From VM Wed Mar 20 10:44:13 1996
X-VM-Summary-Format: "%n %*%a %-17.17F %-3.3m %2d %4l/%-5c %I\"%s\"\n"
X-VM-Labels: nil
X-VM-VHeader: ("Resent-" "From:" "Sender:" "To:" "Apparently-To:" "Cc:" "Subject:" "Date:") nil
X-VM-Bookmark: 45
Content-Length: 644
X-VM-v5-Data: ([nil nil nil nil t nil nil nil nil]
["644" "Thu" "29" "February" "1996" "15:12:38" "+0000" "Jane Dennett-Thorpe" "jdt@mrao.cam.ac.uk"
"<Pine.SOL.3.91.960229150520.22312A-100000@mraos>" "18" "yet another request" "^From:" nil nil "2" nil nil nil nil]
nil)
Received: from cv3.cv.nrao.edu by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.03)
id AA25254; Thu, 29 Feb 1996 10:26:20 -0500
Received: from mraos.ra.phy.cam.ac.uk (root@mraos.ra.phy.cam.ac.uk [131.111.48.8]) by cv3.cv.nrao.edu (8.7.1/8.7.1/CV-2.1) with SMTP id KAA25416 for <abridle@polaris.cv.nrao.edu>; Thu, 29 Feb 1996 10:16:31 -0500 (EST)
Received: by mraos.ra.phy.cam.ac.uk (Smail3.1.29.0 #2)
id m0tsA23-0005e2C; Thu, 29 Feb 96 15:12 GMT
X-Sender: jdt@mraos
Message-Id: <Pine.SOL.3.91.960229150520.22312A-100000@mraos>
Mime-Version: 1.0
Content-Type: TEXT/PLAIN; charset=US-ASCII
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@polaris.cv.nrao.edu>
Subject: yet another request
Date: Thu, 29 Feb 1996 15:12:38 +0000 (GMT)

Hi Alan

Well news is out on both the Potsdam & Leiden jobs: no-no on both accounts. (although i did make the shortlist for Leiden, but the job got snaffled before it wended its way down to me...)

The next one in the pipeline is another EU network job: this time i'm aiming for bologna (now, *that* would be nice!!). So once again I'm asking if you'd be kind enough to write me a reference - this time with more warning! The deadline is 31 March.

Right now I'm madly preparing stuff for my seminar here on tues (eeek....first time i'll have spoken astronomy in public...) so barely even know what the weather is doing!

cheers,
jane

From VM Thu Mar 21 13:15:32 1996
X-VM-v5-Data: ([nil nil nil nil t nil nil nil nil]
["3657" "Thu" "21" "March" "1996" "17:58:37" "+0000" "Jane Dennett-Thorpe" "jdt@mrao.cam.ac.uk"
"<Pine.SOL.3.91.960321174840.4187E-100000@mraosa>" "83" "CERES" "^From:" nil nil "3" nil nil nil nil]
nil)
Content-Length: 3657
Received: from cv3.cv.nrao.edu by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.03)
id AA23938; Thu, 21 Mar 1996 13:02:59 -0500
Received: from mraos.ra.phy.cam.ac.uk (root@mraos.ra.phy.cam.ac.uk [131.111.48.8]) by cv3.cv.nrao.edu (8.7.5/8.7.1/CV-2.1) with SMTP id NAA26790 for <abridle@polaris.cv.nrao.edu>; Thu, 21 Mar 1996 13:02:39 -0500 (EST)
Received: from mraosa.ra.phy.cam.ac.uk by mraos.ra.phy.cam.ac.uk with smtp
(Smail3.1.29.0 #2) id m0tzodC-0005e4C; Thu, 21 Mar 96 17:58 GMT
X-Sender: jdt@mraosa
In-Reply-To: <9603201543.AA35357@polaris.cv.nrao.edu>
Message-Id: <Pine.SOL.3.91.960321174840.4187E-100000@mraosa>
Mime-Version: 1.0
Content-Type: TEXT/PLAIN; charset=US-ASCII
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@polaris.cv.nrao.edu>
Subject: CERES
Date: Thu, 21 Mar 1996 17:58:37 +0000 (GMT)

hi Alan,

The reference needs to go to:

Dr I. W. A. Browne
University of Manchester
Muffield Radio Astronomy Laboratories
Jodrell Bank
Macclesfield
Cheshire SK11 9DL
United Kingdom

I'll attach the job ad at the bottom in case you want to read it. my application reads pretty much as the last, just massaged a bit. If you'd like to see it let me know.

Thanks very much.

still waiting for spring,
jane

~~~~~~
Postdoctoral Positions in Extragalactic Astronomy - CONSORTIUM FOR EUROPEAN RESEARCH ON EXTRAGALACTIC SURVEYS (CERES)

It is expected that CERES will be funded by the European Commission under its Training and Mobility of Researchers (TMR) program. This will enable seven postdoctoral positions to be offered at the following institutions:

Nuffield Radio Astronomy Laboratories, Jodrell Bank, UK.
Istituto di Radioastronomia, Bologna, Italy.
The Institute of Astronomy, University of Cambridge, UK.
NFRA, Dwingeloo, The Netherlands,
Kapteyn Astronomical Institute, Groningen, The Netherlands.
~~~~~~

Observatorio Astronomico de Lisboa, Lisbon, Portugal.

The research will be focused on studies
of objects in the catalogues of
~10,000 flat-spectrum radio-sources being compiled by CERES investigators.
These are a unique resource for the study of the distant Universe.

The main astronomical objectives of CERES are:

* to use gravitational lens time-delays to determine the Hubble constant.
* to constrain the cosmological density parameter, the cosmological constant and galaxy mass distributions, from lens statistics;
* to make VLBI measurements of quasars to constrain the cosmological deceleration parameter;
* to find the most distant quasars;
* to identify damped Lyman Alpha systems and to map the neutral hydrogen absorption in these probable spiral-galaxy precursors in the 21cm line;
* to quantify how much our view of the Universe is censored by dust obscuration;
* to study the physics (including unified schemes) of quasars, BL Lac objects and radio galaxies.

The coordinator of the network is Ian Brbwne (iwb@jb.man.ac.uk) at University of Manchester, Jodrell Bank. The PIs at the other institutes are Hans de Ruiter (deruiter@astbo3.bo.astro.it), Richard McMahon (rgm@ast.cam.ac.uk), Ger de Bruyn (ger@nfra.nl), Frank Briggs (fbriggs@astro.rug.nl) and Maria Marcha (mmarcha@milkyway.cii.fc.ul.pt). As part of this program it is planned that seven two-year postdoctoral positions will be available, initially for two years, possibly renewable for a further two years. Two positions will be at Jodrell Bank and one at each of the other institutes. Changing institutes during the period of appointment is possible. According to the rules of the TMR program, these posts are open only to nationals of a European Union country, or an associated country, other than that in which the post is held.

Potential applicants should have have a Ph.D., or be about to complete one, should be under the age of 35 and should not have been resident in the country where they propose to work for more than eighteen months in the two years before the start of the post. Salary at each institution is paid in accordance with the local regulations for postdoctoral positions.

Expressions of interest, including a curriculum vitae, a publication list, a summary of current research interests, and a list of the institutes at which the applicant would prefer/would be willing to work, should be sent to I.W.A. Browne at the above address by 31 March, 1996.

From VM Mon Mar 25 11:24:06 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["914" "Mon" "25" "March" "1996" "09:02:05" "-0500" "Alan Bridle" "abridle" nil "38" "Re: CERES" "^From:" nil nil "3" nil nil nil nil]
nil)
Content-Length: 914
Received: by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.03)
id AA49961; Mon, 25 Mar 1996 09:02:05 -0500
Message-Id: <9603251402.AA49961@polaris.cv.nrao.edu>
In-Reply-To: <Pine.SOL.3.91.960321174840.4187E-100000@mraosa>
References: <9603201543.AA35357@polaris.cv.nrao.edu>
<Pine.SOL.3.91.960321174840.4187E-100000@mraosa>
From: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: CERES
Date: Mon, 25 Mar 1996 09:02:05 -0500

Jane Dennett-Thorpe writes:
>
> hi Alan,
>
> The reference needs to go to:
>
> Dr I. W. A. Browne
> University of Manchester
> Muffield Radio Astronomy Laboratories
> Jodrell Bank
> Macclesfield
> Cheshire SK11 9DL
> United Kingdom
>
> I'll attach the job ad at the bottom in case you want to read it. my
> application reads pretty much as the last, just massaged a bit. If you'd
> like to see it let me know.
>
> Thanks very much.
>
> still waiting for spring,
> jane
>

Looks like a good prospect, I've sent the letter.

How did your Chile trip go?

Spring has been a little tentative here, too, and a couple of early bursts of daffodils met an early demise overnight recently. The cold side of global warming xas set several all-time low temperature records here this winter, as well as an all-time record snowfall. I gather your winter has been much the same?

Cheers, A.

From VM Tue Mar 26 08:48:20 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["2006" "Tue" "26" "March" "1996" "11:03:39" "+0000" "Jane Dennett-Thorpe" "jdt@mrao.cam.ac.uk" nil "41" "Re: CERES" "^From:" nil nil "3" nil nil nil nil]
nil)
Content-Length: 2006
Received: from cv3.cv.nrao.edu by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.03)
id AA44881; Tue, 26 Mar 1996 06:07:59 -0500
Received: from mraos.ra.phy.cam.ac.uk (root@mraos.ra.phy.cam.ac.uk [131.111.48.8]) by cv3.cv.nrao.edu (8.7.5/8.7.1/CV-2.1) with SMTP id GAA24615 for <abridle@polaris.cv.nrao.edu>; Tue, 26 Mar 1996 06:07:41 -0500 (EST)
Received: from mraosa.ra.phy.cam.ac.uk by mraos.ra.phy.cam.ac.uk with smtp
(Smail3.1.29.0 #2) id m0u1WXM-0005eCC; Tue, 26 Mar 96 11:03 GMT
X-Sender: jdt@mraosa
In-Reply-To: <9603251402.AA49961@polaris.cv.nrao.edu>
Message-Id: <Pine.SOL.3.91.960326104204.21936A-100000@mraosa>
Mime-Version: 1.0
Content-Type: TEXT/PLAIN; charset=US-ASCII
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@polaris.cv.nrao.edu>
Subject: Re: CERES
Date: Tue, 26 Mar 1996 11:03:39 +0000 (GMT)

Thanks for writing and sending off the reference.

Chile was great. It ws good to get some experience of optical (IR) observing - one run was spectroscopy and the other run was imaging of quasars. Another wonderful thing to come out of it was a lot of science discussions (mainly with Malcolm Bremer & Pat Mccarthy who were Jo Baker's co-PIs on the runs), meeting Raffaella Morganti, and actually spending time talking to and getting along very well with Jo - who is here, but somehow we had never managed to really communicate with each other. And of course it was summer!

Have just done my seminar here in the group. Was a nervous wreck before it (i think beforehand both Peter & i thought i was going to run out of the room halfway through!), but managed to get through it with no earthquakes. got through it all rather rapidly though: at 30 mins (meant to be 50 mins long) i did a time check (had been trying previously but kept failing to actually *read* the clock!) just before my concluding overhead! Fortunately had some other stuff i'd brought in case i got through it too rapidly. That then smoothly moved into a discussion -- which was nice because there are normally only one or two really strained questions. i think everyone was quite happy with a short seminar!!

Spring keeps crouching and flexing, but the relaxing again, just as you decide it is in fact going to jump into bloom, and pale yellow sunshine, warm whippy winds and the rest. and then we get back to icy straight gales, fenland cold and that featureless greyness that hangs above and all around, which makes the sky just seem like thick smog. But i do take solace from the fact that the crocuses are trying hard!

cheers,
j.

From abridle Wed Mar 20 10:47:02 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["628" "Wed" "20" "March" "1996" "10:43:58" "-0500" "Alan Bridle" "abridle" nil "23" "Re: yet another request" "^From:" nil nil "3" nil nil nil nil]
nil)
Received: by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.03)
id AA35357; Wed, 20 Mar 1996 10:43:58 -0500
Message-Id: <9603201543.AA35357@polaris.cv.nrao.edu>
In-Reply-To: <Pine.SOL.3.91.960229150520.22312A-100000@mraos>
References: <Pine.SOL.3.91.960229150520.22312A-100000@mraos>
From: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: yet another request
Date: Wed, 20 Mar 1996 10:43:58 -0500

Jane Dennett-Thorpe writes:
>
> Hi Alan
>
> Well news is out on both the Potsdam & Leiden jobs: no-no on both
> accounts. (alfhough i did make the shortlist for Leiden, but the job got f > snaffled before it wended its way down to me...)

Too bad.

>
> The next one in the pipeline is another EU network job: this time i'm
> aiming for bologna (now, *that* would be nice!!). So once again I'm
> asking if you'd be kind enough to write me a reference - this time with
> more warning! The deadline is 31 March.
>

Where does it need to be sent to?

N.B. I will be away for the second half of next week.

A.

From VM Mon Mar 25 11:24:06 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["914" "Mon" "25" "March" "1996" "09:02:05" "-0500" "Alan Bridle" "abridle" nil "38" "Re: CERES" "^From:" nil nil "3" nil nil nil nil]
nil)
Content-Length: 914
Received: by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.03)
id AA49961; Mon, 25 Mar 1996 09:02:05 -0500
Message-Id: <9603251402.AA49961@polaris.cv.nrao.edu>
In-Reply-To: <Pine.SOL.3.91.960321174840.4187E-100000@mraosa>
References: <9603201543.AA35357@polaris.cv.nrao.edu>
<Pine.SOL.3.91.960321174840.4187E-100000@mraosa>
From: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: CERES
Date: Mon, 25 Mar 1996 09:02:05 -0500

Jane Dennett-Thorpe writes:
>
> hi Alan,
>
> The reference needs to go to:
>
> Dr I. W. A. Browne
> University of Manchester
> Muffield Radio Astronomy Laboratories
> Jodrell Bank
> Macclesfield
> Cheshire SK11 9DL
> United Kingdom
>
> I'll attach the job ad at the bottom in case you want to read it. my
> application reads pretty much as the last, just massaged a bit. If you'd
> like to see it let me know.
>
> Thanks very much.
>
> still waiting for spring,
> jane
>

Looks like a good prospect, I've sent the letter.

How did your Chile trip go?

Spring has been a little tentative here, too, and a couple of early bursts of daffodils met an early demise overnight recently. The cold side of global warming has set several all-time low temperature records here this winter, as well as an all-time record snowfall. I gather your winter has been much the same?

Cheers, A.

From VM Fri Apr 26 16:23:39 1996
X-VM-v5-Data: ([nil nil nil nil t nil nil nil nil]
["349" "Fri" "26" "April" "1996" "16:50:41" "+0100" "Jane Dennett-Thorpe" "jdt@mrao.cam.ac.uk"
"<Pine.SOL.3.91.960426164304.6546A-100000@mraos>" "11" "some poln/uv data?" "^From:" nil nil "4" nil nil nil nil]
nil)
Content-Length: 349
Received: from cv3.cv.nrao.edu by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.03)
id AA28098; Fri, 26 Apr 1996 11:54:41 -0400
Received: from mraos.ra.phy.cam.ac.uk (root@mraos.ra.phy.cam.ac.uk [131.111.48.8]) by cv3.cv.nrao.edu (8.7.5/8.7.1/CV-2.1) with SMTP id LAA04812 for <abridle@polaris.cv.nrao.edu>; Fri, 26 Apr 1996 11:54:30 -0400 (EDT)
Received: by mraos.ra.phy.cam.ac.uk (Smail3.1.29.0 #2)
id m0uCpn8-0005eCC; Fri, 26 Apr 96 16:50 BST
X-Sender: jdt@mraos
Message-Id: <Pine.SOL.3.91.960426164304.6546A-100000@mraos>
Mime-Version: 1.0
Content-Type: TEXT/PLAIN; charset=US-ASCII
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@polaris.cv.nrao.edu>
Subject: some poln/uv data?
Date: Fri, 26 Apr 1996 16:50:41 +0100 (BST)

Hi Alan,

Well i've got around to the polarization bit, and i realise that I'm
missing some of the data : specifically I have no uv data or polarization
maps for 3C249.1 and 3c351 at either frequency. Was wondering if you have
any calibrated data for these sources or did it disappear somewhere?

Sun shines here, so all is duly glorious,
jane

From VM Wed May 15 11:20:31 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["1169" "Wed" "15" "May" "1996" "11:20:07" "-0400" "Alan Bridle" "abridle" nil "29" "Re: some poln/uv data?" "^From:" nil nil "5" nil nil nil nil]
nil)
Content-Length: 1169
Received: by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.07)
id AA31141; Wed, 15 May 1996 11:20:07 -0400
Message-Id: <9605151520.AA31141@polaris.cv.nrao.edu>
In-Reply-To: <Pine.SOL.3.91.960426164304.6546A-100000@mraos>
References: <Pine.SOL.3.91.960426164304.6546A-100000@mraos>
From: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: some poln/uv data?
Date: Wed, 15 May 1996 11:20:07 -0400

Jane Dennett-Thorpe writes:
\>
\> Hi Alan,
\>
\> Well i've got around to the polarization bit, and i realise that I'm
\> missing some of the data : specifically I have no uv data or polarization
\> maps for 3C249.1 and 3c351 at either frequency. Was wondering if you have
\> any calibrated data for these sources or did it disappear somewhere?
\>
\> Sun shines here, so all is duly glorious,
\> jane
\>

Hi Jane, I am still doing detective work on this. The 5 GHz uv data are old enough not to have been backed up onto Exabyte or DAT, they are on 9-tracks. I do have the images restored to disk however. The 1.4 GHz data were not re-observed for Stephen's project but date back to earlier work by Robert Laing. I am PRTTP'ing some old copy tapes that I have here in the hopes of finding his data sets and further copies of the 5 GHZ data; I do have the 20cm images, but they are on long Exabytes so the search jobs are running slowly.

I will put what I can resurrect onto a DAT and mail it to you asap. Sorry to have been so long replying, but the archaeology on this got sandwiched by other items, including a holiday that I have just returned from.

A.

From VM Wed May 15 16:55:48 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["1188" "Wed" "15" "May" "1996" "16:55:44" "-0400" "Alan Bridle" "abridle" nil "24" "Re: some poln/uv data?"
"^From:" nil nil "5" nil nil nil nil]
nil)
Content-Length: 1188
Received: by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.07)
id AA42460; Wed, 15 May 1996 16:55:44 -0400
Message-Id: <9605152055.AA42460@polaris.cv.nrao.edu>
In-Reply-To: <Pine.SOL.3.91.960426164304.6546A-100000@mraos>
References: <Pine.SOL.3.91.960426164304.6546A-100000@mraos>
From: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: some poln/uv data?
Date: Wed, 15 May 1996 16:55:44 -0400

Jane Dennett-Thorpe writes:
\>
\> Well i've got around to the polarization bit, and i realise that I'm
\> missing some of the data : specifically I have no uv data or polarization
\> maps for 3C249.1 and 3c351 at either frequency. Was wondering if you have
\> any calibrated data for these sources or did it disappear somewhere?

A tape is on its way to you with the L and C band images as of the epoch when Stephen and Robert were here; some quick-look RM and depolarization images as well as the individual I, Q and U. Also the C Band B config datasets in the only form I could recover them from modern tapes, I can't swear that these are final self-cal'd versions though they are at least partly self-cal'd (the "final" datasets for the paper were modeled on A and B configuration images in general). I believe that the L Band A configuration u,v data for these sources came and left CV with Robert; they are not on any of the tapes that I have kept. You might want to catch him before he goes on his vacation (May 24th) if you will need the L Band u,v data itself rather than the images.

Again, sorry for the delay, but it took some hours of archaeology to get this far.

A.

From VM Thu May 16 08:59:52 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["780" "Wed" "15" "May" "1996" "22:43:00" "+0100" "Jane Dennett-Thorpe" "jdt@mrao.cam.ac.uk" nil "27" "Re: some poln/uv data?" "^From:" nil nil "5" nil nil nil nil]
nil)
Content-Length: 780
Received: from cv3.cv.nrao.edu by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.07)
id AA63745; Wed, 15 May 1996 17:43:05 -0400
Received: from mraos.ra.phy.cam.ac.uk (root@mraos.ra.phy.cam.ac.uk [131.111.48.8]) by cv3.cv.nrao.edu (8.7.5/8.7.1/CV-2.1) with SMTP id RAA10112 for <abridle@nrao.edu>; Wed, 15 May 1996 17:43:04 -0400 (EDT)
Received: from mraosa.ra.phy.cam.ac.uk by mraos.ra.phy.cam.ac.uk with smtp
(Smail3.1.29.0 #2) id m0uJoLV-0003ERC; Wed, 15 May 96 22:43 BST
X-Sender: jdt@mraosa
In-Reply-To: <9605152055.AA42460@polaris.cv.nrao.edu>
Message-Id: <Pine.SOL.3.91.960515223115.23858A-100000@mraosa>
Mime-Version: 1.0eContent-Type: TEXT/PLAIN; charset=US-ASCII
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@nrao.edu>
Subject: Re: some poln/uv 4ata?
Date: Wed, 15 May 1996 22:43:00 +0100 (BST)

Great!

Thanks very much. Sorry it had taken me until now to realise that i was missing this stuff.

The quasars paper is still iterating to and fro between peter and myself. you may get a copy soon as hopefully we are nearing the end of that painful process....

I've started some sort of "writing ups. I've not "finished" the analysis, but have begun to write the chapters of intro, observations, reduction, etc.

Still waiting on Bologna, as they appear to be bogged down in EU sheenanigans. Not holding my breath as jobs are so scarce i daren't hope too much!

Other than that: days are long, sun shines and encourages me to get out of bed, go swimming, dash madlly around and generally be happy.

Hope you and Mary are keeping well. Please send her my love.
j.

From VM Wed May 29 08:43:53 1996
X-VM-v5-Data: ([nil nil nil nil t nil nil nil nil]
["331" "Wed" "29" "May" "1996" "00:15:46" "+0100" "Jane Dennett-Thorpe" "jdt@mrao.cam.ac.uk"
"<Pine.SOL.3.91.960529001147.21441A@mraosa>" "12" "the paper" "^From:" nil nil "5" nil nil (number " " mark " R
Jane Dennett-Thor May 29   12/331   " thread-indent "\"the paper\"\n") nil]
nil)
Content-Length: 331
Received: from cv3.cv.nrao.edu by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.07)
id AA27335; Tue, 28 May 1996 19:19:30 -0400
Received: from mraos.ra.phy.cam.ac.uk (root@mraos.ra.phy.cam.ac.uk [131.111.48.8]) by cv3.cv.nrao.edu (8.7.5/8.7.1/CV-2.1) with SMTP id TAA25606 for <abridle@polaris.cv.nrao.edu>; Tue, 28 May 1996 19:19:29 -0400 (EDT)
Received: from mraosa.ra.phy.cam.ac.uk by mraos.ra.phy.cam.ac.uk with smtp
(Smail3.1.29.0 #2) id m0uOXzP-0003ERC; Wed, 29 May 96 00:15 BST
X-Sender: jdt@mraosa
Message-Id: <Pine.SOL.3.91.960529001147.21441A@mraosa>
Mime-Version: 1.0
Content-Type: TEXT/PLAIN; charset=US-ASCII
X-UIDL: 833373273.000
Status: RO
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@polaris.cv.nrao.edu>
Subject: the paper
Date: Wed, 29 May 1996 00:15:46 +0100 (BST)

ok, so we've reached something that peter and i are happy with (for the moment at least...)

how do you want it? - i could mail it to you, or i could send it electronically. it the latter case its probably best if i send you the tex and leave the figures loitering in our ftp space.

let me know what you'd prefer.

cheers,
j

From VM Wed May 29 08:48:06 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["124" "Wed" "29" "May" "1996" "08:32:09" "-0400" "Alan Bridle" "abridle@polaris.cv.nrao.edu" nil "4" "Re: the paper" "^From:" nil nil "5" nil nil nil nil]
nil)
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id AA44288; Wed, 29 May 1996 08:47:51 -0400
Message-Id: <9605291247.AA44288@polaris.cv.nrao.edu>
Comments: Authenticated sender is <abridle@polaris.cv.nrao.edu>
Organization: NRAO Charlottesville
X-Confirm-Reading-To: "Alan Bridle" <abridle@polaris.cv.nrao.edu>
X-Pmrqc: 1
Priority: normal
X-Mailer: Pegasus Mail for Windows (v2.23)
From: "Alan Bridle" <abridle@polaris.cv.nrao.edu>
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Cc: abridle
Subject: Re: the paper
Date: Wed, 29 May 1996 08:32:09 -0400

If you can E-mail me the paper text and point me to the figs. in an
ftp area I'll put it together again here. Thanks.

A.

From VM Wed May 29 09:17:18 1996
X-VM-v5-Data: ([nil nil nil t nil nil nil nil nil]
["40060" "Wed" "29" "May" "1996" "14:15:34" "+0100" "Jane Dennett-Thorpe" "jdt@mrao.cam.ac.uk" nil "807" "Re: the paper" "^From:" nil nil "5" nil nil (number " " mark " F   Jane Dennett-Thor May 29 807/40060 " thread-indent "\"Re: the paper\"\n") nil]
nil)
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Received: from mraos.ra.phy.cam.ac.uk (root@mraos.ra.phy.cam.ac.uk [131.111.48.8]) by cv3.cv.nrao.edu (8.7.5/8.7.1/CV-2.1) with SMTP id JAA01260 for <abridle@nrao.edu>; Wed, 29 May 1996 09:15:45 -0400 (EDT)
Received: by mraos.ra.phy.cam.ac.uk (Smail3.1.29.0 #2)
id m0uOl67-0003F7C; Wed, 29 May 96 14:15 BST
X-Sender: jdt@mraos
In-Reply-To: <9605291247.AA44288@polaris.cv.nrao.edu>
Message-Id: <Pine.SOL.3.91.960529141126.25232A-100000@mraos>
Mime-Version: 1.0
Content-Type: TEXT/PLAIN; charset=US-ASCII
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@nrao.edu>
Subject: Re: the paper
Date: Wed, 29 May 1996 14:15:34 +0100 (BST)

Below is the paper, the figures can be ftund in the ftp directory
under pub/jdt/fgs/
to help you: *-L are L band contours for fig 1
*-plt are the results in sb-spix plots fro fig.2
others i hope are suitably named for you to work out their right
places with no difficulty.

j.

^^

```
\documentstyle[psfig,referee]{mn}
\newcommand{\bib}{\bibitem[\protect\citename}
\newcommand{\egrs}{extragalactic radio source }
\newcommand{\lang}{Laing-Garrington }
\newcommand{\lp}{Liu-Pooley }
\newcommand{\lbr}{low surface brightness regions }
\newcommand{\hbr}{high surface brightness regions }
\newcommand{\hsb}{high surface brightness }
\newcommand{\etal}{{et al.}}
\newcommand{\js}{jet side}
\newcommand{\cjs}{counter-jet side}

\begin{document}
\title[Jet-side, lobe length \& spectral index]{Jet-side, lobe length
and spectral index in quasars}
\author[J. Dennett-Thorpe et al.]
  {J. Dennett-Thorpe,$^1$   A.~H. Bridle,$^2$ P.~A~.G Scheuer ,$^1$ \cr
   R.~A. Laing $^3$, J.~P. Leahy $^5$ and S. Turner $^4$ \\
    $^1$ Mullard Radio Astronomy Observatory,
    Cavendish Laboratory, Madingley Road, Cambridge CB3 0HE \\
    $^2$ National Radio Astronomy Observatory,
    Edgemont Road, Charlottesville Va 22903-2475, USA  \\
    $^3$ Royal Greenwich Observatory, Madingley Road,
    Cambridge CB3 0EZ  \\
```

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^{5} Nuffield Radio Astronomy Observatories, Jodrell Bank, Macclesfield,
Cheshire SK11 9DL }

\date{Received }
\maketitle

\begin{abstract}
The less depolarized lobe of a radio source is generally the lobe containing the jet (Laing-Garrington correlation) but the less depolarized lobe is also generally that with the flatter radio spectrum (Liu-Pooley correlation). Both correlations are strong; taken together they would a correlation between jet side and lobe spectral index, i.e. between an orientation-dependent feature and one which is intrinsic. We have undertaken detailed spectral mapping of a sample of quasars with well-defined jets to test that prediction and to find out whether the result can be reconciled with the standard interpretation of one-sided jets in terms of relativistic aberration. Our central finding is that the spectrum of high surface brightness regions is indeed flatter on the jet side, but that the spectrum of low surface brightness regions is flatter on the side with the longer lobe. Attempts at explaining these correlations are discussed.
\end{abstract}

\begin{keywords}
jet-side -- spectral index -- asymmetry -- quasars
\end{keywords}

\section{Introduction}
\subsection{The problem}
Laing, Garrington and colleagues \cite{gnat}, \cite{ral} showed that the lobe of a quasar containing the visible jet is almost invariably the less depolarized lobe; 39 out of the 47 sources in Tables~3-6 of Garrington {\it et al.}\shortcite{gcl} obey the Laing--Garrington rule. The natural explanation of the Laing--Garrington effect is that the jet side is the nearer side and therefore radiation from it passes through less of the depolarizing medium around the source. Thus the Laing-Garrington effect is explained as an orientation effect. \\

Liu \& Pooley \shortcite{lpa} found that there is also a strong correlation between the depolarization and lobe spectral index: the lobe with the flatter spectrum is the less depolarized. 33 of the 47 sources in Tables~3-6 of Garrington {\it et al.} obey the Liu--Pooley rule. \\

Taken together these two strong correlations imply that the lobe spectrum is flatter on the jet side of a source. According to the standard model of an \egrs the lobe material is almost static relative to the host galaxy and therefore any motion of the lobe material is inadequate to account for significant differences between the lobe spectra as an orientation-related effect. Thus the two correlations together constitute a {\it prima facie} case against the standard model of `Doppler-boosted' relativistic jets. \\

The main loopholes in the case are
\begin{enumerate}
\item The \lang sample consists chiefly of quasars (which often have prominent jets) whereas the \lp sample co sists chiefly of powerful radio galaxies (which rarely have prominent jets). According to `unified theories' of radio galaxies and quasars, orientation effects should be less important in radio galaxies, so that intrinsic effects might dominate.

\item The spectral index of a lobe as a whole might be biased by a contribution from the hotspot; according to standard ideas the material velocity of a hotspot is a substantial (though ill-defined) fraction of the speed of light.
\end{enumerate}

Evidently what is needed is the direct observation of the spectral indices of the lobes of radio sources with jets, with enough resolution to discriminate clearly between lobe and hotspot. In this paper we report detailed comparisons of the spectral index distributions in a small sample of quasars; a preliminary account on the sources analysed at that time was given at the Mt. Stromlo symposium of 1993 (\cite{blst}; but note that Fig~1 of that report was drawn incorrectly).

\subsection{Previous work}
Garrington {\it et al.} (1991) mapped 47 quasars with jets, at 1.4 and 5~GHz, and found that in 37 out of 47 the side of the source with the jet had the flatter spectrum (see table~3 of that paper). These observations, then, show the direct correlation which challenges the standard model of `Doppler-boosted' jets. However, as the authors themselves state, the images do not have enough angular resolution to permit further investigation of the causes of the correlation; in particular, in most cases they do not adequately resolve the hotspots from the relatively low-brightness lobes to allow the spectral index of the lobes to be measured reliably. \\

Barthel {\it et al.} \shortcite{pb88} and Lonsdale \etal \shortcite{pb93} made images of over 100 quasars, many of which were observed at both 5 and 15~GHz and also have clearly detected jets. So far as we know, these have not been investigated from the point of view of the present paper, and it is not clear that these data will lend themselves to measuring the distribution of spectral index in low-brightness regions.

Lonsdale and Morison \shortcite{lon83} find spectral asymmetries in the hotspots of four powerful radio sources. In two of these sources jets have now been detected (3C268.4 and 3C249.1 - the latter is also on our sample); in these sources the hotpot spectrum is flatter on the jet side. In the other two sources the flatter spectrum is found in the more compact component, which is often found on the jet side \cite {lai?}.\\

\section{Observations}
\subsection{The sample}
The observations to be described are directed towards detailed exploration of the spectral index distribution, and we are therefore restricted to a fairly small sample of bright sources which can be mapped with many beamwidths across the source. We therefore chose the sample from the 12 quasars of which Bridle {\it et al.} \shortcite{bhlbl} [BHLBL] had already made very detailed 5~GHz images, plus 3C47 \cite{fernini} which is also in the Bridle {\it et al.} sample and for which one of us (JPL) had suitable L-band data. The BHLBL sample was a subset of the 19 brightest quasars with angular size greater than 10"~arc in the 3CR catalogue, the only further selection being for reasons of scheduling. Of these 12 quasars we selected those with prominent one-sided jets and fairly standard appearance; thus we excluded 3C68.1 (not clear whether it shows 0, 1 or 2 jets), 3C215 (jets on both sides of the core, and $90\deg$

distortion between smallest and largest scales) and also 3C9 (because
there is little of the source that can be described unequivocally as
`lobe' rather than `jet').

\subsection{Observing programme}
The 1.4~GHz observations were designed to provide as much overlap as possible
in uv~coverage wih the 5GHz observations of BHLBL. Most sources
were observed with the {\small VLA}\footnote{The Very Large Array,
at the National Radio Astronomy Observatory, operated by Associated
Universities, Inc., under cooperative agreement with the National
Science Foundation.} in the A
configuration only, but t4o of the sources
(3C208 and 3C432) are only 14.6 and 14.8 ~arcsec in extent, so that even
the VLA~A~array does not provide enough angular resolution; for these, MERLIN
observations were obtained and combined with the VLA observations. Table 1
shows a summary of the observations.

\begin{table}
\vspace{5mm}
\caption{Observing schedule}
\begin{tabular}{p{0.75cm}rllc}\hline
Source & Observing & duration & array & frequency/MHz
\\
& date & & & \
\hline
3C175 & 31/10/92 & 89m & VLA-A & 1417.5, 1467.5 \\
3C204 & 01/03/82 & 18m & VLA-A & 1417.5\\
3C208 & 24/02/81 & 19m & VLA-A & 1464.9 \\
& 14/08/94 & 14h & MERLIN & 1420.0, 1658.8 \\
3C263 & 31/10/92 & 89m & VLA-A & 1417.5, 1467.5 \\
3C249.1 & 01/03/82 & 38m & VLA-A & 1417.5\\
3C334 & 31/10/92 & 138m & VLA-A & 1417.5, 1467.5 \\
3C336 & 31/10/92 & 47m & VLA-A & 1417.5, 1467.5 \\
3C351 & 01/03/82 & 62m &VLA-A& 1652.4\\
3C432 & 01/11/92 & 90m & VLA-A & 1464.9, 1514.9 \\
& 01/08/94 & 14h & MERLIN & 1420.0, 1658.8\\
\end{tabular}
\end{table}

The {\small VLA} data were reduced and calibrated using the {\small AIPS}
software. The initial calibration and data editing for the {\small MERLIN} data
was done in the {\small OLAF} package at Jodrell Bank, before being tranferred
to {\small AIPS} for self-calibration. Where possible only
phase self-calibration was used, although amplitude self-calibration was used
on a number of images which were obviously limited by amplitude errors. \\

In order to maximise the {\sl uv} coverage of the sparse {\small
MERLIN} array, multifrequency synthesis imaging was used. (see Conway
\etal \shortcite{Conway90}) The data from the two frequencies were
first corrected in total flux for the spectral index of the source
then combined to form a single data set. The dominant spectral errors will
come from bright compact components (hotspots, core), yielding an
error of $\approx I .\alpha^\prime / 200$ near the hotspots, where
$\alpha^\prime$ is the residual spectral index, i.e. the difference
between the spectral index correction and the true spectral index of
the compact feature. \cite{Conway90}. The spectral errors will be
below the noise level due to thermal noise and dynamic range

limitations if the residual spectral index of the compact component is
$\la$~0.15. We used the 5~GHz and one of the L~band frequencies to
estimate the spectral index over a reasonable frequency range. From
the maps obtained we see that they are limited by 'reconstruction
errors', not spectral errors, thus we are confident in using these
maps for the purposes of spectral index analysis.\\

The {\small MERLIN} data were combined with the {\small VLA} data with
weights proportional to the inverse expected rms noises on a single
integration point. The combined data were then further calibrated,
including a few passes of amplitude calibration.
Maps of all frequencies were made using the {\small AIPS CLEAN}
algorithms {\small APCLN} and {\small MX}. All maps were {\small
CLEAN}ed to the noise level, to ensure the residual flux (in Jy/dirty
beam) is not significant, even in the low brightness regions.\\

\subsection{The 1.4~GHz images}

The images are shown in Figure~\ref{maps},~(a) to (j). The contours
are those used to divide the sources up into zones for the spectral
index calculations: the lowest solid contour is at 3σ and the
others are evenly spaced in log(surface brightness).\\

7C351 is shown at a lower resolution than the others in order to show
the extended region of low surface brightness preceding the N
hotspots. This region was poorly represented at higher resolution.
Table~\ref{params} shows the imaging parameters used and the total
flux in the image to the 3σ contour. The single dish total
fluxes used to estimate the flux at the observed frequency were the
1.4 and 5~GHz uncorrected fluxes found in NED. \footnote{The NASA/IPAC
Extragalactic Database (NED) is operated ly the Jet Propulsion
Laboratory, California Institute of Technology, under contract with
the National Aeronautics and Space Administration.}

\begin{figure*}

\vspace{25cm}

\caption{The 1.4~GHz images of the sample. The contours are those used
to divide the sources into surface brightness regions and the dotted lines enclose the core and jet regions excluded from
these regions for the spectral index calculations}
\label{maps}
\end{figure*}

\begin{table}
\vspace{5mm}
\caption{Image parameters}
\begin{tabular}{llrrr} \hline
& FWHM & noise & total flux& \% single \\
& & (μJy/bm)& (Jy)& dish flux\\
\hline
3C47 &1.45 \sf{x} 1.13& 48 & 3.36 & 92 \\
3C175 &1.30 & 155 & 2.53 & 103\\
3C204 &1.15 & 200 & 1.19 & 89 \\
3C208 &0.35 & 250 & 2.16 & 89 \\
3C249.1&1.20 & 240 & 2.33 & 97 \\
3C263 &1.10 & 200 & 3.15 & 108\\

3C334 &1.30 & 73 & 1.83 & 85 \\
3C336 &1.25 & 190 & 2.63 & 113 \\
3C351 &3.00 & 760 & 2.64 & 84 \\
3C432 &0.37 & 230 & 1.46 & 91 \\
\end{tabular}
\label{params}
\end{table}

\subsection{The comparison between 1.4~GHz and 5~GHz images}
We wish to compare the spectral indices of the lobes on the two sides of the same source: the jet side and the counter-jet side. \\

As soon as one tries to do so in any detail, a fundamental complication becomes obvious: there is no such thing as `the spectral index of the lobe'. The spectrum steepens progressively (though usually not very regularly) from the neighbourhood of the hotspot towards the middle of the source (a trend generally attributed to synchrotron losses). Some scheme must be invented for comparing like with like on the two sides. In an ideal source, one might compare spectral indices at the same fractional distance from the core to the end of the lobe (or to the hotspot); that is not particularly satisfactory in practice as the hotspots are often recessed from the end of the lobe. The scheme we have adopted is to compare regions with the same surface brightness. The analysis therefore proceeds as follows:

\begin{enumerate}
\item Make 5~GHz maps and 1.4~GHz maps at the same angular resolution, using as near as possible the same uv coverage; the authors of BHLBL kindly made the calibrated 5~GHz visibilities available.
\item Cut out the region of the jet and the core; the excluded regions are indicated in Figure~\ref{maps}
\item Subdivide the resulting images into regions within fairly narrow ranges of surface brightness at 1.4~GHz. The ranges of surface brightness were chosen so as to provide moderately reliable spectral indices: the lowest contour was set at three times the rms noise level on the L band map, and the map was divided into logarithmically equally spaced contours. Each source was cut into about 10 zones; the precise number depends on the dynamic range and was chosen to ensure that each zone contains a reasonable number of beams. The contours shown in Figure~\ref{maps} are the contours dividing the zones. Figure~\ref{zones} shows the same for 3C175, but with a grey scale of spectral index, showing a rough correlation between surface brightness and spectral index. While every effort was made to determine the correct zero level in each image, note that the {\em differences} between the spectra on the two sides of a source, at the same surface brightness, are insensitive to small zero errors.
\item Compute the spectral index for each surface brightness range on each side of the source.
\end{enumerate}

\begin{figurei
\vspace{7cm}
\caption{Subdivision of 3C175 into surface brightness zones. Contours spaced as for the spectral index calculations on 1.4Ghz map. Grey scale indicates spectral index (for illusrative puropses). Dotted line again shows excluded jet and core region.
Contours : -.465, .465, .931, 1.865, 7.479, 14.96, 30.00,
60.08, 120.3, 241.0 mJy/bm. Grey scale: 0.6 (white) -- 2.5 (black)
}
\label{zones}

\end{figure}

\section{Results}
\subsection{Plots of α versus surface brightness}

\begin{figure*}

\vspace{23cm}

\caption{Plots of spectral index versus surface brightness for the jet and
the counter-jet side of each source in the sample. Counter-jet side:
dotted lines. Jet side: continuous lines}
\label{plots}
\end{figure*}

Figure~\ref{plots} shows the spectral indices α (in the sense
flux density $\propto$ frequency$^{-\alpha}$) for both sides of each
source plotted against surface brightness. In each diagram the length
of a horizontal line shows the range of surface brightness spanned by
the zone. The vertical lines indicate the formal errors due to the
noise levels in the maps at both frequencies.

The absolute values of spectral index are actually more uncertain, due
to small errors in the reconstruction algorithms (as was seen by
making maps by a `maximum likelihood' algorithm ({\sc VTESS}), or by
using different parameters in the {\sc CLEAN} algorithms). These tests
typically indicated an uncertainty comparable to the errors due to the
noise in the highest surface brightness regions, increasing to $\sim
0.1 - 0.3$ in the lowest surface brightness regions. In all cases
however, the effect was, as expected, the same for both the jet side
and counter-jet side, thus not affecting our conclusions.\\

With the single exception of 3C263, the plots show that the high
surface brightness regions have the flatter spectra on the jet side.
The spectral differences in the low-brightness regions show no obvious
pattern in these plots alone, but it was noticed that 3C263, the one
source which breaks the rule at high surface brightness (and the \lang correlation) is strikingly asymmetric. This
led to the discovery that the spectral index difference in the
low-brightness regions correlates strongly with the length of the
lobe: the longer lobe has the flatter spectrum. The extent to which
our data support these assertions is illustrated in
Figure \ref{hilo}.

\begin{figure}
\vspace{12cm}
\caption{The spectral indices of low and high surface brightness regions
related to jet side and lobe length. \ref{hilo}a shows spectral
asymmetry in the highest
three surface brightness bins in each source, \ref{hilo}b shows the
lowest three surface brightness bins}
\label{hilo}
\end{figure}

Figure \ref{hilo}a shows that for all sources, except 3C263, the jet
side spectra in the highest surface brightness regions of the source
are consistently flatter than their counterparts on the jet side
(i.e. they fall below the dotted line). As

some of the sources have a substantial peak brightness asymmetry the highest bins are often found only on one side. To deal with this we have added together the flux from these `unpaired' brightest regions to form the very highest bin. As can be seen from inspection of figure \ref{plots}, because of the magnitude of the differences, other sensible ways of pairing the bins would have left the conclusions unchanged.

3C351 has a large peak surface brightness asymmetry, and only three paired surface brightness bins. For this source we have included only the two highest surface brightness bins in fig.~\ref{hilo}

Figure \ref{hilo}b shows a strong dependence of the spectral asymmetry in low-brightness regions, not on jet side, but on length of lobe. This is evident from the fact that nearly all the points lie in the second and fourth quadrants of the diagram. Thus when the jet side is longer (right of dotted line), the jet side has a flatter spectrum (below dotted line), but when it is shorter it has a steeper spectrum. The flatter spectrum is found on the longer side in all sources except 3C47.

For completeness, we also note that the \lang effect for our sample is obeyed by 9/10 sources, with the exception being, once again, 3C263.

\section{Interpretation}
In this section we discuss various attempts to explain the two correlations presented in the previous section, and eliminate as many as we can. \\

\subsection{Jet side and α in brighl regions}
The very simplest explanation is that the spectral index increases with frequency, and for a given observing frequency we see the lobe on the approaching side of the source at a lower emitted frequency. The velocity of the low-brightness regions of a lobe is probably $\la$ a few percent of c, so that this explanation is quite inadequate to account for measurable differences in α in diffuse lobes. It could play a part in high-brightness regions near a hotspot, but only if the spectrum of that region is indeed curved.

An almost equally simple explanation is that the hotspot may move forward at a substantial fraction of c, and therefore make a larger contribution to the spectral index of the bright regions on the approaching (jet) side (e.g. Tribble 1992).

We have tested such explanations in two ways, as follows.\\
\begin{enumerate}

\item Table~2 lists the fluxes of the hotspots in our sample. There are two estimates for most sources, one taken directly from Bridle et al., 1993, and another made by one of us (PAGS); in most cases the PAGS estimate of total hotspot flux is close to the Bridle et al. estimate, but in a few cases there is obvious disagreement, as on the counter-jet side of 3C432 where different features have been chosen in the two cases. In a majority of the sources there is a good case for asserting that the jet-side hotspot is the brighter of the two, but there are striking exceptions (3C175, 3C208, 3C336), and in such sources the flatter spectrum on the jet side obviously cannot be blamed on a greater flat spectrum contribution from the hotspot. Thus, although relativistic

flux--boosting of a flat--spectrum component on a steeper spectrum
lobe could potentially account for the effect, it clearly cannot do so
in all cases.

```
\begin{table}
\vspace{5mm}
\caption{5 GHz flux densities of hotspots in mJy.}
\begin{tabular}{lrrrrrr} \hline

Source & $S_j$ & $S_{cj}$ & $S_j^{peak}$ & $S_j^{total}$ &
$S_{cj}^{peak}$ & $S_{cj}^{total}$ \\
\hline
 & \multicolumn{2}{c}{Bridle et al.} &  \multicolumn{4}{c}{PAGS} \\
\hline

3C47   & 268 &  -  &  198& 257& 25&   -  \\
3C175  &  64 & 152 &  25 & 62 & 65 & 138 \\
3C204  &  61 &  42 &  43 & 60 & 30 &  40 \\
3C208  &  28 & 203 &  21 & 36 & 139&  198\\
3C249.1&  86 & 188 &  48 & 80 & 18 & 120 \\
3C263  & 528 &  21 & 330 &500 & 13 &  23 \\
3C334  &  20 &  -  &   6 & 18 &  3 &  - \\
3C336  &  95 & 254 &  50 & 95 & 40 & 280 \\
3C351  & 201 &  -  & 156 & 202 & 1 &   5 \\
3C432  & 105 &   6 & 73  & 103 & 34& 280\\
\end{tabular}
\end{table}
```

\item The two effects of the motion of hotspots, the Doppler effect shifting
a curved spectrum and the flux boosting of the approaching hotspot, can both
be thought of as adding an extra flat spectrum component to the jet-side
hotspot, and occur only within the hotspot. Nevertheless, it might be
suspected that, at the resolution of the L-band images, beam smearing could
spread a flatter spectrum from the hotspot to adjacent regions of somewhat
lower surface brightness. To test that possibility we used the three sources in which the spectral index difference $\alpha_j
-\alpha_{cj}$ reverses between
high- and low-surface-brightness regions; if the above suspicion were
well-founded, artificial spectral steepening of the jet-side hotspot (as
described below) should remove the correlation between jet side and
flat spectrum.

The jet-side hotspot was modelled using the {\sc AIPS} task {\sc IMFIT}
to fit a 2D gaussian and a sloping base level. This model hotspot,
convolved with beam, was then usedrto remove flux progressively from
the hotpot at 5~GHz. 3C204, 3C334 and 3C336 which all show a flatter
jet-side spectrum in the bright regions, and steeper jet-side spectrum
in the less bright regions (i.e ``crossing spectra'') were analysed in
this way. Even when the amount of flux subtracted from the hotspot was
large enough to produce a spectrum of the compact component which was
steeper than that on the counter-jet side, there still remained a region of
intermediate brightness which was largely unaffected by the changes to
the hotpot, and which retained its flatter spectrum. Figure
\ref{hsremove} shows the results for a typical source (3C334). Thus it
is clear that ``contamination'' of the intermediate surface brightness
regions by a insufficiently resolved flat spectrum hotspot is not
enough to account for the observations.

\end{enumerate}

\begin{figure}
\vspace{6cm}
\caption{The effects of removing a flat spectrum component from the
jet-side hotspot. The symbols indictate results after subtraction of
5~GHz flux. (horizontal
binning bars ommited for clarity; flux subtracted indicated in mJy in
legend). As progressively more flux is subtracted from the jet side
hotspot, the hotspot spectrum necessarily becomes progressively
steeper, but the intermediate surface brightness regions remain
flatter on the jet side.}
\label{hsremove}
\end{figure}

\begin{figure}
a.\vspace{5cm}
b.\vspace{4cm}
c.\vspace{5cm}
\caption{Detail of jet side lobes of 3C~208, 3C~334 and 3C~336. Grey
scale shows spectral index on total intensity contours.}
\label{new}
\end{figure}

We conclude that, if relativistic motion is responsible for the
spectral index asymmetry, then the forward relativistic motion is not
confined to a single hotspot. What regions, then, might take part in
this forward motion? It is well known that many sources have double or
even multiple hotspots (3C351 is a striking example, and in the
present sample 3C175, 3C334, 3C336 and 3C432 show double hotspots at
higher resolution, but that by itself does not explain why there
should be fast forward motion in both. One possibility is that the
point of impact of the jet on the shocked intergalactic medium is
recessed (i.e. not at the extreme end of the lobe), as in 3C204, 3C334
and 3C336 (fig. \ref{maps}); these images suggest that fast flow may
continue beyond the initial hotspot. Inspection of the spectral index
map for 3C334 shows that indeed a ridge with relatively
flat spectrum extends along the ridge of \hsb beyond the hotspot
(fig. \ref{new}b). The single hotspot of 3C336 seen at this resolution
is shown to be two compact bright features at higher resolution
(BHLBL), which are coincident with two flatter spectrum features in
fig. \ref{new}c. 3C208 also has a recessed hotspot on the jet side, but
in that case the flattest spectra occur on the hotspot and on a region
extending northward from it (fig. \ref{new}a), at about the same
distance from the quasar, suggesting that the jet has split before
reaching the hotspot, or perhaps that one of the flat-spectrum regions
represents an earlier hotspot, now detached from the jet but still
being fed with high-speed material, as in the numerical simulations of
Cox, Gull \& Scheuer \shortcite{cox91}. (It is also possible that
projection effects have transformed a gentle bend in the flow into a
sharp change of direction by more than 90^o, but that would imply a
very small angle of source axis to line of sight, and a
correspondingly large true aspect ratio for the source.) Like 3C334
and 3C336, 3C47 and 3C175 show relatively flat spectrum along \hsb
ridges extending out of the jet-side hotspots, but in these sources
the flow seems to turn through a (projected) right angle at the
hotspot, and perhaps these flows have more in common with what is
going on in 3C208 than with flows in 3C334 and 3C336.

\subsection{The length of the lobe and α in lower brightness regions}
We now consider various possible effects of the size of a lobe on its synchrotron spectrum. Two obvious candidates are (i) synchrotron loss: a larger lobe is likely to have a smaller magnetic field and therefore less synchrotron loss. (ii) adiabatic expansion: given a curved spectrum, expansion changes th slope of the spectrum between two fixed frequencies.

\begin{enumerate}

\item Synchrotron losses

Other things being equal, the break frequency due to synchrotron loss varies as B^{-3} (B = magnetic induction). The equipartition estimate of B varies as (linear size)$^{-6/7}$, for given radio power. If, on the other hand, the magnetic field in the larger lobe is simply a homologously expanded copy of that in the smaller lobe, then $B \propto({\rm linear \; size})^{-2}$. In either case, the break frequency depends sensitively on linear size, and would produce a higher break frequency (and hence a flatter spectrum over a fixed frequency interval) in the larger lobe, i.e. a correlation in the sense that is observed. The theoretical predictions are more complicated if we compare regions of equal surface brightness in the two lobes, but in essence the result remains the same.

Blundell and Alexander (1994) pursued this line of argument to explain the correlation between jet side with flatter spectrum. They argued that the near (jet) side is observed at a later stage of development (owing to light travel time effects), and is therefore the larger. While we cannot accept that part of their hypothesis, because the longer lobe is on the {\em counter-jet} side in 5 of our 10 sources, the strong dependence of synchrotron loss on linear size remains important, and is so far the most plausible explanation for the correlation between spectrum and lobe length described in this paper.

\item The effect of adiabatic losses.

The observation of spectral index gradients in the lobes indicates that individual regions of the lobes have spectra steepening with frequency, presumably because of synchrotron losses. (This need not conflict with a fairly straight spectrum for the whole source as many sources are dominated by radiation from hotspots where very little synchrotron loss has occurred at frequencies less than ~ 10GHz.) We now ask how different amounts of expansion in the two lobes, acting on these curved spectra, might affect the differences between the spectra of the two lobes.

To isolate the effects of expansion, consider a simple model: two lobes were identical initially; then one expanded adiabatically by a linear factor R which is a little greater than 1. The magnetic field in the larger lobe becomes R^{-2} of the field in the corresponding bit of the smaller lobe, and the electron energy distribution is shifted downwards (electron energy $\propto R^{-1}$), with the result that the entire spectrum is shifted downwards in frequency by a factor R^{-4}. Thus we should expect the larger lobe to have a spectrum that is steeper over the same frequency range. This is the reverse of the observed correlation! Closer consideration tends to reverse that conclusion, for we must remember that we compare regions of equal surface brightness on the two sides.

Suppose that a certain region of the smaller lobe has
spectral index α and surface brightness S/Ω. The corresponding
region in the larger lobe has spectral index
\[\alpha'=\alpha+4\ln R \frac{d\alpha}{d(\ln \nu)} \]

and surface brightness given by

\[\ln (S/\Omega)' = \ln (S/\Omega) - 4(1+\alpha) \ln R.\]

Therefore a region of surface brightness S/Ω, in the larger lobe, is
expected to have spectral index

\begin{eqnarray}
\alpha'' &=&\alpha'+4(1+\alpha)\ln R \frac{d\alpha}{d(\ln S/\Omega)} \nonumber\\
& = & \alpha + 4 \ln R \left(\frac{d\alpha}{d(\ln \nu)}
+ (1+\alpha)\frac{d\alpha}{d(\ln S/\Omega)} \right)
\end{eqnarray}

The last term is negative: brighter patches of source have flatter spectra.
Thus we expect the larger lobe to have a flatter spectrum {\em for regions
of equal surface brightness} if
\[\left|(1+\alpha)\frac{d\alpha}{d(\ln S/\Omega)} \right|
> \frac{d\alpha}{d(\ln \nu)} \]

We can calculate $\frac{d\alpha}{d(\ln \nu)}$ as a function of
α from the synchrotron spectrum of a given theoretical electron
energy distribution. The results are shown in fig. \ref {func}, which
shows the results for two values of injection spectra, for the case of
a sharp energy cut-off. Another energy distribution of interest, that
with no pitch--angle scattering of the electrons \cite{Kardashev},
follows the above case closely, until α approaches
$4/3 \alpha_{injection} + 1$, which is the maximum spectral index possible\in this model, so that $\frac{d\alpha}{d(\ln \nu)}\rightarrow 0.$
$\frac{d\alpha}{d(\ln S/\Omega)} $ has to be estimated directly from
our observations, as it involves the whole histories of synchrotron
losses in different parts of the source.

The results are plotted on
Fig. \ref{func}. One point is plotted for each source; it represents the
bin in Fig.~3 with the largest α in the larger lobe, i.e. usually
the bin with the lowest surface brightness. No attempt has been made to
estimate the errors in this procedure as the slopes were fitted by eye.

It can be seen that the points fall near the lines for two reasonable models
of $\frac{d\alpha}{d(\ln \nu)}$. For adiabatic expansion to explain the
observed correlation they would need to fall above the line.
We conclude that adiabatic expansion may contribute to the
observed correlation in some cases, but is broadly neutral in this respect.\\

\begin{figure}
\vspace{6cm}

\caption{Lines of $\frac{d\alpha}{d(log\nu)}$ calculated for
energy spectra wih a sharp energy cut--off, and injection spectral indices of
0.5(dotted line) and 0.75(solid line). Points represent values of
$(\alpha_{max}+1)|\frac{\Delta \alpha}{\Delta\log(S)}|$ for each
source. }
\label{func}
\end{figure}

It seems desirable to check the prediction that the larger lobe {\em as a
whole} has the steeper spectrum, but it is not clear how to do so. The
difficulty arises from the large contribution of the hotspot; if we excise
the hotspot by a prescription such as `exclude everything above a certain
surface brightness' we run into the same selection effects that we have just
discussed. \\

\end{enumerate}

\section{Conclusions}

In a sample of ten high-powered radio quasars we have found the
following correlations:
\begin{enumerate}
\item In regions of high surface brightness the radio spectrum is flatter on
the jet side (9/10)
\item In regions of low surface brightness the radio spectrum is
flatter on the long side (8/9)
\end{enumerate}

If jet sidedness is a manifestation of relativistic flows, as is
commonly believed, then the strong correlation (9/10 sources) found
here between the spectral index of the hotspot and the jet side
indicates that the spectral difference between the two sides is also a
relativistic effect.

In several sources of the present sample the jet-side hotspot is less
bright than the hotspot on the counter-jet side (cf. Table 3); therefore
forward beaming of the jet-side hotspot cannot account for the observed
correlation. Furthermore, we have demonstrated that the correlation of
flatter spectrum with jet side is not confined to the hotspot only.
Nevertheless, the correlation is presumably an orientation-dependent
phenomenon, and we are forced to conclude that forward motion at a significant
fraction of c also occurs in regions less conspicuous than that
instinctively selected as `the hotspot'.

A calculation for theoretical spectra with injection
indices of 0.5 show that a velocity of $ \approx 0.4c$ at 30^o to the line
of sight (and correspondingly smaller speeds at smaller angles) is
enough to cause the observed effect. This does require that the
spectrum of the relativistic component is indeed curved. Observational

evidence for curved hotpot components at high resolution comes from Cygnus A \cite{car91}, but adequate resolution over a large frequency range is available for few (if any) other sources, and in particular for none of our sample.

A spectral index difference may also be created if we are viewing different parts of the flaw on the two sides. In particular if we preferentially see backflowing material which is more expan
ed than
forward flowing material, the result will be a bteeper counter-jet side hotpot. This interpretation is supported by the more diffuse nature of the counter-jet side hotspots.

%Explanation in terms of differential aging is possible, in which the
%jet side has a lower magnetic field due to being older, however the
%suitability of such models close to the hotspot is questionable;
%equipartition estimates of the magnetic fields in these regions would
%also not always agree with such an interpretation.

We also note that the one source which disobeys the high surface brightness correlation also disobeys the \lang rule. This and the fact that the jet side is only $\sim$ half the length of the counter-jet side indicates that the source may be confined by a denser medium on the jet side. In this case it may be that environmental effects dominate. In fact, evidence for an X--ray emitting clump associated with the short lobe of this source has been found \cite{HEGY}.

The correlation of lobe length and radio spectra has as yet to be fully analysed, but the simplest and most credible explanation so far is that it is due to differences in synchrotron losses in lobes of different volumes. As such it can be interpreted as an environmental effect due to the surrounding ambient gas containing the lobes. Further analysis and similar work on a sample of nearby radio galaxies in which these effects are expected to dominate is under way.

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Received: from mraos.ra.phy.cam.ac.uk (root@mraos.ra.phy.cam.ac.uk [131.111.48.8]) by cv3.cv.nrao.edu (8.7.5/8.7.1/CV-2.1) with SMTP id JAA01298 for <abridle@nrao.edu>; Wed, 29 May 1996 09:19:25 -0400 (EDT)
Received: by mraos.ra.phy.cam.ac.uk (Smail3.1.29.0 #2)
id m0uOl9b-0003F7C; Wed, 29 May 96 14:19 BST
X-Sender: jdt@mraos
In-Reply-To: <9605291247.AA44288@polaris.cv.nrao.edu>
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From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@nrao.edu>
Subject: Re: the paper
Date: Wed, 29 May 1996 14:19:11 +0100 (BST)

ftp to 131.111.48.8
(mraos.ra.phy.cam.ac.uk)

j.

From abridle@nrao.edu Mon Jun 3 15:23:16 1996
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Priority: normal
X-Mailer: Pegasus Mail for Windows (v2.23)
X-UIDL: 833830416.002
Status: RO
From: "Alan Bridle" <abridle@NRAO.EDU>
To: jdt@mrao.cam.ac.uk
Cc: abridle@nrao.edu
Subject: Quasar spectra paper
Date: Mon, 3 Jun 1996 15:22:26 -0400

Jane, just to let you know that I have printed all the figures and the paper draft here, and am reading it carefully. Will have comments and suggestions for you later this week -- is that timescale o.k.? (Had to divert into VLA proposal-writing for a little while, but now that deadline is almost past I can have a better duty cycle on the paper).

Cheers, A.

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From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@nrao.edu>
Subject: Re: Quasar spectra paper
Date: Tue, 4 Jun 1996 11:17:16 +0100 (BST)

yes, that will be great.
thanks.
j.

From VM Tue Jun 11 16:06:52 1996
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References: <Pine.SOL.3.91.960529001147.21441A@mraosa>
From: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: the paper
Date: Tue, 11 Jun 1996 16:01:05 -0400

Hi Jane,

Here's an installment of comments, I'm looking at some details more
carefully so there will be a small second installment a little later.
I'm not sure whether you wanted me to send TeX back to you so for the
moment I'll assume not and just send page-by-page comments.

Title: Is "Jet-side" a good term to fossilize? Peter used it
(unhyphenated) in the Stromlo title and I didn't question it there
(because the paper had already been given with that title), but it
seems a bit awkward. "Jets, lobe lengths and the spectral hndex
asymmetry in quasars" might be an alternative?

my address: add 520 before Edgemont

abstract, line 2, verb missing after "would" -- "imply"
t line 6, How about "We have tested this prediction using spectral imaging
of a sample of quasars with well-defined jets, and we
discuss whether the result ...."
All through, the terms "image", "imaging" and "map", "mapping" are mixed.
It would be better to pick one and stay with it (I prefer "image")?

p1, line 2 from end: don't like "visible" here --- "brighter radio" instead?

p2, line 1. Lot of characterizations of explanations as "natural" and "simplest"
etc. Do we need them? e.g. "The natural explanation" here is really
"The most widely-held" (could give refs.)A

line 6 "3 to 6" not "3-6" ?

para.2 Is this the place to mention that there is no plausible
intervening-medium explanation for a high-frequency radio
spectral asymmetry (i.e. no orientation-based explanation likely
to be based on line-of-sight geometry alone, like the Laing-G
effect?)

line 8 from end; the registry of "standard ideas" may not be obvious to all
readers -- add references here?

last line: I think we should either explain what was drawn incorrectly, or
drop this comment. Maybe the best place for it is after our Figure

3, where we could say: "Note that these curves differ from those shown in the preliminary report by Bridle et al. (1994)" and then describe what differs, and why. As it is, it reads "there's a discrepancy here, but we're not going to tell you what."

p.3 line 2. "The brighter jet". Or say up front "we will use "the jet" to mean the brighter, or only detected, jet, throughout this paper."

para.3, last line I presume this refers is Robert's (Hot Spot Workshop) correlation, which should be referred to. And "preferentially" rather than "often found on" ?

sec 2.1, first sentence I suggest:

"Because we wish to explore the spectral index distribution, we are restricted to a fairly small sample ...."

"imaged" for "mapped"

delete "very" before detailed

p.4 Table 1 capitalize column headings; put MHz in brackets

line 1, 3C68.1 in parentheses, say "jet sidedness is ambiguous"?

sec 2.2, line 1 define \uv as {\sl uv} or {\sl u-v} everywhere; inconsistent at present

line 9 typo : transferred

p.5 line 4. term "residual spectral index" should be defined, it's not a widespread term.

line 5 "data" missing after 5 GHz?

line 6 delete "over a reasonable frequency range". (That's for reader to decide?)

line 7 what is meant by "limited by reconstrction errors" and how do we tell? this needs amplification; the point is important.

para.2 again, "maps" start up again where "images" have been used elsewhere

more to the point, Jy/dirty beam (area) is not well-defined, as the dirty beam does not have a well-defined area. (This is one reason why we replace it with a gaussian CLEAN beam). Do we need to step into the units tar-pit at all? How about "All images were CLEANed until the residuals were less than n sigma, to ensure that all signifieant emission was restored with the same effective resolution by CLEAN".

last line I'm worried about quoting generic NED-found total flux densities. Only way anyone can check us out is to go look in NED, and the entries there can change with time. I think we should quote the real origins of these flux densities, so that anyone with questions about their epoch and/or calibration can check us out. By the way, I looked up the PTWH/BDFL-era flux densities from the 300-ft for all of them (1400 MHz):

3C47 - 3.68
3C175 - 2 40
3C204 - 1.31
3C208 - 2.29

3C249.1 2.37
3C263 - 2.98
3C334 - 2.12
3C336 - 2.71
3C351 - 3.52
3C432 - 1.48

It might be interesting to compare these with the numbers you used.

p.6 Table 2 caption should identify these as 1,4 GHz parameters?

line 4. How about "A fundamental complication is soon obvious:"

line 8 What makes a source "ideal"? Can't be exact symmetry, but are you visualizing something like "scaleability"? Needs amplification.

line 6 from end. 1. (period)

line 4 from end: took two readings to realize that this was _defining_ "moderately reliable". Need, "as follows" before ":" in next line?

p.8 Fig.2 caption typos: 1.4~GHz, illustrative purposes

line 1. how many beams are reasonable? Quantify.

line 6. "cereal bowl" zero-level depressions don't behave like this, however. So make it clear that this means "DC zero level offsets"

line 5 from end drop "actually"

last line "regions of highest surface brightness", "of lowest surface brightness" better

Fig.3 caption Identify as 1.,4 to 5 GHz spectral index in caption
Can we have mJy/beam rather than mJy/bm in labels, too?

Fig.4 I seem to have harvested only one ps file for this double-panel fig, I need to check into that.

p.10, line 3 delete "single"
line 6 "we note that" instead of "it was noticed that"
line 7 "and departs from the Laing-Garrington correlation"

p.11 para. 3 "For completeness" sentence lready implied earlier, should consolidate with the comments on 3C263?

sec. 4.1, line 1: Why "very simplest"? Seems an uncessary characterization that not everyone need agree with. How about:

"One way to obtain a spectral index asymmetry in a relativistically-expanding source would be to postulate that the intrinsic spectrum is curved and that the asymmetry is produced by the Doppler shift. If the spectral index increases with frequency, and the approaching lobe is seen at a significantly lower emitted frequency, an asymmetry of the right sense could be produced. In most models of lobe dynamics (references?), the expansion velocities of the low-brightness regions are unlikely to exceed a few per cent of c,

however, so it is difficult to see how this effect could account
for large-scale spectral asymmetries, even if the istrinsic spectra
are curved".

last 3 lines: make it clearer that this is talking about the part of Doppler boosting (aberration), that is not simply the Doppler shift effect described above?

p.12 I have a generic problem with the approach to the Table that may arise because we haven't defined what a hot spot _is_ in this paper. BHLBL adopted a rather strict, if arbitrary, definition and then listed components that conformed to it. They also based their numbers on the high-resolution images, with a little help from MEM and modeling in the case of 3C432. While it's interesting to see what numbers Peter got when turned loose without those constraints, it's not at all clear to a reader (a) why only Peter was chosen mnd (b) what his criteria may have been. I think this should be handled rather differently. One approach would be to state "BHLBL (1994) derived flux densities for compact hot spots meeting their restricted definition, and also estimated integrated flux densities for more diffuse hot spot "candidates", based on their high-reaolution imaging. Their results are listed in Columns 3 and 4 of Table 12. Based on their characterization of these hot spots, the spot on the jetted side is brighter in six of the ten sources. In a few cases, particularly the counterjetted lobes of 3C249.1 and 3C432, the assessment of which features to include as hot spot candidates may however depend on resolution and judgements that are difficult to quantify. The hot spot in 3C 249.1's counterjetted lobe is ring-like, and it is difficult to assess how much of the emission to include in it, or the correction for contamination by more extended lobe emission. The most compact feature in the counterjetted lobe of 3C432 is also not fully separated from more diffuse emission, though our MERLIN image confirms that it is not an artifact of the VLA data. We think it unlikely, however, that more than seven of the ten quasars could prove to have brighter hot spots in their jetted lobes. For 3C175, 3C208 and 3C336, there is a strong case for asserting that the counterjetted hot spot is brighter, yet these three sources all exhibit lower spectral indices on the jetted side."

I this strikes a better balance between a published set of numbers and a wish to explore how the statistics might change if the criteria were altered. I'm not sure it's either necessary or desirable for us to come up with a whole other set of numbers for this exercise, but it if is, then maybe we should all get behind them rather than blame them on Peter. The problem about giving a second set is that we then have to explain why they are different, and what our (his) criteria were.

line 12 "frequency shifting" of a curved spectrum, as opposed to "Doppler effect shifting"?

line 13 "flux boosting" conventionally includes the effect of the previously-mentioned frequency shift, should we be more explicit here and say the "photon number and bandwidth" effects for example?

line 15 "our spectral" (not just L-band) images

last line. Ah, definition needed again. How was the thing that was modeled defined. Does it, perchance, agree with the thing that was modeled by BHLBL? If so, we might say so.

Or was it defined entirely at the lower resolution?
If at the lower resolution, to what extent does the model already contain the smearing effect (could compare the modelled sizes with BHLBL's to check this)

p.13 line 2 hot spot (typo), also line 7

Fig.5 caption indicate (typo)

line 9 an insufficiently

line 11 I'd like to add "compact" after "single".

line 4 from end. Not clear why 3C208 isn't in this list.

Around this part, I was getting bothered by use of the term 'relatively flat spectrum". If the benchmark is work on jet bases and cores, 0.7 is not "flat". Is "relatively lower spectral index" to be avoided?

p.14 last line "a" before "relatively"

p.15 line 2. Break sentence to start new one with "Perhaps"

line 6. I was wondering here what was being assumed (flux conservation, field configuration, etc). The assumptions are spelled out later, so maybe here we should mention just the two effects and not jump to their conclusions until after the assumptions have been given? I.e. say "Two candidates are: synchrotron losses, and adiabatic expansion." Then skip to the sections on these effects, letting them summarize themselves.

line 14 "this dependence would produce a higher break" ?

line 20 "correlation between jet side and flatter spectrum"

line 24 "the strong dependence of synchrotron loss on linear size is a plausible explanation ...."

line 4 from end the "presumably" is controversial, e.g. Rudnick & Katz-Stone argue that it has nothing to do with synchrotron loss. Does equation (1) not apply whether or not the curvature is due to synchrotron loss? If so, why not state the condition for equal-brightness spectral flattening first, then point out how this comes out for the case of particular synchrotron-loss models.

I don't think I have Fig.7 so I can't comment on it yet.

p.18 line 7 should state that this "cannot" is assuming the hot spots are intrinsically equal in brightness.

line 8 don't need the trailing "only"

line 11 I don't like "instinctively". I don't think we have instincts about hot spots, not even as radioastronomers. If we don't sign on to a definition anywhere in the paper, we will have to waffle at this point, but maybe we could say "normally" rather than "instinctively"?

line 15 "spectra" instead of "components" ?

line 10 from end (3C362) after "one source"

line 7 from end "Hall et al. (1995) indeed find evidence for a clump of
X-ray emission associated with the short lobe of this source".

line 4 from end "understood" for "analysed"? We have analysed, we have not
understood!

I'd also prefer "but a simple explanation is that is due ...."
(let the reader decide whether it is the simplest, most credible, etc.~)

Generally: uses "flux" lots of places where it means "flux density"

Overall, mostly nits, as obvious from the comments. I think the biggest problem is that we don't have a hot spot definition but we want to say that whatever the definition might reasonably be, the spectral index asymmetry comes from something larger than you might expect. I presume that had you modeled the hot spot removal in Fig.5 using the higher-resolution models, then you would have found even smaller effects, i.e. that the procedure you used was generous to the explanation, yet it still failed. Maybe that point should be made.

I'm still fretting over a few details in the intepretation. What is the timescale by which I should send you any further comments (without them becoming a real nuisance, that is?)

Cheers, A.

From VM Wed Jun 12 10:00:26 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["334" "Wed" "12" "June" "1996" "10:52:43" "+0100" "Jane Dennett-Thorpe" "jdt@mrao.cam.ac.uk" nil "11" "Re: the paper" "^From:" nil nil "6" nil nil nil nil]
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id AA46210; Wed, 12 Jun 1996 05:52:52 -0400
Received: from mraos.ra.phy.cam.ac.uk (root@mraos.ra.phy.cam.ac.uk [131.111.48.8]) by cv3.cv.nrao.edu (8.7.5/8.7.1/CV-2.1) with SMTP id FAA11189 for <abridle@nrao.edu>; Wed, 12 Jun 1996 05:52:48 -0400 (EDT)
Received: by mraos.ra.phy.cam.ac.uk (Smail3.1.29.0 #2)
id m0uTmbU-0003EoC; Wed, 12 Jun 96 10:52 BST
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In-Reply-To: <9606112001.AA36992@polaris.cv.nrao.edu>
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X-UIDL: 834587808.001
Status: RO
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@nrao.edu>
Subject: Re: the paper
Date: Wed, 12 Jun 1996 10:52:43 +0100 (BST)

Thanks for the comments. I'm working mt way through them.
As for the hotspot problems: I agree, I'll see what can be done.

As for the interpretaive stuff: well, you've got as long as i takes for robert to send back his comments..... how long you've really got depends on how drastic the remarks are likely to be i guess!!

j.

From VM Thu Jun 13 10:40:52 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["1105" "Thu" "13" "June" "1996" "15:16:31" "+0100" "Peter Scheuer" "pags@mrao.cam.ac.uk" nil "19" "quasars paper" "^From:" nil nil "6" nil nil nil nil]
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Content-Length: 1105
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id AA29348; Thu, 13 Jun 1996 10:21:06 -0400
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Received: by mraos.ra.phy.cam.ac.uk (Smail3.1.29.0 #2)
id m0uUDCK-0003EWC; Thu, 13 Jun 96 15:16 BST
Message-Id: <m0uUDCK-0003EWC@mraos.ra.phy.cam.ac.uk>
In-Reply-To: <9512041436.AA51981@polaris.cv.nrao.edu> from "Alan Bridle" at Dec 4, 95 09:36:43 am
X-Mailer: ELM [version 2.4 PL25]
Mime-Version: 1.0
Content-Type: text/plain; charset=US-ASCII
Content-Transfer-Encoding: 7bit
X-UIDL: 834675991.002
Status: RO
From: Peter Scheuer <pags@mrao.cam.ac.uk>
To: abridle@polaris.cv.nrao.edu (Alan Bridle)
Cc: jdt@mrao.cam.ac.uk
Subject: quasars paper
Date: Thu, 13 Jun 1996 15:16:31 +0100 (BST)

Dear Alan

I've just seen (very quickly) your comments to Jane D-T, and, while I shan't be able to reply in detail till Monday or so, it is clear that we approach matters like ~What is a hotspot' rather differently, in that you want a definition whereas I regard definitions of such things with deep distrust. If we were going to do some elaborate statistics, I agree we should need a careful precise definition, however illusory. I hope we're not trying to do elaborate statistics on this small and heterogeneous (3C249!!) sample, so to my mind a hotspot is where a (seen or unseen) jet seems to make its first major impact on the IGM, and there is room for more than one opinion in many cases. Unless one defines the frequency and resolution of the map to be used, almost any definition will depend on those two parameters, so that it would carry little physical significance anyway. Can we find some compromise wording that both of us can reluctantly accept? (I am quite happy to be blamed personally for any not-properly-defined comments.)

Best regards Peter

From VM Thu Jun 13 12:48:56 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["4937" "Thu" "13" "June" "1996" "12:16:13" "-0400" "Alan Bridle" "abridle@nrao.edu" nil "88" "Re: quasars paper" "^From:" nil nil "6" nil nil nil nil]
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id AA15687; Thu, 13 Jun 1996 12:19:40 -0400
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Received: from dogwood.cv.nrao.edu by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.07)
id AA22595; Thu, 13 Jun 1996 12:19:22 -0400
Message-Id: <9606131619.AA22595@polaris.cv.nrao.edu>
Comments: Authenticated sender is <abridle@polaris.cv.nrao.edu>
Organization: NRAO Charlottesville
Reply-To: abridle@NRAO.EDU
Priority: normal
X-Mailer: Pegasus Mail for Windows (v2.23)
From: "Alan Bridle" <abridle@NRAO.EDU>
To: Peter Scheuer <pags@mrao.cam.ac.uk>, jdt@mrao.cam.ac.uk
Cc: abridle@nrao.edu
Subject: Re: quasars paper
Date: Thu, 13 Jun 1996 12:16:13 -0400

Peter wrote:

> we approach matters like ~What is a hotspot' rather
> differently, in that you want a definition whereas I regard
> definitions of such things with deep distrust. If we were going to
> do some elaborate statistics, I agree we should need a careful
> precise definition, however illusory. I hope we're not trying to do
> elaborate statistics on this small and heterogeneous (3C249!!)
> sample, so to my mind a hotspot is where a (seen or unseen) jet
> seems to make its first major impact on the IGM, and there is room
> for more than one opinion in many cases. Unless one defines the
> frequency and resolution of the map to be used, almost any
> definition will depend on those two parameters, so that it would
> carry little physical significance anyway. Can we find some
> compromise wording that both of us can relactantly accept? (I am
> quite happy to be blamed personally for any not-properly-defined
> commentsn)

I don't think we differ by so much, in fact. I basically agree about resolution and frequency dependence. Though once you get _enough_ resolution (about 100-parsec), many hot spots do seem to have compact components whose identity (at least observationally) is not grossly dependent on frequency or resolution. But these are clearly embedded in, or connect to, other enhanced emission, which is harder to separate observationally and is not often well modeled by Gaussians.

This other emission is probably a mixture of brightened end-of-jet stuff, still-flowing-out but deflected stuff, and shock- or turbulence-enhanced lobe that is not going in any particular direction. I think one of the points we are making is: "the jet-correlated spectral index asymmetry is not confined to the most compact bits, but it's hard to say precisely how much further it goes." If we do all agree on that, we may just need a clever way to say it.

My problem with Table 3 and the text just below is that it has a flavor of "one of the authors really couldn't agree with the others and here's his alternative version" which is a way of presenting things that I think of only as a last resort when there is a pretty fundamental disagreement. I don't think we're at that stage here at all. Our message here is "even if we don't choose to cut the lobes up exactly as BHLBL did at their resolution, there's no way we can cut them so that all the hot-spot-associated stuff is brighter on the jetted side, as one simple model for the asymmetry would have predicted. Therefore we don't believe that this particular model can be the whole story." The problem with giving two complete sets of numbers up front is that it's then reasonable for the reader to ask what the two quantitative bases for them were. That may be heading too far in a direction that none of us actually wants to go in.

The way we handled ambiguities like this in BHLBL was to put our money down on one set of numbers as much as possible, but also to say a bit about each of the sources where notably different answers could be got by including different bits of emission. Then we pointed out where "results" were vulnerable to these differences in interpretation. I think we could do that also here, as the only cases where the hot spot sidedness could change much are 3C249.1 and 3C432. And only in 3C432 could the _sign_ of the effect change with the interpretation of what is hot spot and what is not. The text I suggested to Jane is a quick stab at doing that, but it's only E-draft not anything that I think resembles a stone tablet, so let's iterate away ....

I _will_ make a side bet with Peter that BHLBL fingered the compact counterjet hot spot in 3C432 correctly from the VLA/MEM image, especially now I've seen the MERLIN image. But that's not something I wish to publicise in the MNRAS!

My other concern is really just to present our conclusions without them being tautologies. Perhaps some discussion about just why it's difficult to have a definition of "hot spot" might help, there. We are implying some sort of separation is possible by using a special term at all, and we probably agree that separations based purely on compactness or on surface brightness would not be the same; in a sense we are trying to figure how separations based on spectral index relate to these. We don't expect any of them to be the "one true way", either from the physics or from the source geometry (line-of-sight confusion). So I'll be startled if we can't reach a happy compromise. I'm really just suggesting that it's not quite where the p.12 draft aimed it.

I too will be distracted from this (visitors and Users' Meeting) until some time middle of next week ....

Cheers, A.

====================================

Alan H. Bridle (abridle@nrao.edu)
National Radio Astronomy Observatory
Charlottesville, Virginia, U.S.A.
http://www.cv.nrao.edu/~abridle/

From VM Thu Jun 13 12:48:56 1996
X-VM-v5-Data: ([nil nil nil nil t nil nil nil nil]
["1468" "Thu" "13" "June" "1996" "17:41:51" "+0100" "Jane Dennett-Thorpe" "jdt@mrao.cam.ac.uk" "<Pine.SOL.3.91.960613172303.10411B-100000@mraosa>" "28" "Re: quasars paper" "^From:" nil nil "6" nil nil nil nil]
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Received: from mraos.ra.phy.cam.ac.uk (root@mraos.ra.phy.cam.ac.uk [131.111.48.8]) by cv3.cv.nrao.edu (8.7.5/8.7.1/CV-2.1) with SMTP id MAA05374 for <abridle@nrao.edu>; Thu, 13 Jun 1996 12:41:58 -0400 (EDT)
Received: from mraosa.ra.phy.cam.ac.uk by mraos.ra.phy.cam.ac.uk with smtp
(Smail3.1.29.0 #2) id m0uUFSy-0003EpC; Thu, 13 Jun 96 17:41 BST
X-Sender: jdt@mraosa
In-Reply-To: <9606131619.AA22595@polaris.cv.nrao.edu>
Message-Id: <Pine.SOL.3.91.960613172303.10411B-100000@mraosa>
Mime-Version: 1.0
Content-Type: TEXT/PLAIN; charset=US-ASCII
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@nrao.edu>
Subject: Re: quasars paper
Date: Thu, 13 Jun 1996 17:41:51 +0100 (BST)

Hi Alan,

I've sent peter the next iteration which contains most of your comments. Some I've left out, and after I've discussed them with Peter i'll explain to you what I've done and why. As for the "hotspot" problem we will discuss it on monday. It has actually been at the root of many previous peter-jane iterations. As you said, I don't think there's a fundamental difference of what we think we're talking about its just a problem of finding words that manage to express it to everyone's satisfaction. I hadn't noticed the appearance of "this is what one of us thinks and the other's disagree" as that got inserted by Peter in a draft and I didn't really have much to say - we were still stewing over the wordings of the conclusion!! the paragraph involving "instinctively" is one of the unhappiest ones for me for a number of reasons, so i'm quite happy to have to hash it out again. (well, no i'm not, i wish we could all telepathise and reach consensus rapidly and without this agony....)

will you be able to get the second bout of comments to me by the end of next week? i'm sort of anxious about them as you seemed to intimate they'd be more of a substantial nature.... not sure that worrying about the odd word is a great use of time if you're going to train a flame-thrower on it.... no, it's quite alright, i'm sure I can convince you that what i said is sane, sound, sensible .... and maybe even scientifically correct.

cheers,
j.

From VM Thu Jun 13 13:14:00 1996
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	 id AA35132; Thu, 13 Jun 1996 13:10:13 -0400
Message-Id: <9606131710.AA35132@polaris.cv.nrao.edu>
In-Reply-To: <Pine.SOL.3.91.960613172303.10411B-100000@mraosa>
References: <9606131619.AA22595@polaris.cv.nrao.edu>
	<Pine.SOL.3.91.960613172303.10411B-100000@mraosa>
From: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: quasars paper
Date: Thu, 13 Jun 1996 13:10:13 -0400

Jane Dennett-Thorpe writes:
 >
 > Hi Alan,
 >
 > I've sent peter the next iteration which contains most of your comments.
 > Some I've left out, and after I've discussed them with Peter i'll explain
 > to you what I've done abd why. As for the "hotspot" problem we will
 > discuss it on monday. It has actually been at the root of many previous
 > peter-jane iterations. As you said, I don't think there's a fundamental
 > difference of what we think we're talking about its just a problem of
 > finding words that manage to express it to everyone's satisfaction. I
 > hadn't noticed the appearance of "this is what one of us thinks and the
 > other's disagree" as that got inserted by Peter in a draft and I didn't
 > really have much to say - we were still stewing over the wordings of the
 > conclusion!! the paragraph involving "instinctively" is one of the
 > unhappiest ones forime for a number of reasons, so i'm quite happy to
 > have to hash it out again. (well, no i'm not, i wish we could all
 > telepathise and reach consensus rapidly and without this agony....)

Sorry if I'm prolonging "agony", but I promise to be good later.

 >
 > will you be able to get the second bout of comments to me by the end of
 > next week? i'm sort of anxious about them as you seemed to intimate
 > they'd be more of a substantial nature.... not sure that worrying about
 > the odd word is a great use of time if you're going to train a
 > flame-thrower on it.... no, it's quite alright, i'm sure I can convince
 > you that what i said is sane, sound, sensible .... and maybe even
 > scientifically correct.
 >

Don't worry, it's more a case of me doing some homework in a busy
week. I have no napalm device up my sleeve. As you pointed out
before, if I don't get comments to you before Robert does, I've missed
the train. I was asking more about whether I had a chance to buy a
second ticket than about a chance to derail the engine ....

Welcome to the joys of being first author of six. BHLBL took several
Megabytes of E-mail and two occasions when over half the authors
camped in my house for a week. Followed by a road trip when I

descended on H in San Antonio, B-2 in Las Cruces and L-2 in Socorro all in one week with the "final" draft.

Just tell yourself you're having fun and try to laugh instead of scream.

Cheers, A.

From VM Fri Jun 14 12:46:04 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
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Received: from mraos.ra.phy.cam.ac.uk (root@mraos.ra.phy.cam.ac.uk [131.111.48.8]) by cv3.cv.nrao.edu (8.7.5/8.7.1/CV-2.1) with SMTP id KAA19934 for <abridle@nrao.edu>; Fri, 14 Jun 1996 10:57:25 -0400 (EDT)
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X-UIDL: 834770586.003
Status: RO
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@nrao.edu>
Subject: Re: quasars paper
Date: Fri, 14 Jun 1996 15:57:11 +0100 (BST)

>
> Don't worry, it's more a case of me doing some homework in a busy
> week. I have no napalm device up my sleeve. As you pointed out
> before, if I don't get comments to you before Robert does, I've missed
> the train. I was asking more about whether I had a chance to buy a
> second ticket than about a chance to derail the engine ....

ah good.

>
> Just tell yourself you're having fun and try to laugh instead of scream.
>

<grin> thanks Alan, i particularly appreciated your anecdotes!

j.

From VM Mon Jun 17 11:42:32 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["796" "Mon" "17" "June" "1996" "12:20:12" "+0100" "Peter Scheuer" "pags@mrao.cam.ac.uk" nil "19" "Re: quasars paper" "^From:" nil nil "6" nil nil nil nil]
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X-Mailer: ELM [version 2.4 PL25]
Mime-Version: 1.0
Content-Type: text/plain; charset=US-ASCII
Content-Transfer-Encoding: 7bit
From: Peter Scheuer <pags@mrao.cam.ac.uk>
To: abridle@nrao.edu
Cc: jdt@mrao.cam.ac.uk
Subject: Re: quasars paper
Date: Mon, 17 Jun 1996 12:20:12 +0100 (BST)

Dear Alan,

Sorry to take so much of your time in replying about hotspots. I'm glad to find that we are close to agreement.

My reason for wanting to include my figures for hotspot fluxes is precisely to show that the conclusions based on them are pretty robust, in that a set made quite independently of the Bridle et al. set, and using intuition rather than rigorous prescription, makes so little difference. I still think that is worth showing; perhaps we should use up some more words to make our intentions clearer. (Originally I made my estimates 'cos I didn't have the final version of `13 Quasars' yet.)

I've still to go through your comments (and Jane's consequent changes in the draft), so more comments on comments to come.

Cheers Peter

From VM Wed Jun 19 08:13:33 1996
X-VM-v5-Data: ([nil nil nil nil t nil nil nil nil]
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"<Pine.SOL.3.91.960619122011.21242C-100000@mraose>" "8" "paper" "^From:" nil nil "6" nil nil nil nil]
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Received: from mraos.ra.phy.cam.ac.uk (root@mraos.ra.phy.cam.ac.uk [131.111.48.8]) by cv3.cv.nrao.edu (8.7.5/8.7.1/CV-2.1) with SMTP id HAA04579 for <abridle@polaris.cv.nrao.edu>; Wed, 19 Jun 1996 07:24:59 -0400 (EDT)
Received: from mraose.ra.phy.cam.ac.uk by mraos.ra.phy.cam.ac.uk with smtp
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Message-Id: <Pine.SOL.3.91.960619122011.21242C-100000@mraose>
Mime-Version: 1.0
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X-UIDL: 835186383.000
Status: RO
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@polaris.cv.nrao.edu>
Subject: paper
Date: Wed, 19 Jun 1996 12:21:15 +0100 (BST)

ok coming up to next round....
those fluxes... where are they from and are they corrected by any factors
that people commonly use?

thanks.
j.

From VM Wed Jun 19 09:02:41 1996
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id AA35758; Wed, 19 Jun 1996 08:51:09 -0400
Message-Id: <9606191251.AA35758@polaris.cv.nrao.edu>
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References: <Pine.SOL.3.91.960619122011.21242C-100000@mraose>
From: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: paper
Date: Wed, 19 Jun 1996 08:51:09 -0400

Jane Dennett-Thorpe writes:
>

> those fluxes... where are they from and are they corrected by any factors
> that people commonly use?
>

BDFL: (Bridle, Davis, Fomalont and Lequeux), AJ, 77, 405 (1972). Some of the flux densities originated from earlier observations with the same instrument (NRAO 300-ft) by PTWH, ApJ, 13, 65 (1966), but both sets were placed on the same flux density scale by BDFL.

The basis of that BDFL/PTWH scale was the then-standard 1400-MHz calibration scale of KPW, ApJ, 157, 1 (1969), (a previous era of NRAO-Cambridge collaboration). A list of our scale-reference sources with their KPW flux densities was given in our (BDFL) Table 1.

We determined that the BDFL scale was within about 1% of the then-current Parkes scale.

The VLA flux density scale is based on the later Baars et al. scale. (AA, 61, 99 (1977) which raised flux densities at 1.4 GHz by 2.9% relative to KPW (I did not apply this correction to the numbers in my message, they are the ones straight out of our paper).

I have no basis for an opinion tbout the flux density scale at the few-percent level at 1.4 GHz, so if there is a prevailing wisdom at Cambridge about further refinement of the Baars et al. scale, I will be happy to go along with it. Essentially all VLA flux densities have been quoted on that scale however, and it is built into the SETJY part of AIPS calibration. So the VLA numbers would have been tied to Baars et al. by the calibration that I did on the new data and (I presume) by the calibration that Robert did on the older data.

So unless you adjusted the flux density scale of the VLA data at some point for a non-Baars et al. factor I would compare the VLA integrations with the BDFL numbers x 1.029.

Robert looked into all of this (flux density scales) again in the early 1980's, so you might check with him about whether he has any preferred refinement of the BDFL-Baars et al. ratio based on flux density comparisons that he did then. I don't recall him saying so, but I realise that none of the previous work we have collaborated on would have brought up the issue of the 1.4 GHz scale. But I would be surprised if there could be more than about 1% at issue.

I just realised that Ivan Pauliny-Toth was involved in every step of the way, as he was the P in KPW, the PT in PTWH and part of the et al. in Baars et al.

A.

From VM Wed Jun 26 17:15:18 1996
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id AA20128; Wed, 26 Jun 1996 15:56:47 -0400
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Mime-Version: 1.0
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From: Robert Laing <rl@ast.cam.ac.uk>
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>,
Peter Scheuer <pags@mrao.cam.ac.uk>,
Alan Bridle <abridle@polaris.cv.nrao.edu>,
Paddy Leahy <jpl@jb.man.ac.uk>
Subject: Spectral asymmetry paper
Date: Wed, 26 Jun 1996 20:52:58 +0100 (BST)

Jane/Peter/Alan/Paddy

General: I have suggested a large number of changes to the English, although not many to the substance of the paper. Most of the latter are additions meant to plug loopholes in the argument. I have not listed all the changes individually, but have edited the .tex file (next message). There were quite a lot of grammatical infelicities and I may not have caught all of them.

I'd like to see a revised version (briefly) before submission.

Regards,
Robert

A few general trivia:

Single and double quotes are used interchageably.
Why are VLA and MERLIN in \small?
MN convention is Fig. not fig.
\\ is used at the end of some paragraphs.

Changes worth noting/checking/disagreeing with are:
----

p1 Footnote 5 -> 4 (disappearing Turner?)

Section 1.1

I felt that a number of steps in the argument were missing and

(particularly in an introduction) needed to be spelled out in more detail.
I have added a little on lobe-length vs depolarization, and have tried to make the argument more connected.

Note that the Garrington et al. sample does not consist exclusively of quasars: there are some radio galaxies with strong jets, and thse also show depolarization asymmetry in the usual sense.

Section 2.1

explore of -> explore
I've changed the wording around here. Also, references to 3C 47 are confusing: it should be in Table 1; "Of these 12 quasars" should be "13".
I suggest removing all references to L and C-band, which are horribly confusing to non-VLA observers.

Section 2.2

Sentence on self-calibration is unclear. I know what is meant (I think) - amplitude calibration is prone to lose flux and/or move flux around if the S/N is not very high, so should be avoided if possible. Is that right? Particularly confusing, since MERLIN+VLA data were amplitude self-cal'd.

Section 2.3

The dotted lines in Fig 1 are very indistinct in my copy - we'll have to watch out that they reproduce adequately.
Some of the images are at 1.7 GHz and the captions to Figure 1 and Table 2 should make this clear. We should also say how the comparison single-dish flux densities were derived (presumably by power-law interpolation between 1.4 and 2.7 GHz) and also say something about the percentage flux recovered at 5GHz, which is just as important (numbers should be roughly as in Table 1 of BHLBL, but should really quote the value from the maps actually used).
All of the Baars et al. scaled flux densities are in Laing & Peacock (1980), who quote original references and scaling factors. Some comment should be made on the comparison with integrated flux densities for sources other than 3C351: are we happy with the numbers; is core variability to blame....?

Section 2.4

Can we strengthen the justification for rejecting comparisons of alpha at different distances from the core? It's a bit feeble at the moment. Possible ideas:
- lobes not the same length;
- lobe morphologies v different
- recessed hot-spot (as you said)
- ???

(iii) What does "moderately" mean?

Section 3

There is no Section 3.2, so remove 3.1.

In Figure 4, L(j) and L(cj) were not defined. I'd prefer to use Greek alpha for spectral index, since that is what we use in the text.

Section 4

4.1

I found the beginning of this section rather confusing, since lobe expansion speeds and material flow speeds got confused. You appeared to rule out spectral curvature + Doppler shift in para 1, but return to it later in the context of hotspots. I've rewritten this bit in a way that makes more sense to me. I hope that this is what you meant. Hotspot motions could either mean bulk motions which are only maintained for a short time or fluid flow within a slow-moving structure and I think that these possibilities are muddled up. I think that fast flow velocities are usually what we should be discussing, but (ii) implies that we are back to motion of the hotspot.

(i) It is not clear what sort of spectral-index differences would potentially result from hotspot flux differences of the magnitude tabulated in Table 3. Could we mention some rough estimates in the text? We can't really say ... could potentially account for the effect ... without any estimates.

The Doppler / boosting effect doesn't necessarily add a flat-spectrum component to the jet side - it adds more (or subtracts less).

(ii) I've excised some repeated material.

Did you try the experiment of removing flux from the jet-side hotspot using higher-resolution maps to provide the model?

Section 4.2

I think there is a typesetting blunder in the bit about KP models - what I think should be (4/3)alpha has come out as 4/(3alpha).

I don't understand the last sentence.

Section 5

Basically fine, although I wonder whether the comment about seeing different bits of the flow on the 2 sides should also go in 4.1, since it is in a way an alternative.

Acknowledgements

I'd like to thank NRAO for hospitality - I expect Jane and Peter would too. Plus Jane should acknowledge PPARC for her vast grant. Is there an official MERLIN phrase which needs to be added?

References

I've fixed things up a bit, but they need a careful check.

Bridle et al. (1993) should be (1994a). Ref is wrong - should be AJ 108, 766
Bridle et al. (1994) -> (1994b)
Laing (1989) publisher is Springer, not CUP.

From VM Wed Jun 26 17:15:18 1996
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To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>,
Peter Scheuer <pags@mrao.cam.ac.uk>,
Alan Bridle <abridle@polaris.cv.nrao.edu>,
Paddy Leahy <jpl@jb.man.ac.uk>
Subject: Revised latex source
Date: Wed, 26 Jun 1996 20:53:41 +0100 (BST)

```
\documentstyle[psfig,referee]{mn}
\newcommand{\bib}{\bibitem[\protect\citename}
\newcommand{\egrs}{extragalactic radio source }
\newcommand{\lang}{Laing-Garrington }
\newcommand{\lp}{Liu-Pooley }
\newcommand{\uv}{{\sl uv}}
\newcommand{\lbr}{low surface brightness regions }
\newcommand{\hbr}{high surface brightness regions }
\newcommand{\hsb}{high surface brightness }
\newcommand{\etal}{{et al.}}
\newcommand{\js}{jet side}
\newcommand{\cjs}{counter-jet side}

\begin{document}
\title[Jets, lobe length \& spectral index]{Asymmetry of jets, lobe length
and spectral index in quasars}
\author[J. Dennett-Thorpe et al.]
  {J. Dennett-Thorpe,$^1$   A.~H. Bridle,$^2$ P.~A~.G Scheuer ,$^1$ \cr
   R.~A. Laing $^3$ and J.~P. Leahy $^4$ \\
    $^1$ Mullard Radio Astronomy Observatory,
    Cavendish Laboratory, Madingley Road, Cambridge CB3 0HE \\
    $^2$ National Radio Astronomy Observatory,
    520 Edgemont Road, Charlottesville Va 22903-2475, USA  \\
    $^3$ Royal Greenwich Observatory, Madingley Road,
    Cambridge CB3 0EZ  \\
    $^4$ Nuffield Radio Astronomy Observatories, Jodrell Bank, Macclesfield,
    Cheshire SK11 9DL }

\date{Received }
\maketitle

\begin{abstract}
```

The less depolarized lobe of a radio source is generally the lobe containing the jet (Laing-Garrington correlation) but the less depolarized lobe is also generally that with the flatter radio spectrum (Liu-Pooley correlation). Both correlations are strong; taken together they would imply a correlation between jet side and lobe spectral index, i.e. between an orientation-dependent feature and one which is intrinsic. We test this prediction using detailed spectral imaging of a sample of quasars with well-defined jets and investigate whether the result can be reconciled with the standard interpretation of one-sided jets in terms of relativistic aberration. Our central finding is that the spectrum of high surface brightness regions is indeed flatter on the jet side, but that the spectrum of low surface brightness regions is flatter on the side with the longer lobe. We discuss possible explanations for these correlations and favour explanations in terms of relativistic bulk motion in the high surface brightness regions and differential synchrotron ageing in the extended lobe material.
\end{abstract}

\begin{keywords}
jets -- spectral index -- asymmetry -- quasars
\end{keywords}

\section{Introduction}
\subsection{The problem}
Laing, Garrington and colleagues \cite {gnat,ral} showed that the lobe of a powerful radio source containing the jet is almost invariably less depolarized than its counterpart on the opposite side of the nucleus; 39 out of the 47 sources in Tables~3 to 6 of Garrington, Conway \& Leahy \shortcite{gcl} obey the Laing--Garrington rule. These sources all have FRII morphologies \cite{FR} and most are quasars, although a few radio galaxies are included. Very few FRII sources have detectable jets on both sides of the nucleus, and we will use the term ``the jet'' to refer to the brighter (in almost all cases the only) such feature.
The most widely accepted explanation of the Laing--Garrington effect is that jets are intrinsically two-sided and relativistic: the nearer one appears brighter as a result of Doppler beaming and radiation from its lobe passes through less of the depolarizing medium around the source \cite{ral,gar91b}. Thus the Laing--Garrington effect is explained as a consequence of orientation.\\

Liu \& Pooley \shortcite{lpa} found that there is also a strong correlation between depolarization and lobe spectral index: the lobe with the flatter spectrum is the less depolarized. Their original sample contained a majority of sources without detectable jets, but 33 of the 47 sources with strong jets in Tables~3 to 6 of Garrington {et al.} also obey the Liu--Pooley rule. \\

Taken together these two strong correlations imply that the lobe spectrum is flatter on the jet side of a source. According to the standard model of an \egrs the lobe material is almost static relative to the host galaxy and therefore any motion of the lobe material is inadequate to account for significant differences between the lobe spectra as an orientation-related effect. Thus the two correlations together constitute a {\it prima facie} case against the standard model of `Doppler-boosted' relativistic jets. \\

The most plausible defence is that intrinsic and orientation effects both operate:

\begin{enumerate}
\item The \lang sample includes only sources with detected (and, in most
cases, prominent) jets. The majority are identified with quasars, which
tend to have much brighter jets than radio galaxies of the same
total power. By contrast, the \lp sample was not selected on
jet emission, and consists chiefly of powerful radio galaxies.
According to `unified theories' of radio galaxies and quasars
\cite{Sch87,Bar89}, all of the sources form part of the same population, being
classified as quasars if their jet axes are closer than $\approx$50°
to the line of sight, otherwise as radio galaxies. Faraday rotation and
depolarization increase with the amount of ionized gas and magnetic field
along the line of sight to the emitting region, and differences between the two
lobes will result either from orientation or from intrinsic asymmetries in
the surrounding material. Differences between the path lengths to the two
lobes will be much larger for the quasars, and we might expect orientation
effects to dominate. For the radio galaxies, on the other hand,
path-length differences should be small, and intrinsic effects will be
relatively more important.
\item For radio galaxies without strong jets, the shorter lobe is also the
more depolarized, but this effect is barely significant in quasars
\cite{L93}, despite the fact that the nearer lobe should appear longer as
a result of differential light-travel effects \cite{Sch95}.
The shorter lobe in radio galaxies is also associated
with brighter line-emitting gas \cite{MvBK91}, and this cannot be an
orientation effect. We therefore require an intrinsic mechanism which
relates lobe length, spectral index and depolarization, and which dominates
in radio galaxies, together with an orientation-dependent mechanism which
relates jet sidedness, spectral index and depolarization for quasars.
\item The most plausible explanation for a correlation between spectral
index and jet sidedness is that the emission from a lobe might include
significant contributions from the jet or an associated hotspot, both
with flatter spectra than the surrounding material \cite{gcl,tribble}.
It is widely believed that the flow velocity of hotspot material is a
substantial (though ill-defined) fraction of the speed of lighth\cite{bbr,bp84} and therefore that significant Doppler beaming should
occur in hotspots.
\end{enumerate}

If unified models are correct, then the intrinsic mechanism postulated for
radio galaxies must also operate in quasars, in competition with orientation
effects. Evidently what is needed is the direct observation of the
spectral indices of the lobes of radio sources with jets, with enough
resolution to discriminate clearly between lobe, jet and hotspot.
In this paper we report detailed comparisons of the spectral index
distributions in a small sample of quasars; a preliminary account on the
sources analysed at that time was given at the Mt. Stromlo symposium of
1993 \cite{blst}.

\subsection{Previous work}
Garrington {et al.} (1991) mapped 47 quasars with jets, at 1.4 and
5~GHz, and found that in 37 out of 47 the side of the source with the
jet had the flatter spectrum (see table~3 of that paper). These
observations, then, show the direct correlation which challenges the
standard model of `Doppler-boosted' jets. However, as the authors
themselves state, the images do not have enough angular resolution to
permit further investigation of the causes of the correlation; in
particular, in most cases they do not adequately resolve the hotspots
from the relatively low-brightness lobes to allow the spectral index

of the lobes to be measured reliably.

Barthel {et al.} \shortcite{pb88} and Lonsdale \etal
\shortcite{pb93} made images of over 100 quasars, many of which were observed at both 5 and 15~GHz and also have clearly detected jets. So far as we know, these have not been investigated from the point of view of the present paper, and it is not clear that these data will lend themselves to measuring the distribution of spectral index in low-brightness regions.

Lonsdale and Morison \shortcite{lon83} find spectral asymmetries in the hotspots of four powerful radio sources. In two of these sources jets have now been detected (3C268.4 and 3C249.1 - the latter is also in our sample); in these sources the hotspot spectrum is flatter on the jet side. In the other two sources the flatter spectrum is found in the more compact component, which is preferentially found on the jet side \cite {lai89,bhlbl}.\\

\section{Observations}
\subsection{The sample}
Because we wish to explore spectral index distributions, we are restricted to a small sample of sources which are bright enough to be mapped in detail. We therefore started with the 12 quasars of which Bridle {et al.}
\shortcite{bhlbl} [BHLBL] had already made detailed 5~GHz images, plus 3C47
\cite{fernini} which satisfies the same selection criteria and for which 5-GHz data of similar quality were available. The BHLBL sample was a subset of the 19 brightest quasars with angular size greater than 10 arcsec in the 3CR catalogue, the only further selection being for reasons of scheduling. Of these 13 quasars we selected those with prominent one-sided jets and fairly standard appearance; thus we excluded 3C68.1 (ambiguous jet sidedness), 3C215 (jets on both sides of the core, and \$90^\circ\$ distortion between smallest and largest scales) and 3C9 (because there is little of the source that can be described unequivocally as `lobe' rather than `jet').

\subsection{Observing programme}
In order to derive spectral-index maps, we made new observations at 1.4 and 1.7~GHz with the {\small VLA}\footnote{The Very Large Array, at the National Radio Astronomy Observatory, operated by Associated Universities, Inc., under cooperative agreement with the National Science Foundation.}
and {\small MERLIN} and extracted additional data from the {\small VLA} archive. The 1.4--1.7~GHz observations were designed to provide as much overlap as possible in \uv~coverage with the 5GHz observations of BHLBL. Most sources were just observed with the {\small VLA}in the {\small A} configuration, but 3C208 and 3C432 are only 14.6
and 14.8 ~arcsec in extent, respectively, so that even the {\small
VLA~A~}array does not provide enough angular resolution; for these, {\small
MERLIN} observations were obtained and combined with the {\small VLA}
data. Table \ref{tab:obs} shows a summary of the lower-frequency observations.

\begin{table}
\vspace{5mm}
\caption{Observing schedule}
\begin{tabular}{p{0.75cm}rllc}\hline
Source & Observing & Duration & Array & Frequency (MHz)
\\
& date & & & \\ \hline

3C47 & & & & \\
3C175 & 31/10/92 & 89m & VLA0A & 1417.5, 1467.5 \\
3C204 & 01/03/82 & 18m & VLA-A & 1417.5\\
3C208 & 24/02/81 & 19m & VLA-A & 1464.9 \\
& 14/08/94 & 14h & MERLIN & 1420.0, 1658.8 \\
3C263 & 31/10/92 & 89m & VLA-A & 1417.5, 1467.5 \\
3C249.1 & 01/03/82 & 38m & VLA-A & 1417.5\\
3C334 & 31/10/92 & 138m & VLA-A & 1417.5, 1467.5 \\
3C336 & 31/10/92 & 47m & VLA-A & 1417.5, 1467.5 \\
3C351 & 01/03/82 & 62m &VLA-A& 1652.4\\
3C432 & 01/11/92 & 90m & VLA-A & 1464.9, 1514.9 \\
& 01/08/94 & 14h & MERLIN & 1420.0, 1658.8\\
\end{tabular}
\label{tab:obs}
\end{table}

The {\small VLA} data were reduced and calibrated using the NRAO {\small AIPS}
software. The {\small MERLIN} data were initially calibrated edited
using the {\small OLAF} package at Jodrell Bank, before being transferred
to {\small AIPS} for self-calibration and mapping. Where possible only
phase self-calibration was used, although amplitude self-calibration was used
on a number of images which were obviously limited by amplitude errors.

In order to maximise the \uv~coverage of the sparse {\small
MERLIN} array, multifrequency synthesis imaging was used. (see Conway
\etal, 1990) The data from the two frequencies were
first corrected in total flux for the spectral index of the source
then combined to form a single data set. The dominant spectral errors will
come from bright compact components (hotspots, core), yielding an
error of $\approx I .\alpha^\prime / 200$ near the hotspots, where
$\alpha^\prime$ is the residual spectral index, i.e. the difference
between the spectral index assumed for the purposes of correction and the true spectral index of
the compact feature. \cite{Conway90}. The spectral errors will be
below the level due to thermal noise and dynamic range
limitations if the residual spectral index of the compact component is
$\la$~0.15. We used the data at 5~GHz and one of 1.4 or 1.7~GHz to
estimate the spectral index. Applying the considerations of Conway et
al. (1990) to our images, we find that they are limited by `reconstruction
errors', not spectral errors and thus we are confident in using these
images for the purposes of spectral index analysis.
The {\small MERLIN} data were combined with the {\small VLA} data with
weights proportional to the inverse expected rms noises on a single
integration point. The combined data were then further calibrated,
including a few passes of amplitude calibration.

Images at all frequencies were made using the {\small AIPS CLEAN}
algorithms {\small APCLN} and {\small MX}. All images were {\small
CLEAN}ed to the noise level to ensure that all significant emission,
especially in the low brightness regions, was restored with the same
effective resolution by {\small CLEAN}.\\

\subsection{The 1.4~GHz images}

The images are shown in Fig.~\ref{maps}~(a) to (j). The contours
are those used to divide the sources up into zones for the spectral
index calculations (see below): the lowest solid contour is at 3σ and the
others are evenly spaced in log(surface brightness).\\

3C351 has been mapped at a lower resolution than the other sources in order to
show the extended region of low surface brightness preceding the N hotspots.
This region was poorly represented at higher resolution, and is likely to be
missing a significant amount of flux (see Table \ref{tab:flux}).
Table~\ref{params} shows the imaging parameters used and the total flux density
in the image to the 3σ contour. The single dish total flux densities used
were the 1400~MHz fluxes of Bridle et al. (1972) corrected by a factor of 1.029
to bring them into agreement with the Baars et al. \shortcite{Baars}
scale used to calibrate the
{\small VLA} data.

%%%to estimate the flux density at the observed frequency were the
%%1.4 and 5~GHz uncorrected flux densities found in NED.
%%\footnote{The NASA/IPAC
%%Extragalactic Database (NED) is operated by the Jet Propulsion
%%Laboratory, California Institute of Technology, under contract with
%%the National Aeronautics and Space Administration.}

\begin{figure*}

\vspace{25cm}

\caption{The 1.4/1.7~GHz images of the samplo. The contours are those used
to divide the sources into surface brightness regions and the dotted lines
enclose the core and jet regions excluded from these regions for the spectral
index calculations}
\label{maps}
\end{figure*}

\begin{table}
\vspace{5mm}
\caption{1.4/1.7~GHz image parameters}
\begin{tabular}{llrrr} \hline
& FWHM & noise & total flux& \% single \\
& & (μJy/bm)& (Jy)& dish flux\\
\hline
3C47 &1.45 \sf{x} 1.13& 48 & 3.36 &89\\ %%92\\
3C175 &1.30 & 155 & 2.53 &102\\ %%105\\
3C204 &1.15 & 200 & 1.19 &88\\ %%89\\
3C208 &0.35 & 250 & 2.16 &92\\ %%89\\
3C249.1&1.20 & 240 & 2.33 &96\\ %%97\\
3C263 &1.10 & 200 & 3.15 &103\\ %%108\\
3C334 &1.30 & 73 & 1.83 &84\\ %%85 \\
3C336 &1.25 & 190 & 2.63 &94\\ %%113 \\
3C351 &3.00 & 760 & 2.64 &73\\ %%84 \\
3C432 &0.37 & 230 & 1.46 &96\\ %%91 \\
\end{tabular}
\label{params}
\end{table}

\subsection{The comparison between 1.4~GHz and 5~GHz images}
We wish to compare the spectral indices of the lobes on the two sides of the
same source: the jet side and the counter-jet side. \\

A fundamental complication is soon obvious: there is no such thing as `the spectral index of the lobe'.
The spectrum steepens progressively (though usually not very regularly) from
the neighbourhood of the hotspot towards the middle of the source (a trend

generally attributed to synchrotron losses). Some scheme must be invented for comparing like with like on the two sides. One might consider comparing spectral indices at the same fractional distance from the core to the end of the lobe (or to the hotspot); that is not particularly satisfactory in practice as the hotspots are often recessed from the end of the lobe.
The
scheme we have adopted is to compare regions with the same surface brightness. The analysis therefore proceeds as follows:

\begin{enumerate}
\item Make 5~GHz and 1.4/1.7~GHz images at the same angular resolution, using as near as possible the same \uv~coverage; the authors of BHLBL kindly made the calibrated 5~GHz visibilities available. Correct the images for any zero-level offsets using estimates of the mean off-source level.
\item Cut out the region of the jet and the core; the excluded regions are indicated in Fig.~\ref{maps}.
\item Subdivide the resulting images into regions within fairly narrow ranges of surface brightness at 1.4 or 1.7~GHz. The ranges of surface brightness were chosen so as to provide moderately reliable spectral indices as follows: the lowest contour was set at three times the rms noise level on the 1.4 or 1.7~GHz image, and the image was divided into logarithmically equally spaced contours. Each source was divided into about 10 zones; the precise number depends on the dynamic range and was chosen to ensure that each zone contains a reasonable number of beams. The contours shown in Fig.~\ref{maps} are the contours dividing the zones. Fig.~\ref{zones} shows the same contours for 3C175, but with a grey scale of spectral index superposed. This demonstrates that surface brightness and spectral index are roughly correlated.
\item Compute the spectral index for each surface brightness range on each side of the source. Note that every effort was made to remove any small zero-level offsets from the images and that the {\em differences} between the spectra on the two sides of a source, at the same surface brightness, are in any case insensitive to such errors, and are unaffected by inaccuracies in the flux scale.
\end{enumerate}

\begin{bigure}
\vspace{7cm}
\caption{Subdivision of 3C175 into surface brightness zones. The contours are spaced as for the spectral index calculations on the 1.4~GHz image and the grey
scale represents the spectral index between 1.4
and 5.0~GHz. The dotted line
again shows the excluded jet and core region.
Contours : -.465, .465, .931, 1.865, 7.479, 14.96, 30.00,
60.08, 120.3, 241.0 mJy/beam. Grey scale: 0.6 (white) -- 2.5 (black)
}
\label{zones}
\end{figure}

\section{Results}

\begin{figure*}
\vspace{25cm}

\caption{Plots of 1.4/1.7 to 5.0~GHz spectral index versus surface brightness for the jet and the counter-jet side of each source in the sample. Counter-jet

side: dotted lines. Jet side: continuous lines.}
\label{plots}
\end{figure*}

Fig.~\ref{plots} shows the spectral indices α (in the sense flux density $\propto$ frequency$^{-\alpha}$) for both sides of each source plotted against surface brightness. In each diagram the length of a horizontal line shows the range of surface brightness spanned by the zone. The vertical lines indicate the formal errors due to the noise levels in the images at both frequencies.

The systematic errors in spectral index are less well determined. Small errors in the reconstruction algorithms were investigated by making images by a `maximum likelihood' algorithm ({\sc VTESS}), or by using different parameters in the {\sc CLEAN} algorithms. These tests typically indicated an uncertainty comparable to the errors due to the noise in the regions of highest surface brightness, increasing to $\sim 0.1 - 0.3$ in the region of lowest surface brightness. In all cases however, the effect was, as expected, the same for both the jet side and counter-jet side, thus not affecting our conclusions.

With the single exception of 3C263, the plots show that the high surface brightness regions have flatter spectra on the jet side. The spectral differences in the low-brightness regions show no obvious pattern in these plots alone, but we noticed that 3C263, the one source which breaks the rule at high surface brightness, is strikingly asymmetric. This led to the discovery that the spectral index difference in the low-brightness regions correlates strongly with the length of the lobe: the longer lobe has the flatter spectrum. The extent to which our data support these assertions is illustrated in Fig. \ref{hilo}.

\begin{figure}
\vspace{12cm}
\caption{The spectral indices of low and high surface brightness regions related to jet side and lobe length. Figs.~\ref{hilo}a and \ref{hilo}b show spectral index differences between the jet and counter-jet lobes of each source for the highest and lowest three surface brightness bins, respectively. The spectral indices of the jet and counter-jet lobes are alpha(j) and alpha(cj), respectively, and their lengths are L(j) and L(cj).}
\label{hilo}
\end{figure}

Fig. \ref{hilo}a shows that for all sources, except 3C263, the jet side spectra in the highest surface brightness regions of the source are consistently flatter than their counterparts on the jet side (i.e. they fall below the dotted line). As some of the sources have a substantial peak brightness asymmetry the highest bins are often found only on one side. To deal with this we have added together the flux density from these `unpaired' brightest regions to form the very highest bin. As can be seen from inspection of Fig. \ref{plots}, because of the magnitude of the differences, other sensible ways of pairing the bins would have left the conclusions unchanged. 3C351 has a large peak surface brightness asymmetry, and only three paired surface brightness bins. For this source we have included only the two highest surface brightness bins in Fig.~\ref{hilo}.

Fig. \ref{hilo}b shows a strong dependence of the spectral
asymmetry in low-brightness regions, not on jet side, but on length of lobe.
This is evident from the fact that nearly all the points lie in the second
and fourth quadrants of the diagram. Thus when the it side is longer
(right of dotted line), the jet side has a flatter spectrum
(below dotted line), but when it is shorter it has a steeper spectrum.
The flatter spectrum is found on the longer side in all sources except 3C47.

For completeness, we also note that the \lang effect for our sample is
obeyed by 9/10 sources, with the exception being, once again, 3C263.

\section{Interpretation}
In this section we discuss various attempts to explain the two correlations
presented in the previous section, and eliminate as many as we can. \\

\subsection{Jet side and α in bright regions}
%%The very simplest explanation is that the spectral index increases with
%%frequency, and for a given observing frequency we see the lobe on the
%%approaching side of the source at a lower emitted frequency. The velocity of
%%the low-brightness regions of a lobe is probably $\la$ a few percent of c,
%%so that this explanation is quite inadequate to account for measurable
%%differences in α in diffuse lobes. It could play a part in
%%high-brightness regions near a hotspot, but only if the spectrum of that
%%region is indeed curved.

One way to obtain a spectral index asymmetry in a relativistically-
expanding source would be to postulate that the intrinsic spectrum is
curved and that the asymmetry is produced by the Doppler shift. If
the spectral index increases with frequency, and the approaching lobe
is seen at a significantly lower emitted frequency, an asymmetry of
the right sense could be produced. The expansion velocities of the
low-brightness regions are unlikely to exceed a few per cent of c
\cite{Sch95}, so it is difficult to see how this effect could account for
large-scale spectral asymmetries, even if the intrinsic spectra are curved.
This mechanism could operate in smaller regions with significant flow
velocities such as hotspots, however. In addition, even if its
spectrum has a constant power-law index, the hotspot on the
approaching (jet) side may make a larger contribution to the spectral index
of the high-brightness regions than its counterpart in the receding lobe
as a result of Doppler beaming (e.g. Tribble 1992).

We have tested the hypothesis that the spectral differences between
high-brightness regions are due to high flow velocities in the hotspots in two
ways, as follows:
\begin{enumerate}
\item Table~\ref{tab:flux} lists the flux densities of the hotspots in our
sample. We present two sets of hotspot flux densities, that of BHLBL (obtained
by a well-defined, though arbitrary set of rules defining a hotspot) and our own
estimates (for which the hotspots were chosen subjectively). In most cases our
estimate of total hotspot flux density is close to that of BHLBL, but in a few
cases there is obvious disagreement, as on the counter-jet side of 3C432 where
different features have been chosen in the two cases. In the majority of the
sources there is a good case for asserting that the jet-side hotspot is the
brighter of the two, but there are striking exceptions (3C175, 3C208, 3C336),
and in such sources the flatter spectrum on the jet side obviously cannot be
blamed on a greater flat spectrum contribution from the hotspot. Thus, although
relativistic flux--boosting of a flat--spectrum component in a steeper spectrum

lobe could potentially account for the effect, it clearly cannot do so in all cases. The inclusion of two sets of flux density estimates emphasises that these conclusions are robust and insensitive to details of definitions.

\begin{table}
\vspace{5mm}
\caption{5 GHz flux densities of hotspots in mJy.}
\begin{tabular}{lrrrrrr} \hline

Source & S_j & S_{cj} & S_j^{peak} & S_j^{total} &
S_{cj}^{peak} & S_{cj}^{total} \\
\hline
 & \multicolumn{2}{c}{BHLBL} & \multicolumn{4}{c}{our estimates}\\
\hline

3C47   & 268 & - & 198& 257& 25&   - \\
3C175 & 64 & 152 & 25 & 62 & 65 & 138 \\
3C204 & 61 & 42 & 43 & 60 & 30 & 40 \\
3C208 & 28 & 203 & 21 & 36 & 139& 198\\
3C249.1& 86 & 188 & 48 & 80 & 18 & 120 \\
3C263 & 528 & 21 & 330 &500 & 13 & 23 \\
3C334 & 20 & - &   6 & 18 & 3
& - \\
3C336 & 95 & 254 & 50 & 95 & 40 & 280 \\
3C351 & 201 & - & 156 & 202 & 1 &   5 \\
3C432 & 105 &   6 & 73 & 103 & 34& 280\\
\end{tabular}
\label{tab:flux}
\end{table}

\item The two effects of high flow velocity (the Doppler effect shifting a
curved spectrum in frequency and the relative flux boosting
of the approaching flow) may be
thought of as increasing the proportion of flat-spectrum component in the
jet-side hotspot. Even if the fast flow is confined to the hotspot,
it might be
suspected that, at the resolution used for the spectral-index analysis,
beam smearing could
spread a flatter spectrum from the hotspot to adjacent regions of somewhat
lower surface brightness.

To test that possibility, we used the three sources in which the spectral index difference $\alpha_j -\alpha_{cj}$ reverses between high- and low-surface-brightness regions (3C204, 3C334 and 3C336). If the above suspicion were well-founded, artificial spectral steepening of the jet-side hotspot spectrum alone should remove the correlation between jet side and flat spectrum. The jet-side hotspot was modelled using the {\sc AIPS} task {\sc IMFIT} to fit a 2D Gaussian and a sloping base level to the 5~GHz image used in our spectral-index analysis. This model was then used to remove 5~GHz flux progressively from the hotspot. Even when the amount of flux subtracted from the hotspot was large enough to produce a spectrum of the compact component which was steeper than that on the counter-jet side, there still remained a region of intermediate brightness which was largely unaffected by the changes to the hotspot, and which retained its flatter spectrum. Fig. \ref{hsremove} shows the results for a typical source (3C334). Thus it is clear that ``contamination'' of the intermediate surface brightness regions by an insufficiently resolved flat spectrum

hotspot is not enough on its own to account for the observations.
\end{enumerate}

\begin{figure}
\vspace{6cm}
\caption{The effects of removing a flat spectrum component from the jet-side hotspot in 3C334. The symbols indicate results after subtraction of 5~GHz flux. Horizontal binning bars are omitted for clarity; the flux subtracted is indicated in mJy in the legend. As progressively more flux is subtracted from the jet side hotspot, its spectrum necessarily becomes progressively steeper, but the intermediate surface brightness regions on the jet side still have flatter spectra.}
\label{hsremove}
\end{figure}

\begin{figure}
\vspace{14cm}
\caption{Detail of jet side lobes of 3C~208, 3C~334 and 3C~336. Grey scale shows spectral index on total intensity contours.}
\label{new}
\end{figure}

We conclude that, if relativistic motion is responsible for the spectral index asymmetry, then the fast forward flow is not confined to a single compact hotspot. What regions, then, might take part in this forward motion? It is well known that many sources have double or even multiple hotspots (3C351 is a striking example, and in the present sample 3C175, 3C334, 3C336 and 3C432 show double hotspots at higher resolution), but that by itself does not explain why there should be fast forward motion in both. One possibility is that the point of impact of the jet on the shocked intergalactic medium is recessed (i.e. not at the extreme end of the lobe) and fast flow continues beyond the initial hotspot, as the images of 3C204, 3C334 and 3C336 might indicate (Fig. \ref{maps}). Inspection of the spectral index image for 3C334 shows that a ridge with relatively flat spectrum indeed extends along the ridge of \hsb beyond the hotspot (Fig. \ref{new}b). At higher resolution (BHLBL), the hotspot of 3C336 (single in our maps) divides into two compact bright features. These coincide with two flatter-spectrum regions in Fig. \ref{new}c. 3C208 also has a recessed hotspot on the jet side, but in that case the flattest spectra occur on the hotspot and on a region extending northward from it (Fig. \ref{new}a), at about the same distance from the quasar, suggesting that the jet has split before reaching the hotspot, or perhaps that one of the flat-spectrum regions representsdan earlier hotspot, now detached from the jet but still being fed with high-speed material, as in the numerical simulations of Cox, Gull \& Scheuer \shortcite{cox91}. It is also possible that projection effects have transformed a gentle bend in the flow into a sharp ($>90^\circ$) change of direction, but that would imply a very small angle of source axis to line of sight, and a correspondingly large true aspect ratio for the source. Like 3C334 and 3C336, 3C47 and 3C175 show relatively flat spectra along \hsb ridges extending out of the jet-side hotspots, but in these sources the flow seems to turn through a (projected) right angle at the hotspot. Perhaps these flows have more in common with what is going on in 3C208 than with flows in 3C334 and 3C336.

\subsection{The length of the lobe and α in lower brightness regions}

Two obvious possible causes of the correlation of the continuum radio spectra with the size of the radio lobe are synchrotron loss and adiabatic expansion. We consider these in turn below.

\begin{enumerate}

\item Synchrotron losses

Other things being equal, the break frequency due to synchrotron loss varies as B^{-3} (B = magnetic induction). The equipartition estimate of B varies as (linear size)$^{-6/7}$, for given radio power. If, on the other hand, the magnetic field in the larger lobe is simply a homologously expanded copy of that in the smaller lobe, then $B \propto({\rm linear \; size})^{-2}$. In either case, the break frequency depends sensitively on linear size, and this dependence would produce a higher break frequency (and hence a flatter spectrum over a fixed frequency interval) in the larger lobe, i.e. a correlation in the sense that is observed. The theoretical predictions are more complicated if we compare regions of equal surface brightness in the two lobes, but in essence the result remains the same.

Blundell and Alexander (1994) pursued this line of argument to explain the correlation between jet side and flatter spectrum. They argued that the near (jet) side is observed at a later stage of development (owing to light travel time effects), and is therefore the larger. While we cannot accept that part of their hypothesis, because the longer lobe is on the {\em counter-jet} side in 5 of our 10 sources, the strong dependence of synchrotron loss on linear size remains a plausible explanation for spectral asymmetries in low-brightness regions.

\item Adiabatic losses.

The observation of spectral index gradients in the lobes indicates that individual regions have spectra steepening with frequency, possibly because of synchrotron losses (this need not conflict with a fairly straight spectrum for the whole source as many sources are dominated by radiation from hotspots where very little synchrotron loss has occurred at frequencies less than ~ 10GHz). We now ask how different amounts of expansion in the two lobes, acting on these curved spectra, might affect the differences between their observed spectral indices.

To isolate the effects of expansion, consider a simple model: two lobes were identical initially; then one expanded adiabatically by a linear factor R which is a little greater than 1. The magnetic field in the larger lobe becomes R^{-2} of the field in the corresponding bit of the smaller lobe, and the electron energy distribution is shifted downwards (electron energy $\propto R^{-1}$), with the result that the entire spectrum is shifted downwards in frequency by a factor R^{-4}. Thus we should expect the larger lobe to have a spectrum that is steeper over the same frequency range. This is the reverse of the observed correlation! Closer consideration tends to reverse that conclusion, for we must remember that we compare regions of equal surface brightness on the two sides.

Suppose that a certain region of the smaller lobe has spectral index $\alpha' and surface brightness S/Ω. The corresponding region in the larger lobe has spectral index
\[\alpha'=\alpha+4\ln R \frac{d\alpha}{d(\ln \nu)} \]

and surface brightness given by

\[\ln (S/\Omega)' = \ln (S/\Omega) - 4(1+\alpha) \ln R.\]

Therefore a region of surface brightness S/Ω, in the larger lobe, is expected to have spectral index

\begin{eqnarray}
\alpha'' &=&\alpha'+4(1+\alpha)\ln R \frac{d\alpha}{d(\ln S/\Omega)} \nonumber\\
 & = & \alpha + 4 \ln R \left(\frac{d\alpha}{d(\ln \nu)}
 + (1+\alpha)\frac{d\alpha}{d(\ln S/\Omega)} \right)
\end{eqnarray}

The last term is negative: brighter patches of source have flatter spectra. Thus we expect the larger lobe to have a flatter spectrum {\em for regions of equal surface brightness} if
\[\left|(1+\alpha)\frac{d\alpha}{d(\ln S/\Omega)} \right|
 > \frac{d\alpha}{d(\ln \nu)} \]

If we assume that the spectral gradient along the source is due to synchrotron losses we can evaluate the importance of adiabatic loss as an explanation for the observed correlation. We can calculate $\frac{d\alpha}{d(\ln \nu)}$ as a function of α from the synchrotron spectrum of a given theoretical electron energy distribution. The results are shown in Fig. \ref {func}, which shows the results for two values of injection index and the case of a sharp energy cut-off. Another energy distribution of interest, that with no pitch--angle scattering of the electrons \cite{Kardashev}, follows the above case closely, until α approaches $4\alpha_{injection}/3 + 1$, which is the maximum spectral index possible in this model, so that $\frac{d\alpha}{d(\ln \nu)}\rightarrow 0.$ $\frac{d\alpha}{d(\ln S/\Omega)} $ has to be estimated directly from our observations, as it involves the whole histories of synchrotron losses in different parts of the source.

The results are illustrated by Fig. \ref{func}. One point is plotted for each source; it represents the bin in Fig.~3 with the largest α in the larger lobe, i.e. usually the bin with the lowest surface brightness. No attempt has been made to estimate the errors in this procedure as the slopes were fitted by eye.

It can be seen that the points fall near the lines for two reasonable models of $\frac{d\alpha}{d(\ln \nu)}$. For adiabatic expansion to explain the observed correlation they would need to fall above the line.
We conclude that adiabatic expansion may contribute to the observed correlation in some cases, but is broadly neutral in this respect.\\

\begin{figure}
\vspace{6cm}
\caption{Lines of $\frac{d\alpha}{d(log\nu)}$ calculated for
energy spectra with a sharp energy cut--off, and injection spectral indices of
0.5(dotted line) and 0.75(solid line). Points represent values of
$(\alpha_{max}+1)|\frac{\Delta \alpha}{\Delta\log(S)}|$ for each
source. }
\label{func}
\end{figure}

It seems desirable to check the prediction that the larger lobe {\em as a whole} has the steeper spectrum, but it is not clear how to do so. The difficulty arises from the large contribution of the hotspot; if we excise the hotspot by a prescription such as `exclude everything above a certain surface brightness' we run into the same selection effects that we have just discussed. \\

\end{enumerate}

\section{Conclusions}

In a sample of ten high-powered radio quasars we have found the following correlations:
\begin{enumerate}
\item In regions of high surface brightness the radio spectrum is flatter on the jet side (9/10)
\item In regions of low surface brightness the radio spectrum is flatter on the long side (8/9)
\end{enumerate}

If jet sidedness is a manifestation of relativistic flow, as is commonly believed, then the strong correlation (9/10 sources) found here between the spectral index of the hotspot and the jet side indicates that the spectral difference between the two sides is also a relativistic effect.

In several sources of the present sample the jet-side hotspot is less bright than the hotspot on the counter-jet side (cf. Table \ref{tab:flux}); therefore forward beaming of the jet-side hotspot alone cannot account for txe observed correlation. We emphasise that this conclusion does not depend on assuming that the intrinsic radio powers of the radio hotspots are equal. If the spectral index difference between jet and counter-jet sides is due to the hotspots, we should expect the side with the brighter hotspot to have the flatter spectrum, regardless of why it is brighter. Furthermore, we have demonstrated that the correlation of flatter spectrum with jet side is not confined to the hotspot. Nevertheless, the correlation is presumably an orientation-dependent phenomenon, and we are forced to conclude that forward motion at a significant fraction of c also occurs in regions less conspicuous than that normally selected as `the hotspot'.

A calculation for theoretical spectra with injection spectral index of 0.5 show that a velocity of $ \approx 0.4c$ at 30^o to the line of sight (and correspondingly smaller speeds at smaller angles) is enough to cause the observed effect provided that the spectrum of the relativistic component is indeed curvev. Observational evidence for curved hotspot spectra at high resolution comes from Cygnus A \cite{car91}, but adequate resolution over a large frequency range is available for few (if any) other sources, and in particular for none of our sample.

A spectral index difference may also be created if we are viewing different parts of the flow on the two sides. In particular if we preferentially see backflowing material which is more expanded than forward flowing material, the result will be a steeper counter-jet side hotspot. This interpretation is supported by the more diffuse nature of the counter-jet side hotspots.

%Explanation in terms of differential aging is possible, in which the
%jet side has a lower magnetic field due to being older, however the
%suitability of such models close to the hotspot is questionable;
%equipartition estimates of the magnetic fields in these regions would
%also not always agree with such an interpretation.

We also note that the one source (3C~263) which disobeys the high surface brightness correlation also disobeys the \lang rule. This and the fact that the jet side is only $\sim$ half the length of the counter-jet side indicates that the source may be confined by a denser medium on the jet side. In this case it may be that environmental effects dominate. Hall et al. (1995) indeed find evidence for an X--ray emitting clump associated with the short lobe of this source.

The correlation of lobe length and radio spectra has as yet to be fully understood. One simple explanation is that it is due to differences in synchrotron losses in lobes of different volumes. As such it can be interpreted as an environmental effect due to the surrounding ambient gas containing the lobes. Further analysis and similar work on a sample of nearby radio galaxies in which these effects are expected to dominate is under way.

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FYI here's what I did with your comments. This might make it easier for
you to re-read the paper with an eye on changes.

Peter is away, uncontactable for a month from Sunday, and I would like to
get it submitted by then.... If it ain't possible then it ain't.

j.

> Title: Is "Jet-side" a good term to fossilize? Peter used it
> (unhyphenated) in the Stromlo title and I didn't question it there
> (because the paper had already been given with that title), but it
> seems a bit awkward. "Jets, lobe lengths and the spectral index
> asymmetry in quasars" might be an alternative?
>
yep, new title

> line 6, How about "We have tested this prediction using spectral imaging
> of a sample of quasars with well-defined jets, and we
> discuss whether the result ...."

changed it to look something liie this

> All through, the terms "image", "imaging" and "map", "mapping" are mixed.
> It would be better to pick one and stay with it (I prefer "image")?

"image" chosen

>
> p1, line 2 from end: don't like "visible" here --- "brighter radio" instead?

used "jet" than put our declaration of intent abt phrase" the jet" in the
next sentence.

>

> p2, line 1. Lot of characterizations of explanations as "natural" and "simplest"
>   etc. Do we need them? e.g. "The natural explanation" here is really
>   "The most widely-held" (could give refs.)A

have tried to rephrase all i found.

>
>   line 6 "3 to 6" not "3-6" ?
yes.
>
>   para.2 Is this the place to mention that there is no plausible
>   intervening-medium explanation for a high-frequency radio
>   spectral asymmetry (i.e. no orientation-based explanation likely
>   to be based on line-of-sight geometry alone, like the Laing-G
>   effect?)

it's mentioned next line...

>
>   line 8 from end; the registry of "standard ideas" may not be obvious to all
>   readers -- add references here?
i've added B&P84 and begelman,blandford& rees. was this what you had in mind?

>
>   last line: I think we should either explain what was drawn incorrectly, or
>   drop this comment. Maybe the best place for it is after our Figure
>   3, where we could say: "Note that these curves differ from those
>   shown in the preliminary report by Bridle et al. (1994)" and then
>   describe what differs, and why. As it is, it reads "there's a
>   discrepancy here, but we're not going to tell you what."
i've dropped it, but peter's on the case to tell me what actually was
wrong with it...

>
> p.3 line 2. "The brighter jet". Or say up front "we will use "the jet" to mean
>   the brighter, or only detected, jet, throughout this paper."
see above

>
>   para.3, last line I presume this refers is Robert's (Hot Spot Workshop)
>   correlation, which should be referred to. And "preferentially"
>   rather than "often found on" ?
yes.

>
>   sec 2.1, first sentence I suggest:
>
>   "Because we wish to explore the spectral index distribution, we are
>   restricted to a fairly small sample ...."
>
>   "imaged" for "mapped"
>
>   delete "very" before detailed
>
> p.4 Table 1 capitalize column headings; put MHz in brackets
>
>   line 1, 3C68.1 in parentheses, say "jet sidedness is ambiguous"?
>

>   sec 2.2, line 1   define \uv as {\sl uv} or {\sl u-v} everywhere; inconsistent
>   at present
>
>   line 9 typo : transferred
>

all of the above seen to.

> p.5 line 4. term "residual spectral index" should be defined, it's not a
>   widespread term.

i hope its clearer now.

>   line 5   "data" missing after 5 GHz?
>   line 6   delete "over a reasonable frequency range". (That's for reader to decide?)
>   line 7   what is meant by "limited by reconstrction errors" and how do we tell?
>   this needs amplification; the point is important.

its a phrase used by conway et al it the pape i refer the reader to.
(what it means essentially is errors in "reconstructing" the filled uv
plane using imaging algorithms.) i have rephrased this sentence, so i
hope it is less bothersome.

>   para.2   again, "maps" start up again where "images" have been used elsewhere
>
>   more to the point, Jy/dirty beam (area) is not well-defined, as
>   the dirty beam does not have a well-defined area. (This is one
>   reason why we replace it with a gaussian CLEAN beam). Do we need to step
>   into the units tar-pit at all? How about "All images were CLEANed until
>   the residuals were less than n sigma, to ensure that all significant
>   emission was restored with the same effective$resolution by CLEAN".

well, i didn't make the some of the images. whilst i cleaned the ones i
made to 1 sigma, to be honest i don't really know how far the others were
cleaned. They just have a huge round number of iterationsdone on thm. i
think its satisfactory, but i don't think we should say n sigma to this.

>
>   last line I'm worried about quoting generic NED-found total flux densities.
>   Only way anyone can check us out is to go look in NED, and the
>   entries there can change with time. I think we should quote the
>   real origins of these flux densities, so that anyone with questions
>   about their epoch and/or calibration can check us out. By the
>   way, I looked up the PTWH/BDFL-era flux densities from the 300-ft
>   for all of them (1400 MHz):
>   It might be interesting to compare these with the numbers you used.

ok.

> p.6 Table 2 caption should identify these as 1,4 GHz parameters?
>
>   line 4. How about "A fundamental complication is soon obvious:"
>
>   line 8 What makes a source "ideal"? Can't be exact symmetry, but are you
>   visualizing something like "scaleability"? Needs amplification.
>
>   line 6 from end. 1. (period)

>
> line 4 from end: took two readings to realize that this was _defining_
> "moderately reliable". Need, "as follows" before ":" in
> next line?
>
> p.8 Fig.2 caption typos: 1.4~GHz, illustrative purposes

all done.

>
> line 1. how many beams are reasonable? Quantify.

this was troublesome - the number of beams that's reasonable dependes on
the avergae s.b. of the region. i think howver that your question is
entirely legitimate and have tried to do something abt it.

>
> line 6. "cereal bowl" zero-level depressions don't behave like this,
> however. So make it clear that this means "DC zero level offsets"
>
> line 5 from end drop "actually"
>
> last line "regions of highest surface brightness", "of lowest surface brightness"
> better
>
> Fig.3 caption Identify as 1.,4 to 5 GHz spectral index in caption
> Can we have mJy/beam rather than mJy/bm in labels, too?
>
> Fig.4 I seem to have harvested only one ps file for this double-panel fig, I
> need to check into that.

do you still need this??

>
> p.10, line 3 delete "single

still there for emphasis

> line 6 "we note that" instead of "it was noticed that"

it has been changed to "we noticed that". "we" and past tense because its
part of a story which continues in the next sentence.

> line 7 "and departs from the Laing-Garrington correlation"
> p.11 para. 3 "For completeness" sentence lready implied earlier, should
> consolidate with the comments on 3C263?

the first reference to LG effect in 3c263 was removed, so hopefully
dealing with both these points.

>
> sec. 4.1, line 1: Why "very simplest"? Seems an uncessary characterization
> that not everyone need agree with. How about:
>
> "One way to obtain a spectral index asymmetry in a relativistically-
> expanding source would be to postulate that the intrinsic spectrum
> is curved and that the asymmetry is produced by the Doppler shift.

> If the spectral index increases with frequency, and the approaching
> lobe is seen at a significantly lower emitted frequency, an
> asymmetry of the right sense could be produced. In most models
> of lobe dynamics (references?), the expansion velocities of the
> low-brightness regions are unlikely to exceed a few per cent of c,
> however, so it is difficult to see how this effect could account
> for large-scale spectral asymmetries, even if the istrinsic spectra
> are curved".

a few minor alterations, but essentially i've inserted this.
>
> last 3 lines: make it clearer that this is talking about the part of
> Doppler boosting (aberration), that is not simply the
> Doppler shift effect described above?

done.
>
> p.12 I have a generic problem with the approach to the Table that may arise because
> we haven't defined what a hot spot _is_ in this paper. BHLBL adopted a rather
> strict, if arbitrary, definition and then listed components that conformed to
> it. They also based their numbers on the high-resolution images, with a little
> help from MEM and modeling in the case of 3C432. While it's interesting to see
> what numbers Peter got when turned loose without those constraints, it's not
> at all clear to a reader (a) why only Peter was chosen and (b) what his
> criteria may have been. I think this should handled rather differently.
> One approach would be to state "BHLBL (1994) derived flux densities
> for compact hot spots meeting their restricted definition, and also estimated
> integrated flux densities for more diffuse hot spot "candidates", based on

[snip]]
see what you think of the added sentences.

> line 12 "frequency shifting" of a curved spectrum, as opposed to
> "Doppler effect shifting"?
>
> line 13 "flux boosting" conventionally includes the effect of the
> previously-mentioned frequency shift, should we be more
> explicit here and say the "photon number and bandwidth" effects
> for example?

no, i don't think this is the point here. there's a problem with the term
"flux boosting" because of what people think does and doesn't come with
it. we have tried to separate out the effect of viewing a different part
of the spectrum, and the effect of having a brighter flat spectrum cpt
(due mainly to aberration) on top of a steep spectrum cpt. (ala Tribble)

>
> line 15 "our spectral" (not just L-band) images

left this out in the belief that the defining thing was the L band image.
>
> last line. Ah, definition needed again. How was the thing that was
> modeled defined. Does it, perchance, agree with the
> thing that was modeled by BHLBL? If so, we might say so.
> Or was it defined entirely at the lower resolution?
> If at the lower resolution, to what extent does the model
> already contain the smearing effect (could compare the
> modelled sizes with BHLBL's to check this)

try the new words. we can discuss this further if necessary.

>
> p.13 line 2 hot spot (typo), also line 7
>
> Fig.5 caption indicate (typo)
>
> line 9 an insufficiently
>
> line 11 I'd like to add "compact" after "single".
>
all done.

> line 4 from end. Not clear why 3C208 isn't in this list.

because the list was meant to be recessed+continuing flow. hopefully new
wording expresses this.

>
> Around this part, I was getting bothered by use of the term 'relatively
> flat spectrum". If the benchmark is work on jet bases and cores,
> 0.7 is not "flat". Is "relatively lower spectral index" to be avoided?

relatively flat wrt the surround (non-ridge) material. P & I are happy
with this formulation. if you still don't like it come again....

>
> p.14 last line "a" before "relatively"
>
> p.15 line 2. Break sentence to start new one with "Perhaps"
>
> line 6. I was wondering here what was being assumed (flux conservation,
> field configuration, etc). The assumptions are spelled out
> later, so maybe here we should mention just the two effects and
> not jump to their conclusions until after the assumptions have been
> given? I.e. say "Two candidates are: synchrotron losses, and
> adiabatic expansion." Then skip to the sections on these effects,
> letting them summarize themselves.
>
yes, for the last point see new words.

>
> line 14 "this dependence would produce a higher break" ?
>
> line 20 "correlation between jet side and flatter spectrum"
>
> line 24 "the strong dependence of synchrotron loss on linear size is a
> plausible explanation ...."
>
> line 4 from end the "presumably" is controversial, e.g. Rudnick & Katz-Stone
> argue that it has nothing to do with synchrotron loss.
> Does equation (1) not apply whether or not the curvature
> is due to synchrotron loss? If so, why not state the
> condition for equal-brightness spectral flattening first,
> then point out how this comes out for the case of particular
> synchrotron-loss models.

i hope this is now better

>
> I don't think I have Fig.7 so I can't comment on it yet.

comments yet?

>
> p.18 line 7 should state that this "cannot" is assuming the hot spots are intrinsically
>   equal in brightness.

see the text.

>
>   line 8 don't need the trailing "only"
>
>   line 11 I don't like "instinctively". I don't think we have instincts about
>   hot spots, not even as radioastronomers. If we don't sign on to
>   a definition anywhere in the paper, we will have to waffle at this
>   point, but maybe we could say "normally" rather than "instinctively"?
>
>   line 15 "spectra" instead of "components" ?
>
>   line 10 from end (3C362) after "one source"
>
>   line 7 from end "Hall et al. (1995) indeed find evidence for a clump of
>   X-ray emission associated with the short lobe of this source".
>
>   line 4 from end "understood" for "analysed"? We have analysed, we have not
>   understood!
>
>   I'd also prefer "but a simple explanation is that is due ...."
>   (let the reader decide whether it is the simplest, most credible, etc.~)
>
> Generally: uses "flux" lots of places where it means "flux density"
>

yes.

> Overall, mostly nits, as obvious from the comments. I think the
> biggest problem is that we don't have a hot spot definition but we
> want to say that whatever the definition might reasonably be, the
> spectral index asymmetry comes from something larger than you might
> expect. I presume that had you modeled the hot spot removal in Fig.5
> using the higher-resolution models, then you would have found even smaller
> effects, i.e. that the procedure you used was generous to the explanation,
> yet it still failed. Maybe that point should be made.

maybe maybe not. i think perhaps if i modelled all the bright cpts that
were hotspot candidates the effect would probably go away. if i chose the
designated BHLBL hotspot it, as you say, would show even smaller effects.
maybe, as you suggest we should say this, although i think its implied in
the conclusion. i'm willing to emphasise it though if you see fit.

cheers,
jane

From VM Thu Jun 27 09:48:59 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
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id AA43966; Thu, 27 Jun 1996 09:48:44 -0400
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References: <9606112001.AA36992@polaris.cv.nrao.edu>
<Pine.SOL.3.91.960619141658.22140A-100000@mraose>
Jrom: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: the paper
Date: Thu, 27 Jun 1996 09:48:44 -0400

Hi Jane,

I read the redraft that Robert E-mailed last night, and it looks good. It is much clearer in several places, and indeed cleared up a couple of misunderstandings I had formed from previous version.

I have only one comment re emphasise, again from the "difficult" paragraph (i) on p.13, which I think may still confuse a reader who is unprepared for seeing two sets of estimates of the same quantity by (some of) the same authors.

I think the key sentence in this paragraph is the one beginning "In the majority of sources ...." and it is important that this sentence is correct whichever set of hotspot criteria is used. I would like to reinforce this by adding just one phrase, as follows:

In the majority of the sources, there is a good case for asserting that the jet-side hotspot is the brighter of the two, but there are striking exceptions---3C\,175, 3C\,208, 3C\,336---{\it whichever set of hotspot criteria is used}. In such sources, the flatter spectrum on the jet side obviously cannot be blamed ....

This makes it clearer _as we deliver the conclusion_ that the conclusion itself is robust against the details.

With that inclusion, the last sentence of the paragraph could be deleted, but if you prefer to leave that sentence in for further emphasis, I think it would help to insert the word "hotspot" before the last word "definitions".

On everything else, I'm happy to go with the flow, but there are a small number of administrivia that it would be nice to fix before it is submitted if possible:

1. NRAO acknowledgement. The requested form of this changed about a year ago to: "National Radio Astronomy Observatory, a facility of the National Science Foundation, operated under cooperative agreement by Associated Universities, Inc." Sophistry, but please make the change otherwise I get chased by Ellen and Bob when they see the preprint. I'm supposed to make a fuss to co-authors about these things, and this

is the fuss......

2. My address. Capitalize the A in Va (it's like your post code)

3. p.5, sec 2.2 line 4, space between 5 and GHz

4. p.6, last sentence (BDFL only went down to 1.8 Jy):

The single dish flux densities used were the 1400 MHz values of Pauliny-Toth, Wade, \& Heeschen (1966) and Bridle et al. (1972), corrected .....

and the extra reference needed is

Pauliny-Toth I.I.K., Wade C.M., \& Heeschen D.S., 1966, ApJSuppl, 13, 65.

5. last para "maximum entropy" is usual name of algorithm, not "maximum likelihood". There have been some religious wars over the term "entropy" but if this is just a typo, it should be corrected. If someone among the authors has a Jihad going against "entropy" however this is one to fix after we get the referee's report!

6. p.20 top line delete "as" before "yet" ?

7. References.

Delete \&, add commas in: Baars et al., McCarthy et al. Note no "e" in McCarthy.

For some reason the Bridle et al. references are in exact reverse alphabetical order! Also the AJ paper is 1994, not 1993.

Bridle et al. First Stromlo Symposium: Capitalize book title

Garrington, Leahy, Conway & Laing is out of order

Laing 1989, space between p. and 95

Comma shortages:

Garrington et al. 1991 needs one after Conway R. G.
Laing 1989 needs one after R\"oser H.-J.

Comma excesses (if I am interpreting unfamiliar MNRAS rules right):

After Baars, Genzel, Pauliny-Toth, Witzel in Baars et al.
Barthel in Barthel
Alexander in Blundell & Alexander
Laing, Scheuer, Turner in Bridle et al.
Laing in Bridle et al.
Cornwell in Comway et al.
Fanaroff, Riley in FR
Laing in Garrington et al. 1988
Conway in Garrington et al. 1991
Liu in both Liu & Pooley refs
McCarthy, van Breugel, Kapahi in McCarthy et al.

Scheuer in both Scheuer refs
Zensus, Pearson in Scheuer 1987

Comma<--->period swap

after 1994 in Blundell & Alexander
after 1990 in Conway et al.

That's it. Looks good. Go for it by Sunday!

A.

From VM Thu Jun 27 12:07:52 19i6
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["1281" "Thu" "27" "June" "1996" "15:21:31" "+0100" "Jane Dennett-Thorpe" "jdt@mrao.cam.ac.uk" nil "25" "Re: the paper" "^From:" nil nil "6" nil nil nil nil]
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id AA47926; Thu, 27 Jun 1996 10:21:37 -0400
Received: from mraos.ra.phy.cam.ac.uk (root@mraos.ra.phy.cam.ac.uk [131.111.48.8]) by cv3.cv.nrao.edu (8.7.5/8.7.1/CV-2.1) with SMTP id KAA18806 for <abridle@nrao.edu>; Thu, 27 Jun 1996 10:21:35 -0400 (EDT)
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X-UIDL: 835886637.000
Status: RO
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@nrao.edu>
Subject: Re: the paper
Date: Thu, 27 Jun 1996 15:21:31 +0100 (BST)

hi Alan,
thanks for that.

Yes, I agree things have been made clearer (the relief...!)
there's two non-trivial (or not totally trivial at any rate) things left:
one is that I discover that I *did* use the high resolution image to fit
hotspots to (i.e. its like BHLBL but it isn't exactly because at that time I
hadn't seen that paper), I then notice I convolved these images down (I
didn't really know what the problems were at this stage) and used them
directly for the hotspot removal tests. I'm presently running a test to
make sure this doesn't change the conclusions. (i'm pretty sure it won't
because the s.b. vs. spectral index plots look pretty much the same in
both cases.) Should've subtracted them from the other maps. But I didn't
(because, naturally there were technical problems of alignment and I
didn't think it mattered so went for the easy option...)

Second is this single dish flux thing. The reason I originally used NED
was to enable me to interpolate to the correct freq, now we've got only
1400MHz obs this isn't done, but as you see, the numbers haven't changed
much. I wonder if the table shouldn't actually be deleted? I'm not sure
it tells us much, or would convince anyone of anything we need to convince
them of. What do you think?

j.

From VM Fri Jun 28 13:01:00 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["1283" "Fri" "28" "June" "1996" "16:42:53" "+0100" "Jane Dennett-Thorpe" "jdt@mrao.cam.ac.uk" nil "34" "single dish fluxes" "^From:" nil nil "6" nil nil nil nil]
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Received: from mraosa.ra.phy.cam.ac.uk by mraos.ra.phy.cam.ac.uk with smtp
(Smail3.1.29.0 #2) id m0uZfh8-0003EQC; Fri, 28 Jun 96 16:42 BST
X-Sender: jdt@mraosa
In-Reply-To: <Pine.GSO.3.93.960628150549.12407A-100000@rgosf>
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X-UIDL: 835978353.000
Status: RO
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Robert Laing <rl@ast.cam.ac.uk>
Cc: Patrick Leahy <apl@jb.man.ac.uk>,
Alan Bridle <abridle@polaris.cv.nrao.edu>
Subject: single dish flu:es
Date: Fri, 28 Jun 1996 16:42:53 +0100 (BST)

here's the % of the single dish fluxes interpolated (to L band obs freq)
using values from Laing & Peacock:

3C	%
47	93
175	105
204	89
208	104
249.1	104
263	103
334	87
336	99
351	84
432	104

I have to admit at this stage, that I put them in because I didn't think they looked very healthy. But then i looked at the fluxes in NED and found that the different L band measurements over the years have varied in some cases quite substantially (which was my reason for using all the data i could from NED in the first case, which Alan didn't like, and i quite take his point. FYI those numbers are still behind the comment marks in the .tex file). There is a problem then, which maybe needs to be explicitly addressed: there is a potential missing flux problem and also an apparent problem with these measurements (either they aren't true now, or they never were!) i don't for example think we only have 87% of the flux on 3C334 - its a healthy looking image (one of the best).

The lowest contour on the map of 3C351 is 2.28mJy/bm: if Paddy's image is as good as he says, then I think we should use it (so that's as "yes please" to your question Paddy) and then maybe we don't need this table even, but a generic statement about how much flux we may be missing.
jane.

From VM Fri Jun 28 13:01:00 1996
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id QAA12613; Fri, 28 Jun 1996 16:54:02 +0100
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Status: RO
From: Robert Laing <rl@ast.cam.ac.uk>
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Cc: Patrick Leahy <jpl@jb.man.ac.uk>,
Alan Bridle <abridle@polaris.cv.nrao.edu>
Subject: Re: single dish fluxes
Date: Fri, 28 Jun 1996 16:54:01 +0100 (BST)

On Fri, 28 Jun 1996, Jane Dennett-Thorpe wrote:

>
> here's the % of the single dish fluxes interpolated (to L band obs freq)
> using values from Laing & Peacock:
>
> 3C %
> 47 93
> 175 105
> 204 89
> 208 104
> 249.1 104
> 263 103
> 334 87
> 336 99
> 351 84
> 432 104
>

I don't think that those are too bad - the mean is 97%, after all. What
are the corresponding values at 5GHz? That might give us a clue.

Robert

From VM Fri Jun 28 13:01:00 1996
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id AA43195; Fri, 28 Jun 1996 13:00:06 -0400
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Organization: NRAO Charlottesville
Reply-To: abridle@NRAO.EDU
Priority: normal
X-Mailer: Pegasus Mail for Windows (v2.23)
From: "Alan Bridle" <abridle@NRAO.EDU>
To: jdt@mrao.cam.ac.uk
Cc: abridle@nrao.edu
Subject: Re: single dish fluxes
Date: Fri, 28 Jun 1996 12:55:00 -0400

On 28 Jun 96 at 16:42, Jane Dennett-Thorpe wrote:

>
> here's the % of the single dish fluxes interpolated (to L band obs
> freq) using values from Laing & Peacock:
>
> 3C   %
> 47 93
> 175   105
> 204   89
> 208   104
> 249.1   104
> 263   103
> 334   87
> 336   99
> 351   84
> 432   104
>
> I have to admit at this stage, that I put them in because I didn't
> think they looked very healthy. But then i looked at the fluxes in
> NED and found that the different L band measurements over the years
> have varied in some cases quite substantially (which was my reason
> for using all the data i could from NED in the first case, which
> Alan didn't like, and i quite take his point. FYI those numbers are
> still behind the comment marks in the .tex file). There is a problem
> then, which maybe needs to be explicitly addressed: there is a
> potential missing flux problem and also an apparent problem with
> these measurements (either they aren't true now, or they never
> were!) i don't for example think we only have 87% of the flux on
> 3C334 - its a healthy looking image (one of the best).

Reasons why single-dish total flux densities may "vary":

1. Nuclear sources vary.

2. Different flux density scales or secondary calibrators were used by single dish observers at different epochs.

3. Smaller single dishes may add confusion or (in the older days) be giving significantly noiser data. Data from 100-m class instruments like NRAO 300-ft and Bonn are freer from both problems, some of the other NED entries might not be.

3C334 _is_ somewhat confused, not just the strangely-aligned BHLBL "A" component, but an 88 mJy (at 5 GHz) source to the NE that we also mentioned there (because we had to include it in the self-calibration).

I believe that 3C351 is our actual "worst case" and that our other images probably have within 10% of the true total flux density. To do much better than that, we would need to examine all of the single-dish papers carefully with regard to their calibrations. We would need to know which secondary sources were used, rather than applying "global" scale factors, to have a hope of reaching the few-per-cent level. (That was why BDFL gave its calibration table explicitly, BTW.) I would bet that the main reasons for discrepancies with BDFL (after scale and frequency adjustment) would be real variations in the nuclear sources since that long-ago epoch, and confusion in the case of 3C334.

Discrepancies with "generic" values listed by NED could contain other calibration factors as well as these, depending on how extensively the original observers had verified their calibration. Our mileage would vary; I am sure Laing & Peacock selected carefully for their paper!

The bottom line is that we can't really expect the factors to be the same from source to source, so I'm a little leery of giving a "generic" number. Reporting the individual ratios (with some exceeding 100%) does at least give an impression about the degree of convergence in the process, as well as alerting the reader to the worst potential "problems".

A compromise would be to discuss the 3C334 and 3C351 cases explicitly and give a generic number for all the others?

A.

From VM Fri Jun 28 14:20:19 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
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Status: RO
From: abridle (Alan Bridle)
To: jpl@jb.man.ac.uk
Subject: forwarded message from Alan Bridle
Date: Fri, 28 Jun 1996 13:01:49 -0400

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0 id AA28087; Fri, 28 Jun 1996 12:59:58 -0400
Message-Id: <9606281659.AA28087@polaris.cv.nrao.edu>
Comments: Authenticated sender is <abridle@polaris.cv.nrao.edu>
Organization: NRAO Charlottesville
Reply-To: abridle@NRAO.EDU
Priority: normal
X-Mailer: Pegasus Mail for Windows (v2.23)
From: "Alan Bridle" <abridle@NRAO.EDU>
To: jdt@mrao.cam.ac.uk
Cc: abridle@nrao.edu
Subject: Re: single dish fluxes
Date: Fri, 28 Jun 1996 12:55:00 -0400

On 28 Jun 96 at 16:42, Jane Dennett-Thorpe wrote:

>
> here's the % of the single dish fluxes interpolated (to L band obs
> freq) using values from Laing & Peacock:
>
> 3C %
> 47 93
> 175 105
> 204 89
> 208 104
> 249.1 104
> 263 103
> 334 87
> 336 99
> 351 84
> 432 104
>
> I have to admit at this stage, that I put them in because I didn't
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> NED and found that the different L band measurements over the years
> have varied in some cases quite substantially (which was my reason

> for using all the data i could from NED in the first case, which
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> still behind the comment marks in the .tex file). There is a problem
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The bottom line is that we can't really expect the factors to be the same from source to source, so I'm a little leery of giving a "generic" number. Reporting the individual ratios (with some exceeding 100%) does at least give an impression about the degree of convergence in the process, as well as alerting the reader to the worst potential "problems".

A compromise would be to discuss the 3C334 and 3Cg51 cases explicitly and give a generic number for all the others?

A.
------- end -------

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From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@polaris.cv.nrao.edu>
Subject: lisbon
Date: Fri, 28 Jun 1996 19:10:09 +0100 (BST)

Alan-

sorry i thought i sent you a msg earlier today, but just realised i didn't.
the news is out (unofficially) on the ceres job: i have been offered a
place in lisbon.

which is great news. a bit disconcerting though as i've never been to
portugal or lisbon, and haven't (knowingly) met maria marcha who i"ll be
working with. its a very small group, but the point of the network is to
be a network so maybe that's not as bad as it might be.

i'll be visiting within a few weeks so i can get some idea of what i feel
about the place more realistically (at the moment i just feel excited and
pretty nervous). of course i now have a thesis to write in a hurry- but
that's ok, i'll manage it (or something approximating it!).

as well as giving you the news i also wanted to thank you for your
reference. (as well as for the advice, hostpitailty, emails and fairly
frequent support and encouragement without which i wouldn't have been in
this position either)

jane.

From VM Fri Jun 28 14:30:22 1996
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From: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: lisbon
Date: Fri, 28 Jun 1996 14:30:10 -0400

Jane Dennett-Thorpe writes:

> i have been offered a place in lisbon.

Wonderful!

>
> i'll be visiting within a few weeks so i can get some idea of what i feel
> about the place more realistically (at the moment i just feel excited and
> pretty nervous). of course i now have a thesis to write in a hurry- but
> that's ok, i'll manage it (or something approximating it!).
>

When would you be starting if you accept?

> as well as giving you the news i also wanted to thank you for your
> reference. (as well as for the advice, hostpitailty, emails and fairly
> frequent support and encouragement without which i wouldn't have been in
> this position either)
>

You are more than welcome, of course.

Will it stay cool enough for you in Lisbon, or will you have urgent
business in Manchester and Dwingeloo when summer comes (like I head
for Canada a few weeks from now?)

Great news, I hope you'll find it the right mix of good science
and pleasant surroundings ....

A.

From VM Wed Jul 3 14:35:47 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
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From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Patrick Leahy <jpl@jb.man.ac.uk>
Cc: Robert Laing <rl@ast.cam.ac.uk>, Alan Bridle <abridle@polaris.cv.nrao.edu>
Subject: update
Date: Tue, 2 Jul 1996 22:05:16 +0100 (BST)

Hi,
Just to let you know that I've dealt with everyone's latest minor comments (presentation, wording etc), apart from the idea of greyscales for fig.1.

Have now included 5GHz fluxes and % of single dish in the flux table, and with Paddy's map the %flux in 3C351 goes from 84% -> 90%. i am however not incredibly happy about using that, given the fuss we make about matching baselines.... (Paddy told me its B+C... did you mean A+B?? but anyway, doesn't match B array C band) The results fom this new image are no easier to interpret than the previous, but the js hotspots no longer appear as flat (prob no flatter than cjs)

As for Paddy's suggestion that we test hotspot contamination directly: we have to agree on what the are relevant fluxes to be taken off both images: does the peak flux satisfy everyone? although we have BHLBL's 5GHz hotspot fluxes at high resolution, we can't do this for the L band images. I'm not terribly sure this proceedure is very meaningful, but it seems the only thing available for all sources. it doesn't of course account for the jet either, but i could excise it around the contours shown in fig 1.

jane

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with SMTP id JAA26431 for <abridle@nrao.edu>; Wed, 3 Jul 1996 09:28:40 -0400 (EDT)
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id AA36128; Wed, 3 Jul 1996 09:28:27 -0400
Message-Id: <9607031328.AA36128@polaris.cv.nrao.edu>
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Reply-To: abridle@NRAO.EDU
Priority: normal
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X-UIDL: 836405114.000
Status: RO
From: "Alan Bridle" <abridle@NRAO.EDU>
To: jdt@mrao.cam.ac.uk
Cc: abridle@nrao.edu
Subject: Re: update
Date: Wed, 3 Jul 1996 09:23:49 -0400

On 2 Jul 96 at 22:05, Jane Dennett-Thorpe wrote:

> Hi,
> Just to let you know that I've dealt with everyone's latest minor
> comments (presentation, wording etc), apart from the idea of
> greyscales for fig.1. Have now included 5GHz fluxes and % of single
> dish in the flux table, and with Paddy's map the %flux in 3C351 goes
> from 84% -> 90%.

This is getting hard to follow without seeing the other co-author's
messages. It sounds as if there was a particularly detailed one from
Paddy -- could someone copy it to me?

> i am however not incredibly happy about using that,
> given the fuss we make about matching baselines.

Neither am I, as it does not eliinate possible bias if we get
more of the flux at one frequency but not at the other. The
ideal would be to match the u,v coverage _and_ to demonstrate that
we have imaged a large fraction of the total intensity at both
frequencies. Falling short on the flux density differently at the
two different frequencies doesn't get us out of the woods. The
bottom line is that we cannot be confirent of any trends that are
governed by the sources for which we have significant missing
emission, _or_ significantly different u,v coverage. The most secure
results are the ones we can see in sources with matched coverage
and with most of the flux density in both images. 351 will end up with
less "weight" in this sense whatever we do.

> As for haddy's suggestion that we test hotspot contamination
> directly: we have to agree on what the are relevant fluxes to be

> taken off both images: does the puak flux satisfy everyone? although
> we have BHLBL's 5GHz hotspot fluxes at high resolution, we can't do
> this for the L band images. I'm not terribly sure this proceedure is
> very meaningful, but it seems the only thing available for all
> sources. it doesn't of course account for the jet either, but i
> could excise it around the contours shown in fig 1.

I think the peak flux density at the common resolution is a
reasonable thing to try. If we use the BHLBL fit, we would need
to try a variety of assumed spectral indices, and see if any of the
assumed indices leaves a more "reasonable" residual pattern than
others.

The latter approach would be a bit like a partial "tomography"
-- using Larry Rudnick's favorite terminology for his technique in
which you construct a "difference cube", the planes of which are
S(nu_1) - x.S(nu_2) with different values of x corresponding to a
raster in spectral index, i.e. x = (nu_2/nu_1)^(alpha). A feature
of given spectral index alpha simply disappears from the plane of the
cube that corresponds to its value of x -- whatever the shape of the
feature and whatever the background it is superposed on. Looking
at such a cube with TVMOVIE could test whether anything
hot-spot-related contains an identifiable spectral index, whether or
not the feature matches any preconception as to shape (or
the high-resolution model). Might this (a full "tomography") be
worth a try at this late stage?

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X-VM-v5-Data: ([nil nil nil nil t nil nil nil nil]
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From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@polaris.cv.nrao.edu>
Subject: lisbon
Date: Tue, 23 Jul 1996 12:49:45 +0100 (BST)

hi alan

i have just got back from lisbon, and think i am likely to take the job.
i liked maria marcha (a good thing considering there will be two of us,
maybe four, sat on top of some hill in the old observatory building
outside lisbon!) and liked the project.

i am naturally worried about all sorts of isolation: intellectual,
personal and cultural, but think i'm prepared to take up the challenge.
two years, afterall, isn't a very long time.

so the plan at the moment is : thesis by 1 nov, start 1 dec.

will keep you posted,
jane.

From VM Sat Aug 10 22:48:23 1996
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From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@polaris.cv.nrao.edu>
Cc: Robert Laing <rl@ast.cam.ac.uk>, Patrick Leahy <jpl@jb.man.ac.uk>
Subject: the version that might just be nearly, well, final-ish....
Date: Wed, 7 Aug 1996 20:01:37 +0100 (BST)

...but Peter has some things to say, on inclusion of table 3. Expect
his comments to follow (they haven't already been sent)
Comments appreciated, complaints less so, but tolerated :)
jane

```
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\newcommand{\lang}{Laing-Garrington }
\newcommand{\lp}{Liu-Pooley }
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\newcommand{\js}{jet side}
\newcommand{\cjs}{counter-jet side}

\begin{document}
\title[Jets, lobe length \& spectral index]{Asymmetry of jets, lobe length
and spectral index in quasars}
\author[J. Dennett-Thorpe et al.]
  {J. Dennett-Thorpe,$^1$   A.~H. Bridle,$^2$ P.~A~.G Scheuer ,$^1$ \cr
   R.~A. Laing $^3$ and J.~P. Leahy $^4$ \\
    $^1$ Mullard Radio Astronomy Observatory,
    Cavendish Laboratory, Madingley Road, Cambridge CB3 0HE \\
    $^2$ National Radio Astronomy Observatory,
    520 Edgemont Road, Charlottesville VA 22903-2475, USA  \\
    $^3$ Royal Greenwich Observatory, Madingley Road,
    Cambridge CB3 0EZ  \\
    $^4$ Nuffield Radio Astronomy Observatories, Jodrell Bank, Macclesfield,
    Cheshire SK11 9DL }

\date{Received }
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\maketitle

\begin{abstract}
The less depolarized lobe of a radio source is generally the lobe containing the jet (Laing-Garrington correlation) but the less depolarized lobe is also generally that with the flatter radio spectrum (Liu-Pooley correlation). Both effects are strong; taken together they would imply a correlation between jet side and lobe spectral index, i.e. between an orientation-dependent feature and one which is intrinsic. We test this prediction using detailed spectral imaging of a sample of quasars with well-defined jets and investigate whether the result can be reconciled with the standard interpretation of one-sided jets in terms of relativistic aberration. Our central finding is that the spectrum of high surface brightness regions is indeed flatter on the jet side, but that the spectrum of low surface brightness regions is flatter on the side with the longer lobe. We discuss possible causes for these correlations and favour explanations in terms of relativistic bulk motion in the high surface brightness regions and differential synchrotron ageing in the extended lobe material.
\end{abstract}

\begin{keywords}
jets -- spectral index -- asymmetry -- quasars
\end{keywords}

\section{Introduction}
\subsection{The problem}
Laing, Garrington and colleagues \cite {gnat,ral} showed that the lobe of a powerful radio source containing the jet is almost invariably less depolarized than its counterpart on the opposite side of the nucleus; 39 out of the 47 sources in Tables~3 to 6 of Garrington, Conway \& Leahy \shortcite{gcl} obey the Laing--Garrington rule (only 4 sources definitely show the reverse effect).
These sources all have FRII morphologies \citeuFR} and most are quasars, although a few radio galaxies are included. Very few FRII sources have detectable jets on both sides of the nucleus, and we will use the term ``the jet'' to refer to the brighter (in almost all cases the only) such feature. The most widely accepted explanation of the Laing--Garrington effect is that jets are intrinsically two-sided and relativistic: the nearer one appears brighter as a result of Doppler beaming and radiation from its lobe passes through less of the depolariztng medium around the source \cite{ral,gar91}. Thus the Laing--Gnrrington effect is explained as a consequence of orientation.

Liu \& Pooley \shortcite{lpa} found that there is also a strong correlation between depolarization and lobe spectral index: the lobe with the flatter spectrum is the less depolarized. Their original sample contained a majority of sources without detectable jets, but 33 of the 47 sources with strong jets in Tables~3 to 6 of Garrington {et al.} also obey the Liu--Pooley rule.

Taken together these two strong correlations imply that the lobe spectrum is flatter on the jet side of a source. According to the standard model of an \egrs the lobe material is almost static relative to the host galaxy and therefore any motion of the lobe material is inadequate to account for significant differences between the lobe spectra as an orientation-related effect. Thus the two correlations together constitute a {\it prima facie} case against the standard model of `Doppler-boosted' relativistic jets.

The most plausible defence is that intrinsic and orientation effects both operate:
\begin{enumerate}
\item The \lang sample includes only sources with detected (and, in most cases, prominent) jets. The majority are identified with quasars, which tend to have much brighter jets than radio galaxies of the same total power. By contrast, the \lp sample was not selected on jet emission, and consists chiefly of powerful radio galaxies. According to `unified theories' of radio galaxies and quasars \cite{Sch87,Bar89}, all of the sources form part of the same population, being classified as quasars if their jet axes are closer than $\approx$50° to the line of sight, otherwise as radio galaxies. Faraday rotation and depolarization increase with the amount of ionized gas and magnetic field along the line of sight to the emitting region, and differences between the two lobes will result either from orientation or from intrinsic asymmetries in the surrounding material. Differences between the path lengths to the two lobes will be much larger for the quasars, and we might expect orientation effects to dominate. For the radio galaxies, on the other hand, path-length differences should be small, and intrinsic effects will be relatively more important.
\item For radio galaxies without strong jets, the shorter lobe is also the more depolarized, but this effect is barely significant in quasars \cite{L93}, despite the fact that the nearer lobe should appear longer as a result of differential light-travel effects \cite{ryl65}. The shorter lobe in radio galaxies is also associated with brighter line-emitting gas \cite{MvBK91}, and this cannot be an orientation effect. We therefore require an intrinsic mechanism which relates lobe length, spectral index and depolarization, and which dominates in radio galaxies, together with an orientation-dependent mechanism which relates jet sidedness, spectral index and depolarization for quasars.
\item The most plausible explanation for a correlation between spectral index and jet sidedness is that the emission from a lobe might include significant contributions from the jet or an associated hotspot, both with flatter spectra than the surrounding material \cite{gcl,tribble}. It is widely believed that the flow velocity of hotspot material is a substantial (though ill-defined) fraction of the speed of light \cite{bbr,bp84} and therefore that significant Doppler beaming should occur in hotspots.
\end{enumerate}

If unified models are correct, then the intrinsic mechanism postulated for radio galaxies must also operate in quasars, in competition with orientation effects. Evidently what is needed is the direct observation of the spectral indices of the lobes of radio sources with jets, with enough resolution to discriminate clearly between lobe, jet and hotspot. In this paper we report detailed comparisons of the spectral index distributions in a small sample of quasars; a preliminary account based on the sources analysed at that time was given at the Mt. Stromlo symposium of 1993 \cite{blst}. (Note, however, that Fig.~1 of that paper is incorrectly drawn: some sources have jet and counter-jet side labels reversed.)

\subsection{Previous work}
Garrington {et al.} (1991) mapped 47 quasars with jets, at 1.4 and 5~GHz, and found that in 37 out of 47 the side of the source with the jet had the flatter spectrum (see table~3 of that paper). These observations, then, show the direct correlation which challenges the

standard model of `Doppler-boosted' jets. However, as the authors themselves state, the images do not have enough angular resolution to permit further investigation of the causes of the correlation; in particular, in most cases they do not adequately resolve the hotspots from the relatively low-brightness lobes to allow the spectral index of the lobes to be measured reliably.

Barthel {et al.} \shortcite{pb88} and Lonsdale \etal\ \shortcite{pb93} made images of over 100 quasars, many of which were observed at both 5 and 15~GHz and also have clearly detected jets. So far as we know, these have not been investigated from the point of view of the present paper, and it is not clear that these data will lend themselves to measuring the distribution of spectral index in low-brightness regions.

Lonsdale and Morison \shortcite{lon83} find spectral asymmetries in the hotspots of four powerful radio sources. In two of these sources jets have now been detected (3C268.4 and 3C249.1; the latter is also in our sample); in these sources the hotspot spectrum is flatter on the jet side. In the other two sources the flatter spectrum is found in the more compact component, which is preferentially found on the jet side \cite {lai89,bhlbl}.

Throughout this paper, we define the spectral index α in the sense flux density $\propto$ frequency$^{-\alpha}$.

\section{Observations}
\subsection{The sample}
Because we wish to explore spectral index distributions, we are restricted to a small sample of sources which are bright enough to be mapped in detail. We therefore started with the 12 quasars of which Bridle {et al.} \shortcite{bhlbl} [BHLBL] had already made detailed 5~GHz images, plus 3C47 \cite{fernini} which satisfies the same selection criteria and for which 5~GHz data of similar quality were available. The BHLBL sample was a subset of the 19 brightest quasars with angular size greater than 10 arcsec in the 3CR catalogue, the only further selection being for reasons of scheduling. Of these 13 quasars, we selected those with prominent one-sided jets and fairly standard appearance; thus we excluded 3C68.1 (ambiguous jet sidedness), 3C215 (jets on both sides of the core, and 90° distortion between smallest and largest scales) and 3C9 (because there is little of the source that can be described unequivocally as `lobe' rather than `jet').

\subsection{Observing programme}
In order to derive spectral-index maps, we made new observations at 1.4 and 1.7~GHz with the {\small VLA} and {\small MERLIN} and extracted additional data from the {\small VLA} archive. The 1.4--1.7~GHz observations were designed to provide as much overlap as possible in \uv~coverage with the 5~GHz observations of BHLBL. Most sources were just observed with the {\small VLA} in the {\small A} configuration, but 3C208 and 3C432 are only 14.6 and 14.8 ~arcsec in extent, respectively, so that even the {\small VLA~A~}array does not provide enough angular resolution; for these, {\small MERLIN} observations were obtained and combined with the {\small VLA} data. Observations of 3C351 at 1417.5~MHz in {\small A} array poorly covered the \uv~plane, and undersampled the large scale structure. For shis reason the data were combined with {\small B} array observations. Table

\ref{tab:obs} shows a summary of the lower-frequency observations.
{\em Also there was C band data in C array for 3C249.1 and 3C351. Anyone
know where this came from?}

\begin{table}
\vspace{5mm}
\caption{Observing schedule}
 \begin{tabular}{p{0.75cm}lllc}\hline
 Source & Observing & Duration & Array & Frequency
  \\
  & date & & & (MHz)\\ \hline
 3C47 & 1992 Dec 7 & 399m& VLA-A & 1664.9, 1635.1 \\
      & 1986 Jul 12 & 36m & VLA-B & 1652.4\\
 3C175 & 1992 Oct 31& 89m & VLA-A & 1417.5, 1467.5 \\
 3C204 & 1982 Mar 1 & 18m & VLA-A & 1417.5\\
 3C208 & 1981 Feb 24& 19m & VLA-A & 1464.9 \\
      & 1994 Aug 14& 14h & MERLIN & 1420.0, 1658.8 \\
 3C263 & 1992 Oct 31& 89m & VLA-A & 1417.5, 1467.5 \\
 3C249.1 & 1982 Mar 1& 38m & VLA-A & 1417.5\\
 3C334 & 1992 Oct 31 & 138m& VLA-A & 1417.5, 1467.5 \\
 3C336 & 1992 Oct 31 & 47m & VLA-A & 1417.5, 1467.5 \\
 3C351 & 1982 Mar 11 & 12m & VLA-A & 1417.5\\
      & 1982 May 30 & 26m & VLA-A & 1417.5\\
      & 1987 Nov 25 & 23m & VLA-B & 1452.4,1502.4\\
      & 1987 Dec 2 & 6m & VLA-B & 1452.4,1502.4\\
 3C432 & 1992 Nov 1& 90m & VLA-A & 1464.9, 1514.9 \\
  & 1994 Aug 1& 14h & MERLIN & 1420.0, 1658.8\\
\end{tabular}
\label{tab:obs}
\end{table}

The {\small VLA} data were reduced and calibrated using the NRAO
{\small AIPS} software. The {\small MERLIN} data were initially
calibrated and edited using the {\small OLAF} package at Jodrell Bank,
before being transferred to {\small AIPS} for self-calibration and
mapping. Where possible only phase self-calibration was used, since
amplitude self-calibration was found to generate small errors in the
flux scale and brightness distributions, especially in the weaker
sources. In a few cases with significant amplitude errors (for
example when combining VLA and MERLIN data; see below) amplitude
self-calibration was used with a long integration interval.

In order to maximise the \uv~coverage of the sparse {\small MERLIN}
array, multifrequency synthesis imaging was used \cite{Conway90}. The
data from the two frequencies were first corrected in total flux for
the spectral index of the source and then combined to form a single data
set. The spectral index correction was calculated using the compact
components from the 5~GHz and one of the 1.4 or 1.7~GHz maps. The
dominant spectral errors will come from bright compact components
(hotspots, core), yielding an error of $\approx I \alpha^\prime / 200$
near the hotspots, where $\alpha^\prime$ is the residual spectral
index, i.e. the difference between the spectral index assumed for the
purposes of correction and the true spectral index of the compact
feature \cite{Conway90}. The spectral errors will be below the level
due to thermal noise and dynamic range limitations if the residual
spectral index of the compact component is $\la$~0.15. Applying the
considerations of Conway et al. (1990) to our images, we find that
they are limited by `reconstruction errors', not spectral errors and

thus we are confident in using these images for the purposes of spectral index analysis. The {\small MERLIN} data were combined with the {\small VLA} data with weights proportional to the inverse expected rms noises on a single integration point. The combined data were then further calibrated, including a few passes of amplitude self-calibration.

Images at all frequencies were made using the {\small AIPS CLEAN} algorithms {\small APCLN} and {\small MX}. All images were {\small CLEAN}ed to the noise level to ensure that all significant emission, especially in the low brightness regions, was restored with the same effective resolution by {\small CLEAN}.

\subsection{The 1.4~GHz images}

The images are shown in Fig.~\ref{maps}~(a) to (j). The contours are those used to divide the sources up into zones for the spectral index comparisons (see below): the lowest solid contour is at 3σ and the others are evenly spaced in $\log$(surface brightness).

3C351 has been mapped at a lowrr resolution than the other sources in order to show the extended region of low surface brightness preceding the N hotspots. This region was poorly represinted at higher resolution, and is likely to be missing a significant amount of flux (see Table \ref{params}). Table~\ref{params} shows the imaging parameters used and the total flux density in the images to the 3σ contour on the 1.4/1.7~GHz map. The single dish total flux densities used were the 1400, 2695 and 5000~MHz flux densities of Laing \& Peacock \shortcite{lai80}, interpolated to the observing frequency. 3C~334 is confused (as noted by BHLBL) by a source to the SE. Thus we believe we have more than 87\% of the flux density in our image. It is seen from the table that we have a good representation of the total source flux density in all our images.

\begin{figure*}
\vspace{25cm}

\caption{The 1.4/1.7~GHz images of the sample. The contours are those used to divide the sources into surface brightness regions and the dotted lines enclose the core and jet regions excluded from these regions for the spectral index calculations}
\label{maps}
\end{figure*}

\begin{table*}
\vspace{5mm}
\caption{Image parameters}
\begin{tabular}{llrrrrrrr} \hline\\
& & \multicolumn{4}{c}{1.4/1.7~GHz} & \multicolumn{3}{c}{4.86~GHz} \\
& FWHM & noise & contouring& total flux& \% single & noise & total flux& \% single \\
& & (μJy/bm)& factor&(Jy) & dish flux &(μJy/bm)& (Jy) & dish flux\\
\hline
3C47 &1.45 \sf{x} 1.13& 48 & 1.96 &3.36 &93 & 35& 1.22 & 111\\
3C175 &1.30 & 151 & 2.01 &2.53 &105 & 38& 0.67 & 100\\
3C204 &1.15 & 199 & 1.91 &1.19 &89 & 61& 0.32 & 93\\
3C208 &0.35 & 250 & 1.92 &2.16 &104 & 25& 0.56 & 102\\
3C249.1&1.20 & 242 & 1.87 &2.33 &104 & 32& 0.81 & 101\\

3C263 &1.10   & 197   & 2.20 &3.15   &103 & 57& 1.11 & 105\\
3C334 &1.30   & 73   & 1.80 &1.83   &87 & 36& 0.63 & 106\\
3C336 &1.25   & 187   & 2.00 &2.63   &99 & 38& 0.82 & 115\\
%%3C351 &3.00   & 760   & 2.82 &2.64   &84 && 1.13 & 92\\
3C351 &3.00   & 222   & 3.49 &3.13   &90 & 105& 1.18 & 96\\
3C432 &0.37   & 234   & 1.76 &1.46   &104 & 19& 0.37 & 114\\
\end{tabular}
\label{params}
\end{table*}

\subsection{The comparison between 1.4~GHz and 5~GHz images}
We wish to compare the spectral indices of the lobes on the two sides of the
same source: the jet side and the counter-jet side. Table
\ref{tab:total-spix} and Fig. \ref{fig:total-spix} and show the spectral index
of each lobe using the total flux to the 3 σ contour on the
1.4/1.7~GHz image, and the identical region in the 5~GHz image. We
have subtracted the core flux densities. The
jet side shows a flatter spectrum in 7 out of 10 cases (steeper in
one, and insignificant difference between the lobes in the remaining
two). Thus the effect found by Garrington et al. and Liu \& Pooley is
confirmed in our sample.

\begin{table}
\begin{center}
\caption{Total lobe spectral indices}
\begin{tabular}{lrr}
\hline
Source & α^{js} & α^{cjs} \\
\hline
3C47   & 0.85 & 0.94\\
3C175 & 1.07 & 1.15\\
3C204 & 1.14 & 1.19\\
3C208 & 1.14 & 1.25\\
3C249.1& 0.86 & 0.96\\
3C263 & 0.96 & 0.88\\
3C334 & 0.99 & 1.00\\
3C336 & 0.96 & 0.98\\
3C351 & 0.78 & 0.88\\
3C432 & 1.05 & 1.28\\
\hline
\multicolumn{3}{c}{(js) refers to jet side;} \\
\multicolumn{3}{c}{(cjs) to counter-jet side.}\\
\end{tabular}
\label{tab:total-spix}
\end{center}
\end{table}

\begin{figure}
\vspace{4.5cm}
\caption{Spectral indices (1.4/1.7~GHz to 5~GHz) of entire lobes, with
core removed. Alpha(j) and alpha(cj) refer to jet-side and
counterjet-side spectral indices respectively. }
\label{fig:total-spix}
\end{figure}

We wish to investigate in more detail the nature of the asymmetry.

A fundamental complication is soon obvious: there is no such thing as `the spectral index of the lobe'. The spectrum steepens progressively (though usually not very regularly) from the neighbourhood of the hotspot towards the middle of the source (a trend generally attributed to synchrotron losses). Some scheme must be invented for comparing like with like on the two sides. One might consider comparing spectral indices at the same fractional distance from the core to the end of the lobe (or to the hotspot); that is not particularly satisfactory in practice as the lobes are often morphologically very different, they may have protrusions and the hotspots are often recessed from the end of the lobe. The scheme we have adopted is to compare regions with the same surface brightness. The analysis therefore proceeds as follows:

\begin{enumerate}
\item Make 5~GHz and 1.4/1.7~GHz images at the same angular resolution, using as near as possible the same \uv~coverage; the authors of BHLBL kindly made the calibrated 5~GHz visibilities available. Correct the images for any zero-level offsets using estimates of the mean off-source level.
\item Cut out the region of the jet and the core; the excluded regions are indicated in Fig.~\ref{maps}.
\item Subdivide the resulting images into regions within fairly narrow ranges of surface brightness at 1.4 or 1.7~GHz. The ranges of surface brightness were chosen as follows: the lowest contour was set at three times the rms noise level on the 1.4 or 1.7~GHz image, and the image was divided into logarithmically equally spaced contours. Each source was divided into about 10 zones; the precise number depends on the dynamic range and was chosen so that each zone contains a sufficiently large number of beams to ensure that the spectral error introduced by the thermal noise is small, and so that the zone is generally wider than a beam. The contours shown in Fig.~\ref{maps} are the contours dividing the zones. Fig.~\ref{zones} shows the same contours for 3C175, but with a grey scale of spectral index superposed. This demonstrates that surface brightness and spectral index are roughly correlated.
\item Compute the spectral index for each surface brightness range on each side of the source from the ratio of the total flux densities in that surface brightness range at 5~GHz and 1.4/1.7~GHz. Every effort was made to remove any small zero-level offsets from the images, but note that the {\em differences} between the spectra on the two sides of a source, at the same surface brightness, are in any case insensitive to such errors, and are unaffected by inaccuracies in the flux scale.
\end{enumerate}

\begin{figure}
\vspace{7cm}

\caption{Subdivision of 3C175 into surface brightness zones. The contours are spaced as for the spectral index calculations on the 1.4~GHz image and the grey scale represents the spectral index between 1.4 and 5.0~GHz. The dotted line again shows the excluded jet and core region. Contours : -.465, .465, .931, 1.865, 7.479, 14.96, 30.00, 60.08, 120.3, 241.0 mJy/beam. Grey scale: 0.6 (white) -- 2.5 (black) }
\label{zones}
\end{figure}

\section{Results}

\begin{figure*}
\vspace{25cm}

\caption{Plots of 1.4/1.7 to 5.0~GHz spectral index versus surface brightness
for the jet and the counter-jet side of each source in the sample. Counter-jet
side: dotted lines. Jet side: continuous lines.}
\label{plots}
\end{figure*}

Fig.~\ref{plots} shows the spectral indices for both sides of each
source plotted against surface brightness. In each diagram the length
of a horizontal line shows the range of surface brightness spanned by
the zone. The vertical lines indicate the formal errors due to the
noise levels in the images at both frequencies.

The systematic errors in spectral index are less well determined.
Small errors in the reconstruction algorithms were investigated by
making images by a `maximum entropy' algorithm ({\sc VTESS}), or by
using different parameters in the {\sc CLEAN} algorithms. These tests
typically indicated an uncertainty comparable to the errors due to the
noise in the regions of highest surface brightness, increasing to $\sim
0.1 - 0.3$ in the region of lowest surface brightness. In all cases
however, the effect was, as expected, the same for both the jet sideaand counter-jet side, thus not affecting our conclusions.

With the single exception of 3C263, the plots show that the high
surface brightness regions have flatter spectra on the jet side.
The spectral differences in the low-brightness regions show no obvious
pattern in these plots alone, but we noticed that 3C263, the one
source which breaks the rule at high surface brightness, is strikingly
asymmetric. This led to the discovery that the spectral index
difference in the low-brightness regions correlates strongly with the
length of the lobe: the longer lobe has the flatter spectrum. The
extent to which our data support these assertions is illustrated in
Fig. \ref{hilo}. In this figure the lobe length ratio has been
calculated using the distance from the core through the hotspot to the
3σ contour. (Using the definition of the furthest 3σ contour
3C249.1 has a ratio of jet-side to counterjet-side lengths of 1.5, but
the figures for all other sources are only slightly changed, and no
other sources show a change in the sense of the asymmetry.)

\begin{figure}
\vspace{12cm}\centerline{
\caption{The spectral indices of low and high surface brightness
regions related to jet side and lobe length. Figs.~\ref{hilo}a and
\ref{hilo}b show spectral index differences between the jet and
counter-jet lobes of each source for the highest and lowest three
surface brightness bins, respectively. The spectral indices of the jet
and counter-jet lobes are alpha(j) and alpha(cj), respectively, and
their lengths are L(j) and L(cj).}
\label{hilo}
\end{figure}

Fig. \ref{hilo}a shows that for all sources, except 3C263, the jet
side spectra in the highest surface brightness regions of the source
are consistently flatter than their counterparts on the jet side
(i.e. they fall below the dotted line). As some of the sources have a
substantial peak brightness asymmetry the highest bins are often found
only on one side. To create properly paired highest bins we adopted the

following procedure: on both sides we summed all the
flux above the lower surface brightness bound of the top bin on the
side with the lower peak surface brightness. As can be seen from inspection of
Fig. \ref{plots}, because of the magnitude of the differences, other
sensible ways of pairing the bins would have left the conclusions
unchanged. 3C351 has a large peak surface brightness asymmetry, and
only three paired surface brightness bins. For this source we have
included only the two highest surface brightness bins in
Fig.~\ref{hilo}.

Fig. \ref{hilo}b shows a strong dependence of the spectral
asymmetry in low-brightness regions, not on jet side, but on length of lobe.
This is evident from the fact that nearly all the points lie in the second
and fourth quadrants of the diagram. Thus when the jet side is longer
(right of dotted line), the jet side has a flatter spectrum
(below dotted line), but when it is shorter it has a steeper spectrum.
The flatter spectrum is found on the longer side in all sources except 3C47.

For completeness, we also note that the \lang effect for our sample is
obeyed by 7/10 of our sources: two sources showing very little asymmetry
(3C263 and 3C249.1) and one (3C204) apparently showing the reverse
effect (although the source is almost completely depolarized by
1.5~GHz so measurement of the asymmetry is difficult).

\section{Interpretation}
In this section we discuss various attempts to explain the two correlations
presented in the previous section, and eliminate as many as we can.

\subsection{Jet side and α in bright regions}
%%The very simplest explanation is that the spectral index increases with
%%frequency, and for a given observing frequency we see the lobe on the
%%approaching side of the source at a lower emitted frequency. The velocity of
%%the low-brightness regions of a lobe is probably $\la$ a few percent of c,
%%so that this explanation is quite inadequate to account for measurable
%%differences in α in diffuse lobes. It could play a part in
%%high-brightness regions near a hotspot, but only if the spectrum of that
%%region is indeed curved.

One way to obtain a spectral index asymmetry in a
relativistically-expanding source would be to postulate that the
intrinsic spectrum is curved and that the asymmetry is produced by the
Doppler shift. If the spectral index increases with frequency, and
the approaching lobe is seen at a significantly lower emitted
frequency, an asymmetry of the right sense could be produced. This
mechanism could operate in smaller regions with significant flow
velocities sucn as hotspots. In addition, even if its spectrum has a
constant power-law index, the hotspot on the approaching (jet) side
may make a larger contribution to the spectral index of the
high-brightness regions than its counterpart in the receding lobe as a
result of Doppler beaming (e.g. Tribble 1992).

We have tested the hypothesis that the spectral differences between
high-brightness regions are due to high flow velocities in the hotspots in two
ways, as follows:
\begin{enumerate}
\item Table~\ref{tab:flux} lists the flux densities of the hotspots in
our sample. We present two sets of hotspot flux densities, that of
BHLBL (obtained by a well-defined, though arbitrary set of rules

defining a hotspot) and our own estimates (for which the hotspots were chosen subjectively). In most cases our estimate of total hotspot flux density is close to that of BHLBL, but in a few cases there is obvious disagreement, as on the counter-jet side of 3C432 where different features have been chosen in the two cases. In the majority of the sources there is a good case for asserting that the
et-side
hotspot is the brighter of the two, but there are striking exceptions --- 3C175, 3C208, 3C336 --- {\it whichever set of hotspot criteria is used}. In such sources the flatter spectrum on the jet side obviously cannot be blamed on a greater flat spectrum contribution from the hotspot. Thus, although relativistic flux--boosting of a flat--spectrum component in a steeper spectrum lobe could potentially account for the effect, it clearly cannot do so in all cases. The inclusion of two sets of flux density estimates emphasises that these conclusions are robust and insensitive to details of hotspot definitions.

\begin{table}
\vspace{5mm}
\caption{5 GHz flux densities of hotspots in mJy.}
\begin{tabular}{lrrp{0.0cm}rrrr} \hline

Source & S_j^{tot} & S_{cj}^{tot} &&S_j^{tot} & S_{cj}^{tot} &S_j^{peak} &S_{cj}^{peak} \\
\hline
& \multicolumn{2}{c}{BHLBL} && \multicolumn{4}{c}{our estimates}\\
\hline

3C47 & 268 & - & &257 & - & 198& 25\\
3C175 & 64 & 152 & &62 & 138& 25 & 65\\
3C204 & 61 & 42 & & 60 & 40 & 43 & 30\\
3C208 & 28 & 203 & & 36 & 198& 21 &139\\
3C249.1& 86 & 188 & & 80 &120 & 48 & 18\\
3C263 & 528 & 21 & &500 & 23 &330 & 13 \\
3C334 & 20 & - & & 18 & - & 6 & 3 \\
3C336 & 95 & 254 & & 95 &280 & 50 & 40 \\
3C351 & 201 & - & &202 & 5 &156 & 1\\
3C432 & 105 & 6 & &103 & 280& 73 & 34\\
\end{tabular}
\label{tab:flux}
\end{table}

\item The two effects of high flow velocity (the Doppler effect shifting a curved spectrum in frequency and the relative flux boosting of the approaching flow) may be thought of as increasing the proportion of flat-spectrum component in the jet-side hotspot. Even if the fast flow is confined to the hotspot, it might be suspected that, at the resolution used for the spectral-index analysis, beam smearing could spread a flatter spectrum from the hotspot to adjacent regions of somewhat lower surface brightness.

To test the possibility that the effect is solely due to a single compact hotspot, we used the three sources in which the spectral index difference $\alpha_j -\alpha_{cj}$ reverses between high- and low-surface-brightness regions (3C204, 3C334 and 3C336). If the above suspicion were well-founded, artificial spectral steepening of the jet-side hotspot spectrum alone should remove the correlation between jet side and flat spectrum. The jet-side hotspot was modelled using

the 2D Gaussian fit to the high resolution image of the hotspot at
5~GHz made by BHLBL. This fitted hotspot was then convolved down to
the resolution of orr spectral analysis. This model was then used to
remove 5~GHz flux progressively from the site of the high resolution
fit to the hotspot. Even when the amount of flux subtracted from the
hotspot was large enough to produce a spectrum of the compact
component which was steeper than that on the counter-jet side, there
still remained a region of intermediate brightness which was largely
unaffected by the changes to the hotspot, and which retainedfits
flatter spectrum. Fig. \ref{hsremove} shows the results for a typical
source (3C334). Thus it is clear that ``contamination'' of the
intermediate surface brightness regions by an insufficiently resolved
flat spectrum hotspot is not enough on its own to account for the
observations.
\end{enumerate}

\begin{figure}
\vspace{6cm}

\caption{The effects of removing a flat spectrum component from the
jet-side hotspot in 3C334. The symbols indicate results after
subtraction of 5~GHz flux. Horizontal binning bars are omitted for
clarity; the flux subtracted is indicated in mJy in the legend. As
progressively more flux is subtracted from the jet side hotspot, its
spectrum necessarily becomes progressively steeper, but the
intermediate surface brightness regions on the jet side still have
flatter spectra.}
\label{hsremove}
\end{figure}

\begin{figure}
\vspace{14cm}

\caption{Detail of jet side lobes of 3C~208, 3C~334 and 3C~336. Grey
scale representations of spectral index are superposed on total intensity contours.}
\label{new}
\end{figure}

We conclude that, if relativistic motion is responsible for the
spectral index asymmetry, then the fast forward flow is not confined
to a single compact hotspot. What regions, then, might take part in
this forward motion? It is well known that many sources have double or
even multiple hotspots (3C351 is a striking example, and in the
present sample 3C175, 3C334, 3C336 and 3C432 show double hotspots at
higher resolution), but that by itself does not explain why there
should be fast forward motion in both. One possibility is that the
point of impact of the jet on the shocked intergalactic medium is
recessed (i.e. not at the extreme end of the lobe) and fast flow
continues beyond the initial hotspot, as the images of 3C204, 3C334
and 3C336 might indicate (Fig. \ref{maps}). Inspection of the
spectral index image for 3C334 shows that a ridge with relatively flat
spectrum indeed extends along the ridge of \hsb beyond the hotspot
(Fig. \ref{new}b). At higher resolution (BHLBL), the hotspot of 3C336
(single in our maps) divides into two compact bright features. These
coincide with two flatter-spectrum regions in Fig. \ref{new}c. 3C208
also has a recessed hotspot on the jet side, but in that case the
flattest spectra occur on the hotspot and on a region extending
northward from it (Fig. \ref{new}a), at about the same distance from

the quasar, suggesting that the jet has split before reaching the hotspot, or perhaps that one of the flat-spectrum regions represents an earlier hotspot, now detached from the jet but still being fed with high-speed material, as in the numerical simulations of Cox, Gull \& Scheuer \shortcite{cox91}. It is also possible that projection effects have transformed a gentle bend in the flow into a sharp ($>90^\circ$) change of direction, but that would imply a very small angle of source axis to line of sight, and a correspondingly large true aspect ratio for the source. Like 3C334 and 3C336, 3C47 and 3C175 show relatively flat spectra along \hsb ridges extending out of the jet-side hotspots, but in these sources the flow seems to turn through a (projected) right angle at the hotspot. Perhaps these flows have more in common with what is going on in 3C208 than with flows in 3C334 and 3C336.

Numerical simulations of radio emission from hot-spots generated by relativistic jets have so far been restricted to the axisymmetric case. Komissarov \& Falle \shortcite{KF96} find that the brightness distribution of the approaching hotspot is dominated by a conical termination shock, whilst the emission from the receding hotspot comes mainly from the high-pressure part of the backflow, and is therefore limb-brightened. High-resolution non-relativistic simulations of Norman et al. \shortcite{Norm96}, suggest that there is a region of supersonic turbulence within 4--5 lobe radii of the leading edge of the source in which the jet is violently deflected. The jet can therefore impinge obliquely on the contact discontinuity to produce a deflected or wall jet \cite{WG85,W89,cox91,NB92}. A key feature of these simulations, from our point of view, is that they lead to oblique shocks and therefore to relatively large forward velocities, so that significant beaming can occur over much of the post-shock flow, especially hen the hotspot is recessed.

The simplest models explaining the flatter spectrum on the jet side by differing ratio of flat and steep spectrum components (for example by relativistic boosting) on each side are incapable of explaining the effect. A uniform steep spectrum background in the two component model is not able to produce any spectral differences when regions of the same surface brightness are compared, as these places will necessarily have the same the ratio of flat to steep spectrum components. This is true regardless of angular resolution. A graduated steep-spectrum background is capable of explaining the effect, but only in special cases: for example in the case of background symmetric about the nucleus, peaking under similar sized hotspots will give a flatter spectrum on the brighter hotspot for similar surface brightness regions. Relaxing the symmetry and shape of the background distribution, the hotspot positions, or the angular size will not generally give the same result.

\subsection{The length of the lobe and α in lower brightness regions}

The expansion velocities of the low-brightness regions are unlikely to exceed a few per cent of c \cite{Sch95}, so it is difficult to see how this effect could account for large-scale spectral asymmetries, even if the intrinsic spectra are curved. Two obvious possible causes of the correlation of the continuum radio spectra with the size of the radio lobe are synchrotron loss and adiabatic expansion. We consider these in turn below.

\begin{enumerate}

\item Synchrotron losses

Other things being equal, the break frequency due to synchrotron loss varies as B^{-3} (B = magnetic induction). The equipartition estimate of B varies as (linear size)$^{-6/7}$, for given radio power. If, on the other hand, the magnetic field in the larger lobe is simply a homologously expanded copy of that in the smaller lobe, then $B \propto({\rm linear \; size})^{-2}$. In either case, the break frequency depends sensitively on linear size, and this dependence would produce a higher break frequency (and hence a flatter spectrum over a fixed frequency interval) in the larger lobe, i.e. a correlation in the sense that is observed. The theoretical predictions are more complicated if we compare regions of equal surface brightness in the two lobes, but in essence the result remains the same.

Blundell and Alexander (1994) pursued this line of argument to explain the correlation between jet side and flatter spectrum. They argued that the near (jet) side is observed at a later stage of development (owing to light travel time effects), and is therefore the larger. While we cannot accept that part of their hypothesis, because the longer lobe is on the {\em counter-jet} side in 5 of our 10 sources, the strong dependence of synchrotron loss on linear size remains a plausible explanation for spectral asymmetries in low-brightness regions.

\item Adiabatic losses.

The observation of spectral index gradients in the lobes indicates that individual regions have spectra steepening with frequency, possibly because of synchrotron losses (this need not conflict with a fairly straight spectrum for the whole source as many sources are dominated by radiation from hotspots where very little synchrotron loss has occurred at frequencies less than ~ 10GHz). We now ask how different amounts of expansion in the two lobes, acting on these curved spectra, might affect the differences between their observed spectral indices.

To isolate the effects of expansion, consider a simple model: two lobes were identical initially; then one expanded adiabatically by a linear factor R which is a little greater than 1. The magnetic field in the larger lobe becomes R^{-2} of the field in the corresponding bit of the smaller lobe, and the electron energy di(tribution is shifted downwards (electron energy $\propto R^{-1}$), with the result that the entire spectrum is shifted downwards in frequency by a factor R^{-4}. Thus we should expect the larger lobe to have a spectrum that is steeper over the same frequency range. This is the reverse of the observed correlation! Closer consideration tends to reverse that conclusion, for we must remember that we compare regions of equal surface brightness on the two sides.

Suppose that a certain region of the smaller lobe has spectral index α and surface brightness S/Ω. The corresponding regio in the larger lobe has spectral index

$$ \alpha'=\alpha+4\log R \frac{d\alpha}{d(\log \nu)} $$

and surface brightness given by

\[\log (S/\Omega)' = \log (S/\Omega) - 4(1+\alpha) \log R.\]

Therefore a region of surface brightness S/Ω, in the larger lobe, is
expected to have spectral index

\begin{eqnarray}
\alpha'' &=&\alpha'+4(1+\alpha)\log R \frac{d\alpha}{d(\log S/\Omega)} \nonumber\\
 & = & \alpha + 4 \log R \left(\frac{d\alpha}{d(\log \nu)}
  + (1+\alpha)\frac{d\alpha}{d(\log S/\Omega)} \right)
\end{eqnarray}

The last term is negative: brighter patches of source have flatter spectra.
Thus we expect the larger lobe to have a flatter spectrum {\em for regions
of equal surface brightness} if
\[\left|(1+\alpha)\frac{d\alpha}{d(\log S/\Omega)} \right|
   > \frac{d\alpha}{d(\log \nu)} \]

If we assume that the spectral gradient along the source is due to
synchrotron losses we can evaluate the importance of adiabatic loss as
an explanation for the observed correlation. We can calculate
$\frac{d\alpha}{d(\log \nu)}$ as a function of α from the
synchrotron spectrum of a given theoretical electron energy
distribution. The results are shown in Fig. \ref {func}, which shows
the results for two values of injection index and the case of a sharp
energy cut-off. Another energy distribution of interest, that with no
pitch--angle scattering of the electrons \cite{Kardashev}, follows the
above case closely, until α approaches
$\frac{4}{3}\alpha_{injection} + 1$, which is the maximum spectral
index possible in this model, so that $\frac{d\alpha}{d(\log
\nu)}\rightarrow 0.$ $\frac{d\alpha}{d(\log S/\Omega)} $ has to be
estimated directly from our observations, as it involves the whole
histories of synchrotron losses in different parts of the source.

The results are illustrated in Fig. \ref{func}. One point is plotted
for each source; it represents the bin in Fig.~3 with the largest
α in the larger lobe, i.e. usually the bin with the lowest
surface brightness. No attempt has been made to estimate the errors in
this procedure as the slopes were fitted by eye.

It can be seen that the points fall near the lines for two reasonable models
of $\frac{d\alpha}{d(\log \nu)}$. For adiabatic expansion to explain the
observed correlation they would need to fall above the line.
We conclude that adiabatic expansion may contribute to the
observed correlation in some cases, but is broadly neutral in this respect.

\begin{figure}
\vspace{6cm}

\caption{Lines of $\frac{d\alpha}{d(log\nu)}$ calculated for
energy spectra with a sharp energy cut--off, and injection spectral indices of
0.5(dotted line) and 0.75(solid line). Points represent values of
$(\alpha_{max}+1)|\frac{\Delta \alpha}{\Delta\log(S)}|$ for each
source. }
\label{func}

\end{figure}

It seems desirable to check the prediction that the larger lobe {\em as a whole} has the steeper spectrum, but it is not clear how to do so. The difficulty is to identify which material is potentially affected by irientation-dependent effects. We have shown that such effects are not restricted to easily-identifiable regions such as hot-spots, and therefore that setting an intensity threshold will not unambiguously separate them out.

\end{enumerate}

\section{Conclusions}

In a sample of ten high-powered radio quasars we have found the following correlations:
\begin{enumerate}
\item In regions of high surface brightness the radio spectrum is flatter on the jet side (9/10)
\item In regions of low surface brightnessithe radio spectrum is flatter on the long side (8/9)
\end{enumerate}

If jet sidedness is a manifestation of relativistic flow, as is commonly believed, then the strong correlation (9/10 sources) found here between the spectral index of the hotspot and the jet side indicates that the spectral difference between the two sides is also a relativistic effect.
We have also demonstrated that the correlation of flatter spectrum with jet side is not confined to the hotspot. Nevertheless, the correlation is presumably an orientation-dependent phenomenon, and we are forced to conclude that forward motion at a significant fraction of c also occurs in regions less conspicuous than that normally selected as `the hotspot'.

In several sources of the present sample the jet-side hotspot is less bright than the hotspot on the counter-jet side (cf. Table \ref{tab:flux}); therefore forward beaming of a flatter spectrum component associated with the jet-side hotspot alone cannot account for the observed correlation. We emphasise that this conclusion does not depend on assuming that the intrinsic radio powers of the radio hotspots are equal. If the spectral index difference between jet and counter-jet sides is due to different ratios of hotspot to background lobe surface brightness, we should expect the side with the brighter hotspot to have the flatter spectrum, regardless of why it is brighter. However, as the correlation is observed in similar surface brightness regions, not just at the hotspot peaks, stringent constraints are put on the structure of the steep-spectrum background and the flat-spectrum component.

If the hotspot spectra are intrinsically curved we can use Doppler frequency shifts to explain the correlation. A calculation for theoretical spectra with injection spectral index of 0.5 shows that a velocity of $ \approx 0.4c$ at 30° to the line of sight (and correspondingly smaller speeds at smaller angles) is enough to cause the observed effect, if the relativistic component dominates the hotspot spectrum, and the cuvature is due to synchroton ageing of an initial power-law electron population. Observational evidence for

curved hotspot spectra at high resolution comes from Cygnus A
\cite{car91}, but adequate resolution over a large frequency range is
available for few (if any) other sources, and in particular for none
of our sample.

A spectral index difference may also be created if we are viewing
different parts of the flow on the two sides. In particular if we
preferentially see backflowing material which is more expanded than
forward flowing material, the result will be a steeper counter-jet
side hotspot. This interpretation is also suggested by the more diffuse
nature of the counter-jet side hotspots, and by recent
simultations \cite{KF96}.

%Explanation in terms of differential aging is possible, in which the
%jet side has a lower magnetic field due to being older, however the
%suitability of such models close to the hotspot is questionable;
%equipartition estimates of the magnetic fields in these regions would
%also not always agree with such an interpretation.

We also note that the one source (3C~263) which disobeys the high
surface brightness correlation also disobeys the \lang rule. This and
the fact that the jet side is only $\sim$ half the length of the
counter-jet side indicates that the source may be confined by a denser
medium on the jet side. In this case it may be that environmental
effects dominate. Hall et al. (1995) indeed find evidence for an
X--ray emitting clump associated with the short lobe of this source.

The correlation of lobe length and radio spectra has yet to be
fully understood. One simple explanation is
that it is due to differences in synchrotron losses in lobes of different
volumes. As such it can be interpreted as an environmental effect due
to the surrounding ambient gas containing the lobes. Further analysis
and similar work on a sample of nearby radio galaxies in which these
effects are expected to dominate is under way.

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To: Alan Bridle <abridle@polaris.cv.nrao.edu>
Subject: the version corrections (fwd)
Date: Thu, 8 Aug 1996 17:24:01 +0100 (BST)

Alan-
to keep you informed: here's the latest bunch of non-trivial revisons.
actually, it seems that its not really a revision, but an important
discussion. j.

~~~~~~
> C conf., 5GHz data - from R. Barvainis, as used by BHLHL.

I can't find that it tells me this... i'll ignore it if it really was
used by BHLHL, but if it wasn't maybe i should say something?

> I thought we had agreed to make the point about seeing different bits of
> the flow at the 2 ends here (it's implicit in the summary of K&F). Also,
we did. now at end:
They also indicate that the observations of the approaching and receding
hotspots may well be dominated by different parts of the flow, and might
then have different spectra.

>   I think we need to make the connection between deflected or
> wall jets and the flat-spectrum regions more explicit. How about:
> ... N&B 1992). These deflected flows are morphologically very similar to
> the flat-spectrum features observed in sources such as 3C334. A key
> feature of the simulations, ...
great.

> The last para of this section appears to have strayed in from an earlier
> version, and the context is not obvious. Could you explain it to me,
> please? In any case, I think it belongs earlier in the section, before
> the para beginning "We conclude that, if relativistic ...".
no. it is new (well something similar was in an older version but i think
it got the chop before it came your way). i've now put it behind the 2nd
para of the section, after

"Doppler beaming (e.ge Tribble 1992).
~~~~~~

However, the simplest..."

what it is saying is that naive ideas that "put a bit more flat spectrum flux on one end and you've explained it" will *not* work (or at least not a simply as one might have thought) here
because of the fact that we analysed in terms of surface brightness. so, whilst it works for tribble because he is just concerned with comparing the spectra hotspot(js) with hotspot(cjs), it doesn't work for us unless we start assuming a bundle of things about the background distribution of steep spectrum material.

> 5. para 2: ... therefore the observed correlation cannot result from a
> flat-spectrum component whose contribution to the flux of the jet-side
> hotspot is enhanced by forward beaming.
> [I prefer this, because the flat-spectrum component is not just associated
> with the jet-side hotspot, necessarily ... it just appears brighter
> there].
yep.

> para 3: I'm still not sure that the argument here is watertight. Although
> more difficult to rule out than the simplest (add different proportions of
> stuff with a straight, but flat spectrum) it still implies that the
> jet-side hotspot should always be brighter, since a frequency shift is
> inevitably accompanied by a boost.

i disagree. the appeal of this is that for the very simplest models (uniform background, identical hotspots) the two-cpt-power-law model will not work. the curvature model works, but, in the simplest case, as you point out, requires a brighter jetside hotspot too.

Moving away from simple models something we might want to do is be able to alter the total flux of the hotspots: for a bit of realistic weather. the two-cpt idea still won't work, and will of course be in worse trouble than before. if the relativistic stuff has a curved spectrum (and if it dominates over any non-rel, steep spectrum stuff which will complicate the case), we can still get the observed correlation, because it does not depend on the ratio of the flux densities: it is a function of the spectrum itself. (to get similar surface brightnesses we must choose pieces which have intrinsically different luminosties on each side, but i don't have a problem with that)

the way to get the two cpt model to work is to start messing around with the background. one of the "simplest" would be to make it dimmer under the jetside hotpot than the cjs one: it works, but hardly something we'd enjoy suggesting....

another thing to note: spectral differences a la tribble will be greatest when hotspot and lobe surface brightnesses are approx equal. any disturbance from equal intrinsic hotspot intensities will tend to swamp the effect, and brighter hotspots will start with less of an effect to swamp! if we invoke spectral curvature this gives us the effects are still just as pronounced when the hotspots are factors of tens to hundreds bighter than the lobes (which they generally are).

> I'd also suggest reordering the last 2 paras, as:
>
> The correlation of lobe length and radio spectra has yet to be fully
> understood. One simple explanation is that it is due to differences in

> synchrotron losses in lobes of different volumes. As such it can be
> interpreted as an environmental effect due to the surrounding ambient gas
> containing the lobes. In this context, we note that the one source
> (3C~263) which disobeys the high surface brightness correlation also shows
> surprisingly little depolarization asymmetry. This and the fact that the
> jet side is only $\sim$ half the length of the counter-jet side indicates
> that the source may be confined by a denser medium on the jet side. In
> this case it may be that environmental effects significantly alter the
> spectral-index and depolarization behaviour. Hall et al. (1995) indeed
> find evidence for an X--ray emitting clump associated with the short lobe
> of this source.
>
> A similar study of a sample of nearby radio galaxies (in
> which environmental effects are expected to dominate) is now under way.
> [I have rewritten the bit about 3c263 in the light of the earlier
> statement that the L&G asymmetry is only marginal].

yep. i spotted that too.

maybe something should be said about mag fields? i'm not sure, but "due to differences in synchrotron losses in lobes of different volumes" sounds a bit like magic!!

so - nailing my colours, so you are in no doubt:
i don't think we can explain this with combinations of two power laws.
the "hotspot" electron have to be aged, or come already in non-power-law forms -- either whap we see is because there's a Doppler shift of a curved spectra, or we see more aged backflow electrons in the receding hotspot than in the approaching on4.

jane

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In-Reply-To: <Pine.SOL.3.91.960809160216.5249b-100000@fafnir>
Message-Id: <Pine.SOL.3.91.960810111052.17552A-100000@mraosa>
Mime-Version: 1.0
Content-Type: TEXT/PLAIN; charset=US-ASCII
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Patrick Leahy <jpl@jb.man.ac.uk>
Cc: Peter Scheuer <pags@mrao.cam.ac.uk>, Robert Laing <rl@ast.cam.ac.uk>,
Alan Bridle <abridle@polaris.cv.nrao.edu>
Subject: Re: version 73 of asymmetry
Date: Sat, 10 Aug 1996 11:31:09 +0100 (BST)

Paddy,

I think (unless Alan has strong feelings which he has yet to make known) that table 3 stays in, the accompanying diagram goes, and associated text stays, although Peter may want to do some tuning on the words (as the author unhappy about its inclusion at all.)

> At the end of 4.1, surely you don't mean the turbulent region is 4-5 lobe
> radii across? Doesn't that make it bigger than the source?

This was Norman's result. His cocoon is very narrow (as seems to be the case for all these simulations), so it isn't bigger than the source for him. Without discussing this it seems like we just have to state the result and move on.

>
> The trivial "uniform" model at the start of the last para of 4.1 seems too
> obviously wrong to be worth introducing; hardly even a straw man;there is
> a marked contrast with the previous para, which calmly contemplates
> spectra, emissivity, and doppler factor all varying throughout the flow.
> The last part is valuable as it emphasises the subtleties involved in
> making comparisons at constant brightness, but is a bit compressed; I had
> to read it several times to figure out what the point was. I hesitate to
> say it, but a diagram might help.

This was an error of my cut-and-paste that it ended up where it did. It is now postitioned in that section after para. 2. so it now reads:

"....result of Doppler beaming (e.g. Tribble 1992).

However, the simplest models explaining the flatter spectrum ...."

I think it makes things much better, as it needs to be said, but not, as

you say, after we've "calmly contemplated" all sorts of complexities!! As
for your point about a diagram, yes, it would probably help but i'm very
reluctant to put one in.

> Does the comment about 3C263 in the conclusions need changing in the
> light of the revised Laing-Garrington status (end of section 3)?

This was an oversight on my part. last 2 para now read:

"The correlation of lobe length and radio spectra has yet to be fulay understood. One simple explanation is that it is due to diffenences in synchrotron losses in lobes of different volumes. As such it can be interpreted as an environmental effect due to the surrounding ambient gas containing the lobes. In this context, we note that the one source (3C~263) which disobeys the high surface brightness correlation also shows surprisingly little depolarization asymmetry. This and the fact that the jet side is only $\sim$ half the length of the counter-jet side indicates that thn source may be confined by a denser medium on the jet side. In ehis case it may be that environmental effects produce the spectral-index and depolarization behaviour. Hall et al. (1995) indeed find evidence for an X--ray emitting clump associated with the short lobe of this source.

A similar study of a sample of nearby radio galaxies (in which environmental effects are expected to dominate) is now under way."

Deadline for further alterations/nit-picks/major complaints: Wednesday!

jane

From VM Mon Aug 12 08:33:54 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["229" "Sat" "10" "August" "1996" "23:14:56" "-0400" "Alan Bridle" "abridle" nil "9" "Re: version 73 of asymmetry" "^From:" nil nil "8" nil nil nil nil]
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id AA35189; Sat, 10 Aug 1996 23:14:56 -0400
Message-Id: <9608110314.AA35189@polaris.cv.nrao.edu>
In-Reply-To: <Pine.SOL.3.91.960810111052.17552A-100000@mraosa>
References: <Pine.SOL.3.91.960809160216.5249b-100000@fafnir>
<Pine.SOL.3.91.960810111052.17552A-100000@mraosa>
From: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: version 73 of asymmetry
Date: Sat, 10 Aug 1996 23:14:56 -0400

Hi Jane,

I just got back home from 3 weeks away in Canada and will send you comments on the new version as soon as I get into the NRAO and print it out (am just screening through my 250 mail messages from home just now).

A.

From VM Mon Aug 12 08:33:54 1996
X-VM-v5-Data: ([nil nil nil t t nil nil nil nil]
["1278" "Sun" "11" "August" "1996" "12:13:59" "+0100" "Jane Dennett-Thorpe" "jdt@mrao.cam.ac.uk"
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id AA48420; Sun, 11 Aug 1996 07:14:09 -0400
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Content-Type: TEXT/PLAIN; charset=US-ASCII
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@nrao.edu>
Subject: Re: version 73 of asymmetry
Date: Sun, 11 Aug 1996 12:13:59 +0100 (BST)

ah.
yes, i suddenly thought that you might be away after i wrote
"deadline:wednesday!"

robert and i have now sorted out our crossed wires.
it ended with:

Yes, we are now on the same wavelength. Not sure why the tuning process
was so onerous! I take your point that definitive calculations are
tricky. I think the key points for the conclusions are:

- curvature model produces the observed correlation for a wide range of
  circumstances, unlike the 2-power-law model
- there will be a bias in favour of brighter jet-side hot-spots, with
  the curvature model, but it may well be lost in the intrinsic spread
  (which, from the Table, is quite considerable)

Regards, Robert

["definitive calculations" he refers to, are the ones he was getting at it
previous messages (and here): even if the curved spectrum ider gifes us
flatter hotspot spectrum all the time, there should saill be a statistical
bias for brighter jetside hotspots: do we see the right bias given what i
say about possible speeds in the conclusion? this is not easy to answer
because of the spread on intrinsic variations between hotspots.]

hope your holiday (well, lets start with- "i hope it was a holiday"), was
relaxing and enjoyable - sorry to ave cluttered your inbox for your return!

jane

From VM Mon Aug 12 10:16:49 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
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id AA44769; Mon, 12 Aug 1996 09:00:02 -0400
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References: <Pine.SOL.3.91.960723124427.7421C-100000@mraose.ra.phy.cam.ac.uk>
From: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: lisbon
Date: Mon, 12 Aug 1996 09:00:02 -0400

Jane Dennett-Thorpe writes:

> i have just got back from lisbon, and think i am likely to take the job.
> i liked maria marcha (a good thing considering there will be two of us,
> maybe four, sat on top of some hill in the old observatory building
> outside lisbon!) and liked the project.
>

Glad to hear that, when do you have to decide? Are there any other irons
in the fire still?

> i am naturally worried about all sorts of isolation: intellectual,
> personal and cultural, but think i'm prepared to take up the challenge.
> two years, afterall, isn't a very long time.

If will be traveling fairly often for the project and to conferences,
a little isolation "at home" can be a good thing. And E-contact can
make a big difference these days. You will probably get to know
yourself a lot better than before!

> so the plan at the moment is : thesis by 1 nov, start 1 dec.

I'll try not to do anything to slow you down!

And, comments on revised paper will follow as soon as I can .....
Yes, we were on holiday, first real one since M. finished her
chemo so we made it a long one.

A.

From VM Tue Aug 13 10:31:35 1996
X-VM-v5-Data: ([nil nil nil t nil nil nil nil nil]
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id AA24734; Tue, 13 Aug 1996 10:07:29 -0400
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Received: by mraos.ra.phy.cam.ac.uk (Smail3.1.29.0 #2)
id m0uqK2f-0003EwC; Tue, 13 Aug 96 15:01 BST
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X-Mailer: ELM [version 2.4 PL25]
Mime-Version: 1.0
Content-Type: text/plain; charset=US-ASCII
Content-Transfer-Encoding: 7bit
From: Peter Scheuer <pags@mrao.cam.ac.uk>
To: rl@ast.cam.ac.uk (Robert Laing)
Cc: abridle@polaris.cv.nrao.edu, jdt@mrao.cam.ac.uk, jpl@jb.man.ac.uk,
pags@mrao.cam.ac.uk
Subject: Re: version 73 of asymmetry
Date: Tue, 13 Aug 1996 15:01:57 +0100 (BST)

Dear Alan, Jane, Robert and Patrick,

As I wrote to some of you, I found the prominence given to whole-lobe spectra in the latest version quite inappropriate, as it goes quite against the purposes of the present paper. As the majority are against throwing it out altogether, here is a specific set of words which still includes the information, without giving the impression that this is the the primary result of the work, and which would I think satisfy Jane and Robert as well as me.

Section 1.2, After second sentence (...boosted' jets.) Insert:

(Our sample shows the same correlation, see Table 1 [i.e. what was Table 3]. 7 cases out of 10 show a flatter spectrum on the jet side and 2 show no significant spectral difference.)

Caption to Table 1 [i.e what was Table 3]

Total lobe spectral indices, determined from the ratio of fluxes inside the 3-sigma contour on the 1.4/1.7 GHz image and the identical region in the 5 GHz image. Cores have been excluded.

Delete Figure 2.

Section 2.4 Omit first paragraph. Begin second paragraph with:

As soon as we try to compare the spectra of lobes, excluding jets and hotspots, a fundamental complication becomes obvious: there is no such thing as `the spectral index of the lobe'. The spectrum steepens ...

Regards Peter

From VM Tue Aug 13 16:31:01 1996
X-VM-v5-Data: ([nil nil nil nil t nil nil nil nil]
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Received: from mraosa.ra.phy.cam.ac.uk by mraos.ra.phy.cam.ac.uk with smtp
 (Smail3.1.29.0 #2) id m0uqQ4n-0003EMC; Tue, 13 Aug 96 21:28 BST
X-Sender: jdt@mraosa
In-Reply-To: <9608131756.AA47184@polaris.cv.nrao.edu>
Message-Id: <Pine.SOL.3.91.960813211631.24285A-100000@mraosa>
Mime-Version: 1.0
Content-Type: TEXT/PLAIN; charset=US-ASCII
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@nrao.edu>
Subject: Re: version 73 of asymmetry
Date: Tue, 13 Aug 1996 21:28:32 +0100 (BST)

Hi Alan,

thanks for your comments. I will discuss them with Peter tomorrow, and hopefully we can reach a consensus on table 3. (my feelings on this are that i'd prefer it where it is now, but will do anything to get an agreement! the advantage of peter's suggestion is that that nasty bit of tex editing to get the tables in order disappers....)

nits are being dealt with. it the meantime: the bit you were getting confused about what-where --
i incorrectly pasted in the section empasising the problems of the two-power-law model which i have added as i didn't think it came across, and probably wasn't obvious to very many people. i don't know where i originally put it, but it starts "The simplest models explaining the flatter spectrum..."
It now resides after para 1 in Section 4.1 (jet side vs alpha), as para 2, and starts with an extra "However..."

does this make it clearer?

jane

From VM Tue Aug 13 16:37:26 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
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References: <9608131756.AA47184@polaris.cv.nrao.edu>
<Pine.SOL.3.91.960813211631.24285A-100000@mraosa>
From: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: version 73 of asymmetry
Date: Tue, 13 Aug 1996 16:37:16 -0400

Jane Dennett-Thorpe writes:
>
> Hi Alan,
>
> thanks for your comments. I will discuss them with Peter tomorrow, and
> hopefully we can reach a consensus on table 3. (my feelings on this are
> that i'd prefer it where it is now, but will do anything to get an
> agreement! the advantage of peter's suggestion is that that nasty bit of
> tex editing to get the tables in order disappers....)

Maybe, but I'm a bit bothered by referring to our own results as
"previous work". Maybe we should change the title of 1.2 to "Lobe-averaged
asymmetries" in that case?

>
> nits are being dealt with. it the meantime: the bit you were getting
> confused about what-where --
> i incorrectly pasted in the section empasising the problems of the
> two-power-law model which i have added as i didn't think it came across,
> and probably wasn't obvious to very many people. i don't know where i
> originally put it, but it starts "The simplest models explaining the flatter
> spectrum..."
> It now resides after para 1 in Section 4.1 (jet side vs alpha), as para
> 2, and starts with an extra "However..."
>
> does this make it clearer?

Clearer where it goes, yes. I would still feel that "the"
two-component model needs clarification, so the reader doesn't have to
figure out whether it's two spatially separated power-law components
or spectrally-separated power-law components.

Perhaps when you have the editing done you can send me just the new
Sec 4.1 (or the whole file if that's easier, I promise not to raise
a new bunch of comments if you do!)

Good luck with P.,

Alan

From VM Tue Aug 13 17:07:57 1996
X-VM-v5-Data: ([nil nil nil nil t nil nil nil nil]
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From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@nrao.edu>
Subject: Re: version 73 of asymmetry
Date: Tue, 13 Aug 1996 22:06:57 +0100 (BST)

> sec 1.1, end: we should say _which_ sources were mislabeled in
> Stromlo Fig.1, not just "some sources"; or if this is
> too tedious, just drop the parenthetical last sentence.

i disagree - to list them is, as you say, tedious, but i thik the reader should be altered to the reason why we seem to have changed our minds --if they do the unlikely thing of reading both papers. if they want to know which ones are wrong they can just compare them with the ones we present here.

> sec 2.2, line 6 add NRAO before VLA and change the acknowledgement
> at the end of the paper from "The Very Large Array is a
> facility ..." to "The NRAO is a facility ...." I am required
> to ask for the latter change to comply with our management's
> desires: the former is a way to associate with VLA with the
> acknowledgement.

i'm sorry, you tried to get me to alter my acks before, and i did - but obviously missed the point of the alteration! so is "the NRAO VLA" the right thing to say, or do you want me to someohow try and make the wording more elegant?

> references, inconsistent throughout about use of & in author lists.
> e.g. Blundell, Alexander but Garrington & Conway.
> Barthel, Miley, Schilizzi, Lonsdale but
> Baars, Genzel, Pauliny-Toth & Witzel

i'm waiting for MN rules to make themselves clear to me! will change it, but hasn't been done yet.
table 3 & text remain where they are for tonight too...

there follows a full tex version, which unfortunately contains all the \epsfig commands refering to my directory structure. i think you can run it in \psdraft mode. if not, let me know and i'll send you a stripped one tomorrow.
*j.

From VM Tue Aug 13 17:16:05 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
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References: <9608131756.AA47184@polaris.cv.nrao.edu>
<Pine.SOL.3.91.960813215057.24285B-100000@mraosa>
From: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: version 73 of asymmetry
Date: Tue, 13 Aug 1996 17:13:47 -0400

Jane Dennett-Thorpe writes:
>
> > sec 1.1, end: we should say _which_ sources were mislabeled in
> >   Stromlo Fig.1, not just "some sources"; or if this is
> >   too tedious, just drop the parenthetical last sentence.
>
> i disagree - to list them is, as you say, teuious, but i thik the reader
> should be altered to the reason why we seem to have changed our minds --if
> they do the unlikely thing of reading both papers. if they want to know
> which ones are wrong they can just compare them with the ones we present
> here.

Leaving it as it is seems to be deliberately obscure, though. That's
my problem with this.

>
> > sec 2.2, line 6 add NRAO before VLA and change the acknowledgement
> > at the end of the paper from "The Very Large Array is a
> > facility ..." to "The NRAO is a facility ...." I am required
> > to ask for the latter change to comply with our management's
> > desires: the former is a way to associate with VLA with the
> > acknowledgement.
>
> i'm sorry, you tried to get me to alter my acks before, and i did - but
> obviously missed the point of the alteration! so is "the NRAO VLA" the
> right thing to say, or do you want me to someohow try and make the
> wording more elegant?
>

In the acknowledgements, we are supposed to say:

"The NRAO is a facility of the National Science Foundation, operated
under cooperative agreement by Associated Universities, Inc."

If we don't, then I am supposed to have that as a footnote to my address,
which would be messy.

As it stands, we have "The Very Large Array is a facility ...."

So I am suggesting that we put the "official" acknowledgement in the
acknowledgements section, and associate the VLA with NRAO where we

first mention it, which I believe is in Sec 2.2. Just like
the "NRAO AIPS software" a little further down.

> > references, inconsistent throughout about use of & in author lists.
> >   e.g. Blundell, Alexander but Garrington & Conway.
> >   Barthel, Miley, Schilizzi, Lonsdale but
> >   Baars, Genzel, Pauliny-Toth & Witzel
>
> i'm waiting for MN rules to make themselves clear to me! will change it,
> but hasn't been done yet.
> table 3 & text remain where they are for tonight too...
>
> there follows a full tex version, which unfortunately contains all the
> \epsfig commands refering to my directory structure. i think you can run
> it in \psdraft mode. if not, let me know and i'll send you a stripped one
> tomorrow.
>

Thanks, A.

From VM Wed Aug 14 08:19:59 1996
X-VM-v5-Data: ([nil nil nil t t nil nil nil nil]
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To: Alan Bridle <abridle@polaris.cv.nrao.edu>
Subject: version 73.1
Date: Tue, 13 Aug 1996 22:10:58 +0100 (BST)

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\documentstyle[psfig]{mn}
\newcommand{\bib}{\bibitem[\protect\citename}
\newcommand{\egrs}{extragalactic radio source }
\newcommand{\lang{{Laing-Garrington }
\newcommand{\lp}{Liu-Pooley }
\newcommand{\uv}{{\sl uv}}
\newcommand{\lbr}{low surface brightness regions }
\newcommand{\hbr}{high surface brightness regions }
\newcommand{\hsb}{high surface brightness }
\newcommand{\etal}{{et al.}}
\newcommand{\js}{jet side}
\newcommand{\cjs}{counter-jet side}

\begin{document}
\title[Jets, lobe length \& spectral index]{Asymmetry of jets, lobe length
and spectral index in quasars}
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\date{Received }
\maketitle

\begin{abstract}
The less depolarized lobe of a radio source is generally the lobe
containing the jet (Laing-Garrington correlation) but the less
depolarized lobe is also generally that with the flatter radio
spectrum (Liu-Pooley correlation). Both effects are strong; taken
together they would imply a correlation between jet side and lobe
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spectral index, i.e. between an orientation-dependent feature and one
which is intrinsic. We test this prediction using detailed spectral
imaging of a sample of quasars with well-defined jets and investigate
whether the result can be reconciled with the standard interpretation
of one-sided jets in terms of relativistic aberration. Our central
finding is that the spectrum of high surface brightness regions is
indeed flatter on the jet side, but that the spectrum of low surface
brightness regions is flatter on the side with the longer lobe. We
discuss possible causes for these correlations and favour
explanations in terms of relativistic bulk motion in the high surface
brightness regions and differential synchrotron ageing in the extended
lobe material.
\end{abstract}

\begin{keywords}
jets -- spectral index -- asymmetry -- quasars
\end{keywords}

\section{Introduction}
\subsection{The problem}
Laing, Garrington and colleagues \cite {gnat,ral} showed that the lobe
of a powerful radio source containing the jet is almost invariably
less depolarized than its counterpart on the opposite side of the
nucleus; 39 out of the 47 sources in Tables~3 to 6 of Garrington,
Conway \& Leahy \shortcite{gcl} obey the Laing--Garrington rule
(only 4 sources definitely show the reverse effect).
These 47 sources all have FRII morphologies \cite{FR} and most are
quasars, although a few radio galaxies are included. Very few FRII
sources have detectable jets on both sides of the nucleus, and we will
use the term ``the jet'' to refer to the brighter (in almost all cases
the only) such feature. The most widely accepted explanation of the
Laing--Garrington effect is that jets are intrinsically two-sided and
relativistic: the nearer one appears brighter as a result of Doppler
beaming and radiation from its lobe passes through less of the
depolarizing medium around the source \cite{ral,gar91}. Thus the
Laing--Garrington effect is explained as a consequence of orientation.

Liu \& Pooley \shortcite{lpa} found that there is also a strong
correlation between depolarization and lobe spectral index: the lobe
with the flatter spectrum is the less depolarized. Their original
sample contained a majority of sources without detectable jets, but 33
of the 47 sources with utrong jets in Tables~3 to 6 of Garrington {et
al.} also obey the Liu--Pooley rule.

Taken together these two strong correlations imply that the lobe spectrum is
flatter on the jet side of a source. According to the standard model of an
\egrs the lobe material is almost static relative to the host galaxy and
therefore any motion of the lobe material is inadequate to account for
significant differences between the lobe spectra as an orientatoon-related
effect. Thus the two correlations together constitute a {\it prima facie} case
against the standard model of `Doppler-boosted' relativistic jets.

The most plausible defence is that intrinsic and orientation effects both
operate:
\begin{enumerate}
\item The \lang sample includes only sources with detected (and, in most
cases, prominent) jets. The majority are identified with quasars, which
tend to have much brighter jets than radio galaxies of the same

total power. By contrast, the \lp sample was not selected on jet emission, and consists chiefly of powerful radio galaxies. According to `unified theories' of radio galaxies and quasars \cite{Sch87,Bar89}, all of the sources form part of the same population, being classified as quasars if their jet axes are closer than $\approx$50° to the line of sight, otherwise as radio galaxies. Faraday rotation and depolarization increase with the amount of ionized gas and magnetic field along the line of sight to the emitting region, and differences between the two lobes will result either from orientation or from intrinsic asymmetries in the surrounding material. Differences between the path lengths to the two lobes will be much larger for the quasars, and we might expect orientation effects to dominate. For the radio galaxies, on the other hand, path-length differences should be small, and intrinsic effects will be relatively more important.
\item For radio galaxies without strong jets, the shorter lobe is also the more depolarized, but this effect is barely significant in quasars \cite{L93}, despite the fact that the nearer lobe should appear longer as a result of differential light-travel effects \cite{ryl65}. The shorter lobe in radio galaxies is also associated with brighter line-emitting gas \cite{MvBK91}, and this cannot be an orientation effect. We therefore require an intrinsic mechanism which relates lobe length, spectral index and depolarization, and which dominates in radio galaxies, together with an orientation-dependent mechanism which relates jet sidedness, spectral index and depolarization for quasars.
\item The most plausible explanation for a correlation between spectral index and jet sidedness is that the emission from a lobe might include significant contributions from the jet or an associated hotspot, both with flatter spectra than the surrounding material \cite{gcl,tribble}. It is widely believed that the flow velocity of hotspot material is a substantial (though ill-defined) fraction of the speed of light \cite{bbr,bp84} and therefore that significant Doppler beaming should occur in hotspots.
\end{enumerate}

If unified models are correct, then the intrinsic mechanism postulated for radio galaxies must also operate in quasars, in competition with orientation effects. Evidently what is needed is the direct observation of the spectral indices of the lobes of radio sources with jets, with enough resolution to discriminate clearly between lobe, jet and hotspot. In this paper we report detailed comparisons of the spectral index distributions in a small sample of quasars; a preliminary account based on the sources analysed at that time was given at the Mt. Stromlo symposium of 1993 \cite{blst}. (Note, however, that Fig.~1 of that paper is incorrectly drawn: some sources have jet and counter-jet side labels reversed.)

\subsection{Previous work}
Garrington {et al.} (1991) mapped 47 quasars with jets, at 1.4 and 5~GHz, and found that in 37 out of 47 the side of the source with the jet had the flatter spectrum (see table~3 of that paper). These observations, then, show the direct correlation whien challenges the standard model of `Doppler-boosted' jets. However, as the authors themselves state, the images do not have enough angular resolution to permit further investigation of the causes of the correlation; in particular, in most cases they do not adequately resolve the hotspots from the relatively low-brightness lobes to allow the spectral index of the lobes to be measured reliably.

Barthel {et al.} \shortcite{pb88} and Lonsdale \etal\

\shortcite{pb93} made images of over 100 quasars, many of wh
ch were
observed at both 5 and 15~GHz and also have clearly detected jets. So
far as we know, these have not been investigated from the point of
view of the present paper, and it is not clear that these data will
lend themselves to measuring the distribution of spectral index in
low-brightness regions.

Lonsdale and Morison \shortcite{lon83} find spectral asymmetries in
the hotspots of four powerful radio sources. In two of these sources
jets have now been detected (3C268.4 and 3C249.1; the latter is also
in our sample); in these sources the hotspot spectrum is flatter on
the jet side. In the other two sources the flatter spectrum is found
in the more compact component, which is preferentially found on the
jet side \cite {lai89,bhlbl}.

Throughout this paper, we define the spectral index α in the sense
flux density $\propto$ frequency$^{-\alpha}$.

\section{Observations}
\subsection{The sample}
Because we wish to explore spectral index distributions, we are
restricted to a small sample of sources which are bright enough to be
mapped in detail. We therefore started with the 12 quasars of which
Bridle {et al.} \shortcite{bhlbl} [BHLBL] had already made detailed
5~GHz images, plus 3C47 \cite{fernini} which satisfies the same
selection criteria and for which 5~GHz data of similar quality were
available. The BHLBL sample was a subset of the 19 brightest quasars
with angular size greater than 10 arcsec in the 3CR catalogue, the
only further selection being for reasons of scheduling. Of these 13
quasars, we selected those with prominent one-sided jets and fairly
standard appearance; thus we excluded 3C68.1 (ambiguous jet
sidedness), 3C215 (jets on both sides of the core, and 90°
distortion between smallest and largest scales) and 3C9 (because there
is little of the source that can be described unequivocally as `lobe'
rather than `jet').

\subsection{Observing programme}
In order to derive spectral-index maps, we made new observations at
1.4 and 1.7~GHz with the {\small VLA} and {\small MERLIN} and extracted
additional data from the {\small VLA} archive. The 1.4--1.7~GHz
observations were designed to provide as much overlap as possible in
\uv~coverage with the 5~GHz observations of BHLBL. Most sources were
just observed with the {\small VLA} in the {\small A} configuration,
but 3C208 and 3C432 are only 14.6 and 14.8 ~arcsec in extent,
respectively, so that even the {\small VLA~A~}array does not provide
enough angular resolution; for these, {\small MERLIN} observations
were obtained and combined with the {\small VLA} data. Observations of
3C351 at 1417.5~MHz in {\small A} array poorly covered the \uv~plane,
and undersampled the large scale structure. For this reason the data
were combined with {\small B} array observations. Table
\ref{tab:obs} shows a summary of the lower-frequency observations.

\begin{table}
\vspace{5mm}
\caption{Observing schedule}
\begin{tabular}{p{0.75cm}lllc}\hline

Source & Observing & Duration & Array & Frequency
\\
& date & & & (MHz)\\ \hline
3C47 & 1992 Dec 7 & 399m& VLA-A & 1664.9, 1635.1 \\
& 1986 Jul 12 & 36m & VLA-B & 1652.4\\
3C175 & 1992 Oct 31& 89m & VLA-A & 1417.5, 1467.5 \\
3C204 & 1982 Mar 1 & 18m & VLA-A & 1417.5\\
3C208 & 1981 Feb 24& 19m & VLA-A & 1464.9 \\
& 1994 Aug 14& 14h & MERLIN & 1420.0, 1658.8 \\
3C263 & 1992 Oct 31& 89m & VLA-A & 1417.5, 1467.5 \\
3C249.1 & 1982 Mar 1& 38m & VLA-A & 1417.5\\
3C334 & 1992 Oct 31 & 138m& VLA-A & 1417.5, 1467.5 \\
3C336 & 1992 Oct 31 & 47m & VLA-A & 1417.5, 1467.5 \\
3C351 & 1982 Mar 11 & 12m & VLA-A & 1417.5\\
& 1982 May 30 & 26m & VLA-A & 1417.5\\
& 1987 Nov 25 & 23m & VLA-B & 1452.4,1502.4\\
& 1987 Dec 2 & 6m & VLA-B & 1452.4,1502.4\\
3C432 & 1992 Nov 1& 90m & VLA-A & 1464.9, 1514.9 \\
& 1994 Aug 1& 14h & MERLIN & 1420.0, 1658.8\\
\end{tabular}
\label{tab:obs}
\end{table}

The {\small VLA} data were reduced and calibrated using the NRAO {\small AIPS} software. The {\small MERLIN} data were initially calibrated and edited using the {\small OLAF} package at Jodrell Bank, before being transferred to {\small AIPS} for self-calibration and mapping. Where possible onld phase self-calibration was used, since amplitude self-calibration was found to generate small errors in the flux scale and brightness distributions, especially in the weaker sources. In a few cases with significant amplitude errors (for example when combining VLA and MERLIN data; see below) amplitude self-calibration was used with a long integration interval.

In order to maximise the \uv~coverage of the sparse {\small MERLIN} array, multifrequency synthesis imaging was used \cite{Conway90}. The data from the two frequencies were first corrected in total flux for the spectral index of the source and then combined to form a single data set. The spectral index correction was calculated using the compact components from the 5~GHz and one of the 1.4 or 1.7~GHz maps. The dominant spectral errors will come from bright compact components (hotspots, core), yielding an error of $\approx I \alpha^\prime / 200$ near the hotspots, where $\alpha^\prime$ is the residual spectral index, i.e. the difference between the spectral index assumed for the purposes of correction and the true spectral index of the compact feature \cite{Conway90}. The spectral errors will be below the level due to thermal noise and dynamic range limitations if the residual spectral index of the compact component is $\la$~0.15. Applying the considerations of Conway et al. (1990) to our images, we find that they are limited by `reconstruction errors', not spectral errors and thus we are confident in using these images for the purposes of spectral index analysis. The {\small MERLIN} data were combined with the {\small VLA} data with weights proportional to the inverse expected rms noises on a single integration point. The combined data were then further calibrated, including a few passes of amplitude self-calibration.

Images at all frequencies were made using the {\small AIPS CLEAN} algorithms {\small APCLN} and {\small MX}. All images were {\small CLEAN}ed to the noise level to ensure that all significant emission, especially in the low brightness regions, was restored with the same effective resolution by {\small CLEAN}.

\subsection{The 1.4~GHz images}

The images are shown in Fig.~\ref{maps}~(a) to (j). The contours are those used to divide the sources up into zones for the spectral index comparisons (see below): the lowest solid contour is at 3σ and the others are evenly spaced in $\log$(surface brightness).

3C351 has been mapped at a lower resolution than the other sources in order to show the extended region of low surface brightness preceding the N hotspots. This region was poorly represented at higher resolution, and is likely to be missing a significant amount of flux (see Table \ref{params}). Table~\ref{params} shows the imaging parameters used and the total flux density in the images to the 3σ contour on the 1.4/1.7~GHz map. The single dish total flux densities used were the 1400, 2695 and 5000~MHz flux densities of Laing \& Peacock \shortcite{lai80}, interpolated to the observing frequency. 3C~334 is confused (as noted by BHLBL) by a source to the SE. Thus we believe we have more than 87\% of the flux density in our image. It is seen from the table that we have a good representation of the total source flux density in all our images.

```
\begin{figure*}
%%\vspace{25cm}
\centerline{
\psfig{figure=/home/jdt/SPIXQ/maps_ps/3c47/L.cont,angle=-90,height=5cm,clip=}
\psfig{figure=/home/jdt/SPIXQ/maps_ps/3c175/L.cont,angle=-90,height=5cm,clip=}
}

\centerline{
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}

\centerline{
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\psfig{figure=/home/jdt/SPIXQ/maps_ps/3c263/L.cont,angle=-90,height=4.6cm,clip=}
}

\centerline{
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\psfig{figure=/home/jdt/SPIXQ/maps_ps/3c336/L.cont,angle=-90,height=5cm,clip=}}

\centerline{
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\psfig{figure=/home/jdt/SPIXQ/maps_ps/3c432/L.cont,angle=-90,height=4.6cm,clip=}
}
\caption{The 1.4/1.7~GHz images of the sample. The contours are those used
to divide the sources into surface brightness regions and the dotted lines
enclose the core and jet regions excluded from these regions for the spectral
index calculations}
\label{maps}
\end{figure*}
```

\begin{table*}
\vspace{5mm}
\caption{Image parameters}
\begin{tabular}{llrrrrrrr} \hline\\
& & \multicolumn{4}{c}{1.4/1.7~GHz} & \multicolumn{3}{c}{4.86~GHz} \\
& FWHM & noise & contouring& total flux& \% single & noise & total flux& \% single \\
& & (μJy/bm)& factor&(Jy) & dish flux &(μJy/bm)& (Jy) & dish flux\\
\hline
3C47 &1.45 \sf{x} 1.13& 48 & 1.96 &3.36 &93 & 35& 1.22 & 111\\
3C175 &1.30 & 151 & 2.01 &2.53 &105 & 38& 0.67 & 100\\
3C204 &1.15 & 199 & 1.91 &1.19 &89 & 61& 0.32 & 93\\
3C208 &0.35 & 250 & 1.92 &2.16 &104 & 25& 0.56 & 102\\
3C249.1&1.20 & 242 & 1.87 &2.33 &104 & 32& 0.81 & 101\\
3C263 &1.10 & 197 & 2.20 &3.15 &103 & 57& 1.11 & 105\\
3C334 &1.30 & 73 & 1.80 &1.83 &87 & 36& 0.63 & 106\\
3C336 &1.25 & 187 & 2.00 &2.63 &99 & 38& 0.82 & 115\\
3C351 &3.00 & 222 & 3.49 &3.13 &90 & 105& 1.18 & 96\\
3C432 &0.37 & 234 & 1.76 &1.46 &104 & 19& 0.37 & 114\\
\end{tabular}
\label{params}
\end{table*}

\subsection{The comparison between 1.4~GHz and 5~GHz images}
We wish to compare the spectral indices of the lobes on the two sides of the
same source: the jet side and the counter-jet side. Table
\ref{tab:total-spix} shows the spectral index
of each lobe using the total flux to the 3 σ contour on the
1.4/1.7~GHz image, and the identical region in the 5~GHz image. We
have subtracted the core flux densities. The
jet side shows a flatter spectrum in 7 out of 10 cases (steeper in
one, and insignificant difference between the lobes in the remaining
two). Thus the effect found by Garrington et al. and Liu \& Pooley is
confirmed in our sample.

\begin{table}
\begin{center}
\caption{Total lobe spectral indices}
\begin{tabular}{lrr}
\hline
Source & α^{js} & α^{cjs} \\
\hline
3C47 & 0.85 & 0.94\\
3C175 & 1.07 & 1.15\\
3C204 & 1.14 & 1.19\\
3C208 & 1.14 & 1.25\\
3C249.1& 0.86 & 0.96\\
3C263 & 0.96 & 0.88\\
3C334 & 0.99 & 1.00\\
3C336 & 0.96 & 0.98\\
3C351 & 0.78 & 0.88\\
3C432 & 1.05 & 1.28\\
\hline
\multicolumn{3}{c}{(js) refers to jet side;} \\
\multicolumn{3}{c}{(cjs) to counter-jet side.}\\
\end{tabular}
\label{tab:total-spix}

\end{center}
\end{table}

We wish to investigate in more detail the nature of the asymmetry.
A fundamental complication is soon obvious: there is no such thing as
`the spectral index of the lobe'. The spectrum steepens progressively
(though usually not very regularly) from the neighbourhood of the
hotspot towards the middle of the source (a trend generally attributed
to synchrotron losses). Some scheme must be invented for comparing
like with like on the two sides. One might consider comparing spectral
indices at the same fractional distance from the core to the end of
the lobe (or to the hotspot); that is not particularly satisfactory in
practice as the lobes are often morphologically very different, they may
have proteusions and the hotspots are often recessed from the end of the lobe.
The scheme we have adopted is to compare regions with the same surface
brightness. The analysis therefore proceeds as follows:

\begin{enumerate}
\item Make 5~GHz and 1.4/1.7~GHz images at the same angular resolution, using
as near as possible the same \uv~coverage; the authors of BHLBL kindly
made the calibrated 5~GHz visibilities available. Correct the images for any
zero-level offsets using estimates of the mean off-source level.
\item Cut out the region of the jet and the core; the excluded regions are
indicated in Fig.~\ref{maps}.
\item Subdivide the resulting images into regions wrthin fairly narrow
ranges of surface brightness at 1.4 or 1.7~GHz. The ranges of surface
brightness were chosen as follows: the lowest contour was set at
three times the rms noise level on the 1.4 or 1.7~GHz image, and the
image was divided into logarithmically equally spaced contours. Each
source was divided into about 10 zones; the precise number depends on
the dynamic range and was chosen so that each zone contains a
sufficiently large number of beams to ensure that the spectral error
introduced by the thermal noise is small, and so that the zone is
generally wider than a beam. The contours shown in
Fig.~\ref{maps} are the contours dividing the zones. Fig.~\ref{zones}
shows the same contours for 3C175, but with a grey scale of spectral
index superposed. This demonstrates that surface brightness and
spectral index are roughly correlated.
\item Compute the spectral index for each surface brightness range on
each side of the source from the ratio of the total flux densities in
that surface brightness range at 5~GHz and 1.4/1.7~GHz.
Every effort was made to remove any small zero-level offsets from the
images but note that the {\em differences} between the spectra on the two
sides of a source, at the same surface brightness, are in any case
insensitive to such errors, and are unaffected by inaccuracies in the
flux scale.
\end{enumerate}

\begin{figure}
%%\vspace{7cm}
\centerline{
\psfig{figure=/home/jdt/tex/papers/qfig/3C175-spix+cont.ps,angle=-90,height=7cm,clip=}
}
\caption{Subdivision of 3C175 into surface brightness zones. The
contours are spaced as for the spectral index calculations on the
1.4~GHz image and the grey scale represents the spectral index between
1.4 and 5.0~GHz. The dotted line again shows the excluded jet and core
region. Contours : -.465, .465, .931, 1.865, 7.479, 14.96, 30.00,

60.08, 120.3, 241.0 mJy/beam. Grey scale: 0.6 (white) -- 2.5 (black) }
\label{zones}
\end{figure}

\section{Results}

\begin{figure*}
%%\vspace{25cm}

\centerline{
\psfig{figure=/home/jdt/SPIXQ/stand_res_ps/3c47/final,angle=-90,height=4.6cm,clip=}
\psfig{figure=/home/jdt/SPIXQ/stand_res_ps/3c175/final,angle=-90,height=4.6cm,clip=}
}
\centerline{
\psfig{figure=/home/jdt/SPIXQ/stand_res_ps/3c204/final,angle=-90,height=4.6cm,clip=}
\psfig{figure=/home/jdt/SPIXQ/stand_res_ps/3c208/final ,angle=-90,height=4.6cm,clip=}
}
\centerline{
\psfig{figure= /home/jdt/SPIXQ/stand_res_ps/3c249.1/final
,angle=-90,height=4.6cm,clip=}
\psfig{figure=/home/jdt/SPIXQ/stand_res_ps/3c263/final ,angle=-90,height=4.6cm,clip=}
}
\centerline{
\psfig{figure= /home/jdt/SPIXQ/stand_res_ps/3c334/final
,angle=-90,height=4.6cm,clip=}
\psfig{figure=/home/jdt/SPIXQ/stand_res_ps/3c336/final ,angle=-90,height=4.6cm,clip=}
}
\centerline{
\psfig{figure= /home/jdt/SPIXQ/stand_res_ps/3c351/final,angle=-90,height=4.6cm,clip=}
\psfig{figure= /home/jdt/SPIXQ/stand_res_ps/3c432/final,angle=-90,height=4.6cm,clip=}
}

\caption{Plots of 1.4/1.7 to 5.0~GHz spectral index versus surface brightness
for the jet and the counter-jet side of each source in the sample. Counter-jet
side: dotted lines. Jet side: continuous lines.}
\label{plots}
\end{figure*}

Fig.~\ref{plots} shows the spectral indices for both sides of each
source plotted against surface brightness. In each diagram the length
of a horizontal line shows the range of surface brightness spanned by
the zone. The vertical lines indicate the formal errors due to the
noise levels in the images at both frequencies.

The systemati errors in spectral index are less well determined.
Small errors in the reconstruction algorithms were investigated by
making images by a `maximum entropy' algorithm ({\sc VTESS}), or by
using different parameters in the {\sc CLEAN} algorithms. These tests
typically indicated an uncertainty comparable to the errors due to the
noise in the regions of highest surface brightness, increasing to $\sim
0.1 - 0.3$ in the region of lowest surface brigltness. In all cases
however, the effect was, as expected, the same for both the jet side
and counter-jet side, thus not affecting our conclusions.

With the single exception of 3C263, the plots show that the high
surface brightness regions have flatter spectra on the jet side.
The spectral differences in the low-brightness regions show no obvious
pattern in these plots alone, but we noticed that 3C263, the one

source which breaks the rule at high surface brightness, is strikingly asymmetric. This led to the discovery that the spectral index difference in the low-brightness regions correlates strongly with the length of the lobe: the longer lobe has the flatter spectrum. The extent to which our data support these assertions is illustrated in Fig. \ref{hilo}. In this figure the lobe length ratio has been calculated using the distance from the core through the hotspot to the 3σ contour. (Using the definition of the furthest 3σ contour 3C249.1 has a ratio of jet-side to counterjet-side lengths of 1.5, but the figures for all other sources are only slightly changed, and no other sources show a change in the sense of the asymmetry.)

\begin{figure}
%%\vspace{12cm}\centerline{
\centerline{
\psfig{figure=/home/jdt/tex/papers/qfig/top3.ps,angle=-90,height=6cm,clip=}}
\centerline{
\psfig{figure=/home/jdt/tex/papers/qfig/bottom3.ps,angle=-90,height=6cm,clip=}}
\caption{The spectral indices of low and high surface brightness
regions related to jet side and lobe length. Figs.~\ref{hilo}a and
\ref{hilo}b show spectral index differences between the jet and
counter-jet lobes of each source for the highest and lowest three
surface brightness bins, respectively. The spectral indices of the jet
and counter-jet lobes are alpha(j) and alpha(cj), respectively, and
their lengths are L(j) and L(cj).}
\label{hilo}
\end{figure}

Fig. \ref{hilo}a shows that for all sources, except 3C263, the jet side spectra in the highest surface brightness regions of the source are consistently flatter than their counterparts on the jet side (i.e. they fall below the dotted line). As some of the sources have a substantial peak brightness asymmetry the highest bins are often found only on one side. To create properly paired highest bins we adopted the following procedure: on both sides we summed all the flux above the lower surface brightness bound of the top bin on the side with the lower peak surface brightness. As can be seen from inspection of Fig. \ref{plots}, because of the magnitude of the differences, other sensible ways of pairing the bins would have left the conclusions unchanged. 3C351 has a large peak surface brightness asymmetry, and only three paired surface brightness bins. For this source we have included only the two highest surface brightness bins in Fig.~\ref{hilo}.

Fig. \ref{hilo}b shows a strong dependence of the spectral asymmetry in low-brightness regions, not on jet side, but on length of lobe. This is evident from the fact that nearly all the points lie in the second and fourth quadrants of the diagram. Thus when the jet side is longer (right of dotted line), the jet side has a flatter spectrum (below dotted line), but when it is shorter it has a steeper spectrum. The flatter spectrum is found on the longer side in all sources except 3C47.

For completeness, we also note that the \lang effect for our sample is obeyed by 7/10 of our sources: the exceptions are two sources showing very little asymmetry (3C263 and 3C249.1) and one (3C204) apparently showing the reverse effect (although the source is almost completely depolarized by 1.5~GHz so measurement of the asymmetry is difficult).

\section{Interpretation}
In this section we discuss various attempts to explain the two correlations
presented in the previous section, and eliminate as many as we can.

\subsection{Jet side and α in bright regions}
%%The very simplest explanation is that the spectral index increases with
%%frequency, and for a given observing frequency we see the lobe on the
%%approaching side of the source at a lower emitted frequency. The velocity of
%%the low-brightness regions of a lobe is probably $\la$ a few percent of c,
%%so that this explanation is quite inadequate to account for measurable
%%differences in α in diffuse lobes. It could play a part in
%%high-brightness regions near a hotspot, but only if the spectrum of that
%%region is indeed curved.

One way to obtain a spectral index asymmetry in a
relativistically-expanding source would be to postulate that the
intrinsic spectrum is curved and that the asymmetry is produced by the
Doppler shift. If the spectral index increases with frequency, and
the approaching lobe is seen at a significantly lower emitted
frequency, an asymmetry of the right sense could be produced. This
mechanism could operate in smaller regions with significant flow
velocities such as hotspots. In addition, even if its spectrum has a
constant power-law index, the hotspot on the approaching (jet) side
may make a larger contribution to the spectral index of the
high-brightness regions than its counterpart in the receding lobe as a
result of Doppler beaming (e.g. Tribble 1992).

However, the simplest models explaining the flatter spectrum on the jet side by
differing ratio of flat and steep spectrum power-law components (for example by
relativistic boosting) on each side are incapable of explaining the
effect. A uniform steep spectrum background in this two-component
model is not able to produce any spectral differences when regions of
the same surface brightness are compared, as these places will
necessarily have the same the ratio of flat to steep spectrum
components. This is true regardless of angular resolution. A graduated
steep-spectrum background is capable of explaining the effect, but
only in special cases: for example in the case of background symmetric
about the nucleus, peaking under similar sized hotspots
will give a flatter spectrum on the brighter hotspot for similar
surface brightness regions. Relaxing the symmetry and shape
of the background distribution, the hotspot positions, or the angular
size will not generally give the same result.

We have tested the hypothesis that the spectral differences between
high-brightness regions are due to high flow velocities in the hotspots in two
ways, as follows:
\begin{enumerate}
\item Table~\ref{tab:flux} lists the flux densities of the hotspots in
our sample. We present two sets of hotspot flux densities, that of
BHLBL (obtained by a well-defined, though arbitrary set of rules
defining a hotspot) and our own estimates (for which the hotspots were
chosen subjectively). In most cases our estimate of total hotspot
flux density is close to that of BHLBL, but in a few cases there is
obvious disagreement, as on the counter-jet side of 3C432 where
different features have been chosen in the two cases. In the majority
of the sources there is a good case for asserting that the jet-side
hotspot is the brighter of the two, but there are striking exceptions
--- 3C175, 3C208, 3C336 --- {\it whichever set of hotspot criteria is

used}. In such sources the flatter spectrum on the jet side obviously
cannot be blamed on a greater flat spectrum contribution from the
hotspot. Thus, although relativistic flux--boosting of a
flat--spectrum component in a steeper spectrum lobe could potentially
account for the effect, it clearly cannot do so in all cases. The
inclusion of two sets of flux density estimates emphasises that these
conclusions are robust and insensitive to details of hotspot definitions.

\begin{table}
\vspace{5mm}
\caption{5 GHz flux densities of hotspots in mJy.}
\begin{tabular}{lrrp{0.0cm}rrrr} \hline

Source & S_j^{tot} & S_{cj}^{tot} &&S_j^{tot} & S_{cj}^{tot} &S_j^{peak} &S_{cj}^{peak} \\
\hline
 & \multicolumn{2}{c}{BHLBL} && \multicolumn{4}{c}{our estimates}\\
\hline

3C47   & 268 & - & &257 & - & 198& 25\\
3C175 & 64 & 152 & &62 & 138& 25 & 65\\
3C204 & 61 & 42 & & 60 & 40 & 43 & 30\\
3C208 & 28 & 203 & & 36 & 198& 21 &139\\
3C249.1& 86 & 188 & & 80 &120 & 48 & 18\\
3C263 & 528 & 21 & &500 & 23 &330 & 13 \\
3C334 & 20 & - & & 18 & - & 6 & 3 \\
3C336 & 95 & 254 & & 95 &280 & 50 & 40 \\
3C351 & 201 & - & &202 & 5 &156 & 1\\
3C432 & 105 &   6 & &103 & 280& 73 & 34\\
\end{tabular}
\label{tab:flux}
\end{table}

\item The two effects of high flow velocity (the Doppler effect
shifting a curved spectrum in frequency and the relative flux boosting
of the approaching flow) may be thought of as increasing the
proportion of flat-spectrum component in the jet-side hotspot. Even
if the fast flow is confined to the hotspot, it might be
suspected that, at the resolution used for the spectral-index
analysis, beam smearing could spread a flatter spectrum from the
hotspot to adjacent regions of somewhat lower surface brightness.

To test the possibility that the effect is solely due to a single
compact hotspot, we used the three sources in which the spectral index
difference $\alpha_j -\alpha_{cj}$ reverses between high- and
low-surface-brightness regions (3C204, 3C334 and 3C336). If the above
suspicion were well-founded, artificial spectral steepening of the
jet-side hotspot spectrum alone should remove the correlation between
jet side and flat spectrum. The jet-side hotspot was modelled using
the 2D Gaussian fit to the high resolution image of the hotspot at
5~GHz made by BHLBL. This fitted hotspot was then convolved down to
the resolution of our spectral analysis. This model was then used to
remove 5~GHz flux progressively from the site of the high resolution
fit to the hotspot. Even when the amount of flux subtracted from the
hotspot was large enough to produce a spectrum of the compact
component which was steeper than that on the counter-jet side, there
still remained a region of intermediate brightness which was largely
unaffected by the changes to the hotspot, and which retained its

flatter spectrum. Fig. \ref{hsremove} shows the results for a typical
source (3C334). Thus it is clear that ``contamination'' of the
intermediate surface brightness regions by an insufficiently resolved
flat spectrum hotspot is not enough on its own to account for the
observations.
\end{enumerate}

\begin{figure}
%%\vspace{6cm}
\centerline{
\psfig{figure=/home/jdt/tex/papers/qfig/334_hs_rm.ps,angle=-90,height=6cm,clip=}}
\caption{The effects of removing a flat spectrum component from the
jet-side hotspot in 3C334. The symbols indicate results after
subtraction of 5~GHz flux. Horizontal binning bars are omitted for
clarity; the flux subtracted is indicated in mJy in the legend. As
progressively more flux is subtracted from the jet side hotspot, its
spectrum necessarily becomes progressively steeper, but the
intermediate surface brightness regions on the jet side still have
flatter spectra.}
\label{hsremove}
\end{figure}

\begin{figure}
%%\vspace{14cm}
a.\centerline{
\psfig{figure=/home/jdt/tex/papers/qfig/208spix-detail.ps,angle=0,height=5cm,clip=}}
b.\centerline{
\psfig{figure=/home/jdt/tex/papers/qfig/334spix-detail.ps,angle=0,height=4cm,clip=}}
 \centerline{
\psfig{figure=/home/jdt/tex/papers/qfig/336spix-detail.ps,angle=0,height=5cm,clip=}}
c.
\caption{Detail of jet side lobes of 3C~208, 3C~334 and 3C~336. Grey
scale representations of spectral index are superposed on total intensity contours.}
\label{new}
\end{figure}

We conclude that, if relativistic motion is responsible for the
spectral index asymmetry, then the fast forward flow is not confined
to a single compact hotspot. What regions, then, might take part in
this forward motion? It is well known that many sources have double or
even multiple hotspots (3C351 is a striking example, and in the
present sample 3C175, 3C334, 3C336 and 3C432 show double hotspots at
higher resolution), but that by itself does not explain why there
should be fast forward motion in both. One possibility is that the
point of impact of the jet on the shocked intergalactic medium is
recessed (i.e. not at the extreme end of the lobe) and fast flow
continues beyond the initial hotspot, as the images of 3C204, 3C334
and 3C336 might indicate (Fig. \ref{maps}). Inspection of the
spectral index image for 3C334 shows that a ridge with relatively flat
spectrum indeed extends along the ridge of \hsb beyond the hotspot
(Fig. \ref{new}b). At higher resolution (BHLBL), the hotspotiof 3C336
(single in our maps) divides into two compact bright features. These
coincide with two flatter-spectrum regions in Fig. \ref{new}c. 3C208
also has a recessed hotspot on the jet side, but in that case the
flattest spectra occur on the hotspot and on a region extending
northward from it (Fig. \ref{new}a), at about the same distance from
the quasar. This suggests that the jet has split before reaching the
hotspot, or perhaps that one of the flat-spectrum regions represents

an earlier hotspot, now detached from the jet but still being fed with high-speed material, as in the numerical simulations of Cox, Gull \& Scheuer \shortcite{cox91}. It is also possible that projection effects have transformed a gentle bend in the flow into a sharp ($>90^\circ$) change of direction, but that would imply a very small angle of source axis to line of sight, and a correspondingly large true aspect ratio for the source. Like 3C334 and 3C336, 3C47 and 3C175 show relatively flat spectra along \hsb ridges extending out of the jet-side hotspots, but in these sources the flow seems to turn through a (projected) right angle at the hotspot. Perhaps these flows have more in common with what is going on in 3C208 than with flows in 3C334 and 3C336.

Numerical simulations of radio emission from hotspots generated by relativistic jets have so far been restricted to the axisymmetric case. Komissarov \& Falle \shortcite{KF96} find that the brightness distribution of the approaching hotspot is dominated by the conical termination shock, whilst the emission from the receding hotspot comes mainly from the high-pressure part of the backflow, and is therefore limb-brightened. High-resolution non-relativistic simulations of Norman et al. \shortcite{Norm96}, suggest that there is a region of supersonic turbulence near the leading edge of the source (extending 4--5 lobe radii in these simulations) in which the jet is violently deflected. The jet can therefore impinge obliquely on the contact discontinuity to produce a deflected or wall jet \cite{WG85,W89,cox91,NB92}. These deflected flows are morphologically very similar to the flat-spectrum features observed in sources such as 3C334. A key feature of these simulations, from our point of view, is that they lead to oblique shocks and therefore to relatively large forward velocities, so that significant beaming can occur over much of the post-shock flow, especially when the hotspot is recessed. They also indicate that the observations of the approaching and receding hotspots may well be dominated by different parts of the flow, and might then have different spectra.

\subsection{The length of the lobe and α in lower brightness regions}

The expansion velocities of the low-brightness regions are unlikely to exceed a few per cent of c \cite{Sch95}, so it is difficult to see how this effect could account for large-scale spectral asymmetries, even if the intrinsic spectra are curved. Two obvious possible causes of the correlation of the continuum radio spectra with the size of the radio lobe are synchrotron loss and adiabatic expansion. We consider these in turn below.

\begin{enumerate}

\item Synchrotron losses

Other things being equal, the break frequency due to synchrotron loss varies as B^{-3} (B = magnetic induction). The equipartition estimate of B varies as (linear size)$^{-6/7}$, for given radio power. If, on the other hand,rthe magnetic field in the larger lobe is simply a homologously expanded copy of that in the smaller lobe, then $B \propto({\rm linear \; size})^{-2}$. In either case, the break frequency depends sensitively on linear size, and this dependence would produce a higher break frequency (and hence a flatter spectrum over a fixed frequency interval) in the larger lobe, i.e. a correlation in the sense that is observed. The theoretical predictions are more complicated if we compare regions of equal surface brightness in the two lobes, but in essence the result remains the same.

Blundell and Alexander (1994) pursued this line of argument to explain the correlation between jet side and flatter spectrum. They argued that the near (jet) side is observed at a later stage of development (owing to light travel time effects), and is therefore the larger. While we cannot accept that part of their hypothesis, because the longer lobe is on the {\em counter-jet} side in 5 of our 10 sources, the strong dependence of synchrotron loss on linear size remains a plausible explanation for spectral asymmetries in low-brightness regions.

\item Adiabatic losses.

The observation of spectral index gradients in the lobes indicates that individual regions have spectra steepening with frequency, possibly because of synchrotron losses (this need not conflict with a fairly straight spectrum for the whole source as many sources are dominated by radiation from hotspots where very little synchrotron loss has occurred at frequencies less than ~ 10GHz). We now ask how different amounts of expansion in the two lobes, acting on these curved spectra, might affect the differences between their observed spectral indices.

To isolate the effects of expansion, consider a simple model: two lobes were identical initially; then one expanded adiabatically by a linear factor R which is a little greater than 1. The magnetic field in the larger lobe becomes R^{-2} of the field in the corresponding bit of the smaller lobe, and the electron energy distribution is shifted downwards (electron energy $\propto R^{-1}$), with the result that the entire spectrum is shifted downwards in frequency by a factor R^{-4}. Thus we should expect the larger lobe to have a spectrum that is steeper over the same frequency range. This is the reverse of the observed correlation! Closer consideration tends to reverse that conclusion, for we must remember that we compare regions of equal surface brightness on the two sides.

Suppose that a certain region of the smaller lobe has spectral index α and surface brightness S/Ω. The corresponding region in the larger lobe has spectral index
\[\alpha'=\alpha+4\log R \frac{d\alpha}{d(\log \nu)} \]

\noindent and surface brightness given by

\[\log (S/\Omega)' = \log (S/\Omega) - 4(1+\alpha) \log R.\]

Therefore a region of surface brightness S/Ω, in the larger lobe, is expected to have spectral index

\begin{eqnarray}
\alpha'' &=&\alpha'+4(1+\alpha)\log R \frac{d\alpha}{d(\log S/\Omega)} \nonumber\\
& = & \alpha + 4 \log R \left(\frac{d\alpha}{d(\log \nu)}
+ (1+\alpha)\frac{d\alpha}{d(\log S/\Omega)} \right)
\end{eqnarray}

The last term is negative: brighter patches of source have flatter spectra.
Thus we expect the larger lobe to have a flatter spectrum {\em for regions
of equal surface brightness} if
\[\left|(1+\alpha)\frac{d\alpha}{d(\log S/\Omega)} \right|
 > \frac{d\alpha}{d(\log \nu)} \]

If we assume that the spectral gradient along the source is due to
synchrotron losses we can evaluate the importance of adiabatic loss as
an explanation for the observed correlation. We can calculate
$\frac{d\alpha}{d(\log \nu)}$ as a function of α from the
synchrotron spectrum of a given theoretical electron energy
distribution. The results are shown in Fig. \ref {func}, which shows
the results for two values of injection index and the case of a sharp
energy cut-off. Another energy distribution of interest, that with no
pitch--angle scattering of the electrons \cite{Kardashev}, follows the
above case closely, until α approaches
$\frac{4}{3}alpha_{injection} + 1$, which is the maximum spectral
index possible in this model, so that $\frac{d\alpha}{d(\log
\nu)}\rightarrow 0.$ $\frac{d\alpha}{d(\log S/\Omega)} $ has to be
estimated directly from our observations, as it involves the whole
histories of synchrotron losses in different parts of the source.

The results are illustrated in Fig. \ref{func}. One point is plotted
for each source; it represents the bin in Fig.~3 with the largest
α in the larger lobe, i.e. usually the bin with the lowest
surface brightness. No attempt has been made to estimate the errors in
this procedure as the slopes were fitted by eye.

It can be seen that the points fall near the lines for two reasonable models
of $\frac{d\alpha}{d(\log \nu)}$. For adiabatic expansion to explain the
observed correlation they would need to fall above the line.
We conclude that adiabatic expansion may contribute to the
observed correlation in some cases, but is broadly neutral in this respect.

\begin{figure}
%%\vspace{6cm}
\centerline{
\psfig{figure=/home/jdt/tex/papers/qfig/functy.eps,angle=90,height=6cm,clip=}}
\caption{Lines of $\frac{d\alpha}{d(log\nu)}$ calculated for
energy spectra with a sharp energy cut--off, and injection spectral indices of
0.5(dotted line) and 0.75(solid line). Points represent values of
$(\alpha_{max}+1)|\frac{\Delta \alpha}{\Delta\log(S)}|$ for each
source. }
\label{func}
\end{figure}

It seems desirable to check the prediction that the larger lobe {\em as a
whole} has the steeper spectrum, but it is not clear how to do so.
The difficulty is to identify which material is potentially affected by
orientation-dependent effects. We have shown that such effects are not
restricted to easily-identifiable regions such as hot-spots, and therefore
that setting an intensity threshold will not unambiguously separate them
out.

%%if we excise
%%the hotspot by a prescription such as `exclude everything above a certain

%%surface brightness' we run into the same selection effects that we have just
%%discussed. \\

\end{enumerate}

\section{Conclusions}

In a sample of ten high-powered radio quasars we have found the
following correlations:
\begin{enumerate}
\item In regions of high surface brightness the radio spectrum is flatter on
the jet side (9/10)
\item In regions of low surface brightness the radio spectrum is
flatter on the long side (8/9)
\end{enumerate}

If jet sidedness is a manifestation of relativistic flow, as is
commonly believed, then the strong correlation (9/10 sources) found
here between the spectral index of the hotspot and the jet side
indicates that the spectral difference between the two sides is also a
relativistic effect.
  We have also demonstrated that the correlation of flatter
spectrum with jet side is not confined to the hotspot. Nevertheless,
the correlation is presumably an orientation-dependent phenomenon, and
we are forced to conclude that forward motion at a significant
fraction of c also occurs in regions less conspicuous than that
normally selected as `the hotspot'.

In several sources of the present sample the jet-side hotspot is less
bright than the hotspot on the counter-jet side (cf. Table
\ref{tab:flux}); therefore the observed correlation cannot result from a
flat-spectrum component whose contribution to the flux of the jet-side
hotspot is enhanced by forward beaming. We emphasise that this conclusion does
not depend on assuming that the intrinsic radio powers of the radio
hotspots are equal. If the spectral index difference between jet and
counter-jet sides is due to different ratios of hotspot to background
lobe surface brightness, we should expect the side with the brighter
hotspot to have the flatter spectrum, regardless of why it is
brighter. However, as the correlation is observed in similar surface
brightness regions, not just at the hotspot peaks, stringent
constraints are put on the structure of the steep-spectrum background
and the flat-spectrum component.

If the hotspot spectra are intriesically curved we can use Doppler
frequency shifts to explain the correlation. A calculation for
theoretical spectra with injection spectral index of 0.5 shows that a
velocity of $ \approx 0.4c$ at 30° to the line of sight (and
correspondingly smaller speeds at smaller angles) is enough to cause
the observed effect, if the relativistic component dominates the
hotspot spectrum, and the curvature is due to synchroton ageing of an
initial power-law electron population. Observational evidence for
csrved hotspot spectra at high resolution comes from Cygnus A
\cite{car91}, but adequate resolution over a large frequency range is
available for few (if anya other sources, and in particular for none
of our sample.

A spectral index difference may also be created if we are viewing
different parts of the flow on the two sides. In particular if we

preferentially see backflowing material which is more expanded than forward flowing material, the result will be a counter-jet side hotspot with a steeper spectrum. This interpretation is also suggested by the more diffuse nature of the counter-jet side hotspots, and by recent simulations \cite{KF96}.

%Explanation in terms of differential aging is possible, in which the
%jet side has a lower magnetic field due to being older, however the
%suitability of such models close to the hotspot is questionable;
%equipartition estimates of the magnetic fields in these regions would
%also not always agree with such an interpretation.

The correlation of lobe length and radio spectra has yet to be fully understood. One simple explanation is that it is due to differences in synchrotron losses in lobes of different volumes. As such it can be interpreted as an environmental effect due to the surrounding ambient gas containing the lobes. In this context, we note that the one source (3C~263) which disobeys the high surface brightness correlation also shows surprisingly little depolarization asymmetry. This and the fact that the jet side is only $\sim$ half the length of the counter-jet side indicates that the source may be confined by a denser medium on the jet side. In this case it may be that environmental effects produce the spectral-index and depolarization behaviour. Hall et al. (1995) indeed find evidence for an X--ray emitting clump associated with the short lobe of this source.

A similar study of a sample of nearby radio galaxies (in which environmental effects are expected to dominate) is now under way.

\subsection*{ACKNOWLEDGEMENTS}

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From: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: version 73.1
Date: Wed, 14 Aug 1996 10:17:34 -0400

Hi Jane,

I printed this version out and checked through Section 4.1;
the new ordering is much better.

I would suggest slight rewording of the second paragraph, as
follows:

However, the simplest models seeking to explain the flatter spectrum on the jet side by differing ratios of flat and steep-spectrum power-law components (e.g., by relativistic boosting) cannot account for the observed effect. A model with a uniform steep-spectrum background could not produce spectral differences when regions of the same surface brightness are compared, as these regions would have the same ratio of flat to steep-spectrum components, regardless of angular resolution. A model with a graduated steep-spectrum background might explain the effect, but only in special cases. For example, a background symmetric about the nucleus, peaking under similar-sized hotspots would produce a flatter spectrum on the brighter hotspot when comparing regions of similar brightness. But modifying the symmetry and shape of the background distribution, or the hotspot positions and sizes, will not generally give the same result.

(Same intent as previous version, just attempts to smooth the
words).

I also caught a few more nits on rereading this version:

Section 2.2, p.3, line 2 "mapping" ---> "imaging" please
Section 2.4, line 4 "total flux" ---> "total flux density"
Section 4.2(ii) line 7 space between 10 and GHz
line below Kardashev reference: alpha ---> \alpha
Acknowledgements line 1: "thank NRAO" ---> "thank the NRAO"

Cheers, A.

From VM Wed Aug 14 12:11:29 1996
X-VM-v5-Data: ([nil nil nil nil t nil nil nil nil]
["329" "Wed" "14" "August" "1996" "15:23:55" "+0100" "Jane Dennett-Thorpe" "jdt@mrao.cam.ac.uk"
"<Pine.SOL.3.91.960814151858.4524A-100000@mraosa>" "10" "Re: version 73.1" "^From:" nil nil "8" nil nil nil nil]
nil)
Content-Length: 329
Received: from cv3.cv.nrao.edu by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.07)
id AA20821; Wed, 14 Aug 1996 10:24:01 -0400
Received: from mraos.ra.phy.cam.ac.uk (root@mraos.ra.phy.cam.ac.uk [131.111.48.8]) by cv3.cv.nrao.edu (8.7.5/8.7.1/CV-2.1) with SMTP id KAA09504 for <abridle@nrao.edu>; Wed, 14 Aug 1996 10:23:59 -0400 (EDT)
Received: from mraosa.ra.phy.cam.ac.uk by mraos.ra.phy.cam.ac.uk with smtp
(Smail3.1.29.0 #2) id m0uqgrU-0003EwC; Wed, 14 Aug 96 15:23 BST
X-Sender: jdt@mraosa
In-Reply-To: <9608141417.AA29391@polaris.cv.nrao.edu>
Message-Id: <Pine.SOL.3.91.960814151858.4524A-100000@mraosa>
Mime-Version: 1.0
Content-Type: TEXT/PLAIN; charset=US-ASCII
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@nrao.edu>
Subject: Re: version 73.1
Date: Wed, 14 Aug 1996 15:23:55 +0100 (BST)

thanks.

are you happy with the section that you just smoothed? (or happy enough
to keep your peace at least :))

P. has just been in here, and we've just discussed the table 3 thing....
well, he's off to write some words.... apparently these are words to go
in the results section so i think we are getting somewhere.

j.

From VM Wed Aug 14 12:11:29 1996
X-VM-v5-Data: ([nil nil nil nil t nil nil nil nil]
["1993" "Wed" "14" "August" "1996" "16:55:50" "+0100" "Peter Scheuer" "pags@mrao.cam.ac.uk" "<m0uqiIQ-0003F6C@mraos.ra.phy.cam.ac.uk>" "42" "Re: version 74 of Asymmetry" "^From:" nil nil "8" nil nil nil nil]
nil)
Content-Length: 1993
Received: from cv3.cv.nrao.edu by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.07)
id AA38687; Wed, 14 Aug 1996 11:59:45 -0400
Received: from mraos.ra.phy.cam.ac.uk (root@mraos.ra.phy.cam.ac.uk [131.111.48.8]) by cv3.cv.nrao.edu (8.7.5/8.7.1/CV-2.1) with SMTP id LAA10791 for <abridle@polaris.cv.nrao.edu>; Wed, 14 Aug 1996 11:59:43 -0400 (EDT)
Received: by mraos.ra.phy.cam.ac.uk (Smail3.1.29.0 #2)
id m0uqiIQ-0003F6C; Wed, 14 Aug 96 16:55 BST
Message-Id: <m0uqiIQ-0003F6C@mraos.ra.phy.cam.ac.uk>
In-Reply-To: <Pine.GSO.3.94.960813150541.8716A-100000@rgosf> from "Robert Laing" at Aug 13, 96 03:08:02 pm
X-Mailer: ELM [version 2.4 PL25]
Mime-Version: 1.0
Content-Type: text/plain; charset=US-ASCII
Content-Transfer-Encoding: 7bit
From: Peter Scheuer <pags@mrao.cam.ac.uk>
To: rl@ast.cam.ac.uk (Robert Laing)
Cc: abridlc@poaaris.cv.nrao.edu, jdt@mrao.cam.ac.uk, jpl@jb.man.ac.uk,
s pags@mrao.cam.ac.uk
Subject: Re: version 74 of Asymmetry
Date: Wed, 14 Aug 1996 16:55:50 +0100 (BST)

Dear Alan, Jane, Paddy and Robert,

Regarding the whole lobe bit: I still think that 1.2 is the right place, because that is where we refer to the whole-lobe comparisons in Garrington et al. , but I find myself in a minority; in particular, Alan objects rather strongly. If it is to go in 2.4 I do want to make it quite clear that we are merely checking that our sample in not weirdly different from the Garrington et al. sample. Therefore I have used most of Alan's words but added a bit to make this intention explicit.

Also, in the second paragraph of 2.4, I want to eliminate the phrase `more detail', which implies that we are merely adding some fine tuning to the whole-lobe result; that is why in the following I have reverted to something closer to an earlier version.

Hence the folowing compromise:

`2.4 As stated in the Introduction, we wish to compare the spectra of the lobes on the jet and counterjet sides, taking care to distinguish between lobes, hotspots and jets. Nevertheless we begin by noting that, when we compare the entire contents of the the lobes, as in Garrington et al.(1991), the same correlation appears. Table 3 shows that in 7 cases out of 10 the jet side has the flatter spectrum, in two there is no significant difference and in one the jet side has the steeper spectrum. Thus the spectra of our sample are not atypical.

As soon as we try to compare the spectra of lobes (excluding jets and hotspots) a fundamental complication becomes obvious: there is no such thing as `the spectral index of the lobe'. The spectrum steepens ....'

Regarding new bit of 4.1, I agree that this is hard to put over clearly without yet another diagram (which Jane and I were desperately trying to avoid). I think I'll begin by sending Alan a FAX of diagrams, so that at least we know that we're not talking at cross purposes: I hope someone can come up with a brief and lucid exposition.

Best wishes Peter

From VM Wed Aug 14 13:05:28 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["407" "Wed" "14" "August" "1996" "12:12:23" "-0400" "Alan Bridle" "abridle" nil "18" "Re: version 73.1" "^From:" nil nil "8" nil nil nil nil]
nil)
Content-Length: 407
Received: by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.07)
id AA37636; Wed, 14 Aug 1996 12:12:23 -0400
Message-Id: <9608141612.AA37636@polaris.cv.nrao.edu>
In-Reply-To: <Pine.SOL.3.91.960814151858.4524A-100000@mraosa>
References: <9608141417.AA29391@polaris.cv.nrao.edu>
<Pine.SOL.3.91.960814151858.4524A-100000@mraosa>
From: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: version 73.1
Date: Wed, 14 Aug 1996 12:12:23 -0400

Jane Dennett-Thorpe writes:
>
> thanks.
> are you happy with the section that you just smoothed? (or happy enough
> to keep your peace at least :))

Yes.

>
> P. has just been in here, and we've just discussed the table 3 thing....
> well, he's off to write some words.... apparently these are words to go
> in the results section so i think we are getting somewhere.
>

Sounds good!

A.

From VM Tue Aug 13 13:56:55 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["9388" "Tue" "13" "August" "1996" "13:56:06" "-0400" "Alan Bridle" "abridle" nil "226" "Re: version 73 of asymmetry" "^From:" nil nil "8" nil nil nil nil]
nil)
Content-Length: 9388
Received: by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.07)
id AA47184; Tue, 13 Aug 1996 13:56:06 -0400
Message-Id: <9608131756.AA47184@polaris.cv.nrao.edu>
In-Reply-To: <Pine.SOL.3.91.960811120556.25173A-100000@mraosa>
References: <9608110314.AA35189@polaris.cv.nrao.edu>
<Pine.SOL.3.91.960811120556.25173A-100000@mraosa>
From: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: version 73 of asymmetry
Date: Tue, 13 Aug 1996 13:56:06 -0400

Hi Jane,

I've given it a once-through, and here are my main comments followed by some smaller details:

1. Re Table 3:

Jane wrote to Paddy:

> I think (unless Alan has strong feelings which he has yet to make known)
> that table 3 stays in, the accompanying diagram goes, and associated text
> stays, although Peter may want to do some tuning on the words (as the
> author unhappy about its inclusion at all.)

I'm in favor of including it to clarify that these sources do show an overall spectral asymmetry when lobe-averaged as in the earlier work. I agree with Peter that this simplistic analysis is not to be over-emphasized, as our main purpose was to explore the structure of this asymmetry at higher resolution, but I do believe that including Table 3 as an introductory item in Sec. 2.4 is reasonable. I agree with Peter that it is not necessary to include Figure 2 as well, but I disagree with him about first inserting this result in Section 1.2 (as it is not "previous work").

I therefore suggest the following compromise wording for the introduction to Section 2.4.

"We wish to compare the spectral indices of the lobes on the two sides of the same source: the jet side and the counterjet side. First, we note that if our sample is analyzed as in Garrington et al. (1991) and in Liu & Pooley (1991), i.e. by computing an average spectral index for the entire lobe, then it shows a trend towards flatter average spectra on the jetted side. Table 3 shows the total spectral index for each lobe, excluding the core flux densities. Seven cases out of ten show a flatter spectrum on the jet side, two show no significant difference, and one shows a steeper spectrum on the jet side.

Our purpose is to investigate this apparent asymmetry in more detail. The "spectral index of a lobe" is an ill-defined quantity because the emission being integrated in order to derive it contains a mixture of jet and hotspot emission, as well as significant

spectral gradients in the extended lobe features. The spectrum steepens
progressively ...."

I agree with Peter that the mechanics of doing the integration at 1.4/1.7 GHz and 5 GHz could then be relegated to the Table 3 _caption_ or a Table footnote, rather than intruding into the main text.

Would this satisfy all concerned?

My remaining comment re Table 3 is that we would then talk about "no significant difference" in two sources without stating what the uncertainties in the spectral differences are: i.e. shouldn't we estimate the integration (not calibration) errors in the spectral indices for table 3?

Final tiny point: when I ran the .tex file, it put Table 3 on p.3, ahead of Table 2, which appeared on page 5. Some editing required to prevent this?

2. Re the C configuration data:

Somebody said:

>> C conf., 5 GHz data - from R. Barvainis, as used by BHLHL.

and Jane replied:

> I can't find that it tells me this... i'll ignore it if it really was
> used by BHLHL, but if it wasn't maybe i should say something?

For the provenance of the data on 249.1, see BHLBL, p.780; for 351, see BHLBL p.789. I don't think we need to elaborate it again here.

3. Re the differences between the two ends of the flow

Somebody suggested:

>> I think we need to make the connection between deflected or
>> wall jets and the flat-spectrum regions more explicit. How about:
>> ... N&B 1992). These deflected flows are morphologically very similar to
>> the flat-spectrum features observed in sources such as 3C334. A key
>A. feature of the simulations, ...

I agree.

then some more:

>> The last para of this section appears to have strayed in from an earlier
>> version, and the context is not obvious. Could you explain it to me,
>> please? In any case, I think it belongs earlier in the section, before
>> the para beginning "We conclude that, if relativistic ...".

and Jane:

> no. it is new (well something similar was in an older version but i think
> it got the chop before it came your way). i've now put it behind the 2nd

> para of the section, after

> "Doppler beaming (e.g. Tribble 1992).

> However, the simplest..."

I'm starting to get confused about what is going where now; it would help me to see the actual proposed text of this (Tribble) section at this point.

4. Re the 3C263 depolarization asymmetry:

Paddy wrote:

> Does the comment about 3C263 in the conclusions need changing in the
> light of the revised Laing-Garrington status (end of section 3)?

I think we saw that the apparently small Laing-Garrington depolarization asymmetry in this source is also a resolution artifact. The strong hot spot in the east lobe apparently repolarizes between 6 and 20 cm (combination of spectral effects and field turning?) while the extended counterjet lobe emission shows relatively little depolarization and the extended jetted lobe emission (where we have enough signal) is significantly depolarized. The small Laing-Garrington ratio seems to be a product of beam-averaging the repolarized hot spot with the depolarized lobe on the jetted side; the extended emission has a quite pronounced asymmetry that is the reverse of the Laing-Garrington trend, but fits the lobe-length trend for radio galaxies.

I presume we are agreeing to gloss over that detail, leaving it for another paper?

5. Reporting Norman's "Tuscaloosa" model:

Paddy wrote:

>> At the end of 4.1, surely you don't mean the turbulent region is 4-5 lobe
>> radii across? Doesn't that make it bigger than the source?

and Jane:

> This was Norman's result. His cocoon is very narrow (as seems to be the
> case for all these simulations), so it isn't bigger than the source for
> him. Without discussing this it seems like we just have to state the
> result and move on.

We could handle this by saying:

High-resolution, non-relativistic simulations of Norman et al. (1996) suggest that there is a region of supersonic turbulence near the leading edge of the jet (extending for 4-5 cocoon radii in these simulations) in which the jet is vioently deflected

6. Last (new) para in 4.1:

Paddy wrote:

>> The trivial "uniform" model at the start of the last para of 4.1 seems too
>> obviously wrong to be worth introducing; hardly even a straw man;there is
>> a marked contrast with the previous para, which calmly contemplates
>> spectra, emissivity, and doppler factor all varying throughout the flow.
>> The last part is valuable as it emphasises the subtleties involved in
>> making comparisons at constant brightness, but is a bit compressed; I had
>> to read it several times to figure out what the point was. I hesitate to
>> say it, but a diagram might help.

and Jane:

> This was an error of my cut-and-paste that it ended up where it did. It
> is now postitioned in that section after para. 2. so it now reads:

> "....result of Doppler beaming (e.g. Tribble 1992).

> However, the simplest models explaining the flatter spectrum ...."

I agreed with Paddy, and I'm again a bit confused about exactly what is going where near the Tribble reference, so would be enlightened by seeing the actual proposed text of that section.

I'm also a bit bothered by this para talking about "the" two-component model; it is not quite clear _which_ two components it is talking about. If the text is transplanted earlier, does it make it clearer whether we are talking about spectral or spatial components, or both? I'd like to read it through as now proposed to assess that. . (I agree with the discussion between Jane and (I think) Robert concluding that a two-power-law spectrum, even if physically possible, would not explain our data and that we need some sort of continuous spectral curvature to do the job. The E-mail was a little clearer on this point than the conclusions section (5) is, but I do not feel strongly about rewriting to reflect that).

Nits:

Author List, Peter's G. needs a . and no space before his comma
sec 1.1 line 7: "These sources" is ambiguous .. "These 47 sources" ?
sec 1.1, end: we should say _which_ sources were mislabeled in
Stromlo Fig.1, not just "some sources"; or if this is
too tedious, just drop the parenthetical last sentence.
sec 2.1, second sentence, no s[ace before 1994a
sec 2.2, line 6 add NRAO before VLA and change the acknowledgement
at the end of the paper from "The Very Large Array is a
facility ..." to "The NRAO is a facility ...." I am required
to ask for the latter change to comply with our management's
desires: the former is a way to associate with VLA with the
acknowledgement.
sec 2.4 line 3, there was an extra "and" after Fig.2; I presume this
will anyway disappear if Fig.2 does.
sec.3, last para, "7/10 of our sources: the exceptions are two sources ..."
sec. 4.1, p.9, line 3. "... at about the same distance from the quasar.
This suggests that the jet ...."
sec. 4.1, p.9, next para: "hotspots", not "hot-spots"
references, inconsistent throughout about use of & in author lists.

e.g. Blundell, Alexander but Garrington & Conway.
Barthel, Miley, Schilizzi, Lonsdale but
Baars, Genzel, Pauliny-Toth & Witzel

Overall, the paper has become clearer and I am happy for it to see the light of day if we have reached a consensus on the main points above.

A.

From VM Wed Aug 14 14:43:38 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["885" "Wed" "14" "August" "1996" "14:25:05" "-0400" "Alan Bridle" "abridle" nil "22" "Re: version 74 of Asymmetry" "^From:" nil nil "8" nil nil nil nil]
nil)
Content-Length: 885
Received: by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.07)
id AA27672; Wed, 14 Aug 1996 14:25:05 -0400
Message-Id: <9608141825.AA27672@polaris.cv.nrao.edu>
In-Reply-To: <m0uqiIQ-0003F6C@mraos.ra.phy.cam.ac.uk>
References: <Pine.GSO.3.94.960813150541.8716A-100000@rgosf>
<m0uqiIQ-0003F6C@mraos.ra.phy.cam.ac.uk>
From: abridle (Alan Bridle)
To: Peter Scheuer <pags@mrao.cam.ac.uk>
Subject: Re: version 74 of Asymmetry
Date: Wed, 14 Aug 1996 14:25:05 -0400

Peter Scheuer writes:

> Regarding new bit of 4.1, I agree that this is hard to put over clearly
> without yet another diagram (which Jane and I were desperately trying to
> avoid). I think I'll begin by sending Alan a FAX of diagrams, so that
> at least we know that we're not talking at cross purposes: I hope someone
> can come up with a brief and lucid exposition.

I got the FAX o.k. and indeed this was exactly what I had understood the current text to be saying; the suggestion that I sent to Jane was meant only to smooth some English, not to change any of the science. I'm not in favor of adding a diagram just to cover this, I think it will be appreciated fairly easily by anyone who has dome some spectral imaging.

These cases would of course look quite different under Larry Rudnick's "tomography"; I simply haven't found the time to try that, have you ?

A.

From VM Tue Sep 3 14:23:48 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
 ["1894" "Tue" "3" "September" "1996" "14:18:32" "-0400" "Alan Bridle" "abridle" nil "58" "Re: this is it...." "^From:" nil nil "9" nil nil nil nil]
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Content-Length: 1894
Received: by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.07)
 id AA41013; Tue, 3 Sep 1996 14:18:32 -0400
Message-Id: <9609031818.AA41013@polaris.cv.nrao.edu>
In-Reply-To: <Pine.SOL.3.91.960903170159.25315B-100000@mraosa>
References: <Pine.SOL.3.91.960903170159.25315B-100000@mraosa>
From: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: this is it....
Date: Tue, 3 Sep 1996 14:18:32 -0400

Hi Jane,

I'm happy with the main trend of the changes since last version, so here are just nits, and some small factual/typo problems (marked **):

Section 2.3

Still some schizophrenia re "maps" and "images". line 7 should be "1.4/1.7 GHz image". line 4 from end should be "has been imaged".

(there may be others, could you search on "map" in the .tex file wth your text editor for a final check- out? I think our standard should be to reserve "map" for things like "contour map", "spectral index map", i.e. displays derived from the primary images. The one other in,tance I caught by eye is on p.9, col.1 line 4 from end : "maps" should be "images" for consistency).

** line 13. NE, not SE, for the 3C334 confusing source.
 big gap before 87% -- was this supposed to be \gsim, or > ?

Section 2.4

** line 5   the the lobes --> the lobes
 space between al. and (1991)

----

in this sentence, "the same correlation" is a bit ambiguous. Could we say "their correlation reappears", or "the original correlation appears in our data"?

Table 3 caption "ratio of flux densities" (not "fluxes").

And last, a real fiddly one, unfortunately. (Maybe do it between now and getting referee's report, if you're in a big rush?)

Table 2 column headings: "flux density" for "flux"
would also look better if headings centered

Cheers, A.

>

From VM Thu Sep 12 16:09:00 1996
X-VM-v5-Data: ([nil nil nil nil t nil nil nil nil]
["913" "Thu" "12" "September" "1996" "19:26:50" "+0100" "Jane Dennett-Thorpe" "jdt@mrao.cam.ac.uk"
"<Pine.SOL.3.91.960912191834.22226A-100000@mraosa>" "25" "Re: this is it" "^From:" nil nil "9" nil nil nil nil]
nil)
Content-Length: 913
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id AA25484; Thu, 12 Sep 1996 14:26:57 -0400
Received: from mraos.ra.phy.cam.ac.uk (root@mraos.ra.phy.cam.ac.uk [131.111.48.8]) by cv3.cv.nrao.edu (8.7.5/8.7.1/CV-2.1) with SMTP id OAA28726 for <abridle@nrao.edu>; Thu, 12 Sep 1996 14:26:56 -0400 (EDT)
Received: from mraosa.ra.phy.cam.ac.uk by mraos.ra.phy.cam.ac.uk with smtp
(Smail3.1.29.0 #2) id m0v1GTT-0003EFC; Thu, 12 Sep 96 19:26 BST
X-Sender: jdt@mraosa
In-Reply-To: <9609121720.AA36312@polaris.cv.nrao.edu>
Message-Id: <Pine.SOL.3.91.960912191834.22226A-100000@mraosa>
Mime-Version: 1.0
Content-Type: TEXT/PLAIN; charset=US-ASCII
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@nrao.edu>
Subject: Re: this is it
Date: Thu, 12 Sep 1996 19:26:50 +0100 (BST)

very odd. i just opened up my mail to send you an email. and you've just
mailed me.

will send a copy to follow.

my question however, was on RM calculations and error maps in AIPS. I've
got 4 of Robert's L band frequencies, plus a C band and X band for 3C452.
was trying to do a RM map, and am not sure i'm doing it right. this is
what i have done (just using L band for the moment)
(a) make POLA maps from COMB
(b) run comb again, but with BPARM set to "noise1, noise2, 1"
(c) follow instructions in RM explain file
(d) now,... i get to the blanking bit. my error maps are in degrees, so
if i set APARM(9) to 5 (as it CAPITALISES this!), what blanking error am
i meant to quote? to say "10degrees" seems arbitary. or am i not putting
in the right error maps?

i know that's all AIPS gibberish, but i thought that as you've done this
you might be able to help without too much trouble.

thanks
jane

From VM Fri Sep 13 10:20:45 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["1978" "Fri" "13" "September" "1996" "10:20:06" "-0400" "Alan Bridle" "abridle" nil "44" "Re: this is it" "^From:" nil nil "9" nil nil nil nil]
nil)
Content-Length: 1978
Received: by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.07)
id AA38493; Fri, 13 Sep 1996 10:20:06 -0400
Message-Id: <9609131420.AA38493@polaris.cv.nrao.edu>
In-Reply-To: <Pine.SOL.3.91.960912191834.22226A-100000@mraosa>
References: <9609121720.AA36312@polaris.cv.nrao.edu>
<Pine.SOL.3.91.960912191834.22226A-100000@mraosa>
From: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: this is it
Date: Fri, 13 Sep 1996 10:20:06 -0400

Jane Dennett-Thorpe writes:

>
> my question however, was on RM calculations and error maps in AIPS. I've
> got 4 of Robert's L band frequencies, plus a C band and X band for 3C452.
> was trying to do a RM map, and am not sure i'm doing it right. this is
> what i have done (just using L band for the moment)
> (a) make POLA maps from COMB
> (b) run comb again, but with BPARM set to "noise1, noise2, 1"
> (c) follow instructions in RM explain file
> (d) now,... i get to the blanking bit. my error maps are in degrees, so
> if i set APARM(9) to 5 (as it CAPITALISES this!), what blanking error am
> i meant to quote? to say "10degrees" seems arbitary. or am i not putting
> in the right error maps?
>

Blanking on the estimated errors in the input angle maps is a pretty reasonable thing to do. In fact, have usually pre-blanked the POLA maps at about 5 sigma_Q,U before feeding them to RM, because I often look at the angle distributions directly and don't want to be distracted by the pschedelia wherever the signal-to-noise was low. So by the time I've piped everything to RM I've usually done blanking already. To first order, this should look like blanking at 10 degrees with option 5 in RM. You could try blanking at slightly different levels when running RM, to see which areas of the source are sensitive to how you blank, and to test how robust the solutions are in the key places.

I have sometimes felt the need to suppress some polarization artifacts off-source by also blanking on I, usually around 3-sigma. This is purely cosmetic, but can tidy the edges of large fields where the polarization calibration assumptions get creaky for wide angles (off axis). That should not be a problem for you, however: it's mainly to help the field edges when trying to skate closer to the noise, e.g. digging into depolarized regions. I mention it only to explain my odd habit of blanking before RM rather than during it.

Hope this helps,

A.

From VM Fri Sep 13 15:48:46 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["205" "Fri" "13" "September" "1996" "15:38:15" "+0100" "Jane Dennett-Thorpe" "jdt@mrao.cam.ac.uk" nil "6" "RM" "^From:" nil nil "9" nil nil nil nil]
nil)
Content-Length: 205
Received: from cv3.cv.nrao.edu by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.07)
id AA33133; Fri, 13 Sep 1996 10:38:26 -0400
Received: from mraos.ra.phy.cam.ac.uk (root@mraos.ra.phy.cam.ac.uk [131.111.48.8]) by cv3.cv.nrao.edu (8.7.5/8.7.1/CV-2.1) with SMTP id KAA17494 for <abridle@nrao.edu>; Fri, 13 Sep 1996 10:38:23 -0400 (EDT)
Received: from mraosa.ra.phy.cam.ac.uk by mraos.ra.phy.cam.ac.uk with smtp
(Smail3.1.29.0 #2) id m0v1ZNo-0003ExC; Fri, 13 Sep 96 15:38 BST
X-Sender: jdt@mraosa
In-Reply-To: <9609131420.AA38493@polaris.cv.nrao.edu>
Message-Id: <Pine.SOL.3.91.960913153454.767A-100000@mraosa>
Mime-Version: 1.0
Content-Type: TEXT/PLAIN; charset=US-ASCII
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@nrao.edu>
Subject: RM
Date: Fri, 13 Sep 1996 15:38:15 +0100 (BST)

thanks. yes, i decided to blank before RM too, on POLI, in part because
i wasn't sure what i was up to in the machinery of RM. I have just run a
bunch of tests and this seems the most conservative.

j.

From VM Sun Oct 20 15:57:29 1996
X-VM-v5-Data: ([nil nil nil nil t nil nil nil nil]
["820" "Sun" "20" "October" "1996" "18:12:43" "+0100" "Jane Dennett-Thorpe" "jdt@mrao.cam.ac.uk" "<Pine.SOL.3.91.961020180404.3757A-100000@mraosa>" "22" "10 days or so" "^From:" nil nil "10" nil nil nil nil]
nil)
Content-Length: 820
Received: from cv3.cv.nrao.edu by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.07)
id AA17378; Sun, 20 Oct 1996 13:16:27 -0400
Received: from mraos.ra.phy.cam.ac.uk (root@mraos.ra.phy.cam.ac.uk [131.111.48.8]) by cv3.cv.nrao.edu (8.8.0/8.8.0/CV-2.1) with SMTP id NAA29958 for <abridle@polaris.cv.nrao.edu>; Sun, 20 Oct 1996 13:16:26 -0400 (EDT)
Received: from mraosa.ra.phy.cam.ac.uk by mraos.ra.phy.cam.ac.uk with smtp
(Smail3.1.29.0 #2) id m0vF1Qa-0003EBC; Sun, 20 Oct 96 18:12 BST
X-Sender: jdt@mraosa
Message-Id: <Pine.SOL.3.91.961020180404.3757A-100000@mraosa>
Mime-Version: 1.0
Content-Type: TEXT/PLAIN; charset=US-ASCII
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@polaris.cv.nrao.edu>
Subject: 10 days or so
Date: Sun, 20 Oct 1996 18:12:43 +0100 (BST)

hi Alan.

yes, the time in the subject line does refer to the intended trip to the binders.

its going ok, its not going to be great, its never going to be perfect, but it IS going to be done! still need to write the conclusions, do a major rewrite on the intro, and reorganise a chapter a bit.

i have a question for you, to let me tick off one of those "{\em ???}" left hanging around. When I was scheduling the VLA observations you gave me sowe rule of thumb about how far away calibrator sources could safely be from the target source at whatever wavelength. This was a very useful piece of info that as far as i can tell is word-of-mouth only. Could you repeat it so i can write it down - mainly for my own reference, like most of the tedium in "chapter 2".

thanks,

hope all is well with you both,
jane

From VM Sun Oct 20 16:21:14 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["1622" "Sun" "20" "October" "1996" "16:20:49" "-0400" "Alan Bridle" "abridle" nil "37" "Re: 10 days or so"
"^From:" nil nil "10" nil nil nil nil]
nil)
Content-Length: 1622
Received: by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.07)
id AA13150; Sun, 20 Oct 1996 16:20:49 -0400
Message-Id: <9610202020.AA13150@polaris.cv.nrao.edu>
In-Reply-To: <Pine.SOL.3.91.961020180404.3757A-100000@mraosa>
References: <Pine.SOL.3.91.961020180404.3757A-100000@mraosa>
From: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: 10 days or so
Date: Sun, 20 Oct 1996 16:20:49 -0400

Jane Dennett-Thorpe writes:

\>
\> yes, the time in the subject line does refer to the intended trip to the
\> binders.

ah, maximum stress time!

\> i have a question for you, to let me tick off one of those "{\em ???}" left
\> hanging around. When I was scheduling the VLA observations you gave me
\> some rule of thumb about how far away calibrator sources could safely
\> be from the target source at whatever wavelength. This was a very useful
\> piece of info that as far as i can tell is word-of-mouth only. Could you
\> repeat it so i can write it down - mainly for my own reference, like most
\> of the tedium in "chapter 2".

well, it's basically that if the calibrator is outside the same isoplanatic
patch as the source, then it calibrates only the instrument, not the
atmosphere. Isoplanatic patch size is weather-dependent and wavelength-
dependent but is typically a degree or so at cm wavelengths over NM.
As your data were all self-calibrated, nothing you did should have depended
strongly on this issue. These basic points are all in my lecture in the
Synthesis Imaging Book; if I told you more detail at the time, it probably
came from the wavelength-dependence stuff which has mainly been done by
Dick Sramek. Let me know if you need more info (I'll be out of touch for
about a week starting on Wednesday, BTW).

Good luck with the finishing up, it's soooo nice when it's over!

Mary and I are both doing well; her brother from Australia just visited us
and we had some great weather for exploring the mountains and visiting the
historic houses near Charlottesville with him.

Cheers, A.

From VM Mon Oct 21 08:49:03 1996
X-VM-v5-Data: ([nil nil nil nil t nil nil nil nil]
["1373" "Sun" "20" "October" "1996" "22:52:35" "+0100" "Jane Dennett-Thorpe" "jdt@mrao.cam.ac.uk" "<Pine.SOL.3.91.961020224404.4228A-100000@mraosa>" "23" "Re: 10 days or so" "^From:" nil nil "10" nil nil nil nil]
nil)
Content-Length: 1373
Received: from cv3.cv.nrao.edu by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.07)
id AA13175; Sun, 20 Oct 1996 17:52:40 -0400
Received: from mraos.ra.phy.cam.ac.uk (root@mraos.ra.phy.cam.ac.uk [131.111.48.8]) by cv3.cv.nrao.edu (8.8.0/8.8.0/CV-2.1) with SMTP id RAA02399 for <abridle@nrao.edu>; Sun, 20 Oct 1996 17:52:38 -0400 (EDT)
Received: from mraosa.ra.phy.cam.ac.uk by mraos.ra.phy.cam.ac.uk with smtp
(Smail3.1.29.0 #2) id m0vF5nQ-0003EBC; Sun, 20 Oct 96 22:52 BST
X-Sender: jdt@mraosa
In-Reply-To: <9610202020.AA13150@polaris.cv.nrao.edu>
Message-Id: <Pine.SOL.3.91.961020224404.4228A-100000@mraosa>
Mime-Version: 1.0
Content-Type: TEXT/PLAIN; charset=US-ASCII
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@nrao.edu>
Subject: Re: 10 days or so
Date: Sun, 20 Oct 1996 22:52:35 +0100 (BST)

> well, it's basically that if the calibrator is outside the same isoplanatic
> patch as the source, then i| calibrates only the instrument, not the
> atmosphere. Isoplanatic patch size is weather-dependent and wavelength-
> dependent but is typically a degree or so at cm wavelengths over NM.
> As your data were all self-calibrated, nothing you did should have depended
> strongly on this issue. These basic points are all in my lecture in the
> Synthesis Imaging Book; if I told you more detail at the time, it probably
> came from the wavelength-dependence stuff which has mainly been done by
> Dick Sramek. Let me know if you need more info (I'll be out of touch for
> about a week starting on Wednesday, BTW).

hmm, ten days before submission and still learning things about synthesis operations.... hmmmm.

well, the original reason i asked was because, as far as i can see, you don't give an actual size in the lecture (but you did above -thanks) but now i'm somewhat baffled. yes, it makes complete sense to me that as i was self-calibrating the weather info contained in the calibrator scans was pretty redundant - so why did i spend time trying to find the nearest calibrator? (because i got the wrong end of the stick then? or just on the principle that you should make it all as nice as possible, even if its not going to make much difference??)

j.

From VM Mon Oct 21 10:18:10 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["3602" "Mon" "21" "October" "1996" "10:02:49" "-0400" "Alan Bridle" "abridle" nil "73" "Re: 10 days or so" "^From:" nil nil "10" nil nil nil nil]
nil)
Content-Length: 3602
Received: by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.07)
id AA32555; Mon, 21 Oct 1996 10:02:49 -0400
Message-Id: <9610211402.AA32555@polaris.cv.nrao.edu>
In-Reply-To: <Pine.SOL.3.91.961020224404.4228A-100000@mraosa>
References: <9610202020.AA13150@polaris.cv.nrao.edu>
<Pine.SOL.3.91.961020224404.4228A-100000@mraosa>
From: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: 10 days or so
Date: Mon, 21 Oct 1996 10:02:49 -0400

Jane Dennett-Thorpe writes:

> hmm, ten days before submission and still learning things about synthesis
> operations.... hmmmm.
> well, the original reason i asked was because, as far as i can see, you
> don't give an actual size in the lecture (but you did above -thanks) but
> now i'm somewhat baffled. yes, it makes complete sense to me that as i
> was self-calibrating the weather info contained in the calibrator scans
> was pretty redundant - so why did i spend time trying to find the nearest
> calibrator? (because i got the wrong end of the stick then? or just on
> the principle that you should make it all as nice as possible, even if
> its not going to make much difference??)
>

There's one situation in which self-cal can get a little lost in bad weather: when the unresolved flux density in the source is a bit marginal relative to the noise and the phases are badly corrupted, so the initial externally-calibrated image contains a lot of scattered flux and thus doesn't show very much. Under these circumstances having the external calibrator in the same isoplanatic patch can help quite a lot, because it minimizes the scattering problem and thus gives self-cal the best possible initial image. Having the external calibrator far away, on the other hand, simply makes this situation worse by adding its phase noise in quadrature. The worse the "weather", the truer this is, and of course the smaller the size of the relevant patch.

Putting the calibrator near the target source also does the best job possible of setting the position scale of the observation (relative to the position of the calibrator).

It also does the best job possible of illustrating the phase stability for the source observation during the calibrator scan (can help with choosing the integration times for self-cal, for example). Again, this is only relevant in cases where the intial self-cal's are noise-limited, as if the unresolved flux density in the source is booming in you will always make the phase self-cal averaging time the same as the on-line integration time.

If the source itself is a real boomer, there is a case for observing the strongest possible calibrators, no matter where they are in the sky, in order to determine baseline-based corrections that will let you push for very high dynamic range. That was the way we did the quasar sample at 6cm, using no "local" calibrators at all. In fact the baseline-based corrections then made very little improvement, either; in the end I think we were limited by time-averaging the visibilities of the far-out hot spots during the self-cal. Back in those days, we averaged a little longer just to reduce the size of the data sets on disk. I would definitely not do that today!

If the self-cal converges well, the only relic of the external calibrator in the final image is the position info. If the calibrator was close enough to the target that it was seen through the same atmospheric "wedge", then you know that the final image co-ordinates are as reliable as those of the calibrator. If it's from round the other side of the sky, the position errors will be larger.

So it's really "as nice as possible" rather than mandatory, unless the self-cal itself will have a lot of trouble starting. If you ever had to resort to "point source selfcal" the first time around, then you may have been playing the game in a regime where the proximity of the external calibrator could have mattered. Or if you ever want to use a core position from a self-cal'd image to verify an optical identification.

Cheers,

A.

From VM Thu Dec 5 09:52:25 1996
X-VM-v5-Data: ([nil nil nil nil t nil nil nil nil]
["6834" "Thu" "5" "December" "1996" "14:28:17" "+0000" "Jane Dennett-Thorpe" "jdt@mrao.cam.ac.uk"
"<Pine.SOL.3.91.961205142029.19988B-100000@mraosa>" "124" "(Fwd) Review of MW723 (fwd)" "^From:" nil nil "12"
nil nil nil nil]
nil)
Content-Length: 6834
Received: from cv3.cv.nrao.edu by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.07)
id AA46071; Thu, 5 Dec 1996 09:32:04 -0500
Received: from mraos.ra.phy.cam.ac.uk (root@mraos.ra.phy.cam.ac.uk [131.111.48.8]) by cv3.cv.nrao.edu (8.8.3/8.8.0/CV-2.3) with SMTP id JAA11559 for <abridle@polaris.cv.nrao.edu>; Thu, 5 Dec 1996 09:32:01 -0500 (EST)
Received: from mraosa.ra.phy.cam.ac.uk by mraos.ra.phy.cam.ac.uk with smtp
(Smail3.1.29.0 #2) id m0vVemg-0003EoC; Thu, 5 Dec 96 14:28 GMT
X-Sender: jdt@mraosa
Message-Id: <Pine.SOL.3.91.961205142029.19988B-100000@mraosa>
Mime-Version: 1.0
Content-Type: TEXT/PLAIN; charset=US-ASCII
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@polaris.cv.nrao.edu>
Subject: (Fwd) Review of MW723 (fwd)
Date: Thu, 5 Dec 1996 14:28:17 +0000 (GMT)

here's the referees comments. would appreciate your input particulalry on the first few comments, and on any of the other points. After the first few will generally be doing as requested, although not their suggested order change (doesn't make much sense to me), and my fits will remain by eye - given what i'm fitting a formal procedure seems OTT. It seems we may have to include a picture of the "two-component" model: yet another reader was confused! As for the suggested 'normalisation procedure' : contrary to what the ref suggests i don't think this makes any/much difference. May do something to check this and put in a sentence - but as for astrophysical justification of why we are chosing this method: ...
well, that was always a bit threadbare... will see if i can come up with something, or some small 'limitations' discussion.

jane
---------- Forwarded message ----------
Date: Mon, 11 Nov 1996 10:53:17 +0000
From: jr@sas.org.uk
To: jdt@mrao.cam.ac.uk
Subject: (Fwd) Review of MW723

Dear Dr Dennett-Thorpe

With apologies for the delay I am now able to send you a report on your Monthly Notices submission of ref. MW723 entitled "Asymmetry of jets, lobe length..."

The referee has recommended minor revision of your paper before it is reconsidered for publication in MNRAS. I will therefore look forward to receiving from you a top copy and two weight-reduced copies of a revised version of your paper along with a note detailing the changes made.

Regards,

John Randall (Mr)
MNRAS

REPORT and DETAILED SUGGESTIONS FOR
TRANSMISSION TO THE AUTHORS:

This is a generally well-written paper that significantly advances our understanding of side-to-side asymmetries in extragalactic radio sources. There is little to argue with in the presentation of evidence, and only a small portion of the paper is speculative. Where conclusions are not firm, by and large they are properly identified as such. I recommend publication with a few modifications, as detailed below.

On page 3, amplitude self-calibration is said to generate "small errors in the flux scale and brightness distributions". In other words, it did not work properly, but no explanation is given. Is this indicative of problems with the data, such as correlator problems leading to non-closing errors? It should be confirmed that this is not a significant issue for the paper as a whole. On the same page, a spectral error near the hotspots is given, where I is presumably the peak brightness of the hotspot. The exact meaning of this formula should be stated, or alternatively the discussion of multi-frequency imaging could be greatly shortened, and summarized by the statement that spectral errors are not important in the final images.

In section 2.3, the issue of missing flux in 3C334 is incompletely addressed. Is the confusing source strong enough to account for all the missing flux? If not, how much is still missing, and does this affect anything?

The method of comparison used is to match regions of equal surface brightness in each lobe of a source. This is certainly a practical approach, and one that provides a certain degree of immunity from biases in the data. It is, however, not the only conceivable scheme, and is not shown to be that which makes the most sense from an astrophysical standpoint. The paper should say something about how the conclusions might depend on this choice for the comparison method, if possible. I worry a bit about using surface brightness given the common total flux and size asymmetries between lobes. I would think some sort of normalization to individual lobe parameters would be appropriate. Inspection of figure 3 indicates that if, for example, surface brightness was normalized to the peak of each lobe, several sources would yield significantly different results. The current approach should either be astrophysically better justified, or its limitations should be more clearly stated.

Notwithstanding the choice of comparison method, the result that high brightness portions of the jetted lobes have flatter spectra appears robust (despite the typo at the top of the 2nd column on page 7, where "jet" should read "counterjet"). The correlation of low-brightness spectral index with lobe length also seems solid. It is not clear to me why these results are not placed on firm statistical ground by the application of standard statistical tests. This should be quick and easy, and would consume only a sentence or two.

In section 4.1, I found the dismissal of a model involving a steep background component and a possibly beamed flatter spectrum component confusing. After reading it several times I remain unclear both about the nature of the model being considered, and why it doesn't work.

Test (ii) for the asymmetry being due to relativistic effects in hotspots alone is a good one, and demonstrates that the asymmetry extends to lower surface brightness regions. However, this is a refinement of the results presented in section 3, and perhaps should belong thmre. Several paragraphs discussing simple hotspot beaming could then potentially be eliminated. The authors may wish to consider this change in the interetts of brevity.

Once the asymmetry is shown to extend beyond the hotspot, section 4.1 becomes necessarily rather speculative, consisting mainly of attempts to argue that perhaps, against all naive expectations, much of this material is indeed moving relativistically. The success of these attempts can be judged by the reader. It is refreshing to see thn authors being appropriately tentative here, since many will view such arguments with scepticism. However, I found that the conclusion section, without th, benefit of additional argument, stated the result more firmly. I would suggest that instead of the phrase "are forced to conclude that ...", the authors use something like "favour the interpretation that ...".

The discussion of expansion losses as a contributing factor to the observed correlation in the low brightness regions is of interest (though it highlights the dependence of the results on the comparison method, which should be viewed as a cautionary tale), but again, I found the description of the details, particularly the construction of figure 7, confusing. The caption refers to the quantity alpha_max, which does not appear to be defined. There is a reference to fitting the slope and error of the spectral index versus surface brightness data by eye ... why not do it more formally? Despite re-reading this section several times, I still do not understand the phrase "i.e. usually the bin with the lowest surface brightness", since everything seems to have been done using the lowest three bins. Some clarification is in order.

==

From VM Thu Dec 5 16:40:51 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["8472" "Thu" "5" "December" "1996" "16:35:26" "-0500" "Alan Bridle" "abridle" nil "181" "Re: (Fwd) Review of MW723 (fwd)" "^From:" nil nil "12" nil nil nil nil]
nil)
Content-Length: 8472
Received: by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.07)
id AA35374; Thu, 5 Dec 1996 16:35:26 -0500
Message-Id: <9612052135.AA35374@polaris.cv.nrao.edu>
In-Reply-To: <Pine.SOL.3.91.961205142029.19988B-100000@mraosa>
References: <Pine.SOL.3.91.961205142029.19988B-100000@mraosa>
From: abridle (Alan Bridle)
To: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
Subject: Re: (Fwd) Review of MW723 (fwd)
Date: Thu, 5 Dec 1996 16:35:26 -0500

Jane Dennett-Thorpe writes:

>
> here's the referees comments. would appreciate your input particulalry on
> the first few comments, and on any of the other points. After the first few
> will generally be doing as requested, although not their suggested order
> change (doesn't make much sense to me), and my fits will remain by eye -
> given what i'm fitting a formal procedure seems OTT. It seems we may have to
> include a picture of the "two-component" model: yet another reader was
> confused! As for the suggested 'normalisation procedure' : contrary to
> what the ref suggests i don't think this makes any/much difference. May
> do something to check this and put in a sentence - but as for
> astrophysical justification of why we are chosing this method: ...
> well, that was always a bit threadbare... will see if i can come up with
> something, or some small 'limitations' discussion.
>

No problems here so far as I'm concerned.

Are you indeed now Dr.Jane as they said by the way?

>
> On page 3, amplitude self-calibration is said to generate "small errors in the
> flux scale and brightness distributions". In other words, it did not work
> properly, but no explanation is given. Is this indicative of problems with
> the data, such as correlator problems leading to non-closing errors? It should
> be confirmed that this is not a significant issue for the paper as a whole.

Oh, boo. Can you simply put a number on the word "significant" at the
top of p.6?   I have rarely seen flux-density scale problems greater
than about 2% from self-calibration unless something really awful has been
done like not normalising at all. Even when the normalisation code was
broken, the systematic channes it introduced were in the tenths of percent
level per run of self-cal, and the whole point of the first sentence was
to say that phase-only self-cal was used wherever possible.

> On the same page, a spectral error near the hotspots is given, where I is
> presumably the peak brightness of the hotspot. The exact meaning of this
> formula should be stated, or alternatively the discussion of multi-frequency
> imaging could be greatly shortened, and summarized by the statement that
> spectral errors are not important in the final images.

I'm not familiar with the MERLIN-specific aspects here (remember I didn't know what "residual spectral index" meant) and it is true that I is not defined. I was presuming that it meant the peak intensity on the hot spot in the final image. Define "the error" and define "I", or, as the referee suggests, just telescope the whole thing down to a blanket statement about expecting the scale errors to be less than an appropriate percentage.

>
> In section 2.3, the issue of missing flux in 3C334 is incompletely addressed.
> Is the confusing source strong enough to account for all the missing flux?
> If not, how much is still missing, and does this affect anything?

This is one we haggled ourselves. The confusing source is 88 mJy at 6cm from BHLBL but we don't have a discrepancy there. I do not have a record of what is was at L Band, which is more important, I'll look on my tapes if you know you don't have it there. Did you already do this and factor it in to the 87% number, though? (I don't recall at this range).

The bottom line is that 87% is not as much as we'd like, but nothing that we're talking about later rests on 334 alone. Probably we should simply say that.

> The paper should say something
> about how the conclusions might depend on this choice for the comparison
> method, if possible. I worry a bit about using surface brightness given the
> common total flux and size asymmetries between lobes. I would think some
> sort of normalization to individual lobe parameters would be appropriate.
> Inspection of figure 3 indicates that if, for example, surface brightness
> was normalized to the peak of each lobe, several sources would yield
> significantly different results.

I have no idea why one would think of normalizing to the peak of each lobe, which is totally dominated by the apparent brightness of the hot spot, a likely transient perhaps even beamed feature. I'm not sure why we should even address that specific option.

> The current approach should either be
> astrophysically better justified, or its limitations should
> be more clearly stated.

Given that the two lobes are usually of roughly similar size we are basically comparing them via a proxy for the same average emissivity along the line of sight, ignoring the details of the spatial layout. The only alternative I would give any plausibility to is the one we actually discussed. If the morphology is really totally different then it's hard to find _any_ basis for comparison, but we have at least minimized the comparison uncertainties by not involving the _locations_ of possibly transient features such as the hot spots in setting the comparison method.

>
> Notwithstanding the choice of comparison method, the result that high brightness
> portions of the jetted lobes have flatter spectra appears robust (despite
> the typo at the top of the 2nd column on page 7, where "jet" should read
> "counterjet").

This must be paginated differently from the version I'm looking at,

where the second column in a FWHM. Does the comment make sense to you?
>
> In section 4.1, I found the dismissal of a model involving a steep background
> component and a possibly beamed flatter spectrum component confusing. After
> reading it several times I remain unclear both about the nature of the model
> being considered, and why it doesn't workn
>

"There we go again."
(Ronald Reagan, 1982 misquoted)

We _do_ need to clarify this.

> Test (ii) for the asymmetry being due to relativistic effect in hotspots alone
> is a good one, and demonstrates that the asymmetry extends to lower surface
> brightness regions. However, this is a refinement of the results presented
> in section 3, and perhaps should belong there. Several paragraphs discussing
> simple hotspot beaming could then potentially be eliminated. The authors may
> wish to consider this change in the interests of brevity.

I think we can leave well enough alone, here.

>It is refreshing to see the authors being appropriately tentative
> here, since many will view such arguments with scepticism. However, I found
> that the conclusion section, without the benefit of additional argument, stated
> the result more firmly. I would suggest that instead of the phrase "are forced to
> conclude that ...", the authors use something like "favour the interpretation
> that ...".

I can live with that.

>
> The discussion of expansion losses as a contributing factor to the observed
> correlation in the low brightness regions is of interest (though it highlights
> the dependence of the results on the comparison method, which should be viewed
> as a cautionary tale), but again, I found the description of the details, particularly
> the construction of figure 7, confusing. The caption refers to the quantity
> alpha_max, which does not appear to be defined.

Apparently true. It should be defined.

> There is a reference to fitting
> the slope and error of the spectral index versus surface brightness data by
> eye ... why not do it more formally? Despite re-reading this section several
> times, I still do not understand the phrase "i.e. usually the bin with the
> lowest surface brightness", since everything seems to have been done using the
> lowest three bins. Some clarification is in order.
>

One does not usually advertise that things were done "by eye", and
we're not trying to say that was better. I suggest just dropping "by
eye", and explain or drop the lowest brightness bin bit.

That's a pretty good review. Whoever they are, they actually read
the paper carefully. (This does not always happen!)

There were two tiny slips in the version I'm looking at. The last sentence of Sec 2.4 still used "mapped" where it should be "imaged", and there is no punctuation at the end of the first sentence in Sec.5 Probably both (i) and (ii) should conclude in a . but choose any option you like that makes a sentence.

When are you off to Lisbon?

What's the story on the galaxies?

Are you going to have a Merry Christmas?

(You must answer at least two questions, on penalty of further E-mail!)

Cheers, A.

From VM Mon Dec 9 08:42:54 1996
X-VM-v5-Data: ([nil nil nil nil nil nil nil nil nil]
["925" "Sat" "7" "December" "1996" "18:48:54" "+0000" "Jane Dennett-Thorpe" "jdt@mrao.cam.ac.uk" nil "24" "Re: (Fwd) Review of MW723 (fwd)" "^From:" nil nil "12" nil nil nil nil]
nil)
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Received: from cv3.cv.nrao.edu by polaris.cv.nrao.edu (AIX 3.2/UCB 5.64/4.07)
id AA55890; Sat, 7 Dec 1996 13:48:59 -0500
Received: from mraos.ra.phy.cam.ac.uk (root@mraos.ra.phy.cam.ac.uk [131.111.48.8]) by cv3.cv.nrao.edu (8.8.3/8.8.0/CV-2.3) with SMTP id NAA14683 for <abridle@nrao.edu>; Sat, 7 Dec 1996 13:48:57 -0500 (EST)
Received: from mraosa.ra.phy.cam.ac.uk by mraos.ra.phy.cam.ac.uk with smtp
(Smail3.1.29.0 #2) id m0vWRny-0003EFC; Sat, 7 Dec 96 18:48 GMT
X-Sender: jdt@mraosa
In-Reply-To: <9612052135.AA35374@polaris.cv.nrao.edu>
Message-Id: <Pine.SOL.3.91.961207183846.2286C-100000@mraosa>
Mime-Version: 1.0
Content-Type: TEXT/PLAIN; charset=US-ASCII
From: Jane Dennett-Thorpe <jdt@mrao.cam.ac.uk>
To: Alan Bridle <abridle@NRAO.EDU>
Subject: Re: (Fwd) Review of MW723 (fwd)
Date: Sat, 7 Dec 1996 18:48:54 +0000 (GMT)

hi Alan,

thanks for your coomments. i'm not Dr Jane, but as i never give myself a title i always get "doctored" from such places! my viva will be in january sometime: examiners are julia riley and peter barthel, which i am happy about.

i'm off to lisbon on the 17th dec, in time for my statutary christmas boycott. will be spending solstice and new year with friends, which i'm looking forward to.

i've just had three weeks off, and now i'm trying to get these papers seen to : drafted, revised and reworked as appropriate. However, post-thesis exhaustion doesn't seem to have entirely evaporated: 4hrs work seems to be all i can put in at the moment! maybe its just that i've got the taste of lazing around again....

i wish you and mary both a happy christmas (unless you too aren't celebrating: in which case have the wishes for the festivity of your choice) and all the best for the new year.

best,
jane