

**National Radio Astronomy Observatory**

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Dr. A.H.BRIDLE  
tel. [804] 296-0375 TWX 910-997-0174

August 19, 1986

Dr. E. Asseo  
Centre de Physique Théorique  
Ecole Polytechnique  
91128 Palaiseau Cedex  
FRANCE

Dear Dr. Asseo,

This is to give permission for you to reproduce Figures 22, 23 and 24 from the article by Perley *et al.* (1984) in *Astrophys. J. Suppl.* **54**, 291 in your review article.

I have no spare glossies of these Figures available just at the moment, but I am now having some new copies made and I will send these to you as soon as possible. This will probably take between one and two weeks. In the meanwhile I enclose Xerox copies of the Figures at slightly larger scale than they were reproduced in the *Astrophysical Journal*. If you cannot wait for the glossies, these Xeroxes might be adequate for your purpose, as they are quite black.

Yours sincerely,

Alan H. Bridle

Estelle ASSEO

Centre de Physique Théorique

de l'École Polytechnique

91128 Palaiseau Cedex

France

Hélène SOL

Groupe d'Astrophysique Relativiste

C. N. R. S. - Observatoire de Paris-Meudon

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92195 Meudon Principal Cedex

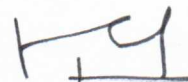
Dear Dr. A. H. Bridle,

We wrote for Physics Reports a review on Extragalactic Magnetic Fields which has been recently accepted for publication. In order to illustrate our work we intend to present one map or photo\* you have obtained and published. We would be very grateful if you would authorize us to do it.

If you agree, could you please send us a reproduction? Or else, please let us know if there is any problem.

Thanking you in advance,

Sincerely yours,



E. Asséo, H. Sol

\* Perley et al, 1984, ApJ Suppl. 54, 291

Fig 22, fig 23 and fig 24

NGC 6251

NATIONAL RADIO ASTRONOMY OBSERVATORY  
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21 June 1984

Dear Arieh,

Thank you for sending me the two preprints of your work on jets dominated by magnetic pressure. I am most impressed at the apparent harmony with the data on NGC 6251 (except for the extensive  $B_1$  regions in the outer jet). I have not yet had time to work through the details of the first paper properly, but look forward to doing so and to discussing your ideas further at the workshop in Green Bank. We will be delighted for you to present the conclusions of your work at this meeting - I would think either Jean Eilek's or Greg Berford's session would be best.

Two comments from my first reading - 1) how reasonable is the Gaussian particle distribution if the departure from axisymmetry in the field is large enough to see? 2) PBW (their p. 332) were less definite about the pinching mode than your p. 27 implies - we said the mode might be relevant, then went on to point out exactly the same difficulty (coupling to the transverse oscillation) that you do.

Best wishes, and I look forward to seeing you at Green Bank

A.B.

THE UNIVERSITY OF CHICAGO  
ASTRONOMY AND ASTROPHYSICS CENTER  
5640 SOUTH ELLIS AVENUE  
CHICAGO • ILLINOIS 60637

May 29, 1984

Dear Alan;

I am enclosing a copy of my paper with Anub Choudhuri on force-free equilibria of magnetized jets, with an application to NGC 6251. This work was motivated by your extensive and comprehensive study of this source with Perley and Willis. Naturally, we would be very interested in your comments, suggestions, and criticism. I am also enclosing a copy of a related work on the polarization P.A. swings in BL Lac objects, which we feel strengthens the argument in favor of nonsymmetric field configurations.

I was glad to learn about the workshop on energy transport that you organize with Jean Eilek. I hope to attend it and present some of the ideas that we discussed in these papers and in ongoing work.

I look forward to hearing from you

best regards,  
Arich

# THE ASTROPHYSICAL JOURNAL

HELMUT A. ABT, *Managing Editor*  
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A. DALGARNO, *Letters Editor*  
Center for Astrophysics  
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August 24, 1983

Dr. A. H. Bridle  
National Radio Astronomy  
Observatory  
Edgemont Road  
Charlottesville, VA 22901

Dear Dr. Bridle:

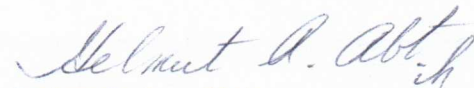
HIGH-RESOLUTION VLA OBSERVATIONS  
OF THE RADIO JET IN NGC 6251  
R. A. Perley, A. H. Bridle, and A. G. Willis

We are pleased to report that your paper noted above has now been accepted for publication in the Supplement Series of The Astrophysical Journal. Our production office in Chicago will advise you regarding the date of publication for the paper. When you receive the edited manuscript and galleys, please make every effort to return them to the production office in Chicago within forty-eight hours. Your cooperation will expedite publication of your paper as scheduled.

We have requested that edited manuscripts and galleys be sent to both you and to Dr. Perley.

Please sign the enclosed Publication Agreement pertaining to copyright assignment and return it as addressed.

Sincerely,



Helmut A. Abt  
Managing Editor

HAA:ih

Enclosure: Publication Agreement

cc: Mr. Elmars Bilsens  
Production Manager

Dr. R. A. Perley  
NRAO  
P. O. Box 0  
Socorro, NM 87801

# THE ASTROPHYSICAL JOURNAL

Kitt Peak National Observatory

Box 26732, Tucson, Arizona 85726

revised

HIGH-RESOLUTION VLA

This will acknowledge receipt of a manuscript entitled  
OBSERVATIONS OF THE RADIO JET IN NGC 6251

by R. A. Perley et al.

together with 30 figures. The paper will receive prompt attention, and I shall notify you if there are any questions regarding publication. **Meantime may I draw your attention to the fact that there is a page charge for papers published in the *Astrophysical Journal*. Unless I hear from you to the contrary, I shall assume that your Department, University, Observatory is willing to pay the charges.**

Please advise whether the 1\* halftone(s) should be printed on text stock within the article or on glossy stock at the end of the issue. If you prefer the former, is it permissible to back them with text? If this instruction is not given by the time this paper is ready for production, the choice will be made at our Production Office.

This title will be included in the semimonthly published list of papers submitted unless you request otherwise by phone. If you do not wish to make preprints available upon request, please inform us accordingly. \*glossy stock, end of issue.

HELMUT A. ABT, *Editor*

DATE 8/18/83



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P.O. 607581

13

Dr. R. A. Perley  
NRAO  
P. O. Box 0  
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# REPORT OF REFEREE

Author, Title Perley et al.: HIGH-RESOLUTION VLA OBSERVATIONS OF  
THE RADIO JET IN NGC 6251

This paper presents important and new observations of NGC6251 which should certainly be published. The lengthy discussion reads rather like a review of theories of large-scale extragalactic jets, which unfortunately obscures some of the most interesting results of these observations. It would be far more useful to the reader to present the observations and straightforward deductions in one paper and a shortened version of the physical discussion in a second paper. Apart from this general criticism I feel the paper could be improved as follows:

## Major points:

(1) One of the most important questions which can be addressed by these observations is "What is the density of thermal matter in the jet?". This is discussed in some detail, but unfortunately the primary data are not presented in the most useful form. It would be useful to have the distribution of E vectors of the jet plotted with 2" resolution at 3 or 4 frequencies rather than the 4"4 resolution of Fig. 17. This figure should also have a scale indicating the degree of linear polarization. Three of the present authors concluded in a previous paper ("Recent WSRT and VLA Observations of the jet radio galaxy NGC6251", IAU # 97) that  $|30| \text{ rad m}^{-2}$  RM was produced internal to the jet since the degree of linear polarization seen at 21 cm is  $\sim 0.6$  of that at 6 cm. In the present paper (pp 25, 42) the ratio  $P_{1480}/P_{4885} \sim 1$  at high resolution. This apparent discrepancy should be explained.

(2) The Discussion section would be more digestible if it presented the first order deductions together and then went on to discuss specific models.

For example (a) Freedom and confinement of the jet  
- include only discussion up to line 14 p.35  
followed by (b) Evidence for a magnetoionic medium in NGC6251 (up to line 10 p.42)  
(c) Constraint on the thermal density of the jet  
and (f) Constraints of the flow velocity along the jet

could be followed by the specific models of page 35-58. This last section (pp 35-58) should be condensed.

## Minor points:

- (1) The discussion of peak flux density vs jet width (p.21, Fig.14) is very difficult to follow.
- (2) Page 61, line 5. Scheuer (MNRAS 1974) has shown that  $\epsilon \ll 1$ . Some reference should be made to this here.
- (3) Page 80, lines 8,9. It is true that the Doppler favouritism argument implies separation asymmetries for features ejected simultaneously. However it is possible that similar features (e.g. bends) could be produced in both the jet and counter-jet at a given distance from this galactic nucleus due to interaction with the surrounding medium.



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July 18, 1983

Dr. R. A. Perley  
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Dr. Alan H. Bridle  
National Radio Astronomy Observatory  
Edgemont Road  
Charlottesville, VA 22901

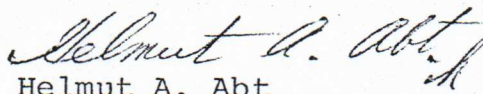
Dear Drs. Perley and Bridle:

Your paper entitled "High-Resolution VLA Observations of the Radio Jet in NGC 6251" by Perley et al. was sent to a competent referee, and a copy of the report is enclosed for your consideration.

This manuscript is too long (and has too many figures) for Part 1 of the *Journal*. If you agree to publication in the Supplements, please provide two abstracts: one of up to three typed pages for publication once within Part 1 of the *Journal* and one of up to three typed pages for publication several times on the back covers of Part 1 and the Supplements. Or if you follow the referee's suggestions for substantial reduction in length, it can fit into the main *Journal*.

The footnote on the title page should be called for with an Arabic number. In general the figure captions should not include interpretations; those should appear in the main text. Do you wish to have the halftone printed on text stock within the paper or on glossy stock at the end of the issue? Does Dr. Willis have an affiliation to be given on the title page?

Sincerely,

  
Helmut A. Abt  
Managing Editor

HAA:ih

Enclosures:

original manuscript + 30 figs. & 1 HT

Report of Referee  
Published by The University of Chicago Press, 5801 Ellis Avenue, Chicago, Illinois 60637  
for THE AMERICAN ASTRONOMICAL SOCIETY



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TWIN CITIES

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(612) 373-3751

22 May, 1983

Dear Alan -

Thanks for the preprint. It's got lots of interesting ideas in it. I enclose ~~two~~ <sup>a</sup> proposals for VLA km's which may be of interest, re: jet/counterjet asymmetries. Of course, I still haven't figured out how to handle twin jets like 449. (LR & J.O. Burns)

Also enclosed, preliminary results on 3C129 east, which shows very similar behavior (successive <sup>2.9</sup> accretion) to the jets you've been working on. I haven't done a full modelling yet (à la Henriksen Budde Chan, or whatever order), but at first blush, looks like  $\left| \frac{dR}{dz} \right|$  important for brightness.

Comments on the preprint -

- doesn't the fact that the isoplethal width stays ~ constant through knots tell you that they're an added feature, & not a contraction of the jet?
- brightness of knots on core side sounds like M87 knots.
- may I suggest consideration of the word "cold" for  $\rho v^2 \gg 2u_{int}$  (i.e. inertia, pressure, dominated by non-rel matter), saving "heavy" for  $\frac{\rho_{int}}{\rho_{ext}} > 1$ ? (Have we had this discussion before?)

Keep up the good work!  
Larry

enc. pieces proposal  
3C129 expansion

# THE ASTROPHYSICAL JOURNAL

Kitt Peak National Observatory

Box 26732, Tucson, Arizona 85726-6732

This will acknowledge receipt of a manuscript entitled HIGH-RESOLUTION VLA OBSERVATIONS OF THE RADIO JET IN NGC 6251  
by R. A. Perley, A. H. Bridle, and A. G. Willis  
together with 30 figures. The paper will receive prompt attention, and I shall notify you if there are any questions regarding publication. **Meantime may I draw your attention to the fact that there is a page charge for papers published in the *Astrophysical Journal*. Unless I hear from you to the contrary, I shall assume that your Department, University, Observatory is willing to pay the charges.**

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This title will be included in the semimonthly published list of papers submitted unless you request otherwise by phone. If you do not wish to make preprints available upon request, please inform us accordingly.

HELMUT A. ABT, *Editor*

DATE 5/19/83



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16 May 1983

Dr. H.A.Abt,  
Managing Editor,  
Astrophysical Journal,  
Kitt Peak National Observatory,  
Box 26732,  
Tucson, AZ 85726.

Dear Dr. Abt,

We enclose two copies of the typescript, with glossies of thirty Figures, for an article entitled "High-resolution VLA Observations of the Radio Jet in NGC6251", by R.A.Perley, A.H.Bridle and A.G.Willis. We are sending the glossy of a further Figure under separate cover, as it is somewhat larger than those included herewith.

We hope that this article will be suitable for publication in Part 1 of the Astrophysical Journal. We request that correspondence, the referee's report, etc. connected with this article be addressed to:

Dr. A.H.Bridle  
National Radio Astronomy Observatory  
Edgemont Road  
Charlottesville, VA 22901.

Due to the unusual length of the paper, we prefer that copies of the proofs be sent both to Dr. Bridle at the above address and to Dr. Perley at this letterhead address. If this cannot be done, however, the proofs should be sent to Dr. Bridle.

Yours sincerely,



R. A. Perley



A. H. Bridle



# Kapteyn Laboratorium

der Rijksuniversiteit te Groningen

Nettelbosje 2 - Postbus 800 - 9700 AV Groningen - Nederland

telefoon (050) 116695 - telex 53572 stars nl

24-4-83

Dear Alan -

Thank you very much for the draft of your (~~and~~ <sup>with</sup> Perley & Willin) paper on N6C 6251.

This is a gold mine of data - and you all deserve great credit for the time and care that you've taken in reduction and analysis.

The most obvious problem (and I'm sure that you appreciate this) is that there seems to be something in this jet for everybody: for enthusiasts of K.H. instabilities, precession, pressure confinement, magnetic confinement, conical shocks, shock reacceleration, vortical turbulence reacceleration, randomised CH fields, etc. etc. The observations do not seem to discriminate between models. ~~This is certainly more~~ The fault certainly lies with the models and not the observations - but it would be nice if you could exclude at least one mechanism that's ever been proposed for jets. You might be able to -- and that is the idea that powerful jets are one-sided because they are relativistic. You do argue that the jet bulk velocity is likely to be less than  $c$  - but you might

make this a bit stronger in the following way:

Hot spots on opposite sides of the galaxy have roughly equal brightness. Therefore it is unlikely that the hot spots are moving relativistically. This means that the thrust of the jet cannot much exceed the internal pressure of the hot spot. ~~as~~ Now let's assume that the jet is relativistic. Then

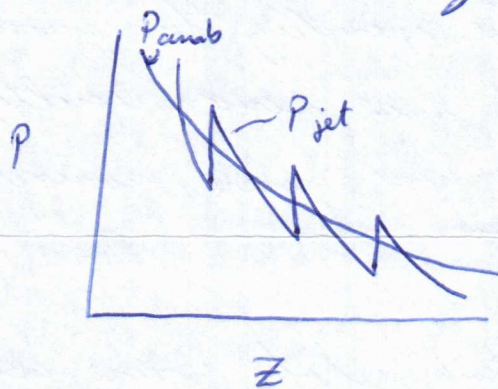
$$\rho_j c^2 \sim P_{hs}$$
$$\Rightarrow \rho_j \sim \frac{P_{hs}}{c^2} \sim 2 \times 10^{-10} \text{ cm}^{-3}$$

a relativistic jet would have to have a very low density not to produce a relativistic hot spot. ~~For~~ in fact - ~~a~~ lower than the equipartition density of relativistic particles in the jet - hence - contradiction.

I estimate  $N_{jet} (rel) \sim 5 \times 10^{-9} \text{ cm}^{-3}$  (my arithmetic may not be flawless). The only way around this is to say that ~~the~~ the hot spot is further from equipartition than the jet - by a large factor. Admittedly. This is another plausibility argument - but I think that it is important to stress that this large <sup>essentially</sup> one sided jet is probably not relativistic. That the side-to-side ~~asymmetry~~ asymmetry is intrinsic.

Concerning your remarks on confinement and reconfinement - I generally agree. With respect to the question of detachment - I certainly agree that it does not take place instantaneously in

a highly supersonic jet. The same - I might add -  
 is true of reconfinement (which was the point of  
~~that~~ my paper). I find it very interesting that  
 the minimum energy density in the jet -  
 and therefore the pressure if relativistic particles  
 dominate - falls off as  $\Phi^{-1.5}$ . Since it  
 is ~~roughly~~ roughly true that  $Z$  (distance from core)  $\sim \Phi$ ,  
 then  $P_{jet} \sim Z^{-1.5}$  - that is, the pressure  
 along the jet - falls in the same way as the  
 pressure in the ambient medium - on average.  
 I suspect that a ~~series~~ <sup>collection</sup> of converging and  
 diverging <sup>conical</sup> shocks conspires to maintain  
 rough pressure balance between the jet and  
 the ambient medium. That is - if we plot  
 pressure in the ambient medium & jet pressure  
 vs.  $Z$  - we have something like



Incidentally - one may also make plausibility  
 arguments that the pressure of ~~thermal pl~~  
 relativistic particles is likely to dominate over  
 the pressure of a thermal plasma. Taking your  
 limit on the number density of thermal plasma  
 at  $\theta = 32''$  ( $n < 4 \times 10^{-3} \text{ cm}^{-3}$ ) one finds



(4)  
 $T$  (thermal plasma)  $> 10^8$  K for the pressure of thermal plasma to dominate over ~~the~~ the minimum pressure of relativistic particles (& magnetic field). In other words the sound speed in the thermal plasma is  
$$c_s > 10^8 \text{ cm/s}$$

Since you want a Mach number on the order of 10 this means that

$$V_{\text{jet}} > 10^9 \text{ cm/s}$$

But if this is true, we begin to violate the thrust condition that I mentioned above. Here - the relativistic plasma probably dominates the pressure ~~is~~ and  $\gamma \sim 4/3$ .

I have dusted off my "Method of characteristics" program and I am trying to model the jet shape. I'll be spending the summer in Ch'ville and should have some results to show you by then. (I hope you're around this summer).

Again - I think that you're all to be congratulated on an excellent piece of work - both observational and interpretive - and thank you again for giving me a preliminary peek at it.

Best regards,

Bob

P.S. Excuse my scrawl - hope it's legible.

UNIVERSITY OF CAMBRIDGE  
DEPARTMENT OF PHYSICS

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ASTRONOMY OBSERVATORY

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Telephone: 0223-66477  
Telex 81292

2.6.83.

Dear Alan,

Here is a possible offering for your jet collection from the recent PKS observations. Most of the sources I look at these days are too faint to show much beyond the, er, classical double structure — hence my adherence to same!

N&C 6251 preprint is causing some considerable ripples here — reactions range from ecstatic to murderous. No-one has yet received it to referee so that rules out one possible place from your list!

I've ex(h)orted people to send you any jets they might have, but am not confident of the results.....

Best wishes,

Ann.



OBSERVATOIRE DU PIC-DU-MIDI, LE 31 January 1983  
65200 BAGNÈRES-DE-BIGORRE

Dear Dr. Bridle,

I do not know by what mystery of the mailing-forwarding system between Kingston, Padova and Bagnères de Bigorre your letter dated Oct 24 arrived on my desk two days ago!

Anyway, thank you for the letter and reprint. I am answering immediately. Please, find enclosed a reprint of my paper on the dust in NGC 6251. It is a revised version, with no photographs. Rick Perley must have told you I had hard time having good illustrations of the very faint and narrow structure of the dust. I submitted the paper to A&A first with a poor illustration that I did not want to publish and that I wanted to be indicative for the referee. The paper in such a form (no <sup>good</sup> illustration) was refused. So, I went to see Claus Radau, the ESO photographer in Munich who made a great job, and I submitted the paper (with the prints) to MNRAS. The opinion of both the Editor and the Referee was even if the prints were great --- they would not survive the different stages of the edition.... It was then suggested to me to publish a short paper (pink pages) with no illustration and just a sketch. This is the paper that I am sending you now. It has not been formally accepted yet and then, please, use it for

private circulation only. I am adding to the paper some photographs, but I am afraid that you will need the sketch in the paper to help you.

Your anomalies of the rotation measures are quite interesting. Unfortunately the image of the galaxy does not extend as far as  $90''$ , but with the amount of material that we have, it is clear that the dust is somewhat patchy, roughly along the jet direction and covers the whole galaxy image, rather north of the jet (on the sky plane). If you want to orientate the prints, the faint galaxy in the south east is just in the direction of the counterjet (Ary would like it!). - By the way, do you have a redshift for this object? - , and the major axis has a p.a. of  $199^\circ$  (Young et al., 1979).

I have an observing run with G. Leharre at Hawaii (CFR) in March again. NGC 6251 and the structure of its dust is amongst our first priorities. I will let you know the new information that we will have.

In passing, I let you know that I am using the photometric information that I have on this galaxy to see some "profile anomalies" in the center. This work is in progress.

With all my best wishes,

Jesus del NI EPO



DEPARTMENT OF PHYSICS  
STIRLING HALL  
Physics  
Engineering Physics  
Astronomy

Queen's University  
Kingston, Canada  
K7L 3N6

3 September 1982

Dr. L. Zaninetti,  
Istituto di Fisica Generale,  
Universita di Torino,  
Corso Massimo d'Azeglio 46,  
10125-Torino,  
ITALY

Dear Lorenzo,

I have waited a little while to answer your question about "wobble wavelengths" in NGC6251 because Rick Perley and I have been working on that very topic in some detail, and I wanted to send you our most complete results.

There are several wavelengths present in the deflections of the NGC6251 jet at different distances from the nuclear core. I enclose graphs showing the deflection of the jet from its mean position angle divided by the angular distance from the core, as a function of angular distance from the core. The graphs show two different distance regimes, namely 0" to 125" and 0" to 500", using data from the VLA 1480 and 1662 MHz observations at a variety of resolutions. The deflections have been computed by fitting Gaussian functions to the transverse intensity profiles of the jet at a very large number of locations, and determining the positions of the peaks in the fitted profiles. The data at different VLA resolutions are in excellent agreement where they overlap, showing that the results are neither very sensitive to, nor biased by, the resolution of the radio data.

Even a very casual inspection of these data shows that the oscillation spectrum is complex - there are obvious "beat" phenomena in the data. Both in plots of deflection against distance and (deflection/distance) against distance (as enclosed) it is clear that different wavelengths dominate at different distances from the core. This is all very healthy for interpretation in terms of Kelvin-Helmholtz instabilities, and Rick Perley will report some of our thinking along those lines at the Workshop in Torino. We have made power spectrum analyses of the VLA deflection data at all resolutions and in various distance windows, using both the deflection and (deflection/distance) data. The latter are of interest because an oscillation whose amplitude grows linearly with distance from the core appears in that data as a simple sine wave.

We have concluded that there is significant power in both sorts of deflection data at projected wavelengths of 143", 31", 17.5", 12" and 9". For  $H=75$  km/s/Mpc, the image scale is 429 pc per arcsec. The long-wavelength wiggle reported previously by the Cambridge group corresponds to the 143" wavelength in this spectrum. The discrepancy over the value of the wavelength is probably due to the fact that they made a visual estimate of the wavelength from a rather noisy plot of their data. If you compare their data directly with ours, you will see that there is sensible agreement. Our data have very much better resolution and signal to noise than theirs however.

In terms of wiggle wavelength to jet radius, the situation is now very complicated. The jet expands in a very complicated manner and the radius changes by a factor of 40 over the range that we can measure. Furthermore, the widths of the jet as estimated from its brighter isophotes do not everywhere show the same structure as the widths estimated from the lower ones. There are changes in the symmetry properties of the profiles in the outer jet which suggest that some of the small-scale structure is clumping and deflecting on scales which are not shared by the more diffuse emission. Broadly speaking though the 143" oscillation dominates a region of the jet where the radius is of order 8". The 31" oscillation dominates where the radius is of order 5.5", and the 9" oscillation where the radius is of order 1.9". The wavelength-to-radius ratios for these are thus ROUGHLY 17.5, 5.6, and 4.75 respectively.

The available constraints on depolarization of the jet make it very difficult to interpret the 9" and 31" oscillations as the dominant helical mode. The 143" oscillation can quite plausibly be the  $n=1$  helical mode however, and we are making that interpretation while preparing our paper on NGC6251. It is then curious that the dominant pinching mode with the same physical parameters for the jet would have a wavelength-to-radius ratio of 5.4 (we estimate the Mach number from the initial expansion rate as being about  $M=9$ ). This is close to the observed values for both the 9" and 31" oscillations where they dominate, and leads to some speculation regarding coupling between the helical and pinching modes.

We should have much to discuss about this and I am glad that I am able to send Rick Perley to your Workshop even though the pressure of teaching here at Queen's means that I cannot come myself. Again my apologies for taking a while to reply to your letter, but you can probably see that the situation has become rather more involved than we thought a year ago, but very probably it also contains much more of the physics that we are all looking for.

I will indeed send preprints of the work as soon as we have them available. The paper on NGC6251 has grown like a balloon and filled my entire summer; the work on NGC315 and 3C219 is therefore waiting for a while until NGC6251 is complete and until the disruptions of the new teaching year have gone by.

Be assured that you are high on our list for receiving the new work when we have it in a legible form ! I am looking forward to meeting you again so that we can resume some of the enjoyable discussions we had while you were in New Mexico. I shall be here at Queen's until the end of December at least. After that I may be going to Charlottesville.

With best personal regards,

Yours sincerely,

A handwritten signature in cursive script, appearing to read "Alan".

Alan H. Bridle  
Professor of Physics