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DEPARTMENT OF PHYSICS
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17 July 1980

Dr. A. Dalgarno,
Letters Editor,
The Astrophysical Journal,
Center for Astrophysics,
60 Garden Street,
Cambridge, MA 02138

Dear Dr. Dalgarno,

We enclose a revised and shortened version of the paper COLLIMATION OF THE RADIO JETS IN 3C31 by A.H.Bridle, R.N.Henriksen, K.L.Chan, E.B.Fomalont, A.G.Willis and R.A.Perley. We are pleased that the referee has recommended publication, but we have chosen to follow the suggestion in your letter of June 9 of reducing the paper's length by one typewritten page, in order that it continue to be considered for publication in Part 2 of the Astrophysical Journal.

We have three reasons for electing to shorten the paper to a length consistent with the page limits for Part 2. First, the paper contains an important new experimental result - that the radio jets in 3C31 do not open at constant cone angle as is presently claimed in the literature. This result has attracted great interest amongst theorists who we have made aware of it and we should like to disseminate it as rapidly as possible. Publication in Part 2 would achieve this more effectively than a preprint distribution. Second, the paper draws on a number of theoretical ideas from the paper by Chan and Henriksen that is scheduled for Part 1 in October, and we would like the two to appear as close together in time as possible. Third, despite the referee's favourable comments regarding brevity of the first manuscript, we have in fact found it possible to shorten it to the length you requested mainly by paying stricter attention to economies of style.

Our responses to the referee's comments are as follows:

Comment (a): A sentence is added on p.3 giving explicit error estimates. CLEAN does not by itself introduce bias, but the width uncertainties do vary over the field due to the finite resolution of the beam. This is covered by our addendum.

Comment (b): Most of the fluctuations are comparable to the uncertainties, so we cannot be sure whether or not they are real. We have added a sentence to this effect; this and our response to comment (a) should now allow readers to draw their own conclusions, if they wish to delve deeper than we do ourselves.

Comment (c): It would indeed be interesting to calculate the polarization, and we had already embarked on this large task. We do not wish to add this to the present paper however because it would not in fact discriminate the models as the referee has suggested. Briefly, once the magnetic transition radius R_1 is fixed by reference to the observed polarization (as we have done in all of the models in this paper), the dynamical importance of the self-consistent field depends mainly on the Alfvenic Mach number at the trans-sonic point. A large number of models would exist with very similar magnetic field and polarization structures, differing mainly in the field strength rather than the field topology. To the extent that these models could actually be distinguished by polarization data, they could be distinguished better as we have suggested by collimation data (which would have greater signal-to-noise due their use of the total intensity). The referee could appreciate this point from a careful reading of Chan and Henriksen, and his comment reinforces our wish to have the Letter appear as close in time to Chan and Henriksen as can be managed.

Comment (d): We know from unpublished VLA data that jet one-sidedness in fact correlates with field configuration and source luminosity. Only the bright base in the first few arcsec of the jet in 3C31 is actually similar to the 'notorious' one-sided jets mentioned by the referee. The bearing that this will have on jet models will not be clear until the relativistic generalisation of our self-similar model is worked through and the role of relativistic Doppler luminosity enhancement can properly be evaluated. We are making progress in this area and we hope to be able to answer the referee's question in a future publication.

We have responded to a number of further suggestions and comments made by the referee in the manuscript of the paper, but which he did not formalise into his report. The new VLA data on radio jets are clearly raising many questions for theorists, and we believe that the basic observational facts and their preliminary interpretation should be made widely known as soon as possible. For this reason we hope that you will find the shortened version acceptable for publication in Part 2 of the journal.

Yours sincerely,

Alan H. Bridle

Alan H. Bridle

Richard N. Henriksen

1. The article merits publication in Ap.J.

2. Although the matter of publication in Part I or Part II is in the hands of the Editor and the authors, I would strongly urge the latter to consider publication in Part I. First, the MS is too long for Part II already, and I don't see obvious candidates for a cut; second, as argued below, some points could, I think, be fruitfully expanded a little bit.

3. The article is too long for Part II, but by itself brief enough.

4. No comments.

5. A few more or less minor points:
   a) Sec. II, p.3: About the deconvolution bias: could you give a number indicating how bad 'little bias' is? How does the applied CLEAN procedure influence this bias?
   b) Sec. II, p.4: Are the 'apparent fluctuations' none the less physically real, or due to errors of some sort? If they are errors, their size (10% or so, I think) are a bit large to sustain the previous 'little bias' claim.
   c) Sec. V, p.9: It would be interesting to include the run of polarization predicted by the Chan/Henriksen model in Figure 2. The polarization might well turn out to be the deciding factor between the CH interpretation and the external pressure model; this point ought to be a little more emphasized. 1) CH <u>and</u> ext. pressure? 2) Wouldn't decide, anyway.
   d) Sec. VI, passim: Some radio jets are notoriously one-sided, but otherwise similar to the 3C31 type. Does this have a bearing on the models discussed here? Yes. More to come elsewhere.

THE ASTROPHYSICAL JOURNAL

HELMUT A. ABT, *Managing Editor*
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602-327-5511

A. DALGARNO, *Letters Editor*
Center for Astrophysics
60 Garden Street
Cambridge, Massachusetts 02138
617-495-4479

June 9, 1980

Dr. R. N. Henriksen
Department of Physics
Stirling Hall
Queen's University at Kingston
Ontario K7L 3N6, Canada

Dear Dr. Henriksen:

We have received your paper, COLLIMATION OF THE RADIO JETS IN 3C31, and have sent it to a referee. It will be necessary for you to prepare a shorter version consistent with our page limit of four journal pages, but you may want to wait for the referee's comments before preparing this revised version. We estimate that the present length of your paper is 4 1/3 journal pages and will need to be shortened by at least 1 typewritten page.

Yours sincerely,

A. Dalgarno/mb

A. Dalgarno
Letters Editor

AD:mb

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DEPARTMENT OF PHYSICS
STIRLING HALL
Physics
Engineering Physics
Astronomy

Queen's University
Kingston, Canada
K7L 3N6

4 June 1980

Dr.A.Dalgarno,
Letters Editor,
The Astrophysical Journal,
Center for Astrophysics,
60 Garden Street,
Cambridge,
MA 02138

Dear Dr. Dalgarno,

We enclose three copies of the manuscript of a paper entitled 'Collimation of the Radio Jets in 3C31', by A.H.Bridle, R.N.Henriksen, K.L.Chan, E.B.Fomalont, A.G.Willis, and R.A.Perley, which we hope will be suitable for publication in Part 2 of the Astrophysical Journal. We also include both glossies and originals of the two Figures; the originals may give better line definition for the curves in Figure 2.

The text makes frequent reference to a theoretical paper by Chan and Henriksen; it may be noted that this paper has been scheduled for publication in Part 1 of the Astrophysical Journal on October 1 1980.

Due to impending sabbatical movements, we request that correspondence concerning this paper be addressed as follows: until August 1st 1980 (mailing date) to Dr. R.N.Henriksen, Department of Physics, Stirling Hall, Queen's University at Kingston, Ontario K7L 3N6, Canada; after August 1st 1980, to Dr. A.H.Bridle, NRAO VLA Program, P.O.Box 'O', Socorro, NM 87801.

Yours sincerely,

Alan H. Bridle

Alan H. Bridle

R.N. Henriksen

Richard N. Henriksen

3C31 Coll. Preprints

Authors, Bicknell
GB, CV, VLA Libs.
Basart
Rees
Blandford
Benford
Baan
Hardee
Wiita
Norman
G. Burbidge
Butcher
Christiansen
M. Davis
De Young
C. Fanti
Feigelson
Menon
Miley
Pacholczyk
Scheuer
Schilizzi
Wardle
Wielebinski
Willses
A. Wilson
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K. Johnston
Högbom
Kellermann
Laing
Rudnick
Strom
...n Breugel
...nson

van der Laan
Seguist
Begelman
Cohen
Owen
Hardee
Mauscher
Sikora (Warsaw)
Bregman
Fukue (Kyoto)
Morita (Sapporo)

Mean Collimation Parameters for 3C31

Θ"	Φ"	μ	α°	arctan μ
4.3	1.06	–	13.3	1 ↑
5.1	1.09	–	12.2	2
6.1	2.12	0.59	19.7	30.4 3 ↓
7.35	2.37	0.61	18.3	31.5
8.45	2.51	0.17	16.9	9.4
9.6	2.87	0.22	17.0	12.5
10.7	3.06	0.24	16.3	13.7
11.75	3.8	0.43	18.4	23.4
13.0	3.9	0.37	17.1	20.1
15.15	4.4	0.18	16.5	10.0
18.0	5.2	0.26	16.3	14.6
21.1	6.5	0.35	17.5	19.4
24.6	7.5	0.35	17.3	19.4
28.5	7.8	0.18	15.6	10.0
31.2	6.9	–	12.6	
34.3	8.5	0.12	14.1	6.9
37.0	8.7	0.07	13.4	4.2
40.9	8.7	0.03	12.1	1.7

North Jet

Θ	Φ	μ	α	arctan μ
5	1.08	–	12.3	[redacted]
10	3.0	0.38	17.1	[redacted] 20.8
15	4.5	0.30	17.1	16.7
20	6.0	0.30	17.1	16.7
25	7.3	0.26	16.6	14.6
30	7.9	0.12	15.0	6.8
35	8.4	0.10	13.7	5.7
40	8.8	0.08	12.6	4.6

South Jet

Θ	Φ	μ	α	arctan μ
5	?	?	?	?
-10	3.4	–	19.3	[redacted]
-15	5.2	0.36	19.7	19.8
-20	6.1	0.18	17.3	10.2
-25	7.0	0.18	15.9	10.2
-30	8.0	0.20	15.2	11.3
-35	9.0	0.20	14.7	11.3
-40	10.0	0.20	14.3	11.3
-45	11.0	0.20	13.9	11.3
-50	12.0	0.20	13.7	11.3

$\alpha = 0.5$
$z = 0.0169$
$D = 50.9$ mpc
$1'' = 239$ pc
10MHz → 10GHz

N jet, 3C31 parameters at 4885 MHz

z″	z(kpc)	JET FWHM″	FWHM (kpc)	B(ν) mJy/″²	Umin [J/m³]	Beq [gauss]	nT [cm⁻³K]	τ1/2 (yrs)
4.3	1.03	1.06	0.253	109	1.6 10⁻¹⁰	1.3 10⁻⁴	4.1 10⁶	3.2×10⁵
5.1	1.22	1.09	0.261	101	1.5 10⁻¹⁰	1.3 10⁻⁴	3.8 10⁶	3.2×10⁵
6.1	1.46	2.12	0.507	53	7.3 10⁻¹¹	8.8 10⁻⁵	1.8 10⁶	5.8×10⁵
7.35	1.76	2.37	0.566	51	6.7 10⁻¹¹	8.4 10⁻⁵	1.7 10⁶	6.2×10⁵
8.45	2.02	2.51	0.600	44	5.9 10⁻¹¹	8.0 10⁻⁵	1.5 10⁶	6.7×10⁵
9.6	2.29	2.87	0.686	30	4.4 10⁻¹¹	6.9 10⁻⁵	1.1 10⁶	8.4×10⁵
10.7	2.56	3.06	0.731	23	3.7 10⁻¹¹	6.3 10⁻⁵	9.2 10⁵	9.6×10⁵
11.8	2.82	3.82	0.913	25	3.4 10⁻¹¹	6.0 10⁻⁵	8.5 10⁵	1.0×10⁶
13.0	3.11	3.92	0.937	24	3.2 10⁻¹¹	5.9 10⁻⁵	8.2 10⁵	1.1×10⁶
18.0	4.30	5.15	1.23	18	2.4 10⁻¹¹	5.0 10⁻⁵	6.0 10⁵	1.4×10⁶
24.6	5.88	7.5	1.79	14	1.6 10⁻¹¹	4.2 10⁻⁵	4.2 10⁵	1.8×10⁶
28.5	6.81	7.8	1.86	8.8	1.2 10⁻¹¹	3.6 10⁻⁵	3.1 10⁵	2.2×10⁶
31.2	7.46	6.9	1.65	7.1	1.2 10⁻¹¹	3.5 10⁻⁵	3.0 10⁵	2.3×10⁶
34.3	8.20	8.5	2.03	6.2	9.6 10⁻¹²	3.2 10⁻⁵	2.4 10⁵	2.6×10⁶
37.0	8.84	8.7	2.08	7.1	1.0×10⁻¹¹	3.3 10⁻⁵	2.6 10⁵	2.5×10⁶
40.9	9.78	8.7	2.08	7.1	1.0×10⁻¹¹	3.3×10⁻⁵	2.6×10⁵	2.5×10⁶

4.57+32	***
3.98+46	***
1.32-04	***
1.63-10	***
4.24+32	***
3.86+46	***
1.28-04	***
1.53-10	***
2.22+32	***
3.55+46	***
8.81-05	***
7.25-11	***
2.14+32	***
3.64+46	***
8.44-05	***
6.65-11	***
1.85+32	***
3.43+46	***
7.96-05	***
5.92-11	***
1.26+32	***
2.92+46	***
6.86-05	***
4.40-11	***
9.65+31	***
2.58+46	***
6.25-05	***
3.65-11	***

1.05+32	***
2.97+46	***
6.00-05	***
3.37-11	***
1.01+32	***
2.94+46	***
5.89-05	***
3.24-11	***
7.55+31	***
2.80+46	***
5.02-05	***
2.35-11	***
5.87+31	***
2.85+46	***
4.20-05	***
1.64-11	***
3.69+31	***
2.22+46	***
3.63-05	***
1.23-11	***
2.98+31	***
1.87+46	***
3.54-05	***
1.17-11	***
2.60+31	***
1.89+46	***
3.21-05	***
9.61-12	***
2.98+31	***
2.06+46	***
3.31-05	***
1.03-11	***

3C31 Jet FWHM (arcsec)

Distance from Central Cpt (")	FWHM" 6cm	FWHM" 21 cm	EQUIV CONE ANGLE
4.3	1.06±0.2		13.3
5.1	1.09±0.2		12.2
6.1	2.12		19.7
7.35	2.37		18.3
8.45	2.51		16.9
9.6	2.87		17.0
10.7	3.06		16.3
11.7		4.0±0.5	19.4
11.8	3.82±0.2		18.4
13.0	3.92±0.2		17.1
15.1	15.2→4.25±0.2	4.6±0.5	17.3 15.9
18.0		5.15±0.5	16.3
21.1		6.51	17.5
24.6		7.5	17.3
28.5		7.8	15.6
31.2		6.9	12.6
34.3		8.5	14.1
37.0		8.7	13.4
40.9		8.7	12.1

↑ ↑

<u>deconvolved</u> FWHMs [arc sec]
from λ6cm and λ20 cm maps

As published in ApJ 241, L145

FWHM of Jet:

more accurate: $2 \arctan \frac{F}{2D}$

a) Northern Jet

CENTER LINE	±0".5 HM1	±0".5 HM2	NUCLEAR DISTANCE"	(→ beam out) FWHM" OF J.	" CONE ANGLE ($\arctan$ FWHM/DIST " to nucleus)
-2.5 +8	-1.5 +9	-4 +7	8.38	3.2 → (2.0±0.7)	(13°.4 ± 4°.5)
-4 +11	-6.5 +12	-6 +10.5	11.7	4.7 → 4.0±0.5	18°.9 ± 2°.2
-5 +14.2	-2.5 +15.5	-7.2 +13.3	15.1	5.2 → (4.6±0.5)	16°.8 ± 2°
-6 +17	-3.3 +18.2	-8.5 +15.8	18.0	5.7 → (5.15±0.5)	16°.0 ± 1°.5
-6.7 +20	-4 +21.8	-10.2 +18.6	21.1	7.0 → 6.51±0.5	17°.2 ± 1°.3
-8.2 +23.2	-4.8 +24.5	-12.1 +21.5	24.6	7.9 → 7.5±0.5	17°.0 ± 1°.0
-9.2 +27	-5.9 +28.5	-13.5 +25.5	28.5	8.2 → 7.8±0.5	15°.3 ± 1°
-10 +29.5	-6.3 +31	-13.1 +28.3	31.2	7.3 → 6.9±0.5	12°.5 ± 0°.8
-11 +32.5	-6.5 +34.5	-14.8 31.3	34.3	8.9 → 8.5±0.5	13°.9 ± 0°.8
-12 +35	-7.5 +36.9	-16 33.9	37.0	9.0 → 8.7	13°.2 ± 0°.8
-12.2 +39	-8.1 +39.9	-16.9 38	40.9	9.0 → 8.7	12°.0 ± 0°.8

b) Southern Jet

+3.1 -10	+1.5 -11	+5.2 -9	10.5	4.21 → 3.4±0.6	17°.9 ± 3°.0
+4 -14	+2 -15.5	+7.5 -12.5	14.6	6.26 → 5.7±0.5	21°.5 ± 2°
+7.5 -18	+4.2 -20.1	+9.5 -17	19.5	6.14 → 5.6±0.5	16°.0 ± 2°
+8 -23	+5 -24.5	+11.5 -21	24.4	7.38 → 6.95±0.5	15°.9 ± 2°.5
+8.7 -27.5	+6 -29.5	+13.5 -24.1	28.8	8.19 → 7.8±0.5	15°.1 ± 1°
+11.4 -30.3	+8.3 -32.4	+15 -28.5	32.4	7.75 → 7.3±0.5	12°.8 ± 0.8
+12.8 -33.1	+9.8 -35.6	+16.6 -31	35.5	8.20 → 7.8±0.5	12°.4 ± 0.7
+14.8 -36.7	+10.3 -39.5	+18.8 -33.6	39.6	10.3 → 10.0±0.5	14°.2 ± 0.7
+16.6 -40	+13.1 -43.4	+21 -36	43.3	10.8 → 10.5±0.5	13°.6
+19.5 -43.8	+14.3 -47.5	+23.5 -40	47.9	11.9 → 11.6±0.5	13°.6

c) Northern - [illegible]

-5.5 +16.4	-3.2 +17.5	-7.3 +15.2	4.3	1.18 → 1.06
-7 +19	-4.3 +20.5	-8.5 +18.2	5.1	1.19 → 1.09±0.20
-8 +23	-3.5 +26	-11 +21.5	6.1	2.19 → 2.12±0.20
-9 +28	-5.9 +30.5	-13.5 +24.5	7.35	2.42 → 2.37
-11 +32	-7.2 +34.5	-15.5 +28.5	8.45	2.56 → 2.51
-13 +36	-8.5 +39	-17.5 +31.6	9.57	2.91 → 2.87
-14.7 +40	-9 +43.8	-19.0 +36.5	10.65	3.10 → 3.06
-16.2 +44.5	-9.2 +49.5	-21.7 +40.5	11.8	3.85 → 3.82
-17.5 +48.8	-11 +53.5	-24.2 +44.8	13.0	3.95 → 3.92
-19.5 +57.5	-12.3 +62.5	-26.5 +53	15.2	4.27 → 4.25

CH Eqns for 3C31

$$\epsilon_B = \frac{\pi}{4}\left[\frac{R_m}{z_{max}-z_{min}}\right]^2 \sim \frac{\pi}{4}\left[\frac{\Phi_{max}}{2\theta_{max}}\right]^2 \cos^2 i \qquad [47]$$

$$\sim \frac{\pi}{4}\left[\frac{8.8}{80}\right]^2 \cos^2 i$$

$$= 0.00950 \cos^2 i$$

ϵ_B also $\sim 0.077 \left[R_s/R_t\right]^{2/3}$ for cold beam [B6]

So $\left[\frac{R_s}{R_t}\right]^{2/3} = 0.1234 \cos^2 i \qquad \frac{R_s}{R_t} = 0.04336 \cos^3 i$

As $\Phi_t \lesssim 3''$, $\Phi_s < 0.13 \cos^3 i$

$R_s < 32 \cos^3 i$ pc.

$V_{z\infty} \sim 10^8$ cm/s

$\rho \sim 10^{-26}$ gm/cm^3

$$\frac{B_\phi^2}{4\pi\rho V_{z\infty}^2} = \frac{B_\phi^2}{4\pi\times10^{-26}\times10^{16}} \sim 10^{-2}$$

$$\Rightarrow B_\phi^2 = 4\pi\times10^{-12}$$

$$B_\phi = 2\sqrt{\pi}\times10^{-6} \sim 4\times10^{-6} \text{ gauss}$$

$k = 1$, $f = 1$

$\alpha = 0.5$ $\nu_{Lo} = 10$, $\nu_{Hi} = 100000$

3C31 Confinement $H_0 = 50$, $z = 0.0177$

			Jy	B_{eq}	U_{min} (J)	u_{min} (J/m³)	nT_{min} (K/m³)
$\theta = 4''$	$\Phi = 1''$	$BA = (0''.93)^2$	$I = .005$	4.7×10^{-5}	5.1×10^{46}	2.1×10^{-11}	1.1×10^{11}
$20''$	$6''$	$(0''.93)^2$	.0015	2.0×10^{-5}	5.5×10^{46}	3.75×10^{-12}	2.0×10^{10} 9.1
$40''$	$8''.8$	$(3.54)^2$	.010	1.4×10^{-5}	6.1×10^{47}	1.92×10^{-12}	1.0×10^{10}