NATIONAL RADIO ASTRONOMY OBSERVATORY
1000 BULLOCK BOULEVARD, N.W. POST OFFICE BOX O SOCORRO, NEW MEXICO 87801
TELEPHONE 505 835 2924 TWX 910 988 1710 VLA SITE 505 772 4011

15 May 1981

Dear Dick,

Some further points regarding HVB -

1 Was it accepted? I haven't heard from you about it?

2 NRAO needs to be advised if it has been accepted. They should be sent a copy of page charge forms for their 50% to be authorized. They will also require 250 reprints. Communicate with the Librarian. NRAO, Edgemont Road, Charlottesville, VA 22901 (Mrs. Don Rayburn!).

3 The "caveat" on p.17 regarding the Jones and Owen model is not appropriate as they were explicitly modelling a steady-state situation where gas ablated is continuously replaced by stellar evolution. Perhaps the "caveat" can be removed at the copy-editing stage, and it could be made clearer that it is in our model, not J. and O., that the radio activity must occur very soon after the encounter. O. himself is rather upset about this.

OPERATED BY ASSOCIATED UNIVERSITIES, INC.,
UNDER CONTRACT WITH THE NATIONAL SCIENCE FOUNDATION

A.

NATIONAL RADIO ASTRONOMY OBSERVATORY
P. O. BOX O
SOCORRO, NEW MEXICO 87801
TELEPHONE 505-835-2924
VLA SITE 505-772-4011
TWX 910-988-1710

POST OFFICE BOX 2
GREEN BANK, WEST VIRGINIA 24944
TELEPHONE 304-456-2011
TWX 710-938-1530

EDGEMONT ROAD
CHARLOTTESVILLE, VIRGINIA 22901
TELEPHONE 804-296-0211
TWX 510-587-5482

SUITE 100
2010 NORTH FORBES BLVD.
TUCSON, ARIZONA 85705
TELEPHONE 602-882-8250

14 April 1981

Prof. R. N. Henriksen,
Institute for Plasma Research,
Stanford University,
Stanford, CA 94305

Dear Dick,

Thank you for sending the resubmitted version of the Jet Refraction paper. I have found a number of minor errors in it which will need correction in proof.

p.12, para. 1, line 10 : units should be $km.s^{-1}.Mpc^{-1}$
p.12, last line : reference should be Bridle, Fomalont and Cornwell (1981)
p.13, line 2 : reference should be Bridle, Fomalont and Cornwell (1981)
p.19, first para., line 2 from end : units should be $km.s^{-1}$
p.19, para. 2, line 1 : o<u>n</u> the bending
p.20, line 2 from end : units should be $km.s^{-1}.Mpc^{-1}$
p.21, line 2 : Table 3 should be Table 1
p.21, several lines : Hubble parameter notated $H_o$, but was $H_0$ earlier in paper
p.22: BCH reference should be 75, 69.
p.22: BFC reference should be A.J., submitted.
p.23: ZH reference: delete 1965, Vol. V, 305 (correct reference is in BFC).

I look forward to receiving the next version of the Turbulence paper. I will be at the University of Texas next week, and will return to the VLA on Friday 24 April to meet with Vincent Icke. With any luck we might find out if he is serious about coming to Queen's next year.

Best wishes,

Alan

Alan Bridle

Interoffice

# National Radio Astronomy Observatory

## Very Large Array

To: Library, Charlottesville

From: Alan Bridle, VLA Alan Bridle 13 April '81

Subject: Enclosed preprint

I enclose three copies of a preprint of a paper which has been submitted to Astrophysical Journal.

A copy has already been given to the VLA Library.

INSTITUTE FOR PLASMA RESEARCH
STANFORD UNIVERSITY
VIA CRESPI, STANFORD, CALIFORNIA 94305

April 3, 1981

Dr. Helmut A. Abt
Managing Editor
The Astrophysical Journal
Kitt Peak National Observatory
P.O. Box 26732
Tucson, AZ 85726

Dear Dr. Abt:

Please find enclosed two copies of the manuscript entitled "Radio Jet Refraction in Galactic Atmospheres with Static Pressure Gradients" by Henriksen et al. This version has been revised largely in accordance with the referee's requests. We have not however added a "ridge line" to Figure 2 because we fitted our model to the mean shape of the two sides of the source. We have now emphasized this point in the text, and we have added a few lines to clarify the relation of our fit to the central structure. I hope that this will prove satisfactory.

Please use my address at Stanford for correspondence until the first week of August 1981 and thereafter my Queen's address. We thank you and the referee for your attention.

Yours sincerely,

RHenriksen

Dr. R.N. Henriksen
for
R.N. Henriksen
J.P. Vallée, and
A.H. Bridle

lbm

Encls.

c. J.P. Vallée
✓A.H. Bridle

Interoffice

# National Radio Astronomy Observatory

## Very Large Array

25 March 1981

To: Jacques

From: Alan

Subject: Refracted jet models and 3C293

With regard to your memo about refracted-jet models, I regret that I see nothing "great" about models which fail to confine a well-documented part of the radio structure by several orders of magnitude, nor models which spread the jet curvature out along an extended track in the effort to hide their failure to fit the observed radio misalignment between the core and the bridges. I also see nothing "great" about mass distributions which imply excessive mass and which have to be cut off at some arbitary "halo" height to avoid this.

In the enclosed paper you will find an application of refracted-jet models to the actual structure of 3C293, together with proper estimates of masses and bremsstrahlung luminosities from a realistic distribution which can indeed be integrated over all space without cheating.

I am sure you will have heard from Dick that the referee of HVB has requested a superposition of the model on the radio contours, as I earlier suggested for HVB, and as is done here.

In revising the paper for resubmission Dick will include some text modifications to distinguish clearly between the regimes of validity of the bridge-lobe model in HVB and the core-bridge model presented in Bridle, Fomalont and Cornwell. In fact I regard the HVB bridge-lobe application as extremely suspect and the product of an unseemly rush to make something of an inappropriate calculation. The regime where jet refraction is most likely to occur is in the inner cores of radio galaxies, where densities and pressures are greatest, and I think the application to the outer structure of 3C293 instead of to the core-bridge misalignment illustrated in the Figure I prepared for HVB has significantly minimised the worth of the observational comparison in HVB. It is for this reason that Bridle, Fomalont and Cornnwell refer to HVB for the theory only.

Yours,

THE ASTROPHYSICAL JOURNAL

HELMUT A. ABT, *Managing Editor*
Kitt Peak National Observatory
Box 26732
Tucson, Arizona 85726
*602-327-5511*

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

March 17, 1981

Dr. R. N. Henriksen
Institute for Plasma Research
Stanford University
Stanford, CA 94305

Dear Dr. Henriksen:

Your paper entitled "Radio Jet Refraction in Galactic Atmospheres with Static Pressure Gradients," written with J. P. Vallee and A. H. Bridle, was sent to a competent referee, and a copy of the report is enclosed for your consideration.

We request that the entire title page be typed double spaced and that the footnotes be called for with Arabic numbers, rather than symbols. Please add a sheet at the end of the manuscript giving the authors' postal addresses (double spaced); the title page need include only the authors' affiliations.

Sincerely,

Helmut A. Abt

Helmut A. Abt
Managing Editor

HAA:cs

Enclosures: original ms., 2 figs.
referee report

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

# REPORT OF REFEREE

Author, Title Henriksen et al: RADIO JET REFRACTION IN GALACTIC ATMOSPHERES WITH STATIC PRESSURE GRADIENTS

This paper is a reasonable extension of previous ideas on the propagation of jets in radio galaxies. Although the basic point of the paper is quite simple, I believe that it has not been published previously, and I feel that it is of sufficient interest and novelty to warrant publication. The writing is clear and concise and the discussion is logical.

However, there are two places where the authors could improve the presentation:

1) At the beginning of §II B the authors claim that "in the supersonic region of the beam, we may replace (9) with $V_j$ = constant," and the rest of the paper ignores variation in $V_j$. It is not immediately clear why this is true, and the authors ought to justify this contention, as the subsequent simplifications depend upon it.

(2) It would be helpful if the ridge-lines of the refracted beams could be superposed upon their maps of 3C293 in Figure 2. This would enable the reader to better judge the adequacy of the model and the parameters given in Table 1.

Although I would be willing to recommend publication of the current version, I do hope that the authors will see fit to make these minor modifications. ← !

I have also corrected some minor errors on pp 6, 8, 12 and 20 of the manuscript.

Alan

However, I will prepare final version with point (1), typos, your addenda, my paragraph (with reference to your or Ed's paper), and Jacques calculation of the ridge line superimposed on the figure and new title page. - It is now HVB, 1981 Ap. J, in press.

D.

16 March 1981

Dick

Regarding your point about equation (15) of HVB and its applicability to the discussion on p.16 of the 3C293 paper:

The trouble is that Equation (15) does not contain the effect we are talking about, as it is applicable in the slab approximation. What determines the actual deflection in a more physical situation (as well as $p_s/(\rho_j v_j^2)$) is the ratio between the gradients of the pressure along the major and minor axes of the confining gas. The physical reason for this will be clear if you visualise the other limit, of a spherical distribution. In this case there is no deflection however close $p_s/\rho_j v_j^2$ is to unity and whatever the value of $\gamma$. In the slab approximation there is no major-axis gradient, so Section IIB of HVB locks out the thing we are talking about on our p.16, namely that the deflections observed will depend on the numerical anisotropy of the pressure gradients. We therefore cannot usefully refer to equation (15) as you suggested.

I now think the slab limit is mainly of academic interest, as it cannot be used to obtain mass and X-ray constraints on the models, either, due to its formal infinite extent.

Cheers,

Alan

N.B. Please note that the 3C293 paper will be Bridle, A.H., Fomalont, E.B., and Cornwell, T.J. (1981) now that it will have the additional MERLIN data.

P.S. BCH will be [illegible]

NATIONAL RADIO ASTRONOMY OBSERVATORY
P. O. BOX O
SOCORRO, NEW MEXICO 87801
TELEPHONE 505-835-2924
VLA SITE 505-772-4011
TWX 910-988-1710

POST OFFICE BOX 2
GREEN BANK, WEST VIRGINIA 24944
TELEPHONE 304-456-2011
TWX 710-938-1530

EDGEMONT ROAD
CHARLOTTESVILLE, VIRGINIA 22901
TELEPHONE 804-296-0211
TWX 510-587-5482

SUITE 100
2010 NORTH FORBES BLVD.
TUCSON, ARIZONA 85705
TELEPHONE 602-882-8250

7 March 1981

Dr.R.N.Henriksen,
Institute for Plasma Research,
Stanford University,
Stanford, CA 94305

Dear Dick,

I enclose a copy of the draft of Ed's and my paper on 3C293. It is clear to me that this work should have preceded the use of 3C293 in "Warps" by Jacques, but unfortunately I stopped work on it when I received the first, incredible, draft of "Warps" from Jacques. I also enclose my request for amendments to "Warps" to deal with the confusions that have arisen.

I am assuming the following constraints. First, Ed and I do not believe that [illegible] need be explained by jet refraction. We were impressed originally by the misalignment between the core and the large-scale structure, which we had already detected at Green Bank (Bridle and Fomalont, A.J., 83, 704 (1978)). The purpose of the VLA proposal was to place constraints on this misalignment and models for it, including precessional and refraction models in the style of Gull and Northover and of Begelman et al. This is what we have now written up, with benefit of the REFJET code and a routine for integrating density and density-squared profiled to compute total masses and bremsstrahlung X-ray luminosities, which I have brought up at the VLA. We do not wish to refer to explicit models of the large-scale Z structure as a refracted jet, and our paper therefore refers to Henriksen, Vallee and Bridle for the ideas (which is the part of HVB that we actually believe).

Second, I gather that you and Jacques wish to retain Jacques' fits for HVB. In that case I ask that the HVB paper note that the core-bridge misalignment has been explicitly modelled by Bridle and Fomalont, and make it crystal clear that the HVB model is intended to apply only in the bridge-lobe region. I think the revised text I am enclosing does this satisfactorily, (a) by dividing the structure explicitly into these regions and (b) by removing the core equipartition parameters from HVB. The latter is desirable anyway as HVB uses a different Hubble constant from Bridle and Fomalont (another of Jacques' effects). I would be prepared to make improved models for the bridge-lobe structure using REFJET, but have not (a) because presumably you want to avoid the embarassment of too many changes in HVB and (b) I am not yet convinced that the large-scale atmosphere is necessary for 3C293. The polarized-intensity maps show clear signs that the ridge-line of the northwestern bridge oscillates over angles that are more or less the same as the transverse extent of the northwestern lobe. This raises the possibility, at least to my mind, that the large-scale Z-structure of 3C293 is due to the final swings of a Hardee-style helical instability rather than due to refraction. Ed and I will make 6cm the minor axis of the galactic light which is in PA 151° ± 2° (Argue et al., 1978). The 1.47 GHz map shows a weak elongated large-scale bridge structure extending in both directions from the galaxy in PA ~125°, which is much closer to the optical minor axis. On both sides of the galaxy, this bridge emission ~~structure~~ terminates in lobes whose major axes lie along PA ~30°. The overall radio structure therefore has an 'S'-shaped morphology whose overall linear size is about 290 kpc (about 4 arc min at $H_0 = 50$ km/sec$^{-1}$/Mpc$^{-1}$).

Bridle and Fomalont (1981) have given a refracted-jet model for the inner [core-bridge] misalignment. Table 1 gives the parameters of theoretical refracted jets which fit the large-scale [bridge-lobe] ~~observed source~~ structure, allowing for uncertainties in the interpretation of the locus of its observed ridge line. We presume here that the numerical solutions of equations (17) and (19) for the model beams describe the bending of the observed radio jets, i.e., that the predicted loci of the beams are the same as the loci of the synchrotron-emitting material. It should be noted that the position angle of the outer pressure term used to fit the radio structure is that of the minor axis of the outer stellar distribution of the optical galaxy. The end directions of the jet will approach the direction of the projected minor axis of the galaxy as $p_s/\rho_{js}V_j^2 >> 1$, according to equation (15). Referring to Figure 1b and to equations (20), we see that only observers at $\Phi = 0°$ and $\theta = 90°$ would avoid such projection effects. In this case, $\Phi = 223°$. In fact, there are so many parameters (including the projection angles) and not all of them independent, that we regard these fits as illustrative rather than unique. In this preliminary account, we have made no attempt to define systematically the parameter space volume that is admissible. However, it appears that the projection angles cannot vary by more than ~10° and the relatively flat portion of the pressure distribution should not differ in scale by more than a factor of 2.

Equations (8) and (10) show that $R \propto p^{1/2\gamma} \propto p^{-3/8}$ for the models shown. Thus, we indeed expect the beam radius R to vary rapidly only when p does, which, in the distributions chosen above, is near $a_3$ and $(1/2)H_a$. Inspection of Figure 2a shows that the jet widths are indeed <u>roughly</u> constant outside the radio core until a <u>projected</u> distance of ~1' (75 kpc) from the galaxy, where they bend, broaden, and decay in intensity. Inverting equations (20) gives this deprojected scale as ~130 kpc, in rough agreement with the pressure scales used to fit the beam curvature (Table 1).

We have seen in Section II that at least initially the refracting pressure required is comparable to the confining pressure. The minimum confining pressures required for the ~~radio components~~ bridge structure in 3C293 can be estimated from the usual equipartition calculations (Bridle and Fomalont, 1981). ~~The equipartition magnetic field strength in the core components, which are about 1200 pc from the nucleus, is about 7 × 10^-4 gauss, requiring a pressure equivalent to nT ~ 10^8 K cm^-3 for confinement.~~ About 14 arc sec (17 kpc, $H_0 = 50$) from the core, the equipartition field strength falls to ~~2.4~~ ~2 × $10^{-5}$ gauss and the minimum value of nT to ~$10^5$ K $cm^{-3}$. Near the middle of the Northwestern bridge, 45 arc sec (54 kpc) from the core, values of 1.1 × $10^{-5}$ gauss and 3 × $10^4$ K $cm^{-3}$ are obtained. The x-ray detectability of media with these minimum pressures will depend strongly on the temperature; for temperatures of $10^7$ K, the densities required would be comparable to those detected in a number of nearby radio galaxies (Fabricant <u>et al.</u>, 1978; Fabbiano <u>et al.</u>, 1979). It is then possible that x-ray observations of 3C293 will

B+F values are for $H_0$=150!

calculated shapes will not vary with the assumed $H_o$. The length parameters in Table 3 may then simply be scaled with $H_o$, while the dimensionless quantities, of course, remain unchanged.

## Acknowledgments

We are indebted to Dr. M. J. L. Kesteven for technical advice concerning the computing facilities of the Queen's University Astronomy Group, and to Drs. E.B. Fomalont and B. Geldzahler for communication of their results on Fornax A.

This research was supported by operating grant (to RNH and AHB) from the Natural Sciences and Engineering Research Council of Canada. RNH also acknowledges the hospitality of Professor P. A. Sturrock and the Institute for Plasma Research at Stanford, where this work was completed. AHB thanks the National Radio Astronomy Observatory and the University of New Mexico for hospitality while on sabbatical leave from Queen's University.

NATIONAL RADIO ASTRONOMY OBSERVATORY
P. O. BOX O
SOCORRO, NEW MEXICO 87801
TELEPHONE 505-835-2924
VLA SITE 505-772-4011
TWX 910-988-1710

POST OFFICE BOX 2
GREEN BANK, WEST VIRGINIA 24944
TELEPHONE 304-456-2011
TWX 710-938-1530

EDGEMONT ROAD
CHARLOTTESVILLE, VIRGINIA 22901
TELEPHONE 804-296-0211
TWX 510-587-5482

SUITE 100
2010 NORTH FORBES BLVD.
TUCSON, ARIZONA 85705
TELEPHONE 602-882-8250

5 March 1981

Jacques

Here are up-dated copies of the codes I am now using for jet refraction calculations at the VLA. REFJET is the modified version of your PDP11 code. SPHINT does integrals needed to compute the total mass and X-ray luminosity of the assumed spheroidal atmosphere. Note that the last two constraints should always be tested when fitting bent radio jets, e.g. they show very clearly that the model you fitted to 3C293 cannot be normalised near the core, and cannot confine the core components that Ed and I observed (by a factor ~1000), without involving enormous masses ($\sim 10^{16} M_\odot$) and huge X-ray luminosities ($\gtrsim 10^{45}$ erg/s).

Alan

INSTITUTE FOR PLASMA RESEARCH
STANFORD UNIVERSITY
VIA CRESPI, STANFORD, CALIFORNIA 94305

Feb 24, 1981
Stanford

Alan,

Here are the lines which I think will handle the problem with 3C293 rather well. It is unfortunate that perhaps the best observed sources for applying equations (17), (19) to, are the wide-angled tails (e.g. NGC 1265). I'm considering trying it out on such sources, but I feel confident.

Jacques may have been somewhat maligned on this point, but not of course on the optical data. --- oh well ---

By the way, what is Lcore for 3C293? I'm guessing about $10^{42}$ erg/sec here as you see! But we can modify that.

I must send copy of turbulence thoughts to Queen's (Kayll and Armo) and to Jean Eilek as promised, but I'll assure them it is preliminary!

Cheers

Dick

Note: 2nd line, ... "source".

Insert. Before §V p 15

We have not attempted to fit the inner structure of 3C293 with either of equations (17) or (19) because of the ~~observational~~ jump in scales between the 1.4 GHz and 15 GHz maps. But it is clear that some inner pressure distribution must have its minor axis (the z axis in fig 1a) approaching PA 135°. Then with $\phi_s = 0°$ and $\phi = 45°$ equation (14) gives with $\gamma = 4/3$ that

$$\rho_{js} V_j^2 = \frac{4}{\ln\sqrt{2}} p_s .$$

Using the core equipartition estimate for $p_s \sim 1.4 \times 10^{-8}$ dynes gives in turn $\rho_{js} V_j^2 \sim 2 \times 10^{-7}$ dynes. Hence $\rho_{js} \sim 2 \times 10^{-23} V_{j8}^{-2}$ gm/cm$^3$, which implies $n_{core} \sim 10 V_{j8}^{-2}$ ($V_{j8}$ is in units of 1000 km/sec) and therefore $T_{core} \sim 10^7 V_{j8}^2$ K. Moreover, taking $L_{core} \sim R_s^2 \rho_{js} V_j^3 \sim \frac{4}{\ln\sqrt{2}} R_s^2 p_s V_j$ gives $L_{core} \sim 2 \times 10^{42} V_{j8} R_{100}^2$ ergs/sec ($R_{100}$ is in units of 100 pc). With $V_{j8} \sim 1$, $R_{100} \sim 1$ once again we might expect a detectable X-ray source. This inner structure in 3C 293 is very similar to that of Fornax A (see §V).

THE UNIVERSITY OF NEW MEXICO
ALBUQUERQUE, NEW MEXICO 87131

19 February 1981

Dr. R. N. Henriksen
Institute for Plasma Research
Stanford University
Stanford, CA 94305

Dear Dick,

In (finally) getting time away from trying to patch together something decent from a number of papers drafted by Jacques, I have had time to get some details together on my paper with Ed on 3C293. It is becoming rapidly clear that the numerical model for the source given by Jacques' sums for the Warps paper is something of a joke. He wants the pressures to drop by less than a factor of two from 2.5 to 100 kpc, in both the spheroid and CH models. Further, the models are supposed to be in pressure equilibrium near a nozzle at about 3 kpc, which means that the core source observed by the VLA is entirely within the nozzle. The slow variation of pressure with height computed by Jacques nevertheless requires total gas masses of order $10^{15}$ to $10^{16}$ solar masses associated with 3C293, unless the pressure normalization is done in the far field (near the lobes), in which case his pressure model fails to confine the inner source by a factor of about a thousand.

Furthermore, although the pressure distribution required to confine the minimum-energy parameters of 3C293 would indeed be only a modest X-ray source at temperatures greater than about $10^8$ K, as noted in the Warps text, the X-ray source associated with the spheroidal or CH models computed by Jacques would be easily the brightest in the sky with the Einstein IPC, if these models were normalised at the nozzle to the actual parameters of the 3C293 core.

This all says that the models for 3C293 quoted in the Warps paper can easily be rejected on total-mass and X-ray luminosity grounds, and should be withdrawn. Where this would leave the rest of the paper is largely up to you. [redacted]

[redacted]

Yours,

DEPARTMENT OF PHYSICS AND ASTRONOMY TELEPHONE 505:277-2616

HV model (CH) for 3C293 pressure

$$\frac{p}{p_s} = \frac{1.86}{1+0.86\left(\frac{z}{2.5}\right)} + \frac{\left(1 - 2.5/z\right)\left(6.5/2.5\right)^{-1}}{1 + \left(z/250\right)^{1.5}} \left(\frac{1.86}{.86}\right)$$

$$= \frac{1.86}{1+0.86\left(\frac{z}{2.5}\right)} + \frac{0.83\left(1 - \frac{2.5}{z}\right)}{\left(1 + \left(z/250\right)^{1.5}\right)}$$

$z_s : z_e$

$$\frac{f}{1+(f-1)\left(\frac{z_e}{z_s}\right)^m} + \frac{\left(1 - z_s/z_e\right)\left(\frac{z_s}{z_e}\right)^m}{1 + \left(z_e/H\right)^{m'}} \frac{f}{f-1}$$

| | | |
|---|---|---|
| $z=2.5$ | $p=$ [redacted] | $p=1.00$ |
| $z=6.5$ | $p=$ | $p=0.72$ [redacted] 1.08 0.57, |
| $z=100$ | $p=$ | $p=$ ~~0.24~~ .70 |
| $z=250$ | $p=$ | $p=$ ~~0.14~~ .43 |

i.e. $\bar{n} \sim 1$ over $V_R = 250\,\mathrm{kpc}$ $\Rightarrow \frac{4}{3}\pi \times (250 \times 1000 \times 3\times10^{16})^3 \times 10^6 \times 1.66\times10^{-27}$

$\Rightarrow 3\times10^{45}$ kg

$\Rightarrow$ **$1.7\times10^{15}$** $M_\odot$ **in gas.**

[redacted]

[redacted]

STANFORD UNIVERSITY
STANFORD, CALIFORNIA 94305
Institute for Plasma Research
~~DEPARTMENT OF PHYSICS~~

Jan 27, 1981

ERL # 311

Dear Allan;

Enclosed please find the updated manuscript on 'warps'. I clearly want to submit it as we are being overtaken!

It is as modified at the VLA but for;

(i) I have left the name order. Jacques really did stimulate my emission on this topic and this probably earns him the right. But I am upset about his attitude and I do not intend to work with him again on the subject if at all avoidable. Therefore I propose that we (you and I) hang up 'warps' at the VLA (I can get it running here) and do a joint collimation-bending treatment on the best observed object. I also want to look at these C-type cluster sources more.

(ii.) ?, V has been converted to (a) ← very hesitant
stake some claim to 3C76.1 (b) describe Fornax A, (c) take account of Jack Burns' preprint and

STANFORD UNIVERSITY
STANFORD, CALIFORNIA 94305

DEPARTMENT OF PHYSICS

(i) to discuss the relation to the nice idea of Jones and Owen (a few paragraphs produced after much thought)
Jack Burns is clearly nearly at the same point in his thinking, so I really feel we must move on this.

(iii) I thought we could let Jacques have his french address in the footnote — we are being very harsh with him otherwise. Nothing else is altered. Please telephone any comments by say Feb 6, otherwise I'll follow your example and launch it at Ap. J.!

— I hope your jaunt to Tucson was relaxing. Geoff and I have been hammering out why turbulence seems to work. I hope to send you a draft in a week or so — still looks good — Do you have any more cases we could analyze? — Anyhow I will not overspill the page — Cheers — Dick

NATIONAL RADIO ASTRONOMY OBSERVATORY
P. O. BOX O
SOCORRO, NEW MEXICO 87801
TELEPHONE 505-835-2924
VLA SITE 505-772-4011
TWX 910-988-1710

POST OFFICE BOX 2
GREEN BANK, WEST VIRGINIA 24944
TELEPHONE 304-456-2011
TWX 710-938-1530

EDGEMONT ROAD
CHARLOTTESVILLE, VIRGINIA 22901
TELEPHONE 804-296-0211
TWX 510-587-5482

SUITE 100
2010 NORTH FORBES BLVD.
TUCSON, ARIZONA 85705
TELEPHONE 602-882-8250

4 December 1980

Dear Dick,

Having just received (yet) another draft of the 3C293 paper from Jacques I am concerned that there may be some developing confusion about revisions to the text. I am therefore enclosing a version which includes the changes I would like to see made, up to the part of the paper where the discussion of 3C76.1 might begin. I believe that the data quality of 3C76.1 are much poorer, and in particular the existence of the S-shape is in dire need of confirmation using the VLA. The subtraction that Jacques is attempting from the WSRT data is unreliable because of the great differences in resolution between the VLA and the WSRT. The best evidence for the S shape is the old NRAO data, and you know my thoughts on whether or not <u>that</u> was publishable. I am helping Jacques draft a proposal for the VLA that would use the old NRAO data as input to the <u>proposal</u>, which is about what it deserves. I still suggest that we give 3C76.1 only a short mention in this paper. I await your redraft with its resonant conclusions, and will get the 3C293 maps in publishable form when I am in Charlottesville next week.

Best wishes

Alan

(copy to JPV).

THE UNIVERSITY OF NEW MEXICO

DEPARTMENT OF PHYSICS AND ASTRONOMY

800 YALE BOULEVARD, N.E.
ALBUQUERQUE, N.M. 87131
TELEPHONE (505) 277-2616

20th Nov 1980

Dear Dick, Jacques

I have some further comments on the whole draft of the refraction paper as received from Jacques. Up to p. 9 it is not bad, my comments are mainly about English. In its present form it really falls apart in Sect. 4. I feel that (a) the results should be presented as overlays of theoretical curves on the actual VLA maps – this will not be hard to do as we have all the original maps in house, (b) the figures as presently drawn are almost totally inscrutable, (c) the observed properties of the radio sources should be used to talk about actual pressures that are required before making hopeful comparisons with atmospheres detected in (other) elliptical galaxies, (d) actual collimation data should be used in place of the vague statements on p. 12/13 – either we can use collimation numbers here or we can't (in which case we shouldn't talk about them). The Argue et al. data on the optical image of 3C293 should be given more prominence than ancient remarks based on the Sky Atlas prints by Wills and Parker or finding charts published at low contrast by Wyndham.

I will redraft the latter part of the paper if you wish.

I am still unhappy about the use of very marginal data from the 4-element interferometer regarding the bending of 3C76.1. It is also not clear that the sources are not members of the Zwicky clusters. What is more important is whether they have near neighbours or whether the clusters have significant X-ray haloes. We may be able to get some information on the last point from the X-ray observers. 3C293 does have detected HI line absorption features which may be relevant.

I enclose the 3C293 maps which will be used in [illegible] 2 and 5.

Still some way to go on this I fear

Best wishes

Alan

THE UNIVERSITY OF NEW MEXICO

DEPARTMENT OF PHYSICS AND ASTRONOMY

800 YALE BOULEVARD, N.E.
ALBUQUERQUE, N.M. 87131
TELEPHONE (505) 277-2616

12 Sept 1980

Dear Dick,

I've received two different versions of the "warps" paper, from Jacques and from you. Basically the theory looks nice, but the choice of source to fit is poor. The evidence for the Z shape is based on a very low-resolution map by Ed Fomalont, John Palimaka and I which we were dubious about publishing but showed to Jacques because he was working on the source at the VLA. There are much better sources to do this with — especially 3C293, where Ed and I have VLA maps showing clear S-symmetry and the optical galaxy has misaligned subsystems, 3C310 (van Breugel, A&A. 1980) also should be a candidate as it is the most S-shaped source known. I'll send maps when I'm back at the VLA next week. Will also comment your version.

Enclosed is the JRASC referee's report. I'll fix some small points and send it back to Lloyd. Call me at the VLA (772-4271) if you have specific words you want inserted.

I enclose a preprint received from R.D.B. As it's a draft, please don't circulate it at Stanford or elsewhere, but keep it to yourself.

Cheers,

Alan

INSTITUTE FOR PLASMA RESEARCH
STANFORD UNIVERSITY
VIA CRESPI, STANFORD, CALIFORNIA 94305

Sept 9, 1980

Allan;

Here is the draft of 'Warps' as presently conceived. I thought that writing it up properly was worth the effort after I saw the confused state of the notes that I sent to you (humble apologies!). Please feel free to jump in with suggestions for improvement. I think really that we should do a proper case with collimation data as well, but that may not exist yet? If you do have substantial changes, add your name and send manuscript to Jacques. I'm hoping that he can have it typed at Orsay's. The typing pool around here is good but vastly over worked!

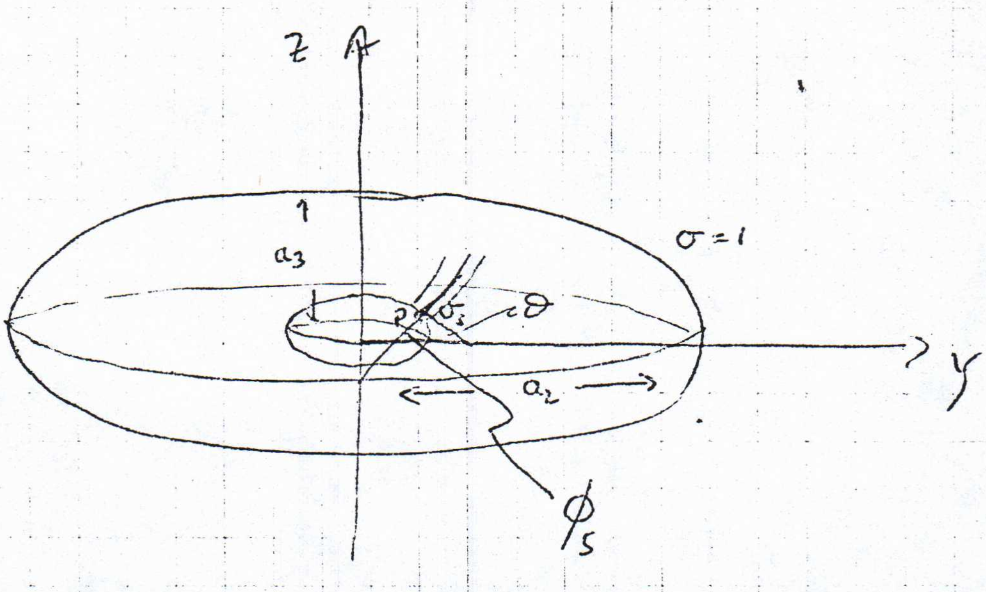
– anyhow, life is good even if money is short. If I don't get a pay cheque soon I'll lose 15 lbs! San Francisco has its delights!

anyhow cheers!

Dick

$$\left\{ \sigma_s = \frac{z_s^2}{a_3^2} + \frac{y_s^2}{a_2^2} \right.$$

pt. $P \equiv (y_s, z_s)$




$$\left\{ \begin{array}{l} z' \equiv \frac{dz}{dy} \\ z'' \equiv \frac{d^2 z}{dy^2} \end{array} \right.$$

$$\left\{ p = p_s \frac{(1 - \sigma_s^{\alpha})}{1 + (p_s/p_{is})(\sigma^{\alpha} - \sigma_s^{\alpha}) - \sigma^{\alpha}} \right. \qquad \left\{ \sigma = \frac{z^2}{a_3^2} + \frac{y^2}{a_2^2} \right.$$

and:

$$(*) \left\{ z'' = -\frac{2\alpha}{(1-\sigma_s^{\alpha})} \left(\frac{p_s}{\rho_s v_z^2}\right) \left(\frac{p_s}{p_{is}} - 1\right) \sigma^{(\alpha-1)} \left(\frac{p}{p_s}\right)^{(2-1/\gamma)} (1 + (z')^2) \left(\frac{y}{a_2^2} z' - \frac{z}{a_3^2}\right) \right.$$

don't try $\alpha \neq 0$ (2 ambiguities)

or:

measure all distances in units of $a_3$

$$z'' a_3 = -\frac{2\alpha}{(1-\sigma_s^{\alpha})} \left(\frac{p_s}{\rho_s v_z^2}\right) \left(\frac{p_s}{p_{is}} - 1\right) \sigma^{(\alpha-1)} \left(\frac{p}{p_s}\right)^{(2-1/\gamma)} (1 + (z')^2) \left( y \frac{a_3^2}{a_2^2} z' - z \right)$$

$$a_3^2 \sigma = z^2 + \frac{a_3^2}{a_2^2} y^2 \quad \text{and} \quad (z')_s \equiv \tan \phi_s$$

try $\alpha = 2$: vary $p_s/p_{is}$, $\frac{p_s}{\rho_s v_z^2}$, $\phi_s$, $z_s, y_s$

N.B. for a slab, put $a_2 \to \infty$

Calculational Summary:

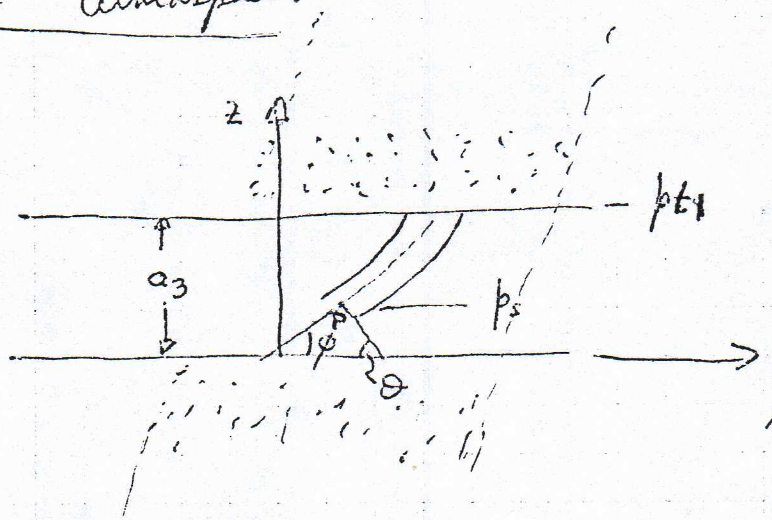
(i) Gravity and magnetic fields are neglected because $V_z^2 \gg c_s^2, c_A^2$

✱ (ii) $V_z$ is taken constant ——— $V_S$ (not COMPONENT ALONG z-AXIS).

1. Spheroidal atmospheres:

See previous sheet

2. Slab atmospheres




$P \equiv (z_s, y_s)$

Then we have an integral:

$$p \equiv p/p_s \quad : \quad \rho \equiv \rho/\rho_s \quad : \quad \rho \equiv p^{1/\gamma}$$

✱ $$\sec^2\phi = \sec^2\phi_s \exp\left\{\left(\frac{2\gamma}{\gamma-1}\right)\frac{p_s}{\rho_s V_z^2}\left(1 - p^{\frac{\gamma-1}{\gamma}}\right)\right\} \qquad \gamma \neq 1$$ ✱

$$\sec^2\phi = \sec^2\phi_s \,(p)^{-\frac{2p_s}{\rho_s V_z^2}} \qquad \gamma = 1, \text{ isothermal}$$

and: ✱ $$\sec^2\phi = 1 + \left(\frac{dz}{dy}\right)^2$$ ✱ $\therefore$ $$z'^a = \left\{\sec^2\phi_s \exp\left[\frac{2\gamma}{\gamma-1}\frac{p_s}{\rho_s V_z^2}\left(1-p^{\frac{\gamma-1}{\gamma}}\right)\right] - 1\right\}^{1/2}$$

$$p = \frac{1 - (z_s/a_3)^{2\alpha}}{1 + \frac{p_s}{p_{t1}}\left(\left(\frac{z}{a_3}\right)^{2\alpha} - \left(\frac{z_s}{a_3}\right)^{2\alpha}\right) - \left(\frac{z}{a_3}\right)^{2\alpha}}$$ for layered slabs

— n sign.

$$1+(z')^2 = \sec^2\phi_s \exp\left\{\left(\frac{\gamma}{\gamma-1}\right)\frac{2p_s}{\rho_s V_z^2}\left(1-\left(\frac{p}{p_s}\right)^{(1-1/\gamma)}\right)\right\}$$

$$2\,z'' = -\sec^2\phi_s \exp\left\{\left(\frac{\gamma}{\gamma-1}\right)\frac{2p_s}{\rho_s V_z^2}\left(1-\left(\frac{p}{p_s}\right)^{(1-1/\gamma)}\right)\right\}$$

$$\times \frac{\gamma}{\gamma-1}\cdot\frac{2p_s}{\rho_s V_z^2}\cdot\left(\frac{\gamma-1}{\gamma}\right)\left(\frac{p}{p_s}\right)^{-1/\gamma}\frac{d(p/p_s)}{dz}$$

$$= -\left(1+z'^2\right)\cdot\frac{2p_s}{\rho_s V_z^2}\left(\frac{p}{p_s}\right)^{-1/\gamma}\frac{d(p/p_s)}{dz}$$

(to write in FORTRAN)

$$\therefore \quad \rightarrow \quad \boxed{z'' = -(1+z'^2)\left(\frac{p_s}{\rho_s V_z^2}\right)\left(\frac{p}{p_s}\right)^{-1/\gamma}\frac{d(p/p_s)}{dz}}$$

where

$$\boxed{\frac{p}{p_s} = \frac{f}{1+(f-1)\left(\frac{z}{z_s}\right)^m} + \frac{\left(1-e^{-z_s/z}\left(\frac{z_e}{z_s}\right)^{-m}\right)}{1+(z/H)^{m'}}\left(\frac{f}{f-1}\right)}$$

– all lengths in units of $z_s$, $p = p/p_s$

$$\frac{d(p/p_s)}{dz} = -\frac{f}{f-1}\left\{\frac{m(f-1)^2\left(\frac{z}{z_s}\right)^{m-1}}{z_s\left[1+(f-1)\left(\frac{z}{z_s}\right)^m\right]^2} + \frac{\left(1-e^{-z_s/z}\right)\left(\frac{z_e}{z_s}\right)^{-m}}{\left[1+(z/H)^{m'}\right]^2}\,(m'/H)\,(z/H)^{(m'-1)}\right.$$

$$\left. - \frac{z_s\, z^{-2}\left(\frac{z_e}{z_s}\right)^{-m}}{\left[1+(z/H)^{m'}\right]}\right\} \quad *$$

*

**or**

$$p/\rho_s = \frac{f}{1+(f-1)\left(\frac{z}{z_s}\right)^{m}} + \frac{(1-\tfrac{1}{2}|?|)\left(\frac{z_e}{?}\right)^{-m}}{1+\left(\frac{z}{H}\right)^{m'}}\left(\frac{f}{(f-1)}\right)$$

CH two power law soln ~ (an <u>internal</u> $\gamma$)

– $f \equiv \left(\frac{\gamma+1}{2}\right)^{\left(\frac{\gamma}{\gamma-1}\right)}$

$\gamma \neq 1$

$\to \gamma = 4/3$ here

$\therefore f = \left(\frac{7}{6}\right)^4$

**or!**

Sum of exponentials with different amplitudes and scale heights.

IGNORE

X

e.g. $p = A_1 e^{-z/h_1} + A_2 e^{-z/h_2}$

$= e^{\frac{z_s - z}{h_1}} + A\, e^{-z/h_2}$ say

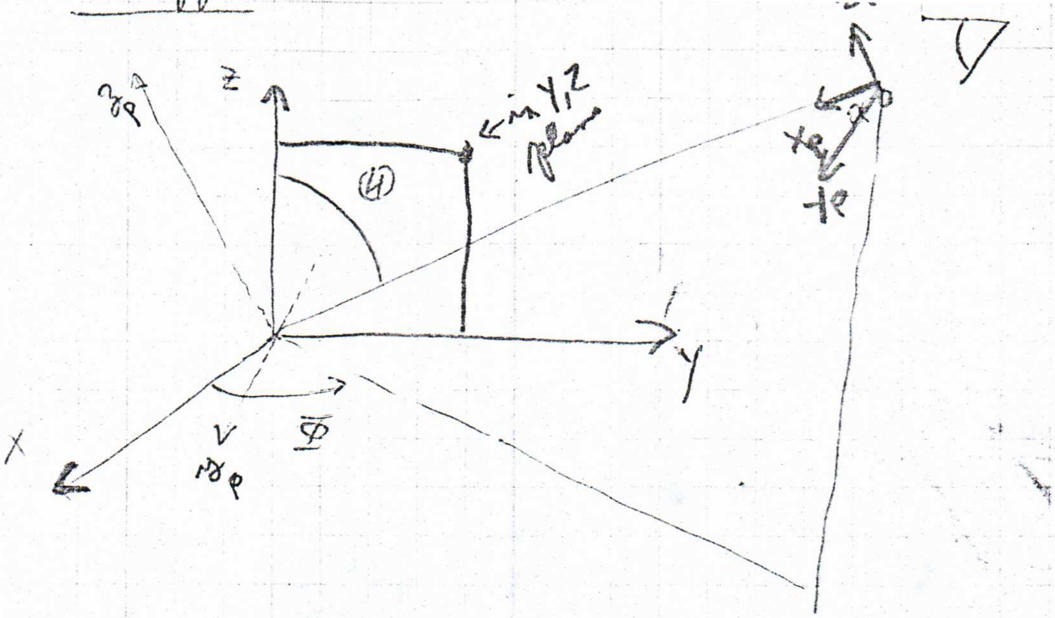
with two terms equal at $z_e$

$$A = e^{z_e/h_2} \cdot e^{\frac{z_s - z_e}{h_1}}$$

$$= e^{z_s/h_1 + z_e\left(\frac{1}{h_2} - \frac{1}{h_1}\right)}$$

$$\therefore p = e^{\frac{z_s - z}{h_1}} + e^{\frac{z_s - z_e}{h_1}} \cdot e^{\frac{z_e - z}{h_2}}$$

we expect: $z_e > h_1$, $h_2 > h_1$




given: $Z(Y)$ what is $z(y)$ ?

$(Z, Y)$ $(z, y)$

Clearly:

$$z = Z\sin\Theta - X\cos\Phi\cos\Theta - Y\sin\Phi\cos\Theta \qquad (X \to 0)$$

$$z = Z\sin\Theta - Y\sin\Phi\cos\Theta$$

and

$$y = -Y\cos\Phi$$

$$y_p = m_2 y + n_2 z \qquad y_p = -y\cos\phi + 0\cdot z$$

$$z_p = m_3 y + n_3 z \qquad z_p = -y\cos\theta\sin\phi + \sin\theta\cdot z$$

| | |
|---|---|
| $l_2 = \hat{y}_p\cdot\hat{x}_p$ | $l_3 = \hat{z}'_p\cdot\hat{x}$ |
| $m_2 = \hat{y}_p\cdot\hat{y}$ | $m_3 = \hat{z}'_p\cdot\hat{y}$ |
| $n_2 = \hat{y}_p\cdot\hat{z}$ | $n_3 = \hat{z}'_p\cdot\hat{z}$ |

now write in Fortran