Aust. J. Phys., 1991, **44**, 565–71

Enhanced Radio Source Scintillation due to Comet Austin (1989c1)

P. Janardhan, S. K. Alurkar, A. D. Bobra and O. B. Slee[A]

Physical Research Laboratory, Navrangpura,
Ahmedabad 380 009, India.
[A] Australia Telescope National Facility, CSIRO,
P.O. Box 76, Epping, N.S.W. 2121, Australia.

Abstract

Enhanced scintillations in the direction of the quasar 2204+29 (3C441) were observed on 13 May 1990 when the tail of Comet Austin passed in front of it. Comparison with previous observations at 103, 327 and 408 MHz of Comet Halley and at 408 MHz of Comet Wilson show that proper occultation geometry is essential for observing enhanced scintillations. It has been shown that the solar elongation ϵ during such observations should be large, typically greater than 60° and in no case less than 30° at 103 MHz. At the time of the occultation the scintillation index (r.m.s./mean source flux) was greater than that expected for this source by a factor of 3. The r.m.s. electron density variation ΔN, at a distance of $0 \cdot 9$ A.U. from the sun and $7 \cdot 3°$ downstream of the nucleus, was found to be $6\ \mathrm{cm}^{-3}$ as compared with $1\ \mathrm{cm}^{-3}$ for the normal solar wind at 1 A.U. The corresponding scale sizes of the turbulence were found to be much finer than normally found in interplanetary scintillation (IPS) caused by the solar wind.

1. Introduction

The question of whether cometary plasma contained in the tail of a comet can cause radio scintillations has been addressed several times, with positive results being reported in some cases (Ananthakrishnan *et al.* 1975; Alurkar *et al.* 1986; Slee *et al.* 1986) and negative results in others (Ananthakrishnan *et al.* 1987; Hajivassiliou and Duffett-Smith 1987). Recently, it has been shown conclusively (Slee *et al.* 1990) that cometary plasma can contain a higher level of turbulence than the normal solar wind and give rise to enhanced scintillations. The importance of occulting geometry and control sources was first pointed out in the correspondence section of *Nature* by Alurkar *et al.* (1989*a*) and Ananthakrishnan *et al.* (1989).

The observation of Comet Austin in May 1990 has again confirmed the importance of having the proper occulting geometry, i.e. solar elongations ϵ in excess of 60°, otherwise meaningful enhancements are not observable due to the proximity to the sun which causes normal solar-wind IPS to dominate and swamp any enhancements due to the comet. The observations on Comet Austin have also confirmed the existence of finer scale sizes of turbulence in the tail than expected in the normal solar wind.

0004-9506/91/050565$05.00

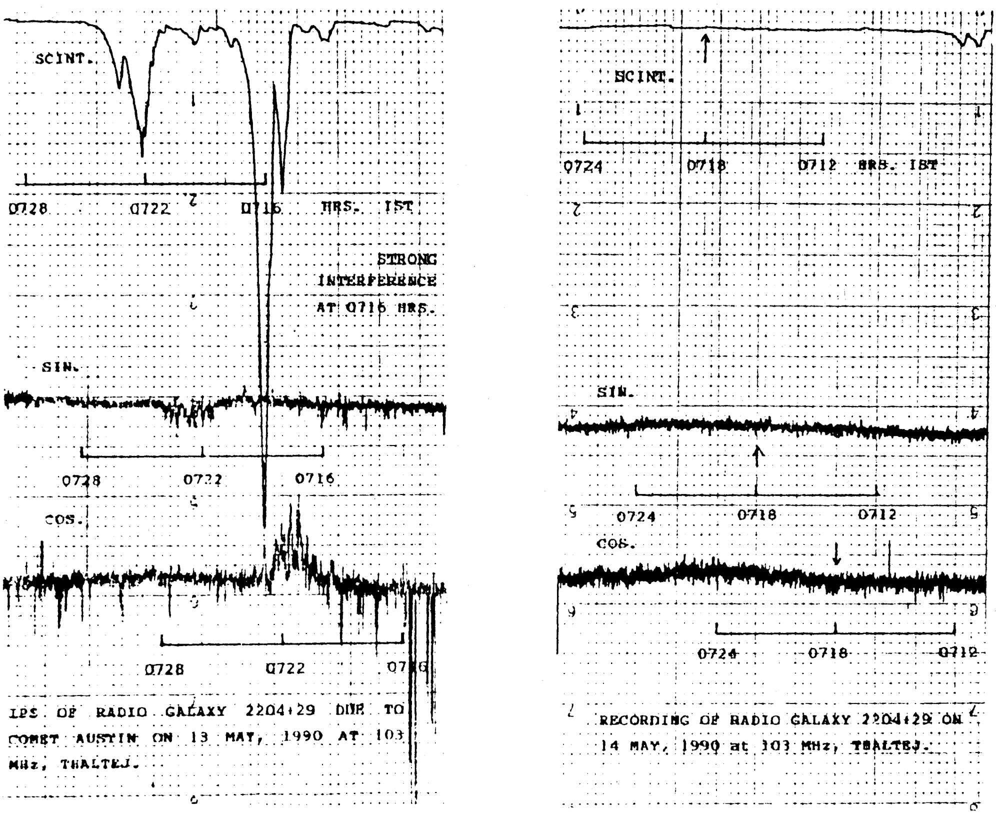

Fig. 1. The 103 MHz recordings of enhanced scintillations of 3C441 during occultation by Comet Austin on 13 May (left) and also on a control day 14 May 1990.

2. Observations and Results

The observations were made with a dipole array of area 20 000 m^2 operating at 103 MHz. This antenna is a filled aperture phased array, comprising 4096 full wave dipoles polarised horizontally in the NS direction. The two north and south halves of the array form a correlation-type interferometer observing sources at meridian transit. The 32 beams formed by the array, using a beam forming network called the Butler matrix, are deployed in declination and are each $1\cdot8°$ NS$\times1\cdot8°$ EW and cover $\pm30°$ of declination centred on the zenith. A pair of identical beams is connected, during each observation, to a correlation-type receiver which yields sine and cosine quadrature outputs. The rapidly changing intensity fluctuations are picked up by a device called a scintillometer whose output is proportional to the square of the scintillating flux of the source. A full description of the system can be found in Alurkar *et al.* (1989*b*).

The occulted source declination was such that its position was between the third and fourth northern beams of the array. The observations were thus made after combining the responses of these two beams by using a T-connector with good isolation and equal lengths of cable to add the adjacent Butler matrix outputs. The beamwidth for this observation was therefore $3\cdot6°$ NS$\times1\cdot8°$EW. Fig. 1 shows the actual chart recordings of the occulted source on 13 and 14

May 1990. The source was monitored continuously for about two weeks prior to and after the occultation and, except for the date of the occultation, it did not show detectable scintillations. The source 0038+33 (3C19) was the closest scintillating source to 2204+29 and was monitored as a control source. Several other scintillating sources, namely CTA21, 3C42, 3C48, 3C123, 3C144, 3C161 and 3C196, which were observed regularly and were lying in the declination range −5° to 33° also did not show enhanced scintillation during the period under consideration. It has been shown (Hewish *et al.* 1985) that large scale interplanetary transients typically cover a solid angle of $\pi/2$ sr in heliographic latitude and longitude. They also showed a strong correlation between the total plasma density along the line of sight to a source and enhancement in scintillation. Thus, the enhancement observed only in the direction of the occulted source rules out the presence of a large scale transient.

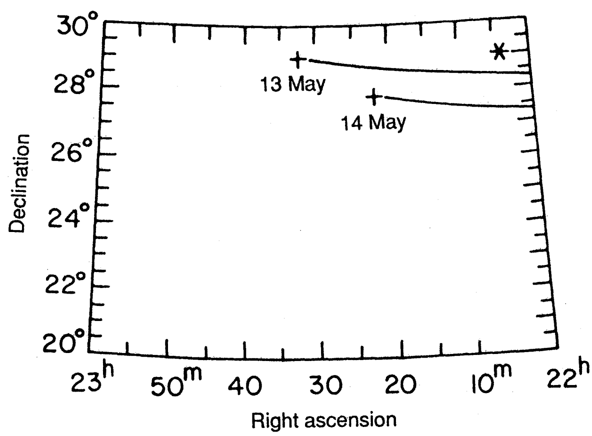

Fig. 2. Path of cometary nucleus as projected on the sky. The asterisk shows the position of 3C441, while the crosses give the nuclear positions at Ahmedabad transit on 13 and 14 May 1990. The lines indicate the approximate direction of the cometary axis.

Fig. 2 shows the path of the cometary nucleus projected onto the plane of the sky; the crosses are the nuclear positions at Ahmedabad transit on the two days including the occultation date of 13 May. The lines indicate the approximate directions along which the cometary tail axis would lie. These directions include a small correction of +3° to the azimuth of the anti-solar vector to account for the so-called 'tail-lag', which is caused by the interaction of the comet's velocity with the radially directed solar wind. The ephemeris for the comet is that published in IAU Circular No. 4985 (March 27, 1990).

Ideally, we require a wide-angle blue-sensitive photograph of the comet within a few hours of the radio observation in order to define the position angle of the tail axis, about which the densest part of the plasma should be concentrated. It is clear that an accurate value for the tail-lag is needed to define the position of the radio source with respect to the tail axis. If the tail-lag were as much as +5°, then the source would be shining through the densest plasma on the axis. If the tail-lag were zero, then the source would be 5° off-axis during the observation, for which one may expect scintillation effects to be significantly reduced.

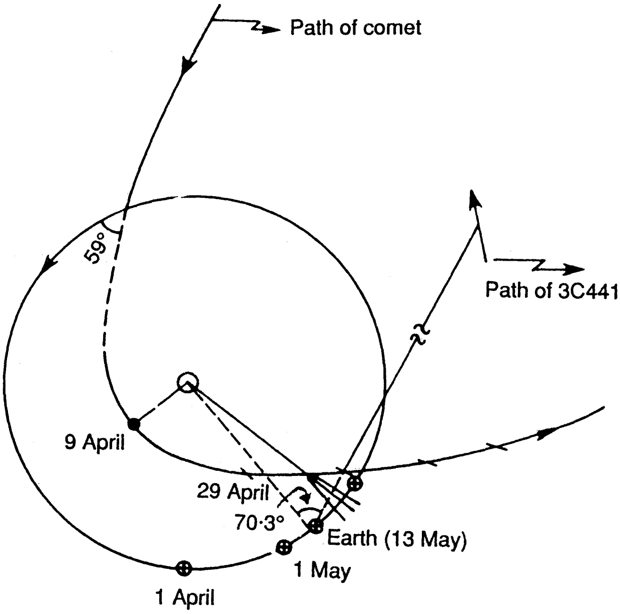

Fig. 3. Occultation geometry showing relative positions of the sun, earth and Comet Austin in May 1990.

Fig. 3 shows the relative positions of the sun, earth and Comet Austin during the observations at 103 MHz, while Table 1 gives the solar elongations for various observations. It can be seen that in all observations where the occulting geometry has been favourable, i.e. for ϵ in excess of 60°, a positive result has been reported. During the first reported observations of enhancements in scintillation (Ananthakrishnan *et al.* 1975), the solar elongation was only 20° but at 327 MHz this elongation is well into the region where weak interplanetary scattering prevails.

Table 2 gives the parameters of the comet, while Table 3 gives the occulted and control source parameters along with the calculated scintillation index for different days and the corresponding scintillation index expected from the RKH model (Readhead *et al.* 1978). It can be seen that the scintillation index m of 0·43 on 13 May for the source 2204+29 is greater by a factor of 3 than that expected from the RKH model, which gives $m = 0 \cdot 14$. The scintillation indices were calculated from the chart recordings of the sine, cosine and scintillometer outputs following the calibration procedure suggested by Duffett-Smith (1976), after first correcting the sine and cosine channels for the effects of automatic gain control used in the system.

To check the possibility that at least some of the intensity variations may be due to ionospheric scintillation of the radio source, the ionospheric conditions were monitored with an ionosonde at PRL, Ahmedabad. The ionograms taken during the time of transit of the source showed no spread-F or sporadic-E echoes, both of which have been correlated with ionospheric radio scintillations.

Table 1. Occulted source elongations for different events

Date	Frequency (MHz)	Comet	Occulted source (R.A. & Dec. 1950)	ϵ (deg.)	Result
05/01/74	327	Kohoutek	2025–150	20·0	Positive
18/12/85	103	Halley	2314+038	86·5	Positive
11/02/86	327	Halley	2052–106	11·2	Negative
29/03/86	408	Halley	1827–360	86·0	Positive
01/05/87	408	Wilson	0606–795	92·8	Positive
02/05/87	408	Wilson	0637–752	93·0	Positive
13/05/90	103	Austin	2204+292	70·3	Positive

Table 2. Comet parameters

Date at 1400 UT	N. coord.[A] (R.A. & Dec.)	Distance (A.U.) T. centric	H. centric	ϵ (deg.)	PA of tail[B] (deg.)
12 May	22 42·2+30 00·44	0·3597	0·9020	62·4	268·3
13 May	22 32·4+28 57·38	0·3443	0·9221	65·4	266·0
14 May	22 22·0+27 45·74	0·3296	0·9420	68·6	263·7

[A] Coordinates are those of the comet nucleus.
[B] Position angles of the tail are given at 0200 UT. The transit time of the source was 0152 UT.

Table 3. Occulted and control source parameters

Source	Approx. coord. (1950)	Date (1990)	ϵ (deg.)	Scintillation index Observations	RKH model	Source diam.[A] (arcsec)
3C441[B]	2204+29	13/05	70·3	0·43	0·14	1·0
3C19	0038+33	12/05	37·0	0·16	0·18	0·8
		14/05	38·0	0·17	0·18	0·8
3C42	0126+30	12/05	26·0	0·16	0·14	1·2
3C123	0434+30	12/05	24·0	0·18	0·22	0·8

[A] Equivalent gaussian diameter (Readhead and Hewish 1974).
[B] Occulted source.

The geomagnetic planetary index, another indicator of fine ionisation structure in the ionosphere, was very low to moderate throughout 13 May. Finally, solar activity which influences both the ionosphere and solar wind velocity and structure was low to moderate during the week preceding and including the occultation date.

For making a quantitative estimate of the electron content in the plasma turbules contained in the tail, the power spectrum of intensity variations of the source was taken using the data around the transit time. Fig. 4 shows the spectrum of 3C441, where the values have been normalised to the highest spectral density. On the assumption that the thin screen scattering theory of Salpeter (1967) is valid for these observations, the scale sizes of the turbulence can be calculated. The scale size is given by $a = v/2\pi f_2$, where v is the velocity of the diffraction pattern across the observer and f_2 is the width of the scintillating power spectrum at the exp(−0·5) points. The width f_2 was found to be 0·923 Hz, as can be seen from Fig. 4. Assuming that the plasma at this point in the tail has not yet been accelerated to typical solar-wind velocities, we can assign a velocity of $v = 100\ \mathrm{km\,s^{-1}}$ (Jockers 1981). Thus,

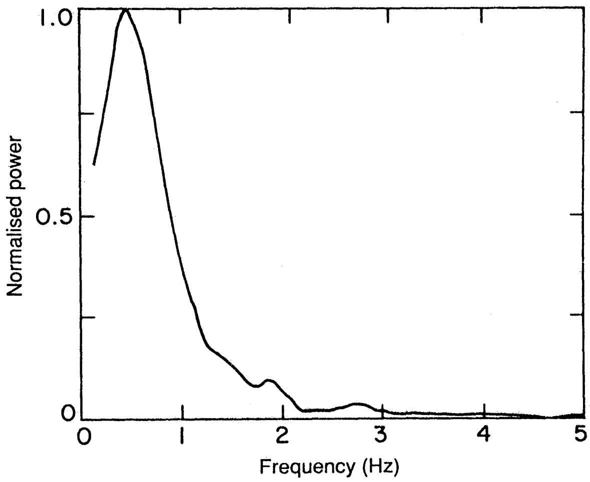

Fig. 4. Normalised power spectrum of enhanced scintillations of 3C441 caused by the ion tail of Comet Austin on 13 May 1990.

the scale size is $a = 17$ km, a much finer scale of turbulence than the typical values of 100–1000 km for IPS in the normal solar wind. If the occultation were to take place at the edge of the tail, where the tail plasma merges with the solar wind, then one can expect the velocities to approach that of the normal solar wind, i.e. around 400 km s^{-1}. This would give a scale size $a = 68$ km, which is also a much finer scale than expected.

Table 4. Estimated scale sizes and ΔN in the tail of Comet Austin

Velocity (km s^{-1})	Scale size (km)	ΔN (cm^{-3})	References
25	4	11	Scherb *et al.* (1990)
100	17	6	Jockers (1981)
400	68	3	Av. solar wind velocity

For a gaussian electron density correlation function, the r.m.s. phase deviation imposed across a wavefront emerging from a thin screen containing plasma turbulence is given by

$$\phi = (2\pi)^{1/4} r_e \lambda (aL)^{1/2} \Delta N,$$

where $r_e = 2 \cdot 82 \times 10^{-13}$ cm is the classical electron radius, $\lambda = 291$ cm is the operating wavelength, $a = 17 \times 10^5$ cm is the scale size, $L = 10^{11}$ cm is the thickness of the screen assumed (Jockers 1981) and ΔN is the r.m.s. electron density deviation. For weak scattering, the scintillation index is given by $m = \sqrt{2}\,\phi$. In the present case $m = 0 \cdot 43$, so $\phi = 0 \cdot 304$ rad, and thus we get $\Delta N \approx 6$ cm^{-3}. If the mean density in the tail is taken to be 100 ions cm^{-3} (Schmidt and Wegmann 1982), then this value corresponds to a 6% modulation in the ion density at a distance of about 1 A.U., while the normal solar wind shows about 4% modulation around $0 \cdot 1$ A.U. Table 4 shows the scale sizes and r.m.s. electron density deviations obtained assuming different velocities for the diffraction pattern. All scale sizes obtained lie in the range 4–70 km which are much finer than those of IPS from the solar wind.

3. Discussion and Conclusions

Since the occultation of the source took place only on one day, it was not possible to see if there was a gradient of scale sizes as one moved away from the axis of the comet. Nevertheless, our value of 17 km for the scale sizes 2° from the tail axis is in good agreement with the observations of Comet Wilson by Slee *et al.* (1990). Since no photographs of the comet are available around this period, an accurate estimate of the tail-lag, opening angle and thickness is not possible. It is possible that the actual tail-lag was much larger than the assumed 3°, thus bringing the point of occultation much closer to the axis. A re-analysis of Halley's comet data (Alurker *et al.* 1986), taking into account the tail-lag, is being carried out in view of the new results obtained during the observations of Comet Wilson (Slee *et al.* 1990) and the present observations of Comet Austin.

With regard to the accuracies of the values of a and ΔN, it is apparent from Table 4 that the velocity of the plasma is not known to better than a factor of 4, causing scale sizes to have the same inaccuracy. This would in turn lead to a variation in ΔN by a factor of 2. This may become worse when the error in L is also taken into consideration.

Acknowledgments

We thank the staff of the Radio Astronomy and Ionospheric groups at the PRL for their assistance. We also thank Dr Ashok Ambastha and Dr A. Bhatanagar for their help and suggestions. Financial support for this work came from the Department of Space and the Department of Science & Technology, Govt of India.

References

Alurkar, S. K., Bhonsle, R. V., and Sharma, A. K. (1986). *Nature* **322**, 439–41.
Alurkar, S. K., Sharma, A. K., Janardhan, P., and Bhonsle, R. V. (1989*a*). *Nature* **388**, 211–12.
Alurkar, S. K., Bobra, A. D., Nirman, N. S., Venat, P., and Janardhan, P. (1989*b*). *Ind. J. Pure Appl. Phys.* **27**, 322–30.
Ananthakrishnan, S., Bhandari, S. M., and Rao, A. P. (1975). *Astrophys. Space Sci.* **37**, 275–82.
Ananthakrishnan, S., Manoharan, P. K., and Venugopal, V. R. (1987). *Nature* **329**, 698–700.
Ananthakrishnan, S., Manoharan, P. K., and Venugopal, V. R. (1989). *Nature* **338**, 212.
Duffett-Smith, P. J. (1976). Ph.D. Thesis, Univ. of Cambridge.
Hajivassiliou, C. A., and Duffett-Smith, P. J. (1987). *Mon. Not. R. Astron. Soc.* **229**, 485–93.
Hewish, A., Tappin, S. J., and Gapper, G. R. (1985). *Nature* **314**, 137–40.
Jockers, K. (1981). *Icarus* **47**, 397–411.
Readhead, A. C. S., and Hewish, A. (1974). *Mem. R. Astron. Soc.* **78**, 1–49.
Readhead, A. C. S., Kemp, M. C., and Hewish, A. (1978). *Mon. Not. R. Astron. Soc.* **185**, 207–25.
Salpeter, E. E. (1967). *Astrophys. J.* **147**, 433–48.
Scherb, F., Magee-Sauer, K., Roesler, F. L., and Harlander, J. (1990). *Icarus* **86**, 172–88.
Schmidt, H. U., and Wegmann, R. (1982). *In* 'Comets' (Ed. L. L. Wilkening), pp. 538–60 (Univ. Arizona Press).
Slee, O. B., McConnel, D., Lim, J., and Bobra, A. D. (1986). *Nature* **325**, 699–701.
Slee, O. B., Bobra, A. D., Waldron, D., and Lim, J. (1990). *Aust. J. Phys.* **43**, 801–11.

Manuscript received 5 April, accepted 5 July 1991