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VLBI Observations of the Quasar DA 193

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Summary. The structure of DA 193 has been studied at 10.65 GHz using the U.S. *VLBI* network and the Effelsberg radiotelescope. It is a core-halo source, most of the flux coming from a region less than one milli-arc s (3 pc) in extent. The shape of the observed radio continuum spectrum can be closely reproduced using this structure and simple assumptions involving only synchrotron self-absorption; any other mechanisms which can influence the spectrum are therefore probably not significant in this source.

Key words: radio spectra – quasars – *VLBI*

Introduction

DA 193 is a powerful high-frequency radio source, identified optically with an 18th magnitude quasar (Ross, 1972; Edwards et al., 1975) at a redshift of 2.365 (Wills and Wills, 1976; Wills, 1980). The radio spectrum has a pronounced turnover at ~ 5 GHz, and the polarization is low ($\lesssim 1\%$, Berge and Seielstad, 1972; Altschuler and Wardle, 1976).

This source has become of special interest lately because of the possible detection by Bell and Seaquist (reported by Bell, 1980) of broad absorption features in its spectrum, attributed to radio recombination lines. If real, these lines probably originate in ionized gas located along the line of sight to the radio nucleus. This then raises the possibility that the turnover in the radio continuum spectrum may be due to free-free absorption in the same ionized gas; the low degree of linear polarization, which would be due to beam Faraday depolarization in line-of-sight ionized gas, lends some support to this interpretation.

We have made *VLBI* observations of DA 193 in order to determine whether the structure of the source provides any further support for the free-free absorption mechanism. If the turnover is due to synchrotron self-absorption, then the brightness temperature of the source is likely to be in the range 10^{11}–10^{12} K, and the angular size less than a few milli arc s. If, however, the turnover is due to free-free absorption, the brightness temperature may be considerably less than that, and the angular size greater. Any structural information, particularly evidence relating to the free-free absorption hypothesis, would obviously be useful in interpreting the recombination line data. And as it is generally assumed that the structure in radio source spectra is due to synchrotron self-absorption, evidence of free-free absorption in at least one case would be important.

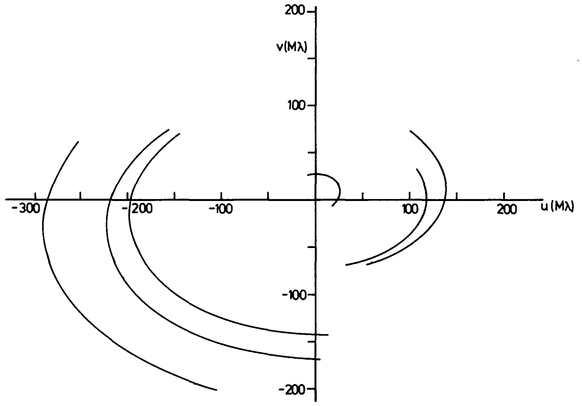

Fig. 1. The diurnal tracks for the six interferometers in the (U, V) plane. The units of U and V are in millions of wavelengths

Table 1. Elements of the interferomter

Antenna	Diameter (m)	System noise temperature (K)	Sensitivity (K/Jy)
Effelsberg	100	75	1.25
Haystack	37	90	0.13
NRAO	43	130	0.26
OVRO	40	60	0.19

Observations

DA 193 [$05^{\mathrm{h}}52^{\mathrm{m}}01^{\mathrm{s}}.41$, $39^\circ48'21''.9$ (1950.0)] was observed at 10.65 GHz on June 10/11, 1979 with a four station interferometer whose elements were the Effelsberg 100 m, the Haystack 37 m, the NRAO 43 m and the OVRO 40 m telescopes. Relevant characteristics of the telescopes are given in Table 1, and the U–V tracks of the interferometer system are illustrated in Fig. 1. The polarization was left circular on the sky. Data were accumulated for periods ranging from 6 to 12 h depending on the baseline. The recording of the signals was carried out with the standard MkII *VLBI* system with a bandwidth of 2 MHz and the subsequent cross correlations were performed at the Max Planck Institut für Radioastronomie in Bonn. Hydrogen maser oscillators at all stations provided the time and frequency standards.

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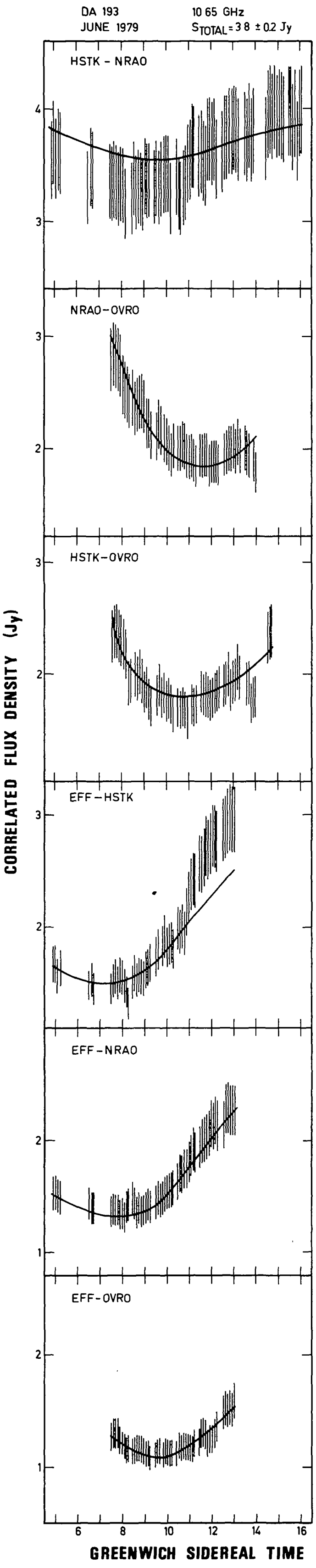

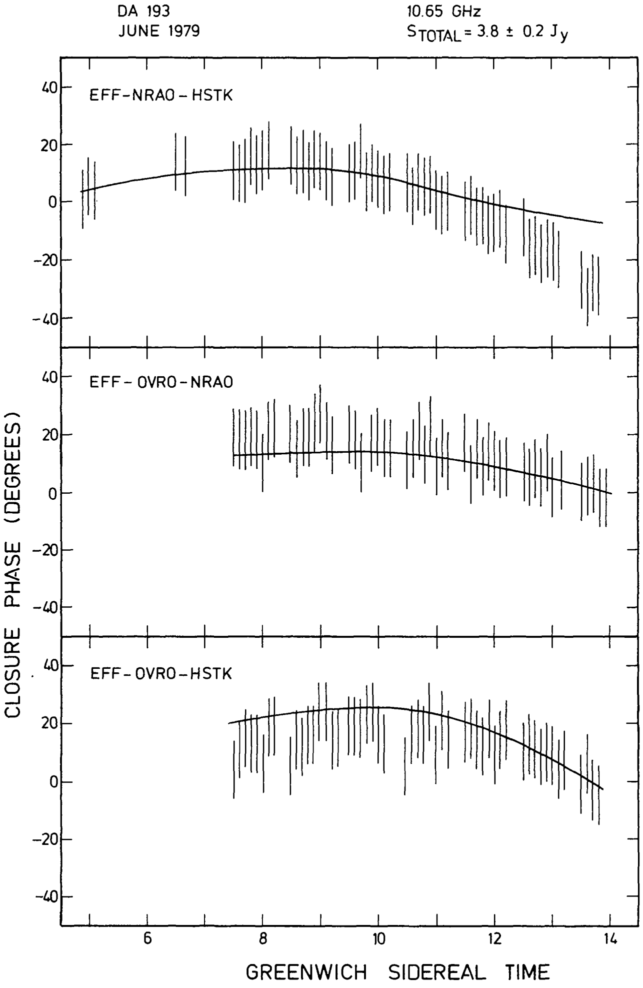

Fig. 2. Fringe amplitudes for the individual baselines and closure phases for three independent triangles. The error bars are 2σ in length, and the curves are from the model shown in Fig. 3

Standard calibration of the visibility amplitudes (Cohen et al., 1975) was made; the estimated errors are $\pm 10\%$. Errors in closure phase are estimated to be $\pm 10°$. Plots of the visibility amplitudes and closure phases are shown in Fig. 2.

These data were used in an iterative procedure (Pauliny-Toth et al., 1976) to derive the source brightness distribution. A preliminary model of the structure consisting of an unresolved core component and an extended halo component was derived by inspection of the visibility amplitude data. This model was decomposed into a grid of point sources spaced 0.1 milli arc s apart. The amplitude at each grid point was then varied iteratively to reduce the r.m.s. deviations between the observed visibility amplitudes and closure phases, and those of the model. The final grid was smoothed with a Gaussian beam of 0.3 milli arc s at FWHM [or 0.44 $(\lambda/_D)_{\min}$]. The contour map corresponding to this grid is shown in Fig. 3, and the fit of the unsmoothed model to the data is shown in Fig. 2. A similar result was achieved when the iterative procedure was used with the visibility amplitudes alone.

The fit to the data is within the errors with the exception of the last two hours on the MPI-Haystack baseline, where some of the flux on the scale of 0.5 to 1 milli arc s is not properly accounted for.

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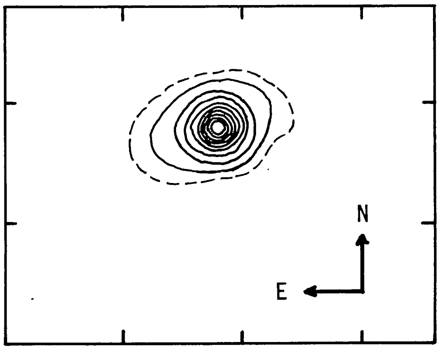

Fig. 3. Model of DA193 obtained from the *VLBI* observations and smoothed with a 0.3 milli arc s beam. Contours are 5% (dashed), 10, 20, ... 100% of the peak brightness temperature, which is 1.8 10^{11} K. The tick marks are spaced by 1 milli arc s

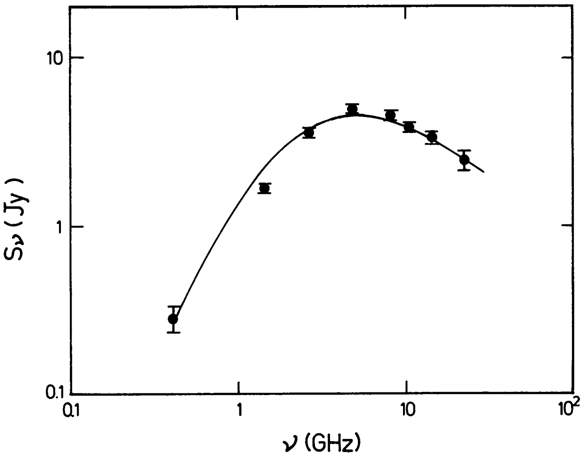

Fig. 4. Radio continuum spectrum of DA193. The observed flux densities are from Table 2. The curve was derived from the present *VLBI* observations, as described in the text

Table 2. Flux densities of DA193

ν(GHz)	S_ν(Jy)	Ref.
0.41	0.28 ± 0.05	1
1.41	1.62 ± 0.03	2
1.47	1.62 ± 0.08	3
2.70	3.48 ± 0.09	4
4.89	4.92 ± 0.04	3
8.10	4.56 ± 0.28	4
10.6	3.80 ± 0.20	5
14.8	3.2 ± 0.2	3
22.5	2.4 ± 0.3	3

1. Colla et al. (1973)
2. Willis (unpublished Westerbork observations)
3. Perley and Fomalont (unpublished *VLA* observations)*
4. Altschuler and Wardle (1977)
5. Present observations

* These fluxes are from the *VLA* calibrator list (version 31, January, 1979) kindly provided by Dr K. Johnston. Each value is an average of several measurements, and the errors are the standard deviations in each set

Discussion

These observations reveal that DA 193 has a simple core-halo structure. There is no evidence of the marked asymmetric jet structure seen in many nuclear radio sources (Readhead et al., 1979; Readhead and Wilkinson, 1980), although it is possible that in DA193 the jet is seen end-on. The major axis of the halo has a position angle of ~110°; this is similar to the position angle of linear polarization in DA 193, ~80°–115° (Berge and Seielstad, 1972; Altschuler and Wardle, 1977), but Altschuler and Wardle have found from a statistical sample that these quantities are generally unrelated.

At this frequency most of the flux of DA193 (~3.3 Jy) originates within the 1 milli arc s halo (3 pc, at a redshift of 2.365 with $H_0 = 75$ km s^{-1} Mpc^{-1} and $q_0 = 1/2$), and the remaining 0.5 Jy comes from the unresolved core (<1 pc). The corresponding brightness temperatures of the components are in the region of 10^{11} K, indicating that synchrotron self-absorption can probably account for the turnover in the continuum spectrum.

To explore this matter somewhat further, we have computed the integrated spectrum of DA193 using the model obtained from the *VLBI* measurements and the simplest possible assumptions: a constant maximum brightness temperature of 10^{12} K and a constant high-frequency spectral index of -0.7 over the entire source. Spectra were computed point by point from

$$S\alpha\nu^{2.5}\,[1-\exp\{-(\nu/\nu_0)\alpha^{-5/2}\}]$$

(cf. Kellermann, 1966), and then summed to produce the integrated spectrum. α is the high-frequency spectral index and ν_0 is the frequency at which the optical depth is unity, calculated from

$$\nu_0 = \nu_1 \left[\frac{T_1}{10^{12}}\right]^{1/(2-\alpha)} \text{GHz},$$

where T_1 is the brightness temperature measured at a grid point, and $\nu_1 = 10.65$ GHz. The resulting spectrum is shown in Fig. 4; it matches the shape of the observed spectrum reasonably well, and a better fit could obviously be obtained with more sophisticated assumptions.

It would therefore appear that synchrotron self-absorption is the dominant mechanism affecting the *entire* spectrum at least down to 0.4 GHz. If free-free absorption is not significant even at 0.4 GHz, the emission measure of any line-of-sight ionized gas must be less than $\sim 10^6\,(T_e/10^4)^{3/2}$ pc cm^{-6}.

The shape of the observed spectrum is, in itself, not an argument against free-free absorption. Even a random distribution of line-of-sight ionized gas can produce a fairly gentle turnover as observed, depending on the filling factor and distribution of cloud sizes (Shaver, 1981). But if free-free absorption were responsible for the turnover in the spectrum of DA193, the peak brightness temperature would have to be in excess of 10^{12} K, and the agreement between calculated and observed spectra in Fig. 4 would have to be coincidental. At the very least, therefore, these *VLBI* observations do not support an interpretation in terms of free-free absorption.

Assuming that the core and halo of DA193 are uniform synchrotron self-absorbed components, it seems likely that it is self absorption in the halo that causes the peak in the spectrum at 5 GHz. The corresponding magnetic field can be estimated from

$$B = 2.5\;10^{-5}\,\frac{\nu^5\theta^4}{S^2(1+z)} \quad \text{Gauss}$$

where ν is the frequency (in GHz) of the peak flux density S (in Jy) of a component of diameter θ (in milli arc s) for a source of redshift z (Terrell, 1966). The resulting value of B for the halo component is $\sim 10^{-3}$ Gauss.

The calculated equipartition magnetic field (e.g. Kellermann, 1974) for this component is ~ 0.1 Gauss. It thus seems likely that particle energy dominates the energetics of the halo, and that expansion of the structure could be expected.

On the other hand the core probably peaks in flux density at a frequency considerably in excess of 20 GHz and thus may have a magnetic field closer in value to the equipartition field (Shaffer et al., 1977). Such a field may be sufficiently strong to contain the particles in what would be the early stages of evolution of the core component. *VLBI* observations at 6 and 1.3 cm will be required to further delineate the spectrum of this component.

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References

Altschuler, D.R., Wardle, J.F.C.: 1976, *Mem. Roy. Astron. Soc.* **82**, 1

Altschuler, D.R., Wardle, J.F.C.: 1977, *Monthly Notices Roy. Astron. Soc.* **179**, 153

Bell, M.B.: 1980, in *Radio Recombination Lines*, ed. P. A. Shaver, Reidel, Dordrecht, p. 259

Berge, G.L., Seielstad, G.A.: 1972, *Astron. J.* **77**, 810

Cohen, M.H., Moffet, A.T., Romney, J.D., Schilizzi, R.T., Shaffer, D.B., Kellermann, K.I., Purcell, G.H., Grove, G., Swenson, G.W., Yen, J.L., Pauliny-Toth, I.I.K., Preuss, E., Witzel, A., Graham, D.: 1975, *Astrophys. J.* **201**, 249

Colla, G., Fanti, C., Fanti, R., Ficarra, A., Formiggini, L., Gandolfi, E., Gioia, I., Lari, C., Marano, B., Padrielli, L., Tomasi, P.: 1973, *Astron. Astrophys. Suppl.* **11**, 291

Edwards, T., Kronberg, P.P., Menard, G.: 1975, *Astron. J.* **80**, 1005

Kellermann, K.I.: 1966, *Australian J. Phys.* **19**, 195

Kellermann, K.I.: 1974, in *Galactic and Extra-Galactic Radio Astronomy*, ed. G. L. Verschuur and K. I. Kellermann, Springer-Verlag, New York, p. 320

Pauliny-Toth, I.I.K., Preuss, E., Witzel, A., Kellermann, K.I., Shaffer, D.B., Purcell, G.H., Grove, G.W., Jones, D.L., Cohen, M.H., Moffet, A.T., Romney, J., Schilizzi, R.T., Rinehart, R.: *Nature* **259**, 17

Readhead, A.C.S., Wilkinson, P.N.: 1980, *Astrophys. J.* **235**, 11

Readhead, A.C.S., Pearson, T.J., Cohen, M.H., Ewing, M.S., Moffet, A.T.: 1979, *Astrophys. J.* **231**, 299

Ross, H.N.: 1972, Ph. D. Thesis, Univ. of Toronto

Shaver, P.A.: 1981 (in preparation)

Terrell, J.: 1966, *Science* **154**, 1281

Wills, D., Wills, B.J.: 1976, *Astrophys. J. Suppl.* **31**, 143

Wills, D.: 1980 (as reported by Bell, 1980)