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4C 18.68: A QSO WITH PRECESSING RADIO JETS?

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ABSTRACT

High resolution VLA radio maps at 20 cm and 6 cm wavelengths of the quasar 4C 18.68 reveal an extended halo ($\sim 20''$) containing complex curved structures extending east and west from the central source. The central source has a flat spectrum, while the spectrum generally steepens with distance from the center of the structure. The details of the structure and polarization of the emission suggest relativistic ejection in opposing directions by a precessing or rotating double jet with a period of $\sim 5 \times 10^4$ years, consistent with the presence of two interacting massive bodies in the central source.

Subject headings: quasars — radio sources: extended

I. INTRODUCTION

The radio source 4C 18.68 has been identified (Wills and Wills 1976) with a 16.5 mag QSO of redshift $z = 0.313$, denoted 2305+187 by Hewitt and Burbidge (1980). Direct imaging (Hutchings *et al.* 1981) has shown the QSO to be extended in the NE-SW direction by 2″–3″ and also suggests a jetlike feature extending several arcseconds to the SW. These results await verification and amplification with improved data. The object was observed with the VLA[1] as part of a program to correlate optical and radio morphology of low redshift QSOs. In view of the extraordinary structure in this object, we present a discussion of its radio properties on their own.

The QSO is of above average total luminosity but not extraordinarily so. The limited published spectroscopic information (Wills and Wills 1976) does not suggest anything unusual. The X-ray luminosity (Matilsky 1981) appears to be normal for a QSO of this redshift. It is not known if this quasar lies in a cluster since the optical plate did not allow detection of normal galaxies at this redshift. The luminosity distance of the source is 1000 Mpc, and the angular scale is 2.8 kpc per arcsecond (assuming $H_0 = 100$ km s^{-1} Mpc^{-1}, and $q_0 = 0$).

This *Letter* presents total intensity and polarization maps of this source made with the VLA at 20 cm and 6 cm with beamwidths of 1″.3 and 0″.4 (FWHP), respectively.

[1]The VLA is a facility of the National Radio Astronomy Observatory, operated by Associated Universities, Inc., under contract with the National Science Foundation.

II. OBSERVATIONS AND REDUCTION

The observations were taken with the completed VLA in its highest resolution (A) configuration on 1981 April 25 (Thompson *et al.* 1980). The source was observed at two frequencies, centered on 1465 MHz and 4885 MHz (hereafter referred to as 20 cm and 6 cm wavelengths) with a 50 MHz bandwidth. Two 10-minute scans were made, separated by about 2 hours in hour angle in each frequency. The absolute flux density scales were determined using 3C 138, 3C 286, and 1803+784. A calibration source (2136+141) was observed several times during the observations for the purpose of polarization calibration. The known intrinsic position angles of linear polarization of 3C 138 and 3C 286 were used to determine the absolute position angle of linear polarization. The internal consistency of the calibration gives an accuracy of $\pm 20°$ and $\pm 5°$ for the position angles of the 20 cm and 6 cm maps, respectively.

The resulting maps were CLEANed (Högbom 1974) and, in addition, a self-calibration procedure was used on the 6 cm total intensity map since the structure was dominated by several main components (Schwab 1980). The resulting dynamic range exceeds 100 to 1 at both wavelengths, and this, rather than noise, limits the reliability of features on the maps.

The smallest spacing of the VLA in the A configuration is 1 km, and the largest scale structure "visible" to the VLA in these observations is approximately 35″ at 20 cm and 10″ at 6 cm. The maps are therefore only complete for structures of angular scale less than these scale sizes. At 20 cm and 6 cm the shortest spacings show fringe amplitudes of 90% and 70% of the total (previously measured) flux densities, respectively, so that although the 20 cm map is reasonably complete, a significant fraction of the total intensity is missing at 6 cm, presumably in large scale structure not visible at this resolution.

III. RESULTS: THE MAPS

Figures 1 and 2 are the total intensity maps at 20 cm and 6 cm, respectively, and Figures 3 and 4 show the polarization vectors on simplified versions of these maps. The principal features are labeled A to E in Figures 3 and 4. The restoring beams used after the CLEAN procedure were circular Gaussians of 1″.3 and 0″.4 (FWHP) at 20 cm and 6 cm, respectively.

The optical position of the QSO is at $\alpha = 23^h05^m17^s.16$, $\delta = 18°45'5''.7$, $(\pm 0''.5)$ and is shown with a cross in Figure 3. It coincides with the flat spectrum component in the 6 cm map (feature A) within the optical position errors. The 20 cm positions appear to be displaced by $\sim 0''.3$ to the west with respect to the 6 cm data. Since the observations were taken in the early morning, we consider that the 20 cm displacement is probably an ionospheric wedge effect, but at 6 cm the effect is only one-tenth of this.

A low resolution map at 6 cm was made with the same synthesized beam as the 20 cm map to estimate the spectral indices of the main features in the small-scale structure of the source.

The maximum polarization is 5% at 20 cm and 8% at 6 cm. An estimate of the galactic Faraday rotation in the direction of the source, kindly provided by Dr. P. Kronberg, shows a rotation of position angle of $-100° \pm 20°$ at 20 cm and $-12° \pm 4°$ at 6 cm. The directions of the 6 cm polarization vectors are therefore close to the intrinsic position angles for the source, but the rotation between 20 cm and 6 cm of $-88° \pm 20°$ coupled with the uncertainty of $\pm 20°$ in the calibration make it impossible to estimate the intrinsic position angle at 20 cm with any accuracy. Relative changes, however, should still reflect changes in the polarization angle in the source since the angular scale is small.

IV. DISCUSSION

The radio structure of 4C 18.68 is remarkable in showing (a) extensive curved structure, seen particularly with the high resolution 6 cm observations, and (b) a large halo, ~ 60 kpc in diameter, seen clearly in the 20 cm data. The detailed structure of the features B and C suggests a curved jet and the possibility that this structure represents the path traced by the material flung out in a precessing or rotating beam. In particular, the unresolved edges NE of B and SW of C and the curva-

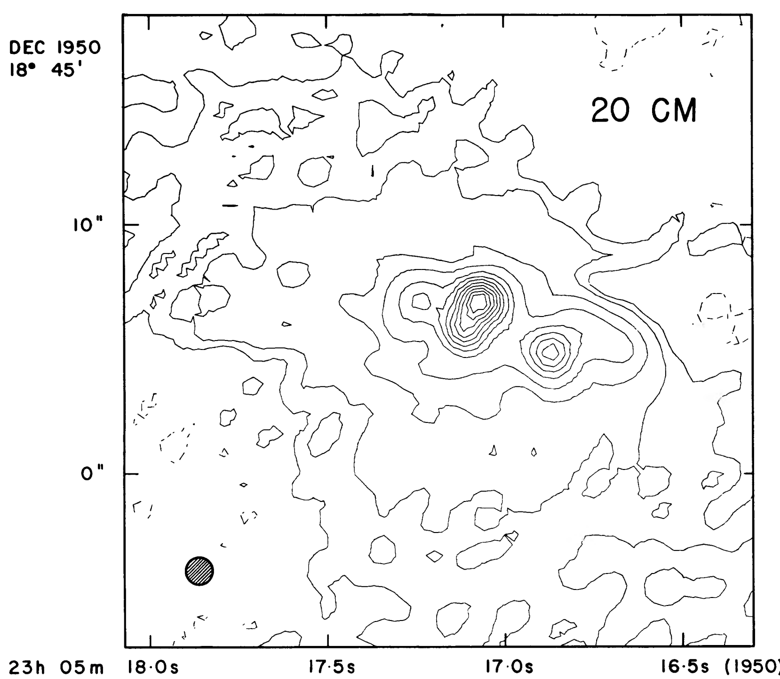

FIG. 1.—20 cm VLA map of 4C 18.68. Positions may be shifted W by 0″.3 in R.A. by an ionospheric wedge. The contour levels are −1, 1, 2, 5, 10, 20, 30, 40, 50, 60, 70, 80, and 90% of the peak brightness which is 0.131 Jy per beam area. The beam size is 1″.3 FWHP and is shown by the shaded circle. The optical QSO lies near the SE of the central double source. Note that the shape of the outer halo has its long axis rotated from the inner structure. The linear size scale for this source is 2.8 kpc per arcsecond ($H_0 = 100$ km s^{-1} Mpc^{-1}, $q_0 = 0$).

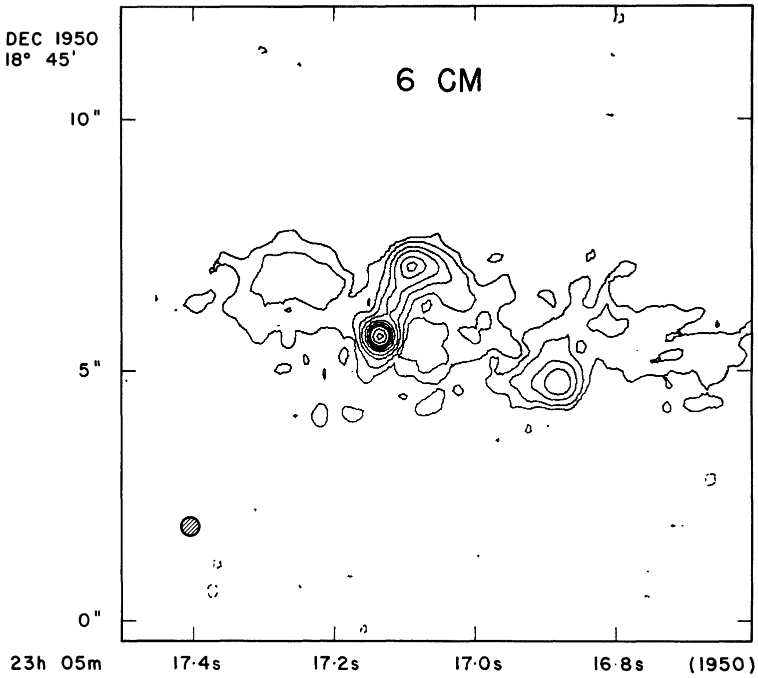

FIG. 2.—6 cm VLA map of 4C 18.68. Contour levels are −1, 1, 2, 5, 10, 20, 30, 40, 50, 70, and 90% of the peak brightness which is 0.0815 Jy per beam area. The beam size is 0″.4 FWHP and is shown by the shaded circle. The optical QSO lies 0″.3 E of the most intense peak. A $\frac{1}{2}$% contour surrounding the whole structure has been omitted to allow the complex, curved structure to stand out (see Fig. 3).

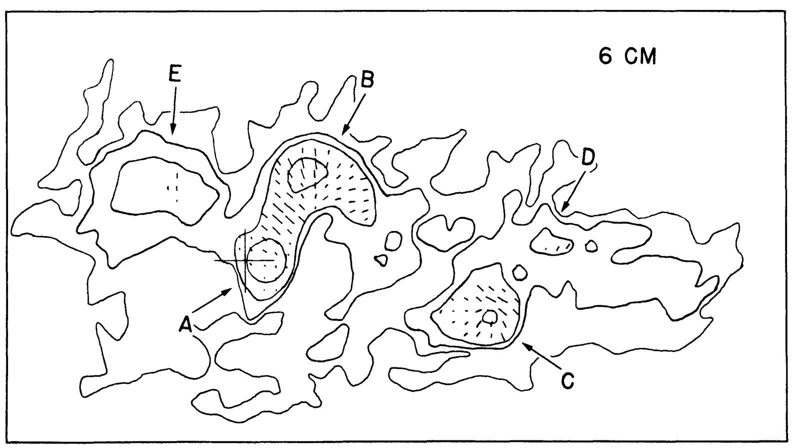

FIG. 3.—6 cm linear polarization distribution superposed on selected total intensity contours of 4C 18.68. The $\frac{1}{2}$% intensity contour omitted for clarity in Fig. 2 is included here. The lengths of the line segments indicate the polarized intensities, and their orientations show the position angles of the ***E*** vectors. The maximum polarized signal is 1.9 mJy per beam. The main features of the source are labeled A to E. The optical position of the quasar, with error bars, is shown by a cross.

ture of the rest of the features suggest an increase in intensity at B and C due to looking through a greater thickness of emitting material. However, if the motions are relativistic, there will also be an enhancement of intensity due to beaming effects for material approaching the observer (Ryle and Longair 1967; Scheuer and Readhead 1979). In support of this, we also note the relative overall faintness of the structure to the east of A.

The structure at 20 cm fits in well with that at 6 cm, taking into account the reduced resolution and the flat spectrum of A relative to the rest of the source. The jetlike feature D shows up particularly clearly at 20 cm due to its steep spectral index. The large halo apparent

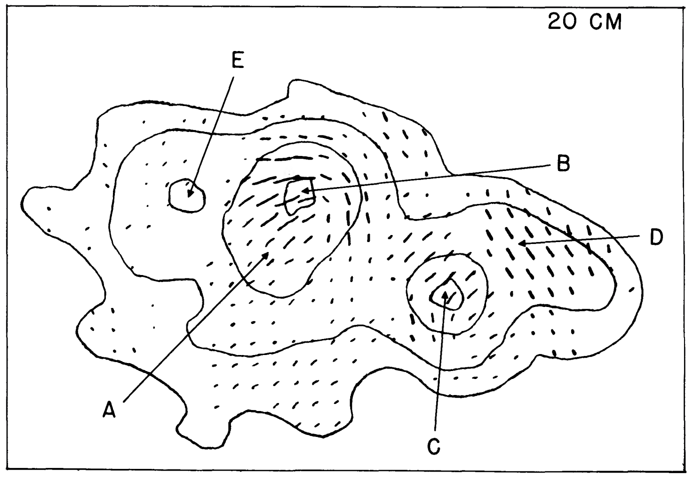

FIG. 4.—20 cm linear polarization distribution superposed on selected total intensity contours of 4C 18.68. Vector representation as in Fig. 3. Maximum polarized intensity is 6.6 mJy per beam. The main features of the source are labeled A to E, as in Fig. 3.

at 20 cm is not visible at 6 cm due to both the exclusion of large-scale structure from the 6 cm observations and the low surface brightness of the halo at 6 cm. The outer contours at 20 cm show a large-scale symmetry suggestive of earlier emission compatible with the symmetry of the jets. There is a noticeable steepening of the intensity contours in the north-west direction. However, as mentioned earlier, some large-scale structure may also be missing from the 20 cm map, so one should not attach too much significance to the shape of the outer contour.

Note that the outer detailed radio structure has an axis which lies E-W, while the optical structure ($\sim 2''$) is extended NW-SE along the direction of AB in Figure 3 (Hutchings *et al.* 1981). The ejection of the radio-emitting material, therefore, appears to be roughly perpendicular to optical extension.

The central component, A, has a flat spectrum, while the spectra of other features of the source are much steeper and show a tendency to steepen with increasing distance from the central source, an effect noticed in a number of extended sources. The following values were derived for spectral indices of the labeled components (Fig. 3): A: 0.05; B: -0.8; C: -1.0; D: -1.4, and E: -1.3. These values do not vary by more than 10% between estimates based on central intensities or point spread functions and the background level estimates which range from 0 to 10% of the peak.

Previous observations at 6 cm in 1969 and 1974 gave flux densities of 0.44 ± 0.02 Jy and 0.45 ± 0.03 Jy (Shimmins, Manchester, and Harris 1969; Condon and Jauncey 1974), so there is no evidence for radio variability so far. However, the flux density of the central component is only 0.05 Jy at 6 cm, so variability in this component alone might not have been detected.

The minimum energy of the particles comprising the emitting regions outside the central source was computed using the procedure outlined by Miley (1980). Excluding the halo and assuming a simple cylindrical geometry gives an energy of $\sim 10^{57}$ ergs. The halo accounts for approximately this amount again. The magnetic fields indicated by these minimum energies are $\sim 2 \times 10^{-5}$ gauss in the central region and $\sim 10^{-5}$ gauss in the halo.

It is interesting to note that there is no evidence from these data for the classic edge-brightened radio "lobes," nor is there any edge-brightening in the halo. Either the source has only recently become active or the intergalactic medium is rare enough to allow relatively free dispersion of the energetic plasma into the surroundings so that the general confinement mechanisms usually invoked to explain the lobes do not apply in this case. In this connection one notes that the luminosity of 3×10^{25} W Hz^{-1} sr^{-1} at 178 MHz places this quasar among the most luminous in the group of complex sources showing a well-defined axis close to the central object (Fanaroff and Riley 1974).

The source is not very highly polarized, as mentioned before, but the configuration of the polarization vectors follows the curved structure quite closely, suggesting the magnetic field is along the long axis of symmetry of the emitting material. The magnetic field configuration in the AB feature is similar to that seen in other high luminosity jets, but in the model suggested below the material is flowing radially outward from the emitting region. However, adjacent bits of material will not be independent, and differential flow or stretching of the field lines may account for the observed orientation of the vectors along the curved path in this case.

We believe that this structure suggests the path traced out by a rotating or precessing beam about an axis inclined at an intermediate angle to the line of sight. The large number of free parameters make it difficult to fit a unique model, but preliminary model fitting to the inner part of the structure has been done using a program kindly provided by Dr. P. C. Gregory. This shows that, if we assume the emission has been roughly constant and equal in opposite directions from the central object, the ratio of intensities on the two sides of the source and the geometry of the structure suggest a moderately relativistic jet velocity of about $0.7c$ at a half cone angle of $\sim 20°$ about an axis inclined at about 50° to the line of sight. This jet velocity and the structure of the source then give an approximate precession period of $\sim 5 \times 10^4$ years which is compatible with a model of two interacting massive objects in the central source (Begelman, Blandford, and Rees 1980). If this time scale is correct, the steepening of the spectrum with distance from the central source cannot be due to synchrotron losses.

It is not possible to fit the outer curved structure with these parameters, in particular feature D. Two of many possibilities are: (a) that the cone angle of the precession has changed with time, or (b) that the outer structure *has* been affected by the passage of the system as a whole through space or by a change in the local conditions in the external medium into which the energetic particles are expanding. In support of this, one notes the steepening of the slope of the intensity contours in the northwest direction on the 20 cm map.

The optical position is displaced to the east of the flat spectrum object by $0''.3 \pm 0''.5$. This may not be significant, but it is interesting to note that the model does allow an apparent displacement of the peak of the radio emission from the optical position in this direction.

The model suggested above appears to fit the data reasonably well, but there are of course several other possibilities. If the constraint that the emission has been roughly constant in opposite directions is removed (as seems to be the case in some observed jets), the data then allow a wider range of axis inclinations and jet velocities. Alternatively, the curved structure may be explained in terms of an abrupt change in orientation of the jet-emitting object rather than smooth precession.

V. CONCLUSION

Several examples of curved jets in radio galaxies and quasars have now been found and the suggestion has been made that this is due to the rotation or precession of the central jet-emitting object, e.g., NGC 326 (Ekers *et al.* 1978). We present the radio structure of 4C 18.68 as another possible example of a double-beam, precessing, relativistic jet. The prototype object is of course SS 433, and the recent papers on this source (Hjellming and Johnston 1981*a*, *b*) were carefully considered in the study of 4C 18.68. The type of model which fits these data strongly suggests application to many other sources in which complex structure is seen but less clearly delineated (Gregory and Gower, in preparation). The understanding of these phenomena clearly relates to the question of duplicity in active galactic nuclei and/or close interactions between galaxies.

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REFERENCES

Begelman, M. C., Blandford, R. D., and Rees, M. J. 1980, *Nature*, **287**, 307.
Condon, J. J., and Jauncey, D. L. 1974, *A.J.*, **79**, 1220.
Ekers, R. D., Fanti, R., Lari, C., and Parma, P. 1978, *Nature*, **276**, 588.
Fanaroff, B. L., and Riley, J. M. 1974, *M.N.R.A.S.*, **167**, 31P.
Hewitt, A., and Burbidge, G. 1980, *Ap. J. Suppl.*, **43**, No. 1, 57.
Hjellming, R. M., and Johnston, K. J. 1981*a*, *Nature*, **290**, 100.
______. 1981*b*, *Ap. J.*, (*Letters*), **246**, L141.
Högbom, J. A. 1974, *Astr. Ap. Suppl.*, **15**, 417.
Hutchings, J. B., Crampton, D., Campbell, B., and Pritchet, C. 1981, *Ap. J.*, **247**, 743.
Matilsky, T. 1981, private communication.
Miley, G. K. 1980, *Ann. Rev. Astr. Ap.*, **18**, 165.
Ryle, M., and Longair, M. S. 1967, *M.N.R.A.S.*, **136**, 123.
Scheuer, P. A. G., and Readhead, A. C. S. 1979, *Nature*, **277**, 182.
Schwab, F. 1980, *Proc. Soc. Photo-Opt. Instrum. Eng.*, **231**, 18.
Shimmins, A. J., Manchester, R. N., and Harris, B. J. 1969, *Australian J. Phys.*, *Ap. Suppl.*, No. 8.
Thompson, A. R., Clark, B. G., Wade, C. M., and Napier, P. J. 1980, *Ap. J. Suppl.*, **44**, 151.
Wills, D., and Wills, B. J. 1976, *Ap. J. Suppl.*, **31**, 143.

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