LOW FREQUENCY, HIGH RESOLUTION OBSERVATIONS OF VIRGO A

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SUMMARY

Observations are reported of the angular structure of the central region of Virgo A at 151 and 408 MHz which complement those obtained by synthesis techniques at higher frequencies. The radio counterparts of the jet and counter-jet are shown to have different sub-structures at these low frequencies. The probable low frequency cut off in the spectra of these components is unlikely to be due to synchrotron self absorption in compact subcomponents.

INTRODUCTION

This paper presents the results of work done at Jodrell Bank on the central region of Virgo A using the Mk I-Mk III interferometer at 151 and 408 MHz. The maximum baseline lengths available with this instrument were about 12 000 and 32 000 wavelengths respectively, thus allowing us to obtain structural information in the range of a few seconds to several tens of seconds of arc at these comparatively low frequencies. Virgo A has previously been studied using synthesis techniques at comparable resolving powers but only at the higher frequencies of 2695 and 5000 MHz (Hogg et al. 1969; Graham 1970). The present results therefore complement this work and now enable us to comment on the structure of the central region of the source over a much wider range in frequency than was possible before.

For a detailed discussion of previously published work the reader is referred to the review given by Graham.

OBSERVATIONS

The Mk I (76 m) and the Mk III (38 m × 25 m) telescopes are connected via microwave and U.H.F. links to form an interferometer with a baseline of 23·5 km. Fringe amplitudes were read by eye from analogue chart recordings. The methods of calibration and data reduction used were essentially similar to those described by Anderson & Donaldson (1967).

The visibility curves obtained at the two frequencies are shown in Figs 1 and 2 for 151 MHz and 408 MHz respectively. The error bars shown represent the random errors due to the combination of system noise and various other uncertainties in the correction procedures. The systematic errors in the calibrations, which affect the scales of the visibility curves, are ± 20 per cent at 151 MHz and |± 15 per cent at 408 MHz. Also shown, by the solid lines, are the visibility curves which would be given by the model brightness distributions proposed in the following section.
The visibility data collected were analysed by fitting models, whose components had gaussian brightness distributions, to the observed curves. This process has been described in detail elsewhere (e.g. Anderson & Donaldson 1967).

We now discuss individually the results obtained at the two frequencies.

(a) 151 MHz

At 151 MHz the visibility data are well fitted by a model consisting of only two components, each being defined by a flux, two dimensions and an orientation. The dimensions of these components are not very well defined, however, for they depend quite strongly on the type of model fitted. The general shape of the visibility curve can be reproduced by various models with different combinations of constraints on the relative elongation and position angles of the components. However, certain parameters must be different for the two components; for example, they cannot be elongated along the same position angle. The best agreement is obtained if the component widths only are constrained to be equal, and this is the model whose parameters are given in Table I.
The errors were estimated by generating various models with parameters differing from the ones given above and estimating by eye when the fit became unacceptable.

(b) 408 MHz

Because there is no evidence for variations in visibility with hour angle corresponding to component separations of order 40′′ arc in the 408 MHz visibility curve, one of the two components of the proposed 151 MHz model must be weak or almost completely resolved at this higher resolution. Simple two-component models could not be made to fit the data at 408 MHz. An extension of the generalized fitting procedure to models having three components was considered dangerous, bearing in mind the many available degrees of freedom, therefore only the simplest possible three component model is proposed. This consists of three unresolved (<1′′·4) components equally spaced along a line in position angle 290°. The optimum separation between the adjacent points is 6′′·3 and the flux densities were 7, 7·8 and 8·6 flux units. The computed visibility curve does deviate considerably from the observed data and the arbitrary nature of the model must be emphasized; it is certain, however, that complex structure with three or more components having characteristic spacings of 6–7′′ arc exists at this frequency.

DISCUSSION

(1) General features

The most striking aspect of the above results is the change in the apparent structure of the source between 151 and 408 MHz. Because the present measurements were made with the same physical baseline it is difficult to tell if this is an effect due to the different resolving powers attained or to differences in the radio structure at the two observing frequencies. However, when we consider these results in the light of Graham’s 5 GHz synthesis map (beam size 6″·5 × 28″) it is possible to go some way toward distinguishing between the two effects. This map reveals that the central region of the source consists of three individual components one of which is unresolved and which is coincident with the optical nucleus. Flanking the nucleus are two elongated components corresponding in position to the optical jet and counter-jet. There is a remarkable similarity between the proposed 151 MHz model and these extended outer components. Their relative elongations and position angles are very similar indeed whilst the slightly larger separation of the components in the model (43° compared with ∼35° for the map) is probably a reflection of the asymmetry in their brightness distributions which the model does not include. In case it should be thought that the appearance of the map influenced our attempts at model fitting it is worth noting that the main...
features of the 151 MHz model were determined well before the publication of Graham's paper (Wilkinson 1969). We conclude, therefore, that the structure of the outer components is not a strong function of frequency and that the major reason for the disparity between the 408 MHz results and those at 151 MHz lies in inherent differences between the structures of the components which become apparent when they are observed with an instrument with a resolving power of \(\sim 1''\) arc.

(2) Differences between the outer components

The agreement between the size and position angles of the map and the 151 MHz model components enables us to suggest, with some degree of certainty, that the stronger component at 151 MHz should be identified with the Np component in Graham's map. This is the one which is associated with the optical jet. We now know that one of these outer components must be strongly resolved at 408 MHz, and the fact that the position angle of the 408 MHz model is very close to that of the jet makes it likely that it is the Sf component which has been nearly resolved out. This is corroborated by the small peak seen at 4\(^{h}\) 20\(^{m}\) on the 408 MHz visibility curve, for this is at the correct position angle for it to represent the residual effect of the Sf component.

The fact then that the Np component contains sub-structure, while the Sf component does not, agrees with the 2695 MHz map of Hogg et al. This map shows complex structure in the region of the jet but only a diffuse lower brightness area in the position of the Sf component. The 151 MHz model also shows this component to be less well defined when compared with the Np one, as can be seen from the allowable errors on their position angles.

The 408 MHz model shows some similarities with the 2695 MHz map as well, for the separation of the outer components at 408 MHz (12''·6) is close to that of the two unresolved regions at 2695 MHz which are centred on the nucleus and the two strongest knots in the optical jet (\(\sim 14''\)). This, together with the position angle agreement, strongly suggests that the radiation at 408 MHz seen on this baseline is emanating from an area extending from the nucleus along the jet.

(3) The spectra of the components

It is difficult to tell if the proposed 151 MHz model accounts for all the flux coming from the outer components since the flux assigned to the individual components is model dependent; however all the various models tried gave component fluxes within the errors quoted in Table I. If we plot the fluxes given in Table I on the spectra of the outer components given by Graham then it seems that they exhibit a low frequency cut off between 1407 and 151 MHz; this effect was also deduced by Graham from other evidence.

The absence of an obvious third component at 151 MHz is also consistent with Graham's conclusions about the central region, for it implies that the nuclear source is weak at 151 MHz, i.e. it exhibits a strong cut off at low frequencies.

One way to explain the cut off in the radiation from the outer components, noted by Graham, is by synchrotron self absorption in a number of compact sub-components. However, the fact that the weaker, and hence on this explanation, more strongly self absorbed Sf component is almost totally resolved at 408 MHz suggests that this explanation is unlikely to be correct.
CONCLUSIONS

The results reported here partly fill in a gap in the radio data available on M87; but, because we have had to use model fitting techniques, the amount of reliable information which can be extracted concerning component parameters is limited. Nonetheless, we have shown that the ostensibly similar outer components in the central region which constitute the radio counterparts of the jet and counter-jet have very different underlying structures; and that the low frequency cut off probably occurring in the radiation coming from these components is unlikely to be caused by synchrotron self absorption in a large number of sub-components.

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REFERENCES
