POLARIZATION MEASUREMENTS OF DISTANT SOURCES

R.G. Conway
University of Manchester, Jodrell Bank

Polarization measurements, in addition to their interest for deciphering the internal physics of radio sources, are relevant to cosmology because estimates of n_e, the thermal electron density, may be obtained from measurements of the Faraday effect. We have:-

Position Angle	χ	=	$\chi_o + R.\lambda^2$
Rotation Measure	R	=	$K.\int n_e B_{\parallel} d\ell$
	K	=	0.8×10^6 rad.m^{-2}/(cm^{-3}G.pc)

The foreground plasma, along the line of sight to the observer, can be investigated using R (see the following contribution by P.P. Kronberg). The degree of polarization, m, is not affected by foreground rotation, but is decreased if there is a contribution to $\int n_e B_{\parallel} d\ell$ arising within the source. The rotation from the back will be rotated relative to that from the front at long wavelengths but not at short wavelengths ("front-back depolarization"). If the Faraday dispersion Δ is the rotation measure of the equivalent uniform slab, then the polarization falls to one half at

$$\lambda_{\frac{1}{2}} = (1.90/\Delta)^{\frac{1}{2}} \mathrm{m}$$

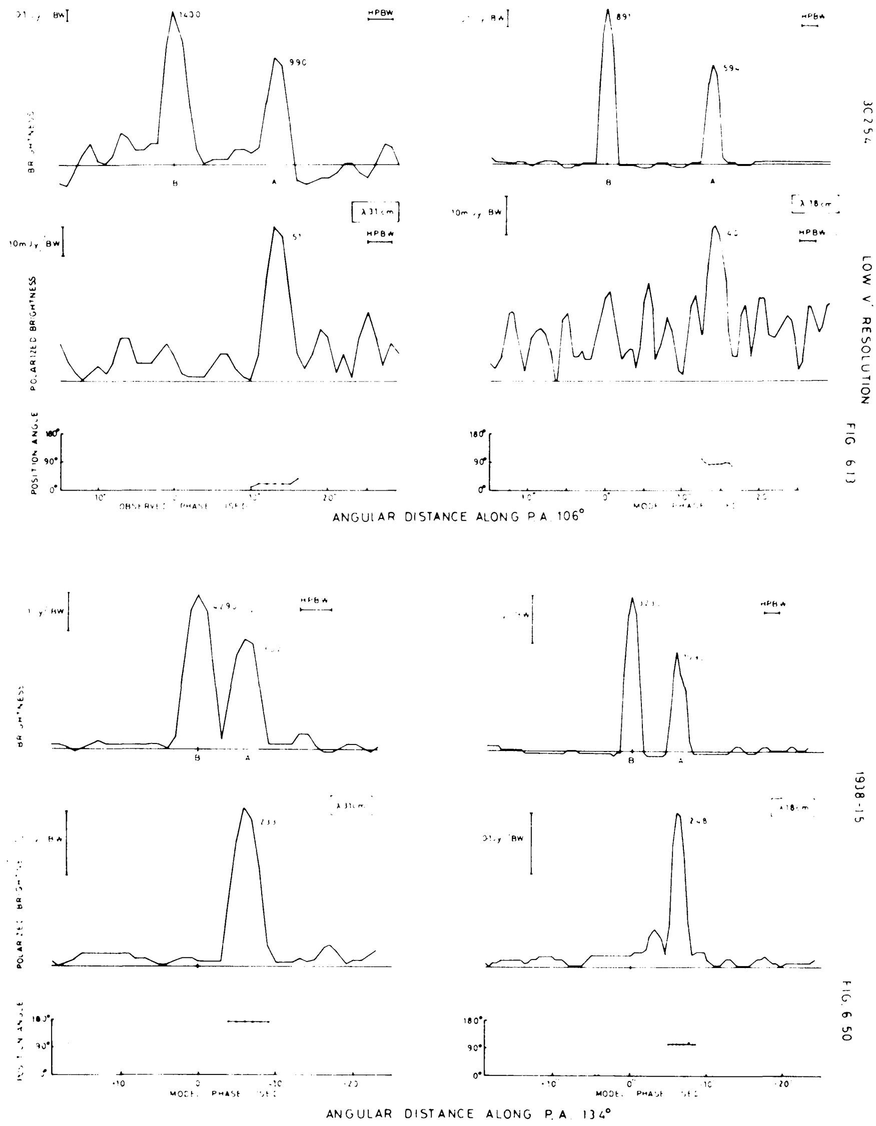
Hence one may estimate n_e within the source from measurements of $\lambda_{\frac{1}{2}}$, provided i) that side-side variations of R can be neglected ii) that the source is transparent.

Conway et al. (1974) estimated n_e in quasars this way, using only those sources which on spectral evidence seemed to contain no opaque components. Assumption i) regarding side-side depolarization rested on rather slender evidence (see below).

The values of n_e ranged from 3.10^{-5} to 3.10^{-2}cm^{-3}. (Note that because of an error the published values were too low by x10). The values show considerable scatter, but do increase on average with z, as

$$n_e = 10^{-4} \times (1+z)^{3.4 \pm 3.7}$$

D. L. Jauncey (ed.), Radio Astronomy and Cosmology, 361-366. *All Rights Reserved.*



Figs 1 and 2 Polarization measurements at λ18 and 31 cm made with a 23 km interferometer by R.J. Davis. Upper 3C254, lower PKS1928-15. For each source the top strip distribution gives I(θ), the middle strip gives mI(θ) and the lowest strip gives χ(θ).

https://doi.org/10.1017/S0074180900016338 Published online by Cambridge University Press

Clearly the data agree with a wide range of cosmologies. One might expect $n_e \propto (1+z)^3$ since the ambient density presumably has this form. The mean $n_e/(1+z)^3$ is $1.4 \times 10^{-4} cm^{-3}$ compared with a closure density of 3×10^{-6} cm^{-3}, an apparent enhancement over the ambient of at least a factor of 50. Since ram-pressure models, e.g. De Young and Axford (1967) no longer seem satisfactory, we do not appear to have a means of predicting this enhancement factor. However, if there were a satisfactory theory of radio sources which predicted the enhancement, we could explore the ambient density of the Universe as a function of z by means of these measurements.

More evidence is now available on the distribution of polarization, which bears on the assumption that "side-side depolarization" is negligible. Hogbom and Carlssen (1974) have published maps of polarization at 21 cm obtained with the WSRT in Holland. They comment that regions of low T_b are more polarized than those of high T_b: bridges may be ∿20% but hot spots are usually <10%. This is clearly relevant for source physics, but we should remember that the sources studied have large angular size, low luminosity and low redshift. At high redshift, surface brightness decreases as $(1+z)^{-4}$ and high-z sources tend to show only hot spots. Hence Hogbom and Carlssen's remark about low T_b regions may not be important for distant sources.

Hogbom and Carlssen selected extended sources. R.J. Davis at Jodrell Bank (unpublished measurements) selected a sample of 20 sources with very compact components. The observations with a 23 km interferometer at λ18 and 31 cm give strip-distributions along the major axis (Figs 1 and 2).

Although the intensity ratio of the components is near unity, the polarizations are often very dissimilar, especially at λ31 cm. Effectively all the polarized flux comes from one component. When this is the case the integrated polarization follows that of the polarized component, and "beating", or the side-side depolarization of Component A by component B does not occur. There seems no rule as to which component will be the more polarized: it does not depend on intensity, spectral index, nor on proximity to the optical object. We are investigating this effect further in larger samples complete to defined selection limits. We suspect that the effect may not be universal but may relate to this particular sample, possibly because the components are so compact.

Conway, Burn and Vallee (in press) mapped 72 sources from the 4C catalogue using the WSRT at 6 cm and 21 cm (Fig. 3). Out of the 72 sources, 45 are double with $\theta \gtrsim 12''$, and 4 are triple with a central component. Taylor and Conway (unpublished) have measured the same set of sources at 18 cm and 31 cm, giving polarizations at four wavelengths of each component of the 45 double sources. The optical fields have been studied by Padrielli at Bologna (Padrielli and Conway, in press), who finds 19% to coincide with a blue object or quasar, 24% with a Galaxy, while 57% are unidentified. The majority are near or beyond

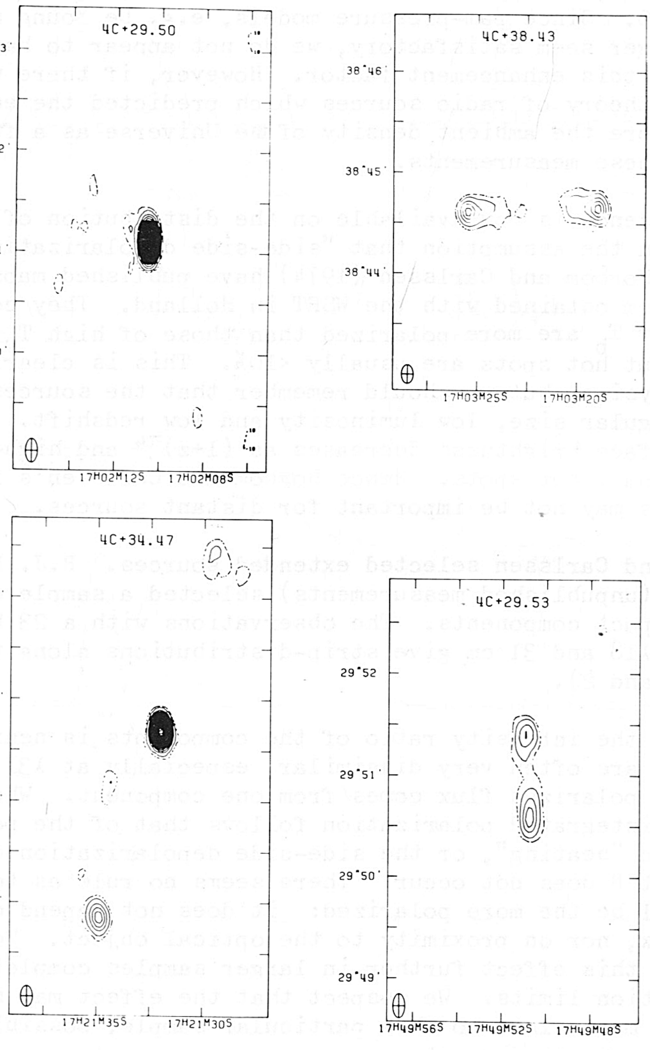


Fig. 3 Maps of 4 sources from the sample studied by Conway, Burn and Vallee. The beam of the WSRT at λ6 cm, 7 arcsec in RA, is shown in the lower left corner of each map.

https://doi.org/10.1017/S0074180900016338 Published online by Cambridge University Press

the P.S.S. plate limit, and we suggest $z \sim 0.25$ for G, $z \sim 0.5$ for U and $z \sim 1.0$ for B objects. For calculating n_e, only very approximate z-values are required, as the dependence on both z and q_o of the derived n_e is very low. For fixed $\lambda_{\frac{1}{2}}$, S α and θ, the derived values of n_e do not vary by more than a factor 1.9 within the ranges $0.1 < z < 2.0$ and $\theta < q_o < 1$. Though the n_e values obtained for radio sources will not help to decide q_o, they will, when z is measured, be useful for studying $n_e(z)$. The n_e values of these sources, or rather for the components, range from 10^{-4} to 3×10^{-2} cm^{-3}, very similar to those of the known quasars studied previously.

Even with 4 wavelengths of measurement, the solution for rotation measure may be ambiguous (Haves, 1975). We believe that for 33 sources in the 4C sample unambiguous values for RM can be obtained from the integrated polarizations, giving the intrinsic position angle and hence the orientation of the B-vector on the sky. For 16 of these sources, unambiguous solutions can be obtained for both components. The orientation of the B vectors in the components is usually but not always close to the major axis of the source. If θ_B is the angle projected on to the sky between these two directions, the most probable value of θ_B is $15^o \pm 10^o$. Approximately one third of the sources have θ_B greater than 45^o, i.e. The B vector lies more nearly across the major axis than along it. These statistics are very similar to the results collected by Haves and Conway (1975).

In all cases (even where RM is ambiguous) it is clear that the rotation measures of the two components of a double source are always closely equal. The median value of RM_A-RM_B is 8 rad.m^{-2}. We may draw two conclusions:

i) the differential Faraday rotation between two components produces negligible "beating" even when both are polarized. Hence the assumption by Conway et al. (1974) that "side-side depolarization" can be neglected is supported by the subsequent data.

ii) if a double source were embedded in a cocoon of plasma, one would expect the more distant component to show an extra contribution in rotation measure. If one assumes a separation of 100 kpc, and a field of 10^{-7} Gauss, the value of 8 rad.m^{-2} suggests that the density of such a cocoon is not more than $10^{-3}(1+z)^2$ electrons.cm^{-3}.

References

Conway R.G., Haves P., Kronberg P.P., Stannard D., Vallee J.P. and Wardle J.F.C. (1974). M.N.R.A.S. 168, 137

De Young D.S. and Axford W.I. (1967). Nature 216, 129

Haves P. (1975). M.N.R.A.S. 173, 553

Haves P. and Conway R.G. (1975). M.N.R.A.S. 173, 53P

Hogbom J.A. and Carlssen I. (1974). Astron. and Astrophys. 34, 341

DISCUSSION

Ryle: I think it may be dangerous to deduce too much information from the integrated polarization from components of double sources. The polarization structure of Cygnus A observed with 2" arc resolution shows a highly complex situation in the tail, with 8 or so components each having strong percentage polarization and considerable complexity in the heads. Similar complexity is evident in many of the 48 3C sources observed by Pooley and Henbest. At larger red-shifts, where the components cannot be so well resolved, the integrated polarization may have a magnitude and position angle which varies in a way not attributable in a simple way to Faraday rotation.

Conway: I entirely agree about Cygnus A, which I am sure is very complex. I would differ in regarding it as typical: Cygnus A is better described as a rogue elephant among sources. It has always been a puzzle to explain why integrated polarizations behave with the regularity that they do - $m(\lambda)$ always decreases, position angle varies as λ^2 and so on - when one expects a random drunkard's walk behaviour from the addition of many domains. However, the regularities are there, and need explanation. My working hypothesis is that in each component there is one dominant domain. My present results suggest that the dominant domains in double sources are connected, and have the same position angle. Clearly, as you say, we need the maximum resolution at as many wavelengths as possible. A.J. Kerr, a student at Jodrell Bank, is at present studying 96 3CR sources at 31 cm at resolutions going down to 1 arcsec. This is a pilot project for polarization work with Jodrell Bank's new Multi-Element Radio-linked system at present being put together.