SYMMETRY IN RADIO GALAXIES

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I. Introduction

One of the most striking properties of the radio galaxies is the predominance of a symmetrical double lobed structure. Any model to explain the energy release and collimation in radio galaxies must be able to produce this symmetry as the normal morphology. Although this large scale symmetry in radio galaxies is a well known phenomenon, I feel it is worth reemphasising since our current attention is more sharply focussed on the small scale and often much less symmetric structures which are seen with the higher resolution radio telescopes (VLB, VLA etc).

Throughout this paper I will argue that these simple morphological considerations can already put many constraints on radio galaxy theories.

II. 1-D Symmetry

(a) Component Intensity and Separation

Fig. 1a shows the distribution of the ratio of the flux densities of the components of double radio sources and fig. 1b shows the distribution of the ratio of the separation of the components from the central galaxy. Given the very wide range in power ($\gtrsim 10^5$:1) and separation ($\gtrsim 10^4$:1) of radio galaxies this symmetry is quite remarkable. The centroids are 1.5 for the intensity ratio and 1.25 for the separation ratio distribution. The degree of symmetry in either the intensity ratio (Mackay 1973) or the separation ratio (Longair and Riley 1979) can be used to put a limit $\lesssim$ 0.2c on the component ejection velocity. With somewhat dubious assumptions about the component evolution this can be further reduced to $\lesssim$ 0.03c (Mackay 1973).

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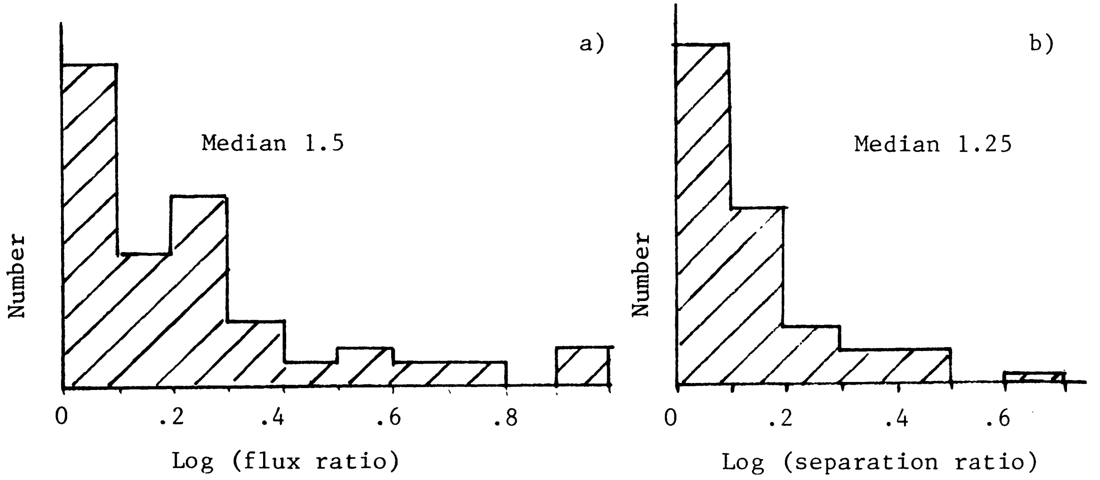

Figure 1. The distribution of the logarithm of the ratio of a) the stronger to the fainter component of 3C radio sources (from Mackay 1971) and b) the furthest to the closest component (from Ingham and Morrison 1975).

When asymmetry does occur it is well correlated between intensity and separation in the sense that the parent galaxy is closer to the centroid than the center (Fomalont 1969). In analysis of a magnitude limited sample of 93 Southern radio galaxies (Shaver et al, this meeting) there were no exceptions to the rule that the fainter component is further from the parent galaxy than the brighter component. The result for this sample is especially significant because the identifications are with bright galaxies coincident with a radio core component and consequently there is no significant selection bias towards centroid identifications. Ryle and Longair (1967) assumed that this asymmetry resulted from the age difference between the front and back components of an expanding double source. This correctly predicts the sense of this effect (the back component is seen at an earlier epoch when it is closer and stronger), however this model requires uncomfortably high values of v/c and it fails for the one radio galaxy (NGC612) for which we can tell front from back (Ekers et al 1978b). A more straightforward explanation of this result which is more consistent with current ideas on radio galaxy formation is to postulate gradients or irregularities in the external medium which cause a lobe encountering a higher density to be both closer and brighter.

(b) Small scale symmetry

The high degree of symmetry seen in the large scale structure is usually reduced as we go to higher resolution (e.g. compare the 3C maps made with the 1 mile telescope and the 5 km telescopes). In the closest radio galaxy, Centaurus A (see papers in this symposium), we find a strange mixture of symmetry and asymmetry. The very large outer

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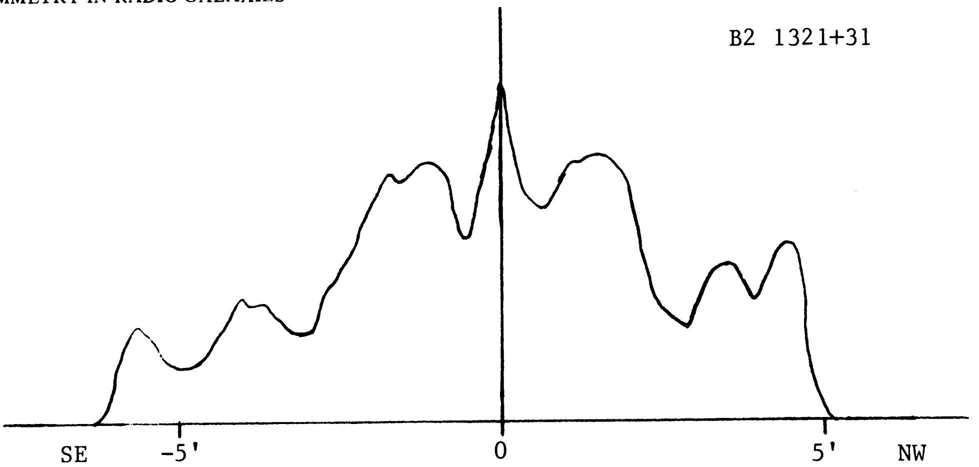
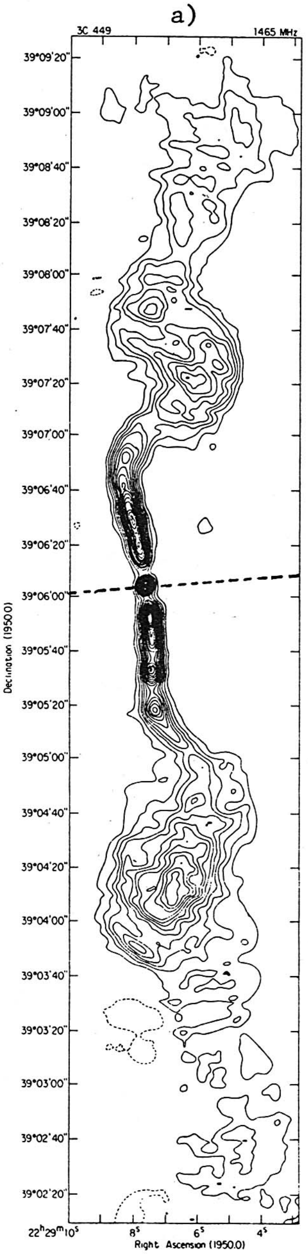


Figure 2. Brightness of the jet in B2 1321+31 as a function of the distance from the nucleus (from Ekers et al 1981).

lobes (1 - .1 Mpc scale) have almost identical integrated flux density (Cooper, Price and Cole 1965), the middle structure (10 kpc scale) is completely one sided, the inner double (1 kpc scale) is very symmetric, while the jet from the nucleus (100 pc scale) is again one sided on the same side!

A general conclusion which can be drawn from this is that the energy output over long time scales (ie integrated in the extended lobes) is divided equally between the two sides. The asymmetry on smaller scales could result from many effects such as short time scale fluctuations in the energy supply (e.g. Rudnick, this symposium), local variations causing the energy beams to become visible in a patchy manner, relativistic effects due to bulk motion of the plasma supplying energy to the lobes, or anisotropic radio emission. Simple observations of morphology can already be used to distinguish between some of these types of explanation. For example, relativistic effects can only explain one sided asymmetry, while very short time scale switchings from side to side are already excluded because most long asymmetric jets are completely one sided.

The jets in radio galaxies show a transition from mainly symmetrical structures in low luminosity sources to one sided structures at higher luminosity (Bridle, this symposium). Some of the symmetric low luminosity jets have an even higher degree of symmetry. Fig. 2 shows the brightness of the jet in B2 1321+31 as a function of distance from the nucleus of the galaxy (Bridle et al in preparation). In addition to the equality of total flux there is a striking one to one correspondence in the brightness changes along the jets. This kind of behaviour will be very hard to model in theories using local instabilities to change the appearance of a jet, but is natural in models using large scale symmetry e.g. a spherically symmetric density



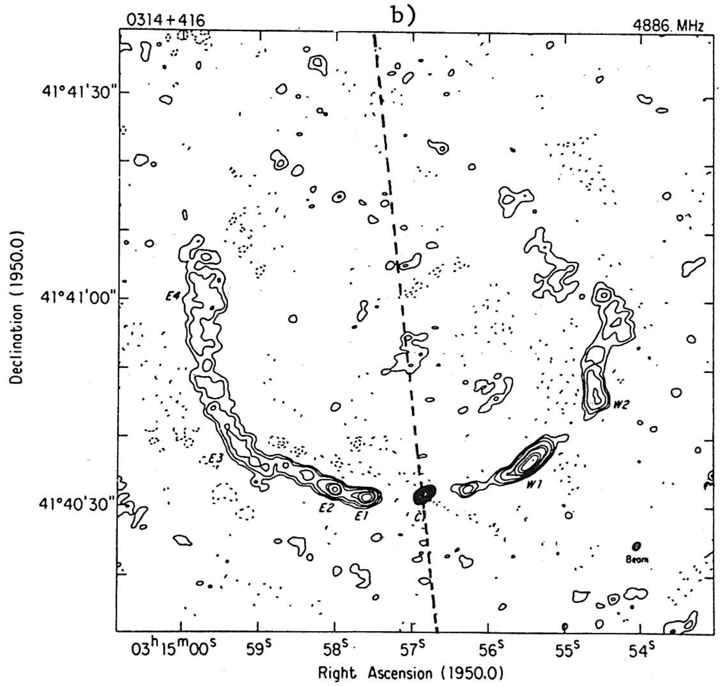


Figure 3. Examples of sources with mirror symmetry. Dashed line indicates line of symmetry. a) VLA observation of NGC1265 at 5GHz (from Owen et al 1978), b) VLA observation of 3C449 at 1.4 GHz (from Perley et al 1979).

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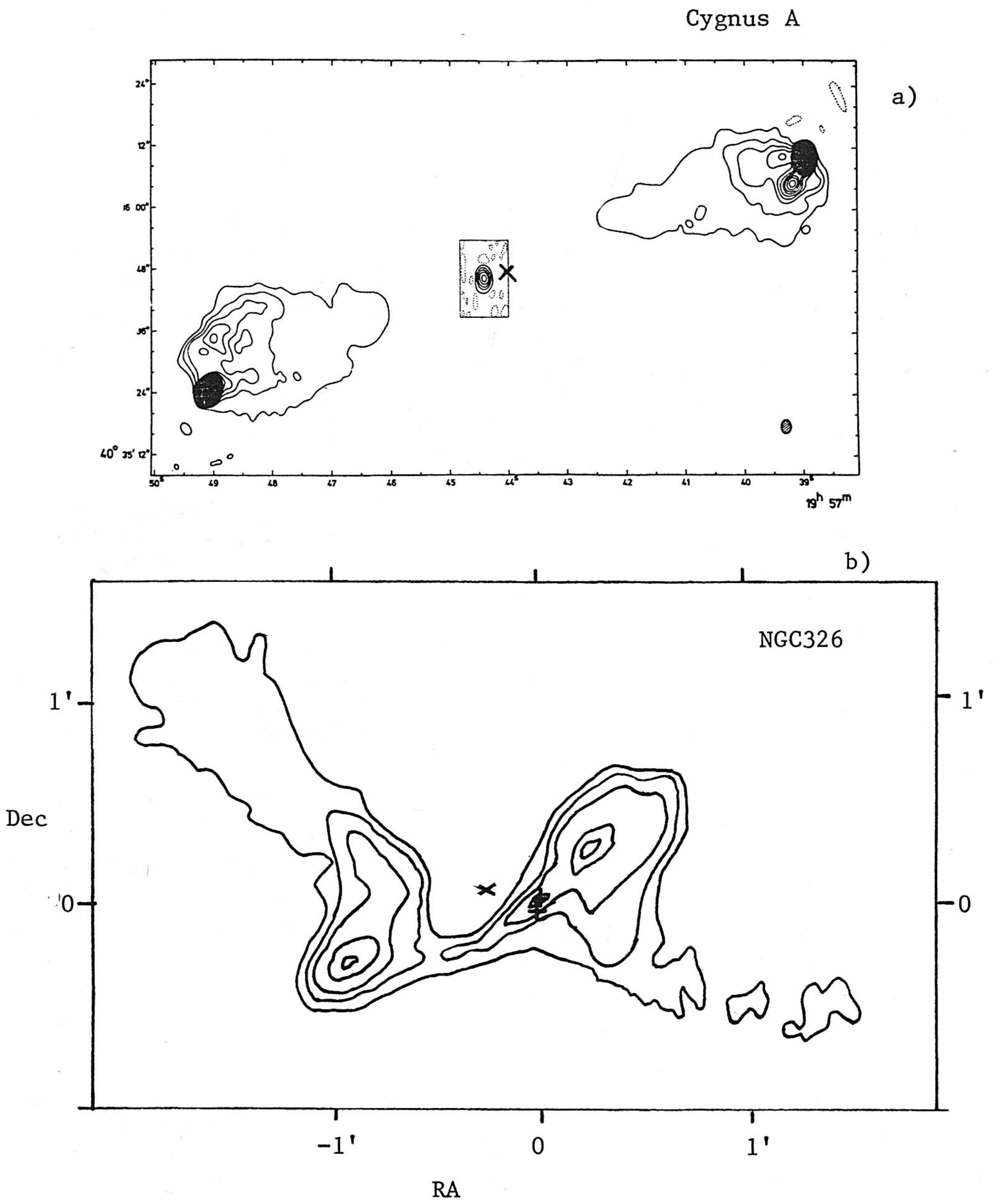

Figure 4. Examples of inversion symmetric sources. The X indicates the center of symmetry. a) Map of Cygnus A at 5 GHz (from Hargrave and Ryle 1974), b) VLA observation of NGC326 at 5GHz and 1.4 GHz (lowest contour). The pair of galaxies are indicated by $_{+}^{+}$ (Ekers, Fanti, Fomalont, Lari and Parma in preparation).

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distribution in the surrounding medium or a time varying ejection maintaining two sided symmetry over long time scales.

III 2-D Symmetry

(a) Mirror and Inversion Symmetry

Most of the radio galaxies mapped in two dimensions have a well aligned linear structure but some, especially those of lower luminosity, have spectacular two dimensional symmetry. The two dimensional symmetries are of two types. The examples NGC1265 and 3C449 (fig. 3) have a strong symmetry when reflected about a line. This is reflection or mirror symmetry (also called C type). Cygnus A and NGC326 (fig. 4) have strong symmetry when reflected through a point. This is inversion or rotational symmetry (also called S or Z type).

If you have any doubts about the reality of these symmetries try comparing the figure with a transparent copy - turned over for the mirror symmetrical source and rotated by 180° for the inversion symmetric source. In the mirror symmetric sources the symmetry line usually changes in angle a little between the inner and outer structure. It should also be noted that the point of inversion symmetry is often significantly displaced from the nucleus of the radio galaxy. In the case of NGC326 (fig. 4b) this displacement is considerable and the jets from the nucleus to the lobes do not have the same symmetry as the lobes.

(b) Statistical Results

It is useful to define a quantitative measure of the degree of deviation from colinearity for use in statistical studies. The small inserts in fig. 5 show one such measure. This figure also shows the distribution of the distortions for three classes of objects. The B2 radio galaxies (fig. 5a) are a complete sample of bright galaxies ($M_p <$ 15.7). This sample has a large fraction of distorted structures almost equally distributed between the mirror and inversion symmetric classes. The 3CR sample (fig. 5b) has much higher average radio luminosity because it is not a magnitude limited sample. It is much more strongly peaked near $\chi = 0°$ (more colinear sources) and again the number of distorted sources are equally distributed between the mirror and inversion symmetric classes. Finally, a sample of radio galaxies from Abell clusters shows a very strong preference for strong mirror symmetric distortions (the head tail radio sources) and a complete absence of inversion symmetric sources. An analysis of the distortions in a sample of Southern radio galaxies by Shaver et al (this symposium) shows that the degree of distortion is larger when the radio galaxy has a nearby companion.

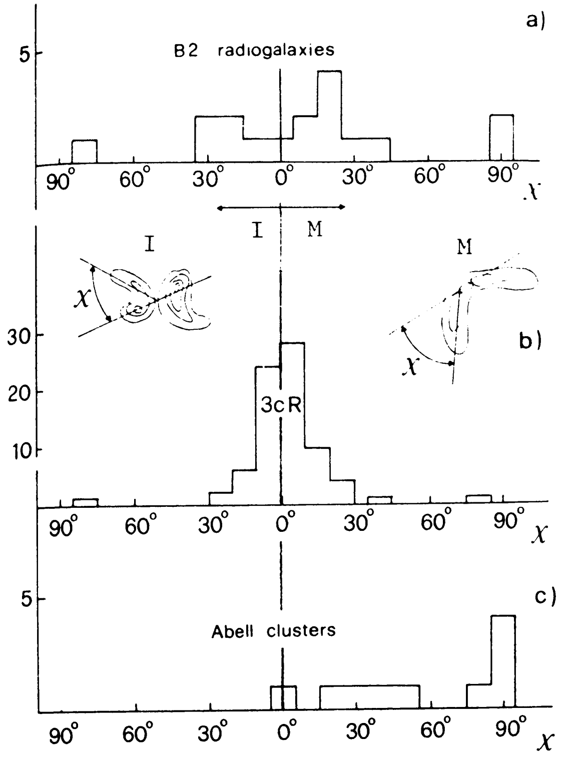

Figure 5. The definition and distribution of the distortion angle χ for a) B2 radio galaxies, b) 3CR radio galaxies, and c) radio galaxies in the Abell clusters. (Ekers et al 1981).

Summarizing these results we can conclude that i) the amount of distortion increases with decreasing radio luminosity, ii) the inversion symmetry is most likely to occur in isolated multiple systems, and that iii) rich clusters convert all morphologies to strong mirror symmetric distortions.

(c) Projection Effects

We can never measure more than the two dimensional projection of the three dimensional radio galaxies. Some take the point of view that the third dimension should be ignored because it is unknown and frown on models that invoke a specific three dimenisonal structure. With everyday objects we can rely on experience to suggest the appropriate three dimensional shapes. We immediately visualize three dimensional houses or trees or light bulbs when we see two dimensional images of them because our experience reminds us what they look like from other directions. Since we never experience radio galaxies from any other direction, our two dimensional maps remain stuck as two dimensional images in our minds.

Two additional points should be kept in mind when considering the effects of projection on morphology: i) intrinsic distortions from linear structures can be amplified by projection, and ii) projection can break mirror symmetry but not inversion symmetry.

Perhaps the only good way we have to get a feel for the three dimensional structures is by looking at a large number of distorted objects. By assuming these are viewed at random angles some constraints can be put on the three dimensional structure. For example an analysis of the 3C sample by Ingham and Morrison (1975) shows that both the source bending and most of the asymmetry in component separation ratio (15-30%) must be intrinsic to the source.

(d) Models

Relative translation between the parent radio galaxy and the surrounding medium can give a natural explanation of the mirror symmetric sources. Large relative velocities are expected in clusters and seem to give a very plausible explanation of the extreme mirror symmetric distortions such as in NGC1265 (Miley et al 1972). The more complex mirror symmetric distortions such as seen in 3C449 (fig. 3b) can be explained in an an analagous way by the slower orbital motion of the radio galaxy about its companion (Blandford and Icke 1978).

Possible explanations of the inversion symmetric distortions involve rotation of the radio ejection axis with respect to the extragalactic medium. Rotation (or shearing) of the medium itself is unlikely because of the large scales ($>$1 Mpc) involved in inversion symmetric sources like 3C315 (e.g. Miley 1980). A simple rotation of the engine is also inadequate to explain the kind of inversion symmetry seen in sources like NGC326 (fig. 4b) and 3C315 (Hogbom 1979). For these the projection of a more complicated precessional motion of the ejection axis is required (Ekers et al 1978a). The presence of nearby companions in most (all?) sources with strong inversion symmetry may provide a clue to the mechanism for swinging the ejection axis. Although they could not directly torque a nuclear engine deep inside the galaxy (such as a black hole), they could influence it by dumping fresh material with different angular momentum or by distorting the gas distribution which may be collimating the jet further out from the nucleus (Smarr private communication).

A different class of model which might be able to explain some inversion and mirror symmetry uses the effcts of bouyancy on jets or plasmons traversing a medium with strong density gradients. Ejection perpendicular to the gradient will produce mirror symmetric bending while ejection at an angle to the gradient can lead to an inversion symmetry. Recent support for this model is given by the observation of the inversion symmetric source 3C293 (Bridle et al 1981). This has a jet which curves towards the minor axis as it comes out of a very flattened galaxy at an oblique angle.

IV. Other Axes

When the radio data is combined with other information on the parent galaxy we can investigate more of the symmetry axes in the system.

Various investigations now show that the major radio axis is preferentially aligned with the minor optical axis of the galaxy (Palimaka et al 1979, Guthrie 1979, Shaver et al this symposium). However many clear exceptions to this correlation occur. Probably the unexpected complexity of the optical morphology of the elliptical galaxies (oblate, prolate or triaxial and some twisted isophotes!) complicate this issue and if we could pin down the physical meaning of the radio axis it might help unscramble the three dimensional optical structure. A clearer correlation is found with the axes defined by dust lanes in elliptical galaxies. The radio axis is usually nearly perpendicular to the dust lane and hence normal to a gaseous disk in these systems (Kotanyi and Ekers 1979), but again there are some clear exceptions.

Finally, we now have enough optical data to make a statistical comparision between the radio ejection axis and the optical rotation axis. The distribution of differences in fig. 6 is taken from the compilation in Ekers and Simkin (1981). This distribution clearly

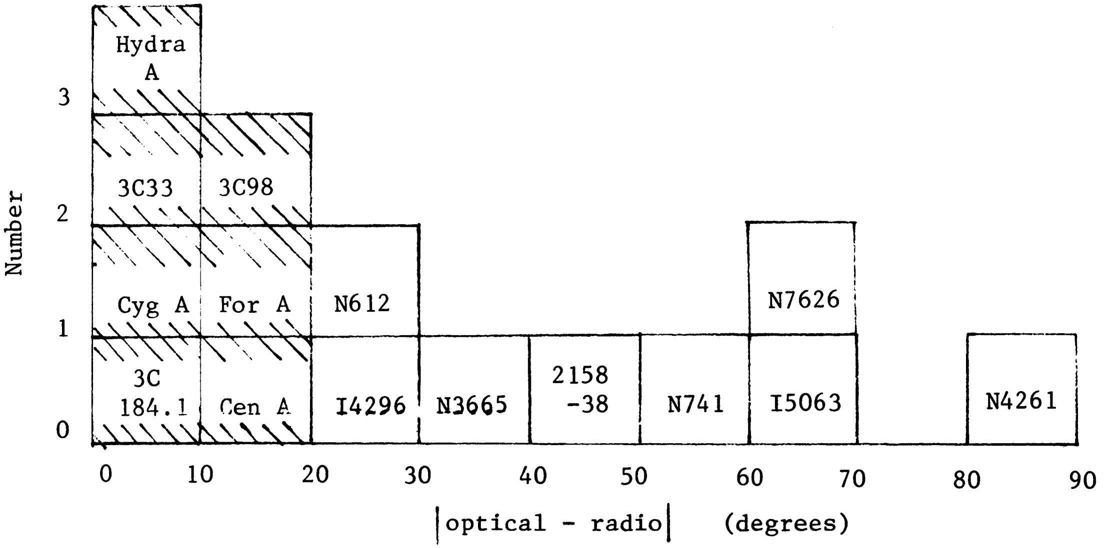

Figure 6. The distribution of differences between the position angle of the optical rotation axis and the inner radio axis of 15 radio galaxies. Objects with radio power 10^{24} WHz^{-1} Ster^{-1} at 1.4 GHz are cross hatched. (from the compilation in Ekers and Simkin 1981).

favours radio ejection along the optical axis but again with many exceptions. However, this also shows that the higher power radio galaxies (shaded) are much more accurately aligned with the rotation axis than those of lower power. This result in combination with the concepts of varying ejection axis direction suggested by the inversion symmetric sources and a general tendency for highly distorted sources to have lower luminosity suggests the following scenario. If the central engine in a radio galaxy happens to be well aligned with the rotation axis a long lived well collimated radio source results and the magnetic field and particle energy from the beam will build up in the lobes. On the other hand if the engine (or whatever does the collimation) is waving the beam about no well collimated structure will form and the energy from the nucleus will be spread over a much larger volume and a much smaller fraction of it will come out of the synchrotron window.

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