Anisotropic continuum emission in active galaxies

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AN important question in our understanding of active galaxies is whether the radiation from the nucleus is emitted isotropically or along a preferred axis. If the radiation is emitted along a particular axis or cone, it could affect significantly our estimates of the total energy release from the nucleus and hence our understanding of the physical conditions in the nuclear region. In addition we could also overestimate the true diversity in the different types of active galaxies. For example, in the so-called *unified schemes*, the appearance of an object depends on its orientation to the line of sight. The observed properties could be significantly different when the object is viewed along the cone or axis of ejection rather than at a large angle to the line of sight, leading to a classification of the two cases as two different types or classes of objects. Also, if one could identify an isotropic and a non-isotropic component, one might be able to use the relative prominence of these two components as a statistical indicator of orientation relative to the line of sight, and probe the geometry of the nuclear region. There has been mounting evidence in favour of anisotropic emission in a variety of active galaxies, ranging from the luminous radio galaxies and quasars to the relatively weak spiral and Seyfert galaxies[1-5]. In this article I attempt to review some of the observational results and theoretical ideas which have helped to mould our current understanding of active galaxies. I start with the powerful radio galaxies and quasars which are amongst the most luminous, most distant and largest objects known in the Universe.

Radio galaxies and quasars

The vast majority of powerful extragalactic radio sources associated with elliptical galaxies and quasars have two lobes of emission on either side of an optical galaxy or quasar. Their overall extent ranges from those which are less than a few parsecs and are well within the confines of the optical galaxy to the giant ones which are over several megaparsecs in size. The extended lobes exhibit a rich variety of structures reflecting different physical processes, such as interaction with the external environment, precession of the ejection axis or the development of instabilities, which could affect their morphology. The sources with extended (> tens of kpc) structure are often classified into the low-luminosity Fanaroff–Riley class I (FRI) sources, which usually have diffuse outer lobes, and the high-luminosity ($>2\times10^{25}$ W Hz^{-1} sr^{-1} at 178 MHz) FRII sources, which tend to have bright hot spots at the outer edges (Figure 1). The FRI and FRII sources differ in a number of other aspects as well. Both types exhibit radio jets which are narrow ridges in the brightness distribution of the radio sources and are believed to be signatures of the beams carrying energy from the active nucleus of the parent galaxy to the outer lobes. However, the jets in FRI sources are usually two-sided with magnetic fields which are predominantly orthogonal to the axis of the jet, while the FRII sources tend to have one-sided jets with magnetic field lines which are largely along the axis of the jet. There also appear to be differences in the morphology of the parent galaxies and their environments, suggesting a fundamental difference in these two types of sources[6-9].

Radio sources have also been traditionally classified into the extended steep-spectrum sources and the compact flat-spectrum ones. The extended sources are dominated by optically thin emission from the extended lobes which have a power-law radio spectrum with a spectral index $\alpha>0.5$. Here α is defined as $S\propto\nu^{-\alpha}$, where S is the flux density of the source while ν represents the frequency of observation. The radio emission from the flat-spectrum sources is dominated by the nuclear or core component which is associated with the active nucleus of the parent galaxy and has a flat and often complex radio spectrum due to its high optical depth. Considerable evidence now suggests that the bulk of the core-dominated sources may be normal lobe-dominated ones seen at a small angle to the line of sight.

Bulk relativistic motion

The genesis of such schemes lay in the early suggestion by Rees[10] of the possibility of the existence of bulk relativistic motion in the nuclei of active galaxies. The observed flux density, S, at a particular frequency, of an optically thin, spherical source which is approaching the observer is given by $S=S_0/(\gamma(1-\beta\cos\phi))^{3+\alpha}$, where $v=\beta c$ is the bulk velocity of motion, γ the corresponding

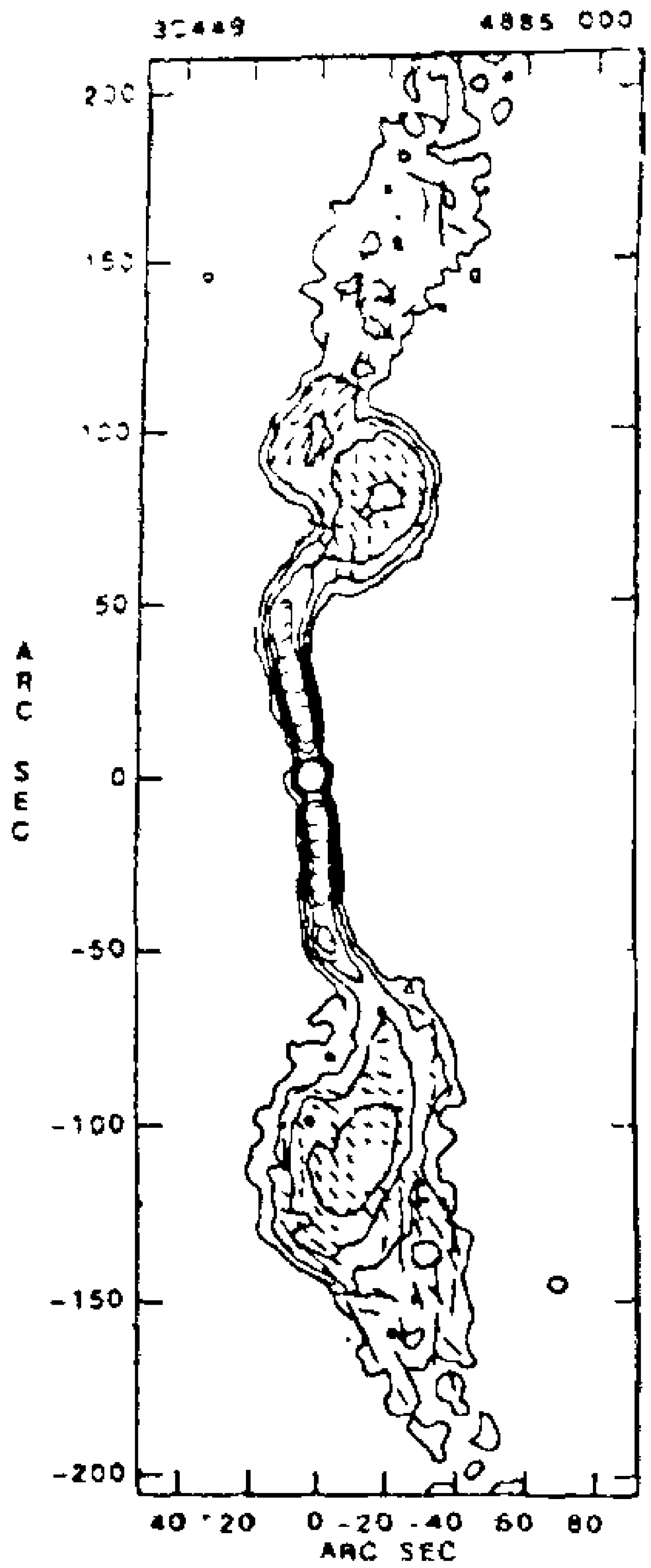

Figure 1a. The Fanaroff–Riley class I radio galaxy 3C449 with two-sided jets and diffuse outer lobes on opposite sides of the flat-spectrum nuclear component. The vectors indicate the direction of the magnetic field lines which are orthogonal to the direction of the jet (Killeen, Cornwell and Perley, in preparation)

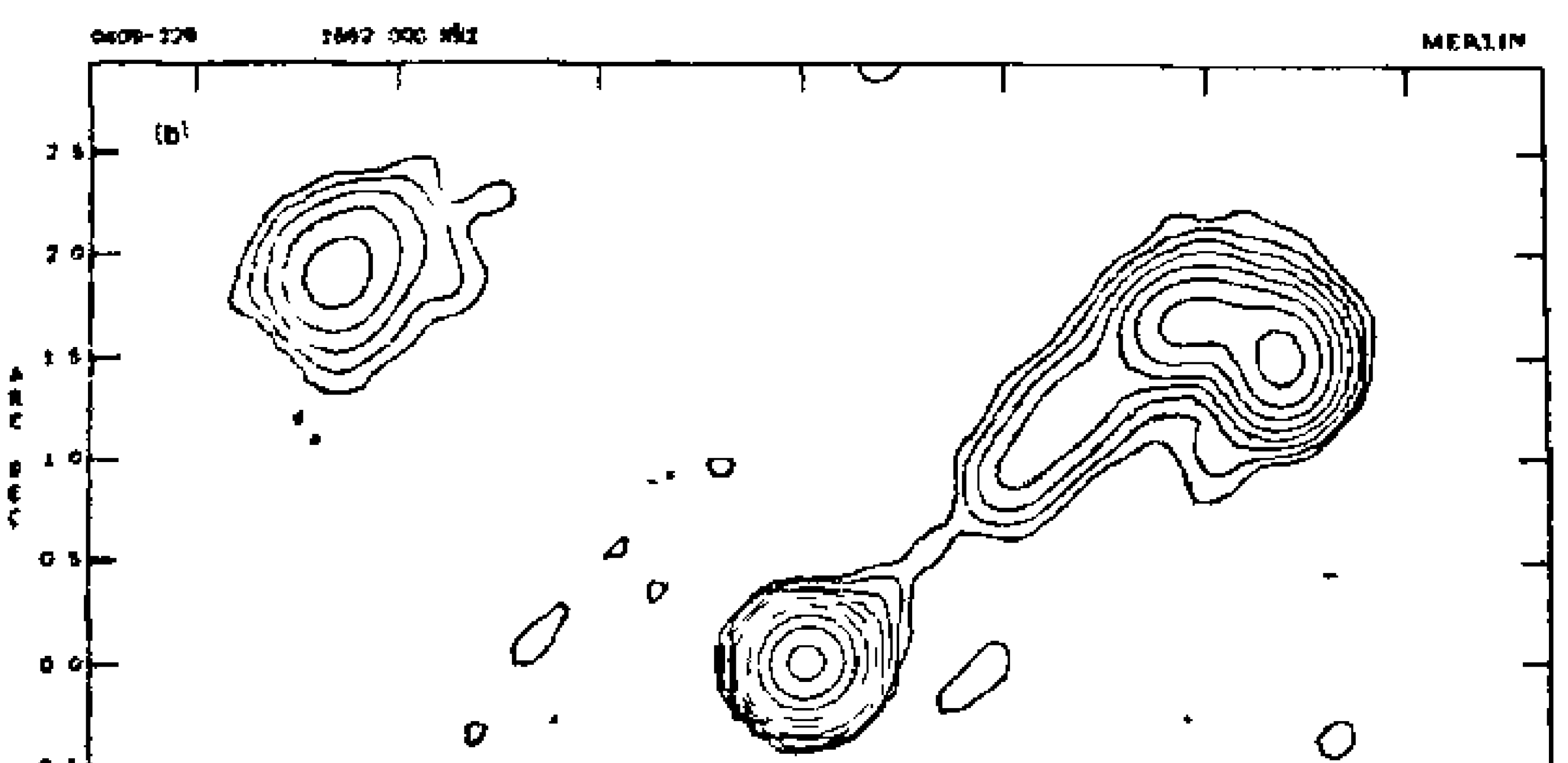

Figure 1b. The quasar 0409+229 with a one-sided radio jet and prominent hot spots on opposites sides of the nucleus[54], characteristic of Fanaroff Riley class II sources. Quasars with weaker cores and almost all FRII radio galaxies are more collinear than the structure shown here. The magnetic field lines in these one-sided jets tend to be along the axis of the jet.

Lorentz factor, ϕ the angle of ejection to the line of sight and S_0 the intrinsic flux density. The index in the above equation reduces to $(2+\alpha)$ for a quasi-continuous jet where the plasmons have a finite lifetime. Needless to say, this is a very simplistic scenario. For example, in a non-steady jet, the radio emission could arise behind shocks in the flow of the jet. Non-planar shocks and optical depth effects are further complications which will also affect the observed flux density[11].

A reasonably wide range of observations of compact core-dominated sources can be interpreted in the relativistic beaming framework. This includes superluminal motion of features in the nuclear radio jets which appear to traverse outwards from the nucleus with apparent velocities which could be as high as about $20c$, where c is the velocity of light. In the conventional scenario, this can be understood easily if the radio-emitting components are ejected from the nucleus with a velocity of $\sim c$ along an axis close to the line of sight[12,13]. The apparent transverse velocity of separation, β_{app}, of the component from the nucleus is related[14] to the true velocity β by $\beta_{app} = \beta \sin\phi/(1-\beta\cos\phi)$. β_{app} has a maximum value of $\gamma\beta = (\gamma^2-1)^{\frac{1}{2}}$ when $\sin\phi = 1/\gamma$.

The nuclear jets which are imaged with angular resolutions on the scale of milliarcsec using very-long-baseline-interferometry techniques tend to be one-sided even though the outer lobes are reasonably symmetric. The nuclear jets tend to point in the same direction as the large-scale jets which can extend for a hundred kpc or more. In the relativistic beaming scenario the apparent one-sidedness is a natural consequence of bulk relativistic motion since the flux density of the approaching jet is enhanced while that of the receding one is diminished. Although this appeared to be a viable explanation for the nuclear jets where there is direct evidence of bulk relativistic motion, it was not clear whether such an explanation was also tenable for the extended radio jets. Early arguments relied on their occurrence preferentially in sources with strong cores, and correlations with symmetry parameters which also depended on orientation[15]. The most convincing evidence that the extended radio jets are on the approaching side, as expected in the relativistic beaming scenario, comes from the strong correlation of depolarization asymmetry with jet sidedness[16–18]. These observations have shown that for a sample of mostly quasars the lobe on the side facing the jet exhibits very little depolarization between $\lambda 6$ and 20 cm while the lobe on the opposite side shows strong depolarization. If the depolarization is attributed to ionized gas in the parent galaxy or its 'halo', the jet and the lobe on the same side must be approaching us. Similar studies for radio galaxies belonging to both FR class I and class II are in progress.

The problem of detecting much lower Compton-scattered X-ray flux density compared to those predicted by measuring the size and brightness of the compact component can be alleviated by invoking bulk relativistic motion in the active nucleus[19, 20]. Variability of radio sources in both total intensity and linear polarization can also be understood with a reasonable degree of success using models of flow of plasma in the form of jets with high velocities. However, the variability of compact radio sources at low frequencies ($\leq$ 1 GHz) could also be due to refraction of radio waves by irregularities in the interstellar medium, a phenomenon referred to as refractive interstellar scintillation or RISS (ref. 21).

Unified schemes

If compact core-dominated sources can be understood with a reasonable degree of success in terms of relativistic jets inclined at small angles to the line of sight, it is important to enquire into the nature of their parent population which should be inclined closer to the plane of the sky.

The first attempt to understand what the unbeamed parent population of the compact core-dominated quasars might be was made by Scheuer and Readhead[13]. In their classic paper they suggested that the unbeamed quasars would appear as radio-quiet quasars. The most important objection to this scenario arose with the realization after deep imaging of compact radio sources with both the Very Large Array and MERLIN that they have lobes of extended emission with properties similar to those of the luminous double-lobed sources. The extended emission is believed to be traversing outwards at best with only mildly relativistic velocities and should appear with similar intensities even when the source is at a large angle to the line of sight. The radio-quiet quasars were often found to be weak radio sources with luminosities which were too low for the Scheuer–Readhead scenario to be correct.

The detection of extended emission in core-dominated sources led naturally to the suggestion that the normal lobe-dominated quasars are the unbeamed counterparts of the core-dominated ones[22,23]. Orr and Browne[23] showed the source counts of radio sources and the fraction of flat-spectrum sources in samples complete to different flux density limits to be consistent with such a scenario, while Kapahi and Saikia[22] arrived at a similar conclusion by correlating source symmetry parameters with the degree of core prominence which is being used as a statistical measure of source orientation. These initial studies were confined to radio properties of quasars which are of high radio luminosity and belonged to class II of the Fanaroff and Riley classification scheme.

It is important to enquire whether such a scheme could be extended to the optical and X-ray continuum of these sources. The principal argument against such an extension was the small range in emission line equivalent widths of quasars. Since, unlike the continuum, the line luminosity is not expected to depend significantly on orientation, relativistic beaming of the continuum should cause a large spread in the equivalent width of the emission lines, with the core-dominated sources having lower equivalent widths than the lobe-dominated ones. Jackson *et al.*[24] observed a sample of 46 radio-loud quasars using the faint-object spectrograph in the Isaac Newton Telescope to show that the equivalent widths of the [OIII] emission line is anticorrelated with the degree of core prominence (Figure 2). Earlier evidence of a beamed optical continuum came from comparisons of the optical magnitude or luminosity of core- and lobe-dominated quasars with similar extended radio luminosity[25, 26]. Browne and Murphy[27] have also shown that for a given extended radio luminosity the X-ray continuum for core-dominated quasars is stronger than for the lobe-dominated ones.

The demonstration that the continuum radiation has an anisotropic component is of fundamental importance since this affects the overall energy budget and also the models for the emission line regions which must take account of the fact that different parts of the line-emitting region must be seeing different photoionizing continuum radiation. It is important to note that thermal radiation from an optically thick disk whose direction is parallel to the radio axis[28] is also likely to produce anisotropic continuum radiation. Since the effects of relativistic motion dominate in core-dominated sources, this effect may be noticeable in weak-cored sources and remains to be investigated.

The existence of anisotropic continuum radiation also implies that the assumption that selection of

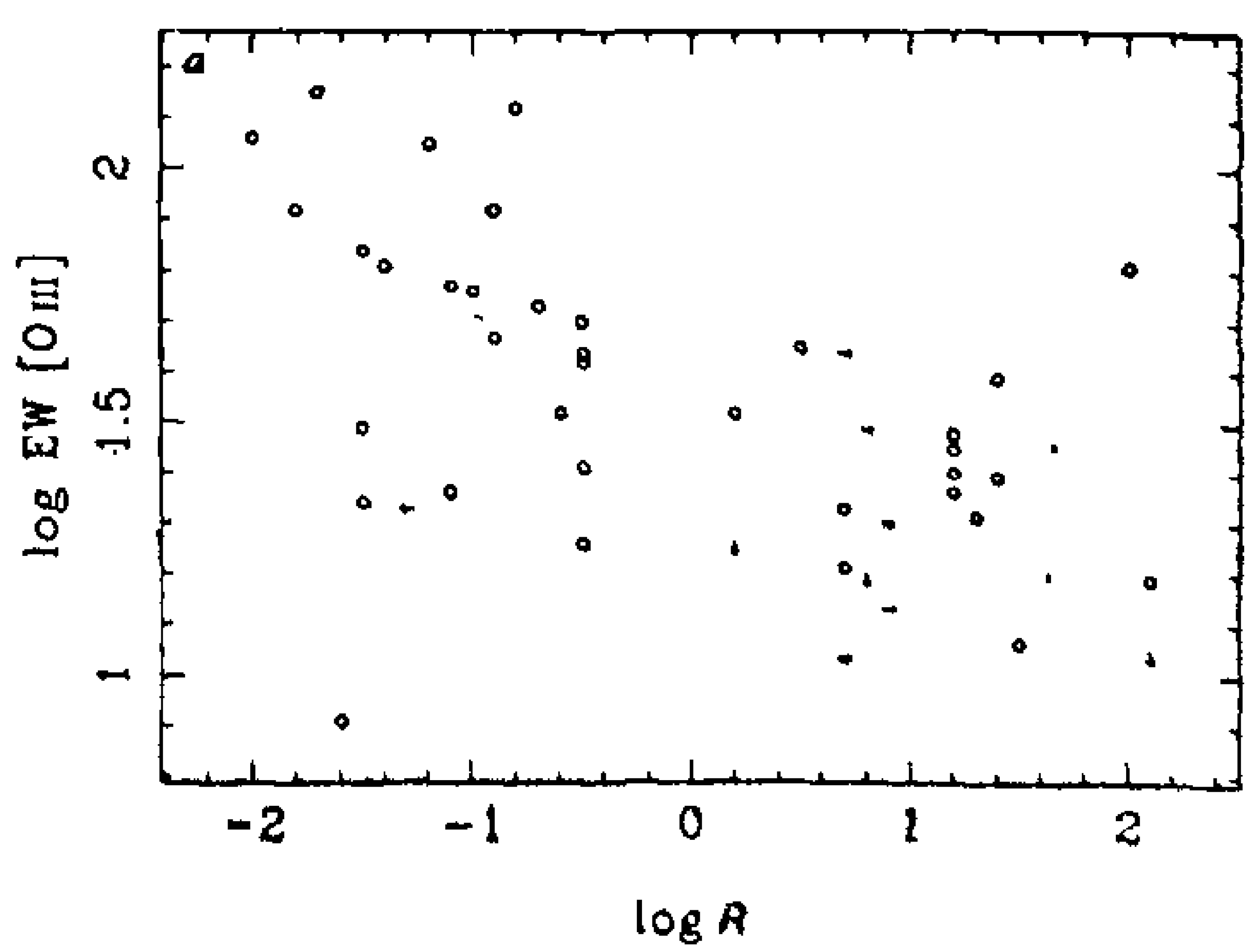

Figure 2. The anticorrelation of the equivalent width of the [OIII] emission line for a sample of quasars with R, the ratio of the nuclear or core flux density to that of the extended emission[24].

quasars by their optical or X-ray brightness leads to samples which are randomly distributed in the sky is possibly not valid. A property which is likely to be orientation independent is the environments of these sources. If the core- and lobe-dominated quasars differ only in their orientation, then their environments, for example their local galaxy density, must be similar. Although there have been a few studies of the environments of radio sources, it is not clear at this stage whether there is any significant difference between the core- and lobe-dominated sources[29,30].

The next piece to be fitted in this puzzle are the luminous Fanaroff–Riley class II radio galaxies, whose extended lobes of radio emission with hot spots at the outer edges and one-sided jets when detected are similar to those of the quasars, except that the galaxies have much weaker cores. Owen[31] suggested that the radio galaxies may be the unbeamed quasars, with the lobe- and core-dominated quasars being seen at progressively smaller angles to the line of sight. This was discussed further by Scheuer[32] and Barthel[33] who presented and suggested several statistical tests of such a scenario. To explain the spectral differences between the radio galaxies and quasars several magnitudes of extinction are required[34].

In Figures 3*a* and 3*b* I show the projected linear size and the misalignment angle, Δ, of a large sample of Fanaroff–Riley class II radio galaxies and quasars selected at 178 MHz, plotted against the fraction of emission from the core, f_c at an emitted frequency of 8 GHz, which is being used as a statistical indicator of the orientation of the source to the line of sight. If the galaxies appear as quasars when inclined at a small angle to the line of sight, they should have larger

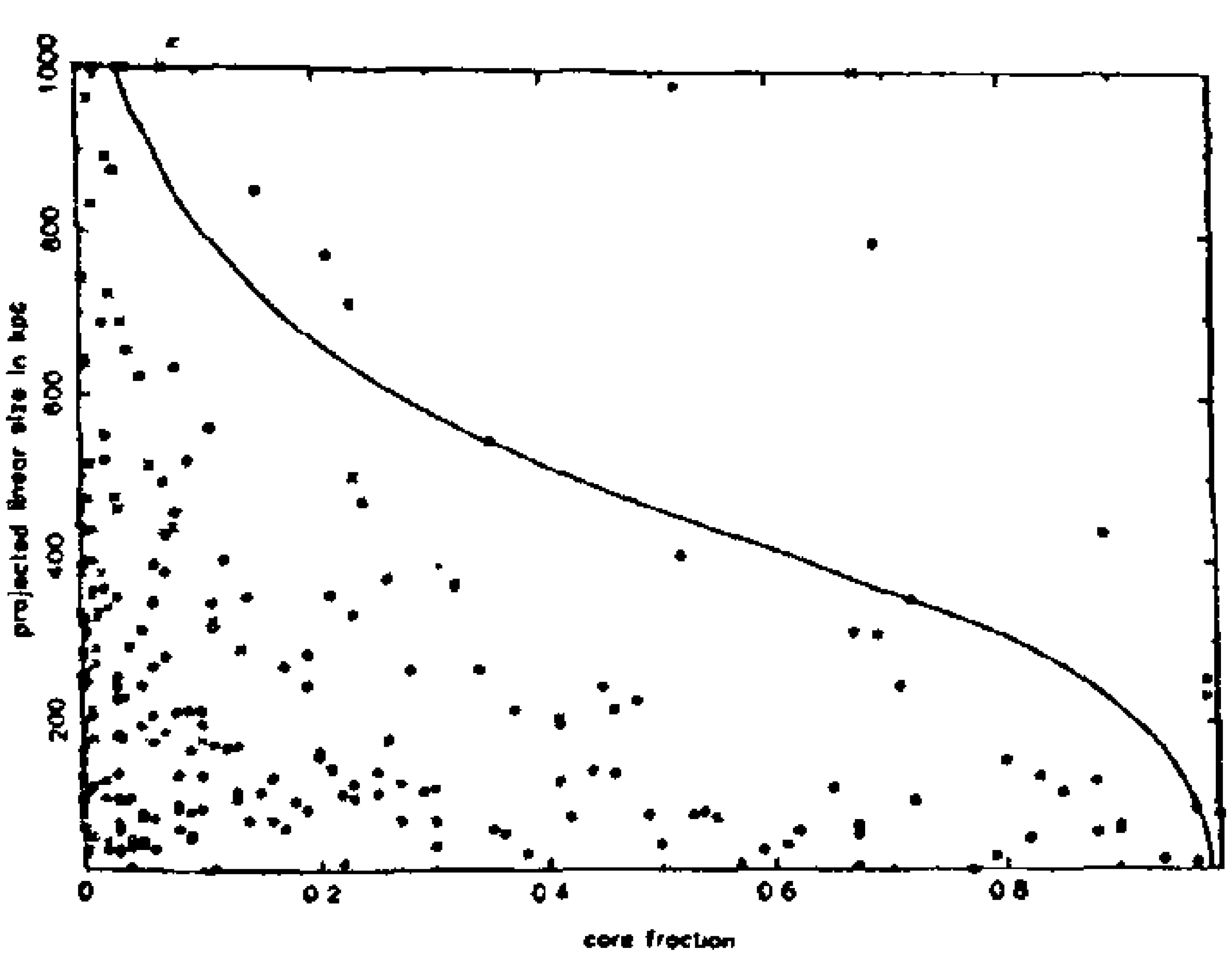

Figure 3a. The projected linear size in kpc is plotted against the fraction of emission from the core, f_c, which is being used as a statistical measure of orientation of the source, for a sample of radio galaxies (×) and quasars (○). The continuous line indicates an upper envelope to the diagram based on the relativistic beaming scenario[35].

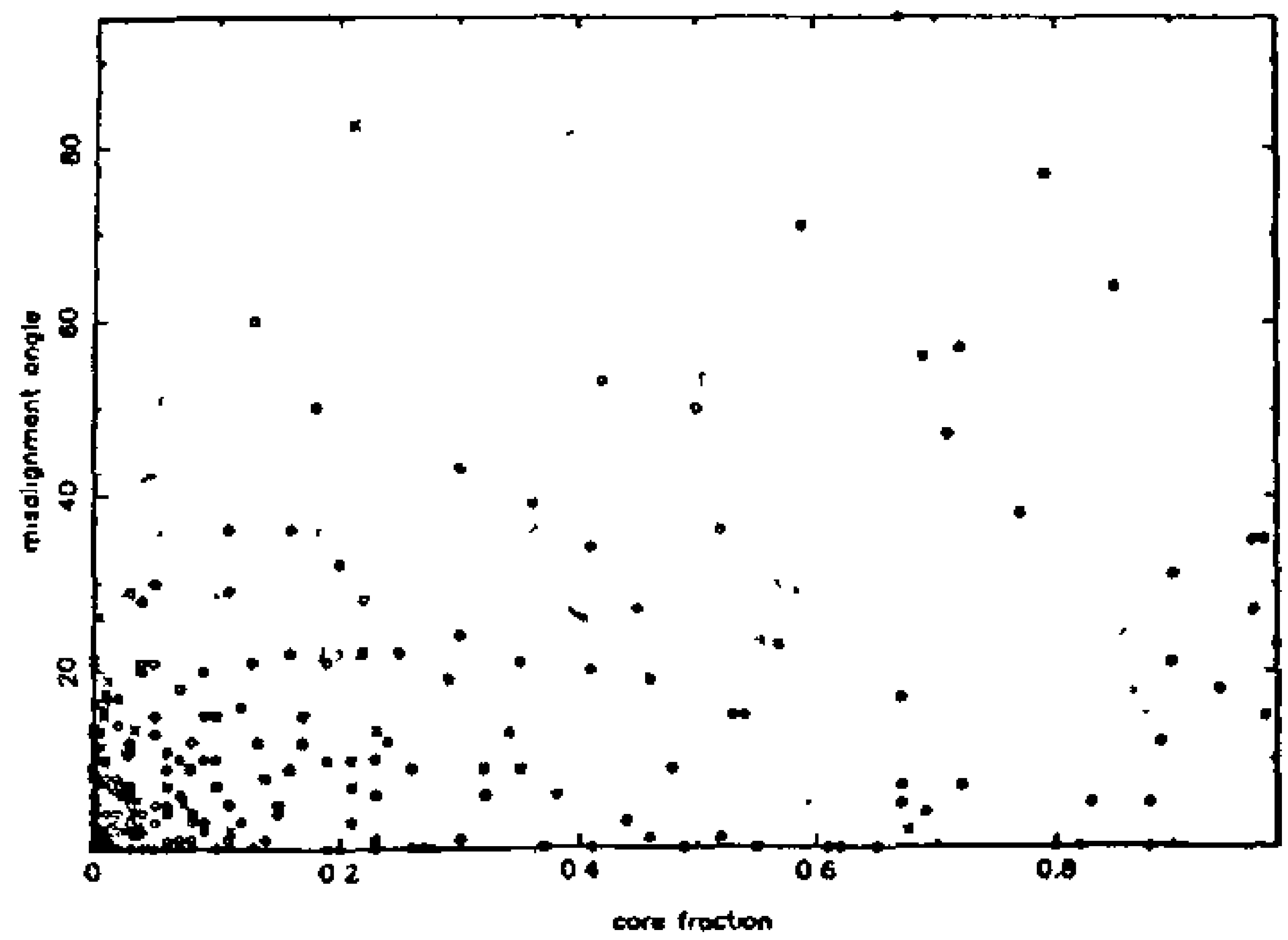

Figure 3b. The misalignment angle, Δ, defined as the supplement of the angle formed at the nucleus by the outer hot spots, plotted against the fraction of emission from the core[36]

projected sizes and appear more collinear than the quasars besides having weaker cores. The f_c–l diagram is consistent with the expected trend. For sources seen in the plane of the sky the degree of observed non-collinearity is similar to the intrinsic values, while for sources seen at small angles the intrinsic non-collinearity can appear amplified when projected onto the plane of the sky. I had earlier used this as a test of unification of lobe- and core-dominated quasars. Extension of this test to both radio galaxies and quasars shows that, while Δ is almost invariably less than about 20° for galaxies, the quasars tend to have higher values especially for the core-dominated ones[35,36]. This is what is expected in the unification scheme.

Another possible test of such schemes is to monitor the variability of the nuclear or core emission. For the beamed sources, small intrinsic changes either in the flux density or orientation can cause significantly larger observed changes in the brightness of the core. Comparison of the flux densities of small samples of core- and lobe-dominated sources suggests that this may indeed be the case[36], although studies of larger samples are required to establish this.

Blazars

The most extreme form of variability is exhibited by the blazars, a term which has been used to describe the BL Lac-type objects and the highly polarized quasars or HPQs (refs. 37–39). The BL Lac-type objects are relatively nearby and have weak or no emission lines while the HPQs have spectra with prominent emission lines, similar to those of other quasars. However, for both types of objects, the optical nuclear emission is highly polarized (⩾ 3%) and strongly variable. These similarities and the disappearance of the emission lines in a few cases during an outburst when the continuum is significantly enhanced led to the belief that they are similar kinds of objects; they were collectively called blazars. However, more recently a number of significant differences have been recognized, which suggest that they are intrinsically different[40]. The HPQs are invariably radio sources and have a core-dominated radio structure. Although initial polarimetric surveys which had a large proportion of lobe-dominated quasars selected from low-frequency surveys suggested that only a small fraction exhibit blazar-like activity, our perception has changed significantly after observations of samples of sources selected at a high radio frequency ($\geqslant 1$ GHz) and hence with a larger proportion of core-dominated objects. Surveys by various workers[41–43] show that at least 60% and perhaps all flat-spectrum core-dominated objects exhibit blazar activity. The objects have active and quiescent phases so that more frequent observations are required to detect such activity in all of them.

The blazar characteristics of the HPQs whose extended radio emission is similar to other radio-loud quasars is consistent with the unified scheme where these flat-spectrum sources are believed to be at small angles to the line of sight. Such an explanation for blazar behaviour in terms of relativistic jets pointed close to the line of sight was suggested by Blandford and Rees[44].

But now, what about the BL Lacs which are relatively nearby and with lower luminosities characteristic of FR class I sources for the extended emission? If they too are inclined at small angles to the line of sight as suggested by their blazar characteristics, core-dominated radio structure, and observation of superluminal motion in a number of them[45–47], then what is the unbeamed parent population of the BL Lacs? A possible suggestion is that they are the low-luminosity relatively nearby Fanaroff–Riley class I radio galaxies[48–50]. Their radio, X-ray and optical properties appear to be consistent with such an interpretation[51–52]. The correlation of Hine and Longair[53] in which the emission line strength is weaker for the low-luminosity Fanaroff–Riley class I sources than the more luminous class II ones would also be consistent with this interpretation. In this scenario the flat-spectrum radio galaxies without evidence of blazar characteristics are either BL Lacs in a quiescent phase or galaxies seen at somewhat intermediate angles[54].

Anisotropic optical and infrared emission

With strong observational evidence in favour of anisotropic beams of continuum emission from the luminous radio galaxies and quasars, a lot of effort has been spent in trying to understand the interaction of these beams with the interstellar medium of the host galaxies, and also to look for evidence of an active nucleus in the scattered light when the nucleus is hidden from us by an obscuring torus or disk.

Antonucci[55] made polarimetric observations of the FR class II radio galaxy 3C234 and found that the broad lines and the continuum are both strongly polarized, and hence scattered into our line of sight. An opaque torus hides the broad lines and the continuum nuclear source whose estimated luminosity is similar to that of quasars. Such observations provide strong evidence in favour of the quasar–galaxy unification scheme for FR class II sources, and need to be enlarged for a larger sample of sources.

A striking example of possible scattering of a beam of radiation from the nucleus is seen in the radio galaxy 2152–69 where a high-ionization cloud roughly along the radio axis but well separated from the active galaxy is strongly linearly polarized (12 ± 3%) and has a spectrum which rises sharply towards the blue[56, 57]. A natural explanation is that a beam of radiation from the nucleus is scattered to our line of sight by the cloud, which is ionized by the beam and exhibits high-excitation emission lines.

Another interesting discovery made independently by McCarthy *et al.*[58] and Chambers *et al.*[59] showed that the long axes of the distant radio galaxies tend to be aligned with the radio structure. This is in contrast to that of nearby radio galaxies (redshift $\leqslant 0.2$) where the radio structure tends to be perpendicular to the major axis of the optical galaxy particularly for the giant sources[60] and for those with strong cores[61]. The alignments for the high-redshift galaxies are known to occur at infrared wavelengths as well[62, 63]. The most popular explanation for the alignment effect is star formation induced by the radio source[64, 65], as has been seen in the nearby radio galaxy PKS0123–016 where star formation is possibly induced by the interaction of the radio jet with Minkowski's object[66, 67]. However, the detailed nature of the optical–infrared continuum continues to be controversial. The rest-frame ultraviolet light from the high-redshift galaxies 3C277.2 and 3C368 is linearly polarized with the E-vector perpendicular to the radio axis. For 3C368 the polarized emission is also extended suggesting that at least some of the light from the extended optical images is due to scattering of beamed nuclear emission, probably by dust[68]. Not all the light can be scattered nuclear radiation. Dust scattering poses problems for explaining the infrared alignments because of the inefficiency in scattering red light. Also, the presence of stellar absorption features in their ultraviolet spectra provides perhaps the best evidence that the extended optical–infrared continuum consists of stars[69]. A young stellar population induced by the radio source, together with the presence of gas and dust which may be clumped differently, appears to provide a plausible scenario for the optical–infrared continuum emission[70].

The emission-line properties of radio galaxies have been investigated in recent years by a number of authors[71–76]. The emission lines tend to be along the radio axis, are generally much smaller than the radio lobes and can be best understood in terms of an anisotropic ionizing continuum source. The similarity of the extended emission lines to the nuclear emission lines lends support to such a scenario. In a few cases, the detection of emission-line gas well beyond the radio hot spots provides further evidence in favour of an anisotropic beam of continuum emission from the nucleus[75].

Seyfert galaxies and their unification

Seyfert galaxies have prominent emission lines and are classified spectroscopically into two main types. The Seyfert 1s have broad permitted lines and narrow forbidden lines while for the Seyfert 2s the permitted and forbidden lines are both narrow. The optical polarization of Seyfert 1 galaxies is aligned with their radio structure, while for Seyfert 2 galaxies these two features appear to be orthogonal[77].

There has been mounting evidence in the last few years or so, that the ionizing radiation from the nucleus escapes in two wide, oppositely-directed cones, the axes of the cones being similar to that of the radio structures (Figure 4). The existence of these cones of emission has been inferred from a variety of arguments. Unger *et al.*[78] found that the extended narrow-line regions in Seyfert galaxies appear to be more extended in a direction along a radio axis than in the direction perpendicular to it. Wilson *et al.*[79] suggested that there is an energy deficit when comparing the ionizing photon flux required for the extended narrow-line region than inferred from direct observations of the nucleus. The most spectacular evidence is the cones of high ionization gas which point back towards the nucleus. Such cones have been seen in the most extended systems, such as NGC1068, NGC4388, NGC5728 and NGC5252 which is perhaps the most impressive example[80].

The emergence of cones of ionizing radiation is a natural consequence of a simple scheme for the nuclear region of Seyfert galaxies in which the central ionizing continuum source and the broad line region (BLR) which extends to about a few parsec are surrounded by a torus of material that defines the cones of emission. The narrow-line region, or NLR, which lies beyond the BLR, extends to about a few hundred parsecs. In such a scheme the appearance of the source would depend on the orientation of the cone with respect to the line of sight. If our viewing angle is within the cone of emission of the galaxy it will appear as a Seyfert 1 where we will

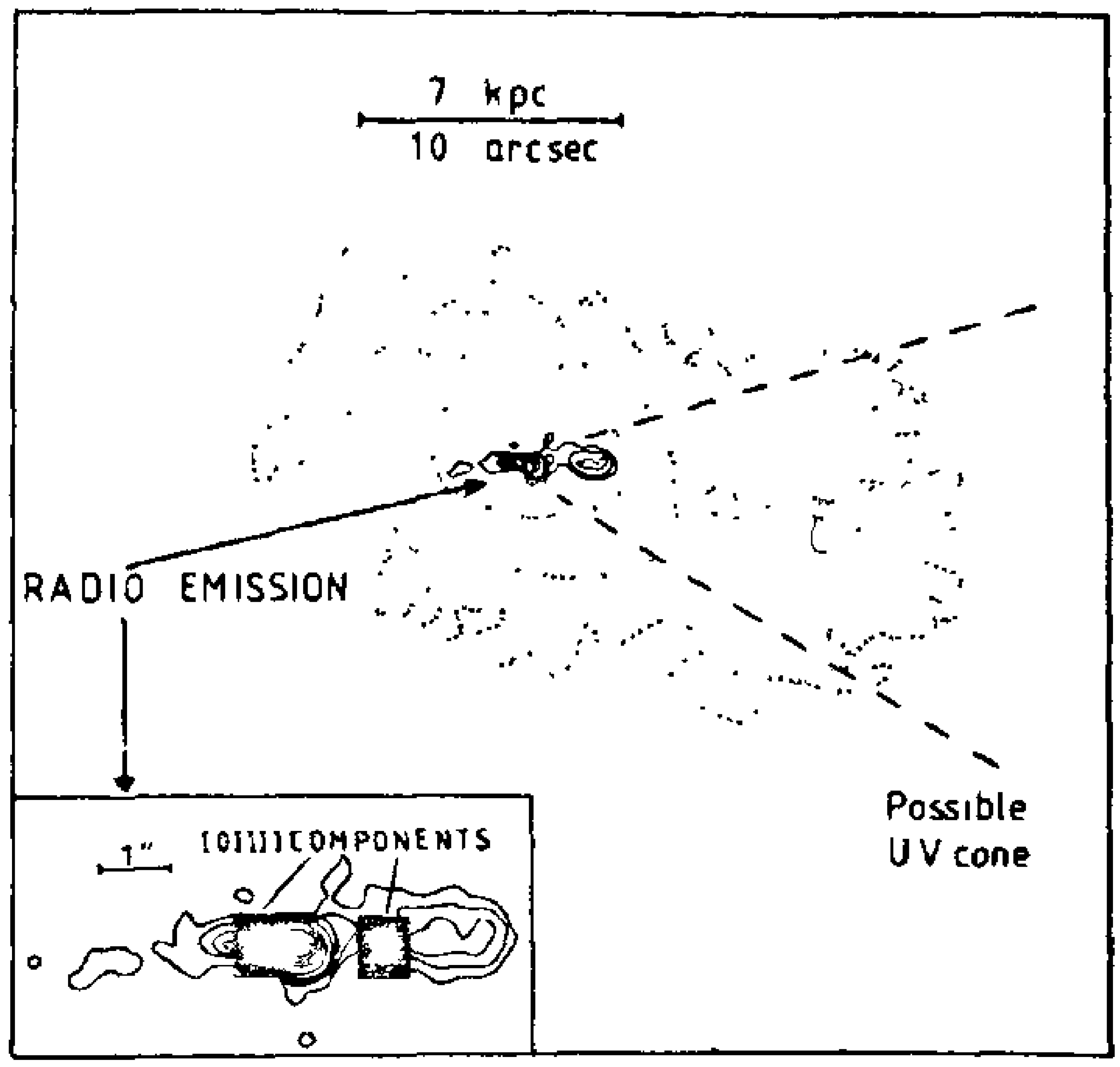

Figure 4. Relationship between the radio and the extended [OIII] gas in the Seyfert galaxy Mkn 78 (ref. 91). The dotted contours show the galaxy in [OIII] λ5007 Å. The extended emission seen on the west is the extended narrow-line region and the possible cone of UV radiation from the nucleus is indicated. The continuous contours represent the radio emission, which is also shown in the inset with blobs of [OIII] emission superimposed on it.

see the broad emission lines, while at larger angles to the line of sight the broad line region and the nucleus would be obscured by the torus. The galaxy would then be classified as a Seyfert 2. The possibility that orientation may play a role in the observed properties of Seyferts is old[81]. But the possibility that the differences between the different types of Seyferts may be due to their orientation became a very attractive idea with the discovery of 'hidden' Seyfert 1 nuclei in several Seyfert 2 galaxies.

Spectropolarimetric observations of the classic Seyfert 2 galaxy NGC1068 show that the polarized flux density has emission lines characteristic of a Type 1 Seyfert while the overall spectrum has strong narrow lines, characteristic of a Seyfert 2. Polarization of the emission lines implies that the polarization is due to reflection. The position angle of polarization is orthogonal to the radio structure, as in other Type 2 Seyferts, implying that the photons last flight was roughly along the radio axis[4,82]. Spectropolarimetric observations of the north-east knot in NGC1068 also show evidence of broad emission lines characteristic of a Seyfert 1, suggesting again that we are seeing the nuclear light reflected by this cloud. There have been similar searches for hidden Seyfert 1 nuclei in a number of other Seyfert 2s. Although not all searches have been successful, hidden Seyfert 1 nuclei have been seen in a number of cases[4], such as Mrk 3, Mrk 348, Mrk463E, NGC591 and NGC7674.

An interesting example is the edge-on spiral galaxy NGC4388 in the Virgo cluster of galaxies. The distribution, ionization and kinematics of the emission line gas provide evidence of wide ionization cones extending both below and above the disk of the galaxy. The axes of the cones are similar to the radio axis but the regions of ionized emission extend far beyond the radio structure. A Seyfert 2 nucleus was identified by Phillips and Malin[83] but more recent spectroscopic observations have shown evidence of extended broad Hα emission outside the nucleus, which must be due to scattering of emission from a hidden Seyfert 1 nucleus[84,85]. Multifrequency radio observations of this source with high resolution and sensitivity have helped to identify the true nucleus of the galaxy from which radio-emitting plasma is squirting out in opposite directions[86].

Although evidence of hidden Seyfert 1 nuclei has been seen in a number of Seyfert 2 galaxies it is natural to enquire whether this is true of all Seyfert 2 galaxies. If Seyfert 2s do not appear to have broad emission lines because they are hidden from our view, why do we see their featureless continuum which is believed to arise below the BLR? If this too is scattered light it must be polarized. Polarimetric observations of the continuum are required to establish whether this is the case. The unification of the different types of Seyferts in a simple scenario where orientation relative to the line of sight plays an important role is attractive and appears to have a reasonable degree of truth. However, it seems premature to conclude that all Seyfert 2s have a Seyfert 1 nucleus and rob nature of the ability to make genuine Seyfert 2s.

Concluding remarks

Observations have demonstrated the existence of narrow collimated beams of non-thermal emission and broader cones of ultraviolet radiation in a variety of active galaxies. Detailed studies of our galaxy also suggest similarities to the structures seen in more active spiral nuclei[87]. Unification schemes which attempt to understand different types of active galaxies as being intrinsically similar but appearing to be different because of their orientation relative to the line of sight have had an impressive degree of success. But there is no dearth of sources which make us feel uncomfortable: The VLBI image of the compact steep-spectrum quasar 3C48 made by Wilkinson *et al.*[88] is difficult to understand as a normal double-lobed radio galaxy seen end-on; the extended weak emission seen around the BL Lac object 3C66A in a deep Westerbork image (de Bruyn 1991, private communication) makes the projected size of the source about a couple of Mpc, which is too large for a source seen end-on; a group of one-sided sources whose asymmetry if attributed to relativistic beaming of the large-scale emission would be incompatible with their relatively weak nuclear radio emission where the velocities are expected to be higher[89]; the classic source 3C273 which appears one-sided[90] to a level of ~4000 to 1 although a feature seen on the approaching side has been suggested to be the counter-lobe seen in projection[54]—just a few of the many possible examples for the high-luminosity radio galaxies and quasars. However, the success in explaining many of the gross features suggests that the basic ideas must be true at some level. Or are we re-enacting the story of the epicycles? As we continue to 'dance round in a ring and suppose' (Robert Frost, *The Secret Sits*), it is perhaps important to keep in mind the advice given by Hamlet to Horatio when he found the ghost 'wondrous strange': 'And therefore as a stranger give it welcome. There are more things in heaven and earth, Horatio, Than are dreamt of in your philosophy.'

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