UNIFIED MODELS FOR ACTIVE GALACTIC NUCLEI AND QUASARS

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1.   INTRODUCTION

Because the critical central regions of Active Galactic Nuclei (AGN) and quasars are strongly nonspherical but spatially unresolved, orientation effects have been the source of much confusion. In fact, it now appears that much of the variety in AGN types is just the result of varying orientation relative to the line of sight.

We can define an extreme hypothesis, the straw person model (SPM), in which there are two basic types of AGN: the radio quiets and the radio louds. For each type there is a range in intrinsic luminosity, and the luminosity controls some properties such as the Fanaroff and Riley classes. However, at a given intrinsic luminosity, all other properties such as spectroscopic classification and VLBI component speeds are ascribed to orientation. This model is only a caricature of the unification idea, and is already ruled out on many grounds, but it will be useful for organizing the discussion. I'll describe what I consider to be convincing evidence that orientation effects are important and widespread. The true situation may be in some sense half way between the SPM and the hypothesis that orientation doesn't affect classification at all. To us optimists, the orientation cup is half full rather than half empty. Although it is too soon to say for sure, the hypothesis that most objects' classifications would be different if seen from other directions is a tenable one today.

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There is a nice simplification which seems to be quite solid and generalizable. It appears from observation that the IR/optical/UV properties of lobe-dominant radio sources are generally similar to those of radio quiet AGN. (Probably the core-dominant radio louds have these components too, but they are often swamped by anisotropic emission.) Radio louds are not *modified* versions of the quiets; instead, they have complete and rather normal radio quiet AGN inside, plus seemingly unrelated radio sources. This is not a semantic distinction. A key illustration of the observational importance of the point is the behavior of the lobe-dominant radio sources in the millimeter region of the spectrum. Historically, it has often been speculated that the lobe-dominant quasars simply have spectral cutoffs at lower frequencies than the quiets. This idea has been used, for example, in trying to explain slight differences of the broad line ratios in louds and quiets. It implies a large flux in the putative turnover region around 1 mm. The observations say that there is a gigantic hole in the spectral energy distributions at that point, so that the IR sources are like those in the quiets, and unrelated to the radio cores (Antonucci et al 1990). For this reason, I will first discuss the quiets, and then the louds, carrying over the folklore as much as possible, and treating the radio emission as an added separate component.

Section 2 will contain a list of types and a summary of the phenomenology of the quiets; a detailed description of the prototype Seyfert 2/1, NGC 1068; an update on polarization observations of quiets in general, as it bears on unified models; nonpolarimetric evidence for unification of the quiets; and a discussion of many fine points in the debate about just how close the SPM is to the truth.

The radio louds will be discussed in Section 3. After presenting some phenomenology, I discuss the evidence for unification of the *narrow line radio galaxies* (NLRGs) with the *broad line radio galaxies* (BLRGs) and lobe-dominant radio quasars, and the resulting relaxation or resolution of the statistical anomalies associated with relativistic beaming. Some history of the unification ideas for blazars and other core-dominant radio sources with lobe-dominant broad line radio galaxies and quasars are also presented, as are many fine points regarding the accuracy of the SPM.

The SPM incorporates the following assumptions. Among the radio quiets, all have broad line regions and optical *featureless continua* (FCs), which are surrounded by optically opaque tori, and the tori are oriented perpendicular to the (weak) radio jets. Face-on objects are called Type 1 spectroscopically, and the edge-on objects are called Type 2. All sources have intrinsically the same geometry, e.g. torus opening angle. For the Type 2s, we can see the Type 1 nucleus in reflected (polarized) light. The radio loud sources have, in addition, twin synchrotron-emitting jets which,

at least at their bases, undergo bulk relativistic motion. The jet "opening angle" is small so that the synchrotron emission is beamed into a cone set by the jet speed; all jets have the same speed intrinsically. Observed close to the jet direction, beamed synchrotron radiation from the base of the jet contributes heavily to or dominates the optical flux, leading to a *blazar* classification.

The final section of this paper is a wish list for some future projects.

Table 1 provides a summary of abbreviations used in the text.

2. RADIO QUIET AGN

2.1 *Types and Phenomenology*

The SPM says that there are two basic spectroscopic classifications of quiets: Type 1 and Type 2. The latter have permitted and forbidden lines from a *narrow line region* (NLR) in their flux spectra. Typically, the line widths are $\lesssim 1000$ km/sec and $F([O\ III]\lambda 5007)/F(H\beta) \sim 10$. The Type 1s have the same characteristics, but in addition, exhibit permitted lines from the *broad line region* (BLR), with widths $\sim 10,000$ km/sec, and ratios indicative of optical depth effects in addition to recombination and collisional excitation. They also have strong variable featureless continua in proportion to their broad line emission. At low nuclear luminosities, the host galaxies are clearly visible and the term Seyfert galaxy is used instead of quasar. At high bolometric luminosities, it had been thought that Type 2s are very scarce, but arguably there are many hiding as a subset of the ultraluminous infrared galaxies.

Table 1 Abbreviations

AGN	Active Galactic Nucleus/Nuclei
BAL	Broad Absorption Line (Quasar)
BBB	Big Blue Bump
BLR	Broad Line Region
BLRG	Broad Line Radio Galaxy
FC	Featureless Continuum/Continua
FR1 and FR2	Fanaroff and Riley class
FSCD	Flat Spectrum Core-Dominant (Radio Source)
GRO	(Compton) Gamma Ray Observatory
LINER	Low-Ionization Nuclear Emission Region
NLR	Narrow Line Region
NLRG	Narrow Line Radio Galaxy
NLXG	Narrow Line X-Ray Galaxy
OVV	Optically Violently Variable (Quasar)
SPM	Straw Person Model
SSLD	Steep Spectrum Lobe-Dominant (Radio Source)

Finer gradations can be made. As the strength of the narrow components increases relative to the broad components, the AGN are sometime assigned to Types 1.5, 1.8, and 1.9. [Historically, the 1.9 category has been reserved by Osterbrock for objects showing detectable broad Hα but not Hβ, based on moderate resolution and signal-to-noise ratio (SNR) spectral data.] These ideas are described in Osterbrock (1989).

Generally speaking, the Type 1s have strong keV X-ray emission and the Type 2s do not. Strong X rays have been detected from a few of the objects historically called 2s, and, in fact, some of these show traces of broad Hα in high SNR, starlight-subtracted spectra. Strong X-ray sources with very weak or undetectable broad lines have been called *narrow-line X-ray galaxies.*

It is likely that a subset of the *Liner* (low ionization nuclear emission region) galaxies constitutes the low luminosity end of the AGNs. Any broad lines and featureless continua are swamped by starlight and are generally not detected.

Finally, some radio quiet AGN have broad absorption troughs extending P-Cygni style to the blue of some of the resonance emission lines. These are called *broad absorption line objects* or BALs.

2.2 *Some History*

There are two obvious possibilities for explaining the lack of detectable broad lines and strong nuclear featureless continua in the Seyfert 2s: either Seyfert 2s don't have these components, or they are obscured, at least from Earth's point of view. Several early papers had suggested that the Seyfert 2s might have obscured featureless continua, or even broad lines like the Seyfert 1s.

Rowan-Robinson (1977) found that Seyfert 2s have excess dust emission relative to the optical continuum, in comparison with Seyfert 1s. He concluded: "This suggests that it is dust surrounding the optical core which attenuates the broad wings and causes the distinction between Type 1 and Type 2 spectra." In a footnote, he says that M.V. Penston argued privately that this could be interpreted in terms of an orientation effect, rather than an actual difference in dust content. This was a wonderful insight, but it seemed inconsistent with the existence of weak featureless continua *with low reddening* in Seyfert 2s (Koski 1978).

Lawrence & Elvis (1982) derived an elaboration of this picture from an array of statistical correlations among X-ray, narrow line, and broad line emission. They concluded that, at least for the luminous Seyfert 2s, there may be FC sources and BLRs absorbed by nuclear dust in the plane of the host galaxy. This still deviates from the SPM in being inconsistent with the existence of unreddened weak FC light in the 2s and, therefore, was

rejected by Ferland & Osterbrock (1986). It was also inconsistent with growing evidence, primarily radio, that the nuclear axes are unrelated to the host galaxy axes. Nevertheless, it predated and foreshadowed the SPM model. In fact, it may be almost the whole story for some Seyfert 2s with edge-on host galaxies.

Two more early papers come to mind. In 1984, Osterbrock recognized that the nuclear axes must be tipped relative to those of the host galaxies, and noted that if the BLR is a disk perpendicular to the radio jets, "the escape of both radio plasma and ionizing photons mainly through the conical sections along the axis can explain many of the observed correlations..." This doesn't necessarily mean that the 2s have hidden BLRs, but it does mean that their FCs are made anisotropic by shadowing by an opaque torus oriented perpendicular to the weak radio jets, and this is part of the SPM.

Finally, I quote from Neugebauer et al (1980), who discuss the early *IUE* observations of NGC 1068, the brightest and best-observed Seyfert 2. They estimated that extrapolation of the observed FC provides only a sixth the number of ionizing photons needed to produce their dereddened narrow Lyα flux, but argued that the FC itself is *unreddened*. One suggestion they made is that there may be multiple FC sources inside the nucleus, only a minority of which are uncovered from our point of view (equivalent to opaque partial covering of a single source). That would "require a special geometry so that the ultraviolet sources are visible to the ionized (NLR) gas but are invisible from the Earth."

Some of this work preceded our spectropolarimetric studies. However, when I drew an opaque torus surrounding the FC source and BLR in the radio galaxy 3C 234 (Antonucci 1982a,b; 1984; see Figure 1) oriented perpendicular to the radio axis, and indicated that FC and BLR photons were seen only by scattering due to optically-thin polar electrons, I was blissfully unaware of these papers. My sole goal was to account for the polarized flux showing a Type 1 spectrum, with a high polarization, oriented perpendicular to the radio axis. (In this picture, the FC is present, weak but unreddened, as observed.) In retrospect, I can see that large pieces of that picture were already present in the literature.

2.3   *NGC 1068*

The object referred to above, 3C 234, happens to be radio loud. It is what I would call a Type 2 spectroscopically, i. e. a "Narrow Line Radio Galaxy."[1] But Miller and I (Antonucci & Miller 1985) found that the

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[1] Osterbrock has called it a Broad Line Radio Galaxy because the broad wings of Hα are detectable in total flux. Our justification for the NLRG classification is given in Antonucci & Barvainis (1990).
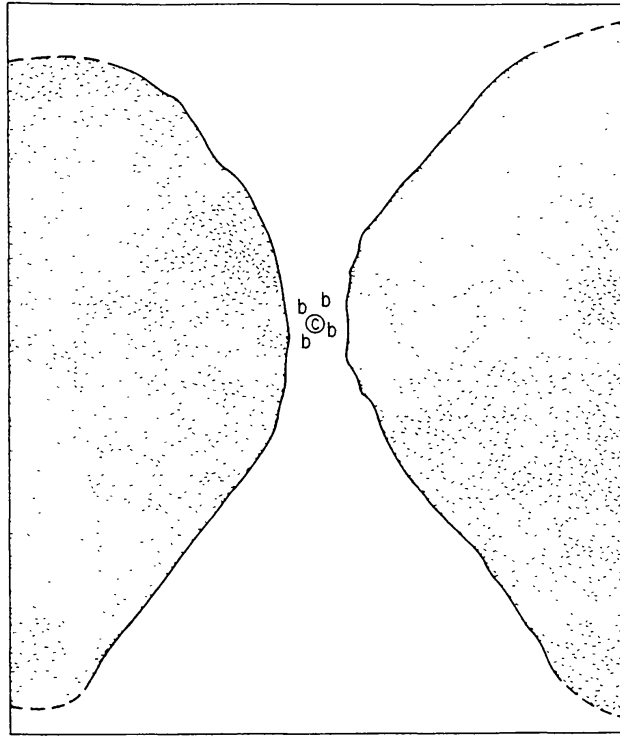
Figure 1 Cutaway drawing of a continuum source and broad-line clouds surrounded by a geometrically and optically thick disk. Only photons traveling out the poles can scatter into the line of sight. The result would be a high perpendicular polarization and a Type 1 spectrum in polarized flux. The radio structure axis is vertical. (From (Antonucci 1982a, 1984.)

Seyfert 2 galaxy NGC 1068 has almost identical properties: a Type 1 spectrum in polarized flux, a high ($\sim 16\%$) FC and BLR polarization, and a polarization position angle perpendicular to the radio jet. (Of course, in the "radio quiet" objects, the radio sources are relatively very small and weak.) Figure 2 shows the polarized flux spectrum from Miller et al (1991). We had taken the data on NGC 1068 in 1980, but only gradually figured out what they meant. It was harder than understanding 3C 234 because of some complications due to the strong host galaxy contribution.

To reiterate, our reasoning on NGC 1068 (and 3C 234) was as follows. The polarization of the FC after starlight correction is approximately 16%, independent of wavelength. (Miller & Antonucci 1983; a similar conclusion was reached by McLean et al 1983). Since the polarized flux spectrum shows broad permitted lines, at normal equivalent widths for a Seyfert 1, we concluded that the polarization had to result from reflection (scattering) of the light from a hidden Seyfert 1 nucleus into the line of sight (Antonucci & Miller 1985). The scattering couldn't be azimuthally symmetric on the
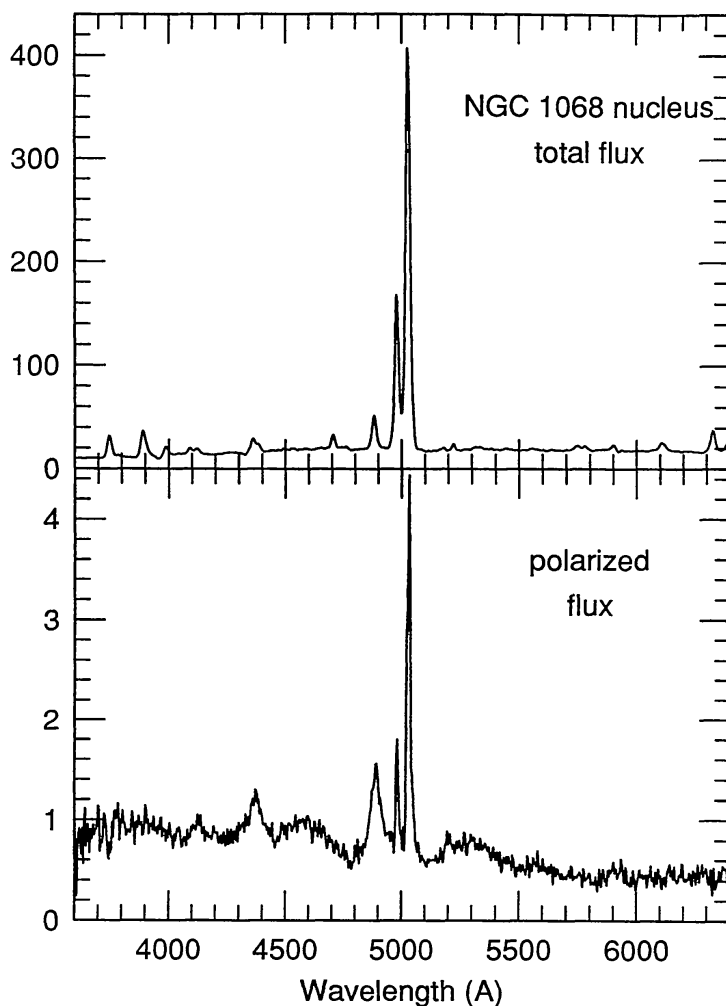
Figure 2 Spectropolarimetry of NGC 1068 by Miller et al 1991. The flux spectrum (*top*) indicates a Type 2 classification, while the polarized flux (*bottom*) is indistinguishable from the flux spectra of Type 1 Seyferts.

sky or no polarization would result. In fact, the polarization direction is perpendicular to the photons' last flights before being reflected into the line of sight, so the FC and BLR photons stream out mainly along the polar direction, where a few are scattered towards Earth. It could be that the equatorial plane, except for the line of sight, is simply evacuated and has no scatterers, but we thought it more plausible that those directions were blocked by an opaque torus.

The ratio of several-keV X-ray luminosity to broad line luminosity is quite constant for Type 1 radio quiet objects (Seyferts and radio quiet quasars); NGC 1068 (and some other reflected-light objects) have the same ratio. Suppose that's not a coincidence. Then the X rays must be reflected into the line of sight just as the broad emission lines are. This idea,

supported by subsequent theory and X-ray spectroscopy, requires that the scatterers be free electrons rather than dust grains. Many arguments concerning the nature of the scatterers can be found in Antonucci & Miller (1985), Snijders et al (1986), Antonucci (1988,1992) and references therein, Bailey et al (1988), Kinney et al (1991), Elvis & Lawrence (1988), and Sokolowski et al (1991).

The case for electron scattering has recently been strengthened by the direct observation of 16% wavelength independent polarization in the satellite UV by Code et al (1993) using the WUPPE shuttle-borne telescope.

I'll touch on some recent observational and theoretical work on NGC 1068 as regards the innermost regions and the unified models. This is mostly a summary of a more detailed discussion in Section I of Antonucci (1992).

Krolik and collaborators have published a number of theoretical papers on the NGC 1068 nucleus (Krolik & Begelman 1986, Krolik & Begelman 1988, Krolik & Kallman 1987, Krolik & Lepp 1989, Pier & Krolik 1992b, and Balsara & Krolik 1992). The early papers invoke a dusty molecular torus around NGC 1068, with a few-pc-scale inner edge set by torus ablation, and a few-pc-scale highly photoionized wind in the polar direction which derives from vaporized torus material.

The ablation radius (see Krolik & Begelman 1988) isn't necessarily the sublimation radius, possibly a disadvantage in that Type 1 AGN generally show rising spectra in the very near IR. NGC 1068 does not, but by the unification hypothesis that would be due to an orientation effect rather than a lack of very hot dust. Pier & Krolik (1992b) suggest that the hottest dust is contained in low-angular-momentum material plunging in towards the center; this material would have a finite lifetime against ablation and could perhaps survive long enough to make some near-IR light. Another speculation that occurs to me is that some small grains in the Pier & Krolik torus could be transiently heated to high temperature by single photons, but that obviously requires more thought.

Krolik & Begelman (1988) point out that it is challenging theoretically to understand the maintenance of a large geometrical thickness in a dusty torus, although Pier & Krolik (1992a) theorize that radiation pressure can do the job. A new idea which has not yet been thoroughly worked out is that the rotating molecular disk is actually thin, avoiding the difficulty of maintaining the disk height. The thin disk simulates a thick one because of centrifugally-driven outflows blocking photons at moderate latitudes (Konigl 1992). However, it could also be argued that nature does have a way of maintaining a thick molecular disk. The Galactic Center pc-scale torus, which may be closely analogous to that of NGC 1068, is known to be somewhat thick geometrically (see e.g. the discussion of Genzel 1989).

In the context of this theoretical work, some subsequent observations have been quite gratifying, while some require at least a quantitative revision of model parameters. Krolik & Kallman predicted that the ionized wind should show the Fe K-α line in the X-ray spectrum with enormous equivalent width, and with energy indicative of high ionization. The X-ray spectra from *Ginga* and *BBXRT* have a lot of information in them, despite limited resolution in the former case and limited SNR in the latter. Overall it's fair to say that the predictions were borne out and the photoionized electron region was confirmed. [The data were taken and analyzed by Koyama et al (1989) and Marshall and the BBXRT Team (1992).]

In a paper describing a *Rosat* image of NGC 1068, Wilson et al (1992) suggest that the observed X-ray continuum could come largely from the off-nuclear starburst, rather than coming from the nucleus via reflection. My guess is that this isn't true. First, it would make the normal X-ray/broad Hβ ratio a coincidence, and, second, it would make the approximate agreement of the Kα equivalent width with the Krolik & Kallman prediction a coincidence. (Adding a major extra *direct* component would make the very high observed equivalent width hard to understand at all.) X-ray polarimetry is required to make a test.

With ground-based (Pogge 1988) and *HST* (Evans et al 1991) emission line imaging, it has been shown that the high ionization lines have roughly a single-cone geometry. The apex coincides with the nuclear H$_2$O megamaser (Claussen & Lo 1986) and with a nuclear cloud of $\sim 7 \times 10^7$ $M_\odot$ of H$_2$ which has been detected in CO by Planesas et al (1991). (See Evans et al 1991.) We presume the maser (and the CO) arises in the dusty torus and we are trying to use the maser emission (and possibly some thermal lines) to get a torus rotation curve. Eddington arguments indicate that Keplerian rotation *may* extend into the torus, in the supermassive black hole picture. Our pilot VLBI observations do, in fact, detect the maser, and reveal a strong E-W velocity gradient (Gwinn et al 1992).

Krolik & Lepp (1989) show that the molecular torus, exposed to Seyfert 1 like X rays, must have a $\sim 10^{-3}$ ionized fraction and hence significant free-free opacity at low radio frequencies. Comparing VLA observations at 1.3 cm to Merlin observations at 6 cm (sensitive to similar spatial frequencies), we tentatively confirm this (Muxlow 1992). A high quality European VLBI Network map at 20 cm is required to be sure. We also hope to see high frequency radio waves originally from the core, reflected off the scattering electrons.

One surprise from the *HST* imaging is that the FC source seems to be quite large (Lynds et al 1991; Caganoff et al 1991; L. Armus et al 1993, personal communication; and the discussion in Antonucci 1992). The

spatial resolution of the bright optical hotspot, and its probable location just north of the cone apex, suggested to Lynds et al and Evans et al the detection of reflected light from a mirror ~10 pc in size. But it's more complicated than that, because the *HST optical* spectrum of the hotspot doesn't show the broad lines, and is mostly starlight! (See Caganoff et al 1991.) So, the mirror is probably even more diffuse and extended than the optical hotspot, which may be a partially obscured central star cluster.

Miller et al (1991) observed the polarized light reflected off *dust clouds* in a conical region in the host galaxy on arcsec (~100 pc) scales (see also Scarrott et al 1991). Spectropolarimetry of the off-nuclear dust clouds reveals the Seyfert 1 spectrum, but unlike in the nuclear case, the spectrum has been multiplied by essentially a Rayleigh scattering law, consistent with reflection by small grains. Also, the permitted lines, reflected off the "cold" dust grains, are narrower than those reflected off the nuclear particles. This suggests that the *nuclear* particles are indeed warm electrons, and provides a temperature estimate of ~300,000 K.

Miller et al find that self-consistent models of the electron scattering region require an extended (~1″) nuclear mirror, a conclusion predating the *HST* data described above. On the theoretical side, the expectations are still contentious (Krolik 1992; W. Mathews 1992, personal communication). However, using values of electron temperature and bolometric luminosity updated from those used by Krolik & Begelman (1986), Balsara & Krolik (1992) also find that the mirror must be large. J. Miller, T. Hurt, and I are now analyzing some multiaperture *HST* UV spectropolarimetry, which should provide more information on the size of the mirror.

Miller et al also find that the observed IR luminosity of the torus is less than expected if it is exposed to the luminosity they derive for the occulted FC. They propose that the optical/UV emission is somehow "prebeamed." This would be an unpleasant complication, and might predict, if generalized, a range of broad line equivalent widths among different objects which is larger than observed. [J. Miller (1992, personal communication) says this objection is avoided if the prebeaming is due to mirror-like inner walls of the torus.] I personally think that the arguments used, while very clever and qualitatively correct, do not have the precision required to establish pre-beaming with certainty. For example, Miller et al must assume that the broad Hβ and the narrow [O III] lines are converted into polarized flux by the off-nuclear dust clouds with equal efficiency. Since the [O III] region is quite extended, it could actually be reflected with lower efficiency. Also, Pier & Krolik (1992b) have pointed out that the torus is known to be so opaque that the Miller et al assumption of isotropic IR emission from the torus may not be correct. [Incidentally, the torus, if real and on very small (pc) scales, must be anisotropic in the near IR and

quite close to edge-on, according to the analysis of new IR images by Cameron et al (1993).]

2.4 *Polarimetric Observations of Other Radio Quiet AGN*

I noticed in 1983 (see Antonucci 1983, updated in Antonucci 1988) that the Type 2 objects with intrinsic nuclear optical continuum polarization tend to have polarization position angles perpendicular to the radio axes. NGC 1068 is just one example. The observed polarizations, taken from Martin et al (1983) for my 1983 paper, were typically a couple percent, as in NGC 1068. Also as in the case of NGC 1068, the optical spectra were strongly dominated by host galaxy starlight, according to Koski (1978), so that their nuclear continuum polarizations were probably much higher. Using Koski's values for starlight contamination, they'd be similar to that of NGC 1068 (16%).

When some of these objects were observed spectropolarimetrically by Miller & Goodrich (1990), they showed broad permitted lines in their polarized flux spectra just like NGC 1068 does. However, these authors found considerably lower dilution of the nuclear light by starlight than Koski did, and so derived intrinsic nuclear polarizations of only a few percent. This is not really expected in the torus model. Various selection effects and modifications of the basic model can be invoked (see their discussion), including reflection off the torus itself, but the low polarizations admit the possibility that the obscuration is by, say, a warp in a thin disk of dust rather than a thick torus. [See Phinney (1989) for the suggestion that AGNs have thin but warped dusty disks.] It remains necessary to account for the perpendicular radio alignments, however.

Roughly speaking, if Miller & Goodrich had used the Koski values for starlight contamination, correction of the data would not only result in a high nuclear polarization, but it would also result in wavelength-independent polarization, removing the rise observed with frequency, just as in NGC 1068. In these ways, it would be "nice" if the Koski values were correct. Koski's values were influenced mainly by spectral shape, whereas Miller et al used stellar absorption lines. One can speculate on the cause of the different values, e.g. the Miller & Goodrich technique might miss any ultra-rapidly rotating central stellar clusters. Also, J. Miller (1992, personal communication) points out that their values derive from the Mg Ib equivalent widths, which could be distorted by neighboring weak emission lines. To be quite certain, it is necessary to observe in the *HST* ultraviolet, where the starlight contamination is small. R. Cohen, J. Krolik, L. Kay, and I have a small allocation of *HST* time to do this, and to look for FC polarization in some of the many cases where the starlight so dominates the optical that ground-based observations are useless. As of

this writing, it appears that the "Co-Star" corrective optics for *HST* will destroy its spectropolarimetric ability, so hopefully we can settle these questions before they are installed!

Because the polarization shows a rise to the blue in several of the Miller & Goodrich objects even after their starlight correction, they suggest that dust contributes to the reflection of nuclear light. They note that this would be the case in NGC 1068 as well, if it were moved out to the distances of the other objects and observed with their aperture.

One Miller & Goodrich object, Mrk 463E, seems to show a spatially resolved mirror in subarcsec-resolution *HST* images (Uomoto et al 1993). The extinction to the BLR seems to be only $A_v \sim 7$ based on the apparently direct detection of broad permitted lines in the near IR (Blanco 1992). However, the column to the X-ray source seems to be very large (Koyama 1992).

Kay (1990) and Tran et al (1992) have found more Seyfert 2s with broad permitted lines in the polarized flux, but the FC polarizations are generally much less than that of NGC 1068. It may be possible in such cases, especially for the *variable* Seyfert 2 Mrk 477, to invoke dust transmission polarization, placing the dust outside the BLR but inside the starlight and narrow line region. However, Tran et al note the crucial point that in many cases, while the FC polarization is low, only high lower limits can be placed on the polarization of the broad lines! Conceivably this means that the SPM applies, except that the FC extends above the torus.

I have limited this discussion so far to the spectropolarimetric studies because they seem more interpretable than the filter work, especially in the context of unified models. For this purpose, it is important to be able to look for broad lines in polarized flux. It is also helpful for the crucial procedure of separating out objects with extrinsic, non-nuclear polarization. These generally have polarizations of the starlight and the narrow lines similar to those of the FC, and are often polarized by transmission though dust in the host galaxy or in the Milky Way (see, e.g. Thompson & Martin 1988).

Good filter data have been gathered on many Seyferts, however, for example by Brindle et al (1990a,b). A result of this work for the present context is that they confirm the tendency for perpendicular alignment in the Type 2s. (These authors and I disagree on the results for the Type 1s, but our differences aren't clearly relevant to this article, so won't be discussed here.)

Other excellent filter and spectropolarimetric data are coming from Wills and collaborators. For example, they seem to have cracked the complicated case of the bright IR-selected quasar IRAS 13349+2438 (Wills et al 1992b). The polarization of this object rises with frequency to

8% in the U band. Wills et al show that the polarized flux distribution closely mimics the total flux distribution of a normal UV-excess quasar, and that all of the data can be explained by a wavelength-independent reflection component accompanied by a transmitted reddened component of quasar light. A different-appearing object but with a similar explanation is the ultraluminous infrared galaxy IRAS 23060+0505 (Hough et al 1991). The incredible $Z = 2.3$ IRAS galaxy F10214+4724 has recently been shown to have $\sim 17\%$ broadband optical polarization which could indicate an occulted and reflected quasar or even an occulted and reflected starburst (Lawrence et al 1993). Other luminous IRAS galaxies show broad permitted lines in polarized flux, such as IRAS 20460+1925 (Kay & Miller 1988) and IRAS 22017+0319 (Kay et al 1992). Spectropolarimetric surveys of luminous IRAS galaxies are being carried out by several of us, and plenty of new results on the hidden nucleus or "Quasar 2" problem should be available soon.

Spectropolarimetry is photon-intensive, and complicated and tricky in its data reduction. However, it can provide interpretable information unobtainable in any other way, and it has a bright future both for studying unified models, and for understanding the BLR (Chen & Halpern 1990) and Big Blue Bump (BBB) components (Laor et al 1990, Antonucci 1992, Antonucci et al 1992) of unobscured objects.

2.5 Nonpolarimetric Evidence for Unification of Radio Quiet Objects

It was noted in Section 2.2 that some pieces of the unification puzzle were coming together based on nonpolarimetric data. For example, the hidden nuclear source in NGC 1068 was inferred by an ionizing-photon-counting argument. Subsequent work by Pogge (1988) and by Evans et al (1991) showed fairly convincing evidence for an "ionization cone" in [O III]λ5007 images. While similar emission line nebulae and ionizing photon deficits have now been found in many other objects, the interpretations aren't always clear. In some cases, the morphology could represent the distribution of gas clouds; alternatively, anisotropy of the continuum could be established intrinsically by, say, a thick accretion disk, rather than by shadowing by a dusty torus. Each case must be considered individually.

Wilson and collaborators have been particularly active in gathering data and applying the above two arguments (e.g. Ulvestad et al 1981, Haniff et al 1988, Roos et al 1988; see also Unger et al 1987 and Pedlar et al 1992). Their work provides a wealth of information on the narrow line regions, but for the present purpose, the most important features are: 1. a general tendency for extended narrow line emission to align with the radio structure; 2. some sharply defined conical or biconical nebulae suggestive of

shadowing (here see also Tadhunter & Tsvetanov 1989, Storchi-Bergmann & Boratto 1991, Storchi-Bergmann et al 1992b); and 3. a general deficit of observed ionizing photons relative to what's needed to ionize the nebulae. Kinney et al (1991) show that point 3 is not generally due to continuum reddening in the 2s, but rather to opaque partial covering or occultation/reflection, echoing the Neugebauer finding for NGC 1068 ten years earlier.

Regarding the cones, the increasing number of good sharp-edged cases is important. It shows that there are many sources of ionizing radiation hidden from our view. Since some similar objects must be exposed to us, these cone-objects must correspond to some known source of hard ionizing continuum in galactic nuclei: They can only be hidden Seyfert 1s.

In the case of those showing a general alignment with the radio sources, but not sharp-edged conical morphologies, it might be worth taking much deeper images. Perhaps sharp edges would be apparent in some cases. But the SPM is not the whole story because NGC 4151, a Type 1, has an aligned NLR too! We don't expect to see a projected cone in that case because, according to the SPM, we are inside the unobscured solid angle. Yet the *HST* [O III] image does look rather like a cone on subarcsecond scales (H. Ford et al, personal communication)! Perhaps a clue to what's going on comes from the fact that the NGC 4151 X-ray column in our line of sight is large: Most of the X-ray source is quite obscured from our point of view. Similarly, the nuclear UV spectrum shows absorption by clouds which are opaque at the Lyman limit (Kriss et al 1992). Maybe ionization cone gas, but not the Earth, has a clear view of the 13.6–500 eV emission. This could be due either to different locations or sizes of the X-ray and optical sources or simply a lack of dust in the X-ray absorbing gas. In any case, it's a complication, and is outside the SPM.

Apparent nuclear "dusty tori" on $\lesssim 1''$ scales have recently been reported in *HST* images of the liners M51 and NGC 4261 (H. Ford, personal communication, and Jaffe et al 1993). (The latter object, also known as 3C 270, is radio loud.) The small tori lie perpendicular to the associated linear radio sources and in the case of M51, the possible emission line cone. The NGC 4261 image is shown in Figure 3.

I'm confident that the optical blazar components in the radio emitters are highly beamed (e.g. Section 3.3 of this paper). However, there does not seem to be evidence for strong intrinsic directionality of the Big Blue Bump component in either the loud or quiet Type 1 objects (Boroson 1992). In a recent preprint Francis (1993) constrains the directionality of the BBB in Large Bright Quasar Survey optically-selected quasars by studying the line equivalent width distribution, assuming the line radiation is isotropic. He finds that both thin and thick accretion disk beam patterns
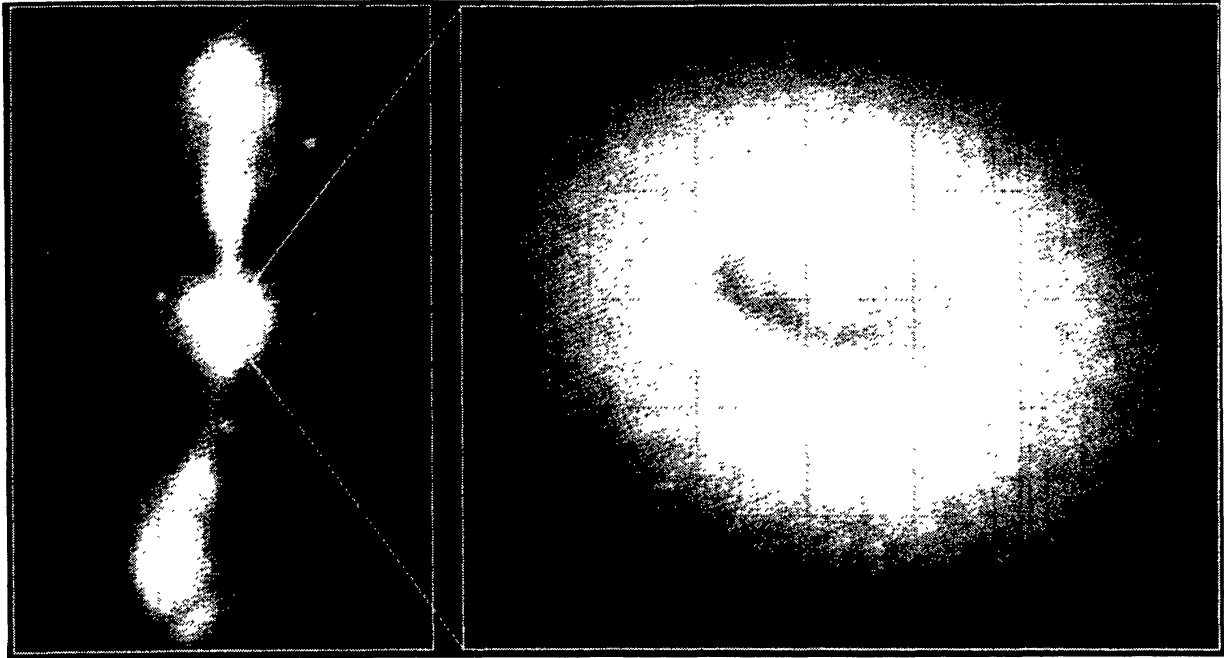
Figure 3   (*a*) Composite image of the radio jets and optical galaxy as observed from the ground (NGC 4261). (*b*) High-resolution optical image of the galaxy core, showing a dusty torus oriented perpendicular to the radio jets. Deconvolved *HST* image from Jaffe et al 1993.

are ruled out, although they can be saved by getting rid of the edge-on objects with dusty tori.

2.6   *Tests of the SPM, and Some Related Issues*

In this section, I discuss a number of arguments which have been presented to test the straw person model, i.e. the universality of obscuring tori, all with the same opening angle and optical depth, and all with optically thin polar reflection regions.

2.6.1   NUCLEAR RADIO EMISSION AND FAR-INFRARED EMISSION   There is no doubt that the nuclear sources of the famous Type 2s are longer and stronger, statistically, than those of the famous Type 1s (Ulvestad & Wilson 1984a,b). Similar statements can be and have been made regarding other isotropic components such as CO and far IR luminosity. These facts have sometimes been used to argue against the SPM. However, they are not useful in this context because "fame" connotes strong differential selection effects for the 1s and 2s. For example, selection by UV excess takes Seyfert 2s from much higher on the luminosity function than Seyfert 1s, in the SPM. A Seyfert 2 needs to be so luminous that the (~ 1–10%?) of the FC reflected into the line of sight produces a strong UV excess relative to the host galaxy.

As far as the radio source length differences are concerned, some obvious contributors in the context of the SPM would be foreshortening of the 1s, and the greater dynamic ranges on the maps of the Type 2s. A selection effect such as that described above, and the effect of dynamic range on source size, were both mentioned as possibilities by Ulvestad & Wilson in their 1984 papers. These effects were confirmed in studies by Edelson (1987), Ulvestad & Wilson (1989), and Giuricin et al (1990).

In general, if one wants to test the SPM with comparisons of isotropic properties, the correct thing to do is to *select by one such property, and then compare the distributions of another*. This is never done. The next best thing to do is to select in some mysterious way, but at least match the samples *a posteriori* for one isotropic property before comparing the distributions of another. A couple of attempts have been made to do this, e.g. Ulvestad's (1986) comparison of 10μ power of the spectroscopic types, at fixed radio power. The Type 1s were considerably stronger. The arguments in the Pier & Krolik theory paper (1992b) indicate that the 10μ emission is predominantly polar and not isotropic, at least in NGC 1068. Therefore, this test doesn't necessarily rule out the SPM. Similarly, Ulvestad finds that, at fixed radio power, the 2s are weaker in [O III]. The only way to accommodate this in the SPM is to suppose that some of the [O III] emission is occulted in the 2s. This would be consistent with the spectropolarimetry data. However, it is also possible that these two tests signal the breakdown of the SPM, and the necessity for at least one parameter in addition to orientation. One possibility would be that small opening angles, which would statistically tend to result in Type 2 classifications, somehow correlate with power in the radio jets.

2.6.2   TWO TYPES OF 2S?   Several authors have decided that there are two distinct types of Seyfert 2s—those with thick tori and hidden Seyfert 1 nuclei, and those without. I'd like to see some evidence for a bimodal distribution of some isotropic parameter before adopting this point of view. A recent paper by Neff & Hutchings (1992; their Figure 1) suggests that Seyfert 2s occupy two disjoint regions in a far IR color-luminosity diagram, but in histogramming their data I see no strong evidence for it. [Some supporting arguments for two types of 2 are given in Hutchings & Neff (1991), which the interested reader can consult.] Similarly, it is sometimes assumed that there are two types of 1s—those with molecular tori, and those without. Again, this may be, but it is not yet supported with any evidence, as far as I know.

The notion of "two types of 2" has recently arisen in another context: Moran et al (1992) have noted that the hidden Seyfert 1s reported so far all have relatively high radio luminosity, and the authors conclude that

they are thus qualitatively different from "ordinary" 2s. However, no bimodal distribution is claimed. More important, profound selection effects went into the polarization studies; for example, as noted earlier, they are generally the most powerful UV-excess Type 2s, so it's no surprise they are also powerful in the radio (and in CO, and in far IR emission, etc, etc). Also, as noted in Section 2.5 above, the ionization cone objects are almost certainly hidden 1s and they do not all have such high radio power. Moran et al entitle the section of their paper with this argument, "Demise of the Strong Unified Model for Seyfert Classification." That's premature!

2.6.3 THE EXTENDED NARROW LINE REGIONS OF TYPES 1 AND 2 Predictions about the relative sizes and morphologies of the extended narrow line regions are implicit in the unification model. Pogge (1989) states that, while some Seyfert 2s show nice ionization cones as predicted, in general the emission line images of his sample are inconsistent with the SPM. The Seyfert 1s are less likely to have extended nebulae, a result the author argues is not simply due to foreshortening and dynamic range effects (i.e. the glare of the Type 1 nucleus). Also, Type 2s are found to differ more in their Hα and [N II] vs [O III] morphologies than the Type 1s.

   As with the early reports of differences in the radio properties, it is difficult to interpret these differences, because severe selection effects may be present. It might be worthwhile to match the 1s and 2s for, say, radio power, and then repeat this study.

2.6.4 NUCLEAR INFRARED EMISSION FROM THE DUSTY TORUS? The nuclear IR emission from the putative dusty tori must account for all of the optical/UV energy intercepted. Both these quantities are difficult to determine. The only attempt at a systematic comparison is that of Storchi-Bergmann et al (1992b). They did about as well as can be done with present data. A strong point of their study was the fairly consistent results on nuclear luminosity obtained via ionization parameter arguments applied to multiple resolved narrow line clouds in the same object. Their conclusion is that the infrared data are consistent with the torus model in all nine cases with adequate data. Some anisotropy of the IR emission is required for two objects, NGC 1068 and NGC 3281, a feature expected by Pier & Krolik (1992b).

2.6.5 WHAT ABOUT THE MICRO-SEYFERTS? Peimbert & Torres-Peimbert (1981), Filippenko & Sargent (1985), and others have shown that careful starlight subtraction can reveal weak broad Hα emission in "10–50%" of all normal spirals (Filippenko 1987) and in many ellipticals as well. Suppose the torus model is true for these. Are they in their hearts Type 1 or

Type 2? Is the weak broad emission direct or reflected? Are the Hα wings polarized?

The prototypical case, M81, seemed like a good candidate for reflection: Unlike low-luminosity Seyfert 1s, it does not show variations in the broad Hα line (Filippenko & Sargent 1988), suggesting the possibility of smoothing by light travel time through the volume of a mirror. My collaborators P. Coleman, L. Kay, and R. Barvainis, and I are struggling with a spectropolarimetric data set designed to determine whether the wings of these objects are highly polarized. Anecdotally, D. Axon (personal communication) tells us that the wings of the M81 Hα line have low polarization.

2.6.6 X-RAY EMISSION What does the SPM predict for X-ray photometry and spectroscopy? As noted earlier, the torus in NGC 1068 is thought to be Compton-thick, so that the high energy continuum from the hidden Seyfert 1 will make it through directly only in the Klein-Nishina regime. *GRO* data are anxiously awaited. The X rays we do see at a few keV are at a level and slope consistent with that expected from reflection (see Section 2.2). Also the high-ionization K-α emission line from the electron scattering zone is seen. Since we see this zone directly, and the continuum source only in reflection, a very large equivalent width was both predicted and observed.

If we tilt the torus so as to get a smaller absorbing column (more realistically, but outside the SPM, we can just consider tori with lower column densities), the ~ 10 keV X rays can break through. This expectation has been gloriously verified in several cases! See the papers of Awaki et al (1990, 1991a,b), Warwich et al (1989), and on the infrared galaxy NGC 4945, Iwasawa et al (1992). Koyama et al (1993) find that this is true for the NLRG IC 5063 as well (see Section 3.2 for more information on 1C 5063); Koyama (1992) and Awaki et al (1991b) also provide delightful discussions of the *Ginga* results on Type 2 AGN generally, including Cyg A and the IRAS-selected Seyfert 2s.

A good examination of the X-ray data on UV-detected Seyfert 2s in the context of the unified model has just been published by Mulchaey et al (1992). They find high columns ($N_H \sim 10^{22}$–10^{24} cm^{-2}) to be generic and note that "The mere presence of UV emission combined with hard X-ray absorption argues strongly for a special geometry which must have the general properties of the unified model." However, these authors find that the strict SPM is probably inconsistent with the X-ray nondetection of Seyfert 2 counterparts to the very luminous Seyfert 1s. They also state that if all Seyferts have 30° opening angles, and if all of the tori are transparent to hard X rays, then the Seyfert 2s would overproduce the hard X-ray

background. This is important information, but from the point of view of ruling out the SPM, note that their second supposition is known to be inconsistent with the case of NGC 1068. Also, the 30° figure, which means a large ratio of 2s to 1s, isn't well justified, and conflicts with the low FC polarizations being observed. As they conclude, such a small opening angle, for high luminosity objects especially, seems unlikely.

The SPM model probably does get nailed by the large opening angle suggested by the low polarizations, versus the smaller opening angle derived from the space density of infrared-selected or host-galaxy selected 1s and 2s (e.g. Lawrence 1991). A minimal adjustment would be to assign the low polarizations to scattering off the torus itself, rather than to gas arranged along the polar axis.

It takes, of course, just a small conceptual leap from the Seyfert 2s to explain the Narrow Line X-ray Galaxies (NLXGs): Their columns are low enough so that the keV X rays get through, but little or no FC and broad line emission does.

2.7 Broad Absorption Line Quasars

Around 10% of the radio quiet quasars have broad absorption lines. It has been argued on spectroscopic grounds that the covering factor of broad absorption clouds can only be of order 10%. Together these two fairly robust statements require that many and perhaps all radio quiets have broad absorption line clouds, i.e. thermal material expelled at velocities ~ 0.01–0.1 c. There are no known radio loud broad absorption line quasars, and the underrepresentation of the radio louds is highly statistically significant. All of this information can be found in reviews such as that of Turnshek (1988), with an update on the radio properties provided by Stocke et al (1992a).

It has been speculated that the radio quiets may have polar outflows like the radio louds, but that the outflows are thermal in nature (like SS 433?) and they are manifest as broad absorption lines. [At the level of rampant speculation, I wonder if the radio quiets might have thermal jets because of inverse Compton cooling. Brown (1990) finds that the relativistically hot gas in a radio jet only survives because of the relativistic bulk motion away from the core.] Broad absorption lines as polar outflows from radio quiet AGN have been discussed by Barthel (1992) and by Begelman (1993b). Barthel would like to use strong Fe II as an indication of a pole-on orientation in radio quiets, because it seems to correlate with core dominance in the radio louds. Some support derives from the fact that strong Fe II quiets tend to have narrow permitted lines (Zheng & O'Brien 1990, Boroson & Green 1992), as do core-dominant (pole-on) radio emitters. (Since such correlations are far from perfect, Fe II strength and line

width can only be orientation indicators in a statistical sense.) Wills et al (1992c) show a very impressive inverse correlation of CIV line peak flux (normalized to the continuum) with line width; since the correlation is identical for the quiets and louds, this suggests that line width is in fact an orientation indicator for the quiets, too.

The opposite point of view, that BALs are nearly edge-on systems, is supported by some arguments given in Turnshek (1988), Wills et al (1992b), and Antonucci et al (1993).

2.8   Beam Patterns Diagnosed by Voids in the Lyα Forest Due to Foreground AGNs

There is a delightful new approach to studying the beam patterns of quasars and narrow line radio galaxies, and even the putative misdirected quasars lurking among the IRAS galaxies. The idea is based on the well-known "proximity effect" whereby quasars seem to cause a decrease in the number of Lyα forest lines in their redshift vicinity, probably by increasing the ionization level of the responsible clouds. By choosing objects close to the lines of sight to distant quasars, we can, in principle, determine the beam pattern of the foreground object by the relative void it creates in the forest in the spectrum of the background object. There are already some hints of confirmation of the expected beam patterns (Moller & Kjaergard 1992, Dobrzycki & Bechtold 1991). Limiting factors are, of course, finding such close alignments, and the small-number statistics of forest lines.

3.   RADIO LOUD OBJECTS

3.1   Types and Phenomenology

I'll present a description which is simple but I believe fairly robust and general. Among the lobe-dominant radio loud objects, the optical properties are much the same as those of the quiets: There are Type 1 (Broad Line Radio Galaxy and Radio Quasar) spectra, and Type 2 (Narrow Line Radio Galaxy) spectra. An ambiguity is the role of the "optically dull" radio galaxies, those (low radio luminosity, edge-darkened) FR 1s which have very weak narrow emission lines, and no detectable broad lines or FC. I can't prove it, but I'll assume the latter are not seen because of an inability of the nuclear light to compete with the host galaxy starlight. These objects are analogous to some weak liners on the radio quiet side, but their diffuse radio emission helps to call attention to them. Whether or not the optically dull FR 1s have weak FCs and broad emission lines doesn't matter for most of what follows. The (high radio luminosity, edge-

brightened) FR 2s do show either strong narrow lines or broad lines and featureless continua.

The core-dominant radio sources generally show a highly variable, usually rather red, polarized optical component.[2] In cases where this component dominates any normal FC and emission lines, they are historically called BL Lac objects. In some other cases, broad lines show through, at least at times. Such objects have been called OVVs, for *Optically Violently Variable quasars*. The polarized, variable objects collectively are called blazars. *Most* core-dominant radio sources are now known to be blazars (e.g. Fugmann & Meisenheimer 1988, Impey et al 1991, Wills et al 1992a). In fact, a red, variable, highly polarized component can generally be detected in the recalcitrant ones like 3C 273 by being patient, or by looking in the near IR. Morphologically, the blazar IR/optical component is simply the high frequency tail of the radio core emission (e.g. Landau et al 1986, Impey & Neugebauer 1988). As expected in this picture, there appear to be no radio quiet blazars (Jannuzi et al 1993a).

I've argued that the historical division of the blazars into BL Lacs and OVVs is seriously misleading and has damaged many studies on parent populations and cosmological evolution. One problem is that there is no subdivision in this taxonomy for the blazars with relatively large narrow line equivalent widths (e.g. NGC 1275 = 3C 84, 3C 371). Also, with the BL Lac/OVV categories, an object's classification is a sensitive function of time, and SNR! Historically, the detection of broad emission lines meant that an object was called an OVV instead of a BL Lac. For example, Moore & Stockman (1984) classify 1308+326 as an OVV based on the Miller et al (1978) detection of luminous broad Mg II $\lambda 2800$Å. The same reasoning would then require reassignment of many classical BL Lacs to the OVV category, including OJ 287, 0215+015, AO 0235+164 and 1803+784. Many authors still call these BL Lacs. As far as I know, no one has ever presented evidence for a bimodal distribution of equivalent widths in broad-line blazars, so the OVV/BL Lac division is not qualitative. If, despite this, we pick an arbitrary equivalent width criterion to separate the two classes, an object's type would no longer be a function of SNR, but it would still be a sensitive function of time in many cases. (Of course, for low luminosity objects, the equivalent width cutoff must account for starlight contamination as well.)

Given this fuzzy situation, people who use the BL Lac/OVV categories

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[2] This component may be the key to the historical perception that the FSCD optical fluxes were predictable from the radio fluxes. That idea, together with the supposedly "normal" emission line equivalent widths (a selection effect I think: Antonucci & Ulvestad 1985) has been used as an argument against optical beaming.

owe it to their readers to spell out their working definitions. It isn't acceptable simply to refer the reader to the Hewitt & Burbidge (1987) catalog, as is sometimes done. The Hewitt & Burbidge verbal definition is inconsistent with the assignments in their table. Their verbal definition excludes objects with *any* emission lines (including BL Lac itself). It also requires high radio polarization but not high optical polarization, which is puzzling because the latter and not the former comes from an optically thin region.

There probably are meaningful subcategories among the blazars; some statistical differences have been seen between "BL Lacs" and "OVVs" (e.g. Worrall & Wilkes 1990, Wehrle et al 1992, Kollgaard et al 1992, Padovani 1992, and Ohashi et al 1992, who suggest that for the former objects the X-ray synchrotron radiation may dominate the inverse Compton due to a statistically higher jet blueshift). The obvious defensible qualitative time-independent physical criterion is FR 1 vs FR 2 diffuse radio emission. The reason for the differences discovered between "BL Lacs" and "OVVs" could be partly the preponderance of FR 1s in the first group and FR 2s in the second, but seems also to involve the relative contrast of the highly beamed emission. Note that one cannot simply associate all of the famous "BL Lacs" with FR 1s as is sometimes done. The diffuse radio properties don't allow it. The recent study by Kollgaard et al (1992) makes this clear: "*the parent population of the BL Lacertae objects contains both FR 1 and FR 2 radio sources*" (their italics). For more diatribes on blazar classifications, see Antonucci & Ulvestad (1985), Antonucci et al (1986), Antonucci (1988); and also Lawrence's (1990) excellent summary of the optical properties of VLBI sources in general.

With the FR 1 and FR 2 divisions, the SPM predictions for cosmological evolution are clear: little or no evolution of the former, strong positive evolution of the latter. That is the behavior of the putative parents. Modest deviations have been considered by Vagnetti et al (1991).

A substantive unresolved observational question remains. Do all blazars show direct, unpolarized broad emission lines, albeit often at very low equivalent widths? In the SPM, this is equivalent to asking whether all double radio galaxies have hidden BLRs. There is a way to make a more sensitive test of this than in the past, which I describe in the final section of this article. My guess, based on Occam's razor, is that the answer is yes, and I'll include this in the SPM. It has only a marginal impact on the subsequent discussion, however.

Finally, there has recently been a lot of work on "X-ray-selected BL Lac objects." These turn out to be generally similar to the radio-selected objects, and they have parents that tend to be relatively luminous FR 1s (e.g. Kollgaard et al 1992b). (To be model-independent, they have rela-

tively high FR 1 level diffuse radio component power, and relaxed radio morphology.) They, and their putative FR 1 parents, both lack the strong positive cosmological evolution of FR 2 radio galaxies and quasars. The X-ray-selected BL Lacs have on average lower radio/X-ray ratios than the radio selected ones. This is thought not to result merely from the obvious selection effect, but to indicate that the X rays are less strongly beamed than their radio counterparts. As supporting evidence, D. Worrall (personal communication) notes that the X-ray-selected objects have a large range in radio flux while the converse is not true. The X-ray-selected ones are known, statistically, to have less optical variability and polarization (Stocke et al 1985) even when account is taken of the higher starlight contamination (Jannuzi 1990, Jannuzi et al 1993b). This does not, of course, mean that they are qualitatively different from the radio selected ones, i.e. that there are two separate populations.

Morris et al (1991) report on a large study of objects which they call X-ray-selected BL Lacs. Their definition is based on a line equivalent width limit, and requires no optical polarization or variability. They find strong *negative* evolution in this population. I wonder if this could be exaggerated or distorted by selection efforts. They reject some possibilities, but there are others, such as the redshift sensitivity of the ability of an object with a typical emission line spectrum to meet their 5Å equivalent width definition (i.e. whether a strong line falls in their spectrum range).[3] Morris et al argue that their fluxes alone indicate some negative evolution via the V/V_{max} test, but of course, their sample selection is upstream of even this test. Their requirement that the Ca K break be less than 25% could also result in redshift or flux selection effects. See also Browne & Jackson (1992) for discussion of other selection effects which could influence conclusions on "BL Lac evolution."

3.2 *Unification of Broad-Line and Narrow-Line Lobe Dominant Radio Sources*

Most of the science in this section is on the radio side, but I'll open with the optical/IR polarimetry for consistency with the last section, and to provide some necessary background for the statistical tests of the SPM. This section is a summary and slight update of the more detailed discussion in Antonucci & Barvainis (1990). (See also Antonucci 1992.)

We have argued in the first of the above papers that there are now at least eight narrow line radio galaxies for which polarimetric evidence

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[3] A selection effect undoubtedly biasing the OVVs to low redshift, is the following: the synchrotron component, whether diagnosed by its effect on polarization and variability or on reducing line equivalent width, is generally redder than the isotropic AGN emission (e.g. Wills et al 1992a, see Figures 4 & 5).

indicates that they are actually broad line radio galaxies or quasars whose axes (and radio jets) lie in the sky plane, and whose FC sources and BLRs are obscured, probably by opaque tori. The first case is 3C 234, a NLRG which shows high perpendicular polarization, and a quasar spectrum and luminosity in polarized light. (It also has quasar-like far-IR and narrow line luminosities.) We discuss the classification of 3C 234 in some detail in Antonucci & Barvainis (1990). Specifically, we assert that in all relevant respects, it is identical optically to NGC 1068 except for the starlight fraction. The lower starlight fraction allows us to spot the reflected wings from broad Hα in total flux in 3C 234 much more easily than in NGC 1068.

The highly polarized but quiescent object OI 287 is also best interpreted as an occulted/reflected quasar, but here the *parallel* polarization indicates a *thin* disk (Goodrich & Miller 1988; see Antonucci et al 1983 for its possible connection to BALs). The anecdotal evidence for a dearth of quasar 2s, at least among the radio quiets, and the generally low and parallel polarization of quasars, suggests that thin tori may be more common at high luminosity. Note that this is a deviation from the SPM, in which all opening angles are the same. T. Hurt, J. Miller, and I are now reducing improved ground-based spectropolarimetry of a large new sample of radio galaxies which may bear in this question. (It is too soon to say on what spatial scales the small parallel polarizations arise.)

At least three NLRGs—Cen A, IC 5063, and 3C 223.1—have spectral upturns at 2μ, and high FC polarizations in the near IR, all perpendicular to the radio axes. In the former cases, the FC polarization wavelength-dependence has been checked and is found to be flat. The most likely explanation is that these nuclei also fit the SPM, but are only seen at 2μ, because *kpc-scale* dust lanes, perhaps merger debris, block our optical view of the whole nuclear regions (Antonucci & Barvainis 1990). This point of view was bolstered by the discovery of weak broad Hα in the polarized flux spectrum of IC 5063 (Inglis et al 1993), as well as strong X rays seen through a column at $\sim 2 \times 10^{23}$ cm^{-2} in that object (Koyama et al 1992). For Cen A, the nuclear molecular torus has been detected at other wavelengths, including in the form of a very broad base to the CO J $= 2-1$ line (Israel 1992) and as an apparent thick rotating torus (Figure 2 of Rydbeck et al 1993). It is also known that hot H$_2$ emission from Cen A comes from within 60 pc of the nucleus (P. Blanco, personal communication). Barvainis and I have some tentative additional examples of high IR polarization, but these need to be checked.

The case for Cen A as a misdirected blazar or at least BLRG was made quite convincing by the studies of the off-nuclear narrow emission line clouds by Morganti et al (1992); Prieto et al (1993) report similar results on 3C 227.

Imaging polarimetry is less specific than spectropolarimetry for the present purpose. We cannot be sure that the light is polarized by reflection, and we cannot be sure of the nature of the reflected sources. Nevertheless, the observed high perpendicular polarization detected in the nuclear light, or from off-nuclear patches, is probably due to reflection of nuclear light. Quite a few cases have now been reported: PKS 2152-69, 3C 368, 3C 277.2, 3C 265, 3C 17, 3C 42, 3C 226, and 3C 324 (PKS 0116+08 is also significantly polarized but the discoverers give no radio position angle). The references to these can be found in the most recent paper, Tadhunter et al (1992), except for 3C 324 which is reported in Cimatti & di Serego Alighieri (1992). Even more examples have just been published by di Serego Alighieri et al (1993). There is an increased incidence of this phenomenon at high redshift, presumably with contributions from the wavelength-dependence of dilution by starlight, and the increased scattering efficiency of dust with frequency.

My collaborators and I have some *HST* time for UV imaging pola-rimetry of radio galaxies, but the observations haven't yet been taken. We are especially anxious to see Cygnus A, because of the controversy surrounding its polarization. This prototypical Classical Double NLRG, has a strong nucleus at 2μ (Djorgovski et al 1991), but this is probably dust emission, providing perhaps indirect, but certainly not direct evidence for an obscured quasar. The near IR spectrum does not show broad emission lines (Ward et al 1991), so clearly we aren't seeing the quasar directly just by going to 2μ. We probably *do* see the quasar directly by going above a few keV, however (Koyama 1992).

Tadhunter et al (1990) report detection of a "giant bipolar reflection nebula" scattering light from a hidden nucleus in Cyg A. However, Good-rich & Miller (1989) and J. Miller (1991, personal communication) argue that the spectropolarimetry and the low off-nuclear polarization are incon-sistent with this. Specifically, the polarized flux spectrum has good SNR and yet shows no broad lines. Also, the polarization of the *spatially resolved* ($\sim 3''$) *featureless continuum* seems much too low for reflection. (The spatial resolution makes it difficult to invoke extreme geometrical cancellation to explain very low polarization in the reflected light model.) My conclusion is that reflected light from a quasar probably doesn't dominate the observed FC. However, there may well still be a quasar down there! A compact radio source, a tiny nuclear narrow line source (Vestergaard & Barthel 1992), and the very heavily absorbed X-ray source (Koyama 1992) may mark the spot.

Radio galaxies, like Seyferts, tend to have extended narrow line regions aligned with the radio axes; these regions have line ratios indicative of photoionization by hard sources. They are quite spectacular in the distant

luminous objects. The emission line nebulae can sometimes be traced *beyond the radio hotspots*, a strong indication that the morphology derives, at least in part, from a hidden quasar in the nucleus rather than just jet-gas interaction (van Breugel & McCarthy et al 1989).

My guess is that the NLRG/Quasar unification is true at a level sufficient to solve the statistical problems with beaming that arise when it is applied to quasars alone (see below).

3.3 *Arguments for Unification of Blazars and Other Flat-Spectrum Core-Dominant (FSCD) Radio Sources with Double-Lobed Sources*

The historical arguments for relativistic motion in the line of sight were

1. Linear, milliarcsec jets undergoing superluminal motion in FSCDs; Figure 4 provides an illustration.[4]
2. Radio variability timescales suggesting upper limits to the angular sizes which imply gross violation of the Compton limit on brightness temperature (updated in Section 4); and
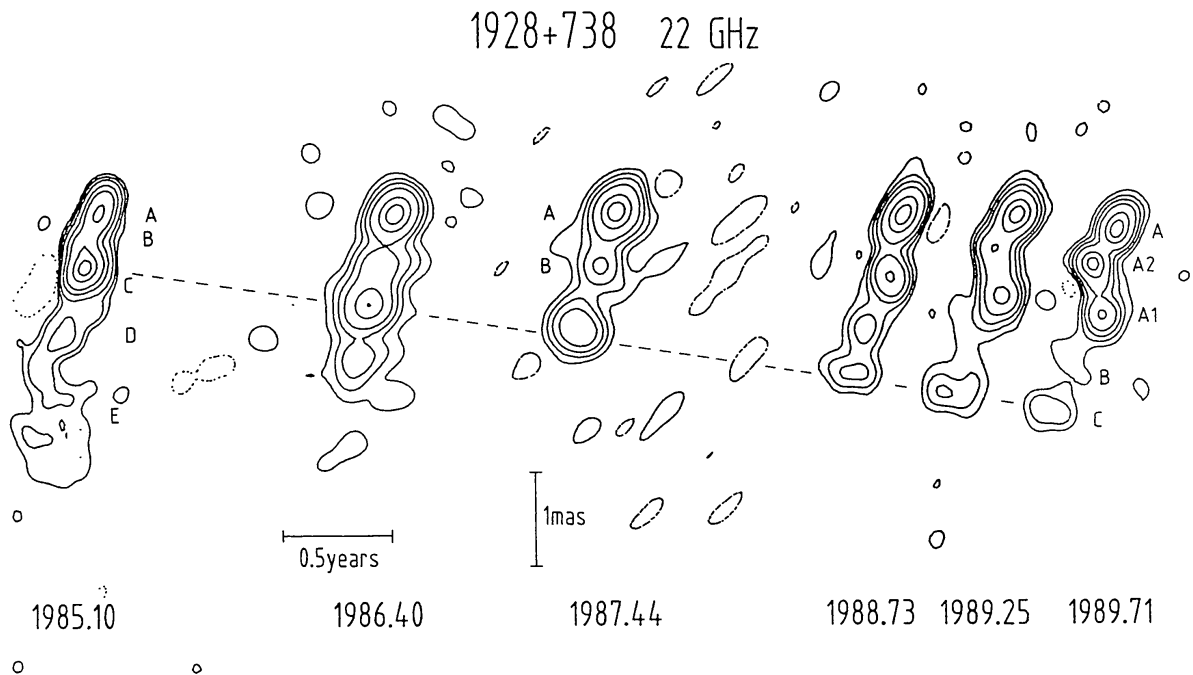
Figure 4 Superluminal motion in the FSCD quasar $1928+738$ at $=0.30$. The proper motion of Component C relative to A corresponds to $4\,h^{-1}\,c$ for $q_0 = 1/2$ (Hummel et al 1992).

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[4] For an introduction to the theory of these jets, which is, unfortunately, not in fantastic shape, see Begelman et al (1984) and Blandford (1992). Some important early work can be found in Scheuer (1974) and Blandford & Rees (1974).

3. IR variability timescales shorter than the light crossing times for black
   hole event horizons, even for Eddington-limited black holes.

Recently, detection of tremendous γ-ray luminosities for blazars using the Compton Gamma Ray Observatory has provided both compelling new arguments for beaming and also key diagnostics of jet physics (Hartman et al 1992, Blandford 1993).

We now know that *most* FSCDs are blazars (polarized optically, and variable), e.g. Impey & Tapia (1988), Wills (1988), and Wills et al (1992a). In 1978, Blandford & Rees argued that the blazar optical data alone strongly suggest incoherent synchrotron radiation by jet-like sources all pointing nearly at the Earth. This idea is called the beam model. Blandford & Konigl (1979) then applied the concept to FSCDs in general. Both of these papers also suggested that the superluminal milliarcsec jets were simply the bases of the arcsec jets of normal doubles which happened to be pointed in our direction. This notion has become known as the *Unified Scheme*. [Scheuer & Readhead (1979) did some similar work, but they supposed that the misdirected superluminals were radio quiet. Subsequent data, most clearly the large halo fluxes of the blazars, showed that misdirected blazars must be radio loud.]

Kapahi & Saikia (1982) and Orr & Browne (1982) adopted a simplified version of these ideas in which all sources have relativistic jets undergoing uniform linear motion at a constant and universal value of the relativistic γ factor, and found agreement with a variety of morphological and source count data. (Actual VLBI jets show directly that the assumptions used here are indeed major simplifications.)

The Unified Scheme idea obviously predicts that diffuse radio halos should appear projected on the strong cores of the FSCDs, with properties appropriate for end-on double lobes. As radio astronomers learned to achieve high dynamic range in their maps, several groups, including (separately) Browne, Ulvestad, and Wardle, made maps of samples of FSCDs and detected diffuse radio emission in many cases. Figure 5 shows a spectacular modern-quality blazar VLA map. Then, Ulvestad and I applied the scorched-Earth method to this test, obtaining high dynamic range maps of all of the blazars known at the time of the Angel & Stockman (1980) review paper. This enabled us to make some consistency checks regarding parameters like diffuse-component radio power and projected linear size. But it also allowed us to make a direct argument that the Unified Scheme *must* be qualitatively correct. This direct argument or proof resulted in the personal religious conversion of the present author.

The postulates of this proof are 1. strong anisotropy of the core emission, and 2. approximate isotropy of the diffuse and often two-sided arcsec scale
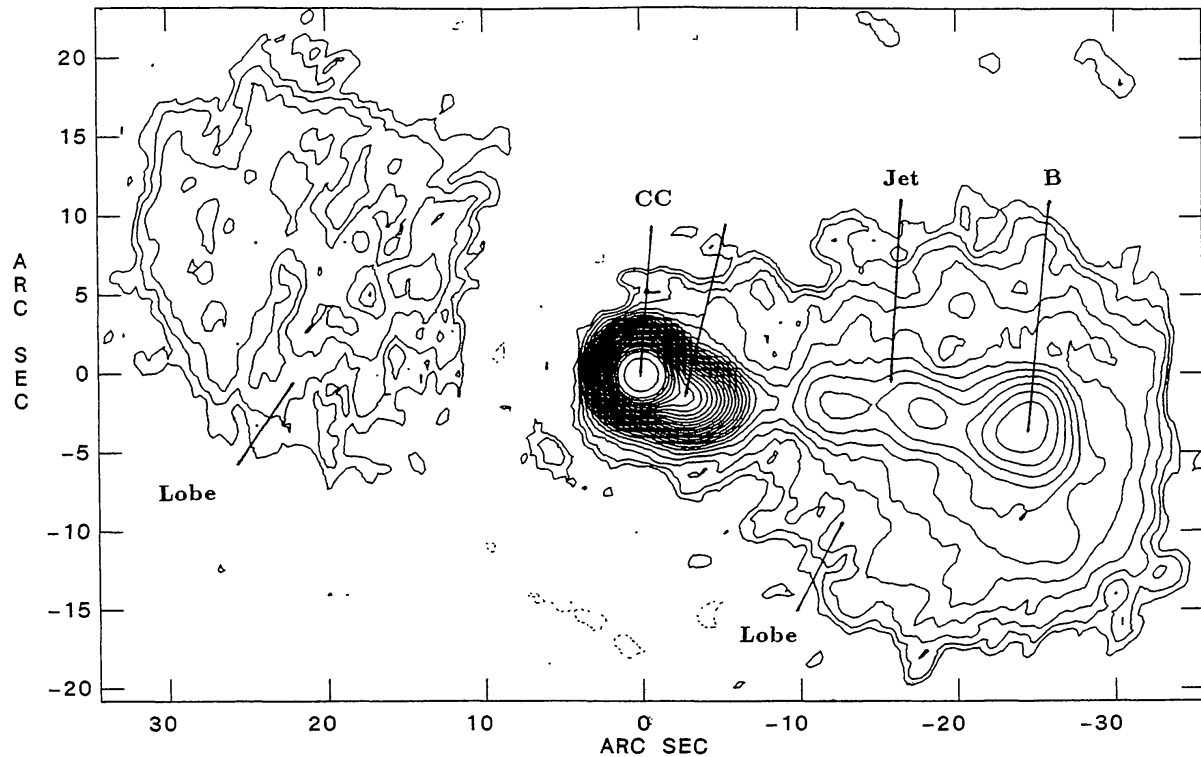
Figure 5   A very high dynamic range map of the blazar 3C371 by Wrobel & Lind (1990).
The extended radio flux of blazars is used in the text to argue for the Unified Scheme for
radio sources. Here the association of a blazar with a normal double is obvious. The projected
linear size, 42 h^{-1} kpc, is small compared with normal edge-brightened doubles, consistent
with substantial foreshortening.

emission which we and others had discovered. Several of our objects had
sufficient 178 MHz flux *in the diffuse emission alone* to get into the 3C
catalog, and many had sufficient diffuse flux to get into the 4C catalog.
Therefore, misdirected, but otherwise equivalent, objects must be in the
catalogs. Such objects, with large and powerful diffuse sources, can only
be normal doubles. In fact, if the core anisotropy is anywhere near that in
the simplest beaming models, of order *all* normal doubles must be mis-
directed blazars. It also follows immediately that the optical and X-ray
blazar components are highly anisotropic, because we don't see them from
the misdirected parent objects.[5] (See also Wills et al 1992a, Makino et al
1991, and Shastri 1991.)

Postulate number 1 was not known with very high confidence in 1985,
and various models were conceived which generically can be called wide-
cone models, which posit that the radio waves are beamed into a cone

[5] It is amusing that the "equivalent width test" of continuum beaming, the lower expected
emisssion line equivalent widths in the blazars (discussed in Moore & Stockman 1984,
Antonucci & Ulvestad 1985, and Impey et al 1991), can now be done in the X ray as well as
in the optical (Ohashi et al 1989, 1992).

much larger than $1/\gamma$ radians; in fact, it may be that some modelers were motivated by statistical arguments about parent populations, which I think turned out to be flawed. These models predict strong deviations from the canonical core-jet VLBI source morphology and kinematics. Certainly many VLBI sources deviate significantly from the SPM, but that model is turning out to be a fair approximation for most sources. (Jet curvature, amplified by projection effects, is not a problem for the SPM.) Cohen (1990) refers to the wide-cone model predictions and contrasts them with the observations. For example, he describes the motions observed in 3C 273 and states that "This does not fit at all well into any of the 'wide-cone' schemes." My point is that I'm becoming confident that our first postulate pretty much follows from VLBI data and faith in special relativity.

It is important to note that this reasoning implies that many (or all) FR 1 as well as FR 2 jets must start out relativistic; both FR 1 and FR 2 sources are required as parents of blazars based on the diffuse radio emission. The FR 1s must then somehow decelerate on kpc (or smaller) scales. This idea is supported by the fact that arcsec-scale maps of FR 1 jets generally show mysterious gaps near the cores, as well as by some recent VLBI imaging and kinematic studies (see Section 3.5.8).

In the last several years, we've been getting some reports on the VLBI speeds in the cores of lobe-dominant double sources: The speeds have been coming in at 1–5 c rather than 5–10 c as seen in the blazars, just as the SPM predicts! [The latest salvos were fired by Hough et al (1992b,c) and Hooimeyer et al (1992a,b); see also Hough & Readhead (1989) and Zensus et al (1987).] In fact, it is turning out that the less core-dominant the source, the slower the speed, and the larger the projected linear size of the diffuse emission, in alarming agreement with the SPM. After reading e.g. Lind & Blandford (1985) on the plausibility of wide cone models, I felt that the SPM was pretty naive, but lately, by reading observational papers, I am becoming more naive, rather than less.

As a final note, I think that the highly beamed, but relatively low proper motions BL Lacs do in some cases show slow motions because they are oriented at less than the optimal angle to the line of sight. Superluminal motion had been detected in three BL Lacs as of 1989. All are extremely core dominant, but slow. (See Gabuzda et al 1989 for the numbers, and for counter-arguments).

3.4   *Depolarization and Other Asymmetries*

Fanaroff-Riley Class 2 sources have double lobes which are fairly similar in flux, and yet they are fed by jets which are very dissimilar in flux. In fact, the "counterjets" are very hard to detect at all. Furthermore, the superluminal milliarcsec jets are essentially always on the same side of the

cores as the arcsec jets. In the beam model, the jet asymmetry is nicely explained as the result of Doppler boosting of the flux from the near jet, and diminution of the flux from the far jet. In order to test this, we need to know whether the jetted sides are indeed the near sides.

Laing and collaborators (Laing 1988, Garrington et al 1988) discovered a spectacular lobe depolarization asymmetry among the FR 2s. The nature of the asymmetry is that the side with the *less* depolarized lobe is almost invariably the jetted side. (See Figure 6 for an example.) The most likely interpretation is that we are measuring beam depolarization caused by Faraday rotation measure gradients in a halo, and the less-depolarized side is the near side. In other words, the near side is always the jetted side! How can this be, unless the jet radiation is beamed? This was argued in a picturesque and emphatic manner in Scheuer (1987), in a section entitled "Why Relativistic Beaming is True." [Note that at least in some cases, we do know the depolarization is from a foreground screen placed between the lobes rather than thermal gas mixed into the lobe volumes, e.g. Taylor et al (1990), Fernini et al (1991), and Clarke et al (1992).]

Two complementary puzzles immediately arose regarding the depolarization asymmetry, however. First, in the discovery samples, which are almost exclusively quasars, the effect is much too strong for a randomly oriented population. Garrington et al (1988) note that the above explanation for the asymmetry requires that the jet is generally "at a small angle to the line of sight." Similarly, Laing (1988) says that for his sample, "The sources observed here must then be oriented within about 45° of the line of sight." The second puzzle is that Pedelty et al (1989a,b) did not see the very strong side-to-side depolarization pattern found by Laing and Garrington et al, in their sample of FR 2s. Instead, Pedelty et al argued that, at least in their sample, intrinsic environmental asymmetries (outside the SPM) dominate. For example, they found that the sides with the stronger depolarization are generally the sides closer to the nucleus. (It would be nice to refer everything to the jetted sides, but jets were not detected in the Pedelty et al objects.)

The Pedelty et al sample consisted of distant NLRGs. From the optical spectropolarimetry perspective, the puzzles could be resolved via unification of NLRGs with BLRGs and radio loud quasars (see Antonucci 1989). The Laing and Garrington et al objects are pointing roughly at us, because of the selection effect of direct detection of the FC and BLR, so that orientation/beaming effects are strong. The Pedelty et al objects are preselected by the occultation of the FC and BLR, so that they lie close to the sky plane: Beaming effects are small, and intrinsic/environmental asymmetries dominate. Several other important statistical anomalies arise in applying the beam model to quasars alone, and these are lessened or

eliminated by unification with the NLRGs. This point was made strongly by Barthel (1989), and resulted in *his* religious conversion to beaming. Compare his earlier paper entitled "Feeling Uncomfortable" (Barthel 1987) to Barthel (1989).

Further confidence in this explanation derives from some sparse but intriguing depolarization images in the literature. For example, the inner halves of each lobe of 3C 234 are depolarized, just as one would hope! More discussion of these points as of early 1989 can be found in Antonucci (1989).

Since 1989, much additional information on this and related asymmetries has been gathered and analyzed. Garrington et al (1991) added 22 additional jetted sources (with size $>30''$) to the 25 (with size $<30''$) in Garrington et al (1988), and found that, just in the interval from 20 cm to 6 cm, they could detect depolarization in 37; it is stronger in the nonjetted side in 34 out of the 37 cases. They also find that the emission on the jetted side is flatter by $\Delta\alpha \sim 0.1$ in spectral index, on average, possibly due to hotspot beaming (e.g. Tribble 1992). The Garrington et al (1991) sample is not intended to be complete, but does include most known single-jet objects. The single-jet selection criterion strongly favors quasars over radio galaxies, and in the beam model, selects for objects preferentially oriented near the line of sight. This paper, and the companion interpretive one (Garrington & Conway 1991), continue the trend that among objects selected in this way, orientation/beaming effects seem to dominate. Similarly, McCarthy et al (1991), studying additional distant FR 2 NLRGs, continue to echo Pedelty et al in finding strong intrinsic/environmental effects. For example, the primary result of the McCarthy et al paper is that the extended line emitting gas is brighter on the side with the closer of the two radio lobes. From the point of view of the beam model, given that this correlation is present in the NLRGs, it should continue statistically for the quasars, although it should probably become noisier. It is still strong in the quasars found by McCarthy et al in the literature.

Tribble (1992) summarizes the situation nicely. He also concludes that intrinsic asymmetries exist, but that for the sources near the line of sight (BLRGs and quasars), orientation and beaming effects dominate. The intrinsic asymmetries are, of course, outside the SPM.

3.5   *Tests of the Correctness and Generality of the SPM, and Other Related Issues*

There isn't really a clear separation between the material in the last section and in this one. Section 3.4 contains much of the material which I personally found interpretable and compelling, it makes a fairly connected story, and it follows the intellectual thread that I have followed most

504   ANTONUCCI
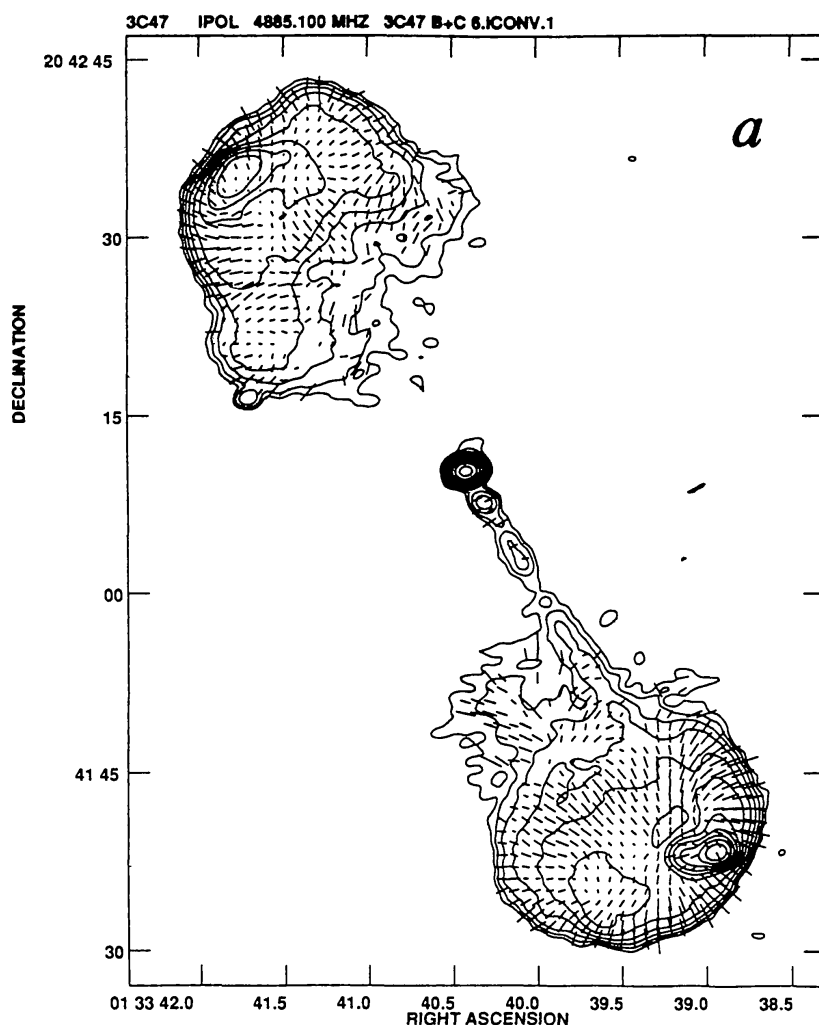
Figure 6   Depolarization mapping of the quasar 3C47 by Fernini et al 1991. (*a*) At 5 GHz both radio lobes are highly polarized. (b) At 1.5 GHz the lobe on the jetted side is still highly polarized, whereas the "counterjet" lobe is almost completely depolarized.

closely. There is, of course, a large amount of additional high quality work in the literature. I will touch on several of these other areas here.

3.5.1   TESTS USING OSTENSIBLY ISOTROPIC PROPERTIES: LINE EMISSION If FSCD and SSLD (Steep Spectrum Lobe Dominant) radio quasars are the same except for orientation, they should arguably have the same distribution of ratios of, say, F([O III] $\lambda 5007$)/F(radio lobes). One can argue about how secure the isotropy assumption is for these quantities, but it's certainly plausible. Heckman (1983) discussed this point, and concluded that the core-dominant and lobe-dominant quasars differed greatly, and that the unified scheme failed.
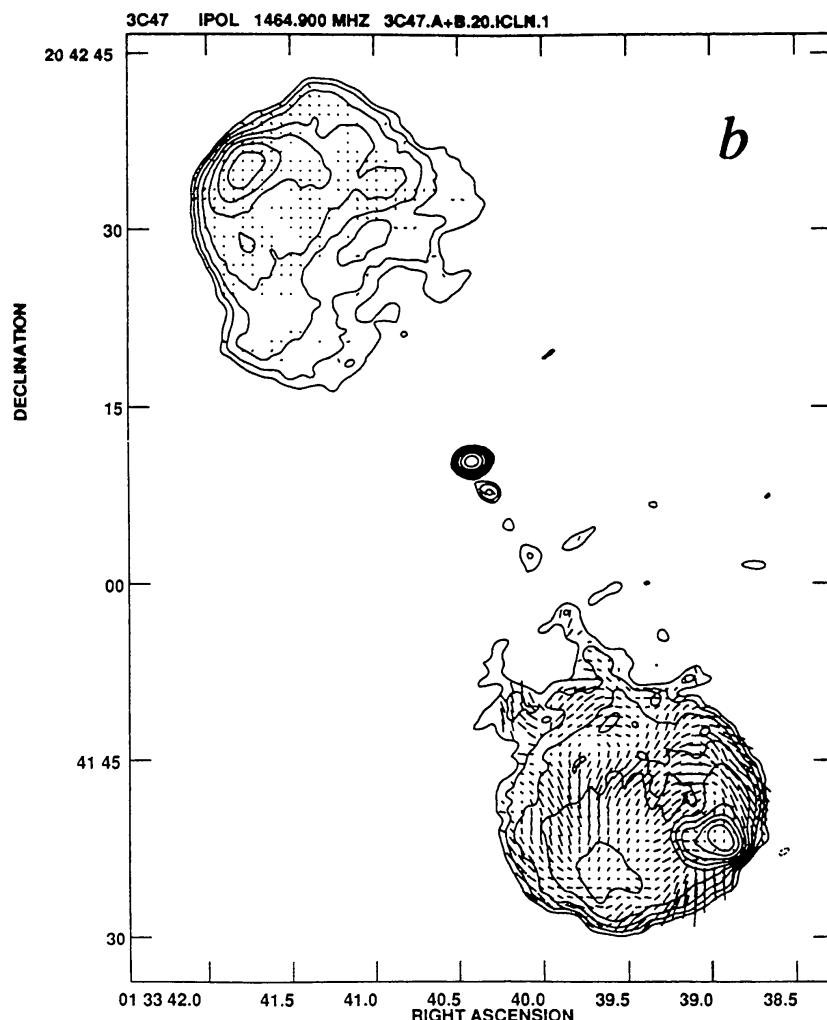
3C47   IPOL   1464.900 MHZ   3C47.A+B.20.ICLN.1

Figure 6—continued.

The Heckman test wasn't decisive because the methodology was imperfect. As noted in Section 2, to make such a test, one should select by one isotropic property (e.g. lobe radio power) and then compare another (such as [O III] power). Failing that, one could select in some arbitrary way, but then at least match the samples for their distribution in one isotropic property, and compare another. In this early study, neither plan was adopted. Famous objects of one type were simply compared with famous objects of the other type. By an obvious selection effect, the FSCDs had much less diffuse (isotropic) radio power than the SSLDs, and so, in the unified models, were taken from far lower in the luminosity function, and were quite different beasts. The same methodological limitation hinders use of host galaxies for testing the model (Boroson et al 1985).

Many others have since made related tests, although now people generally do the required matching. For example, Jackson & Browne (1991a,b) have concluded that, for quasars alone, some expectations of the SPM are verified (e.g. [O III] equivalent width as a function of radio core dominance—a test of optical beaming). However, certain line ratios such as Fe II/[O III] also depend on core dominance even within the quasars—so that the SPM must invoke anisotropy of the Fe II emission, aside from that produced by shadowing by the torus. This is consistent with the findings of Boroson (1989). The Fe II data may in fact indicate the breakdown of the SPM. Various authors (e.g. Lawrence 1991) have found that the [O III] emission is weaker at a given lobe power in NLRGs compared with broad line radio louds. Just as in the radio quiet case (Section 2.6.1), the SPM would have to invoke partial obscuration of the [O III] clouds by the torus. This is made more palatable by the finding that the classes are indistinguishable in the lower-ionization [O II]λ3727 line (Hes et al 1993). Finally, Rawlings & Saunders (1991) use the narrow lines and the "jet power" to test the unification of quasars and BLRGs with NLRGs, and the results are consistent with the simplest SPM.

3.5.2. OTHER TESTS INVOLVING OSTENSIBLY ISOTROPIC PROPERTIES Far-IR emission is probably fairly isotropic in NLRGs and lobe-dominant BLRGs and quasars. What does the ratio of far-IR flux to lobe radio flux tell us about unification of these two classes? (Extending this test to FSCDs wouldn't be valid because their far-IR emission is from the jet, and by hypothesis at least, beamed.) The *IRAS* data aren't sensitive enough to make a really good test: Hardly any of the objects are detected individually. But Heckman et al (1992) extracted some useful information from the *IRAS* archives anyway. They cleverly co-added the *IRAS* data on 42 quasars, and on 75 NLRGs, with $z \geqslant 0.3$. The result was detections of both classes!

The result of their study can be characterized either as "the cup is half full" or "the cup is half empty." The good news is that "The (mid- and far-IR) appears to be the energetically-dominant wavelength regime for the radio galaxies and is comparable to the optical/near-UV regime for the quasars. Thus, these powerful radio galaxies contain potent sources of radiation that are either hidden or energetically unimportant at shorter wavelengths." On the other hand, the SPM is apparently ruled out by the average three times larger mid-far IR/radio lobe luminosity ratio in the quasars. There are various ways out of this dilemma: 1. It's possible that lobe luminosity is mildly anisotropic, not because of optical depth effects, of course, but because of the magnetic field configuration; 2. it's possible that the detected signal is contributed by just a few objects and is subject

to small number statistics; 3. optical depth effects could cause the IR emission to be anisotropic; or 4. it is possible that the beamed synchrotron component contributes significantly to the FIR in those quasars with relatively strong cores, and moderate superluminal motion, as pointed out to me by C. Lawrence. He and I will try to observe the Heckman et al sample members at ~ 1 mm to test for this. The IR luminosity distributions (and far IR spectral energy distributions of the individual objects which provide evidence of optical depth effects) must ultimately be compared, and they probably overlap greatly. On balance, however, the results of Heckman et al suggest that unification is partly true, but not as simple as in the SPM.

What about the lower luminosity nearby FR 2s? There is nothing in the literature, and informally I have heard contradictory things. E. S. Phinney (1988, personal communication), finds that the far-IR [O III] match gets worse for lower power FR 2s, implying that the SPM is a worse approximation there. T. Heckman (1992, personal communication) finds that the match is good at 100μ and that the broad line objects are somewhat brighter at 12μ, just as Pier & Krolik (1992b) expect for the SPM.

Another isotropic property is the galaxy density around the AGN. There is no definitive study here, but some attempts have been made for the low redshift objects (FR 1s versus nearby blazars or BL Lacs and FSCD radio galaxies). Prestage & Peacock (1988) came within a factor of a few of matching diffuse radio powers of SSLD and FSCD radio galaxies in their tests, and concluded that the former tend statistically to lie in richer environments than the latter. Qualitatively, the perception that "BL Lacs" avoid richer environments has been breaking down recently. Falomo (1991) finds that the nearby BL Lacs have environments similar to those of FR 1 radio galaxies, as expected in the SPM. (See, for example, Falomo et al 1993.) See also the new study by Fried et al (1993).

What about the host galaxies themselves? For the nearby FR 1 blazars, we expect to see giant elliptical hosts, and almost always do (Miller 1981, Wurtz & Stocke 1993, Abraham et al 1991). This is closely consistent with the SPM, but there are several fascinating claimed exceptions, in which the host appears to be a disk galaxy! (See Abraham et al 1991 and McHardy et al 1991, but also Stocke et al 1992b and Romanishin 1992.) In searching for diffuse radio emission associated with blazars, we and others are *almost* always successful, but the failures indicate that the parents can be extremely weak radio galaxies; maybe a few can even be radio-quiet disk galaxies. It would be of interest to combine the optical data with definitive radio data in these cases.

Among moderately distant FR 2s, Hutchings (1987) finds that hosts are large and luminous for both the NLRGs and the quasars, with broad

overlap in their properties, but statistical differences in the means. The samples are matched (though not selected) by diffuse radio luminosity. If this is true (see the discussion of Abraham et al 1993), it requires at least a range in torus opening angle, contrary to the SPM.

Finally in this category, there have been spectacular discoveries regarding the hosts of high Z NLRGs and quasars. Both have very large, luminous continuum and emission line fuzz, and the fuzz of the two classes is similar and consistent with unification (Lehnert et al 1992).

3.5.3   PROJECTED LINEAR SIZES OF THE DIFFUSE RADIO EMISSION   The SPM

predicts that the projected linear sizes of the diffuse radio emission is smallest for the blazars and other FSCDs, medium for the BLRGs and radio quasars, and largest for the NLRGs. In an influential paper on linear sizes, Schilizzi & de Bruyn (1983) reached conclusions inconsistent with the SPM, but the results are hard to interpret. They compared FSCD quasars with SSLD quasars, expecting (but not finding) that the latter are much larger. Their FSCDs had FR 1 diffuse radio power, and their SSLDs were basically FR 2. It is very hard to interpret the projected linear size comparison in that case, especially since FR 1s are edge-darkened, so their sizes depend entirely on surface brightness sensitivity. Also of course, excluding NLRGs should have substantially reduced the amplitude of the signal. Ulvestad and I (Antonucci & Ulvestad 1985) attempted to do this with a better matched sample, and without restricting the parents to quasars, obtaining a satisfactory result for the SPM. Separately, Hickson, Olszewski, Miller, and I performed the test for just the few known FR 2 blazars (objects with hotspots and thus well-defined projected linear sizes), and concluded that all was well (Antonucci et al 1987). I think this result is holding up; see, for example, the gorgeous map of the $\sim 42\ h^{-1}$ kpc hotspot blazar 3C 371 by Wrobel & Lind (1990 reproduced in Figure 5). (That article also shows how high quality maps can be perfectly supportive of the SPM, while a lower quality map in the literature seemed to refute it!)

Barthel (1989) has shown that the "completed 3CR" quasar and NLRG diffuse radio sources have sizes and number densities consistent with the SPM in the $0.5 < Z < 1.0$ interval. The evolution of the sizes with redshift is more controversial (see Kapahi 1990, who also cites a Z dependence of the relative space densities, and Gopal-Krishna & Kulkarni 1992). This seems to be a tricky question.

One good piece of advice for this work is to make sure to include the true BLRGs with the quasars in these studies, and to make sure to include objects that are, in this scheme, NLRGs like 3C 234, in with the NLRGs. In some cases, I'm not sure where an object belongs, e.g. 3C 109 has highly polarized broad lines and continuum together with unpolarized narrow

lines, like 3C 234, but is polarized by dust transmission according to Goodrich & Cohen (1992). [It has strong X rays with a moderate 4×10^{21} atoms/cm^2 column (Allen & Fabian 1992).] It is probably also worth carefully excluding the many steep-spectrum compact sources which seem to be physically different and not directly related to the unified models.

Regarding the source counts at low diffuse radio power, Lawrence (1991) finds that narrow line objects greatly predominate. Although it could still be that the broad lines are simply harder to spot than the narrow lines when starlight dominates, this result probably means that low luminosity objects tend to have larger covering factors (which is outside the SPM). Of course, there is no guarantee that all the low luminosity objects have BLRs at all.

3.5.4 LUMINOSITY FUNCTIONS The luminosity function has been discussed by many people. Phinney (1984) gives a nice introduction to the theoretical expectations. After ruminating over the quasar luminosity function and some crude early information on diffuse radio emission, he concluded that, either 1. (most) unbeamed quasars aren't classified as quasars, 2. simple unification of FSCD and SSLD quasars is wrong, or 3. the synchrotron jet is not smooth and homogeneous with a tophat velocity profile. (See his section IV: "Lies, Damned Lies, and Beaming Statistics.")

Phinney favored options 2 and 3, but now I believe we know that option 1 is at least partially correct. Some true quasars oriented in the sky plane are classified observationally as radio galaxies. Perhaps more important, Phinney assumed the beamed objects have isotropic *optical* emission, which is contradicted by the subsequent discovery that *most* have a strong contribution from jet synchrotron emission. He required the parents to be as bright in the optical as the beamed objects. Given the steepness of the quasar luminosity function, this caused a great underestimate of the number of available parents. The possible mild intrinsic anisotropy of the BBB itself also has an effect (see Jackson & Browne 1991a,b). Of course, Phinney's reasons 2 and 3 are probably true as well!

Urry & Padovani have written many papers on the *radio* luminosity functions, without making any assumption about optical isotropy. References to these papers, and the punch line for beaming models, are given in Urry & Padovani (1992). (See also Padovani & Urry 1992.) They break down the object categories slightly differently than I do, but their conclusion still applies: All is well with the beaming/orientation idea unifying the blazars, radio quasars, and NLRGs. The SPM is not correct, however: The assumption of fixed γ-factor in all objects must be relaxed. The data require that there is a range with a mean value of ~ 7. Urry & Padovani find a mean value of only 3 for the X-ray selected objects,

qualitatively consistent with the idea, mentioned earlier, that they are less highly beamed than the radio-selected objects.

Jackson & Browne (1991a,b) separate the diffuse radio emission explicitly, and also keep track of the requirements on optical anisotropy. They find that, in order to make the SPM work, the optical continuum and the permitted Fe II and Hβ lines must all be stronger in the pole-on objects, even among the quasars (i.e. this is not just an effect of an obscuring torus). The BBB anisotropy requirement is qualitatively inconsistent with the conclusions of P. Francis (Section 3.5 above), but this disagreement should be put on a quantitative footing. The line anisotropy requirements could be true for the radio louds but they are not supported by some tests for analogous effects among the quiets (Section 2.5, quoting Boroson 1992).

3.5.5 MICROLENSING OF "BL LACS"? The original Ostriker & Vietri paper (1985) made several arguments that some BL Lacs are microlensed nuclei of OVV quasars at high redshift. I disagree with most of them, and Ulvestad and I have argued that various observations are inconsistent with their hypothesis being widely true (Ulvestad & Antonucci 1986). For example, we cite the observable large emission line luminosities of the nearby BL Lac galaxies relative to randomly selected giant ellipticals based on the data of Miller et al 1978 (J. Miller, personal communication), the morphologies and the large projected angular sizes of their radio halos (take a look at the numbers!), and problems with the cases of positional offsets claimed by Ostriker & Vietri. While the idea can't be ruled out for every individual case, the Ostriker & Vietri motivation was the perceived strong statistical anomalies in e.g. the redshift distribution, which could only be remedied if their idea were it *quite widely* applicable.

In fact, I think their anomolous redshift distribution is a classic case of what goes wrong when you mix the different types of BL Lacs! Ostriker & Vietri cite several distant BL Lac objects with high-Z absorption line systems. Their parents are luminous quasars, because they *do* show luminous broad emission lines: They are no different qualitatively from what Ostriker & Vietri call OVV quasars. Based on the paucity of such objects, they say there are "too many" local BL Lacs, and indeed there are, because the nearby objects have FR 1 radio galaxies, with a high local space density, as parents, and are a completely different class.[6]

Ostriker & Vietri state that their model is "immediately testable on the basis of absorption line studies and by direct imaging." It predicts that the

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[6] It is interesting that Burbidge & Hewitt (1987, 1991) recognized the two different types of "BL Lacs," though they argued the the OVV-like objects are not at their cosmological distances.

nearby objects should show absorption lines at higher redshifts than their (narrow) emission lines (and host galaxy or putative lens galaxy absorption lines). This has never been seen. Similarly, the model predicts that the nearby BL Lacs can appear anywhere in the apparent host galaxy, again contrary to the observations (e.g. Abraham et al 1991 and related comment by Merrifield 1992) at least in the large majority of cases (Ulvestad & Antonucci 1986, Merrifield 1992). Also, the whole idea that microlensing can amplify an OVV nucleus into a BL Lac has been disputed by Gear (1991) on the grounds that the *radio* cores are known to be much too large for this and the radio/optical spectral energy distributions are the same for the BL Lacs as for the OVVs. [On the other hand, small amplitude flickering of the radio flux has been attributed to microlensing of relativistic jets by Gopal-Krishna & Subramanian (1991).] There are many other aspects of this debate, e.g. Padovani (1992) finds that the amplification distribution expected for microlensing is inconsistent with the Ostriker & Vietri requirements and also the different Kollgaard et al (1992a) VLBI polarization results for so-called BL Lacs vs OVVs.

In their second round, Ostriker & Vietri (1990) cite the case of $0846+51W1$, noting that it has changed its classification from a BL Lac to an OVV at a redshift of 1.86, and it is only $12''$ from a foreground galaxy. But as explained in Section 3.1 above, this is normal behavior for those objects, whether or not there is a nearby galaxy. They also analyze statistically the "BL Lacs" in the HB catalog. The problems with this are similar to those in their first paper. For example, they argue based on the known distant luminous BL Lacs and quasars, including radio quiet ones, that the ratio of the density of the former to the latter is $\sim 10^{-4}$, so that we expect only $\sim 10^{-4}$ BL Lacs closer than 3C 273, by extrapolating to zero redshift at constant BL Lac/quasar ratio. Again, in my opinion, this is entirely invalid. The nearby objects' parents are FR 1 radio galaxies.

There may, of course, be individual cases, perhaps short-lived, of "BL Lacs" as microlensed OVVs; once again, they should be characterized by: generally off-center locations; grossly abnormal optical/radio ratios (Gear 1991); and absorption lines with redshifts much greater than that of the putative parent galaxy. A possible example is AO $0235+164$ which has an absorption line system with a higher redshift than one of the emission line systems (Stickel et al 1988). In its optical properties it is quite unlike most BL Lacs thought to be nearby, and it has never been argued to be nearby. It is a complicated system. Recent pro and con observations of other examples include Wurtz & Stocke (1993) on MS $0205.7+3509$ and Falomo et al (1992) on PKS 0537-441.

3.5.6 COUNTERJETS OF FR 2 RADIO SOURCES According to the SPM, the counterjets are weak because of Doppler disfavoritism (e.g. Begelman

1993a). Weak counterjets are now being detected in some cases, which is on balance a victory for the beam model as opposed to, say, the flip-flop or alternating-side ejection model. The counterjets do exist! However, they are not just weaker but otherwise identical copies of the jets. It's crucial to note that *such "copy" counterjets may exist at the level expected in the SPM* (modulo redshifting effects, etc) but still below detectability. What has been detected so far (e.g. Bridle 1990, 1992; D. Hough, personal communication) are knotty structures that tend to have emission at radii at which the main jets have bends or flares. One can imagine that at these radii, both the jet and the counterjet are disturbed, so that some synchrotron emitting plasma is slowed and emits more isotropically. *Optical* emission indicative of counterjets has been reported in two lower luminosity objects with single sided radio jets (Stiavelli et al 1992 on M87 and Axon et al 1989 on 3C 120).

3.5.7   INTRADAY VARIABILITY OF BLAZAR RADIO EMISSION   "Low frequency variability," a slow, large-amplitude variation in the meter-wave radio fluxes of some blazars, historically appeared inconsistent with the SPM. This problem has largely gone away with the recognition of the role of refractive interstellar scintillation (see e.g. Dennison & Rickett 1990). However, a new type of variability ("Intraday" or sometimes "Micro"), which is equally virulent in terms of its requirements on brightness temperature, has recently been recognized (e.g. Quirrenbach et al 1992). This is relatively small amplitude variability at cm wavelengths, on timescales of days or even less. If truly unaccountable as a propagation effect (there is *some* evidence for correlated variability in the optical), or as microlensing (Gopal-Krishna & Subramanian 1991), or as a lighthouse effect (Gopal-Krishna & Wiita 1992, Camerzind & Krockenberger 1992), this discovery alone shows the SPM is wrong or incomplete. The reason is that it would require gamma factors ten times those inferred from superluminal motion speeds.

According to Marscher (1992), the SPM, made more realistic by assuming that the radio emission is from shocks, can barely account for the observations, and only if the phenomenon isn't too widespread. If it is, more serious modifications of beaming such as coherent processes will have to be considered (e.g. Weatherall & Benford 1991 and Lesch & Pohl 1992). If that turns out to be the case, we will have to think carefully about the ramifications. Much of the science described in this article could probably survive the disaster.

3.5.8   DO THE FR 1 JETS START OUT RELATIVISTIC?   According to the SPM, and really the beam model generally, many of them, perhaps all, must do so. The reason is that some blazars and other fast superluminal sources

have diffuse radio power at the FR 1 level. Of course, on ~ 10 kpc scales (~ 10 arcsec for $Z \sim 0.1$) the jets are fairly symmetric and thus nonrelativistic.

One clue that the jets may indeed start out relativistic is the short gaps seen near the nuclei in FR 1s at arcsec scales. This could be attributed to relativistic jets emitting beamed radiation which misses us, but then slowing and becoming isotropic. In fact these gaps, examined more closely, are better described as regions of weak one-sided jets.

A wonderful new result is that the stronger jet is generally on the same side as the less-depolarized lobe, just as is the FR 2s (de Ruiter et al 1993). It is sometimes possible to verify that this is due to beam depolarization of the counterjet lobes (see Taylor et al 1990 for spectacular data on Hydra A = 3C 218).

Classical tests for relativistic jets on parsec scales are 1. one-sidedness on VLBI maps, and 2. core proper motion corresponding to $\gtrsim c$. Some such information is becoming available for FR 1s.

Regarding sidedness, as noted, weak single subarcsec jets sometimes appear in the gaps at the bases of FR 1 jets. On VLBI scales a one-sided jet is seen in the well-studied case of NGC 315 [$S_{1.6\,\mathrm{GHz}}$(jet) $\geqslant 50 \times S_{1.6\,\mathrm{GHz}}$(counterjet); Venturi et al 1993]. This is consistent with the SPM, with relativistic bases for the FR 1 jets as required. In this case the ~ 10 arcsec scale jet is double, but with a sidedness ratio of 20 to 1. Venturi et al quote a model-dependent inference that the arcsec-scale jet is slow and so intrinsically asymmetric. More troubling to me, at least at first sight, is that the knots have proper motion $\beta_{\mathrm{app}} \lesssim 0.5\,c$, rather than the $\beta_{\mathrm{app}} \gtrsim c$ expected in the SPM.

This same puzzle, a one-sided milliarcsec jet with a stationary knot, has been reported for NGC 6251. But a crucial update by Jones & Wehrle (1991, 1992) may solve the problem. The stationary knot is still there but a new, probably superluminal component has appeared halfway between it and the core! This strongly supports the idea or excuse that some VLBI knots in FR 1s are slow-moving or stationary shocks, and that the true flow speed is indeed relativistic. Similar behavior is sometimes seen in luminous sources such as 4C39.25 (Shaffer et al 1987). This is consistent with the beam model/Unified Scheme, but the stationary shocks are outside the SPM.

More discussion of the hypothesis of relativistic bases of FR 1 jets can be found in Laing's 1992 article from the Baltimore jets meeting.

4. THINGS TO COME

My conclusion is that the SPM is true to zeroth order and that it represents major progress. Some of the evidence for orientation effects is so robust

that it won't ever go away, so in that sense we are in the refinement rather than the testing stage, though the refinements are fairly major. The strict SPM is *not* true to first order and so is an unsatisfactory description of what's going on. But more work is required to elucidate this and it may well be that most objects have orientation-dependent classifications.

Some desirable future studies include:

1. For NGC 1068, determine the spatial scale of the obscuring material and also of the reflecting material. Both are possible now. For example, one could try mapping NH_3 emission with low resolution VLBI, e.g. the VLA-A array plus the nearby VLBA antennas, for $\sim 0.1''$ resolution. Millijansky level fluxes are expected. This and other lines (the megamaser, and maybe a high-density, high temperature thermal line in which the mm arrays could get good resolution, such as CS $J = 5-4$) could provide a rotation curve for the obscuring torus. It just might show Keplerian motion.

2. Perform *HST* polarimetry of the FCs in Seyfert 2s and NLRGs, deep in the UV where starlight is much less important. Perform more ground-based and space-based imaging polarimetry, and spectro-polarimetry of the off-nuclear UV patches discovered in radio galaxies by Van Breugel, Dey, and others.

3. It is important to know whether all pole-on objects show BLRs. In particular, we want to know whether all blazars have broad line emission. The limiting factor in past studies has always been systematics in the fluxing of the spectra, rather than shot noise. We can trade the systematic errors for random ones by measuring the polarized flux spectra, scaling to the total flux spectra, and subtracting. Unpolarized emission lines would fall out.

4. More IR polarimetry, spectropolarimetry, and spectroscopy of narrow line radio galaxies with IR excesses is needed: These excesses are suggestive of penetration of kpc-scale dust lanes.

5. As noted in Section 3.5.1, Hes et al (1993) find that [O II]$\lambda 3727$ luminosities of broad line and narrow line radio loud objects of a fixed lobe power match each other well. They explain the mismatch in [O III]$\lambda 5007$ as a result of partial obscuration of the higher-ionization [O III] clouds. This predicts that the [O III] should show up at some level, perhaps greatly broadened, in the polarized flux in some cases.

6. We need high-quality, scaled array depolarization mapping of all kinds of objects, but especially FR 2 NLRGs.

7. Carry out more deep searches for FR 2 NLRG jets, and FR 2 quasar counterjets.

8. Continue the VLBI studies of sidedness and motions in FR 1 cores.

9. Complete the proper motion studies in the radio cores of lobe-selected samples.

10. Make definitive CO and low-frequency cutoff observations of radio quiet quasars, to check for agreement with the thermal model and consistency with some IRAS galaxies as misdirected quasars.

11. An investigation of blazars in apparently spiral hosts, and/or with zero or very low diffuse radio luminosity is needed. Could the Galactic Center source Sgr A look like a weak blazar from any location? Or could the spirals really be S0s, which would make them unremarkable?

12. Continue observational work on the intraday radio variability, especially definitive radio/optical monitoring to determine for certain whether or not the variations are intrinsic to the sources.

13. More work must be done on the theory of deceleration of FR 1 jets from relativistic to nonrelativistic speeds.

14. In theory, of course, a big, big question is: What causes the difference between the radio loud and radio quiet AGN?, and why is it so closely connected to the host galaxy type? There has been speculation that some radio galaxies are mainly nonthermal and kinetic-energy emitters, that radio quasars are more mixed, and that radio quiet AGN emit most of their energy thermally. This has been attributed to a range of $L/L_{Eddington}$, and to a varying ratio of rotational and accretion power. One new bit of information is the Heckman et al (1992) discovery (Section 3.5.2 above) that, at least for the average FR 2 NLRG, thermal emission does seem to dominate the electromagnetic luminosity. This thermal dust emission is probably reprocessed quasar nuclear emission, according to the SPM; hence, there really is no observational case for "nonthermal AGN." Similarly, to the extent to which the unification is correct, a quasar does not become a NLRG because the fueling rate diminishes. (See e.g. Begelman et al 1984.)

Brown's (1990) article on 3C 196 is quite interesting. He shows that "parsec-scale radio jets in compact, luminous objects will [always] be superluminal," because jets that do not undergo bulk relativistic motion are doomed to have their electrons Compton cooled to non-relativistic energies. [Related arguments have been used by Daly (1992) to constrain the emission from hidden quasars inside radio galaxies although the conundrum of electron reacceleration influences the aging argument there.]

It has been speculated that radio quiet objects have polar outflows, which are, however, composed of thermal rather than nonthermal gas (e.g. Begelman 1993b and Barthel 1992). The outflow may be the cause of broad absorption lines in favorably oriented objects. Could it be that radio quiet objects have (for some reason!) bulk-subrelativistic

jets, in which any relativistic electrons are Compton-cooled below the energies required for synchrotron emission? Brown (1990) remarks casually that slower jets may be manifest as sources of X rays (from the Compton cooling). Can someone model this and make a prediction regarding an excess X-ray component in the radio quiets versus the (lobe-dominant) radio louds? Or would the electrons never get hot enough to produce the X-rays?

15. Back on the observational side, the correlations emerging between Mg II broad absorption lines, Fe II, excess far-IR emission, and polarization are ripe for exploitation (see e.g. Wills et al 1992b and Boroson & Meyers 1992).

16. It is possible in principle to use Thomson-scattered radio waves in cluster cooling flows to see the beam patterns of the putative misdirected blazars directly, and to learn something about their lifetimes! This isn't easy but it might make a great thesis project. (See Wise & Sarazin 1992.)

17. Finally, spectrophotometry might be profitably employed to obtain multidirectional views of such Galactic sources as young stellar objects and asymptotic giant branch stars which are obscured by dusty tori.

ACKNOWLEDGMENTS

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