Astronomical and Astrophysical Transactions (*AApTr*), 2012, Vol. 27, Issue 4, pp. 557–602,
ISSN 1055-6796, Photocopying permitted by license only, ©Cambridge Scientific Publishers

A panchromatic review of thermal and nonthermal active galactic nuclei

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Received 13 May, 2011

The first short part of this review is a general, but very detailed, critique of the literature advocating the existence of a class of Seyfert galaxies intrinsically lacking broad emission lines and (sometimes) the thermal "Big Blue Bump" optical UV continuum component. Many uncertainties and erroneous assumptions are made in these papers, and almost all the conclusions are weak or erroneous. Panchromatic properties of all types of radio loud AGN are then reviewed in detail.

Radio galaxies usually show subparsec-scale radio core sources, jets, and a pair of giant radio lobes. The optical spectra sometimes show only relatively weak lines of low-ionization ionic species, and no clear nuclear continuum in the optical or UV region of the spectrum. Some show strong high-ionization narrow lines. Finally, a few radio galaxies add broad bases onto the permitted lines. These spectral categories are the same as those for radio-quiet AGN and quasars.

By the 1980s, data from optical polarization and statistics of the radio properties required that many narrow line radio galaxies do in fact produce strong optical/UV continuum. This continuum and the broad line emission are hidden from the line of sight by dusty, roughly toroidal gas distributions, but they are seen in polarized flux. *The radio galaxies with hidden quasars are referred to as "thermal."*

Do all radio galaxies harbor hidden quasars? We now know the answer using arguments based on radio, infrared, optical and X-ray properties. Near the top of the radio luminosity function, for FRII, GPS, and CSS galaxies, the answer is yes. Below the top of the radio luminosity function, many do not. At low radio luminosities, most do not. Instead these *"nonthermal" weakly-accreting galaxies* manifest their energetic output only as kinetic energy in the form of synchrotron jets. These kinetic-energy-only ("nonthermal") radio galaxies are a subset of those with only weak low-ionization line emission. This applies to all types of radio galaxies, big FR II doubles, as well as the small young GigaHertz-Peaked-Spectrum and Compact Steep Spectrum sources. Only a few FR I sources are of the thermal type.

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I. TERMINOLOGY

Almost all Radio Quiet Seyfert galaxies, *defined by narrow emission line ratios*, show the energetically dominant *thermal* "Big Blue Bump" optical/UV continuum components. Many are hidden from direct view, and are only seen in polarized light. Many authors have argued, however, that some Seyfert 2s intrinsically lack these components (or at least the broad emission lines) and such objects are often referred to as True Seyfert 2s and sometimes as nonthermal Seyferts. The methodologies used are critiqued in detail, and it is concluded that all such claims are dubious at best.

This paper concerns primarily radio loud active galactic nuclei (AGN). "Radio loud" is sometimes defined by an absolute radio luminosity cutoff, and sometimes (less usefully) by a ratio of radio to optical luminosity. The nomenclature is multifaceted, complex, and very confusing for a newcomer. We will divide the AGN into two broad classes, which correspond to the two popular and persuasive central-engine models. The presence of an optical/UV continuum of the type called the Big Blue Bump will be called "thermal" because there is a consensus that this is thermal radiation from a copious opaque and probably usually geometrically thin accretion flow. This includes the radio loud quasars, the Broad Line Radio Galaxies, and the objects that have similar accretion flows hidden from the line of sight. (Some papers define the Big Blue Bump as the excess over a notional power law extending from the near-IR to the far-UV or X-ray, but that is not the most common usage, or the present usage.) The Big Blue Bump is virtually always accompanied by conspicuous broad permitted emission lines[1] from regions collectively called the Broad Line Region. This combination is called a Type 1 spectrum.

By contrast, a radio loud AGN which lacks visible broad lines is called a Narrow Line Radio Galaxy ("Type 2" optical spectrum). The narrow-line spectra of all radio types vary enormously from optically weak Low Ionization Galaxies — sometimes loosely called Low Excitation Galaxies — like M87, to very powerful High Ionization Galaxies like Cygnus A. The former are turning out to be almost all "nonthermal" radio galaxies, lacking a powerful Big Blue Bump and Broad Line Region, even a hidden one.[2]

If the Big Blue Bump is directly visible in the total-flux spectrum, the object is called a radio loud quasar,[3] or if low in optical luminosity (e.g. $M(V) > -23$ for $H_0 = 50$ km sec^{-1} Mpc^{-1}, as adopted for the older Veron-Cetty and Veron catalogs), it may be called a Broad Line Radio Galaxy.[4] In fact when it's clear from context, "quasars" will be taken to include Broad Line Radio Galaxies.[5]

For radio-bright objects at redshifts of larger than a few tenths, the presence of a (directly visible or hidden) optical/UV Big Blue Bump is general — except in those rare objects whose optical/UV spectrum is overwhelmed by beamed synchrotron emission from the bases of favorably oriented relativistic jets ("Blazars"). For objects with a large contribution to the optical/UV continuum by highly variable, highly polarized beamed synchrotron radiation, the general term is Blazars, defined in Stein 1978. Blazars are defined as the union of two classes: 1) objects in which a Big Blue Bump/Broad Line Region is still discernible against a strong synchrotron component (Optically Violently Variable Quasars, also known as Highly Polarized Quasars) with 1960s–1970s technology, and 2) objects with a pure synchrotron

[1] Possible exception to this one discussed in the next section.
[2] Note that there is only a little evidence yet that the thermal and nonthermal objects are bimodal in any property, and such isn't necessarily expected theoretically.
[3] Recall that this paper is largely restricted to radio loud AGN.
[4] It is sometimes argued that at these low luminosities, there are some relatively subtle differences with respect to the quasars, e.g., van Bemmel and Barthel 2001, but such a distinction will not be made here.
[5] For redshifts above a few tenths, the first two words of "Narrow Line Radio Galaxy" are often dropped, because the broad line objects are unambiguously called quasars.

continuum in those old spectra, and little or no detectable line emission or absorption (BL Lac Objects). However, it's been known since the 1970s at least that many historically defined "BL Lacs" show emission lines, both narrow and broad, especially (but not necessarily) when observed in low states. For example, BL Lac itself has weak narrow emission lines, and stellar absorption lines (Miller, 1981); now we know that broad lines are often visible as well (Vermeulen *et al.*, 1995). In fact it is well known that many highly polarized, violently variable quasars are indistinguishable from BL Lacs when in high states (Miller and French, 1978; see also Miller, 1981).

None of these, "BL Lac" nor "High Polarization Quasar," nor "Optically Violently Variable Quasar" is very well defined, and many studies have been damaged by blindly using these historical categories — sometimes just from catalog classifications, or by trying to mimic them with equivalent width cutoffs, which result in classifications changing with time (Antonucci, 2002b; Antonucci *et al.*, 1987)! It is also still often incorrectly asserted that the parent population (equivalent objects at more than a few degrees inclination) for "BL Lacs" is FR I double radio sources[6] (the lower-luminosity edge-darkened ones). Complete disproof of this assertion has been around for decades, e.g., Kollgaard *et al.* (1991). Yet people still write about FR II radio emission in BL Lacs as a "problem" for the unified model. This has invalidated studies of unification, cosmological evolution, and radio physics (e.g., Ostriker and Vietri, 1985, 1990). See Jackson and Wall (1999) for a well-informed and sensible discussion. Similarly many beamed radio quasars have diffuse emissions similar to FRI galaxies, e.g. Antonucci (2002b).

Great care is required in classifying AGN, and the price of carelessness is spurious results. For example, historically 3CR382, 3CR390.3 and similar objects were called Broad Line Radio Galaxies (Type 1 optical spectrum), and this is still reasonable. But the same was done for 3CR234, because in fact the broad H-α line is visible in the total-flux spectrum. This wasn't an error in its historical context, but we now know that the broad lines and Big Blue Bump are seen only by reflection (Antonucci, 1982, 1984; Tran *et al.*, 1995; Young *et al.*, 1998). Therefore from the point of view of unified schemes, such objects must be included with the Narrow Line Radio Galaxies (Type 2 optical spectrum), just as we keep Seyfert 2s (with hidden Big Blue Bump/Broad Line Region) separate from the Seyfert 1s. It would be great if a multi-dimensional classification scheme could be shown in a drawing, but a confusing "tesseract" would be needed (Blandford, 1993). Even a tesseract might oversimplify the true situation.

II. THERMAL AND NONTHERMAL EMISSION IN SEYFERT GALAXIES

A. AGN with Big Blue Bumps, but said to lack Broad Emission Lines

Laor and Davis' (2011) modeling paper has a convenient list of observational papers reporting on a very, very few quasars with Big Blue Bumps, yet little or no detectable broad line emission. One limitation of these analyses is that any equivalent width upper limits rely on making an assumption about the broad line width. However, extremely large line widths are exceptional for quasars, and do not occur in the faint but detectable broad lines in some of these very weak-lined quasars, so the limits on broad line equivalent widths are probably fairly close to the truth.

Laor and Davis (2011) also cite some papers on a very different kind of AGN. These papers claim (dubiously in my opinion: Antonucci, 2002a) that for a few nearby AGN there

[6] FR I and II radio sources are discussed in Sec. II.C.

is intrinsically no detectable broad line emission, and in some cases no thermal Big Blue Bump, at an interesting level. The authors refer to these as "True Type 2 Seyfert Galaxies."

B. Critique of polarimetric evidence said to support the existence of True Seyfert 2s

Most well-known Seyfert 2s have hidden broad line regions (HBLRs), often detectable in polarized (scattered) light. Many authors assert that there are others which lack BLRs, both visible and hidden. They may be called "True Seyfert 2s," or synonymously "Non-Hidden-BLR" (non-HBLR) Seyfert 2s. (Some authors seem to consider any lacking the BBB/BLR component to be non-thermal emitters.) This has led to a small industry which attempts to find other differences between the two types. In my opinion, most of the arguments for True Seyfert 2s are spurious and there are few if any strong candidates, except the one mentioned at the end of Section II. Then the secondary literature comparing the putative two types of Seyfert 2 has no merit.

1. HBLRs revealed later

Seyfert 2s are sometime said to lack broad lines in polarized flux, which is undefined because it's a qualitative statement based on quantitative data of limited SNR, and subject to interpretation. One should *never* say, "certain objects lack a hidden BLR." It's crucial to say that they lack a *detection* of an HBLR, or else the deductions made from it will be incorrect.

Hidden broad lines are often detected at later epochs, or at higher SNR, so a classification of a non-HBLR nuclei today doesn't mean it will still be one tomorrow. Tran (2010a,b) notes that: "Changes in the central engine or the obscuration could result in changes in appearance of the AGN. For example, NGC 2110 and NGC 5252 *were originally classified as non-HBLR S2s*, but perhaps due to their intrinsic broad-line variability, later found to be [HBLRs]." Another reason broad lines may appear in later data in some cases is the vastly improved SNR of (for example) Keck data relative to the original Lick observations.

Finding reflected broad lines is *very* photon-intensive and you have to be very lucky in finding a well-placed mirror with the right properties.

2. Lack of stated upper limits

Few if any upper limits have been published for broad lines of candidates, in either flux or polarized flux. This is astonishing to me.

Flux limits would be more helpful because the limits in equivalent width are very misleading unless they are quoted relative to the pure AGN continuum. That's never done as far as I know, for the simple reason that the continua are virtually pure starlight in most cases, and no AGN continuum can be discerned. Upper limits to line equivalent widths must be raised by a very large and unknown factor because of this effect, before comparison with Seyfert 1s.

3. Polarization may not be due to scattering

If there *are* actually upper limits in any published papers, they wouldn't be intelligible without showing that the polarization is caused by scattering of nuclear light. This is done only intermittently for the True Seyfert 2 candidates.

Now let's consider the assumption of scattering polarization in more detail. For a large minority of Seyfert 2s, the nuclear polarization is due to dust transmission on large scales, usually in the host galaxy plane. Few authors seem to know this! The arguments for my

statement are 1) there is a dearth of edge-on Type 1 Seyferts (Keel, 1980; Lawrence and Elvis, 1982), and 2) the AGN axes are unrelated to those of the hosts. Thus many Seyfert 2s get their classification from host-galaxy obscuration of the BBB and BLR sources.

But more to the point, they get their polarization from transmission through large-scale dust, as shown definitively by Thompson and Martin (1988); see also Barth *et al.* (1999) for the nature of polarization of low luminosity AGN. While large-scale dust transmission polarization is usually in the disk plane for Spirals, it can be in any direction in Ellipticals.

This effect has baffled most X-ray astronomers, who think that a Type 2 classification necessarily indicates a high-inclination view of a nuclear torus.

Objects with dust transmission polarization can be recognized by the shape of their (Serkowski) polarization curves if the nuclear emission can be isolated and the SNR is high. Few (but some!) True 2 candidates have data with sufficient SNR to test this possibility; that's needed because this very common and mundane explanation should be ruled out before invoking a more exotic scenario.

Also, it is by no means trivial to correct the data for Galactic interstellar polarization. A good simple recipe is given in the appendix of Antonucci (1984); it is adequate for most projects. A much more careful treatment is used in Kishimoto *et al.* (2004).

As with all these points, I'm not implying that there are no good papers which address these points as best as can be done. Perhaps my intended reader is an astronomer who wants to read the papers critically, and concentrate on the better ones.

To summarize, when the polarization is due to dust transmission rather than scattering, which is very common, the polarized flux is roughly just a much noisier version of the total flux and means nothing.

4. Upper limits depend on assumed line widths

If upper limits on equivalent widths or fluxes on broad lines are (ever) presented, they would actually depend very sensitively on the assumed line widths. This is what led Stockton *et al.* (1994) astray in claiming (after a lot of Keck time doing spectroscopy) that the radio galaxy Cygnus A lacks broad emission lines. Of course they had to assume a particular line width in order to calculate their upper limits to any possible broad emission lines.

The scattered lines just happen to be much broader than Stockton *et al.* assumed. If interested in the gory details, see Tadhunter *et al.* (1990); Antonucci *et al.* (1994); and Ogle *et al.* (1997) for correction of the Stockton *et al.* claim.

In propagating the errors in any argument, a large term needs to be included for this.

5. "Secure non-detections" of broad lines

Tran *et al.* (2011) argue for a lack of BLR components in total or polarized flux in NGC3147, NGC4698, and 1ES 1927+654. (I will return to NGC3147.) The non-detections of polarized broad lines in all three is described as "secure." I can't find equivalent width or polarized flux limits for any of them in the paper, however.

And outside of some very specific context, I'm not even sure that a non-detection can *be* secure.

6. Spectropolarimetry at Hα often required

At modest SNR, Hα observations are required because it's a much stronger line than Hβ, and less subjection to extinction. Please see Antonucci (1984, Fig. 2), and Laing *et al.* (1994), where this is discussed in detail. Usually limits on Hβ are of only mild interest to me.

7. Near-IR polarimetry often required

Often the obscuration of the reflecting region is too great even to detect Hα in polarized light.

In the nearest, prototypical radio galaxies Cen A (FR I) and Cyg A (FR II), the host galaxies are very well-resolved. They famously have gorgeous 1–100kpc dust lanes with A(V)$\sim$ a few, which obscure the whole nuclear region.

In both these cases, the optical polarization is very low ($\lesssim 1\%$), but the NIR polarization is extremely high ($\sim 20\%$: Capetti *et al.*, 2000 for Cen A; Tadhunter *et al.*, 2000 for Cygnus A). The reason is that the nuclear occultation/reflection regions are only visible through the dust lanes at relatively long wavelengths. Barvainis and I predicted and found the same effect in 3C223.1, and in that paper we discuss this situation generally (Antonucci and Barvainis, 1990). In all three cases the polarization angle is precisely perpendicular to the radio jets, as expected in the Unified model. By the Copernican Principle, it is likely that in other cases one would have to go even farther into the IR to detect the occulation/reflection region, so these observations only provide a lower limit to those lost to optical spectropolarimetry.

This is just one example of the incompleteness of optical polarization surveys for hidden broad lines.

8. Dilution of polarization by a starburst blue/UV component

The nuclear regions of most well-studied Seyfert 2s are dominated by starburst light in the blue/UV part of the spectrum. Many papers (Cid Fernandes and Terlevich, 1995; Heckman *et al.*, 1995, etc.) have shown this.

In spectropolarimetry, the giveaway is higher polarization in the broad lines than in the continuum (*after* careful subtraction of the old stars). There is a "second (blue) featureless continuum" source which dilutes the polarization in the continuum but not in the broad lines; it is so nearly ubiquitous that Goodrich and Miller (1988) gave it a name, FC2; (see also Tran, 1995). But FC2 is not featureless in the UV; it shows strong hot-star photospheric features. (This was first discovered in Antonucci, 1984, reporting on 3C234, the first reflected-light AGN.)

Similarly there is an HST survey of ultraviolet spectropolarimetry of Seyfert 2s (Hurt, 1996) which confirms the great strength of a (low-polarization, starburst) continuum source dominating over the scattered nuclear light in most cases.

Many papers use the observed continuum polarization directly, although it has no meaning at all.

On a related note, it has always baffled me that Tran (1995) has reported some very low (2–3% for Mrk 477) polarizations for broad emission lines in certain Seyfert 2s. As explained in Antonucci (2002a), "the way to measure the broad line polarization, and hence the polarization of the scattered light alone, is to divide the polarized flux of the line by its total flux. However, it is generally impossible to see the line clearly in total flux, so one just derives high lower limits to the broad line polarization in most cases. Tran (1995) claimed to measure the broad line percent polarization, and thus needed the total line flux in some objects. However, M. Kishimoto and I looked carefully at the case of Mrk477, in preparing a paper on polarization imaging. We examined the total-flux plots, overlaying the permitted Balmer lines on top of various forbidden lines; we saw little or no evidence for broad wings in the total flux. (You can try this in your own homes.) We thus placed an upper limit on the total flux of the broad components (with shaped matched to that of the lines in polarized flux), leading to conservative lower limits on broad Hα and Hβ polarizations of 10%. Thus we disagree with the intrinsic values of only 2–3% quoted in Tran (1995). H. Tran kindly allowed us to use the same data that he used.

9. It takes luck to find hidden broad line regions!

From Tran *et al.* (2011): "Could the [True 2s] be the hidden counterparts to the [NLS1]. . . ? This can be ruled out by the simple observation that no emission lines of any kind, broad or narrow, are seen in the polarized flux spectra."

That's absolutely wrong because you only get scattered broad lines when you have a favorably placed mirror with significant optical depth and covering factor. You have to be damn lucky and surely this is a case of "absence of evidence does not equal evidence of absence."

10. Isotropic selection is key for polarization and other surveys

Several early papers reported that well-studied Seyfert 1s and 2s differ systematically in various intrinsic properties. For example, it was claimed that the Type 2s have stronger FIR emission, stronger CO, etc, and that this limited the applicability of the spectroscopic aspect of the unified model. (The same sorry story played out in tests of the beaming aspect of the unified model; see e.g., Antonucci and Ulvestad, 1985; Heckman, 1983.)

NGC1068 and NGC4151 have the same UV excess, but we're only seeing 1% of the nuclear UV in the former case, so that AGN comes from five magnitudes higher on the luminosity function!! Nothing can be concluded about unification by comparing NGC1068 to NGC4151.

More recently, Bianchi *et al.* (2008) uncritically attribute to Gu and Huang (2002) the conclusion that Seyfert 2s with "no hidden broad lines" are more luminous than those with hidden broad lines. There are no selection criteria at all, except that they need to have polarization measurements in the literature! There is an obvious and huge selection effect (Antonucci, 2002a) such that the hidden BLR objects tend to have systematically larger optical flux, and even more importantly, they have much better contrast against the host galaxy starlight. That's probably why the hidden BLRs were detected in the first place. (See Kay, 1994 for near-proof!)

A very powerful comparison of the Seyfert types was made by Keel *et al.* (1994), who expertly analyzed the spectra of a substantial sample of Seyferts of both types. The reason this is a fundamental paper which is much, much stronger than all preceding and almost all subsequent analyses of Seyfert galaxies is that the objects were selected independently of orientation with respect to the line of sight. Thus the Type 1s and the Type 2s can be considered equivalent in the unified model (modulo the statistical preference for 2s expected for large torus covering factor, a modest effect). The samples were selected by 60μ flux, with a modest warmth criterion using 25μ flux, which just excluded most of the starburst galaxies.

We have followed up this sample with a rather long series of papers, e.g. Pringle *et al.* (1999), Schmitt *et al.* (2001), and Schmitt *et al.* (2003), etc. As expected in the Unified Model, most or all of the claimed intrinsic differences between Seyfert 1s and 2s disappeared.

Samples which aren't isotropically selected produce uninterpretable (actually misinterpretable) results, because they compare 1s and 2s which are intrinsically quite different. Studies with highly biased samples have no merit.

Here is a related and shockingly widespread practice: Conclusions are routinely drawn from noisy luminosity-luminosity plots: (e.g., the influential paper Rawlings and Saunders, 1991). I'm sure that plotting the number of bars versus the number of bookstores in cities and towns will show a fantastic correlation with a nearly infinite statistical significance, but that doesn't mean drinkers like to read, or that readers like to drink. Bigger cities just have more of everything. Similarly plots involving dependent axes are ubiquitous in the journals, probably because you always get a correlation if you do that. A higher level of scholarship will be required to make progress.

As noted, there is now a second-order body of spurious literature resulting from the True 2s movement: there are many other papers which supposedly compare the hidden broad line

objects with those without detections in existing data, without due (or any) regard for these concern listed above. In my opinion, this literature has no merit.

C. Critique of non-polarimetric evidence said to support the existence of True Seyfert 2s

1. Independent analysis by Stern and Laor (2012)

Stern and Laor (2012) have stepped in to provide the upper limits on broad line emission for many candidate True 2s (including the popular NGC3147) which are conspicuously absent in most papers proposing candidates. They assumed an uncertain but reasonable velocity prescription for determining the limits to broad emission lines in "True 2s," and presented the relationship of broad line luminosities and limits compared to [O III] λ5007. The limits on broad emission lines are *not significant*; thus, there is no evidence that the "True 2s" have anomalously weak broad lines at all!

2. Rapid X-ray variability

A key to distinguishing an ordinary very common Narrow Line X-ray Galaxy from a scattered source is *rapid* X-ray variability. Bianchi *et al.* (2008) show a variation in X-ray flux in their favorite candidate NGC3147 over an interval of 3.5 years, arguing that the change favors the interpretation that the X-ray continuum is seen directly like that in Seyfert 1 nuclei. But as noted above, much more rapid variations (weeks to months) have been seen in the scattered broad lines in several objects, so the scattering region can easily be small enough to accommodate the X-ray variation in these candidates, which have (almost?) invariably very low luminosities.

In the improved follow-up by Matt *et al.* (2012), their Fig. 1 provides good information on short term x-ray variability over ∼200,000s.

There isn't any.

Please compare with the behavior of some other (non-cherry-picked) exposed nuclei (Seyfert 1s). Figure 1 of Uttley and McHardy (2005) show a similar monitoring period for NGC3227 and NGC5506; and Fig. 1 of Papadakis *et al.* (2008) has four others. The lack of short-term variability in NGC3147 seems to be atypical and perhaps unique if it's an exposed Seyfert 1 type X-ray source. The very low luminosity of the True 2 candidates suggests particularly rapid variability should be seen if the X-ray sources are directly exposed.

Conclusion: though the X-ray change in 3.5 years in NGC3147 was touted as favorable to the idea of an exposed Seyfert 1-like nucleus, the lack of short-term variations show that just the opposite is the case.

Note: there is a new paper with simultaneous X-ray and optical data, by Bianchi *et al.* (2012), which I haven't yet studied carefully. According to the abstract, out of the eight candidates from the literature which they have studied, they have debunked four. For the remaining four, they favor a True 2 interpretation based on non-detections of broad Hβ. Many of the points above should be considered when judging this evidence for True 2s. I believe they negate the argument.

3. Do low X-ray columns indicate a clear optical line of sight?

Low x-ray columns are often invoked legitimately in arguing for an exposed nucleus, if the source can be shown to be Compton thin (strong soft X-rays), and if A(V) / N(H) has the value for diffuse Galactic interstellar clouds. In fact, AGN torus dust tends to have less optical absorption and reddening than standard dust, e.g. Maiolino *et al.* (2001b), strengthening this argument.

Of course one can measure a spurious zero column for opaque objects like NGC1068 because the X-rays, like the optical, are only seen in scattered light. However, X-ray astronomers are usually careful to consider this possibility, and often argue persuasively against it.

In a few cases, e.g. Shu *et al.* (2010), it has been found that the soft X-rays arise from off the nucleus, from diffuse emission or interlopers, invalidating the low column measurement. Presumably these situations are rare.

4. Near-IR emission lines

If the absorption is relatively low, as in a Narrow Line X-ray Galaxy (a well-studied class popular in the 1980s), in principle one could see the broad lines in the NIR (or even weakly at Hα: Shuder, 1980). It seems that published arguments are based at least notionally on observed upper limits to equivalent widths, though I'm not aware of any quantitative values. These would need to be corrected carefully because the NIR is strongly starlight-dominated in Seyfert 2s, especially in the True 2 candidates. There is often a hot dust contribution as well. The corrected upper limits, that is, the values relative to the AGN continuum, would come out very much higher than those measured, and extremely uncertain.

Advocates could make stronger arguments with fluxes rather than equivalent widths, e.g. by setting limits on the flux of a NIR broad line relative to x-rays. One still has to worry about the line width, but avoids the perils of *drastic* equivalent width dilution as described above. The host galaxy dominates in virtually all Seyfert 2s, and it dominates very greatly in the True 2 candidates.

5. The mid-IR calorimeter

An excellent test for a hidden AGN is the "mid-IR (warm) calorimeter," which indicates the luminosity of almost any visible or hidden AGN approximately but robustly. That's why many of us have worked very hard on high-resolution mid-IR imaging (Whysong and Antonucci, 2004 and others cited later in this review).

More importantly, there are many papers by Ogle's group and others on large surveys with the Spitzer IRS spectrograph. Ours and some of the others are based on nearly isotropic samples, i.e. they select on radio lobe flux. Hopefully, my citations later in this review are nearly complete to early 2011.

Clearly, this parameter must be considered when advocating hidden AGN, or the lack thereof.

6. Are the True 2s even Seyfert 2s at all?

Congratulations to any readers who have gotten far enough to reach this key point.

Some of the True 2 candidates have optical spectra inadequate to support a Seyfert classification, or even adequate to disprove a Seyfert classification. I think a True Seyfert 2 should have to be a Seyfert 2, but several proponents disagree, at least implicitly.

As noted, according to Matt *et al.* (2012), the very best candidate may be NGC3147, so I looked at the optical spectra. According to Shu *et al.* (2010) and pc's from the authors, the best data for line measurements is the spectrum in Ho *et al.* (1995). The main reasons is that the line measurements in this case were made after host starlight subtraction. Please take a look at their Fig. 27. The line measurements are given in Ho *et al.* (1997). For [O III] λ5007/Hβ, a value of 6.1 is given, with moderate error bars as discussed in the paper. The narrow Hβ line cannot be seen at all in the unsubtracted spectrum! Thus one would naïvely set a high lower limit to the [O III]λ5007 / narrow Hβ ratio. But this is entirely incorrect because as Ho *et al.* (1995) state (though the figure is not shown), after careful

host subtraction, the narrow Hβ line is clearly detected! Now look at [N II]λ6584/Hα: the measurement is given as 2.71, which is past the Seyfert region in some diagnostic diagrams such as those of Veilleux and Osterbrock (1987) and Bianchi *et al.* (2012, Fig. 1), though those boundaries are somewhat subjective.

The candidate IRAS01072+4954 has an H-II region spectrum! See Valencia-S. *et al.* (2012).

The [O III]λ / narrow Hβ and [N II]λ6584/Hα ratios are biased upward in the uncorrected spectrum. The reason is that the Balmer lines, but not the forbidden lines, are sitting in stellar absorption lines. Thus the uncorrected measurements have no meaning, and the results depend mainly on the accuracy of the starlight subtraction (assuming the authors always do it!). Of course this is a very serious problem for low-luminosity AGN, like most of the True 2 candidates, and it's not a serious problem at higher AGN luminosities.

A good quantitative feeling for the size of the effect can be found in Keel (1983, Equations 2, 3 and 4). Naturally it depends on the age of the stellar population, parametrized by Keel in terms of continuum colors.

I think that many LINERs lack the BBB/BLR at an interesting level, as described in great detail in this paper in the context of radio-loud AGN. However as documented ahead, a significant minority *do* show thermal MIR reprocessing bumps however, and more importantly many *do* show broad lines in polarized flux (e.g. Barth *et al.*, 1999).

Seyferts were always and remain defined solely by optical spectral line ratios, and to show that an object is a True 2 means first to show that it is a Seyfert galaxy to begin with.

A True 2 also means (to me) that despite a secure Type 2 classification, there are upper limits (with all the many caveats described above) to the broad line equivalent widths which are well below some adopted normal range for objects selected in a way to make them as analogous as possible to the candidate. The equivalent width limits *can't* be given relative to the host starlight, or in the NIR, relative to the host and dust emission. It must be relative to the Big Blue Bump component, or it means nothing at all.

D. Disclaimers

- Some of what I said is probably wrong.
- I'm critiquing. I haven't given all the arguments in favor of True 2s, but I haven't cherry-picked: I mentioned the arguments that seem important to me at this moment. Unlike Fox News, I do not strive to be fair and balanced.
- Not all of my arguments apply to all objects or all papers!! These are mainly general comments that I consider in forming an opinion on True 2 candidates, and I heartily recommend that others consider them also. I do *not* want to tarnish the whole field, but I'm afraid I may have made some authors feel guilt by association. The reader must not generalize.
- Some of the points argue the plausibility of identification as common NLXGs, and some of hidden BBB/BLRs. I'm not trying to present a single scenario for all — objects must be considered very carefully and individually. And for some I may mention arguments for both scenarios. I'm not striving here for a big picture.
- I don't really give a damn about whether or not there are True 2s.
- Finally, I know of one excellent candidate for a True 2 in a radio galaxy: see Cohen *et al.* (1997)!! This high-ionization object is a bit complicated but the arguments given are persuasive.

III. BROADEST SKETCH

A. Where to find basic information

Active Galactic Nuclei (AGN) is a term encompassing a variety of energetic phenomena in galactic centers which are thought to be powered directly or indirectly by accretion of matter onto central supermassive black holes. There are many reviews of this field, including several of book length. Perhaps the most technical and broad book-length review is that of Krolik, which was published in 1999. The classic text on spectral analysis of gaseous nebulae and AGN has been updated in 2006 (Osterbrock and Ferland, 2006); it's a wonderful book, but it is biased towards the optical and ultraviolet regions of the spectrum. A new edition (2009) of An Introduction to Radio Astronomy by Burke and Graham-Smith is also noteworthy.

Few theoretical predictions have been borne out in this field, and understanding is still semi-quantitative at best (Alloin *et al.*, 1985; Antonucci, 1988, 2002b; Blaes, 2007; Courvoisier and Clavel, 1991; Koratkar and Blaes, 1999). This review will refer to some fairly general theoretical ideas, but it will mainly organize some observational information on radio galaxy central engines that has become clear over recent years. It will not include a general introduction to AGN (see above references), but will address the nature of the central engines in radio galaxies which is a topic tied up as a practical matter with orientation effects on observations. Orientation effects are introduced in the next section, and as needed throughout the text.

The general topic of orientation effects ("Unified Models") is reviewed in detail in Antonucci (1993). The material in that review is almost entirely "still true." However, it has been updated and elucidated in several more recent (but generally narrower) reviews (Axon, 2001; Cohen *et al.*, 1999; Dopita, 1997; Tadhunter, 2008; Urry and Padovani, 1995; Wills, 1999).

In a nutshell, prior to the mid-1980s, it seemed that radio loud quasars (with their powerful thermal optical/UV light) were quite distinct from radio galaxies; the latter are analogous to quasars in general radio properties, but apparently lacked the strong optical/UV electromagnetic luminosity (Big Blue Bump). In a landmark review of bright extragalactic radio sources, Begelman *et al.* (1984) posited that *"The ratio of mass accretion rate to the mass of the hole may determine whether a [radio loud] active galactic nucleus will be primarily a thermal emitter like an optical quasar or a nonthermal object like a radio galaxy."*

Through optical spectropolarimetry and other means, it was subsequently determined that many radio galaxies, especially the most powerful ones, with strong high-ionization narrow emission lines, actually harbor hidden quasars surrounded by opaque dusty tori, so that the observational appearance depends on the inclination of the radio axis to the line of sight. But now we know that for many radio galaxies, any hidden quasar must be very weak.

The radio quiet and radio loud objects with high ionization are virtually all visible (Type 1) or hidden (Type 2) Seyferts or quasars (e.g., Antonucci, 2002a). At lower radio luminosities of all radio types, we find mostly LINERs[7] (Low Ionization Nuclear Emission Regions). A recent and comprehensive review of LINERs is that of Ho (2008).

B. Nature of geometrical unified models

In the low-redshift universe, there is a near-perfect correspondence between "radio loud" objects — with $L_\nu(1.5\ \mathrm{GHz})$ loosely extending from perhaps $\sim 10^{28}$–10^{36} erg sec^{-1} Hz^{-1}

[7] A few LINERs have strong broad lines, e.g., Filippenko and Halpern (1984). Many LINERs have very inconspicuous broad Hα components, but it isn't clear to me that they are strictly analogous to those in low-luminosity Seyferts. For example, we do not know whether they vary rapidly (L. Ho, 2011, private communication).

— and elliptical hosts. (This paper uses $H_0 = 70$ km sec^{-1} Mpc^{-1}, $\Omega_{\rm matter} = 0.3$, and $\Omega_\Lambda = 0.7$.) For a fiducial $L_\nu \propto\sim \nu^{-1}$ spectrum, for which there is equal power per logarithmic frequency interval — also referred to as "per dex" — the parameter νL_ν gives the power integrated over an interval of 0.30 dex (powers of 10). Thus if one integrates such a spectrum over the "radio region" 30 MHz–300 GHz, the corresponding luminosity is 13.3 times as great; a look at various radio AGN in the NASA Extragalactic Database (http://nedwww.ipac.caltech.edu) shows that the luminosity per dex of the dominant optically thin synchrotron component tends to be lower outside this range, so depending on the application, one may consider this as a crude "radio bolometric correction." Resulting radio powers can exceed 1×10^{45}erg/s. Estimates of energy tied up in 100-kpc scale radio lobes are as high as 1×10^{61} ergs or more, even using the particle/magnetic field minimum-energy assumption and assuming a lack of a dominant proton contribution. (The minimum-energy assumption posits that energy is apportioned between relativistic electrons and magnetic field in such a way as to minimize lobe energy content for a given synchrotron luminosity.)

Unified models assert that certain AGN classes differ only in orientation with respect to the line of sight. These models comprise two separate (though interacting) assertions, as illustrated in Fig. 1. The first to be recognized historically is the effect of relativistic beaming (aberration causing anisotropy in the observed frame) in the powerful synchrotron jets which feed particles and magnetic energy into the radio lobes. When seen at low inclinations, beaming amplifies and speeds up "core" (subparsec scale jet, usual synchrotron-self-absorbed) radio flux variability and (apparent faster-than-light) "superluminal motion." Thus a special fortuitous orientation of a nearly axisymmetric object leads to a different observational category (Blazars). The same objects, seen at higher inclination, are ordinary radio-loud galaxies and quasars (Antonucci and Ulvestad, 1985; Begelman *et al.*, 1984; Kollgaard *et al.*, 1992, etc.). We can call this the beaming unified model (or more loosely, just the beam model, though that term usually connotes some connection with actual physics).

At low redshift, radio-quiet (but not silent) AGN lie in spiral hosts, and go by the name of Seyfert galaxies. They rarely show detectable motions in their weak radio jets — and when they do show motions, the apparent speed is usually much less than the speed of light. More luminous radio quiet objects are called Radio Quiet Quasars, or historically, Quasistellar Objects (QSOs).

But both radio quiet and many radio loud AGN widely exhibit another kind of orientation unification: many well-studied objects include energetically dominant continuum components in the optical-ultraviolet region, referred to as the Big Blue Bump, and widely attributed to thermal radiation from optical thick accretion flows. (Confirmation of the latter can be found in Kishimoto *et al.*, 2005, 2008, 2004.) They are almost always accompanied by broad (5,000–10,000 km/s) permitted emission lines. Both these components reside inside optically opaque dusty structures which to zeroth order have the shadowing properties of tori, and these structures are referred to loosely as the "AGN torus." In some cases we have a direct (low-inclination, polar) view of these compact components (in quasars, Seyfert 1 galaxies, and Broad Line Radio Galaxies). In many other cases (high inclination, equatorial views), we can be sure these two components are present inside the tori using the technique of optical spectropolarimetry, which literally allows us to see the nuclei "from above," using ambient gas and dust as natural periscopic mirrors.

This wonderful trick of optical spectrapolarimetry (e.g. Antonucci, 1982, 1983, 1984; Antonucci and Miller, 1985) uses the polarization property of scattered light to separate the spectrum of hidden sources from any sources of direct light. The above references show that the Big Blue Bump and the Broad Line Region are present but hidden from direct view. The scattering polarization position angle indicates that the photons emerging from these components can only escape from the hidden nuclei if moving along the radio jet (and lobe) axis, so that the other directions must be blocked by an obscuring torus. This is illustrated in Fig. 2, from Tran (1995), illustrating the total and polarized fluxes, for 3CR234. The polarized photons (scattered light) contribute to both plots, of course, but show up with great contrast when plotted alone.



Figure 1 A schematic diagram of the current paradigm for radio-loud AGN (not to scale). Surrounding the central black hole is a luminous accretion disk. Broad emission lines are produced in clouds orbiting outside the disk and perhaps by the disk itself. A thick dusty torus (or warped disk) obscures the Broad-Line Region from transverse lines of sight; some continuum and broad-line emission can be scattered into those lines of sight by warm electrons or dust that are outside the observing torus. Narrow emission lines are produced in clouds much farther from the central source. Radio jets, shown here as the diffuse 2-sided jets characteristic of low-luminosity, or FR I-type, radio sources, emanate from the region near the black hole, initially at relativistic speeds. (Adapted from Urry and Padovani, 1995.)

If all objects fit in with the above descriptions of orientation unification, we would be left with as few as two independent types of "central engines" on relativistic scales[8], those for radio quiet and those for radio loud AGN. But we now know that many radio galaxies lack powerful visible or hidden Type 1 engines (Big Blue Bump, Broad Line Region, copious accretion flows). They occur frequently in some regions of parameter space (as delineated for example by redshift and radio flux or luminosity), and not in others. The purpose of this review is to gather the multiwavelength evidence for the last two statements, and emphasize the dependence of the distribution of central engine types on parameter space, which is the key to avoiding many errors and much confusion and even discord. We will see that a great deal of self-consistent information is available on the occurrence of the two types of radio galaxy/quasar central engines.

C. Types of powerful radio source; scope for unification by orientation

Within the radio loud AGN arena, several types are also distinguished based not on central engine properties but on extended radio morphology. Unfortunately, they do not correspond very closely to the optical categories!

[8] This refers to regions where the jet velocity is almost the speed of light, c, and also the gravitational potential energy per unit mass is of order c^2.

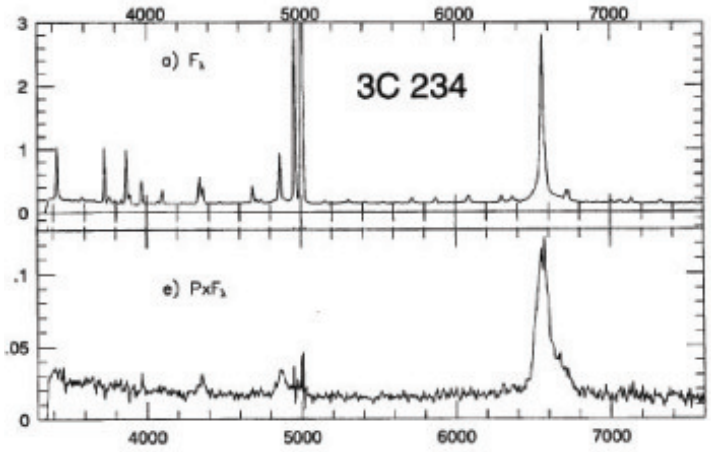


Figure 2 Total and polarized flux for the Narrow Line Radio Galaxy that showed as the first hidden quasar, 3CR234 (Antonucci, 1984; the figure shows the data of Tran *et al.*, 1995). The polarization angle relative to the radio axis shows that photons can only stream out of the nucleus in the polar directions. The polarized flux (akin to scattered light) spectrum shows the hidden quasar features at good contrast. (In this case, however, the scattered ray is itself reddened.)

The most luminous giant ($\ell \gtrsim 100$ kpc) double radio sources are designated FR II ("Classical Double"), for Fanaroff and Riley (1974); those authors noted that a whole suite of properties change together fairly suddenly over a critical radio luminosity (referring to the roughly isotropic diffuse emission). Sources above $\sim 2 \times 10^{32}$ erg/sec/Hz at 1.5GHz show edge-brightening and hot spots, where the radio jets impinge on an external medium, and shocks partially convert bulk kinetic energy to particle and field energy. They also tend to have strong side-to-side asymmetry (generally attributed to relativistic beaming) of the jets over scales from the relativistic region up to tens of kpc. The lower luminosity giant (also $\ell \gtrsim 100$ kpc) objects (FR I galaxies) also have strong side-to-side jet asymmetry, but only on 1–1000pc scales in most cases. An important refinement to the FR classification scheme is that the dependence of the exact radio luminosity cutoff depends on the optical luminosity of the host galaxy (Owen and Ledlow, 1994, but see Best, 2009, Fig. 4a).

The "FR" types of radio galaxy generally have sizes of 25–1000kpc, but large populations of smaller sources exist, and they can still be very powerful. (The small sizes mean that their lobe energy content is very much lower, however.) They are denoted in an inconsistent way, according to their means of discovery. Optically thin, steep-spectrum radio sources which were historically unresolved on arcminute scales, were (and are) called Compact Steep Spectrum (CSS) sources to distinguish them from opaque beamed synchrotron cores; their spectra peak at $\sim$ 100MHz, and they are generally defined to be in the size range 1kpc–15 or 25kpc. Sometimes they are crudely defined to be sources smaller than typical host galaxies. Sources whose extent is less than $\sim$ 1kpc, with even more compact substructure, are often dominated by synchrotron components which are self-absorbed up to $\sim$GHz frequencies[9], and are called Gigahertz-Peaked-Spectrum sources (GPS). (Even tinier sources are being sought by selecting for self-absorption peaks at even higher frequencies.) These classes are

[9] It is proposed by Begelman (1999) that the weak fluxes at low frequencies result from free-free rather than inverse synchrotron absorption. Encouraging follow-up work can be found in Stawarz *et al.* (2008) and Ostorero *et al.* (2010).

reviewed by O'Dea (1998). Since that paper was written, much evidence has accumulated from VLBI proper motions that the sources are small because they are very young ($\sim$ 1000–100,000 years![10]). In at least some cases it is known from faint extended emission that these very young ages refer only to a recent phase of activity, however. Statistically, only a very small fraction of small and very short-lived sources can grow to be huge bright long-lived sources.

The relevant properties of classes will be discussed in turn, generally starting with the radio data and proceeding upwards in frequency. We will discover that some FR II radio galaxies at $z \lesssim 0.5$–1.0 lack powerful hidden quasars. These objects *may* have hidden Type 1 nuclei, but they are constrained to be much weaker than those of the "matched"[11] visible quasars, and thus they are not "unified" (identified) with them via orientation with respect to the line of sight. At low redshifts ($z <\sim 0.5$) it is probable that only a minority of FR II radio galaxies in the 3CR catalog host hidden quasars.

Next, we will tackle the less powerful (FR I) giant radio galaxies, which are by selection nearby in almost all cases. The 3CR catalog flux cutoff of 10 Jy at 178MHz (Laing *et al.*, 1983) corresponds to the FR I vs. II radio luminosity separation at $z \sim 0.2$. Most (but by no means all) of these objects have nuclear spectral energy distributions dominated by synchrotron radiation, with no evidence for visible or hidden "Type 1" central engines.

Finally the small, young GPS and CSS sources will be discussed. Very recent information from the ISO and Spitzer infrared satellites has greatly increased our knowledge of "shadowing unification"[12] at various radio luminosities.

A major caveat of this paper, and of this field, is that most of the information derives from the brightest radio sources, especially those in the 3CR catalog, so no implication is made for unexplored regions of parameter space! Another major caveat is that while we discuss thermal vs. nonthermal galaxies[13], relatively little evidence is presented that any parameter is bimodal, so that there could be a continuum of properties.

D. The Infrared Calorimeter

Radiation absorbed by the dusty torus is largely reradiated as infrared, and many studies have concluded that in reasonably luminous AGN (so that the IR is not dominated by a normal host galaxy), at least the near- and mid-infrared reradiation ($\approx$ 1–40 microns) is dominated by reprocessed nuclear optical/UV/X-ray light. In specific populations, the entire IR seems to be radiated by the torus, because the colors are warm throughout, and there is evidence for only weak star formation (e.g. PAHs) or synchrotron radiation (e.g., strong radio-mm emission). Thus the infrared reradiation of nuclear light can potentially be used as a *calorimetric indicator* for the luminosity of any hidden AGN.

There are at least two ambiguities in using this infrared emission as an AGN calorimeter. The first is that some of the nuclear radiation may not reach the torus, either because of the intrinsic latitude-dependence expected for many models of the Big Blue Bump (e.g. Netzer, 1985), or preferentially planar Broad Line Region absorption (Gaskell *et al.*, 2007; Maiolino *et al.*, 2001c). Both of these effects add noise to the dust reradiation calorimeter, and tend to make hidden quasars look dimmer than visible quasars in the infrared for a given opening angle. Nevertheless most studies show infrared luminosity about as expected, from detailed studies of individual objects (Carleton *et al.*, 1984; Storchi-Bergmann *et al.*, 1992) and for

[10] This material was reviewed recently by Giroletti (2008).

[11] In radio flux and redshift.

[12] As a reminder, unification of broad line and narrow line AGN by orientation of a toroidal nuclear obscurer is here called "shadowing unification." Ascription of superluminal motion and other relativistic effects in subpopulations to orientation is called "beaming unification."

[13] Recall that thermal vs. non-thermal refers not to the radio emission itself, but to the presence of an energetically dominant optical/UV source thought to arise from an accretion disk.

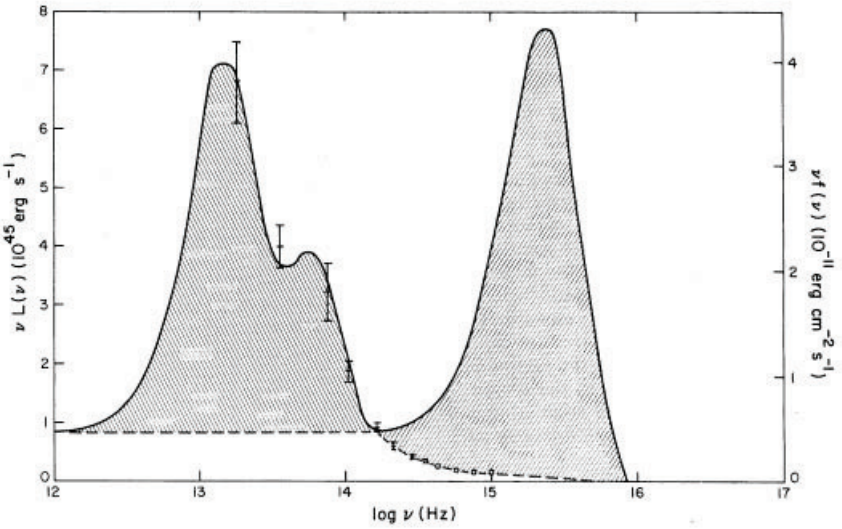


Figure 3 3CR234 continuum observations plus model fits. The ordinate is linear in νL_ν, and the area under any portion of a curve is proportional to the luminosity in that portion of the spectrum. The hidden optical/UV component (Big Blue Bump) has been reprocessed into the infrared in this hidden quasar.

populations of Type 1 and Type 2 objects within isotropically selected samples (Keel *et al.*, 1994). Carleton et al. (1984, see Fig. 3) shows how the infrared calorimeter works, based on the first spectropolarimetric hidden AGN, 3CR234.

Also, although the covering factor deduced from dividing infrared re-emission by Big Blue Bump luminosities are therefore lower limits, they tend to be high ($\sim$ 0.1–1) so that they can't be too far off! Although Maiolino *et al.* (2007) didn't actually integrate over the SED and should therefore be viewed with much caution, it is interesting that they actually find some covering factors nominally greater than one for low-moderate luminosity objects. This was predicted qualitatively by Gaskell *et al.* (2004), who argued that a preponderance of large grains leads to less apparent absorption (spectral curvature) in the optical/UV region than otherwise, and thus one may fall into the trap of inferring very low extinction. The inner torus is expected to lack small grains, most robustly perhaps on the grounds that the torus sublimation radius must be larger for small grains according to radiative equilibrium. The lack of small grains at the sublimation radius is supported by the data of Suganuma *et al.* (2006): see discussion in (Kishimoto *et al.*, 2007).

Another concern with the infrared calorimeter is the expected anisotropy of the thermal dust emission due to the large dust column densities (Pier and Krolik, 1992, 1993). Many Type 2 AGN have X-ray columns of $\gtrsim 1 \times 10^{24}$ cm^{-2}; absorption of mid-IR lines, molecular maps, and the great difference in the average X-ray columns between Type 1 and Type 2 AGN suggest that a commensurate dust extinction is present. (See Maiolino *et al.*, 2001a,b,c for arguments which affect this line of reasoning quantitatively but not qualitatively.)

There is a limit on the anisotropy of the ratio [O III] λ5007/F$_\nu(60\mu)$ in Seyferts from Fig. 3 of Keel *et al.* (1994). The figure shows that in their well-selected sample (60μ flux with a mild 25μ–60μ warmth criterion), Type 1 and Type 2 objects have indistinguishable distributions of L(60μ), L[λ5007], and of course their ratio. The λ5007 line is produced outside the torus in most objects like these: it doesn't appear in polarized flux along with the broad emission lines and Big Blue Bump. Thus it's not significantly hidden inside the

torus, is likely quite isotropic in this parameter space, and is nearly isotropically selected[14], fairly powerful Seyferts.

Torus models do predict that the optical depths will be small in the far-infrared in general. For AGN-dominated infrared SEDs, that means there is an elegant and detailed method of deriving the degree and wavelength-dependence of the dust emission anisotropy. For isotropically selected samples, we can divide composite or representative Type 1 SEDs by those for Type 2, tying them together at 60μ.

In order to make the infrared calorimeter accurate, we need to account for the common anisotropy of the near- and mid-thermal dust emission. There is general agreement on near isotropy past $\sim 30\mu$, as was first predicted by Pier and Krolik (1992, 1993). The main basis for their prediction of anisotropy at shorter wavelengths was that many Seyfert 2's are Compton-thick, including NGC1068 — which is completely opaque and for which $N(H) \gtrsim 10^{25}$ according to the X-ray spectrum (e.g., Pounds and Vaughan, 2006). In Galactic dusty gas this corresponds to $A(V) \sim 1000$. (See e.g., Maiolino *et al.*, 2001a,b for a quantitative correction, which however doesn't greatly affect the discussion of gas vs. dust columns below.) As an aside, I do think that dust-free atomic gas can contribute to the X-ray absorption in some cases (e.g., Antonucci *et al.*, 2004; Risaliti *et al.*, 2011), but the X-ray columns of Type 2 AGN are on average $\gtrsim 100\times$ those of Type 1, so most of the column is connected with the Type 2 classification. Also in some cases, the dust column can be constrained to be similar to the very high X-ray columns. For example, Lutz *et al.* (2000) used the lack of Pf-α at 7.46μ to show that $A(V) > 50$ in NGC 1068.

Recall that one could pick spectral Type 1 (broad-line) radio loud quasars and radio galaxies by some fairly isotropic AGN-related luminosity (e.g., lobe-power), and divide the two spectra to produce a spectrum of diminuation from anisotropy. We were able to do this for the $z > 1$ 3CR (Fig. 4) because all of the radio galaxies seem to host hidden quasars, but only out to $\sim 15\mu$ in the rest frame. *The correction for anisotropy is around a factor of 10 in the near-IR, 1.5–2 on both sides of the silicate feature, and about three in the silicate feature*, but varies significantly from object to object. As expected, it flattens out at ~ 1 at long wavelengths.

Recall that the torus shape was inferred[15] from the high typical polarization of the reflected light in hidden-Broad Line Region objects, which is generally perpendicular to the radio axis, meaning that photons can only escape the nucleus to scatter into the line of sight if they leave the nucleus in the polar directions.

The obscuring dusty tori invoked in the shadowing aspect of the unified model are active, not just passive, components. Modulo factors of order unity for geometry and dust cloud albedo, the tori will reprocess almost all of the incident Big Blue Bump/Broad Line Region luminosity into the infrared. Thus the ratio of re-emitted infrared emission to Big Blue Bump (and often considerable absorbed X-ray) emission tells us the approximate covering factor of the dusty gas which is idealized as a torus shape. There is at least one obscured quasar with a thin obscuring disk — the radio-loud, mini-MgII BAL OI287 (Antonucci *et al.*, 1993; Goodrich and Miller, 1988; Rudy and Schmidt, 1988; Ulvestad and Antonucci, 1988); however, even that one seems to have an upturn longward of 1μ, at least according to the NED figures.

The covering fraction should agree with the fraction of Type 2 (hidden) nuclei in a sample which is selected by any isotropic AGN property. What are the results of this comparison? I'm crudely leaving out intermediate types, and the substantial minority of Seyfert 2s whose

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[14] Isotropic selection means selection on an isotropic AGN property, which avoids powerful biases in comparisons between classes. It is essential in order to produce intelligible results.

[15] A common error is to use the percent polarization of the continuum as the scattering polarization (after correcting for bulge or elliptical starlight). That is usually contaminated by hot stars, and only the broad lines themselves can be used to find, or more often place, a lower limit on, the percent polarization of the scattered nuclear light (Antonucci, 2002a).

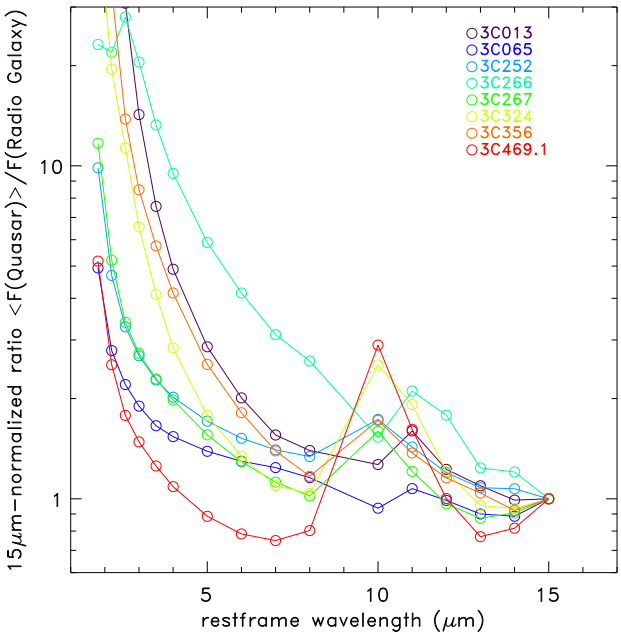


Figure 4 The infrared SEDs of $z > 1$ 3CR quasars and the matched radio galaxy composite, from Hönig *et al.* (2011). Since these radio galaxies are all edge-on quasars, this quotient spectrum measures the orientation dependence at each wavelength.

Type 1 nuclei are hidden by dust in the host galaxy plane (Keel, 1980; Lawrence and Elvis, 1982) rather than by a nuclear torus. Keel *et al.* (1994) found 80 far-IR selected Seyfert 1s and 141 Seyfert 2s (plus some H II galaxies that they weeded out). So one expects a dust covering factor of $\sim$ two-thirds in this parameter space. While the paper describes dust and gas covering factors as "broadly consistent" with the model, it would still be very valuable at this point to take advantage of this sample and actually measure covering factor for the Type 1s based on existing spectral energy distributions.

Figure 4 (from Hönig *et al.*, 2011) shows the quotient SED for $z > 1$ individual quasars and the radio galaxy composite, which however only covers up to 15 microns in the rest frame.[16] Again this plot purports to give us directly the anisotropy as a function of wavelength.

IV. CLASSICAL DOUBLE, OR FR II RADIO SOURCES

A. Spectropolarimetry of radio galaxies and the discovery of hidden quasars

Hidden quasars inside radio galaxies are discussed in Antonucci (1993); Wills (1999), and Tadhunter (2008). I'll describe many relevant observations here, moving from the radio and

[16] Buchanan *et al.* (2006) does this type of division for a 12μ (better than optical, but not ideal) selected sample of Seyfert galaxies. As expected, their anisotropy curve flattens at long wavelengths, but oddly not at a value of unity.

then on up in frequency to the X-ray. First though, I will introduce some background optical information, and will return to that waveband in Section IV.F.

It was noticed in the early 1980s that for some Narrow Line Radio Galaxies and Seyfert 2 galaxies, a small measured optical polarization could often be intrinsically large ($\gtrsim 10\%$) after starlight subtraction, and that the electric vector position angle was generally perpendicular to the radio structure axis (Antonucci, 2002b, 1982, 1983; Draper *et al.*, 1993; McLean *et al.*, 1983; Miller and Antonucci, 1983). Furthermore, the polarized light spectrum (similar to the scattered light spectrum in spectral features) revealed the features of Type 1 AGN, with the first case being the powerful hidden quasar in the radio galaxy 3CR234 shown in Fig. 2 (Antonucci, 1982, 1984; Tran *et al.*, 1995; Young *et al.*, 1998). As noted earlier, this means that the galaxies contain hidden quasars, and that their photons can reach us by exiting the nuclei along the (radio) structural axes and then scattering into the line of sight. The Tran *et al.* (1995) polarized flux spectrum is shown in Fig. 2.

Since then many other radio galaxies, in general those with strong high-ionization lines like 3CR234, have shown hidden quasars in polarized light. These papers include most of them: Cimatti *et al.* (1996, 1997); Cohen *et al.* (1999); Dey *et al.* (1996); Ogle *et al.* (1997); Tran *et al.* (1995, 1998); Young *et al.* (1996) on Cygnus A (see also Antonucci *et al.*, 1994); Cohen *et al.* (1999); Hurt *et al.* (1999); Kishimoto *et al.* (2001); Solórzano-Iñarrea *et al.* (2004); Tadhunter (2005); Tadhunter *et al.* (2002); Vernet *et al.* (2001).

Many Seyfert 2s were subsequently shown to have hidden Type 1 nuclei by this method (Antonucci and Miller, 1985; many references are given in Tran, 2003), but radio loud cases were fewer, at least partially because they are more distant and fainter.

While there is no question that 3CR234 hosts a powerful hidden quasar, it has some properties which make it somewhat special as a radio galaxy: the luminous high-ionization narrow lines and the powerful infrared dust source (see Fig. 3; also Young *et al.*, 1998). Most of the other radio galaxies shown to host hidden quasars in this way share these properties (Cohen *et al.*, 1999). Both properties are rare in FR I radio galaxies, and at low and moderate redshift, many FR IIs differ from this pattern as well (e.g., Hine and Longair, 1979; Table 2 of Cohen and Osterbrock, 1981 on optical spectra; Ogle *et al.*, 2006, Dicken *et al.*, 2009 on infrared observations). Many of these have low-ionization and low luminosity emission lines (Miley and Osterbrock, 1979). (All of my reference lists are undoubtedly incomplete!)

Radio galaxies with $z \gtrsim 1$ usually have resolved optical light, and much of the light is scattered from hidden quasars (Chambers *et al.*, 1987; Cimatti *et al.*, 1993; Dunlop and Peacock, 1993; McCarthy *et al.*, 1987). Spectacular exceptions include 4C41.17 (Dey *et al.*, 1997) and 6C 1908+722 (Dey, 1999); they show optical light extended along the radio axes, but it is mostly unpolarized starlight. However, these $z \sim 4$ objects are observed at higher rest-frame frequencies than explored in other objects.

B. Puzzling statistics on the radio properties of FR II radio galaxies and quasars

There are a few historical papers which are interesting and illustrative of the reasoning that led to much progress on unification. Peter Barthel worked mostly on VLBI observations of superluminal sources in the 1980s, noting that the beam model explained many properties such as superluminal motions and jet sidedness qualitatively, but he was (according to the title of a rumination for a conference) "feeling uncomfortable" because one had to assume that a large fraction of these sources in various samples have jet axes fortuitously close to the line of sight.[17] Barthel later wrote a famous paper (Barthel, 1989) entitled "Are all

[17] When selecting by high-frequency radio flux, one preferentially selects objects whose jet axes point in our general direction because of beaming, but this effect can't explain the apparent preference for this orientation quantitatively.

quasars beamed?" suggesting that those quasars whose axes lie near the sky plane somehow fall out of quasar samples, and (inspired by the spectropolarimetry) might be classified as radio galaxies. Note though that he did not entitle his paper "Do all radio galaxies contain hidden quasars?" The answer to that question would be no, but the answer to the question he posed is still basically yes.

The general idea of beaming to explain superluminal motions and one-sided jets was accepted by most doubters as a result of two key discovery papers reporting on the so-called lobe depolarization asymmetry. There is a very strong tendency for one radio lobe in double-lobed radio quasars to be depolarized at low frequencies by Faraday rotation within the observing beam on the side of the single-jet sources which *lacks* the jet (Garrington *et al.*, 1988; Laing, 1988). Most people accepted that the depolarized lobe must be the more distant one, located behind a large-scale depolarizing magnetoionic medium; thus the polarized lobe is on the near side, so that the jet is also on the near side, as expected for beaming. (A demur can be found in Pedelty *et al.*, 1989.)

The selection criteria in Laing (1988) and in Garrington *et al.* (1988) favored low-inclination sources; nevertheless it is amusing that the former paper has this disclaimer: "The sources observed here must then be oriented within about 45 degrees of the line of sight... to generate sufficient asymmetry in path length..." to fit the depolarization data. Their referees must not have been particularly curious people not to ask for elaboration. We now know that many of the high-inclination sources were masquerading as FR II radio galaxies.

Barthel (1989) focused on the 3CR sources in the redshift interval $0.5 < z < 1.0$, in order to avoid low-luminosity, especially FR I radio galaxies, which he did not propose to identify with quasars, noting that "radio loud quasars invariably[18] have (lobe) luminosities in excess of the Fanaroff and Riley division." He also pointed out that the 3CR radio galaxies above $z = 0.5$ have strong emission lines like quasars.[19] He notes further that, based on early fragmentary data, only a subset of FR II radio galaxies are strong IR dust emitters. Finally, Barthel crucially adds this claim later in the paper: "...including the $0.3 < z < 0.5$ and/or the $1.0 < z < 1.5$ redshift range does not alter [his conclusions] markedly."

I was particularly moved a few years later by a paper by Singal (1993), entitled "Evidence against the Unified Scheme for Powerful Radio Galaxies and Quasars." I reproduce two of his figures here (the present Fig. 5 and 6). His histograms of number densities and cumulative linear size distributions are similar to Barthel's for $z > 0.5$, but he includes low-redshift FR II sources in a new $z < 0.5$ bin, where "all hell breaks loose." The median projected linear size in quasars relative to radio galaxies no longer shows a satisfying reduction expected for foreshortening, and the number density of FR II radio galaxies becomes much higher than those of quasars.

Singal suggested that this spoiled the Unified Scheme, but a clever alternative was suggested by Gopal-Krishna *et al.* (1996). They showed that subject to two assumptions justified or at least motivated by independent observations, Singal's histograms could all be easily understood in the beam model. One hypothesis was that the torus opening is set by the initial radio power of a source; the other was that the luminosity of a growing giant double radio source decreases over time in a certain way. Without going through all the reasoning, it turns out in this case that in the lowest redshift bin, one is preferentially comparing older quasars to younger radio galaxies, canceling (to the modest accuracy attainable) the expected size difference between the two types of radio source.

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[18] "Almost invariably" would have been more accurate, e.g., quasar 1028+313 in Gower and Hutchings (1984).

[19] Today we would say that the large majority of them have strong emission lines.

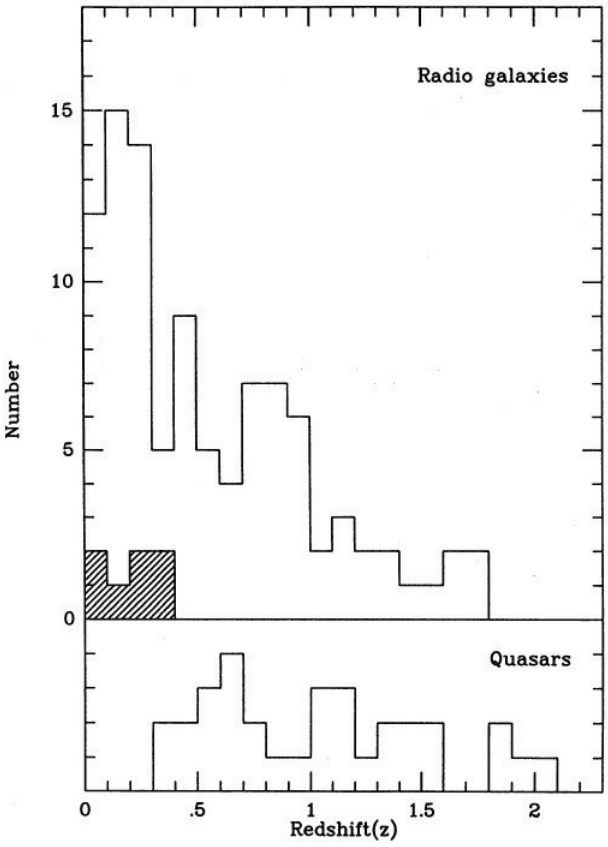


Figure 5 Redshift distribution of 131 radio galaxies and quasars in the 3CR sample, taken from Singal (1993). Crucially, the hashed "Broad Line Radio Galaxies" must be mentally moved to the lower plot for the purposes of this paper. Note the large ratio of the number of radio galaxies to that of quasars at low redshift.

There is another possible explanation for Singal's histograms: there is a population of FR II radio galaxies, concentrated at low redshift, which simply lacks hidden quasars.[20]

C. The infrared calorimeter for visible and hidden FR II radio sources

Distinguishing these two hypotheses motivated my group and others to pursue observations of radio galaxies in the thermal infrared, where the infrared calorimeter (radiation reprocessed as infrared) must show us the putative hidden quasars, independently of orientation. Remember that the spectropolarimetric test for hidden AGN requires a somewhat fortuitous geometry, where a gas and dust cloud must have sufficient optical depth and covering fac-

[20] As we will see, some FR II radio sources do lack quasars, even hidden quasars, and they should form a roughly isotropic distribution. So an easy study would be to look at the strengths of their depolarizations. Another easy armchair ApJ Lett would be to re-create the Singal plots, but leaving out the nonthermal galaxies (no hidden quasars), which should be fairly isotropic and whose removal should make the $z < 0.5$ bin look more like the other bins.

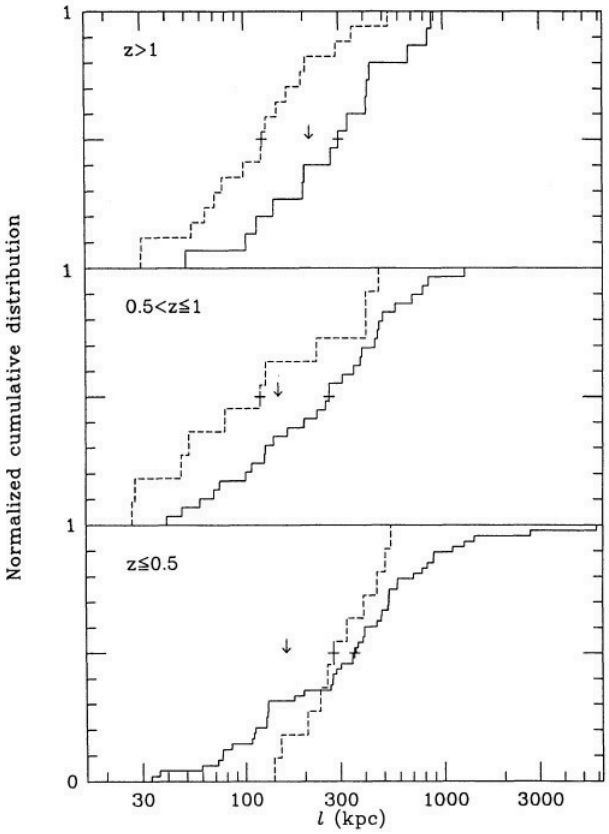


Figure 6 Cumulative distributions of projected linear sizes of radio galaxies (continuous curve) and quasars (dashed curve) in several redshift bins. Crosses mark the median values, and arrows are for a test used by the author, but not referred to here (Singal, 1993). The foreshortening expected in the shadowing Unified Model is not seen at low redshift.

tor to reflect detectable light, and it must have a view of both the hidden quasar and the observer on Earth. Thus it is an incomplete method for finding hidden AGN.

David Whysong and I started imaging 3CR radio galaxies and quasars from Singal's list at Keck Observatory in the 1990s, but equipment problems, terrible weather, and refractory referees delayed our project until ISO and even Spitzer were making big radio galaxy surveys, albeit at low angular resolution. The power and elegance of the infrared calorimeter is shown best however in the composite of high-resolution ($\sim 0.3''$) images reproduced from Whysong's (2005) thesis, and shown here as Fig. 7.

D. Infrared properties of FR II quasars and radio galaxies from the 3CR catalog

Many groups have been seduced by the seeming simplicity and robustness of the infrared calorimeter. A rather complete review of early (pre-Spitzer) observations is given in the Introduction to Cleary *et al.* (2007), reporting on Spitzer observations of 3CR objects with $0.5 < z < 1.4$. Other recent papers include Meisenheimer *et al.* (2001); Siebenmorgen *et al.*

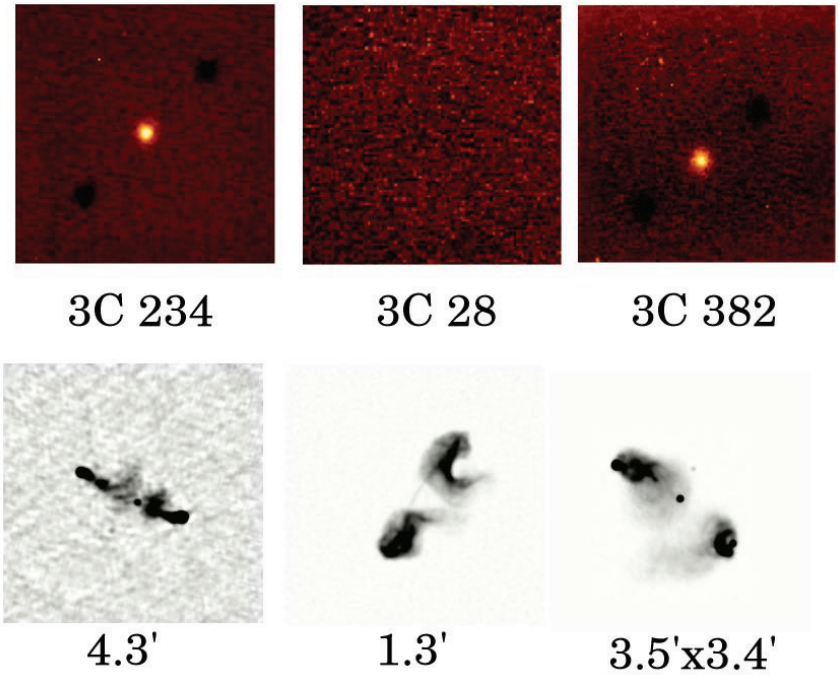


Figure 7 Keck images of three radio-loud FR II AGN, taken in the thermal IR at 11.7μ. 3CR382 is a visible Broad Line Radio Galaxy. 3CR234 is known to be a hidden quasar from its optical polarized flux spectrum. Apparently, 3CR28 does not hide a powerful quasar since no infrared reradiation is detected. (Note that the apparent correlation of radio core strength with central engine type is not a general property.) From Whysong (2005).

(2004); and Whysong and Antonucci (2004), including some 0.3″-resolution Keck data at 11.7μ.

Meisenheimer *et al.* (2001) observed 20 3CR objects with ISO, finding the results compatible with hidden quasars, *except possibly for some at the low luminosity/redshift end.* Relatedly, Siebenmorgen *et al.* (2004) found 68 detected 3CR objects in the ISO archive, finding that, "In most 3CR objects, the mid- and far-IR flux cannot arise from stars nor from the radio core because an extrapolation of either component to the infrared fails by orders of magnitude."

Shi *et al.* (2005) used Spitzer photometry to study a sample of 3CR radio galaxies and steep-spectrum quasars with good Hubble Space Telescope (HST) images, and with "a preference for $z < 0.4$". The data are consistent with the assertion that *most radio galaxies have hidden quasars.* Furthermore, there is evidence for nonzero optical depths at 24μ. Importantly, the entire infrared dust spectrum is generally inferred to be AGN powered, even at 70μ.

Spectroscopy in the optical and the infrared can deliver more specific information. Sometimes the optical narrow line spectrum indicates a lower ionization or luminosity than is actually present, and thus one could conclude that a hidden quasar is not present. Again infrared photometry and spectroscopy are more complete. Haas *et al.* (2005) wrote a key paper which must be kept in mind whenever narrow line spectra are discussed. I hope more work is done along these lines. Haas *et al.* (2005) found that in a set of seven radio galaxies and seven quasars from the 3CR catalog, the radio galaxies observed in the optical have

on average less luminous high ionization lines than the quasars, but that in the relatively transparent mid-IR region, for this small sample of FR IIs at least, *this is not the case*. Haas et al find that "the luminosity ratio [OIII]λ5007Å / [OIV]25.9μ of *most* galaxies is lower by *a factor of 10* than that of the quasars"![21]

Similarly, di Serego Alighieri *et al.* (1997) showed that for some powerful radio galaxies at least, [O III]λ5007Å shows up to some degree in polarized flux, indicating some [O III]λ5007Å is probably hidden by the torus in some cases; but note that it's not always easy to interpret the small polarizations of [O III]λ5007.

Another important consideration is that at least part of the obscuration of the Narrow Line Region in radio galaxies is due to the modest optical-depth kpc-scale dust lanes as seen so dramatically in Cyg A and Cen A. See discussion in Antonucci and Barvainis (1990). Ignoring this information in testing and exploiting the Unified Model will produce erroneous results. Absorption by cold foreground dust is manifest as very deep mid-IR absorption features.

Now let's go back to the figures from Singal (1993), here Fig. 5 and 6. We noted that at low redshift, a *large fraction* of 3CR FR II radio galaxies are *smaller than expected* for high inclination quasars. This could be interpreted as evidence that there are many intrinsically small radio galaxies which lack powerful hidden quasars. By powerful, I mean hidden quasars roughly matched in reradiated Big Blue Bump luminosity with radio galaxies of the same lobe flux and redshift. (Some allowance needs to be made for mid-IR anisotropy.) Alternatively, recall that Gopal-Krishna *et al.* (1996) cleverly noted that two externally motivated assumptions would cause a universally applicable unified model (hidden quasars in all radio galaxies) to lead to data matching the observations; one has to assume that radio sources tend to fade over time, and that the opening angle of the torus increases with the *original* radio power. Our group was fortunate to receive time for Spitzer IRS surveys of several types of radio-loud AGN, including 3CR FR II radio galaxies and quasars (Ogle *et al.*, 2007, 2006). The 2006 paper was the first from a big Spitzer IRS-spectrograph survey.

These infrared data show in fact that many of the 3CR FR II radio galaxies, especially those at $z \lesssim 0.5$ (below the redshift considered in Barthel, 1989), have only weak and cool dust emission. Again if many of these objects have AGN hidden by dust, then the average dust covering factor would need to be reasonably large, so that the dust calorimeter should work at least statistically. Most 3CR FR II radio galaxies with $0.5 < z < 1.0$ do have strong, quasar-like mid-IR emission. This is qualitatively in accord with both Barthel's and Singal's figures (which suggests a dearth of hidden AGN in FR IIs only at $z < 0.5$). Also we now know from Spitzer that essentially *all* the $z \gtrsim 1$ radio galaxies in the 3CR can be unified with quasars by orientation (De Breuck *et al.*, 2010; Haas *et al.*, 2008; Leipski *et al.*, 2010; Ogle *et al.*, 2006, which covers (non-3CR) galaxies up to $z = 5.2$). Compare Fig. 8, showing mid infrared luminosity vs. z, with Figs. 5 and 6 (from Singal, 1993).[22]

Now let's see how the accretion luminosities, taking account of the IR data, compare with $L_{\rm Edd}$ (Fig. 9). Among these radio galaxy black holes, the ones considered to be hidden quasars (for which probably $M_{BH} \sim 10^9 M_\odot$) radiate at $\sim 0.1\%$ of Eddington in dust reradiation only, and the others are below that value. (Figure 9 is a preliminary version of this plot, with some subjective elements, kindly supplied by P. Ogle 2010.) Although this cut isn't always accepted by nature, it's interestingly close to the value expected for the shift from ADAF to thermal optically thick Big Blue Bump ($\dot{m}_{\rm crit} = 1.3\alpha^2$ which produces $L \sim 0.13\%$ of $L_{\rm Edd}$, for 10% efficiency in $\alpha = 0.1$ models: Esin *et al.*, 1997).

If one were to display the apparent *optical* luminosities in Eddington terms, there would be no change in narrow line ionization (see H and L symbols) at this expected location in

[21] Note that this large anisotropy or at least absorption of [O III]λ5007 differs markedly from the situation in the Seyfert sample discussed in Sec. III.D.

[22] One can also see this effect to some extent in the closely related top parts of Fig. 8 of Cleary *et al.* (2007).

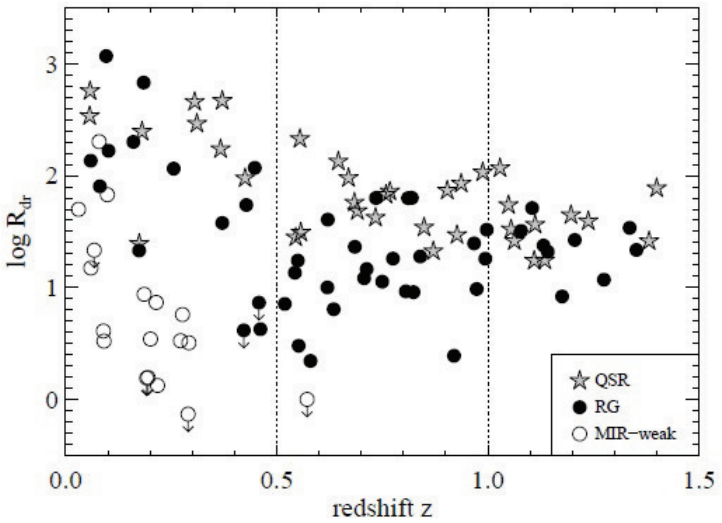


Figure 8 The ordinate shows the 15 micron luminosity νL_ν, normalized to the rest-frame 178 MHz luminosity, also referring to νL_ν. Plotting this normalized infrared luminosity allows us to compare objects of fixed power in the nearly isotropic diffuse radio emission. Thus, there are no selection biases with respect to orientation and so the objects in various categories are directly comparable. Stars represent quasars and filled circles refer to the putative hidden quasars, with L(MIR)∼L(MIR) for visible quasars. Empty circles lack visible or hidden quasars, and their presence at low z can explain the present Figs. 5–7 (see text).

$L/L_{\rm Edd}$ of the accretion mode change. But using the infrared luminosities[23] seems to confirm theory spectacularly, if approximately. It is also very clear that both the ionization level and, more surprisingly, the FR type are tightly correlated with accretion mode, as deduced by many authors over the years, and cited in context in this paper.

When a galaxy lacks an observable Big Blue Bump, even when using the IR reradiation to find it, we can of course only put an upper limit on the flux of that component. According to theory, objects with $L/L_{\rm Edd} \lesssim 0.01$ aren't expected to produce optically thick accretion disks (Big Blue Bumps), so perhaps few weak ones are missed (Begelman *et al.*, 1984). However, the theory isn't yet robust enough to be used in this way with certainty.

There are several fiducial luminosity comparisons that we can make to our infrared upper limits in the radio galaxies: we can compare them to those of matched broad line objects to constrain the universality of the unified model. More important physically, we can compare it to the jet power. The latter is hard to get, and other than for the nearby and powerful object M87, the infrared limits are too high to be of interest in comparing to jet power. But for M87, any hidden quasar must produce much less radiative than kinetic luminosity (Owen *et al.*, 2000; Perlman *et al.*, 2001; Whysong and Antonucci, 2004).

I end this section with some general caveats on unified models and accretion modes for FR II radio sources. 1) We're discussing the highest-luminosity radio sources at each redshift, and in the case of the complete geometrical unification at $z > 1$, we're only talking about

[23] Marchesini *et al.* (2004) present a proxy for this test which could be made without IR data. Using line emission to estimate bolometric luminosities for radio galaxies, they found a probable gap in $L/L_{\rm Edd}$ at ~ 0.01.

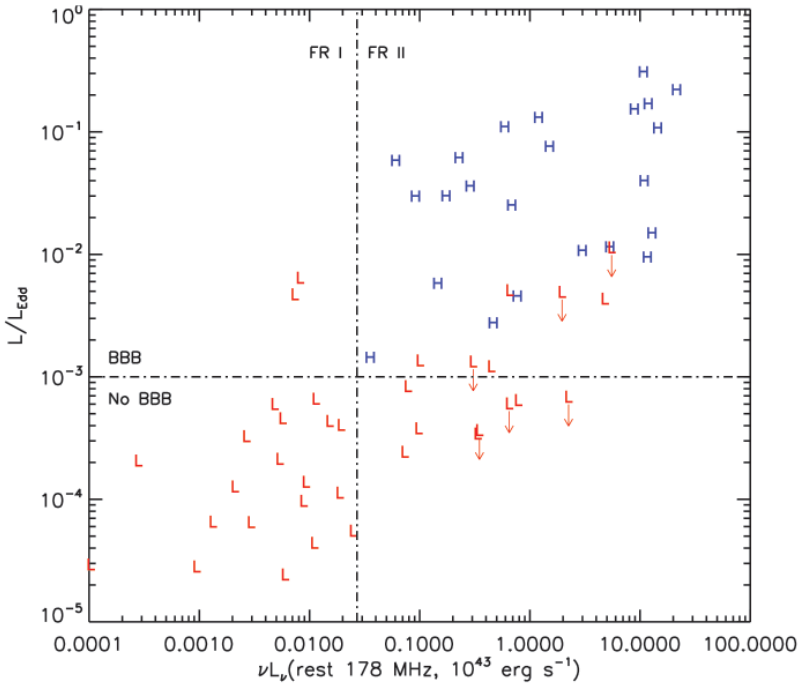


Figure 9 This plot of 3CRR radio sources is preliminary and involves some judgment regarding covering factor, absorption inside the torus, infrared anisotropy, and bolometric corrections. This plot, and the details about these assumptions, can be found in Ogle *et al.* (2011). Masses are based on spiral bulge or elliptical host luminosity. Uncertainties are a factor of several. Note that the objects with quasar-like mid-infrared luminosities are almost all of type FR II, as well as high in ionization level. Details in Ogle *et al.* (2010).

some of the most luminous radio sources in the universe. 2) The statistical significance of the Singal figures makes them robust, but it isn't sufficient for any further investigation by subdivision. 3) At least at the highest redshifts, we know that there is a major contribution to the projected linear sizes of radio sources besides foreshortening. It was shown by Best *et al.* (2000) and subsequent papers that the $z \sim 1$ 3CR radio galaxies' projected linear sizes in the extended gas correlate strongly with ionization level, the smaller ones tending to have shock spectra. Aside from adding noise to the radio size tests, this doesn't affect the discussion too much, though of course it's important from a physical point of view. Note also that that correlation is shown in Best *et al.* (2000) for the radio galaxies alone, where orientation is relatively unimportant, so the claim would have to be softened if made for the entire high-z 3CR sample.

E. Nonthermal optical "compact cores"

Several authors have commented on the optical point sources seen even in some Narrow Line Radio Galaxies which lack a visible Type 1 spectrum. This is different behavior than that in Seyfert 2s, few of which have point sources or variability — their mirrors are extended and spatially resolved by the Hubble Space Telescope in nearby cases, e.g., Capetti *et al.* (1995a,c); Kishimoto 1999; 2002a; 2002b.

It's artificial to separate the FR Is from the FR IIs in this context, because the entire radio galaxy population empirically separates itself in a different way: the large majority of 3CR FR Is (these are nearby, $z \lesssim 0.2$), and many low ($z < 0.5$) and some intermediate ($0.5 < z < 1.0$) redshift 3CR sources have optical nuclei which are consistent with emission from the unresolved bases of the radio jets. References are given below.

In general there are no spectra available of these optical point sources, and certainly no spectropolarimetry. However, the red-region HST point source luminosities *and fluxes* correlate fairly well with the 5GHz (usually flat spectrum) radio cores, which are indeed the bases of jets as shown by VLBI maps. It's important that the correlation shows up in a flux-flux plot as well as in a luminosity-luminosity plot. In luminosity-luminosity plots of AGN (radio loudness vs. optical power is an example of an exception), you will almost always see a correlation because more powerful objects tend to have more of everything. Flux-flux plots have their own peculiarities, but they are *different* peculiarities than in luminosity-luminosity.

Two other very common statistical errors that drive me crazy are: 1. in plots of the form A vs. A/B (or B/A), which are very common, the correlation slope, which may be intrinsically zero, will be strongly biased towards a positive (negative) value — it is *not* a discovery when this happens, if the ordinate range due to errors and population dispersions isn't *much* smaller than the range of the "correlation." People actually publish plots like this all the time, then go as far as analyzing these spurious slopes and trying to extract physics from them. 2. Survival statistics are often used to deal with upper limits, but most astronomical data sets violate the key requirement for this method: that the limits have the same distribution as the detections. In astronomy, we tend to have the exact opposite case: that the upper limits are usually concentrated towards the bottom of the distribution of detections!

Chiaberge and collaborators have worked carefully and doggedly on these sources, and FR IIs are described primarily in Chiaberge *et al.* (2002a, 2000, 2002b). The entire data set and analysis is consistent with (but preceded!) the inferences from the infrared. Chiaberge *et al.* argue that the radio galaxies that fall on the well-populated (putative) synchrotron line in the optical/core-radio plane are likely to be nonthermal AGN. The group of radio galaxies with larger optical flux than expected for synchrotron radiation then host a visible Big Blue Bump/Broad Line Region.

These authors further suppose that any opaque tori would be larger than the optical point sources, in which case they would block the optical light; therefore there are no tori in most such cases. Although M87 is an FR I (or hybrid) source, it's worth mentioning in this section that its HST point source is indeed small, because it varies on timescales of months.[24]

Detailed study of 100 low luminosity 3CR radio galaxies with HST at 1.6μ is quite consistent with the prior conclusions of the Chiaberge *et al.* group. In particular the low ionization galaxies of both FR types show "central compact cores" which are probably nonthermal in nature (Baldi *et al.*, 2010).

Powerful supporting evidence by the same group comes in the form of a spectroscopic survey of $z < 0.3$ galaxies (Buttiglione *et al.*, 2010). As had been noted by e.g., Hine and Longair (1979), FR II radio galaxies can be naturally divided into low and high ionization objects. But Buttiglione *et al.* (2010) go a big step further and assert that their emission-line "excitation index" is bimodal (their Fig. 4)! The first and only other claim of a related bimodality of which I am aware is that of Marchesini *et al.* (2004), who cite such a feature in the distribution of $L/L_{\rm Edd}$ at a value of ~ 0.01. It's worth keeping that value in mind.

Just as for the infrared data, the demographic conclusion from these optical studies is that the fraction of 3CR FR II radio galaxies with visible or hidden quasars is relatively small at low redshift, increasing up to at least $z \sim 0.6$ (see also Varano *et al.*, 2004, and for a slightly different opinion, Dicken *et al.* (2010)).

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[24] However, this in itself is still no proof that it's smaller than any possible torus.

Finally, it's been found that as a group, "radio loud" galaxies and quasars (in this case with a flux cutoff or 3.5mJy at 1.5GHz — which is extremely low compared with the 3CRs) are clustered differently, with the quasars favoring richer environments (Donoso *et al.*, 2010). This result is consistent with the views expressed here because objects with L_ν (1.5GHz) $\gtrsim 10^{33}$ erg/sec/Hz (essentially the range of 3CR radio galaxies and quasars) do cluster more like quasars, according to that paper. Nevertheless it strongly suggests that the shadowing unification doesn't apply at lower radio luminosities.[25]

F. X-rays

Hidden radio quasars are characterized by large ($\sim 10^{22} - 10^{25}$ cm^{-2} or more) cold absorbing columns, like the Seyfert 2s and radio-quiet quasar 2s. The Low Ionization Galaxies generally don't show large columns[26] and this suggests that they lack tori and Broad Line Regions, although it's always possible that the jet continuum emission extends beyond a torus (Hardcastle *et al.*, 2009). See their Fig. 16 and their table 7 for the columns for Low Ionization Galaxies and other classes of AGN. These authors argue persuasively that one can separate X-ray components from hidden quasars and from jet emission, modeling the X-ray spectra with high-column and zero-column components, respectively (see Figure 10).

Thus with reasonable SNR in the X-ray spectrum, one can say which spectral component likely dominates that ostensibly derived from jet synchrotron emission and those directly related to a copious accretion flow — and often one dominates completely. Examples of each type are shown in the FR II galaxies in Rinn *et al.* (2005); Kraft *et al.* (2007); Trussoni *et al.* (2007); and Evans *et al.* (2010). The X-ray spectroscopic survey of high-z 3CR objects of Wilkes *et al.* (2009), like the infrared study of Leipski *et al.* (2010), is extremely supportive of complete unification of 3CR radio galaxies and quasars at $z \gtrsim 1$.

The putative accretion-disk K-α lines in the thermal radio galaxies and quasars seem to be weaker and narrower than in Seyferts, a fact often attributed to an inner edge of an optically thick flat accretion disk at a greater radius than that at which the disks in radio quiets terminate (e.g. Ogle *et al.*, 2005; Sambruna *et al.*, 2009; Tazaki *et al.*, 2010). The accretion disks are often taken to have inner edges at the Innermost Stable Circular Orbit[27], but this is controversial (e.g. Agol and Krolik (2000)). If the innermost part of the opaque thin disk is missing, the efficiency of the standard[28] disk is reduced, and also the thermal spectrum is cooler, so one would expect (but doesn't see) corresponding changes in the spectral line ratios and luminosities (Ogle *et al.*, 2005). Also in a recent study by Molina *et al.* (2008) on a sample selected at 20–40 keV for their six "definite" Broad Line Radio Galaxies, "we only find marginal evidence for weaker reprocessing features in our objects compared to their radio quiet counterparts." More commentary on this can be found in Kaburaki *et al.* (2010).

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[25] Another easy but worthwhile "armchair ApJ Letter" could be written to test whether restriction of the Donoso *et al.* (2010) radio galaxies to those of high radio luminosity would cause their clustering properties to match those of the quasars.

[26] One exception is found in Ramos Almeida *et al.* (2011). For a radio-quiet exception, see Filippenko and Halpern (1984).

[27] An interesting possibility is that a large ISCO results from disk counter-rotation (Garofalo *et al.*, 2010).

[28] Optically thick, geometrical thin disks with the alpha viscosity prescription, e.g., Pringle (1981).

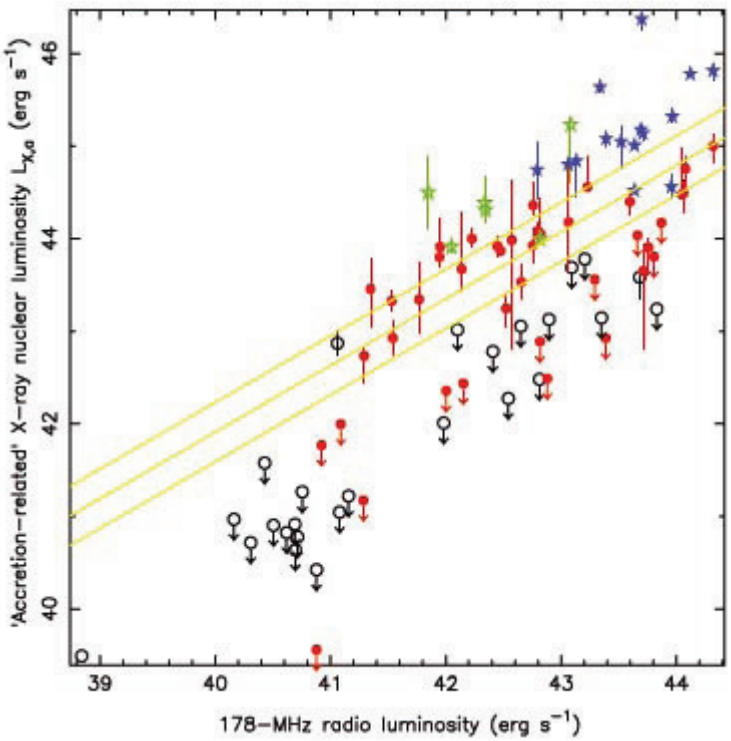


Figure 10 The vertical axis shows the X-ray luminosity for the 'accretion-related' (absorbed) component as a function of 178-MHz total radio luminosity for the $z < 1.0$ 3CRR sample. Regression is for detected Narrow Line Radio Galaxies only. Black open circles indicate Low-Ionization Narrow Line Radio Galaxies, red filled circles High-Ionization Narrow Line Radio Galaxies, green open stars Broad Line Radio Galaxies and blue filled stars quasars. Clearly the Low Ionization objects have little or no thermal emission. (Adapted from Hardcastle *et al.* (2009).)

V. FR I RADIO GALAXIES

A. Radio properties

These lower-luminosity ($\lesssim 2 \times 10^{32}$ erg/s Hz^{-1} at 1.5GHz) big radio doubles generally have fairly symmetric twin jets on $>$ 1kpc scale, and the lobes are edge-darkened with no terminal hotspots. Much of the VLBI data on FR Is (and much of it on low-luminosity FR IIs) come from the group behind these references: Giovannini *et al.* (2001, 2005); T. Venturi, pc, 2010. The data, though somewhat sparse on speeds especially, are consistent with the assertion that FR I jets start out relativistic, with the FR Is being a little slower than the low-luminosity FR IIs. The fraction of sources studied in the isotropically selected 2005 sample which are visibly two-sided on VLBI maps is $\sim$ 30%, vs. 5–10% in earlier core-flux-selected samples. Somewhat of an update was provided by Liuzzo *et al.* (2009), with single-epoch data on low-frequency selected FR Is, with aggregate results consistent with a single unified (beam) model.

The overall statistics on the depolarization asymmetry, another powerful constraint on the inclination distribution, show that the effect is weaker than for quasars, and probably

consistent with an isotropic distribution, though data are scarce. For example, Morganti *et al.* (1997) looked at this for an FR I sample, and found that the depolarization asymmetry is usually weak. Garrington *et al.* (1996) had come to a similar conclusion, noting however that strongly one-sided jet sources have strong depolarization asymmetry. Capetti *et al.* (1995b) found a strong depolarization asymmetry in 2 out of 3 intermediate radio luminosity (between FR I and FR II) radio galaxies. I think that more depolarization work should be done, not just for the AGN field but for understanding galaxy and cluster hot gas atmospheres, where the depolarization presumably takes place.

B. Infrared

Finally I'm getting to a topic that is a little bit controversial. It's not *very* controversial in that everyone seems to agree that most FR Is have predominantly nonthermal radio/infrared/optical and X-ray nuclei, e.g. Müller *et al.* (2004). But it is important not to overgeneralize, and assert a direct connection between FR I morphology and a nonthermal engine.[29] I listed a few exceptions in Antonucci (2002a,b), going back to the first FR I *quasar*, reported in 1984 by Gower and Hutchings. (I don't know why the more common FR I Broad Line Radio Galaxies don't impress people equally, but some extra cachet seems to attach to those of quasar optical/UV luminosity.)

Recently there have been several papers modeling individual FR I nuclei as purely nonthermal, which I think have been contradicted by subsequent Spitzer spectra. For example, consider NGC6251[30], analyzed by Chiaberge *et al.* (2003), for which the spectral index over most of the infrared is inferred to be ~ -0.6. Leipski *et al.* (2009) shows that the mid-IR spectrum exceeds their predictions, and shows strong dust emission features. Our conclusion from the SED is that there is hot dust with at least as much flux as that due to synchrotron radiation. The aperture was $\sim 4''$ but that may not matter much because dust emitting at a few microns must be near a somewhat powerful optical/UV source, i.e., the nucleus. It'd be easy to check from the ground. Thus the substantial near- and mid-IR dust emission may signal a hidden thermal optical/UV also. See however Gliozzi *et al.* (2008), who shows that the X-rays are likely to be dominated by the jet in NGC6251. I think a problem with most published decomposition of radio galaxy infrared spectra is that they require slopes flatter than those of Blazars, opposite to the beaming prediction.

A Spitzer IRS spectrum for BL Lac is shown in Fig. 2 of Leipski *et al.* (2009): the slope is ~ -0.8 between 5 and 30μ, considerably steeper than the synchrotron slopes in most published nonthermal models for radio galaxies. What's more, Impey and Neugebauer (1988) find that "The spectra of Blazars steepen continuously between 10^9–10^{15} Hz... the [frequency] at which the energy distribution turns down in $\sim 2\times10^{11}$ Hz with a very narrow range of spectral indices. Half of the Blazars with less than 10^{11} $L_\odot$ show evidence for thermal infrared components..." to which I'd add: which should be much more conspicuous and thus more widespread in the high-inclination objects (radio galaxies). Moreover, "The average Blazar spectrum is flat ($\alpha \sim 0$) at 10^9 Hz and steepens continuously to $\alpha \sim -1.5$ at 10^{15} Hz. Table 4 shows that the infrared slopes from 3×10^{12} Hz (100μ) to 3×10^{14} Hz (1μ) are *all* steeper than 1." For the SEDs of FR I synchrotron components, with lots of infrared Spitzer data, and both with and without dust bumps, see Leipski *et al.* (2009): in our models, which feature relatively low synchrotron contributions throughout the infrared, the slopes are steeper than those found by other investigators and thus more reasonable in my opinion.

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[29] It is easy to imagine that the few exceptions can be attributed to the grossly different timescales on which the core ($\sim$ 1 yr) and the lobes ($\sim 10^8$ yr) are created. On the other hand, the host-dependence of the luminosity cutoff, strongly suggests environmental factors also play a role (Owen and Ledlow, 1994).

[30] This is the first object with good evidence of a narrow line flux variation: Antonucci (1984), Fig. 1.

There are at least two ways around this objection to the required flatness of the synchrotron components in some of the published infrared decompositions. First, the emission from high-inclination may be dominated by a slow-moving component which is for some reason intrinsically flatter, and not directly related to the strong beamed component (e.g. Chiaberge *et al.*, 2000). Also, the Blazar samples aren't necessarily matched to the lobe-dominated radio galaxy samples and this could conceivably make a difference. They do, however, include many objects with FR I diffuse radio power.

Van Bemmel *et al.* (2004) account for most of the nonstellar radiation from 3CR270 (=NGC4261) with a nonthermal model, but find some evidence for a weak thermal component. Our Spitzer data show a big dust bump, which covers 3μ–100μ, and dominates the infrared energetically, at least as observed in the $4''$ Spitzer aperture. Please see Fig. 9 of Leipski *et al.* (2009) for our spectral decomposition, and the location of the synchrotron component. The Big Blue Bump is extremely well correlated with the Broad Line Region in AGN, and I consider the possible detection of broad polarized H-α in this object by Barth *et al.* (1999) well worth following up. Again skipping ahead to the X-ray, Zezas *et al.* (2005) conclude that 3CR270 is a heavily absorbed nucleus, $N_H \sim 8 \times 10^{22}$ cm^{-2}, far higher than most FR Is (see Figure 10 here; also Balmaverde *et al.*, 2006). Synchrotron is thought by Zezas *et al.* (2005) to contribute only $\sim 10\%$ of the X-ray flux.

The detailed discussion of Cen A in Whysong and Antonucci (2004) still represents our views on this controversial and somewhat complicated case. We think it contains a hidden Big Blue Bump/Broad Line Region. Optical polarization imaging is relevant for this FR I radio galaxy. Capetti *et al.* (2007) have measured the percent polarization of the HST nuclear sources at ~ 6060Å in several FR I galaxies. Restricting to those with PA errors $\leq 10^\circ$ (the error functions have strong tails, unlike the Gaussian function), the seven remaining objects are a few percent polarized at random-looking angles. Cen A has a similarly puzzling optical (R/I band) polarization, influenced greatly by a foreground dust lane (Schreier *et al.*, 1996).

In the near-IR K band however, one can sometimes see through kpc-scale dust lanes of modest optical depth to the nuclear occultation/reflection region (Antonucci and Barvainis, 1990; Whysong and Antonucci, 2004; see also Bailey *et al.*, 1986). Packham *et al.* (1996) report on both the near-IR polarization and the millimeter polarization (which turns out to be crucial): the polarization of the nucleus after various corrections is given as an impressive 17% ("in the near-IR"), and exactly *perpendicular* to the inner radio axis. This is expected for hidden thermal AGN rather than for Blazars. (Refined values can be found in Capetti *et al.*, 2000.) Packham *et al.* remark that the millimeter polarization, given simply as "zero," is "not... consistent... with that of BL Lacs." As noted, we believe that near-IR observations often see through the dust lanes, enabling us to see this very high polarization exactly perpendicular to the radio jet, as we demonstrated with the radio galaxy 2C223.1 (Antonucci and Barvainis, 1990; we used a 1-channel polarimeter [!] but our measurement was accurately confirmed with a modern instrument).

The mere fact that the PA is constant in time for each near-IR observation of Cen A is unlike BL Lacs (or compact synchrotron sources in general), as is the perpendicular relation to the radio jet. We also think that the spatially resolved azimuthal off nuclear near-IR polarization (Capetti *et al.*, 2000) is most consistent with scattering from a normal Type 1 nucleus.

For Cen A, we mention the X-ray spectrum here (Markowitz *et al.*, 2007). The superb Suzaku spectrum shows a column above 10^{23} cm^{-2} for two separate components, and many narrow fluorescent lines, including Fe K-α, like a Seyfert 2.

Going back to the mid-IR data on FR Is and FR IIs generally, an imaging survey of nearby objects at 12μ by van der Wolk *et al.* (2010) revealed results which are generally understandable and consistent with other arguments: the broad line objects, all FR IIs, were easily detected at 7 mJy sensitivity (they quote 10σ!), as well as most of the High-Ionization Narrow Line Objects (also FR IIs). The low-excitation galaxies of both types were not detected.

Spitzer is much more sensitive than any ground-based instrument. The current state of the

mid-IR art survey of FR Is from the IRS spectrograph is described in Leipski *et al.* (2009). Here's where there is a little more controversy. We observed 25 FR I radio galaxies, and carefully removed the star formation contributions as well as possible using the PAH features, and also removed old stellar populations using the Rayleigh–Jeans tail of the starlight, and using the AGB star features at longer wavelengths. We reached the following conclusions for the 15 putative pure-synchrotron sources described in Chiaberge *et al.* (1999). Of the 15 sources with "optical compact cores" from the Chiaberge group and others (see the "Optical" section below), we see four with the infrared dominated by contributions from the host galaxies. In another four of the galaxies with optical point sources (but probably no exposed Big Blue Bump/Broad Line Region), warm dust emission dominates, and is probably at least in part due to hidden nuclei, contrary to the conclusions from the optical papers. In seven cases, synchrotron radiation dominates the mid-IR. The comparison to the Chiaberge *et al.* core decompositions cannot be considered definitive however because of the larger Spitzer aperture.

C. Optical

Some information about the optical point sources was used above to provide context for the IR fluxes, but we must note here that these cores (Chiaberge *et al.*, 1999, 2000; Verdoes Kleijn *et al.*, 2002; Zirbel and Baum, 1995, 2003) have been used to argue for synchrotron optical emission and no powerful hidden AGN or tori in most FR I radio galaxies; Baldi *et al.* (2010) is closely related. Zirbel and Baum (1998, 2003) find that the low-luminosity radio galaxies with detected central compact optical cores are the ones with visible (single or highly one-sided) jets, and thus probably low inclinations. This is compatible with the jet idea for the optical cases.

There has also been a series of papers by the Chiaberge, Capetti group (Capetti *et al.*, 2005) on emission lines from low-luminosity radio galaxies. These papers report that the putative synchrotron continuum is sufficient to produce the observed emission lines, if the covering factors average about 0.3. They estimate the ionizing continuum from that in the UV with power laws.

Another ambiguity is that the UV continuum can be very steep, and the reddening corrections may be very large and uncertain (Chiaberge *et al.*, 2002b). Also the observed "UV excess" in at least a few low luminosity radio galaxies is due to starlight, according to Wills *et al.* (2004). In that case too the ionizing radiation can't be quantified easily.

Capetti *et al.* (2005) also made a factor of 5 correction downward to estimate the H-α emission line flux from the measured flux of the blend with the [N II] doublet. The factor of 5 seems too high to me, and comes not from typical AGN behavior, but from a UGC sample of ordinary LINERs. Also, there was apparently no starlight subtraction before this factor was determined from spectroscopy (Noel-Storr *et al.*, 2003). (The effect of this can be estimated from formulae in Keel, 1983.) Finally, they detected in *most* cases probable broad bases to the H-α line, but not the forbidden lines. These lines are said to be "compatible with the broad lines seen in LINERs" by Ho *et al.* (1997). Any Big Blue Bump accompanying these lines would probably be undetectable, at least with present data, so this is consistent with (but not proof of) the presence of a Big Blue Bump, albeit of low luminosity. Ho (1999; 2009) has argued however that for his LINERs with weak broad H-α, the central engines are radiatively inefficient. My overall conclusion regarding the central compact optical cores is that they are indeed mostly synchrotron sources, but I don't share the same degree of confidence as the various authors.

Let us now return briefly to the question of broad emission lines in FR I galaxies, concentrating on AGN that can be observed with good contrast relative to the host galaxies. The most familiar object of this type is 3C120, with a fast superluminal VLBI source. Several others (Antonucci, 2002b gives a brief compilation) are also highly core dominated, including BL Lac itself, in which the broad lines need to compete with the beamed radiation in order

to be detected. This suggests that a Broad Line Region is sometimes visible in an FR I radio galaxy, when seen at low inclination. Falcke *et al.* (1995) wrote a clever paper on this "missing FR I quasar population."

D. X-rays

This section will be brief because the results of many excellent studies are simple and consistent, within the noise and the limited number of sources analyzed, and the selection biases specific to each. Refer again to the present Fig. 10 (Hardcastle *et al.*, 2009) for strong evidence of very weak (ostensibly) accretion-related power Low-Ionization Galaxies, including both FR types. Other papers are generally very supportive of (and in some ways anticipated) Hardcastle *et al.* (2009).

Some recent surveys with lots of FR I results: Donato *et al.* (2004); Balmaverde *et al.* (2006); Rinn *et al.* (2005); Evans *et al.* (2006); and Hardcastle *et al.* (2006). Overall, the great majority of X-ray spectra of FR I radio galaxies suggest nonthermal emission. This finds strong independent support in that most of these objects (the current Fig. 10) differ from Cen A, and do *not* show the high absorption columns typical of hidden AGN.

VI. SMALL SOURCES: COMPACT STEEP SPECTRUM AND GIGAHERTZ-PEAK SPECTRUM

The radio properties of these young sources are described briefly in Section 1, the Introduction. The classic complete review is O'Dea (1998), while a shorter but recent review is Fanti (2009).

Recall that few can grow into large bright sources, because they are nearly as common as the big ones (as selected in the centimeter region), but have very short kinematic and synchrotron-aging lifetimes. Recall also that many of the tiny kinematic ages probably measure just the age of the current stage of activity, which may repeat many times. It's also possible that their birthrate is extremely high, but that most fade out before they grow.

The experts generally seem to agree that the radio-galaxy/quasar unification holds fairly generally, for the well-studied very radio luminous population. That is, the radio galaxies are in the thermal class. At more modest luminosities, there is less information and some hints from the infrared that this may not be the case. If so, they behave similarly to the giant doubles.

A. Radio properties

Saikia *et al.* (2001) provide several good arguments for small ages and unification by geometry. On the former, kinematic and synchrotron ages are small and generally consistent. On the latter, the authors note that the quasars are more core-dominant in the radio, and they have more asymmetric morphologies consistent with oppositely directed twin jets. Several optical and radio papers present evidence for absorption by molecules and HI, preferentially for the galaxies and thus near the plane according to the Unified Model, e.g., Baker *et al.* (2002); Gupta and Saikia (2006); and Fanti (2009).

B. Infrared

Astronomers studied this class of radio source in the infrared with IRAS (Heckman *et al.*, 1994) and with ISO (e.g., Fanti *et al.*, 2000). These radio emitters show generally high

(quasar-like) power in the aggregate. The ISO mission was able to make many individual detections, but the Fanti *et al.* (2000) paper did not make a comparison of their observed galaxies with GPS/CSS quasars.

In the Spitzer era, Willett *et al.* (2010) presented data for eight *relatively radio-faint* "compact symmetric objects," which heavily overlap the GPS class. Only one was a broad-line object (OQ 208); one was a BL Lac Object. Their Fig. 8 shows a plot of the Si strength vs. equivalent width of the 6.2μ PAH feature, demonstrating that hidden AGN (marked by moderate Si absorption and fairly weak PAHs) probably dominate the mid-IR emission of the galaxies in all cases. The quasar has Si slightly in emission, also as expected for the unified model. However, if considered bolometrically, the AGN luminosities are low (except for the quasar) and PAH features indicate that star formation may contribute significant luminosity. Ionization levels are low. The authors favor Bondi accretion or black-hole spin energy for most of the galaxies, not a thermal Big Blue Bump, so in our parlance they would fall into the non-thermal class.[31]

Our larger Spitzer survey (Ogle *et al.*, 2010) contains 13 quasars and 11 radio galaxies from the 3CR catalog. It contains objects of substantially higher redshift (0.4–1.0) and luminosity (10^{34}–10^{35} erg s^{-1} Hz^{-1} at 1.5 GHz and 5 GHz), as compared with the Willett *et al.* (2010) sample.

The radio luminosities of our sample sound much higher than most FR IIs, where the FR I/II cutoff is $\sim 2 \times 10^{32}$ erg sec^{-1} Hz^{-1} at 1.5GHz, but the CSS and especially the GPS sources are much weaker relative to the big doubles at low frequency. Also note that this and their small sizes indicate that they contain much less energy in particles and fields overall.

It is not so easy to get a complete isotropic sample of GPS sources because they don't have dominant isotropic lobe emission. Possibly one could select by an emission line, preferably in the infrared, after radio classification. We took the GPS sources from Stanghellini *et al.* (1998), a complete GHz-selected sample but likely with beaming effects favoring low inclination. This might not be too bad since we are mainly comparing quasars and radio galaxies, with the latter still at larger inclinations by hypothesis (shadowing Unified Model); however they may not be at the same level on the luminosity function. For the CSS sources, we could find a roughly isotropic sample in the 3CR, and we took them from Fanti *et al.* (1995).

We find that the GPS/CSS galaxies in our sample are *all* powerful thermal dust emitters, with vLv(15μ) $\sim$ 5–500 $\times 10^{43}$ erg s^{-1}. The Si features behave somewhat erratically vs. optical type, although most follow the pattern of emission for quasars and absorption for galaxies. This can be accommodated by clumpy torus models, but since it's specific to the small objects, it might also be from the effects of colder foreground off-nuclear dust. The interpretation of the galaxies as hidden quasars is greatly strengthened by the [Ne V] and [Ne VI] lines detected in all of the quasars and many of the galaxies. We detect no PAH or H_2 features.

In summary, the infrared evidence favors a (nearly?) ubiquitous shadowing unified model for the most radio-luminous small sources. Remember, however, these are the highest-luminosity members of the class, and it's likely that at lower luminosities, some radio galaxies lack the hidden quasars, based on Willett *et al.* (2010).

C. Optical

Bright GPS and CSS radio sources tend to have strong line emission. All three 3CR CSS sources studied by Labiano *et al.* (2005), two radio galaxies and one quasar, show [O III]λ5007 narrow H$\beta > 10$, so they have high ionization. There is evidence for shocks also in these nice HST spectra.

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[31] This refers to the overall SED, and not the infrared emission specifically.

There is a wealth of information in de Vries *et al.* (1999) and Axon *et al.* (2000) on HST imaging of CSS radio galaxies. These groups imaged in the Hα or [O III] λ5007 line in tens of objects. Only the broad line objects have point continuum sources, in accord with the Unified Model. Thus there are almost no known "bare synchrotron" sources[32] as described above for FR I and FR II galaxies. This is not really a demonstrated difference however since until very recently, only the most luminous GPS/CSS sources have been studied in detail. In fact, very recently Kunert-Bajraszewska and Labiano (2010) have reported on line emission on *fainter* small radio sources, finding that many have Low Ionization Galaxies spectra, just like for the giant doubles.

Both de Vries *et al.* (1999) and Axon *et al.* (2000) also found that the line emission lies preferentially parallel to the radio axes, and Axon et al. add that photon counting arguments require a hidden radiation source. Those alone are powerful arguments for unification with quasars.

D. X-rays

There are several papers on X-rays from small radio sources. Guainazzi *et al.* (2006) reported on a small sample of GPS galaxies at redshifts between 0.2 and 1. All four with adequate SNR have large column densities, "consistent with that measured in High-Excitation FR II galaxies," strongly indicating hidden quasars. The radio luminosities are around 10^{34-35} erg s^{-1} Hz^{-1} at 1.5GHz, near the spectral peaks. The 2–10 keV X-ray de-absorbed luminosities are 10^{44}–10^{45} erg s^{-1}. (The authors give their $H_0 = 70$, but no other cosmological parameters, so this is approximate.) Since that band covers only 0.7 dex in frequency, the X-ray luminosity alone is $\gtrsim 1 \times 10^{45}$ erg s^{-1}, and the bolometric luminosity is likely to be at least a few times higher. There is one exception, which is convincingly argued to be Compton-thick and so opaque in the X-ray. Consistent results were reported by Siemiginowska *et al.* (2008).

This group expanded their survey of GPS galaxies (Tengstrand *et al.* (2009); neither study included quasars) and confirms and extends these results, again concentrating on the most radio-luminous objects.

VII. SUMMARY

First hearty congratulations to all the theorists who predicted that accretion would become inefficient below $L \sim 0.01 L_{\rm Edd}$. Apparently, the initial argument to this effect is that of Rees *et al.* (1982). Parts of the theory were anticipated by Shapiro *et al.* (1976) and Ichimaru (1977). More recently, Esin *et al.* (1997) quotes 0.4 $\alpha^2 L_{\rm Edd}$ as the cutoff luminosity in the α prescription, which they find fits well with black hole binary state changes.

The first radio galaxy discovered and interferometrically mapped was Cygnus A, which has a whopping apparent brightness of 8700 Jansky at 178 MHz. At low frequencies, you can actually point the VLA 90 degrees away from Cygnus A and map it in a sidelobe! (F. Owen, pc 2010.) Also interesting: considering the volume enclosed by the Cyg A distance and the very strong cosmological evolution of FR II radio sources, folklore says only one universe in 10,000 should be so lucky as to have such a prize!

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[32] An exception is PKS 0116+082, from Cohen *et al.* (1997). This really anomalous object has high and variable polarization like a Blazar and good limits on broad Hα/λ5007, yet very strong narrow emission lines. There is actually a possible broad Hα line in polarized flux, which is however unexpected in a Blazar. This object is not analogous to the much lower luminosity HST optical point sources studied by Zirbel and Baum, and Chiaberge et al., and discussed in the previous two sections. One point in common though is at least a few percent optical polarization (Capetti *et al.*, 2007).

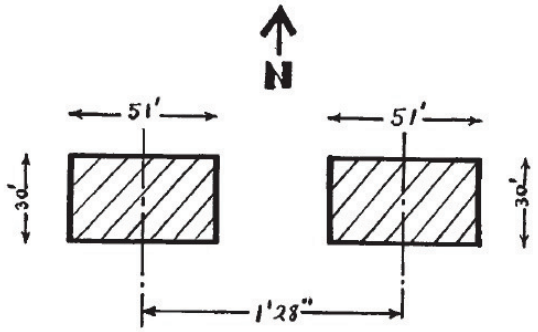


Figure 11 Approximate intensity distribution of the extra-terrestrial radio source in Cygnus (Jennison and Das Gupta, 1953). This very early interferometric observation first revealed the double-lobed nature of most radio galaxies.

The first map of Cygnus A is very impressive for the time, and the map is very charming (Fig. 11 here, from Jennison and Das Gupta, 1953). There is no question that it has a hidden quasar of moderate luminosity (Antonucci *et al.* (1994); Ogle *et al.* (1997); infrared fluxes from NED). See Barthel and Arnaud (1996) to find out how such a modest quasar can be so incredibly powerful in the radio.

We know now that some powerful radio galaxies, and many weaker ones, lack detectable visible or hidden thermal AGN. It is, however, very important to remember that in *all* but a couple of contentious cases, Type 2 radio quiet quasars have hidden AGN, until you get to the LINER (very low luminosity) regime, which then shows ADAF behavior according to most investigators (Elitzur and Shlosman (2006); Chiaberge *et al.* (2000); Ho (2009); many others), along with weak broad wings to Hα in many cases.

The time has come to stop proving this! We have altogether quite settled the question. It's worthwhile exploring more parameter space, e.g., weaker radio/IR/optical/X-ray sources, and to follow up on individual interesting cases, but the overall pattern is clear now for all types of bright radio source.

So what should we do instead? The result of all this work is that we can now hold many things constant while we vary just one thing, the tremendous thermal emission (Big Blue Bump). The two types must differ drastically in their structure on relativistic scales. We are limited by our imaginations in how to take advantage of this situation. My group is trying to determine how the thermal/nonthermal states correlate with VLBI properties, i.e. jet launching, collimation, and proper motion, to the extent that's possible with current VLBI angular resolution, all while holding the large-scale structure constant as far as we can discern. Another obvious observation, which really requires next-generation X-ray telescopes to do well, is to compare the reflection signatures of the two types. The putative accretion disk K-α fluorescence line isn't expected to be so broad or strong if there is no opaque accretion disk at small radii. Next, AGN feedback in galaxy evolution might be mediated by radiation pressure on dust in many cases, or else by PdV work or particles from jets and lobes, or other mechanisms. Here we can keep everything the same (?) as far as the latter go, but turn off the radiation. Does it make a difference? These new data might actually help with the physics of AGN and of galaxies, and not just the astronomy of AGN. Enjoy!

ACKNOWLEDGEMENTS

Several astronomers have provided advice and unpublished data for this paper. These include S. Baum, M. Begelman, P. Best, O. Blaes, S. Buttliglione, M. Chiaberge, C.M. Gaskell, M. Gu, M. Haas, L. Ho, S. Hoenig, W. Keel, P. Kharb, M. Kishimoto, M. Kunert-Bajraszewska, C. Leipski, R. Maiolino, C. O'Dea, F. Owen, S. Phinney, D.J. Saikia, A. Singal, D. Whysong and B. Wills. C. Leipski, S. Hoenig, D. Whysong and P. Ogle provided unpublished figures. P. Ogle, S. Willner, and R. Barvainis suffered the most (after the author), locating many errors and ambiguities. To the extent that the text sounds literate, my editor/typist Debbie L. Ceder deserves credit.

REFERENCES

Agol, E., and J. H. Krolik (2000), *Astrophysical Journal* **528**, 161, arXiv:astro-ph/9908049.
Alloin, D., D. Pelat, M. Phillips, and M. Whittle (1985), *Astrophysical Journal* **288**, 205.
Antonucci, R. (1988), in *Supermassive Black Holes*, edited by M. Kafatos, pp. 26–38.
Antonucci, R. (1993), *Annual Review of Astronomy and Astrophysics* **31**, 473.
Antonucci, R. (2002a), in *IAU Colloq. 184: AGN Surveys*, Astronomical Society of the Pacific Conference Series, Vol. 284, edited by R. F. Green, E. Y. Khachikian, and D. B. Sanders, p. 147, arXiv:astro-ph/0110343.
Antonucci, R. (2002b), in *Astrophysical Spectropolarimetry*, edited by J. Trujillo-Bueno, F. Moreno-Insertis, and F. Sánchez, pp. 151–175, arXiv:astro-ph/0103048.
Antonucci, R., and R. Barvainis (1990), *Astrophysical Journal Letters* **363**, L17.
Antonucci, R., T. Hurt, and A. Kinney (1994), *Nature (London)* **371**, 313.
Antonucci, R., A. L. Kinney, and T. Hurt (1993), *Astrophysical Journal* **414**, 506.
Antonucci, R., M. Kishimoto, C. Boisson, and O. Blaes (2004), in *AGN Physics with the Sloan Digital Sky Survey*, Astronomical Society of the Pacific Conference Series, Vol. 311, edited by G. T. Richards and P. B. Hall, p. 381, arXiv:astro-ph/0311153.
Antonucci, R. R. J. (1982), *Nature (London)* **299**, 605.
Antonucci, R. R. J. (1983), *Nature (London)* **303**, 158.
Antonucci, R. R. J. (1984), *Astrophysical Journal* **278**, 499.
Antonucci, R. R. J., P. Hickson, J. S. Miller, and E. W. Olszewski (1987), *The Astronomical Journal* **93**, 785.
Antonucci, R. R. J., and J. S. Miller (1985), *Astrophysical Journal* **297**, 621.
Antonucci, R. R. J., and J. S. Ulvestad (1985), *Astrophysical Journal* **294**, 158.
Axon, D. J. (2001), in *The Central Kiloparsec of Starbursts and AGN: The La Palma Connection*, Astronomical Society of the Pacific Conference Series, Vol. 249, edited by J. H. Knapen, J. E. Beckman, I. Shlosman, and T. J. Mahoney, p. 193.
Axon, D. J., A. Capetti, R. Fanti, R. Morganti, A. Robinson, and R. Spencer (2000), *The Astronomical Journal* **120**, 2284, arXiv:astro-ph/0006355.
Bailey, J., W. B. Sparks, J. H. Hough, and D. J. Axon (1986), *Nature (London)* **322**, 150.
Baker, J. C., R. W. Hunstead, R. M. Athreya, P. D. Barthel, E. de Silva, M. D. Lehnert, and R. D. E. Saunders (2002), *Astrophysical Journal* **568**, 592, arXiv:astro-ph/0112141.
Baldi, R. D., M. Chiaberge, A. Capetti, W. Sparks, F. D. Macchetto, C. P. O'Dea, D. J. Axon, S. A. Baum, and A. C. Quillen (2010), *Astrophysical Journal* **725**, 2426, arXiv:1010.5277 [astro-ph.CO].
Balmaverde, B., A. Capetti, and P. Grandi (2006), *Astronomy and Astrophysics* **451**, 35, arXiv:astro-ph/0601175.
Barth, A. J., A. V. Filippenko, and E. C. Moran (1999), *Astrophysical Journal* **525**, 673, arXiv:astro-ph/9905290.
Barthel, P. D. (1989), *Astrophysical Journal* **336**, 606.

Barthel, P. D., and K. A. Arnaud (1996), *Monthly Notices of the Royal Astronomical Society* **283**, L45.

Begelman, M. C. (1999), in *The Most Distant Radio Galaxies*, edited by H. J. A. Röttgering, P. N. Best, and M. D. Lehnert, p. 173.

Begelman, M. C., R. D. Blandford, and M. J. Rees (1984), Reviews of Modern Physics **56**, 255.

Best, P. N. (2009), Astronomische Nachrichten **330**, 184.

Best, P. N., H. J. A. Röttgering, and M. S. Longair (2000), *Monthly Notices of the Royal Astronomical Society* **311**, 23, arXiv:astro-ph/9908211.

Bianchi, S., A. Corral, F. Panessa, X. Barcons, G. Matt, L. Bassani, F. J. Carrera, and E. Jiménez-Bailón (2008), *Monthly Notices of the Royal Astronomical Society* **385**, 195, arXiv:0710.4226.

Bianchi, S., F. Panessa, X. Barcons, F. J. Carrera, F. La Franca, G. Matt, F. Onori, A. Wolter, A. Corral, L. Monaco, A. Ruiz, and M. Brightman (2012), ArXiv e-prints arXiv:1209.0274 [astro-ph.GA].

Blaes, O. (2007), in *The Central Engine of Active Galactic Nuclei*, Astronomical Society of the Pacific Conference Series, Vol. 373, edited by L. C. Ho and J.-W. Wang, p. 75, arXiv:astro-ph/0703589.

Blandford, R. (1993), in *Texas/PASCOS '92: Relativistic Astrophysics and Particle Cosmology*, Annals of the New York Academy of Sciences, Vol. 688, edited by C. W. Akerlof and M. A. Srednicki, p. 311.

Buchanan, C. L., J. F. Gallimore, C. P. O'Dea, S. A. Baum, D. J. Axon, A. Robinson, M. Elitzur, and M. Elvis (2006), *The Astronomical Journal* **132**, 401, arXiv:astro-ph/0604222.

Burke, B. F., and F. Graham-Smith (2009), *Infrared Astronomy*.

Buttiglione, S., A. Capetti, A. Celotti, D. J. Axon, M. Chiaberge, F. D. Macchetto, and W. B. Sparks (2010), *Astronomy and Astrophysics* **509**, A6, arXiv:0911.0536 [astro-ph.CO].

Capetti, A., D. J. Axon, M. Chiaberge, W. B. Sparks, F. D. Macchetto, M. Cracraft, and A. Celotti (2007), *Astronomy and Astrophysics* **471**, 137, arXiv:0706.1944.

Capetti, A., D. J. Axon, F. Macchetto, W. B. Sparks, and A. Boksenberg (1995a), *Astrophysical Journal* **446**, 155.

Capetti, A., R. Fanti, and P. Parma (1995b), *Astronomy and Astrophysics* **300**, 643.

Capetti, A., F. Macchetto, D. J. Axon, W. B. Sparks, and A. Boksenberg (1995c), *Astrophysical Journal Letters* **452**, L87.

Capetti, A., E. J. Schreier, D. Axon, S. Young, J. H. Hough, S. Clark, A. Marconi, D. Macchetto, and C. Packham (2000), *Astrophysical Journal* **544**, 269, arXiv:astro-ph/0007435.

Capetti, A., G. Verdoes Kleijn, and M. Chiaberge (2005), *Astronomy and Astrophysics* **439**, 935, arXiv:astro-ph/0504568.

Carleton, N. P., S. P. Willner, R. J. Rudy, and A. T. Tokunaga (1984), *Astrophysical Journal* **284**, 523.

Chambers, K. C., G. K. Miley, and W. van Breugel (1987), *Nature (London)* **329**, 604.

Chiaberge, M., A. Capetti, and A. Celotti (1999), *Astronomy and Astrophysics* **349**, 77, arXiv:astro-ph/9907064.

Chiaberge, M., A. Capetti, and A. Celotti (2002a), *Astronomy and Astrophysics* **394**, 791, arXiv:astro-ph/0207654.

Chiaberge, M., A. Celotti, A. Capetti, and G. Ghisellini (2000), *Astronomy and Astrophysics* **358**, 104, arXiv:astro-ph/0003197.

Chiaberge, M., R. Gilli, A. Capetti, and F. D. Macchetto (2003), *Astrophysical Journal* **597**, 166, arXiv:astro-ph/0307120.

Chiaberge, M., F. D. Macchetto, W. B. Sparks, A. Capetti, M. G. Allen, and A. R. Martel (2002b), *Astrophysical Journal* **571**, 247, arXiv:astro-ph/0202035.

Cid Fernandes, Jr., R., and R. Terlevich (1995), *Monthly Notices of the Royal Astronomical Society* **272**, 423.

Cimatti, A., A. Dey, W. van Breugel, R. Antonucci, and H. Spinrad (1996), *Astrophysical Journal* **465**, 145.
Cimatti, A., A. Dey, W. van Breugel, T. Hurt, and R. Antonucci (1997), *Astrophysical Journal* **476**, 677.
Cimatti, A., S. di Serego-Alighieri, R. A. E. Fosbury, M. Salvati, and D. Taylor (1993), *Monthly Notices of the Royal Astronomical Society* **264**, 421.
Cleary, K., C. R. Lawrence, J. A. Marshall, L. Hao, and D. Meier (2007), *Astrophysical Journal* **660**, 117, arXiv:astro-ph/0612702.
Cohen, M. H., P. M. Ogle, H. D. Tran, R. W. Goodrich, and J. S. Miller (1999), *The Astronomical Journal* **118**, 1963, arXiv:astro-ph/9909215.
Cohen, M. H., R. C. Vermeulen, P. M. Ogle, H. D. Tran, and R. W. Goodrich (1997), *Astrophysical Journal* **484**, 193, arXiv:astro-ph/9703177.
Cohen, R. D., and D. E. Osterbrock (1981), *Astrophysical Journal* **243**, 81.
Courvoisier, T. J.-L., and J. Clavel (1991), *Astronomy and Astrophysics* **248**, 389.
De Breuck, C., N. Seymour, D. Stern, S. P. Willner, P. R. M. Eisenhardt, G. G. Fazio, A. Galametz, M. Lacy, A. Rettura, B. Rocca-Volmerange, and J. Vernet (2010), *Astrophysical Journal* **725**, 36, arXiv:1010.1385 [astro-ph.CO].
de Vries, W. H., C. P. O'Dea, S. A. Baum, and P. D. Barthel (1999), *Astrophysical Journal* **526**, 27.
Dey, A. (1999), in *The Most Distant Radio Galaxies*, edited by H. J. A. Röttgering, P. N. Best, and M. D. Lehnert, p. 19, arXiv:astro-ph/9802163.
Dey, A., A. Cimatti, W. van Breugel, R. Antonucci, and H. Spinrad (1996), *Astrophysical Journal* **465**, 157, arXiv:astro-ph/9601099.
Dey, A., W. van Breugel, W. D. Vacca, and R. Antonucci (1997), *Astrophysical Journal* **490**, 698, arXiv:astro-ph/9707166.
di Serego Alighieri, S., A. Cimatti, R. A. E. Fosbury, and R. Hes (1997), *Astronomy and Astrophysics* **328**, 510, arXiv:astro-ph/9708205.
Dicken, D., C. Tadhunter, D. Axon, R. Morganti, K. J. Inskip, J. Holt, R. González Delgado, and B. Groves (2009), *Astrophysical Journal* **694**, 268, arXiv:0810.5675.
Dicken, D., C. Tadhunter, D. Axon, A. Robinson, R. Morganti, and P. Kharb (2010), *Astrophysical Journal* **722**, 1333, arXiv:1008.2719 [astro-ph.CO].
Donato, D., R. M. Sambruna, and M. Gliozzi (2004), *Astrophysical Journal* **617**, 915, arXiv:astro-ph/0408451.
Donoso, E., C. Li, G. Kauffmann, P. N. Best, and T. M. Heckman (2010), *Monthly Notices of the Royal Astronomical Society* **407**, 1078, arXiv:0910.3667 [astro-ph.CO].
Dopita, M. (1997), *Publications Astronomical Society of Australia* **14**, 230.
Draper, P. W., S. M. Scarrott, and C. N. Tadhunter (1993), *Monthly Notices of the Royal Astronomical Society* **262**, 1029.
Dunlop, J. S., and J. A. Peacock (1993), *Monthly Notices of the Royal Astronomical Society* **263**, 936.
Elitzur, M., and I. Shlosman (2006), *Astrophysical Journal Letters* **648**, L101, arXiv:astro-ph/0605686.
Esin, A. A., J. E. McClintock, and R. Narayan (1997), *Astrophysical Journal* **489**, 865, arXiv:astro-ph/9705237.
Evans, D. A., J. N. Reeves, M. J. Hardcastle, R. P. Kraft, J. C. Lee, and S. N. Virani (2010), *Astrophysical Journal* **710**, 859, arXiv:1001.0588 [astro-ph.CO].
Evans, D. A., D. M. Worrall, M. J. Hardcastle, R. P. Kraft, and M. Birkinshaw (2006), *Astrophysical Journal* **642**, 96, arXiv:astro-ph/0512600.
Falcke, H., Gopal-Krishna, and P. L. Biermann (1995), *Astronomy and Astrophysics* **298**, 395, arXiv:astro-ph/9411106.
Fanaroff, B. L., and J. M. Riley (1974), *Monthly Notices of the Royal Astronomical Society* **167**, 31P.
Fanti, C. (2009), Astronomische Nachrichten **330**, 120.
Fanti, C., R. Fanti, D. Dallacasa, R. T. Schilizzi, R. E. Spencer, and C. Stanghellini (1995),

Astronomy and Astrophysics **302**, 317.
Fanti, C., F. Pozzi, R. Fanti, S. A. Baum, C. P. O'Dea, M. Bremer, D. Dallacasa, H. Falcke, T. de Graauw, A. Marecki, G. Miley, H. Rottgering, R. T. Schilizzi, I. Snellen, R. E. Spencer, and C. Stanghellini (2000), *Astronomy and Astrophysics* **358**, 499, arXiv:astro-ph/0005035.
Filippenko, A. V., and J. P. Halpern (1984), *Astrophysical Journal* **285**, 458.
Garofalo, D., D. A. Evans, and R. M. Sambruna (2010), *Monthly Notices of the Royal Astronomical Society* **406**, 975, arXiv:1004.1166 [astro-ph.CO].
Garrington, S. T., C. F. Holmes, and D. J. Saikia (1996), in *Extragalactic Radio Sources*, IAU Symposium, Vol. 175, edited by R. D. Ekers, C. Fanti, and L. Padrielli, p. 397.
Garrington, S. T., J. P. Leahy, R. G. Conway, and R. A. Laing (1988), *Nature (London)* **331**, 147.
Gaskell, C. M., R. W. Goosmann, R. R. J. Antonucci, and D. H. Whysong (2004), *Astrophysical Journal* **616**, 147, arXiv:astro-ph/0309595.
Gaskell, C. M., E. S. Klimek, and L. S. Nazarova (2007), ArXiv e-prints arXiv:0711.1025.
Giovannini, G., W. D. Cotton, L. Feretti, L. Lara, and T. Venturi (2001), *Astrophysical Journal* **552**, 508, arXiv:astro-ph/0101096.
Giovannini, G., G. B. Taylor, L. Feretti, W. D. Cotton, L. Lara, and T. Venturi (2005), *Astrophysical Journal* **618**, 635, arXiv:astro-ph/0409624.
Giroletti, M. (2008), in *Extragalactic Jets: Theory and Observation from Radio to Gamma Ray*, Astronomical Society of the Pacific Conference Series, Vol. 386, edited by T. A. Rector and D. S. De Young, p. 176, arXiv:0707.3516.
Gliozzi, M., I. E. Papadakis, and R. M. Sambruna (2008), *Astrophysical Journal* **678**, 78, arXiv:0801.2104.
Goodrich, R. W., and J. S. Miller (1988), *Astrophysical Journal* **331**, 332.
Gopal-Krishna,, V. K. Kulkarni, and P. J. Wiita (1996), *Astrophysical Journal Letters* **463**, L1, arXiv:astro-ph/9603096.
Gower, A. C., and J. B. Hutchings (1984), *The Astronomical Journal* **89**, 1658.
Gu, Q., and J. Huang (2002), *Astrophysical Journal* **579**, 205.
Guainazzi, M., A. Siemiginowska, C. Stanghellini, P. Grandi, E. Piconcelli, and C. Azubike Ugwoke (2006), *Astronomy and Astrophysics* **446**, 87, arXiv:astro-ph/0509043.
Gupta, N., and D. J. Saikia (2006), *Monthly Notices of the Royal Astronomical Society* **370**, 738, arXiv:astro-ph/0605399.
Haas, M., R. Siebenmorgen, B. Schulz, E. Krügel, and R. Chini (2005), *Astronomy and Astrophysics* **442**, L39, arXiv:astro-ph/0509340.
Haas, M., S. P. Willner, F. Heymann, M. L. N. Ashby, G. G. Fazio, B. J. Wilkes, R. Chini, and R. Siebenmorgen (2008), *Astrophysical Journal* **688**, 122, arXiv:0807.3966.
Hardcastle, M. J., D. A. Evans, and J. H. Croston (2006), *Monthly Notices of the Royal Astronomical Society* **370**, 1893, arXiv:astro-ph/0603090.
Hardcastle, M. J., D. A. Evans, and J. H. Croston (2009), *Monthly Notices of the Royal Astronomical Society* **396**, 1929, arXiv:0904.1323 [astro-ph.GA].
Heckman, T., J. Krolik, G. Meurer, D. Calzetti, A. Kinney, A. Koratkar, C. Leitherer, C. Robert, and A. Wilson (1995), *Astrophysical Journal* **452**, 549.
Heckman, T. M. (1983), *Astrophysical Journal Letters* **271**, L5.
Heckman, T. M., C. P. O'Dea, S. A. Baum, and E. Laurikainen (1994), *Astrophysical Journal* **428**, 65.
Hine, R. G., and M. S. Longair (1979), *Monthly Notices of the Royal Astronomical Society* **188**, 111.
Ho, L. C. (1999), *Astrophysical Journal* **516**, 672, arXiv:astro-ph/9905012.
Ho, L. C. (2008), *Annual Review of Astronomy and Astrophysics* **46**, 475, arXiv:0803.2268.
Ho, L. C. (2009), *Astrophysical Journal* **699**, 626, arXiv:0906.4104 [astro-ph.GA].
Ho, L. C., A. V. Filippenko, and W. L. Sargent (1995), *Astrophysical Journal Supplement* **98**, 477.
Ho, L. C., A. V. Filippenko, W. L. W. Sargent, and C. Y. Peng (1997), *Astrophysical Journal*

Supplement **112**, 391, arXiv:astro-ph/9704099.
Hönig, S. F., C. Leipski, R. Antonucci, and M. Haas (2011), *Astrophysical Journal* **736**, 26, arXiv:1105.0429 [astro-ph.CO].
Hurt, T. (1996), Vistas in Astronomy **40**, 149.
Hurt, T., R. Antonucci, R. Cohen, A. Kinney, and J. Krolik (1999), *Astrophysical Journal* **514**, 579.
Ichimaru, S. (1977), *Astrophysical Journal* **214**, 840.
Impey, C. D., and G. Neugebauer (1988), *The Astronomical Journal* **95**, 307.
Jackson, C. A., and J. V. Wall (1999), *Monthly Notices of the Royal Astronomical Society* **304**, 160, arXiv:astro-ph/9808054.
Jennison, R. C., and M. K. Das Gupta (1953), *Nature (London)* **172**, 996.
Kaburaki, O., T. Nankou, N. Tamura, and K. Wajima (2010), *Publications of the Astronomical Society of Japan* **62**, 1177, arXiv:1008.0313 [astro-ph.CO].
Kay, L. E. (1994), *Astrophysical Journal* **430**, 196.
Keel, W. C. (1980), *The Astronomical Journal* **85**, 198.
Keel, W. C. (1983), *Astrophysical Journal* **269**, 466.
Keel, W. C., M. H. K. de Grijp, G. K. Miley, and W. Zheng (1994), *Astronomy and Astrophysics* **283**, 791.
Kishimoto, M. (1999), *Astrophysical Journal* **518**, 676, arXiv:astro-ph/9902346.
Kishimoto, M., R. Antonucci, and O. Blaes (2005), *Monthly Notices of the Royal Astronomical Society* **364**, 640, arXiv:astro-ph/0509341.
Kishimoto, M., R. Antonucci, O. Blaes, A. Lawrence, C. Boisson, M. Albrecht, and C. Leipski (2008), *Nature (London)* **454**, 492, arXiv:0807.3703.
Kishimoto, M., R. Antonucci, C. Boisson, and O. Blaes (2004), *Monthly Notices of the Royal Astronomical Society* **354**, 1065, arXiv:astro-ph/0408105.
Kishimoto, M., R. Antonucci, A. Cimatti, T. Hurt, A. Dey, W. van Breugel, and H. Spinrad (2001), *Astrophysical Journal* **547**, 667, arXiv:astro-ph/0010001.
Kishimoto, M., S. F. Hönig, T. Beckert, and G. Weigelt (2007), *Astronomy and Astrophysics* **476**, 713, arXiv:0709.0431.
Kishimoto, M., L. E. Kay, R. Antonucci, T. W. Hurt, R. D. Cohen, and J. H. Krolik (2002a), *Astrophysical Journal* **567**, 790, arXiv:astro-ph/0112520.
Kishimoto, M., L. E. Kay, R. Antonucci, T. W. Hurt, R. D. Cohen, and J. H. Krolik (2002b), *Astrophysical Journal* **565**, 155, arXiv:astro-ph/0110101.
Kollgaard, R. I., E. D. Feigelson, D. C. Gabuzda, and C. J. Lonsdale (1991), in *Bulletin of the American Astronomical Society*, Bulletin of the American Astronomical Society, Vol. 23, p. 1420.
Kollgaard, R. I., J. F. C. Wardle, D. H. Roberts, and D. C. Gabuzda (1992), *The Astronomical Journal* **104**, 1687.
Koratkar, A., and O. Blaes (1999), *Publications of the Astronomical Society of the Pacific* **111**, 1.
Kraft, R. P., M. Birkinshaw, M. J. Hardcastle, D. A. Evans, J. H. Croston, D. M. Worrall, and S. S. Murray (2007), *Astrophysical Journal* **659**, 1008, arXiv:astro-ph/0701458.
Krolik, J. H. (1999), *Active galactic nuclei : from the central black hole to the galactic environment /Julian H. Krolik. Princeton, N. J. : Princeton University Press, c1999.*
Kunert-Bajraszewska, M., and A. Labiano (2010), *Monthly Notices of the Royal Astronomical Society* **408**, 2279, arXiv:1009.5237 [astro-ph.CO].
Labiano, A., C. P. O'Dea, R. Gelderman, W. H. de Vries, D. J. Axon, P. D. Barthel, S. A. Baum, A. Capetti, R. Fanti, A. M. Koekemoer, R. Morganti, and C. N. Tadhunter (2005), *Astronomy and Astrophysics* **436**, 493, arXiv:astro-ph/0504330.
Laing, R. A. (1988), *Nature (London)* **331**, 149.
Laing, R. A., C. R. Jenkins, J. V. Wall, and S. W. Unger (1994), in *The Physics of Active Galaxies*, Astronomical Society of the Pacific Conference Series, Vol. 54, edited by G. V. Bicknell, M. A. Dopita, and P. J. Quinn, p. 201.
Laing, R. A., J. M. Riley, and M. S. Longair (1983), *Monthly Notices of the Royal Astro-*

nomical Society **204**, 151.
Laor, A., and S. W. Davis (2011), *Monthly Notices of the Royal Astronomical Society* **417**, 681.
Lawrence, A., and M. Elvis (1982), *Astrophysical Journal* **256**, 410.
Leipski, C., R. Antonucci, P. Ogle, and D. Whysong (2009), *Astrophysical Journal* **701**, 891, arXiv:0906.2152 [astro-ph.CO].
Leipski, C., M. Haas, S. P. Willner, M. L. N. Ashby, B. J. Wilkes, G. G. Fazio, R. Antonucci, P. Barthel, R. Chini, R. Siebenmorgen, P. Ogle, and F. Heymann (2010), *Astrophysical Journal* **717**, 766, arXiv:1007.0105 [astro-ph.CO].
Liuzzo, E., G. Giovannini, M. Giroletti, and G. B. Taylor (2009), *Astronomy and Astrophysics* **505**, 509, arXiv:0908.4391 [astro-ph.CO].
Lutz, D., R. Genzel, E. Sturm, L. Tacconi, E. Wieprecht, T. Alexander, H. Netzer, A. Sternberg, A. F. M. Moorwood, R. A. E. Fosbury, K. Fricke, S. J. Wagner, A. Quirrenbach, H. Awaki, and K. Y. Lo (2000), *Astrophysical Journal* **530**, 733, arXiv:astro-ph/9910101.
Maiolino, R., A. Marconi, and E. Oliva (2001a), *Astronomy and Astrophysics* **365**, 37, arXiv:astro-ph/0010066.
Maiolino, R., A. Marconi, M. Salvati, G. Risaliti, P. Severgnini, E. Oliva, F. La Franca, and L. Vanzi (2001b), *Astronomy and Astrophysics* **365**, 28, arXiv:astro-ph/0010009.
Maiolino, R., M. Salvati, A. Marconi, and R. R. J. Antonucci (2001c), *Astronomy and Astrophysics* **375**, 25, arXiv:astro-ph/0106192.
Maiolino, R., O. Shemmer, M. Imanishi, H. Netzer, E. Oliva, D. Lutz, and E. Sturm (2007), *Astronomy and Astrophysics* **468**, 979, arXiv:0704.1559.
Marchesini, D., A. Celotti, and L. Ferrarese (2004), *Monthly Notices of the Royal Astronomical Society* **351**, 733, arXiv:astro-ph/0403272.
Markowitz, A., T. Takahashi, S. Watanabe, K. Nakazawa, Y. Fukazawa, M. Kokubun, K. Makishima, H. Awaki, A. Bamba, N. Isobe, J. Kataoka, G. Madejski, R. Mushotzky, T. Okajima, A. Ptak, J. N. Reeves, Y. Ueda, T. Yamasaki, and T. Yaqoob (2007), *Astrophysical Journal* **665**, 209, arXiv:0704.3743.
Matt, G., S. Bianchi, M. Guainazzi, X. Barcons, and F. Panessa (2012), *Astronomy and Astrophysics* **540**, A111, arXiv:1204.0946 [astro-ph.HE].
McCarthy, P. J., W. van Breugel, H. Spinrad, and S. Djorgovski (1987), *Astrophysical Journal Letters* **321**, L29.
McLean, I. S., C. Aspin, S. R. Heathcote, and M. J. McCaughrean (1983), *Nature (London)* **304**, 609.
Meisenheimer, K., M. Haas, S. A. H. Müller, R. Chini, U. Klaas, and D. Lemke (2001), *Astronomy and Astrophysics* **372**, 719, arXiv:astro-ph/0102333.
Miley, G. K., and D. E. Osterbrock (1979), *Publications of the Astronomical Society of the Pacific* **91**, 257.
Miller, J. S. (1981), *Publications of the Astronomical Society of the Pacific* **93**, 681.
Miller, J. S., and R. R. J. Antonucci (1983), *Astrophysical Journal Letters* **271**, L7.
Miller, J. S., and H. B. French (1978), in *BL Lac Objects*, edited by A. M. Wolfe, pp. 228–232.
Molina, M., L. Bassani, A. Malizia, A. J. Bird, A. J. Dean, M. Fiocchi, F. Panessa, A. de Rosa, and R. Landi (2008), *Monthly Notices of the Royal Astronomical Society* **390**, 1217, arXiv:0809.0255.
Morganti, R., P. Parma, A. Capetti, R. Fanti, and H. R. de Ruiter (1997), *Astronomy and Astrophysics* **326**, 919.
Müller, S. A. H., M. Haas, R. Siebenmorgen, U. Klaas, K. Meisenheimer, R. Chini, and M. Albrecht (2004), *Astronomy and Astrophysics* **426**, L29, arXiv:astro-ph/0409719.
Netzer, H. (1985), *Monthly Notices of the Royal Astronomical Society* **216**, 63.
Noel-Storr, J., S. A. Baum, G. Verdoes Kleijn, R. P. van der Marel, C. P. O'Dea, P. T. de Zeeuw, and C. M. Carollo (2003), *Astrophysical Journal Supplement* **148**, 419, arXiv:astro-ph/0306043.
O'Dea, C. P. (1998), *Publications of the Astronomical Society of the Pacific* **110**, 493.

Ogle, P., R. Antonucci, P. N. Appleton, and D. Whysong (2007), *Astrophysical Journal* **668**, 699, arXiv:0707.0896.

Ogle, P., F. Boulanger, P. Guillard, D. A. Evans, R. Antonucci, P. N. Appleton, N. Nesvadba, and C. Leipski (2010), *Astrophysical Journal* **724**, 1193, arXiv:1009.4533 [astro-ph.CO].

Ogle, P., D. Whysong, and R. Antonucci (2006), *Astrophysical Journal* **647**, 161, arXiv:astro-ph/0601485.

Ogle, P. M., M. H. Cohen, J. S. Miller, H. D. Tran, R. A. E. Fosbury, and R. W. Goodrich (1997), *Astrophysical Journal Letters* **482**, L37, arXiv:astro-ph/9703153.

Ogle, P. M., S. W. Davis, R. R. J. Antonucci, J. W. Colbert, M. A. Malkan, M. J. Page, T. P. Sasseen, and M. Tornikoski (2005), *Astrophysical Journal* **618**, 139, arXiv:astro-ph/0408007.

Ogle, P. M., A. E. Wehrle, T. Balonek, and M. A. Gurwell (2011), *Astrophysical Journal Supplement* **195**, 19, arXiv:1003.3642 [astro-ph.CO].

Osterbrock, D. E., and G. J. Ferland (2006), *Astrophysics of gaseous nebulae and active galactic nuclei, 2nd. ed. by D.E. Osterbrock and G.J. Ferland. Sausalito, CA: University Science Books, 2006*.

Ostorero, L., R. Moderski, Ł. Stawarz, A. Diaferio, I. Kowalska, C. C. Cheung, J. Kataoka, M. C. Begelman, and S. J. Wagner (2010), *Astrophysical Journal* **715**, 1071, arXiv:0910.3611 [astro-ph.CO].

Ostriker, J. P., and M. Vietri (1985), *Nature (London)* **318**, 446.

Ostriker, J. P., and M. Vietri (1990), *Nature (London)* **344**, 45.

Owen, F. N., J. A. Eilek, and N. E. Kassim (2000), *Astrophysical Journal* **543**, 611, arXiv:astro-ph/0006150.

Owen, F. N., and M. J. Ledlow (1994), in *The Physics of Active Galaxies*, Astronomical Society of the Pacific Conference Series, Vol. 54, edited by G. V. Bicknell, M. A. Dopita, and P. J. Quinn, p. 319.

Packham, C., J. H. Hough, S. Young, A. Chrysostomou, J. A. Bailey, D. J. Axon, and M. J. Ward (1996), *Monthly Notices of the Royal Astronomical Society* **278**, 406.

Papadakis, I. E., Z. Ioannou, W. Brinkmann, and E. M. Xilouris (2008), *Astronomy and Astrophysics* **490**, 995, arXiv:0809.1750.

Pedelty, J. A., L. Rudnick, P. J. McCarthy, and H. Spinrad (1989), *The Astronomical Journal* **97**, 647.

Perlman, E. S., W. B. Sparks, J. Radomski, C. Packham, R. S. Fisher, R. Piña, and J. A. Biretta (2001), *Astrophysical Journal Letters* **561**, L51.

Pier, E. A., and J. H. Krolik (1992), *Astrophysical Journal* **401**, 99.

Pier, E. A., and J. H. Krolik (1993), *Astrophysical Journal* **418**, 673.

Pounds, K., and S. Vaughan (2006), *Monthly Notices of the Royal Astronomical Society* **368**, 707, arXiv:astro-ph/0602185.

Pringle, J. E. (1981), *Annual Review of Astronomy and Astrophysics* **19**, 137.

Pringle, J. E., R. R. J. Antonucci, C. J. Clarke, A. L. Kinney, H. R. Schmitt, and J. S. Ulvestad (1999), *Astrophysical Journal Letters* **526**, L9, arXiv:astro-ph/9909242.

Ramos Almeida, C., D. Dicken, C. Tadhunter, A. Asensio Ramos, K. J. Inskip, M. J. Hardcastle, and B. Mingo (2011), *Monthly Notices of the Royal Astronomical Society* **413**, 2358, arXiv:1101.1868 [astro-ph.CO].

Rawlings, S., and R. Saunders (1991), *Nature (London)* **349**, 138.

Rees, M. J., M. C. Begelman, R. D. Blandford, and E. S. Phinney (1982), *Nature (London)* **295**, 17.

Rinn, A. S., R. M. Sambruna, and M. Gliozzi (2005), *Astrophysical Journal* **621**, 167, arXiv:astro-ph/0410162.

Risaliti, G., E. Nardini, M. Salvati, M. Elvis, G. Fabbiano, R. Maiolino, P. Pietrini, and G. Torricelli-Ciamponi (2011), *Monthly Notices of the Royal Astronomical Society* **410**, 1027, arXiv:1008.5067 [astro-ph.CO].

Rudy, R. J., and G. D. Schmidt (1988), *Astrophysical Journal* **331**, 325.

Saikia, D. J., S. Jeyakumar, C. J. Salter, P. Thomasson, R. E. Spencer, and F. Man-

tovani (2001), *Monthly Notices of the Royal Astronomical Society* **321**, 37, arXiv:astro-ph/0009175.
Sambruna, R. M., J. N. Reeves, V. Braito, K. T. Lewis, M. Eracleous, M. Gliozzi, F. Tavecchio, D. R. Ballantyne, P. M. Ogle, A. J. Barth, and J. Tueller (2009), *Astrophysical Journal* **700**, 1473, arXiv:0906.0799 [astro-ph.HE].
Schmitt, H. R., R. R. J. Antonucci, J. S. Ulvestad, A. L. Kinney, C. J. Clarke, and J. E. Pringle (2001), *Astrophysical Journal* **555**, 663, arXiv:astro-ph/0103263.
Schmitt, H. R., J. L. Donley, R. R. J. Antonucci, J. B. Hutchings, A. L. Kinney, and J. E. Pringle (2003), *Astrophysical Journal* **597**, 768, arXiv:astro-ph/0307255.
Schreier, E. J., A. Capetti, F. Macchetto, W. B. Sparks, and H. J. Ford (1996), *Astrophysical Journal* **459**, 535.
Shapiro, S. L., A. P. Lightman, and D. M. Eardley (1976), *Astrophysical Journal* **204**, 187.
Shi, Y., G. H. Rieke, D. C. Hines, G. Neugebauer, M. Blaylock, J. Rigby, E. Egami, K. D. Gordon, and A. Alonso-Herrero (2005), *Astrophysical Journal* **629**, 88, arXiv:astro-ph/0504622.
Shu, X. W., T. Liu, and J. X. Wang (2010), *Astrophysical Journal* **722**, 96, arXiv:1008.1502 [astro-ph.HE].
Shuder, J. M. (1980), *Astrophysical Journal* **240**, 32.
Siebenmorgen, R., W. Freudling, E. Krügel, and M. Haas (2004), *Astronomy and Astrophysics* **421**, 129, arXiv:astro-ph/0404040.
Siemiginowska, A., S. LaMassa, T. L. Aldcroft, J. Bechtold, and M. Elvis (2008), *Astrophysical Journal* **684**, 811, arXiv:0804.1564.
Singal, A. K. (1993), *Monthly Notices of the Royal Astronomical Society* **262**, L27.
Solórzano-Iñarrea, C., P. N. Best, H. J. A. Röttgering, and A. Cimatti (2004), *Monthly Notices of the Royal Astronomical Society* **351**, 997, arXiv:astro-ph/0403390.
Stanghellini, C., C. P. O'Dea, D. Dallacasa, S. A. Baum, R. Fanti, and C. Fanti (1998), *Astronomy and Astrophysics Supplement* **131**, 303, arXiv:astro-ph/9803222.
Stawarz, Ł., L. Ostorero, M. C. Begelman, R. Moderski, J. Kataoka, and S. Wagner (2008), *Astrophysical Journal* **680**, 911, arXiv:0712.1220.
Stein, W. A. (1978), in *BL Lac Objects*, edited by A. M. Wolfe, pp. 1–19.
Stern, J., and A. Laor (2012), ArXiv e-prints arXiv:1207.5543 [astro-ph.CO].
Stockton, A., S. E. Ridgway, and S. J. Lilly (1994), *The Astronomical Journal* **108**, 414.
Storchi-Bergmann, T., J. S. Mulchaey, and A. S. Wilson (1992), *Astrophysical Journal Letters* **395**, L73.
Suganuma, M., Y. Yoshii, Y. Kobayashi, T. Minezaki, K. Enya, H. Tomita, T. Aoki, S. Koshida, and B. A. Peterson (2006), *Astrophysical Journal* **639**, 46, arXiv:astro-ph/0511697.
Tadhunter, C. (2005), in *Astronomical Polarimetry: Current Status and Future Directions*, Astronomical Society of the Pacific Conference Series, Vol. 343, edited by A. Adamson, C. Aspin, C. Davis, and T. Fujiyoshi, p. 457, arXiv:astro-ph/0501408.
Tadhunter, C. (2008), *New Astronomy Reviews* **52**, 227.
Tadhunter, C., R. Dickson, R. Morganti, T. G. Robinson, K. Wills, M. Villar-Martin, and M. Hughes (2002), *Monthly Notices of the Royal Astronomical Society* **330**, 977, arXiv:astro-ph/0201391.
Tadhunter, C. N., S. M. Scarrott, and C. D. Rolph (1990), *Monthly Notices of the Royal Astronomical Society* **246**, 163.
Tadhunter, C. N., W. Sparks, D. J. Axon, L. Bergeron, N. J. Jackson, C. Packham, J. H. Hough, A. Robinson, and S. Young (2000), *Monthly Notices of the Royal Astronomical Society* **313**, L52, arXiv:astro-ph/0002179.
Tazaki, F., Y. Ueda, Y. Ishino, S. Eguchi, N. Isobe, Y. Terashima, and R. F. Mushotzky (2010), *Astrophysical Journal* **721**, 1340, arXiv:1008.0722 [astro-ph.HE].
Tengstrand, O., M. Guainazzi, A. Siemiginowska, N. Fonseca Bonilla, A. Labiano, D. M. Worrall, P. Grandi, and E. Piconcelli (2009), *Astronomy and Astrophysics* **501**, 89, arXiv:0903.2444 [astro-ph.CO].

Thompson, I. B., and P. G. Martin (1988), *Astrophysical Journal* **330**, 121.
Tran, H. D. (1995), *Astrophysical Journal* **440**, 597.
Tran, H. D. (2003), *Astrophysical Journal* **583**, 632, arXiv:astro-ph/0210262.
Tran, H. D. (2010a), *Astrophysical Journal* **715**, 1591.
Tran, H. D. (2010b), *Astrophysical Journal* **711**, 1174, arXiv:1001.5318 [astro-ph.CO].
Tran, H. D., M. H. Cohen, and R. W. Goodrich (1995), *The Astronomical Journal* **110**, 2597.
Tran, H. D., M. H. Cohen, P. M. Ogle, R. W. Goodrich, and S. di Serego Alighieri (1998), *Astrophysical Journal* **500**, 660, arXiv:astro-ph/9801063.
Tran, H. D., J. E. Lyke, and J. A. Mader (2011), *Astrophysical Journal Letters* **726**, L21, arXiv:1012.1865 [astro-ph.CO].
Trussoni, E., A. Capetti, and B. Balmaverde (2007), in *The Central Engine of Active Galactic Nuclei*, Astronomical Society of the Pacific Conference Series, Vol. 373, edited by L. C. Ho and J.-W. Wang, p. 223.
Ulvestad, J. S., and R. R. J. Antonucci (1988), *Astrophysical Journal* **328**, 569.
Urry, C. M., and P. Padovani (1995), *Publications of the Astronomical Society of the Pacific* **107**, 803, arXiv:astro-ph/9506063.
Uttley, P., and I. M. McHardy (2005), *Monthly Notices of the Royal Astronomical Society* **363**, 586.
Valencia-S., M., J. Zuther, A. Eckart, M. García-Marín, C. Iserlohe, and G. Wright (2012), *Astronomy and Astrophysics* **544**, A129, arXiv:1203.6063 [astro-ph.CO].
van Bemmel, I., and P. Barthel (2001), *Astronomy and Astrophysics* **379**, L21, arXiv:astro-ph/0109510.
van Bemmel, I. M., F. D. Macchetto, and M. Chiaberge (2004), in *The Interplay Among Black Holes, Stars and ISM in Galactic Nuclei*, IAU Symposium, Vol. 222, edited by T. Storchi-Bergmann, L. C. Ho, and H. R. Schmitt, pp. 75–76.
van der Wolk, G., P. D. Barthel, R. F. Peletier, and J. W. Pel (2010), *Astronomy and Astrophysics* **511**, A64, arXiv:0911.3734 [astro-ph.GA].
Varano, S., M. Chiaberge, F. D. Macchetto, and A. Capetti (2004), *Astronomy and Astrophysics* **428**, 401, arXiv:astro-ph/0407307.
Veilleux, S., and D. E. Osterbrock (1987), *Astrophysical Journal Supplement* **63**, 295.
Verdoes Kleijn, G. A., S. A. Baum, P. T. de Zeeuw, and C. P. O'Dea (2002), *The Astronomical Journal* **123**, 1334, arXiv:astro-ph/0112356.
Vermeulen, R. C., P. M. Ogle, H. D. Tran, I. W. A. Browne, M. H. Cohen, A. C. S. Readhead, G. B. Taylor, and R. W. Goodrich (1995), *Astrophysical Journal Letters* **452**, L5.
Vernet, J., R. A. E. Fosbury, M. Villar-Martín, M. H. Cohen, A. Cimatti, S. di Serego Alighieri, and R. W. Goodrich (2001), *Astronomy and Astrophysics* **366**, 7, arXiv:astro-ph/0010640.
Whysong, D., and R. Antonucci (2004), *Astrophysical Journal* **602**, 116, arXiv:astro-ph/0207385.
Whysong, D. H. (2005), *Accretion modes and unified schemes for FR-II radio galaxies*, Ph.D. thesis (University of California, Santa Barbara, California, USA).
Wilkes, B., J. Kuraszkiewicz, M. Haas, S. P. Willner, M. Ashby, M. Yellen, C. Leipski, R. Antonucci, P. Barthel, M. Birkinshaw, R. Chini, G. G. Fazio, F. Heymann, C. R. Lawrence, P. Ogle, B. Schulz, and D. M. Worrall (2009), in *Chandra's First Decade of Discovery*, edited by S. Wolk, A. Fruscione, and D. Swartz.
Willett, K. W., J. T. Stocke, J. Darling, and E. S. Perlman (2010), *Astrophysical Journal* **713**, 1393, arXiv:1004.0952 [astro-ph.HE].
Wills, B. J. (1999), in *Quasars and Cosmology*, Astronomical Society of the Pacific Conference Series, Vol. 162, edited by G. Ferland and J. Baldwin, p. 101, arXiv:astro-ph/9905093.
Wills, K. A., R. Morganti, C. N. Tadhunter, T. G. Robinson, and M. Villar-Martin (2004), *Monthly Notices of the Royal Astronomical Society* **347**, 771, arXiv:astro-ph/0310256.
Young, S., J. H. Hough, D. J. Axon, A. C. Fabian, and M. J. Ward (1998), *Monthly Notices of the Royal Astronomical Society* **294**, 478.

Young, S., J. H. Hough, A. Efstathiou, B. J. Wills, D. J. Axon, J. A. Bailey, and M. J. Ward (1996), *Monthly Notices of the Royal Astronomical Society* **279**, L72.
Zezas, A., M. Birkinshaw, D. M. Worrall, A. Peters, and G. Fabbiano (2005), *Astrophysical Journal* **627**, 711.
Zirbel, E. L., and S. A. Baum (1995), *Astrophysical Journal* **448**, 521.
Zirbel, E. L., and S. A. Baum (1998), *Astrophysical Journal Supplement* **114**, 177.
Zirbel, E. L., and S. A. Baum (2003), *The Astronomical Journal* **125**, 1795.