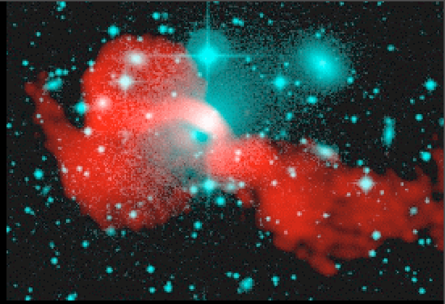

Unobscured AGN through cosmic time

Or, what radio galaxy populations tell us about accretion modes

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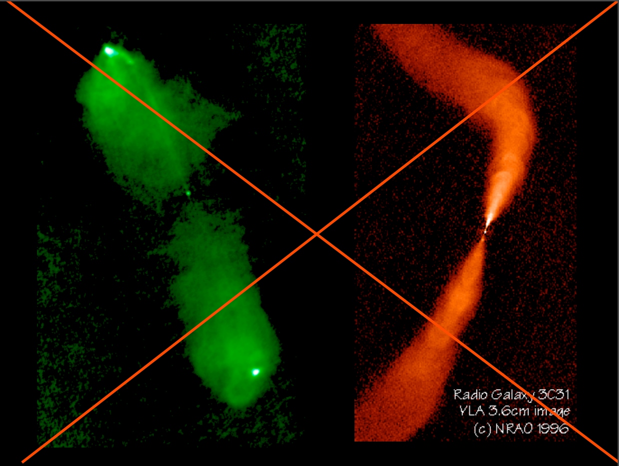
Seeon, June 2007

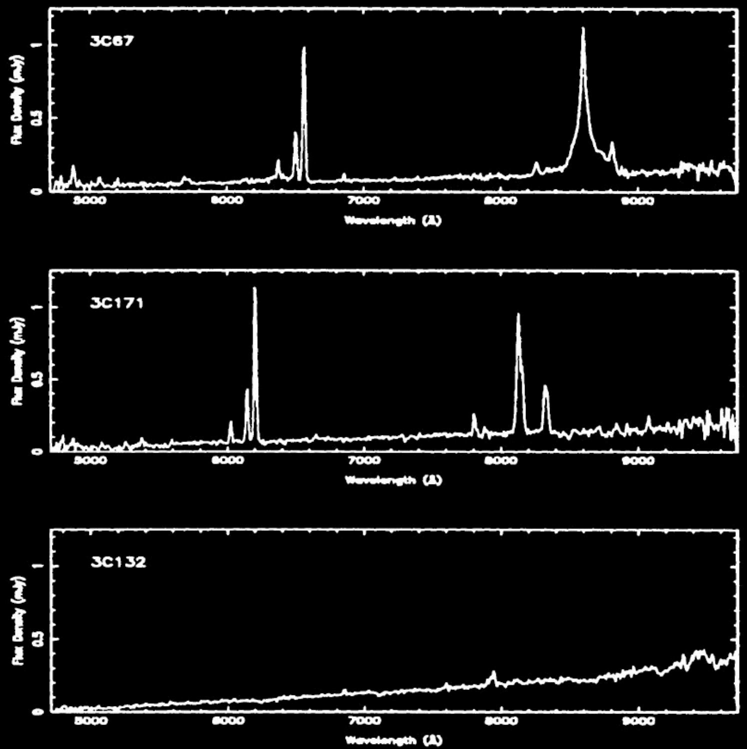
Synopsis

- From a nuclear perspective there are two types of radio-loud AGN – which do *not* map on to the FRI/FRII division. If we want to study the evolution of RL AGN populations, the nuclear, not large-scale radio, properties are what we should focus on.
- It is possible that this dichotomy represents a difference in accretion mode *governed by the nature of what is accreted*. If true, this has a number of interesting consequences.

LERGs



- Radio galaxies' optical spectra can be classed as 'Low-excitation' vs 'High Excitation' (Hine & Longair 79; Laing et al 94; Jackson & Rawlings 97). Based on strength of high-excitation lines like [OIII].
- *Most FRIs are low-excitation* and *most FRIs high-excitation* – but substantial overlap.



BLRG

NLRG

LERG

(all FRIIs)

Laing et al 94

LERGs and unification

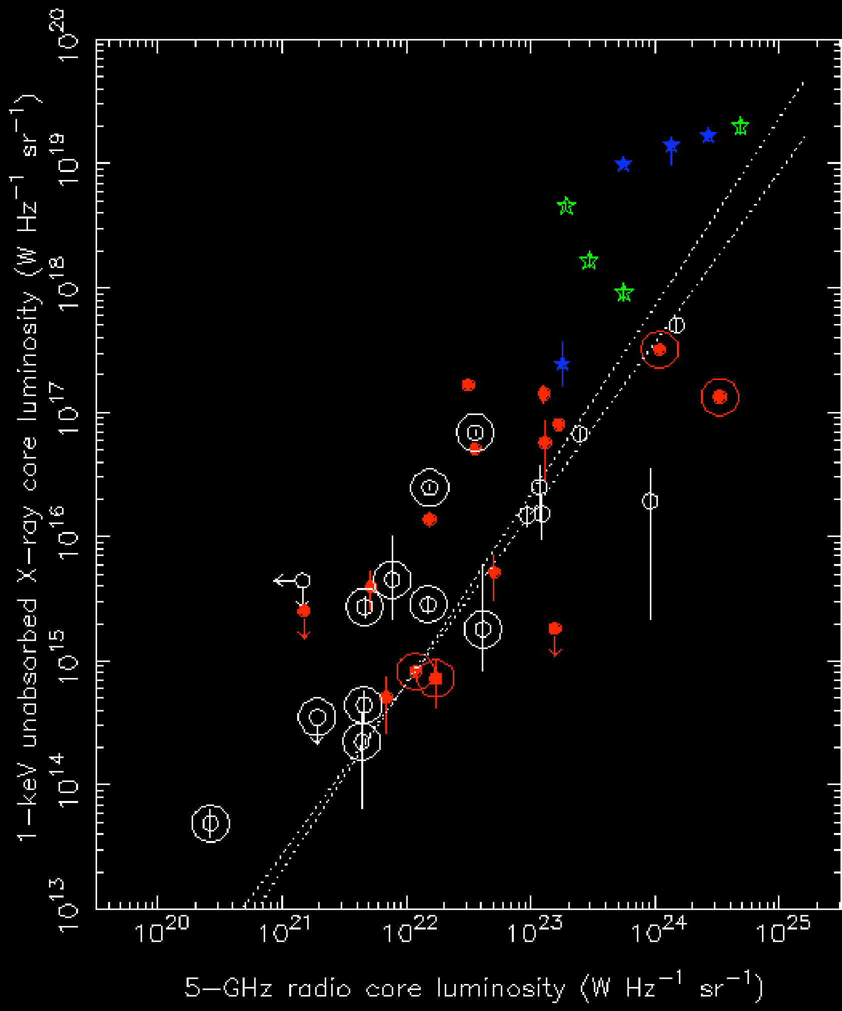
- NLRG can be unified with quasars – narrow-line properties consistent. Standard Barthel 1989 US.
- BLRG basically *are* low-luminosity quasars, MJH et al 98 (in some cases: may be transitional objects in others)
- LERG *cannot* unify with quasars since NLR cannot be hidden => beamed versions of LERG must be lineless, e.g. BL Lac objects.
- FRI and (probably) LERG FRII unification with BL Lac objects, which are lineless, is part of standard picture (e.g. Browne 83; Urry & Padovani 95; MJH et al 03)
- LERG FRIIs have other distinctive properties in the radio (MJH et al 98) and in terms of environments (MJH 04).
- But why are the nuclear emission lines of these systems so different? Look at other properties to find out…

The X-ray view of radio galaxy nuclei

- In the standard AGN picture, accretion discs => optical/ UV continua, photoionization of BLR and NLR, X-rays from corona.
- In sources (e.g. quasars) where we see the accretion disc directly we see strong ~ power-law X-ray emission.
- In sources where the accretion disc is obscured by the torus the corona is too => we see photoelectric absorption of the X-rays, removing the soft X-ray emission.
- => any RG unified with a quasar/BLRG should have a heavily obscured nuclear X-ray component (Seyfert 2/ quasar 2).
- Early results on hard X-rays from NLRG bear this out (e.g. Cyg A, Ueno et al 1994).

X-rays from the nuclear jet

- At the same time, ROSAT and Chandra work has shown that an *unabsorbed* power-law component is present in nearly all RGs.
- Correlation between radio, optical, and X-ray cores => jet origin (from outside torus if present).
- FRIs, NLRG and LERG FRIIs lie on *same* correlation
- Quasars and BLRG lie above it (we see additional unabsorbed accretion-disc related emission).
- (This component is required for unification with BL Lacs to work, so no surprise!)

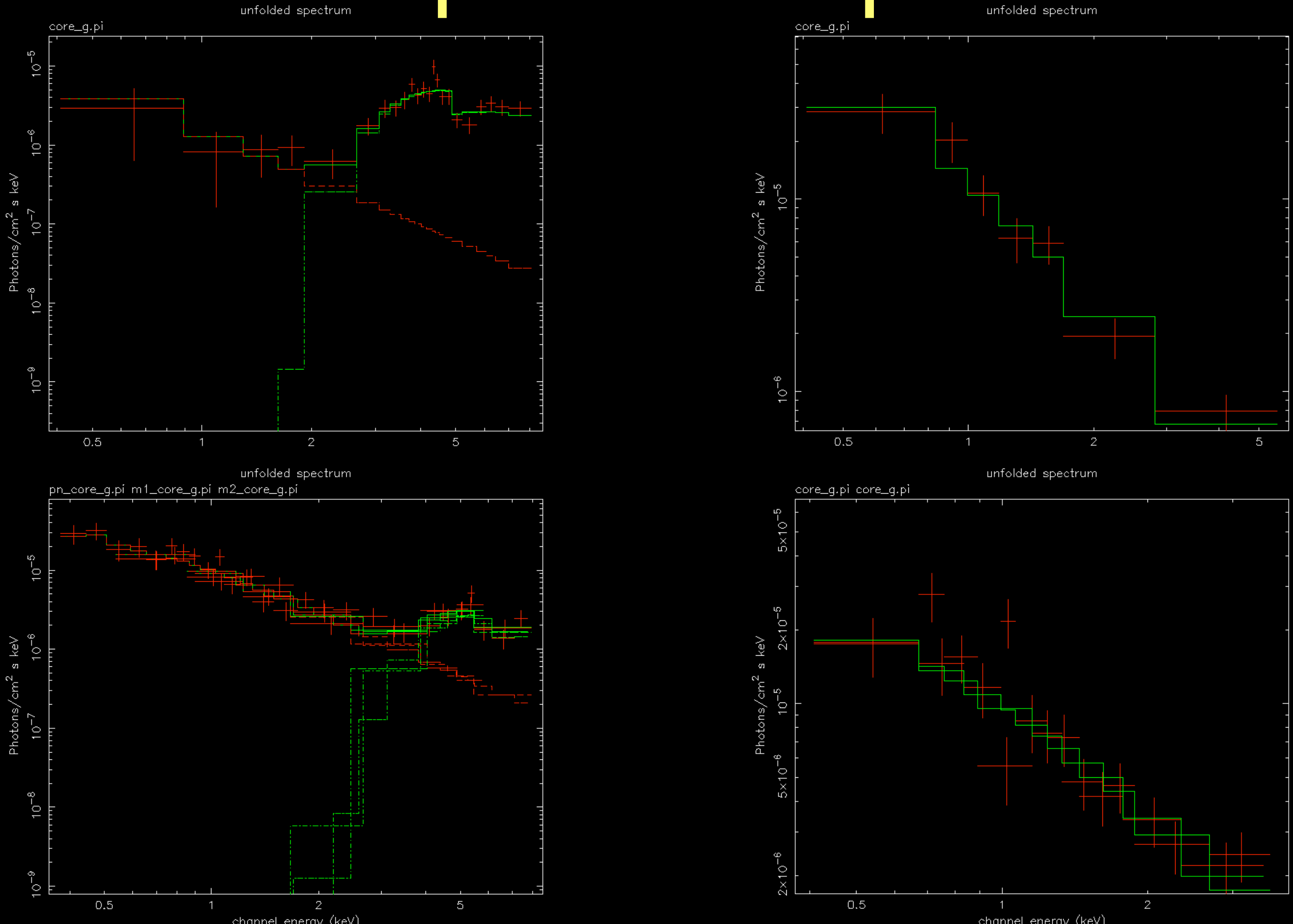


Unabs. X-ray/radio core correlation (MJH et al 06)

Search for absorbed X-rays

- Absorbed X-rays in radio galaxies tell us whether there is a nuclear X-ray component obscured by a torus, which would be a signature of an accretion disc.
- We need to look for absorbed X-rays in a sample containing significant numbers of both low-excitation and high-excitation objects and both FRIs and FRIIs.
- Archival XMM and Chandra data on the well-studied 3CRR sample (Laing, Riley & Longair 83) with $z<0.5$
- Original work on $z<0.1$ done by Dan Evans as part of thesis project (Evans et al 06)
- Now extended to $z<0.5$ (MJH et al 06).
- 41 sources in sample (47% total)

Example FRII spectra



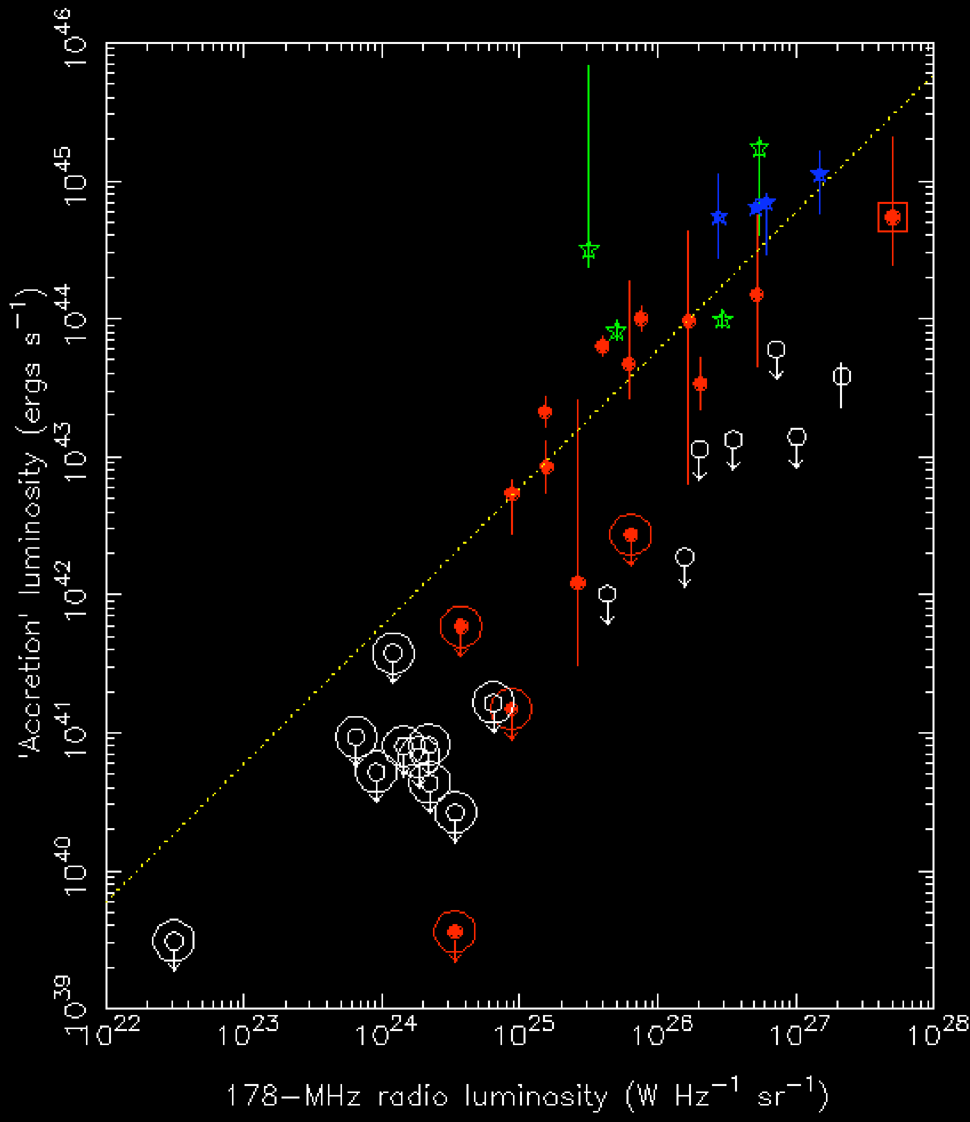
NLRG

LERG

Sample results

- All of the NLRG FRIIs show evidence for an absorbed nuclear component with $N_H \sim 10^{23}$ cm^{-2} – as expected if all have tori + large angle to LOS
- BLRG and quasars generally unabsorbed.
- Almost all the FRIs and LERG FRIIs show no evidence for an absorbed component (exceptions are debatably classed as LERG) although all show the jet-related, unabsorbed component.
- We can put upper limits on the absorbed, ‘accretion-related’ luminosity.

Luminosities



White = LERG
Red = NLRG
Green = BLRG
Blue = quasar

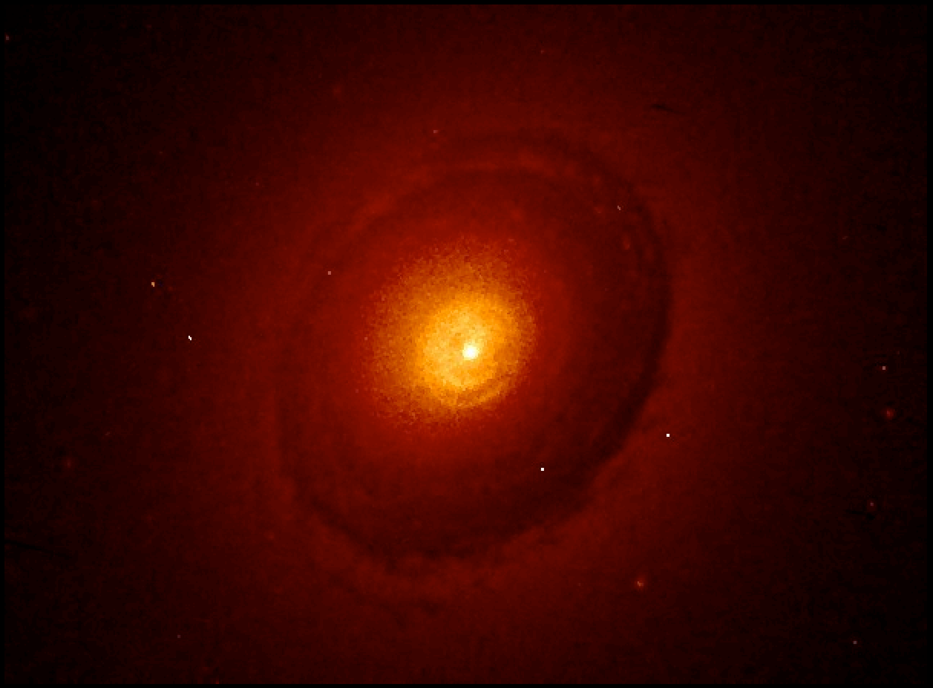
Circle => FRI

Line goes through FRII NLRG

Limits assume $N_H = 10^{23}$ cm^{-2}

Interpretation

- In the X-ray LERGs have no evidence for an obscured AGN component.
- In the optical they show optical jet-related emission, again with no evidence for any hidden AGN (Chiaberge et al 02, Varano et al 04).
- In the IR they show no evidence for obscured nuclei either (e.g. Whysong & Antonucci, Ogle et al)

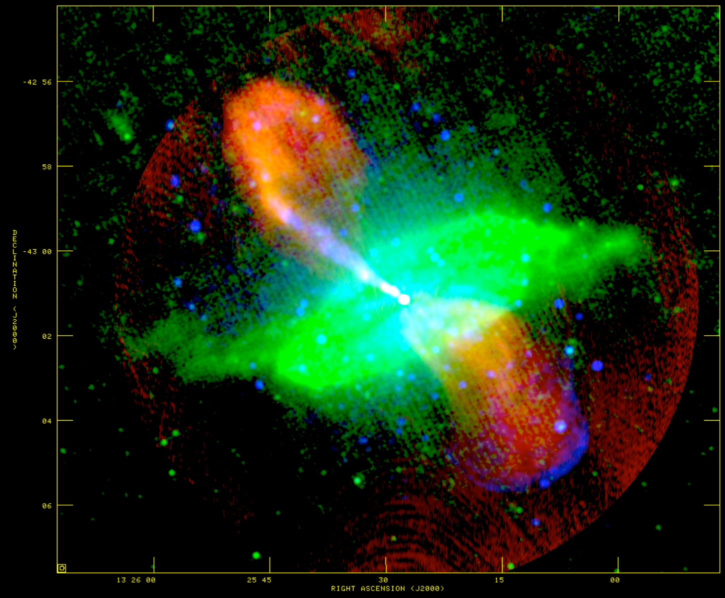


Interpretation

- The simplest picture is that we don't see any evidence for an obscured AGN because it isn't there.
- What we see is what we get in LERGs – and it does not include a radiatively efficient AGN.
- This of course explains the lack of high-excitation photoionized NLR material too. (What narrow lines there are in LERG may be photoionized by the jet itself.)

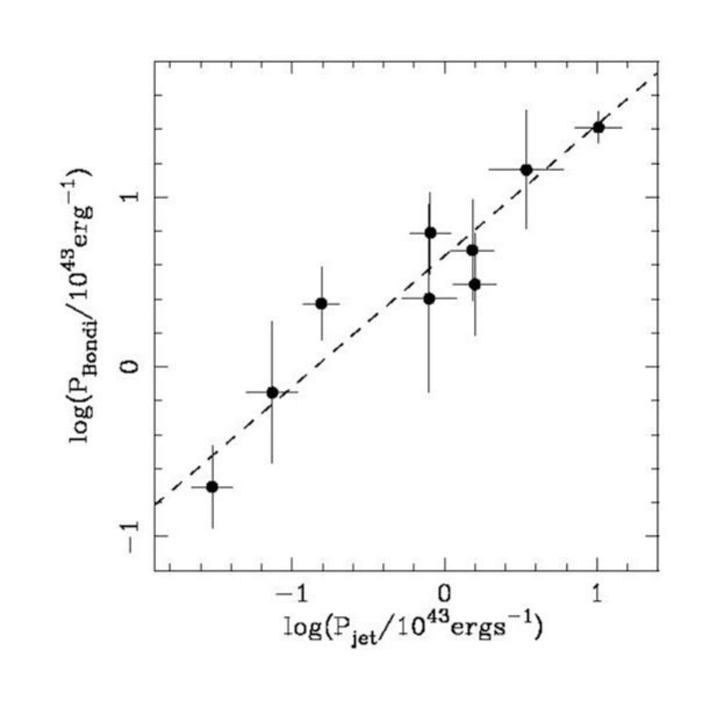
Reminder

- This is not the FRI/FRII dichotomy.
- FRIs *can* have heavily obscured relatively luminous AGN (e.g. Cen A).
- Our most luminous LERGs appear as fairly normal FRIIs morphologically.
- *Both types of nucleus can produce both types of radio morphology – a strong suggestion that morphology is not intrinsic to the AGN.*



Origin of the dichotomy

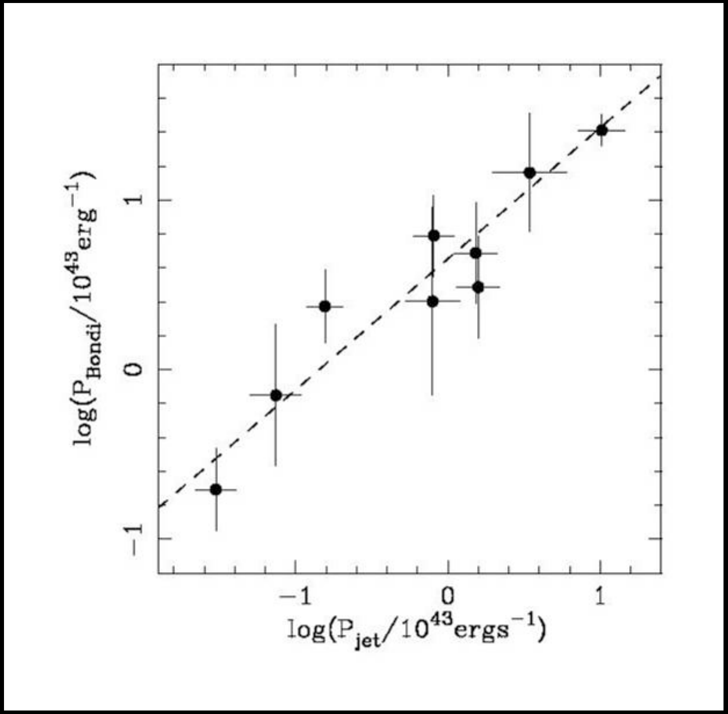
- There are two obvious sources of gas for AGN to accrete: cold neutral material and the hot, X-ray emitting phase of the IGM.
- Allen et al 06 have shown that accretion from the hot phase (shorthand – Bondi accretion) can power nearby low-luminosity objects.
- Best et al 06 argue that Bondi accretion can explain the observed tendency of low-power radio sources to favour massive host galaxies.



Bondi accretion vs. jet power in nearby cluster-centre radio galaxies (Allen et al 06)

Origin of the dichotomy

- Hot-mode accretion would not form a conventional accretion disc – disc, torus and NLR/BLR require a cold fuel supply. It could therefore be radiatively efficient, as we require.
- Could all LERG be powered by 'hot-mode' accretion and all HERG by 'cold-mode'?



Bondi accretion vs. jet power in nearby cluster-centre radio galaxies (Allen et al 06)

Testing hot-mode accretion model

- Bondi accretion is spherically symmetric – not realistic in many situations but possibly the centres of giant ellipticals are better than most.
- Bondi accretion rate is given by

$$\dot{M} = \pi \lambda c_{\rm s} \rho_{\rm A} r_{\rm A}^2$$

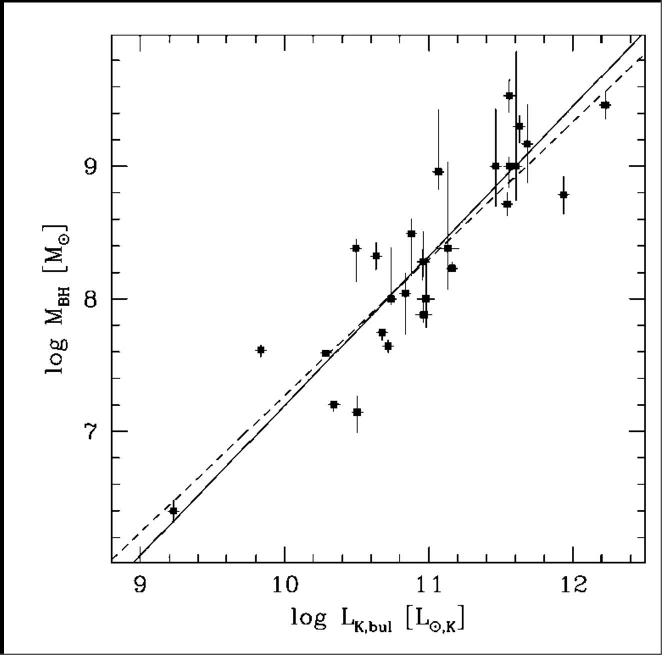
where the accretion radius is

$$r_{\rm A} = \frac{2GM_{\rm BH}}{c_s^3}$$

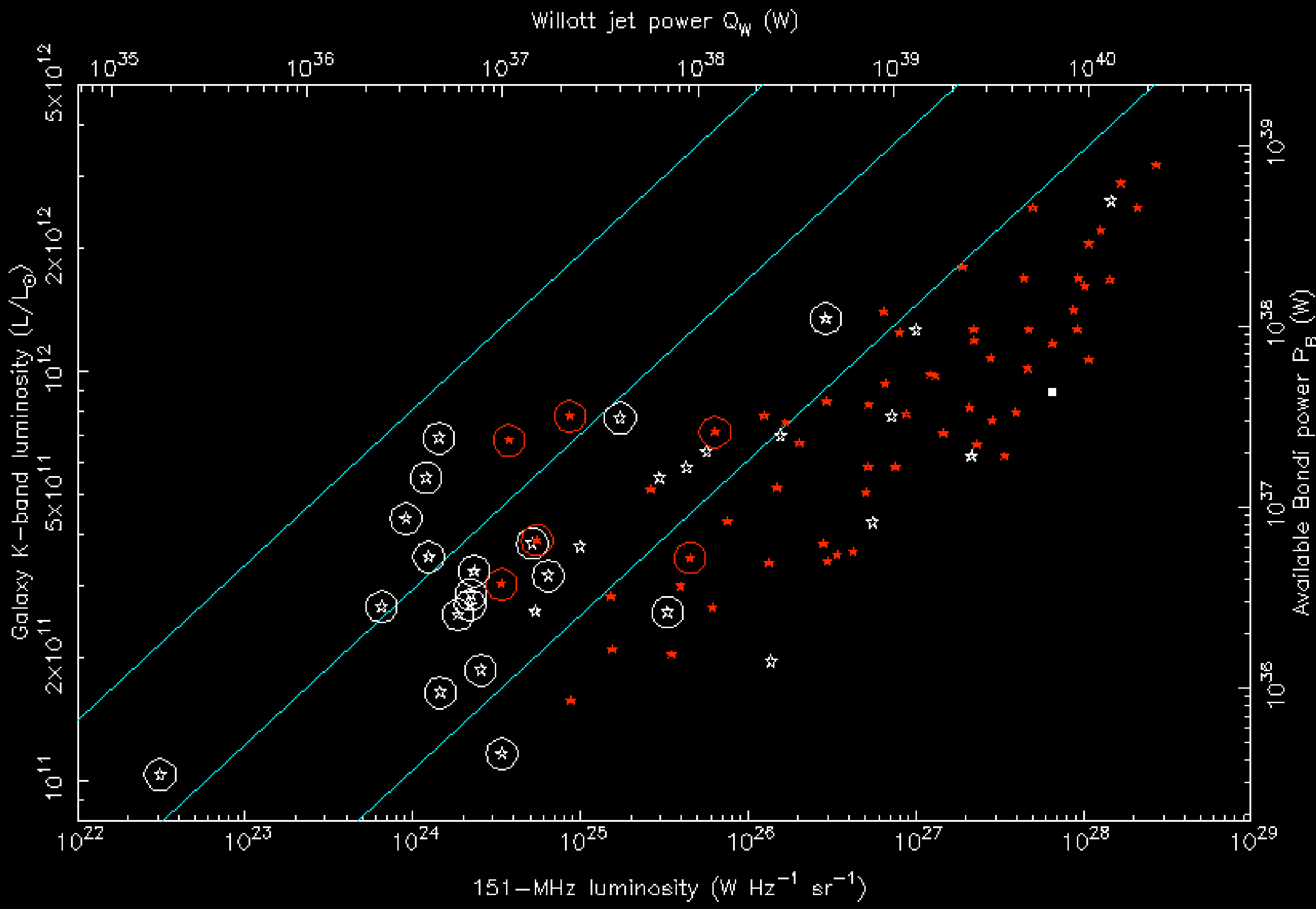
so we need black hole mass and central physical conditions, and compare with jet power.

Bondi estimates

- Black hole mass from galaxy K-band luminosity – dominant source of scatter
- Central parameters of the hot phase from observations of nearby FRIs
- Jet power from the Willott et al 1999 relation normalized using known jet powers of low-luminosity objects.



Bondi rates

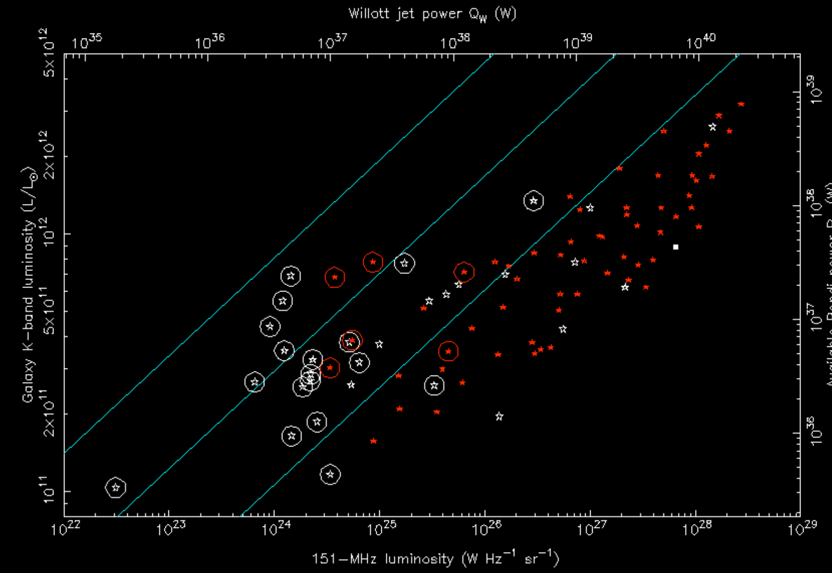


Bondi rates for 3CRR sources assuming f = 10, central electron density 5 x 10^5 m^{-3}, central temp 0.7 keV, and Bondi accretion efficiency 0.1.

White points are low-excitation radio galaxies, red points are NLRG. Circles show FRIs.

Bondi rates

- We see that
  - The FRI sources (circled) lie close to the line(s) of equality.
  - Many LERG FRIIs lie close to the line too
  - The majority of FRII NLRG are a long way away from being able to be powered by hot-mode accretion, *if parameters used are correct.*
  - (All plausible corrections to environmental parameters move NLRG away from line and LERG FRIIS towards it.)

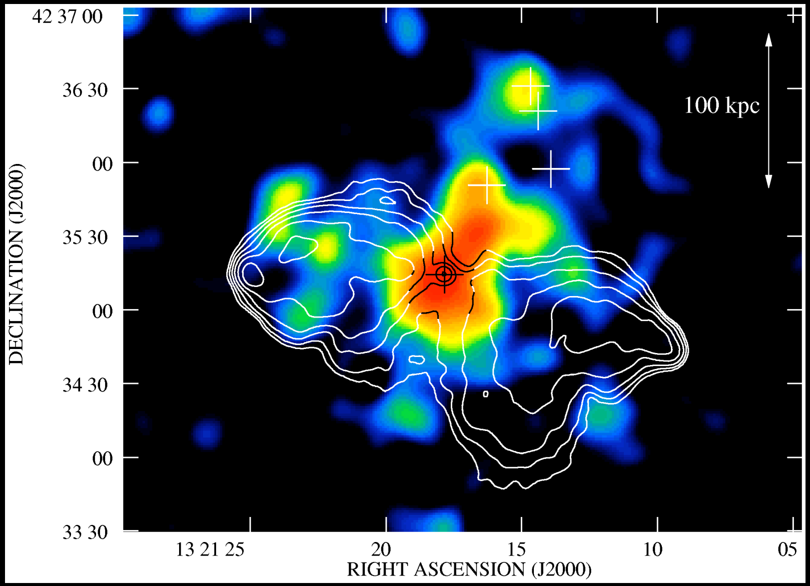


Consequences

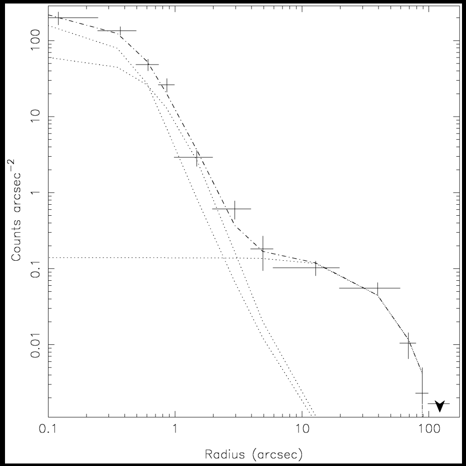
- It's possible that all low-excitation radio-loud AGN (i.e. the vast majority of nearby low-power sources) are powered by hot-mode accretion.
- It's almost certainly impossible that the high-excitation objects (including most powerful FRIIs) get their energy this way – probably powered by cold-mode instead.
- Let's suppose this is true, what follows?

Consequences: Feedback

- True 'feedback' between AGN and hot phase *requires the AGN to be controlled by the hot phase*.
- Only directly possible in hot mode.
- In cold mode accretion the radio source can blow away its atmosphere without affecting its fuel supply.
- Consistent with observations of FRIIs in poor environments which show work done/energy stored comparable to total thermal energy of atmosphere.



Environment of the nearby NLRG FRII 3C285 (MJH et al 2007 ApJ in press.)

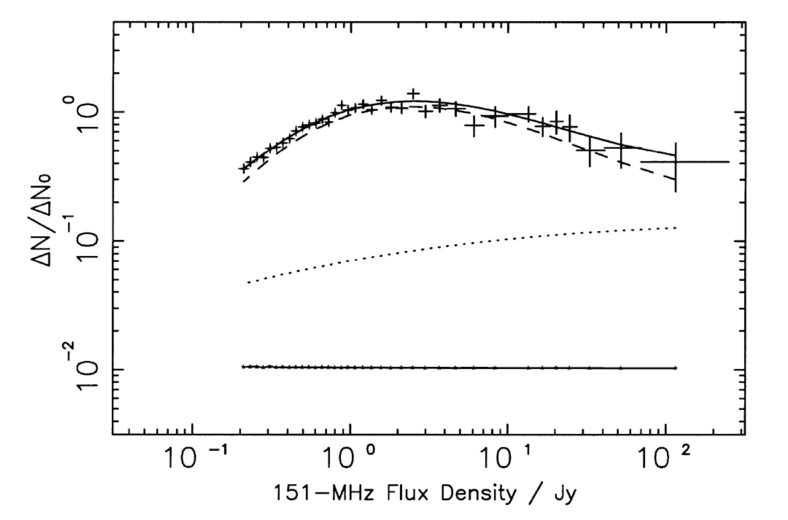


Consequences: environments

- Hot-mode sources need massive central black holes and a good supply of hot gas – they will tend to inhabit the most massive galaxies in relatively rich environments (cf Best et al 06) as observed (Longair & Seldner 79, Prestage & Peacock 88, Owen & White 91, &c).
- Cold-mode sources' power comes from accretion of cold mass and is independent of black hole mass (modulo Eddington limit): so they can inhabit poorer systems, as observed (P&P 88, &c). Cold gas required => merger with gas-rich system (for ellipticals) => merger signatures in high-excitation sources, as observed (e.g. Heckman et al 86).
- *Qualitatively* good agreement with known facts.

Consequences: evolution

- Since the conditions for hot-mode and cold-mode accretion *evolve differently with cosmic time*, we might expect to see differences in the evolution of the populations.
- Will show up as differences in the evolution of low- and high-luminosity sources if accretion mode is not taken into account.
- Evolution models should separate LERG and HERG populations, not FRI and FRII.



Fits of a dual-population model to 151-MHz source counts (Jackson & Wall 99). Dotted line from FRI population, dashed from FRII.

Consequences: jets (or not)

- Hot-mode and cold-mode sources must produce jets which are similar on the pc scale. (The FRI/FRII dichotomy in our picture is due to interaction with the environment, not intrinsic.)
- There are radio-quiet cold-mode sources (RQQ and Seyferts).
- Do all hot-mode sources make jets, or are there radio-quiet hot-mode sources? If so, they will be very hard to detect, but they could have a significant effect on the black-hole mass function at the high end.