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Accretion modes and feedback in radio-loud AGN

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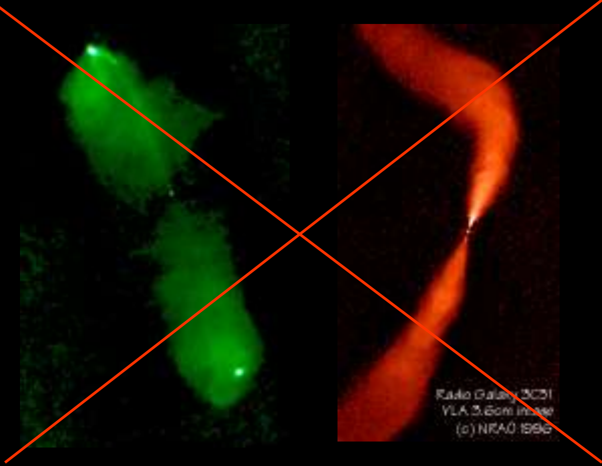
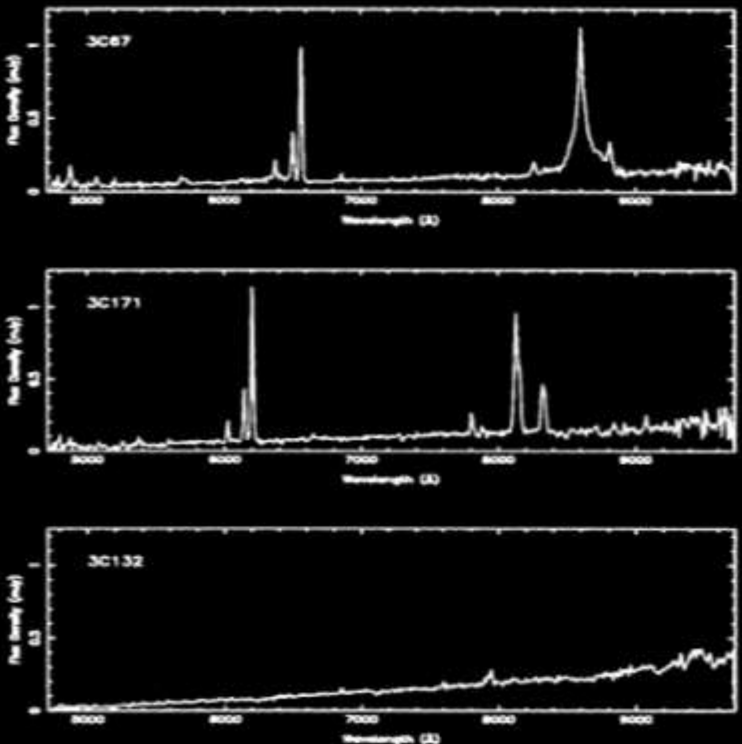
Overview

- The puzzle of LERGs
- Unified models and X-ray emission
- The X-ray properties of radio galaxy nuclei
- Invisible or Compton-thick? The multi-wavelength view
- Accretion modes and accretion origin
- Consequences for feedback



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 FRIIs high-excitation* – but substantial overlap.



BLRG

NLRG

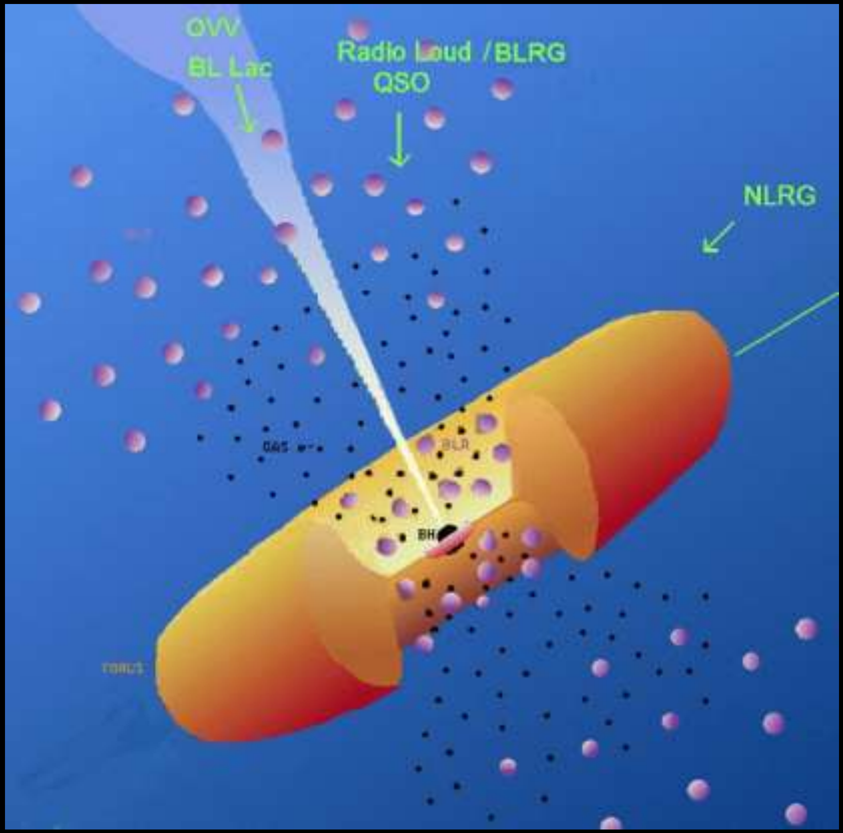
LERG

(all FRIIs)

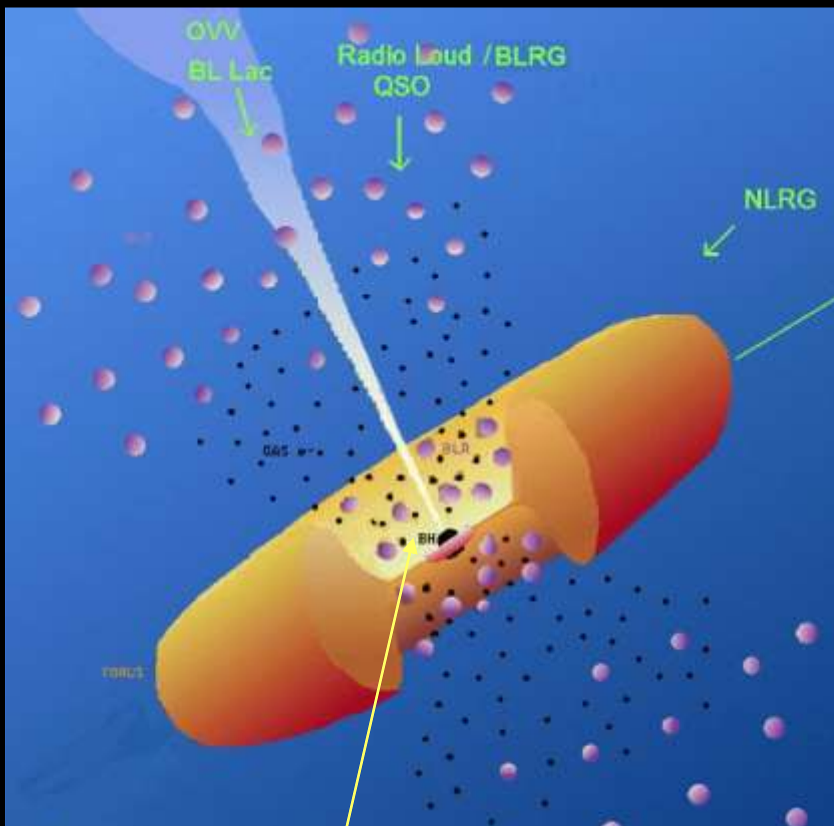
Laing et al 94

LERGs and unification

- NLRG can be unified with quasars/BLRG – narrow-line properties consistent. Standard Barthel 1989 US (w BLRG as weak quasars per MJH et al 98).
- LERG *cannot* unify with quasars/BLRG since NLR cannot be hidden => beamed versions of LERG must be lineless, e.g. BL Lac objects.
- FRI and (probably) LERG FRIIs unify with BL Lacs – part of standard picture (e.g. Browne 83; Urry & Padovani 95; MJH et al 03)
- But **why** are the nuclear emission lines of these systems so different? Look at other properties to find out…

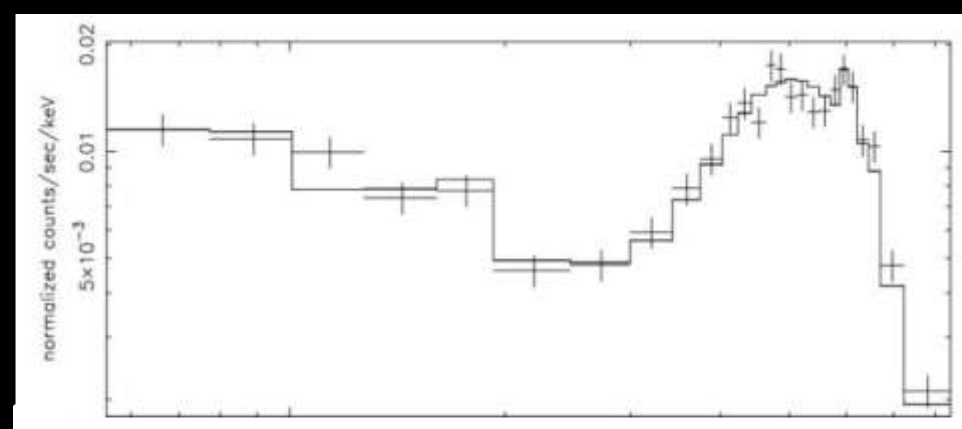


The X-ray view of radio galaxy nuclei



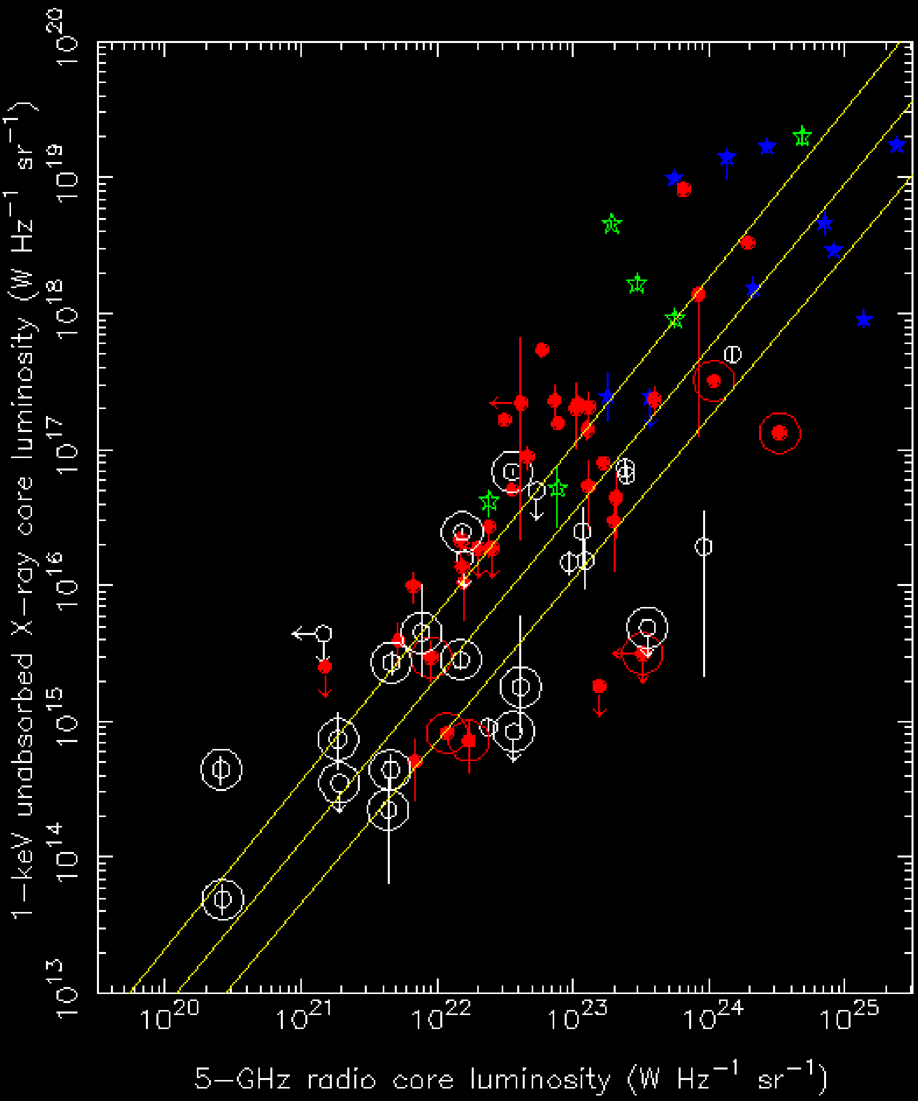
X-ray source

Torus obscures ‘coronal’ X-ray emission from nucleus => narrow-line radio galaxies should have heavily absorbed nuclei, as shown by early hard X-ray results (e.g. Ueno et al 1994)



X-rays from the nuclear jet

- Soft X-ray work (Feigelson et al 1984; Worrall & Birkinshaw 1994; Edge & Röttgering 1995; MJH & Worrall 1999...); 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).
- (Required for unification with BL Lacs to work, so no surprise!)

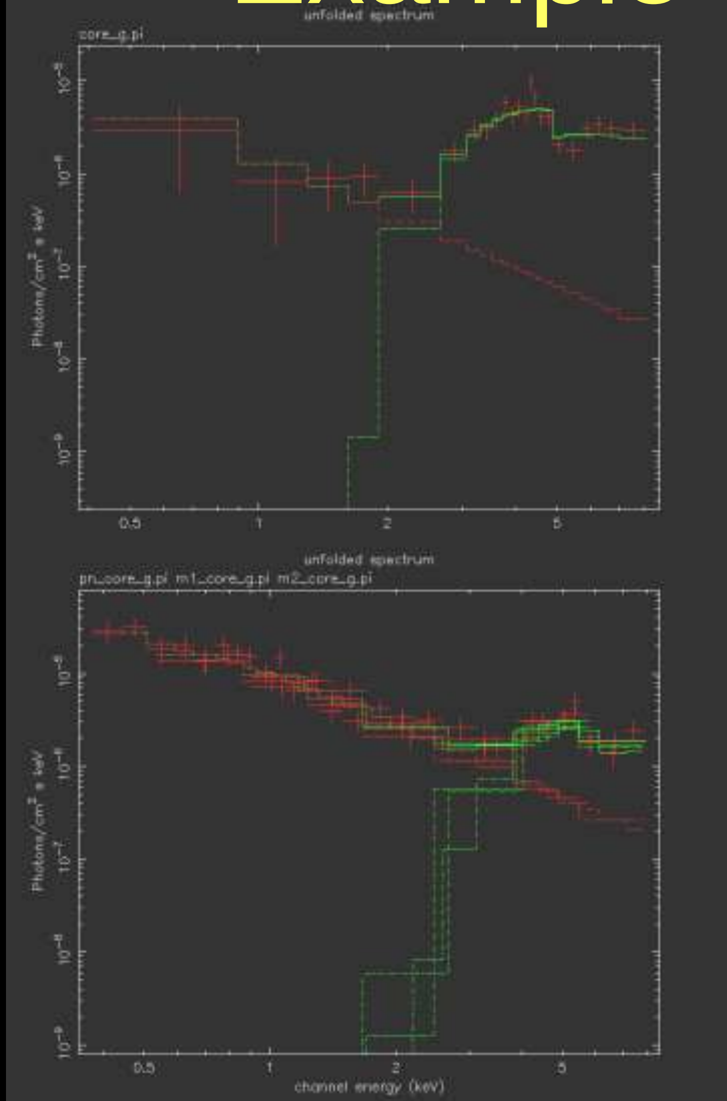


Unabs. X-ray/radio core correlation (updated from MJH et al 06)

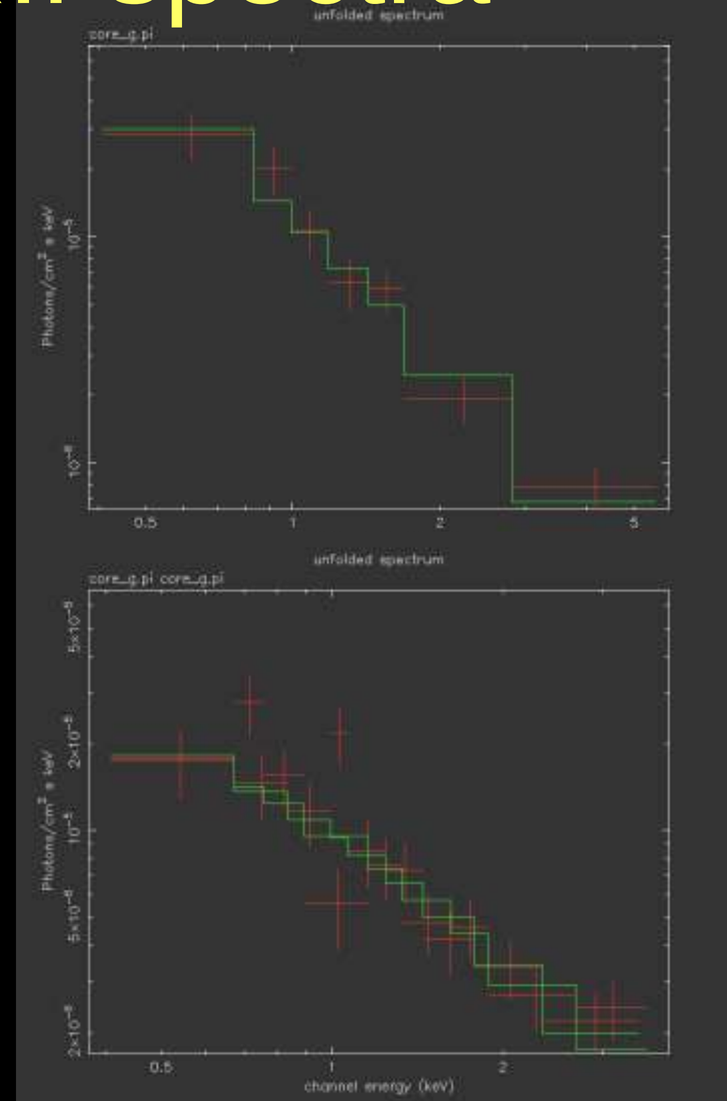
Search for absorbed X-rays

- What classes of objects have X-ray evidence for an obscuring torus?
- 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 on 3CRR sample (Laing, Riley & Longair 83) with $z<1.0$.
- Include sources from Evans et al 2006 ($z<0.1$), Hardcastle et al 2006 ($0.1 < z < 0.5$) and Belsole et al 2006 ($0.5 < z < 1.0$) plus some new observations and archive data since 2006 (e.g. Harris et al in prep.).
- In total 90/137 (66%) of the $z<1.0$ 3CRR sources have Chandra or XMM data – almost all used in the current analysis.

Example FRII spectra



NLRG

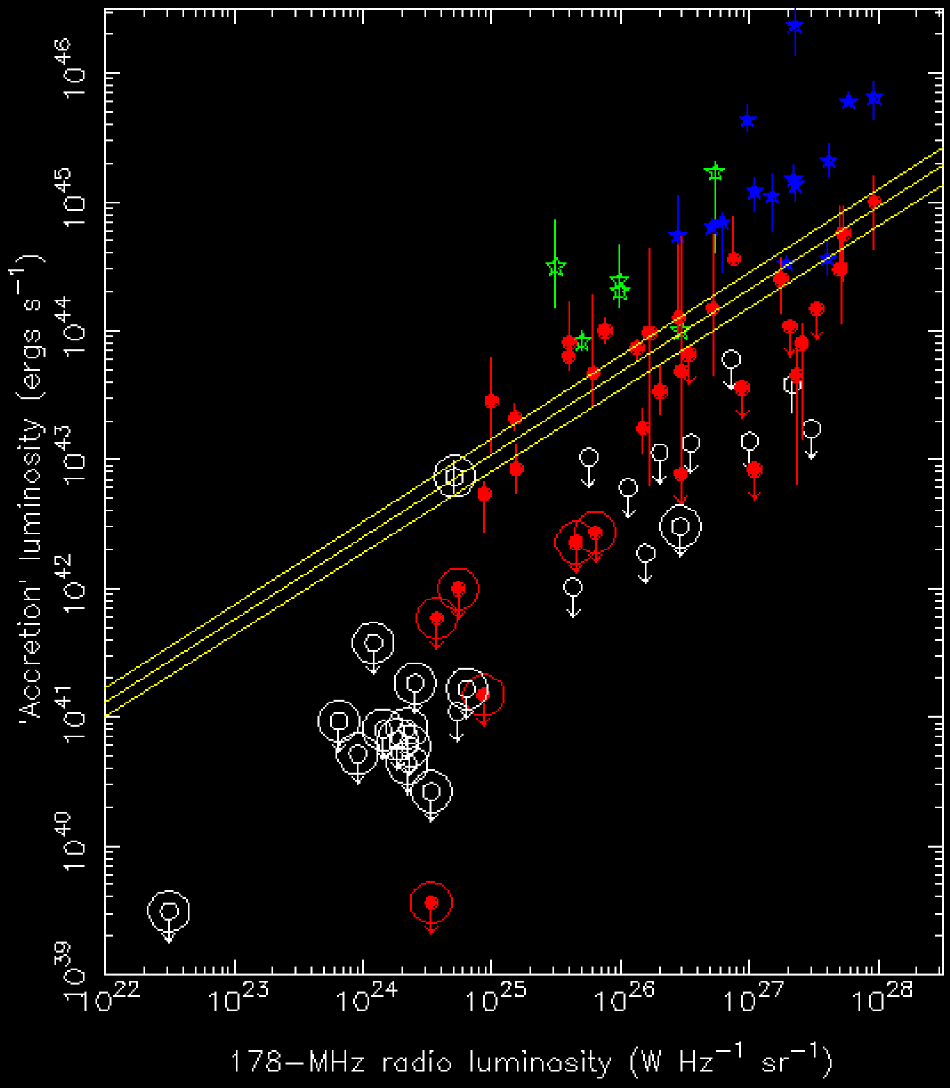


LERG

Sample results

- Almost all of the NLRG (mostly FRIIs) show evidence for an absorbed nuclear component with $N_H \sim 10^{22}$ -10^{24} cm^{-2} – as expected if all have tori + large angle to LOS
- BLRG and quasars generally unabsorbed or at most small absorption columns.
- Almost all the LERGS (FRIs and FRIIs) show no evidence for an absorbed component (exceptions not true LERGs?) although all show the jet-related, unabsorbed component.
- Can put upper limits on the absorbed, ‘accretion-related’ luminosity for sources where no absorbed component is detected by assuming a column density.

Luminosities



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

For quasars and BLRG the luminosity plotted is the total luminosity if no absorbed component is required in the fit.

Circle => FRI

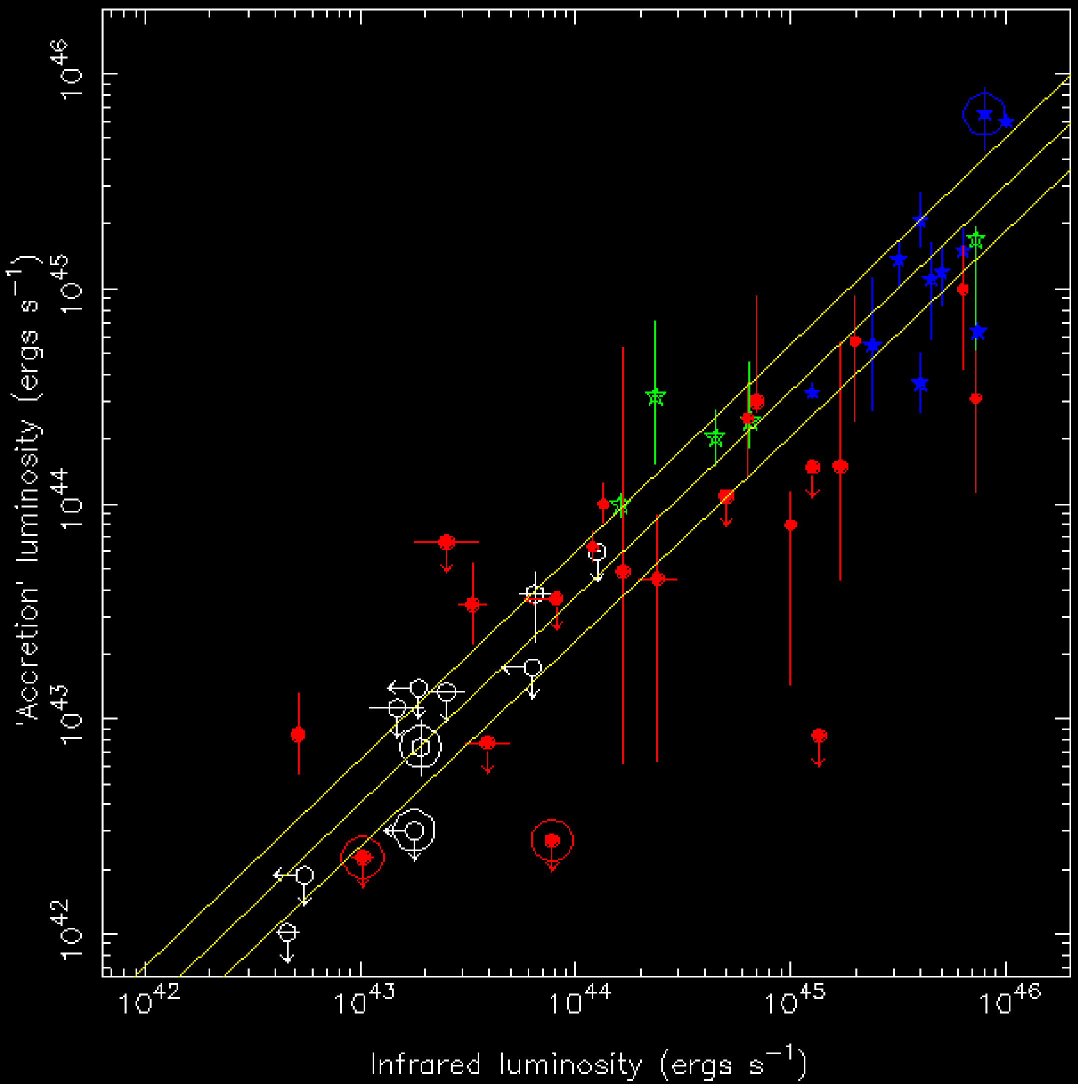
Line goes through FRII NLRG

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

Invisible – or not there?

- We see that the limits for LERGs generally lie below the radio/X-ray correlation for NLRG; however, some NLRG lie in the same region of parameter space.
- A crucial question is whether the undetected sources are just absorbed by columns >> 10^{23} cm^{-2} – i.e., whether they are just Compton-thick.
- Infra-red data give us the answer: Compton-thick sources will be luminous in the IR.
- Spitzer IRS photometry is available for many of our targets. We use the 15-micron luminosities (νf_ν) given by Ogle et al (2006) and Cleary et al (2007), supplemented by our own analysis of other 3CRR sources with z>0.1 (following the method of Ogle et al). 47 objects in our sample.

X-ray vs 15-micron luminosity



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

Circle => FRI

Line goes through all detected points

Limits use $N_H = 10^{23}$ cm^{-2}.
Compton-thick sources would lie far below/right of the correlation.

IR interpretation

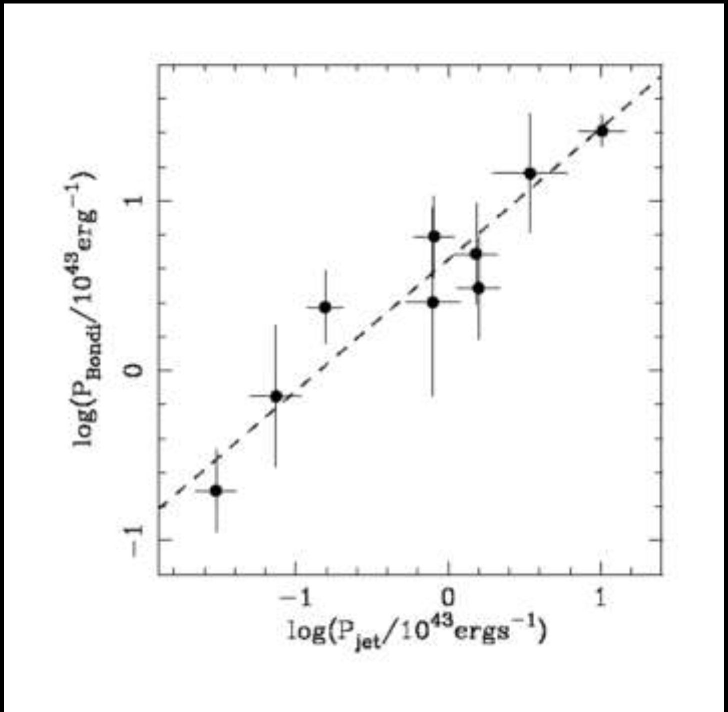
- The only source to lie in the Compton-thick region of parameter space is the NLRG 3C244.1. This may be a genuine example of a Compton-thick radio-loud AGN – a column density of > 3 x 10^{24} cm^{-2} would be required to bring it back onto the regression line.
- Other X-ray detected NLRG lying below the line may provide evidence for more complex absorption structure (clumpy torus models?).
- The two LERGs with detected heavily absorbed X-rays also have IR nuclei at a level that puts them on the correlation – at least one of these lies in a region of high Galactic reddening and is probably really a NLRG.
- No LERG lies in the Compton-thick region. Detections are all low-luminosity and may be affected by host-galaxy emission.

Multi-wavelength interpretation

- No single indicator tells us what is going on:
  - X-ray cannot alone distinguish between Compton-thick and unabsorbed sources because of jet X-ray emission
  - Single-band IR is contaminated by galactic emission at the low-luminosity end and possible jet-related emission at the high end (see Cleary et al); division into mid-IR weak and strong too simplistic since some ‘mid-IR weak’ AGN (Ogle et al) really do have absorbed nuclei in the X-ray.
  - Emission line classification may be wrong because of reddening, poor spectroscopy, extended emission-line regions, photoionization by jet (e.g. Chiaberge et al 2002) etc.
- When all this is taken into account there still seems to be a real LE/HE dichotomy in the data: LERG seem to be accreting in a radiatively inefficient mode (for details see HEC 2006).

Origin of the dichotomy

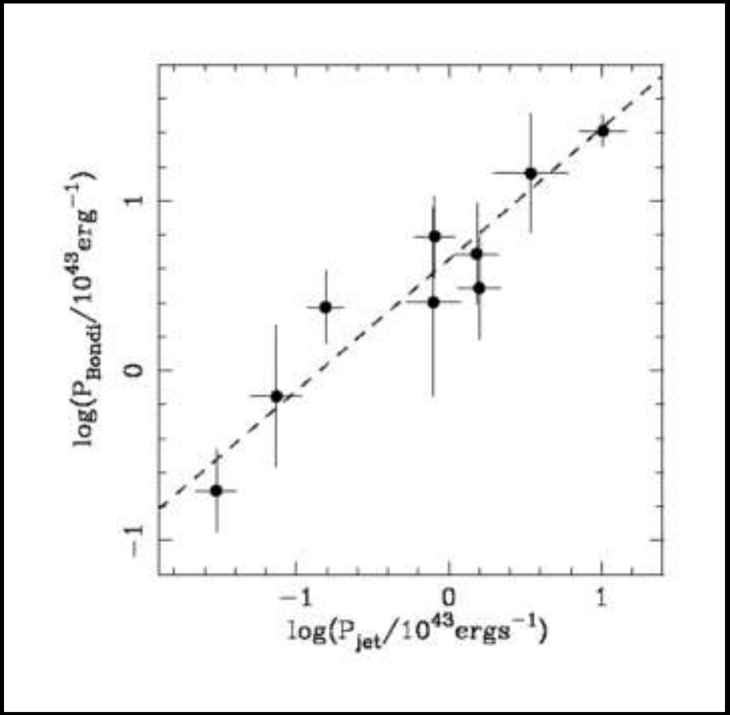
- There are two obvious sources of gas for AGN to accrete: cold neutral material and the hot, X-ray emitting phase of the IGM.
- Allen et al 06 and, more recently, Balmaverde et al 08 have shown that accretion from the hot phase (shorthand – Bondi accretion) can power nearby low-luminosity objects.
- 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

- Accretion directly from the hot phase (w/o cooling) would not form a conventional AGN – thin disk, torus and NLR/BLR all require a cold fuel supply. Hot phase accretion could therefore be radiatively inefficient, as we suggest for LERG.
- 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

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

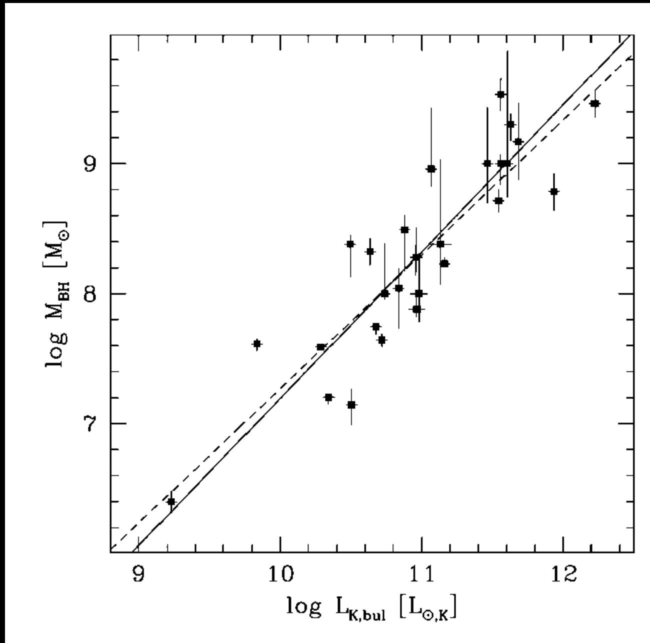
where the accretion radius is $$r_{\rm A} = \frac{2GM_{\rm BH}}{c_s^3}$$

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

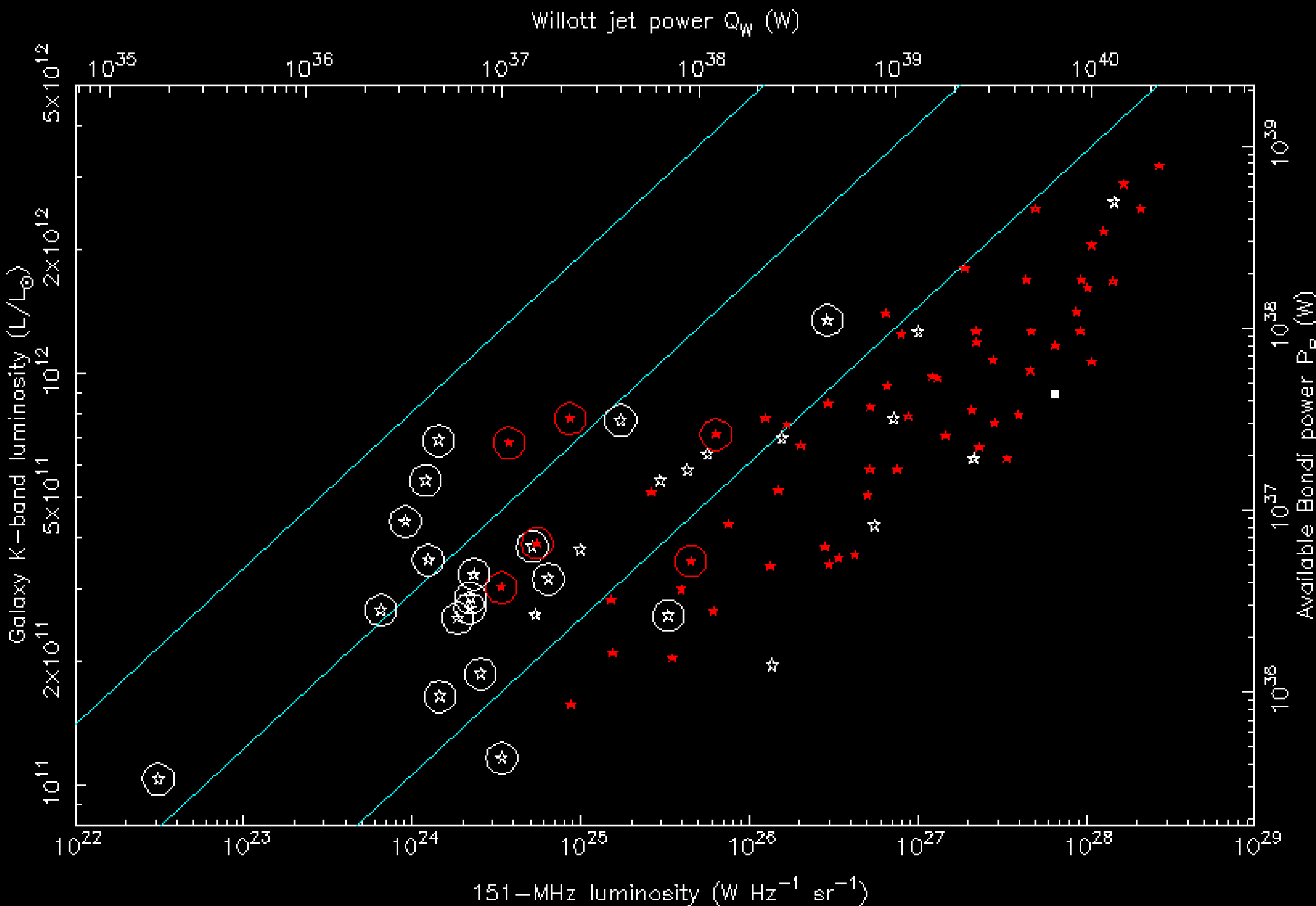
- We assume a fixed accretion efficiency – 10%. Spin not included!

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
- First compared Bondi rate with jet power from models of Laing et al in a few nearby cases. => OK
- Then looked at all 3CRR objects using jet powers from the Willott et al 1999 relation normalized using these known jet powers.



Bondi rates



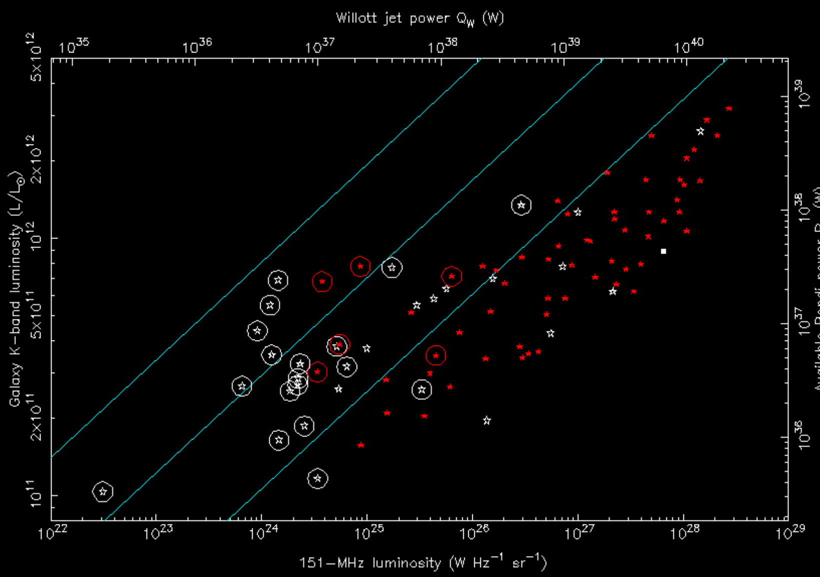
Bondi rates for all 3CRR sources with K-band mag assuming f = 10, central electron density 5 x 10^5 m^{-3}, central temp 0.7 keV, and Bondi accretion efficiency 0.1.

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

Lines indicate uncertainty due to scatter in M-K relation.

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.)



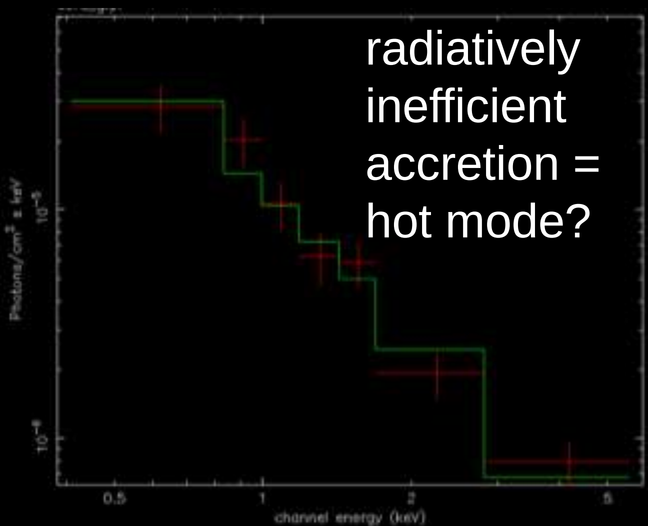
Consequences

- Possible that all low-excitation radio-loud AGN (i.e. the vast majority of nearby low-power sources) are powered by hot-mode accretion (consistent with work of Allen et al and Balmaverde et al).
- Almost certainly *impossible* that the high-excitation objects (including most powerful FRIIs) get their energy this way – probably powered by accretion of cold material instead (consistent with observations of torus, NLR and radiatively efficient accretion disk).
- Let's suppose this is true, what follows?

Consequences – jet generation

- Sources with and without a conventional thin accretion disc must generate (very similar) jets.
- => constrains jet generation models. (Somebody else's problem…)
- (XRB tell us that jets can be generated in a radiatively inefficient accretion state, though the analogy is not exact.)

Consequences: feedback



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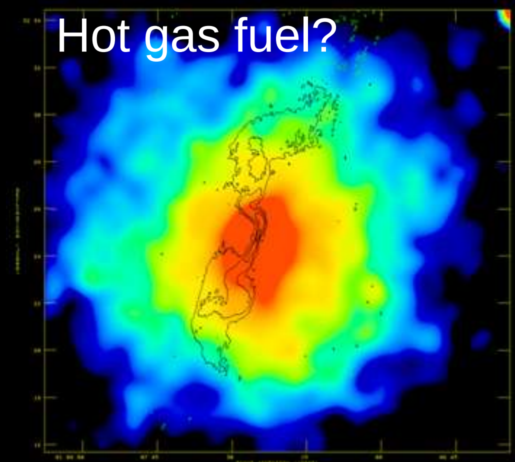
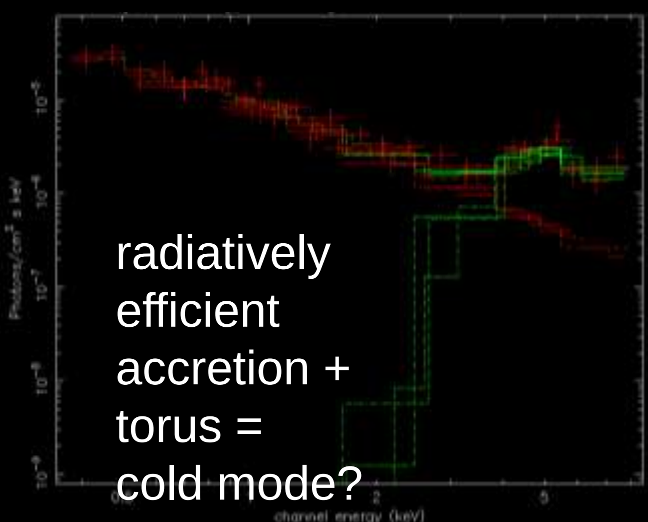


→ *Feedback with hot phase*



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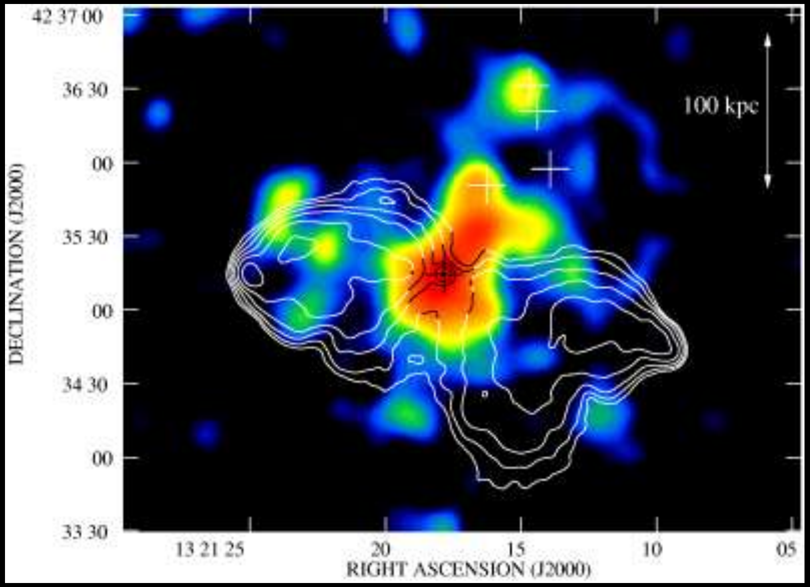
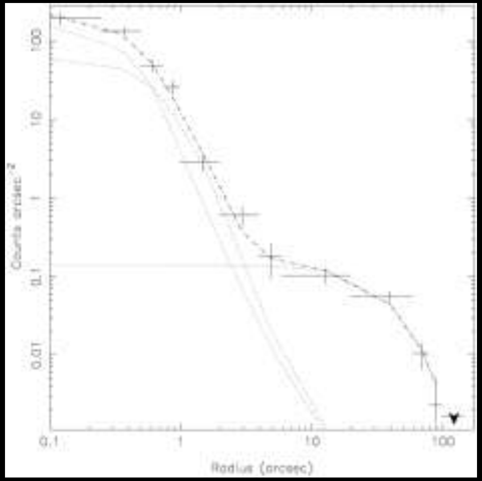
→ *Unregulated heating of hot phase?*

Consequences: feedback

- True ‘feedback’ between AGN and hot phase *requires the AGN to be controlled by the hot phase*.
- Only directly possible (w/o intermediate cooling) in hot mode.
- In cold mode accretion (e.g. fuel supplied by gas-rich merger) the radio source can blow away its atmosphere without affecting its fuel supply.
- Consistent with observations of nearby NLRG 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).



Consequences: feedback

- Croton et al (2006) and many other papers use ‘quasar-mode’ and ‘radio-mode’ to describe the two types of feedback in which, respectively, the AGN drives cold gas out of the galaxy via winds and suppresses hot-gas cooling via radio lobes.
- Unsatisfactory terminology
  - because many quasars are also radio sources
  - because many powerful radio sources, while not quasars, are operating in the ‘quasar mode’
- In our picture the nature of the AGN (X-ray/IR/emission line...) *allows us to establish what mode a given AGN is in*.
- Plausibly, most powerful, distant radio sources are not telling us anything about the ‘radio mode’!

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. Further tests of model required (see Huub's talk?).

Summary

- RG nuclear X-ray emission is complicated by the presence of a soft (jet-related) component, but we think we can detect/set limits on absorbed components with Chandra & XMM.
- Seems plausible that LERG (in the local universe, most FRIs and some FRIIs) are radiatively inefficient.
- Can be related to source of accreting material with important consequences for the types of radio source that engage in ‘feedback’.