Cen A at 1.4 GHz (CSIRO/ATNF/ASTRON/MPIfR).

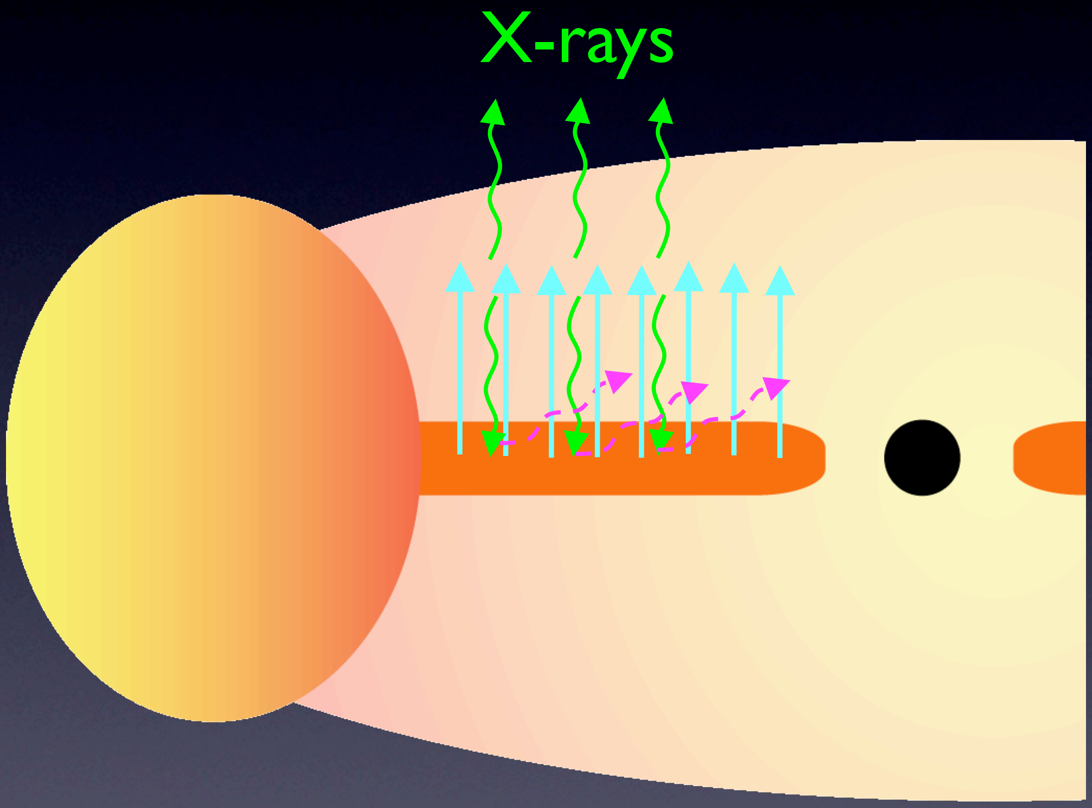
Panchromatic Observations of the Nuclei of 3CRR Radio Galaxies: Implications for Feeding, Feedback, and Black Hole Spin

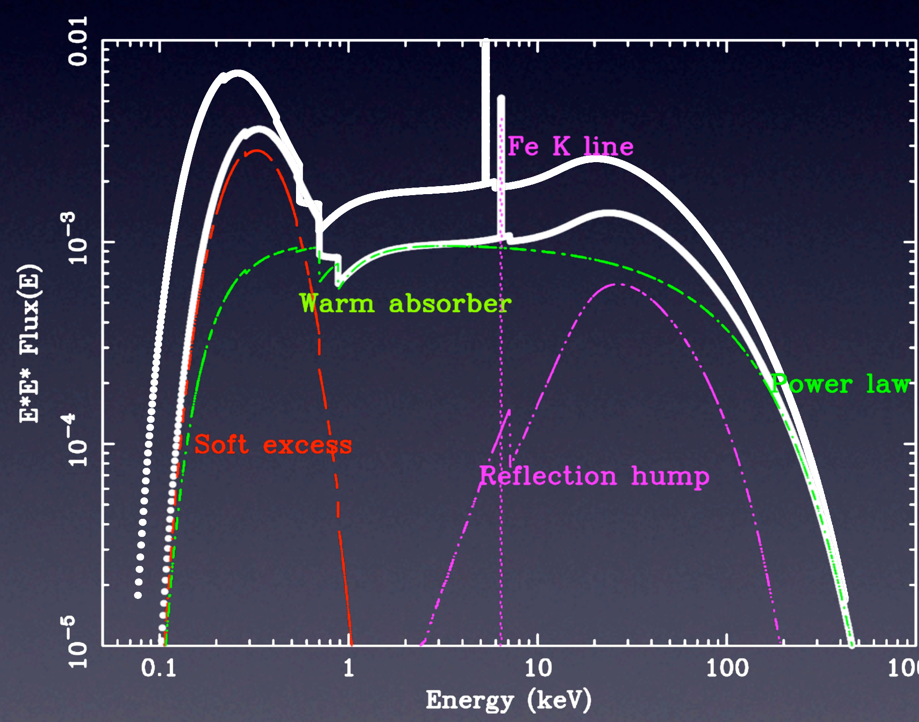
Dan Evans (U.S. National Science Foundation & Harvard-Smithsonian Center for Astrophysics),

Beatriz Mingo (Hertfordshire), Mark Birkinshaw (Bristol), Diana Worrall (Bristol), David Garofalo (JPL), Martin Hardcastle (Hertfordshire), Judith Croston (Southampton), Ralph Kraft (SAO)

1. X-ray Diagnostics

A Cartoon of X-ray Emission in AGN

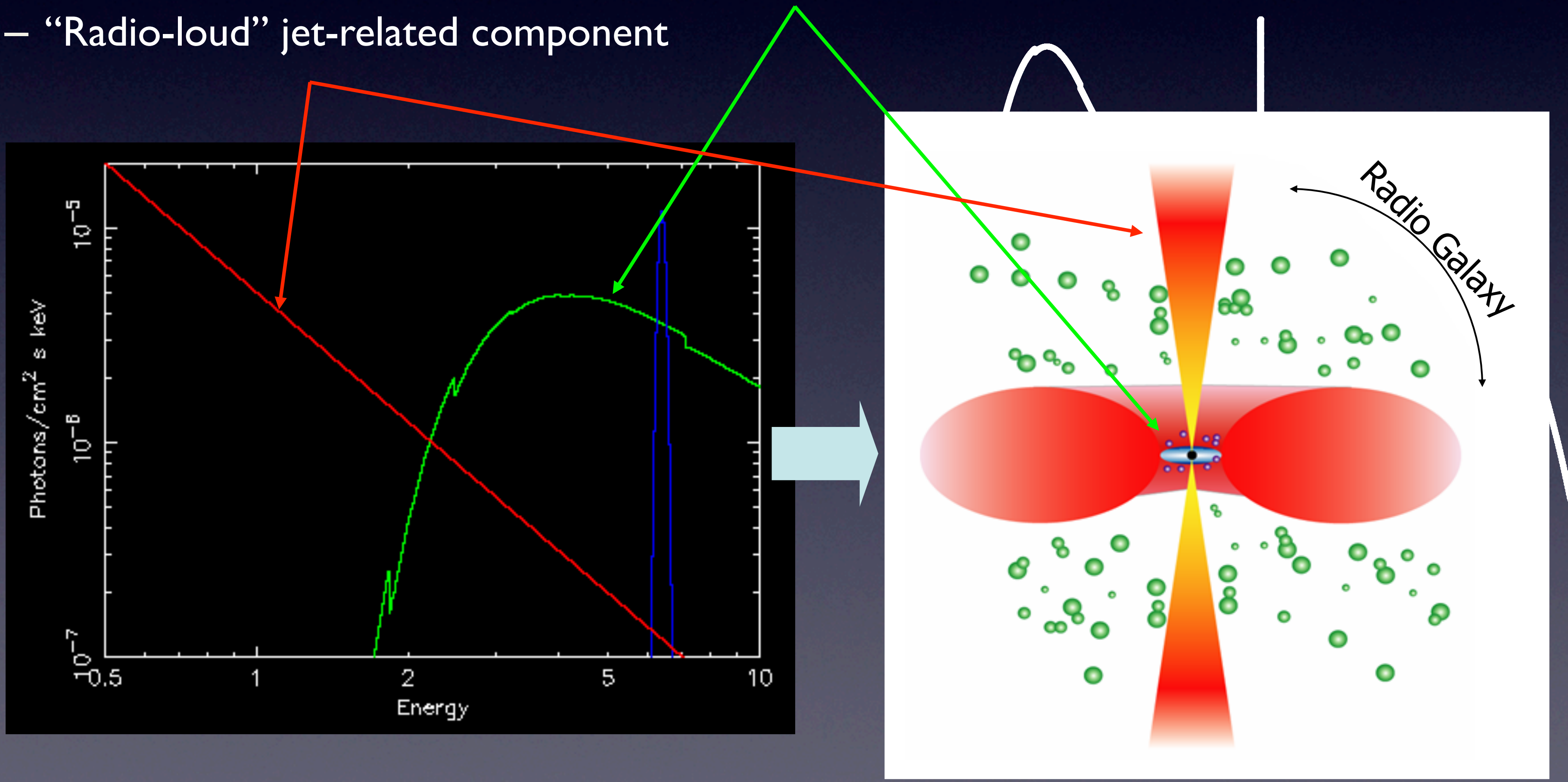




A Cartoon of X-ray Emission in AGN

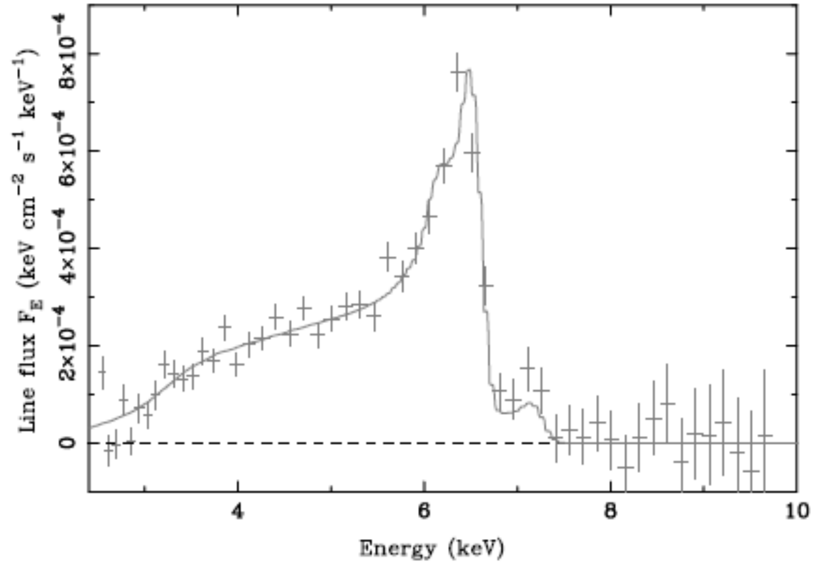
- Luminous accretion disk surrounded by "torus"
- Unification prediction: X-ray continuum emission consists of:

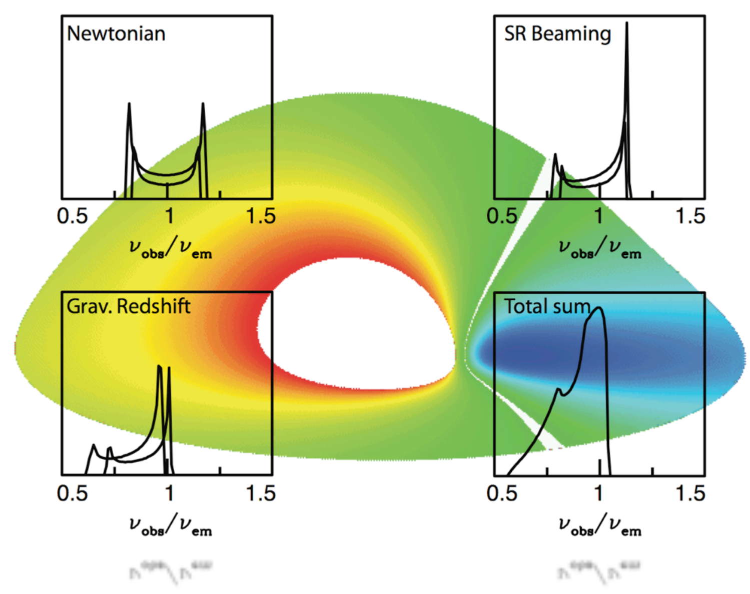
– "Radio-quiet" accretion-related component
– "Radio-loud" jet-related component



Black hole + Disk Diagnostics

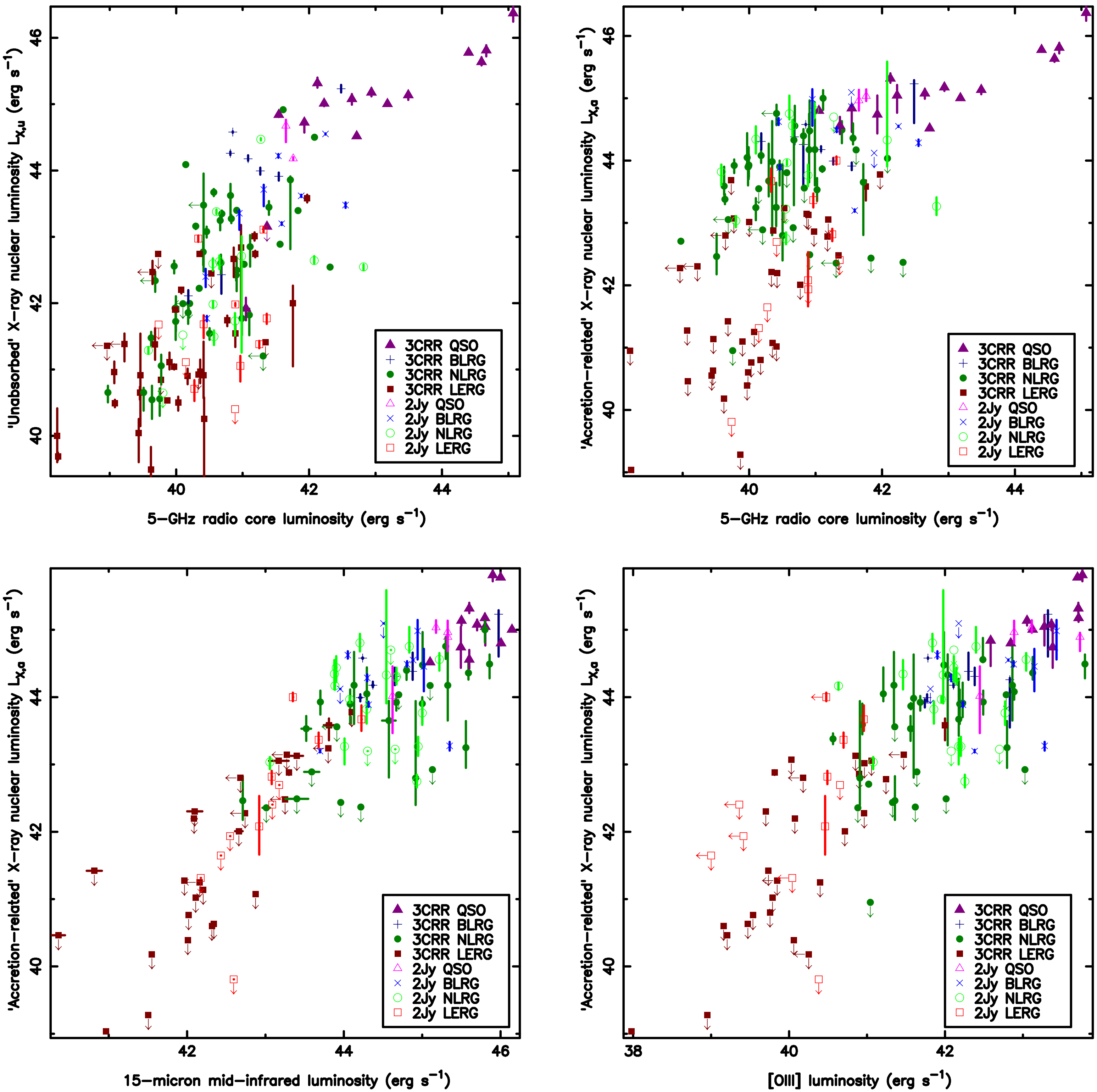
- The 6.4 keV Fe Kα line complex in general consists of a narrow line core, often accompanied by broadened emission
- If we can deconvolve the contributions from the two, we can probe AGN and black hole physical conditions
- Narrow core always attributed to the circumnuclear torus
- Broadened emission may be a relativistically blurred diskline
- Possibility of constraining spin





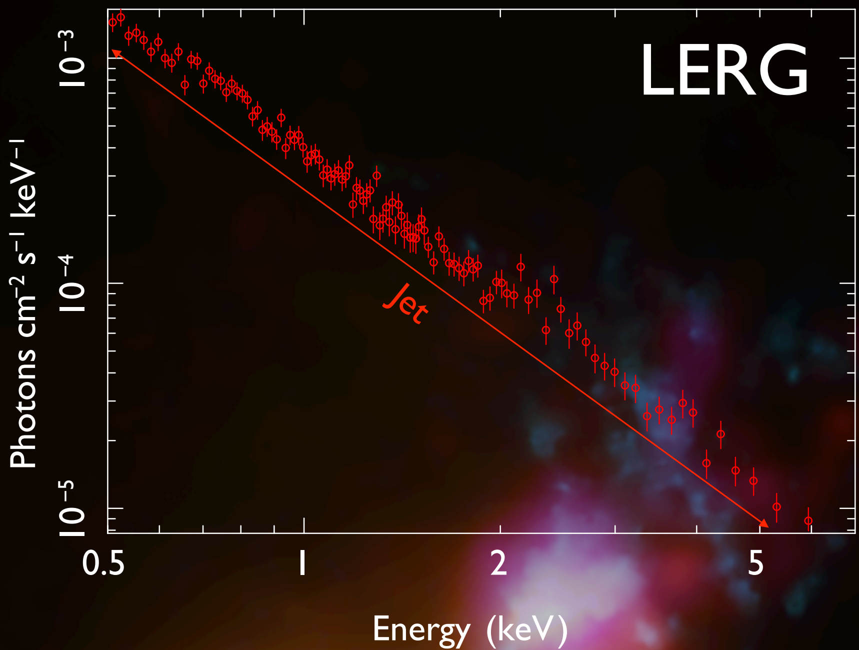
2. Observations of 3CRR Sources at z<1.0

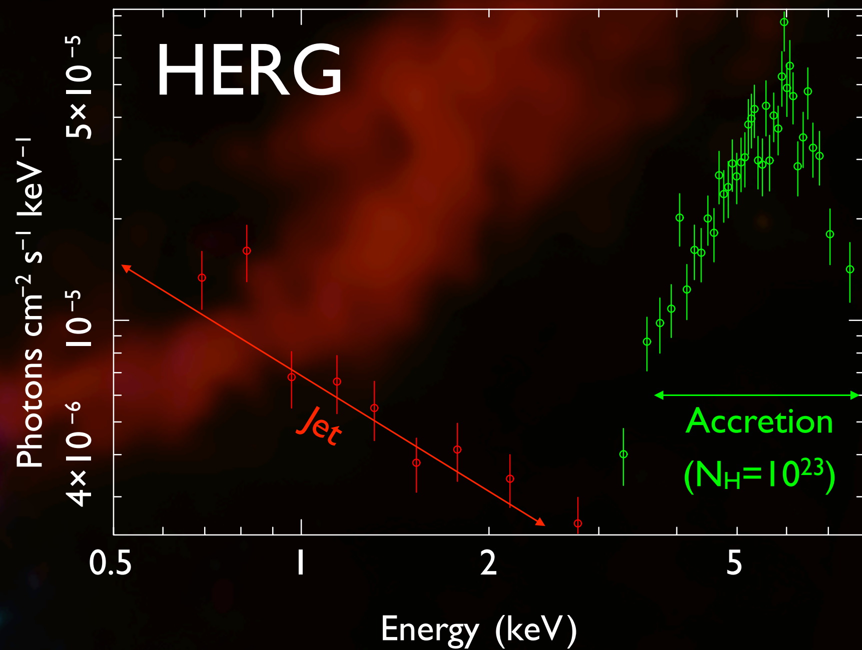
- 135 sources, of which 89 observed with Chandra or XMM-Newton
- Latest work (Mingo et al. 2013, submitted) considers a statistically complete subsample of 2Jy sources at $0.02 < z < 0.7$
- Excellent IR (chiefly Spitzer), optical (GMOS+HST), and radio (VLA) coverage



'Unabsorbed' X-ray nuclear luminosity $L_{X,u}$ (erg s^{-1})
5-GHz radio core luminosity (erg s^{-1})
'Accretion-related' X-ray nuclear luminosity $L_{X,a}$ (erg s^{-1})
15-micron mid-infrared luminosity (erg s^{-1})
[OIII] luminosity (erg s^{-1})
3CRR QSO
3CRR BLRG
3CRR NLRG
3CRR LERG
2Jy QSO
2Jy BLRG
2Jy NLRG
2Jy LERG

Low- and High-Excitation Radio Galaxies

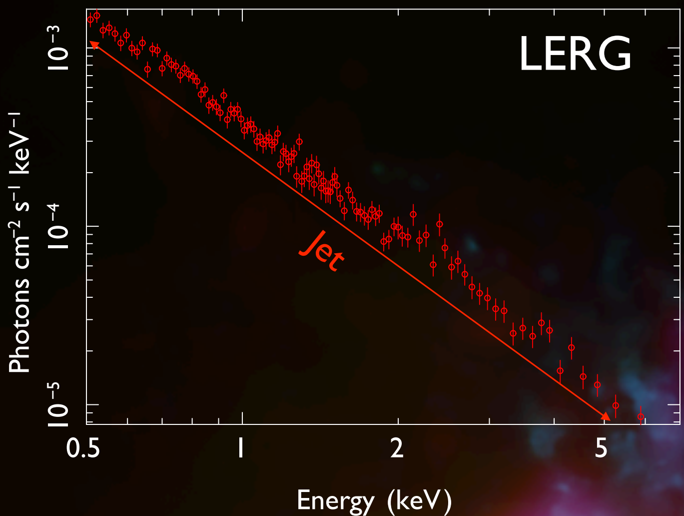


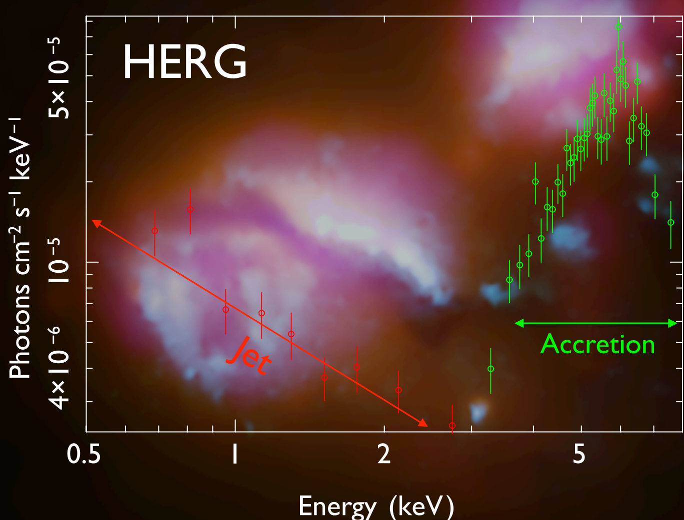


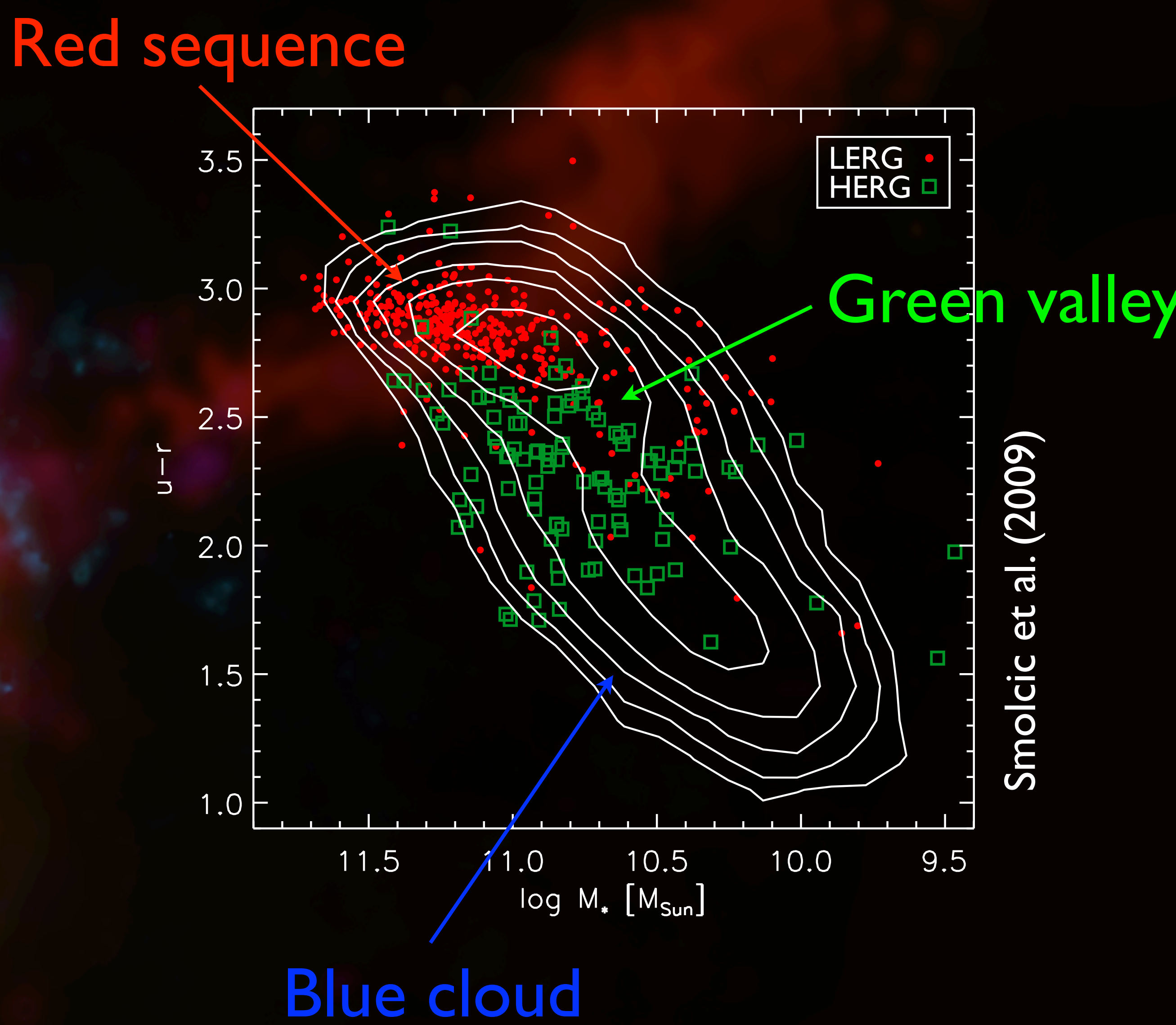
- Weak optical emission lines
- $L/L_{Edd} \sim 10^{-7} - 10^{-4}$
- Jet dominated X-ray emission, ADAFs
- No torus?
- Tend to inhabit gas-rich environments
- Significant feedback between AGN and environment

- Strong optical emission lines
- $L/L_{Edd} \sim 10^{-2}$
- Accretion-dominated X-ray emission
- Narrow Fe Kα lines
- Cold gas signatures
- Tend to inhabit gas-poor environments
- Hot-gas feedback unimportant

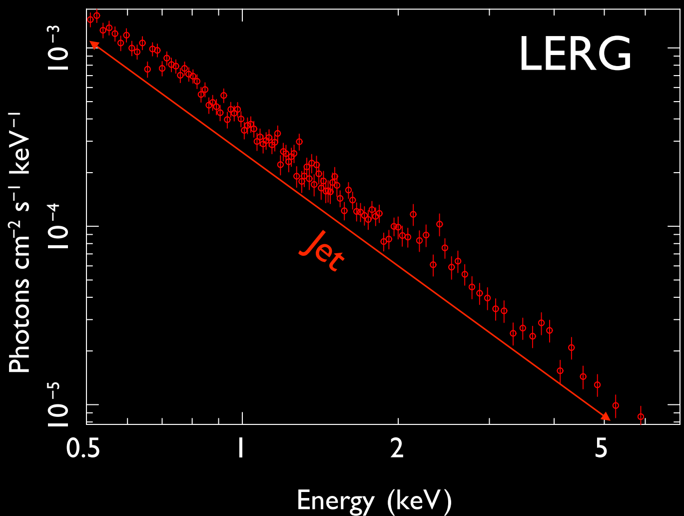
Low- and High-Excitation Radio Galaxies



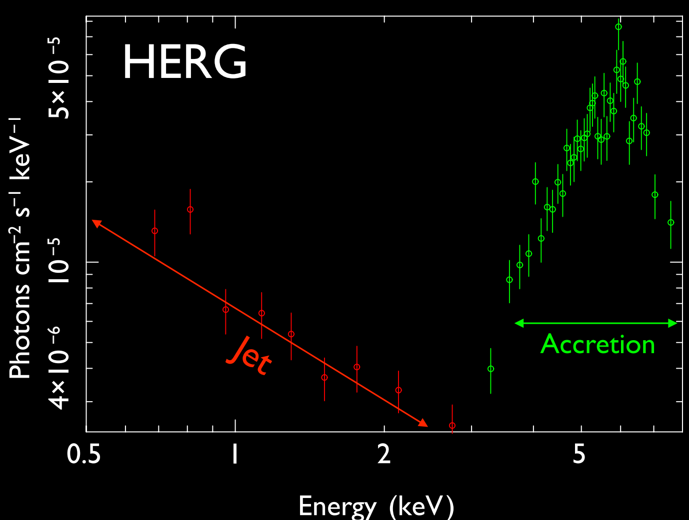




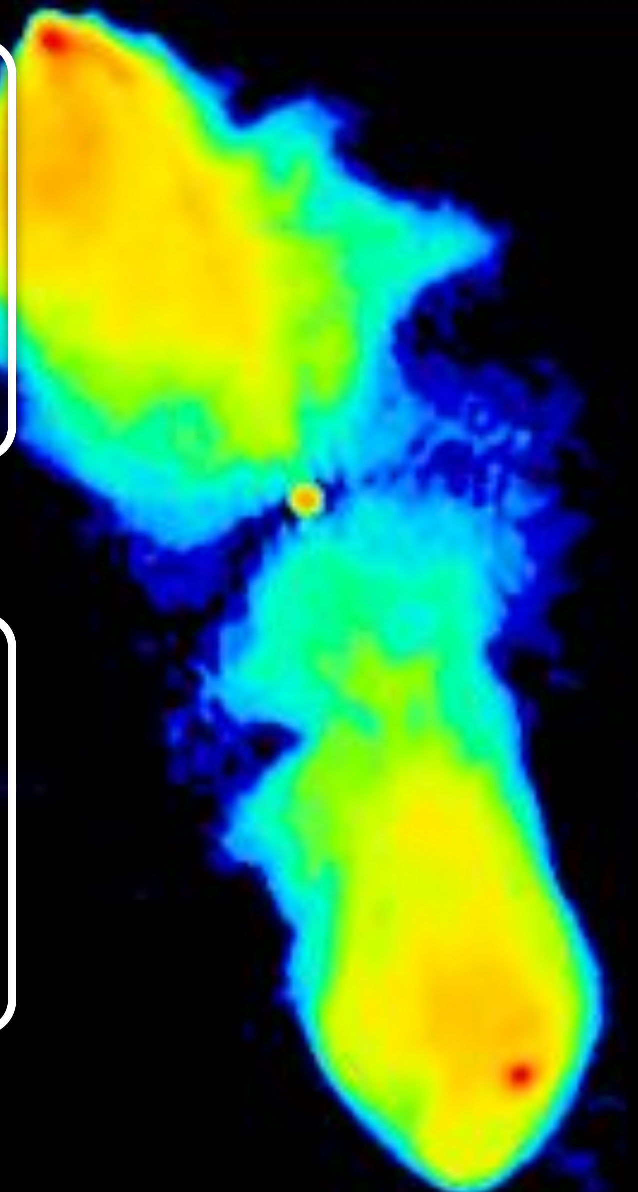
Low- and High-Excitation Radio Galaxies



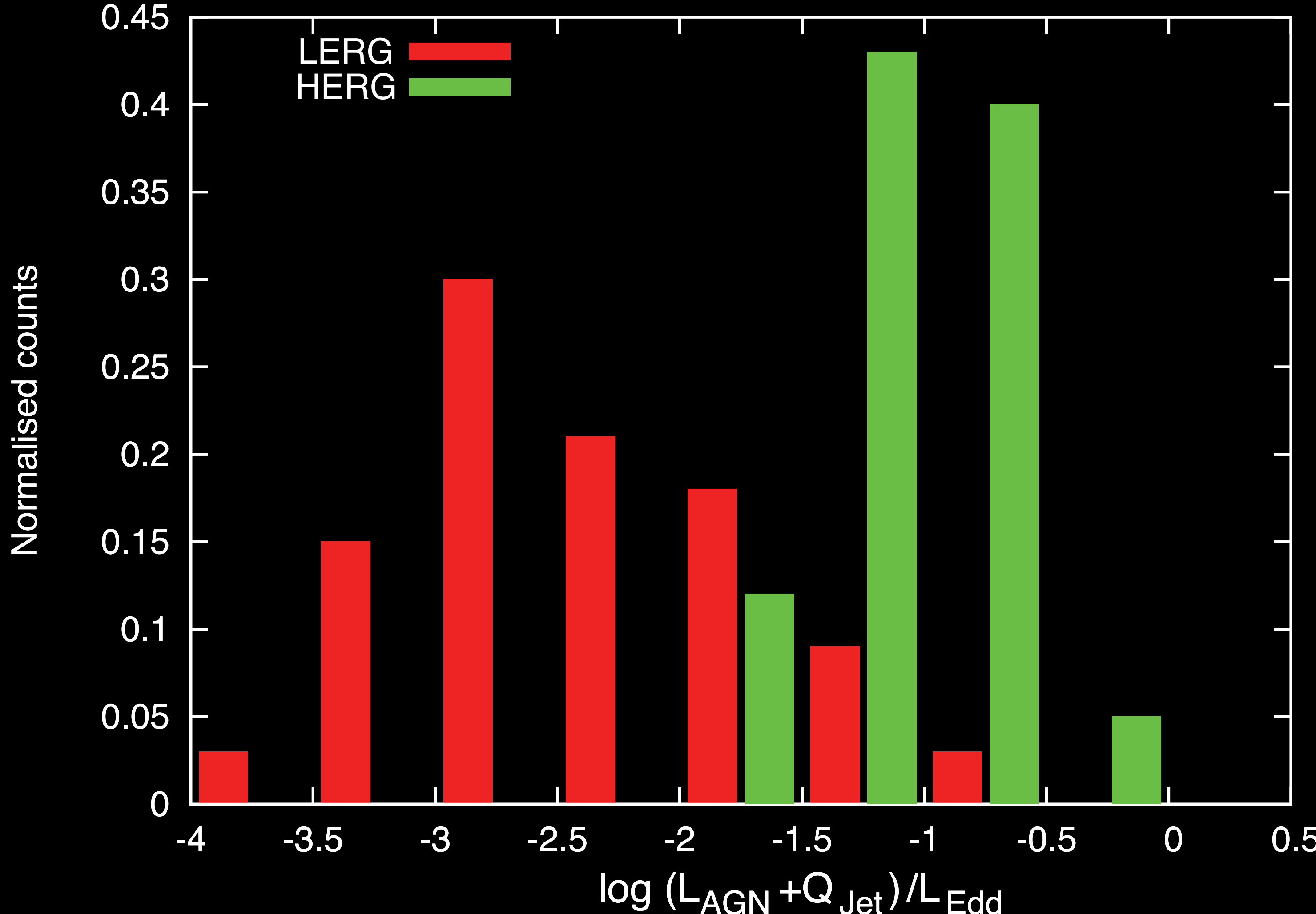
Mostly FRIs, though a significant population of FRIIs at 0.1<z<0.5



Typically FRIIs, though notable exceptions such as Cen A or NGC 3801



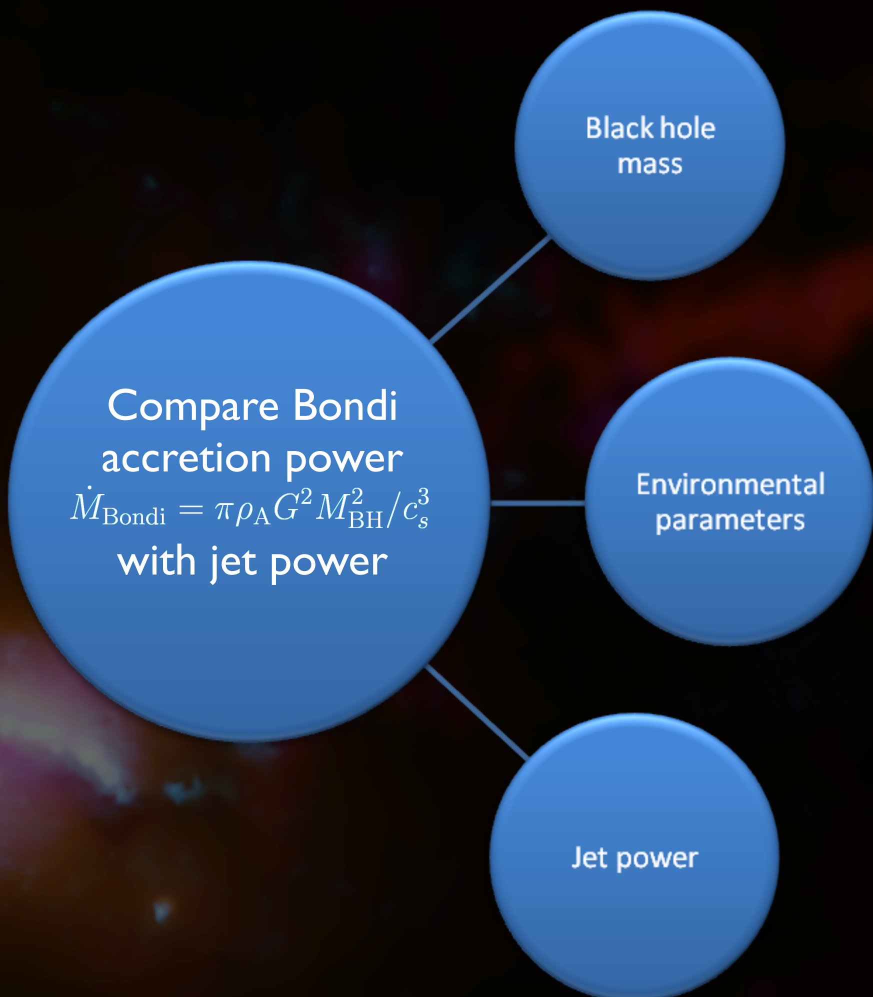
An Eddington Switch?



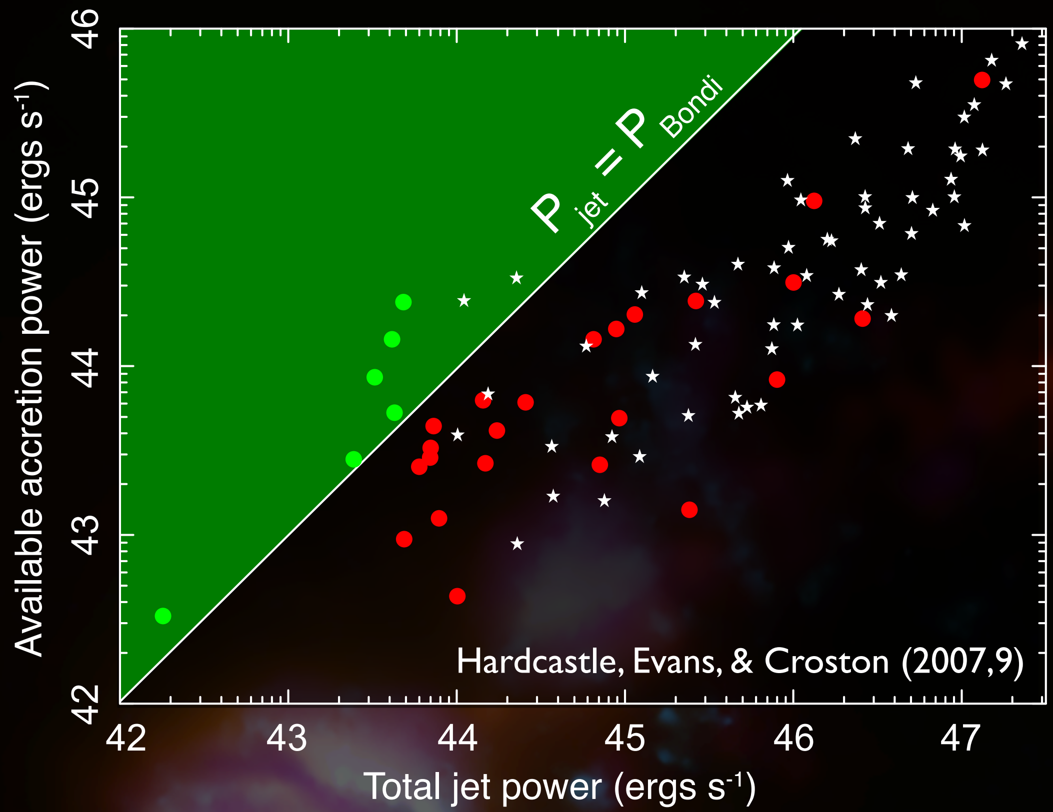
Mingo et al. (2013), MNRAS, submitted

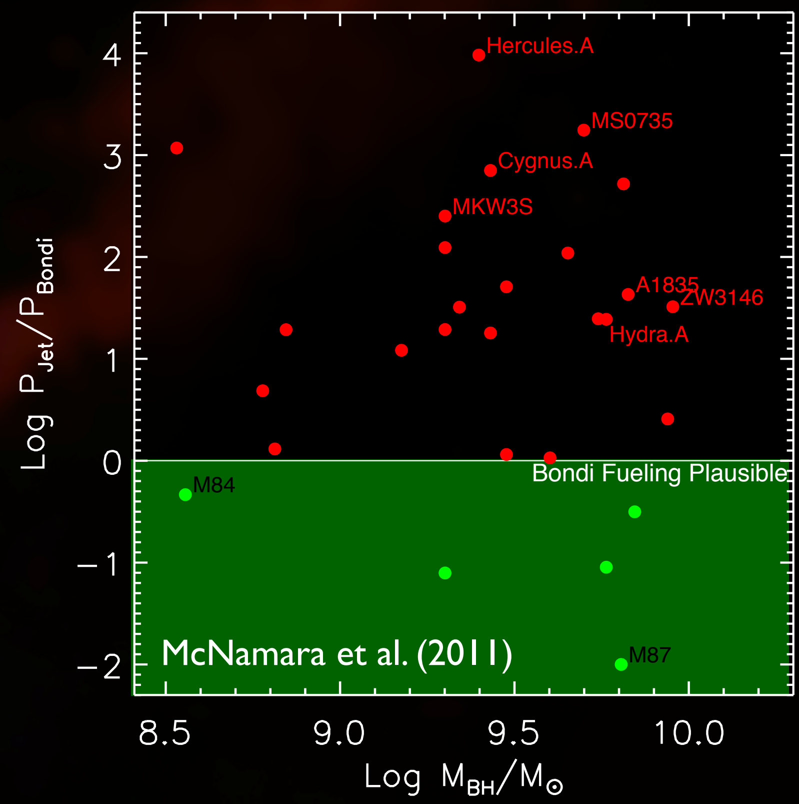
3. Testing Bondi Accretion

Testing Bondi Accretion



Bondi Rates



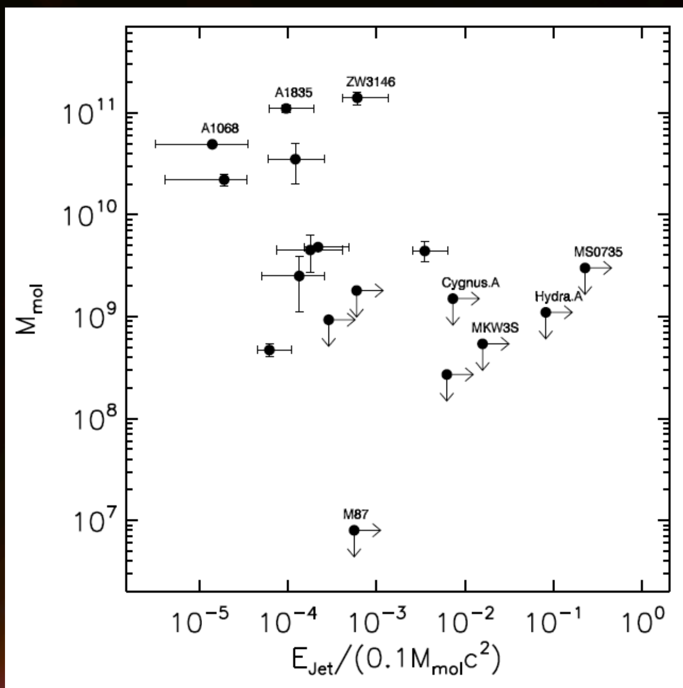


- Only the least powerful LERGs can be powered by Bondi accretion
- The vast majority of HERGs are a long way away from being able to be powered by hot-mode accretion.

4. Testing Cold-Mode Accretion

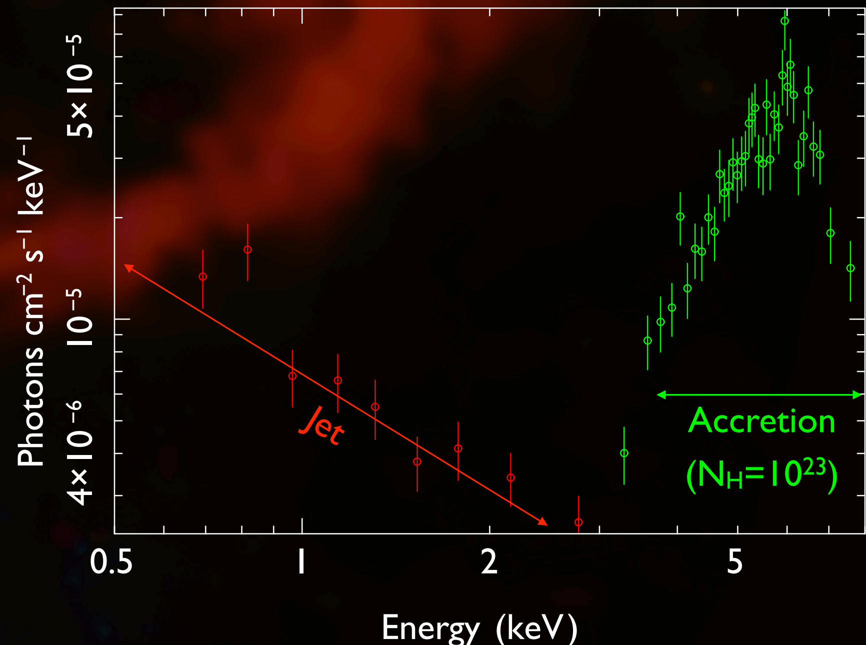
Testing Cold-Mode Accretion

LERG



- No correlation between molecular gas mass and jet power (McNamara et al. 2011)
- No evidence of cold gas structures in X-ray spectra (no torus, no cold disk)

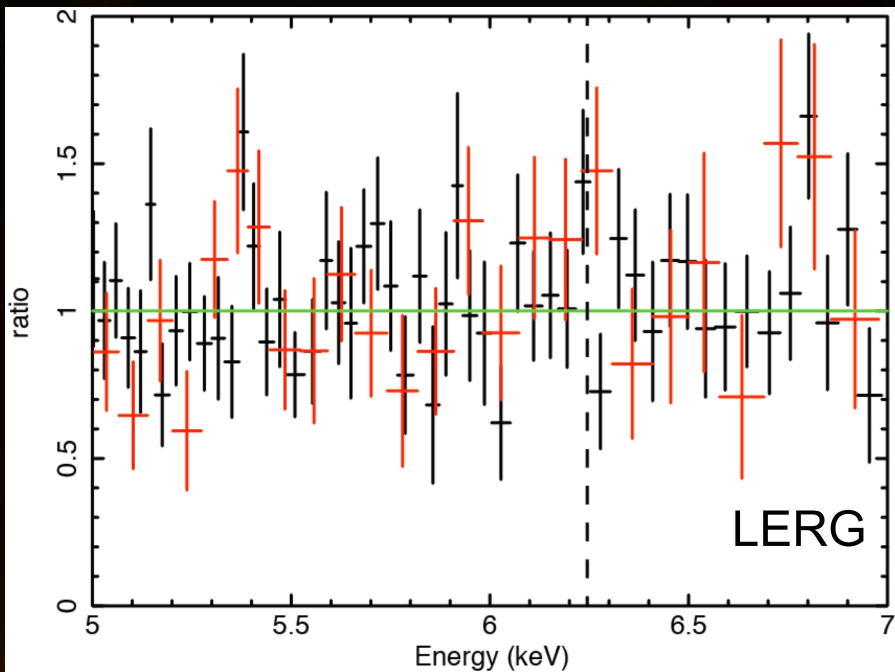
HERG

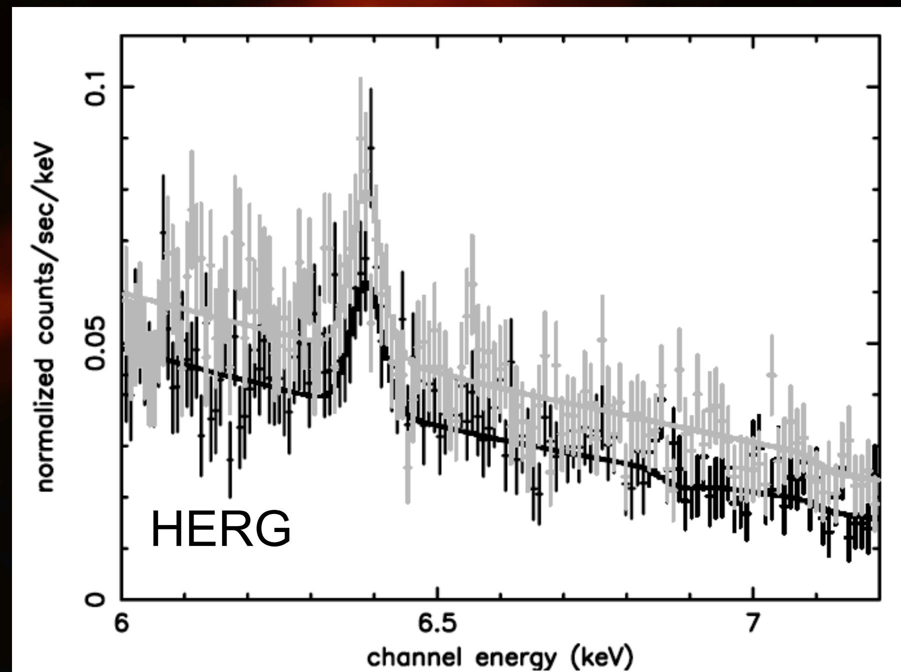


- Evidence for cold gas in the nuclear X-ray spectra
- Need molecular gas estimates for HERGs (e.g., ALMA)

5. Black Hole Spin?

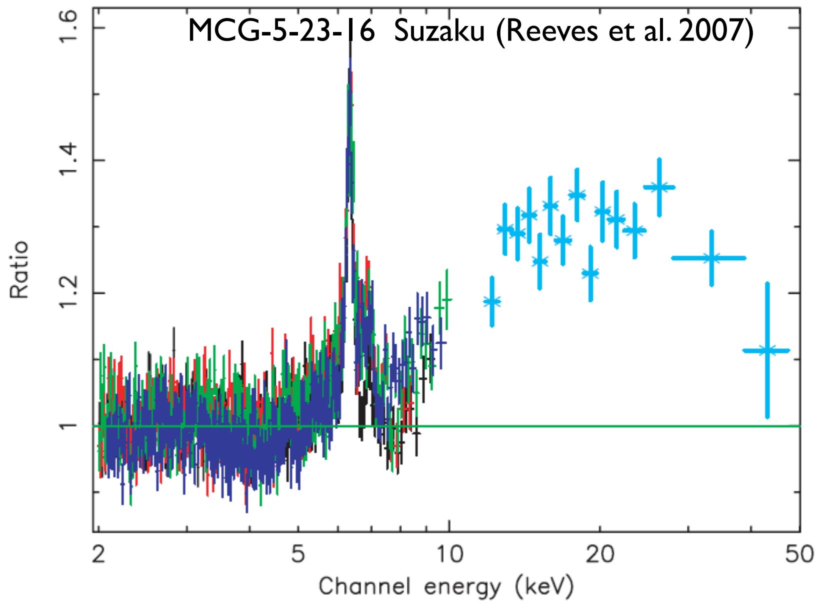
On the Lack of Disklines in RL AGN

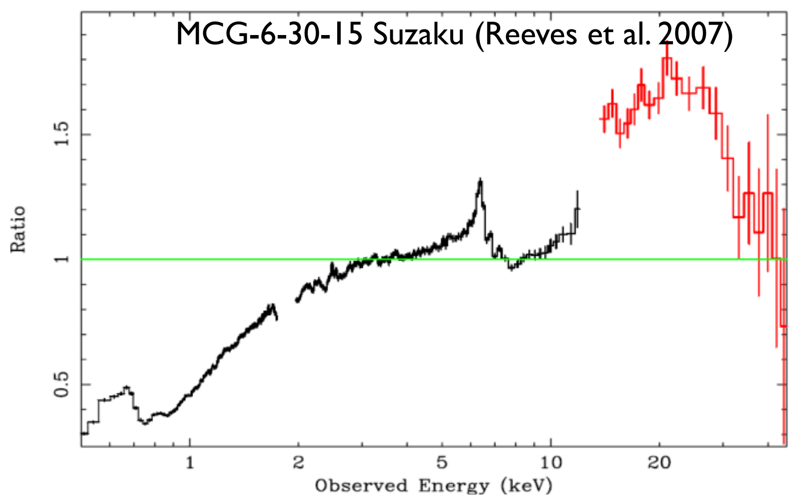




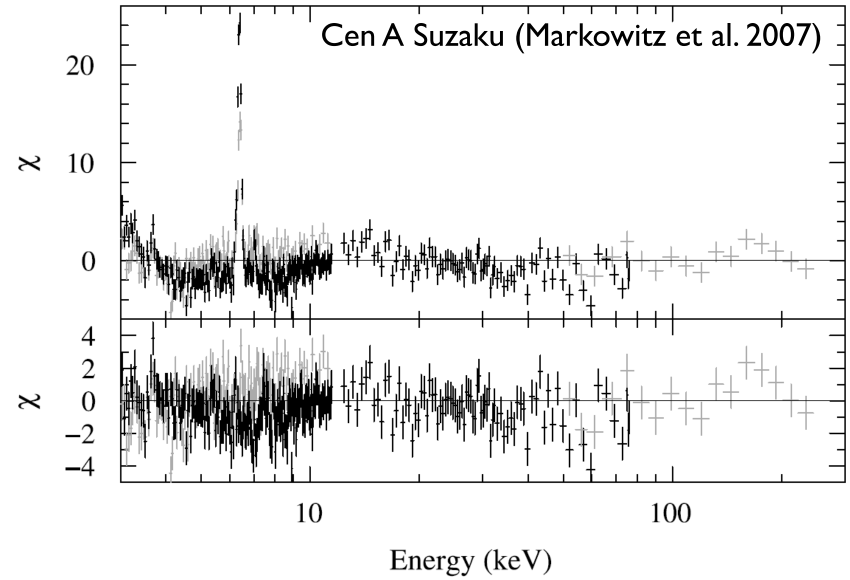
Caveat: Any model must be able to explain the paucity of relativistic disklines in radio-loud AGN

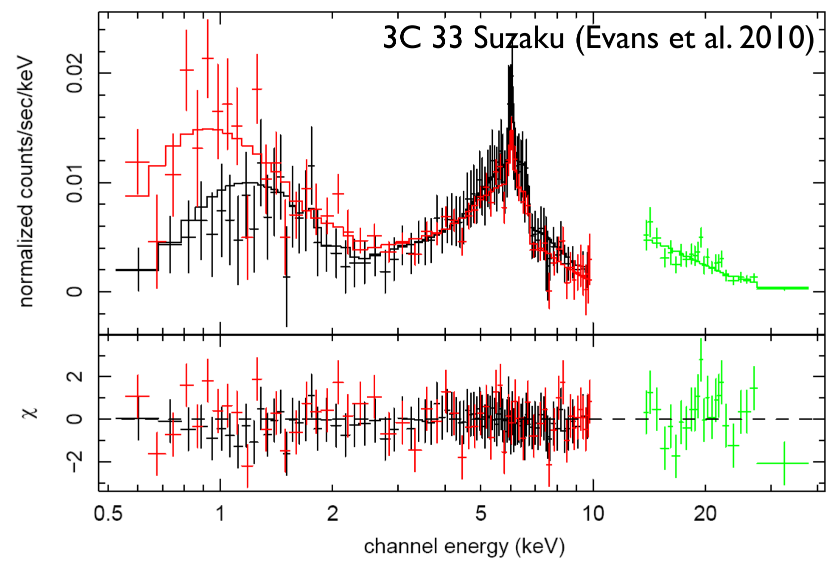
Reflection and Radio-Loudness





Radio-Quiet

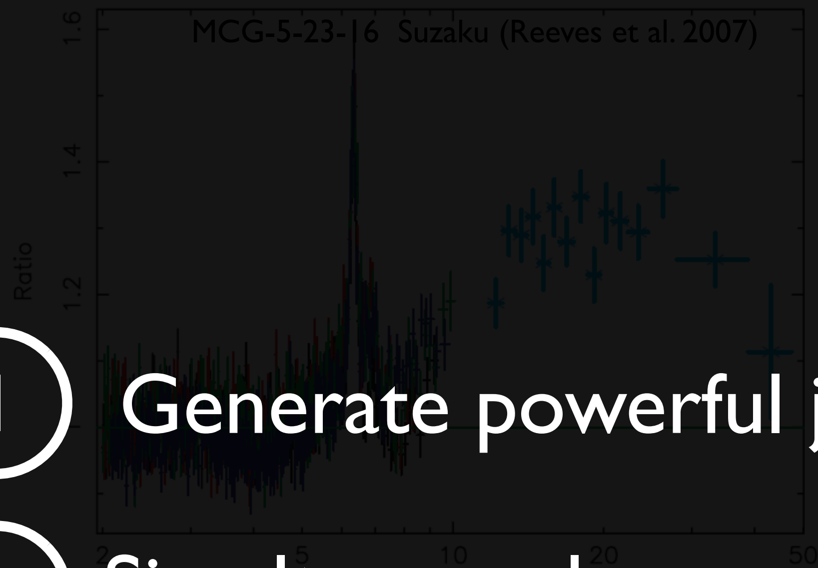


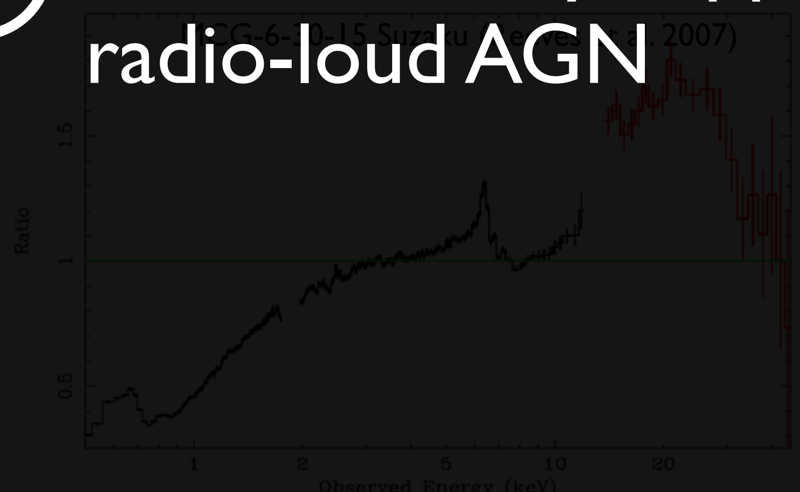


Radio-Loud (HERG)

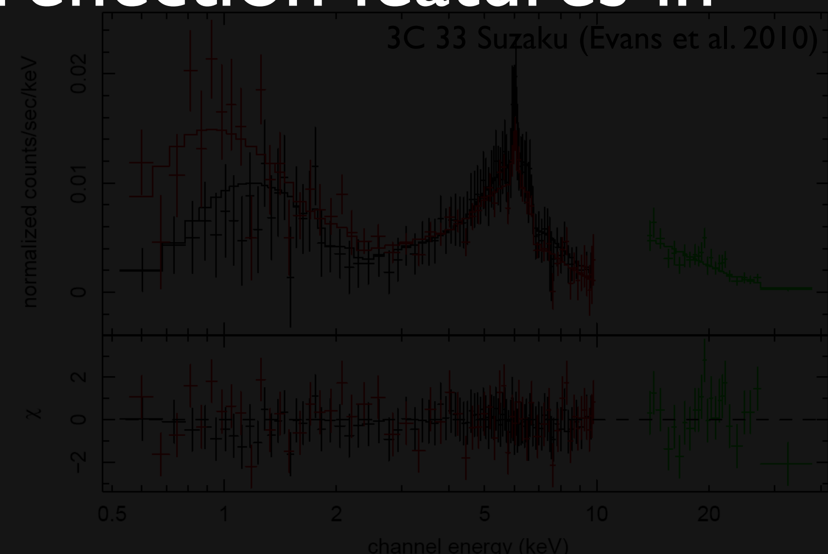
Reflection and Radio-Loudness

1. Generate powerful jets
2. Simultaneously suppress reflection features in radio-loud AGN





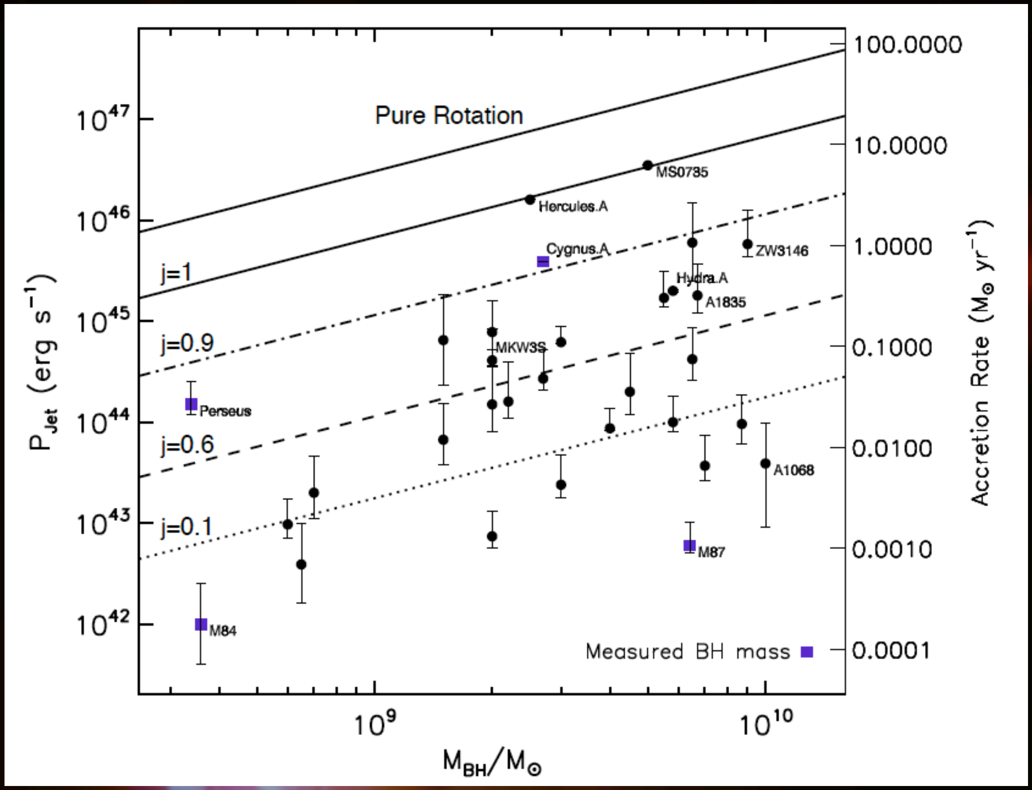
Radio-Quiet



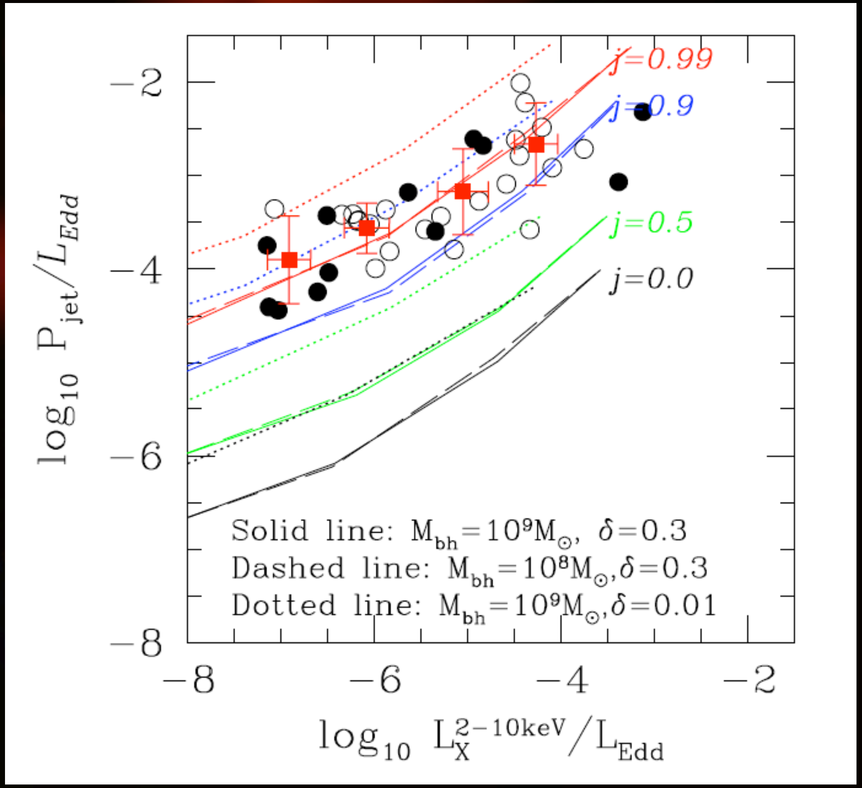
Radio-Loud (HERG)

Hybrid BZ+BP+ADAF Models

Nemmen et al. (2006), Meier et al. (2009)



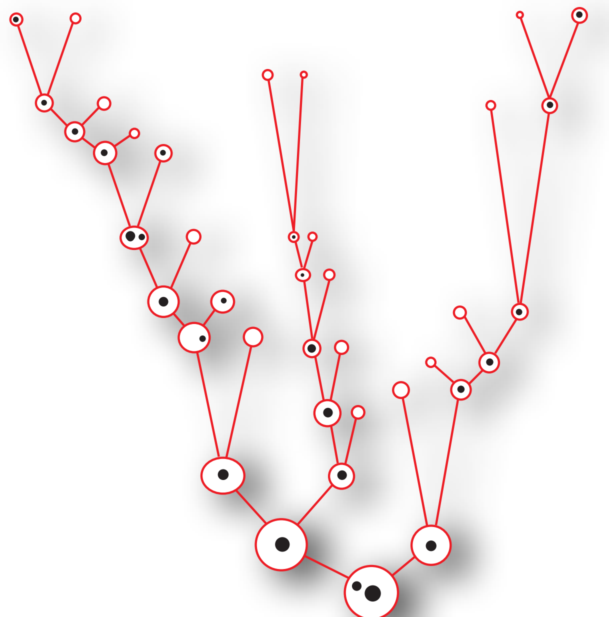
McNamara et al. (2011)



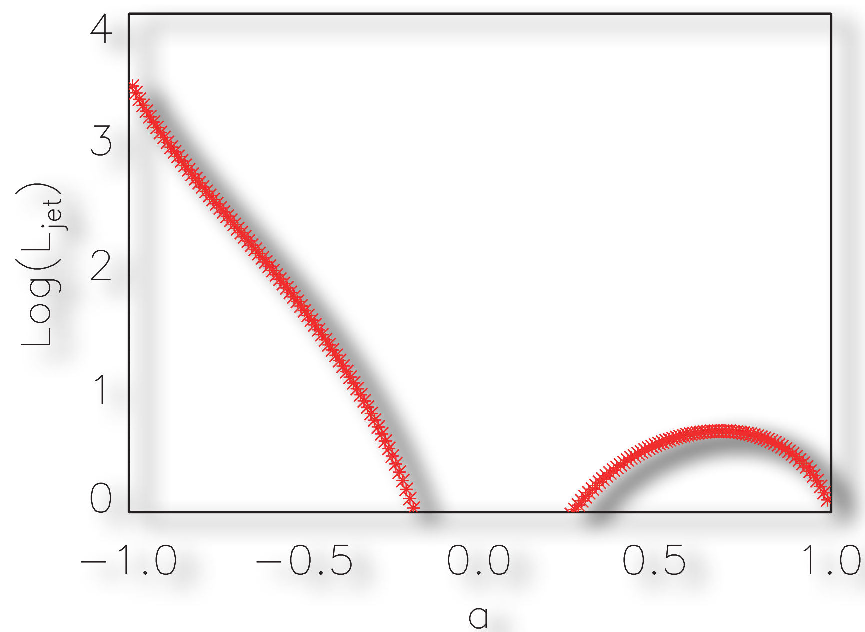
Wu et al. (2011)

Can explain LERGs

Prograde vs. Retrograde Spin



Mergers can produce retrograde spin (Berti & Volonteri 2008)

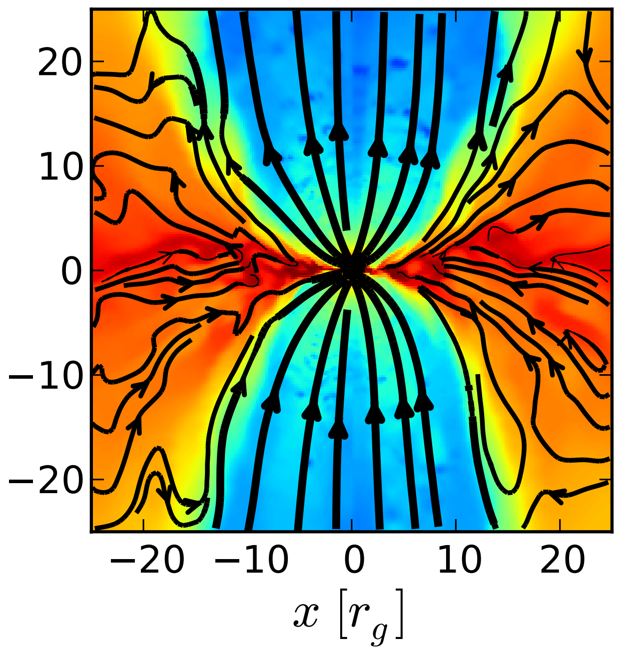


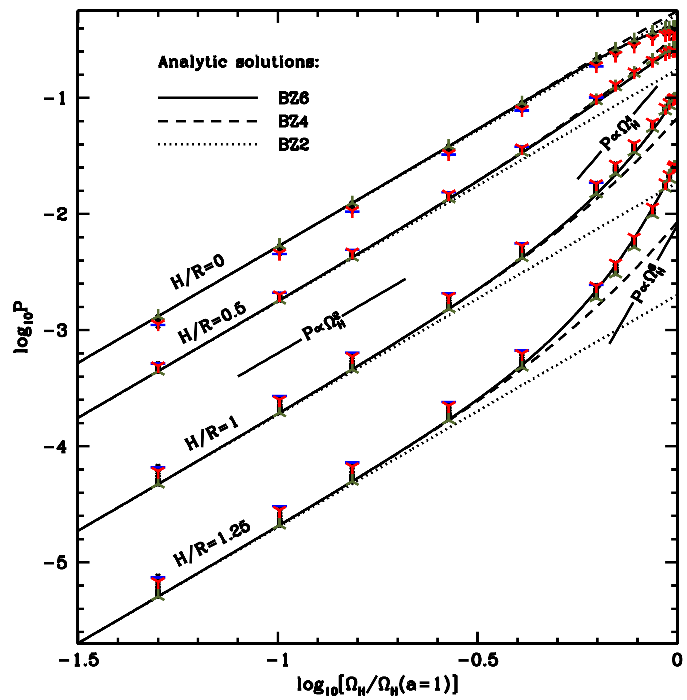
ISCO for an a=-1 black hole is $9R_g$

Is jet power greatest for maximally retrograde black holes?

(Garofalo 2009; Garofalo, Evans, and Sambruna 2010; but c.f. Tchekhovskoy & McKinney 2012)

Magnetically Arrested Accretion on to a Rapidly Spinning Black Hole

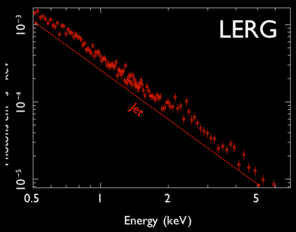


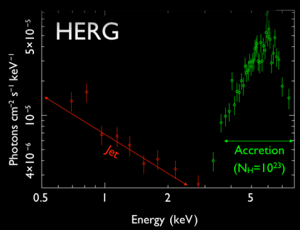


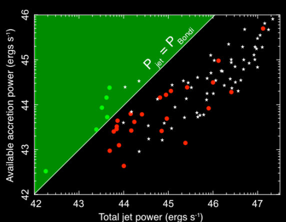
- Geometrically thick disks.
- Efficiency η increases with increasing disk thickness.
- Can easily suppress relativistically broadened Fe Kα line.

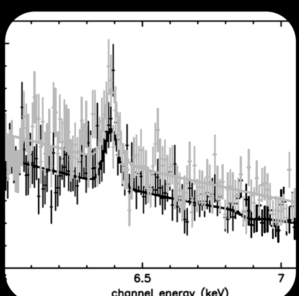
Tchekhovskoy et al. (2010, 2011, 2012)

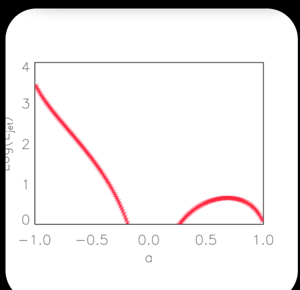
Summary











1. X-ray spectra reveal two distinct types: LERGs and HERGs

   LERGs show unabsorbed X-ray emission from a jet and no torus.

   HERGs show classic disk+torus characteristics.

   Different host galaxies, different environments, different histories?

2. Bondi accretion cannot power many LERGs and all HERGs

   Only the weakest FRI outbursts from LERGs can be powered by Bondi accretion; essentially no HERGs can be.

3. Cold gas mass does not correlate with jet power

   Necessitates a consideration of...

4. Black hole spin?

   Must reconcile models with the fact that RL AGN do not show disklines.

   Consistent with high scale-height disks coupled with rapidly spinning black holes.