AGN from low to high accretion rates

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In the local Universe

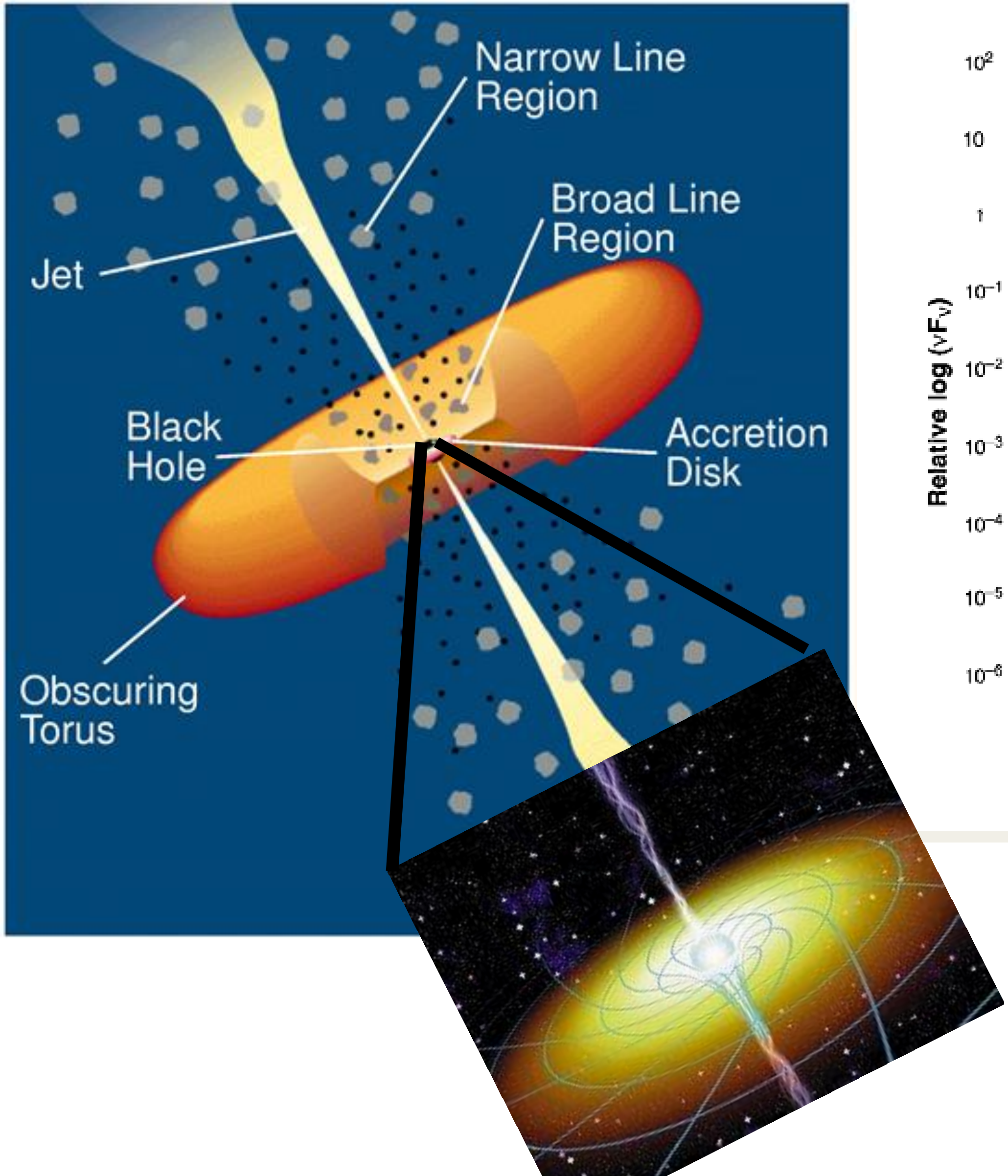
Luminous AGN : ~ 1% of all galaxies

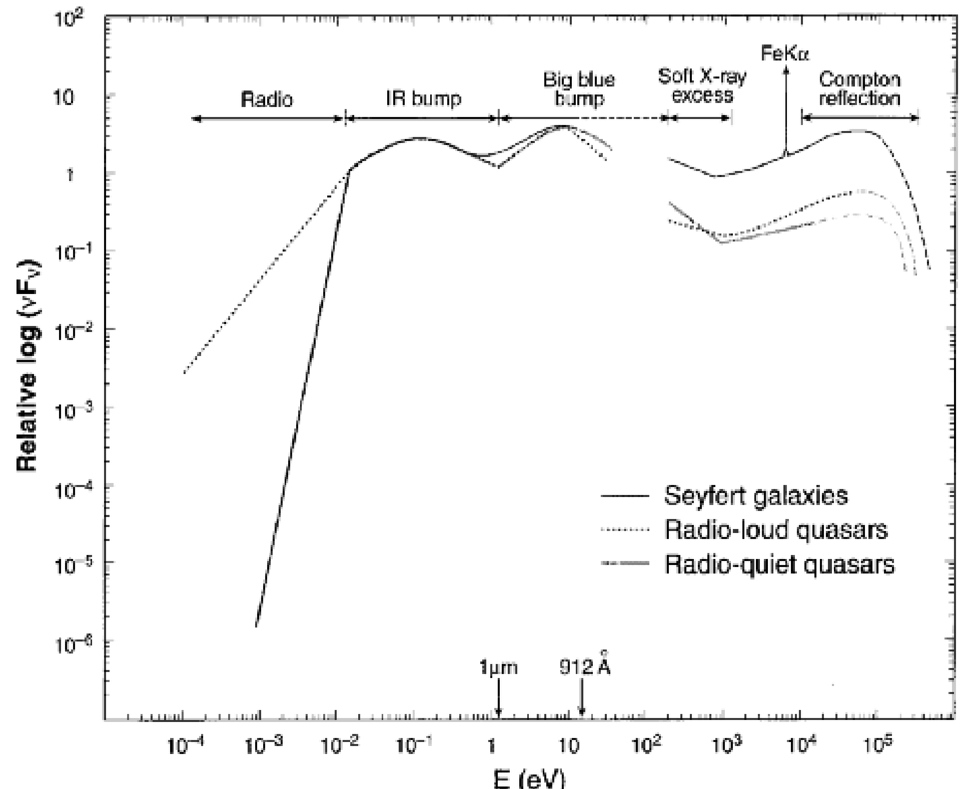
Low Luminosity AGN : ~ 40% of all galaxies

Dormant BH: 60% of all galaxies

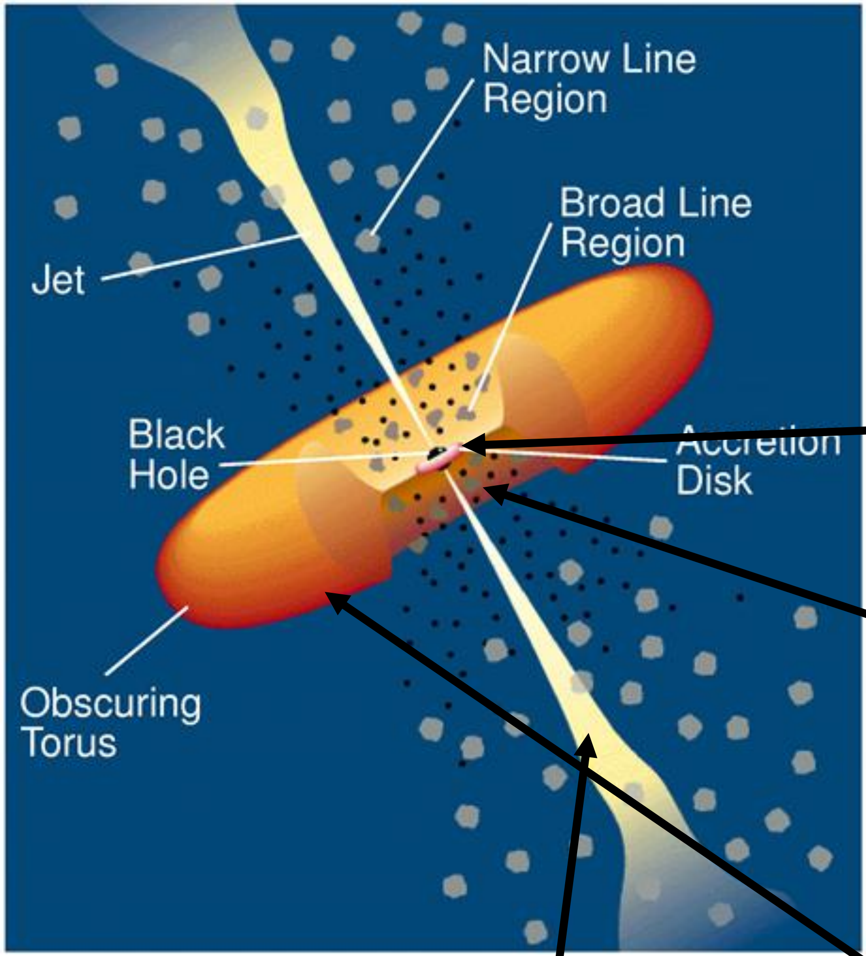
Ho (2008) – “Nuclear Activity in Nearby Galaxies”

Luminous AGNs generally show "universal" SED

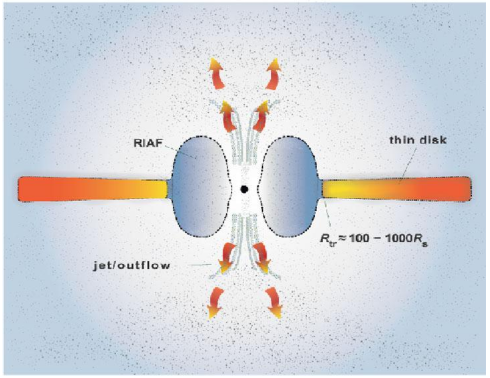




How does this picture change at low accretion rates?



Inefficient accretion flow



Lack of UV photons,

No radiation pressure to sustain the BLR

(Nicastro 2000)

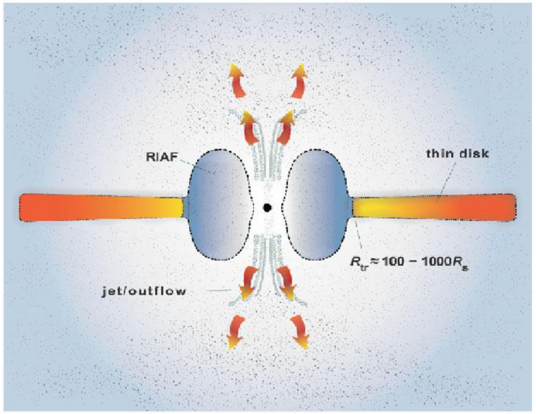
Receeding torus

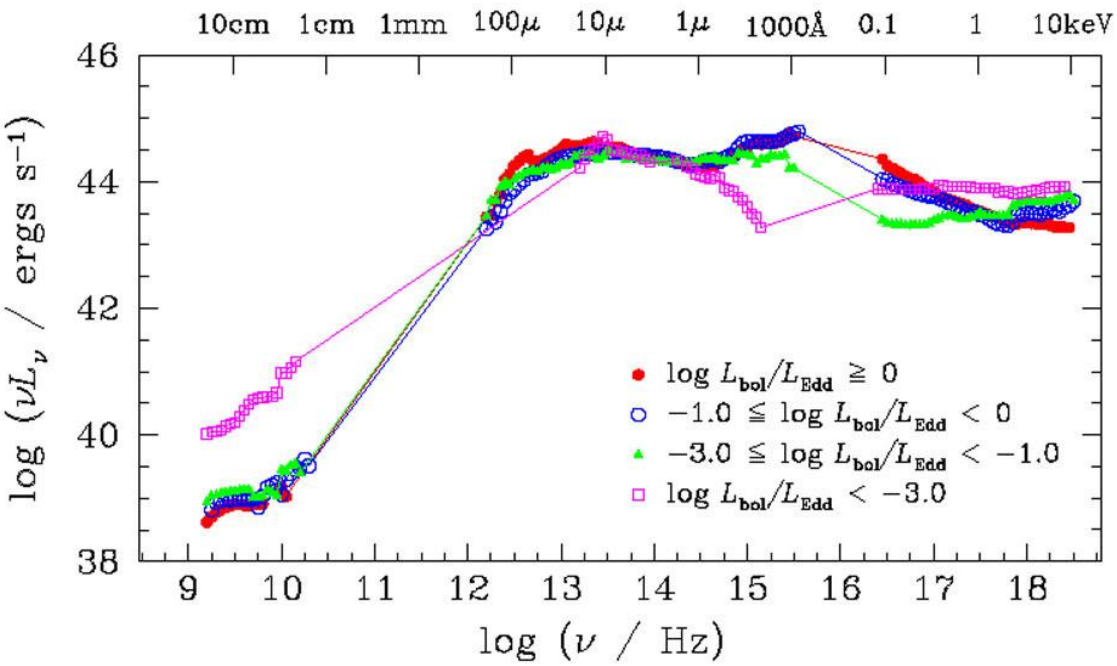
(e.g., Elitzur et al. 2008)

Ubiquitous jet?

(Nagar et al. 2002)

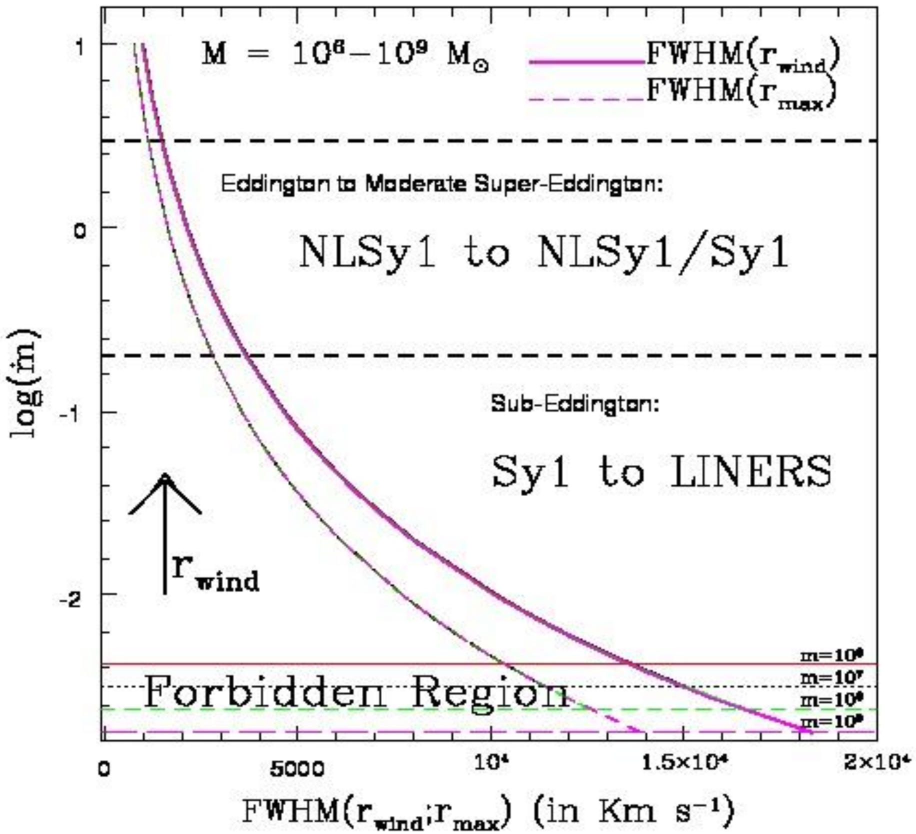
Lack of the ‘big blue bump’ feature





Ho (2008), Ho 1999

Nicastro 2000



the creation of the BLR is connected with disk instabilities occurring in proximity of a transition radius at which the accretion disk changes from gas-pressure dominated to radiation-pressure dominated

Since this transition radius becomes smaller than the innermost stable orbit for very low accretion rates (and therefore luminosities) → **<u>very weak AGN should lack the BLR</u>**

Certified “True” Type 2 Seyfert galaxies: no BLR?

NGC3147
$\log(L_{bol}/L_{Edd}) \sim -4$

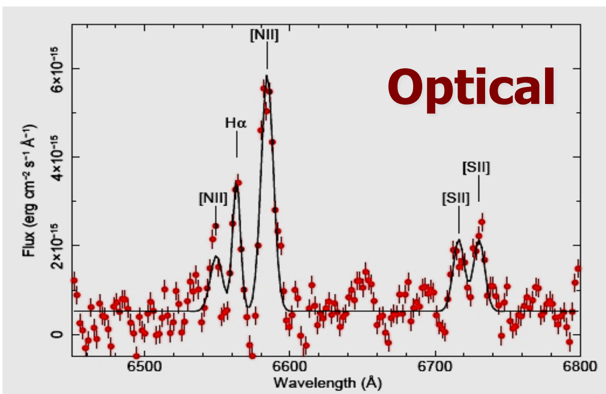
Bianchi et al. 2008

Q2131−427
$\log(L_{bol}/L_{Edd}) \sim -2.6$

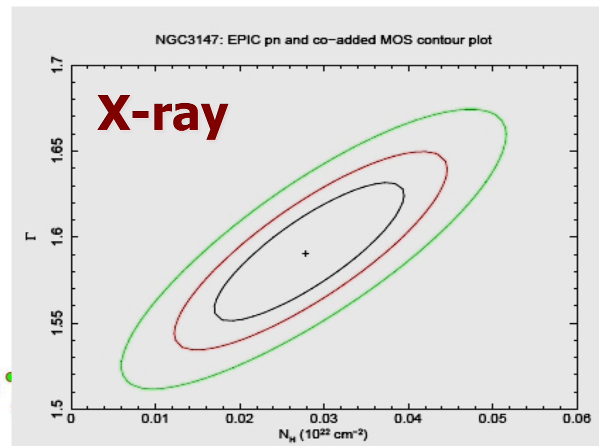
Panessa et al. 2010

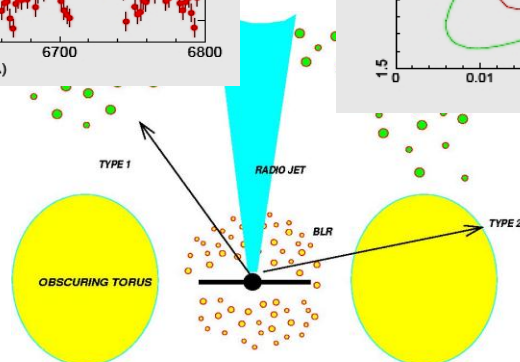
NGC3660
$\log(L_{bol}/L_{edd}) \sim -2$

Bianchi et al. in prep



No broad lines

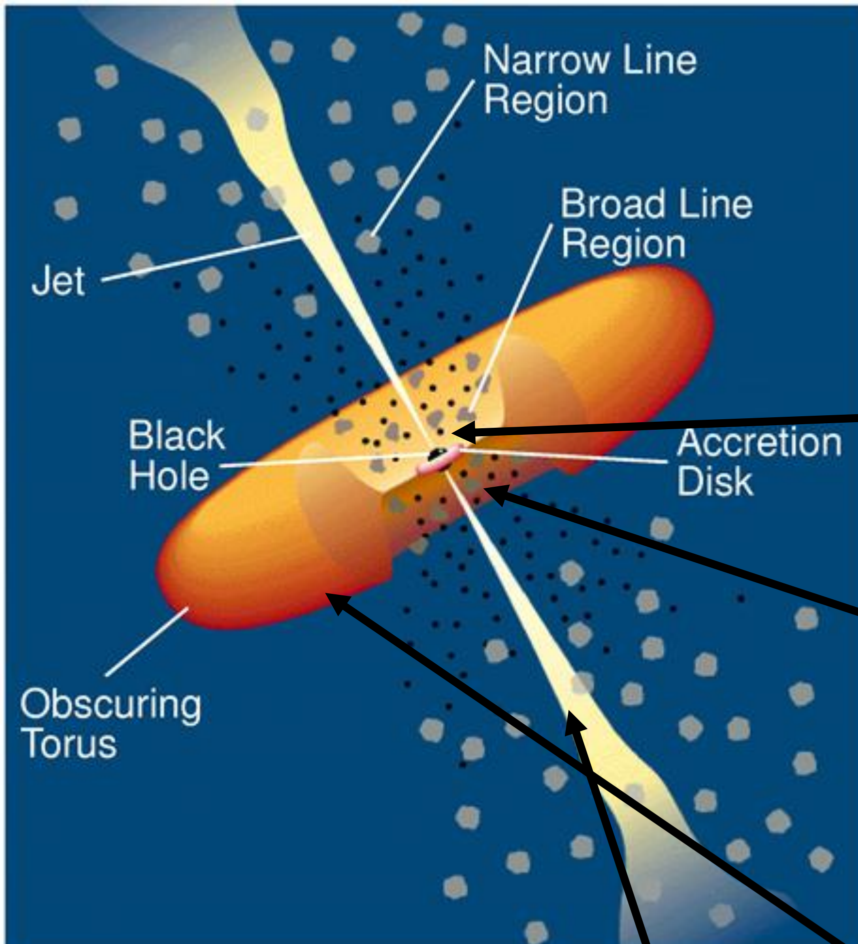




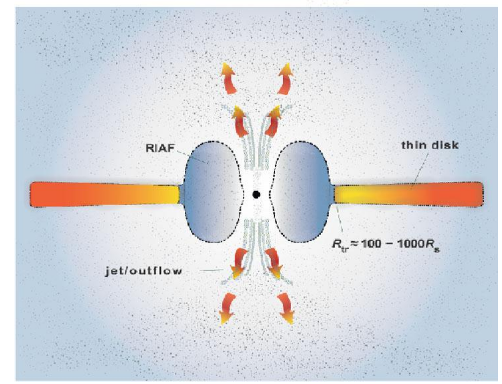
No gas to obscure BLR

Simultaneous observations: it's not an artefact of variability!

How does this picture change at low accretion rates?



Inefficient accretion flow



No BLR → however 25% of LINERs with BLR

(Ho 2008)

Ubiquitous jet?

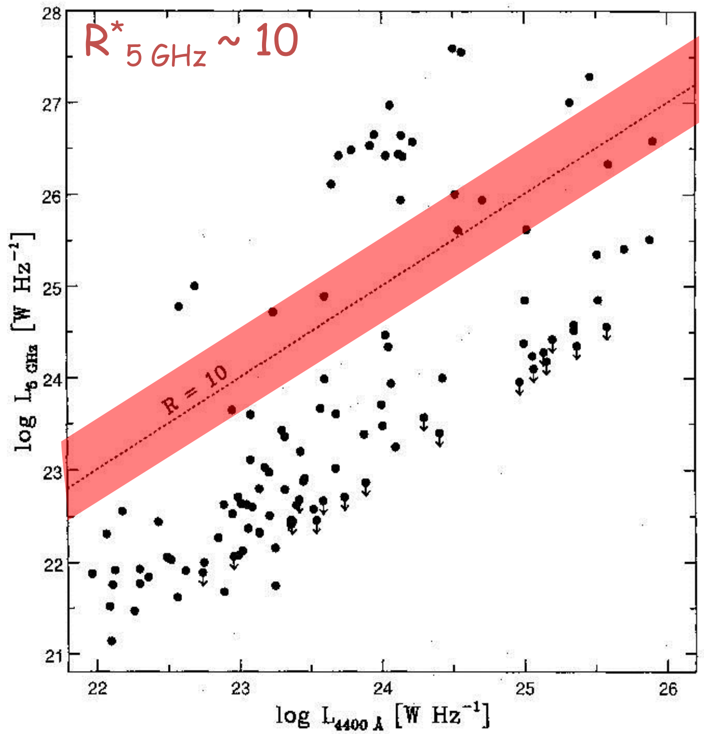
(e.g., Nagar et al. 2002)

Receeding torus

(e.g., Elitzur et al. 2008)

Radio Loud vs Radio Quiet AGN

Padovani 1993

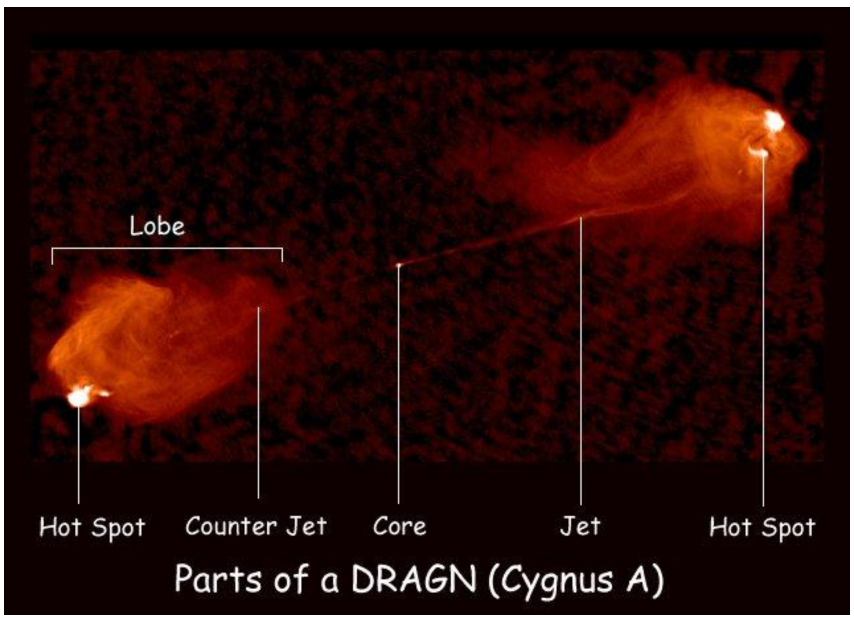


R = L(5 GHz) / L(B) --> Log R = 1 <u>RADIO LOUDNESS</u>

Radio Loud vs Radio Quiet

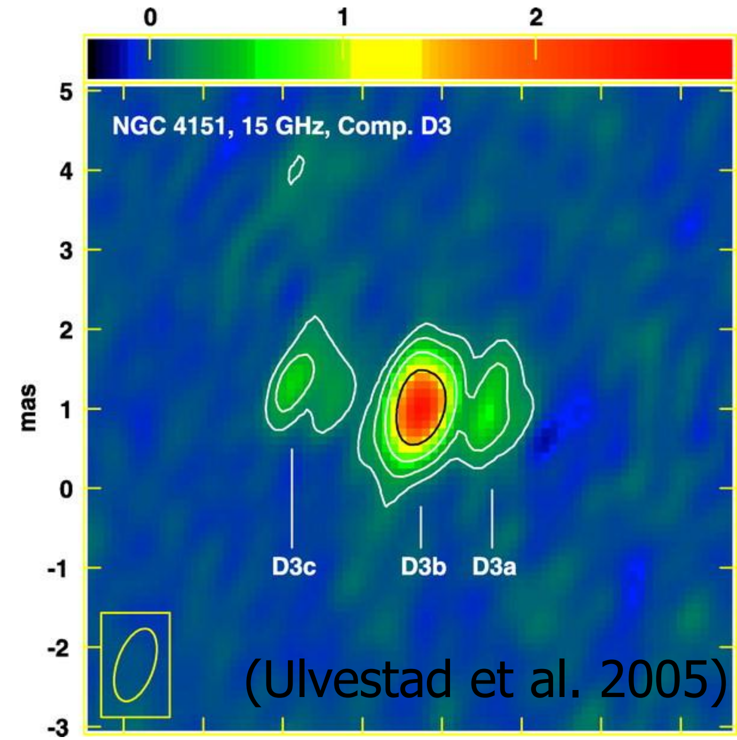
Radio Loud RL:

- ✓ Large scale radio lobes
- ✓ Compact luminous cores often with apparent luminal motions



Radio Quiet RQ:

- ✓ Faint radio sources
- ✓ Emission confined to sub-kpc scale



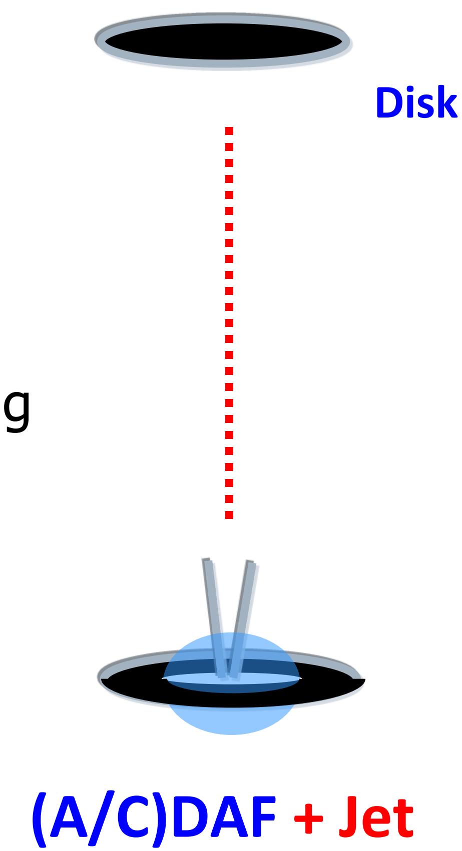
Accretion-ejection at low luminosities

→ Below a critical accretion rate
disks become radiatively inefficient
e.g., advection dominated: ADAFs, CDAFs, RIAFs

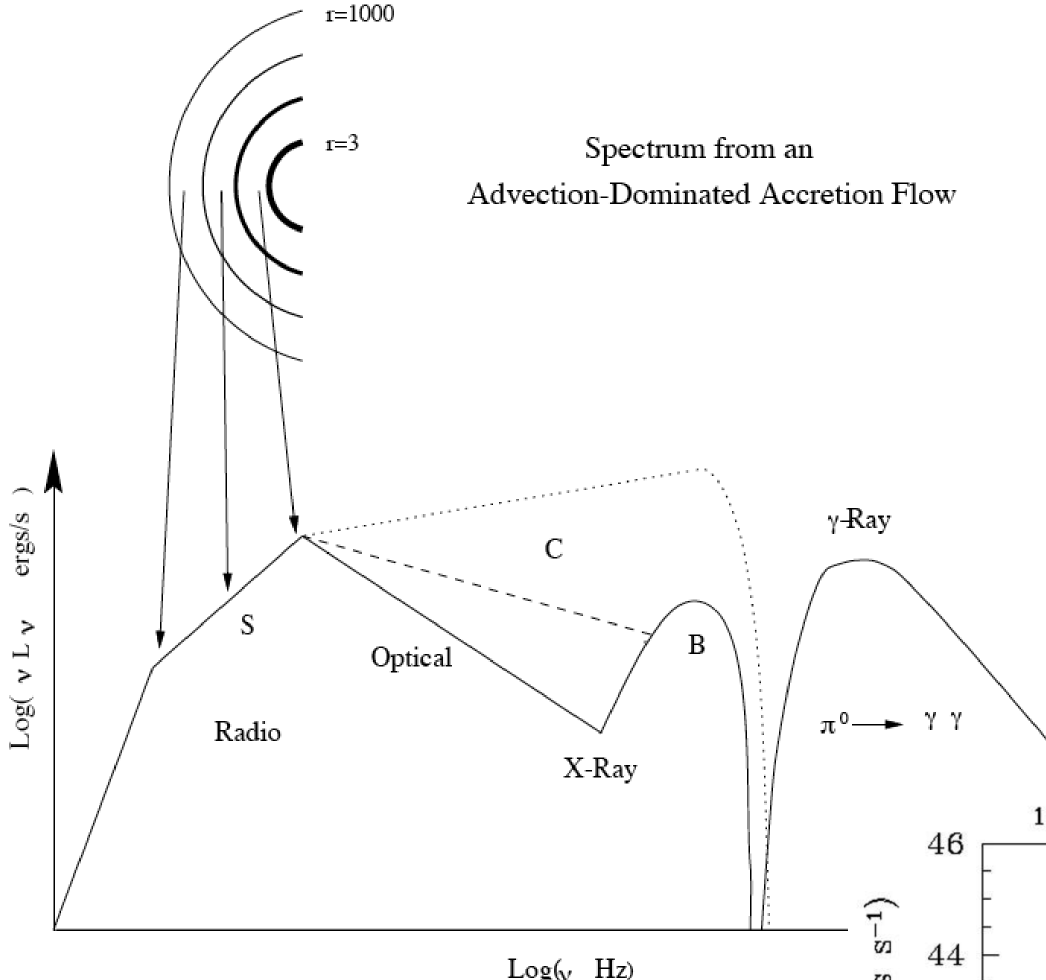
-> At lower accretion rates
disks become less and less prominent, jets remain strong

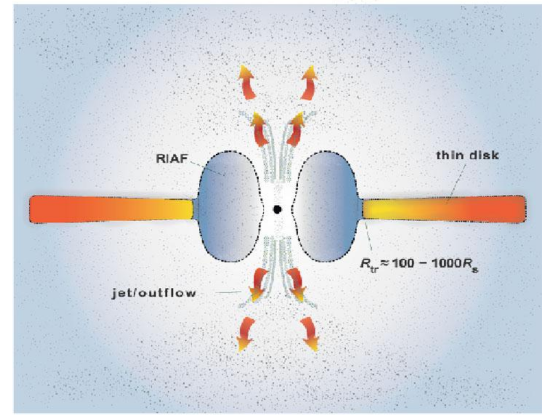
-> Radio Loud - Radio Quiet dichotomy caused by a switch of accretion mode - RQ appear only at high accretion rates

At low luminosity no dichotomy is expected (Nagar et al. 2002)

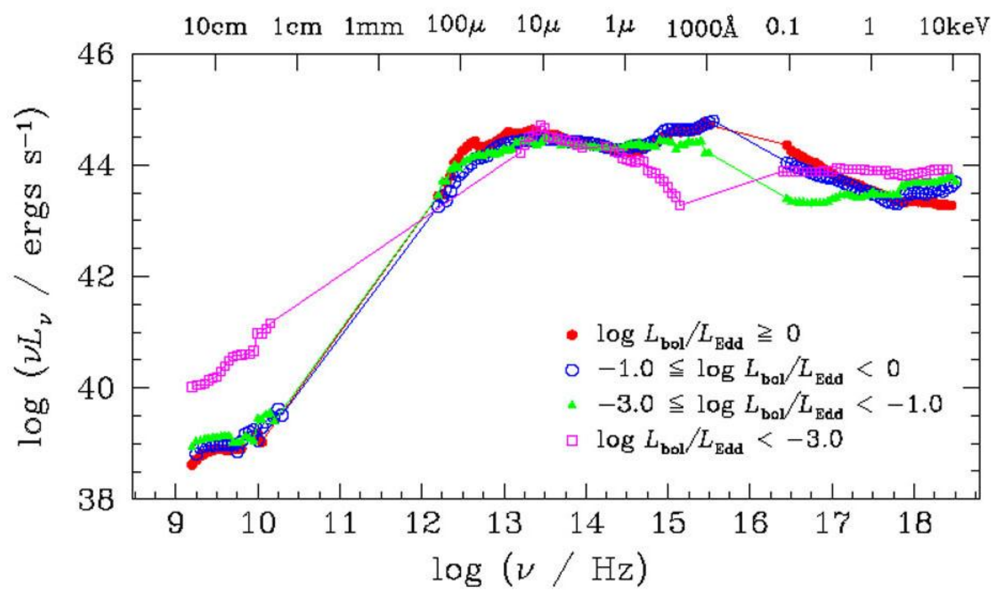


SED of LLAGN





Ho et al. in preparation

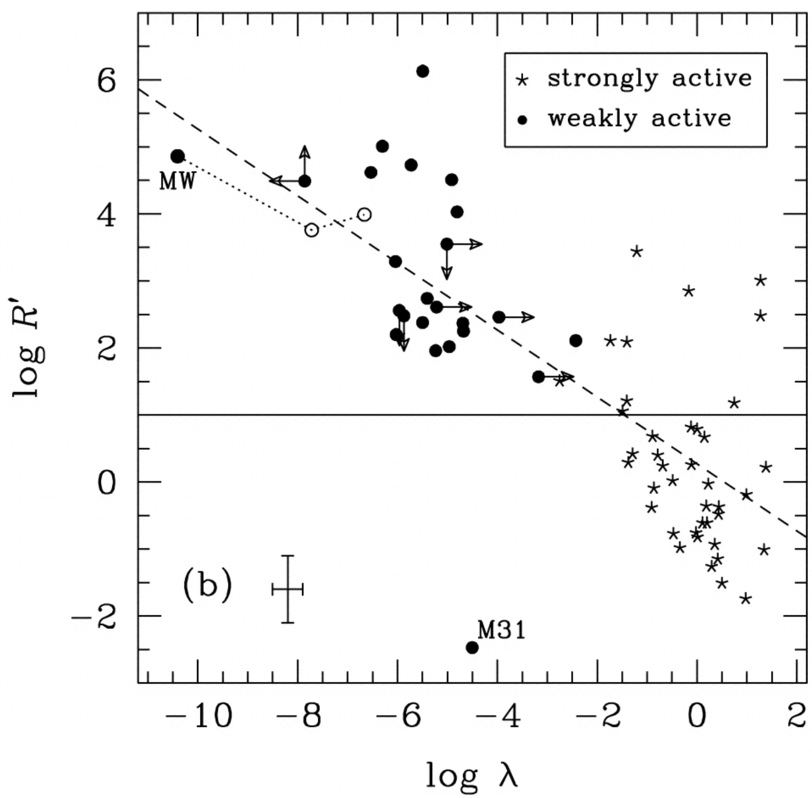


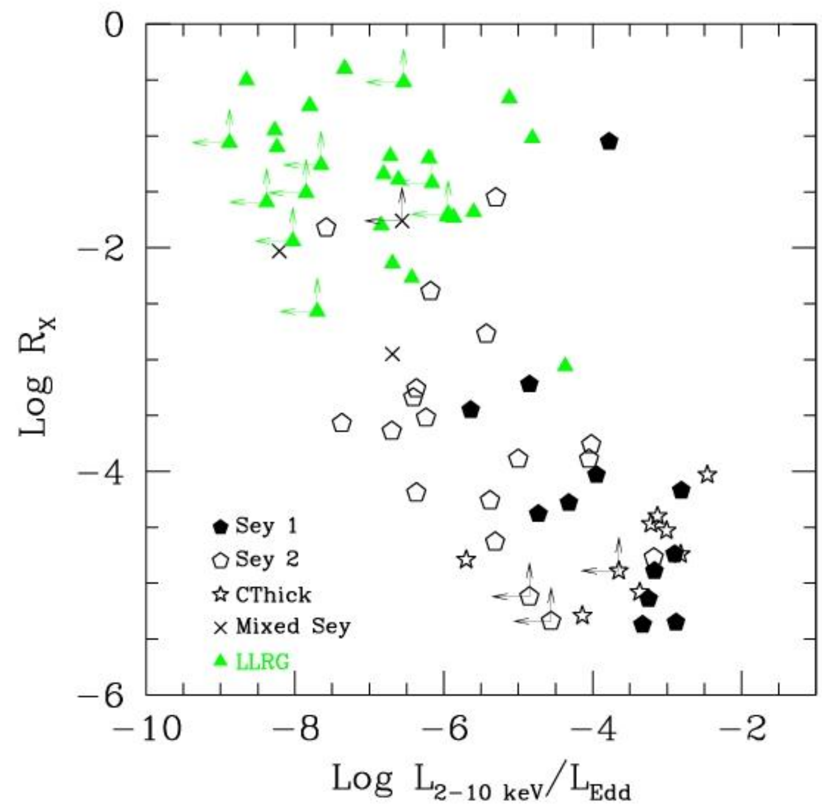
Radio emission higher than luminous RQ

→ LLAGN are radio-loud?

Radio Loudness versus accretion rate

Ho 2002; Terashima & Wilson 2003; Wang, Luo & Ho 2004; Greene, Ho & Ulvestad 2006; Panessa et al. 2007; Sikora, Stawarz & Lasota 2007



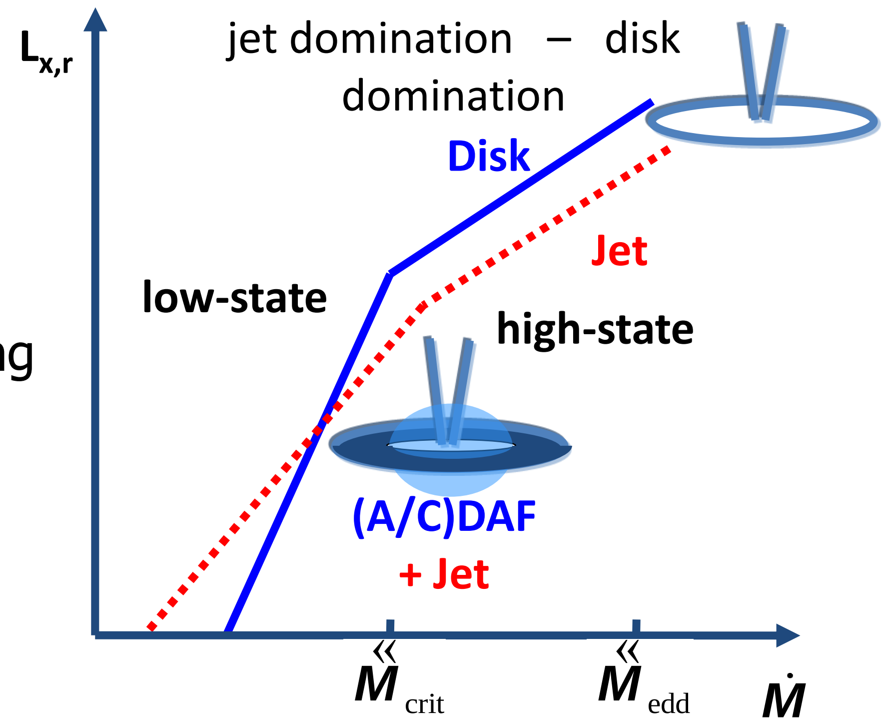


The formation of a jet in LLAGN is related to the accretion rate as in XRBs?

Cannot observe state transitions as in XRBs → AGN statistics

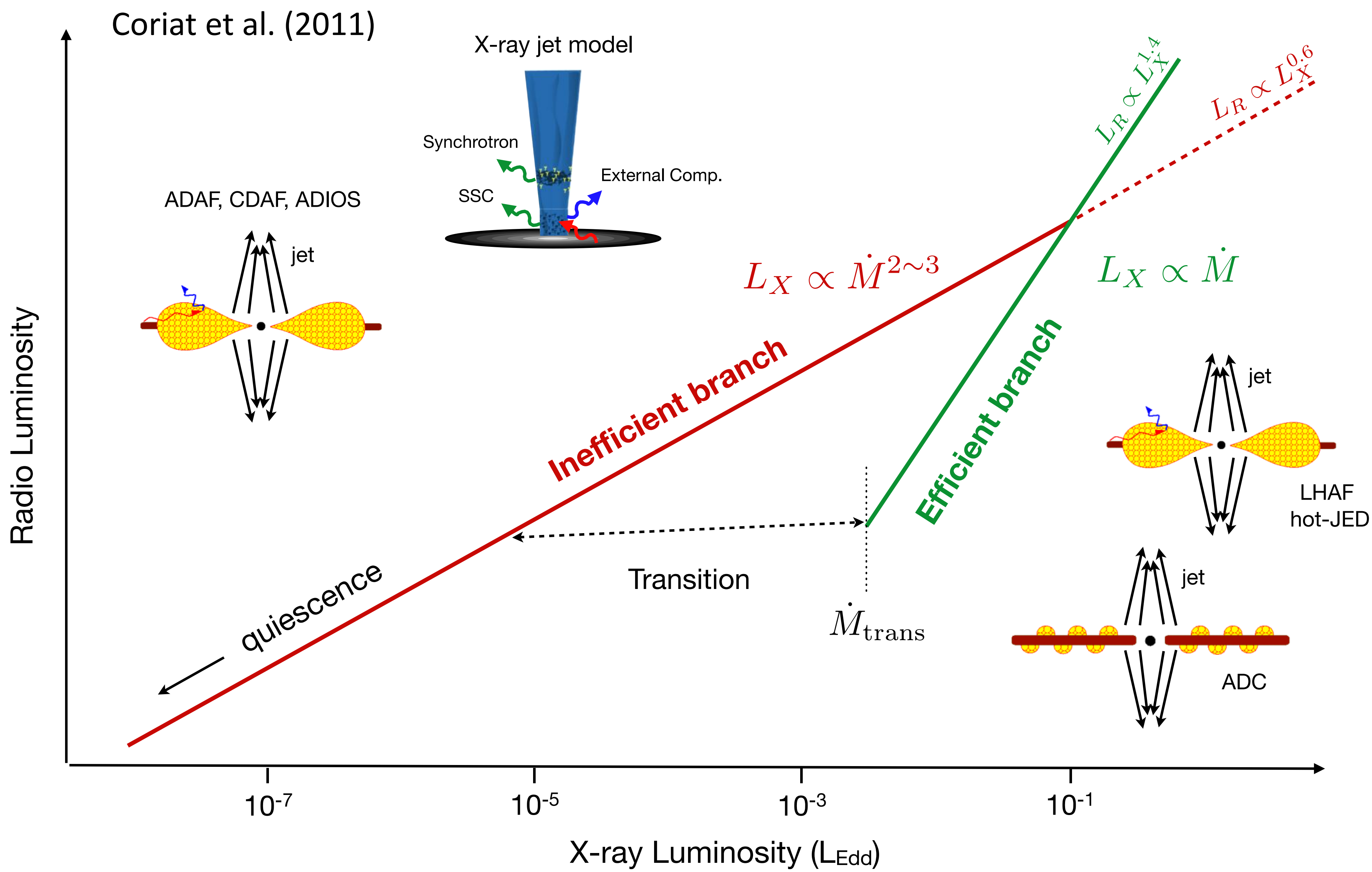
X-ray/radio emission vs accretion

How do X-ray and radio luminosities change depending on the accretion rate (and Luminosity)?



Körding, Falcke, & Markoff (2002);
see also Fender, Gallo, & Jonker (2003)

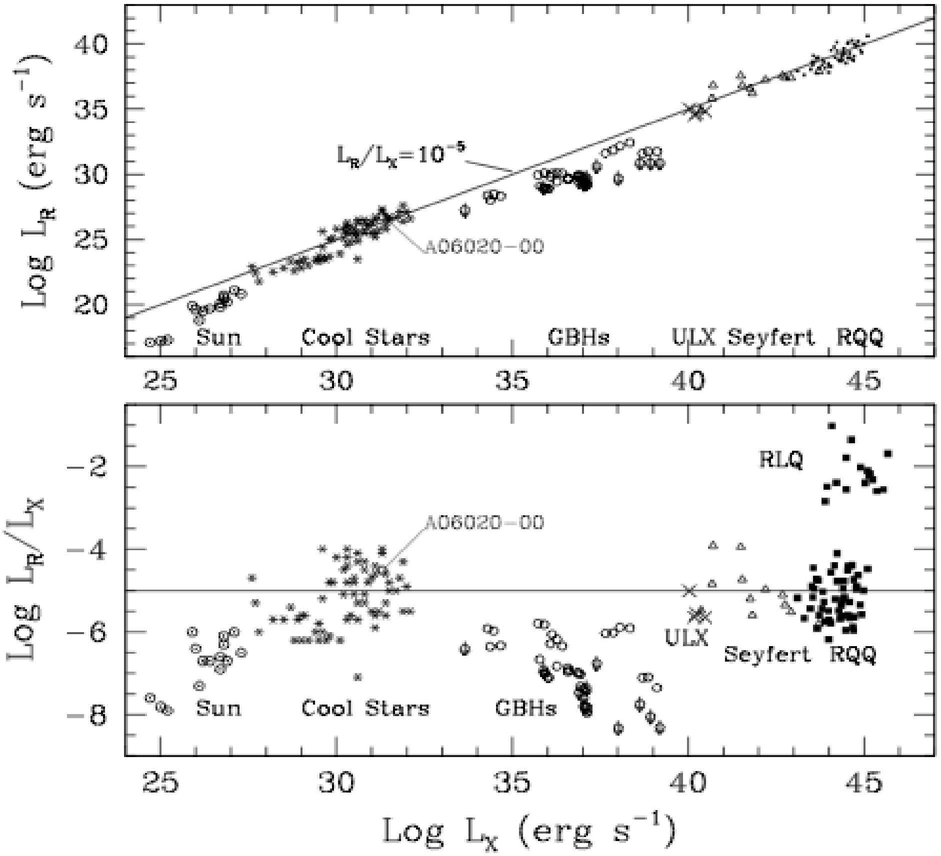
Analogy with black hole X-ray binaries



Hannikainen et al. (1998), Corbel et al. (2003), Gallo, Fender & Pooley (2003)

Scaling Relations: $L_{2\text{-}10\ keV}$ vs. L_{Radio}

(Laor & Behar 2008)

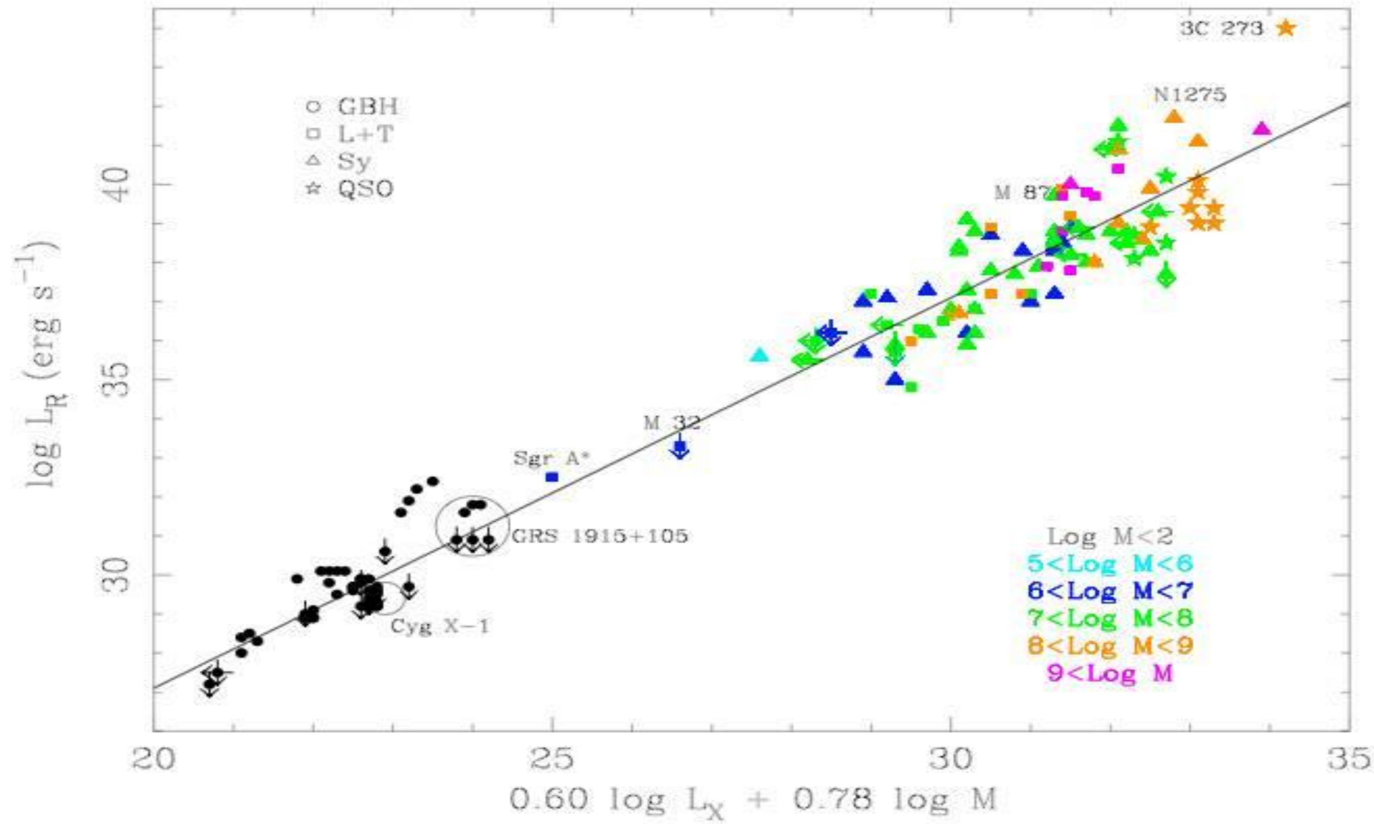


Correlation extended to bright AGN (PG QSOs)

Hypothesis: RQ AGN lie on the same relation as Coronally Active stars and radio emission originates from coronal mass ejections

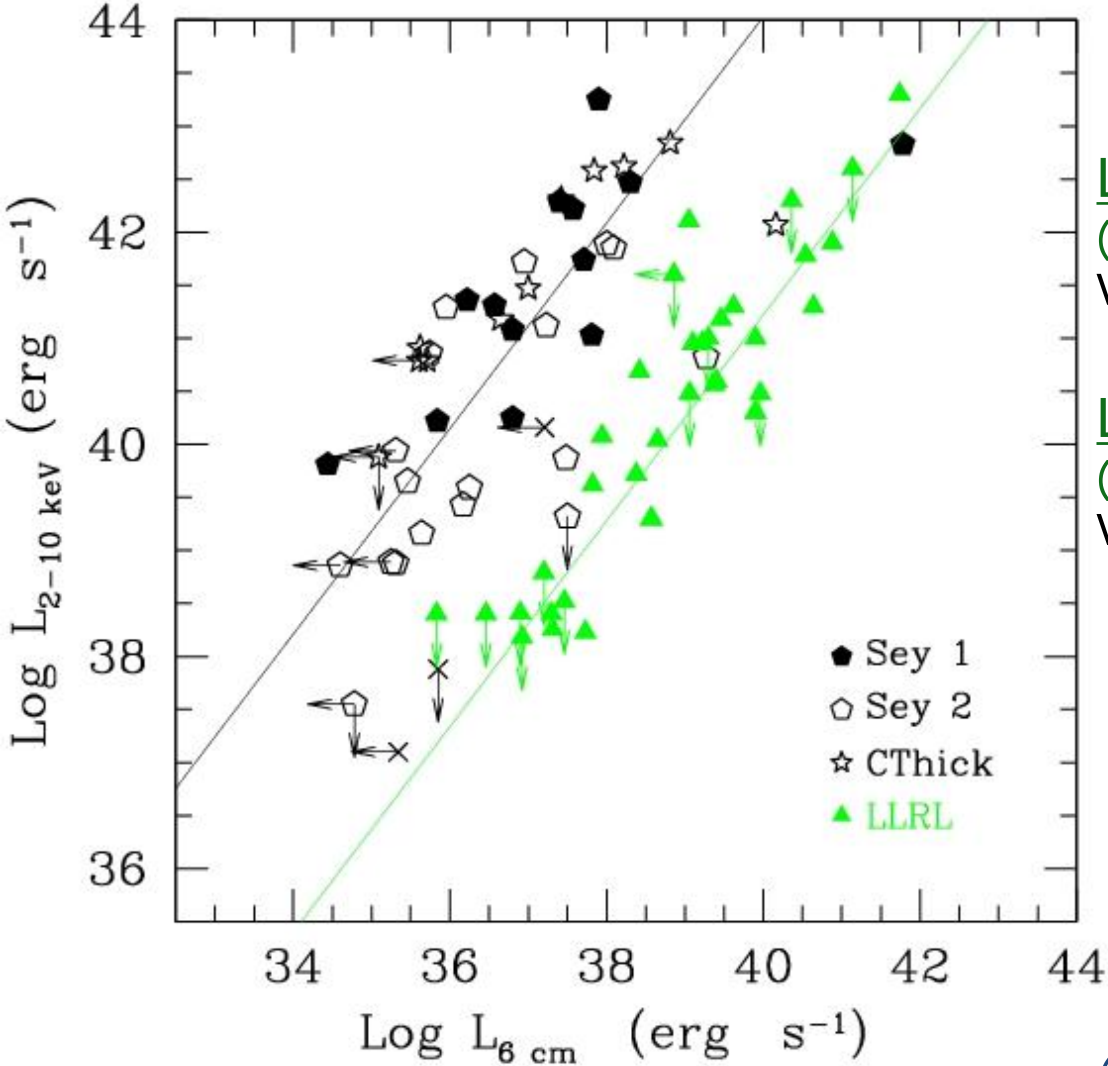
Fundamental plane for BH activity

Merloni et al. 2004, Falcke et al. 2004



- X-ray marginally consistent with optically thin synchrotron emission from a jet
- Radiatively inefficient accretion flows

Scaling Relations: $L_{2\text{-}10\ keV}$ vs. L_{Radio}



Low Luminosity Radio Galaxies
(Balmaverde&Capetti 2005)
VLA + Chandra

Low Luminosity RQ AGN (Palomar)
(Panessa et al. 2007 A&A)
VLA + Chandra/XMM

-> X-ray and radio from the same component?
-> Jet/outflow are disk related
(jet, disc-corona)

(Merloni et al. 2003, Ghisellini et al. 2004)

Origin of radio emission in Radio Quiet

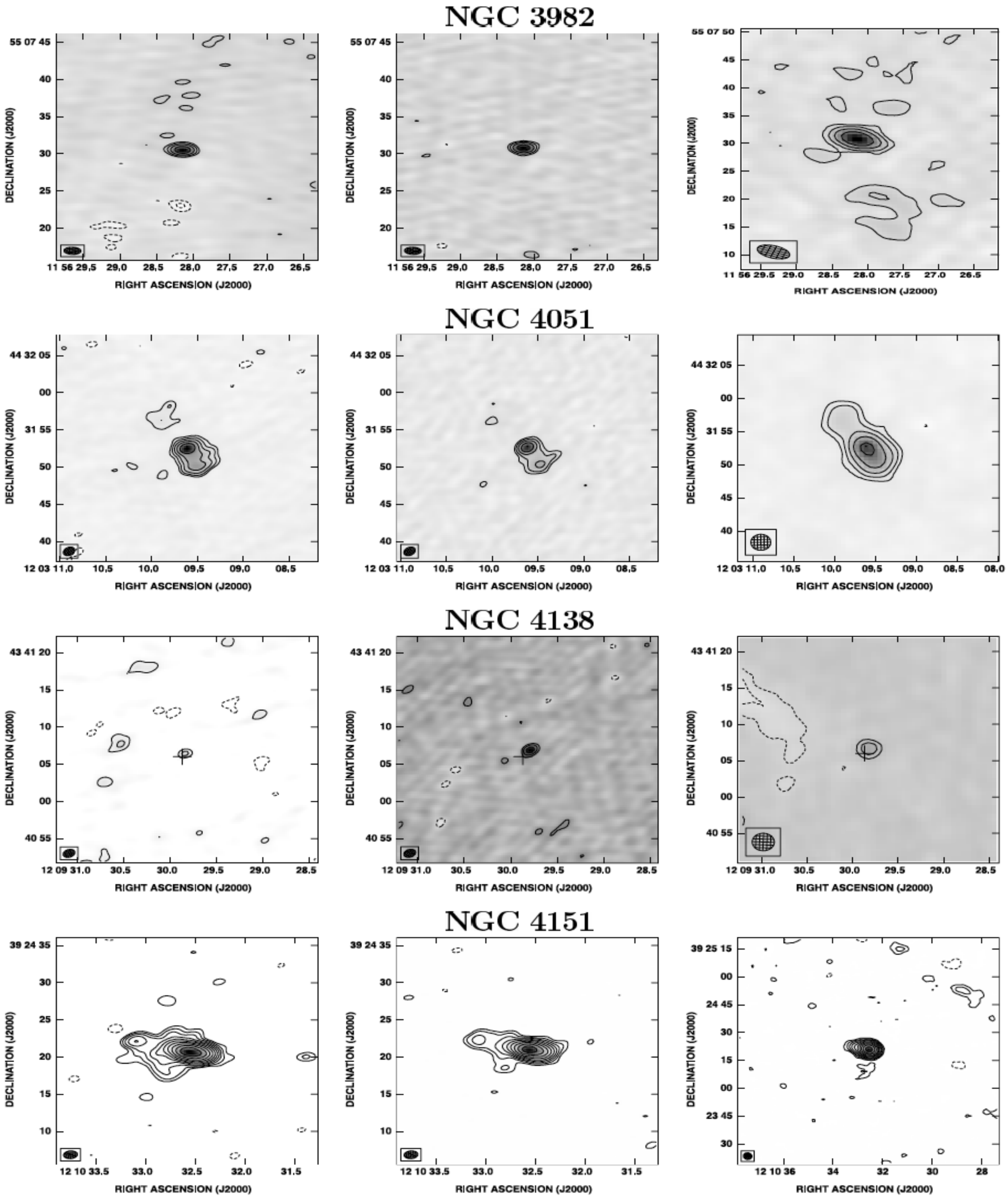
Possible physical mechanisms in Radio-Quiet:

- ✓ Synchrotron emission from a jet:
  - ✓ Relativistic? Sub-relativistic? Weak jet? Outflow?
- ✓ Free-free emission from a molecular torus or corona?
- ✓ ADAF? CDAF? RIAF? …

The LLAGN complete sample

- Optically selected sample of 28 nearby Seyfert galaxies (Cappi et al. 2006, D < 27 Mpc)

  -> 2-10 keV X-ray data (Cappi et al. 2006)
  -> NVSS (Panessa&Giroletti in prep)
  -> VLA 6,20 cm (Ho&Ulvestad 2000)
  -> VLBI 6,20 cm (Giroletti&Panessa 2009+ literature)



VLA Survey of Seyfert nuclei

(Ho&Ulvestad 2000):

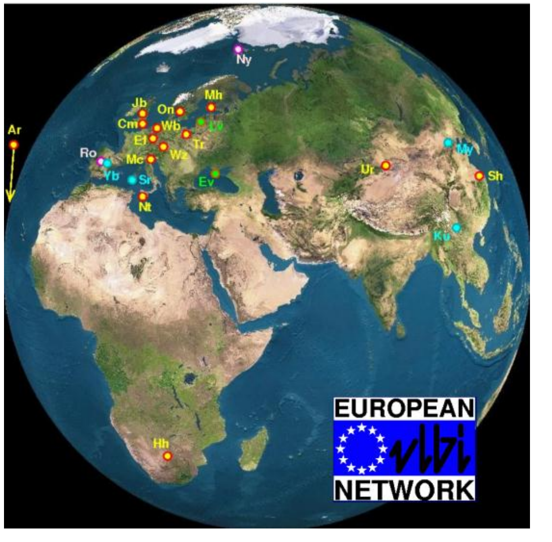
- 6 and 20 cm survey
- 0.12 mJy/beam – 1″
- Linear scales 10-100 pc
- 64% detected at 20 cm
- 82% detected at 6 cm
- Compact unresolved cores + extended linear structures
- Spectral slopes from steep to flat/inverted

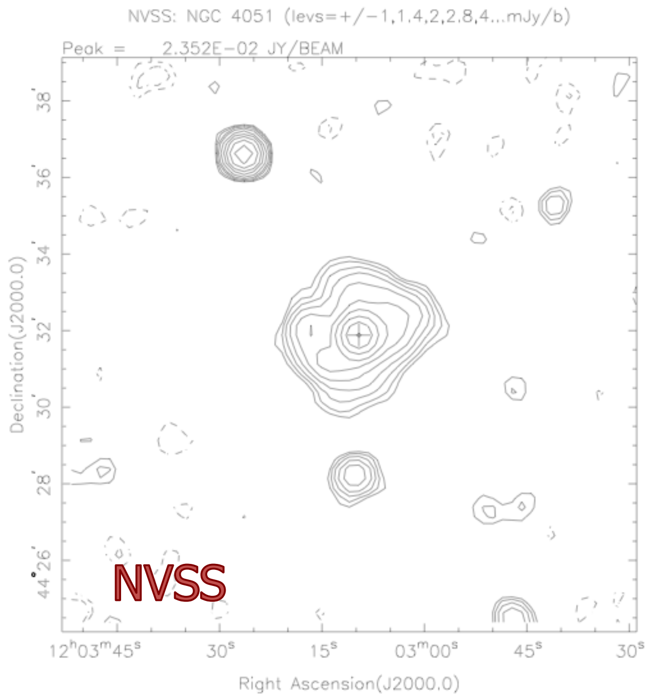
VLBI Observations of a distance limited Complete Sample of Seyferts

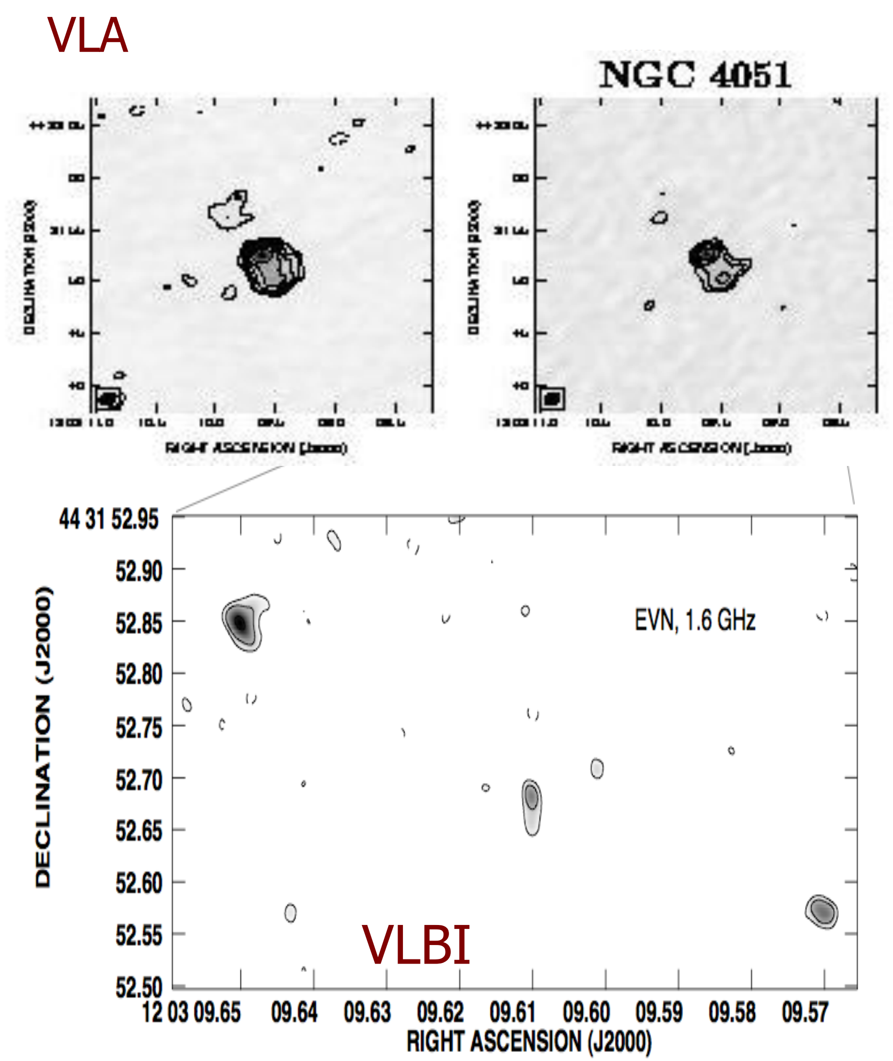
- Complete sample of 28 Seyfert nearby galaxies

- For the first time sources with S < 1 mJy (VLA cores)

- European VLBI Network new observations to complete the sample at mas scales of 23/28 nuclei



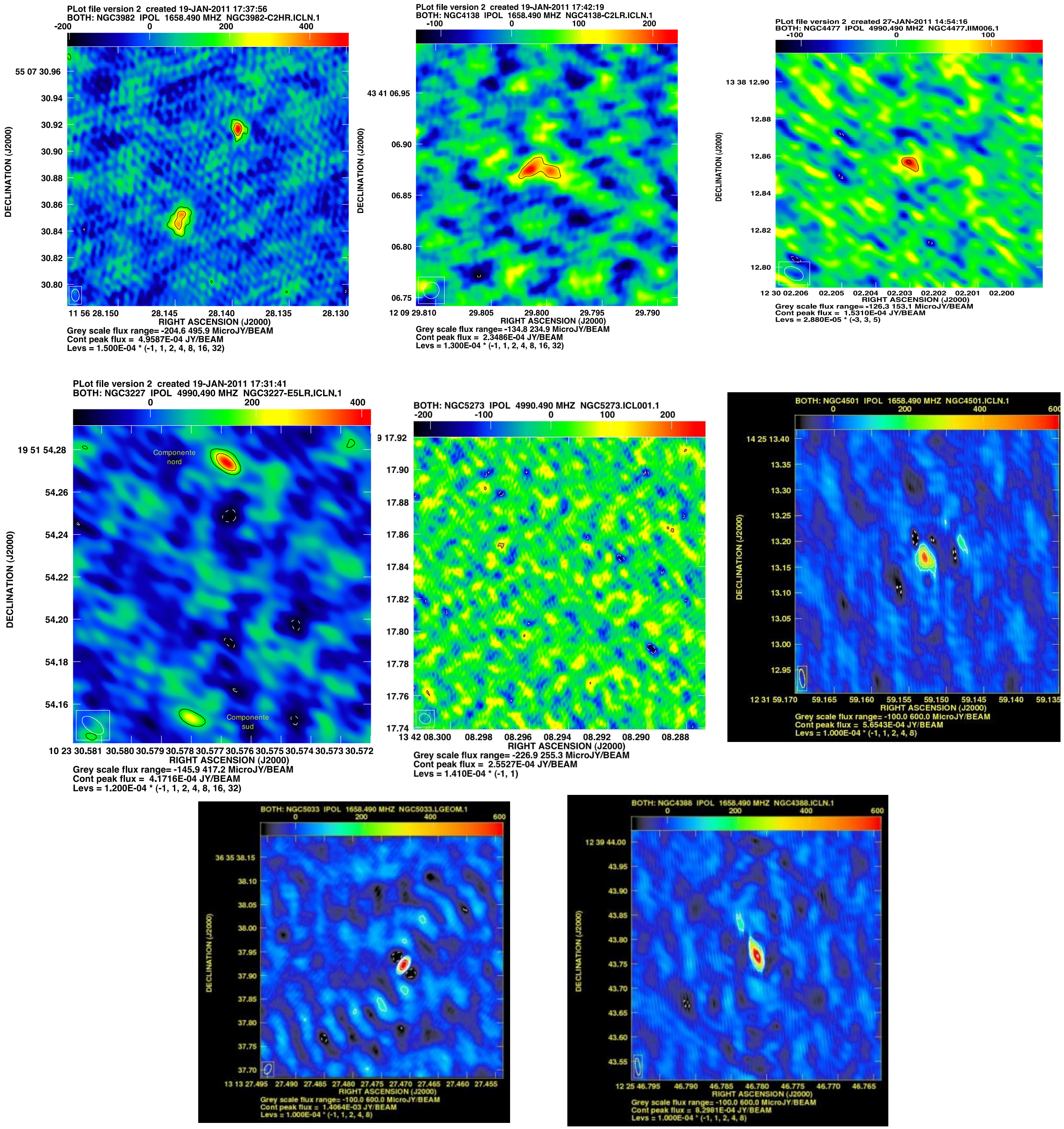




NVSS → up to tens of kpc

VLA → tens of pc up to kpc scales

VLBI < 0.1 pc



VLBI Survey of Seyfert nuclei

- 6 and 20 cm survey
- 90 microJy/beam
- Linear scales 0.05 pc @10 Mpc

Giroletti&Panessa 2009, Bontempi et al. submitted, Panessa&Giroletti 2012 in prep

VLBI Morphology

- ✓ Single compact
- ✓ Double at one freq.
- ✓ Double at both freq.
- ✓ Jet like structure
- ✓ Non detection (8/23)

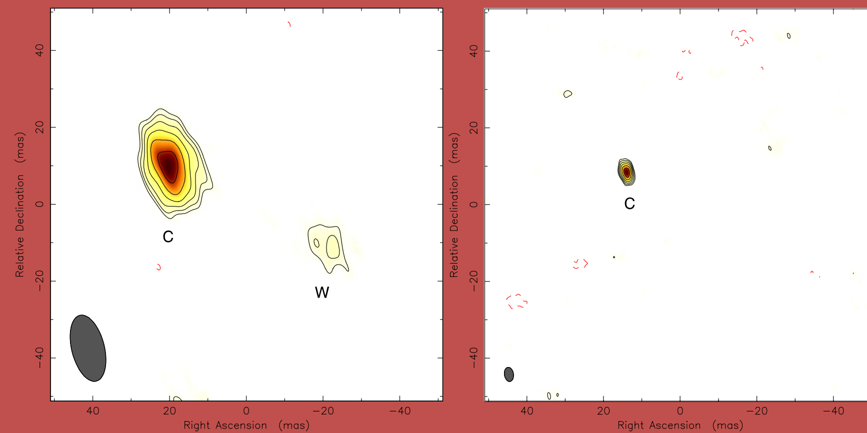


Figure 3. NGC 4138 at 1.7 GHz (left) and 5 GHz (right). Contours are traced at $(-1, 1, 2, 4, \ldots)\times$ the $\sim 3\sigma$ noise level, which is 0.14 and 0.09 mJy beam^{-1} at 1.7 and 5 GHz, respectively. HPBW are shown in the lower left corner, and their size is 8.5 mas $\times$ 17.7 mas in P.A. 14° and 2.4 mas $\times$ 3.7 mas in P.A. 8° at 1.7 and 5 GHz, respectively.

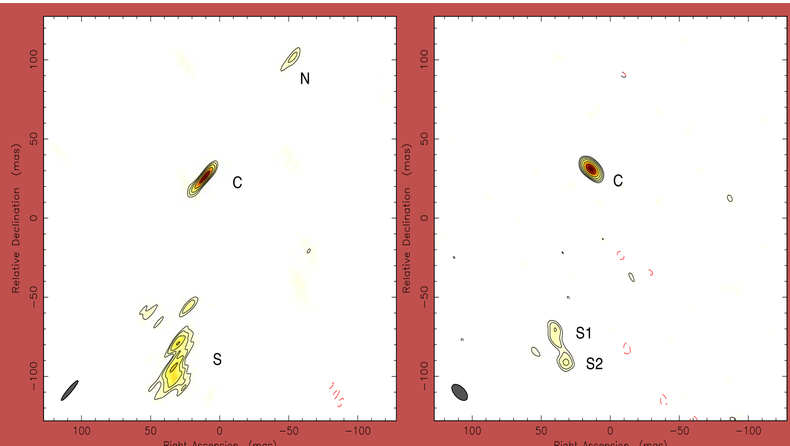


Figure 1. Images of NGC 3227 at 1.7 GHz (left) and 5 GHz (right). Contours are traced at $(-1, 1, 2, 4, \ldots)\times$ the $\sim 3\sigma$ noise level, which is 0.13 and 0.08 mJy beam^{-1} at 1.7 and 5 GHz, respectively. HPBWs are shown in the lower left corner, and their size is 2.9 mas $\times$ 17.3 mas in P.A. -44° and 7.2 mas $\times$ 13.5 mas in P.A. 50° at 1.7 and 5 GHz, respectively.

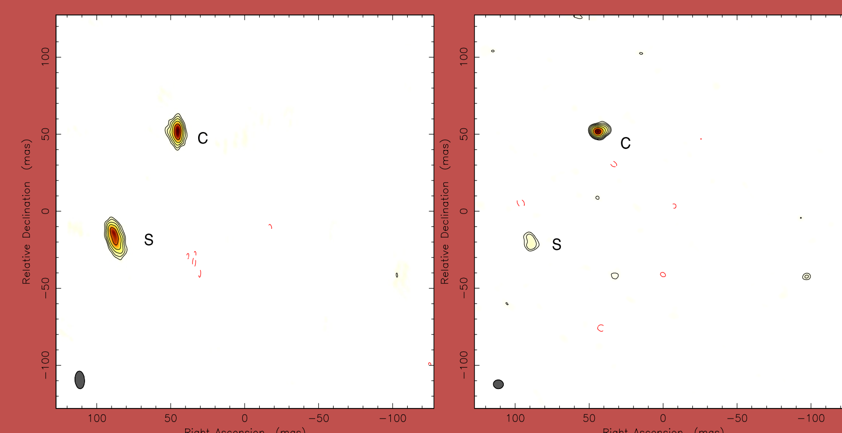


Figure 2. NGC 3982 at 1.7 GHz (left) and 5 GHz (right). Contours are traced at $(-1, 1, 2, 4, \ldots)\times$ the $\sim 3\sigma$ noise level, which is 0.20 and 0.09 mJy beam^{-1} at 1.7 and 5 GHz, respectively. HPBW are shown in the lower left corner, and their size is 6.4 mas $\times$ 11.4 mas in P.A. 4° and 5.7 mas $\times$ 6.8 mas in P.A. 85° at 1.7 and 5 GHz, respectively.

Are radio cores ubiquitous?

At 20 cm (1.4 GHz):

- NVSS : 26/28 (93%)
- VLA : 18/28 (64%)
- VLBI : 12/21 (57%)

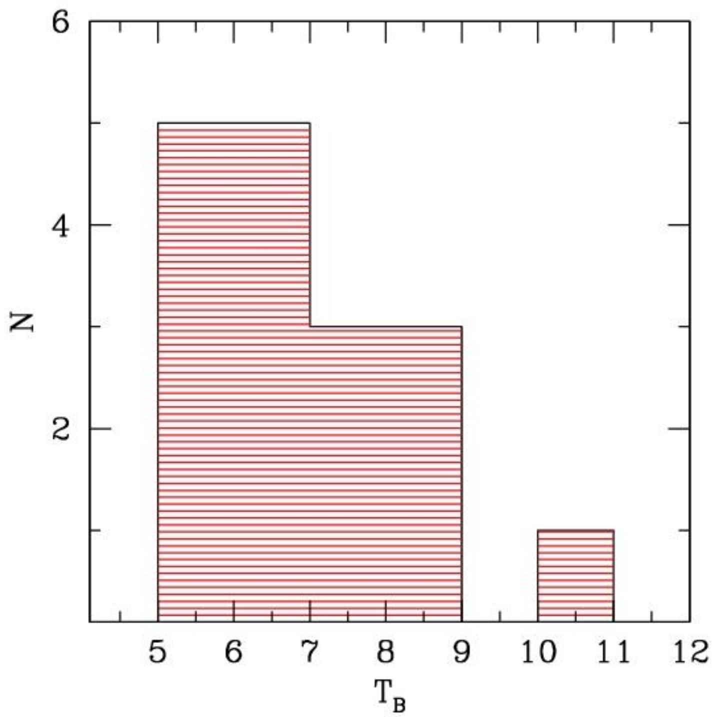
At 6 cm (5 GHz):

- VLA : 23/28 (82%)
- VLBI : 15/23 (65%)

Lower detection rate with respect to VLA
Radio Quiet nuclei are less ubiquitous at
VLBI spatial scale resolution

Brightness Temperatures and Spectral Slopes

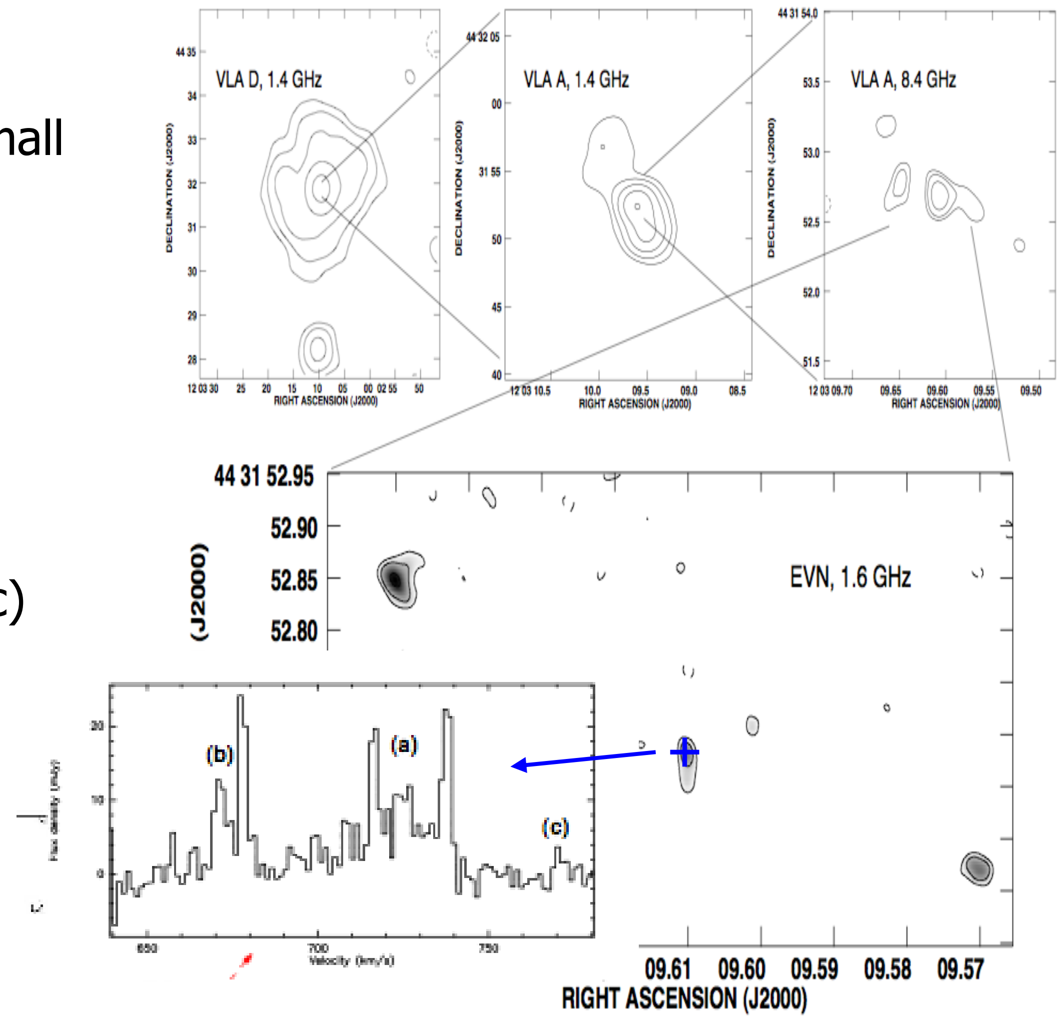
- Peak at relatively low brightness temperature:
  - thermal vs non-thermal



- Radio spectral slope equally distributed between steep, flat and inverted:
  - no correlation between the slope and the optical spectral class type1 vs type2

The Narrow Line Seyfert 1 NGC 4051

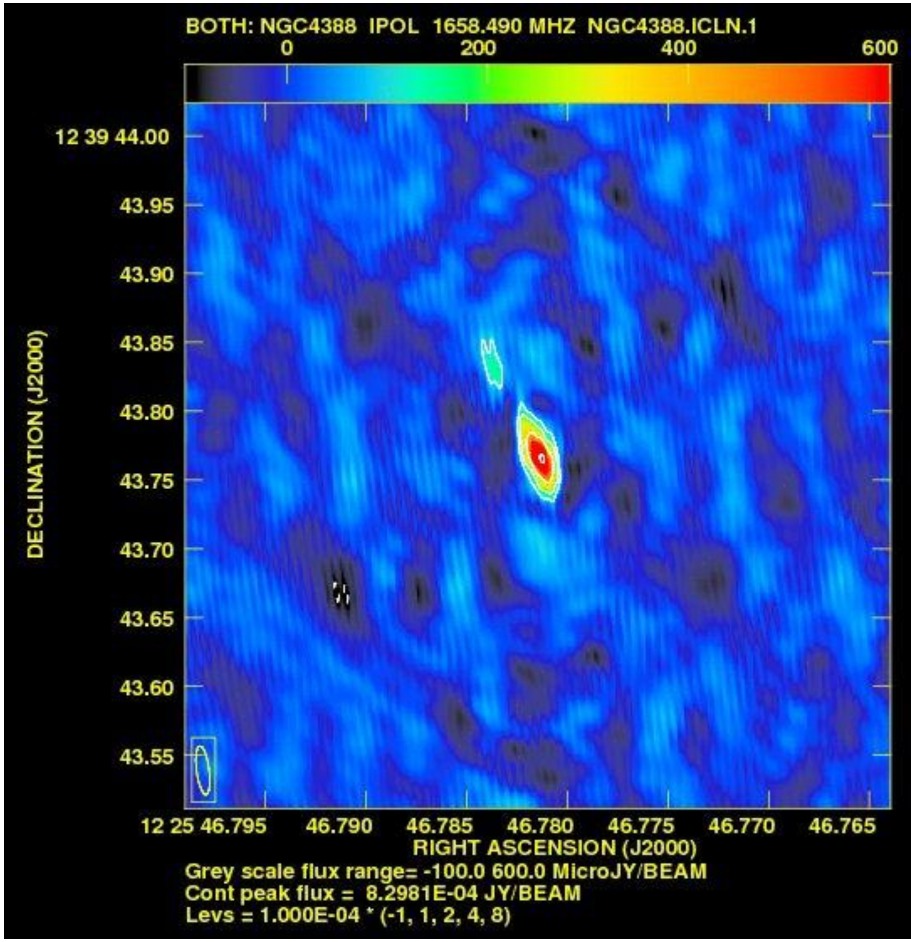
- ✓ At 1.6 GHz 3 sub-mJy components:
  - ✓ Two associated with the VLA small scale double structure
  - ✓ Third is symmetric to the easternmost one
- ✓ Steep spectral index (α = 0.7)
- ✓ $T_B = 10^5$ K - linear size < 0.31 pc (compared to the BLR size 0.006 pc)
- ✓ Log $L_{5\ GHz}/L_{2\text{-}10\ keV}$ < -5.8
- ✓ Log L_X/L_{EDD} =-3.4
- ✓ H_2O Maser coincident with core



Jet base? thermal emission from an outflow/molecular disk/nuclear wind

Type 2 Seyfert: NGC 4388

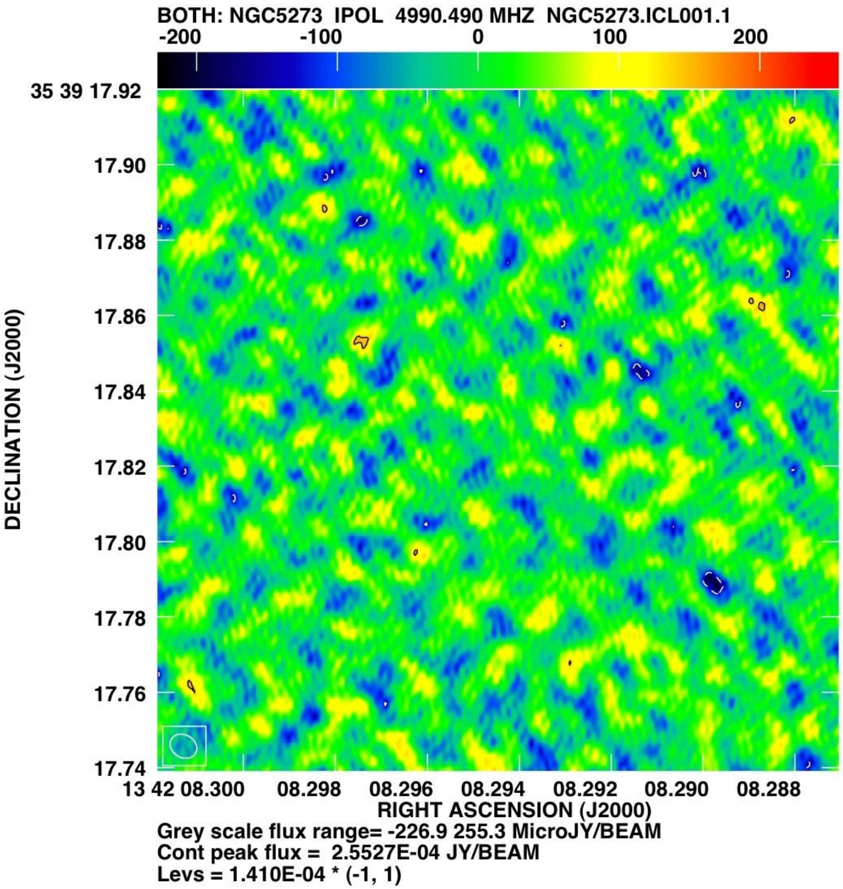
- ✓ Type 1.9 Seyfert galaxy
- ✓ Several VLA detections up to 15 GHz, flat spectrum (Falcke et al. 1998)
- ✓ Detected at 1.6 GHz (not at 5 GHz) -> very steep $\alpha > 1.3$
- ✓ Compact radio emission at 1.3 mJy
- ✓ Extension of 6 mas (0.48 pc)
- ✓ $T_B = 1.3 \times 10^6$ K
- ✓ H_2O Maser emission
- ✓ Log $L_{5\ GHz}/L_{2\text{-}10\ keV} < -6.1$ & Log $L_X/L_{EDD} = -3.17$



No ADAF (steep α, $10^6\ R_S$) --> Free-free emission from the torus?

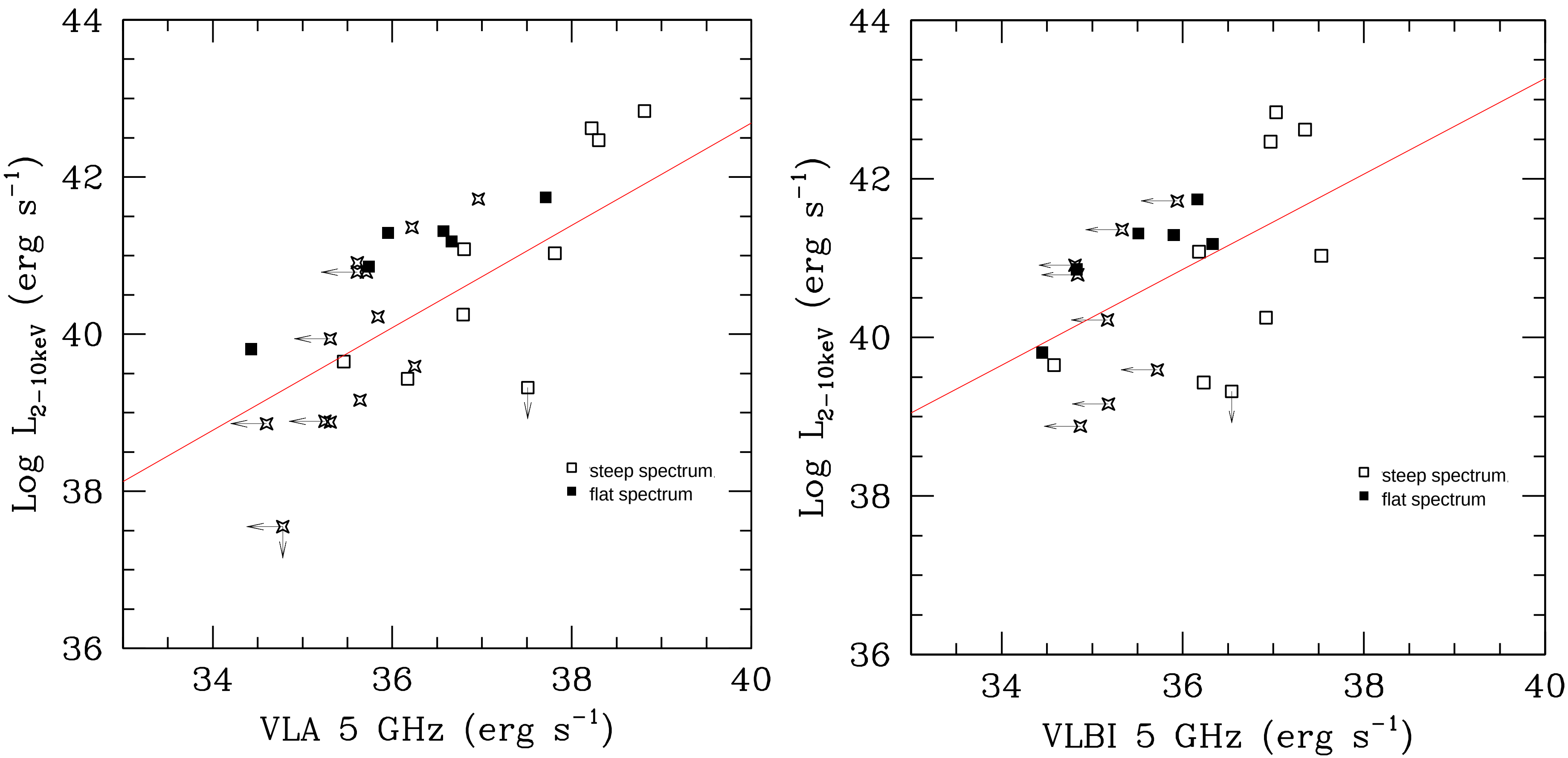
Type 1 Seyfert: NGC 5273

- ✓ Sy 1.5 VLA detection (S= 0.6 mJy, Nagar+99) at 8 GHz, an unresolved flat component
- ✓ EVN non detection!!!
  (3 σ peak < 90 microJy at 1.6 GHz)
  - 95 % of the VLA flux resolved at 20-300 mas scale
  - significant variability
- ✓ Log $L_{5\ GHz}/L_{2\text{-}10\ keV}$ < -6
- ✓ Log L_X/L_{EDD} =-3.2



Resolved radio emission or variable radio source?

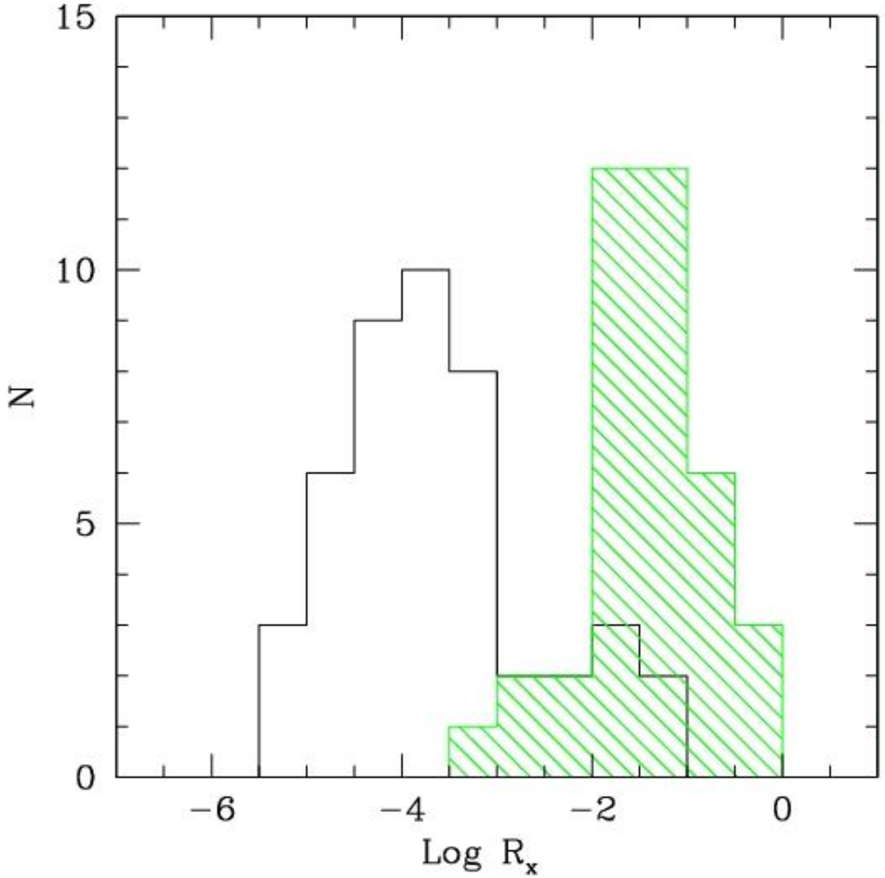
X-ray versus Radio correlation



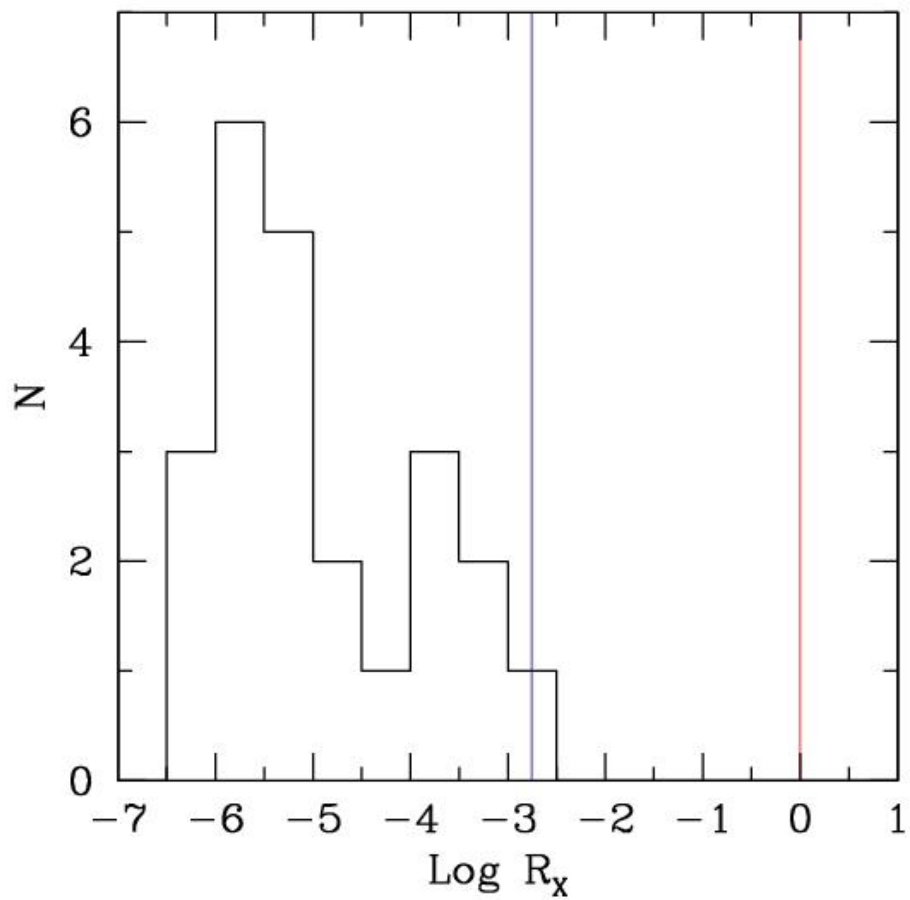
No significant correlation at VLBI sub-pc scales

X-ray radio loudness

R_X = L(5 GHz) / L(2-10 keV)



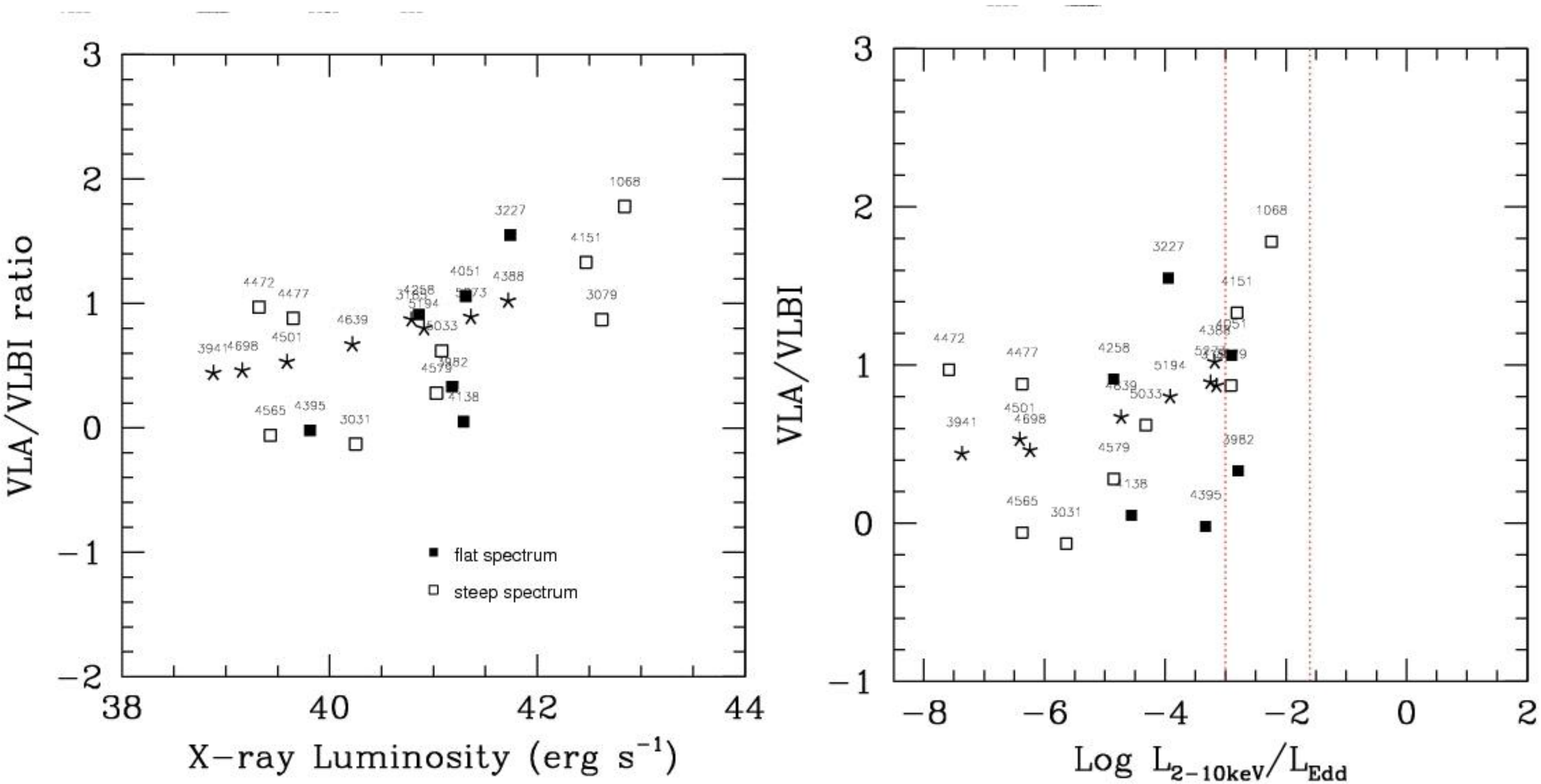
VLA radio data



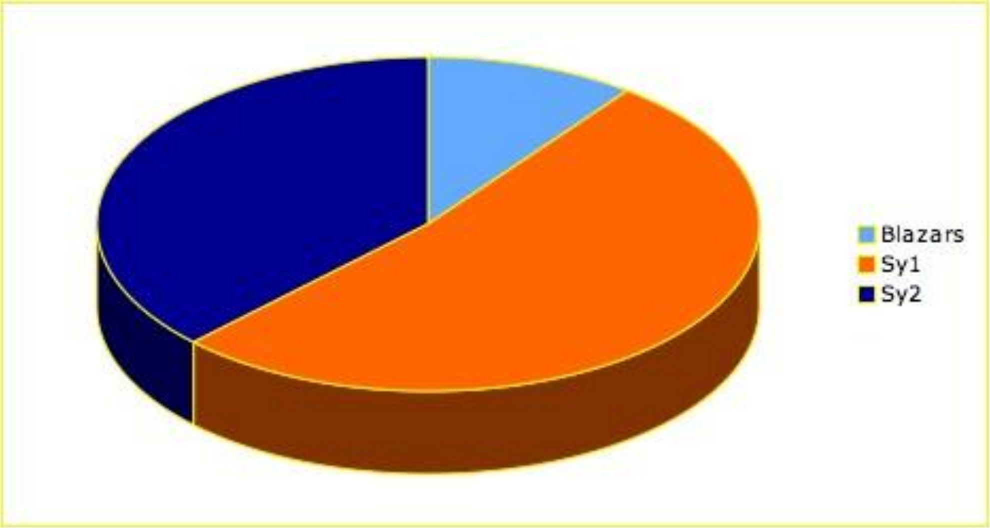
VLBI radio data

✓At higher angular resolution sources are more RQ

Resolved radio emission



Hard X-ray selected INTEGRAL AGN Complete sample

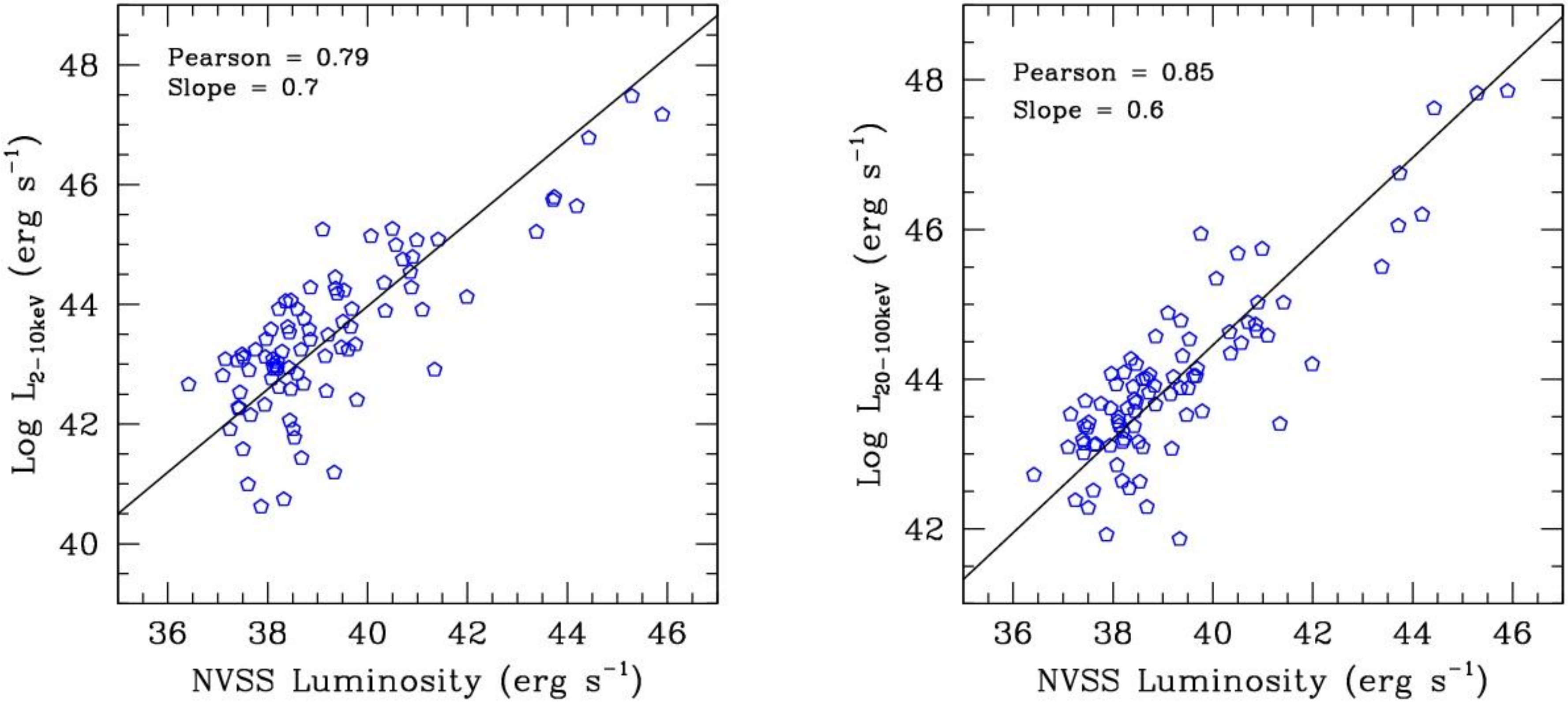


~ 88 Seyfert galaxy
complete sample
between 20-40 keV
(Malizia et al. 2009 MNRAS)

- Hard X-ray selected sample of luminous AGN:

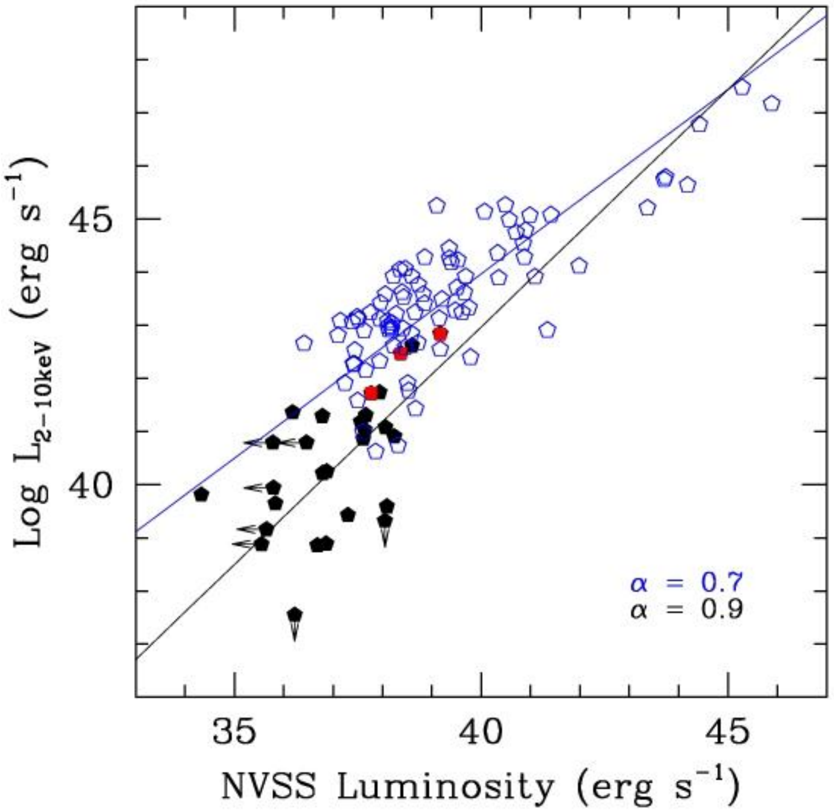
  -> INTEGRAL 20-100 keV (Malizia et al 2009)
  -> 2-10 keV X-ray data (Malizia et al. + literature)
  -> NVSS radio data (Maiorano et al. in prep)

INTEGRAL AGN Complete sample



- ✓ Correlation between 2-10 keV, 20-100 keV vs 20 cm NVSS

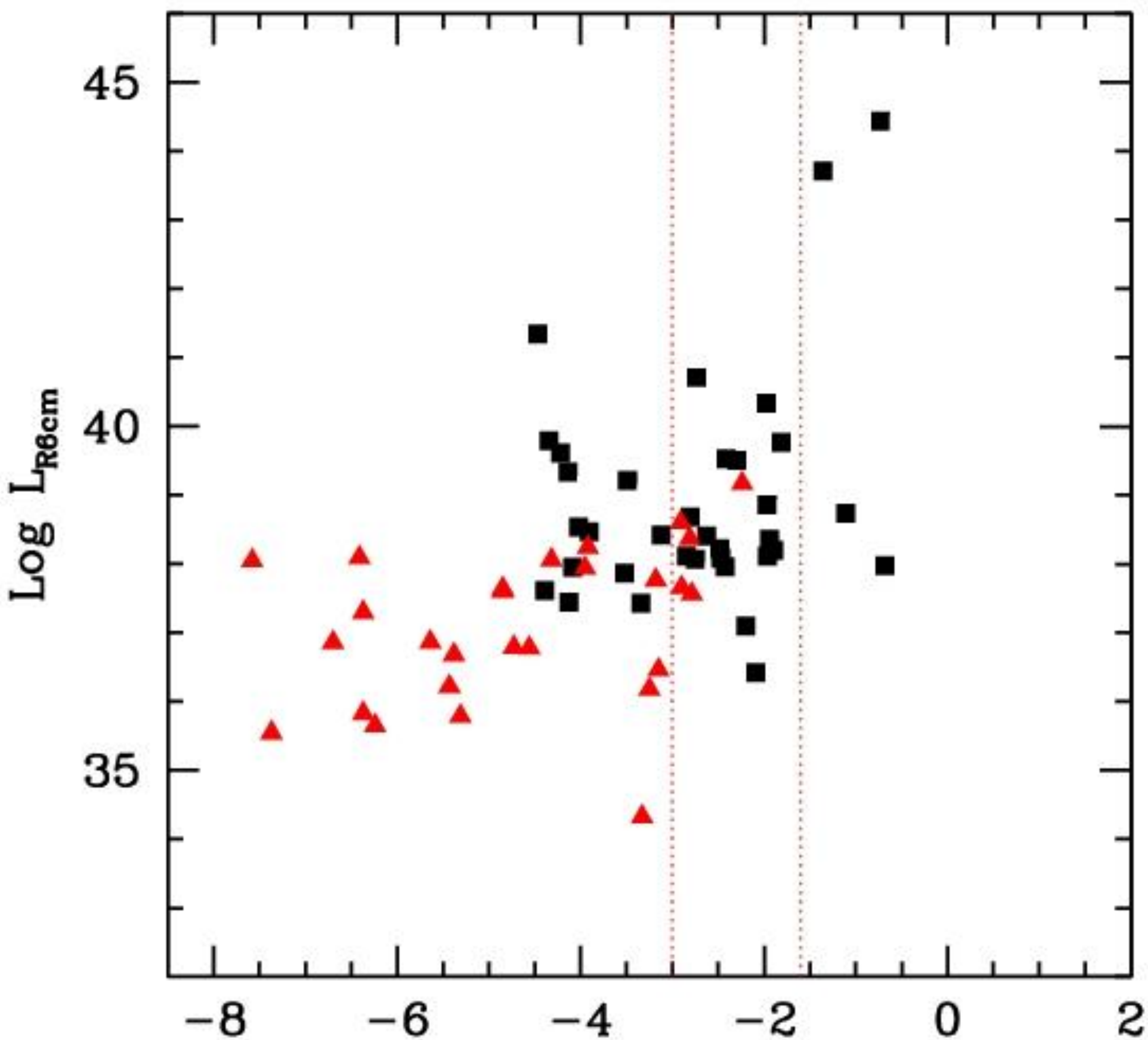
The X-ray versus NVSS correlation



-> INTEGRAL sample

-> Optical sample

✓ Correlation changes slope at low luminosities



45
40
35
Log L_{R6cm}
−8
−6
−4
−2
0
2
Log $L_{2-10keV}/L_{Edd}$

Conclusions

The standard picture of AGN evolves with the accretion rate:

- Evidence of sources with no/weak BLR at low Eddington ratios
- Evidence of dependence of R with the accretion rate

BUT

- At high angular resolution --> 5-100% of emission is resolved
  → the sub-pc cores are extremely RADIO QUIET
- The X-ray vs radio correlation holds at pc-kpc scales
  → extended emission connected to the BH activity

Thank you!