The X-ray and Radio Connection in Local Seyfert Galaxies

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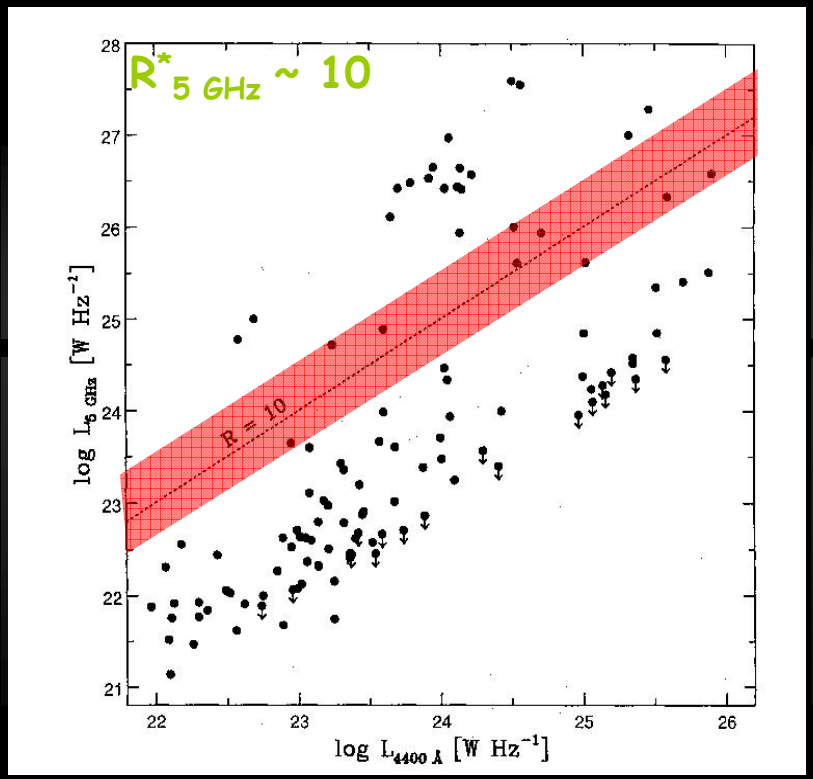
INAF

Radio Quiet vs Radio Loud



Padovani_1993

R = L(5 GHz) / L(B) --> Log R = 10

Radio Loud objects:

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

Radio Quiet (Seyferts):

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

Recent VLA & VLBA surveys show that **all** AGN are radio sources at some level

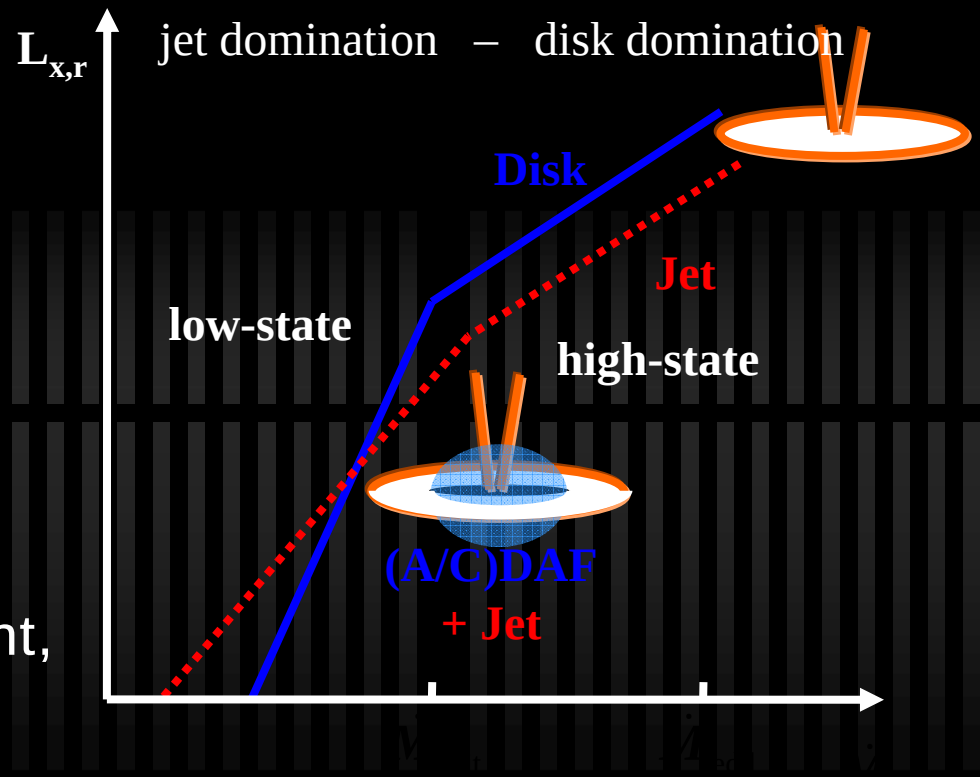
(Ho&Ulvestad 2001; Nagar et al. 2002, 2005)

Origin of radio emission in Radio Quiet

Which is the origin of radio emission in Seyfert galaxies?

How it is related to the accretion flow? To the accretion rate?

✓ At lower accretion rates disks become less and less prominent, jets remain strong.



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

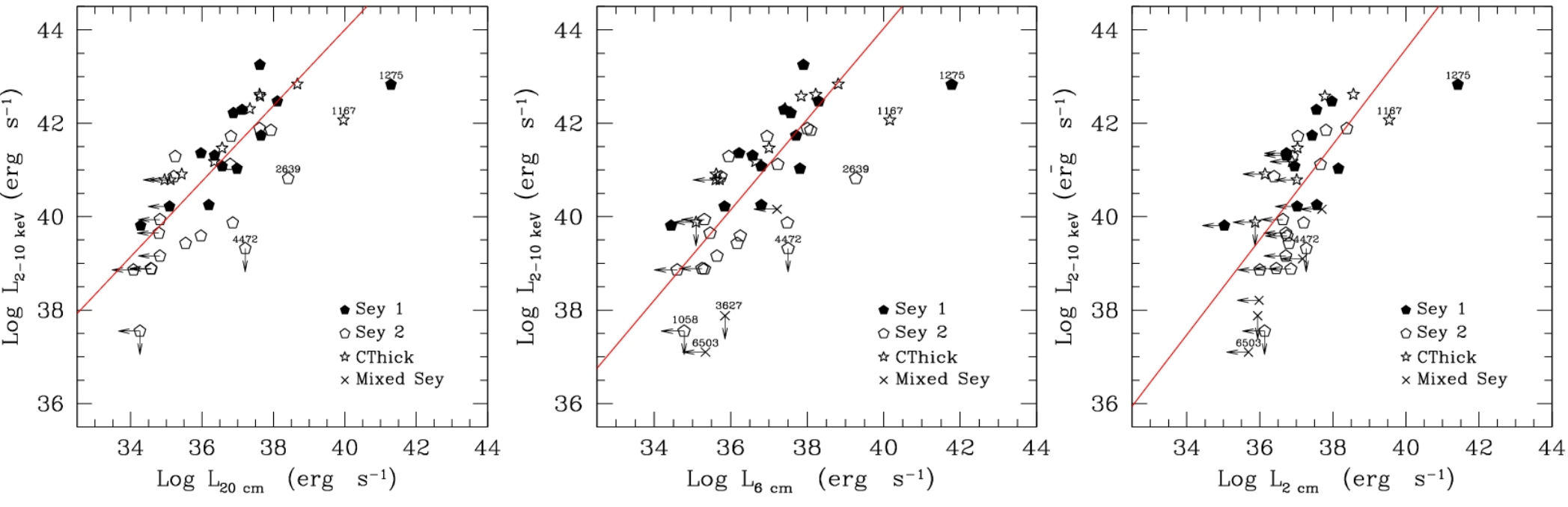
Analogy with black hole X-ray binaries

Multi-wavelength analysis of the Palomar Seyfert Complete Sample

60 Seyfert galaxies (13 type 1, 39 type 2, 8 “Mixed Seyferts”)

- ✓ XMM-Newton & Chandra X-ray images and spectra (Cappi et al. 2006, Panessa 2004, Ph.D. thesis)
- ✓ Accurate optical classification (Ho et al. 1997)
- ✓ Optical, X-ray, M_{BH} correlations (Panessa et al. 2007)
- ✓ VLA & VLBI observations (Ho&Ulvestad 2001, Nagar et al. 2002)

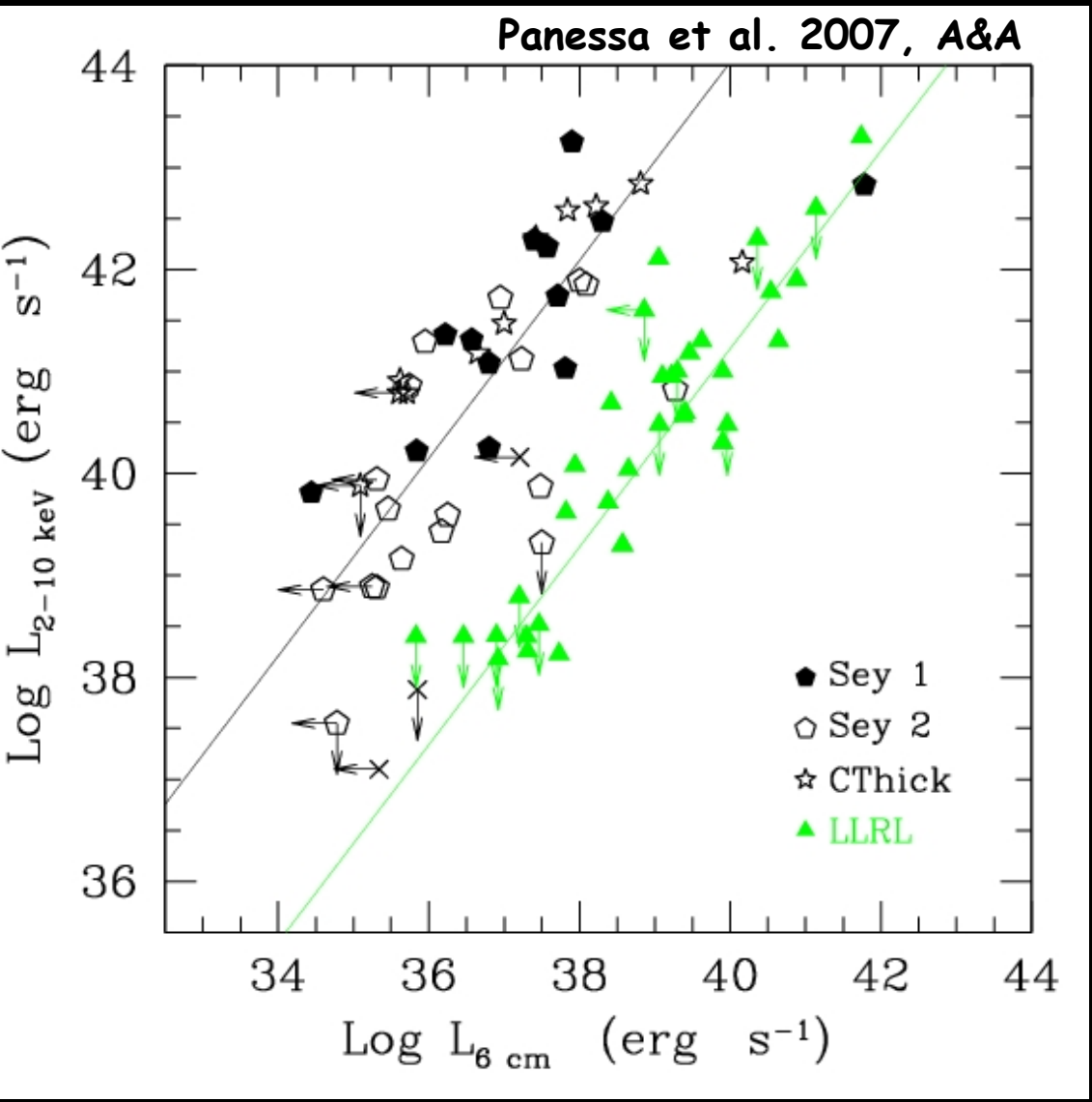
Scaling Relations: $L_{2\text{-}10\ keV}$ vs. L_{Radio}



For a COMPLETE SAMPLE of local SEYFERT GALAXIES:

$\text{Log } L_{2\text{-}10keV} = (0.97 \pm 0.01) * \text{Log } L_{5GHz} + (5.23 \pm 0.28)$

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



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

- The two correlations extend for 8 orders of magnitude --> down to the regime of Low-Luminosity AGNs

In Radio Quiet

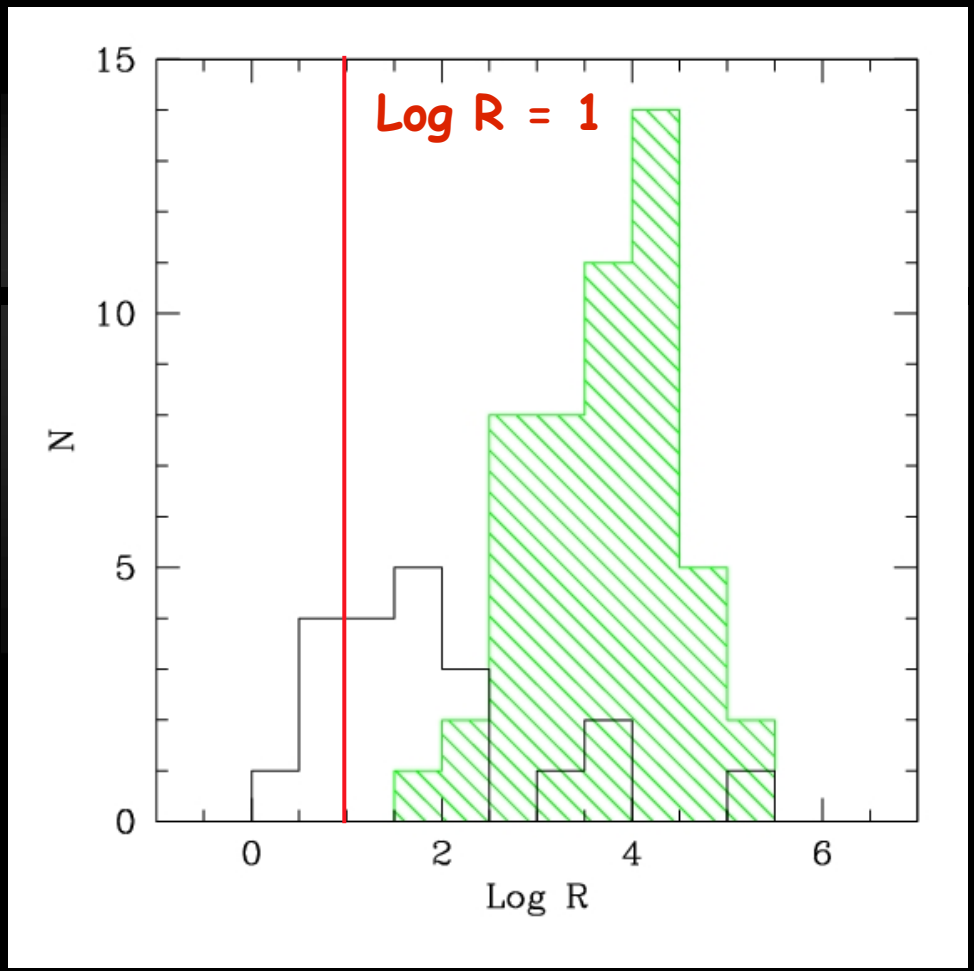
- Some physical parameter that links the jet related power to the corona emission: ex. Corona at the base of the jet

- Radio and X-ray emission produced in outflows

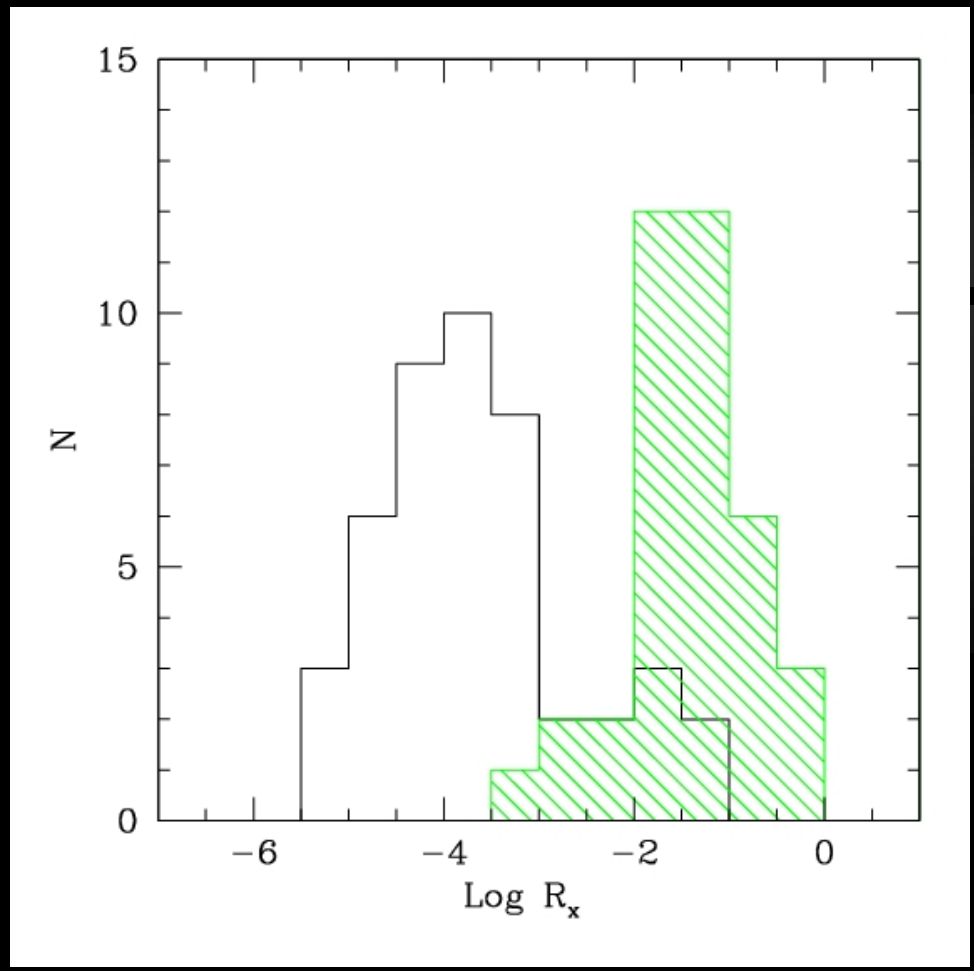
(Merloni et al. 2003, Ghisellini et al. 2004)

Radio Loudness

Are all Sey galaxies Radio-Loud or need a redefinition of the Radio-loudness boundary at low luminosities?

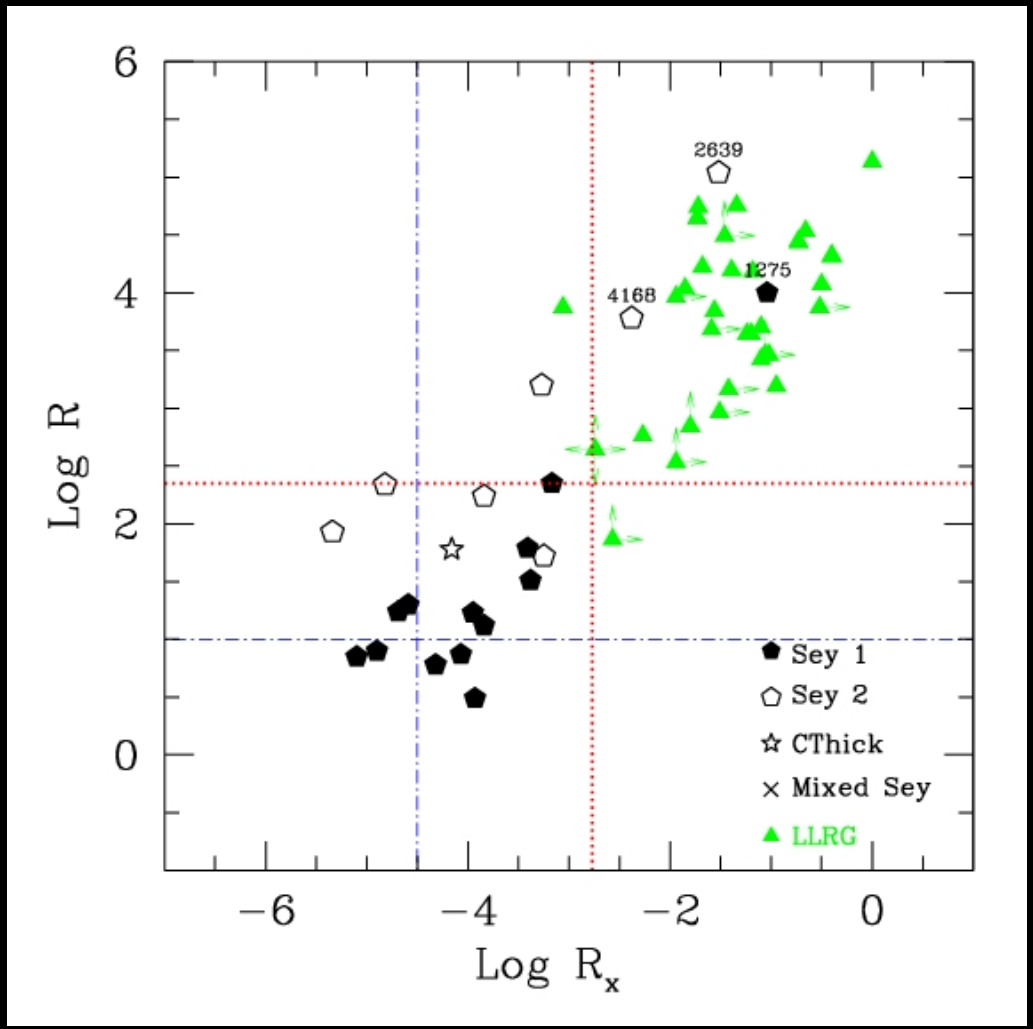


R = L(5 GHz) / L(B)



R(X) = L(5 GHz) / L(2-10 keV)

Radio Loudness



Maximum separation between the two distributions:

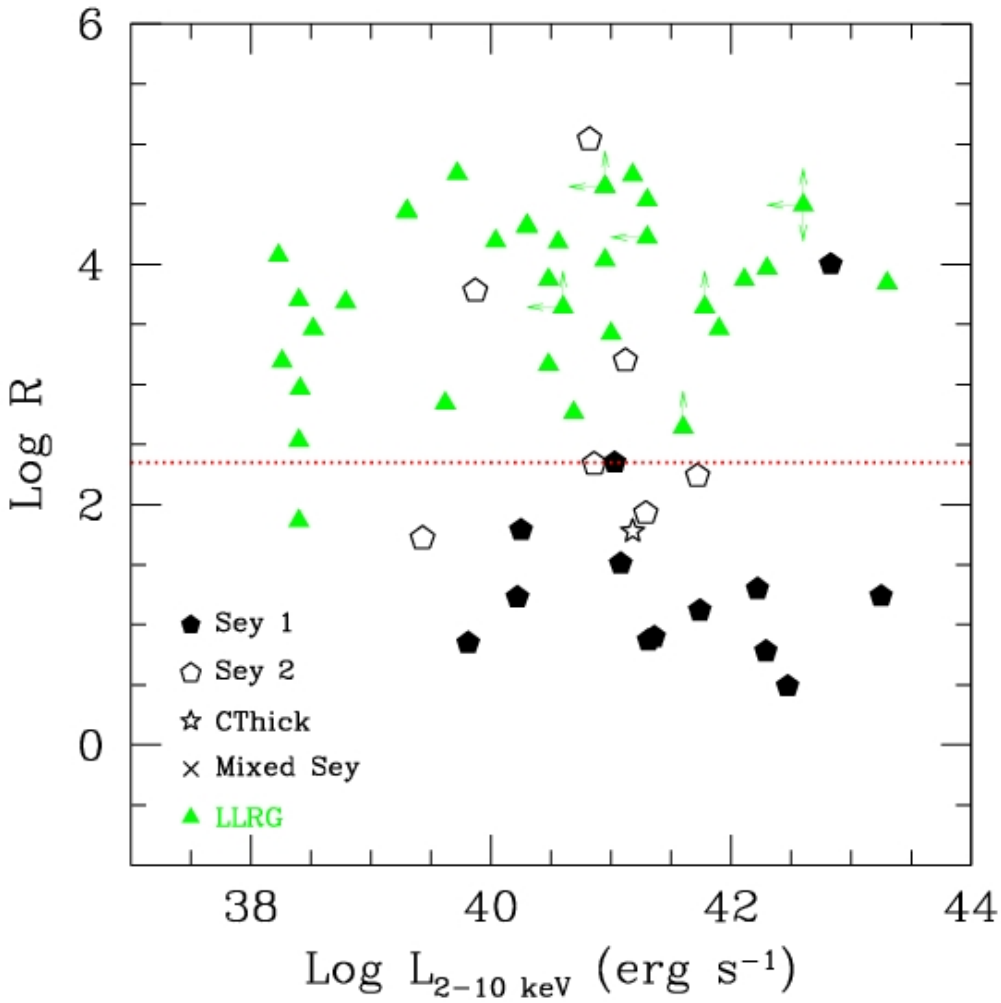
New boundaries at low luminosities?

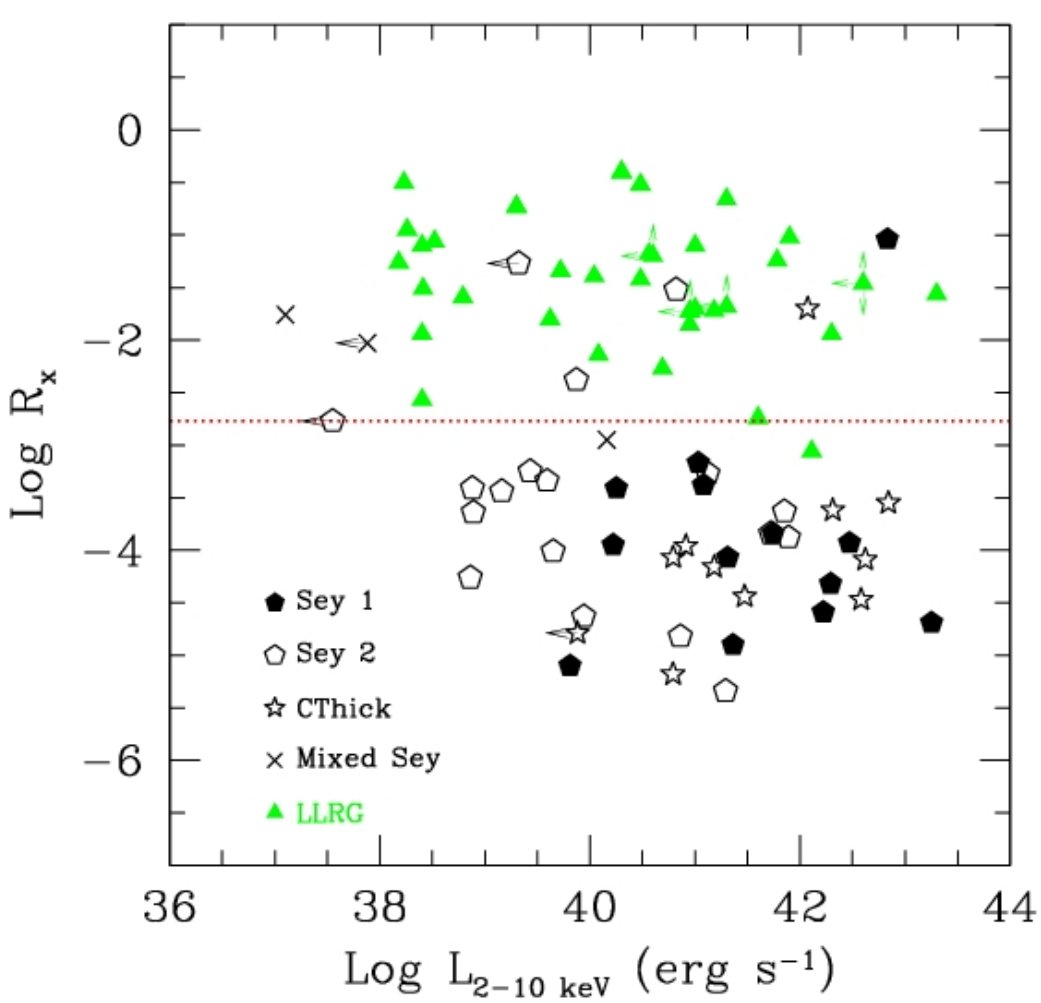
Log R = 2.40 ± 0.05

Log R_X = -2.76 ± 0.02

Radio Loudness

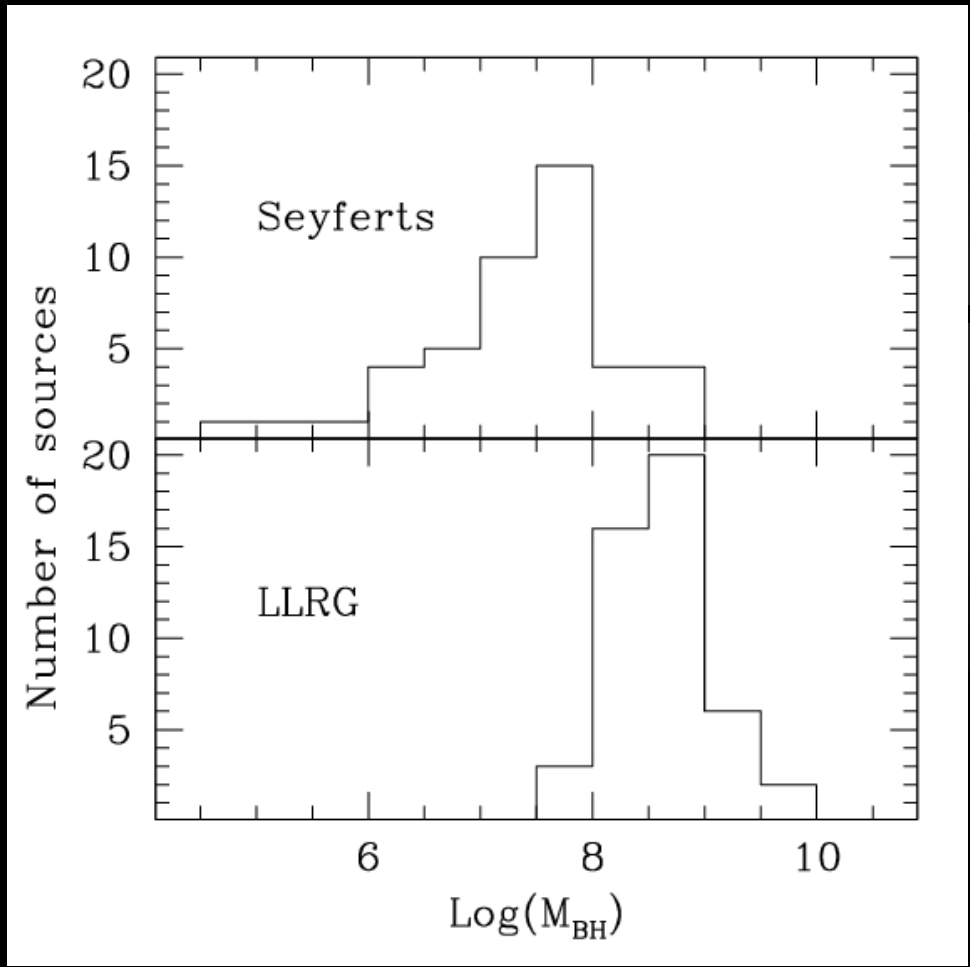
- However, no evidence of a dependence of R with luminosity



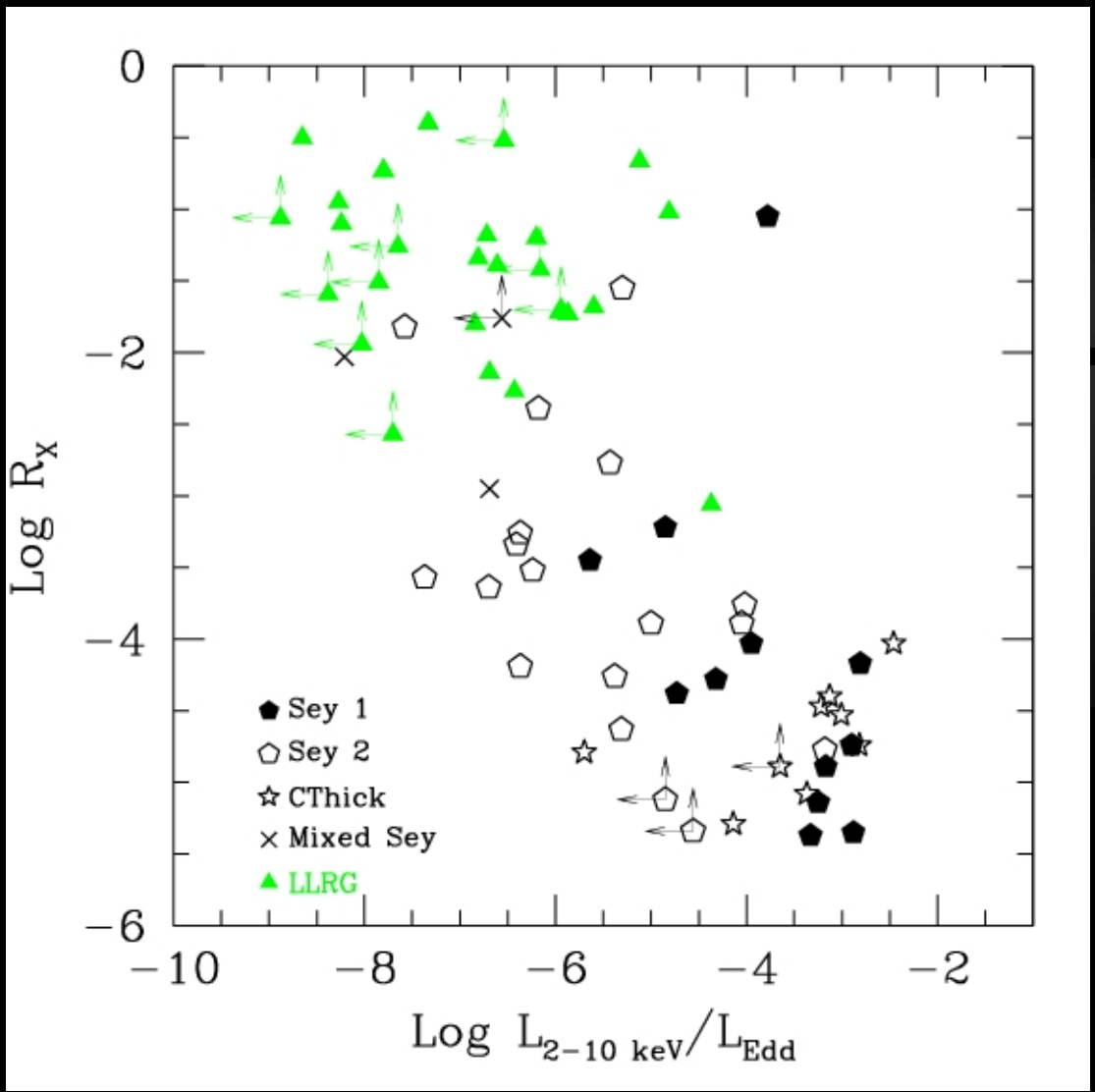


Radio Loudness

- Radio-Loud AGN are associated with massive BHs



Radio Loudness



- Increasing radio-loudness with decreasing Eddington ratio? (Ho et al. 2002, Sikora et al. 2006)

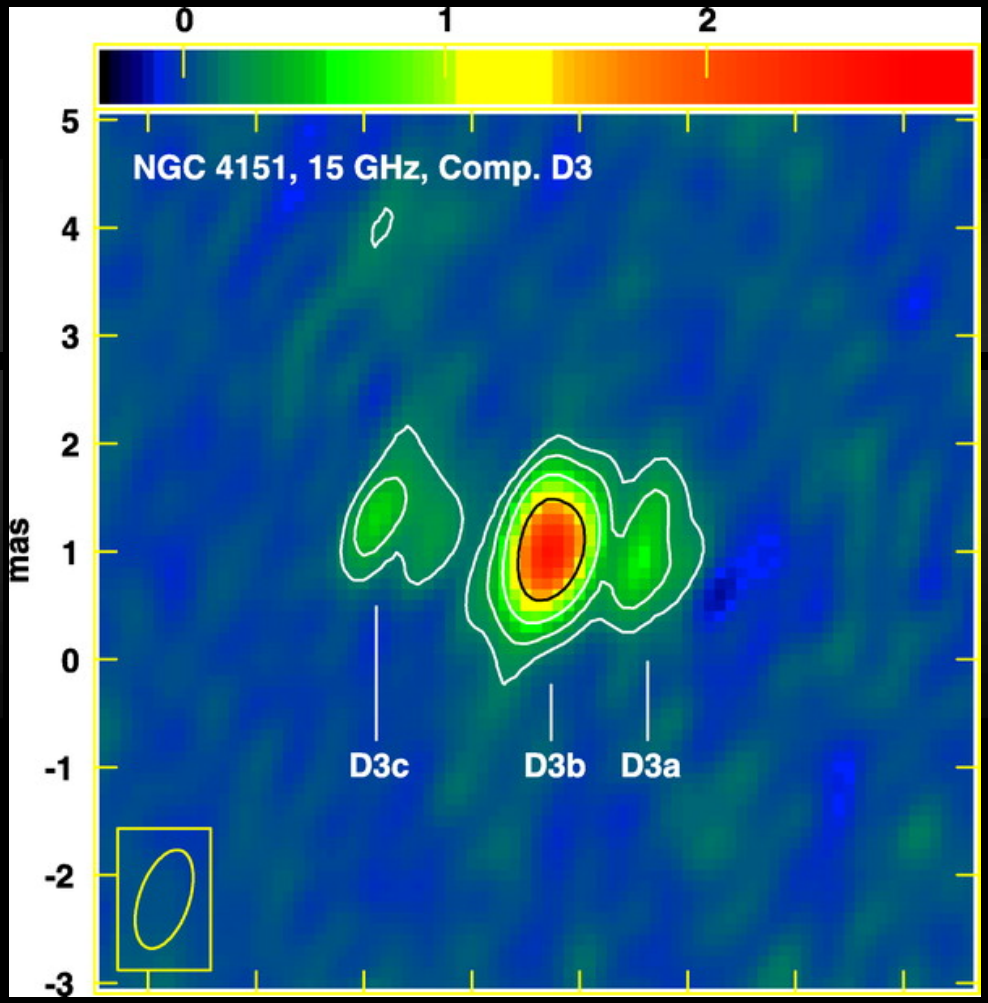
The formation of a jet in LLAGN is related to the accretion rate as in XRBs?

--> Need to look at the radio emission first to see if jets are there!

VLBI Observations of a distance limited Complete Sample of Seyferts

- Complete sample of 27 Seyfert nearby galaxies (Cappi et al. 2006, D < 27 Mpc)
- For the first time sources with S < 1mJy (VLA cores)
- Eupean VLBI Network new observations for 6 objects to complete the sample at mas scales

VLBI Observations of Radio Quiet Nuclei

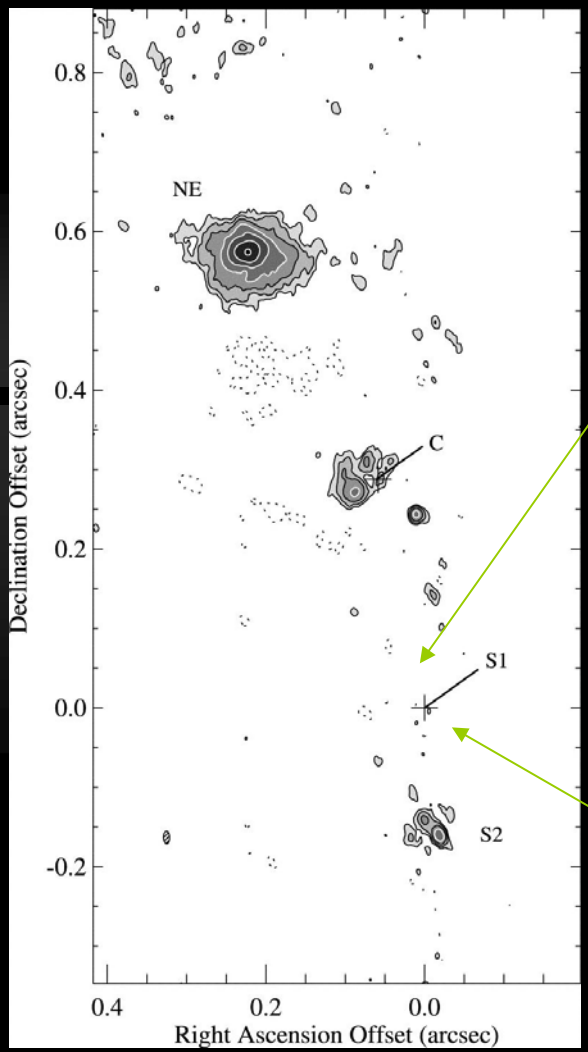


- NGC 4151: radio-quiet Sey 1.5 nucleus
- Radio source size < 0.035 pc, BLR scales
- VLBI compact flat-spectrum radio component with Tb > 2.1 * 10^8 K
- A weak two sided beginning to the large scale radio jet
- Sub-relativistic motions

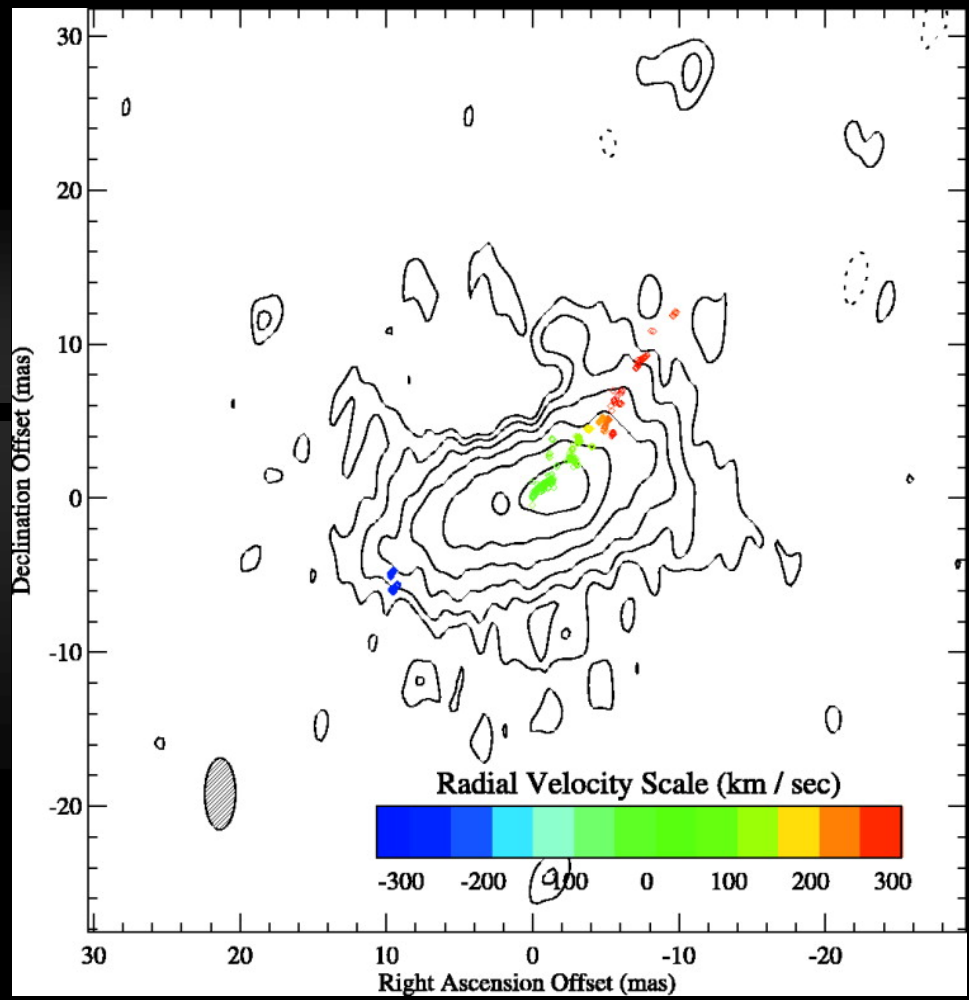
VLBI at 15 GHz Ulvestad et al. 2005

- NGC 1068: S1 component resolved into an extended 0.8 pc long structure oriented perpendicular to the jet and aligned to the maser disk

- Thermal free-free emission from an X-ray-heated corona or wind arising from molecular disk

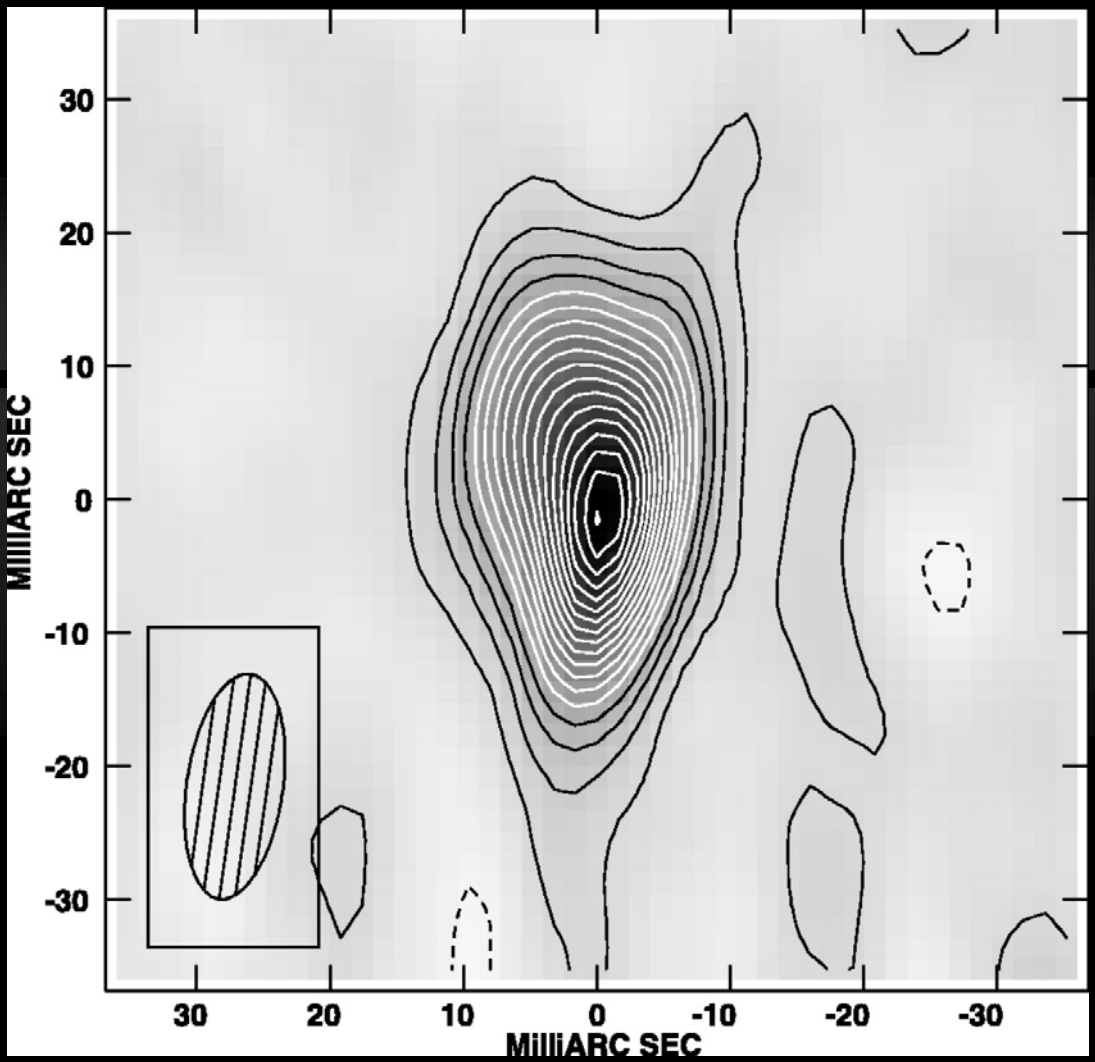


VLBA + phased-VLA 1.4 GHz contour image
Gallimore et al. (2004) + H_2O Maser



Low T_b 2.5 * 10^6 K and flat-inverted spectrum

VLBI Observations of Radio Quiet Nuclei

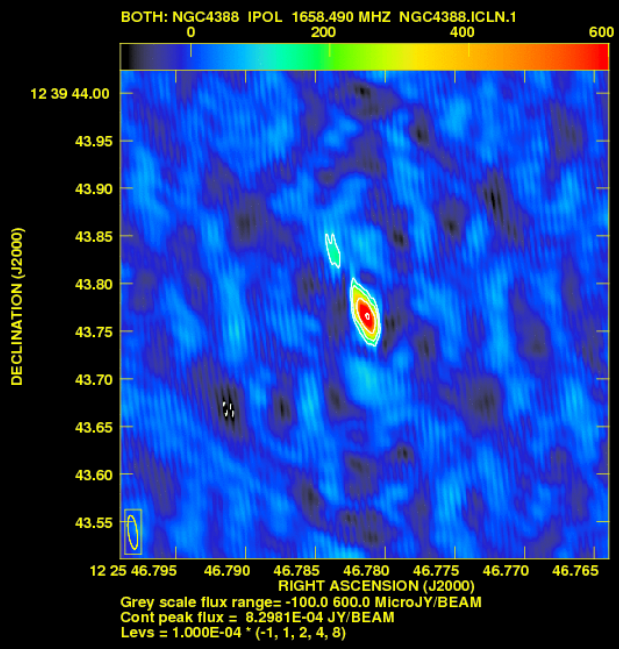


- NGC 4395: radio-quiet type 1 nucleus with L_X/L_{Edd} = 0.004
- Brightness temperature > 2 * 10^6 K
- VLBI elongated structure which suggests radio outflow on sub-pc scales

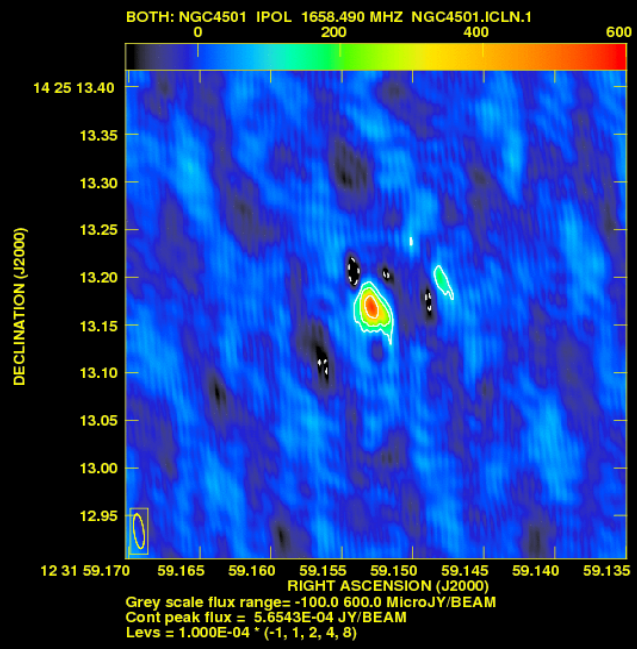
VLBA HSA at 1.4 GHz
(SCALE of 0.021 pc/mas)
Wrobel & Ho (2006)

New VLBI Observations

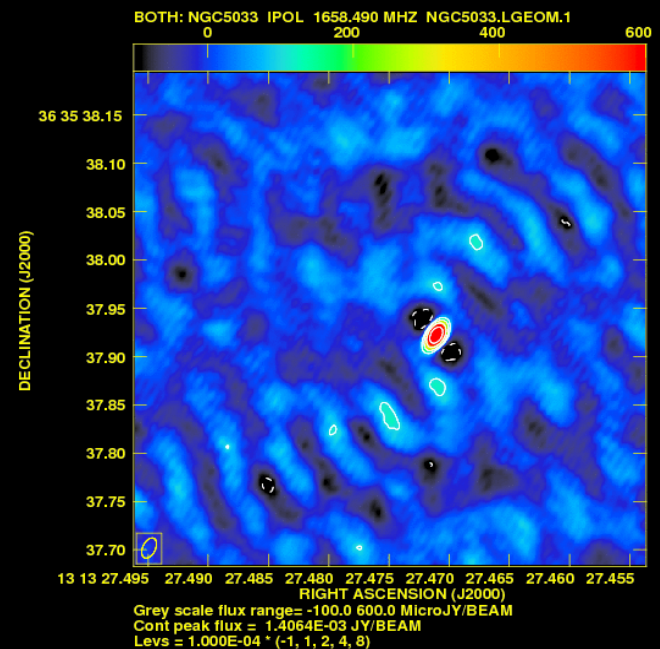
NGC 4388



NGC 4501



NGC 5033



linear resolution is around 0.1 pc VLBA at 5 GHz

Giroletti & Panessa in preparation

New VLBI Observations

- ✓ Six nearby Seyfert galaxies with the EVN at 1.6 and 5 GHz in May 2007 and Feb 2008
- ✓ Unprecedented sensitivity of about 20 microJy (rms)
- ✓ Four galaxies (NGC4051, 4388, 4501, and 5033) are detected at at least one frequency. The brightness temperature is in excess of 10^8 K, i.e. presumably non thermal.

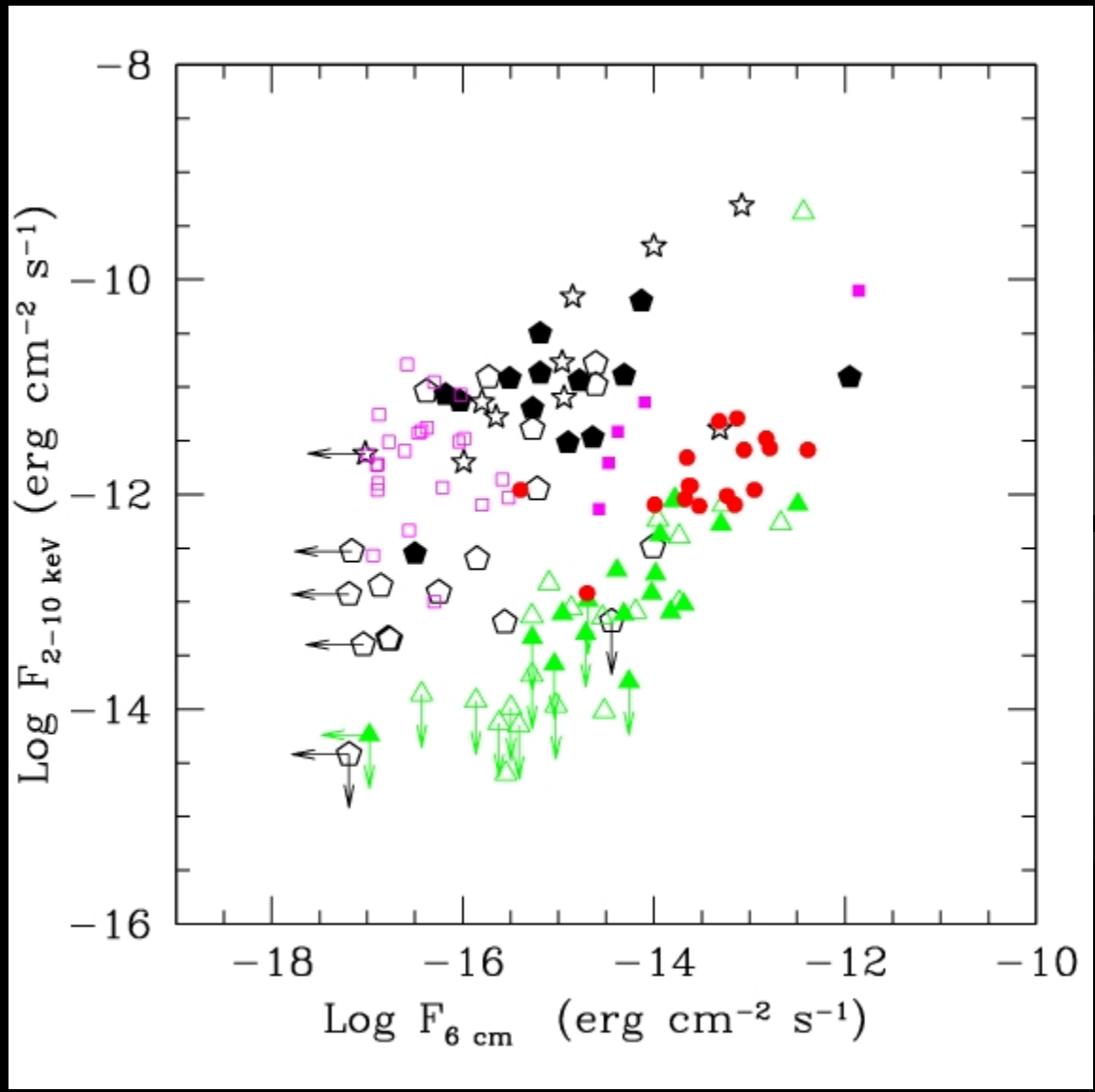
name	peak (mJy/beam)	b_{maj} (mas)	b_{min} (mas)	T_B (>K)
NGC 4388	0.8	17.6	4.5	7.4×10^8
NGC 4501	0.6	18.2	4.9	1.0×10^9
NGC 5033	1.4	11.1	6.4	1.9×10^8

VLBI Observations of a distance limited Complete Sample of Seyferts

- Bright Seyfert nuclei display radio jets and/or outflows
- High brightness temperature
- Flat or inverted spectra
- Proper motions <0.25 c non-relativistic speeds
- 40% of the sample show no detection with VLA

Conclusions

- ✓ Strong X-ray versus radio correlation --> coupling of the X-ray and radio source
- ✓ Same slope for LLRG and nearby Seyfert galaxies
- ✓ Dependence of the Radio-loudness on the Eddington ratio
- ✓ Systematic study for a complete sample of the VLBI radio properties


−8
−10
−12
−14
−16
−18
−16
−14
−12
−10
Log $F_{2-10\ keV}$ (erg cm^{-2} s^{-1})
Log $F_{6\ cm}$ (erg cm^{-2} s^{-1})