EVN SYMPOSIUM 2014
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On the origin of radio emission in Radio-Quiet AGN and their connection to X-rays

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THANKS to: Loredana Bassani, Angela Bazzano, Geoff Bicknell, Paola Castangia, Marcello Giroletti, Elisabetta Maiorano, Angela Malizia, Andrea Tarchi, Pietro Ubertini

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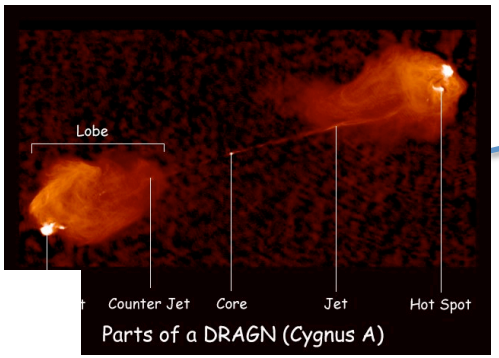
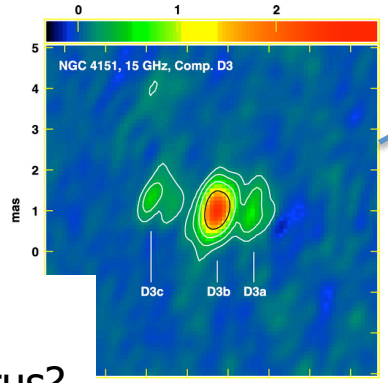
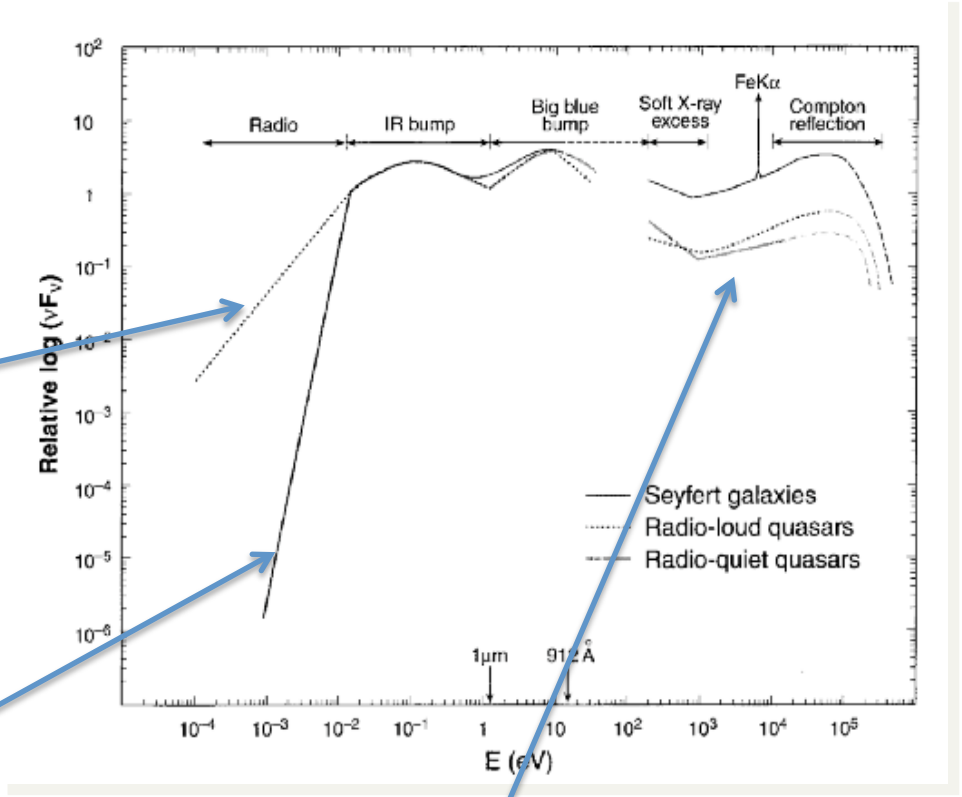
RQ and RL AGN

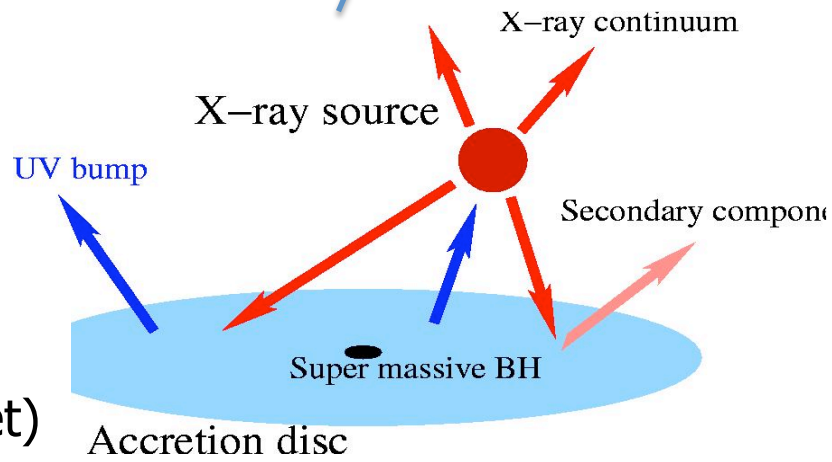


RADIO-LOUD:
Poweful jets



RADIO-QUIET:
Weak jet? SB? Torus?

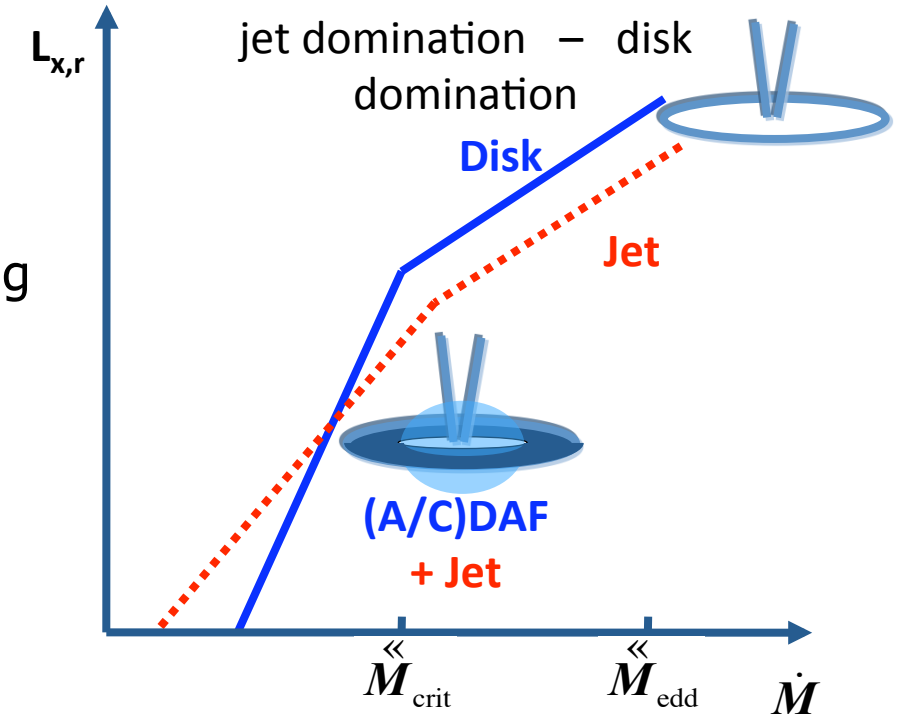




X-RAYS:
Accretion disc + hot corona (+jet)

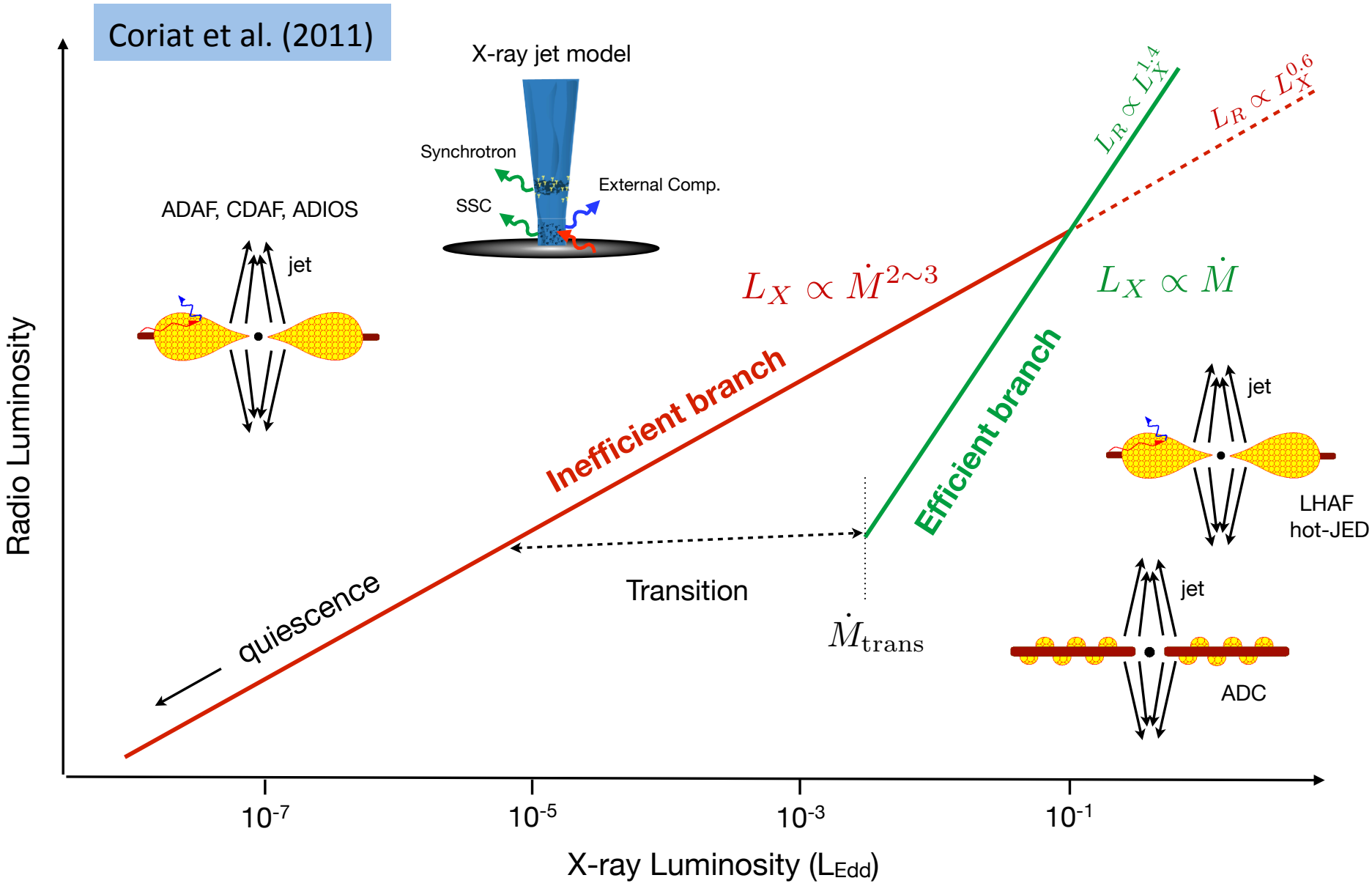
X-ray/radio emission vs accretion

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



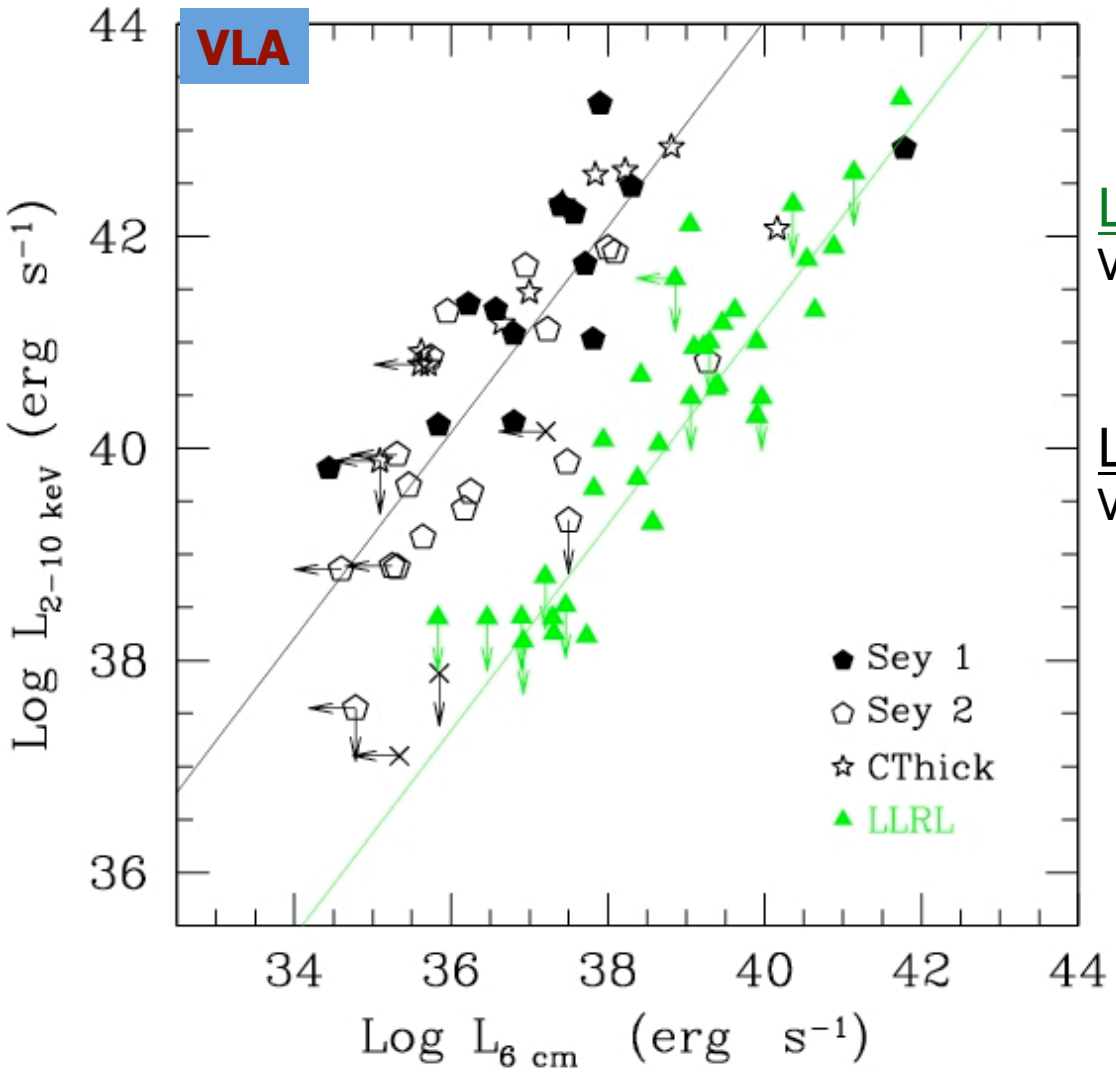
Körding, Falcke, & Markoff (2002);
see also Fender, Gallo, & Jonker (2003)

Analogy with black hole X-ray binaries



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

Optically selected sample: $L_{2\text{-}10\ keV}$ vs. L_{Radio}



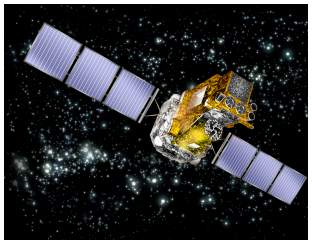
Low Luminosity Radio Galaxies
VLA + Chandra

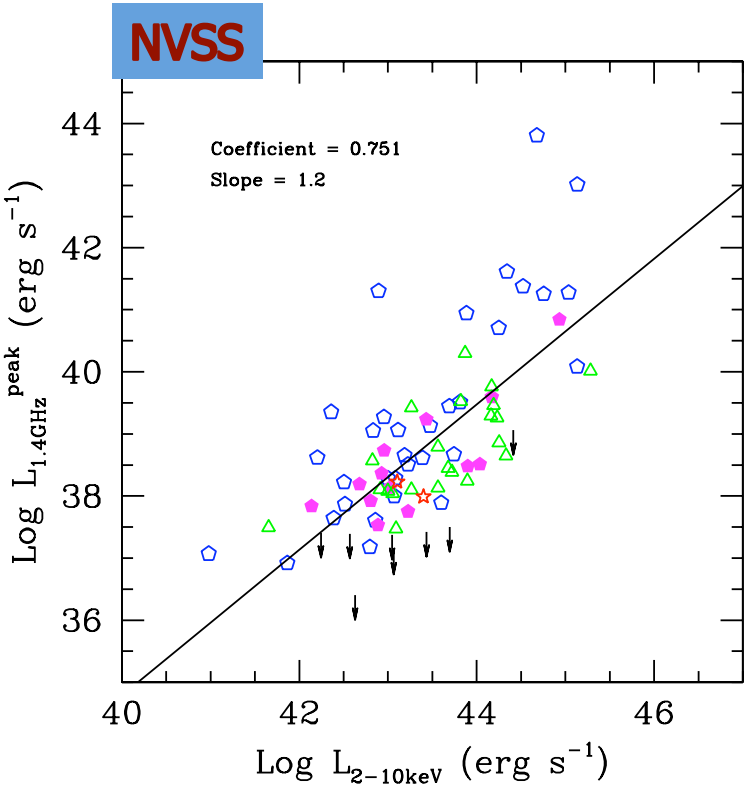
Low Luminosity RQ AGN (Palomar)
VLA + Chandra/XMM

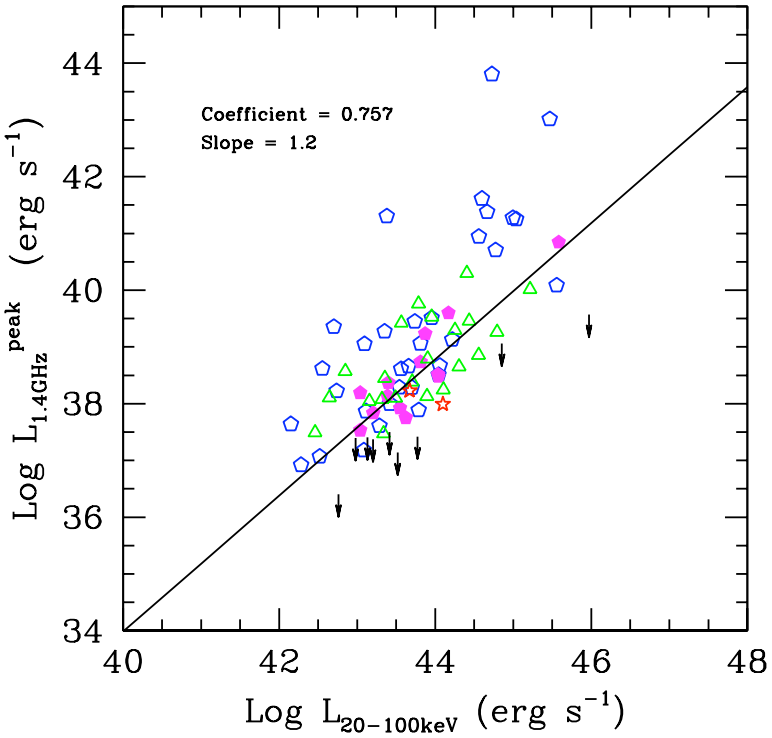
→ X-ray and radio from the same component?
→ Jet/outflow are disk related (jet, disc-corona)

Panessa et al. 2007 A&A

Hard X-ray selected sample







INTEGRAL sample of 79 luminous AGN:

-> INTEGRAL 20-100 keV

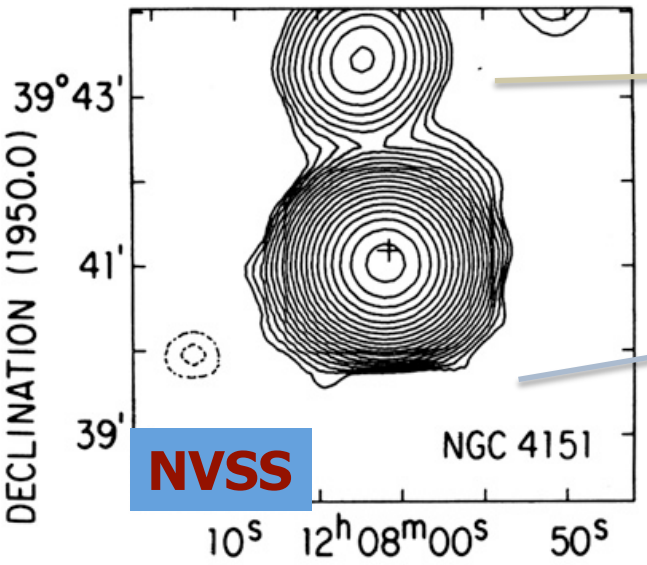
-> 2-10 keV X-ray data

-> NVSS radio data

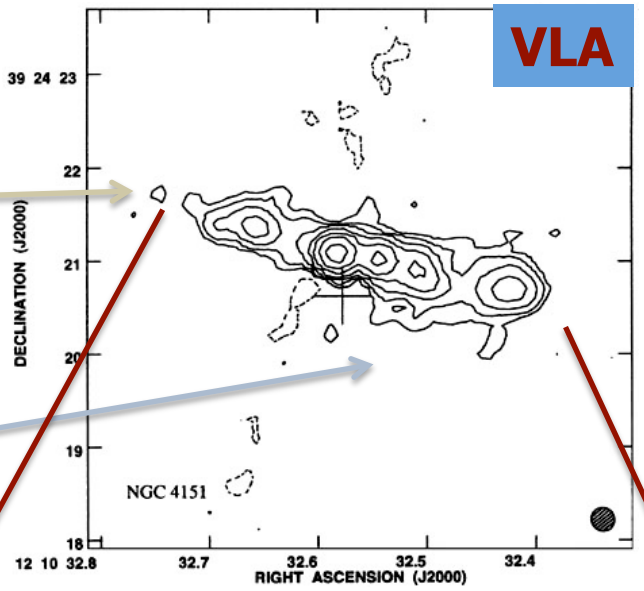
- Significant correlation
- Slope consistent with efficient accretion

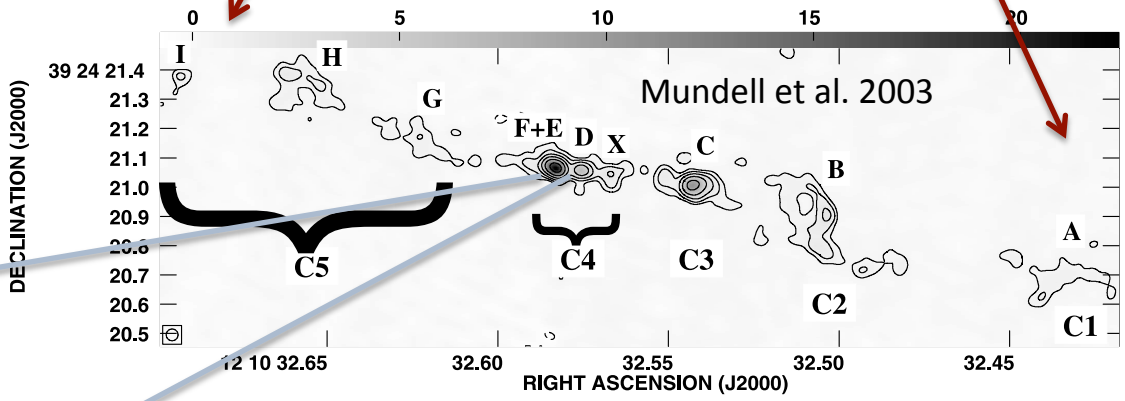
(Panessa et al. accepted, MNRAS)

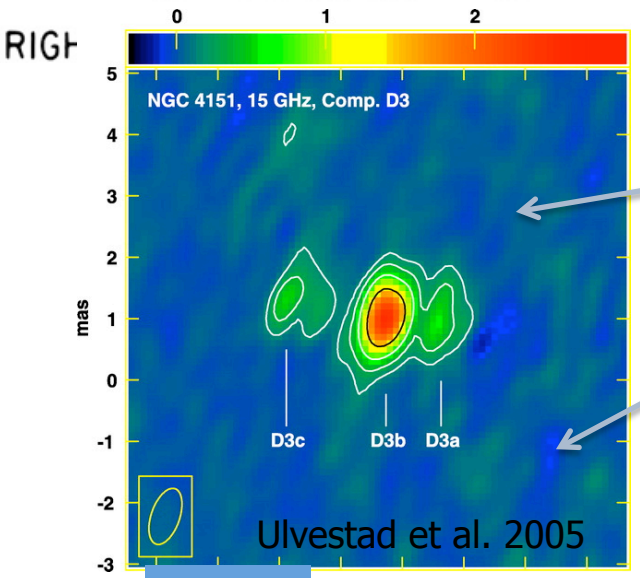
NGC4151 D = 20 Mpc



NVSS





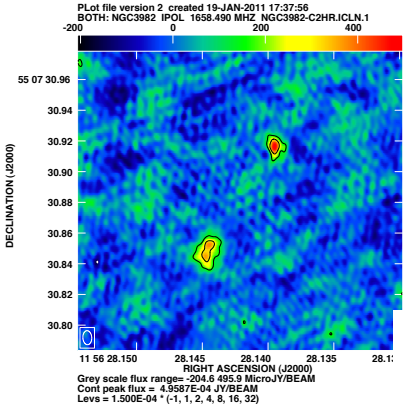


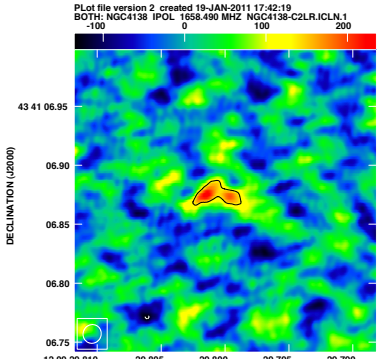
VLBI

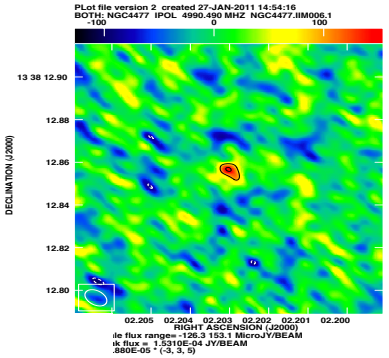
NVSS → up to tens of kpc

VLA → tens of pc up to kpc scales

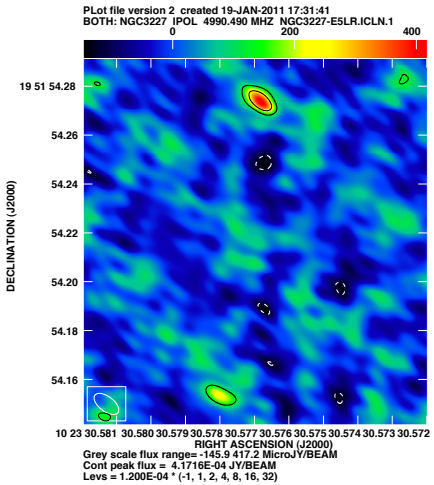
VLBI → < 0.1 pc



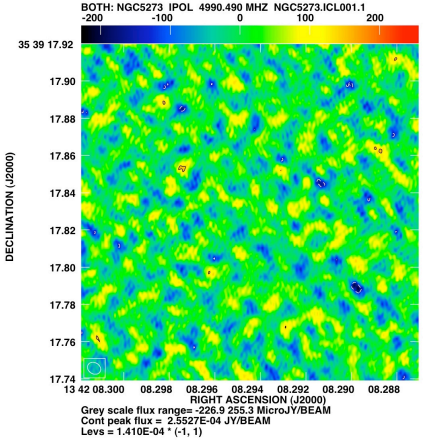


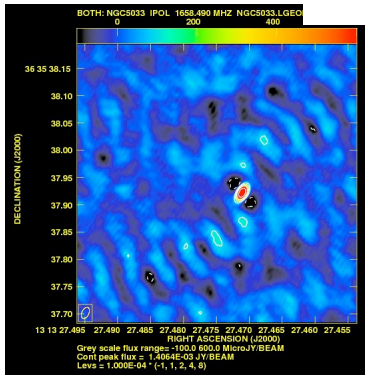


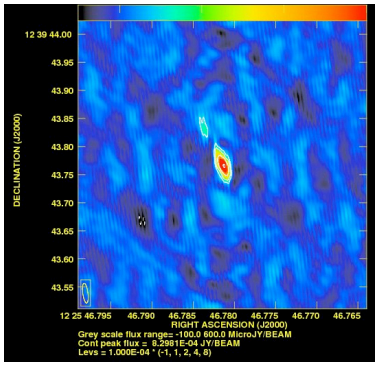
EVN Survey of 23 Seyfert nuclei

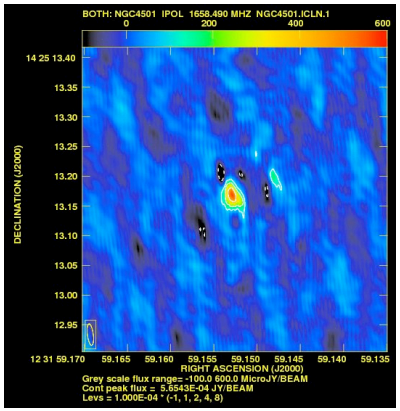


- 6 and 20 cm survey
- 90 microJy/beam
- Linear scales 0.05 pc @10 Mpc









Giroletti & Panessa 2009, Bontempi et al. 2012, Panessa & Giroletti 2013 MNRAS

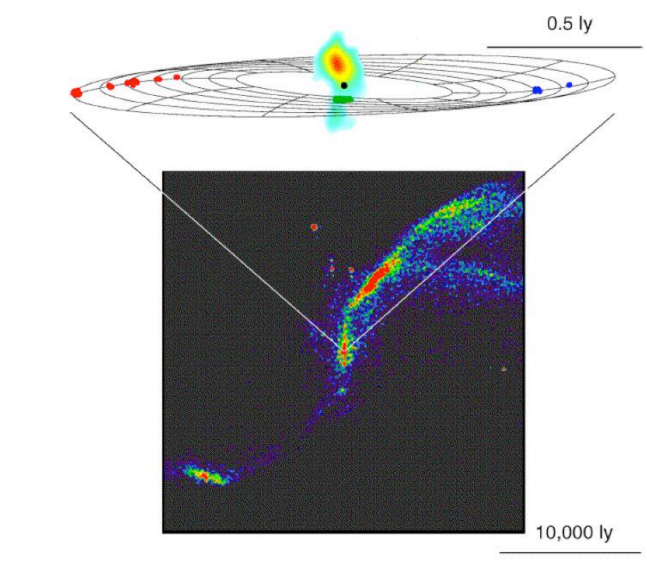
Are sub-pc radio cores ubiquitous?

At 20 cm (1.4 GHz):

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

At 6 cm (5 GHz):

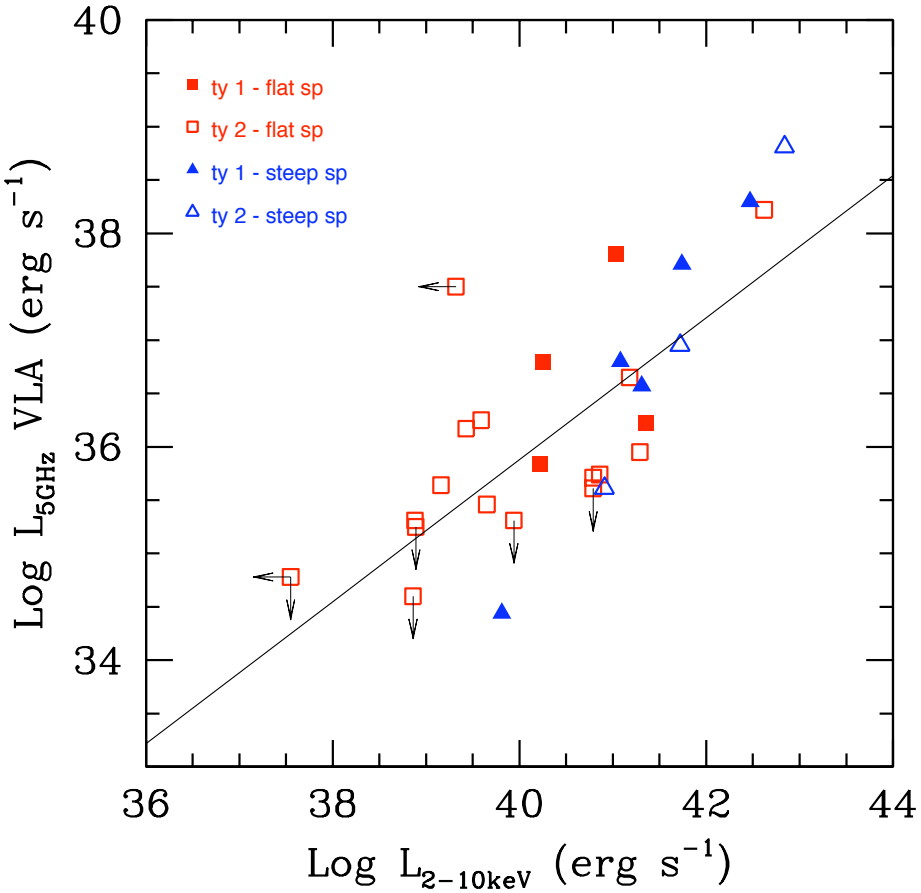
- VLA : 23/28 (82%)
- VLBI : 13/21 (**62%**)

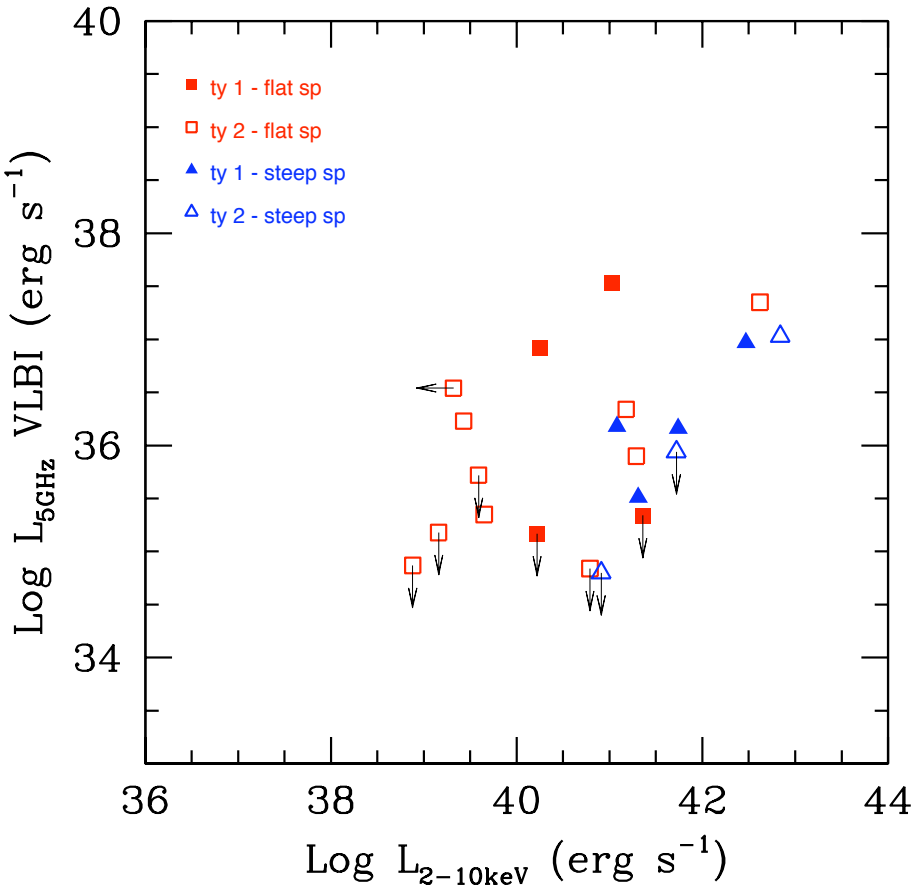


- Lower detection rate with respect to VLA
- RQ nuclei are less ubiquitous at VLBI spatial scale resolution

Water maser detection rate of 26%
→ compared to 7% of maser surveys (Braatz et al.1997)

X-ray versus Radio correlation





No significant correlation at EVN sub-pc scales

Panessa & Giroletti 2013 MNRAS

VLBI Morphology

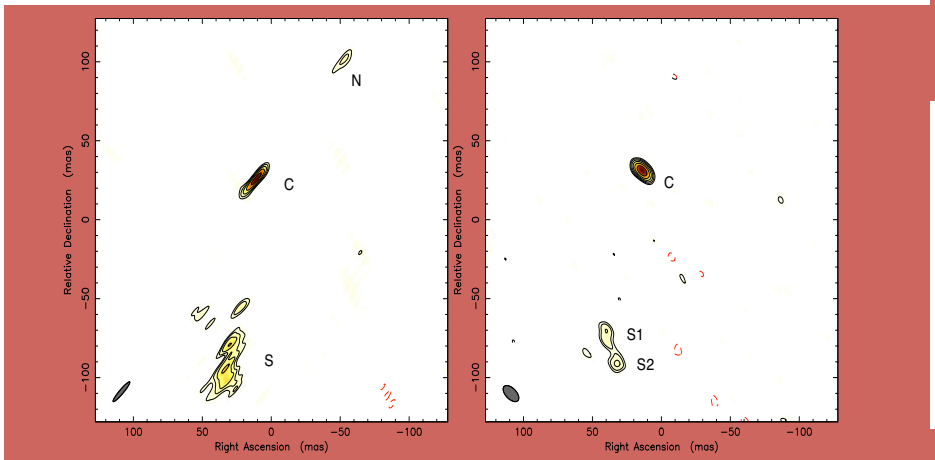


Figure 1. Images of NGC 3227 at 1.7 GHz (left) and 5 GHz (right). Contours are traced at $(-1, 1, 2, 4, \ldots)\times$ the $\sim 3\sigma$ noise level, which is 0.13 and 0.08 mJy beam^{-1} at 1.7 and 5 GHz, respectively. HPBWs are shown in the lower left corner, and their size is 2.9 mas × 17.3 mas in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

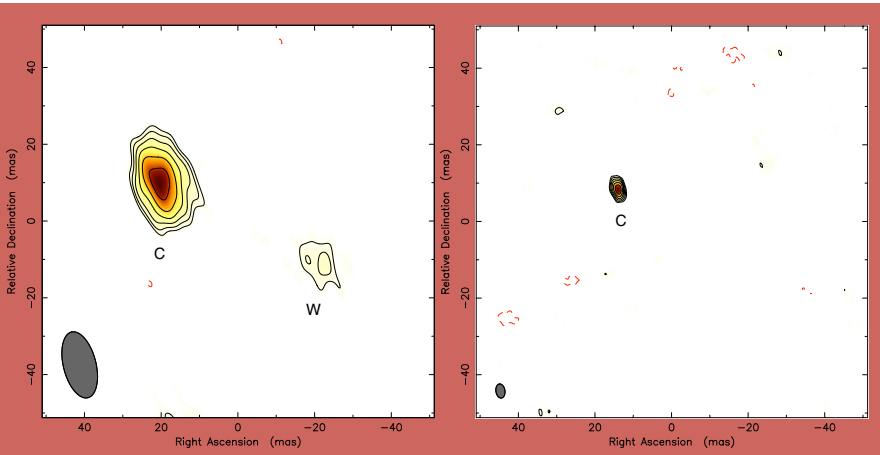


Figure 3. NGC 4138 at 1.7 GHz (left) and 5 GHz (right). Contours are traced at $(-1, 1, 2, 4, \ldots)\times$ the $\sim 3\sigma$ noise level, which is 0.14 and 0.09 mJy beam^{-1} at 1.7 and 5 GHz, respectively. HPBW are shown in the lower left corner, and their size is 8.5 mas × 17.7 mas in P.A. 14° and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

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

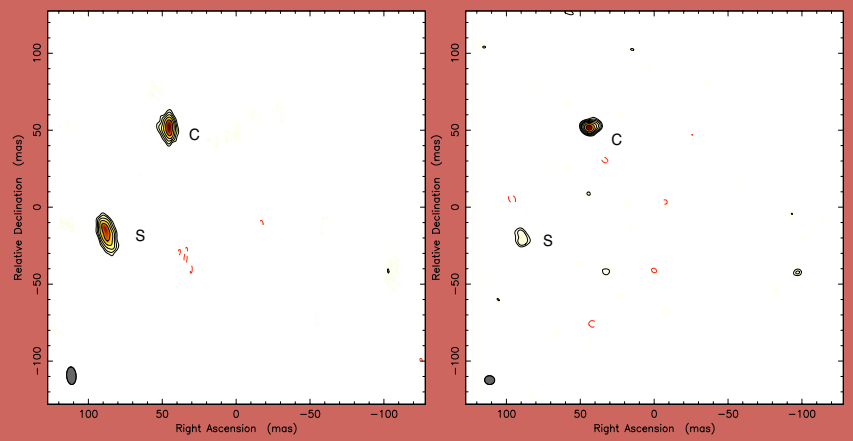
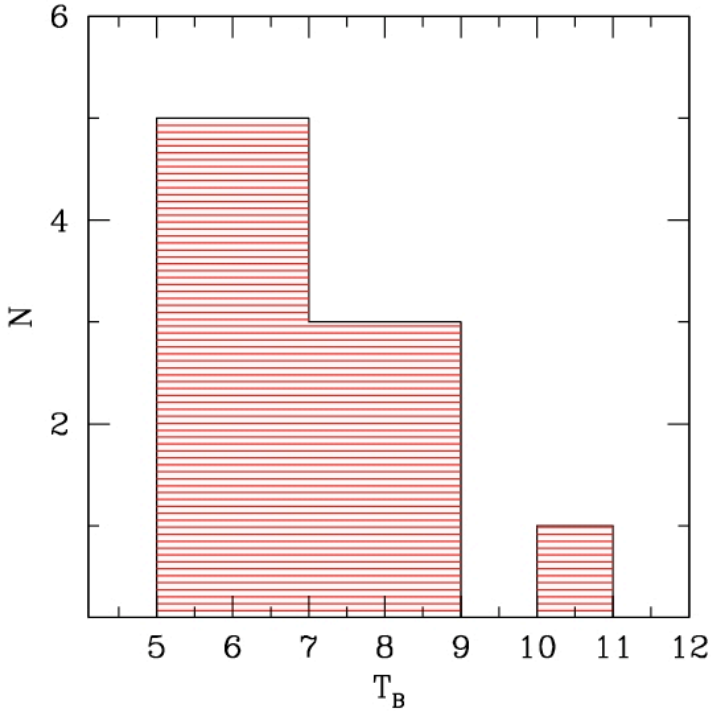


Figure 2. NGC 3982 at 1.7 GHz (left) and 5 GHz (right). Contours are traced at $(-1, 1, 2, 4, \ldots)\times$ the $\sim 3\sigma$ noise level, which is 0.20 and 0.09 mJy beam^{-1} at 1.7 and 5 GHz, respectively. HPBW are shown in the lower left corner, and their size is 6.4 mas × 11.4 mas in P.A. 4° and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

Brightness Temperatures and Spectral Slopes

- Peak at relatively low brightness temperature:
  - thermal vs non-thermal
  - low T(B) are found in type 2



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

NGC 4051

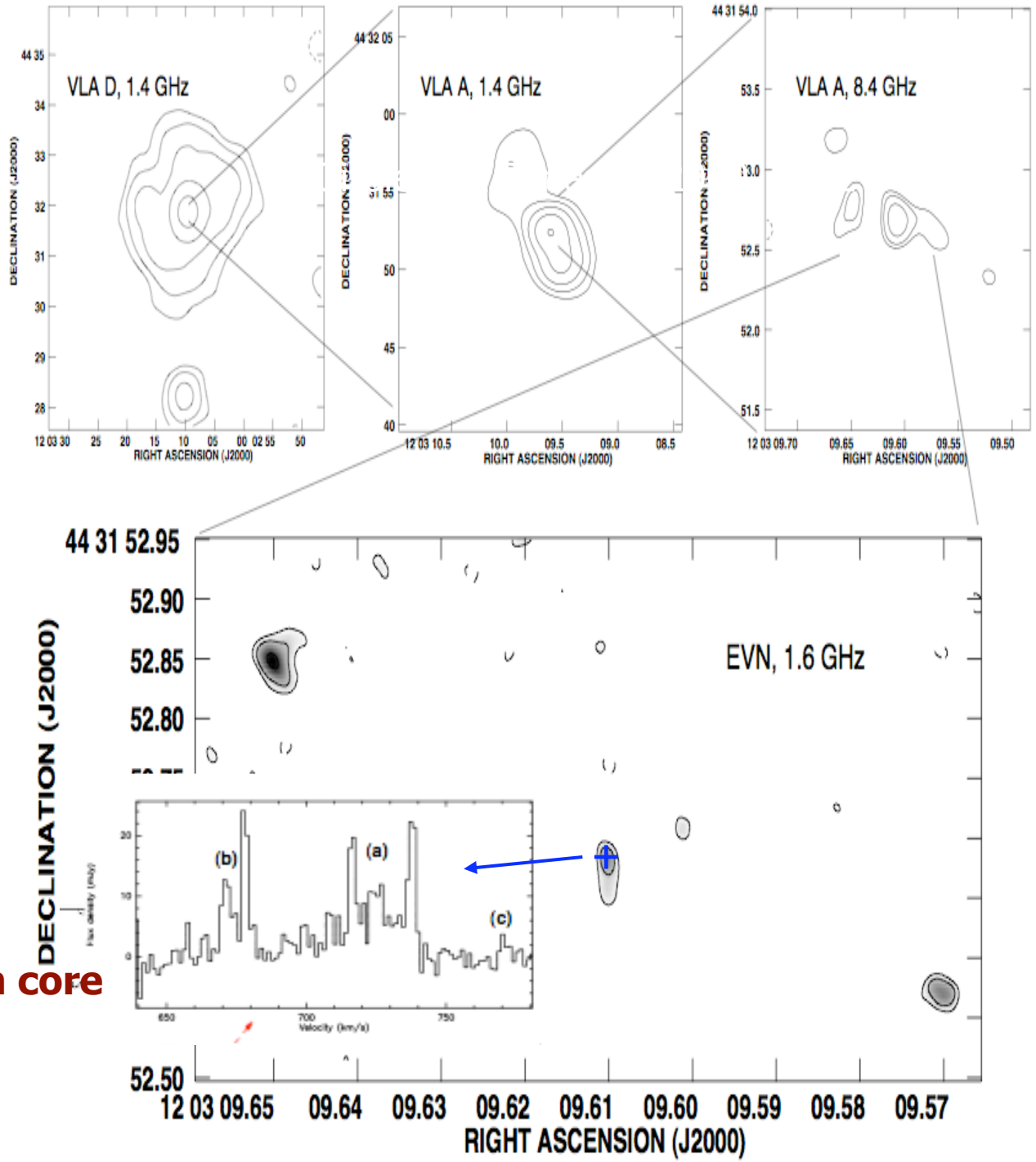
Giroletti & Panessa 2009, ApJL

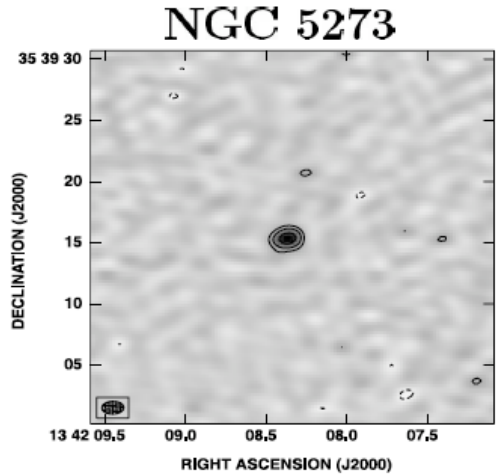
Linear size < 0.31 pc
(BLR size 0.006 pc)

✓ Log $L_{5\ GHz}/L_{2\text{-}10\ keV} < -5.8$

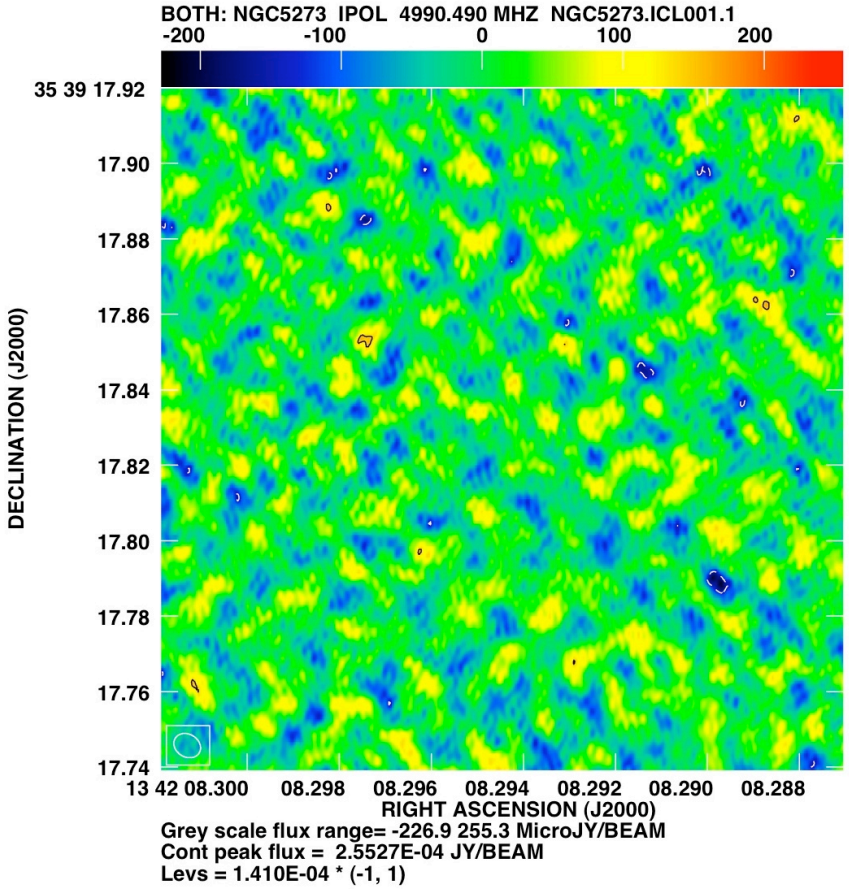
H_2O Maser coincident with core

See also Tarchi et al. 2011, A&A





NGC 5273: a LLAGN with no jet



- ✓ VLA flux of 0.6 mJy
- ✓ VLBI 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?

Giroletti & Panessa 2009, ApJL

Conclusions

The X-ray vs radio correlation holds at pc-kpc scales
→ extended emission connected to the X-ray activity

Spectral slope consistent with efficient branch for luminous AGN

No correlation with EVN sub-pc luminosities

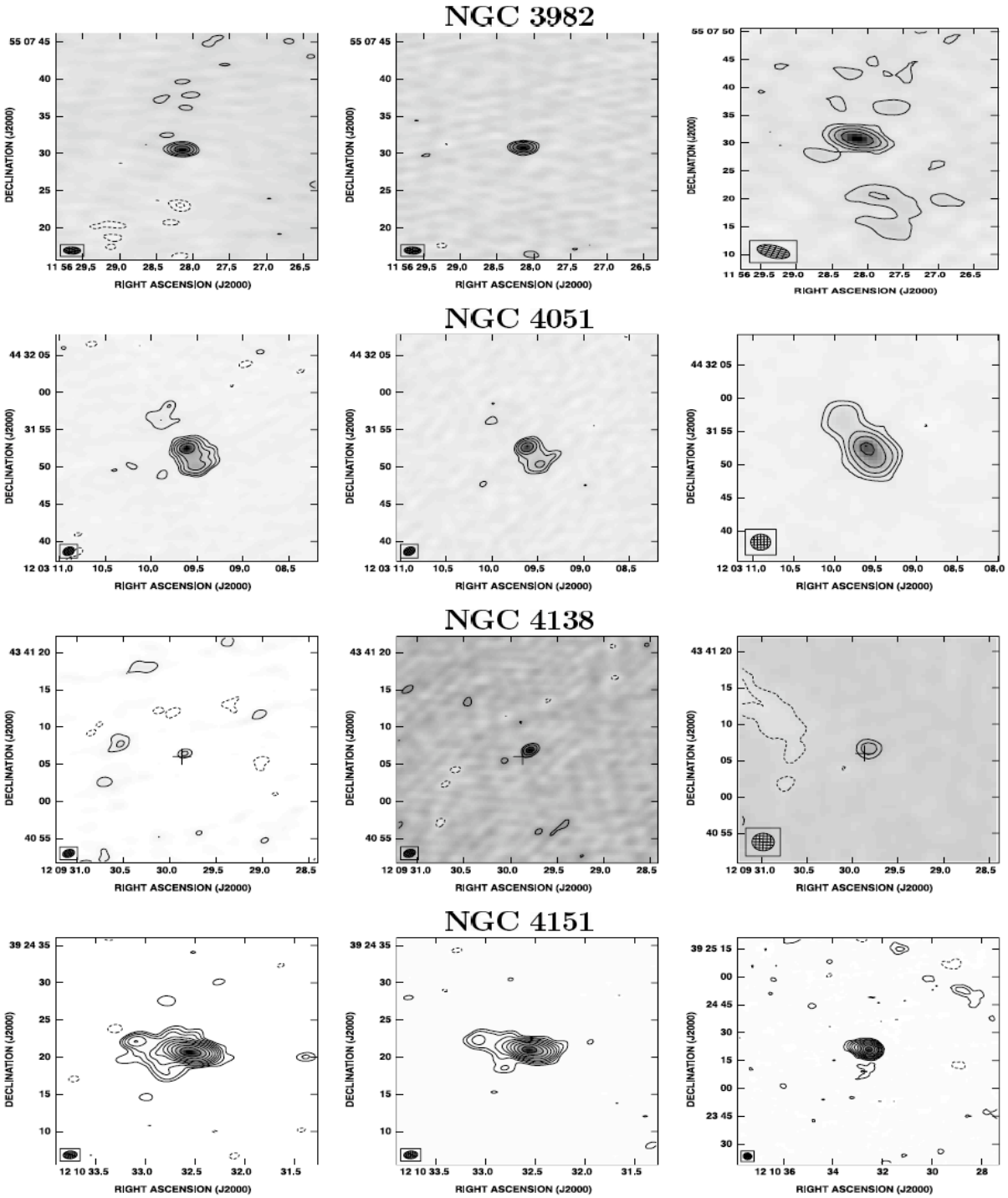
At EVN angular resolution → 5-100% of emission is resolved
→ the sub-pc cores are extremely RADIO QUIET and heterogeneous

...thank you!

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? …



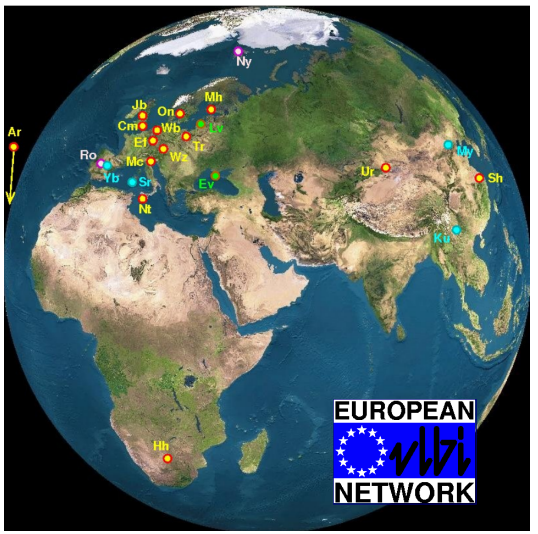
VLA Survey of Seyfert nuclei

(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



VLBI Observations of Radio Quiet Nuclei

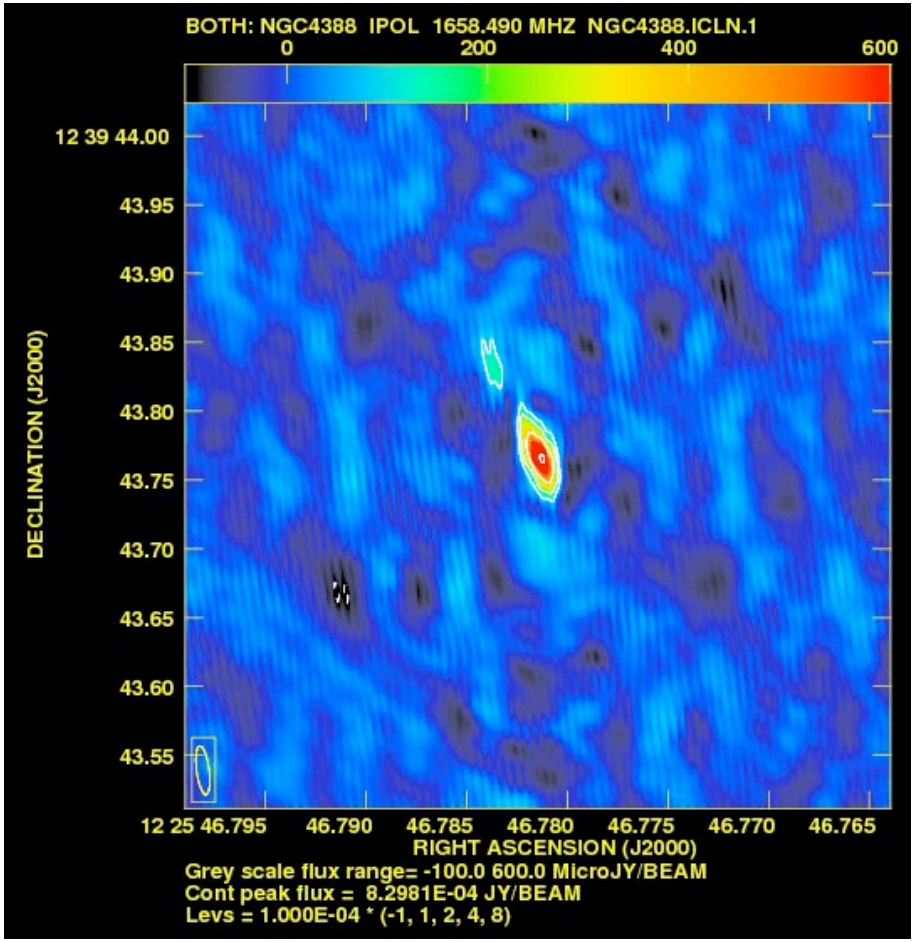
Discriminate between jet synchrontron, SSA, ADAF, free-free emission?

Physical constraints:

- Compactness of the source (ADAF < 10^4 R_S)
- Brightness temperature limits (high T_B -> non thermal emission)
- Spectral indeces (steep, flat or inverted --> Synch, ADAF or SSA)
- Motions (relativistic/sub-relativistic)

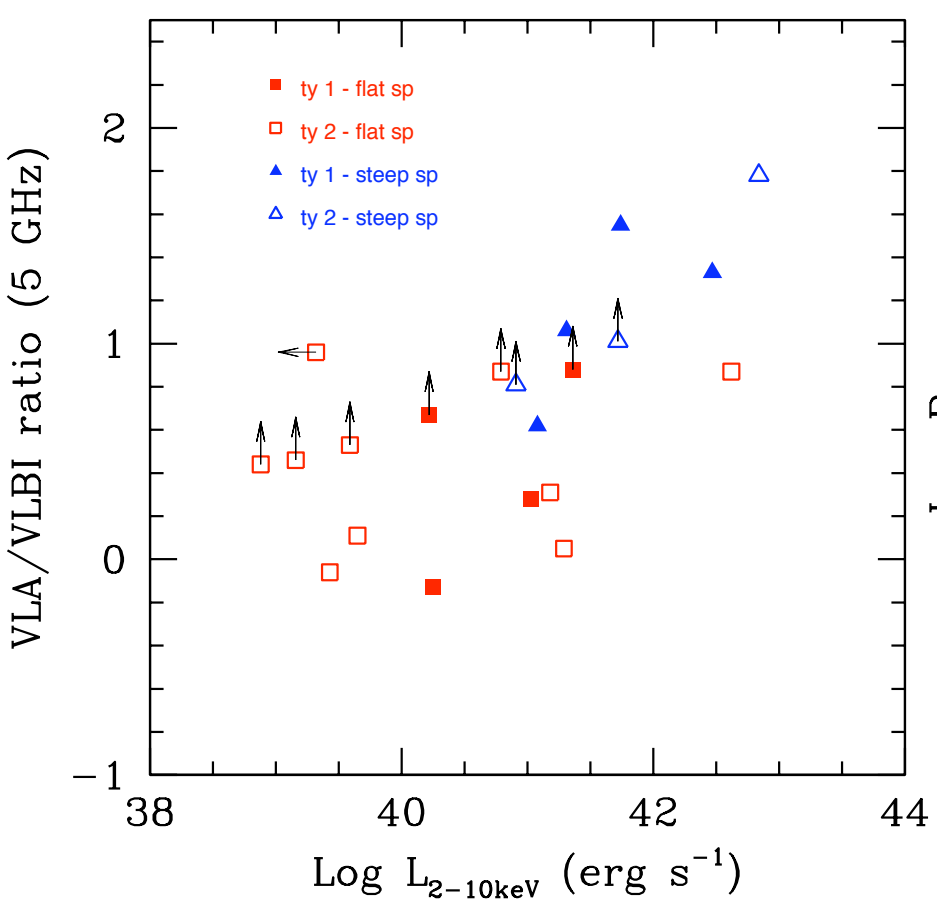
Type 2 Seyfert: NGC 4388

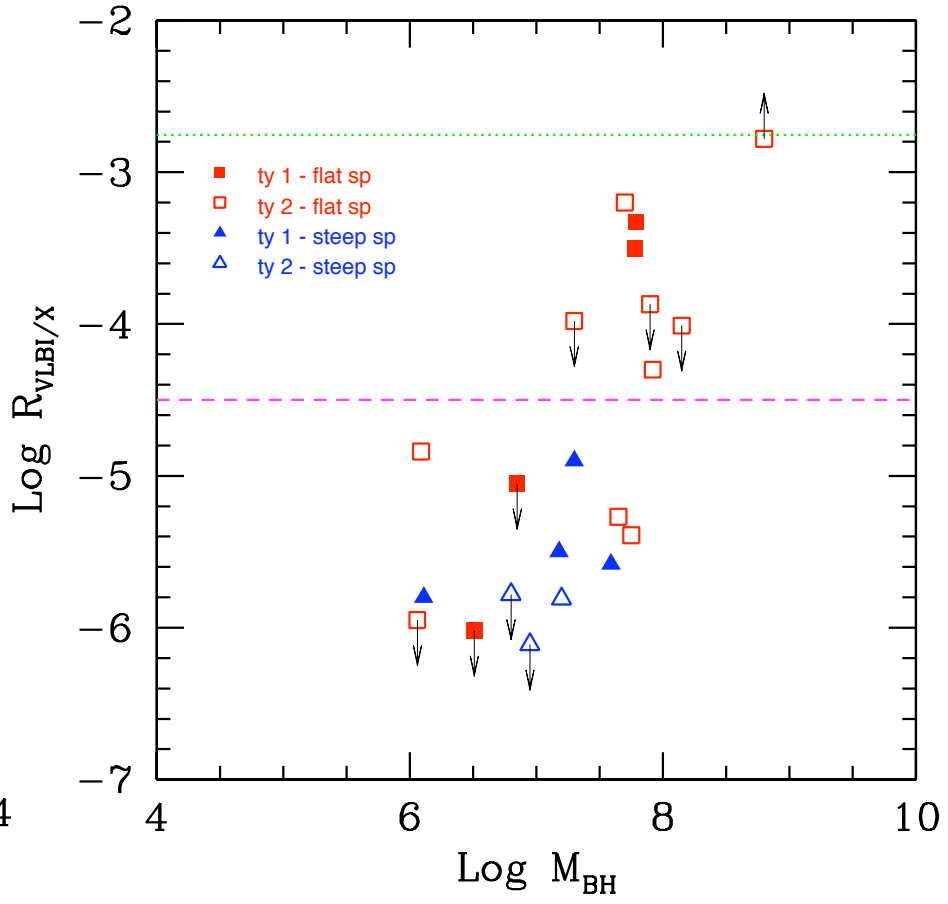
- ✓ Type 1.9 Seyfert galaxy
- ✓ Several VLA detections up to 15 GHz, flat spectrum (Falcke et al. 1998)
- ✓ Detected at 1.6 GHz (not at 5 GHz)
  -> very steep $\alpha > 1.3$
- ✓ Compact radio emission at 1.3 mJy
- ✓ Extension of 6 mas (0.48 pc)
- ✓ $T_B = 1.3 \times 10^6$ K
- ✓ H_2O Maser emission
- ✓ 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?

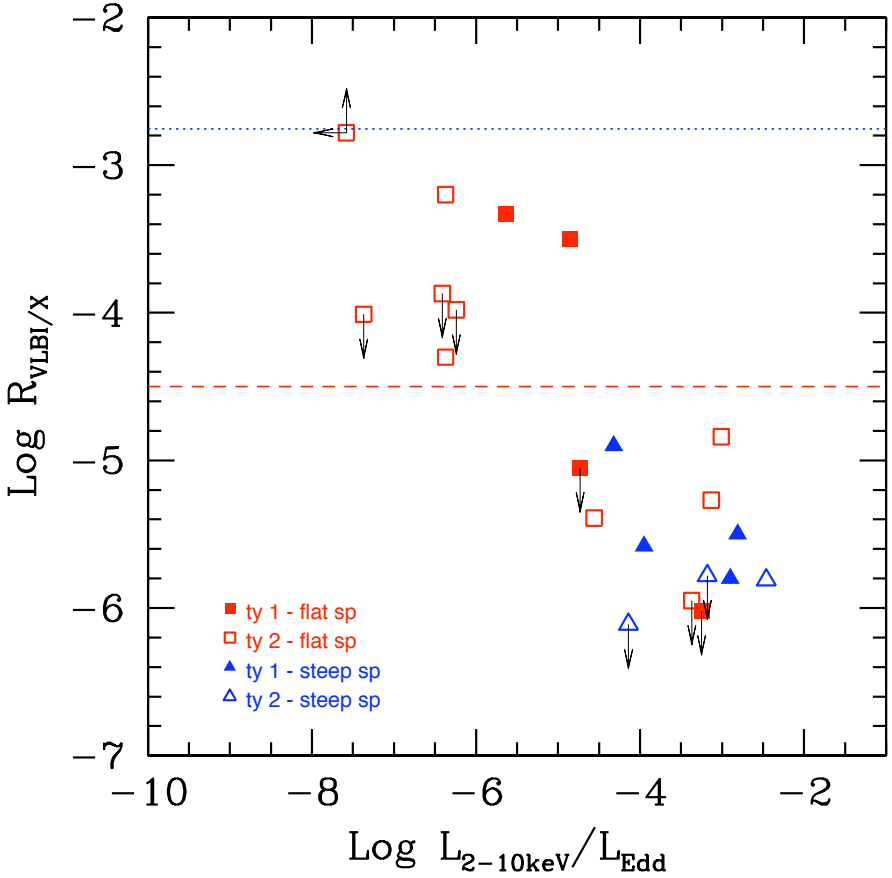
Resolved radio emission at sub-pc scales

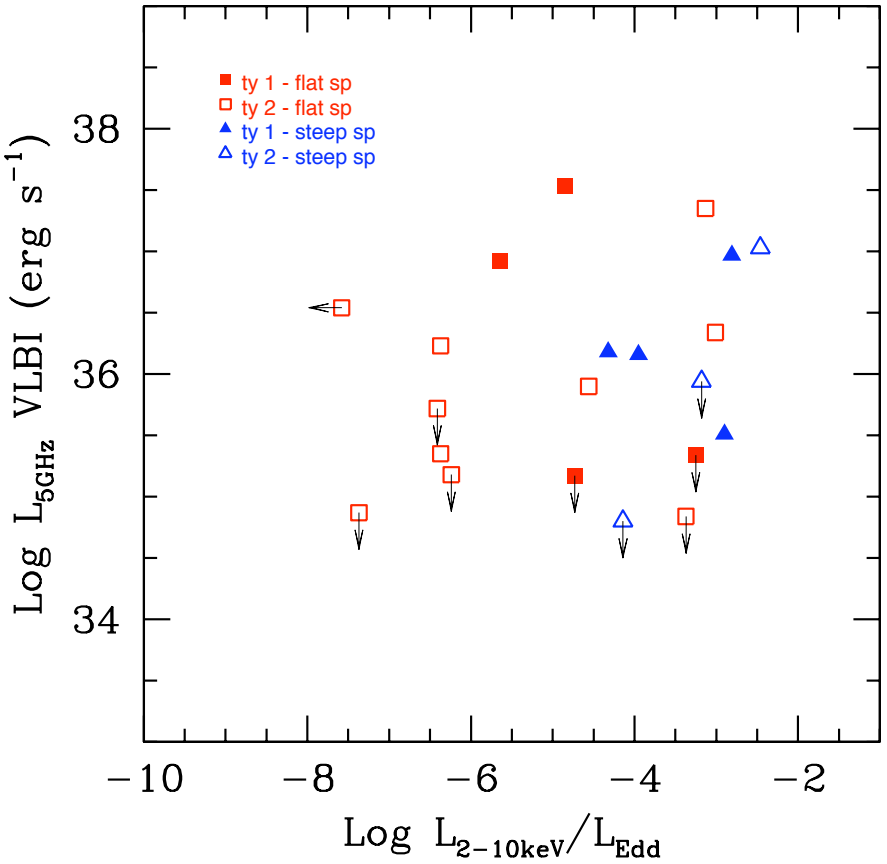




Panessa&Giroletti 2013 MNRAS, submitted

Radio power versus Eddington ratio





Panessa&Giroletti 2013 MNRAS, submitted

Thank you!