Radio jets in Seyfert galaxies VLBI and Fermi view

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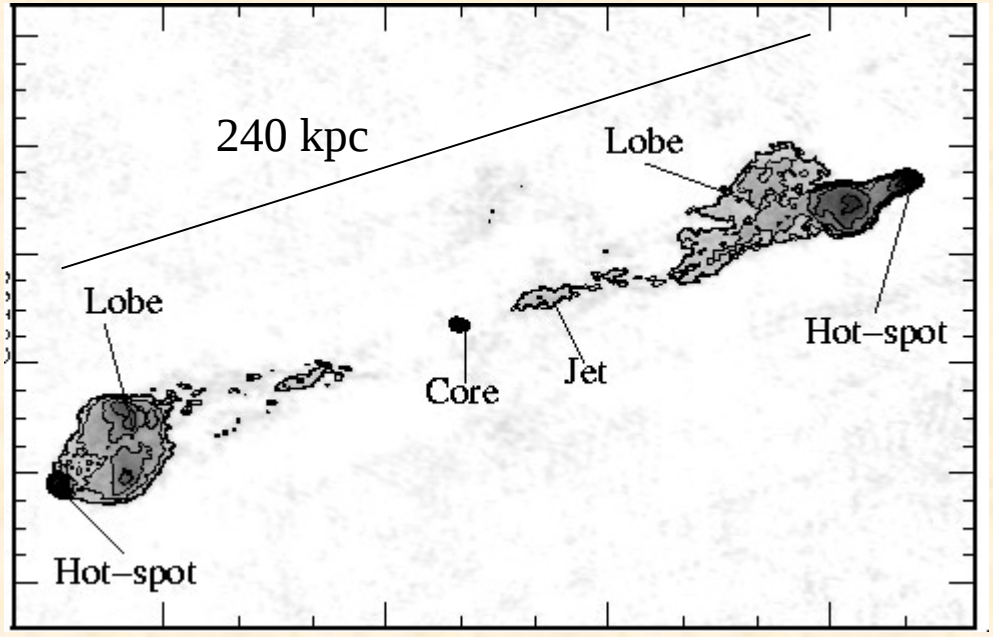
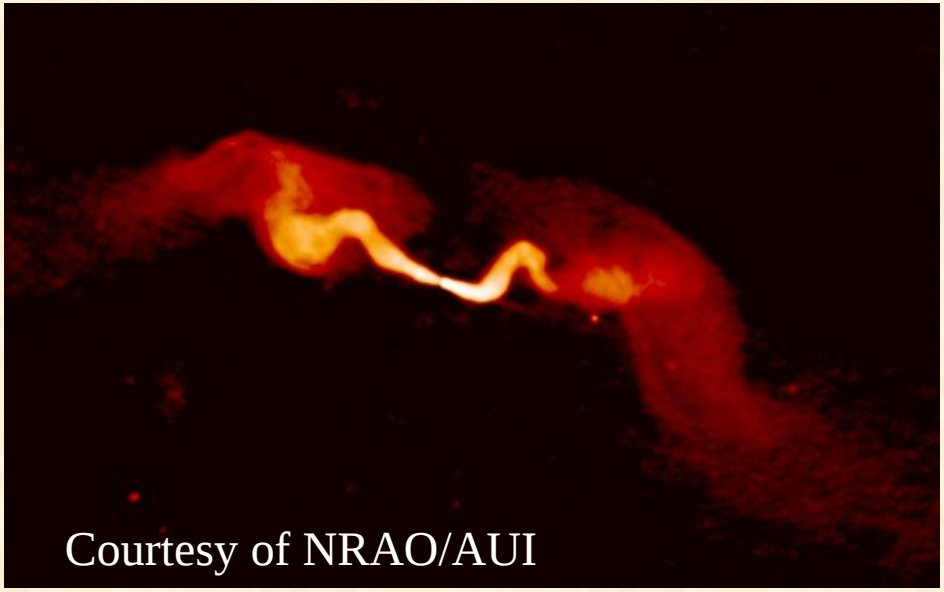
Outline

- Radio-loud and radio-quiet AGN
- γ-ray emission in radio-quiet AGN
- The pc-scale emission from the Seyfert cores
- Future perspectives

Radio emission in RL-AGN

The main ingredient for powerful radio emission is the presence of relativistic jets



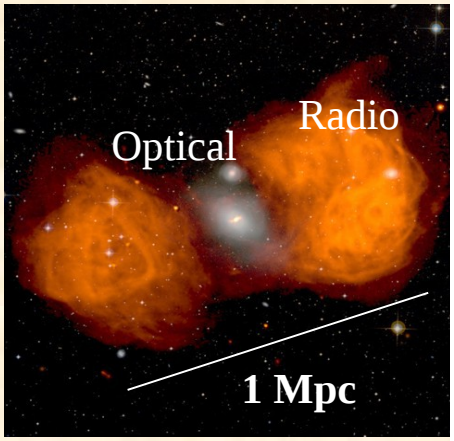


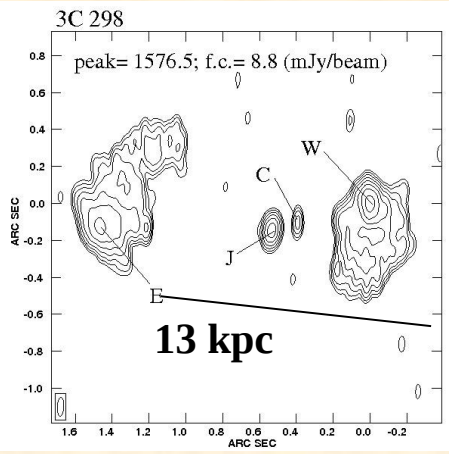
Bipolar outflows channel energy, relativistic particles and magnetic field from the AGN towards the external medium

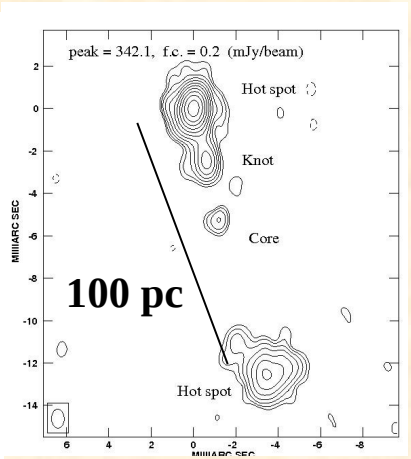
Spectral energy distribution dominated by non-thermal radiation from the jet

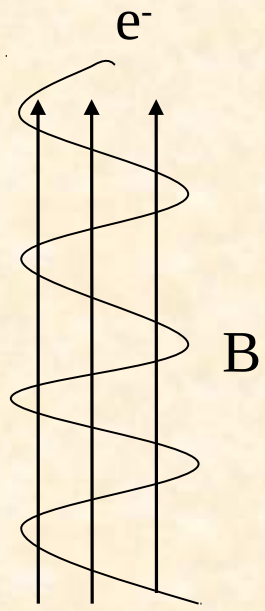
Radio emission in RL-AGN

- $L_{1.4} \geqslant 10^{23}$ W/Hz
- Size: from pc to Mpc
- Ellipticals and quasars









\+ Magnetic field

Relativistic particles

Synchrotron emission

Inverse Compton emission

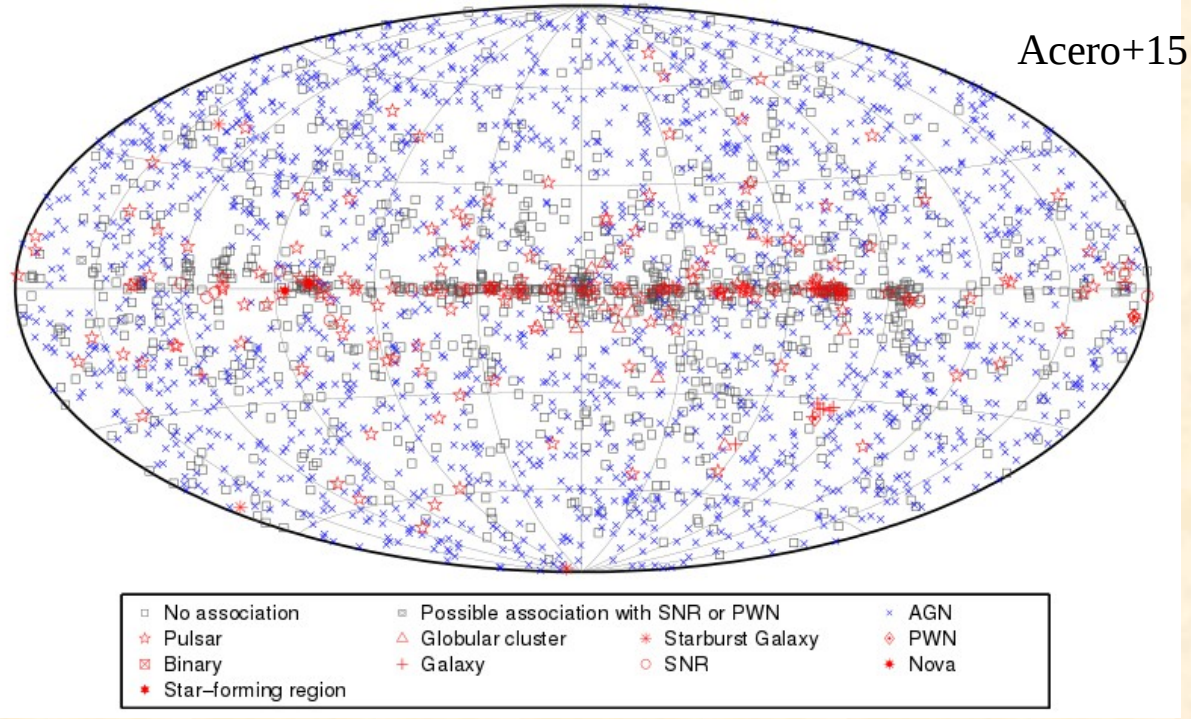
\+ Seed photons

"Only" 15-20% of AGN are radio-loud

γ-ray emission in RL-AGN

58% of 3FGL sources are extragalactic sources

>99% of them are RL-AGN

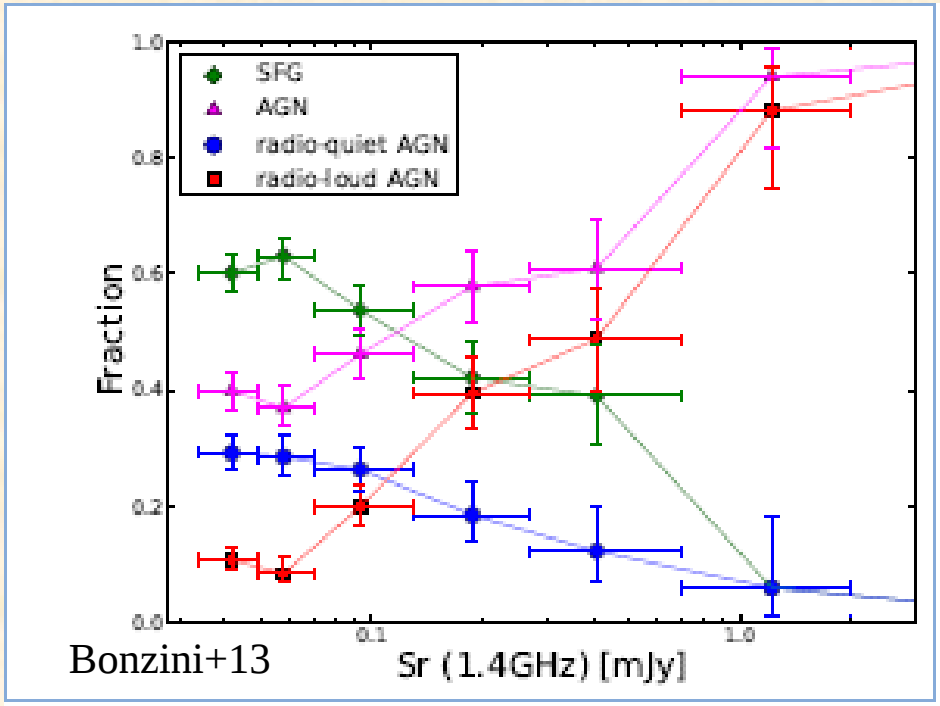


RL-AGN dominate the γ-ray sky

Radio-quiet AGN

SED dominated by thermal emission related to the accretion disk

The majority of AGN are radio-quiet, **not radio-silent!**

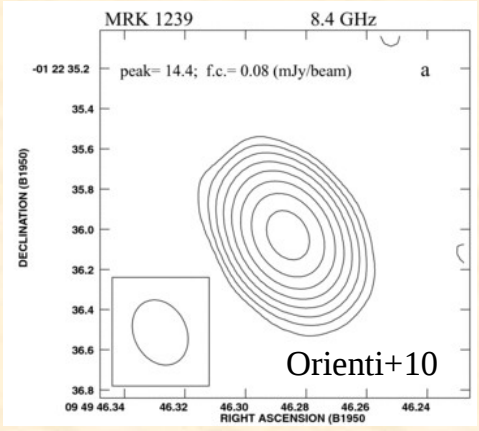


Dominant AGN population < 100 μJy @ 1.4 GHz

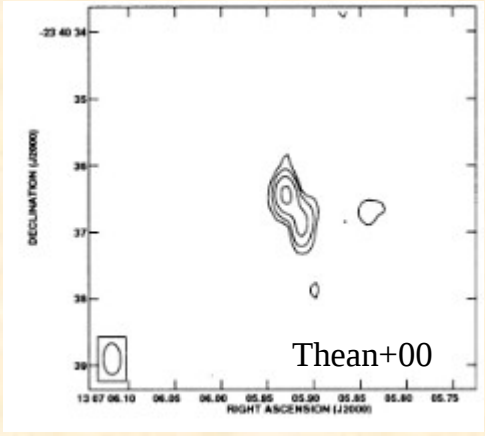
Radio-quiet AGN

- $L_{1.4\ GHz} < 10^{20\text{-}23}$ W/Hz;
- Size: (sub-)kpc scale, within the host galaxy
- Spirals, star-forming, lenticular
- Variety of radio morphology
- Misalignment between pc and kpc scale

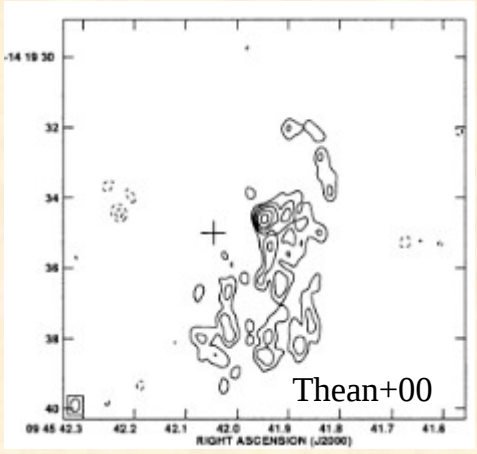
Unresolved



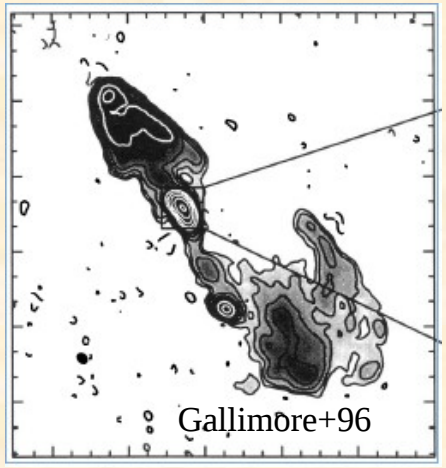
Resolved



Extended



FRII like



Radio-quiet AGN

What is the origin of the nuclear emission?

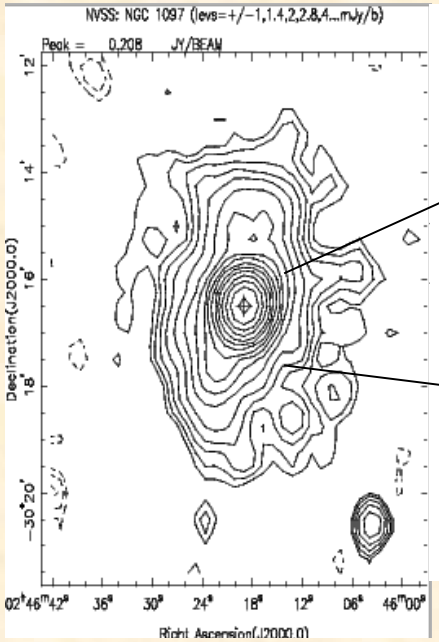
- Thermal emission from AGN wind/hot corona
- ADAF/ADIOS
- Non-thermal jet emission
- Combination of jet and disk emission

The host galaxy contribution

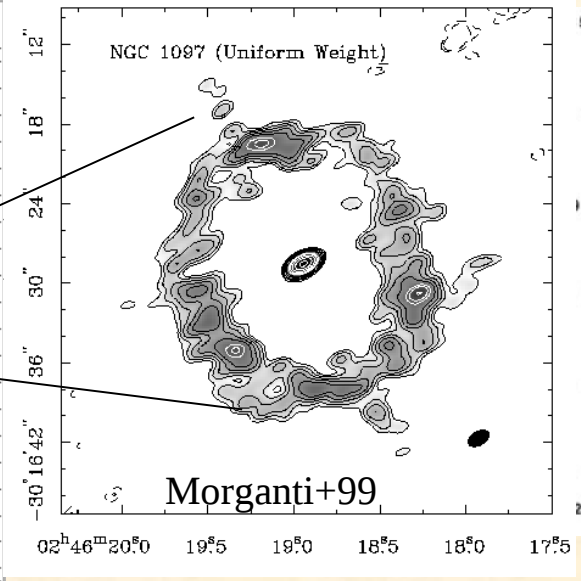
Usually in late-type galaxies → Loads of gas and stars

GALEX

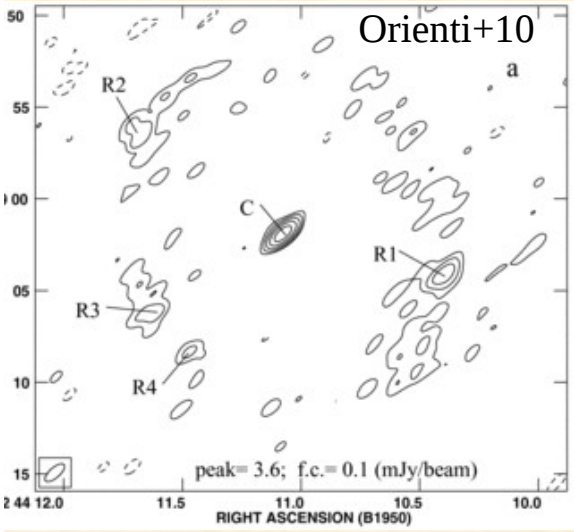
NVSS



VLA-BnA C band



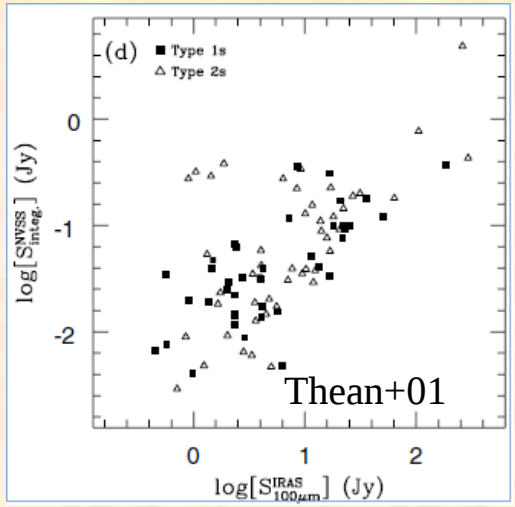
VLA-A X band



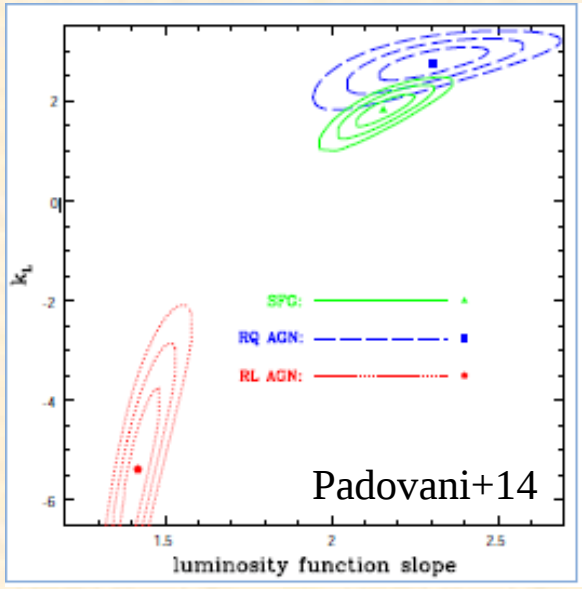
AGN emission hidden by stellar contribution

Radio-quiet AGN

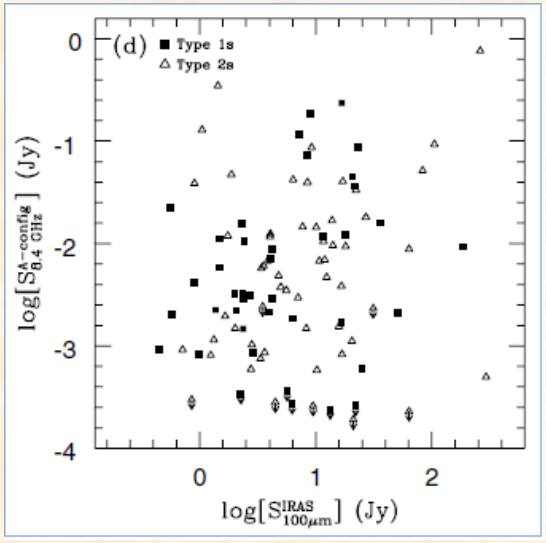
Large fraction from stellar-related processes



Tight radio-FIR correlation



Luminosity evolution similar to SFG



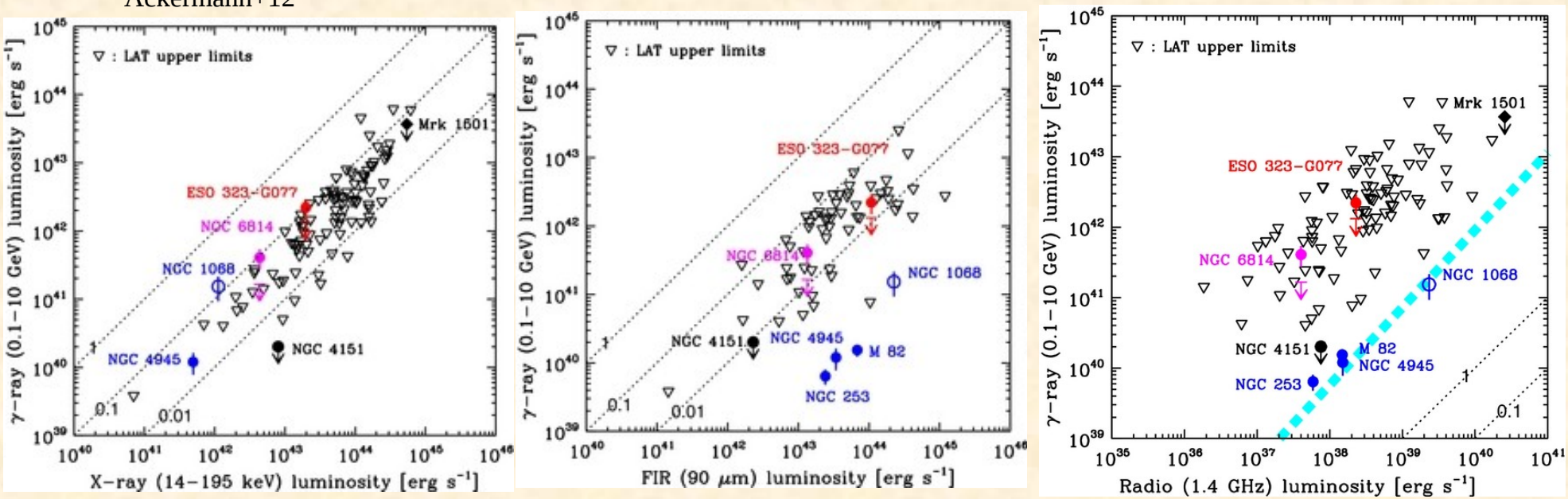
Core: $L_{2cm} \sim 10^{18\text{-}22}$ W/Hz;

No core radio-FIR correlation

High-energy emission

120 hard X-ray selected radio-quiet Seyferts without strong starburst activity to constrain the high-energy emission mechanisms

Ackermann+12



No detection based on 3 years of Fermi-LAT data.

Possible exception: ESO 323-G077

NGC 6814

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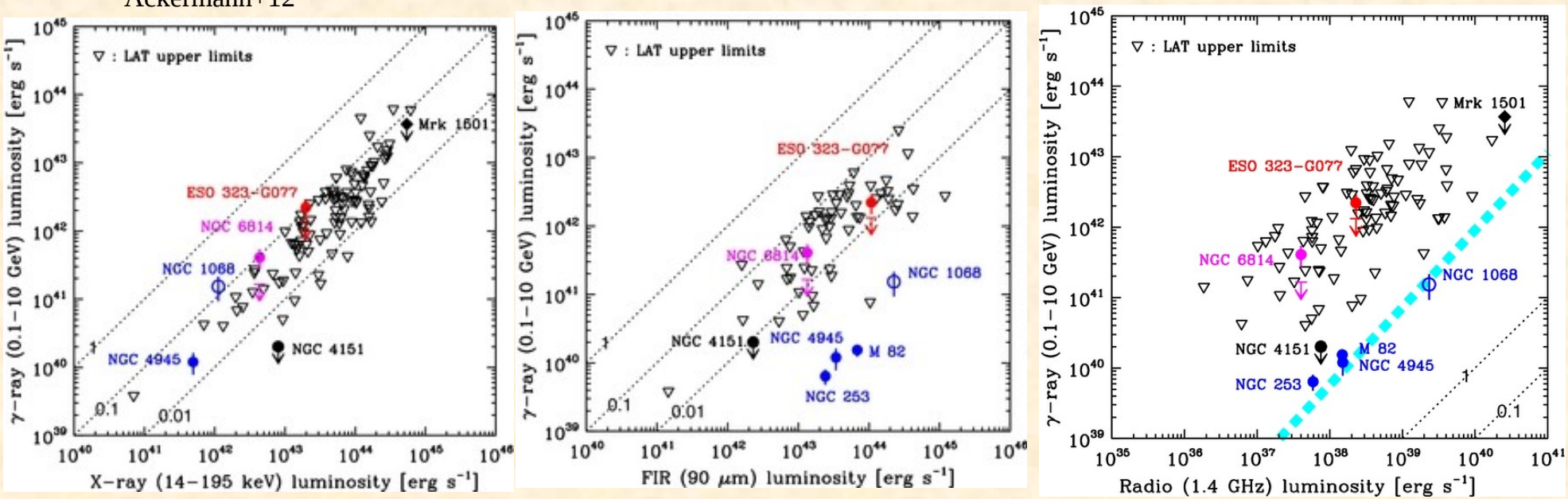

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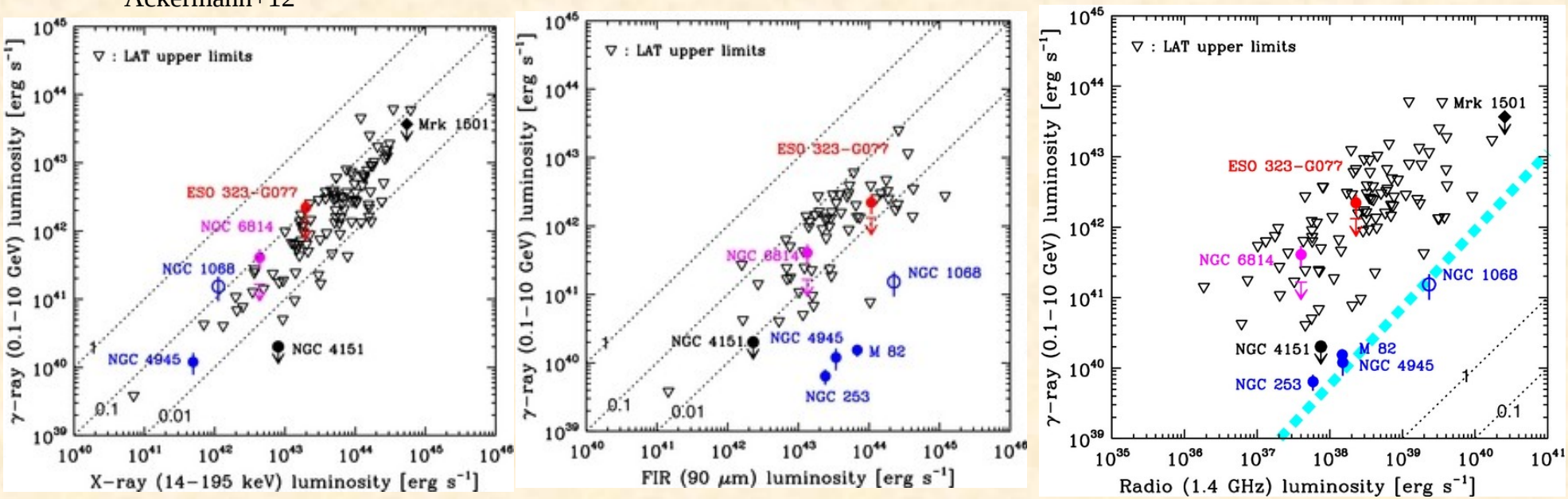

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Mis-associated

Not confirmed in the 3FGL

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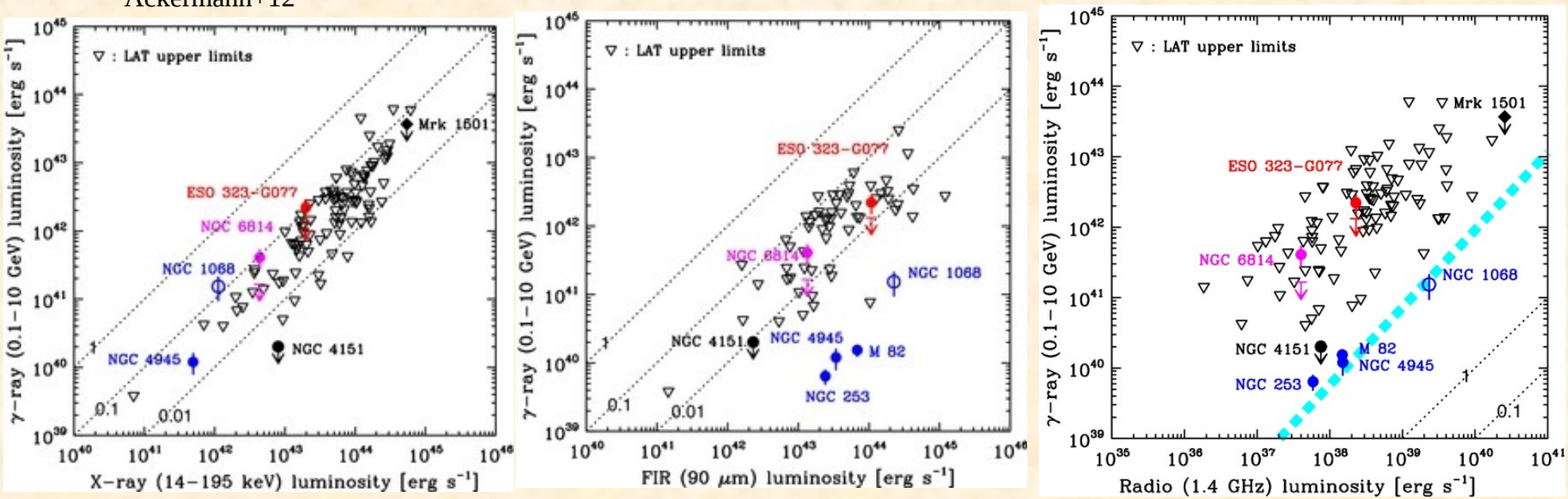

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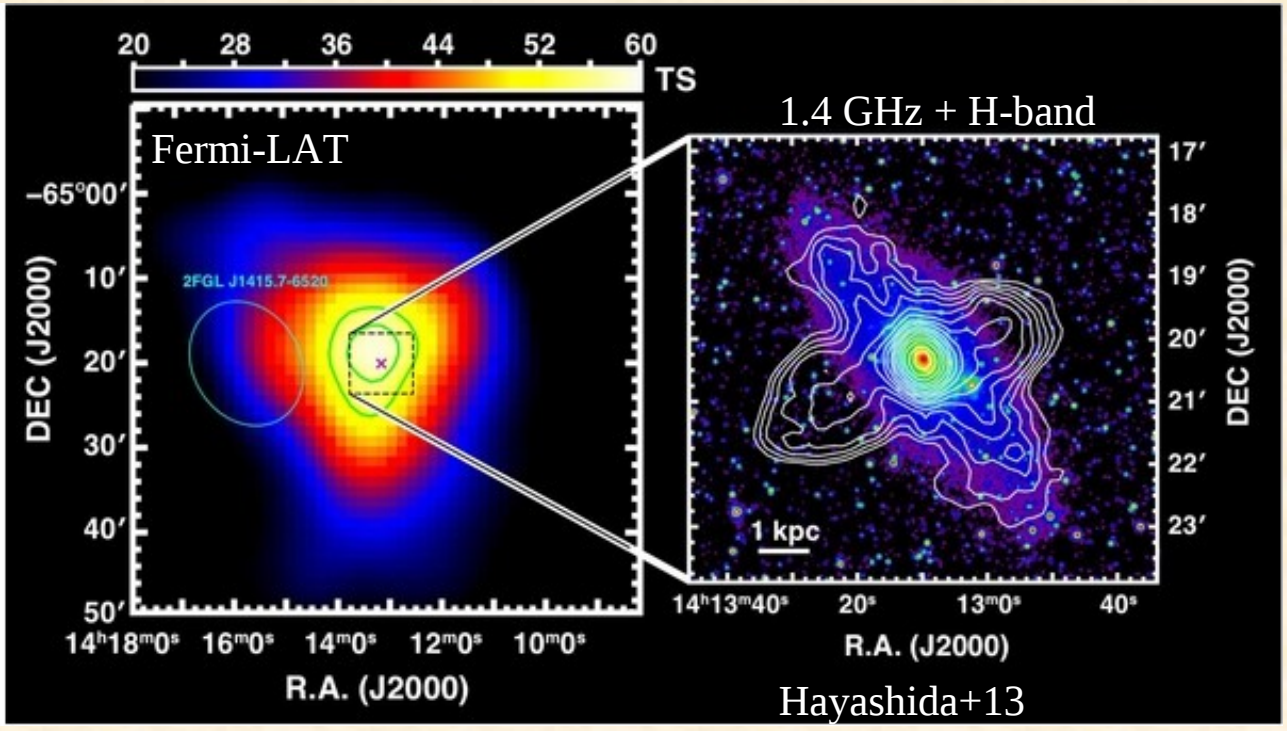
Lγ / LX < 0.1 -0.01: Seyferts are not prominent γ-ray emitters.

Circinus

The analysis of 4 yr of Fermi-LAT data pointed out an excess (~7.3σ) of γ-ray emission above the background in the Circinus region.

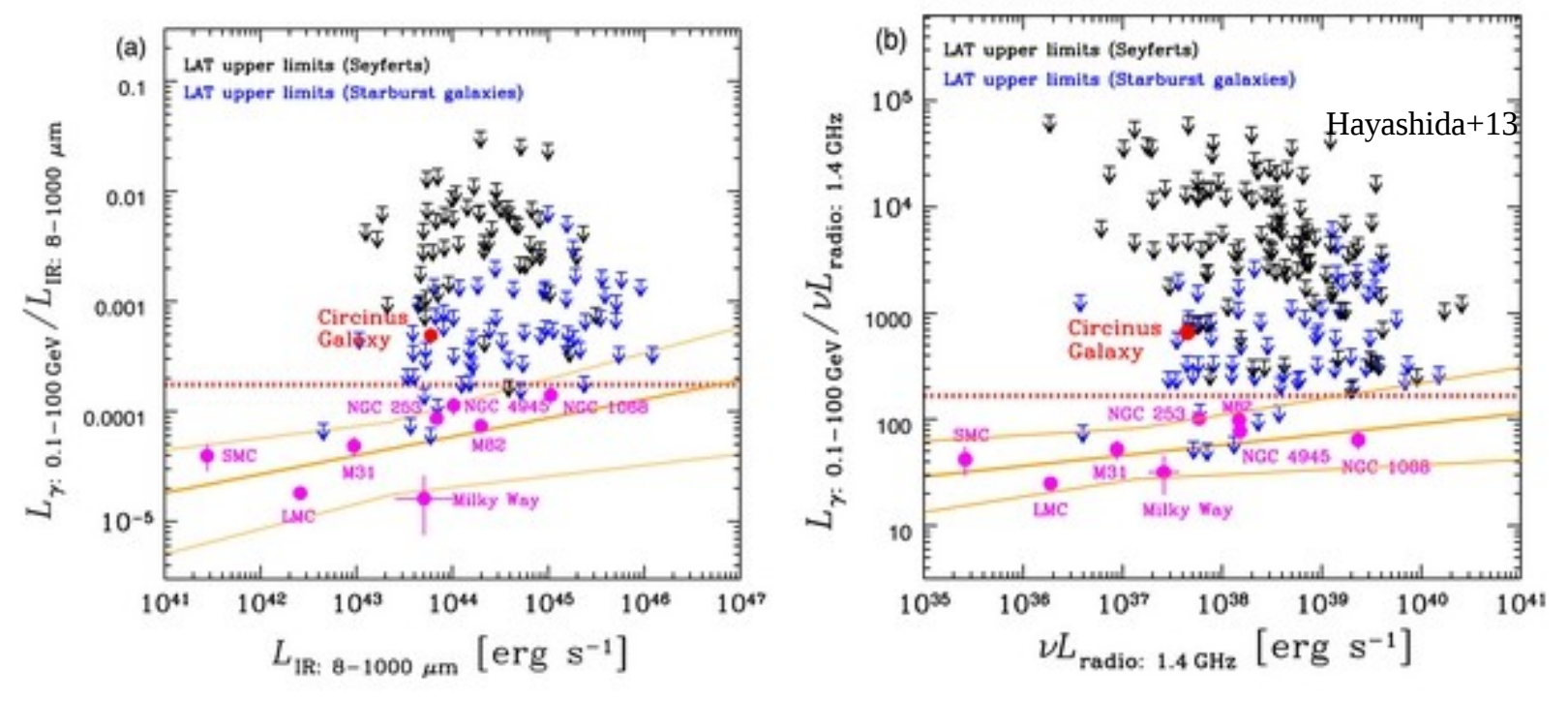


$F_{>0.1\ GeV} = (18.8 \pm 5.8) \times 10^{-9}$ ph cm $^{-2}$ s^{-1} $\Gamma = 2.19 \pm 0.12$

$L\gamma = (2.9 \pm 0.5) \times 10^{40}$ erg/s ⟶ 5-6 times higher than in SFG

Circinus

The γ-ray luminosity is above the value expected for CR in ISM of SFG



Where does the γ-ray emission come from?

IC in the lobes

CR Protons associated with the lobes

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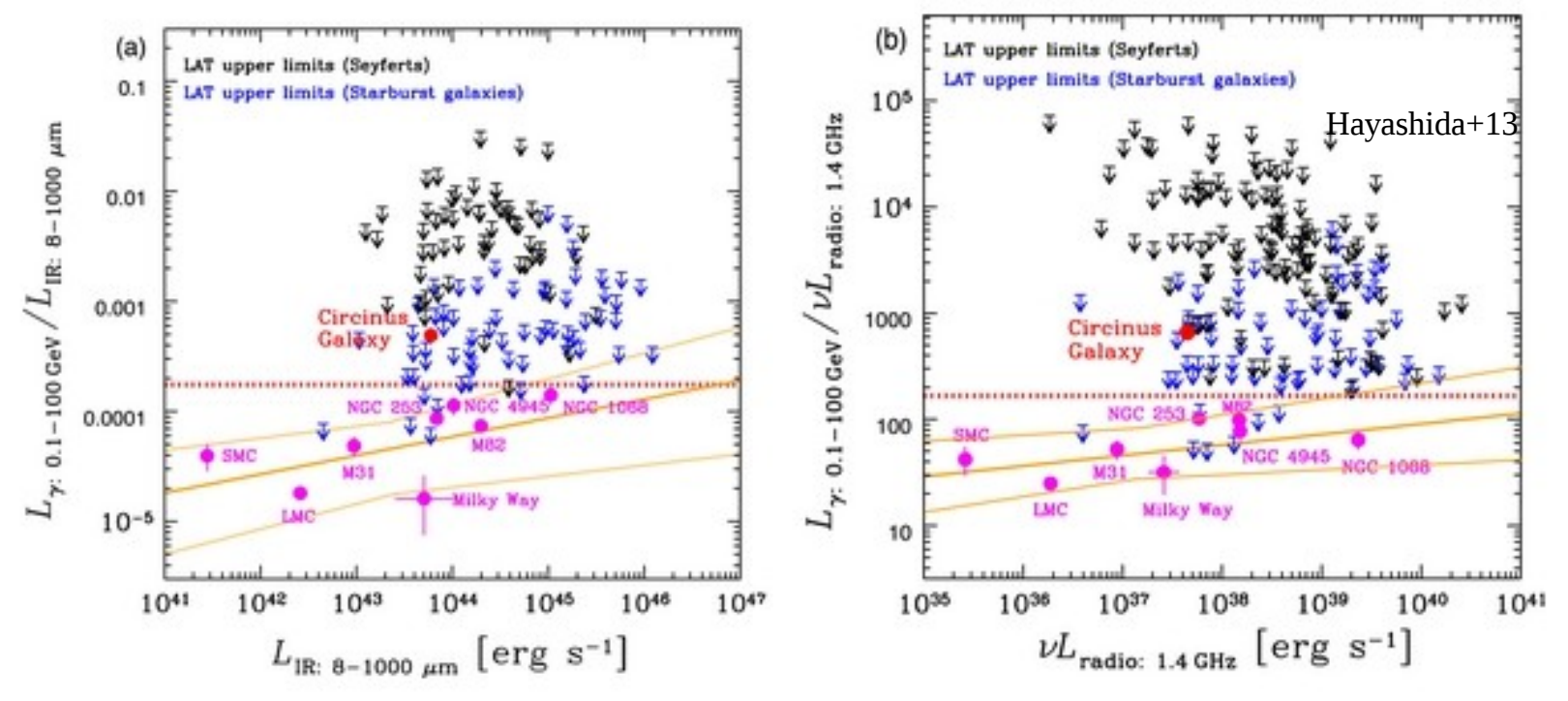

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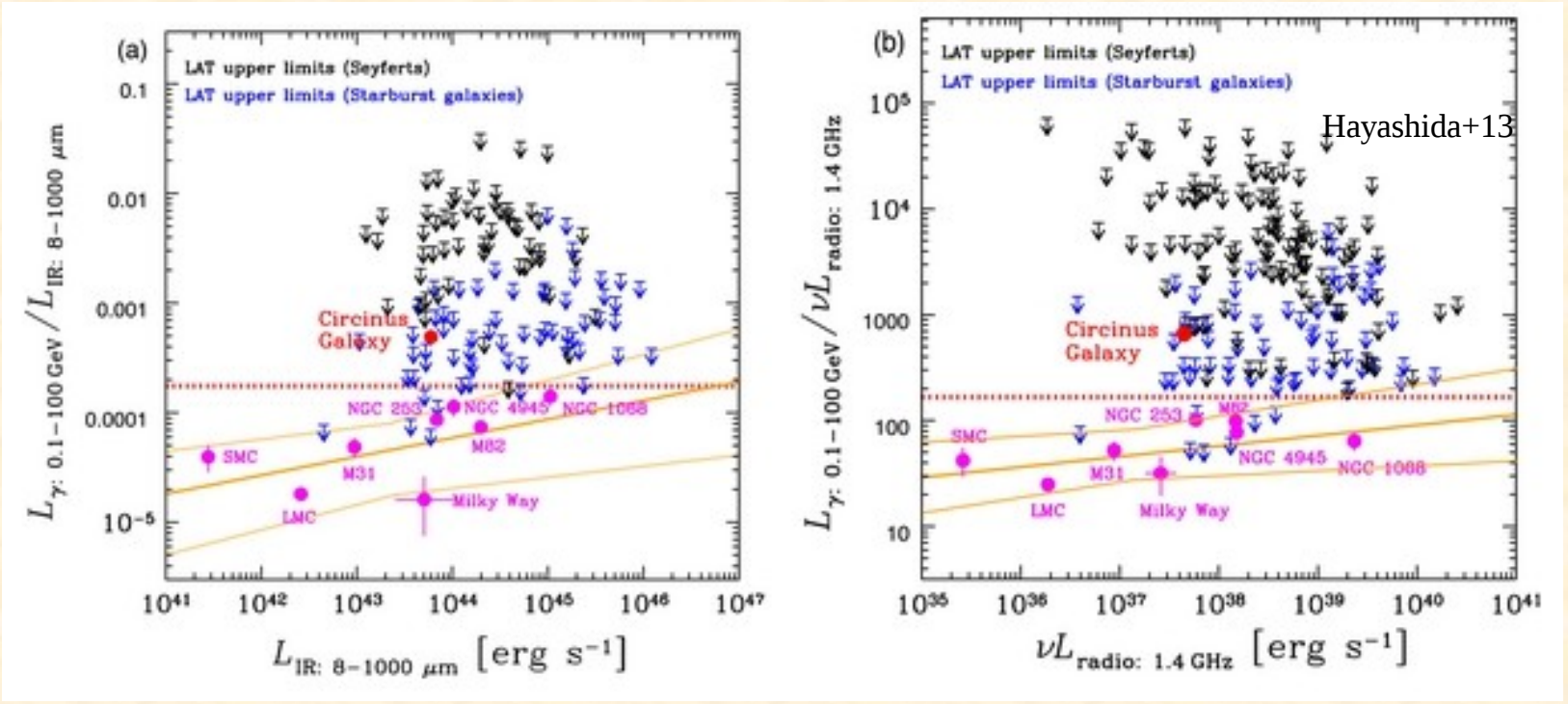

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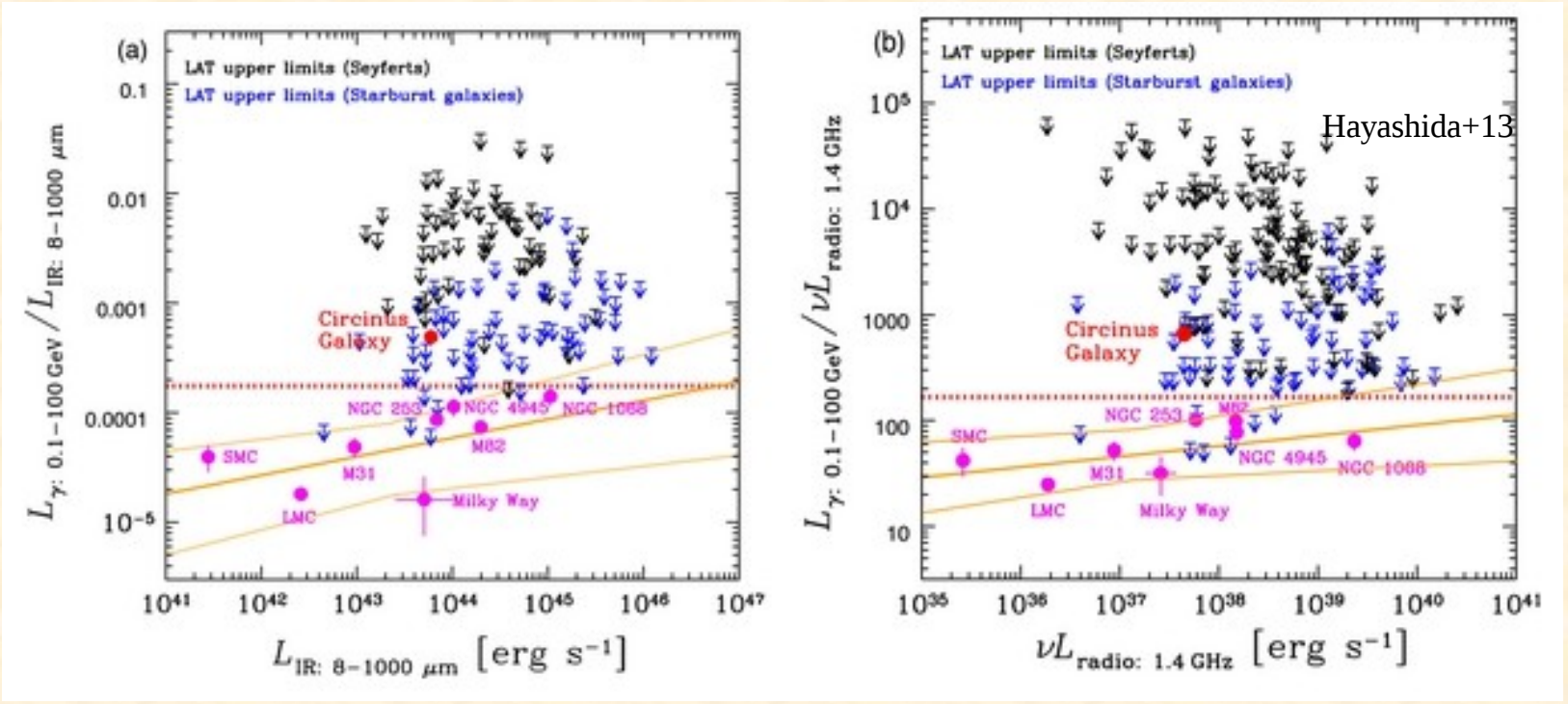

Where does the γ-ray emission come from?

IC in the lobes

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Too far from equipartition

Highly inefficient

No conclusive results

Radio band: Observational requirements

High angular resolution (sub-arcsecond scale)

Separate AGN and stellar emission in the central kpc region

High sensitivity (μJy level)

Pick up the faint contribution from the AGN

Polarization (0.1% level or better)

Disentangling thermal and non-thermal contribution

Resolve regions with well ordered H

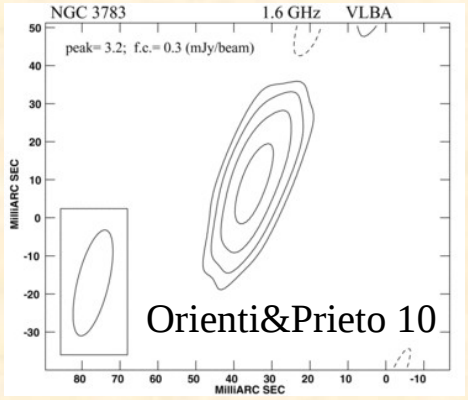
Continuous frequency coverage

Disentangling thermal and non-thermal emission by the spectrum

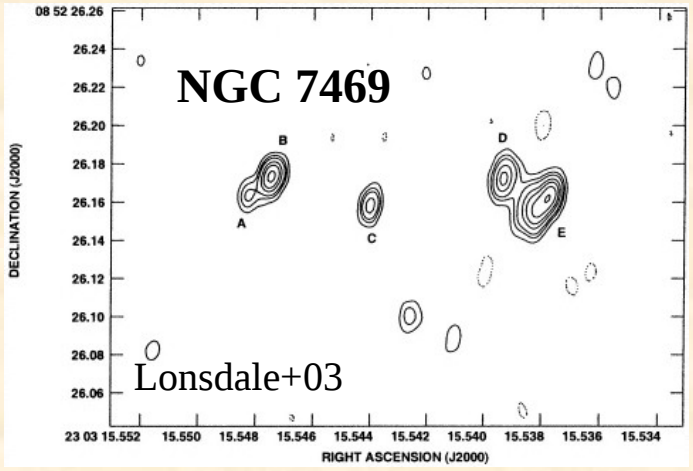
The role of VLBI

VLBI observations of several Seyfert samples
(Nagar+02, Lonsdale+03, Roy+04, Lal+04, Middelberg+04, Anderson+04, Gallimore+04, Orienti&Prieto 10, Giroletti&Panessa 10, Bontempi+12, Panessa&Giroletti 14, Doi+13, Doi+14, Kharb+14....)

Parsec-scale radio emission is almost ubiquitous in Seyfert nuclei

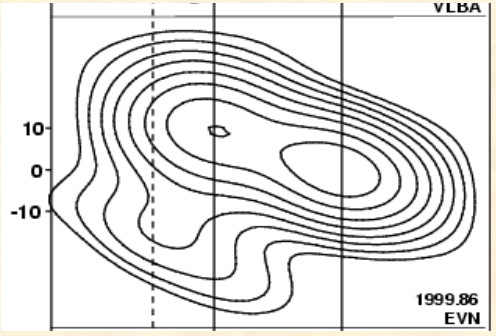


Orienti&Prieto 10



Lonsdale+03

NGC 5506



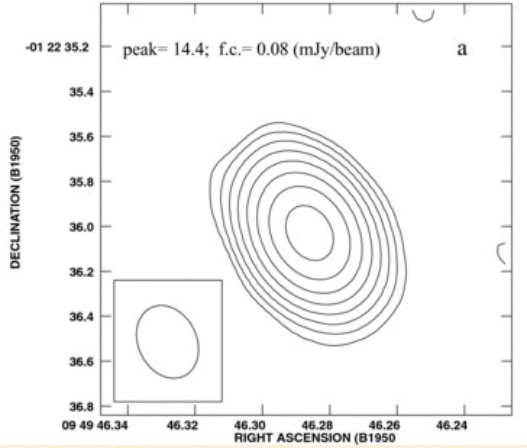
Middelberg+04

VLBI picks up 100% down to a few % of the unresolved sub-arcsec scale central component. What is the “missing” flux?

The missing flux

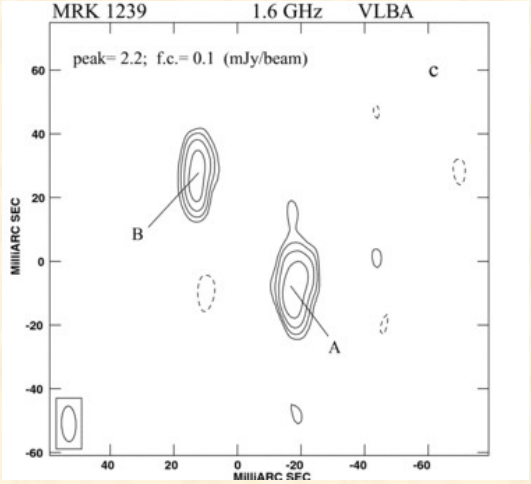
In some Seyfert nuclei there is extended emission which cannot be recovered by the short baseline of VLBA/EVN Networks.

VLA



Orienti&Prieto 10

VLBA



Mrk 1239:

20% of the VLA flux density recovered in VLBA observations

The missing flux

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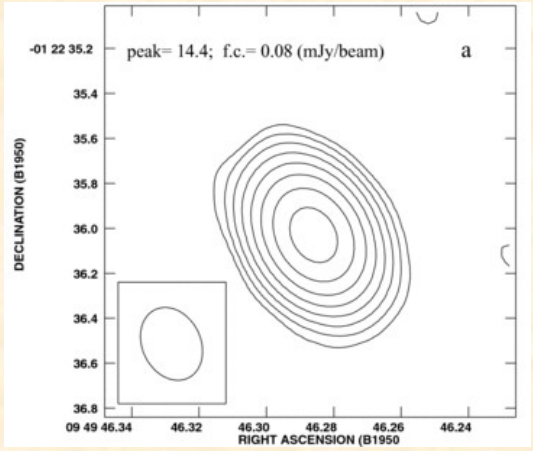
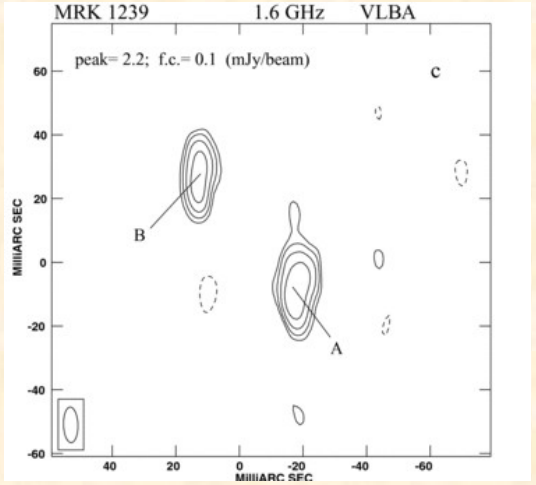
VLA

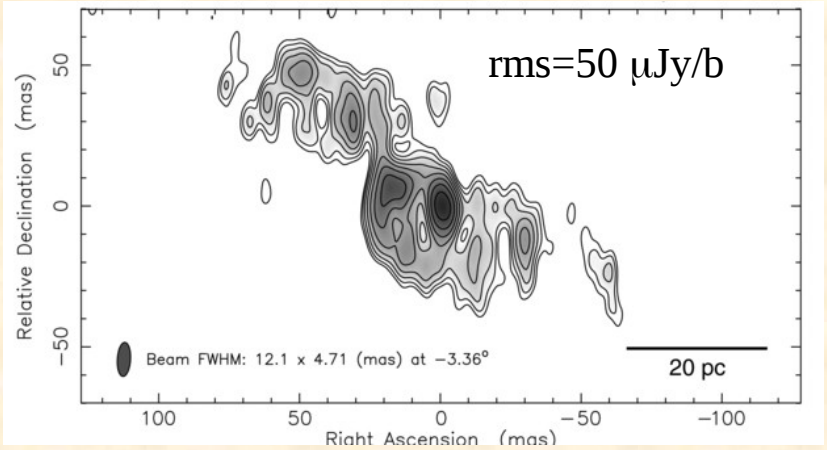


Orienti&Prieto'10

VLBA



VLBA+VLA



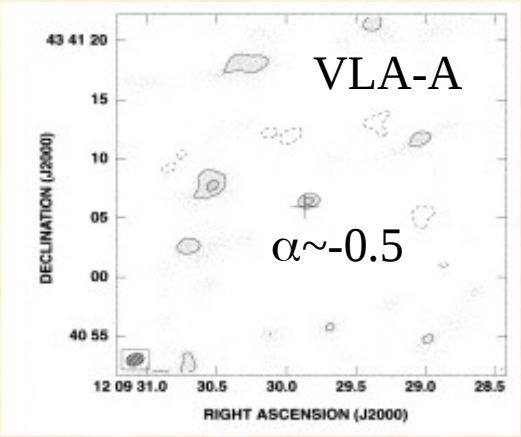
Doi+14

FRI-like radio structure in a RQ-AGN.

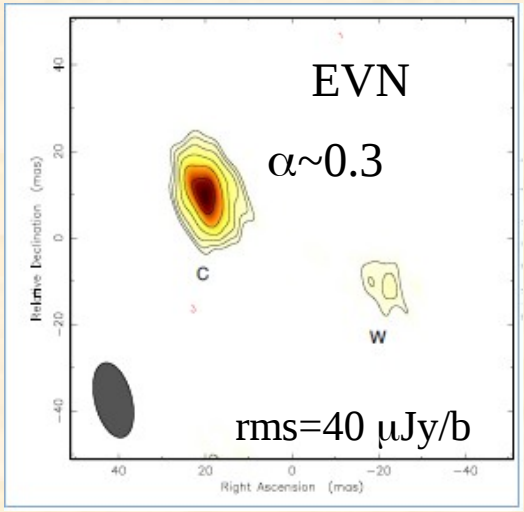
L ~ 10^{39} erg/s in radio and X-rays ⟶ Low efficiency in jet generations?

The missing flux: spectral index?

Steep-spectrum Seyfert nuclei tend to lose more flux on pc-scale than flat-spectrum Seyfert nuclei.



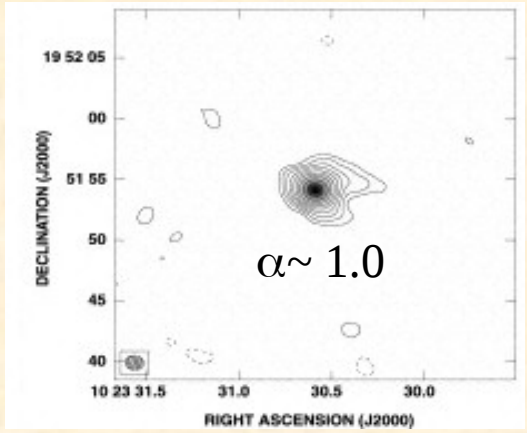
Ho&Ulvestad'01

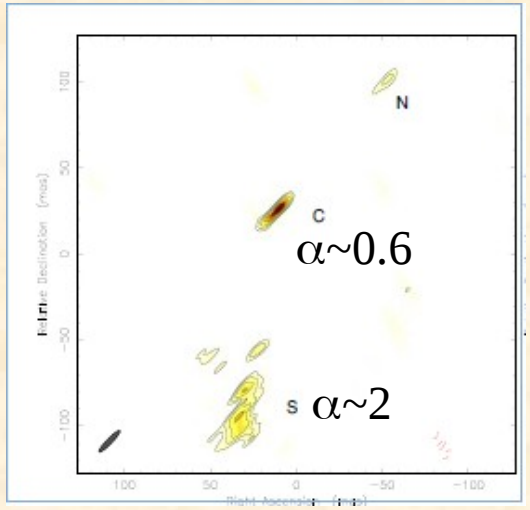


Bontempi+12

NGC 4138:

100% of the VLA flux density recovered in EVN observations





NGC 3227:

15% of the VLA flux density recovered in EVN observations

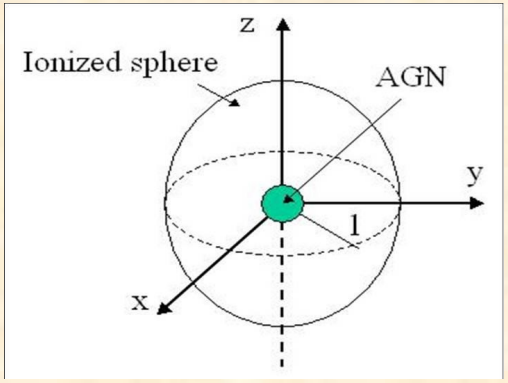
The missing flux density

In the sample of Seyfert nuclei from Prieto et al. 2009, only 20% - 50% of the flux density from the unresolved central region of steep-spectrum Seyfert nuclei is recovered on pc-scale images.

Thermal free-free origin?

$$n_e^2 = 1.84 \times 10^{41} \left(\frac{T}{10^4 \mathrm{K}}\right)^{1/2} D_L^2 S(\nu) V^{-1} g_{ff}^{-1}$$

$n_e \sim 10^3 - 10^4$ cm^{-3}

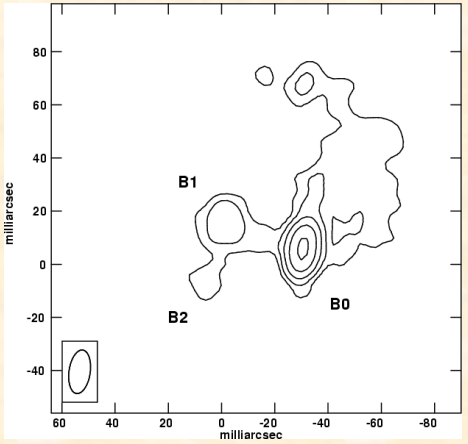


The gas should be too dense, no AGN emission would be visible.

Non-thermal synchrotron origin?

Spectral index distribution in kpc- and pc-scale images suggests the presence of a steep-spectrum low-surface brightness component. In NGC 5506:

- $\alpha_{VLA} \sim 0.8$
- $\alpha_{VLBA} \sim -0.1$



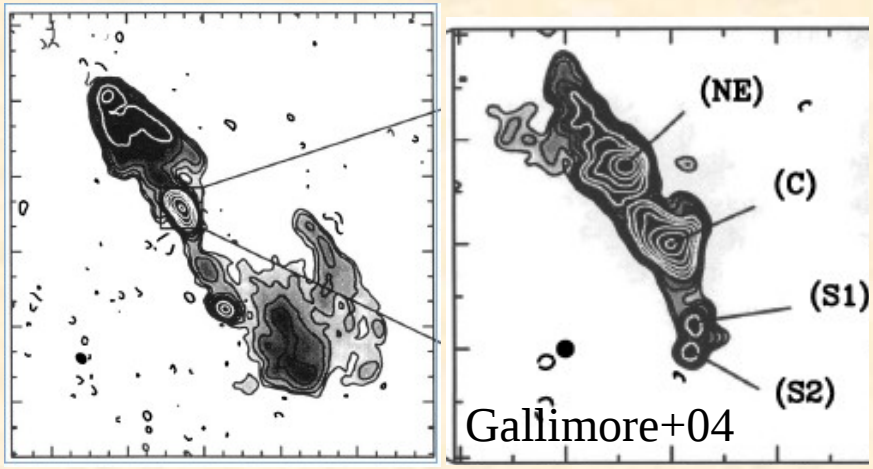
Middelberg et al. (2004)

Extended emission of non-thermal AGN-related origin, like jets, undetected for observational limitation.

Core emission

Some Seyfert nuclei, not all, seem able to form (sub)relativistic non-thermal jet-like structure.

What about the nature of the core emission?



Gallimore+04

S1 is the core region

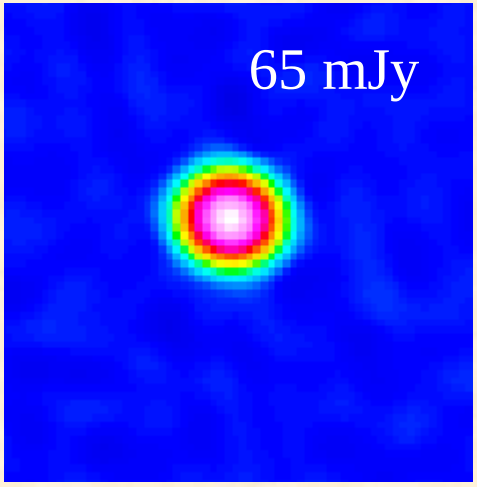
$T_B \sim 2.5 \times 10^6$ K @ 5 GHz

In NGC 1068 the core emission should be **thermal** from AGN wind/corona based on flat/inverted spectrum and the brightness temperature that is too low for SSA

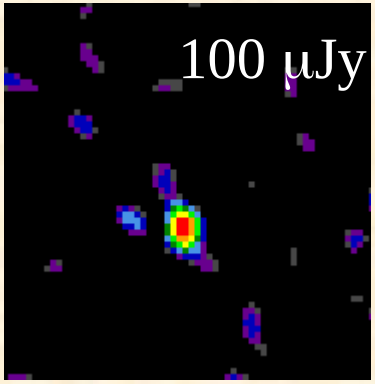
Core emission

High-sensitivity JVLA observations in full polarization

Total intensity



Polarization intensity



0.2% polarization percentage

Inverted spectrum up to 15 GHz → Emitting region size < 100 pc

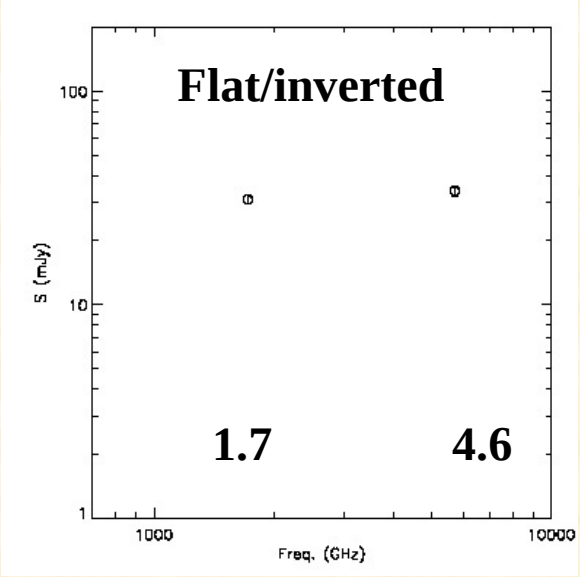
Non-thermal synchrotron emission from a “radio core” similar to RL-AGN?

Advection dominated inflow/outflow solutions?

Thermal vs non-thermal

Good frequency converage for characterizing the spectral shape

Continuous coverage ~1 to >10 GHz

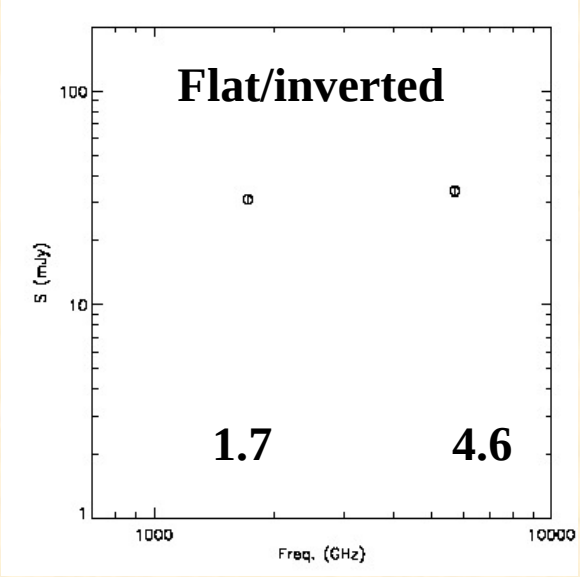


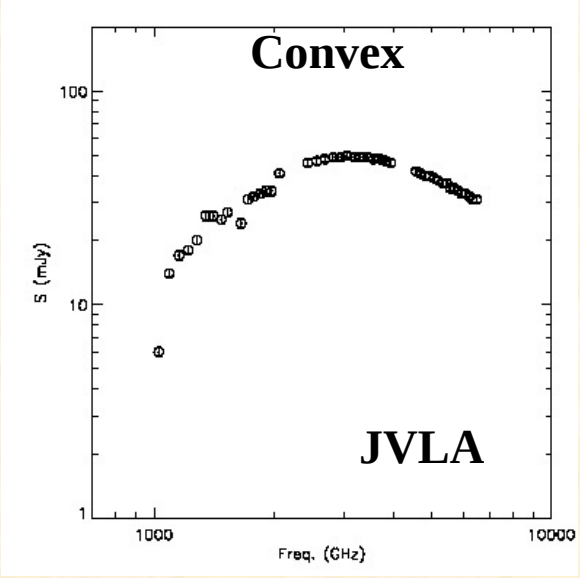
- Non-thermal SSA
- Thermal FFA

Thermal vs non-thermal

Good frequency coverage for characterizing the spectral shape

Continuous coverage ~1 to >10 GHz





Spectral peak + Angular size (VLBI) → Magnetic field

Thermal vs non-thermal

$$H_{SSA} = \frac{\theta^2_{max}\ \theta^2_{min}\ \nu^5_p}{f(\alpha)^5\ S^2_p\ (1+z)}$$

NGC 4477 Bontempi+12

$\nu_p > 5$ GHz $H > 10^9$ G SSA unlikely

In case of FFA

$$n_e^2 = 1.84 \times 10^{41} \left(\frac{T}{10^4 \mathrm{K}}\right)^{1/2} D_L^2 S(\nu) V^{-1} g_{ff}^{-1}$$

$n_e \sim 7.4 \times 10^4$ cm^{-3}

Similar to what is found for the core of NGC 1068 by Gallimore+04

Conclusions

RQ-AGN represent the large majority of AGN population

AGN emission is usually contaminated by stellar-related processes

Seyfert nuclei are not strong γ-ray emitters

Circinus is the only Seyfert in 3FGL with a γ-ray emission exceeding what expected from CR in ISM

The thermal/non-thermal nature of the radio emission from the Seyfert core is not completely established

Some Seyfert nuclei seem able to form (sub)relativistic jets with synchrotron radiation.

Future perspective

- Disentangling the contribution of star-forming activity from the nuclear emission and detecting jet-like structures from the AGN

  Sub-arcsec resolution

- Determining the nature of radio emission fron the central AGN:

Broad-band observations	1-10 GHz
Sensitivity	rms $\leqslant$ 1 μJy
Polarization	Accuracy ~0.1%

- The sensitivity and broad band capabilities of the SKA precursors as well as the high resolution provided by VLBI will provide a step forward in our understanding the nature of the radio emission in RQ-AGN and investigating the dichotomy between RL and RQ.