LeMMINGs
the eMERLIN radio legacy survey of nearby galaxies

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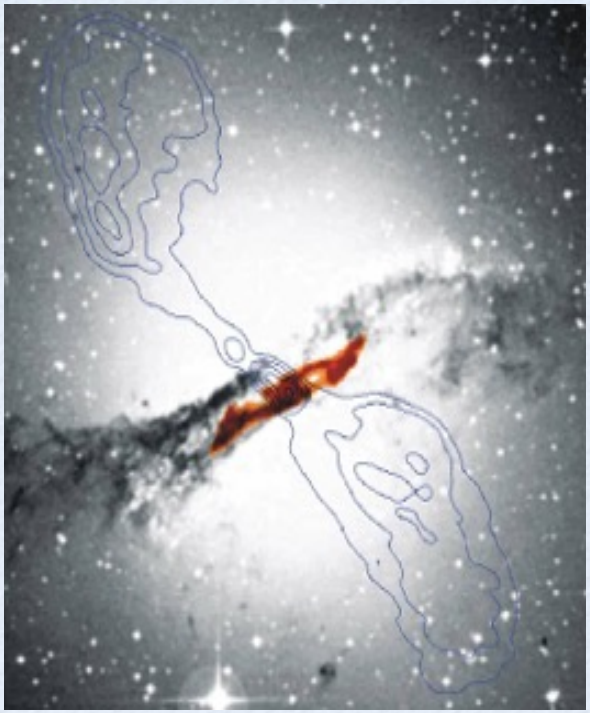
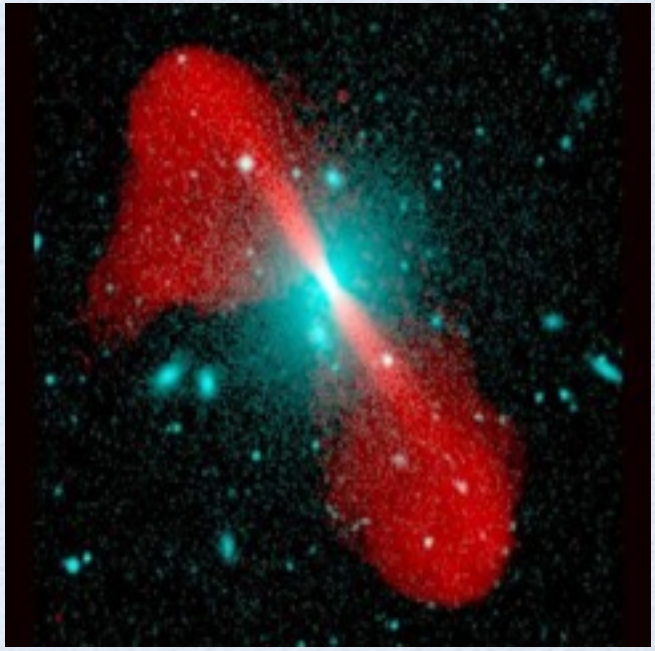
The radio-loud / radio-quiet dichotomy



Among the many differences distinguishing AGN, one of the best known and studied effect is the presence of two populations of AGN, which can be separated on the basis of their radio luminosity with respect to the light emitted in the optical band.

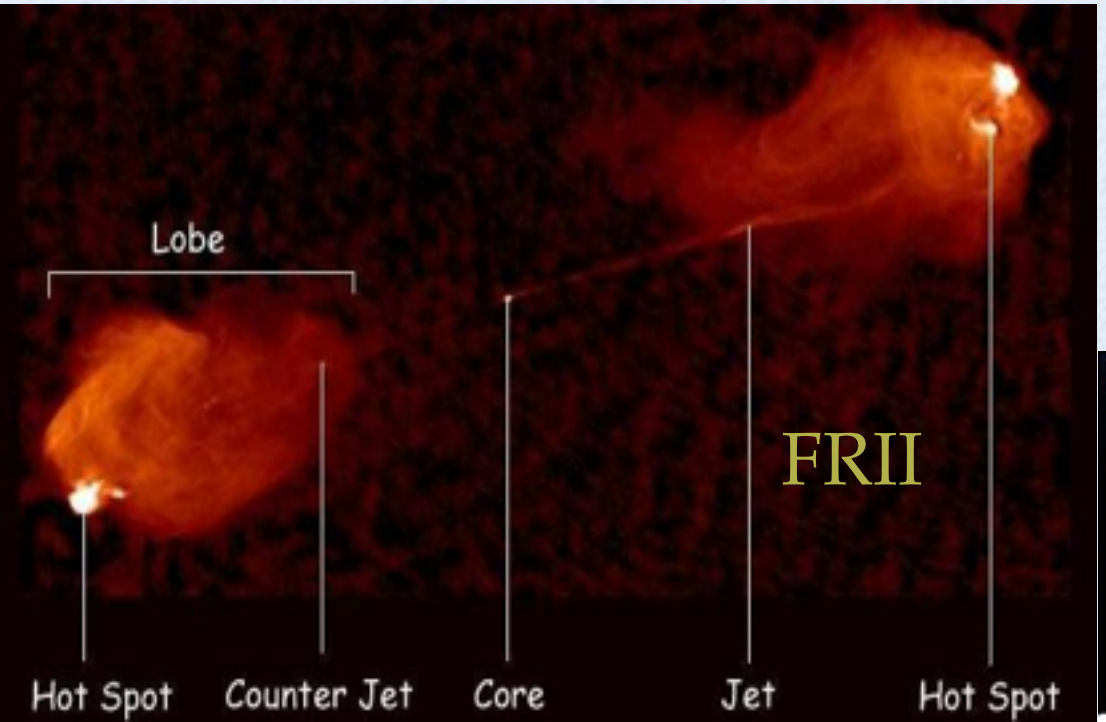


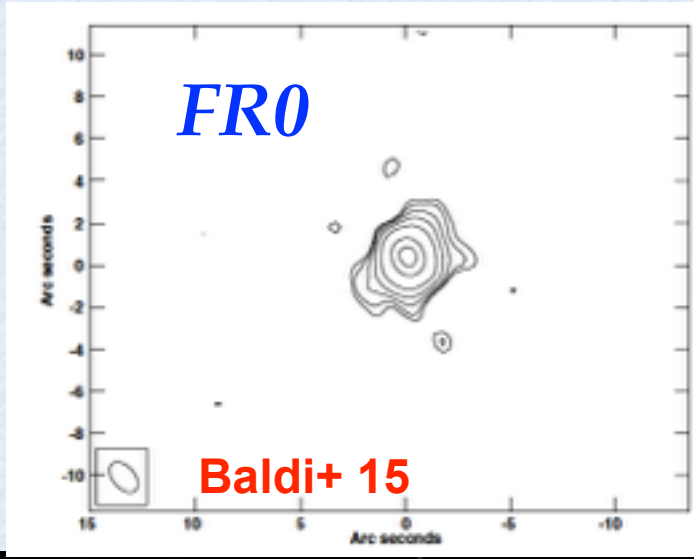
The dichotomy can be parametrized numerically, with a threshold of $L_{radio}/L_o = 10$ (Kellerman + 97) or in X-ray (Terashima & Wilson 03), but in most cases radio-loud AGN can be recognized by the presence of very extended radio-structures clearly associated to large scale jets.

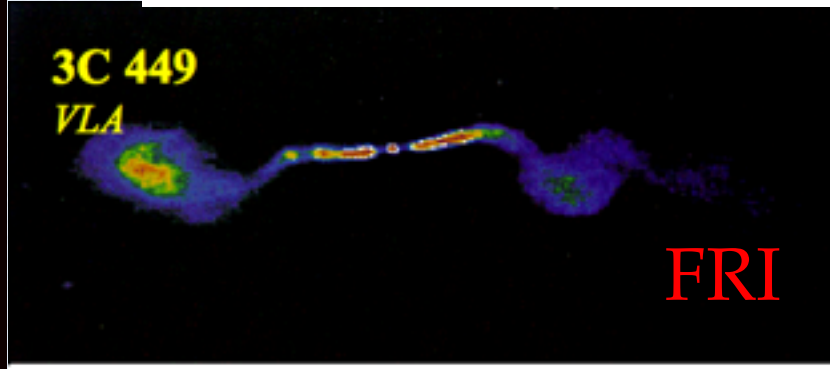
RADIO GALAXIES

- **Radio Galaxies** are RL AGNs with $L_r = 10^{39}$ up to 10^{46} erg s^{-1}.
- Morphologies of extended radio galaxies from pc to Mpc
- Collimated jets connecting the optical galaxy and the extended lobes
- Associated with elliptical galaxies and $M_{BH} > 10^8 M_\odot$

Fanaroff & Riley (1974)

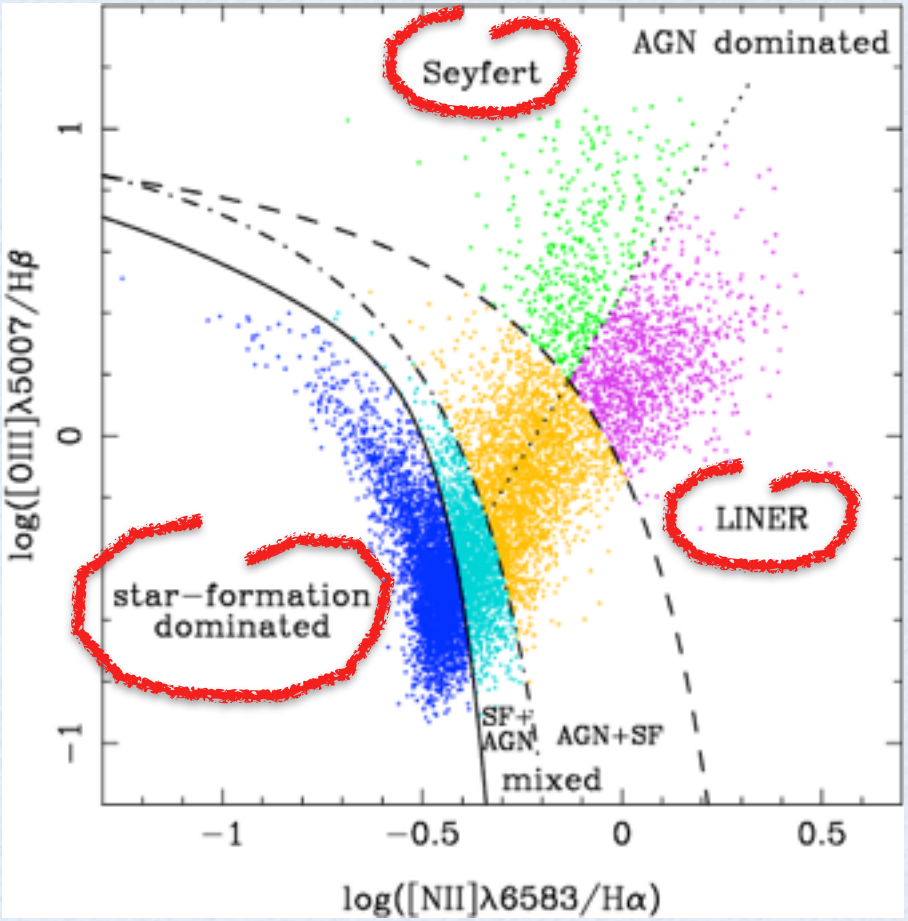






OPTICAL CLASSIFICATION

AGN can be classified on the basis of the emission line ratios.



Active galaxies

Seyfert/HEG ⇨ **standard disc**

LINER/LEG ⇨ **radiatively inefficient disc**

Absorption line galaxies:
no emission lines

BPT: Baldwin+81, Kewley+06, Buttiglione+10

low-luminosity AGN vs QSO

why care about LLAGN and not QSO?

- common, numerous and representative of BH accretion
- similar to quiescent galaxies
- allow to study of galaxy emission
- low accretion regime
- small BH masses
- low end of the luminosity function

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LEMMINGS

e-MERLIN

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Main goals

L-band/C-band high-resolution and high-sensitivity observations of eMERLIN allow to disentangle AGN and SF:

1. low-luminosity AGN (nucleus)
   - radio core, indicative of jet energetics
   - accretion, radio/X-ray connection
   - jets

2. Star formation (host galaxy)

   - individual populations, eg SN, PNe, HII regions
   - unresolved large SF scale emission

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Sample

- Sample = **Palomar bright galaxy sample**
  - Best selected sample of nearby galaxies (Ho et al 1995)
    - Optically selected, $B_T < 12.5$ mag, no radio bias
    - All galaxy types: Active (Seyfert, Liner), **Non-active (HII region, Absorption line galaxies)**
    - All 280 galaxies above Dec +20 [median distance 20Mpc]
    - Strong multi-wavelength coverage
      - Complete HST, Spitzer and (mostly) Herschel imaging
      - Almost complete Chandra imaging (Large Program approved)
      - Complete JVLA imaging
- L-band observations (1.5 GHz)

Shallow sample

- Palomar Sample (103 targets, **Baldi et al. 2018**)
  - rms ~70 microJy/beam and angular resolution 150 mas
  - 47/103 (~46%) of the sample detected (F > 0.2 mJy) at 1.5 GHz
  - Detection fraction:
    1. LINER: 22 / 34 ➔ 65%
    2. Seyfert: 4 / 4 ➔ 100%
    3. HII regions: 16 / 51 ➔ 31%
    4. Absoprtion line galaxies: 5 / 14 ➔ 36%

} ***Active***

} ***Inactive***

  - Extended radio emission appears with UV-tapering
  - Radio morphologies: core/core-jet, one-sided jet, triple sources, double-lobed, complex

Radio morphologies

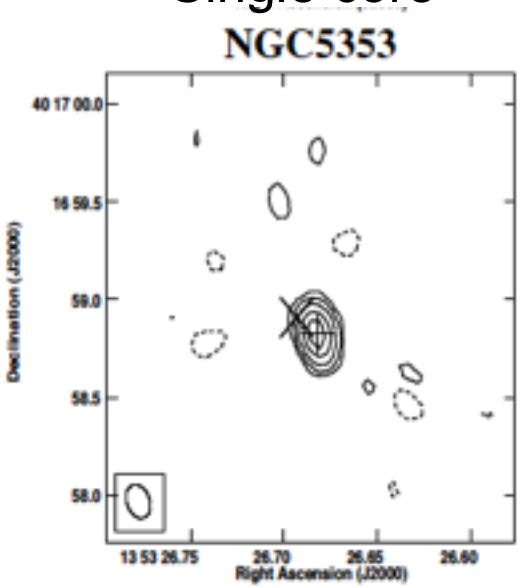
Single core

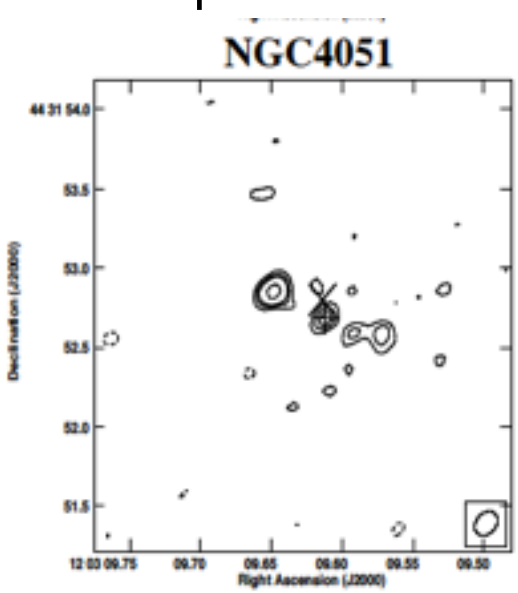
Triple source

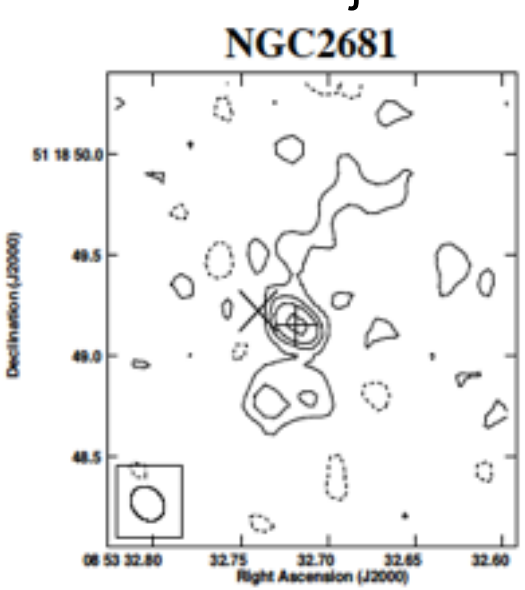
Double jet

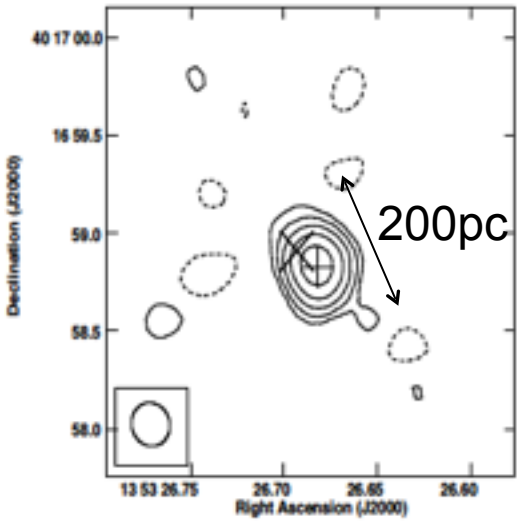
Full resolution

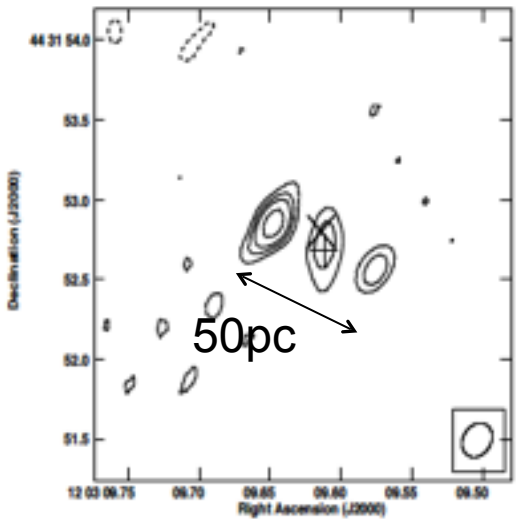
Low resolution

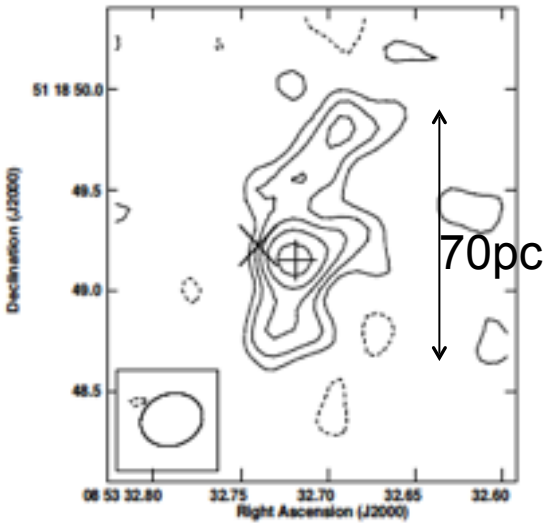












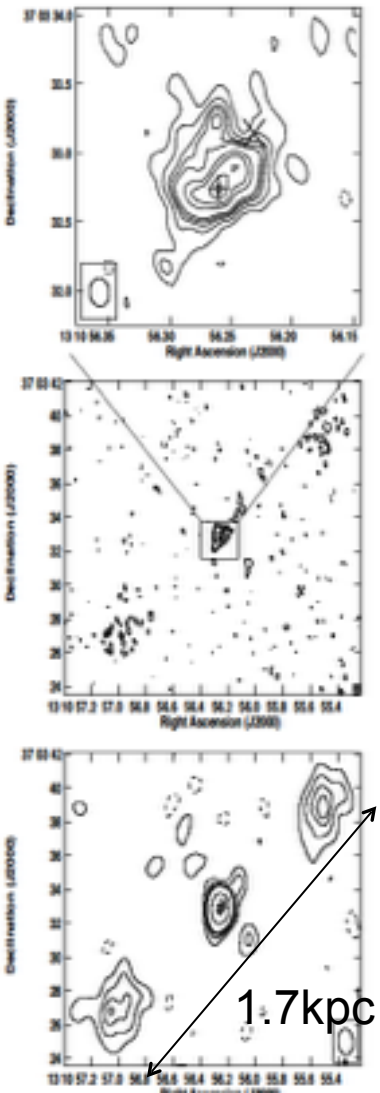
Radio morphologies

Full resolution

Low resolution

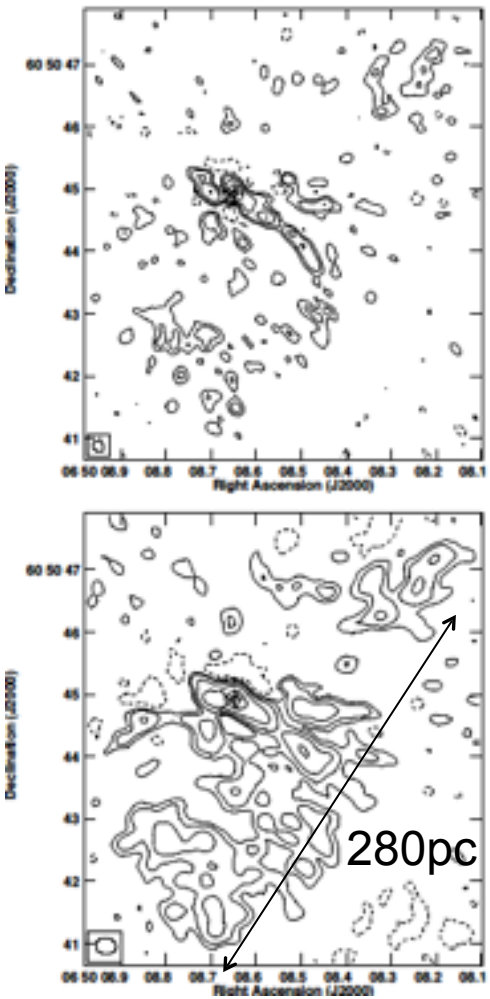
Double-lobed

NGC5005



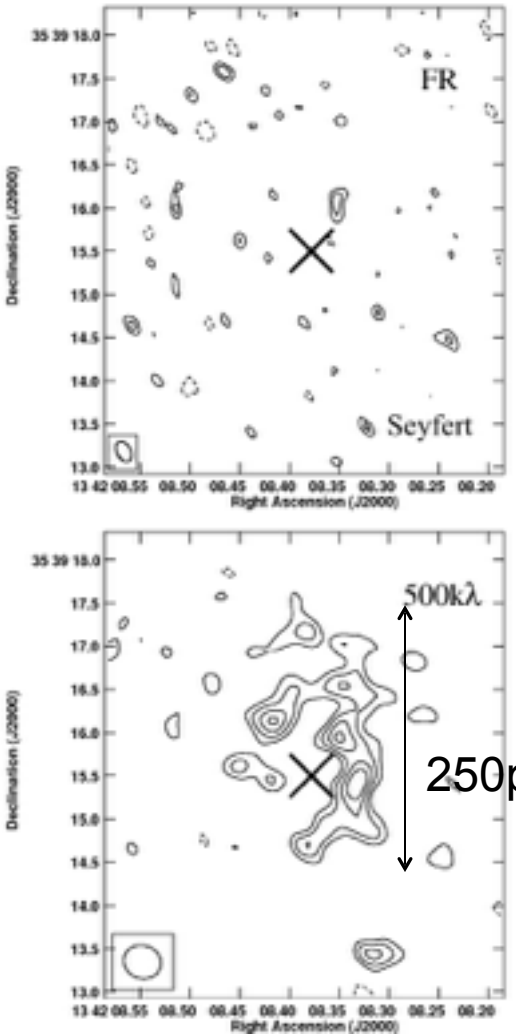
Complex

NGC2273

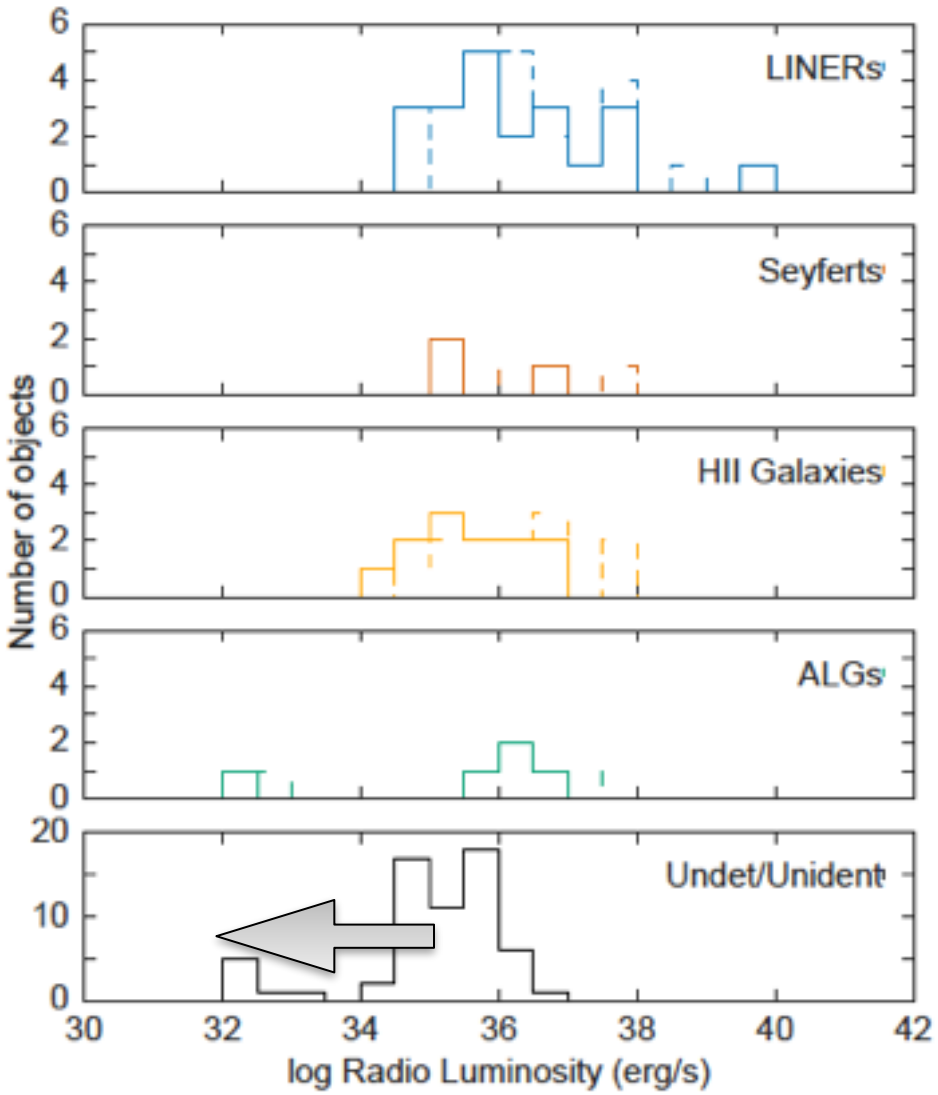


SF ring

NGC5273

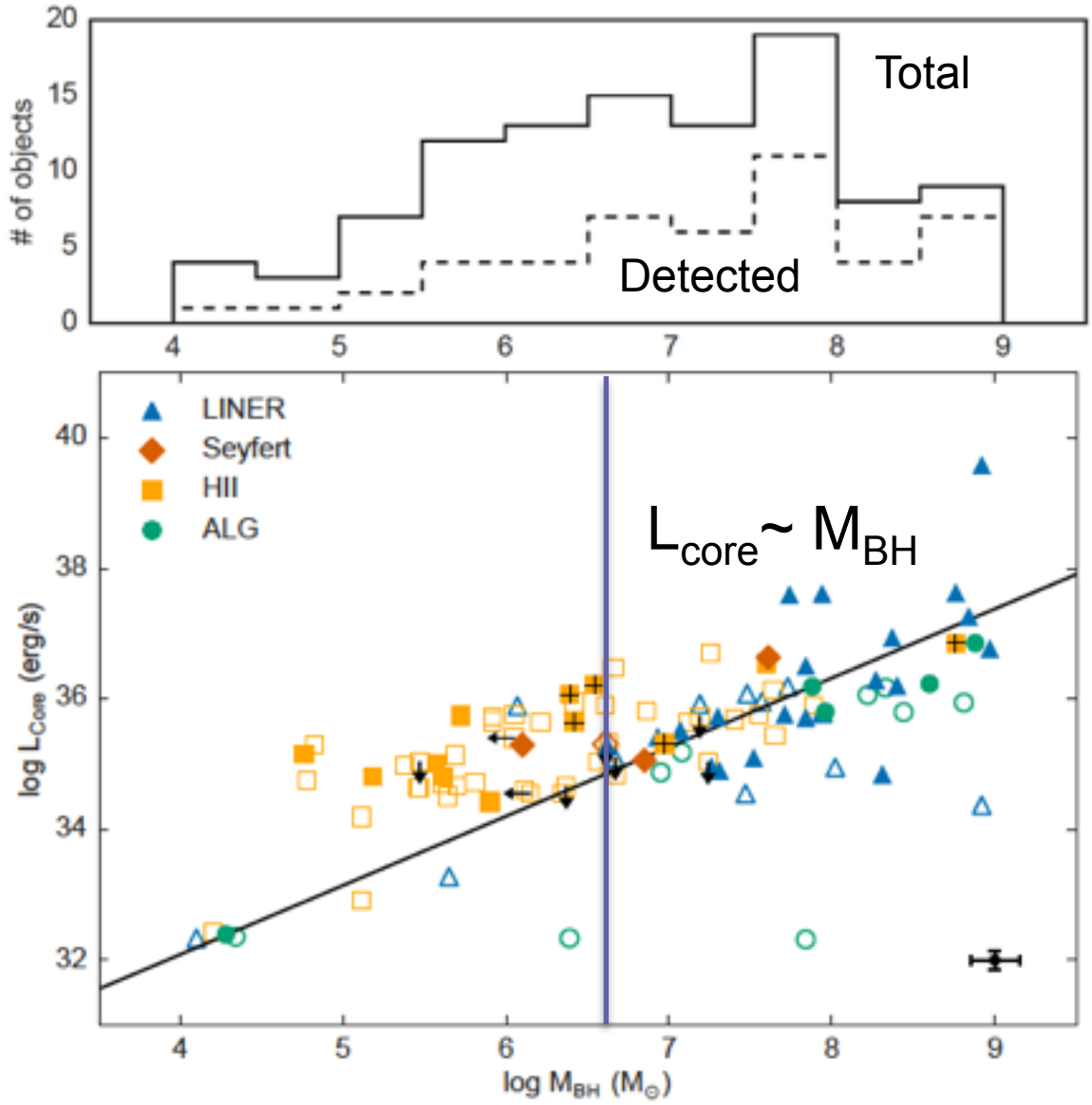


Deeper than any other radio survey of the Palomar sample (Nagar et al. 2002, Filho et al 2006)



- $L_{core} \sim 10^{32}$ - 10^{40} erg s^{-1}
- Within a factor 100 of Sgr A* (in L band), but aim at reaching radio luminosity function within a factor of 10 in C band.
- LINERs are the brightest and more luminous
- jetted sources >10^6 $M_\odot$

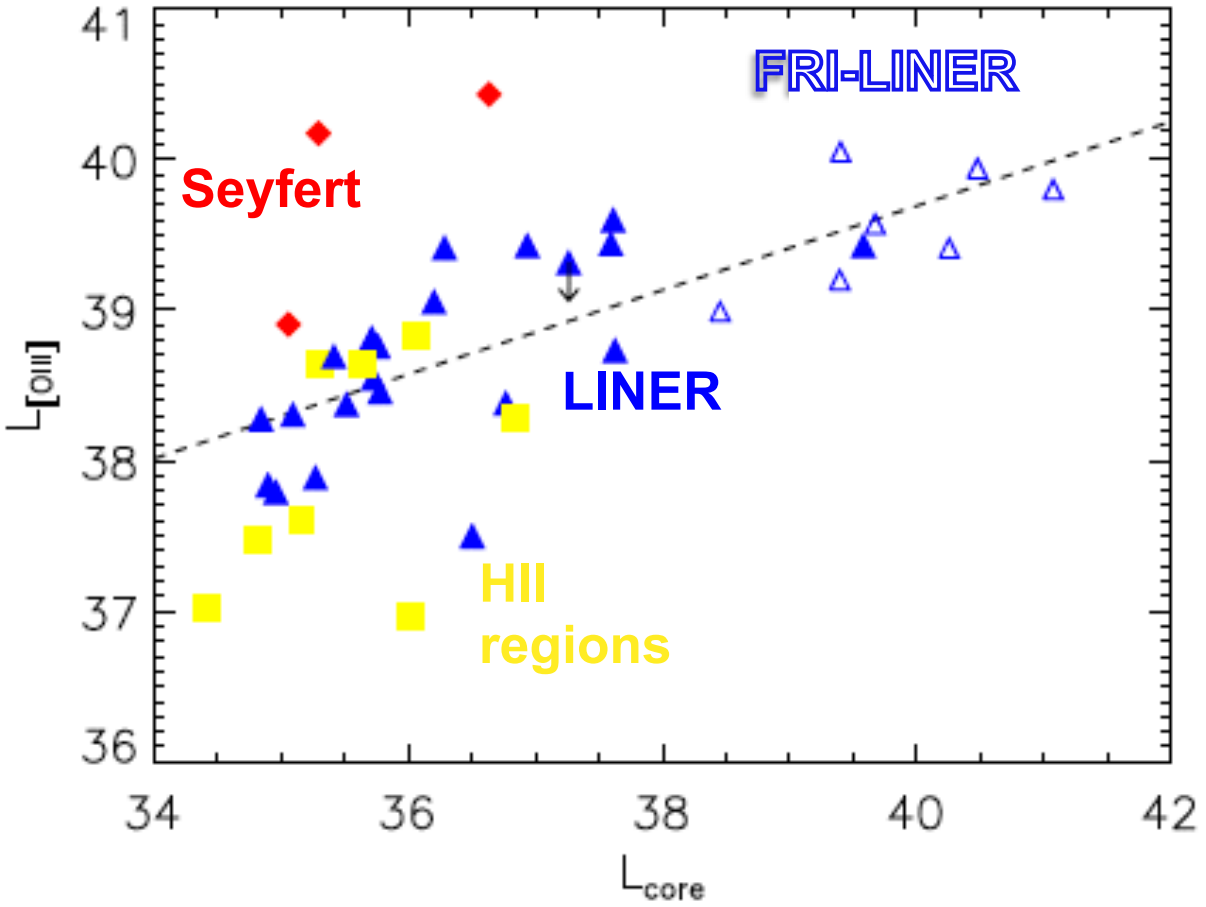
Radio - BH mass



- detection fraction decrease with M_{BH}
- for $M_{BH} > 10^{6.5}\ M_\odot$, $L_{core} \sim M_{BH}$,
- for $M_{BH} > 10^{6.5}\ M_\odot$ a break appears

Hierarchical evolution
+
SF

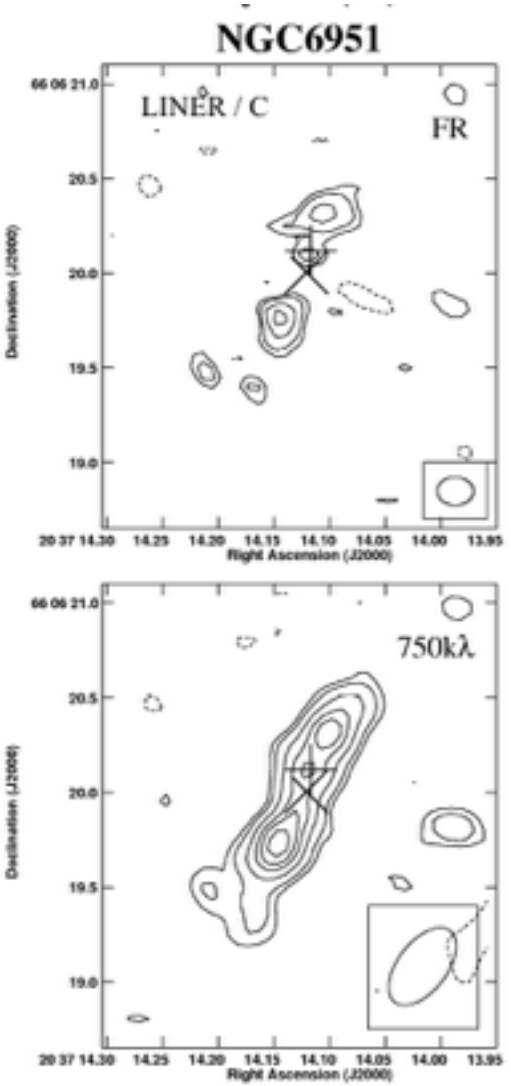
Radio – [OIII] line



LINERs and FRI radio galaxies follow the same liner correlation radio-[OIII]
Seyferts are above the correlation: additional line contribution from?
HII regions are below the correlation: lack of a ionisation source?

LINERs

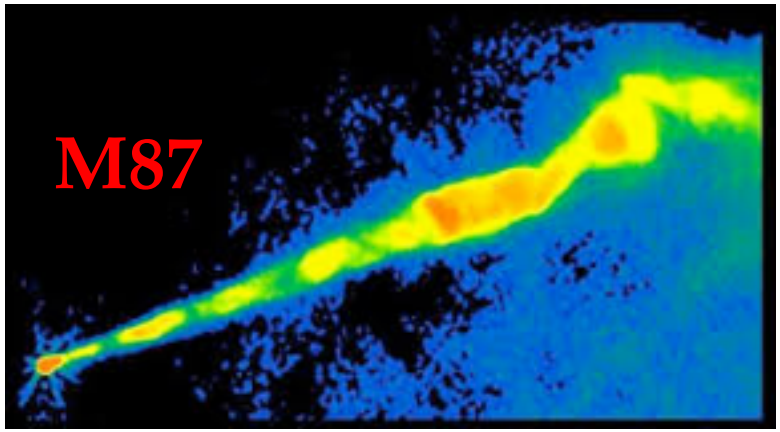
- single core - twin jets (core-brightened morphology)
- high BH masses > 10^7 $M_\odot$
- large radio luminosities
- high T_b > 10^6 K
- radio-loud
- low Eddington ratio >10^{-3}



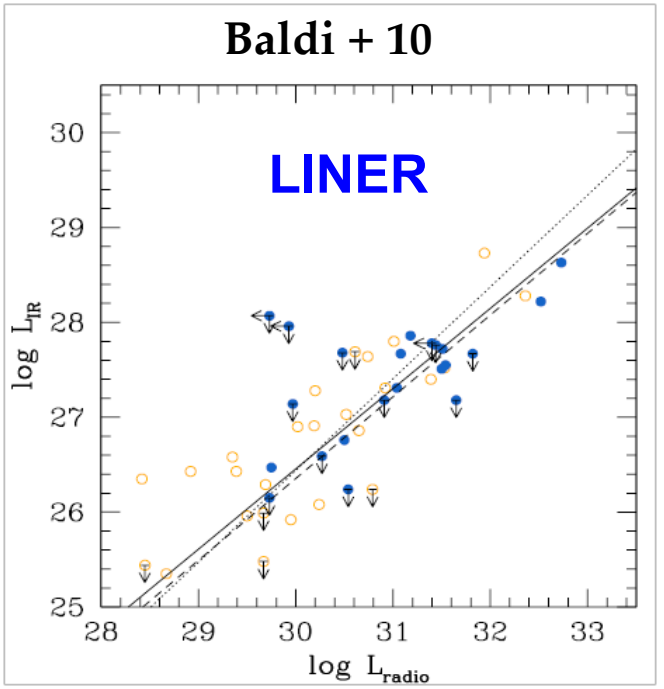
LINERs - FRI

- high radio jet production
- synchrotron dominated nuclei (from jets)
- *radiatively inefficient accretion disc*
- **scaled-down version of FRI**

Chiaberge+ 99, Allen+ 06, Balmaverde+ 06, 08, Best+ 05)

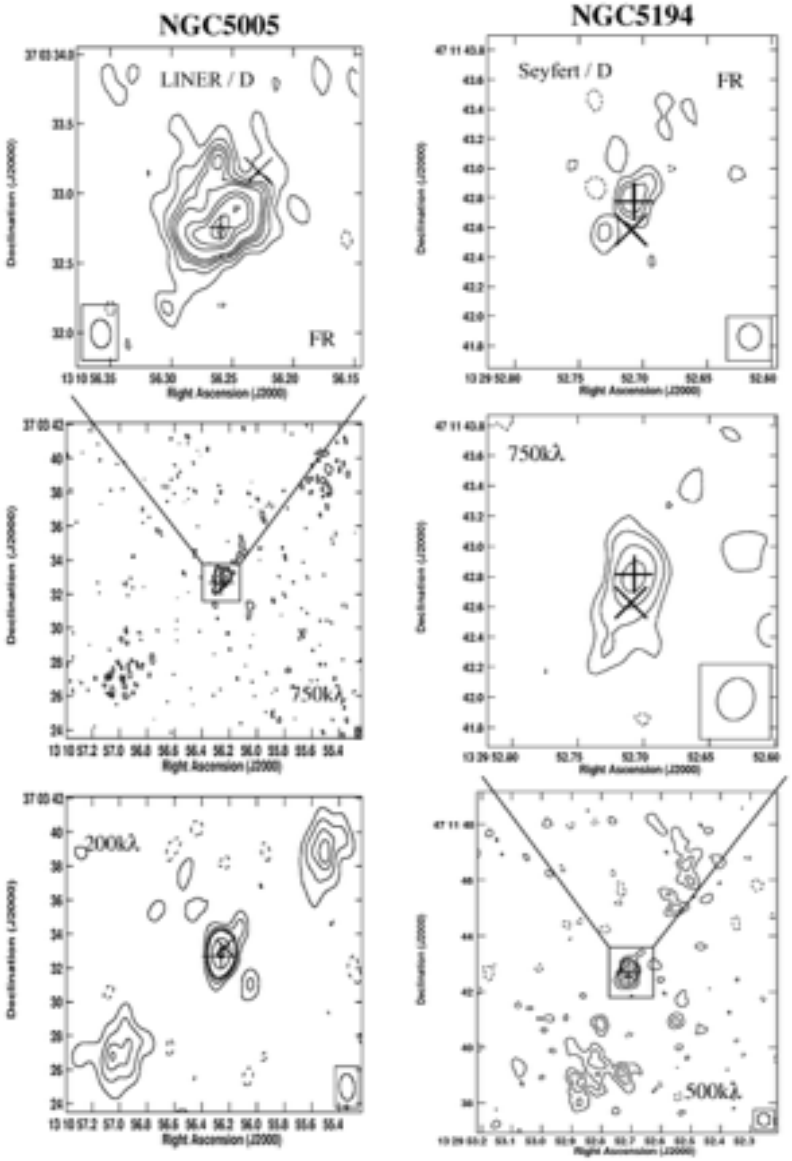


HST



Seyferts

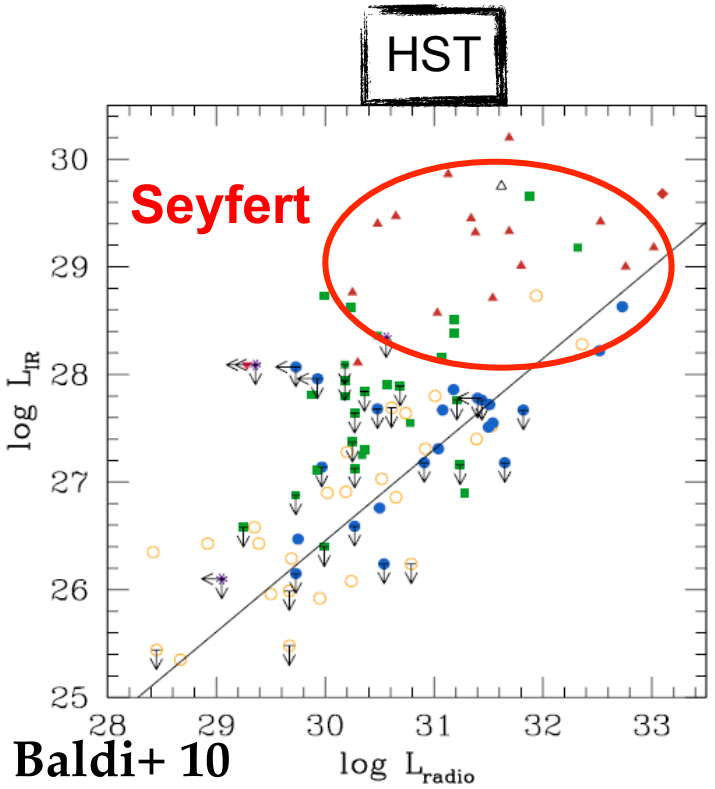
- double lobed (more edge-brightened morphologies)
- high BH mass
- intermediate radio luminosity
- $L_{[OIII]}$ excess
- high Eddington ratio $>10^{-3}$



(low-luminosity) Seyferts

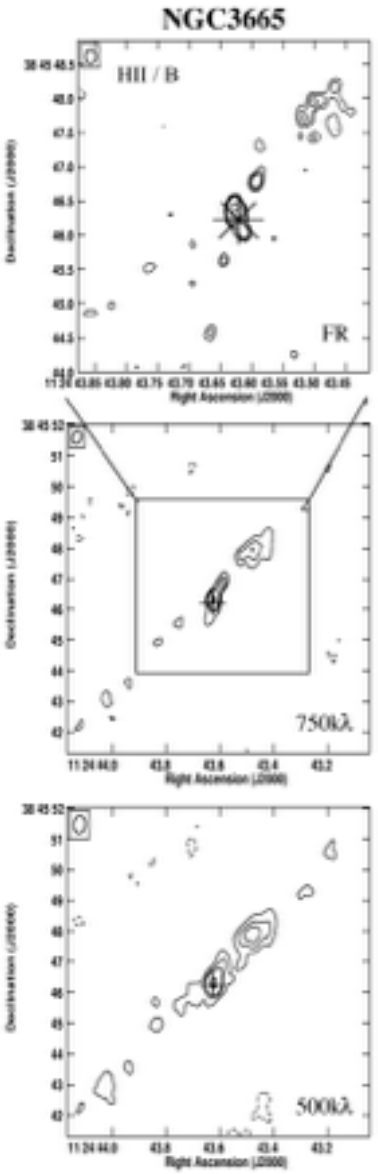
- moderate jet production
- excess wrt synchrotron
- high Eddington ratio
- *standard accretion disc*
- **intermediate position between RL LINER and RQ QSO**

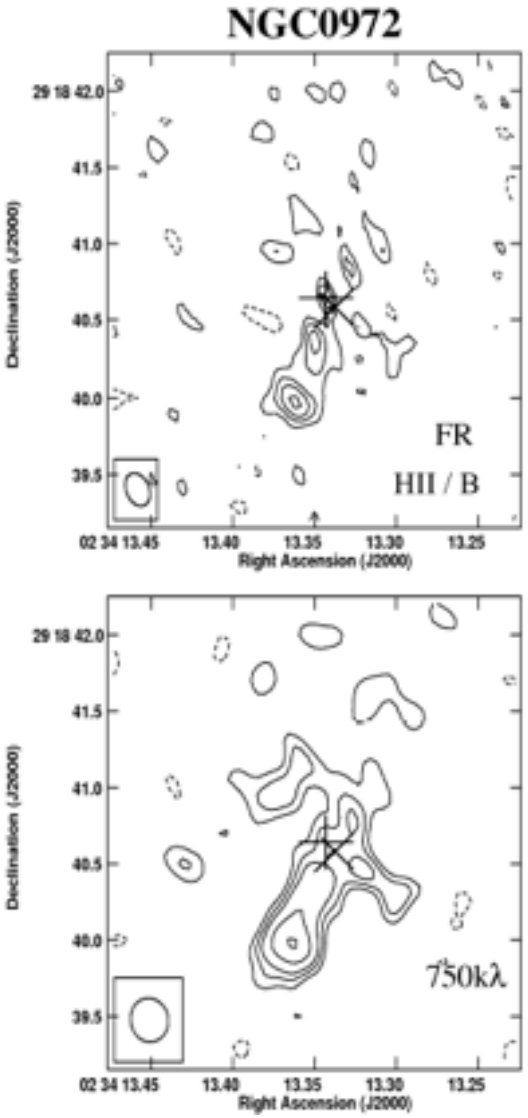
Hardcastle+09, Baldi+ 10
Giroletti & Panessa 13,
Asmus+ 15, Mingo+ 16



HII galaxies

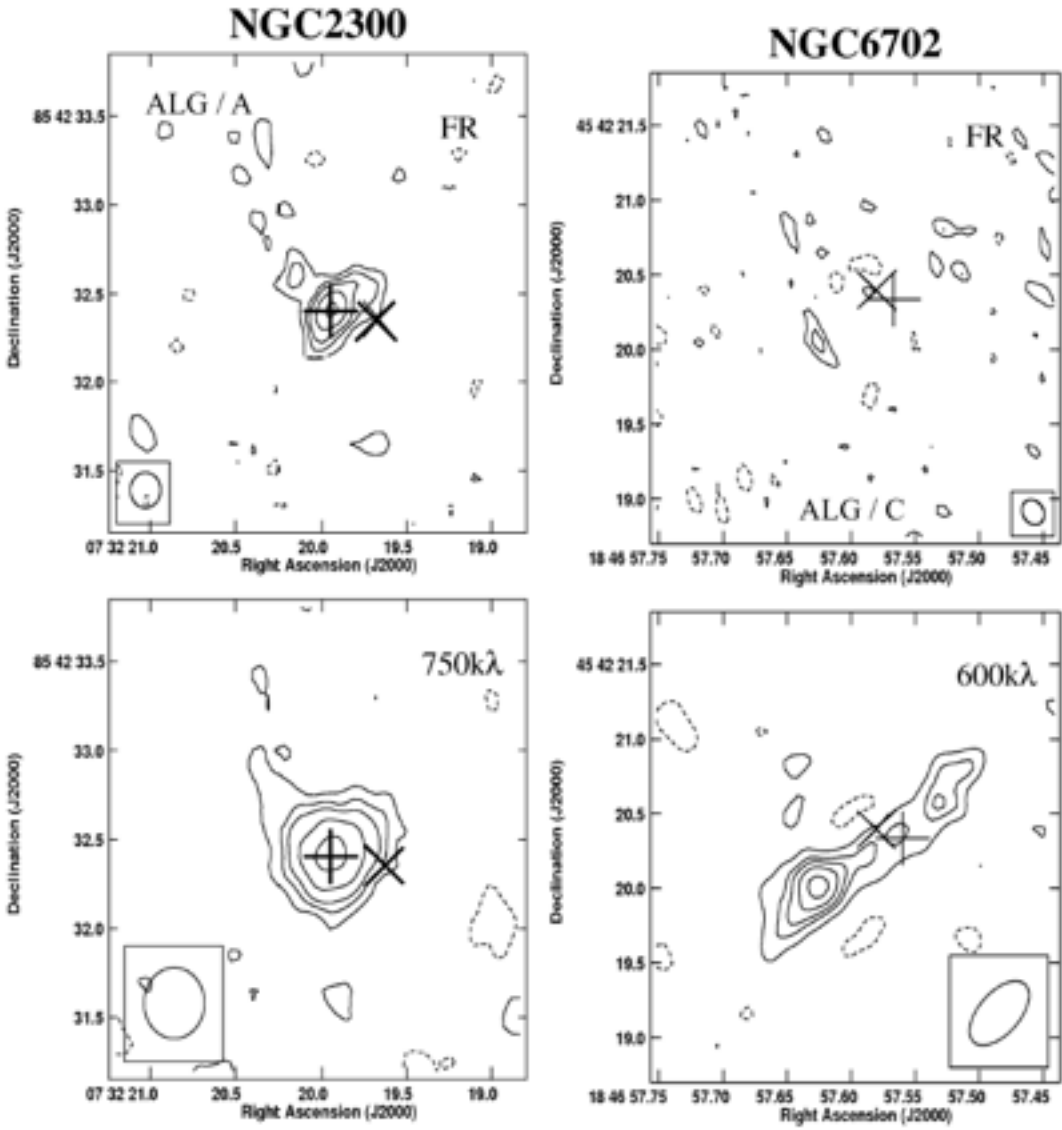
- $L_{[OIII]}$ deficit
- SF dominated
- 5/51 some show jets
- possibly hide a LLAGN (~10^6 $M_\odot$)





Absorption Line galaxies

- core - twin jet
- massive ellipticals
- $M_{BH} > 10^8 M_\odot$
- starving massive BH?
- nuclear recurrent activity?
- duty cycles 10^4-10^8 yr



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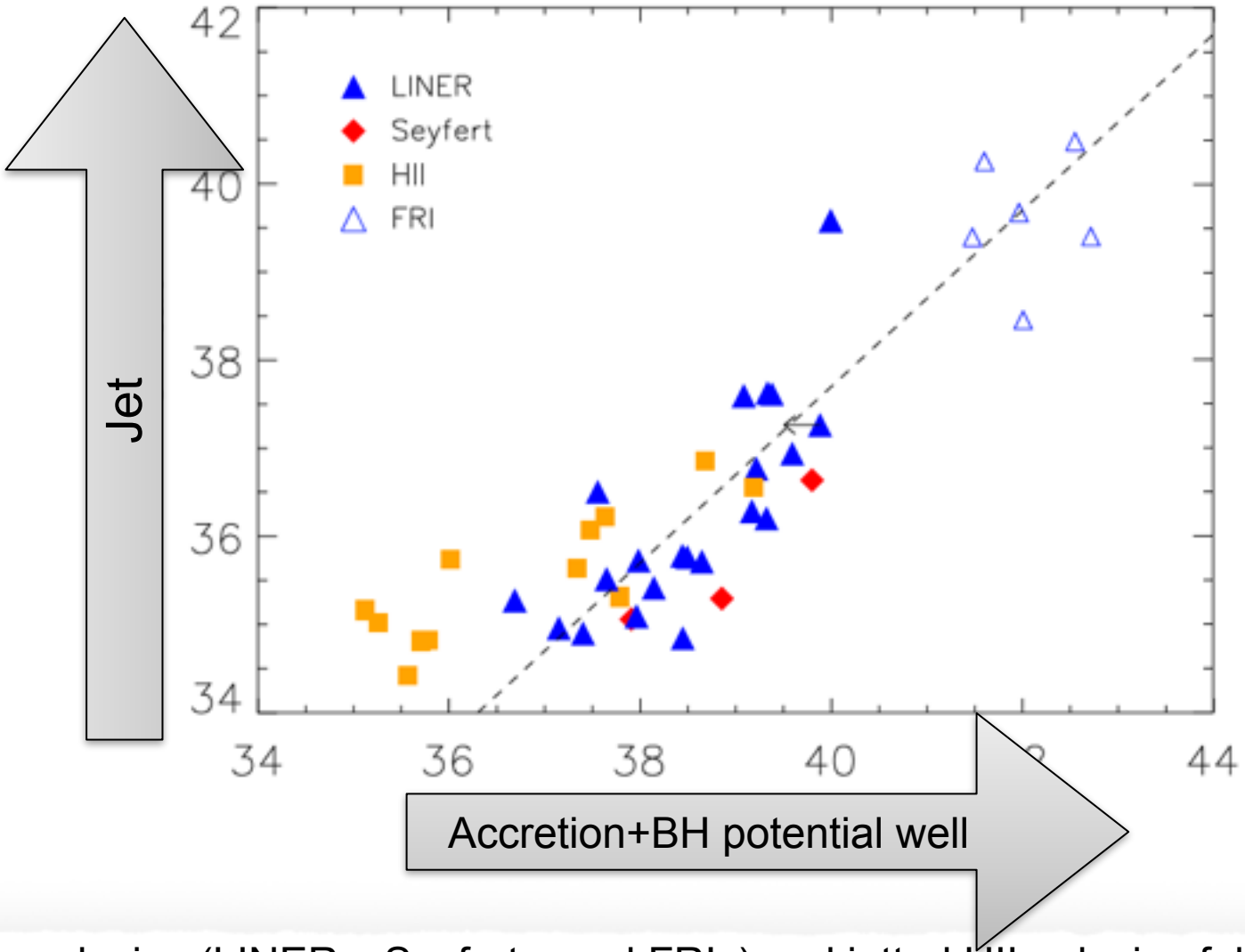
Fundamental plane of BH activity



Merloni et al (2003), Falcke et al (2004), Saikia et al (2015)

Active galaxies (LINERs, Seyferts, and FRIs) and jetted HII galaxies follow a similar correlation in the fundamental plane of BH activity

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CONCLUSIONS

- Nearby galaxy surveys with eMERLIN have great potential for study of LLAGN, jets and star formation on crucial small scales.
  1. LeMMINGs: Palomar sample (103 targets so far, Baldi et al 2018): deepest Palomar radio survey, ~10^{32} erg s^{-1}
  2. pc-scale radio jets from BH down to ~10^6 $M_\odot$

- LINERs are the scaled-down version of FRI radio galaxies

- Low-luminosity Seyferts are in a intermediate position between jetted LINERs and radio-quiet QSO.

- HII galaxies have optically SF dominated but can hide a LLAGN

- ALG can be a mixed population of SF, silent or weakly active BH: possible nuclear recurrence?


THANK YOU