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IN PARTNERSHIP WITH SKAO

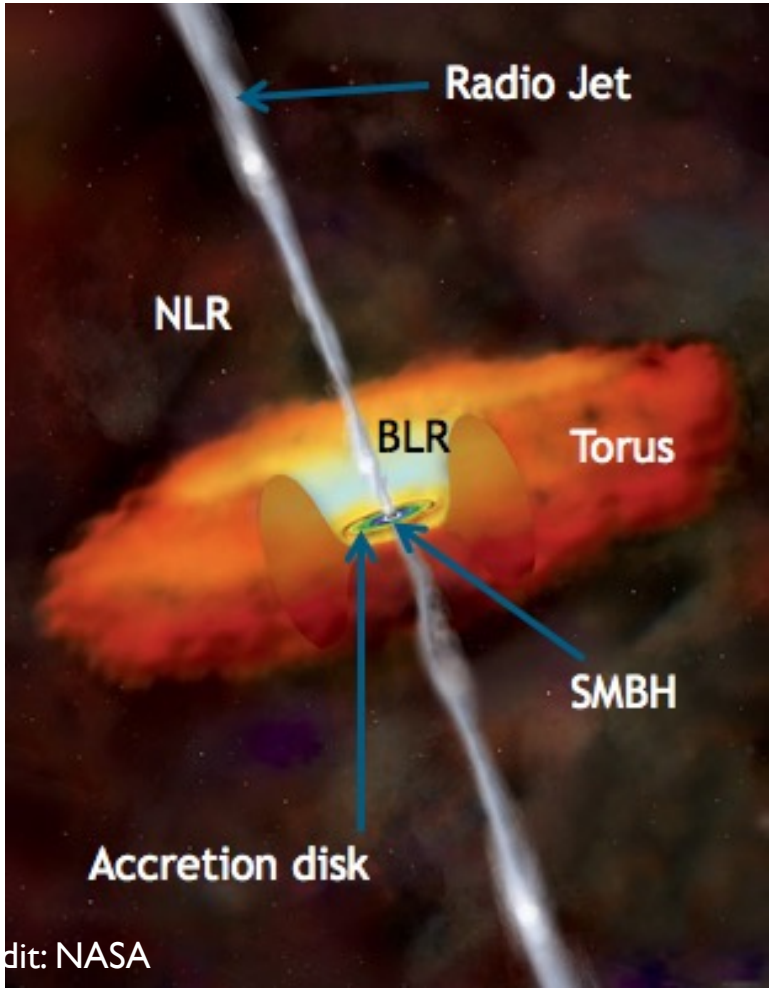
A CENSUS OF NUCLEAR ACTIVITY IN THE LOCAL UNIVERSE

LeMMINGs
the e-MERLIN radio legacy survey of nearby galaxies

ACCRETION AND EJECTION

- AGN are accreting super-massive black holes at the centers of galaxies
- BHs (and galaxies) can be active or inactive if (detected) evidence of accretion or ejection (problem of low-luminosity AGN)
- High-resolution maps in the radio can provide direct views of black-hole accretion even in dusty environments, and can detect AGN at accretion rates below those detectable in other wave-bands.
- Our view of the nuclear activity in the Universe is biased towards massive, bright and unobscured galaxies, which leads to a partial understanding of the BH accretion and ejection

Necessity to go to low luminosities..



dit: NASA

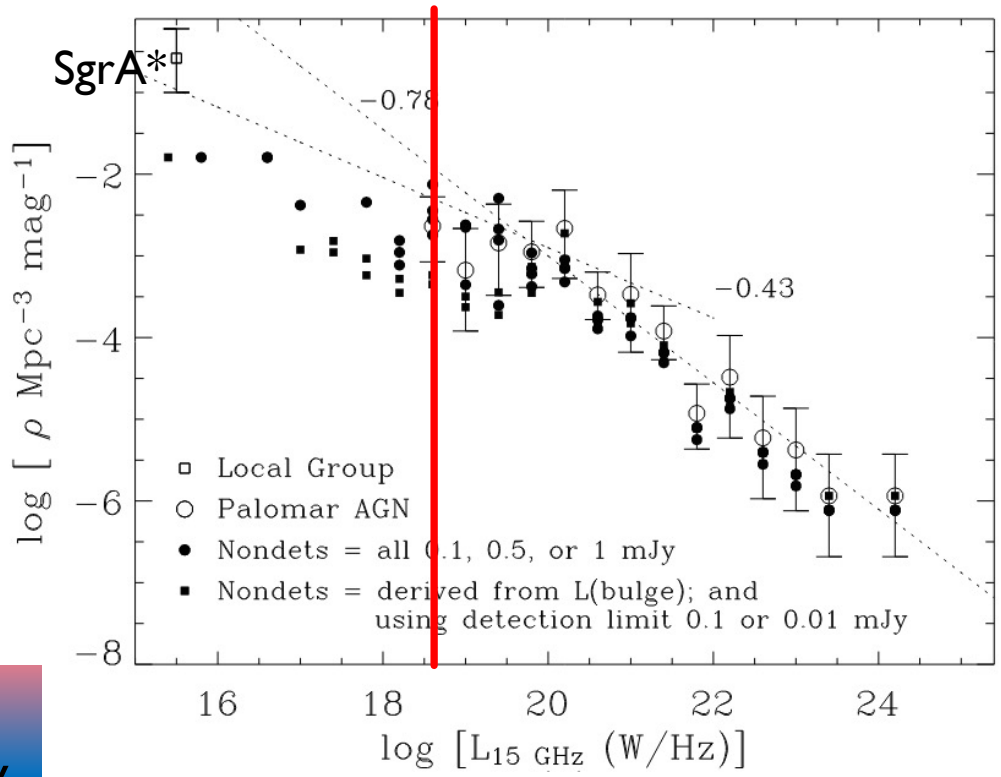
A CENSUS OF NUCLEAR ACTIVITY IN THE LOCAL UNIVERSE

Why care about low-luminosity AGN (LLAGN)?

- They are common, numerous and representative of BH accretion
- similar to quiescent galaxies, allowing the study of nuclear triggering mechanisms
- Higher AGN-galaxy contrast, to study host-BH connection
- smaller BH masses: BH mass function!
- Constraint the low end of the luminosity function

why a census? BH occupation fraction at low BH mass and RLF to constrain scaling relations and the cosmological evolutionary models for SMBHs.

JVLA RL function at 15 GHz



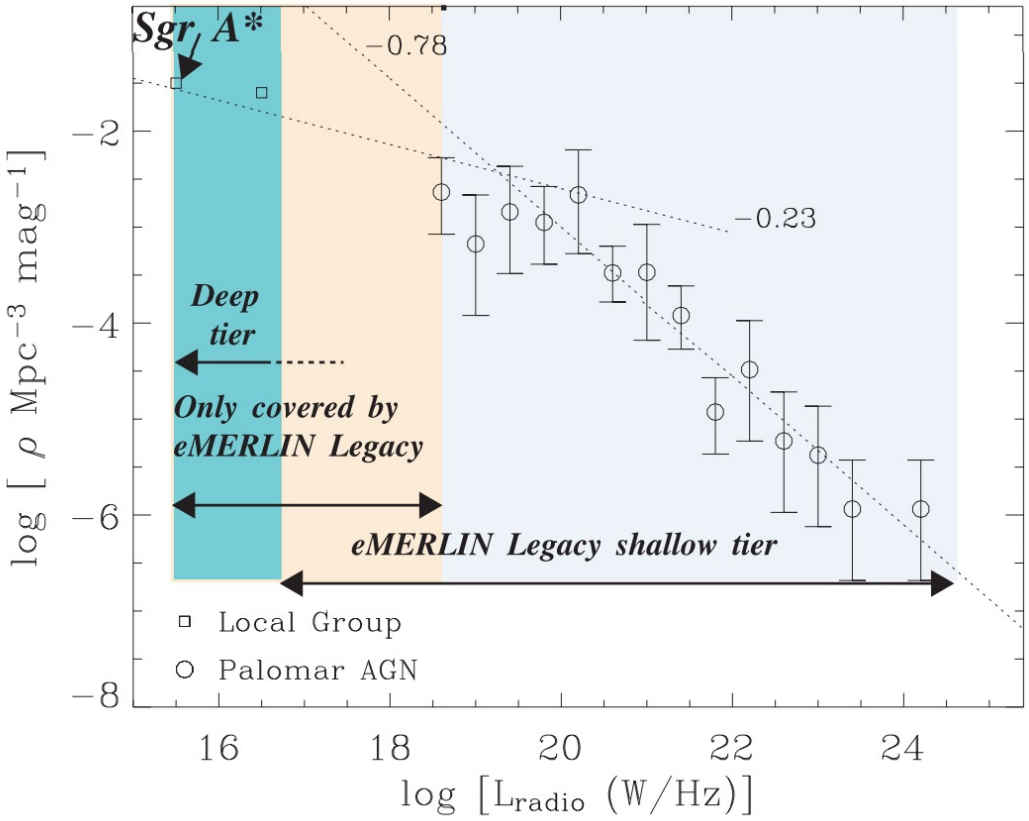
Nagar et al. (2005)

The LeMMINGs survey: Legacy e-MERLIN Multi-band Imaging of Nearby Galaxies

UNIVERSITY OF Southampton

MANCHESTER 1824
The University of Manchester

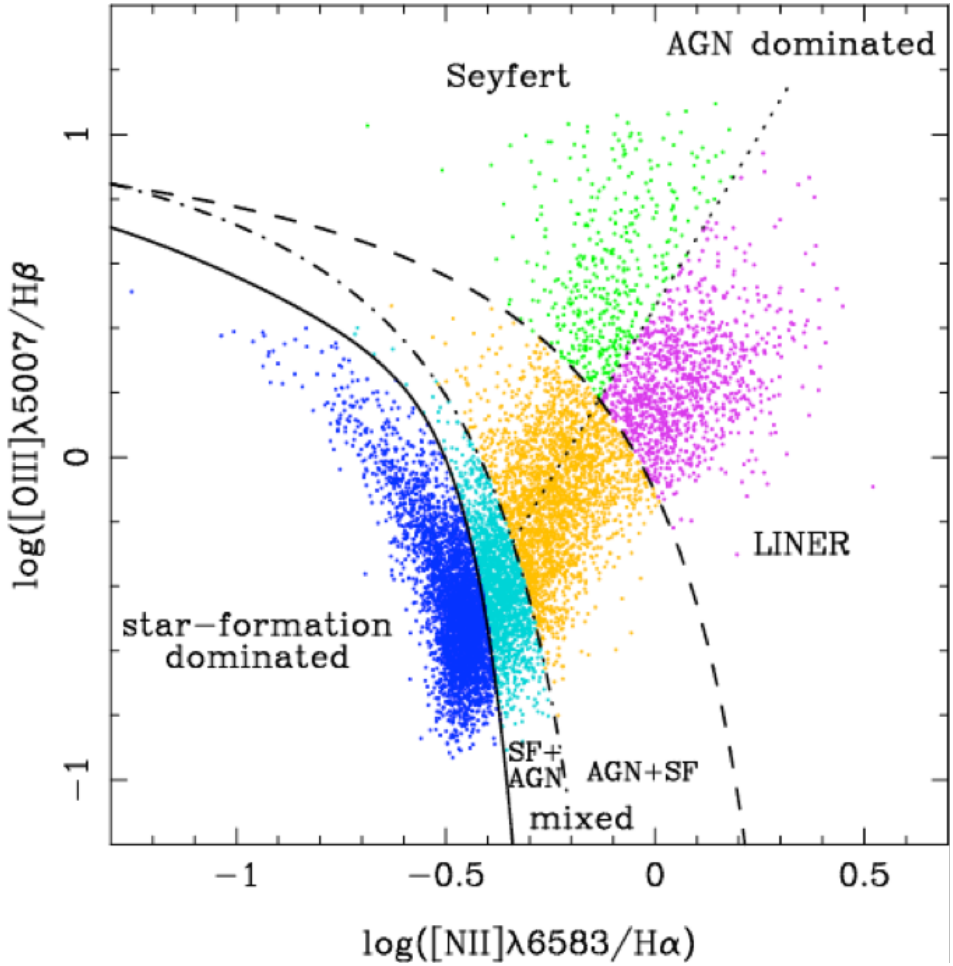
- PI: I. McHardy & R. Beswick. Aims:
  - Studying LLAGN at the low end of the radio luminosity function
  - Star formation – AGN disentagling
- Observations at 1.5 and 5 GHz (L and C band)
  - Reaching angular resolutions of 150 mas and 50 mas respectively
  - Reaching sensitivities of 50-80 uJy/beam
- Two tiers: deep and shallow:
  - Shallow tier: L band maps published in Baldi et al (2018, 2021) a e interpreted in Baldi et al. (2021b).
  - Deep tier: scientifically interested targets (M82, IC10, NGC4151, M51b, NGC6217, NGC5322)



http://lemmingslegacy.pbworks.com/w/page/145646928/FrontPage

The LeMMINGs sample

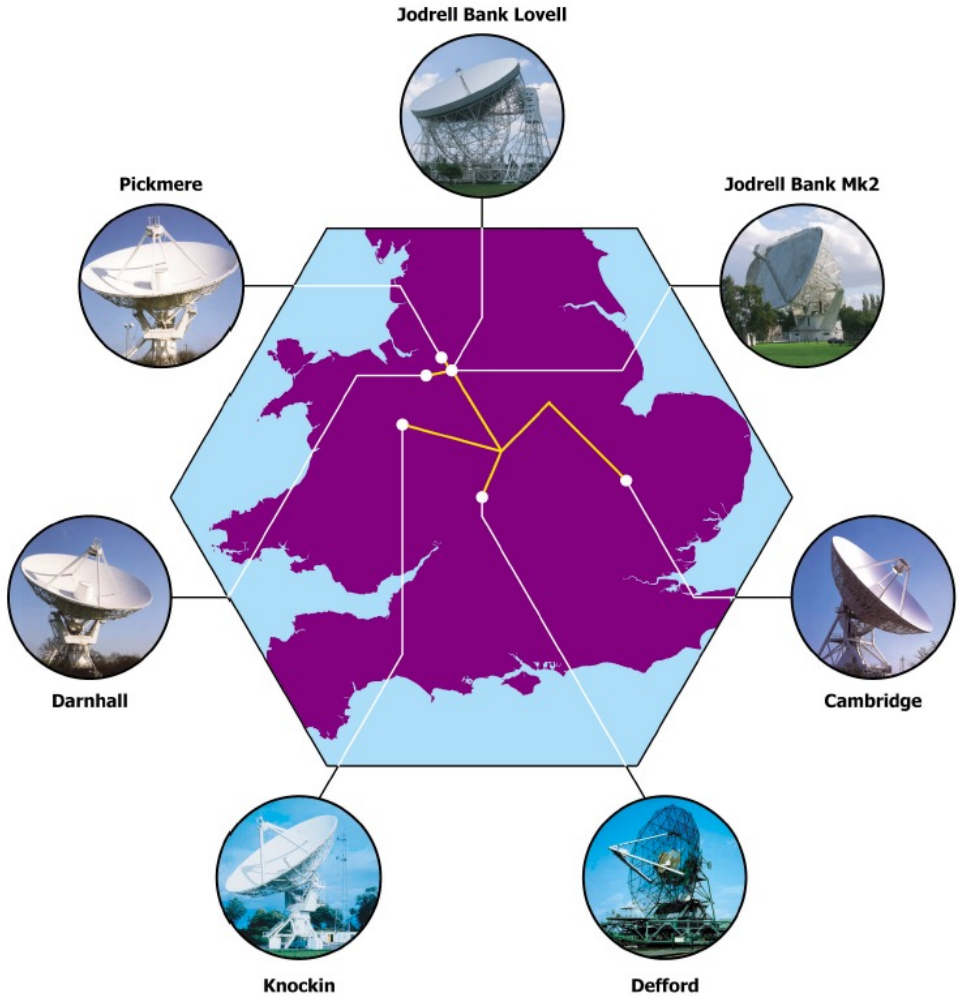
- 'Shallow' = **Palomar bright galaxy sample**
  - Best selected sample of nearby galaxies (Ho et al. 1995)
    - Optically selected, $B_T < 12.5$ mag, no radio bias
    - All galaxy types: Active (Seyfert, LINER), **Non-active HII galaxies, Absorption line galaxies)**
    - All 280 galaxies above Dec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



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

e-MERLIN: a SKA pathfinder

- A UK based radio array made up of 7 antennas, spread across England (max baseline of 220 km)
- High resolution (0.1-0.04 arcsec) and sensitivity (10uJy/beam in 12 hours) in broad frequency bands centres at 1.5, 5 and 22 GHz



OBSERVATIONS

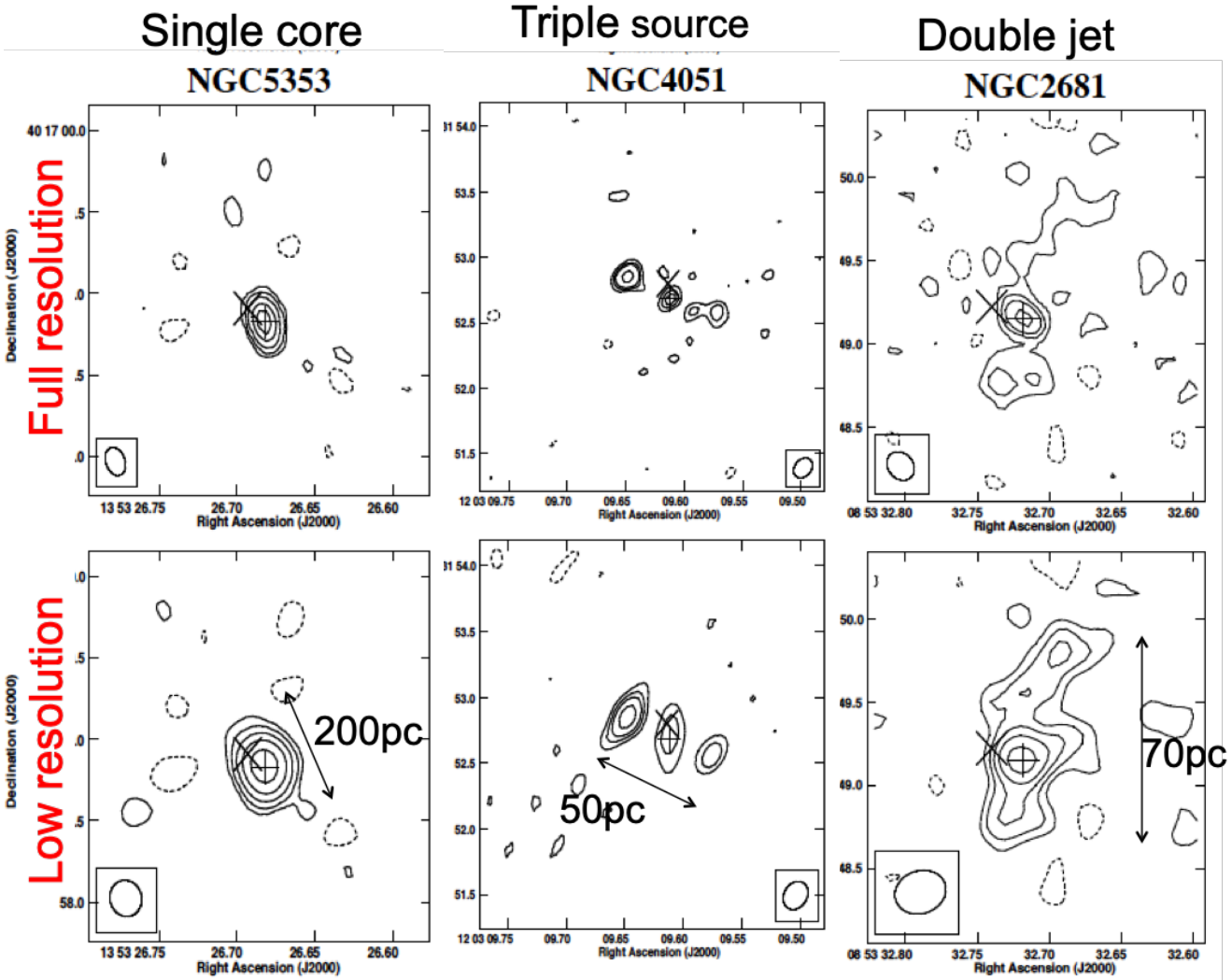
- Total project allocation is 810hrs

  - **Palomar shallow tier** → 280 galaxies (on-source time ~48min/band/source); 750 hours total; no Lovell
  - Median distance = 20Mpc
  - **Deep tier** → 6 Targets observed (sub-set of shallow tier) ~5hrs/band/source; 60 hours total; Lovell

	Number of targets	Sensitivity μJy/bm	Luminosity (at median D)	Approx. On-source time
Shallow (L-band) res ~120mas	280	~80	1.8 * 10^{18} W/Hz	48min
Shallow (C-band) Res ~ 35mas	280	~60	7.2 * 10^{17} W/Hz	48min

L-BAND: RESULTS

Baldi et al. 2018, 2021a



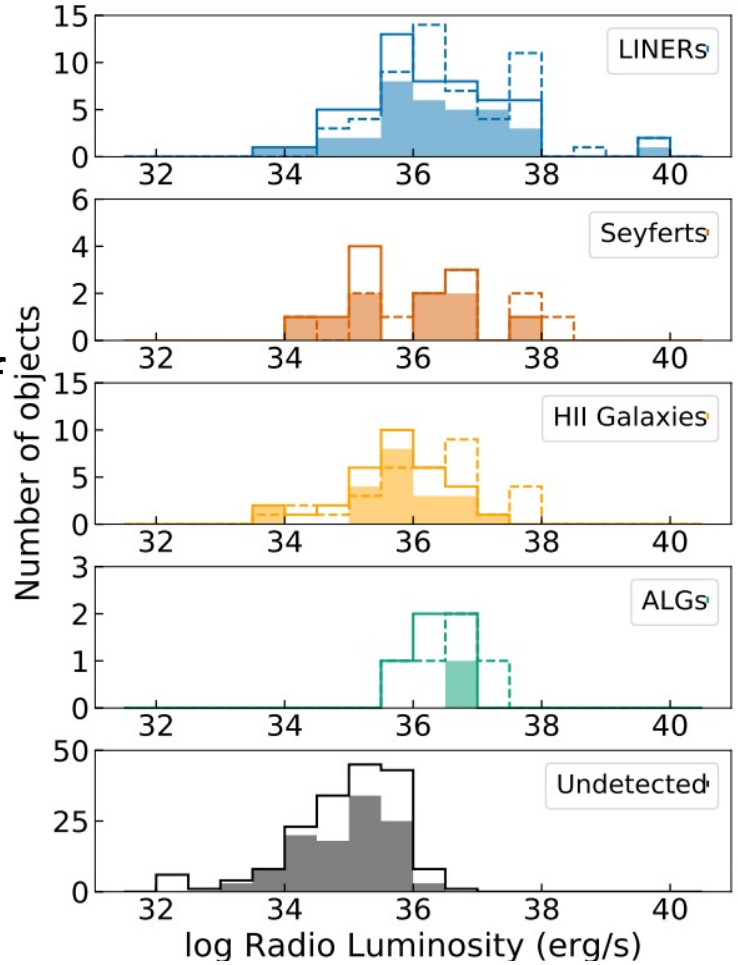
Radio Results from the full sample

- ~45%. of sources detected
- 58/94 LINERs; 13/18 Seyferts; 47/140 HII galaxies; 7/28 ALGs
- ~38% detection/identification of radio core
- Radio jets on scales of 3-6600 pc

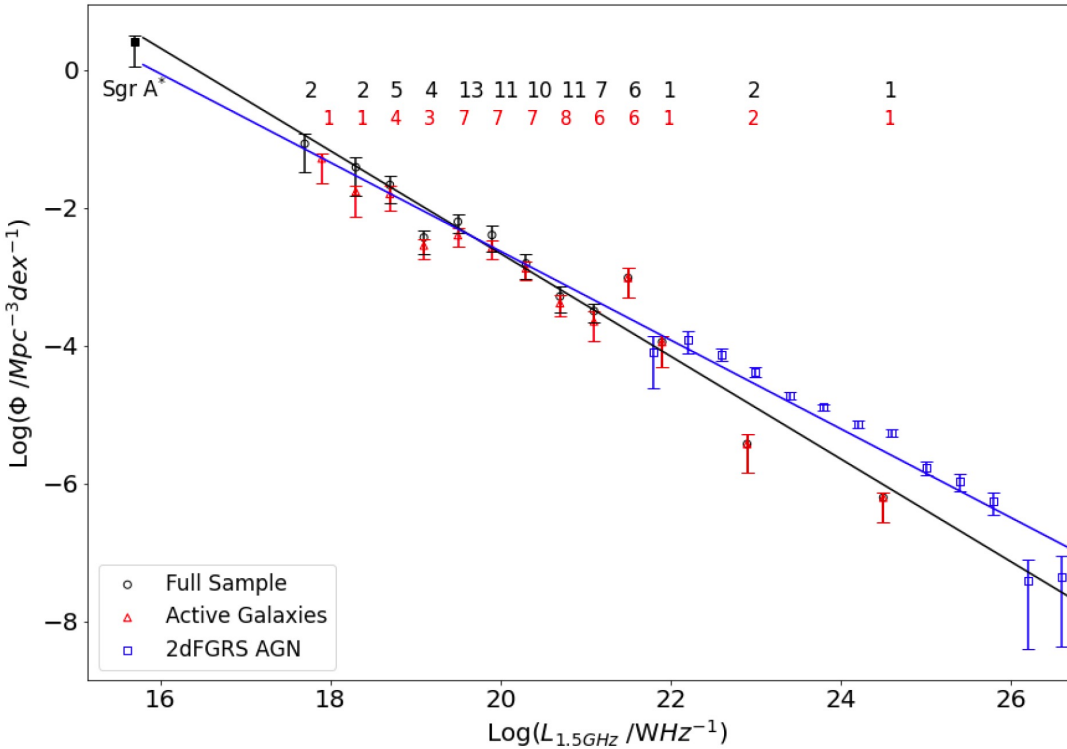
		optical class				
	radio class	LINER	ALG	Seyfert	HII	Tot
core identified	core/core–jet (A)	37	3	6	18	64
	one-sided jet (B)	2	0	1	2	5
	triple (C)	13	2	3	4	22
	doubled-lobed (D)	3	0	1	0	4
	jet+complex (E)	1	0	1	9	11
	Tot core-identified	56	5	12	33	106
	unidentified	2	2	1	14	19
	Tot detected	58	7	13	47	125
	undetected	36	21	5	93	155
	Tot	94	28	18	140	280

RESULTS

- $L_{core} \sim 10^{34}$ - 10^{40} erg s^{-1} ($10^{17.6}$ - 10^{22} W Hz^{-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 most luminous
- jetted sources in HII galaxies and in BH with $M_{BH}>10^6\ M_\odot$



1.5-GHz RL Function



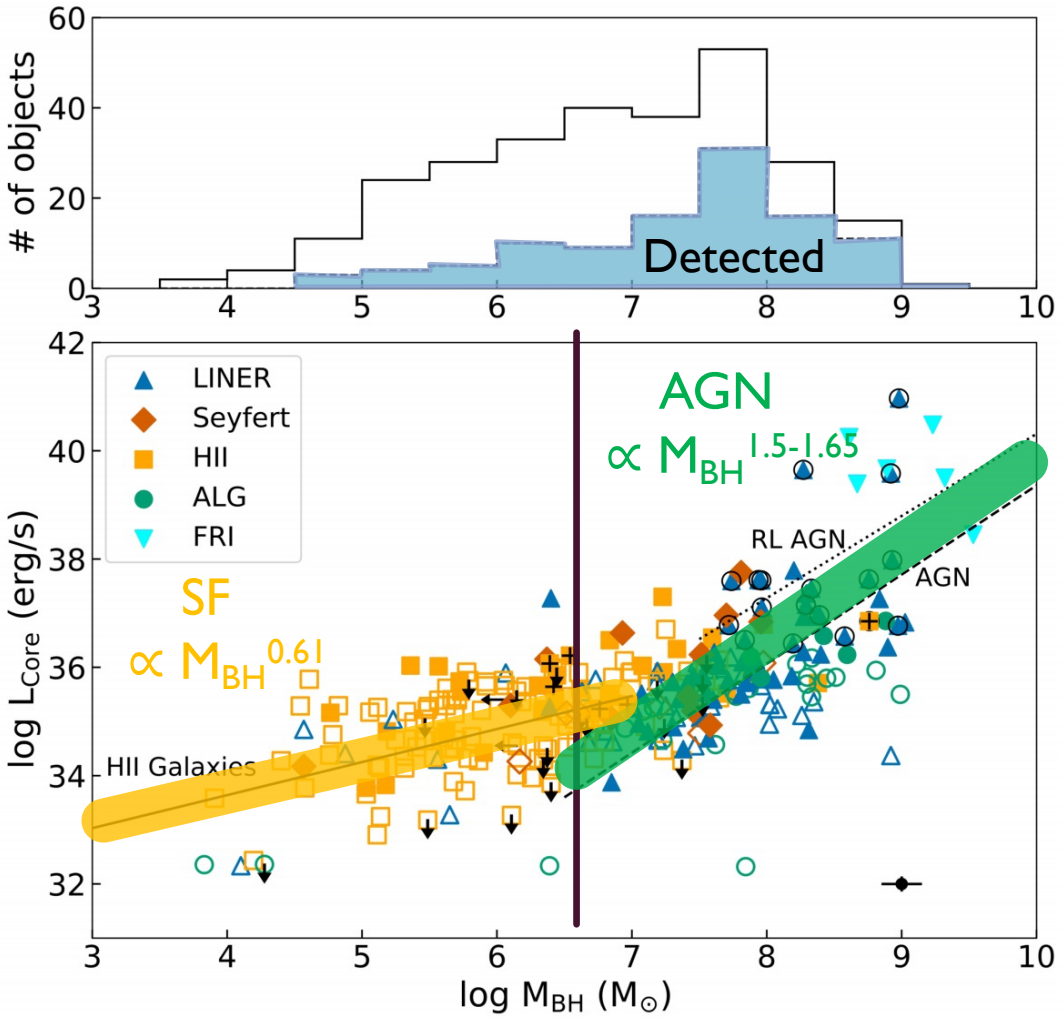
Credits to Carver E.

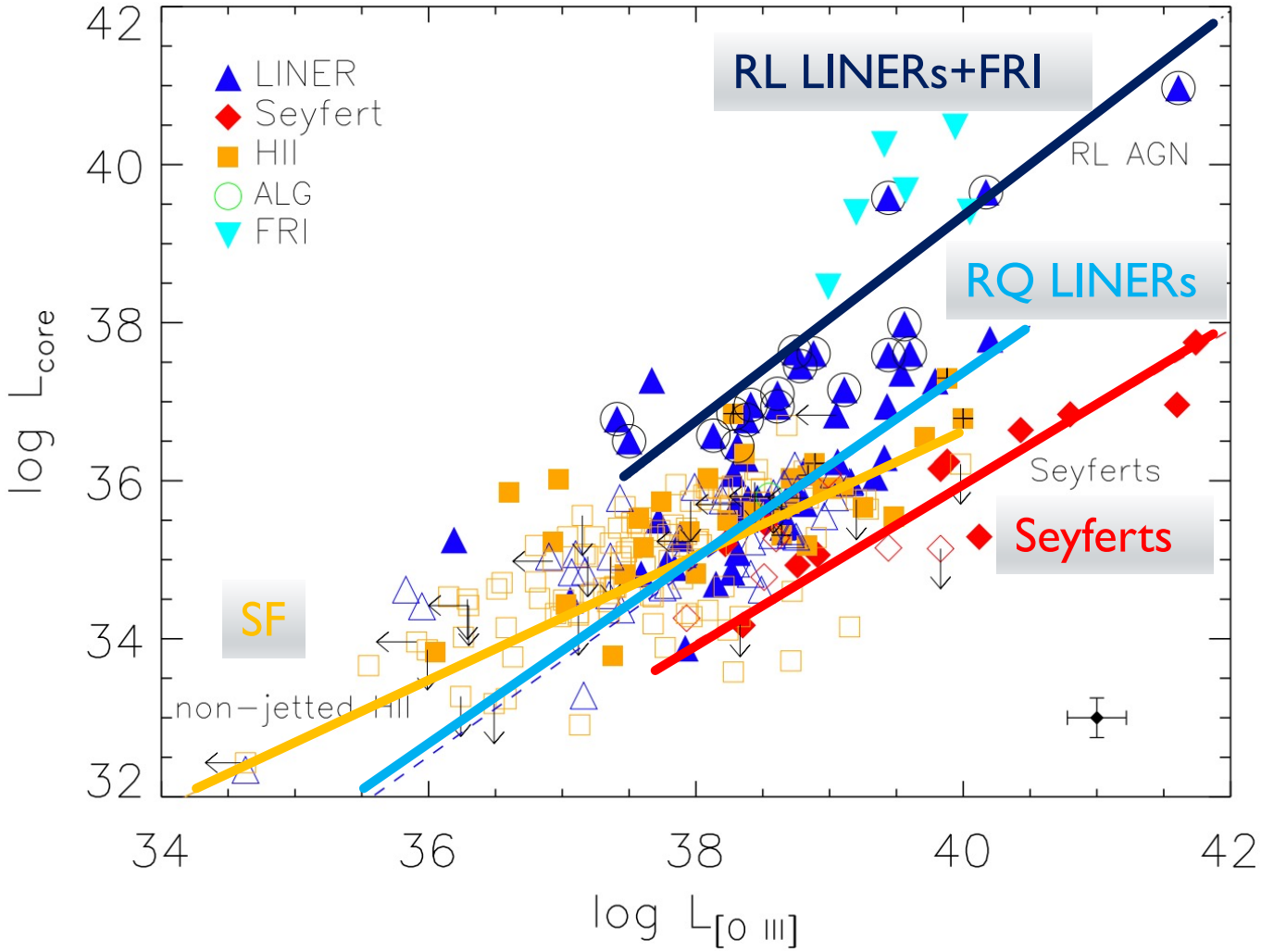
Baldi et al 2018, 2021a

DIAGNOSTICS TO EXPLORE THE ORIGIN OF THE RADIO EMISSION

$L_{CORE} - M_{BH}$ AND $L_{CORE} - L_{[OIII]}$

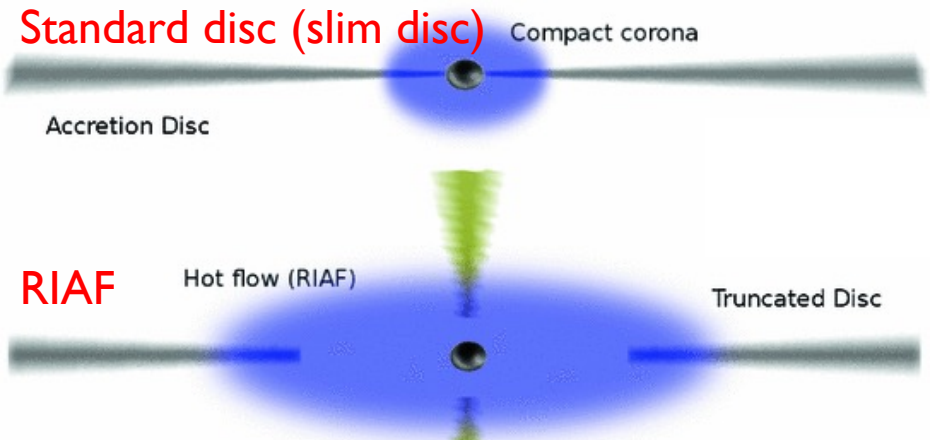
Baldi et al 2021b





ORIGIN OF RADIO EMISSION IN NEARBY GALAXIES

- RQ and RL LINERs show core-brightened radio morphologies, are powered by radiafively inefficient discs (RIAF, with low $\dot{m}$) launghing sub-relativistic and relativistic jets, respectively
- Low-power slow jets and disc/corona winds from moderately high to high-$\dot{m}$ discs (standard disc, SAD) account for the compact and edge-brightened jets of Seyferts, respectively
- Fuel-starved BHs and recurrent activity could account the properties of ALG, which are typically found in evolved ellipticals.
- Jetted HII galaxies may host weakly active BHs
- HII galaxies are powered by nuclear SF.



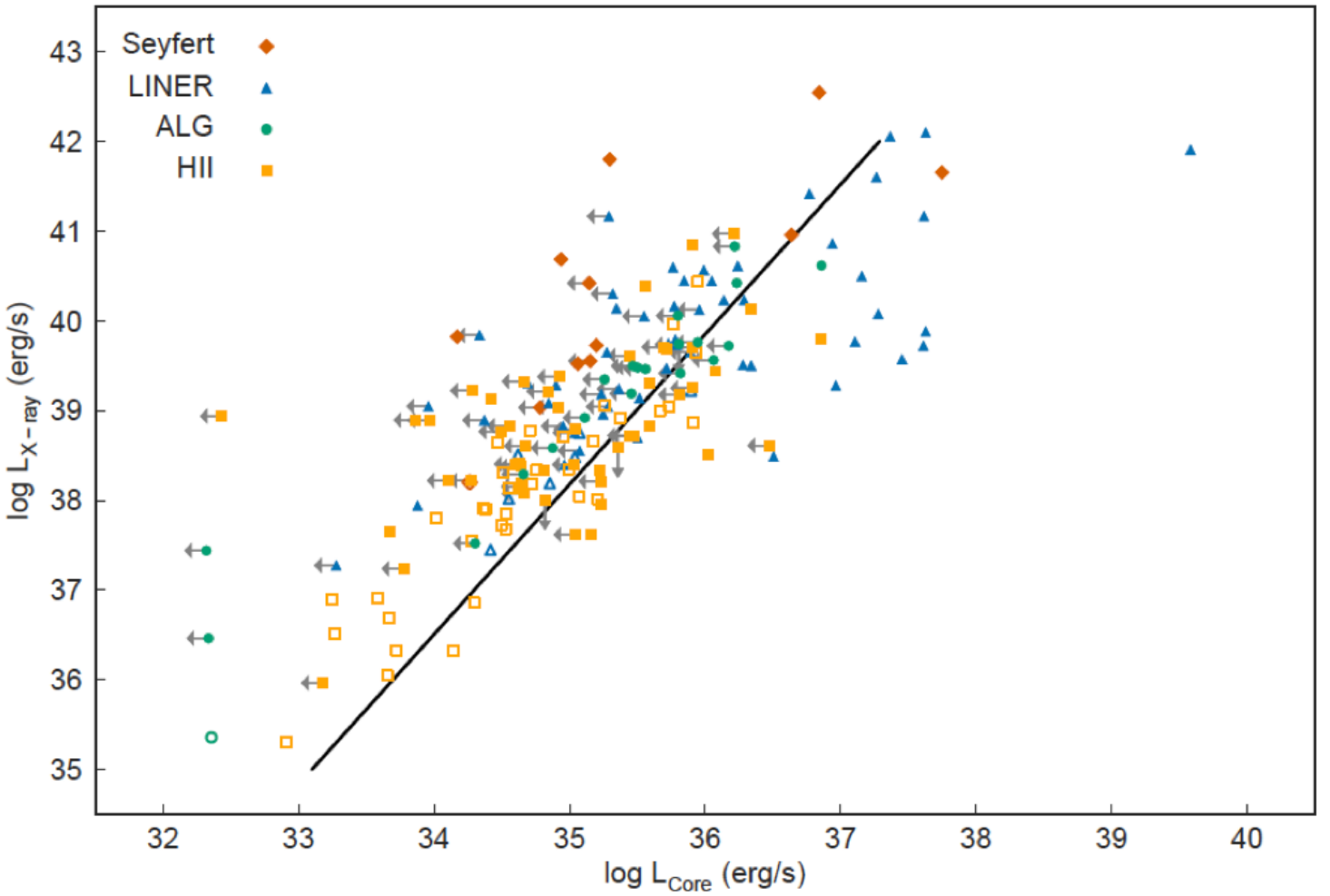
class	radio	$\dot{m}$	disc
RL LINER	relativistic jets	$\lesssim 10^{-3}$	RIAF
RQ LINER	sub-relativistic jets	$\lesssim 10^{-3}$	truncated thick disc
(RQ) Seyfert	sub-relativistic jets	$\lesssim 10^{-2}$	JED/truncated slim disc
	disc/corona wind	$\gtrsim 10^{-2}$	SAD
ALG	(sub-)relativistic jets	$\lesssim 10^{-3}$	recurrent/starving RIAF
jetted H II	sub-relativistic jets and SF	$\lesssim 10^{-3}$	RIAF?
non-jetted H II	SF		

CHANDRA X-RAY

- Palomar Sample (163 archival data + 48 new A
  Chandra obs) in 0.3-10 keV band
- flux limit: 3 x 10^{-15} erg s^{-1} cm^{-2}
- 150/280 (~70%) of the sample detected in 2-1
- Photometry and 2-10 keV spectroscopy (area

	optical class		
X-ray	LINER	ALG	Seyfe
detected	68	13	13
undetected	9	9	1
unobserved	16	6	4
Tot	93	28	18
	~88%.	~59%	~93

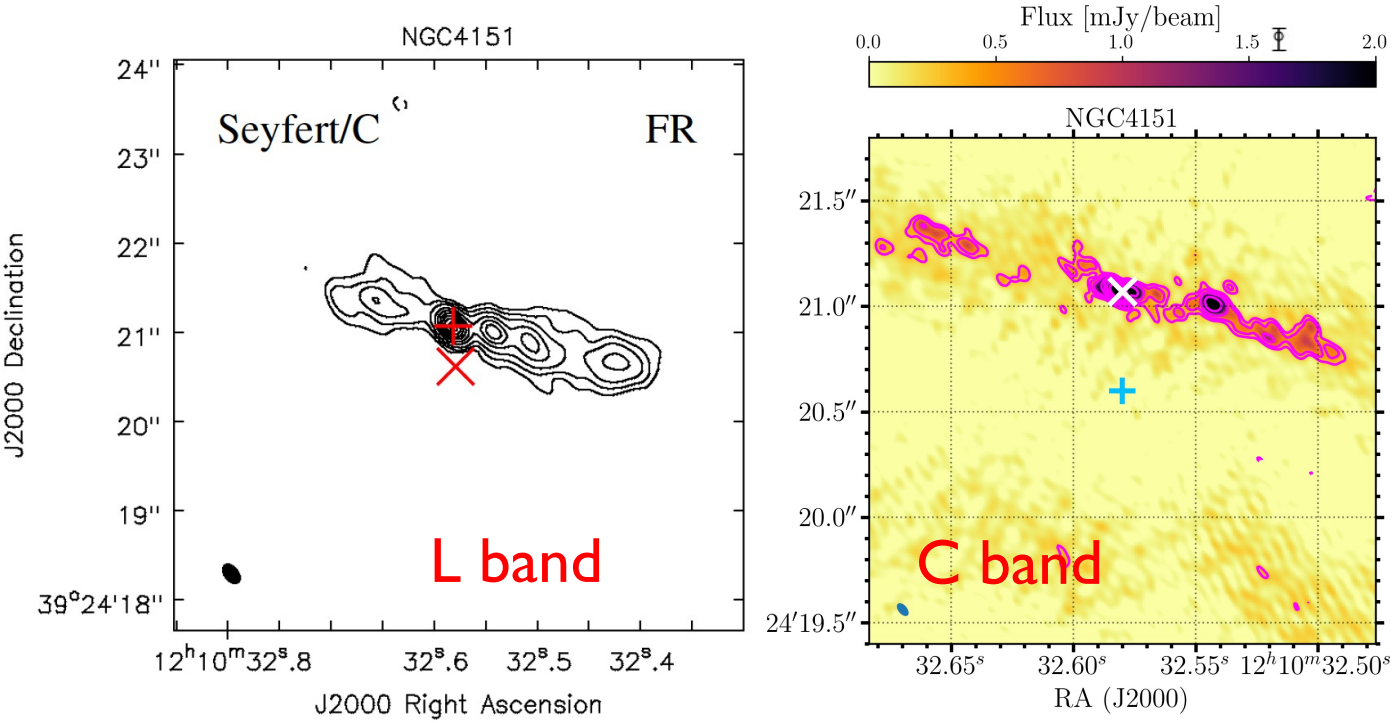
Williams, Baldi et al, in prep.



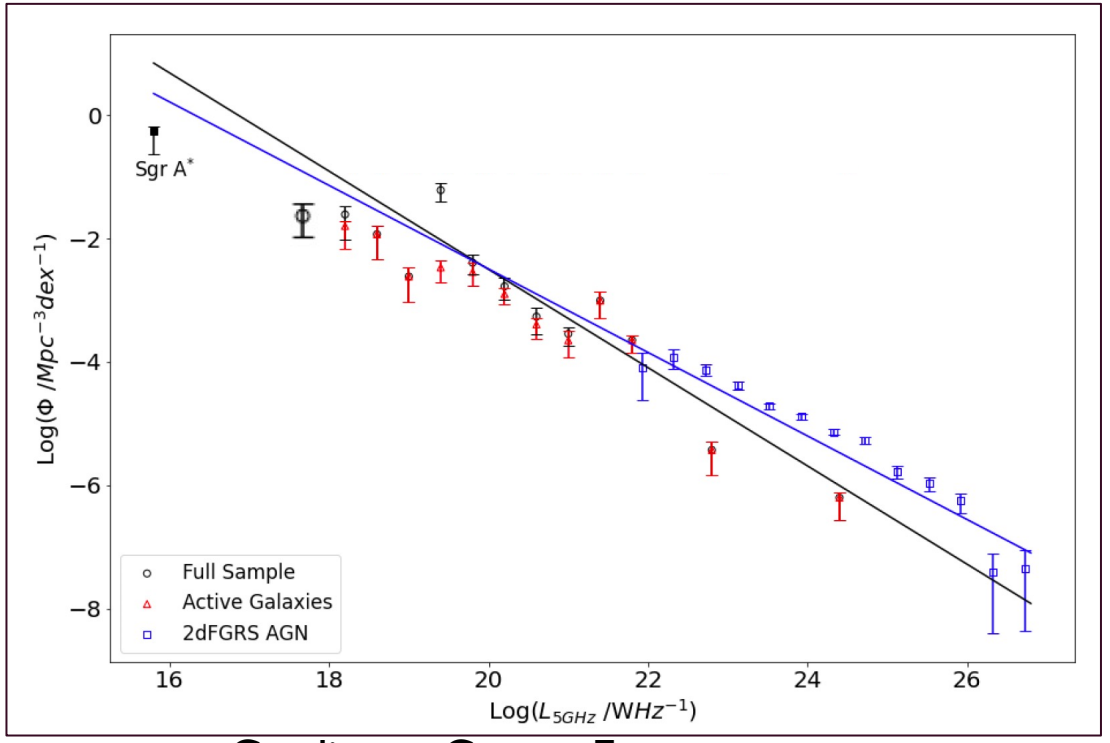
C-BAND OBSERVATION

Williams, Baldi et al, in prep.

- All 280 observations calibrated and imaged at 5 GHz
- Resolution 40-50 mas and sensitivity 59 μJy/beam



5-GHz Radio LF (in prep)> 10^{17} W Hz^{-1}



Credits to Carver E.

SUMMARY AND CONCLUSIONS

- LeMMINGs 1.5 GHz is complete:
  - The deepest high-resolution survey of local galaxies (~$10^{17\text{-}18}$ W Hz^{-1})
  - the presence of a break at $M_{BH} \sim 10^{6.5}\ M_{\odot}$ moving from the SF to AGN regime with increasing BH mass: separating SF galaxies and LLAGN in the local Universe
  - Different disc-jet couplings have been discussed to interpret the radio-[OIII](-X-ray) result:
    - Seyferts, higher $\dot{m}$ accretors than LINERs, mostly produce edge-brightened radio structures
    - Radio-loud LINERs are lower-luminosity counterparts of FRI galaxies
    - Most HII galaxies show no radio core detection, but some have radio jets: a clear sign of AGN activity
    - Absorption Line Galaxies are probably powered by an AGN, but more work needed
  - Specific accretionn-ejection state of active BHs (together with other factors, e.g. BH spin, magnetic field, gas supply, disc spin,..) determine the radio-optical connection in active/inactive galaxies

- LeMMINGs C band is underway soon!
- Plenty of multi-wavelength follow up still to do (full HST and Chandra, JVLA, LOFAR, Spitzer, Herschel)