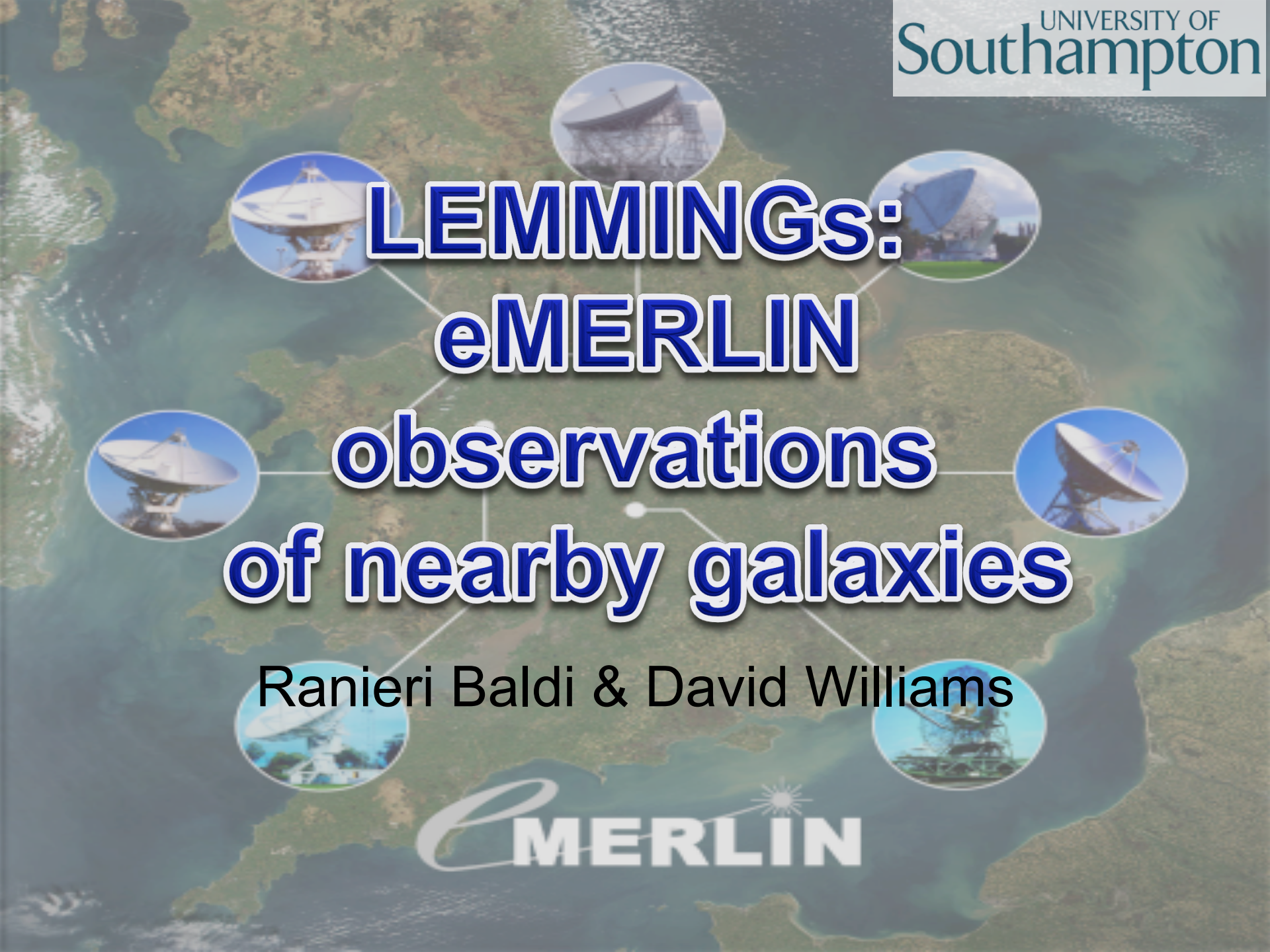
UNIVERSITY OF
Southampton
LEMMINGs:
eMERLIN
observations
of nearby galaxies
Ranieri Baldi & David Williams
eMERLIN

The University of Manchester
Jodrell Bank
Observatory

MANCHESTER 1824

UNIVERSITY OF Southampton
School of Physics and Astronomy

LeMMINGs

Legacy **e-M**ERLIN **M**ulti-band **I**maging of **N**earby **G**alaxie**s**

Rob Beswick (JBCA/e-MERLIN)

Ian McHardy (Southampton)

Plus the LeMMINGs

e-MERLIN Legacy team including

Ranieri Baldi (Southampton)

David Williams (Southampton)

e-MERLIN

Main goals

1. AGN (nucleus)

   - AGN/star formation discrimination
   - accretion, radio/X-ray connection
   - jets

2. Star formation (host galaxy)

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

3. Neutral gas (host galaxy)

   - the fuel for star formation and AGN

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Sample and observing depths

- '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 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
- 'Deep' survey is a **sub-sample** of shallow picking (six) objects with best multi-λ coverage.

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LeMMINGs Sample

- Total project allocation is 810hrs
  - **Palomar shallow tier** → ~280 galaxies (on-source time ~48min/band/source); 750 hours total; no Lovell
  - **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	38	$1.8 * 10^{18}$ W/Hz	48min
Shallow (C-band) Res ~ 35mas	280	15	$7.2 * 10^{17}$ W/Hz	48min
Deep (L-band) with LT	6	8	$7.5 * 10^{16}$ W/Hz	4.8hr
Deep (C-band) with LT	6	3	$2.8 * 10^{16}$ W/Hz	4.8hr

Observations so far: L-band

- Palomar Sample:
  - 11 out of 28 blocks observed
  - 11 blocks calibrated, 103 sources mapped
  - RFI big problem. SERPent (D.Fenech) important
  - Sensitivity: rms ~0.1 mJy/beam
  - Flux densities : 0.1-500 mJy/beam
  - Resolution: 150-200 mas
- Deep Sample:
  - All 6 observed and published or in preparation (M82, IC10, NGC4151, M51b, NGC6217, NGC5322)

Shallow sample

- Palomar Sample (103 targets, **Baldi et al. in prep.**)
  - 46% of the sample detected
  - 35% of the sample: BH pinpointed
  - Detection fraction:
  1. LINER: 21 + (1) / 33 ➔ 67%
  2. Seyfert: 3 + (1) / 4 ➔ 100%

  } ***Active***

  3. HII regions: 8 + (8) /36 ➔ 44%
  4. Absoprtion line galaxies: 4 + (1) /14 ➔ 36%

  } ***Inactive***

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

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Radio morphologies

Single core

NGC5353

Triple source

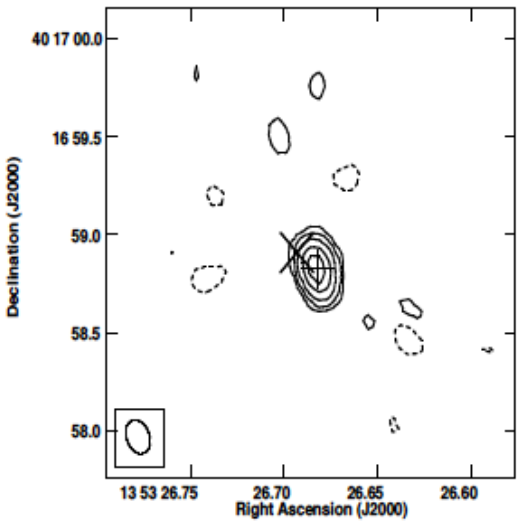
NGC4051

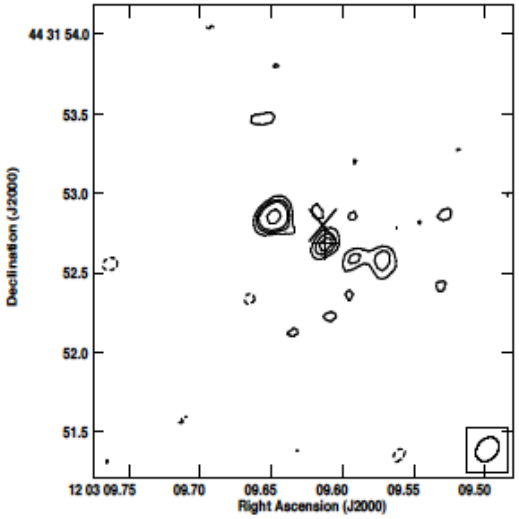
Double jet

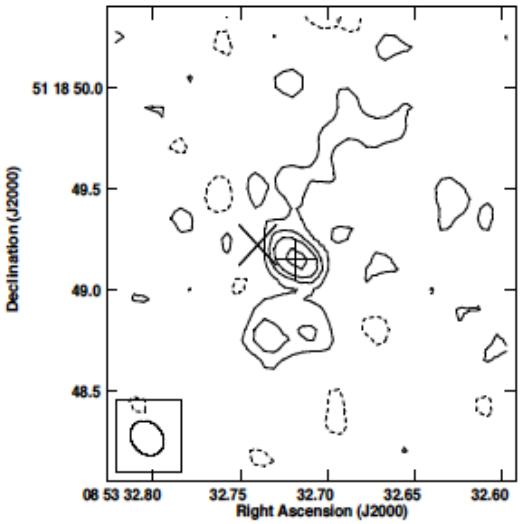
NGC2681

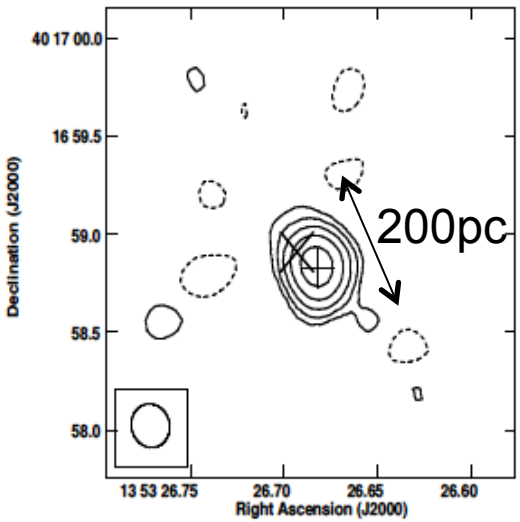
Full resolution

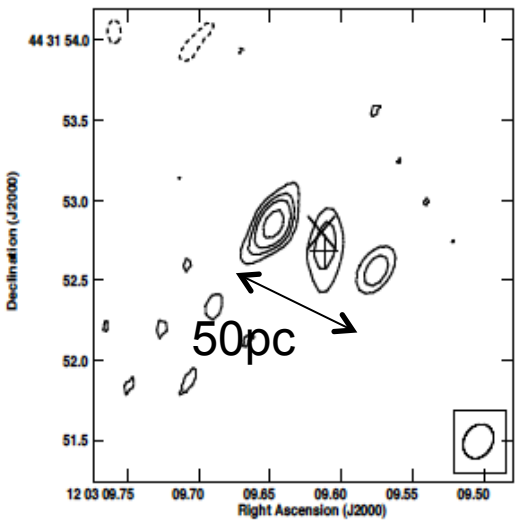
Low resolution

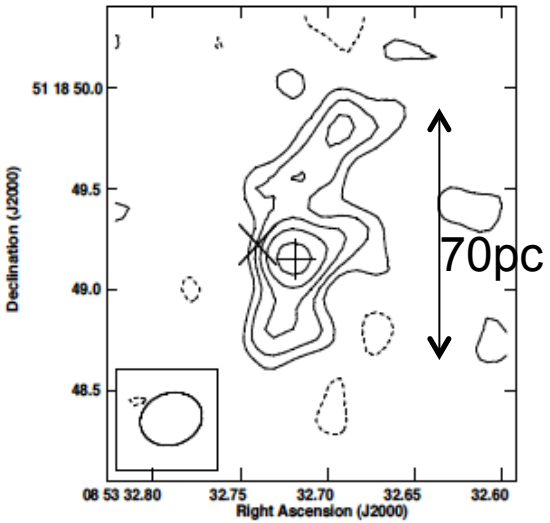










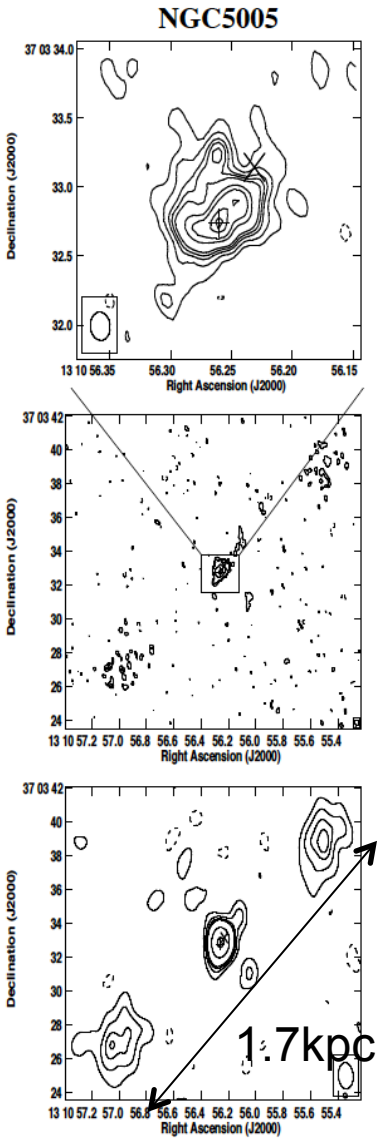


Radio morphologies

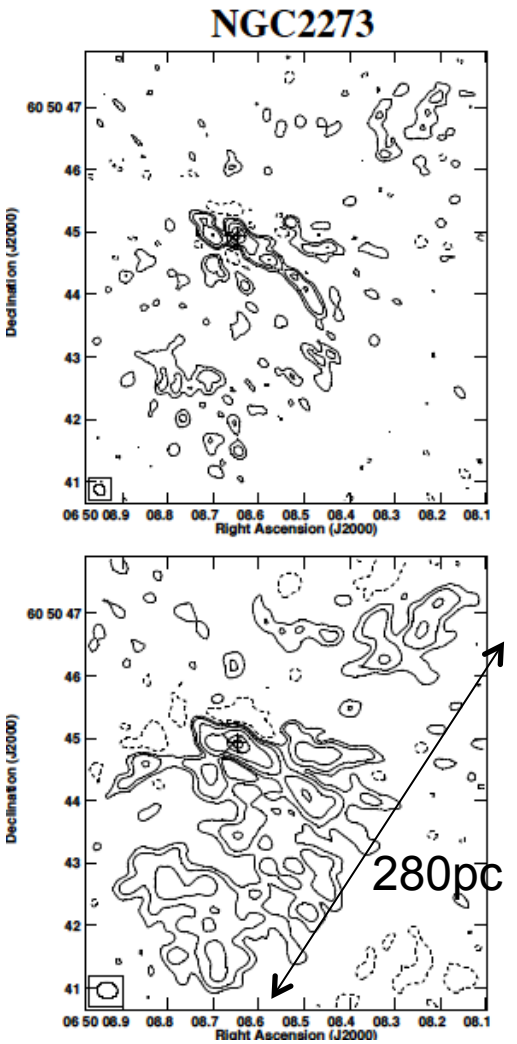
Double-lobed

Full resolution

Low resolution



Complex



Full resolution

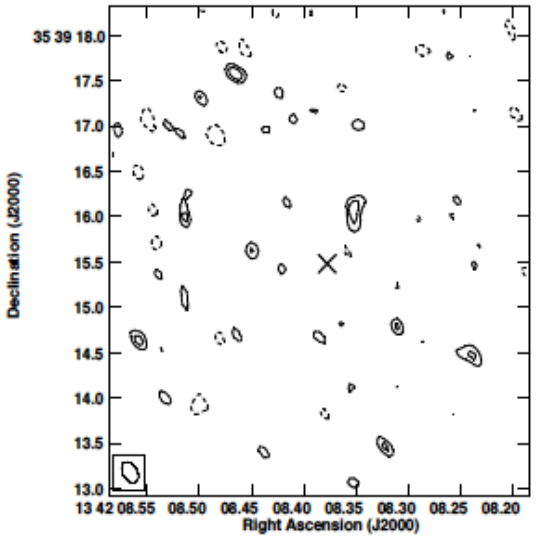
Low resolution

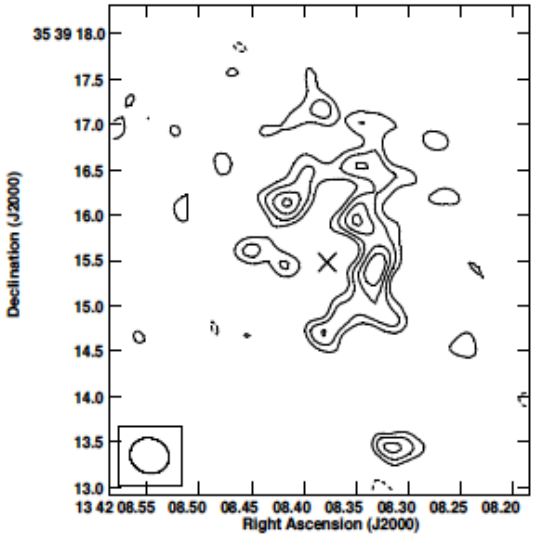
Unidentified sources

Full resolution

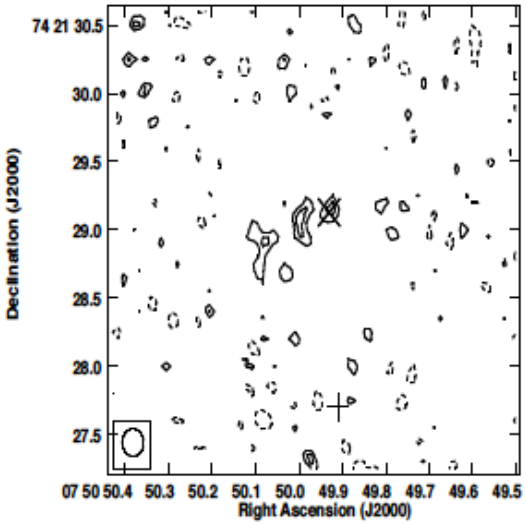
Low resolution

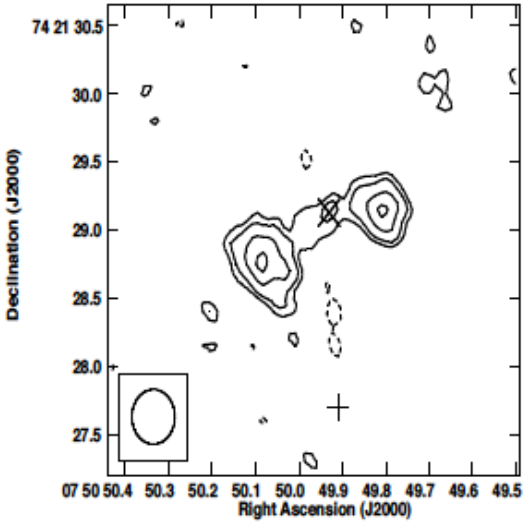
NGC5273



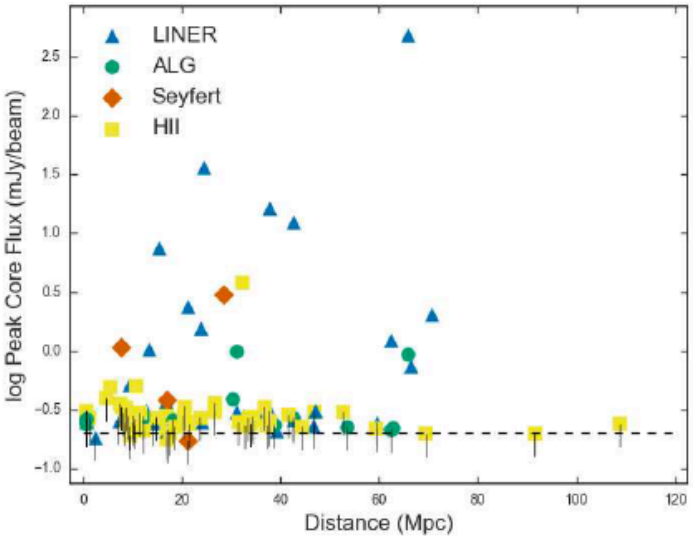


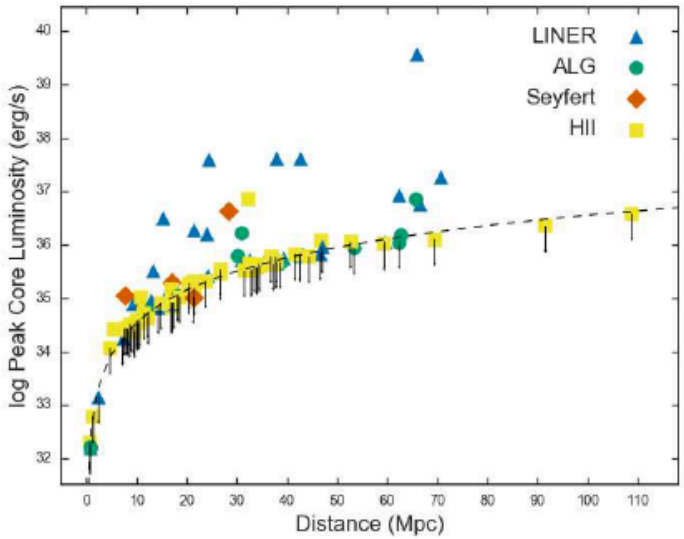
UGC4028

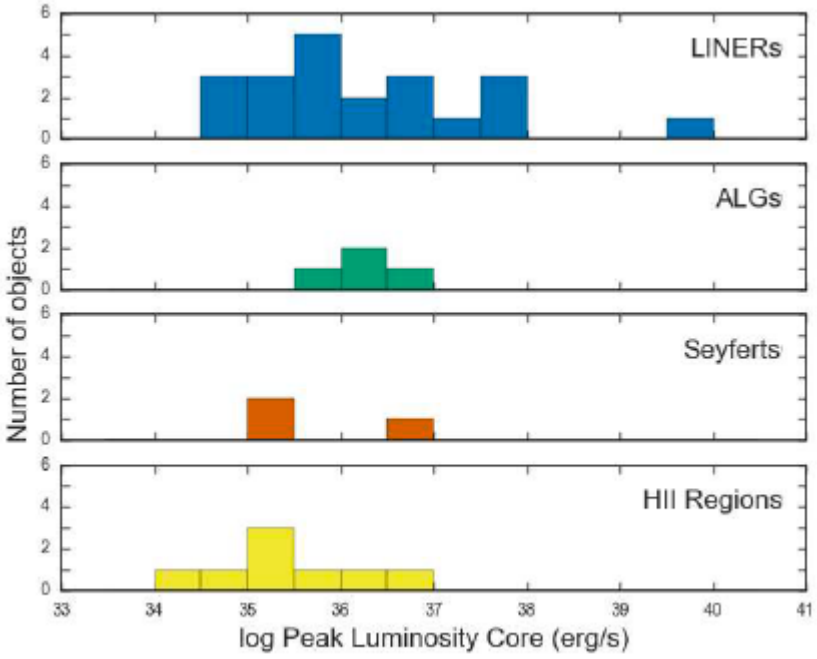




Deeper than any other radio survey of the Palomar sample (Nagar et al. 2002, Filho et al 2006)

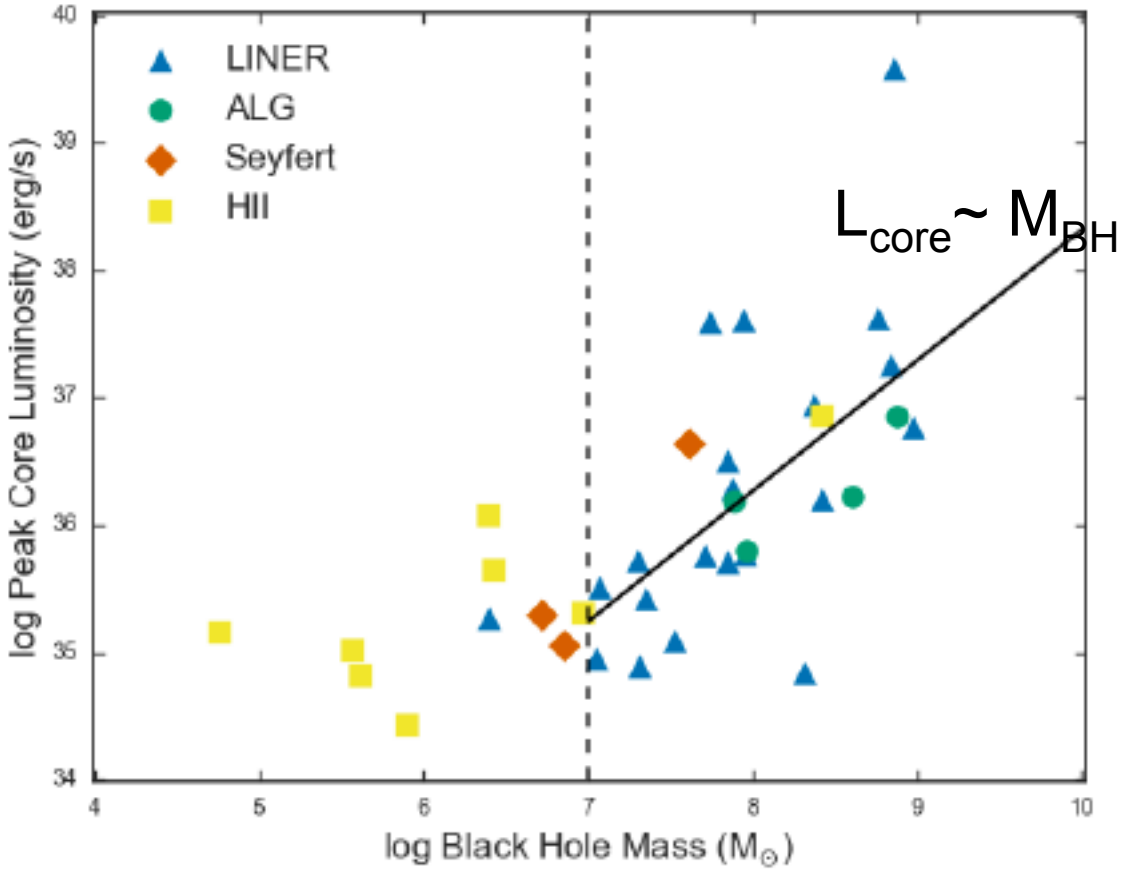




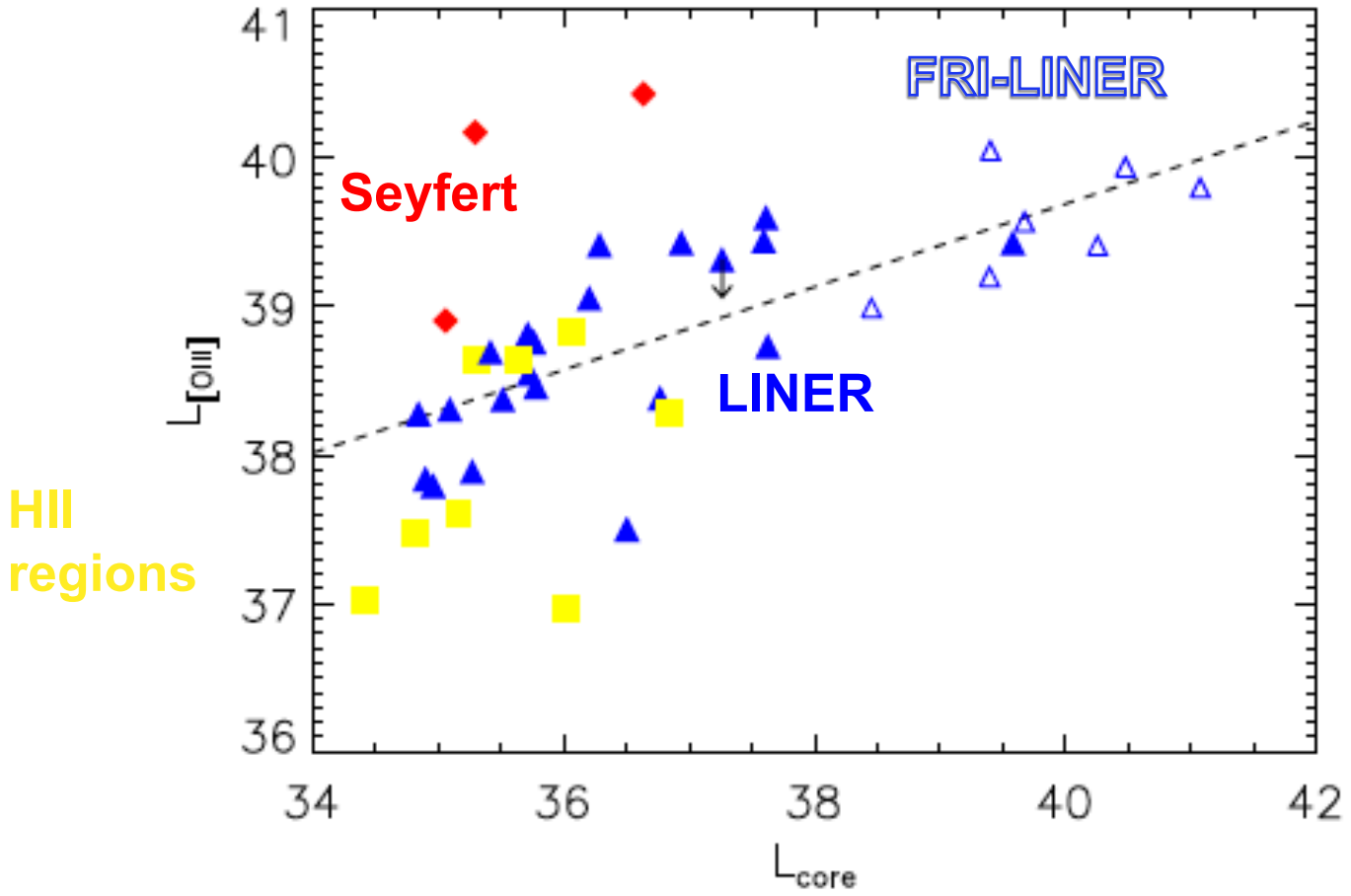


Within a factor 100 of Sgr A* (in L band), but aim at reaching radio luminosity function within a factor of 10 in C band

Radio – BH mass



Radio – [OIII]



LINERs follow the liner correlation line-core of FRI radio galaxies (LINER): ADAF disc
Seyferts are above the correlation: additional line contribution from a thin disc?
HII regions are below the correlation: lack of a ionisation source?

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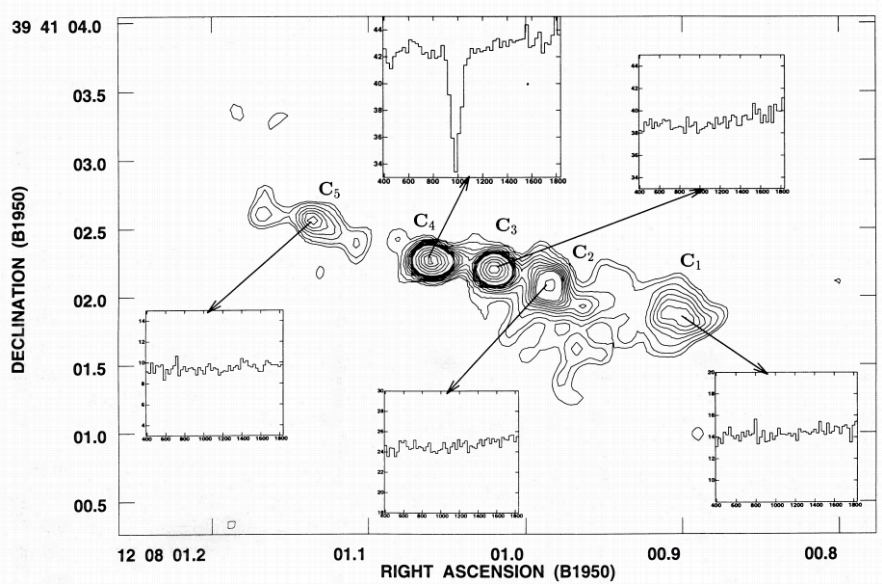
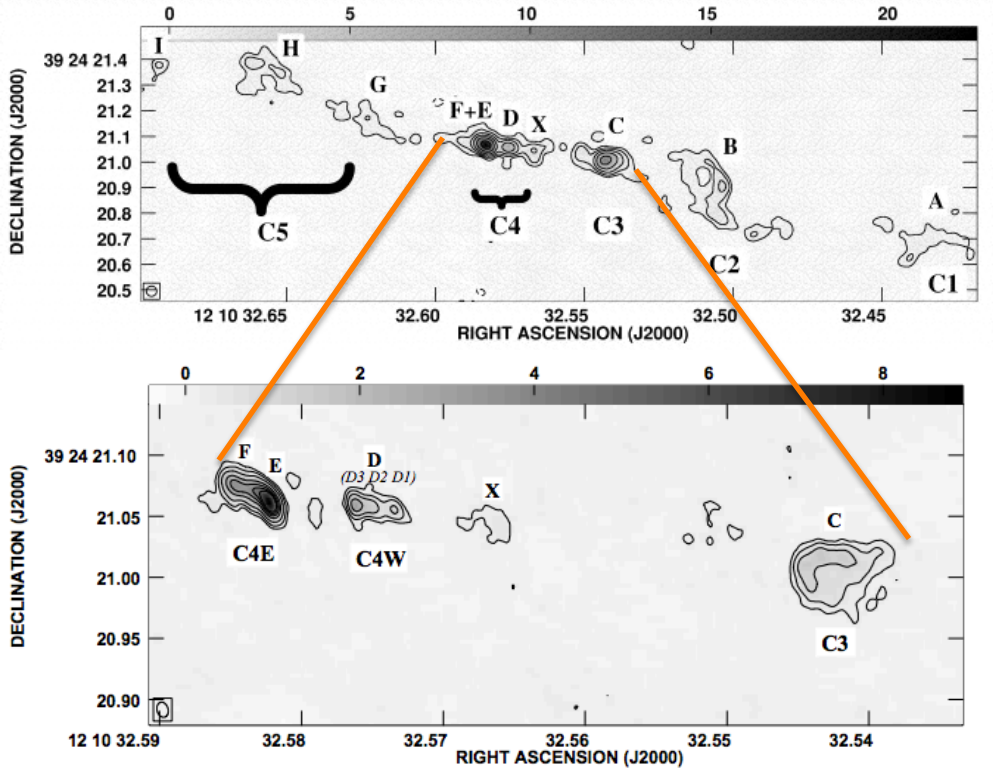
NGC 4151

Right:
VLBA+VLA λ21cm continuum image
Mundell+03

Below:
MERLIN neutral hydrogen image
Mundell+95





Science Goals

- Look for changes in morphology and flux density between 1993 and 2015
- Put an upper limit on the bulk jet speed over this 22 year period
- Compare the radio structure to the emission line region properties from HST images

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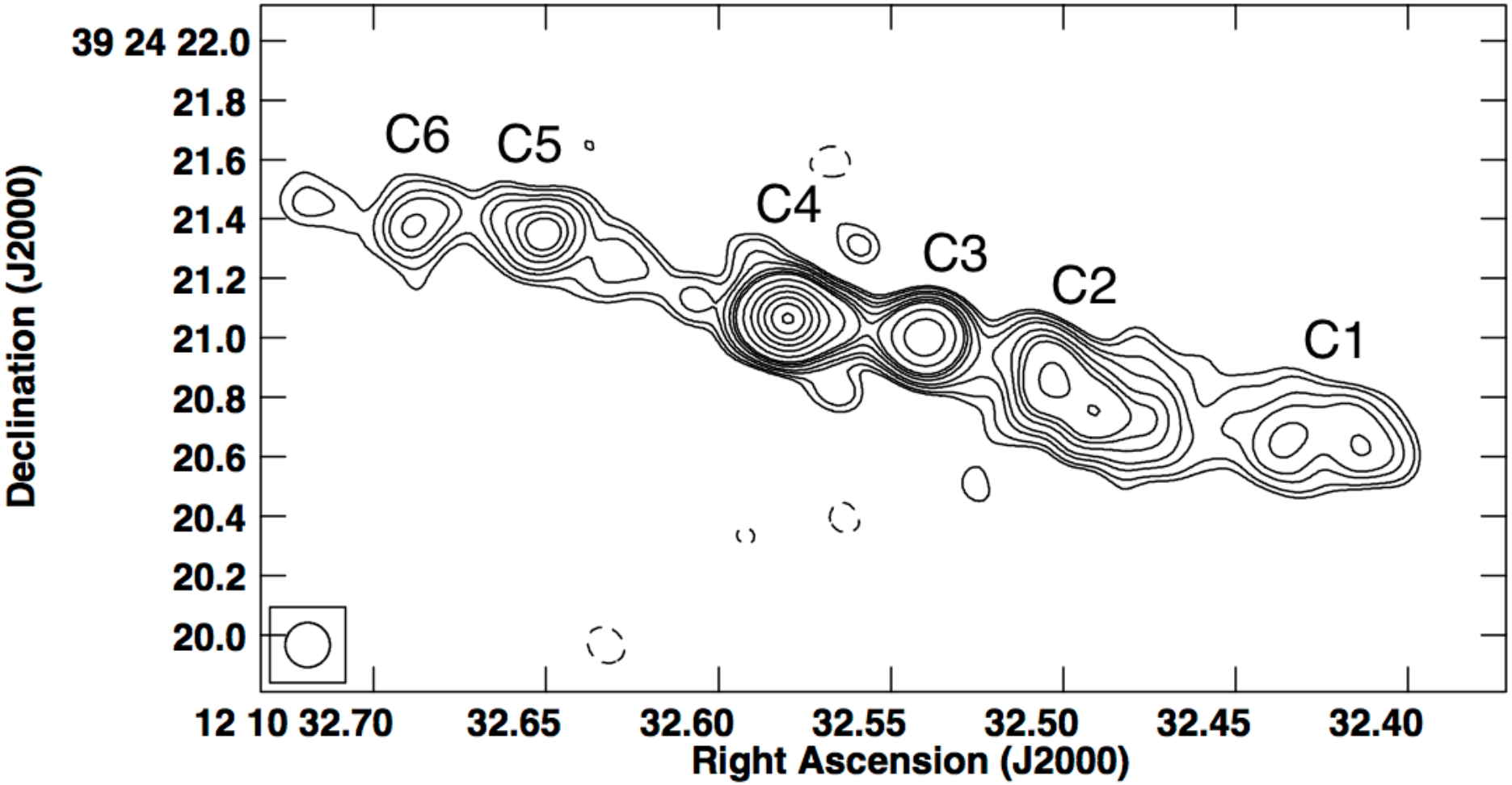
New eMERLIN image



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Results

- The morphology of the central 400 pc jet structure is broadly unchanged in 22 years
- The core component (C4) where the AGN resides has increased by 50% in flux density
- The nearest jet component to the core, C3, has decreased by 30%
- Most of the other components have decreased in flux density
- Upper limit to bulk jet velocity set to 0.04c

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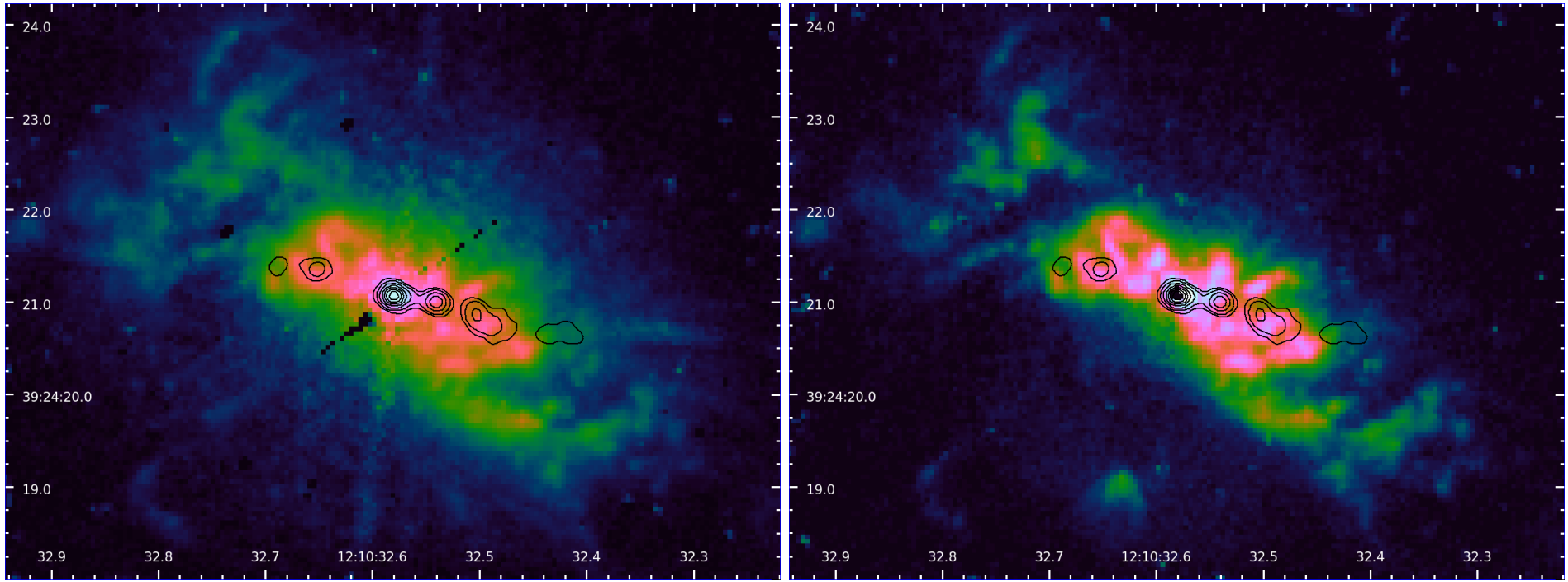
The Emission Line Region



Continuum subtracted HST emission line maps of NGC 4151
Left: Hα Emission Line Image, Right: [OIII] Emission Line Image
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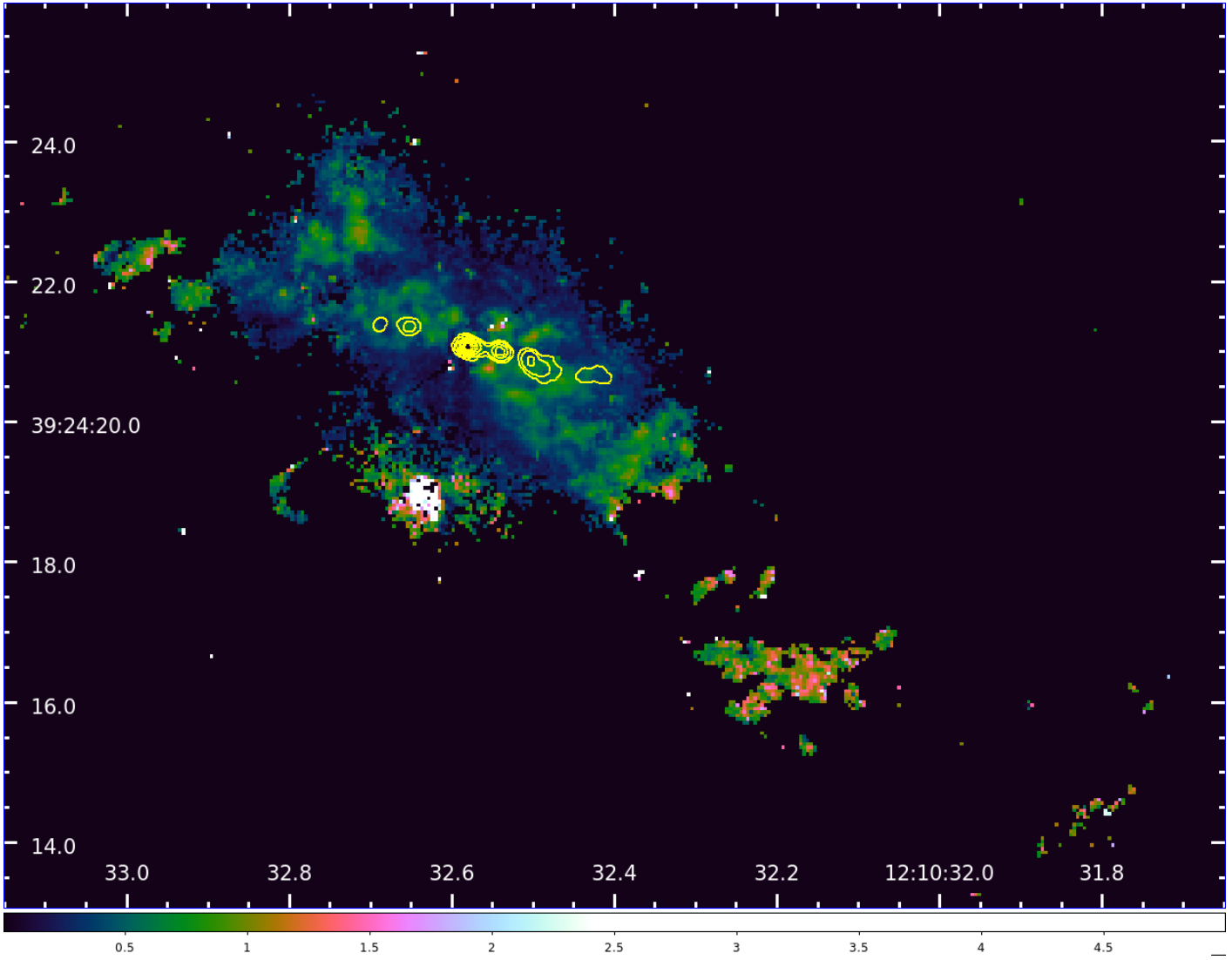
[OIII]/Hα image



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Conclusions (NGC 4151)

- The AGN in NGC 4151 has brightened significantly in a 20 year timescale
- Adiabatic expansion can explain the reduction in flux density of the other components
- Photoionisation from the AGN is responsible for most of the emission lines seen, but…➔
- ➔…the jet could contribute the optical line emission near to the jet components

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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, in prep.): deepest Palomar radio survey, 10 times higher than SgrA*

- Current L-band LeMMINGs observations are going well but suffer from RFI. C-band will be less affected.

- eMERLIN **resolution** is well matched to nearby galaxy studies but **need improved low frequency sensitivity and uv coverage – Lovell telescope**

- If funding were available, more sensitivity on scales in between current eMERLIN and VLA (ie baselines of 80-100km) would help: **the addition of Goonhilly telescope**