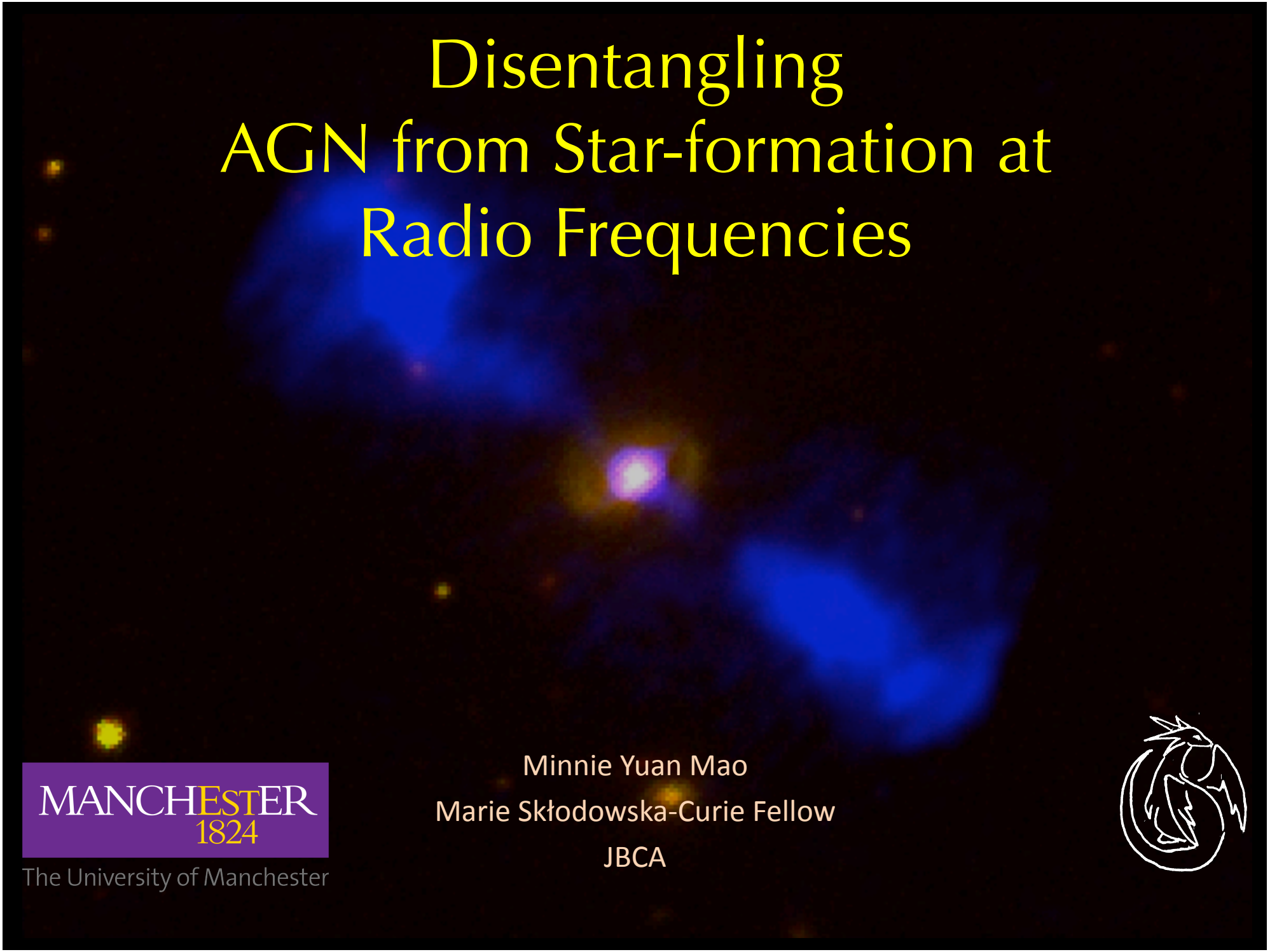
Disentangling AGN from Star-formation at Radio Frequencies



MANCHESTER 1824
The University of Manchester

Minnie Yuan Mao
Marie Skłodowska-Curie Fellow
JBCA

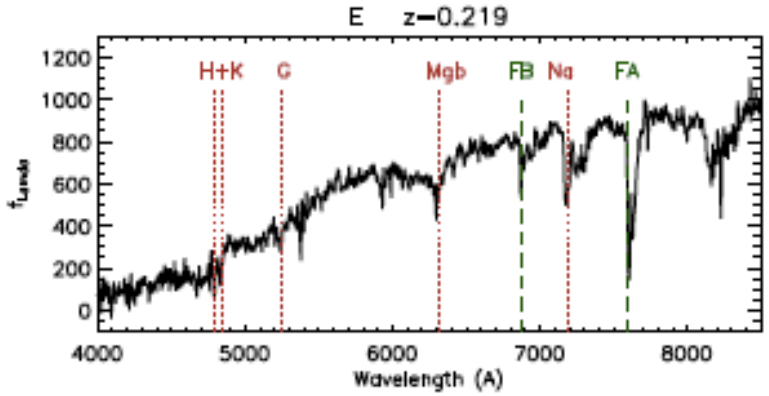
Background

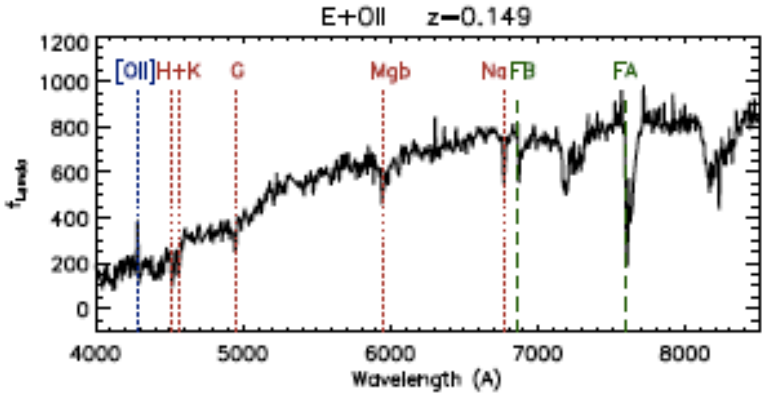
- Extragalactic radio emission from galaxies can be attributed to either star-formation or the presence of AGN
- At ~GHz radio frequencies, both AGN and star-formation emit non-thermal synchrotron emission
- How can we disentangle star-formation from AGN?

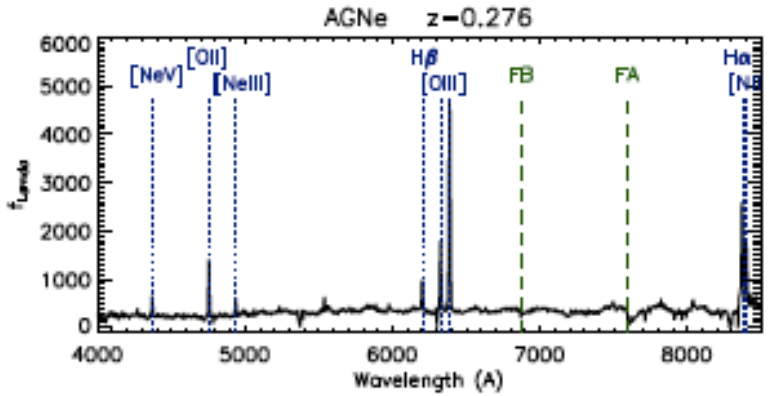
SF vs AGN

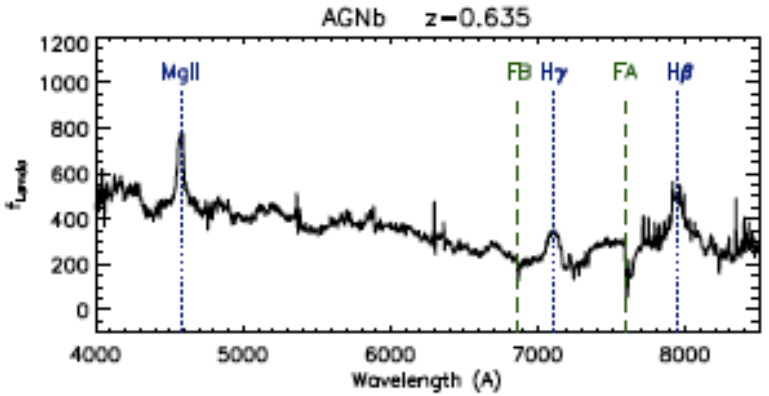
- Optical spectra
- Far infrared radio correlation
- Mid infrared colours
- X-ray hardness ratio
- Radio morphology
- …

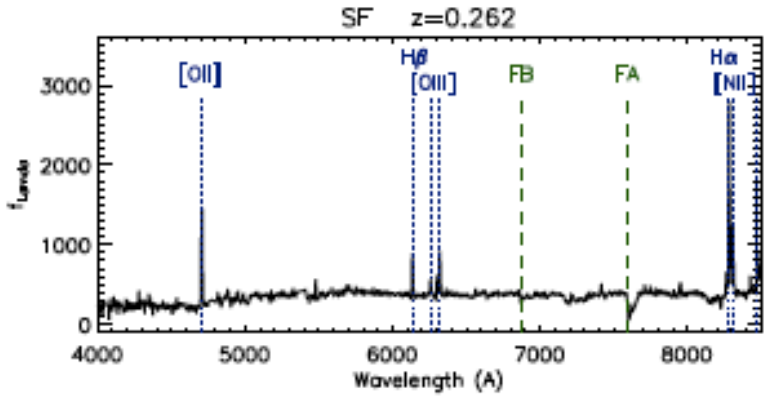
- Importance of multiwavelength ancillary data!

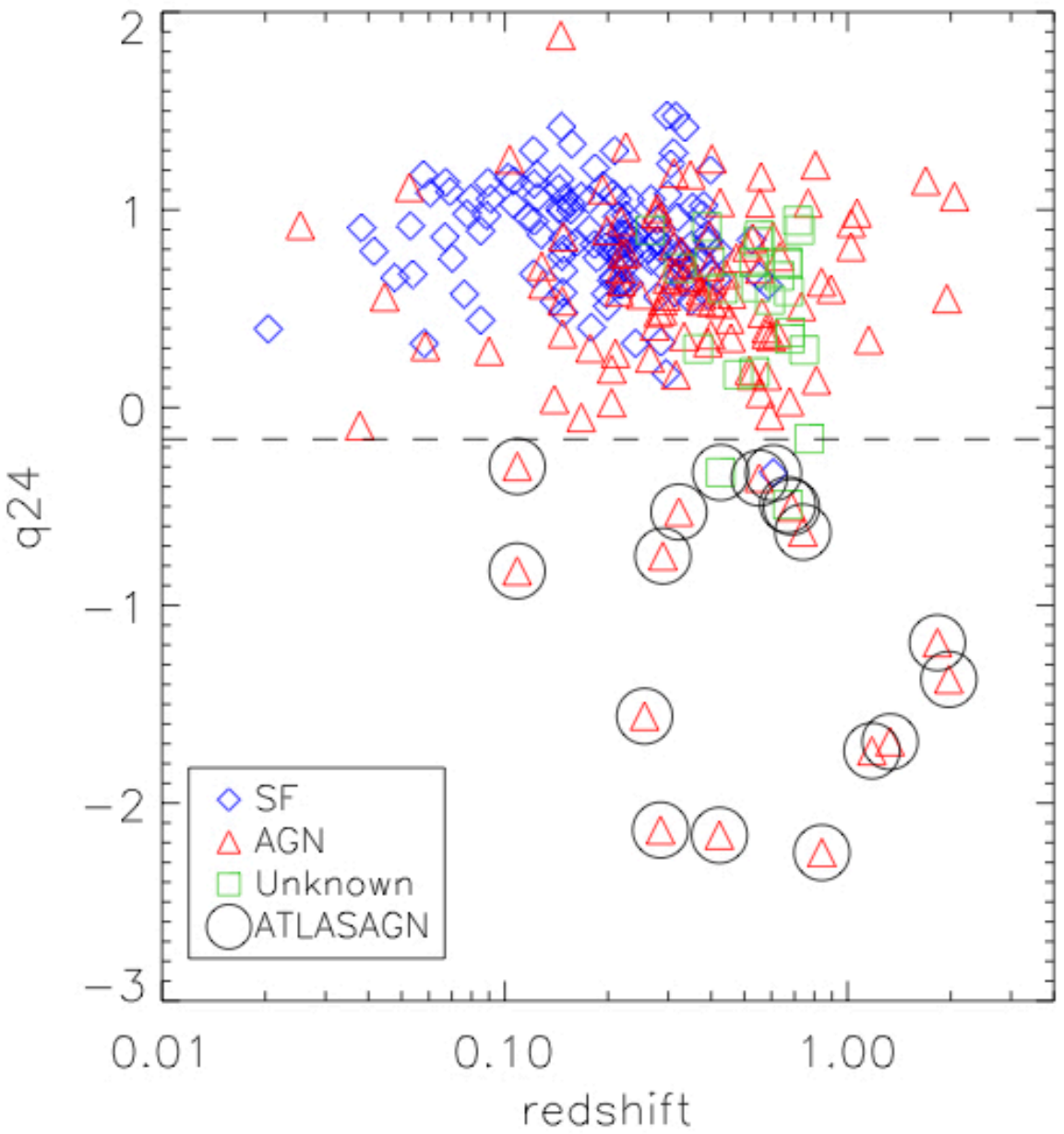

E z=0.219
H+K
G
Mgb
FB
Na
FA
Wavelength (A)

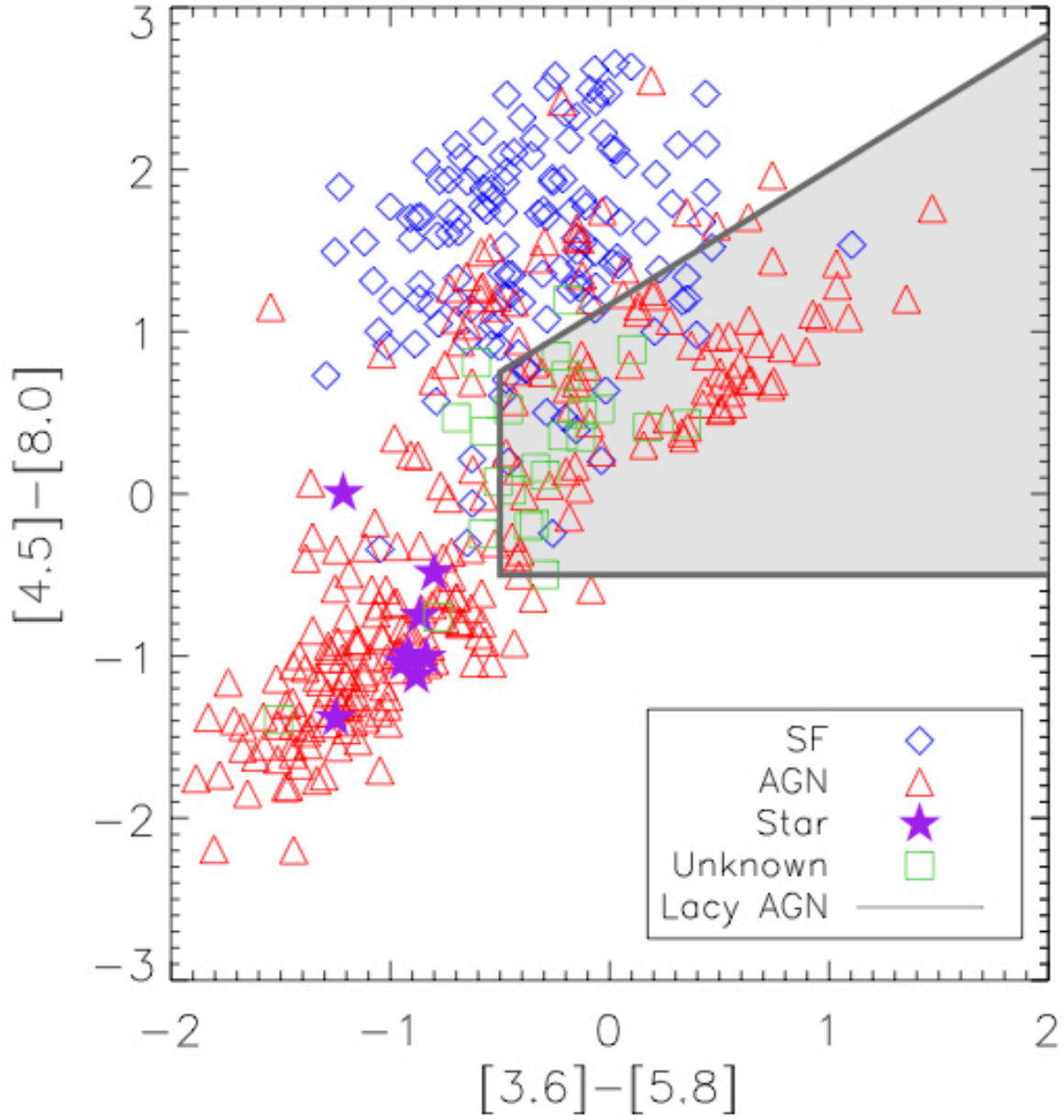

E+OII z=0.149
[OII]
H+K
G
Mgb
Na
FB
FA
Wavelength (A)


AGNe z=0.276
[NeV]
[OII]
[NeIII]
Hβ
[OIII]
FB
FA
Wavelength (A)


AGNb z=0.635
MgII
FB
Hγ
FA
Hβ
Wavelength (A)


SF z=0.262
[OII]
Hβ
[OIII]
FB
FA
Hα
[NII]
Wavelength (A)


2
1
0
−1
−2
−3
q24
0.01
0.10
1.00
redshift
SF
AGN
Unknown
ATLASAGN


3
2
1
0
−1
−2
−3
−2
−1
0
1
2
[4.5]−[8.0]
[3.6]−[5.8]
SF
AGN
Star
Unknown
Lacy AGN

SF vs AGN

- But galaxies aren't binary! (star-forming **or** AGN)
- Many sources exhibit both star-forming **and** AGN characteristics
- E.g.
  - Seyferts
  - LIRGs/ULIRGs
  - Spiral DRAGNs
- eMERGE has detected sources that have an AGN embedded in areas of star-formation
- This is very exciting for Spiral DRAGNs!

Spiral DRAGNs

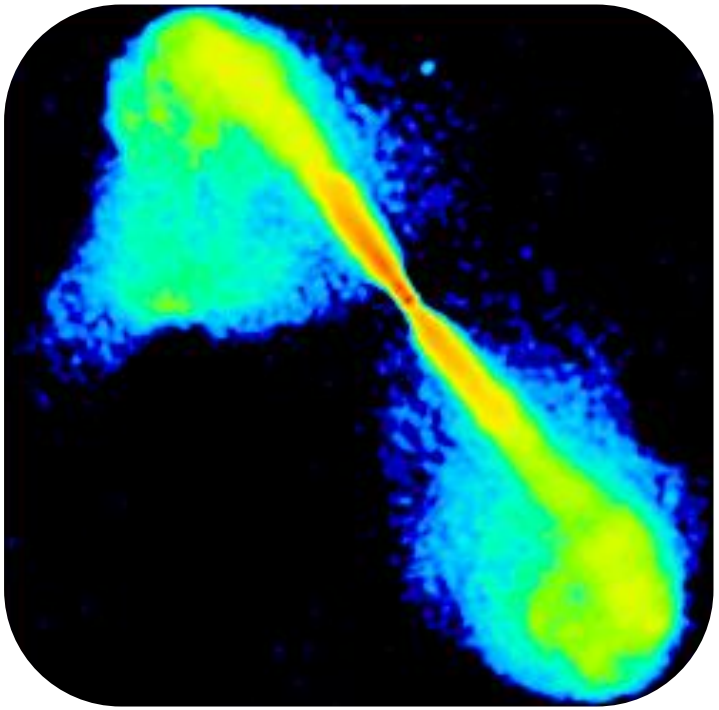
- Frazer Owen
- Ryan Duffin
- Bjorn Emonts
- Bill Keel
- Mark Lacy
- Paddy Leahy
- Emmanuel Momjian
- Glenn Morrison
- David Mulcahy
- Tony Mroczkowski
- Susan Neff
- Ray Norris
- Anna Scaife
- Henrique Schmitt
- Jean Tate
- Vicki Toy
- Sylvain Veilleux

DRAGN:
Double-lobed **R**adio sources **A**ssociated with **G**alactic **N**uclei
(Leahy 1993)

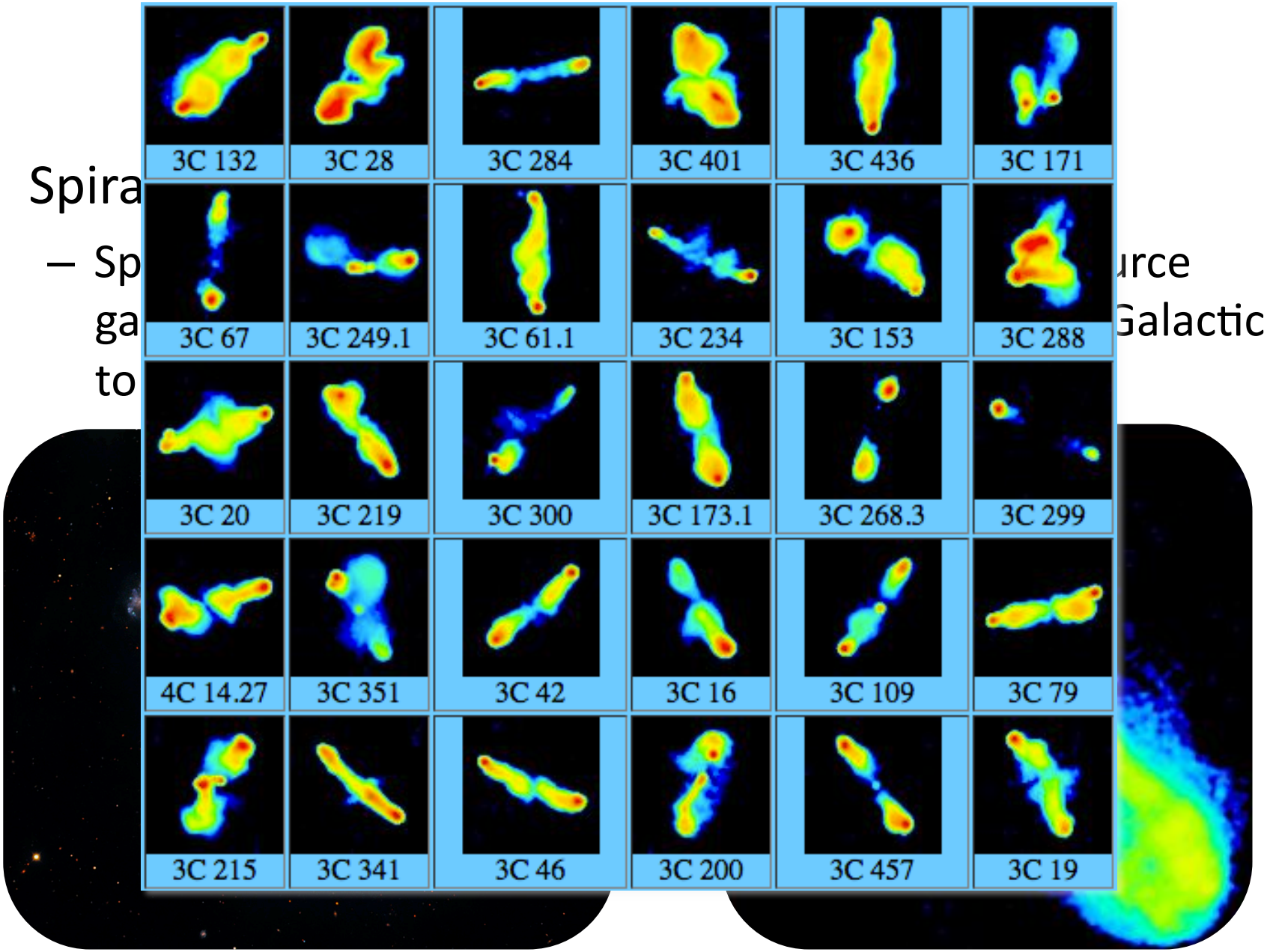
What's in a Name?

- Spiral
  - Spiral refers to spiral galaxies, so named due to their spiral structure

- DRAGNs
  - Double Radio source Associated with Galactic Nuclei

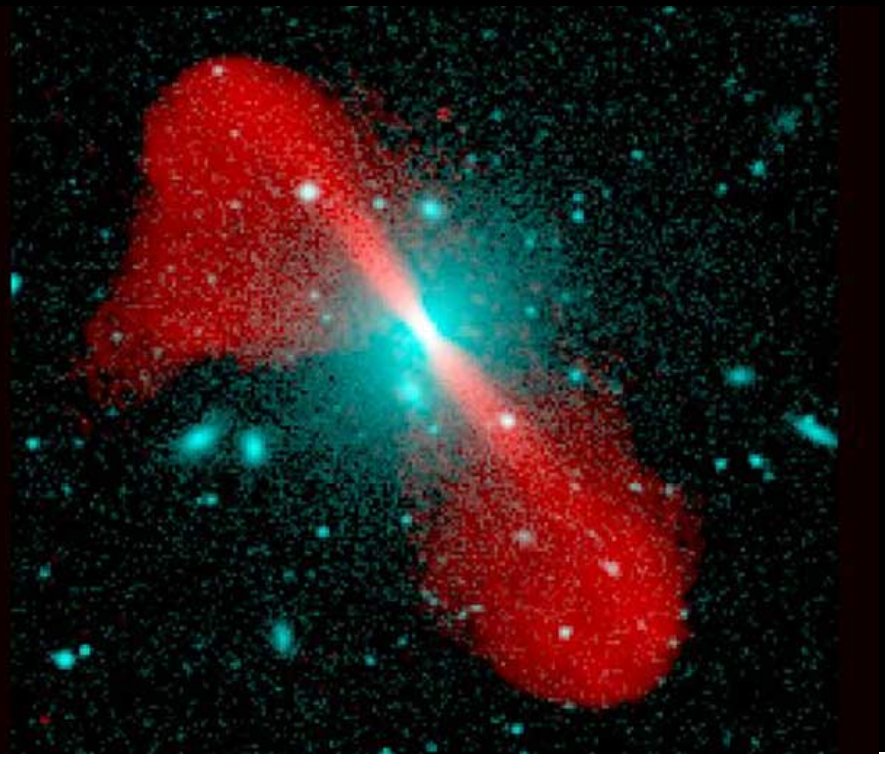


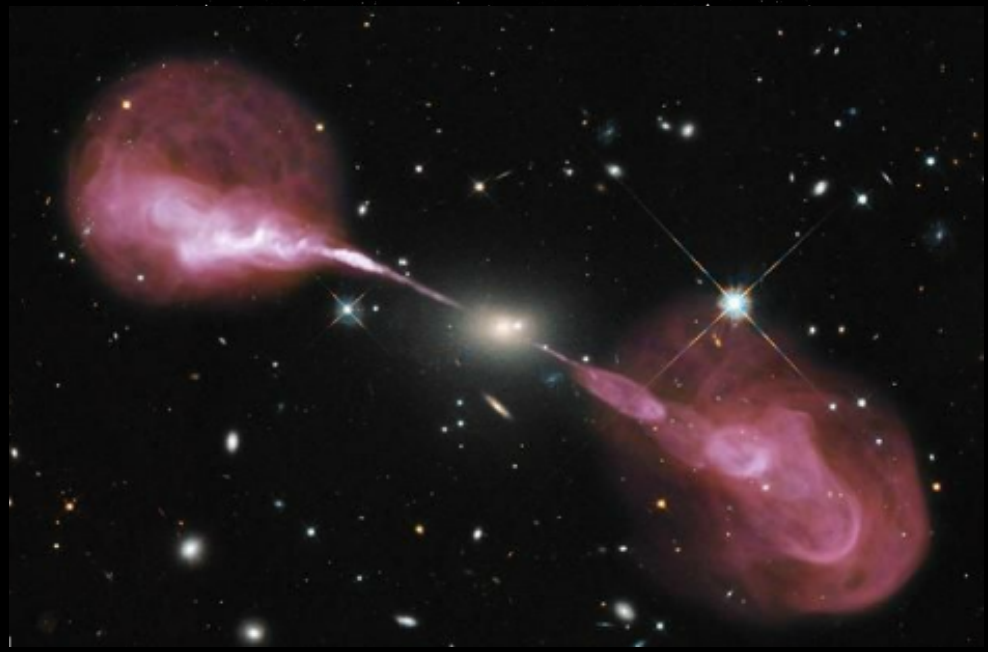
- Spira
  - Sp urce
    ga Galactic
    to



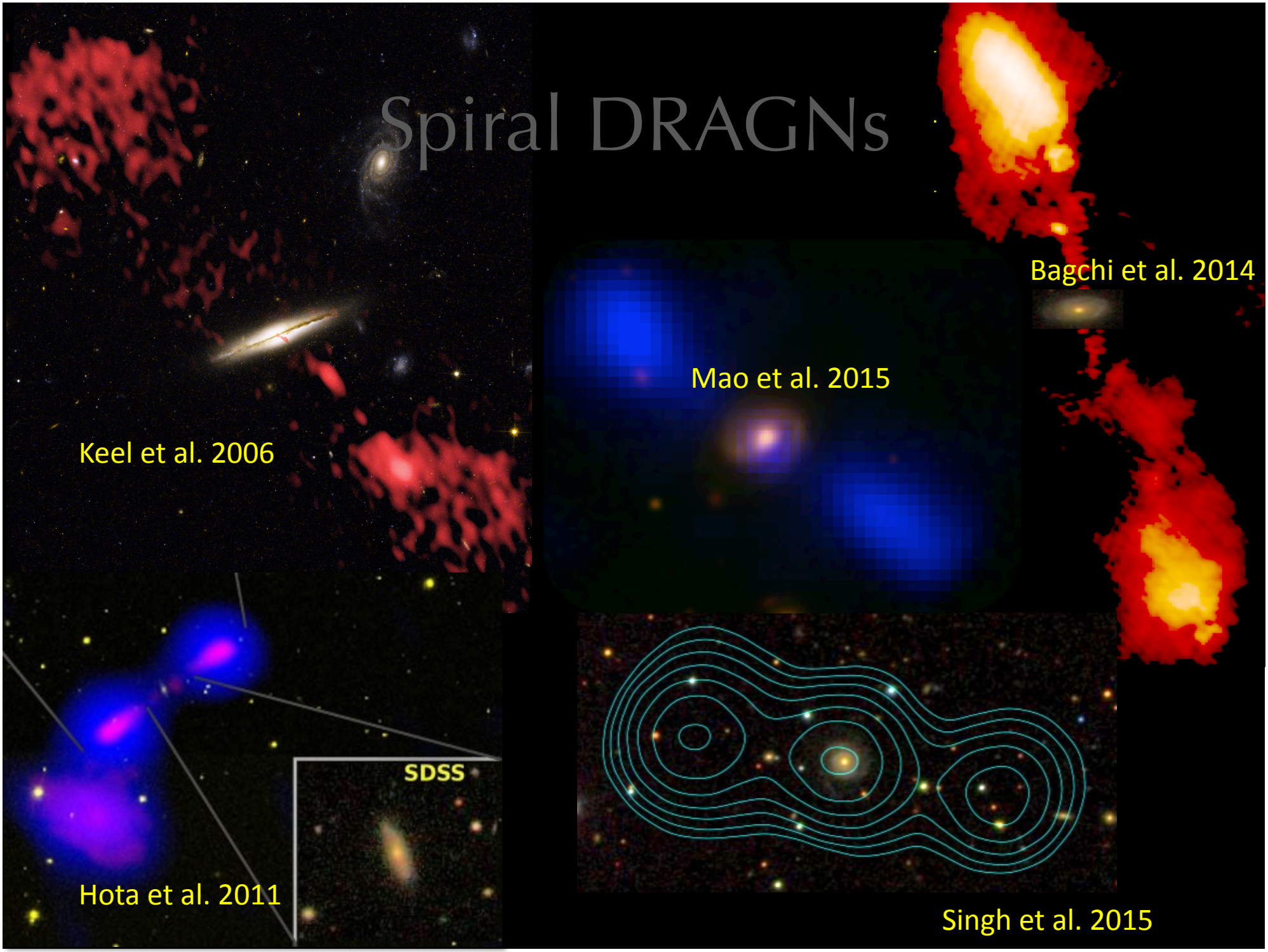
Motivation

Powerful double-lobed radio sources are almost always associated with elliptical galaxies (e.g. Matthews 1964)

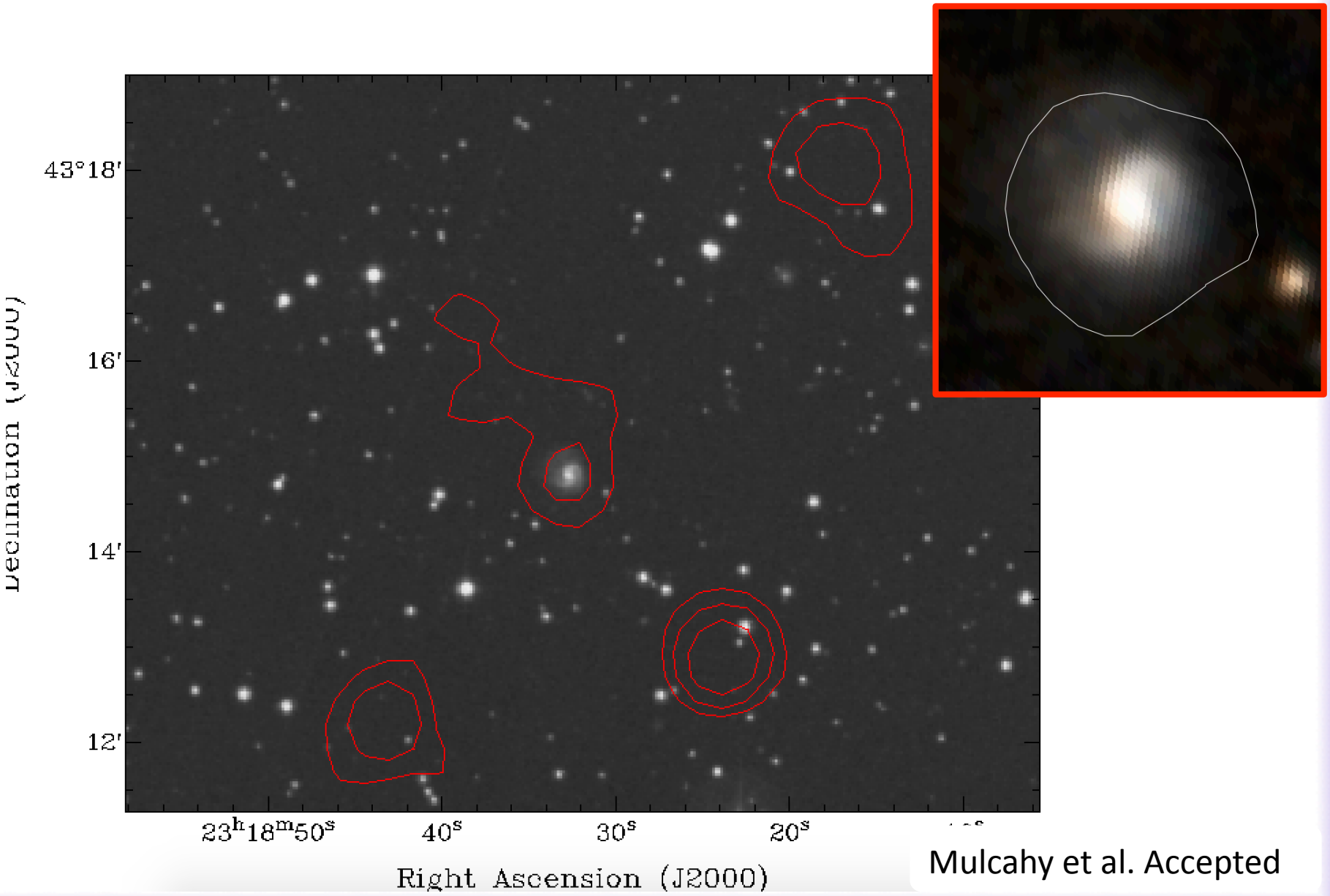




Spiral DRAGNs



New Spiral DRAGN

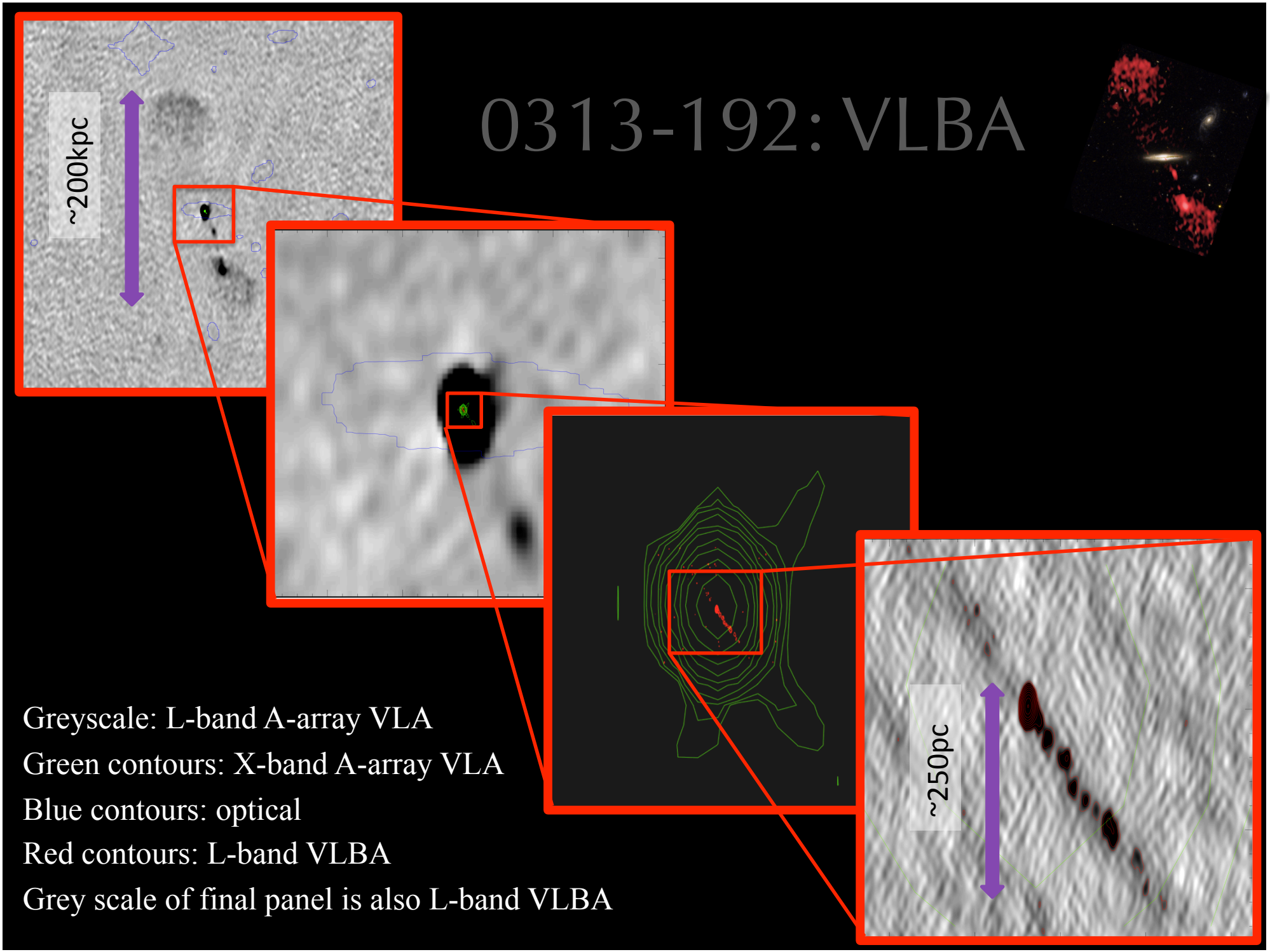


Mulcahy et al. Accepted

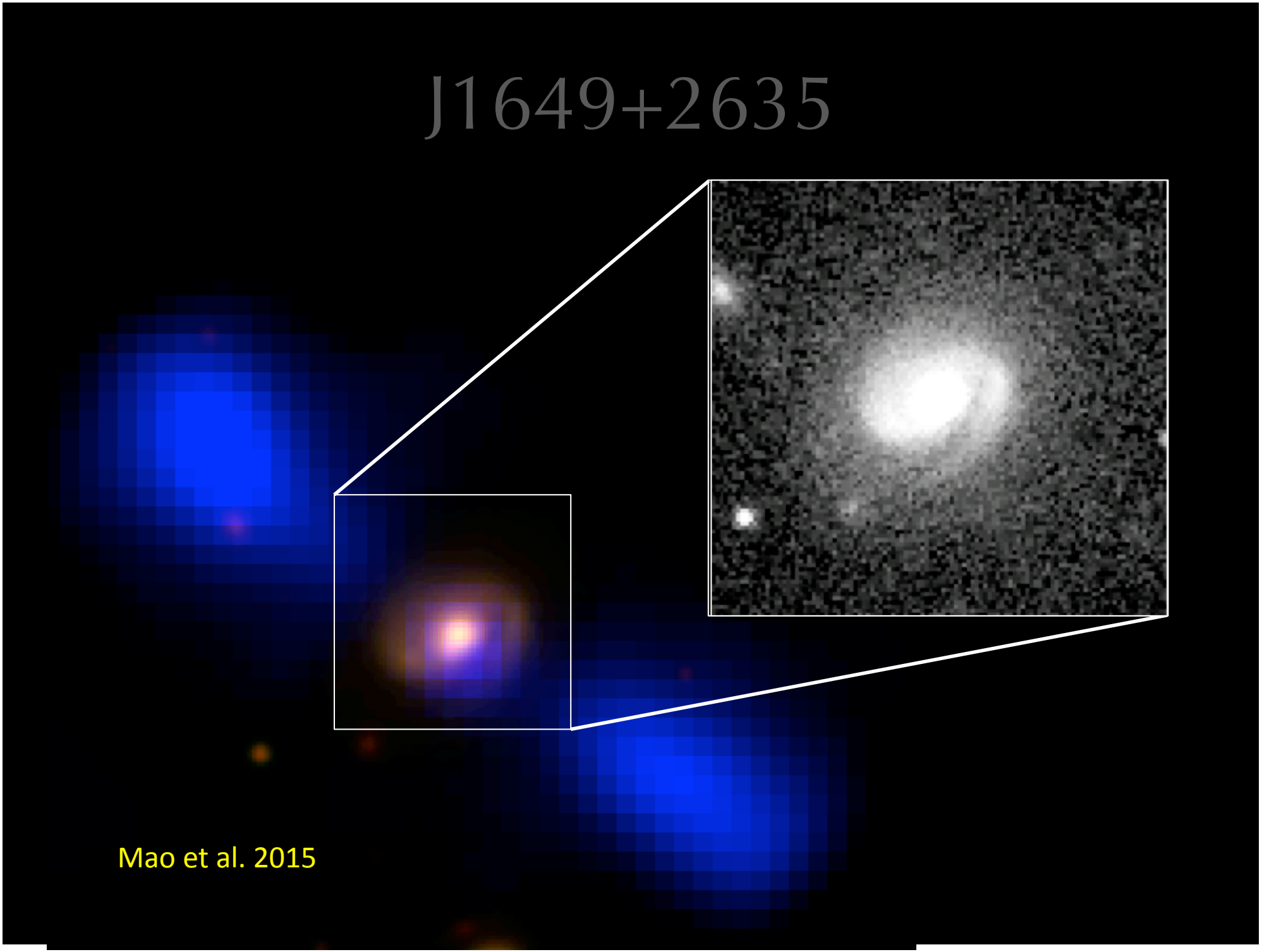
Star-formation and AGN

Heart of the DRAGN

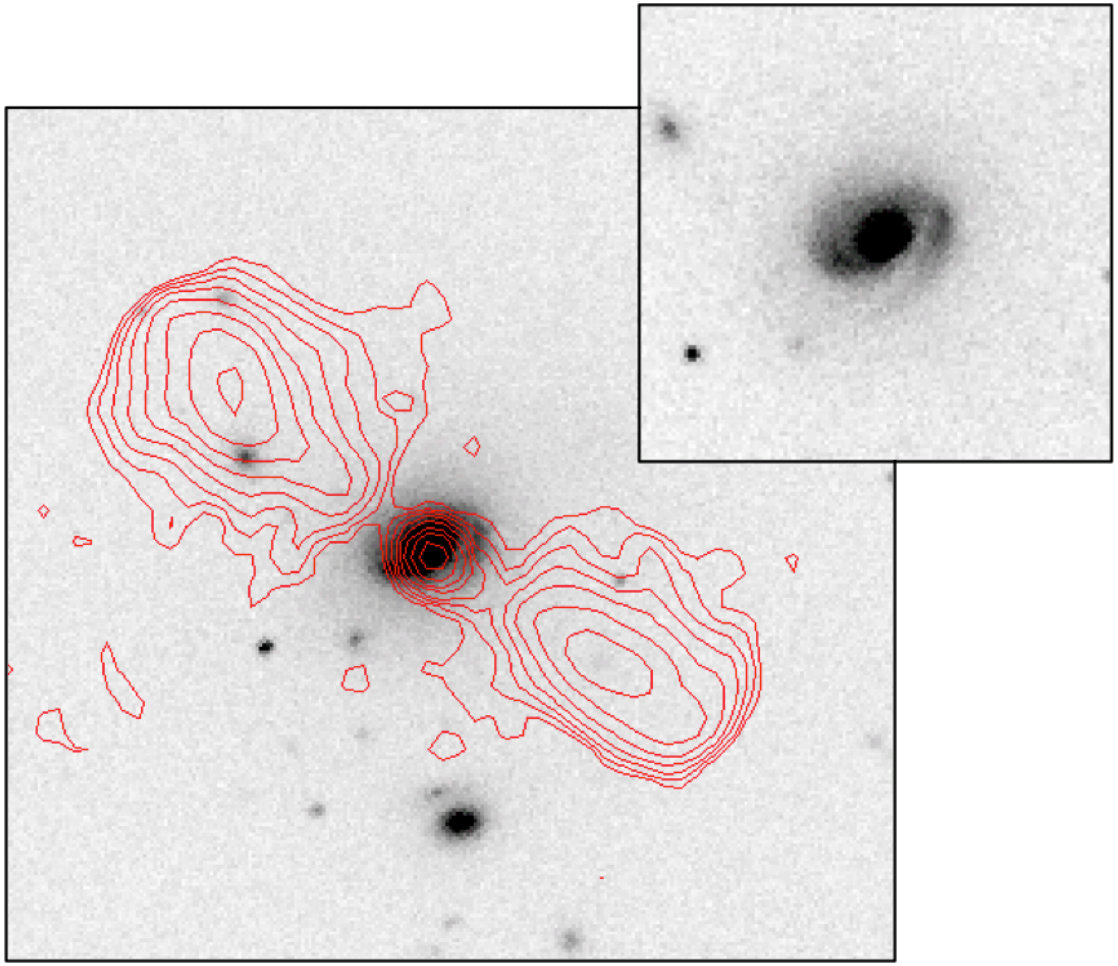
- VLBI can be used for very high angular resolution observations
  - Long Baseline Array (LBA)
  - Very Long Baseline Array (VLBA)
  - European VLBI Network (EVN)
- Rule out chance-alignment…
- Spiral galaxies tend to have more gas than Elliptical galaxies → Jet interaction with ISM?

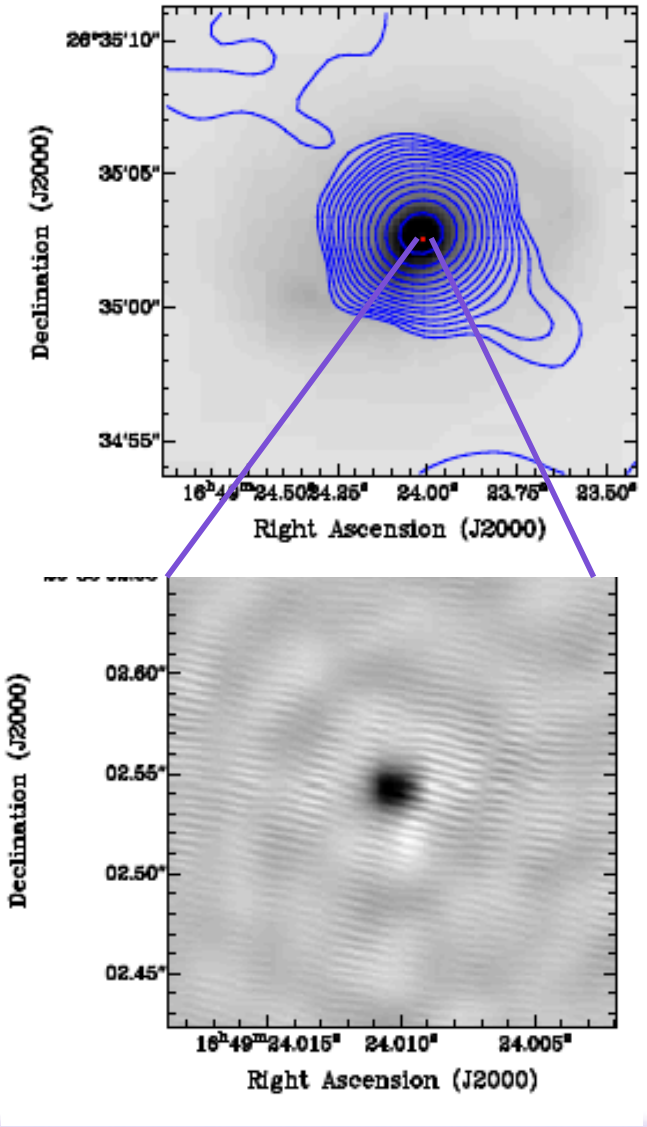

0313-192: VLBA
~200kpc
~250pc
Greyscale: L-band A-array VLA
Green contours: X-band A-array VLA
Blue contours: optical
Red contours: L-band VLBA
Grey scale of final panel is also L-band VLBA

J1649+2635: eEVN and EVN


J1649+2635
Mao et al. 2015

J1649+2635: eEVN (L-band)

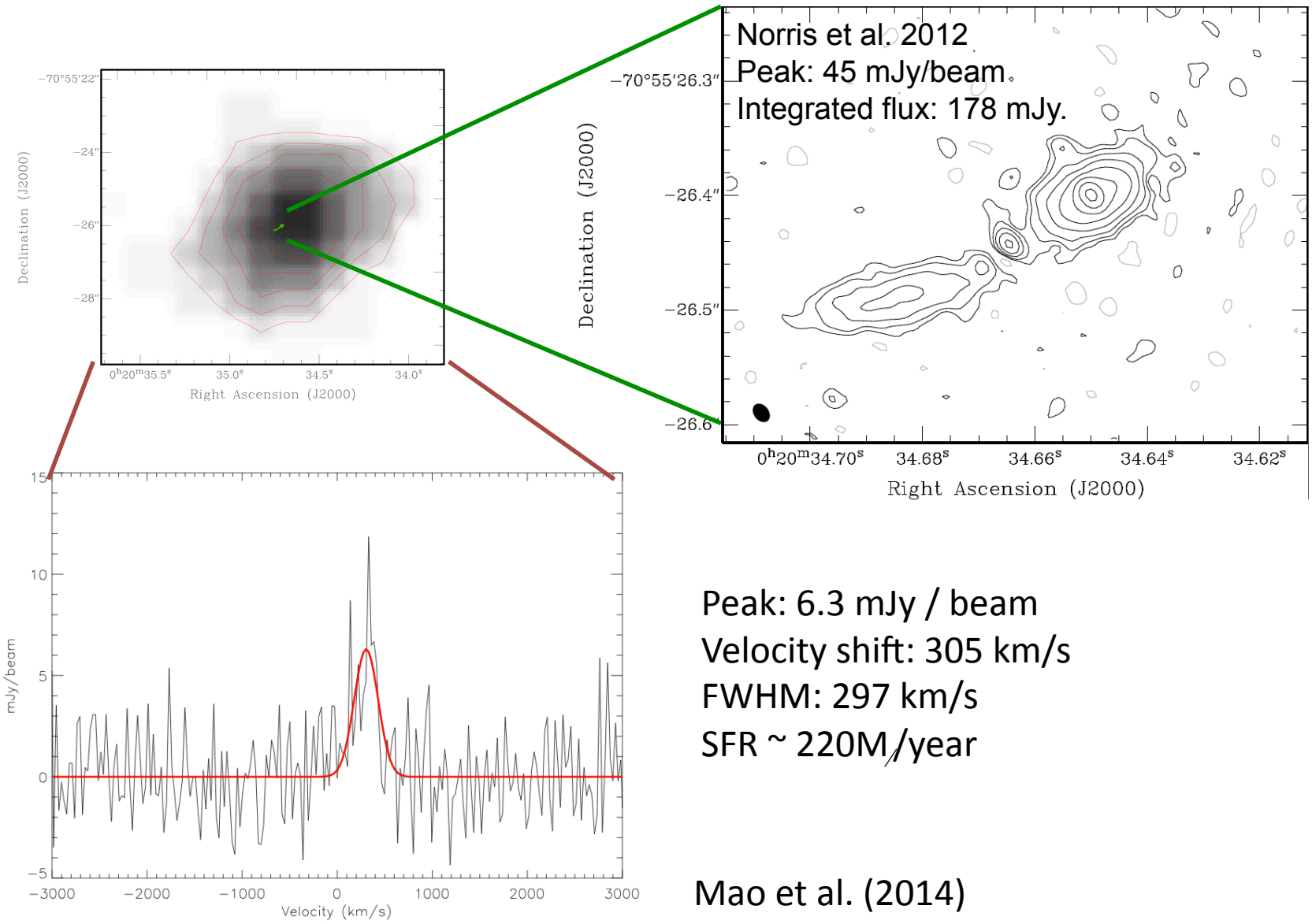




IRAS F00183-7111: a ULIRG

- Ultra Luminous InfraRed Galaxy → $L_{IR} > 10^{12} L_{\odot}$
- IRAS F00183-7111 (F00183) is one of the most luminous sources discovered by IRAS!
- z = 0.3276 (Roy & Norris 1997)
- $S_{70\mu m}$ = 1.5 Jy
- $L_{8\text{-}1000\mu m} = 9 \times 10^{12} L_{\odot}$ (Spoon et al. 2009)
- $L_{4.8GHz} = 3 \times 10^{25}$ W/Hz (Roy & Norris 1997)
- Radio-loud ULIRG!

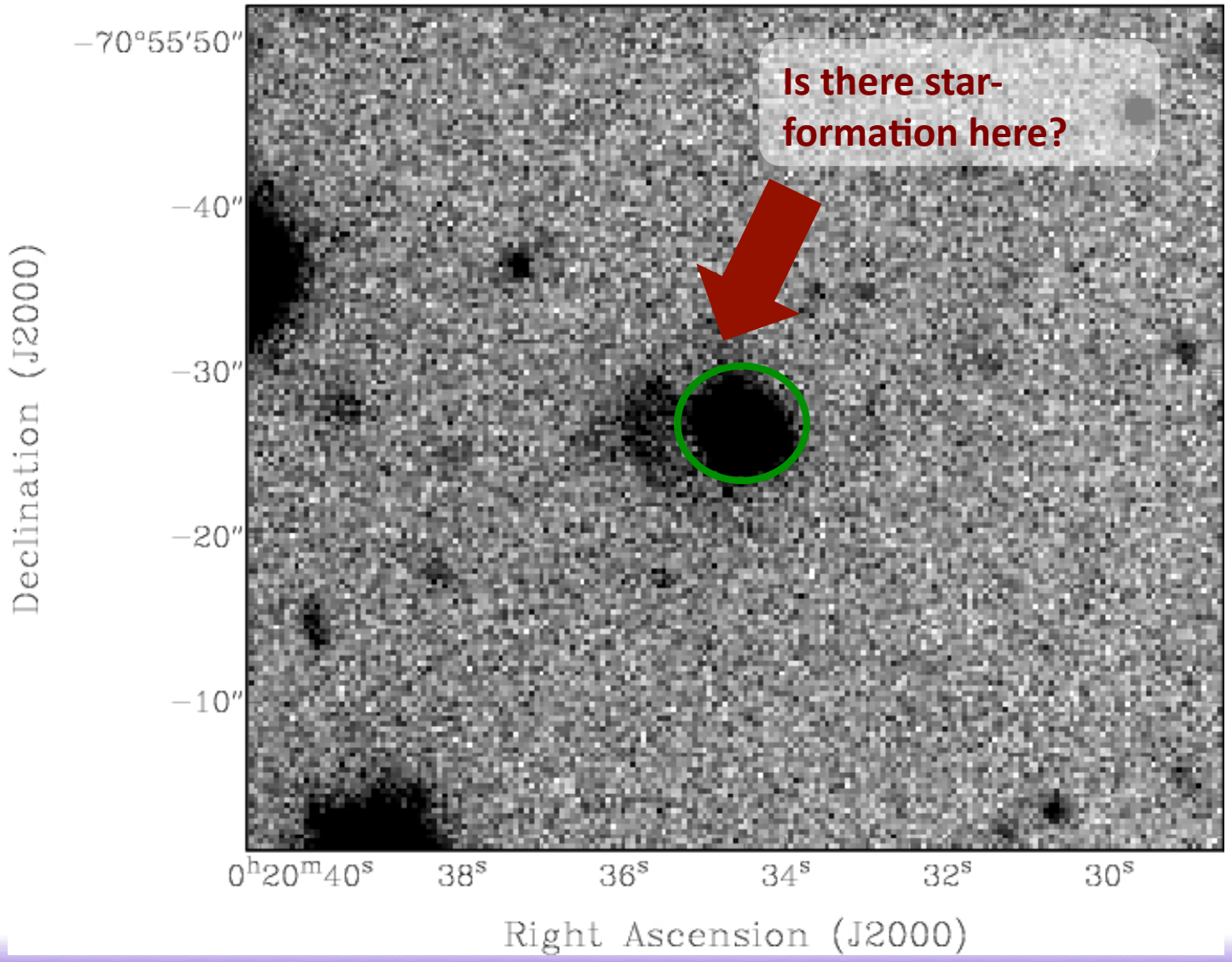
IRAS F00183-7111: a ULIRG



Peak: 6.3 mJy / beam
Velocity shift: 305 km/s
FWHM: 297 km/s
SFR ~ 220M⊙/year

Mao et al. (2014)

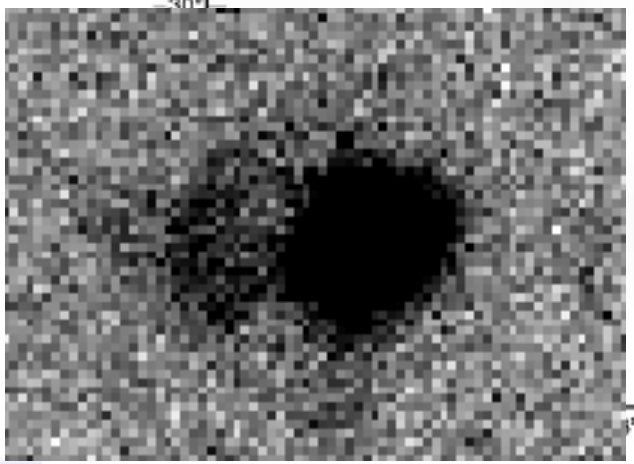
Can we detect star-formation using radio?



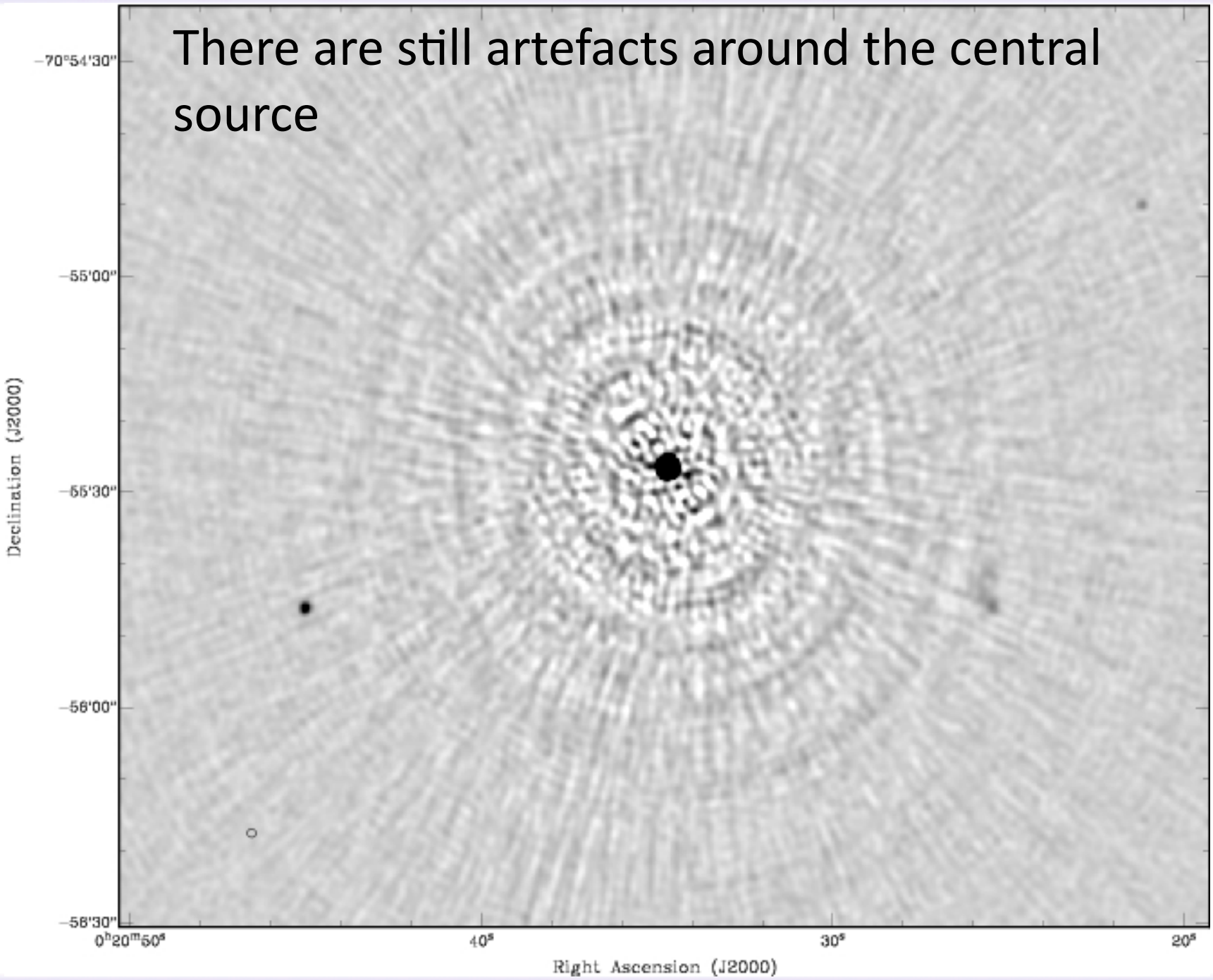
Radio Continuum from Star-Formation

- If we assume ~30% of the IR luminosity is due to star-formation, then using the FIR/ radio correlation we can guesstimate the amount of star-formation we would expect to see in the radio
- $S_{70\mu m}$ = 1.5 Jy → ~0.5Jy from star-formation
- Using q70 = 2.15 (Appleton et al. 2004), we would then expect to detect 3.5mJy at 1.4GHz
- α = -0.97 between 1.4 and 8.6GHz (Drake et al. 2004)
- Expect to detect ~200uJy at 9GHz due to star-formation

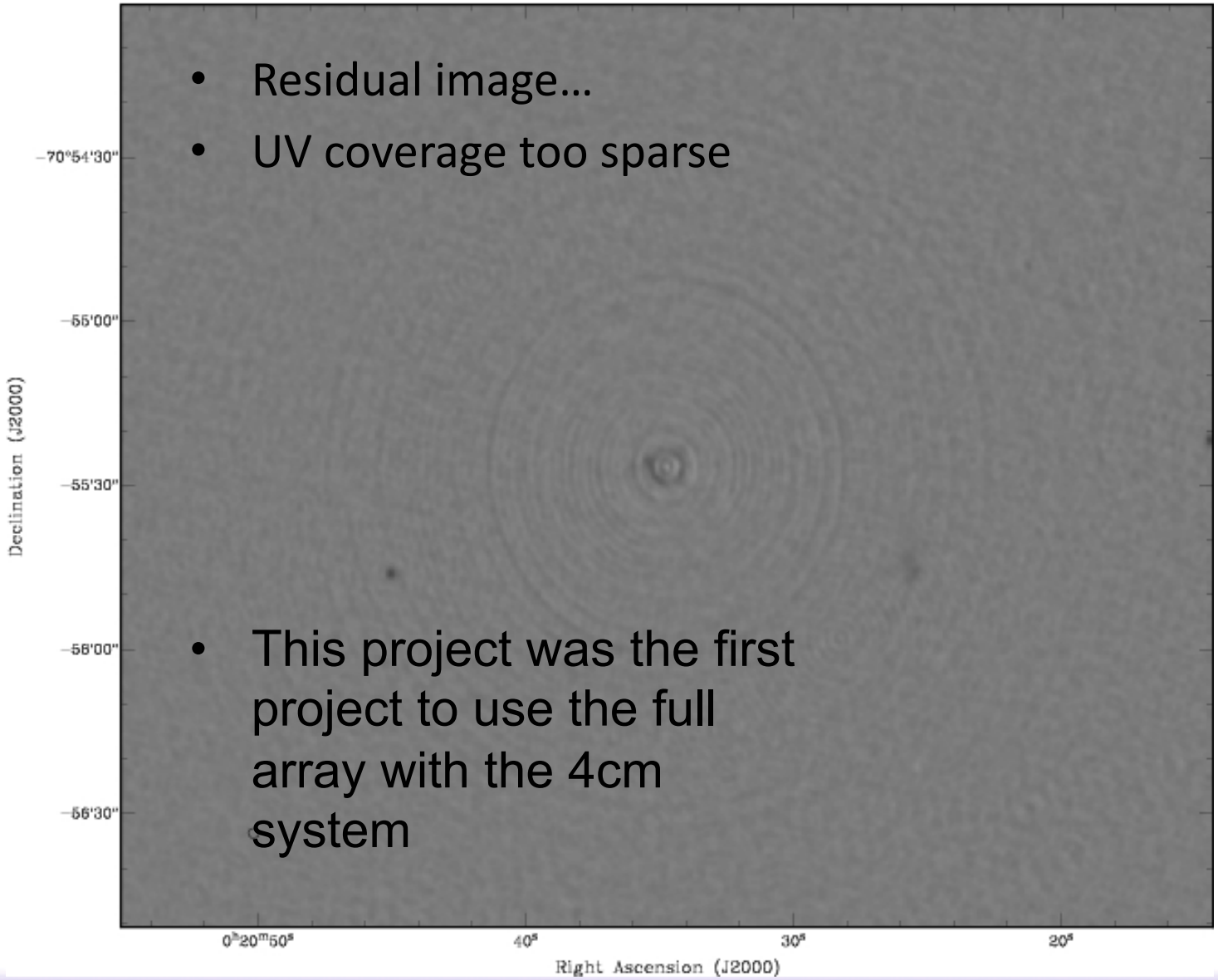
6GHz overlaid with 9.5GHz and optical contours



There are still artefacts around the central source



Dynamic Range Limited



- Residual image…
- UV coverage too sparse

- This project was the first project to use the full array with the 4cm system

The addition of eMERLIN and SKA

- eMERLIN will enable us to detect and resolve nuclear star-formation in spiral DRAGNs (and ULIRGs)
- VLBI observations with VLBA and EVN can pull out the most compact components of the source, but cannot detect slightly extended jet structure or compact SF regions
- SKA-Mid1 will have comparable max. baselines to e-MERLIN with much more complete uv-coverage
- This will enable AGN and SF components to be detected in spiral DRAGNs → powerful radio sources embedded in star-forming galaxies