EVOLUTION AND LIFE CYCLES OF RADIO AGN

A LOFAR PERSPECTIVE

Beatriz Mingo
With thanks to many members of the LOFAR surveys KSP

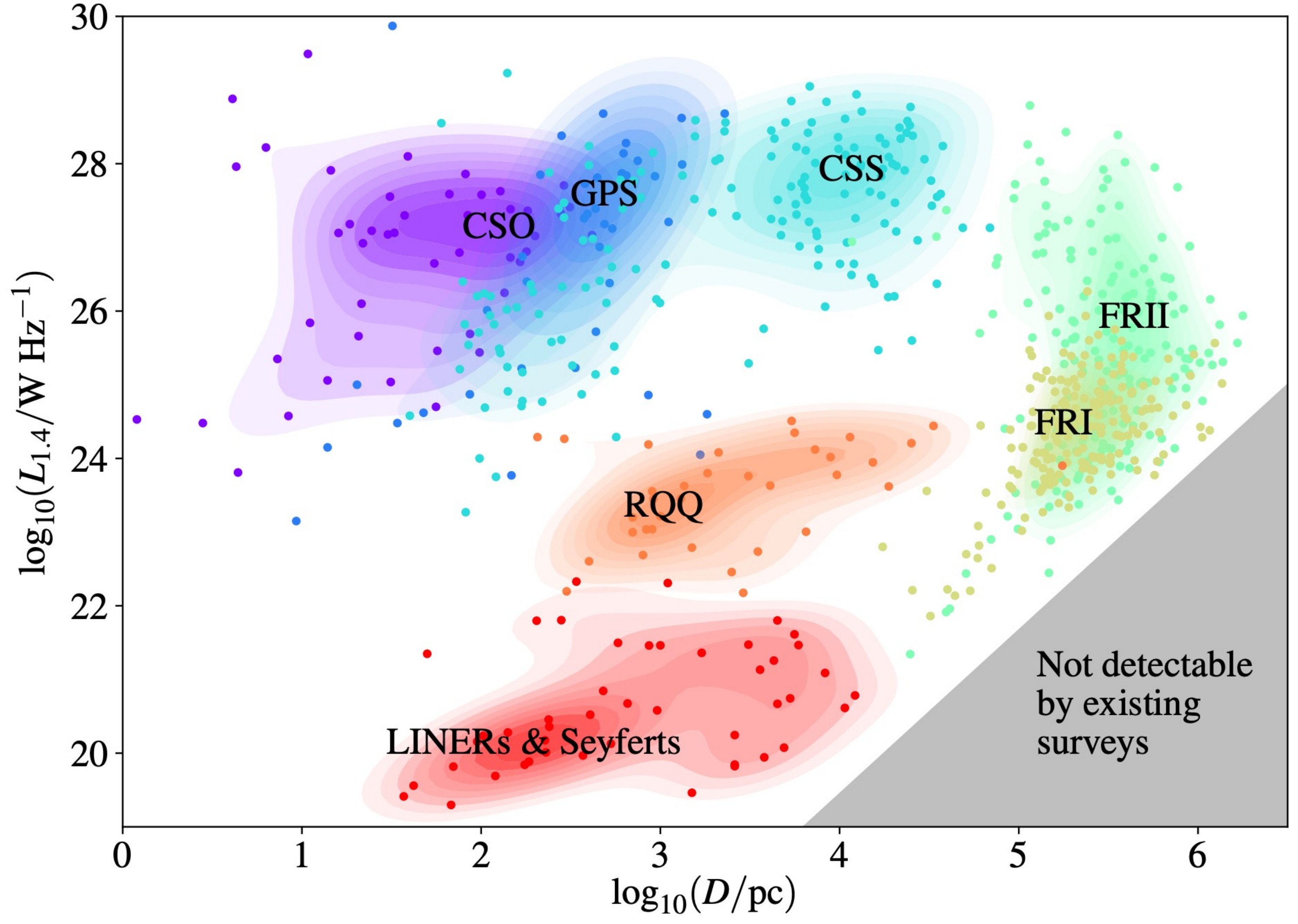
OUTLINE

- Radio AGN: how things fit together
- LOFAR
- LoTSS AGN
- Remnants
- Restarters
- Galaxy-scale sources (GSJ)
- Activity timescales (it's complicated!)
- Summary

See also An & Baan 2012

RADIO AGN FAMILY PICTURE

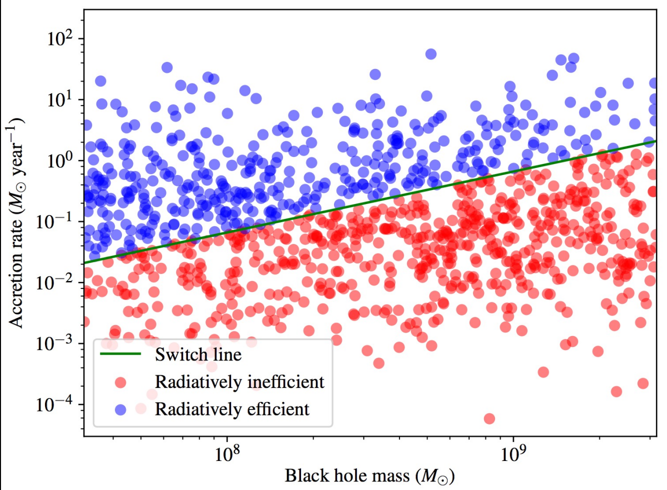
- How do these populations fit together?
  - What conditions give rise to each class?
  - Which classes can evolve into each other?
  - What are their life cycles?
  - What impact do they have on their environments?

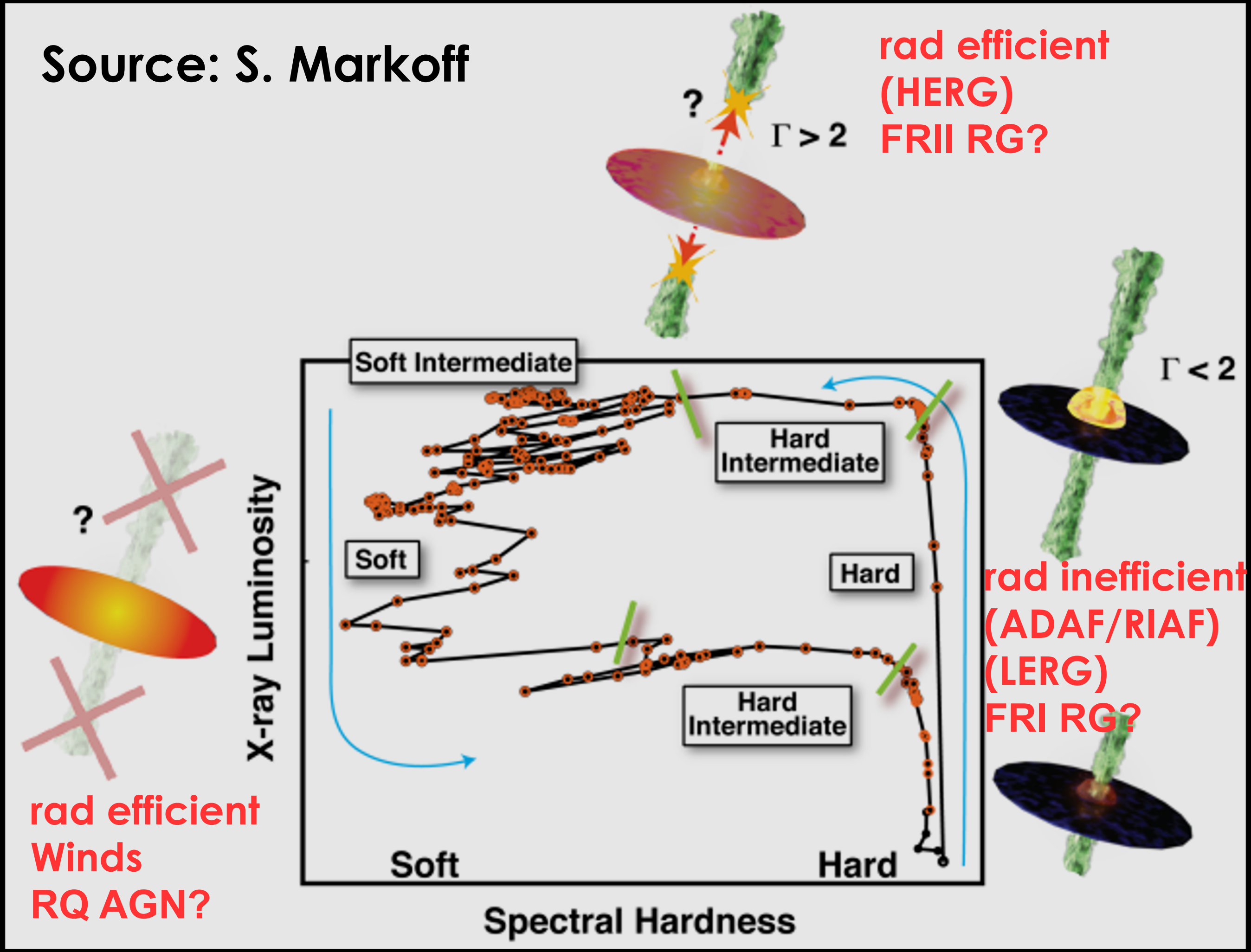


Hardcastle & Croston 2020

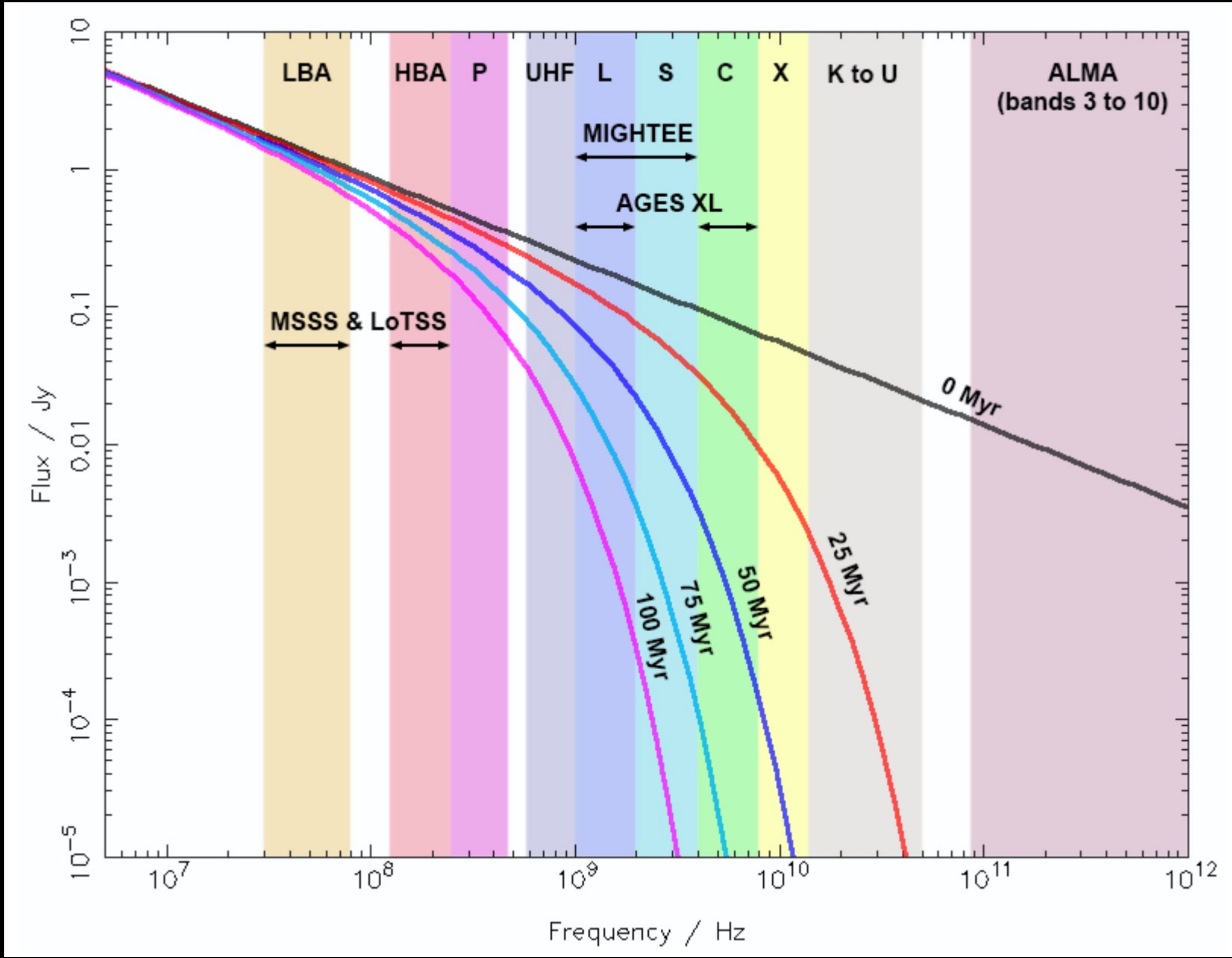
MORPHOLOGY VS ACCRETION: THE XRB LINK

- AGN and XRB:
  - Different sizes, timescales, fueling
- Likelihood of finding **AGN** in a given part of the diagram depends on:
  - Host stellar mass (Sabater+ 2019)
  - Environment (Ineson+ 2015, Hardcastle+Croston+ 2020)
  - Accretion rate (Hardcastle+ 2018)





100 MHZ GHz regime

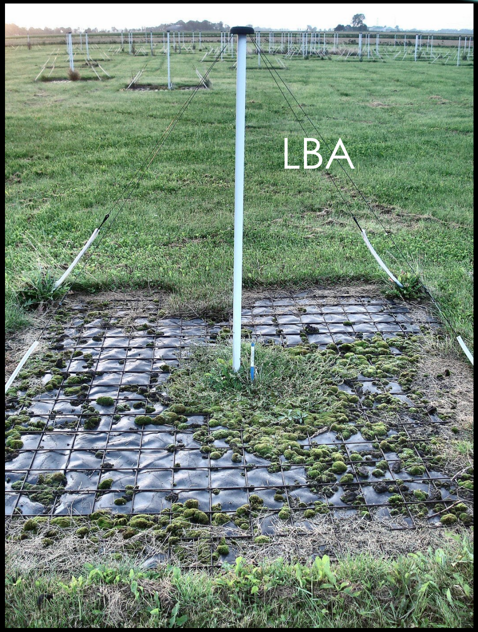


Why low radio frequencies are important

Tell your "radio-quiet" friends:
just because your AGN has no radio jet **now** it doesn't mean it didn't **before** or won't **later**!

LOFAR


Onsala
Birr
Irbene
Dutch stations
Chilbolton
Norderstedt
Bałdy
Potsdam
Borówiec
Jülich
Effelsberg
Tautenburg
Łazy
Nançay
Unterweilenbach
Medicina


LBA

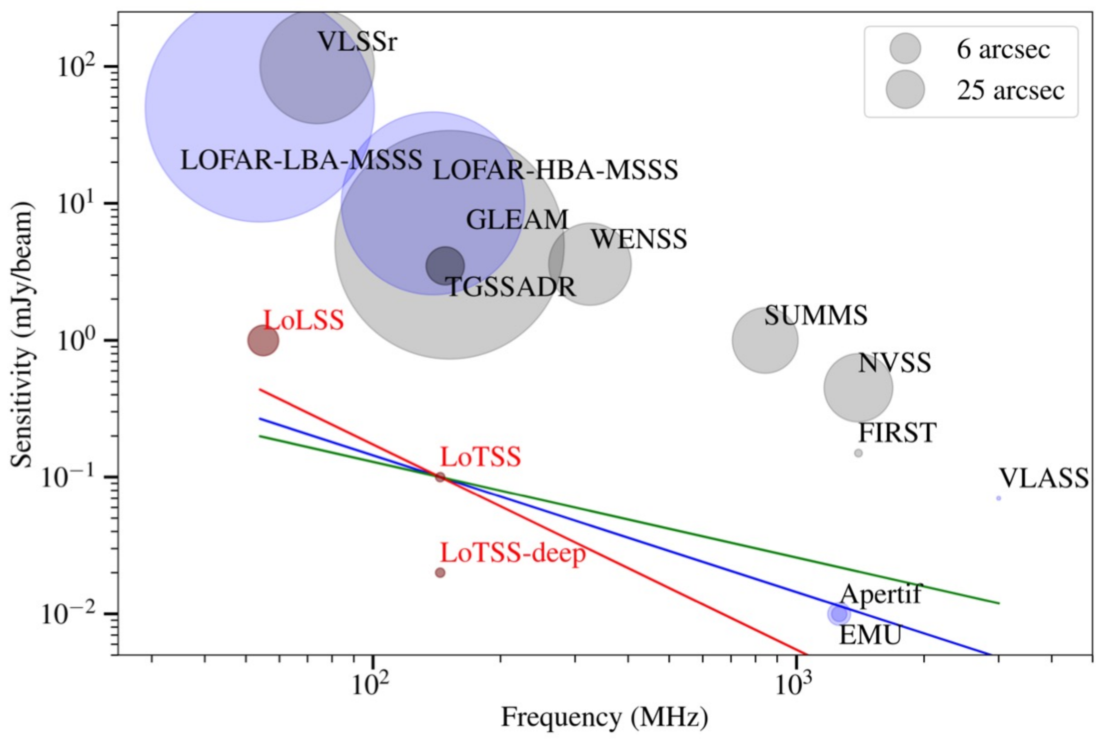

HBA

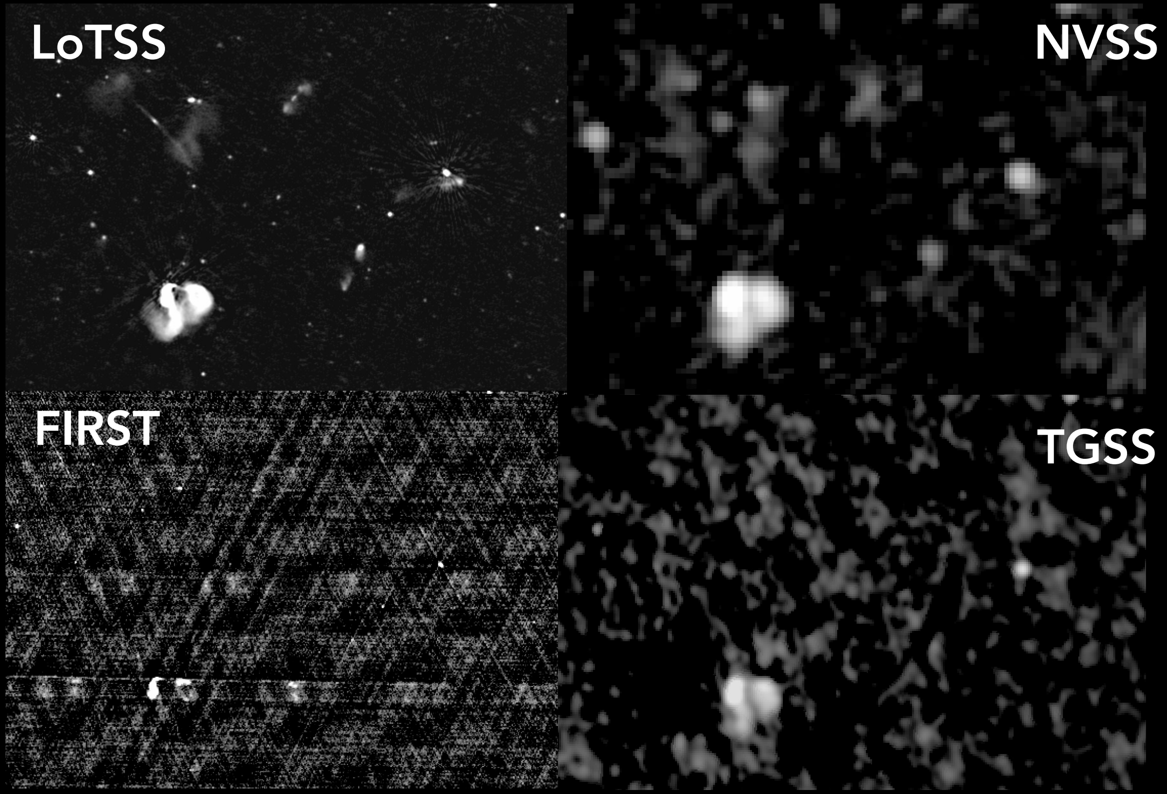
LoTSS = LOFAR Two-metre Sky Survey
www.lofar-surveys.org

LoTSS

DR1 → 320k sources, 424 Sq deg., 70% have redshifts!
Noise limit: 100 μJy/beam

Shimwell+ 2019
Williams+ 2019
Duncan+ 2019

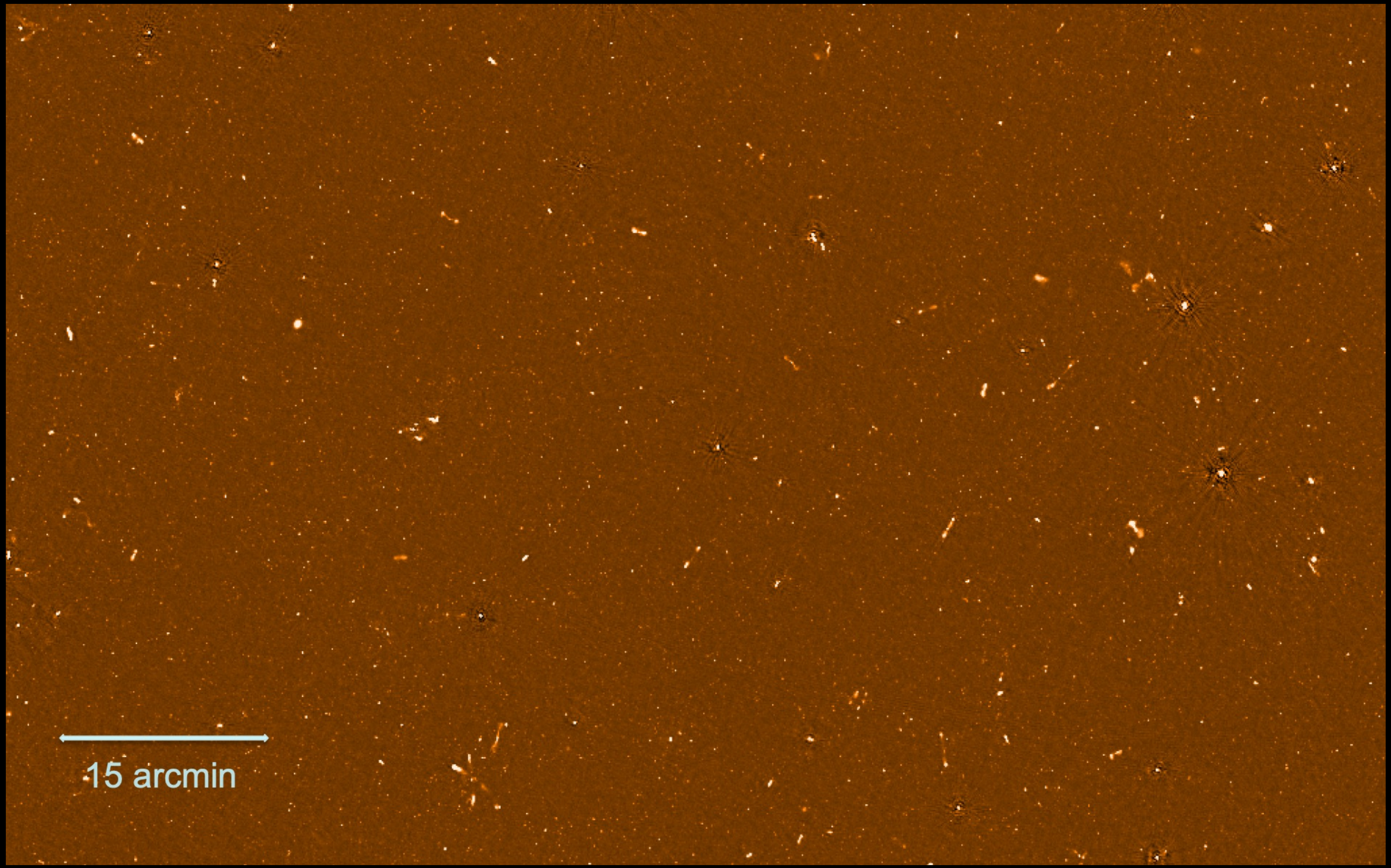




1 deg^2

THE LOFAR DEEP FIELDS

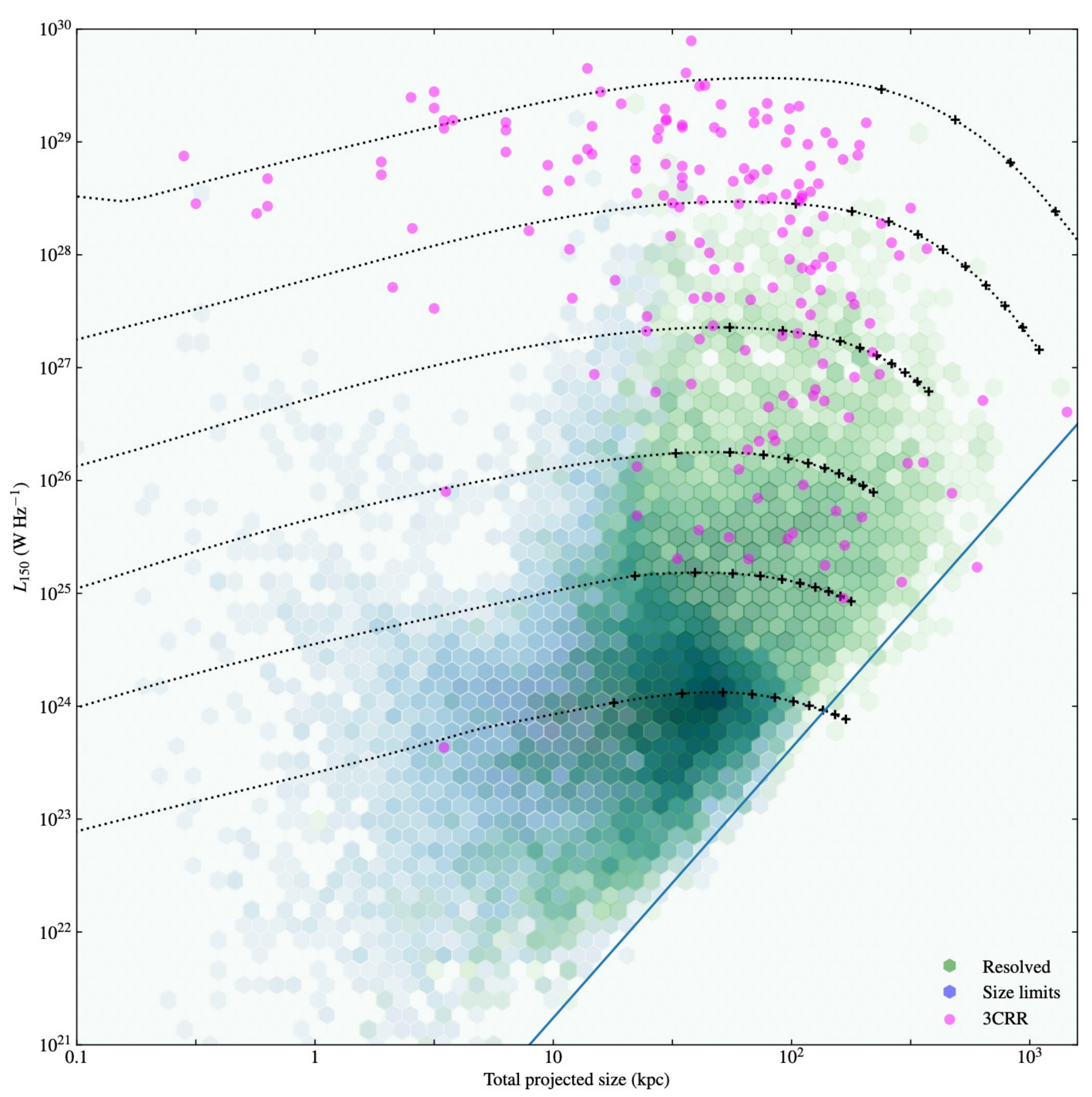
- Elais-N1, Lockman Hole, Bootes
  - **~25 sq. deg.**, 20-40 μJy/beam
  - Deepest: 5000 sources/sq. deg. (x7 more than LoTSS)
- Great multi-λ coverage
  - Optical (ugrizy bands)
  - NIR (J, K, 3.6 μm, 4.5 μm)
  - MIR (5.8 μm, 8 μm, 24 μm)
  - FIR (Herschel)
- Tasse+ 2021
- Sabater+ 2021
- Kondapally+2021
- Duncan+2021

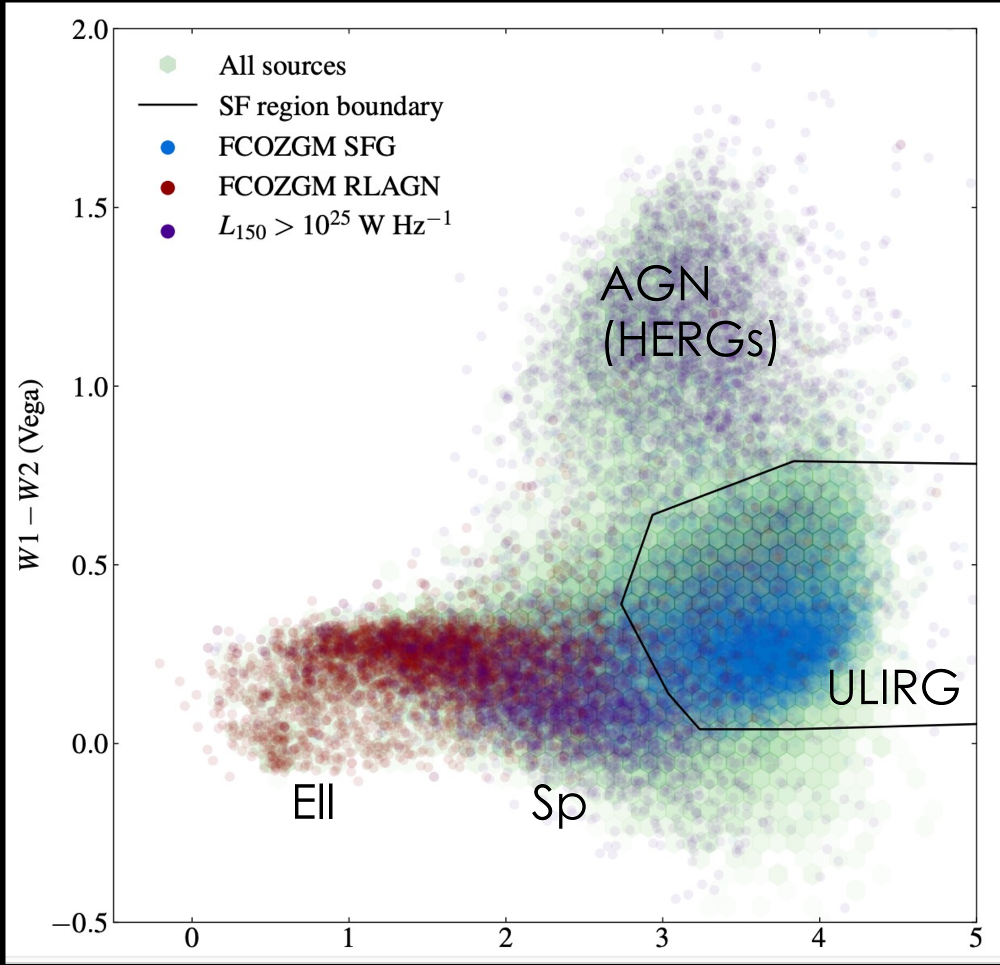


Elais N-1. Credit: P. Best

LoTSS AGN

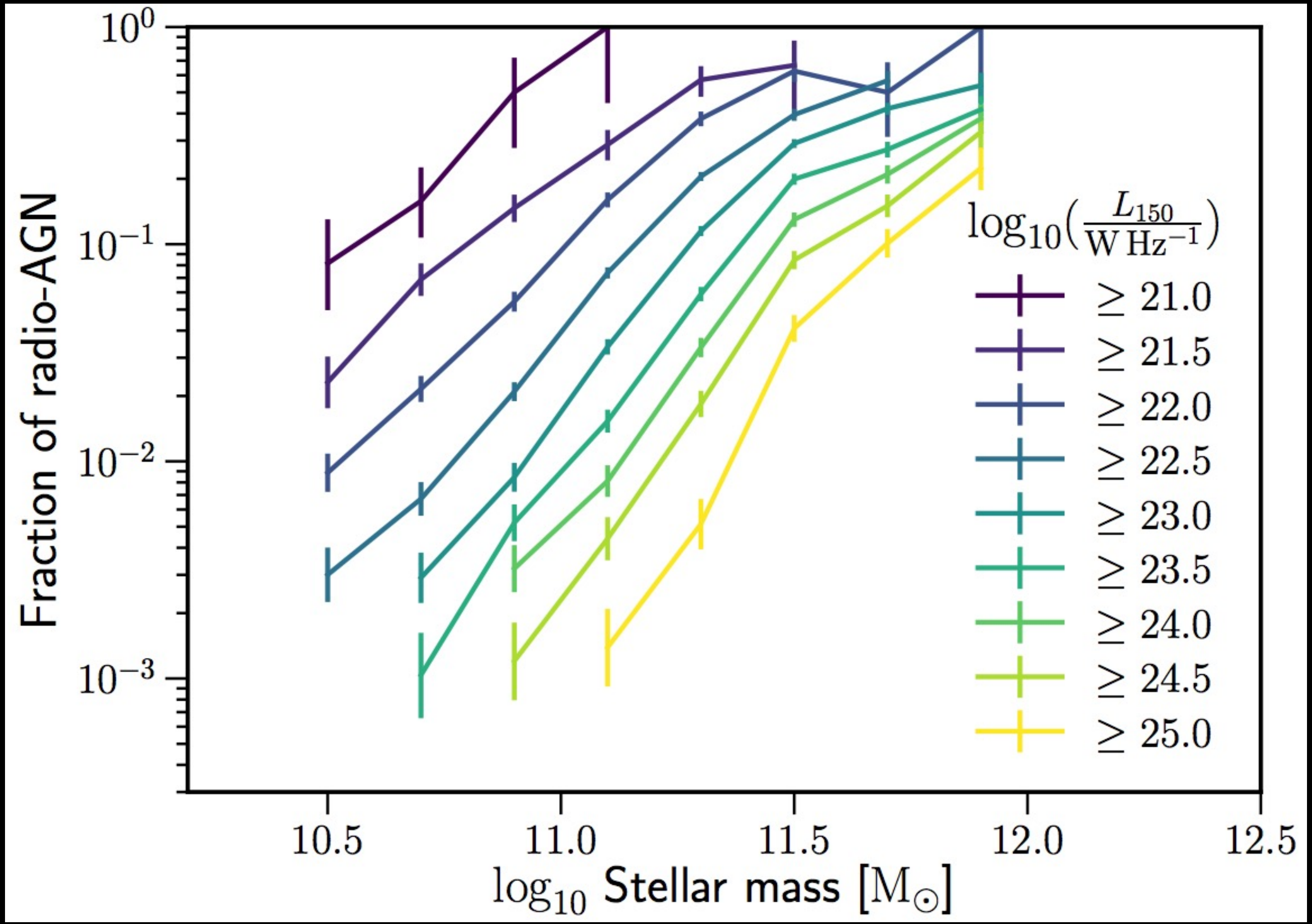
Hardcastle+ 2019

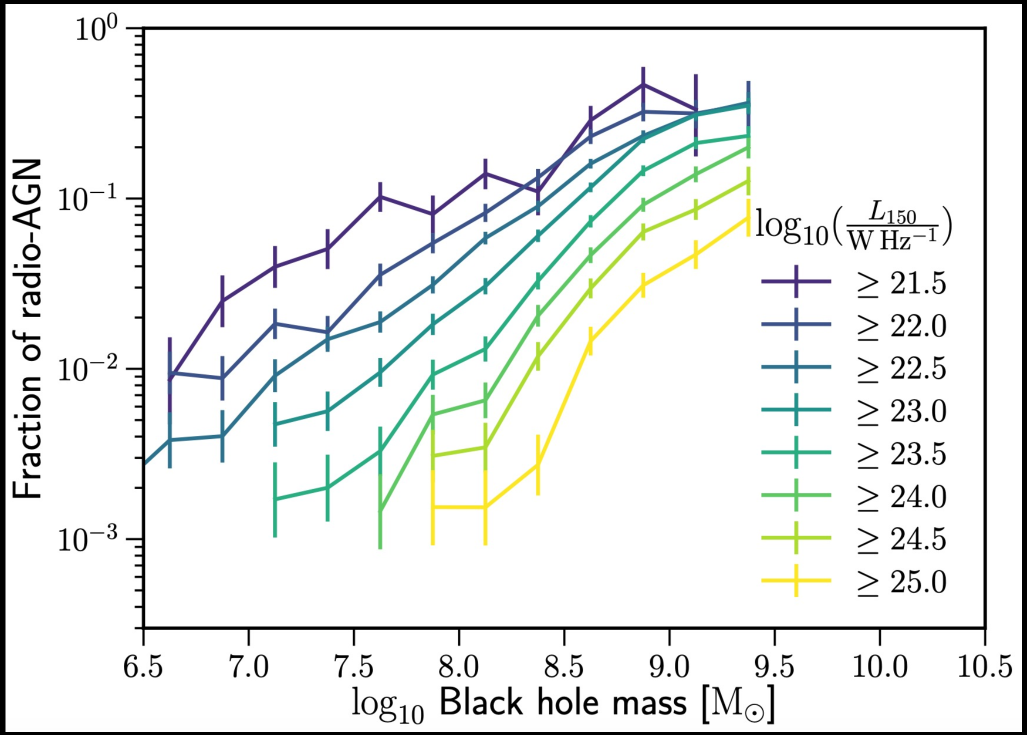




HOST MASS

Sabater+ 2019





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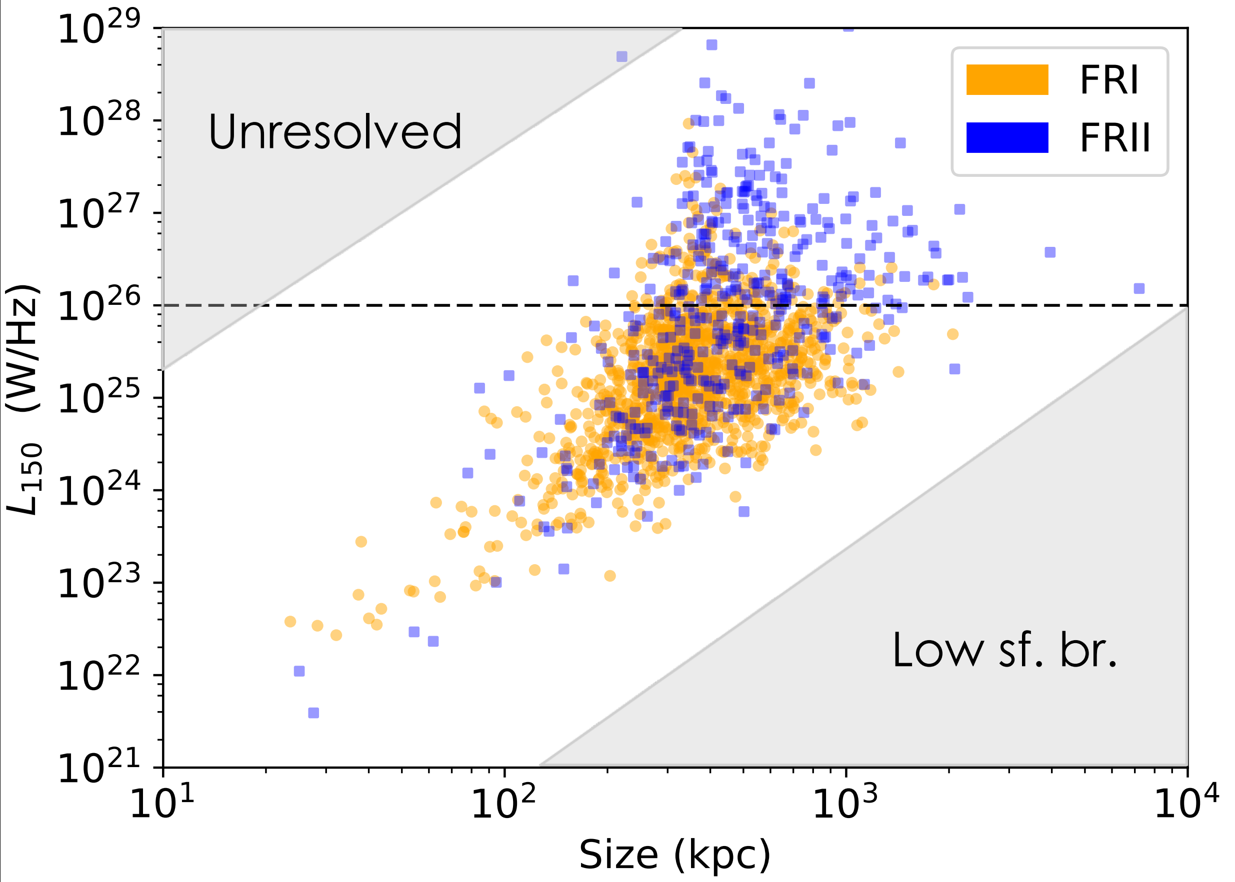
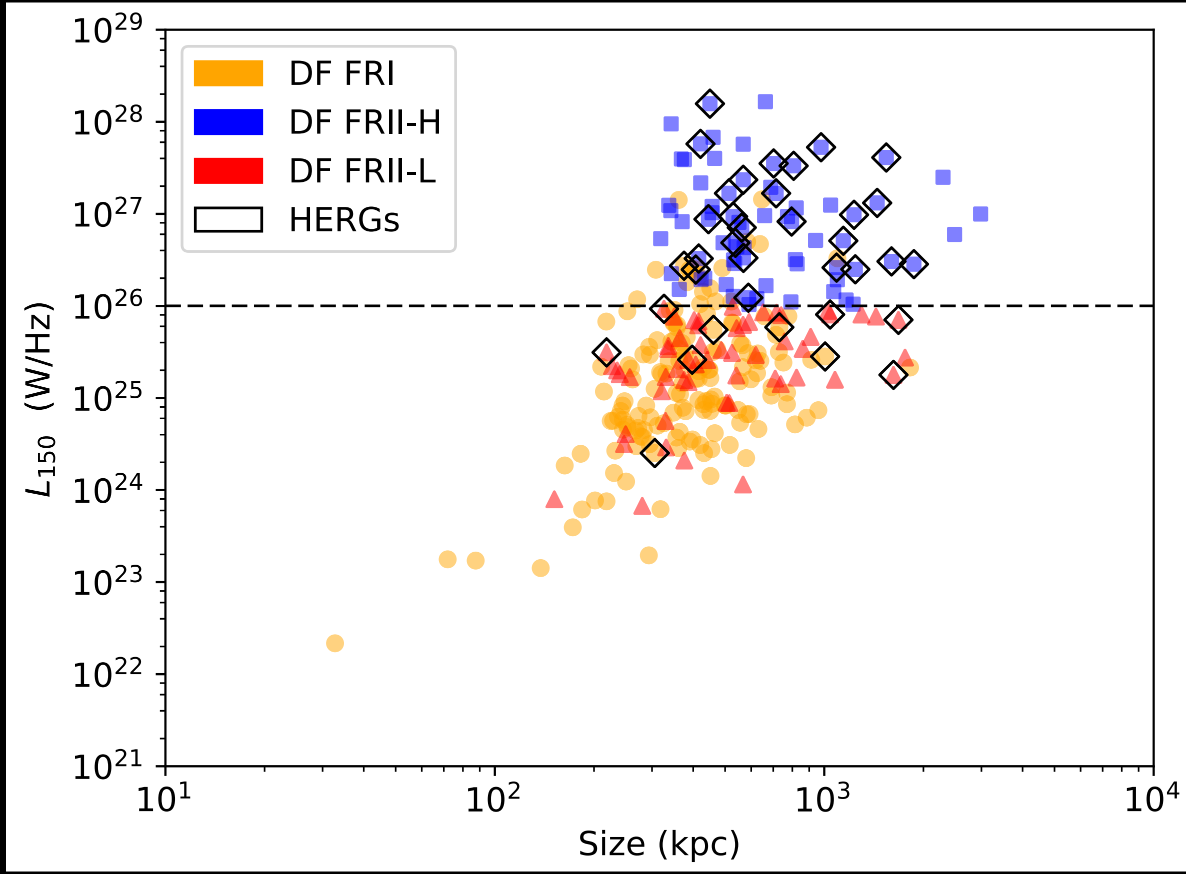
LOW-LUMINOSITY FRII

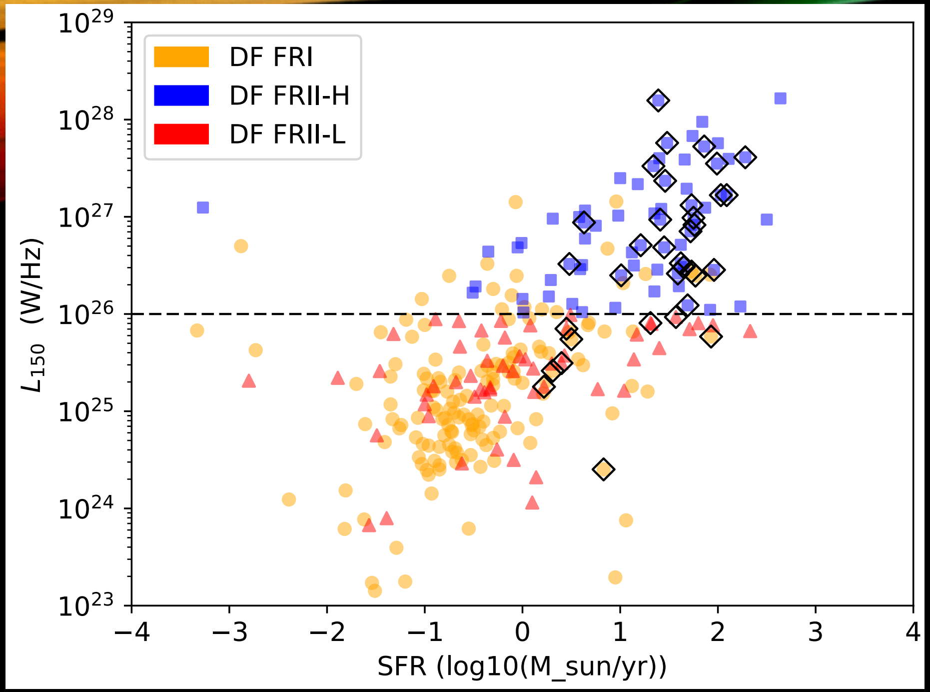
Mingo+ 2019

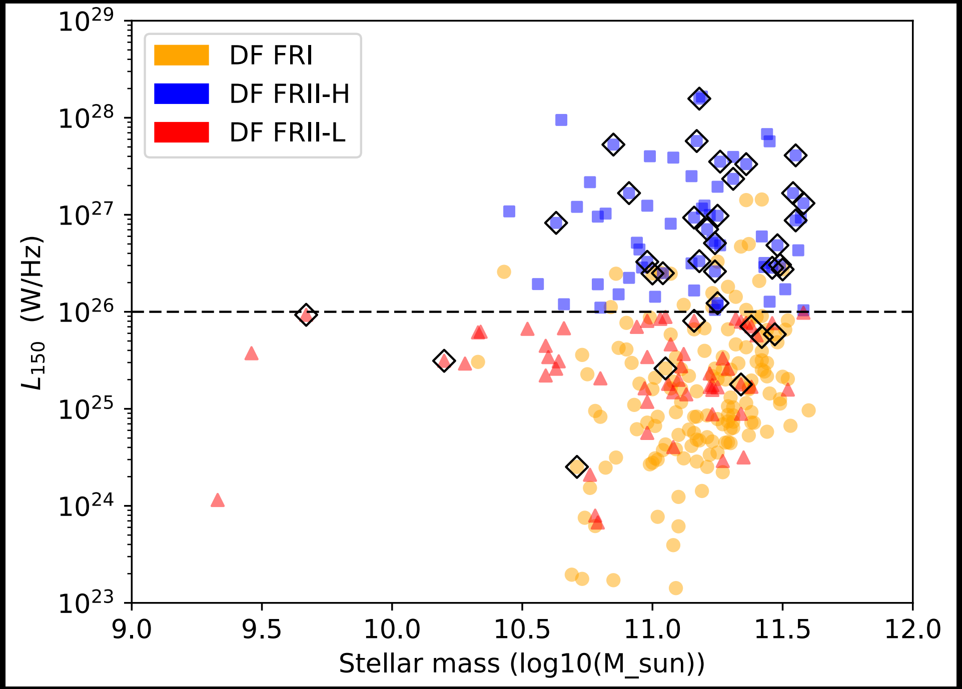


Mingo+ in prep.

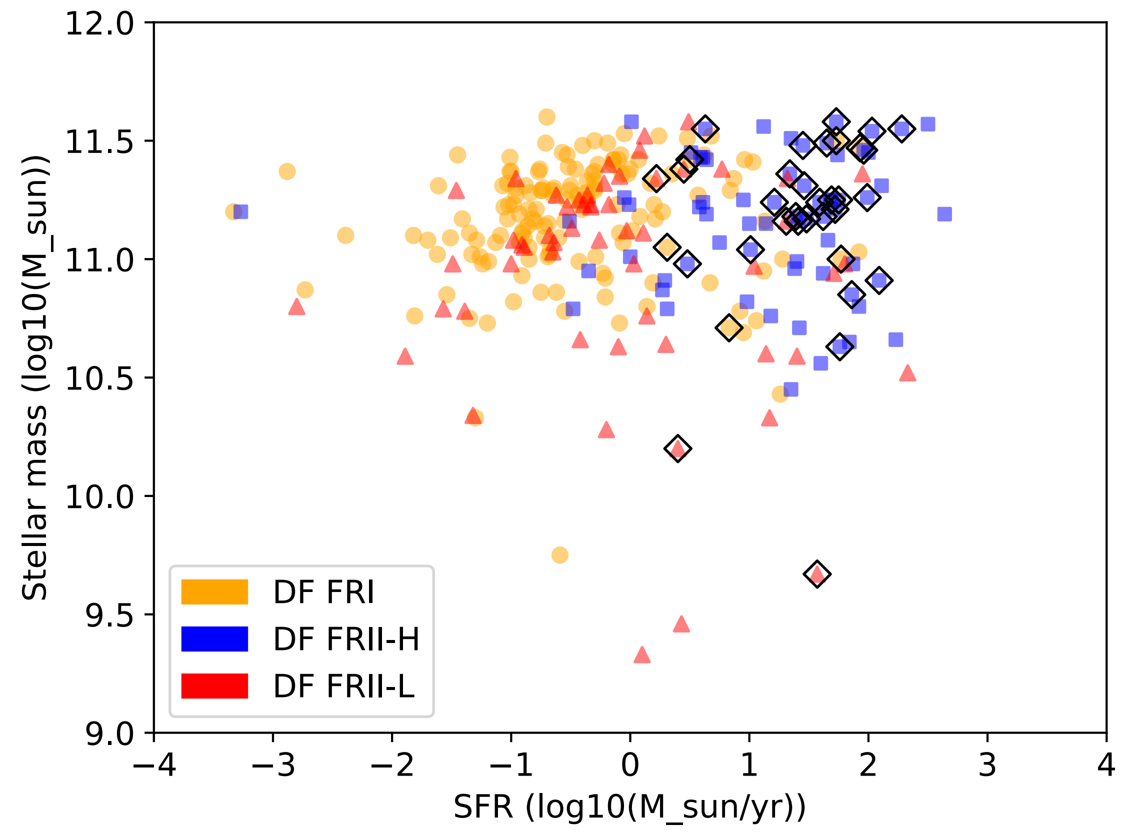


STELLAR MASS, SFR





Mingo+, in prep.

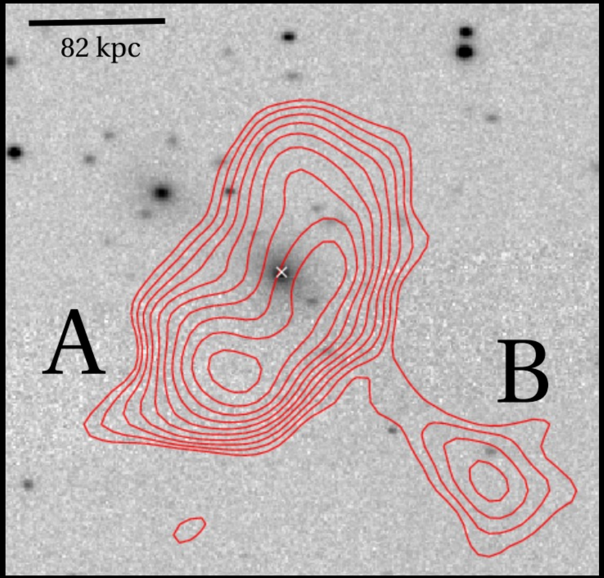


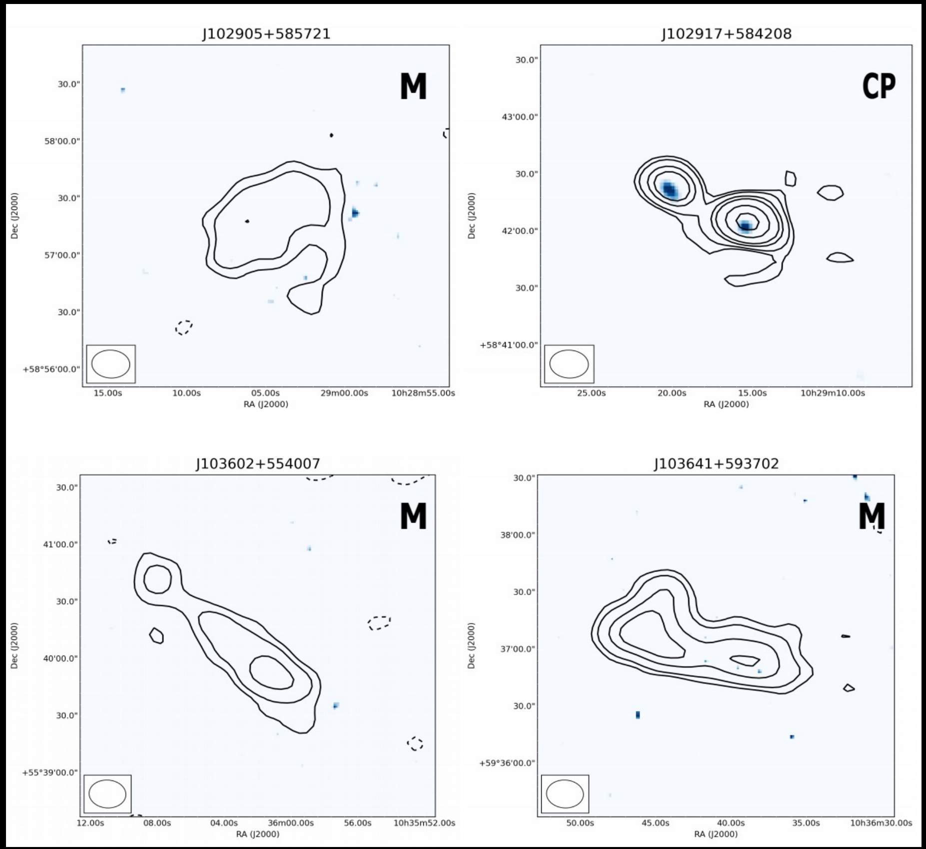
REMNANTS

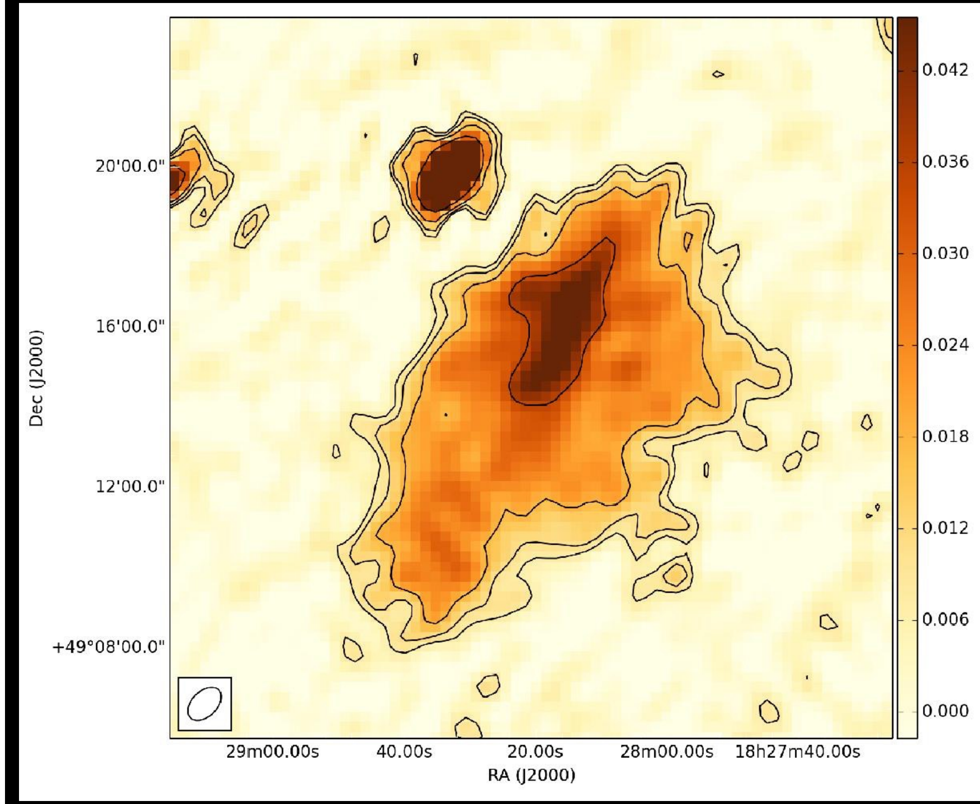
Ages: 100-400 My

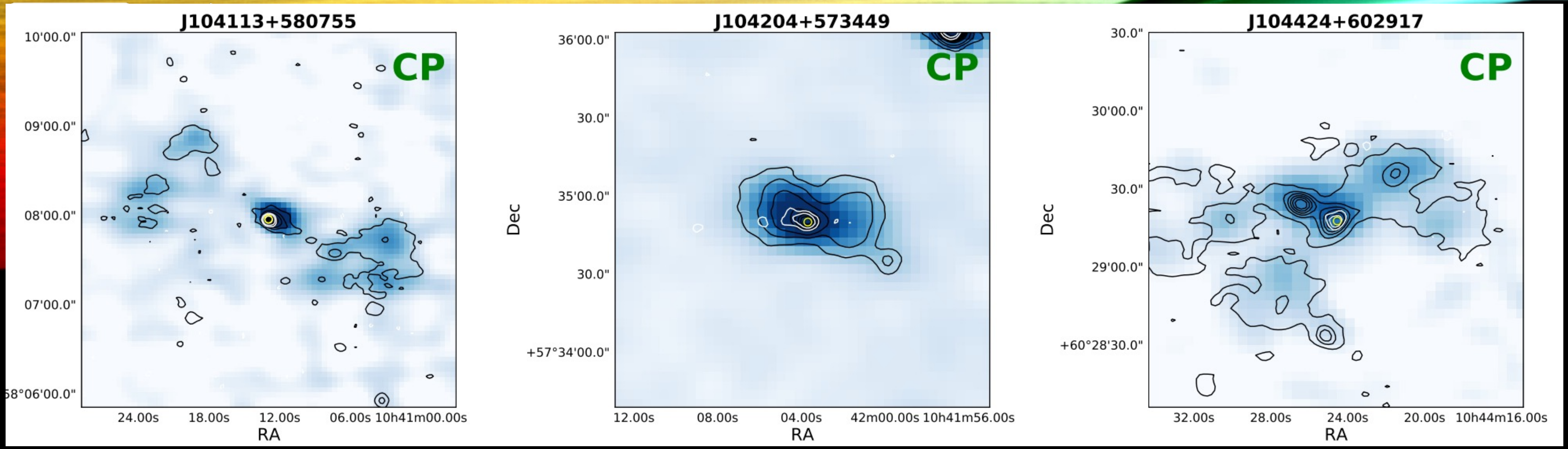
Brienza+ 2016, 2017, 2018; Morganti+ 2021

Shulevski+ 2015



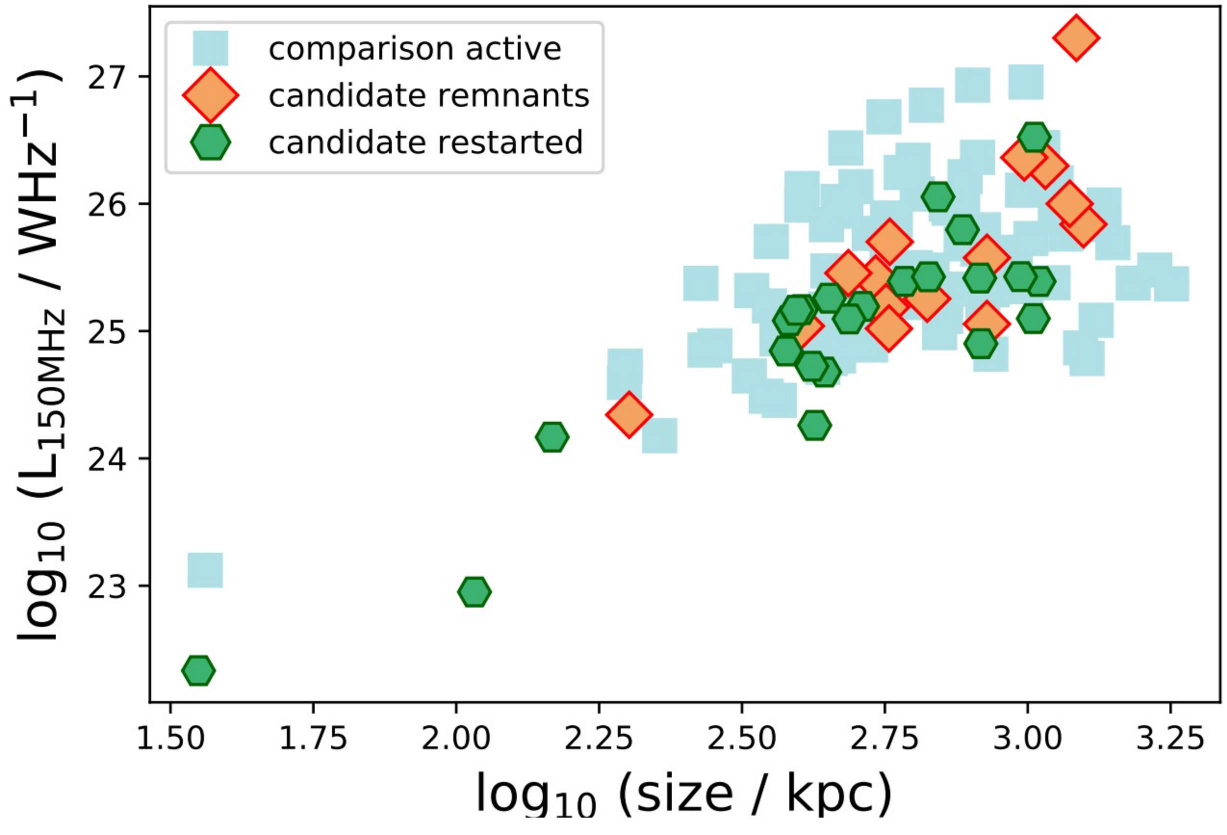


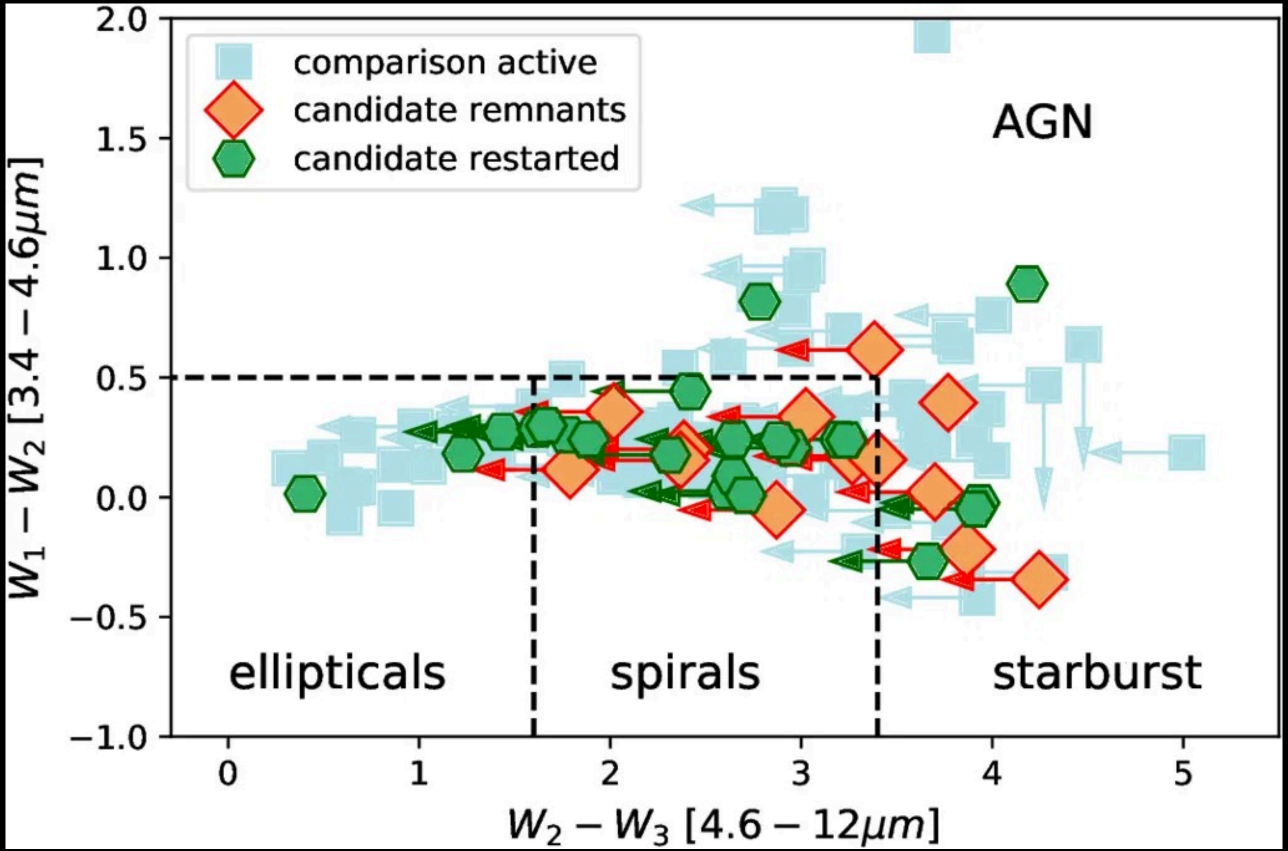




RESTARTERS

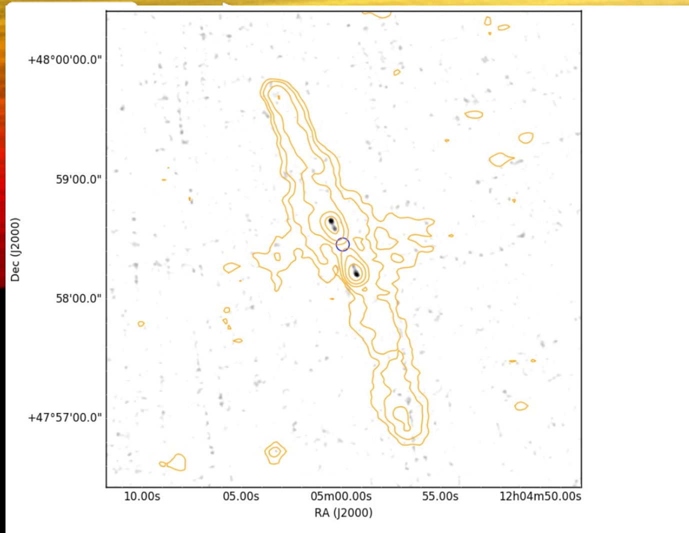
Jurlin+ 2020



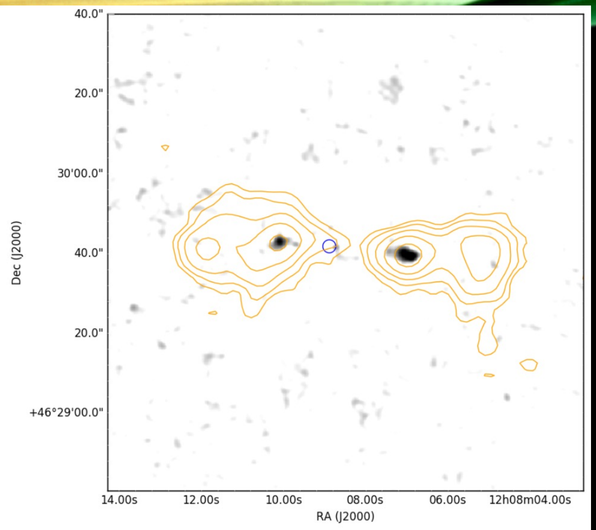


RESTARTERS

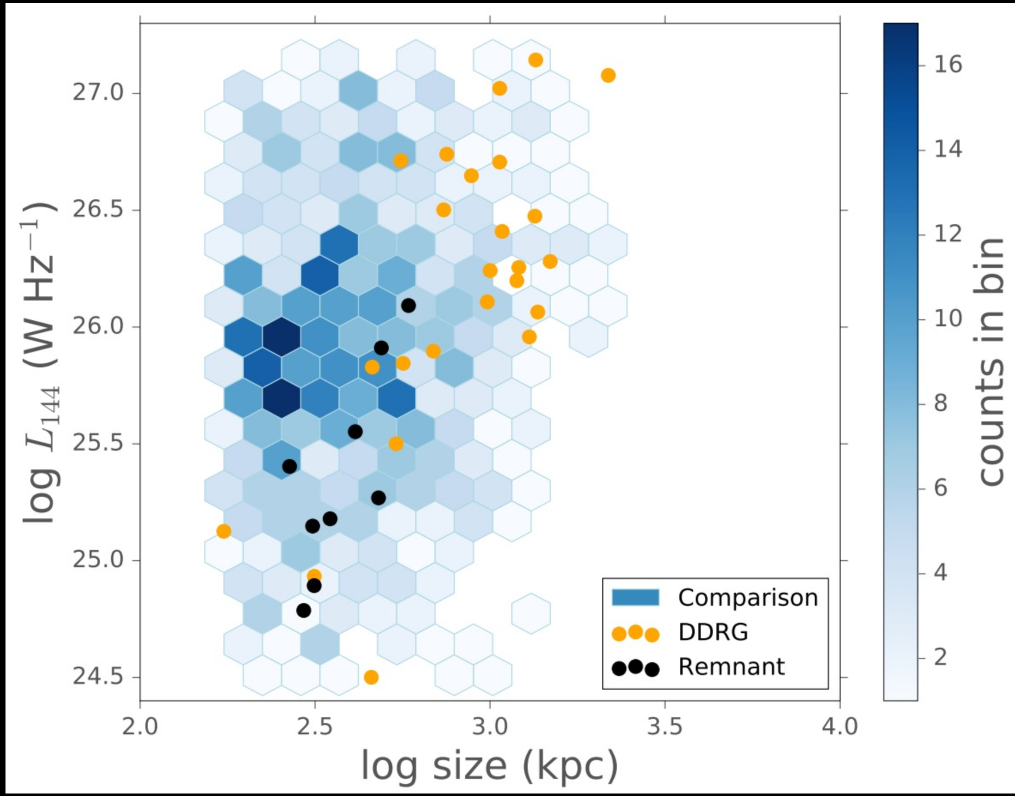
Mahatma+ 2019

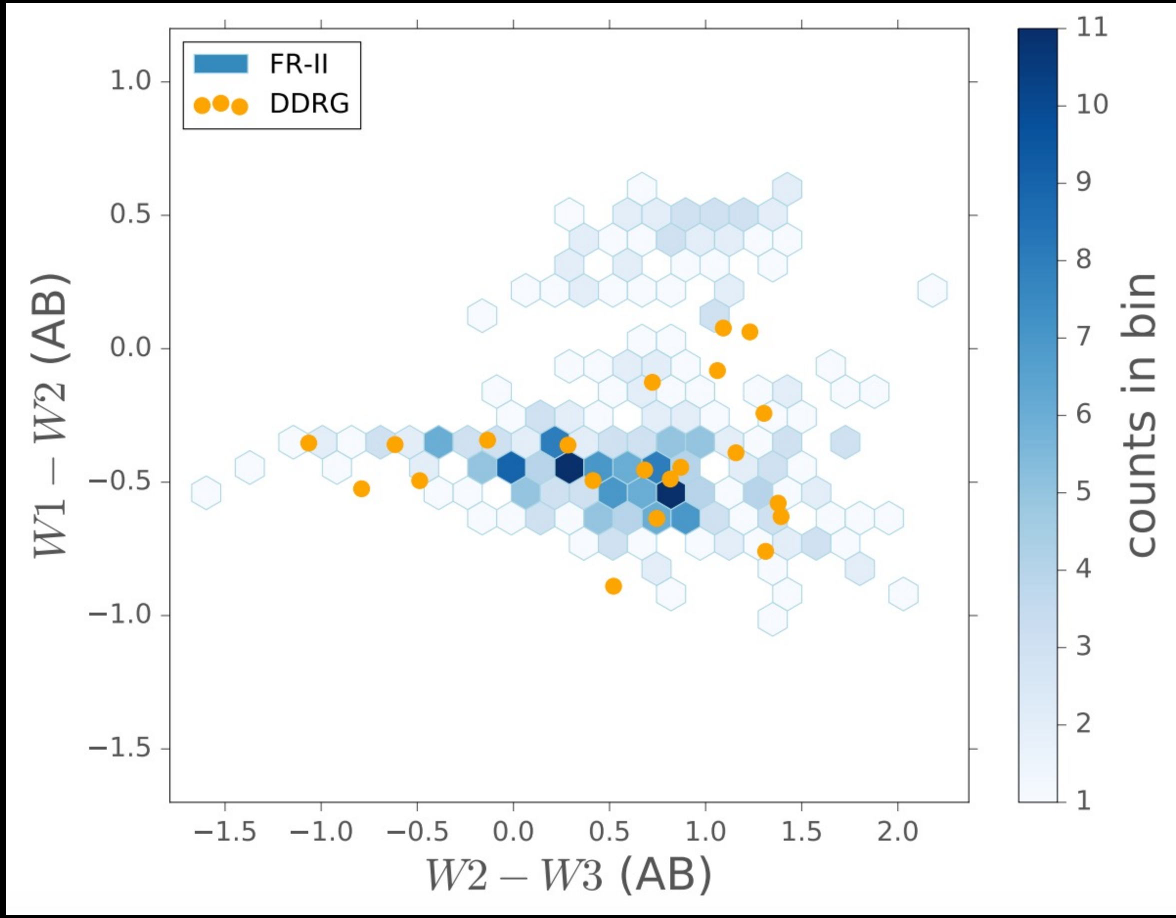


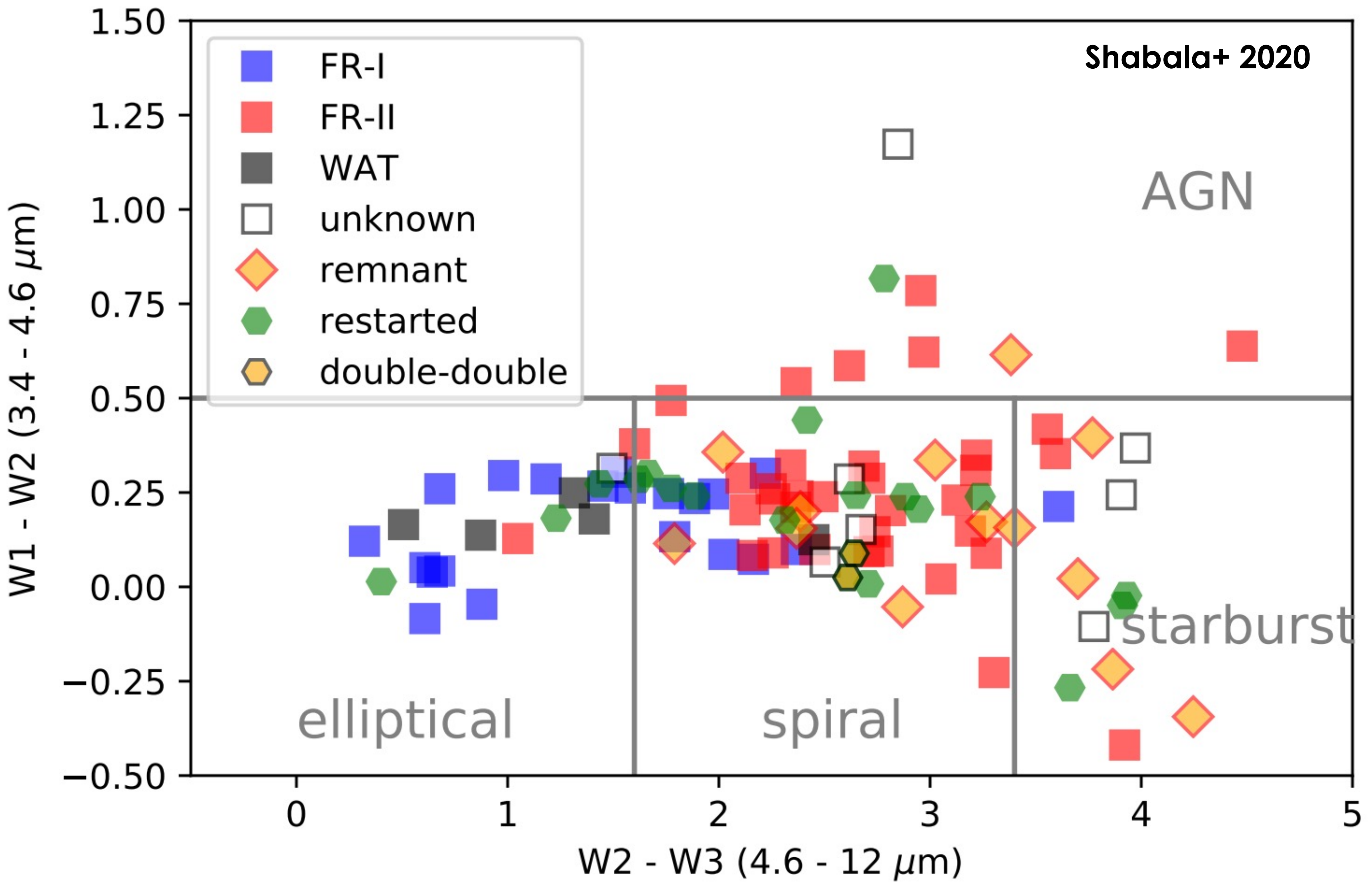
A.1. 11 ILTJ120459.87+475825.4†



A.1. 12 ILTJ120808.48+462940.6





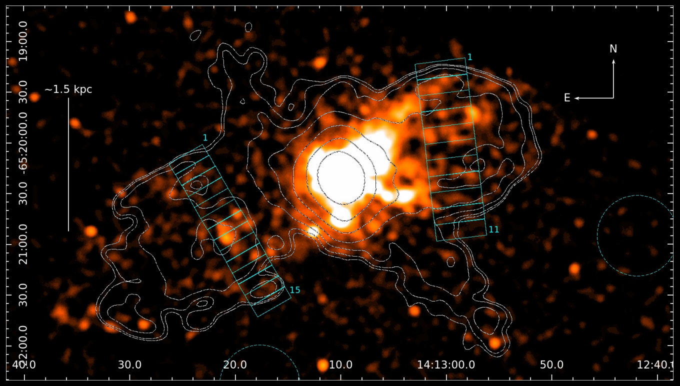


Shabala+ 2020
FR-I
FR-II
WAT
unknown
remnant
restarted
double-double
AGN
starburst
elliptical
spiral
1.50
1.25
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
0
1
2
3
4
5
W1 - W2 (3.4 - 4.6 μm)
W2 - W3 (4.6 - 12 μm)

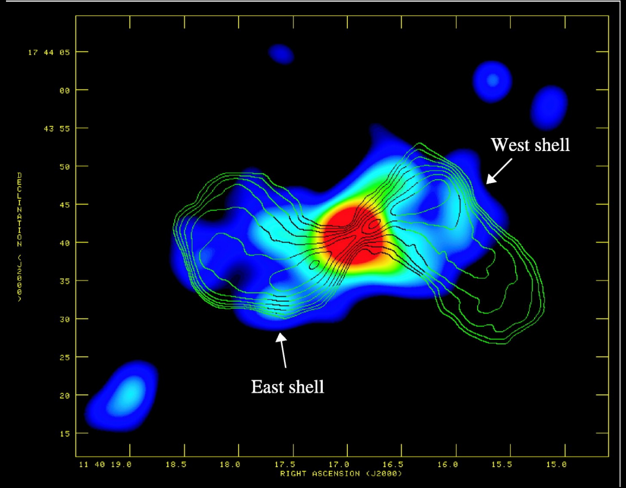
Webster+ 2021

GALAXY-SCALE SOURCES

Circinus (Mingo+ 2012)

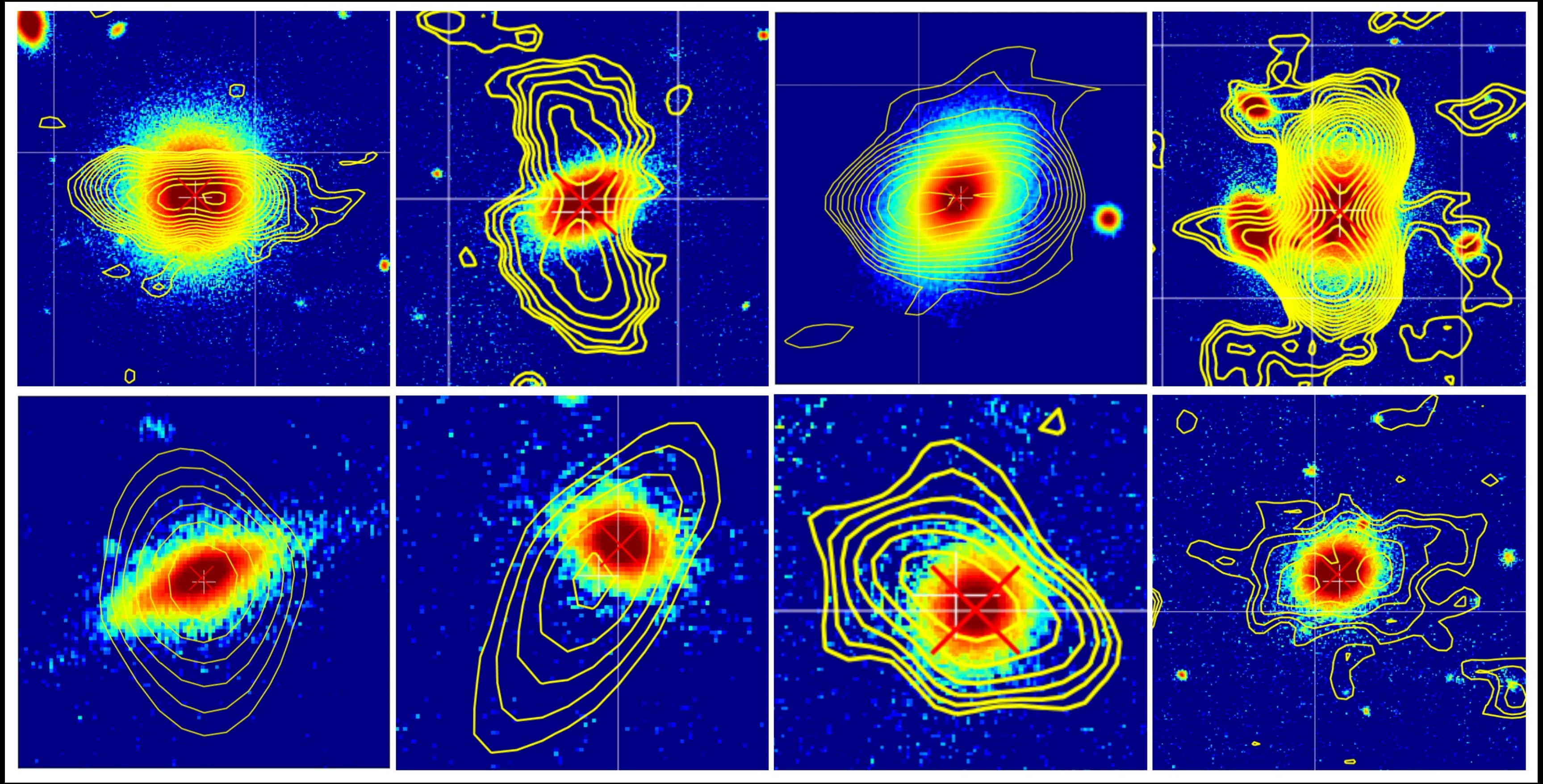


NGC 3801 (Croston+ 2007)



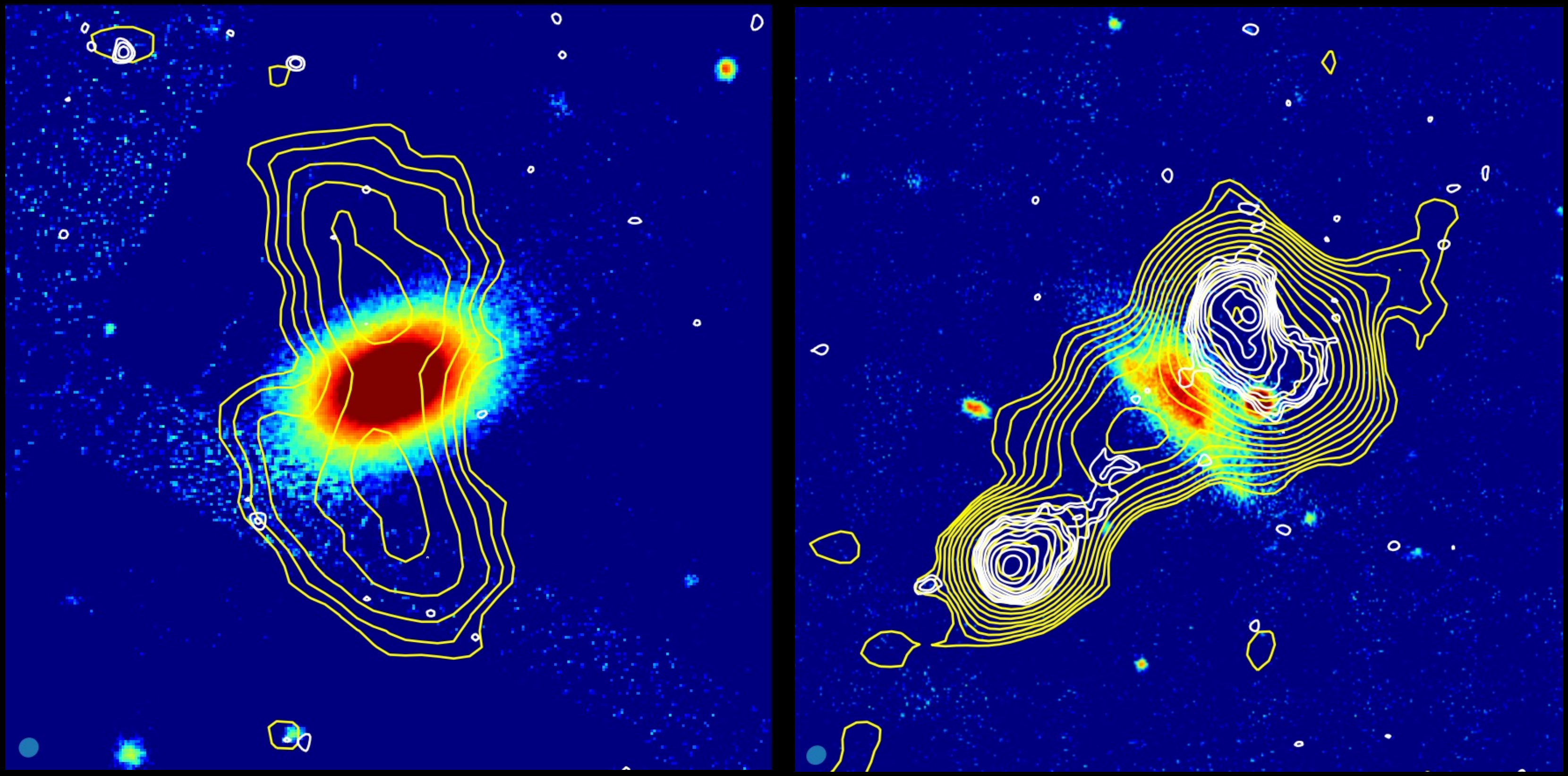
Small and short-lived or young and growing?

50% capable of influencing evolution of hosts, even without shocks



GALAXY-SCALE SOURCES

Webster+ subm.



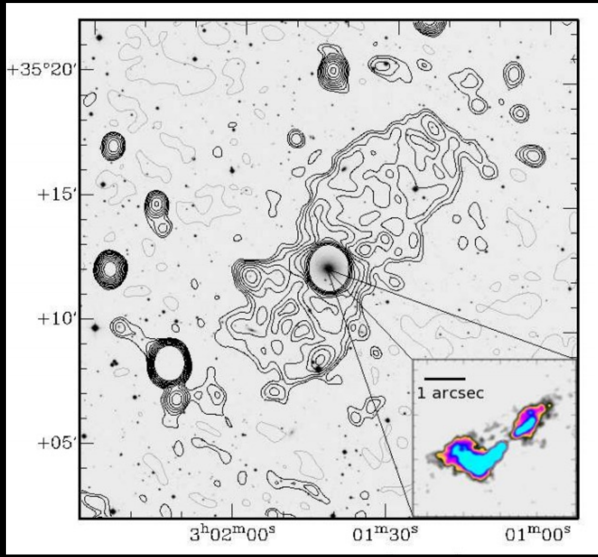
- Subset of 9 sources
- Ages: 10-35 My (spectral)
- Spectral indices no different to ordinary radio galaxies
- 1 remnant found!
- Unlikely to produce strong shocks

AGES AND RECURRENCE

See also Mahatma+ 2020 (spectral vs dynamical age)

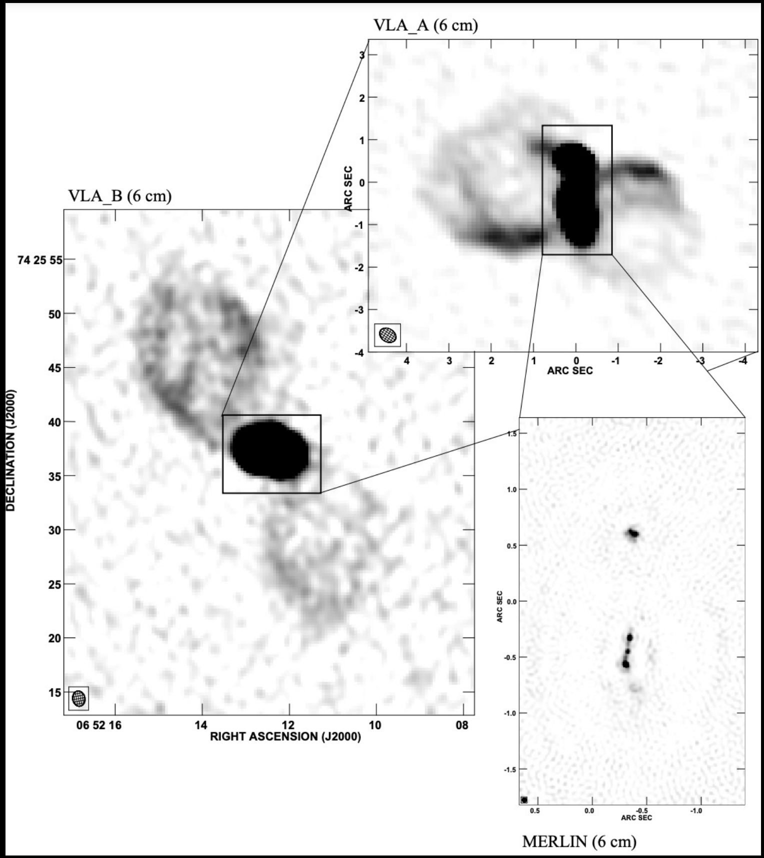
CSS/GPS

Shulevski+ 2012



Ages: <1 My?
Recurrence: 10-100 My?

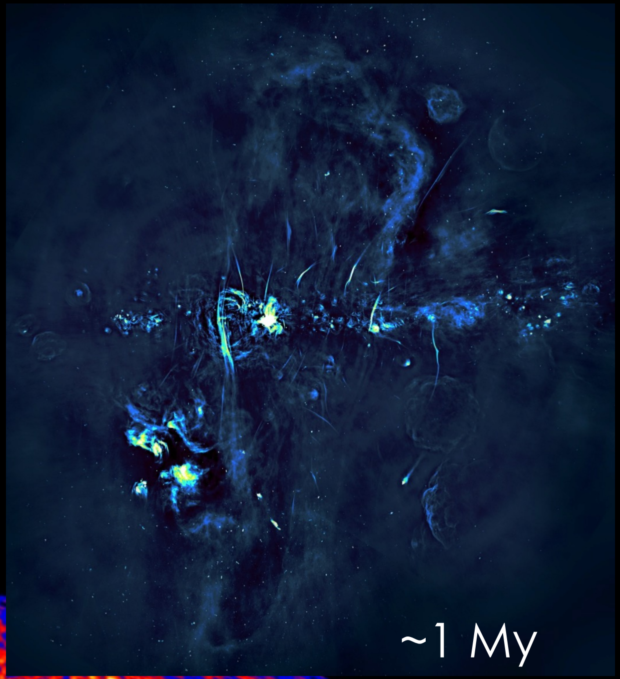
Kharb+ 2006



Ages: 1-50 My?
Recurrence: 10-100 My?

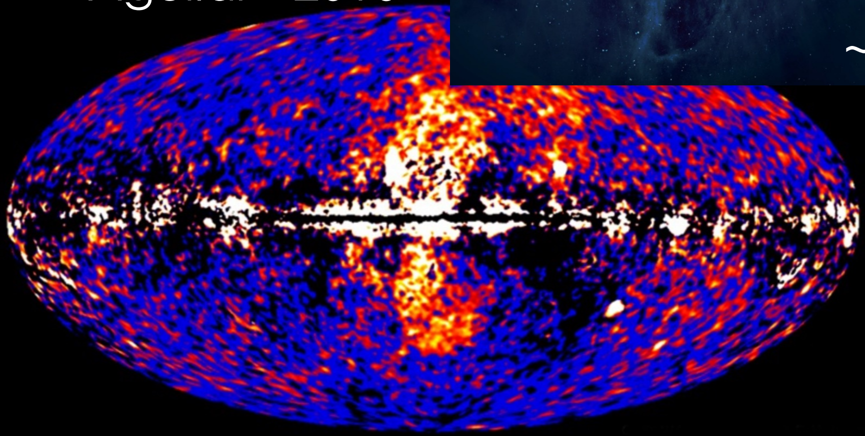
GSJ

Heywood+ 2019



~1 My

Aguilar+ 2010

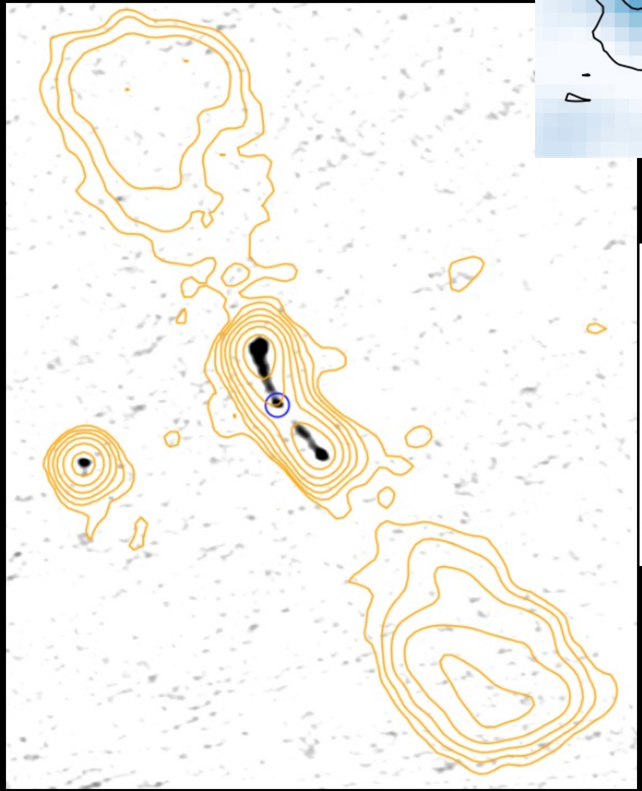


~20-40 My

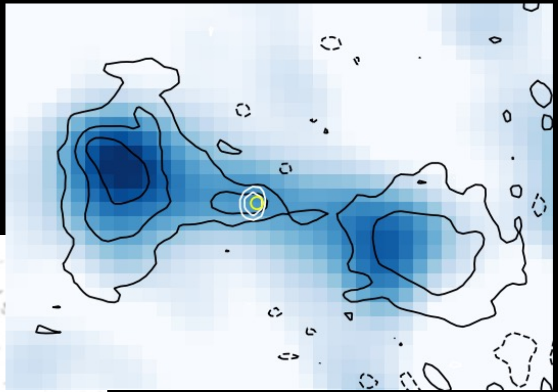
AGES AND RECURRENCE

FRII

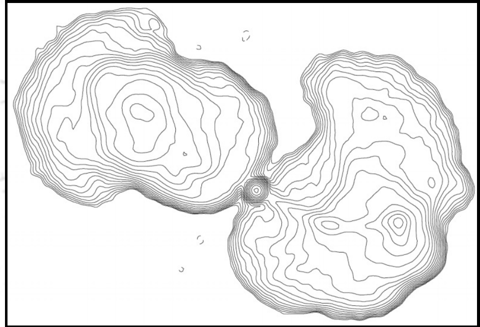
Mahatma+ 2019



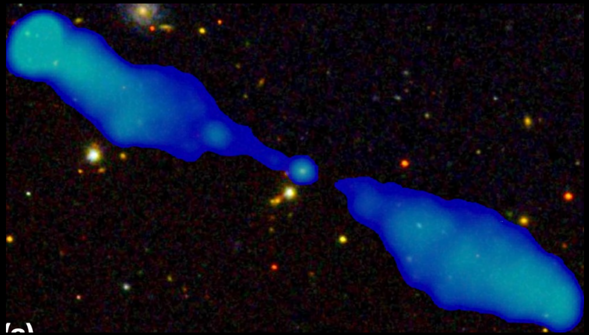
Jurlin+ 2020



Brienza+ 2020



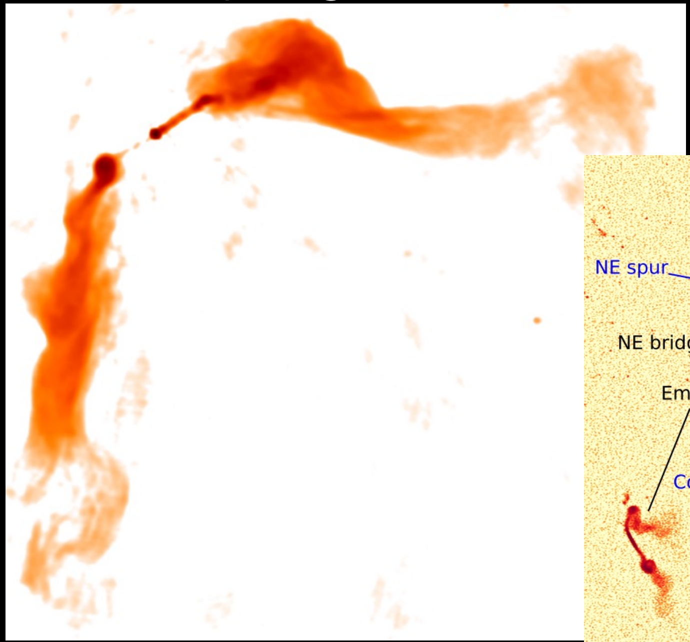
Dabhade+ 2020



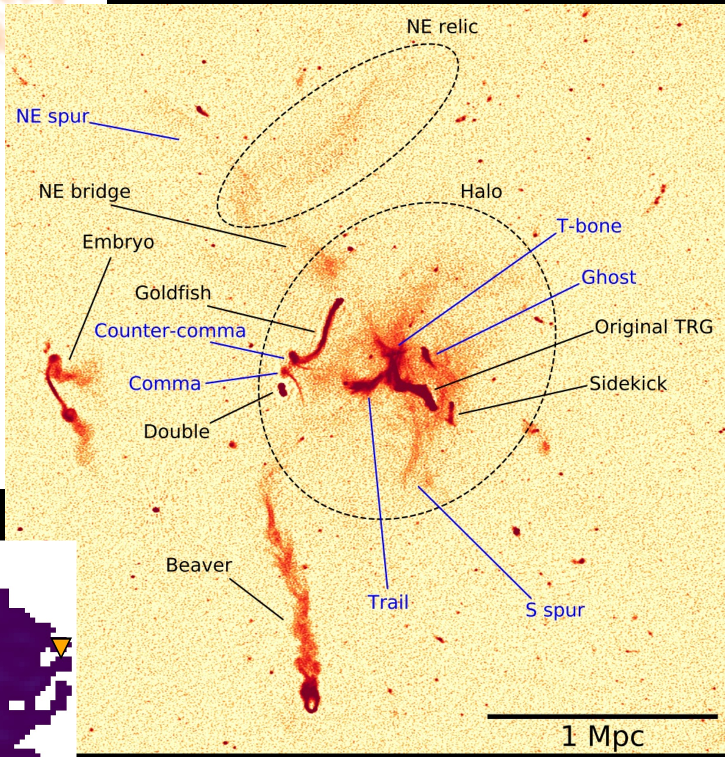
Ages: 10-500 My?
Recurrence: 1-100 My?
(Faster duty cycles sometimes)

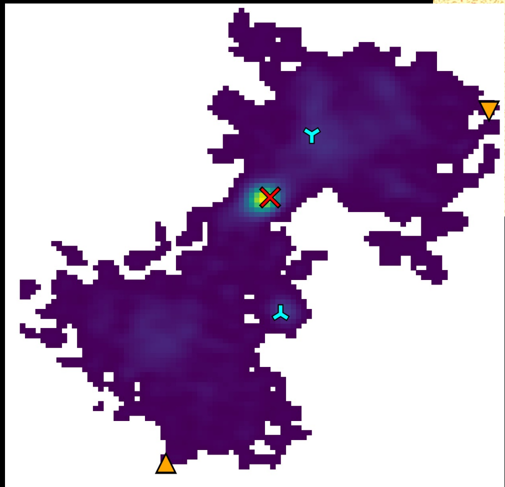
FRI

Bempong-Manful+ 2020



Botteon+ 2020





From FRII-like ages/cycles to "always on"

The Open University

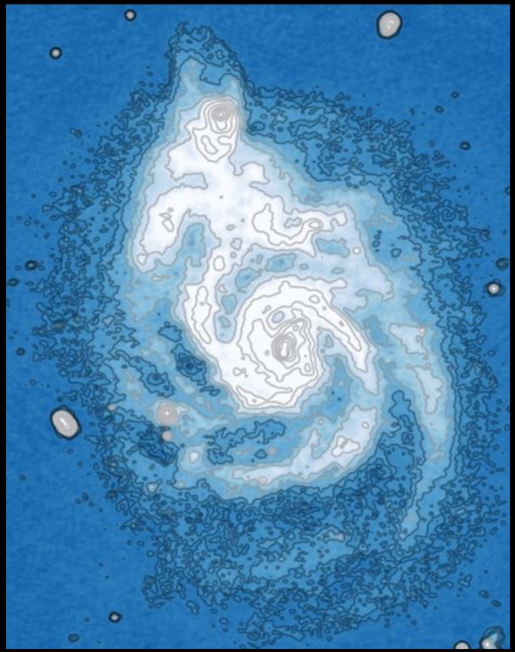
www.lofar-surveys.org

EVEN LOWER: LBA/LoLSS

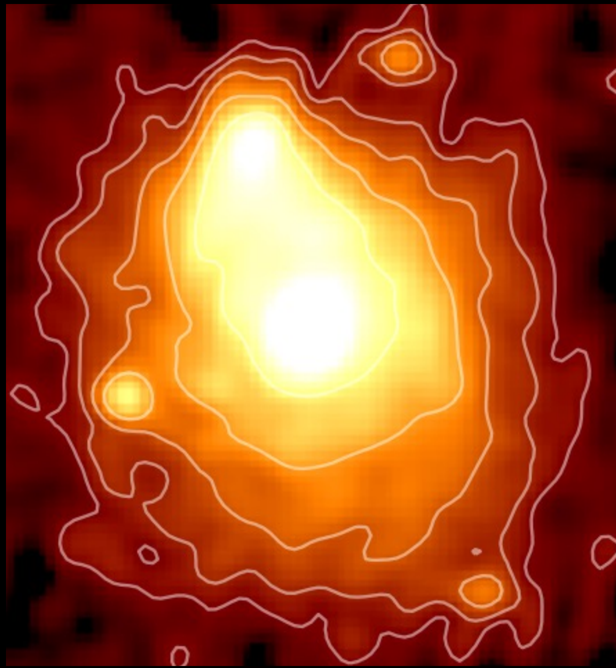
- LoLSS (LOFAR LBA sky survey) preliminary data release: De Gasperin+ 2021
- ~2500 sources, 740 sq deg.
- 42-66 MHz, 47” resolution
- 50% complete @ 17 mJy
  90% complete @ 40 mJy
- Final aim: 15”, 1 mJy/beam

M51 (the Whirlpool Galaxy)

HST



LoTSS
Shimwell+ 2019



LoLSS
De Gasperin+ 2021

CONCLUSIONS

- To constrain the **age and duty cycle** of a given source consider:
    - Host mass (and thus M_{BH})
    - Jet power (luminous = longer-lived; faint = short duty cycle)
    - Gas supply
        - Host properties (WISE c/c plot, optical colours, traces of merger)
        - Large-scale environment
- Look at **low frequencies**! → LoTSS + LoLSS
    - Unveil up to ~1 Gy of jet activity!