LOTSS (HETDEX) GALAXY CLASSIFICATIONS

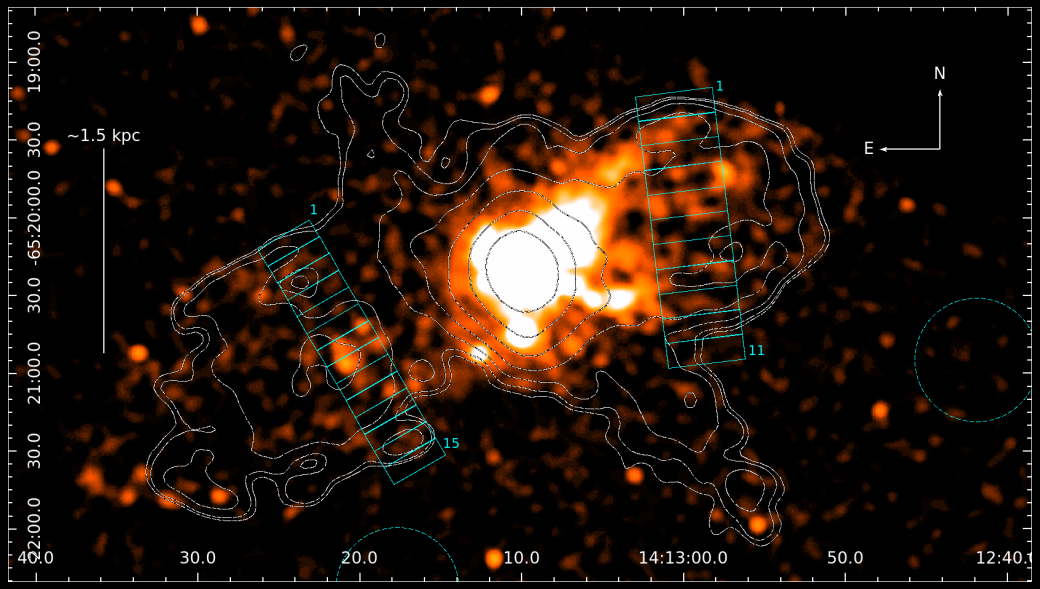
WHAT CAN THEY TEACH US ABOUT AGN LIFE CYCLES?

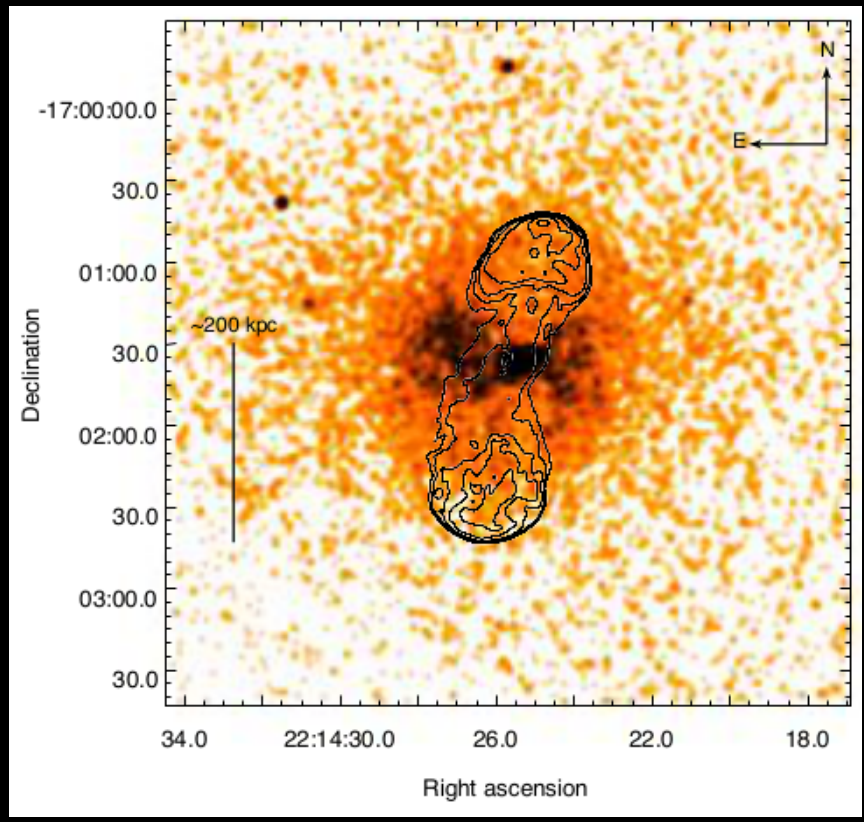
Beatriz Mingo, Judith Croston, Brendan Webster, Joanna Piotrowska

Thanks also to:
Martin Hardcastle, Wendy Williams (Herts), Judith Ineson (Soton),
LOFAR LoTSS/HETDEX team, LGZ volunteers

The Open University

FEEDBACK





E.g. Croston+ 2007, 2011; Mingo+ 2012; Kraft+ 2003; Siemiginowska+ 2012; Kharb+ 2014; Lansbury+ 2018; Rampadarath+ 2018

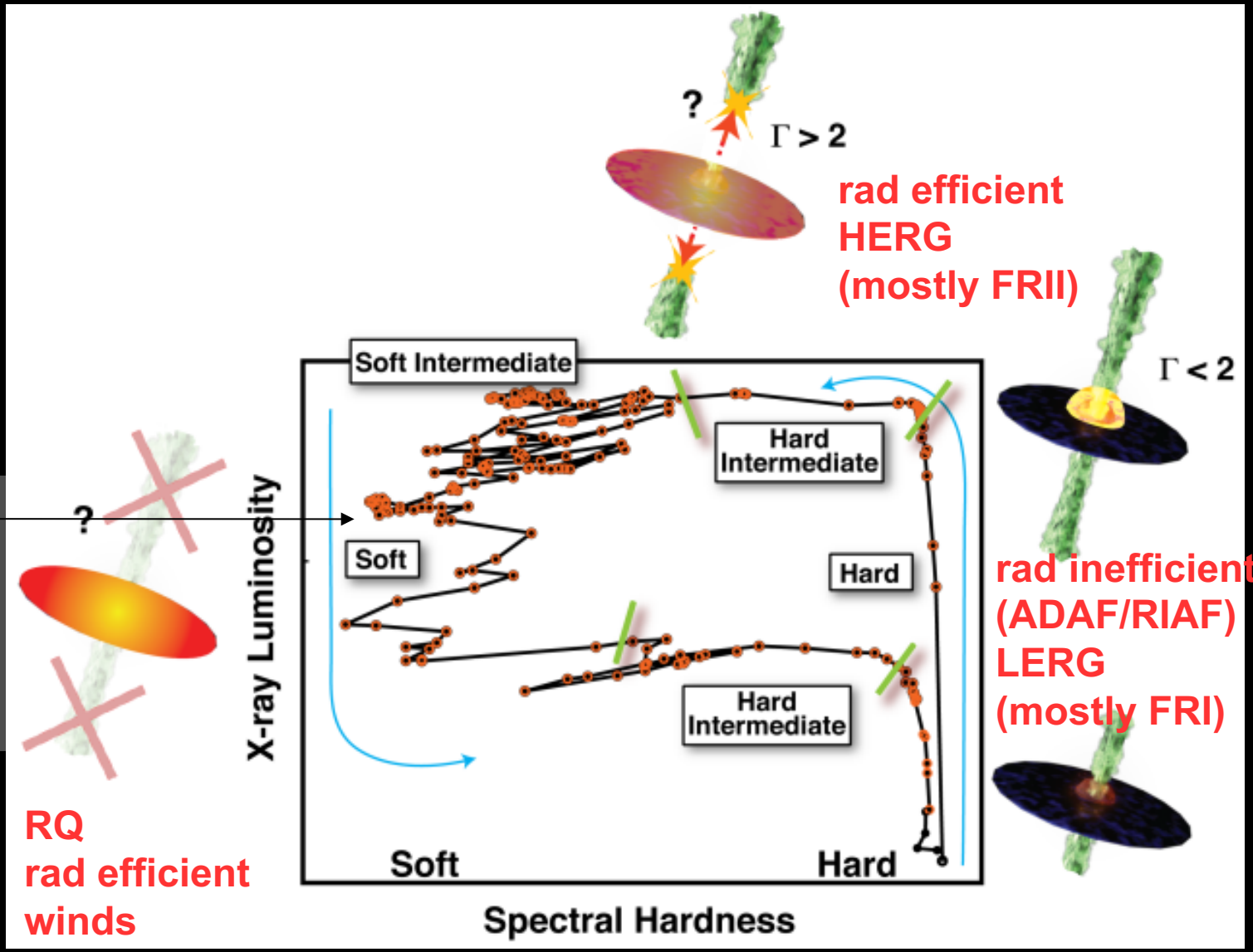
+Wednesday's last session!

THE (LM)XRB LINK

AGN activity is cyclical

See e.g.:
Fender & Gallo 2014
Done+ 2001, 2012
McHardy+ 2005, 2012

AGN can develop jets while in this region, XRB, pulsars, WD, etc cannot. Magnetic flux accretion rate? (Tchekhovskoy+ 2011, Sikora & Begelman 2013) Timescales? (Tadhunter 2016)

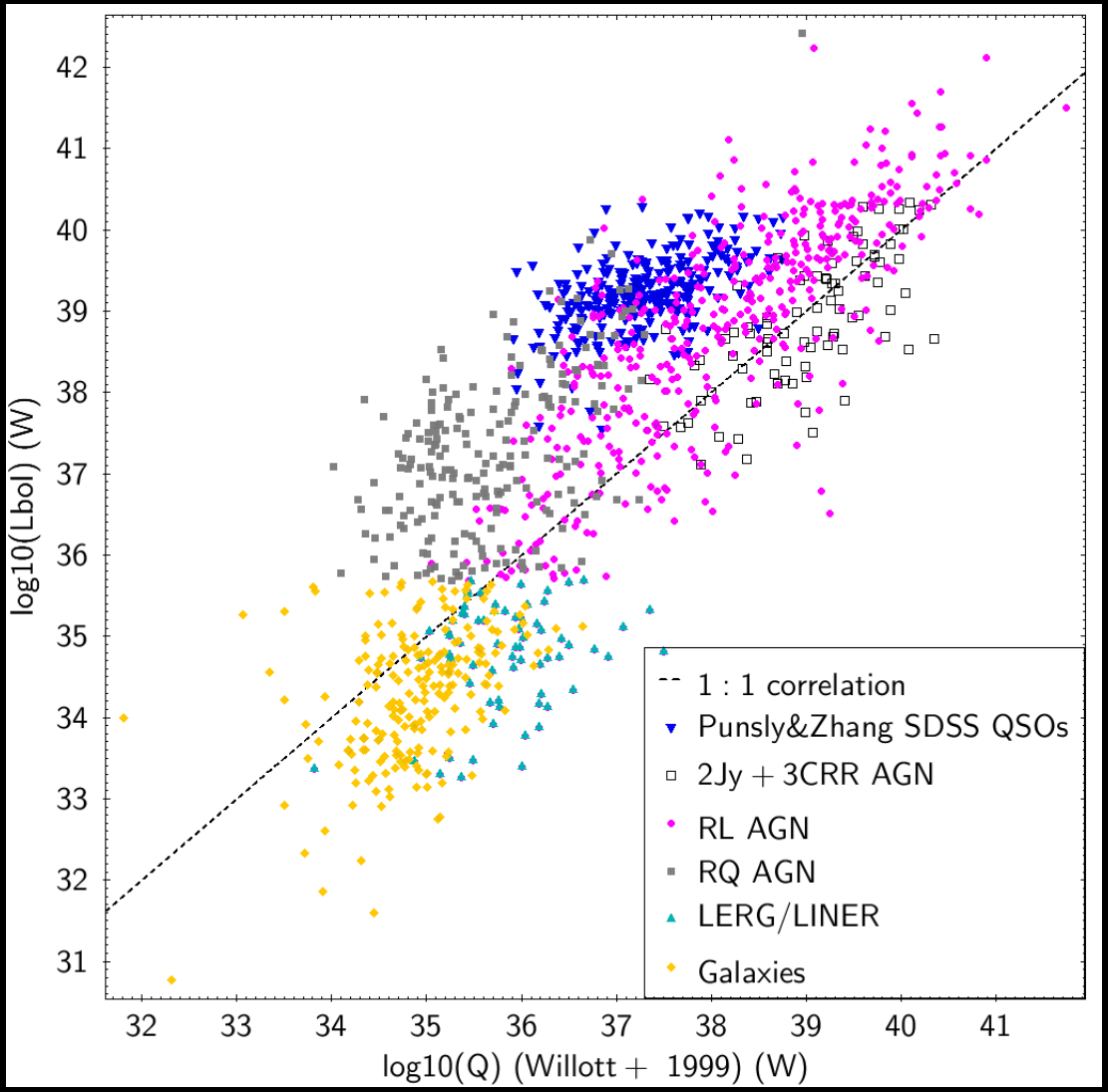


Source: S. Markoff

The Open University

I HAVE A DREAM…

- We need to constrain:
  - Variability
  - Underlying differences in jet power
  - Timescales involved
  - Influence of hosts and environments
  - Biases in measurement
- With large statistics (also for "exotic sources") LOFAR (and eventually SKA) can help!



Mingo+ 2016

LOTSS HETDEX DATASET

- ~16k sources (out of ~325k in the main LoTSS catalogue!)
  - Minimum source size ~8.5" → resolved
  - Flux > 2 mJy (5 RMS cut on the maps)
  - Good host ID (with redshift)
- Ideal playground for automation!
  - We want to select clean samples of radio galaxies, to study:
    - Power
    - Particle content
    - Environment
    - Hosts
    - Evolution

THE FRMAL CODE

(To do: find better name?)

- FRMAL= Fanaroff-Riley Morphological Algorithm for LOFAR
  - Classic definition: distance of core to brightest structures vs total length of the source.
  - Classify each side, only if both agree class is certain:
    - 4 classes (for now): FRI, FRII, hybrid, unclassifiable.
- Main advantages:
  - Better estimation of size, flux than automatic tools (PyBDSF)
  - Clean selection: starting point for jet physics, part. content

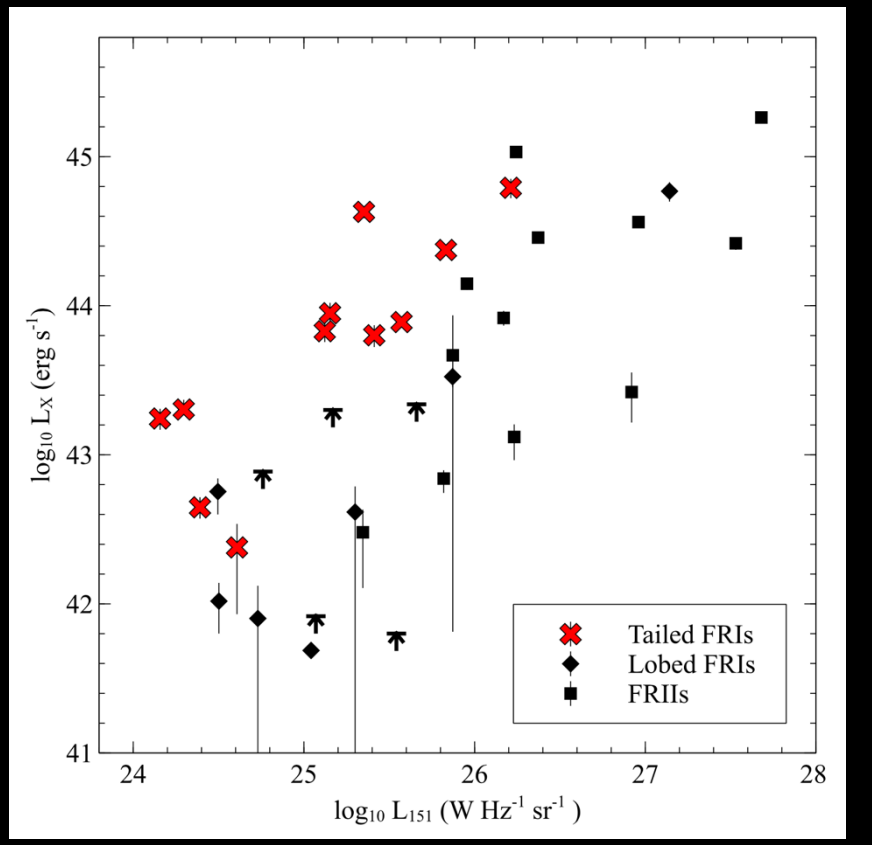
The Open University

See Judith's talk!

FRI & FRII: JUST THE BEGINNING

- FRI and FRII have different particle content (and B)
  - FRI more proton-dominated
- Radio morphology and environment are connected
  - Also dependent on accretion mode
- Different P_jet/L_radio relationships
  - Cavity jet-power scaling relations overestimate FRII P_jet
- LOFAR = more sources, higher z, more accurate classifications
  - What makes an FRI/FRII?

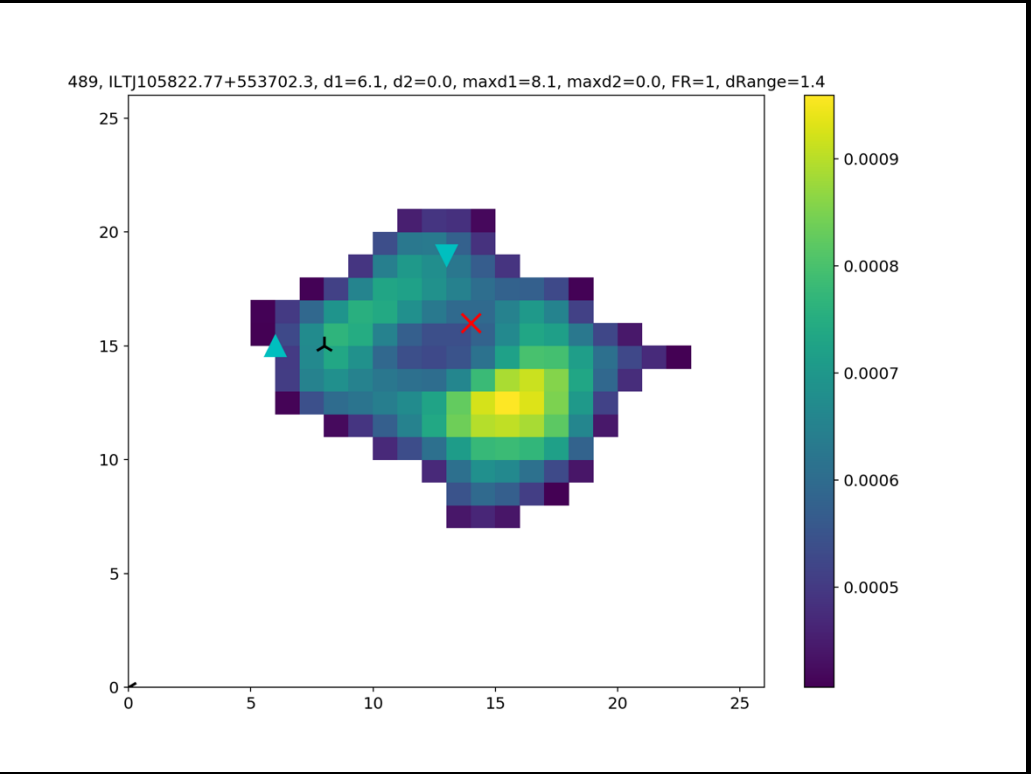
Croston + 2017, 2018, Ineson + 2015

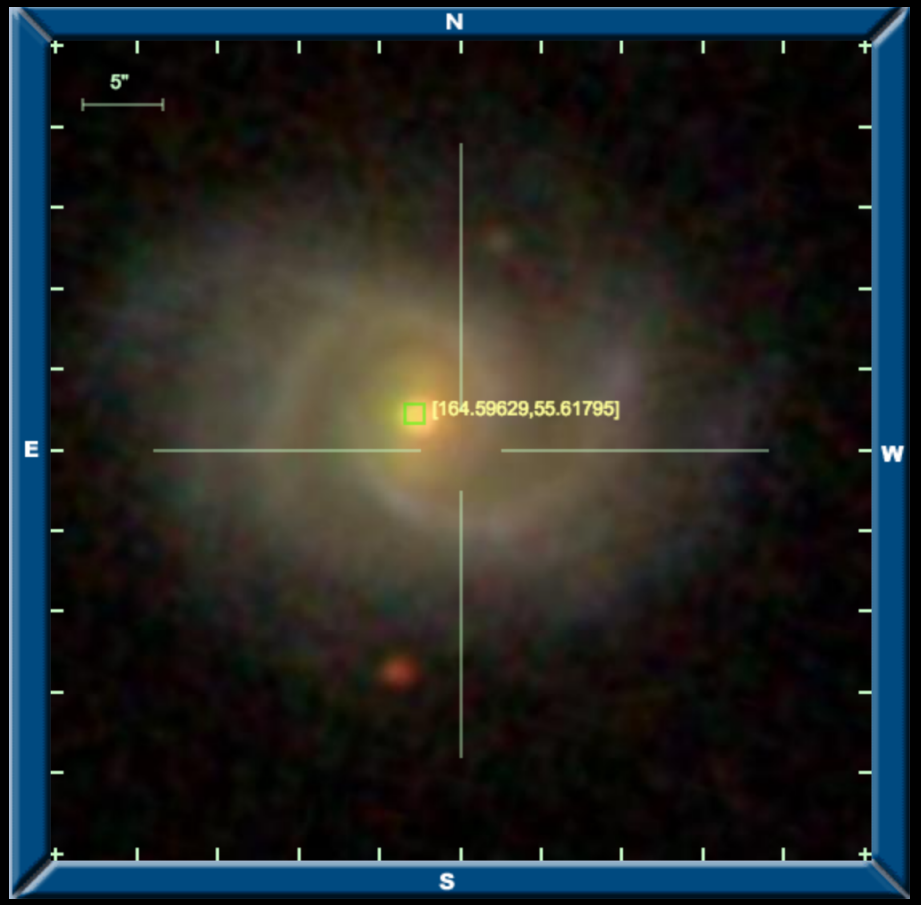


THANK YOU BRENDAN! ☺

GALAXIES = NOISE

LOFAR is really good at picking up star forming galaxies!
~18% of my sample (~2.4k sources)

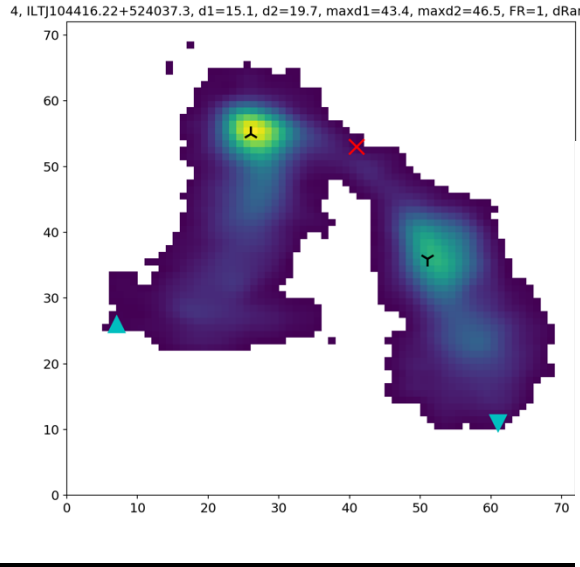


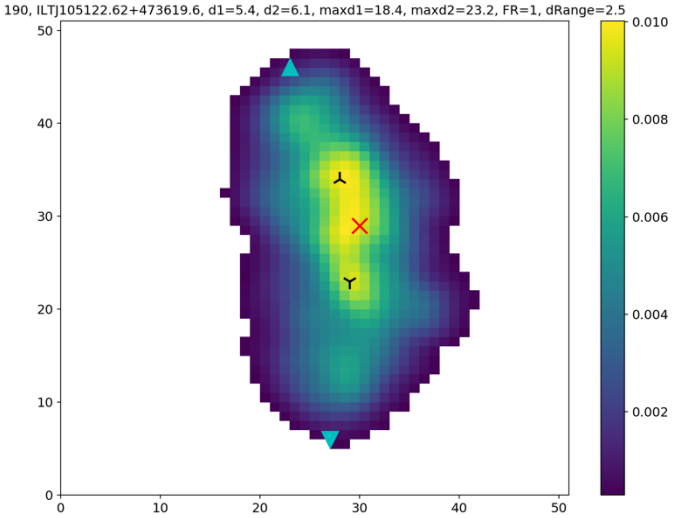


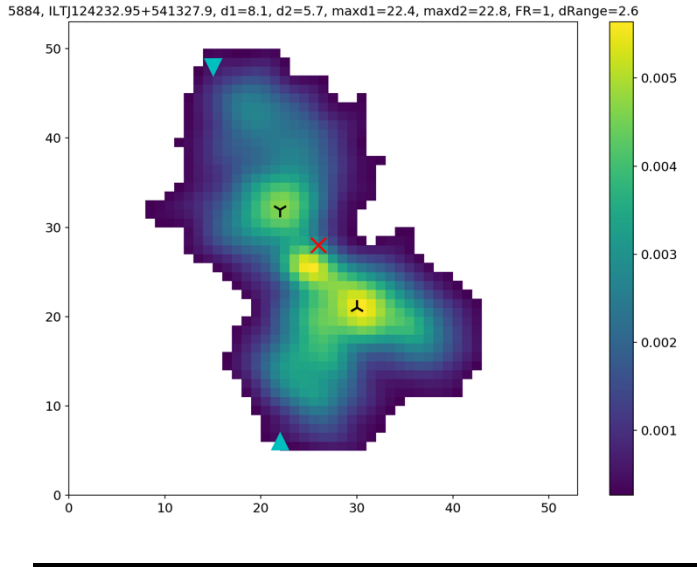
The Open University

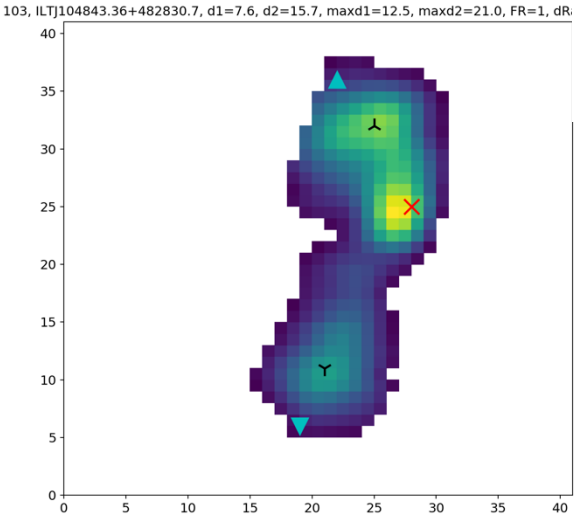
FRI

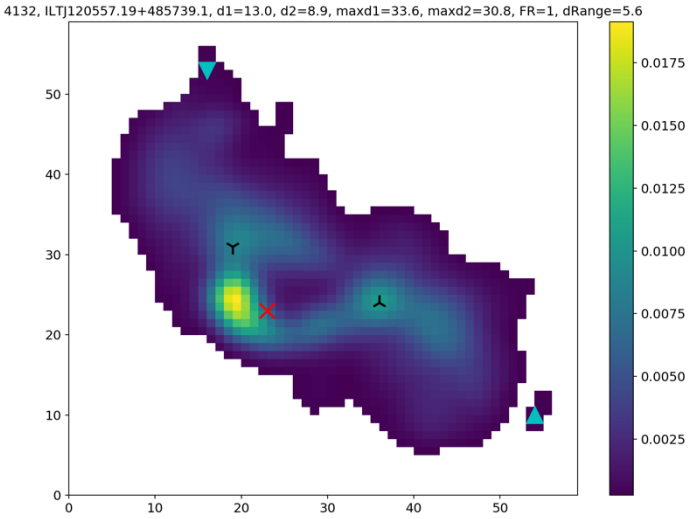
~3800 sources





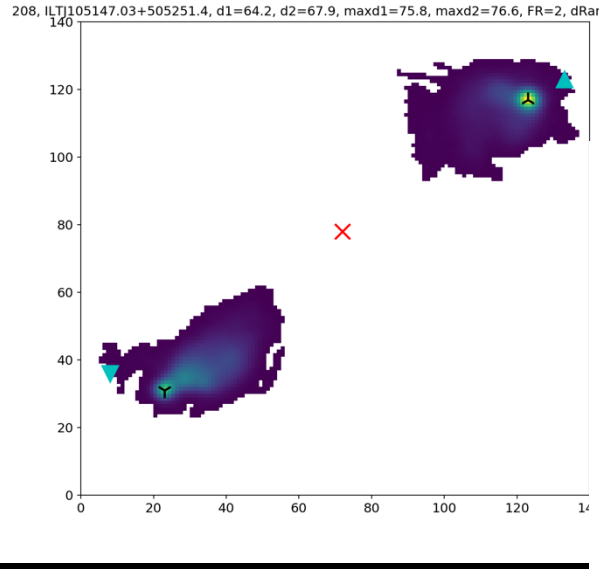


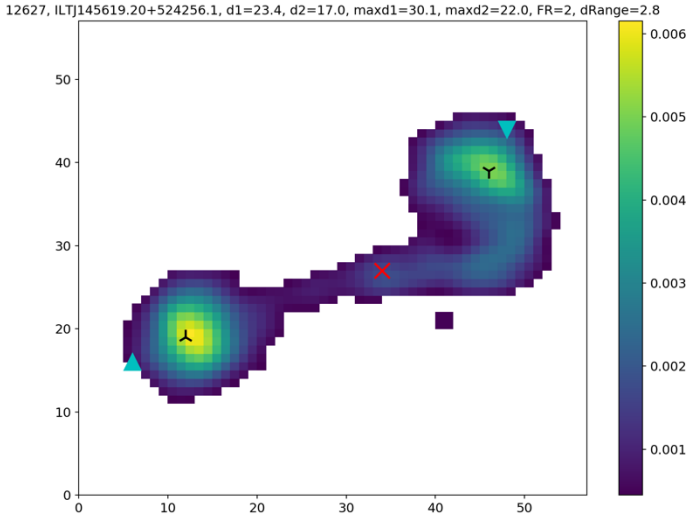


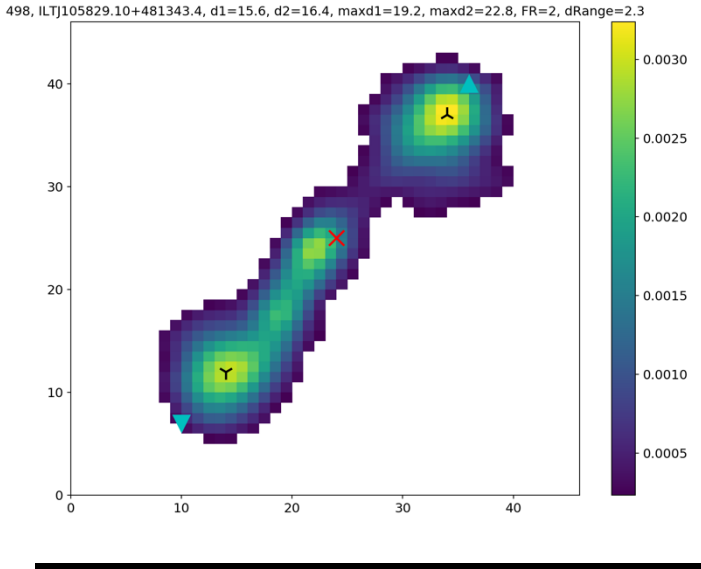


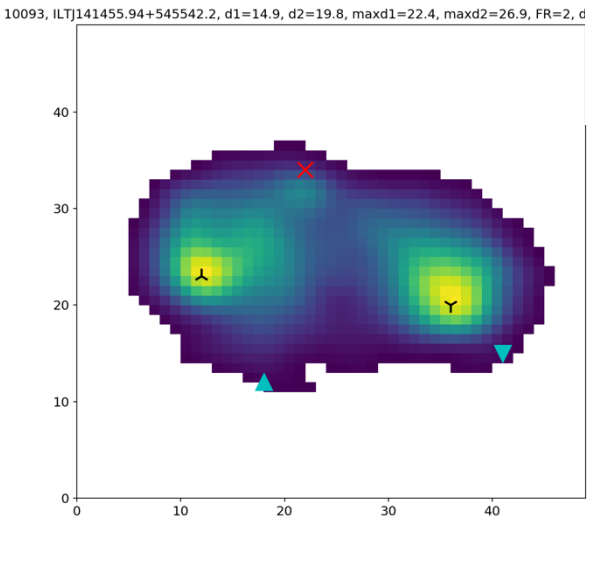
FRII

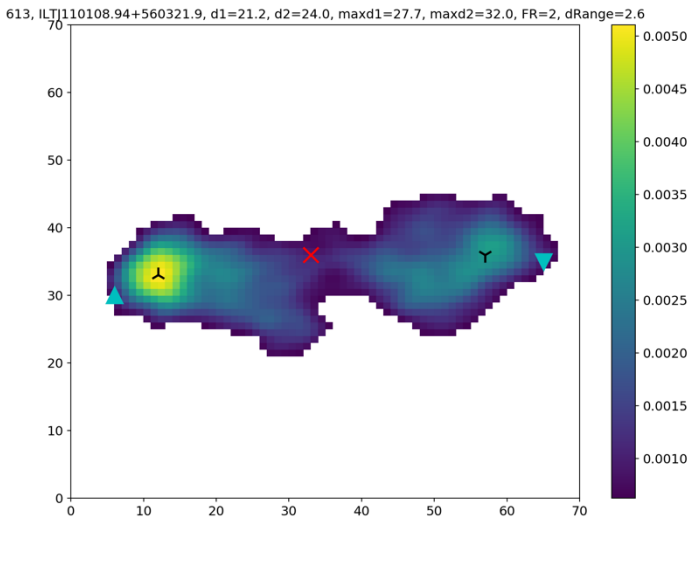
~1300 sources





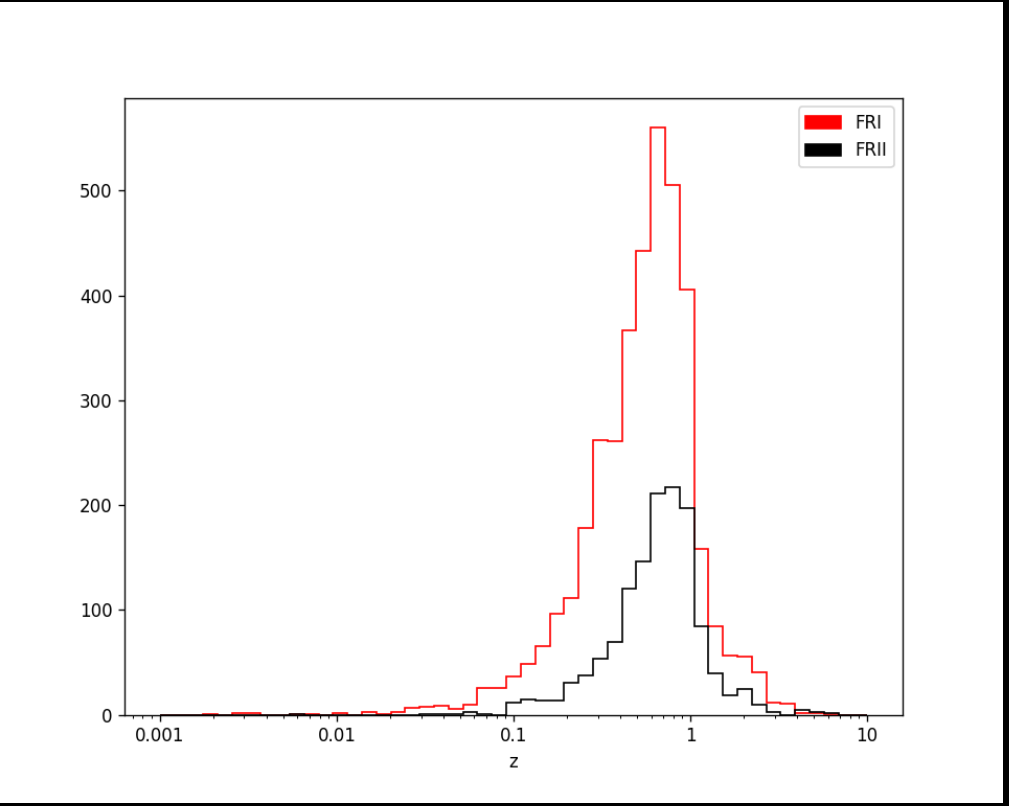






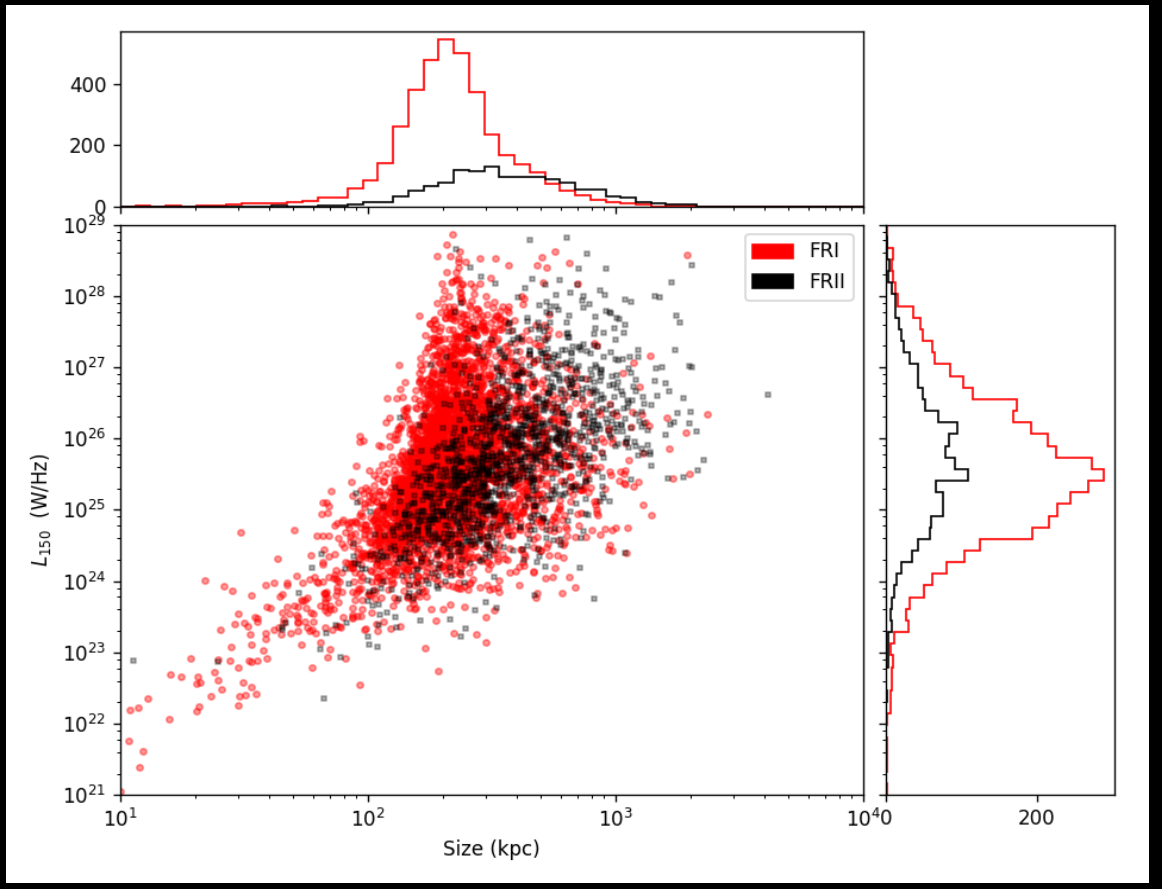
HETDEX CLASSIFICATION RESULTS

- ~13.000 "good" sources
  - ~3800 FRI
  - ~1300 FRII
  - ~1000 hybrid
  - ~2400 galaxies
  - ~5000 unclassifiable (blobs)
- Fairly complete up to z~1
  - Limited by Pan-STARRS



HETDEX CLASSIFICATION RESULTS

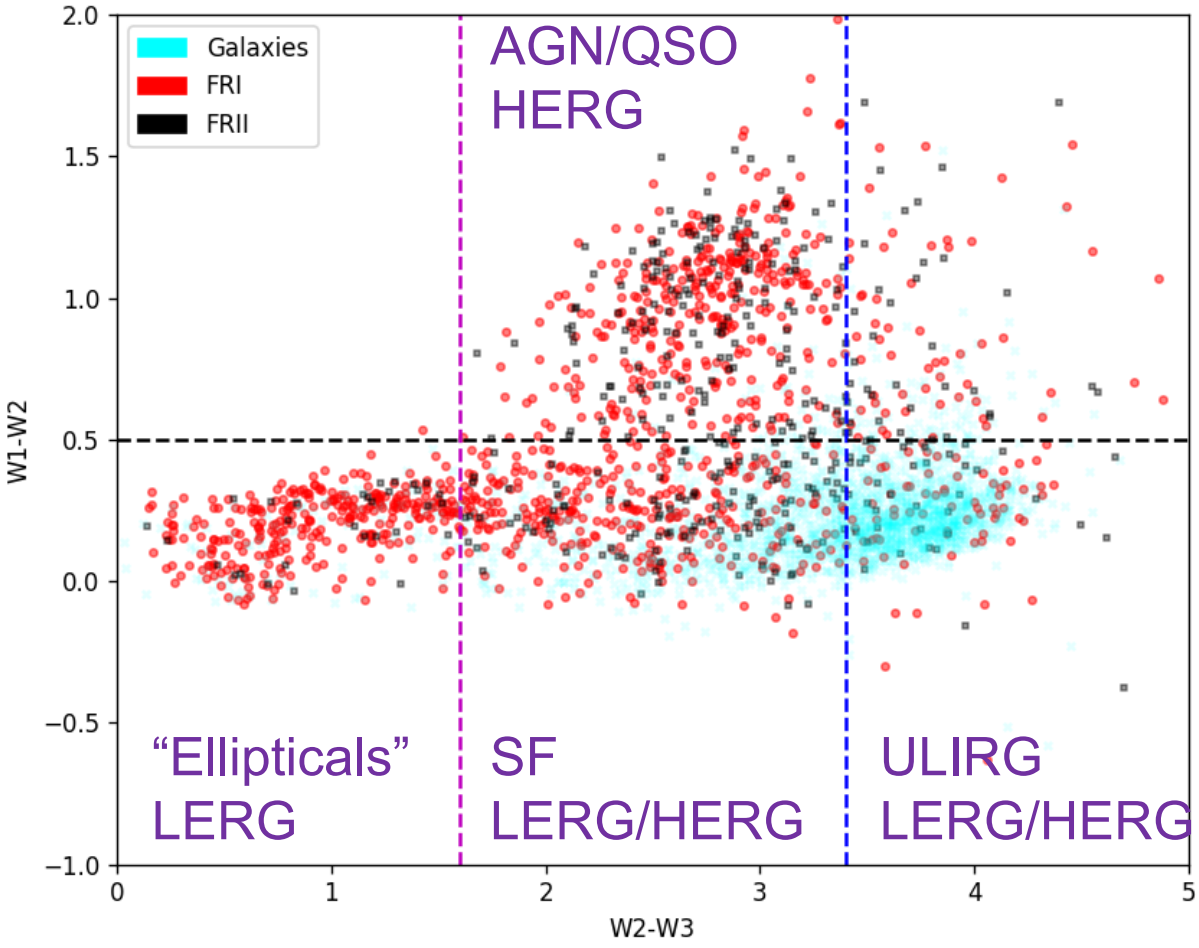
- V. similar L distribution! (Best 2009, Turner & Shabala 2015)
  - FR class related to host and/or environment?
    - We have stats! ☺
- FRII are larger
  - Unable to see very extended emission from FRI even at low freq.
- FRI are far more challenging to classify!



WISE: HOSTS +LERG/HERG

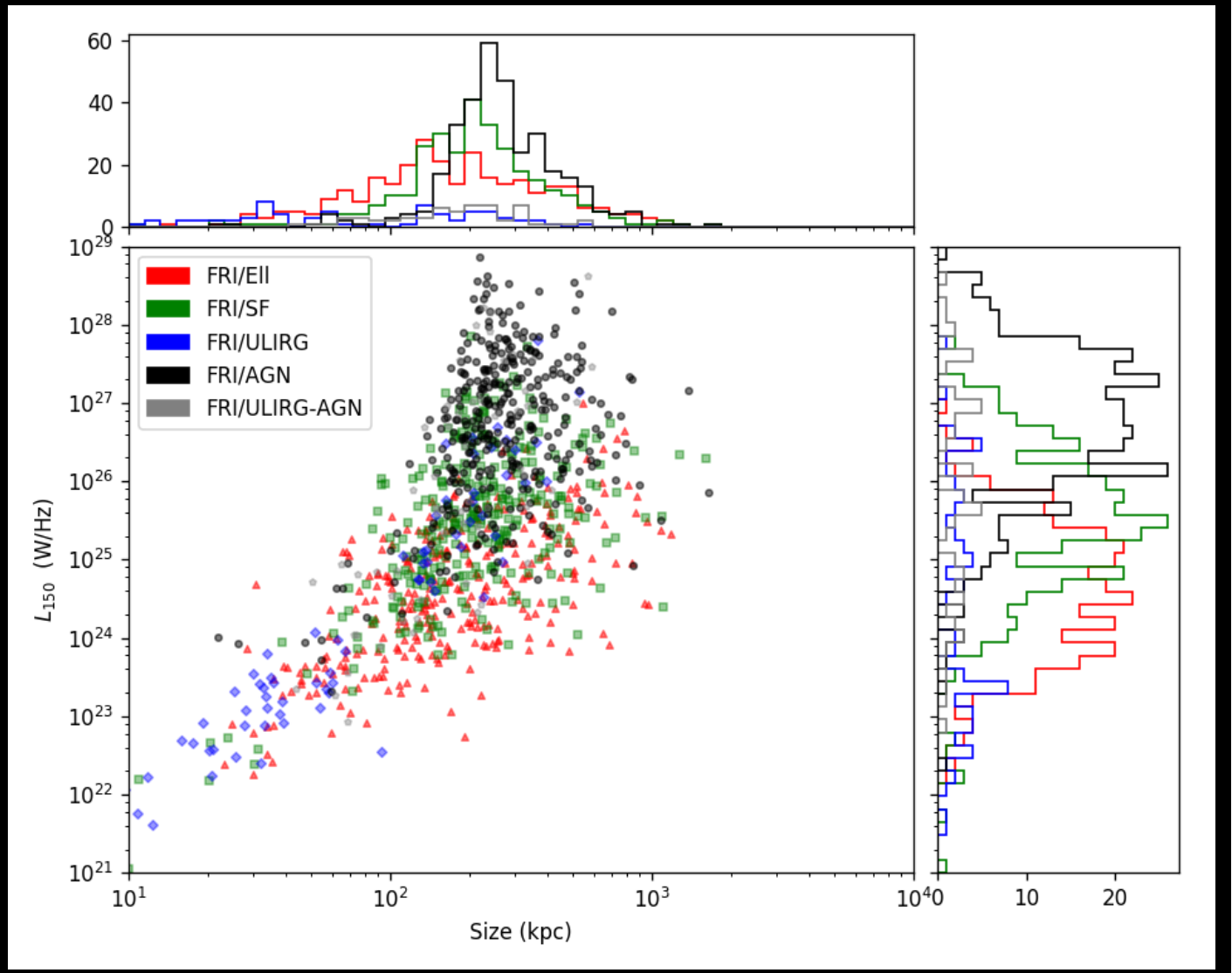
Wright+2010, Lake+2012, Mingo+2016

- Only ~30% W3 detections
  - W3 v. limited in sensitivity, only sees up to Z~1
- WISE colours give information about both the host and HERG/LERG
- Divisions are rough (populations overlap)



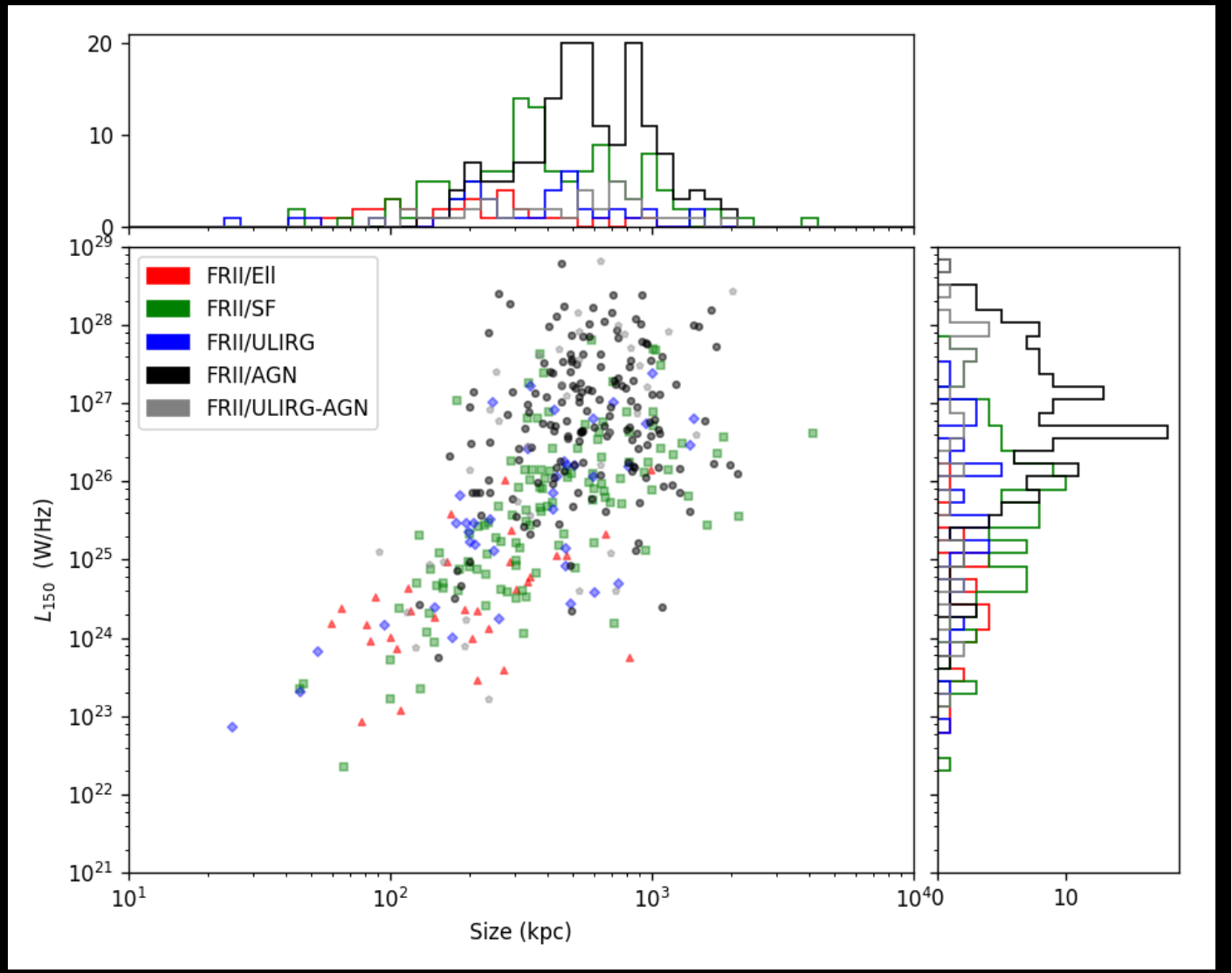
FRI HOSTS

- Surprising number of FRI HERG (hosts with AGN/QSO MIR colours)
  - Higher L150
  - Narrow size dist.
- Hosts with elliptical colours (proportionally) harbour largest FRI (but mind selection effects!)
- Potential contamination from pure SF at low sizes (ULIRG hosts)



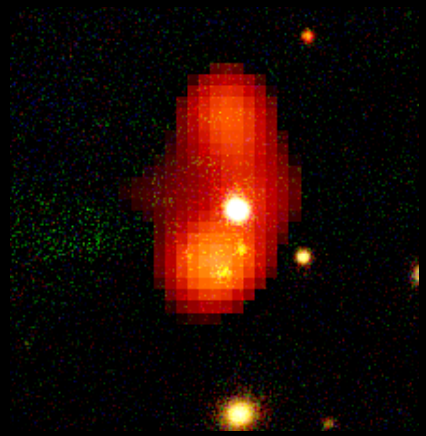
FRII HOSTS

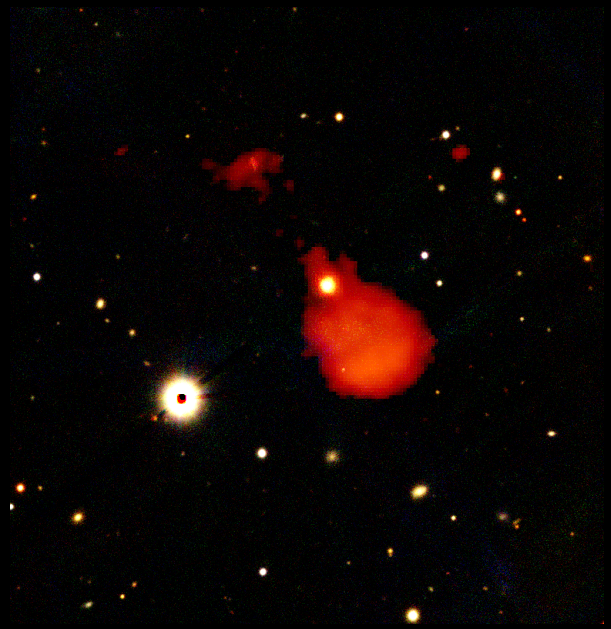
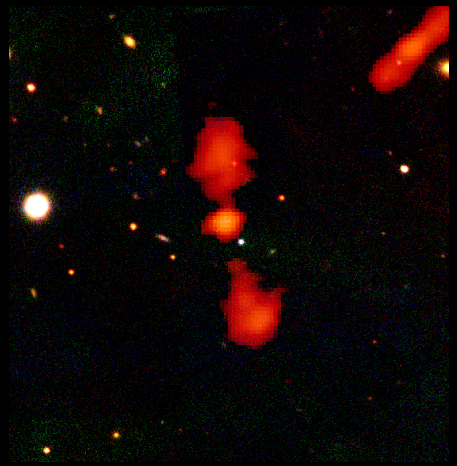
- Few sources… ☹
- Same L150 trend as FRI, but proportionately more AGN hosts (more HERG – expected!)
- Divisions are rough (populations overlap)



The Open University

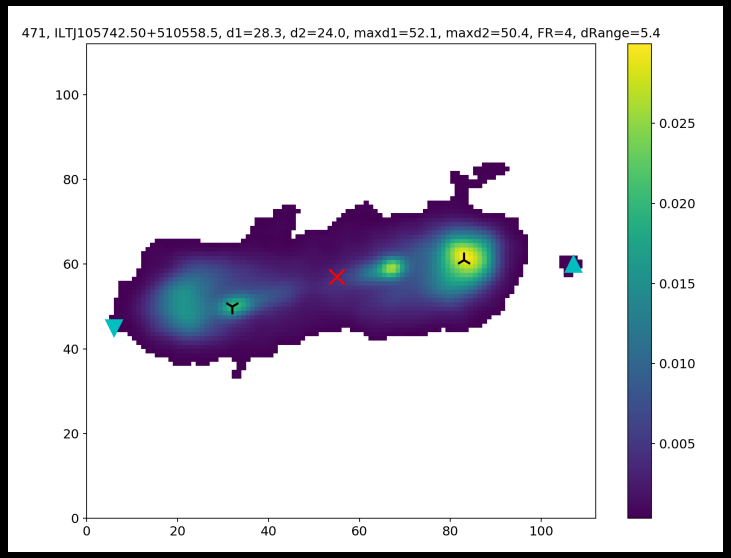
FRI HERGS ARE TRICKY!

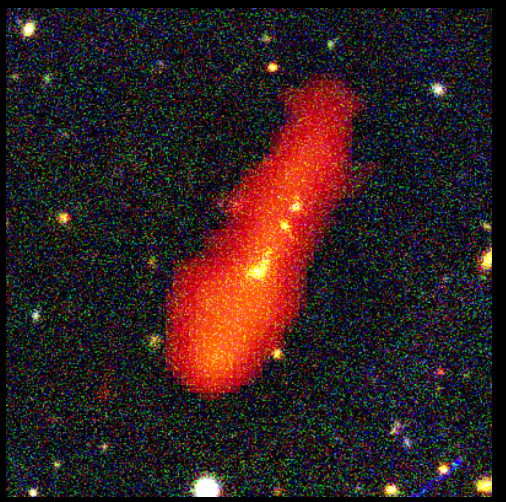


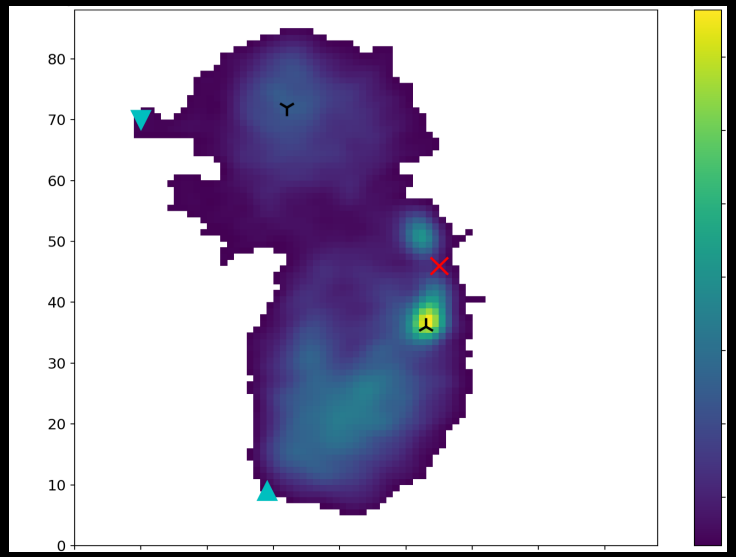




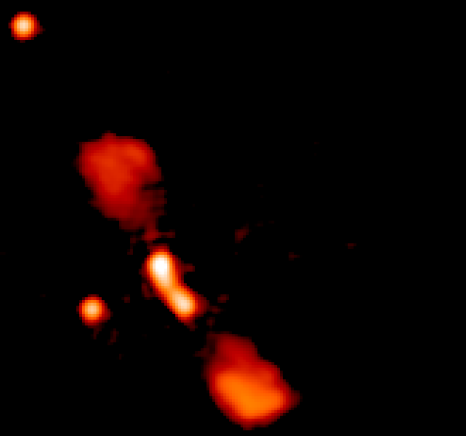

The Open University

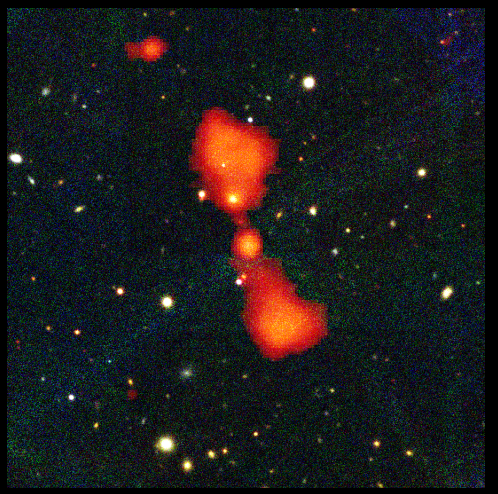
RESTARTERS







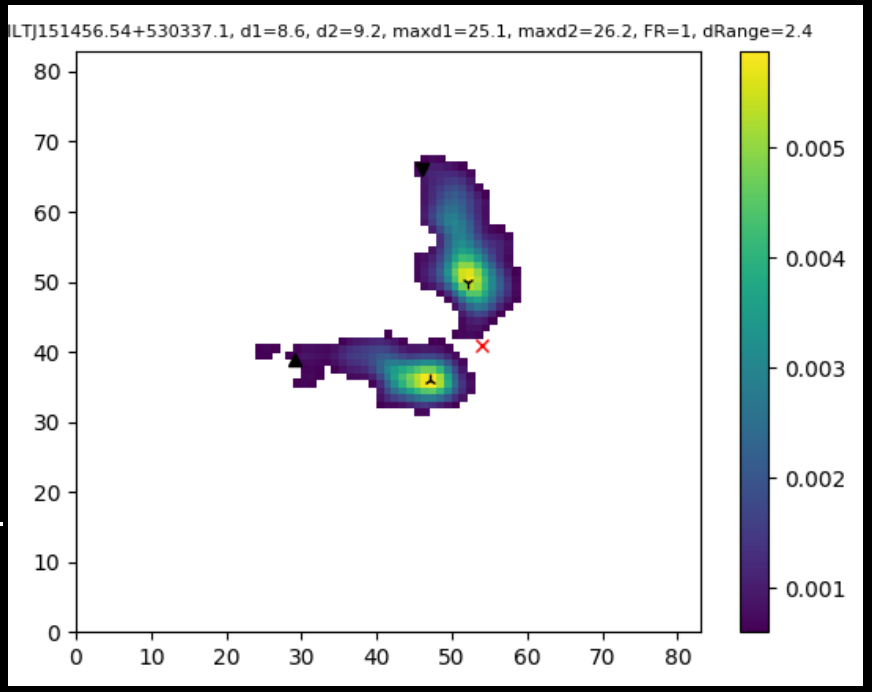




Our best candidates to directly constrain AGN cycles!

NEXT STEPS

- Characterise hosts
  - Morphology, colour, stellar mass, SFR
- Characterise environments
  - Optical, IR, X-rays
  - Predictions (Croston + 2017)
- z binning → evolution?
- Bias, completeness, reliability…
- Sub-populations (D/D, WAT, galaxy-scale sources, hybrids…)



The Open University

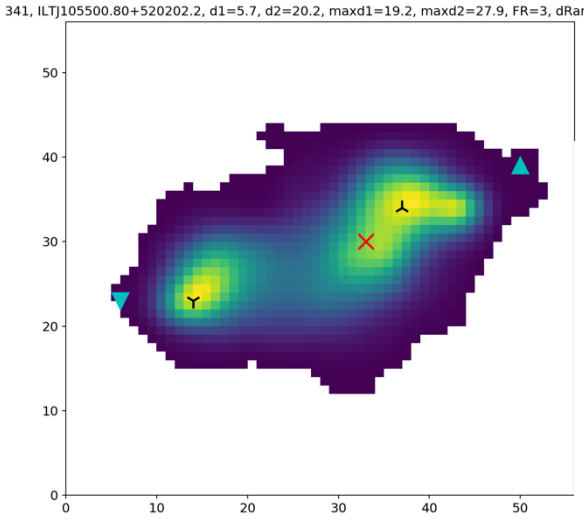
CONCLUSIONS

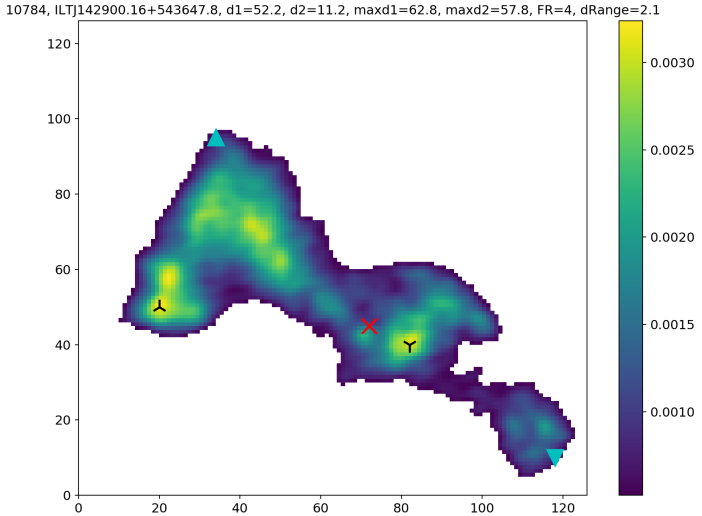
- Early results on classification of the extended LOFAR HETDEX sources show the potential for key radio galaxy science, with heretofore unachievable statistics.
  - We need a systematic approach → SKA
- Selecting clean, reliable samples of FRI/FRII will allow us to explore their properties in the context of z, hosts, environments…
  - Crucial to understand the underlying question: what makes an FRI/FRII? How does this tie back to AGN life cycles?
  - Restarters are great to directly constrain AGN timescales.
  - Crucial to understand what we are not yet seeing!
- This is just the beginning! ☺

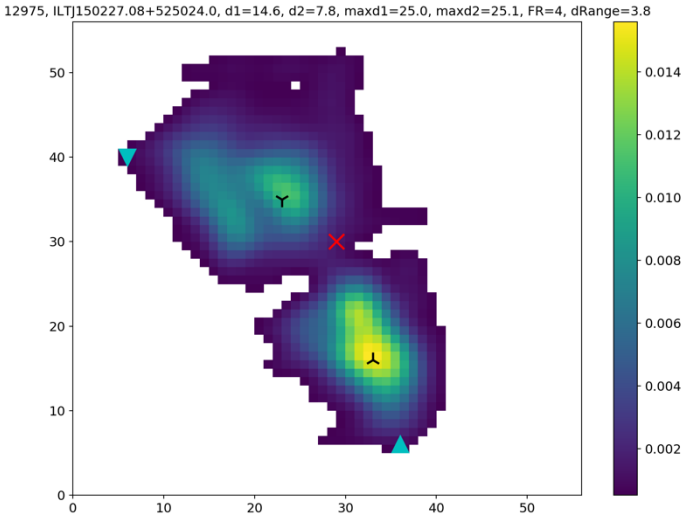
The Open University

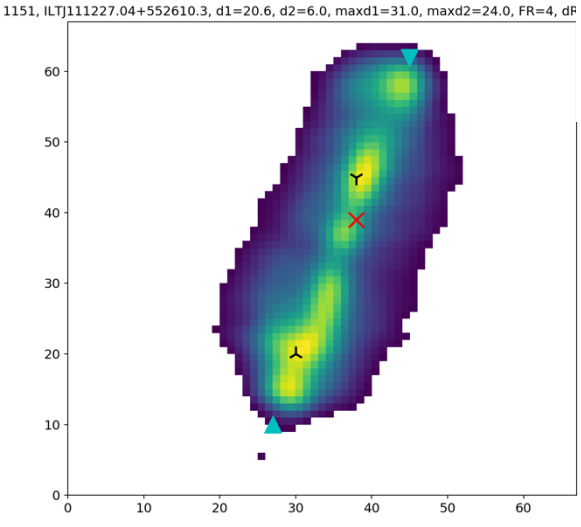
HYBRIDS

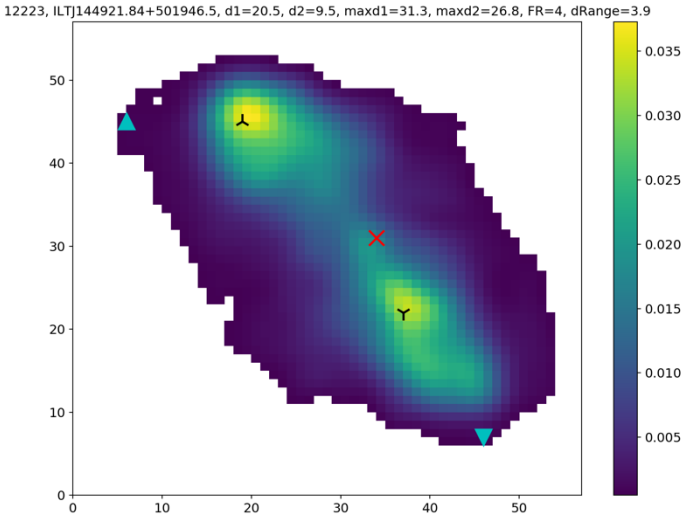
~100 sources





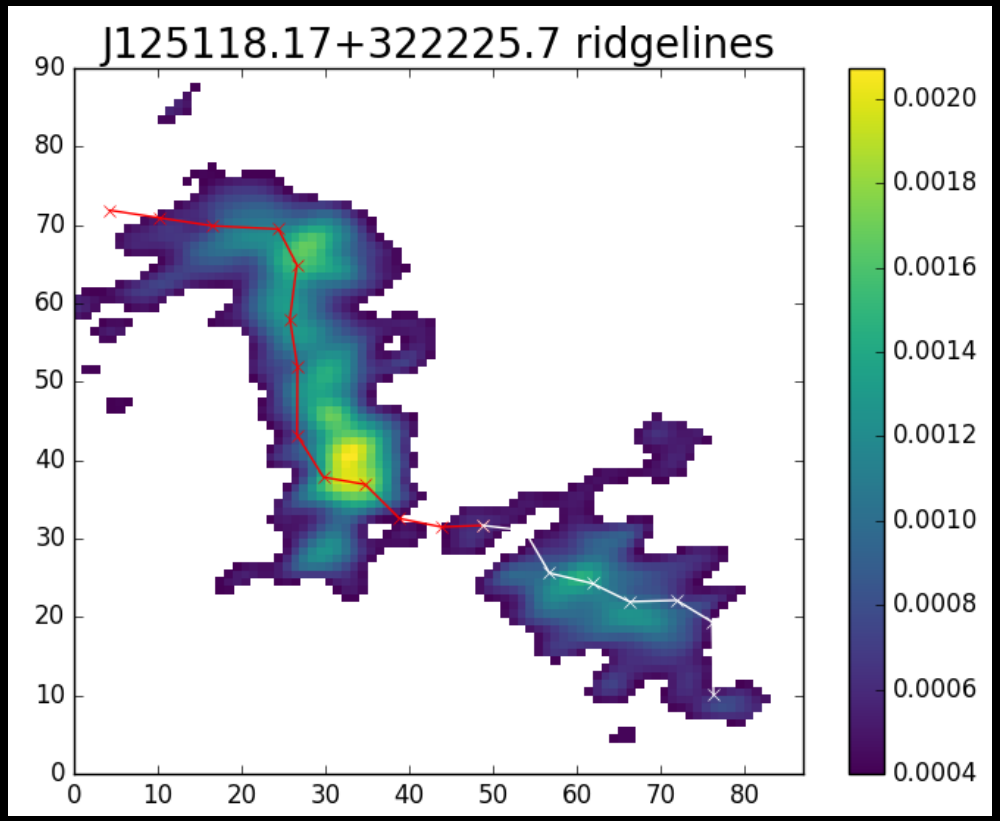




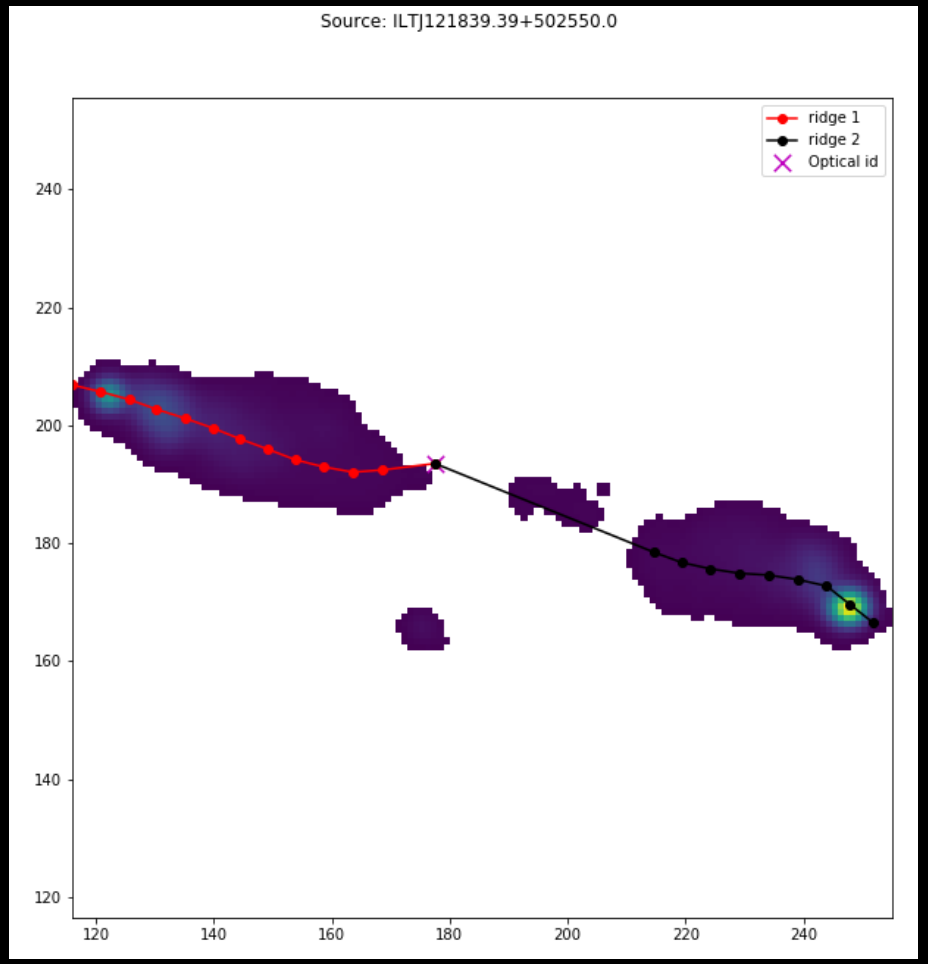


RIDGE-MAPPING

Joanna Piotrowska



H-ATLAS



HETDEX

The Open University

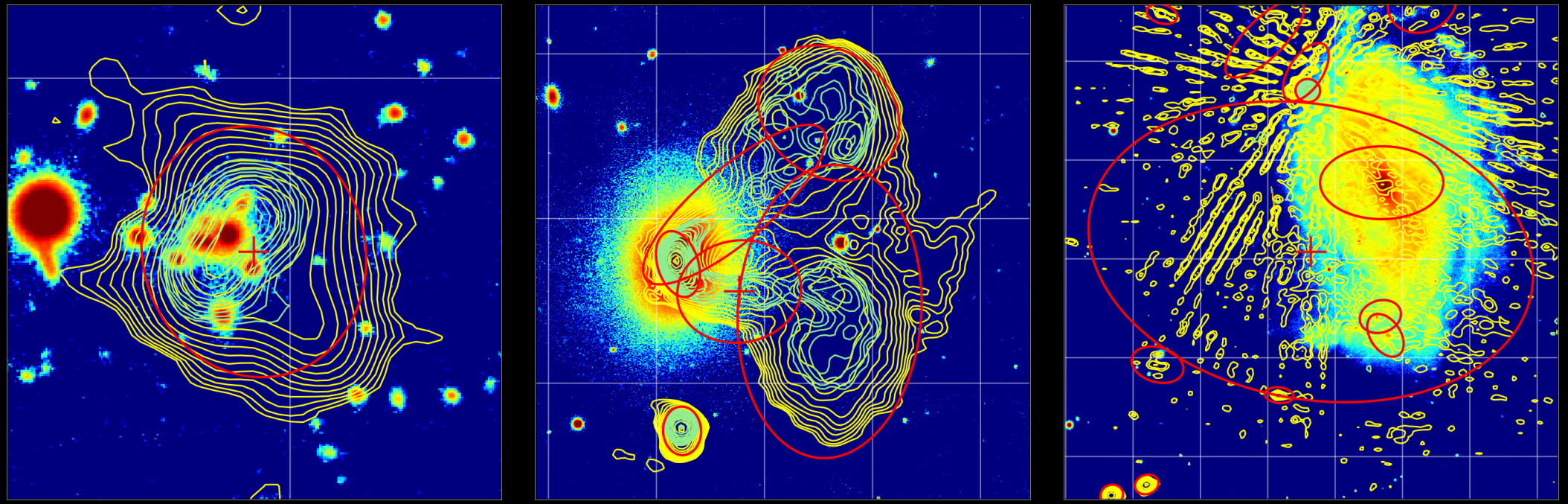
LoTSS: see Wendy's talk!

LOFAR GALAXY ZOO

Biggest challenge: find the host galaxies!

Easier for compact sources (maximum likelihood).

For extended (>12") sources: LOFAR Galaxy Zoo (LGZ)



LOFAR+FIRST contours, Pan-STARRS images (also WISE)