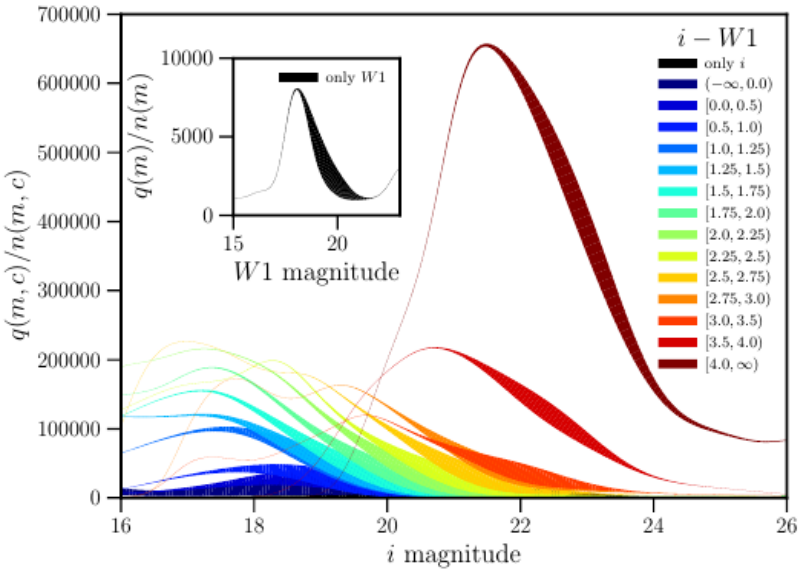
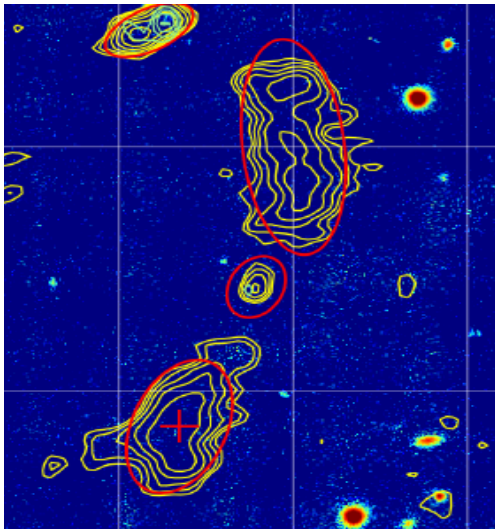
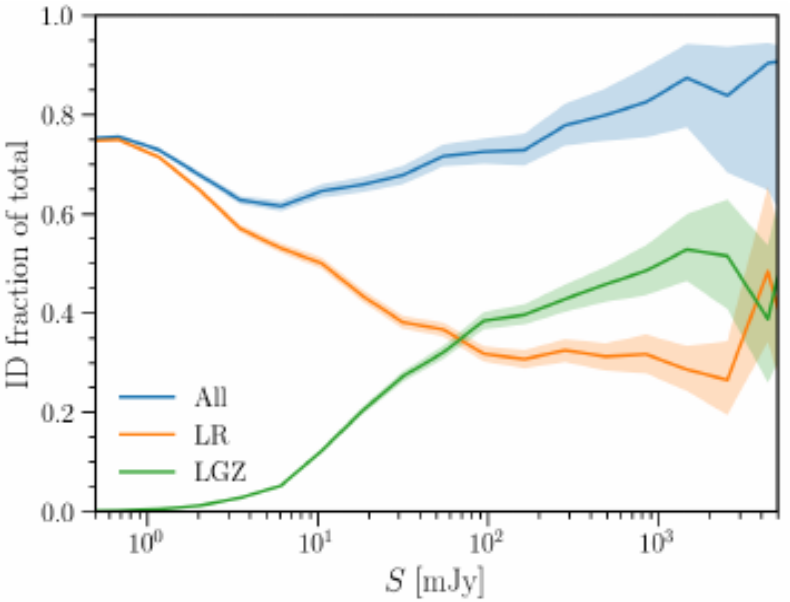
# The LOFAR Two-Metre Sky Survey Data Release 1 (LoTSS DR1)

## optical/IR identifications and value-added catalogue







## Wendy Williams (Leiden Observatory)

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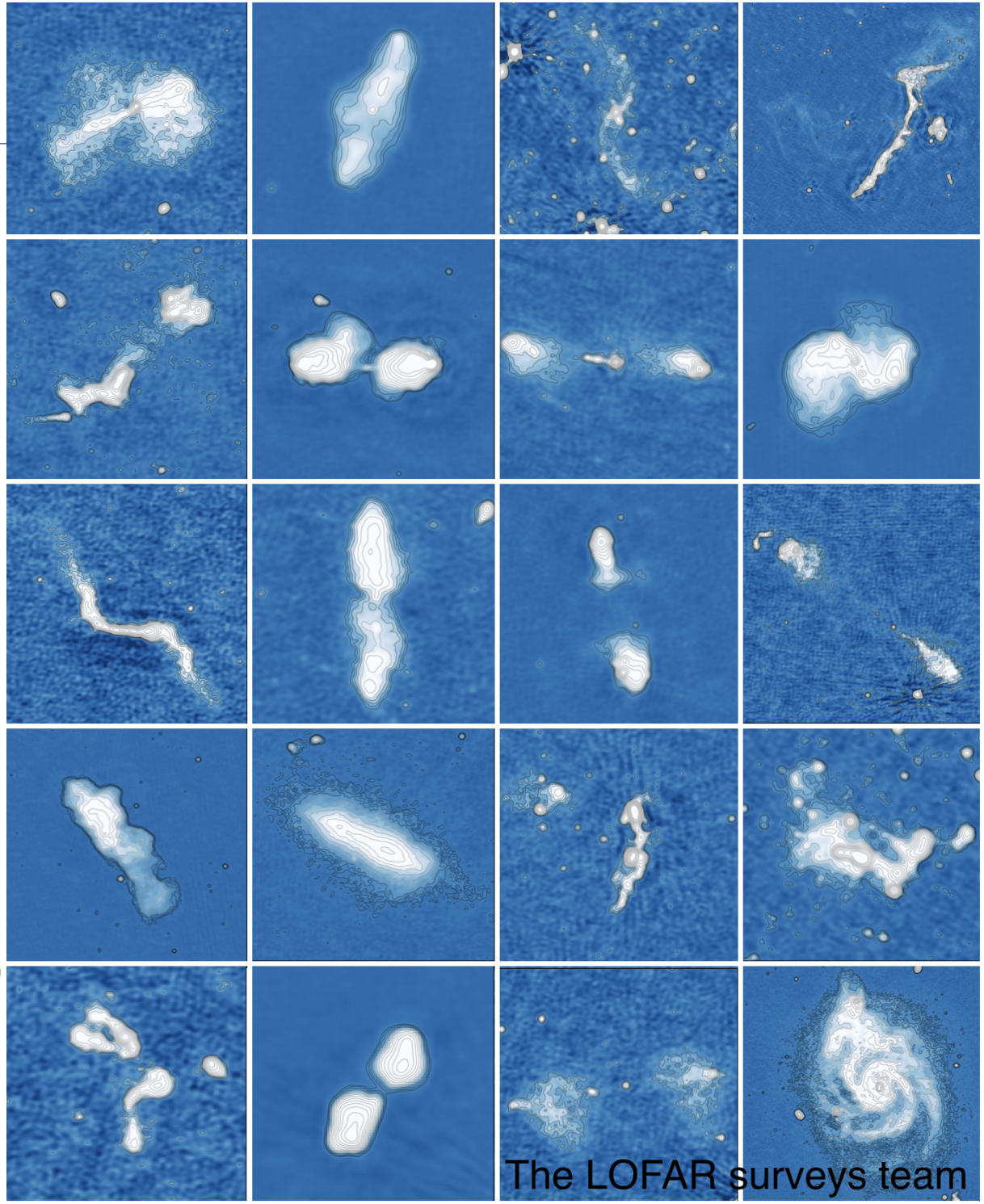
# LoTSS DR1

- Images & Radio Catalogue – Shimwell+ 2019
  - 424 sq deg
  - 6"
  - 70 muJy/bm
  - 320k sources
- Value added catalogue – Williams+ 2019
  - 230k with ID (73%)
- Redshifts – Duncan+ 2019
  - 160k with photo-z's (50%)

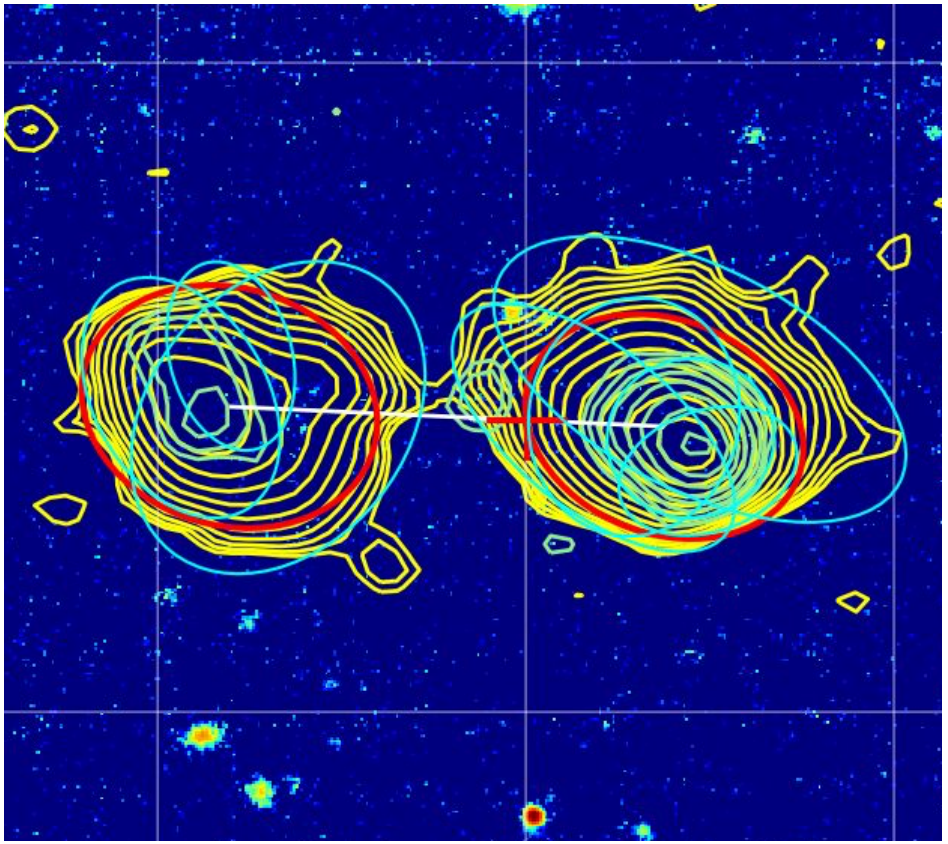


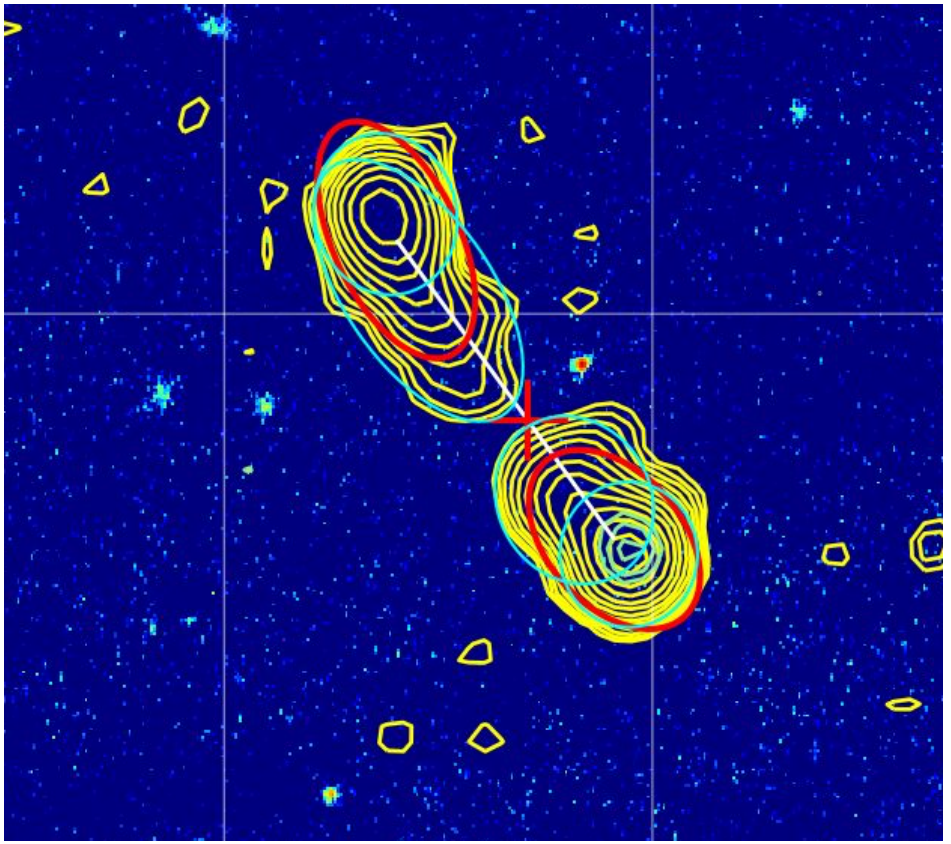
# LoTSS-DR1 VAC Science Highlights

- Mingo, B., et al. in prep
- Wang, L., et al. in prep
- Dabhade, P., et al. submitted
- Gürkan, G., et al. (2019), A&A, 622, A11
- Croston, J. H., et al. (2019), A&A, 622, A10
- Hardcastle, M. J., et al. (2019), A&A, 622, A12
- Mahatma, V. H., et al. (2019), A&A, 622, A13
- Sabater, J., et al. (2019), A&A, 622, A17
- Mooney, S., et al. (2019), A&A, 622, A14
- O'Sullivan, S. P., et al. (2019), A&A, 622, A16
- Morabito, L. K., et al. (2019), A&A, 622, A15

# Value added catalogue

- Source association and deblending
  - Combining components into sources, and splitting up incorrectly combined components





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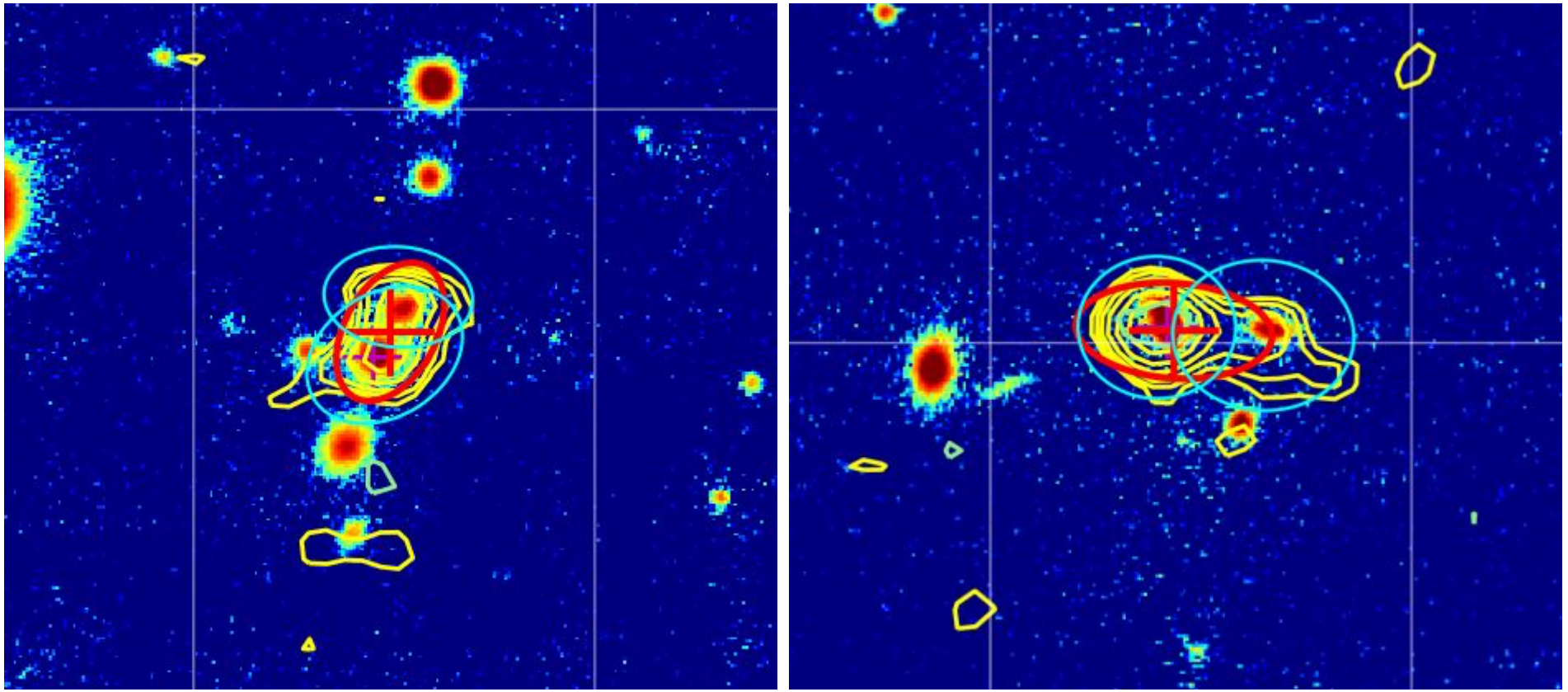


# Value added catalogue

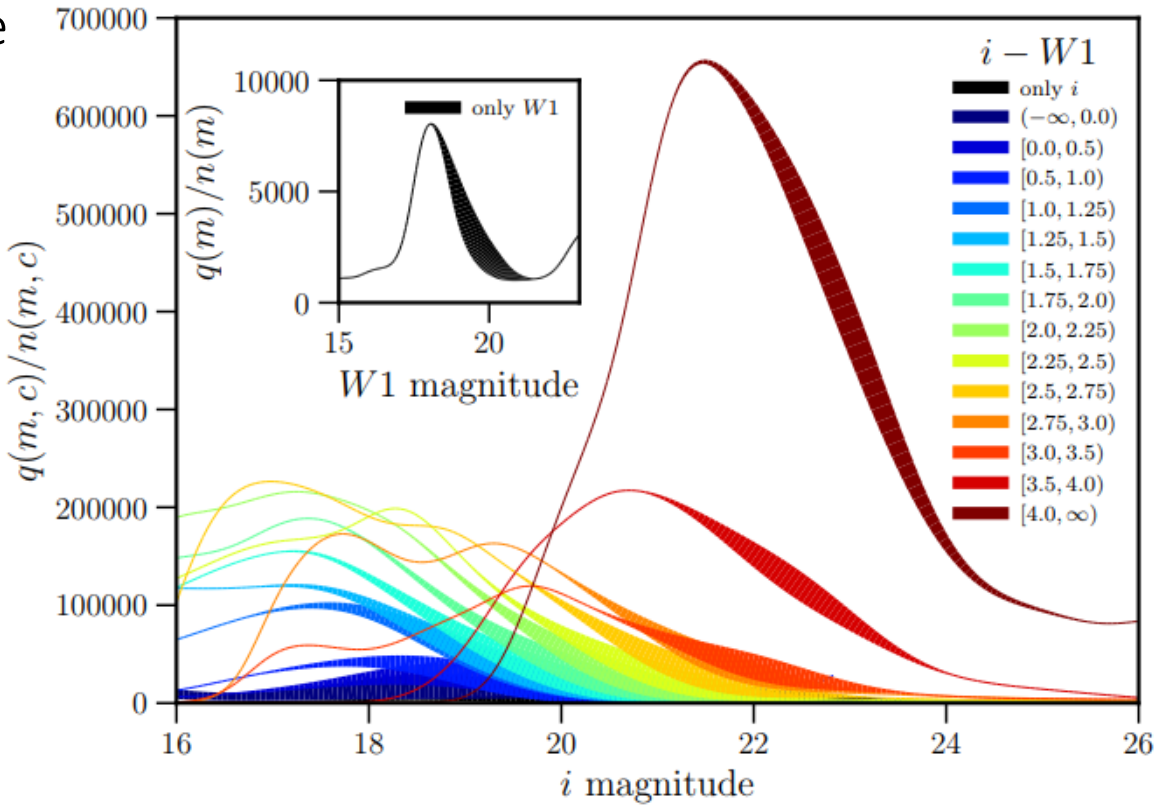
- Source association and deblending
  - Combining components into sources, and splitting up incorrectly combined components
- Optical identifications
  - likelihood ratios
  - visual association and identification (LOFAR galaxy zoo)
- LoTSS tier 1 uses optical/IR data from both
  - PanSTARRS (grizy)
  - AllWISE (3.4, 4.6, 12, 22 μm)
    - Combined into a single catalogue using likelihood ratio matching and including WISE-only and PanSTARRS i-band-only sources

# Likelihood ratio identifications

- For non-complex sources the optical IDs are determined from colour- and magnitude-dependent likelihood ratios
- at a given magnitude(m) and colour (c) we determine:
  - the sky density – n(m,c)
  - the a priori probability that the radio source has a counterpart in this bin – q(m,c)
- for a potential match the likelihood ratio is

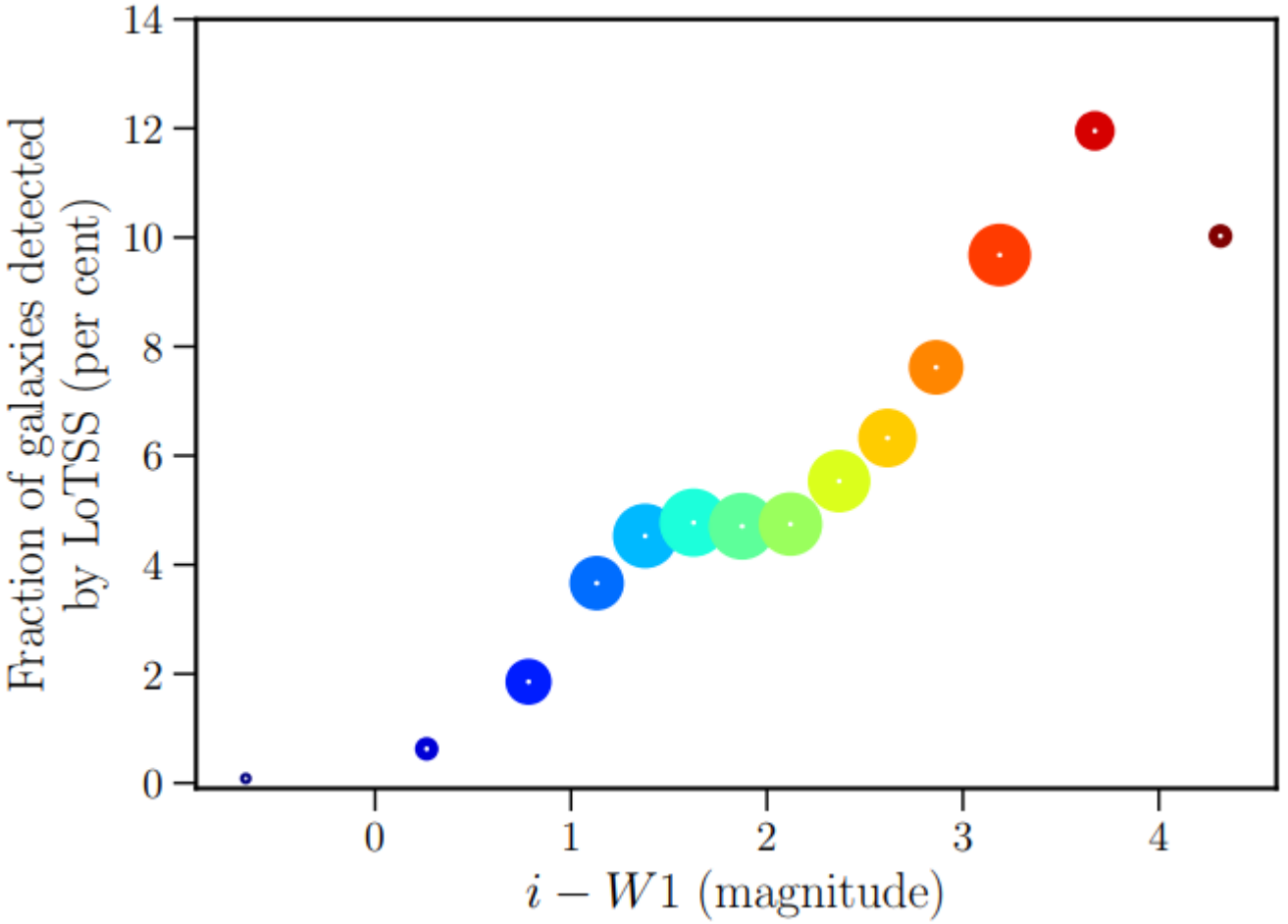
$$LR = \frac{q(m,c)f(r)}{n(m,c)}$$

  - where f(r) is the probability distribution of the offset between the radio and optical positions



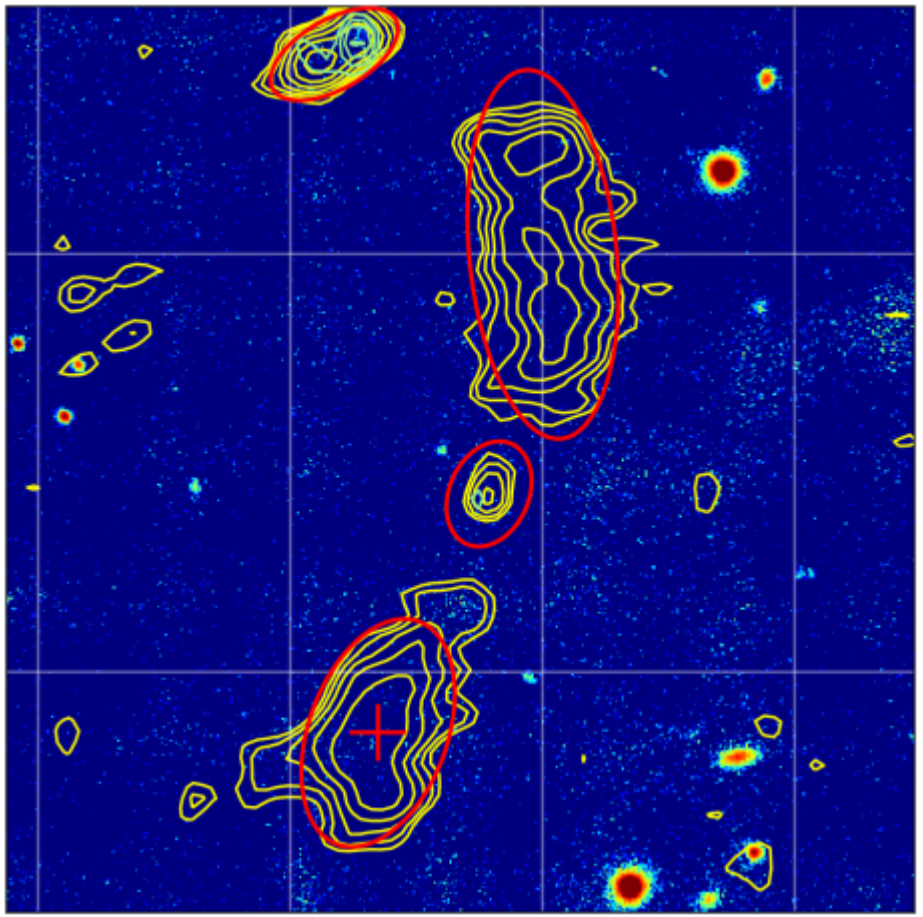
# Likelihood ratio identifications

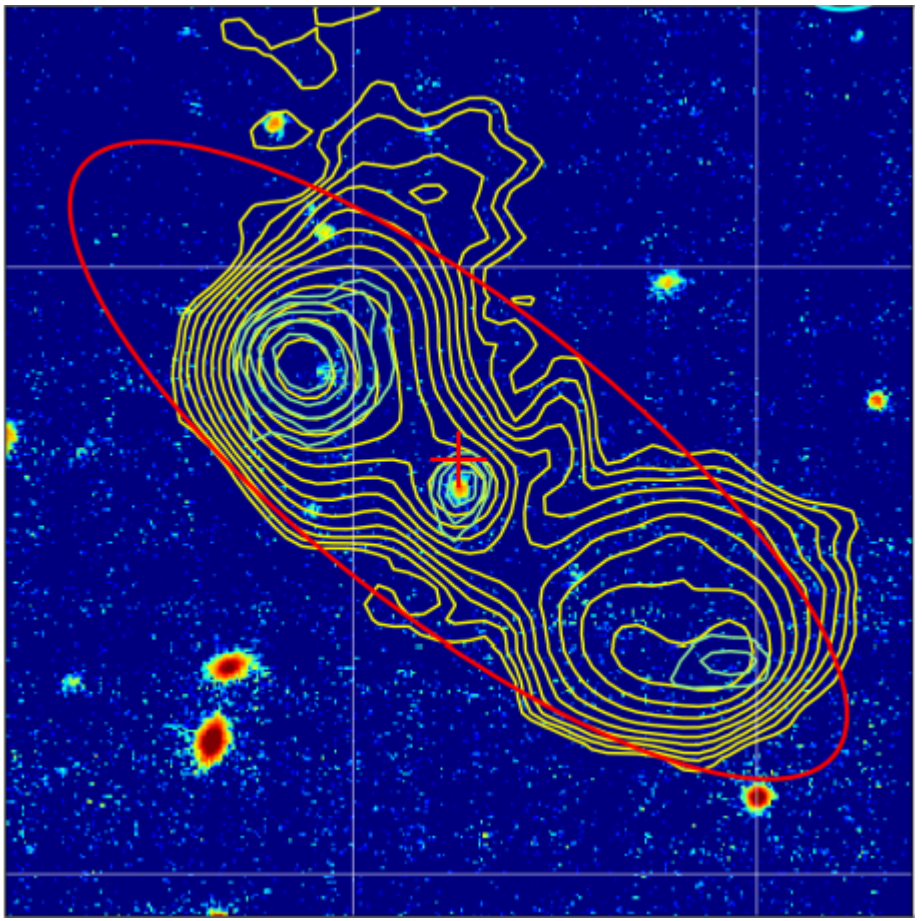
- The probability of the reddest galaxies to host a radio source is an order of magnitude higher than those of the bluest galaxies



# LOFAR Galaxy Zoo

- For complex sources the optical IDs are determined from visual association of radio components and optical identification
  - Expert volunteers / KSP members only
  - 5 views per source





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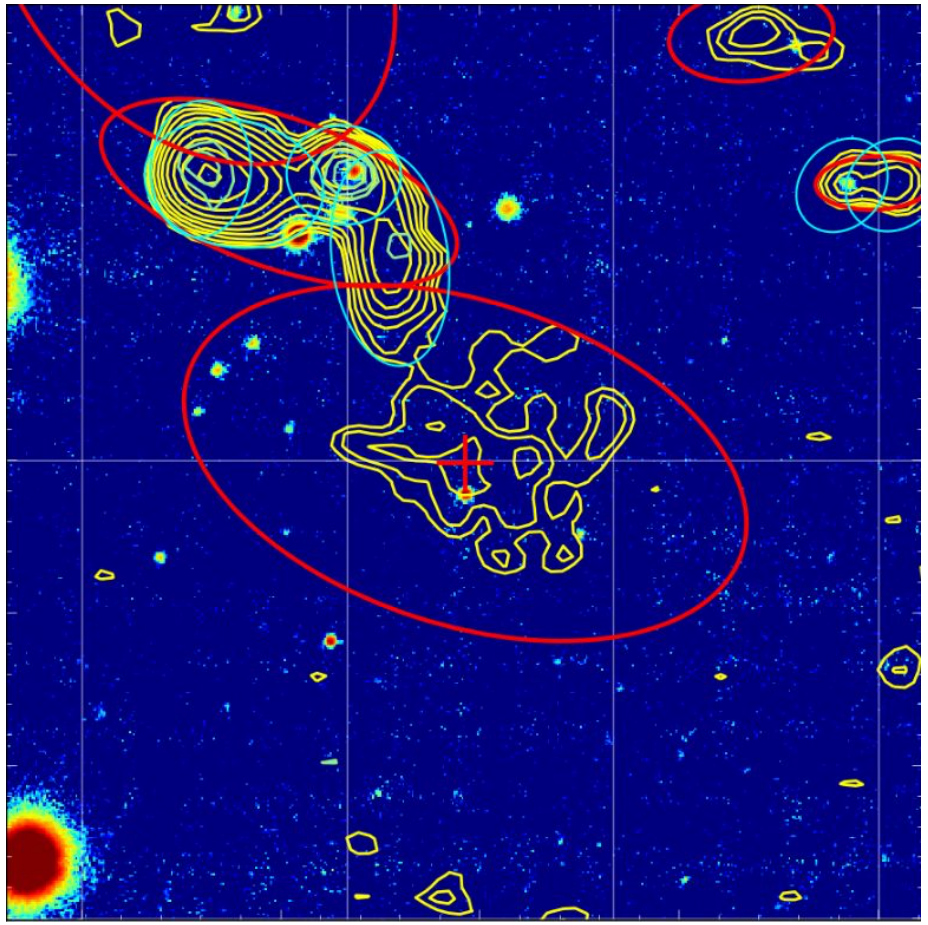
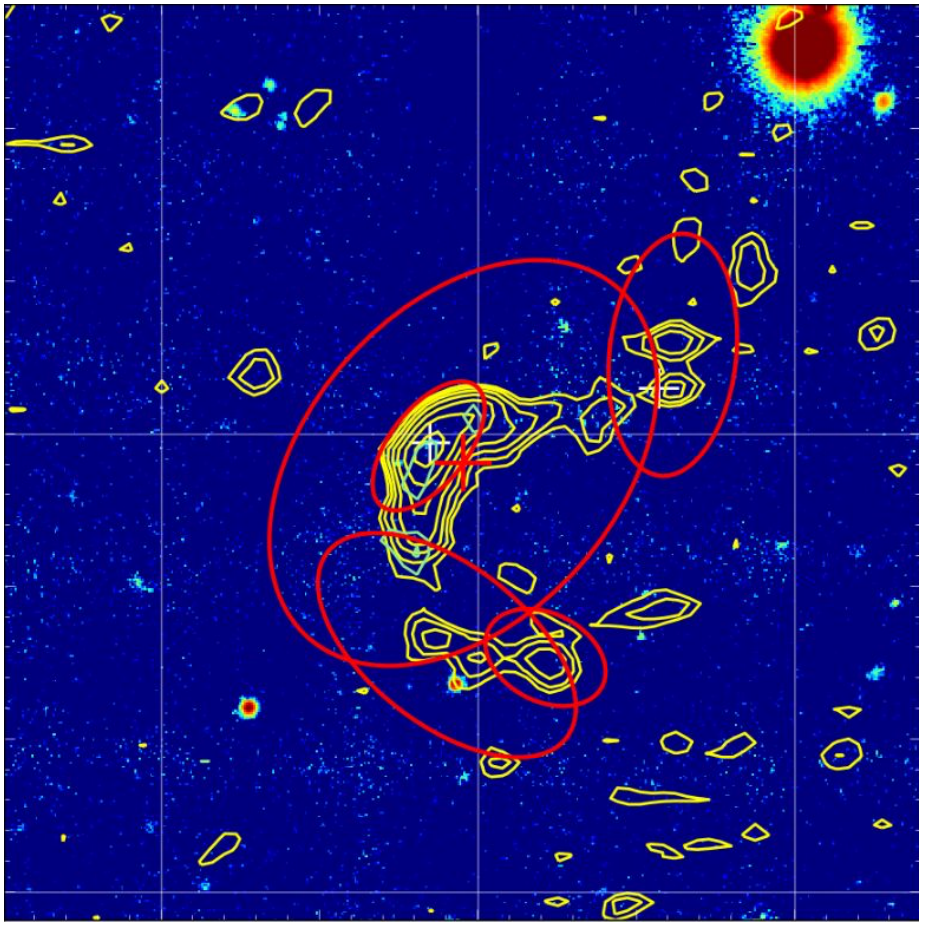
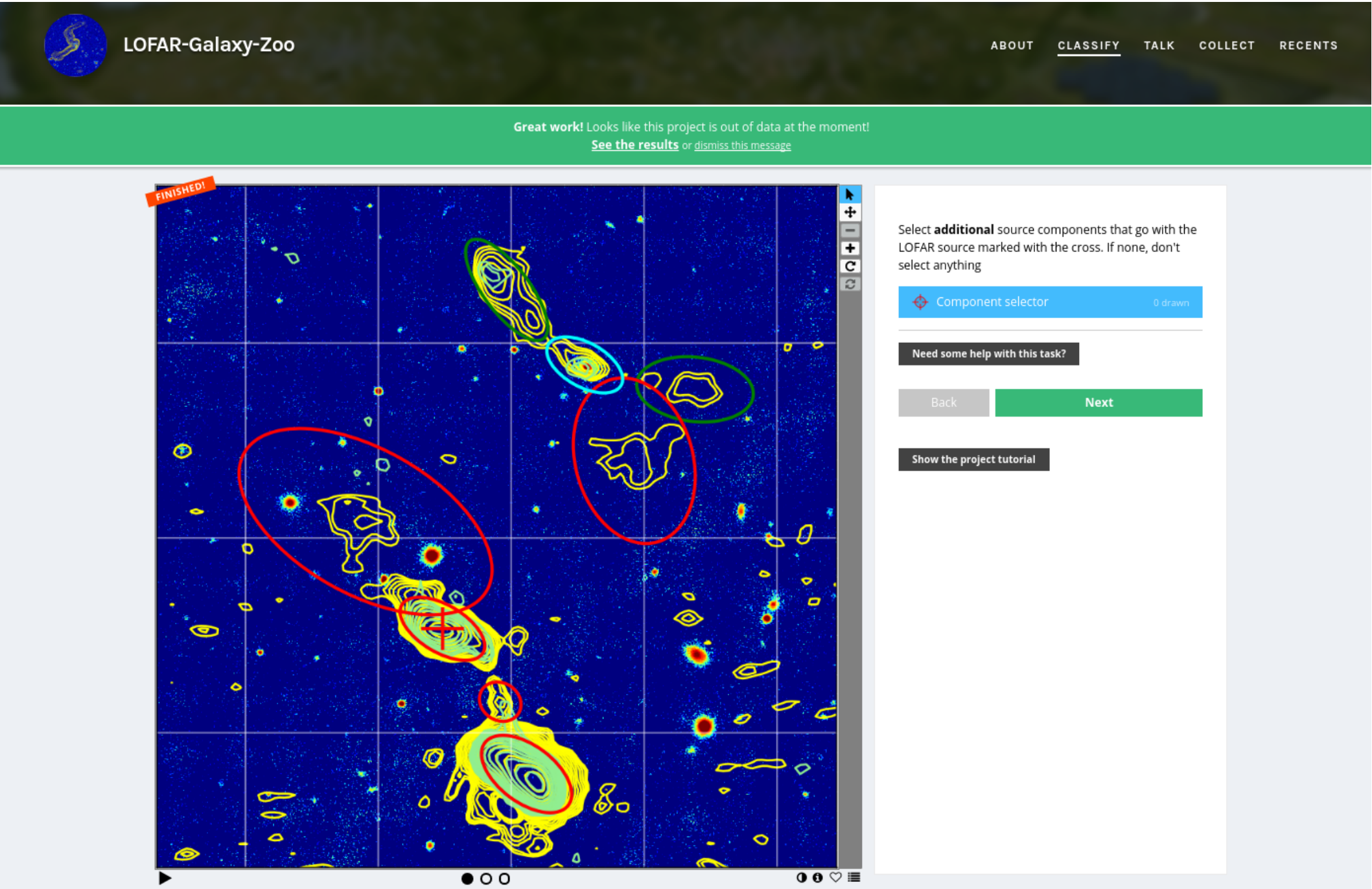
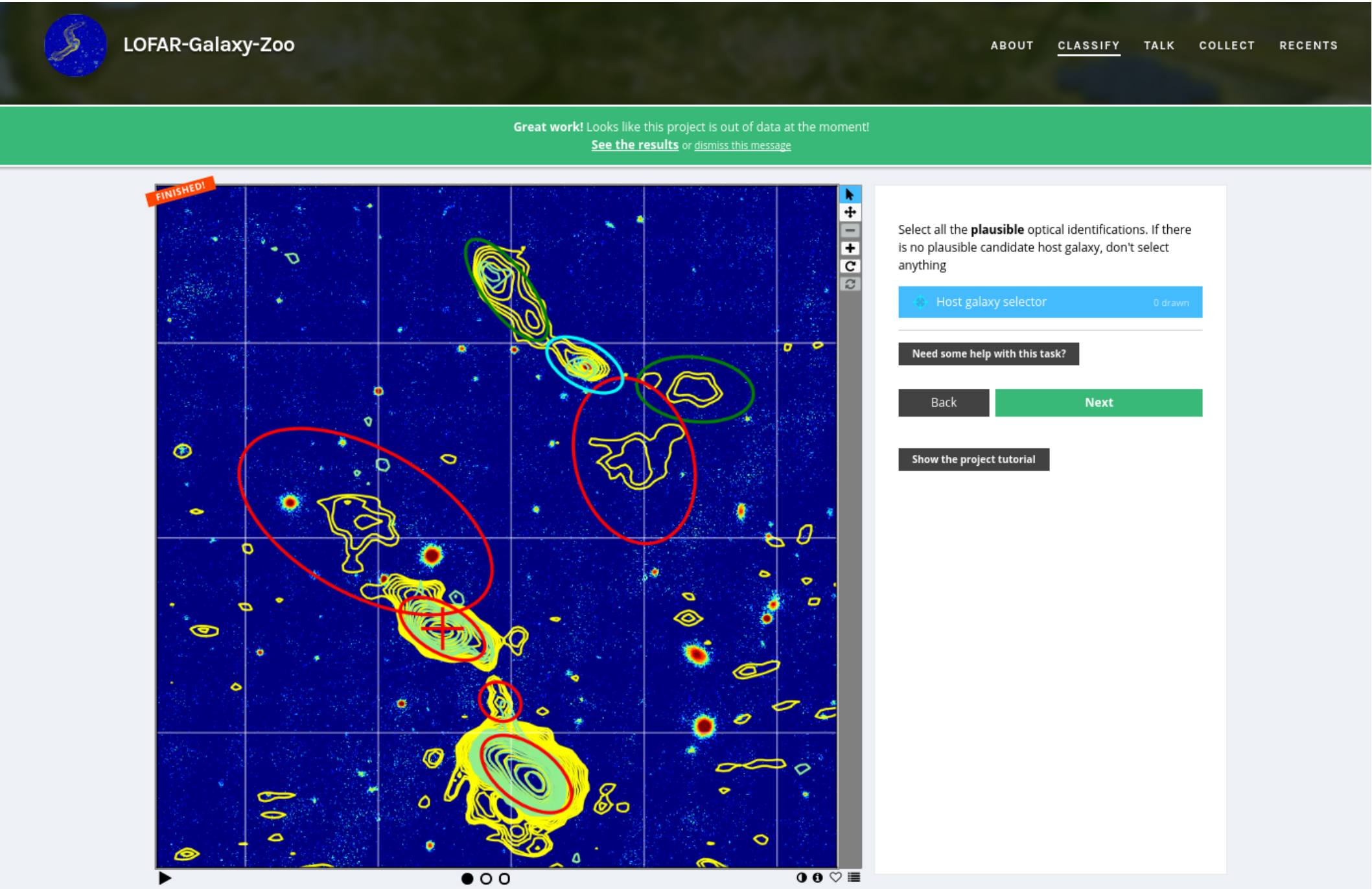
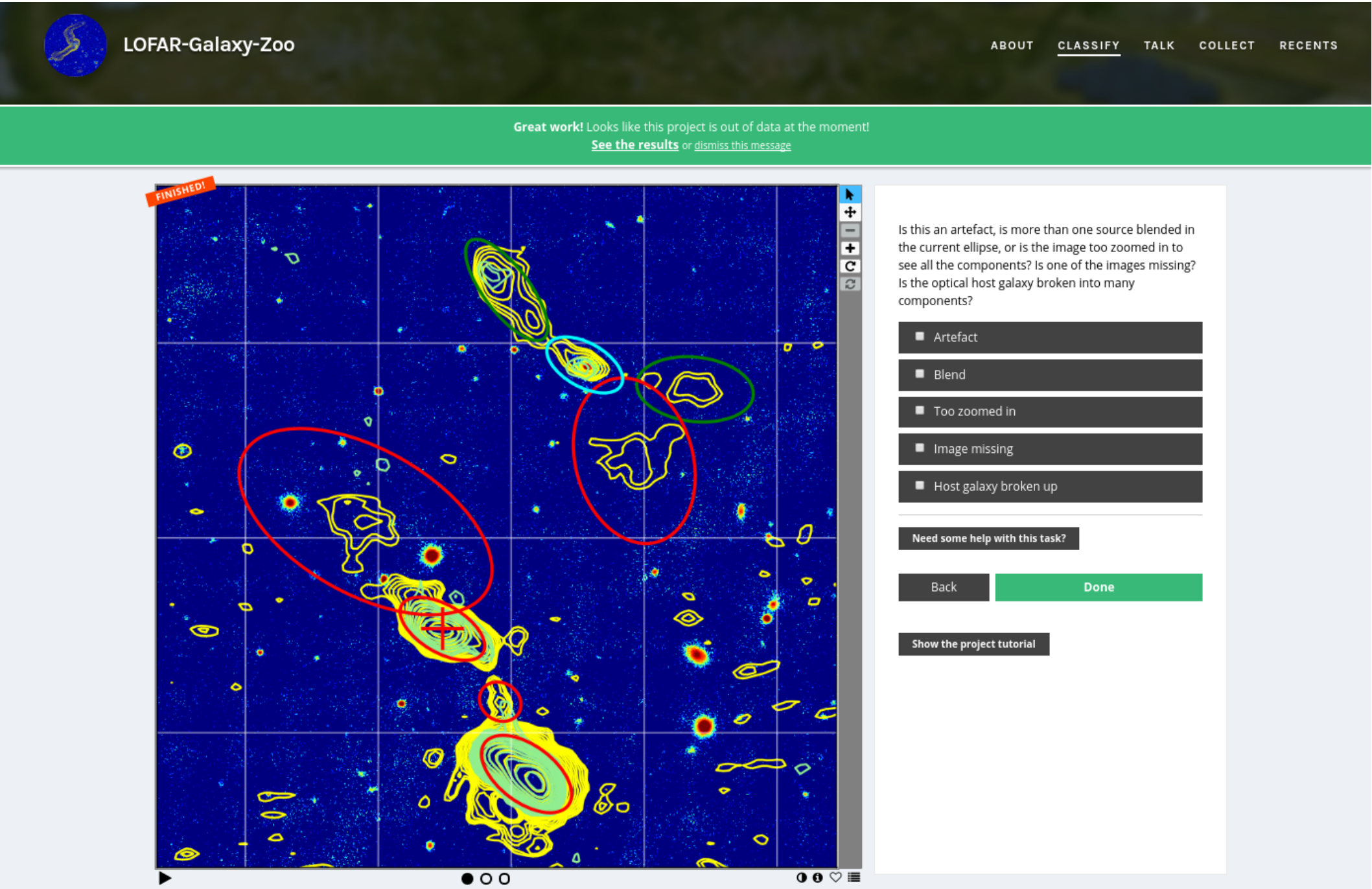




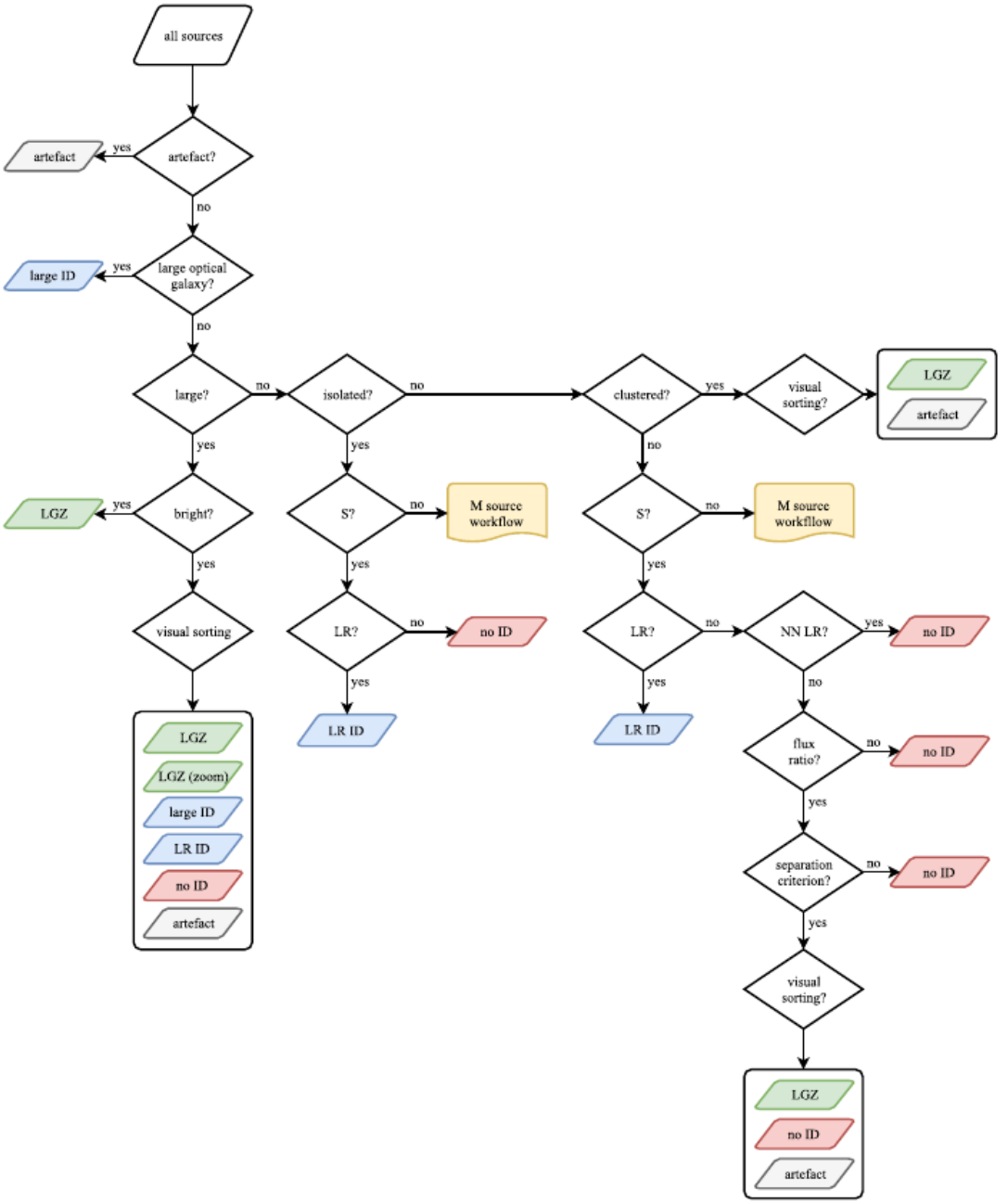

LOFAR-Galaxy-Zoo
ABOUT
CLASSIFY
TALK
COLLECT
RECENTS
Great work! Looks like this project is out of data at the moment!
See the results or dismiss this message
FINISHED!
Select additional source components that go with the LOFAR source marked with the cross. If none, don't select anything
Component selector
0 drawn
Need some help with this task?
Back
Next
Show the project tutorial


LOFAR-Galaxy-Zoo
ABOUT
CLASSIFY
TALK
COLLECT
RECENTS
Great work! Looks like this project is out of data at the moment!
See the results or dismiss this message
FINISHED!
Select all the plausible optical identifications. If there is no plausible candidate host galaxy, don't select anything
Host galaxy selector
0 drawn
Need some help with this task?
Back
Next
Show the project tutorial


LOFAR-Galaxy-Zoo
ABOUT
CLASSIFY
TALK
COLLECT
RECENTS
Great work! Looks like this project is out of data at the moment!
See the results or dismiss this message
FINISHED!
Is this an artefact, is more than one source blended in the current ellipse, or is the image too zoomed in to see all the components? Is one of the images missing? Is the optical host galaxy broken into many components?
Artefact
Blend
Too zoomed in
Image missing
Host galaxy broken up
Need some help with this task?
Back
Done
Show the project tutorial

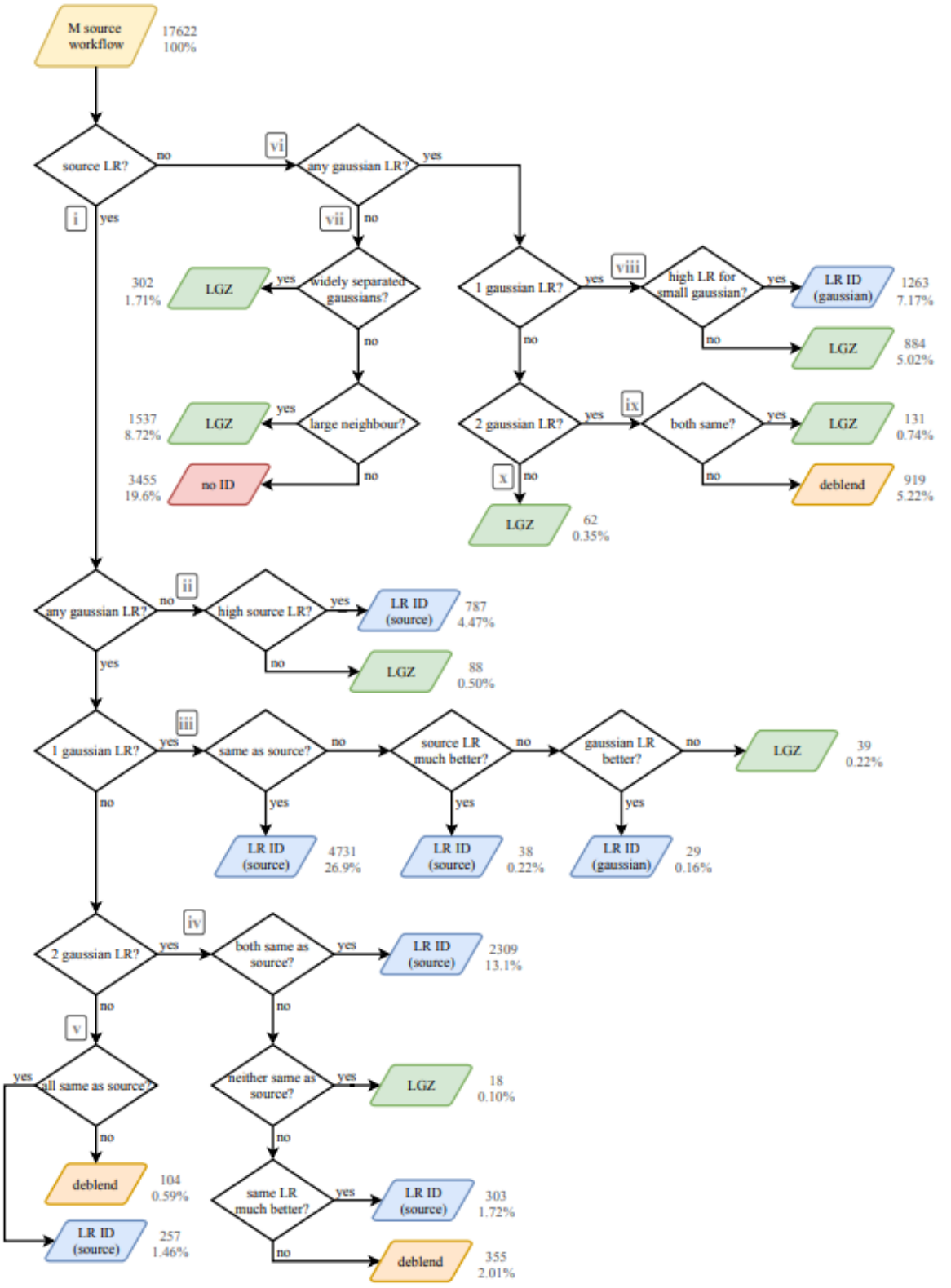
# Selection for LGZ/LR identification

- Sources are selected for either likelihood ratio identification or visual analysis through a decision tree based on the PyBDSF source properties
  - Size
  - Flux
  - Distance to neighbours
  - Likelihood ratios
  - Gaussian components
- Involving some stages of rapid 'expert' pre-filtering to visually sort sources



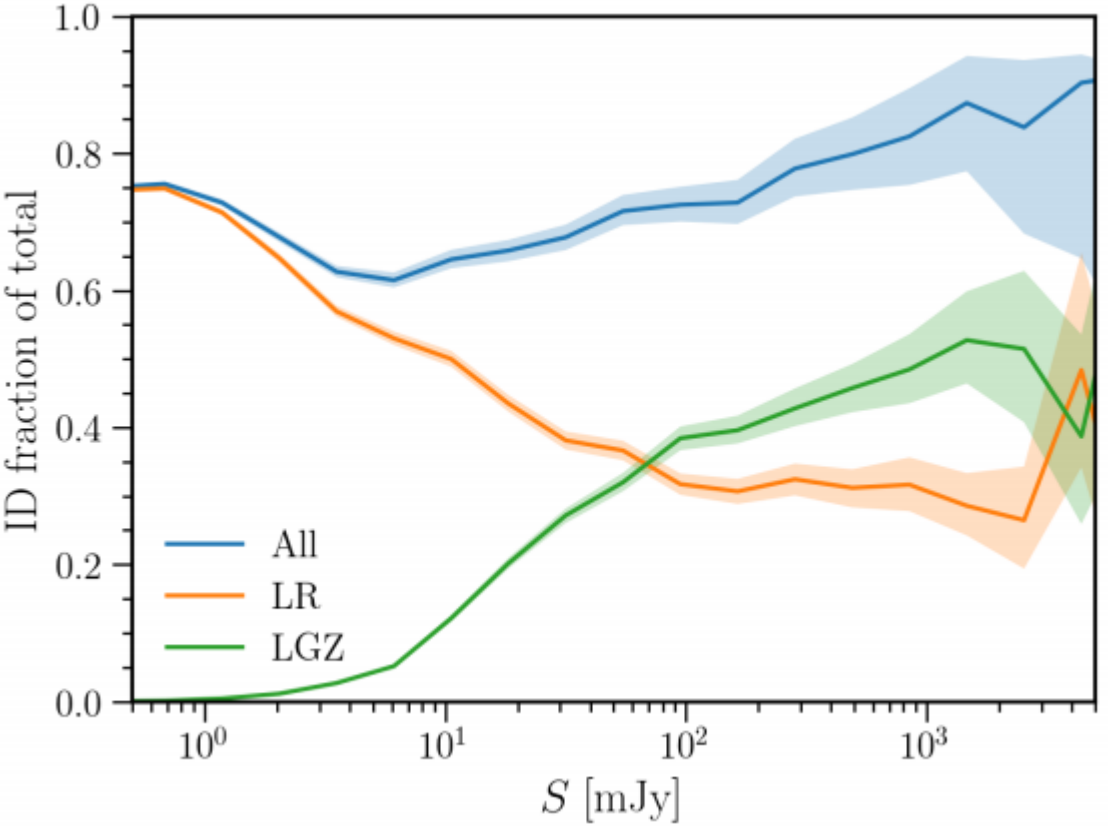
# Selection for LGZ/ LR identification

- Small multiple Gaussian component sources
  - Outputs select either
    - LR identifications
    - LGZ processing
    - 'deblending' for additional 'expert' visual processing
  - Uses LR determined for both the source and its Gaussian components and tries to select 'best' one



# The final catalogue

- IDs for 200k sources (~70%)
  - Most from LR
  - But many interesting/bright source IDs/associations from LGZ




| | Number | Number with ID | ID fraction |
|---|---|---|---|
| All Sources | 318,520 | 231,716 | 0.73 |
| LR | 299,730 | 221,269 | 0.74 |
| LGZ | 11,989 | 7,144 | 0.60 |
| Deblending | 2,435 | 2,338 | 0.96 |
| Bright galaxy | 965 | 965 | 1.00 |
| No ID possible | 3,401 | 0 | 0.00 |

# The final catalogue

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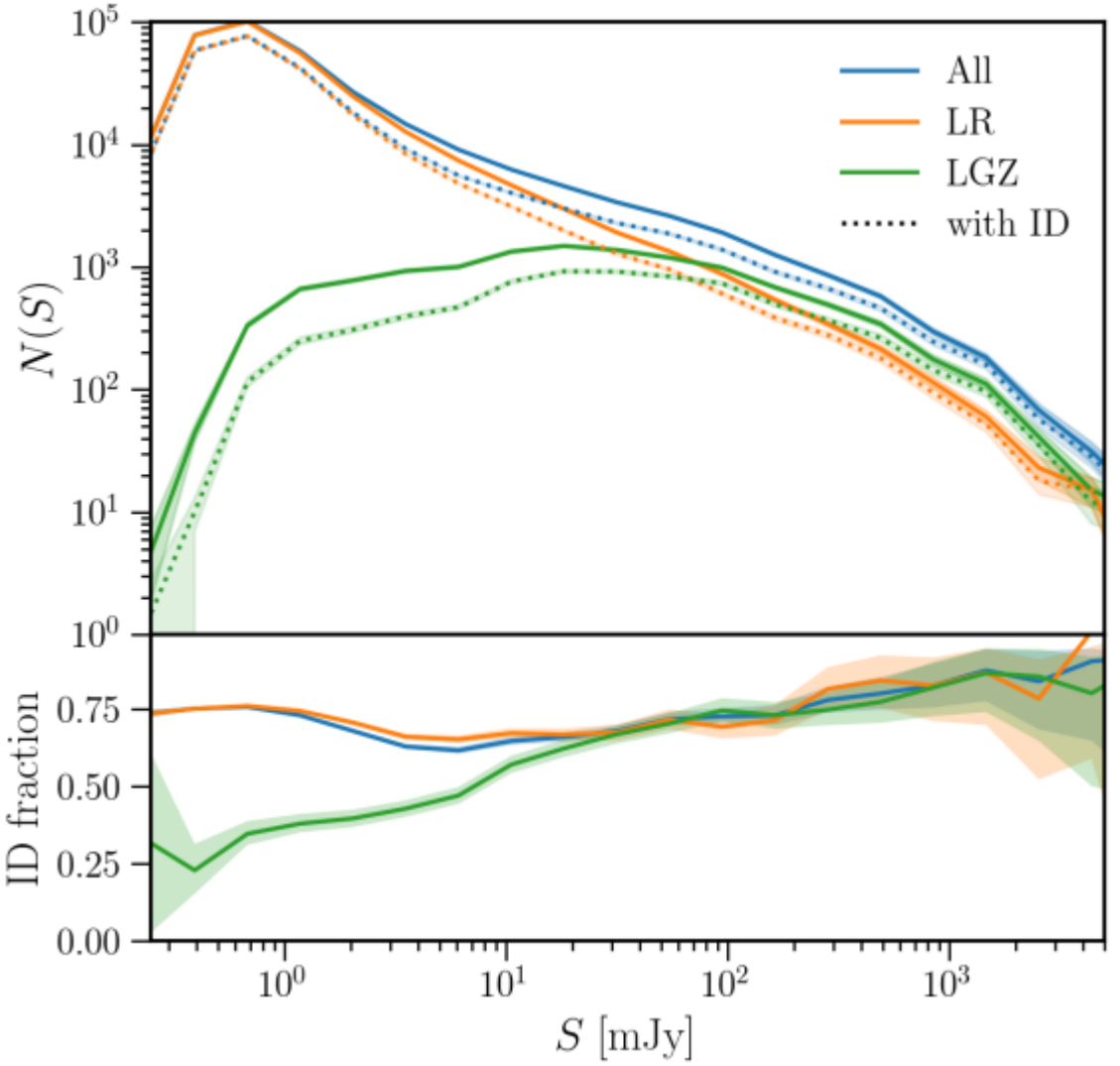
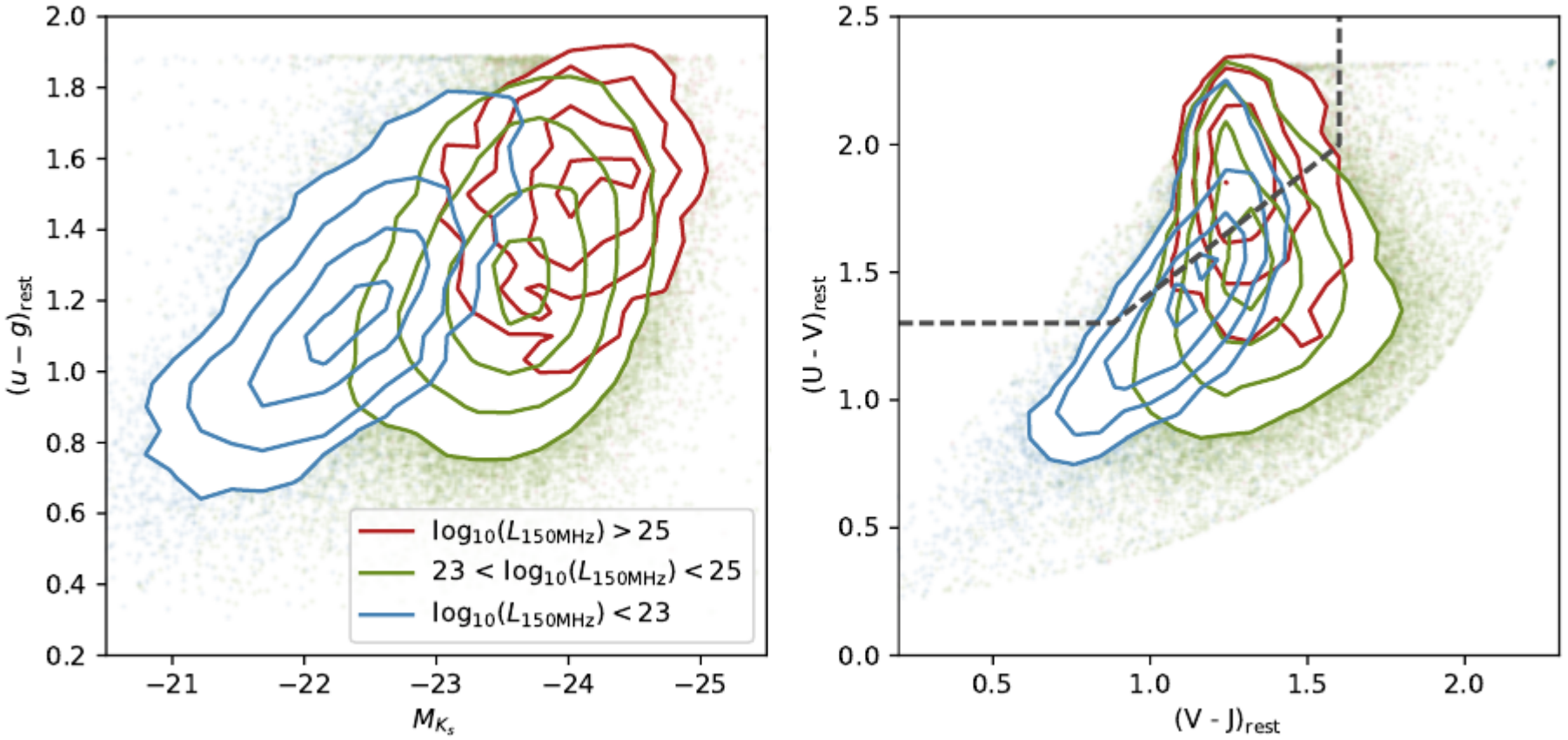
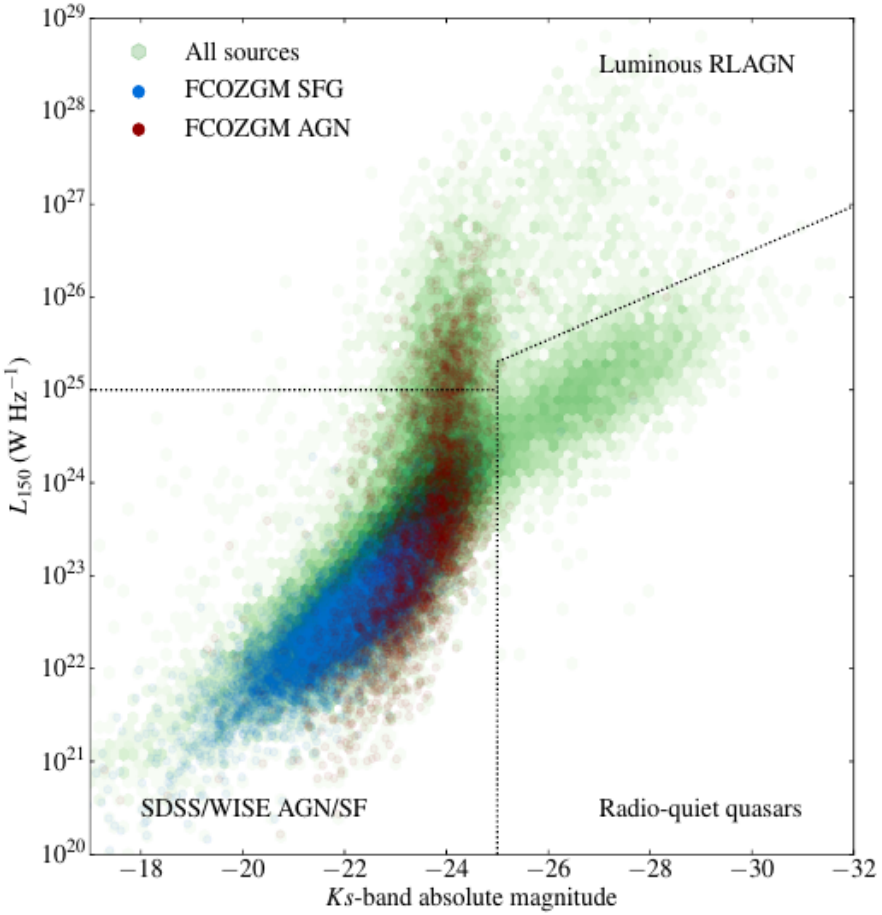


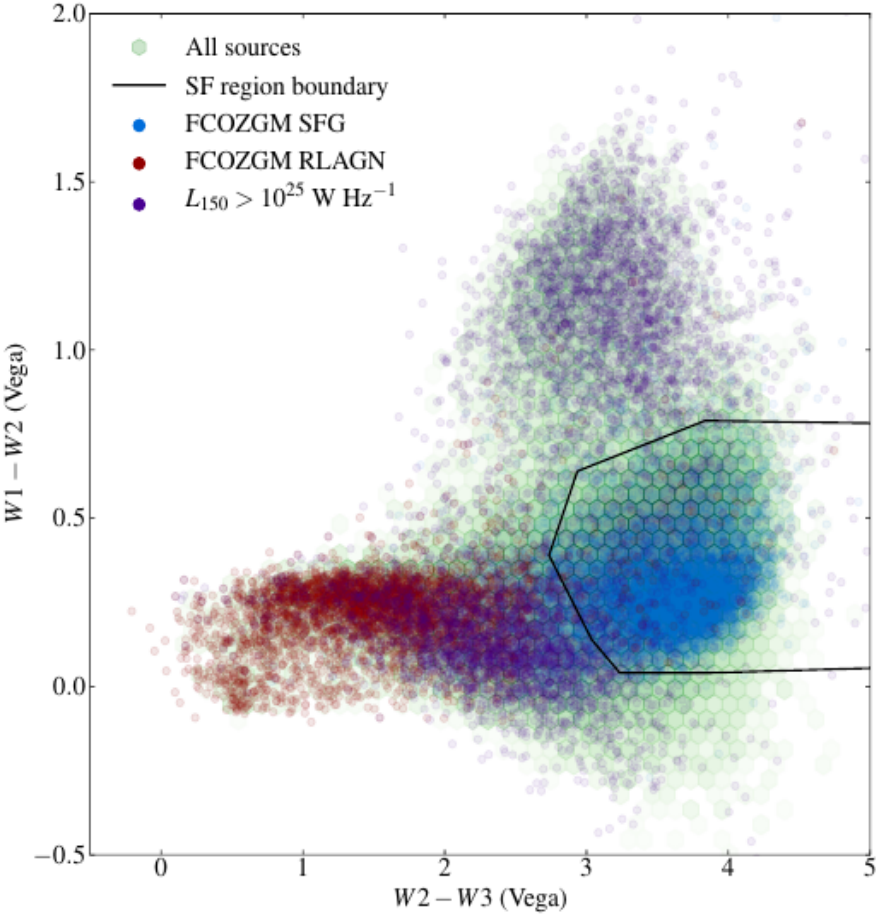
# Redshifts

- 160k with photo-z's (50%) – Duncan+ 2019
- And rest-frame colours



# 23k LoTSS RLAGN



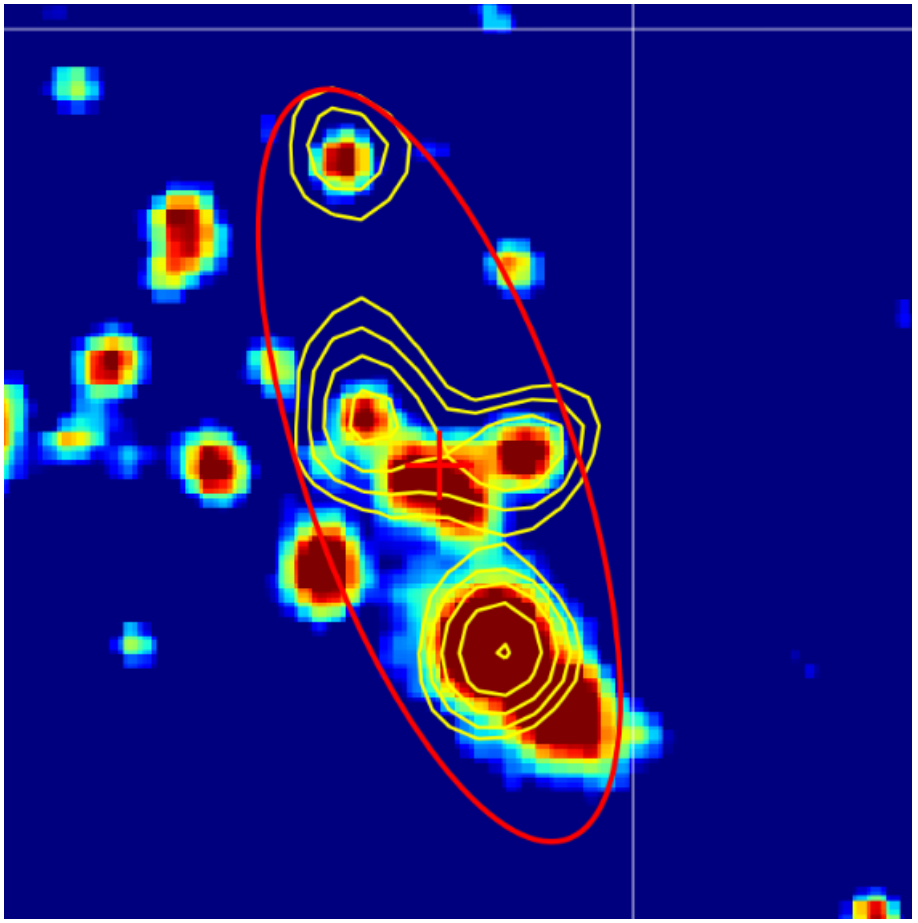

- 72k – flux cut >0.5 mJy – with optical ID – with good z
- RLAGN / SF (23k / 42k) – Spectra (MPAJHU), Luminosity, WISE colour, K mag

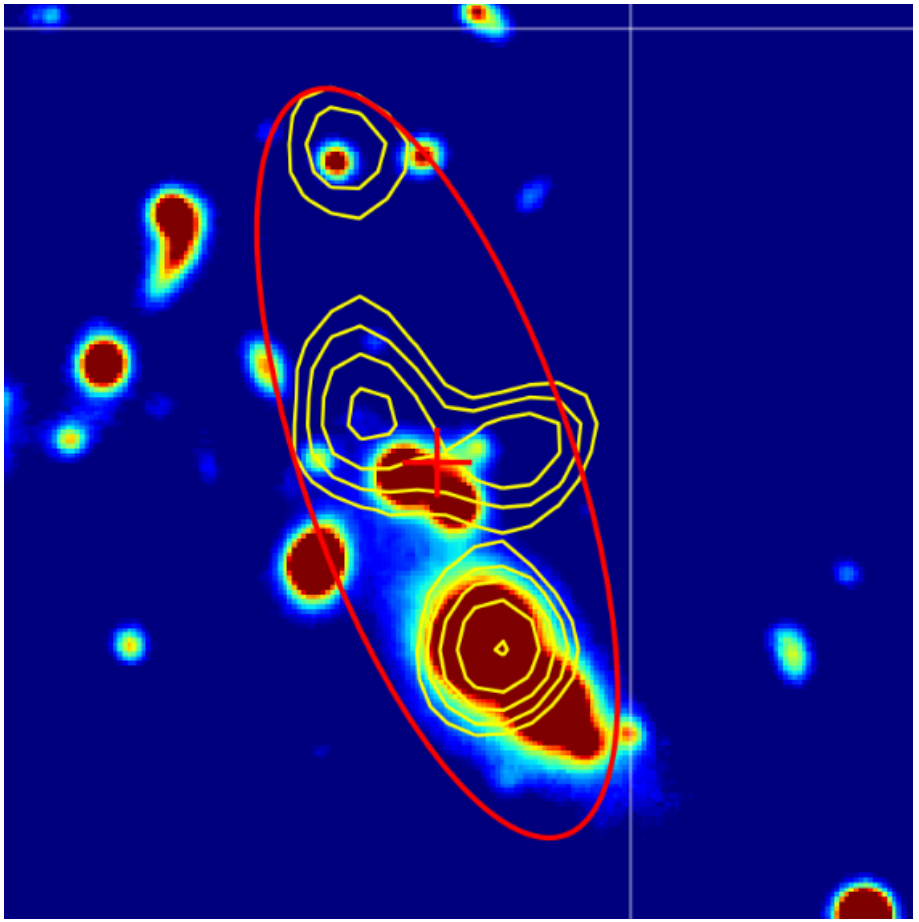
# Cross-Ids for deep fields

- Most of the faint sources are unresolved (easy to ID)
- ...but source density is higher
- Improved selection and prefiltering for LGZ
  - Machine learning (Lara Alegre, Philip Best)
- Further internal LOFAR Galaxy Zoo version 1
  - But with deeper optical images

# Cross-Ids for deep fields

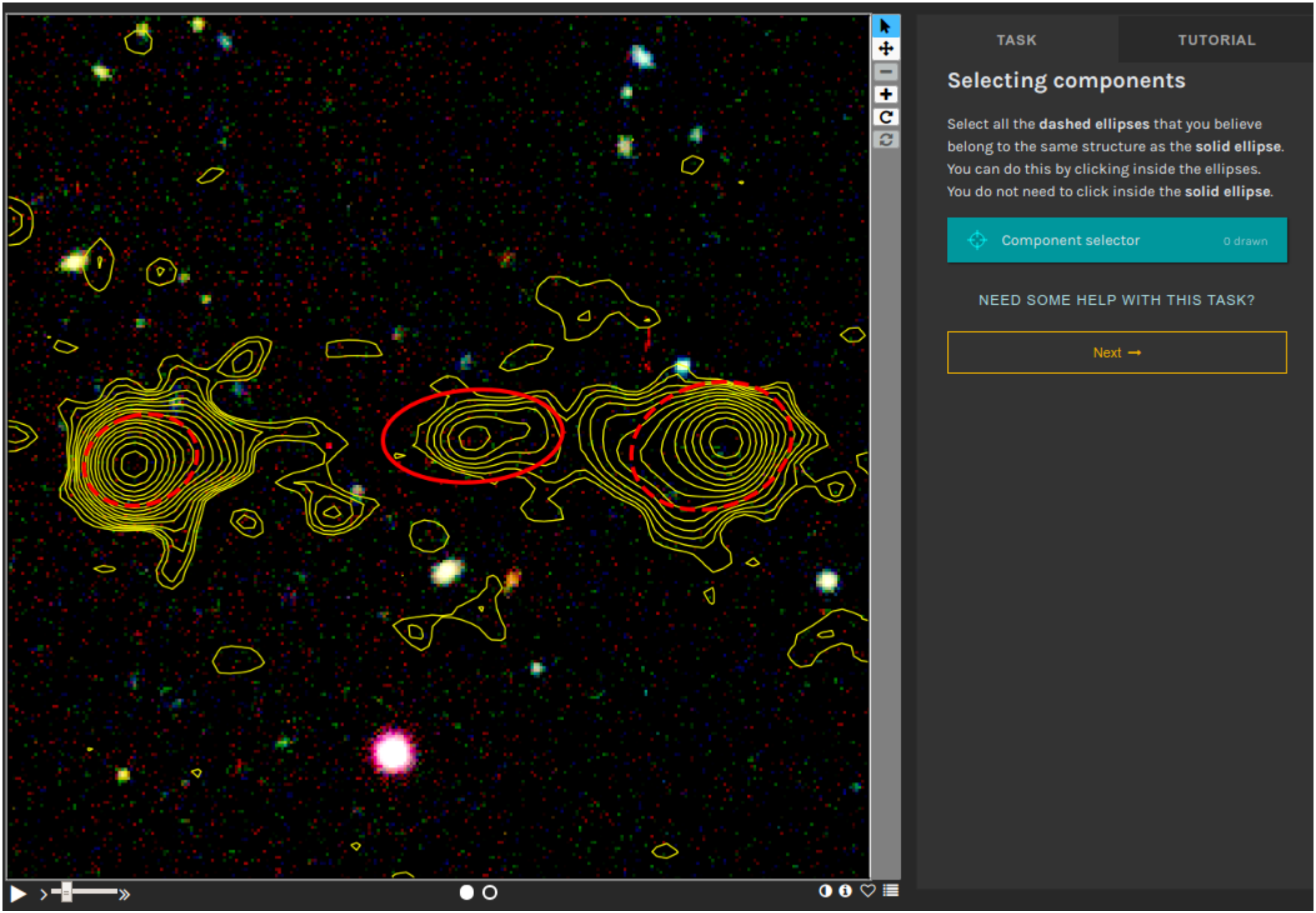
- Deep optical/IR images.... and deeper radio data

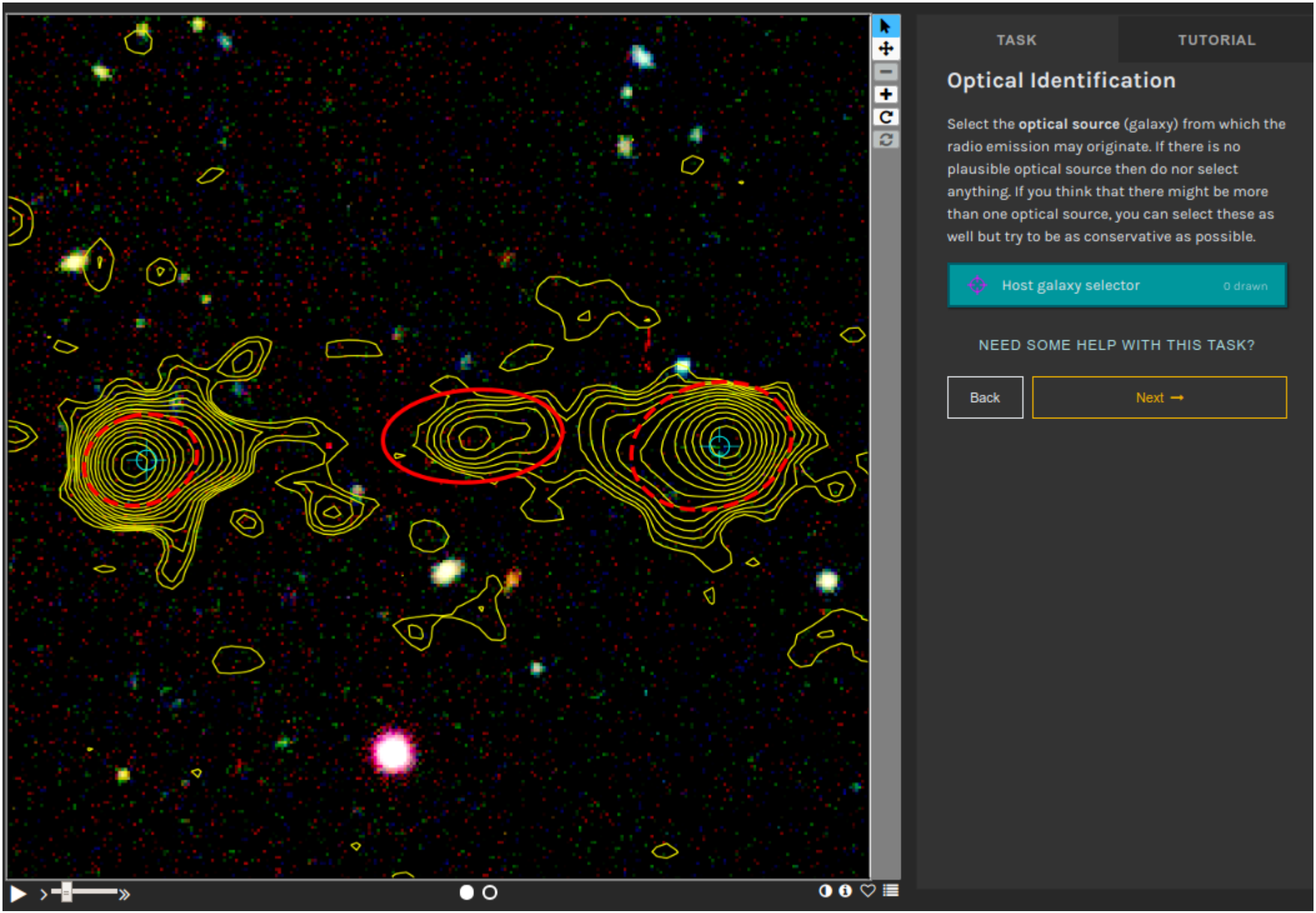


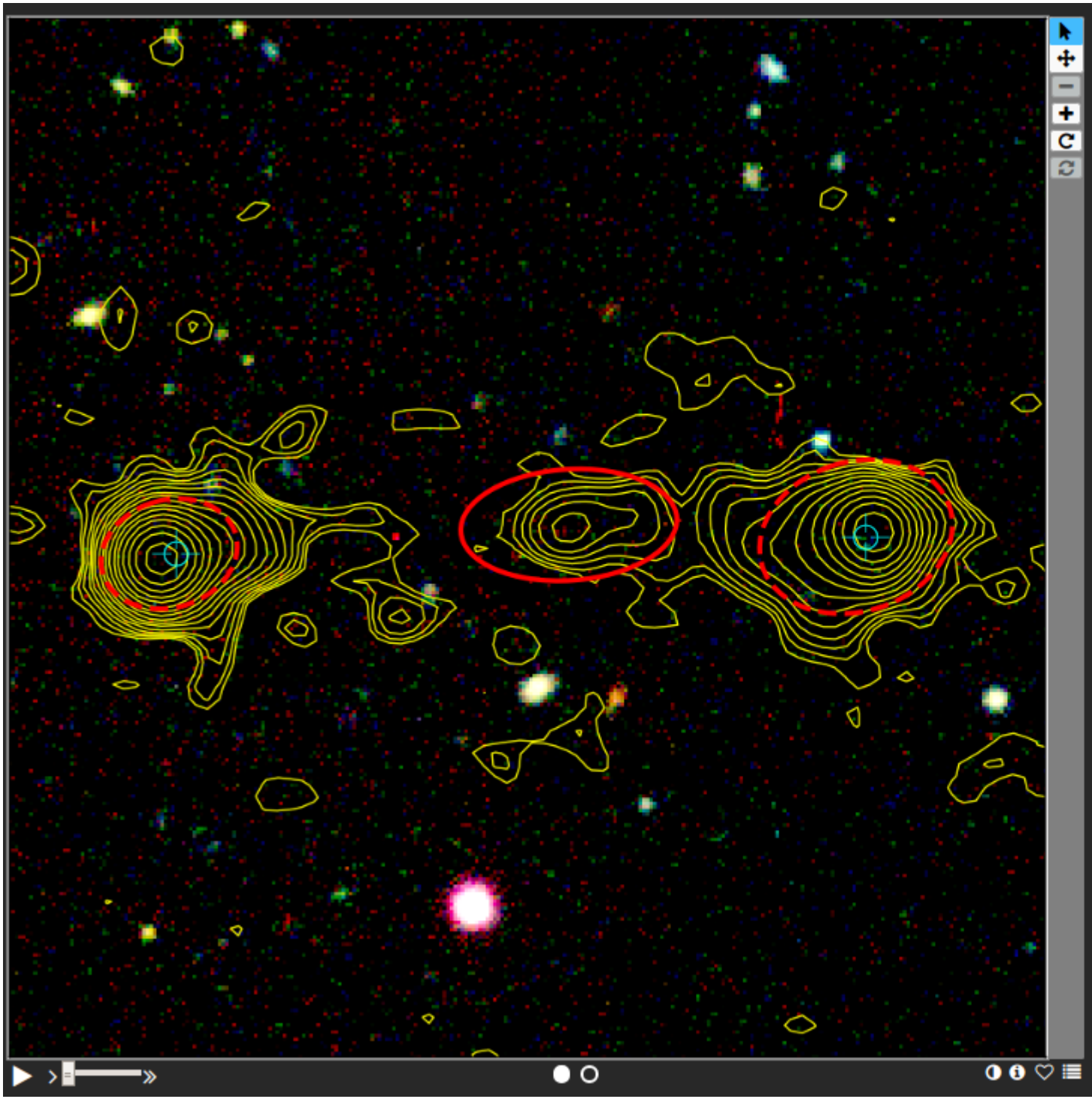


# Cross-Ids for Tier1 DR2

- LRs scale up easily, LGZ less well so
- Improved selection and prefiltering for LGZ
  - Machine learning
  - SOM
- LOFAR Galaxy Zoo version 2
  - Will be public ('inherit' radio galaxy zoo users)
  - Simplified
    - Colour optical image
    - No positions of optical catalogue sources
  - With more documentation
    - Expanded tutorial + video
    - Expanded field guide


TASK
TUTORIAL
Selecting components
Select all the dashed ellipses that you believe belong to the same structure as the solid ellipse. You can do this by clicking inside the ellipses. You do not need to click inside the solid ellipse.
Component selector
0 drawn
NEED SOME HELP WITH THIS TASK?
Next


TASK
TUTORIAL
Optical Identification
Select the optical source (galaxy) from which the radio emission may originate. If there is no plausible optical source then do nor select anything. If you think that there might be more than one optical source, you can select these as well but try to be as conservative as possible.
Host galaxy selector
0 drawn
NEED SOME HELP WITH THIS TASK?
Back
Next

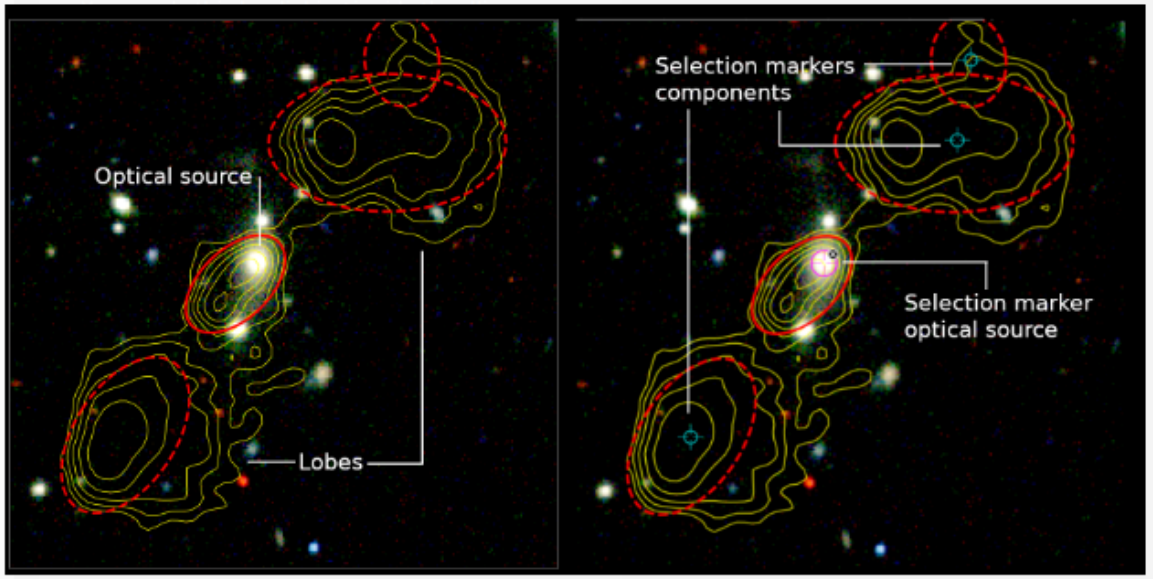

TASK
TUTORIAL
Additional information
Does it not look like a natural source (artefact)? Does it look like several distinct radio sources form part of the same ellipse (blend)? Do you think there is more emission associated with the source outside the image shown (Too zoomed in)? Is part of the optical image missing (image missing)? Or is something else wrong? Let us know!
When you are done you can go on to the next image. Do not forget that you can also click on "Talk" if you have a question or want to discuss this image with others.
Artefact
Blend
Too zoomed in
Image missing
Other
NEED SOME HELP WITH THIS TASK?
Back
Done & Talk
Done

FIELD GUIDE

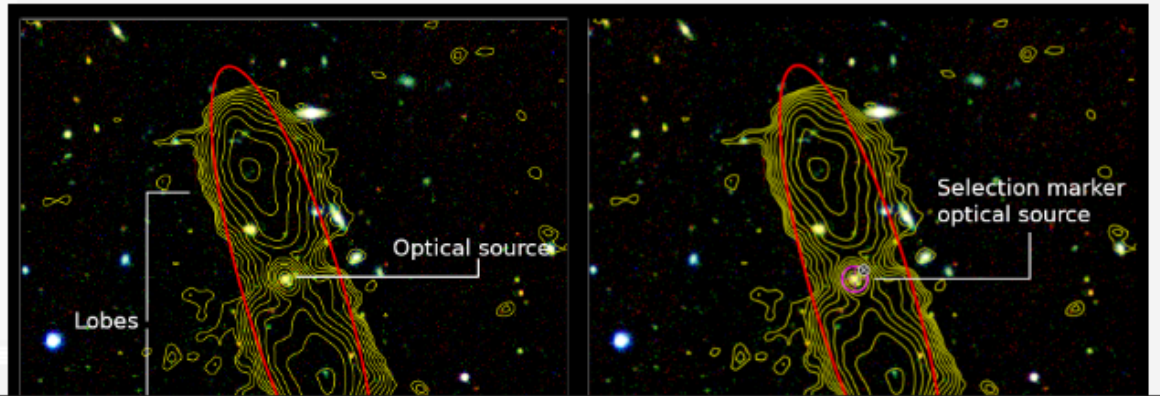
# Common types of (radio) sources

We show five examples of different radio sources and the corresponding way to treat them.

- **Large Double-Lobed Sources**
  Most radio sources are symmetric, as the two jets fan out in opposite directions. In many cases it is easy to find the galaxy hosting the supermassive blackhole from which the radio emission originates, in the middle of the line joining the two lobes.

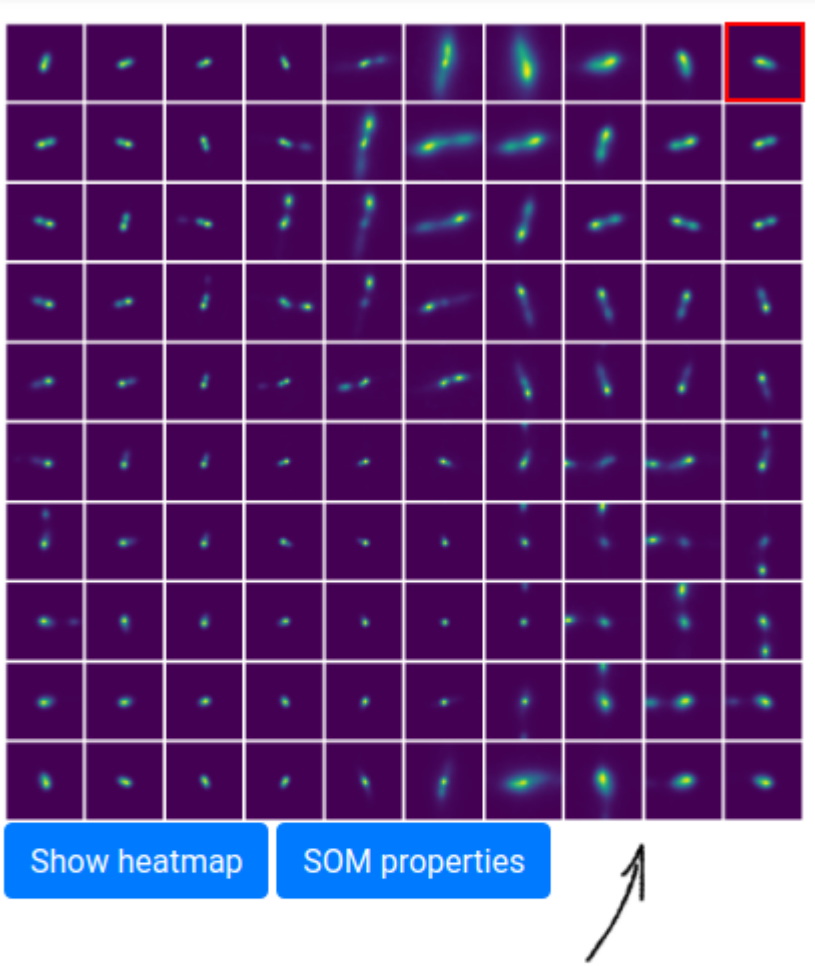



- **Small Double-Lobed Sources**
  Since most radio objects are far away, you will often find the zoomed out version of the previous type of source. These are compact symmetric sources with the optical source galaxy located in the middle.



# Summary

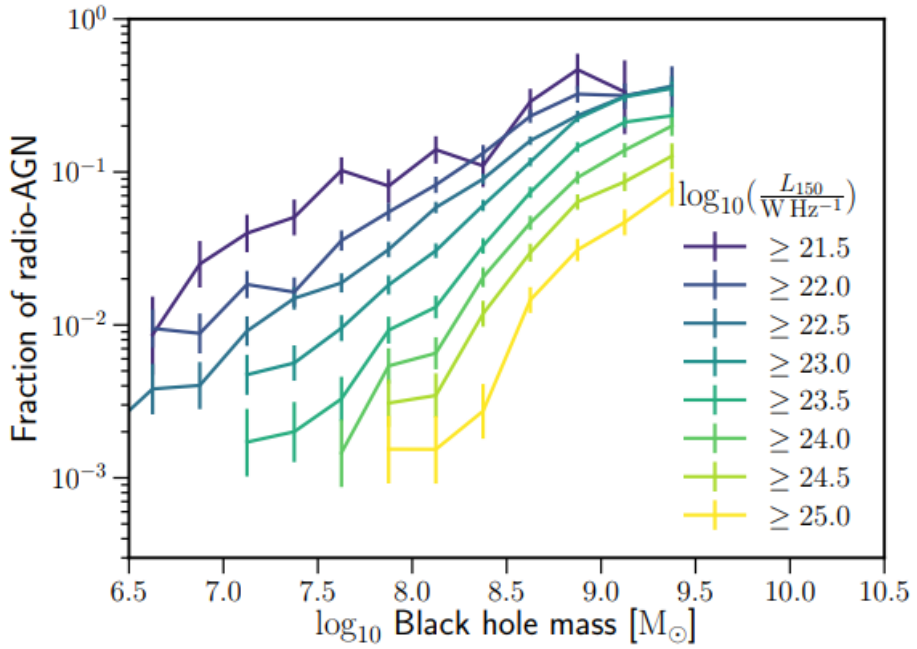
- Providing associations and optical IDs is essential for a vast range of science
- LoTSS DR1 uses both automated likelihood ratio identifications and people-powered visual identifications
  - We will continue in a similar way for the next stages of the survey, but people are working on improvements including machine learning approaches (e.g. SOM – Mostert+ in prep, CLARAN – van Buchem+)

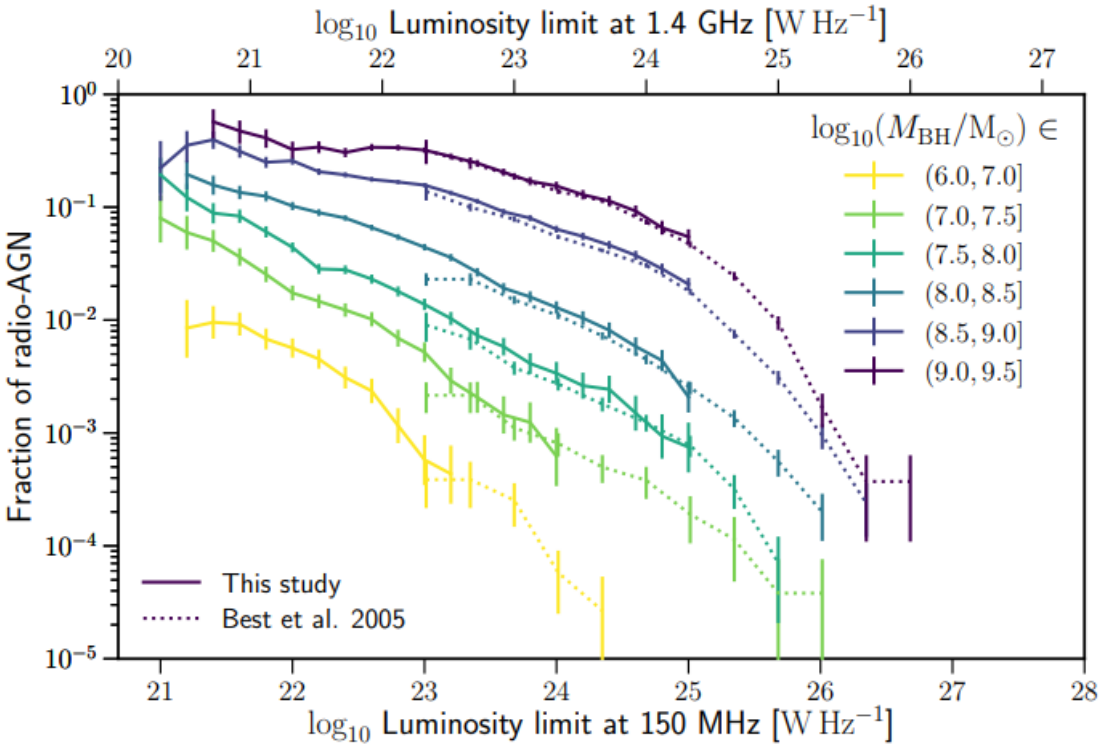


# LoTSS–SDSS RLAGN:
## The most massive galaxies are always switched on

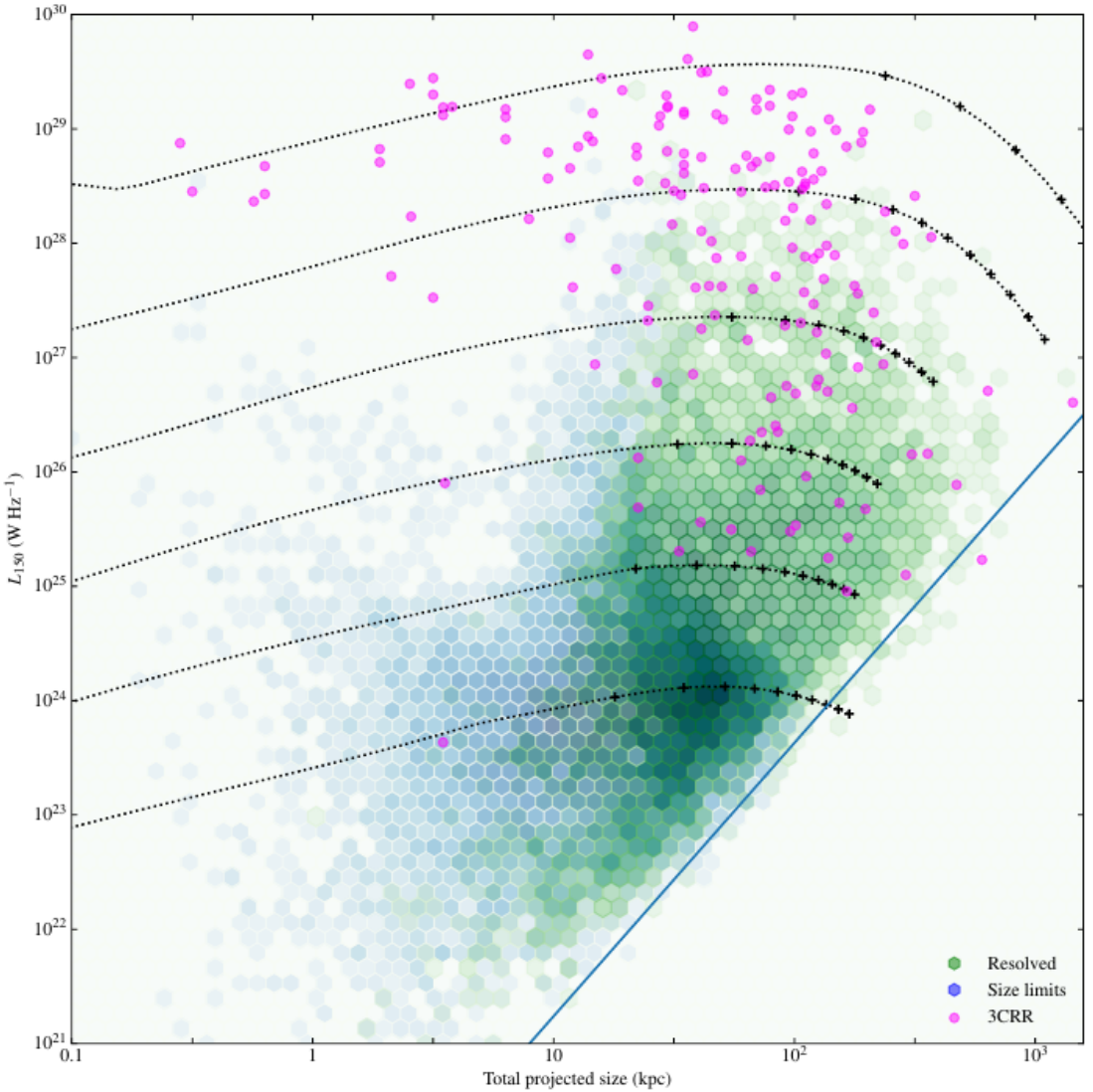
Sabater+ 2019

- 32% of the SDSS DR7 Spectroscopic sample detected in LoTSS
- AGN and SFG separated using combination of multiple criteria (BPT, D4000, WISE colours, radio excess): 2121 AGN at z < 0.3



# 23k LoTSS RLAGN

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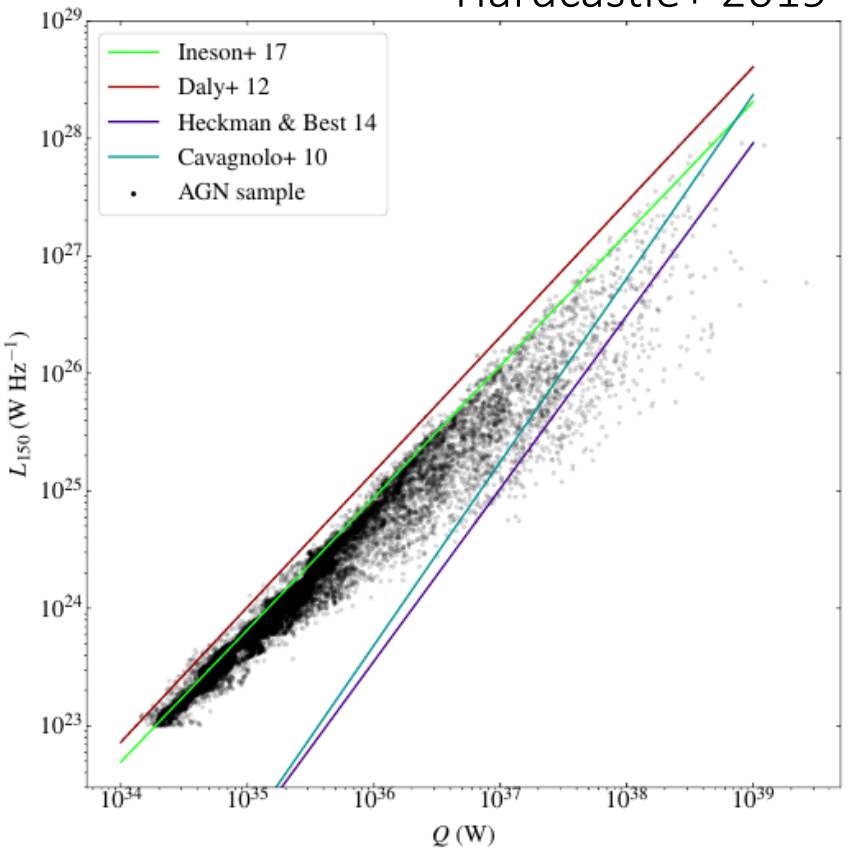
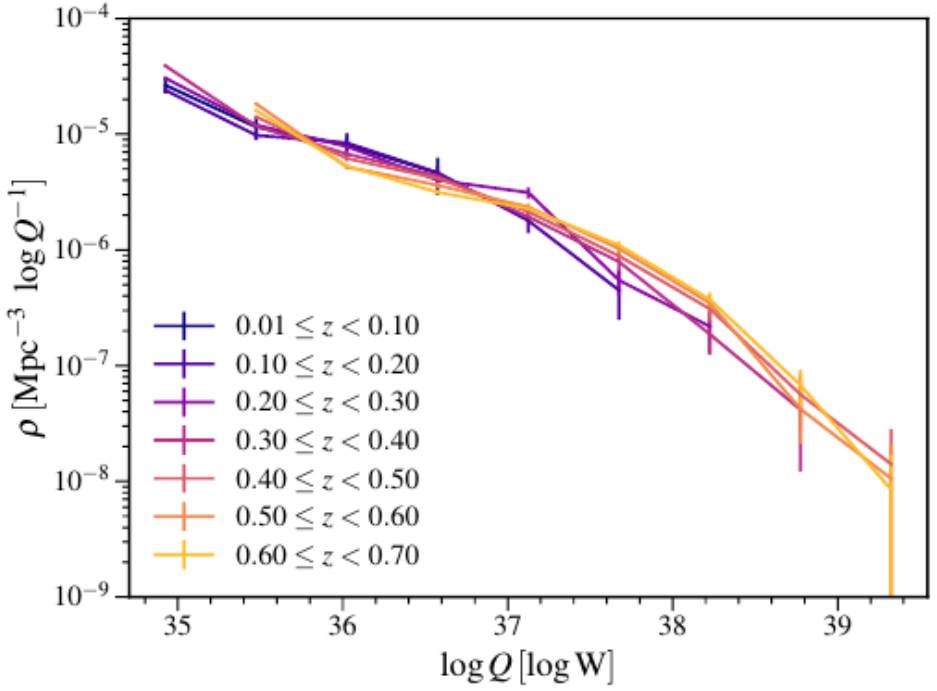
- RLAGN / SF (23k / 42k) – Spectra (MPAJHU), Luminosity, WISE colour, K mag

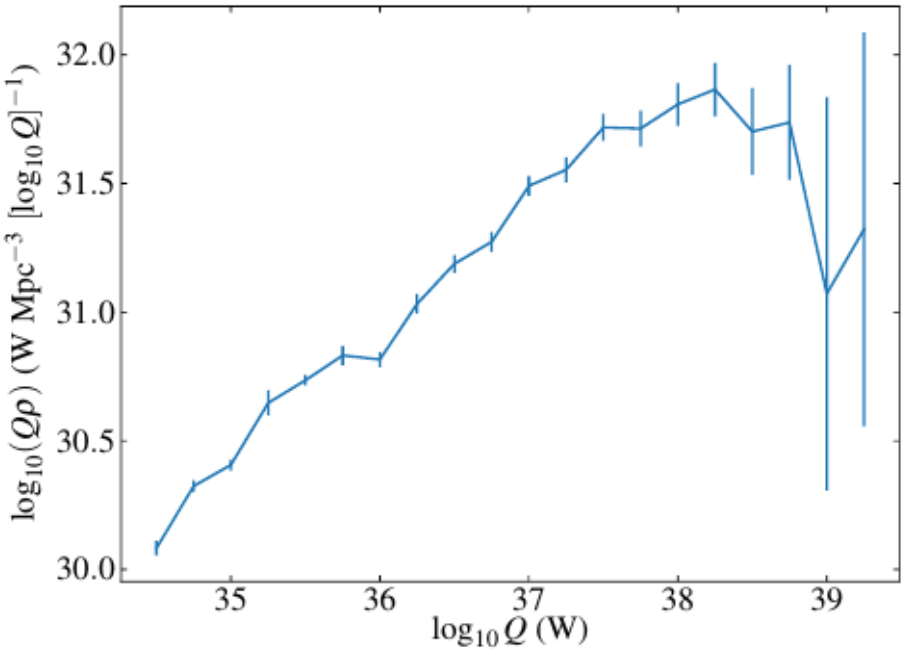
# LoTSS RLAGN KLF

Hardcastle+ 2019

- Infered jet powers – forward modelling of analytical RLAGN models and distributions of environments, redshifts, lifetimes
- kinetic luminosity function ρ(Q)
  - integral of Qρ(Q)d log(Q) – energy per comoving volume injected by all RLAGN jets into their host environments
  - total RLAGN kinetic luminosity density of $7 \times 10^{31}$ W $Mpc^{-3}$ – enough to offset cluster cooling

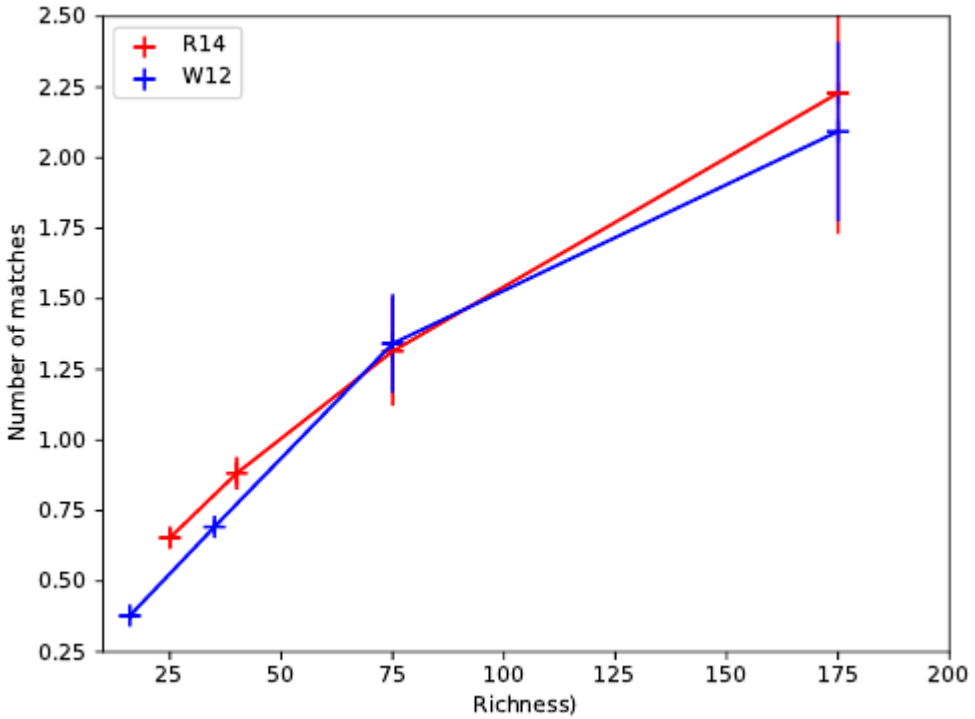


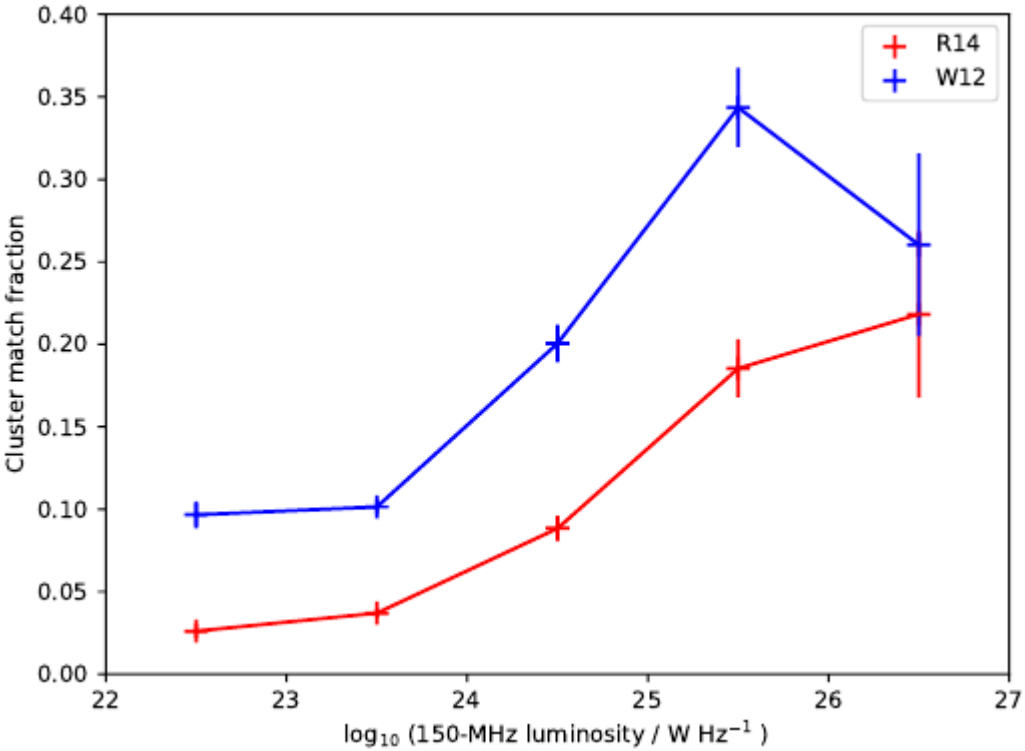



# The environments of LoTSS AGN

- SDSS DR8 group/cluster catalogues
  - RedMaPPer (Rykoff+ 14) – 1000 clusters
  - Wen+ 14 – 4000 clusters
- 10% of AGN associated with an SDSS-catalogued group/cluster




- fraction of AGN with a group/cluster association increases with radio luminosity
- >60% of even the most luminous RLAGN do not have a group/cluster association –> a substantial population of powerful RLAGN in haloes with $M_{200} < 10^{14}\ M_{sun}$