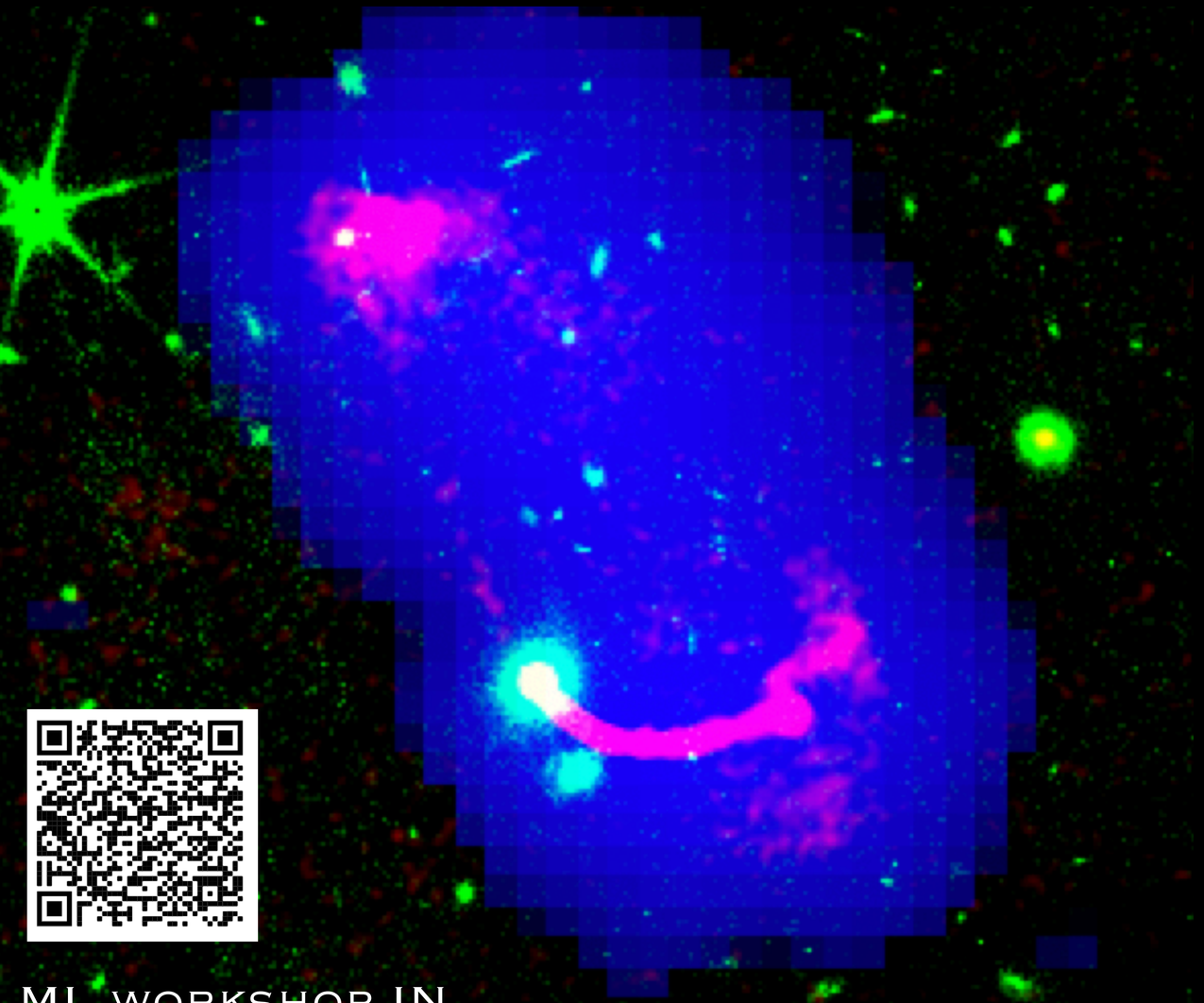
Conventional classification methods, robust training samples, and hands-on examples



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Thüringer Landessternwarte Tautenburg

Collaborators:
COSMOS, MeerKAT-MIGHTEE, LOFAR KSP, RGZ EMU & EMU teams

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Rogue Astrophysics; Astronomy on Tap Jena
elenivardoulaki.com

ML workshop IN Astronomy 23Nov23

Outline

1. What is a radio source
2. Data acquisition
3. Examples from literature
4. Why we need citizen science
5. Radio Galaxy Zoo EMU
6. Hands on (zooniverse.org)

NRAO/AUI/NSF - 300FOOT Telescope - 5 GHz - 1987

The radio sky

NRAO/AUI/NSF - 300FOOT Telescope - 5 GHz - 1987

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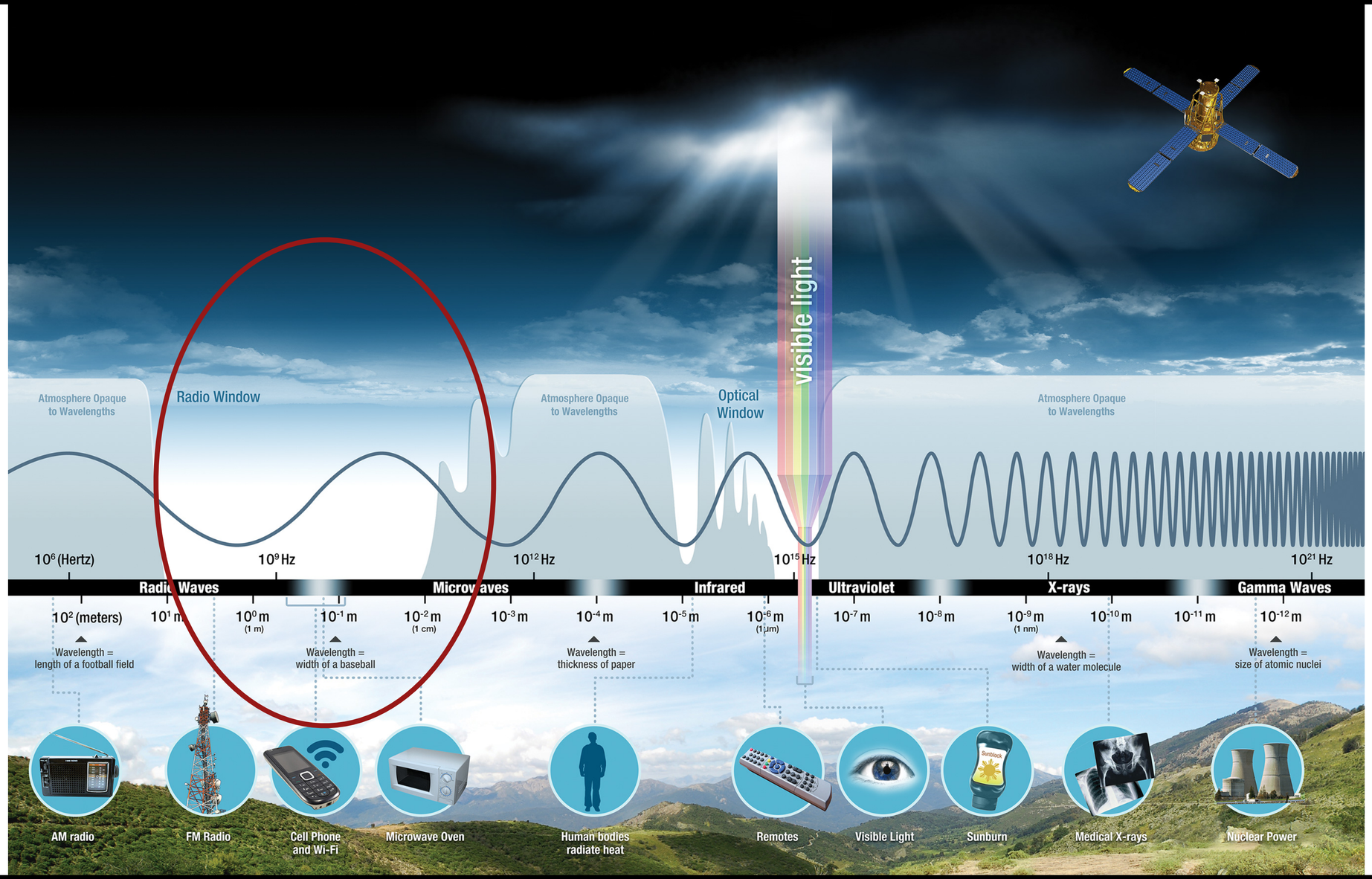
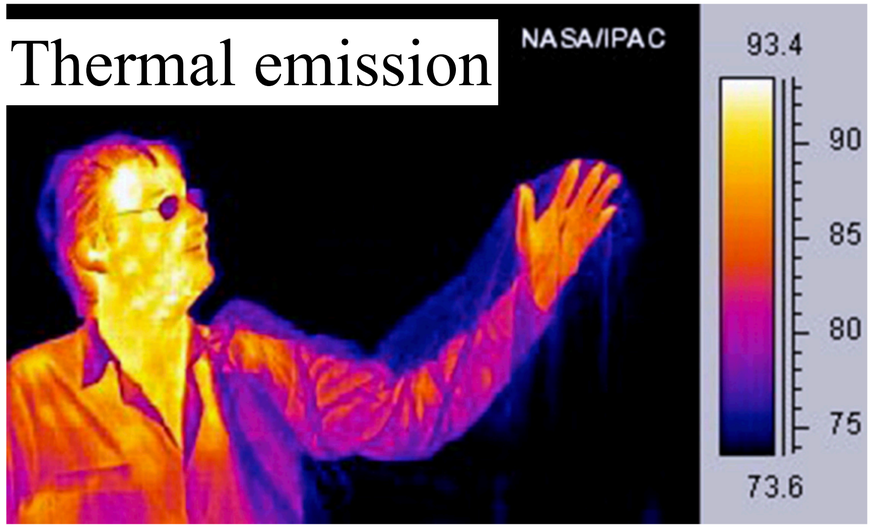
The electromagnetic spectrum

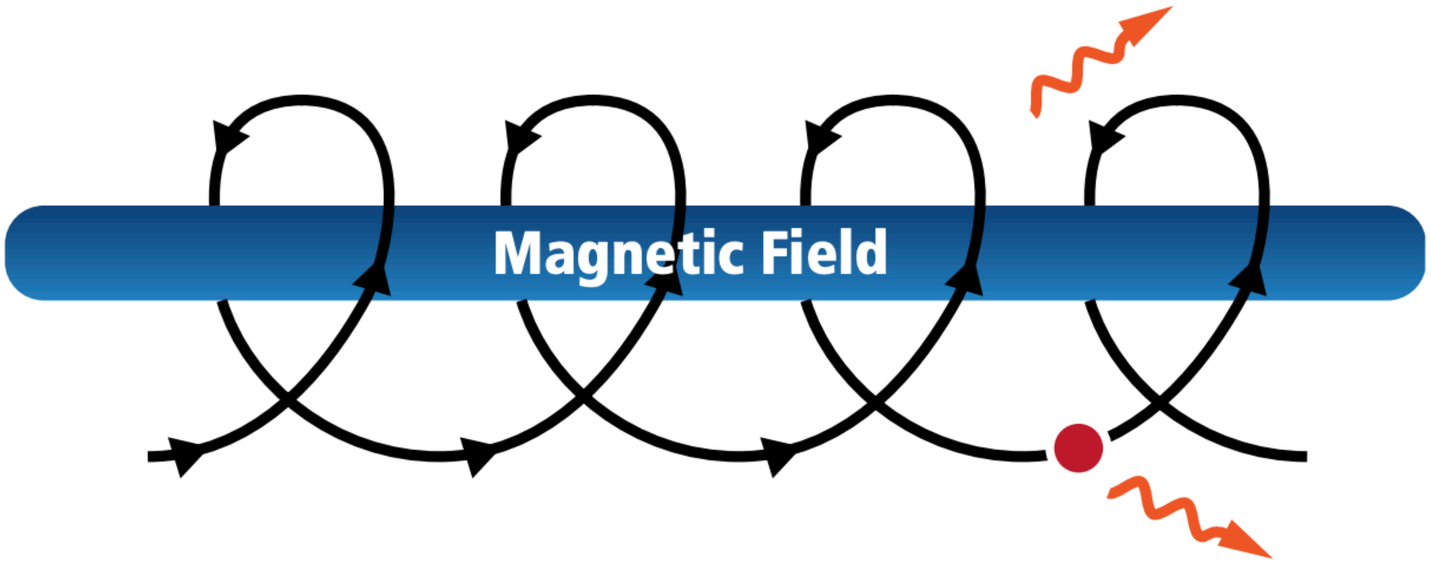


Thermal/non-thermal radiation



Non-thermal emission

If relativistic electrons: synchrotron



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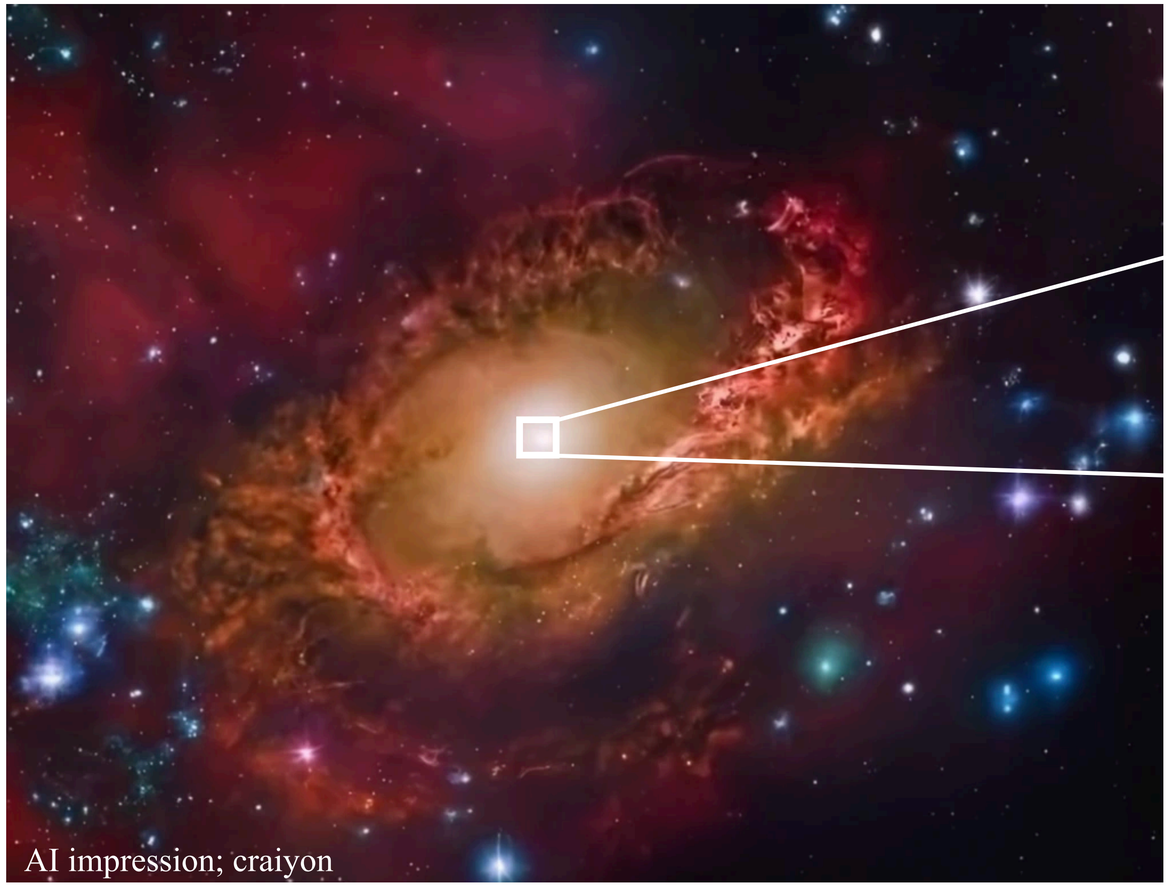
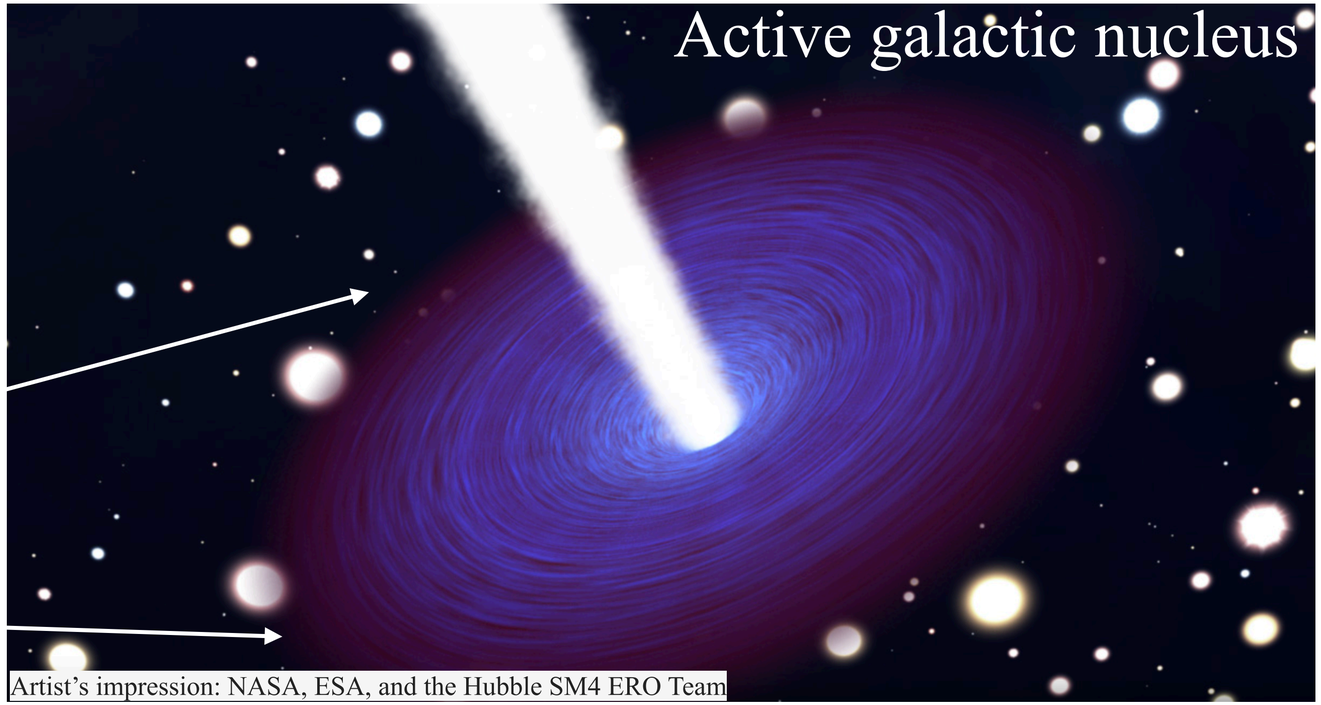
Synchrotron emission

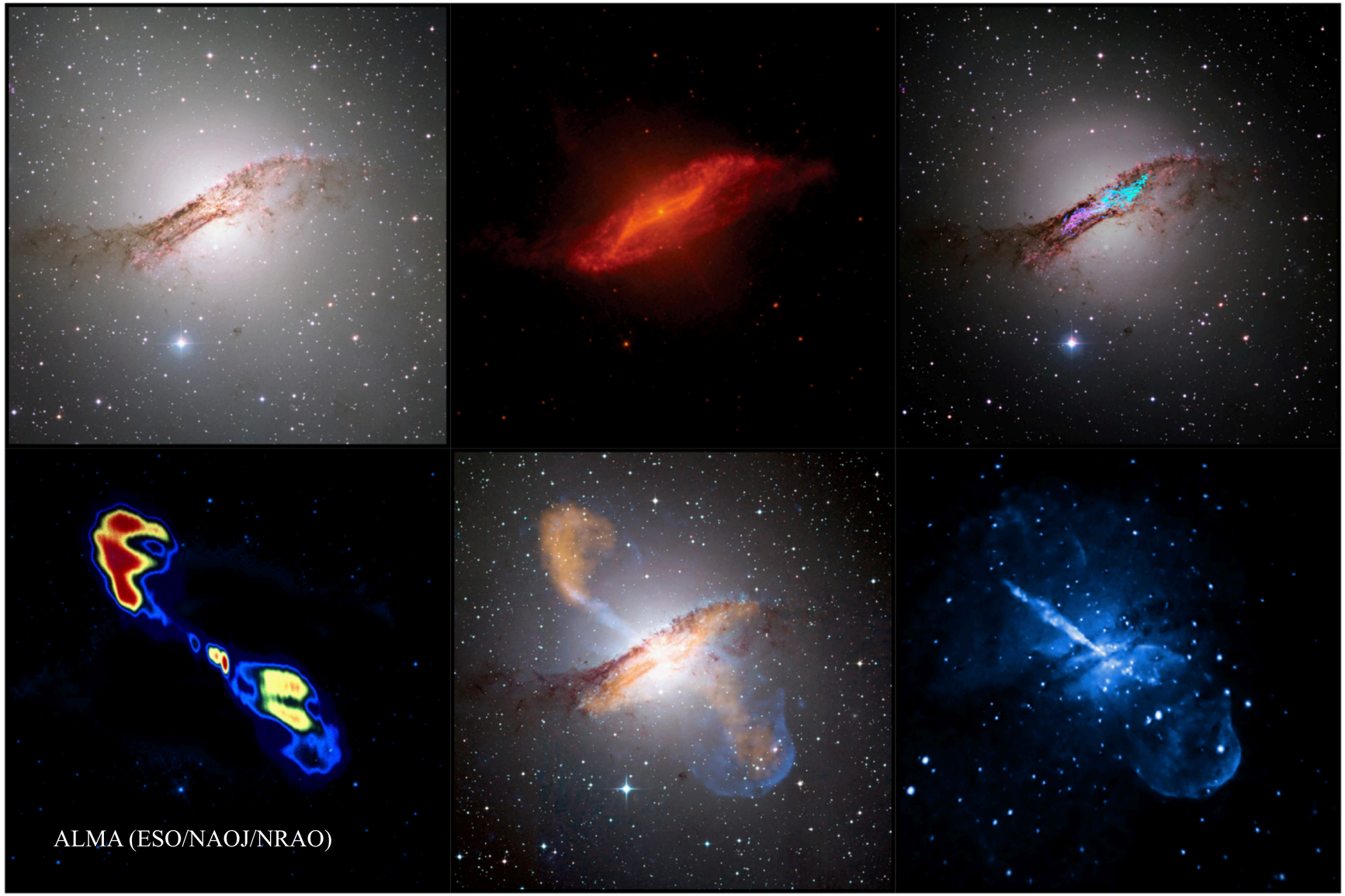




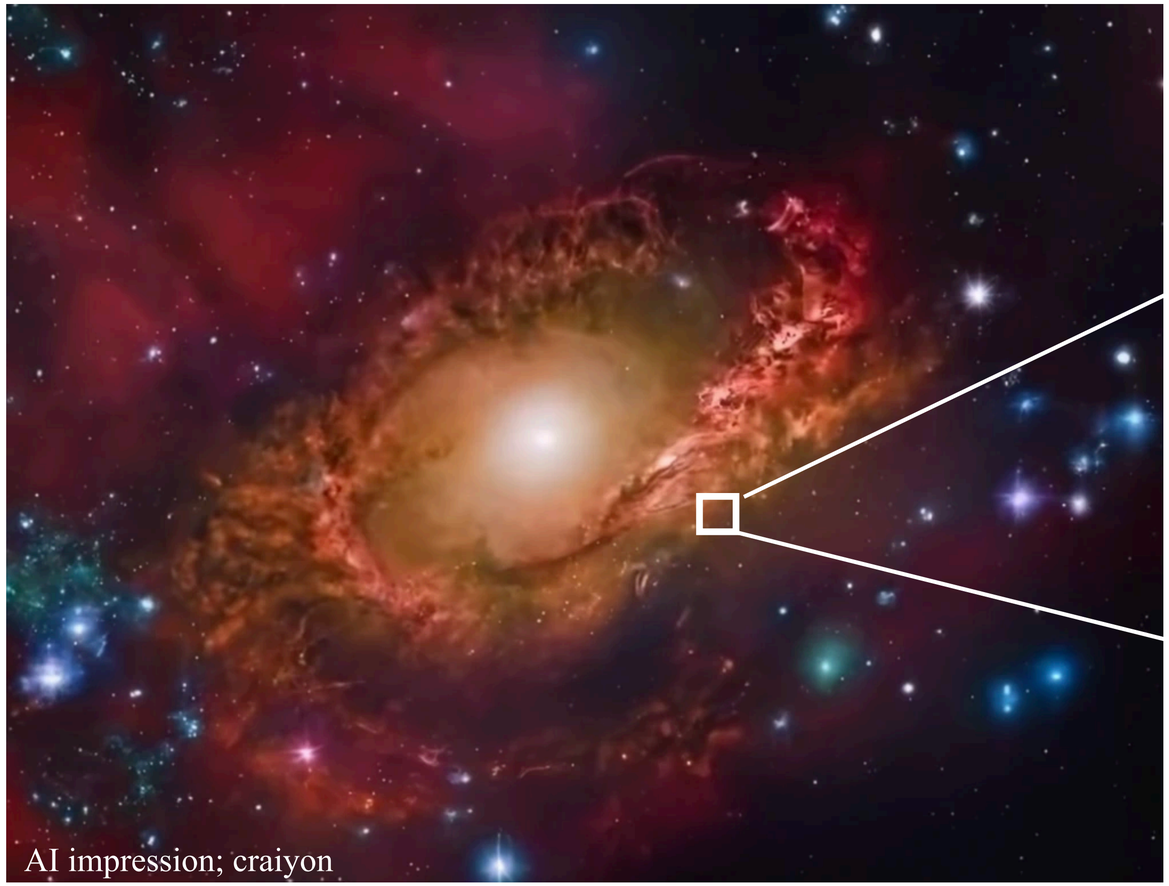
Example of Active Galaxy

Optical ⟶

Radio ⟶

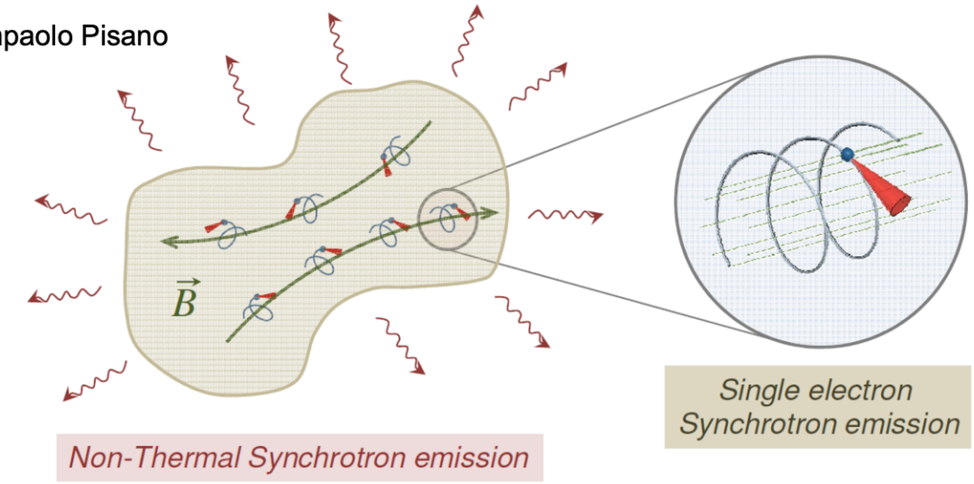


Synchrotron emission

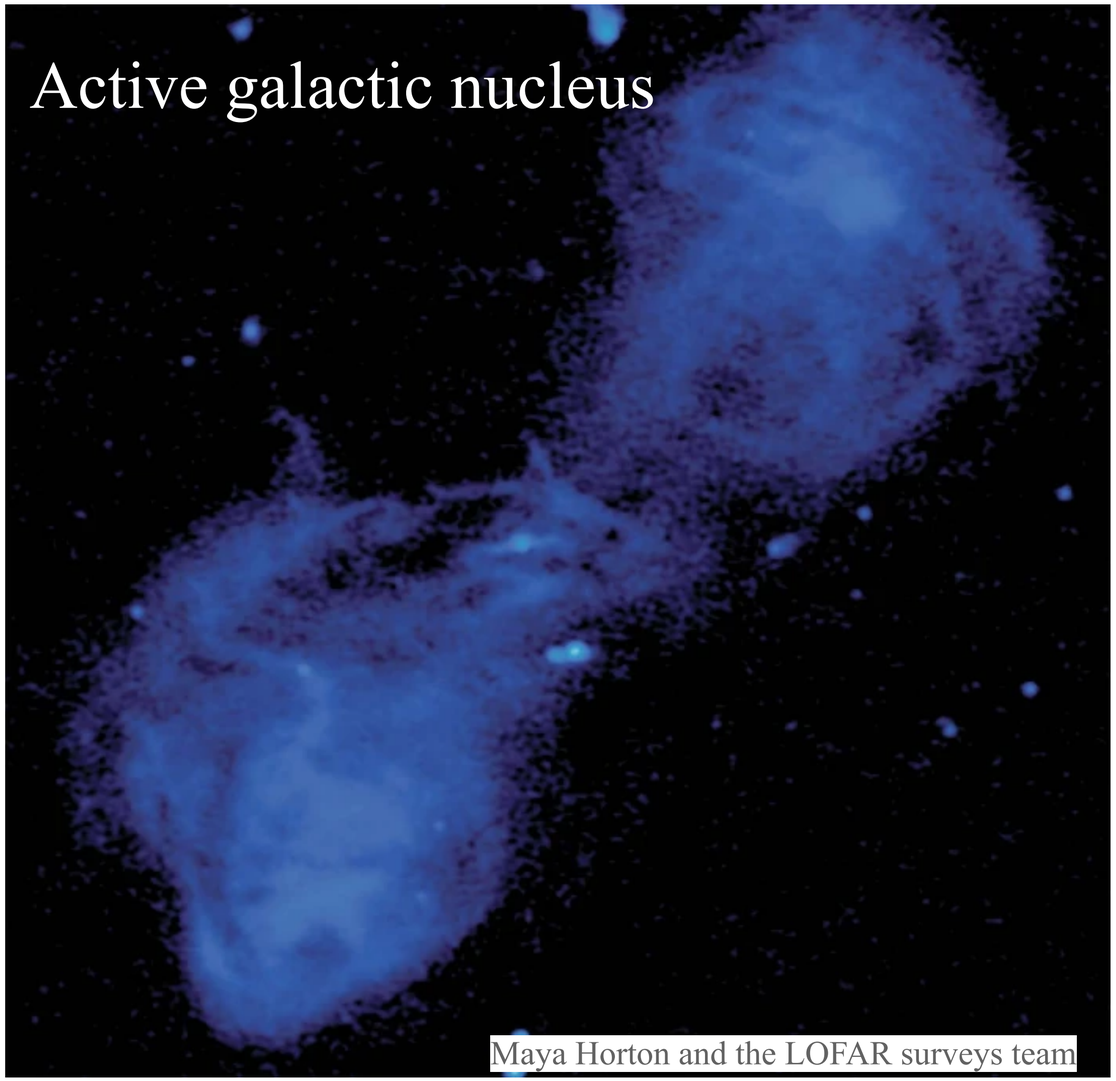


Star forming regions

Image credit: Giampaolo Pisano



Synchrotron emission



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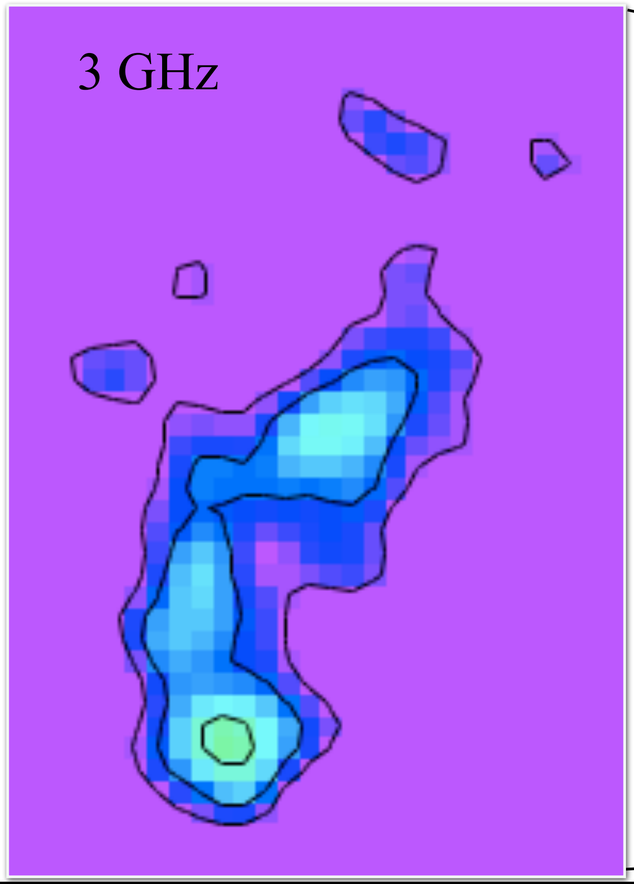
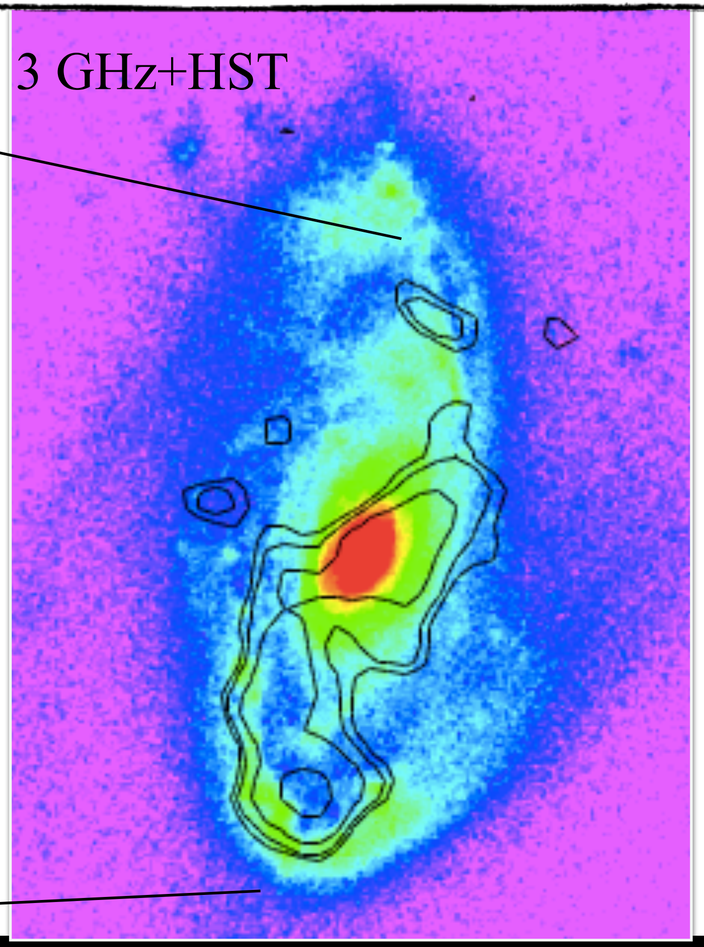
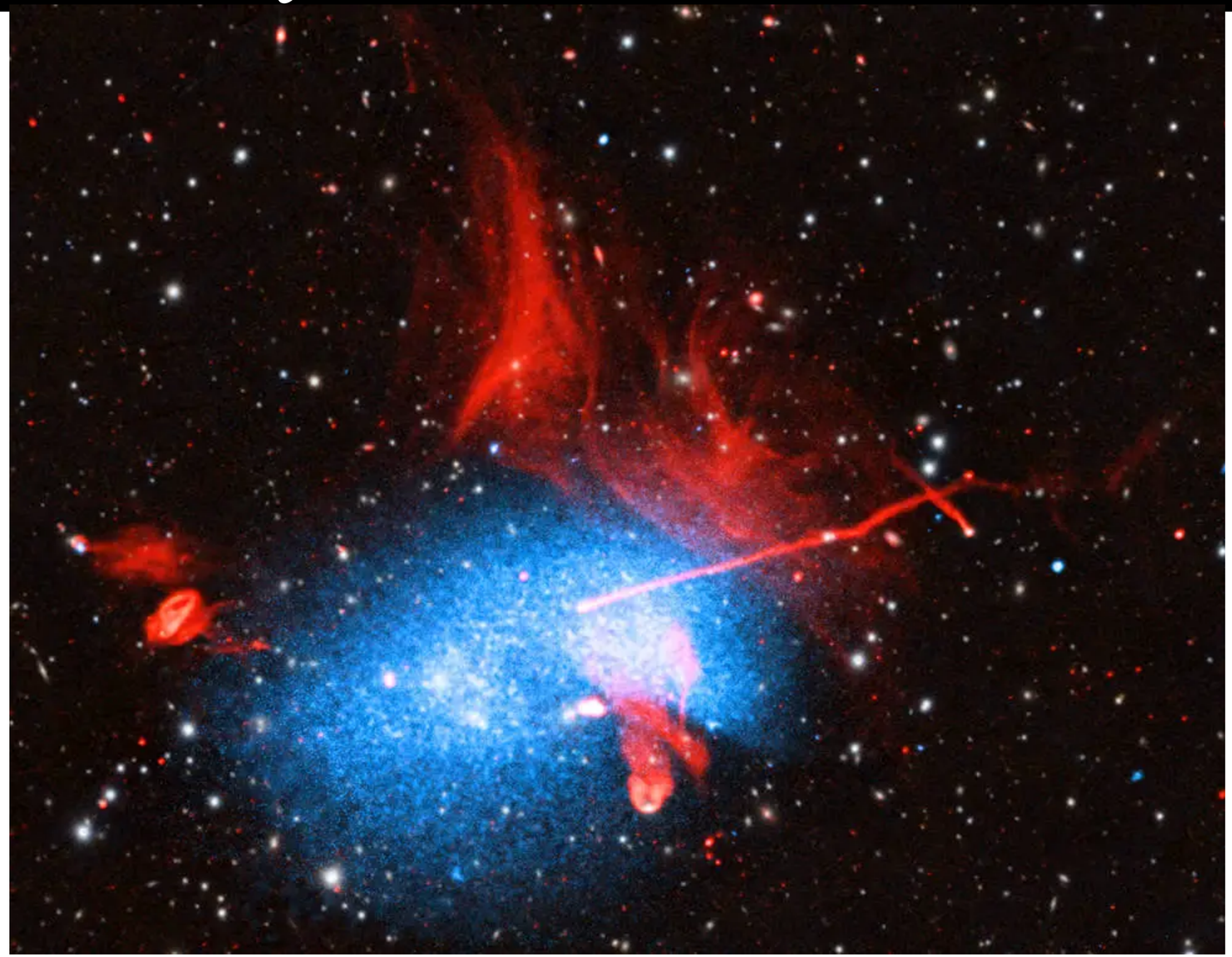
Synchrotron emission

- single frequency classification: highly subjective
- need for multi-wavelength data





Synchrotron emission



X-ray: Chandra: NASA/CXC/Univ. of Bolonga/K. Rajpurohit et al.; XMM-Newton: ESA/XMM-Newton/Univ. of Bolonga/K. Rajpurohit et al. Radio: LOFAR: LOFAR/ASTRON; GMRT: NCRA/TIFR/GMRT; VLA: NSF/NRAO/VLA; Optical/IR: Pan-STARRSu003c/emu003eu003c/strongu003e

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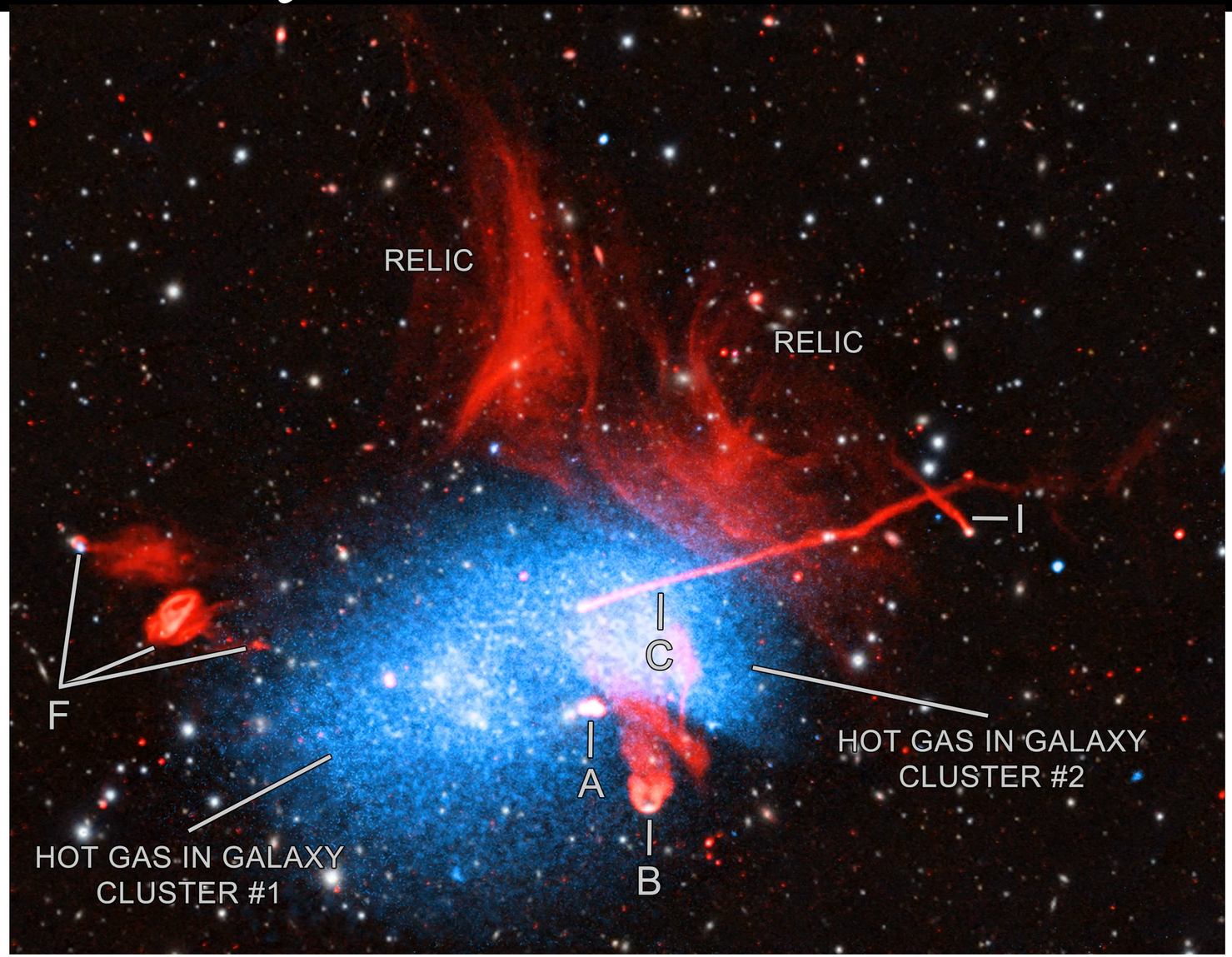
Synchrotron emission



X-ray: Chandra: NASA/CXC/Univ. of Bolonga/K. Rajpurohit et al.; XMM-Newton: ESA/XMM-Newton/Univ. of Bolonga/K. Rajpurohit et al. Radio: LOFAR: LOFAR/ASTRON; GMRT: NCRA/TIFR/GMRT; VLA: NSF/NRAO/VLA; Optical/IR: Pan-STARRSu003c/emu003eu003c/strongu003e

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Data acquisition

Vernesa Smolčić

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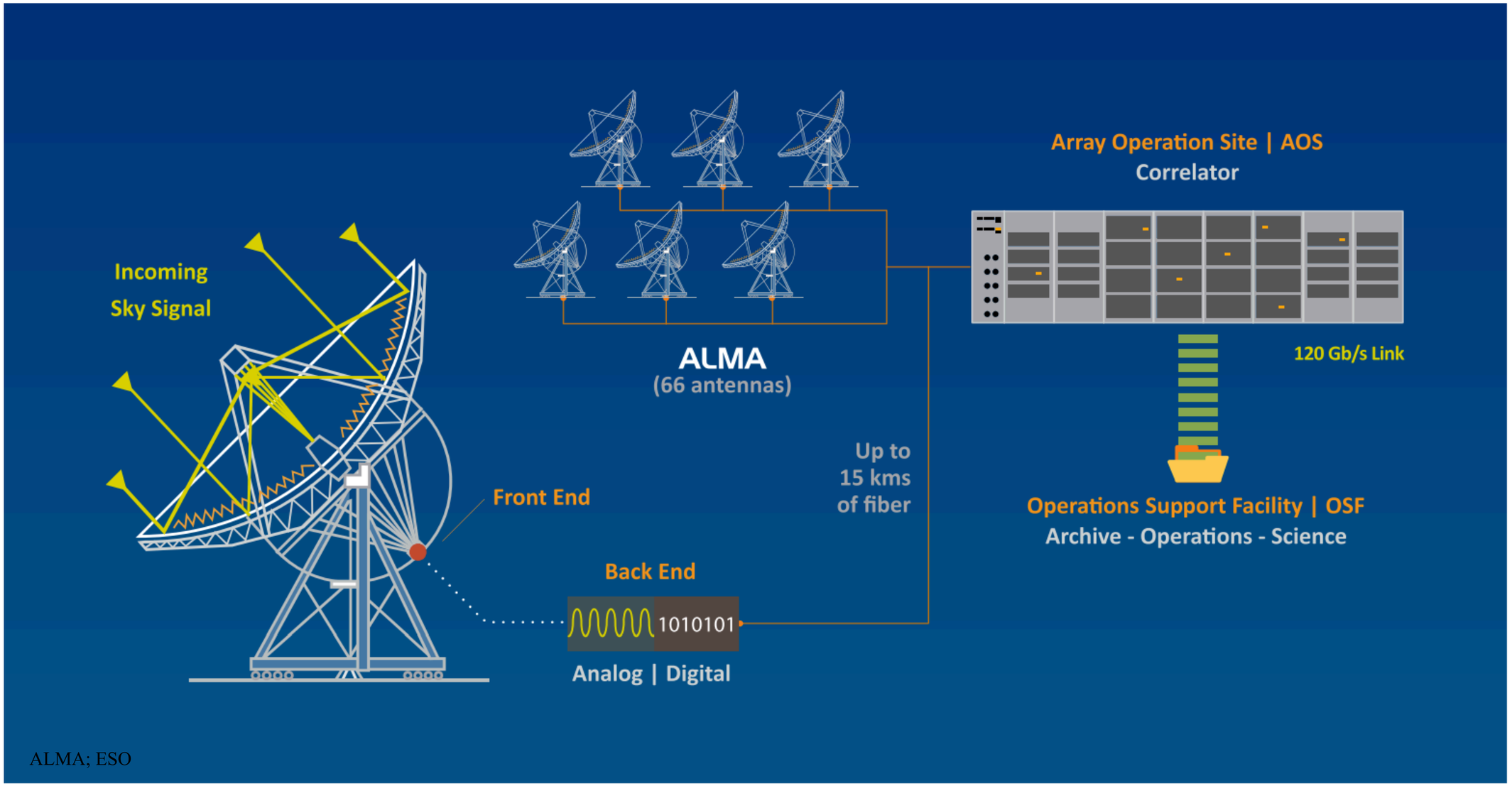
Data acquisition



ALMA; ESO

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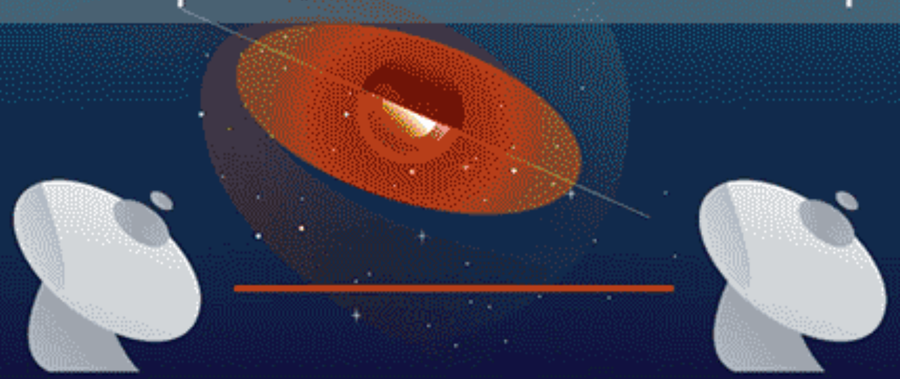
Data acquisition

Interferometry

Interferometry is a powerful tool in astronomy that links together one or more pairs of radio antennas, even those thousands of kilometers apart, to create a new and vastly more powerful “virtual” telescope called an interferometer.



Interferometers harness the space between the antennas: the **larger the spacings, the higher the resolving power,** allowing it to see finer and finer details, like the zoom lens of a camera.

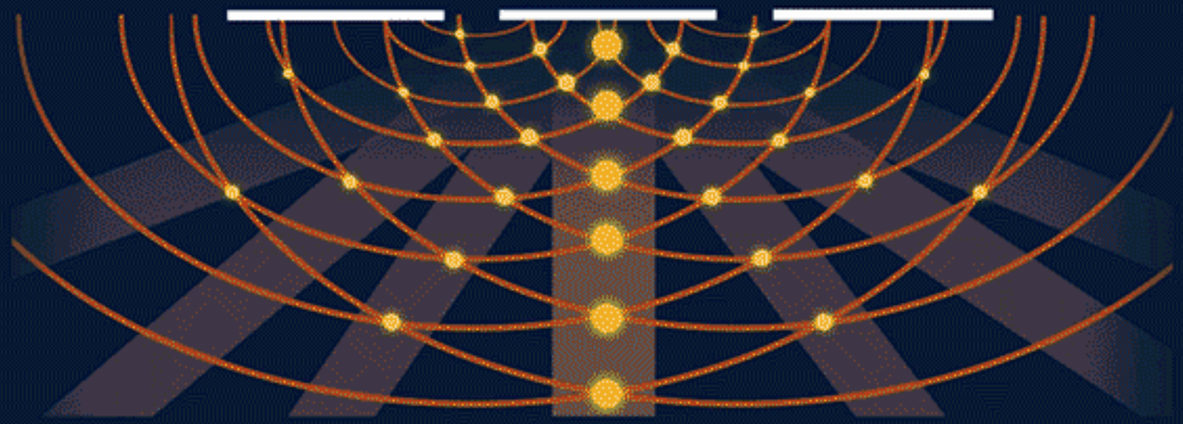
How Is This Done?

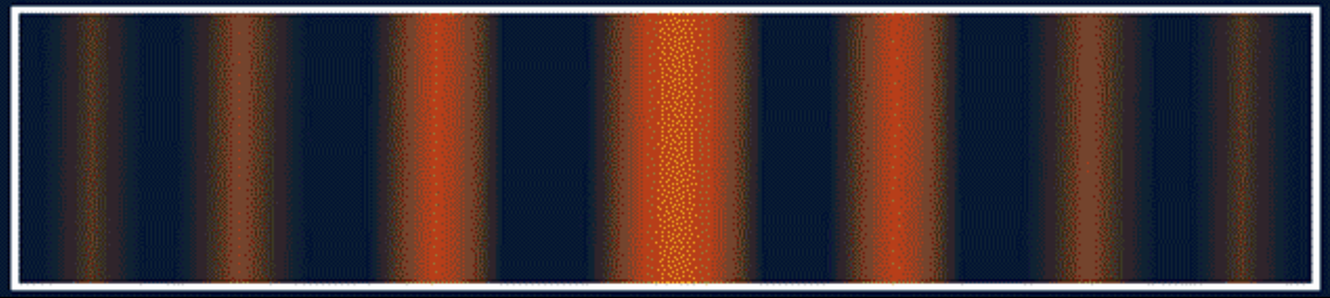
Astronomers reconstruct images of an object in space using interferometers, telescopes that observe the Fourier transform of an object’s brightness pattern on the sky.

Data acquisition

Inteference Pattern

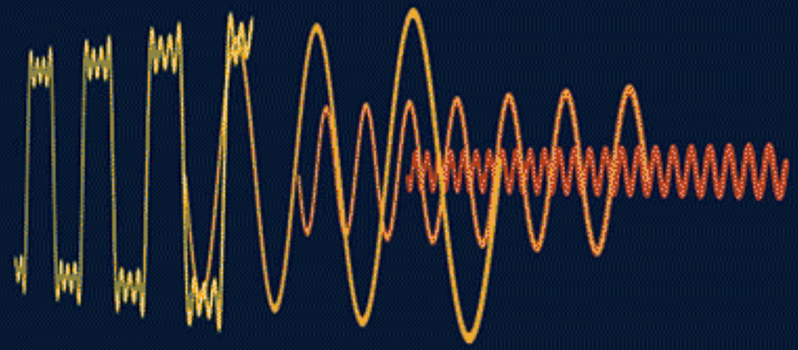
Wave patterns from an interferometer are similar to the wave patterns created when light passes through a pair of slits. In radio astronomy, the antenna pair takes the place of the two slits, but the resulting patterns are similar.



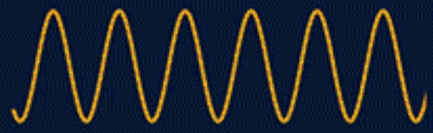


Fourier Transform

The Fourier transform is a mathematical tool that deconstructs any signal into a sum of sine waves.



A sine wave in 2 dimentions looks like a set of stripes



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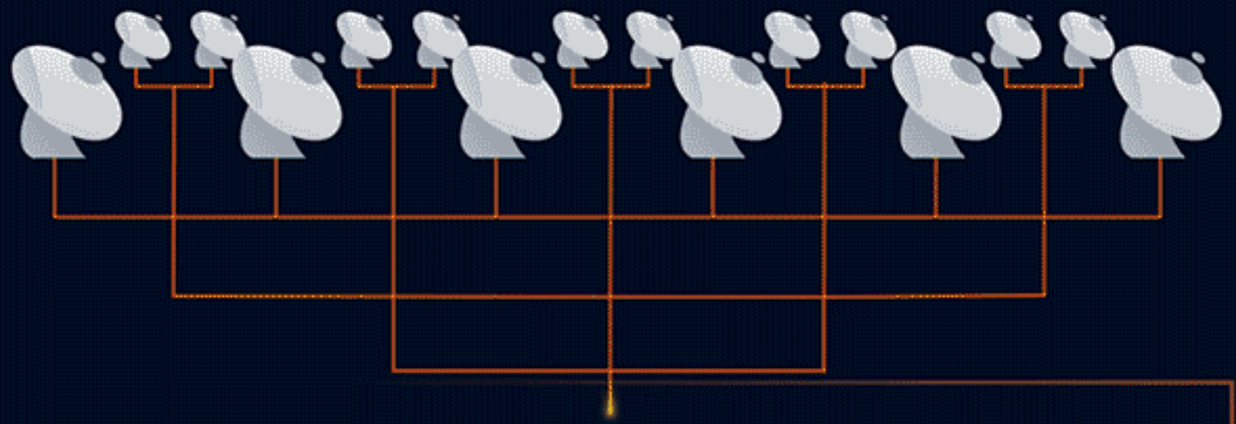
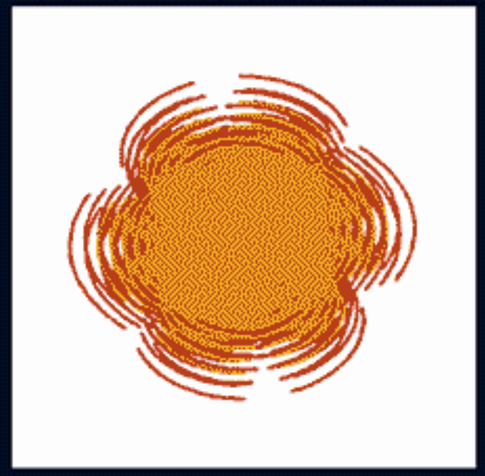
Data acquisition

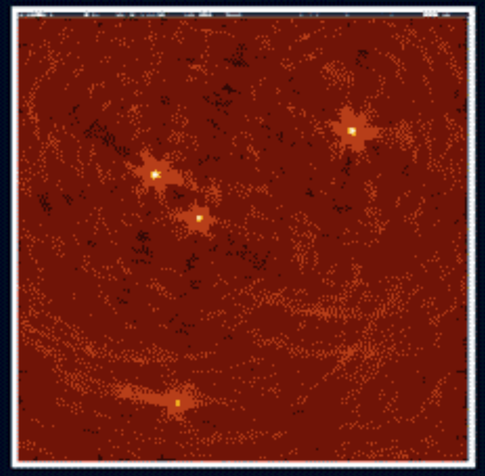
More Antennas = Clearer Picture

Turning this pattern into an image takes many hours of observations. Like a time-lapse exposure, this slowly builds up an image of even a very dim source. It also allows Earth's rotation to, in effect, fill in the empty spaces in the array to produce a more complete picture.



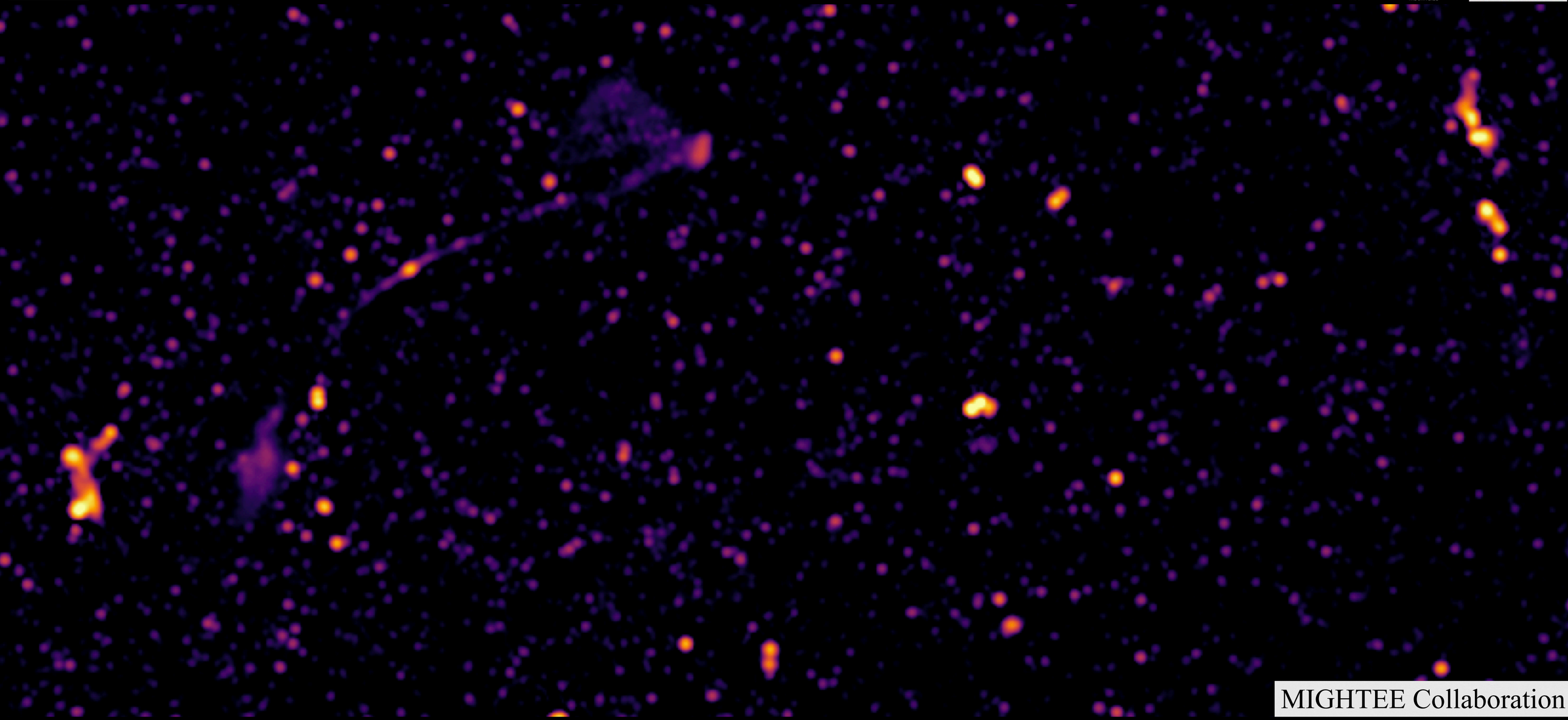


27 Antennas
+
4 hours Earth Rotation Synthesis
+
3 Frequencies



The signals received at each antenna must be matched wave for wave, even for antennas that are half a world away. Atomic clocks at each site allow for their observations to be mathematically combined using a specialized supercomputer called a **correlator.**

The radio sky



MIGHTEE Collaboration

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Multi-wavelength

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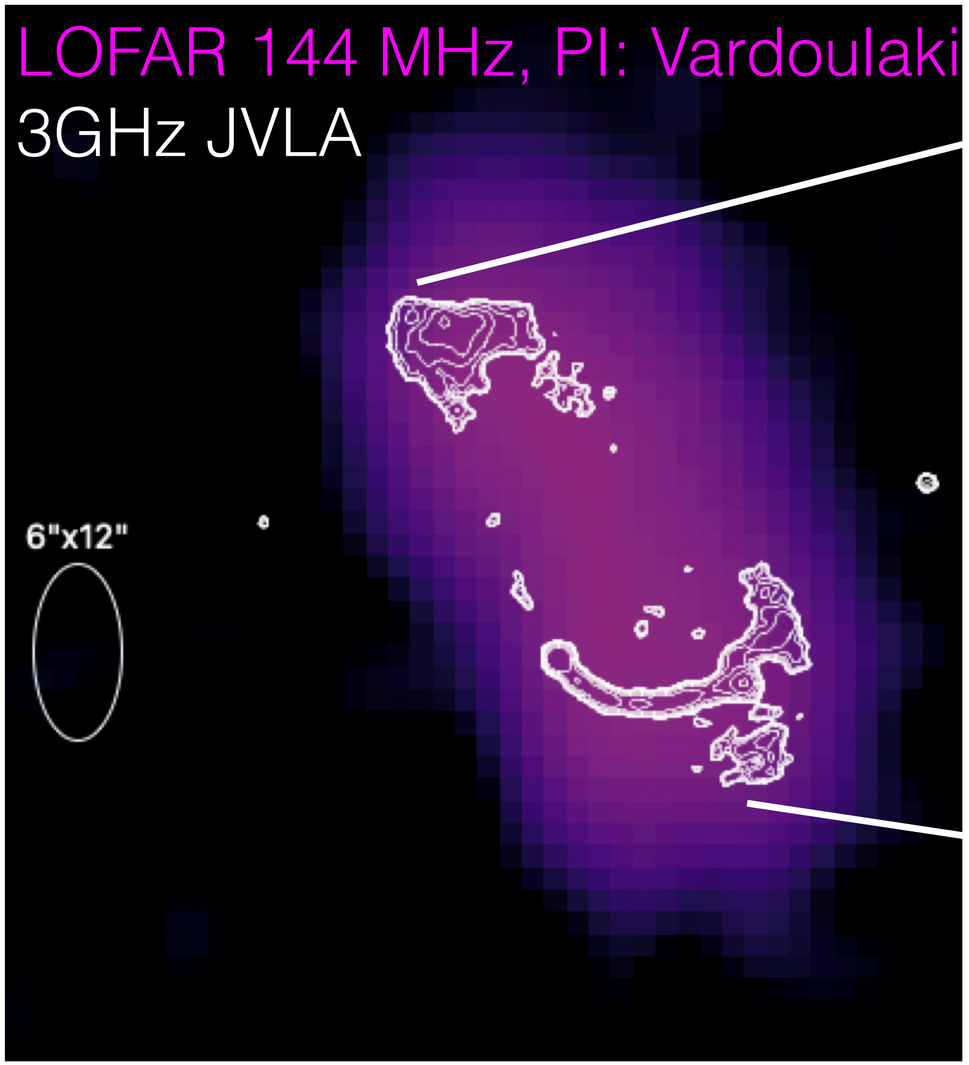
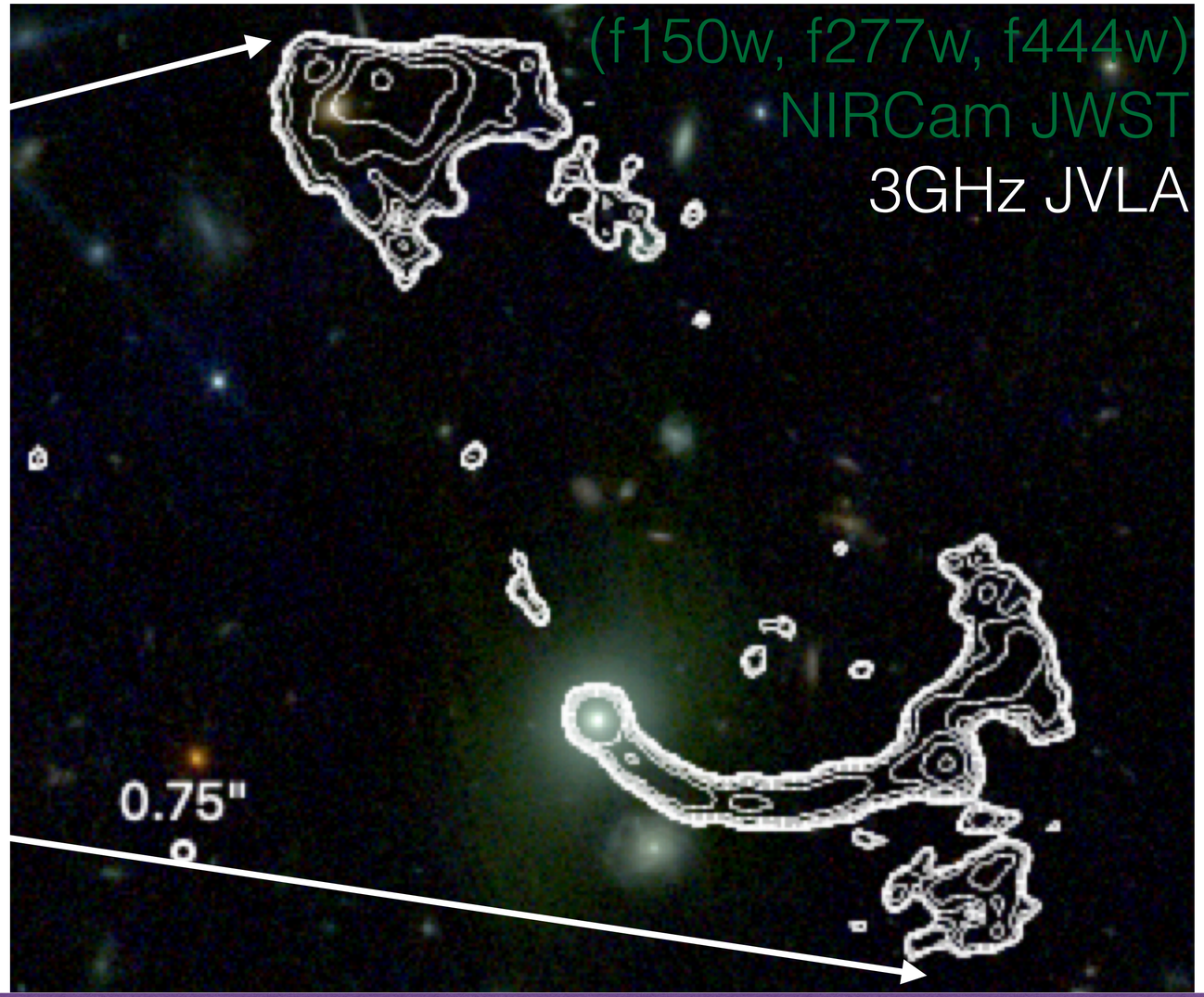
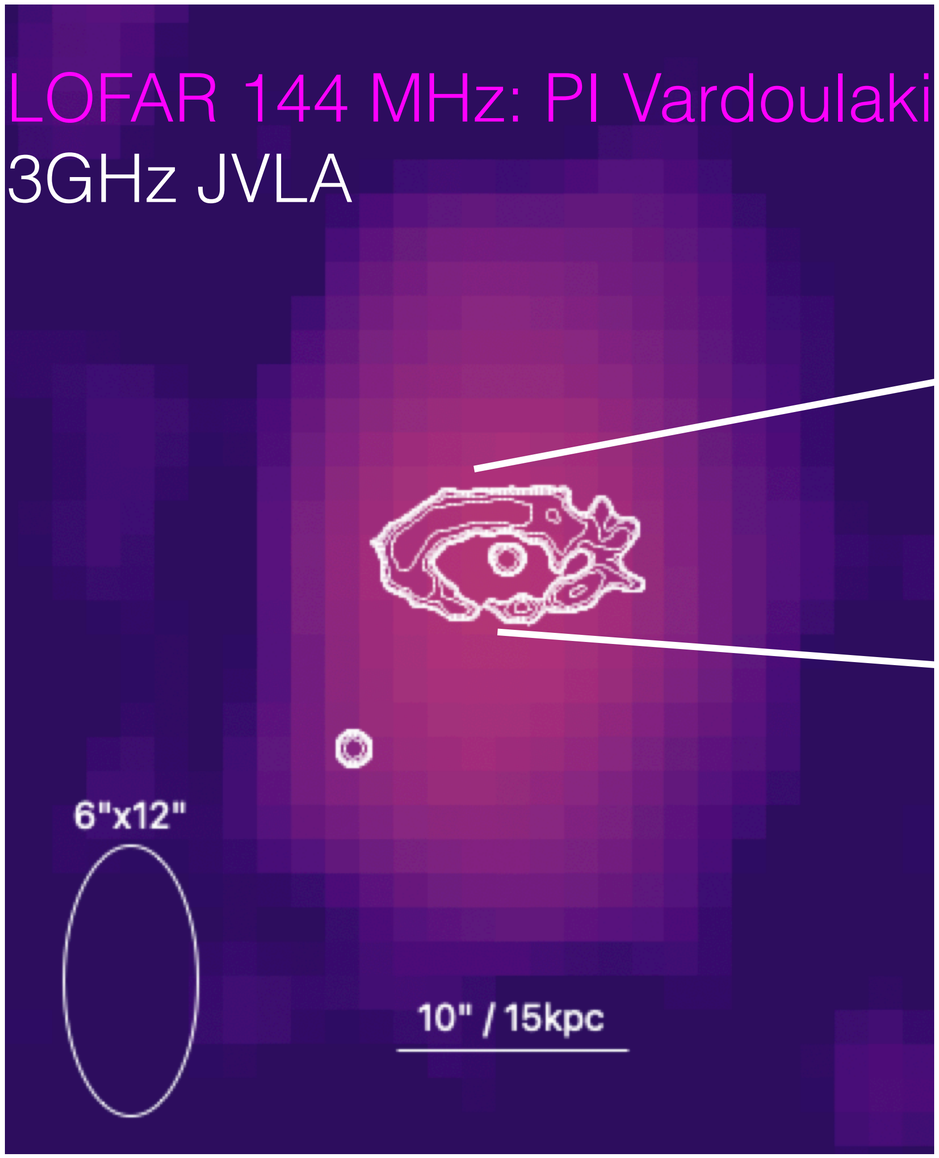
AGN example

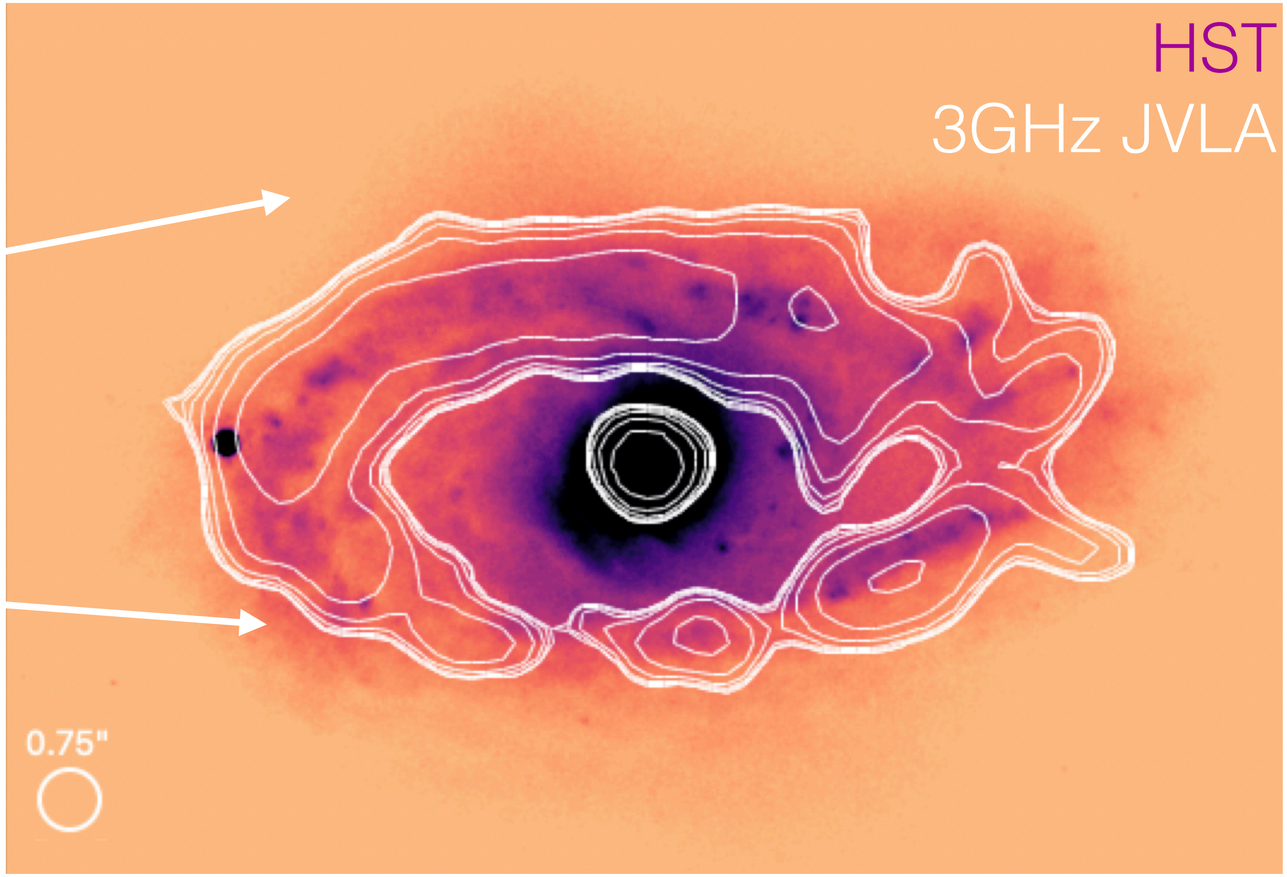




Vardoulaki+21, A&A, 627A, 142;Vardoulaki+19, A&A, 627A, 142

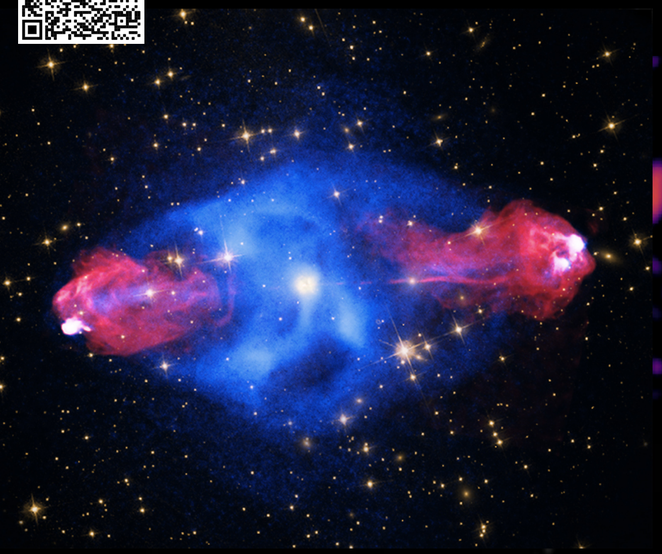
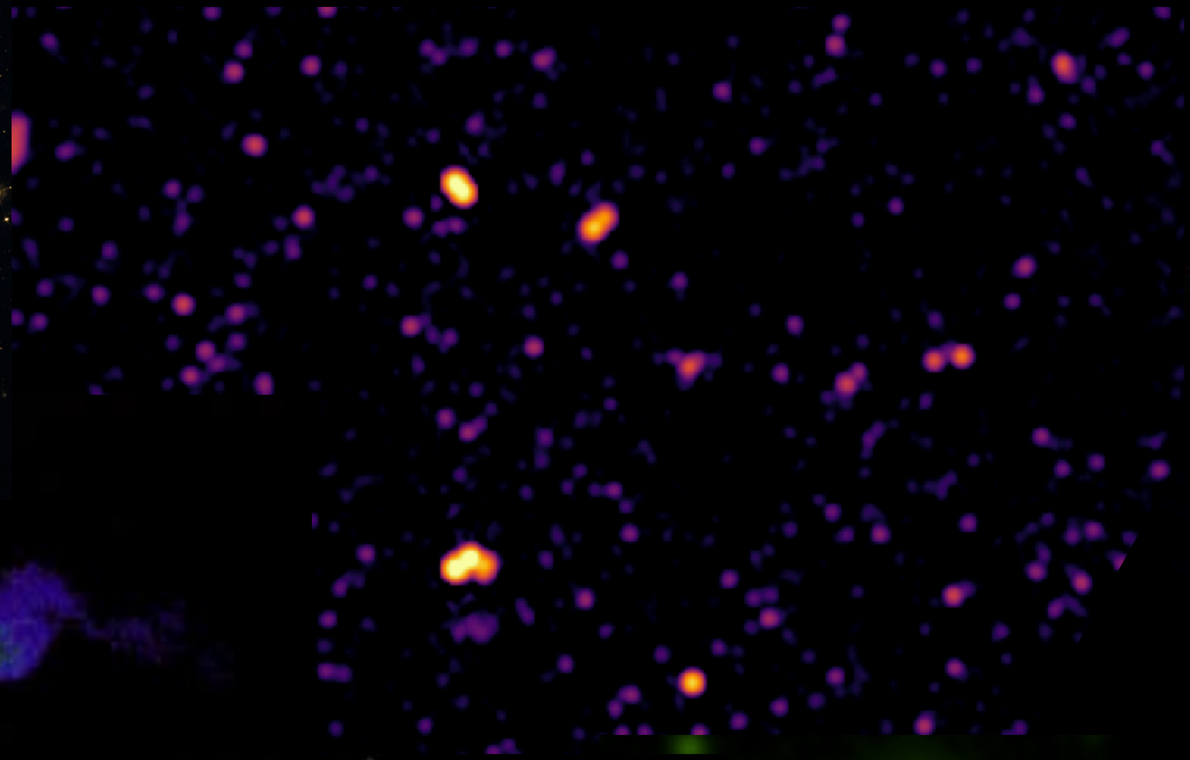
SFG example

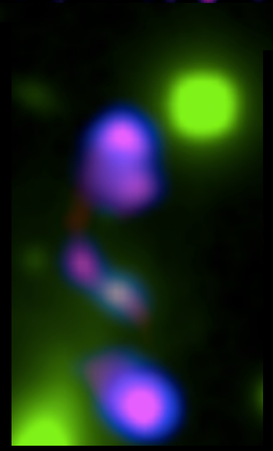
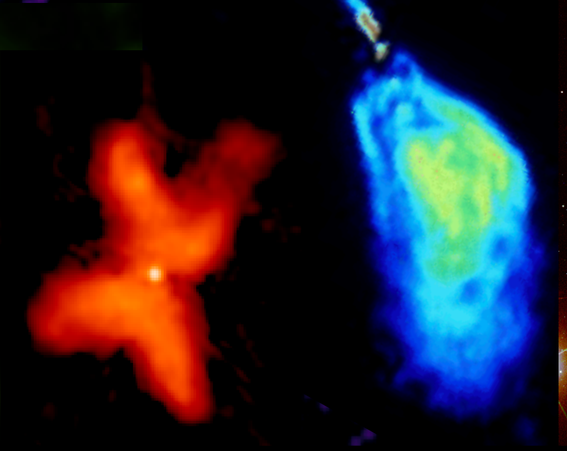


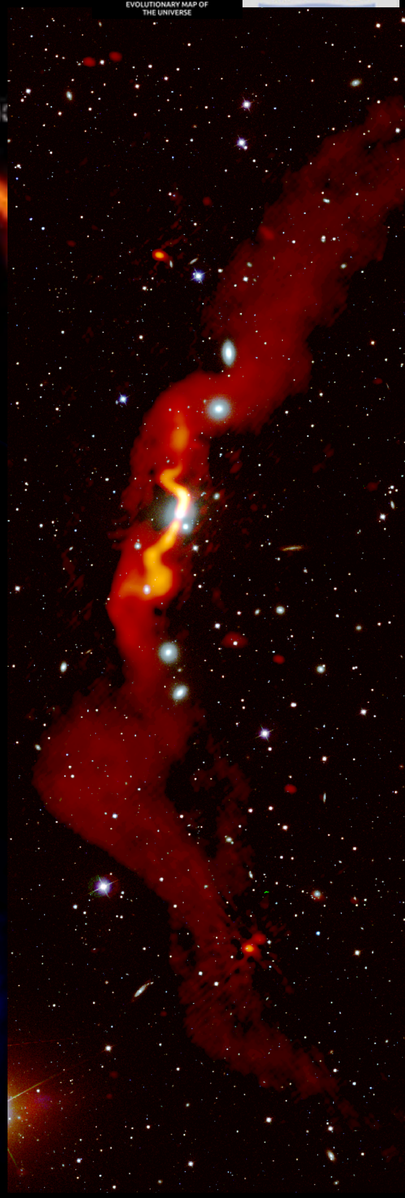


Vardoulaki+19, A&A, 627A, 142

Radio source zoo



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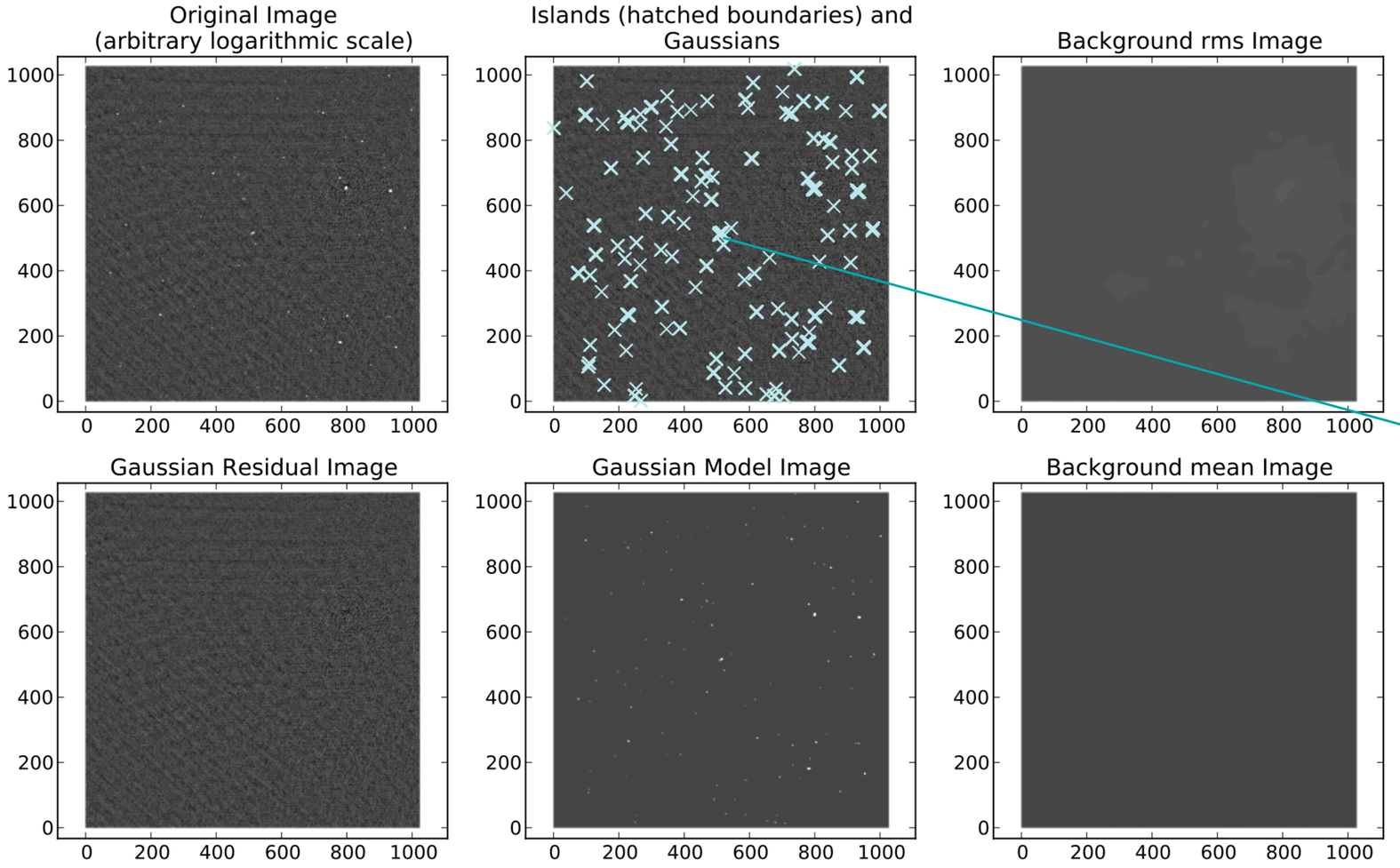
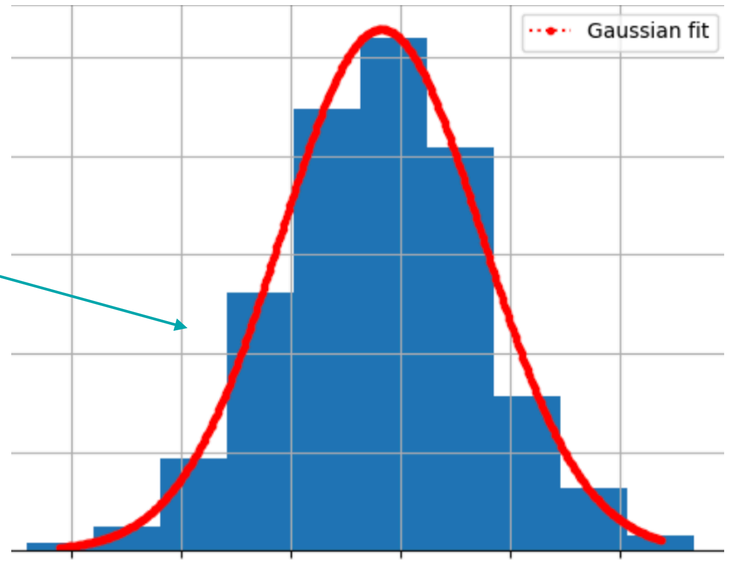
Automatic identification

Simple radio sources - good fit





PyBDSF - Mohan & Rafferty 2015
https://pybdsf.readthedocs.io/

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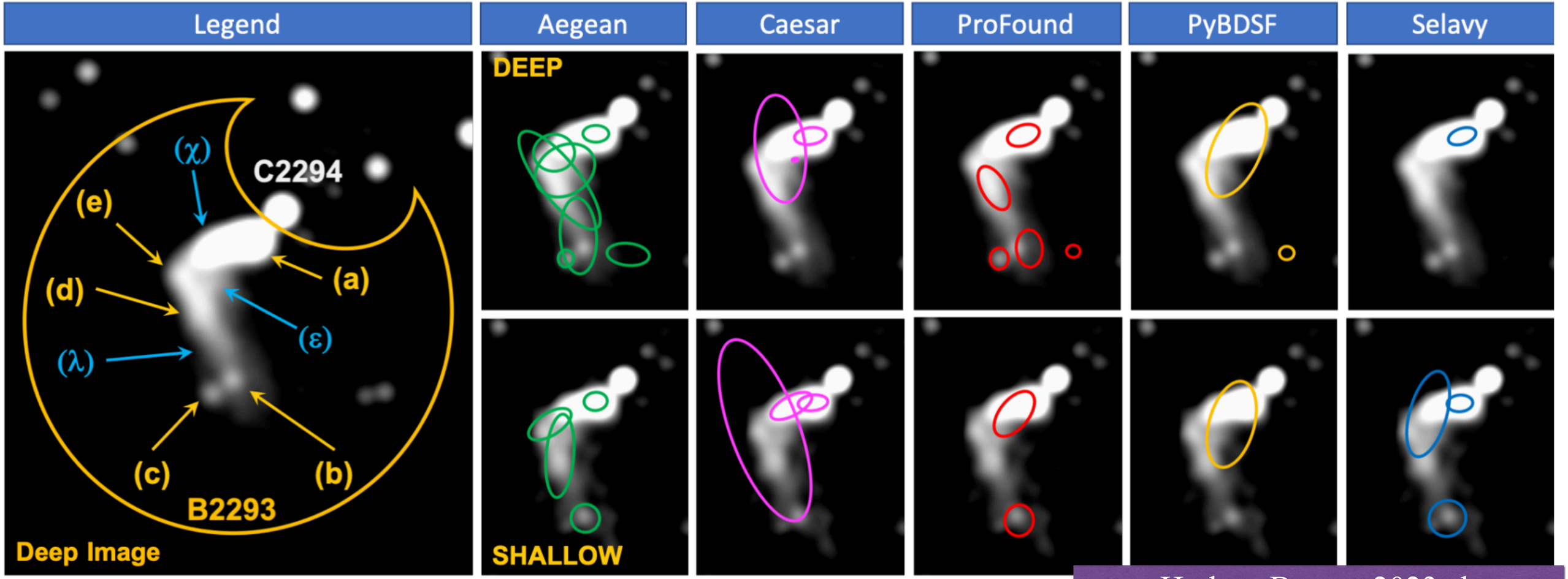
Automatic identification

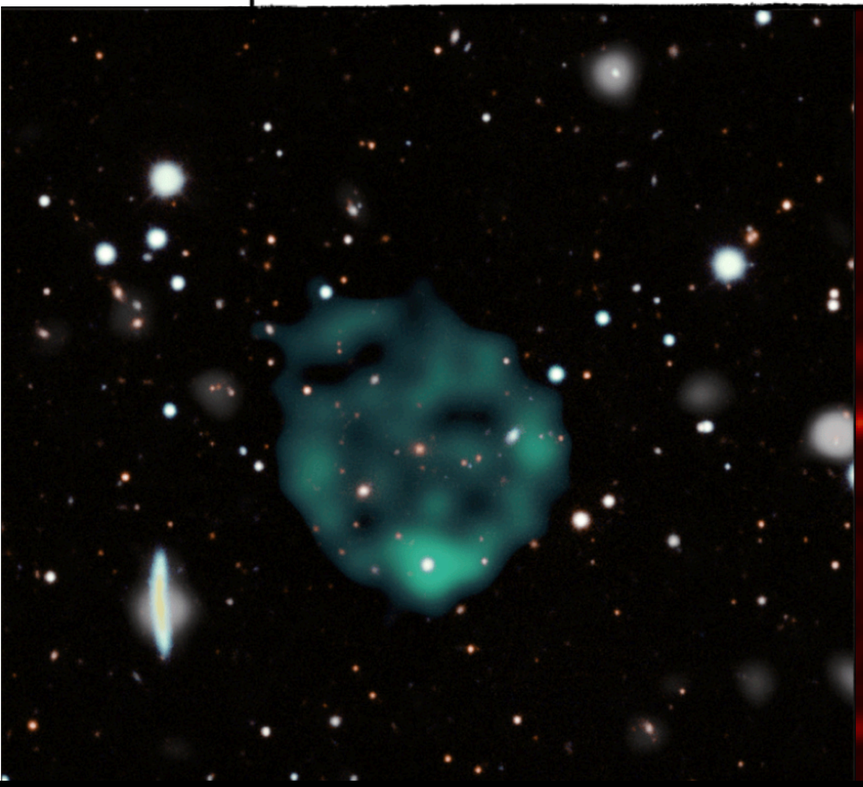
Complex radio source - not a good fit

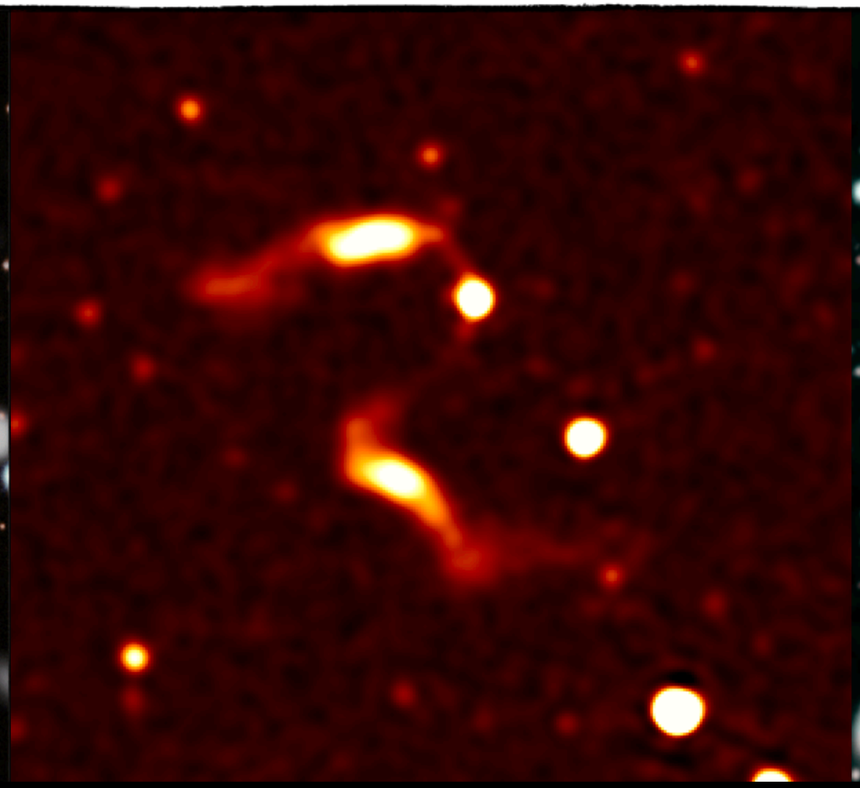


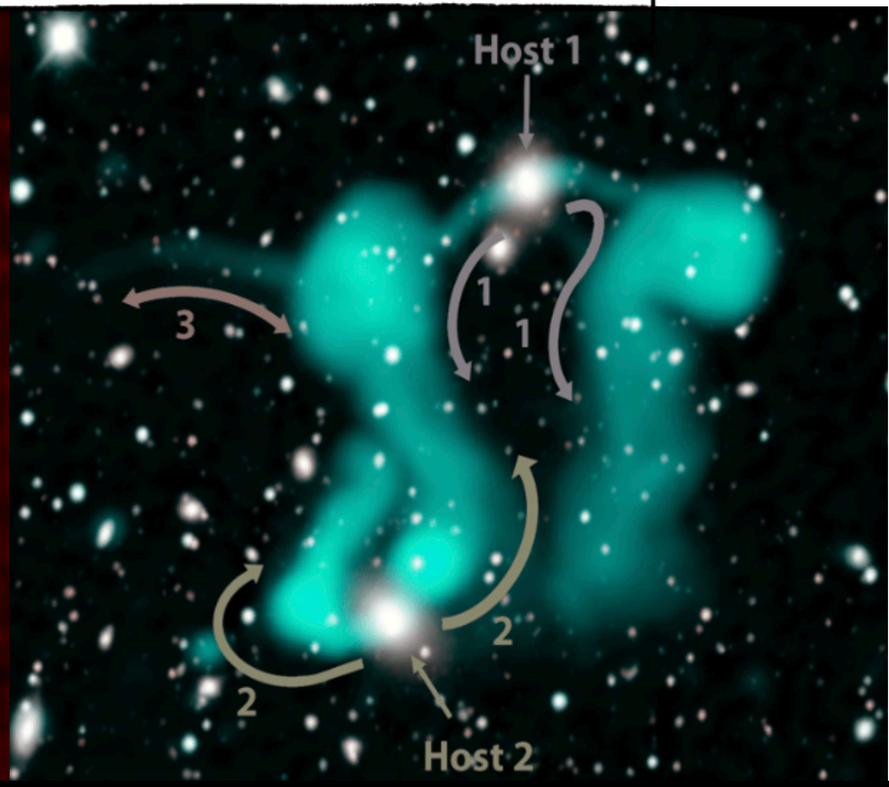
Hydra - Boyce+2023a,b

Why citizen science?

- Automatic algorithms don't always work for all cases: e.g. artefacts or complex images / unexpected objects
- Need for good training samples







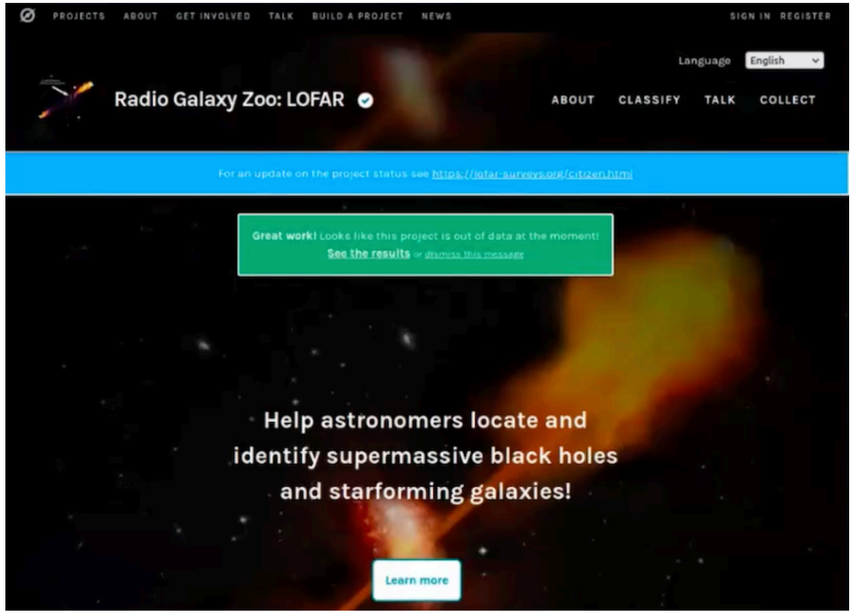
Citizen Science + ML/AI

RGZ; PI: Wong

100,000 sources

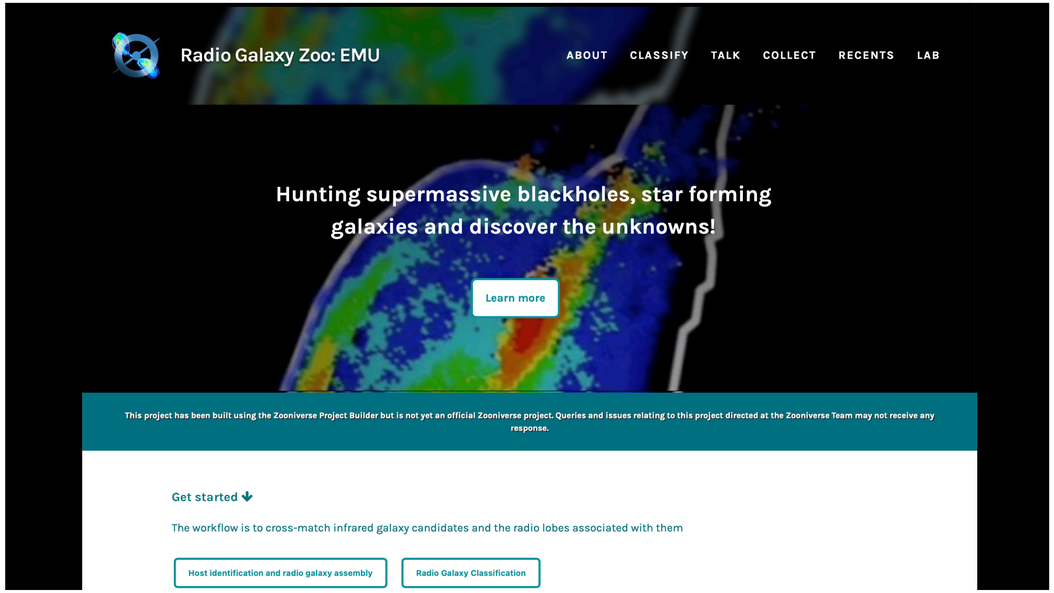
RGZ-LOFAR; PI: Hardcastle

4 million sources



RGZ-EMU; co-PIs: Tang & Vardoulaki

up to 40 million sources



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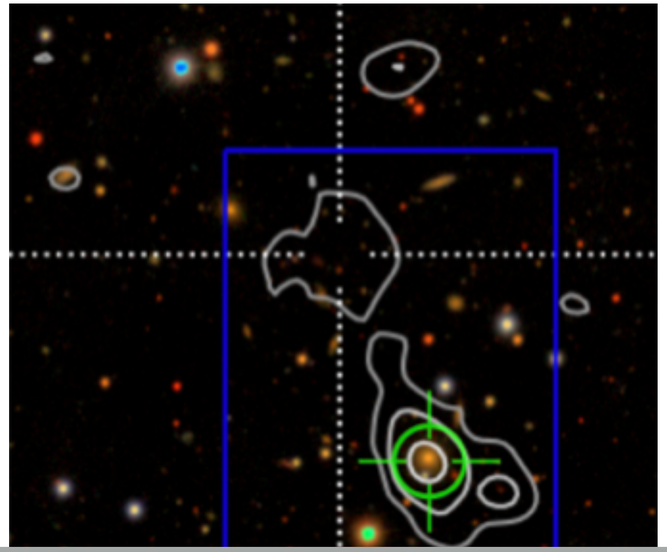
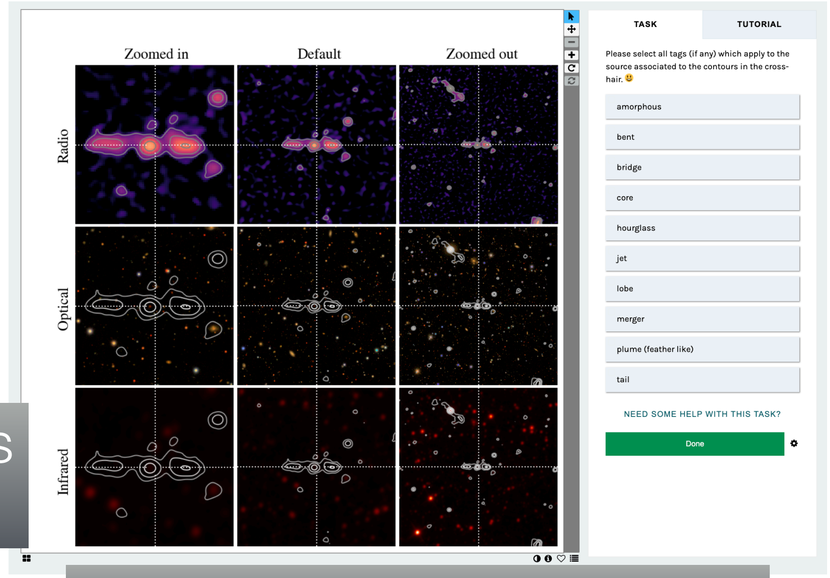
How citizen scientists help

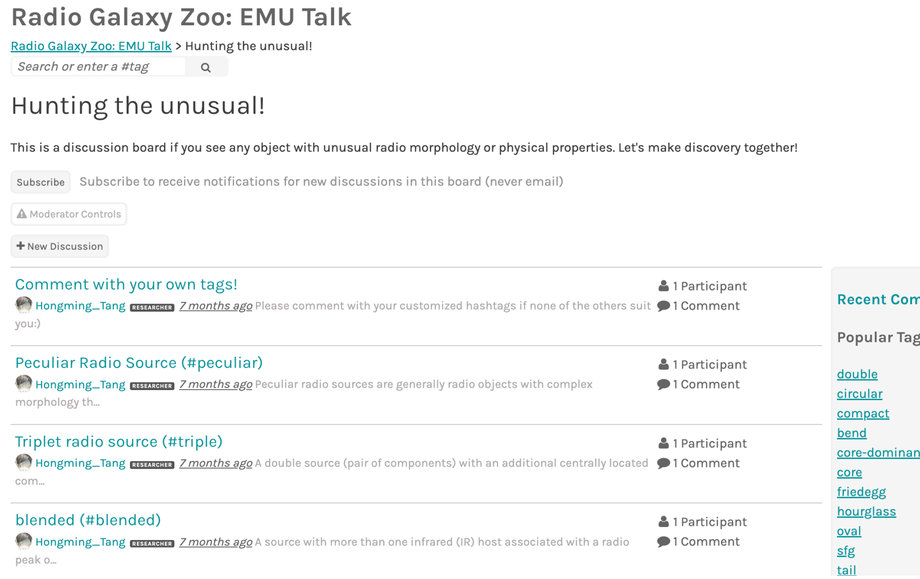
RGZ-EMU; co-PIs: Tang & Vardoulaki



Mark related radio components and the associate host galaxy



Classify sources using tags



Discuss their discoveries with us via the EMU Zoo Talk forum

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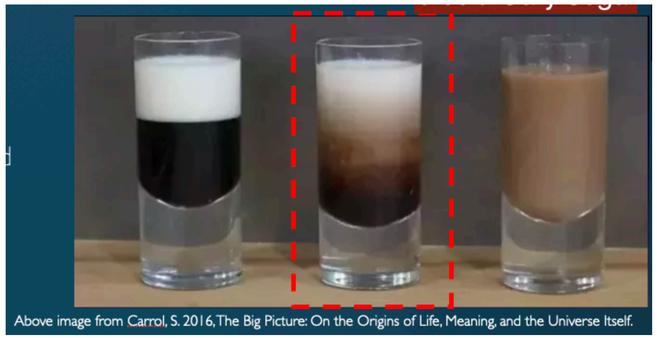
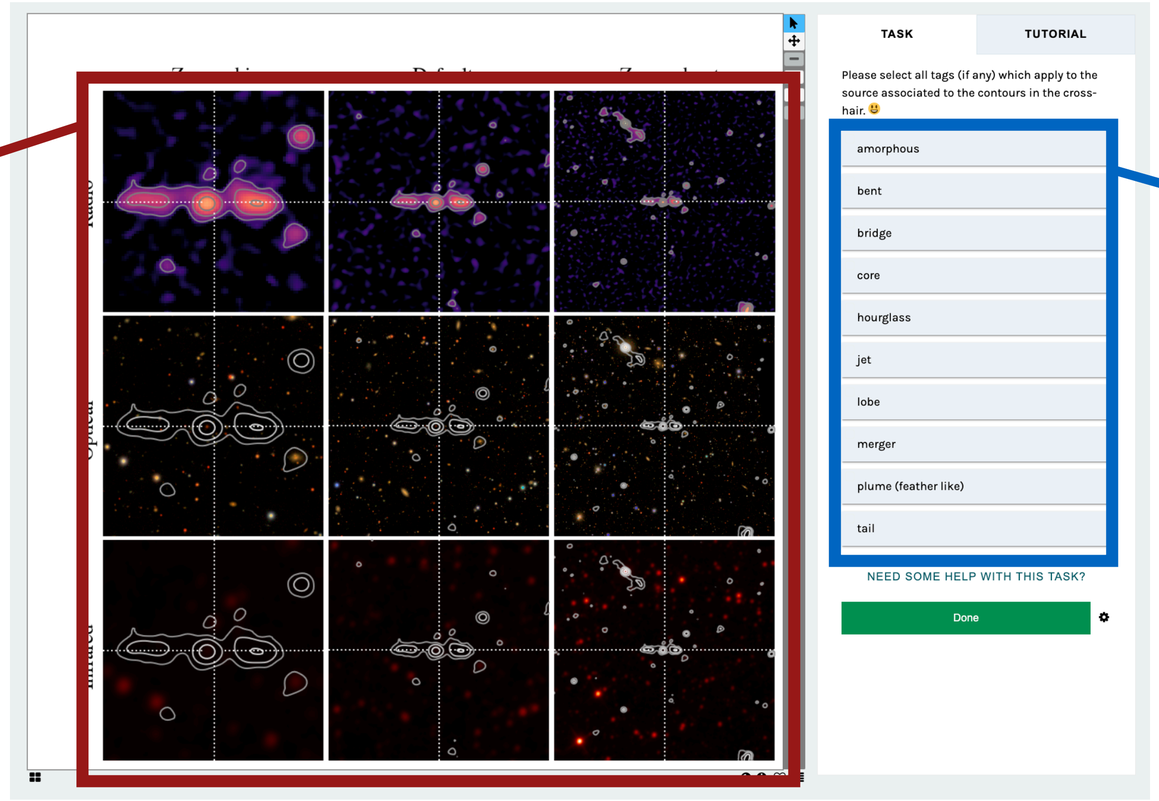
Citizen Science + Machine Learning

- Provide zooters most interesting targets - beta phase

Select object samples with high Complexity (Segal+23)





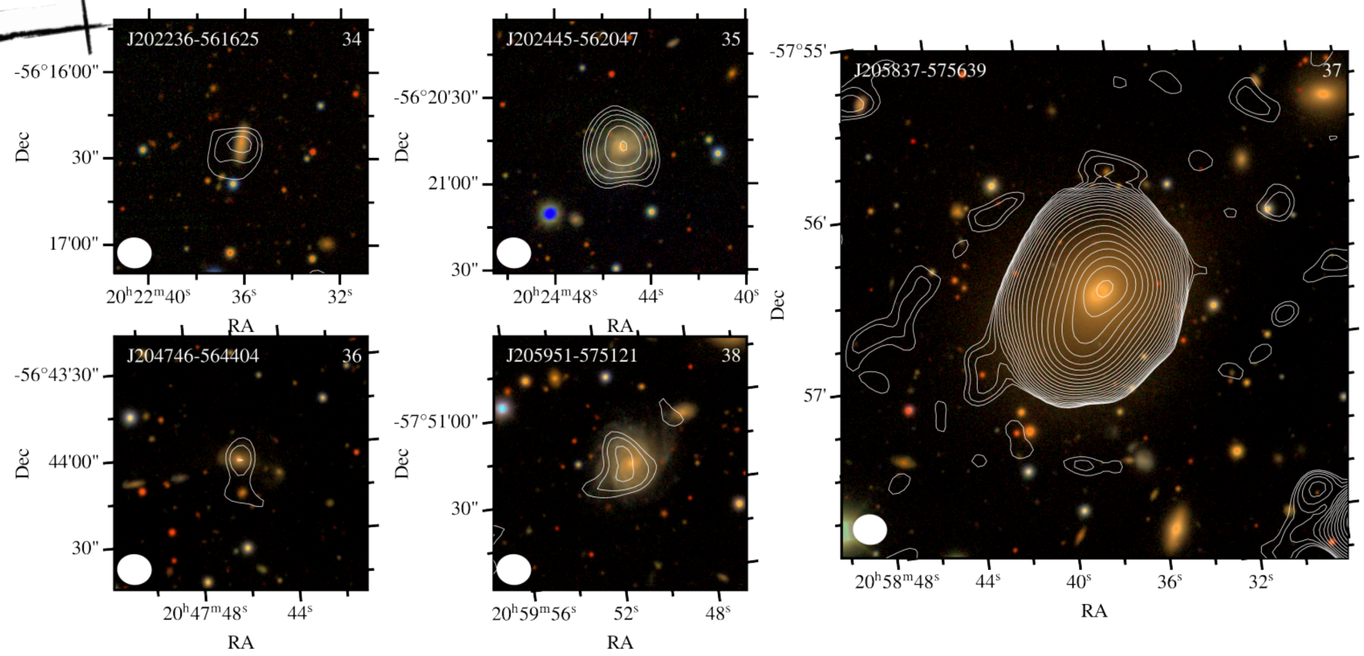
Tags generated via NLP/semantic taxonomy approach (Bowles+22, 23)

GOAL: Combine to EMUCAT Science ready catalogue (Marvil+in prep.)

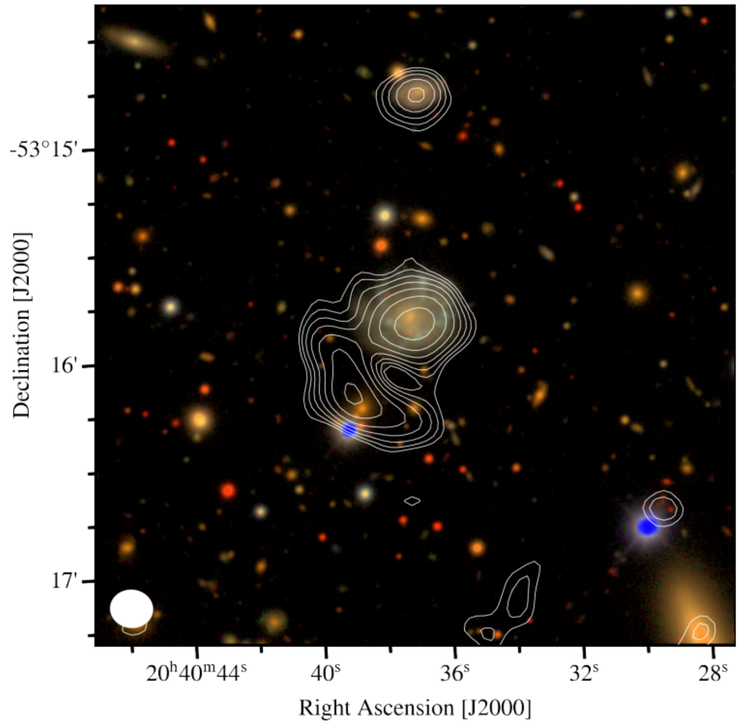
Tag selection - Ontology - Examples

Science classes

SFG



Rare source



Semantic classes

‘traces host galaxy’

“hourglass \ (amorphous ∪ traces host galaxy ∪ bent)”

Bowles, Tang, Vardoulaki et al. 2023, MNRAS, 522, 2584
Bowles, Tang, Vardoulaki et al. 2022 arXiv221014760B

Take home

1. What is a radio source: active galaxy/ star forming galaxy/ other
2. Data acquisition using radio telescopes: interferometry
3. Examples from literature: need for identification/ assembly/ classification
4. Why we need citizen science: millions/ billions of radio sources to classify
5. Radio Galaxy Zoo EMU: built using complexity/ natural language processing
6. Hands on (zooniverse.org)

NRAO/AUI/NSF - 300FOOT Telescope - 5 GHz - 1987

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Material

https://elenivardoulaki.com/material-for-ml-workshop-in-astronomy-23-nov-23/

NRAO/AUI/NSF - 300FOOT Telescope - 5 GHz - 1987

Hands on

https://www.zooniverse.org/projects/hongming-tang/radio-galaxy-zoo-emu

NRAO/AUI/NSF - 300FOOT Telescope - 5 GHz - 1987

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