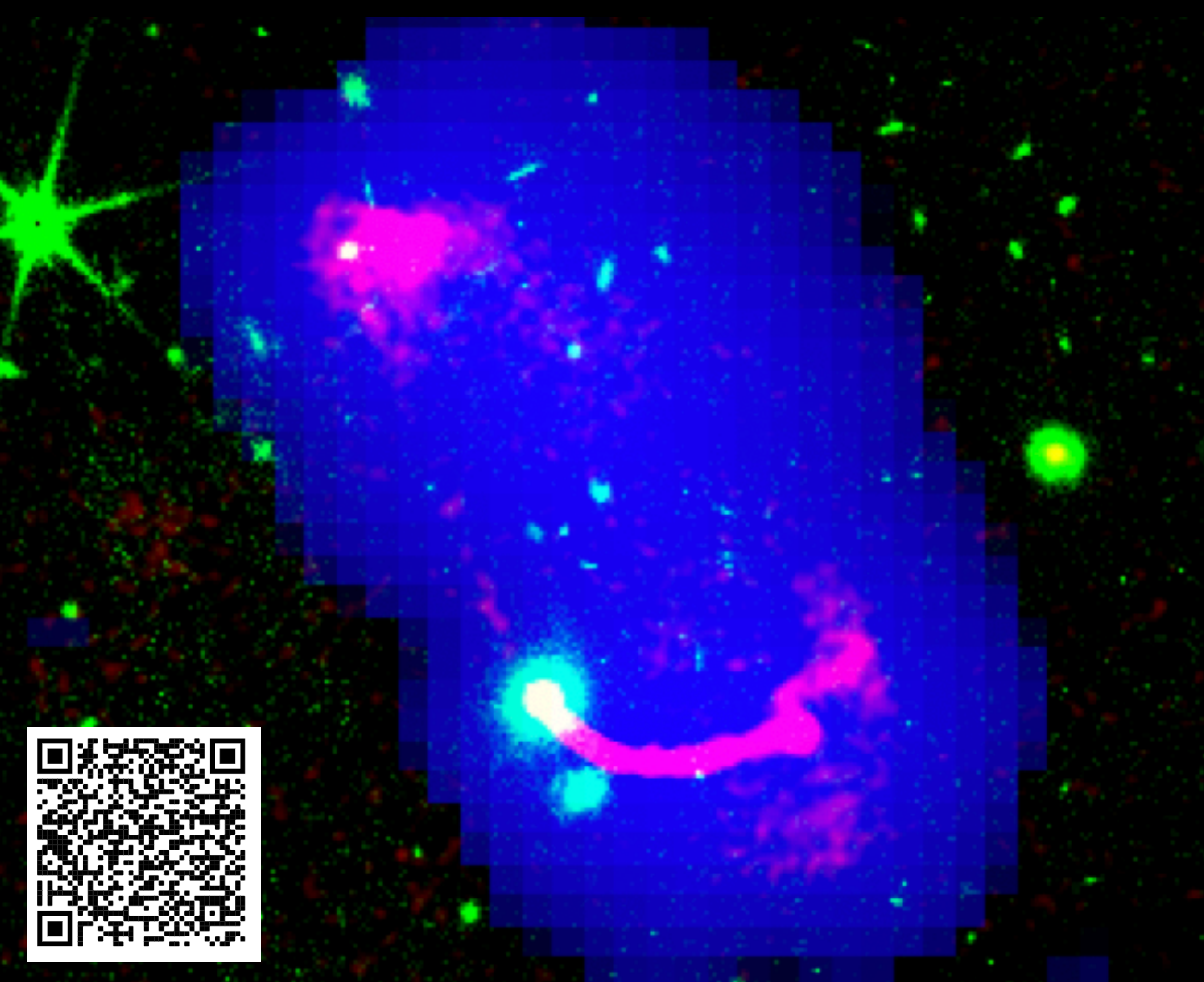
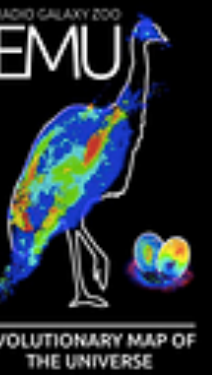
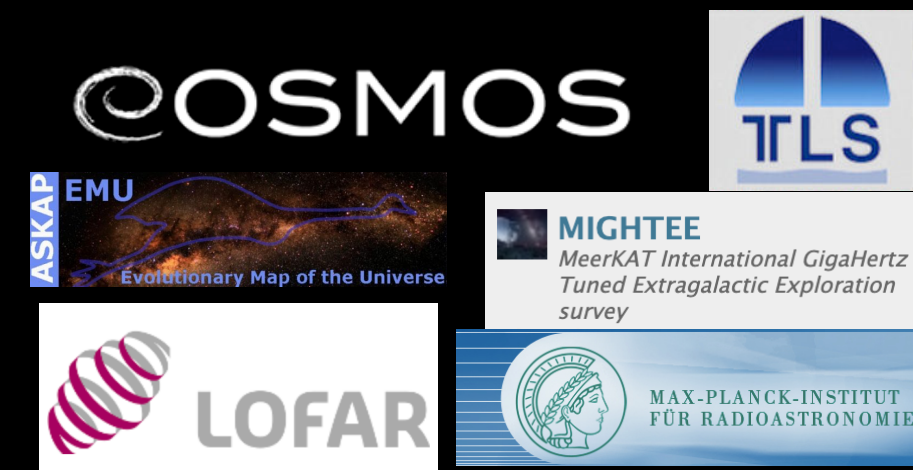


# Conventional classification methods, robust training samples, and hands-on examples



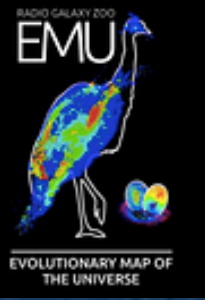
*Eleni Vardoulaki*  
*Thüringer Landessternwarte Tautenburg*

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

[elenivard@gmail.com](mailto:elenivard@gmail.com);  
<https://www.linkedin.com/in/eleni-wardoulaki/>  
Rogue Astrophysics; Astronomy on Tap Jena  
[elenivardoulaki.com](http://elenivardoulaki.com)



# 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

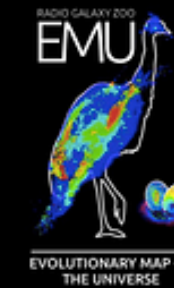
6. Hands on ([zooniverse.org](http://zooniverse.org))



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



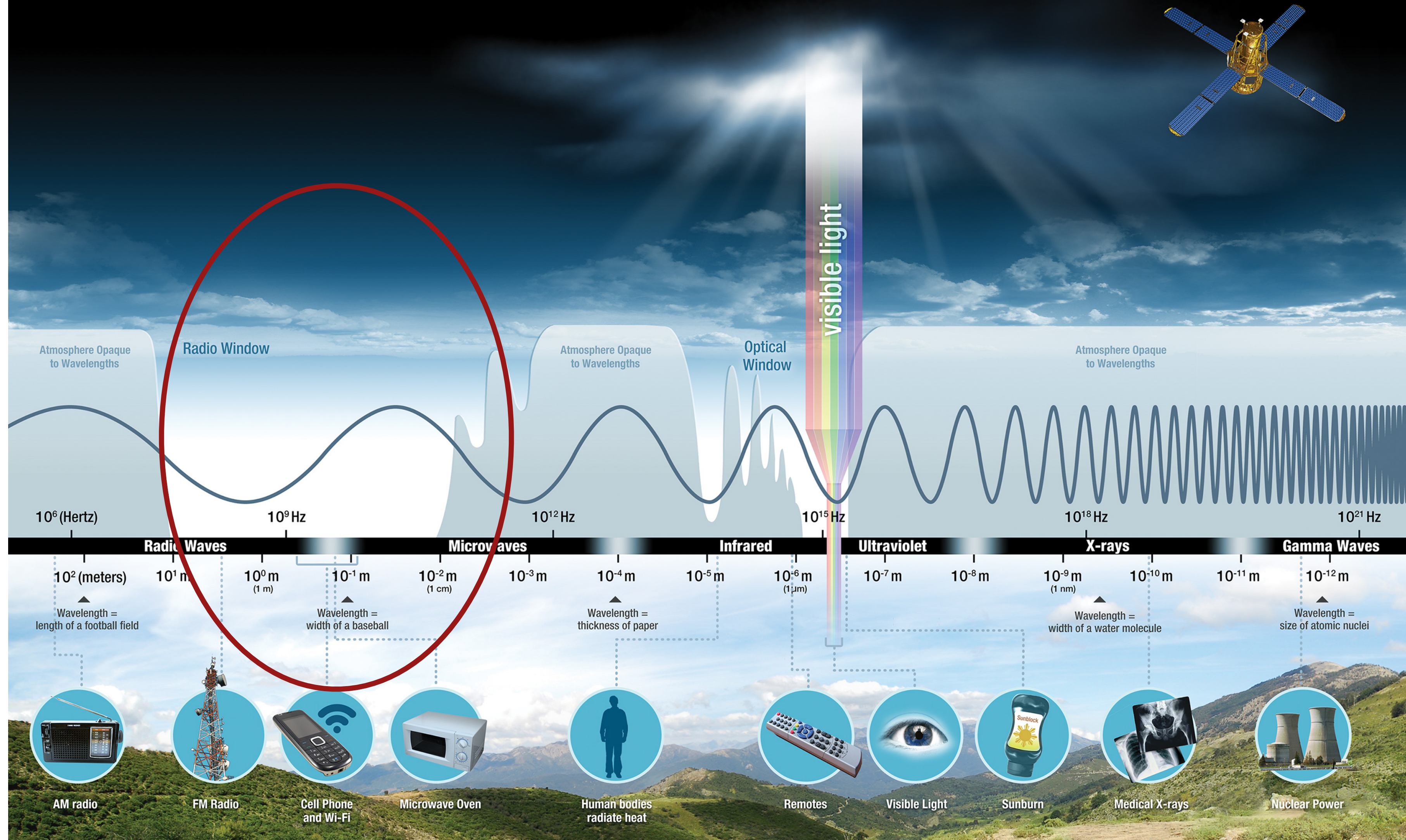
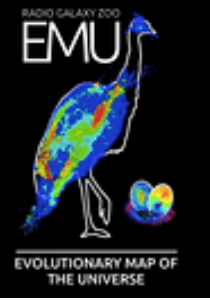
# The radio sky



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

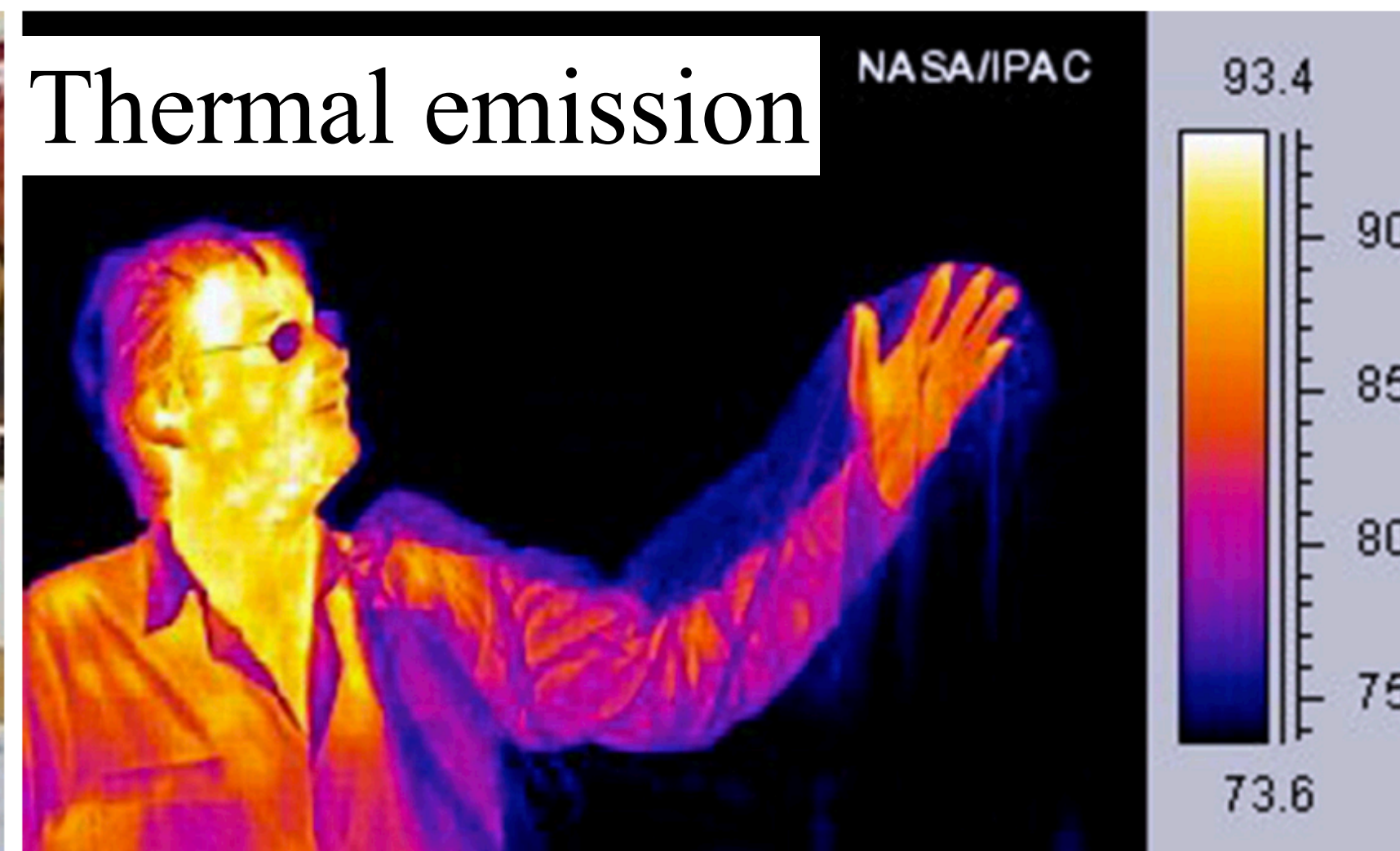
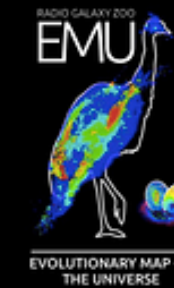


# The electromagnetic spectrum

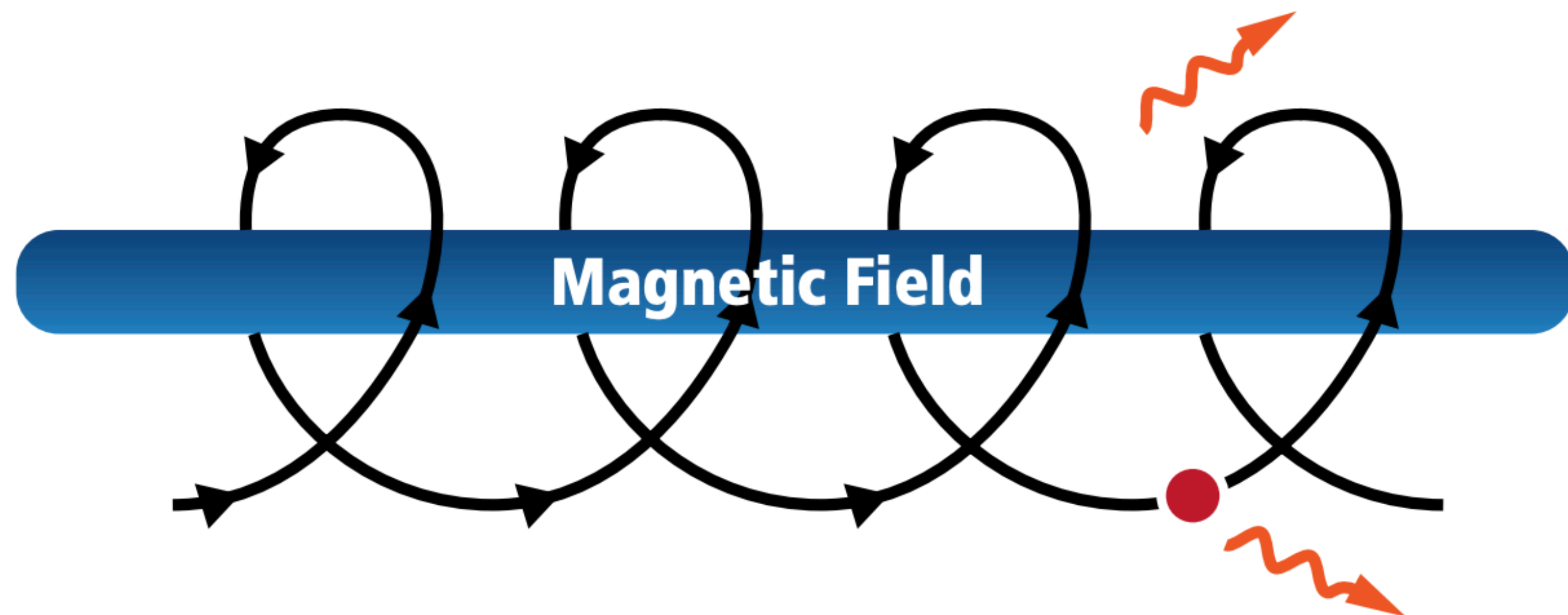




# Thermal/non-thermal radiation

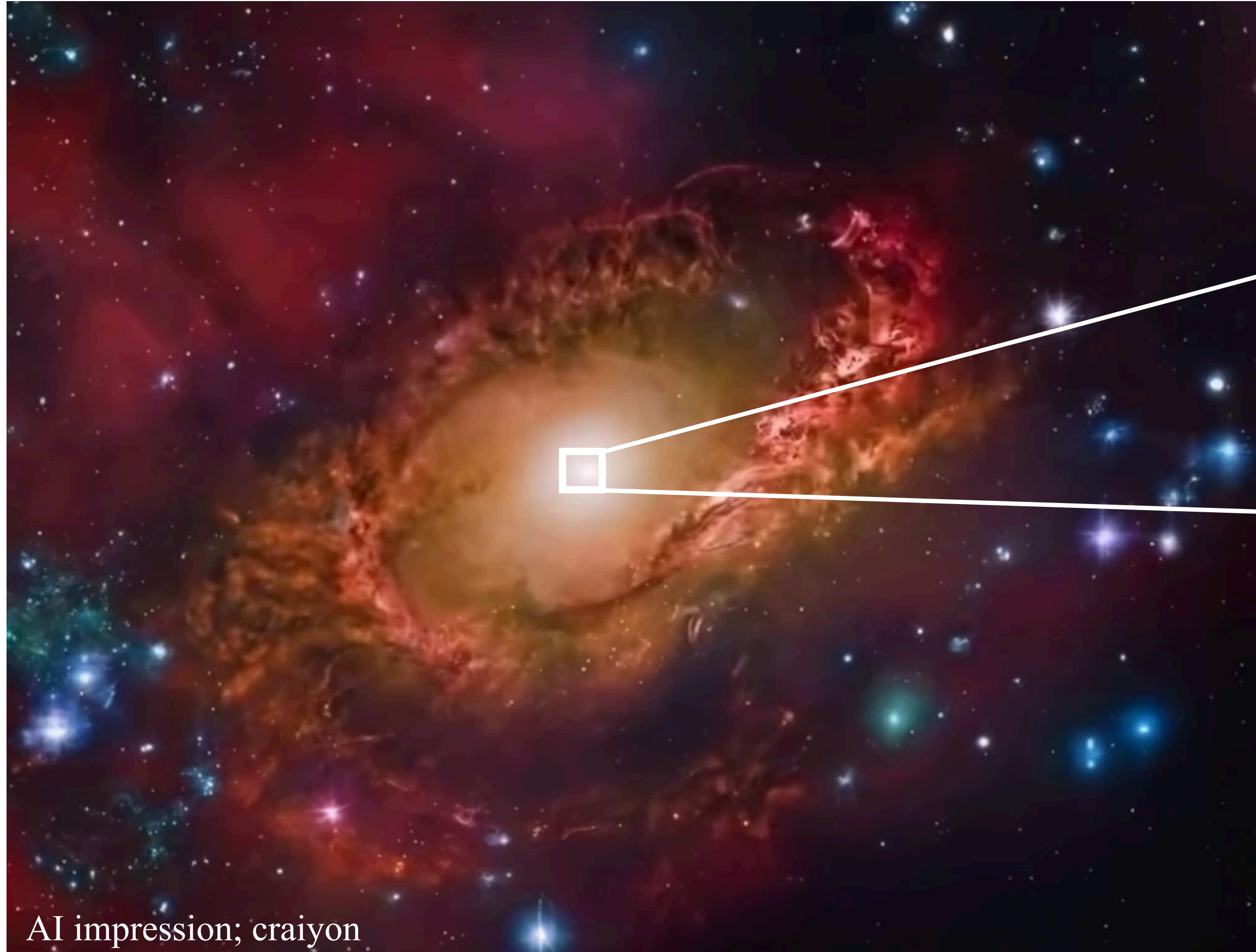
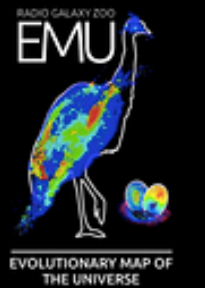


Non-thermal emission  
If relativistic electrons: synchrotron

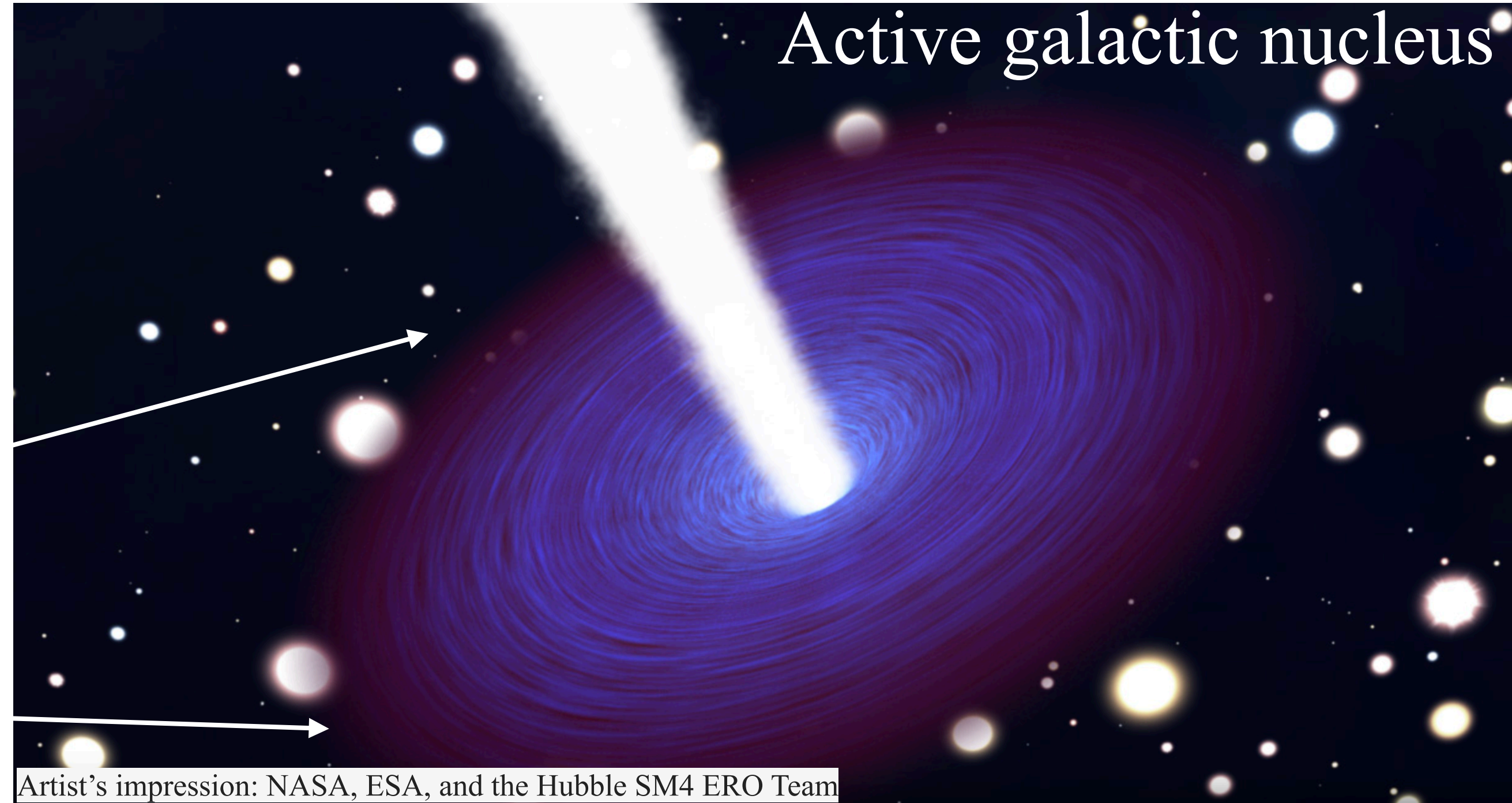




# Synchrotron emission



AI impression; craiyon

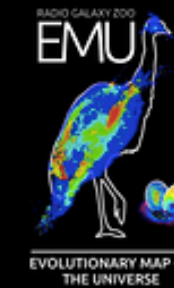


Active galactic nucleus

Artist's impression: NASA, ESA, and the Hubble SM4 ERO Team



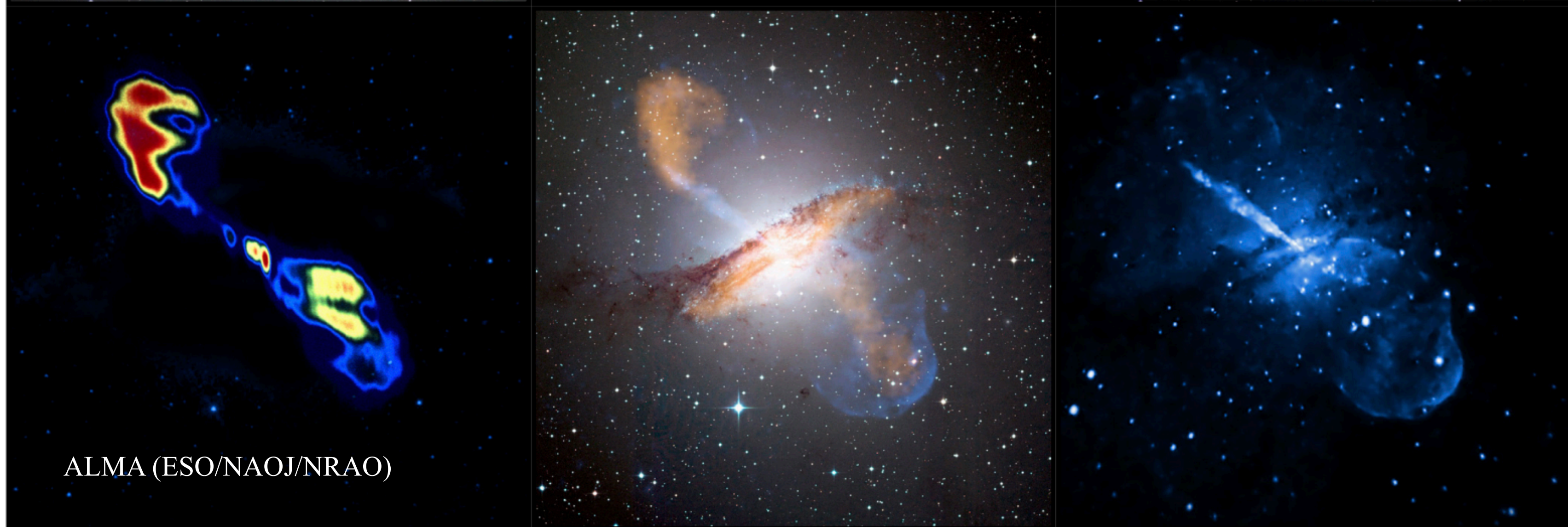
# Example of Active Galaxy



Optical →

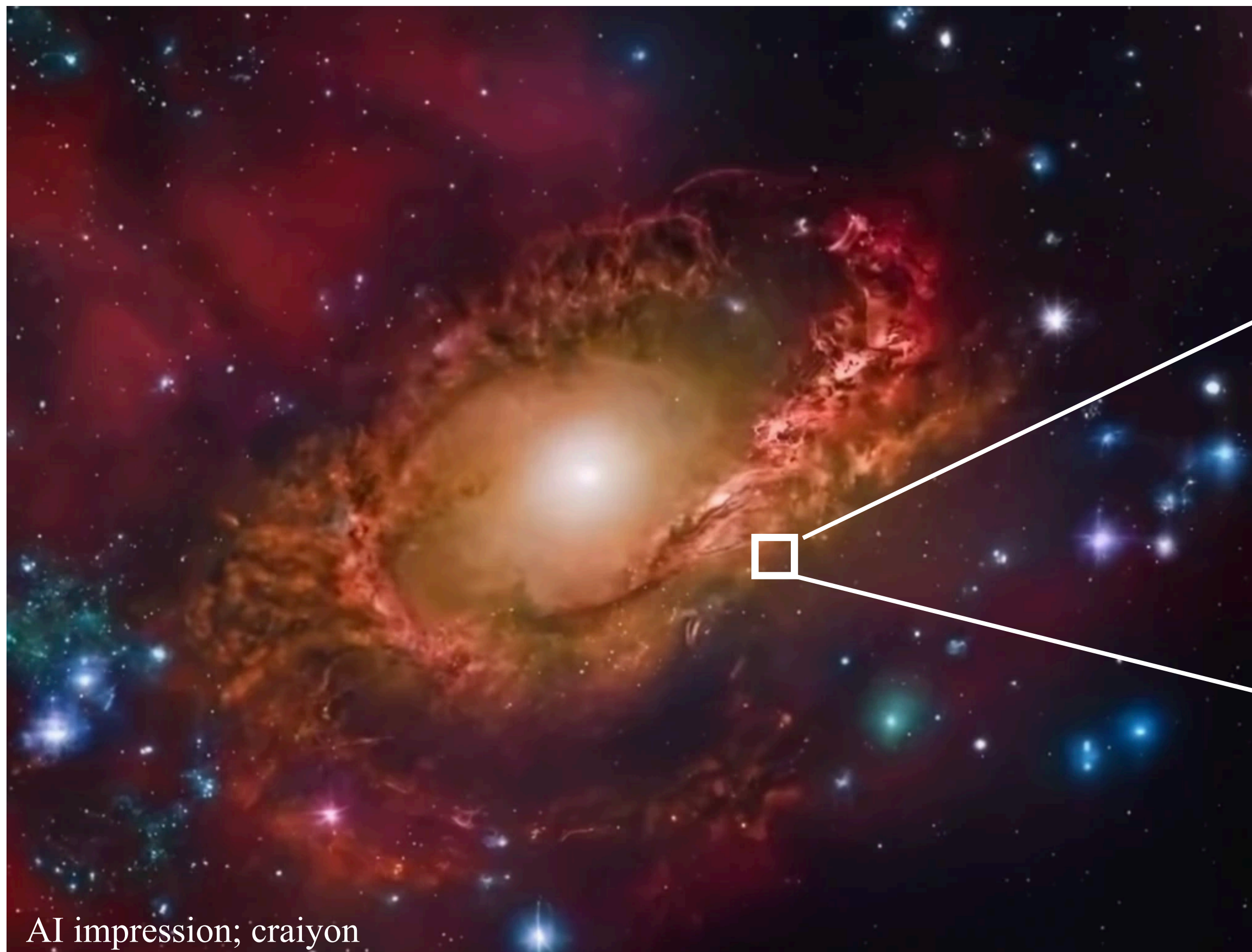
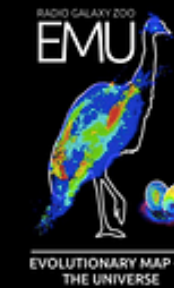


Radio →





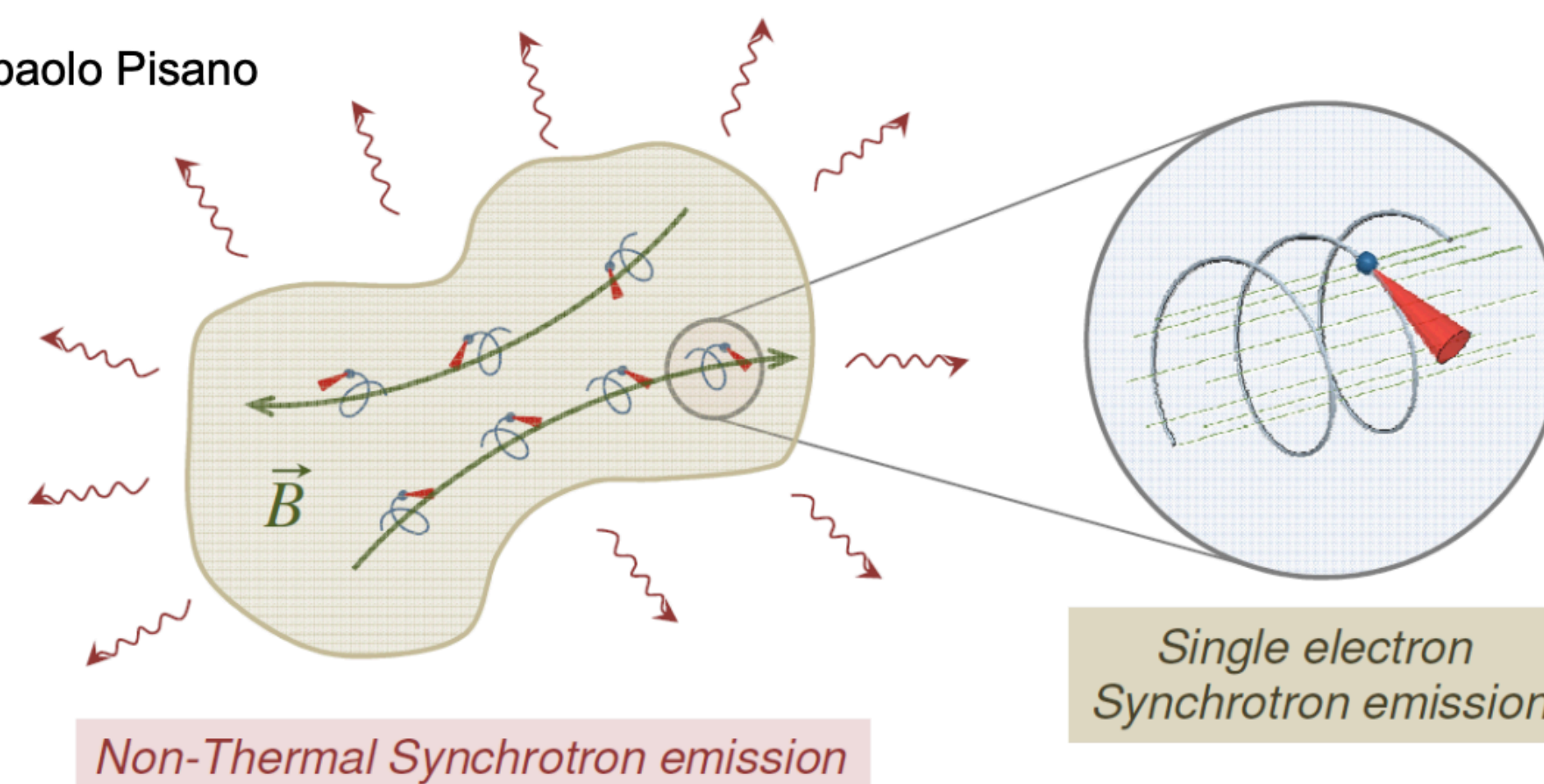
# Synchrotron emission



AI impression; craiyon

## Star forming regions

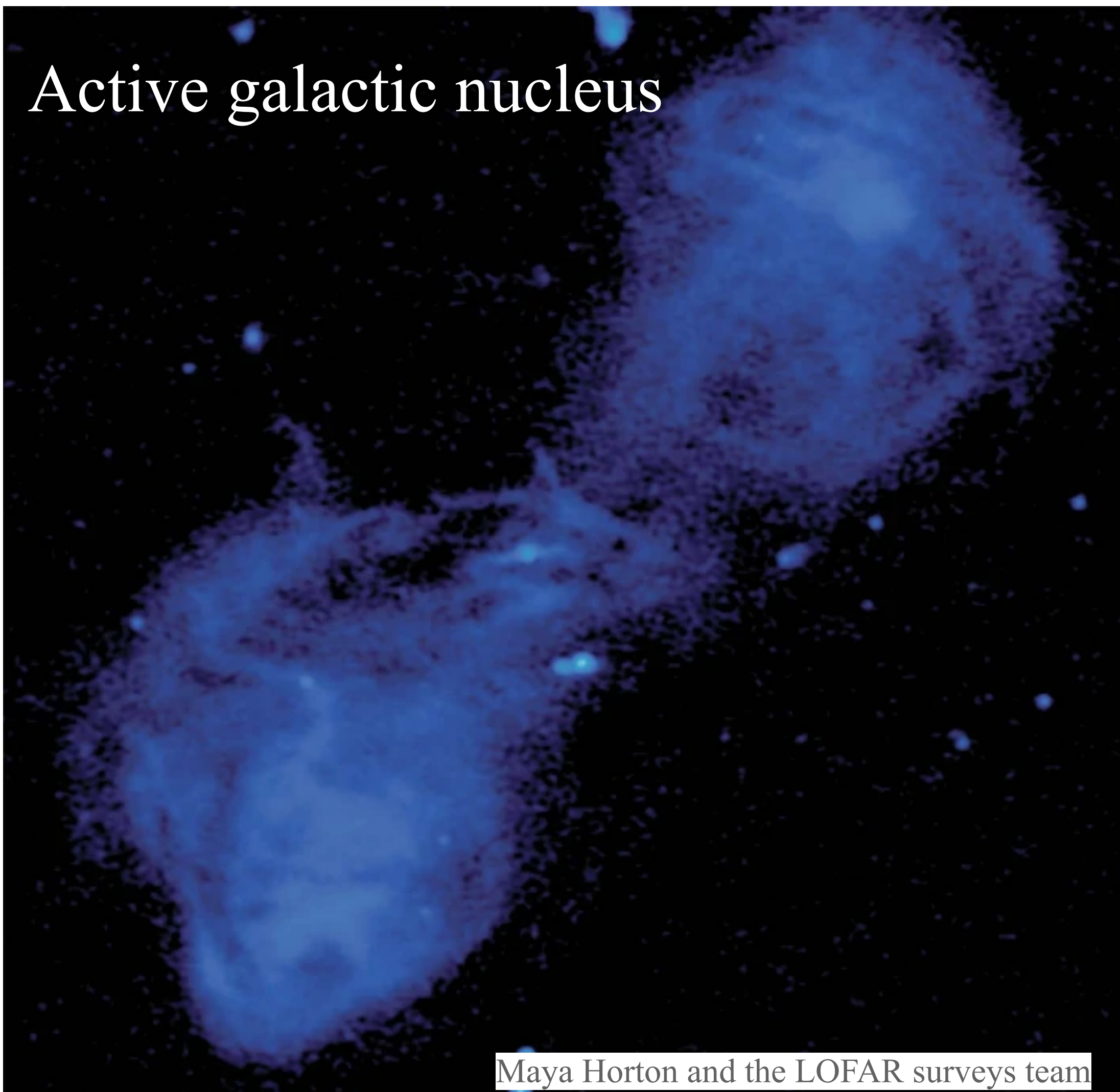
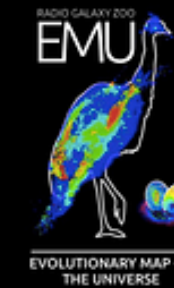
Image credit: Giampaolo Pisano





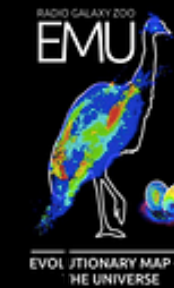


# Synchrotron emission

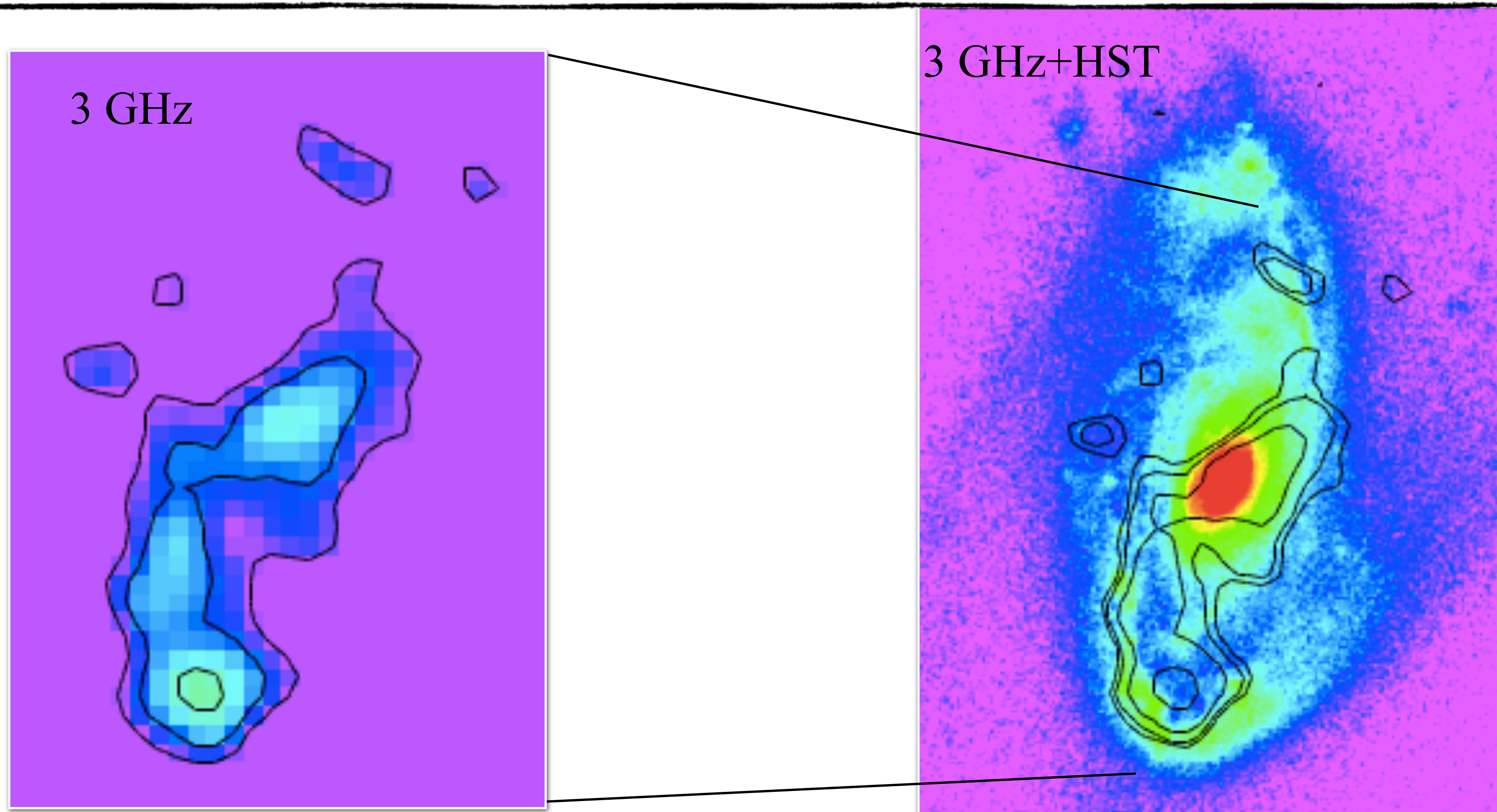




# Synchrotron emission

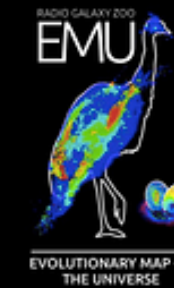


- single frequency classification: highly subjective
- need for multi-wavelength data





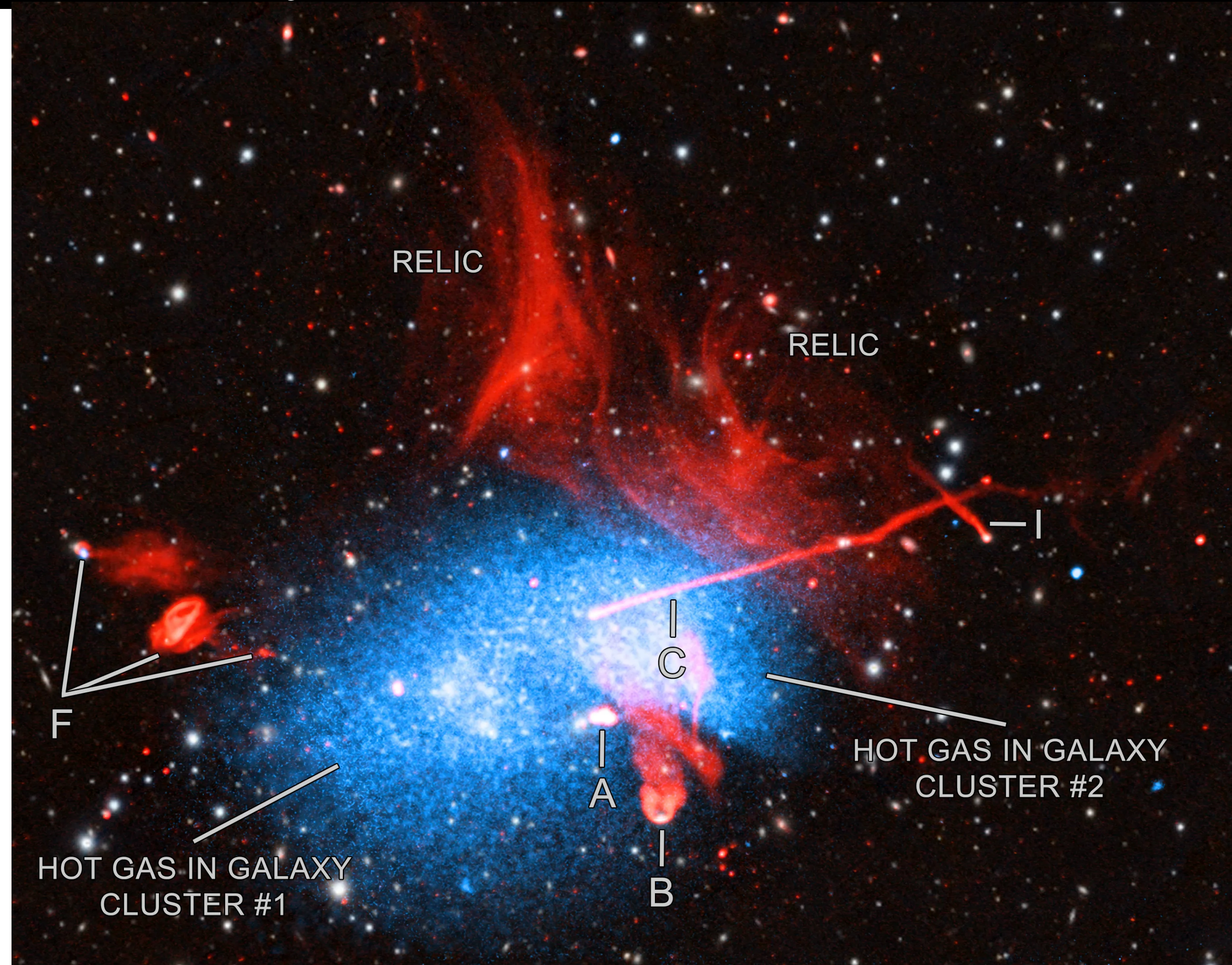
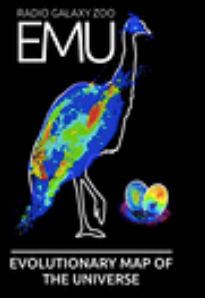
# Synchrotron emission



X-ray: Chandra: NASA/CXC/Univ. of Bologna/K. Rajpurohit et al.; XMM-Newton: ESA/XMM-Newton/Univ. of Bologna/K. Rajpurohit et al. Radio: LOFAR: LOFAR/ASTRON; GMRT: NCRA/TIFR/GMRT; VLA: NSF/NRAO/VLA; Optical/IR: Pan-STARRS003c/emu003eu003c/strongu003e



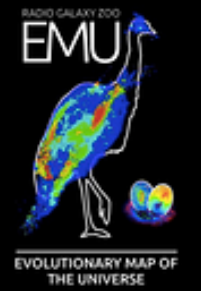
# Synchrotron emission



X-ray: Chandra: NASA/CXC/Univ. of Bologna/K. Rajpurohit et al.; XMM-Newton: ESA/XMM-Newton/Univ. of Bologna/K. Rajpurohit et al. Radio: LOFAR: LOFAR/ASTRON; GMRT: NCRA/TIFR/GMRT; VLA: NSF/NRAO/VLA; Optical/IR: Pan-STARRS003c/emu003eu003c/strongu003e



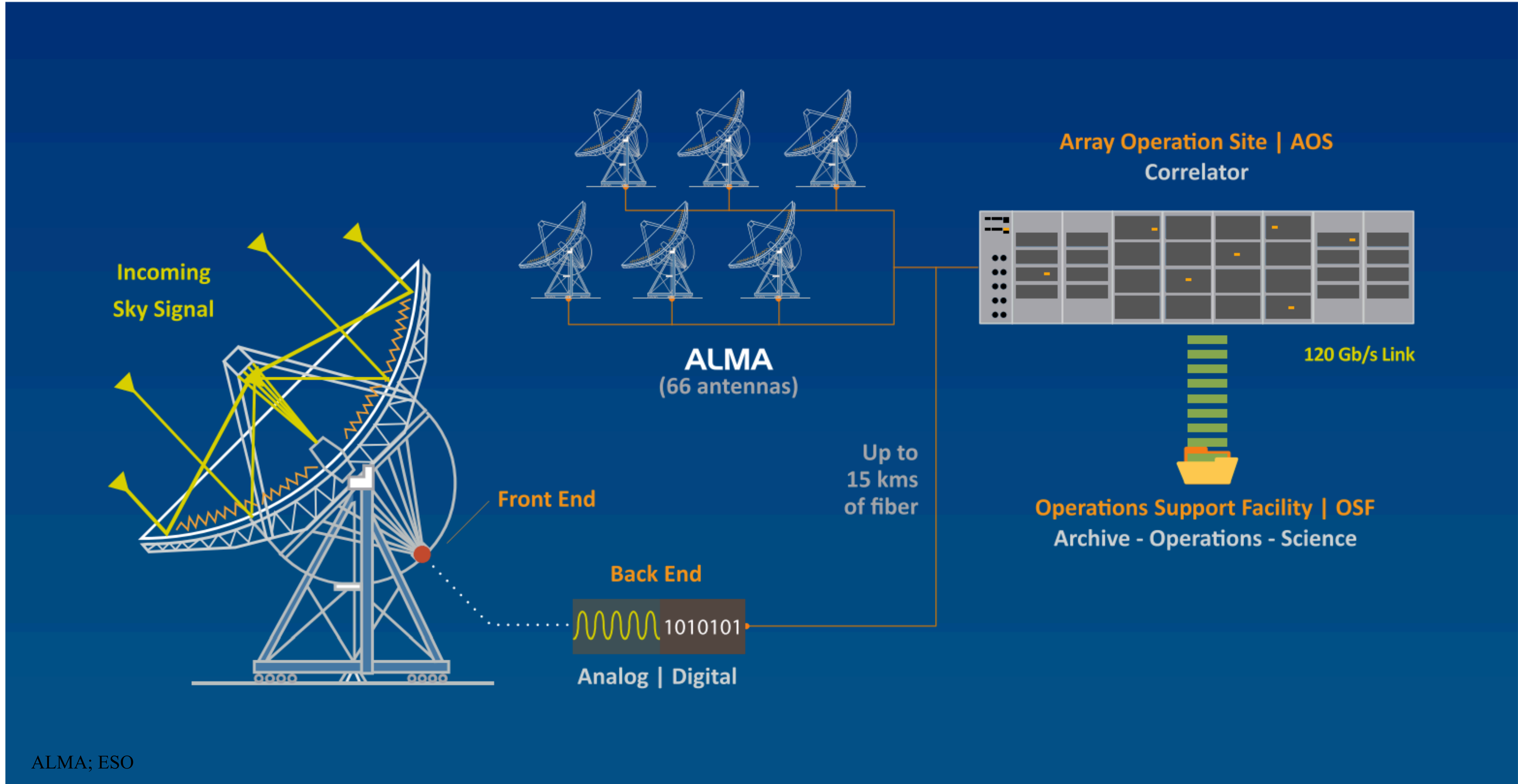
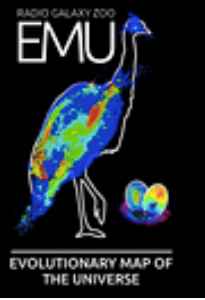
# Data acquisition



Vernesa Smolčić



# Data acquisition

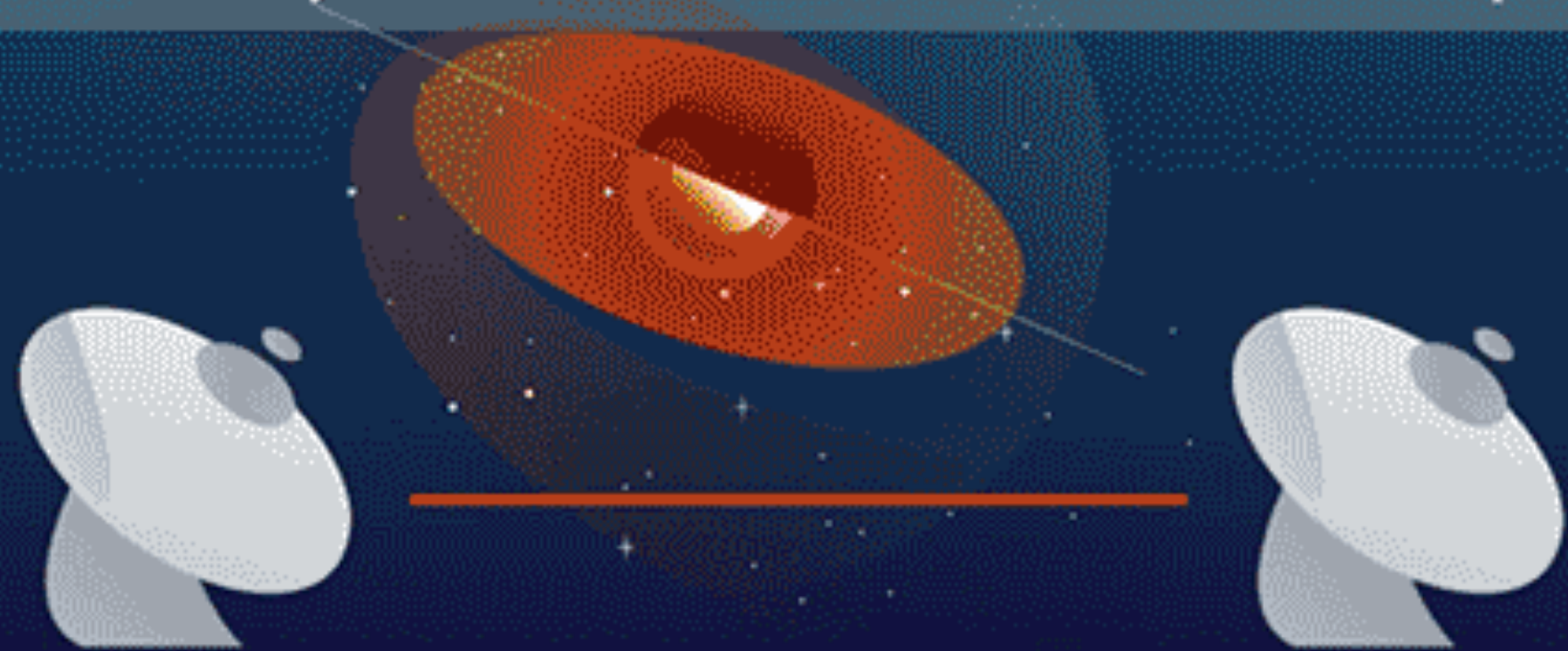




# Interferometry



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.



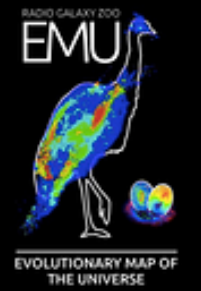
Interferometers harness the space between the antennas: the **larger the spacings, the higher the resolving power**, allowing it to see finer and finer details, like the zoom lens of a camera.

## 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.

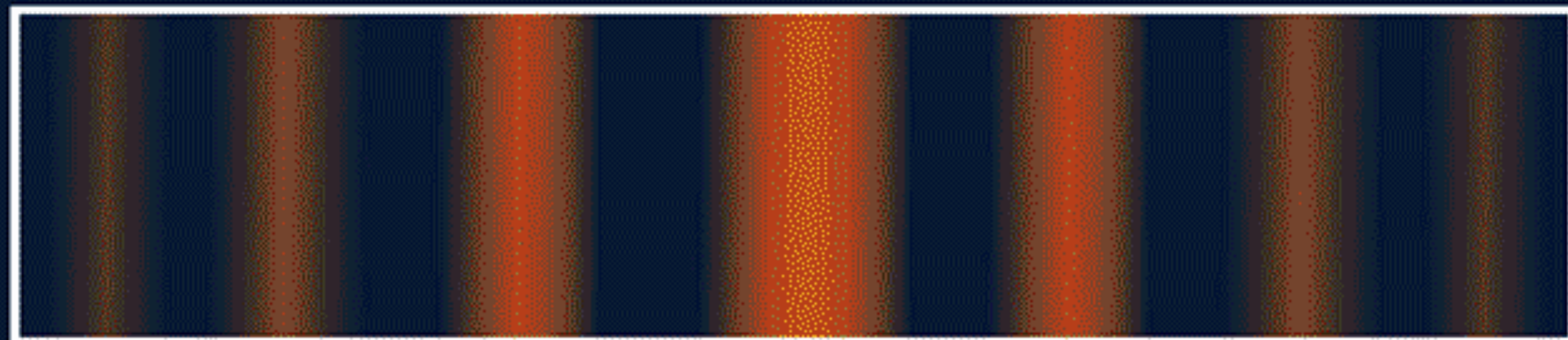
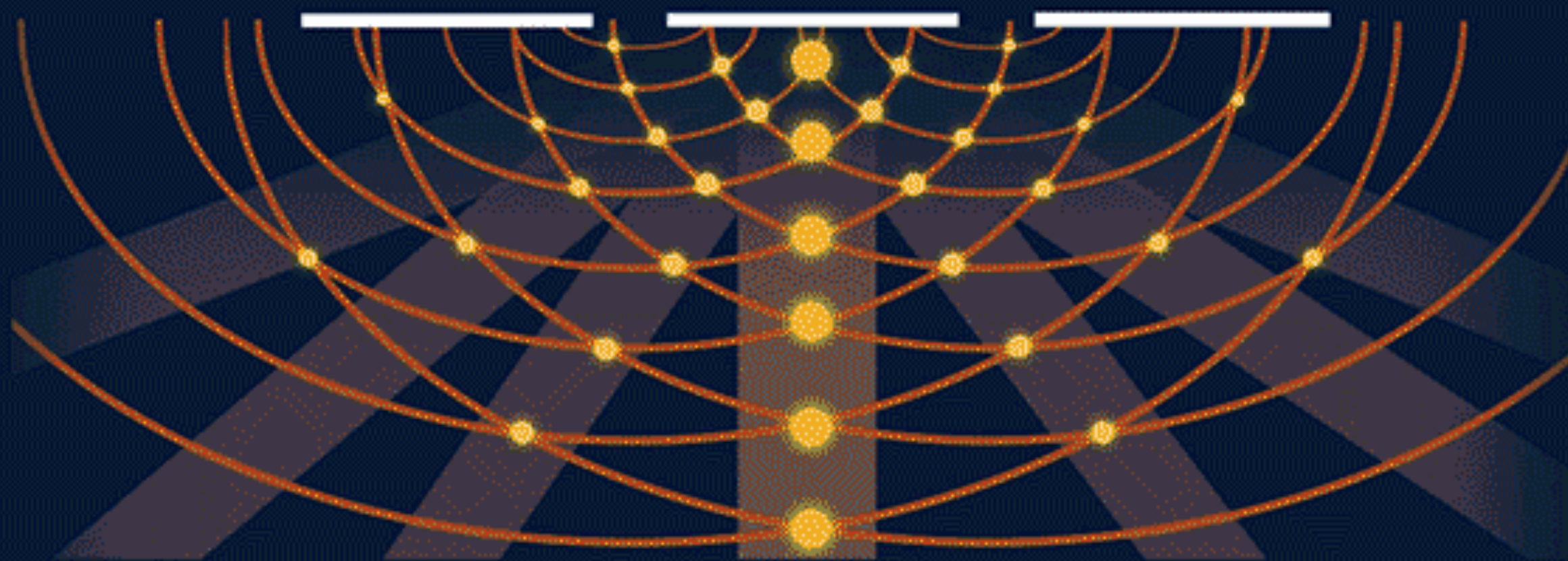


# Data acquisition



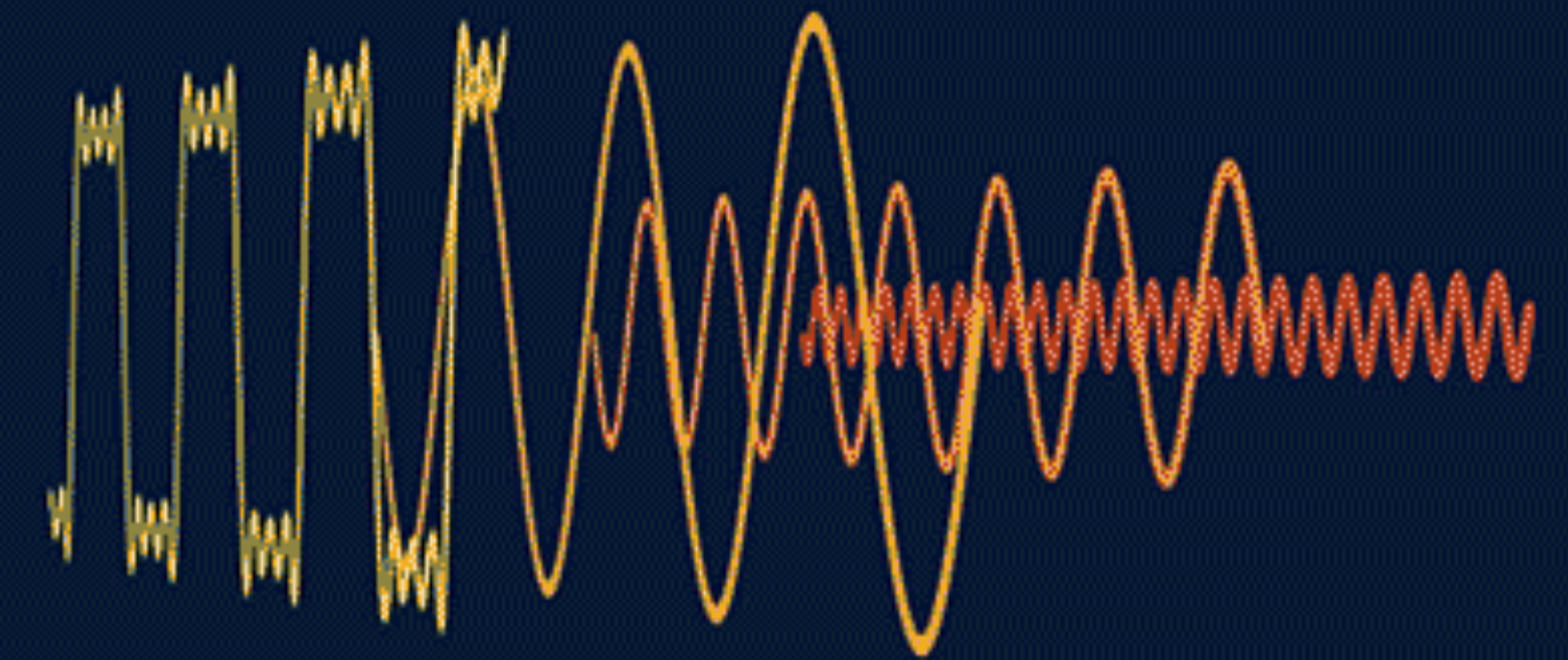
## Interference Pattern

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.

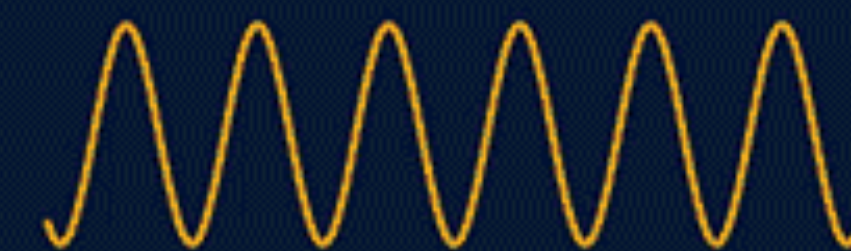


## Fourier Transform

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



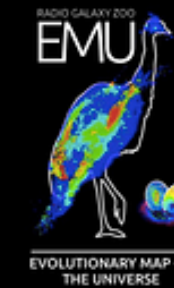
A sine wave in 2 dimensions looks like a set of stripes





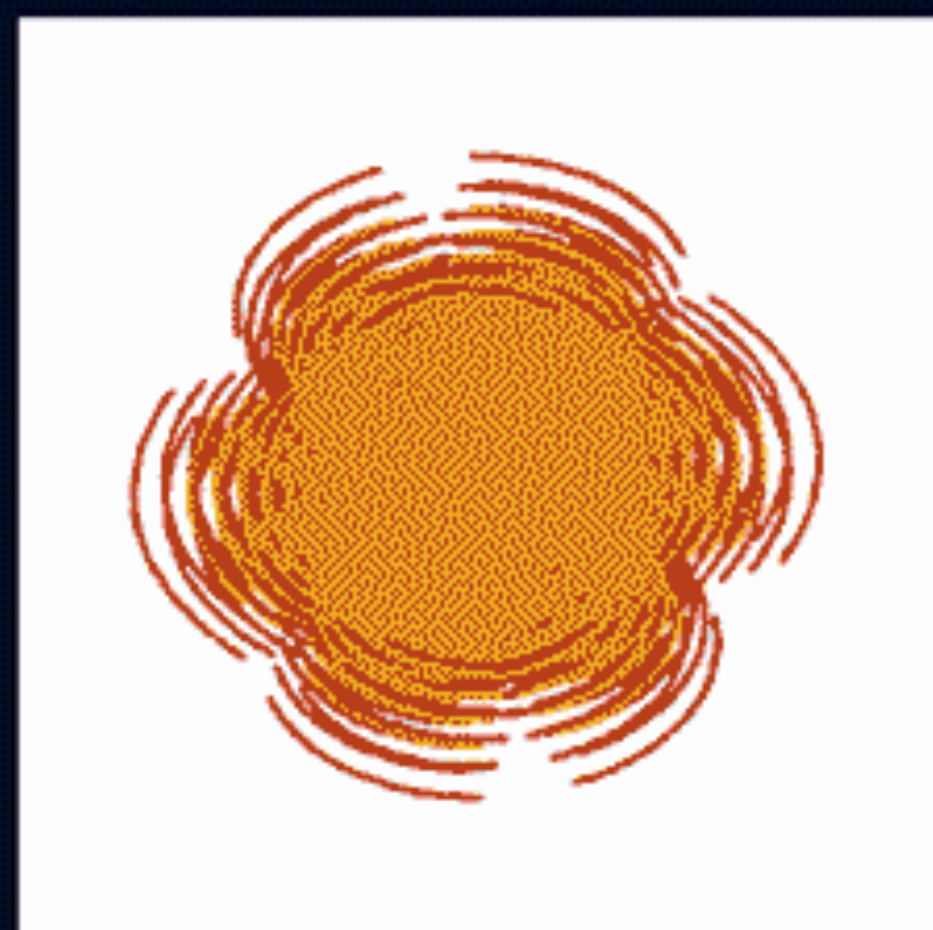
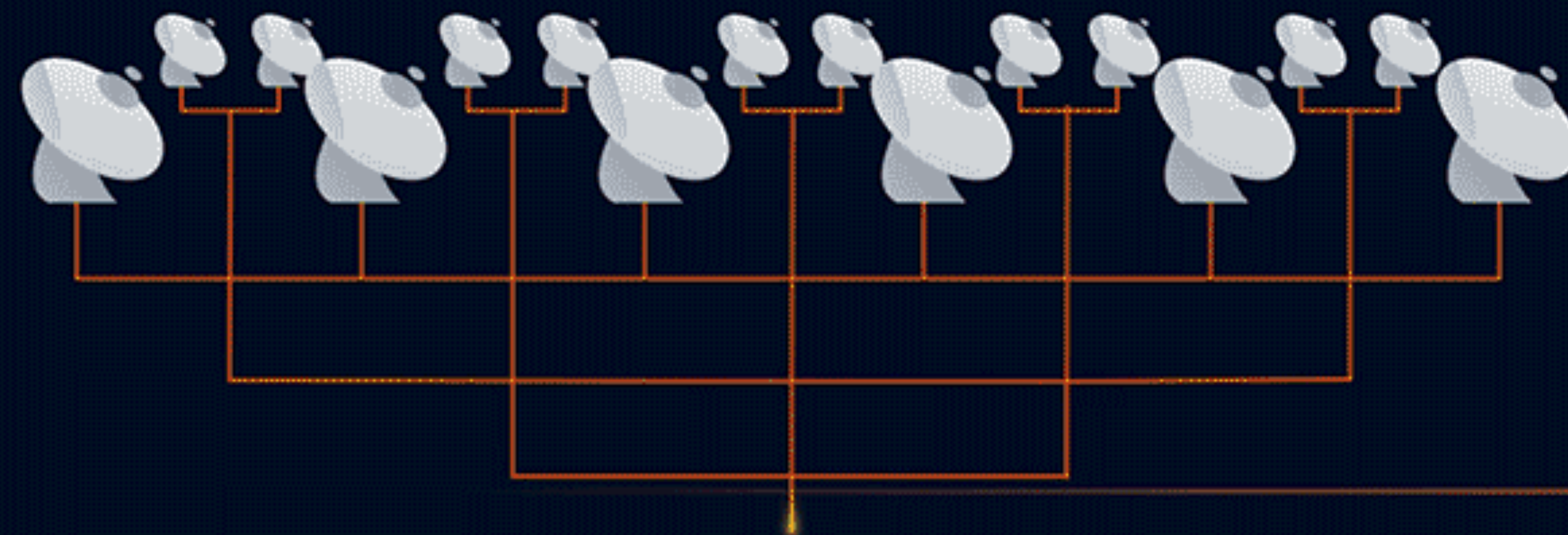


# Data acquisition

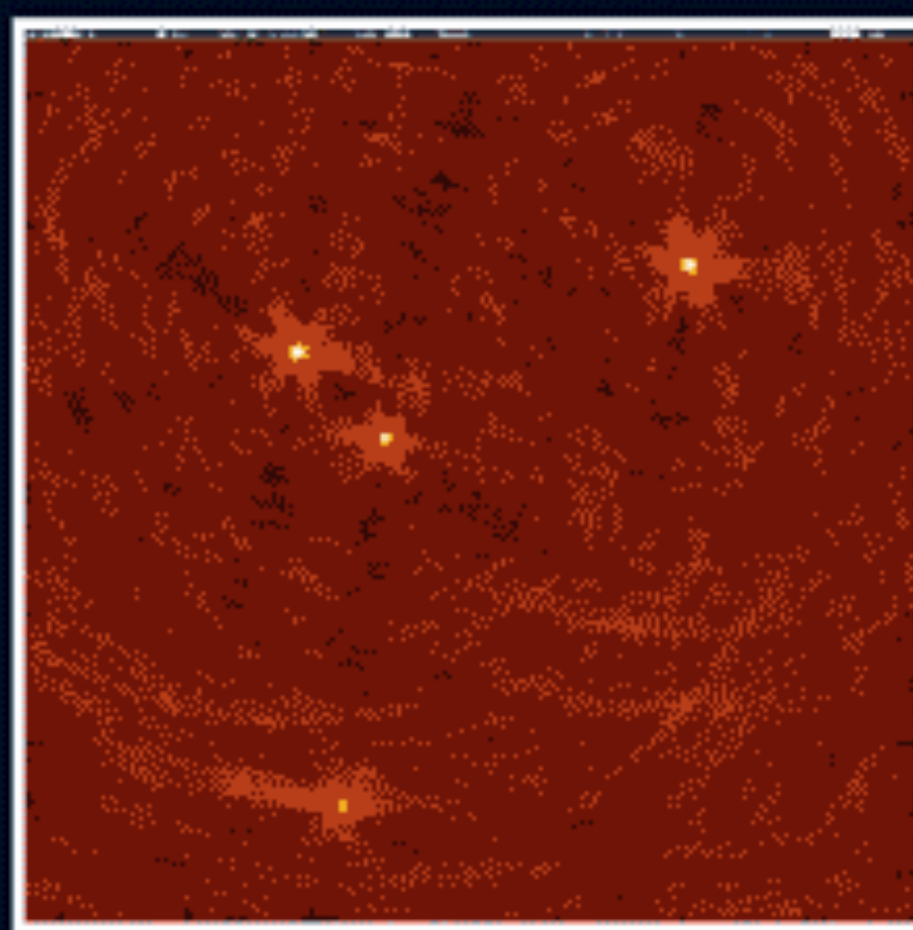


## More Antennas = Clearer Picture

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.



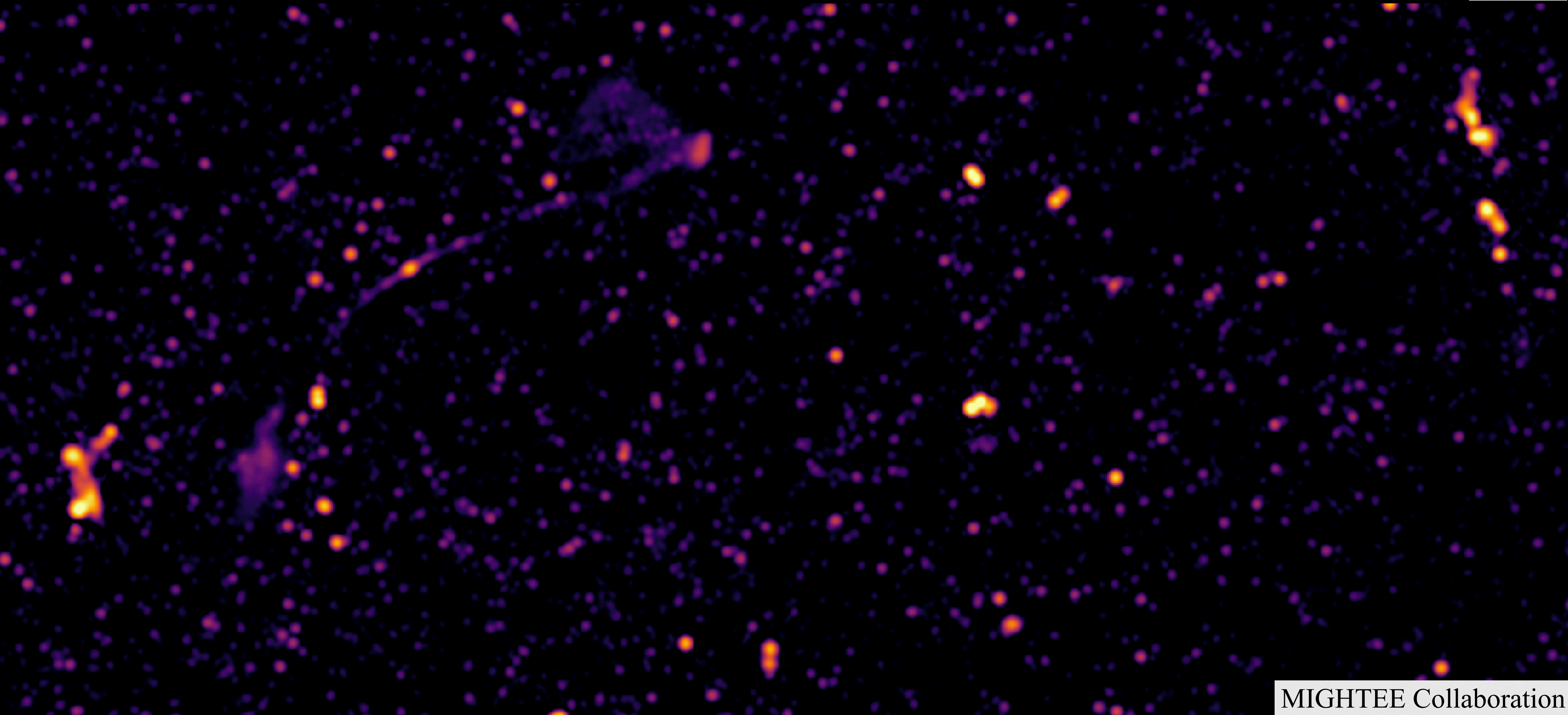
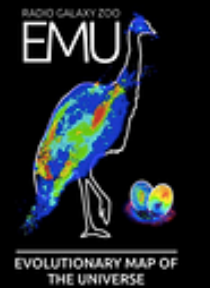
27 Antennas  
+  
4 hours Earth  
Rotation Synthesis  
+  
3 Frequencies



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

ML WORKSHOP IN  
ASTRONOMY 23Nov23

“RADIO SOURCE CLASSIFICATION”

ELENI VARDOULAKI



# Multi-wavelength



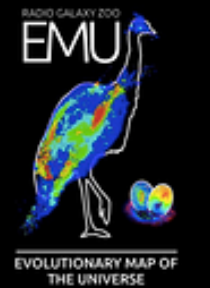
Monochromatic  
Astrophysics



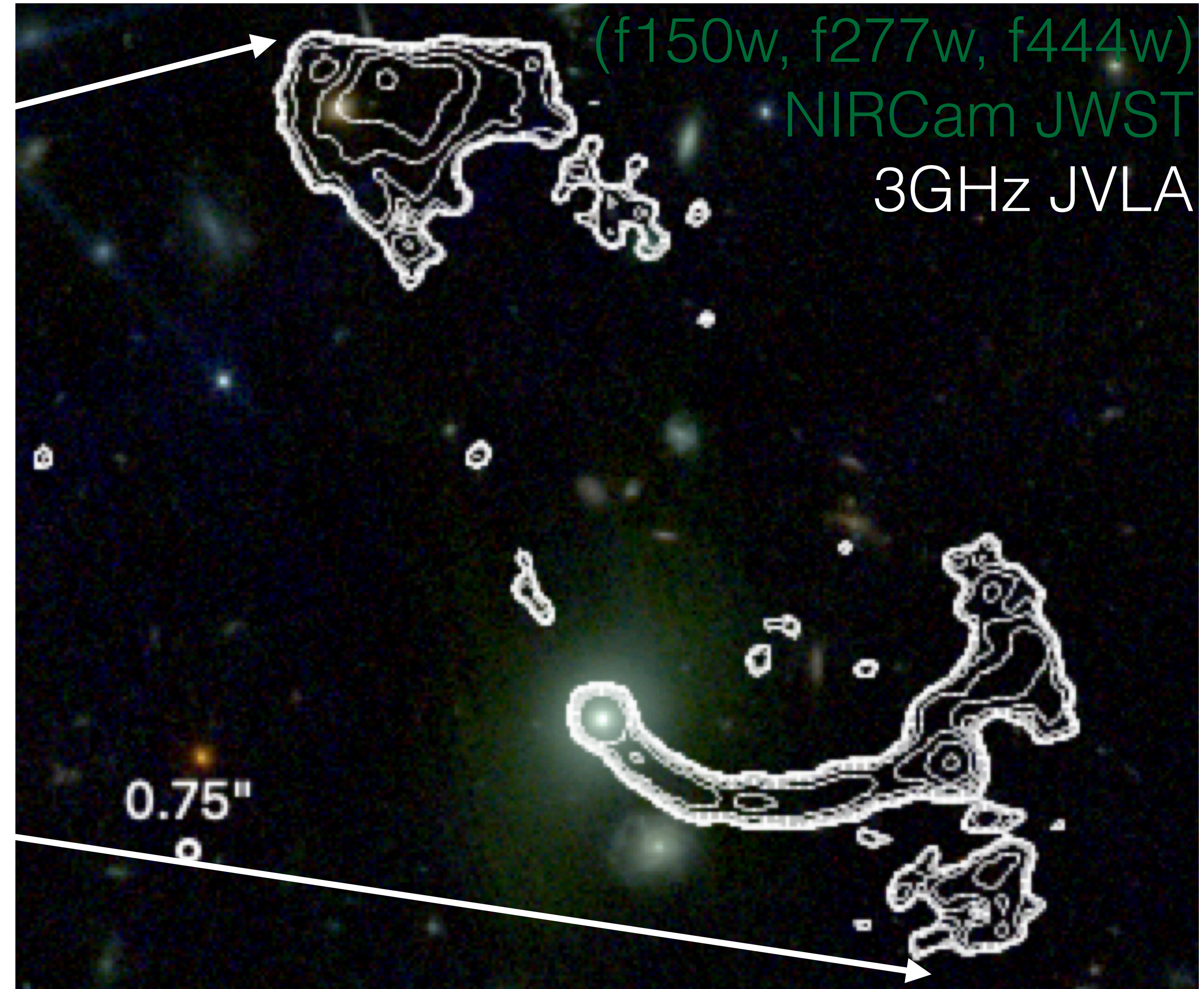
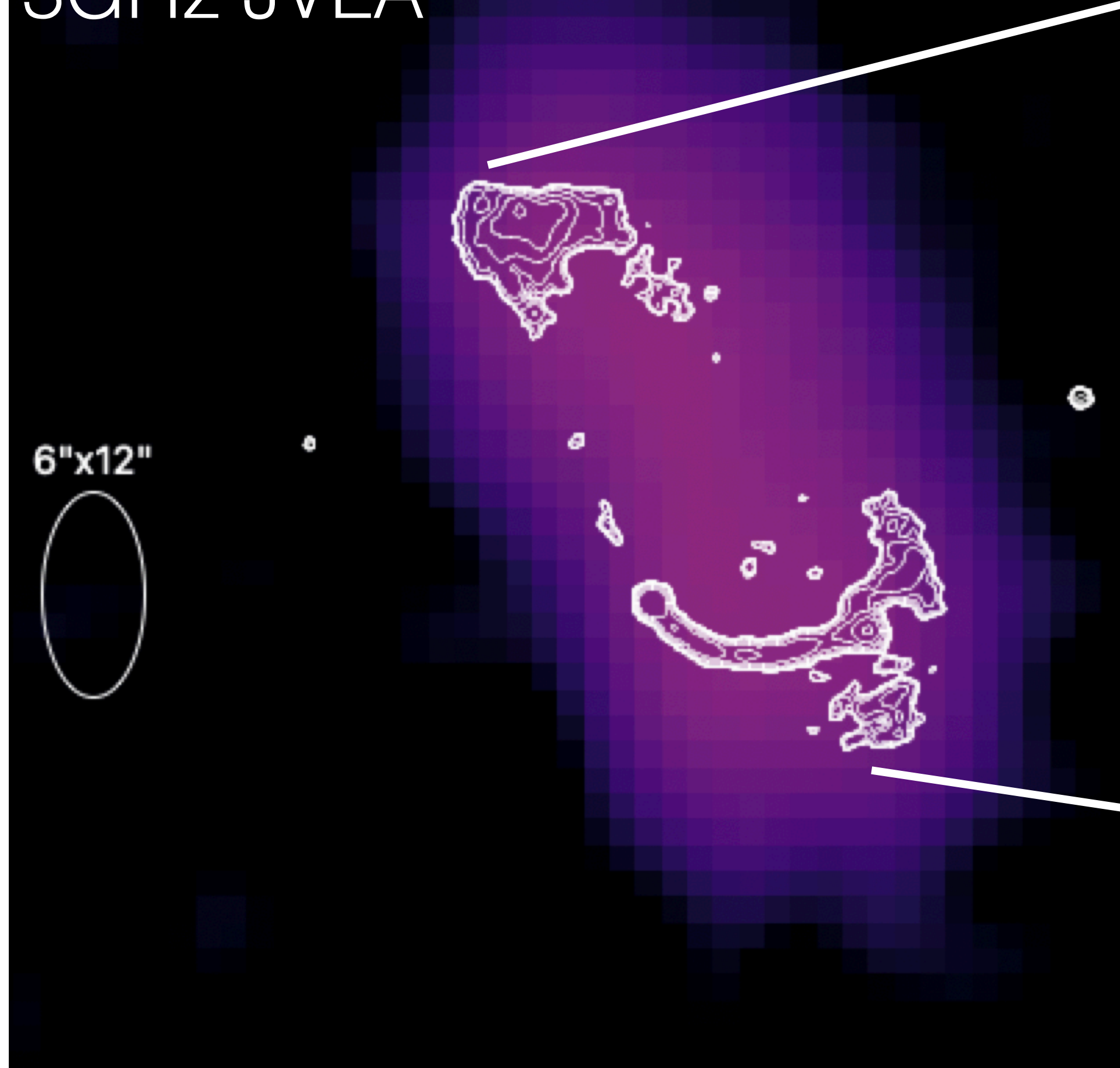
Multi-wavelength  
Astrophysics



# AGN example



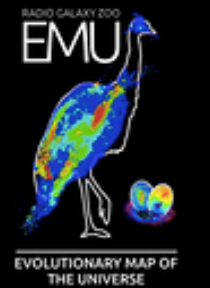
LOFAR 144 MHz, PI: Vardoulaki  
3GHz JVLA



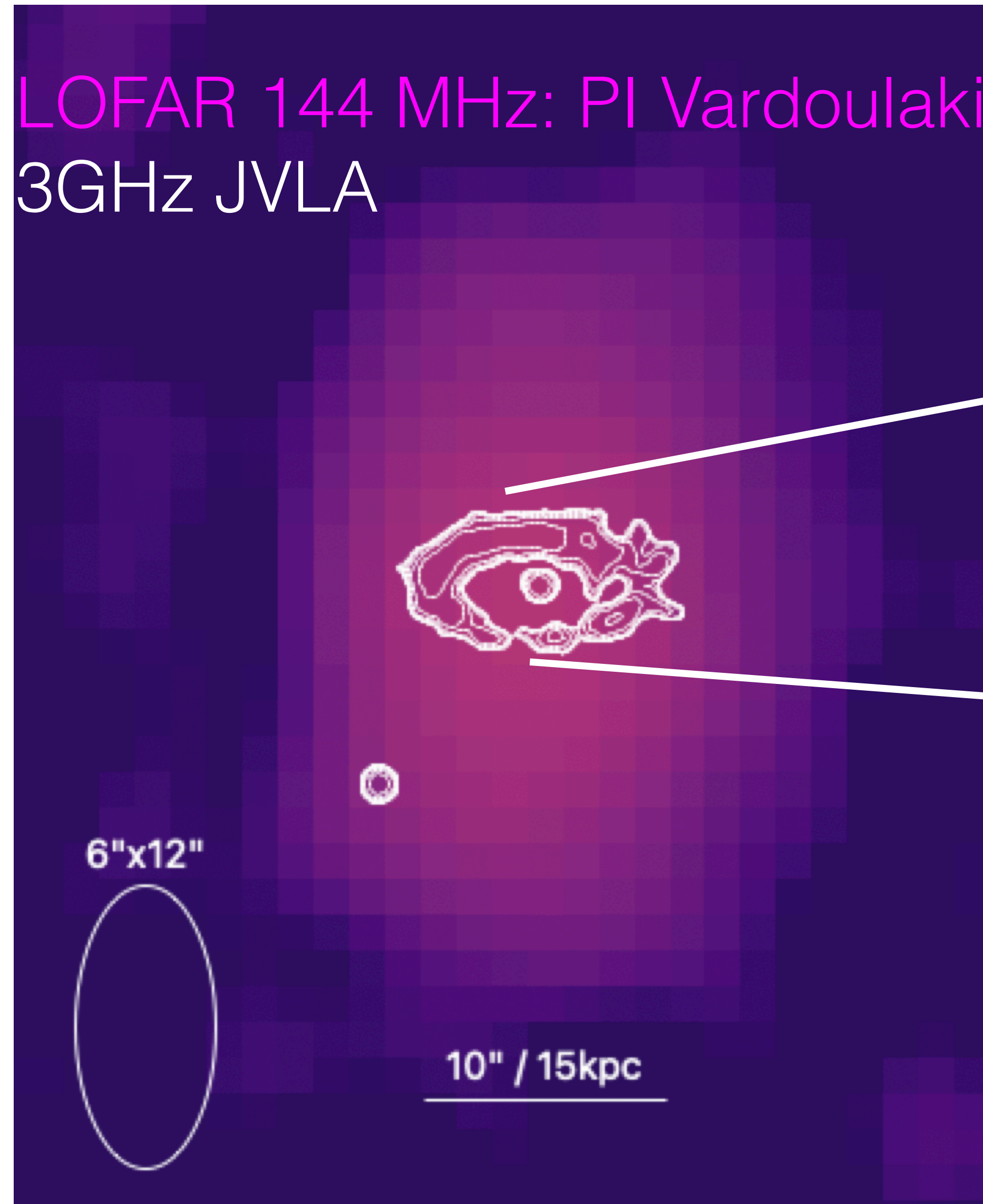
Vardoulaki+21, A&A, 627A, 142; Vardoulaki+19, A&A, 627A, 142



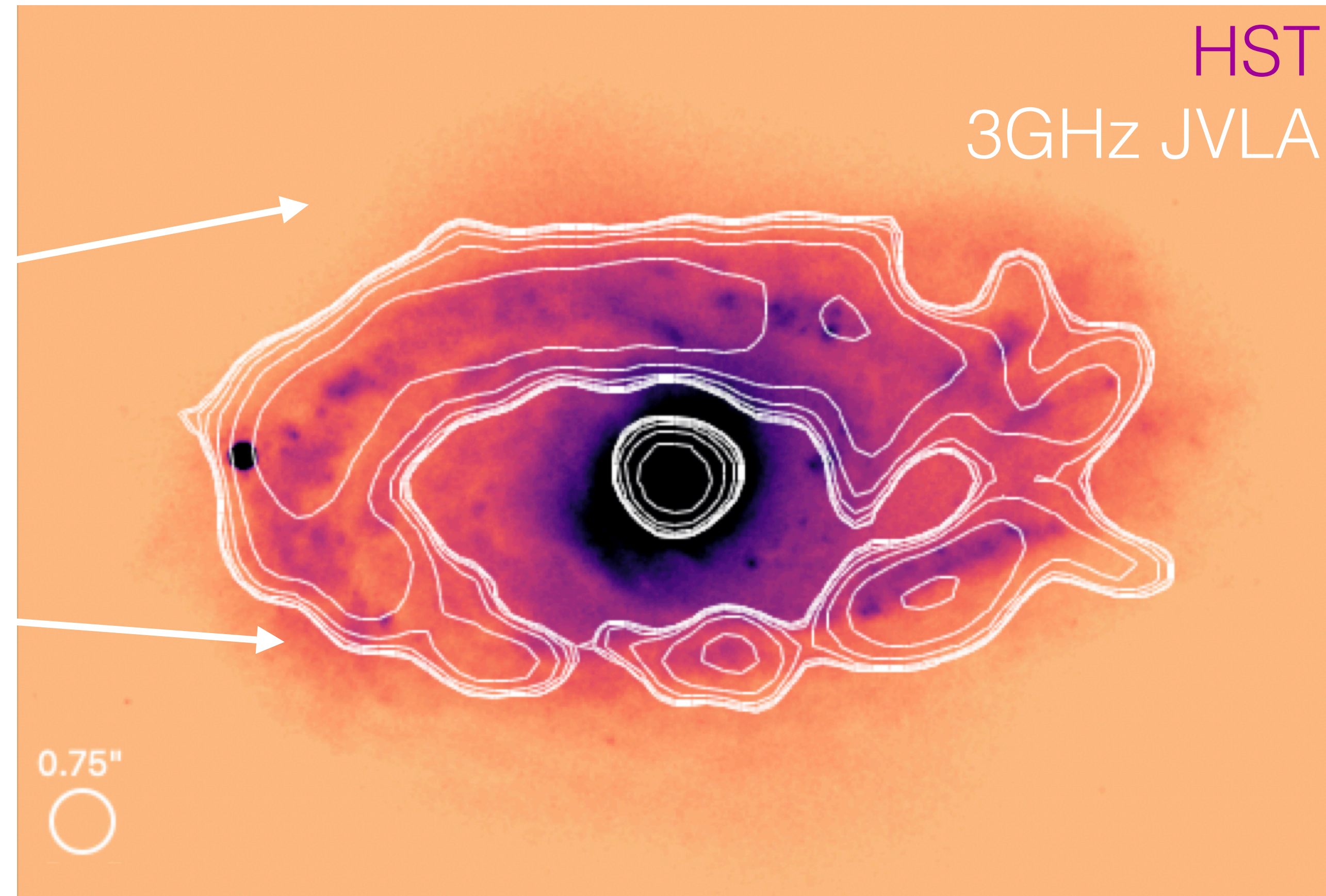
# SFG example



LOFAR 144 MHz: PI Vardoulaki  
3GHz JVLA



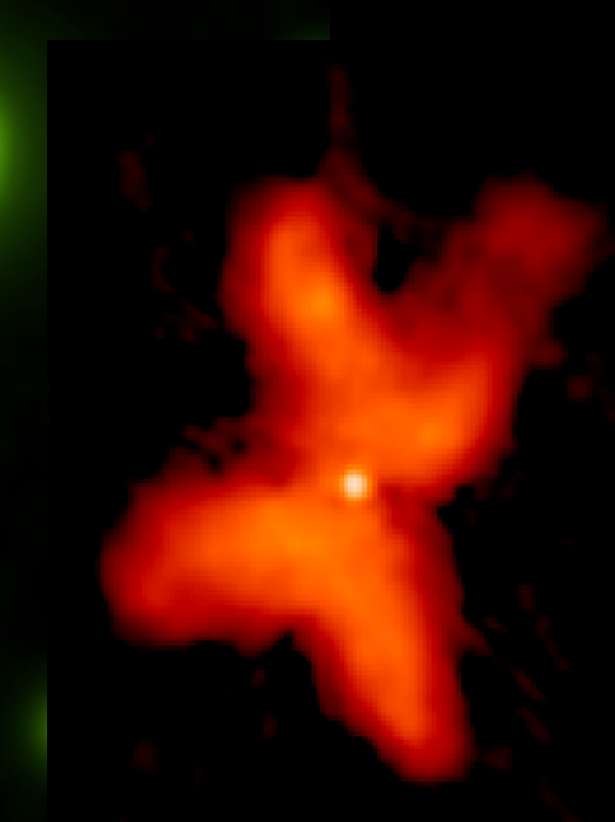
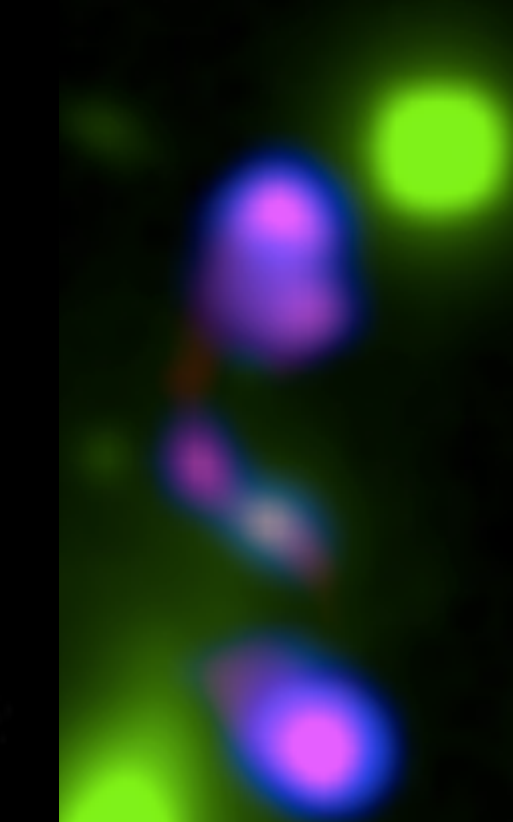
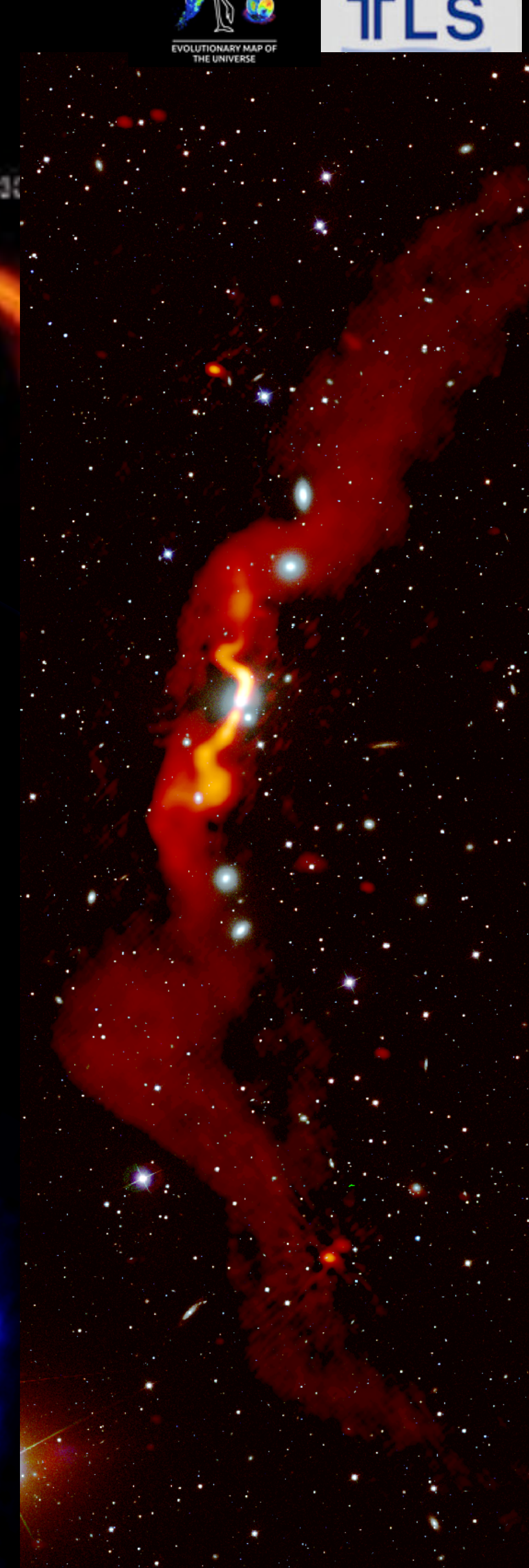
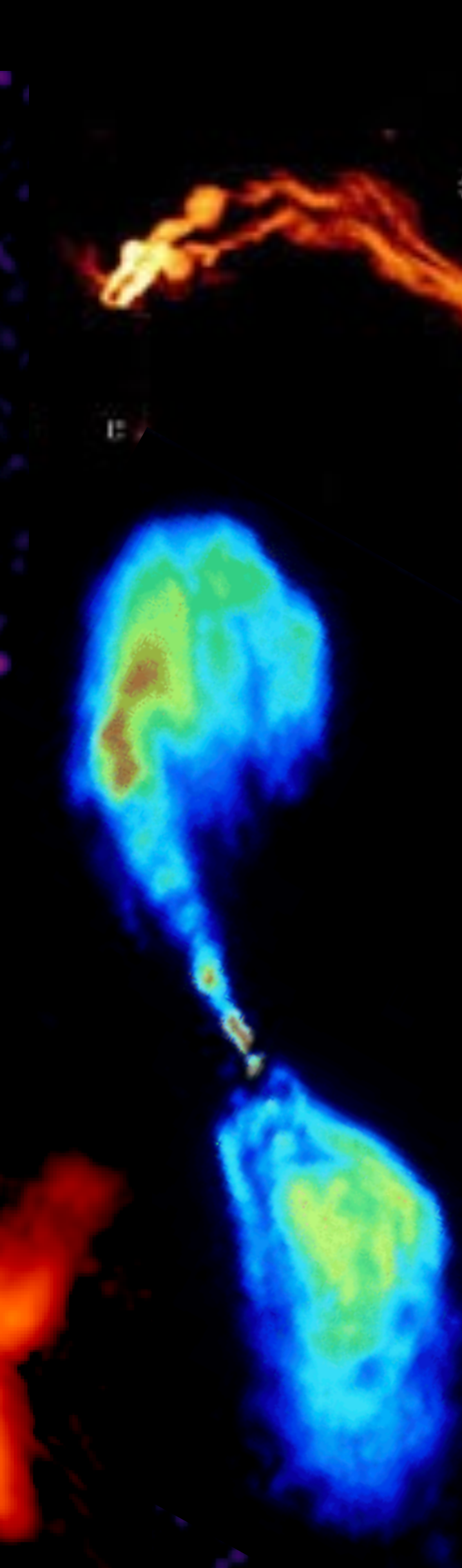
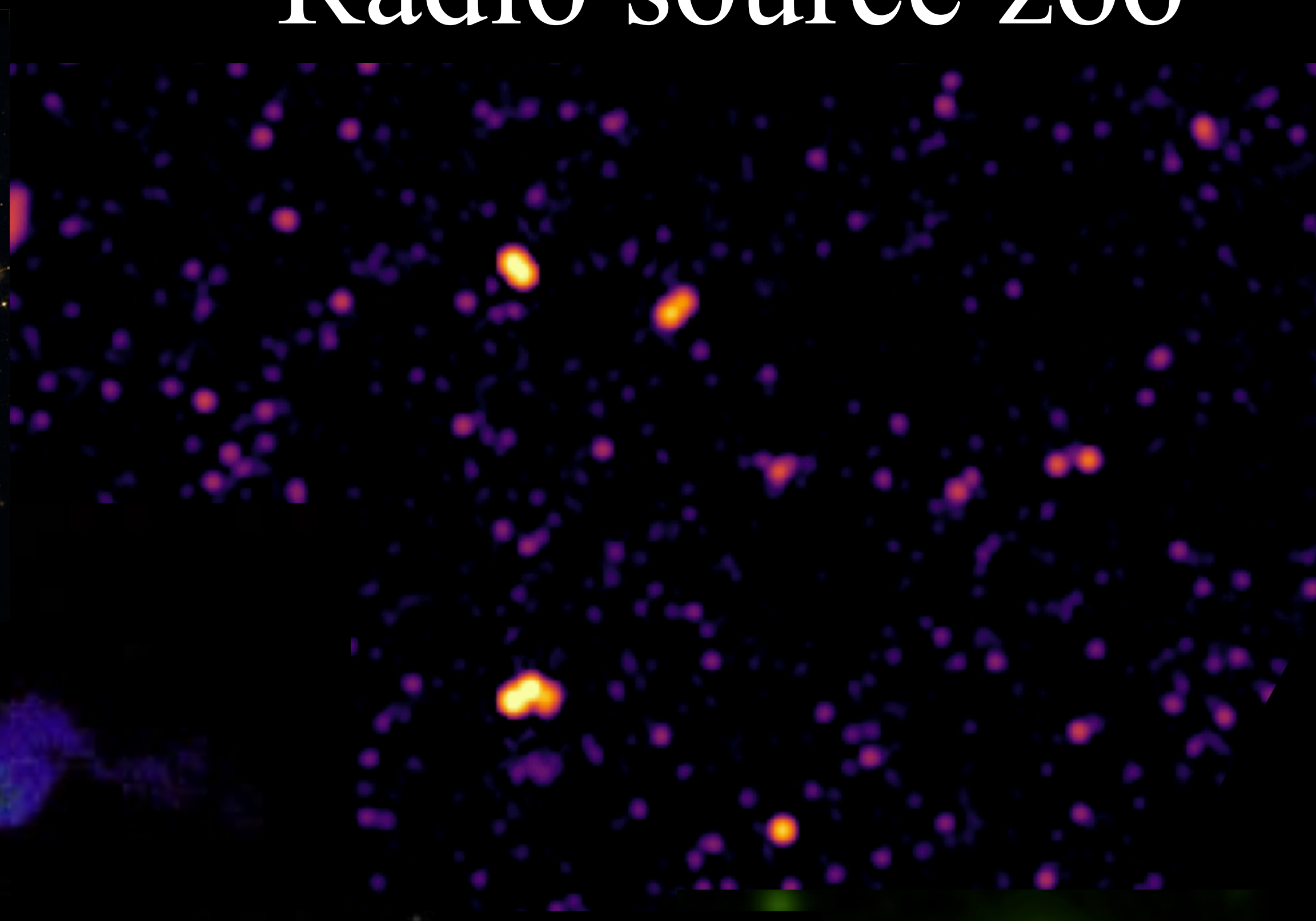
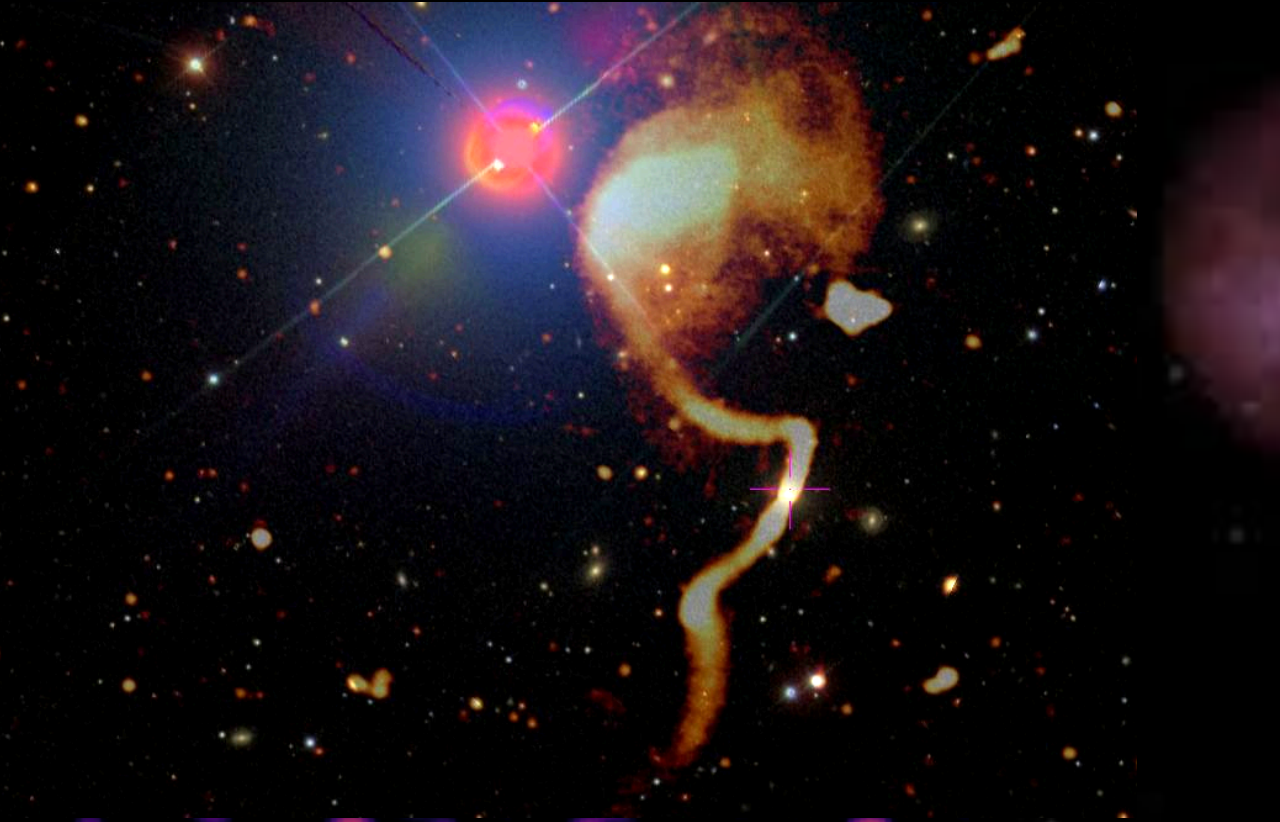
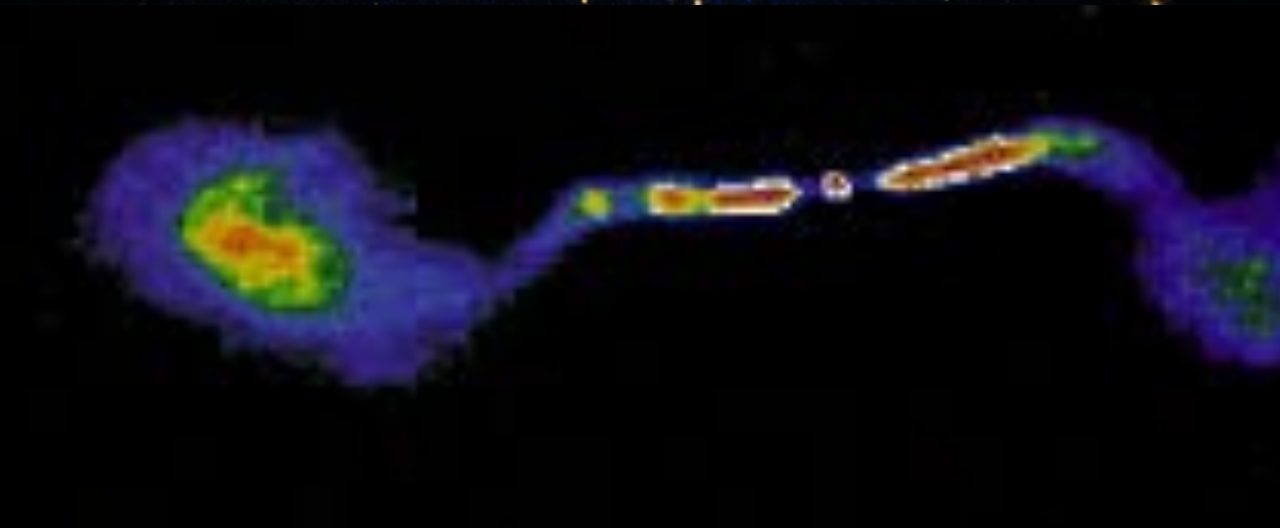
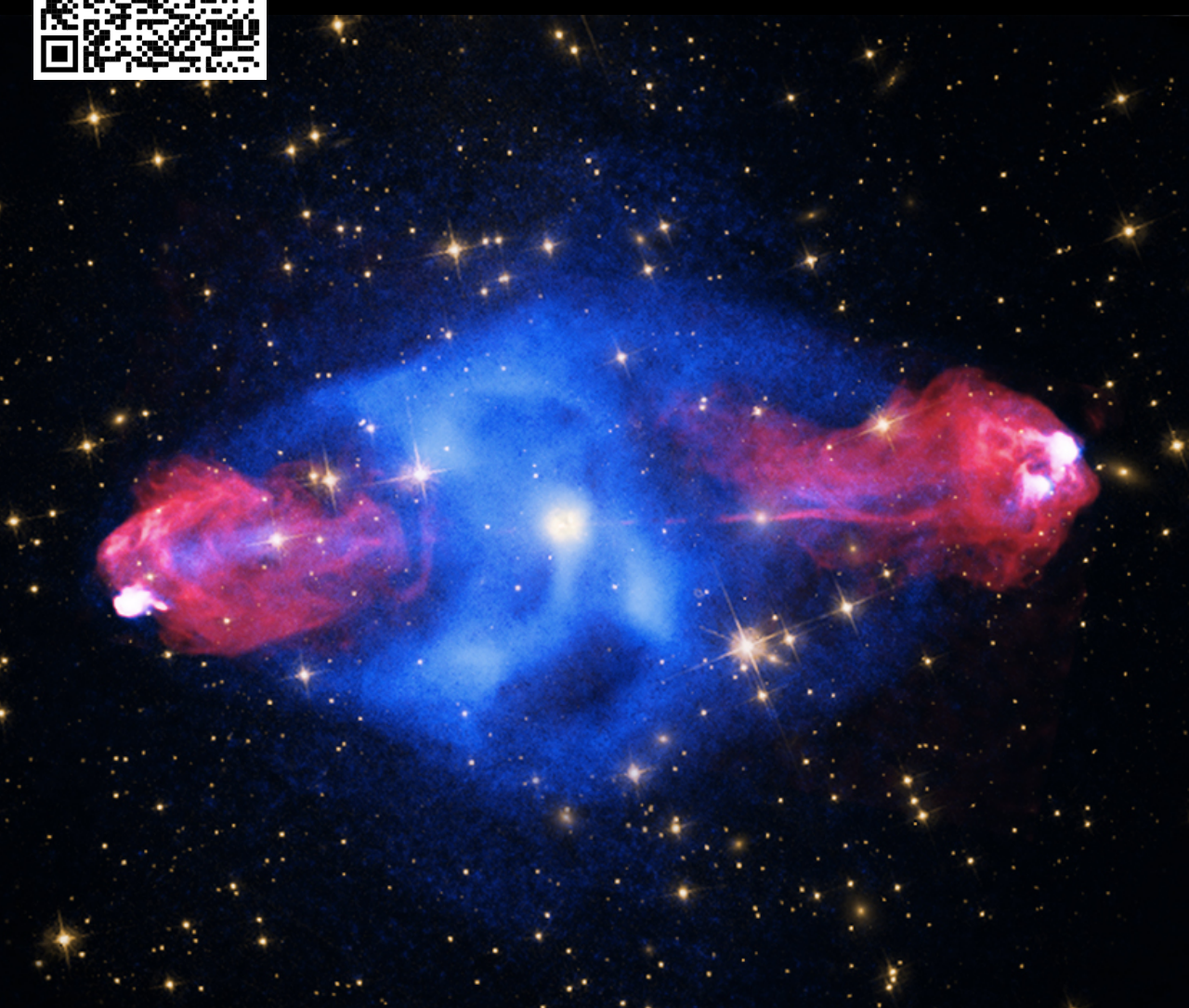
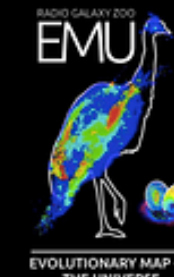
HST  
3GHz JVLA



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

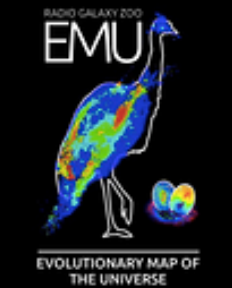


# Radio source zoo

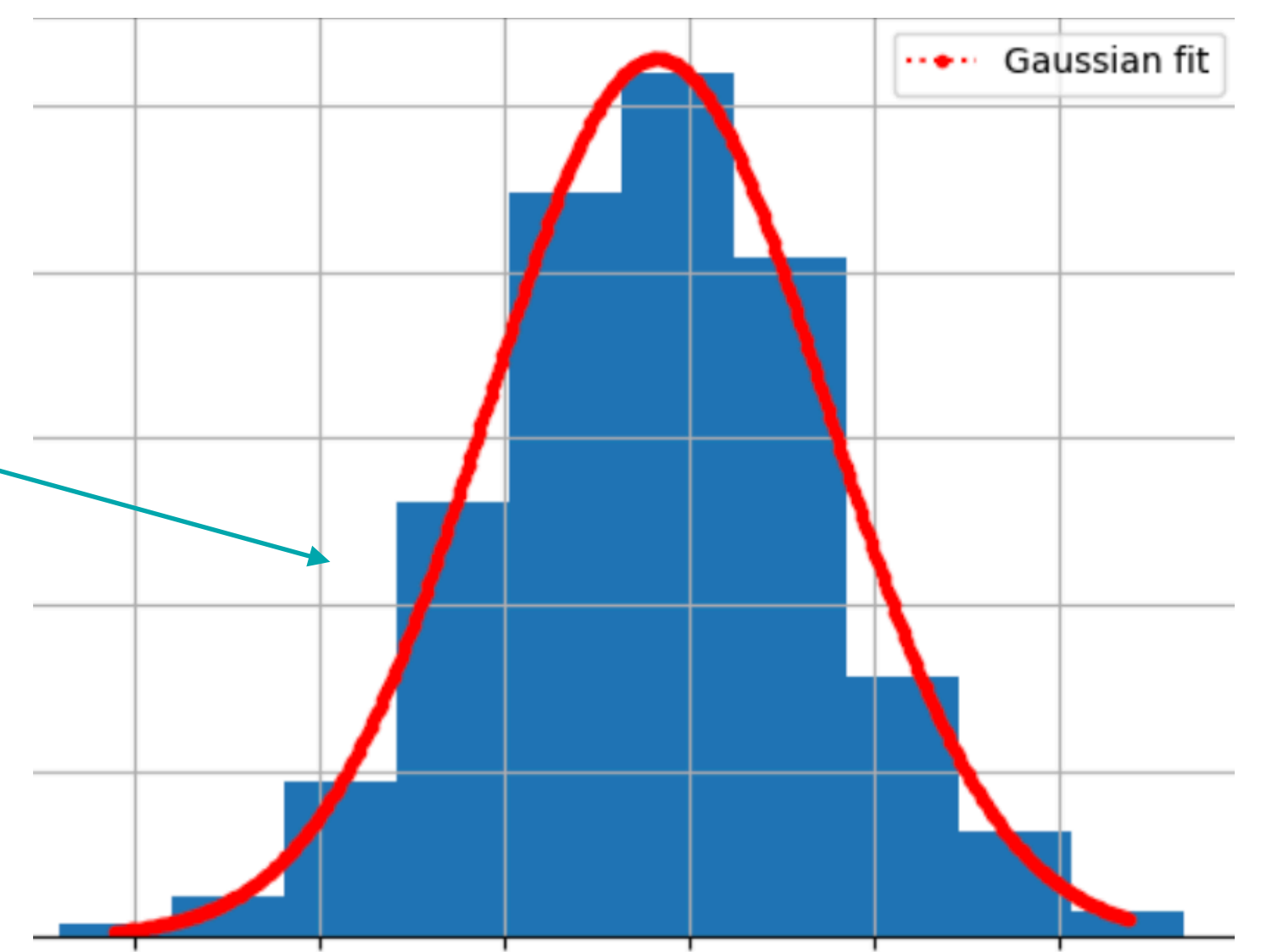
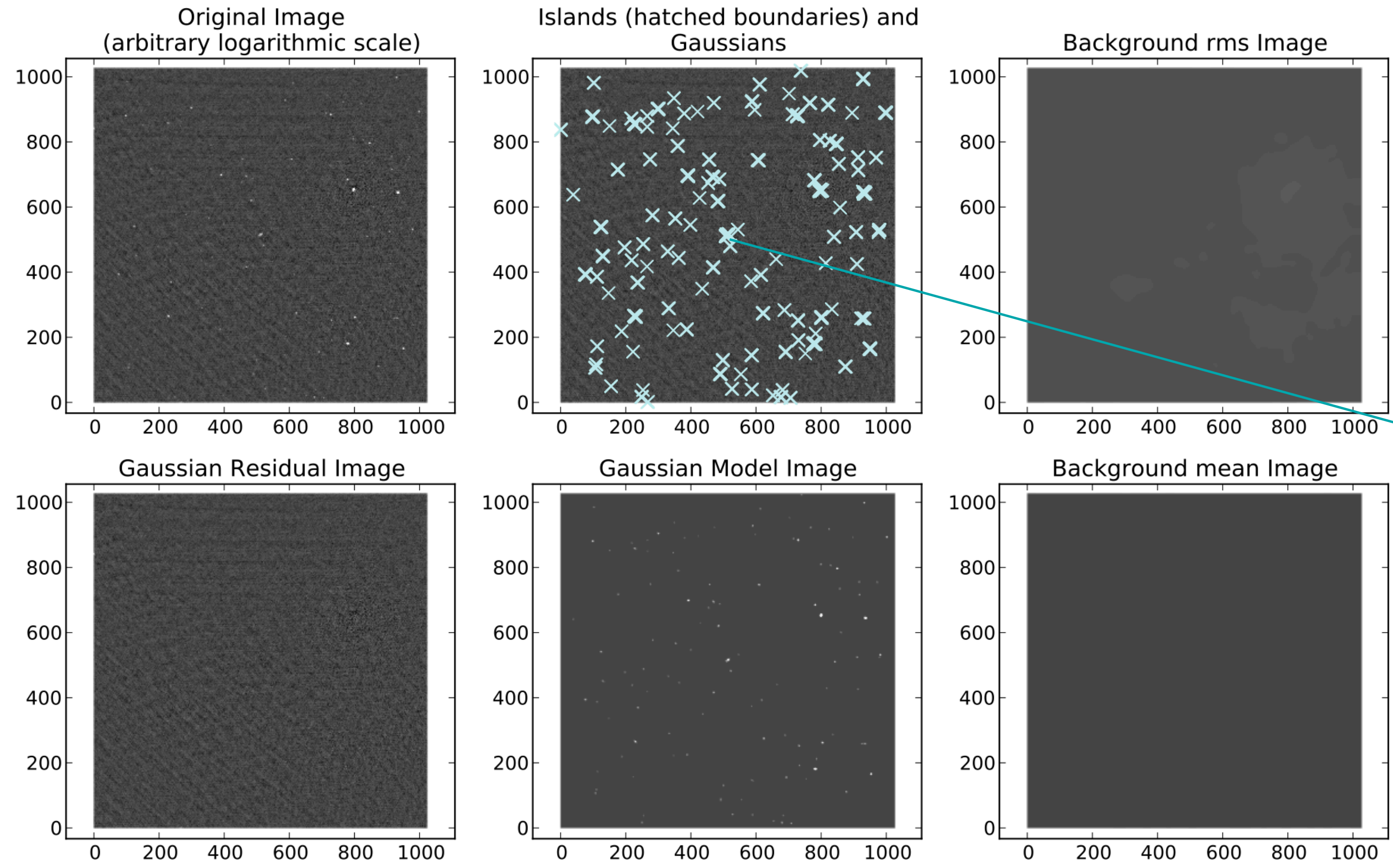




# Automatic identification



## Simple radio sources - good fit



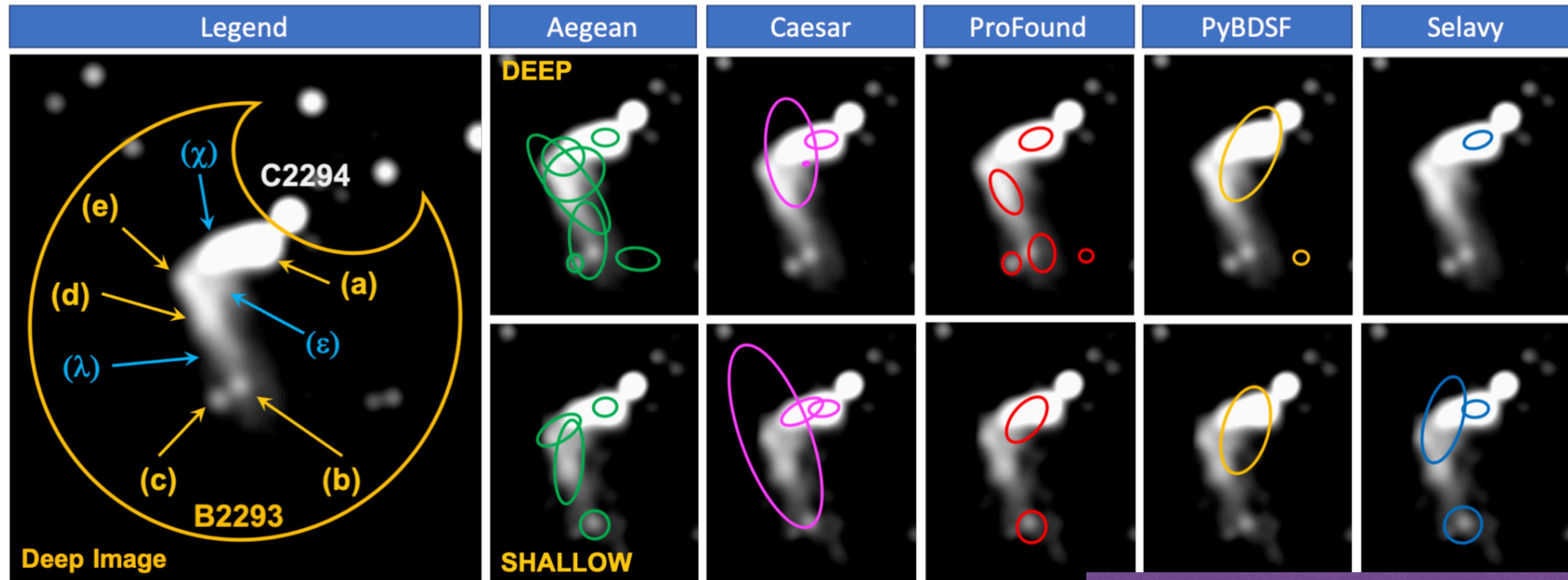
PyBDSF - Mohan & Rafferty 2015  
<https://pybdsf.readthedocs.io/>



# Automatic identification



Complex radio source - not a good fit



Hydra - Boyce+2023a,b

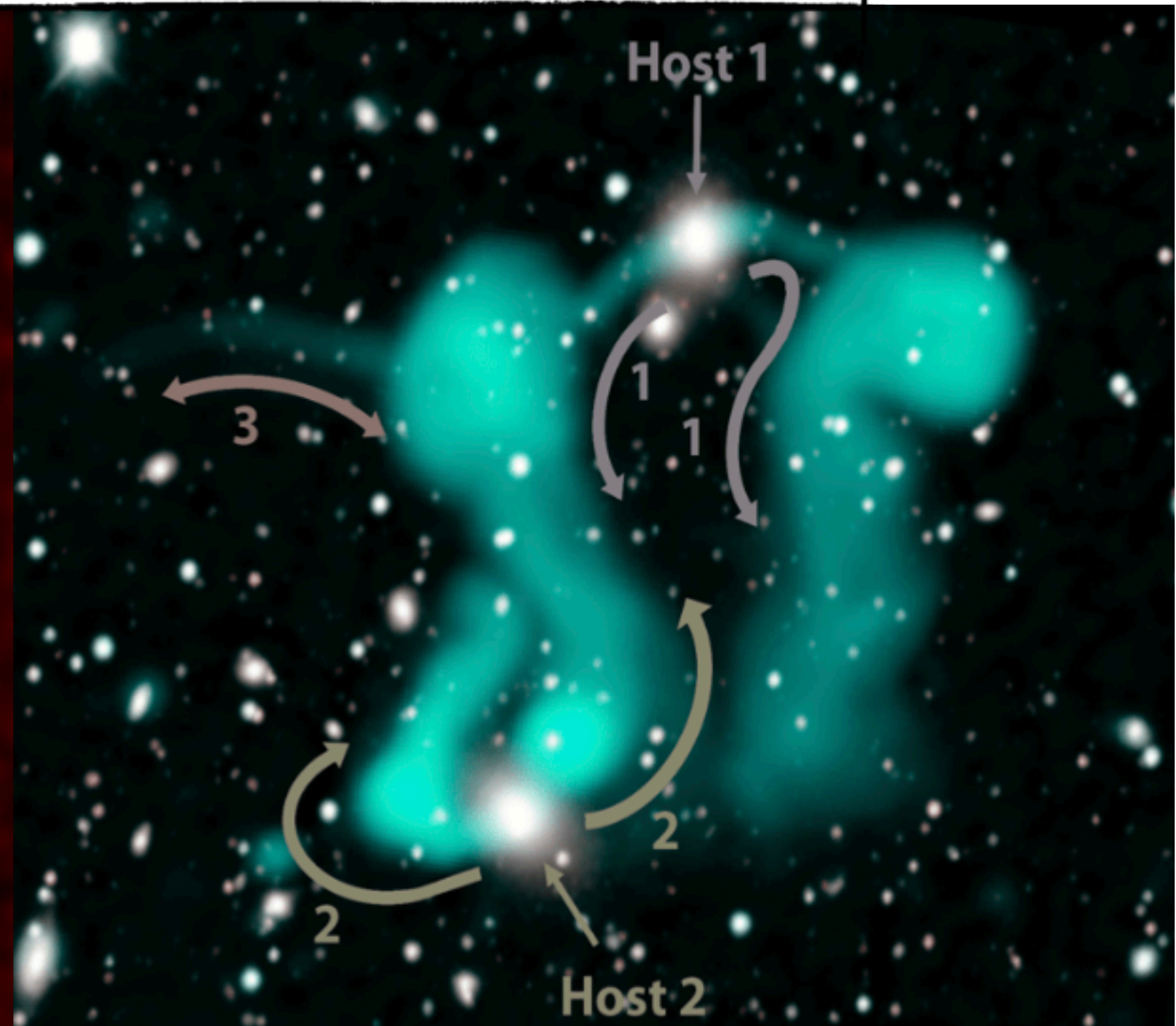
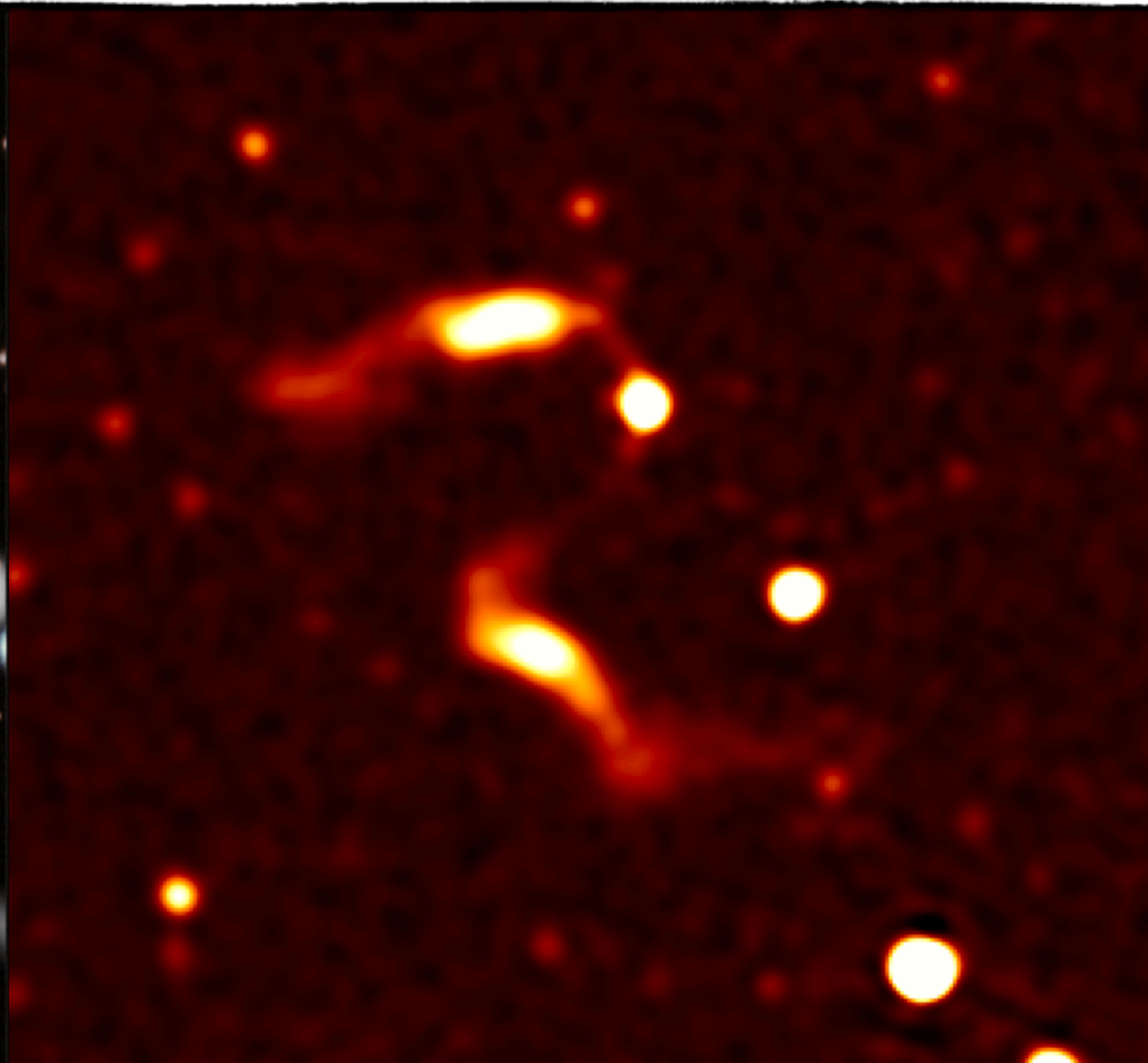




# Why citizen science?

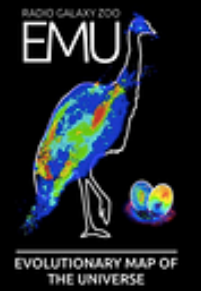


- Automatic algorithms don't always work for all cases: e.g. artefacts or complex images / unexpected objects
- Need for good training samples

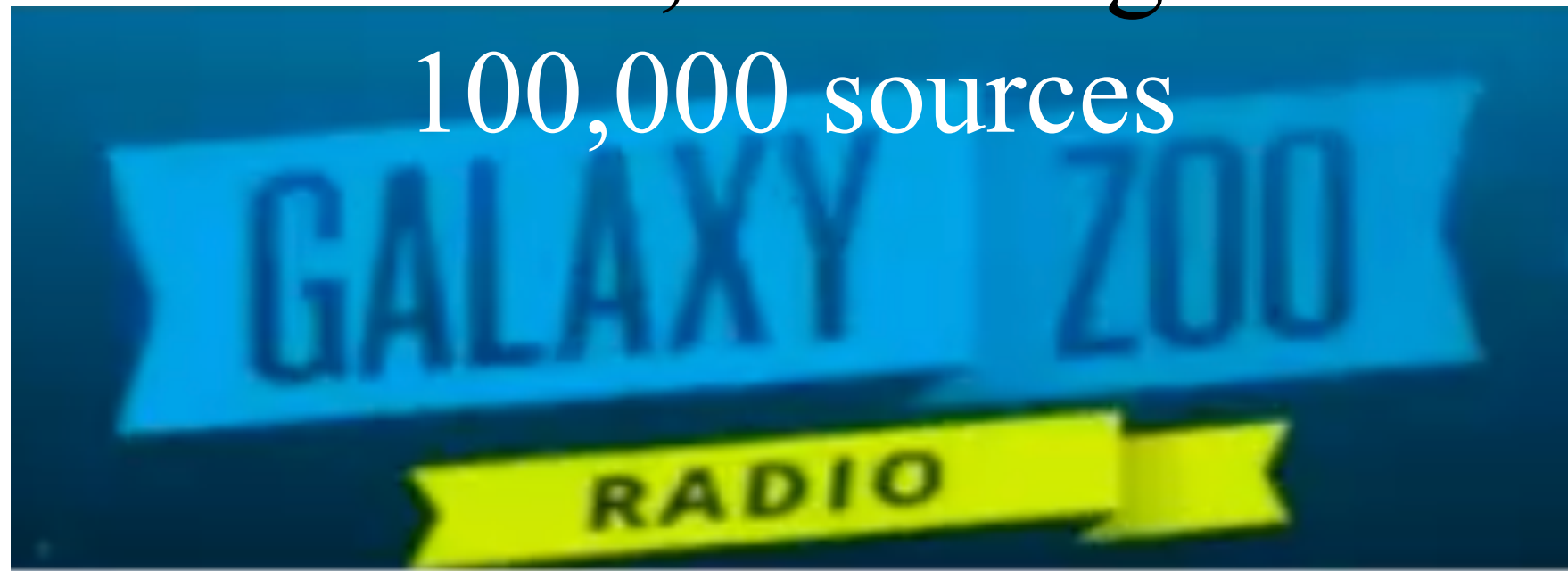




# Citizen Science + ML/AI

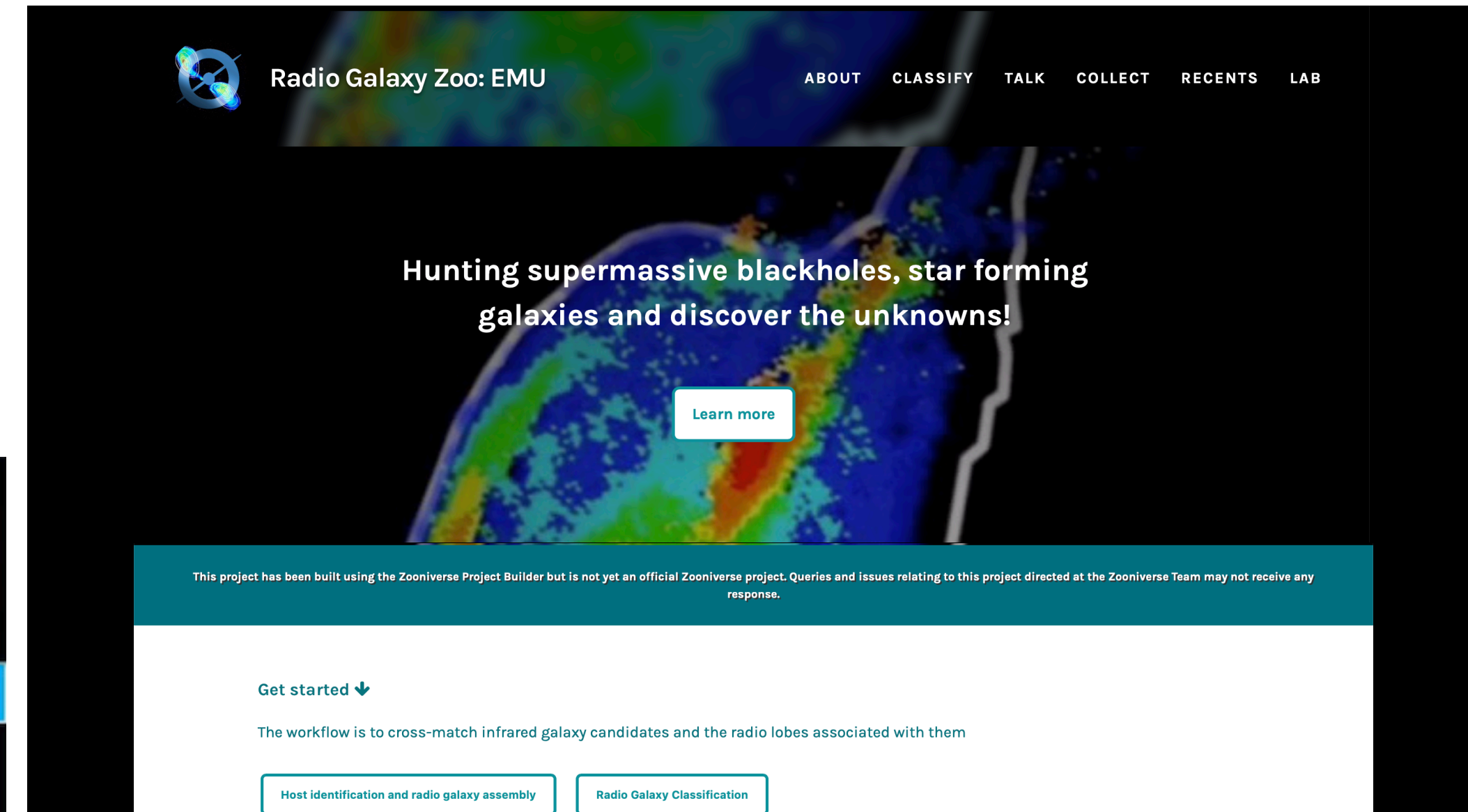
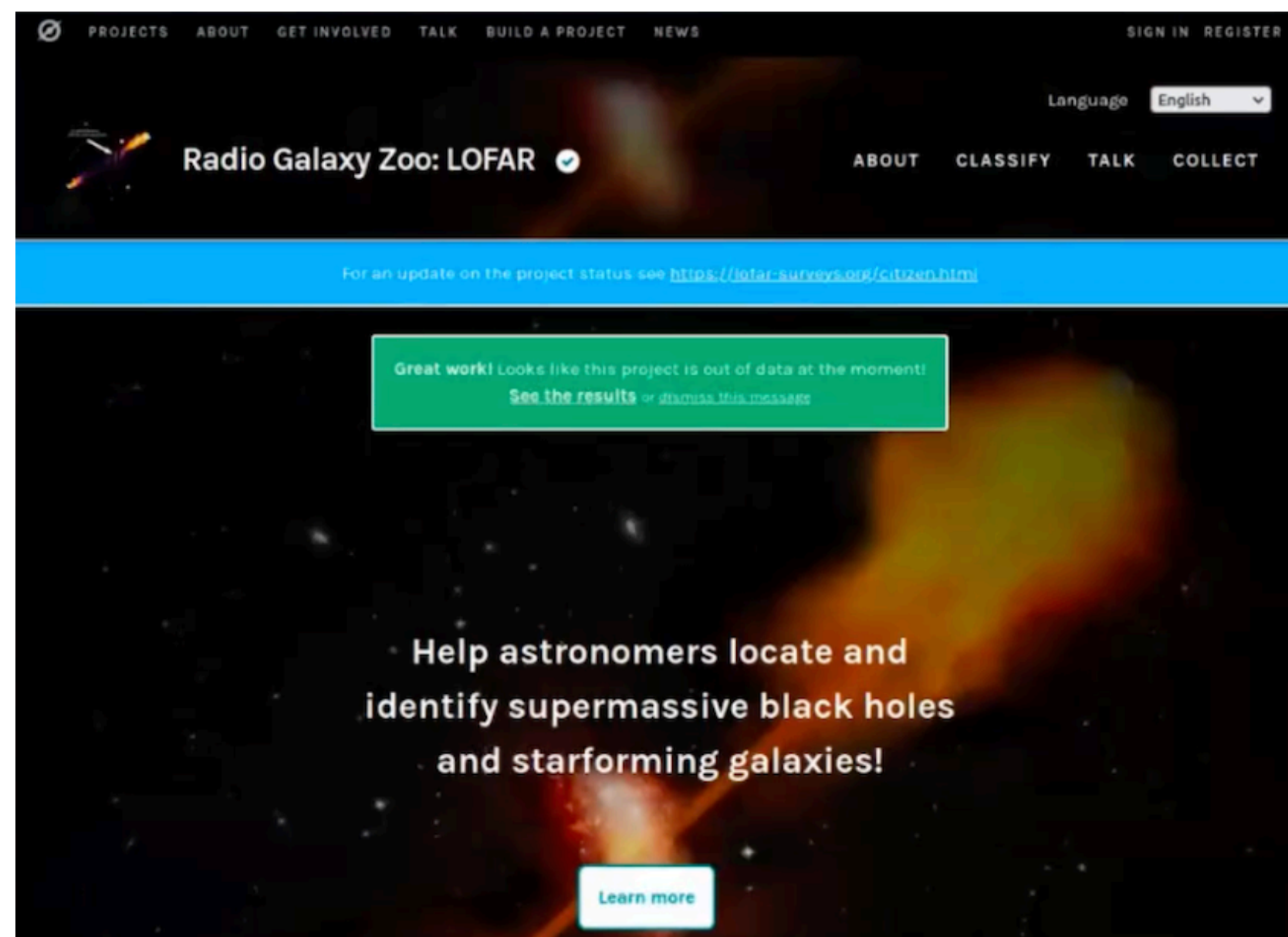


RGZ; PI: Wong  
100,000 sources



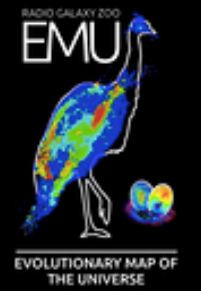
RGZ-EMU; co-PIs: Tang & Vardoulaki  
up to 40 million sources

RGZ-LOFAR; PI: Hardcastle  
4 million sources

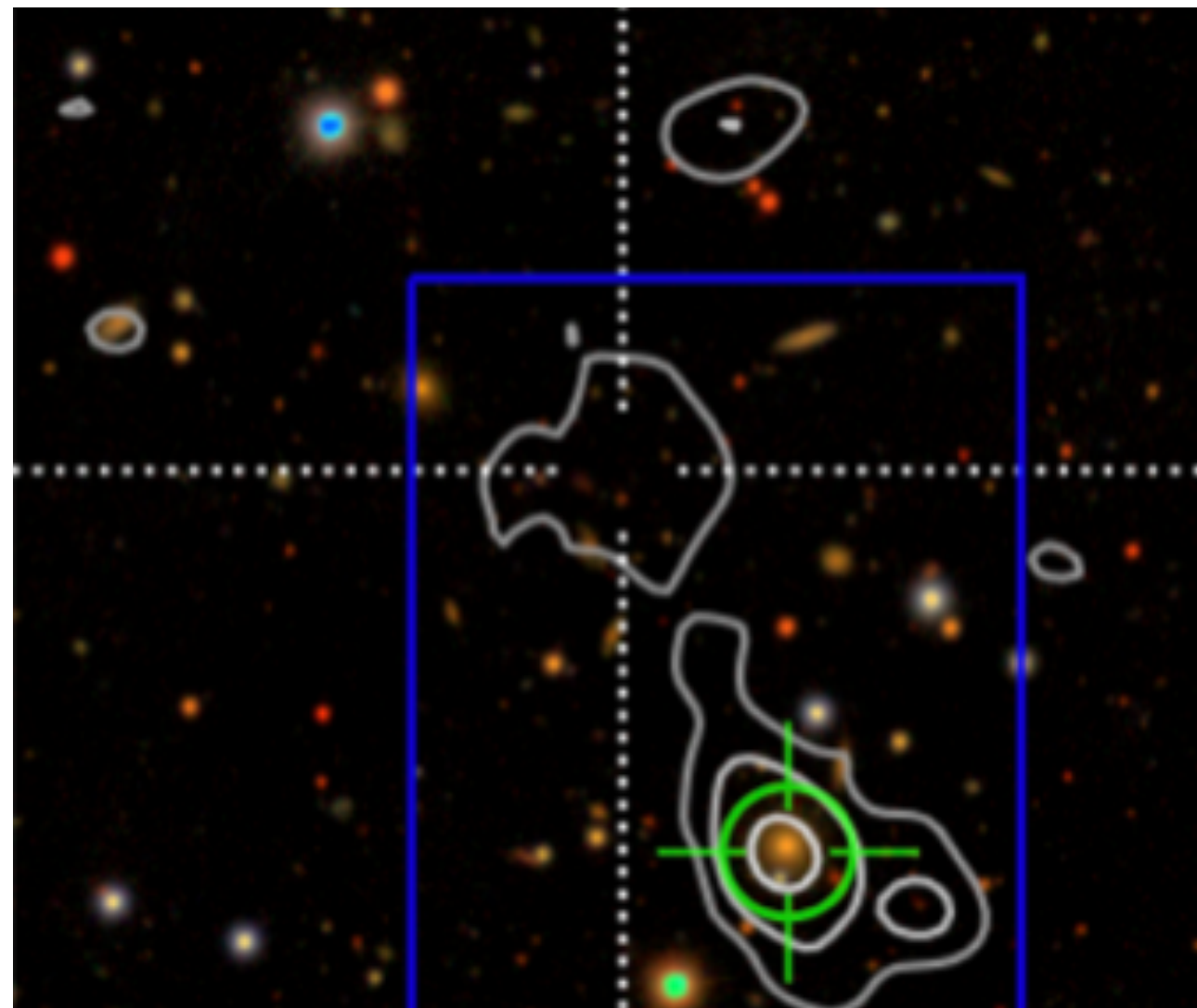




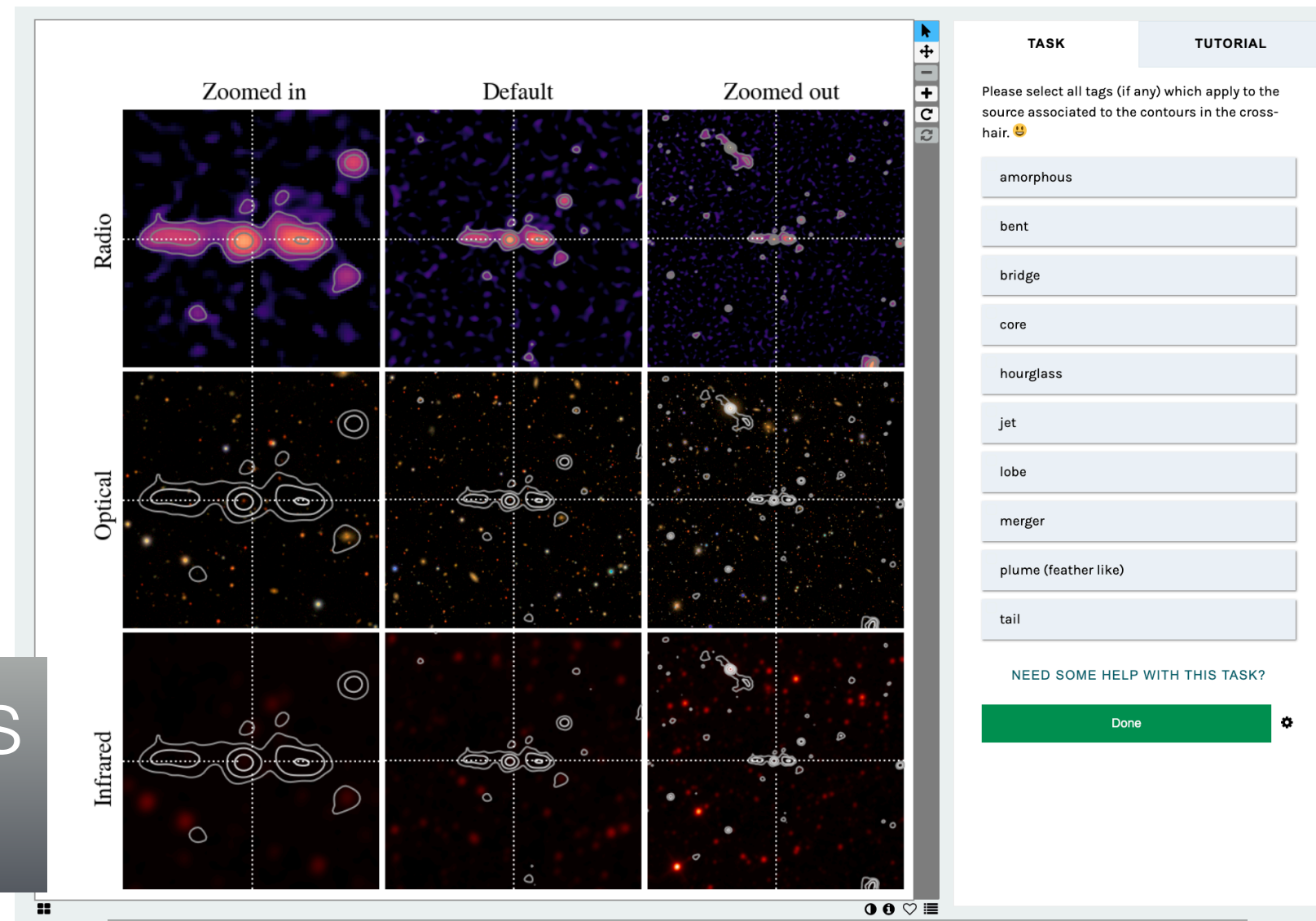
# How citizen scientists help



RGZ-EMU; co-PIs: Tang & Vardoulaki



Mark related radio components and the associate host galaxy



Classify sources using tags

## Radio Galaxy Zoo: EMU Talk

[Radio Galaxy Zoo: EMU Talk](#) > Hunting the unusual!

Search or enter a #tag

### Hunting the unusual!

This is a discussion board if you see any object with unusual radio morphology or physical properties. Let's make discovery together!

Subscribe Subscribe to receive notifications for new discussions in this board (never email)

Moderator Controls

New Discussion

Comment with your own tags!

Hongming\_Tang RESEARCHER 7 months ago Please comment with your customized hashtags if none of the others suit you.) 1 Participant 1 Comment

Peculiar Radio Source (#peculiar)

Hongming\_Tang RESEARCHER 7 months ago Peculiar radio sources are generally radio objects with complex morphology th... 1 Participant 1 Comment

Triplet radio source (#triple)

Hongming\_Tang RESEARCHER 7 months ago A double source (pair of components) with an additional centrally located com... 1 Participant 1 Comment

blended (#blended)

Hongming\_Tang RESEARCHER 7 months ago A source with more than one infrared (IR) host associated with a radio peak o... 1 Participant 1 Comment

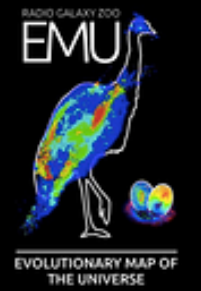
Recent Com

Popular Tag

- double
- circular
- compact
- bend
- core-dominan
- core
- friedegg
- hourglass
- oval
- sfg
- tail

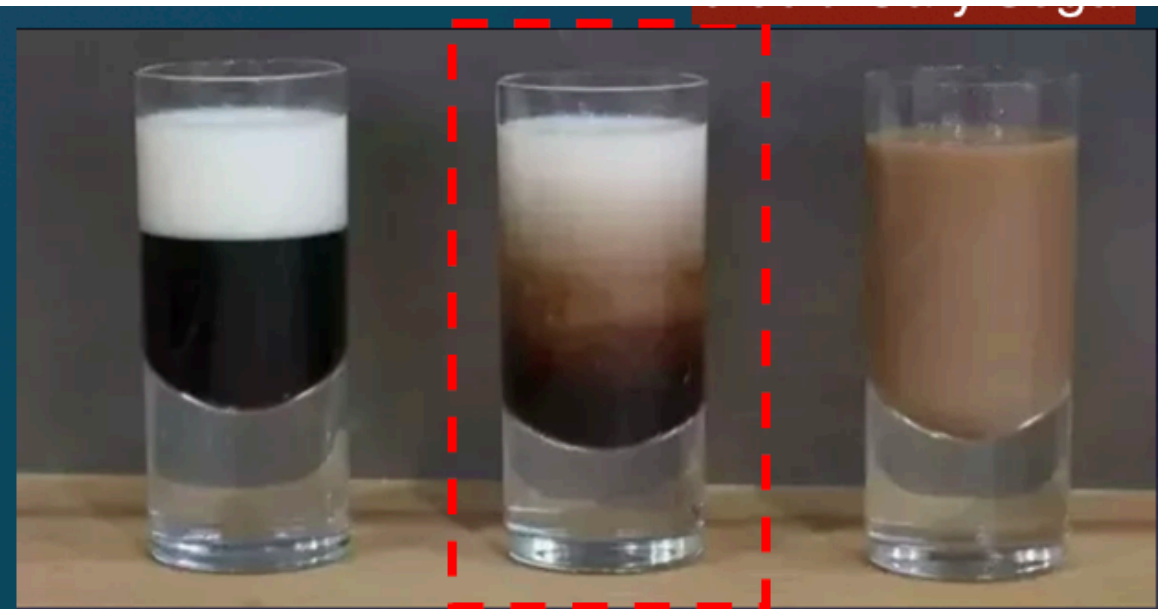
Discuss their discoveries with us via the EMU Zoo Talk forum

# Citizen Science + Machine Learning



- Provide zooters most interesting targets - beta phase

Select object samples  
with high  
**Complexity**  
(Segal+23)



Above image from Carrol, S. 2016, The Big Picture: On the Origins of Life, Meaning, and the Universe Itself.

**TASK** **TUTORIAL**

Please select all tags (if any) which apply to the source associated to the contours in the cross-hair. 😊

- amorphous
- bent
- bridge
- core
- hourglass
- jet
- lobe
- merger
- plume (feather like)
- tail

NEED SOME HELP WITH THIS TASK?

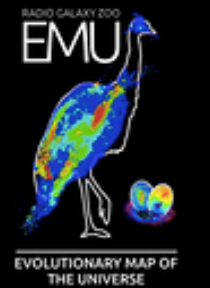
Done

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

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



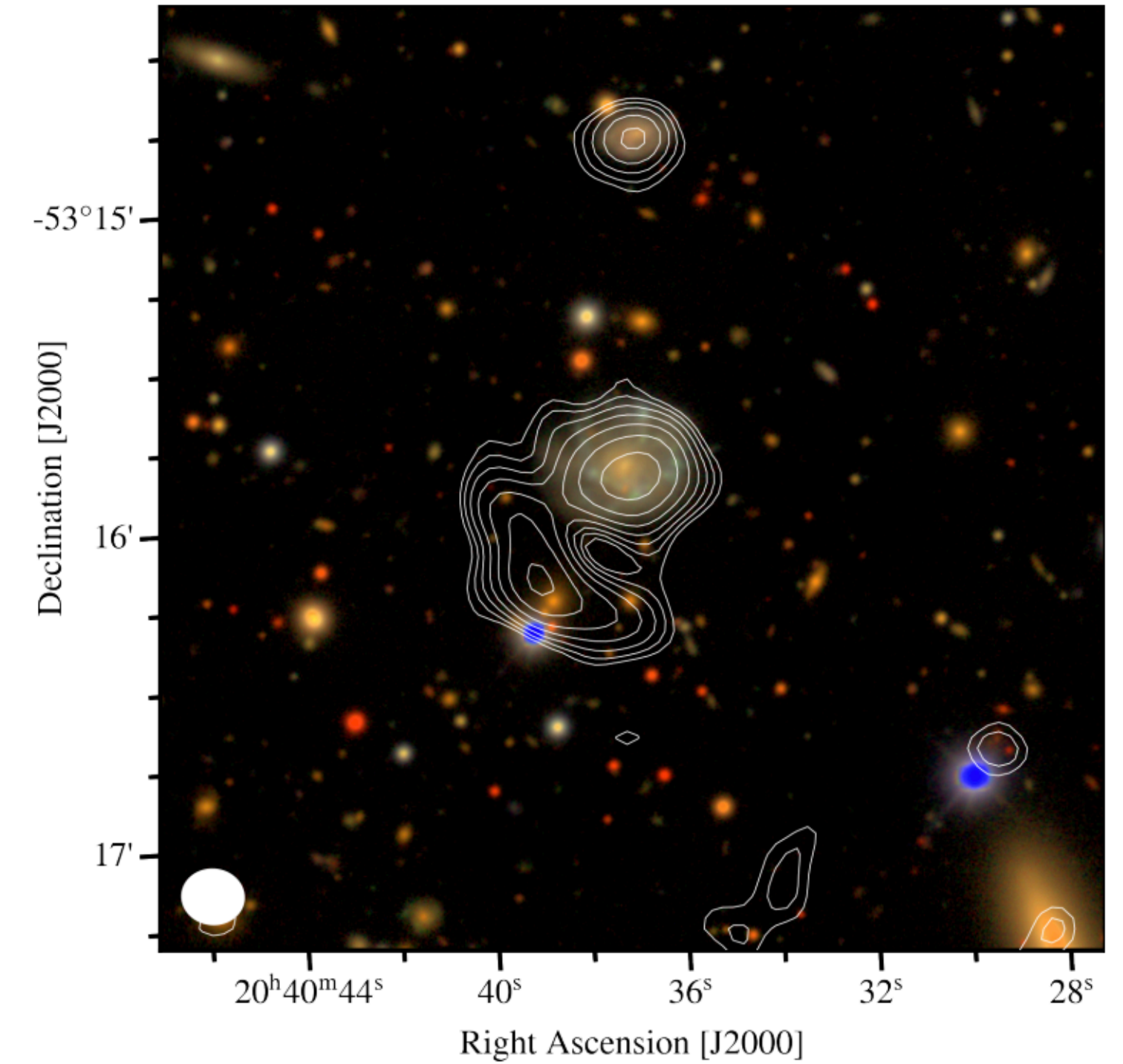
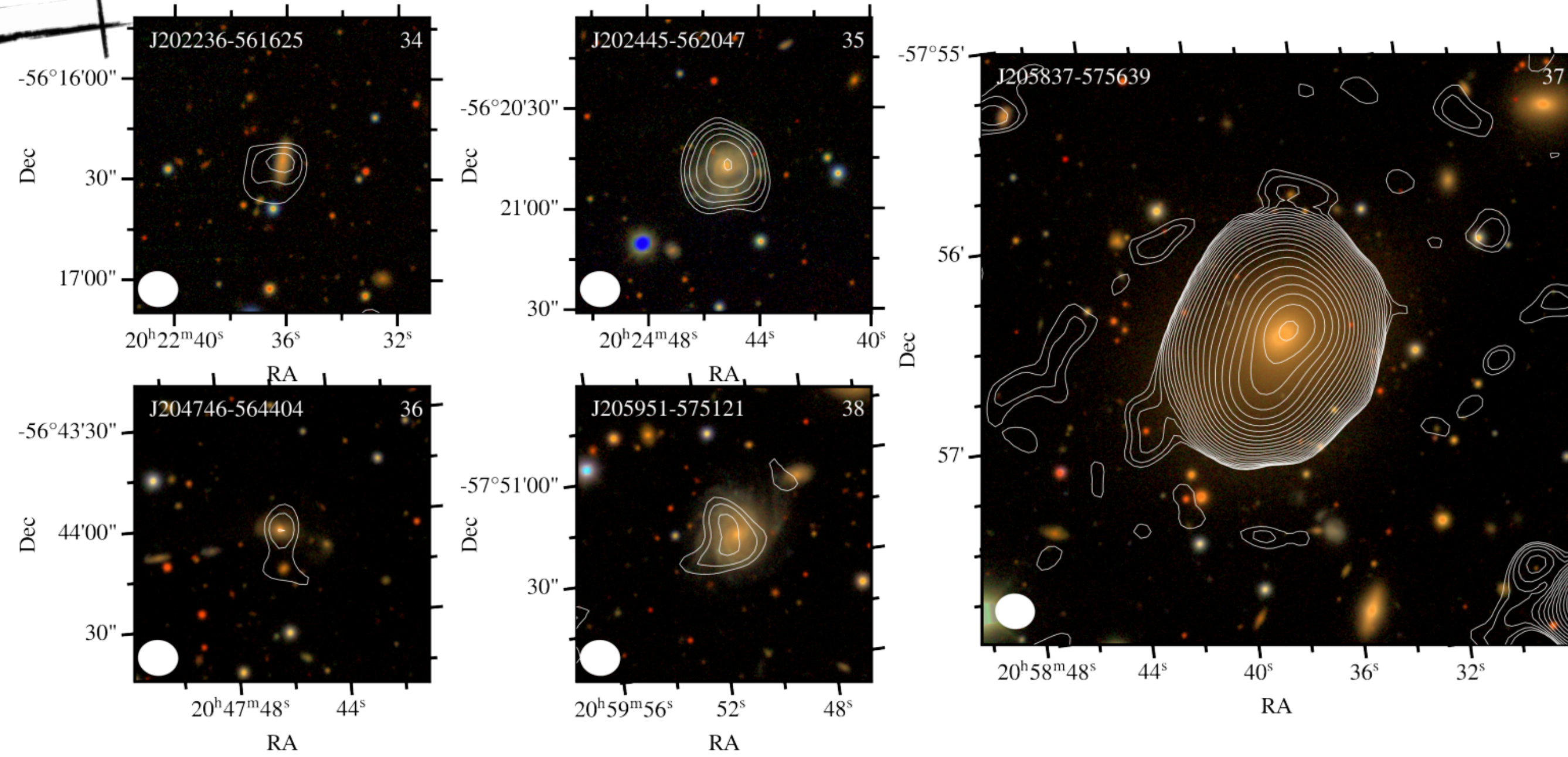
# Tag selection - Ontology - Examples



Science classes

Rare source

SFG



Semantic classes

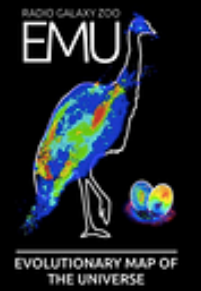
‘traces host galaxy’

“hourglass \ (amorphous U traces host galaxy U 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

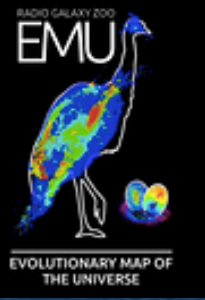
6. Hands on ([zooniverse.org](http://zooniverse.org))



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



# Material



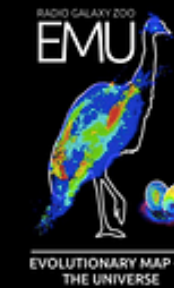
<https://elenivardoulaki.com/material-for-ml-workshop-in-astronomy-23-nov-23/>



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