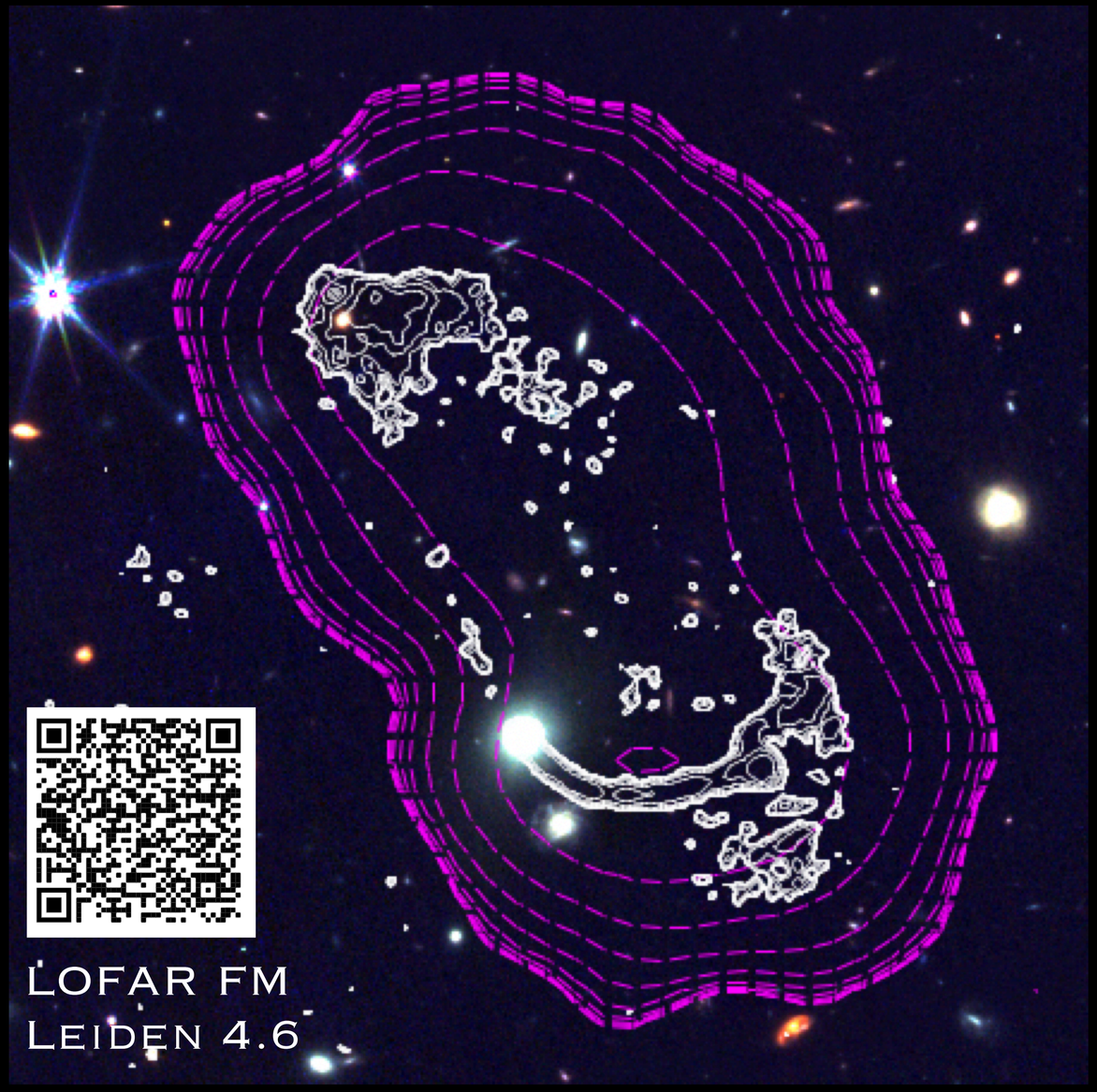
Peering into the unknown with COSMOS LOFAR and JWST observations

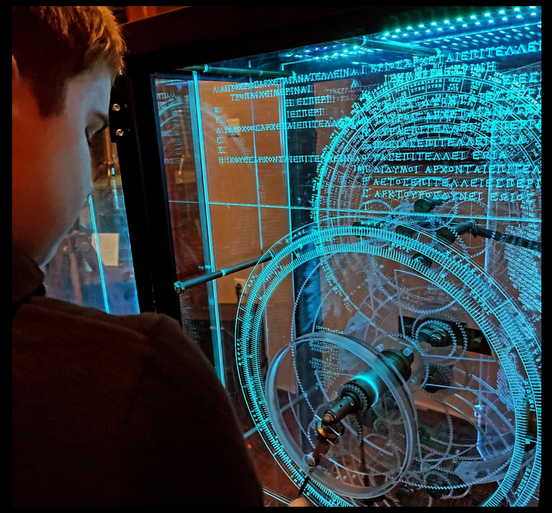


Eleni Vardoulaki
IAASARS National Observatory of Athens
Thüringer Landessternwarte Tautenburg

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

elenivard@gmail.com;
https://www.linkedin.com/in/eleni-vardoulaki/
Rogue Astrophysics
elenivardoulaki.com

Institute of Astronomy, Astrophysics, Space Applications and Remote Sensing
National Observatory Athens
Visitor centres



The case for LOFAR2.0 Greece

Eleni Vardoulaki (LOFAR2.0-GR PI; TLS), Polychronis Papaderos (IA-CAUP), Stergios Amarantidis (IRAM), Nectaria Gizani (HOU), Nikolaos Solomos (HNA - AP/NEO Labs), Giorgos Veldes (HERON LAB), Emmanouil Angelakis (NKUA) , Manolis Marazakis (FORTH), Antony Chazapis (FORTH), Spyros Vasilakos (IAASARS), Manolis Pleionis (NOA), Vassilis Charmandaris (UoC, FORTH) Christos Markou (INPP, NCSR Demokritos), John Antodiadis (FORTH), Alexandros Nindos (UoI), Anastasions Anastasiadis (IAASARS), Anna Belehaki (IAASARS) et al.

The making of LOFAR2.0-GR

We provide preliminary information and expression of intent behind organising, building, operating and sustaining a LOFAR2.0 radio station in Greece (PI: Vardoulaki). With the Bulgaria and Italy stations in the planning, and the development of LOFAR2.0 in the next couple of years (expanding the bandwidth and exploring the long baselines for higher resolution studies), the involvement of Greece in this distributed facility is timely. LOFAR science addresses a number of areas from astrophysics and particle physics to ionosphere studies and space weather, as well as Earth applications. Greece has exceptional scientists working on a wide area related to key science projects (KSPs) of the international LOFAR telescope (ILT) and can play an important role and be a valued partner and contributor.

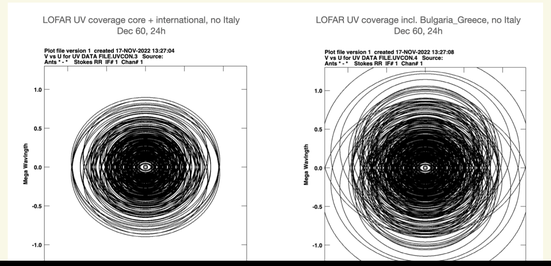
Fig. 1: **The LOFAR International Telescope**: Locations of current and future LOFAR stations. The gold star shows the upcoming LOFAR2.0 Greece station (exact position pending).

Why in Greece

Building a LOFAR2.0 station in Greece is timely and will benefit the local and international communities in several aspects.

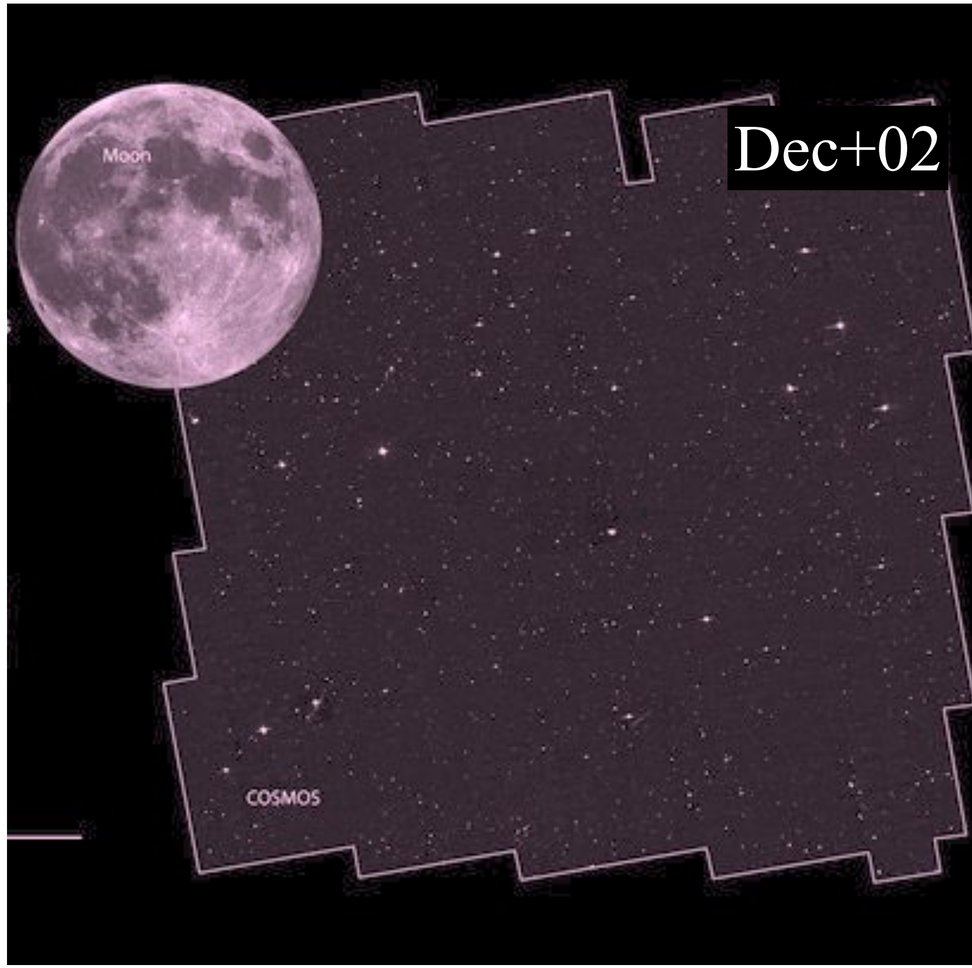
Internationally and technically: It will expand the baselines of the ILT allowing for access to lower declinations. Use of the long baselines is one of the key aspects of LOFAR2.0, and what most, if not all, of the LOFAR2.0 large projects will be aiming for, to obtain higher resolution observati
proving the pipelines for processing
are underway with the re-observing
Vardoulaki). These efforts are aiming
technical bottlenecks and systematic
sensitivity (tens of μJy/beam) and res
vations at declinations below 30 degr

Locally: From astrophysics, particle physics, space science, ionospheric physics and computer science, to exotic science, such as dark matter searches, Greek Universities and Institutes keep research at the forefront and complement the range of KSPs within the ILT. LOFAR2.0-GR will enable Greece to participate in a well-established international telescope network advancing and expanding not only research capabilities, but also teaching and training for the current and future generations of scientists. It will further advance local communities, allowing them to benefit from technology advancements. In the era of big data and artificial intelligence, the expertise an individual can gain from being associated with the ILT collaboration will benefit their career development within and outside academia. Greece can be a hub of training data scientists with high-level expertise, also applicable to the industry and the public sector.



Looking for funding through local governments

Cosmic Evolution Survey - COSMOS

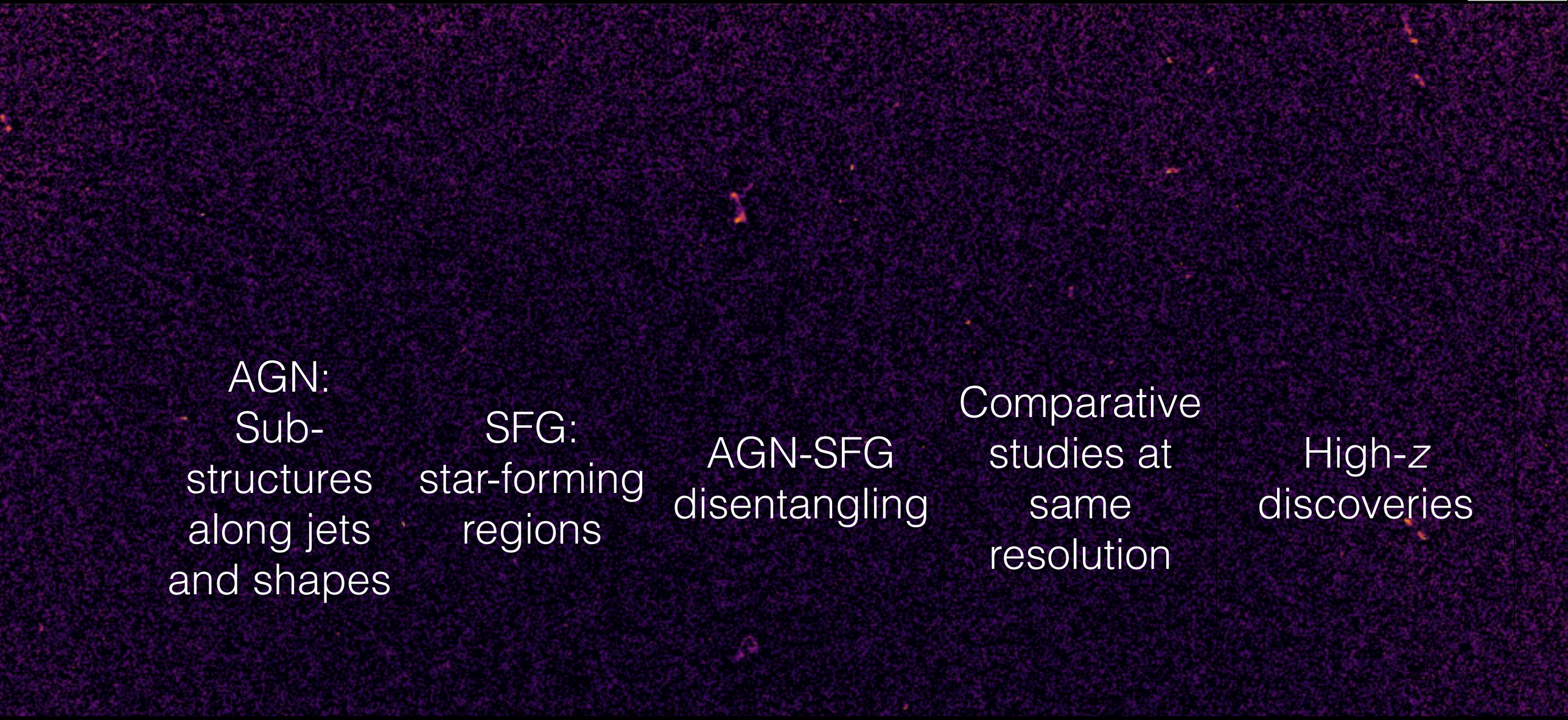


Eleni Vardoulaki
elenivard@gmail.com

Systematic study of radio AGN at 3GHz VLA-COSMOS (2.3 μJy/beam; 0.75”)
Physical properties, hosts, large multi-scale environment, simulations

A closer look at the deep radio sky: Multi-component radio sources at 3 GHz VLA-COSMOS	Vardoulaki+19, A&A, 627A, 142
FR-type radio sources at 3 GHz VLA-COSMOS: Relation to physical properties and large-scale environment⋆	Vardoulaki+21a, A&A, 648A, 102
The M_*–M_{halo} Relation at $0.08 < z < 1.53$ in COSMOS: The Role of Active Galactic Nucleus Radio-mode Feedback	Vardoulaki+21b, RNAAS, 5, 89
Bent It Like FRs: Extended Radio AGN in the COSMOS Field and Their Large-Scale Environment	Vardoulaki+21c, Galaxies, 9, 93
The evolution of the radio luminosity function of group galaxies in COSMOS	Vardoulaki+23, A&A, in press; arXiv:2204.02082
The Jet Paths of Radio AGN and their Cluster Weather	Backöfer, Vardoulaki+23, in prep.

μJy sensitivity+sub-arcsecond resolution



AGN: Sub-structures along jets and shapes

SFG: star-forming regions

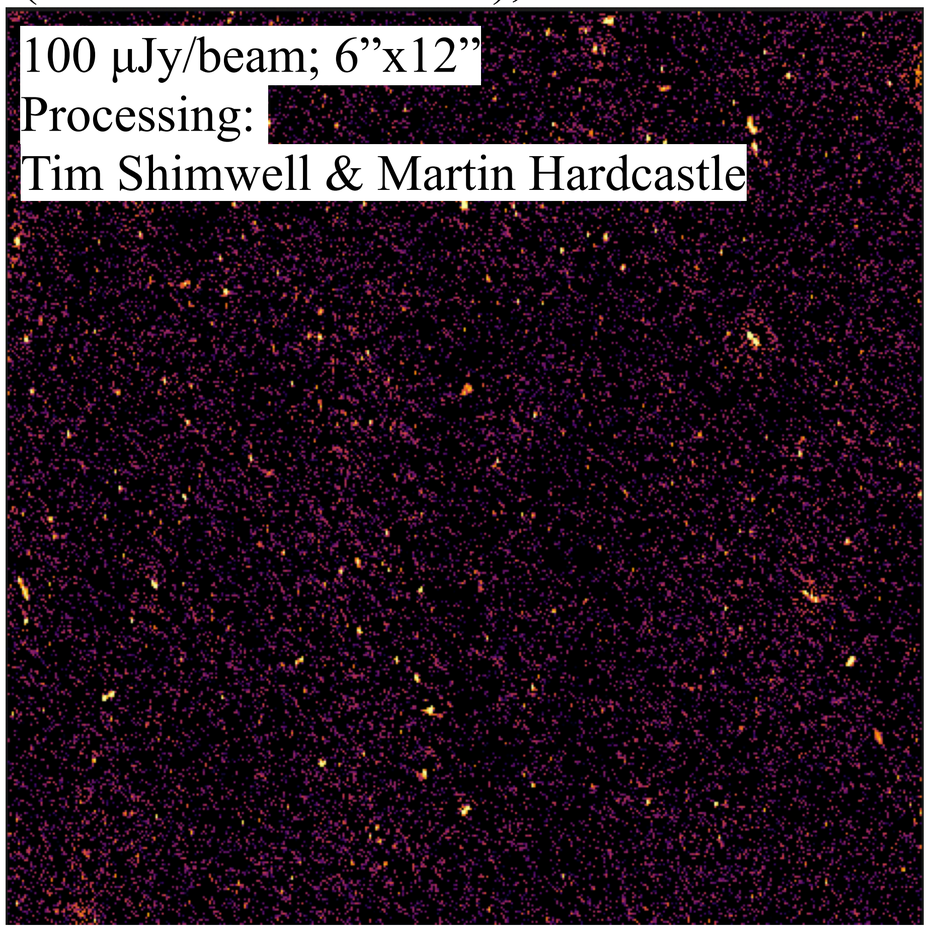
AGN-SFG disentangling

Comparative studies at same resolution

High-*z* discoveries

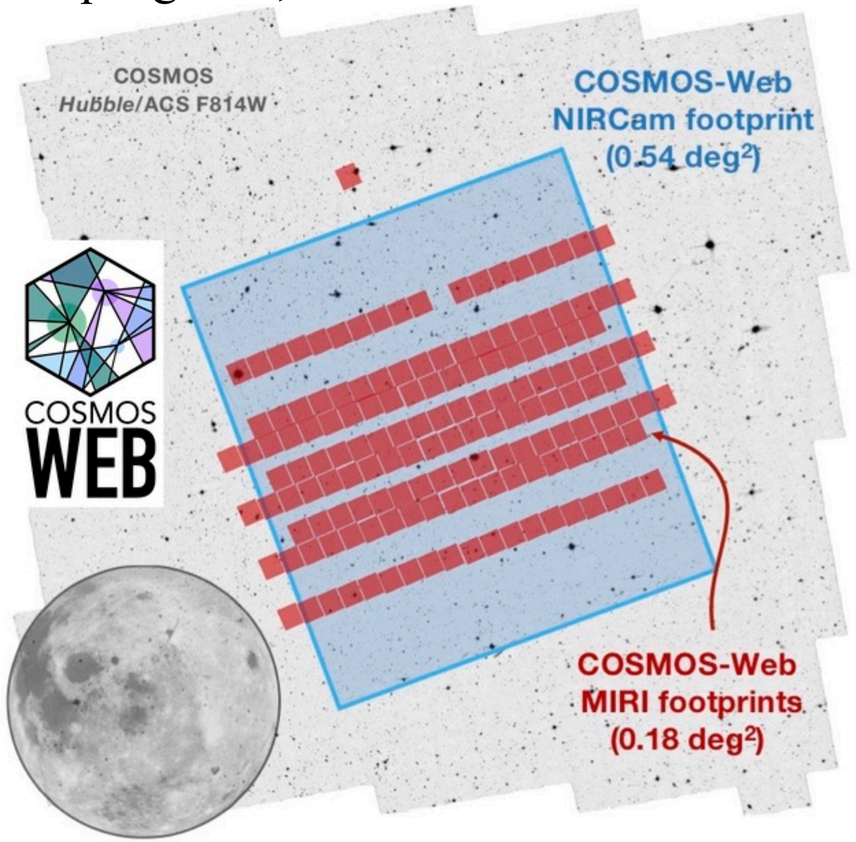
Latest additions

48h DDT LOFAR HBA
(+international stations); PI: Vardoulaki



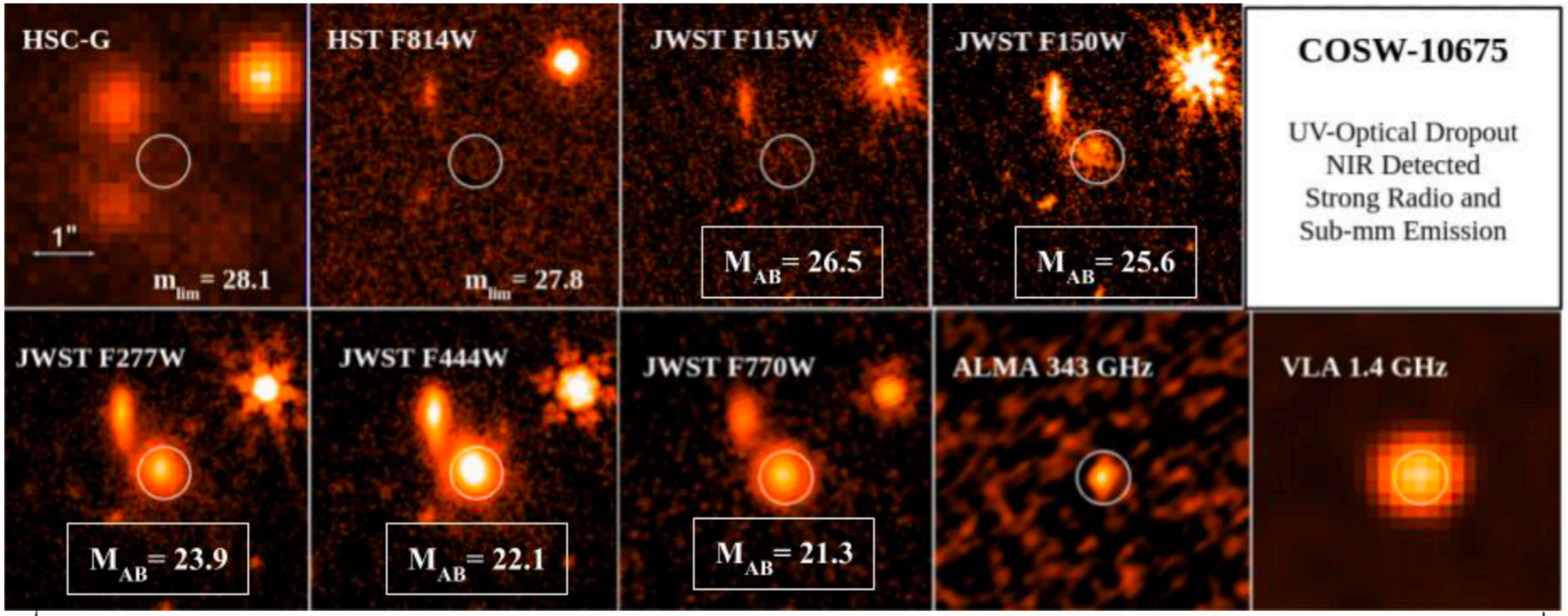
Vardoulaki+ in prep.

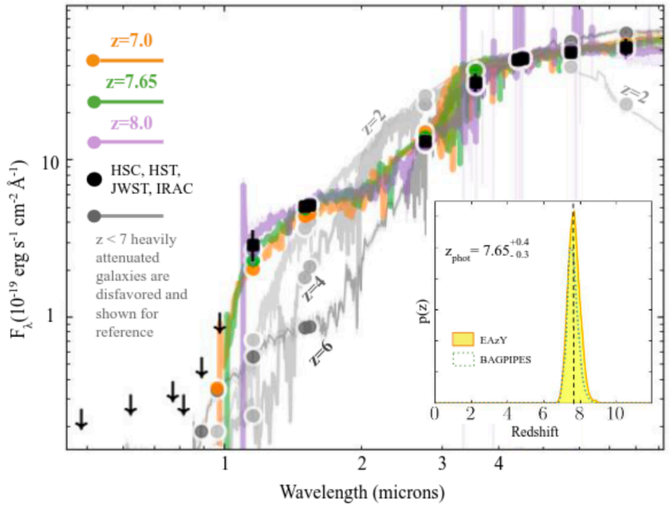
255 hour wide-field Cycle 1 JWST treasury
0.6 sq deg area, NIRCam + MIRI

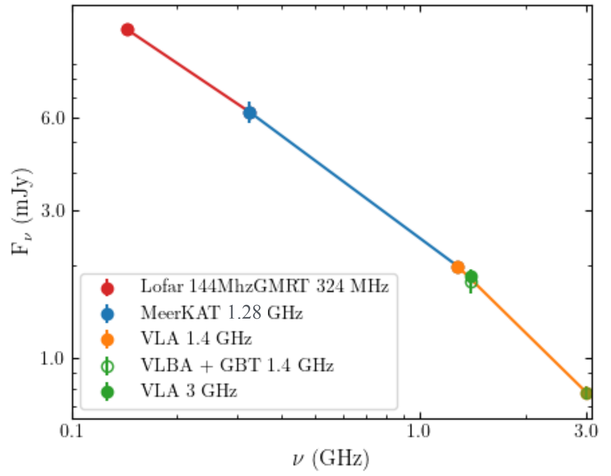


Casey & Kartaltepe + incl.
Vardoulaki, ApJ, 954, 31

Highest z (7.7) obscured AGN





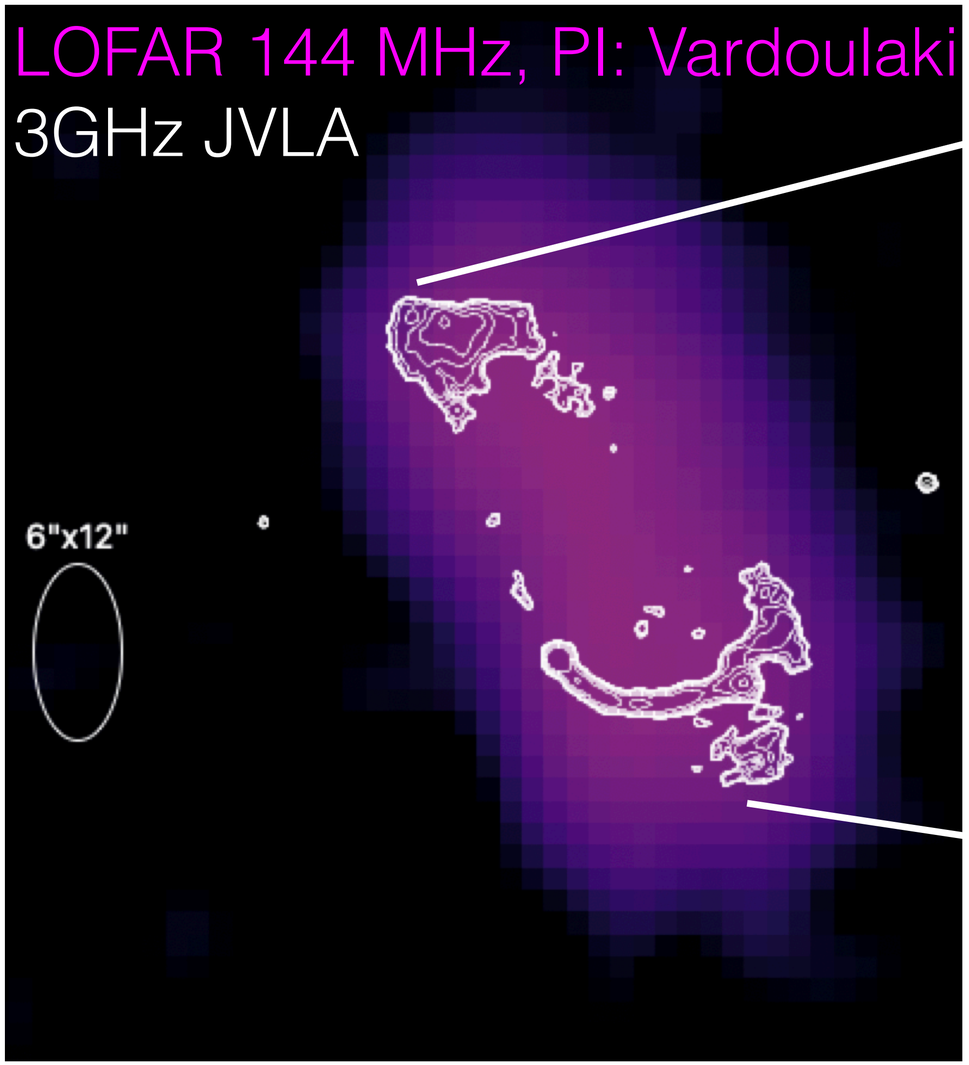


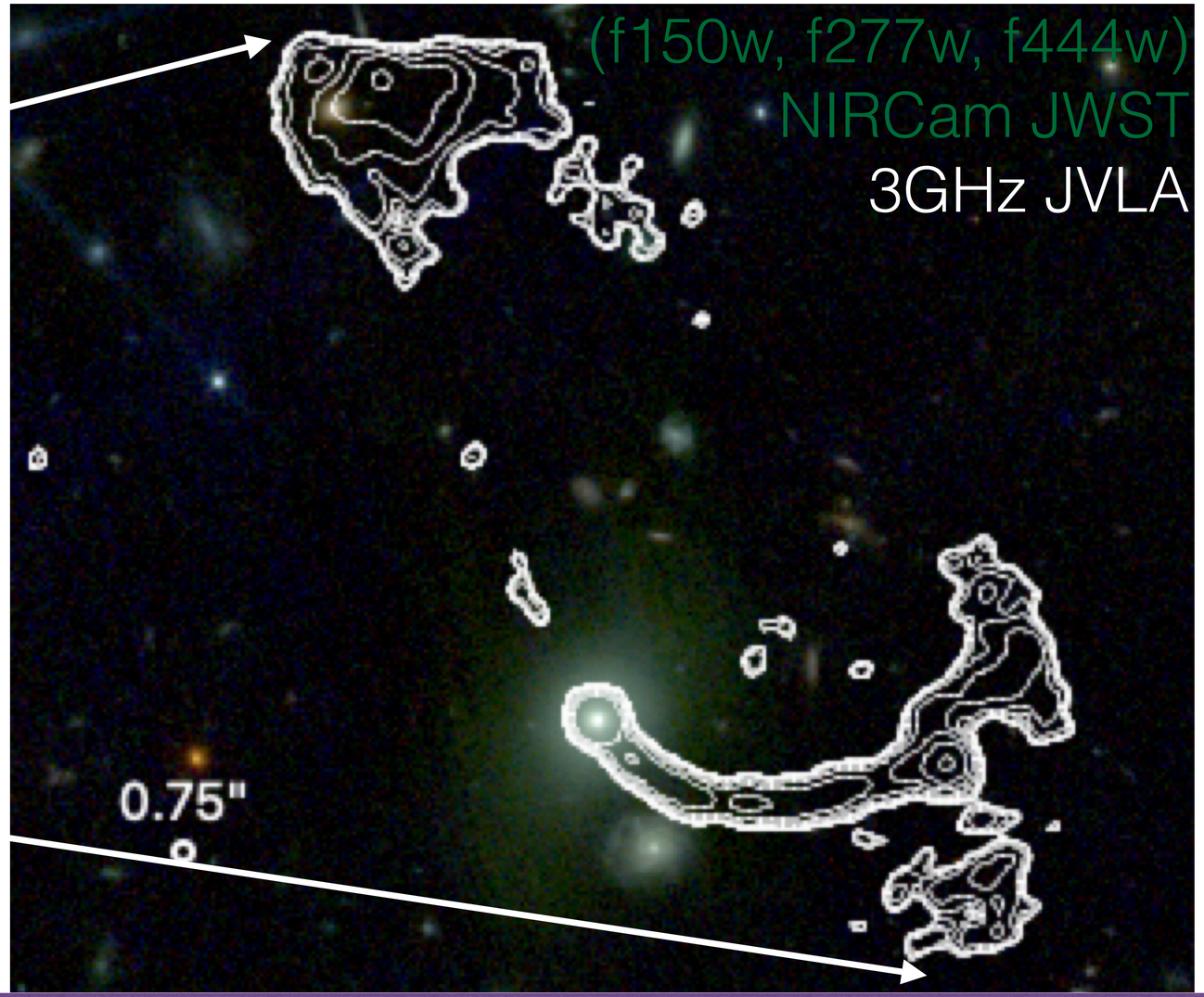
➡ Representative (but observationally scarce) AGN population

➡z_{phot}=7.65(+0.04,-0.03); logM^* = 11.92 ± 0.06 M_{sun}; N_H> 10^{23}cm^{-2}; α=1.2 ($S_\nu \sim \nu^{-\alpha}$)

Lambrides, incl. Vardoulaki+23

sub-arcsecond resolution: AGN examples

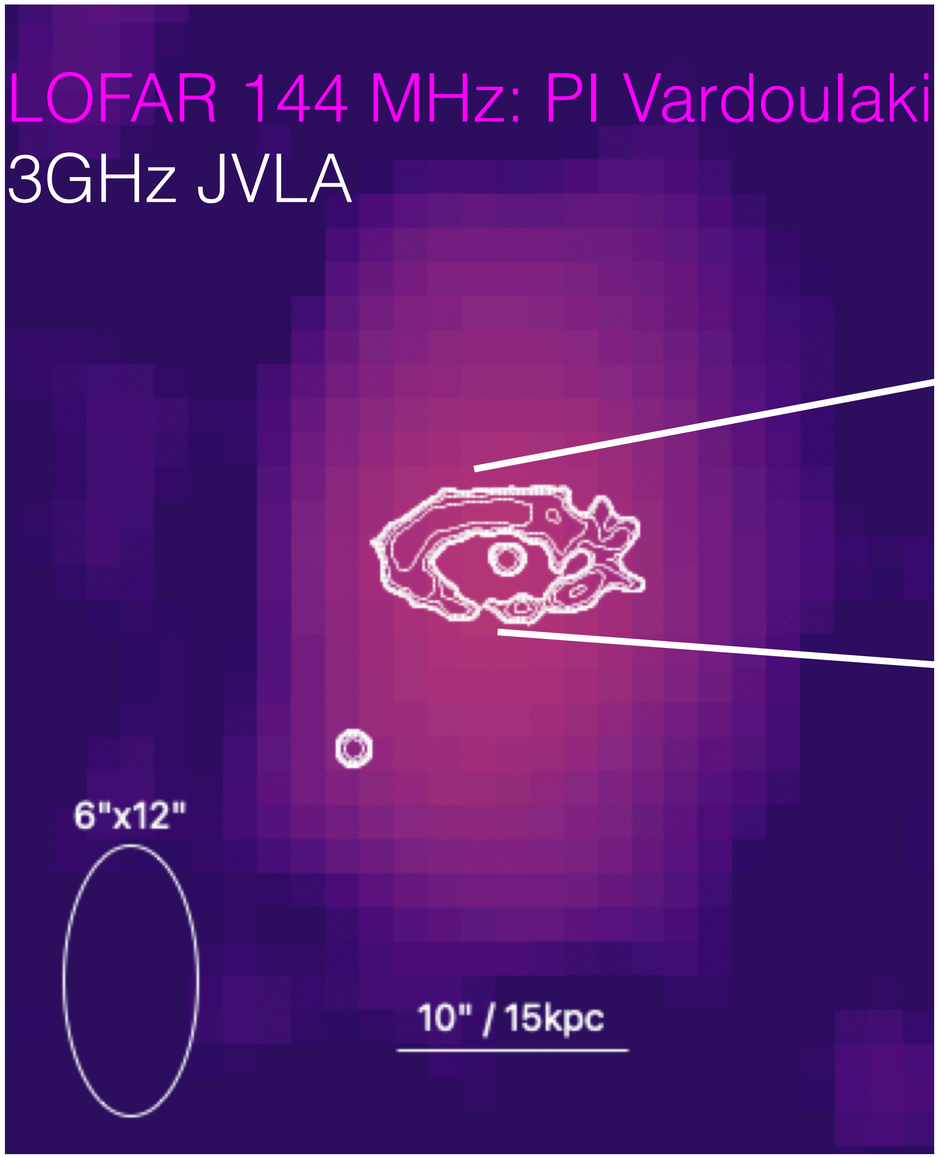


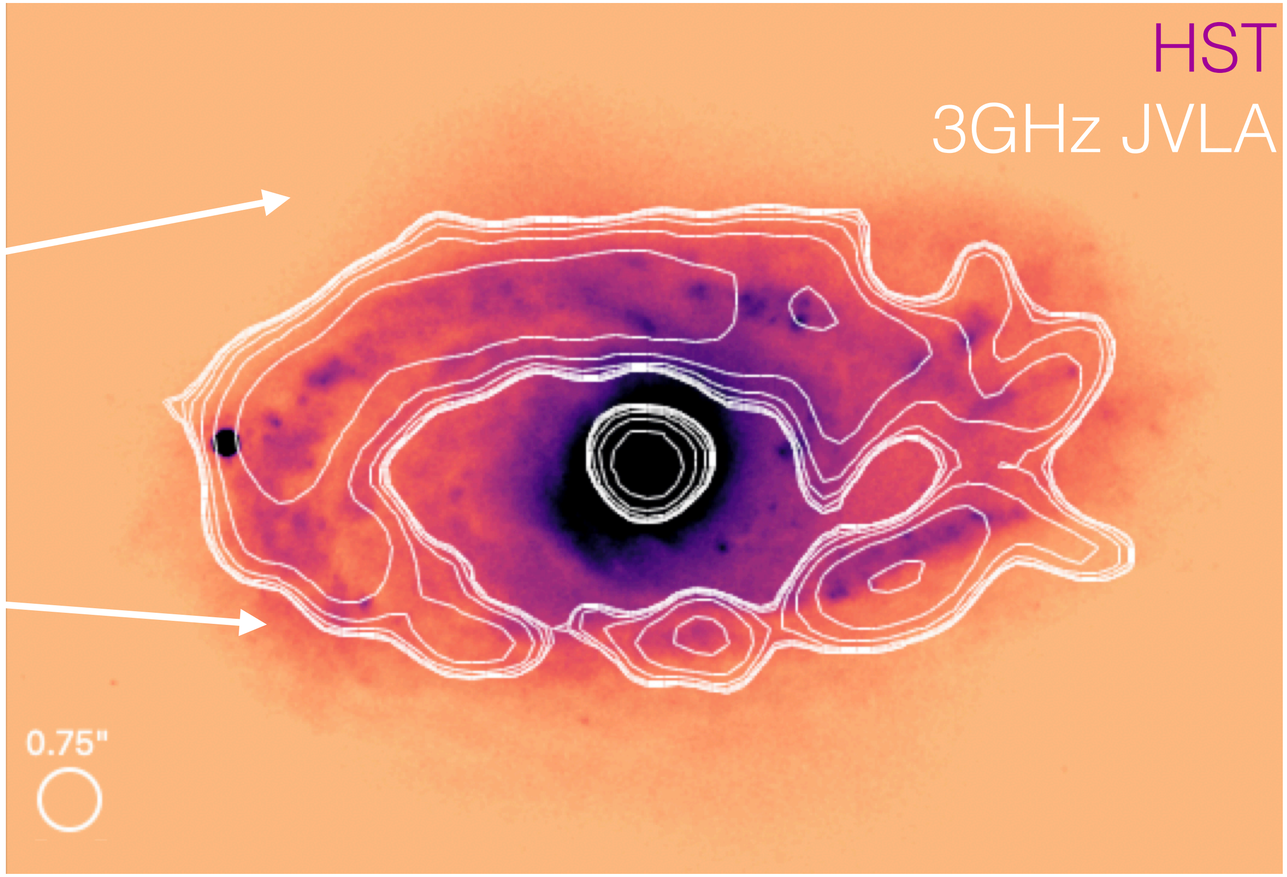


Vardoulaki+21, A&A, 627A, 142;Vardoulaki+19, A&A, 627A, 142

Eleni Vardoulaki
elenivard@gmail.com

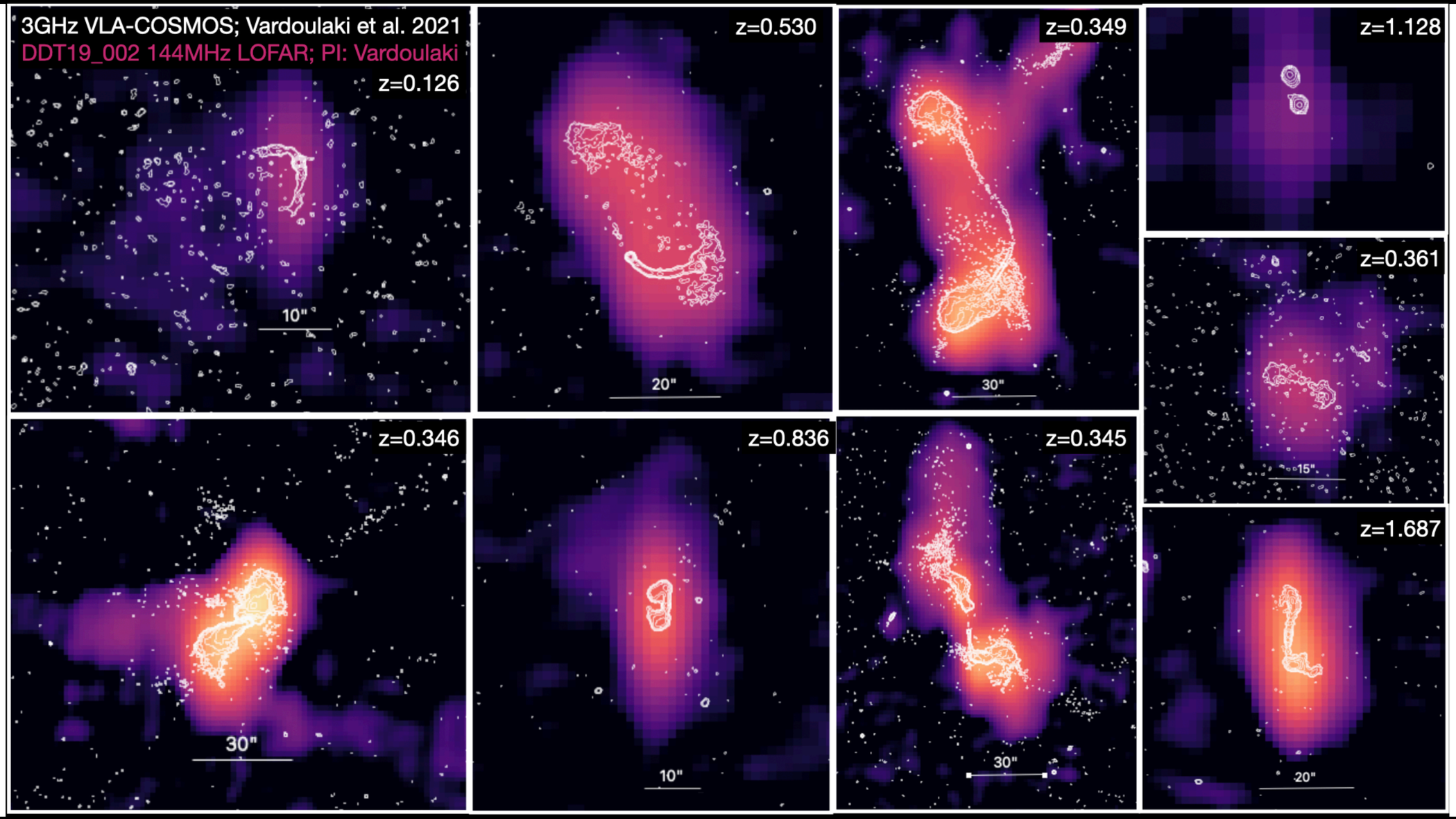
sub-arcsecond resolution: SFG examples



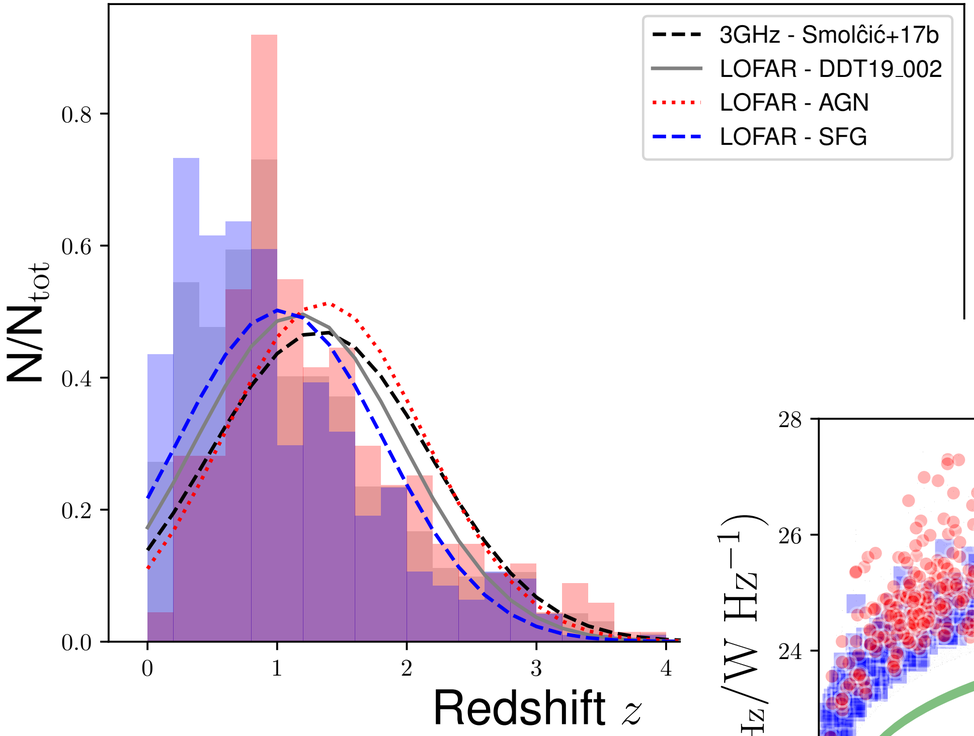


Vardoulaki+19, A&A, 627A, 142

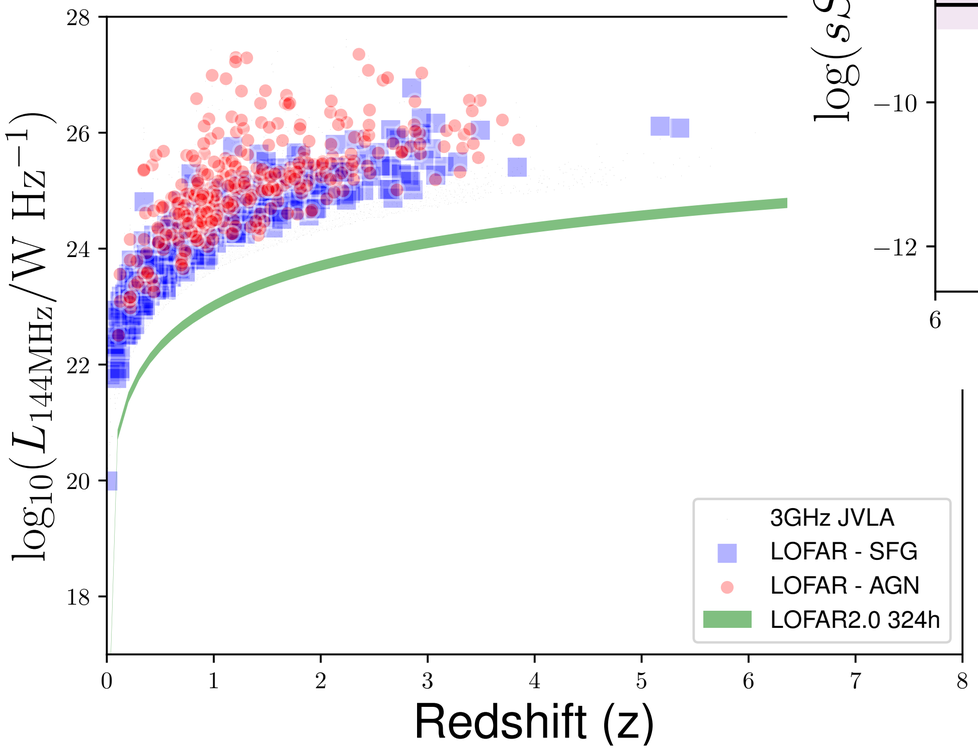
144 MHz v 3 GHz: AGN examples

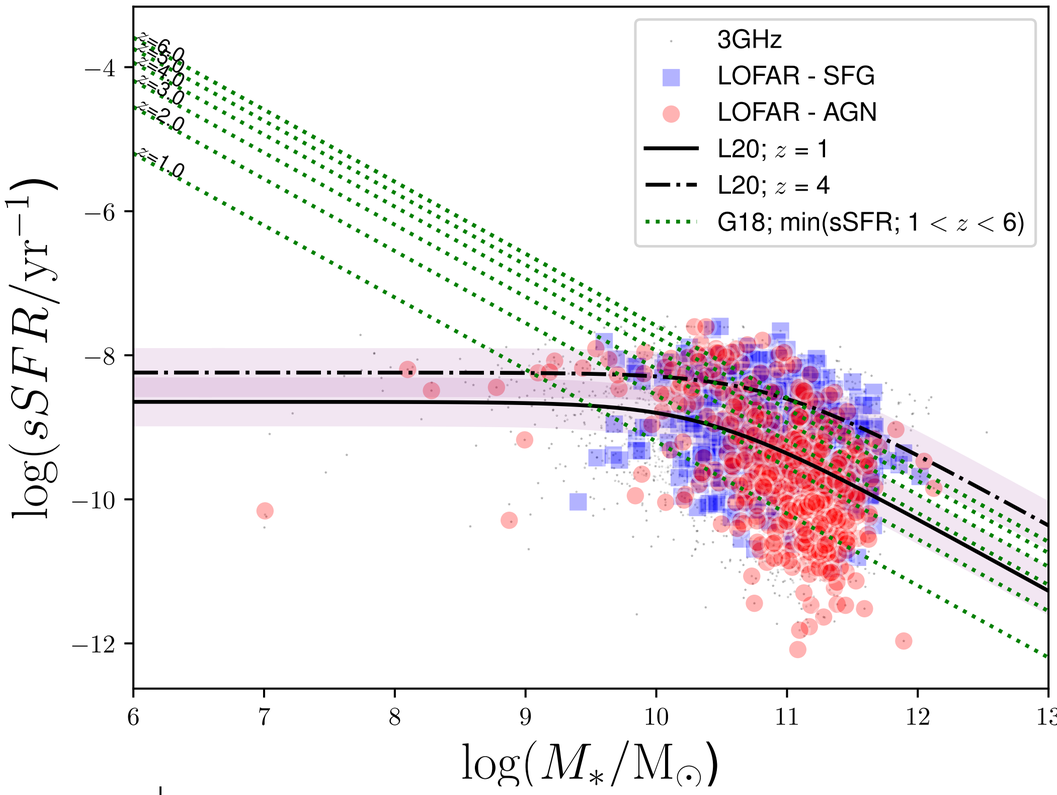


Early analysis - DDT19_002 LOFAR



- ➡100μJy/beam, 144MHz
- ➡~2000 sources (out of 11K at 3GHz)
- ➡Missing fainter radio sources





3GHz data & classification from Vardoulaki+21a, A&A, 648A, 102

Vardoulaki+in prep.

Eleni Vardoulaki

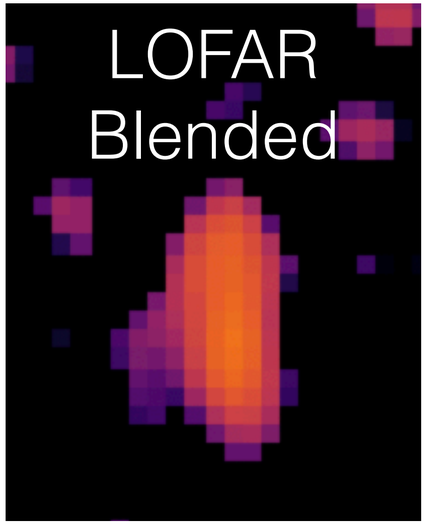
elenivard@gmail.com

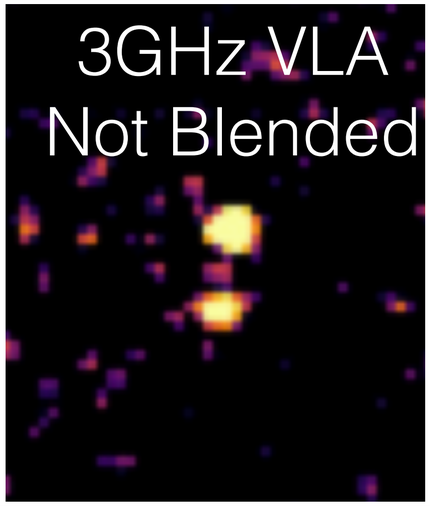
Deblending the LOFAR map - Shouwen Jin

➡used ~200k priors
➡performed PSF fitting with fixed positions
➡ran MonteCarlo simulations to correct the flux bias and uncertainties

➡1873 detections with S/N>3
➡Not suitable for extended sources

➡At hand: Super-deblending catalog with FIR & radio fluxes (LOFAR HBA 144 MHz, VLA 1.4 & 3 GHz, GMRT 310 & 600 MHz and MeerKAT 1.3 GHz)
➡Radio spectral index analysis (masters thesis - Loukas Doukas, NOA)

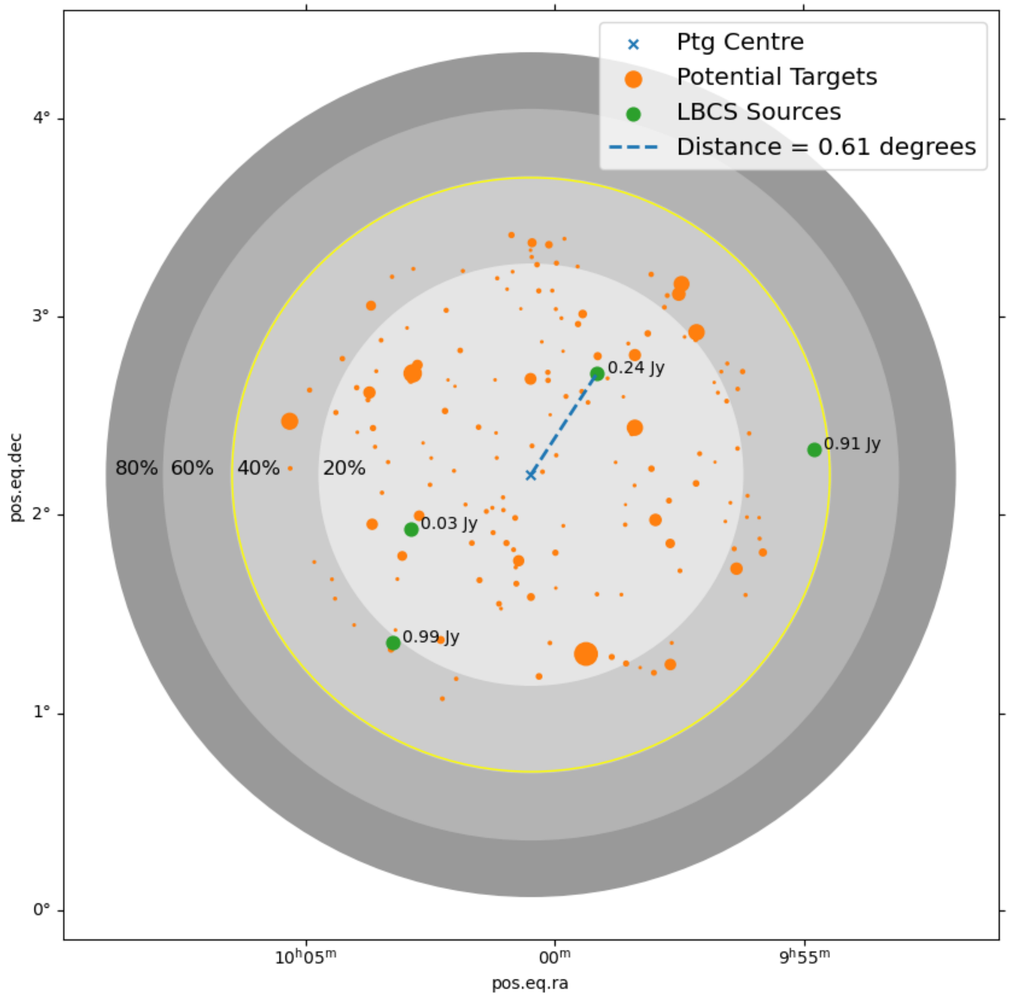




Vardoulaki+in prep.

LOFAR-VLBI - COSMOS+02deg

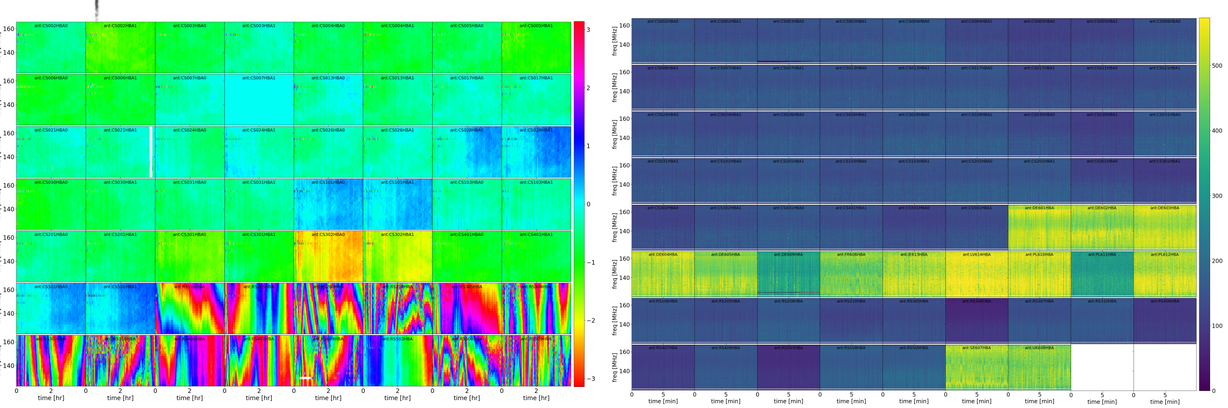
- ➡ cwl VLBI pipeline (Morabito et al.)
- ➡ In processing - 48h (12x4h)
- ➡ Good calibrators in COSMOS
- ➡ Intermediate resolution ~2” (similar to 1.4GHz)
- ➡Target resolution sub-arcsec (similar to 3 GHz)
- ➡1 year - full field - in progress

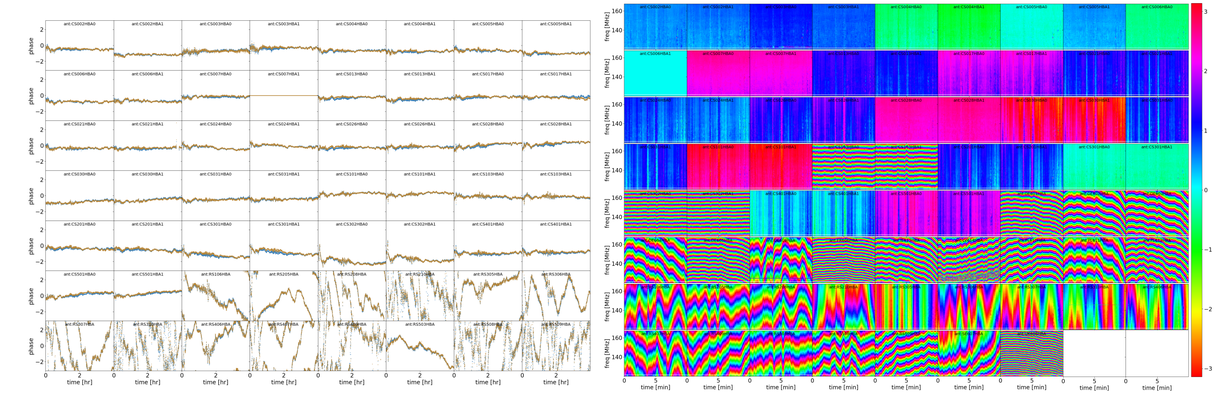


Eleni Vardoulaki
elenivard@gmail.com

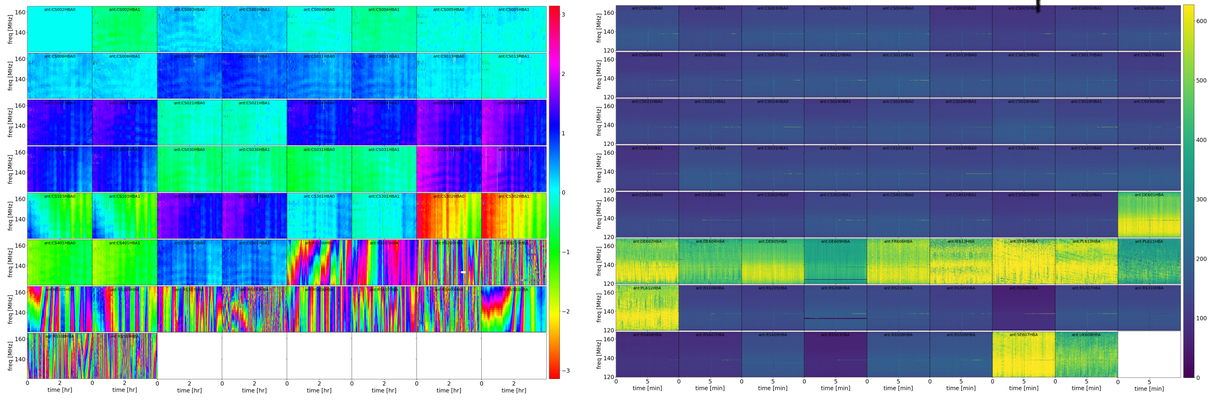
LOFAR-VLBI - COSMOS+02deg

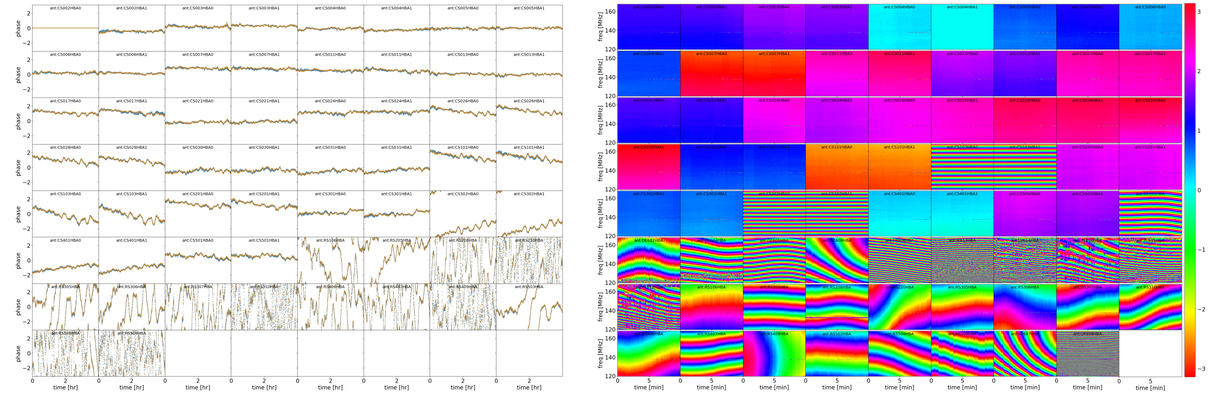
➡LINC target & calibrator cwl-pipeline: best solutions - night observations





Feb 2023 - good

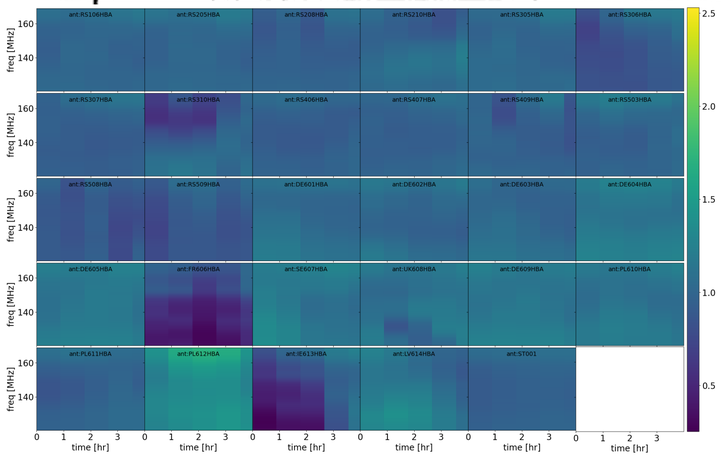


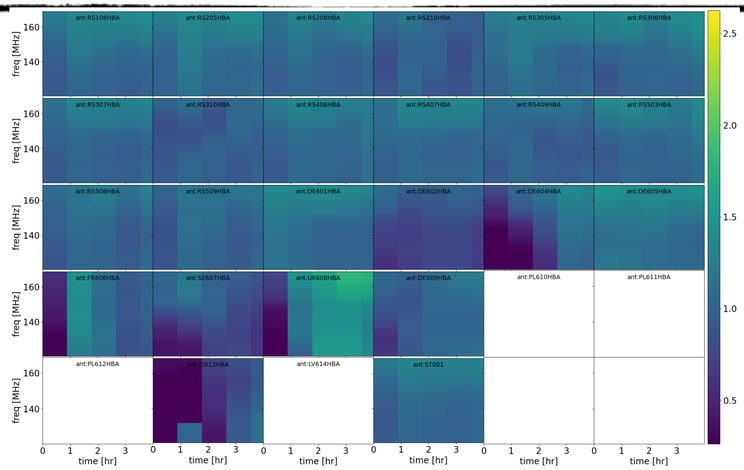


May 2023 - not so good

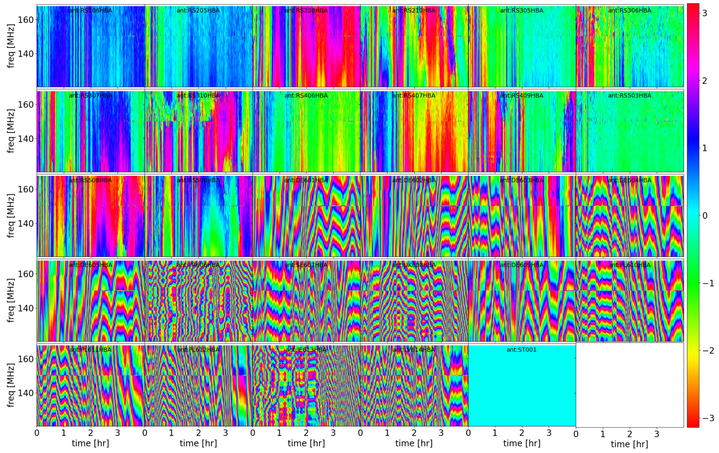
LOFAR-VLBI - COSMOS+02deg

➡Delay Calibrator - cwl-pipeline

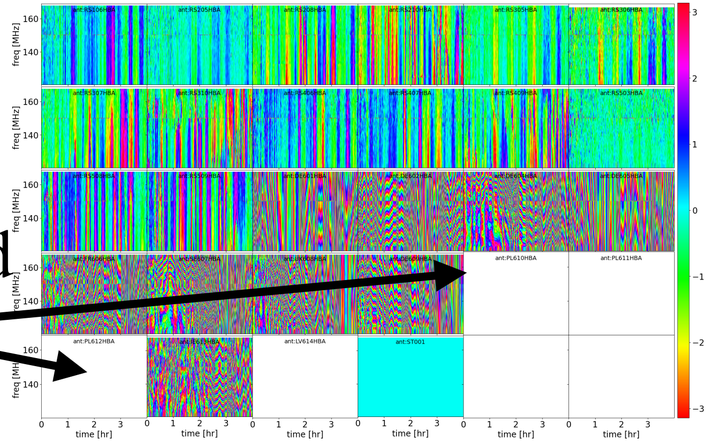




Feb 2023 - good

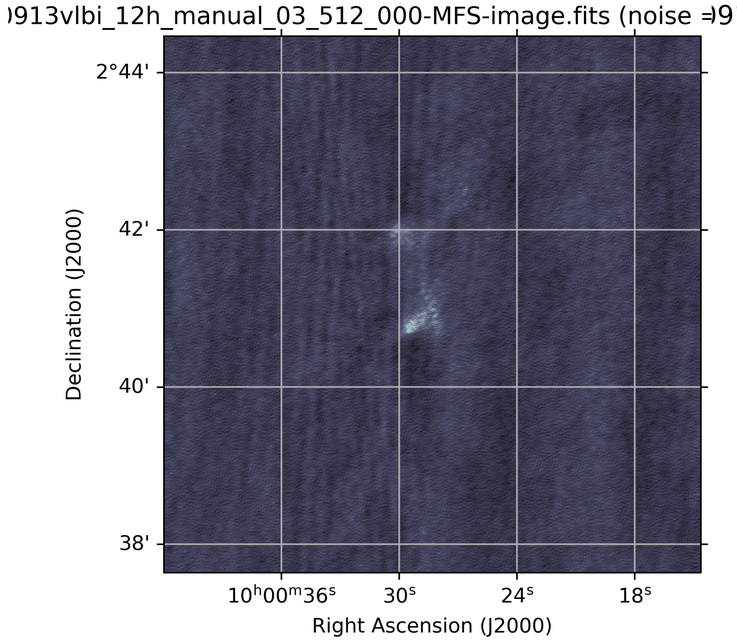


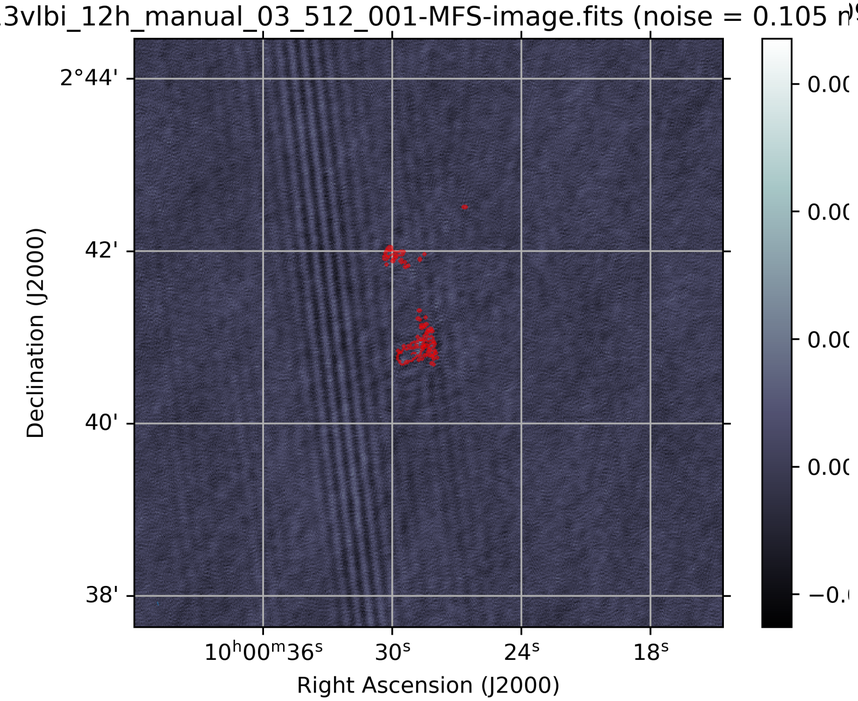
May 2023 - bad
missing IS

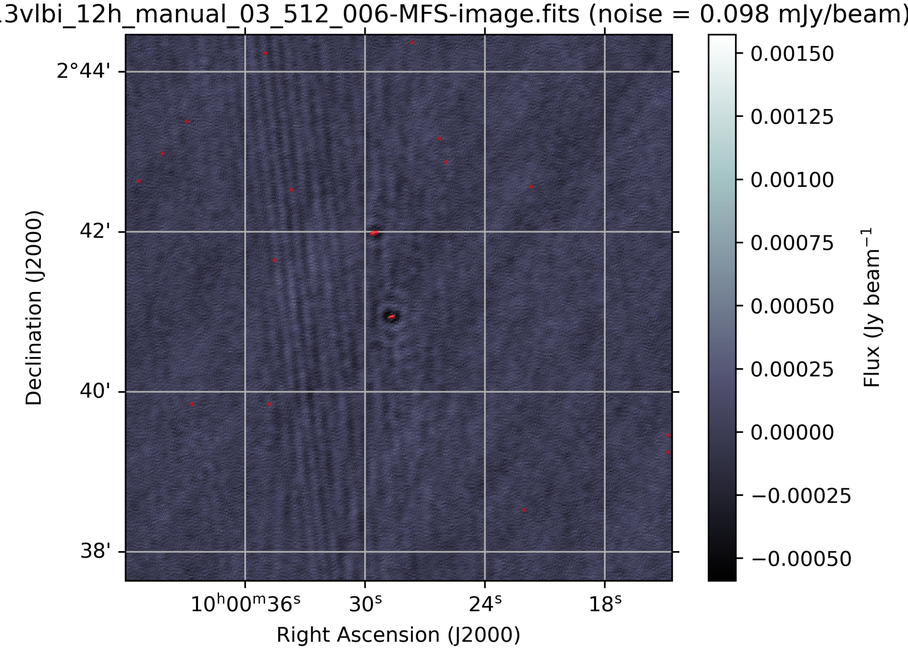


LOFAR-VLBI - COSMOS+02deg

- Self-cal - individual targets - not so good examples of extended radio AGN
- 12h observations



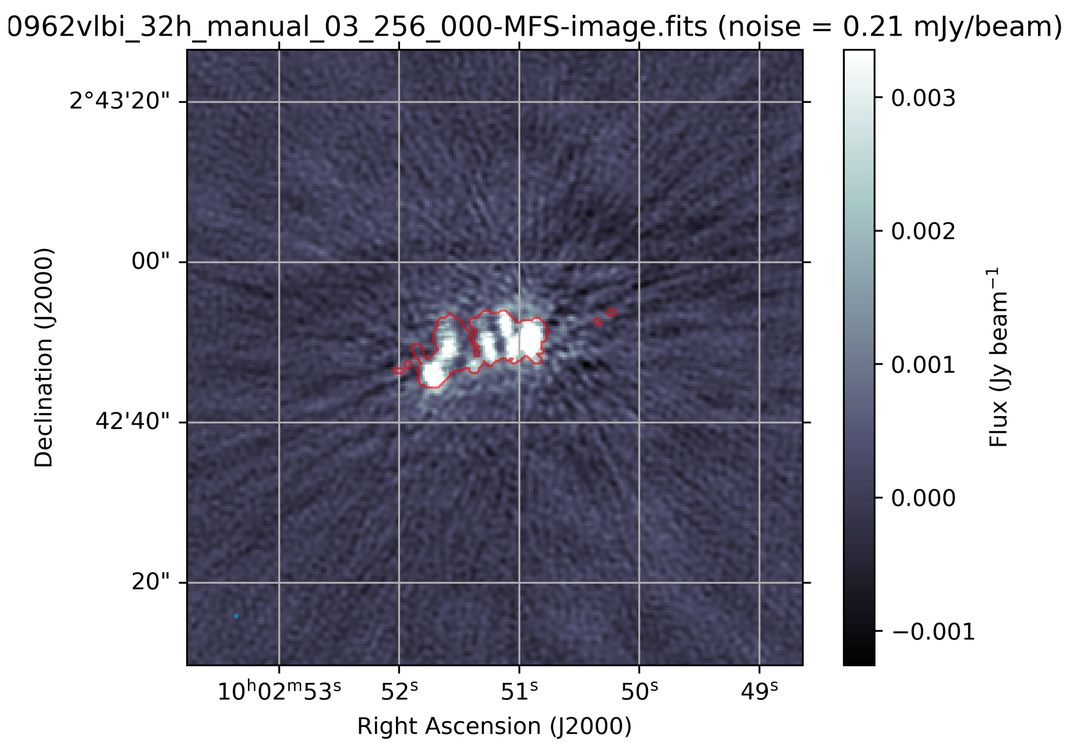




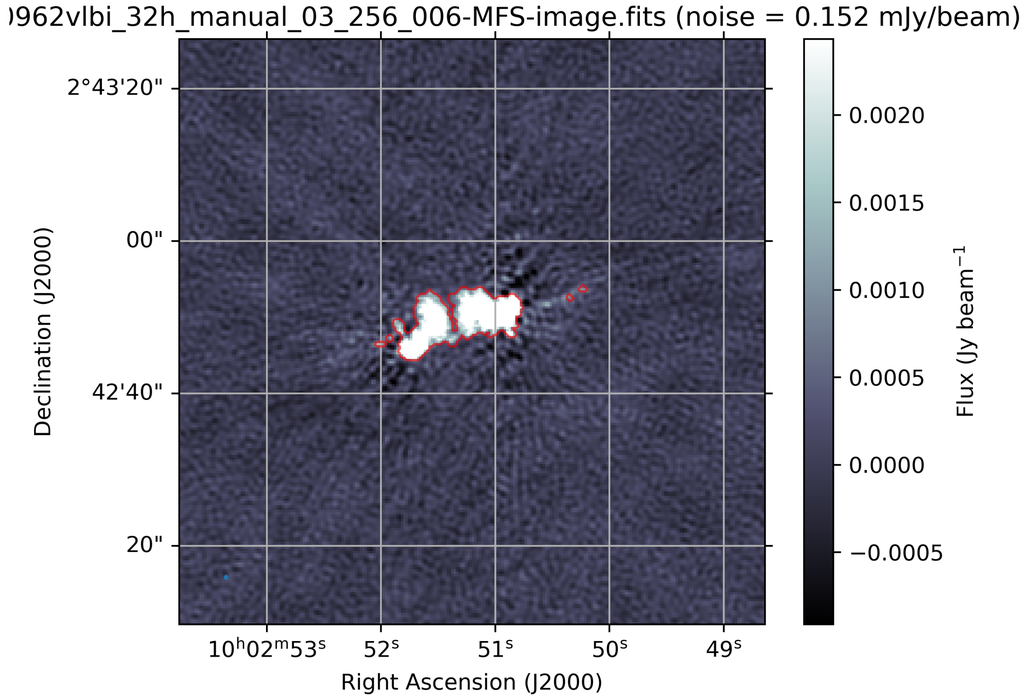
wsclean - finds faint source | 1st iteration | After only 6 iterations - overfitting

LOFAR-VLBI - COSMOS+02deg

➡Self-cal - individual targets - good examples of extended radio AGN
➡32h observations

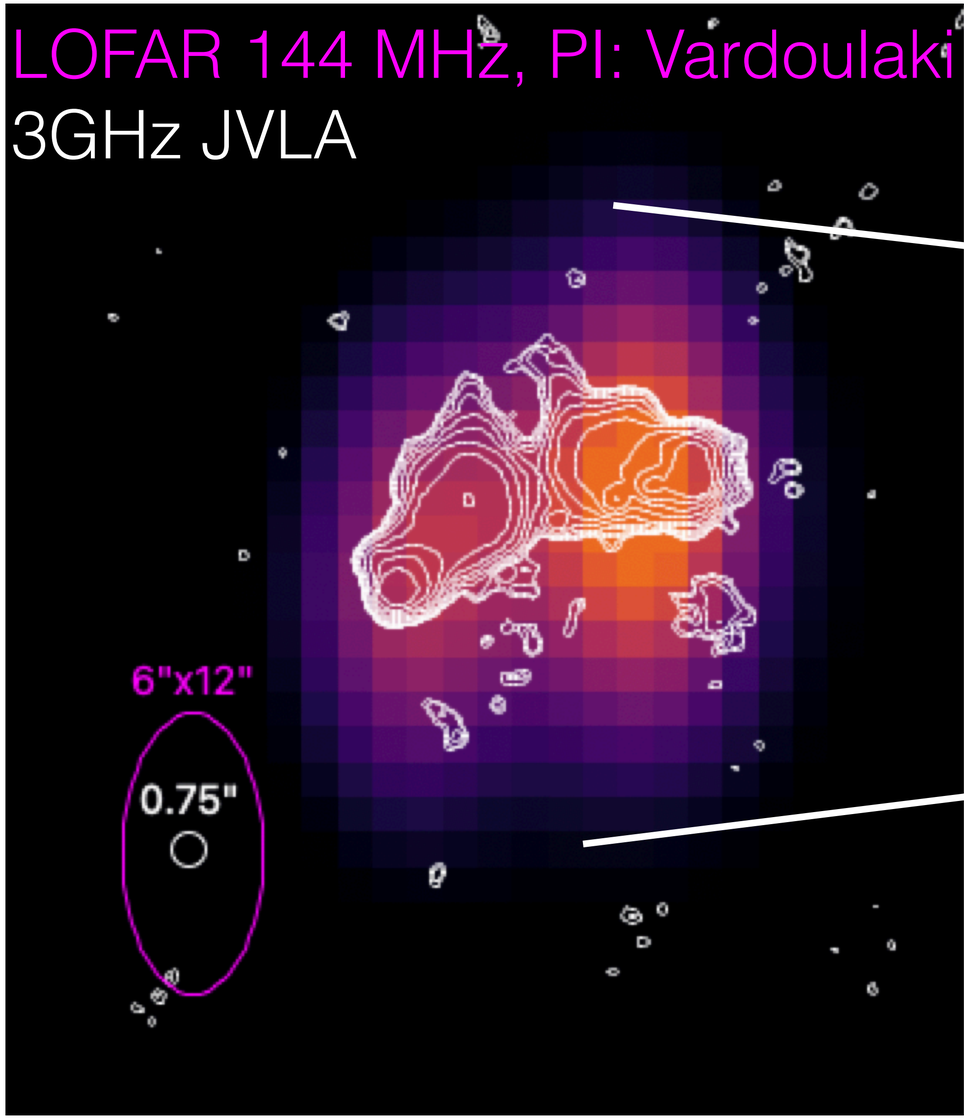


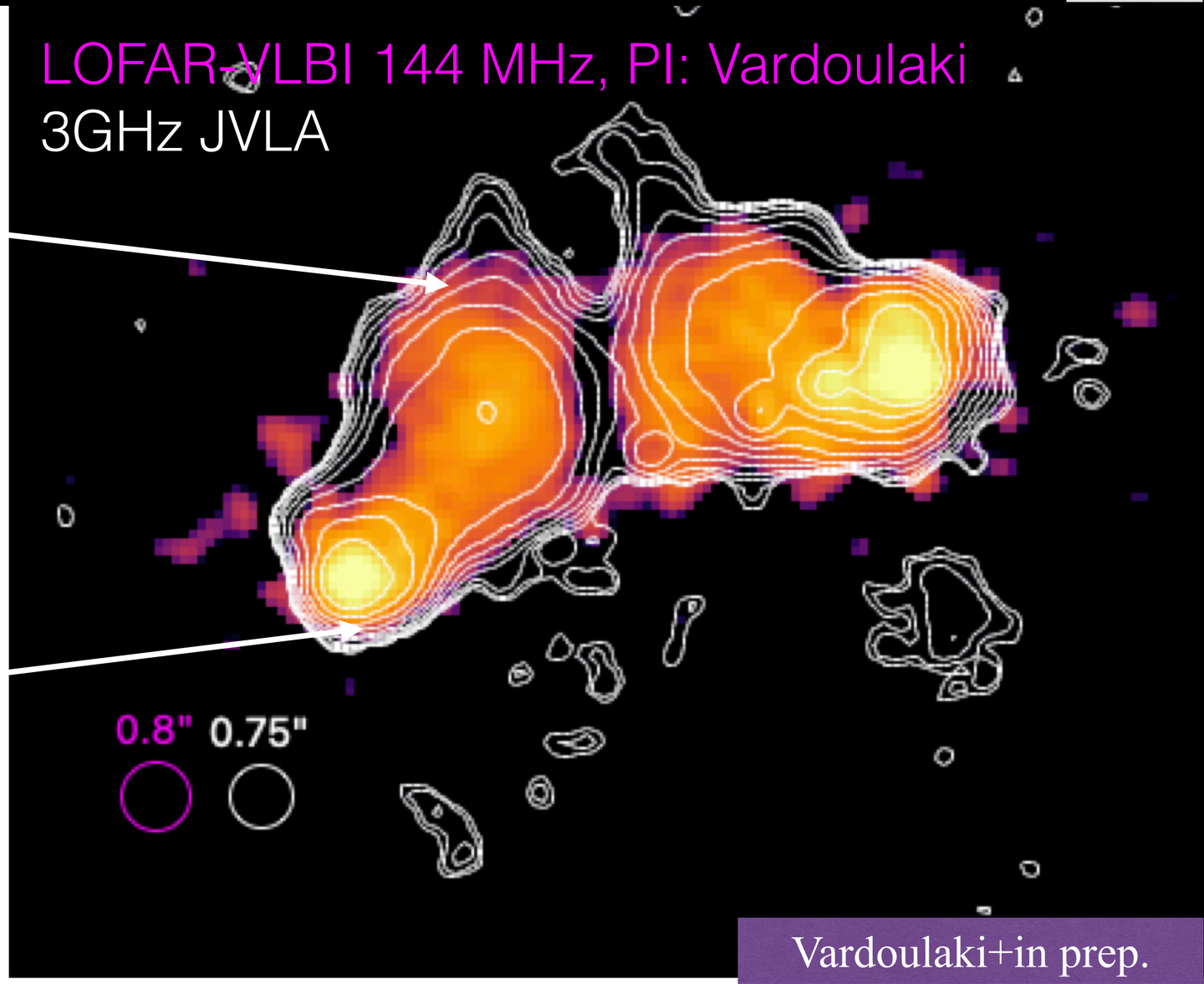
wsclean



6 iterations

sub-arcsecond resolution: AGN examples

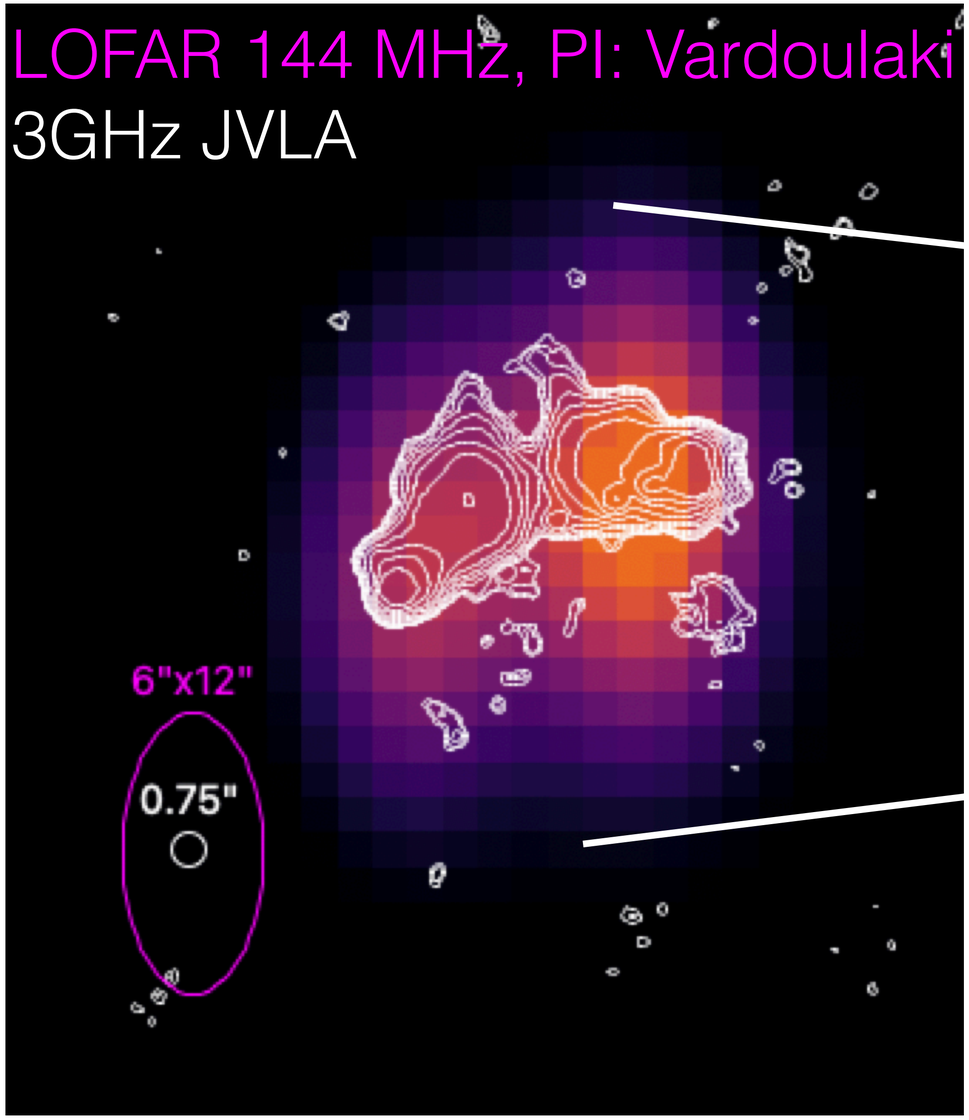




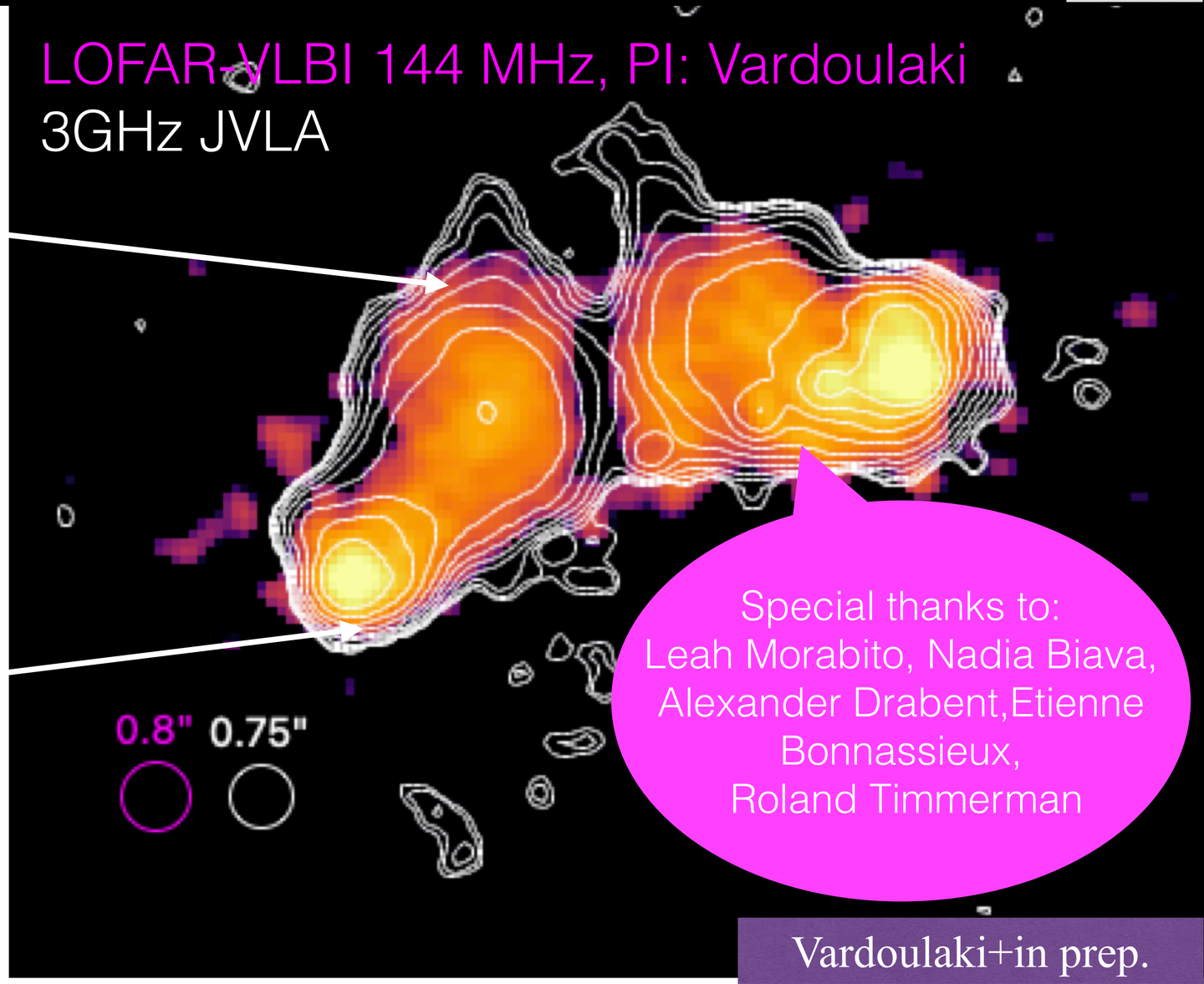
Vardoulaki+in prep.

sub-arcsecond resolution: AGN examples

LOFAR 144 MHz, PI: Vardoulaki
3GHz JVLA



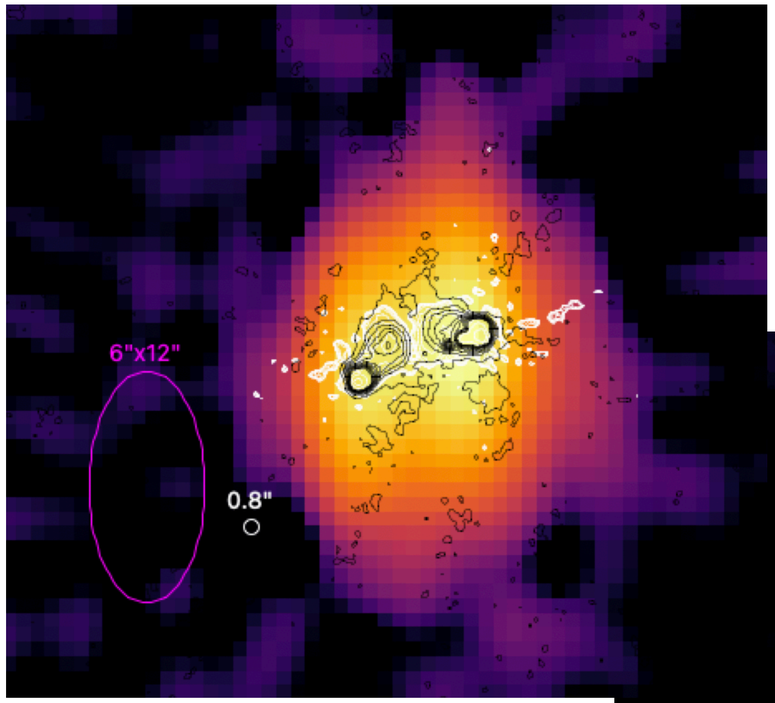
LOFAR-VLBI 144 MHz, PI: Vardoulaki
3GHz JVLA

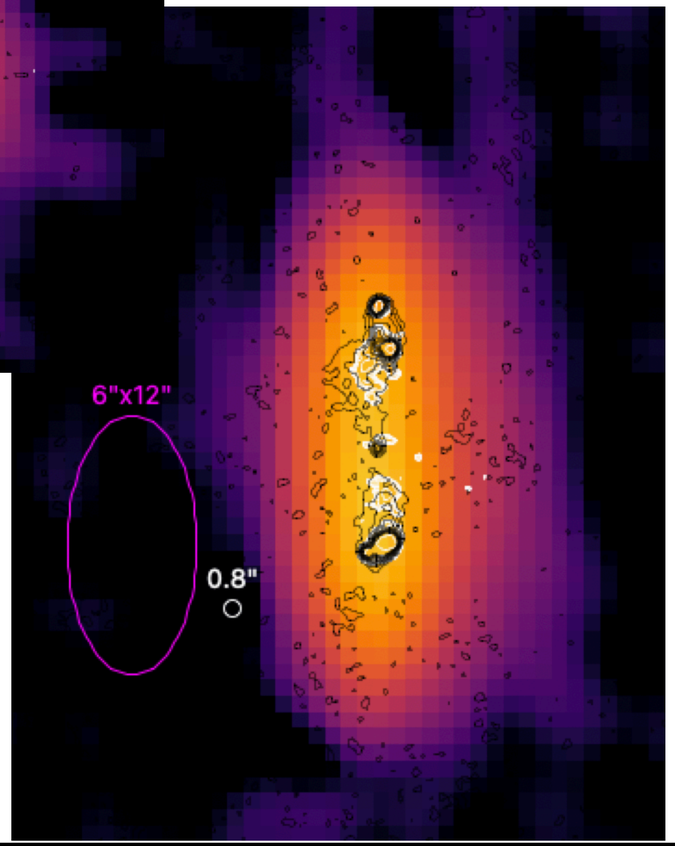


Special thanks to:
Leah Morabito, Nadia Biava, Alexander Drabent,Etienne Bonnassieux,
Roland Timmerman

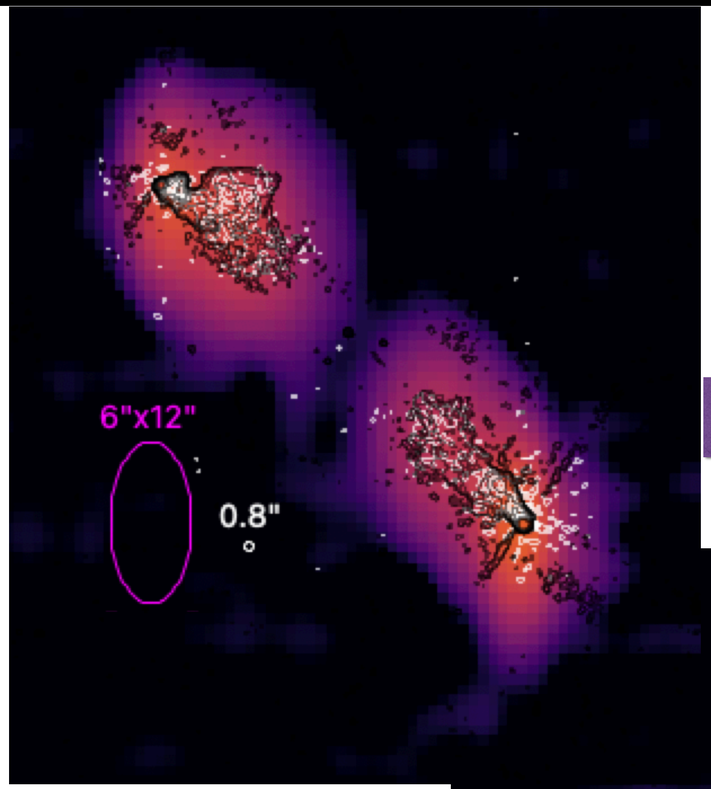
Vardoulaki+in prep.

sub-arcsecond resolution: AGN examples



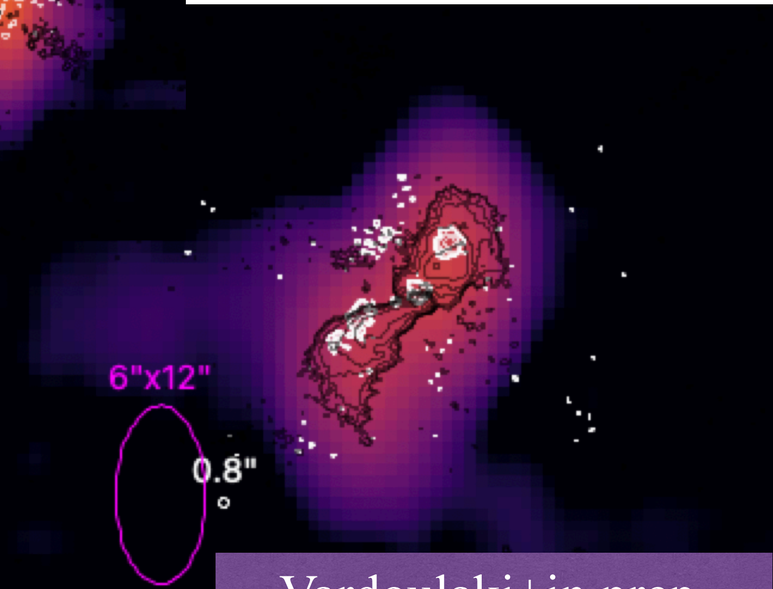


32h out of 48h



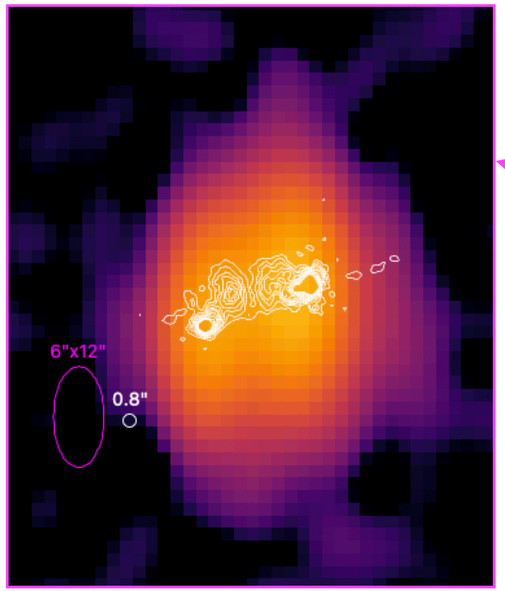
144MHz 6”x12”
144MHz 0.8”
3GHz 0.75”

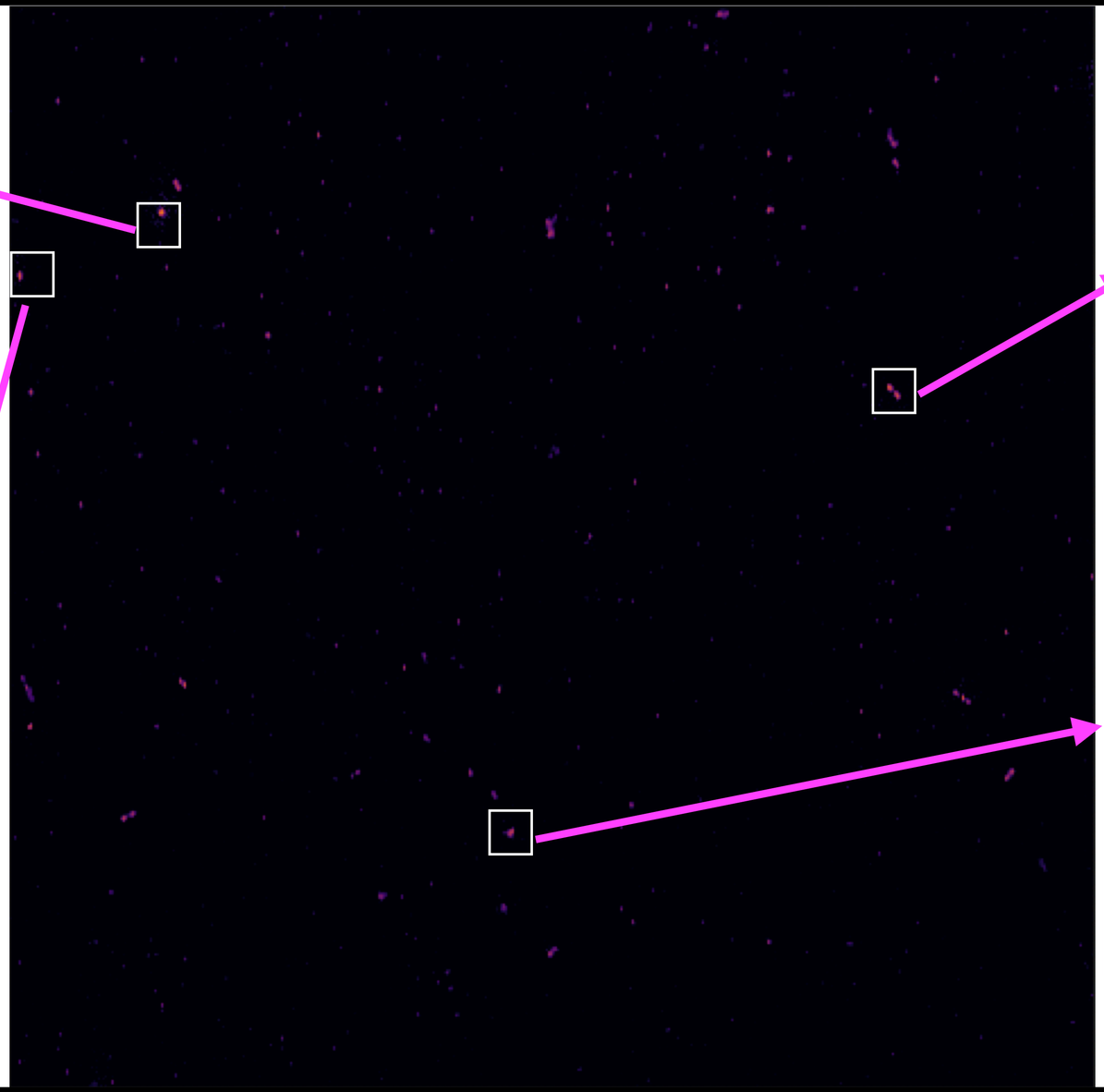
Vardoulaki+in prep.

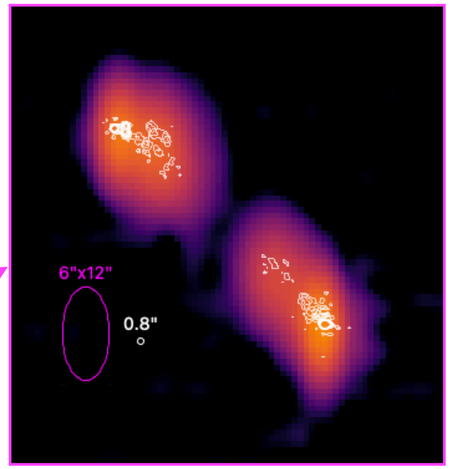


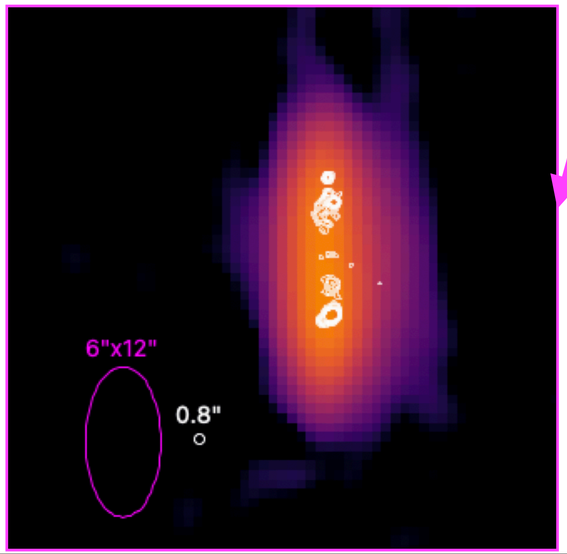
Vardoulaki+in prep.

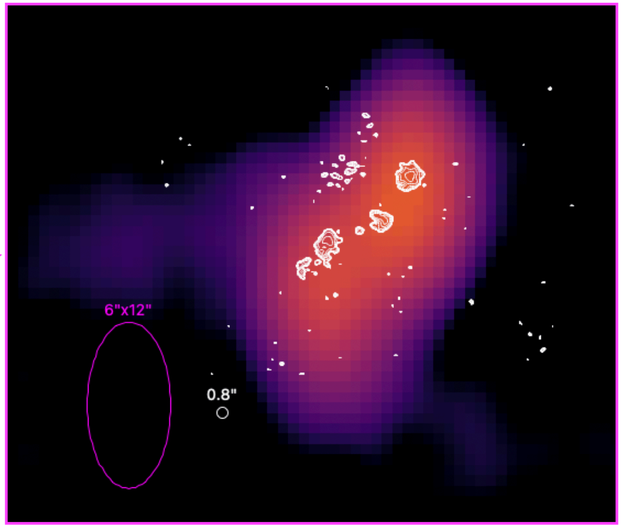
sub-arcsecond resolution: AGN examples











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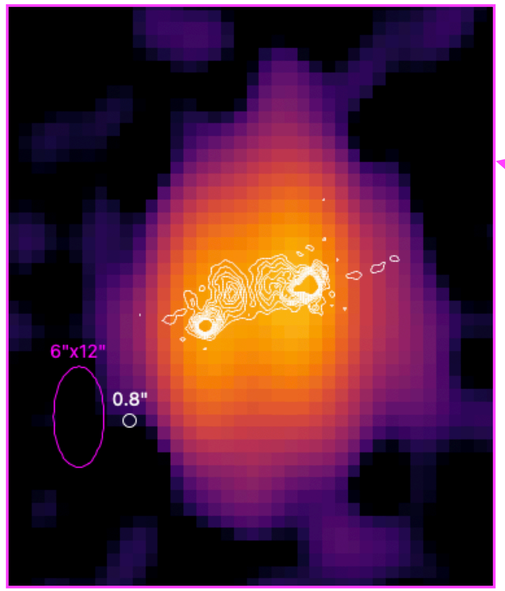
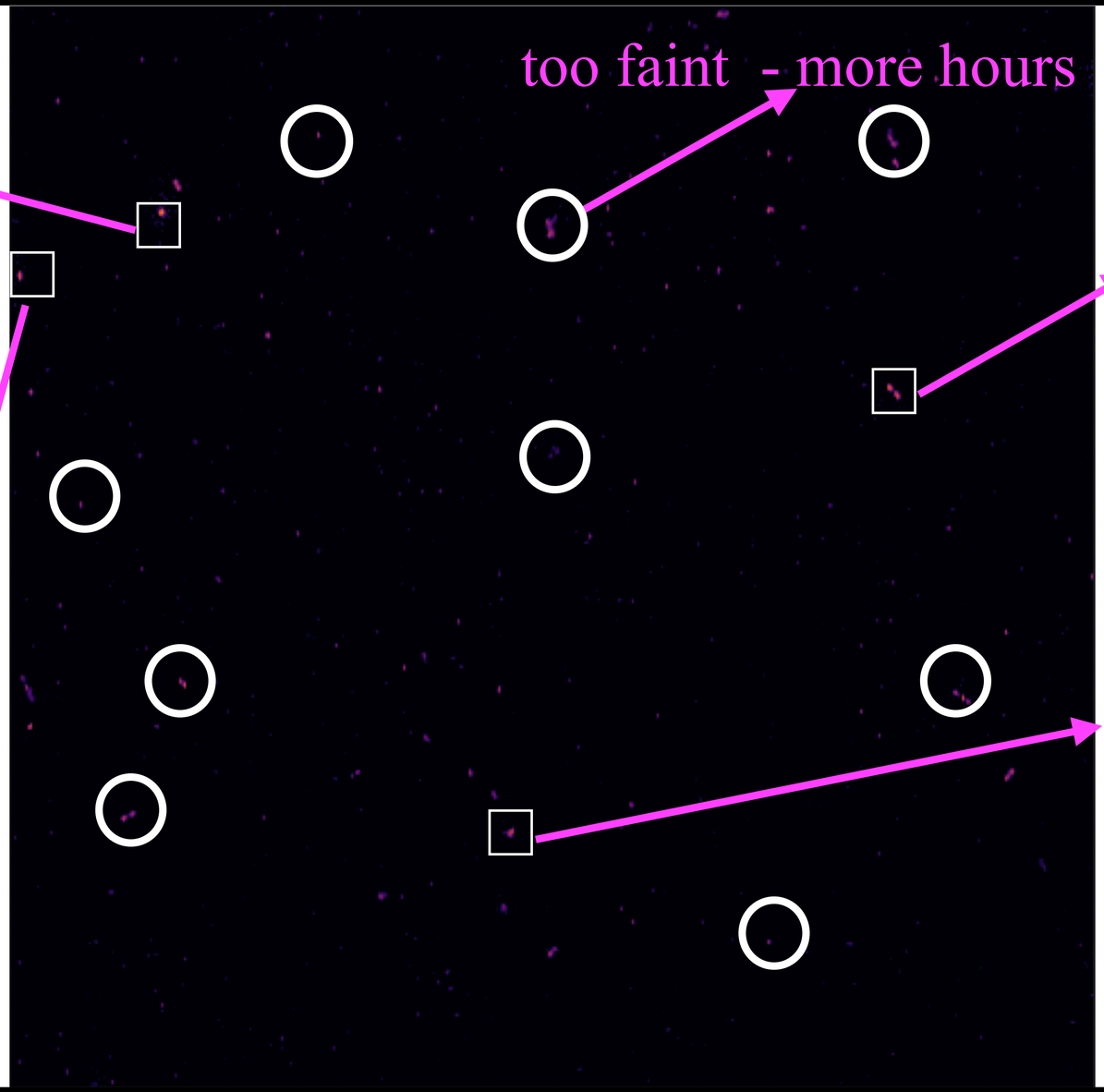
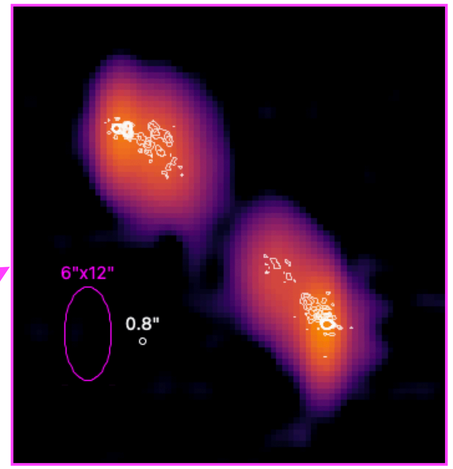
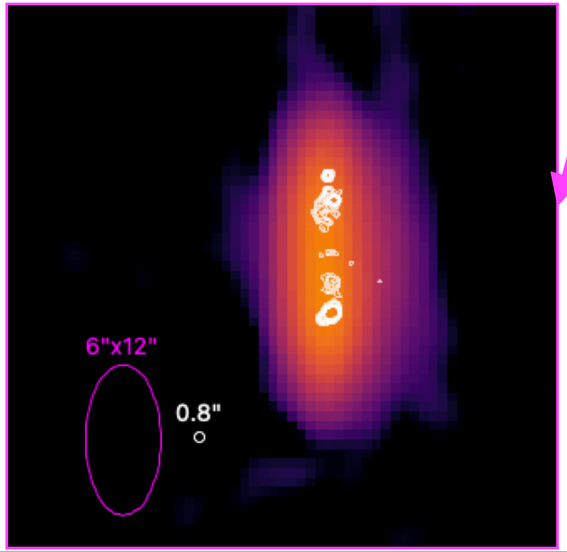
Eleni Vardoulaki
elenivard@gmail.com

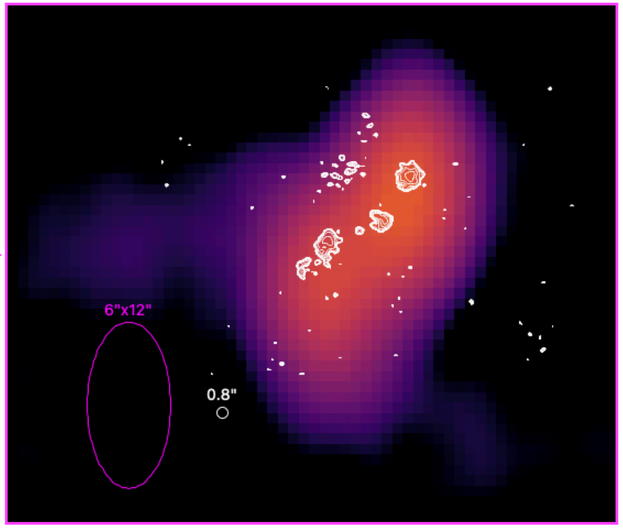
sub-arcsecond resolution: AGN examples











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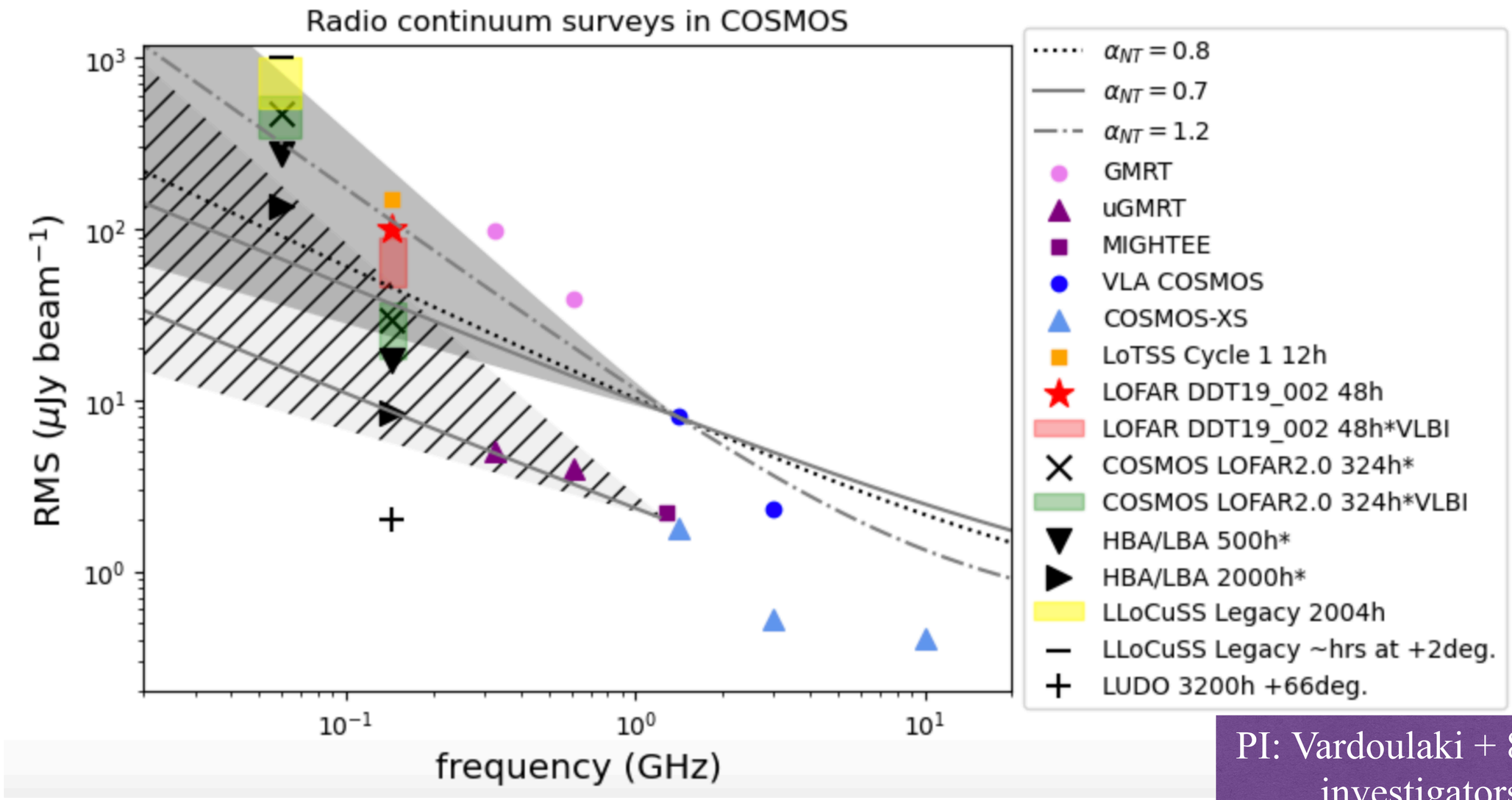
Eleni Vardoulaki
elenivard@gmail.com

LOFAR-VLBI - COSMOS+02deg

➡Next steps:
➡Improve LINC solutions
➡Reduce remaining observations (remaining 3 / 12 4h batches)
➡Obtain sub-arcsec resolution map for the COSMOS field (?)

ECOLE: LOFAR2.0 LBA+HBA 324h

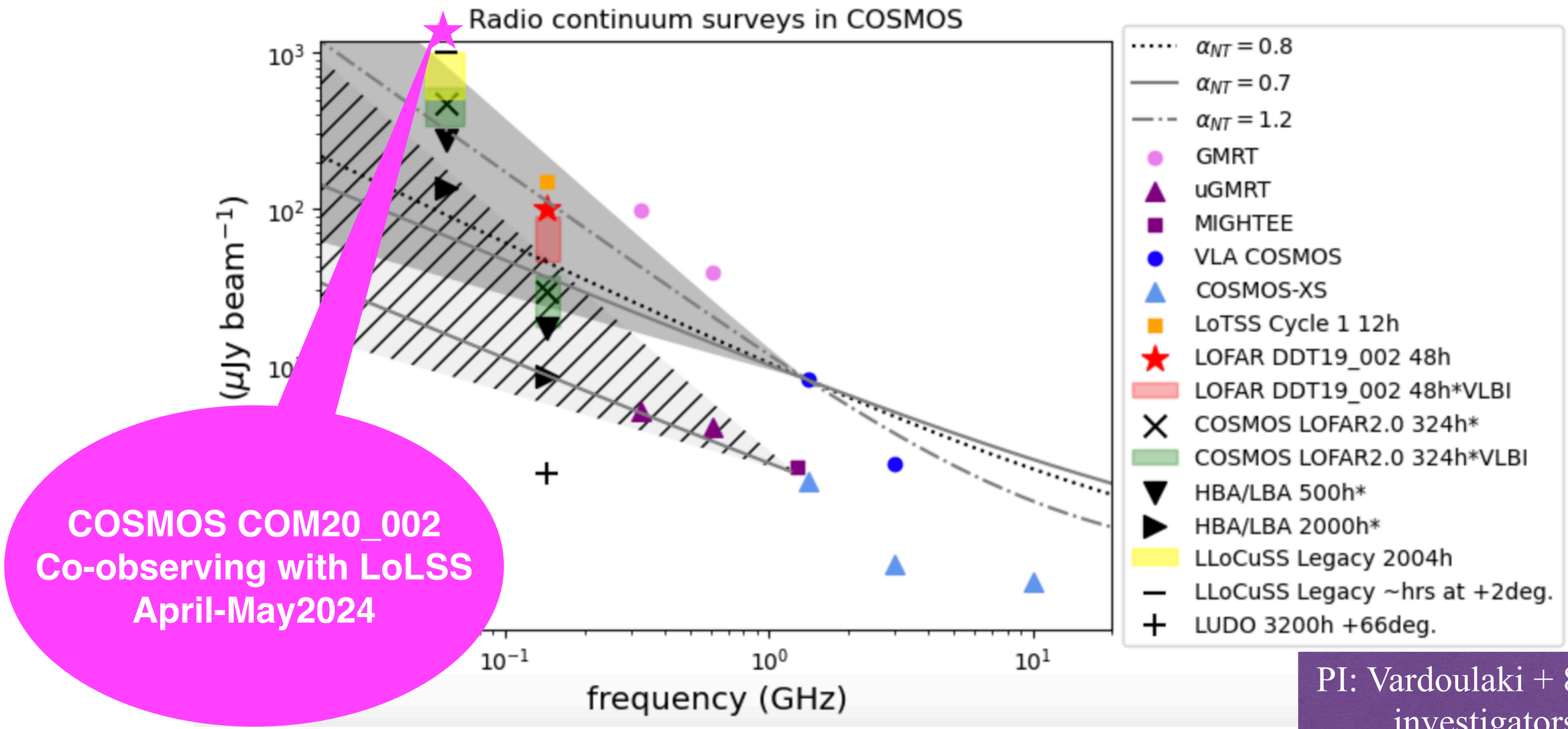


PI: Vardoulaki + 80 co-investigators

Eleni Vardoulaki

elenivard@gmail.com

ECOLE: LOFAR2.0 LBA+HBA 324h



COSMOS COM20_002
Co-observing with LoLSS
April-May2024

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Eleni Vardoulaki
elenivard@gmail.com

ECOLE: LOFAR2.0 LBA+HBA 324h

Answering questions only possible by a multi-frequency & multi-wavelength survey: COSMOS

➡ Is the 'radio continuum emission - star formation rate' calibration universal through cosmic time?
➡What is the significance of dust-obscured galaxies as probed at radio frequencies?
➡What is the interplay between faint radio AGN and their multi-scale environment?
➡What is the abundance and feeling mechanisms of z>6 radio-loud AGN
➡What are the physical mechanisms driving diffuse radio emission galaxy clusters/ groups?

◉*Ancillary science*: NIR-dark Galaxies; Transient Science; Dark Matter Searches; etc

PI: Vardoulaki + 80 co-investigators

Take home

COSMOS is awesome:

high quality multi-wavelength and multi-frequency observations probing multi-scale Universe

- Sub-arcsec resolution and good sensitivity: key to studying physical properties, disentangling, diffuse emission in groups and high-z discoveries
- Proposed LOFAR2.0 ECOLE, HBA+LBA observations of COSMOS