The LOFAR Two Meter Sky Survey(s)

LoTSS wide & deep

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Observatoire de Paris – GEPI/USN
Rhodes University

for the LOFAR Surveys KSP

11/03/2021

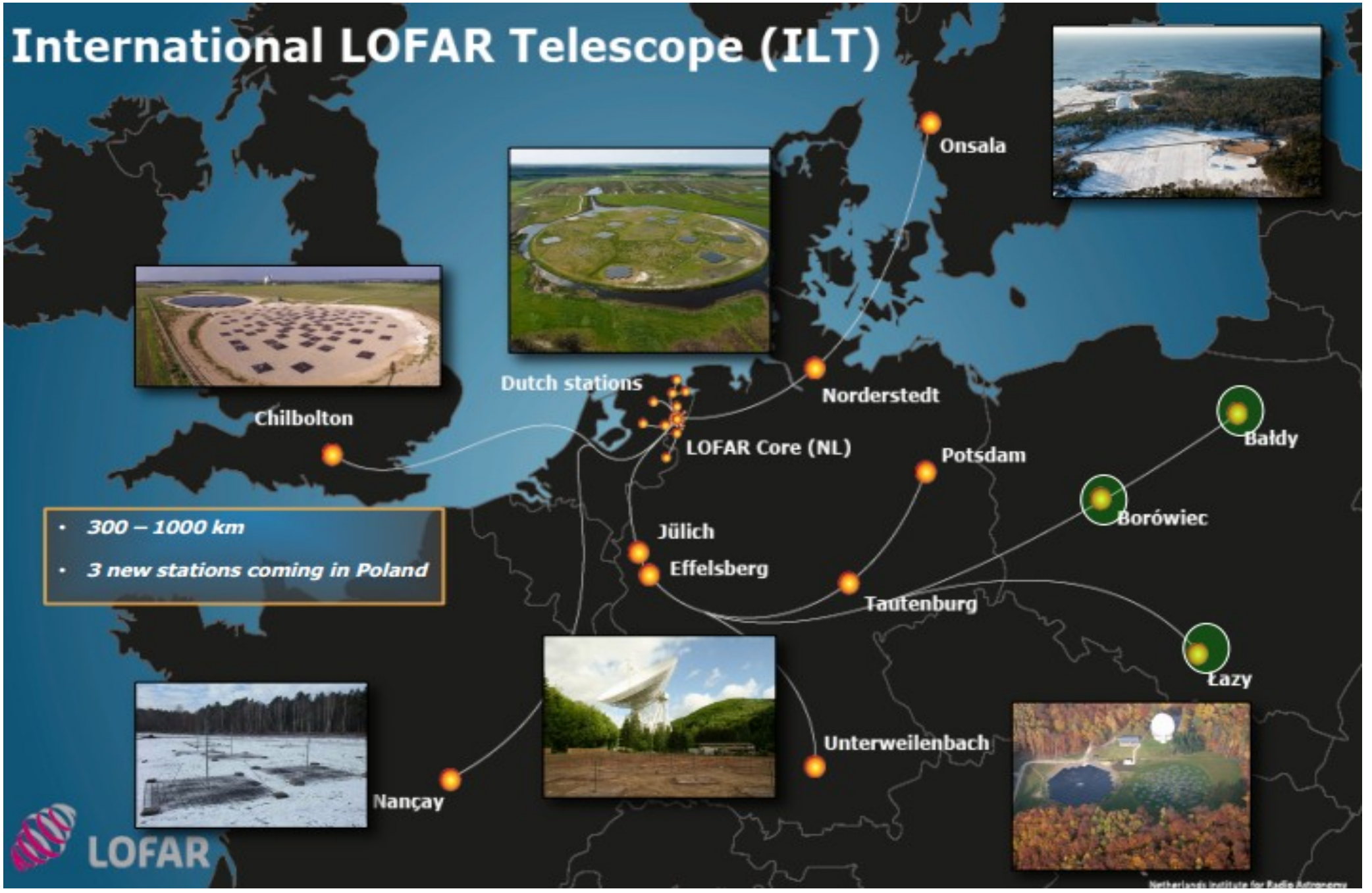
Many thanks to Tim Shimwell for many slides !!!

LOFAR

30MHz - 250MHz

An SKA pathfinder

LOFAR


International LOFAR Telescope (ILT)
Onsala
Dutch stations
Chilbolton
Norderstedt
LOFAR Core (NL)
Potsdam
Bałdy
Borówiec
Jülich
Effelsberg
Tautenburg
Łazy
Unterweilenbach
Nançay
• 300 – 1000 km
• 3 new stations coming in Poland
LOFAR

LoTSS

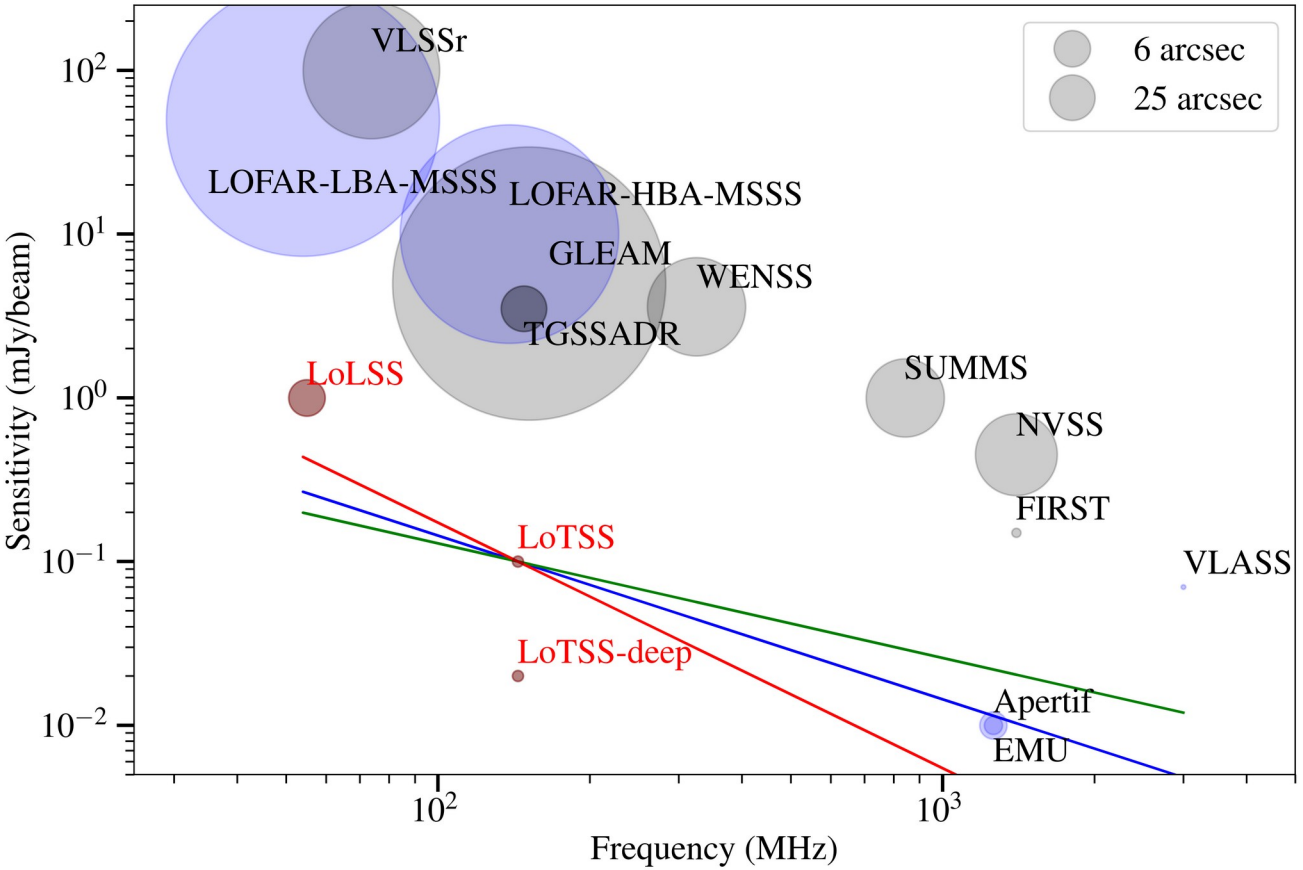
~16,000hrs of LOFAR HBA observations.

120-168MHz, 6” resolution, 0.1mJy/beam noise.

~55% observed.

Always observing with full international array

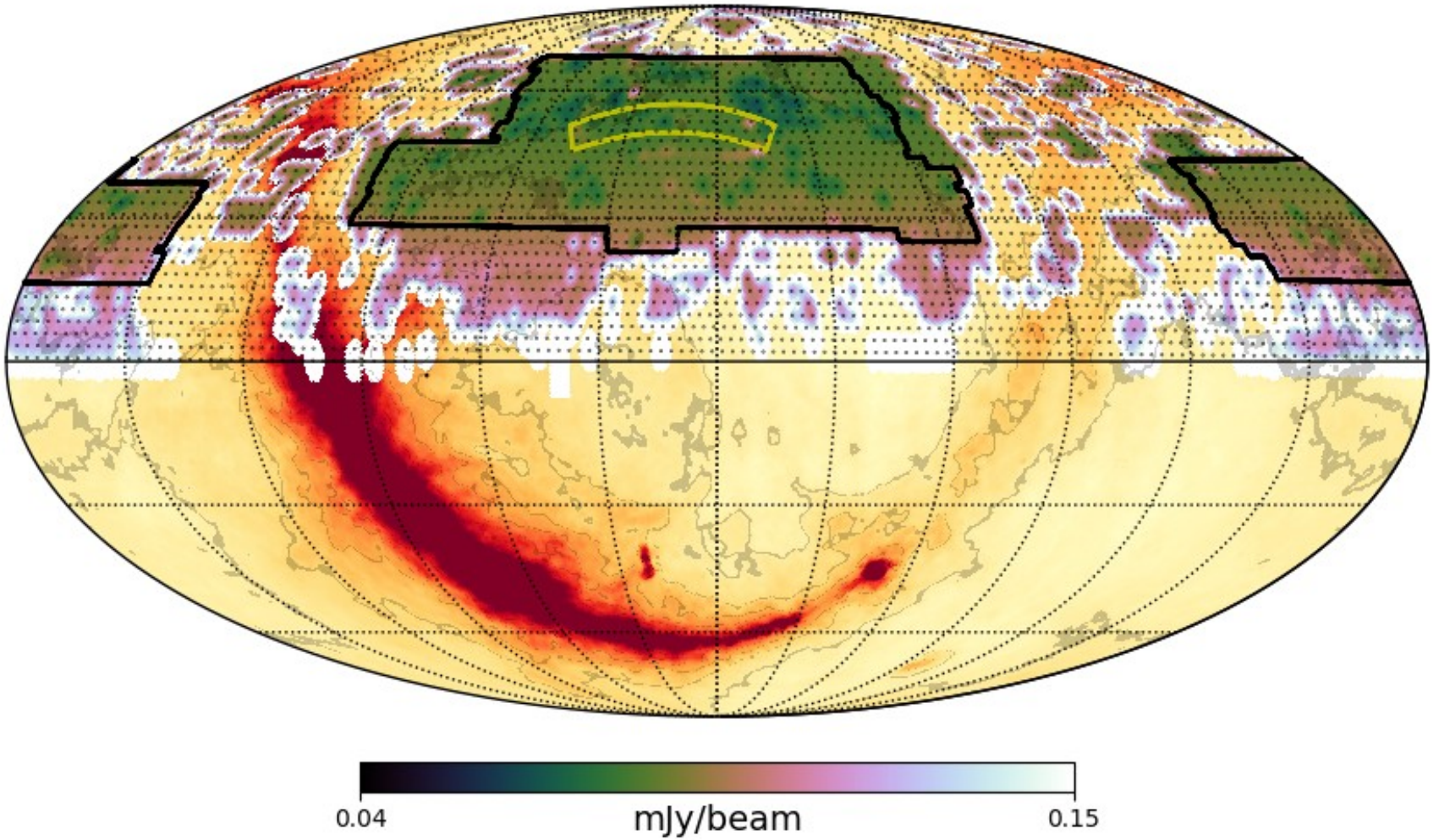
Aiming to complete observations in ~3-4 years and stay relevant even into the SKA era.



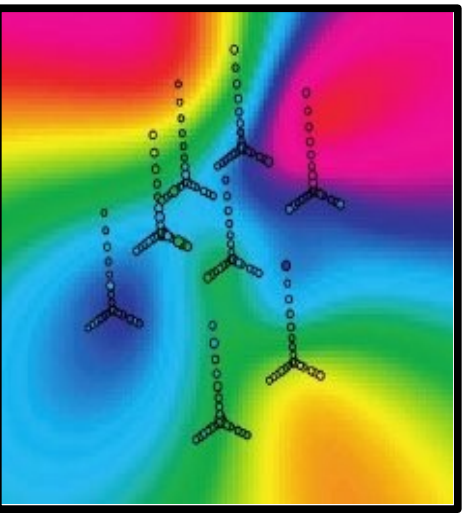
Green $\alpha = -0.7$, blue $\alpha = -1.0$, red $\alpha = -1.5$

LoTSS: Shimwell et al., 2017 & 2019

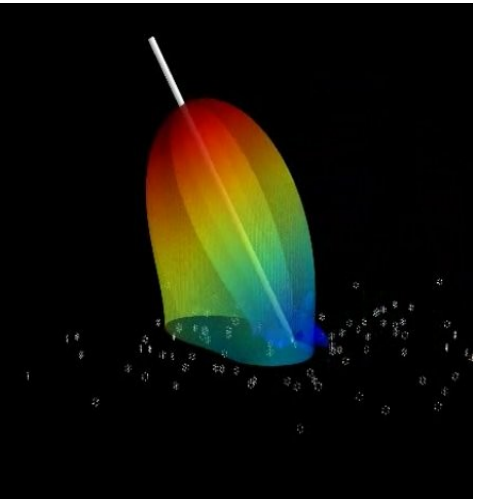
LoTSS data release 2 (LoTSS-DR2)



LoTSS-DR1 (outlined in yellow) is fully public. LoTSS-DR2 (outlined in black) is coming soon. This contains **4,395,448** radio components in 5634 square degrees. It consists of 841 different pointings and a total of 7.6PB of data from 26 different projects were processed using ~9million cpu hours. LoTSS-DR2 is 26% of the Northern sky.



Ionospheric isturbance + Faraday rotation



Station lobes

8 hours integration with LOFAR@~150MHz

Without DDE correction

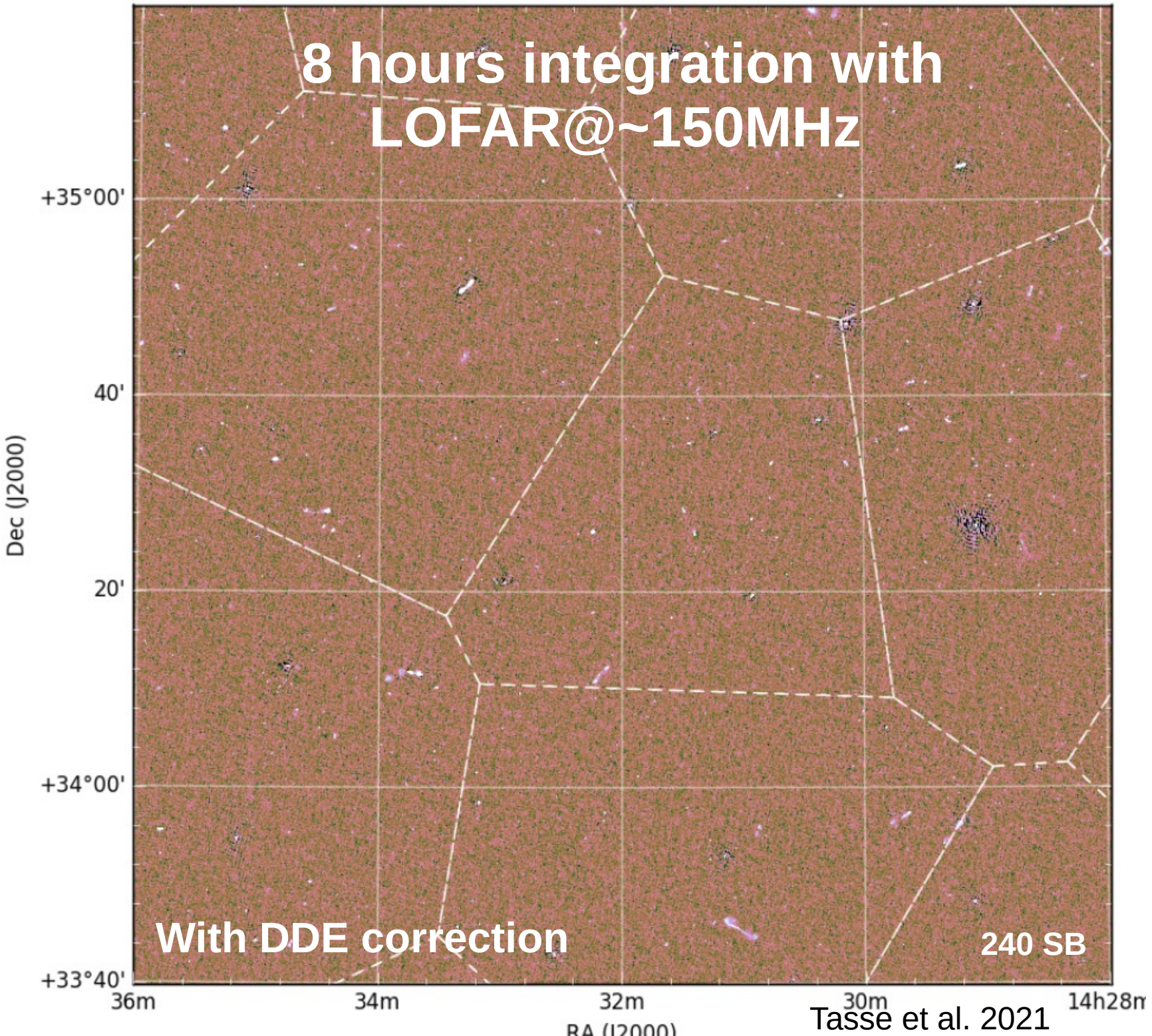
60 SB

+33°40'

36m 34m 32m 30m 14h28m

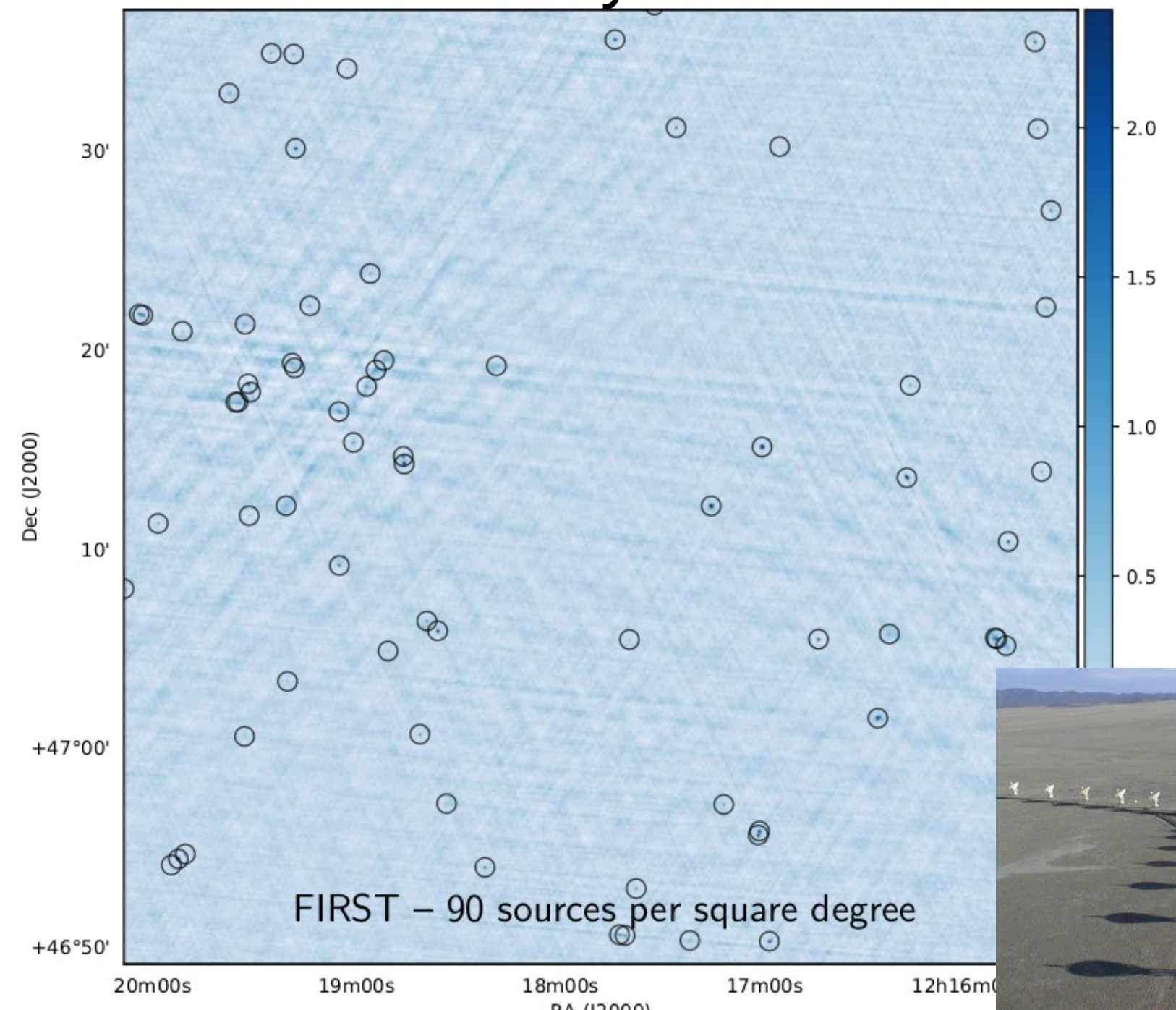
RA (J2000)

Tasse et al. 2021



Tasse et al. 2021

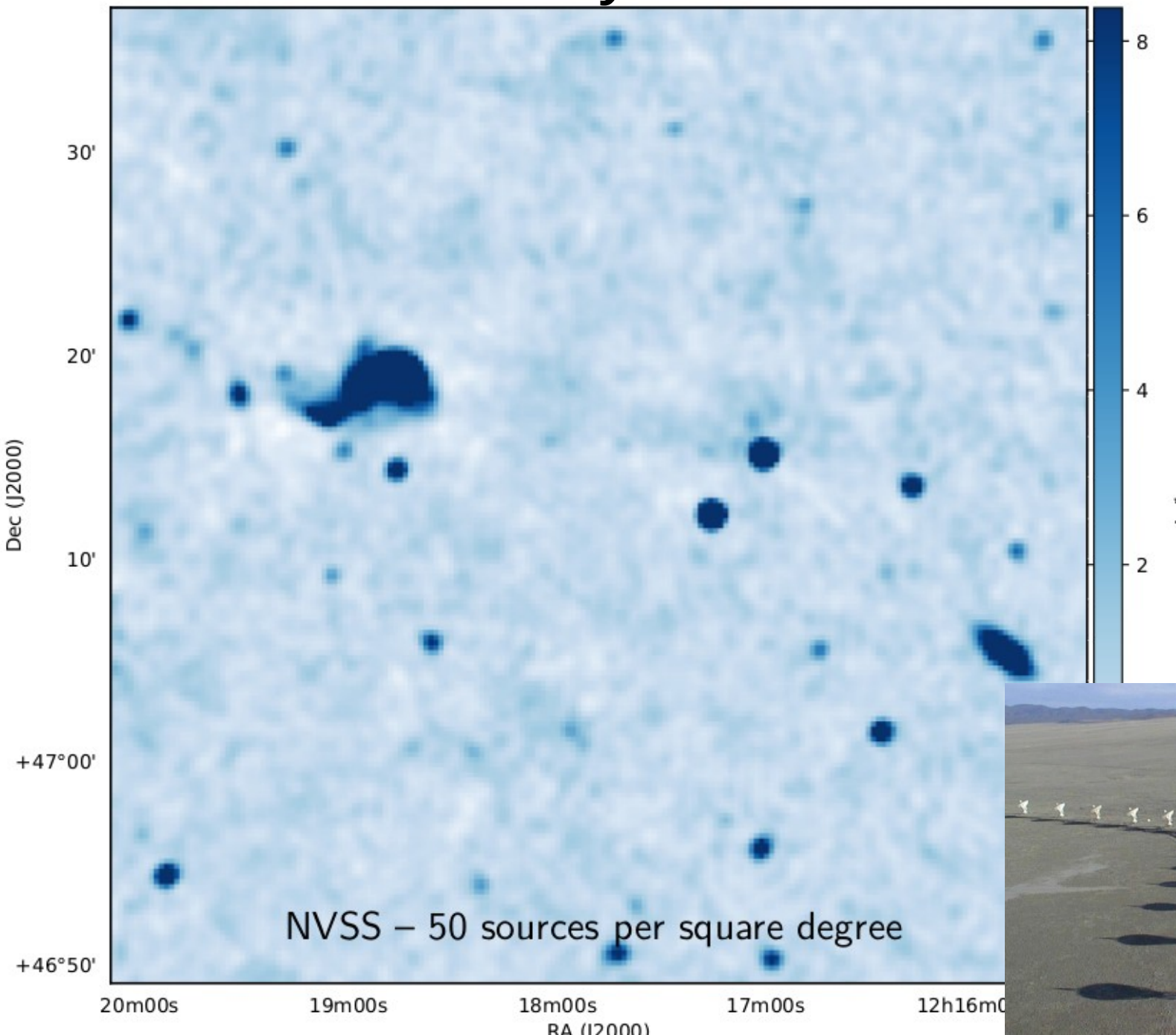
LOTSS – Comparison with existing surveys



Extended configuration

VLA

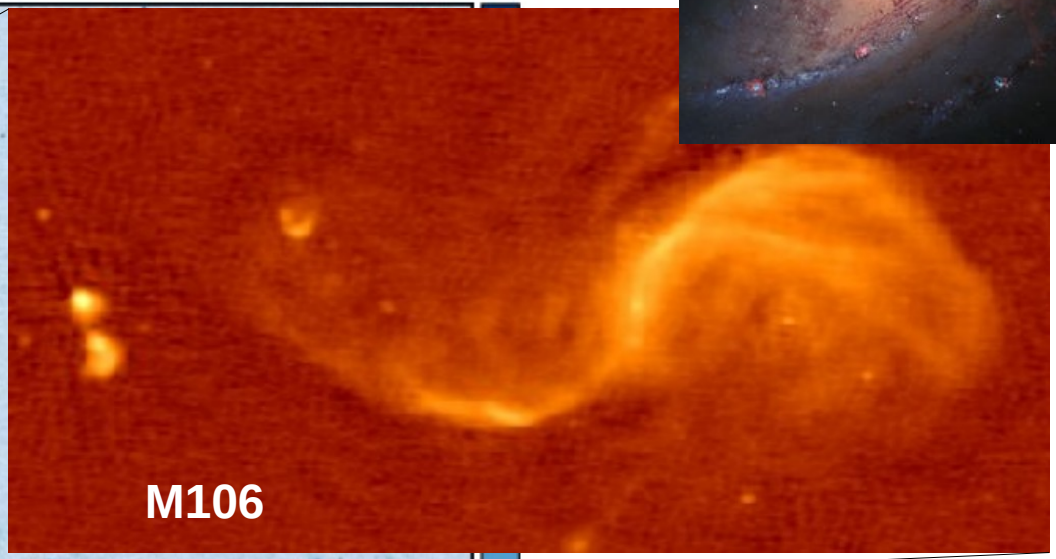
LOTSS – Comparison with existing surveys

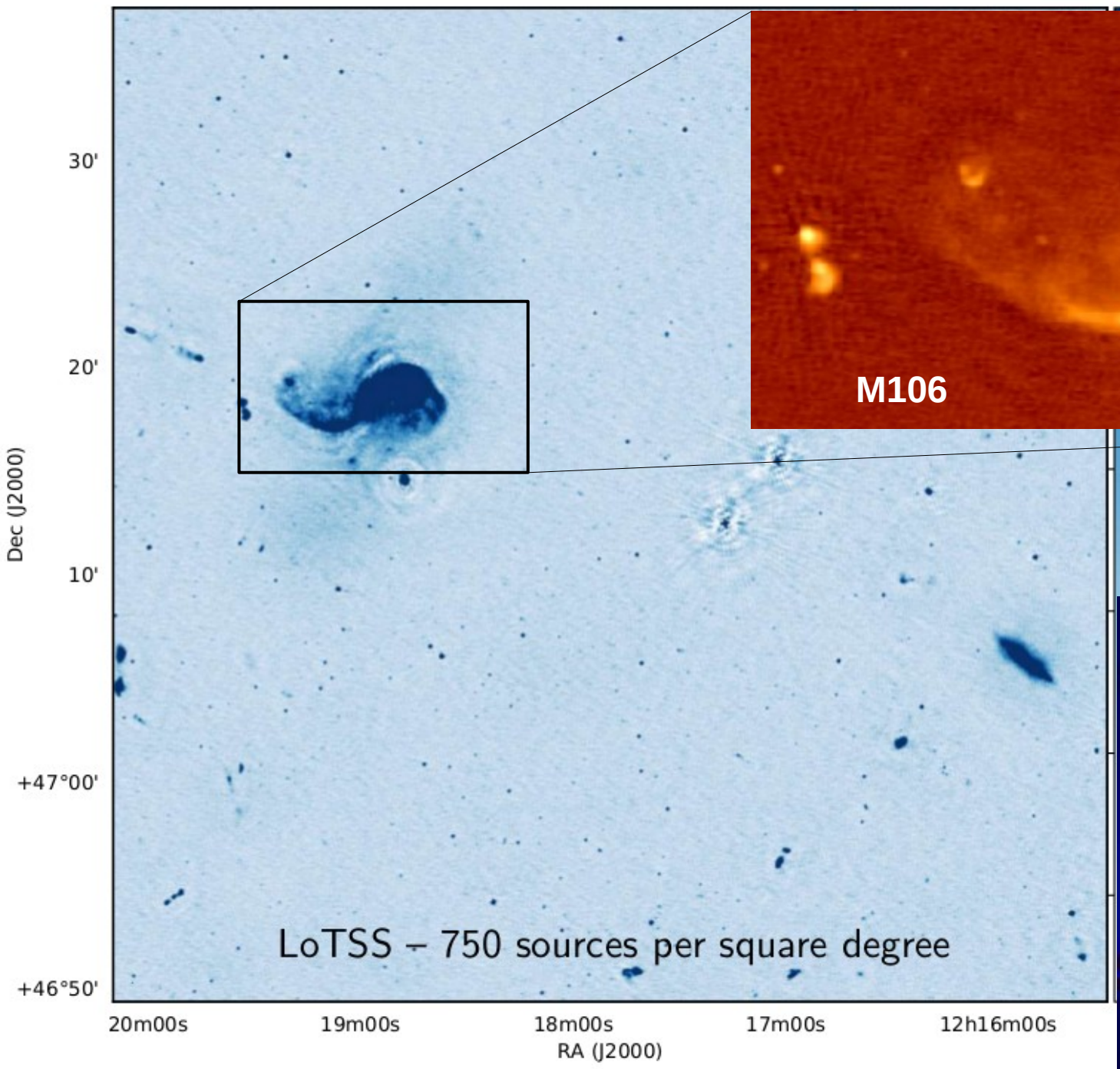


Compact configuration

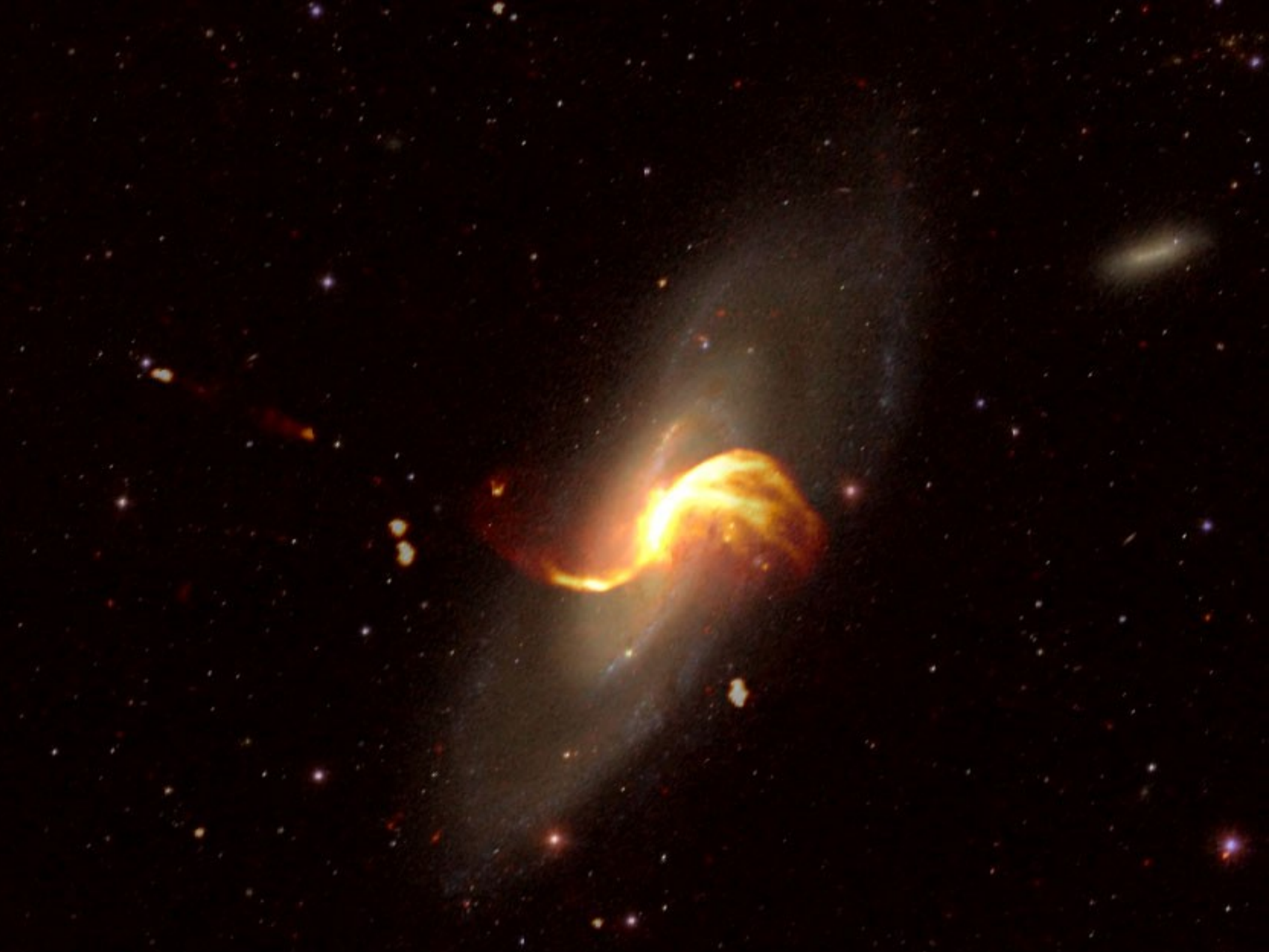
VLA

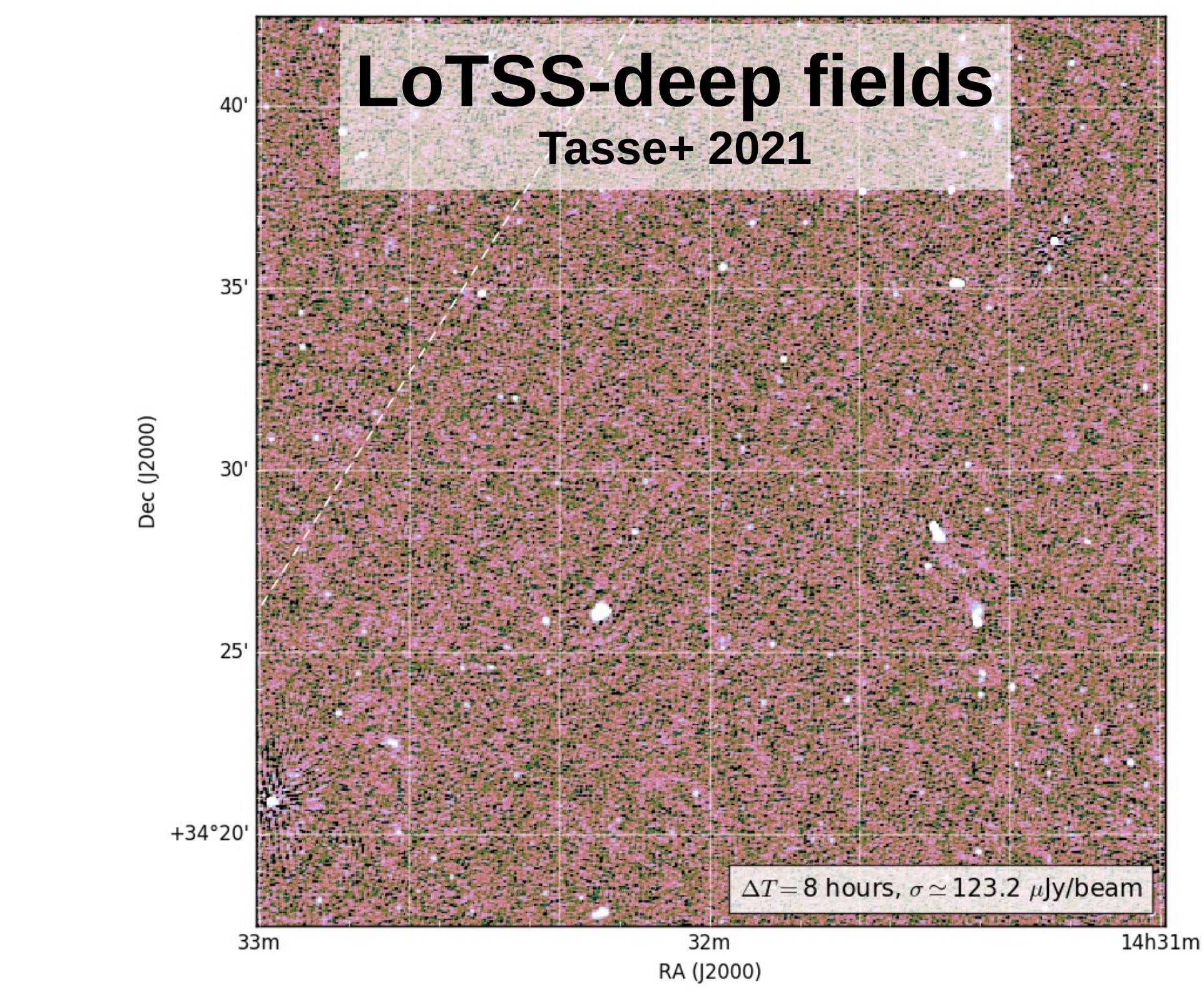
LOTSS – Comparison with existing survevs

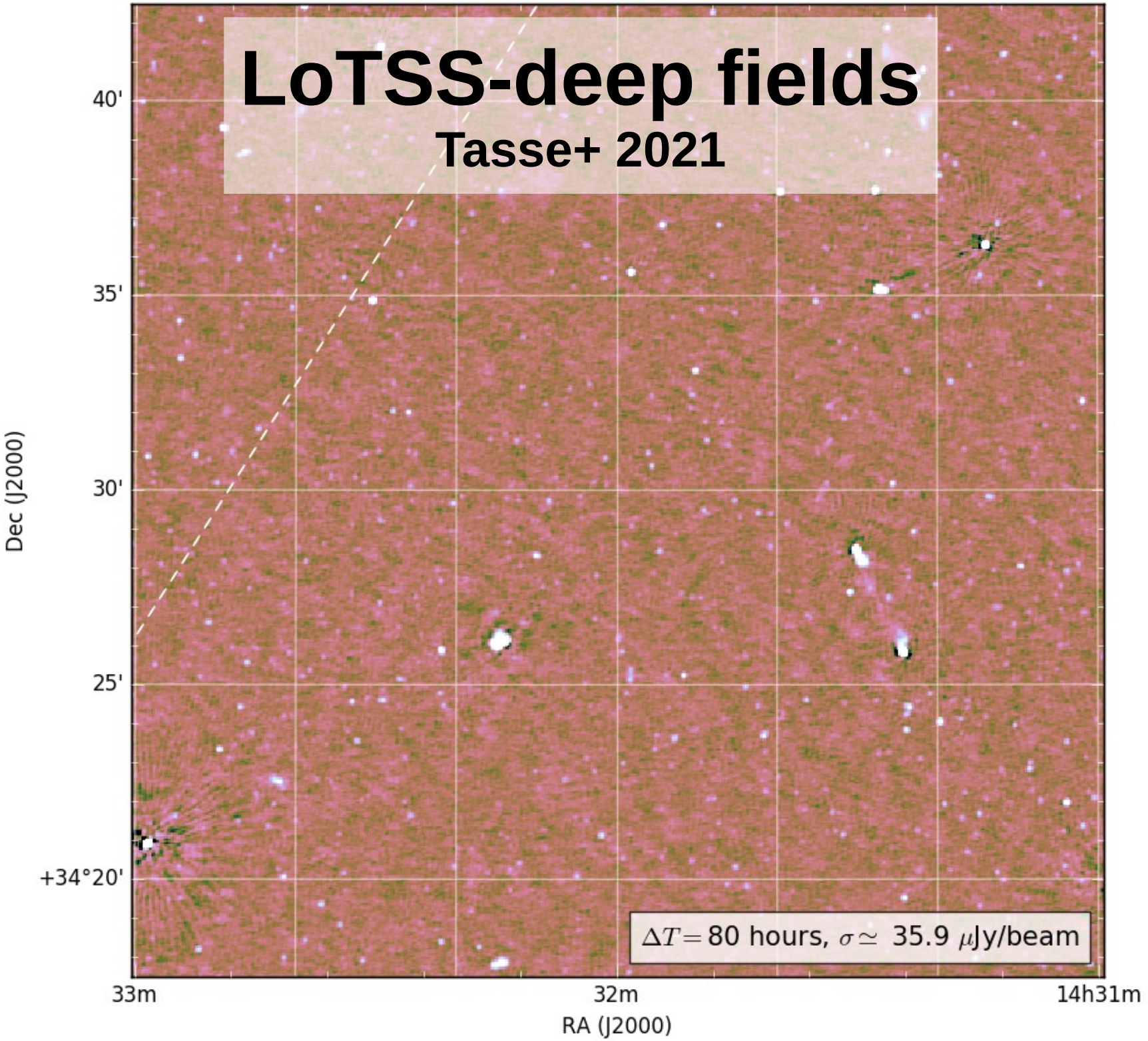


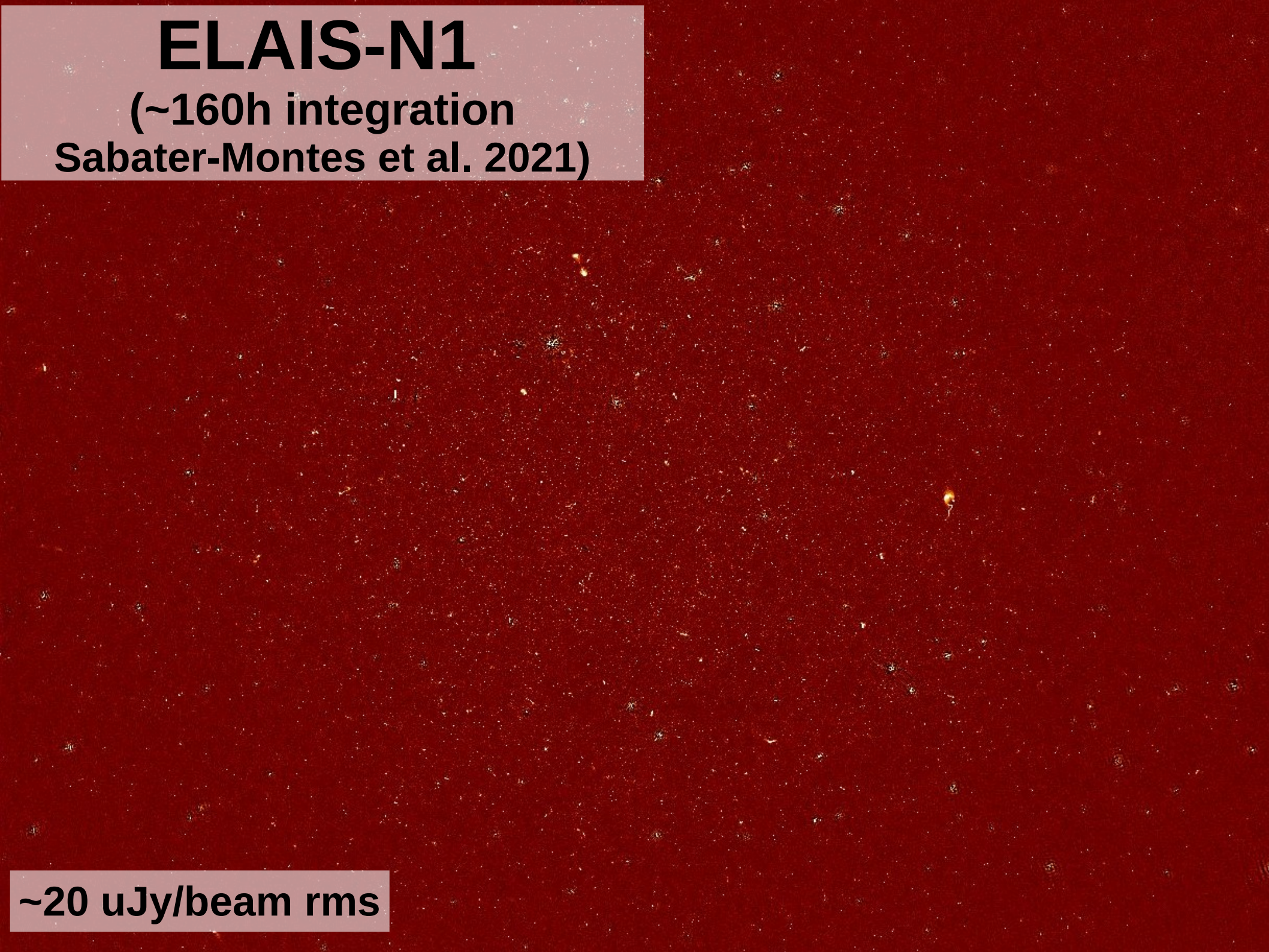


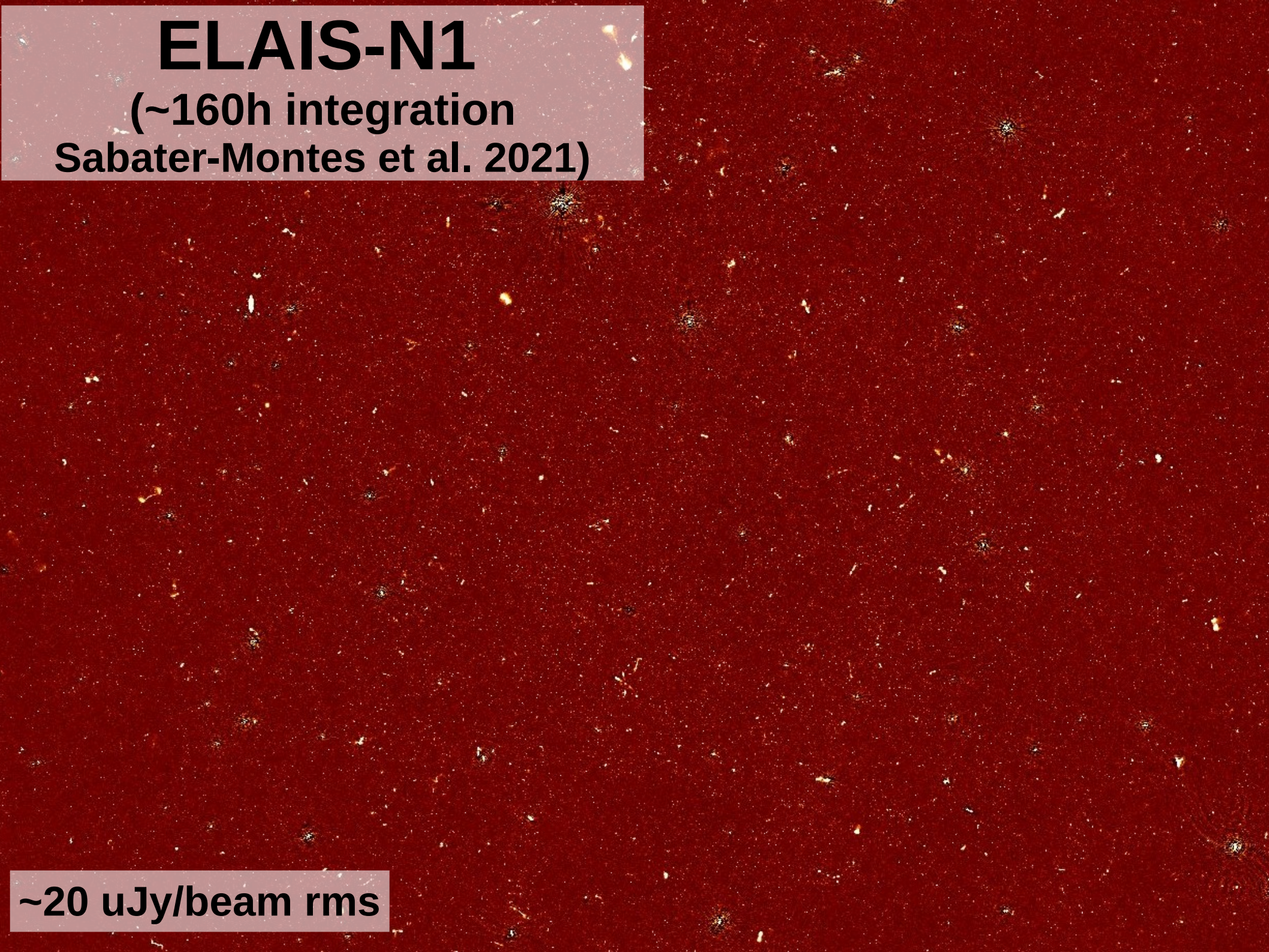
LOFAR




LoTSS-deep fields
Tasse+ 2021
40'
35'
30'
25'
+34°20'
Dec (J2000)
33m
32m
14h31m
RA (J2000)
$\Delta T = 8$ hours, $\sigma \simeq 123.2$ μJy/beam


LoTSS-deep fields
Tasse+ 2021
40'
35'
30'
25'
+34°20'
Dec (J2000)
33m
32m
14h31m
RA (J2000)
$\Delta T = 80$ hours, $\sigma \simeq$ 35.9 μJy/beam


ELAIS-N1
(~160h integration
Sabater-Montes et al. 2021)
~20 uJy/beam rms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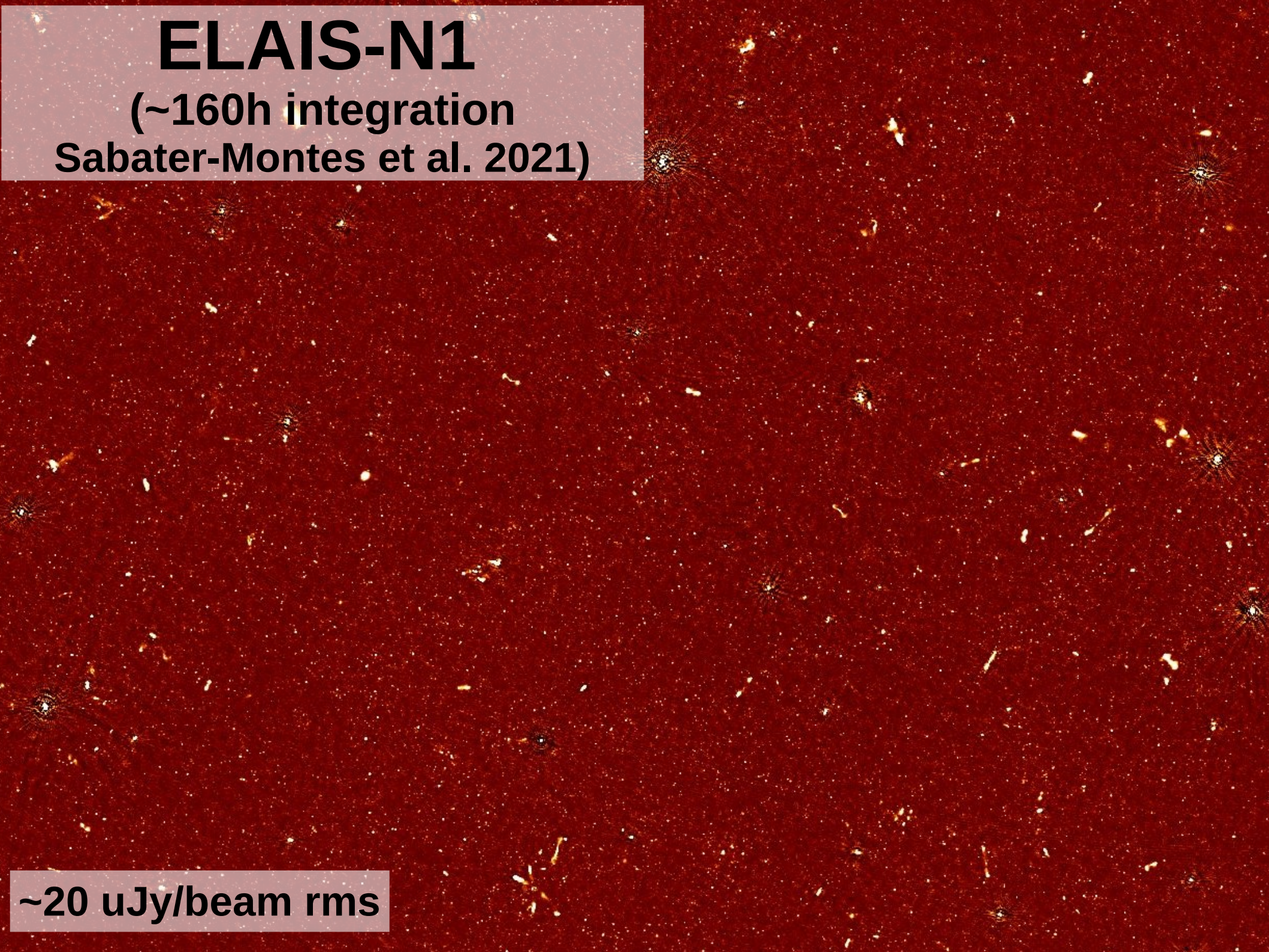
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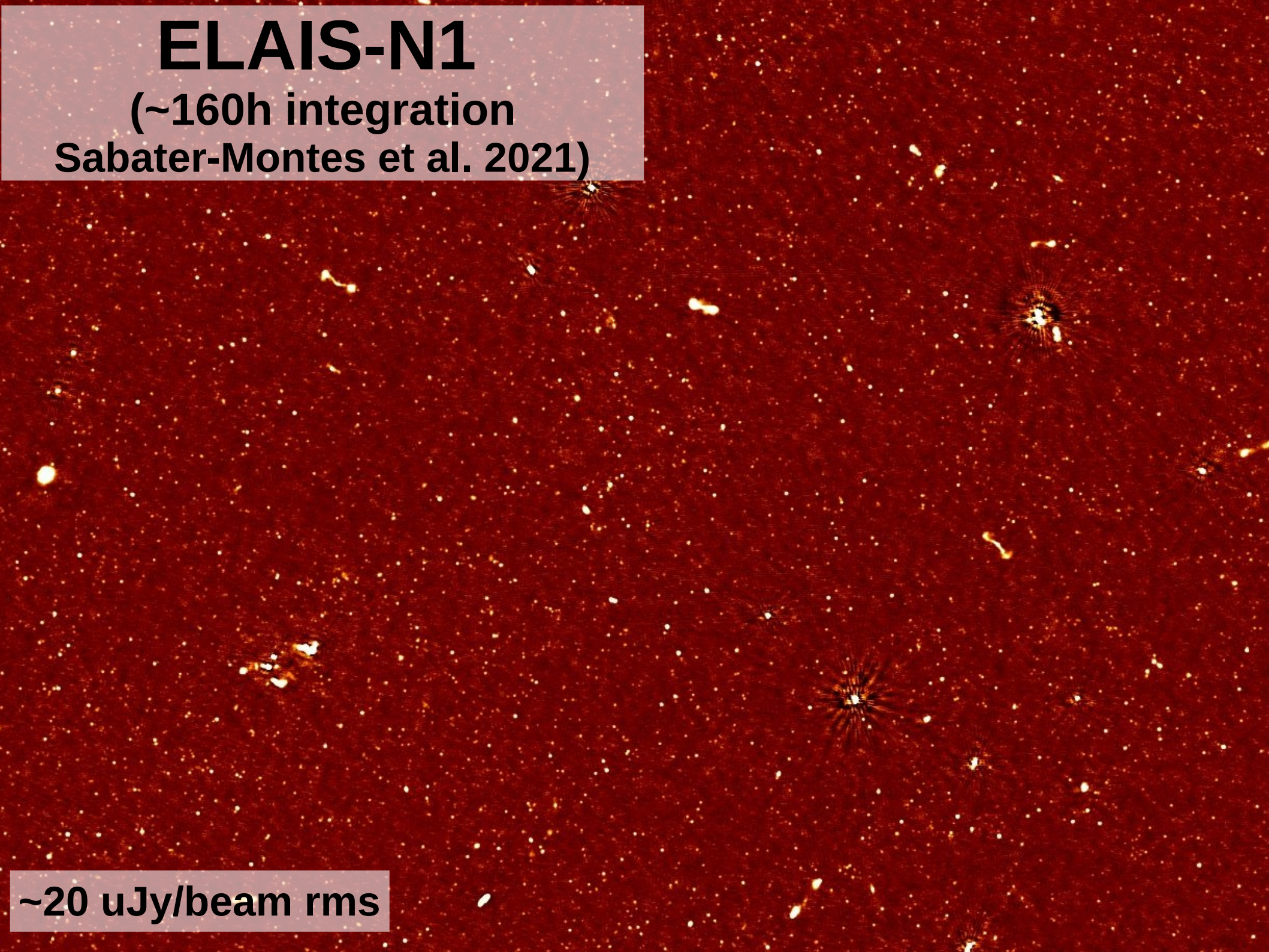
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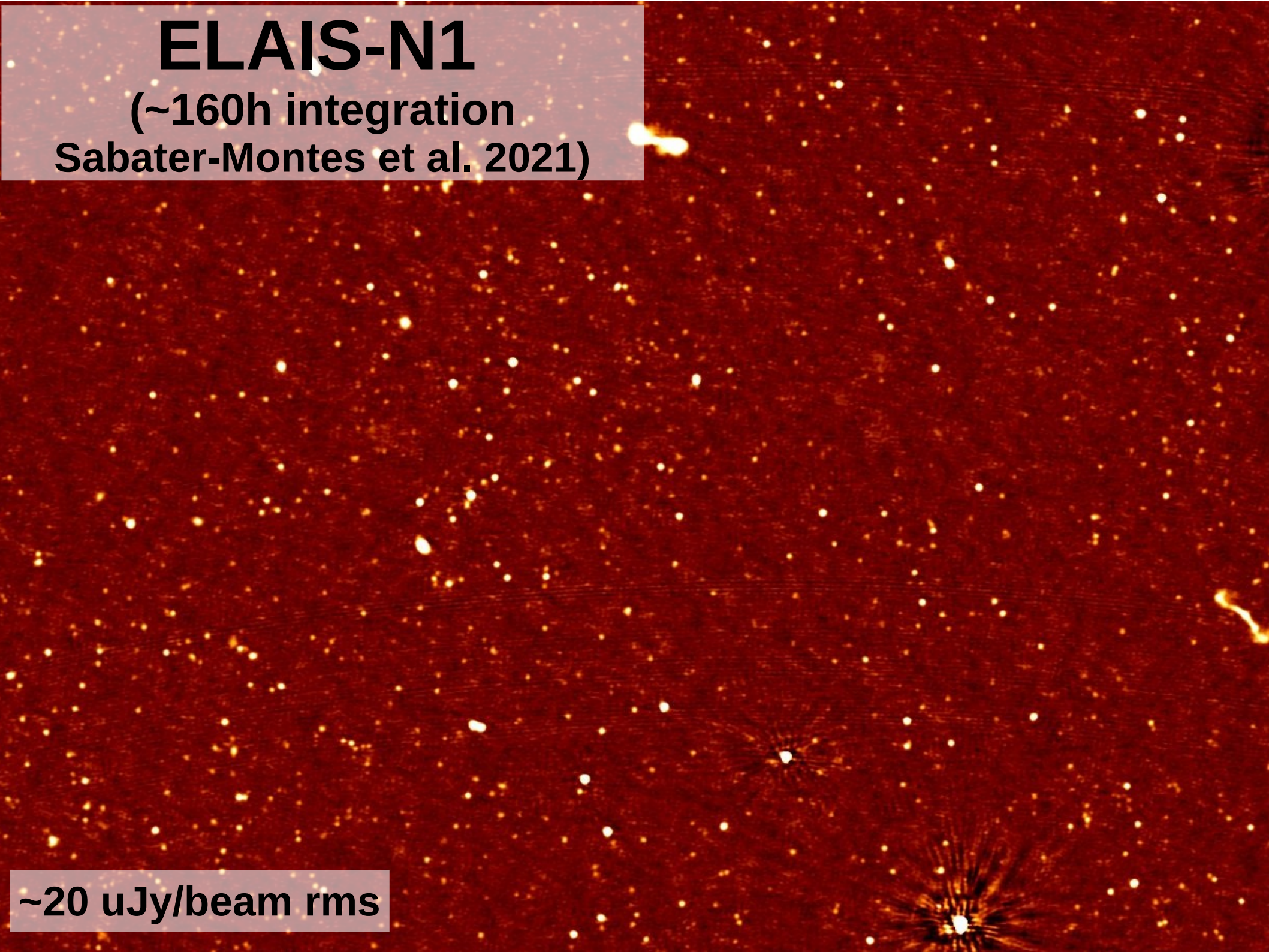
ELAIS-N1
(~160h integration
Sabater-Montes et al. 2021)
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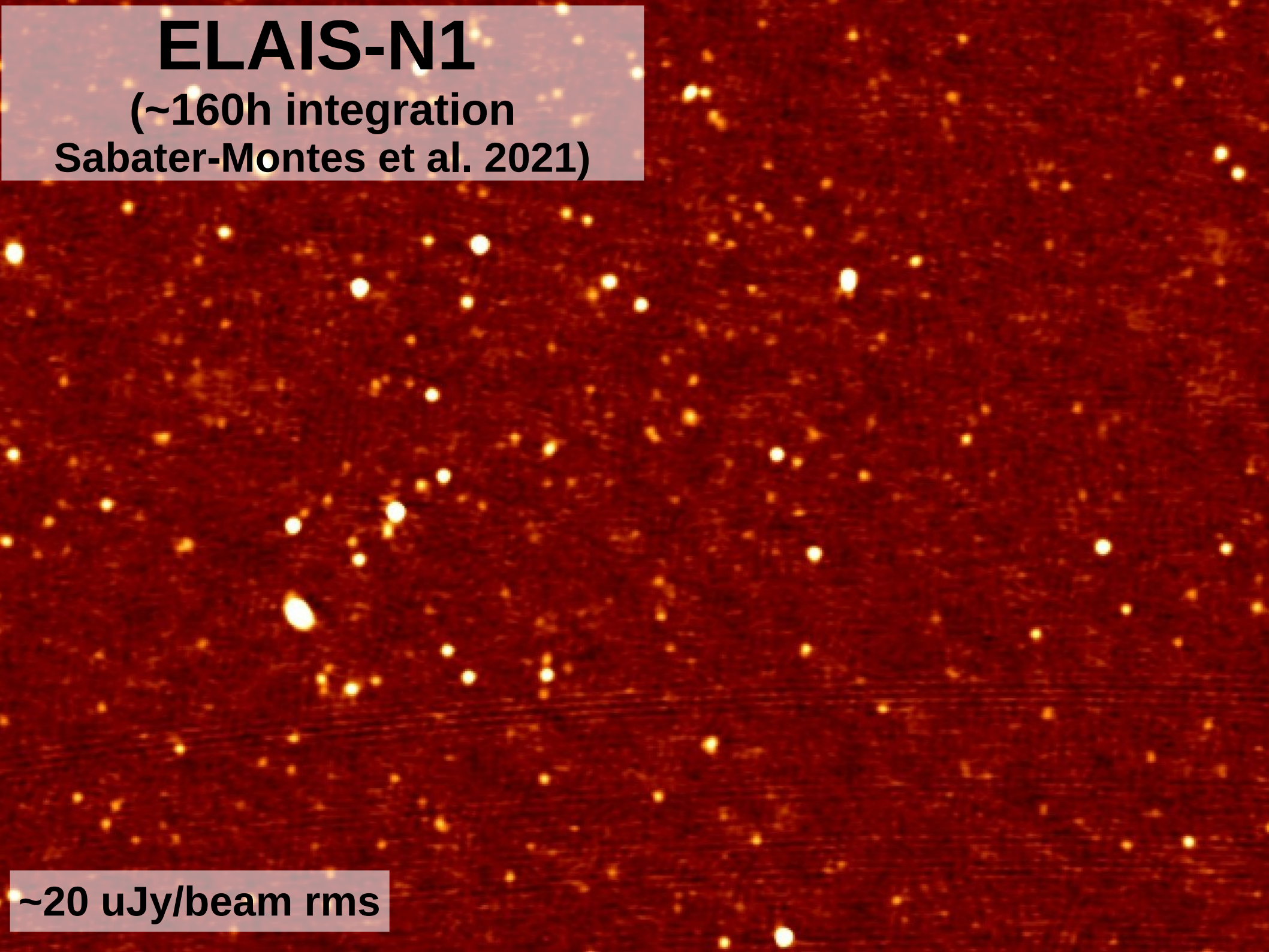
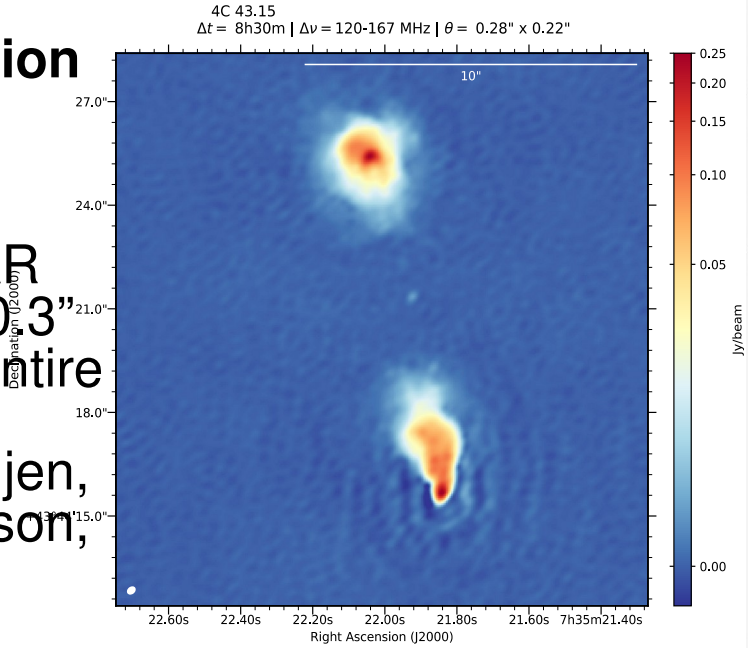

ELAIS-N1
(~160h integration
Sabater-Montes et al. 2021)
~20 uJy/beam rms

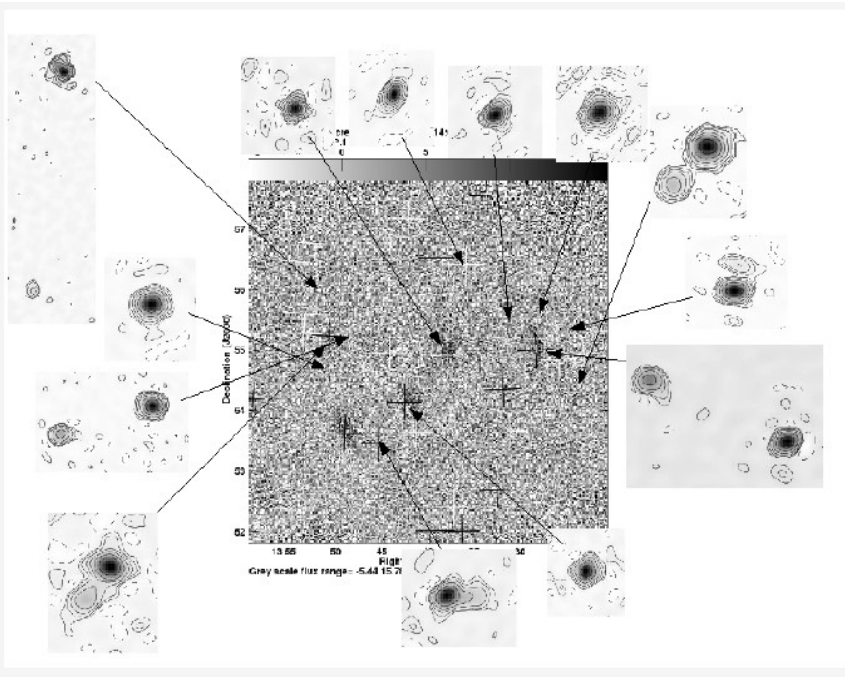
Furthering the LOFAR surveys

Optical followup — WEAVE-LOFAR (Smith+ 2016) will use WEAVE on the WHT and soon begin obtaining spectra for ~a million LOFAR sources.

Radio recombination lines — LoTSS data have sufficient frequency resolution for spectral line work and the data are being analysed to search for RRLs (e.g. Emig+ 2018).

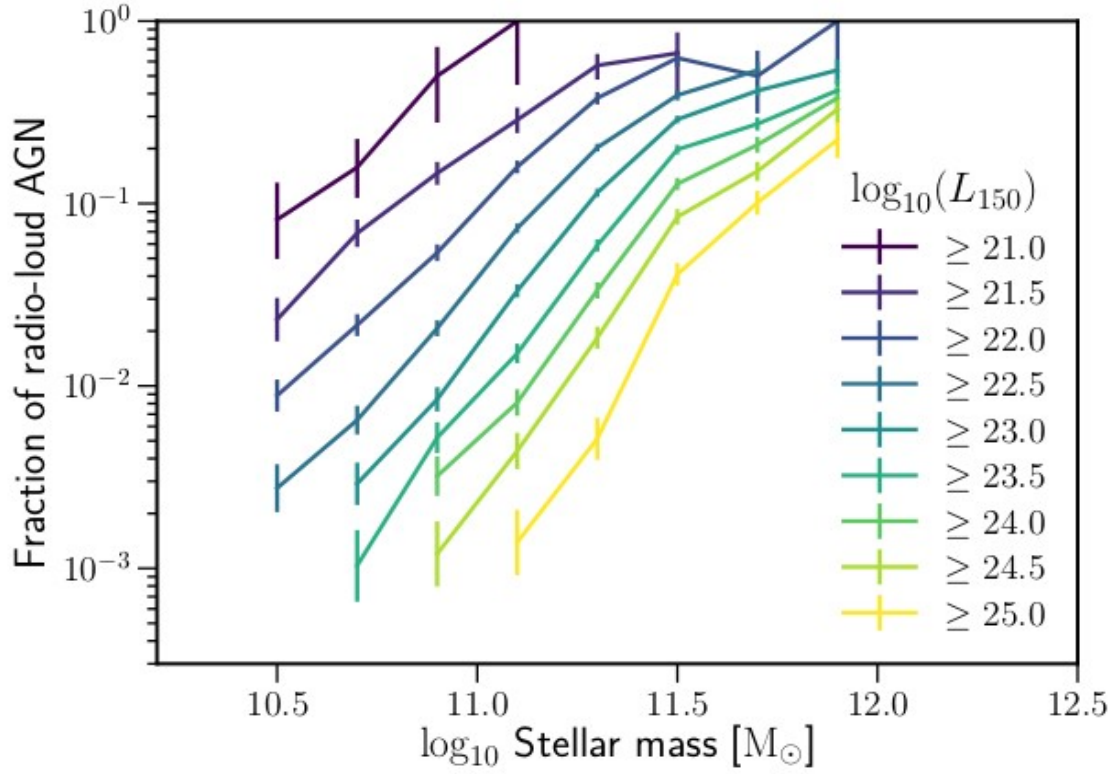
0.3arcsec resolution — LOFAR surveys data are recorded using the full international LOFAR array allowing for 0.3” imaging over the entire surveyed region (images from Sweijen, van Weeren, Jackson, Morabito+)



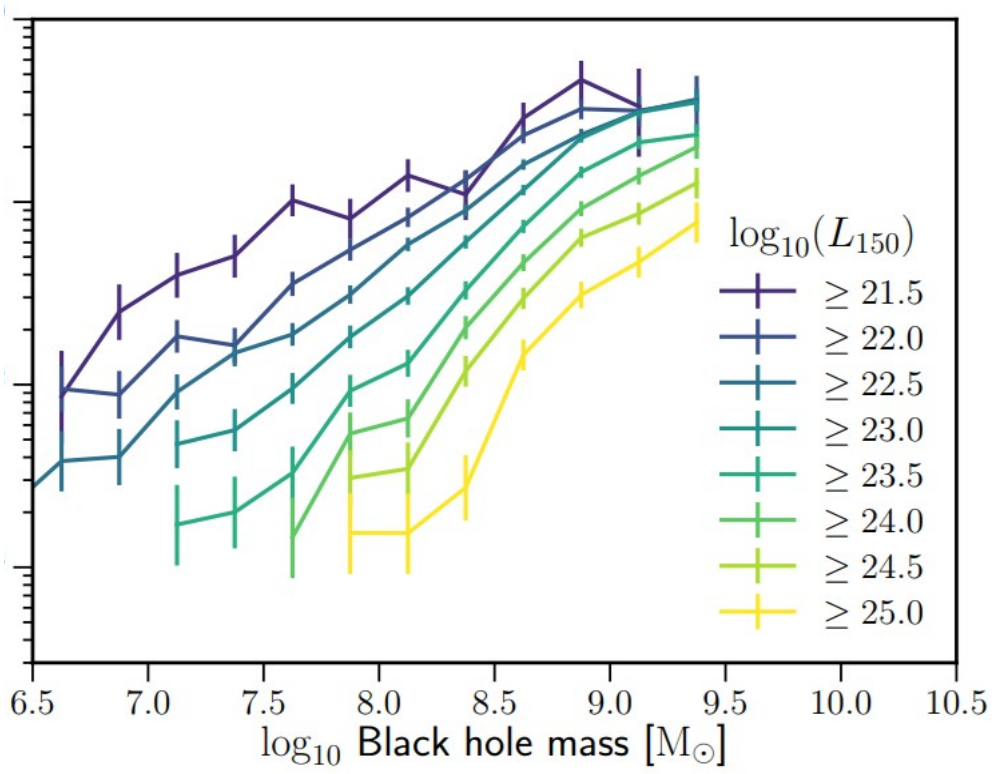


Some scientific results

In the local universe, AGN in massive galaxies *are always on*



Stellar mass



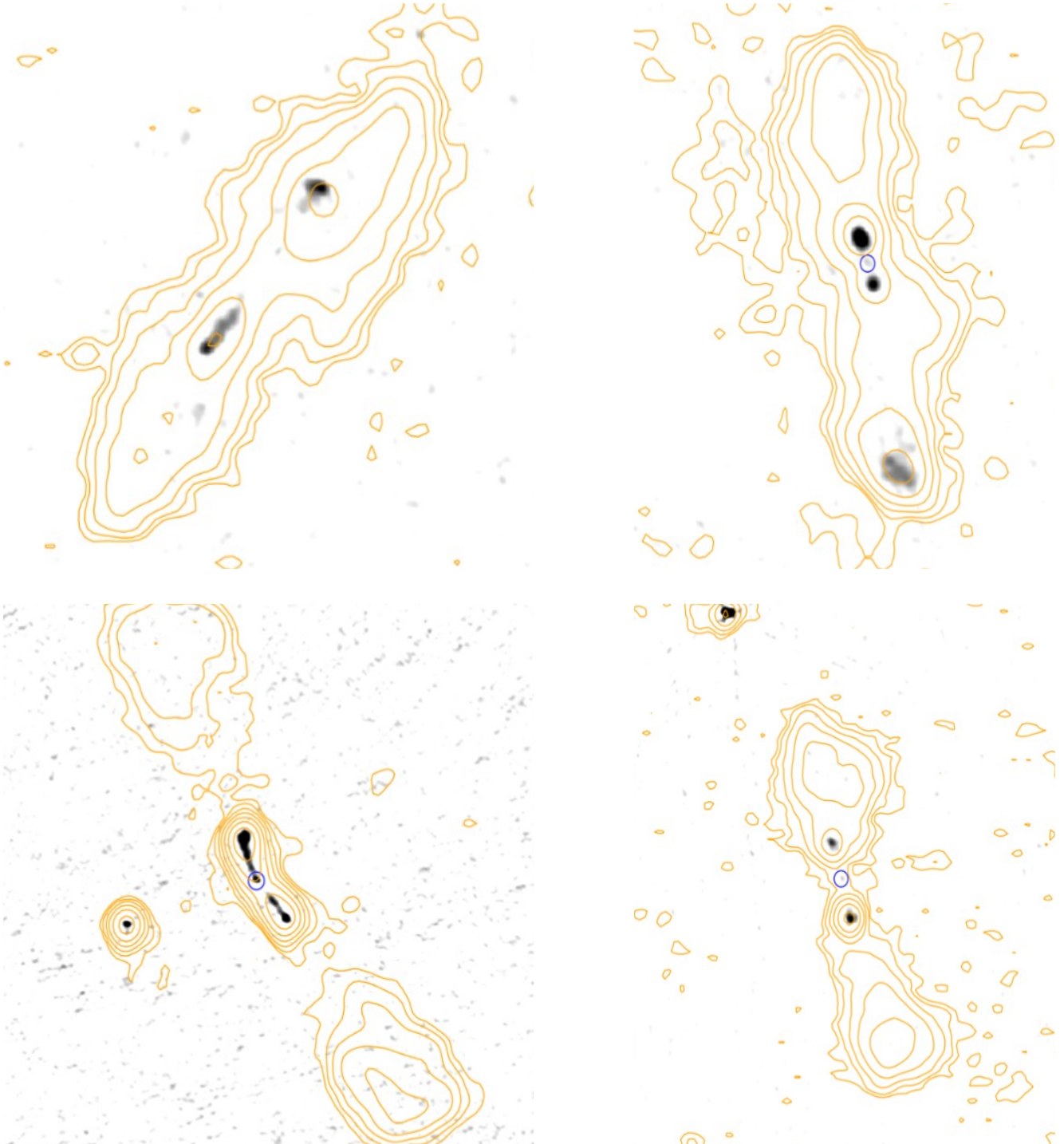
Black-Hole mass

Sabater et al.

Relic AGN or restarted?

Jet dynamics

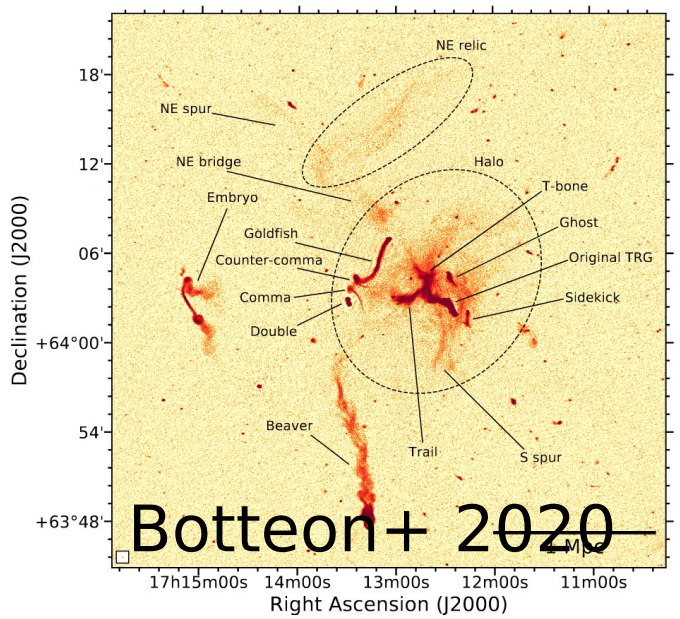
Feedback and duty cycle



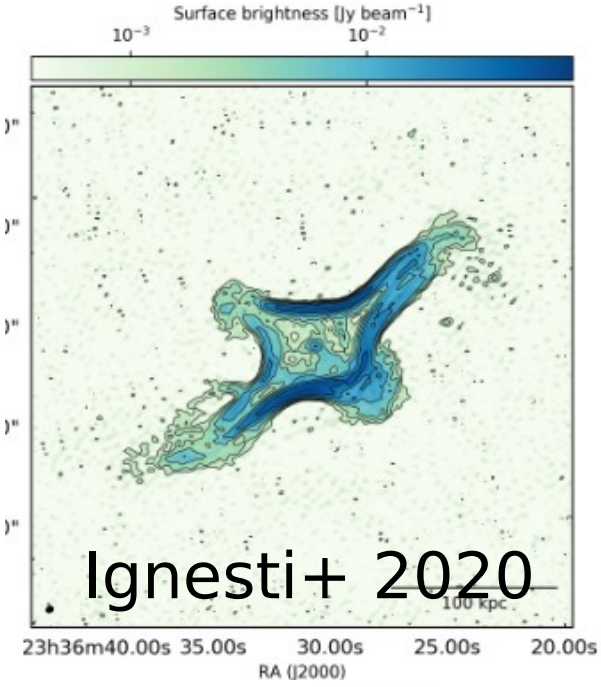
Mahatma et al.

LoTSS-DR2 —Varied science results

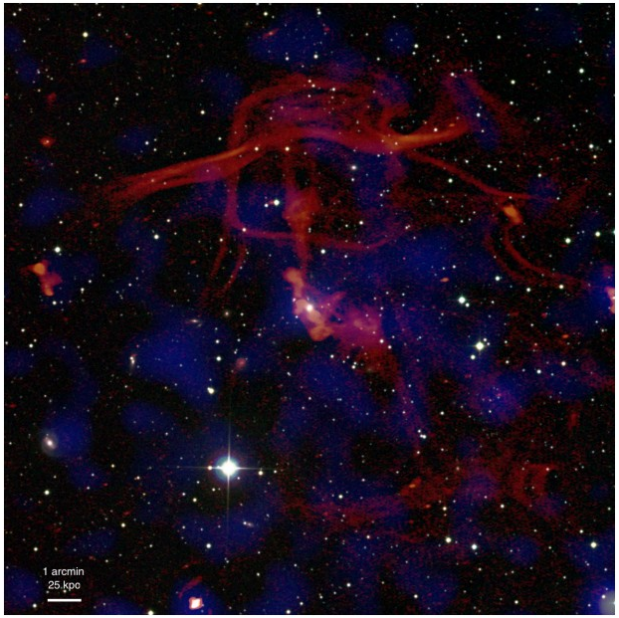
Extraction of calibrated data in a particular direction to allow for easy and custom reimaging to aid projects focussed on smaller samples



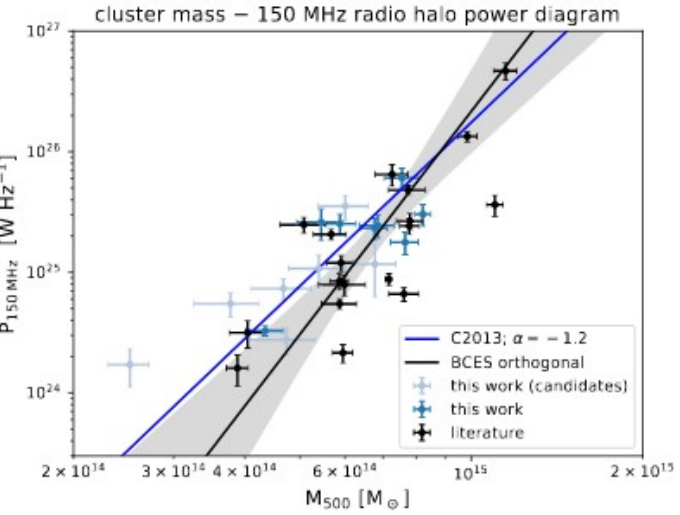
Botteon+ 2020



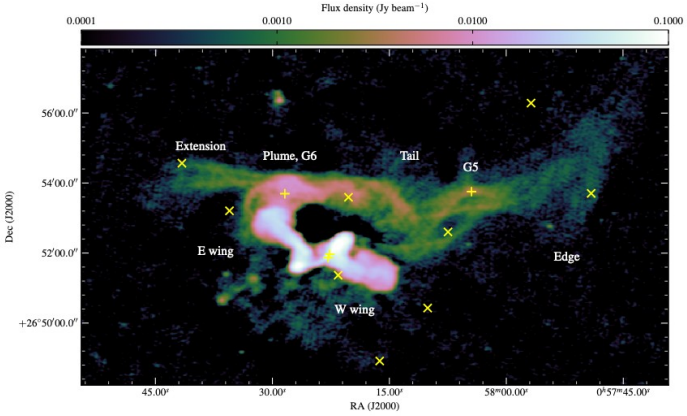
Ignesti+ 2020



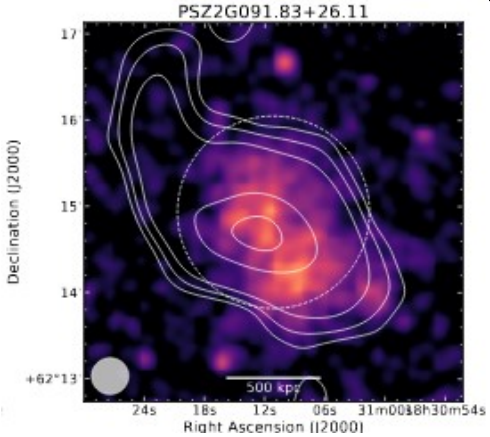
Bienza+ 2020



van Weeren+ 2020

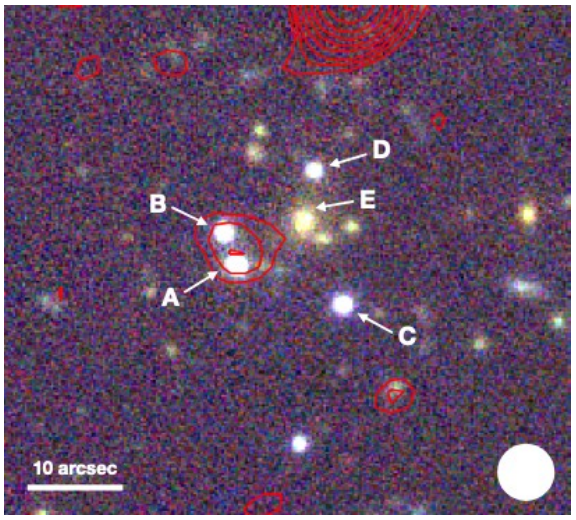


Hardcastle+ 2020

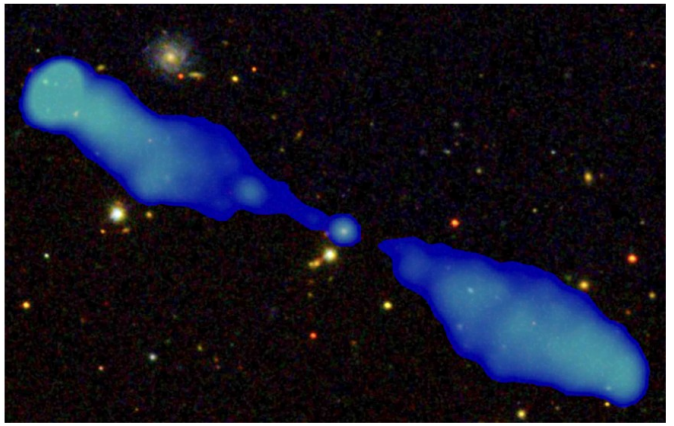


Di Gennaro + 2020

LoTSS-DR2 —Varied science results

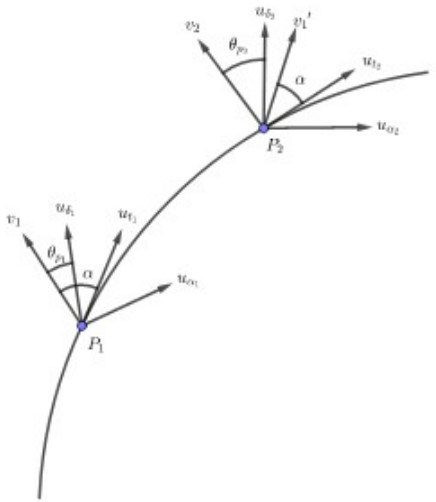


McKean+ Gravitational lenses

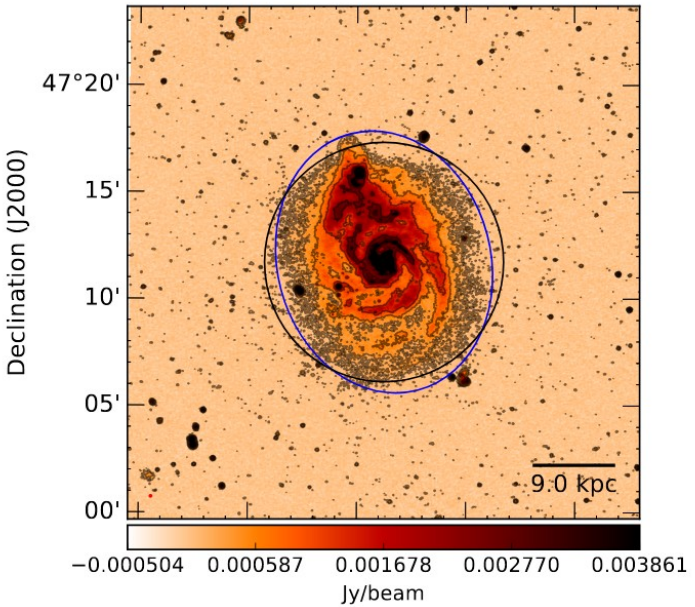


Dabhabe+ 2020 giant radio galaxies
(also Bruni+ in prep)

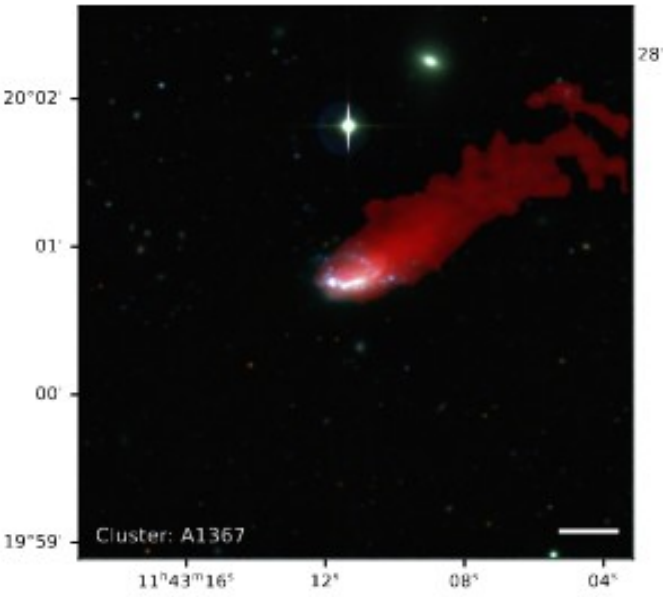
The majority of the science is from large statistical studies or characterising/discovering rarer objects using our standard imaging and catalogue products



Osinga+ 2020 alignment of radio source angles

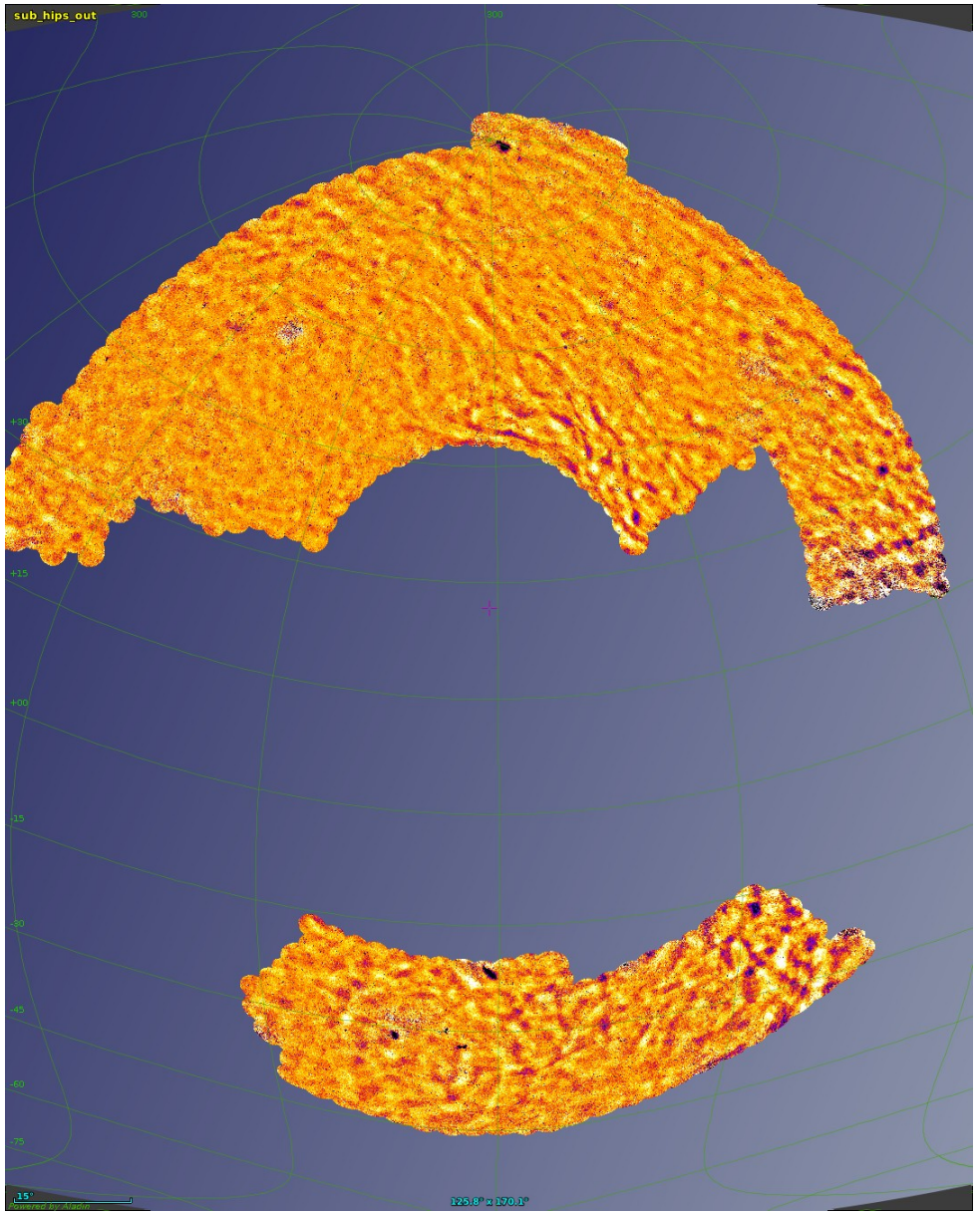


Hessen+ in prep - Nearby galaxy populations



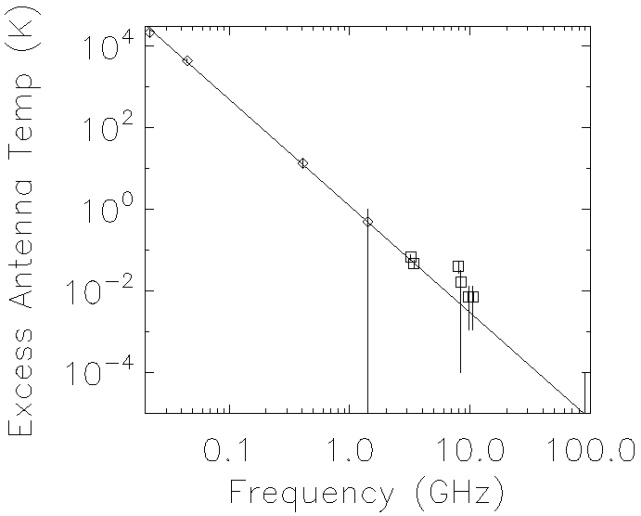
Roberts+ in prep Jellyfish galaxies.

LoTSS-DR2 —Varied science results

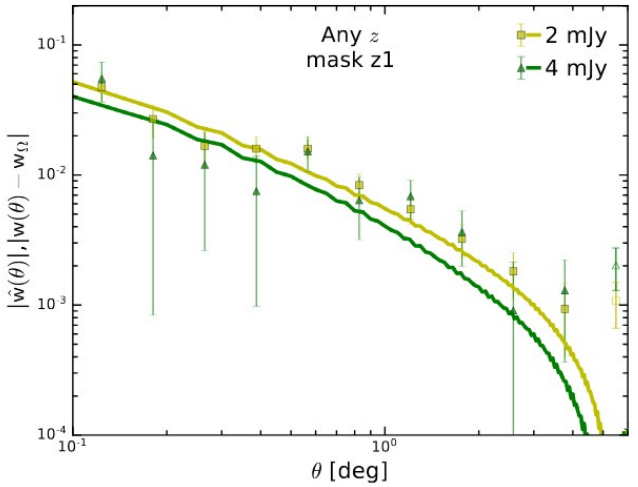


Oei+ in prep - Large scale galactic emission

Wide-area statistical analysis of images allows for cosmological or galactic studies

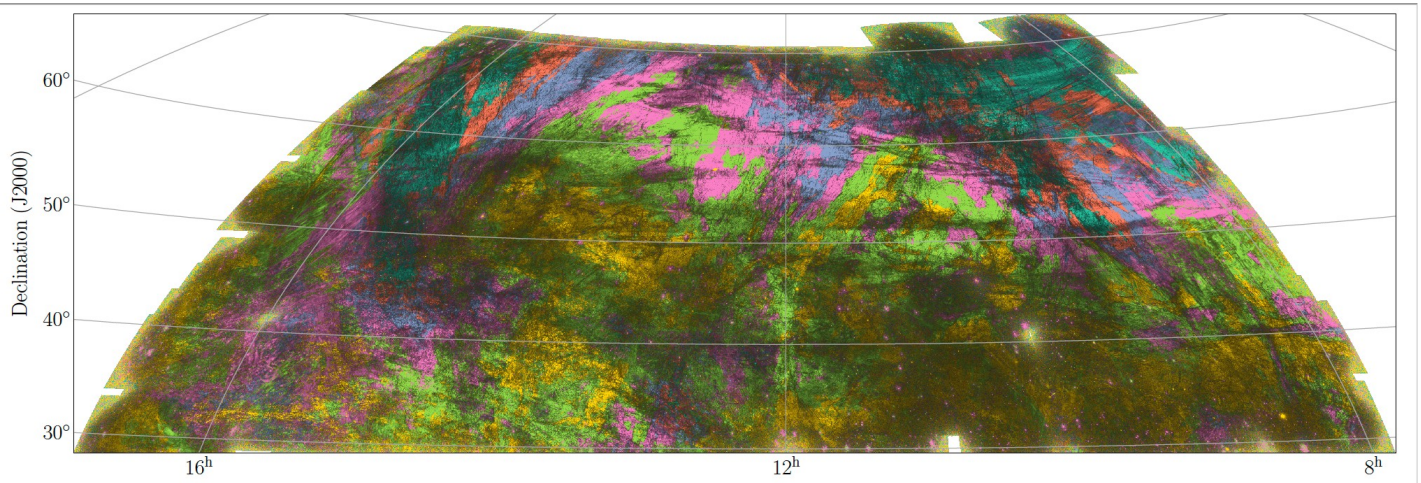


Hardcastle+ 2020 - sky temperature



Siewert+ 2020 - Two-point correlation function compared to cosmological simulations.

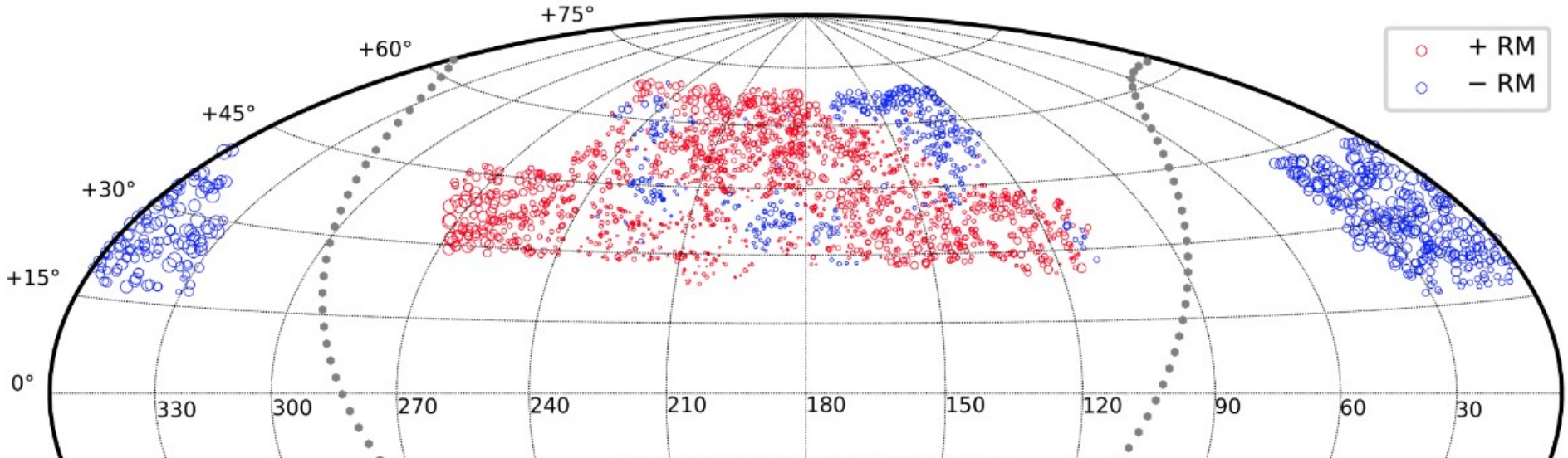
LoTSS-DR2 —Varied science results



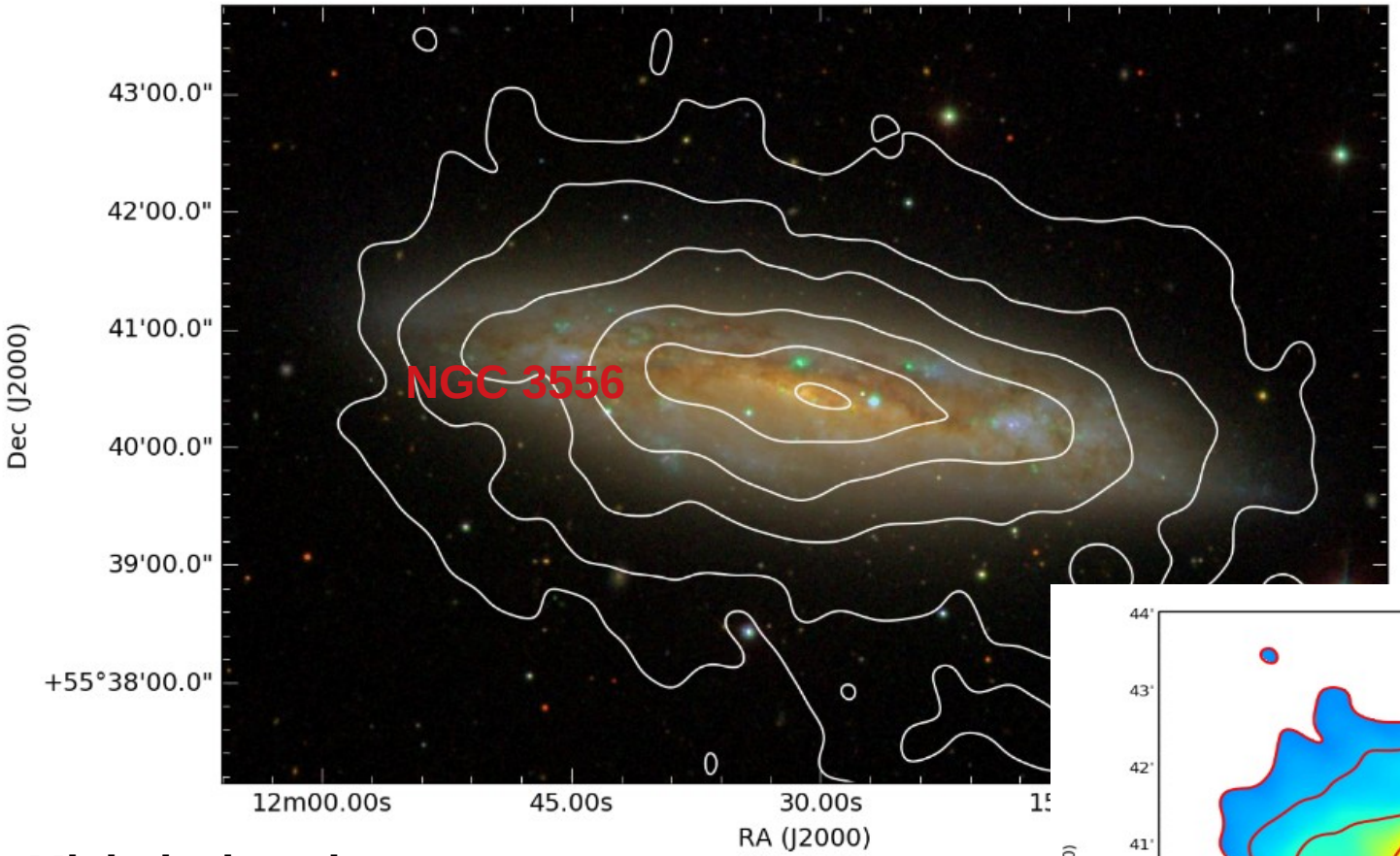
Erceg+ in prep - RM of low surface brightness galactic structures

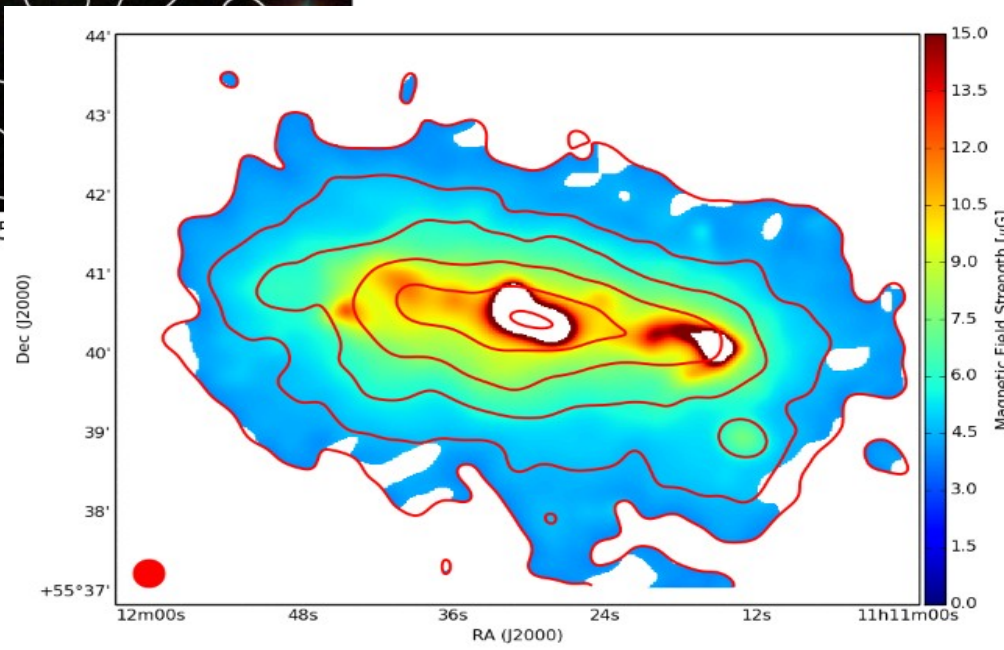
Wide area polarisation at multiple resolutions allows for studies of polarised galactic and extra galactic sources as well as e.g. pulsars or stars

O'Sullivan+ in prep - RM of extra galactic sources



Nearby galaxies





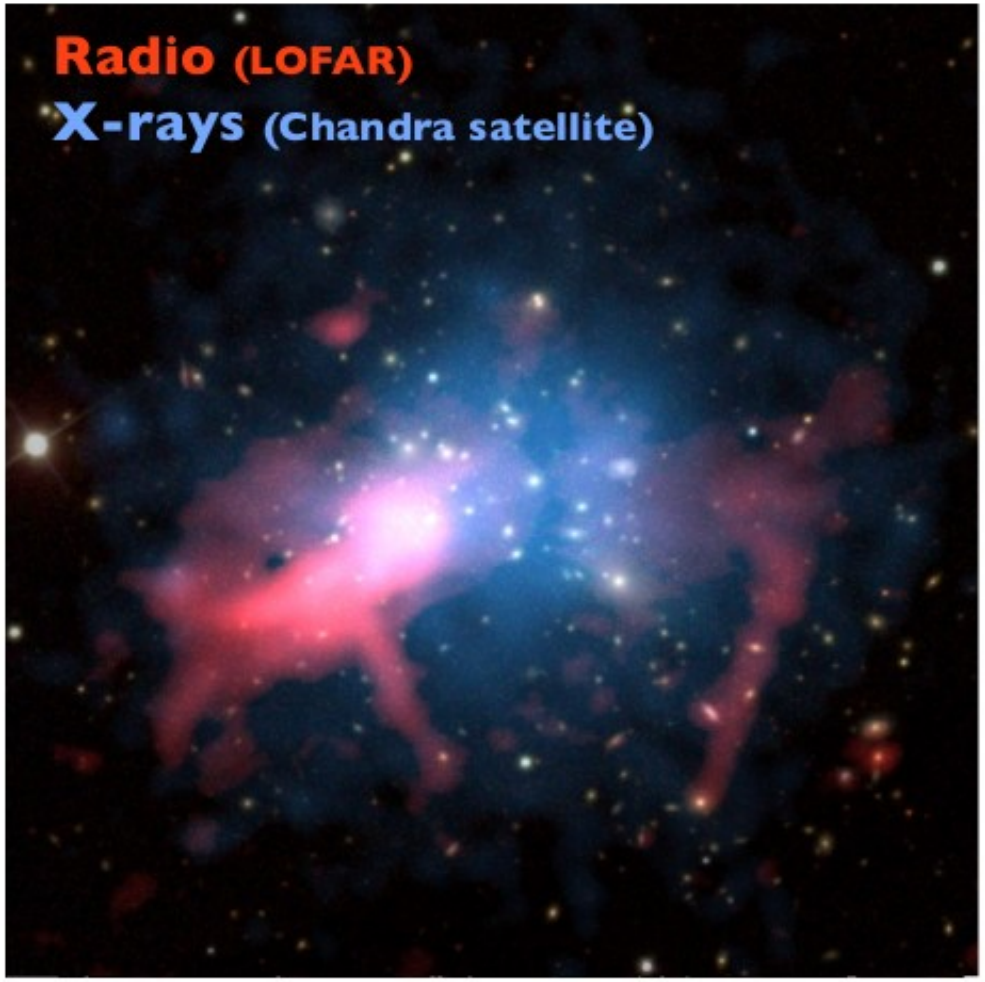
Miskolczi et al.

- Cosmic rays emitting synchrotron in a galactic Haloe
- Constrains on CR Energy, magnetic field and galactic winds speed

Galaxy clusters

See Chiara Ferarri talk

Abell 1914

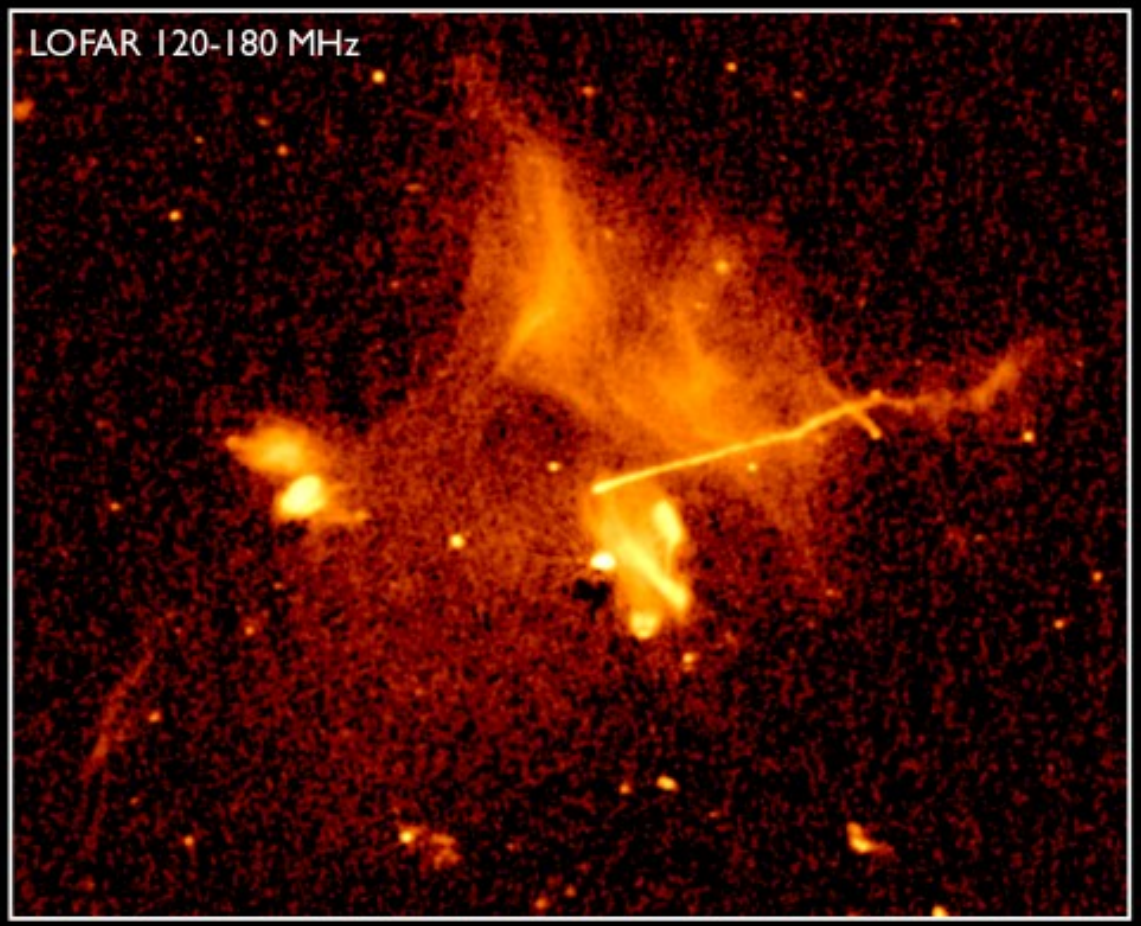


Mandal+ (2018, in prep)

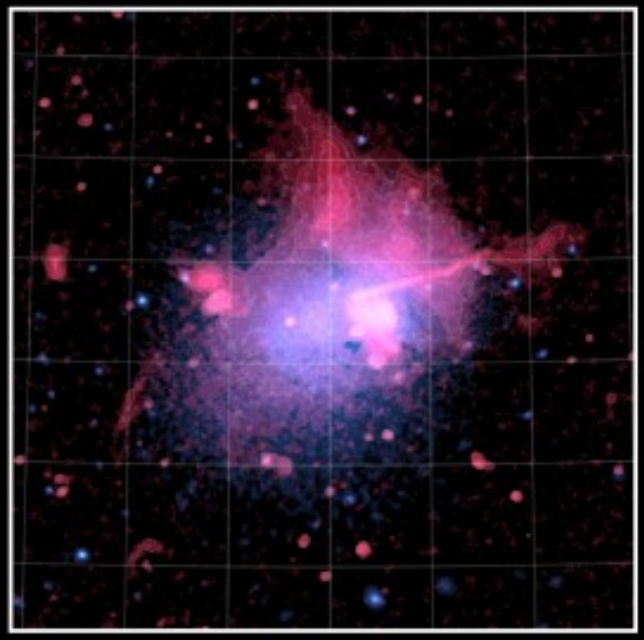
Abell 1132

Wilber+ (2017)

ABELL 2256



Radio (LOFAR)
X-rays (XMM)



- Merging cluster
- z = 0.05

Van Weeren et al.

Unexpected surprise

- We decided to add a V-Stokes image it the end of the pipeline

Unexpected surprise

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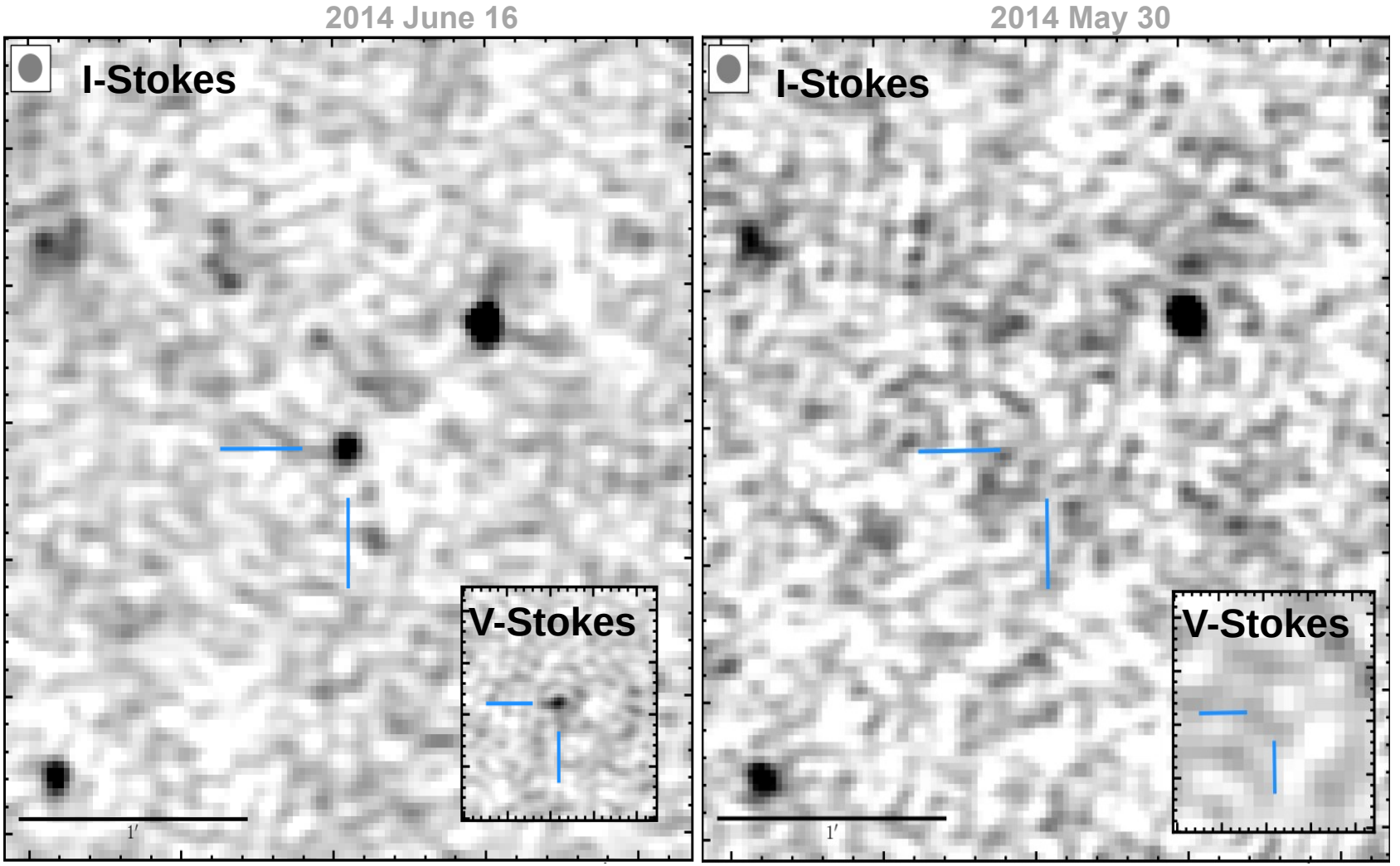
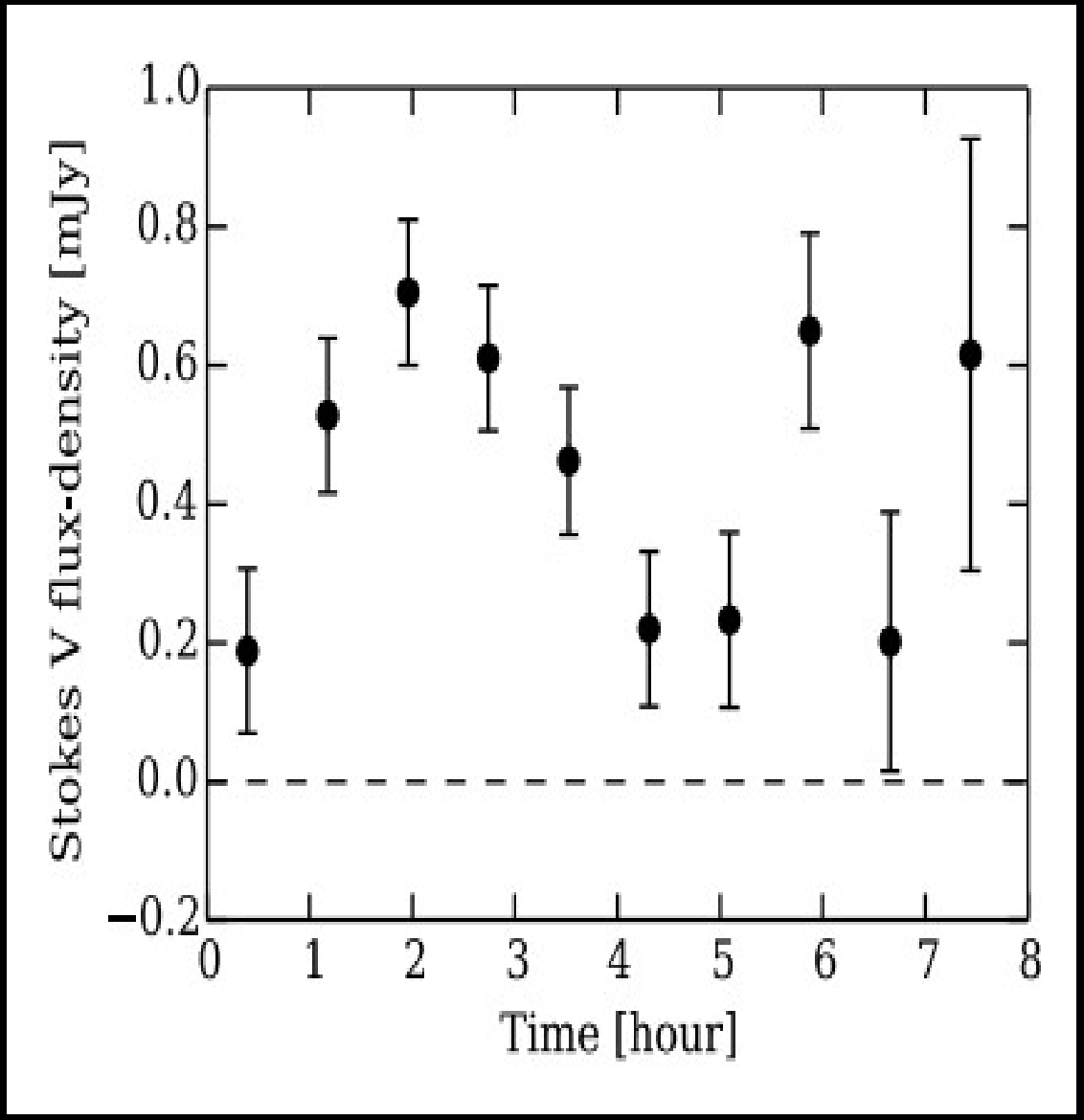


Vedantham, Callingham et al. (Nat. Astro., 2020)

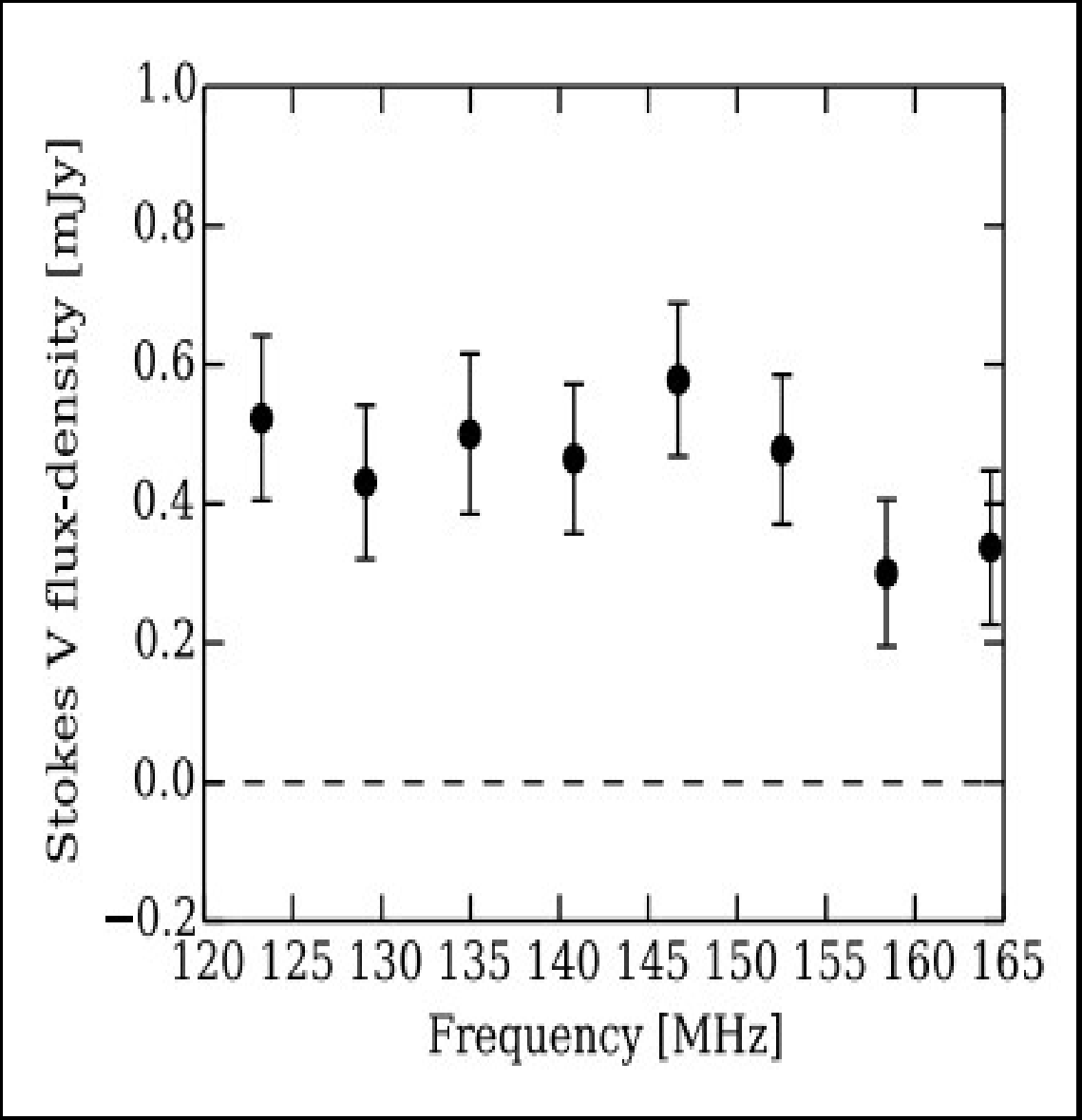
Emission characteristics – variable(ish)



Vedantham, Callingham et al. (Nat. Astro., 2020)

Slide taken from Joe Callingham

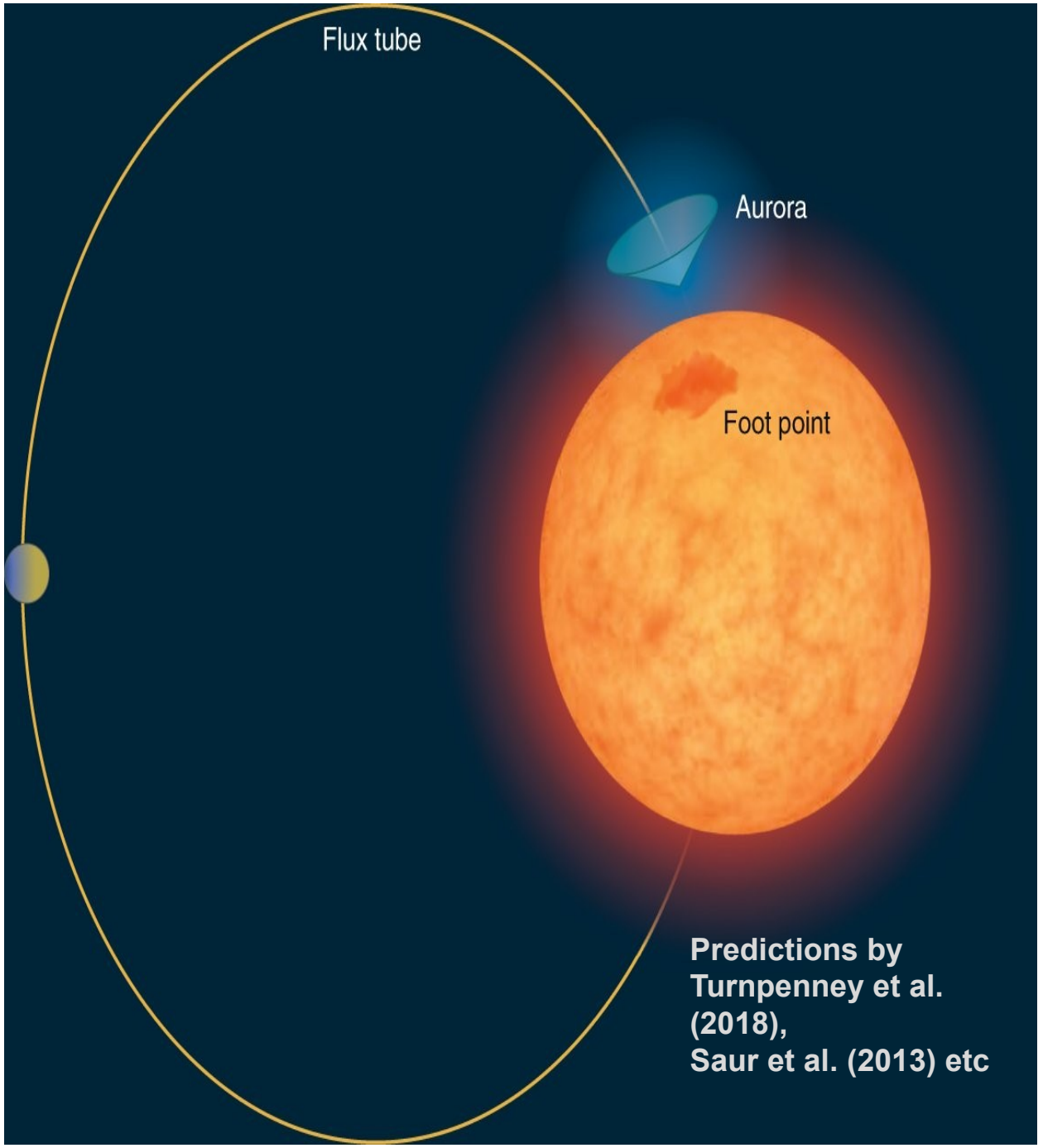
Emission characteristics – flatish



Vedantham, Callingham et al. (Nat. Astro., 2020)

Slide taken from Joe Callingham

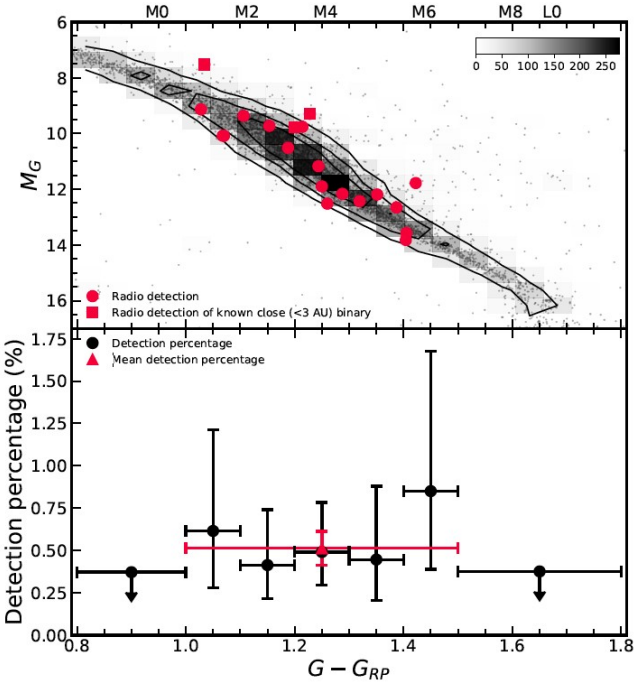
Interpretation of emission



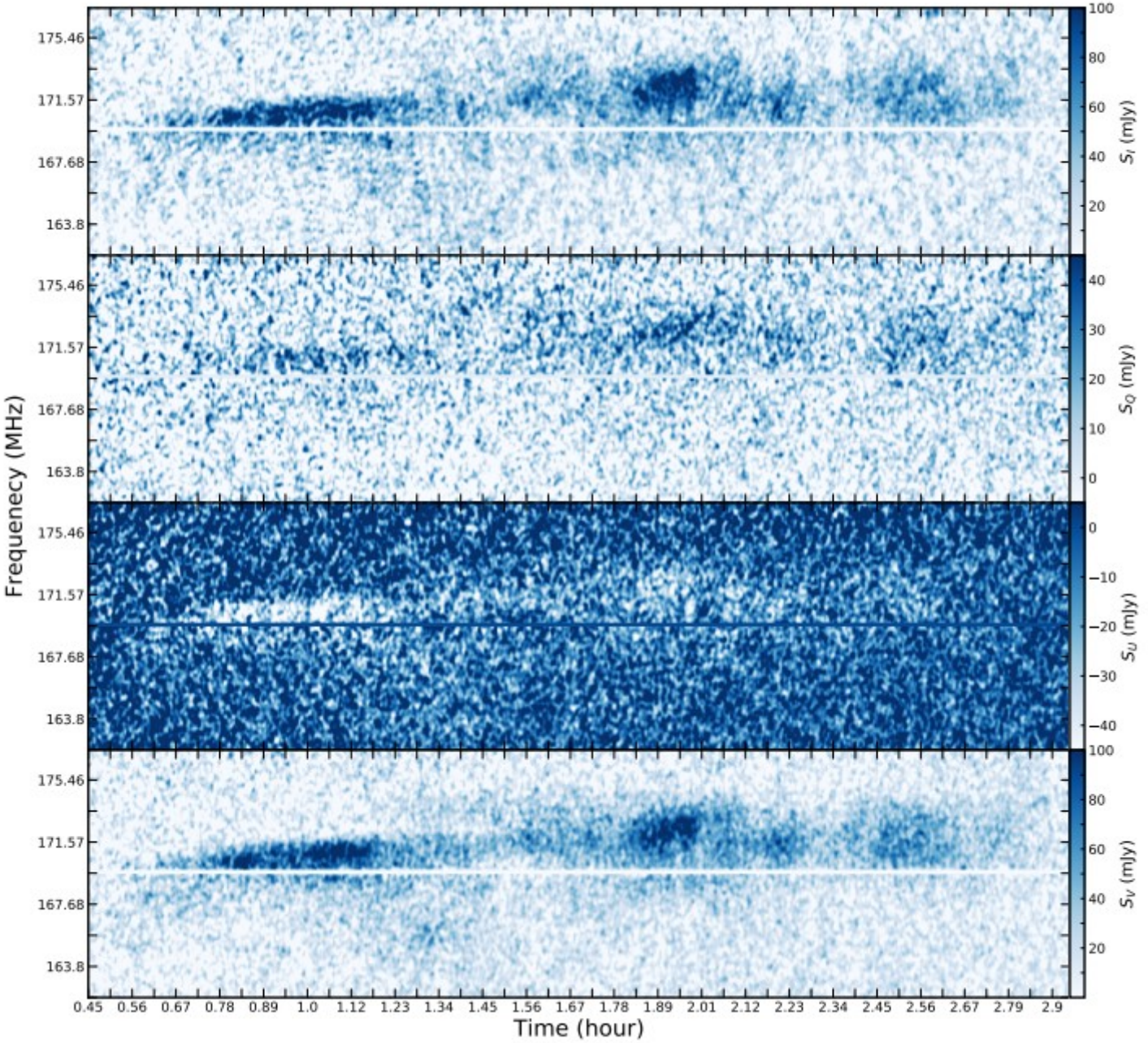
Predictions by Turnpenney et al. (2018), Saur et al. (2013) etc

Most important features:

1. X-ray luminosity (which dictates coronal scale height)
2. Brightness temperature
3. % of circular polarisation
4. Broadband nature
5. Length of detected emission



Callingham+ submitted - detecting populations of stellar systems in Stokes V.



A resolved dynamic spectra built using DynSpecMS (Tasse et. al. In prep)

Slide taken from Joe Callingham

Low-frequency monitoring of flare star CR Draconis: Detection oflong-term electron-cyclotron maser emission, Callingham,++, Under review A&A, 2020

Summary

- **Huge range of scientific topics (it covers most of the fields of astrophysics)**
- **LoTSS is the largest radio astronomy survey to date…** LoTSS-DR2 covers 26% of the Northern sky and contains 4,395,448 sources. This includes our best regions of the sky for LOFAR imaging and is large enough for almost all statistical studies.
- All images, mosaics and catalogues are available on lofar-surveys.org. HIPS maps are also available there. Ambition is to publish late 2020 early 2021.

Beyond LoTSS-DR2 there are a lot of challenges and opportunities on the road to completing LoTSS and fully exploiting the data.

- Surveys team open to collaborations on proprietary products.


Thank you !