

L'Univers profond dévoilé à basses fréquences par les précurseurs de SKA

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Rhodes University (Afrique du Sud)**

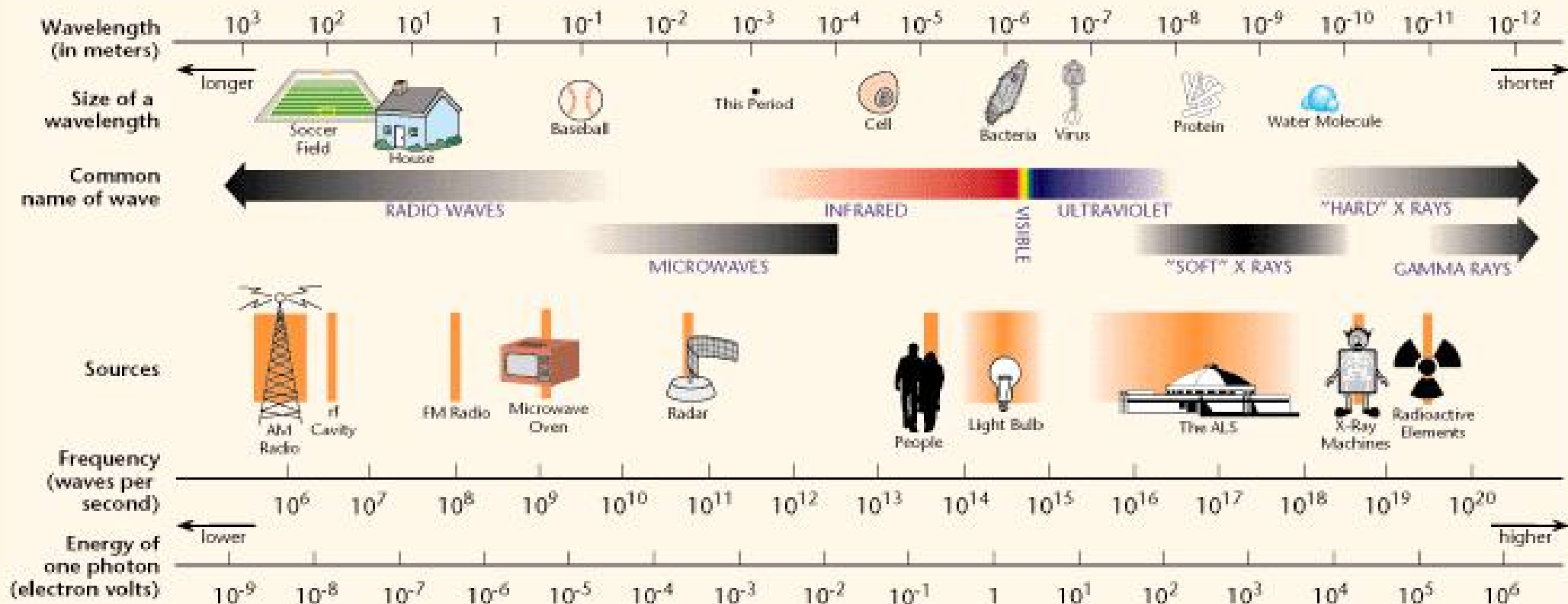
Montgeron - 02/04/2022

Résumé

- Qu'est-ce que la radioastronomie?
 - Les processus d'émission d'ondes radio?
 - Que peut-on étudier en radio?
- Une révolution de la radioastronomie (*à basses fréquences*)
 - Square Kilometer Array (SKA)
 - LOFAR, Low Frequency Array
 - MeerKAT
 - NenuFAR

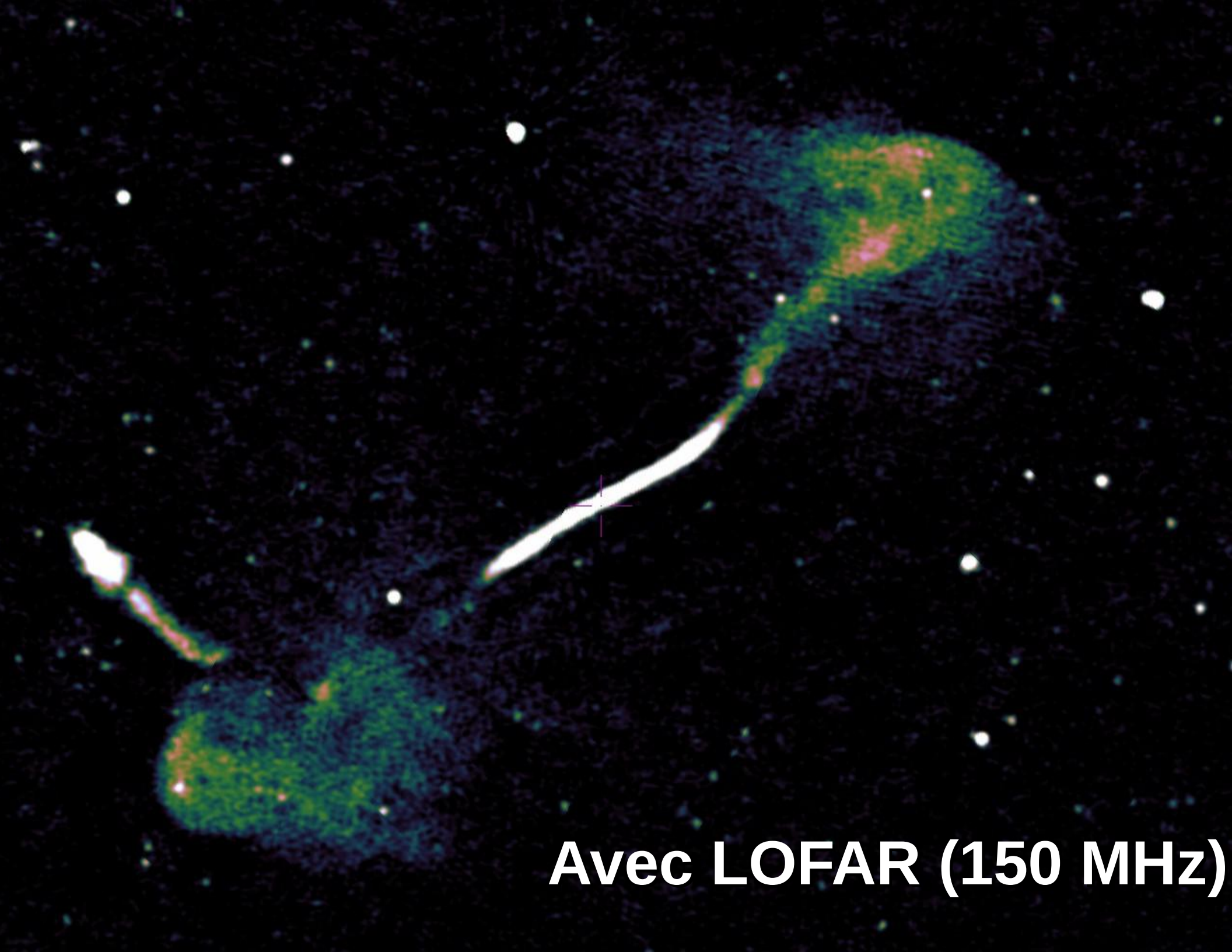
Radio astronomie?

THE ELECTROMAGNETIC SPECTRUM





En optique



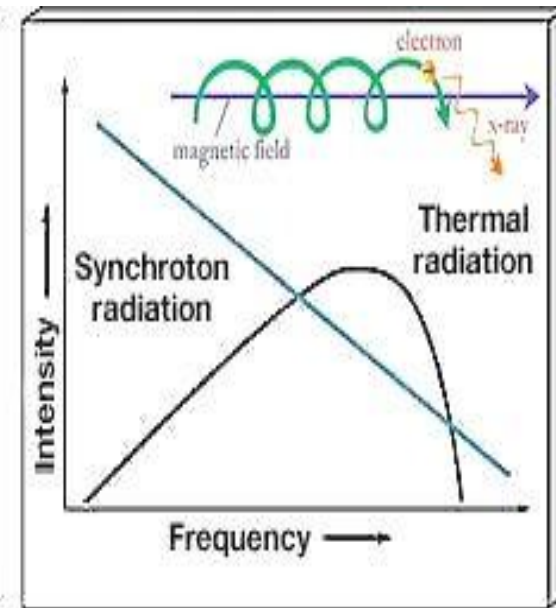
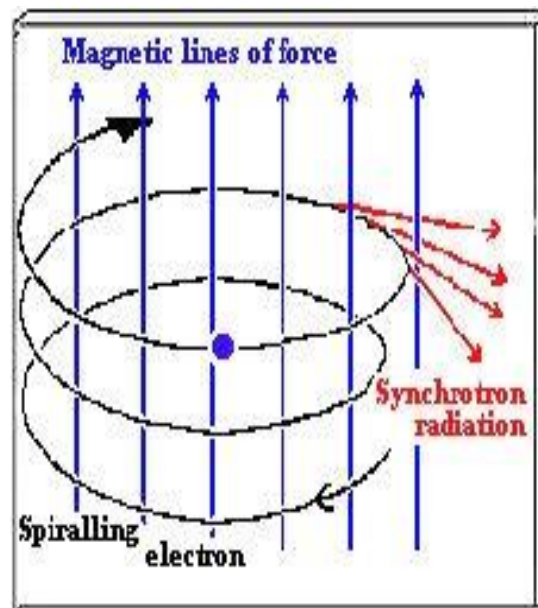
Avec LOFAR (150 MHz)

What physical phenomena emit radio emission?

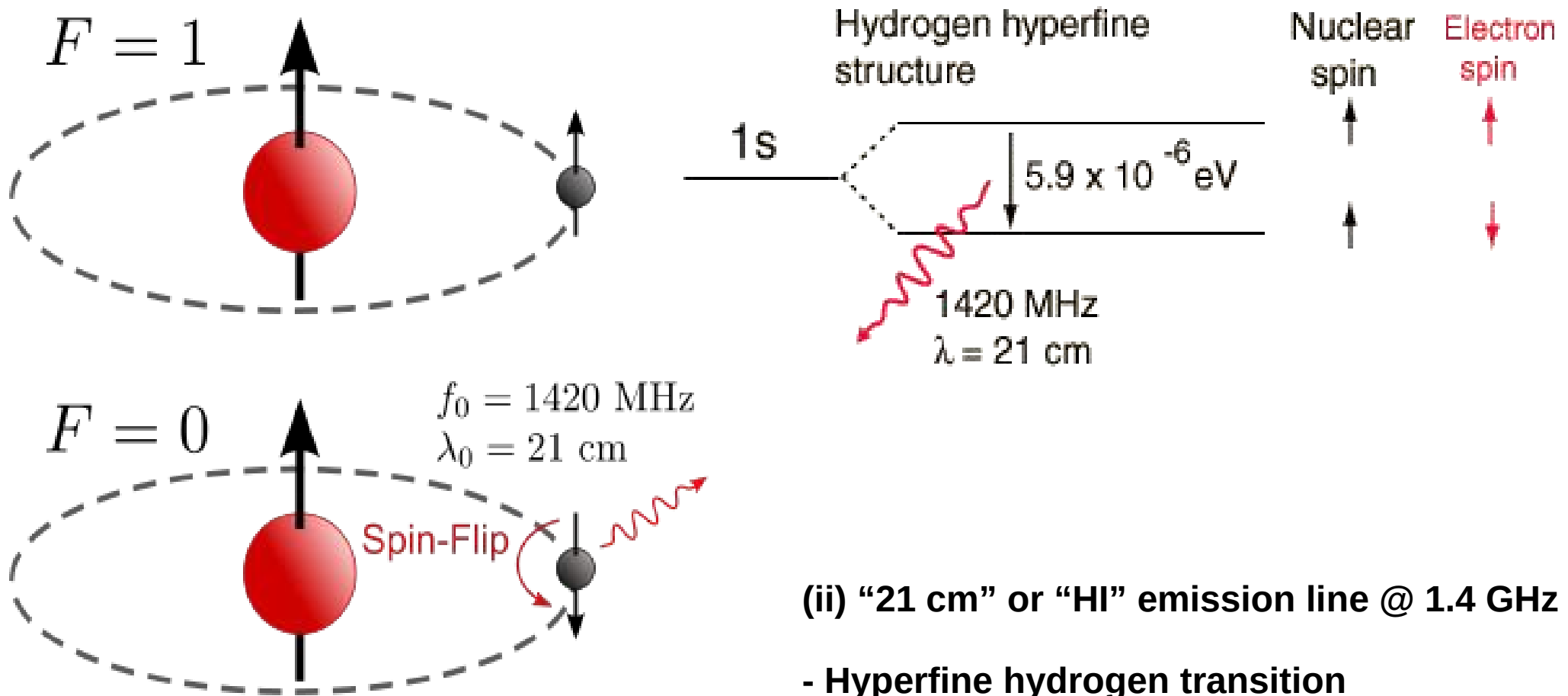


(I) Synchrotron radiation:

- Charged particle in a magnetic field
- Acceleration = emission
- Polarised -> information on the magnetic field
- Continuum emission



What physical phenomena emit radio emission?



(ii) “21 cm” or “HI” emission line @ 1.4 GHz

- Hyperfine hydrogen transition
- “forbidden” transition, one in ~ 10 million years
- But there is so much neutral hydrogen in the universe....

What physical phenomena emit radio emission?

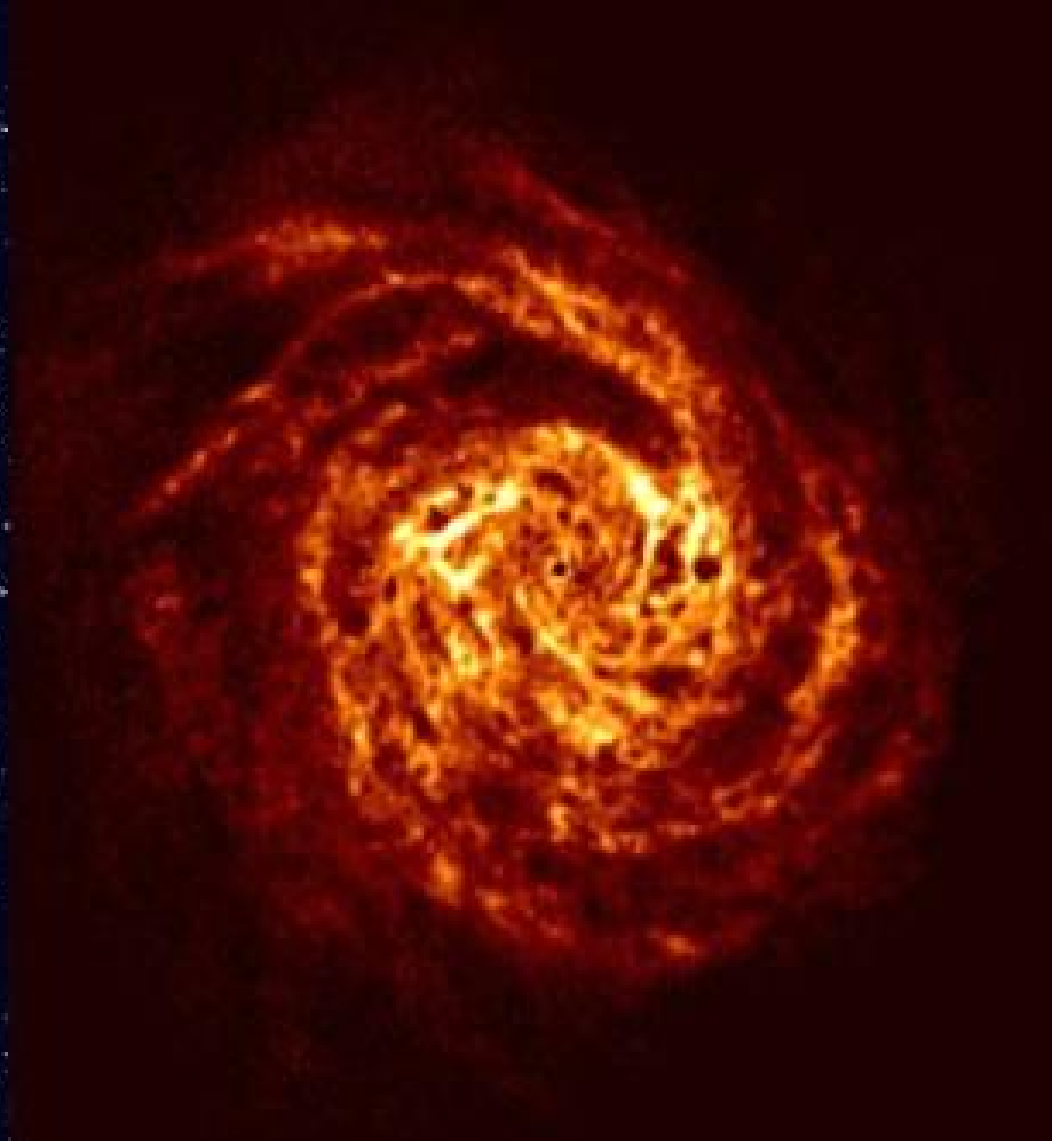


Let's look at M101 with a radio telescope...

What physical phenomena emit radio emission?



Optical



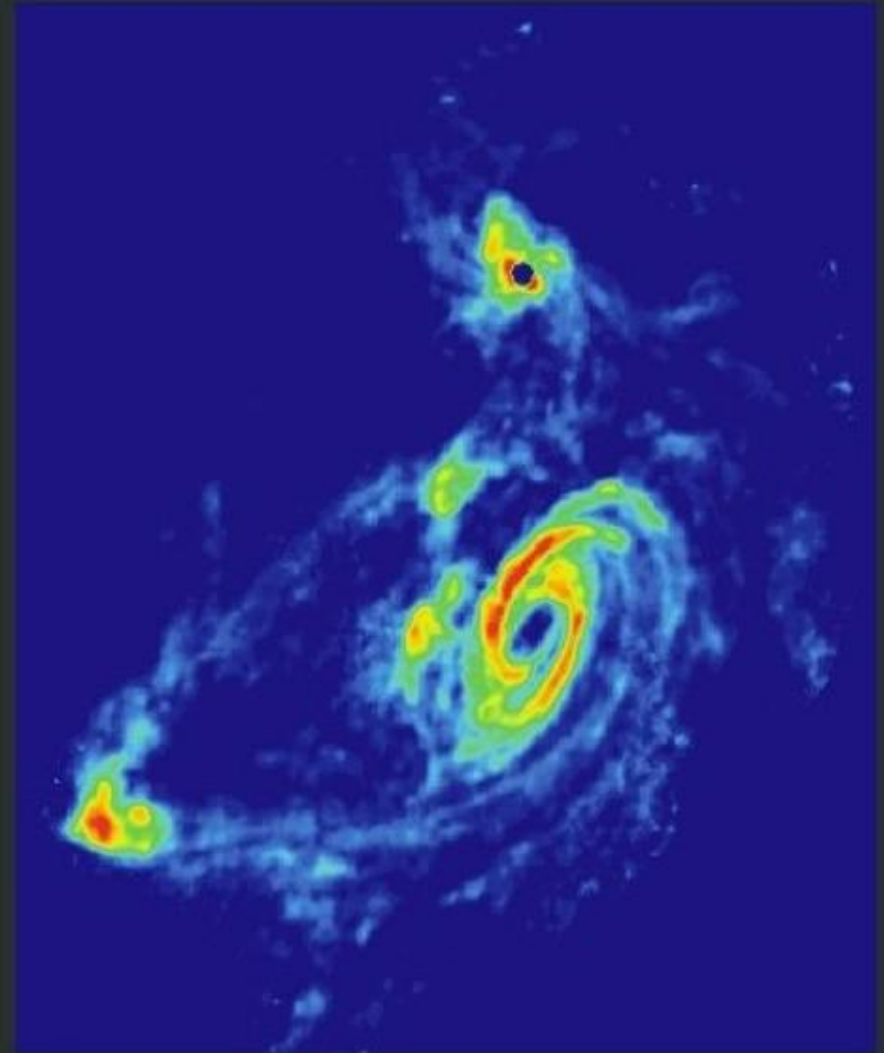
1.4 GHz

TIDAL INTERACTIONS IN M81 GROUP

Stellar Light Distribution



21 cm HI Distribution



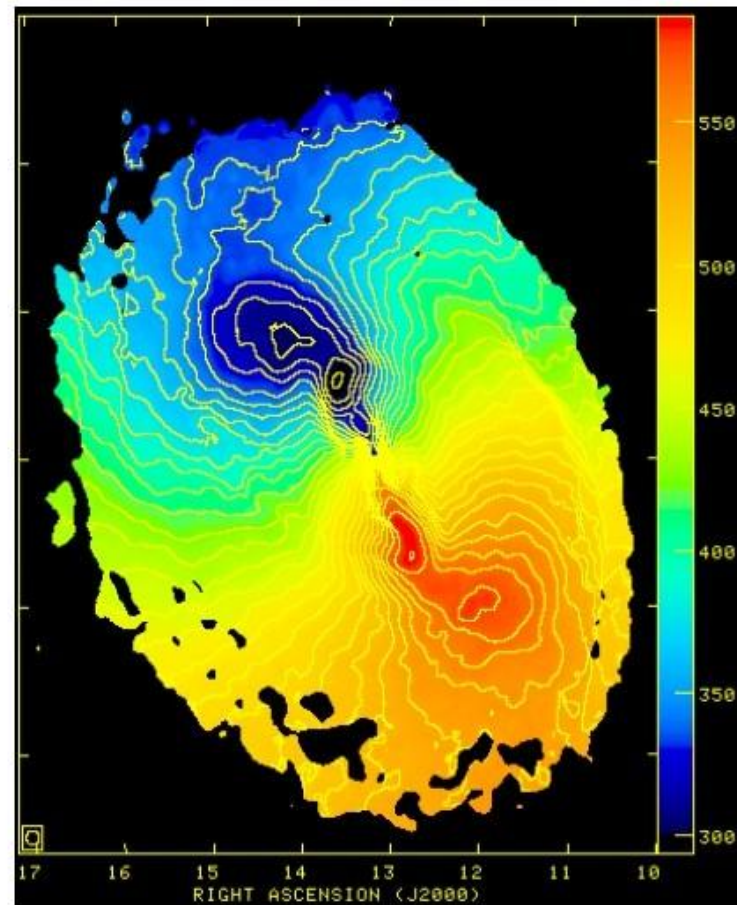
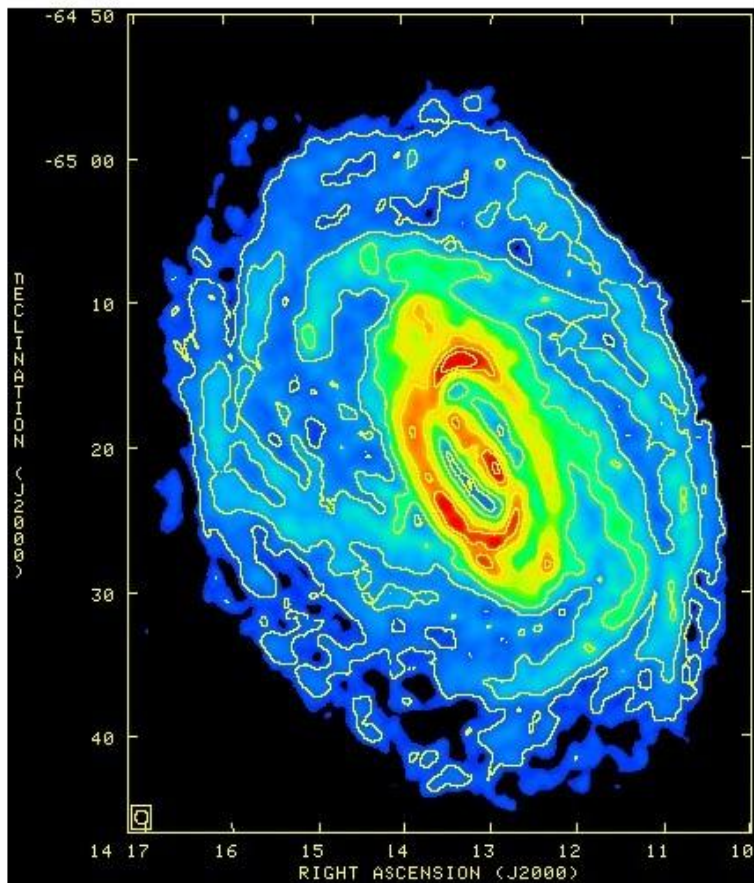
HI en émission

La galaxie Circinus



Carte HI

vitesse radiales



Attention aux fausses couleurs!!

B. Vollmer

How do we observe radio emission?



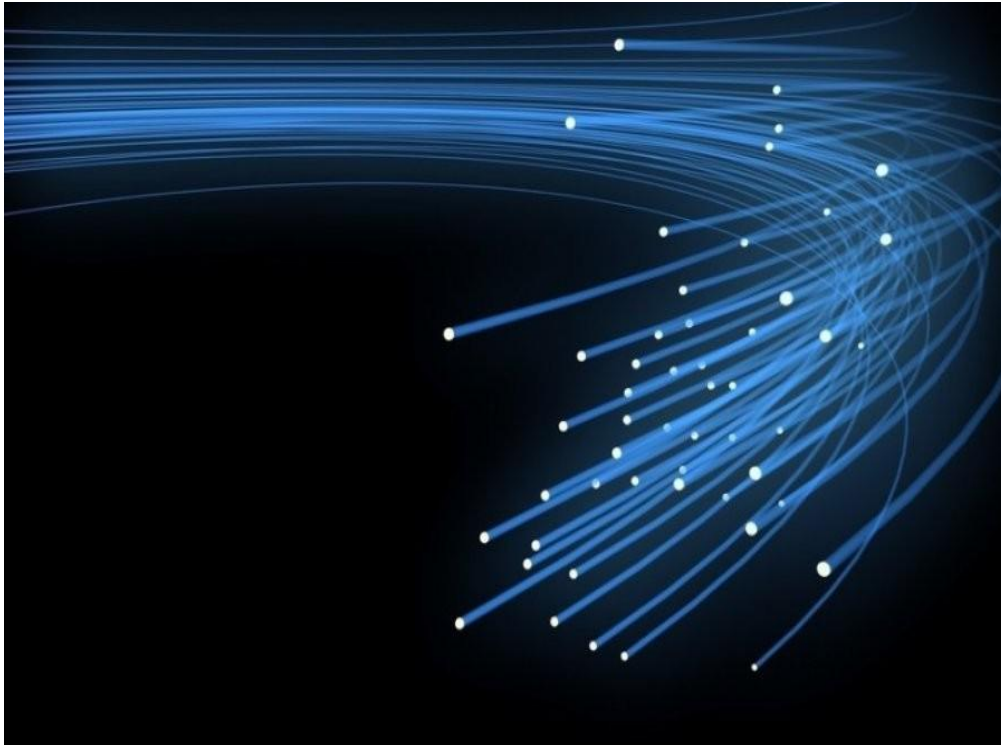
Very Large Array

Interferometer:

- The idea is to combine the signal from individual antenna
- Synthesize a virtual telescope that has a equivalent size of the two most distant antennae

The Square Kilometer Array project

- SKA dishes: 10 times the global internet traffic (1 Exabyte per day)
- The SKA central computer:
 - 2-3 ExaFLOPs of processing required to handle this data.
 - one hundred million PCs.
 - 100 MW electrical consumption
- The SKA will be so sensitive that it will be able to detect an (exo)airport radar on a planet tens of light years away.



SKA: Square Kilometer Array?

Collecting area: 1 sq. km

Resolution: ~10 mas a 1 GHz
(a 1 euro coin at 400 kilometers)

Sensitivity: ~50 nJy/Beam

[8 hours, 500Mhz bandwidth]

Field of view: ~ 1 degré carré

360.000x360.000 pixels images

Survey speed: x10.000

A few huge radiotelescopes prototypes
of the SKA:

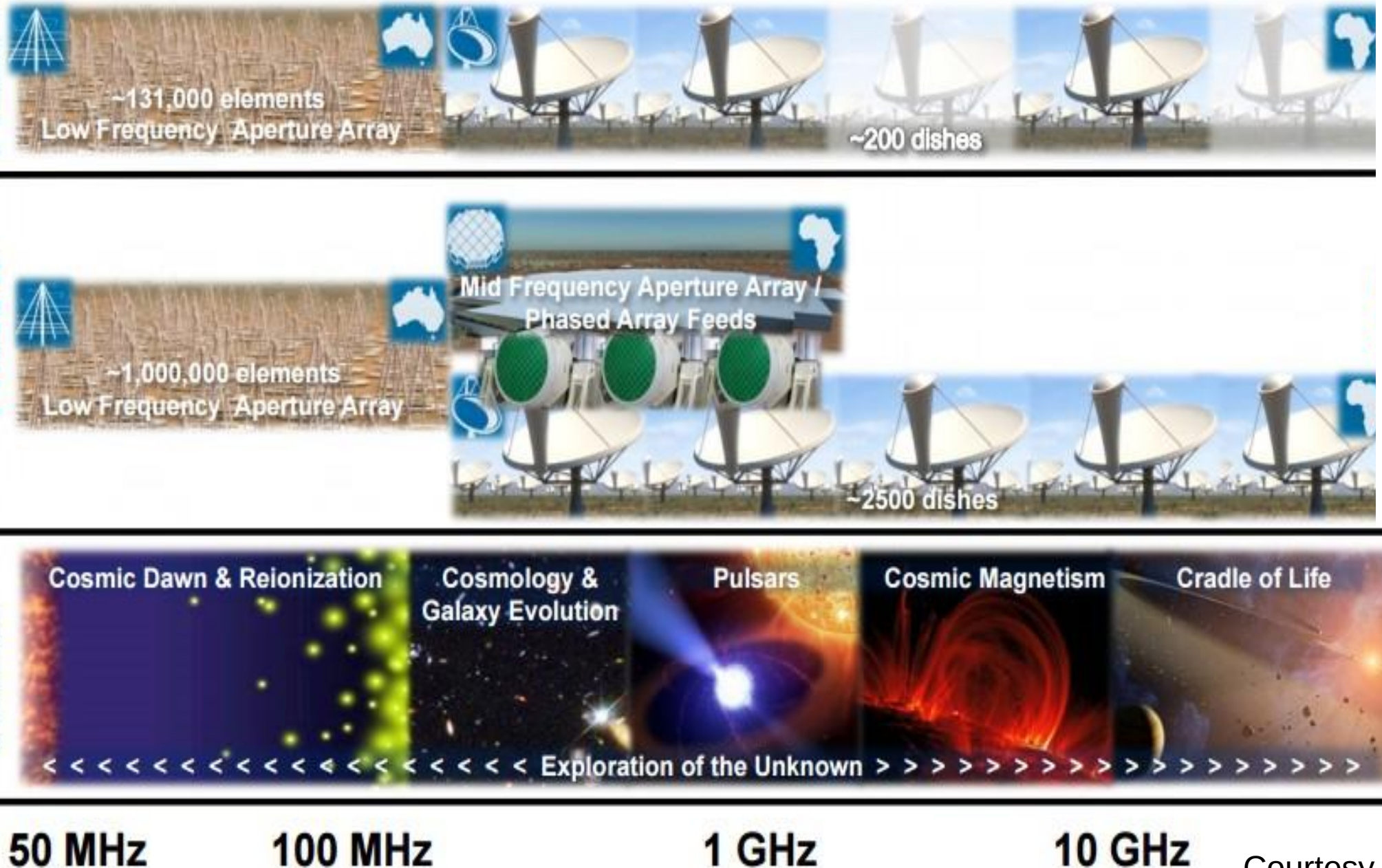
- MeerKAT
- LOFAR
- NenuFAR
- ASKAP
-



SKA: Square Kilometer Array?

Phase II

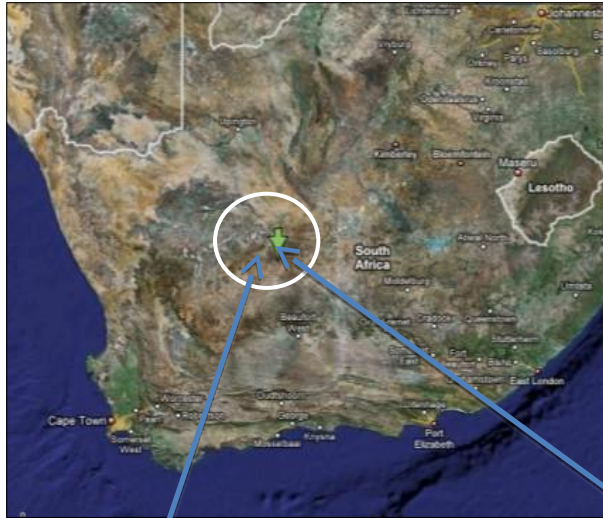
Science



Courtesy T.
Bourke

SKA Phase 2 (SKA2) – ultimate goal

Southern Africa

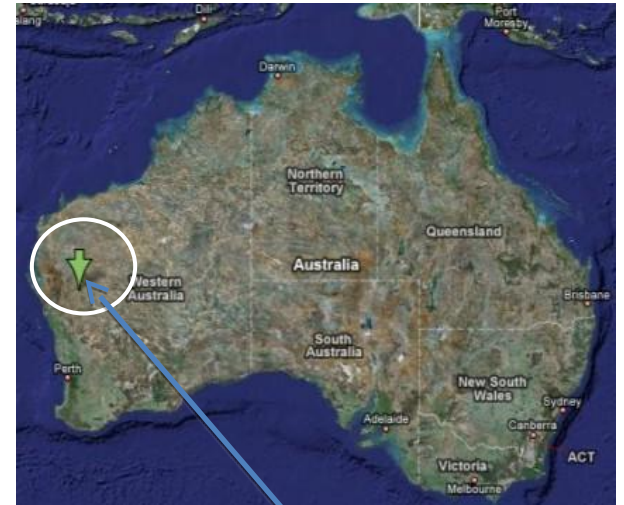


SKA2_MID
2500 Dishes



SKA2_AA
250 x Mid Frequency Aperture
Array Stations

Australia

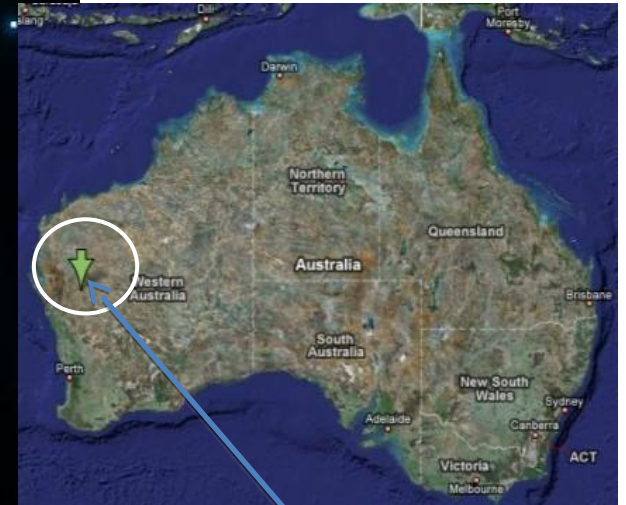


SKA2_LOW
250 x Low Frequency Aperture
Array Stations

SKA Phase 2 (SKA2) – Ultimate Goal

Southern Africa

Australia



SKA2_MID
2500 Dishes



SKA2_AA
250 x Mid Frequency Aperture
Array Stations



SKA2_LOW
250 x Low Frequency Aperture
Array Stations

LOFAR

International LOFAR Telescope (ILT)

- resolution ~ 5 arcsec @ 200 MHz for the dutch core
- resolution ~ 0.2 arcsec @ 50 MHz for the international baselines



Chilbolton



Dutch stations

LOFAR Core (NL)

- 300 – 1000 km
- 3 new stations coming in Poland



Nançay



Effelsberg

Jülich

Unterweilenbach

Tautenburg

Potsdam

Norderstedt

Onsala



Baldy



Borowiec



Łazy

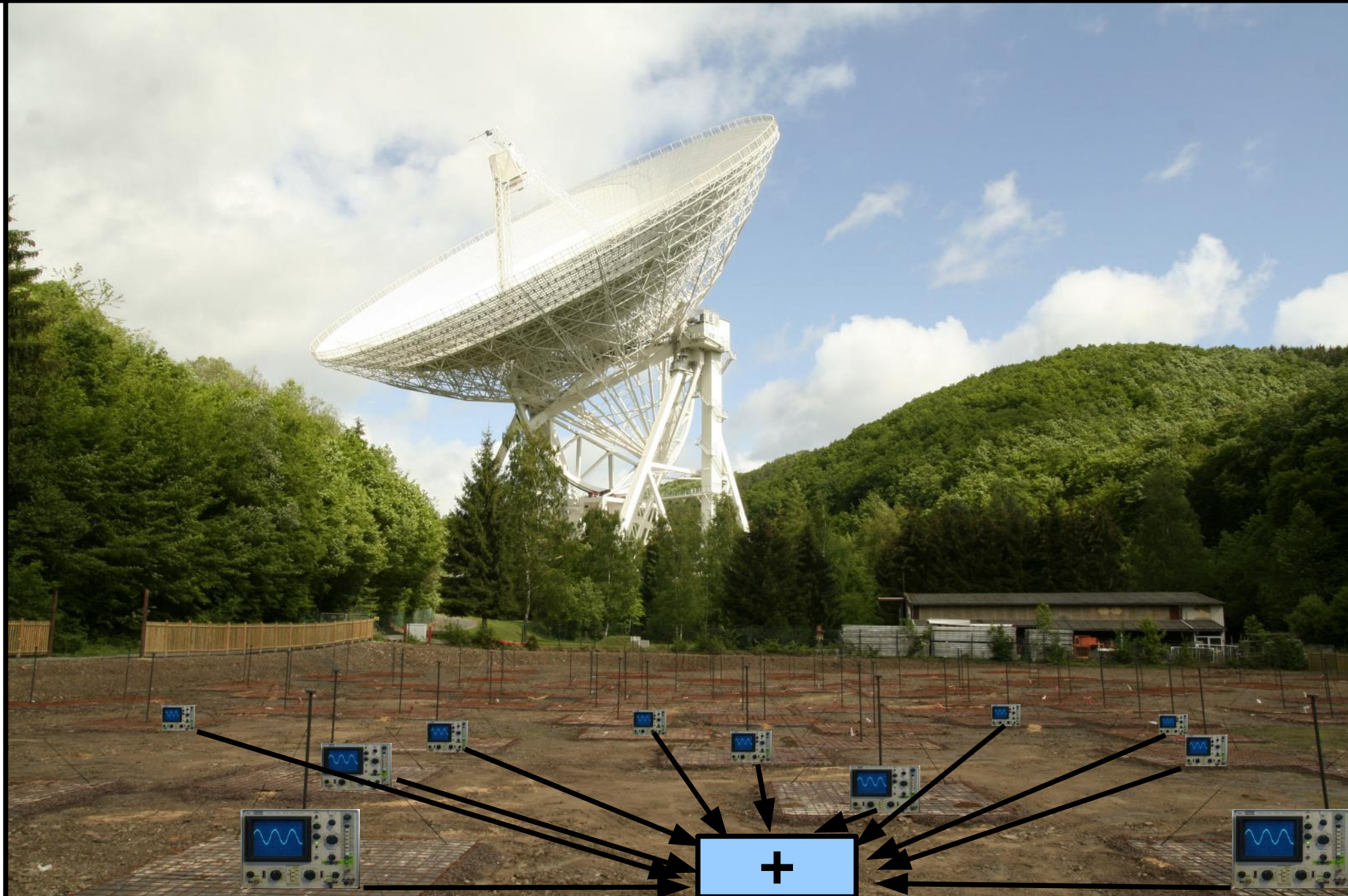


LOFAR

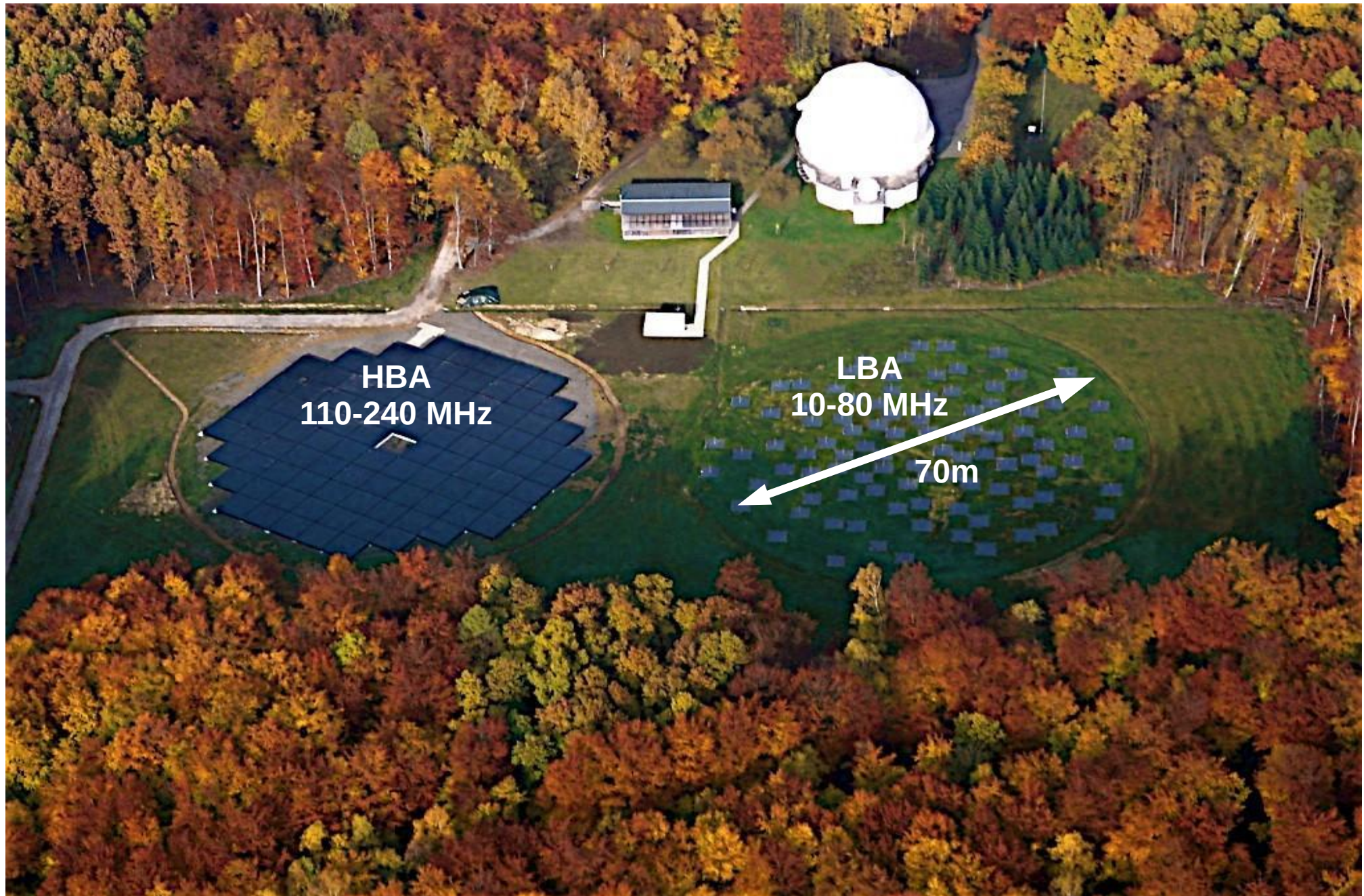
Station LOFAR à Nancay + NenuFAR



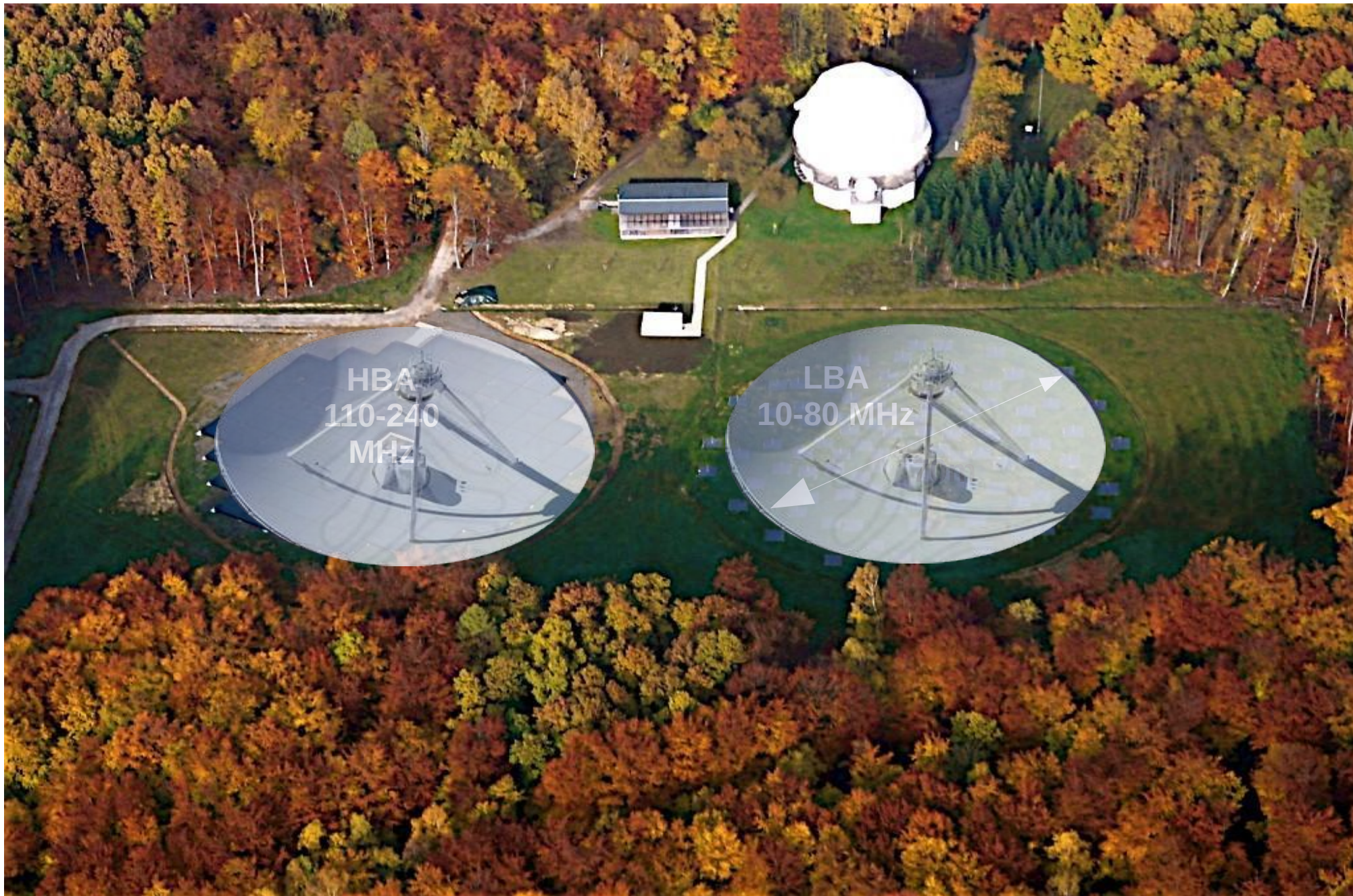
LOFAR station are phased arrays



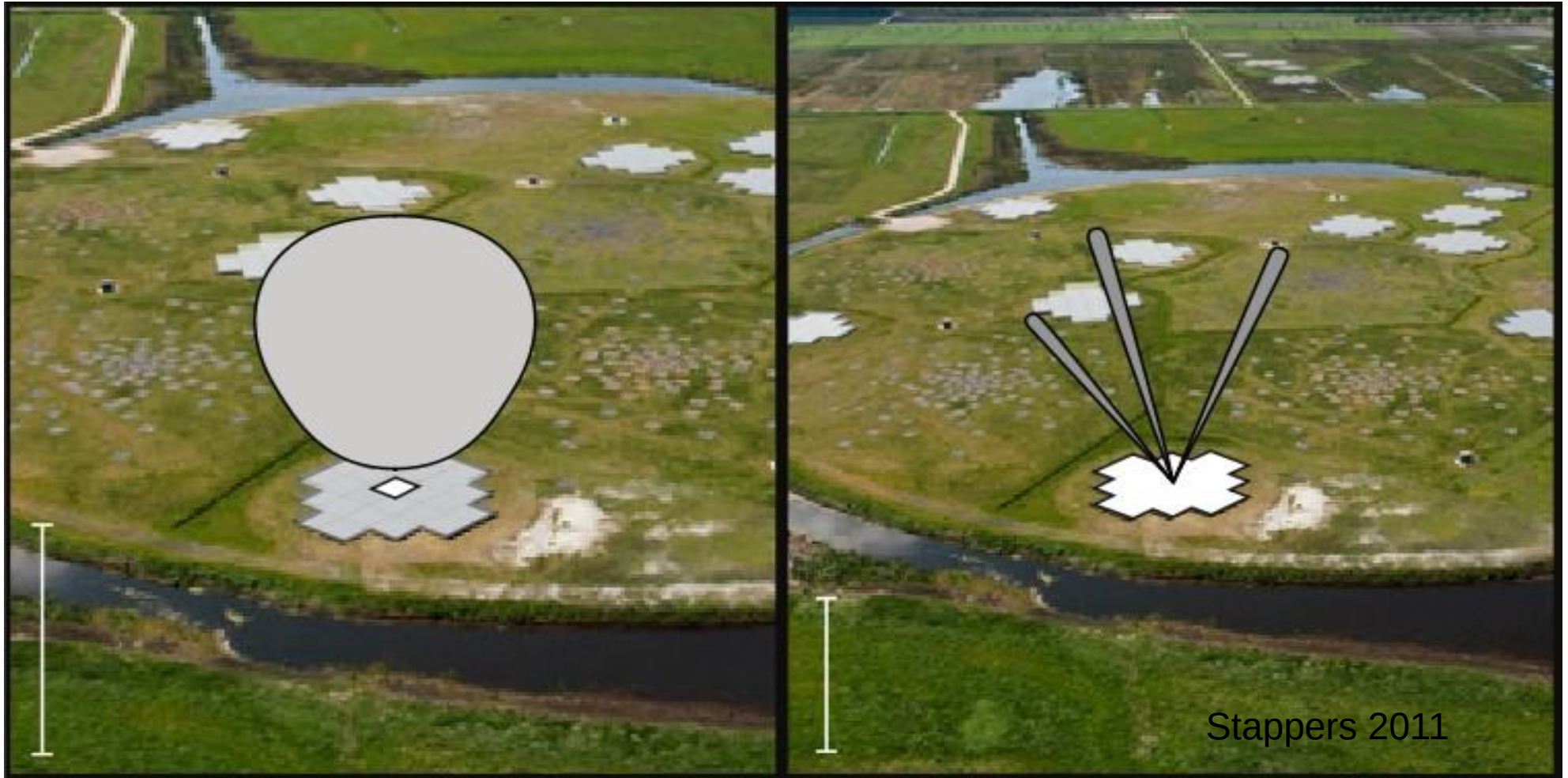
LOFAR station are phased arrays



LOFAR station are phased arrays



LOFAR station are phased arrays



We can point at different directions at the same time :

- Great for transient studies**
- Cover big areas on the sky**
- Calibration**

LoTSS

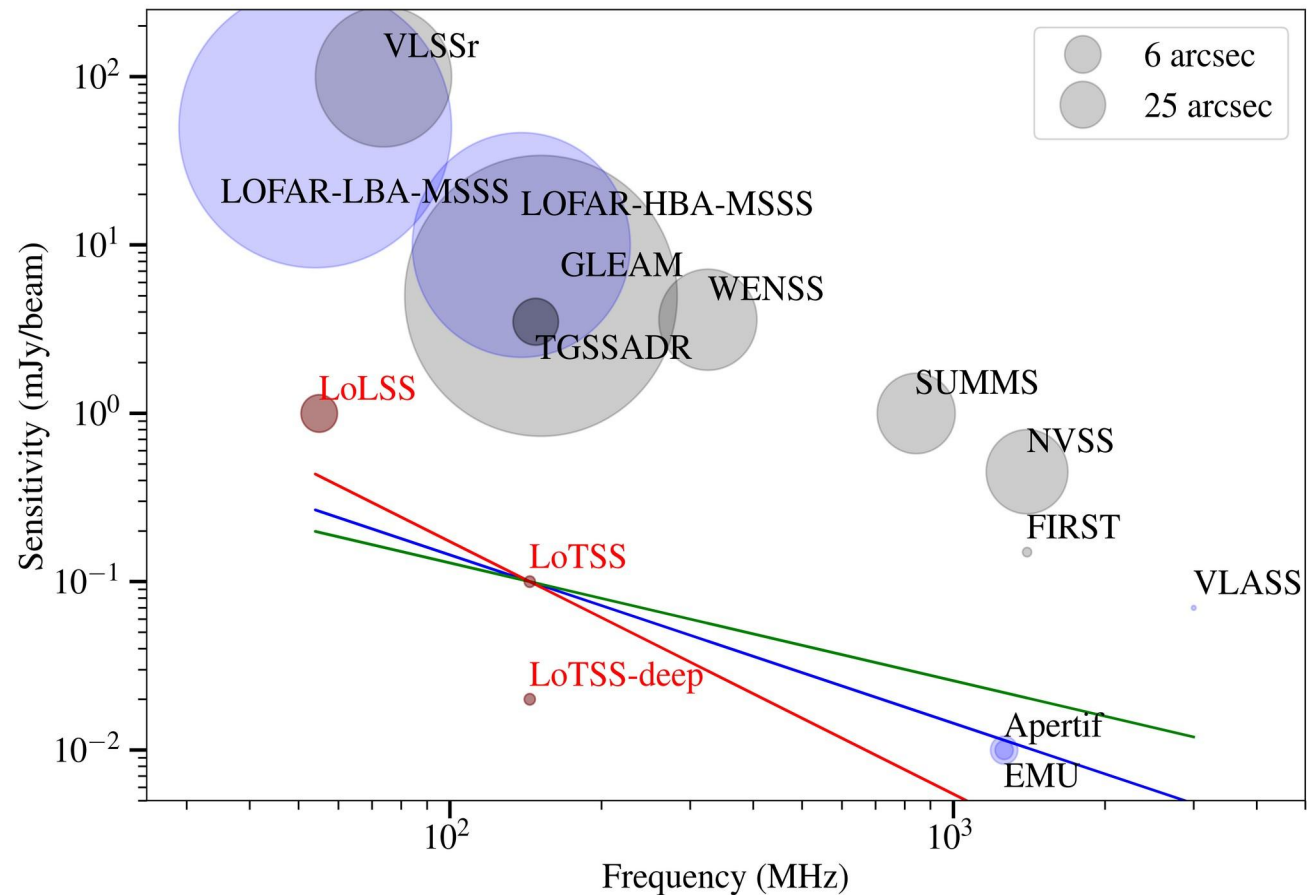
~16,000hrs of LOFAR
HBA observations.

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

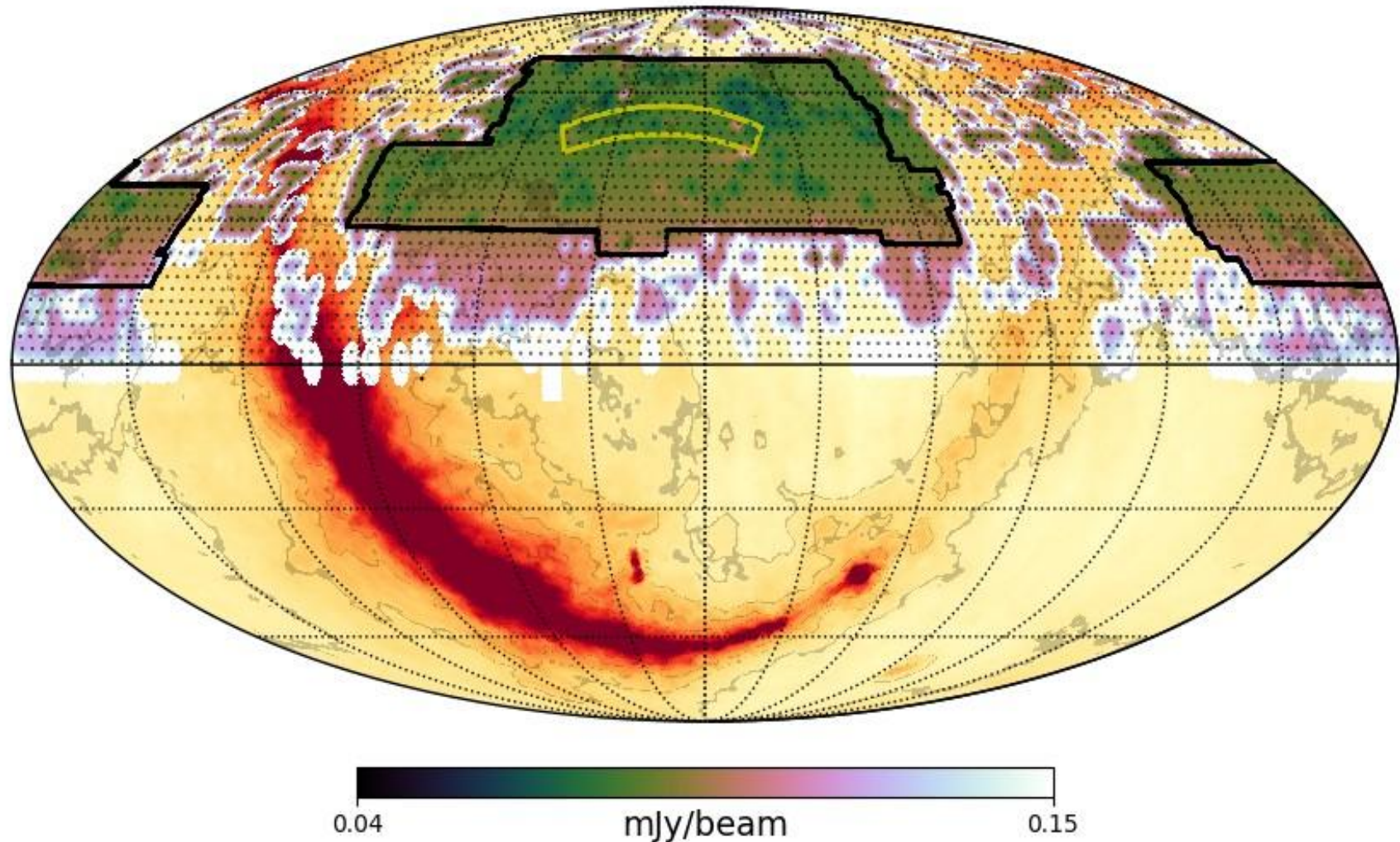
~55% observed.

Always observing with
full international array

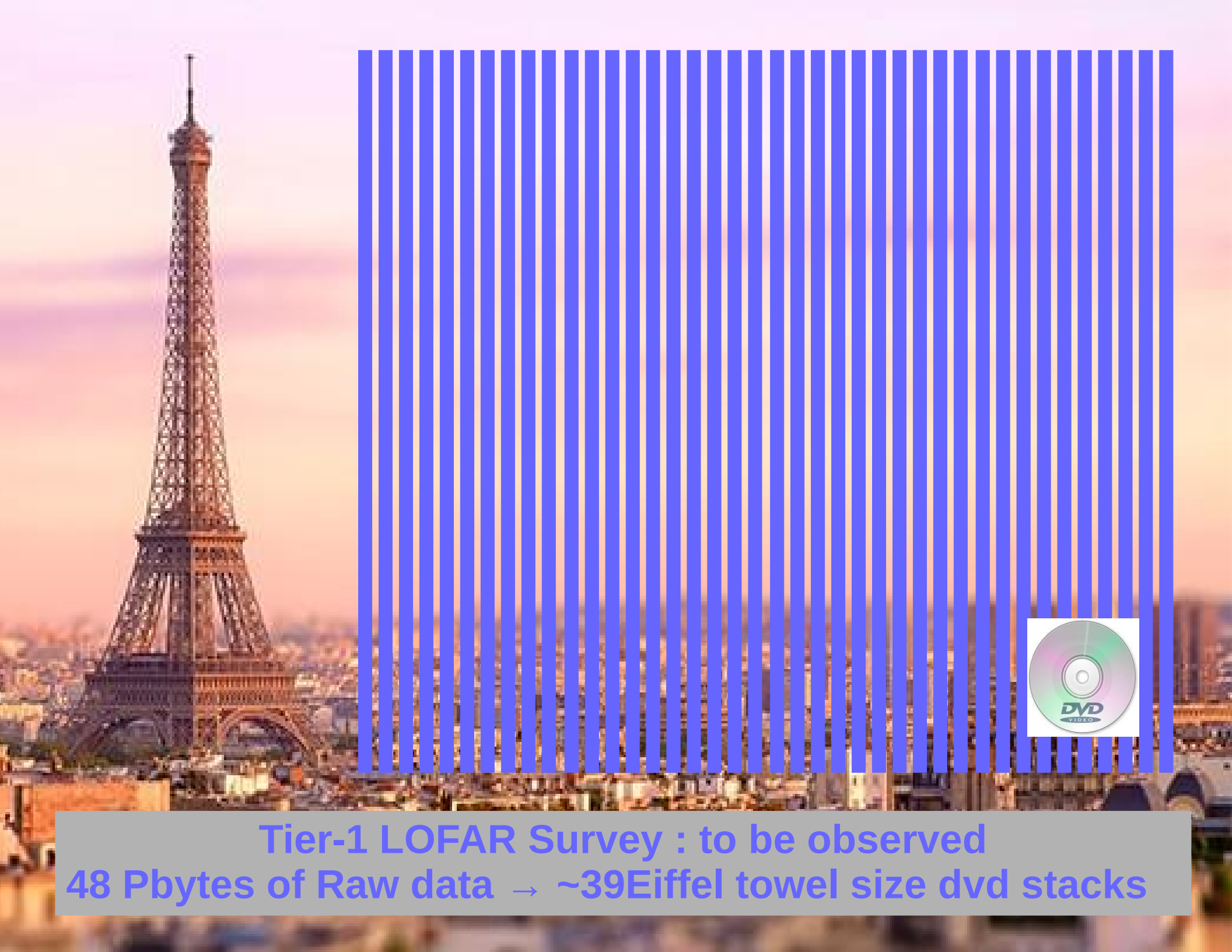
Aiming to complete
observations in ~3-4
years and stay
relevant even into the
SKA era.



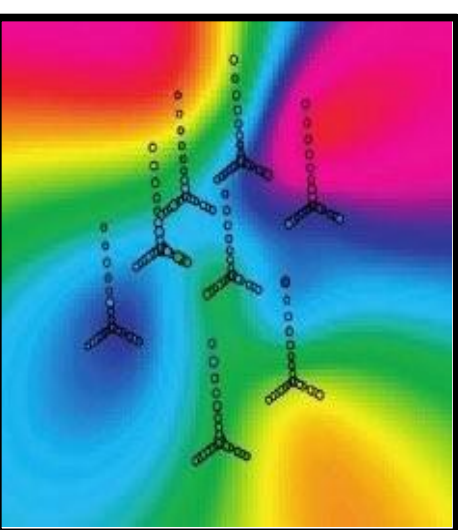
LoTSS data release 2 (LoTSS-DR2)



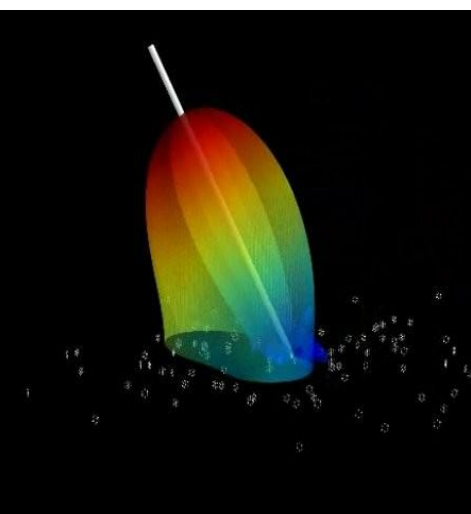
LoTSS-DR1 (outlined in yellow) is fully public. LoTSS-DR2 (outlined in black) is coming soon. This contains **4,395,448** radio components in 5634 square degrees. It consists of 841 different pointings and a total of 7.6PB of data from 26 different projects were processed using ~9million cpu hours. LoTSS-DR2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



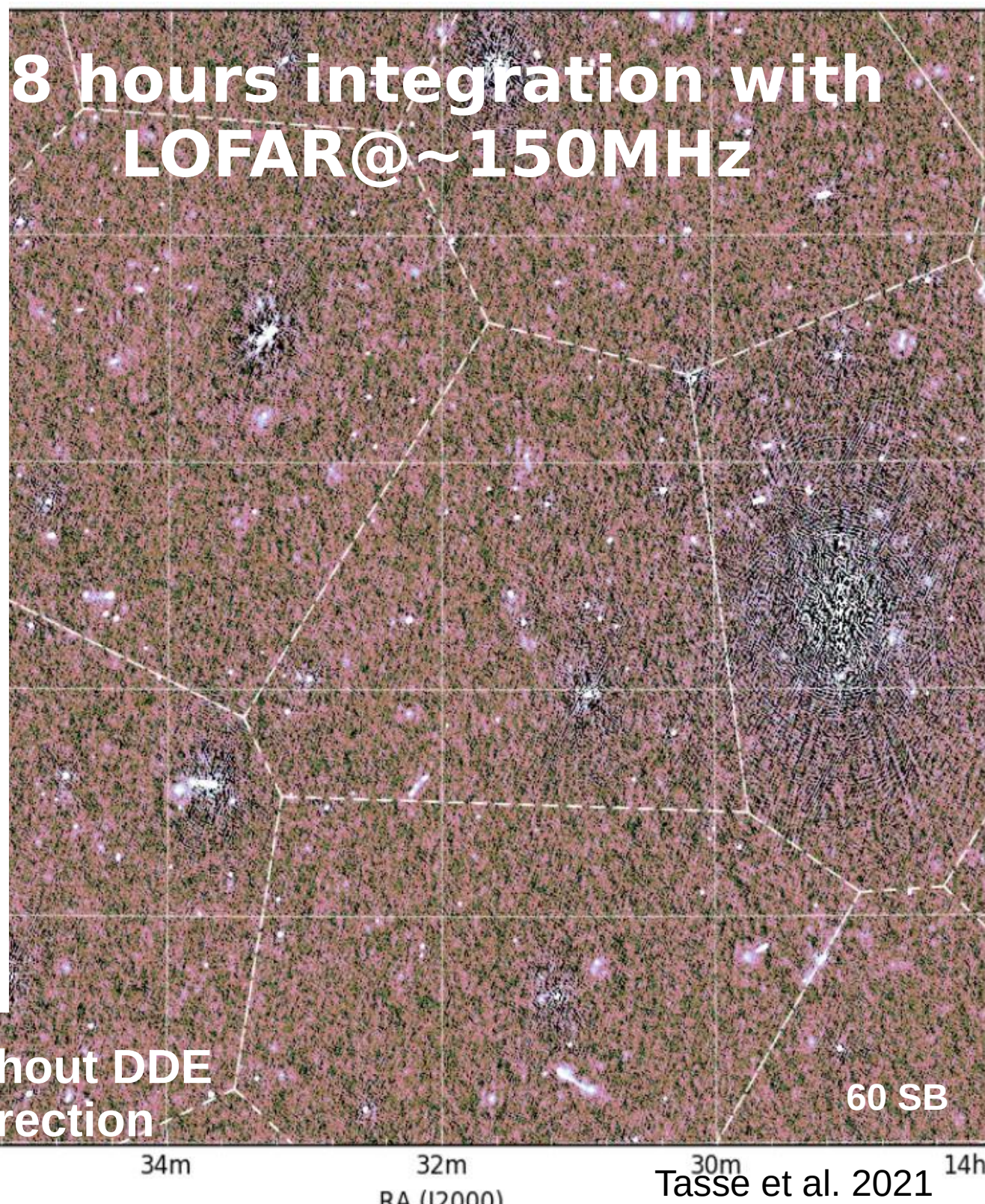
Tier-1 LOFAR Survey : to be observed
48 Pbytes of Raw data → ~39Eiffel tower size dvd stacks



**Ionospheric
disturbance + Faraday
rotation**



Station lobes



**Without DDE
correction**

60 SB

+33°40'
36m

34m

32m

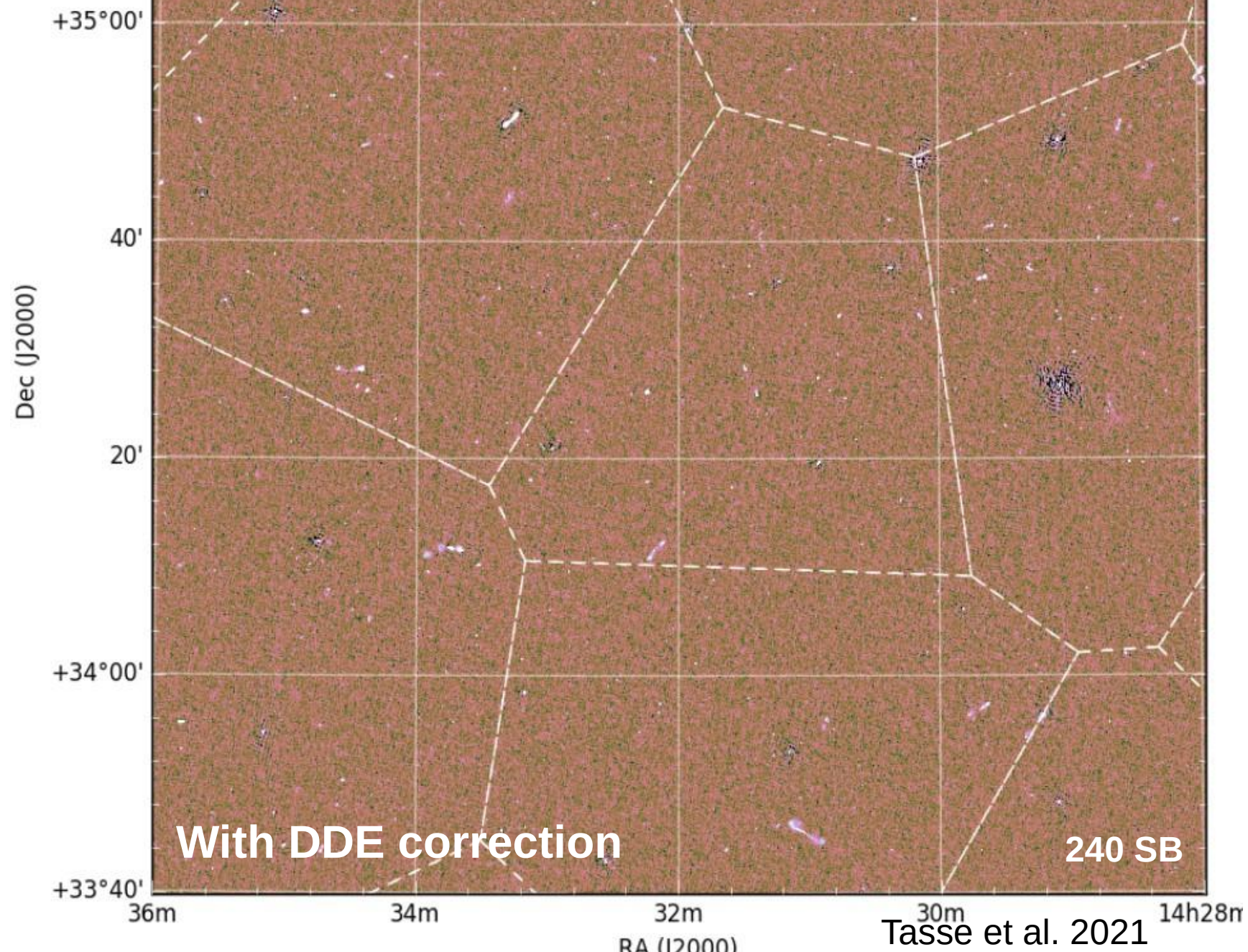
30m

14h28m

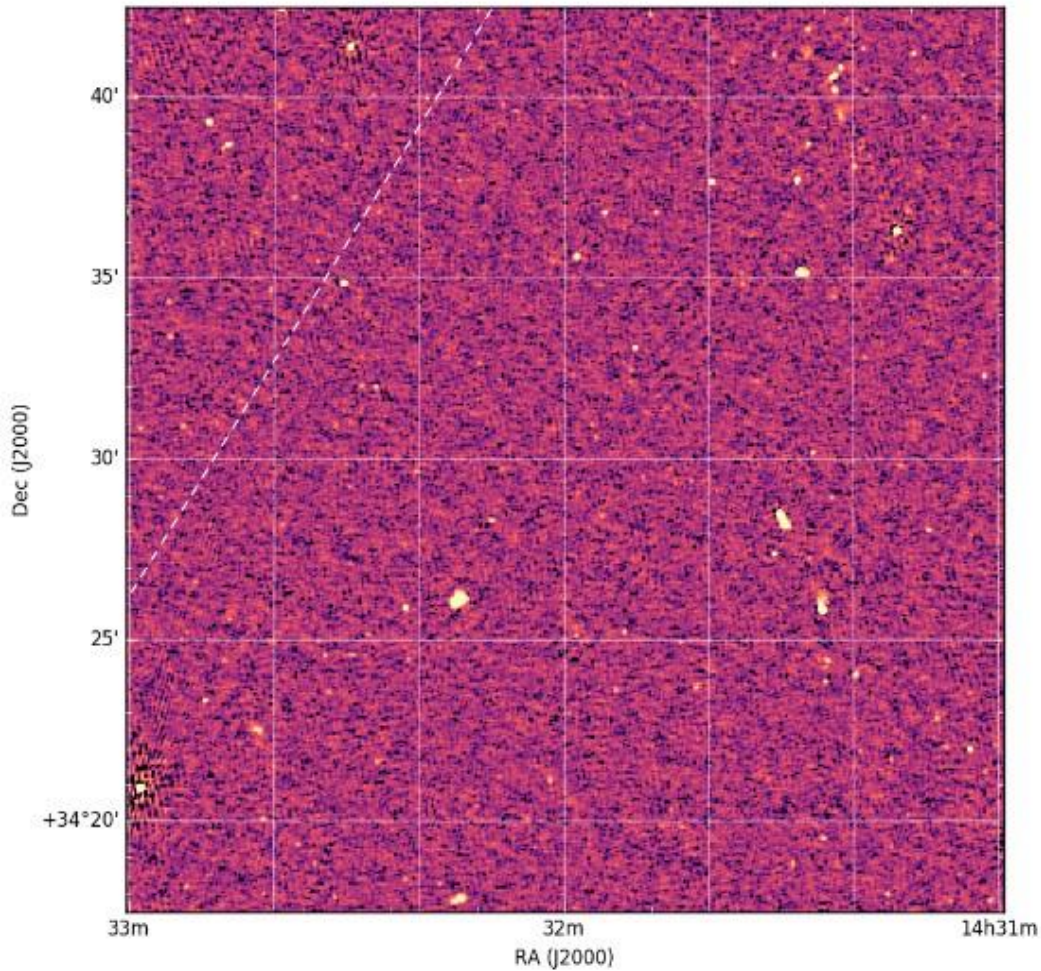
RA (J2000)

Tasse et al. 2021

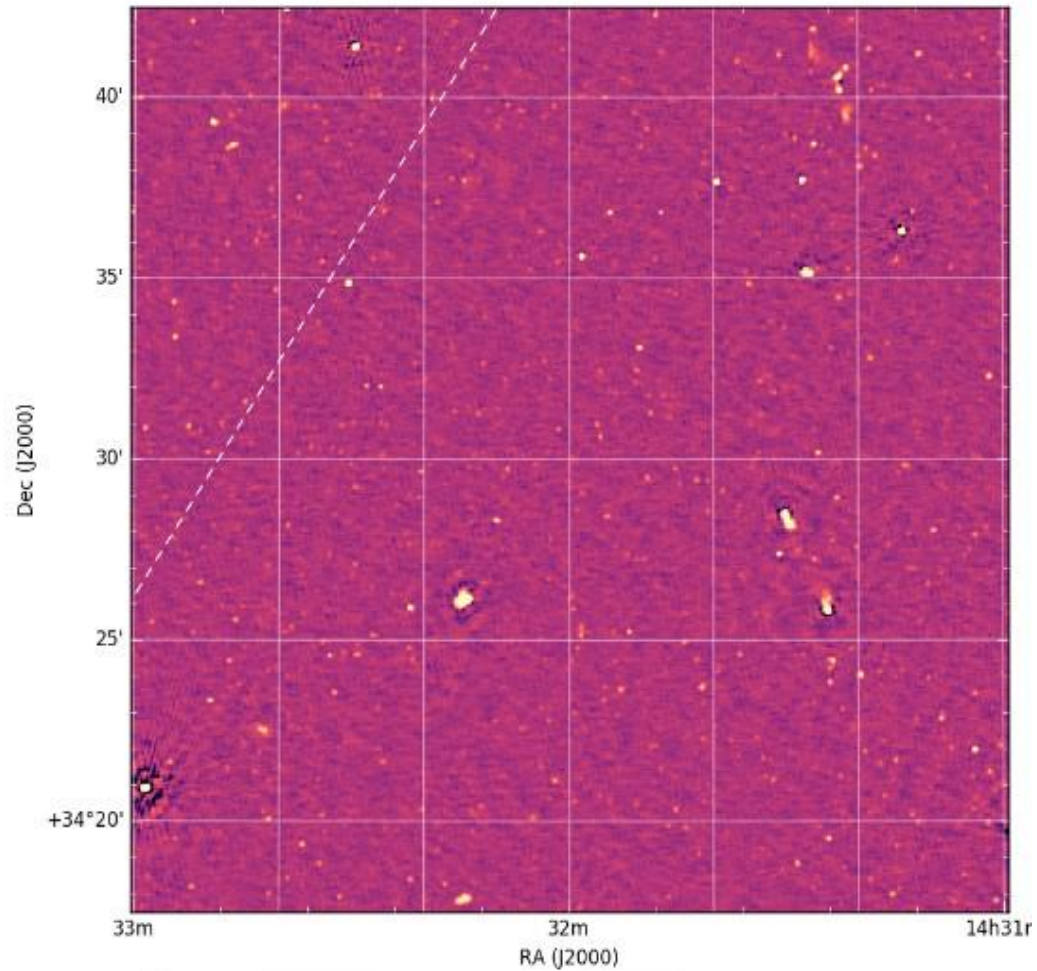
8 hours integration with LOFAR@~150MHz



Tier-2 deep fields



8 hours



80 hours

<https://lofar-surveys.org/>

LOFAR SURVEYS

Welcome The surveys Citizen Science News and media For astronomers Log in

Welcome to the LOFAR Surveys website

Performing increasingly sensitive surveys is a fundamental endeavour of astronomy. Over the past 60 years, the depth, fidelity, and resolution of radio surveys has continuously improved. However, new, upgraded and planned instruments are capable of revolutionising this area of research. The [International Low-Frequency Array \(LOFAR\)](#) is one such instrument. LOFAR offers a transformational increase in radio survey speed compared to existing radio telescopes. It also opens up a poorly explored low-frequency region of the electromagnetic spectrum. An important goal that has driven the development of LOFAR since its inception is to conduct wide and deep surveys in order to advance our understanding of the formation and evolution of galaxies, clusters, and active galactic nuclei (AGN).

Explore this website to learn more about [the LOFAR surveys](#) and their scientific results, including our [data releases](#), [publications](#) and [citizen science programme](#).

NEWS: [Ultra-sensitive radio images reveal thousands of star-forming galaxies in early Universe](#) (07/04/21)

NEWS: [ASTRON press release on LBA survey](#) (19/02/21)

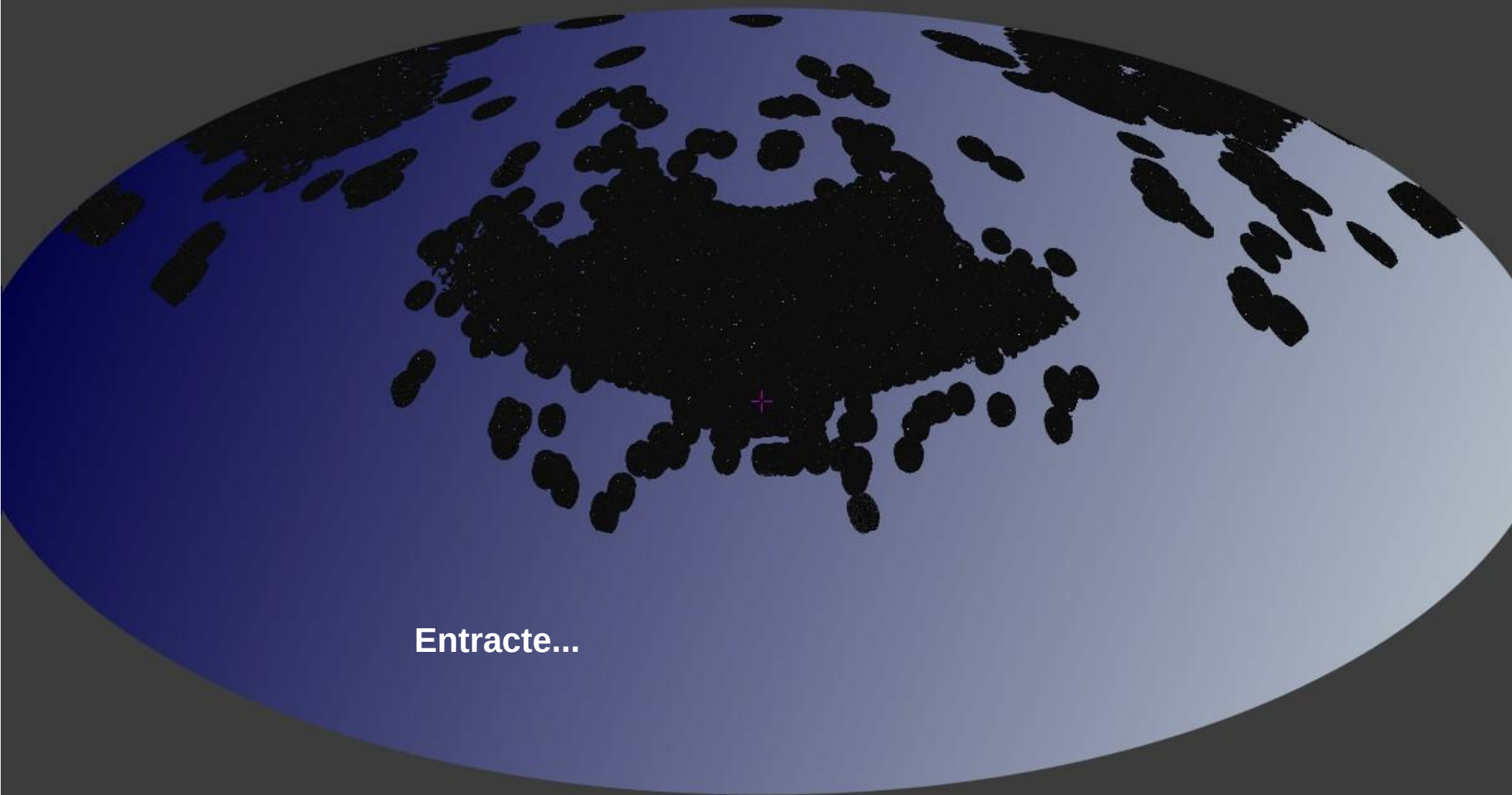
NEWS: [ASTRON press release on RGZ launch](#) (26/02/2020)

NEWS: [Radio Galaxy Zoo \(LOFAR\) launches](#) (25/02/2020)

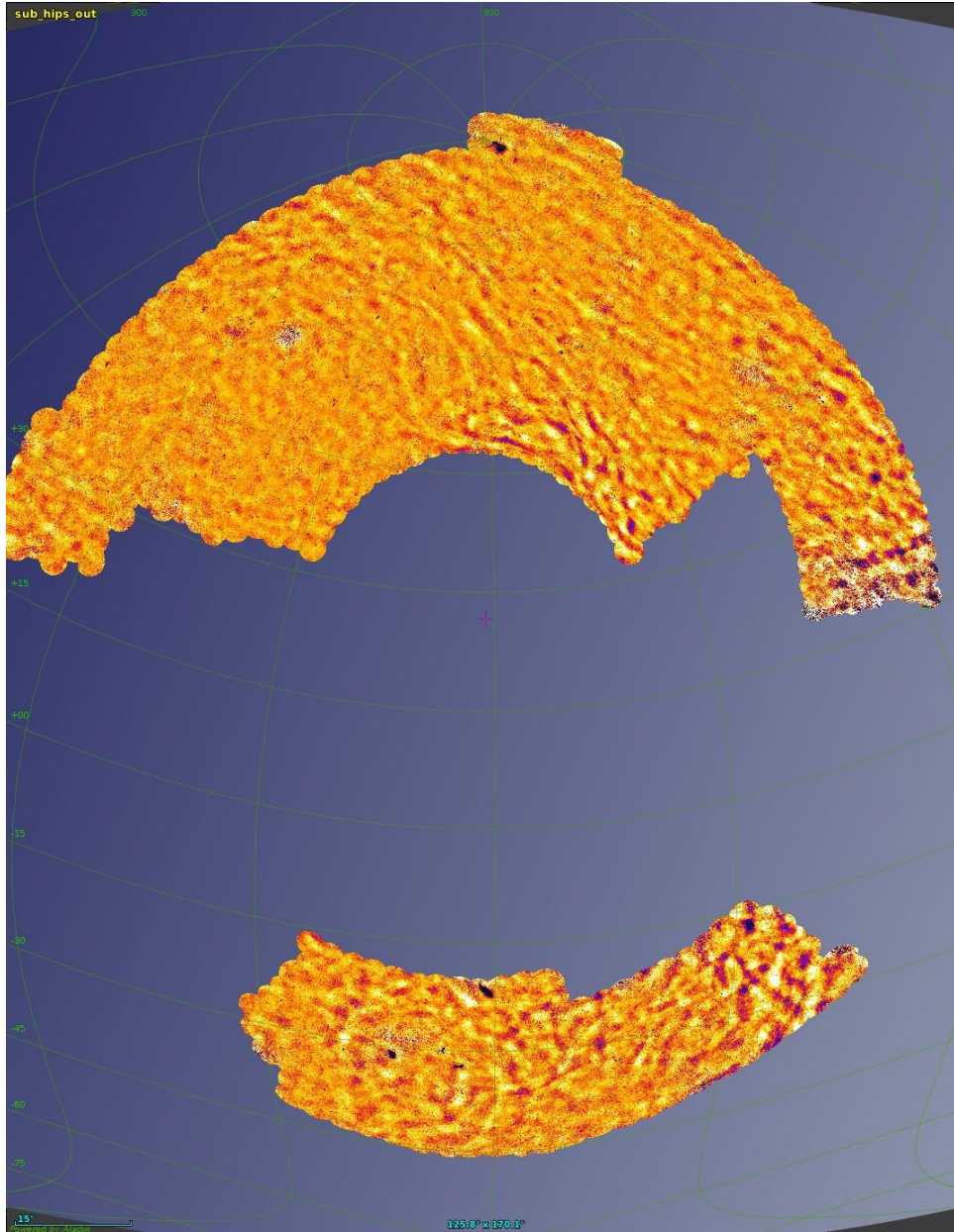
NEWS: [LOFAR pioneers new way to study exoplanet environments](#) (17/02/2020)



- In Astronomy & Astrophysics special issue
 - 25 papers in February 2019 (LoTSS-wide DR1)
 - 14 papers in April 2021 (LoTSS-deep DR1)
- Coming soon:
 - LoTSS-wide DR2
 - eLoTSS (haute résolution angulaire)

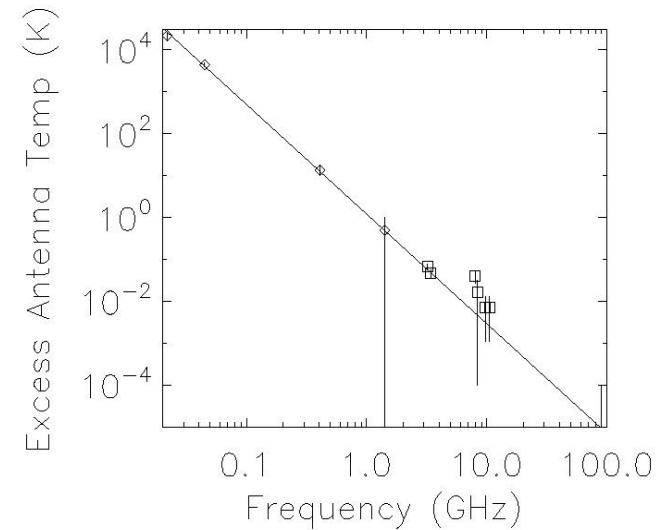


LoTSS-DR2 — Varied science results

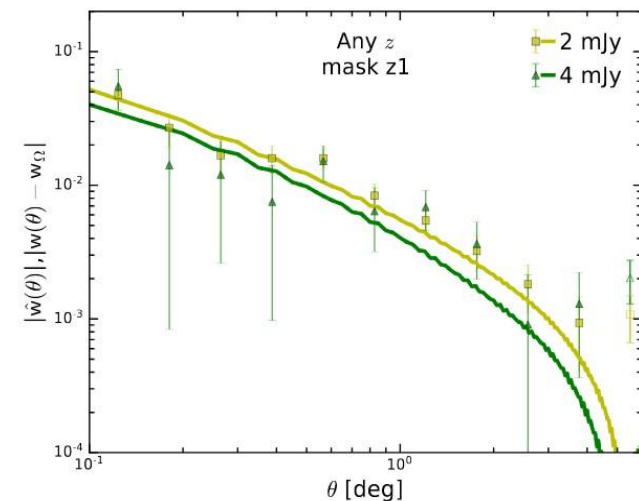


Oei+ in prep - Large scale galactic emission

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

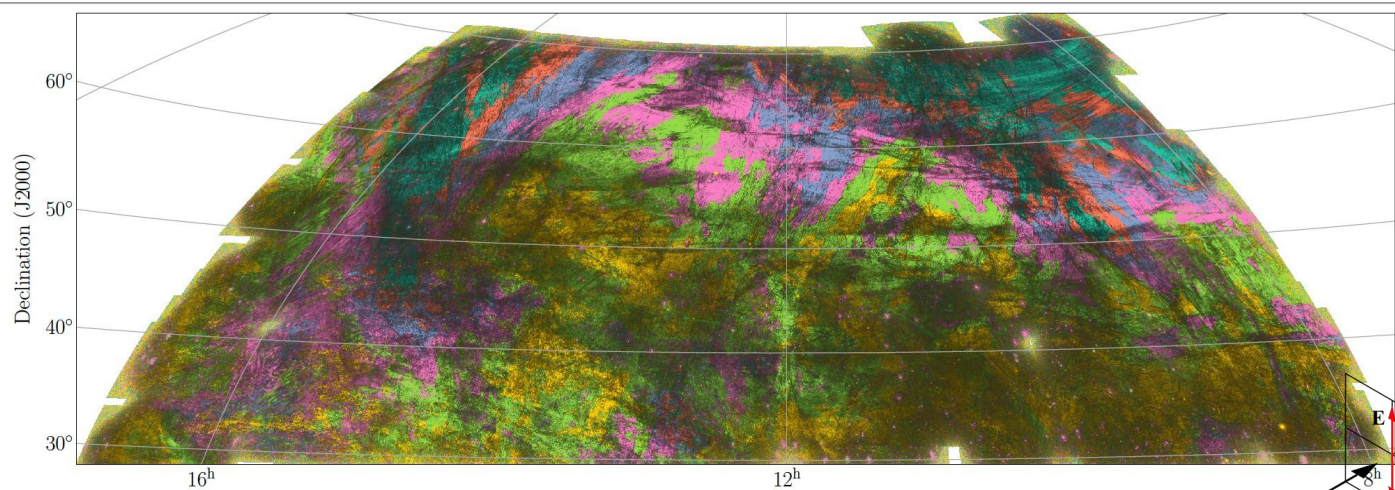


Hardcastle+ 2020 - sky temperature

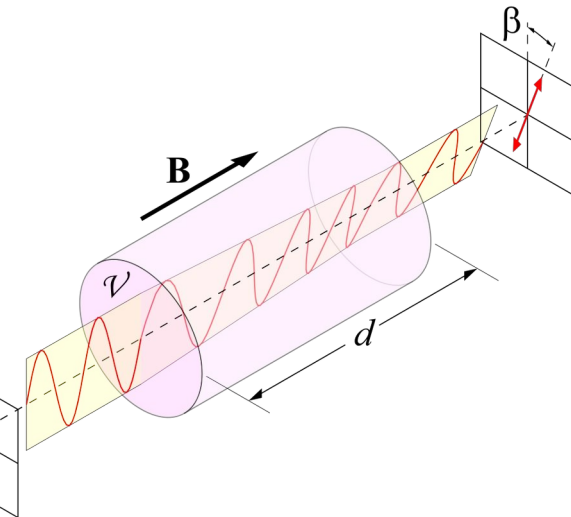


Siewert+ 2020 - Two-point correlation function compared to cosmological simulations.

LoTSS-DR2 — Varied science results

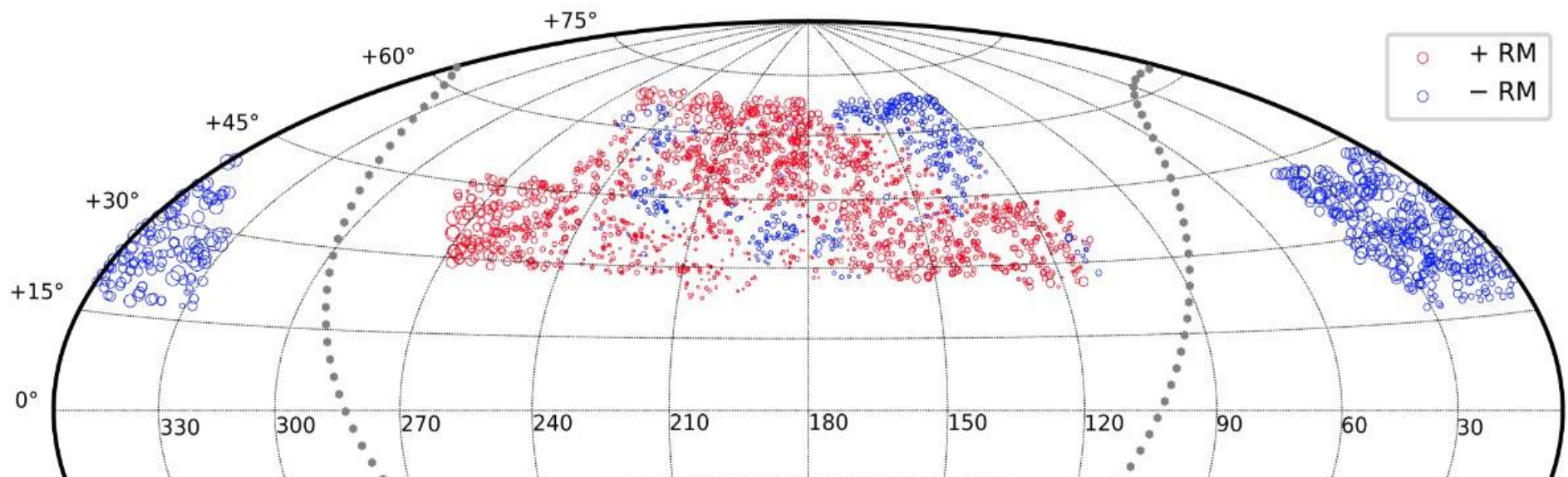


Erceg+ in prep - RM of low surface brightness galactic structures

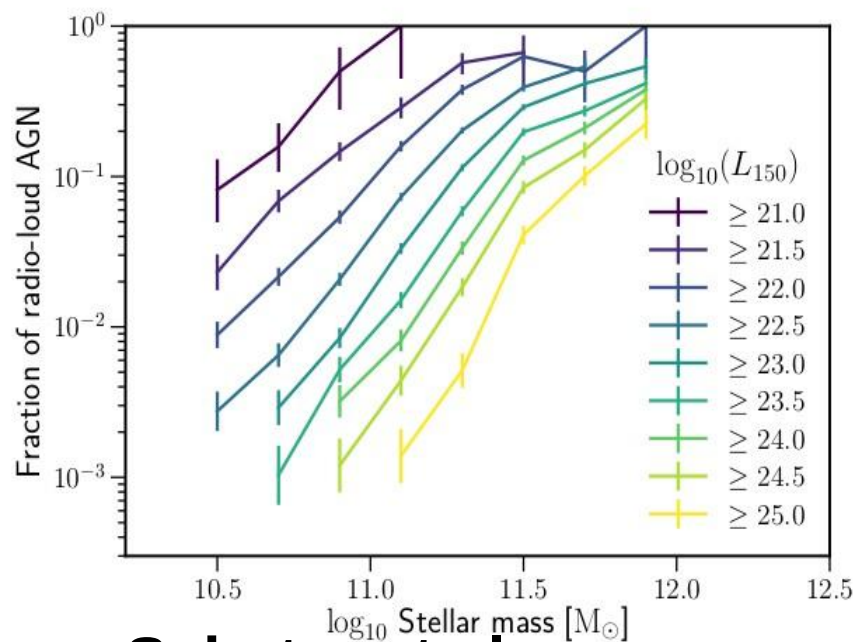
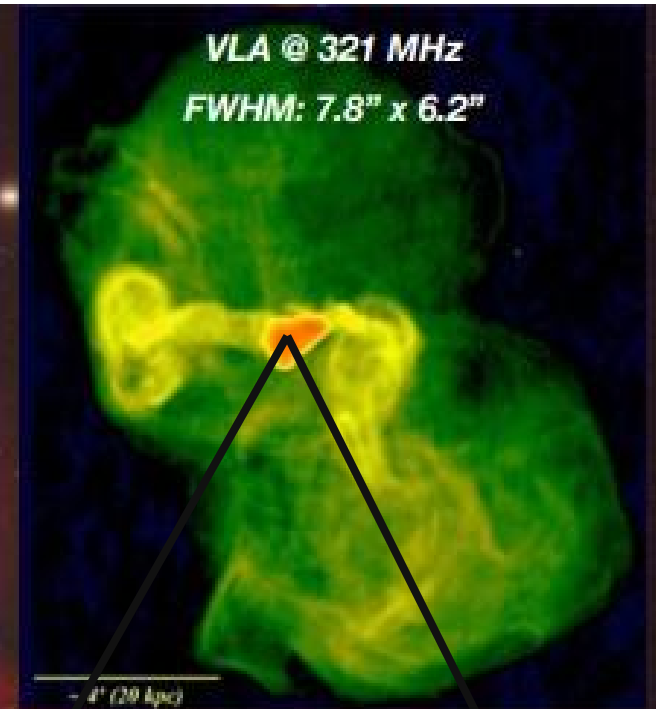
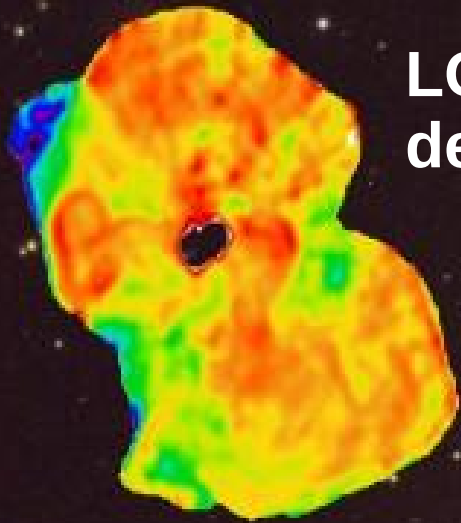


Wide area polarisation at multiple resolutions allows for studies of polarised galactic and extra galactic sources as well as e.g. pulsars or stars

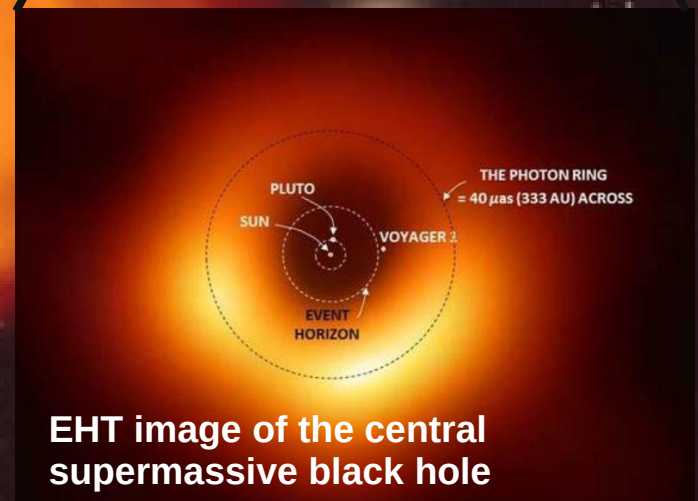
O'Sullivan+ in prep - RM of extra galactic sources



LOFAR M87 image by
de Gasperin et al.

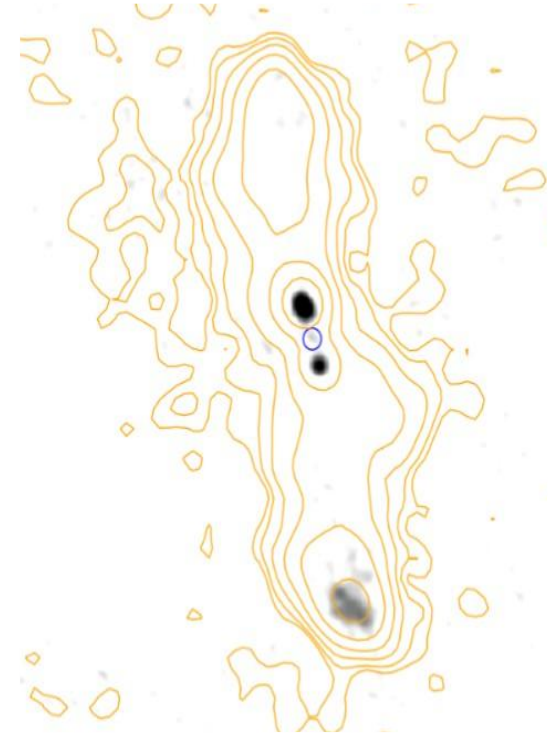
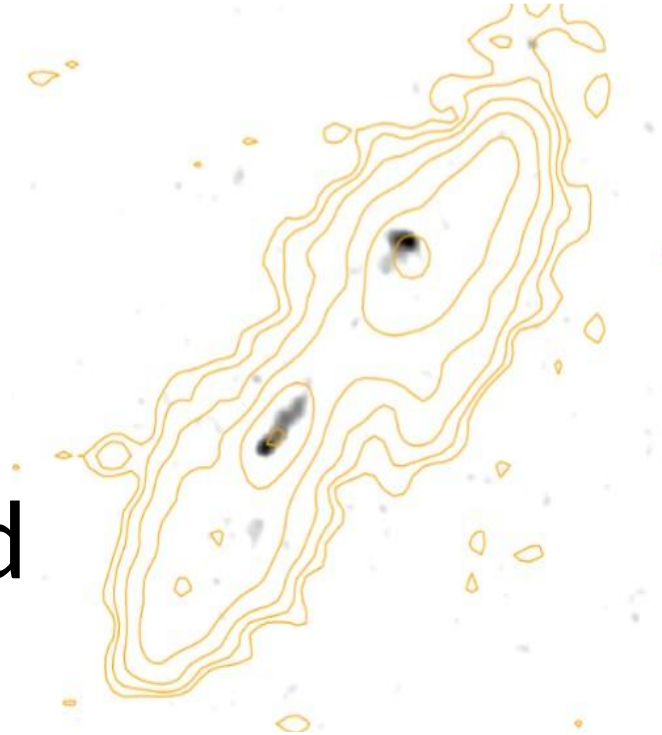


Sabater et al.



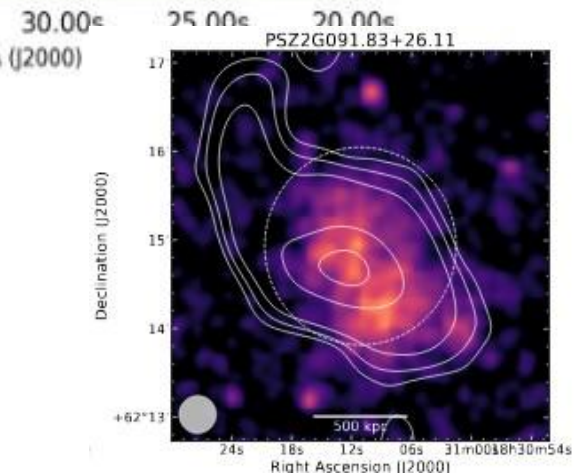
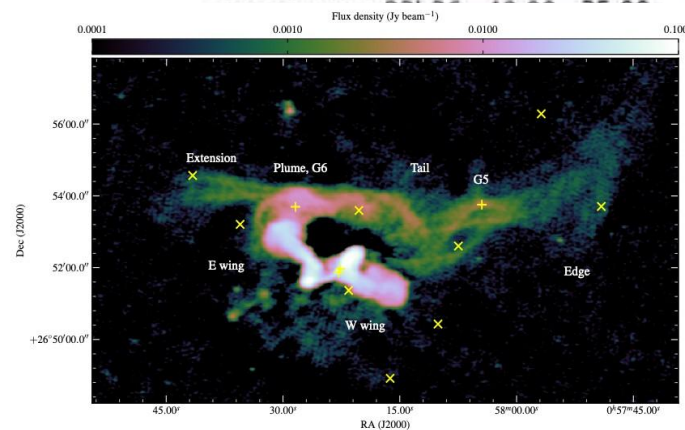
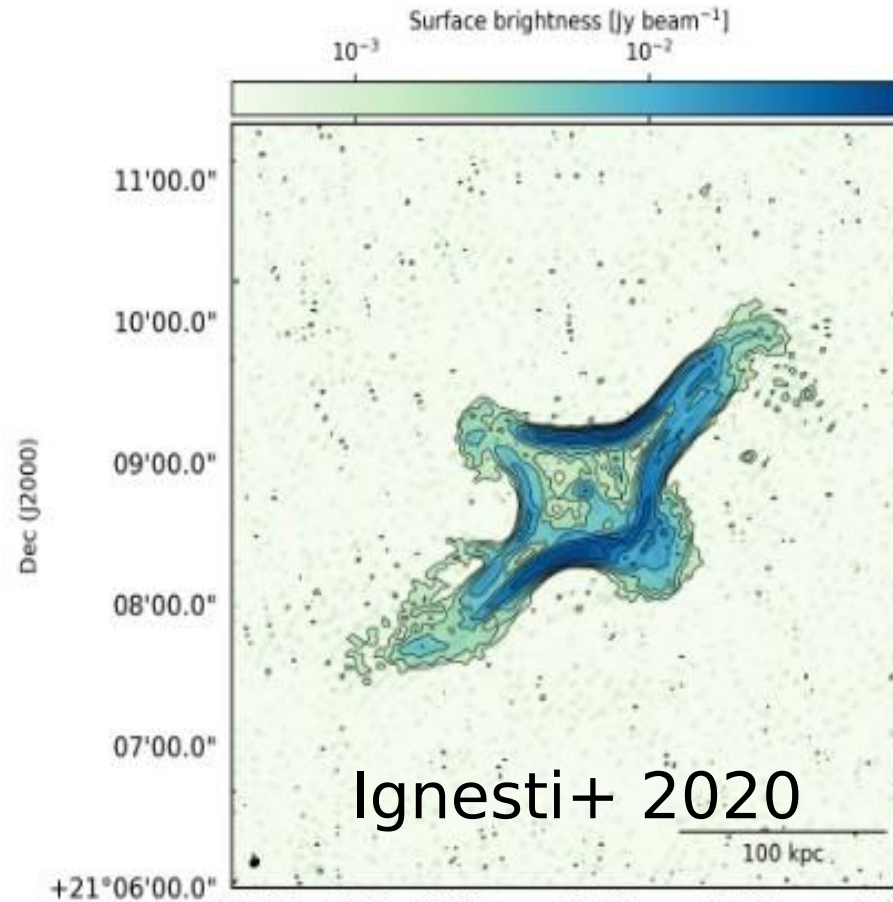
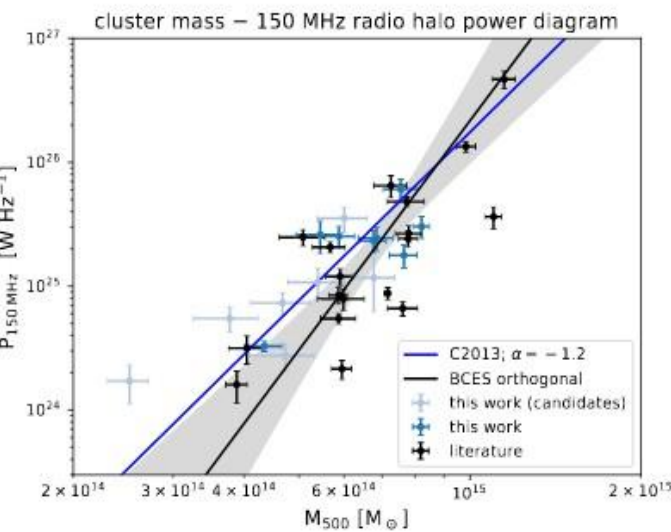
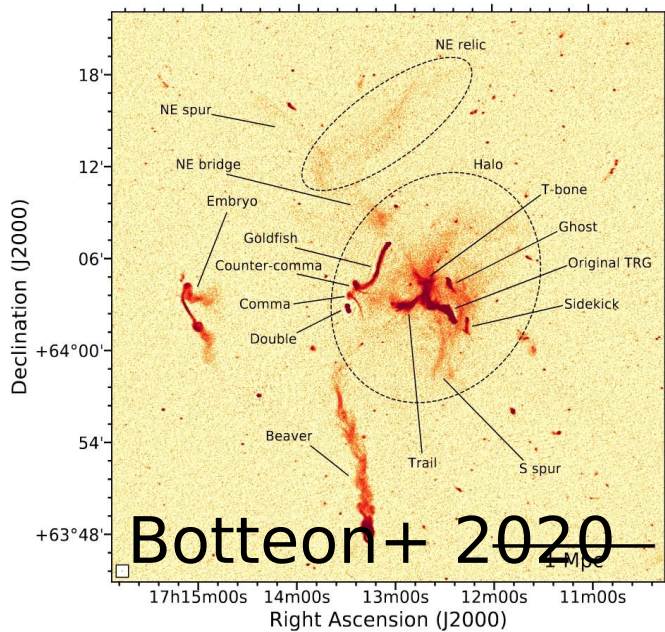
EHT image of the central
supermassive black hole

Jet dynamics Feedback and duty cycle

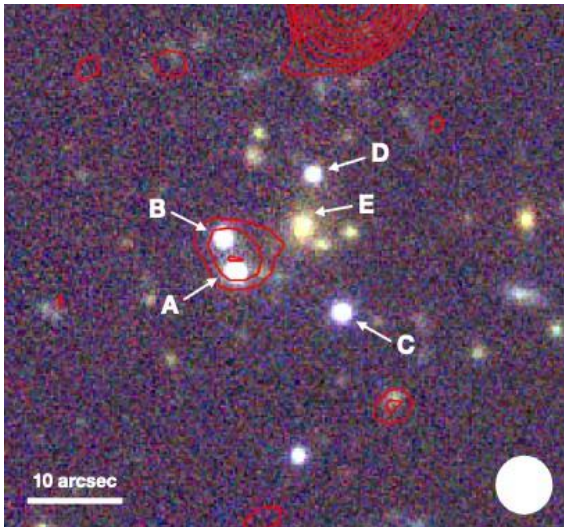


Mahatma et al.

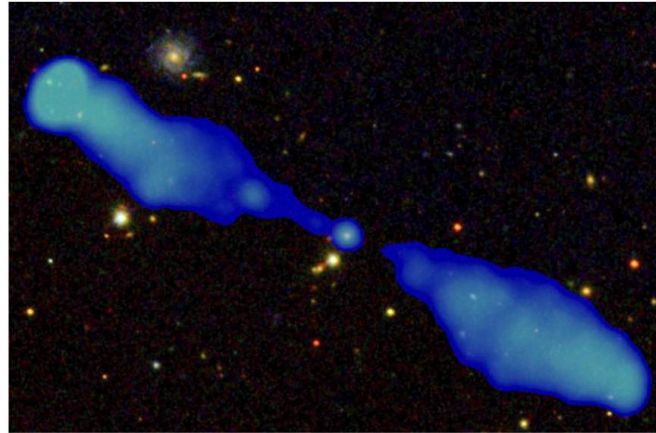
LoTSS-DR2 — Varied science results



LoTSS-DR2 — Varied science results

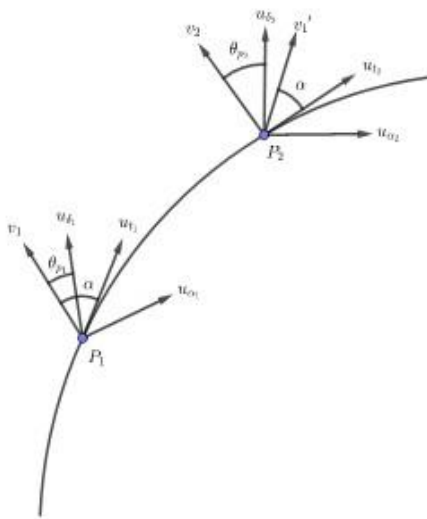


McKean+ Gravitational lenses

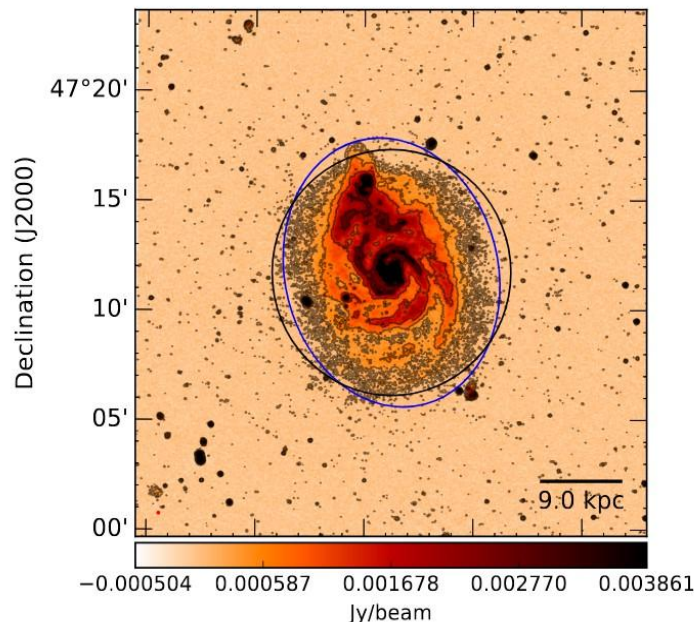


Dabhabe+ 2020 giant radio galaxies
(also Bruni+ in prep)

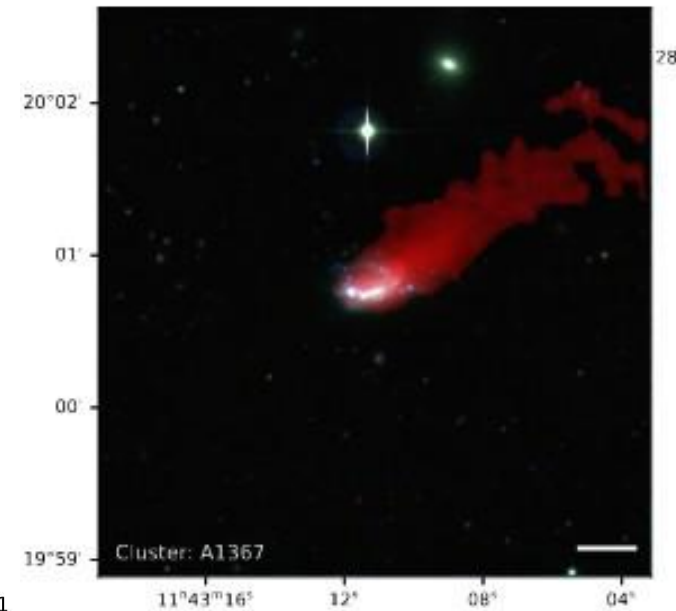
The majority of the science is from large statistical studies or characterising/discovering rarer objects using our standard imaging and catalogue products



Osinga+ 2020 alignment of radio source angles



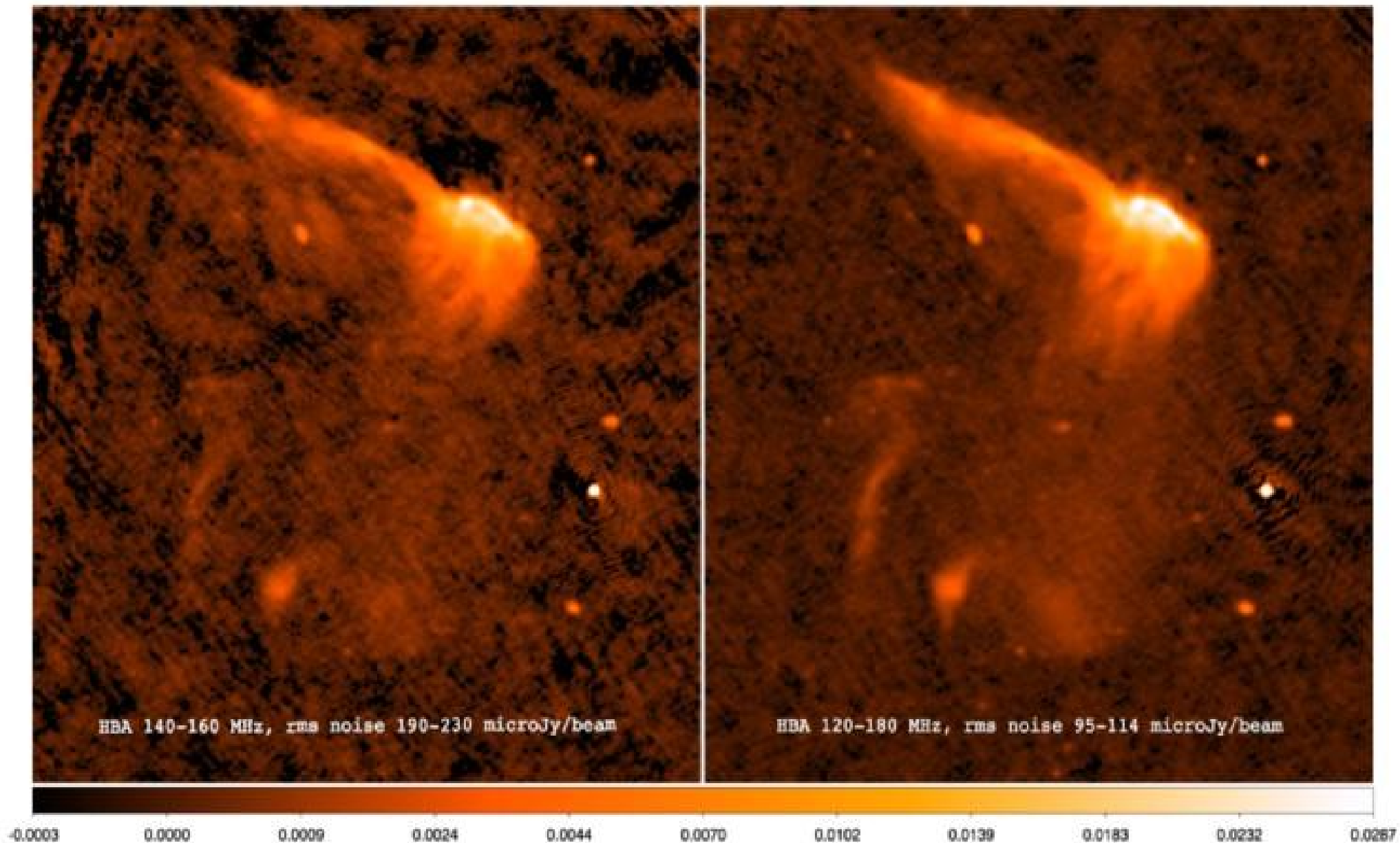
Hessen+ in prep - Nearby galaxy populations

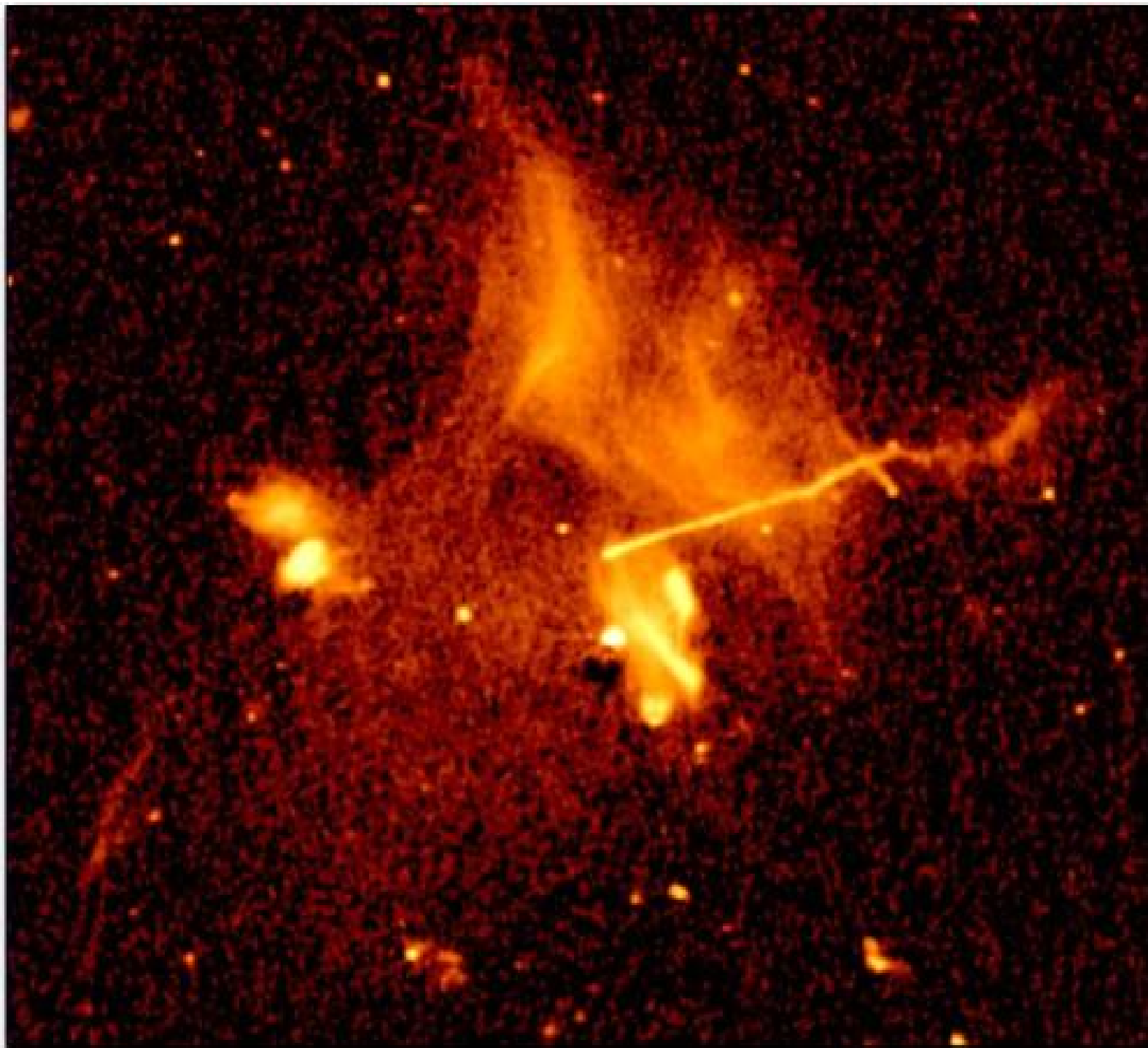


Roberts+ in prep Jellyfish galaxies.

Toothbrush cluster

van Weeren 2014 in prep.





Abell 2256

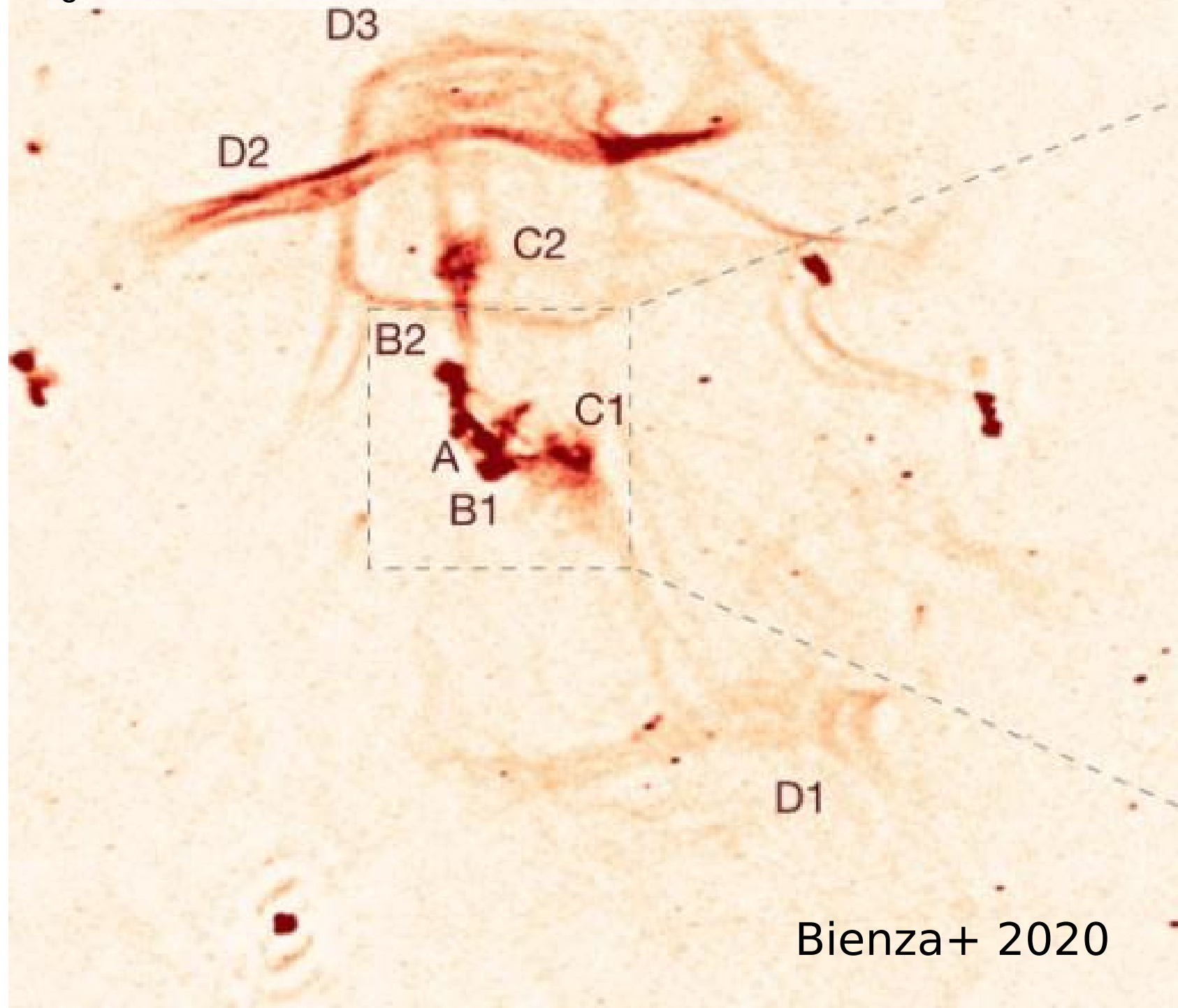
120-180 MHz

5 arcsec

130 μ Jy/beam

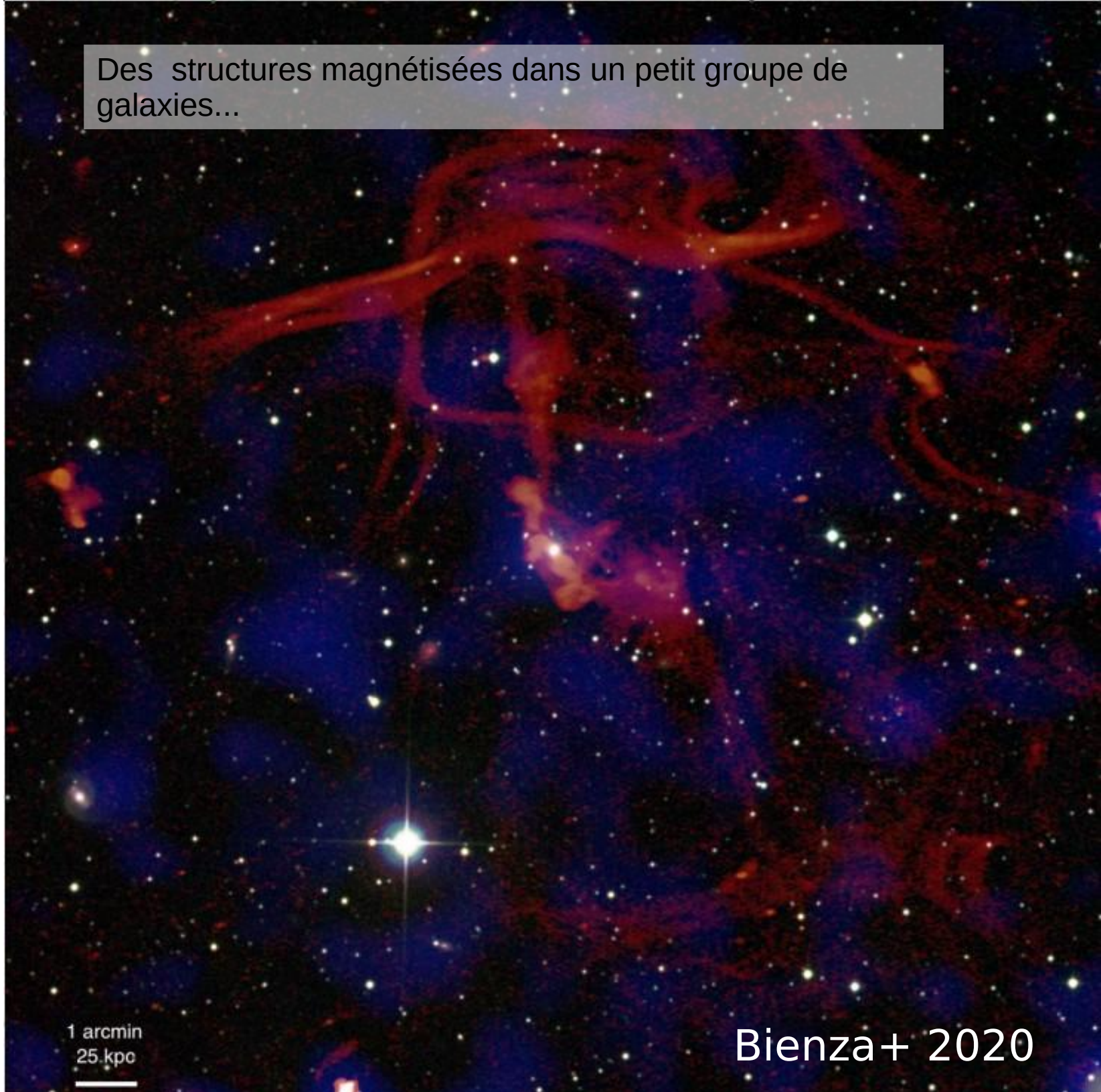
*Image courtesy:
R. van Weeren*

Des structures magnétisées dans un petit groupe de galaxies...



Bienza+ 2020

Des structures magnétisées dans un petit groupe de galaxies...



1 arcmin
25 kpc

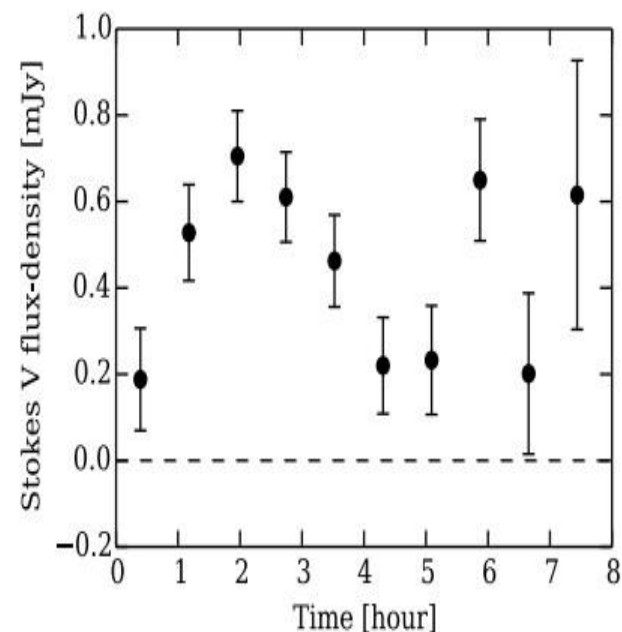
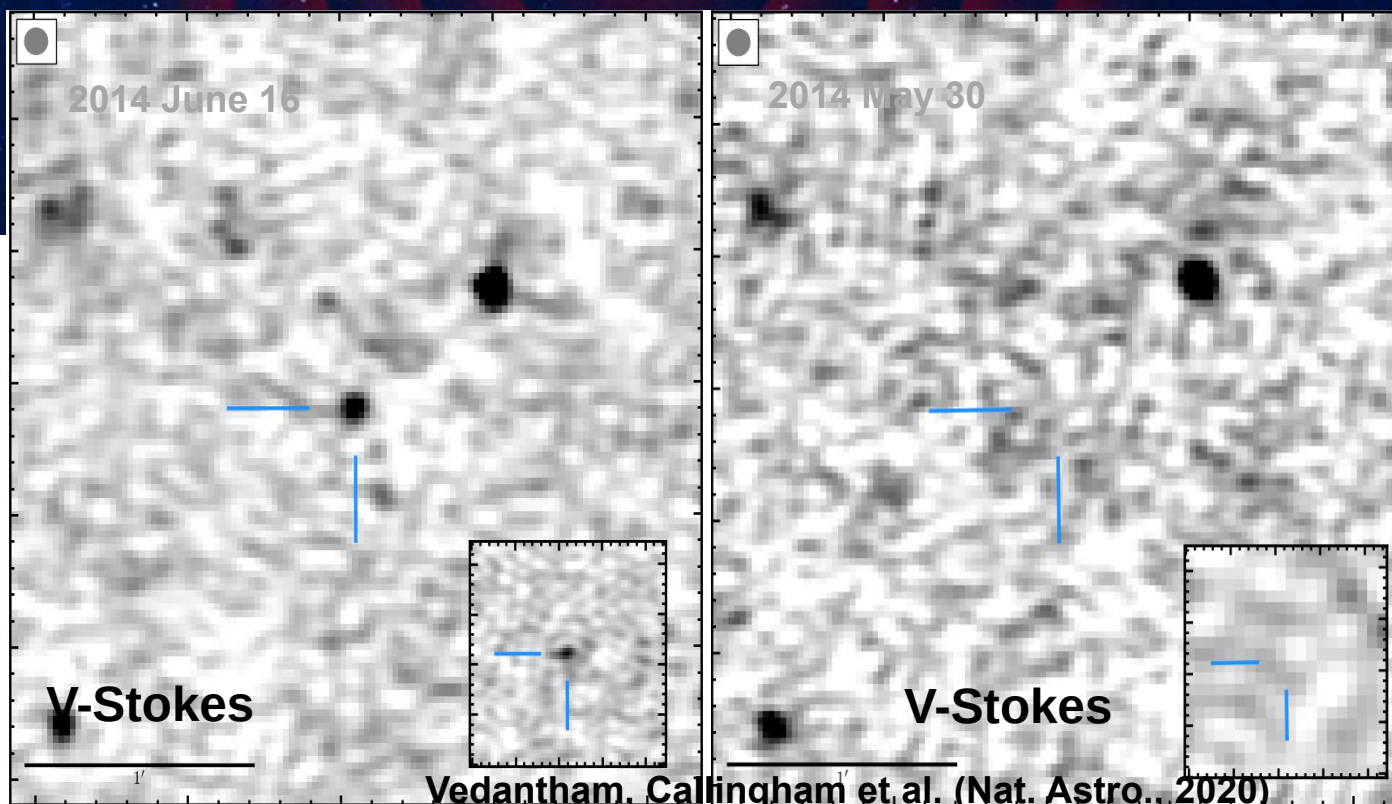
Bienza+ 2020

Ursus Major

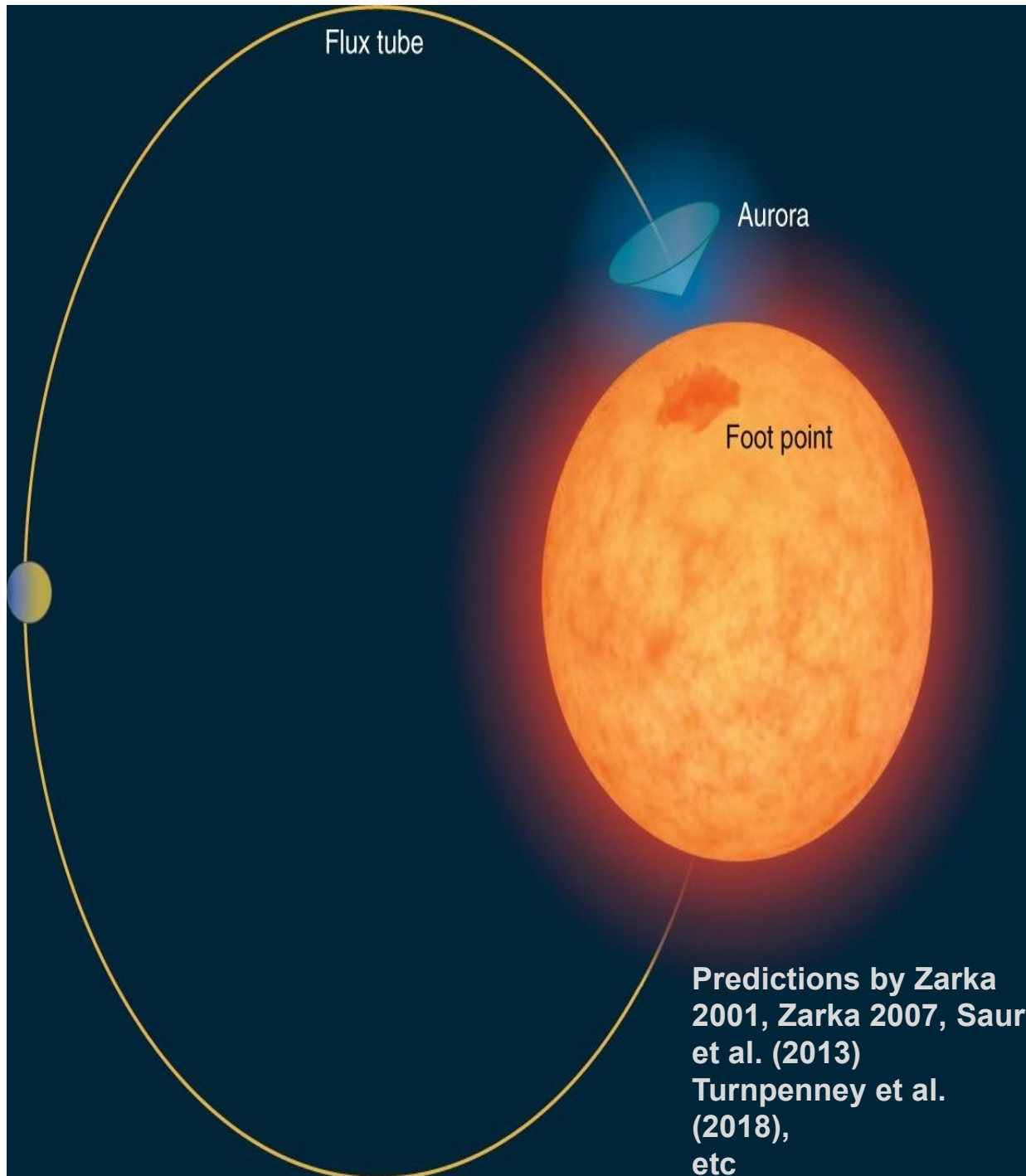
GJ1151 I-Stokes

Unexpected surprise

- Together with Tim Shimwell and Martin Hardcastle we decided to add a V-Stokes image at the end of the pipeline



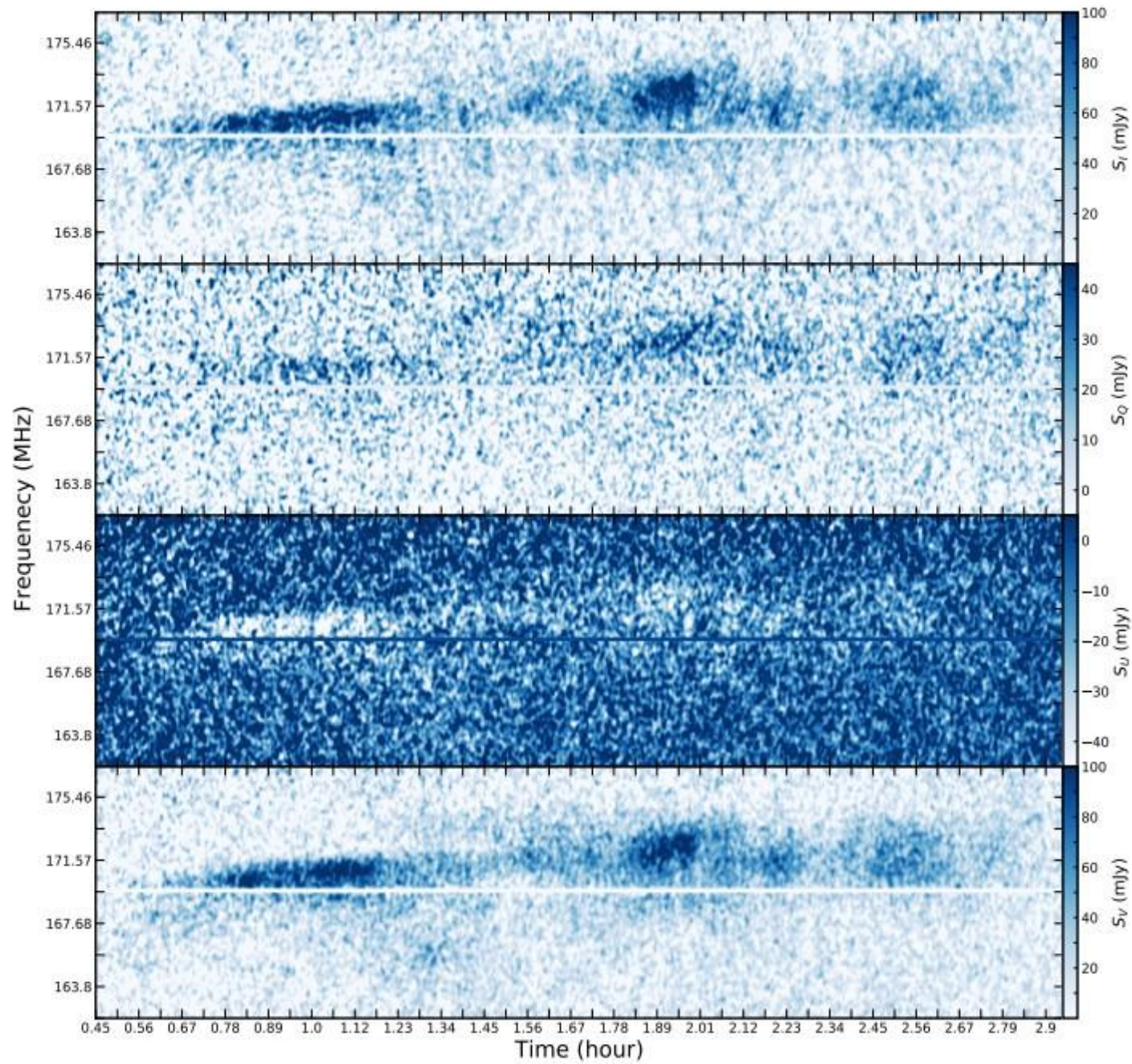
Interpretation of emission



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

Slide taken from Joe Callingham

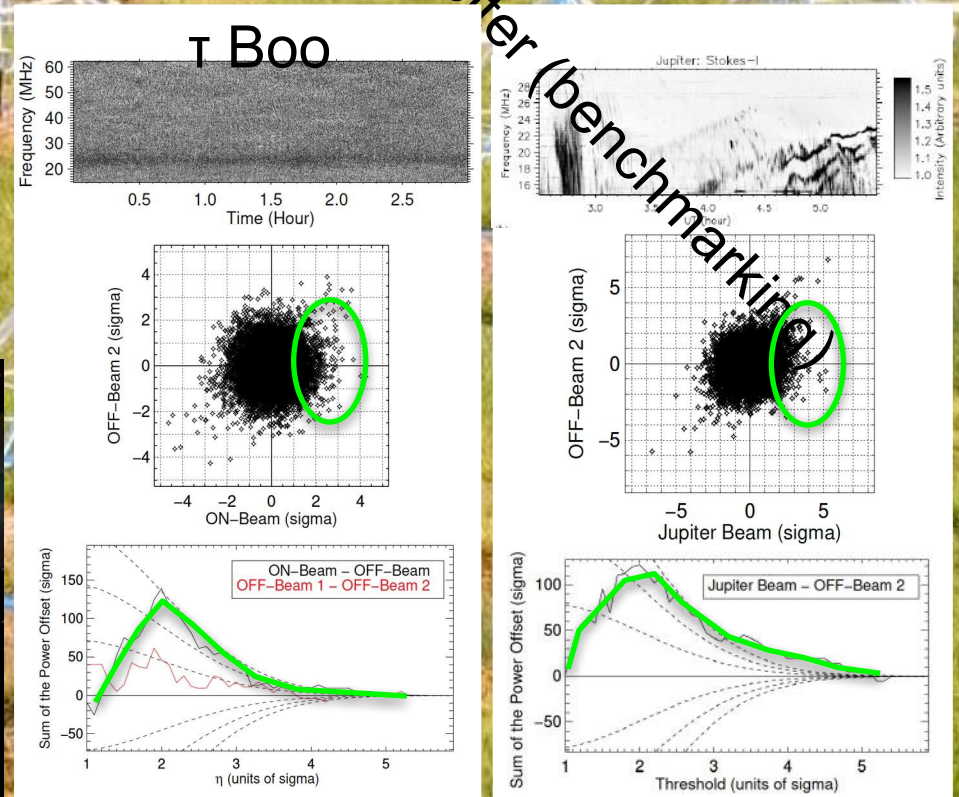


A resolved dynamic
spectra built using
DynSpecMS

Slide taken from Joe
Callingham

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

De LOFAR à NenuFAR

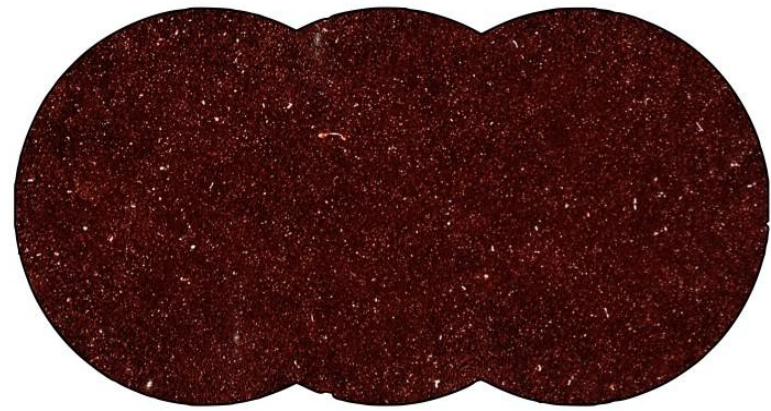


Détection avec LOFAR en mode faisceau de faibles sursauts radio provenant du système de l'exoplanète τ Bootis, 14-21 MHz, 10^{4-5} x Jupiter (3.2σ , à confirmer)
[Turner, Zarka..., A&A 2020]

SKA-0: MeerKAT

- World class/beating cm wavelength telescope
- Local project, but international community involved
- **64 dishes**, spread over 8km
- **0.58-14 GHz** frequency coverage using 3 feeds
- **Construction by 2017**
- Major international science interest
- Discussion underway to **integrate MeerKAT with SKA Phase 1**
- Specifications at <http://public.ska.ac.za>





COSMOS XMM-LSS
19.5 h / 1.6 deg² 37 h / 3.5 deg²

Continuum Early Science data

The MIGHTEE continuum Early Science
data in COSMOS and XMM-LSS
(Heywood et al., MNRAS, 2021)



COSMOS XMM-LSS
140 h / 4.3 deg² 300 h / 14.4 deg²

Full survey data

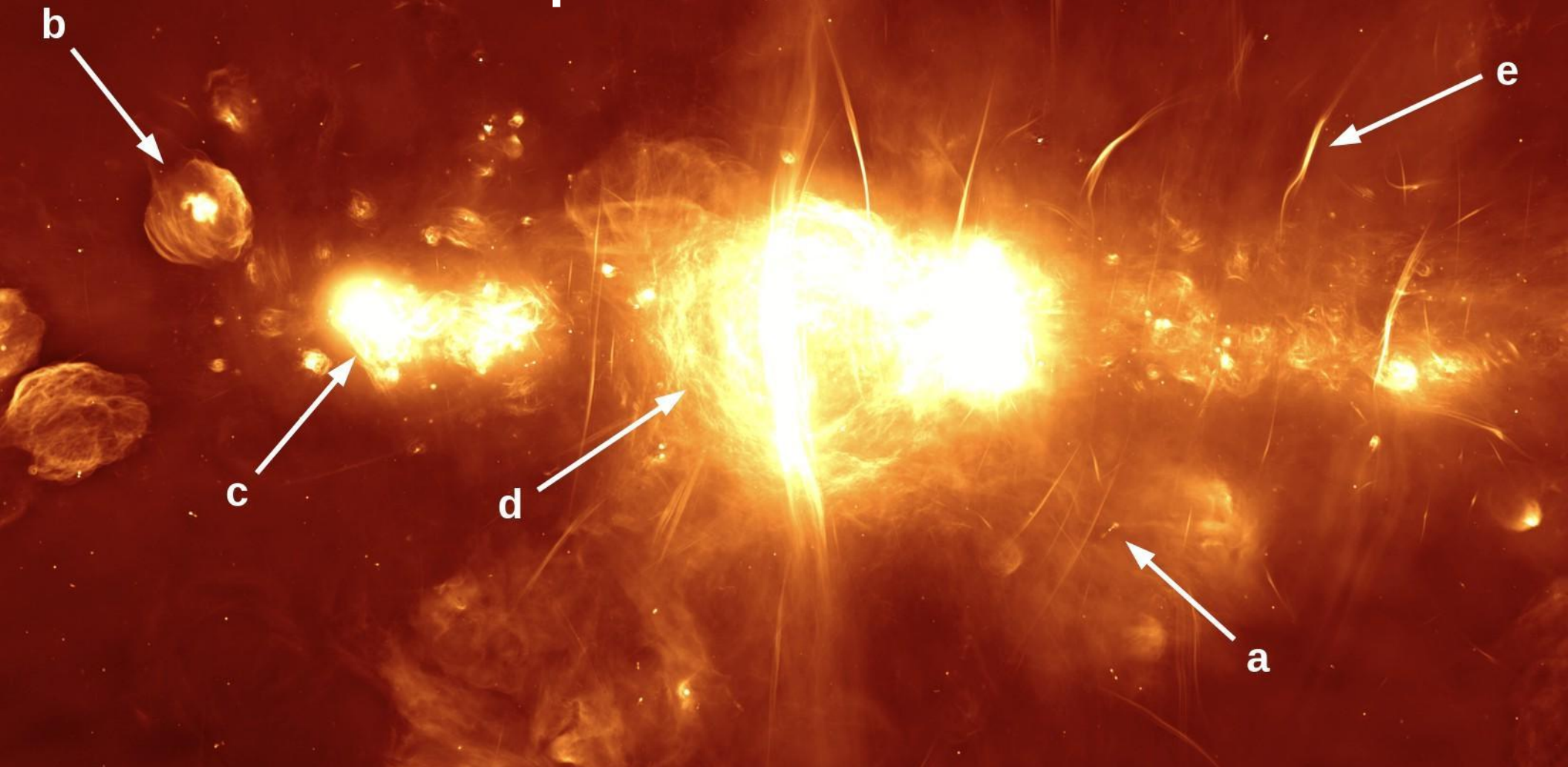


Haywood et al. in
prep

70-hour integr
CDFS (LADU
PKS 0326-288
been peeled.
Haywood et al

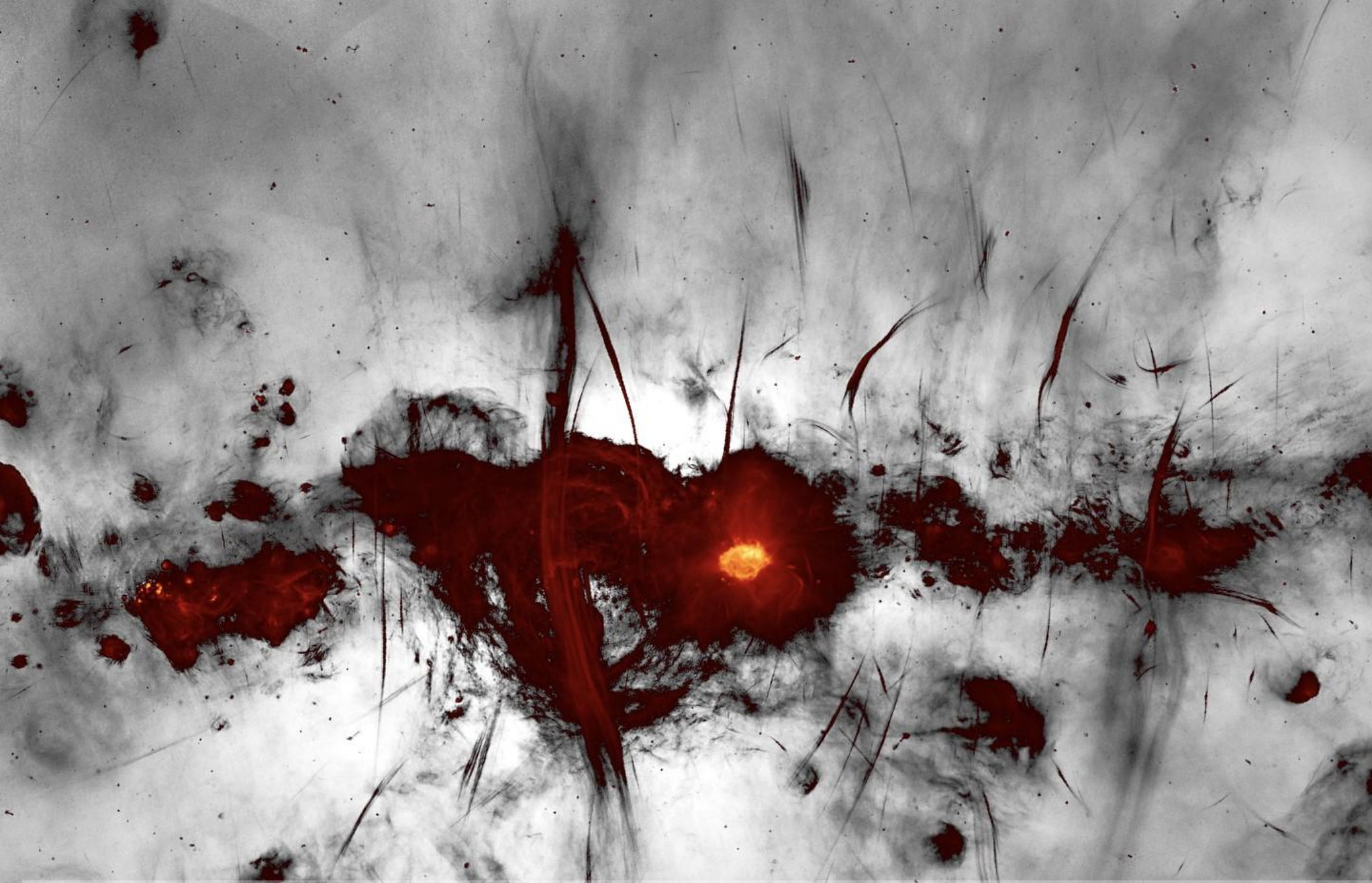
70-hour integr
CDFS (LADU
PKS 0326-288
been peeled.
Haywood et al

Le centre galactique vu par MeerKAT

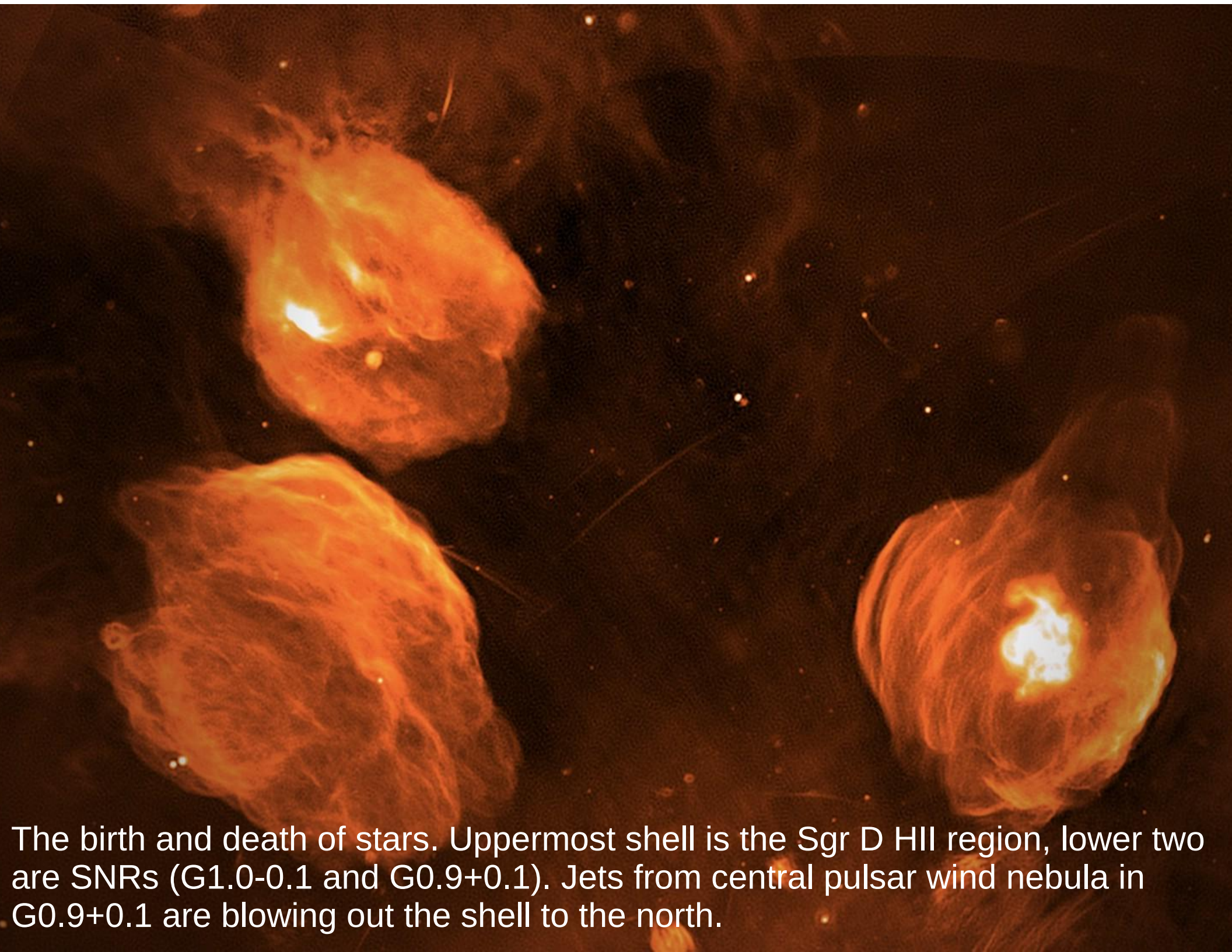


- A: source d'arrière plan
- B: rémanent de supernovae
- C: région de formation stellaire
- D: supershell
- E: filament magnétisé de nature inconnue

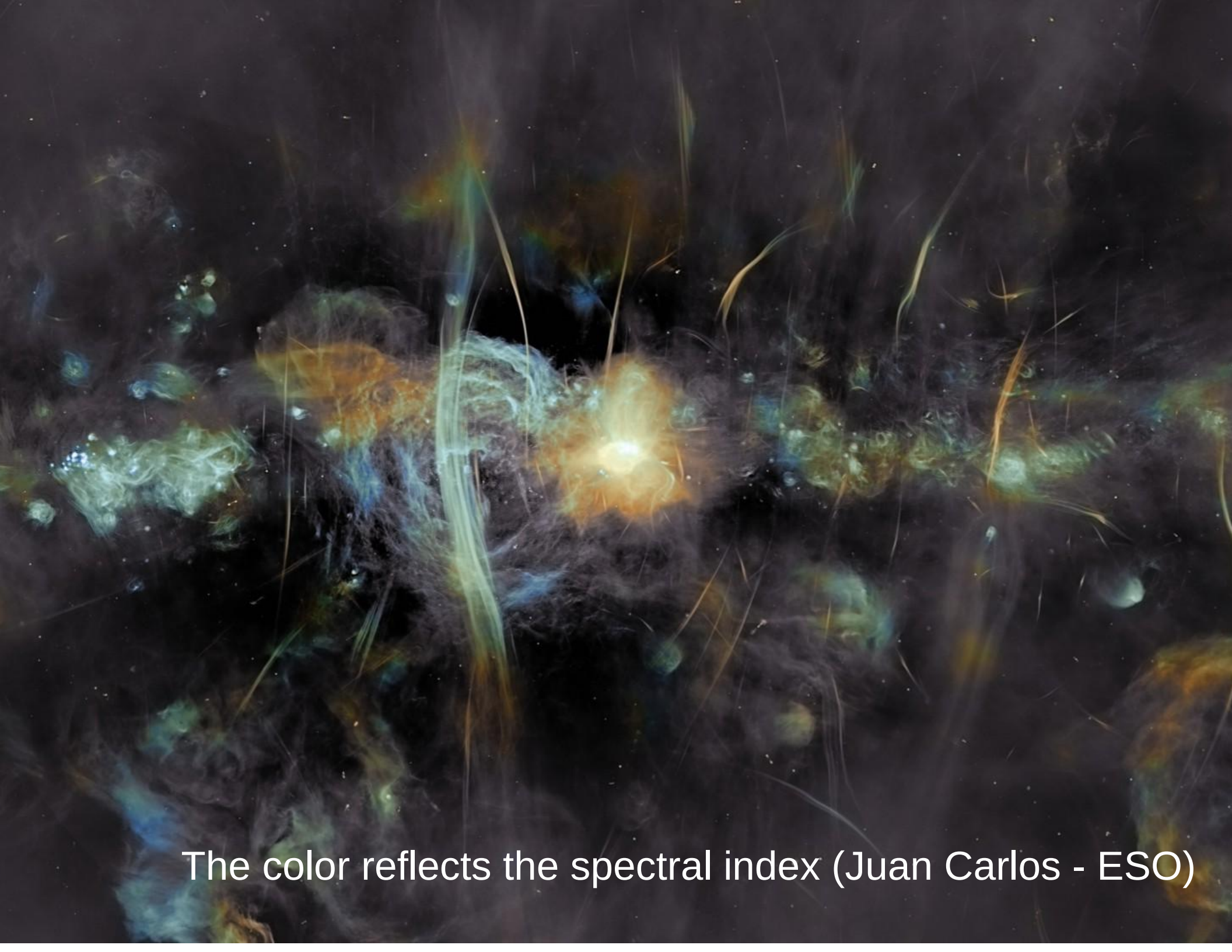




The new Galactic centre mosaic (200 hours of data, 6.5 square degrees, 4'' resolution). Total intensity and spectral index mosaics are now publicly available (Heywood et al., ApJ, 2022).



The birth and death of stars. Uppermost shell is the Sgr D HII region, lower two are SNRs (G1.0-0.1 and G0.9+0.1). Jets from central pulsar wind nebula in G0.9+0.1 are blowing out the shell to the north.



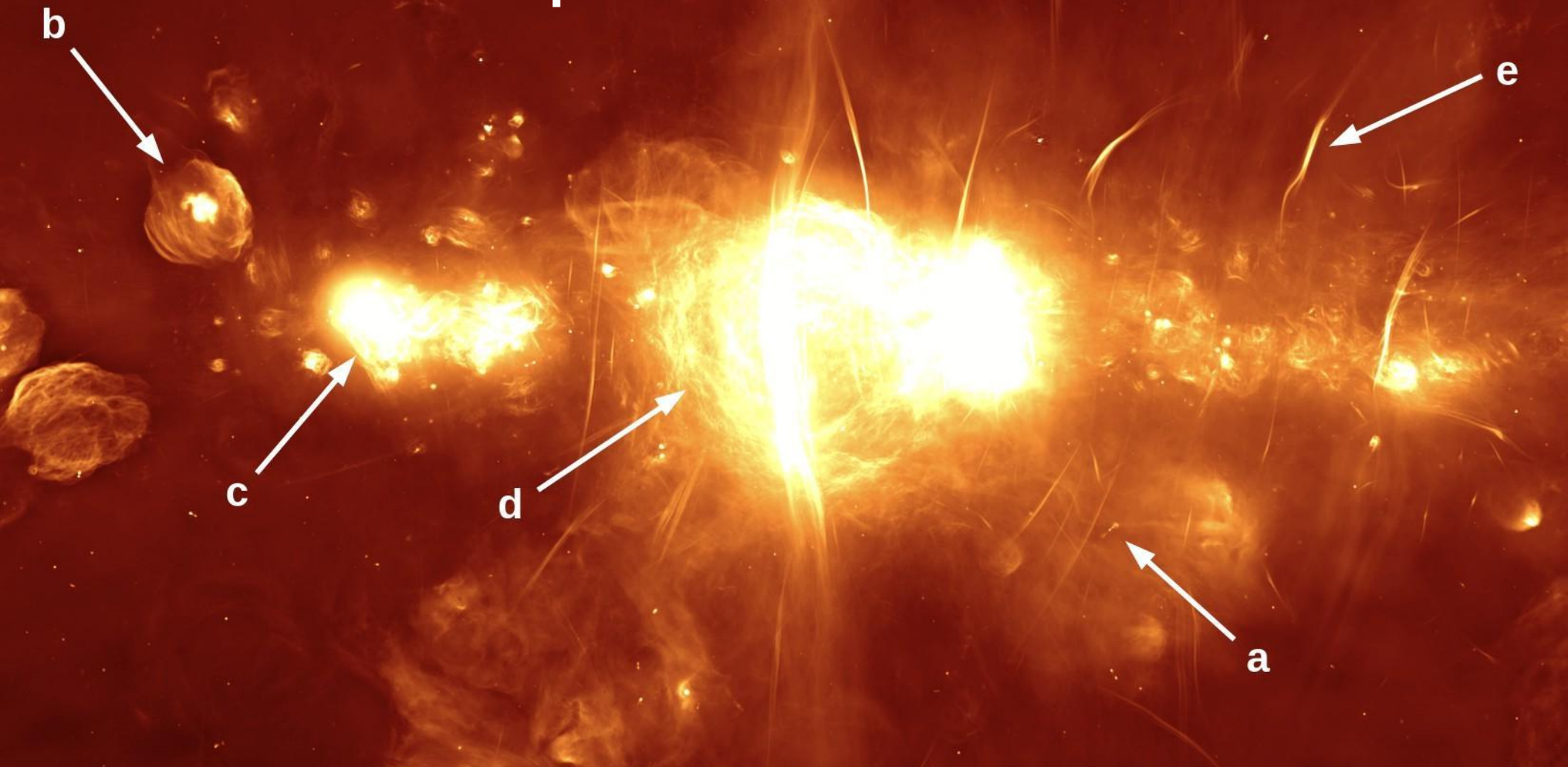
The color reflects the spectral index (Juan Carlos - ESO)

An aerial photograph of a vast, arid desert landscape, likely in Australia, filled with hundreds of white satellite dishes. The dishes are scattered across the reddish-brown, sparsely vegetated terrain, extending towards a distant, hazy horizon. In the center of the image, there is a semi-transparent rectangular box with the word "Merci!" written in a bold, black, sans-serif font. The lighting suggests a bright, sunny day, casting long shadows from the dishes onto the ground.

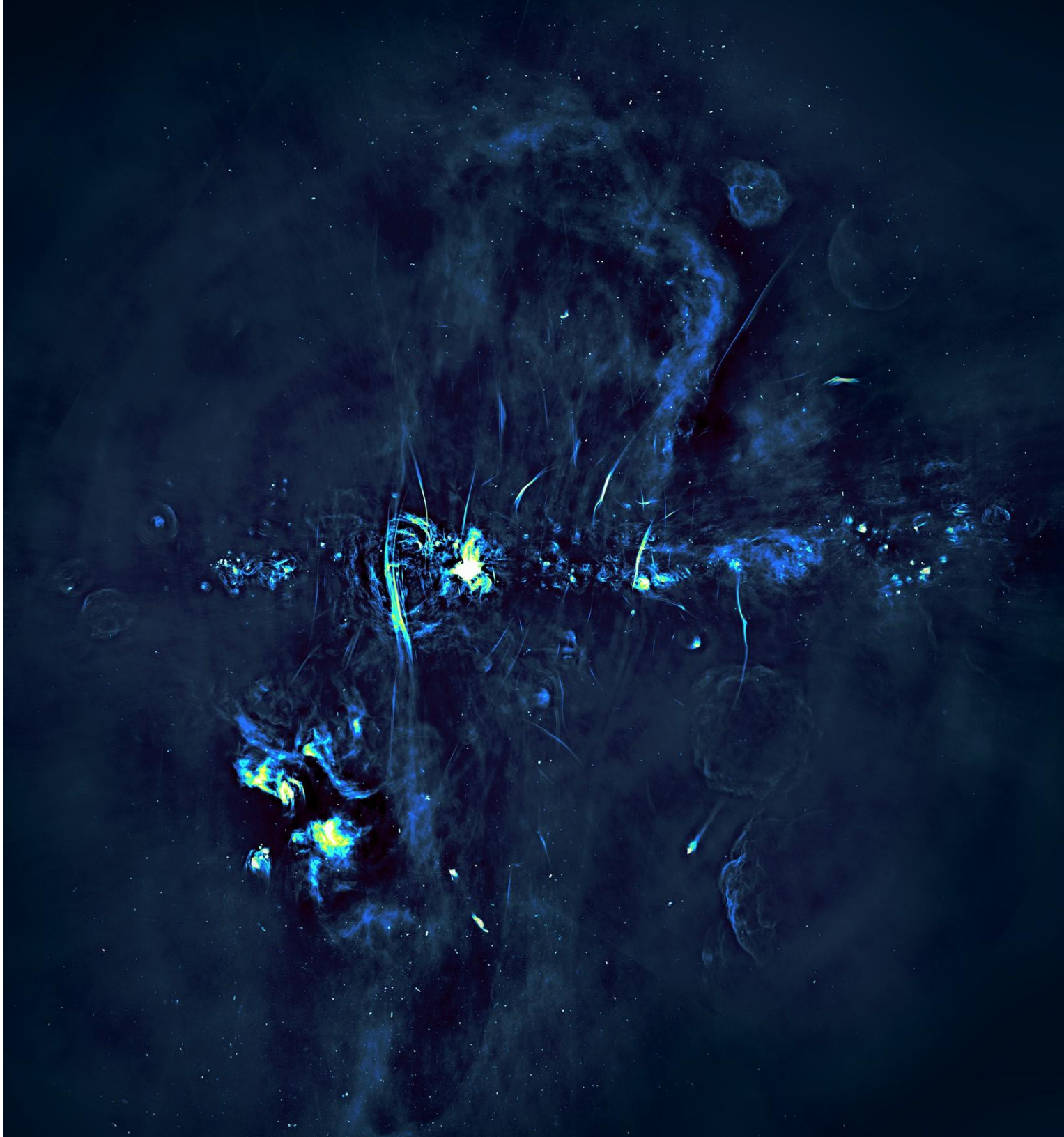
Merci!



Le centre galactique vu par MeerKAT



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Merci!