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

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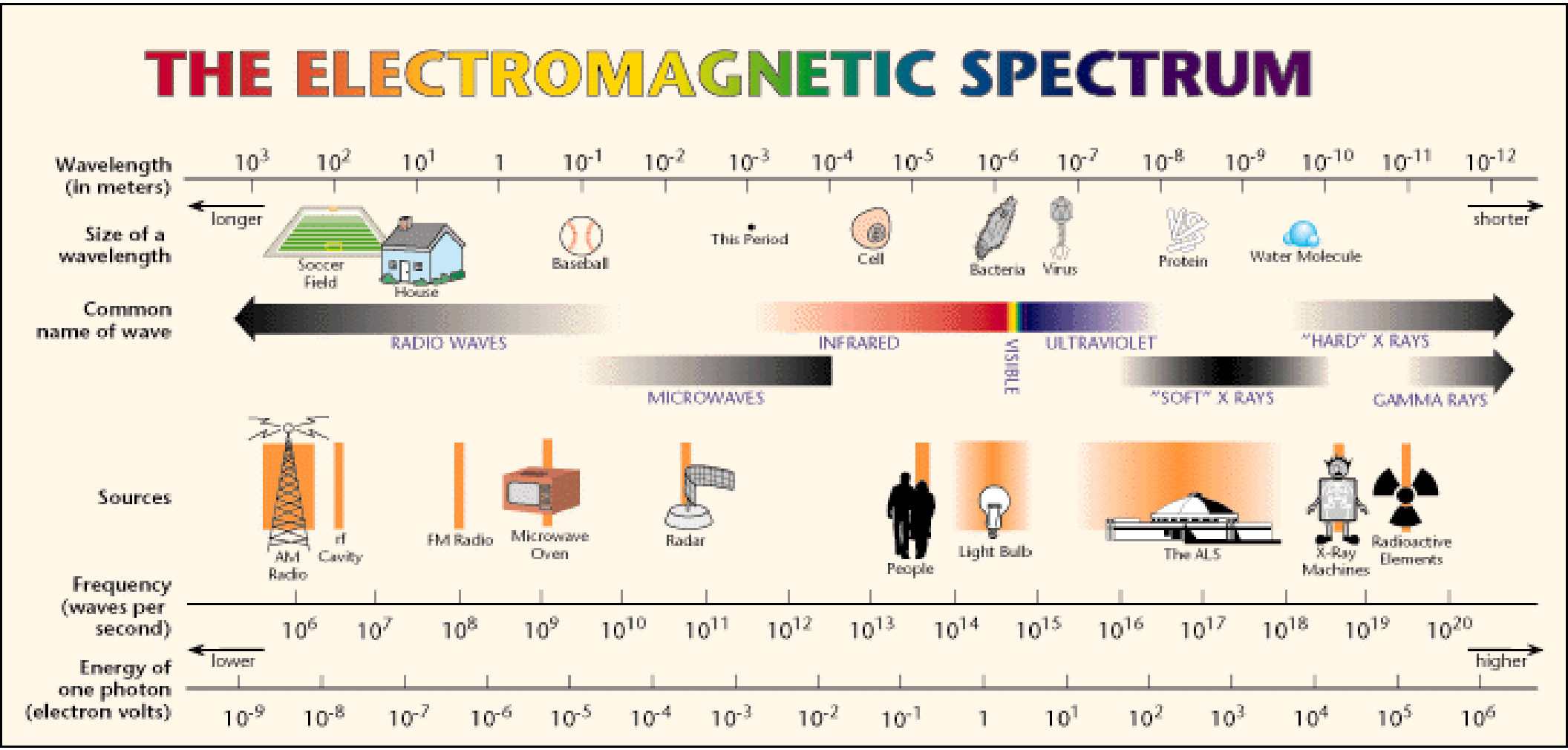
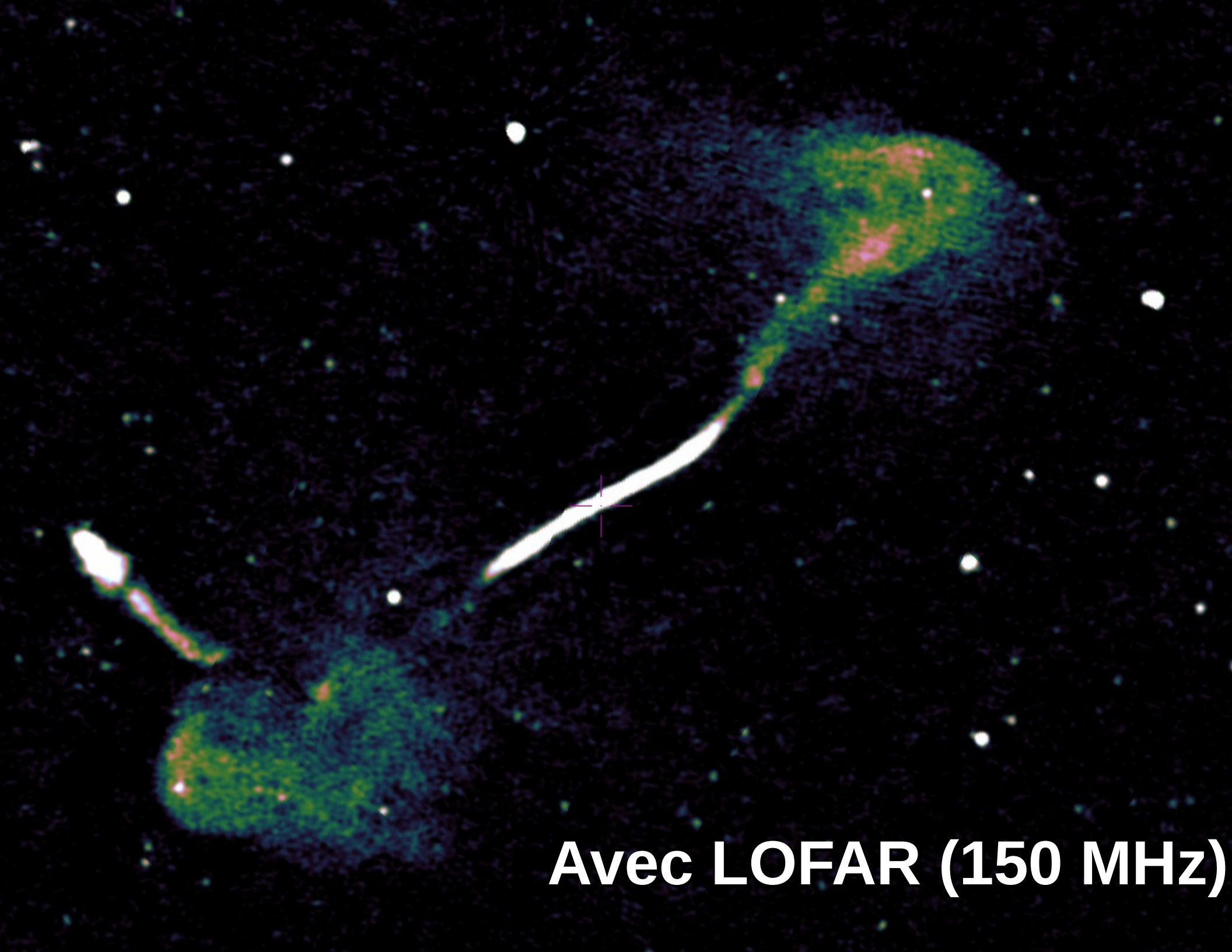
Résumé

- 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?




En optique

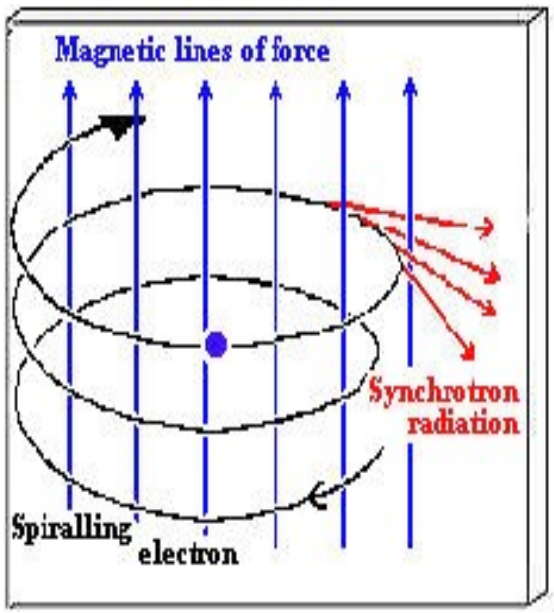

Avec LOFAR (150 MHz)

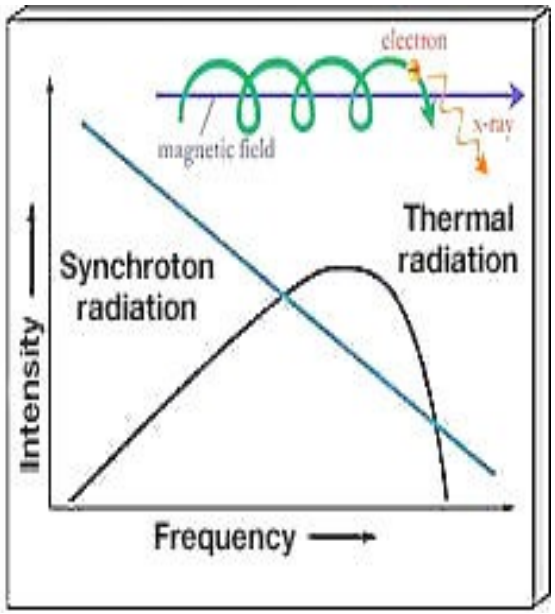
What physical phenomena emit radio emission?

(I) Synchrotron radiation:

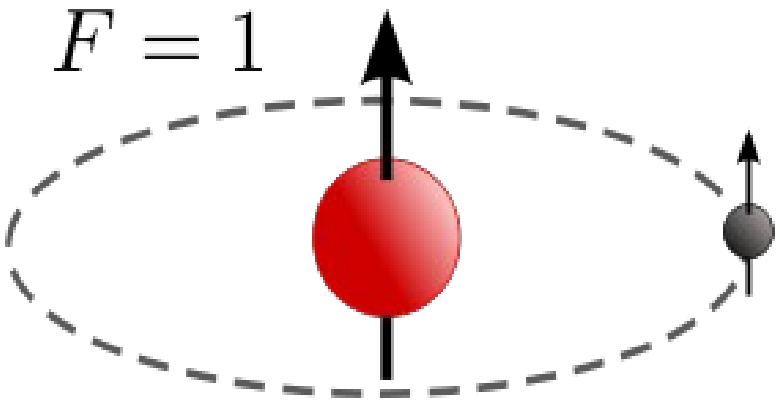
- Charged particule in a magnetic field
- Acceleration = emission
- Polarised -> information on the magnetic field

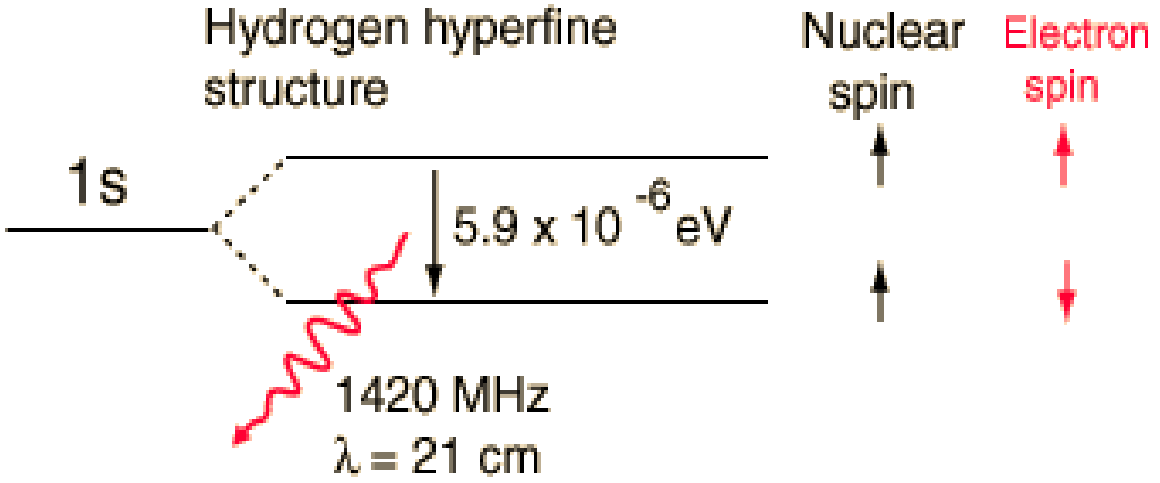
- Continuum emission

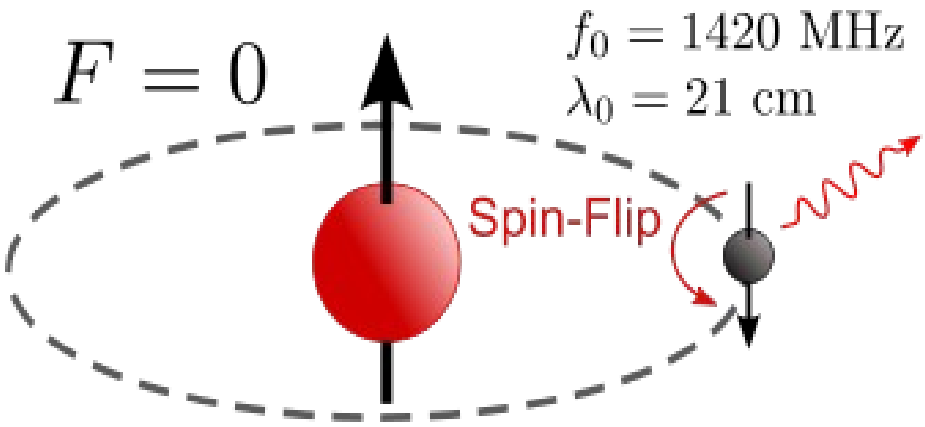




What physical phenomena emit radio emission?







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

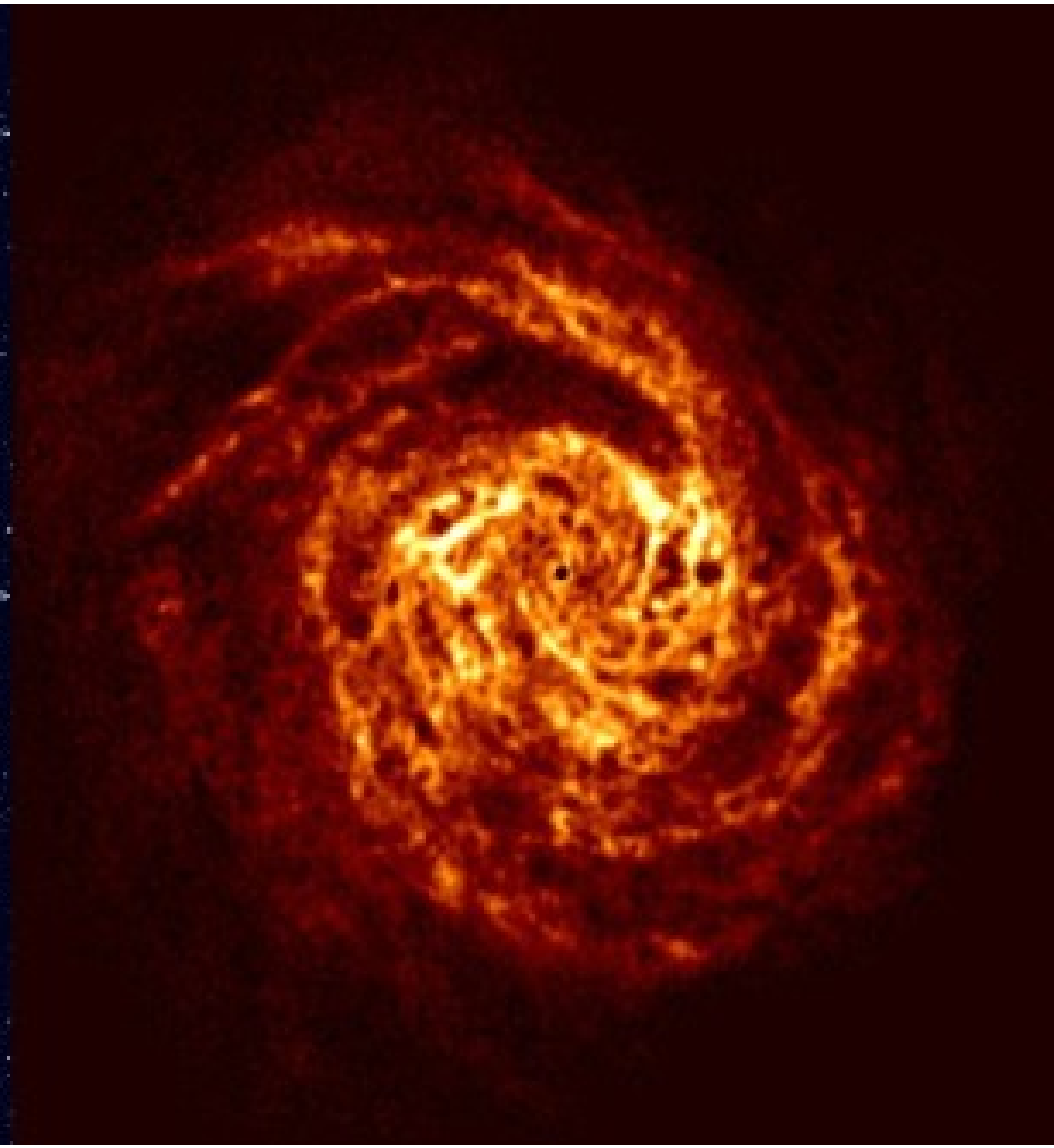
- Hyperfine hydrogen transition
- “forbidden” transition, one in ~10 million years
- But there is so much neutral hydrogen in the universe....

What physical phenomena emit radio emission?

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

What physical phenomena emit radio emission?

Optical

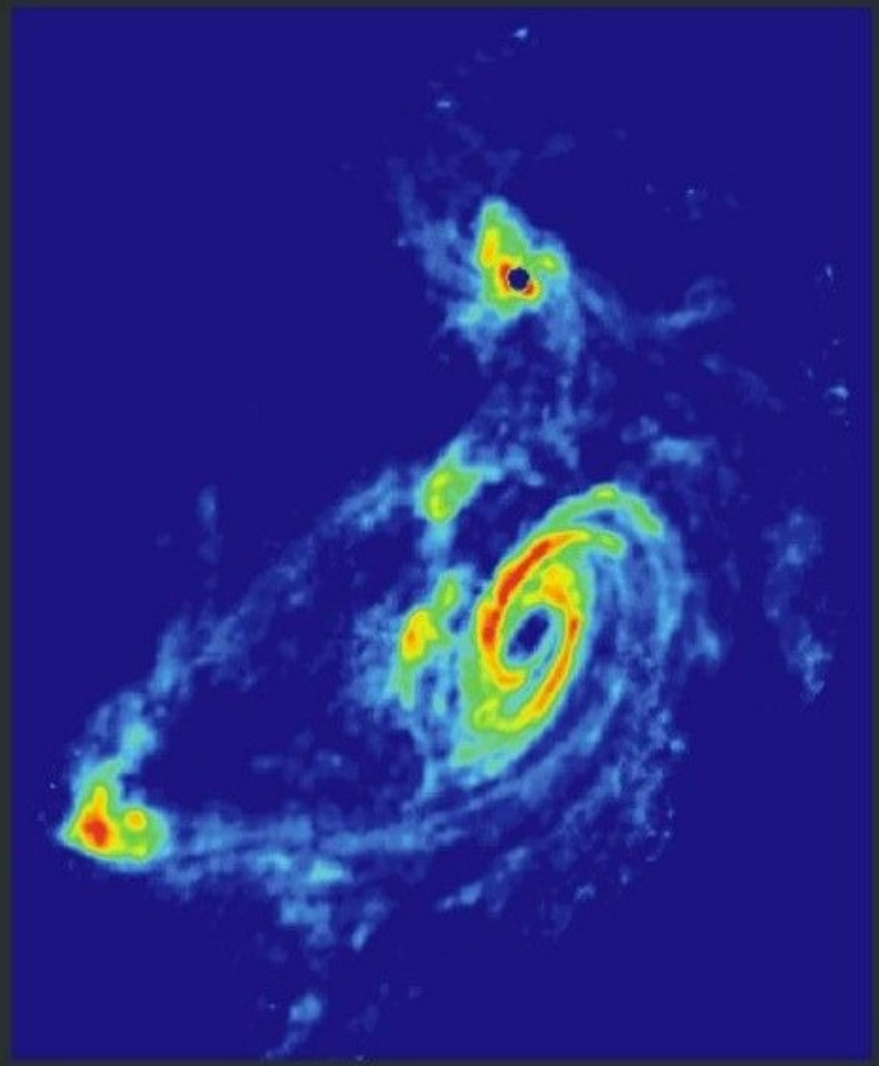


1.4 GHz

TIDAL INTERACTIONS IN M81 GROUP

Stellar Light Distribution

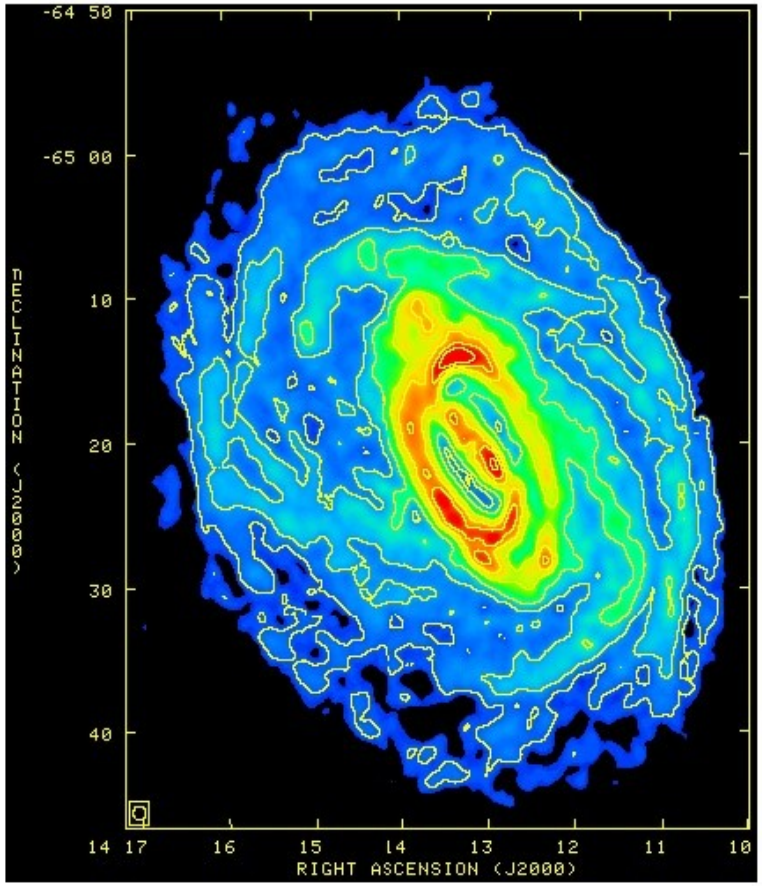
21 cm HI Distribution



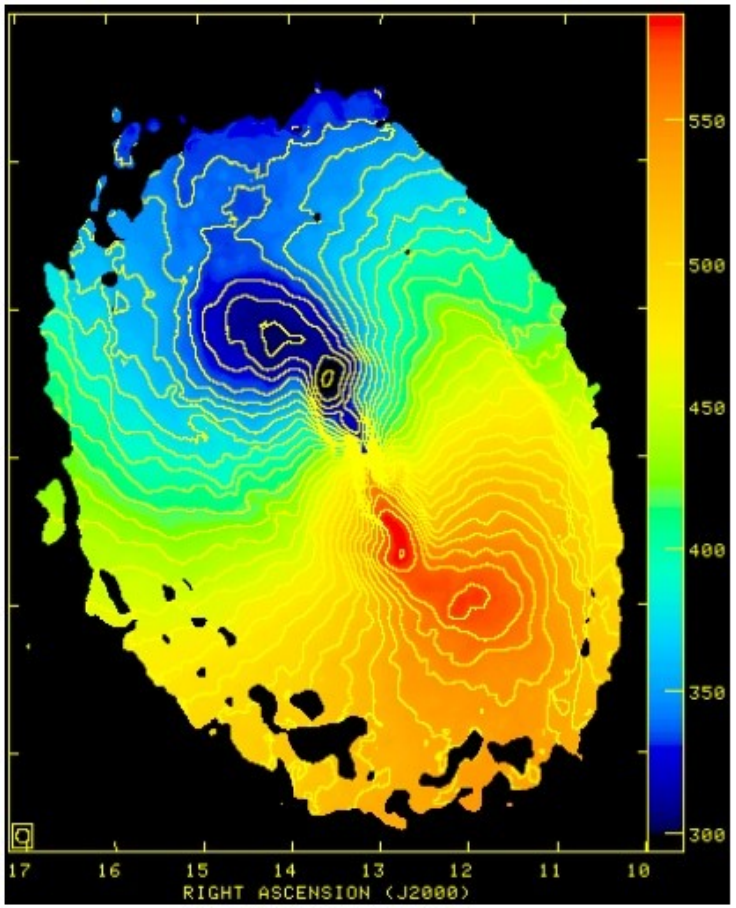
HI en émission

La galaxie Circinus

Carte HI



vitesses radiales



Attention aux fausses couleurs!!

B. Vollmer

How do we observe radio emission?

Interferometer:
- The idea is to combine the signal from individual antenna
- Synthesize a virtual telescope that has a equilavent size of the two most distant antennaes

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

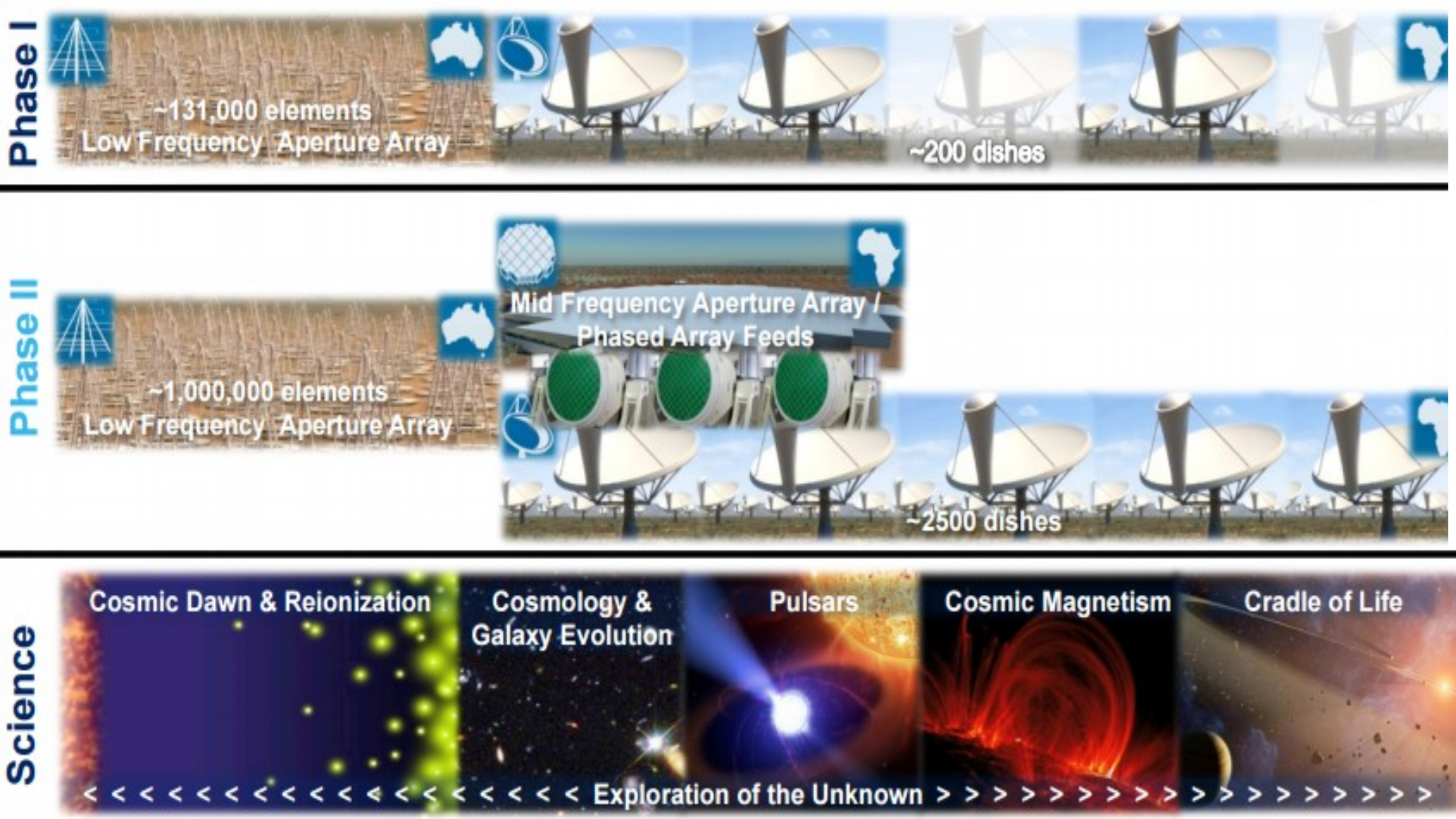
360.000x360.000 pixels images

Survey speed: x10.000

A few huge radiotelescopes prototypes of the SKA:

- **MeerKAT**
- **LOFAR**
- **NenuFAR**
- **ASKAP**
- …..

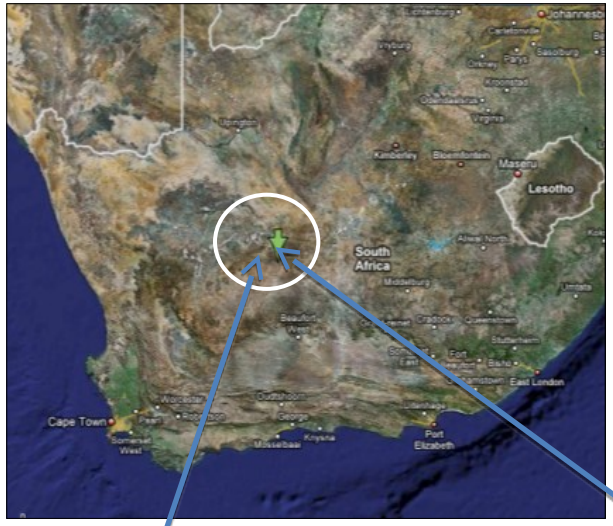
SKA: Square Kilometer Array?



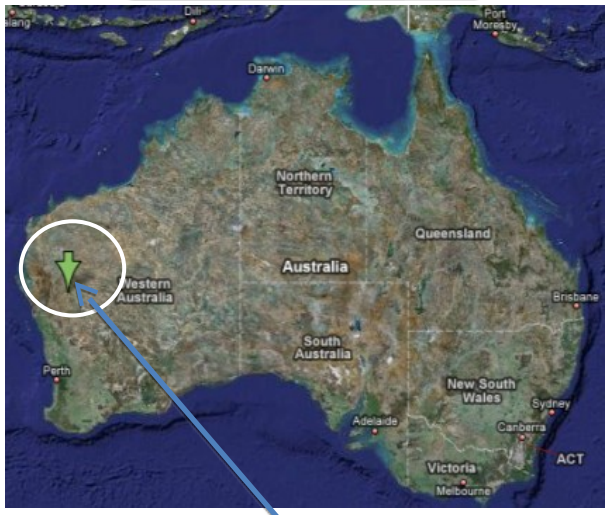
Courtesy T. Bourke

SKA Phase 2 (SKA2) – ultimate goal

Southern Africa



Australia

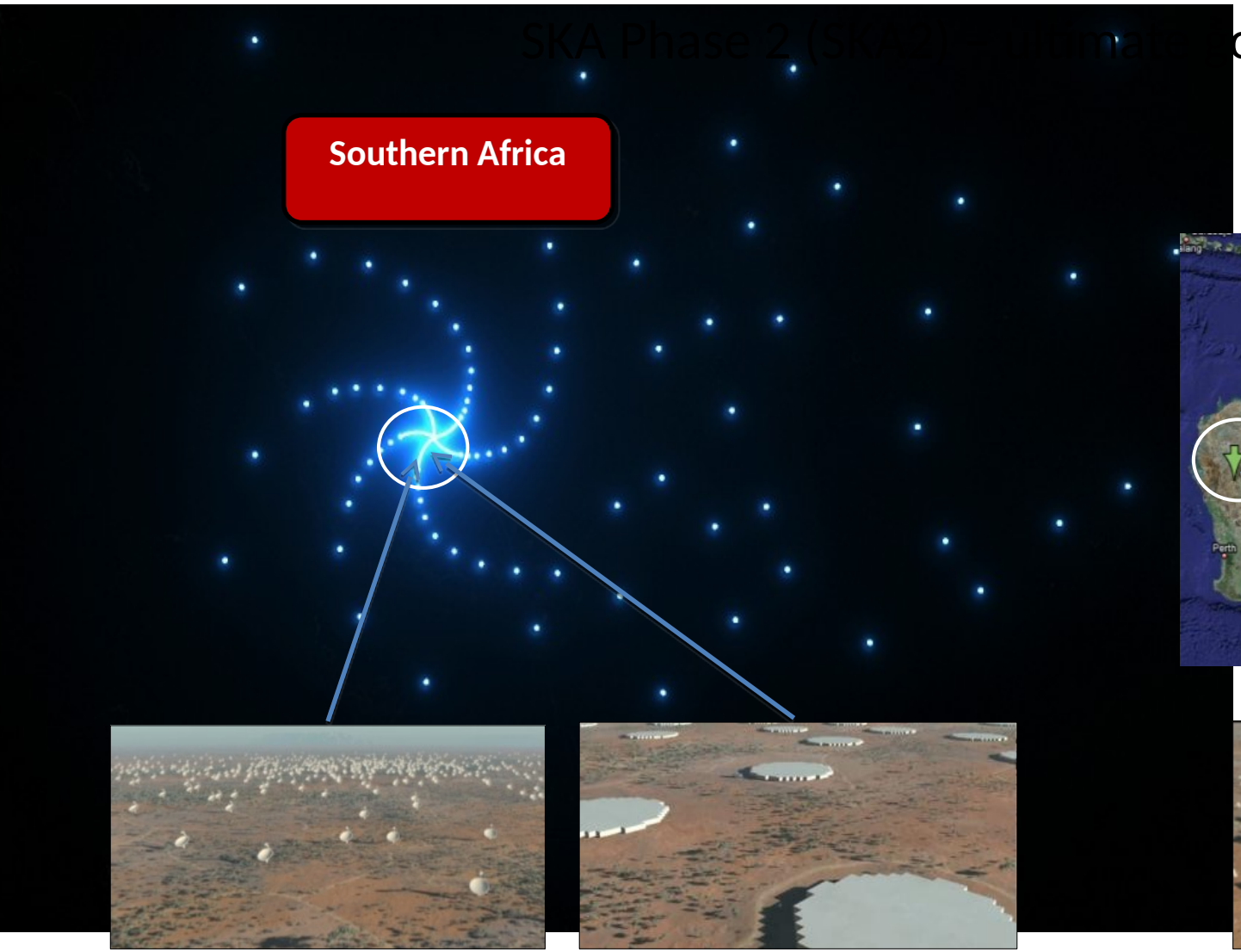


SKA2_MID
2500 Dishes

SKA2_AA
250 x Mid Frequency Aperture Array Stations

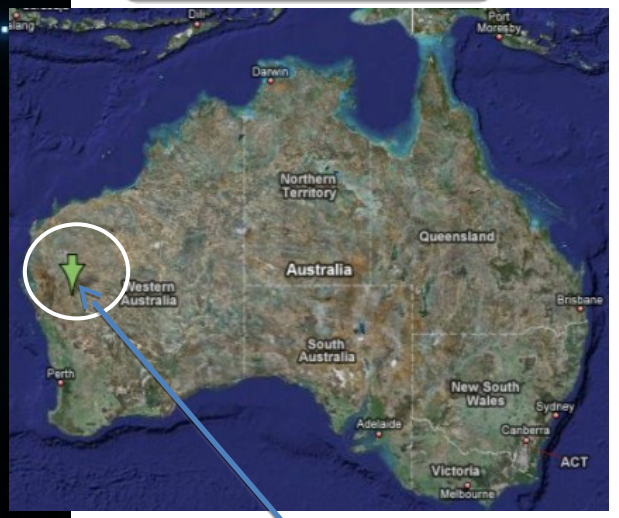
SKA2_LOW
250 x Low Frequency Aperture Array Stations

SKA Phase 2 (SKA2) – Ultimate Goal



SKA2_MID
2500 Dishes

SKA2_AA
250 x Mid Frequency Aperture Array Stations



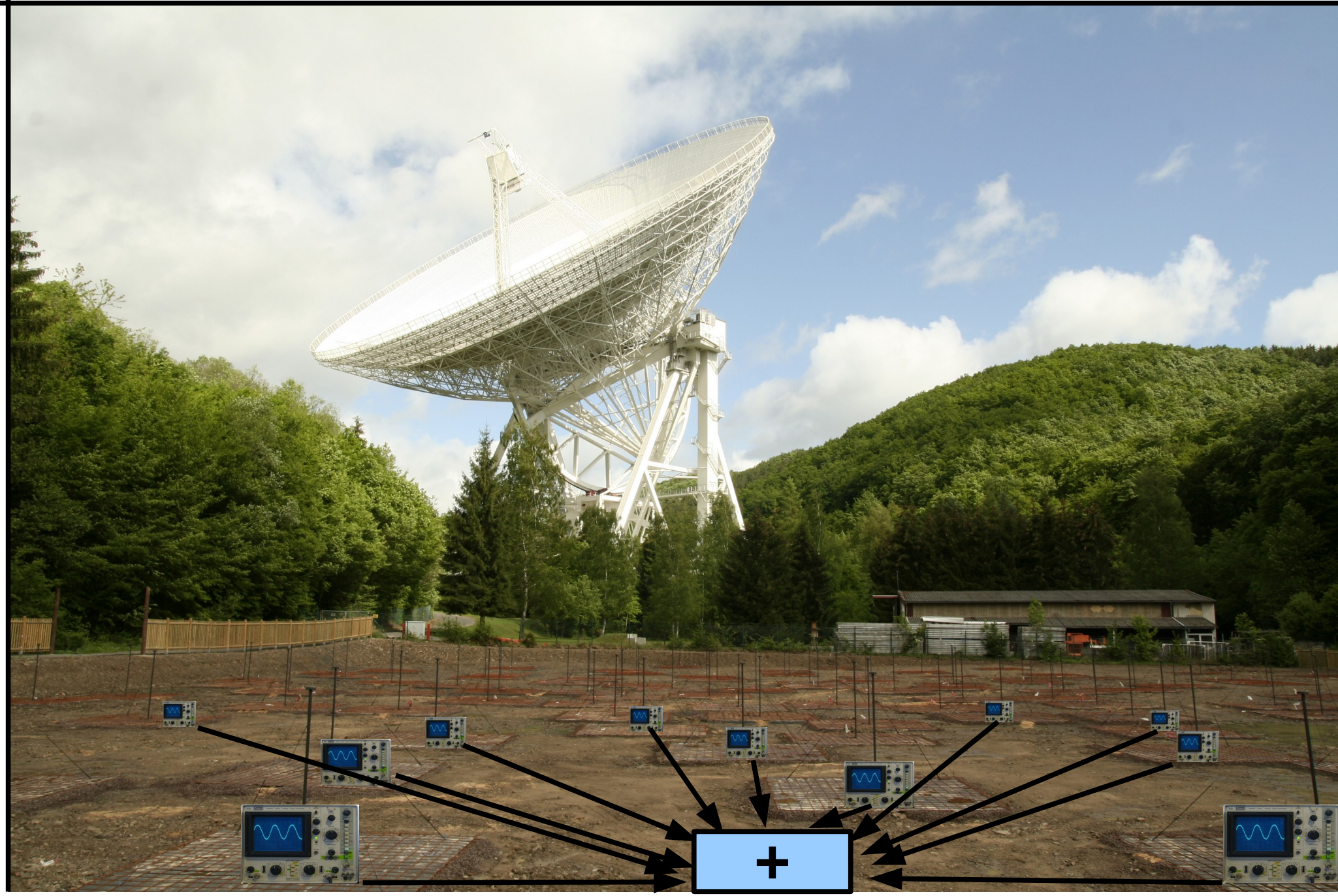
SKA2_LOW
250 x Low Frequency Aperture Array Stations

LOFAR

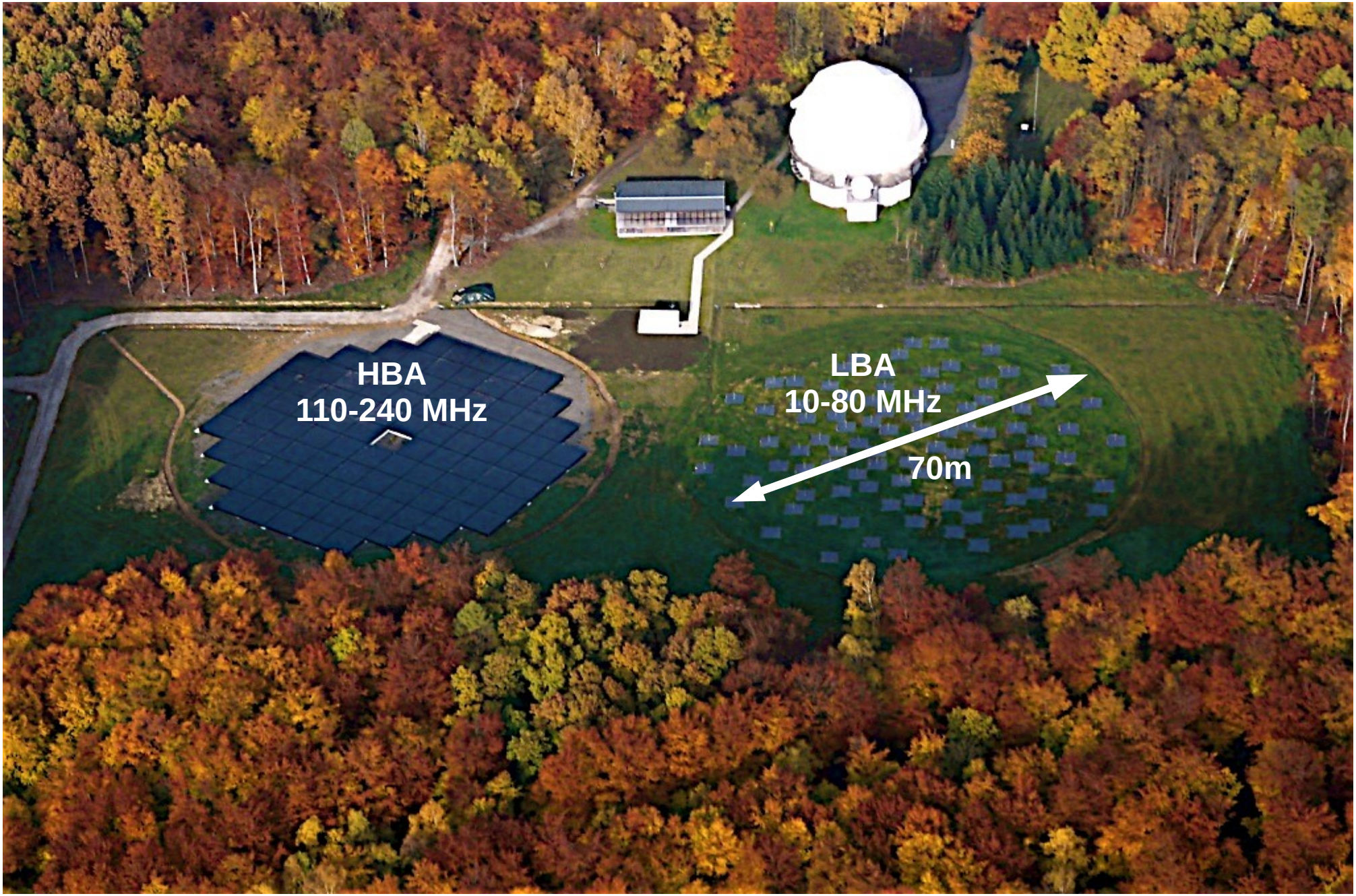

International LOFAR Telescope (ILT)
- resolution ~5 arcsec @ 200 MHz for the dutch core
- resolution ~0.2 arcsec @ 50 MHz for the international baselines
Onsala
Dutch stations
Chilbolton
Norderstedt
LOFAR Core (NL)
Potsdam
Bałdy
Borówiec
Jülich
Effelsberg
Tautenburg
Łazy
Unterweilenbach
Nançay
• 300 – 1000 km
• 3 new stations coming in Poland
LOFAR

Station LOFAR à Nancay + NenuFAR

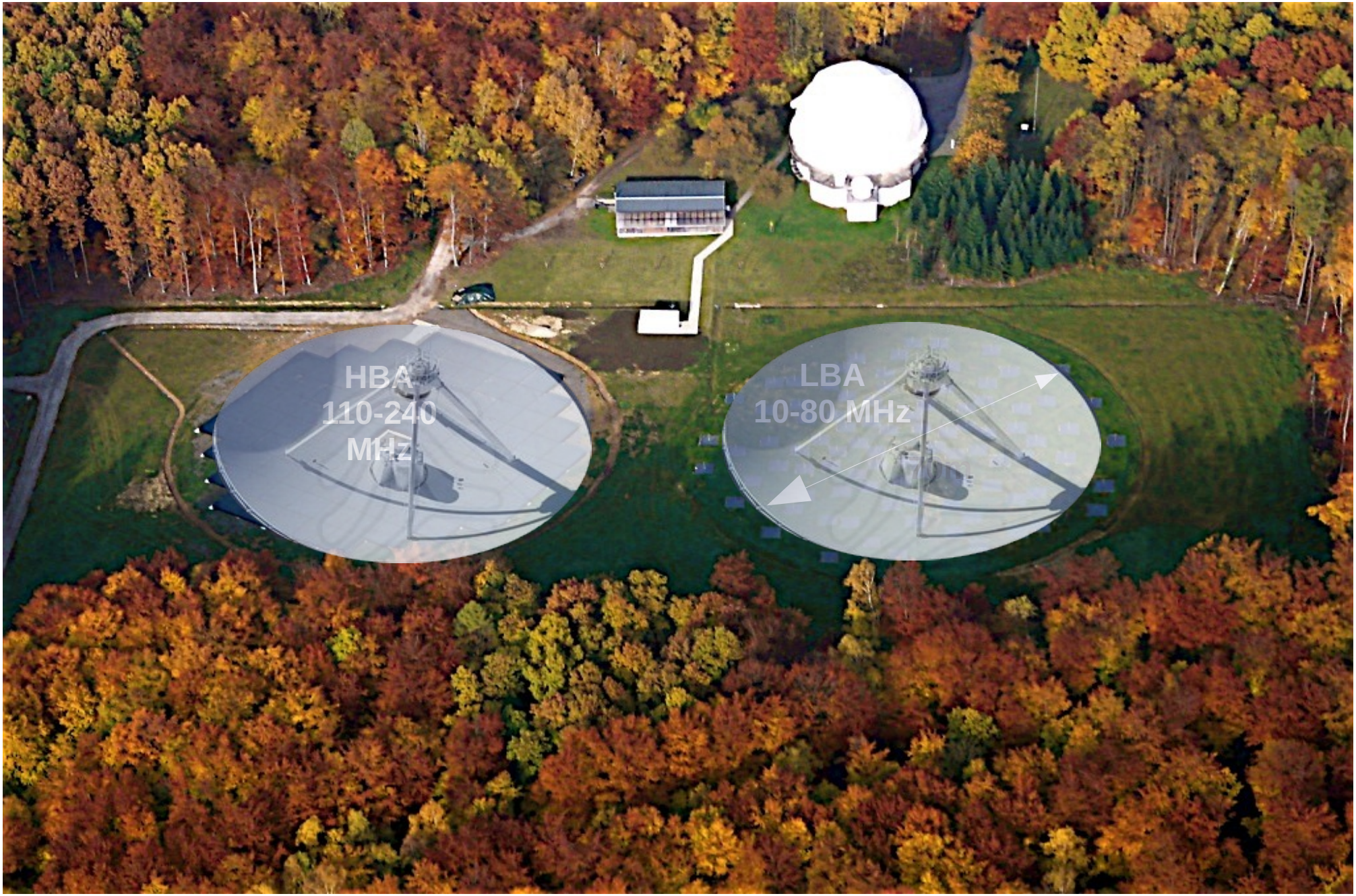
LOFAR station are phased arrays



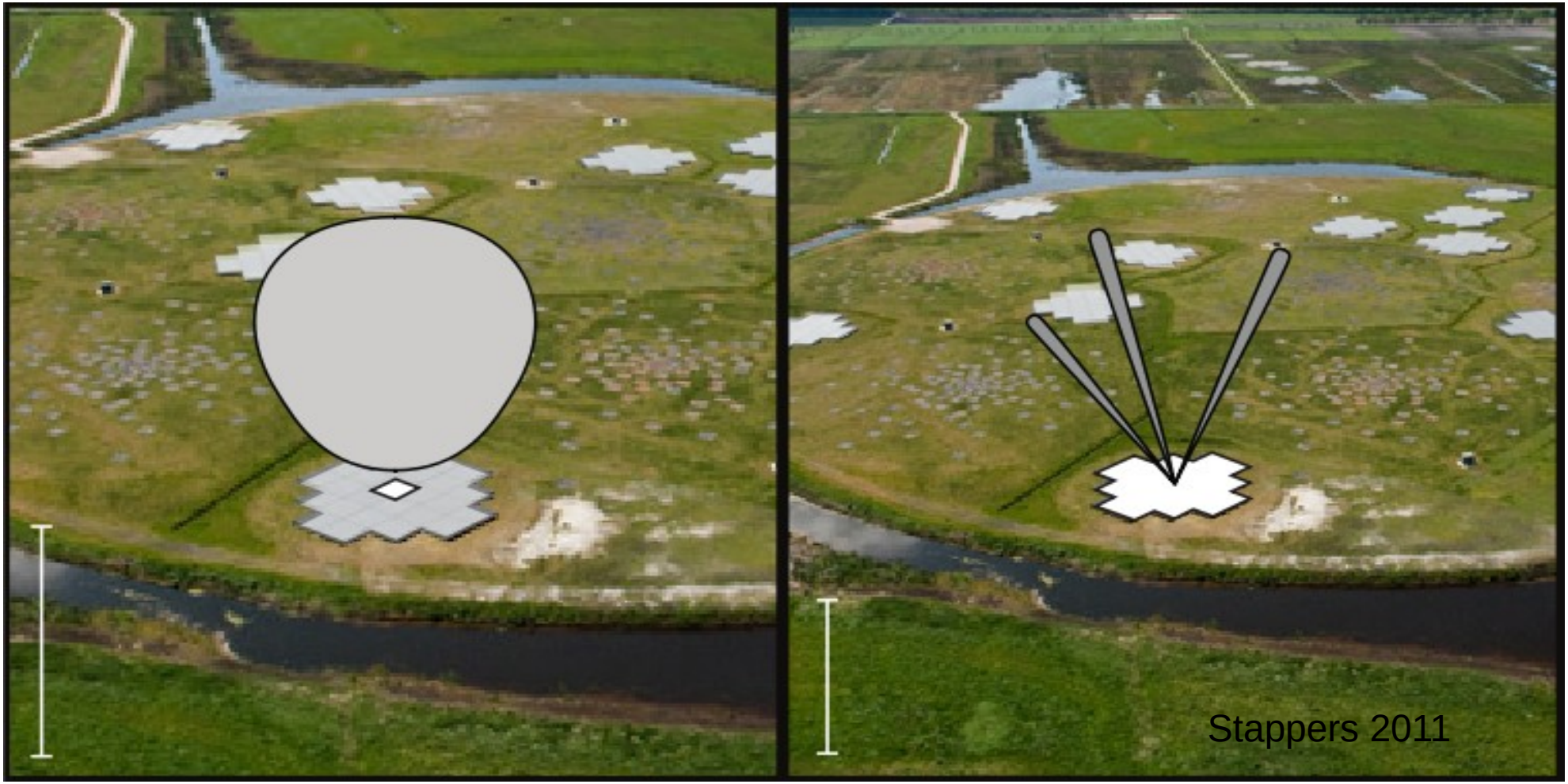
LOFAR station are phased arrays



LOFAR station are phased arrays



LOFAR station are phased arrays



We can point at different directions at the simultaneously :
- Great for transient studies
- Cover big areas on the sky
- Calibration

LoTSS

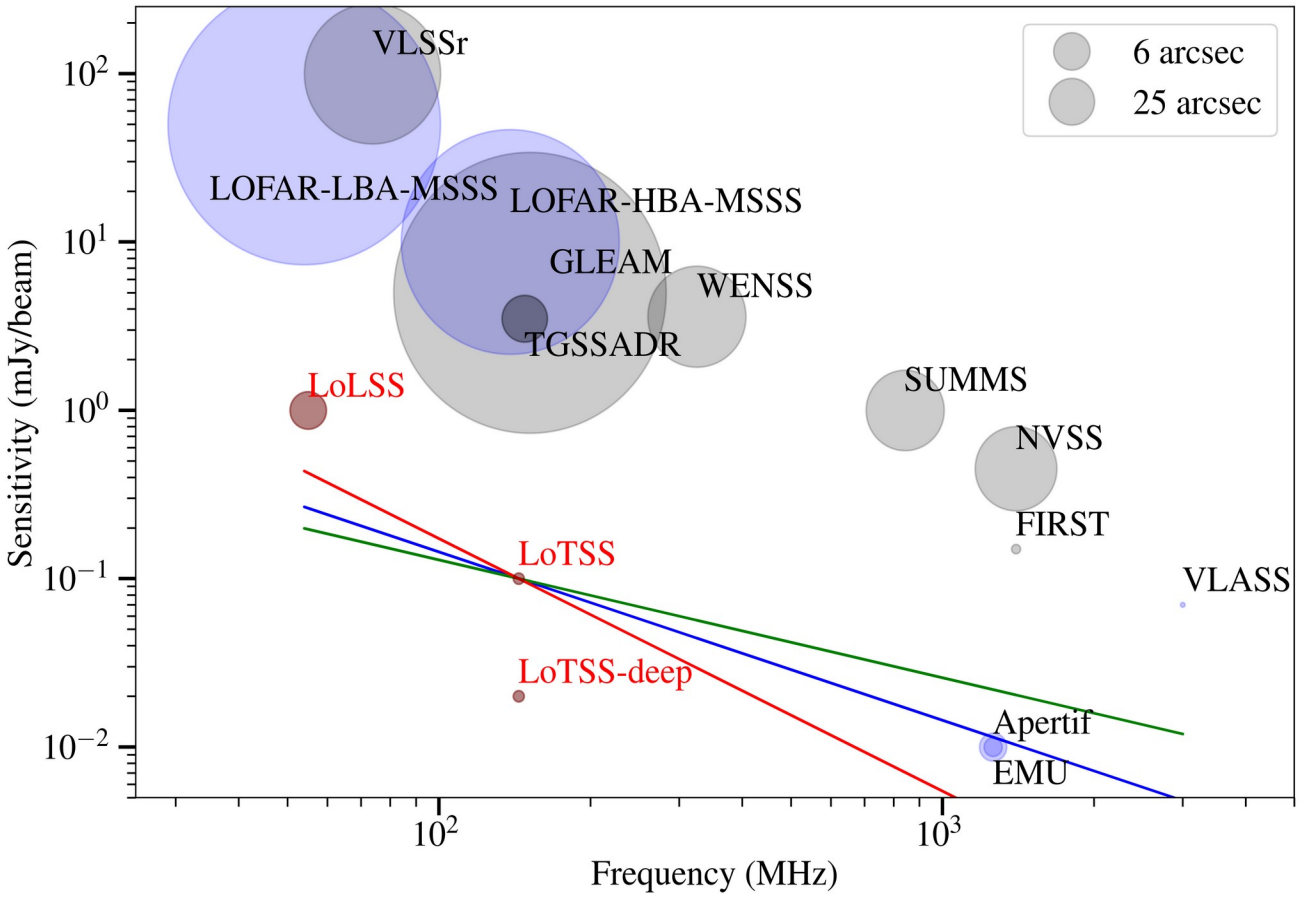
~16,000hrs of LOFAR HBA observations.

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

~55% observed.

Always observing with full international array

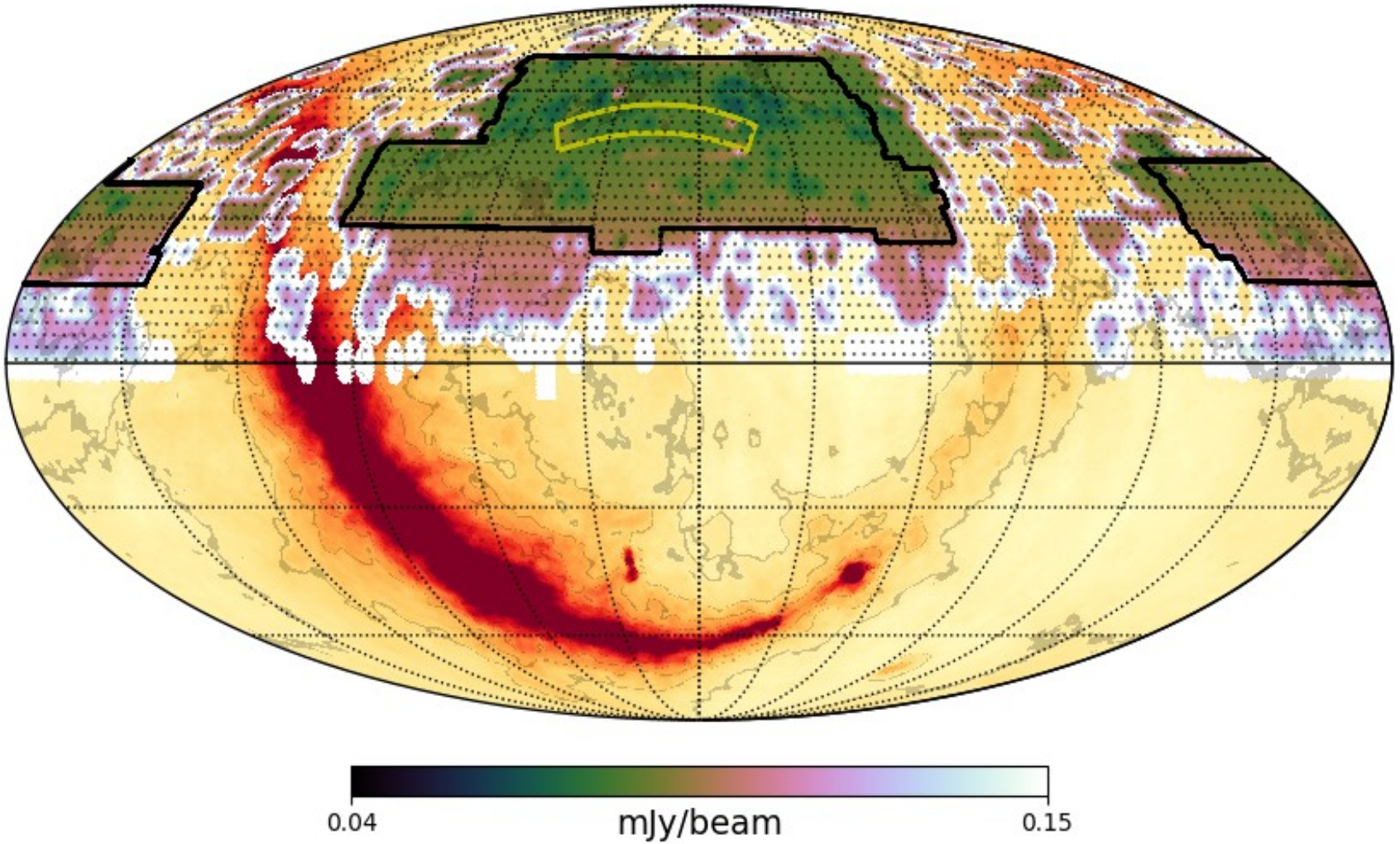
Aiming to complete observations in ~3-4 years and stay relevant even into the SKA era.



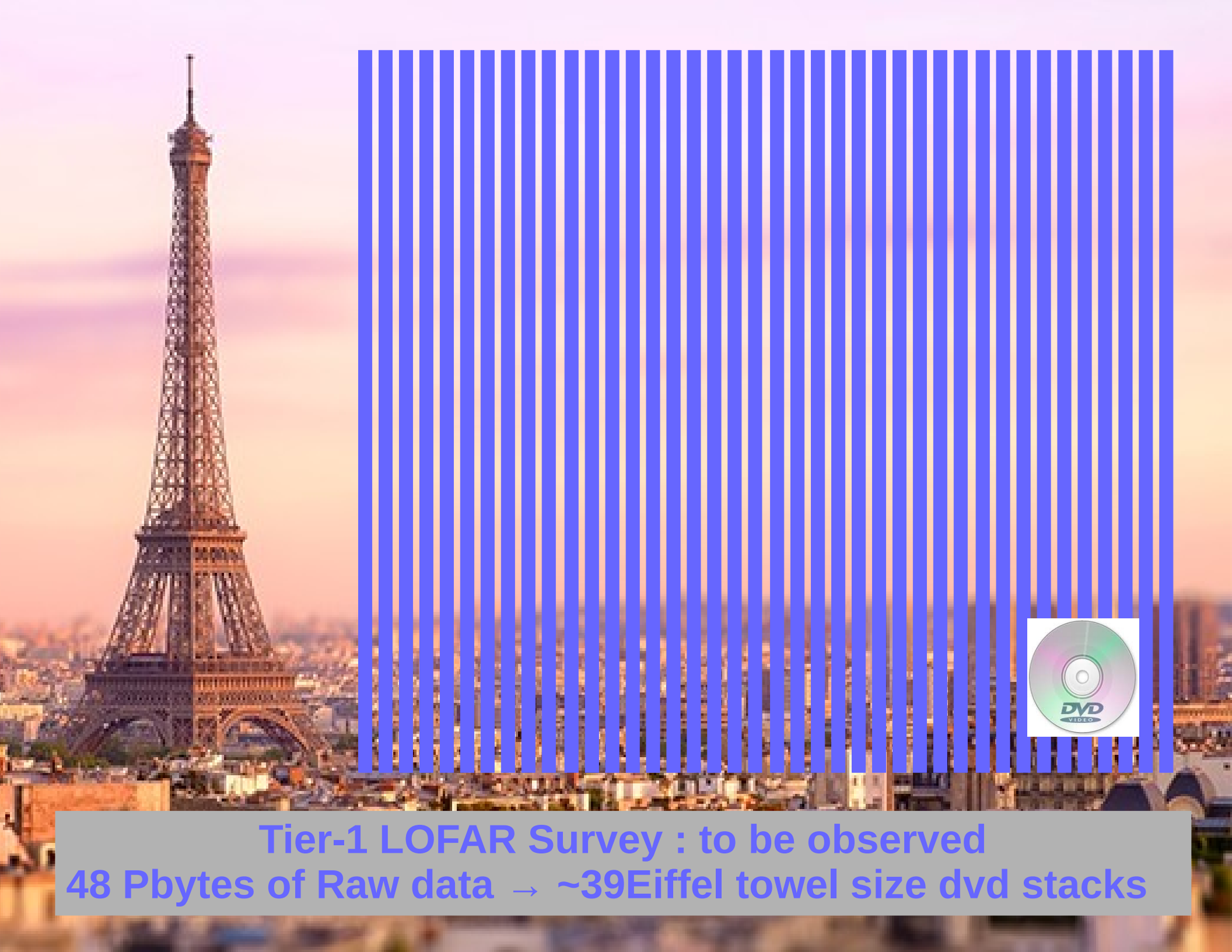
Green $\alpha = -0.7$, blue $\alpha = -1.0$, red $\alpha = -1.5$

LoTSS: Shimwell et al., 2017 & 2019

LoTSS data release 2 (LoTSS-DR2)

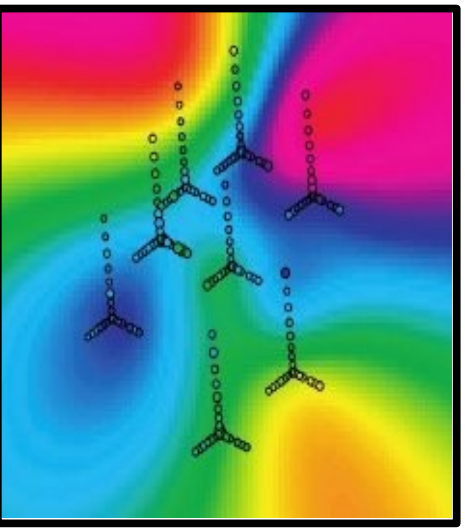


LoTSS-DR1 (outlined in yellow) is fully public. LoTSS-DR2 (outlined in black) is coming soon. This contains **4,395,448** radio components in 5634 square degrees. It consists of 841 different pointings and a total of 7.6PB of data from 26 different projects were processed using ~9million cpu hours. LoTSS-DR2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



Tier-1 LOFAR Survey : to be observed

48 Pbytes of Raw data → ~39Eiffel towel size dvd stacks



Ionospheric isturbance + Faraday rotation

Station lobes

8 hours integration with LOFAR@~150MHz

Without DDE correction

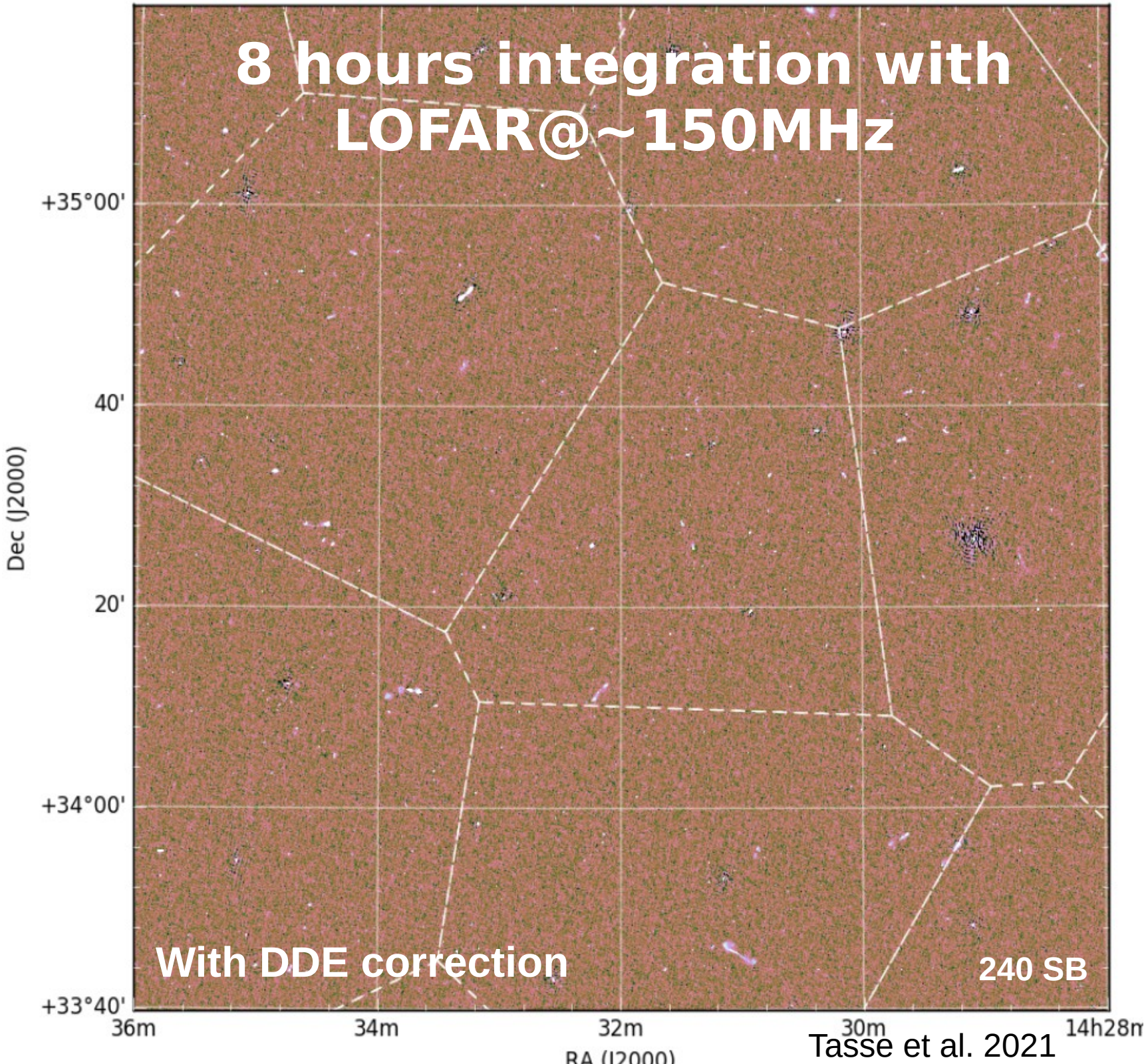
60 SB

+33°40'

36m 34m 32m 30m 14h28m

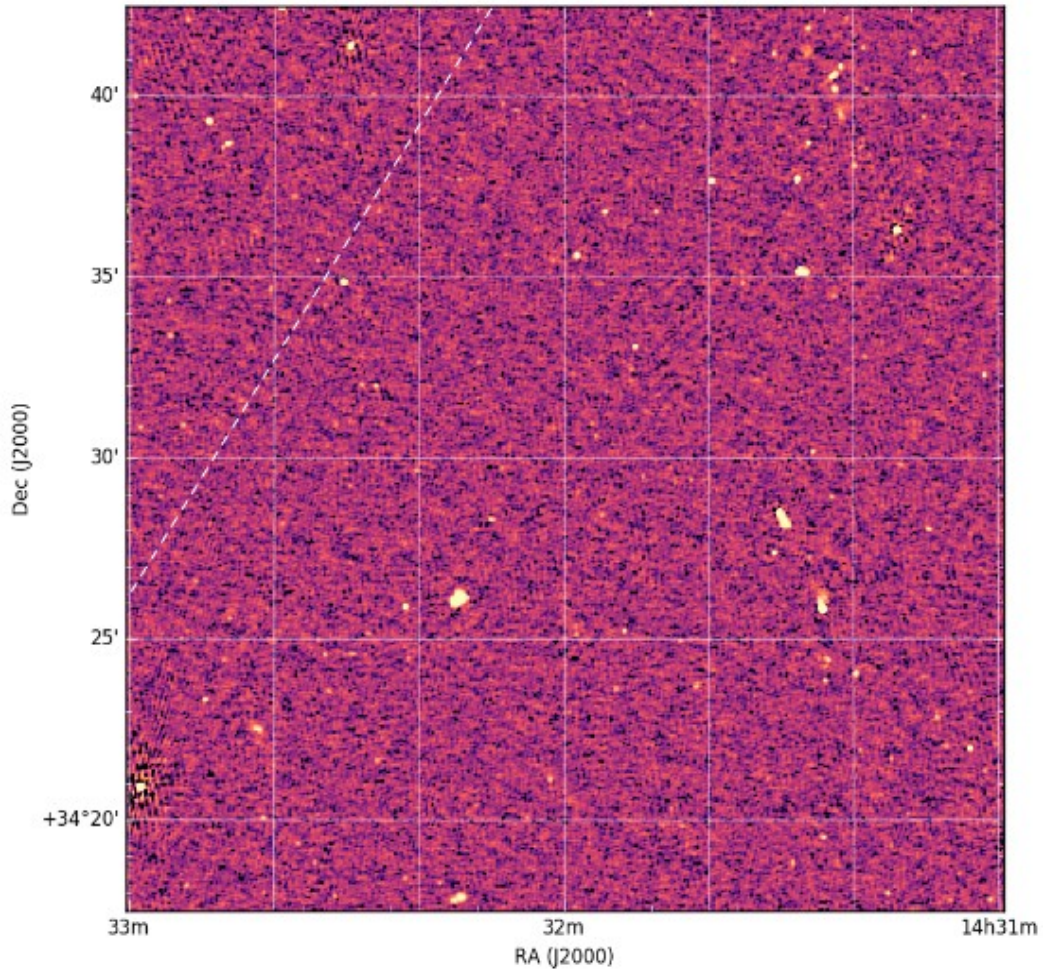
RA (J2000)

Tasse et al. 2021

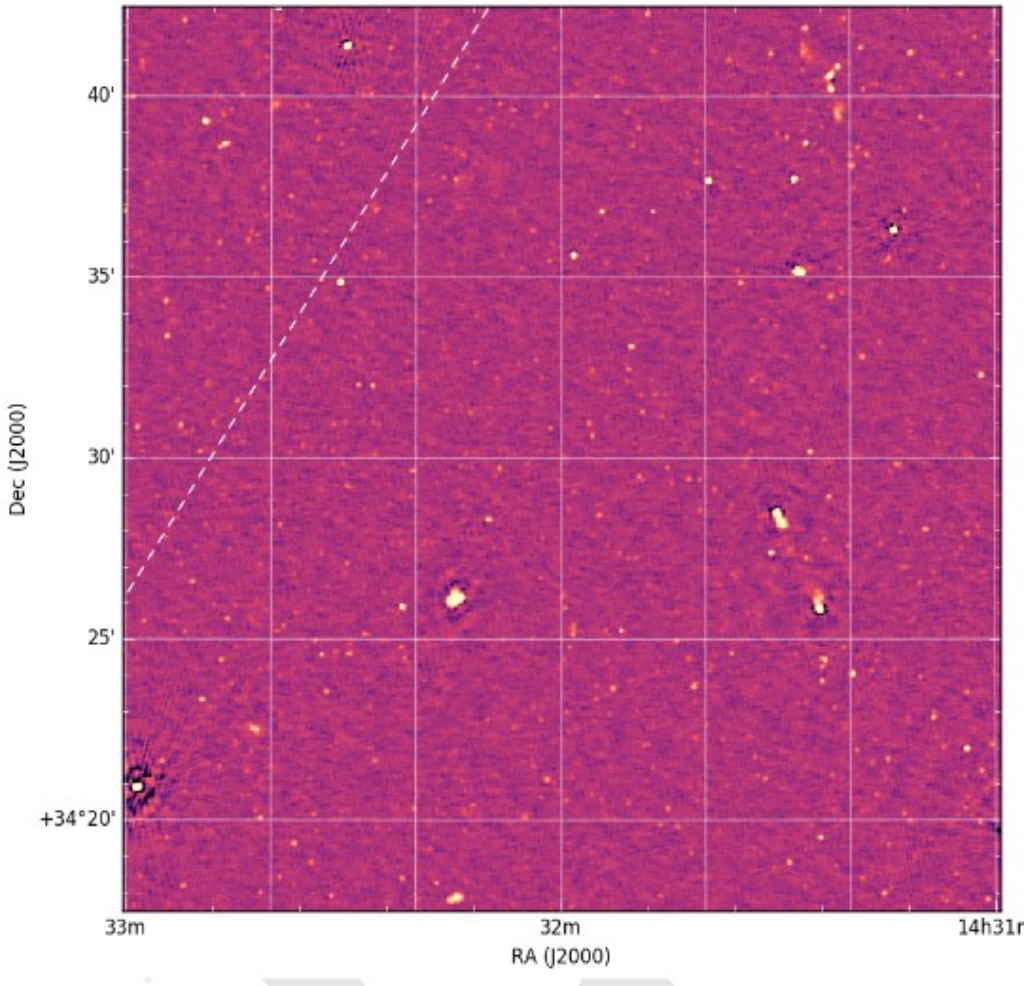


Tasse et al. 2021

Tier-2 deep fields



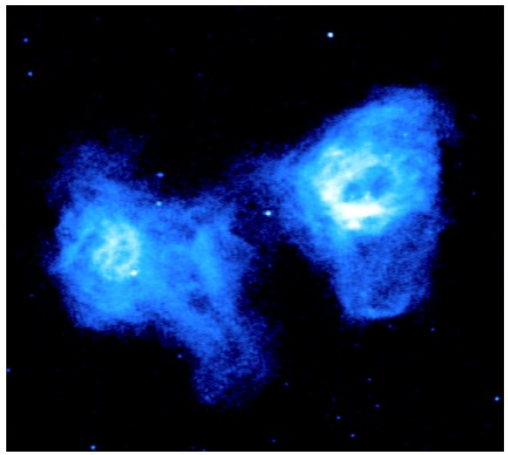
8 hours



80 hours

https://lofar-surveys.org/

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)

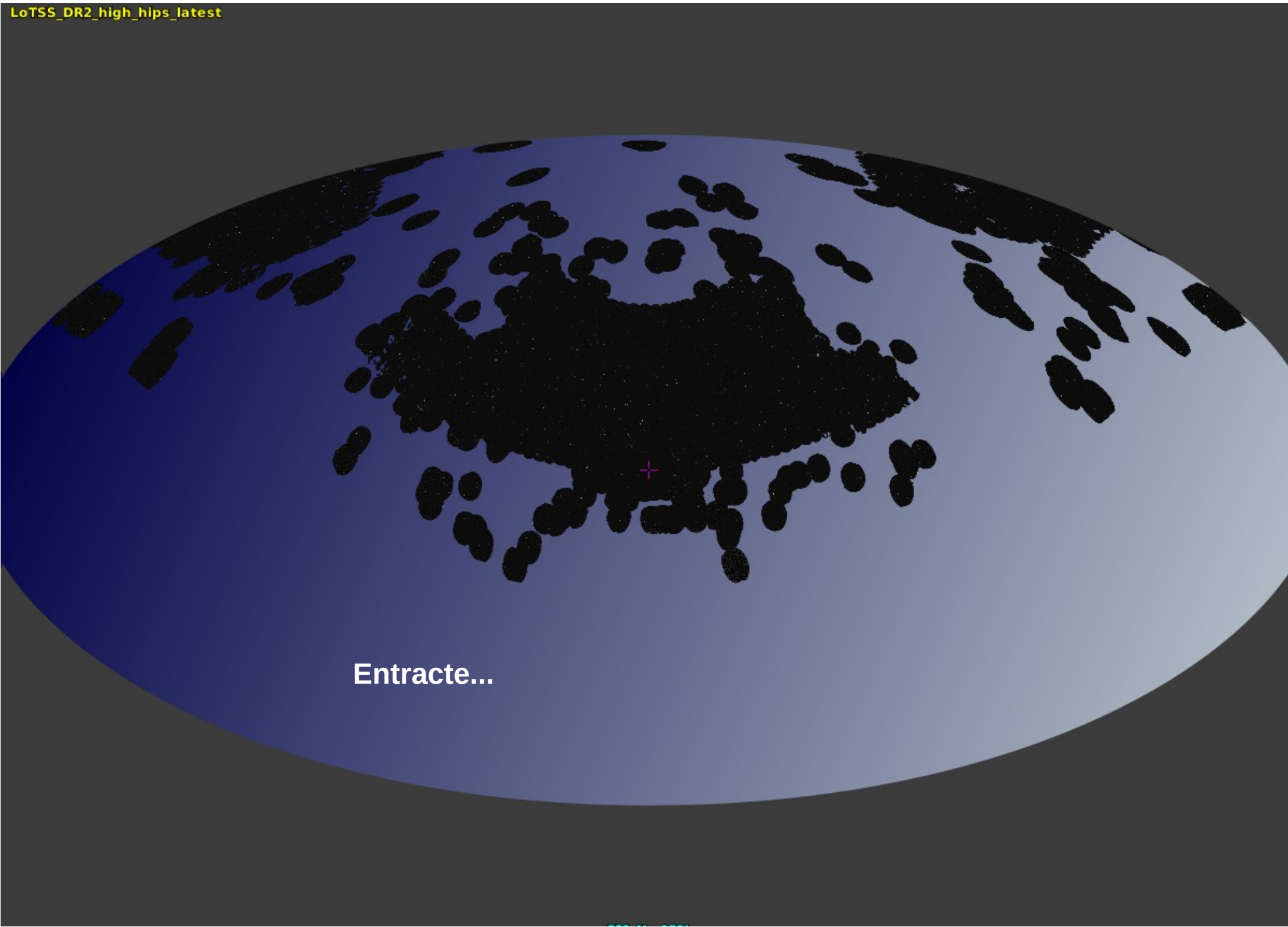
NEWS: ASTRON press release on RGZ launch (26/02/2020)

NEWS: Radio Galaxy Zoo (LOFAR) launches (25/02/2020)

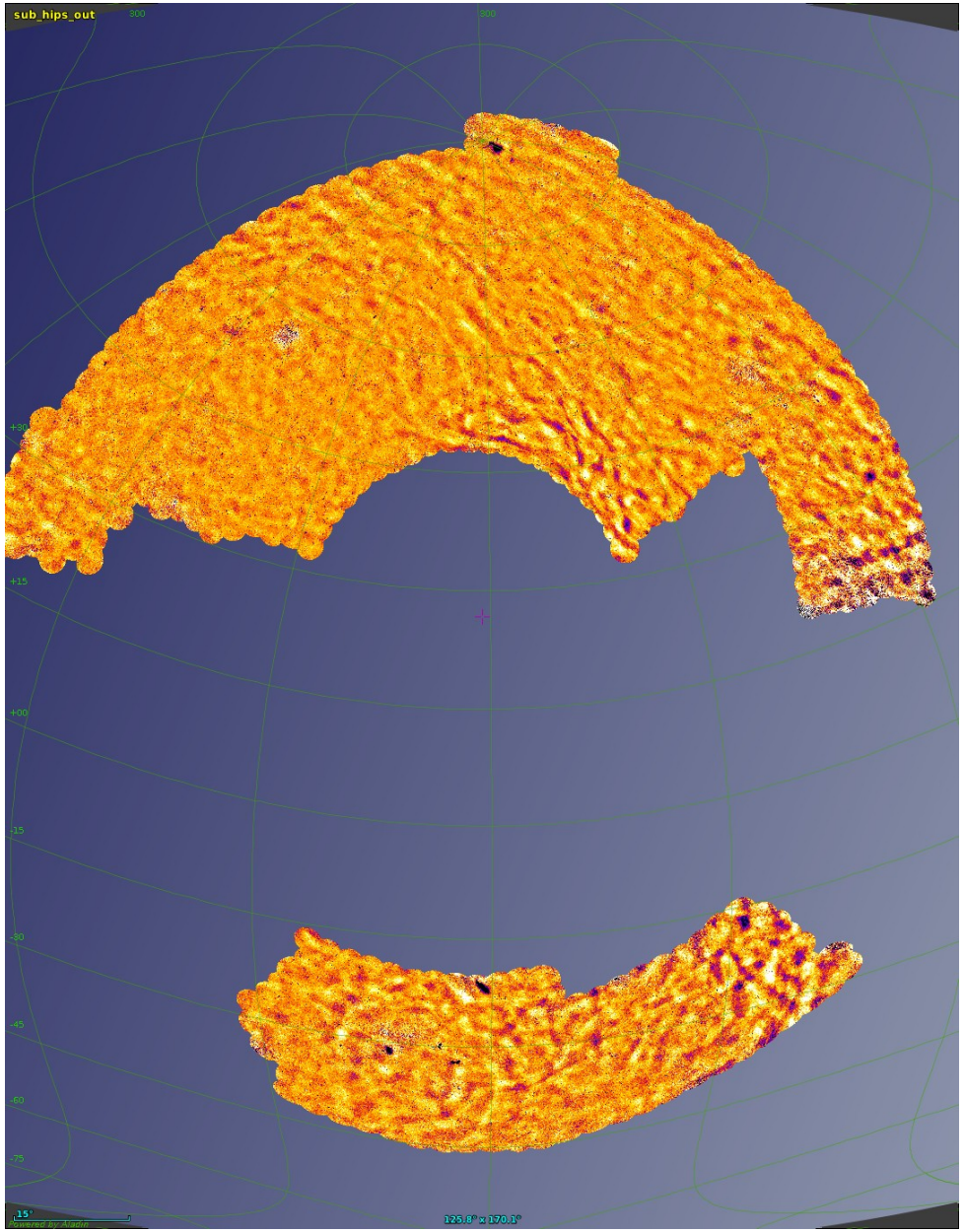
NEWS: LOFAR pioneers new way to study exoplanet environments (17/02/2020)

- **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)**

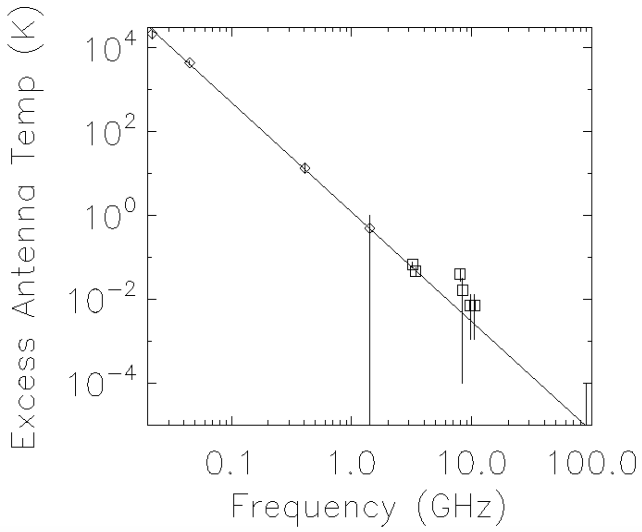

LoTSS_DR2_high_hips_latest
Entracte...

LoTSS-DR2 —Varied science results

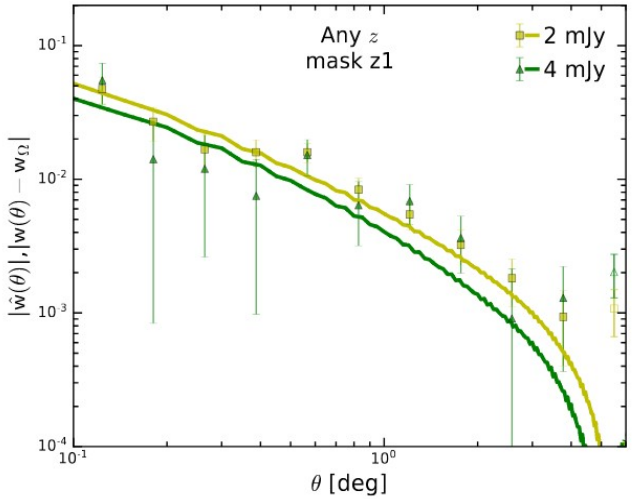


Oei+ in prep - Large scale galactic emission

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

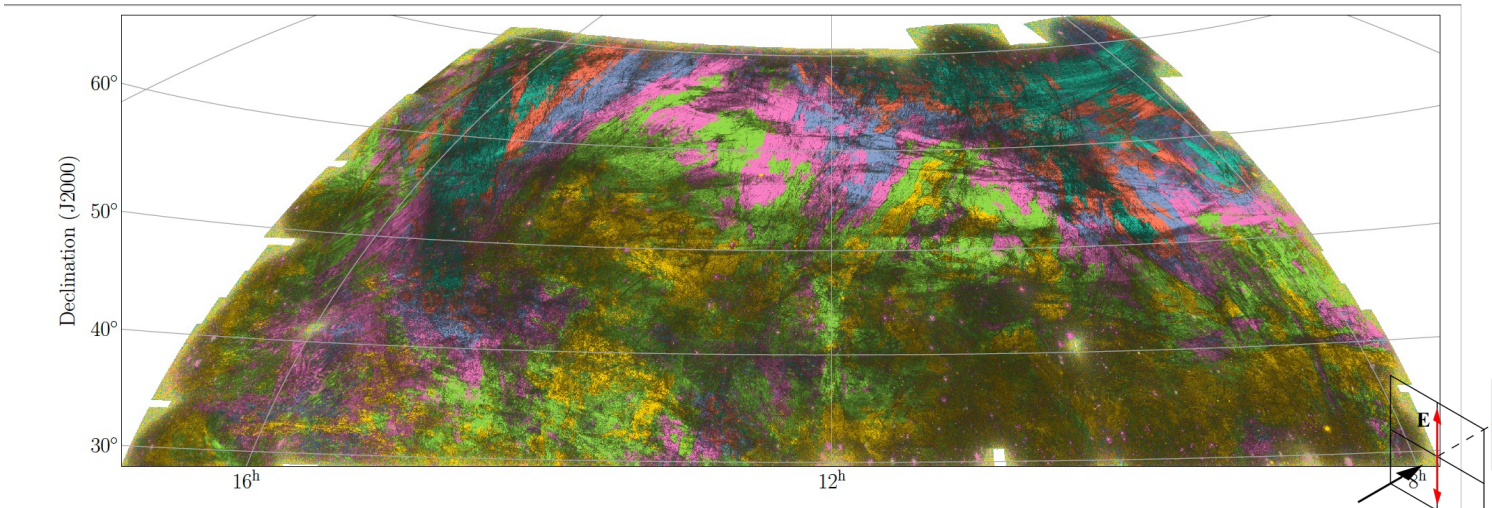


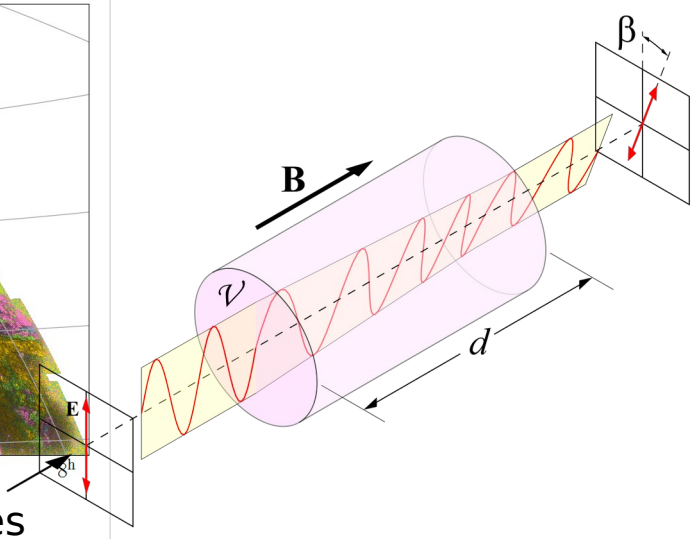
Hardcastle+ 2020 - sky temperature



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

LoTSS-DR2 —Varied science results

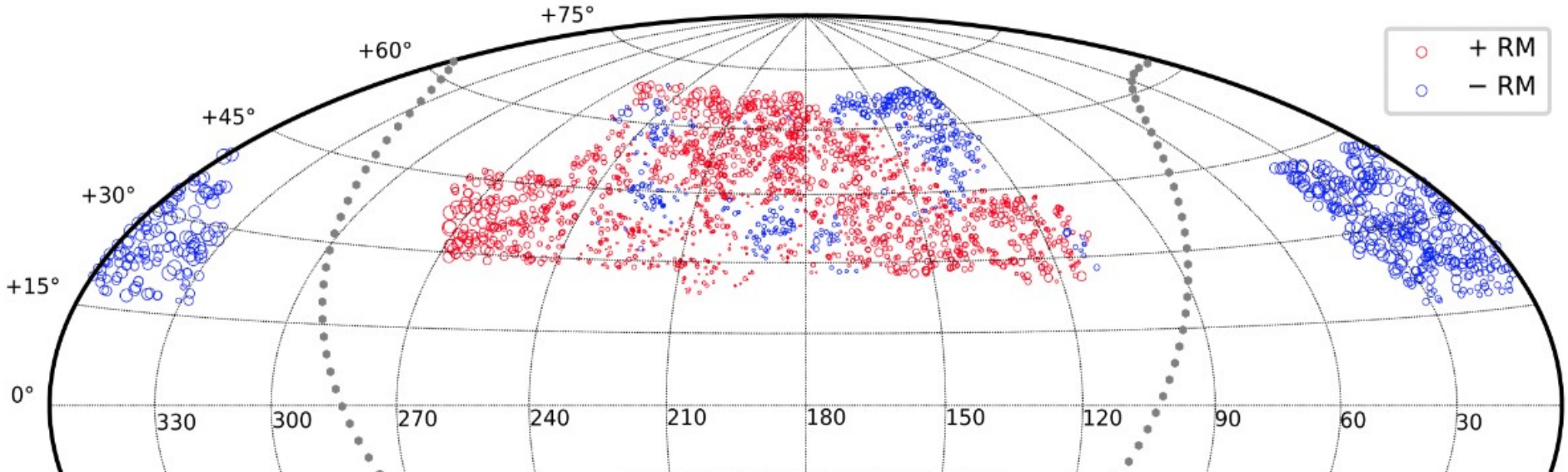


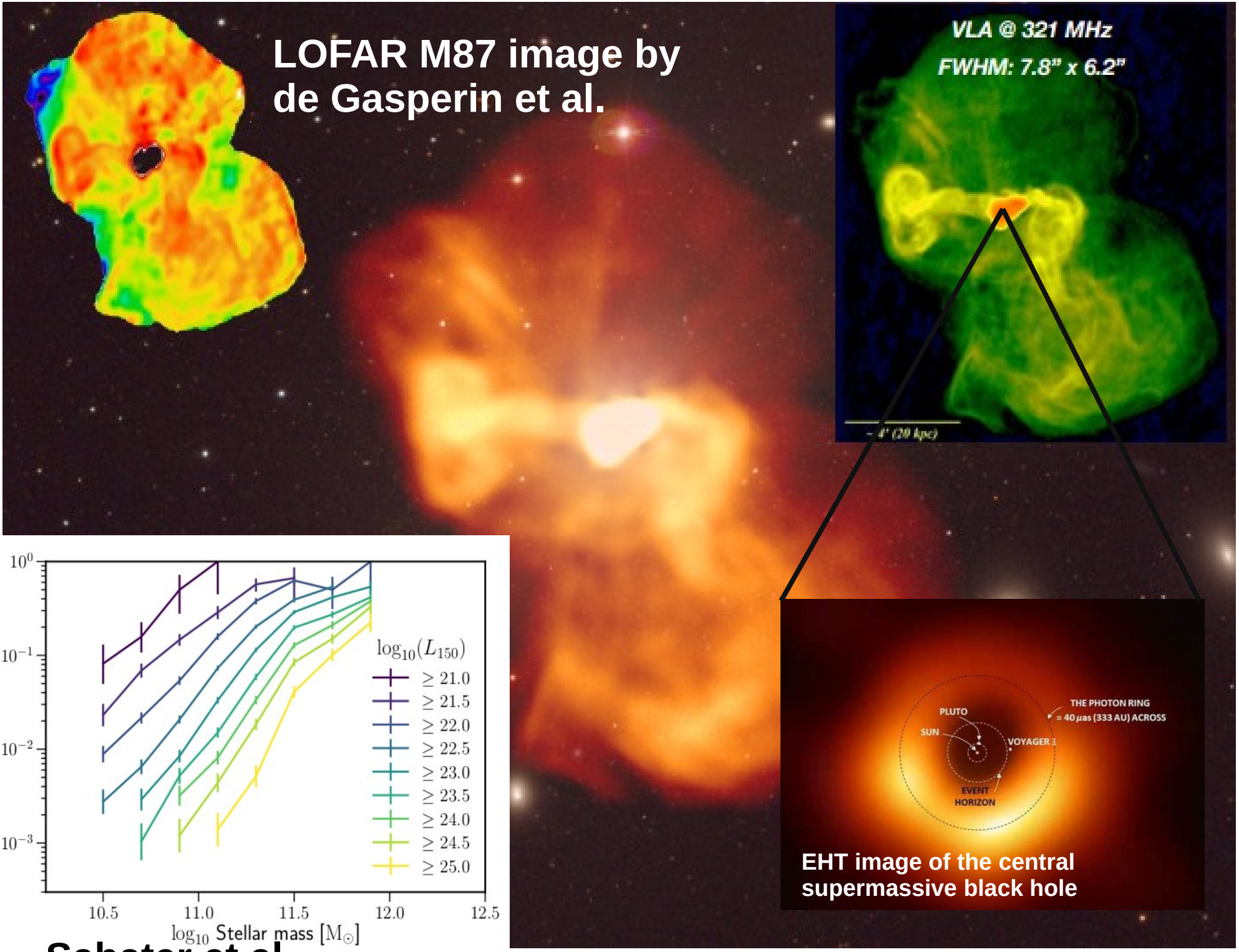


Erceg+ in prep - RM of low surface brightness galactic structures

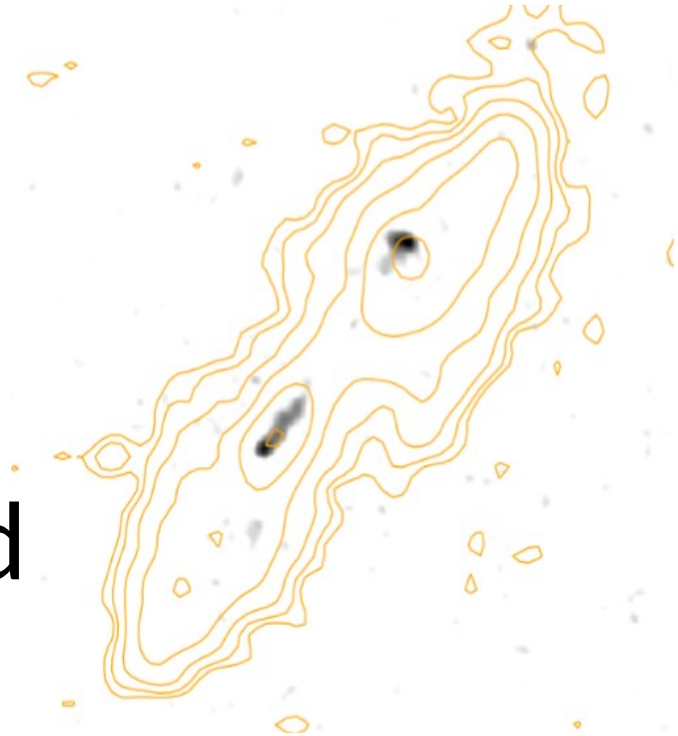
Wide area polarisation at multiple resolutions allows for studies of polarised galactic and extra galactic sources as well as e.g. pulsars or stars

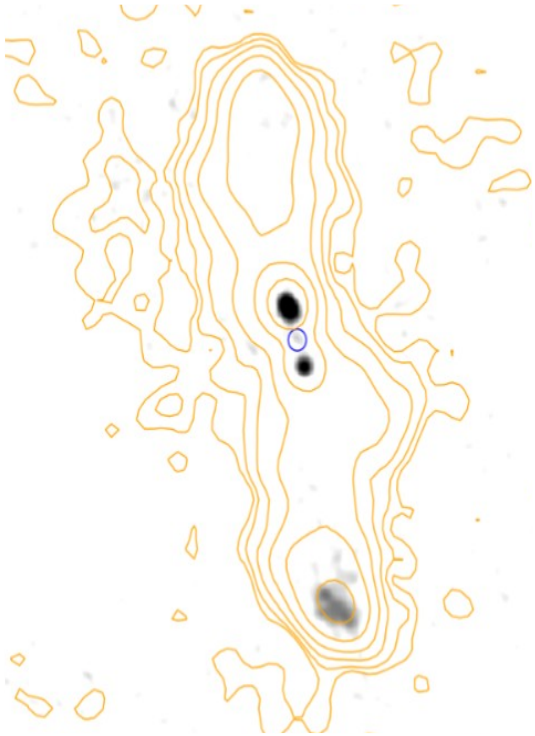
O'Sullivan+ in prep - RM of extra galactic sources

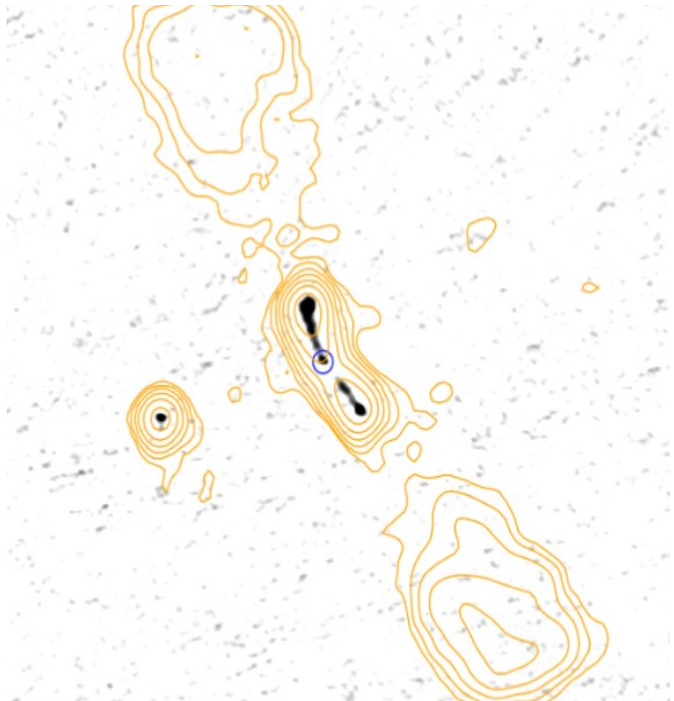



LOFAR M87 image by
de Gasperin et al.
VLA @ 321 MHz
FWHM: 7.8" x 6.2"
~ 4' (20 kpc)
Fraction of radio-loud AGN
10^0
10^{-1}
10^{-2}
10^{-3}
10.5
11.0
11.5
12.0
12.5
$\log_{10}$ Stellar mass [$M_\odot$]
$\log_{10}(L_{150})$
$\geq$ 21.0
$\geq$ 21.5
$\geq$ 22.0
$\geq$ 22.5
$\geq$ 23.0
$\geq$ 23.5
$\geq$ 24.0
$\geq$ 24.5
$\geq$ 25.0
PLUTO
SUN
VOYAGER 1
THE PHOTON RING
= 40 μas (333 AU) ACROSS
EVENT
HORIZON
EHT image of the central
supermassive black hole
Sabater et al.

Jet dynamics
Feedback and duty cycle

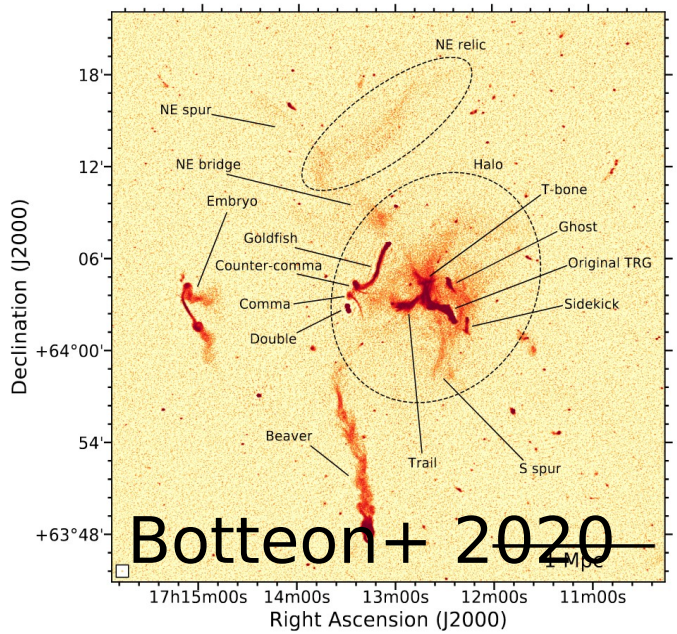




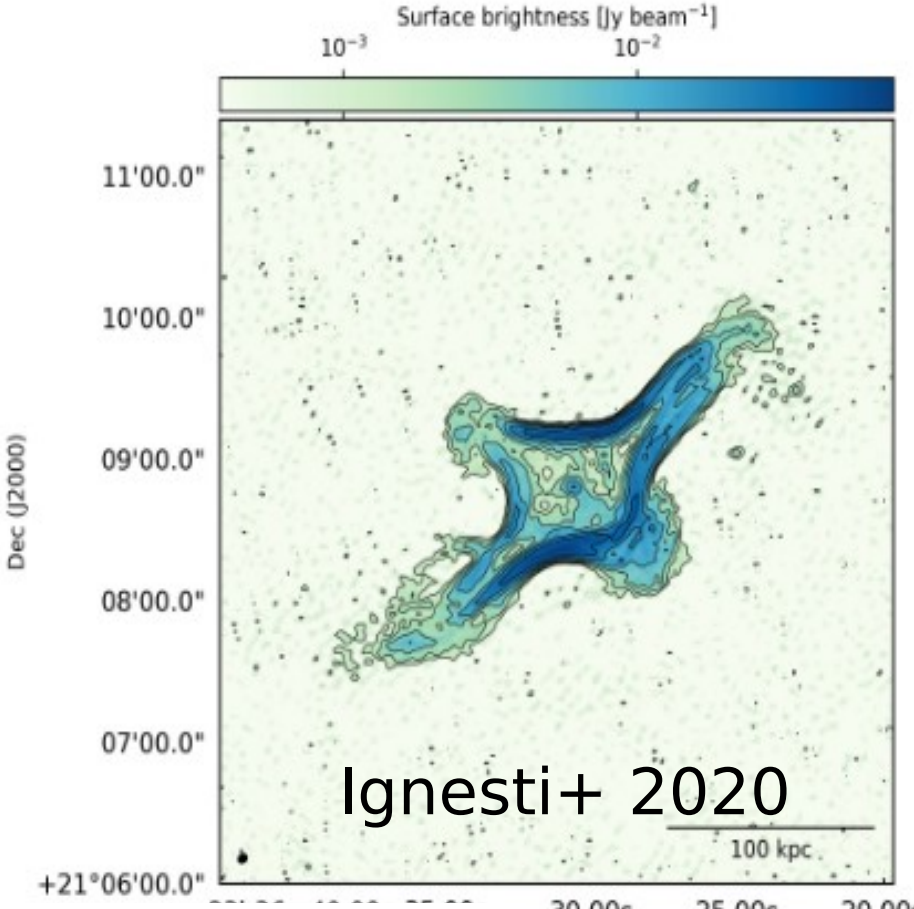


Mahatma et al.

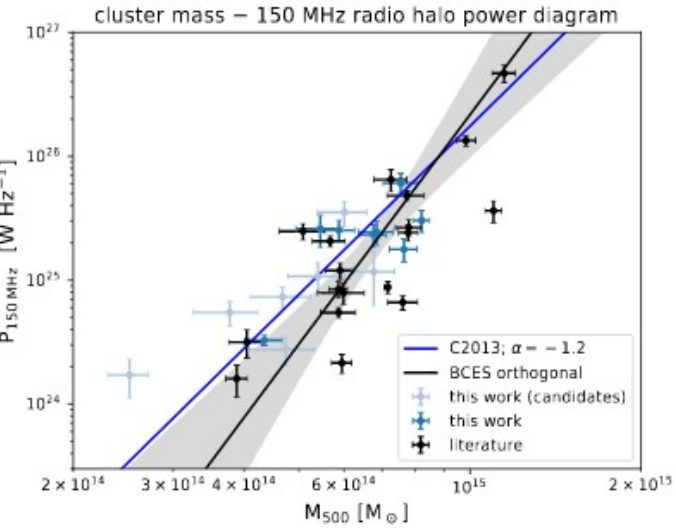
LoTSS-DR2 —Varied science results



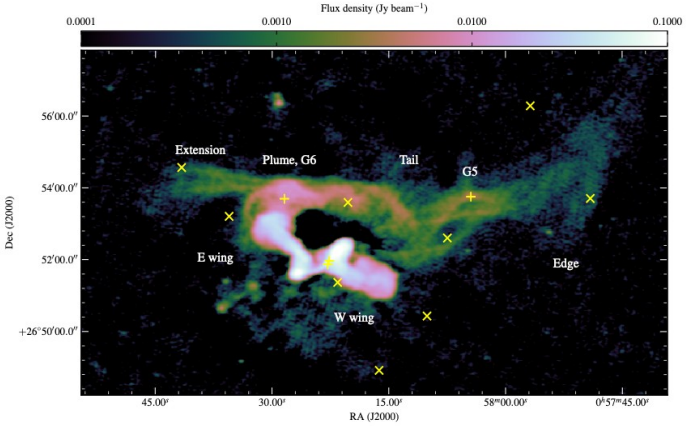
Botteon+ 2020



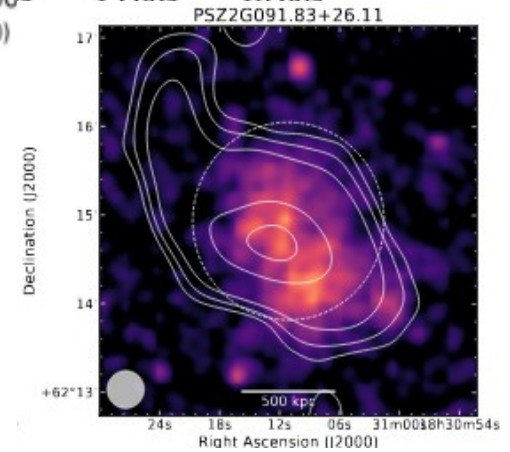
Ignesti+ 2020



van Weeren+ 2020

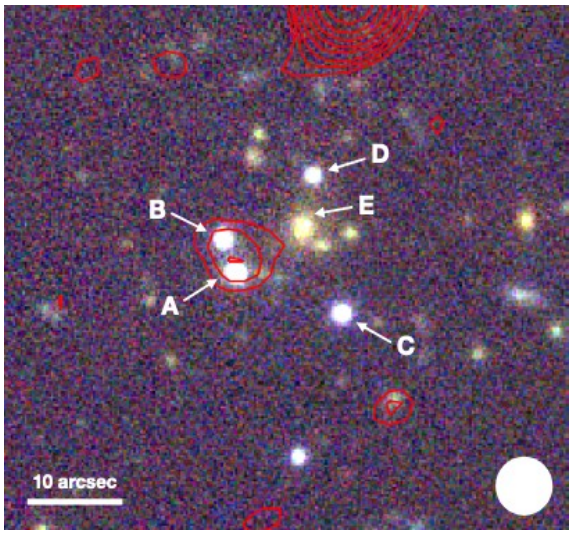


Hardcastle+ 2020

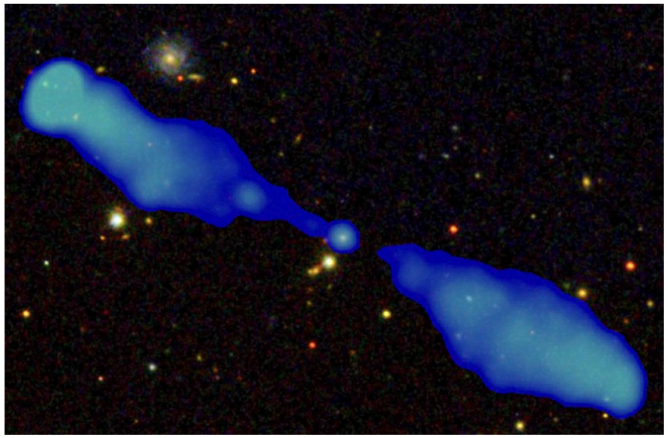


Di Gennaro + 2020

LoTSS-DR2 —Varied science results

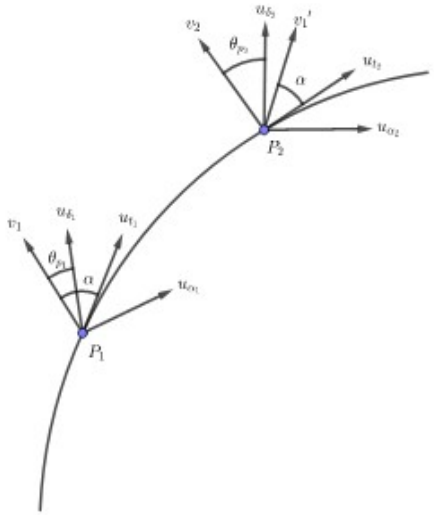


McKean+ Gravitational lenses

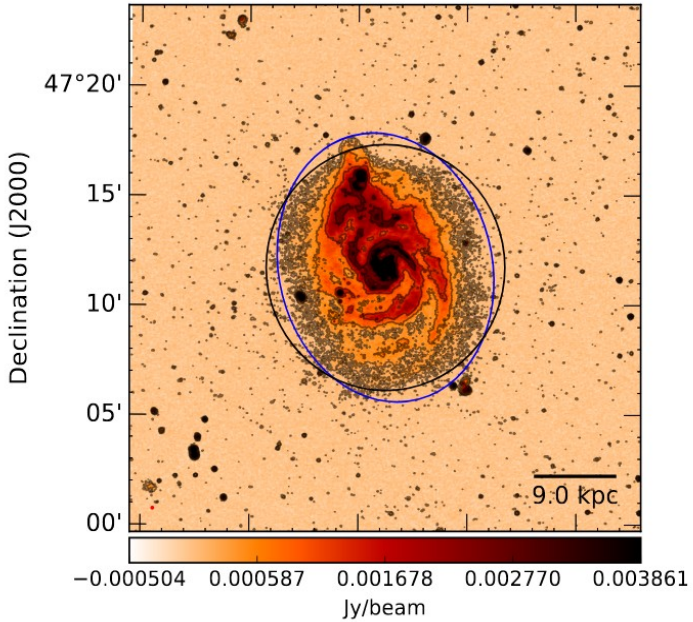


Dabhabe+ 2020 giant radio galaxies
(also Bruni+ in prep)

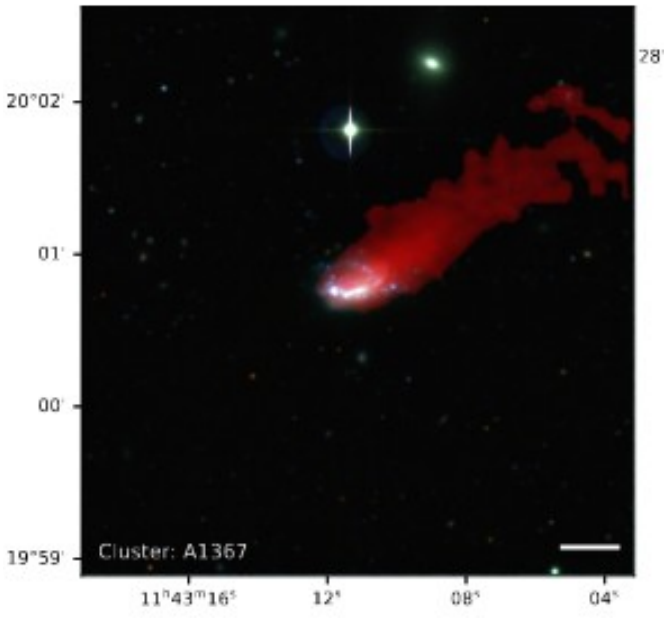
The majority of the science is from large statistical studies or characterising/discovering rarer objects using our standard imaging and catalogue products



Osinga+ 2020 alignment of radio source angles



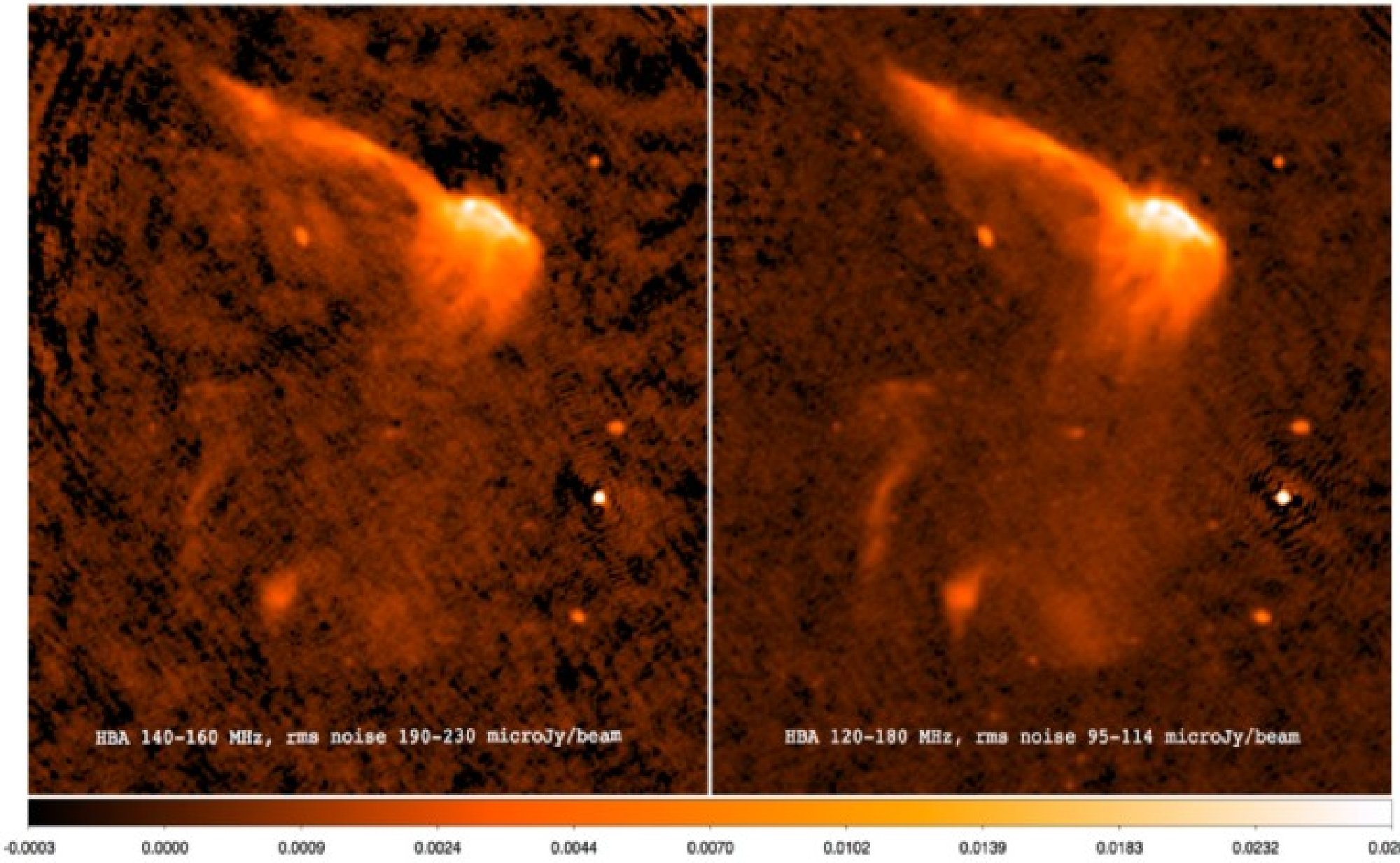
Hessen+ in prep - Nearby galaxy populations

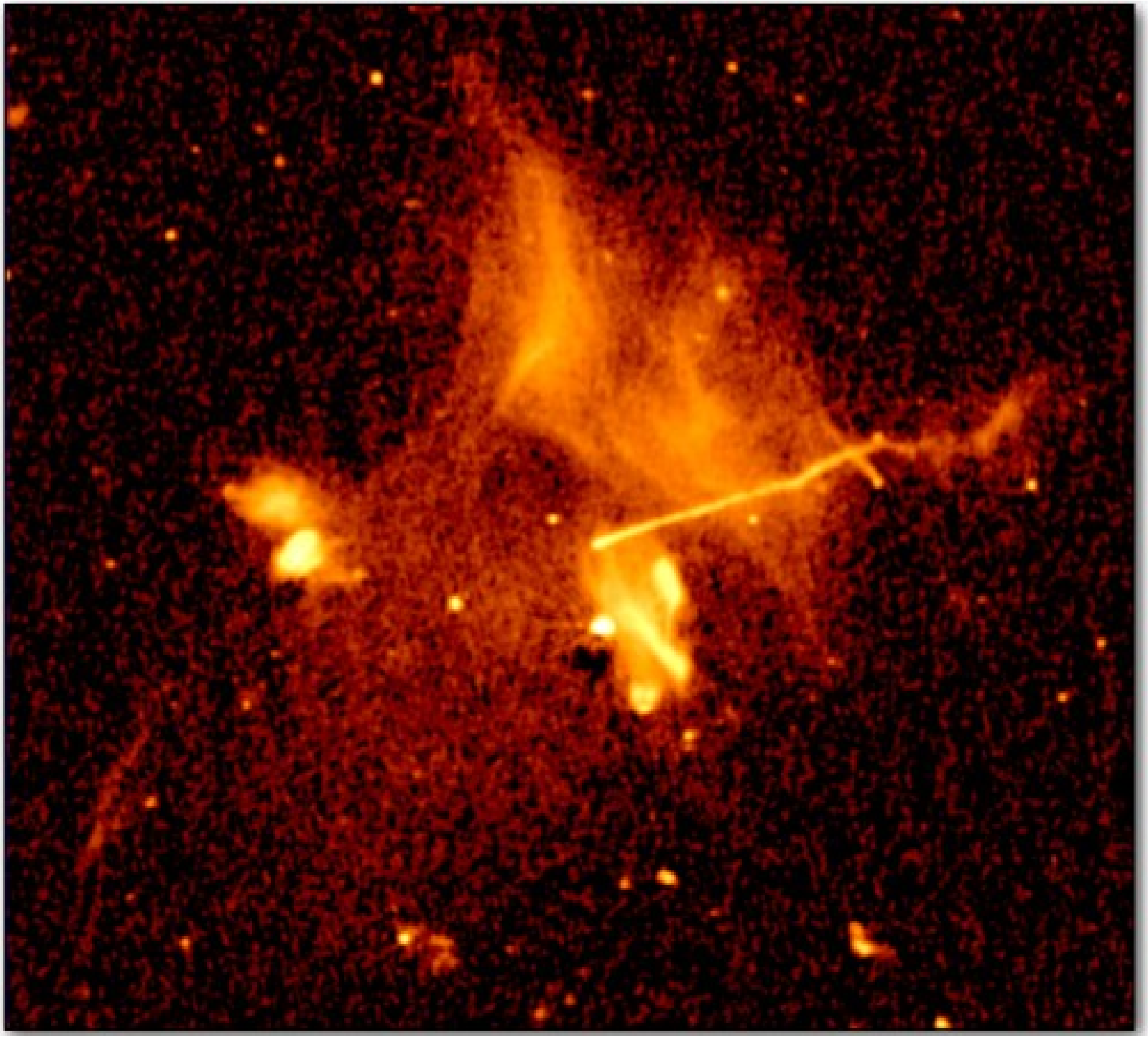


Roberts+ in prep Jellyfish galaxies.

Toothbrush cluster

van Weeren 2014 in prep.



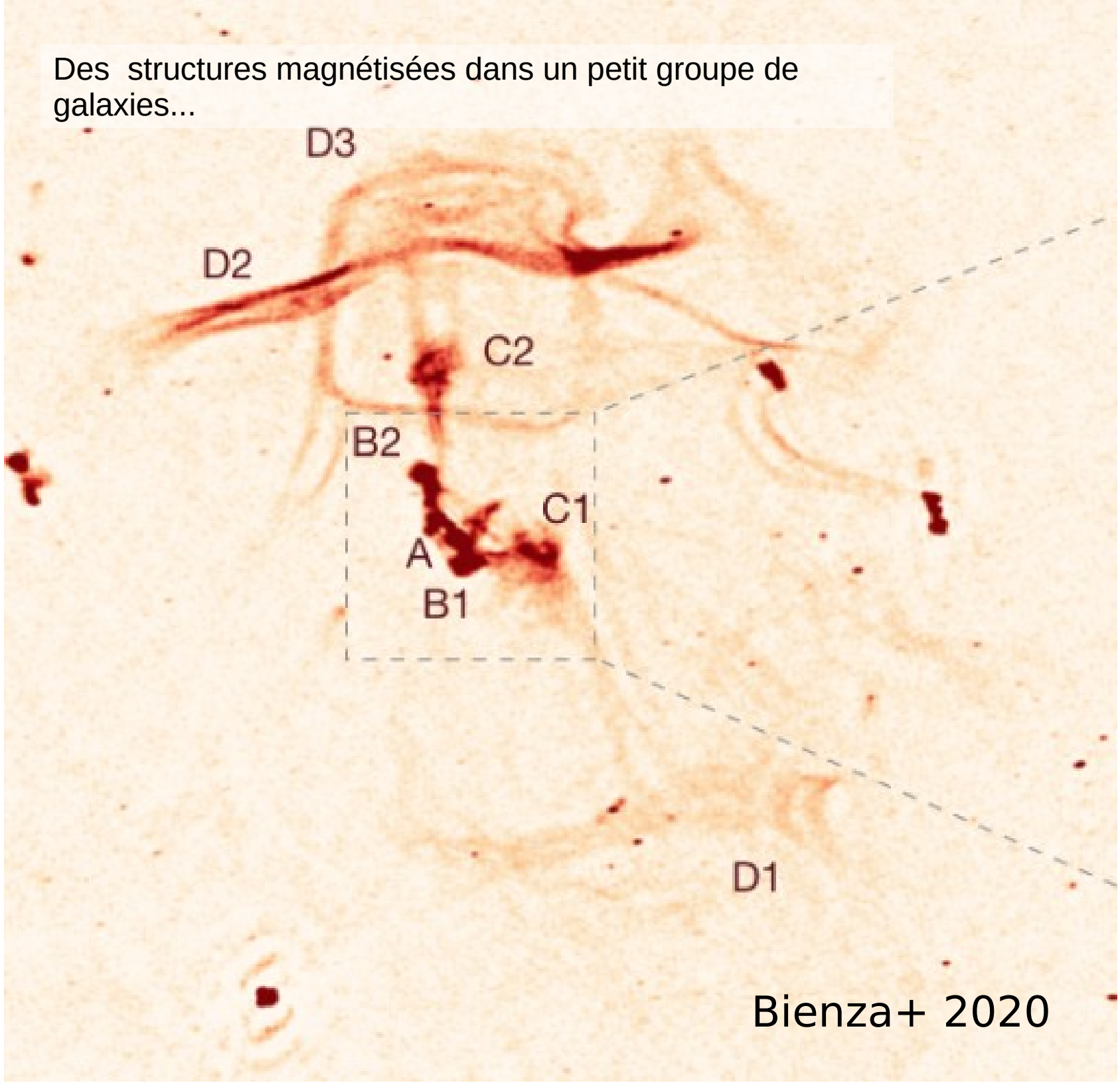


Abell 2256

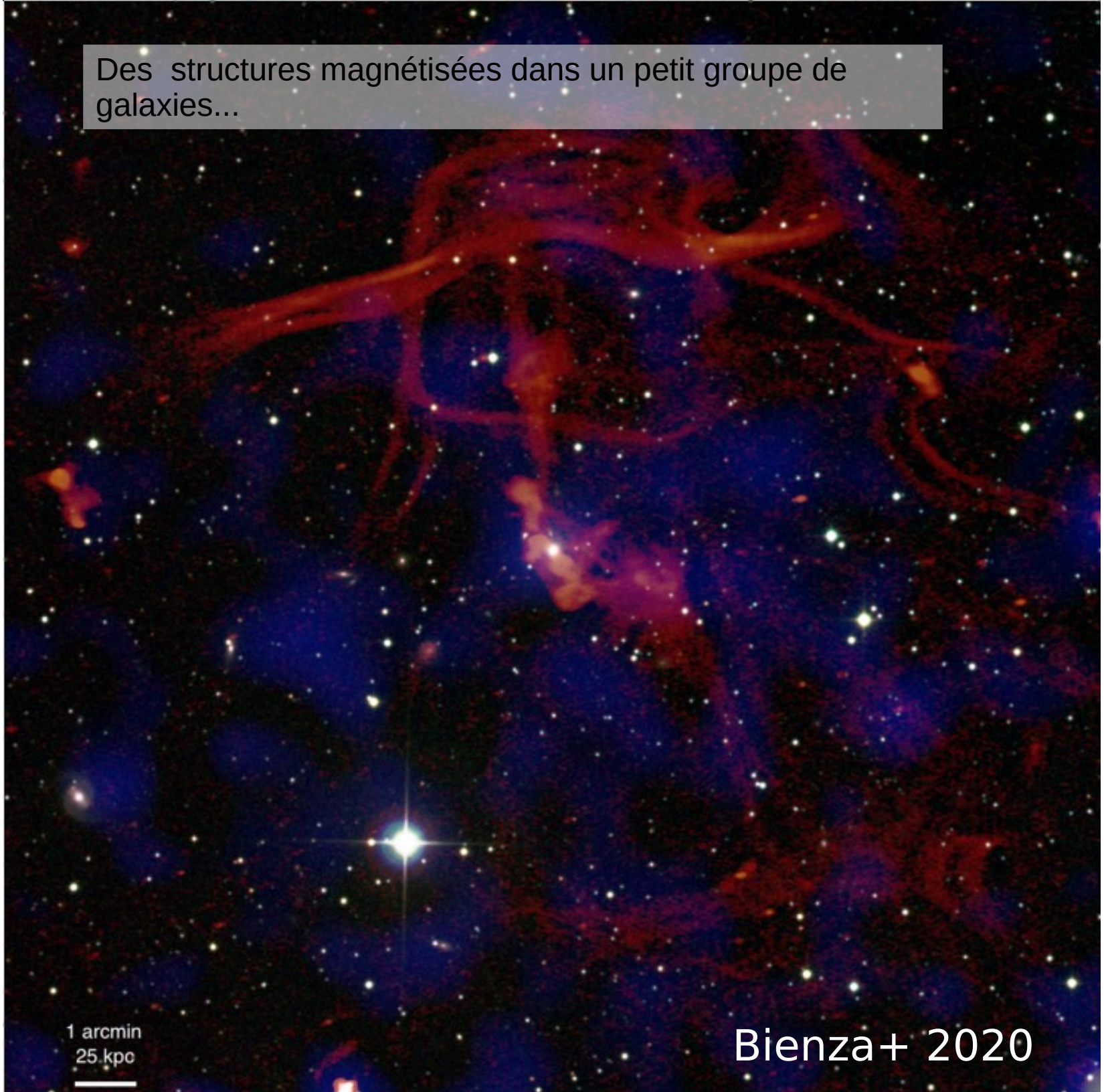
120-180 MHz
5 arcsec
130 μJy/beam

Image courtesy:
R. van Weeren

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

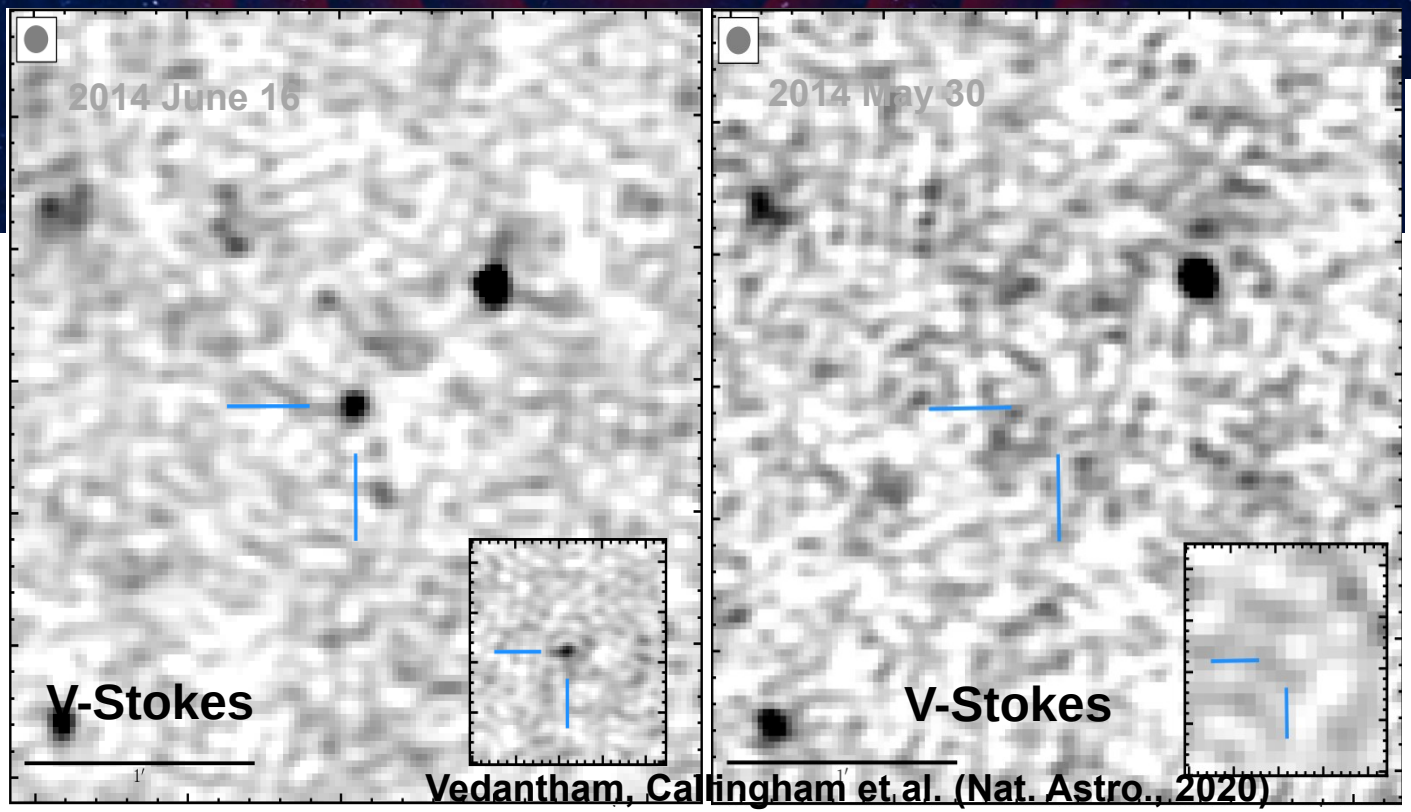


Bienza+ 2020

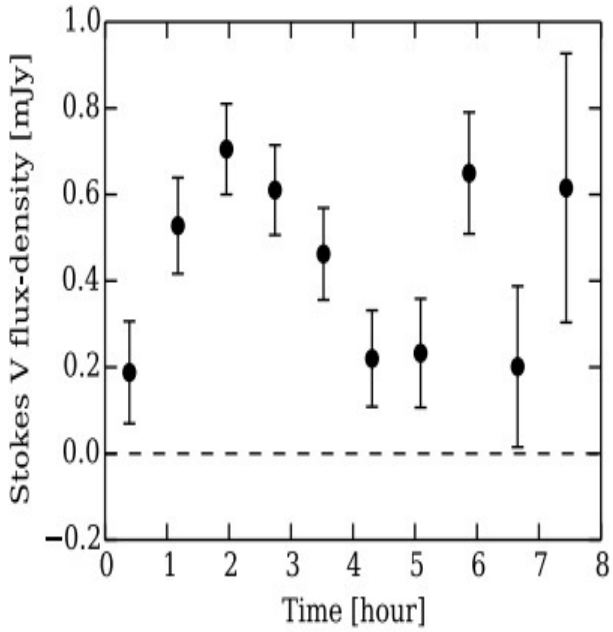

Des structures magnétisées dans un petit groupe de galaxies...
1 arcmin
25 kpc
Bienza+ 2020

Unexpected surprise

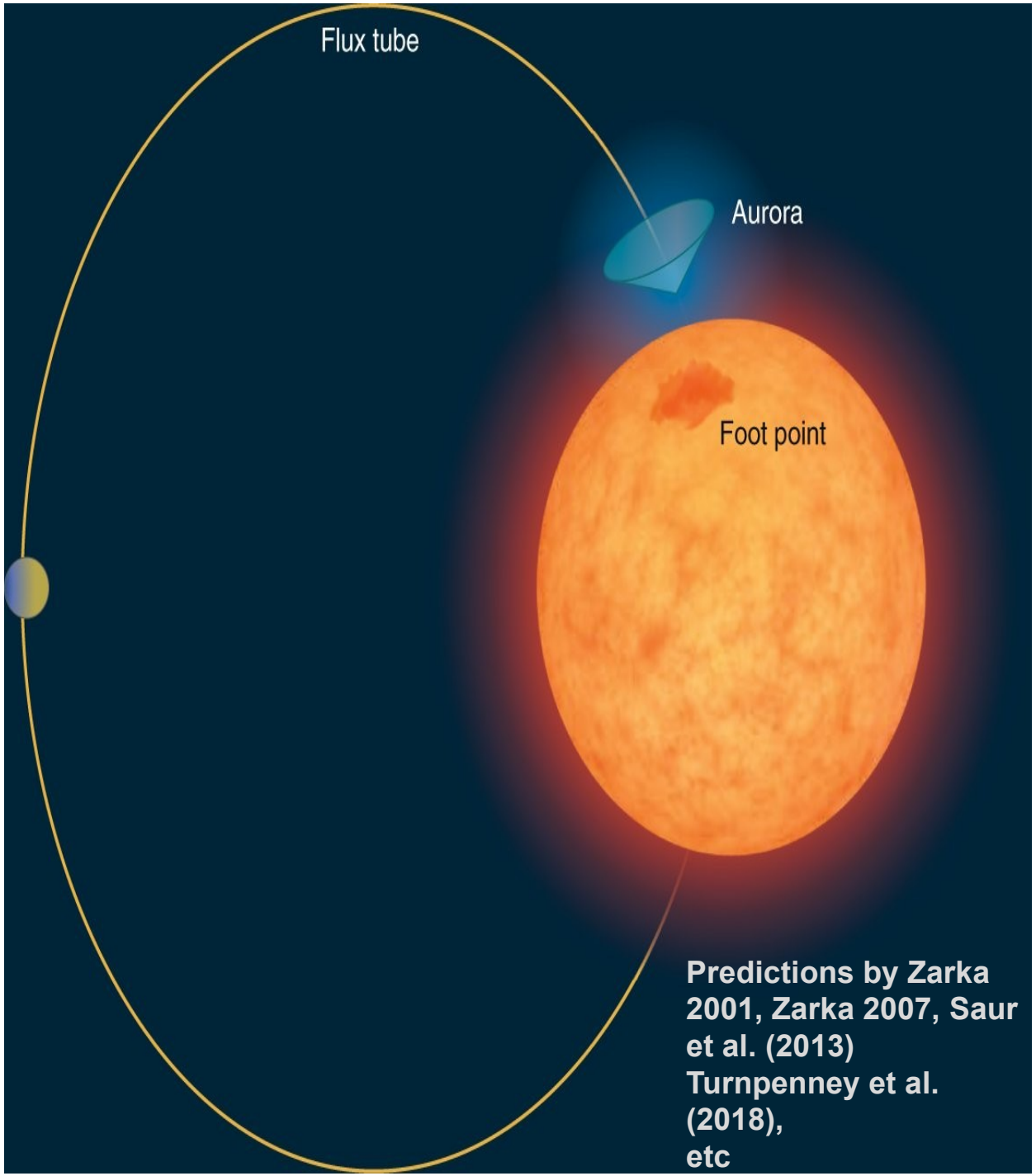
- Together with Tim Shimwell and Martin Hardcastle we decided to add a V-Stokes image it the end of the pipeline



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



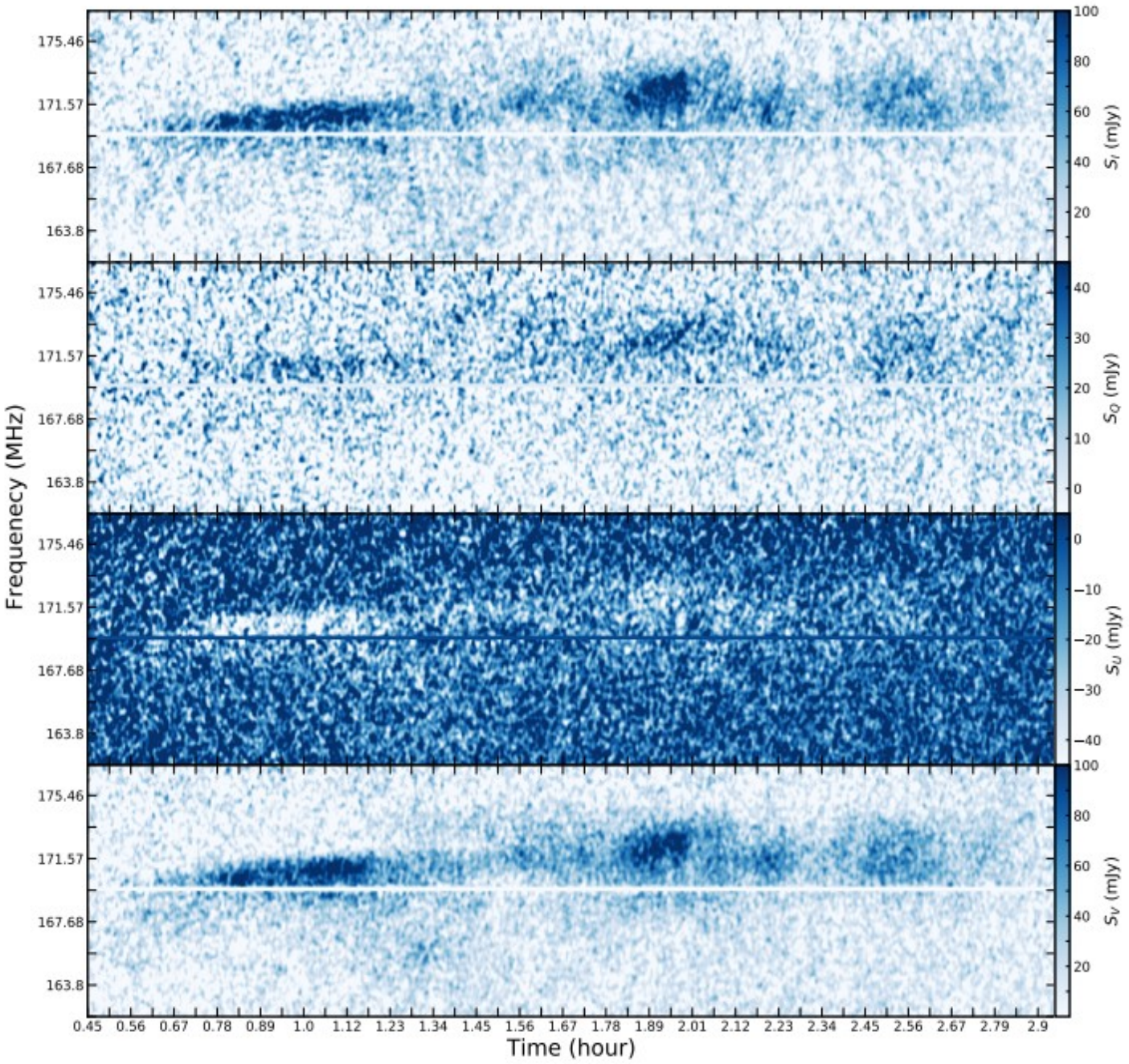
Interpretation of emission



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

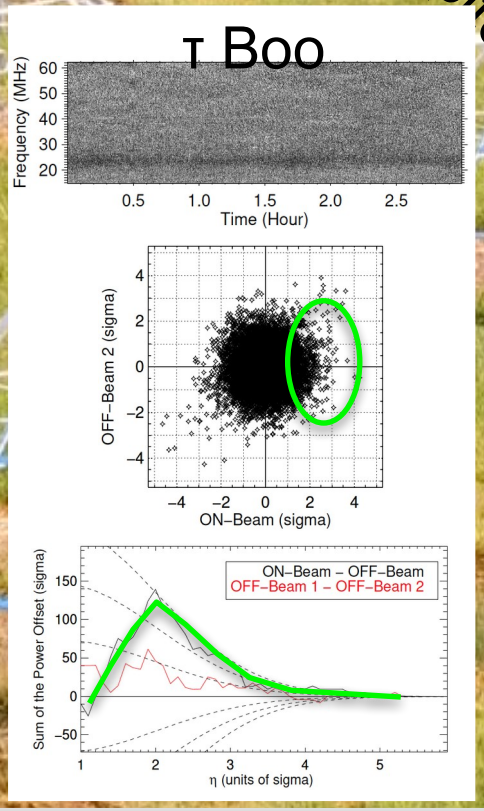


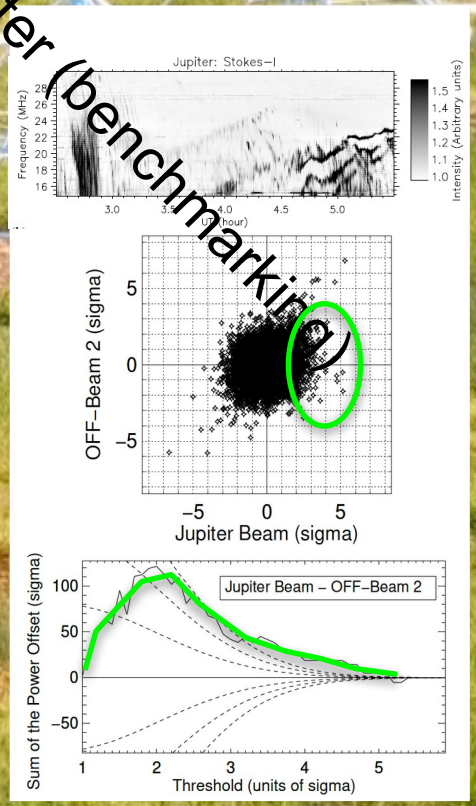
A resolved dynamic spectra built using DynSpecMS

Slide taken from Joe Callingham

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

De LOFAR à NenuFAR





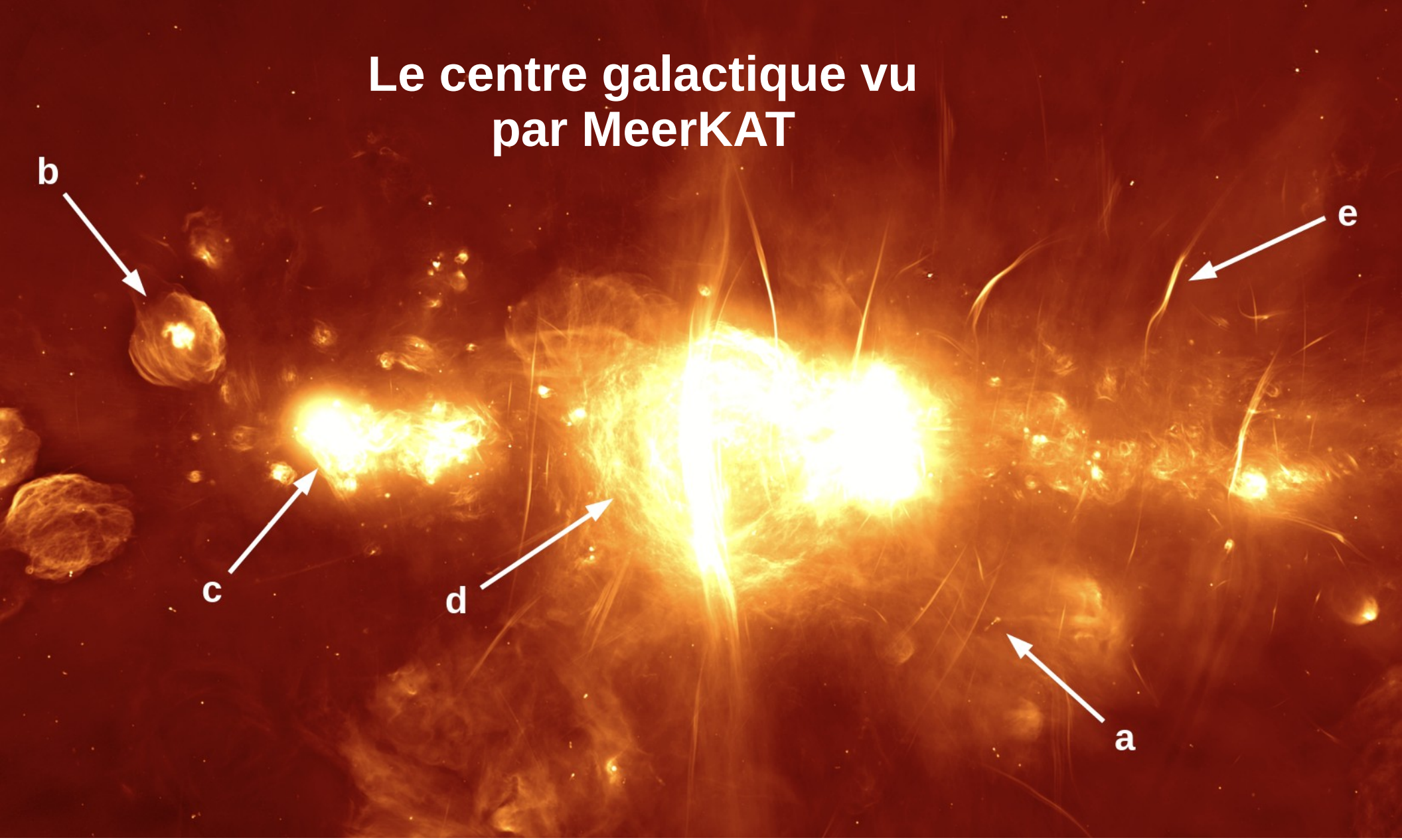
Détection avec LOFAR en mode faisceau de faibles sursauts radio provenant du système de l'exoplanète τ Bootis, 14-21 MHz, $10^{4\text{-}5}$ x Jupiter (3.2 σ, à confirmer) [Turner, Zarka…, A&A 2020]

SKA-0: MeerKAT

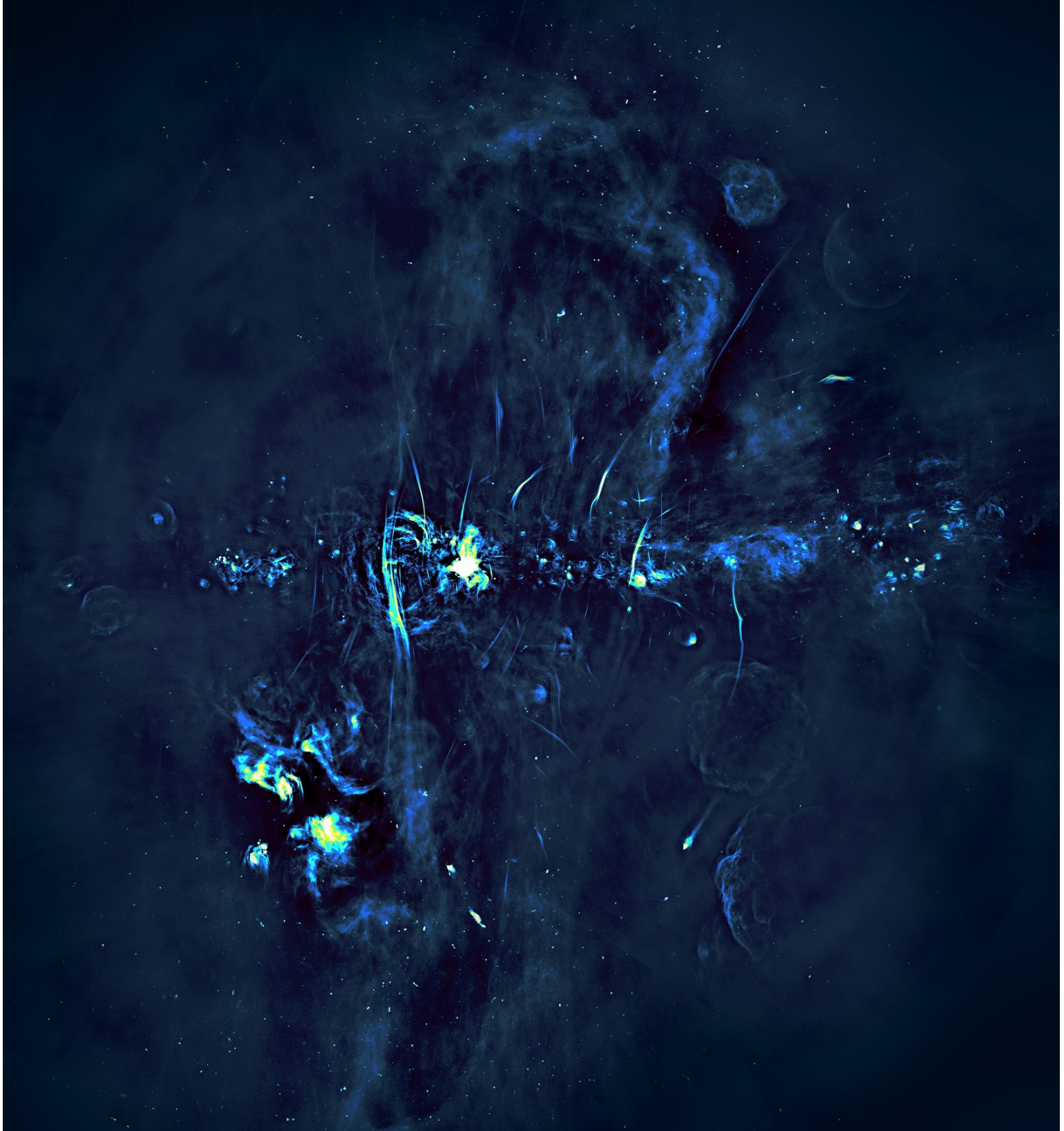
- World class/beating cm wavelength telescope
- Local project, but international community involved
- **64 dishes**, spread over 8km
- **0.58-14 GHz** frequency coverage using 3 feeds
- **Construction by 2017**
- Major international science interest
- Discussion underway to **integrate MeerKAT with SKA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

Le centre galactique vu par le VLA

Le centre galactique vu par MeerKAT



A: source d’arriere plan
B: rémanant de supernovae
C: région de formation stellaire
D: supershell
E: filament magnétisé de nature inconnue



Merci!