

A DECADE OF SCIENCE WITH THE SKA-LOW PRECURSOR: RESULTS, PROSPECTS AND LESSONS LEARNED FROM THE MURCHISON WIDEFIELD ARRAY

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Research Fellow // MWA Principal Scientist

Swiss SKA Days | 2nd September 2024

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on behalf of the MWA Management & Operations teams
Prof. Steven Tingay, Dr. Stefan Duchesne, Mr. Tom Booler, Ms. Venus Chico, Ms. Aoife Stapleton and others
[Prof. Randall Wayth, Ms. Mia Walker, Dr. Ben McKinley and others]



This scientific work uses data obtained from Inyarrimanha Ilgari Bundara / the Murchison Radio-astronomy Observatory. We acknowledge the Wajarri Yamaji People as the Traditional Owners and native title holders of the Observatory site. Establishment of CSIRO's Murchison Radio-astronomy Observatory is an initiative of the Australian Government, with support from the Government of Western Australia and the Science and Industry Endowment Fund. Support for the operation of the MWA is provided by the Australian Government (NCRIS), under a contract to Curtin University administered by Astronomy Australia Limited. This work was supported by resources provided by the Pawsey Supercomputing Research Centre with funding from the Australian Government and the Government of Western Australia.

THE MURCHISON WIDEFIELD ARRAY (MWA)

► The SKA-Low Precursor:

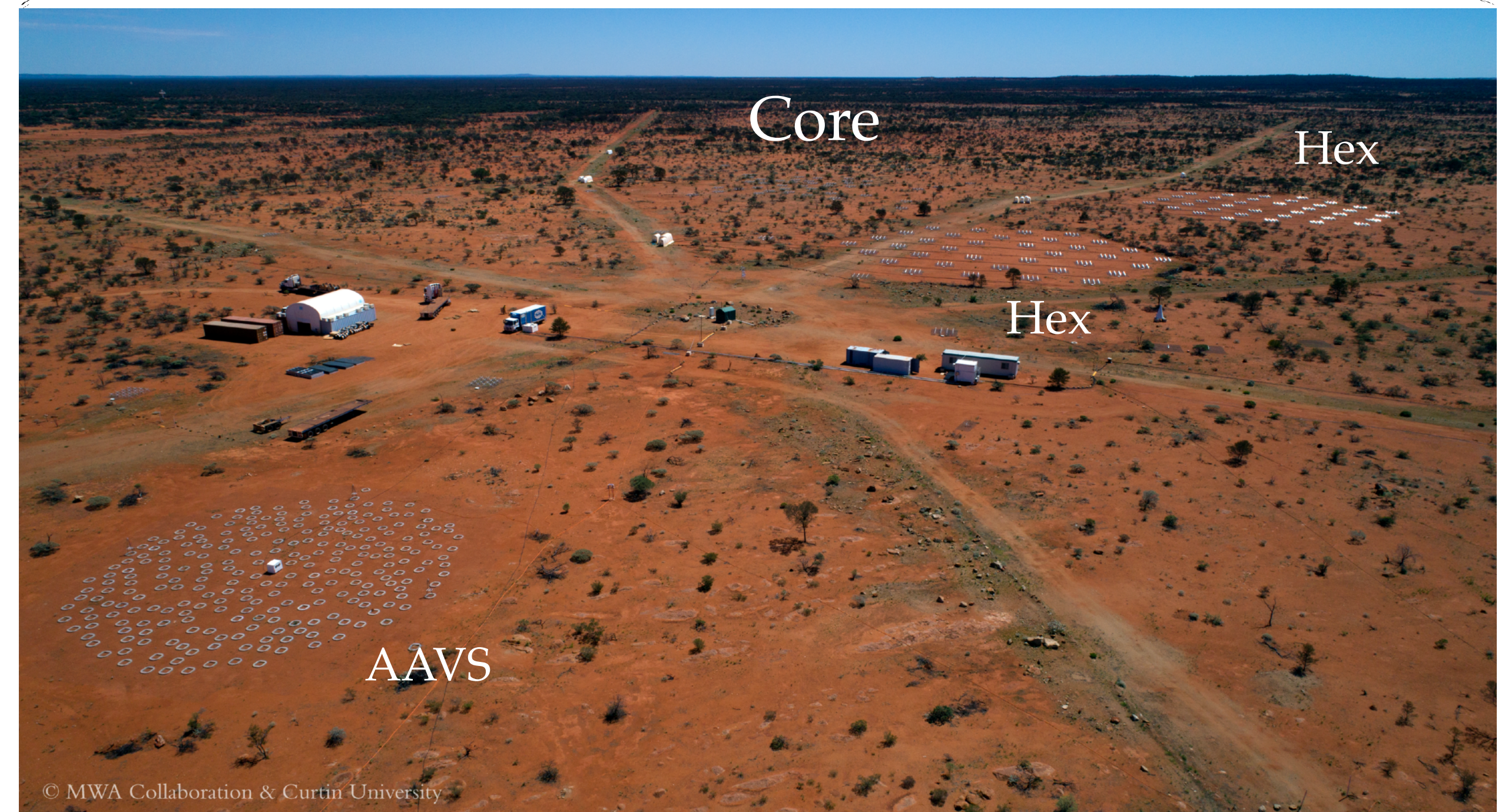
- ◉ *Inyarrimanha Ilgari Bundara*, the CSIRO Murchison Radio-astronomy Observatory (MRO) in Western Australia (725km from Boorloo/Perth)
- ◉ Wajarri Yamaji People: Traditional Owners and native title holders
- ◉ MWA is known as *Gurlgamarnu* in Wajarri (“*the ear that listens to the sky*”)
- ◉ Operating between 72 and 300 MHz



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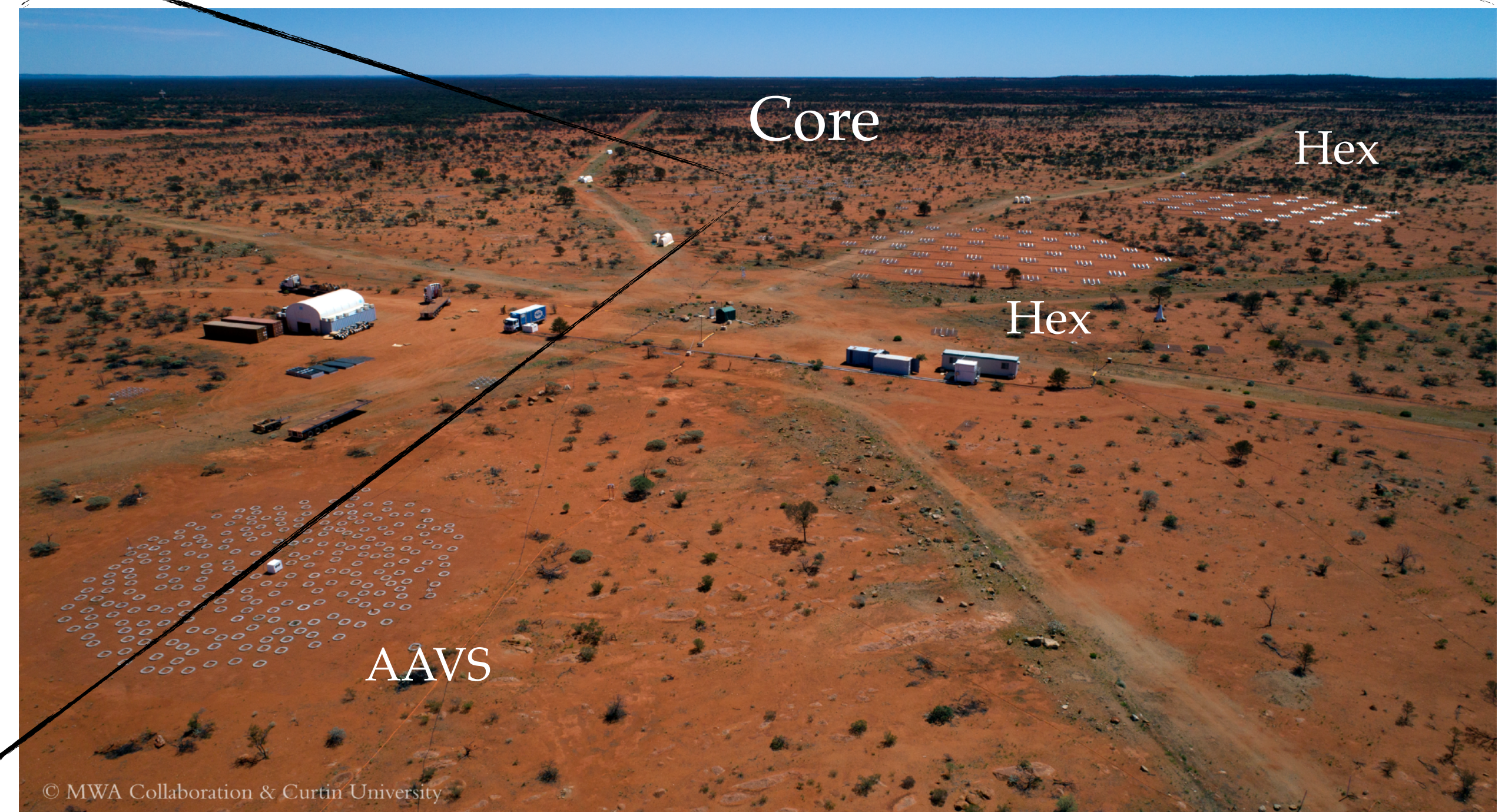
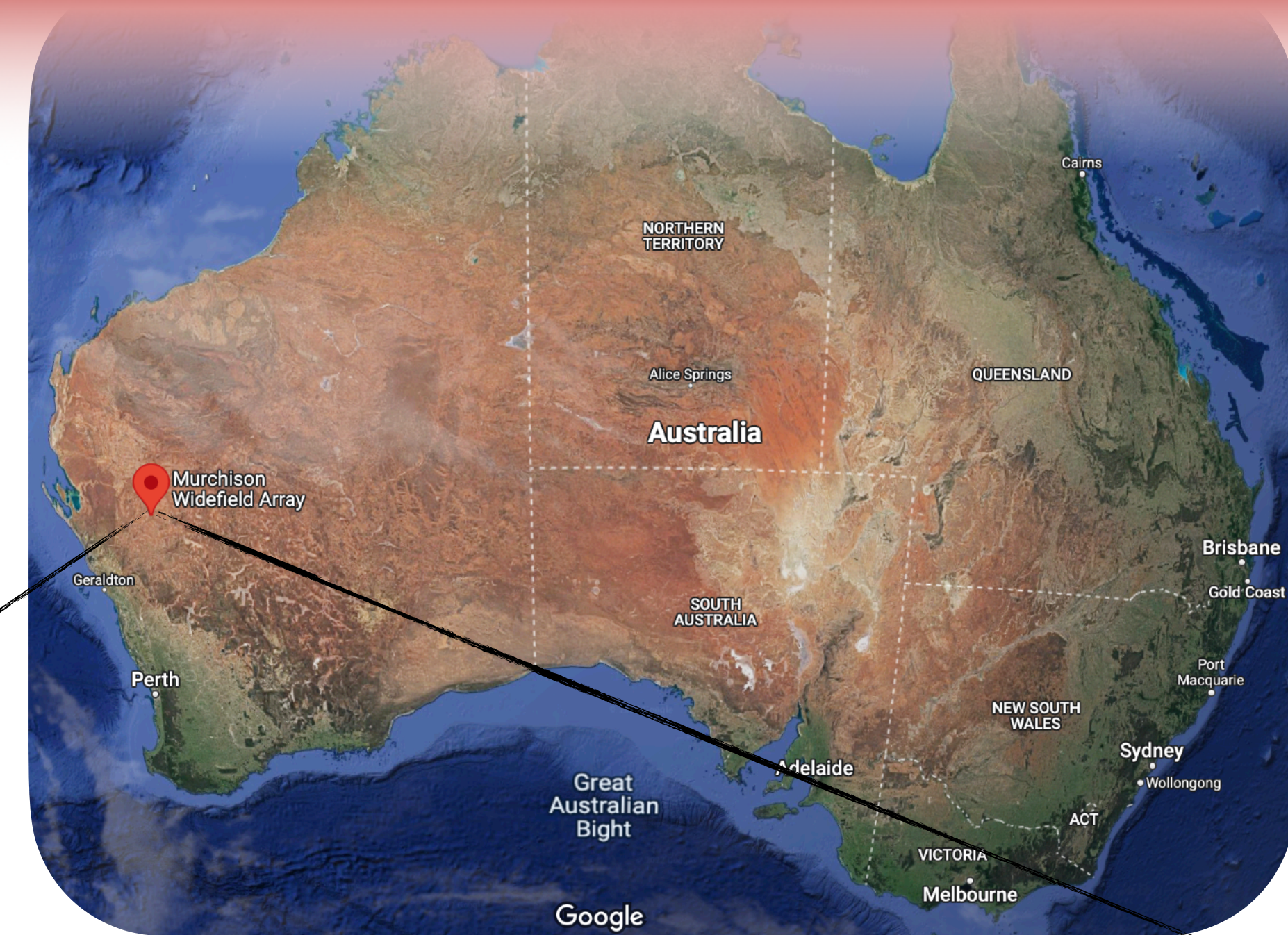
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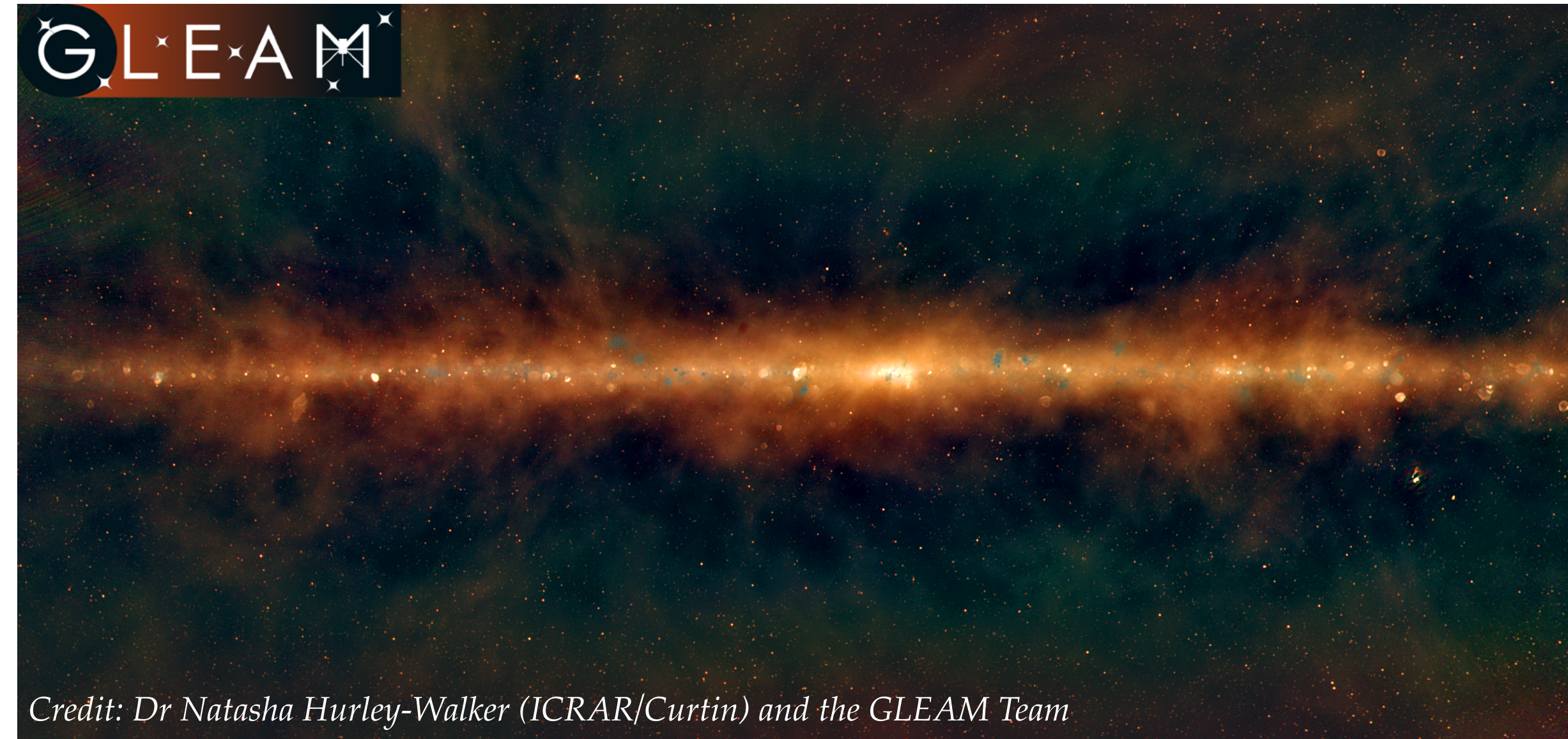
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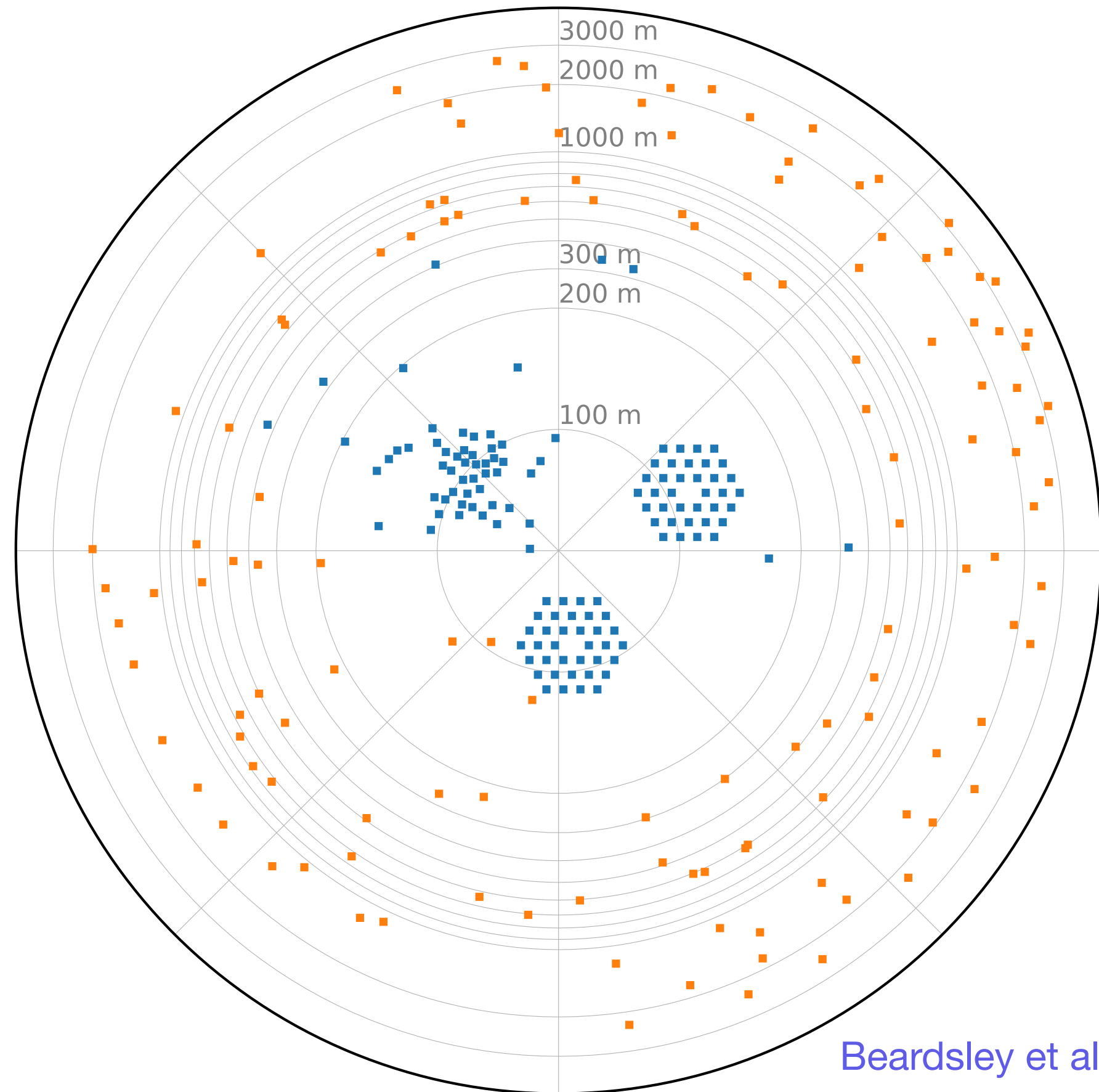
THE MURCHISON WIDEFIELD ARRAY (MWA)

- ▶ Phase I: 2013 — 2016
 - 128T ; 8 m to 2.8 km

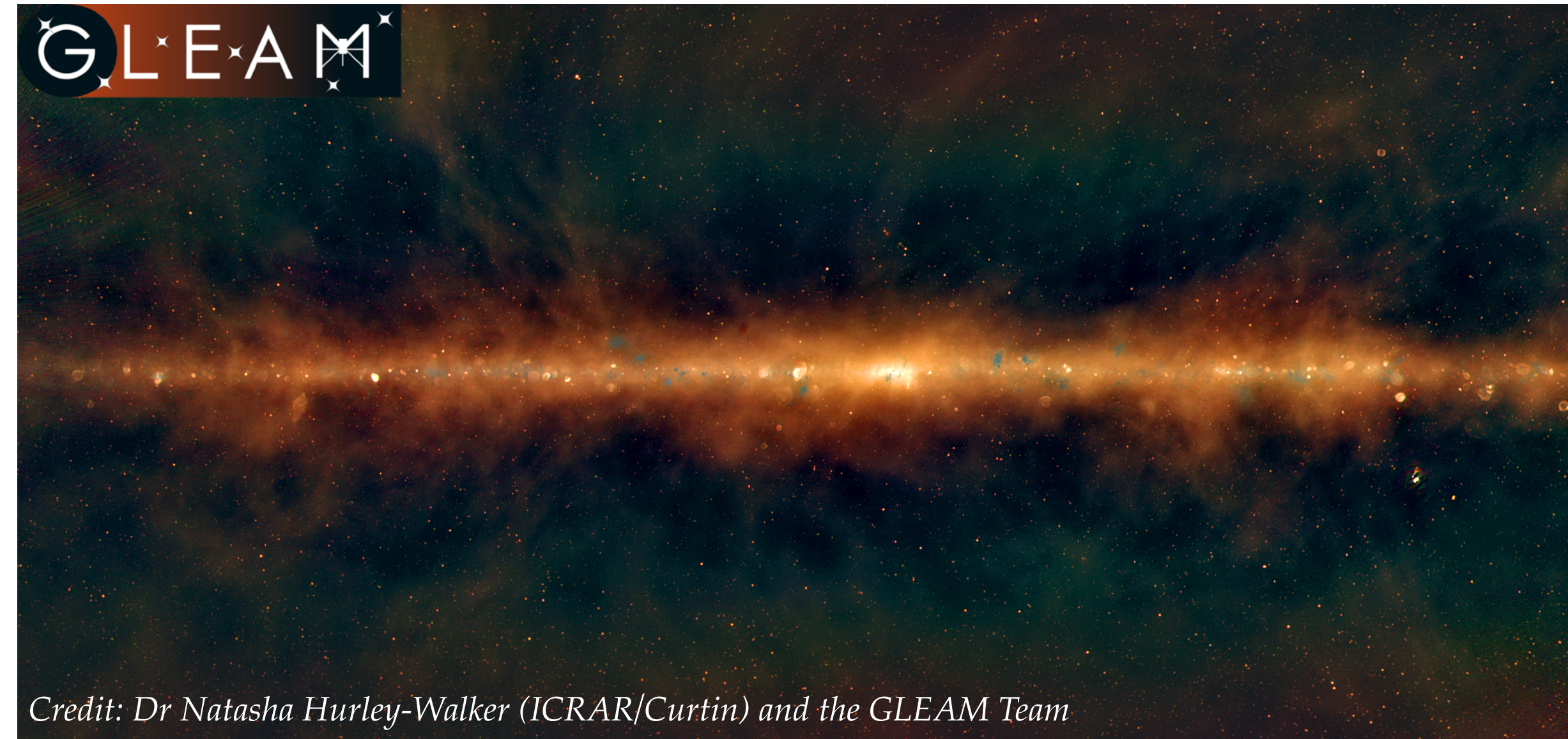


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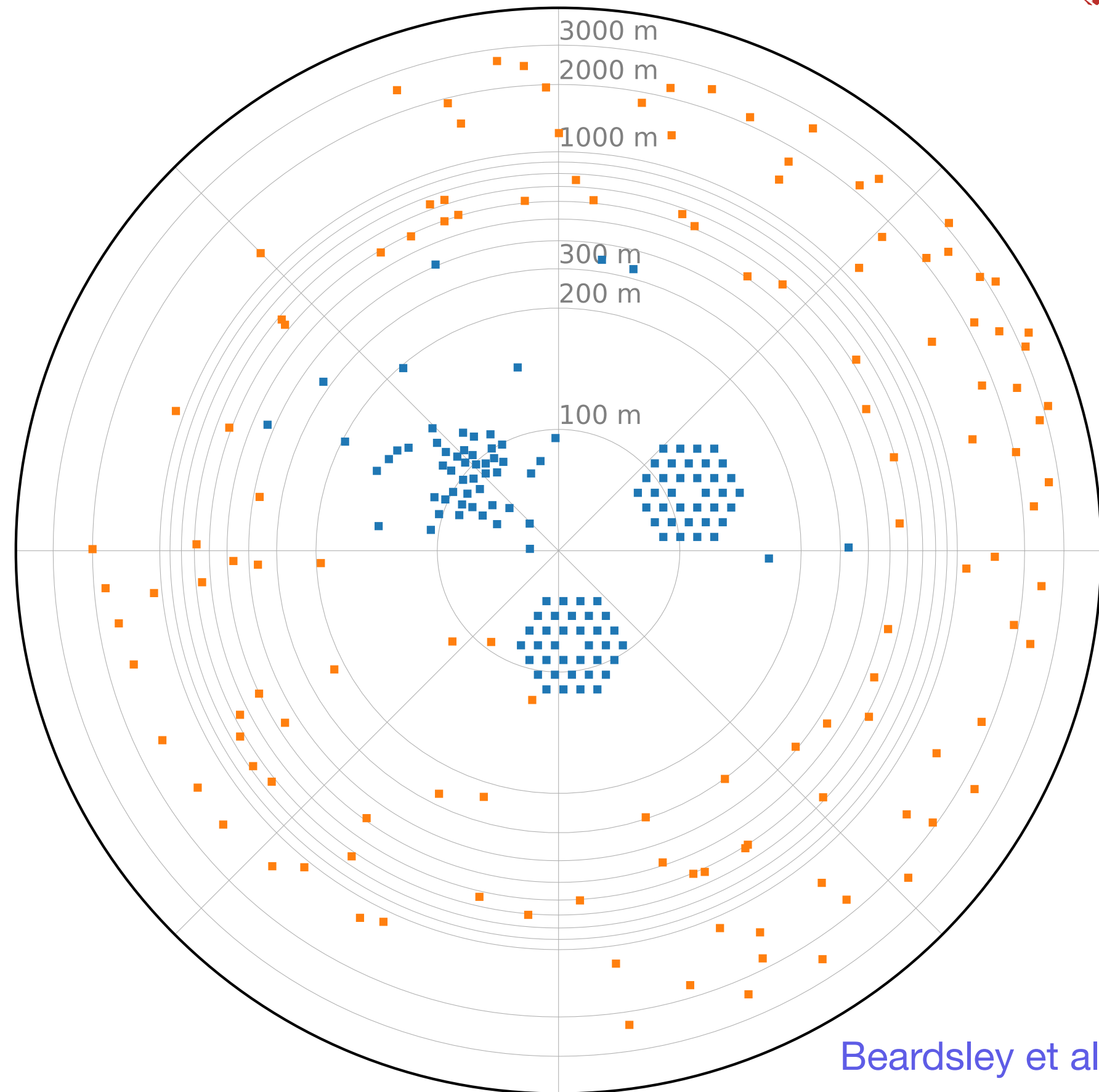
Beardsley et al. (2019)



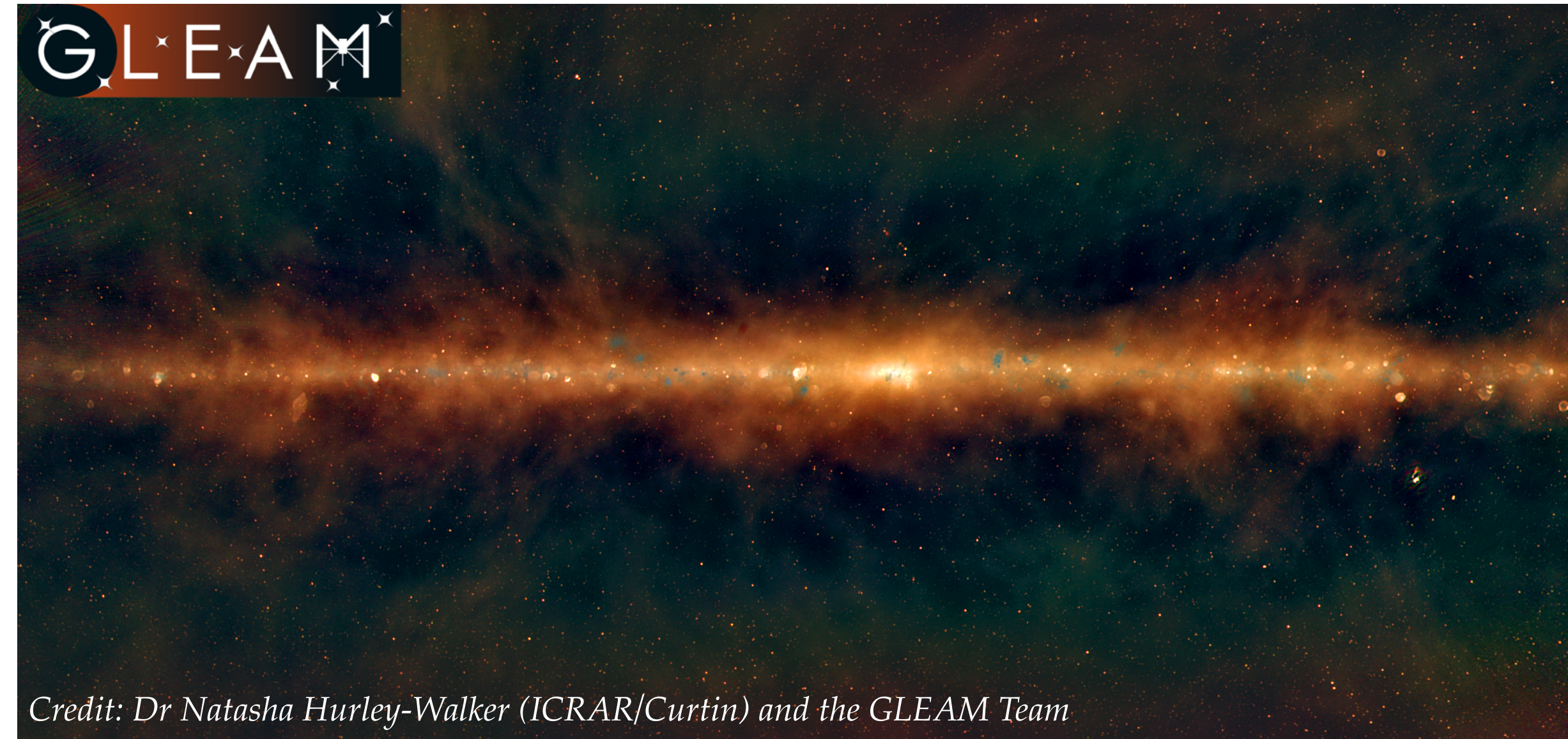
- Phase II: 2016 — 2022
 - 256T across two configurations
 - Compact: ~0.7 km & Hexes
 - Extended: 5.3 km

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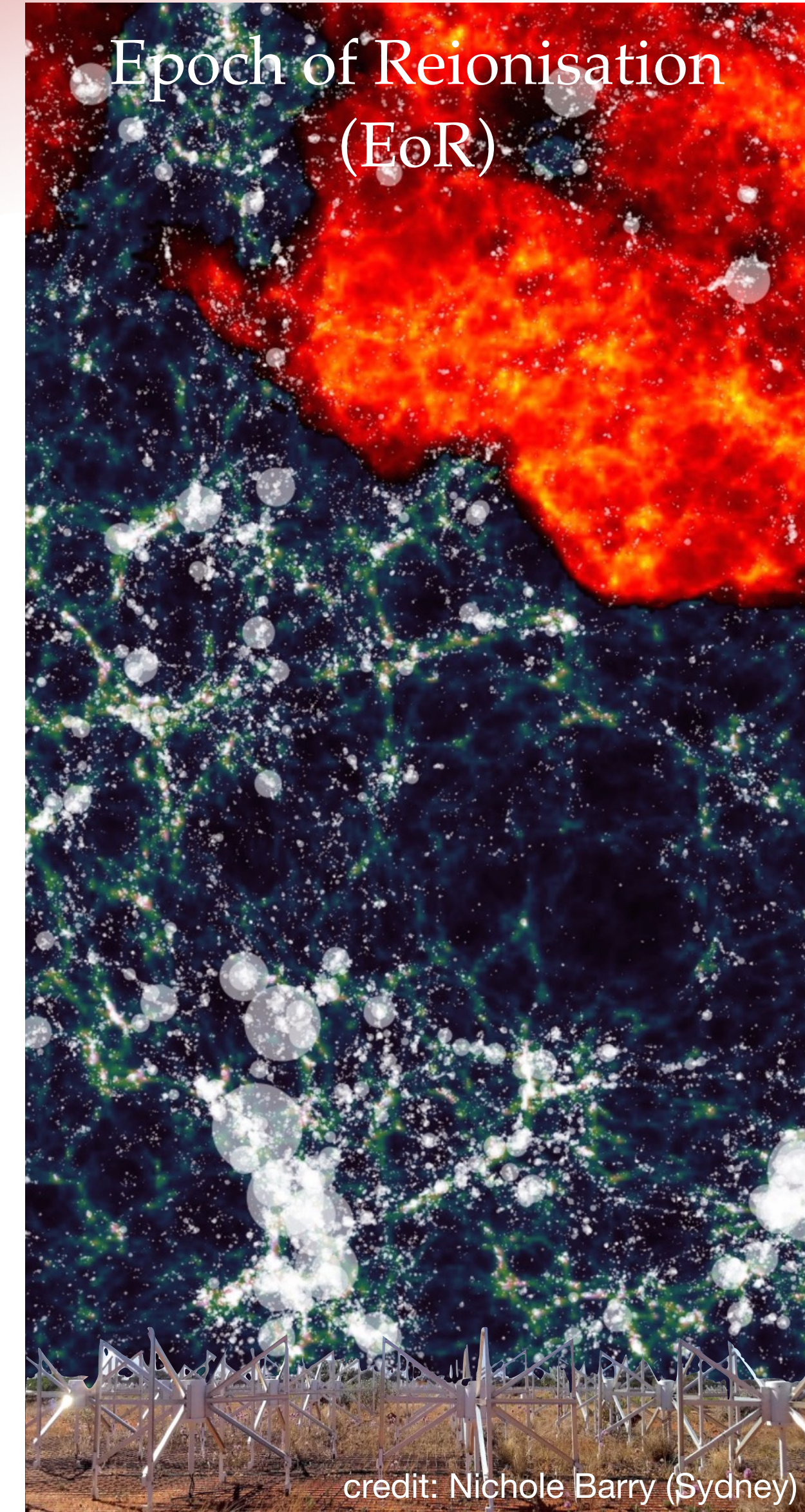
- Phase II: 2016 — 2022
 - ◉ 256T across two configurations
 - ◉ **Compact**: ~0.7 km & Hexes
 - ◉ **Extended**: 5.3 km

- Phase III:
 - ◉ *New correlator* (MWAX)
 - ◉ *New receivers*
 - ◉ *256 tiles correlated*

MWA SCIENCE

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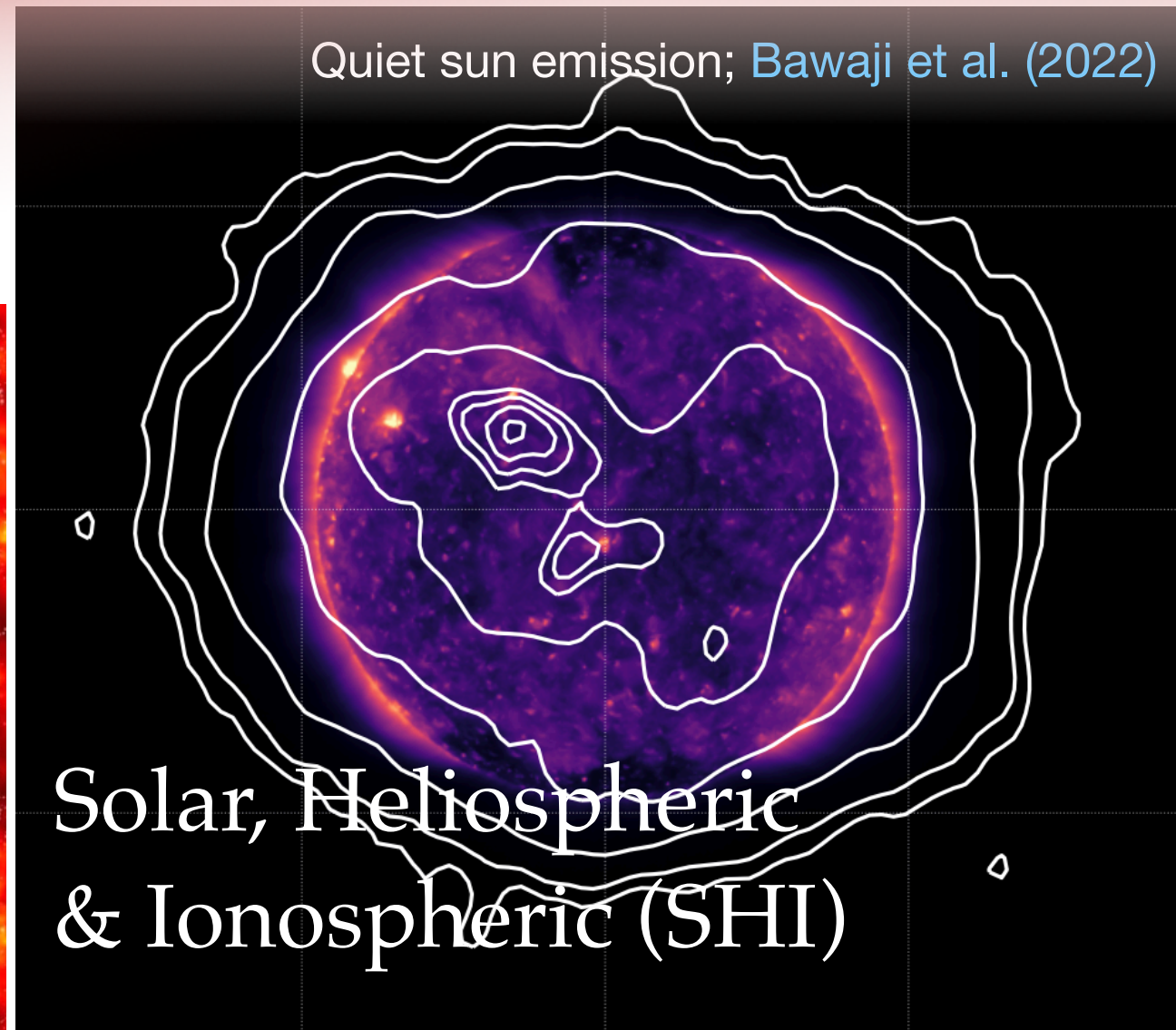
Epoch of Reionisation
(EoR)



credit: Nichole Barry (Sydney)

MWA SCIENCE

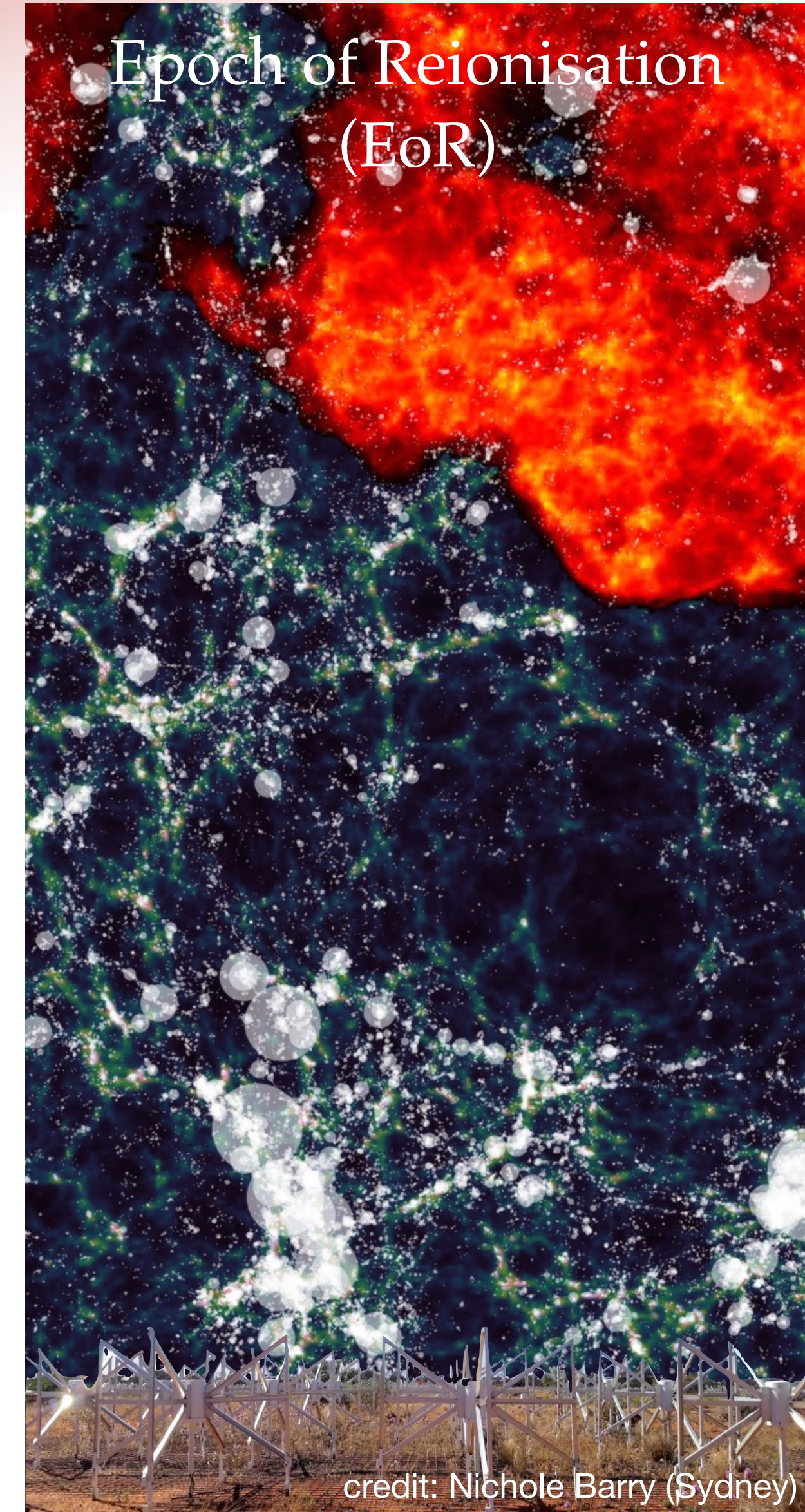
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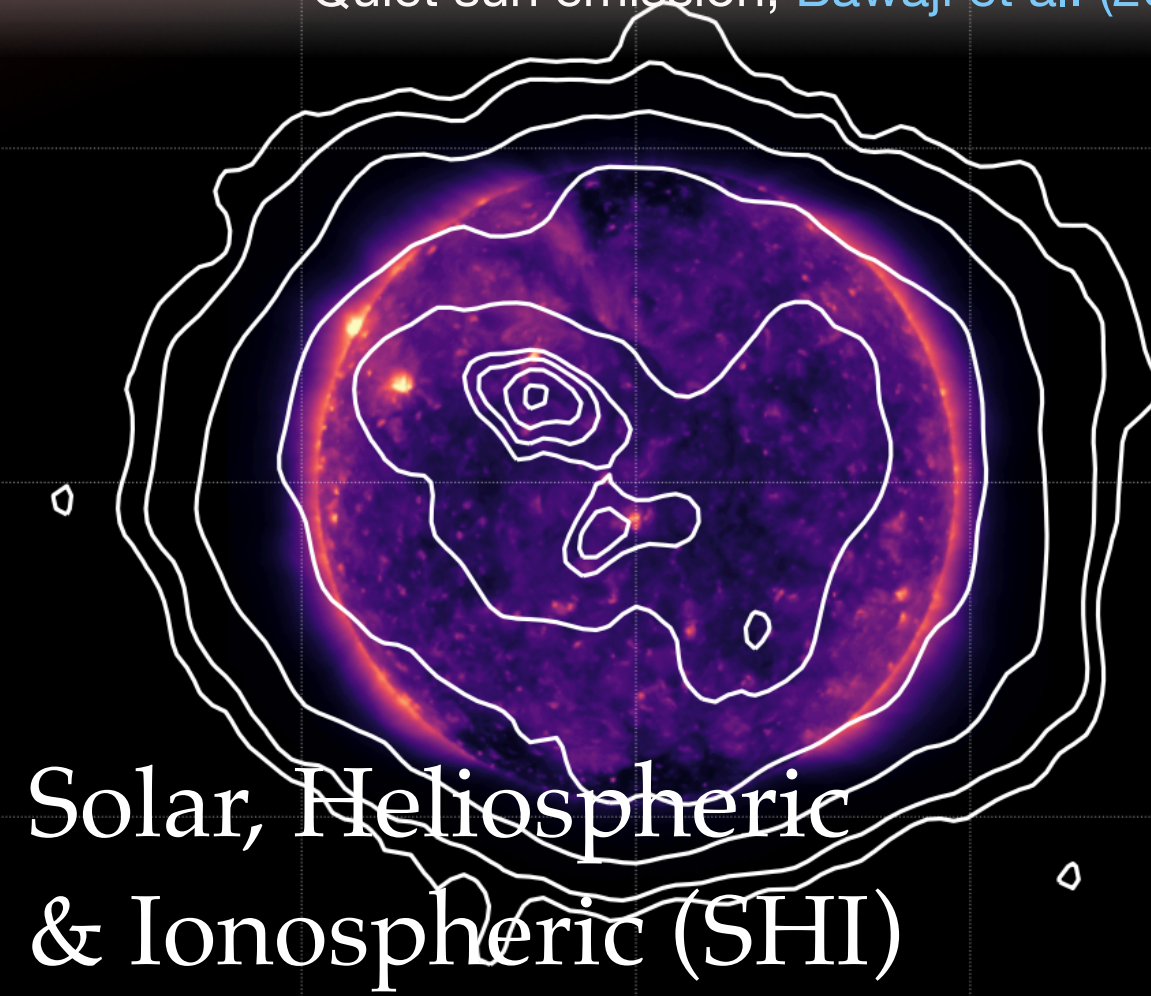
MWA SCIENCE

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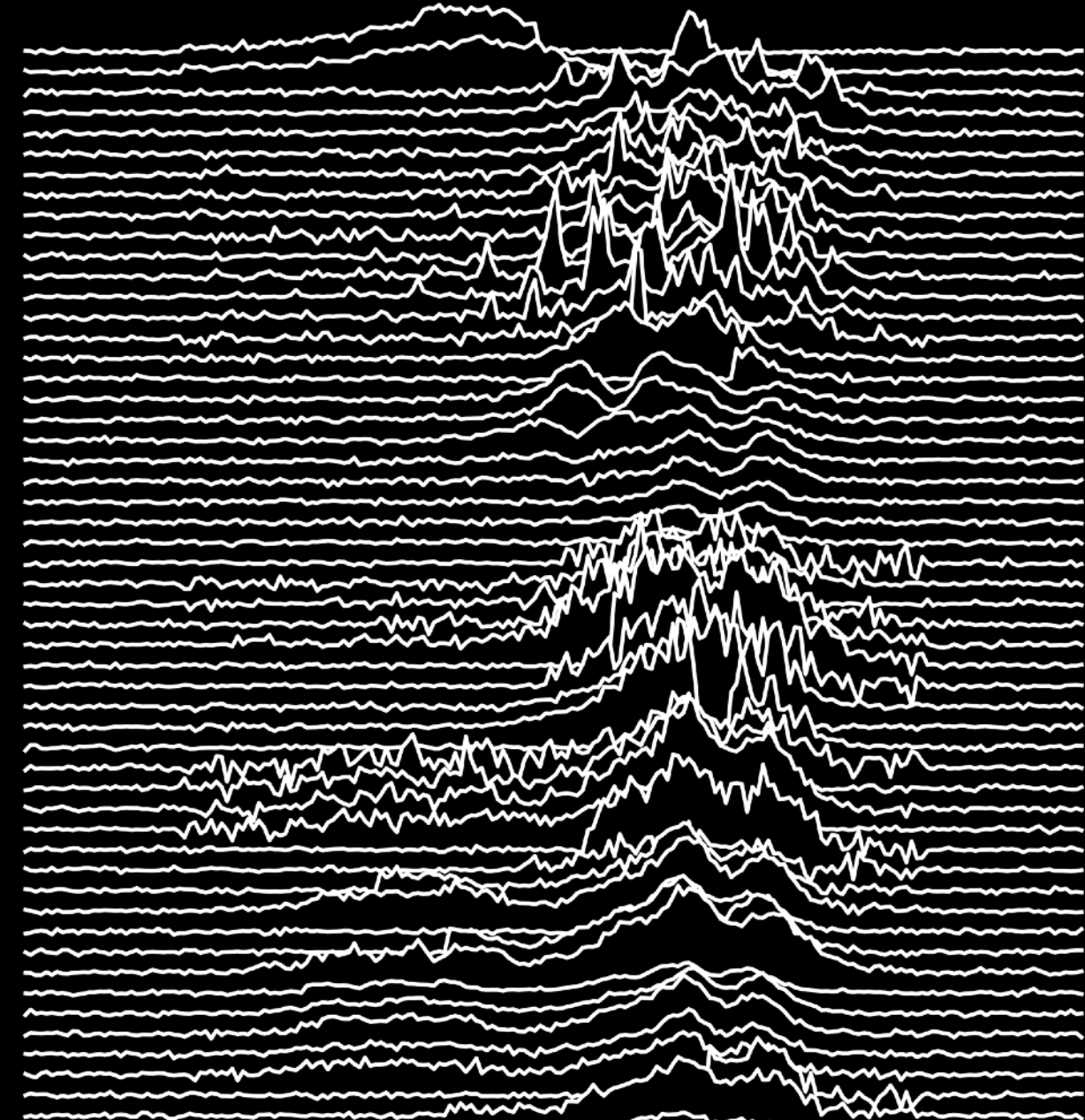


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Quiet sun emission; [Bawaji et al. \(2022\)](#)



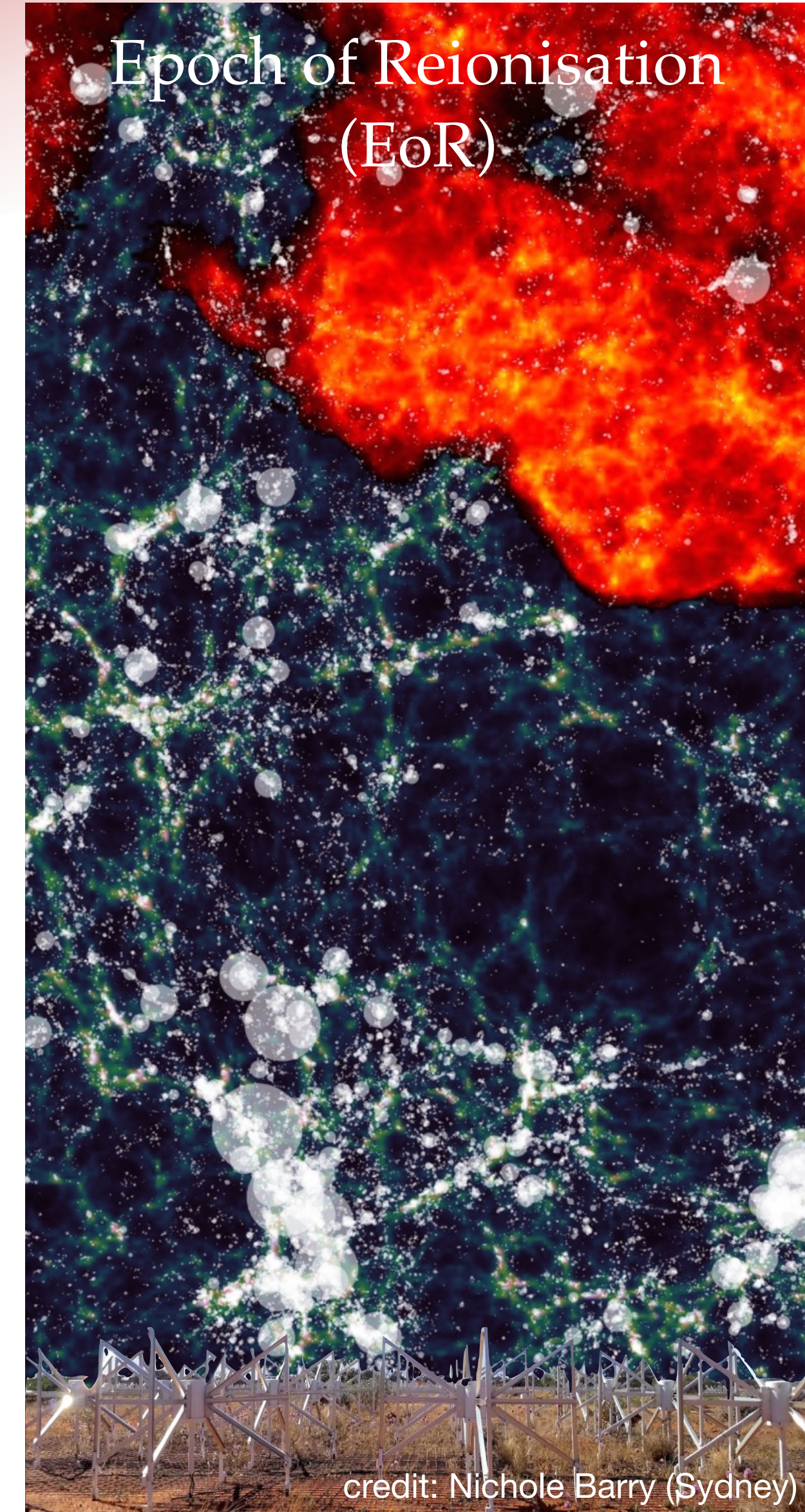
Transients



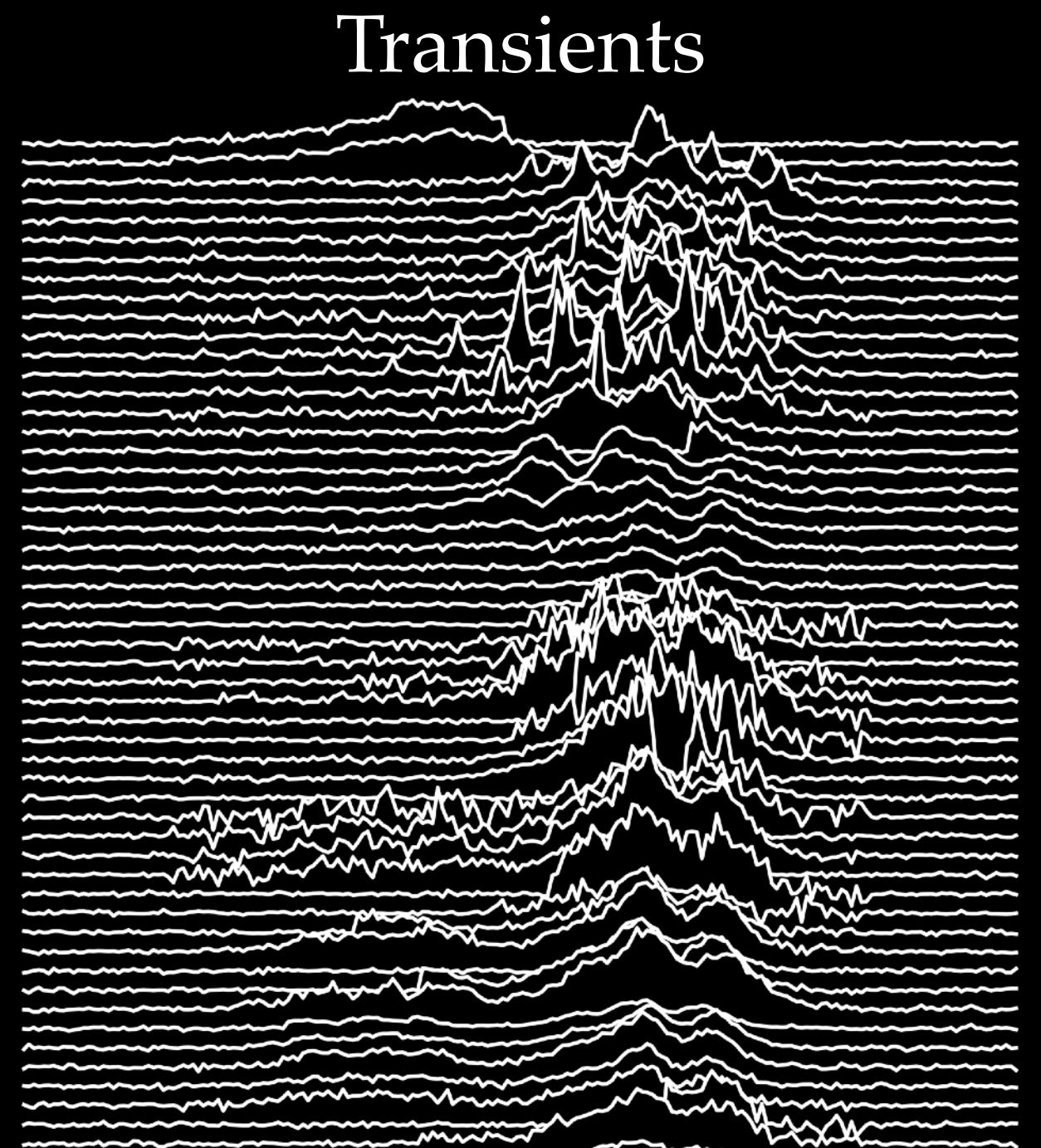
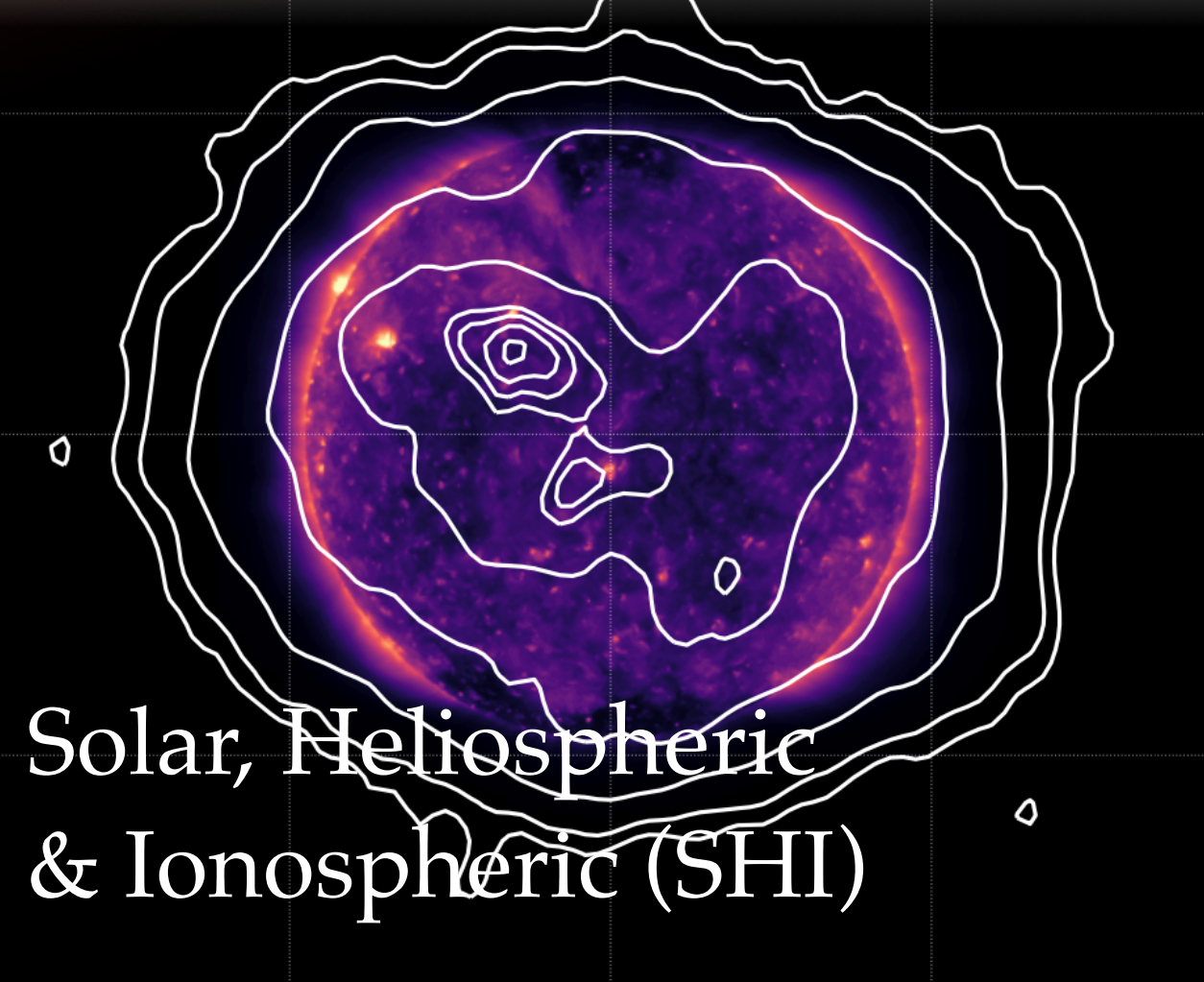
GLEAM-X ULPT; [Hurley-Walker et al. \(2021\)](#)

MWA SCIENCE

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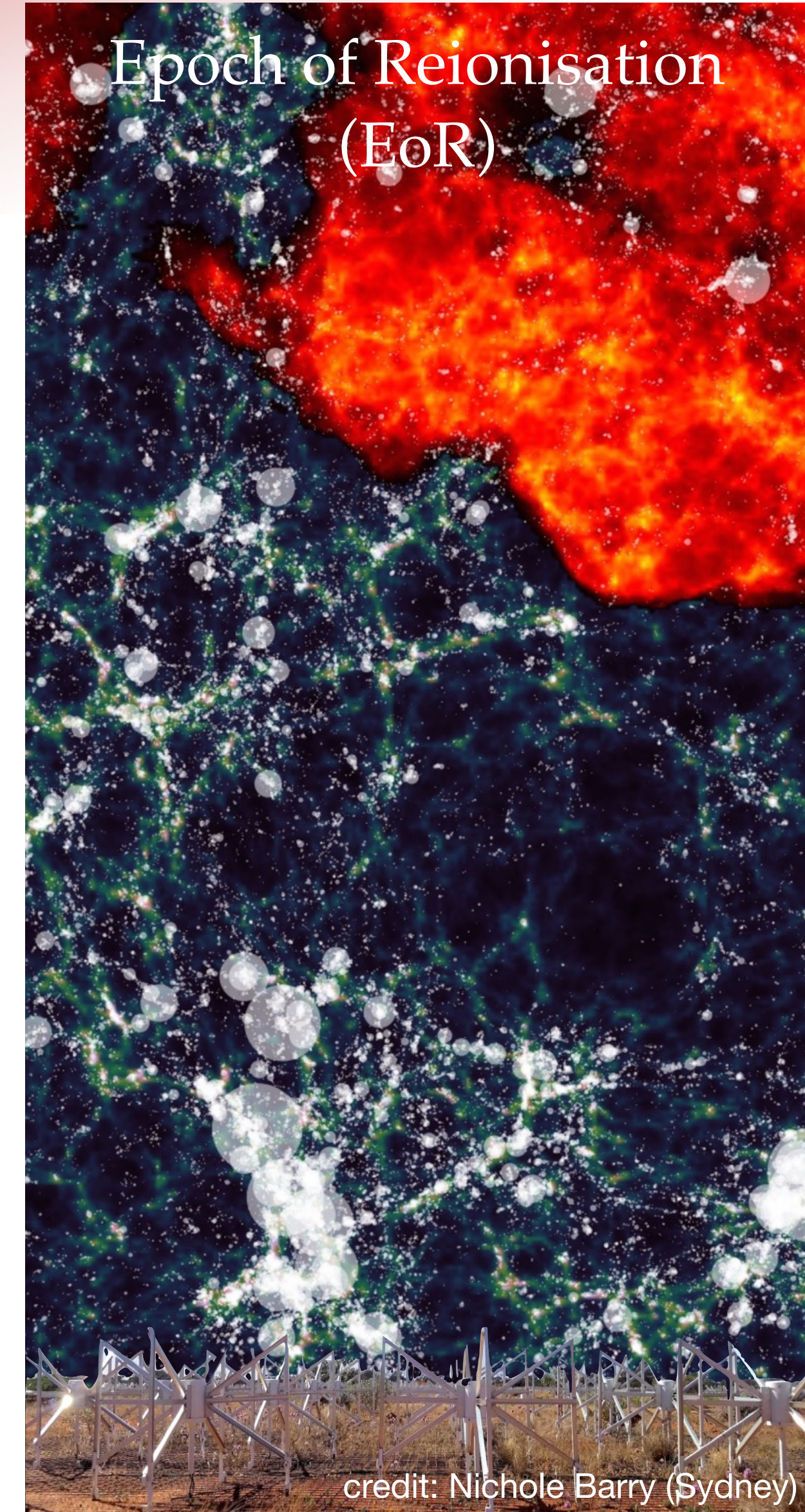
GLEAM-X ULPT; [Hurley-Walker et al. \(2021\)](#)

Pulsars & Fast Transients
(PFT)

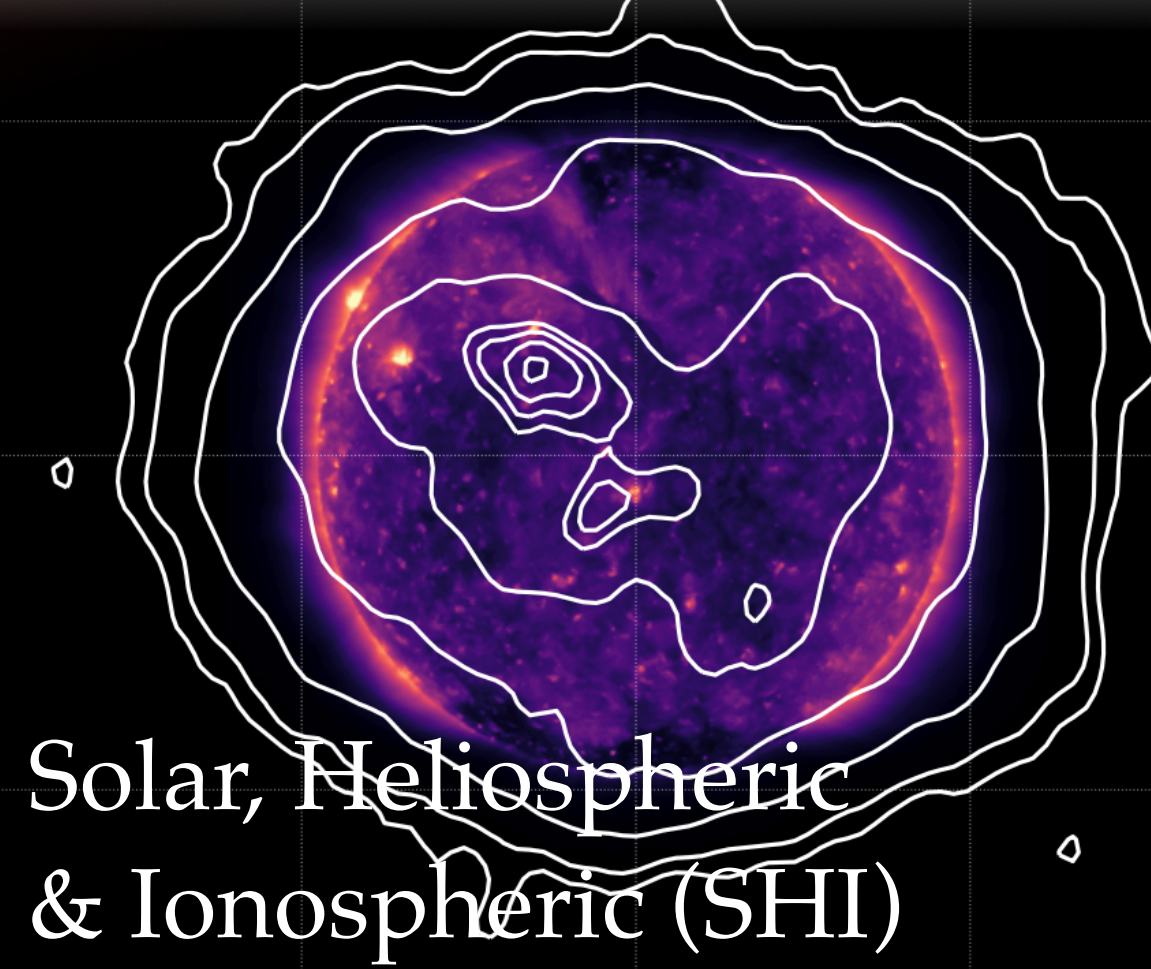


MWA SCIENCE

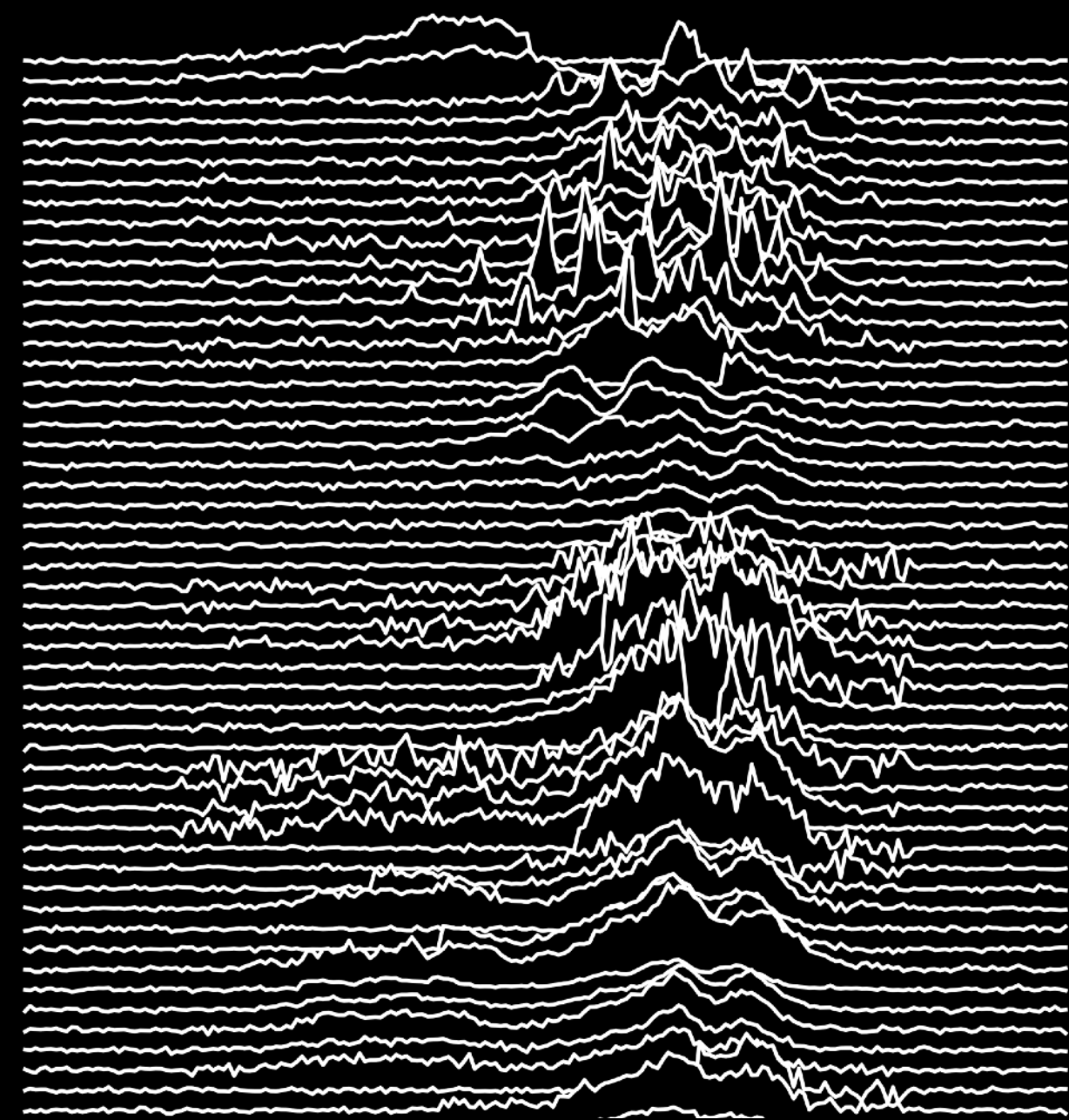
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Transients

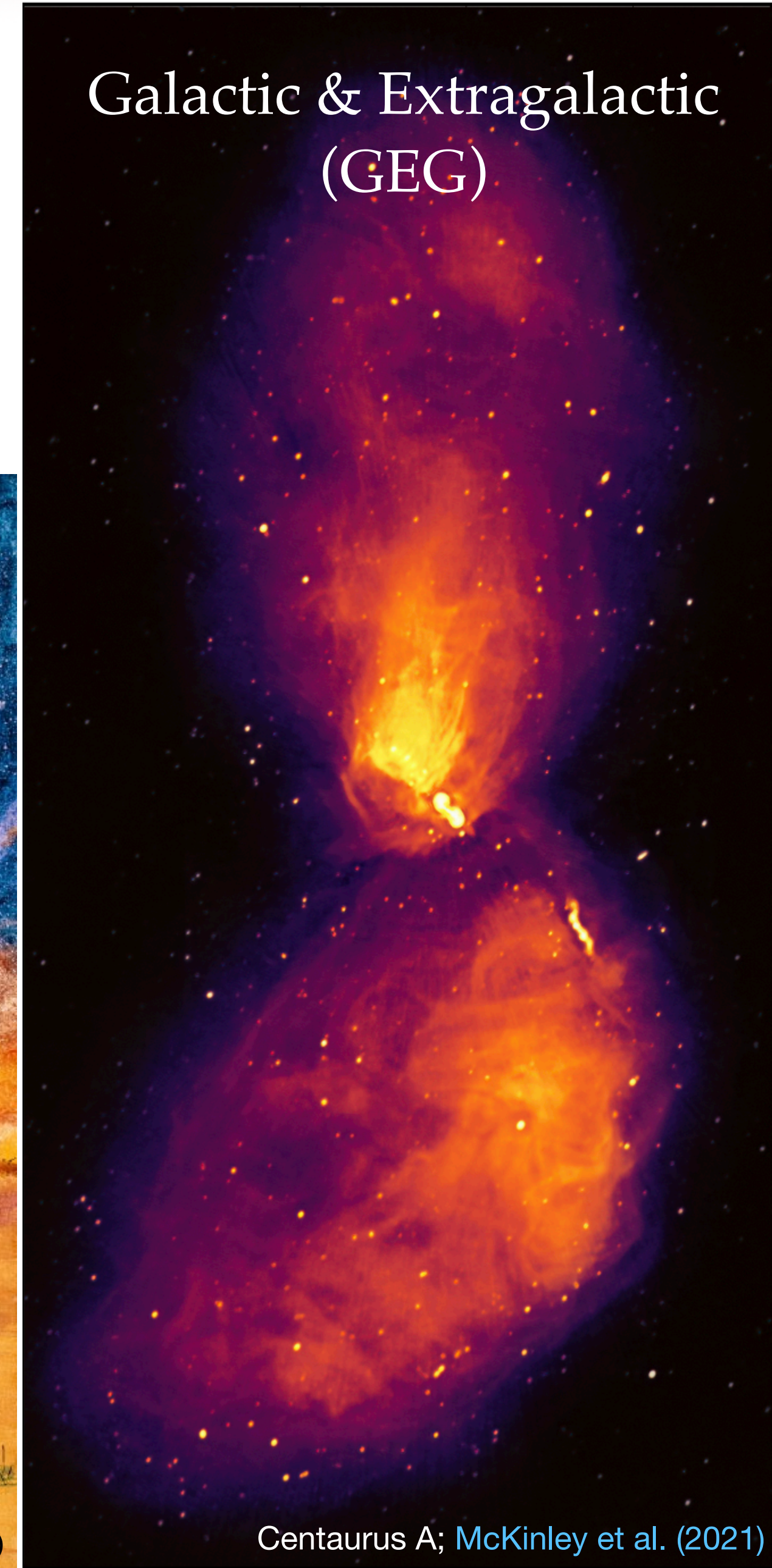


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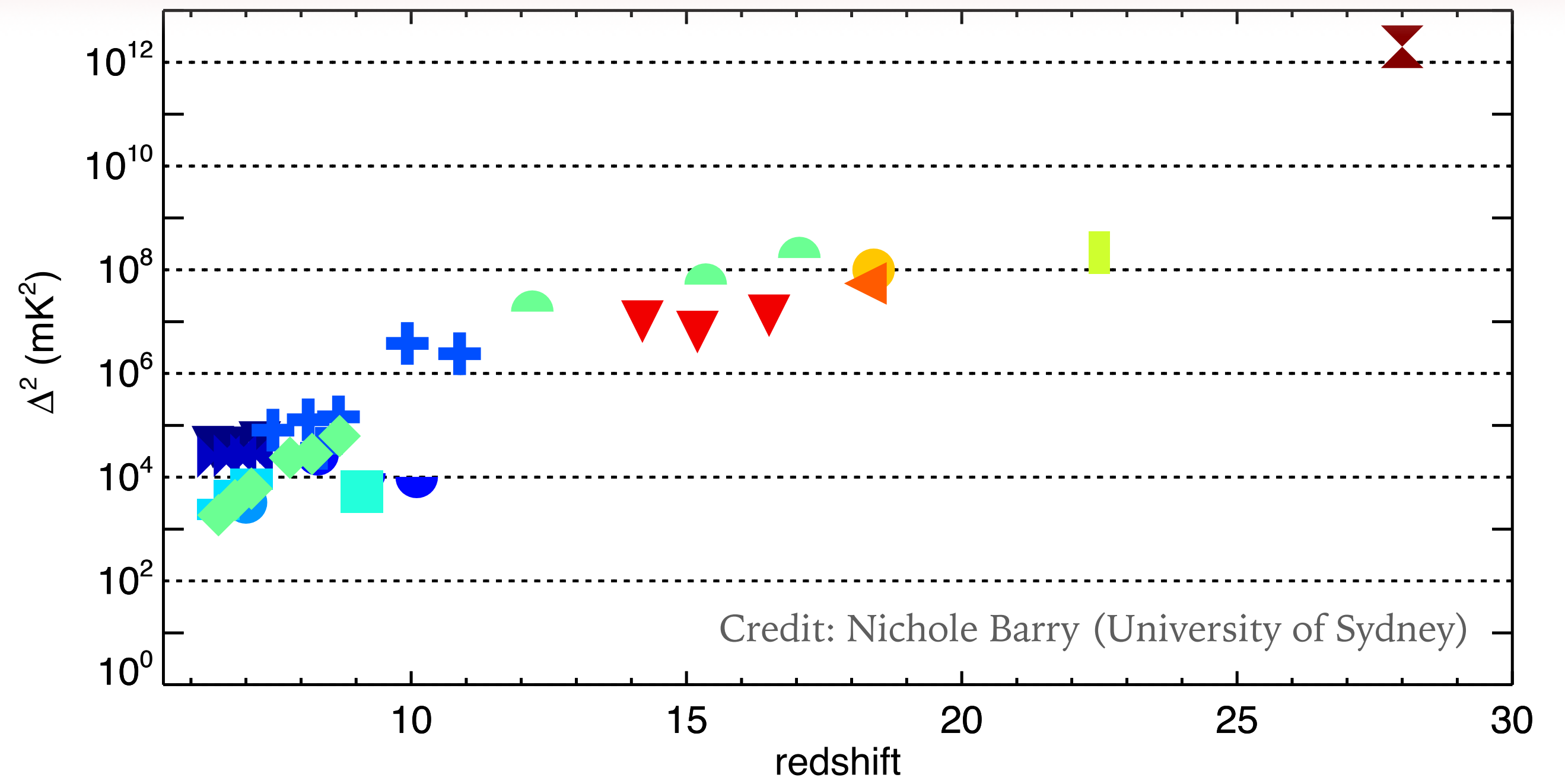


Galactic & Extragalactic
(GEG)



EPOCH OF REIONISATION (EOR)

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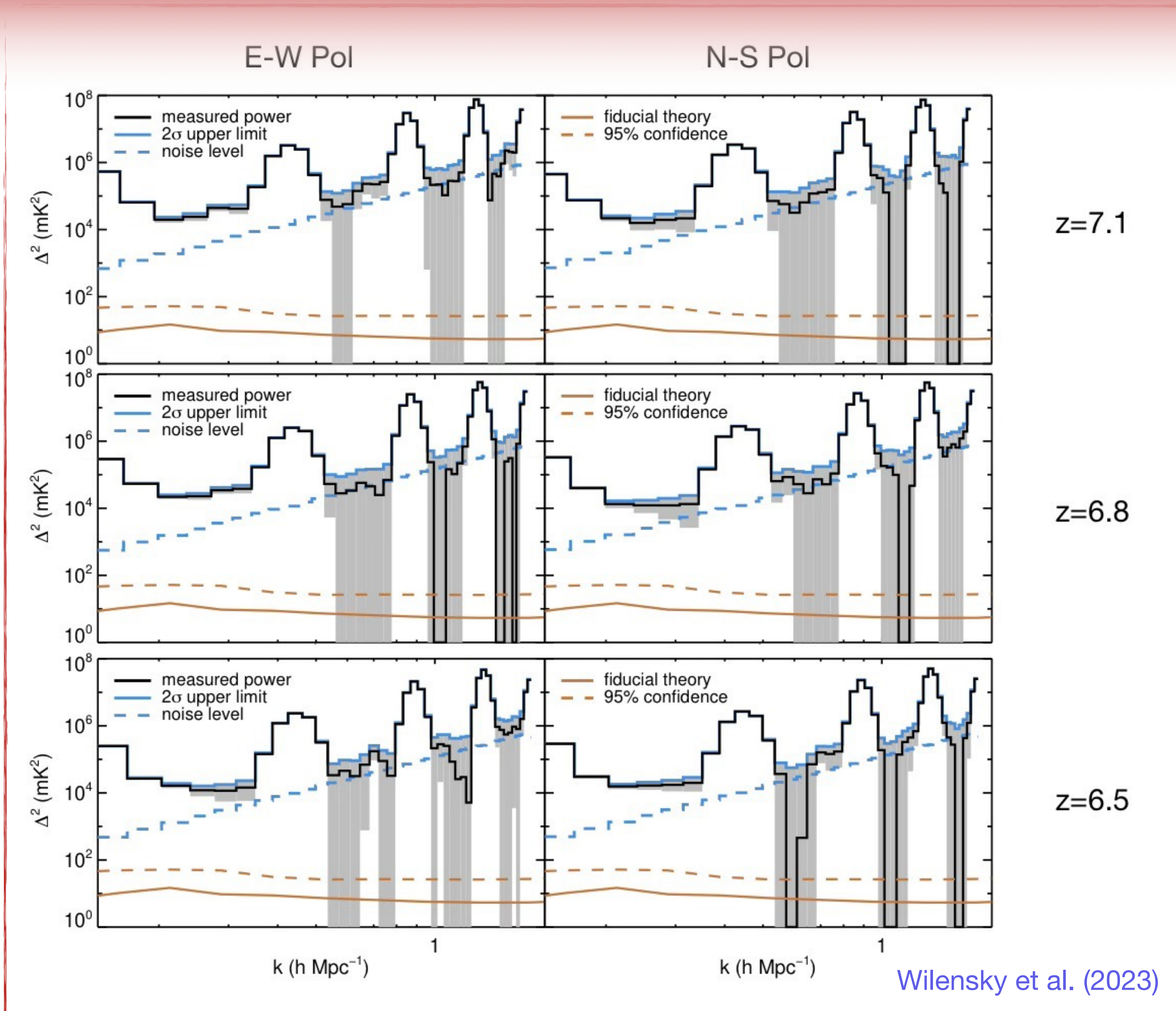
EoR

- ▼ Dillon, 2015
- ⊕ Kolopanis, 2019
- ⊠ Mertens, 2020
- ⊠ Beardsley, 2016
- Barry, 2019
- ◇ Trott, 2020
- ◐ Patil, 2017
- ◑ Li, 2019

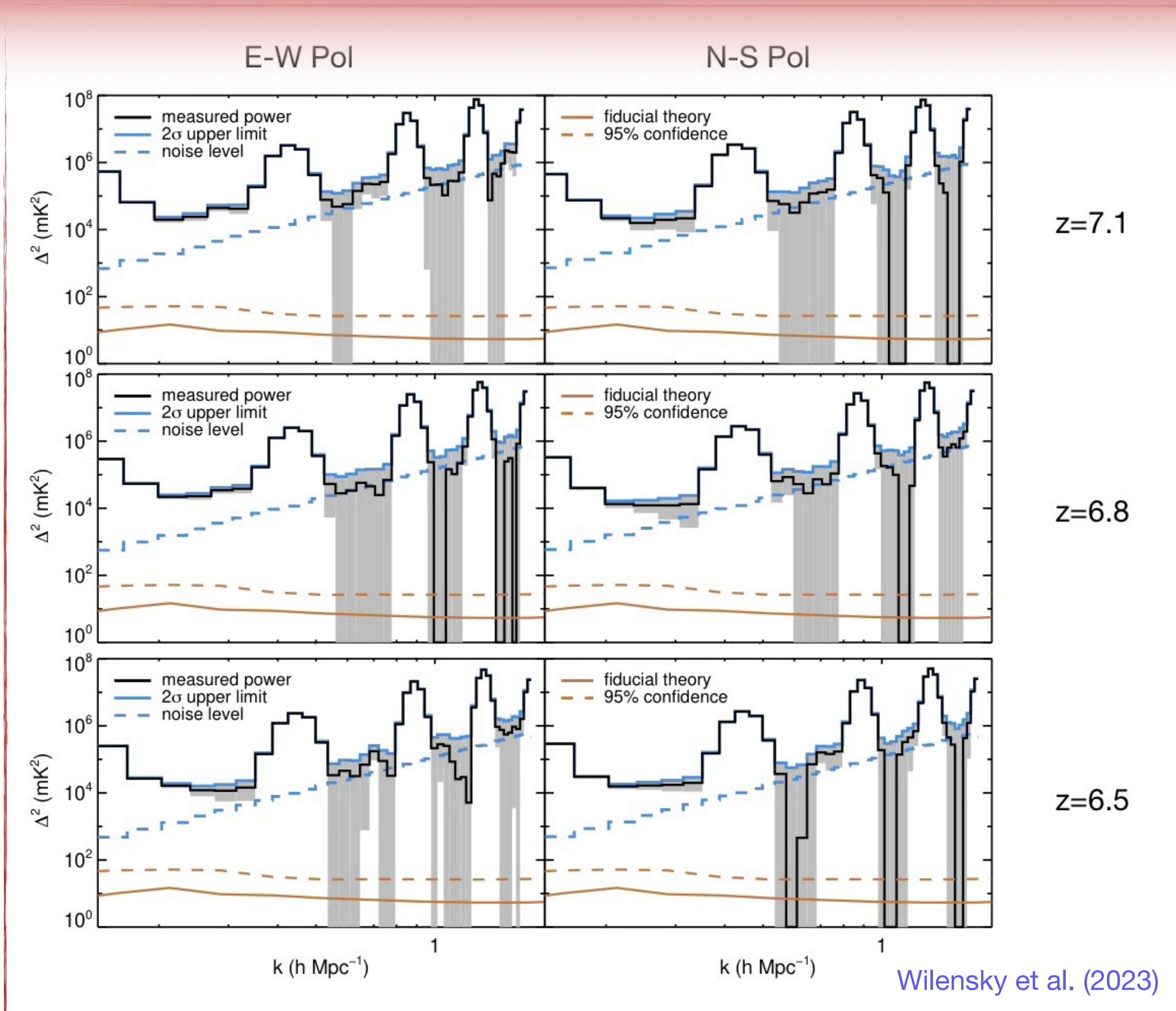
CD

- ◑ Ewall-Wice, 2016
- ◑ Gehlot, 2020
- ◑ Gehlot, 2019
- ◑ Yoshiura, 2021
- Eastwood, 2019
- ⊠ Garsden, 2021

EPOCH OF REIONISATION (EOR)

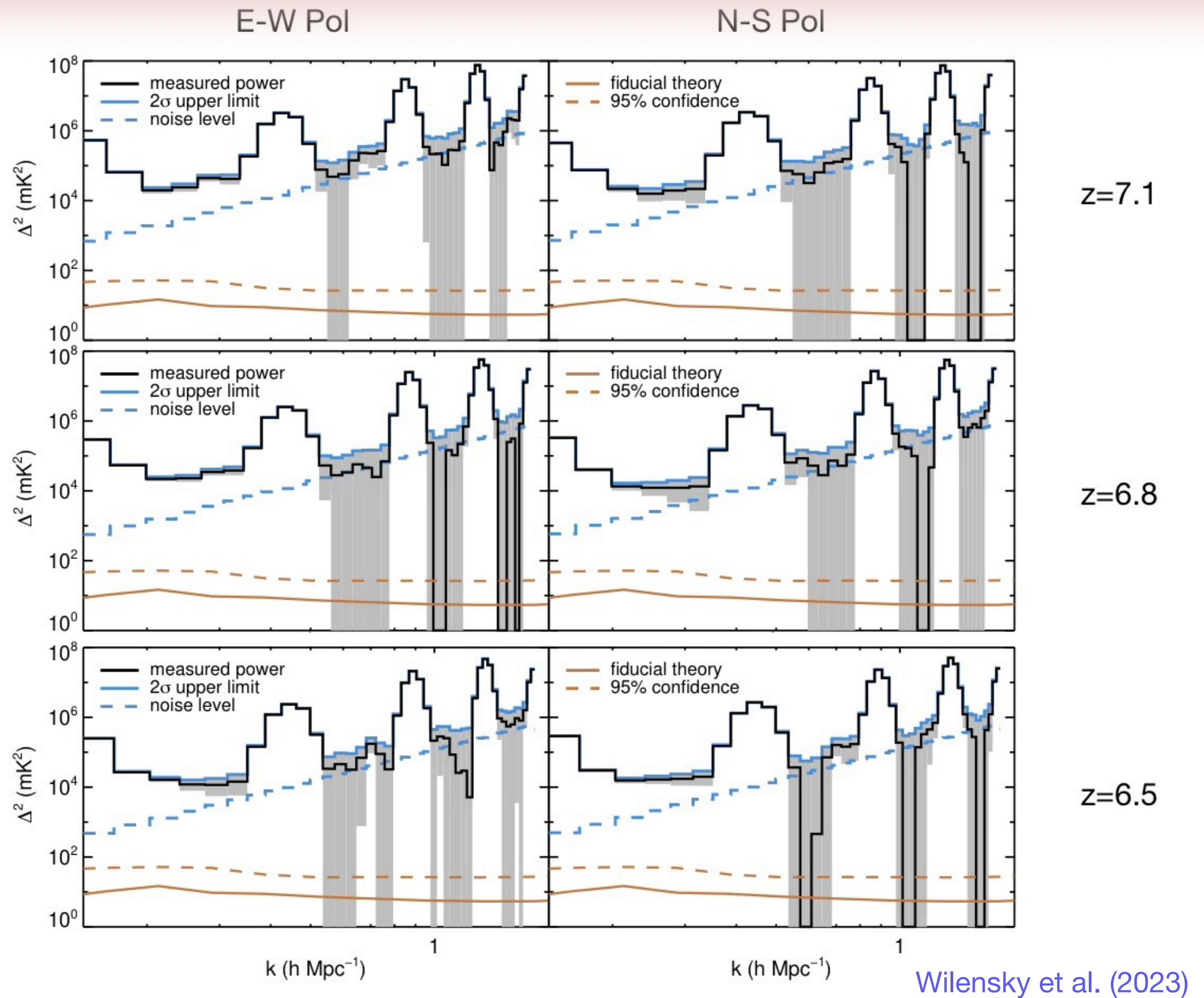


EPOCH OF REIONISATION (EOR)



“Precision, precision, precision”
(attr. Miguel Morales, Aug. 2024)

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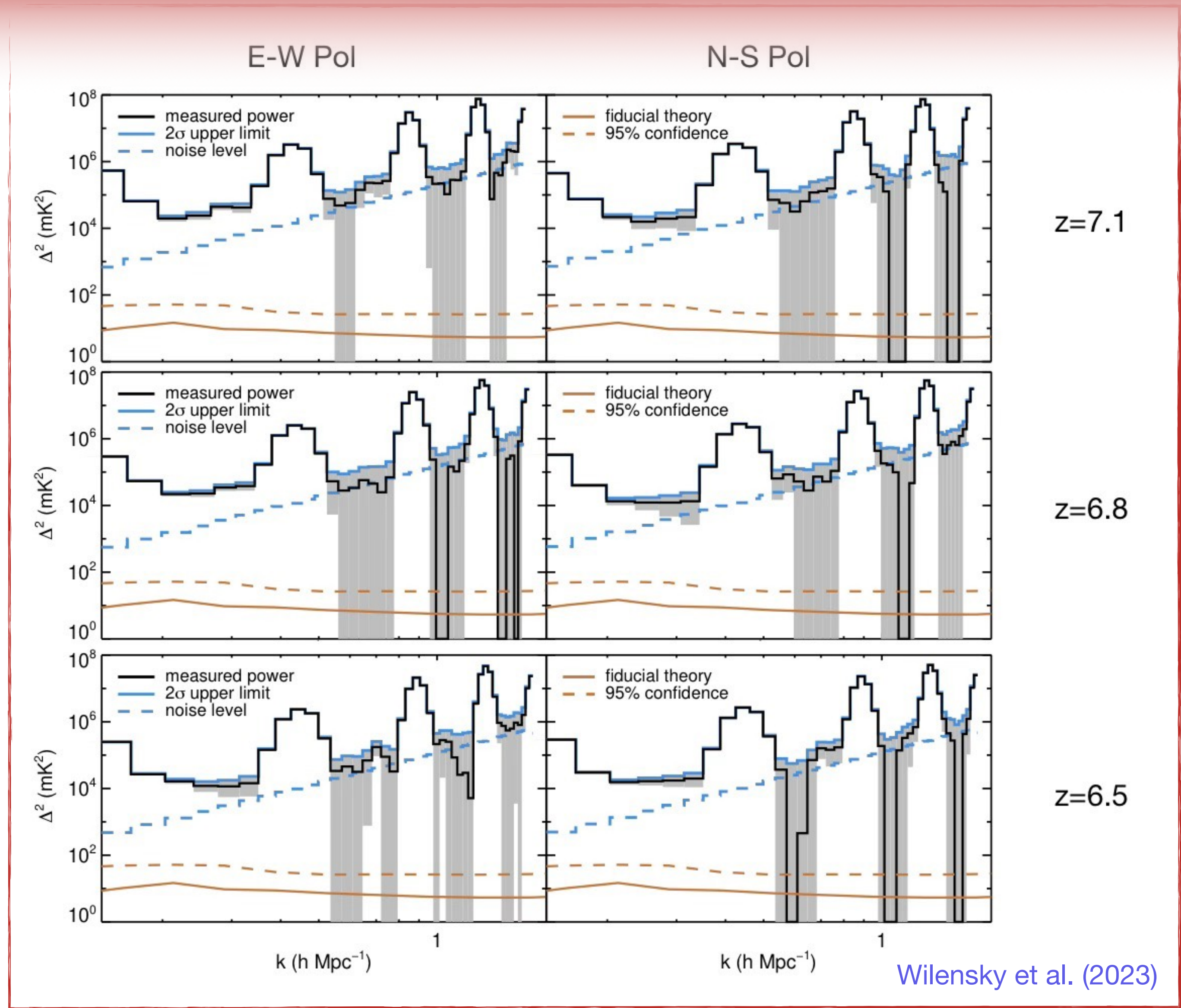


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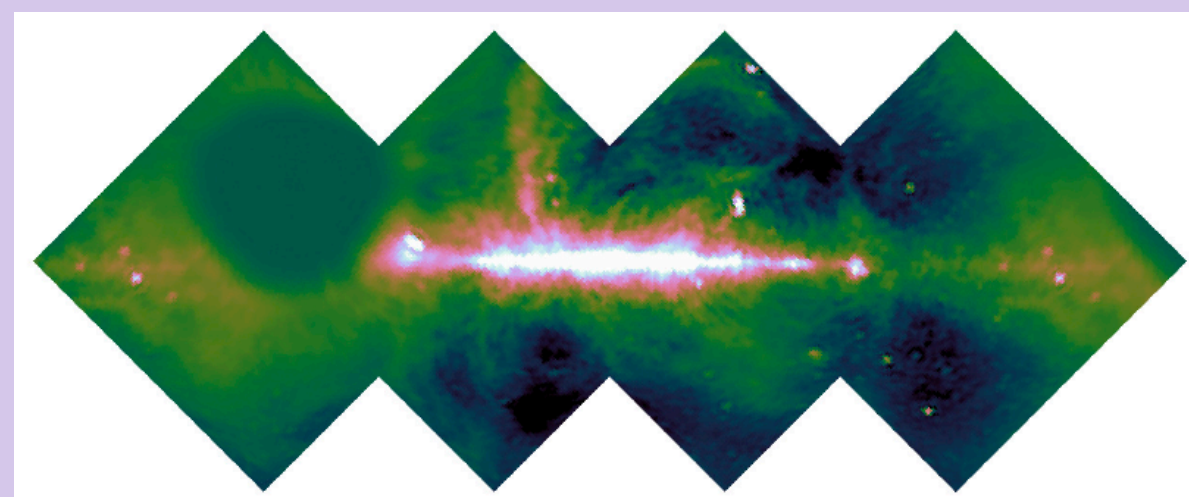
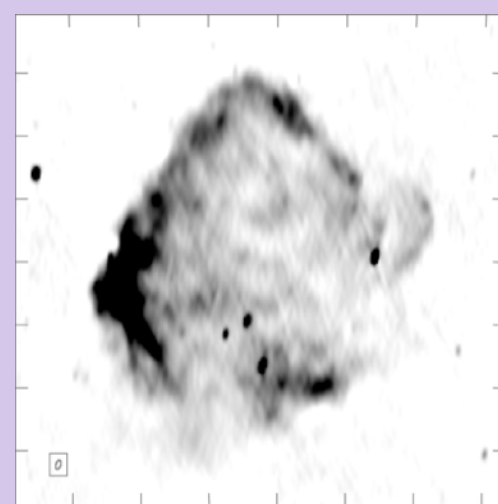
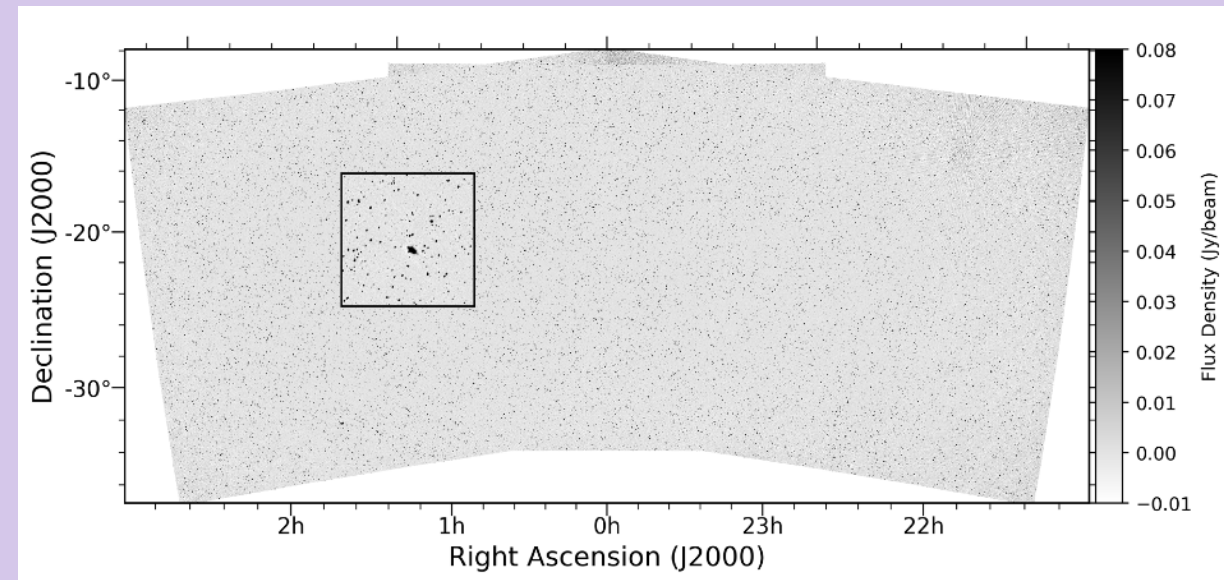


KEY INGREDIENTS

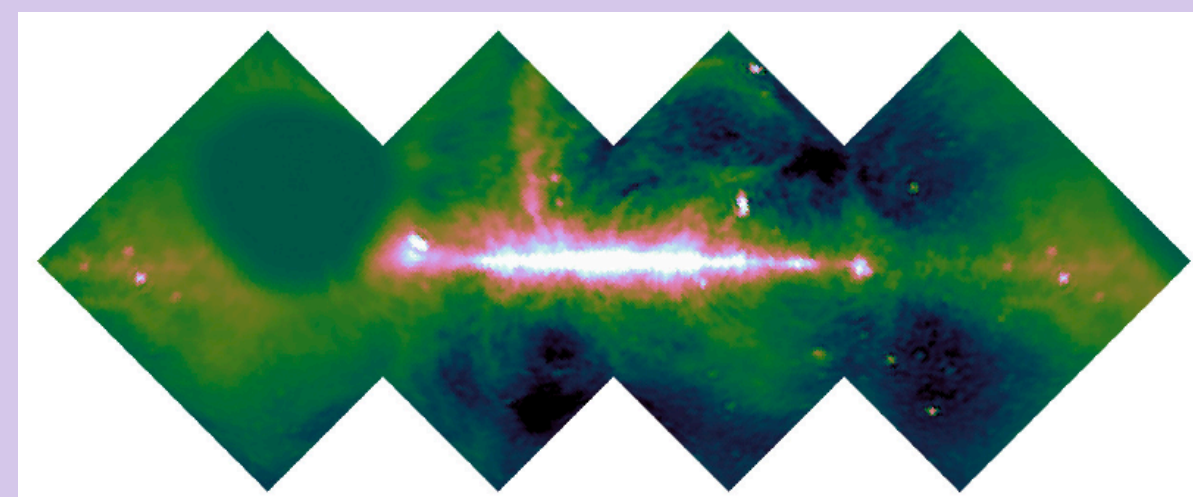
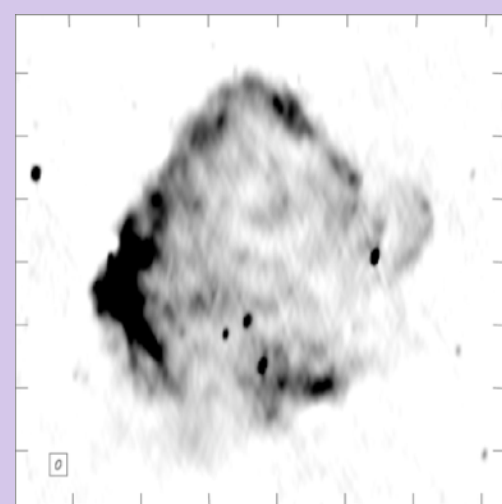
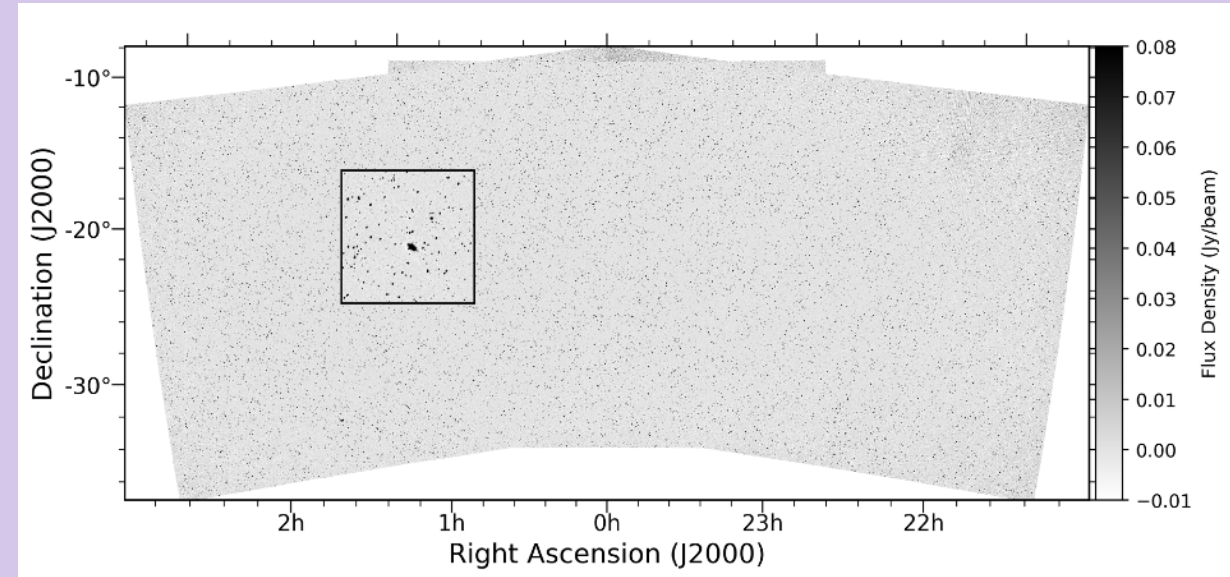
Slide courtesy Miguel Morales (UW)

ASTRO 3D

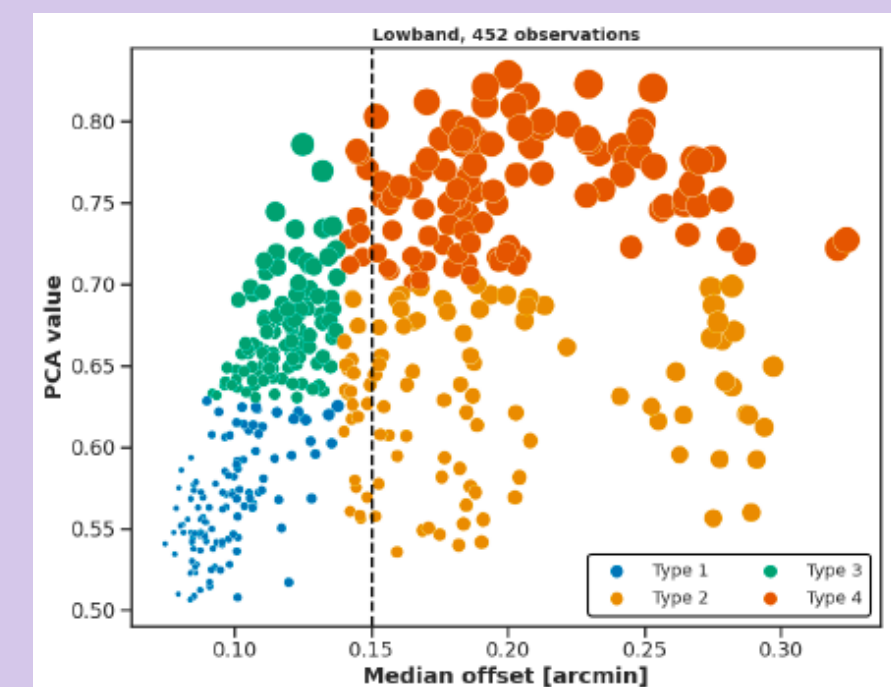
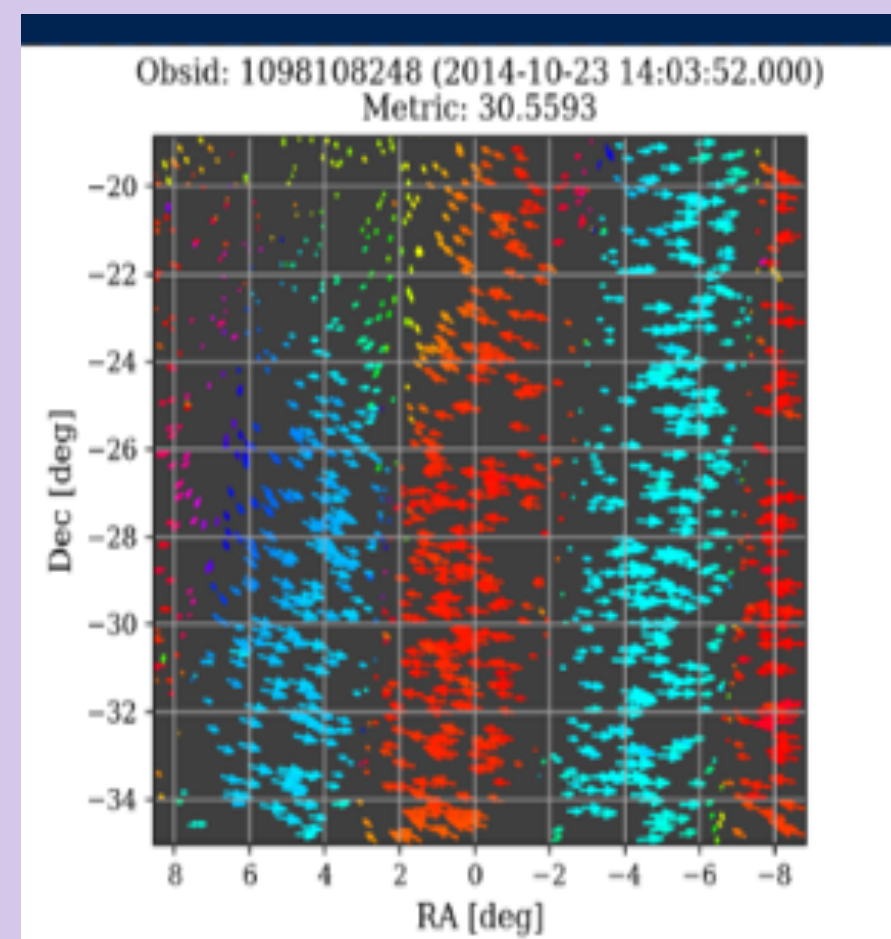
SKY



SKY



IONOSPHERE

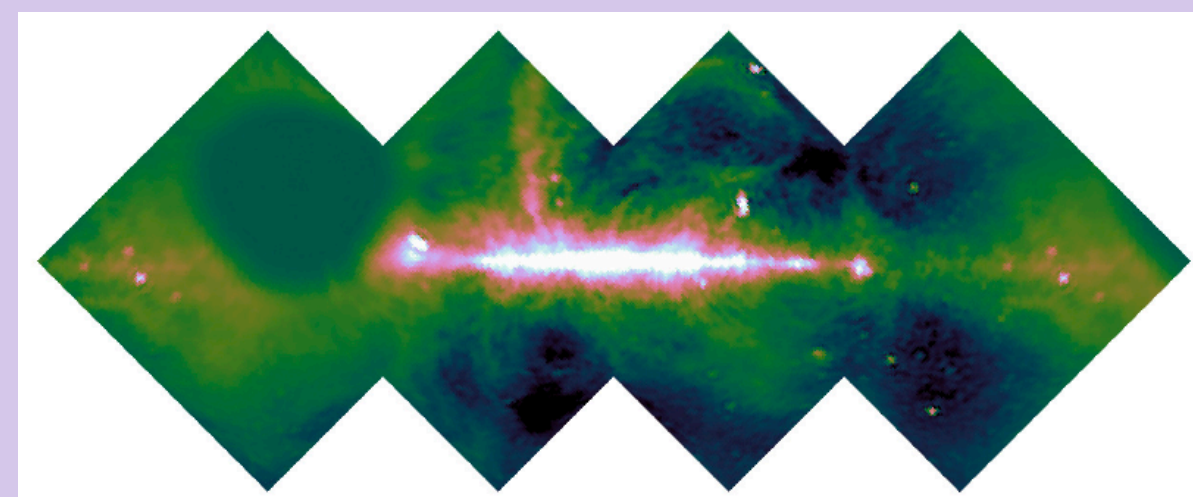
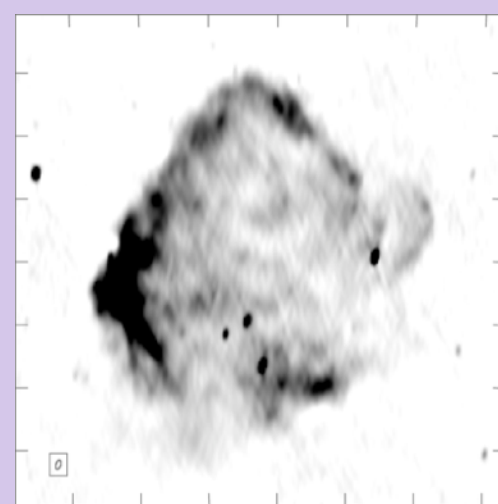
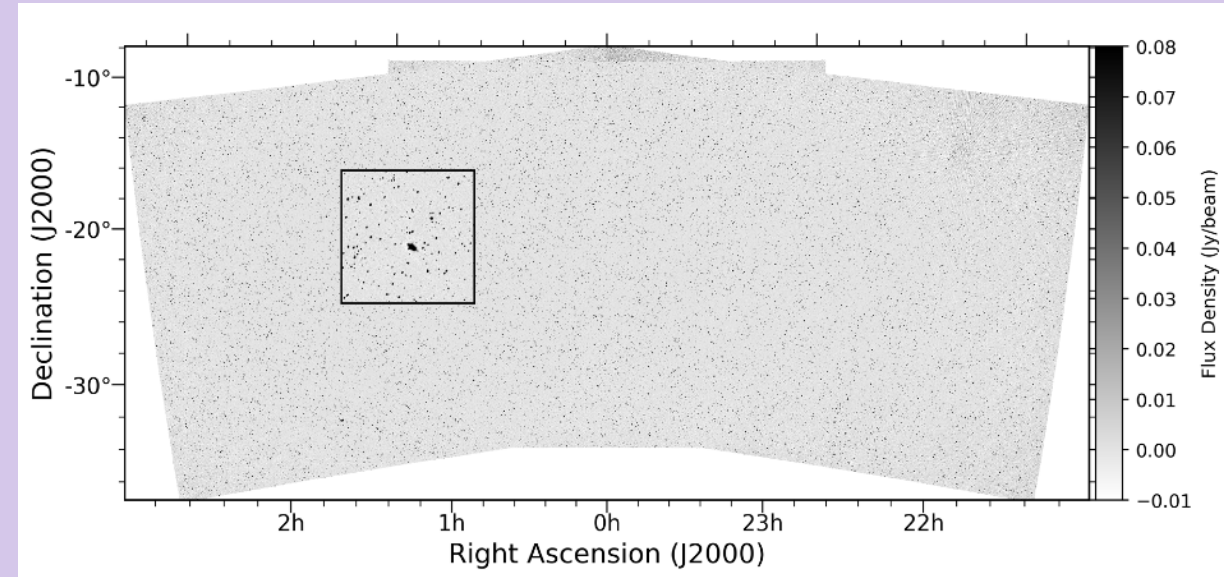


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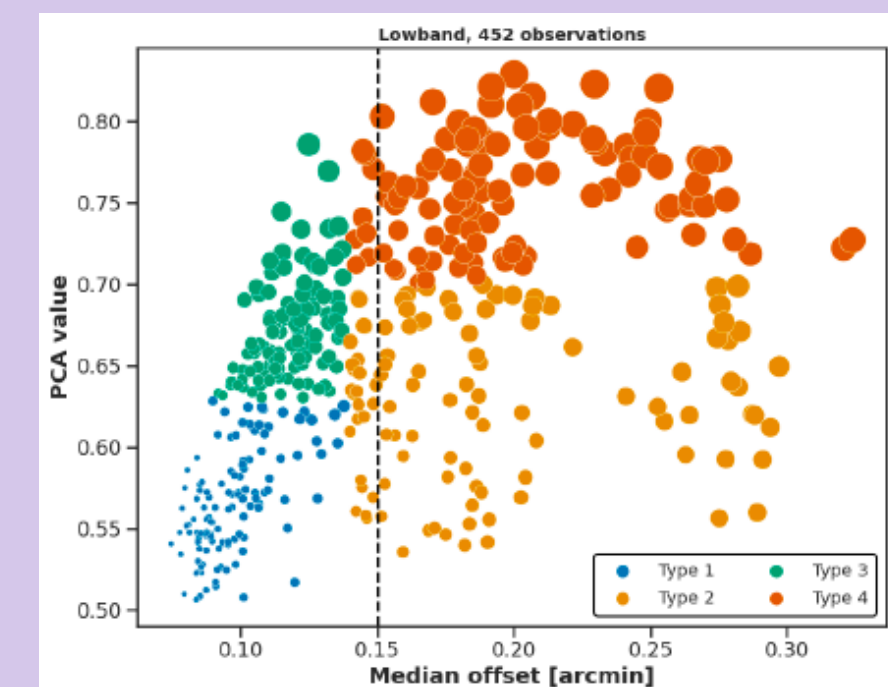
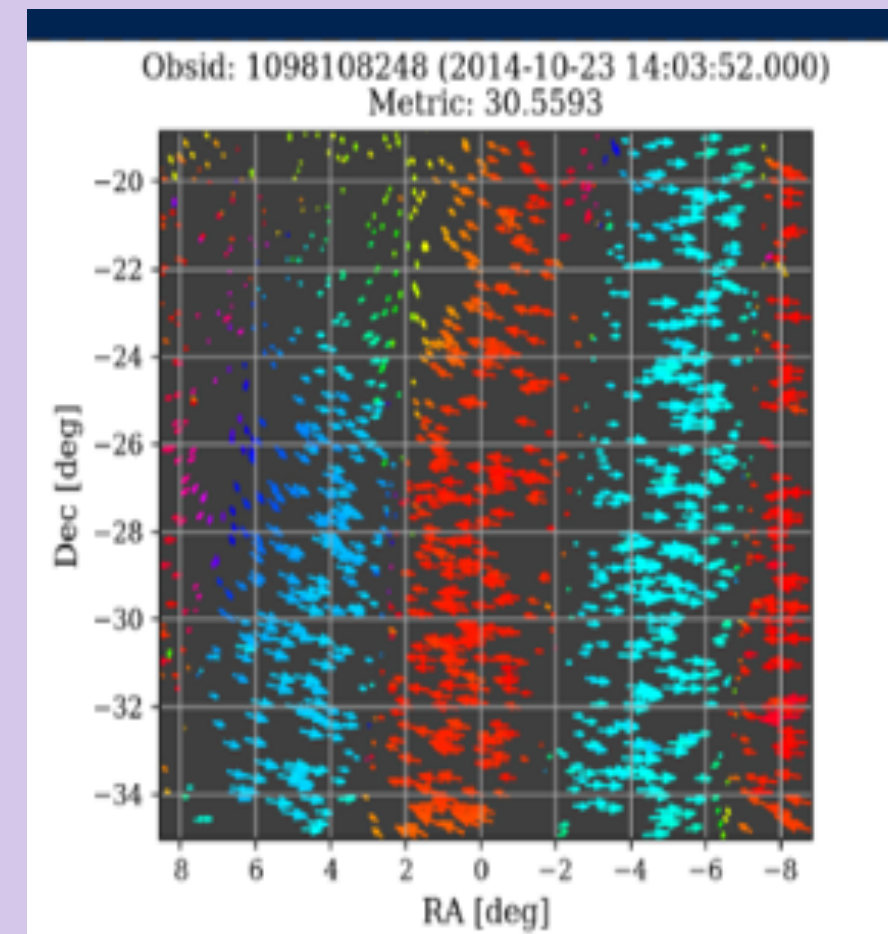
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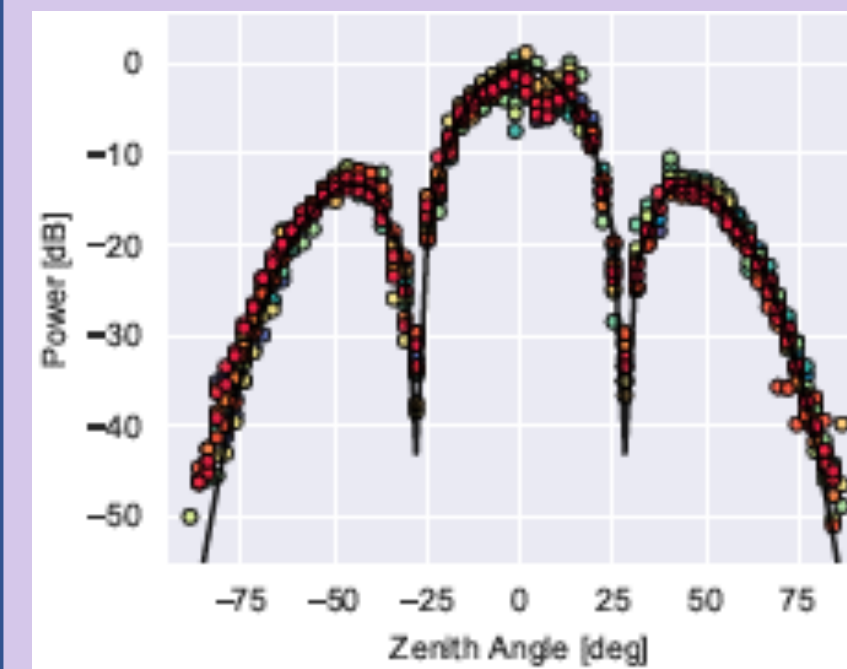
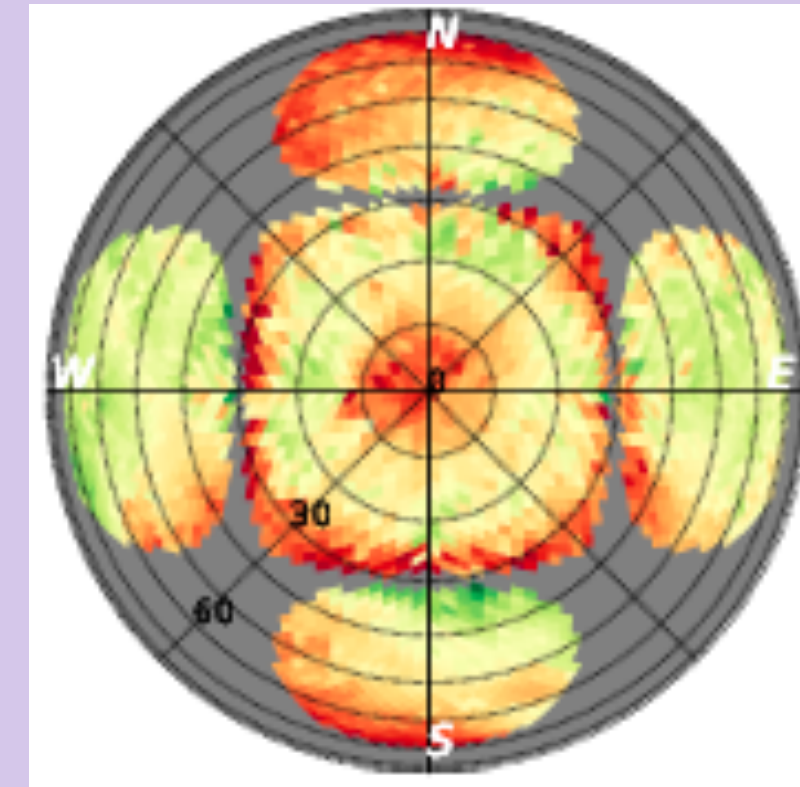
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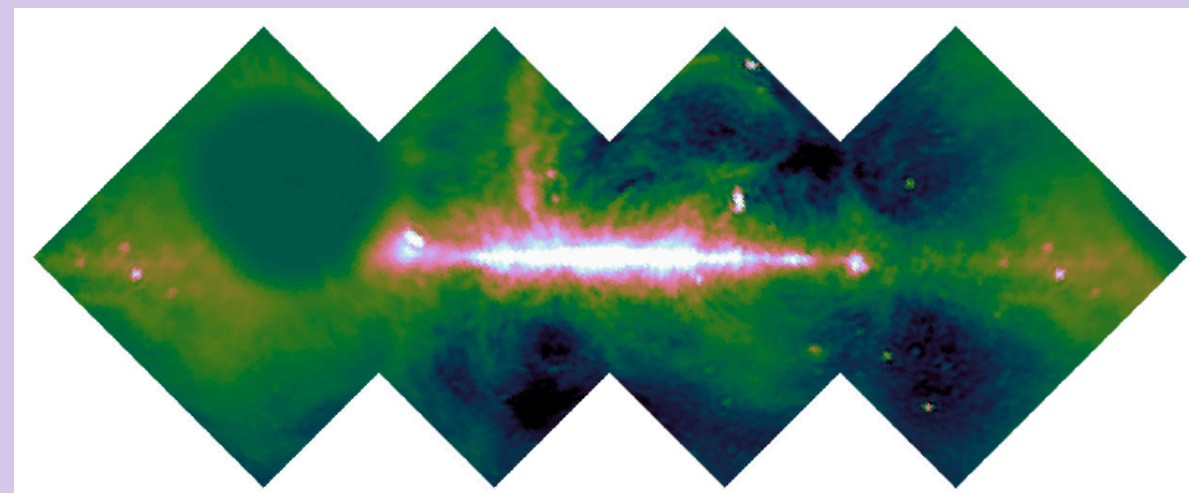
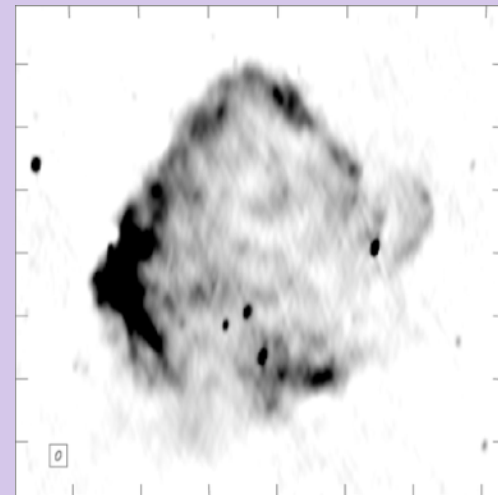
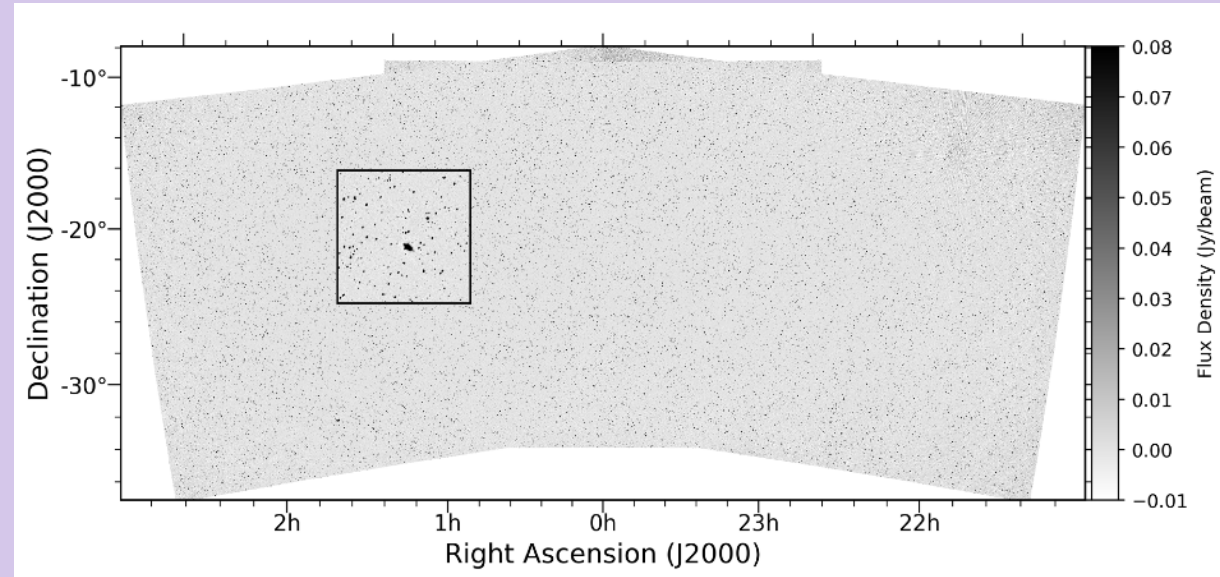
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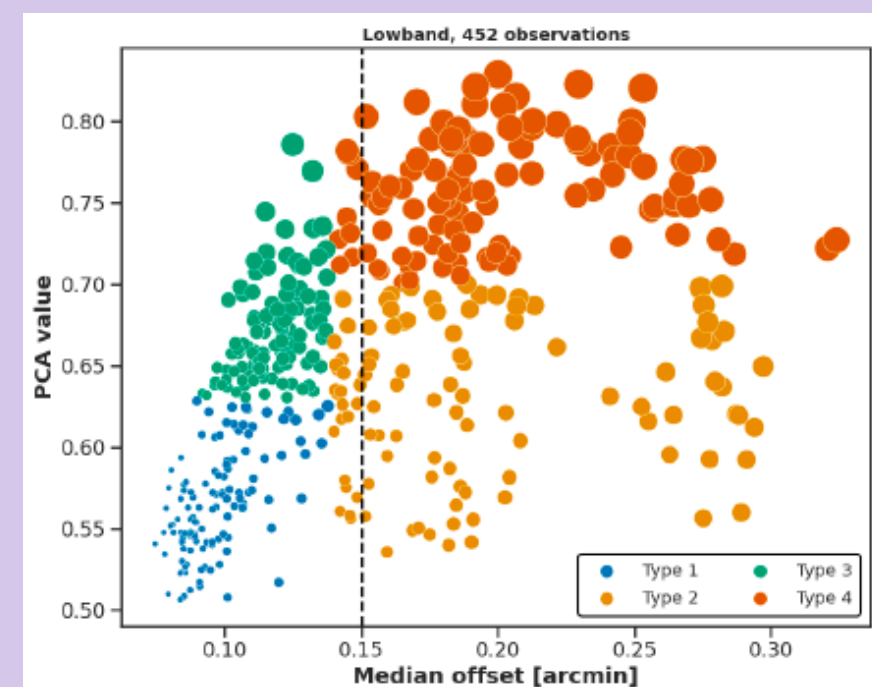
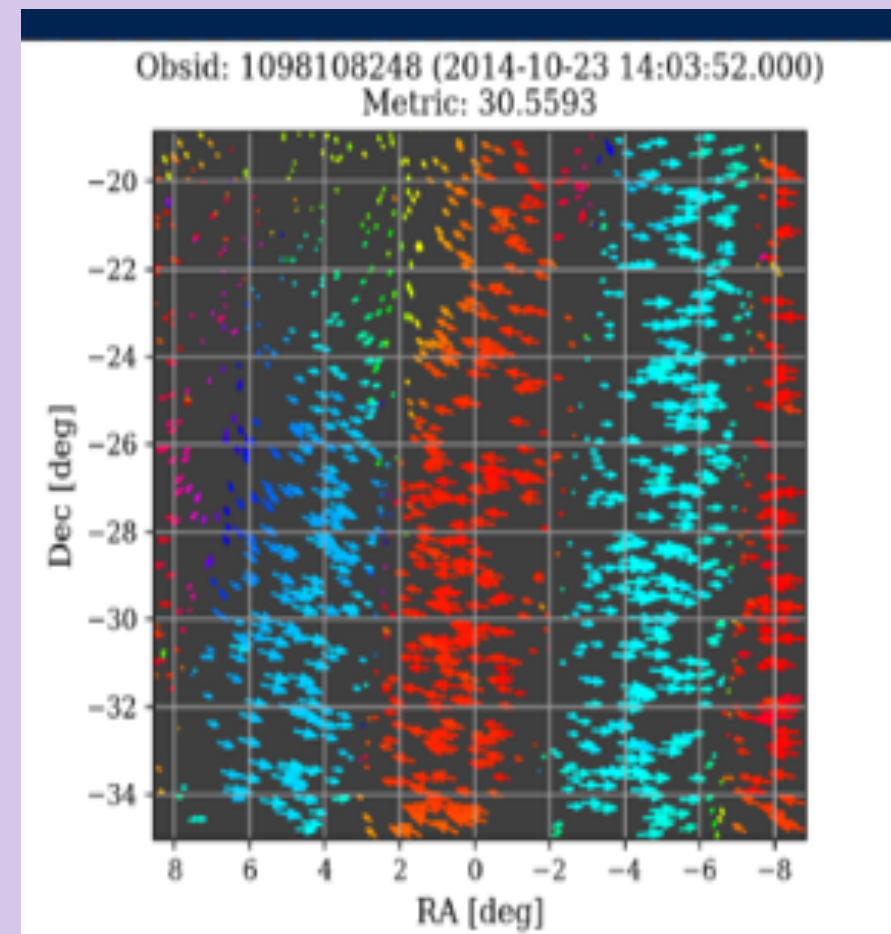
TELESCOPE



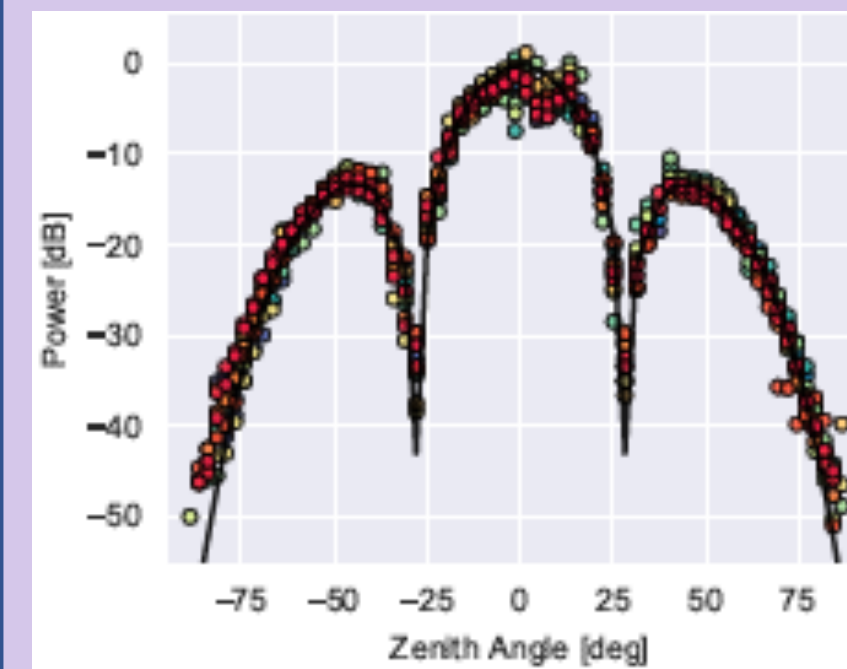
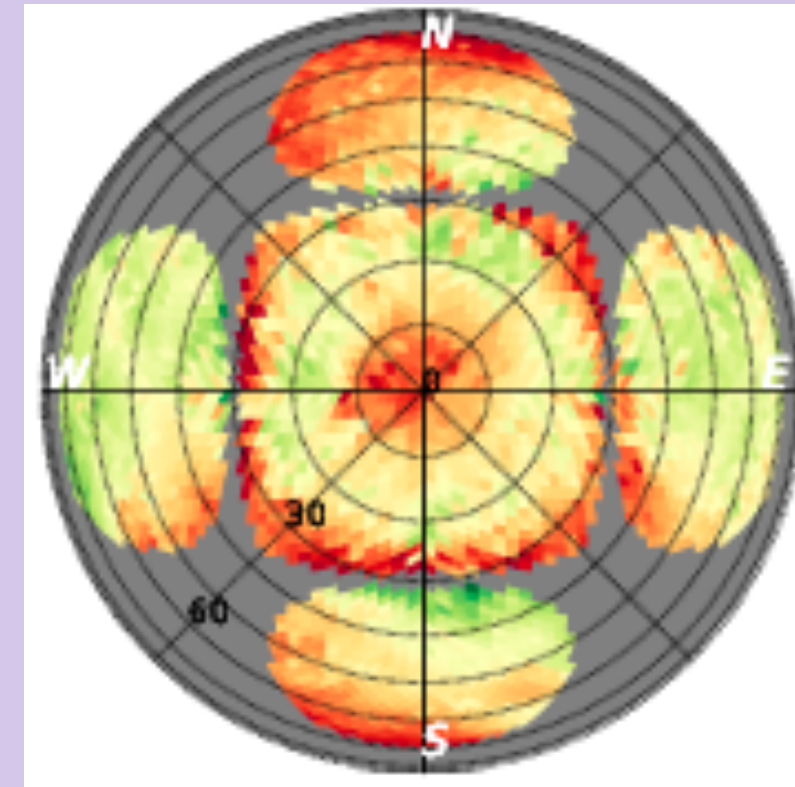
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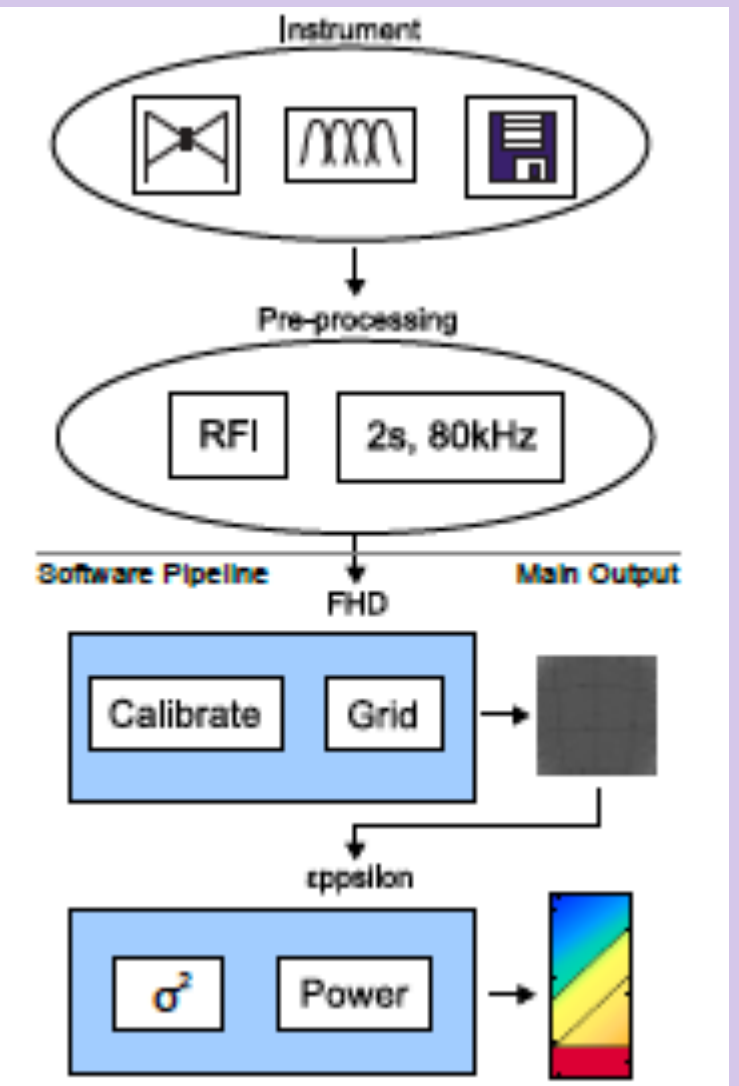
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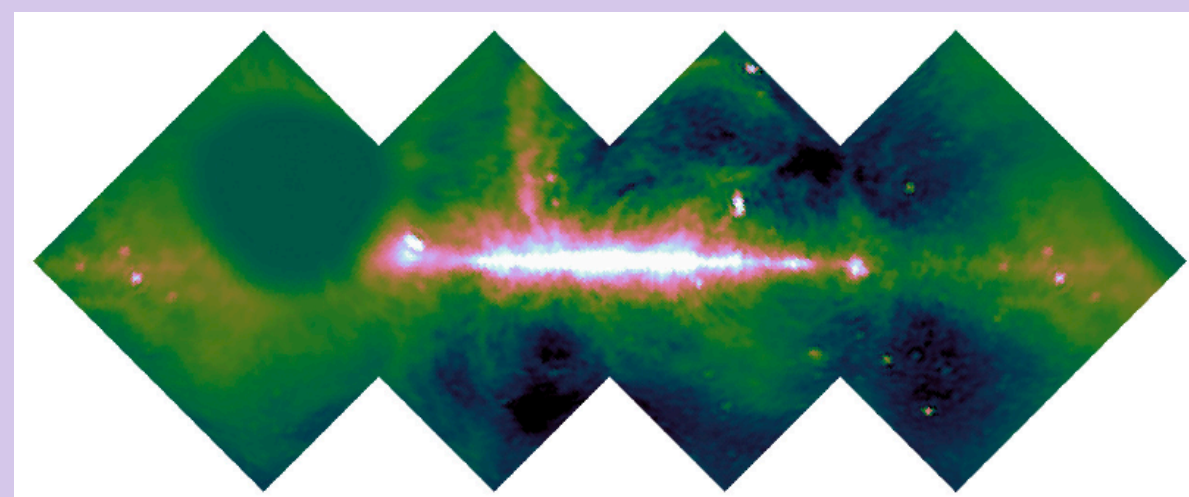
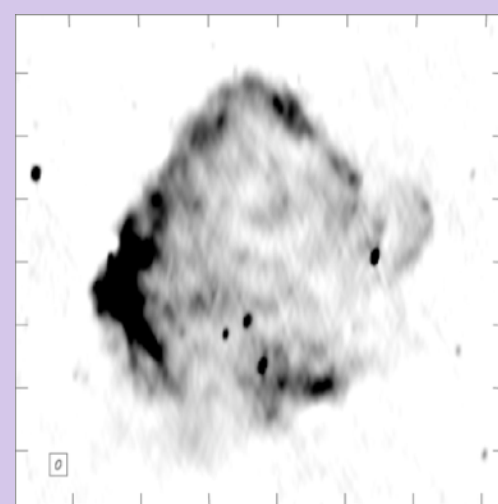
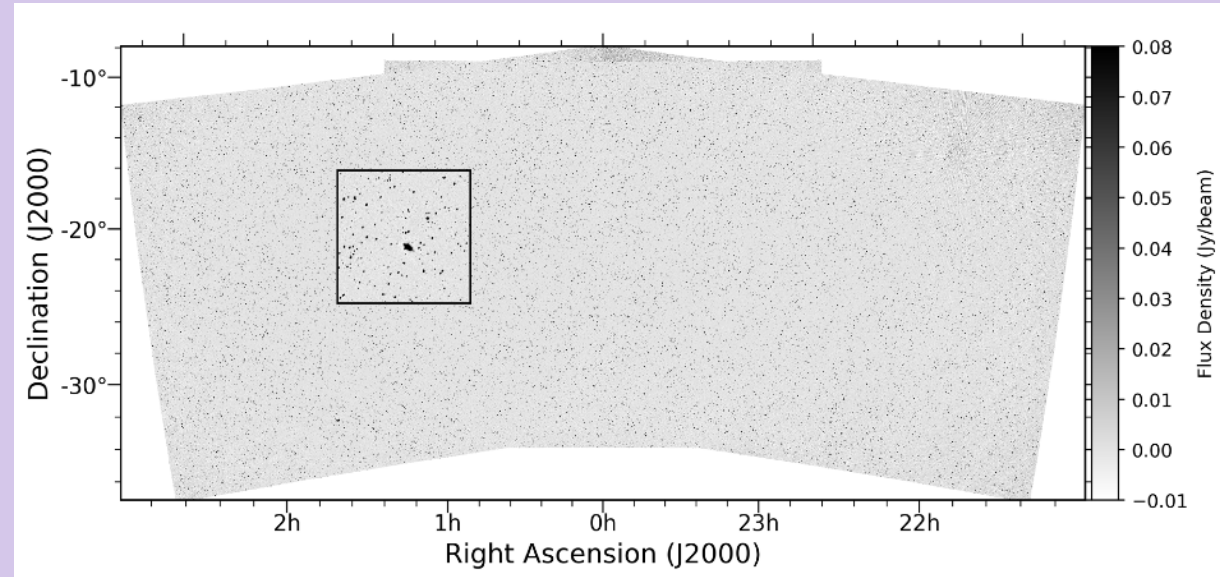


ANALYSIS

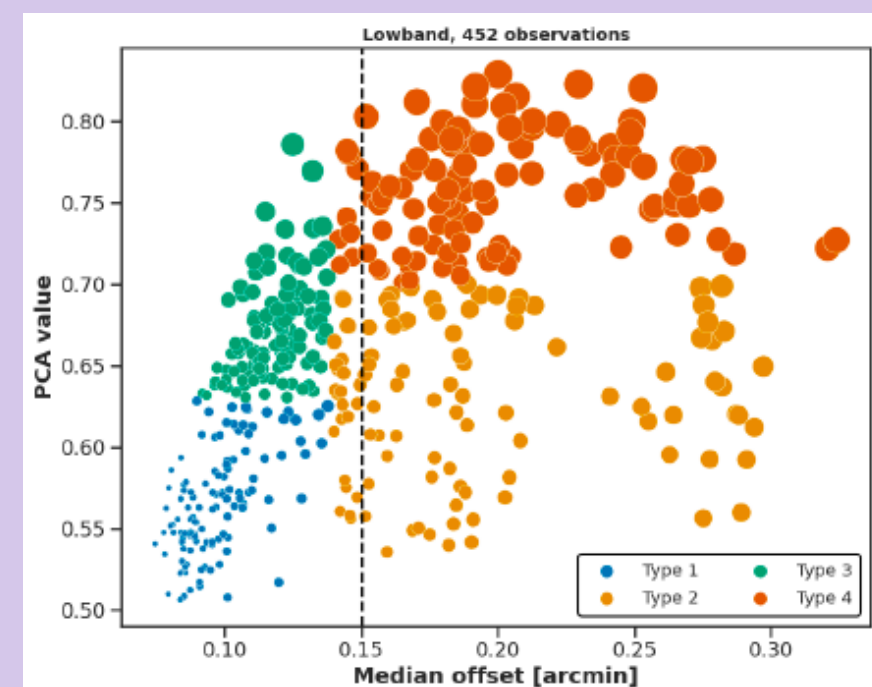
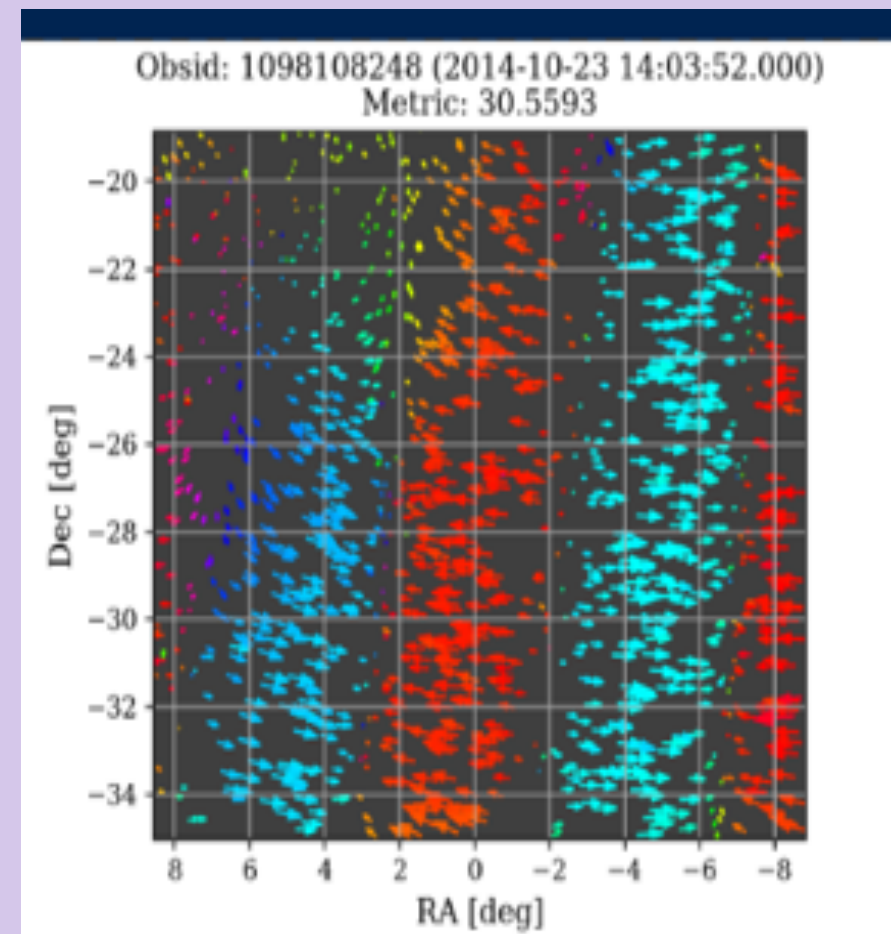


ASTRO 3D

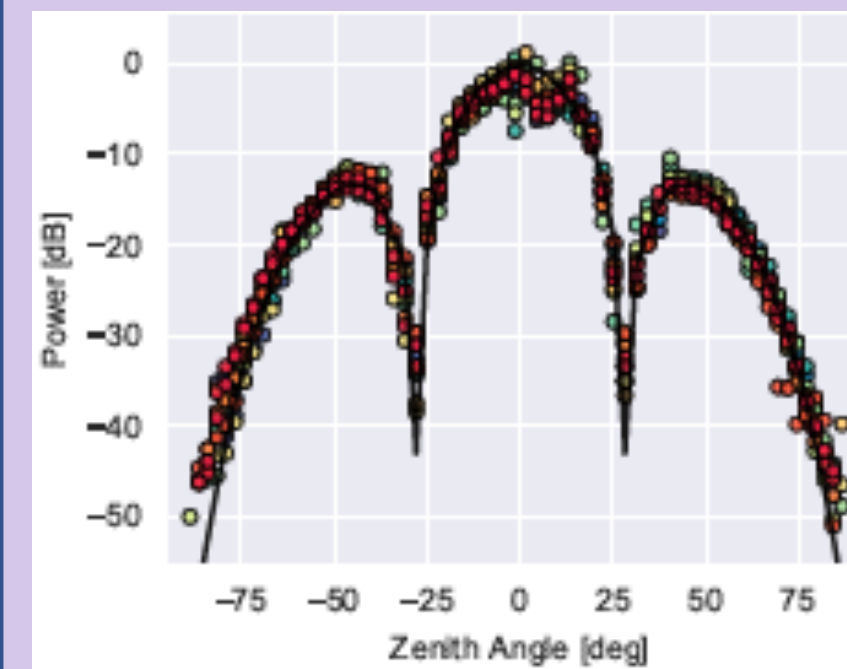
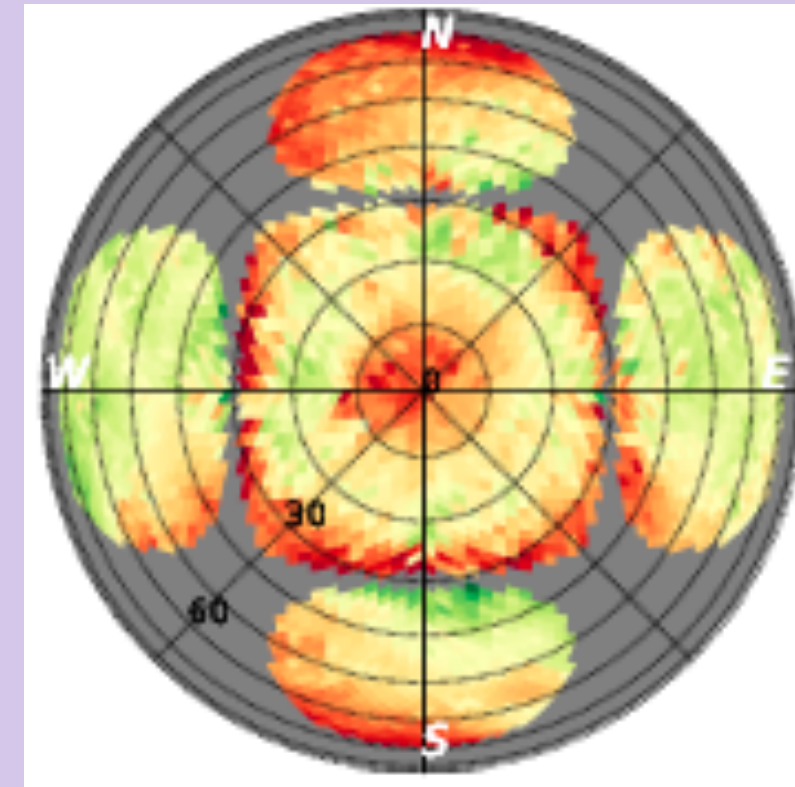
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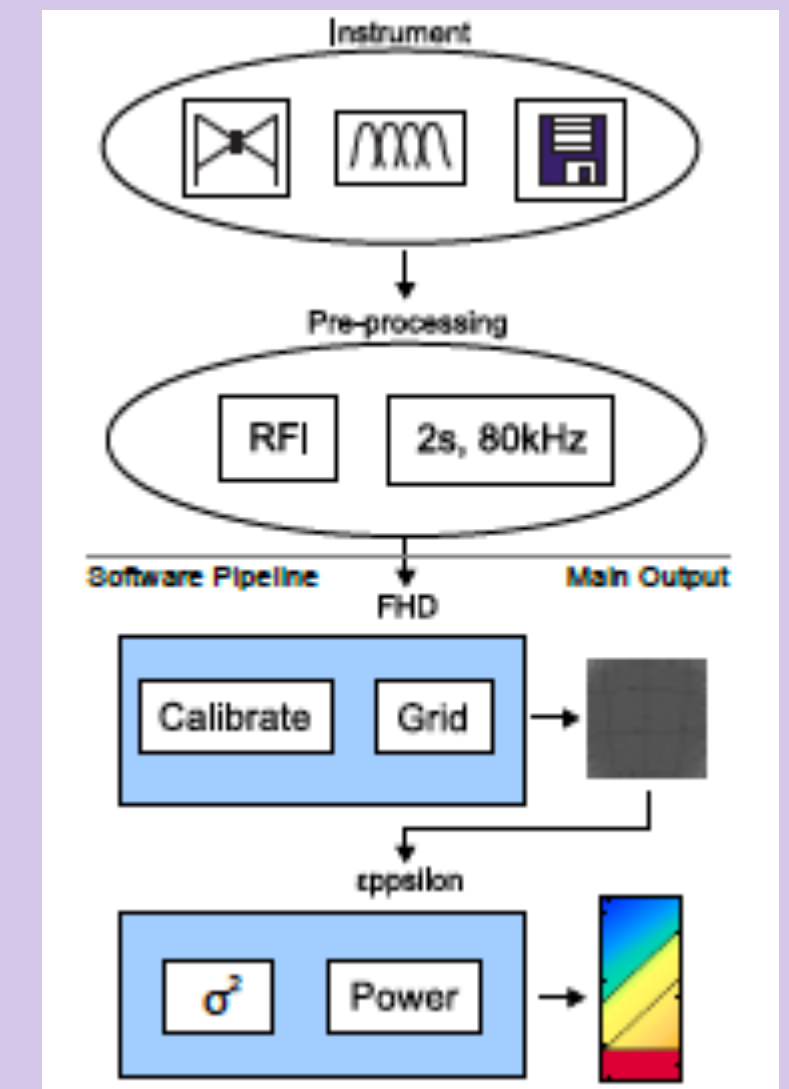
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TELESCOPE



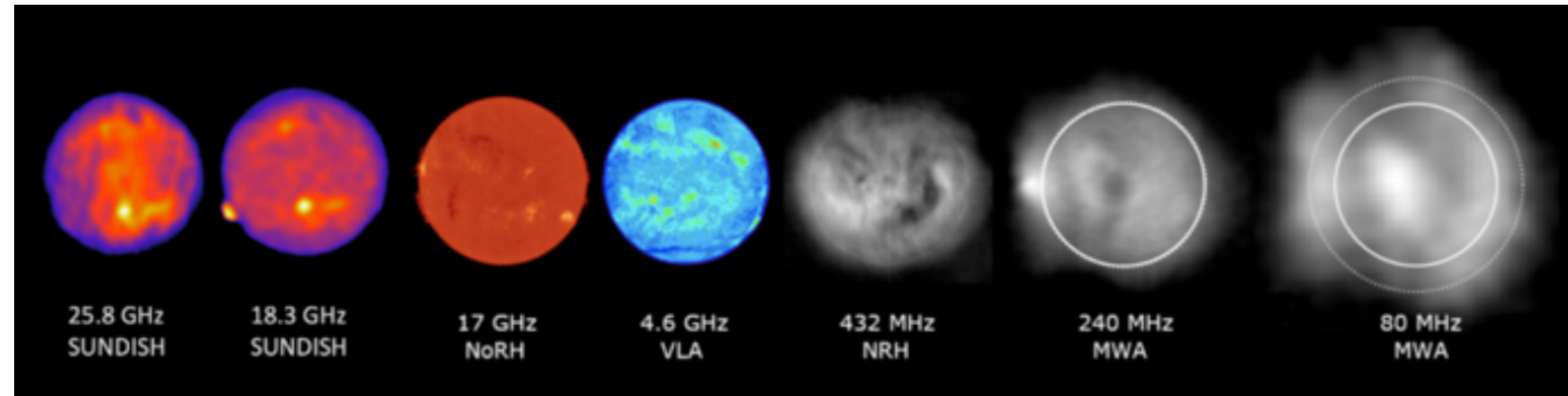
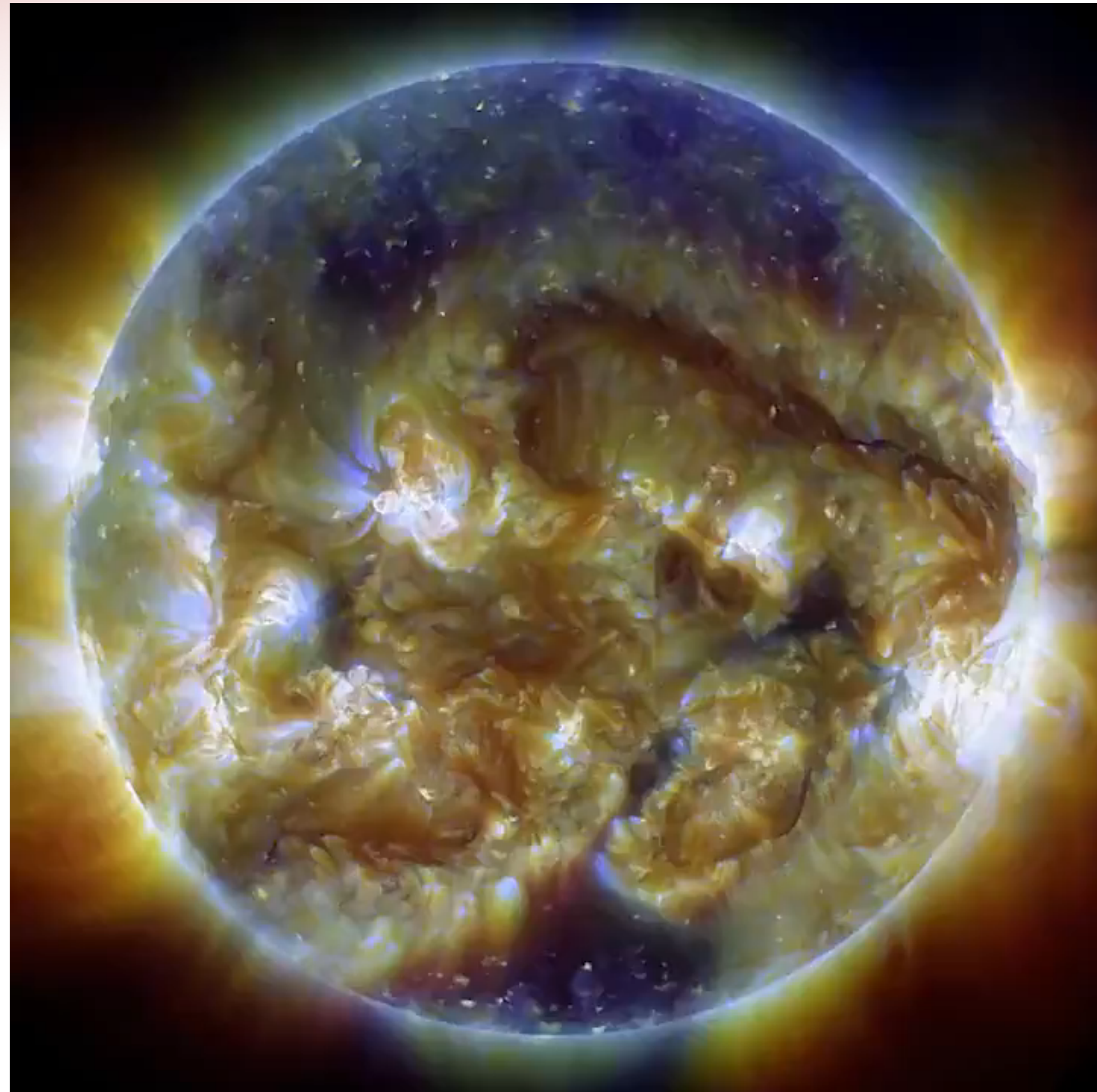
ANALYSIS



Full end-to-end simulations

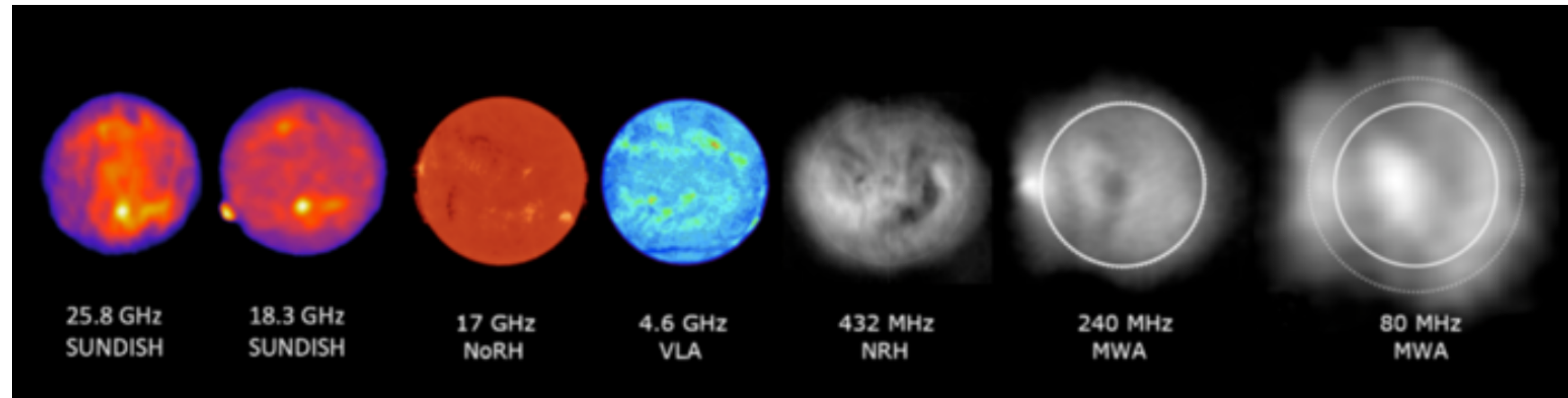
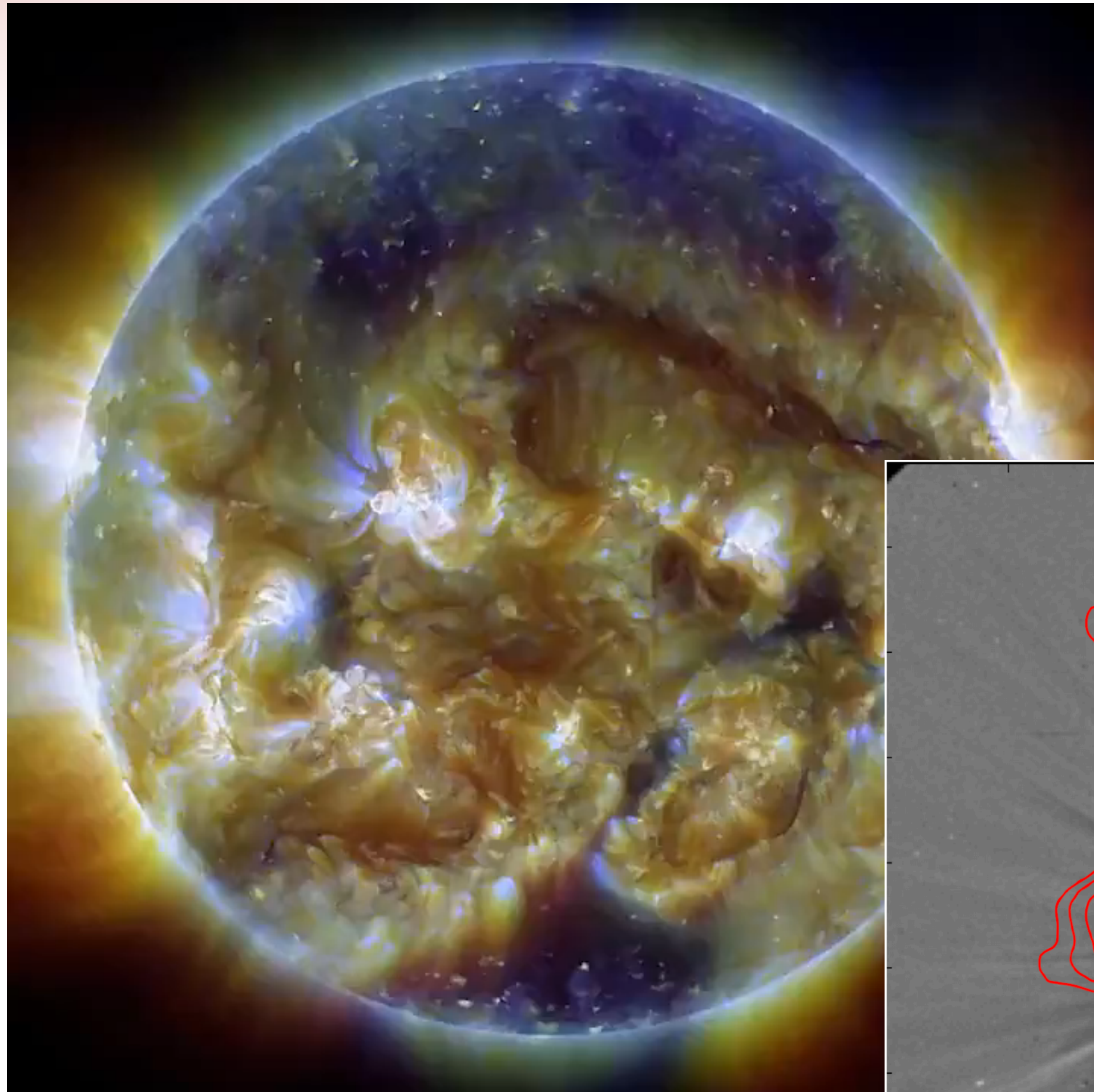
SOLAR, HELIOSPHERIC & IONOSPHERIC (SHI)

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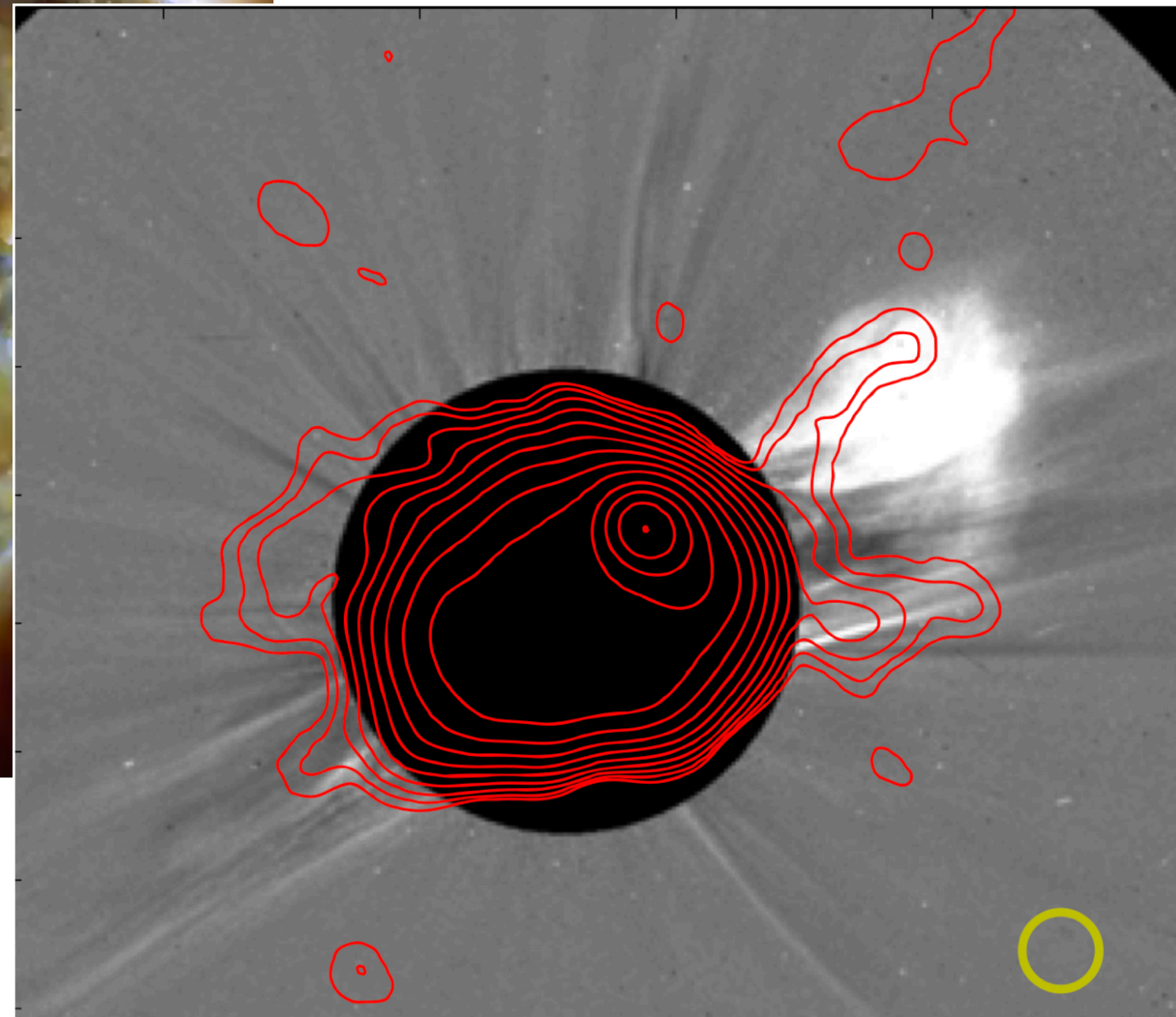
The Sun in the radio; credit: Rohit Sharma

SOLAR, HELIOSPHERIC & IONOSPHERIC (SHI)

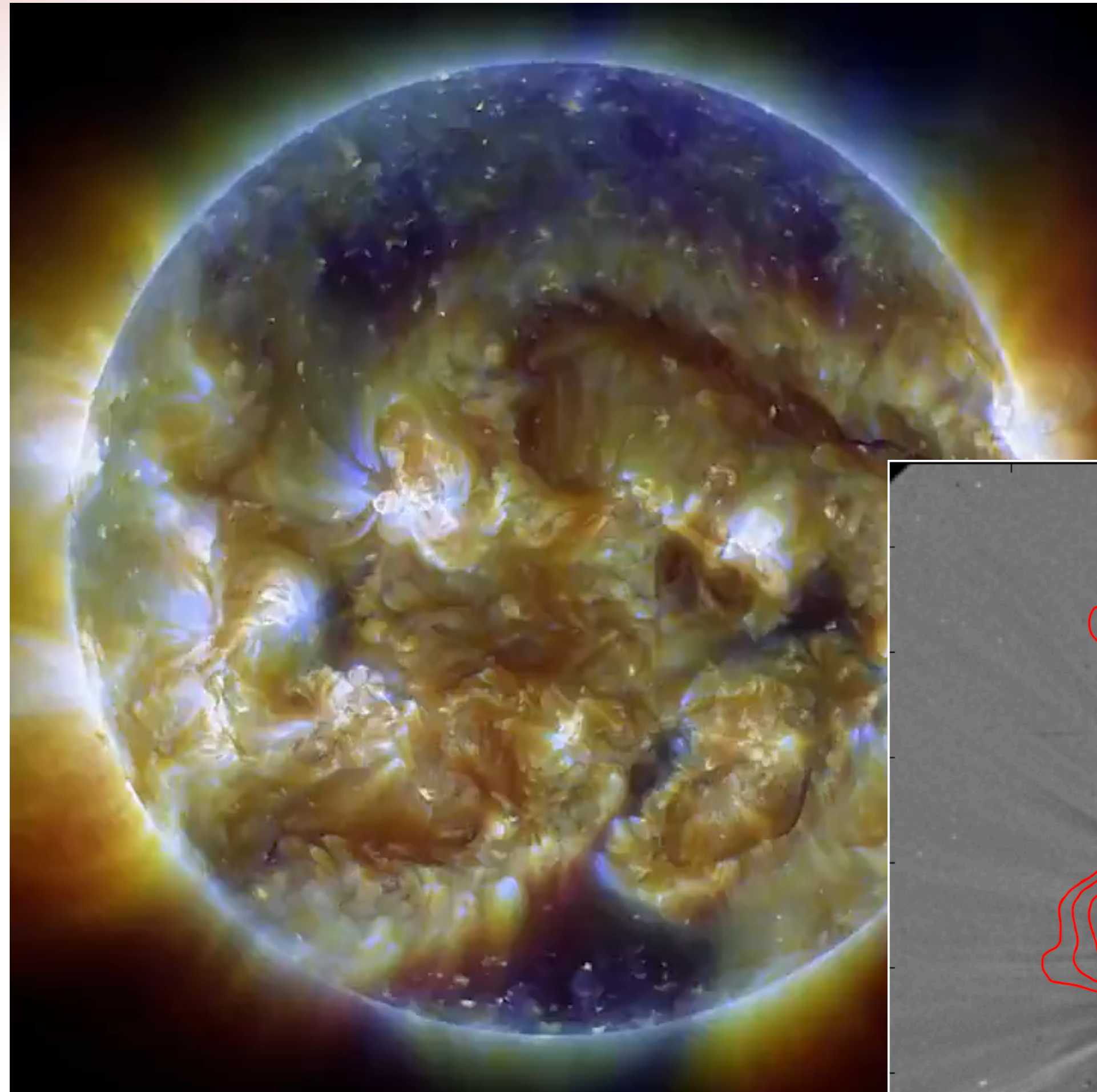


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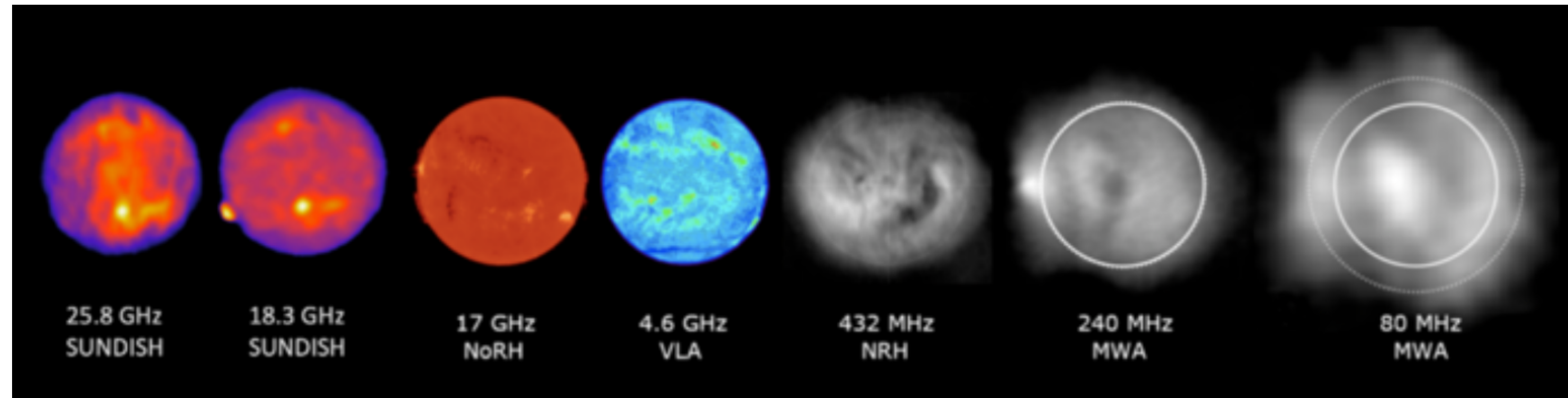
MWA imaging of CME;
Mondal et al. (2019)



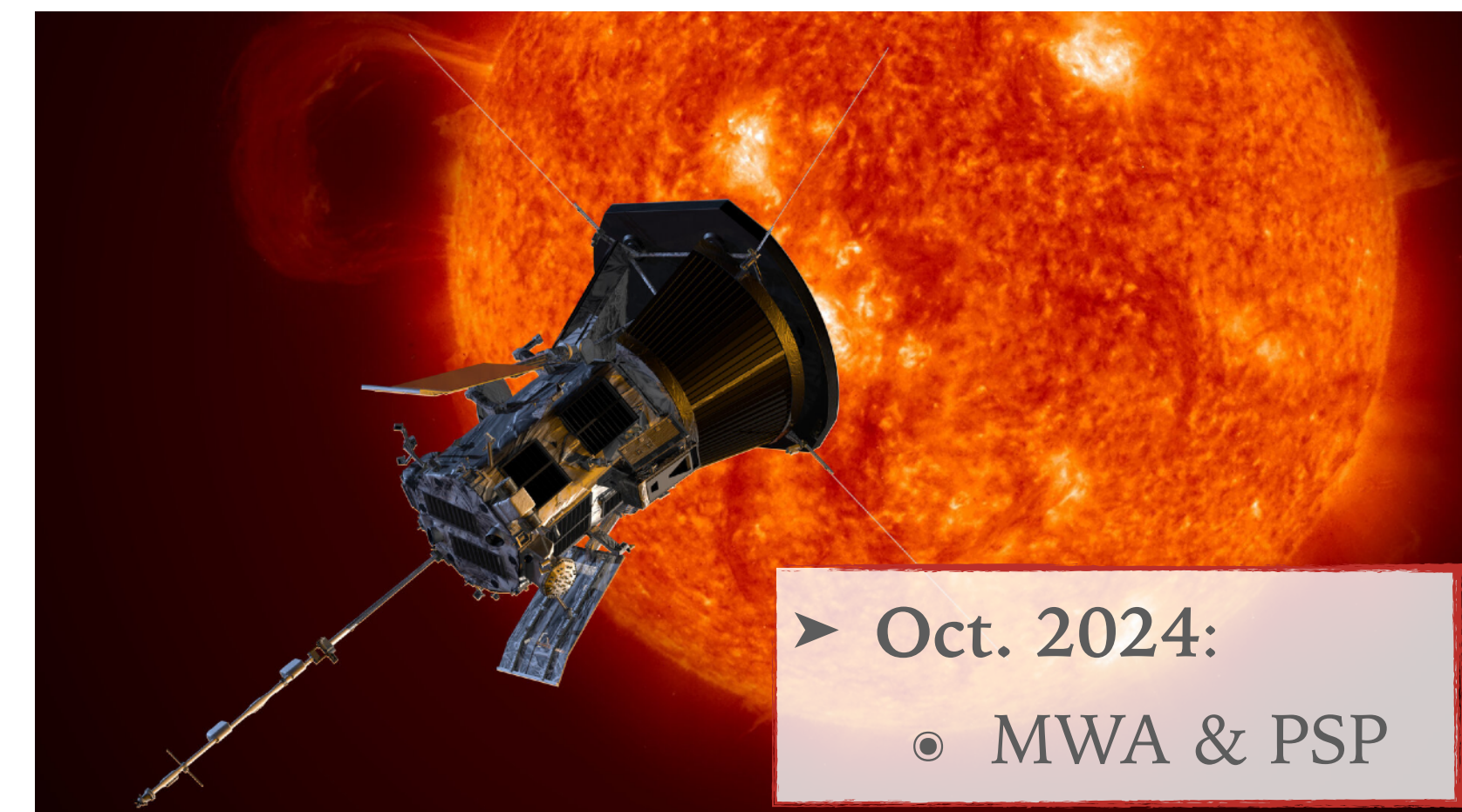
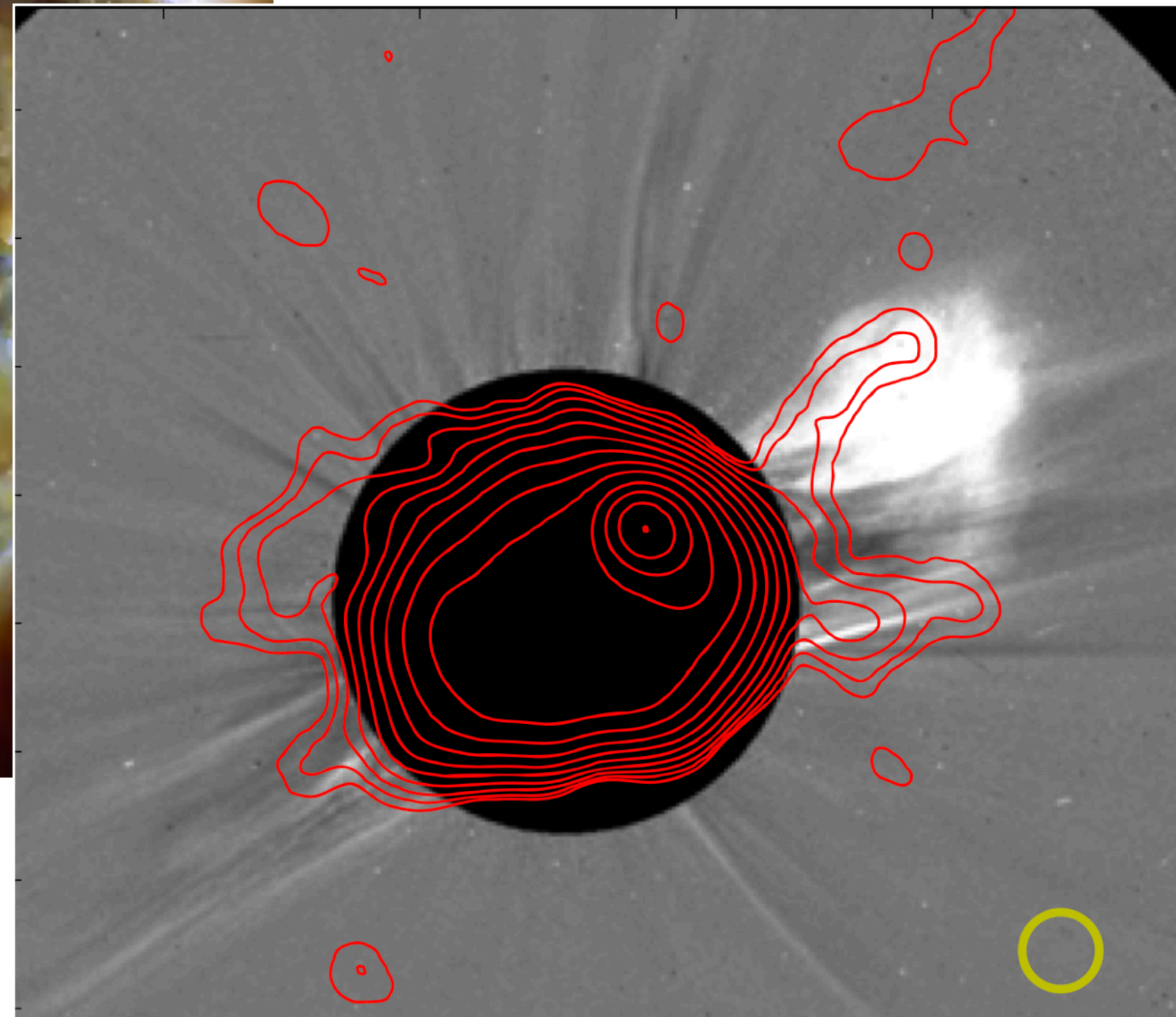
SOLAR, HELIOSPHERIC & IONOSPHERIC (SHI)



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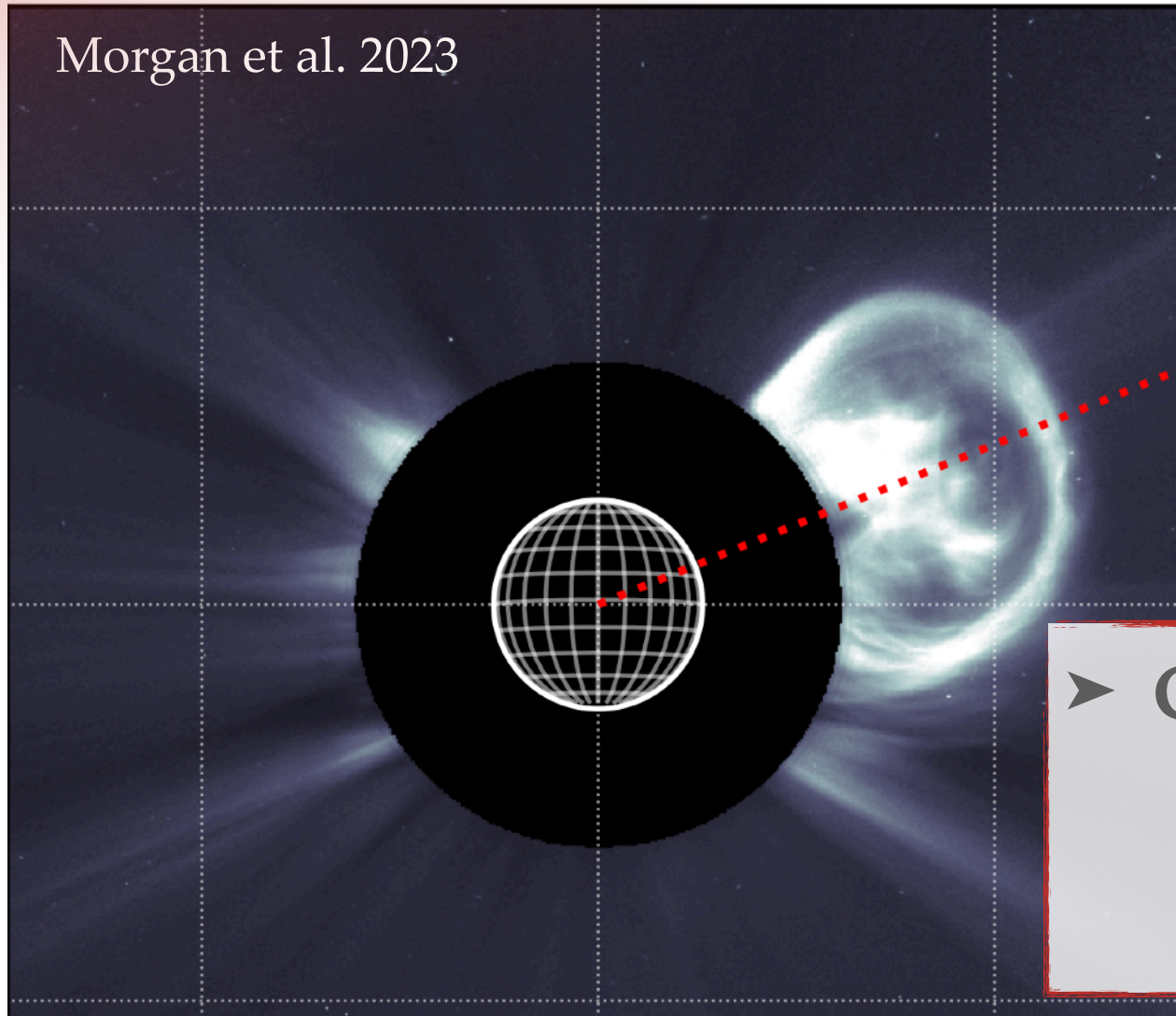


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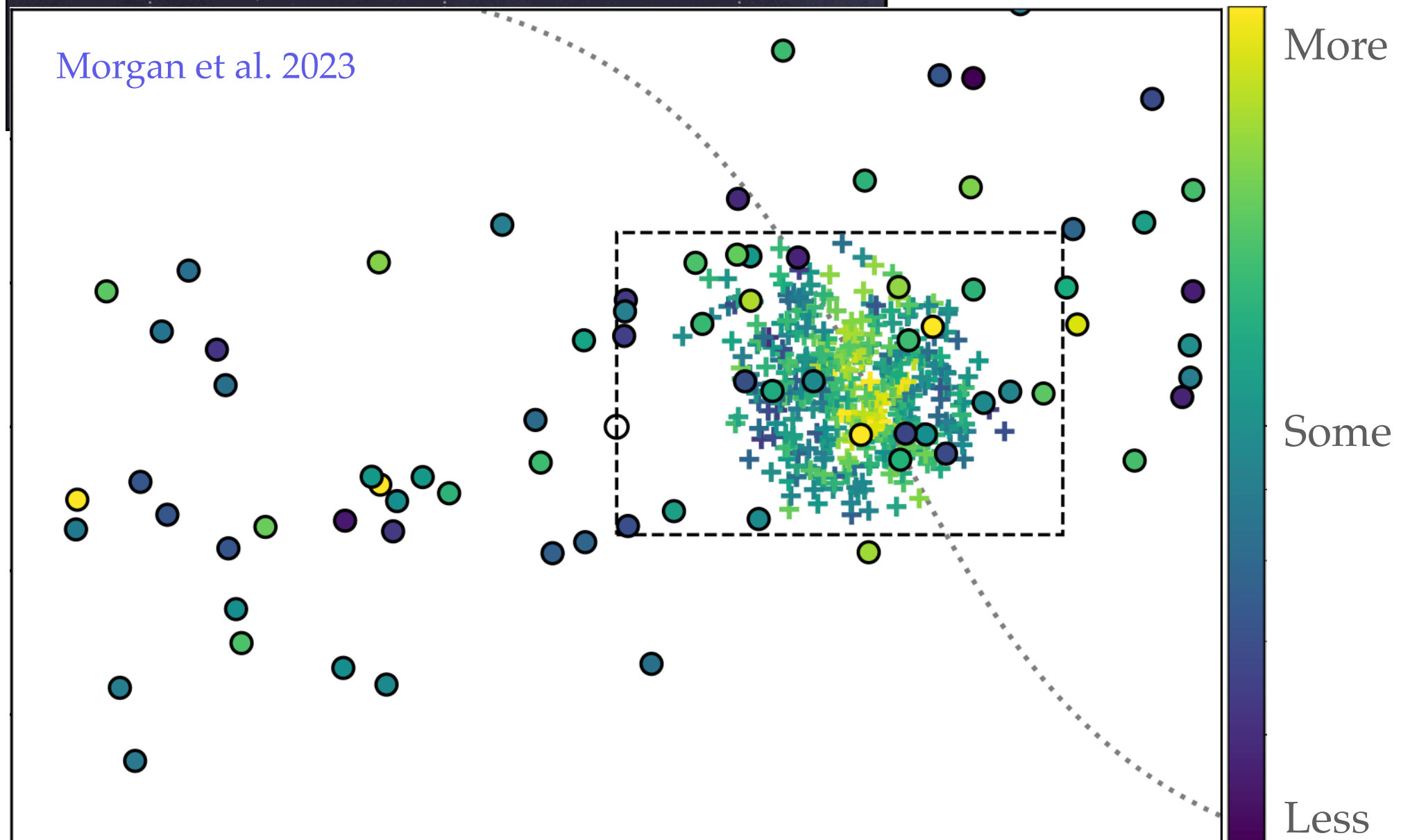


► Oct. 2024:
○ MWA & PSP

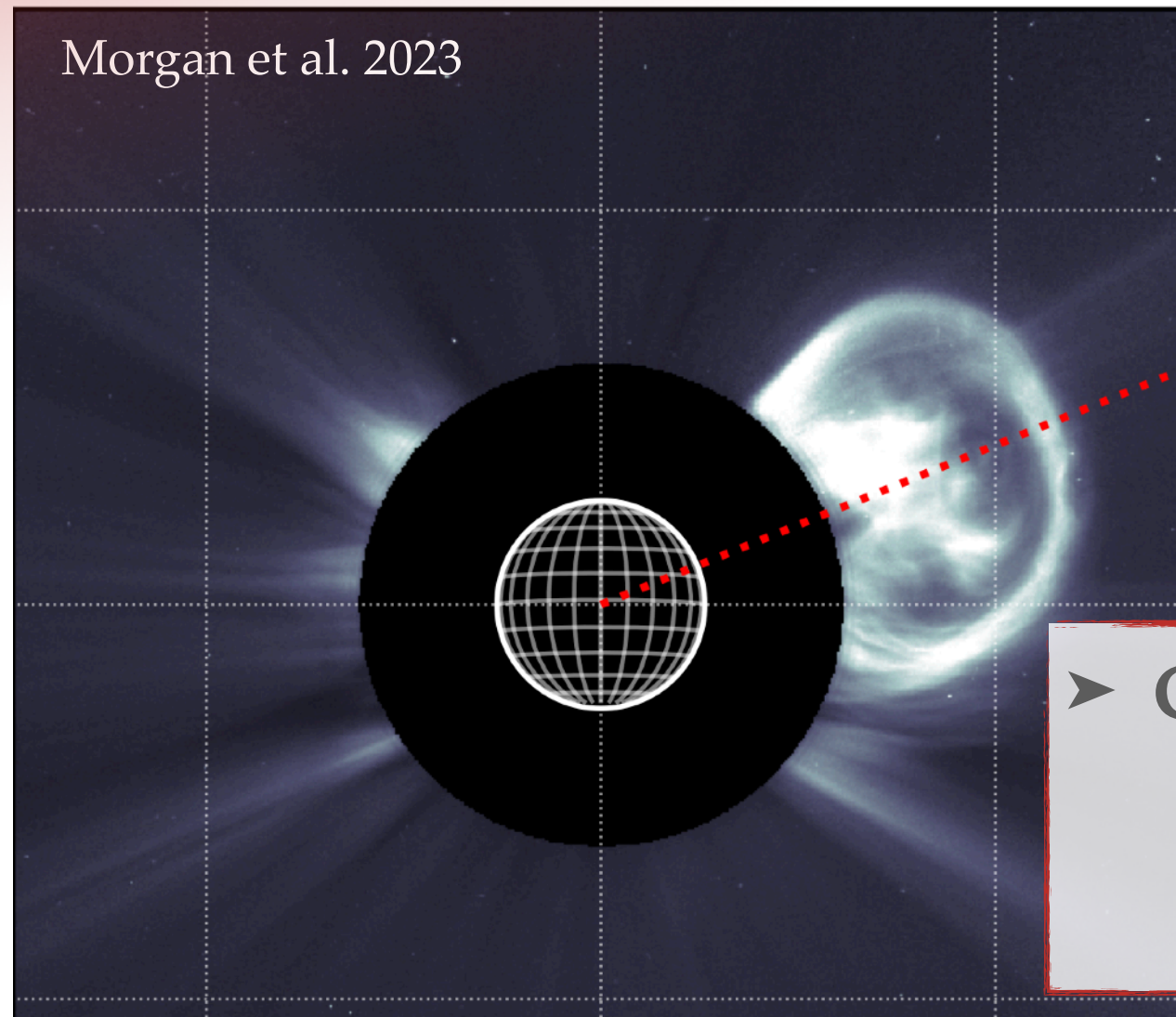
SOLAR, HELIOSPHERIC & IONOSPHERIC (SHI)



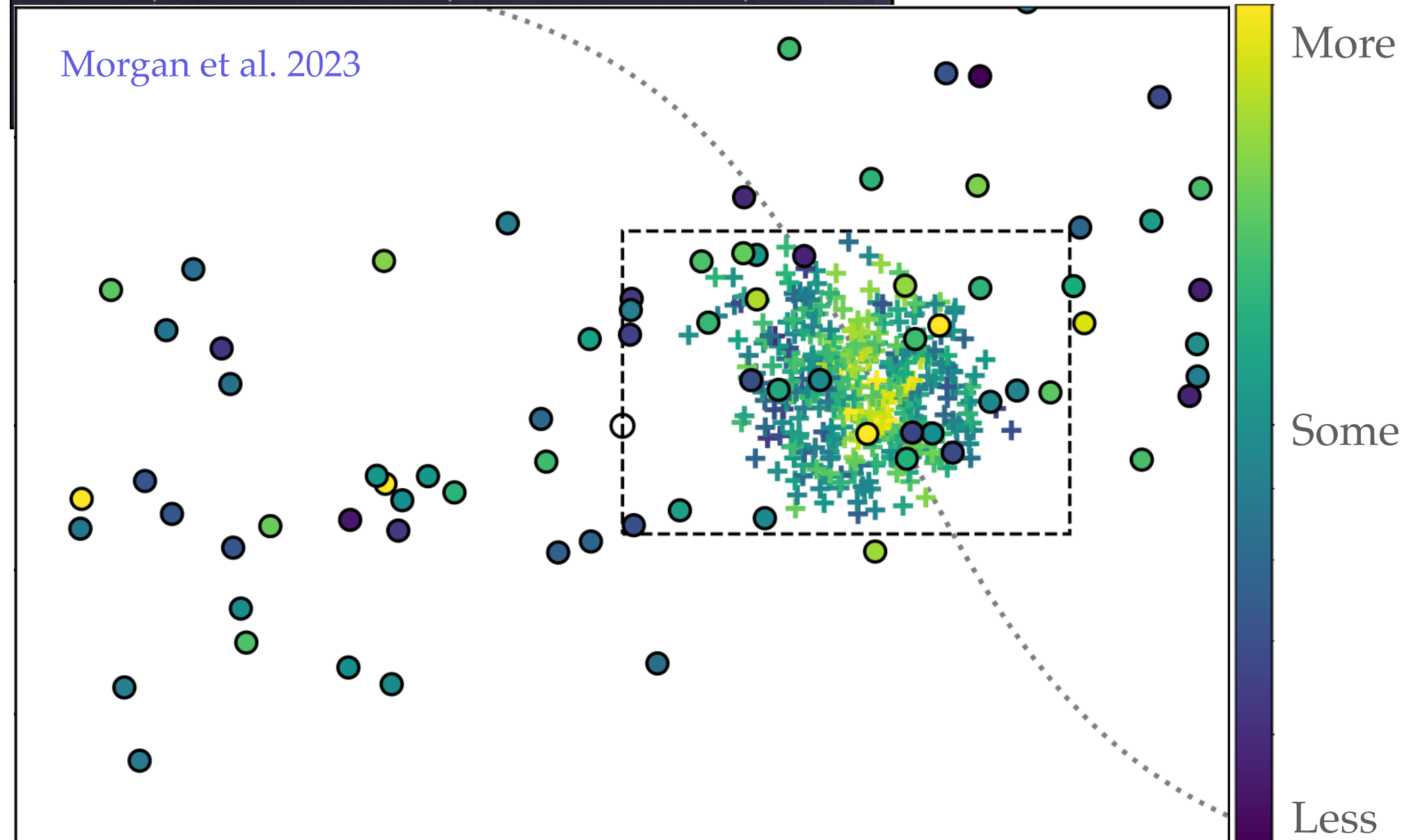
- CME:
 - ⦿ Detection via scintillation



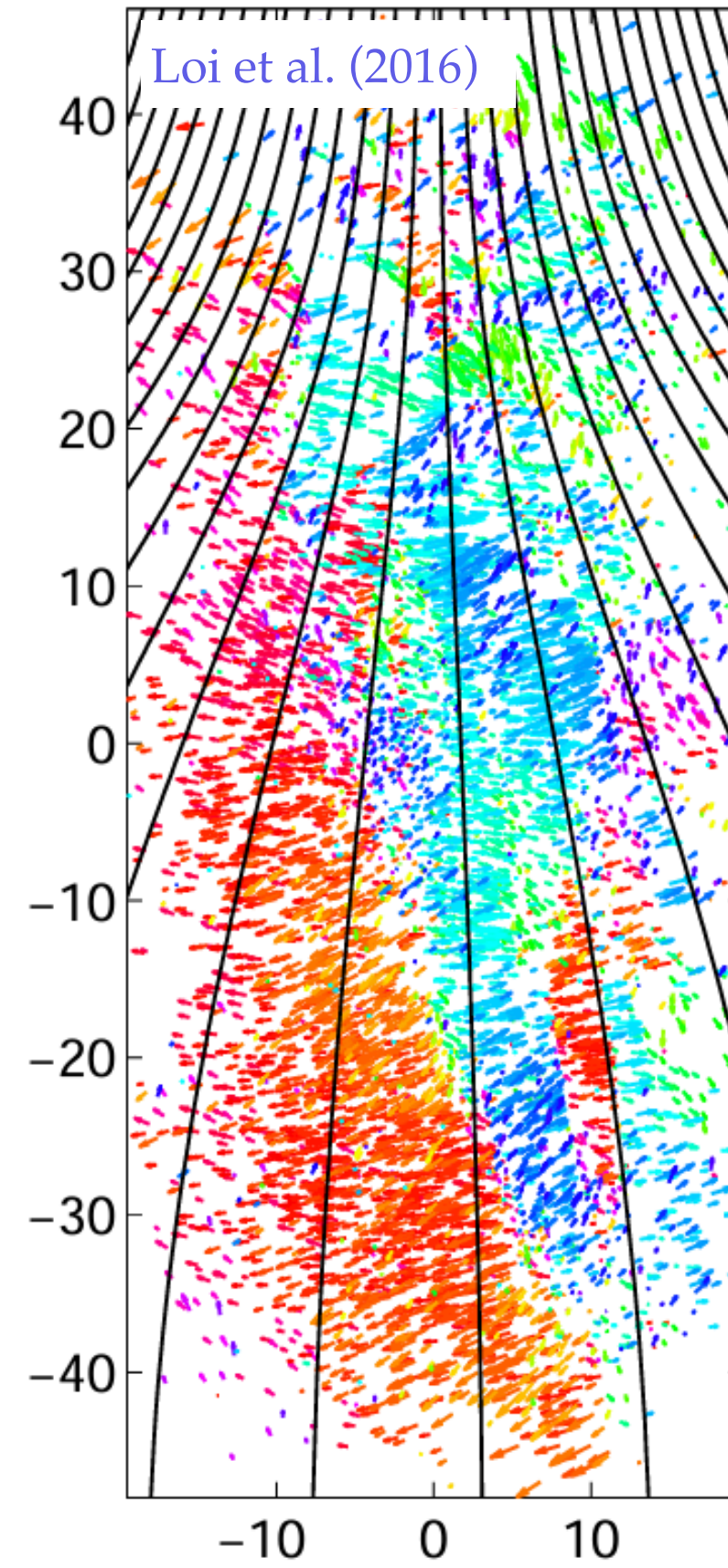
SOLAR, HELIOSPHERIC & IONOSPHERIC (SHI)



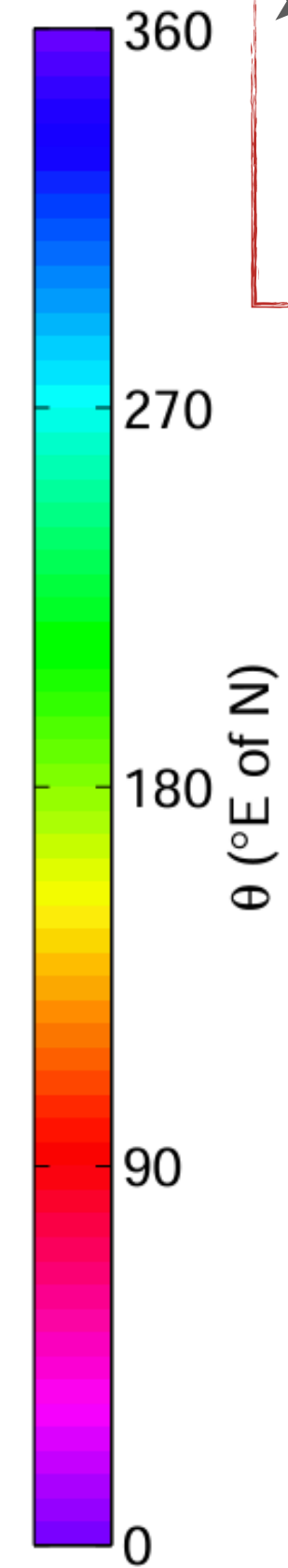
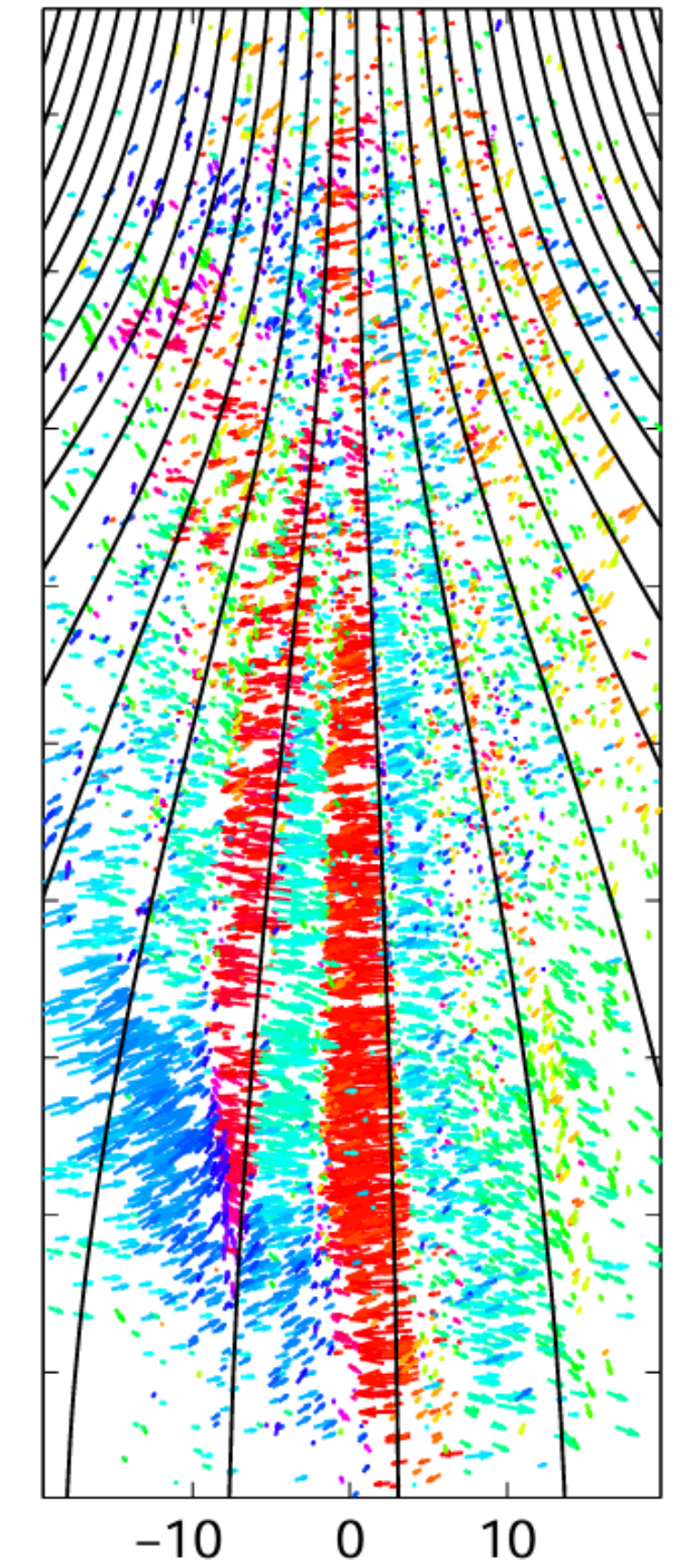
► CME:
○ Detection via scintillation



UTC 2014-08-26 16:34:48

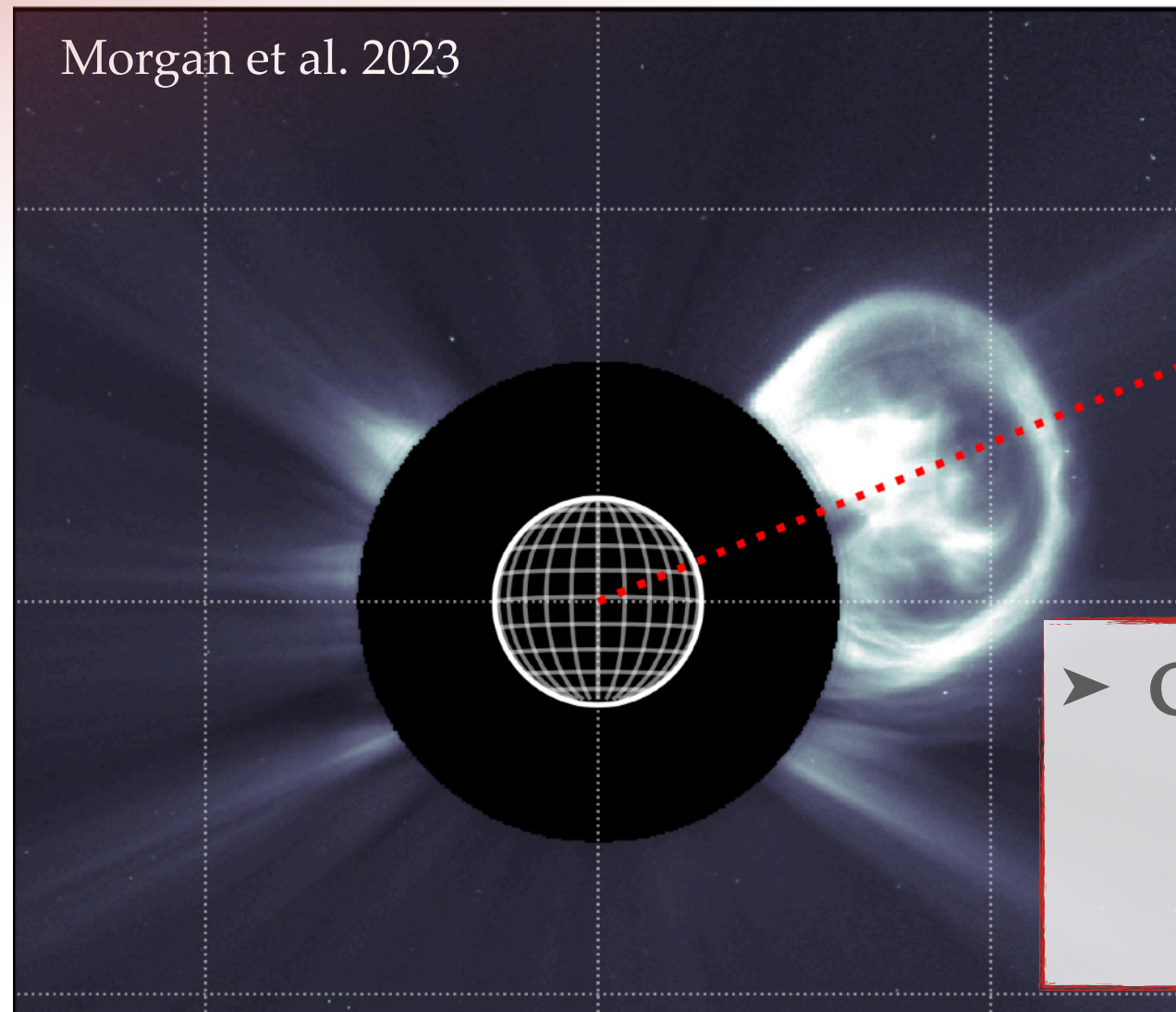


UTC 2014-08-26 18:20:48



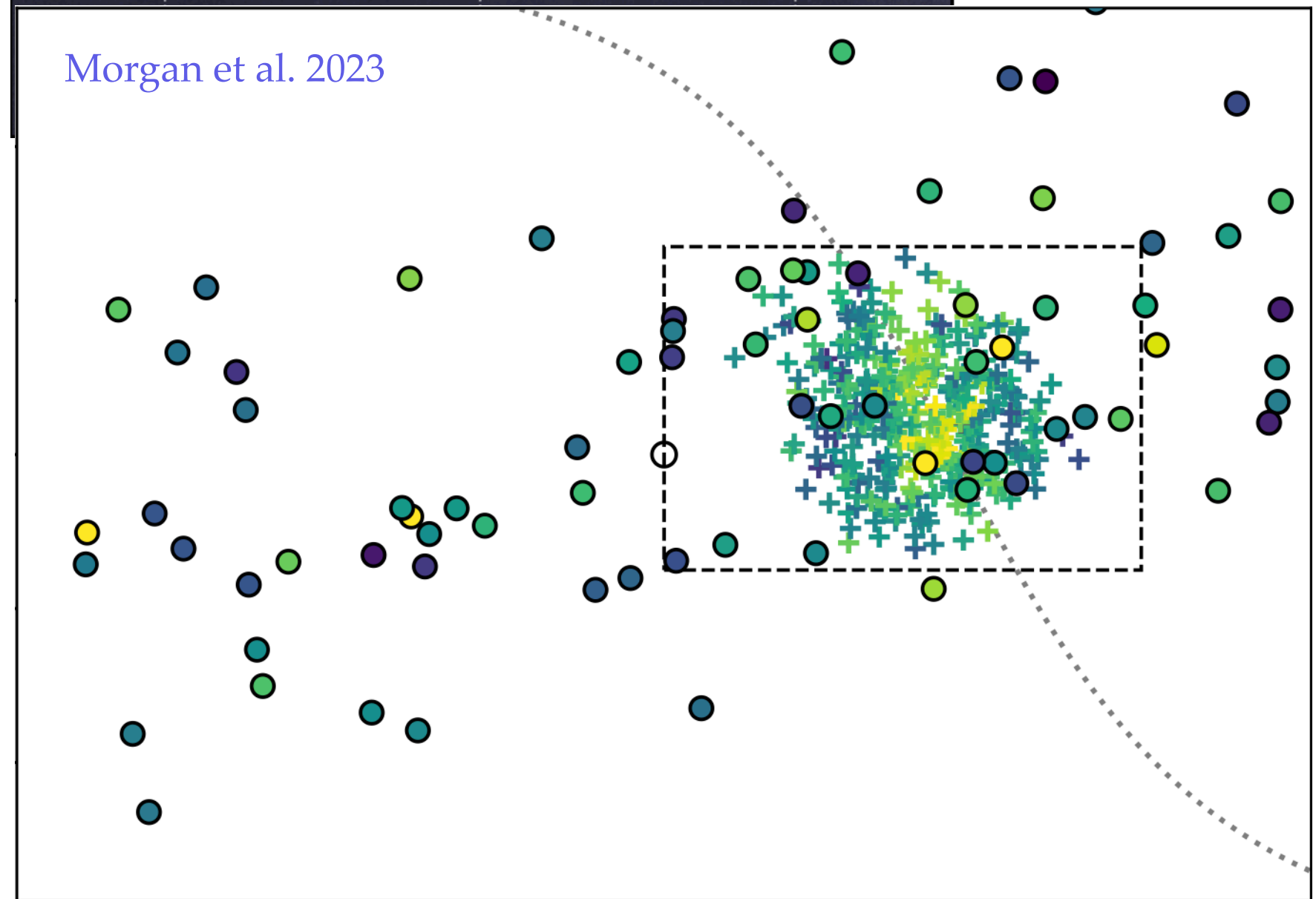
► Ionospheric plasma:
○ Ducts in the wake of TIDS (Loi et al. 2016)

SOLAR, HELIOSPHERIC & IONOSPHERIC (SHI)



Morgan et al. 2023

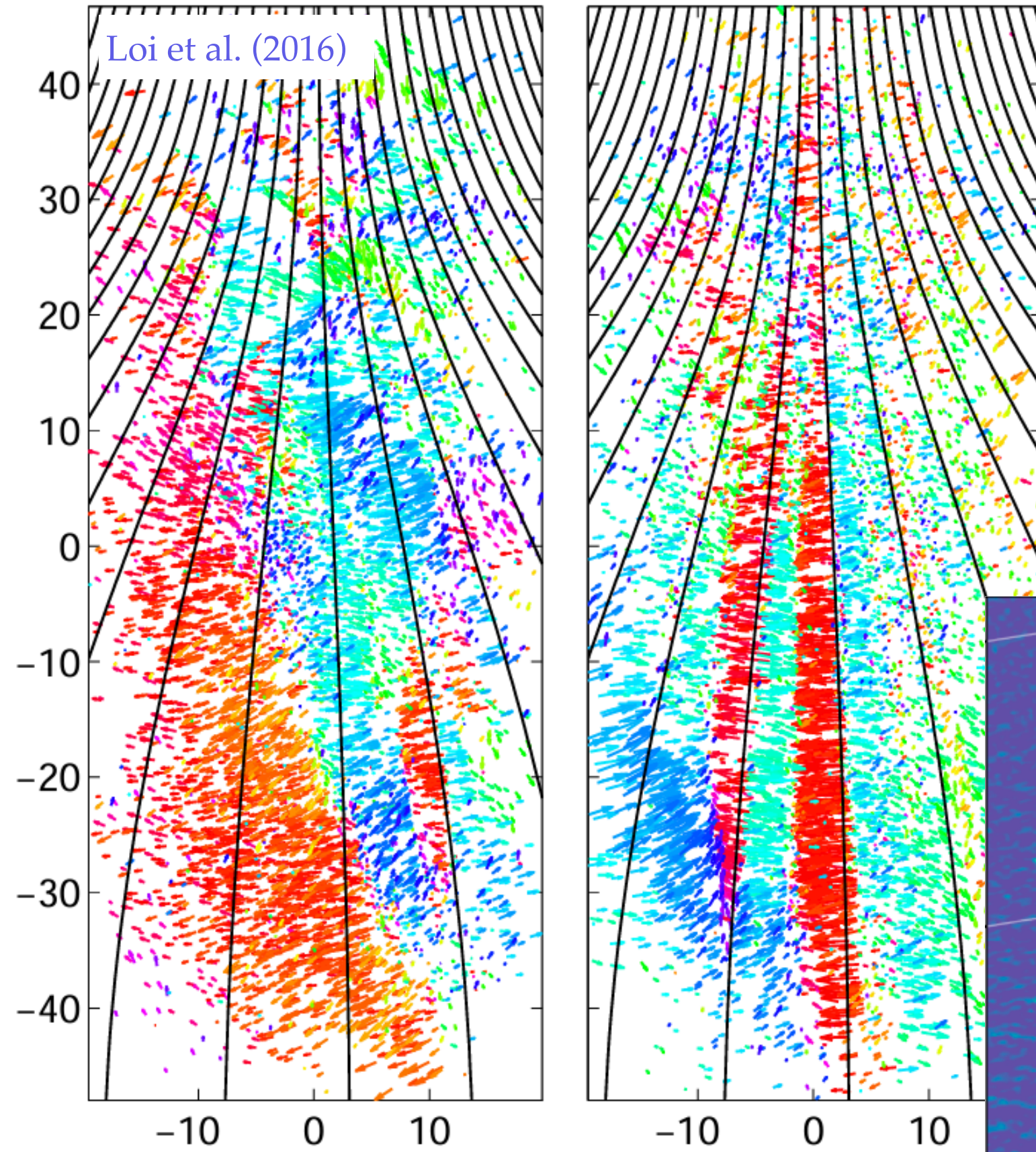
- CME:
 - ⊙ Detection via scintillation



Morgan et al. 2023

More
Some
Less

UTC 2014-08-26 16:34:48 UTC 2014-08-26 18:20:48

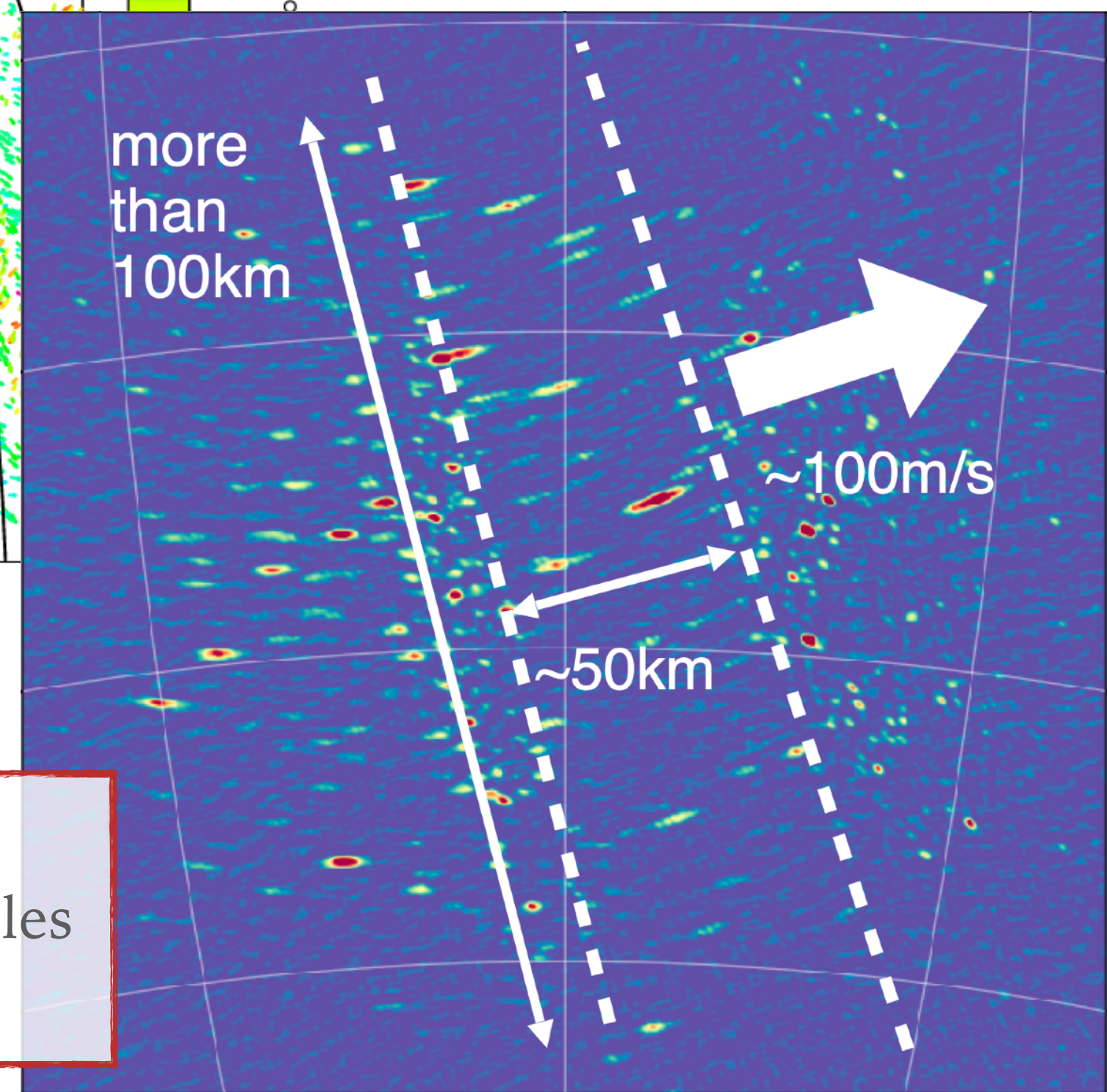


Loi et al. (2016)

360
270
180
pE of N

- Ionospheric plasma:
 - ⊙ Ducts in the wake of TIDS (Loi et al. 2016)

Yoshiura et al. (2024, submitted)



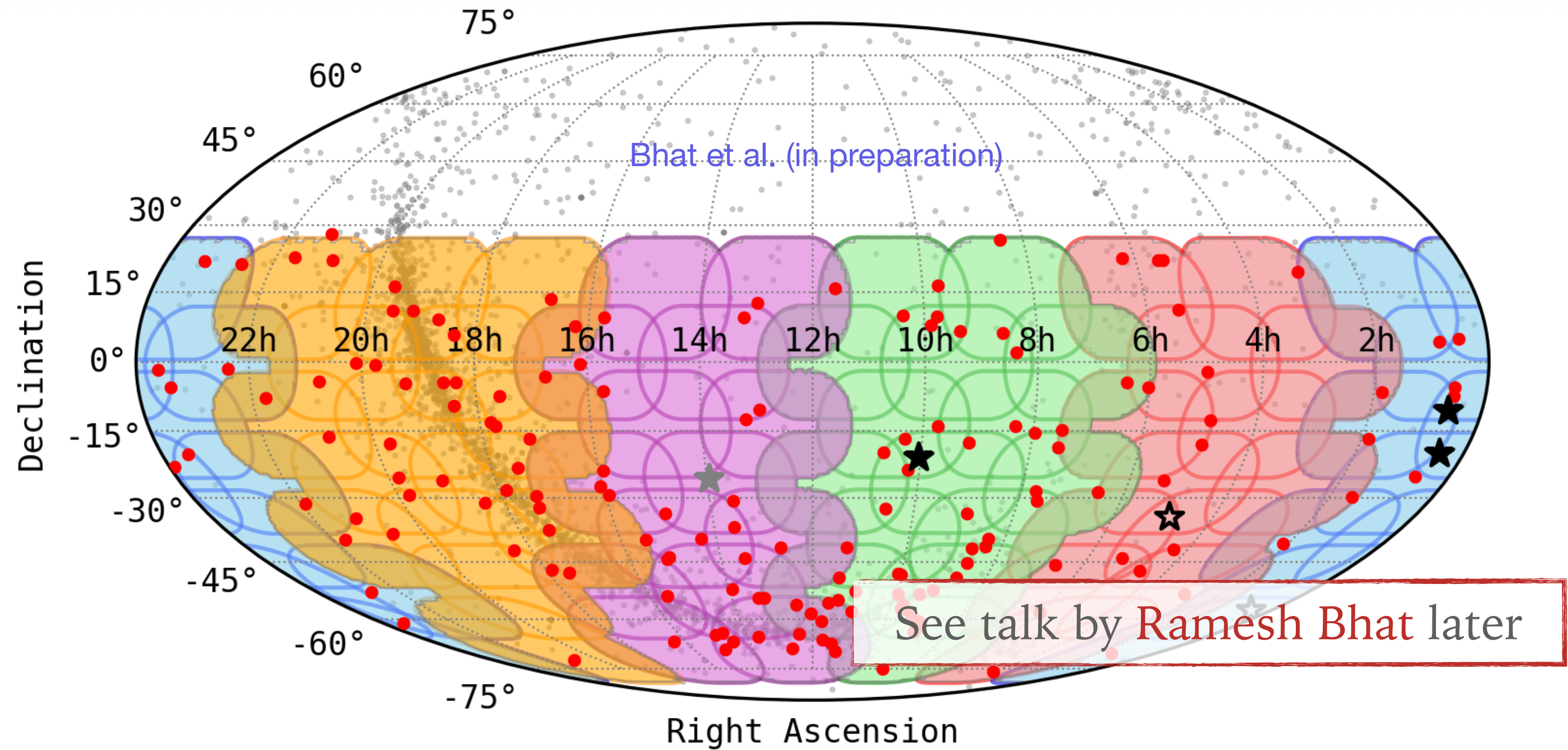
- Ionospheric plasma:
 - ⊙ Travelling, rising bubbles (Yoshiura et al. 2024)

PULSARS & FAST TRANSIENTS

PULSARS & FAST TRANSIENTS

► SMART Pulsar Survey:

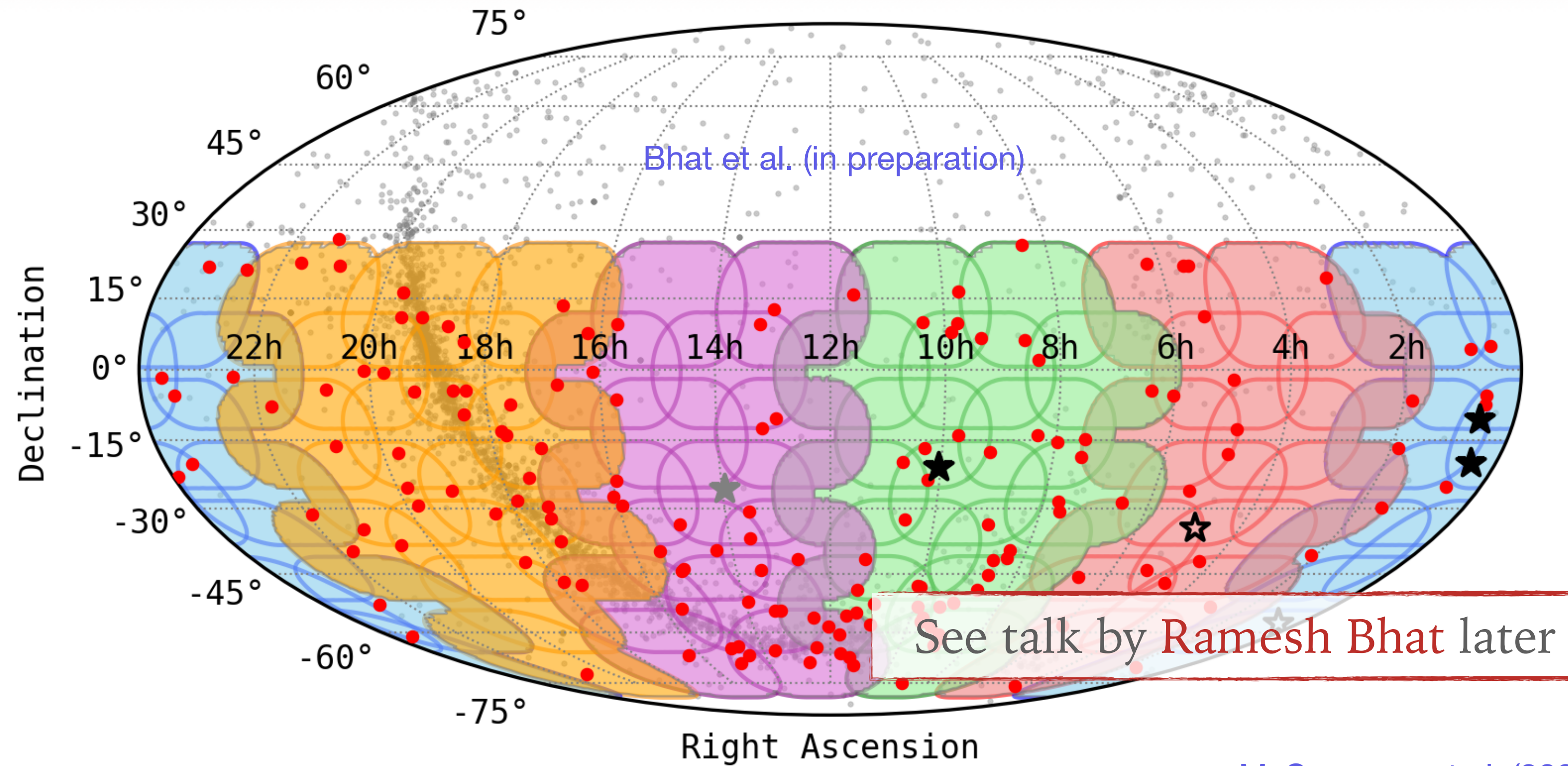
- All-sky in HTR mode (VCS)
- To-date: 200+ known PSRs plus *new and exotic* discoveries
- *Unique legacy value*



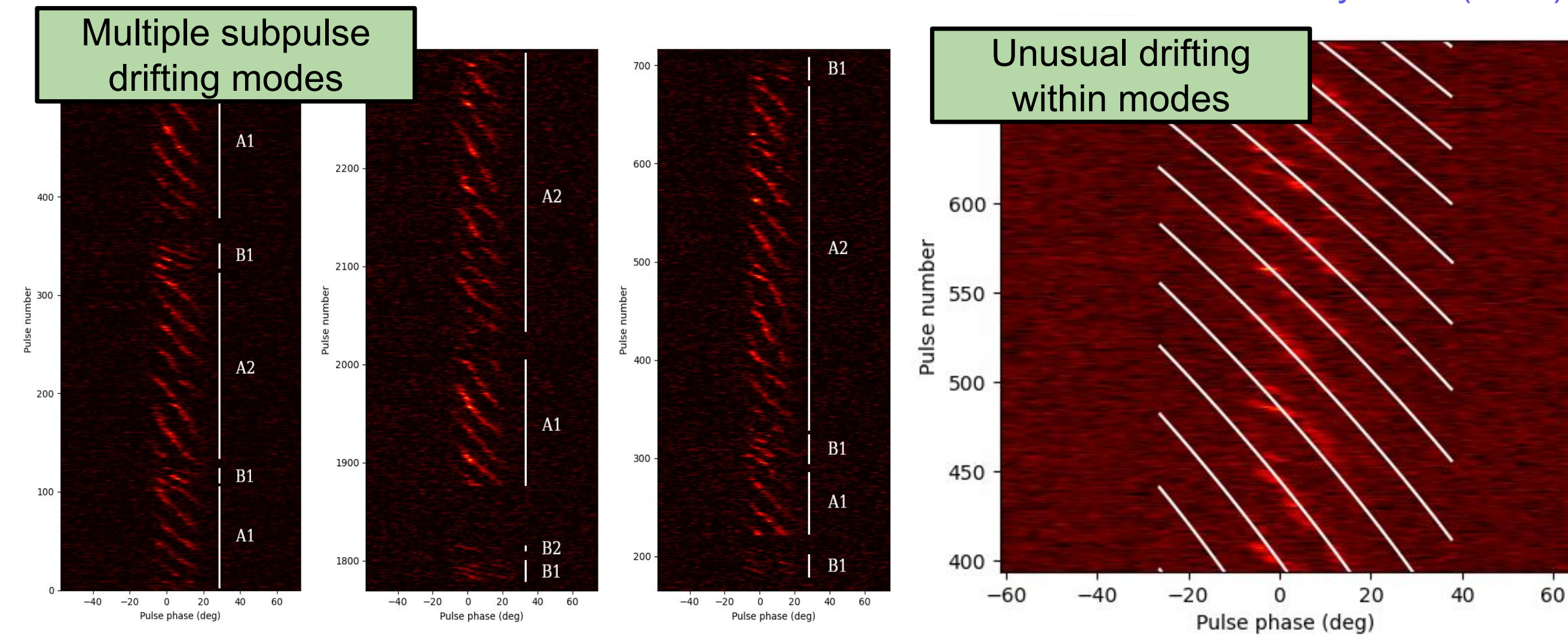
PULSARS & FAST TRANSIENTS

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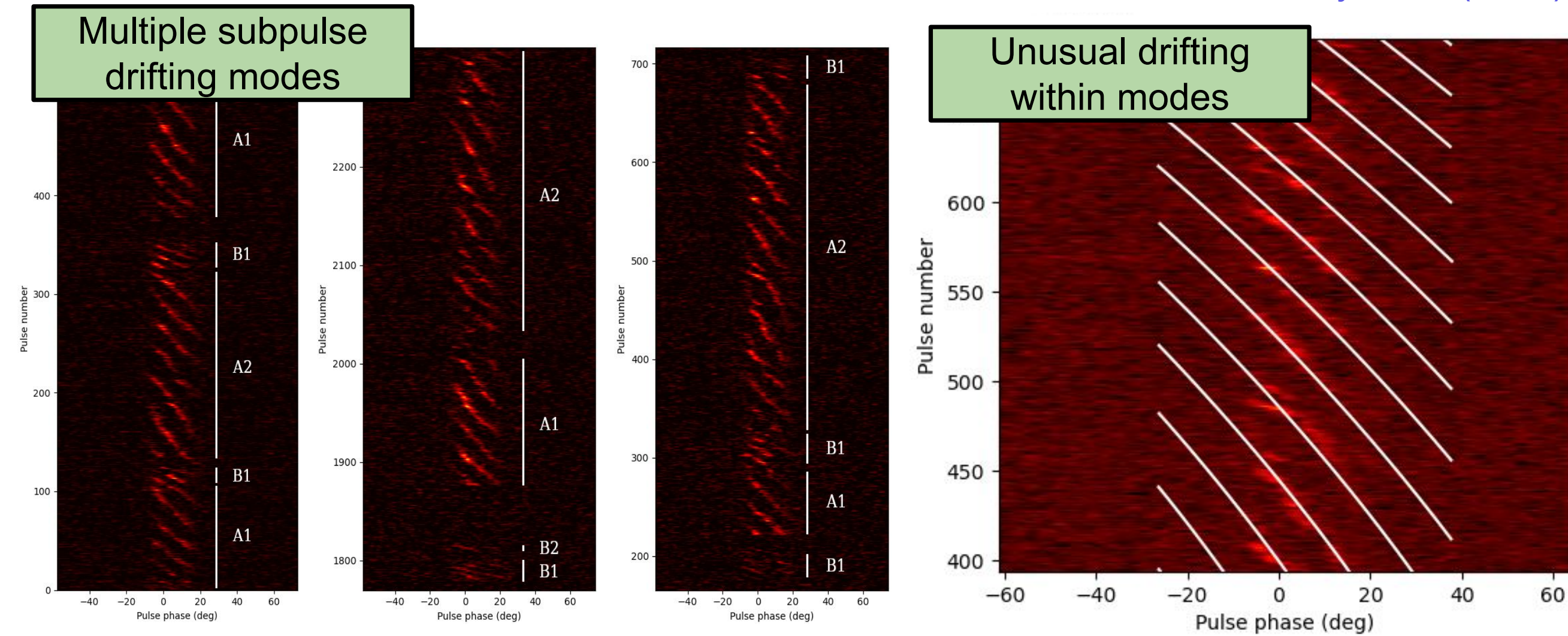
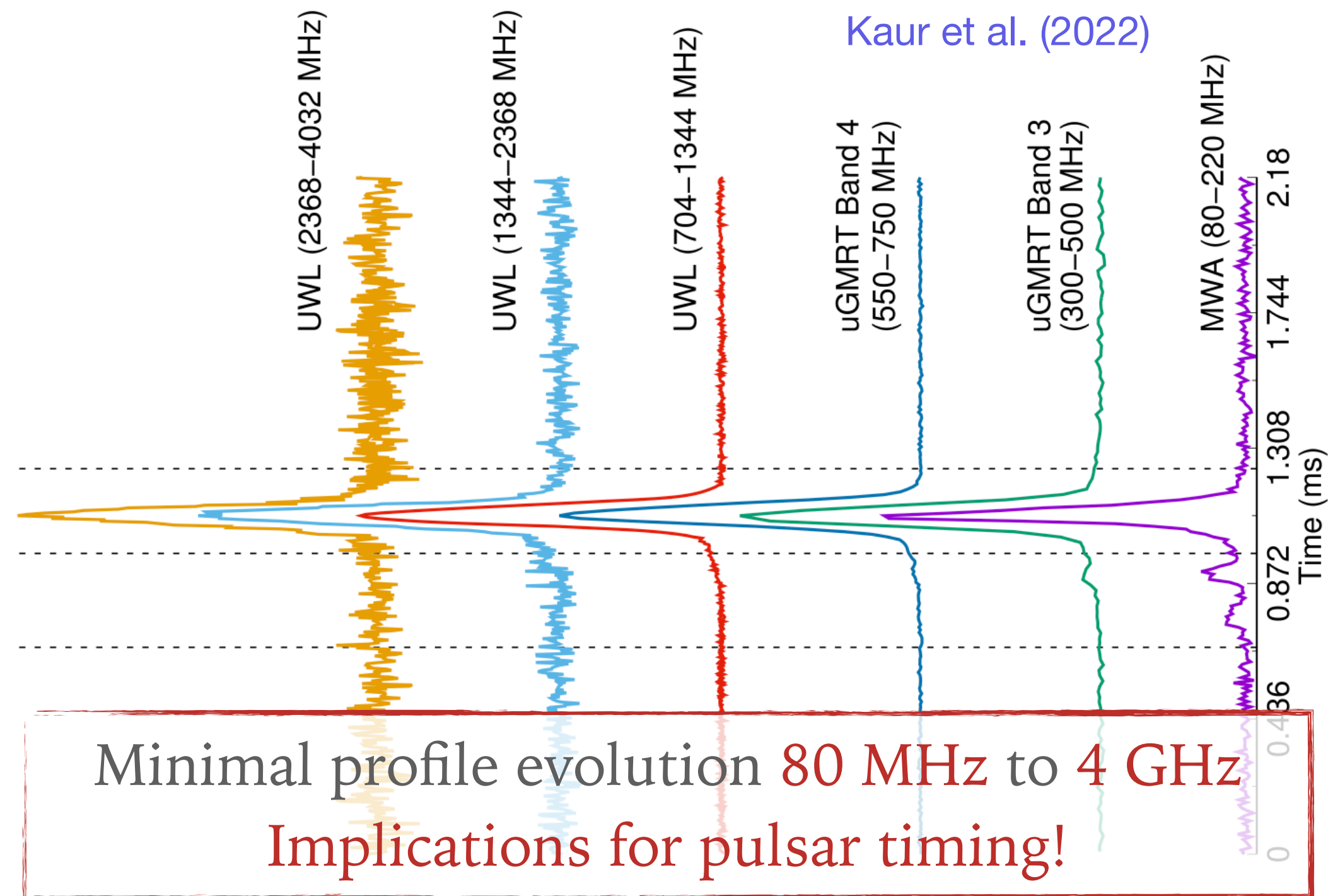
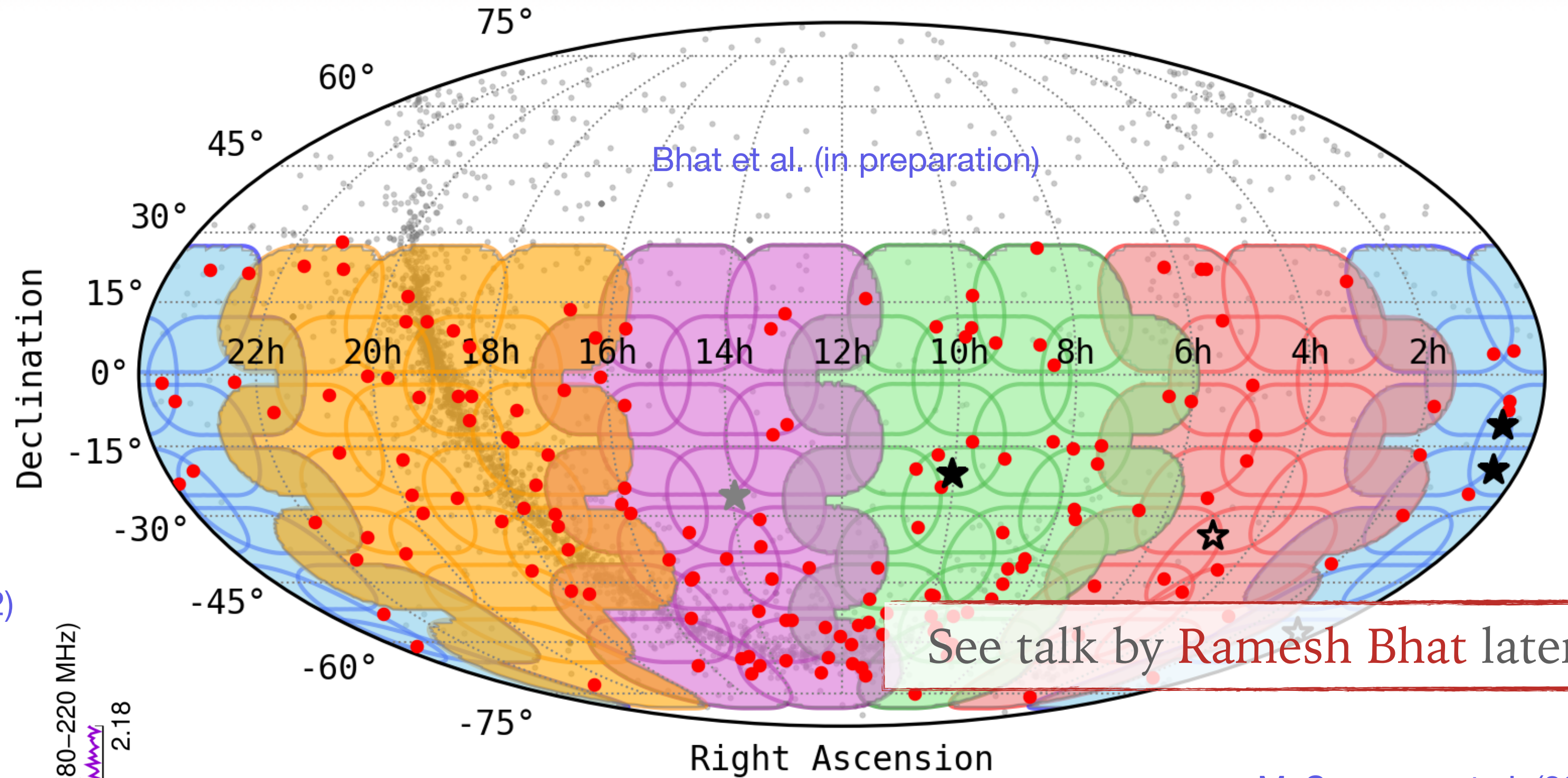
McSweeney et al. (2022)



PULSARS & FAST TRANSIENTS

► SMART Pulsar Survey:

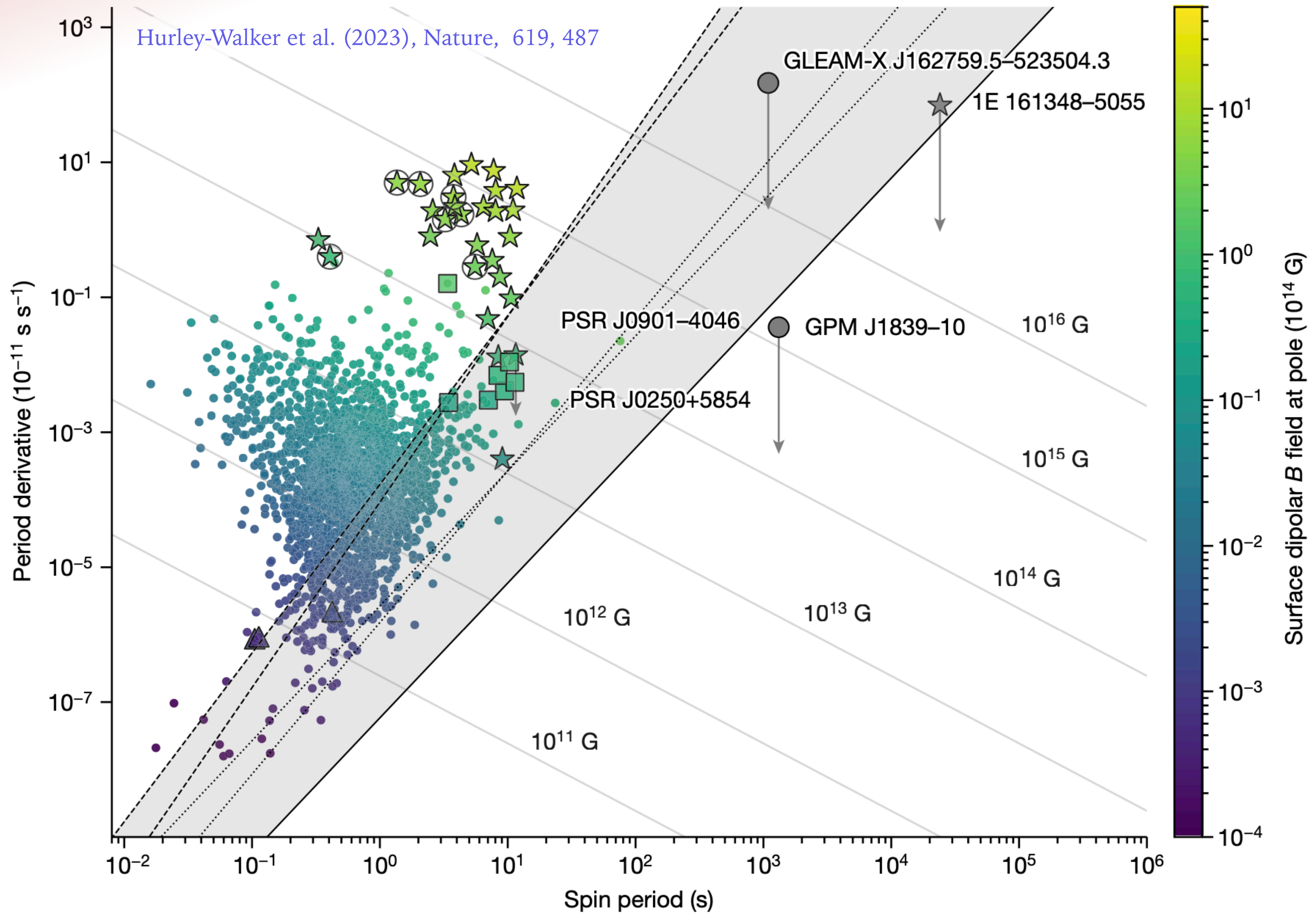
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- *Unique legacy value*



TRANSIENTS

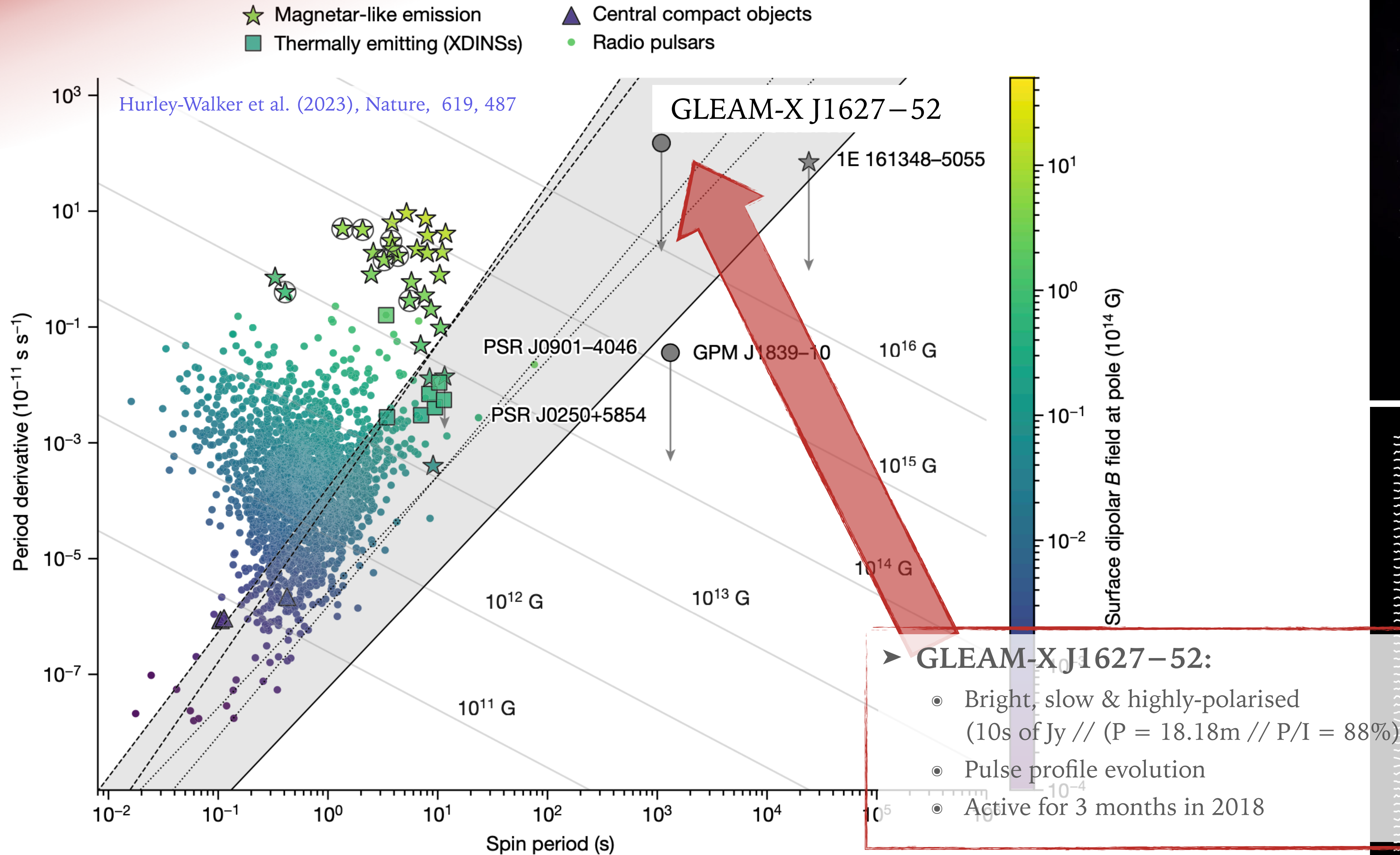
TRANSIENTS

- ★ Magnetar-like emission
- ▲ Central compact objects
- Thermally emitting (XDINSs)
- Radio pulsars

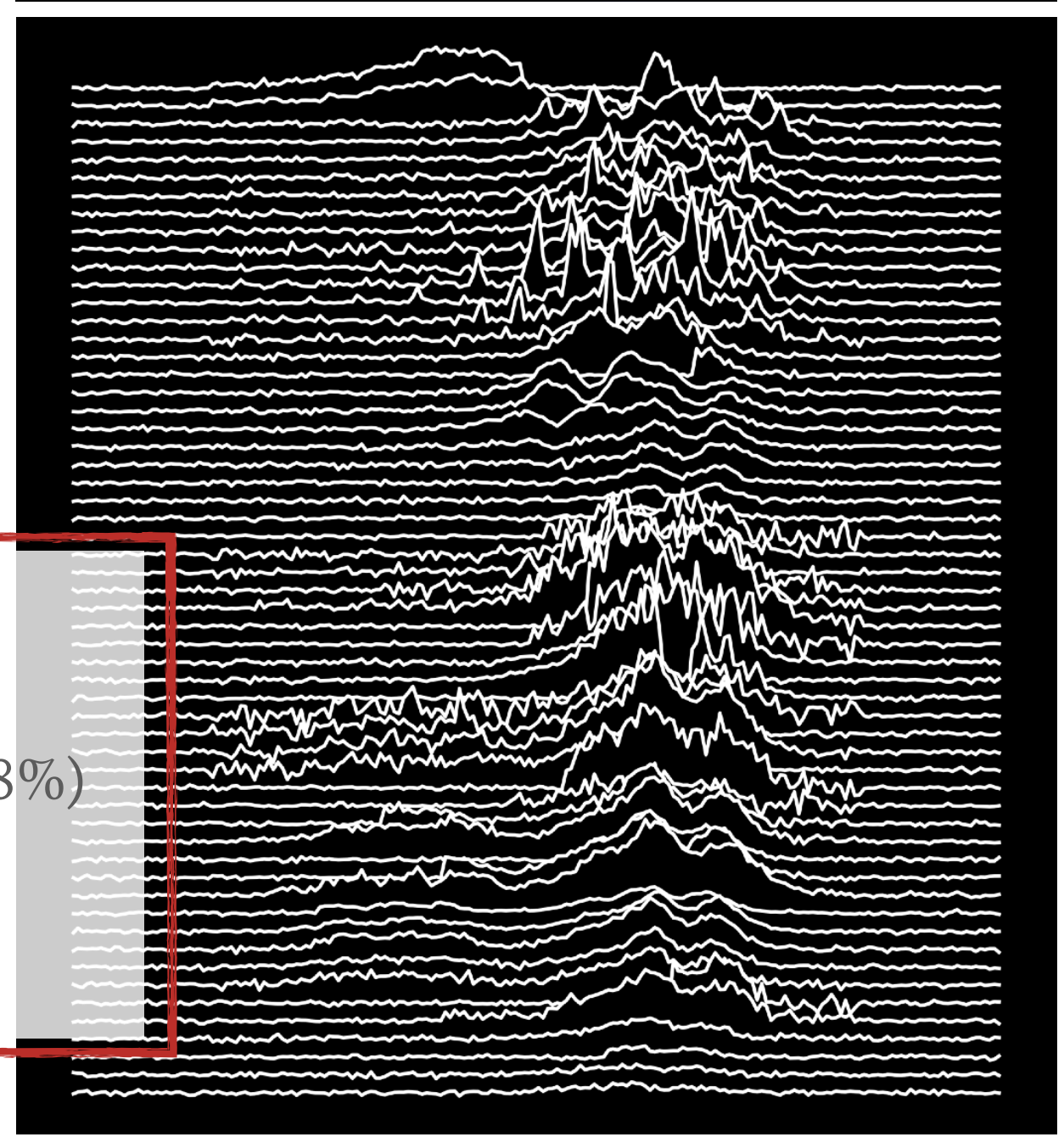
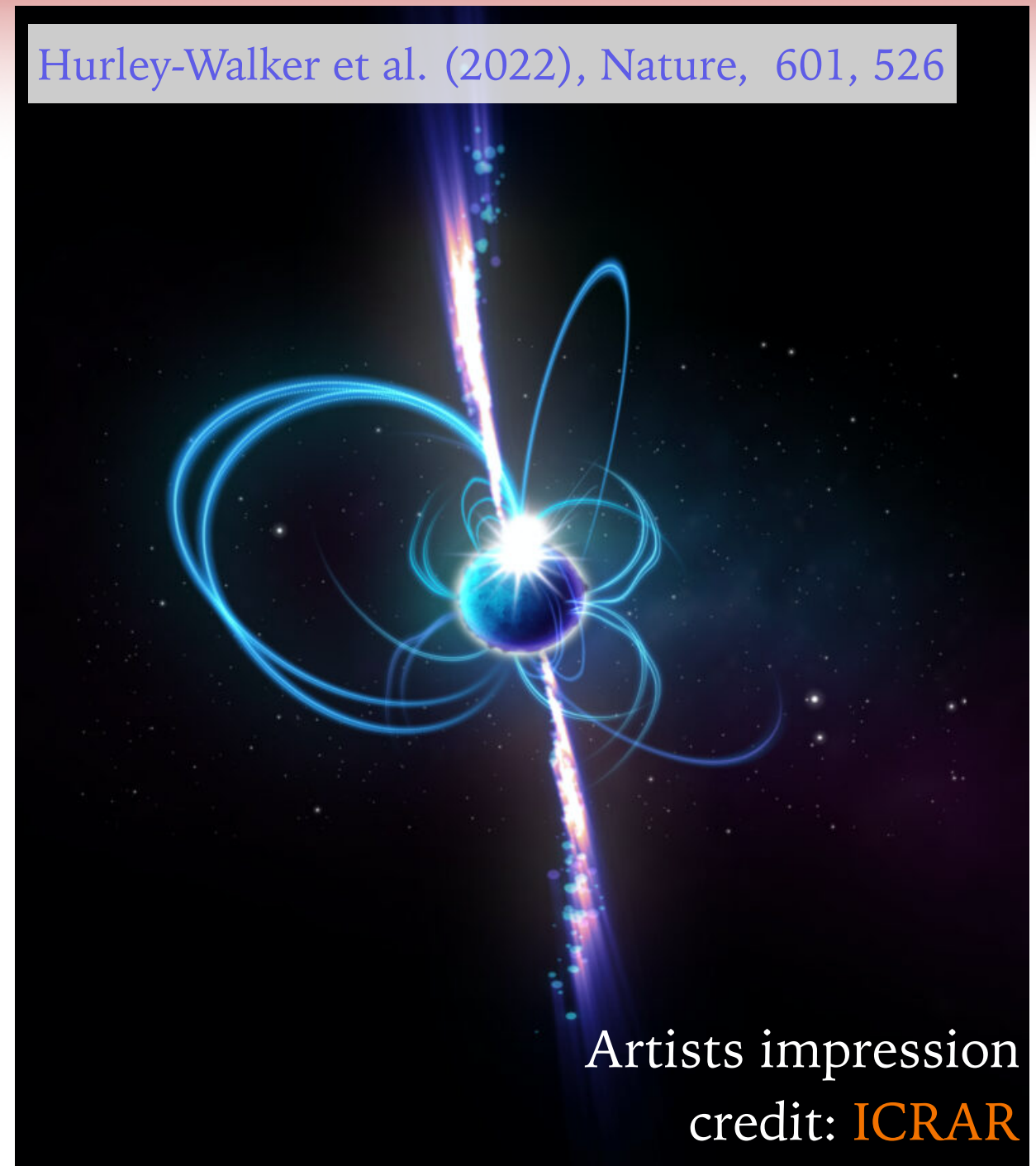


TRANSIENTS

Hurley-Walker et al. (2022), Nature, 601, 526

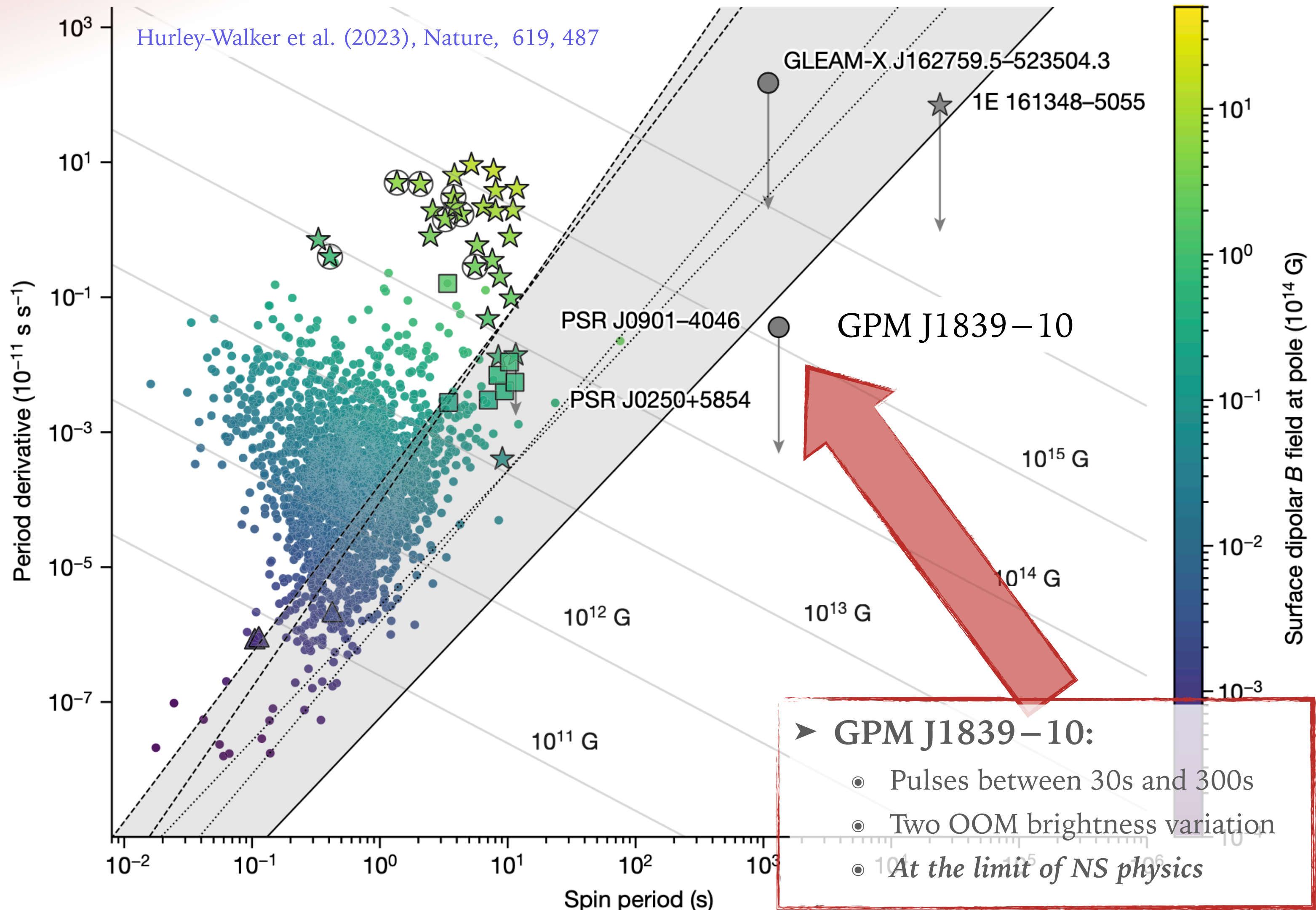


- **GLEAM-X J1627-52:**
- Bright, slow & highly-polarised (10s of Jy // ($P = 18.18\text{m}$ // $P/I = 88\%$))
- Pulse profile evolution
- Active for 3 months in 2018



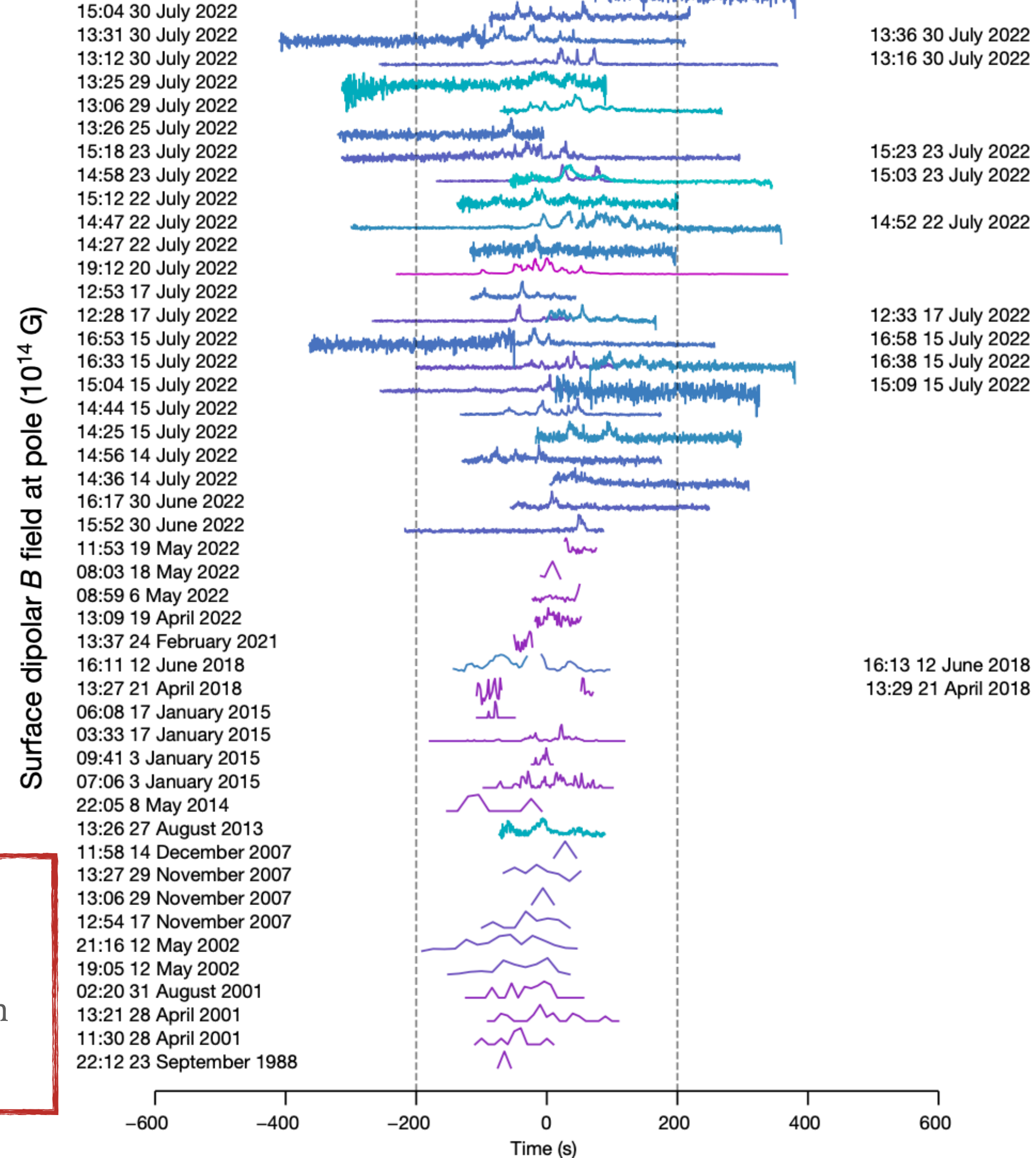
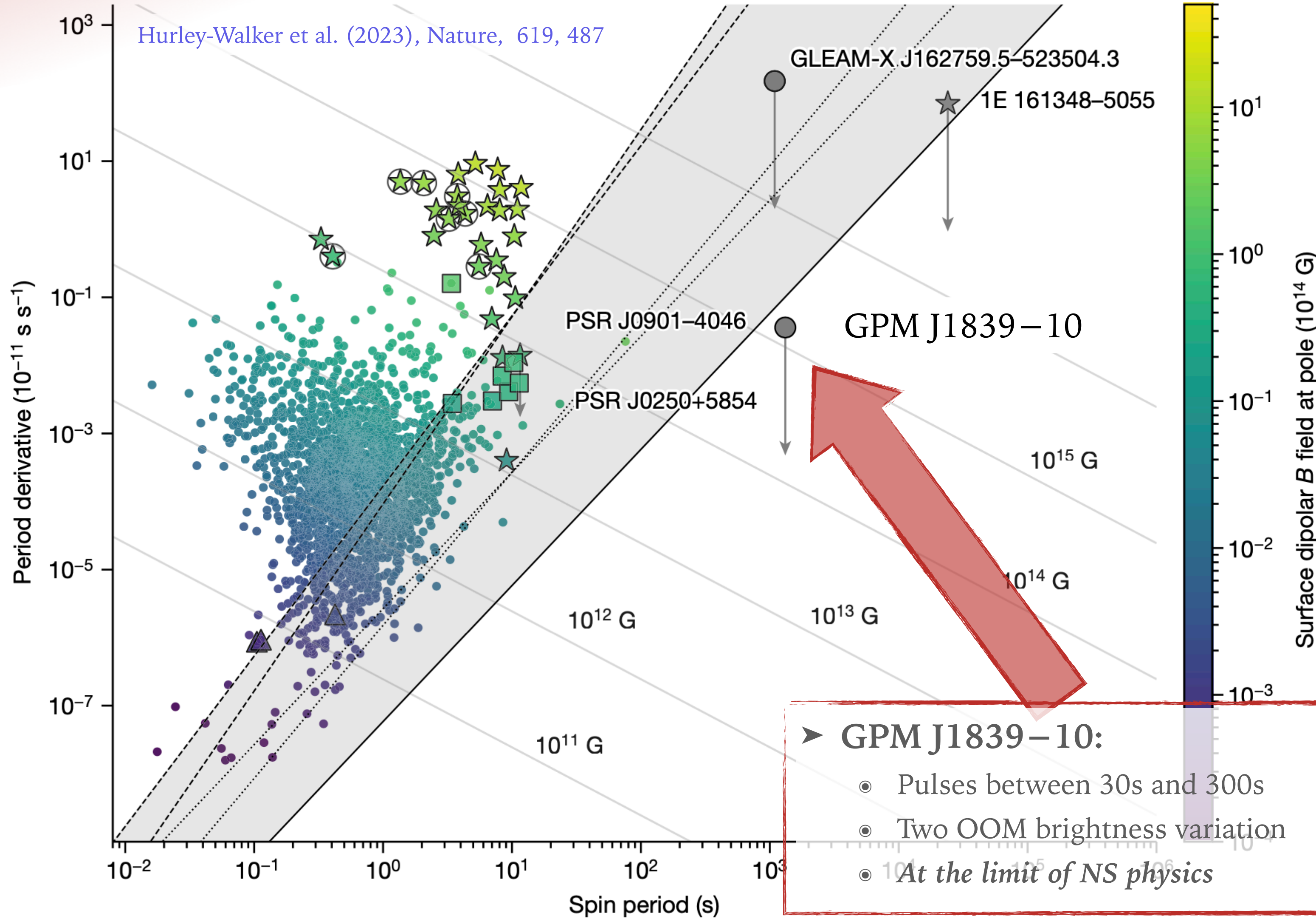
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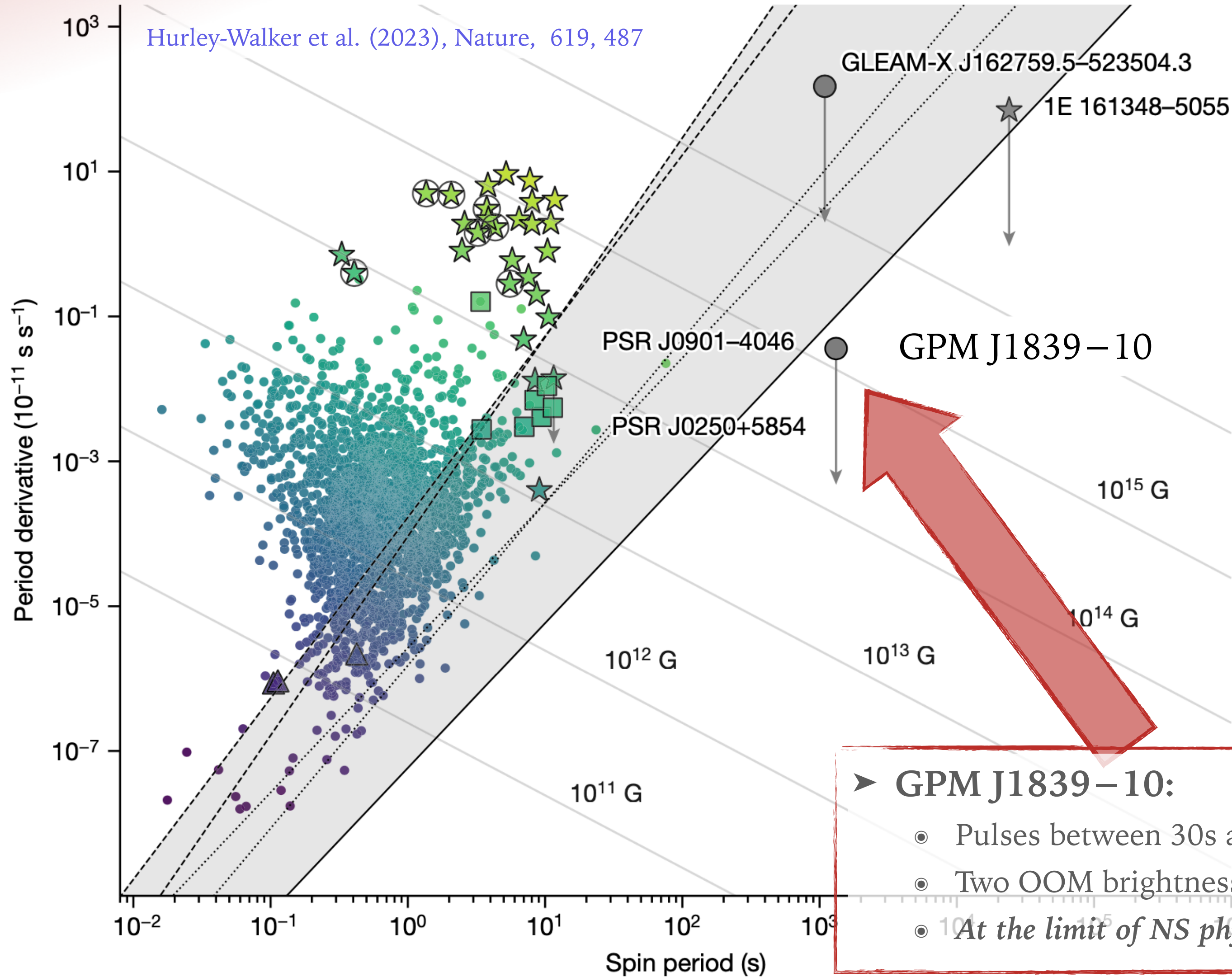
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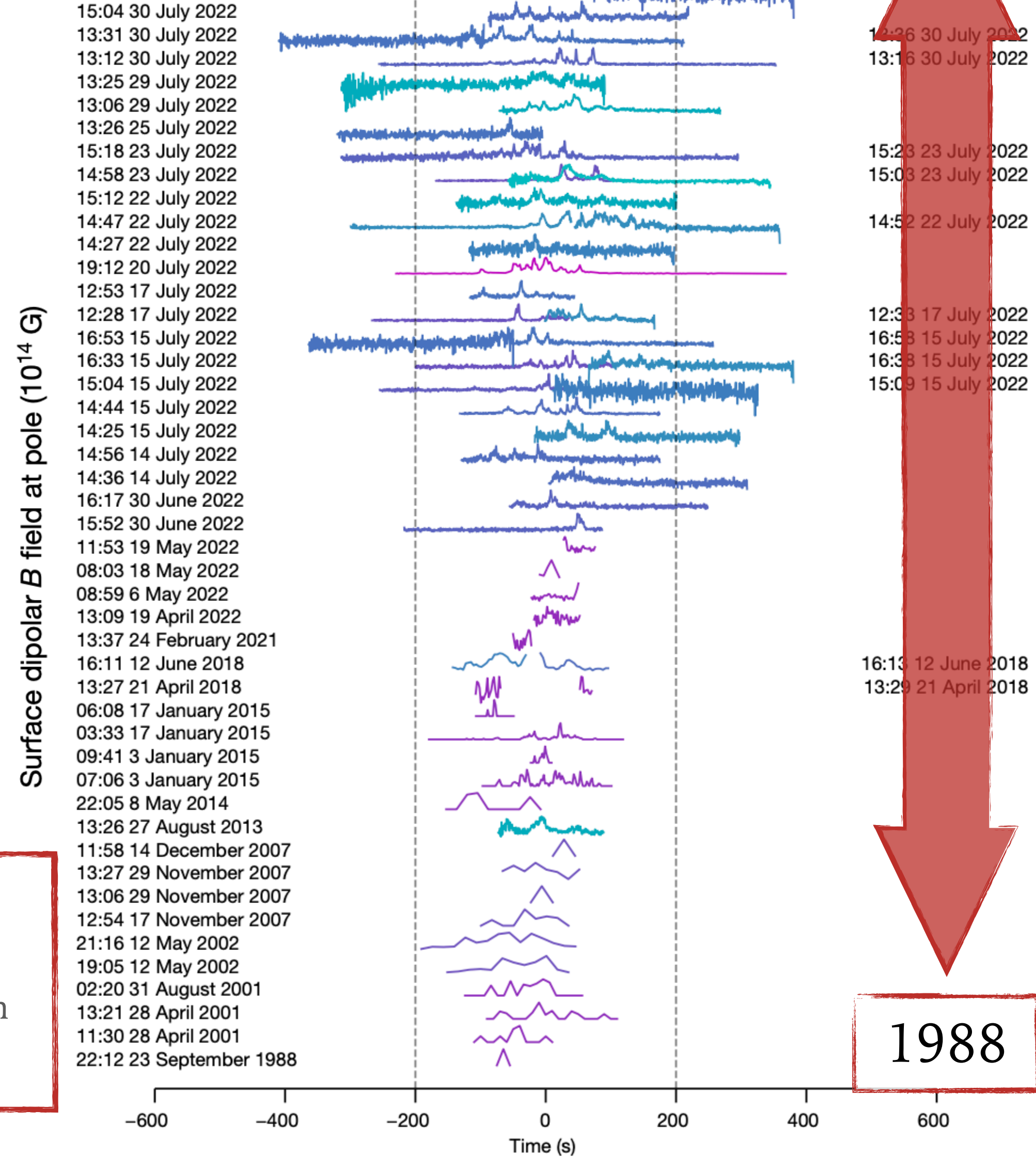
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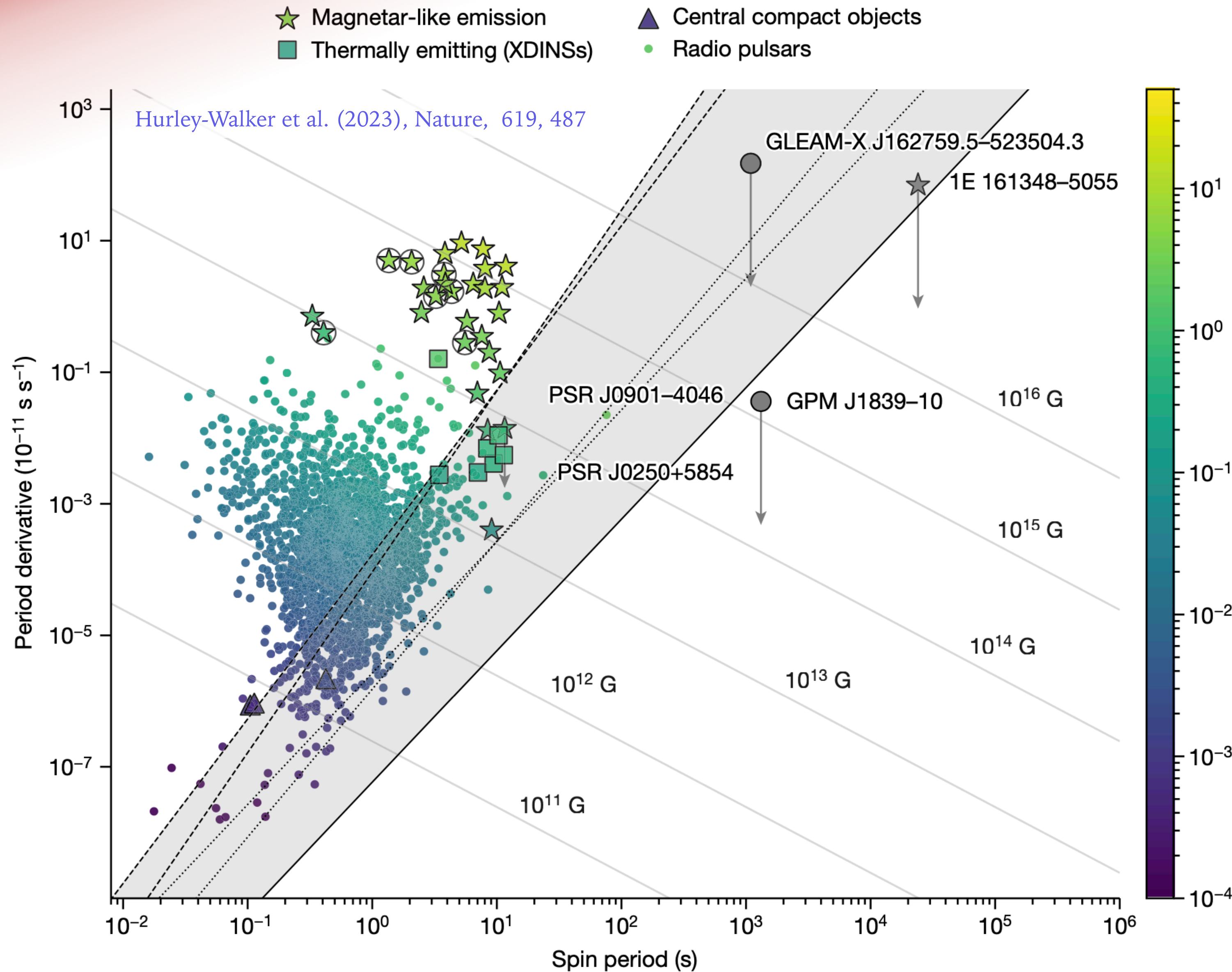


► **GPM J1839-10:**

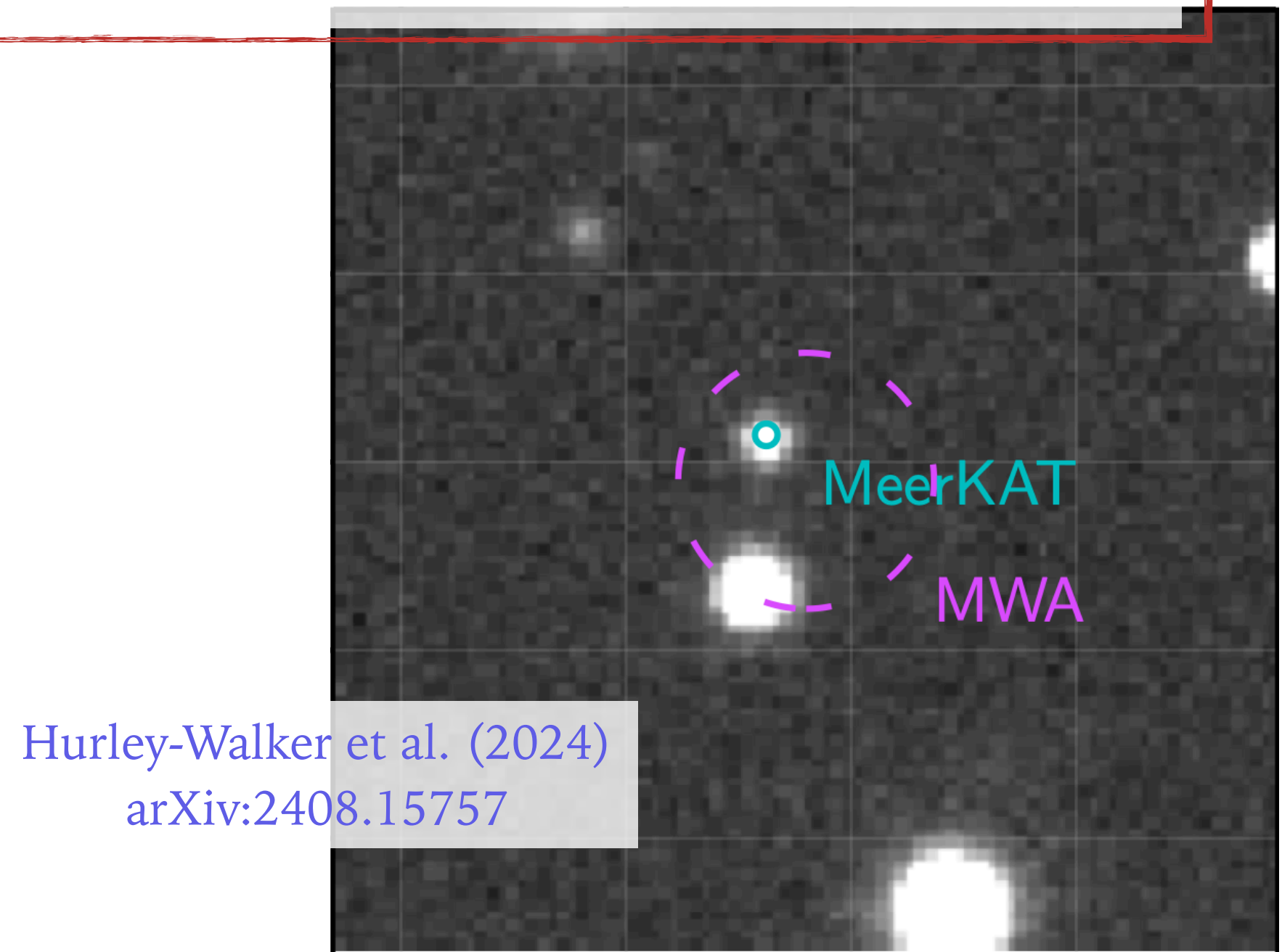
- Pulses between 30s and 300s
- Two OOM brightness variation
- *At the limit of NS physics*



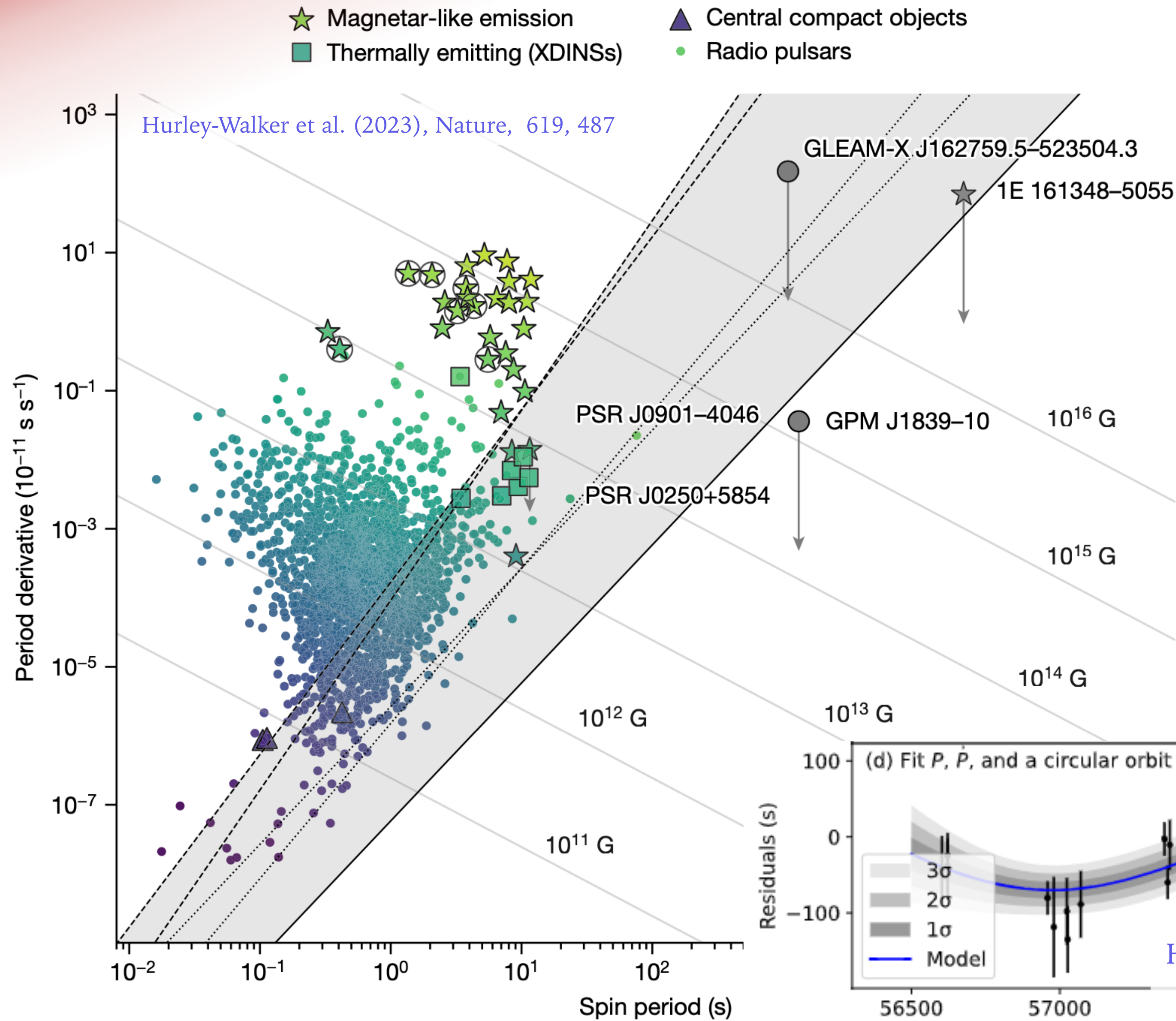
TRANSIENTS



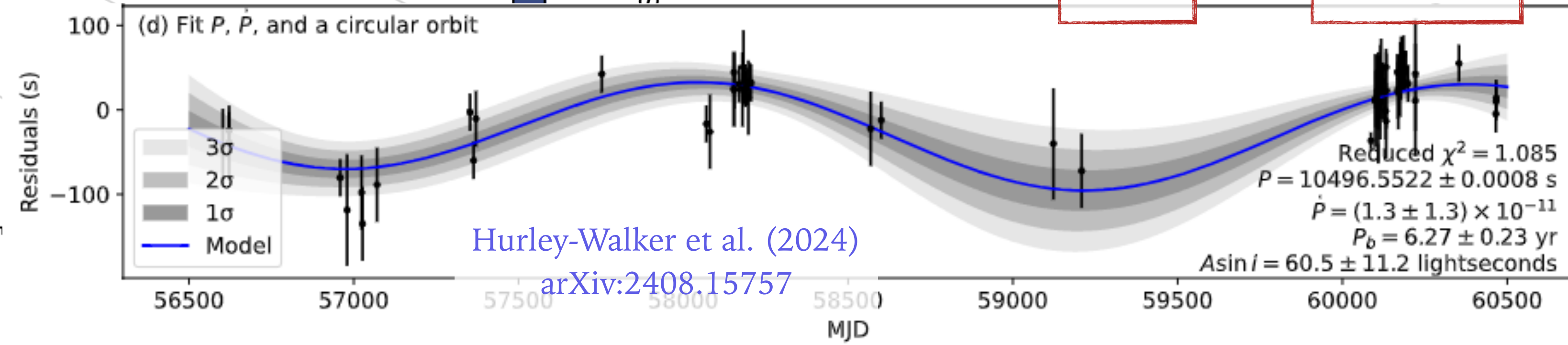
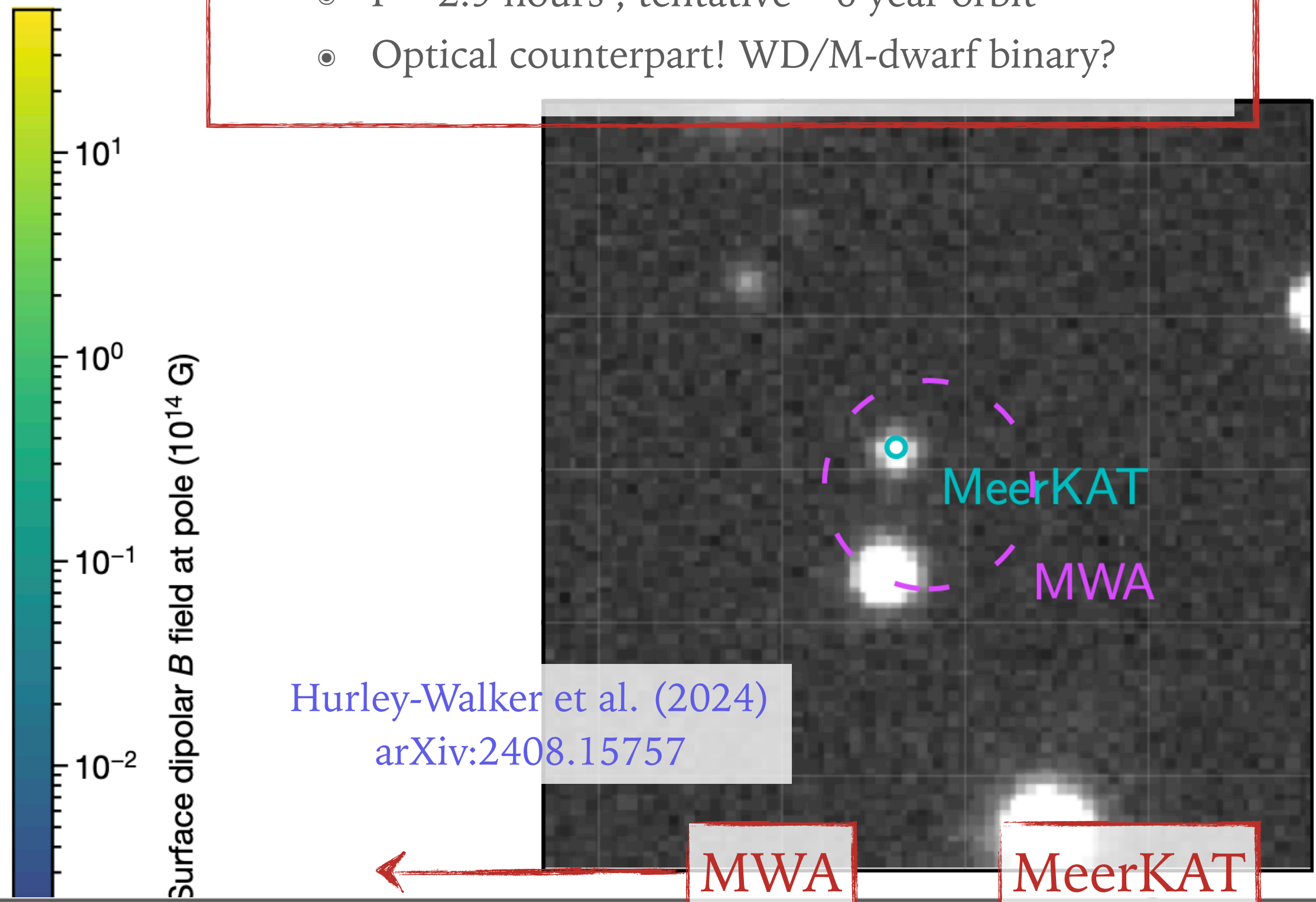
- **GLEAMX J0704-37:**
- Detections spanning 11+ years
 - $P \sim 2.9$ hours ; tentative ~ 6 year orbit
 - Optical counterpart! WD/M-dwarf binary?



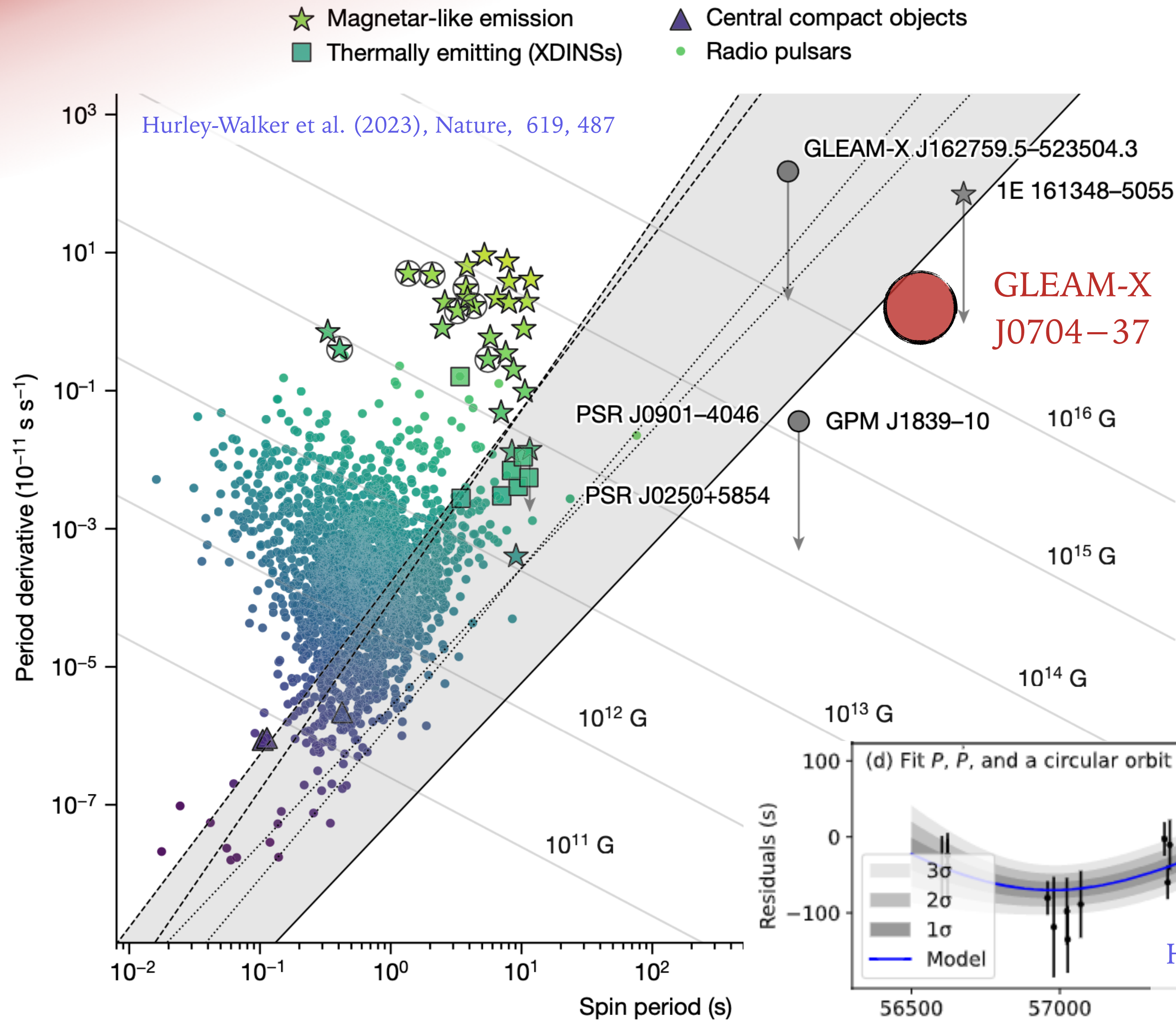
TRANSIENTS



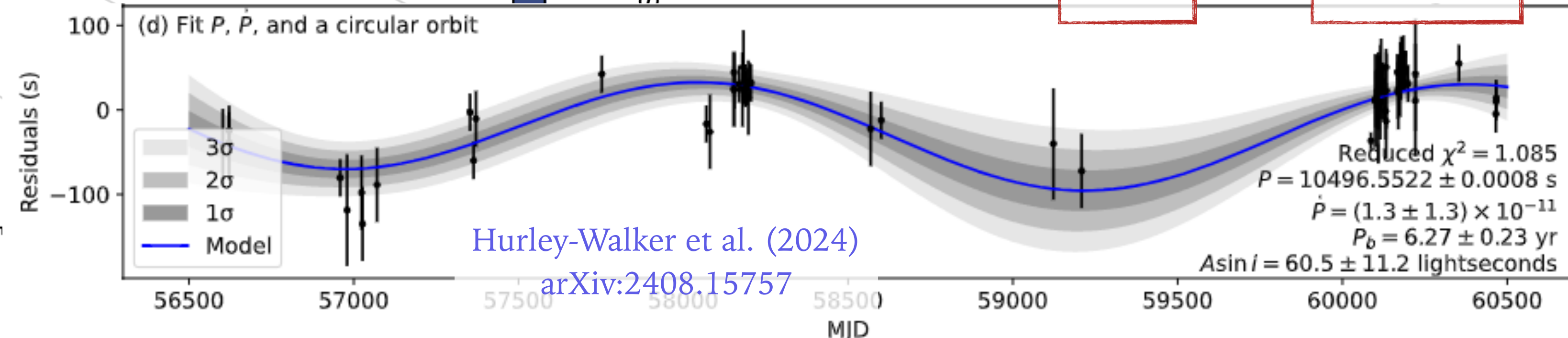
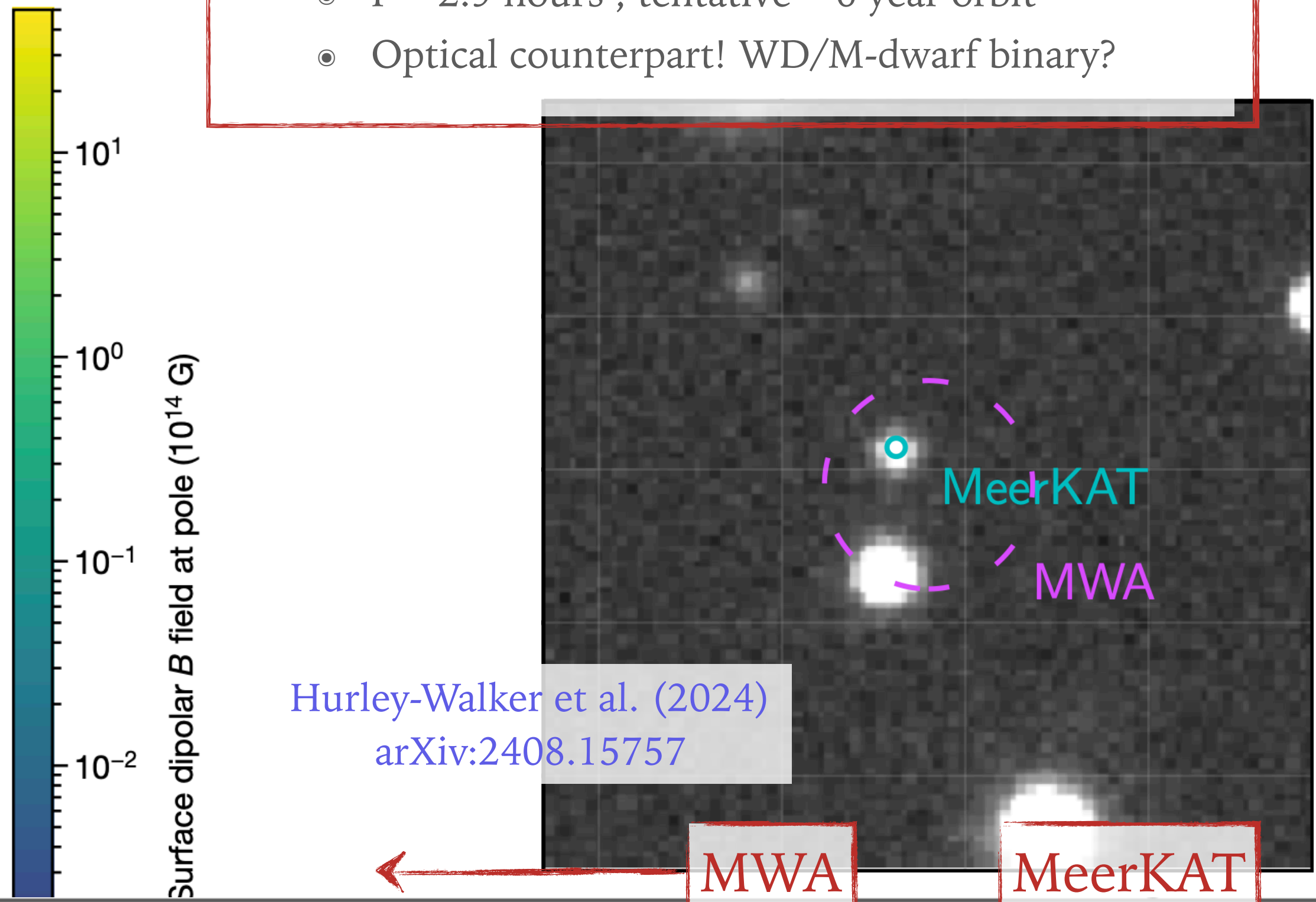
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TRANSIENTS



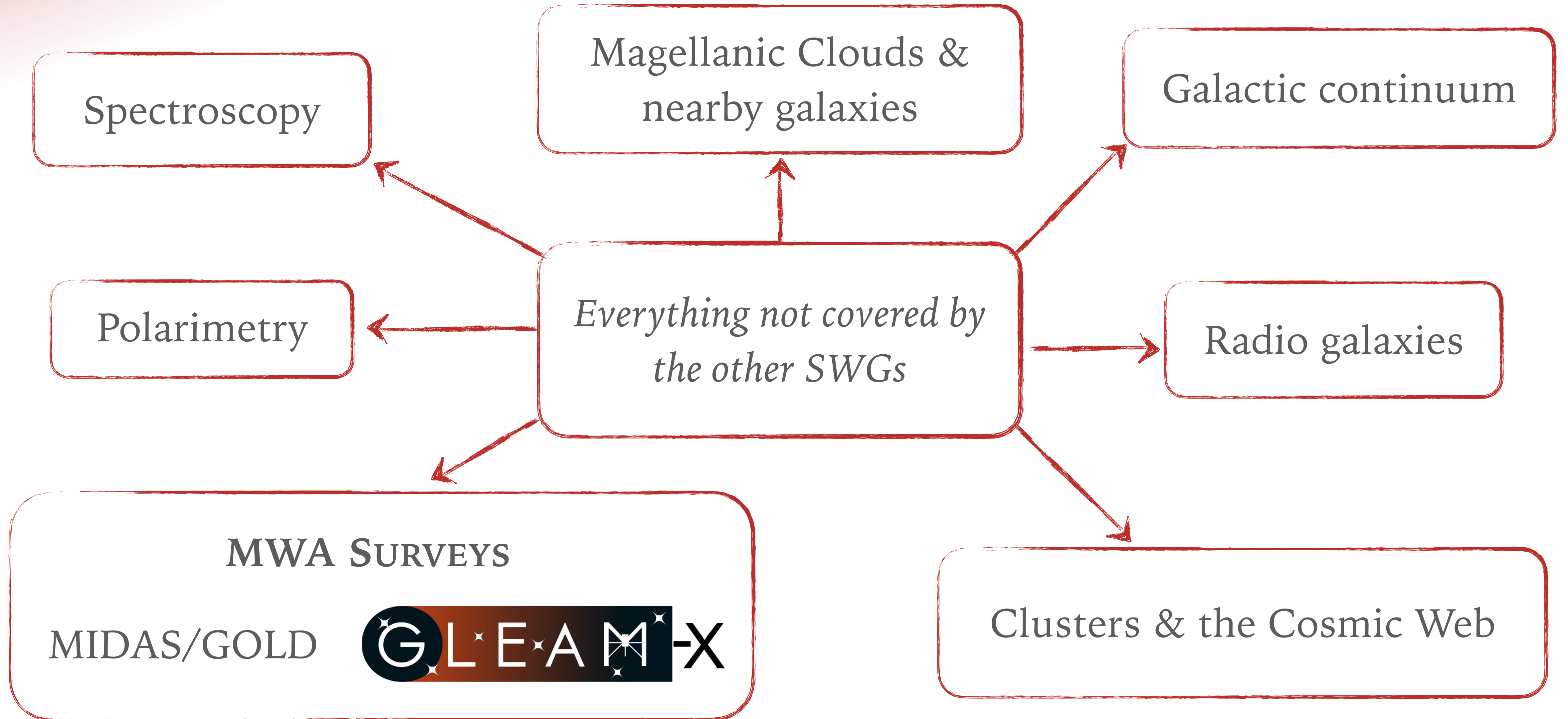
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GALACTIC AND EXTRAGALACTIC

*Everything not covered by
the other SWGs*

GALACTIC AND EXTRAGALACTIC



GALACTIC CONTINUUM

GALACTIC CONTINUUM

► Themes:

- ◉ Diffuse Galactic emission
- ◉ Supernovae
- ◉ HII regions

GALACTIC CONTINUUM

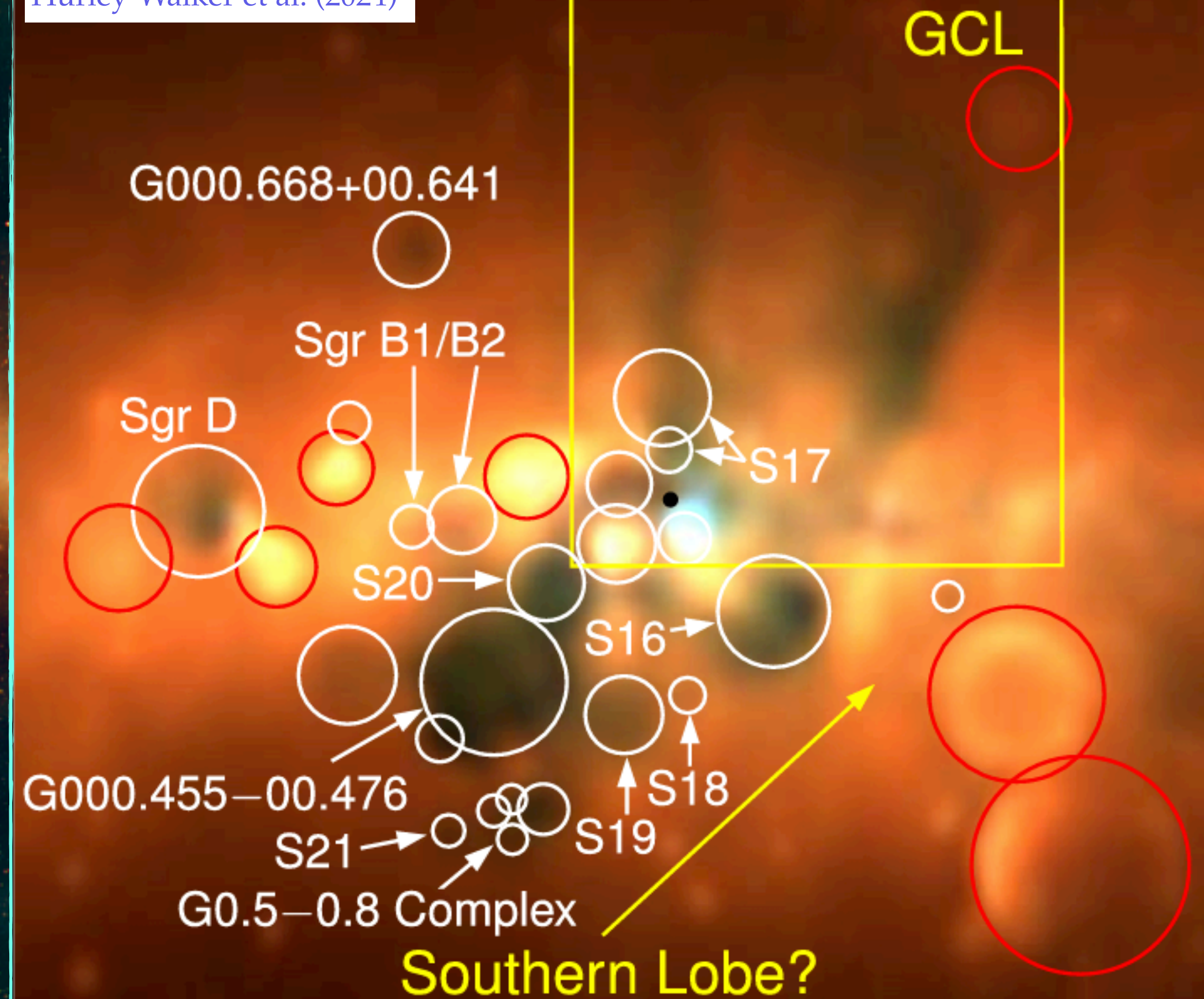
► Themes:

- ◉ Diffuse Galactic emission
- ◉ Supernovae
- ◉ HII regions

► Galactic centre lobe:

- ◉ Shadow against Galactic continuum
- ◉ Low-frequency turnover: thermal absorption
- ◉ Emissivity arguments: distance $\sim 2\text{kpc}$

Hurley-Walker et al. (2024)



GALACTIC CONTINUUM

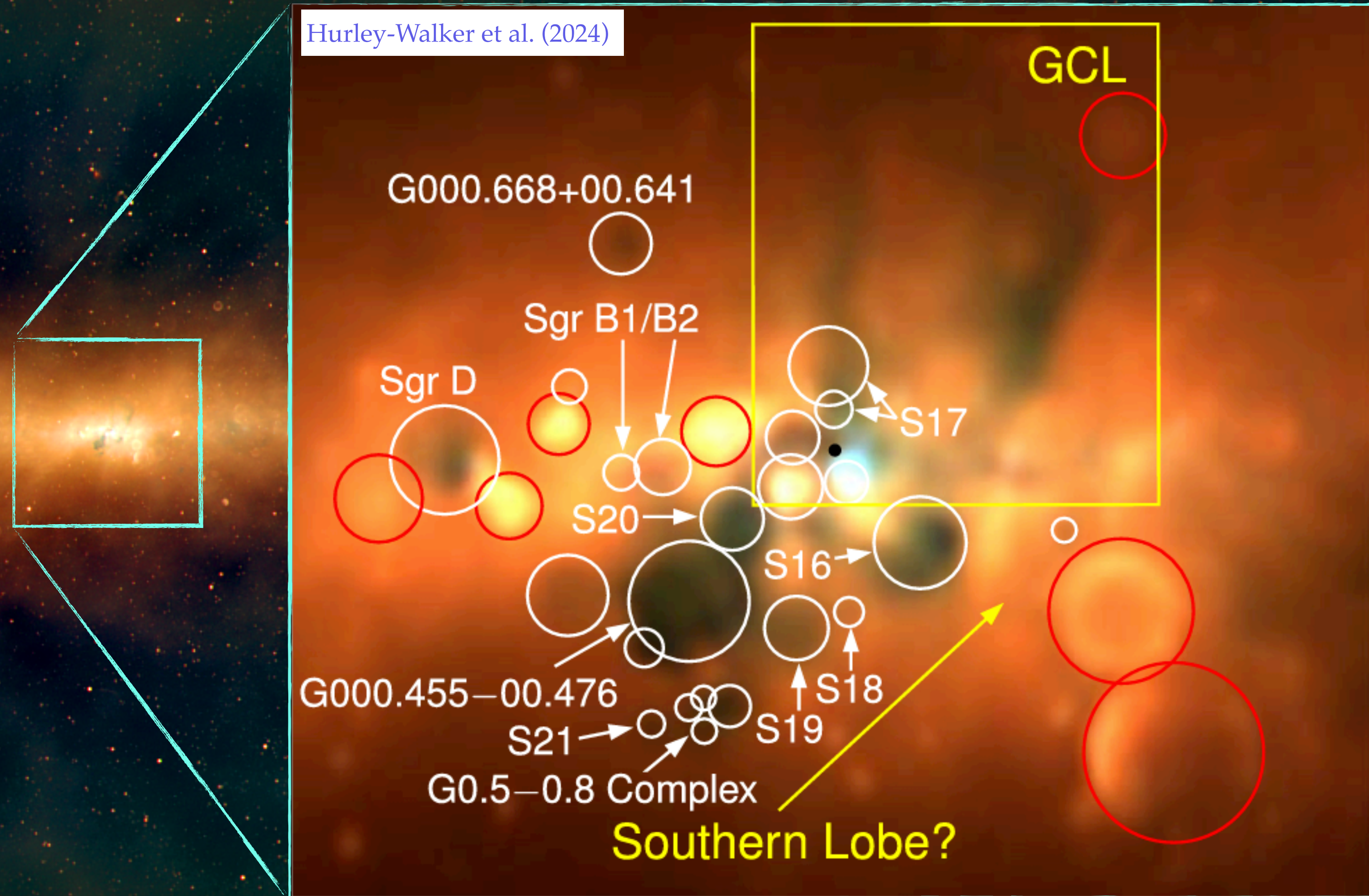
► Themes:

- Diffuse Galactic emission
- Supernovae
- HII regions

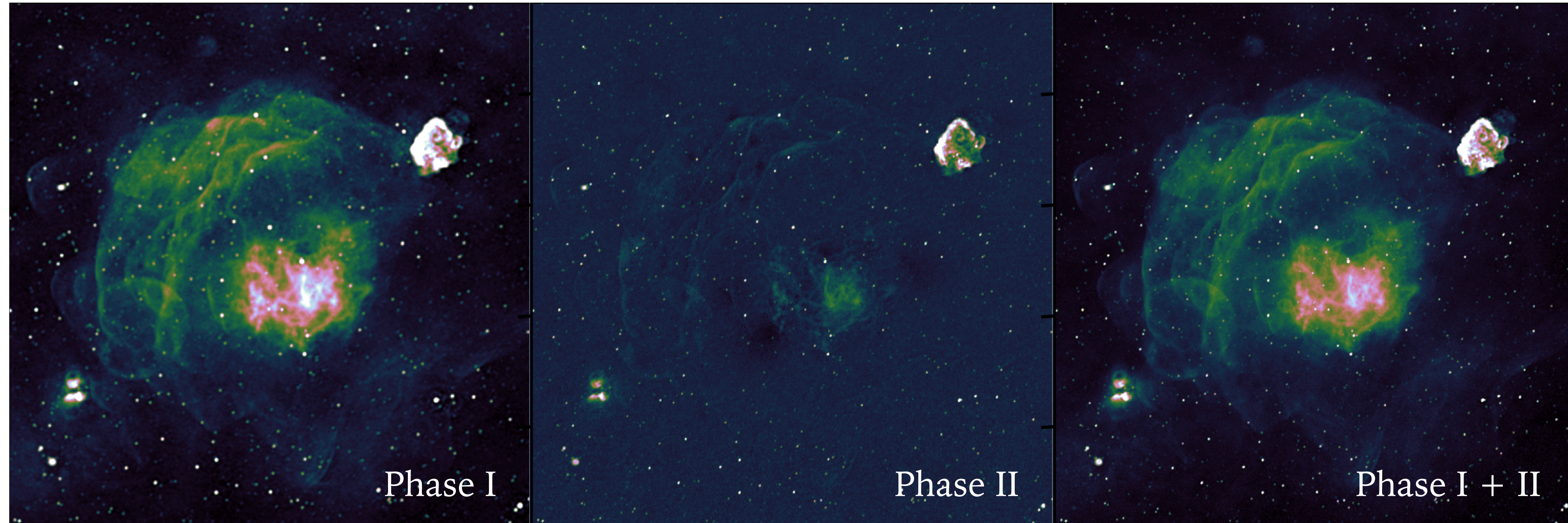
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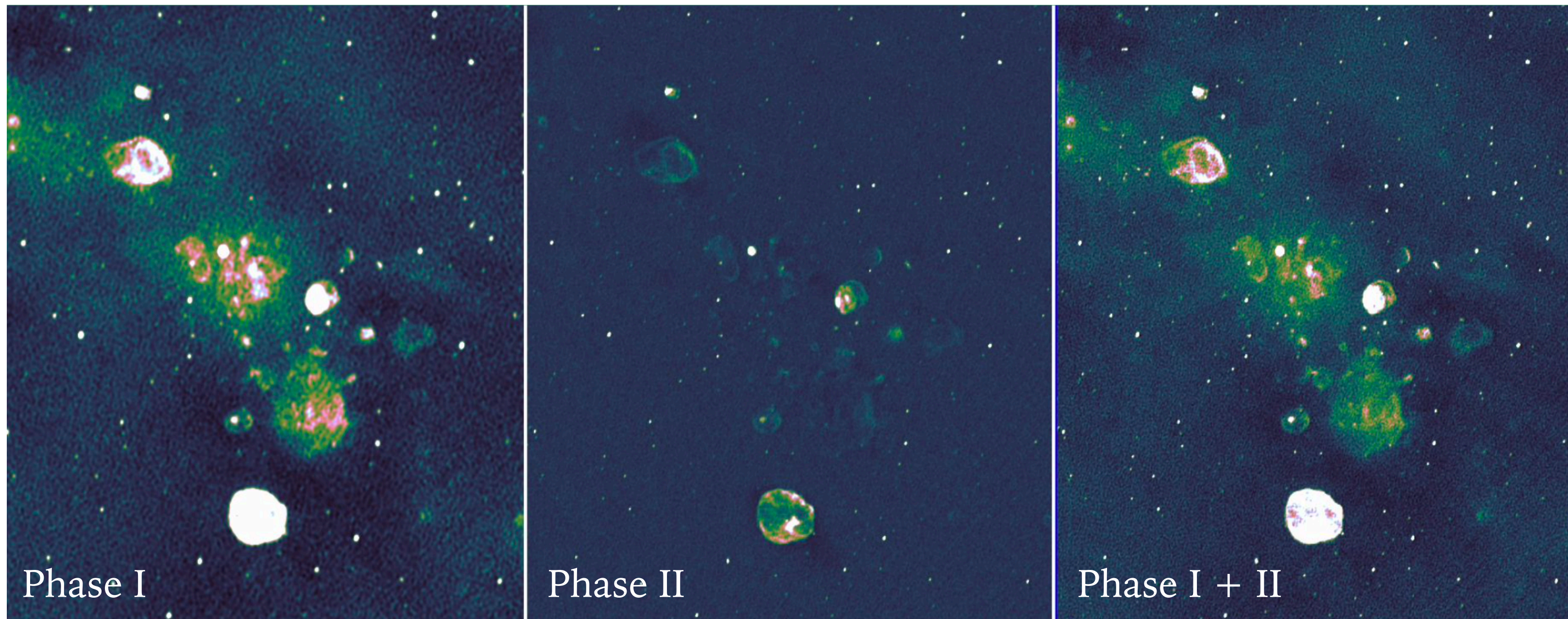
Phase I: we can do better now ...



GALACTIC CONTINUUM



Vela; Hurley-Walker et al. (2022)



Galactic Plane; Mantovanini et al. (2024, in prep.)

GALACTIC CONTINUUM

Colour => spectrum

Blue: absorption

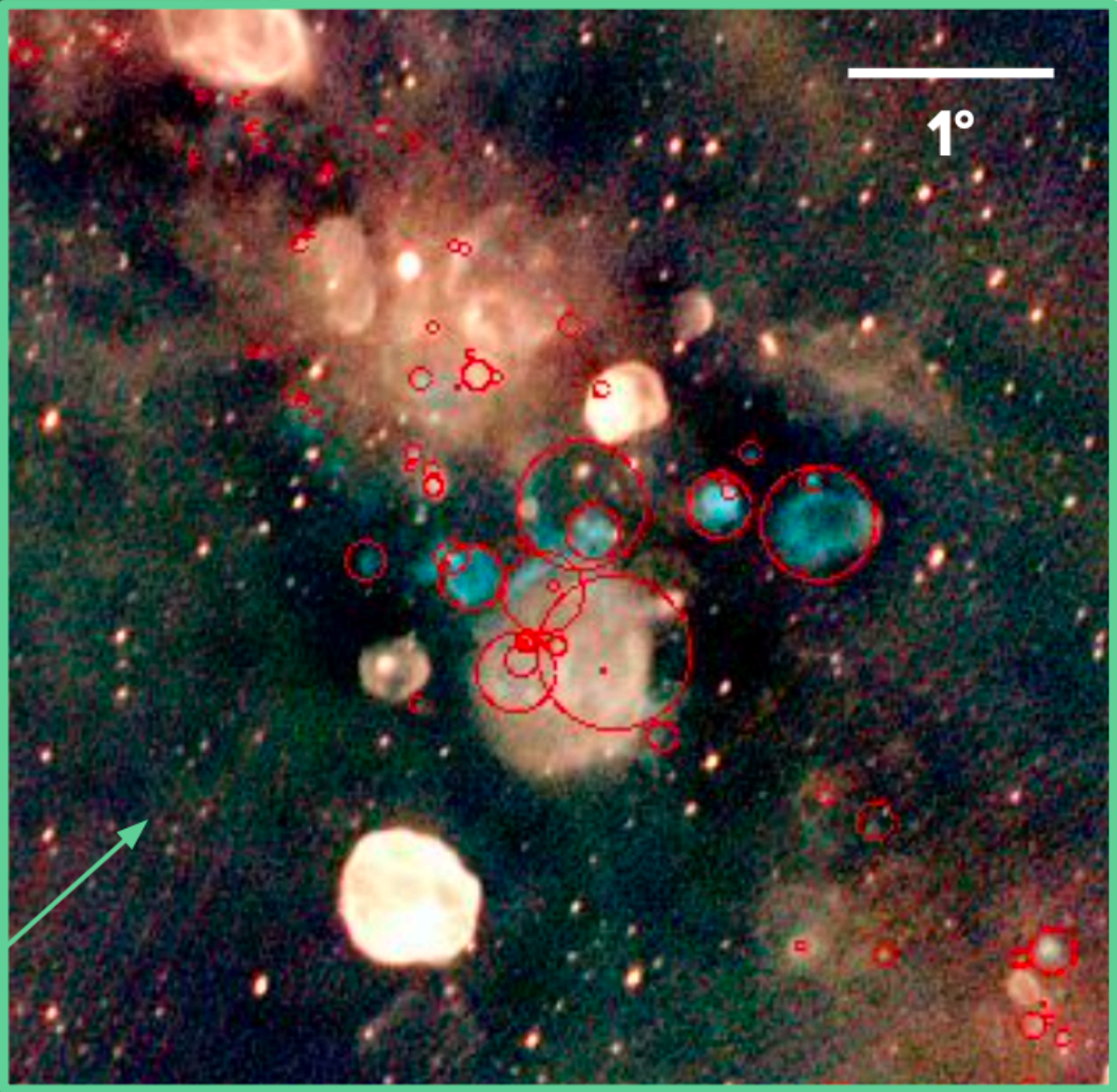
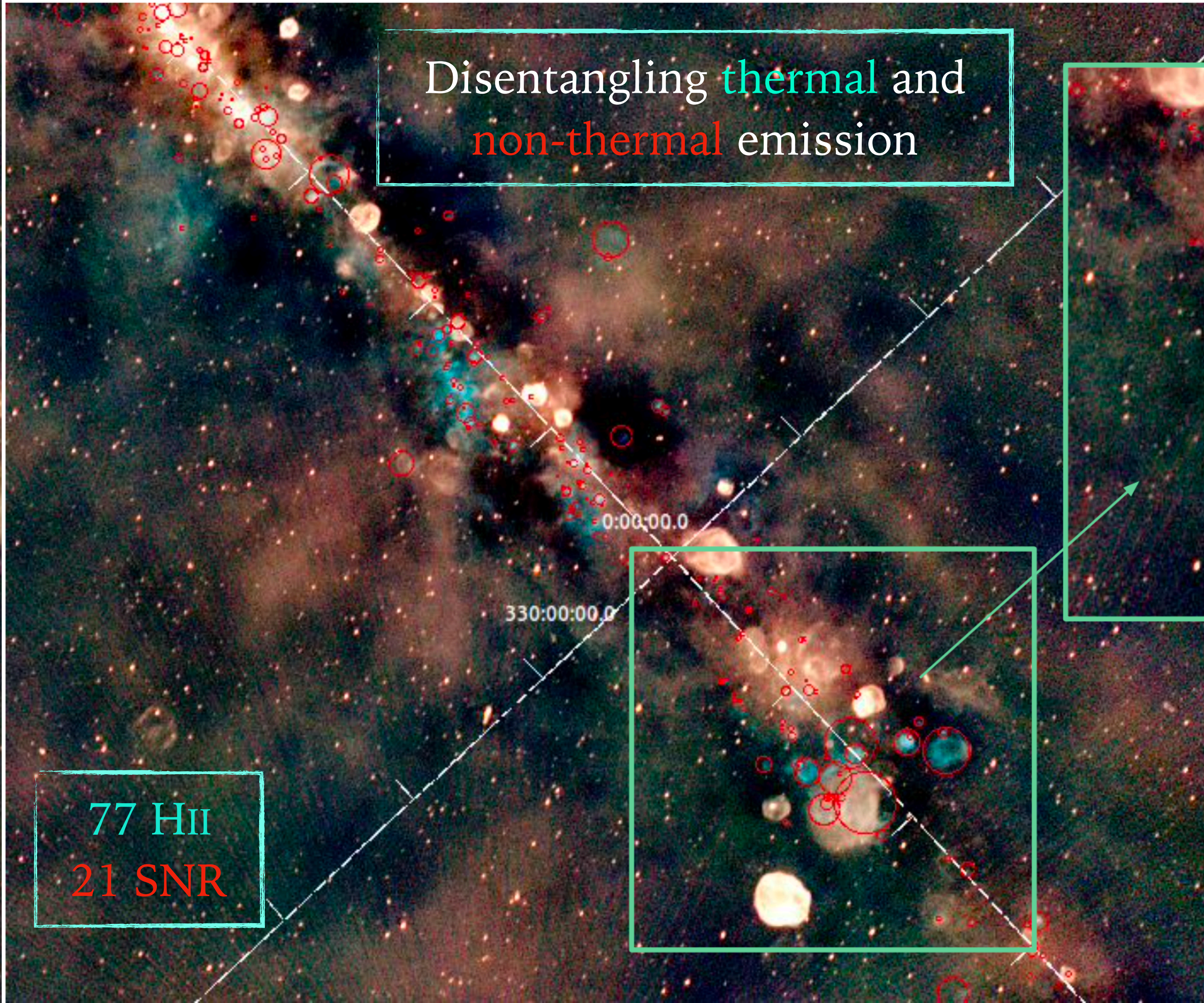
Red: steep



Silvia Mantovanini
PhD student @
Curtin University

GALACTIC CONTINUUM

Colour => spectrum
Blue: absorption
Red: steep



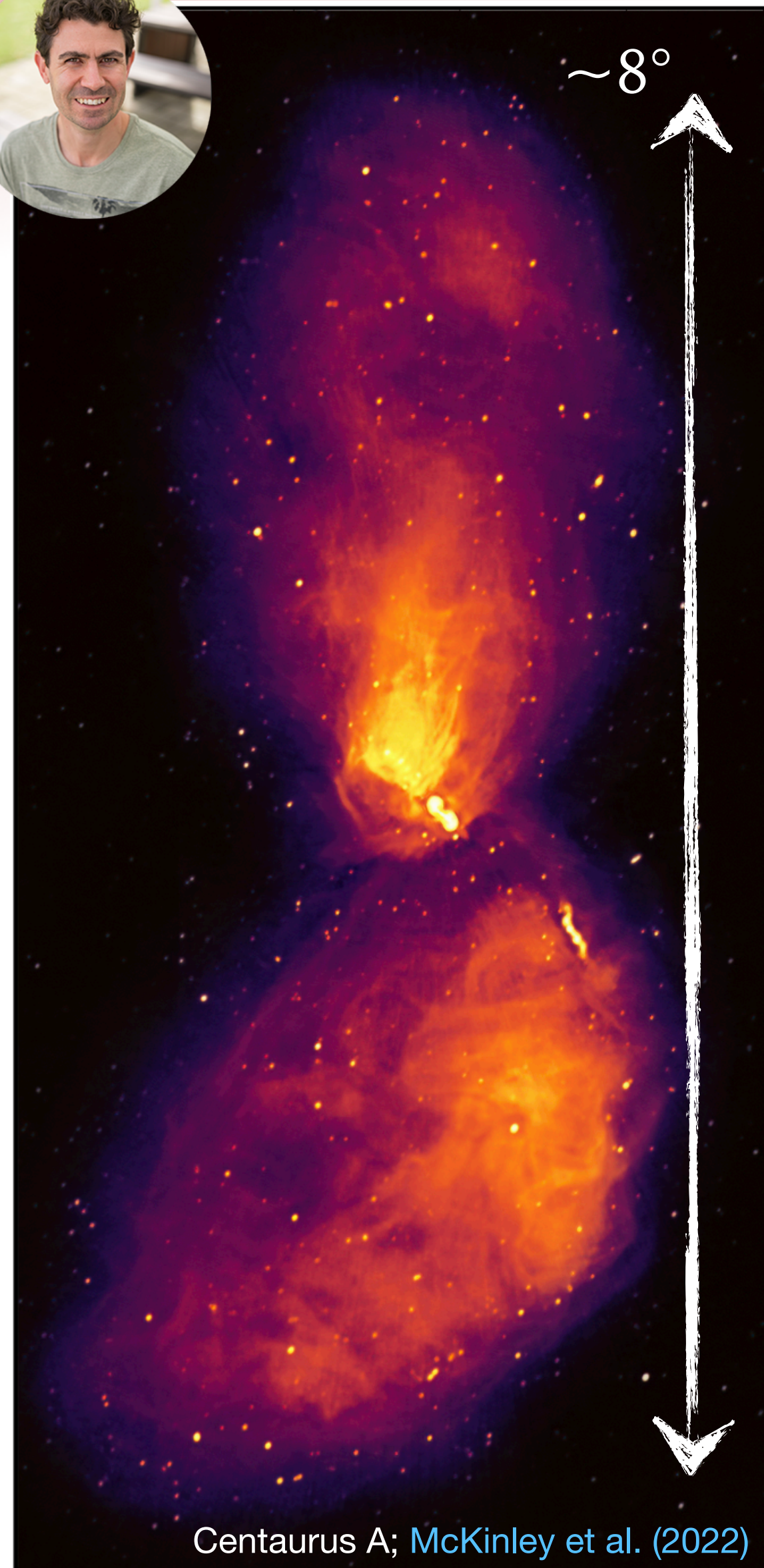
104 – 134 MHz
139 – 170 MHz
170 – 200 MHz



Silvia Mantovanini
PhD student @
Curtin University

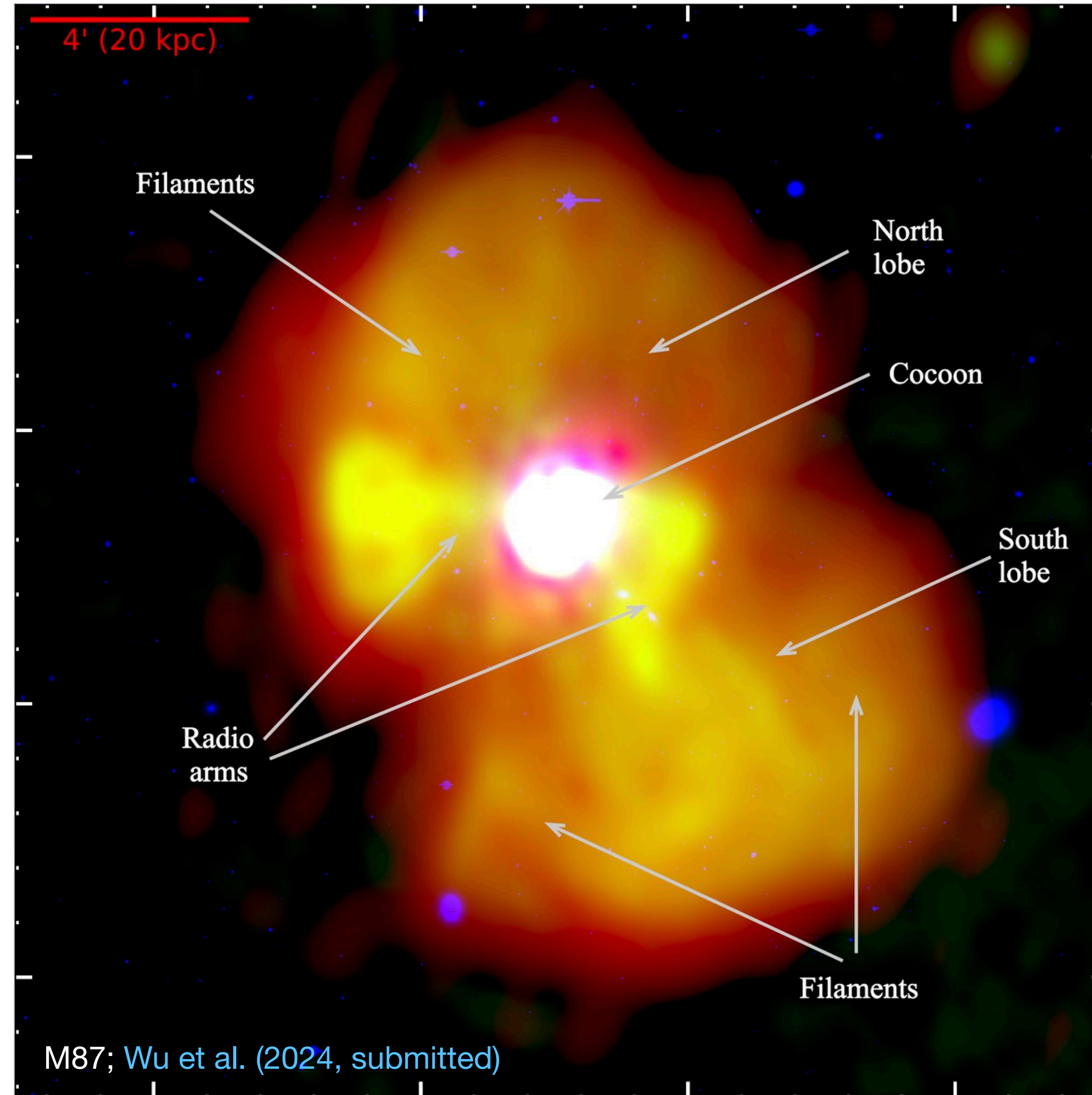
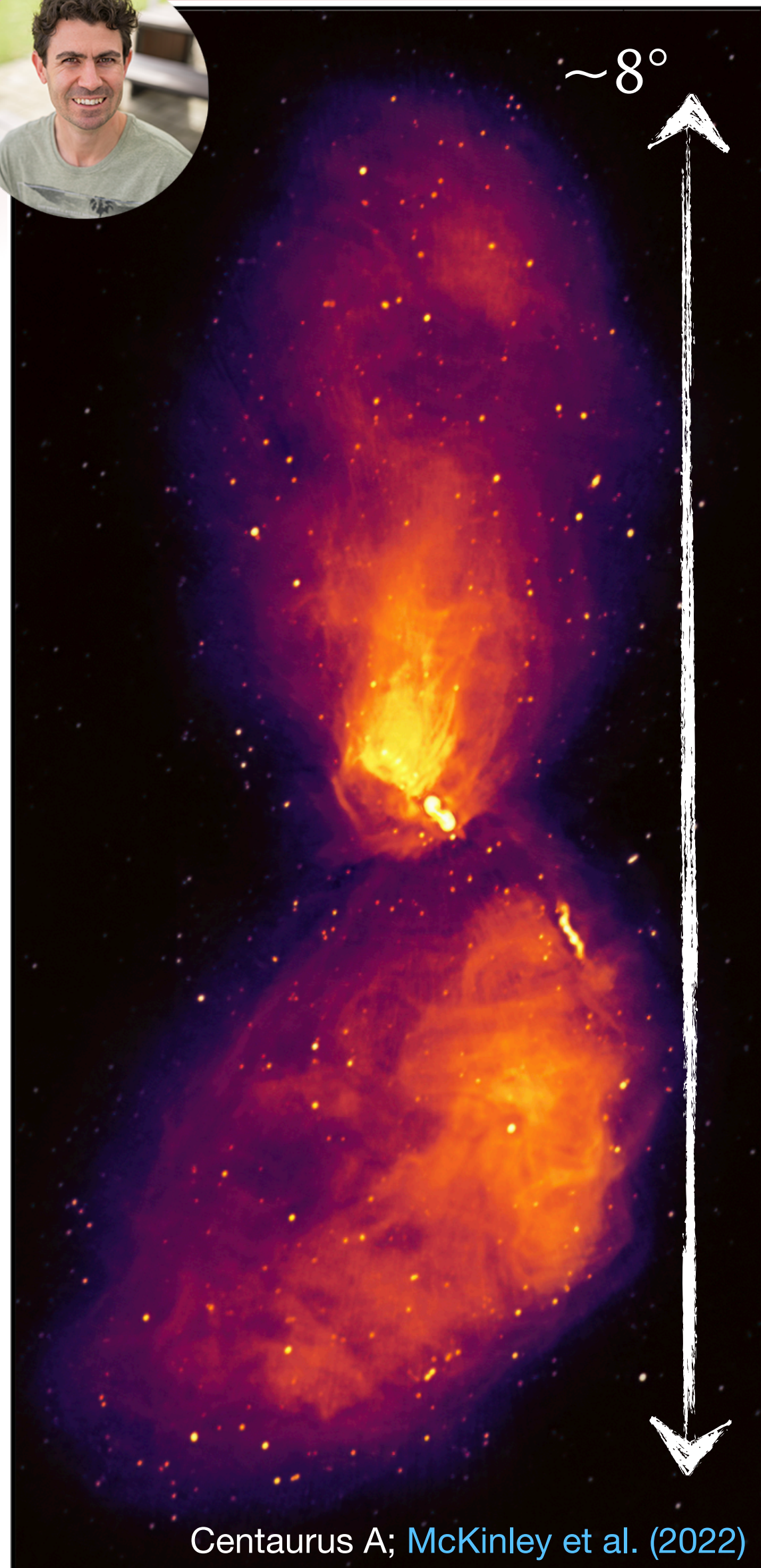
RADIO GALAXIES

RADIO GALAXIES

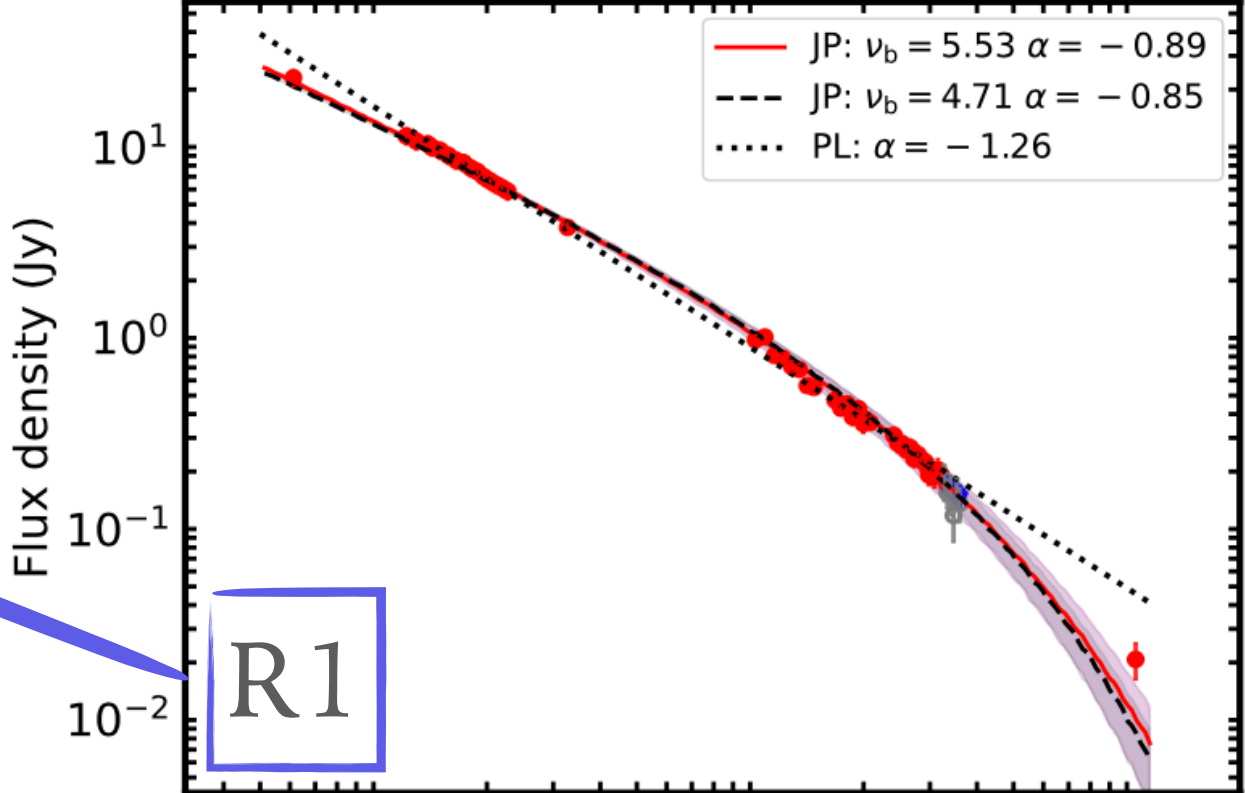
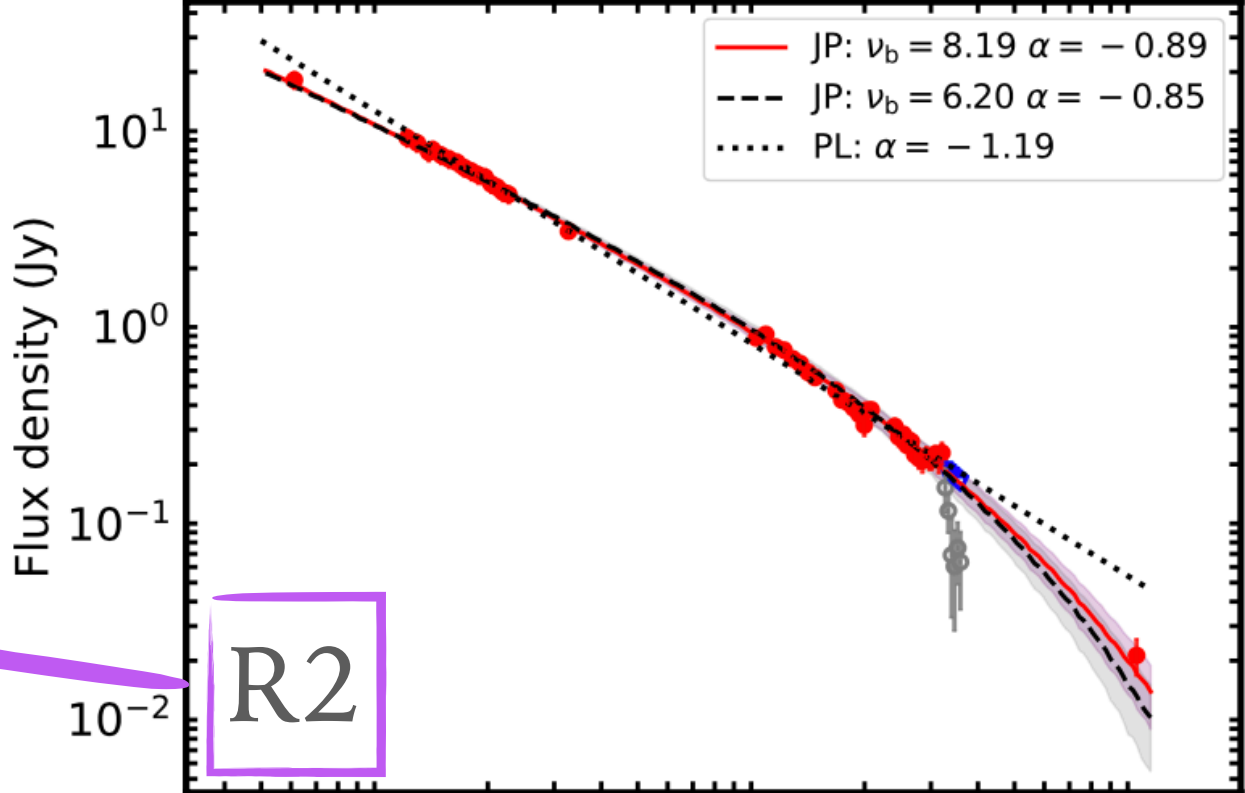
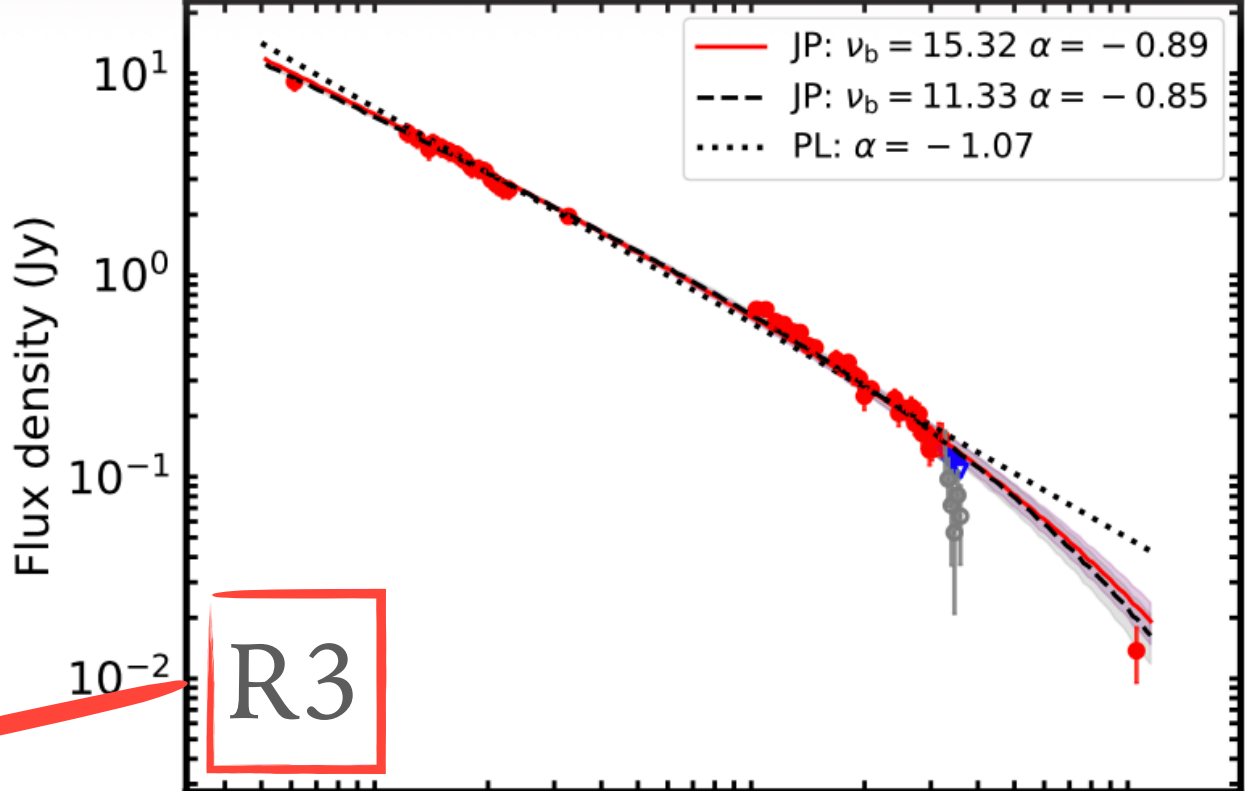
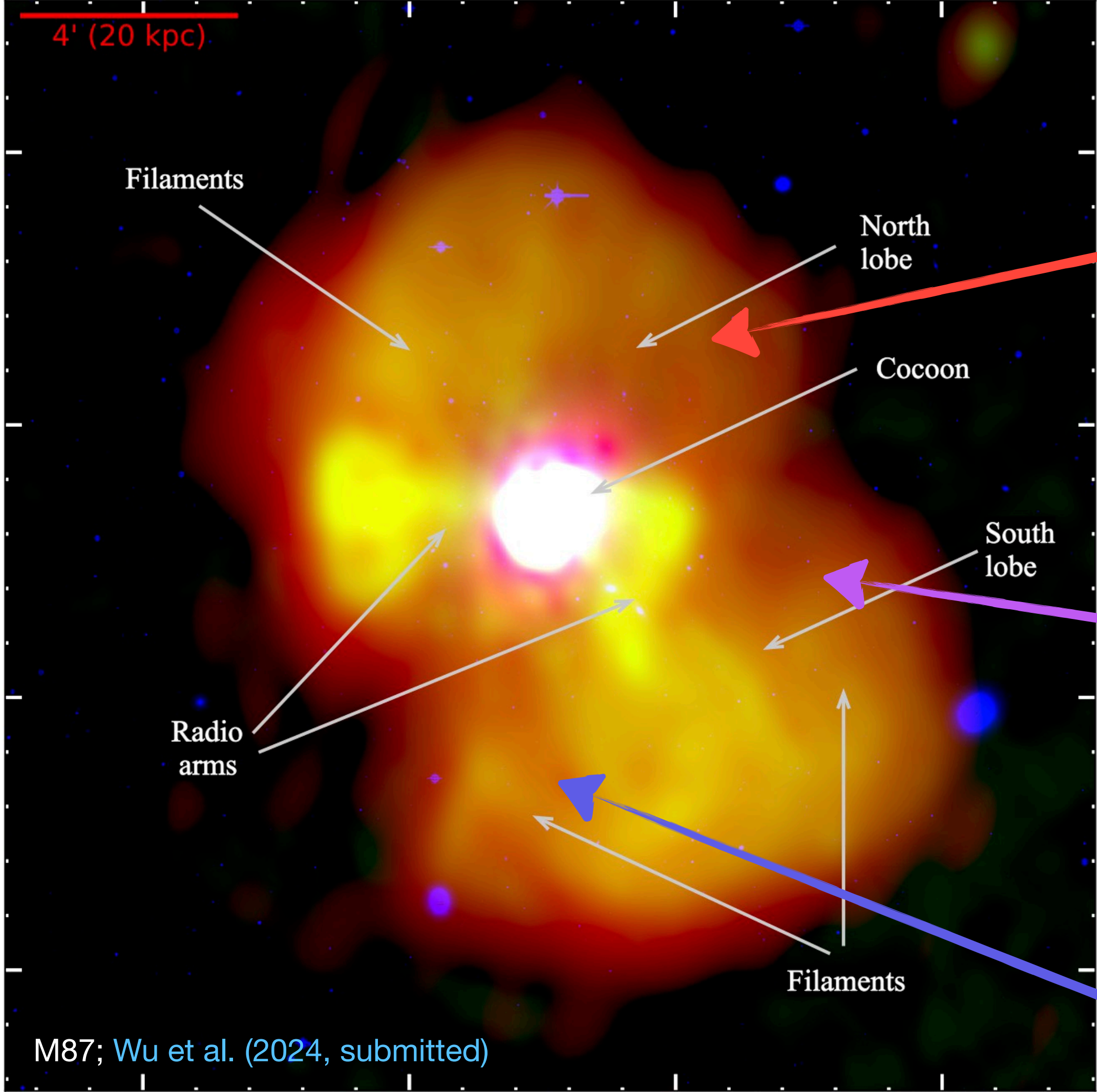
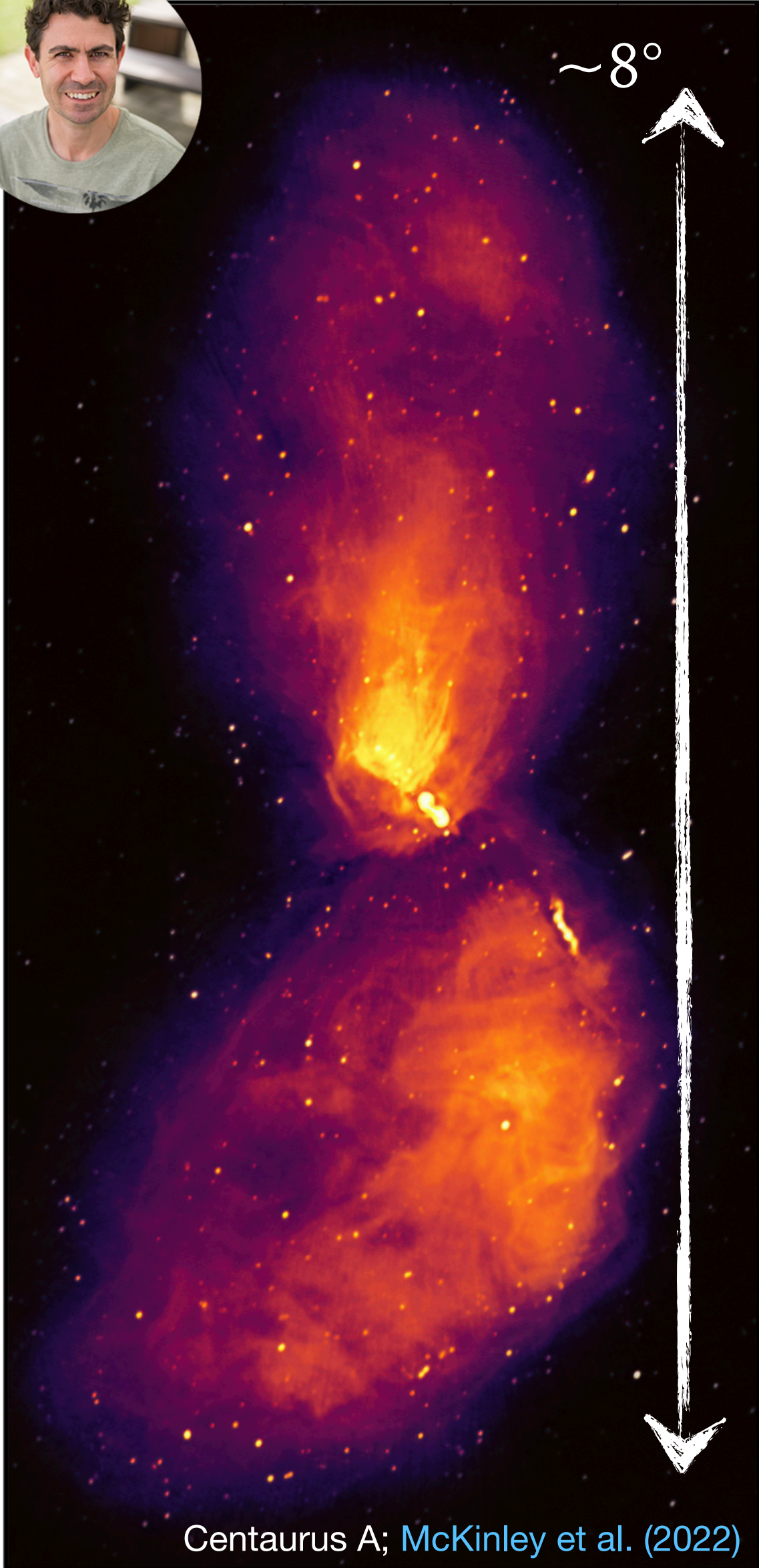


Centaurus A; McKinley et al. (2022)

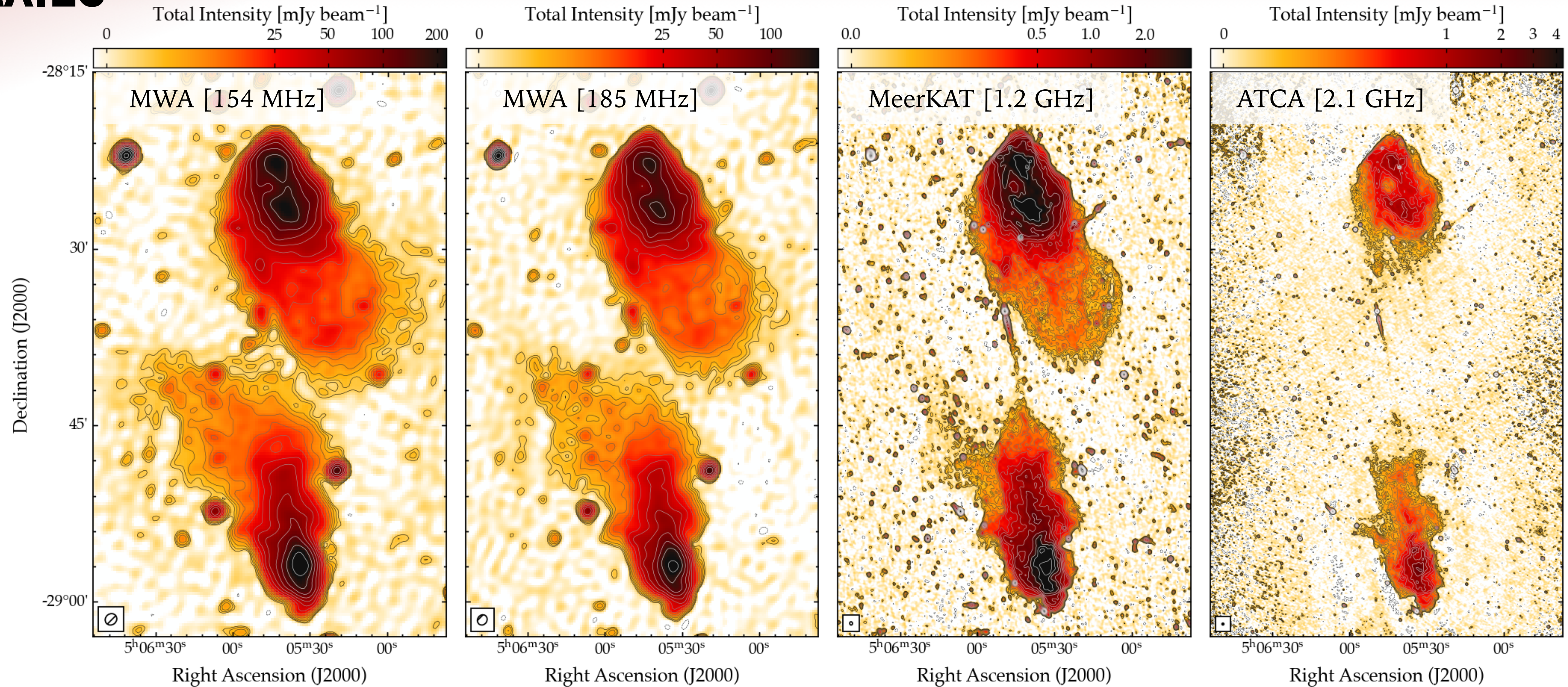
RADIO GALAXIES



RADIO GALAXIES



RADIO GALAXIES

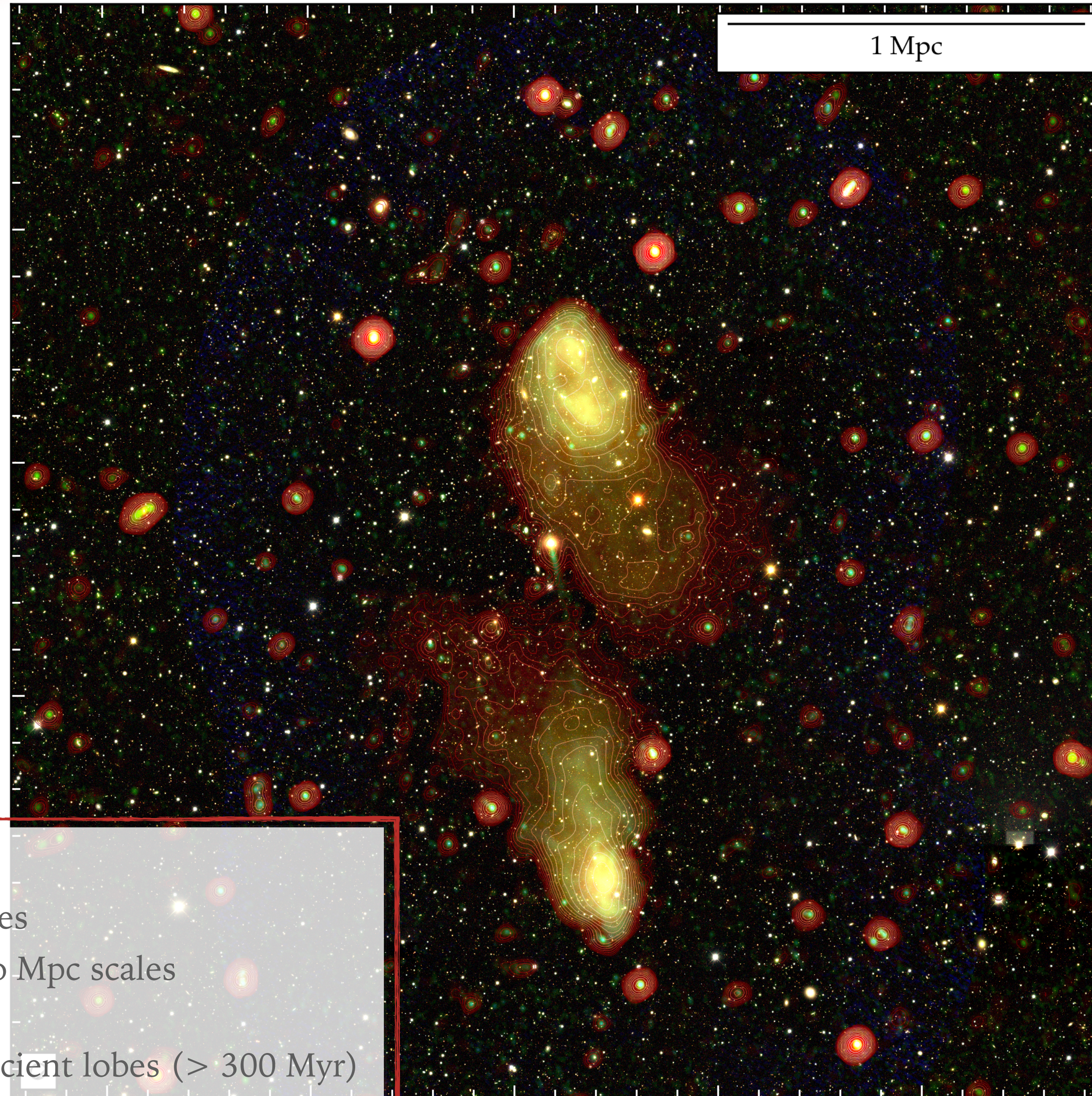


ESO422-G028; Riseley et al. (2024, in prep.)

► Giant radio galaxies:

- ◉ Feeding & feedback in galaxies
- ◉ Injection & ageing from pc to Mpc scales (72 MHz to 7 GHz + VLBI)
- ◉ Young core (~ 10 Myr) // ancient lobes (> 300 Myr)

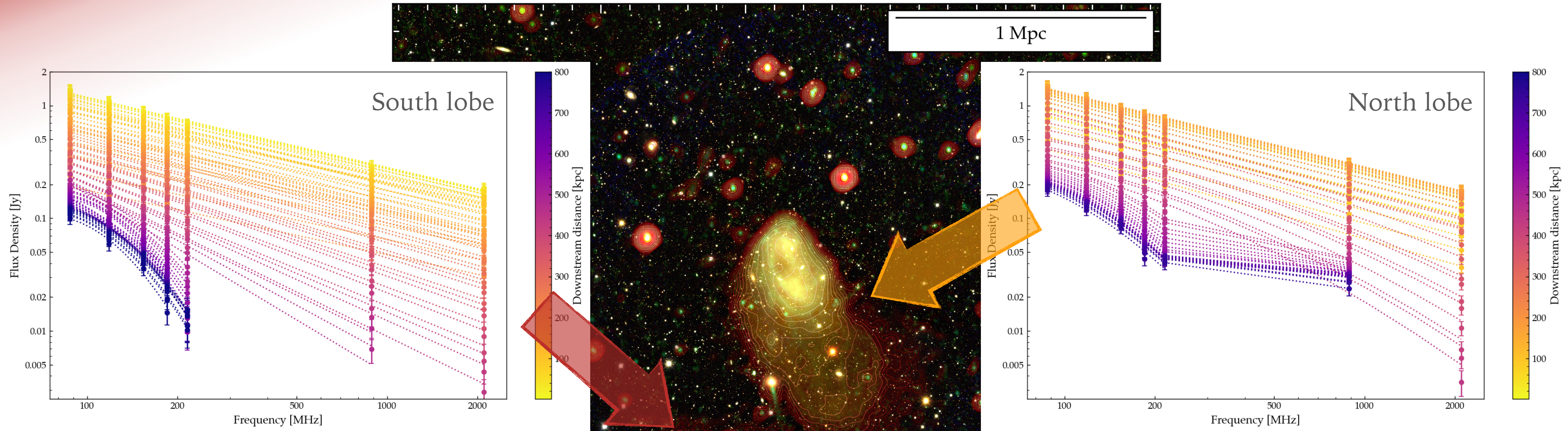
RADIO GALAXIES



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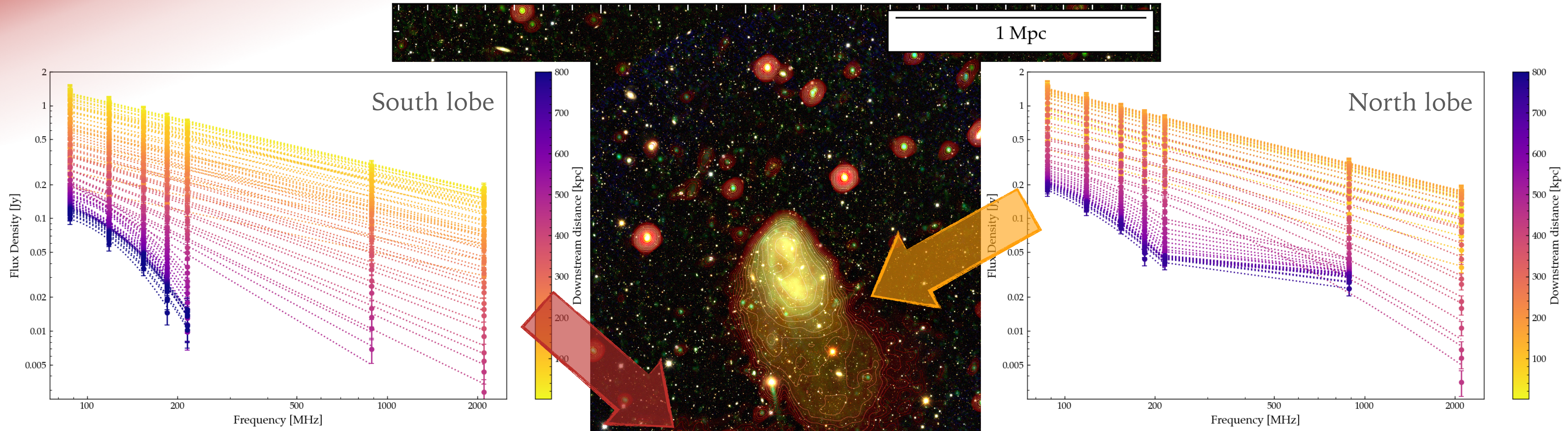
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RADIO GALAXIES



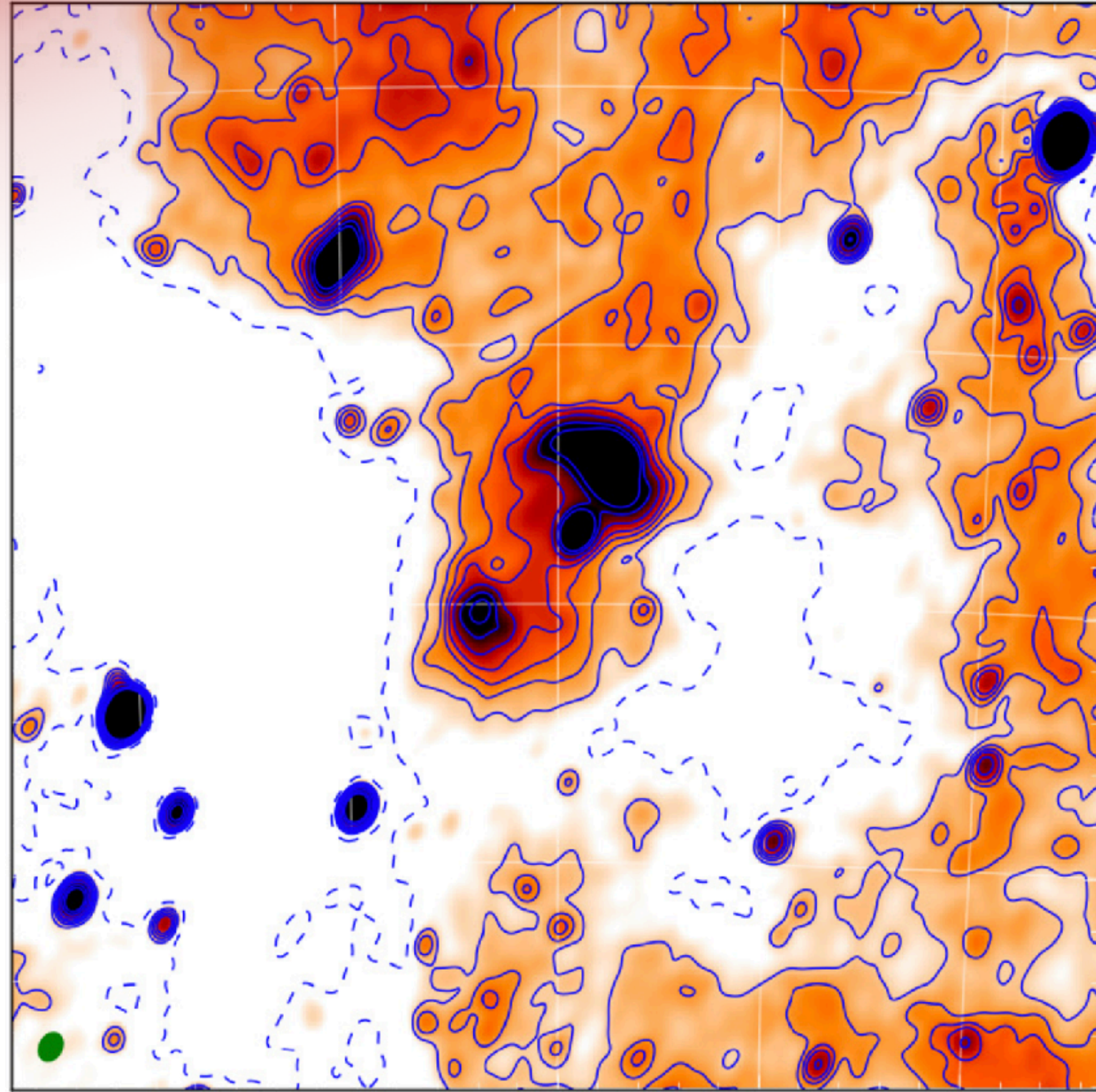
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- Young core (~ 10 Myr) // ancient lobes (> 300 Myr)

Demonstration of Phase I + II joint deconvolution

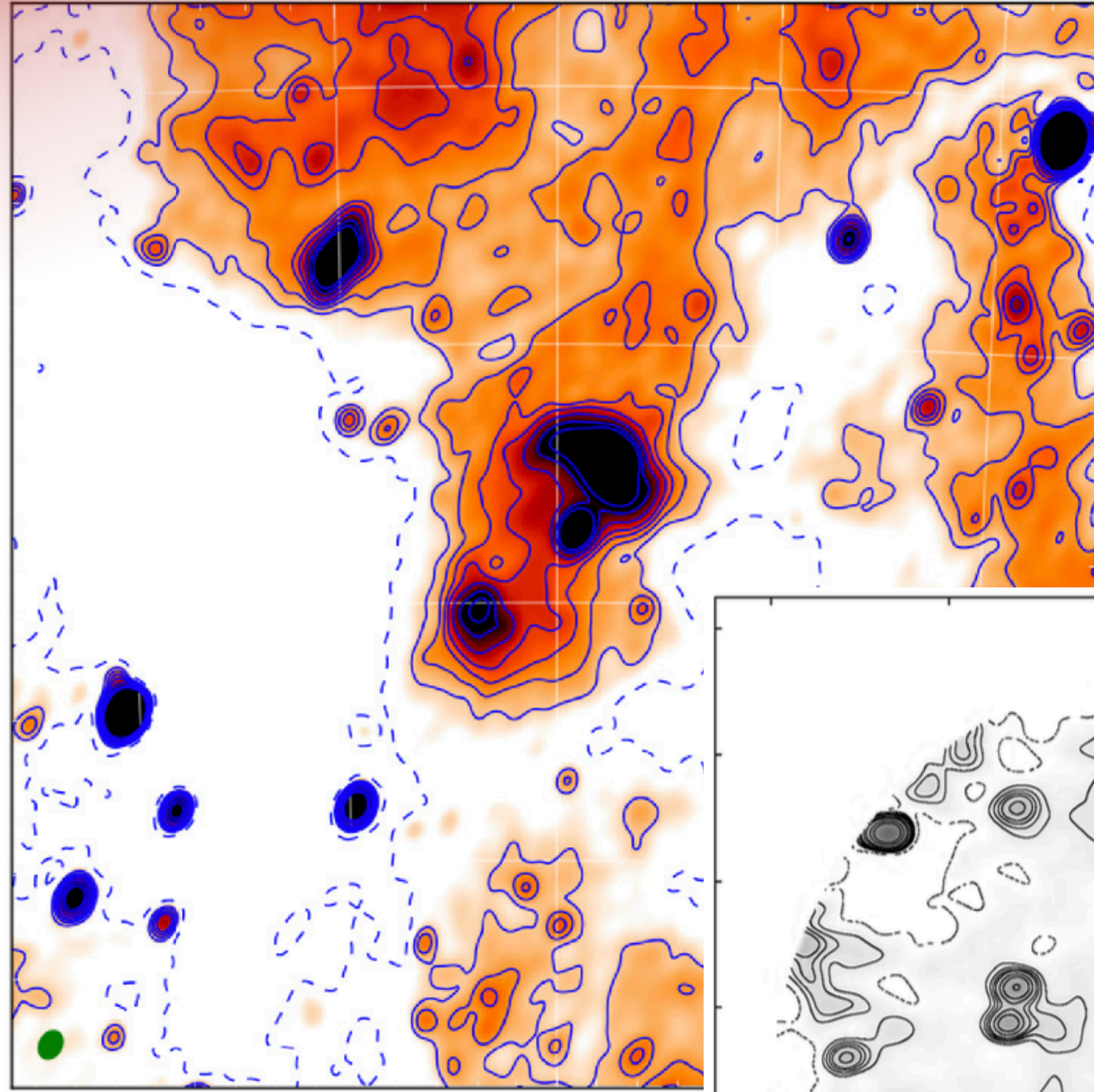
CLUSTERS: ABELL 3667

CLUSTERS: ABELL 3667

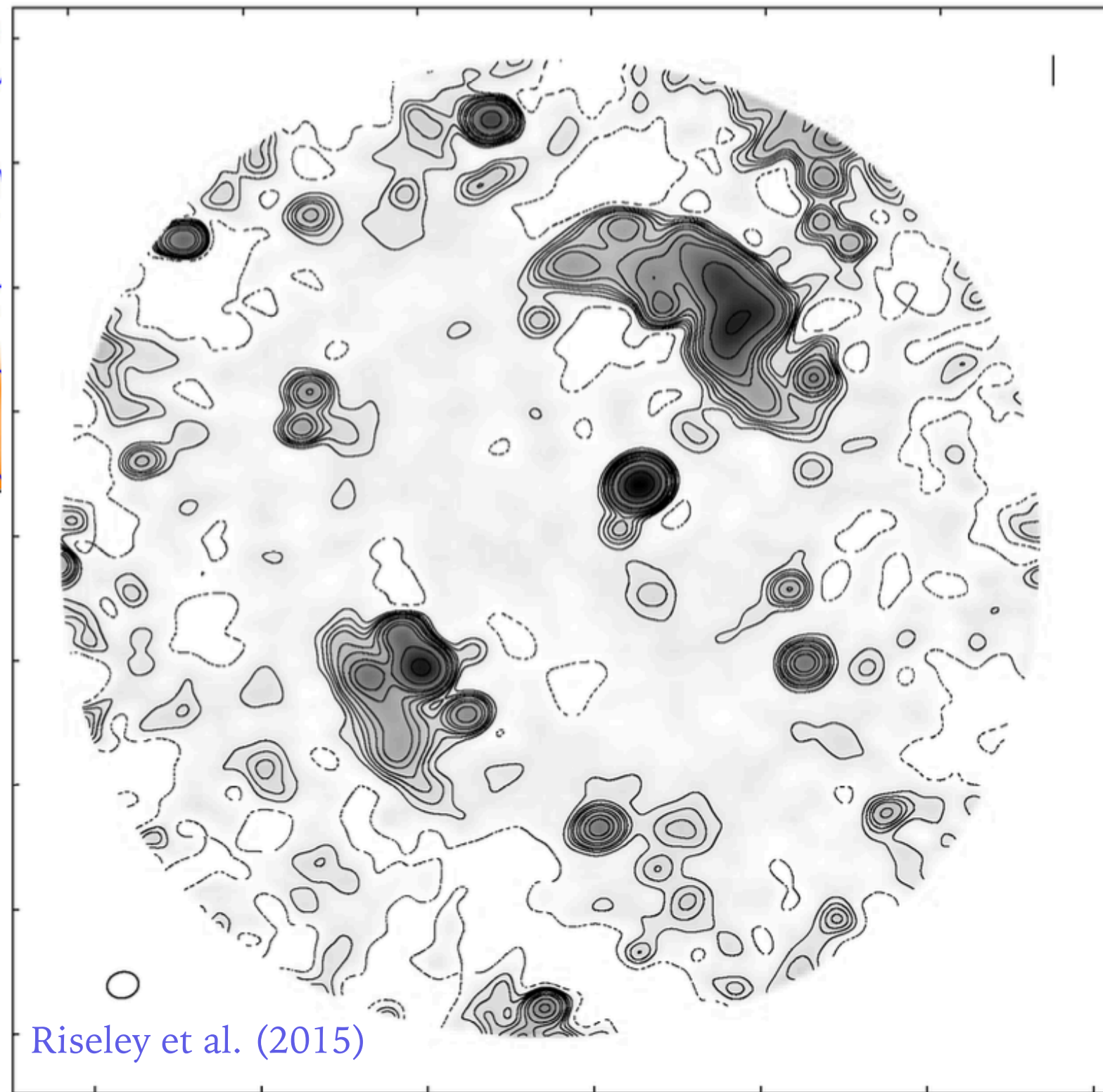


Hindson et al. (2014)

CLUSTERS: ABELL 3667

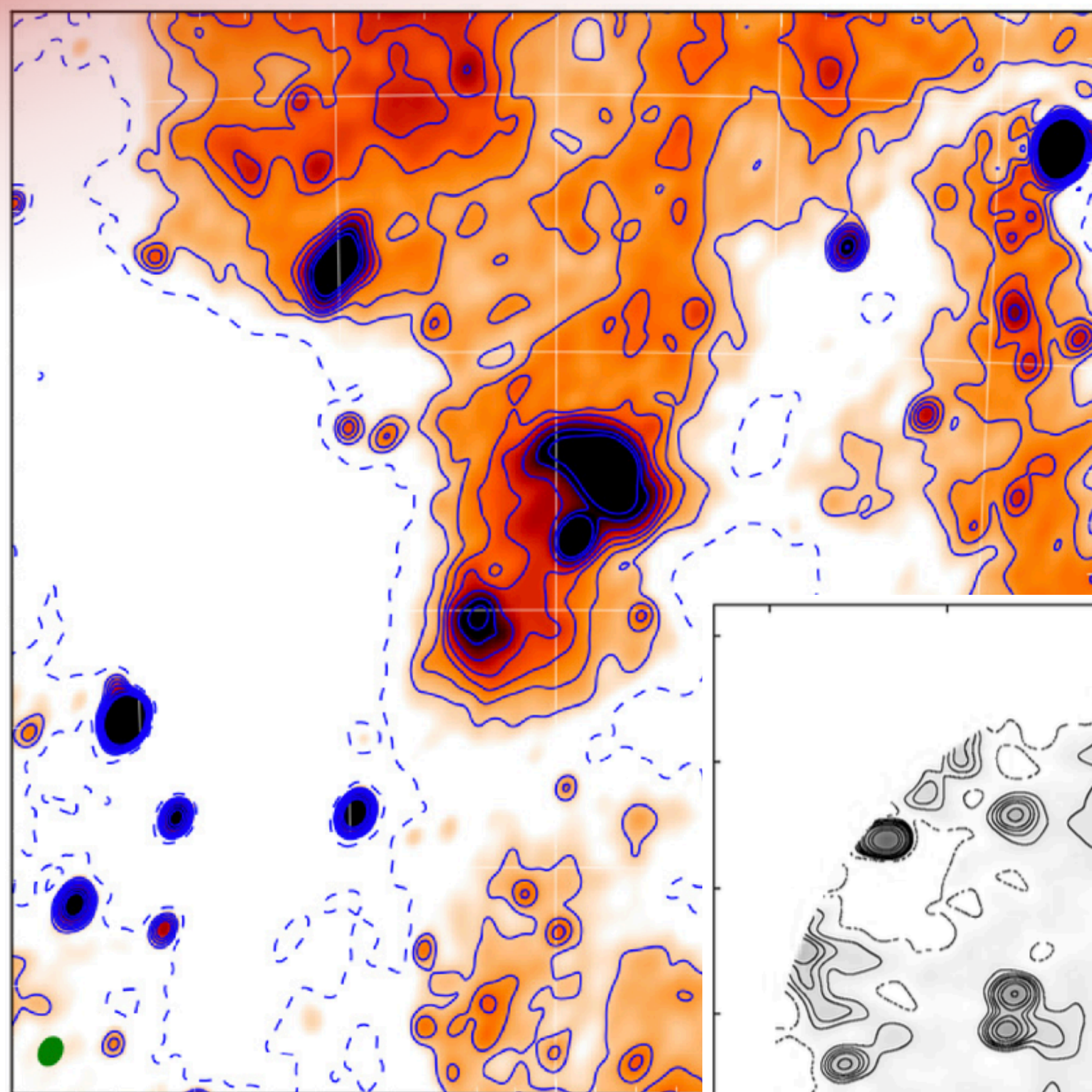


Hindson et al. (2014)

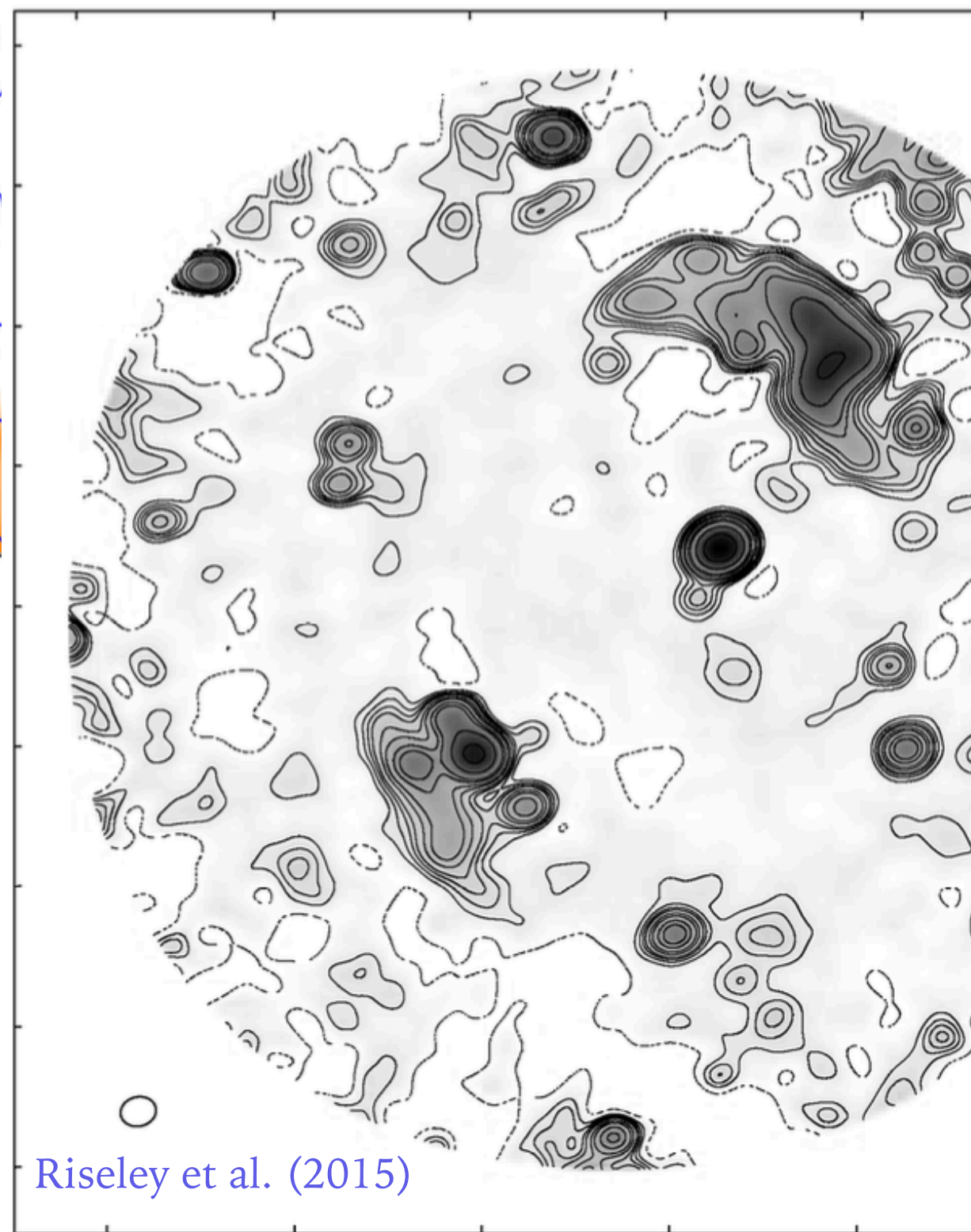


Riseley et al. (2015)

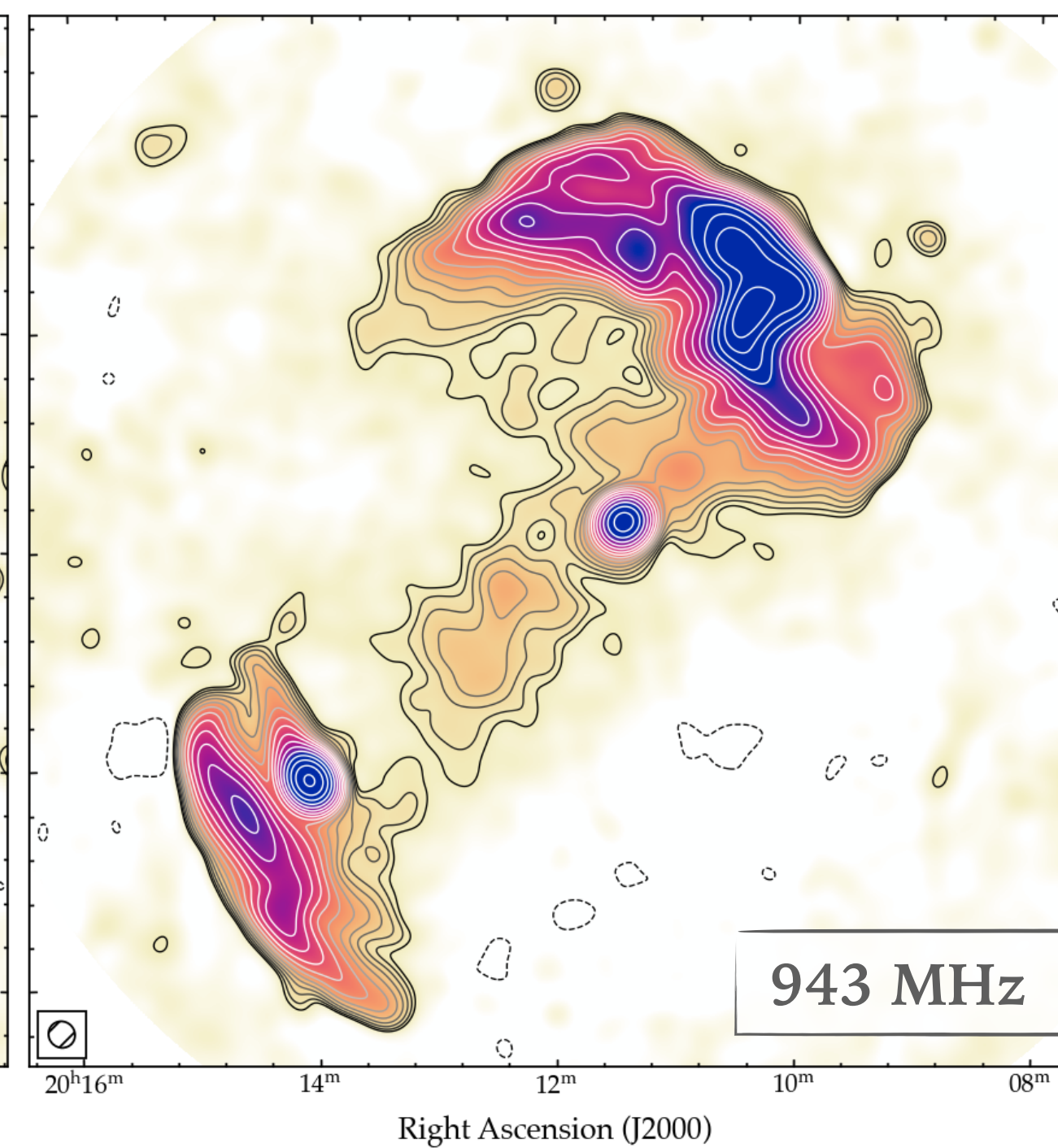
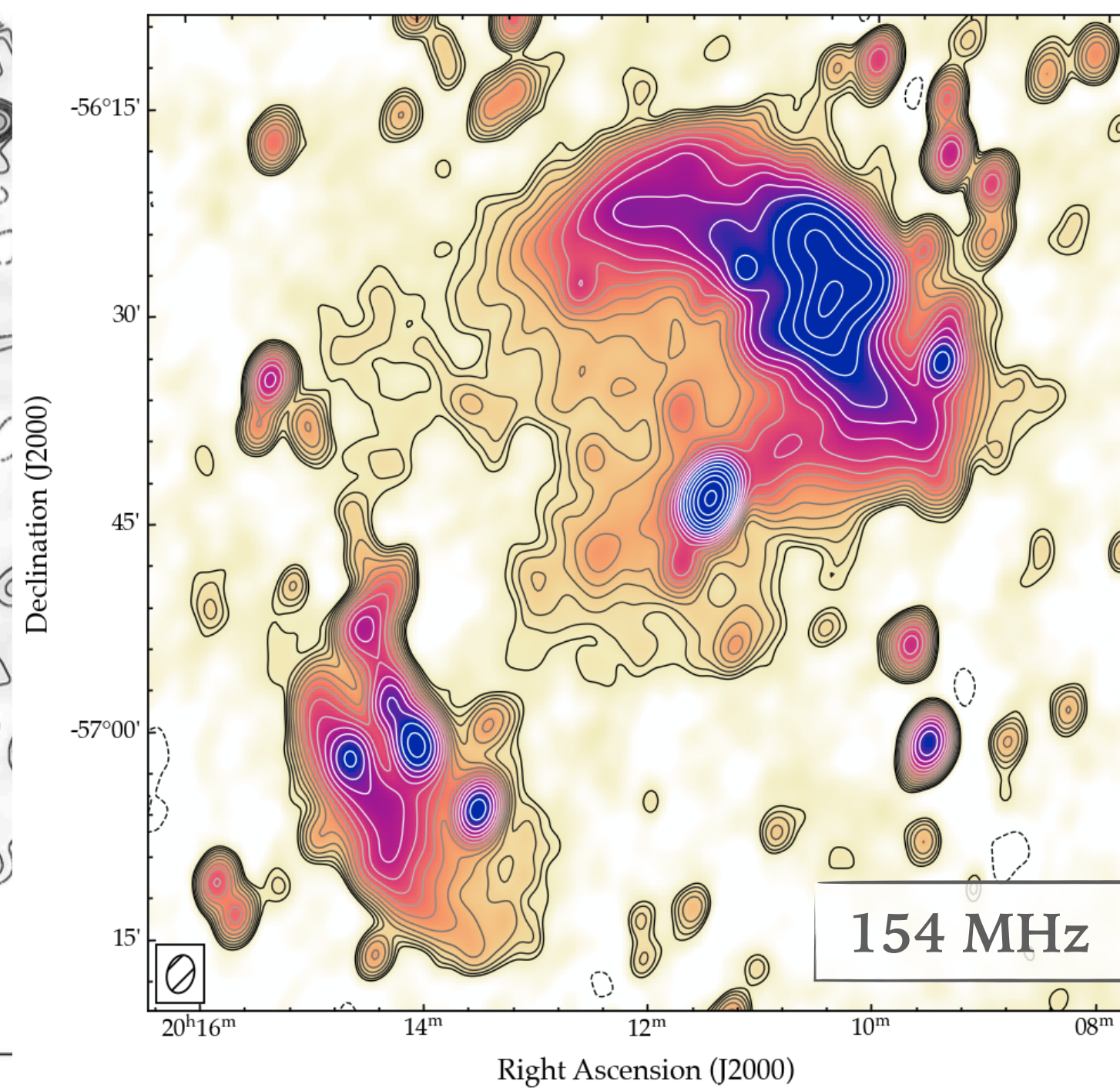
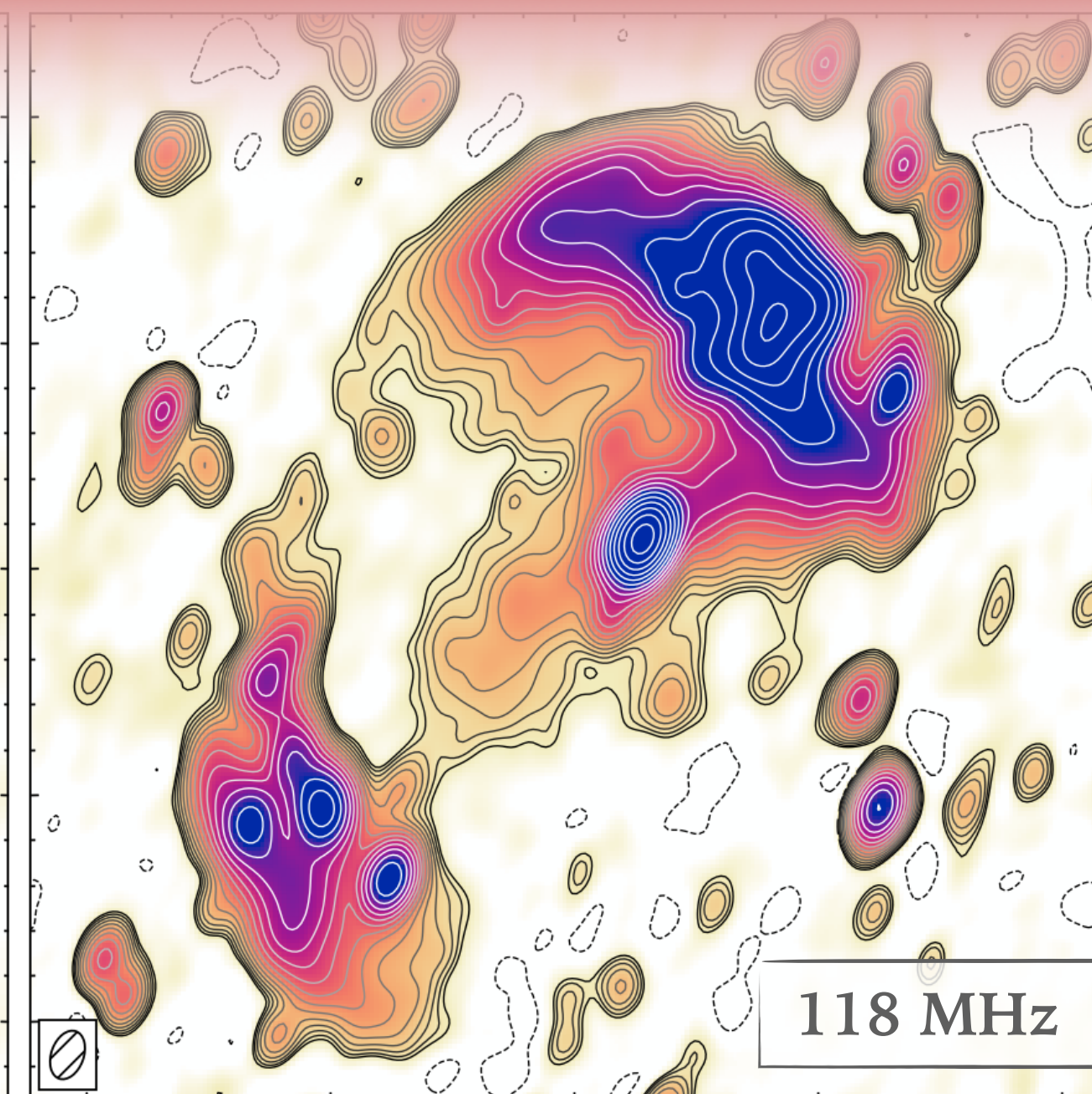
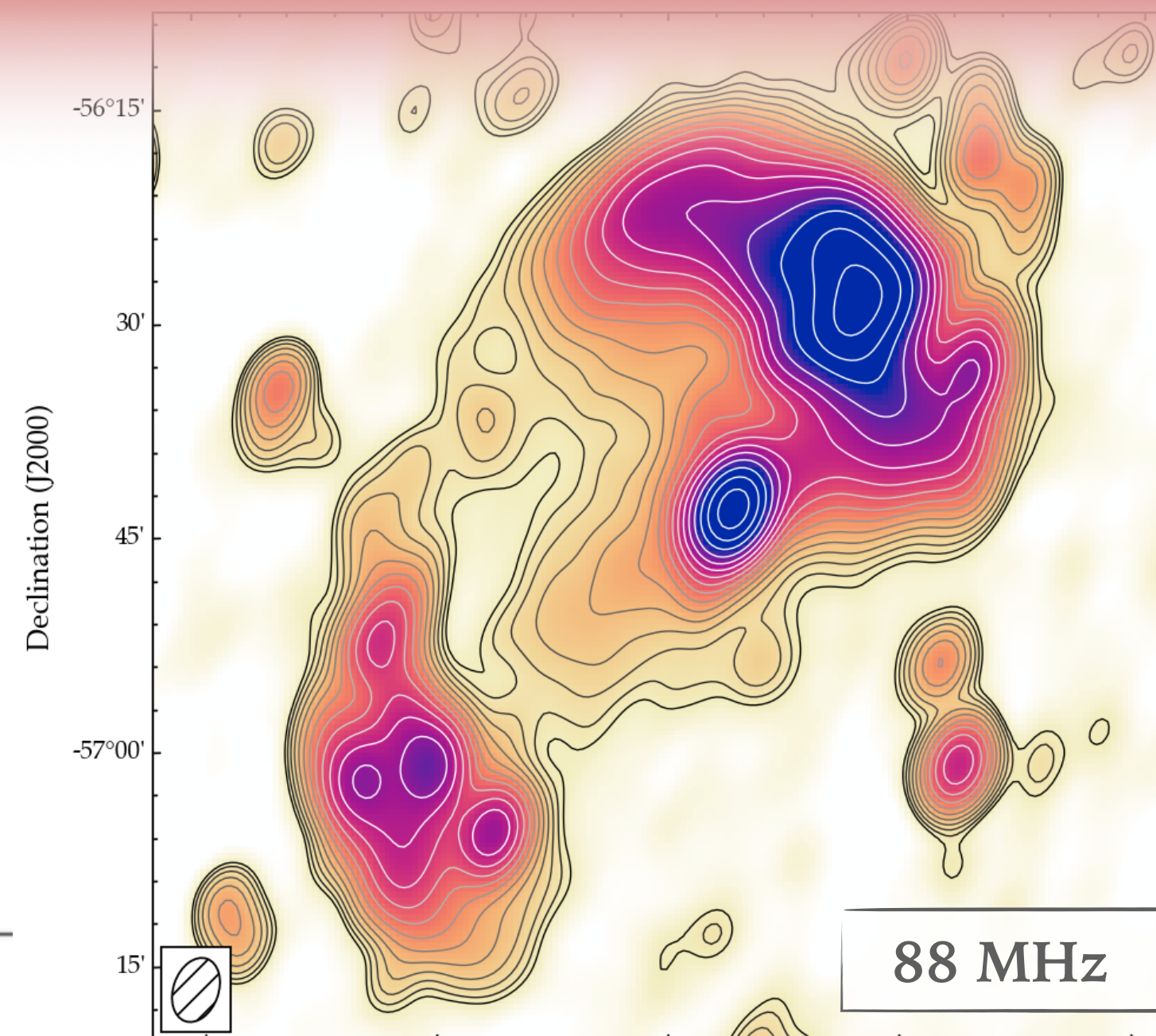
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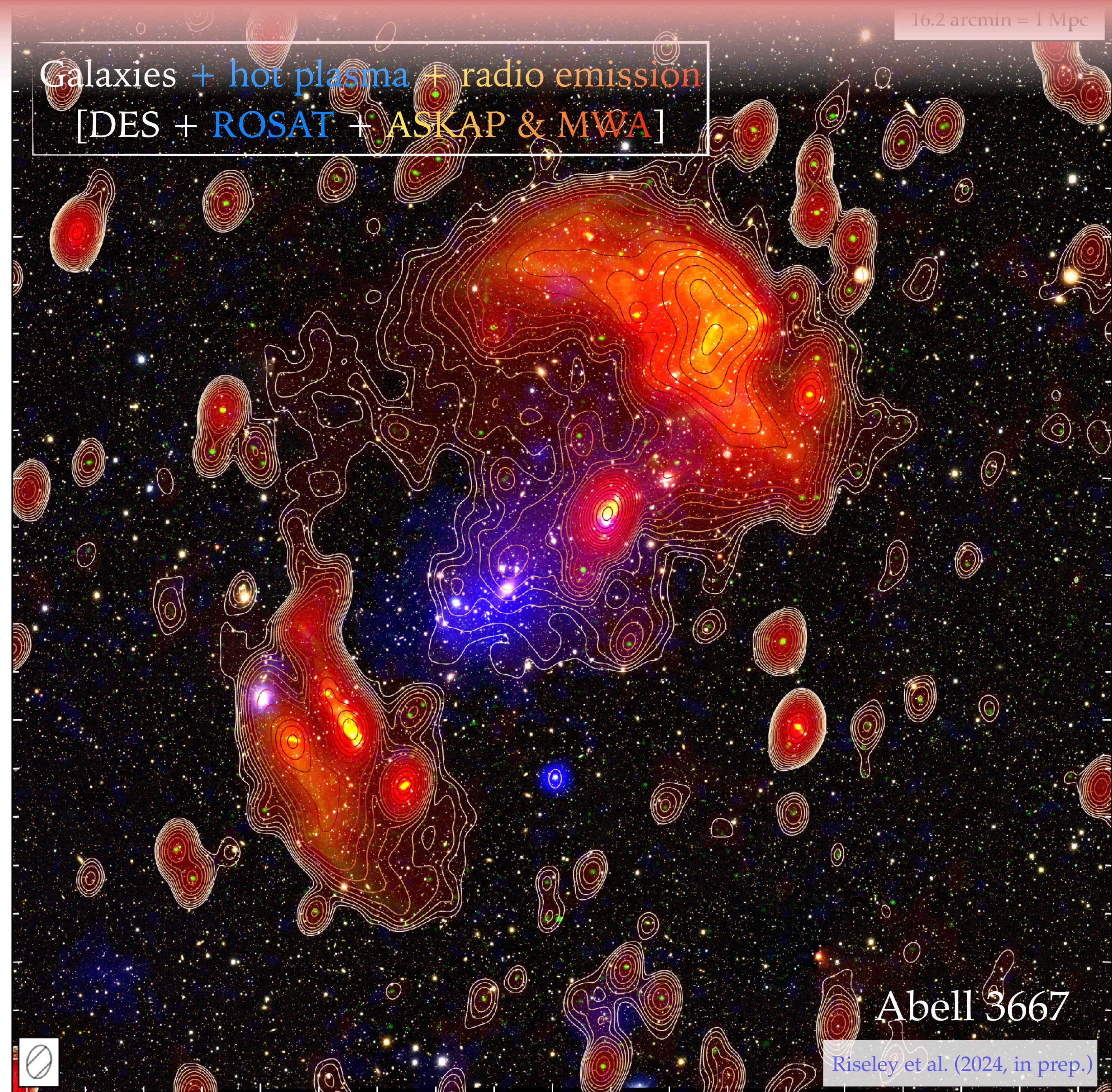
Hindson et al. (2014)



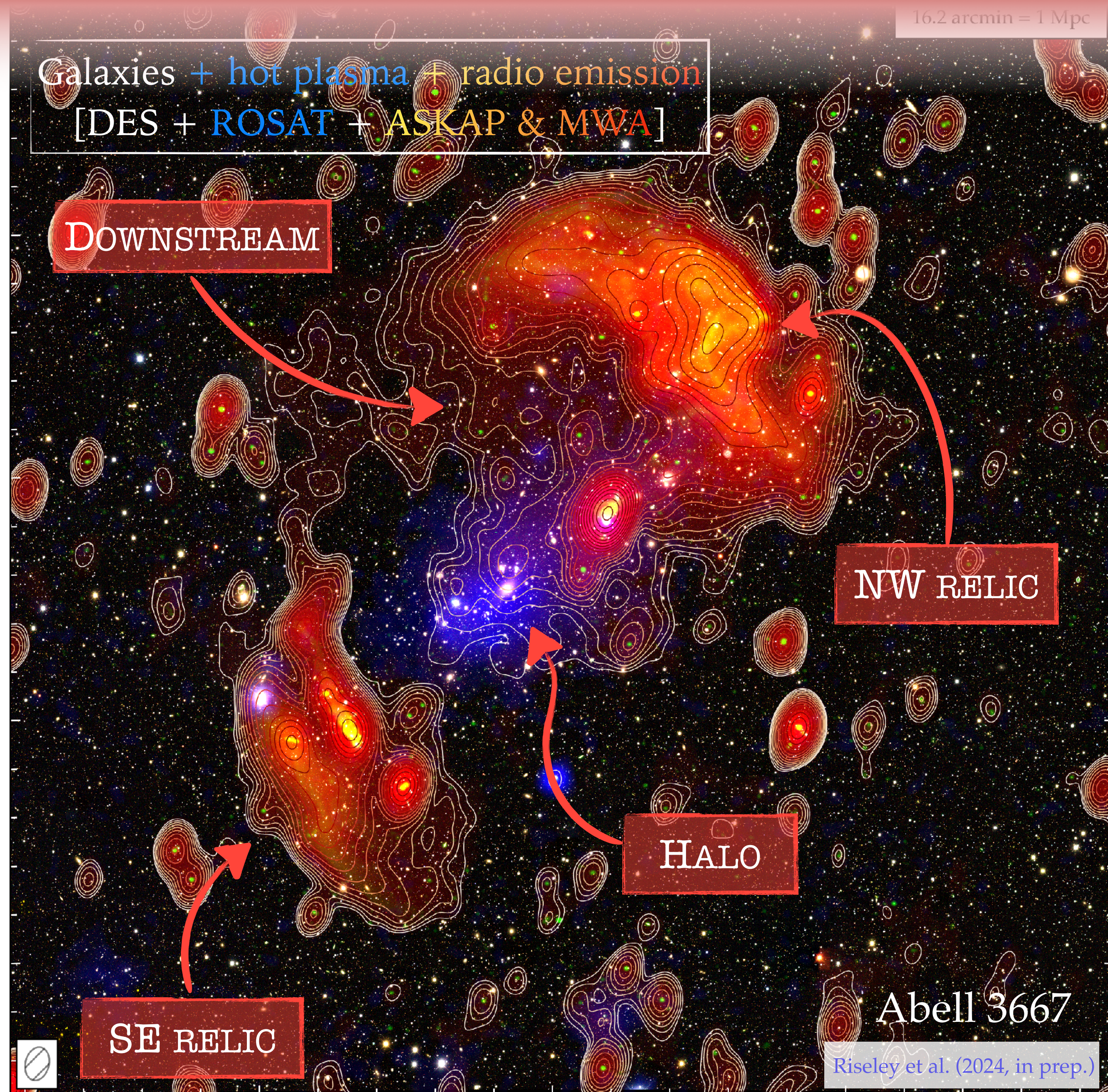
Riseley et al. (2015)



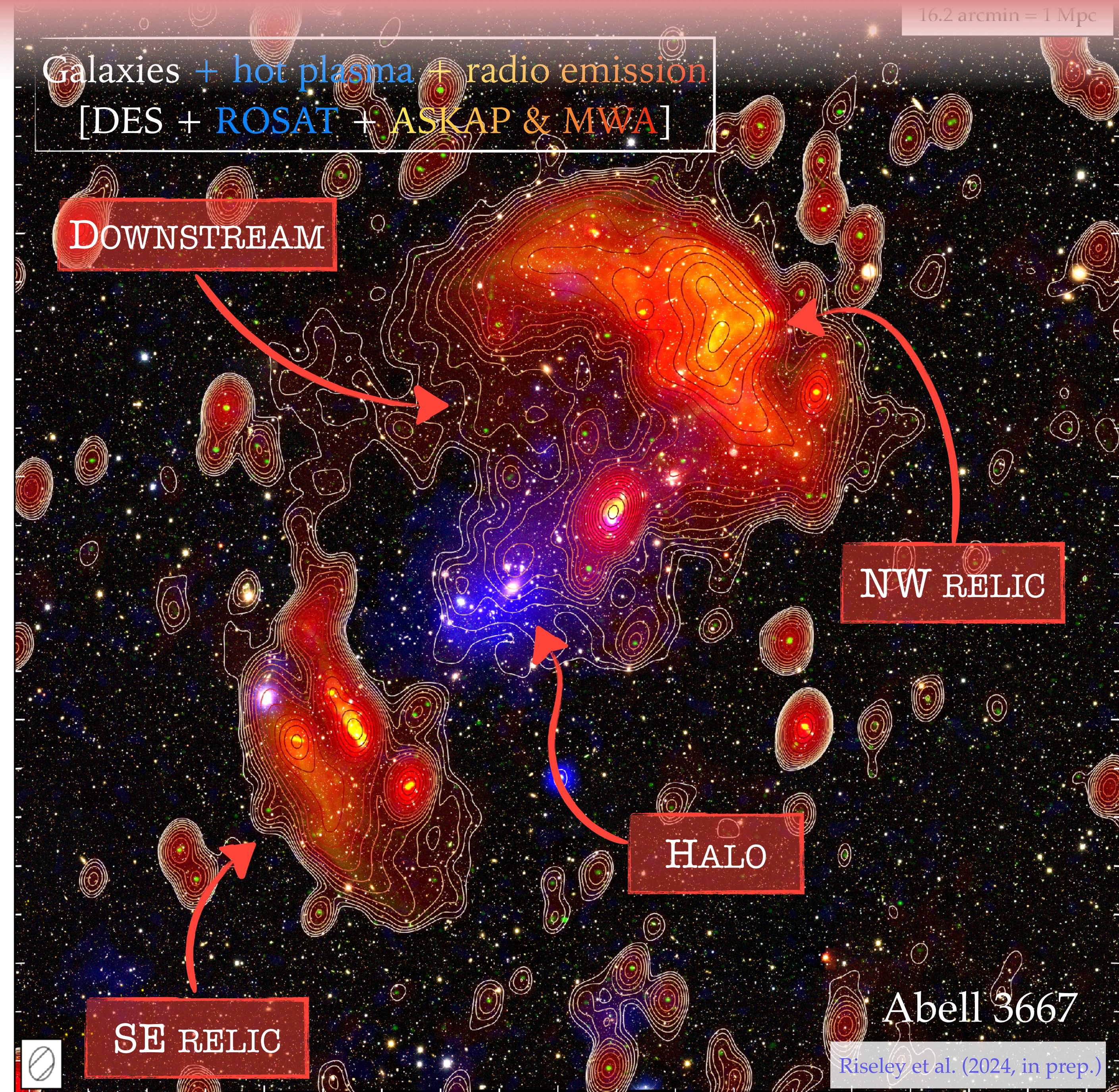
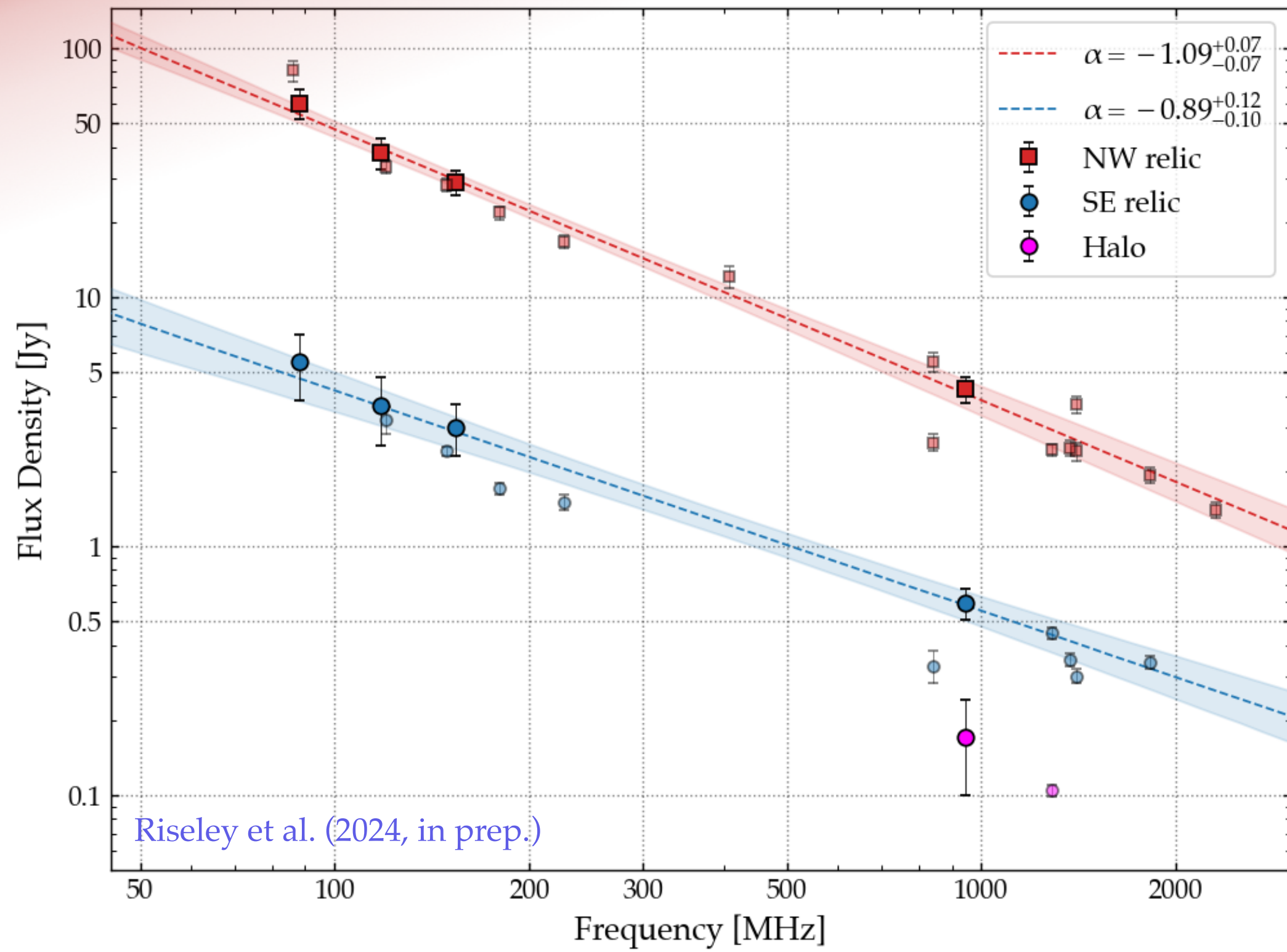
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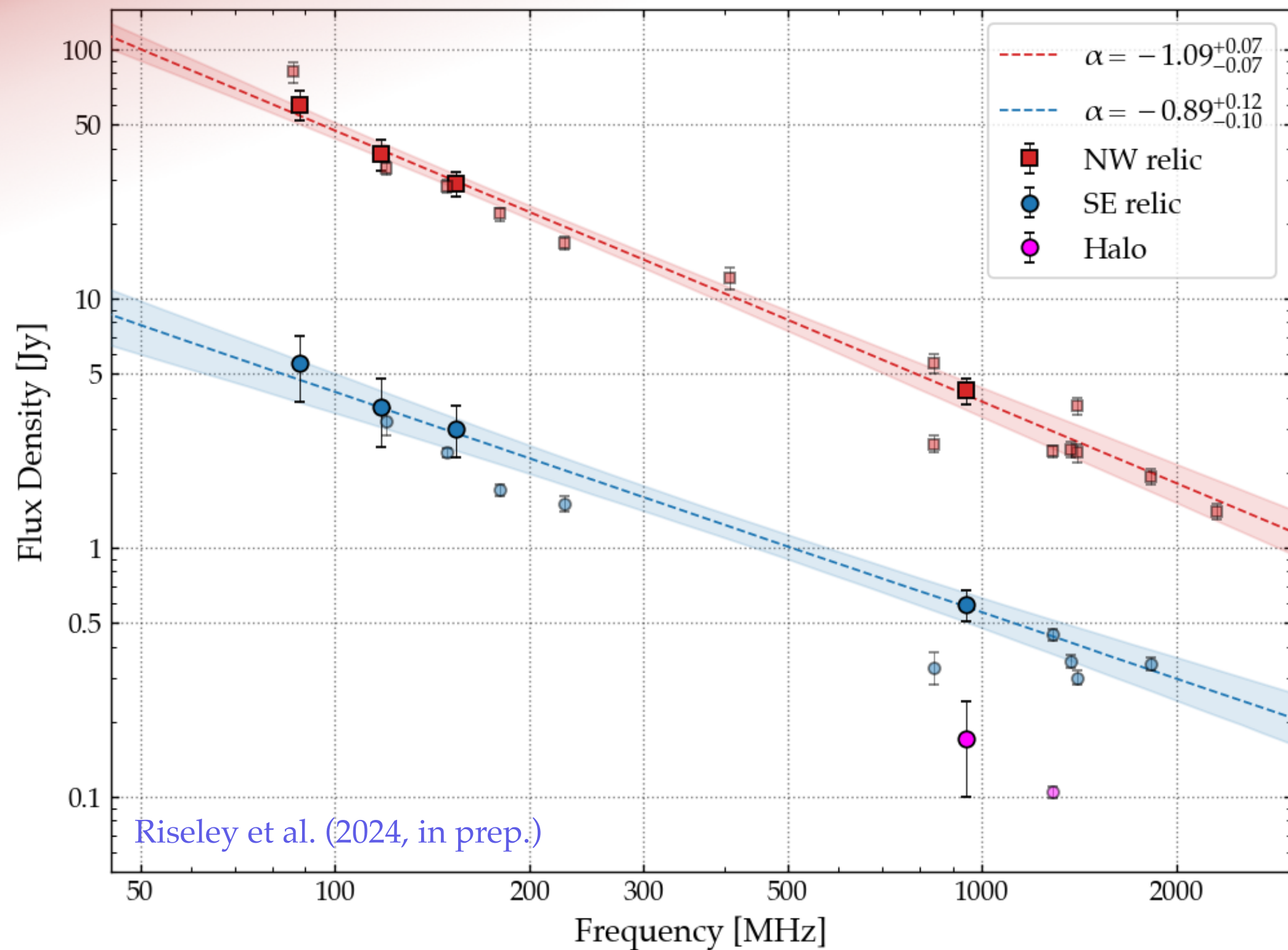
CLUSTERS: ABELL 3667



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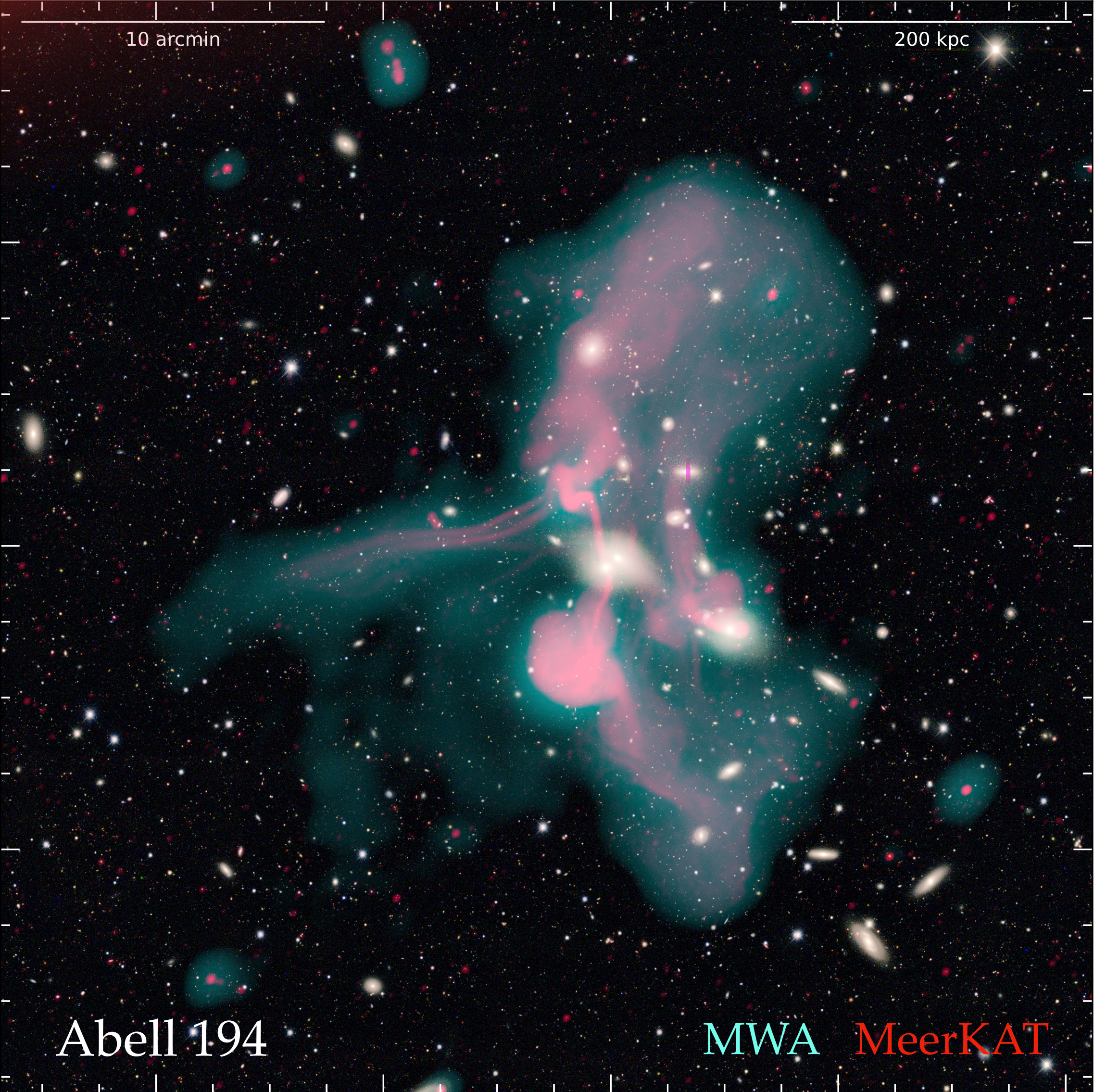


► Clusters:

- ◉ Plasma physics & particle acceleration on the largest scales (shocks & turbulence)
- ◉ *MWA* ideally suited to probing these rich environments

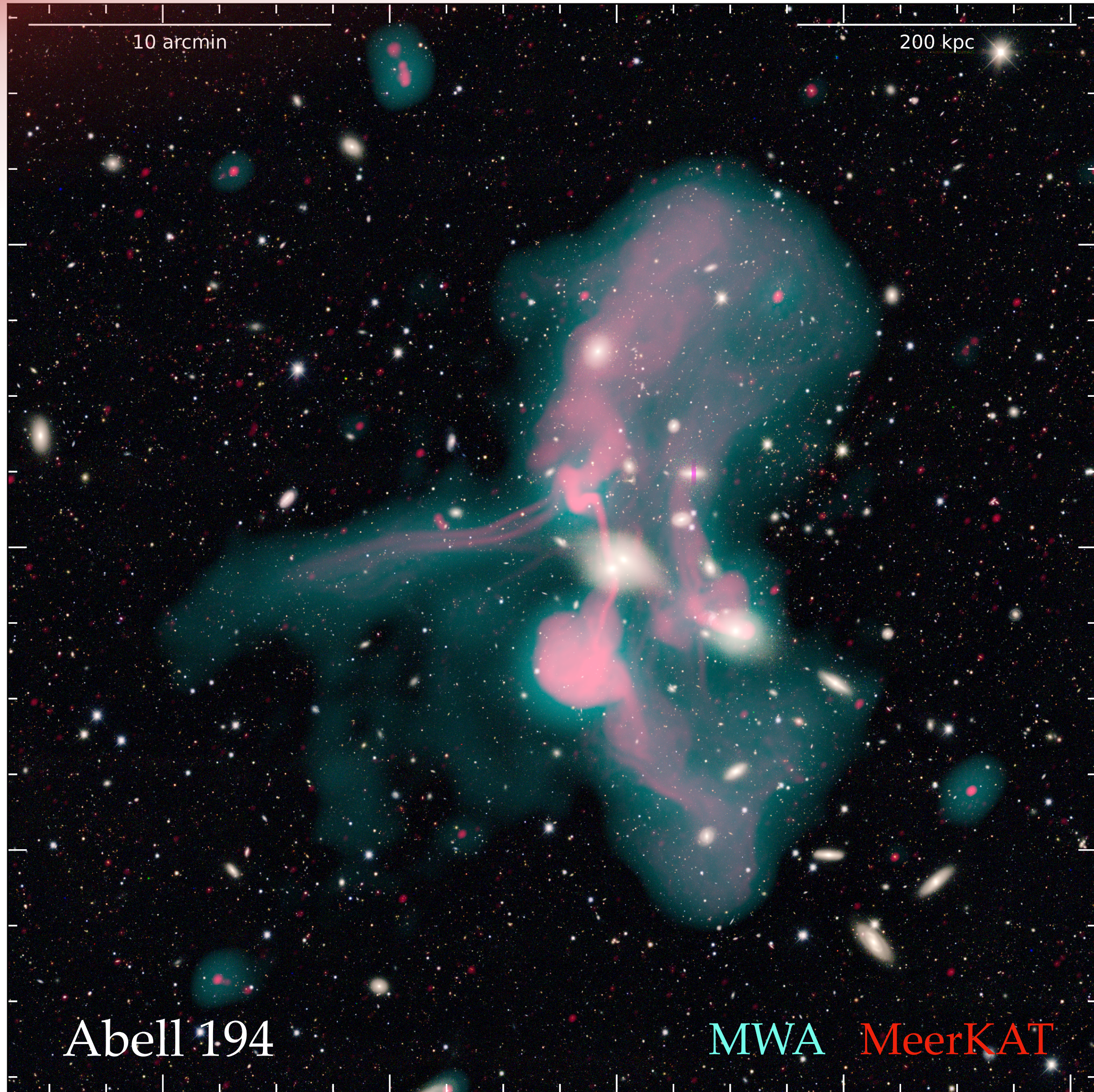


CLUSTERS

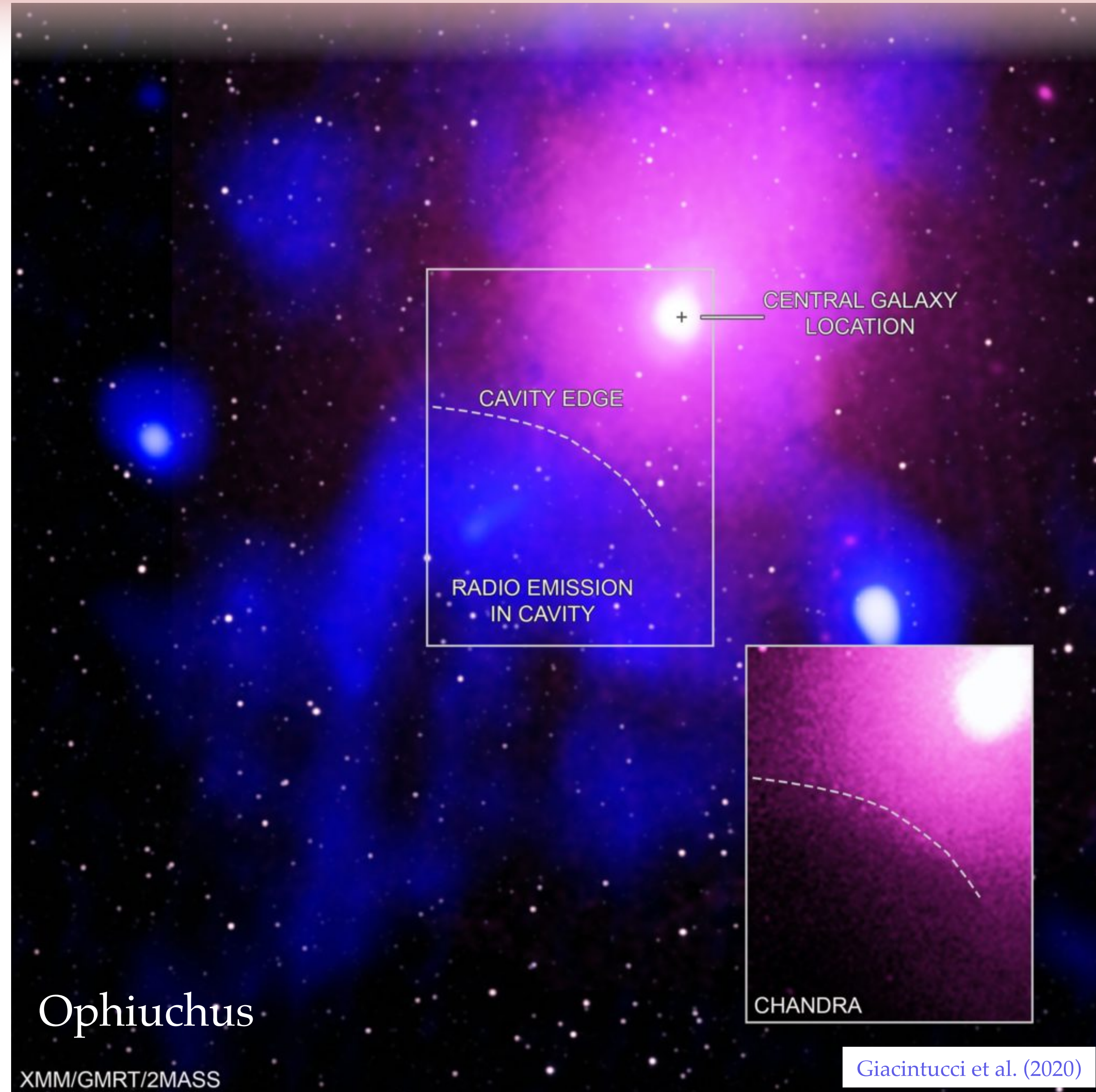


Duchesne et al. (2024, in prep.)

CLUSTERS

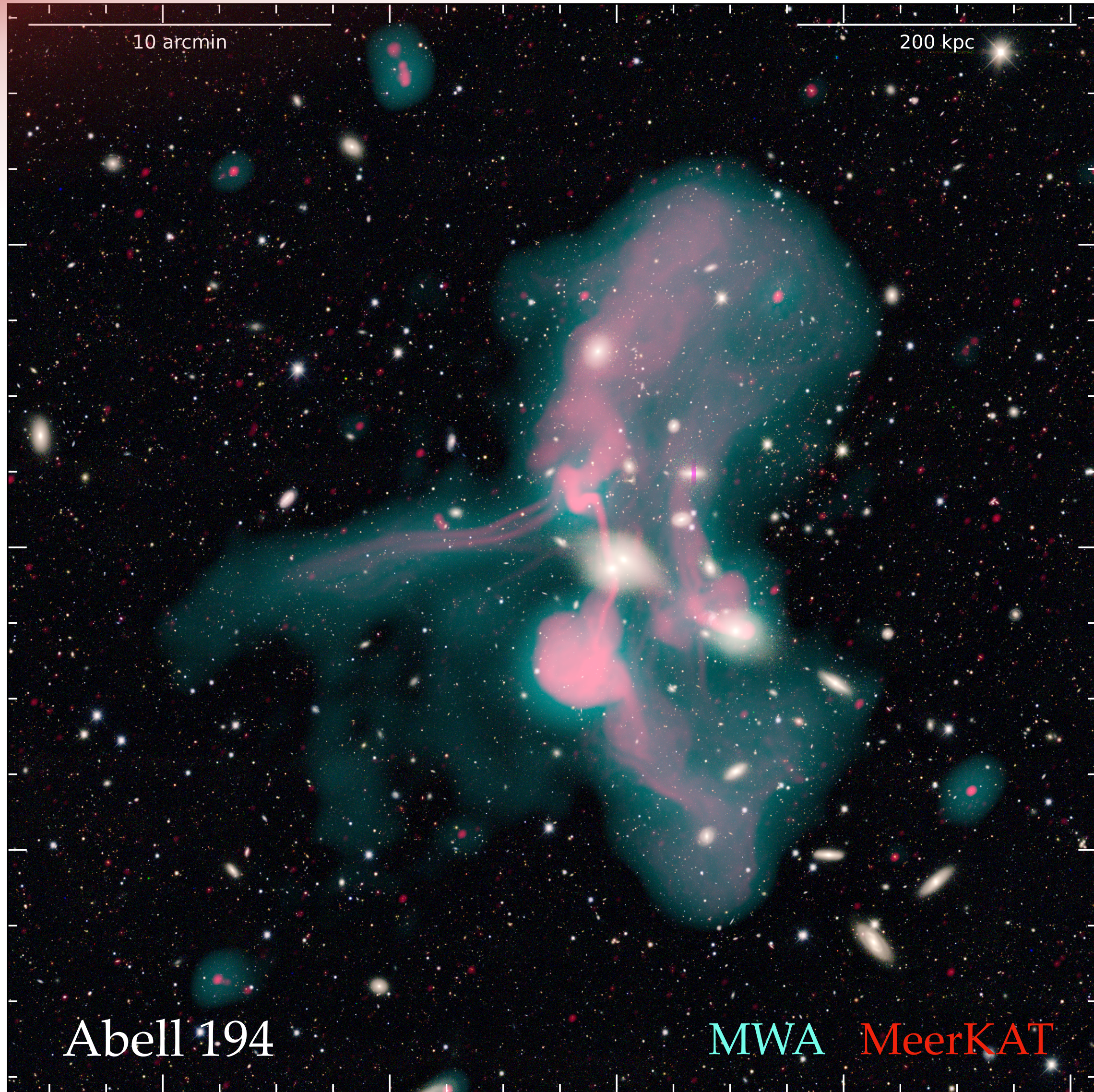


Duchesne et al. (2024, in prep.)

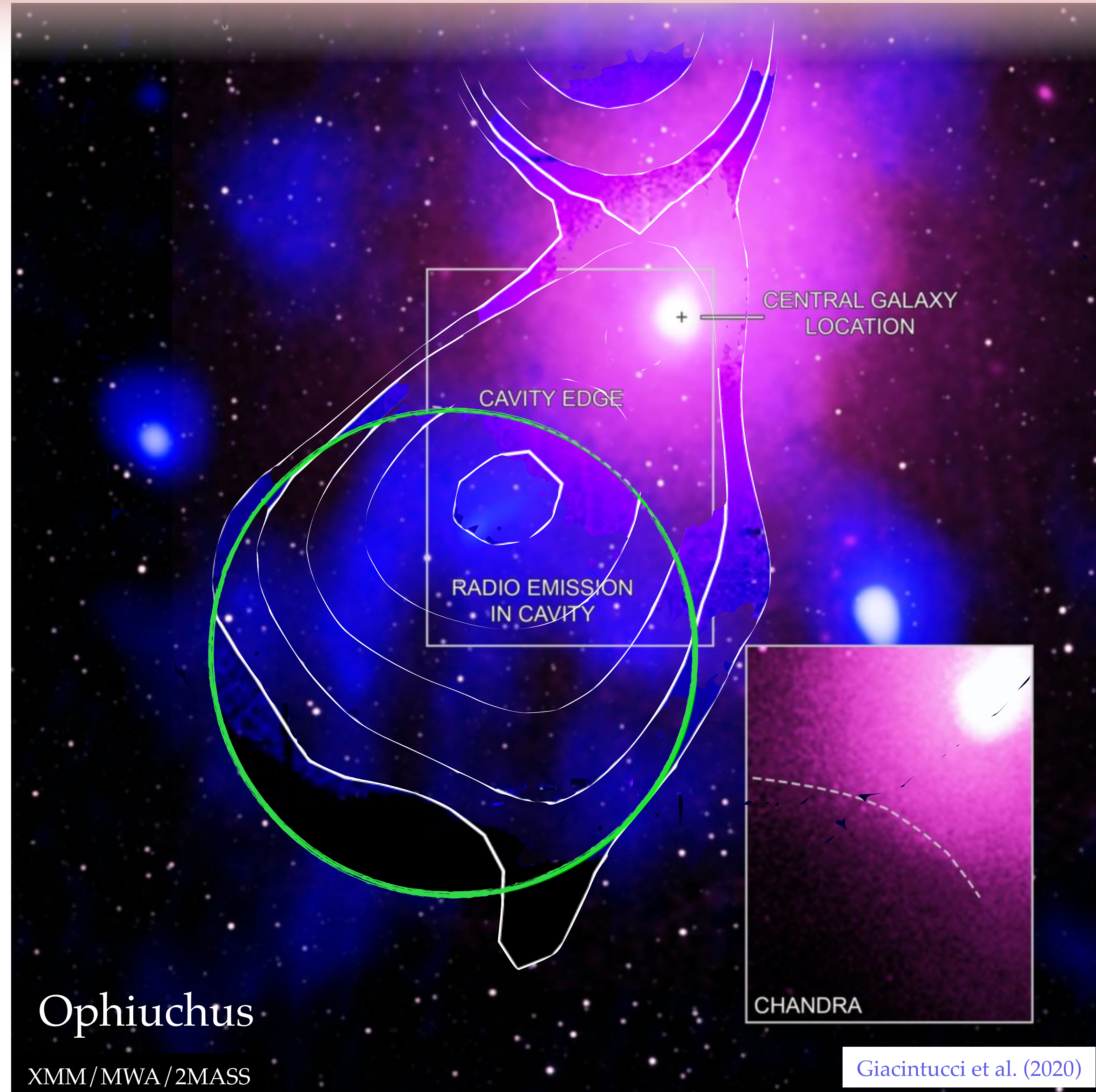


Giacintucci et al. (2020)

CLUSTERS



Duchesne et al. (2024, in prep.)



Giacintucci et al. (2020)

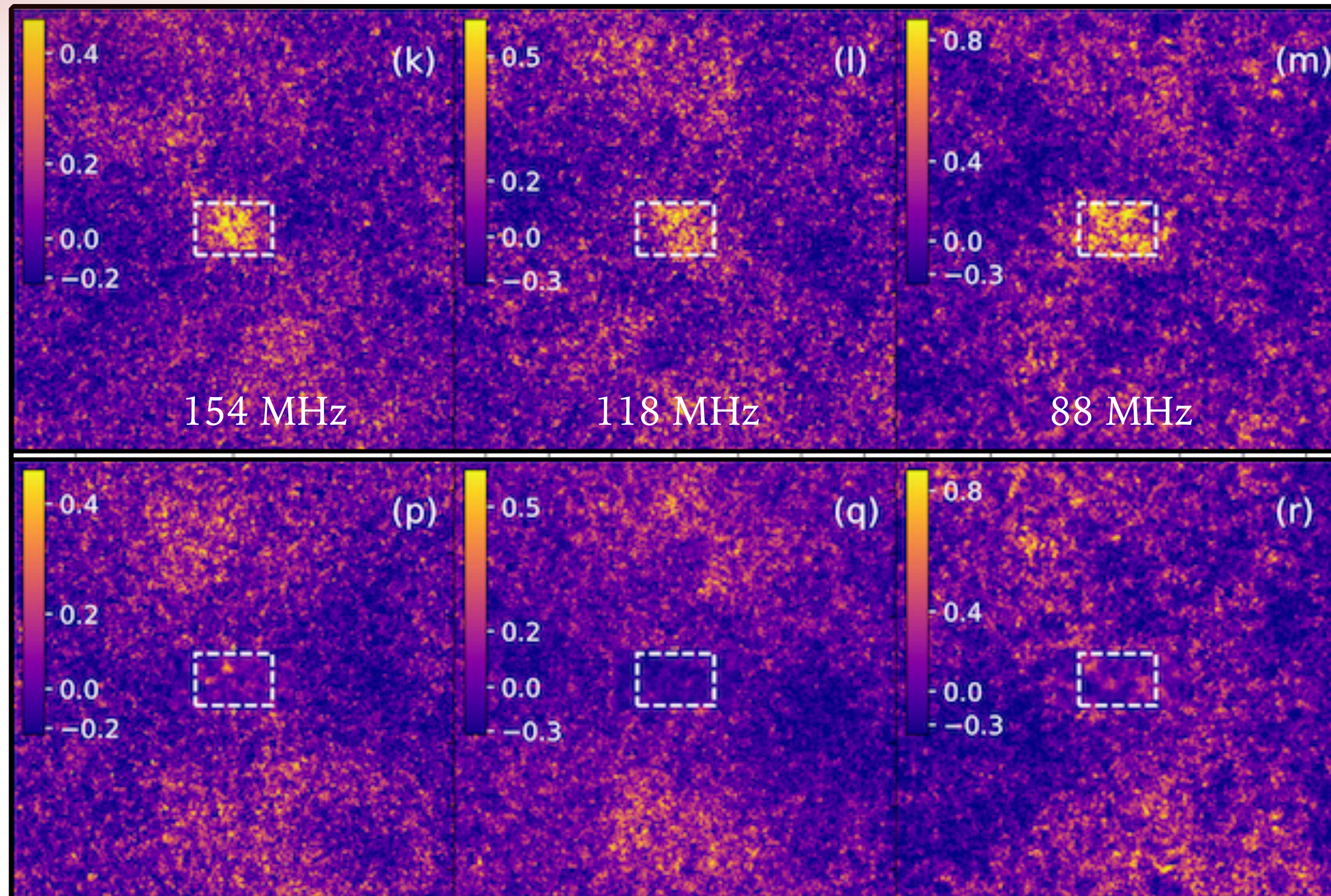
THE COSMIC WEB

Vernstrom et al. (2023), Sci.Adv., 9, 7, ade7233

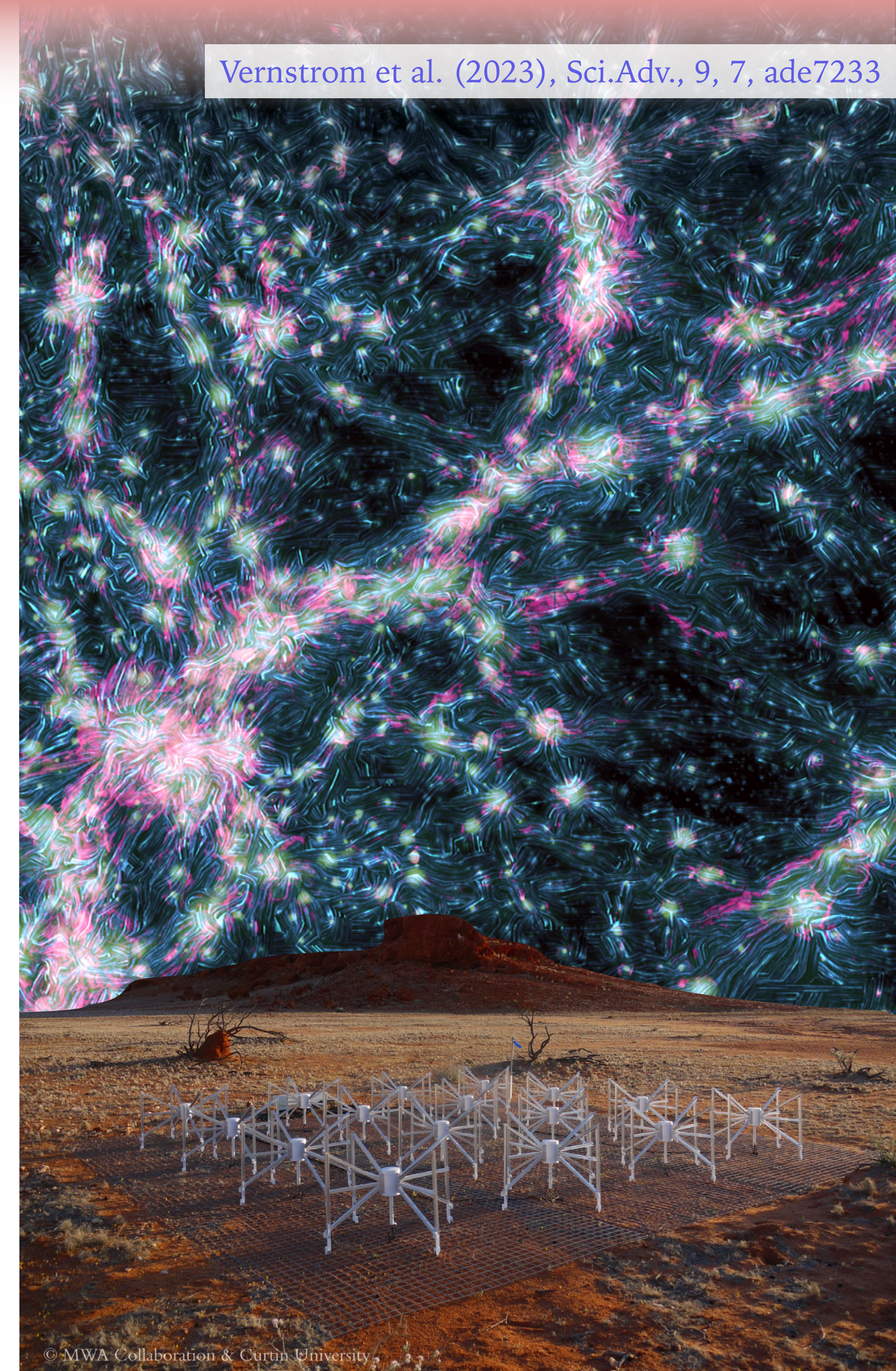


THE COSMIC WEB

Inter-cluster filament stacking; Vernstrom et al. (2021)

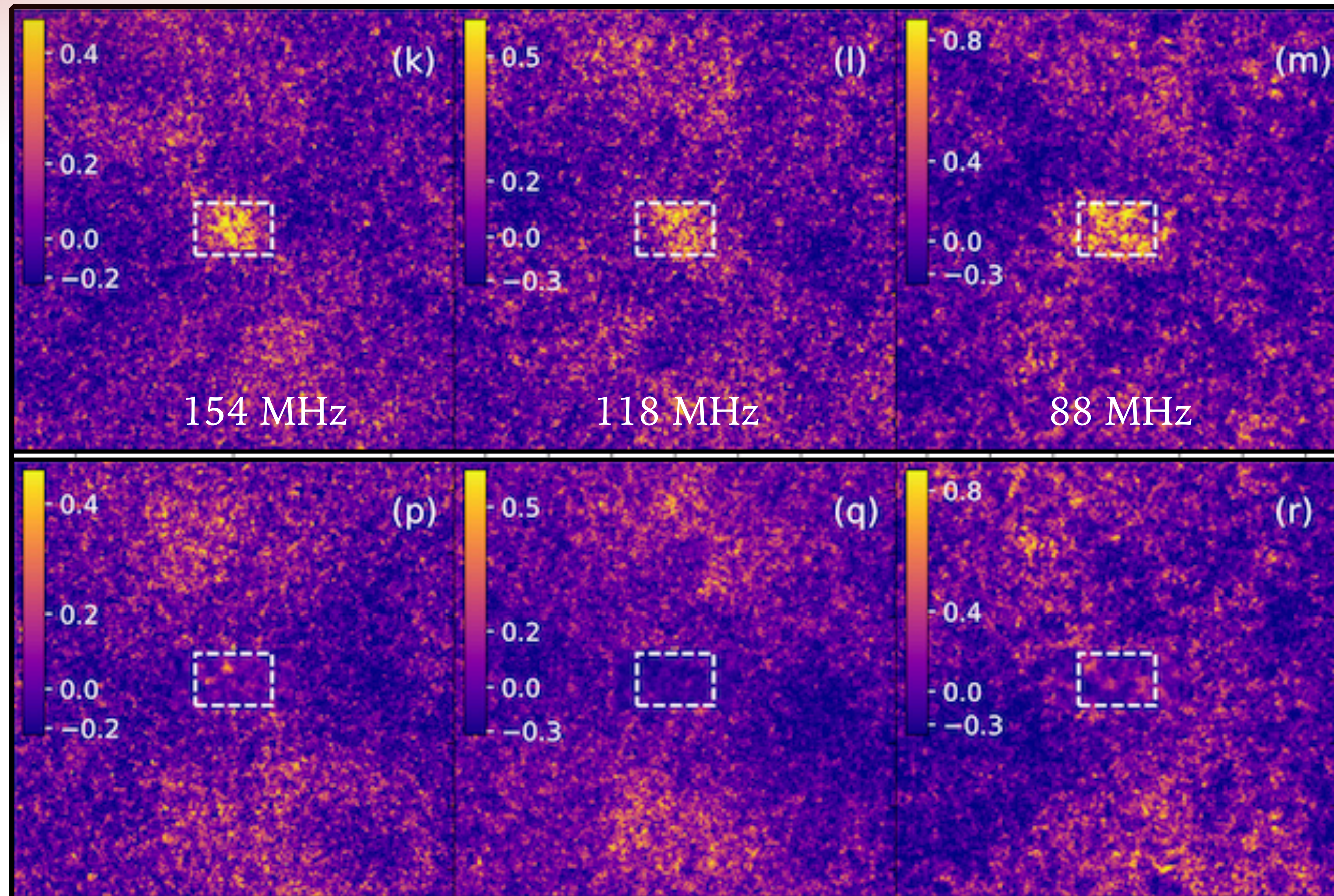


Vernstrom et al. (2023), Sci.Adv., 9, 7, ade7233



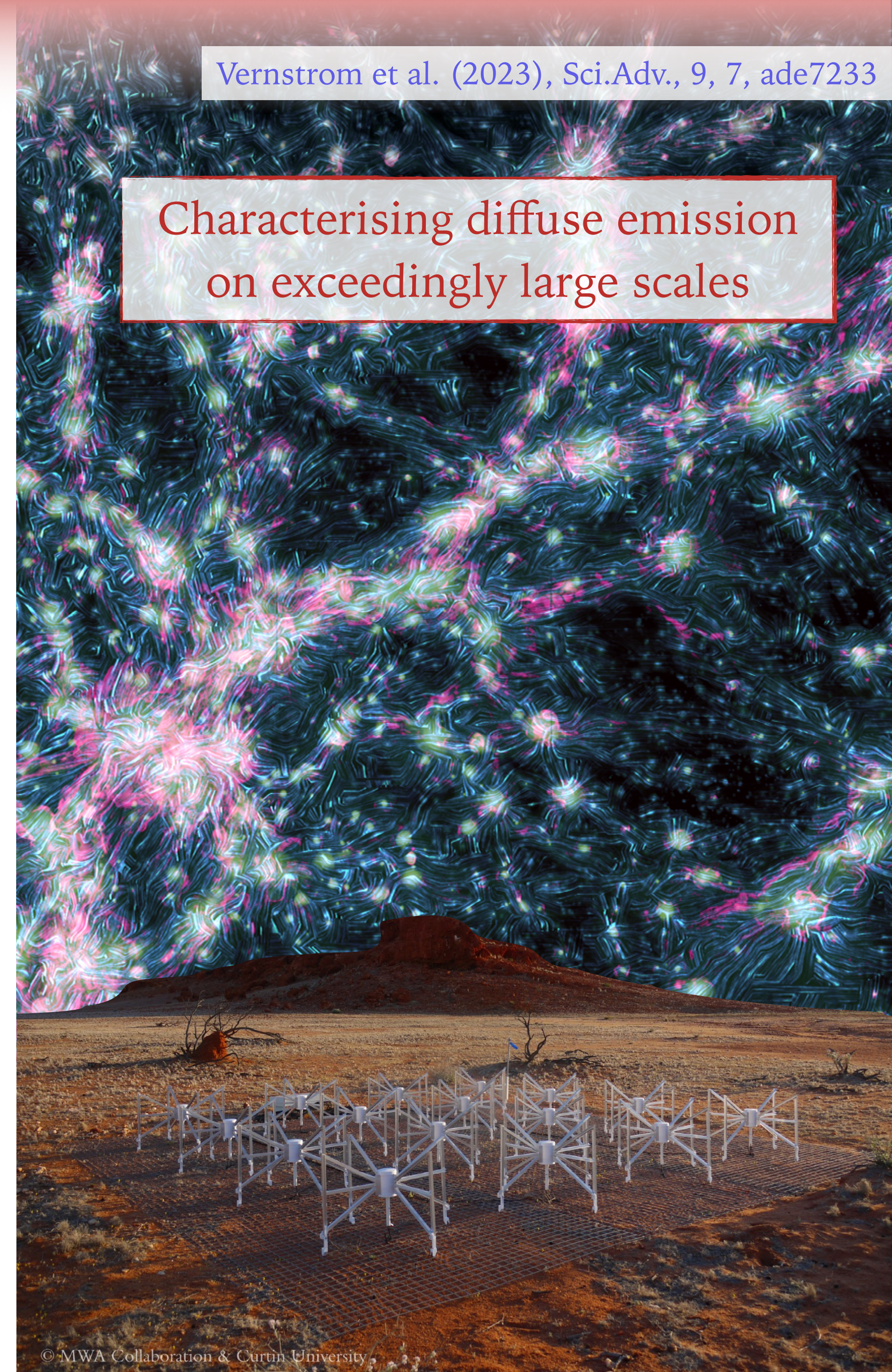
THE COSMIC WEB

Inter-cluster filament stacking; Vernstrom et al. (2021)



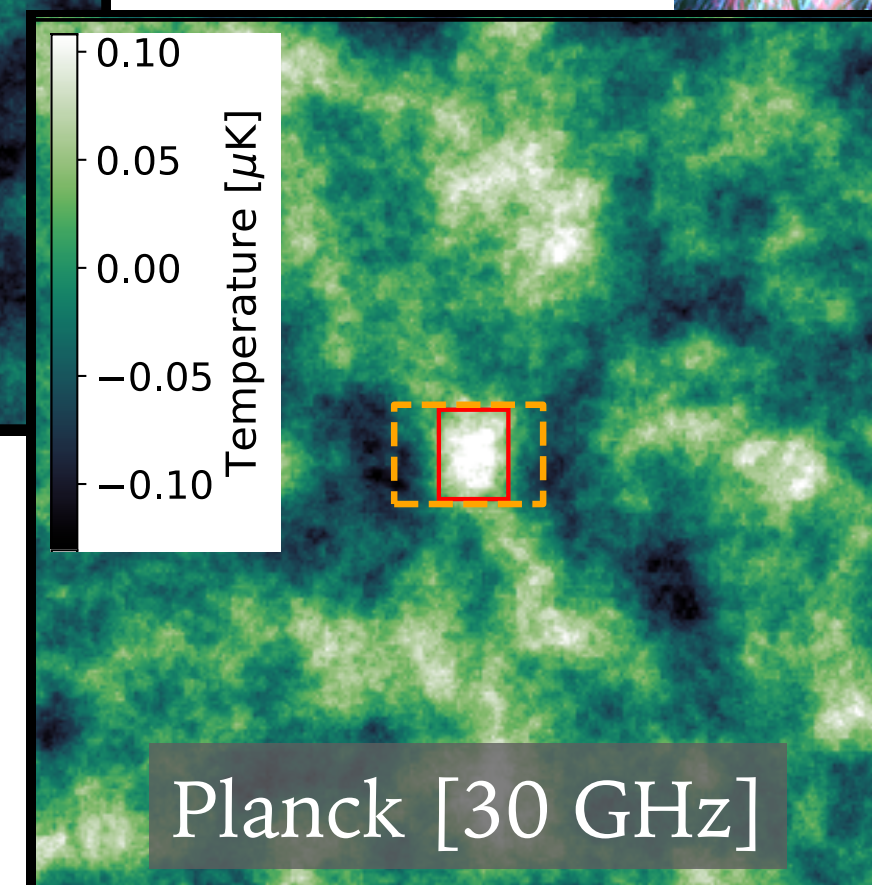
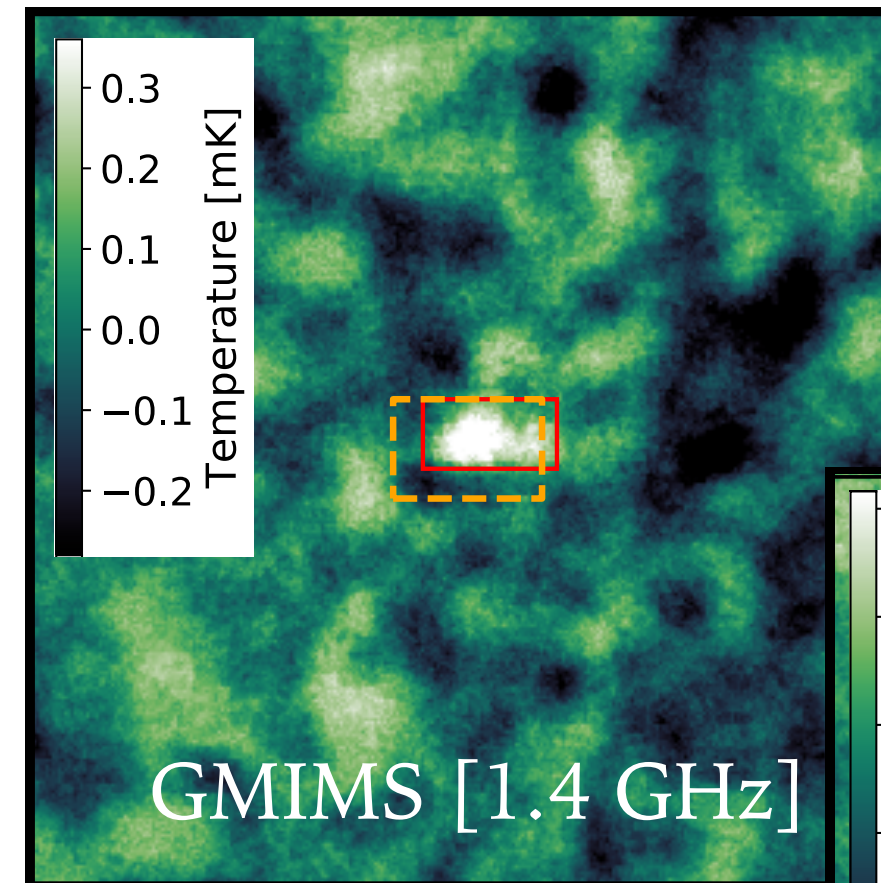
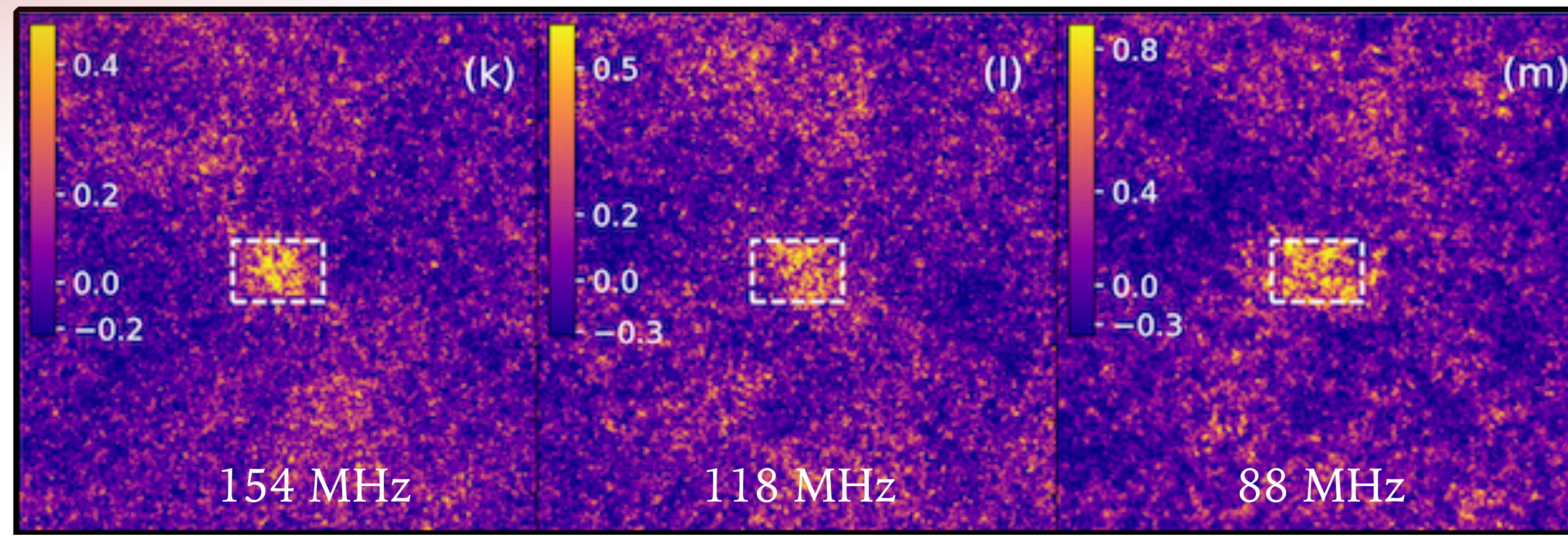
Vernstrom et al. (2023), Sci.Adv., 9, 7, ade7233

Characterising diffuse emission
on exceedingly large scales



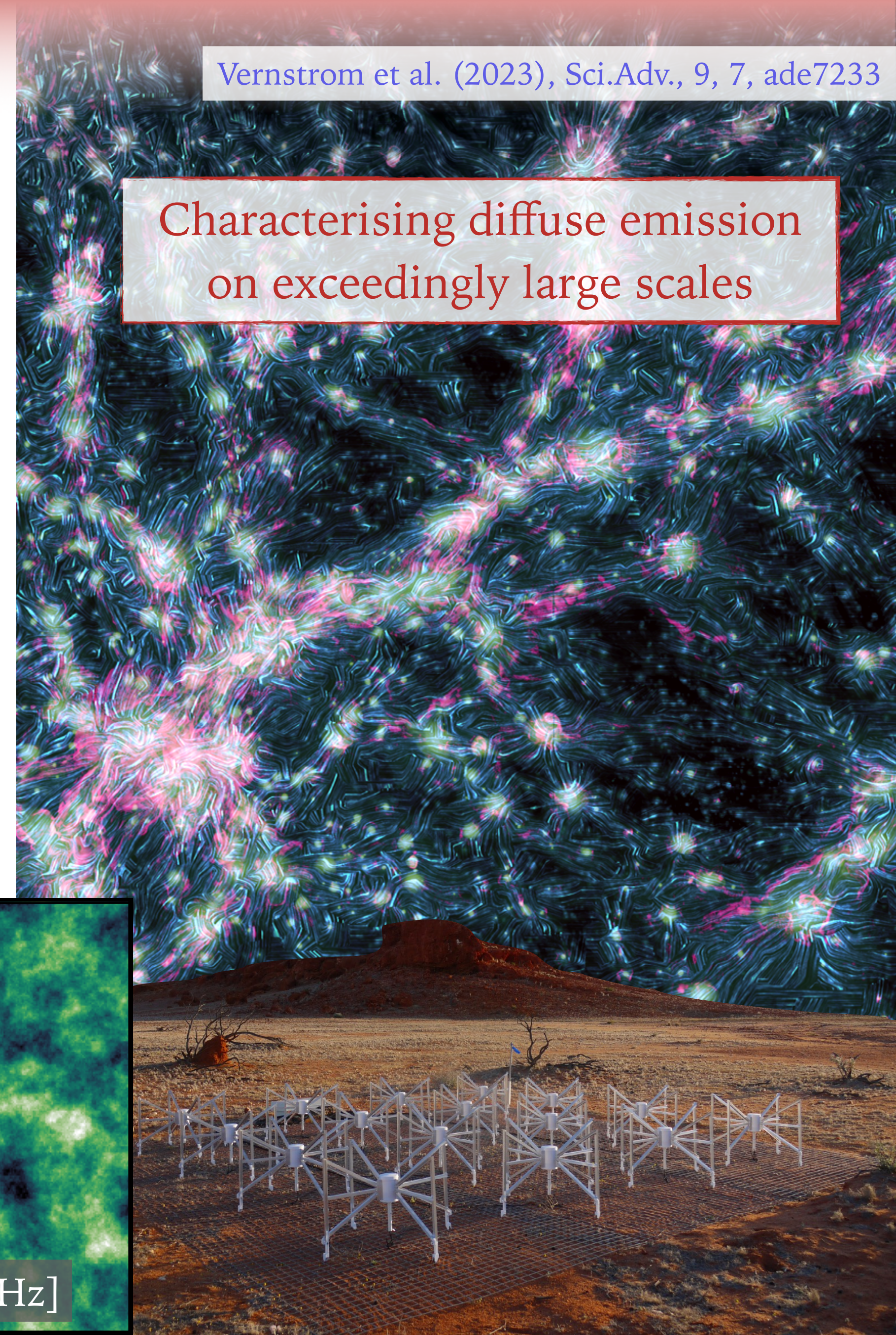
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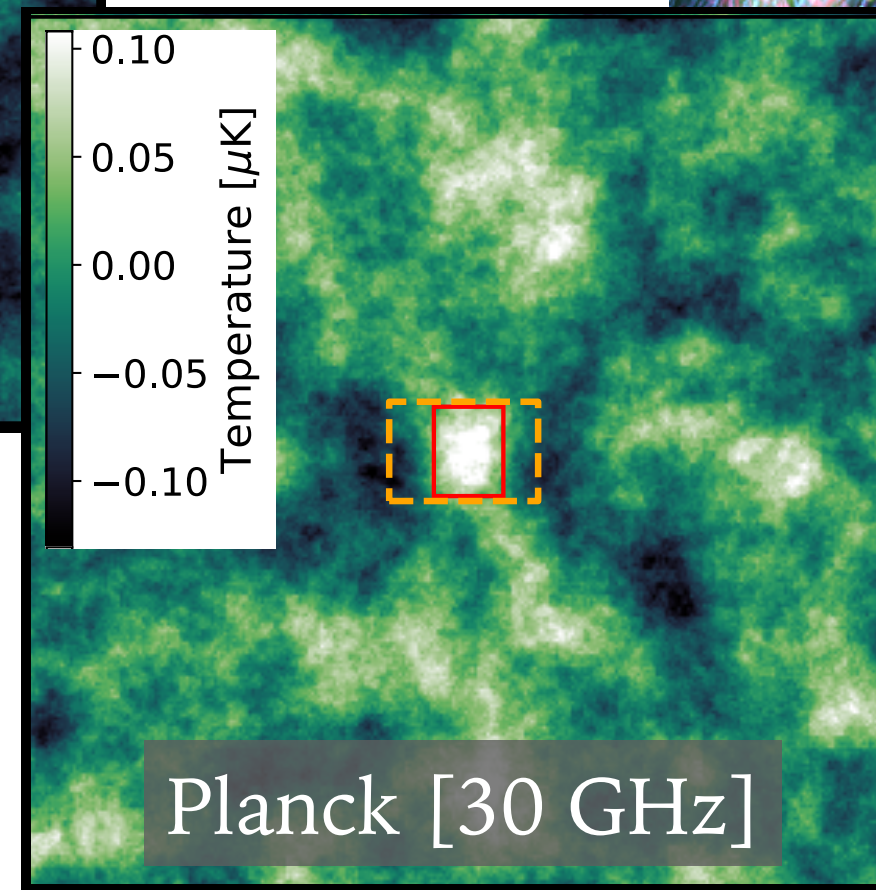
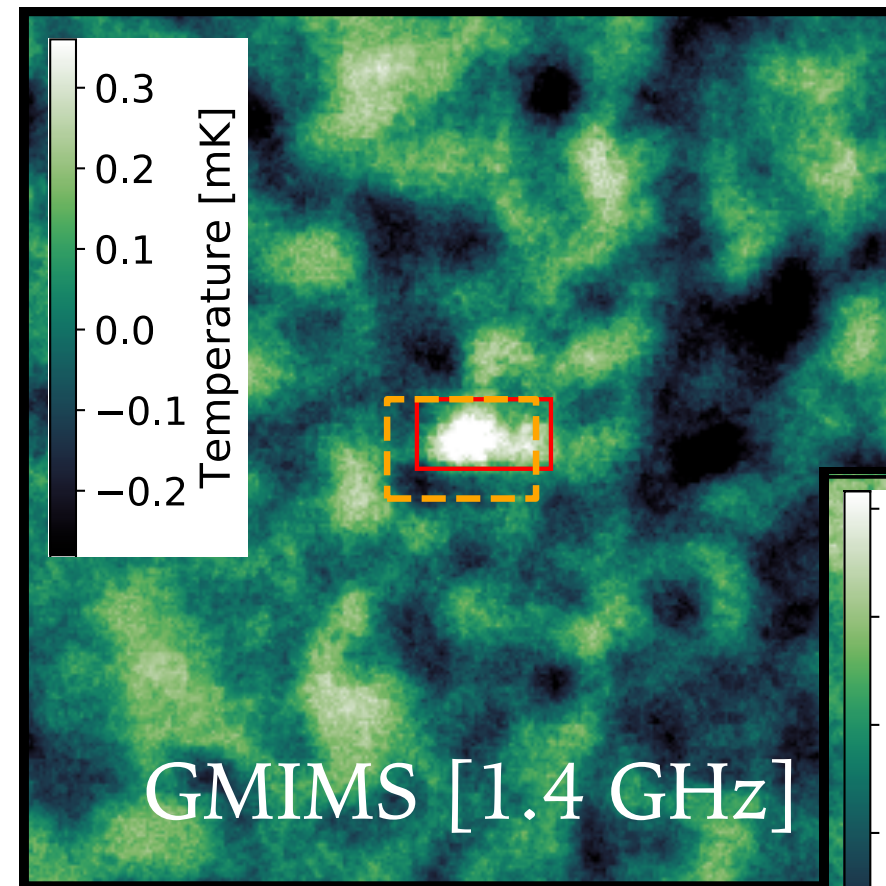
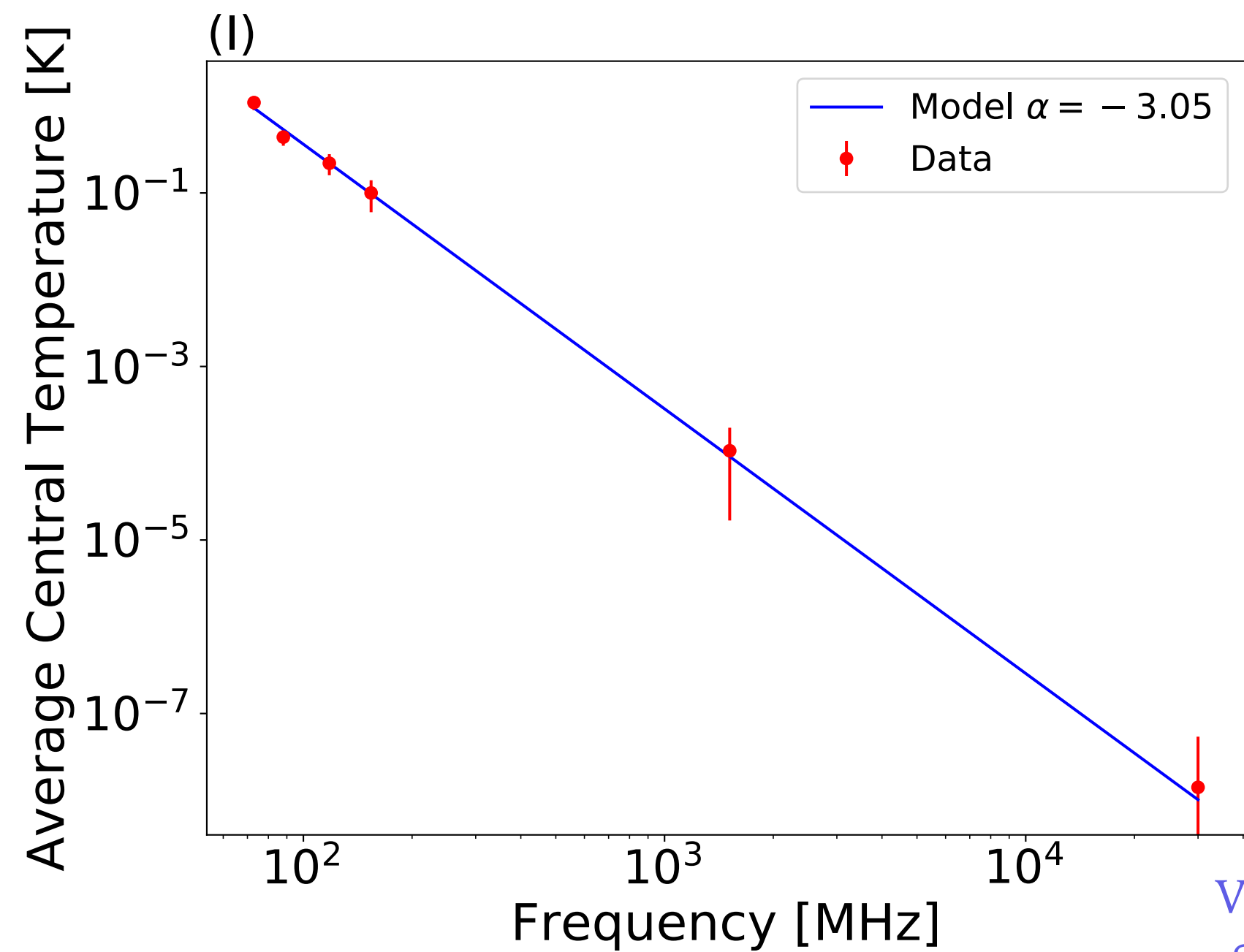
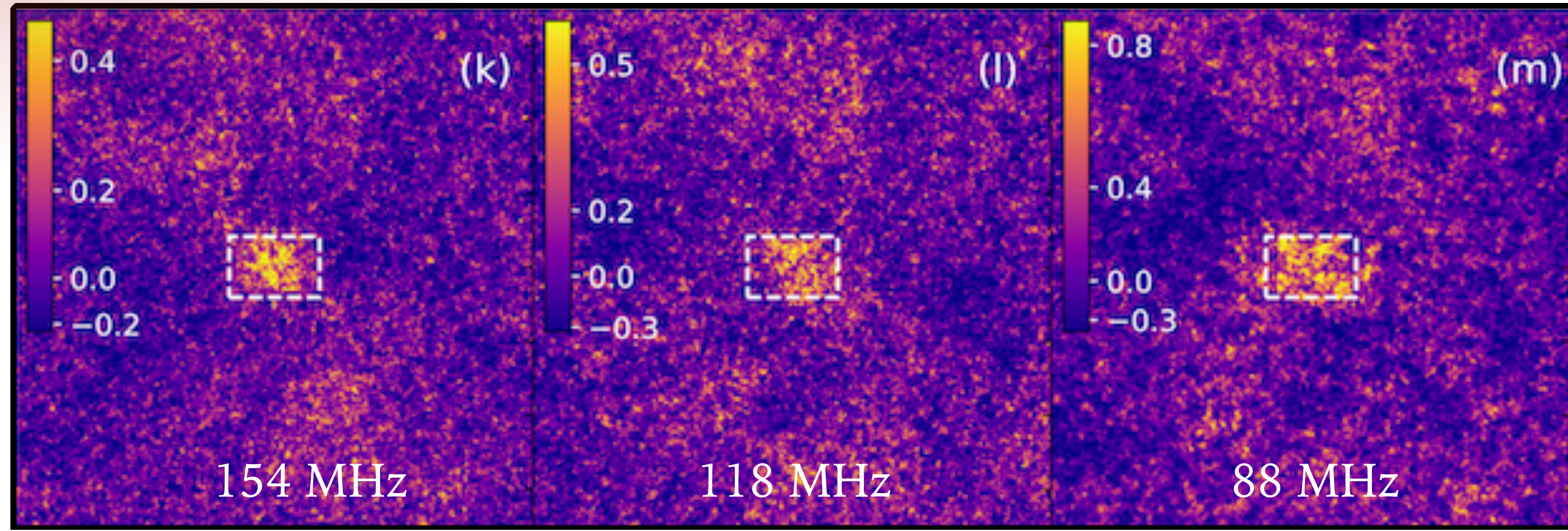
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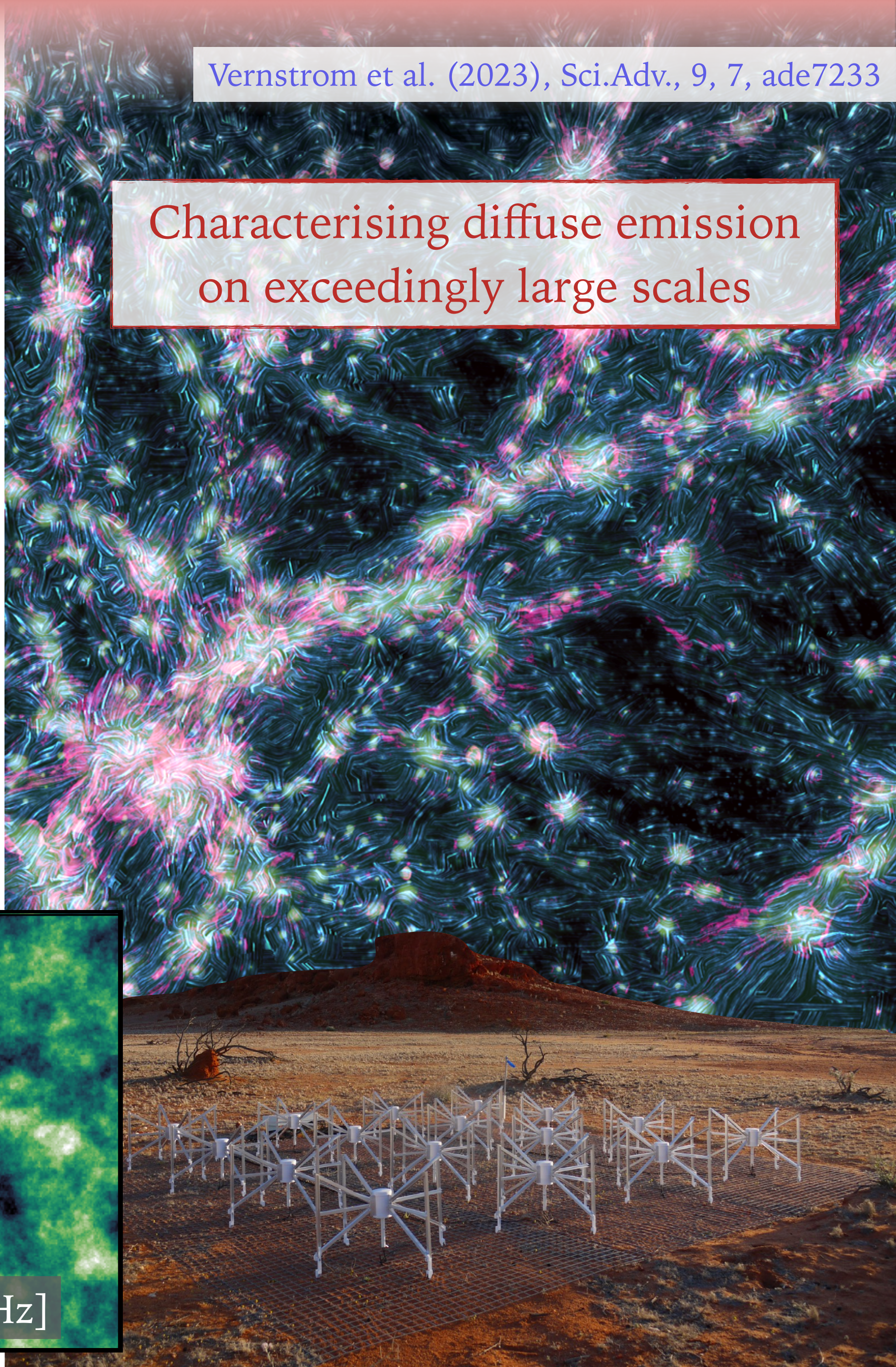
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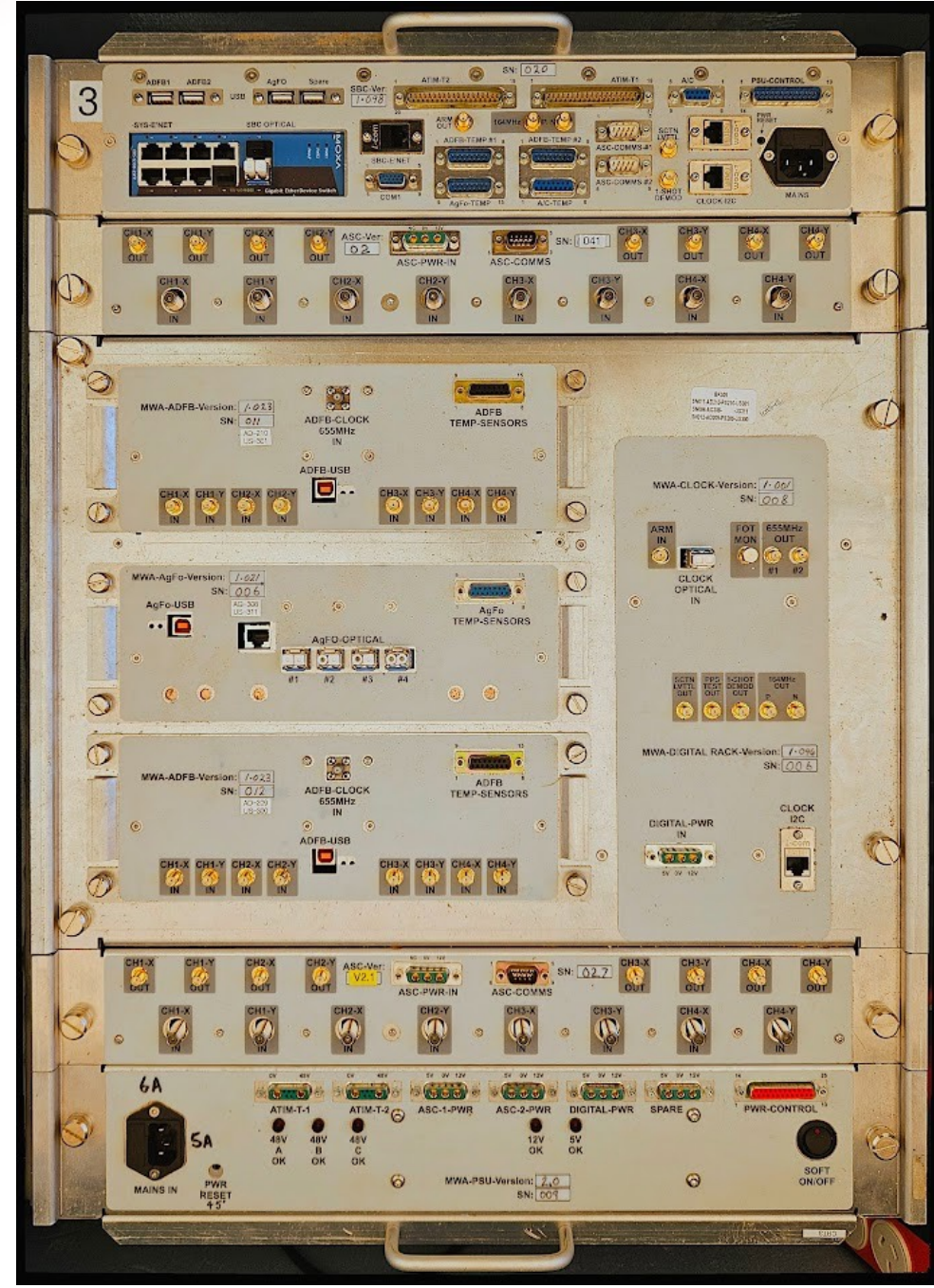
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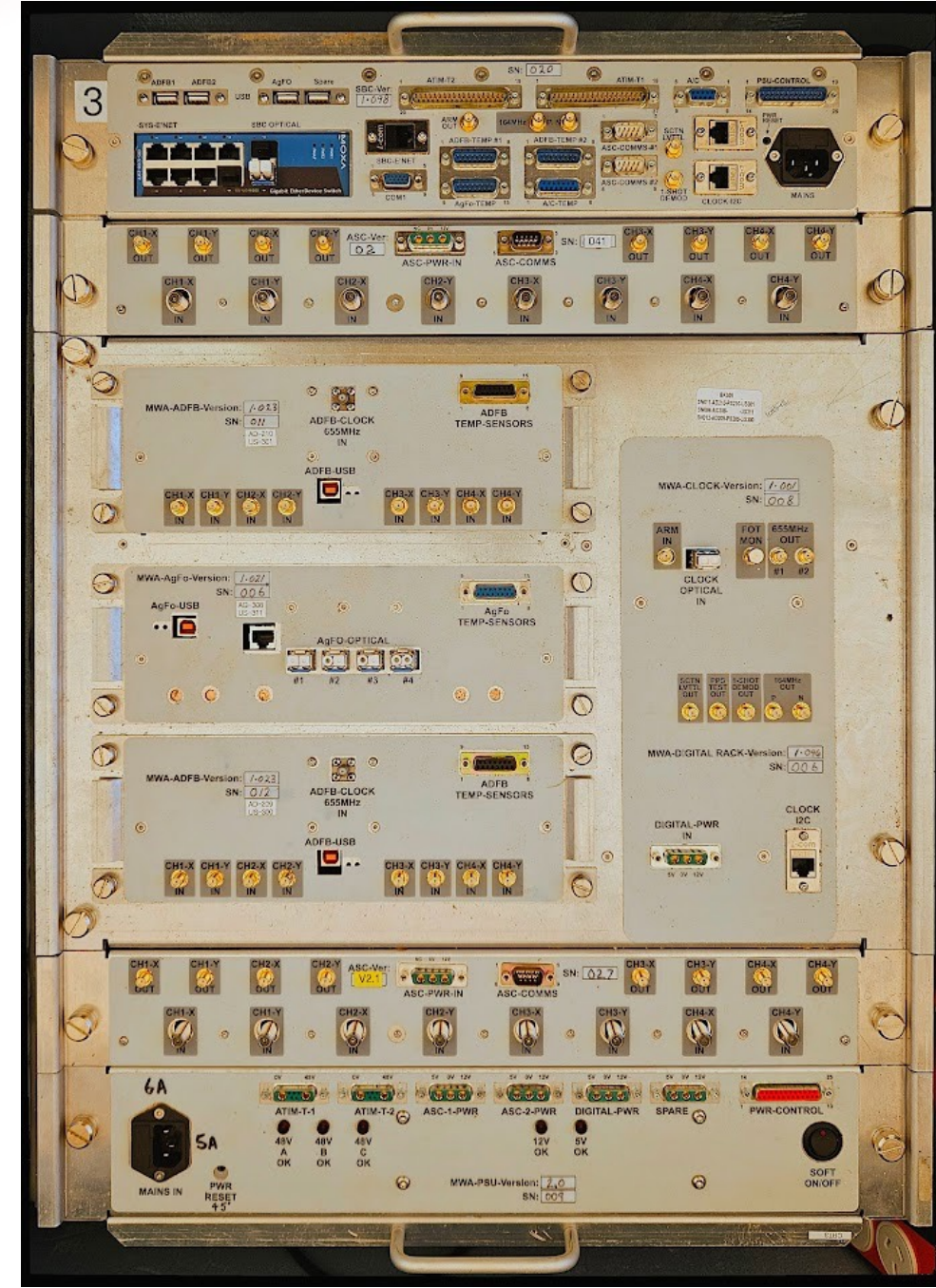
LOOKING TO PHASE III

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16 original receivers

LOOKING TO PHASE III



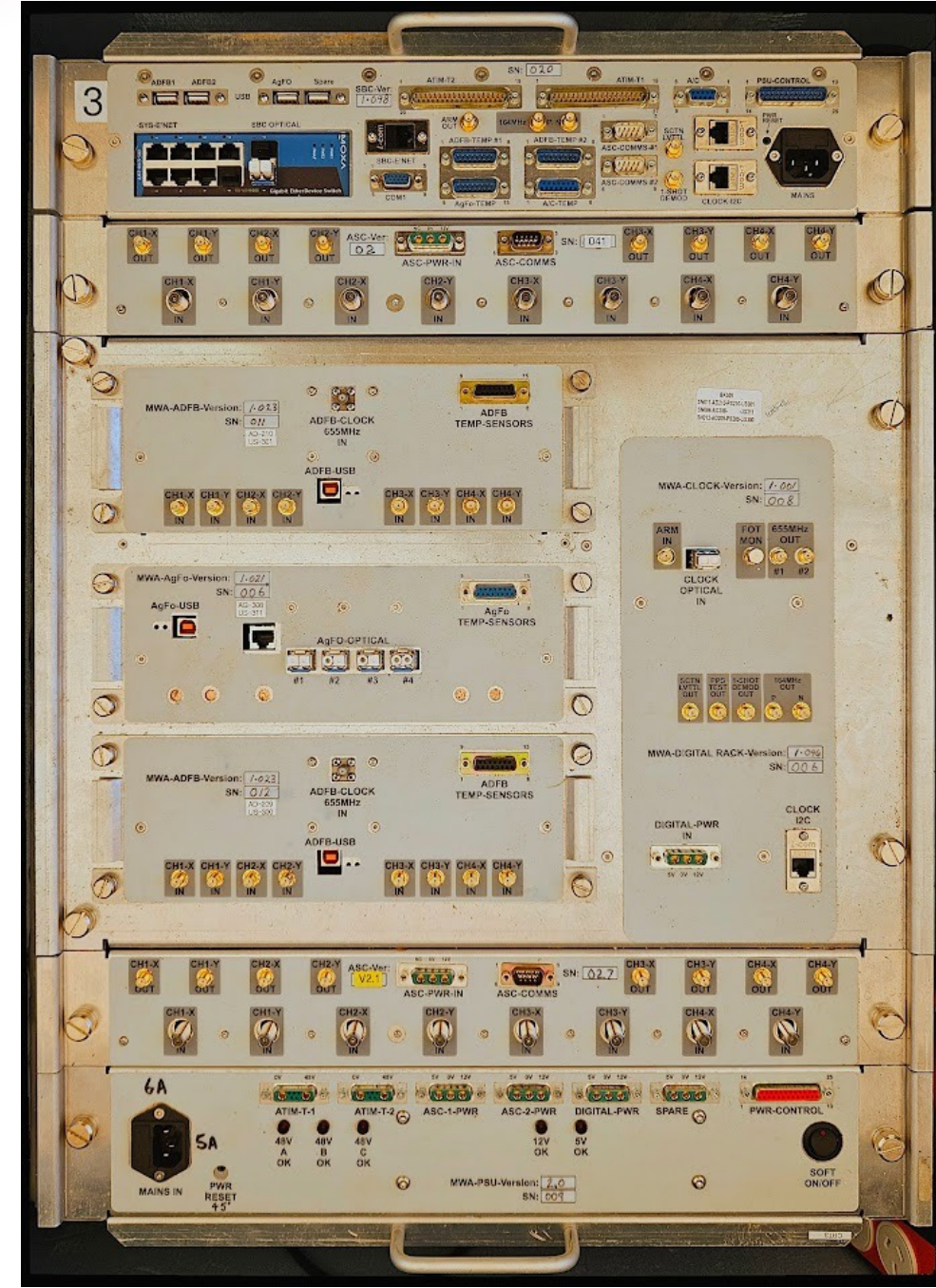
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New correlator

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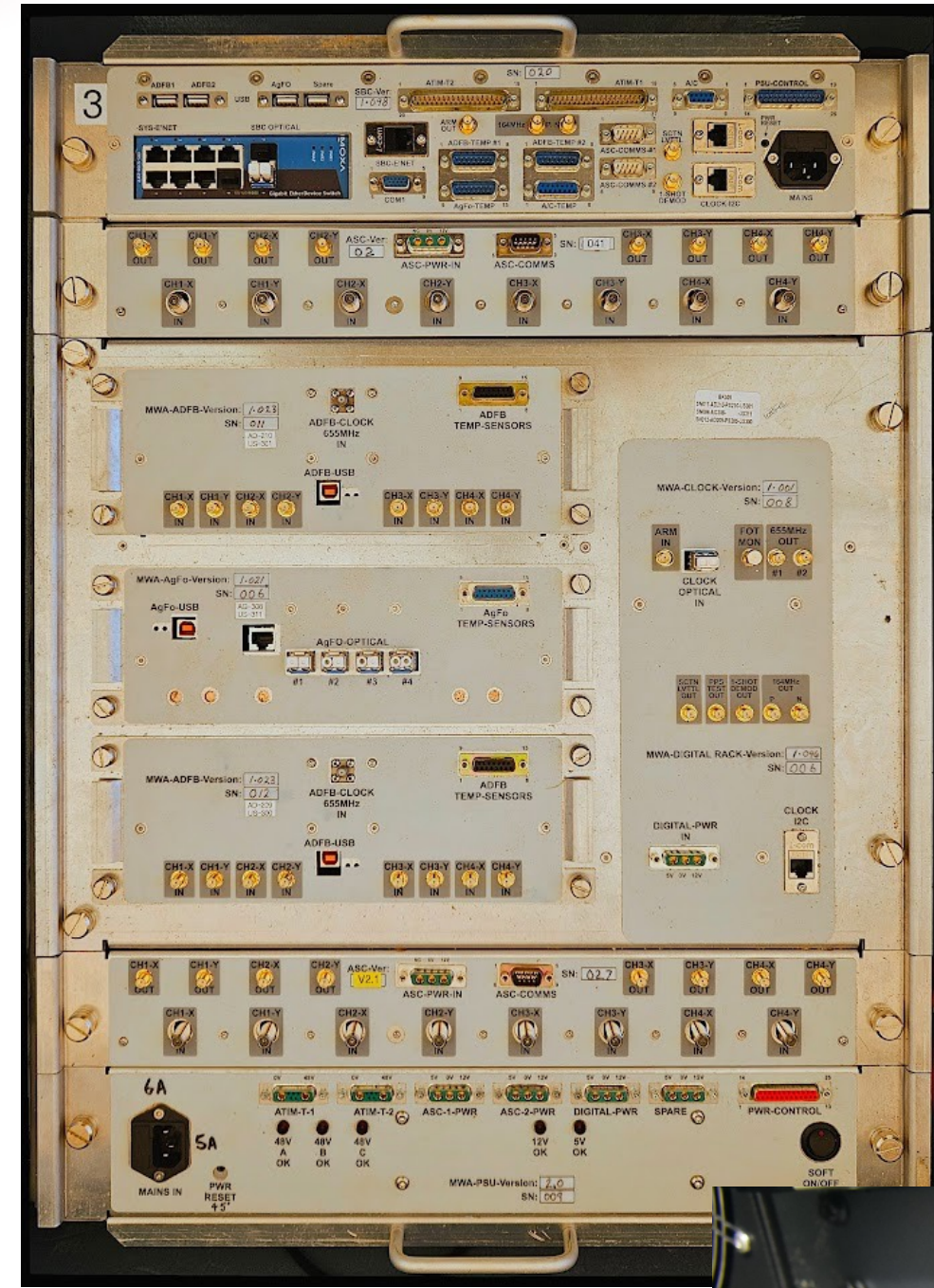
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New MWAX Correlator

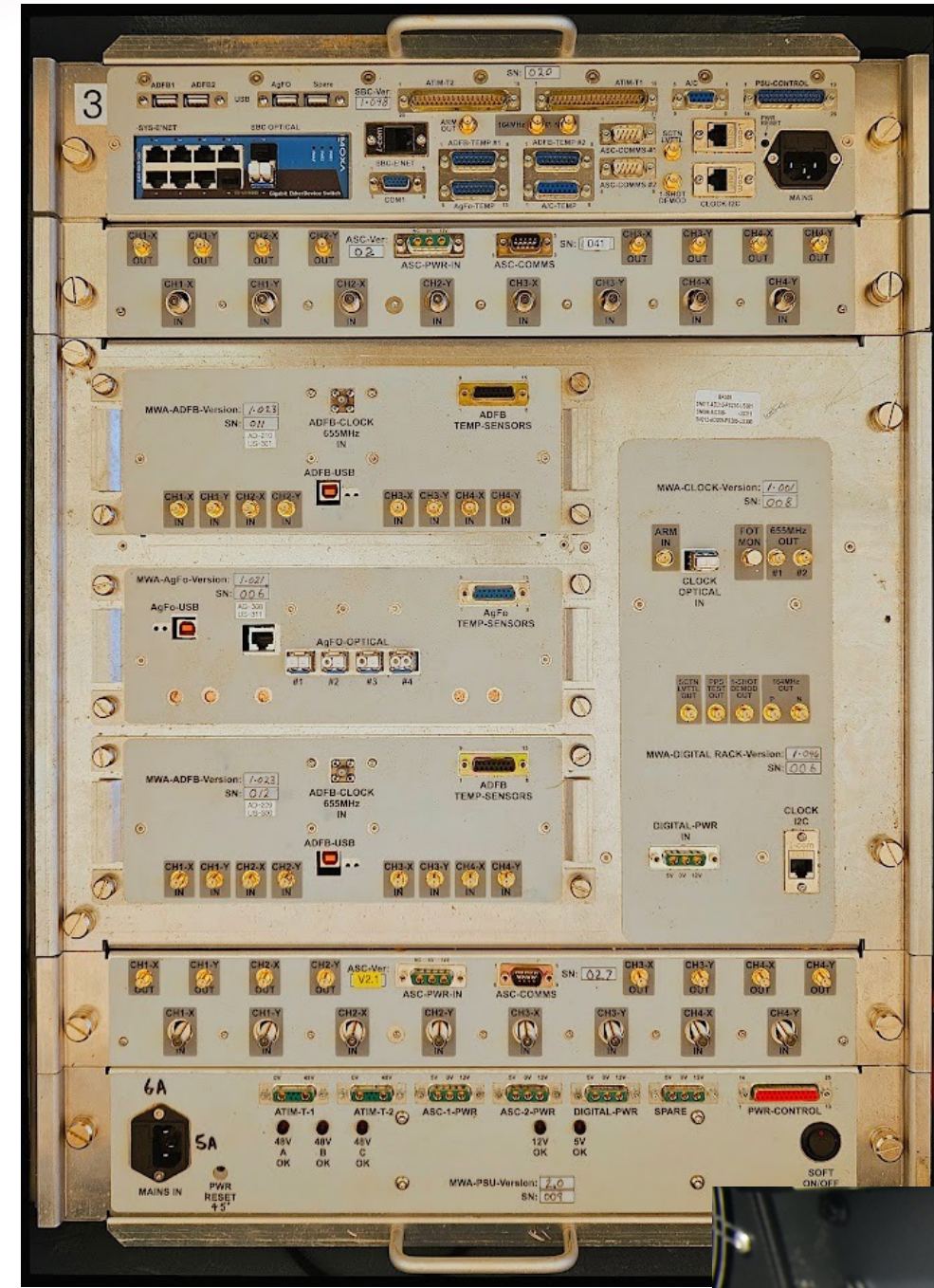


MWAX server; MWA Collaboration & Curtin University

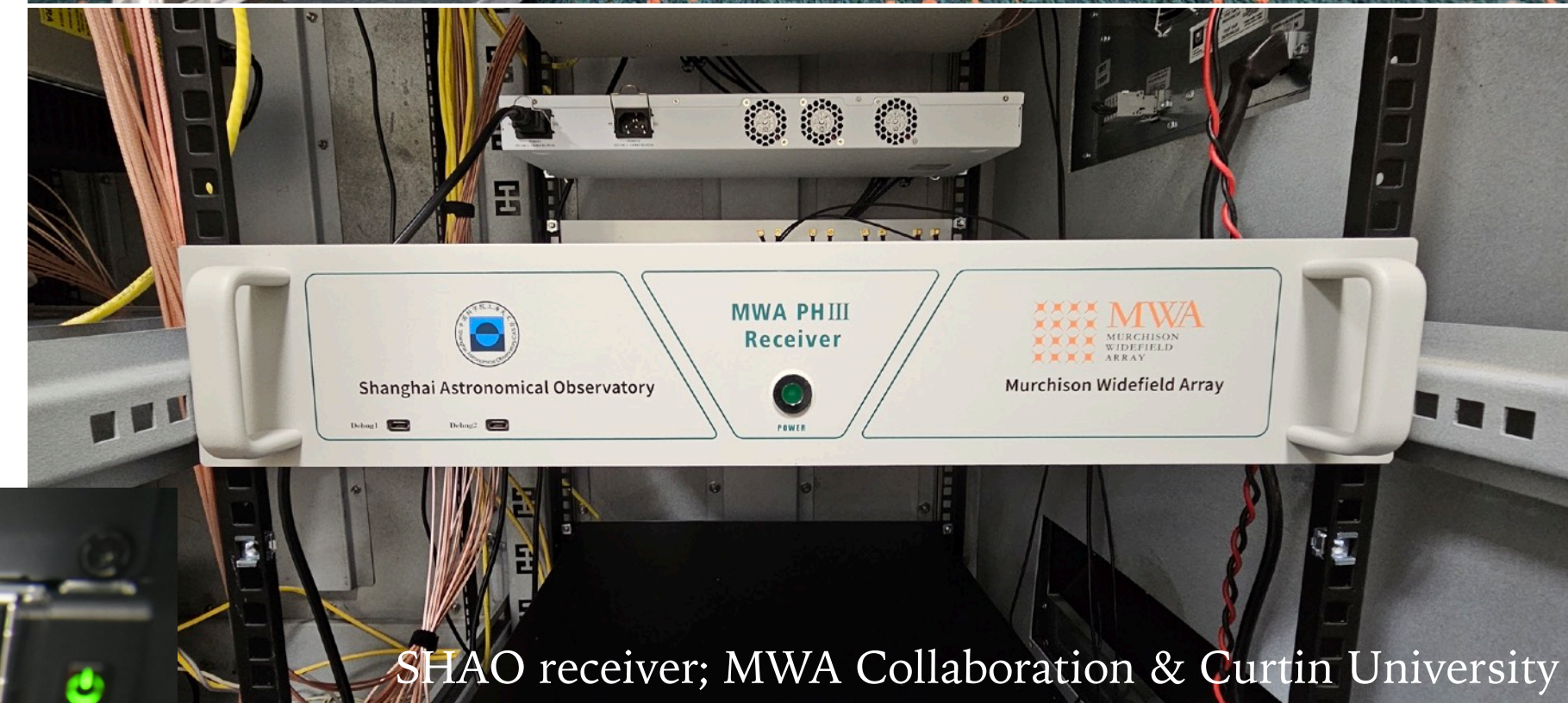
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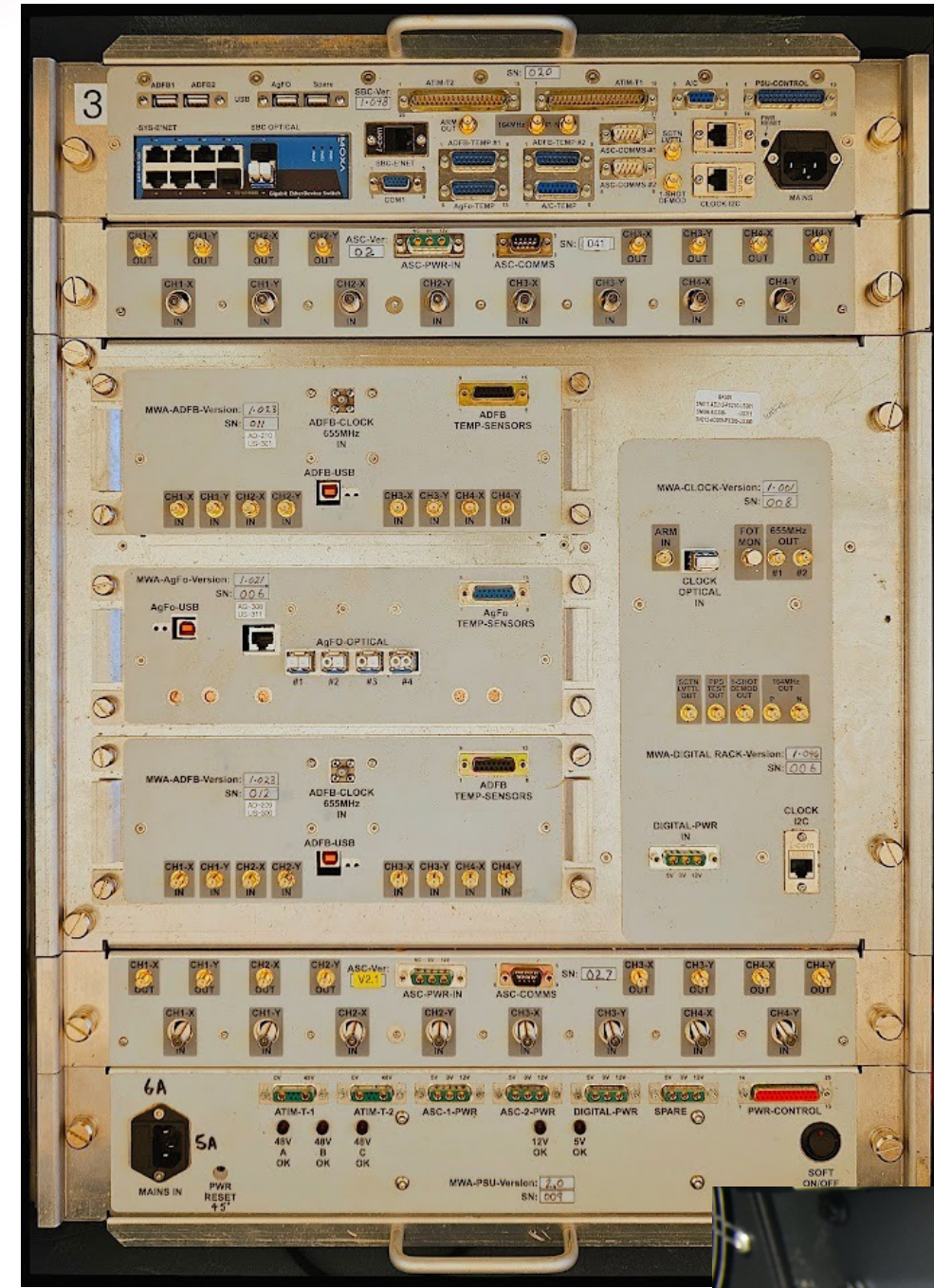
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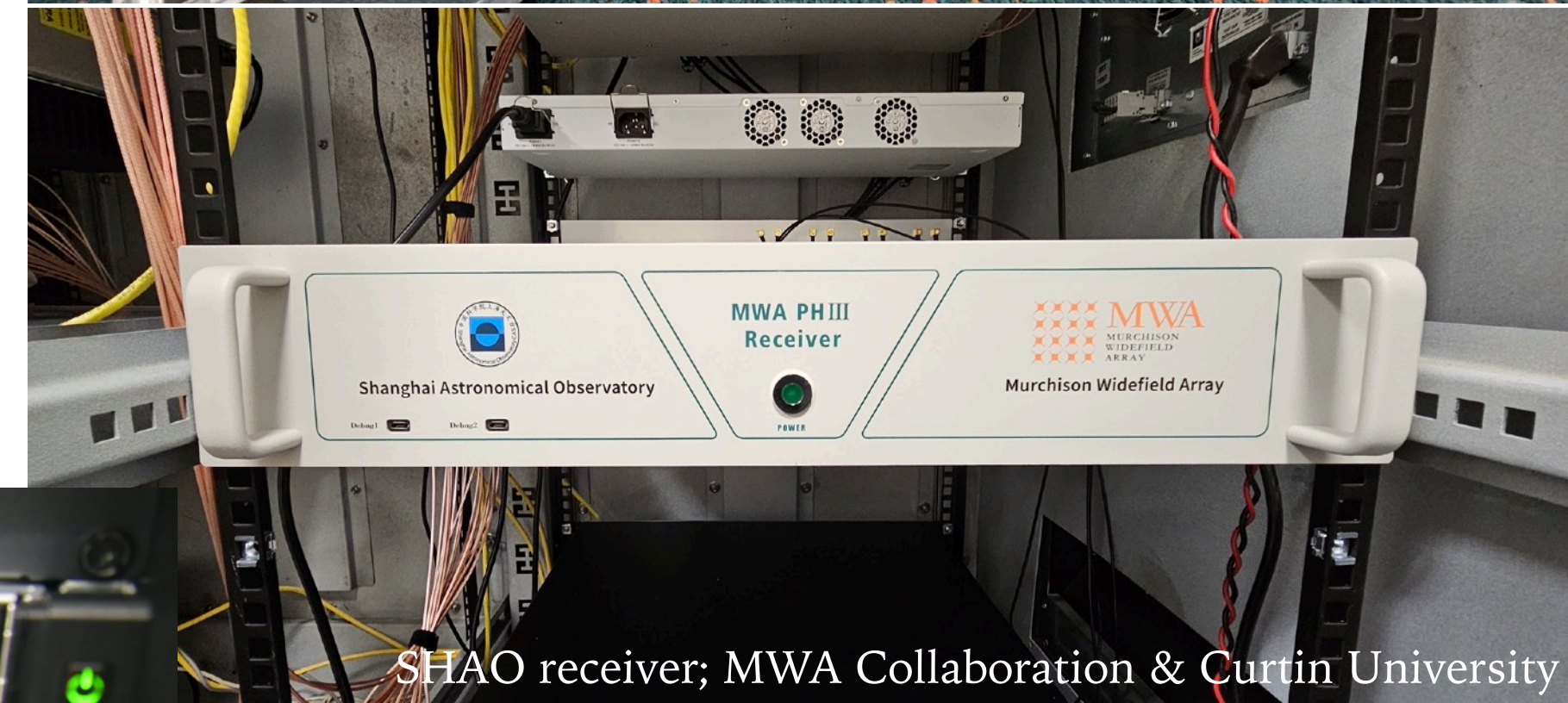
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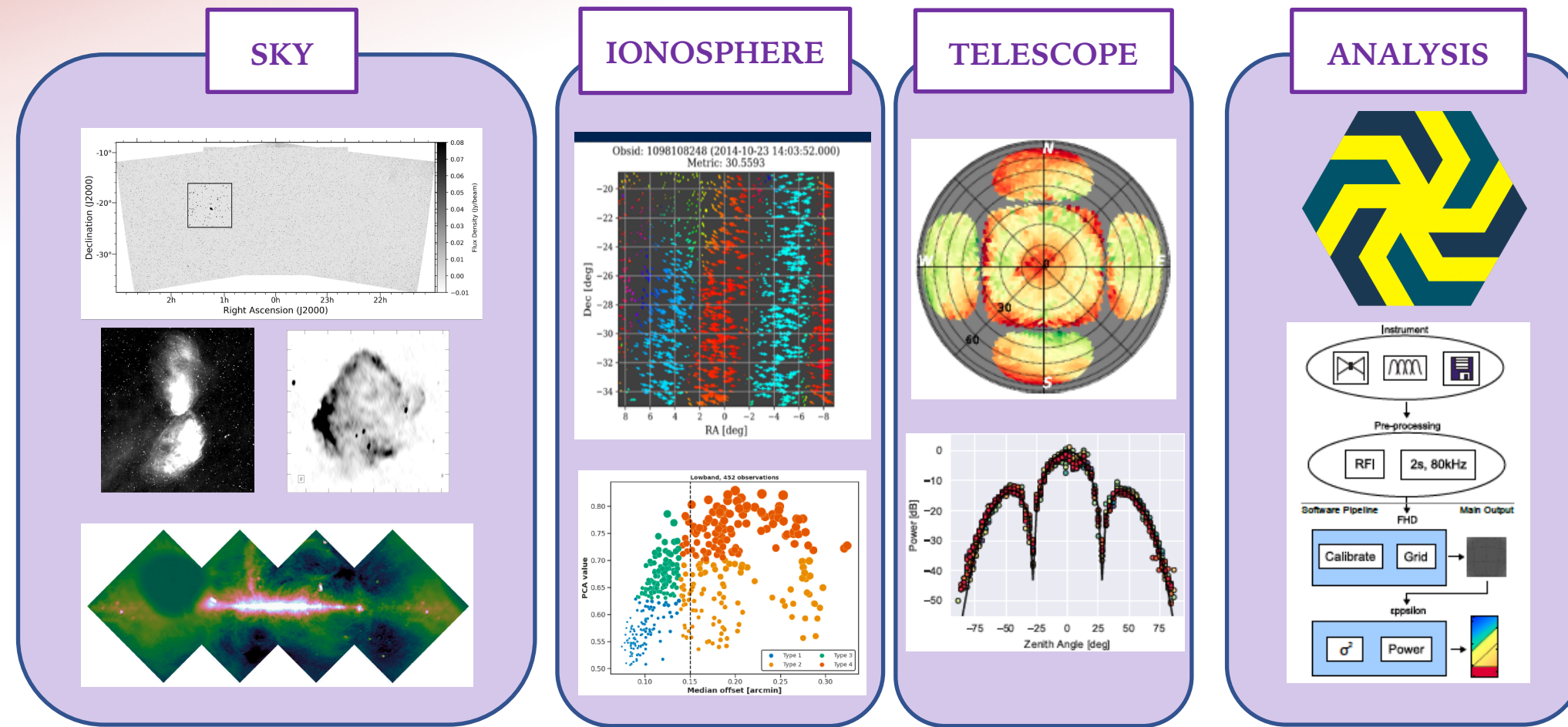


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*On the road to a full
256 tile array!*

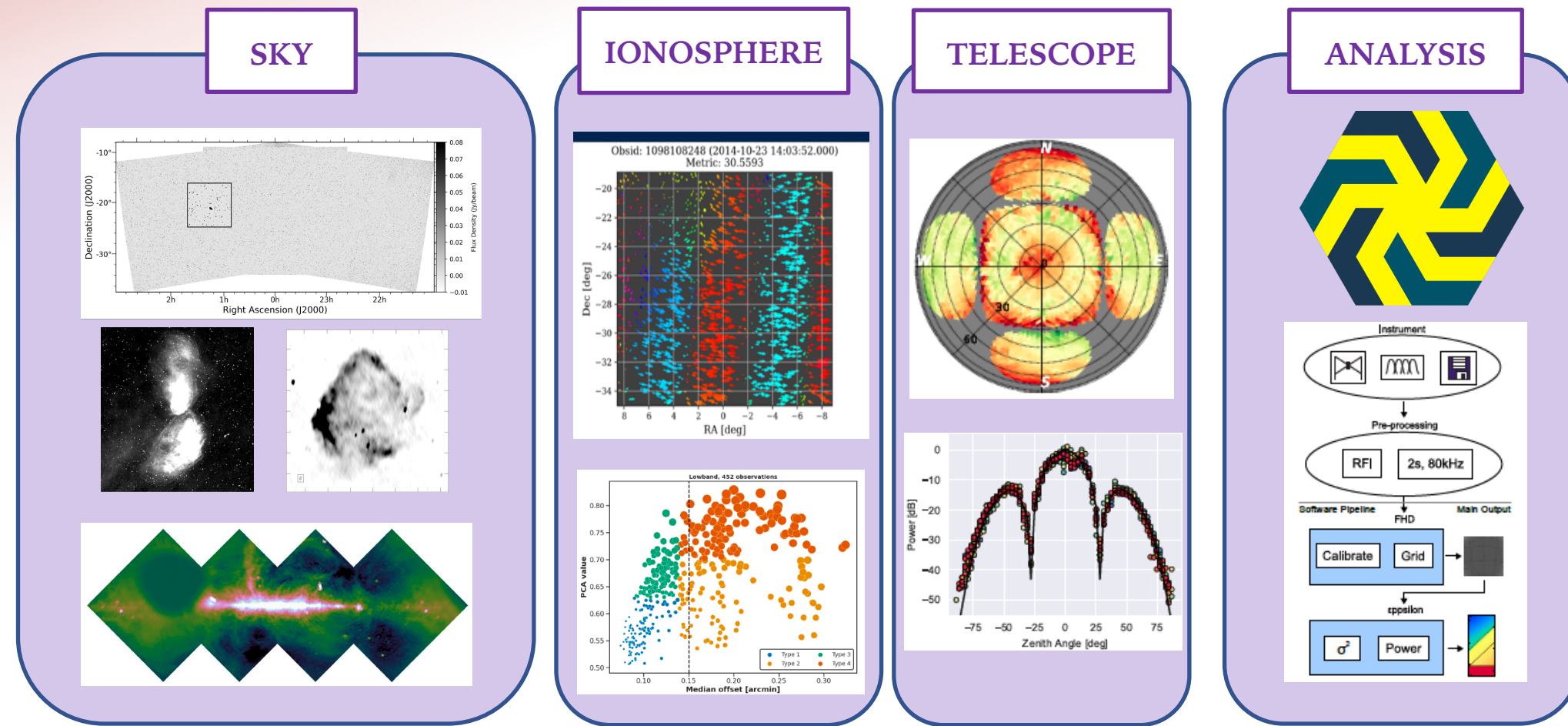
LESSONS LEARNED...

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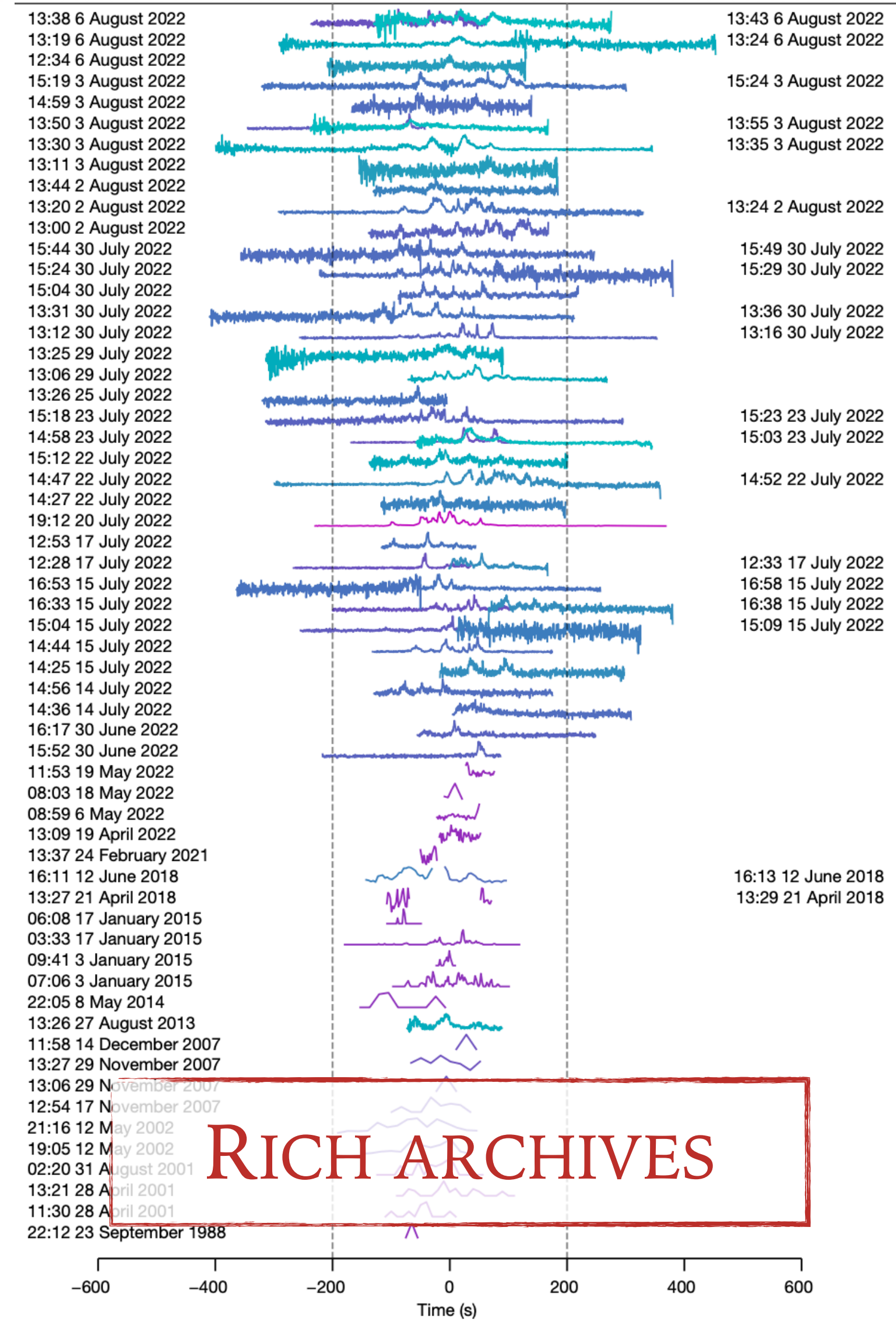


UNDERSTANDING
EVERY STEP

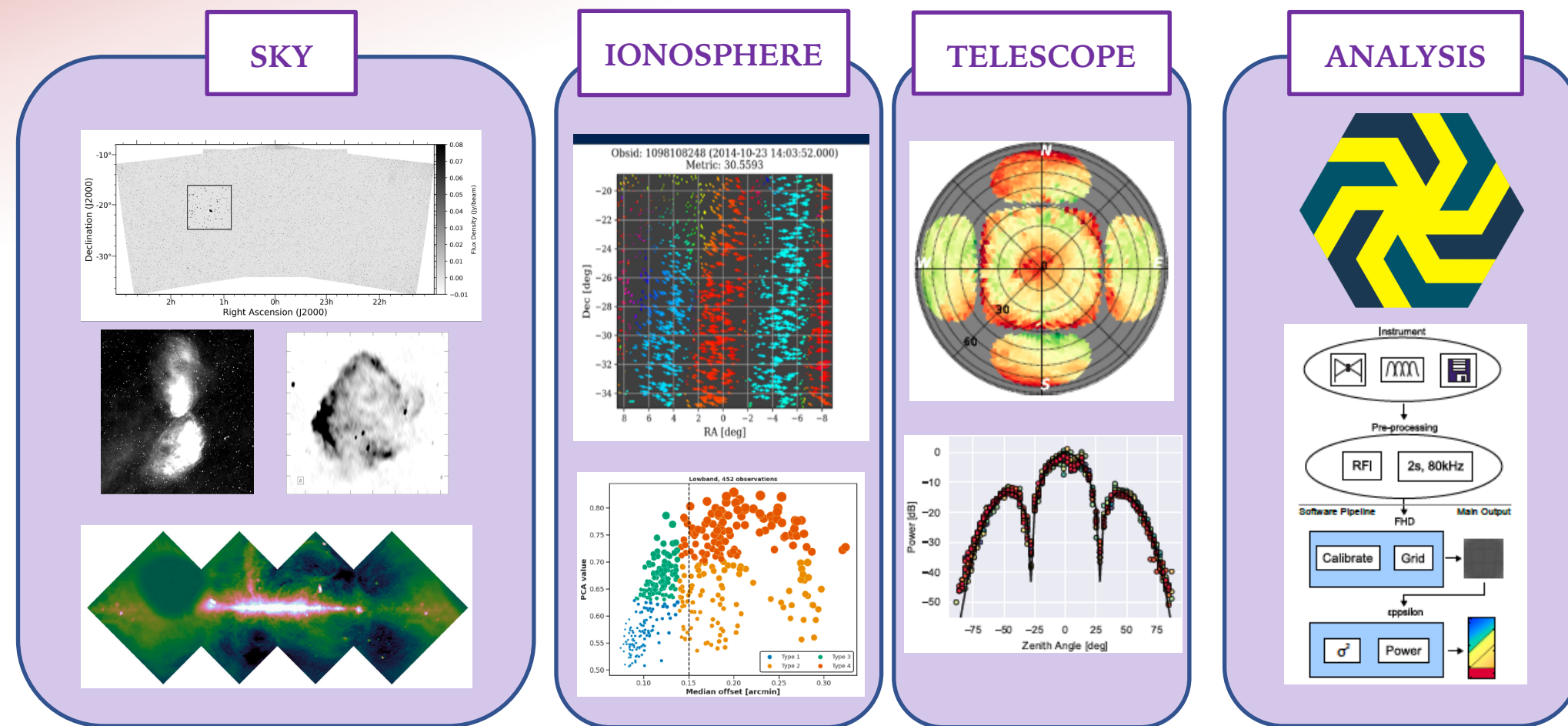
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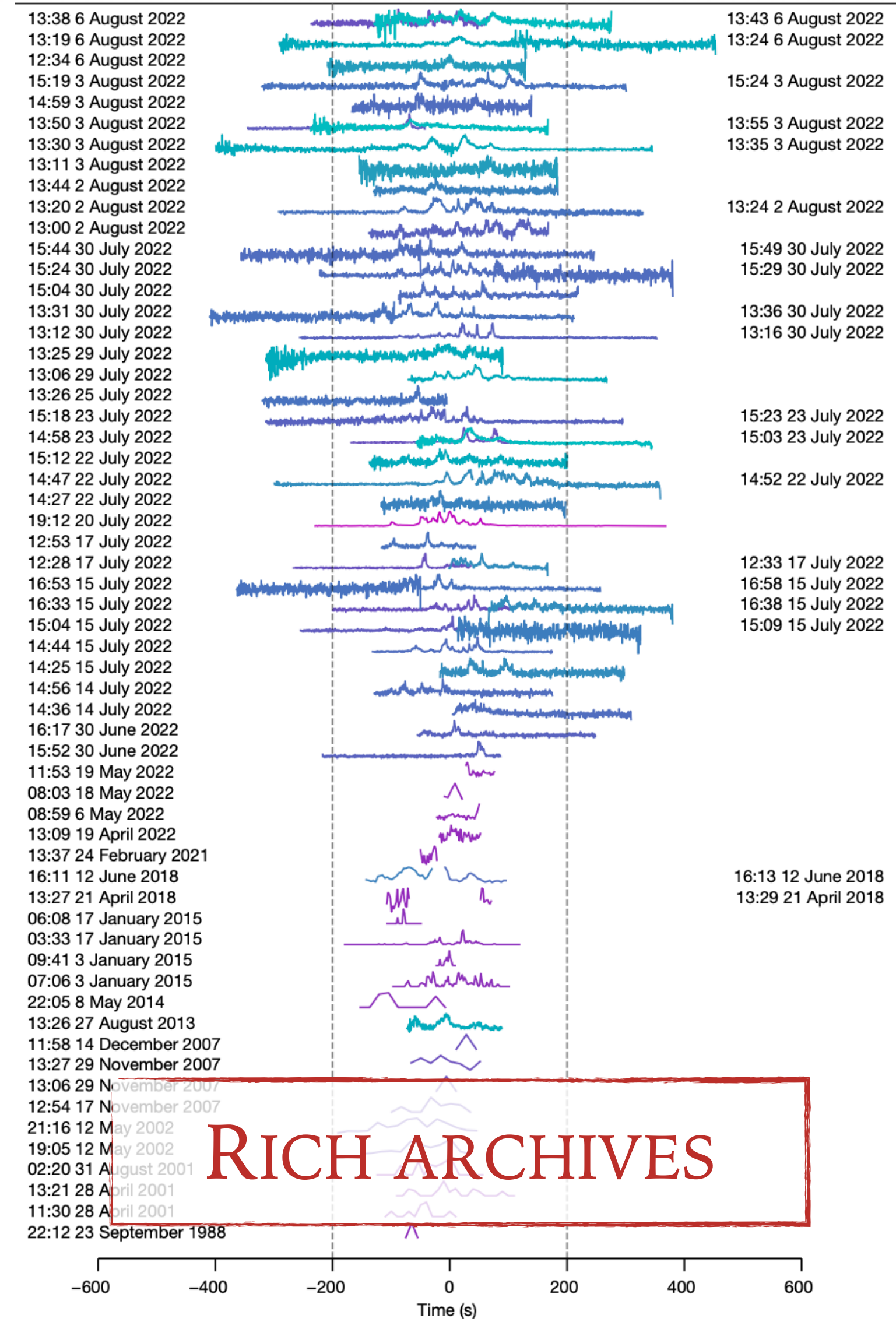
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Ten years of MWA operations; credit: MWA Collaboration

IT'S ABOUT THE PEOPLE

SUMMARY



This scientific work uses data obtained from Inyarrimanha Ilgari Bundara / the Murchison Radio-astronomy Observatory. We acknowledge the Wajarri Yamaji People as the Traditional Owners and native title holders of the Observatory site. Establishment of CSIRO's Murchison Radio-astronomy Observatory is an initiative of the Australian Government, with support from the Government of Western Australia and the Science and Industry Endowment Fund. Support for the operation of the MWA is provided by the Australian Government (NCRIS), under a contract to Curtin University administered by Astronomy Australia Limited. This work was supported by resources provided by the Pawsey Supercomputing Research Centre with funding from the Australian Government and the Government of Western Australia.

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► MWA science highlights:

- ◉ **EoR**: deepest limits through a broad range of advances
- ◉ **SHI**: understanding solar weather; tackling the ionosphere
- ◉ **PFT**: legacy all-sky high time-resolution survey (SMART)
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Thanks for listening. Questions?

