# The long-wavelength view from the land down under: highlights from a decade of science with the Murchison Widefield Array


**Dr. Christopher Riseley (Chris)**

Research Fellow // MWA Principal Scientist

[1.] Dipartimento di fisica e astronomia, Alma Mater Studiorum — Università di Bologna | [2.] INAF -- Istituto di Radioastronomia, Bologna

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

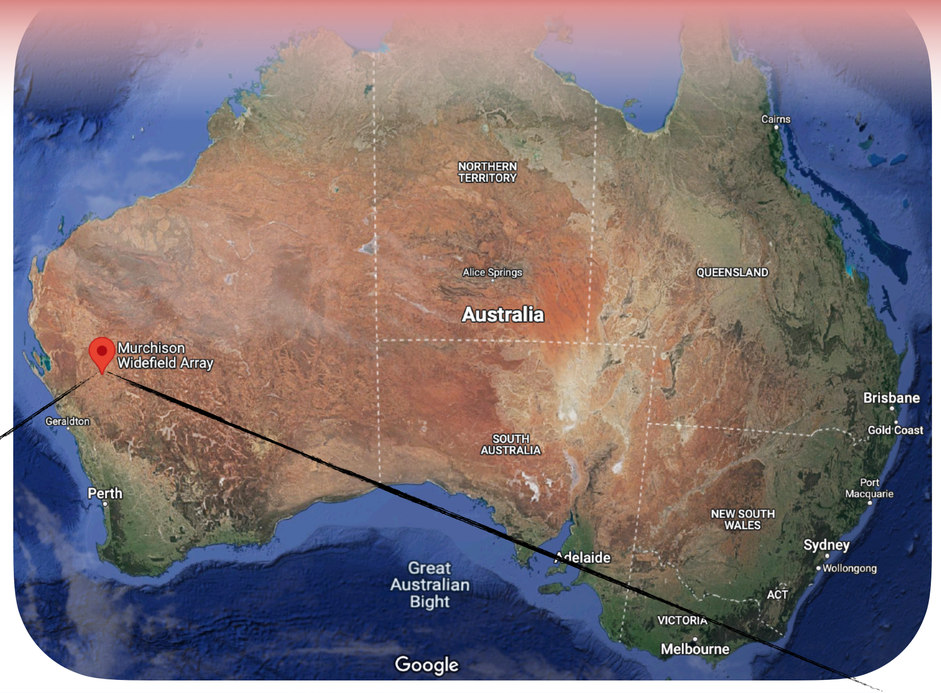
[Prof. Randall Wayth, Ms. Mia Walker, Dr. Ben McKinley and others]


RADIO 2024 | 15th November 2024

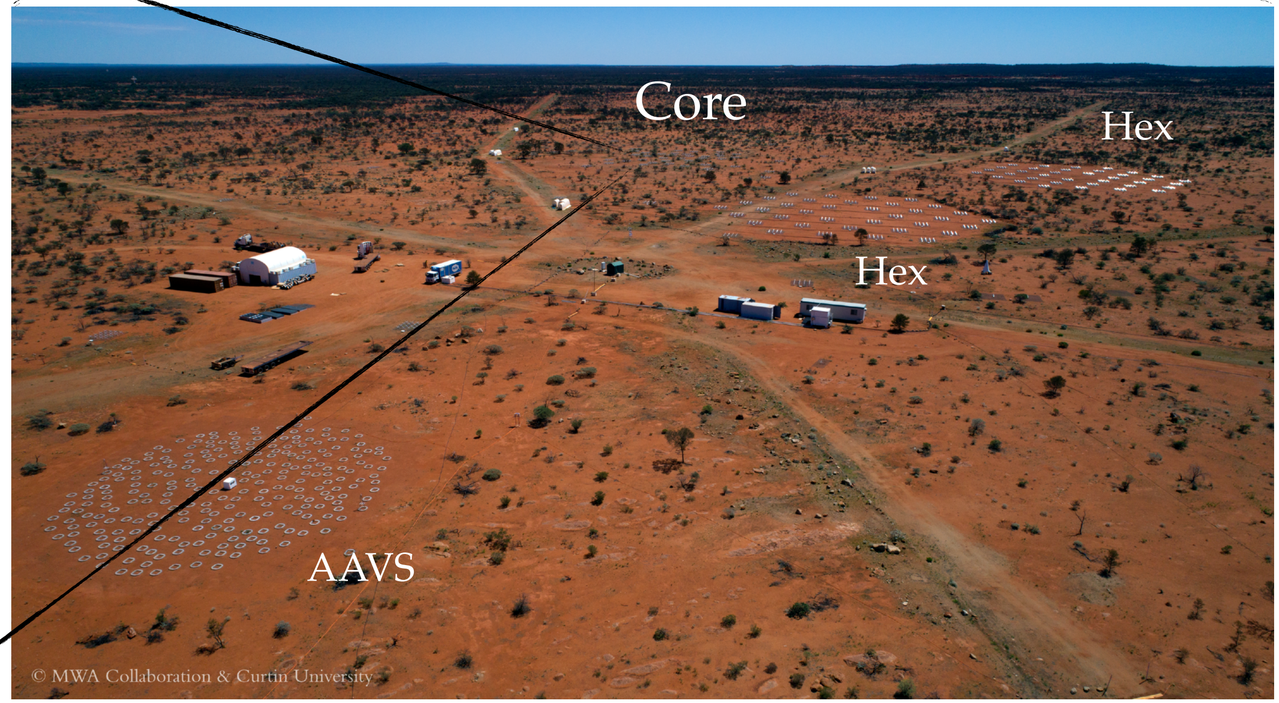

This scientific work uses data obtained from Inyarrimanha Ilgari Bundara / the Murchison Radio-astronomy Observatory. We acknowledge the Wajarri Yamaji People as the Traditional Owners and native title holders of the Observatory site. Establishment of CSIRO's Murchison Radio-astronomy Observatory is 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)
  - Traditional Owners and native title holders: Wajarri Yamaji People
  - MWA is known as *Gurlgamarnu* in Wajarri (*"the ear that listens to the sky"*)
  - Operating between **72 and 300 MHz**

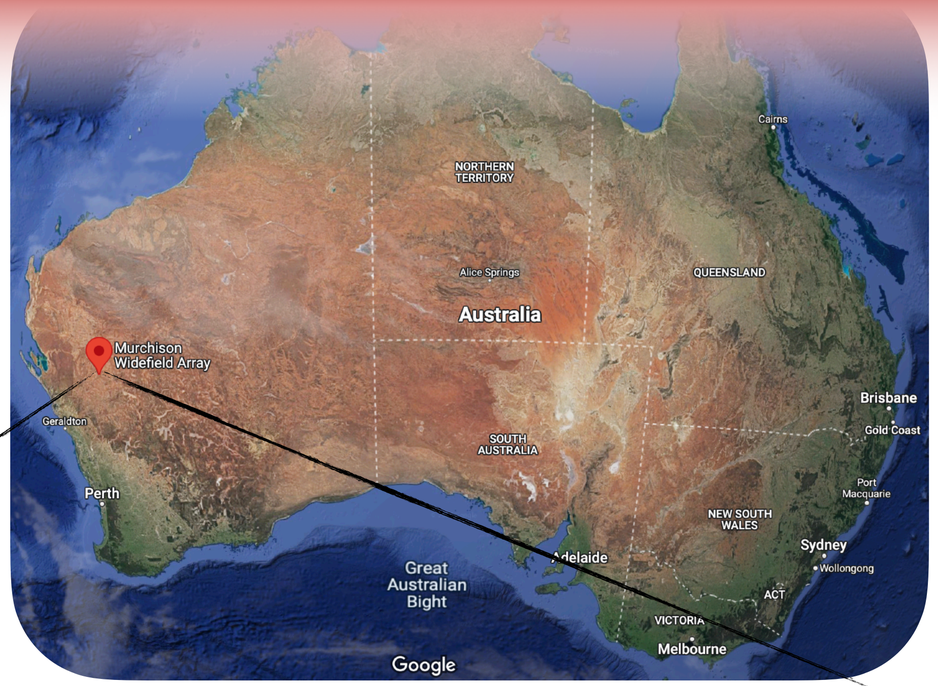






# THE MURCHISON WIDEFIELD ARRAY (MWA)

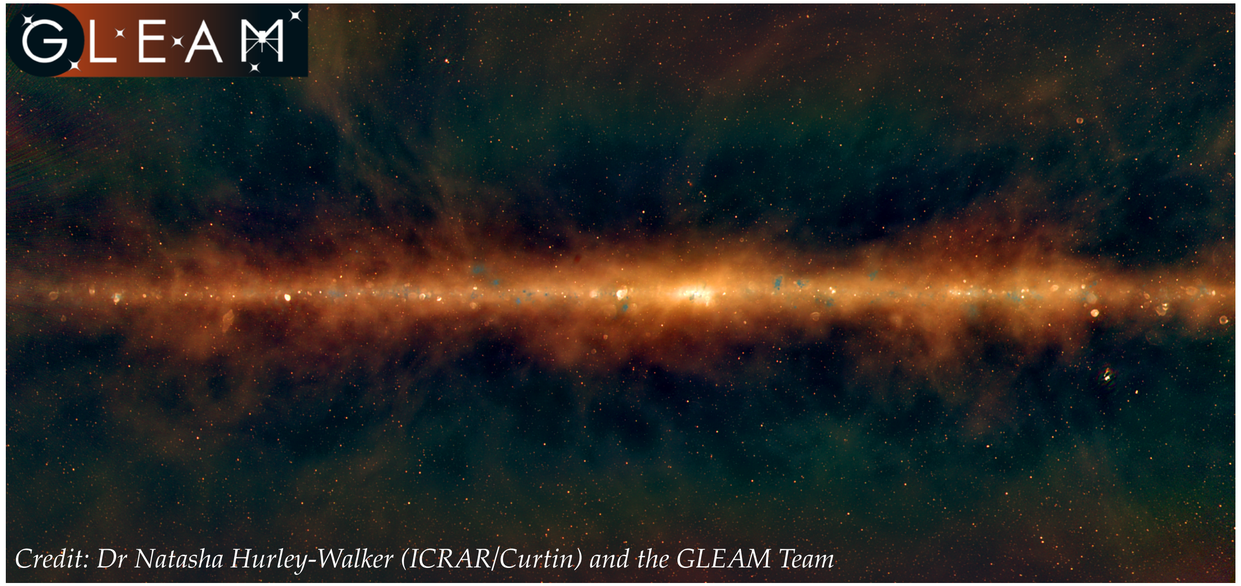
- The SKA-Low Precursor:
  - *Inyarrimanha Ilgari Bundara*, the CSIRO Murchison Radio-astronomy Observatory (MRO) in Western Australia (725km from Boorloo/Perth)
  - Traditional Owners and native title holders: Wajarri Yamaji People
  - MWA is known as *Gurlgamarnu* in Wajarri (“*the ear that listens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





# THE MURCHISON WIDEFIELD ARRAY (MWA)

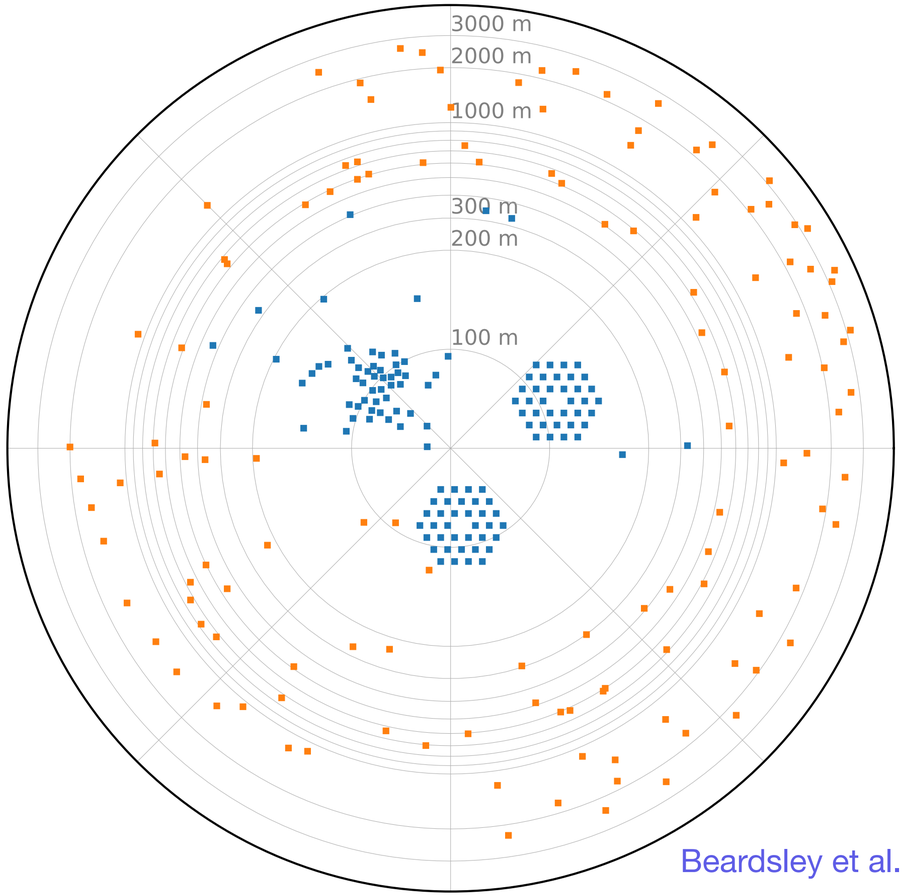
- **Phase I**: 2013 — 2016
  - 128T ; 8 m to 2.8 km



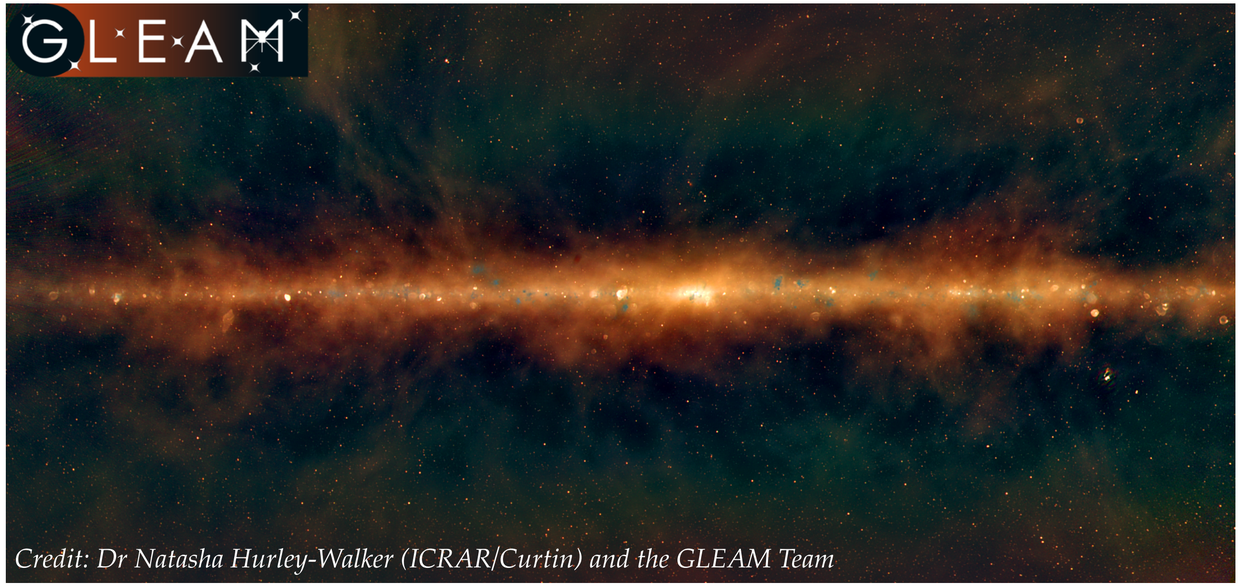

*Credit: Dr Natasha Hurley-Walker (ICRAR/Curtin) and the GLEAM Team*

# THE MURCHISON WIDEFIELD ARRAY (MWA)

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




Beardsley et al. (2019)

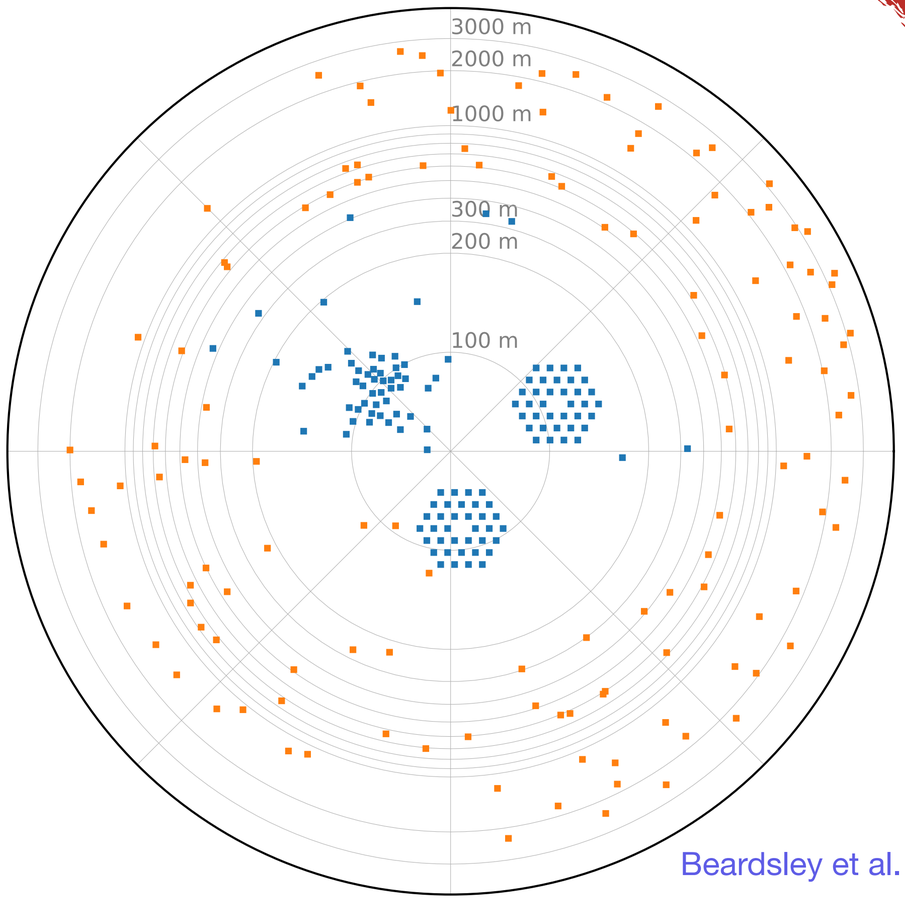



*Credit: Dr Natasha Hurley-Walker (ICRAR/Curtin) and the GLEAM Team*

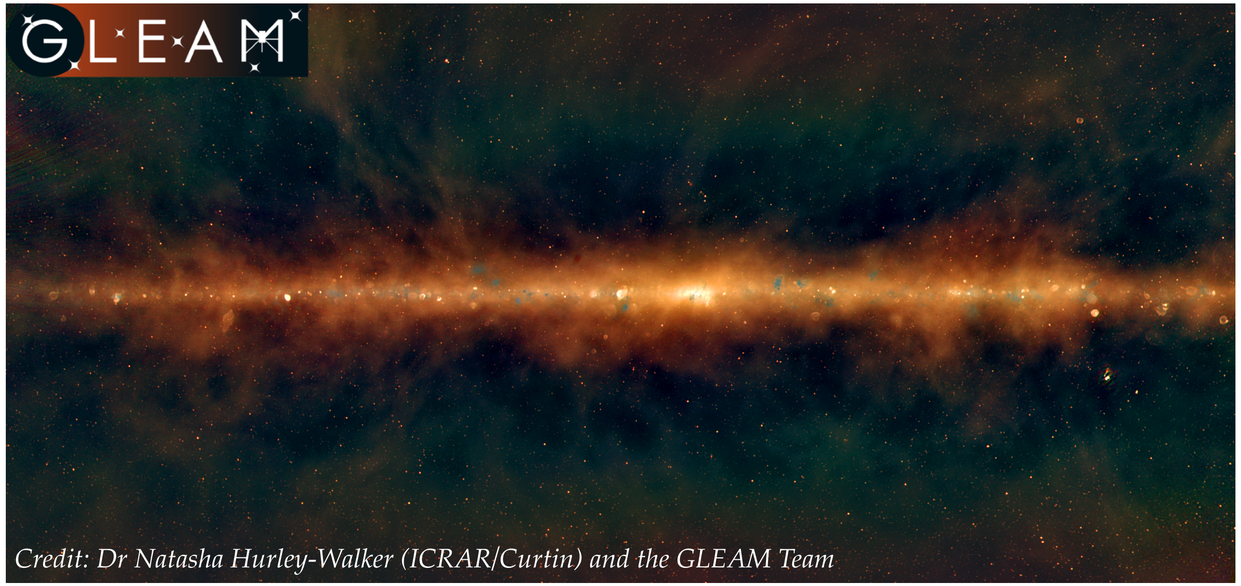
- **Phase II**: 2016 — 2022
  - 256T across two configurations
  - Compact: ~0.7 km & Hexes
  - Extended: 5.3 km

# THE MURCHISON WIDEFIELD ARRAY (MWA)

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




Beardsley et al. (2019)



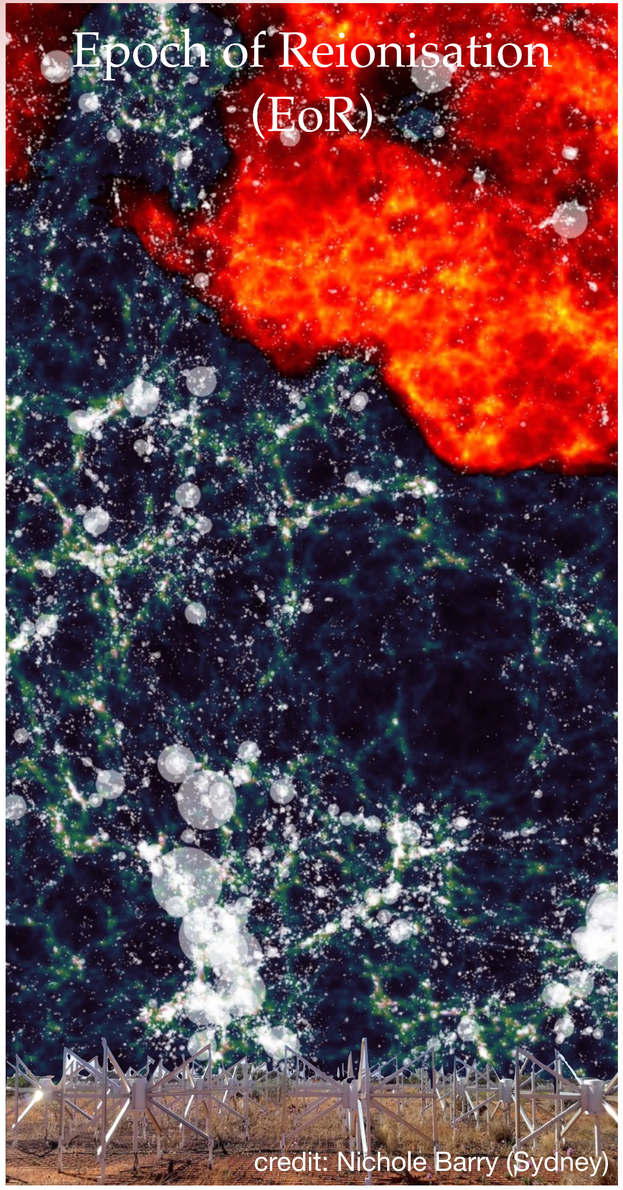

*Credit: Dr Natasha Hurley-Walker (ICRAR/Curtin) and the GLEAM Team*

- **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

## Epoch of Reionisation (EoR)

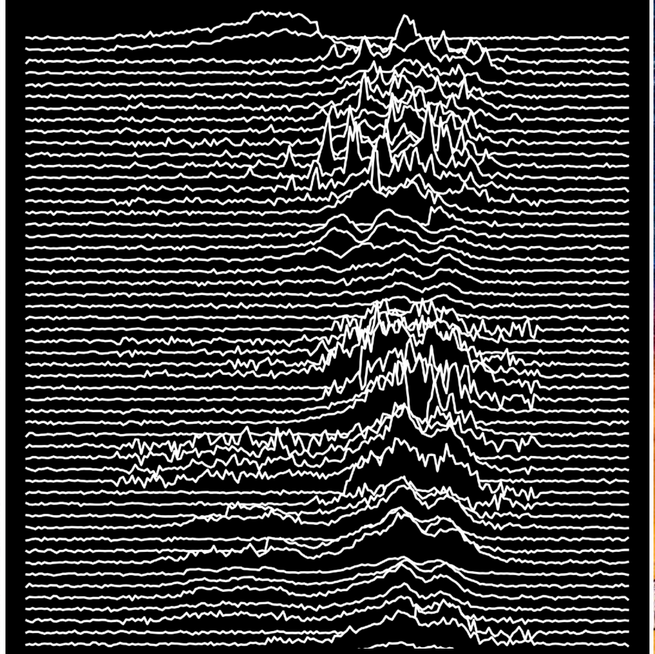


credit: Nichole Barry (Sydney)

Quiet sun emission; Bawaji et al. (2022)

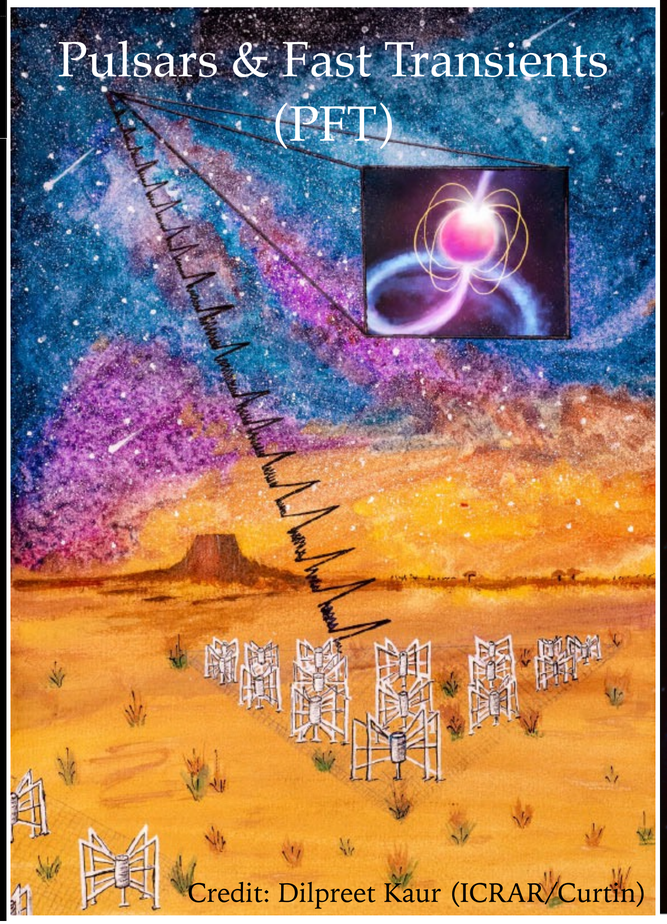
## Solar, Heliospheric & Ionospheric (SHI)

## Transients



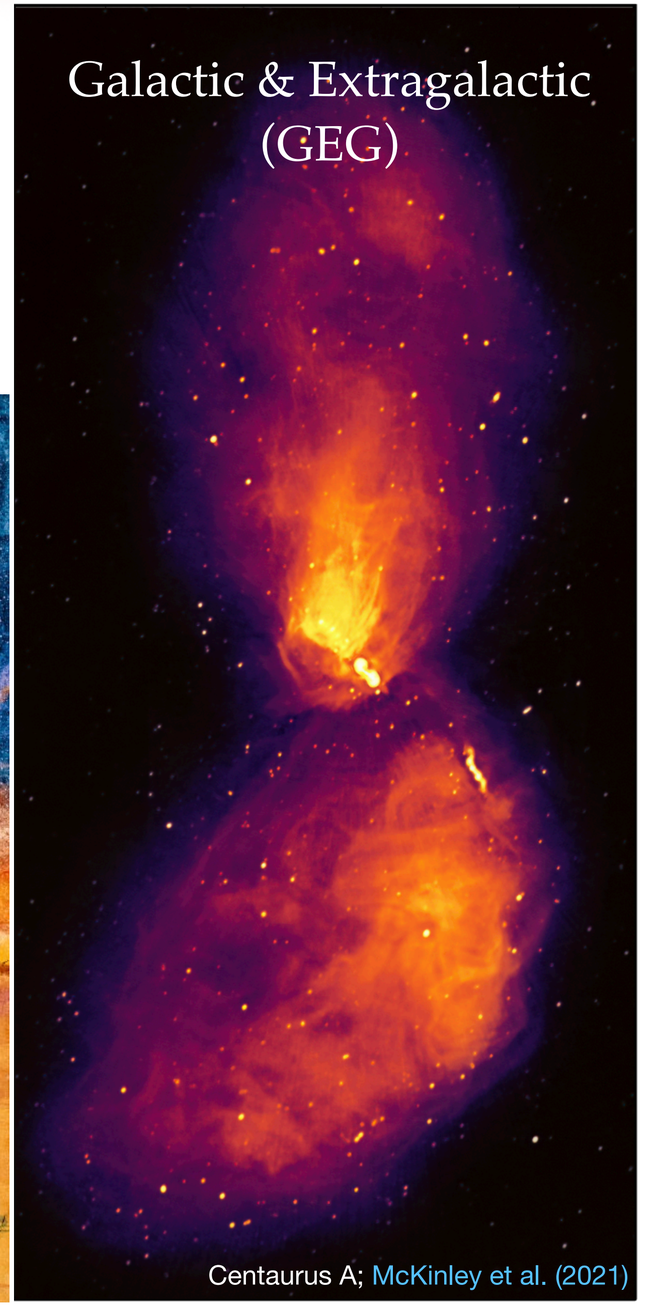
GLEAM-X ULPT; Hurley-Walker et al. (2021)

## Pulsars & Fast Transients (PFT)



Credit: Dilpreet Kaur (ICRAR/Curtin)

## Galactic & Extragalactic (GEG)



Centaurus A; McKinley et al. (2021)

# GALACTIC AND EXTRAGALACTIC

# GALACTIC AND EXTRAGALACTIC

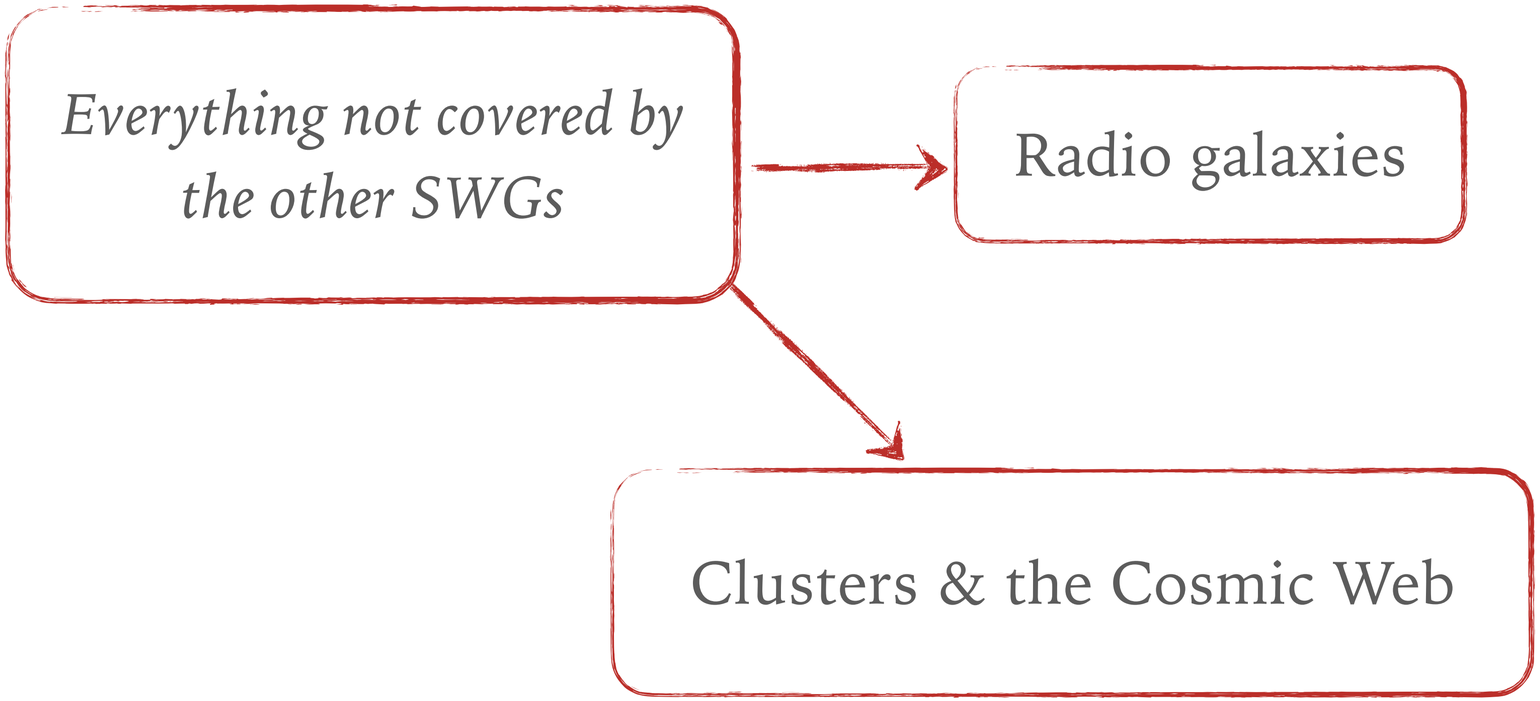
*Everything not covered by the other SWGs*

# GALACTIC AND EXTRAGALACTIC

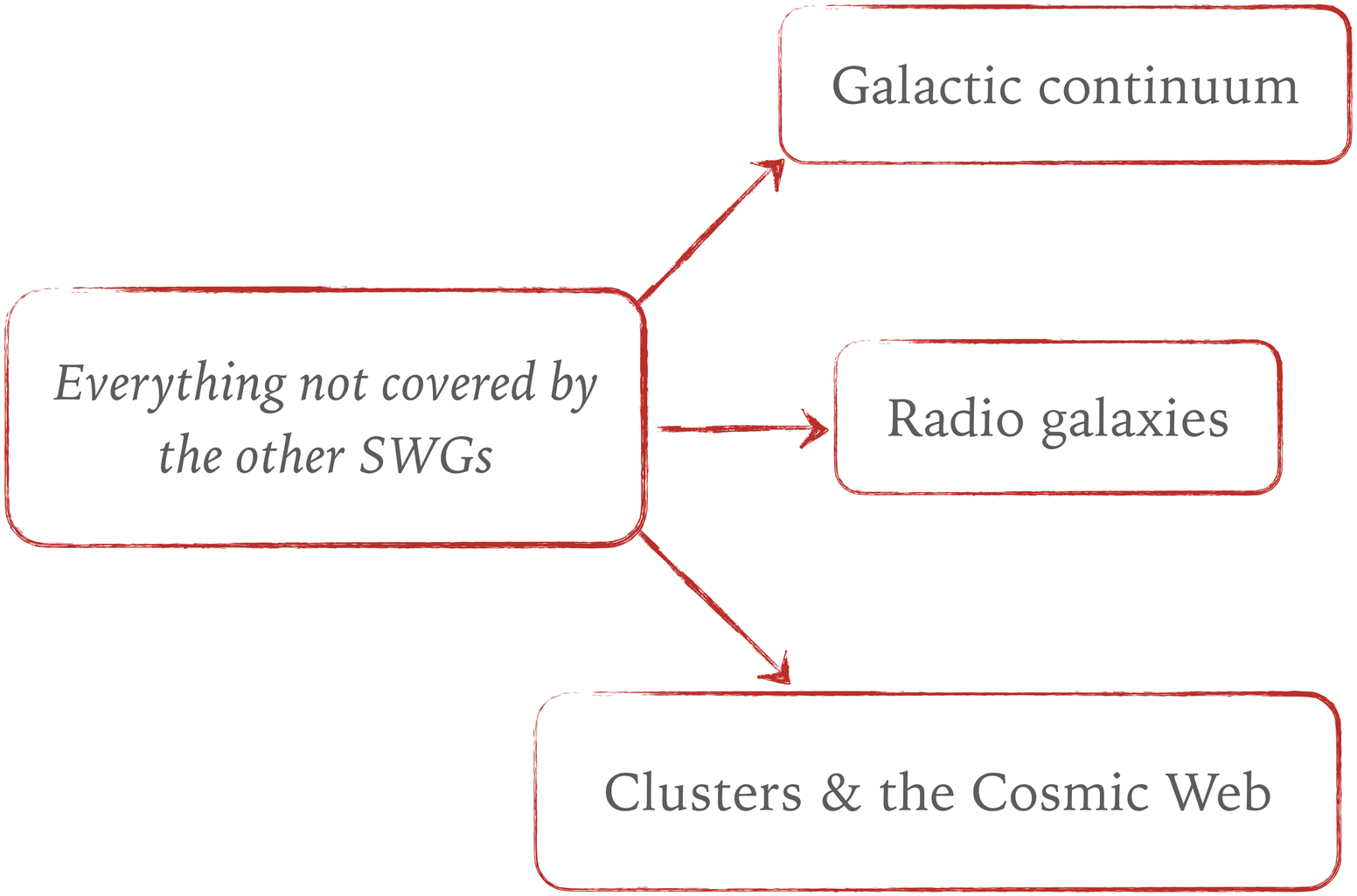
*Everything not covered by the other SWGs*

Clusters & the Cosmic Web

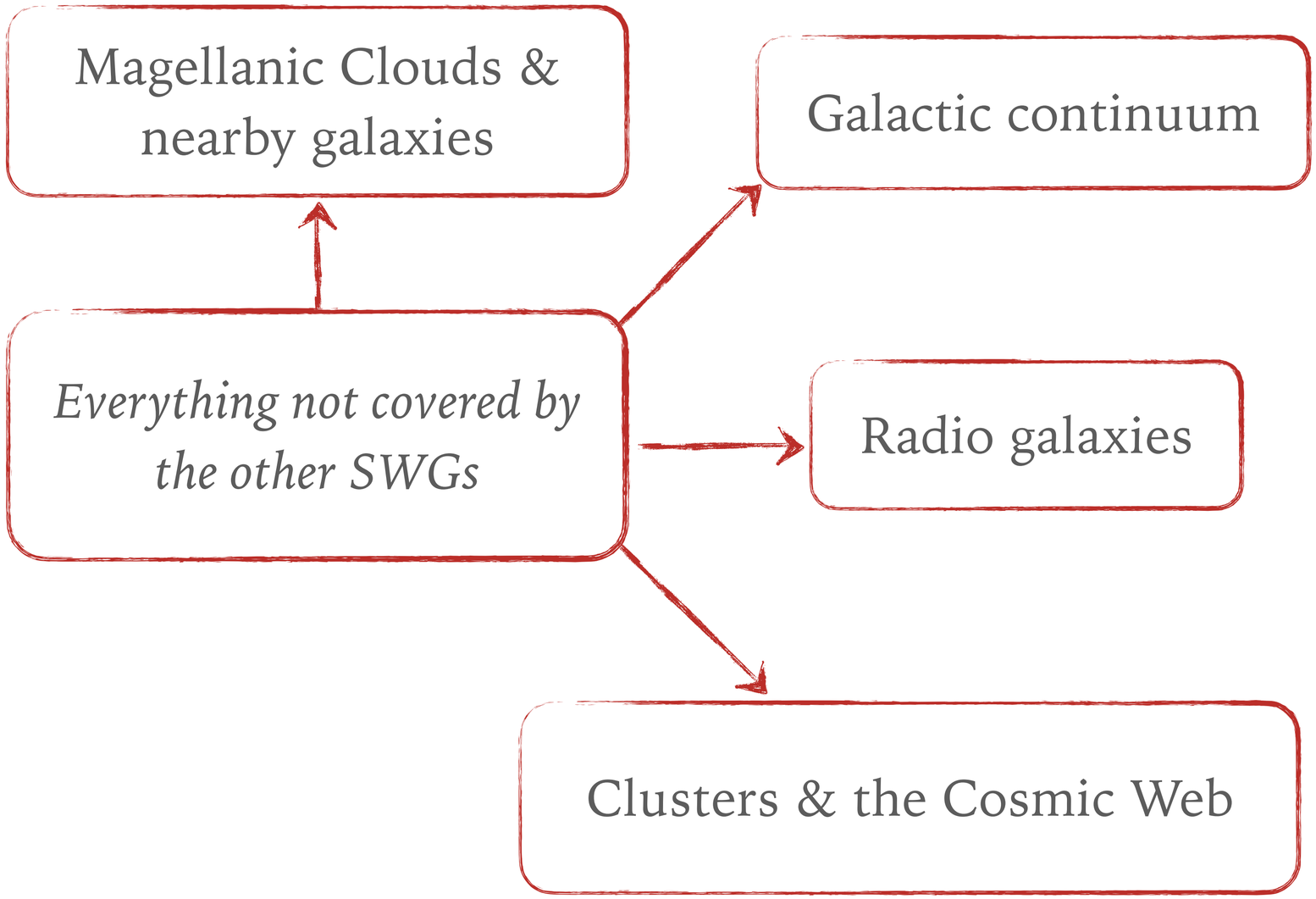
# GALACTIC AND EXTRAGALACTIC



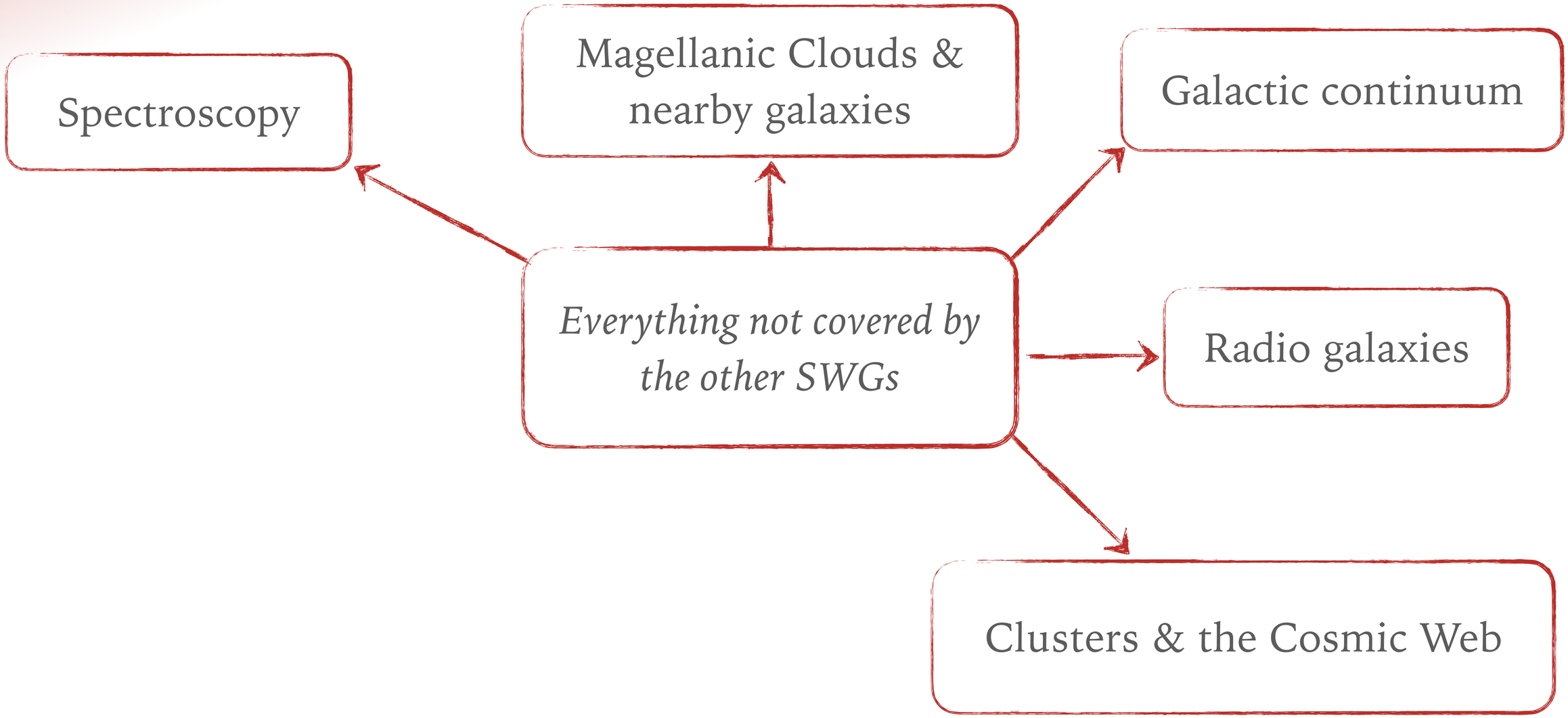
# GALACTIC AND EXTRAGALACTIC



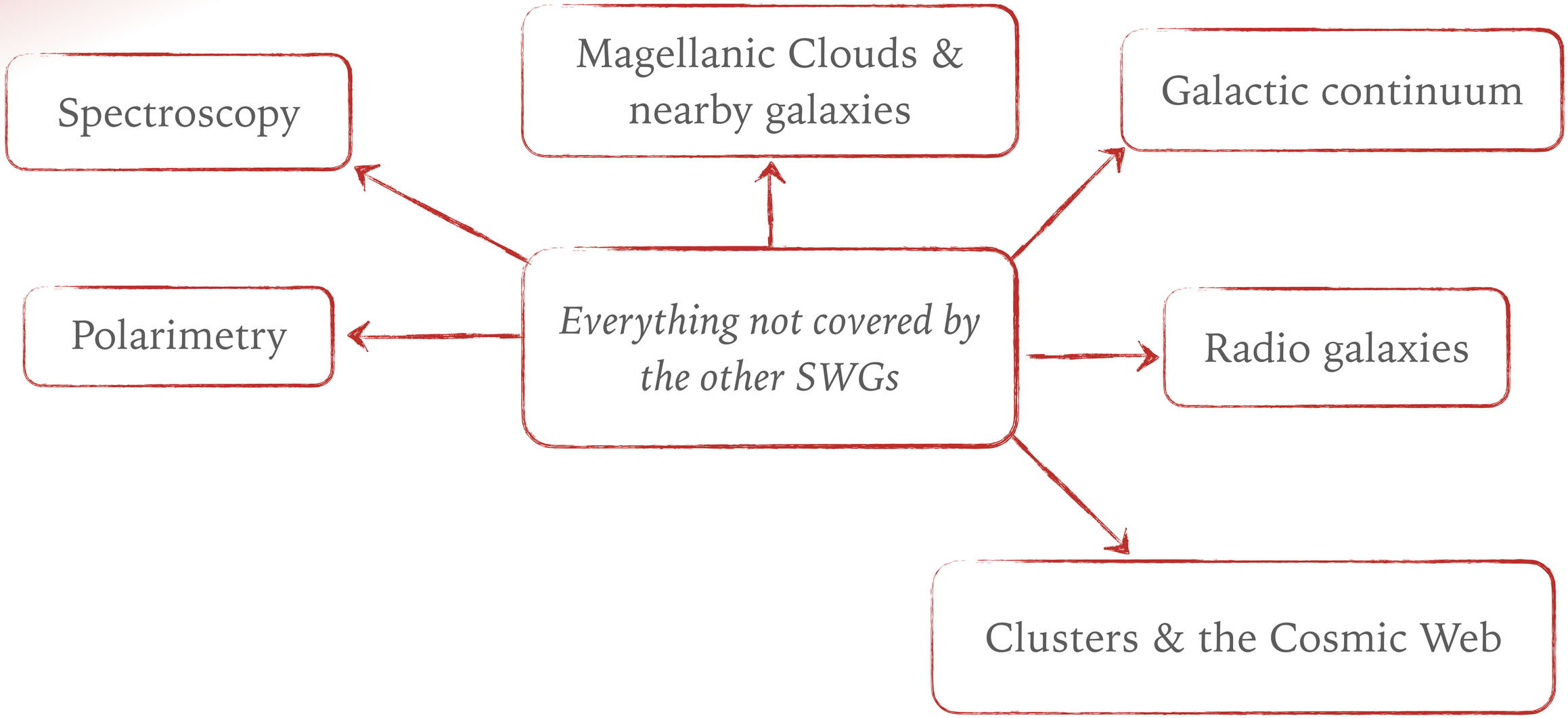
# GALACTIC AND EXTRAGALACTIC



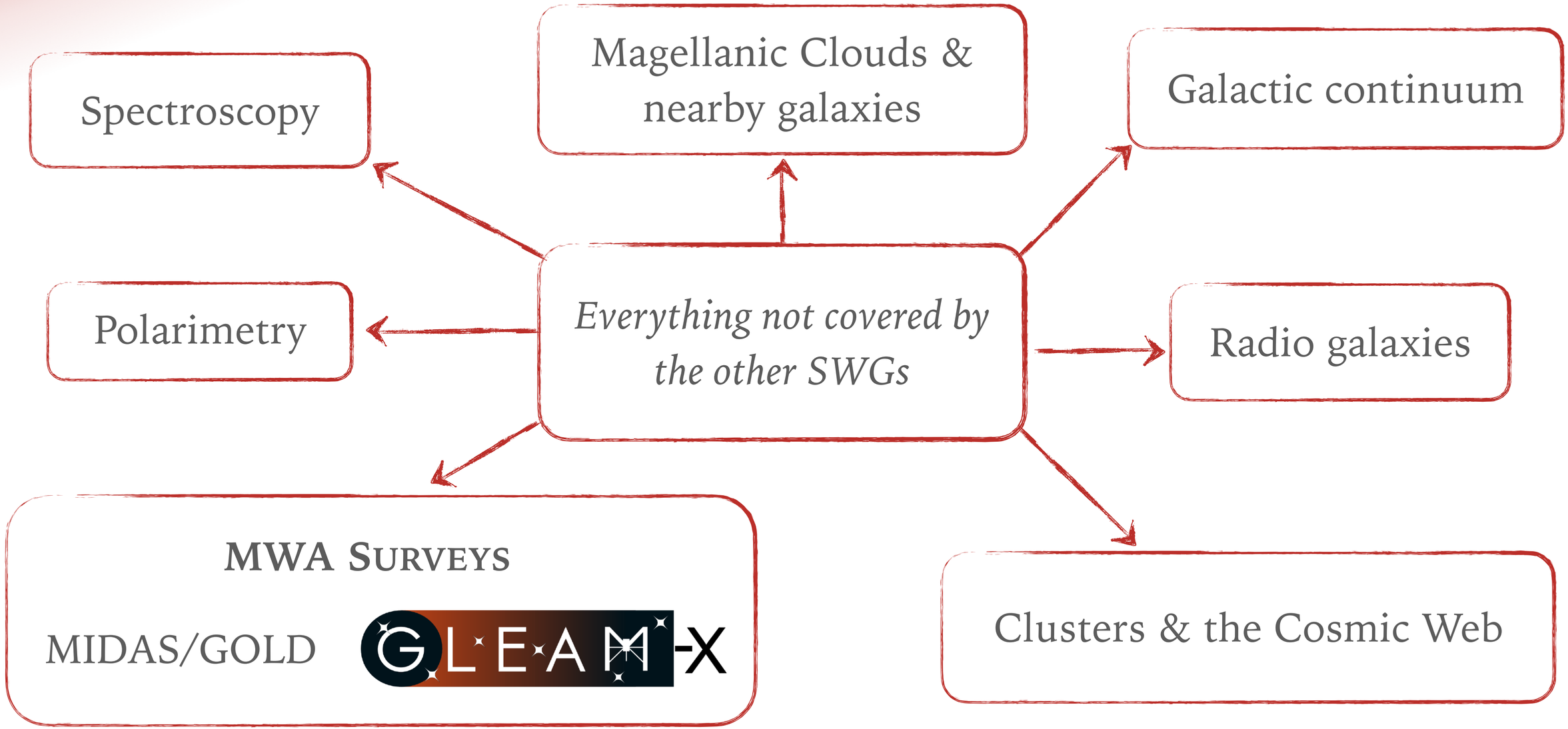
# GALACTIC AND EXTRAGALACTIC



# GALACTIC AND EXTRAGALACTIC

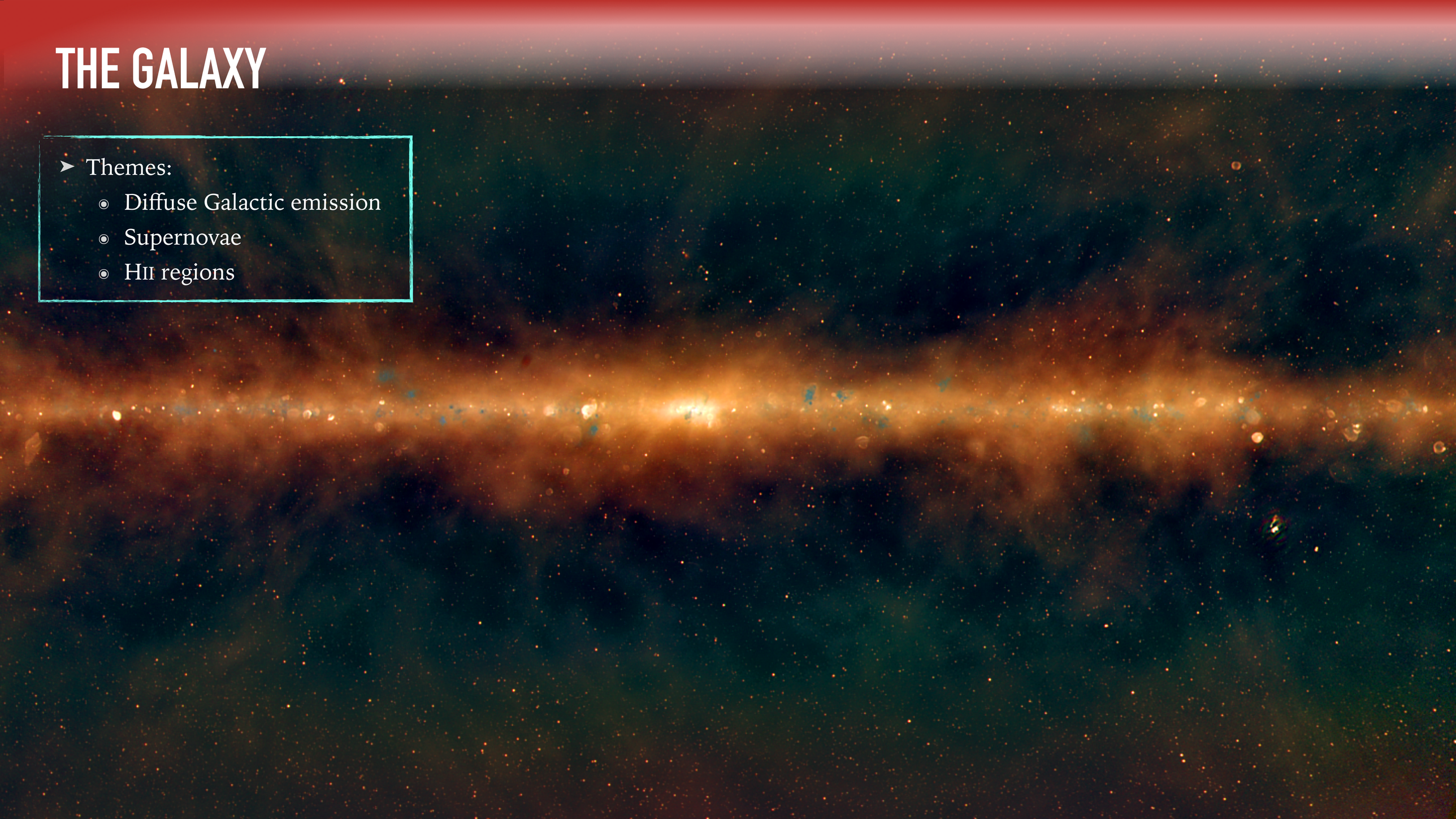


# GALACTIC AND EXTRAGALACTIC



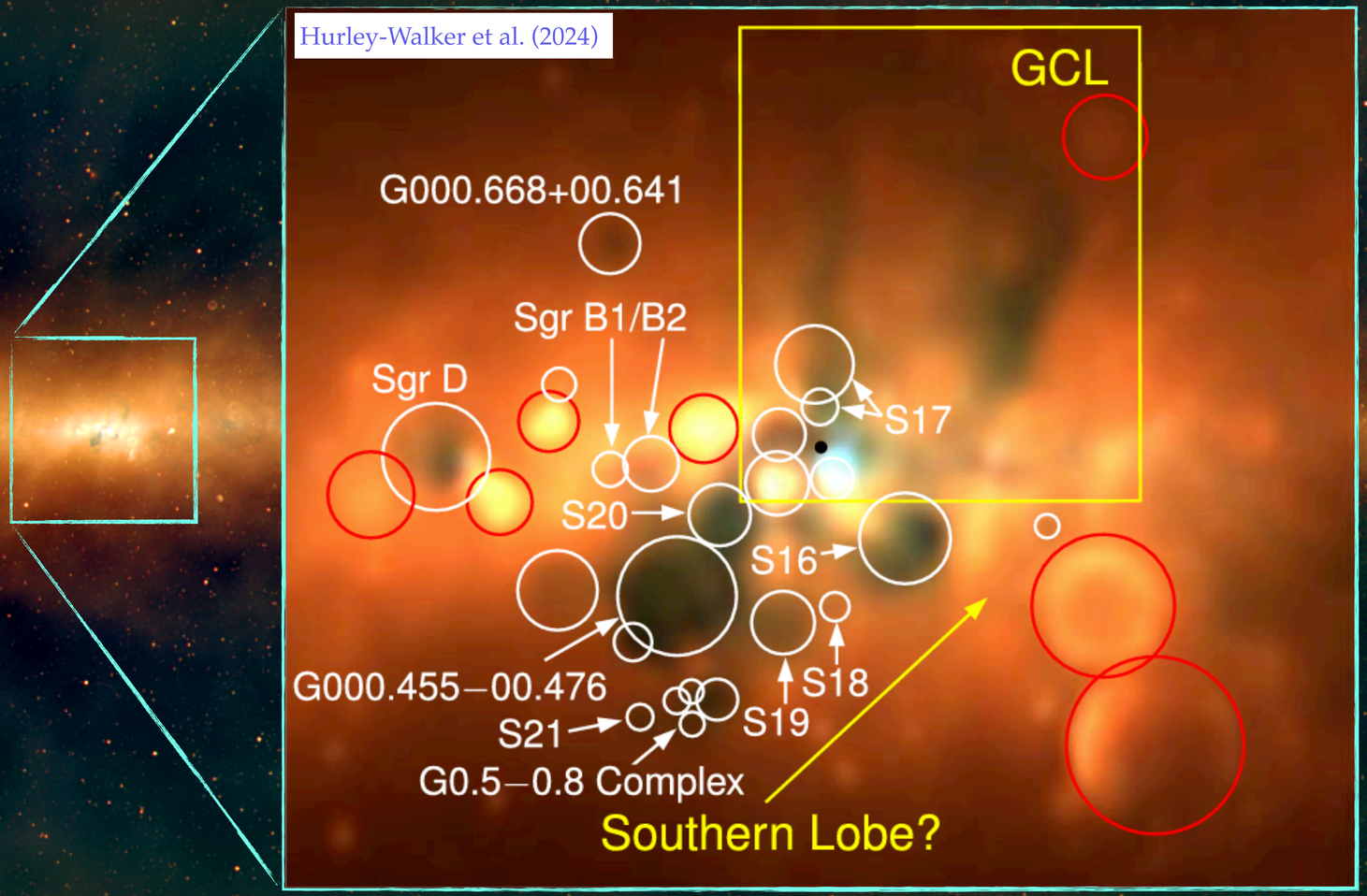
# THE GALAXY

- Themes:
  - Diffuse Galactic emission
  - Supernovae
  - HII regions



# THE GALAXY

- Themes:
  - Diffuse Galactic emission
  - Supernovae
  - HII regions



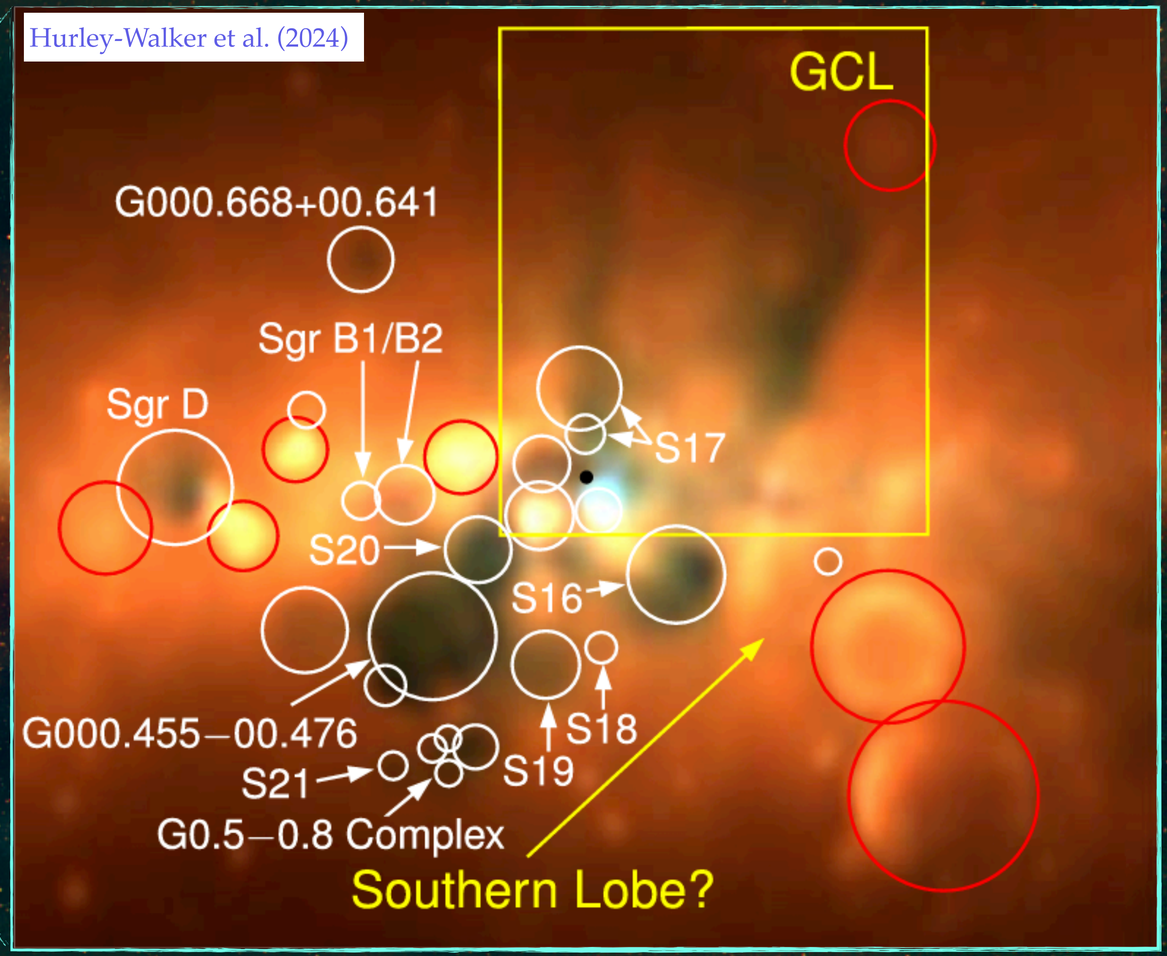

- Galactic centre lobe:
  - Shadow against Galactic continuum
  - Low-frequency turnover: thermal absorption
  - Emissivity arguments: distance ~2kpc

# THE GALAXY

- Themes:
  - Diffuse Galactic emission
  - Supernovae
  - HII regions

- Galactic centre lobe:
  - Shadow against Galactic continuum
  - Low-frequency turnover: thermal absorption
  - Emissivity arguments: distance ~2kpc

Phase I: we can do better now …



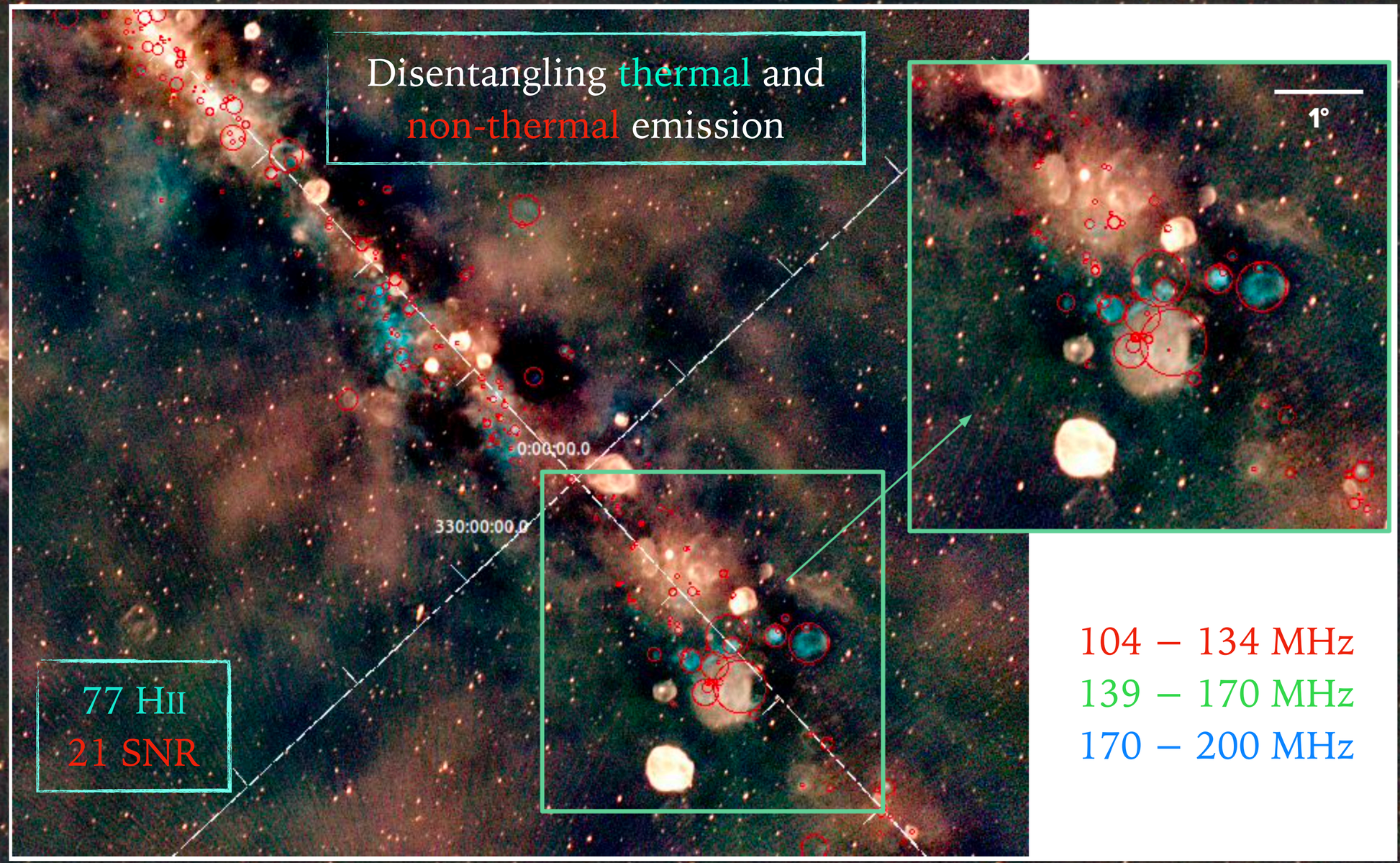
# THE GALAXY

Colour => spectrum
Blue: absorption
Red: steep

Silvia Mantovanini
PhD student @
Curtin University

# THE GALAXY

Colour => spectrum
Blue: absorption
Red: steep



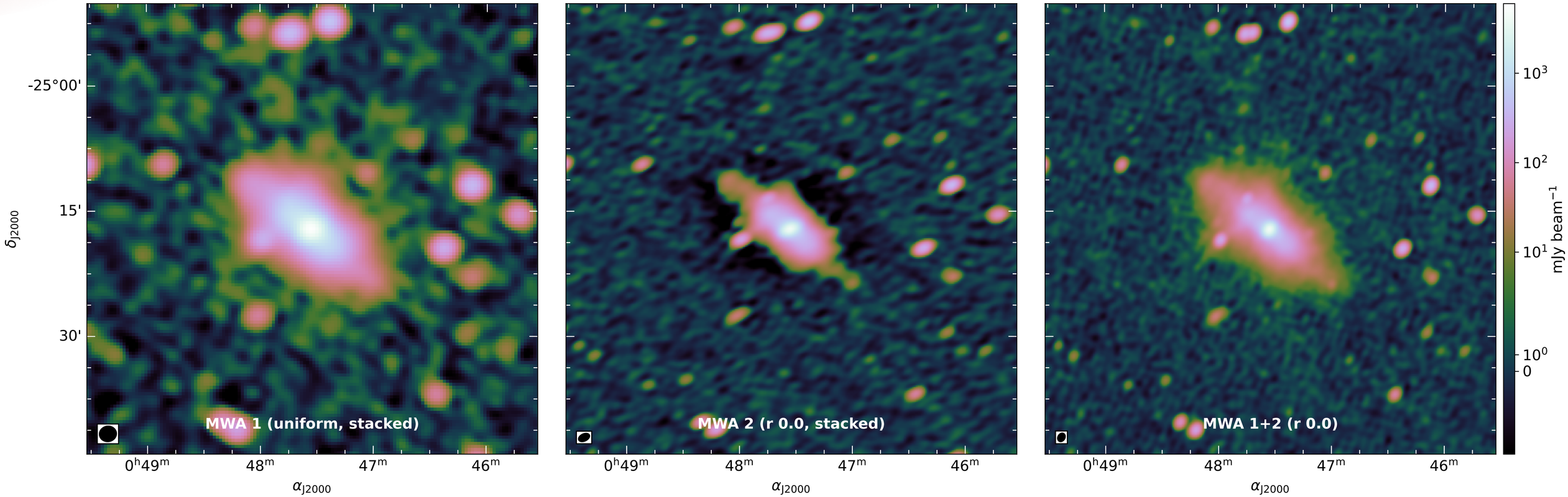

Silvia Mantovanini
PhD student @
Curtin University

# NEARBY GALAXIES

MWA Phase I

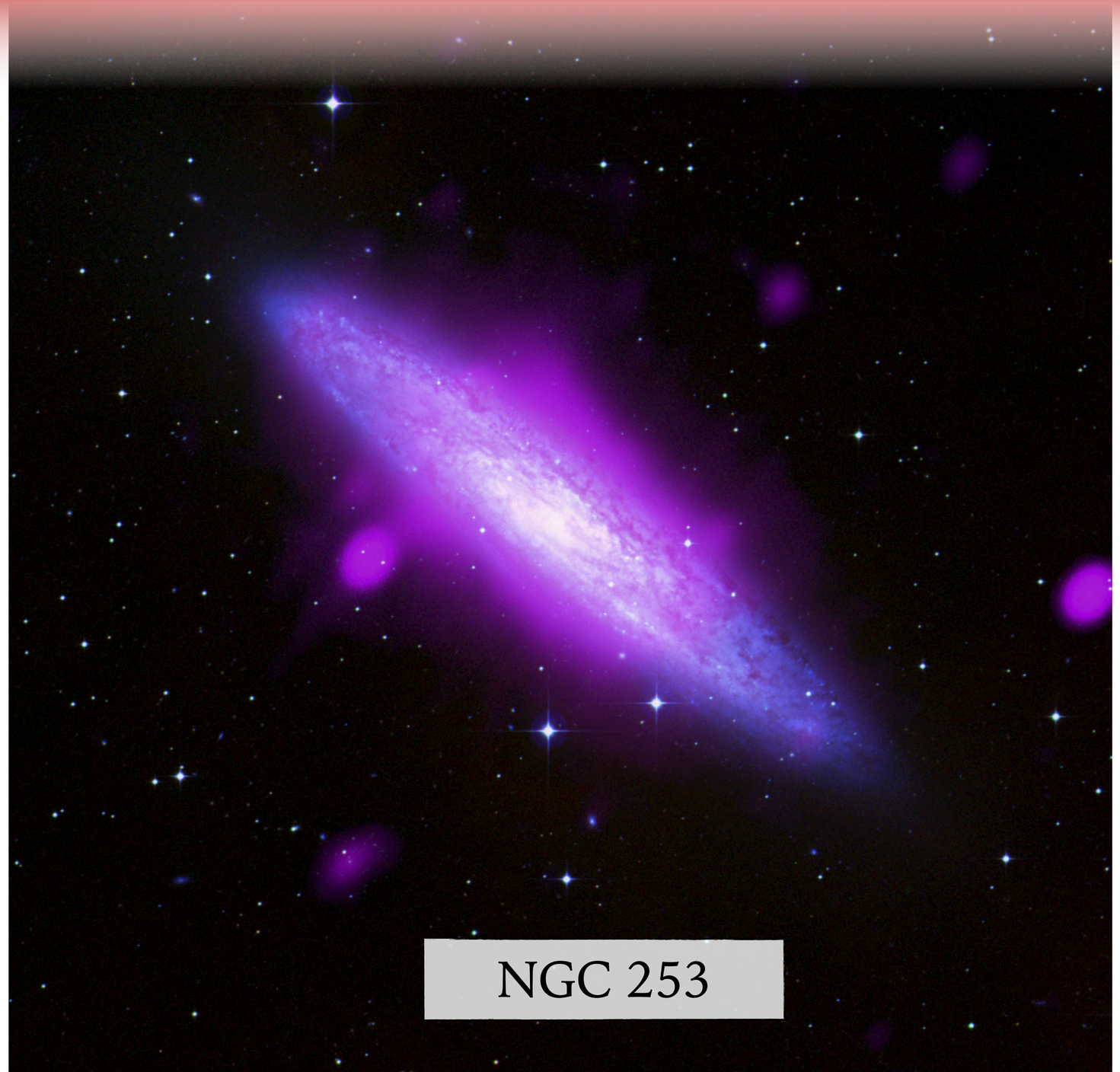
MWA Phase II

MWA Phase I + II



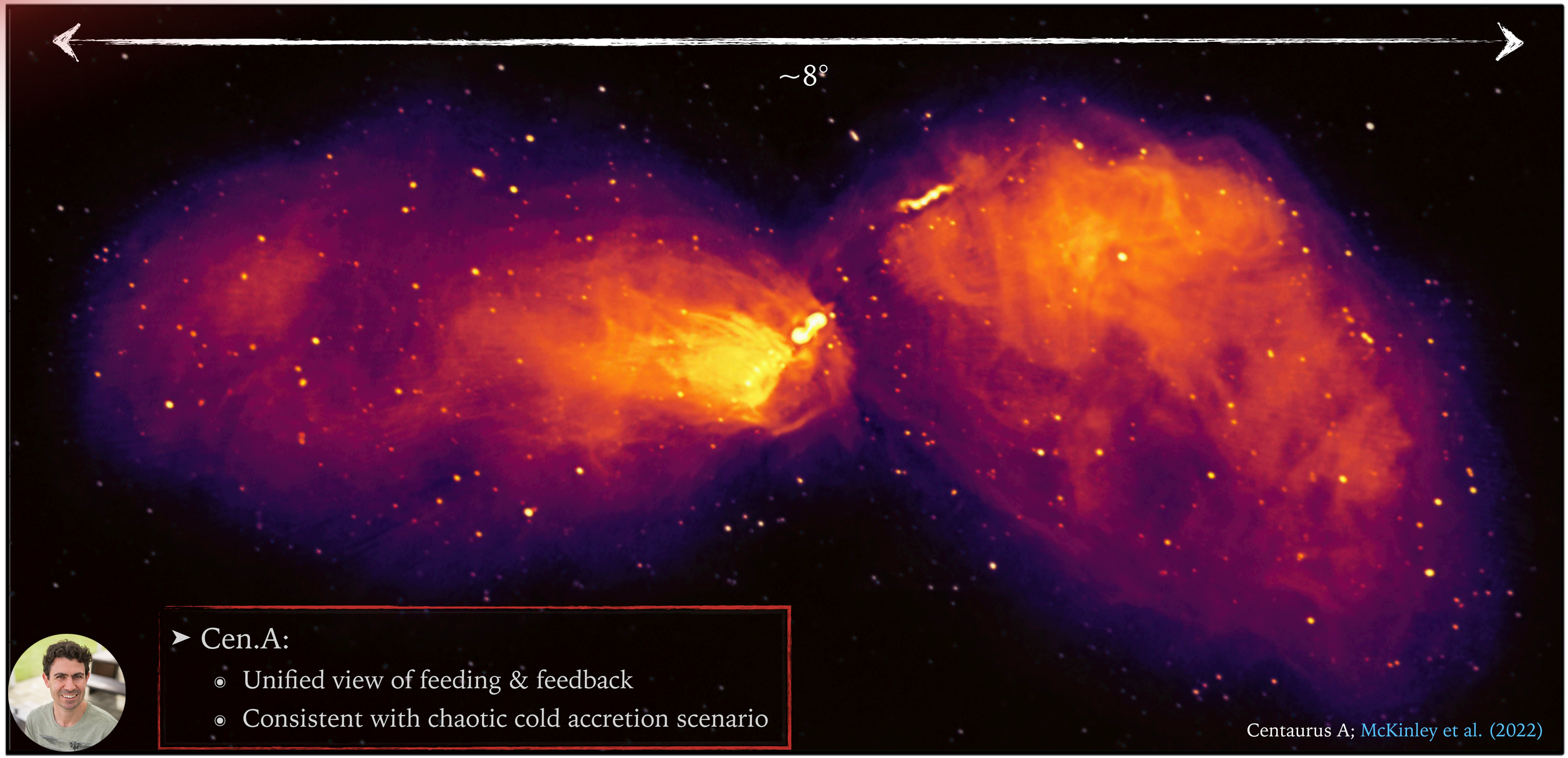

Stefan Duchesne
CERC Fellow @
CSIRO Space & Astronomy

# NEARBY GALAXIES




Stefan Duchesne
CERC Fellow @
CSIRO Space & Astronomy

# RADIO GALAXIES

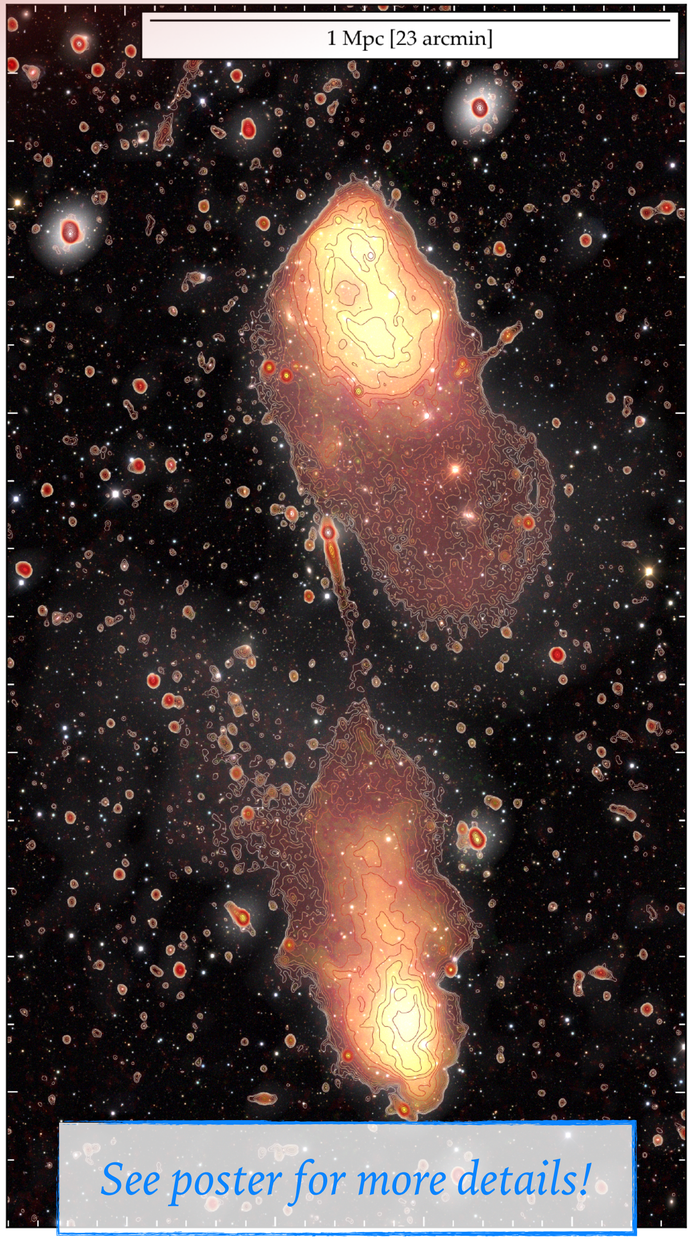





- Cen.A:
  - Unified view of feeding & feedback
  - Consistent with chaotic cold accretion scenario

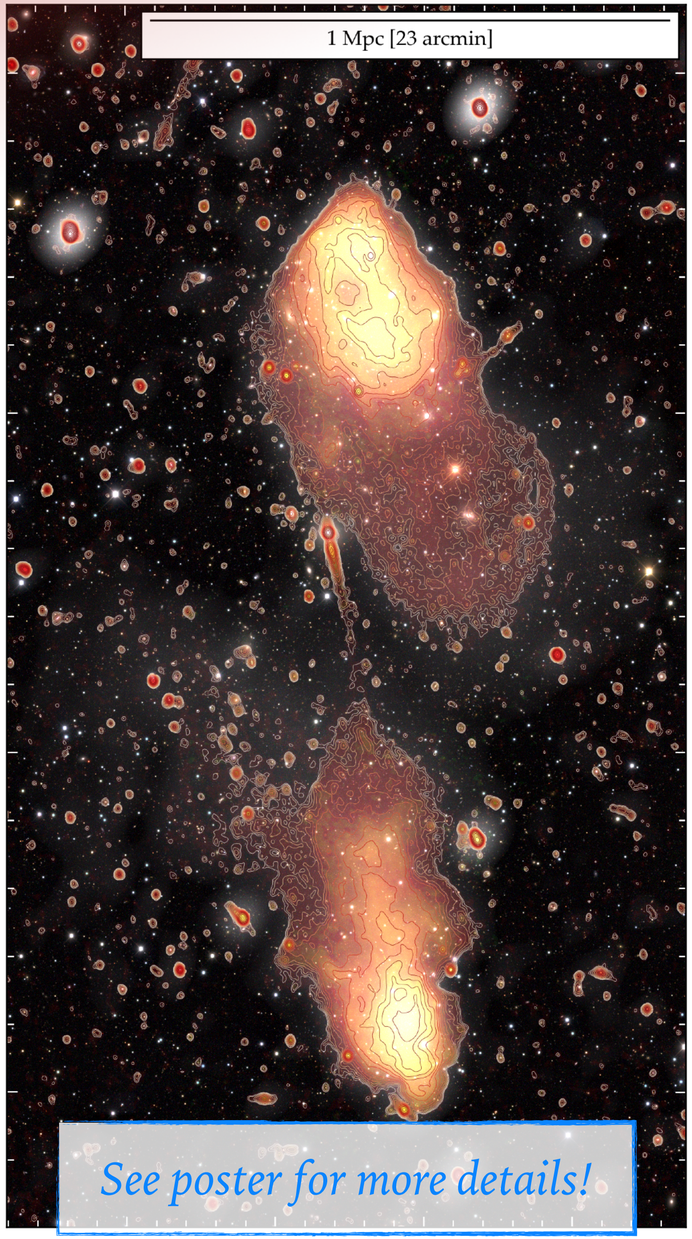
Centaurus A; McKinley et al. (2022)

# GIANT RADIO GALAXIES




*See poster for more details!*

# GIANT RADIO GALAXIES




*See poster for more details!*

MWA [88 MHz]

MWA [118 MHz]

MWA [154 MHz]

MWA [185 MHz]

*Demonstration of Phase I + II joint deconvolution*

MWA [216 MHz]

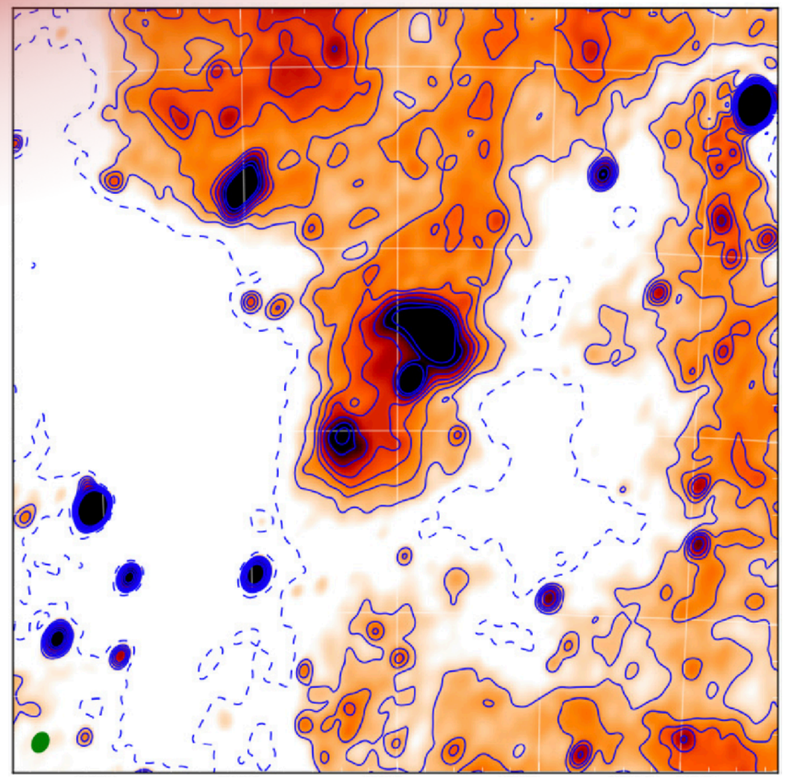
MWA [300 MHz]

MeerKAT [1.2 GHz]

ATCA [2.1 GHz]

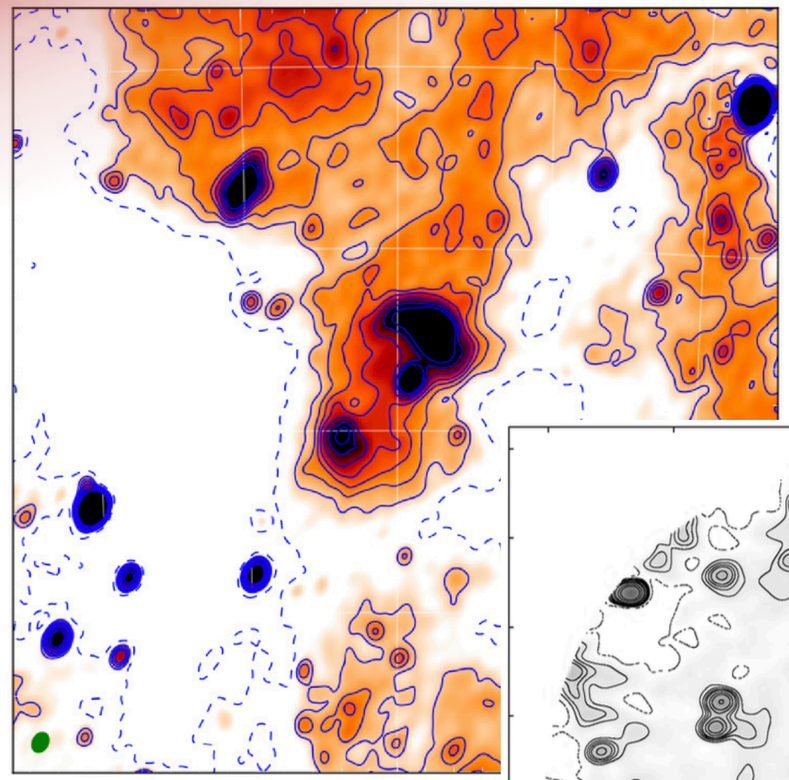
# GALAXY CLUSTERS

# GALAXY CLUSTERS

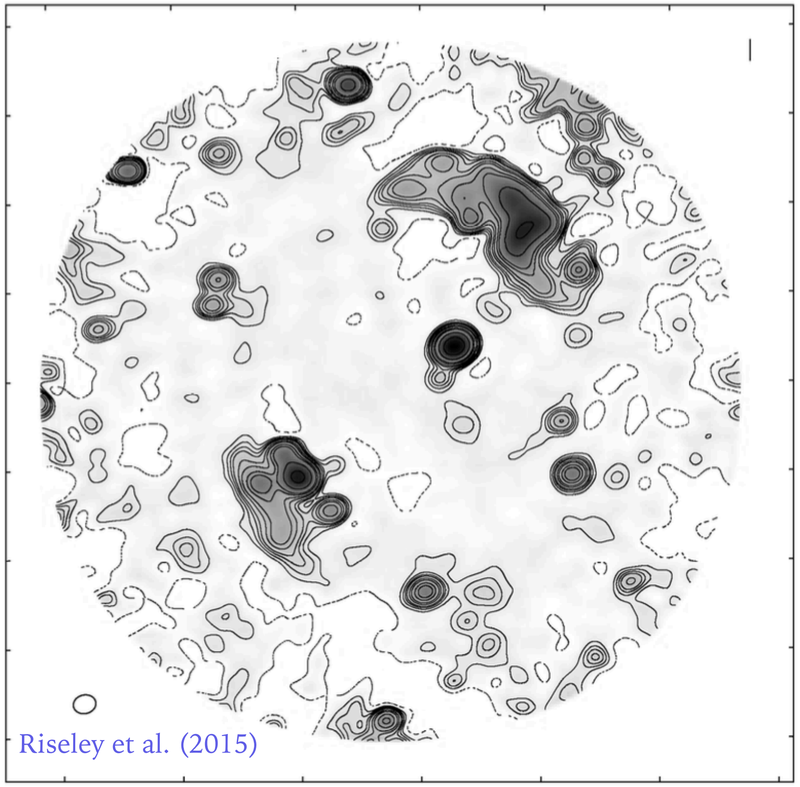


Hindson et al. (2014)

# GALAXY CLUSTERS

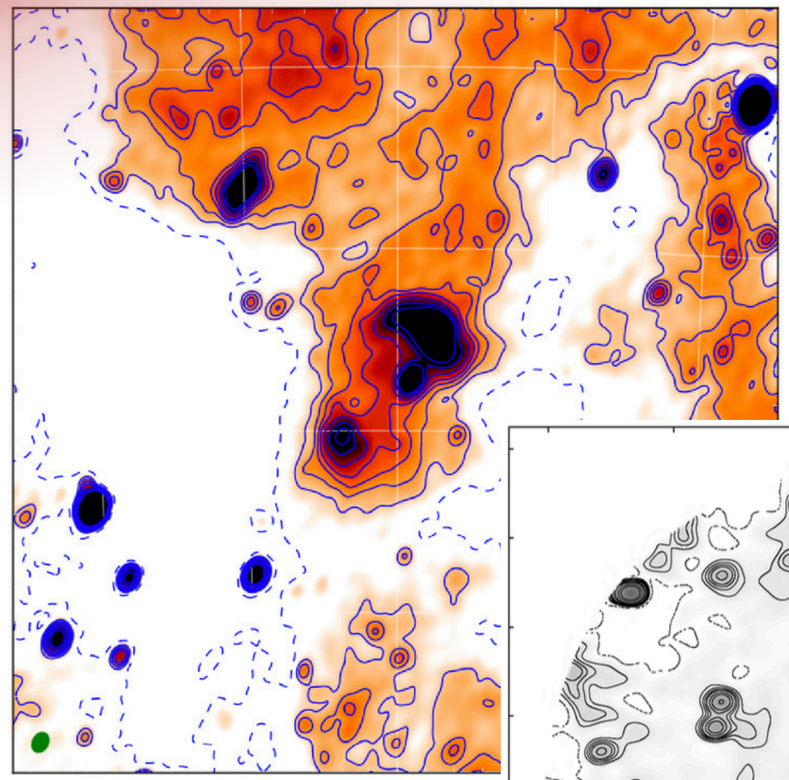


Hindson et al. (2014)

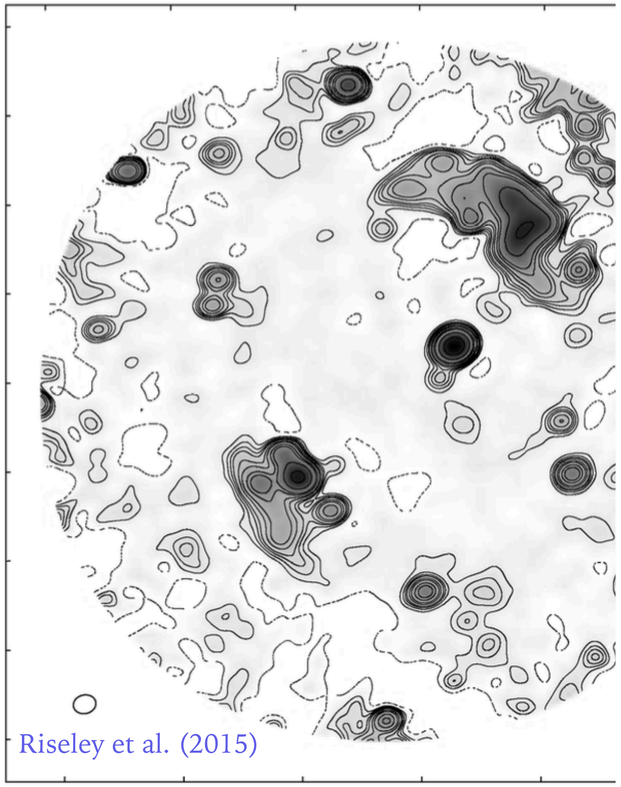


Riseley et al. (2015)

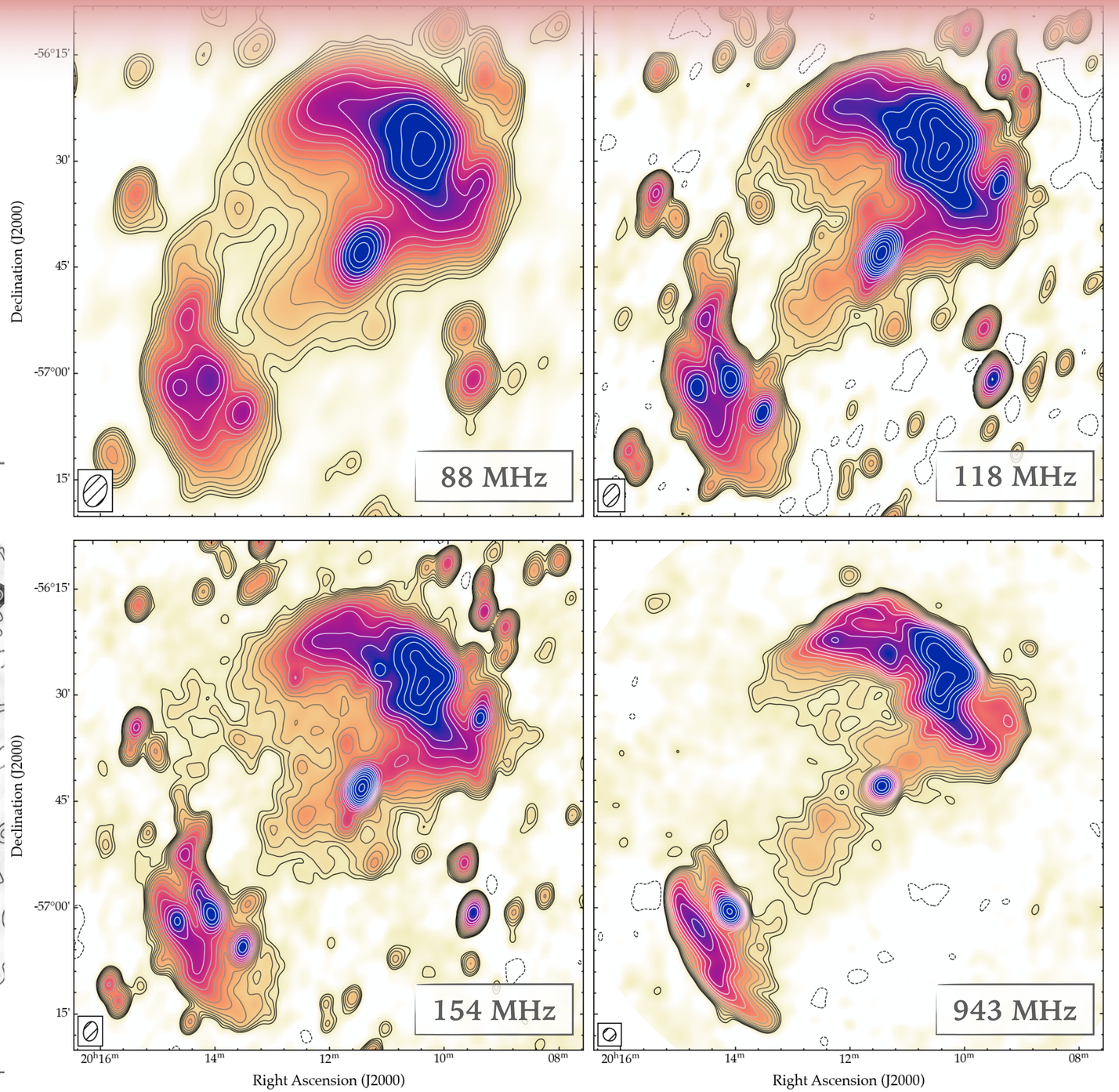
# GALAXY CLUSTERS



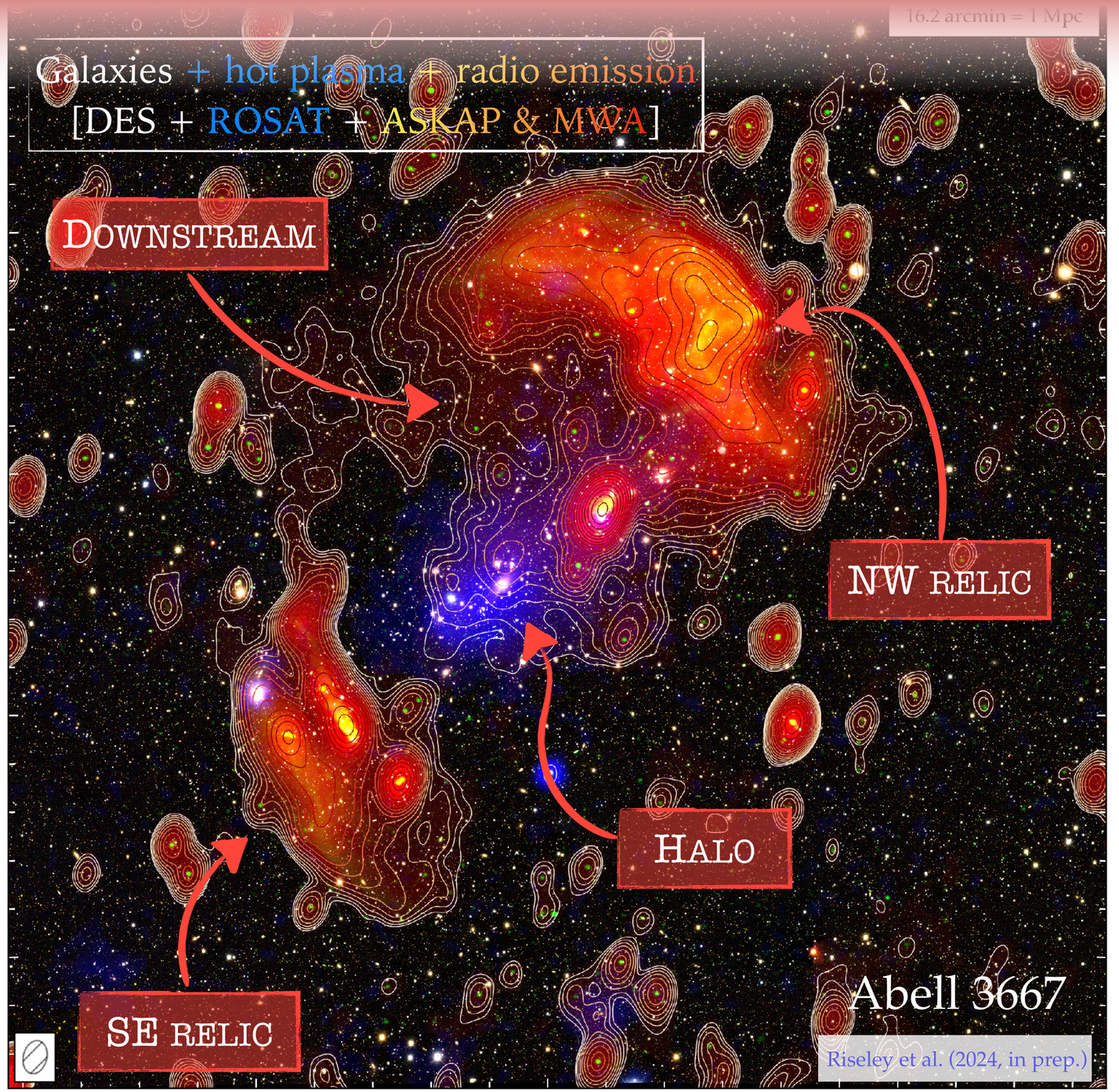
Hindson et al. (2014)



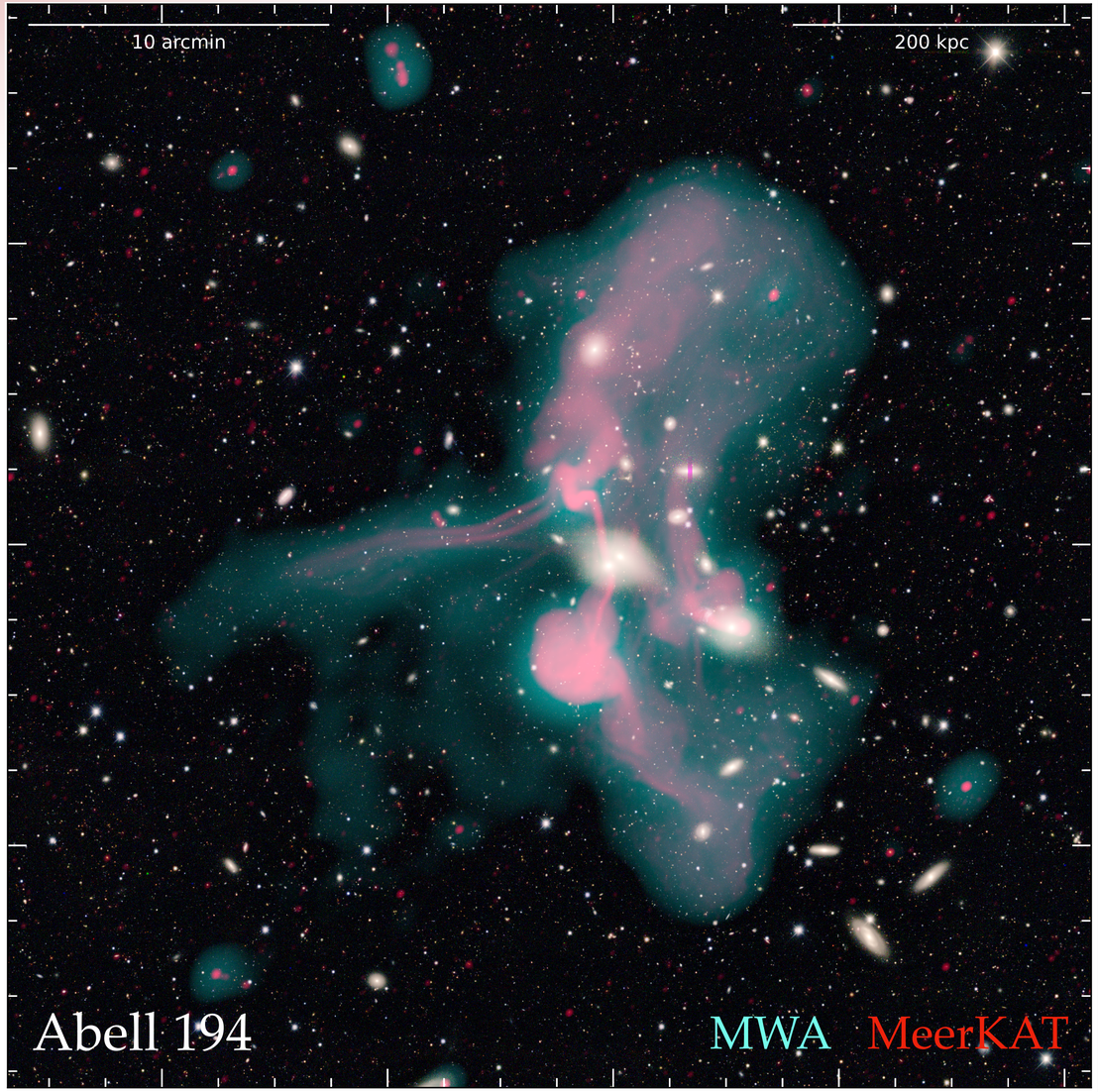
Riseley et al. (2015)



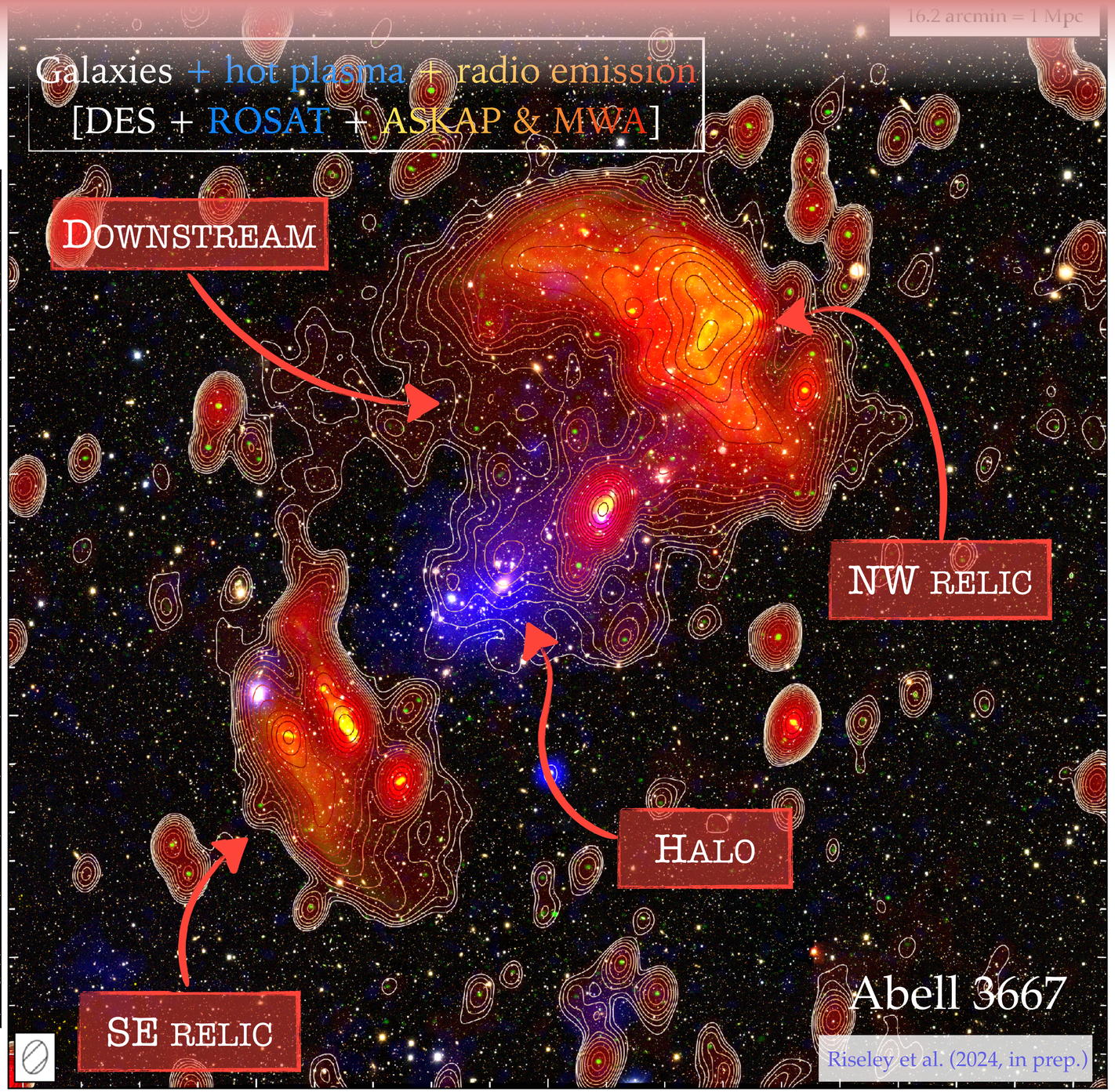
# GALAXY CLUSTERS



# GALAXY CLUSTERS



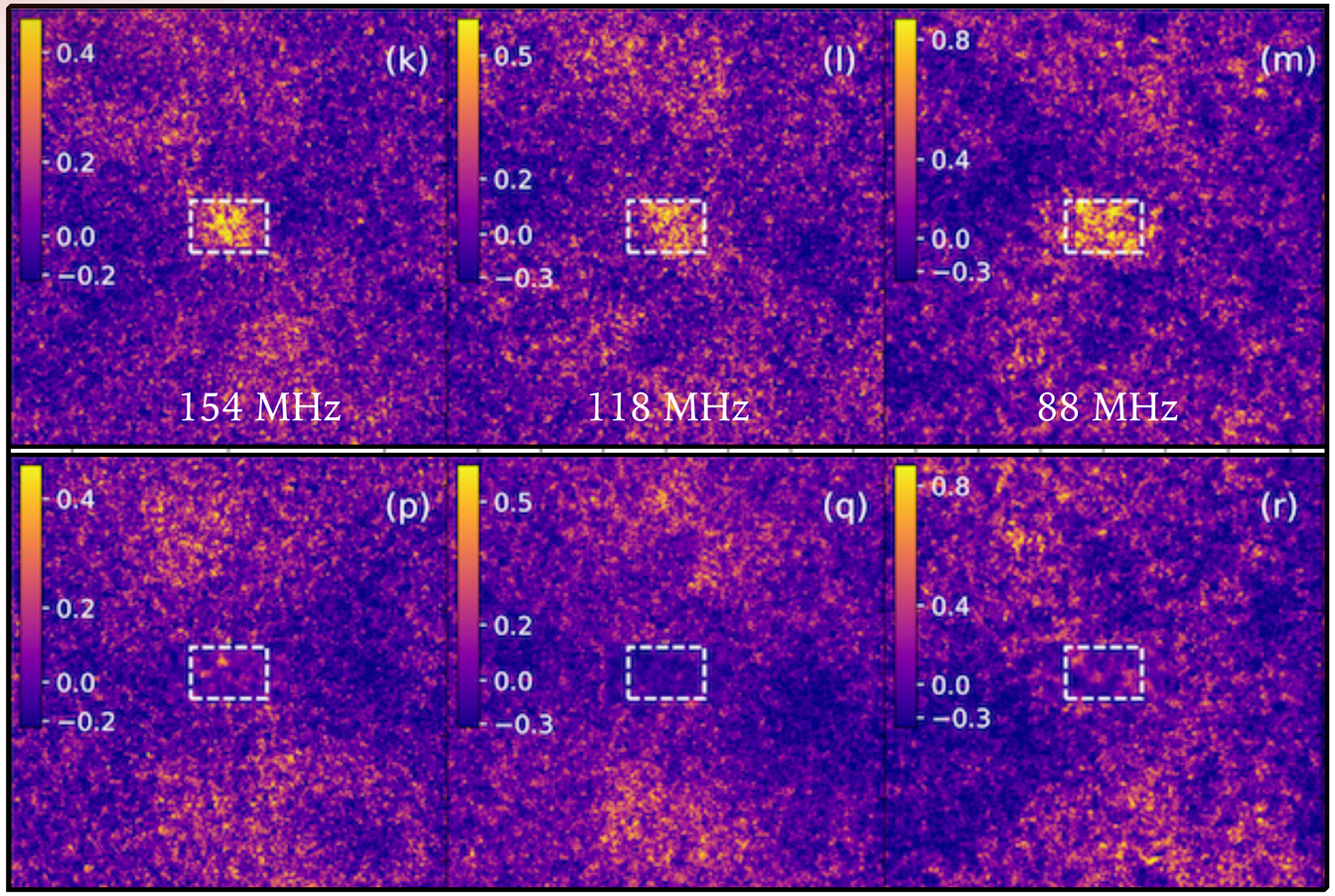

Duchesne et al. (2024, in prep.)




Riseley et al. (2024, in prep.)

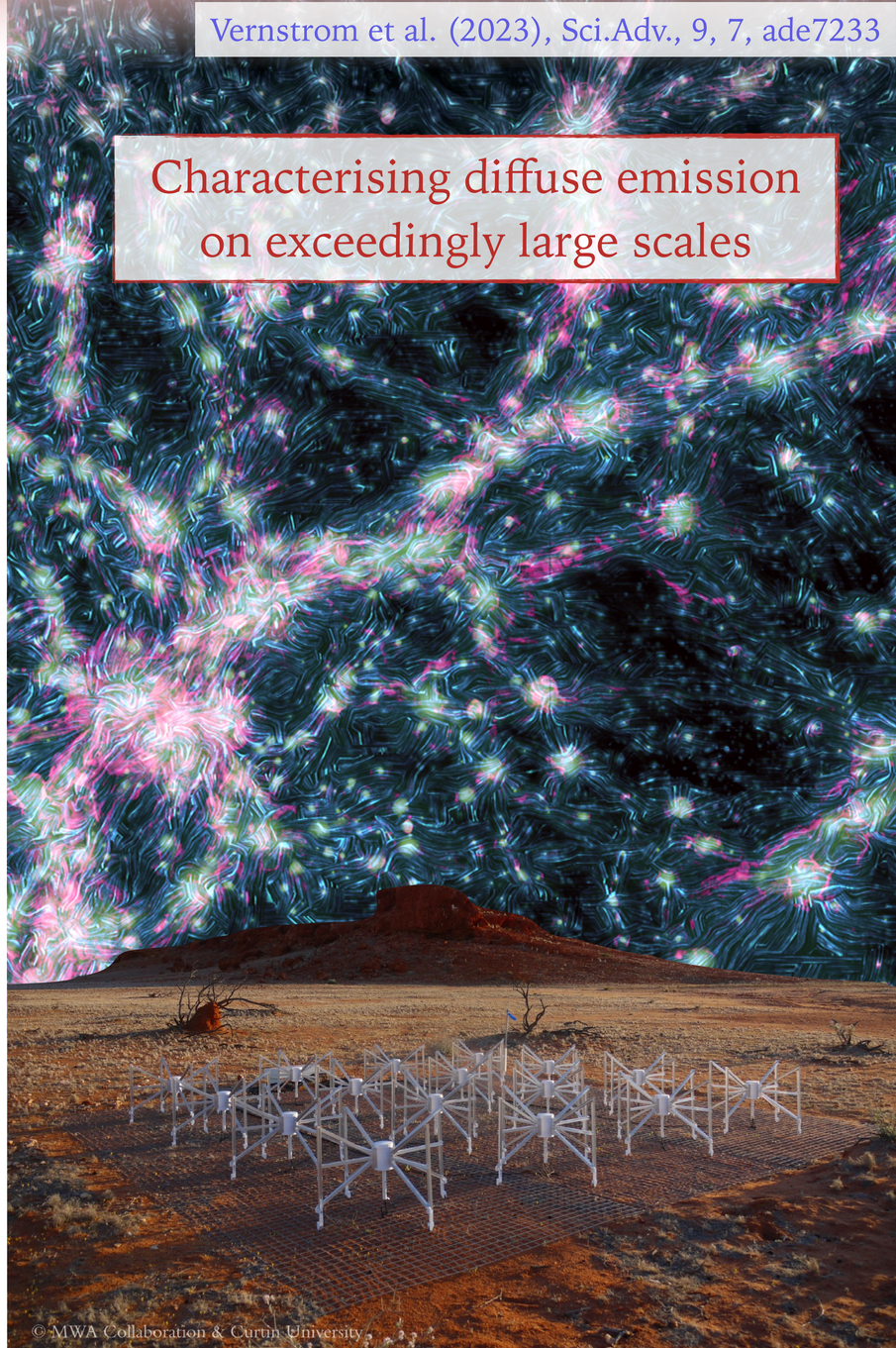
# THE COSMIC WEB

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



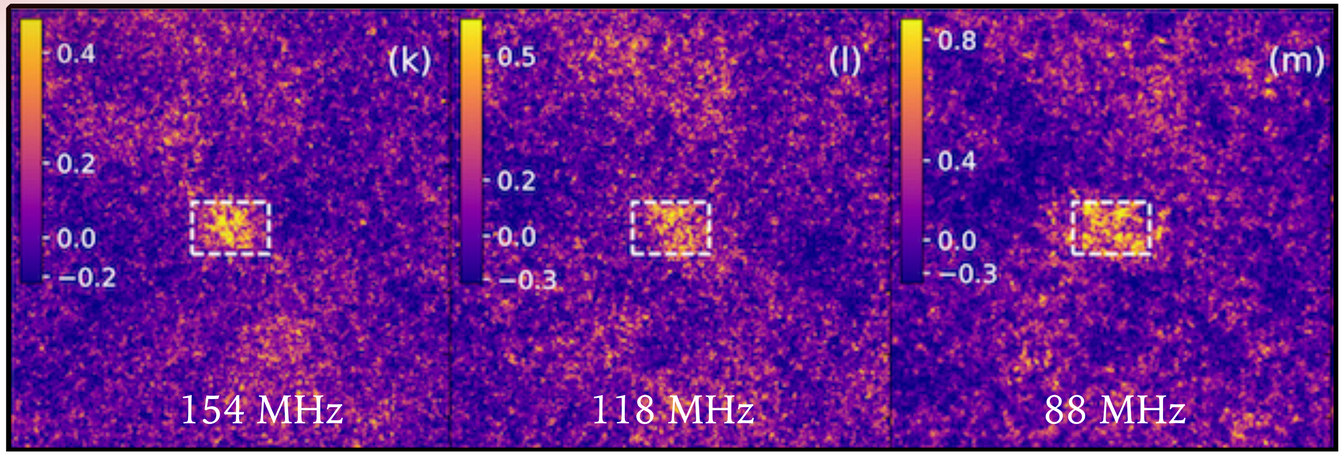

Vernstrom et al. (2023), Sci.Adv., 9, 7, ade7233

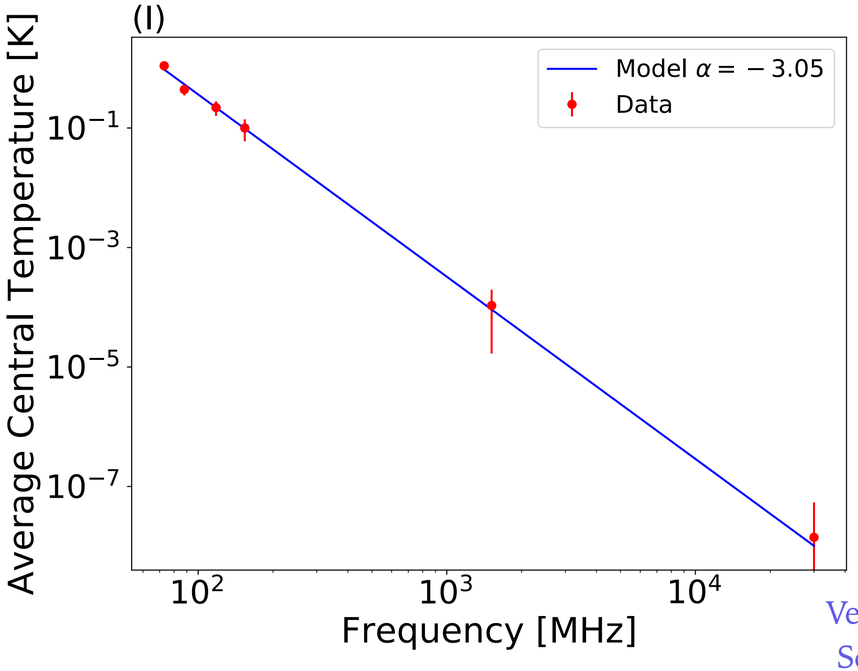
Characterising diffuse emission on exceedingly large scales

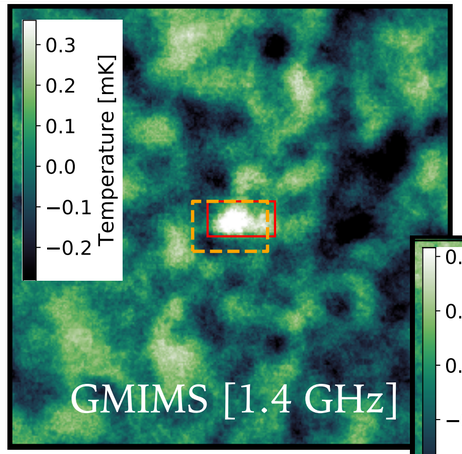


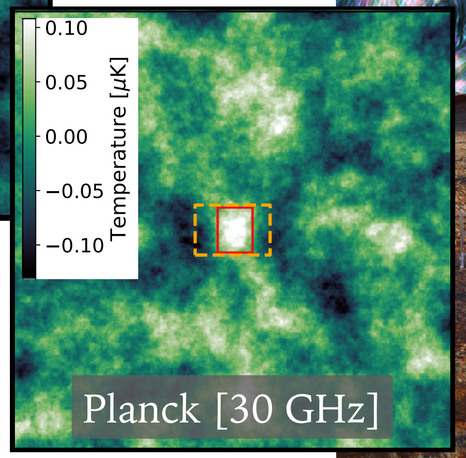
# THE COSMIC WEB

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

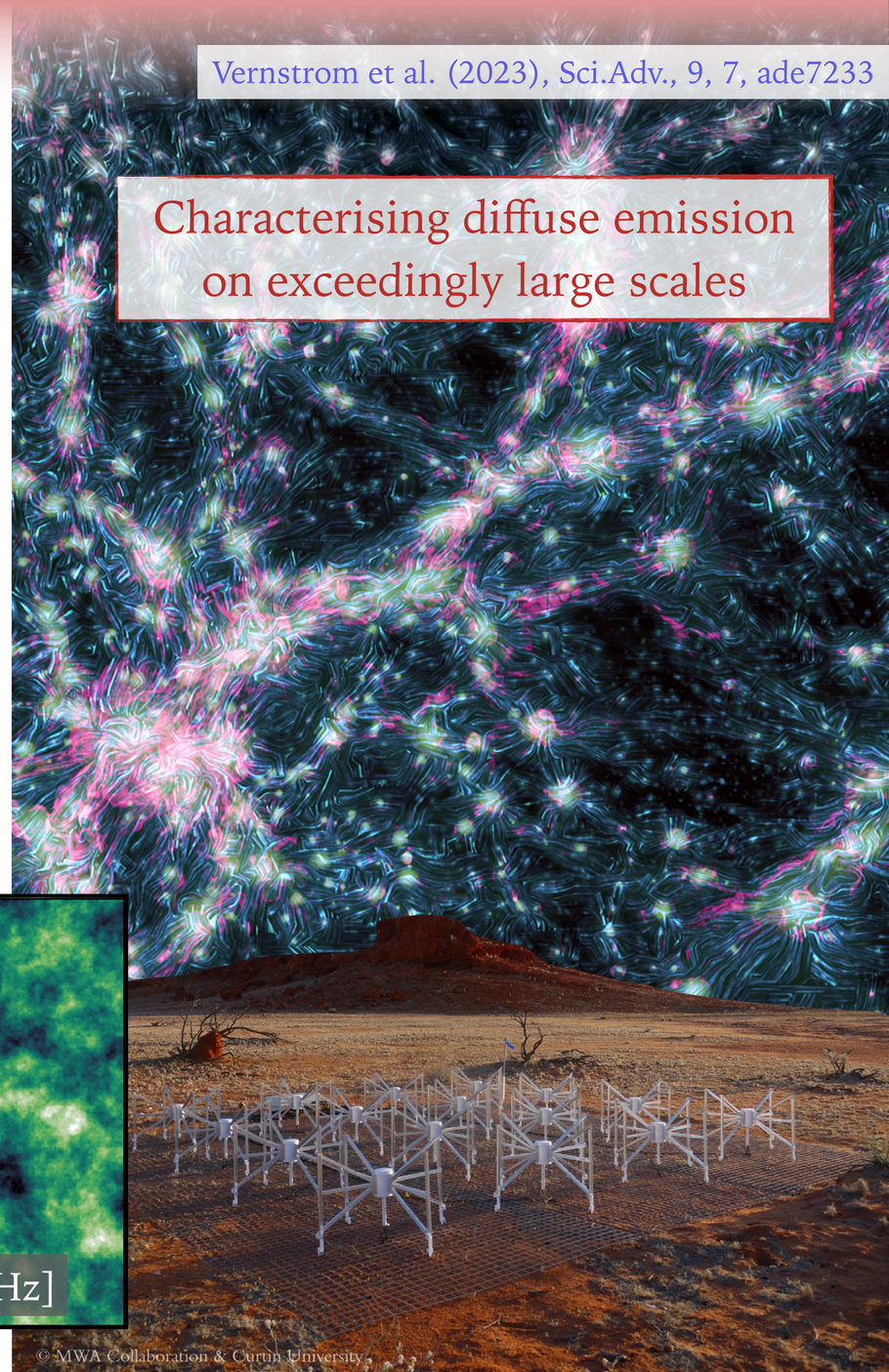


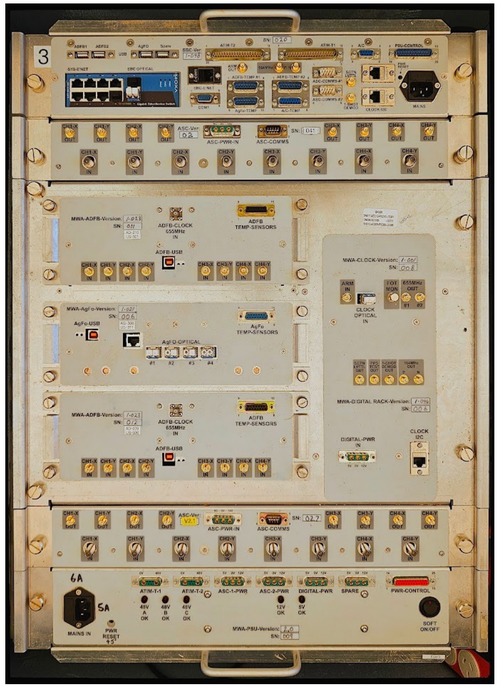




Vernstrom et al. (2023), Sci.Adv., 9, 7, ade7233

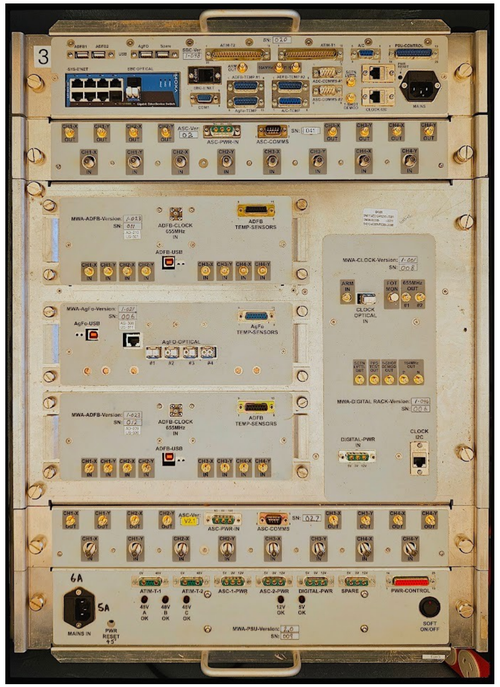


# PHASE III UPGRADES


16 original receivers

# PHASE III UPGRADES

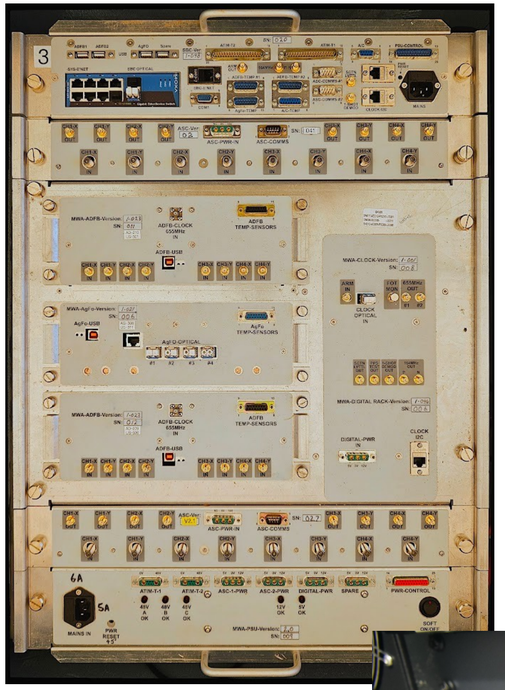




16 original receivers

*New receivers*

*New correlator*

# PHASE III UPGRADES


16 original receivers

SHAO receiver; MWA Collaboration & Curtin University

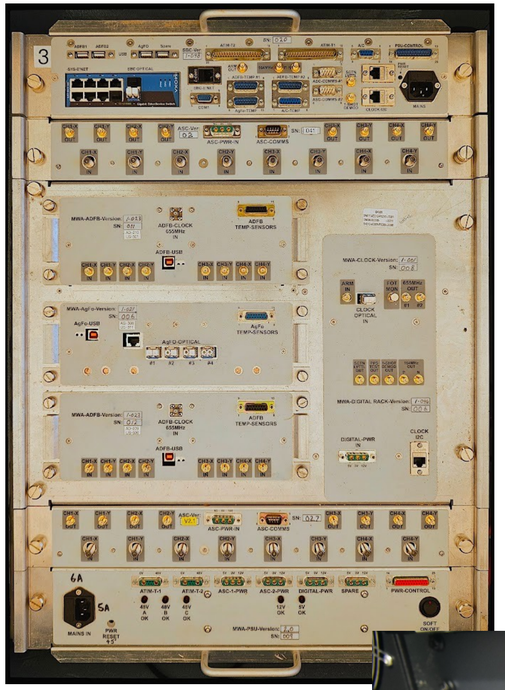
SHAO receiver; MWA Collaboration & Curtin University

16 new receivers

New MWAX Correlator


MWAX server; MWA Collaboration & Curtin University

# PHASE III UPGRADES


16 original receivers

SHAO receiver; MWA Collaboration & Curtin University

SHAO receiver; MWA Collaboration & Curtin University

16 new receivers


MWAX server; MWA Collaboration & Curtin University

New MWAX Correlator

*On target for a full 256 tile array!*

# SUMMARY

- **MWA science highlights:**
  - GEG: cluster palaeontology; AGN variability, feedback & feeding; Galactic SF…
  - 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)
  - Transients: extreme sources lurking in the archives

- **Exciting times ahead:**
  - New correlator & new receivers
  - On track for a 256T array!

MWA MURCHISON WIDEFIELD ARRAY

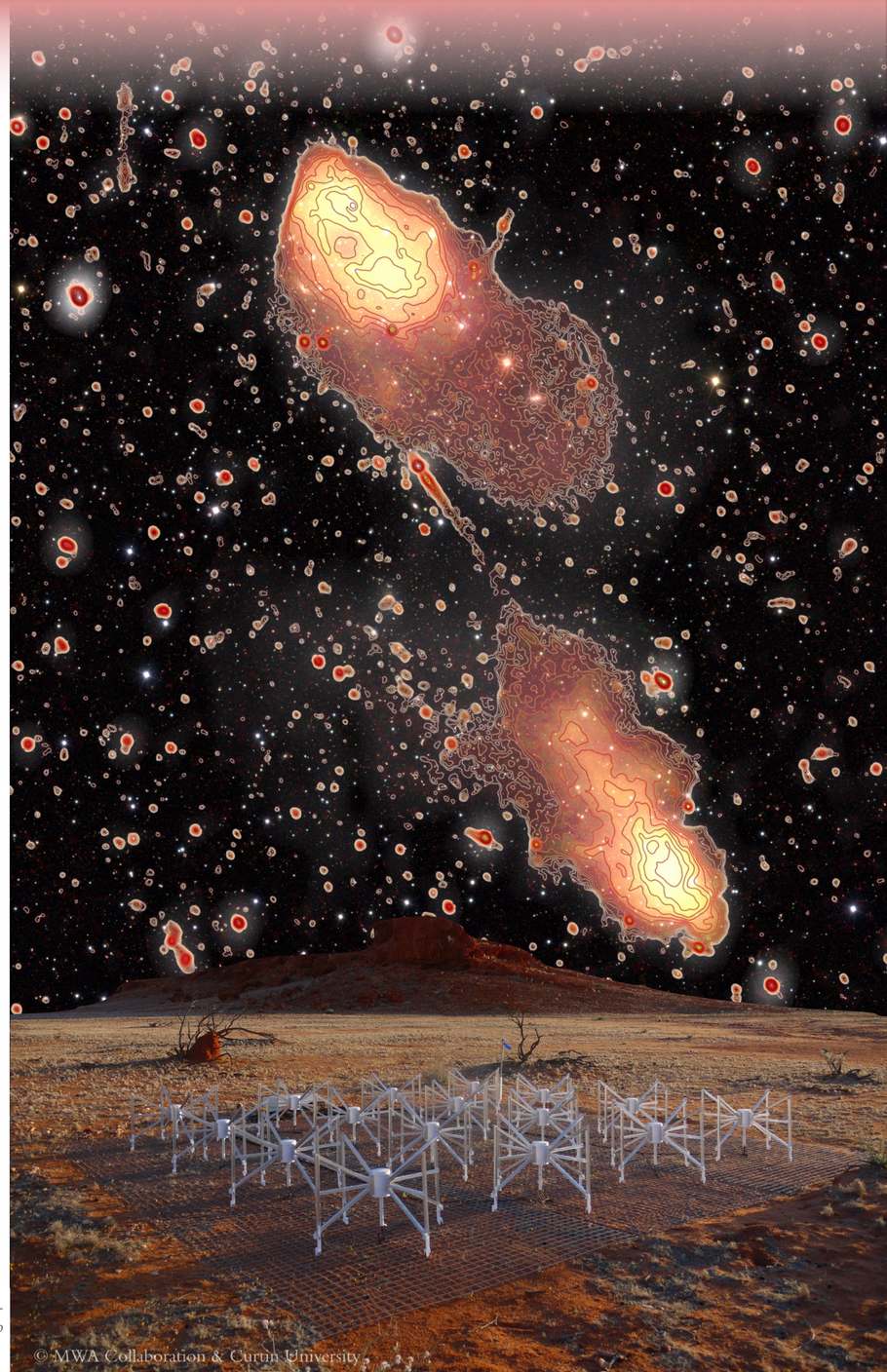
Gurlgamarnu

- **Lessons:**
  - *Precision, precision, precision*
  - Rich archives are essential
  - People-driven

E: scientist@mwatelescope.org @mwatelescope

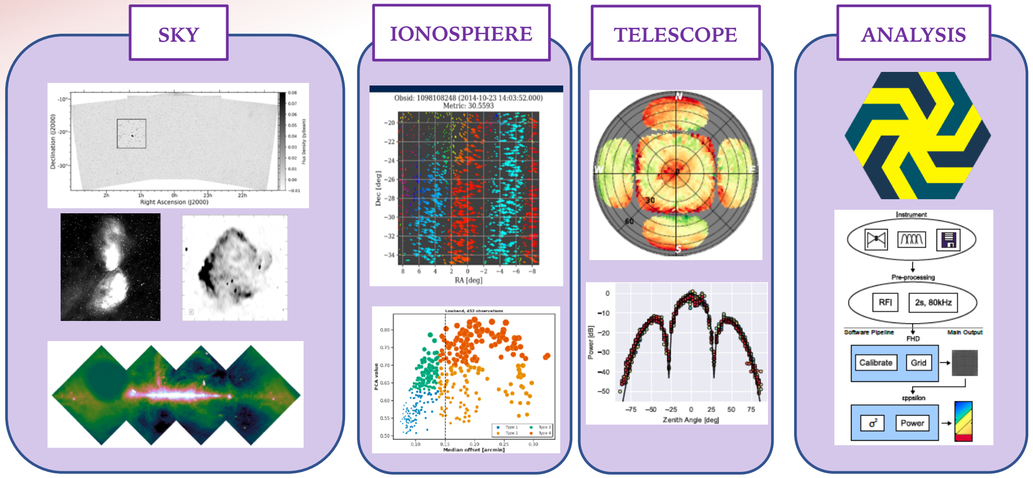
E: chris.riseley.astro@gmail.com @cjriseley

Thanks for listening. Questions?




*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.*

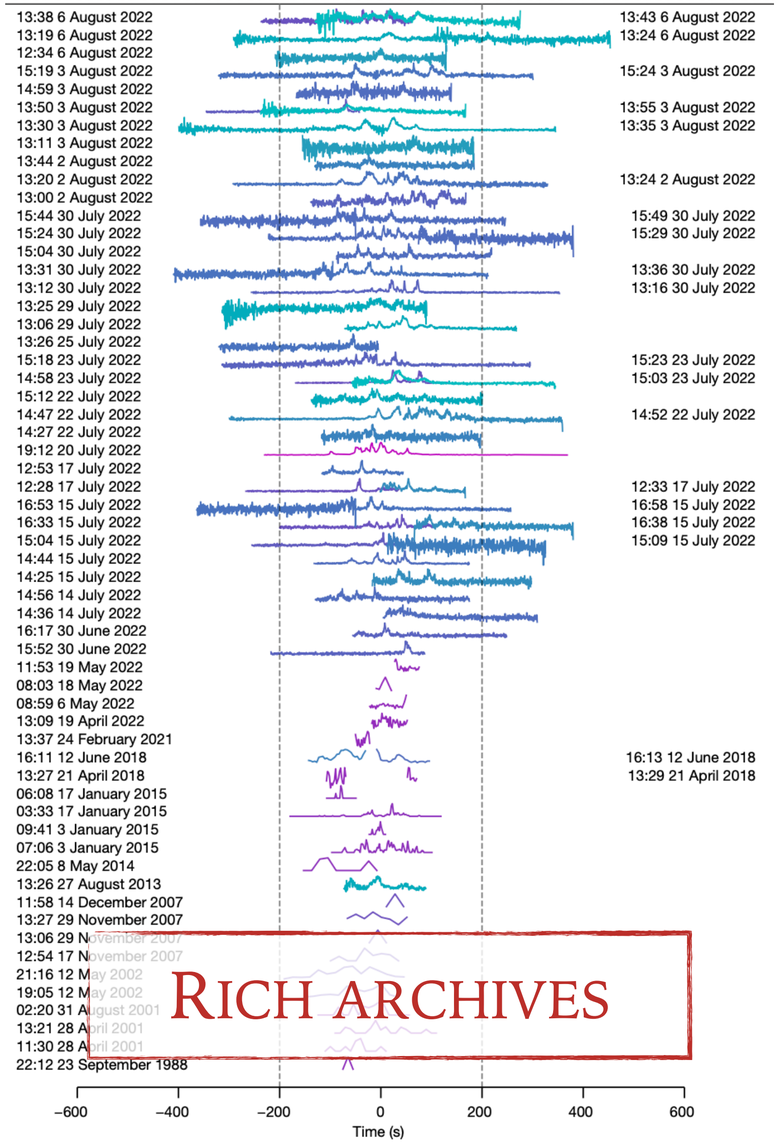
# LESSONS LEARNED...




UNDERSTANDING EVERY STEP

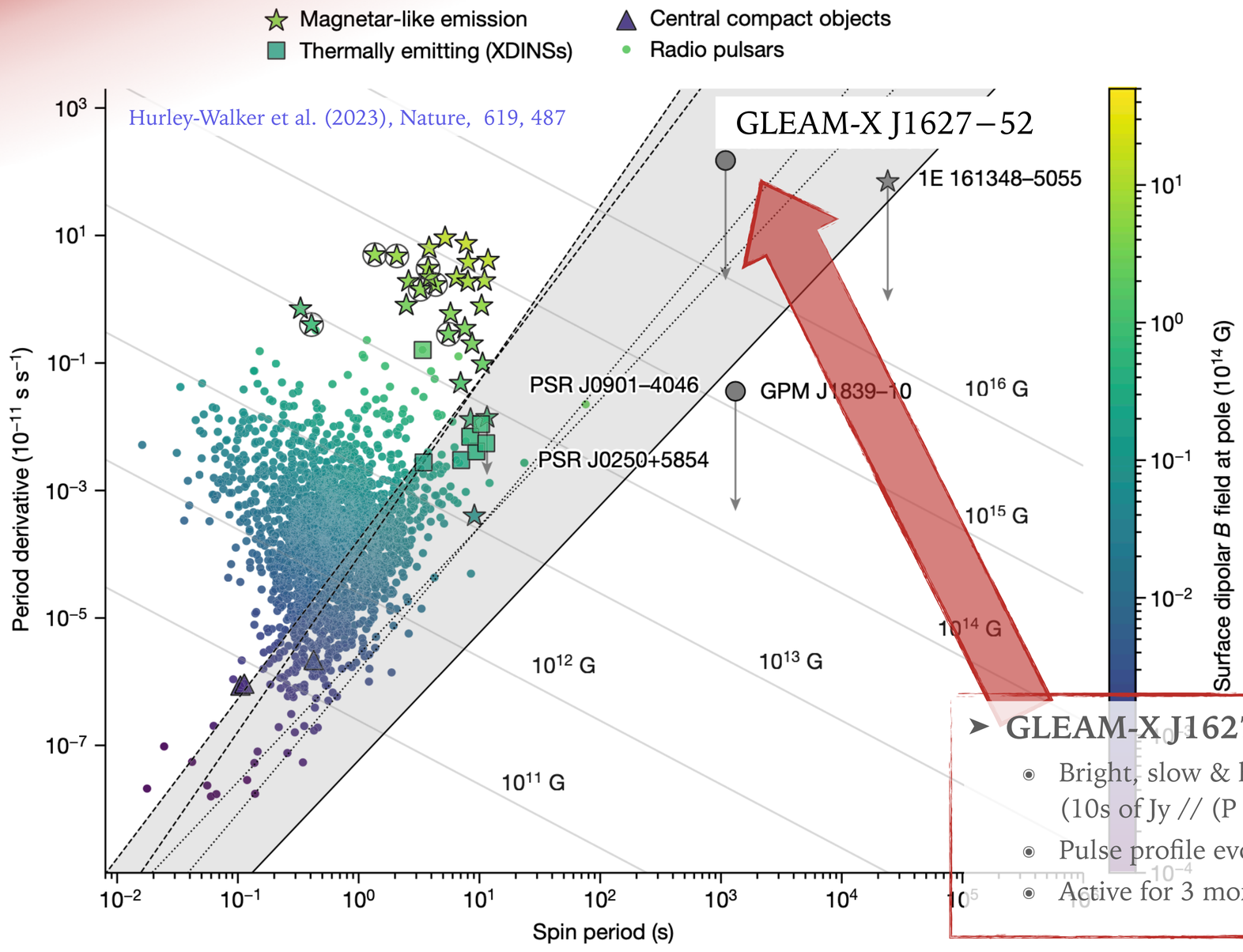
Ten years of MWA operattions; credit: MWA Collaboration

IT'S ABOUT THE PEOPLE

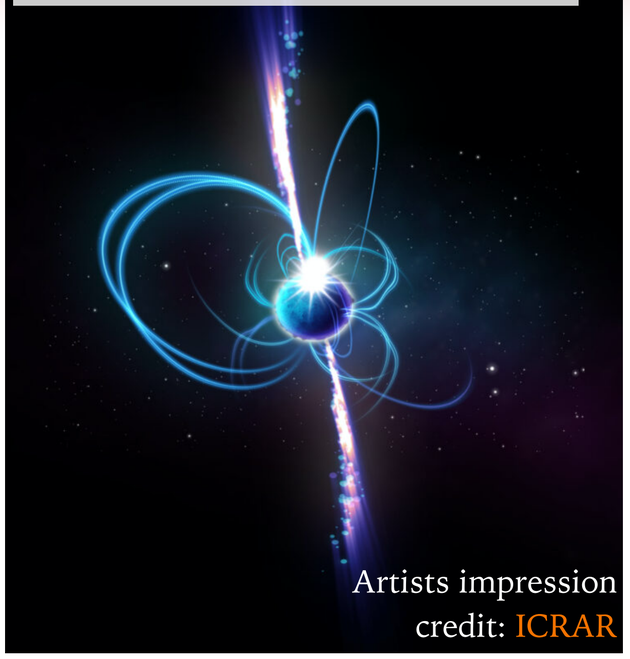



RICH ARCHIVES

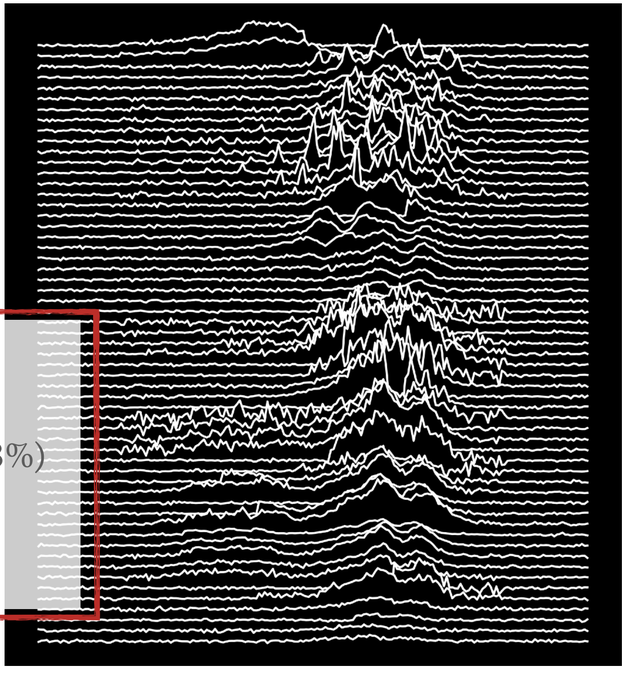
# TRANSIENTS




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

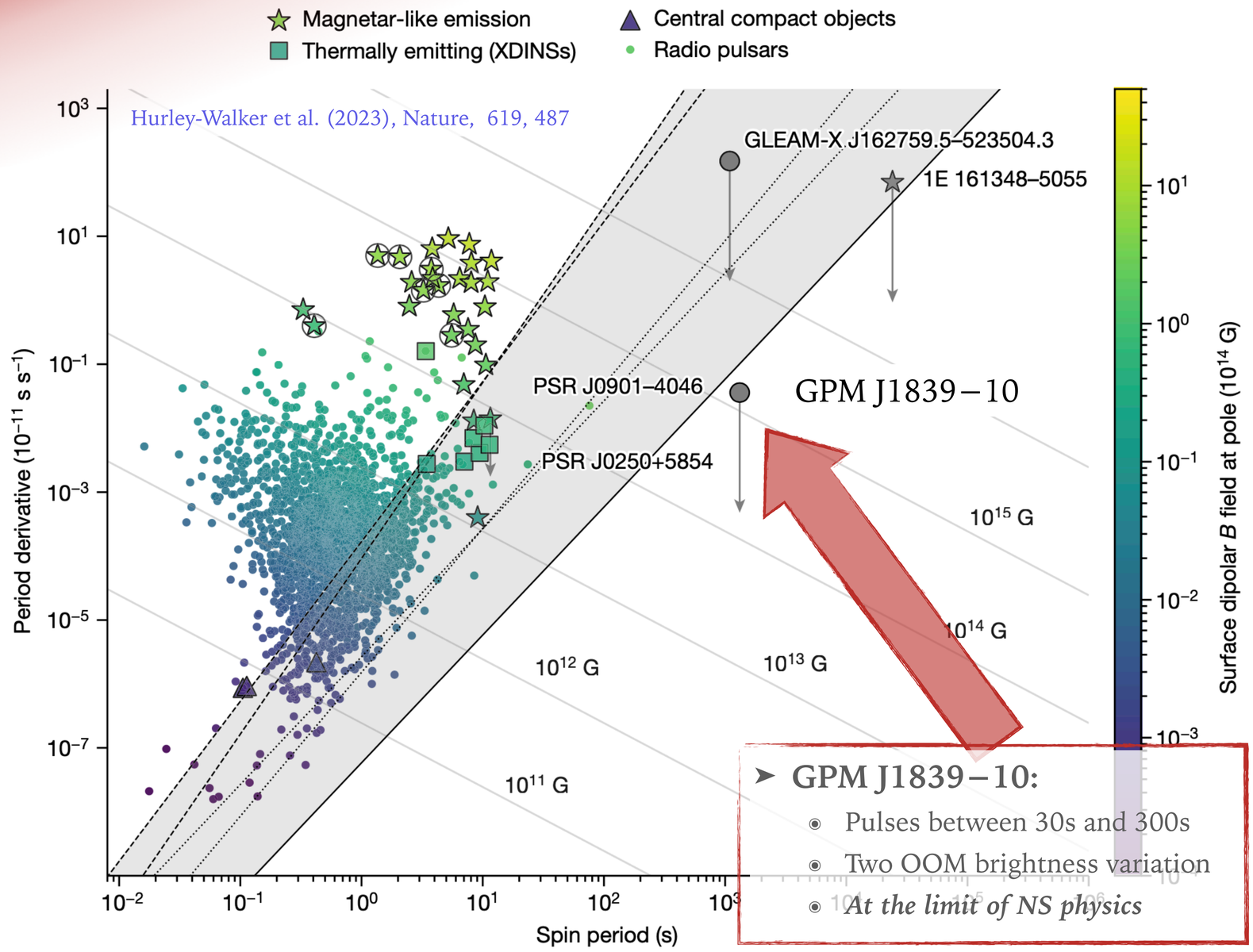


Artists impression
credit: ICRAR

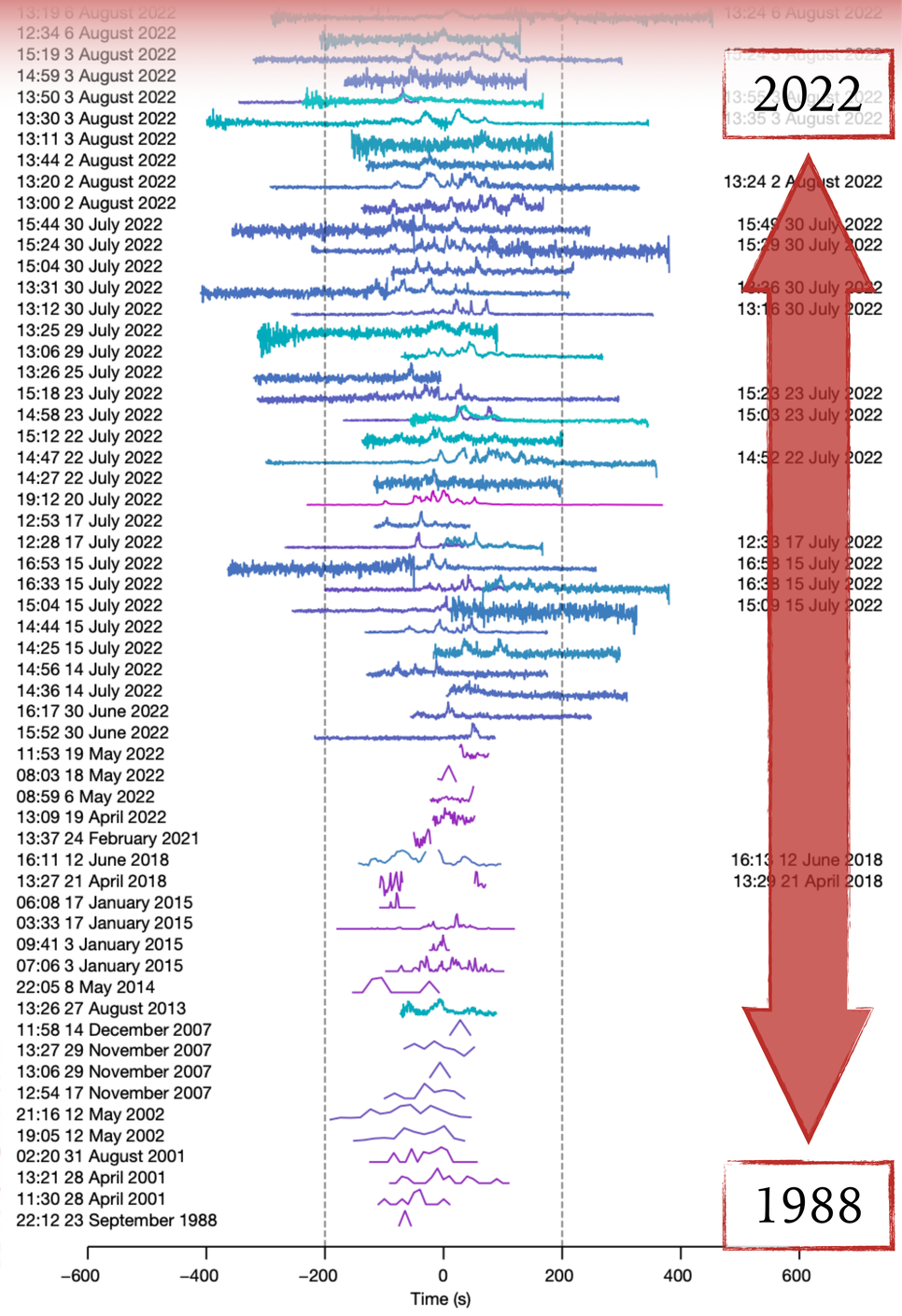


- **GLEAM-X J1627−52:**
  - Bright, slow & highly-polarised (10s of Jy // (P = 18.18m // P/I = 88%)
  - Pulse profile evolution
  - Active for 3 months in 2018

# TRANSIENTS

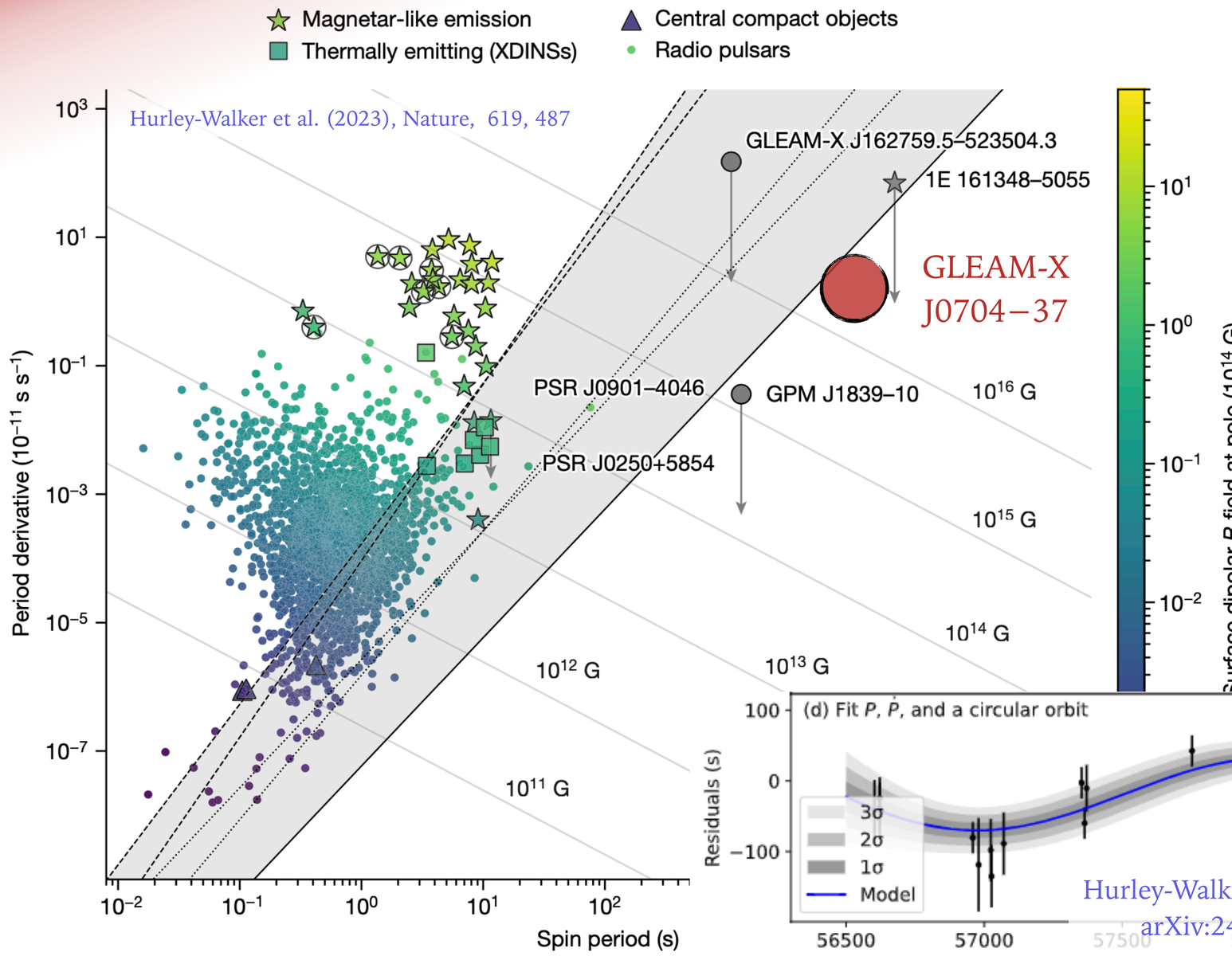


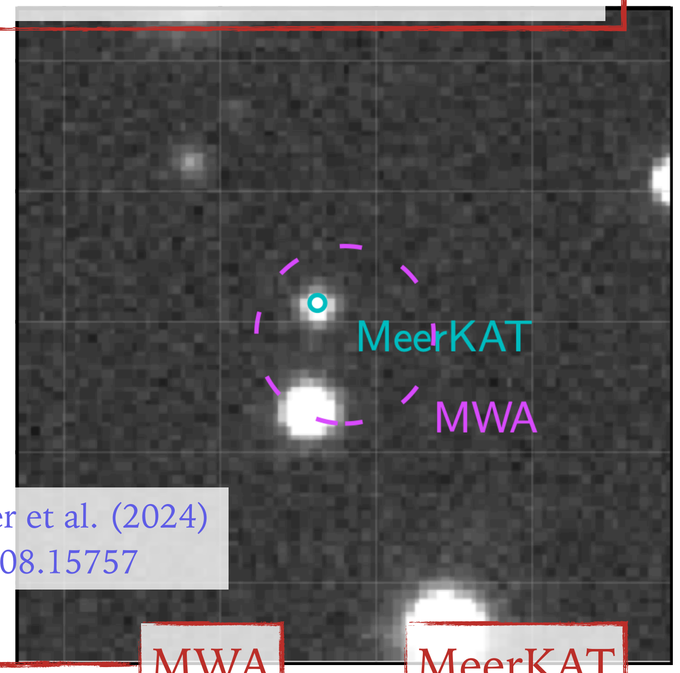

- **GPM J1839−10:**
  - Pulses between 30s and 300s
  - Two OOM brightness variation
  - *At the limit of NS physics*



# TRANSIENTS

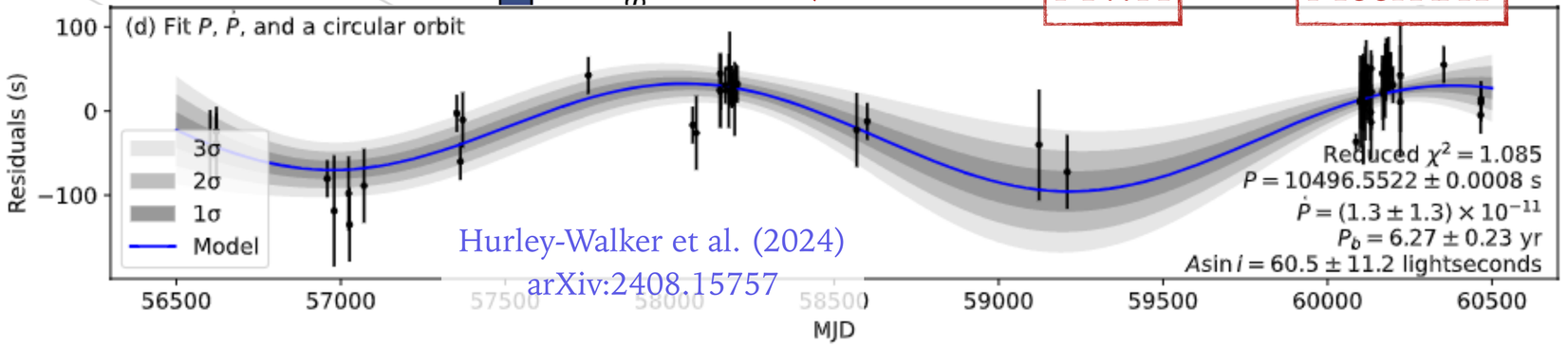
- **GLEAMX J0704−37:**
  - Detections spanning 11+ years
  - P ∼2.9 hours ; tentative ∼6 year orbit
  - Optical counterpart! WD/M-dwarf binary?




Hurley-Walker et al. (2024)
arXiv:2408.15757

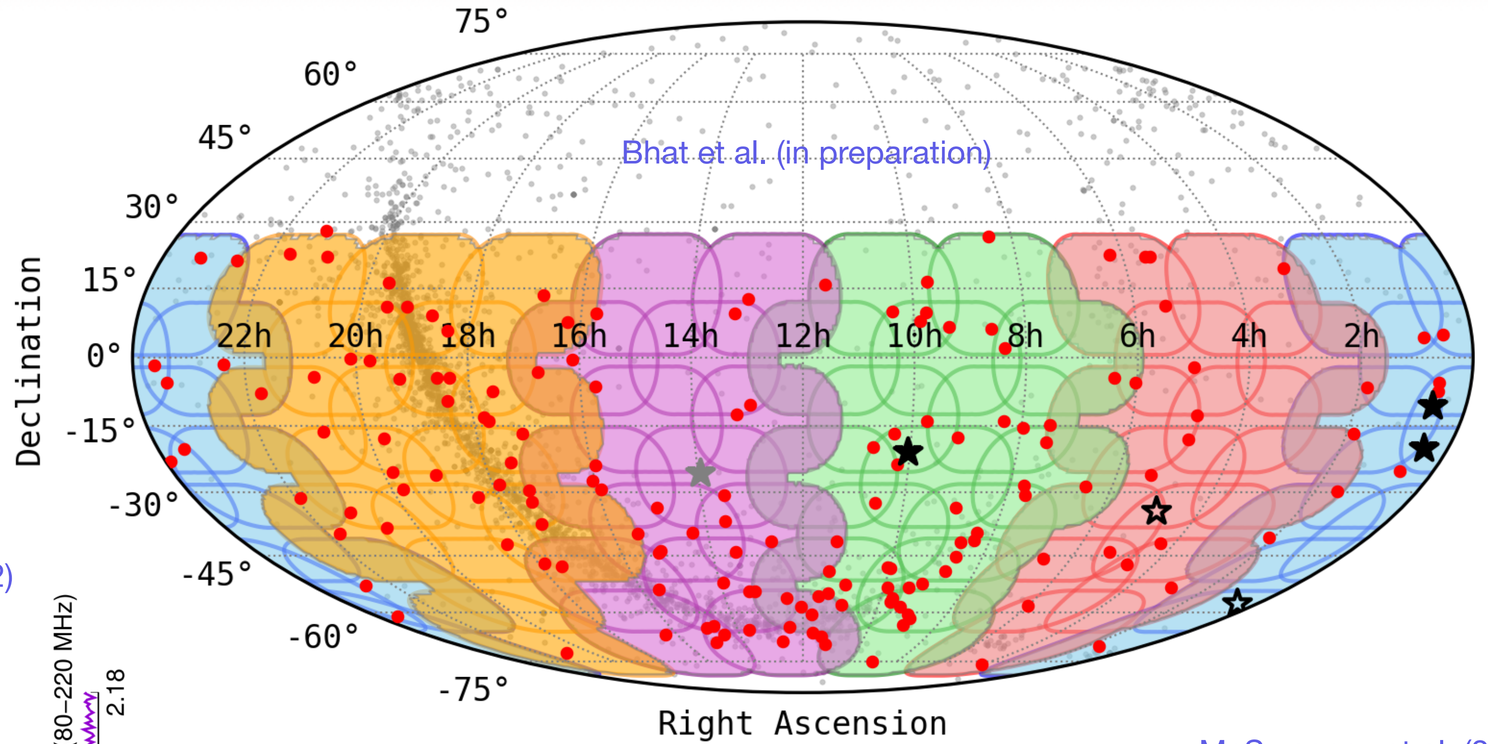
MWA MeerKAT



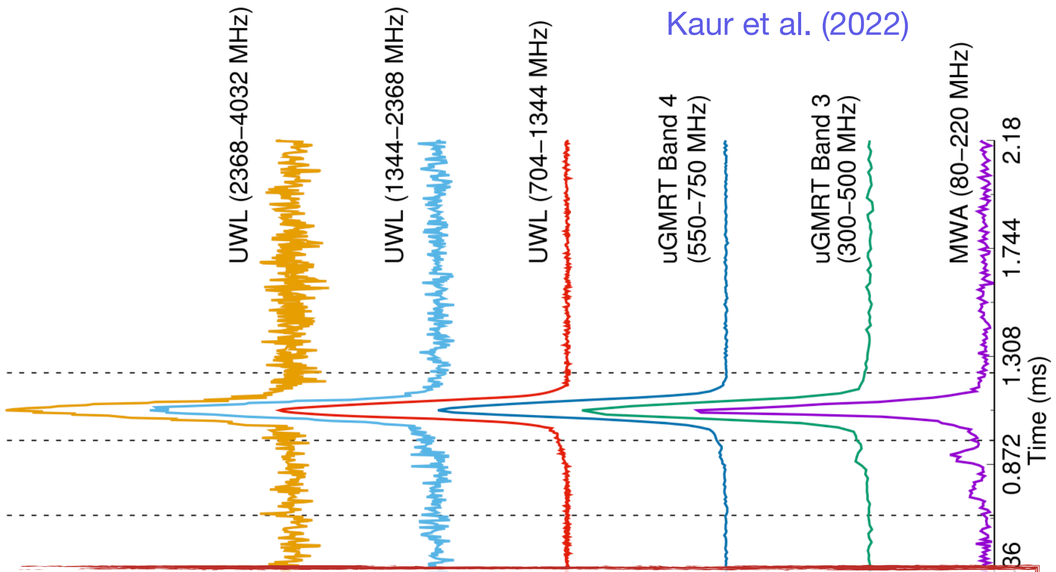

Hurley-Walker et al. (2024)
arXiv:2408.15757

# 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*

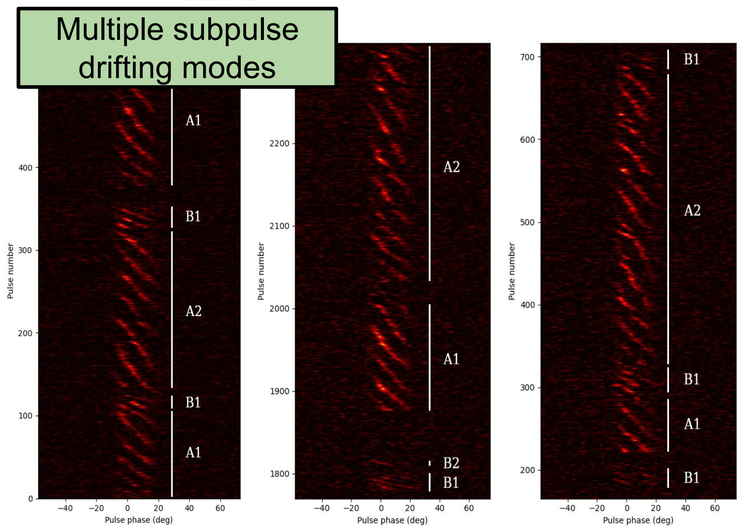


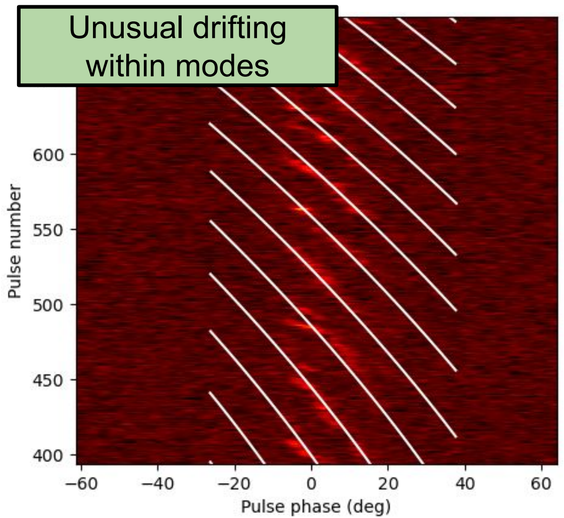

Kaur et al. (2022)




Minimal profile evolution 80 MHz to 4 GHz
Implications for pulsar timing!

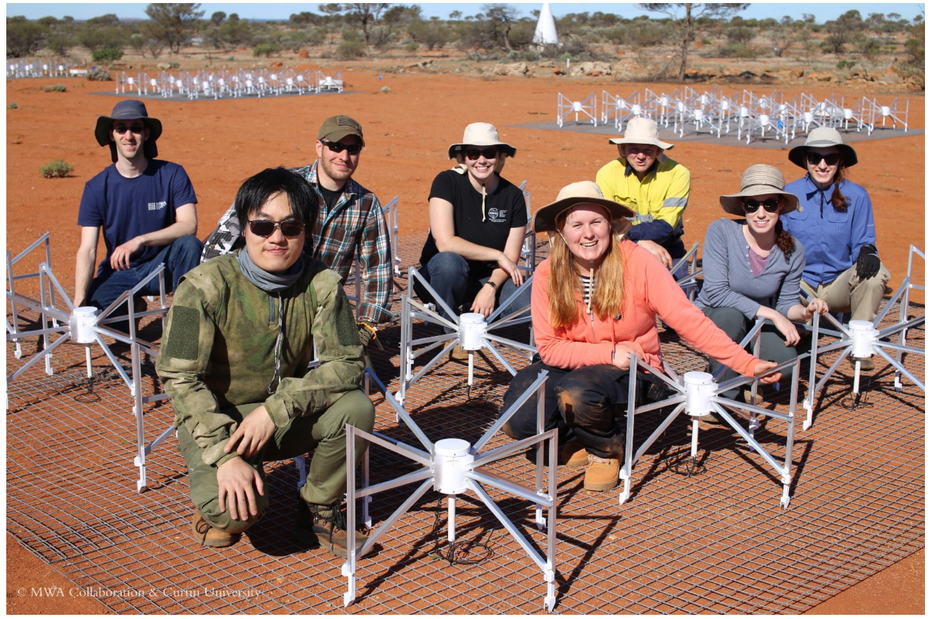
McSweeney et al. (2022)

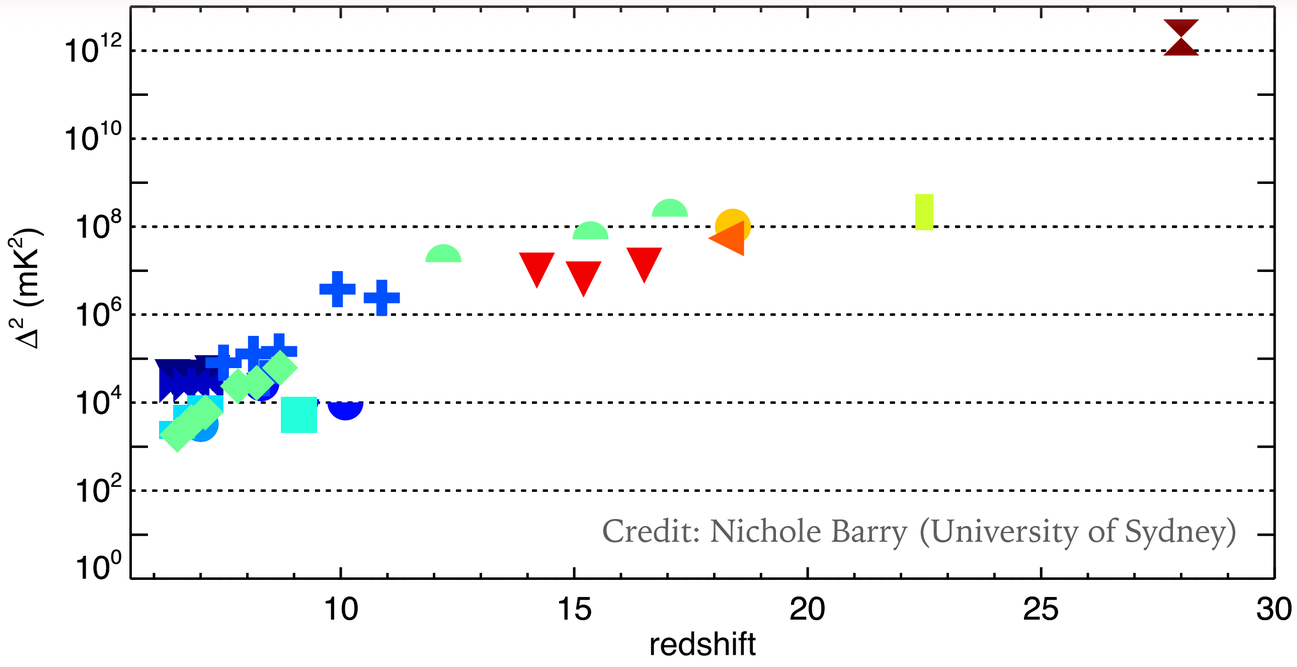


# EPOCH OF REIONISATION (EOR)





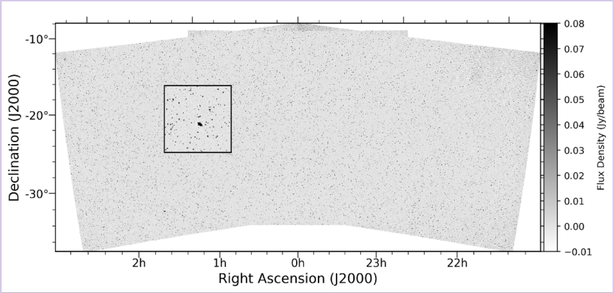

*"Precision, precision, precision"*
(attr. Miguel Morales, Aug. 2024)

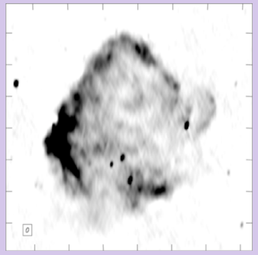
# KEY INGREDIENTS

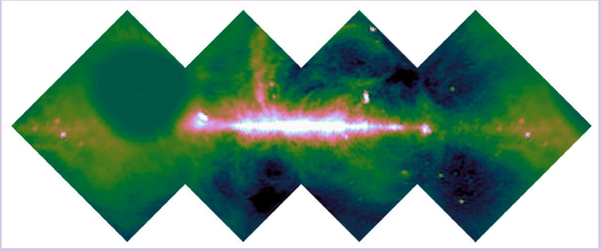
Slide courtesy **Miguel Morales** (UW)

ASTRO 3D

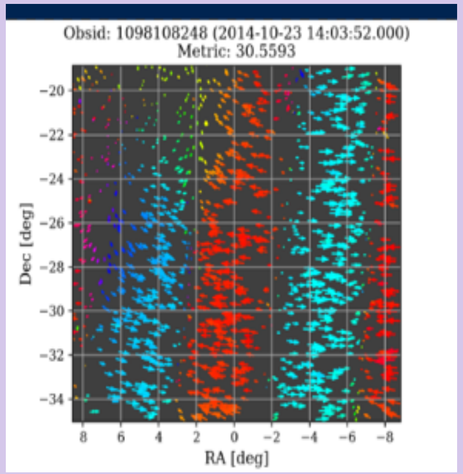
## SKY

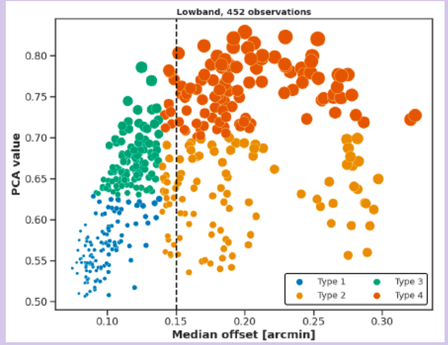


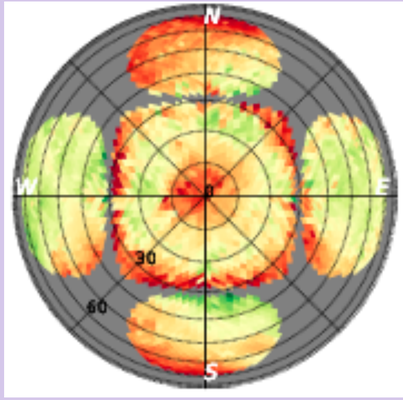


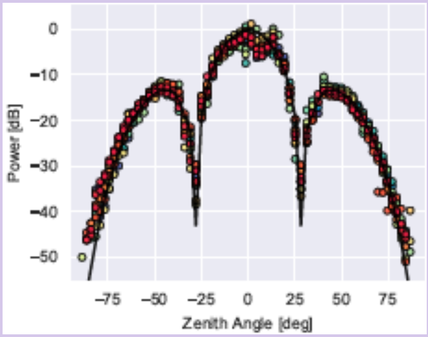
## IONOSPHERE



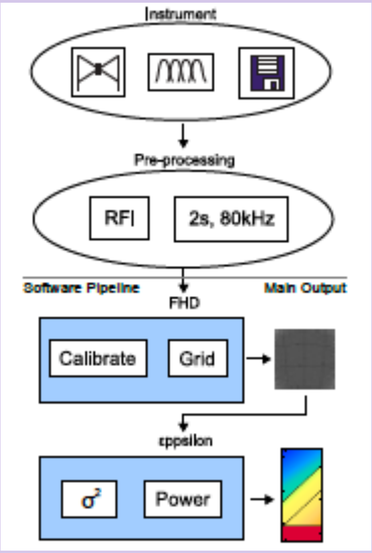




## TELESCOPE



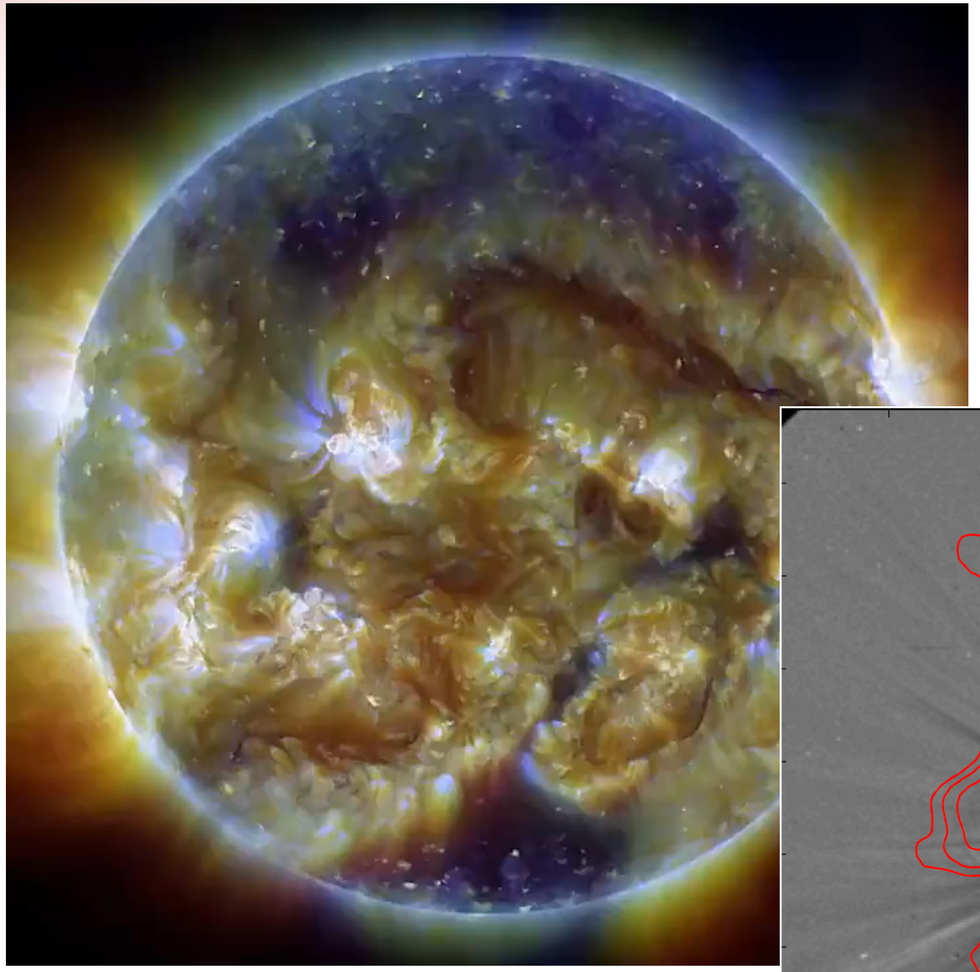



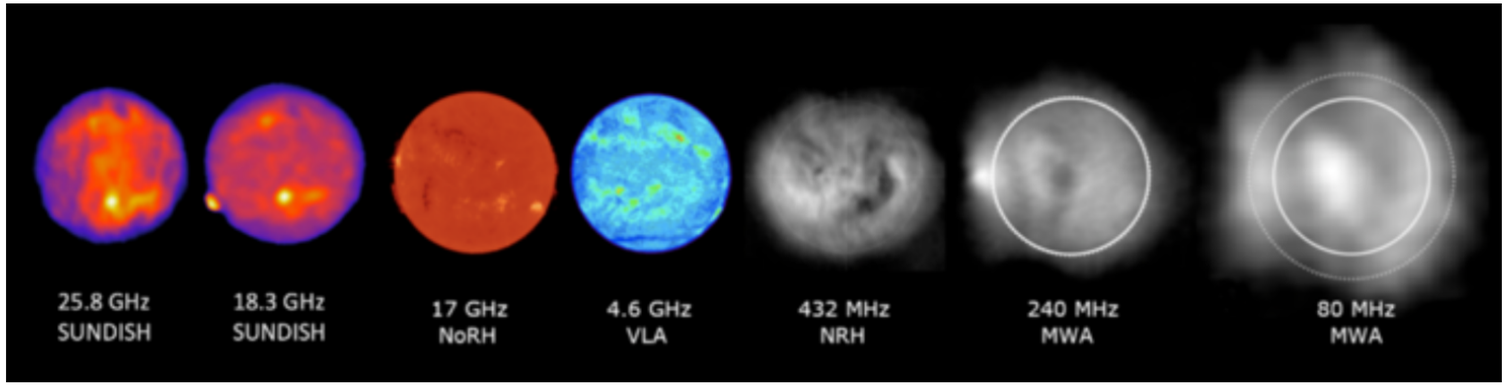

## ANALYSIS



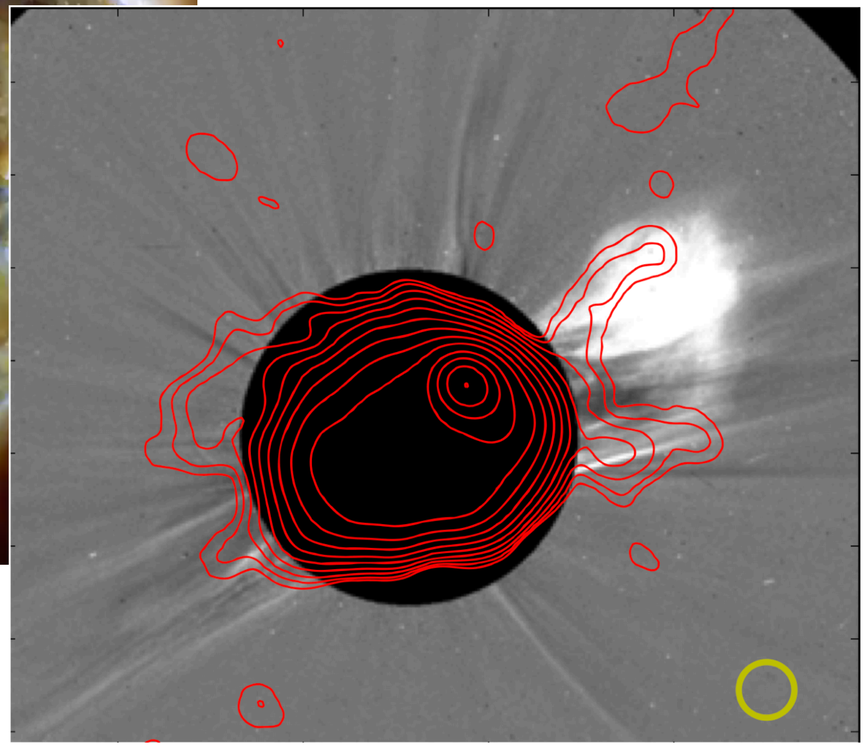

**Full end-to-end simulations**

# SOLAR, HELIOSPHERIC & IONOSPHERIC (SHI)

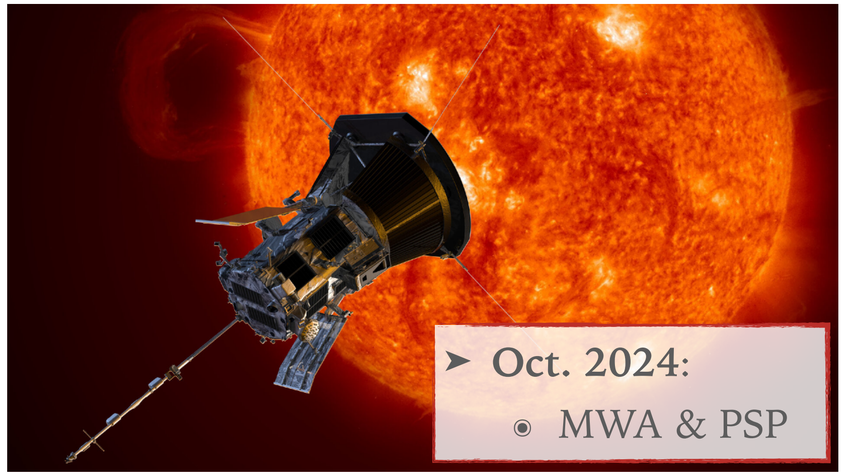





The Sun in the radio; credit: Rohit Sharma

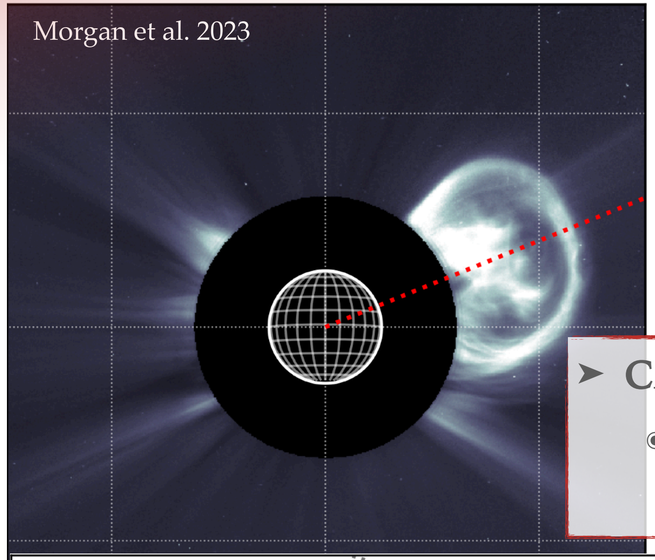


MWA imaging of CME;
Mondal et al. (2019)

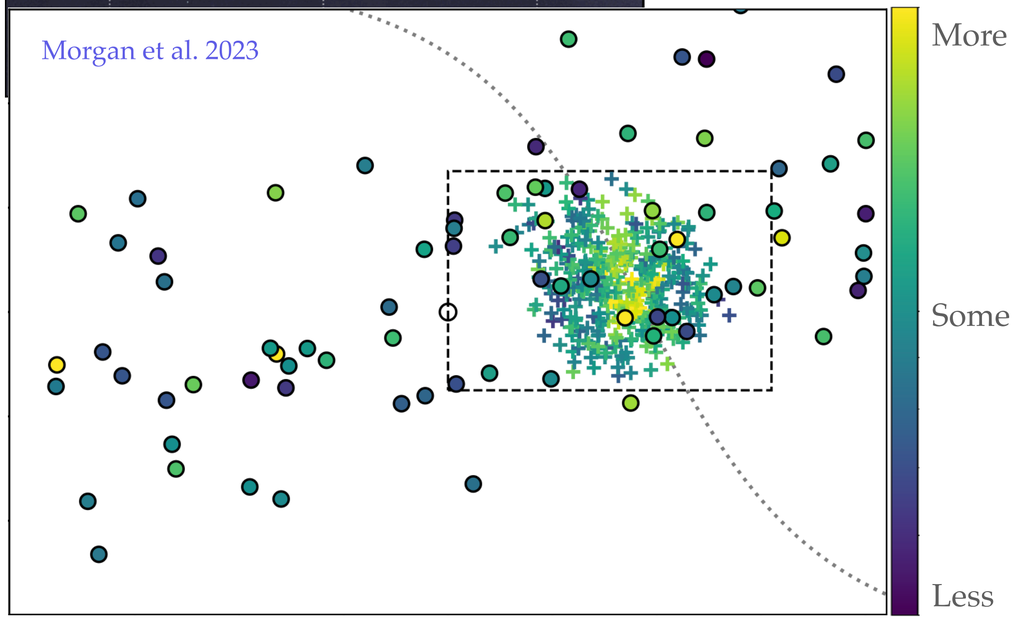


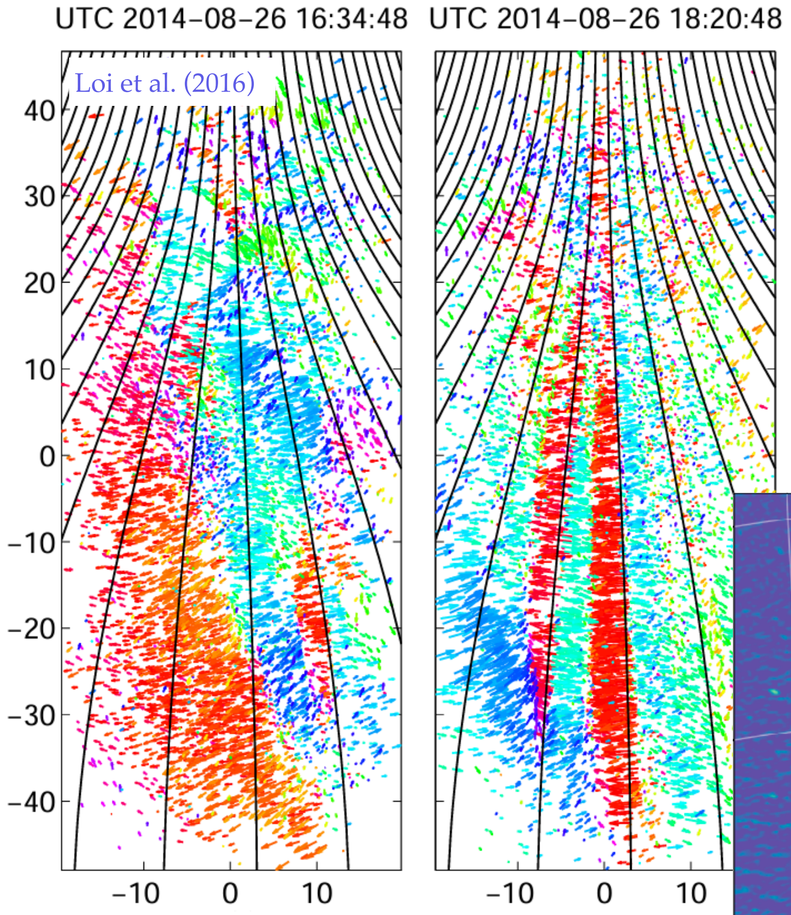
- Oct. 2024:
  - MWA & PSP

# SOLAR, HELIOSPHERIC & IONOSPHERIC (SHI)



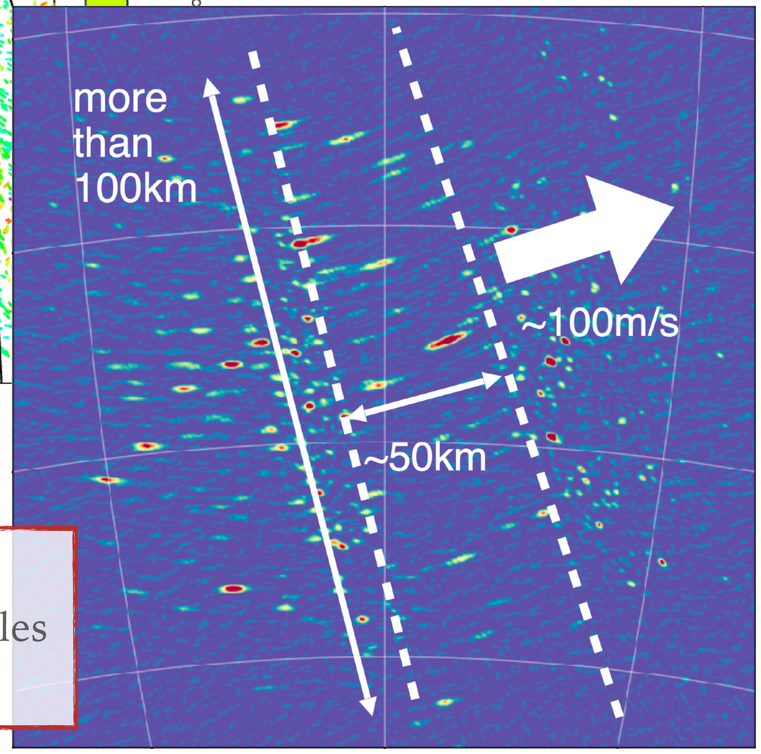

- CME:
  - Detection via scintillation




- 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)