

# The SKAO: Science & Status

Philippa Hartley, SKAO Project Scientist

University of Catania, 27<sup>th</sup> November 2023





# The SKA Observatory

*Building and operating the largest **radio** telescopes in the world*





**Born February 2021**

*One Observatory*

*Two Telescopes*

*Three Continents*

SKAO Global HQ, Jodrell Bank, UK



# The Low telescope

**SKAO**

131,072 x 2 metre log-periodic dipole antennas  
Grouped into 256 stations  
50-350 MHz

Murchison, **Western Australia**  
Located on the traditional lands of the **Wajarri Yamaji**



Credit: SKAO/CSIRO



# The **Mid** telescope

**SKAO**



197 dishes  
(133 x 15m + 64 x 13.5m dishes)  
0.35-15 GHz  
Karoo, **South Africa**

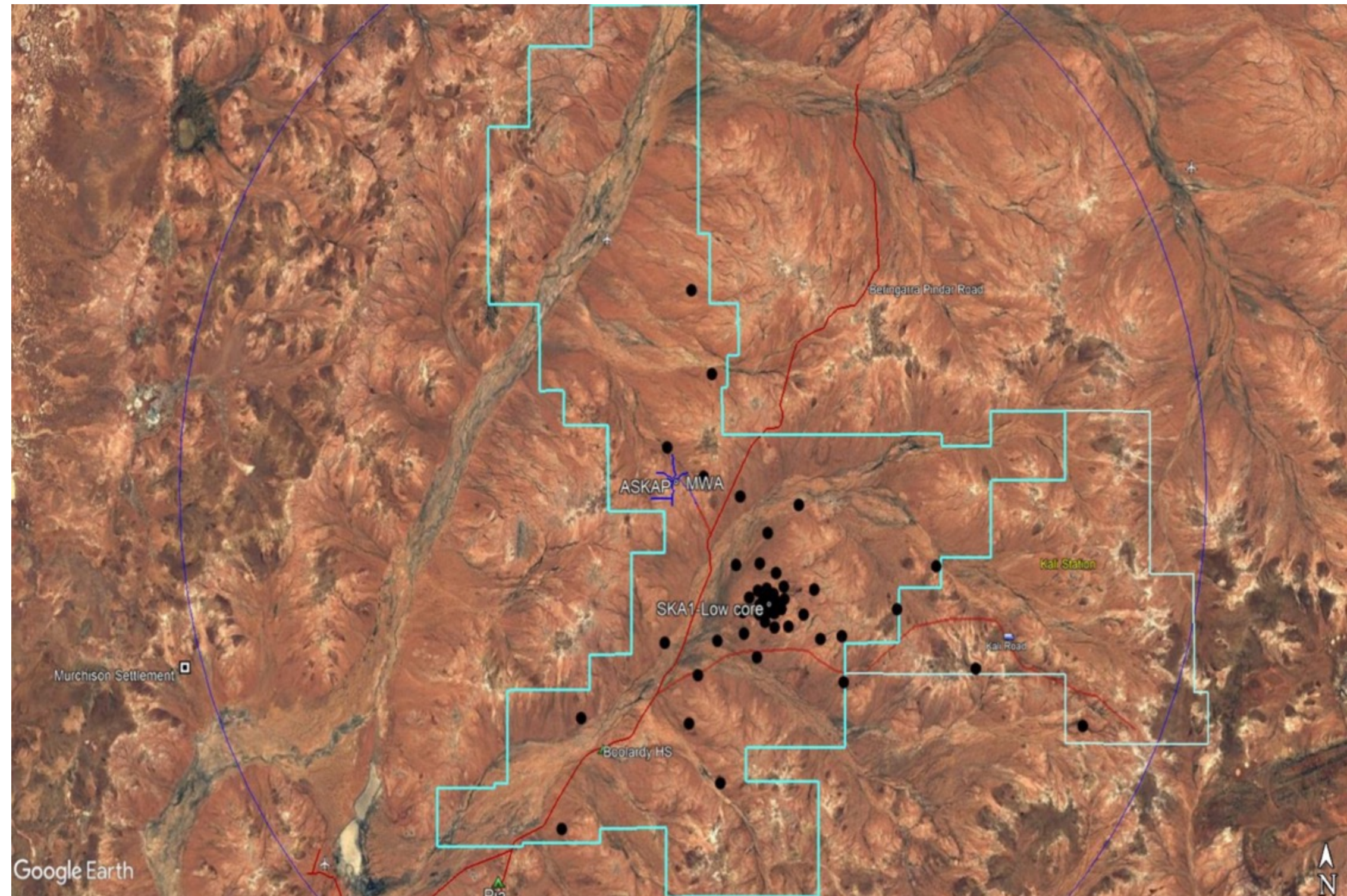
64 MeerKAT dishes





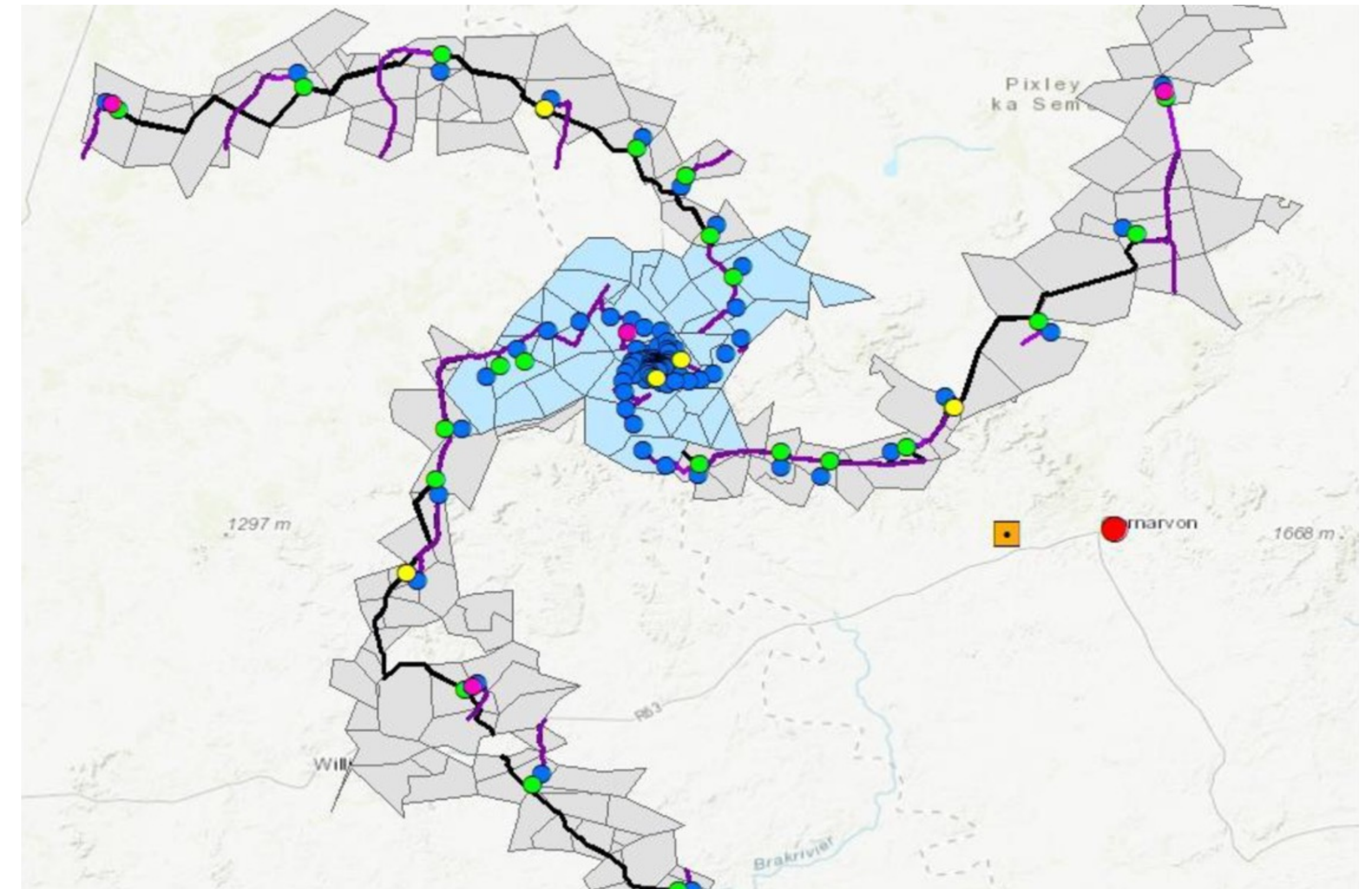
# Baselines

## Murchison, Western Australia



**SKA-Low**  
74 km max baseline  
(11" @ 110 MHz)

## Karoo, South Africa



**SKA-Mid**  
150 km max baseline  
(0.22" @ 1.7 GHz; 34 mas @ 15 GHz)





# A global collaboration



## Full membership:

Australia, China, **Italy**, Netherlands, Portugal, South Africa, Spain, Switzerland, United Kingdom.

## Accession stage:

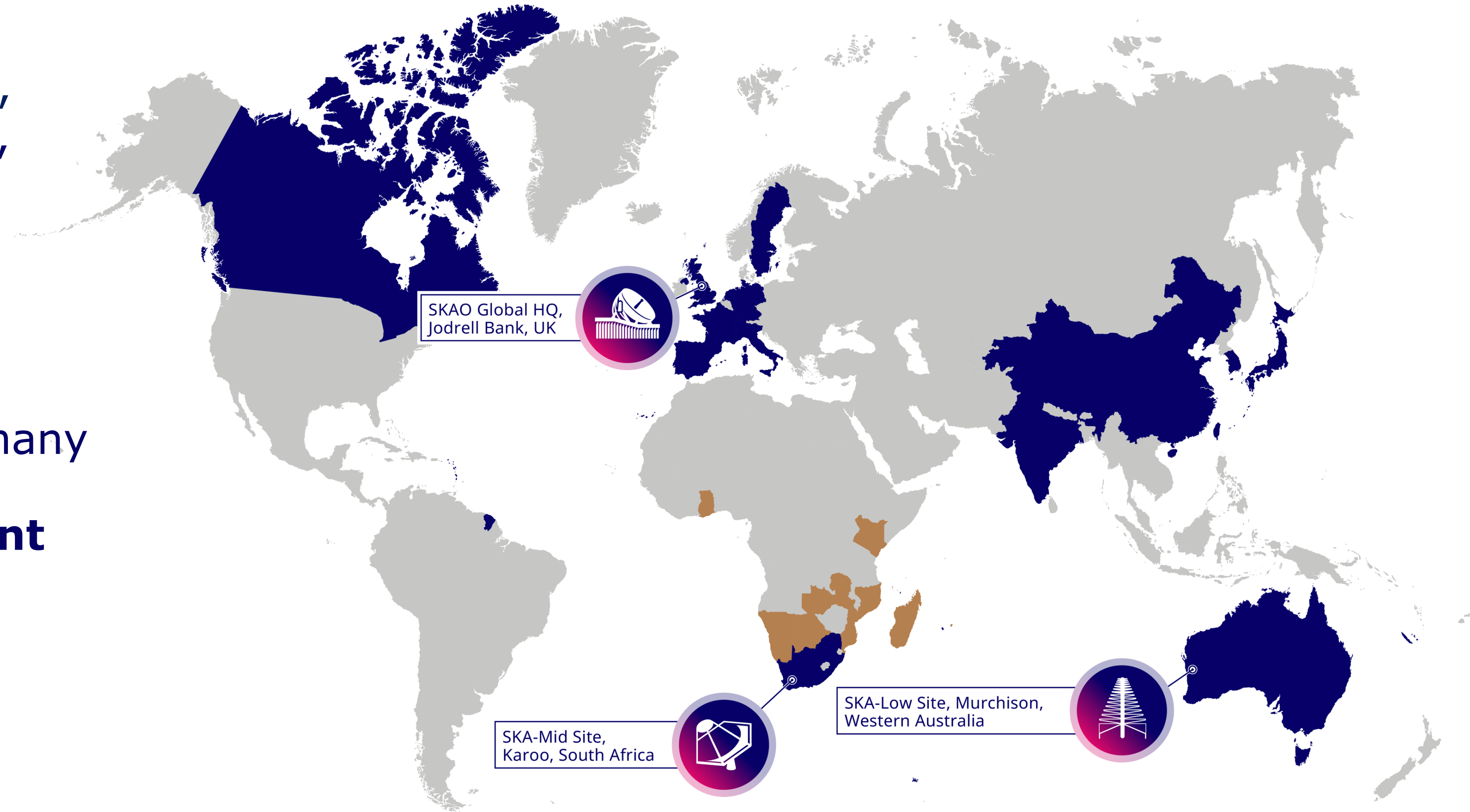
Canada, France, Germany

## Awaiting government decisions:

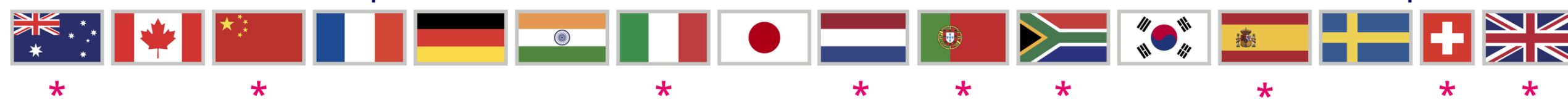
India, Sweden, South Korea

## Early stages:

Japan, South Korea.



SKAO Partnership - includes SKAO Member States\* and SKAO Observers (as of April 2023)



African Partner Countries





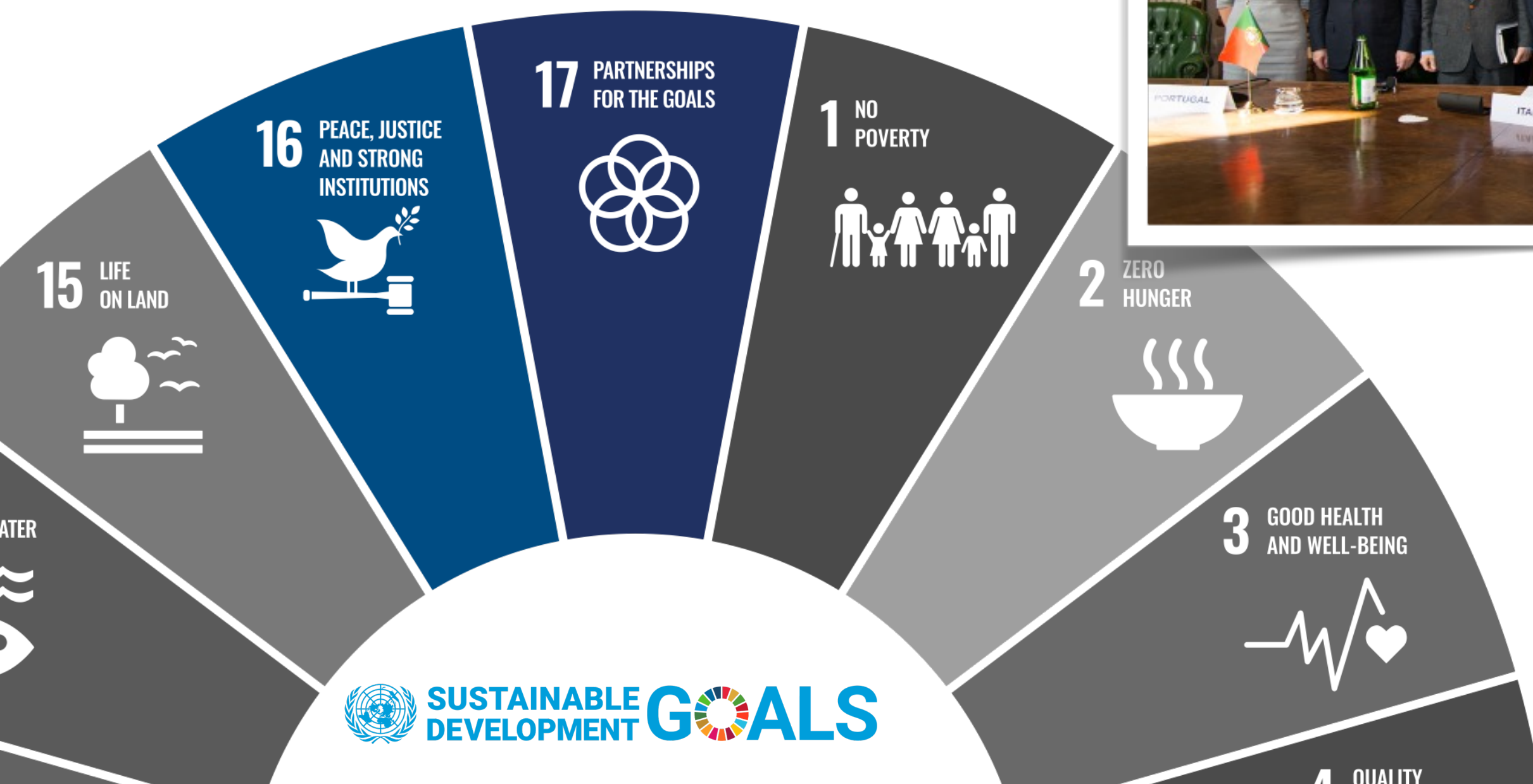
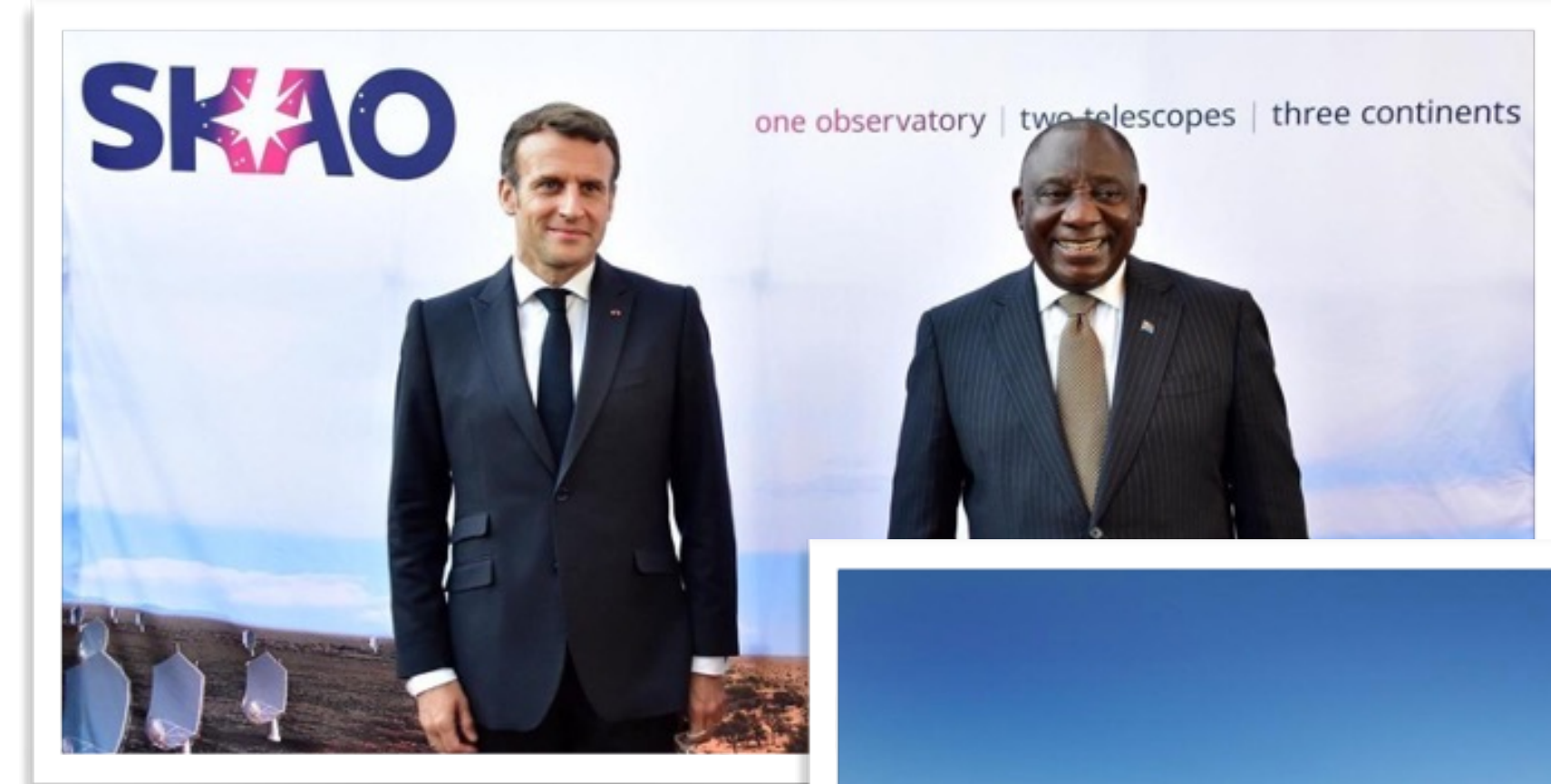
*SKAO's mission is to build and operate cutting-edge radio telescopes to transform our understanding of the Universe and to deliver benefits to society through global collaboration and innovation.*





# SKAO partnership as a science diplomacy tool

- Build international connections
- Encouraging government-level interaction
- A vehicle for collaboration





# SKAO Science Capabilities



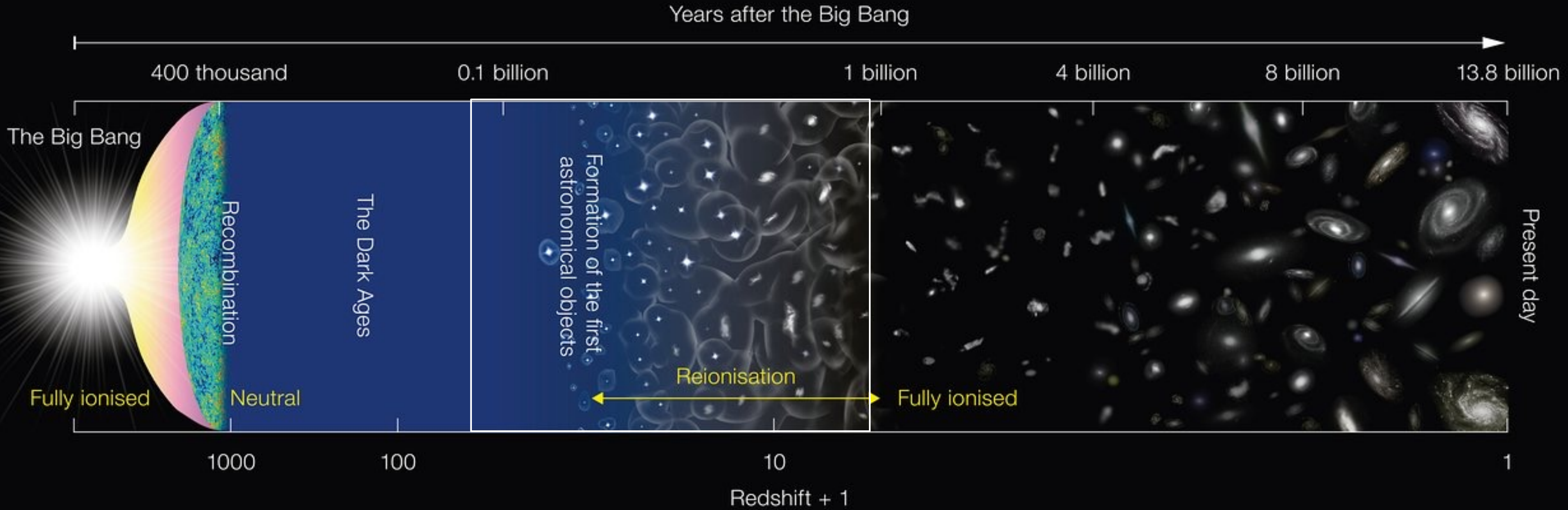


The M81 group



Credit: Keesscherer; NRAO





**Born from an ambition to explore the Cosmic Dawn...**

How and when did the first stars, galaxies and black holes form?



# ...built to answer all kinds of questions

**Galaxy evolution, cosmology and dark energy**

*What is dark matter? How do galaxies form and grow?*

**Origin and evolution of cosmic magnetism**

*What is the role of magnetism across cosmic history?*

**Cradle of life: planets, molecules, SETI**

*How do planets form? Are we alone?*

**Exploration of the unknown**

**Testing gravity using pulsars**

*Was Einstein right?*

**Transient Radio Sky**

*What are Fast Radio Bursts?*

**Our Galaxy, the Milky Way**

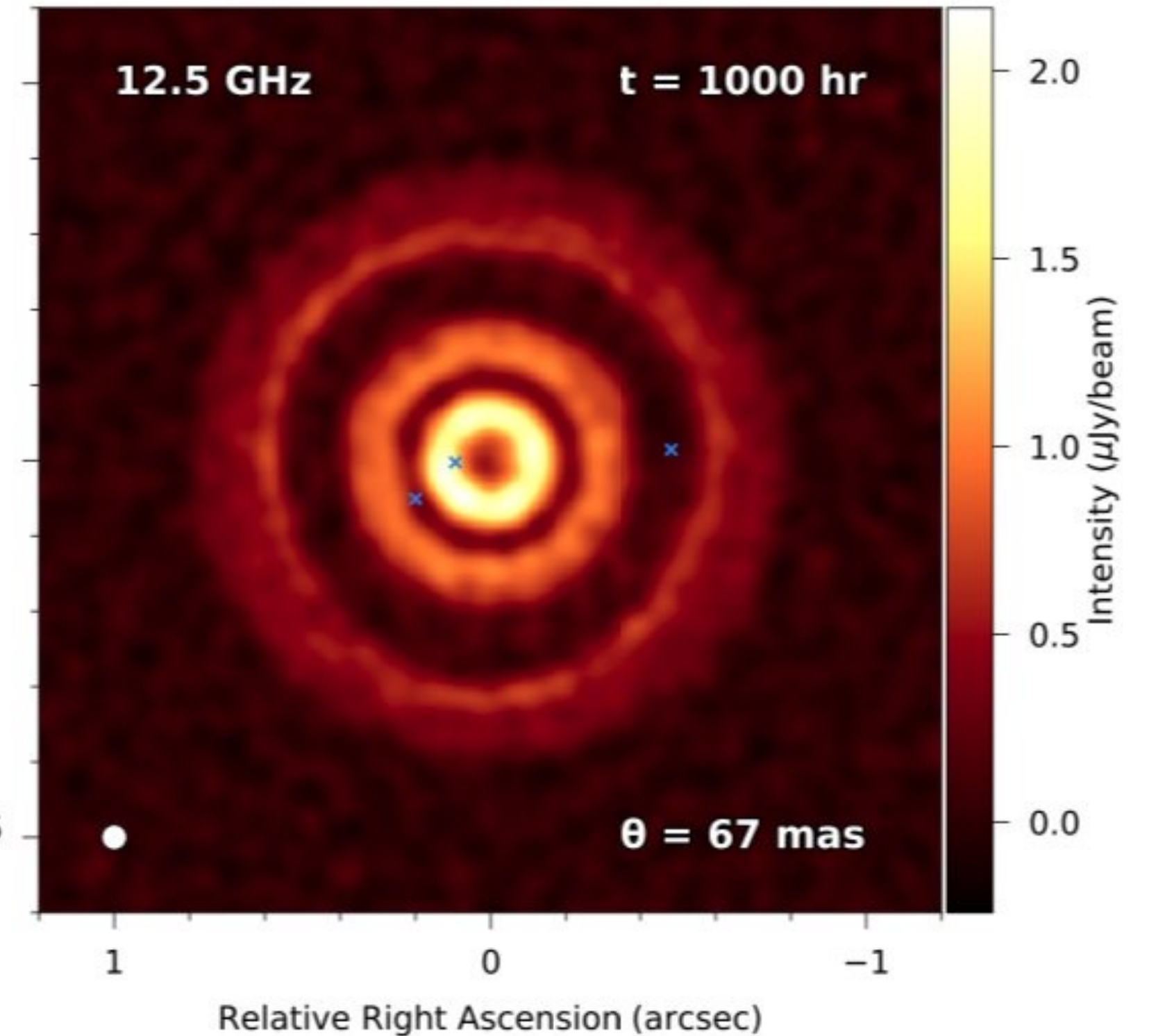
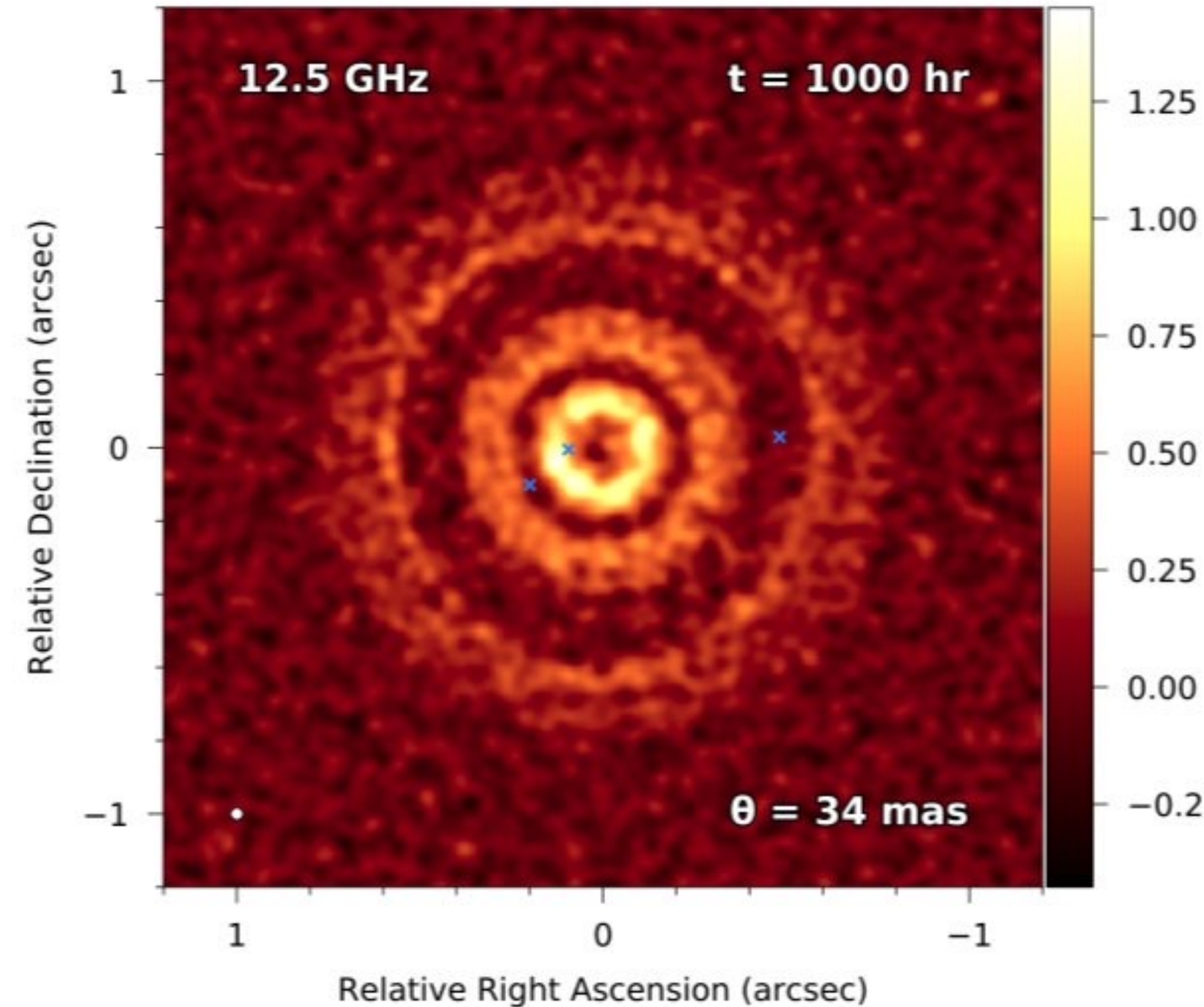
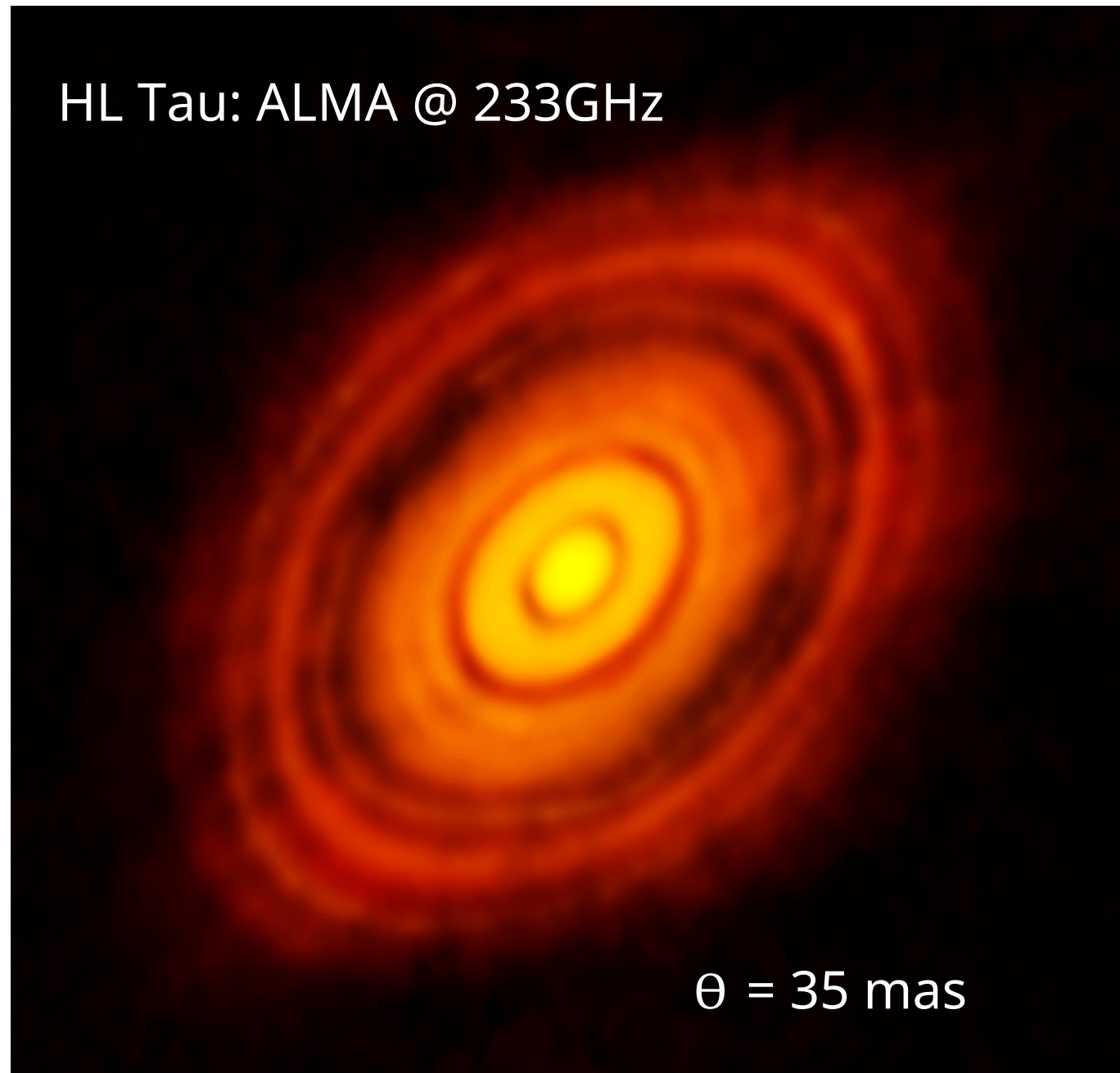
*How does matter cycle between stars and the Interstellar Medium?*

**Huge range of transformational science enabled by SKAO**



# When/Where do Earth-like Planets form in Disks

- Formation of cm+ sized grains is a crucial step on the road to terrestrial planet formation
- Where and how does grain growth proceed?



## SKA-Mid wavelength range will enable study of cm-size grains

- Simulations clearly show deep SKA observations will be able to observe pebbles in disks, and gaps/ring structure due to forming planets  
(Band 5 simulation – Ilee et al. 2020MNRAS.498.5116I)

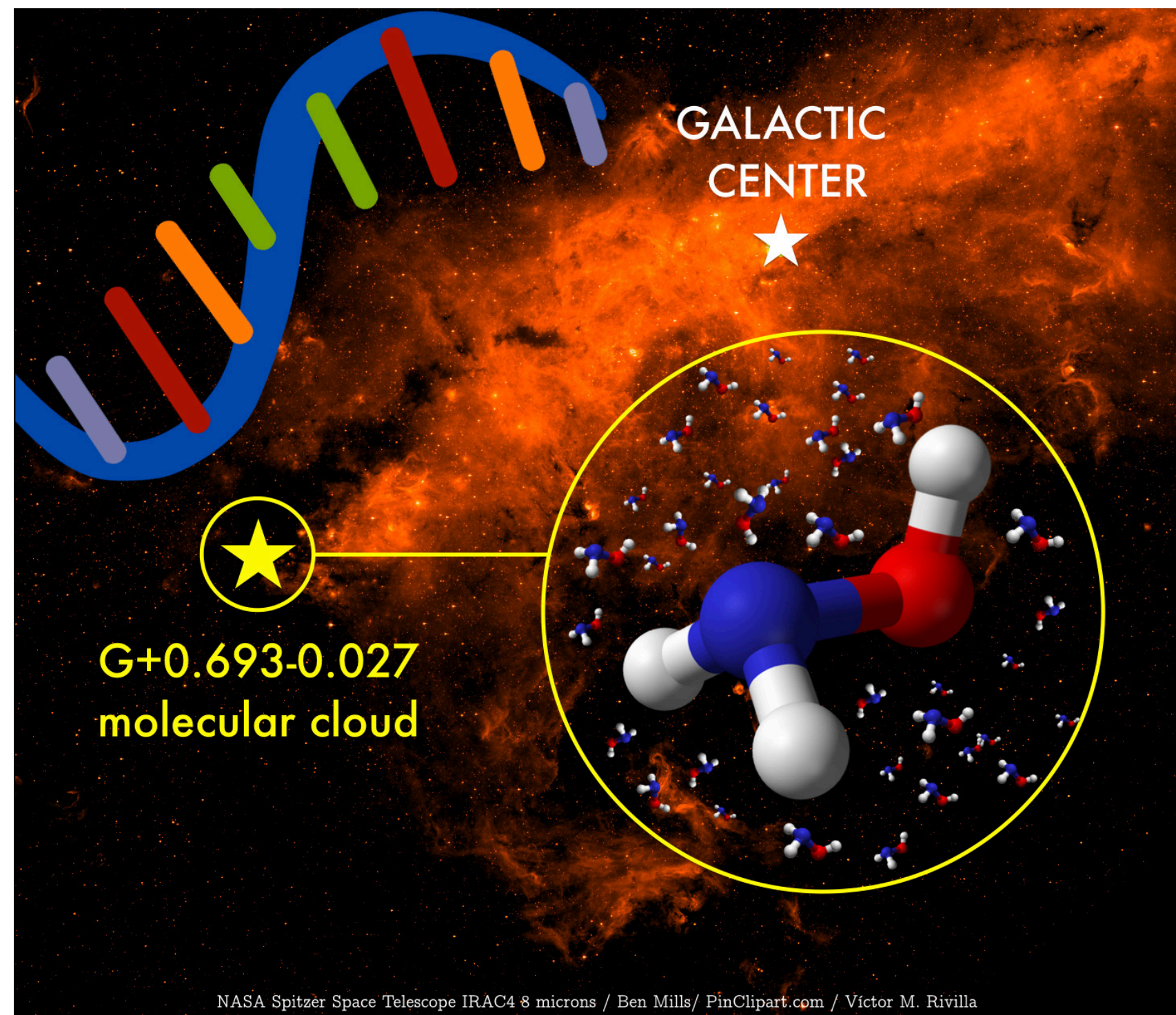




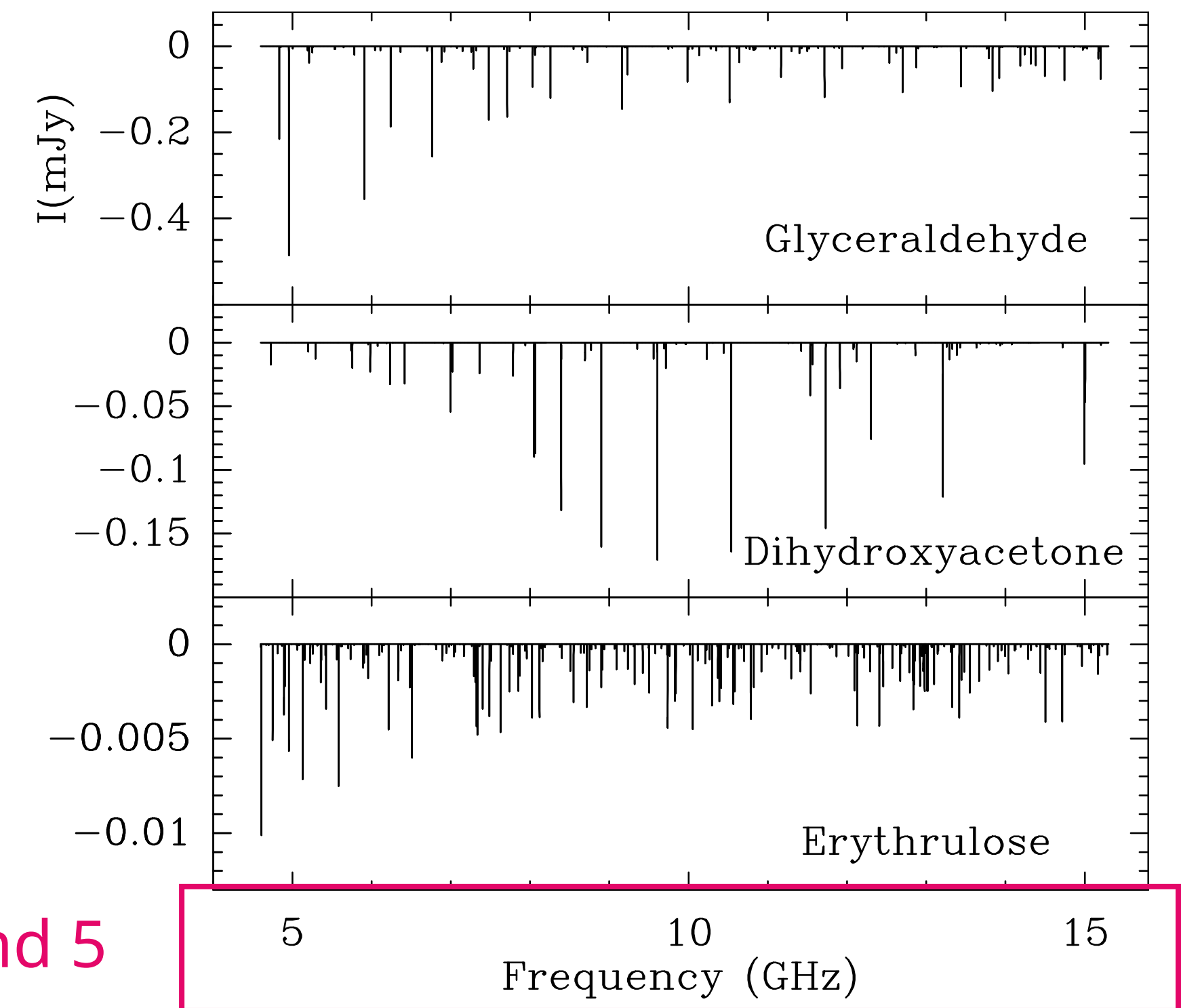
# Pre-biotic molecules in star-forming regions

Building blocks for life on Earth may have arrived from space (panspermia hypothesis)

Detection of key pre-biotic molecules (e.g. **amino acids, complex sugars**) in interstellar space is a “holy grail” of Cradle of Life studies



Detection of hydroxylamine ( $\text{NH}_2\text{OH}$ ),  
key precursor to RNA  
(IRAM 30-m; Rivilla et al. 2020)



Predicted spectrum of key large sugars toward G+0693.

Detection of the brightest (i.e. deepest) lines requires **10s of hours integration with SKA** (Jimenez-Serra et al. 2022)



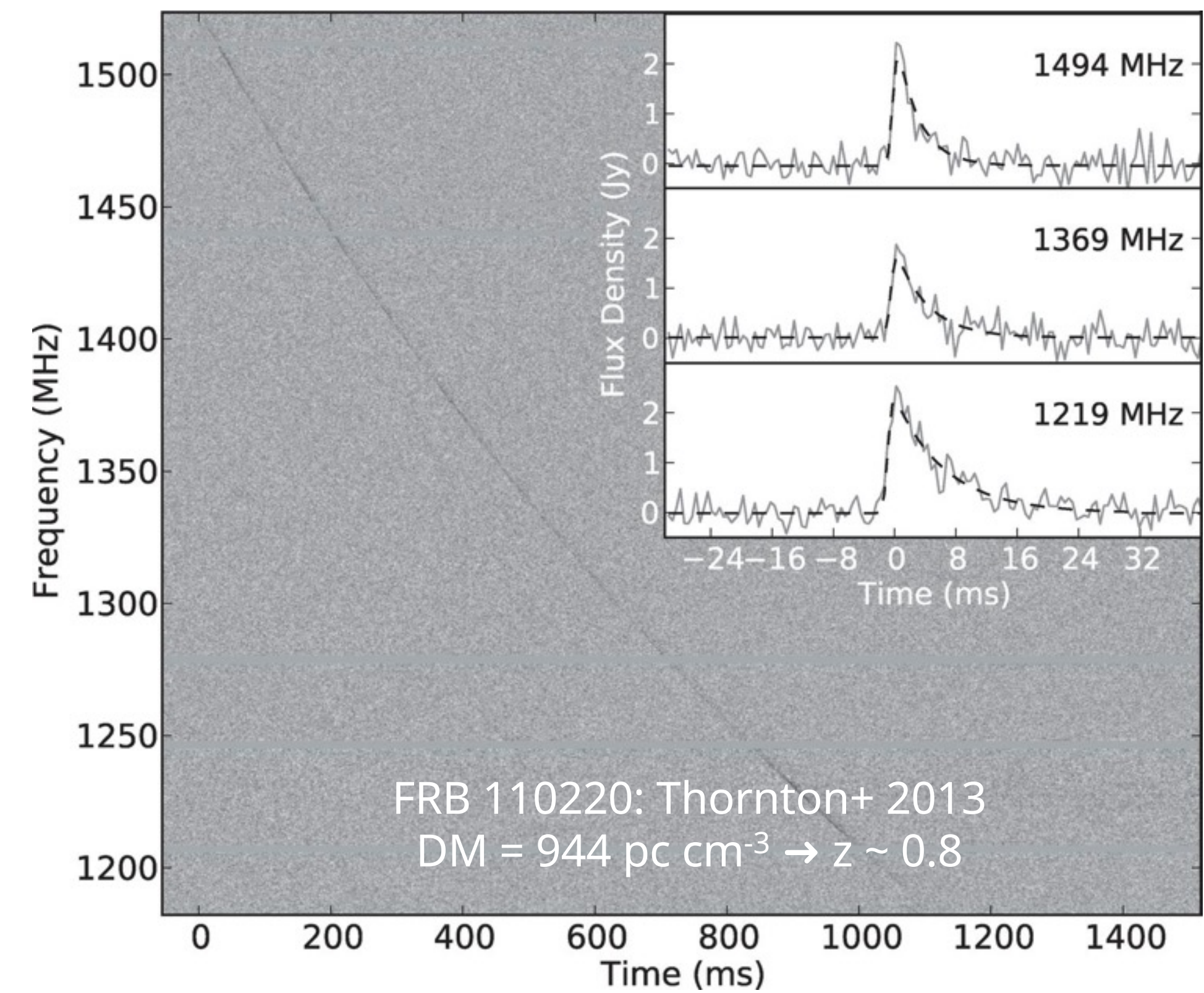
# Fast Radio Bursts (FRBs)

**Bright:** ( $\sim 1$  Jy), Short period: (1–6 msec),

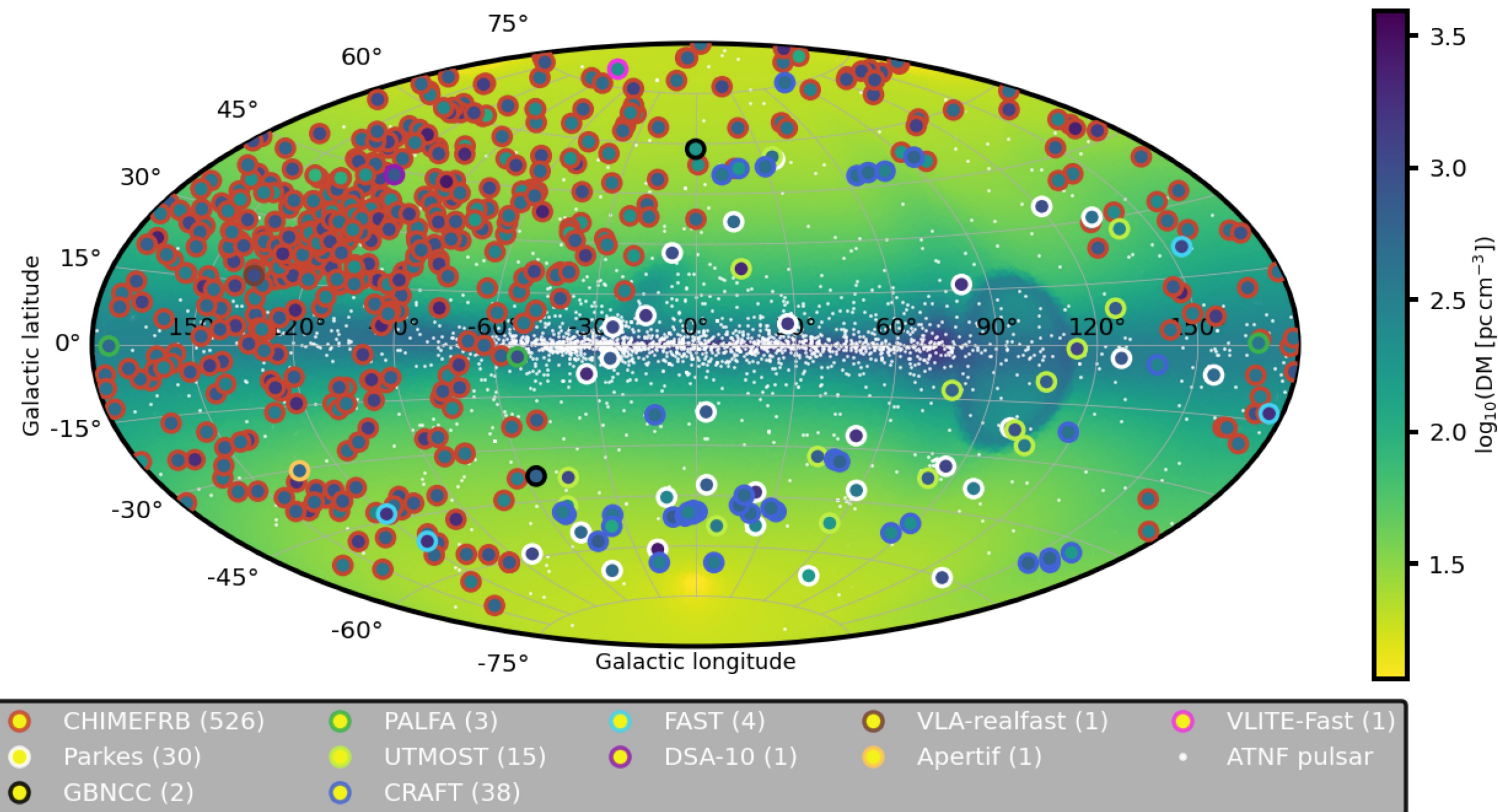
**Extragalactic:**  $DM = 100 - 2500 \text{ pc cm}^{-3}$

Hundreds of FRBs now detected

Estimated event rate:  $1 \times 10^4 \text{ sky}^{-1} \text{ day}^{-1}$



Probe Baryon content  
 along line-of-sight:  
**Missing Baryon Question**



credit: Laura Driessen

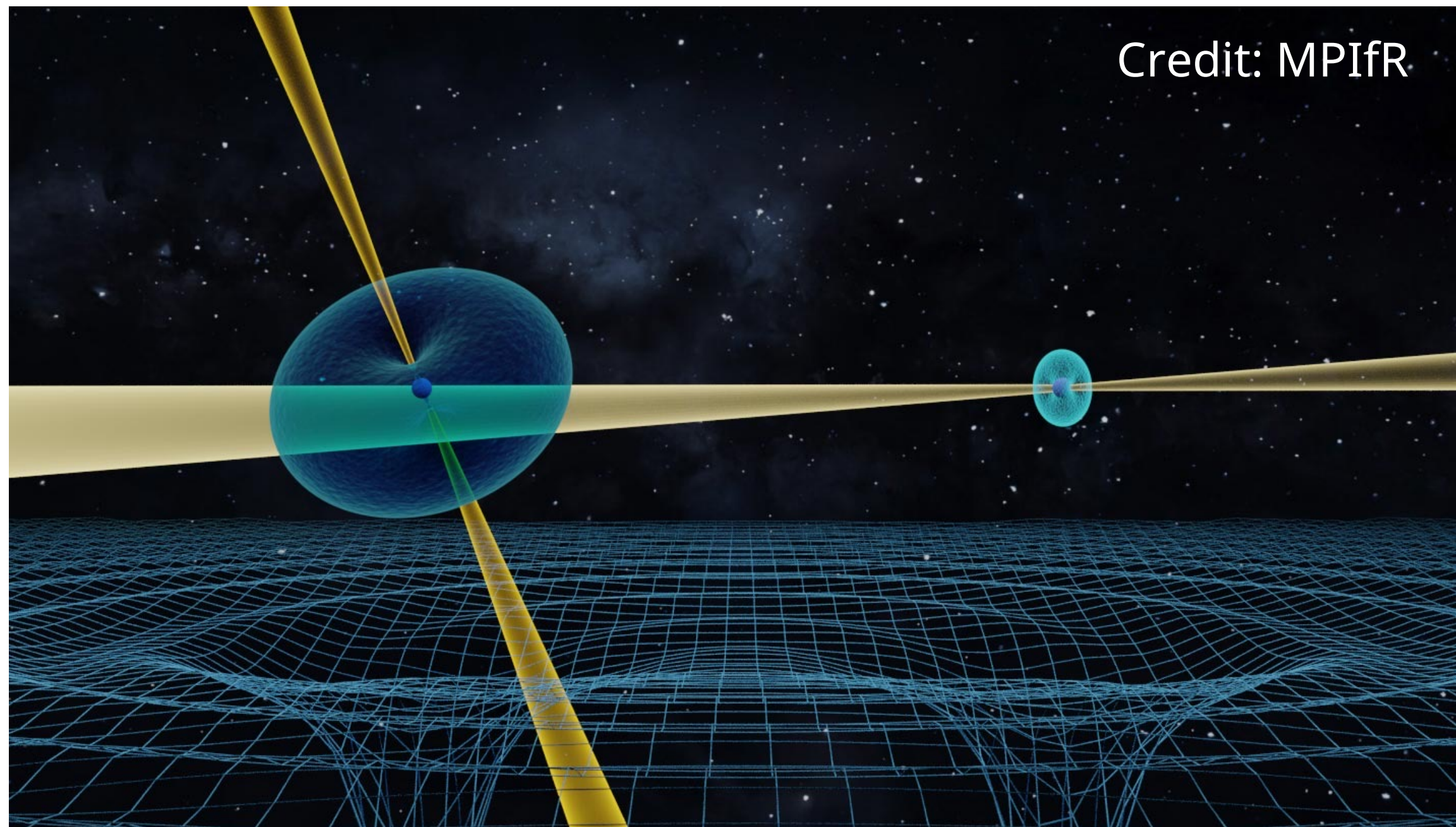




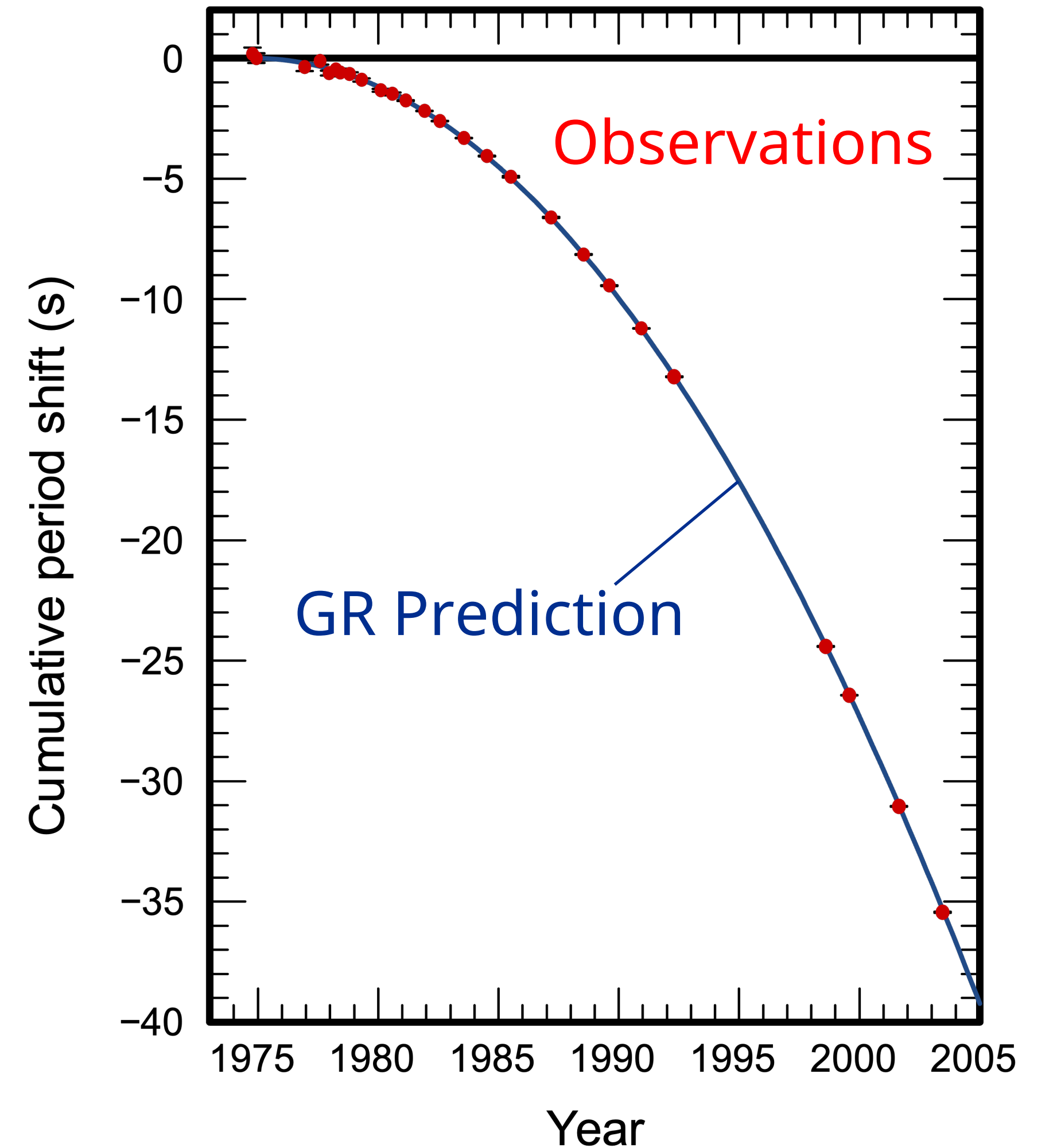
# Test General Relativity in strong field regime

Tests of GR in strong field regime via:

- Pulsar – White Dwarf binaries
- Pulsar – Neutron Star binaries
- **Pulsar – Pulsar binaries**
- Pulsars around Galactic Centre
- **Pulsar – Black Hole binaries**



## Pulsar (Neutron Star) Binary Orbital Decay – Obs. v Theory



99.99% agreement with GR

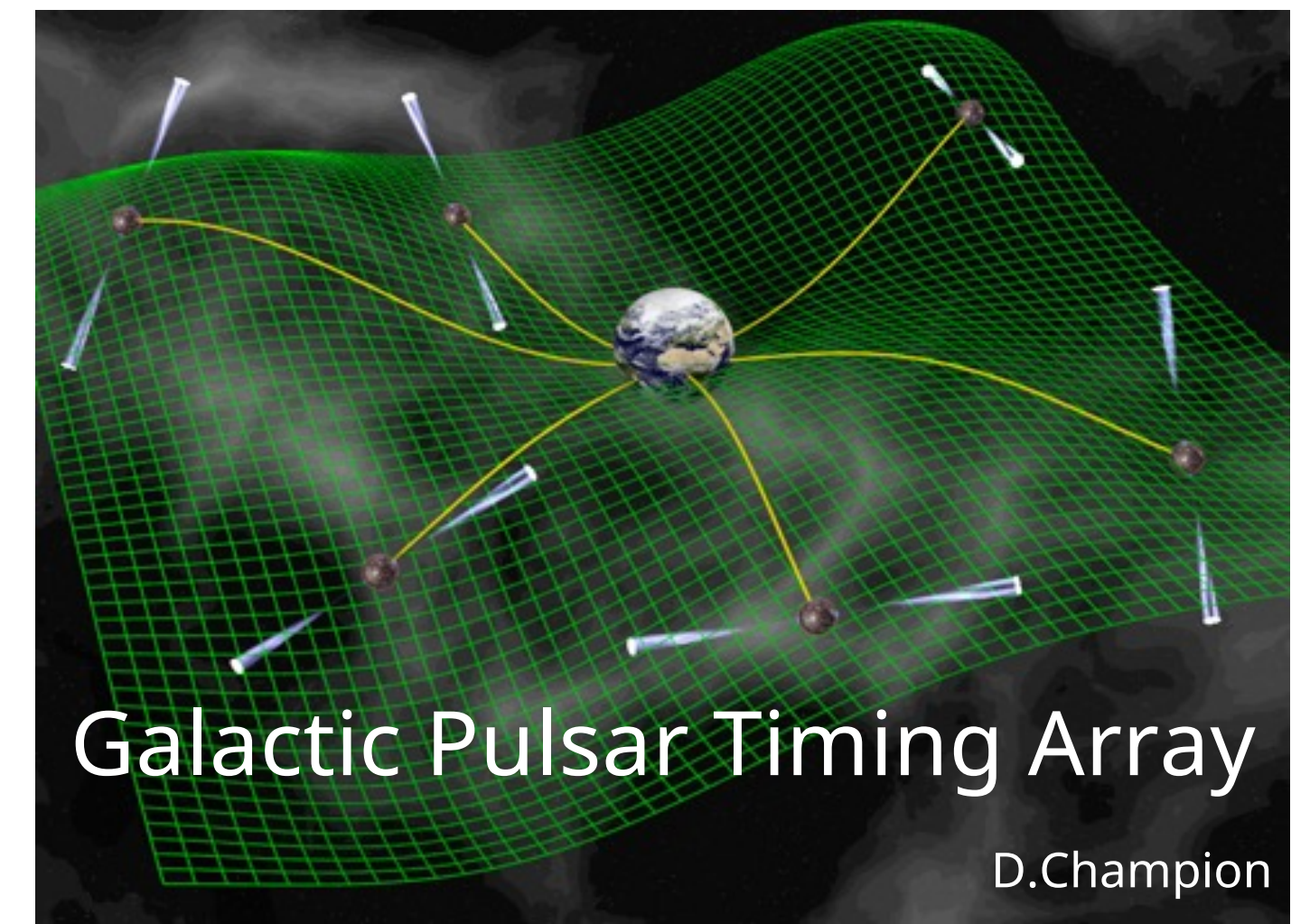
(e.g., Kramer+ 2021 Phy. Rev. X)



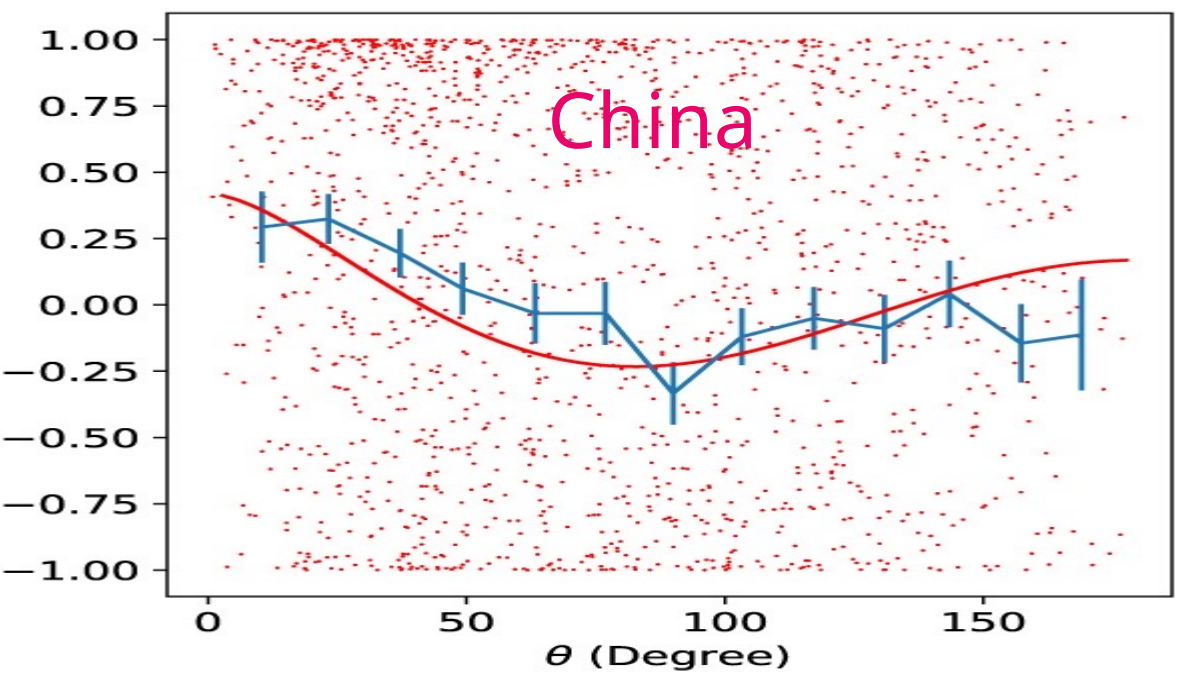
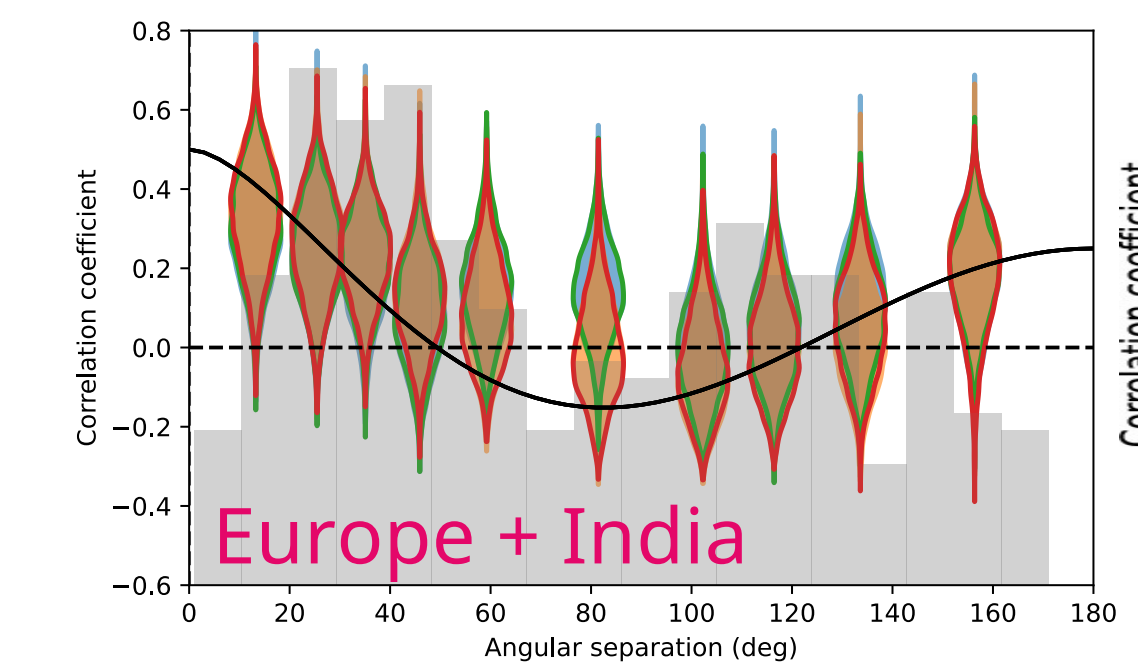
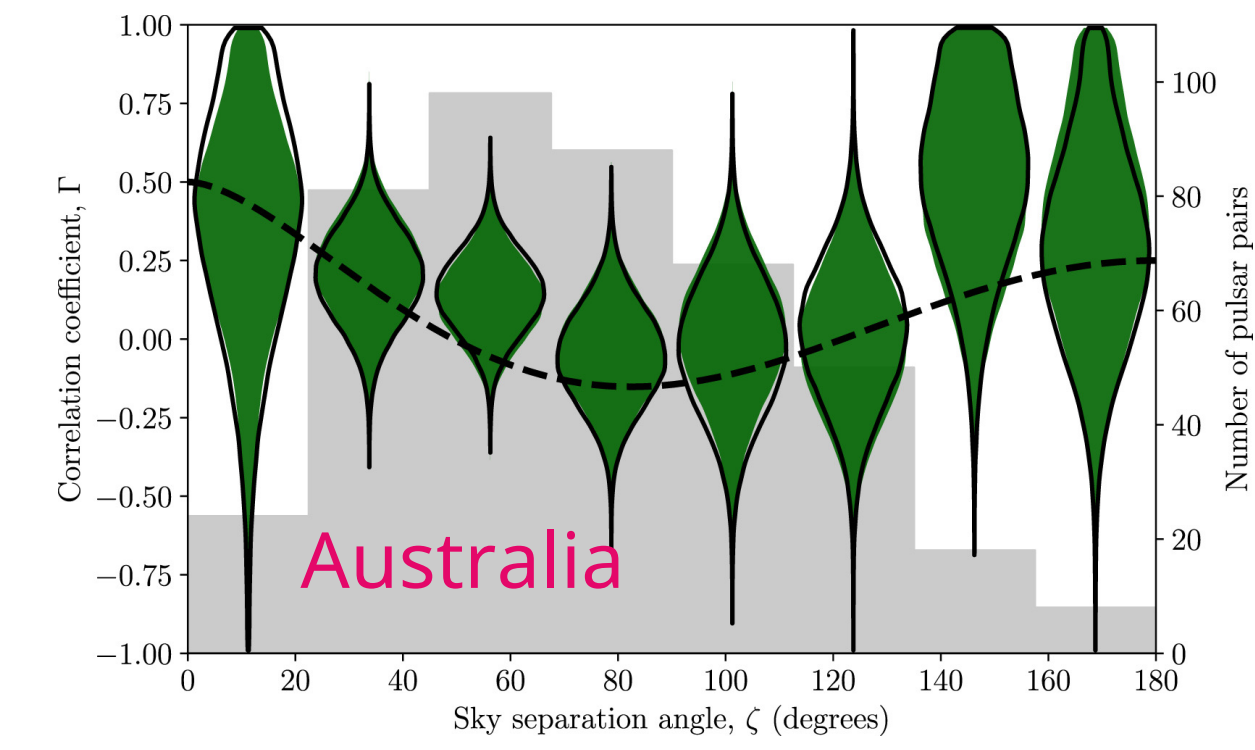
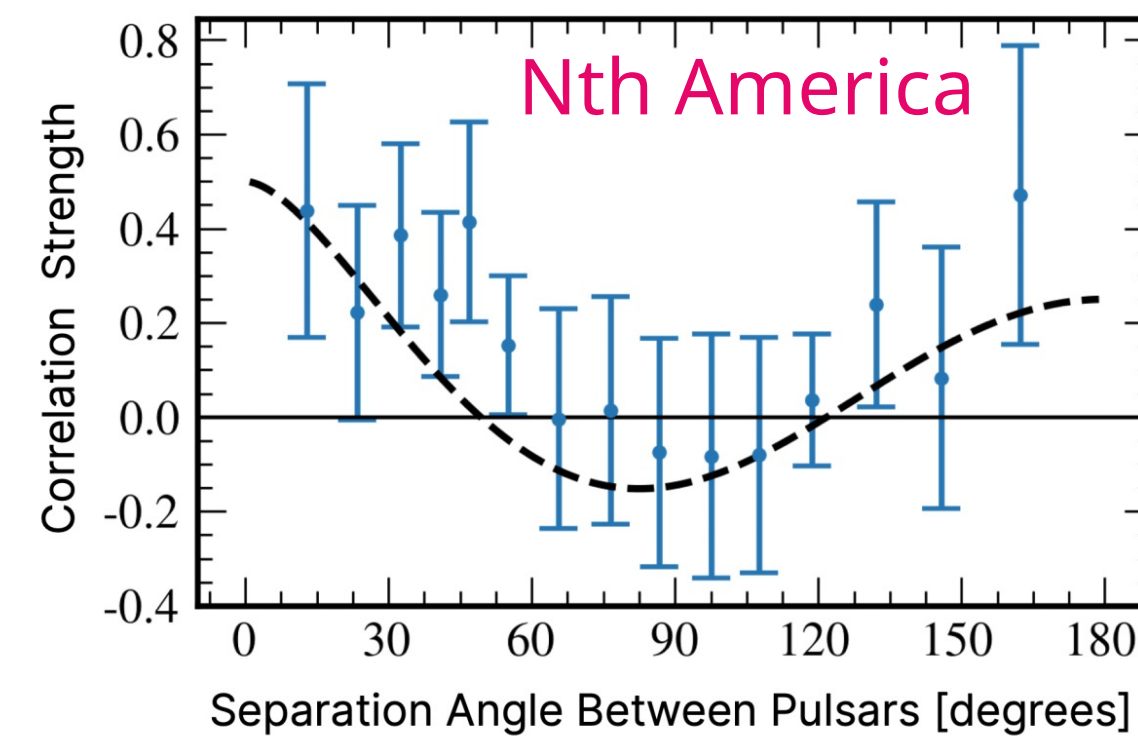
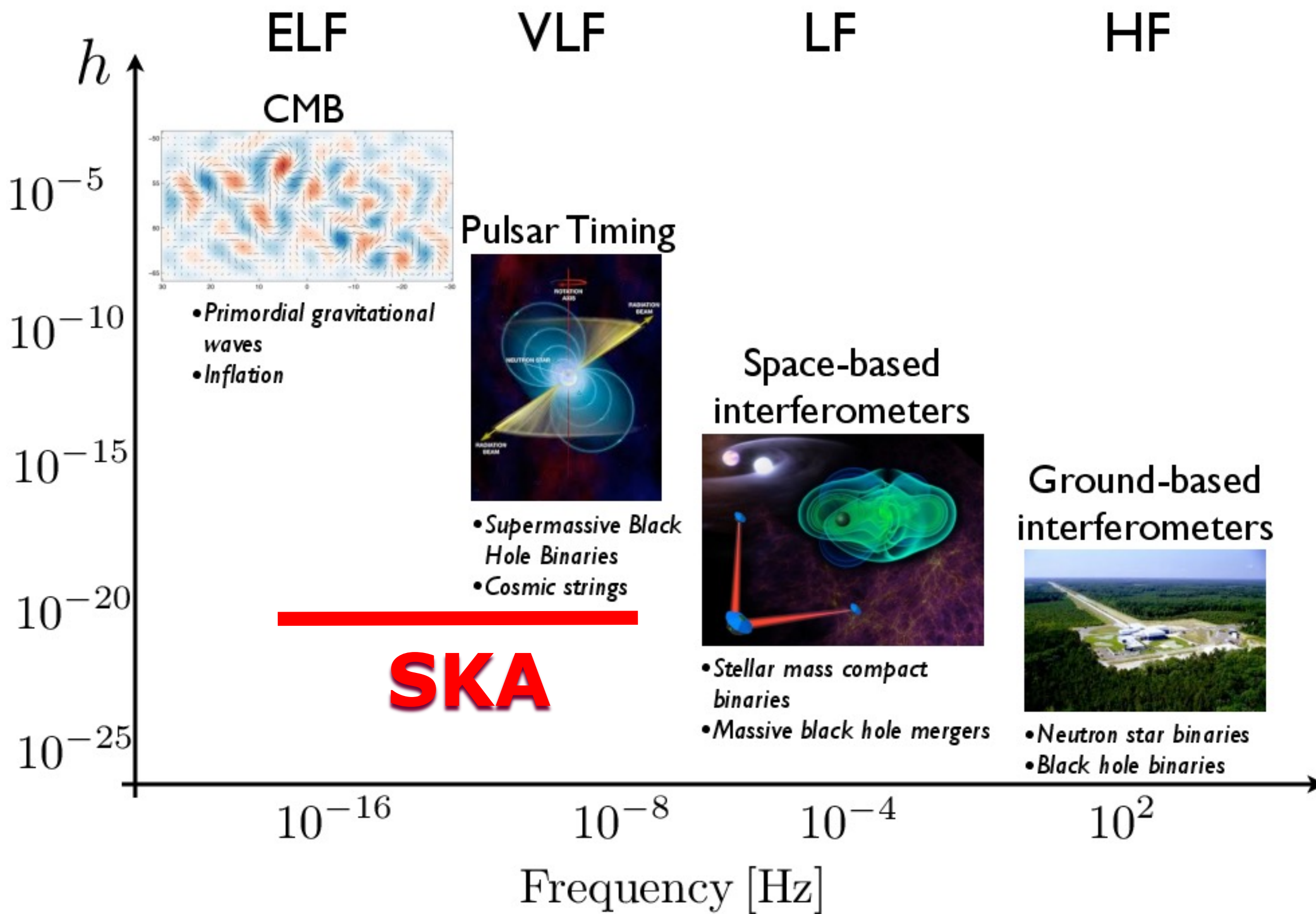


# Gravitational Waves with Pulsars

(Multi-messenger Physics)



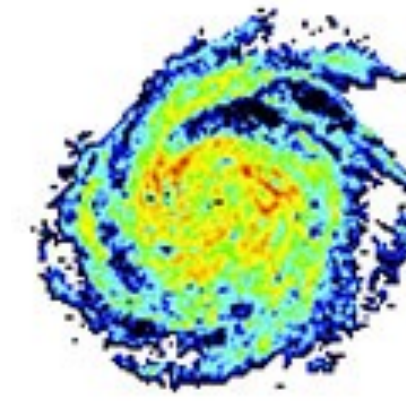
The big picture of gravitational wave astronomy



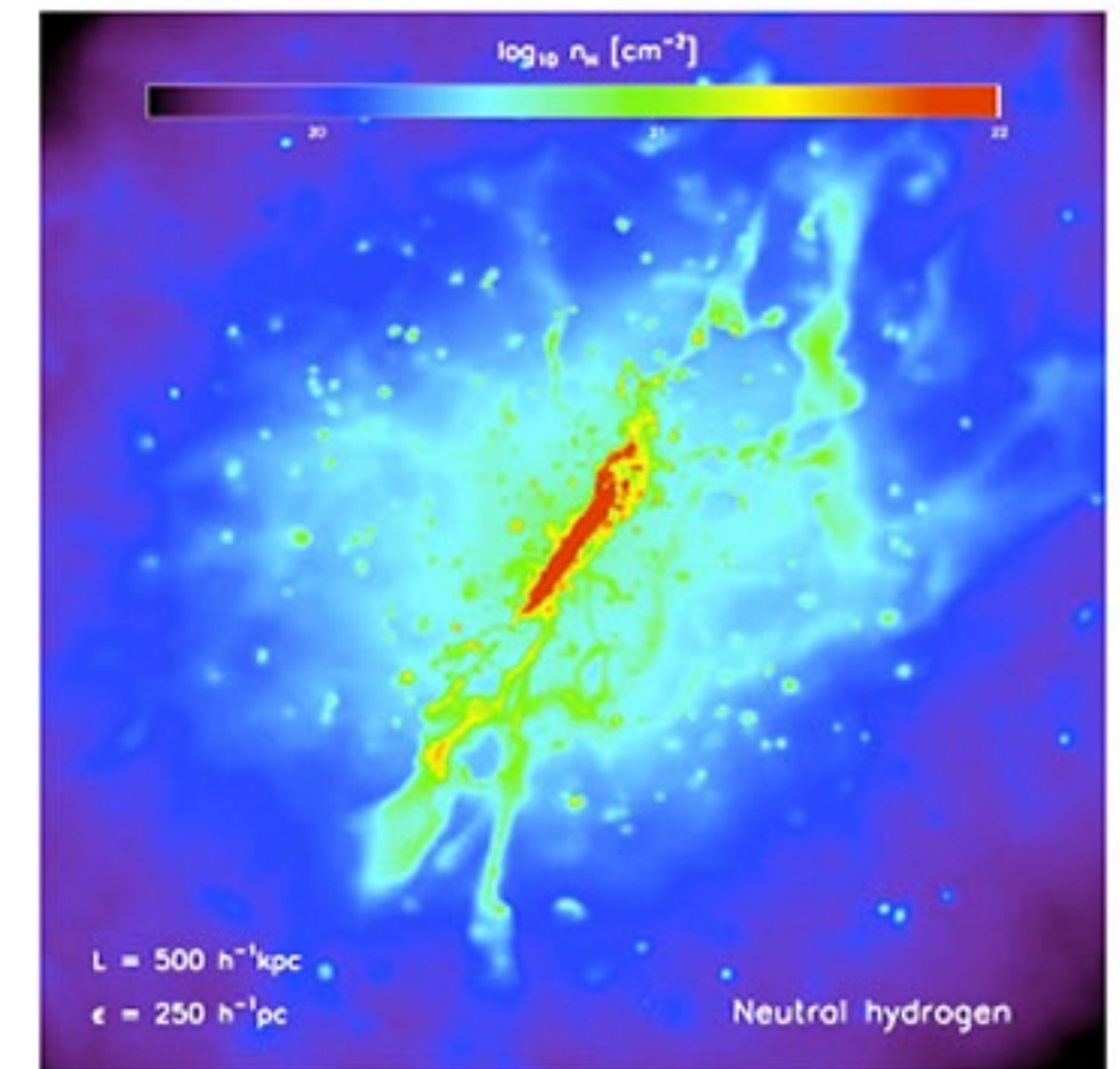
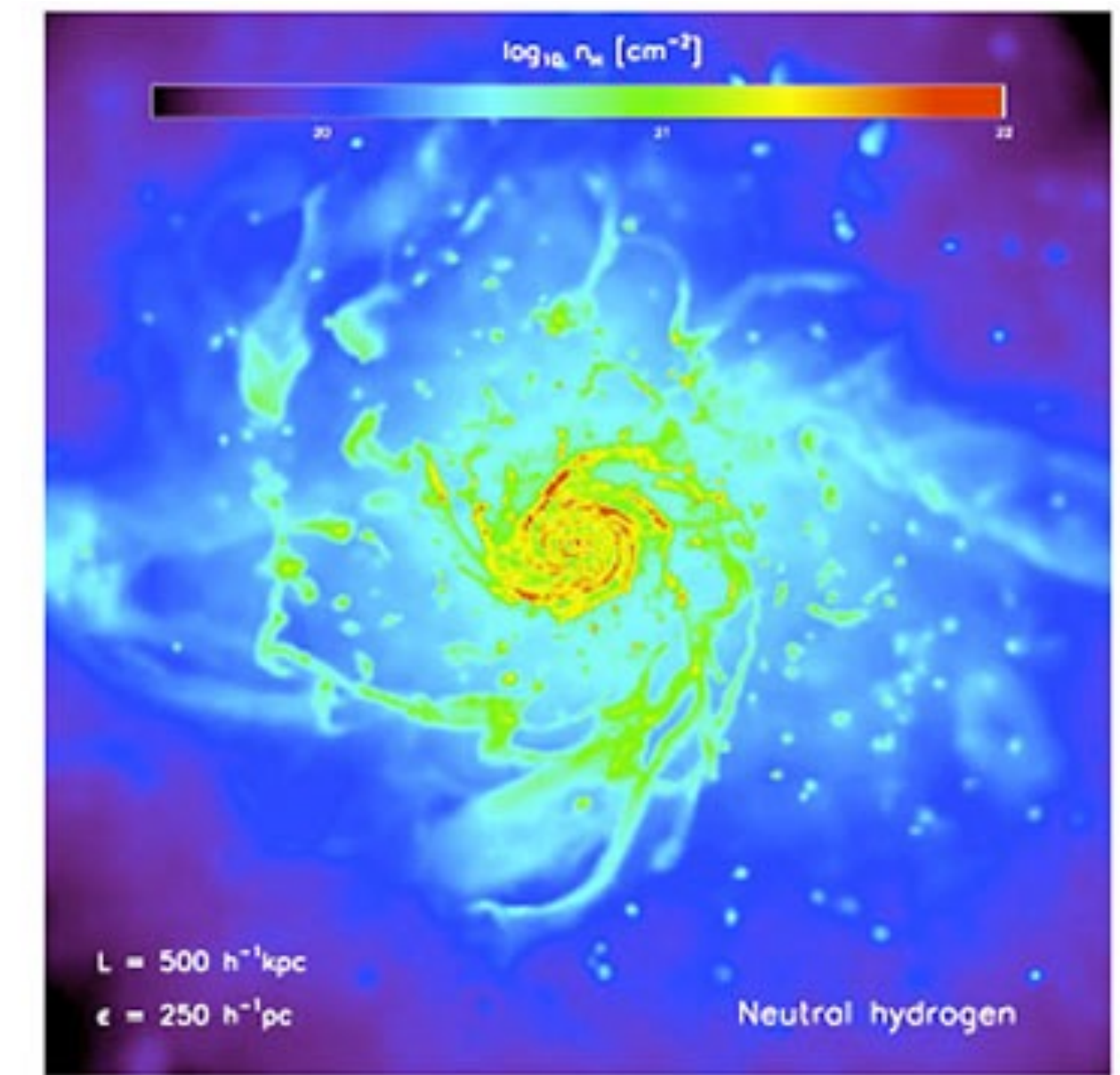


# Galaxy evolution

- How do galaxies accrete and grow from the 'Cosmic Web' ?
- Observations miss the low-density IGM
- SKA will provide resolved observations out to  $z \sim 0.8$
- Measure angular momentum build-up (rotation curves out to large radius)
- *SKA will probe low column density HI in nearby Universe ( $N_{HI} < 10^{18} \text{ cm}^{-2}$ )*



observed



simulated

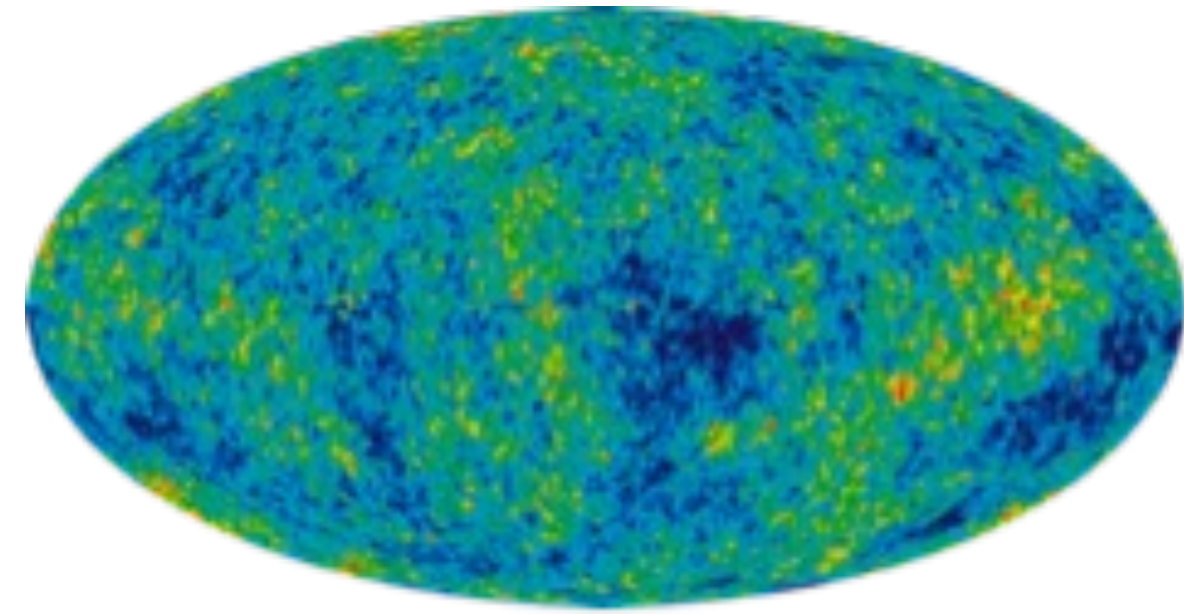
Images courtesy of Tom Oosterloo (SKA HI science working group)



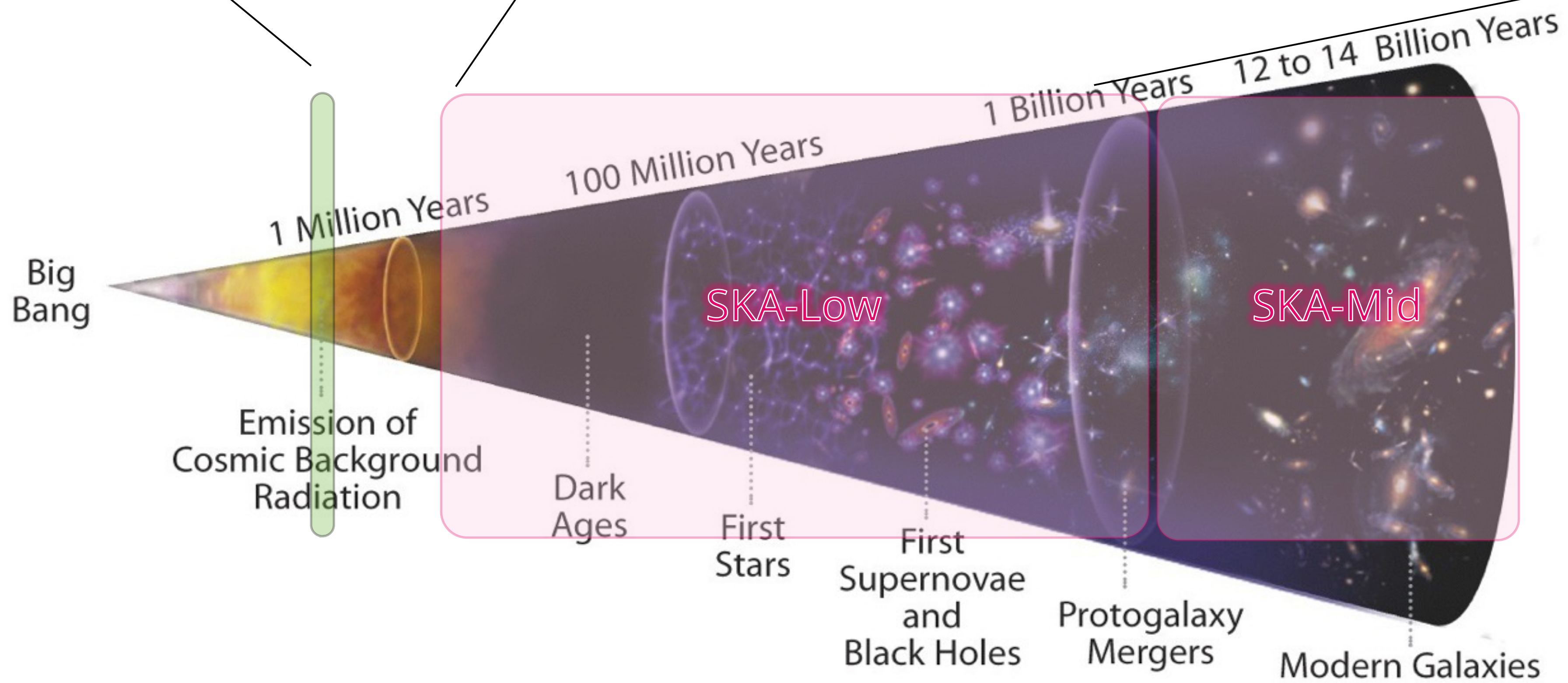
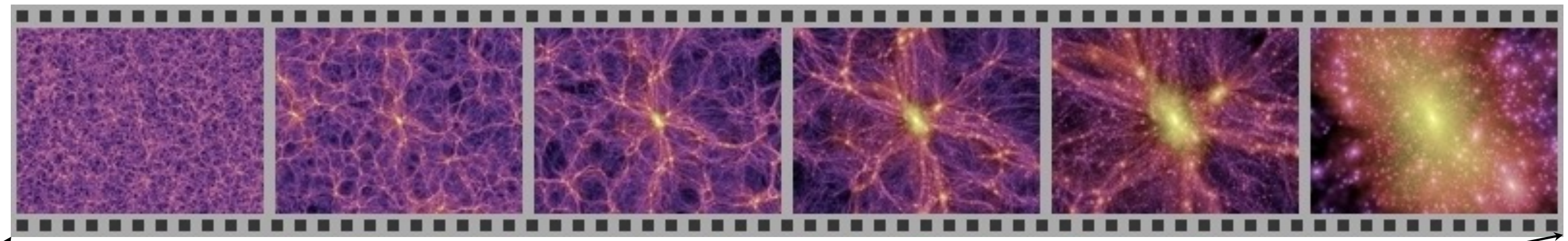


# The Epoch of Reionisation

CMB snapshot at ~400,000 yrs



SKA-Low will observe the evolution of HI emission to make a movie of the Universe from its Dawn until the formation of the first modern galaxies





# 14 Science Working Groups cover the science areas that will be addressed with the SKA telescopes

## Extragalactic Continuum Science Working Group

The Square Kilometre Array (SKA) is a global enterprise to build the largest scientific instrument on Earth, both in physical scale and in terms of the volume of data it will generate. Co-managed from the SKA Organisation headquarters in the UK, the SKA promises to revolutionise our understanding of the universe by observing the cosmos in a range of areas of physics, cosmology and astrophysics. This banner provides a summary of the Extragalactic Continuum Science Working Group and the astronomical community.

## Our Galaxy Science Working Group

The Square Kilometre Array (SKA) is a global enterprise to build the largest scientific instrument on Earth, both in physical scale and in terms of the volume of data it will generate. Co-managed from the SKA Organisation headquarters in the UK, the SKA promises to revolutionise our understanding of the universe by observing the cosmos in a range of areas of physics, cosmology and astrophysics. This banner provides a summary of the Our Galaxy Science Working Group and the astronomical community.

## Star Formation History

Understanding when, where and how stars form to measure the star formation rate density at different redshifts from the present to the first galaxies is a major goal of the SKA. This banner provides a summary of the Star Formation History Science Working Group and the astronomical community.

## Active Galactic Nuclei

AGN feedback processes have become a standard ingredient in models of galaxy evolution, but a understanding of these complex processes and their role in shaping galaxy evolution remains elusive. This banner provides a summary of the Active Galactic Nuclei Science Working Group and the astronomical community.

## Galaxy Clusters

Galaxy clusters are the most massive objects in the universe, containing hundreds to thousands of galaxies. This banner provides a summary of the Galaxy Clusters Science Working Group and the astronomical community.

## Strong Gravitational Lensing

Gravitational lensing produces multiple images of distant galaxies, providing a natural laboratory for studying the properties of dark matter and the evolution of galaxies. This banner provides a summary of the Strong Gravitational Lensing Science Working Group and the astronomical community.

## Extragalactic Spectral Lines Science Working Group

The Extragalactic Spectral Lines Science Working Group is focused on defining the role of magnetic fields in the physical processes that determine the structure and evolution of the Universe. This banner provides a summary of the Extragalactic Spectral Lines Science Working Group and the astronomical community.

## High Energy Cosmic Particles Focus Group

Somehow in the Universe, particles are being accelerated to ultra-high energies. This banner provides a summary of the High Energy Cosmic Particles Focus Group and the astronomical community.

## The cosmic-ray spectrum

Cosmic rays are composed of the same stuff as interstellar matter and atomic nuclei. This banner provides a summary of the cosmic-ray spectrum Science Working Group and the astronomical community.

## Masers as tracers of AGN

At sub-mm wavelengths, masers are powerful probes of the environment around active galactic nuclei. This banner provides a summary of the Masers as tracers of AGN Science Working Group and the astronomical community.

## From Stars to the ISM

The chemical evolution of the galaxy is mainly driven by the star formation rate and the feedback from stars. This banner provides a summary of the From Stars to the ISM Science Working Group and the astronomical community.

## Absorption Lines in Intervening Galaxies

SKA will give access to a population of bright low-redshift galaxies, providing a natural laboratory for studying the properties of dark matter and the evolution of galaxies. This banner provides a summary of the Absorption Lines in Intervening Galaxies Science Working Group and the astronomical community.

## Galactic cosmic rays

Measuring radiation patterns with the SKA will allow us to answer a long-standing question about the origin of galactic cosmic rays. This banner provides a summary of the Galactic cosmic rays Science Working Group and the astronomical community.

## High-redshift galaxies

The early galaxies formed during the first billion years after the Big Bang. This banner provides a summary of the High-redshift galaxies Science Working Group and the astronomical community.

## Cosmology Science Working Group

The SKA Project is a global enterprise to build the largest scientific instrument on Earth, both in physical scale and in terms of the volume of data it will generate. This banner provides a summary of the Cosmology Science Working Group and the astronomical community.

## VLBI with the SKA Science Working Group

The VLBI science working group represents the capabilities in the development of the SKA as a radio interferometer. This banner provides a summary of the VLBI with the SKA Science Working Group and the astronomical community.

## HI Galaxy Science Science Working Group

The HI Science Working Group focuses on defining the role of magnetic fields in the physical processes that determine the structure and evolution of the Universe. This banner provides a summary of the HI Galaxy Science Science Working Group and the astronomical community.

## Proposed SKA1 Cosmology Survey

The SKA1 cosmology survey will provide a unique view of the universe at low redshift. This banner provides a summary of the Proposed SKA1 Cosmology Survey Science Working Group and the astronomical community.

## Dark Matter: Probe the nature of dark matter

Dark Matter: Probe the nature of dark matter through a variety of observational probes. This banner provides a summary of the Dark Matter Science Working Group and the astronomical community.

## Weak Lensing

A statistical measurement of the shapes of millions of galaxies as a function of their position and redshift enables us to measure the gravitational lensing effect of dark matter. This banner provides a summary of the Weak Lensing Science Working Group and the astronomical community.

## Active Galactic Nuclei (AGN)

Recent VLBI observations of a radio galaxy reveal a complex structure. This banner provides a summary of the Active Galactic Nuclei (AGN) Science Working Group and the astronomical community.

## Extragalactic space weather and exoplanet

One key question that astronomy is attempting to answer is whether there are habitable planets around stars other than our Sun. This banner provides a summary of the Extragalactic space weather and exoplanet Science Working Group and the astronomical community.

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## Cosmic Magnetism Science Working Group

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## A dense Faraday Rotation Measure (RM) Grid

The SKA will produce a Faraday RM Grid, comprising polarimetric observations of 2-3 million radio galaxies. This banner provides a summary of the A dense Faraday Rotation Measure (RM) Grid Science Working Group and the astronomical community.

## How do galaxies replenish their gas?

Current models of galaxy evolution predict that galaxies will eventually run out of gas. This banner provides a summary of the How do galaxies replenish their gas? Science Working Group and the astronomical community.

## How is the HI in galaxies linked to AGN activity?

Associated to galaxy evolution is the question of how HI is linked to AGN activity. This banner provides a summary of the How is the HI in galaxies linked to AGN activity? Science Working Group and the astronomical community.

## What is the structure of the Universe on the largest scales?

Our standard cosmology predicts that the majority of baryonic matter in the Universe exists as a cosmic web of diffuse, magnetized plasma. This banner provides a summary of the What is the structure of the Universe on the largest scales? Science Working Group and the astronomical community.

## How do active galaxies influence their environments?

Radio galaxies are the ubiquitous background sources that permeate the radio sky. This banner provides a summary of the How do active galaxies influence their environments? Science Working Group and the astronomical community.

## Transients Science Working Group

The SKA Science Working Group on Transients is a global enterprise to build the largest scientific instrument on Earth, both in physical scale and in terms of the volume of data it will generate. This banner provides a summary of the Transients Science Working Group and the astronomical community.

## Fast radio bursts

Discovered only a decade ago, fast radio bursts (FRBs) are a fascinating astrophysical phenomenon. This banner provides a summary of the Fast radio bursts Science Working Group and the astronomical community.

## 1. Understand Planet Formation

Observation of protoplanets in circumstellar disks is the first step to planet formation. This banner provides a summary of the 1. Understand Planet Formation Science Working Group and the astronomical community.

## 2. Detect and characterize organic building blocks relevant in astrobiology

Organic building blocks relevant in astrobiology are found in protoplanets and comets. This banner provides a summary of the 2. Detect and characterize organic building blocks relevant in astrobiology Science Working Group and the astronomical community.

## 3. Direct detection and characterization of magnetospheres, exoplanets, brown planet interactions

Magnetospheres, exoplanets, and brown planet interactions are key targets for SKA. This banner provides a summary of the 3. Direct detection and characterization of magnetospheres, exoplanets, brown planet interactions Science Working Group and the astronomical community.

## 4. The SKA as a transients discoverer

The SKA will provide unprecedented sensitivity for the discovery of transients. This banner provides a summary of the 4. The SKA as a transients discoverer Science Working Group and the astronomical community.

## 5. Understand our Solar System and its environment

The SKA will be especially relevant for characterizing our Solar System and its environment. This banner provides a summary of the 5. Understand our Solar System and its environment Science Working Group and the astronomical community.

## Cradle of Life Science Working Group

The SKA Science Working Group on Cradle of Life is a global enterprise to build the largest scientific instrument on Earth, both in physical scale and in terms of the volume of data it will generate. This banner provides a summary of the Cradle of Life Science Working Group and the astronomical community.

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## Solar and Heliospheric Physics Science Working Group

The Sun is a surprisingly hard radio source to study. This banner provides a summary of the Solar and Heliospheric Physics Science Working Group and the astronomical community.

## Coronal heating

The solar corona is at the temperature of a million K, while the surface is at only a few thousand K. This banner provides a summary of the Coronal heating Science Working Group and the astronomical community.

## Turbulence and radio wave scattering

Though much of the radio emission from the active Sun is born deep inside the corona, it is heavily distorted and scattered as it propagates out. This banner provides a summary of the Turbulence and radio wave scattering Science Working Group and the astronomical community.

## Cosmic Reionization

Persistent star formation eventually generates a background of Ly $\alpha$  radiation that ionizes the intergalactic medium. This banner provides a summary of the Cosmic Reionization Science Working Group and the astronomical community.

## Image tomography of cosmic reionization

Deep observations with the SKA will measure the structure of reionization. This banner provides a summary of the Image tomography of cosmic reionization Science Working Group and the astronomical community.

## SKA and Solar and Heliospheric Science

The SKA will provide the highest fidelity radio images of the Sun. This banner provides a summary of the SKA and Solar and Heliospheric Science Science Working Group and the astronomical community.

## 21 cm tomography of the reionization era

Simulations of the reionization era show the structure of the intergalactic medium. This banner provides a summary of the 21 cm tomography of the reionization era Science Working Group and the astronomical community.

## Epoch of Reionization Science Working Group

When did the first generations of galaxies form? This banner provides a summary of the Epoch of Reionization Science Working Group and the astronomical community.

## Pulsars Science Working Group

The Square Kilometre Array (SKA) is a global enterprise to build the largest scientific instrument on Earth, both in physical scale and in terms of the volume of data it will generate. This banner provides a summary of the Pulsars Science Working Group and the astronomical community.

## Strong-Field Tests of Gravity

The SKA will discover new pulsars in highly relativistic binary systems that yield unprecedented tests of gravity. This banner provides a summary of the Strong-Field Tests of Gravity Science Working Group and the astronomical community.

## Dense Matter Equation of State

Neutron stars provide unique laboratories to study the physics of matter at densities greater than that of atomic nuclei. This banner provides a summary of the Dense Matter Equation of State Science Working Group and the astronomical community.

## Gravitational Waves

By regularly observing an array of millisecond pulsars, the SKA will be transformed into a unique observatory for low-frequency gravitational waves. This banner provides a summary of the Gravitational Waves Science Working Group and the astronomical community.

## Designed for Pulsar Astrophysics

To address all of the above questions requires significant increases in both the number of discovered pulsars and the precision with which they are studied. This banner provides a summary of the Designed for Pulsar Astrophysics Science Working Group and the astronomical community.

(Gravitational Waves SWG poster coming soon)



www.skao.int



www.skao.int

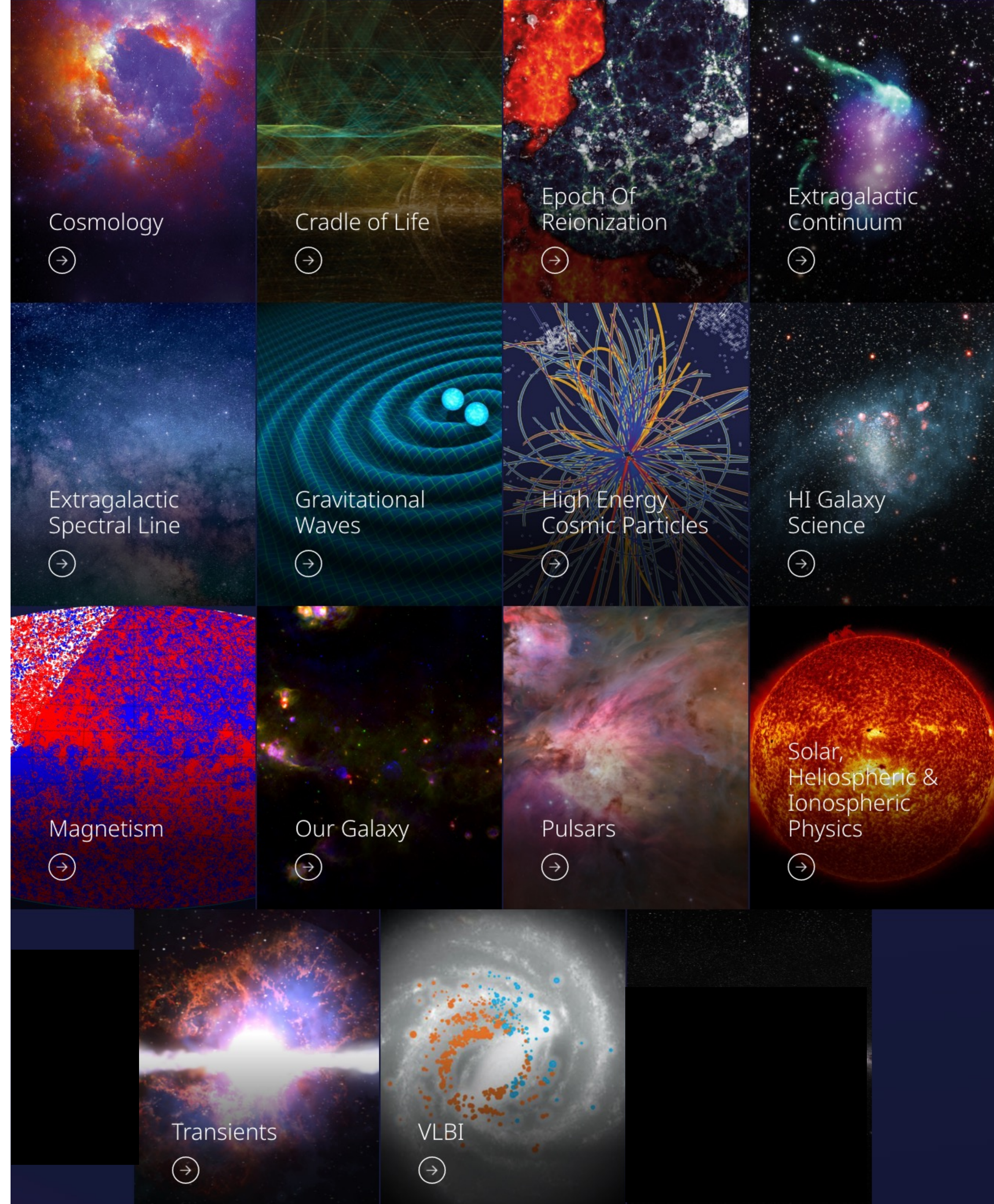


# SKAO Science Working Groups (SWGs)

- Provide a forum for discussion on possible SKAO science projects
- Will facilitate **Key Science Project** (KSP) collaborations
- Are the best way to receive up-to-date information regarding the road to science and operations

## To join a SWG

- Send a request via email to the relevant SWG co-chairs
- Contact details of the co-chairs available on the website
- [www.skao.int/en/science-users/science-working-groups-focus-groups](http://www.skao.int/en/science-users/science-working-groups-focus-groups)



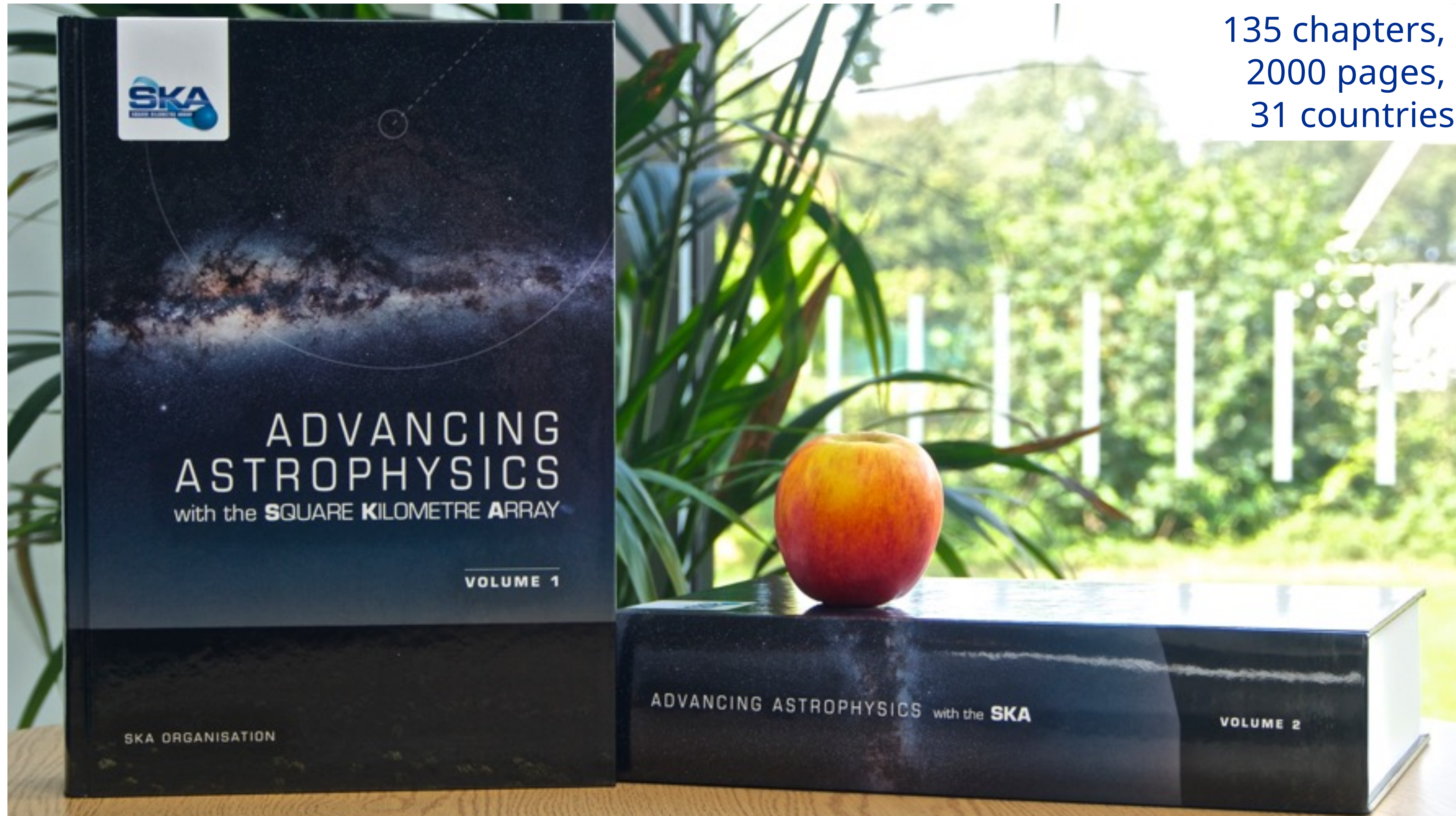


# SKA Science Case

(2015 snapshot ; continuous evolution)

<https://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=215>

135 chapters,  
2000 pages,  
31 countries





# Capabilities & performance estimates

Nominal frequency	110 MHz	300 MHz	770 MHz	1.4 GHz	6.7 GHz	12.5 GHz
Range [GHz]	0.05-0.35	0.05-0.35	0.35-1.05	0.95-1.76	4.6-8.5	8.3-15.4
Telescope	Low	Low	Mid	Mid	Mid	Mid
FoV [arcmin]	327	120	109	60	12.5	6.7
Max. Resolution [arcsec]	10	3.5	0.55	0.3	0.06	0.03
Max. Bandwidth [MHz]	300	300	700	810	3900	2 x 2500
Cont. rms, 1hr [ $\mu$ Jy/beam] <sup>a</sup>	26	14	4.4	2	1.3	1.2
Line rms, 1hr [ $\mu$ Jy/beam] <sup>b</sup>	1850	800	300	140	90	85
Resolution range for Cont. & Line rms. [arcsec] <sup>c</sup>	12-600	6-300	1-145	0.6-78	0.13-17	0.07-9
Channel width [kHz]	5.4	5.4	13.4	13.4	80.6	80.6
Spectral zoom windows x narrowest bandwidth [MHz]	4 x 3.9	4 x 3.9	4 x 3.1	4 x 3.1	4 x 3.1	4 x 3.1
Finest zoom channel width [Hz]	226	226	210	210	210	210

## One hour integrations

### Table Notes:

(a) Line sensitivity assumes fractional bandwidth per channel of  $\Delta\nu/\nu = 10^{-4}$  ( $>10^{-6}$  will be possible)

(b) Continuum sensitivity assumes fractional bandwidth per channel of  $\Delta\nu/\nu = 0.3$

(c) The sensitivity numbers apply to the range of beam sizes given by Min. and Max. beam sizes

Anticipated Science Performance: <https://arxiv.org/abs/1912.12699>





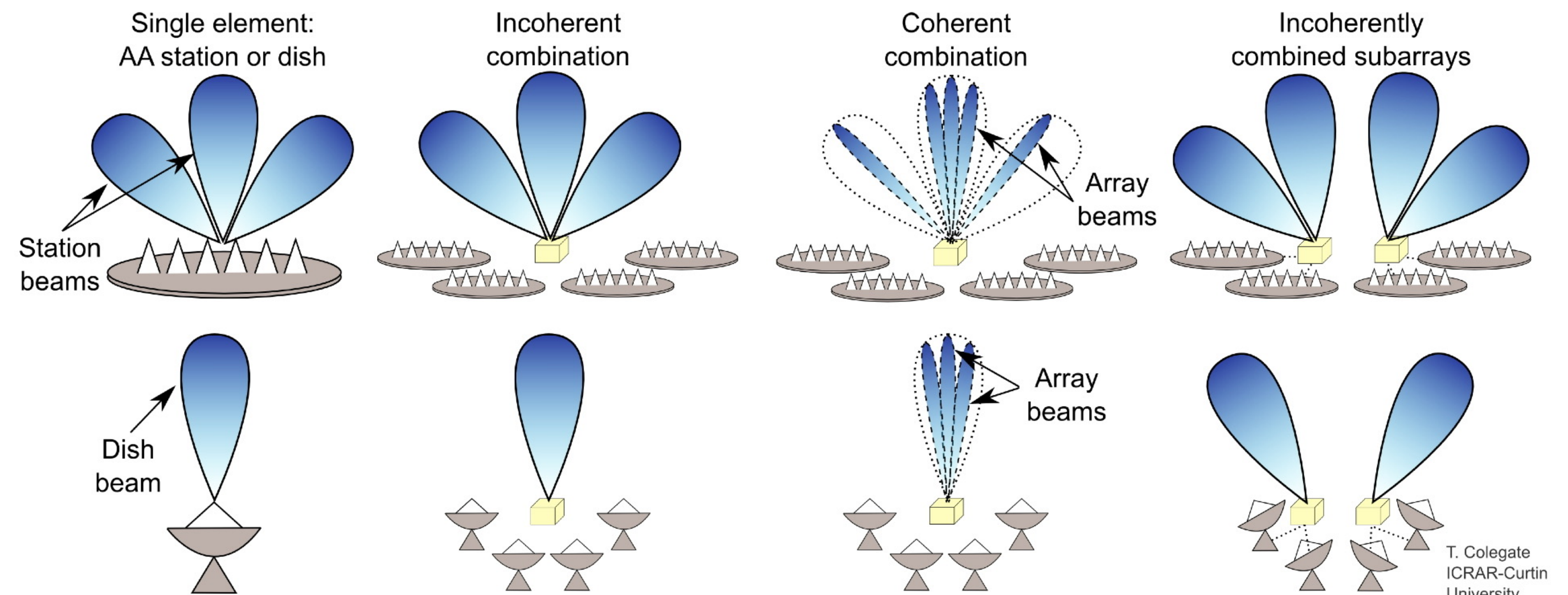
# Non-imaging (Pulsars, Fast Radio Bursts, VLBI, ...)

	Search		Timing		Bandwidth (Max)
Telescope	Beams	Subarrays	Beams	Precision (1 sigma)	
SKA1-Mid	1500	up to 16	16 (8 on B5)	5 ns	300 MHz
SKA1-Low	500	up to 16	16	10 ns	300 MHz

## Possible simultaneously:

- imaging
- VLBI
- pulsar search
- pulsar timing

via commensal / sub-arrays



T. Colegate  
ICRAR-Curtin  
University





# Exploration of the Unknown

Hubble (Lallo: arXiv:1203.0002; Norris AASKA14)

Project	Key project	Planned?	Nat. Geo. top ten?	Highly cited?	Nobel prize?
Use Cepheids to improve value of H0					
Study intergalactic medium with uv spectroscopy					
Medium-deep survey					
Image quasar host galaxies					
Measure SMBH masses					
Exoplanet atmospheres					
Planetary Nebulae					
<b>Discover Dark Energy</b>					
Comet Shoemaker-Levy					
Deep fields (HDF, HDFS, UDF, FF, etc)					
Proplyds in Orion					
GRB Hosts					

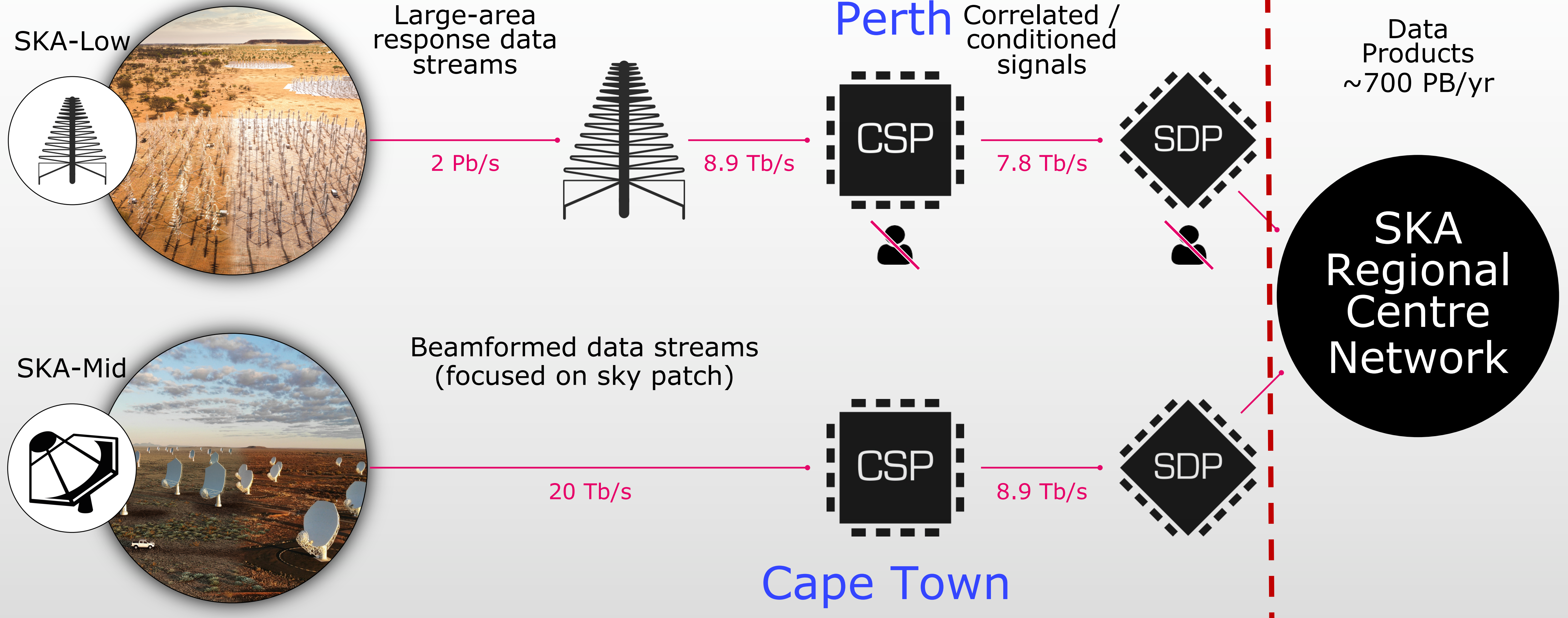


# Science Access





# SKA Regional Centres: SKAO data processing stages





# Telescope Access, based on contribution level

## Key Science Projects (KSPs)

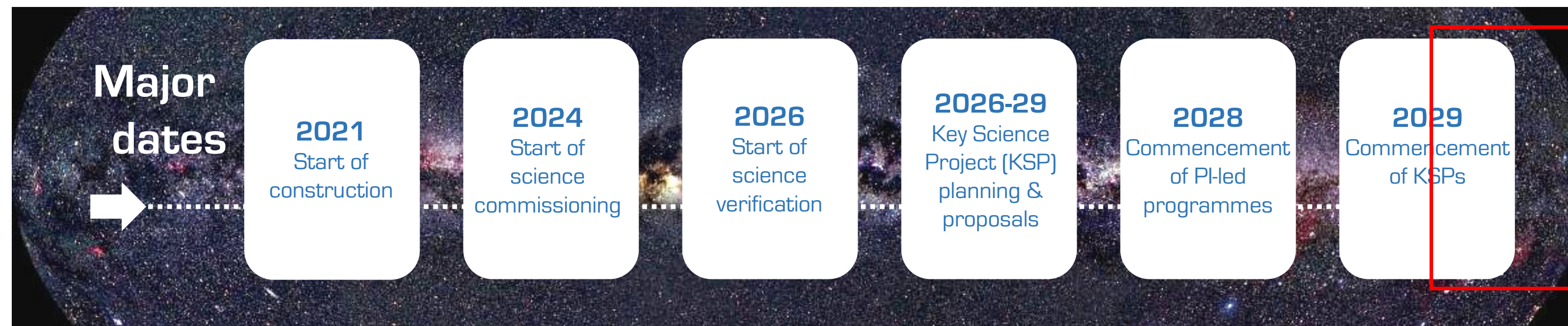
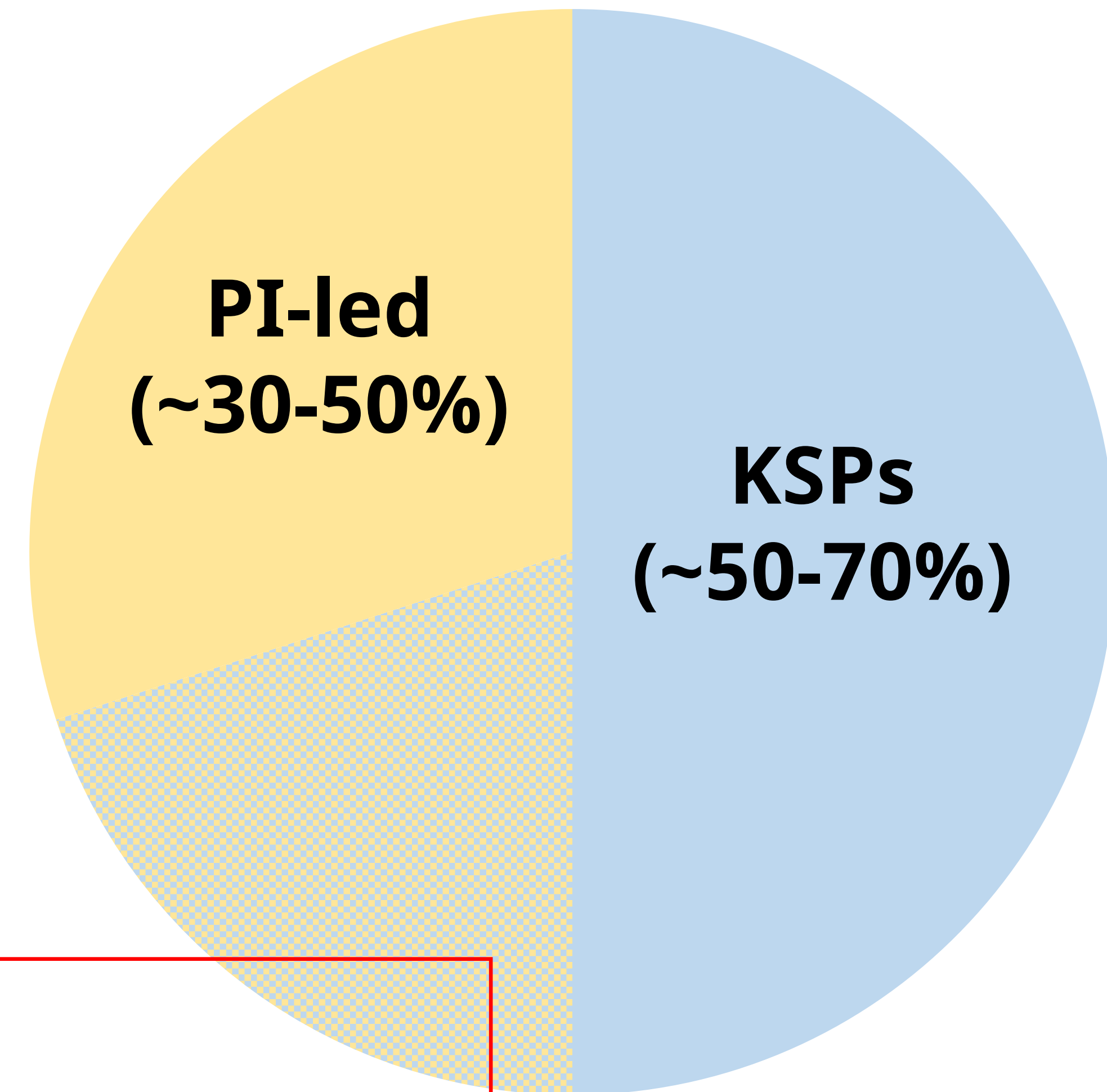
- Large programs (>500 h ?) performed over multiple cycles
- PI & leadership team from SKA-member countries; co-Is from any country (latter may be limited)

## Principal Investigator (PI) Projects

- Small programs (<500 h ?) performed within a single cycle

## Director-General's Discretionary Time

- Time allocated by the D-G outside of the normal TAC process





# Telescope Access

## Commensal Science

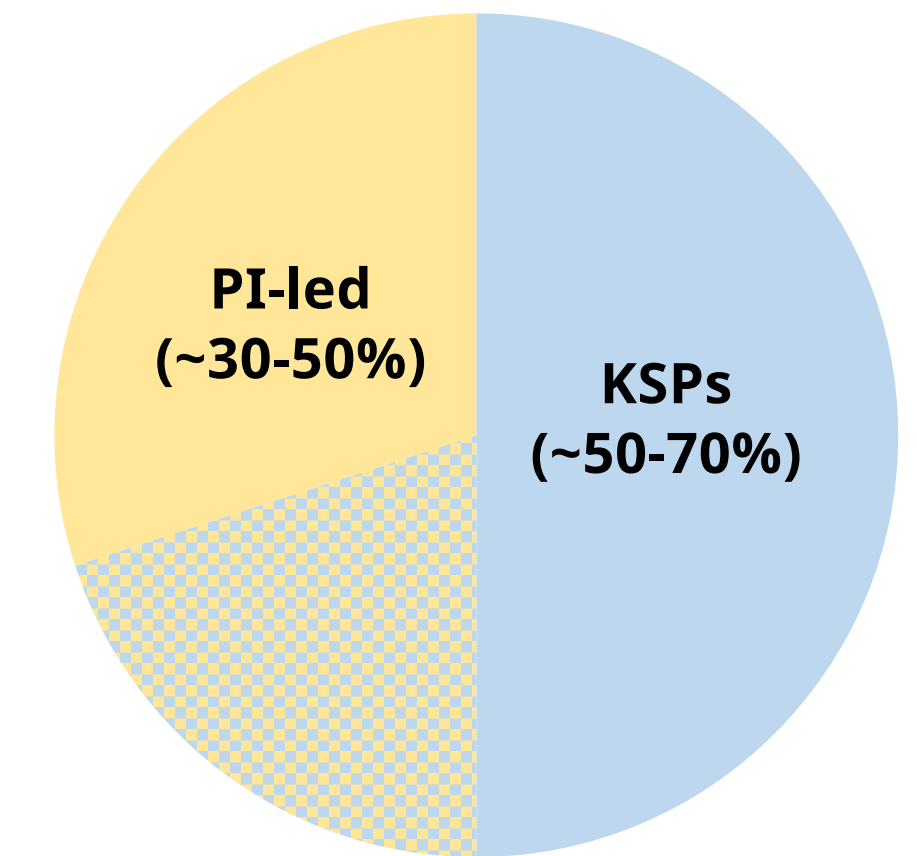
- Different observing projects utilizing the same telescope time (pointing direction); may use same or different observing mode (i.e., continuum imaging, spectral line imaging, pulsar/transient search)
- Maximizes the use of SKA resources
- Commensal science is not "free", will be counted against member share

## Members (and Associate Members)

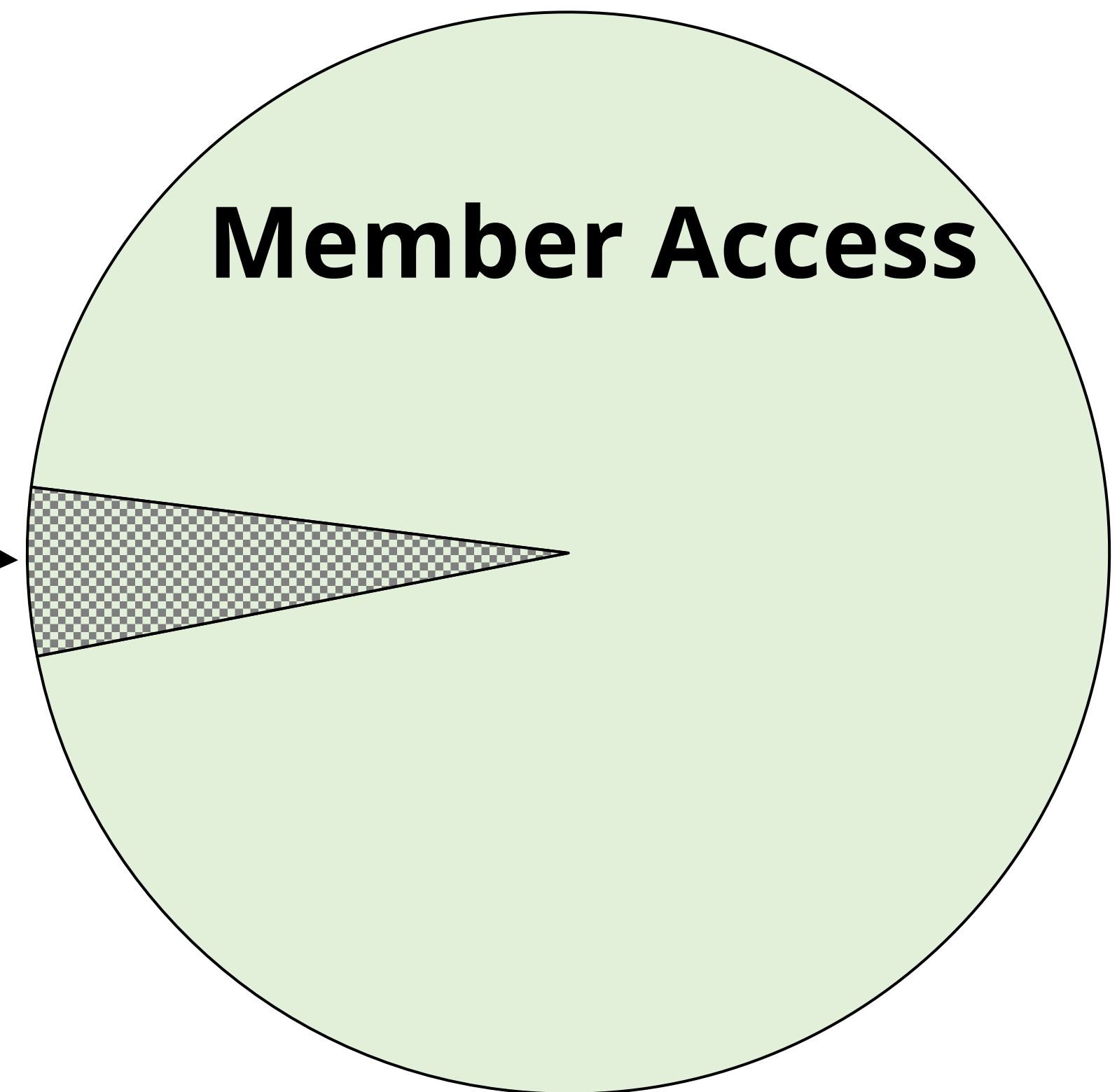
- Can lead any program (KSP, PI)
- Can be part of KSP leadership teams
- Access in proportion to member share

## Non-Members

- Can lead PI programs
- Can be team members of KSPs, but not part of leadership team
- Access capped at **5% ("Open Time"; TBC by Council)**
- Access to any individual non-member entity may be capped



**Open Time**



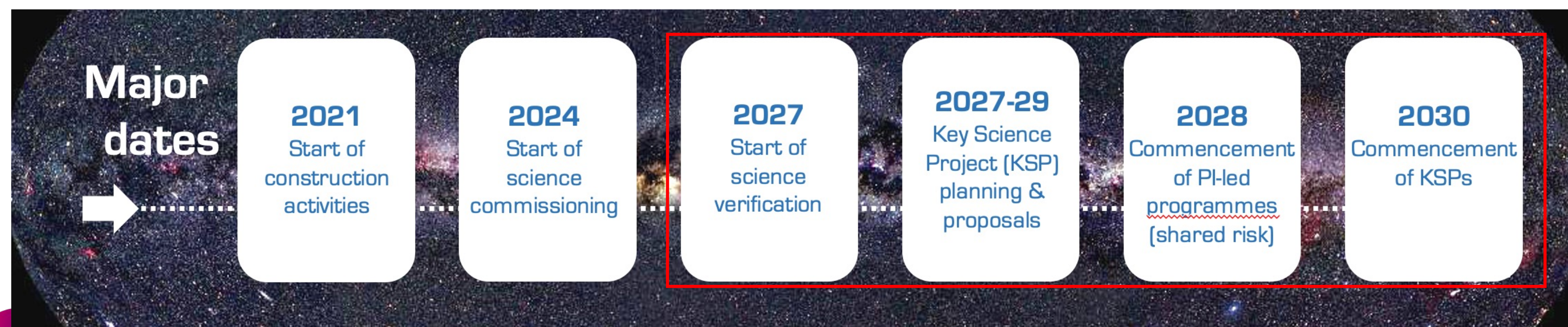
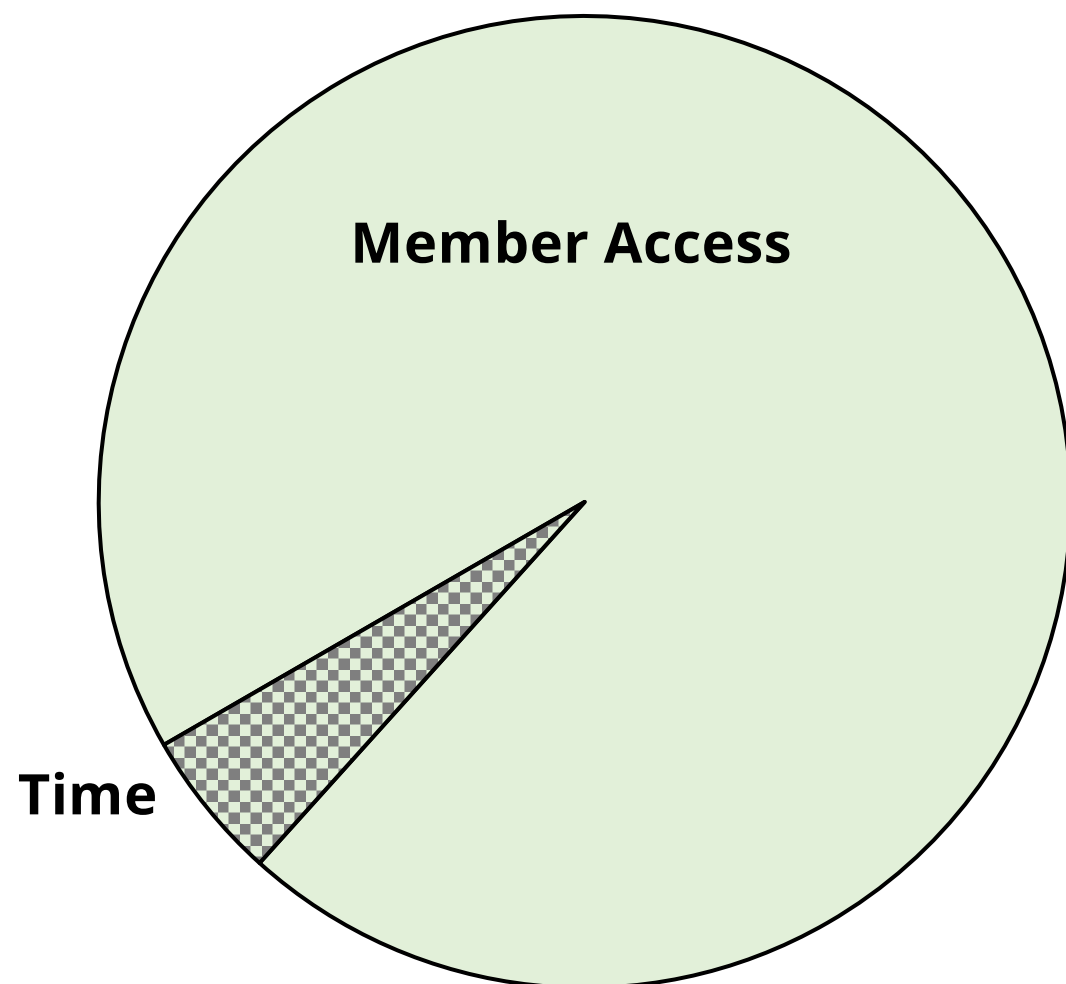
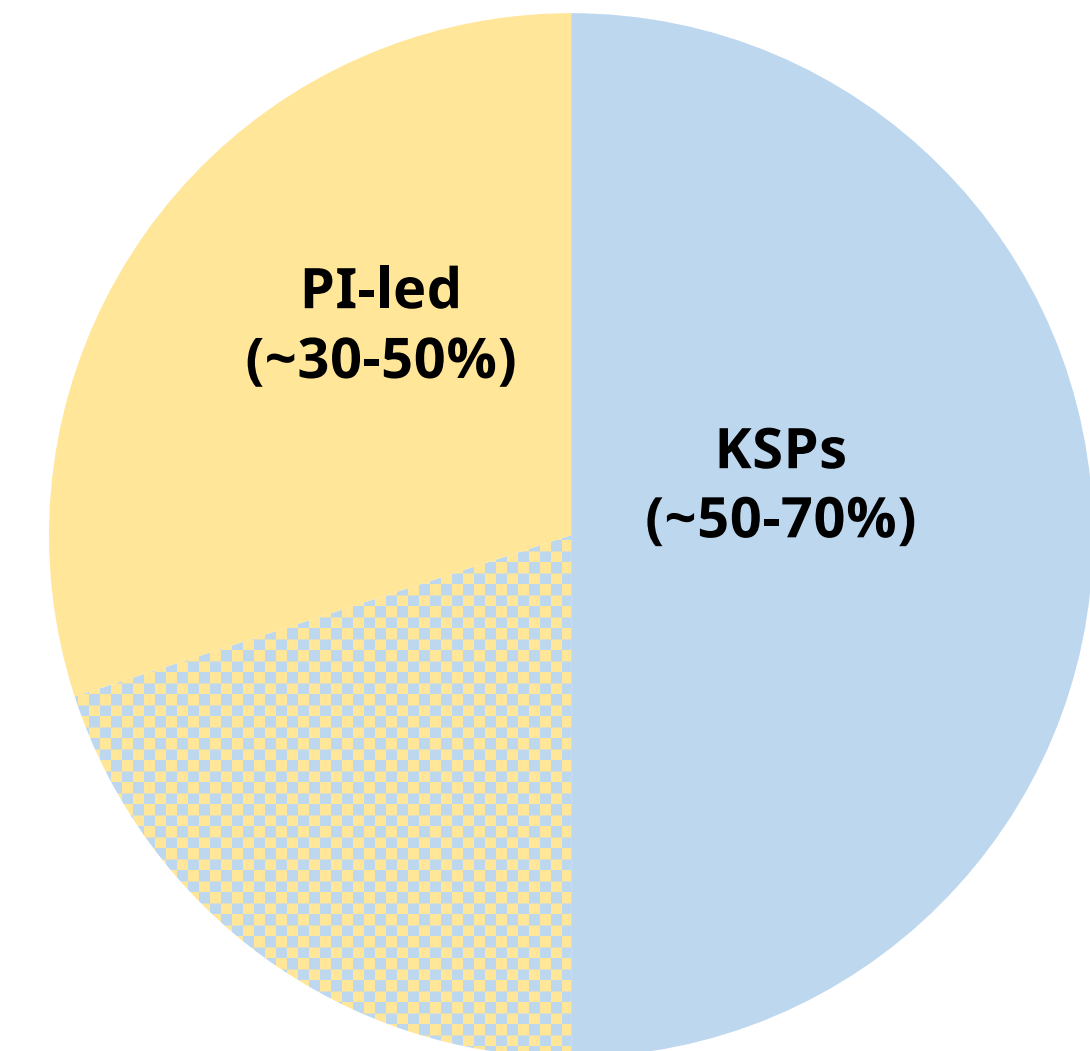


# Telescope access

- **No time has been allocated for any project**
- Science Working Groups are not proto-KSPs
- High Priority Science Objectives are not KSPs
- There are no guaranteed KSPs
- Time allocation will be based on

## SCIENTIFIC MERIT

*and technical feasibility through a common proposal review process*





# Construction Strategy

(Staged Delivery - Target: Design Baseline)

## Array Assemblies (AA)

- Capable as acting as an end-to-end telescope system with pre-defined functionality
- Used to commission the telescopes, and verify against requirements
- Different objectives for different assemblies
- **Science commissioning:** on-sky observations for testing and debugging the system
- **Science verification:** observations to ensure the system meets the needs of the science users (e.g., test observing modes, verify science requirements)
- **AA 0.5** – test array for interferometry, using prototype dishes and (in some cases) receivers; discover system level issues and develop procedures (pointing, tracking, holography)

Milestone Event (earliest)		SKA-Mid (date)	SKA-Low (date)
AA0.5 (test array)	4 dishes 6 stations	2025 Q1	2024 Q4
AA1	8 dishes 18 stations	2026 Q1	2025 Q4
AA2	64 dishes 64 stations	2027 Q1	2026 Q4
<b>Science Verification begins</b>		<b>2027+</b>	<b>2027+</b>
AA*	144 dishes (80+64 MK) 307 stations	2027 Q4	2028 Q1
Operations Readiness Review		2028 Q1	2028 Q2
End of Staged Delivery Programme		2028 Q3	2028 Q3
<b>Early Operations begin (shared risk)</b>		<b>2029+</b>	<b>2029+</b>
AA4	197 dishes 512 stations	TBD	TBD

Updated August 2023





# Construction Strategy

(Staged Delivery - Target: Design Baseline)

- **Goal – SKA-Mid with 197 dishes & SKA-Low with 512 stations**
- Not all funding yet secured, therefore following Staged Delivery Plan (AA\*)
- Roll out the array in stages (Array Assemblies – AAs)
- Maintain a continuously working and expanding facility that demonstrates the full performance capabilities of the SKA Design.
- **AA2 – Start science verification:** observations to ensure the system meets the needs of the science users (e.g., test observing modes, verify science requirements)

First data release to community after AA2 in 2026/27 time-frame (similar to ALMA SV model)

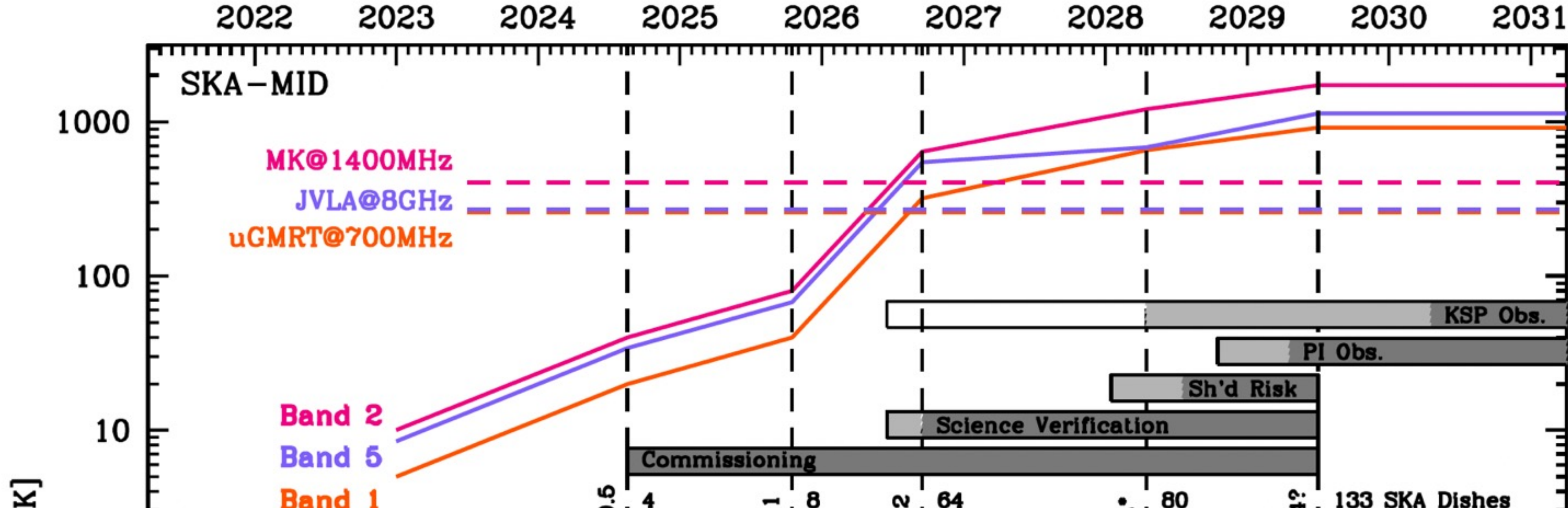
Milestone Event (earliest)		SKA-Mid (date)	SKA-Low (date)
AA0.5 (test array)	4 dishes 6 stations	2025 Q1	2024 Q4
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AA4	197 dishes 512 stations	TBD	TBD

Updated August 2023

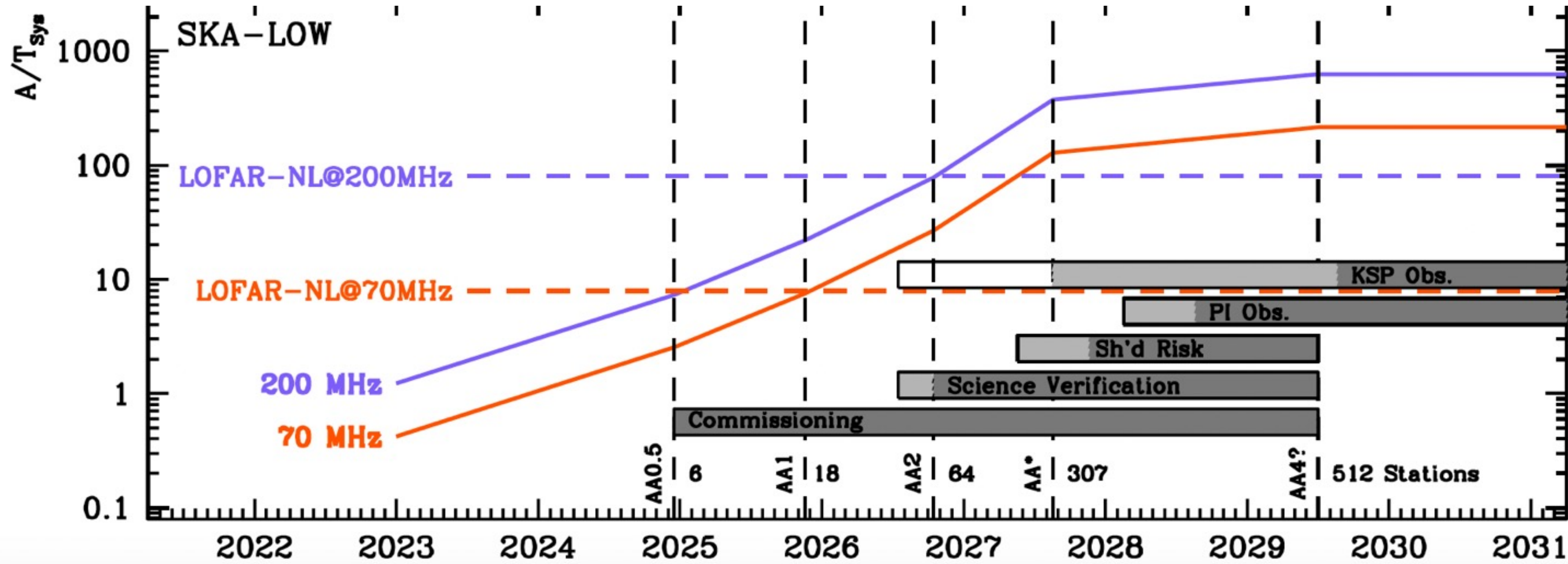




# Evolution of Performance



Around the end of 2026, SKAO becomes the most powerful radio observatory on Earth

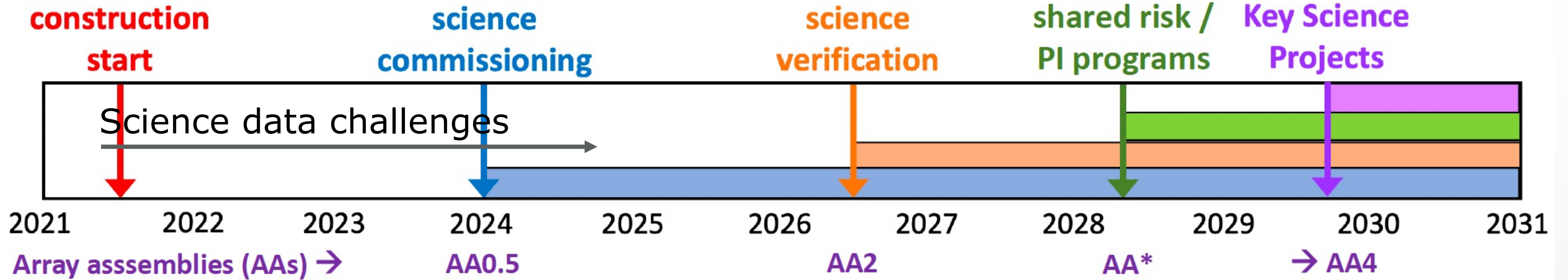


Credit: Mark Sargent





# SKAO Science Timeline



## Scientifically competitive facilities

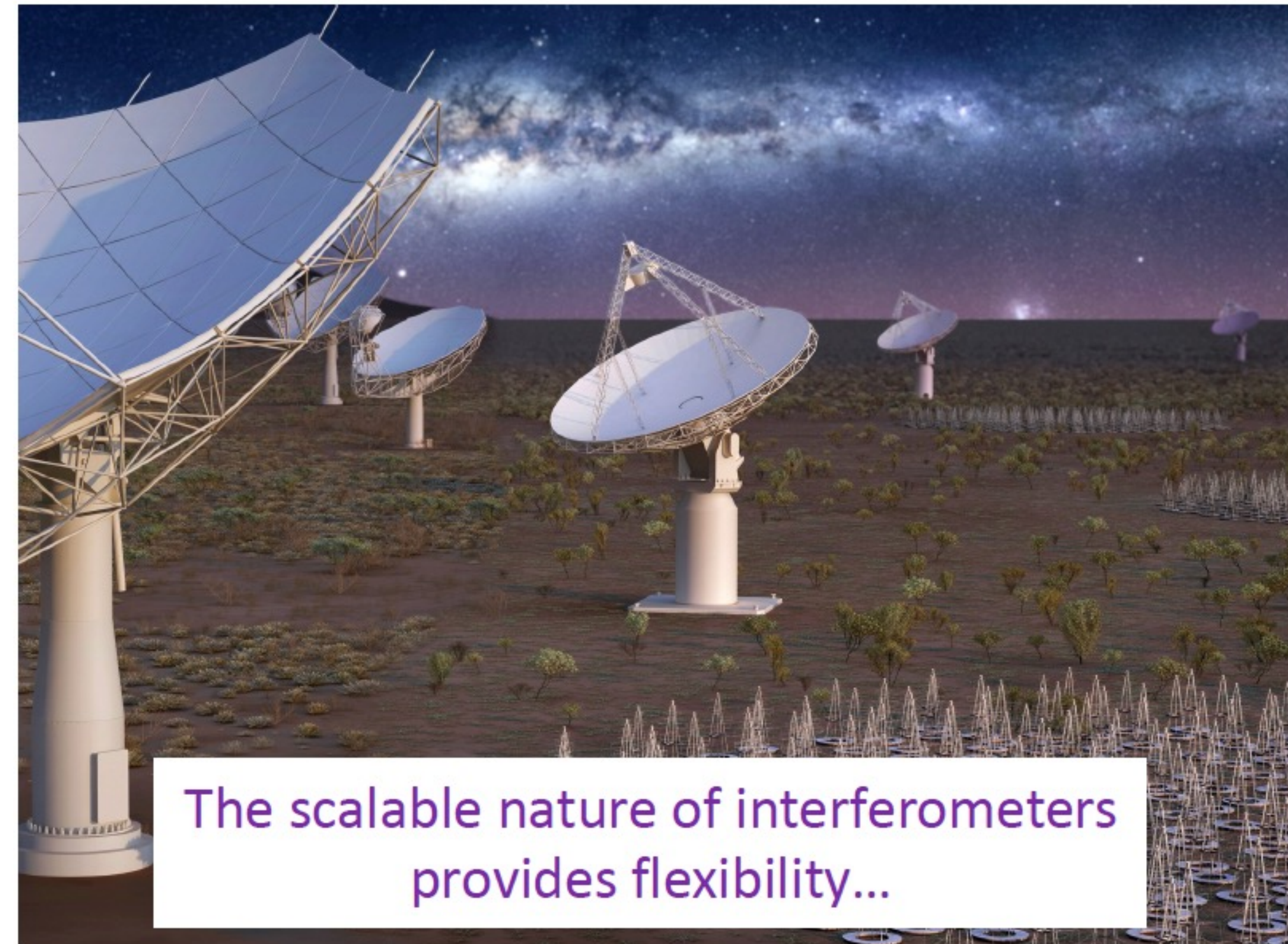
### > mid-2026 (= AA2):

- Calibrated science data demonstrating capabilities will be publicly released
- Call for community “ideas” by ~mid 2025

## Shared-risk observations (“cycle 0”)

### in early 2028 (= AA\*):

- Full proposal solicitation/allocation process
- Call for proposals in by ~mid 2027
- Key Science Projects planning starts in 2026



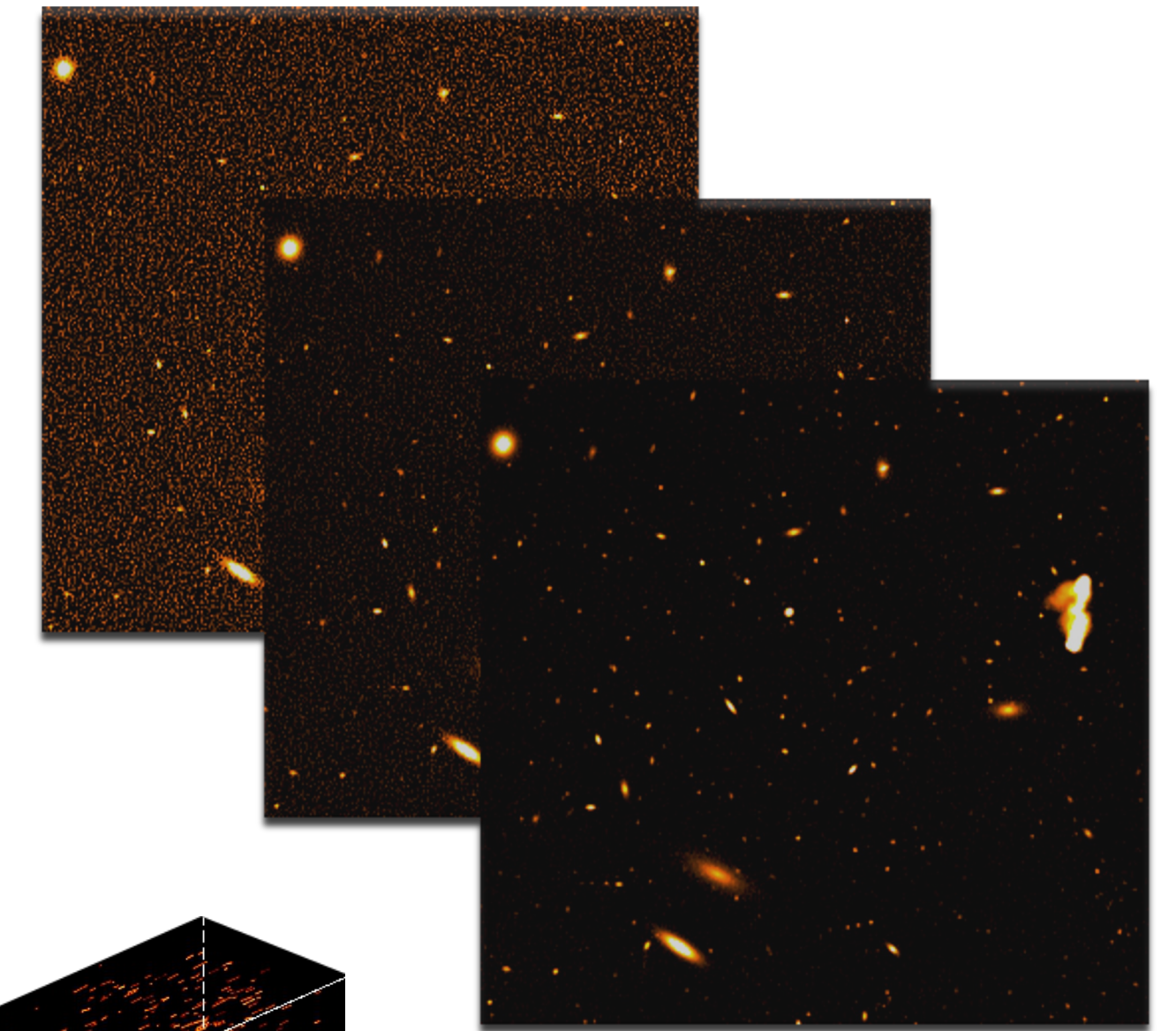
The scalable nature of interferometers provides flexibility...



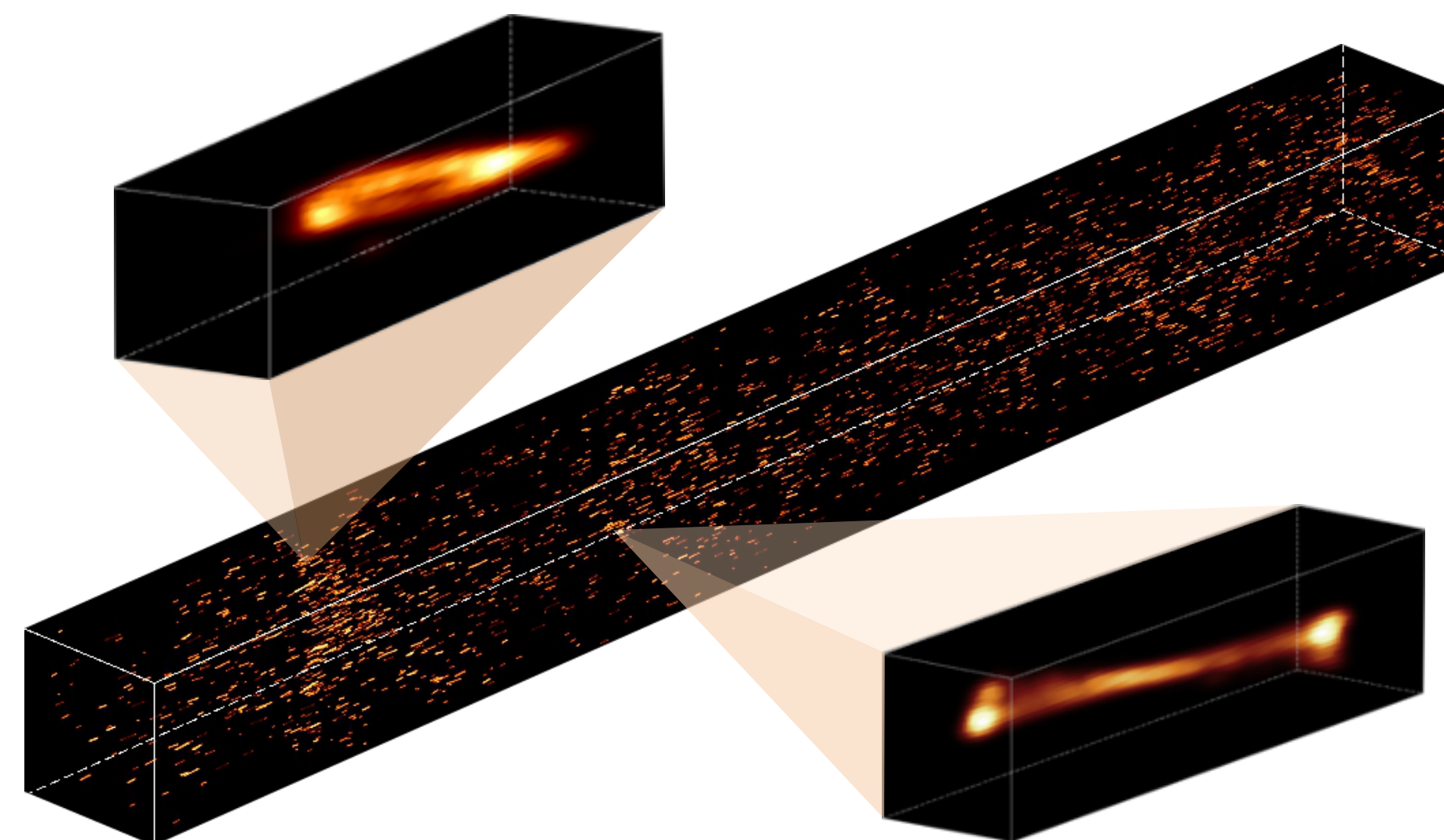
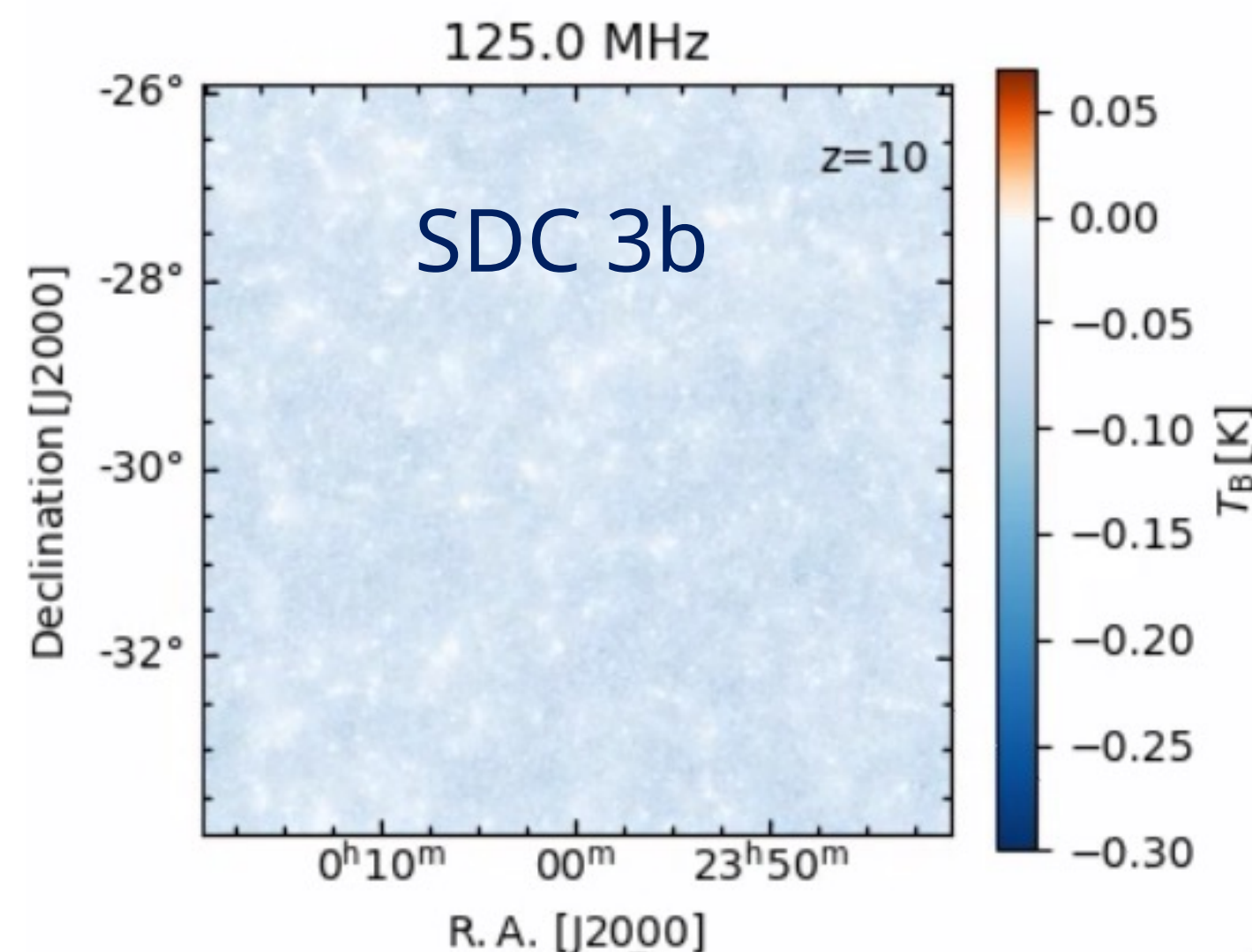
# SKA Science Data Challenges (SDCs)

*"The purpose of SDCs is to prepare the astronomical community, and SKAO itself, for the novel, yet challenging, nature of SKA data"*

- ✓ SDC 1 – Radio Continuum Emission
- ✓ SDC 2 – Neutral Hydrogen Spectral Line Emission
- ✓ SDC 3a – EoR Foreground Removal ("Foregrounds")
- ▽ SDC 3b – Extraction of Cosmological Parameters ("Inference")
- ▽ SDC 4 – Magnetised continuum (Rotation Measure ...)



SDC1, Bonaldi et al., 2021



SDC2, Hartley et al., 2023

*Growing repository of sky models and simulation code for community re-use*



# SKAO Science Data Challenge 3

MAP OF WORLDWIDE PARTICIPATION



Participants

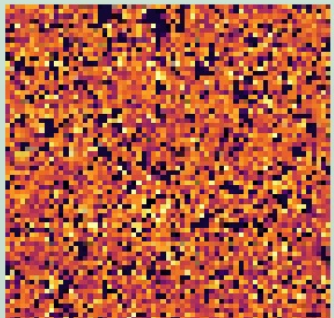
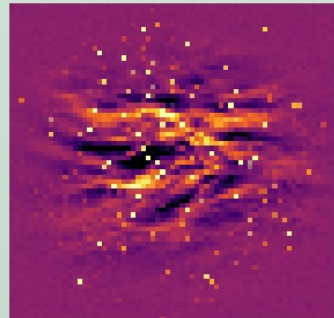


Computing facilities



## THE CHALLENGE IN NUMBERS

Teams analysing <b>7.5 TB</b> of simulated telescope data and a corresponding	<b>234</b> registered participants in	<b>12</b> supercomputing centres providing resources globally
<b>60 GB</b> of image cubes representing different radio frequencies	<b>16</b> countries	

Teams are analysing data which simulates observations of the Epoch of Reionisation signal (left; bright areas are neutral hydrogen, and dark patches are ionised gas). It is obscured by foreground emission (right; orange dots are galaxies, and the ribbon-like shape is diffuse gas in our galaxy). While the features of each image appear equally bright here, in the data cube the background is millions of times fainter than the foreground.



# Upcoming SKA-related Science Meetings

- Science at Low Frequencies (SALF) IX, 11-15 Dec **2023** – Amsterdam, NL  
<https://salfconference.org/2020-9th-annual-science-at-low-frequencies-salf-conference>
- MeerKAT @ 5, 20-23 February **2024** – Stellenbosch, RSA
- Interstellar Frontiers: Bridging SETI, Astrobiology, and the SKA, 11-15 March **2024**, Perth, AU
- Cosmology in the Alps, 18 – 22 March **2024**, Les Diablerets, CH  
<https://indico.skatelescope.org/event/1098/>
- SPARCS (SKA Pathfinder Radio Continuum Surveys) XII, May 6-10 **2024**, Bologna, IT
- Cosmic Magnetism in the Pre-SKA Era, 27-31 May **2024** – Japan  
[http://ska-jp.org/ws/SKAJP\\_MAGWS2024/](http://ska-jp.org/ws/SKAJP_MAGWS2024/)
- IAU GA, August **2024**, Cape Town, various SKA Science events planned and related sessions
- **SKAO Science Conference, Summer 2025, Germany, planning underway**





# SKAO construction update





# Construction Commencement Ceremonies



Consecutive ceremonies took place at the telescope sites in Australia and South Africa on 5<sup>th</sup> December 2022







## SKA-Mid foundations





# Packing and shipping the first SKA-Mid pedestal



Shipping from the China Electronics Technology Group Corporation (CETC)





# Testing the dish lift





# Environmental inspections at the SKA-Mid site





# Roadbed preparation at the SKA-Mid site





# SKA-Low trenching has begun





# And here are all the cables









# Path to Array Assembly 0.5 (AA0.5): Aperture Array Verification System

*Thank you to Jess Broderick  
for these AAVS slides*

## AAVS1

- Pre-Critical Design Review, 1st-gen digitiser, 'SKALA2' antenna



## AAVS2

- 'SKALA4' antenna and Engineering Development Array 2 (EDA2) with Murchison Widefield Array (MWA) antennas



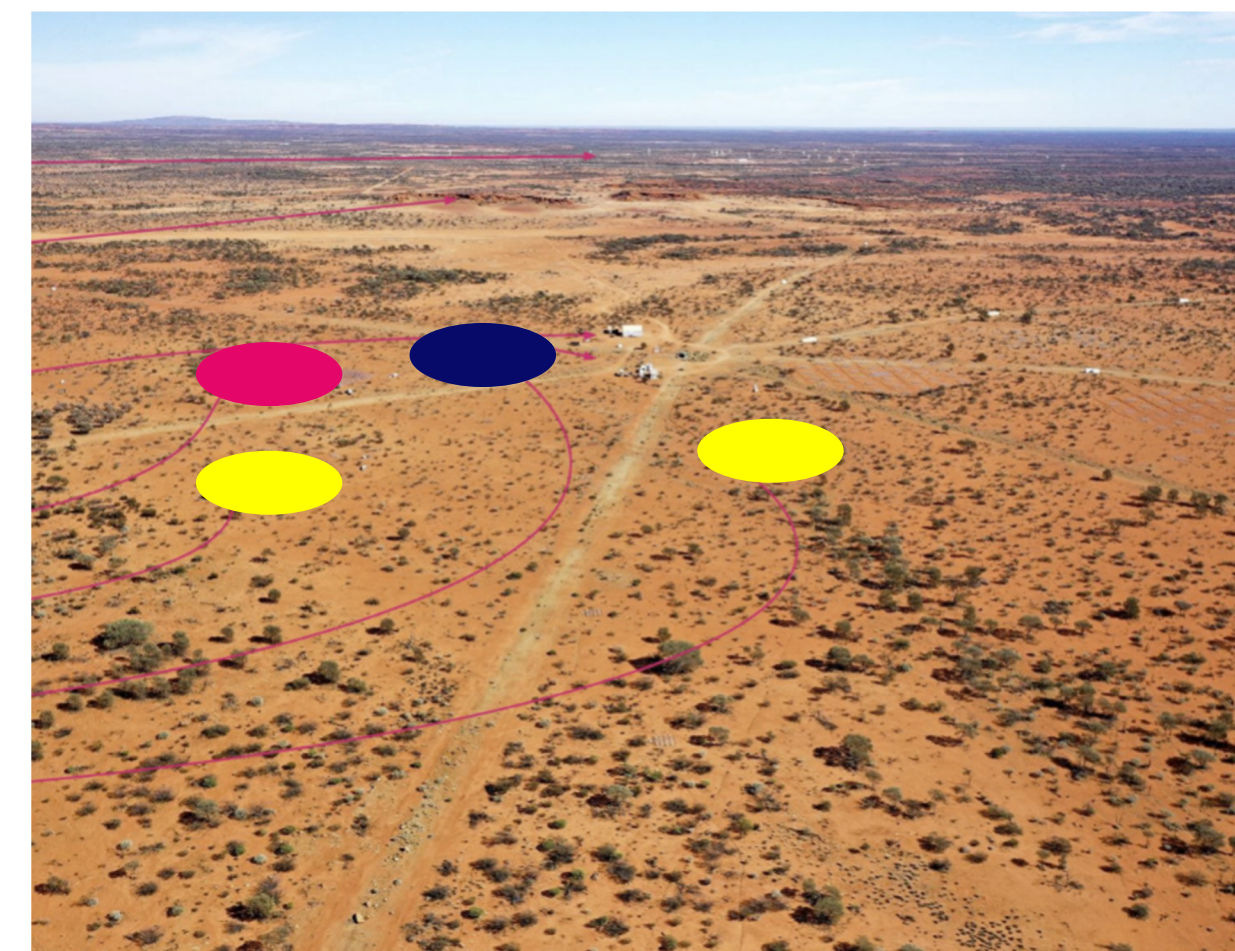
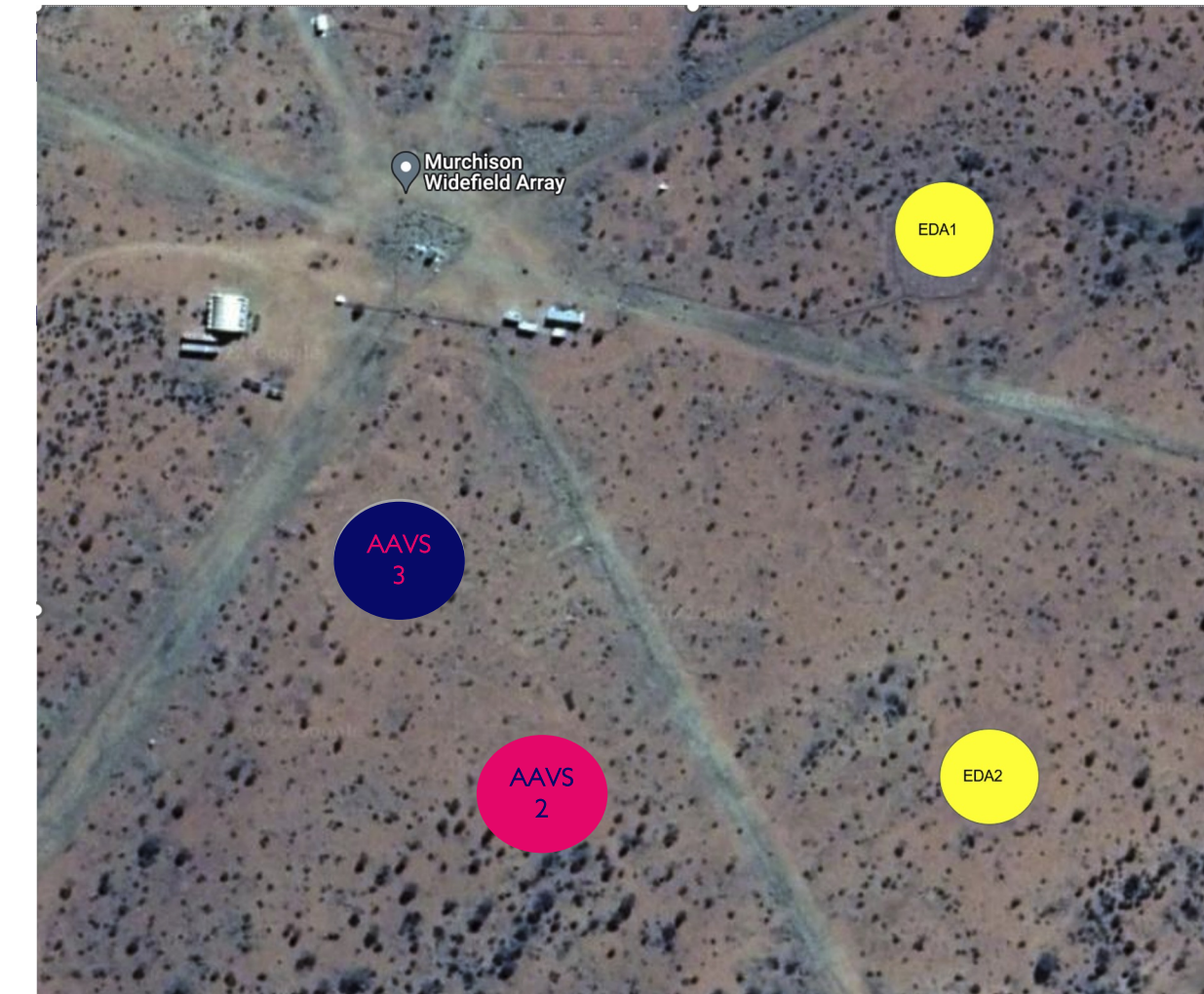
## AAVS2.5

- Upgrades and improvements (heatsinking, network, firmware, antenna power and control)

## AAVS3

- Incorporating final design revisions, full power control and sensing (Power And Signal Distribution), Tile Processing Modules, Monitor Control Calibration System

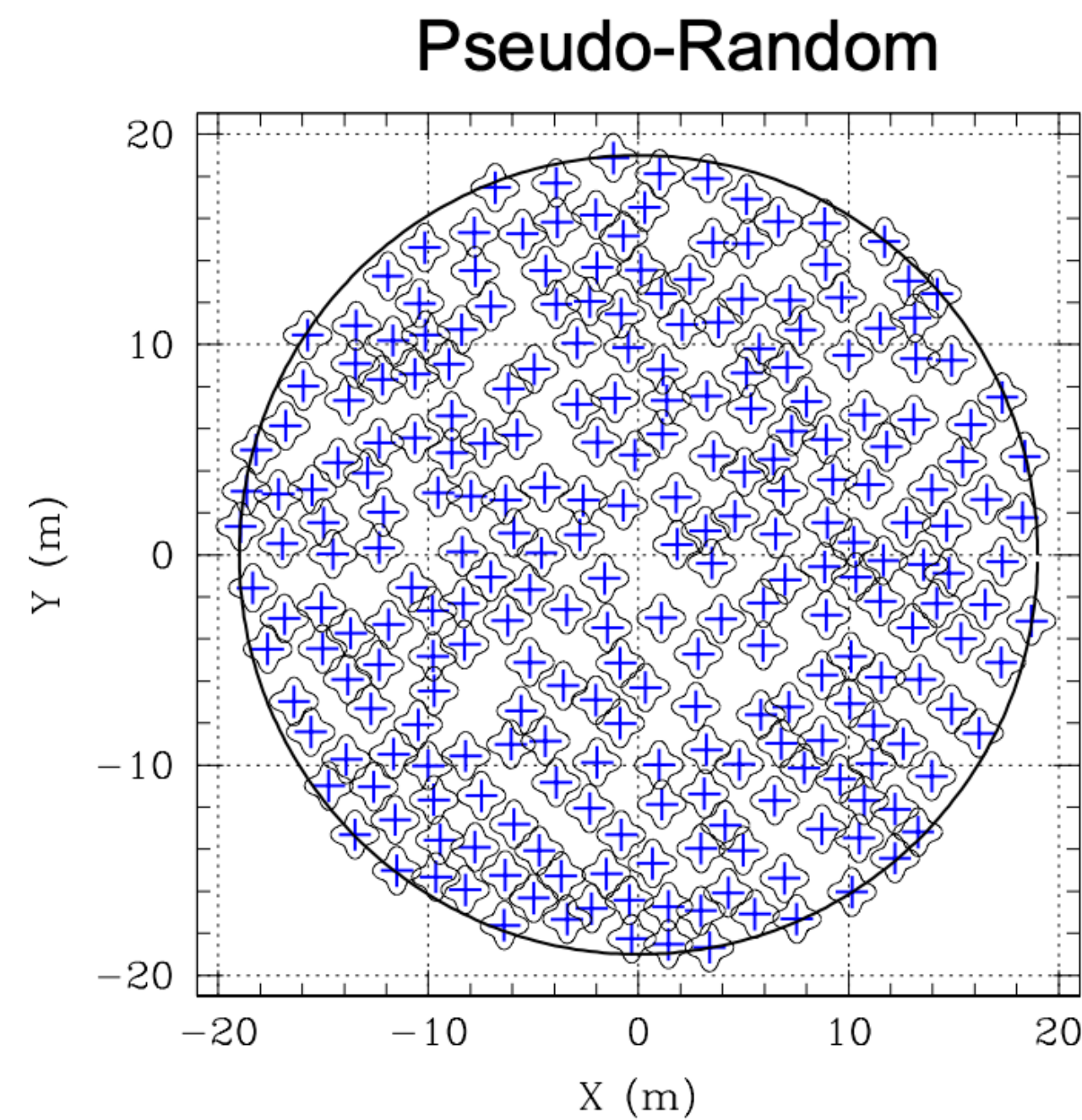
increasing in maturity and completeness  
demonstrators,



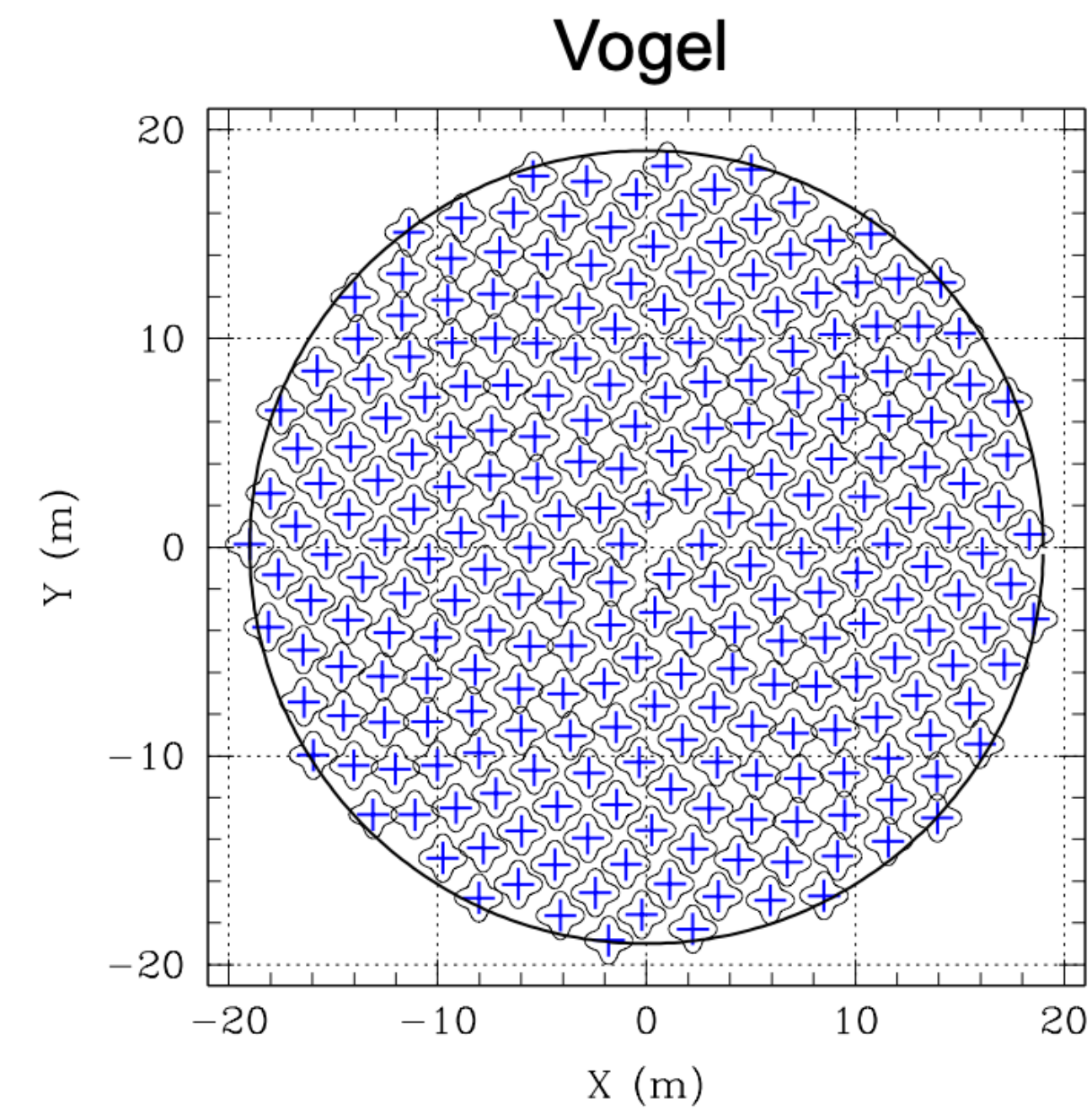


# Why AAVS3?

- AAVS2: bandpass resonances (55, 78 MHz) and embedded element pattern variability.
- 'Vogel' maximally non-redundant spiral pattern. Larger minimum antenna separation ( $\sim 2\text{m}$  cf.  $\sim 1.5\text{-}2\text{m}$ ).
- Vogel configuration may offer better overall performance.
- Comparison of AAVS2 and AAVS3 data will inform a decision on the station antenna configuration for AA0.5 onwards.
- **AAVS3 is the first instrument owned, operated and maintained by SKAO staff in Australia! Ensuring continuity for product development teams and mitigating risk for the delivery of the construction phase.**



AAVS2



AAVS3

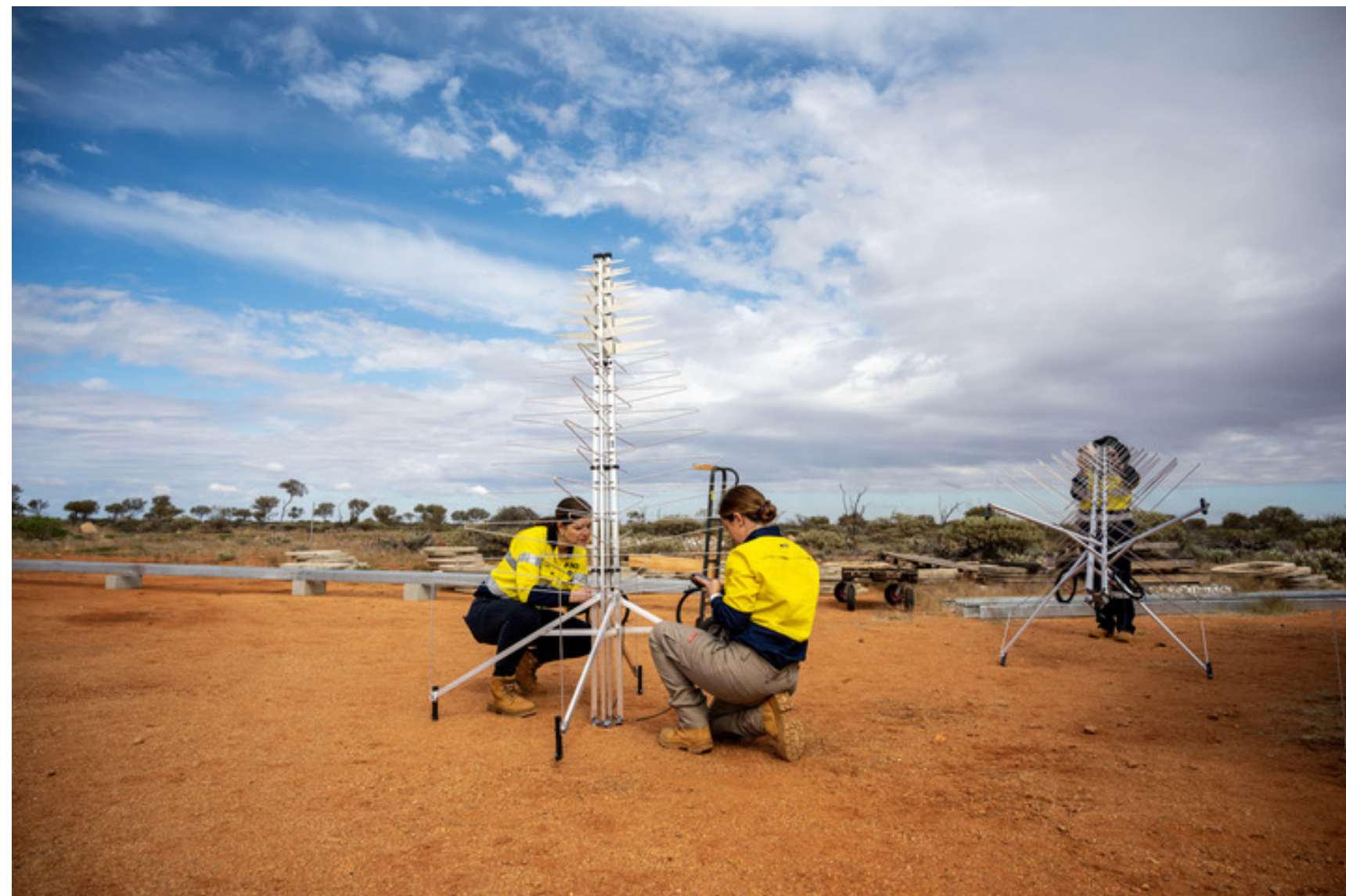




# AAVS3 station rollout

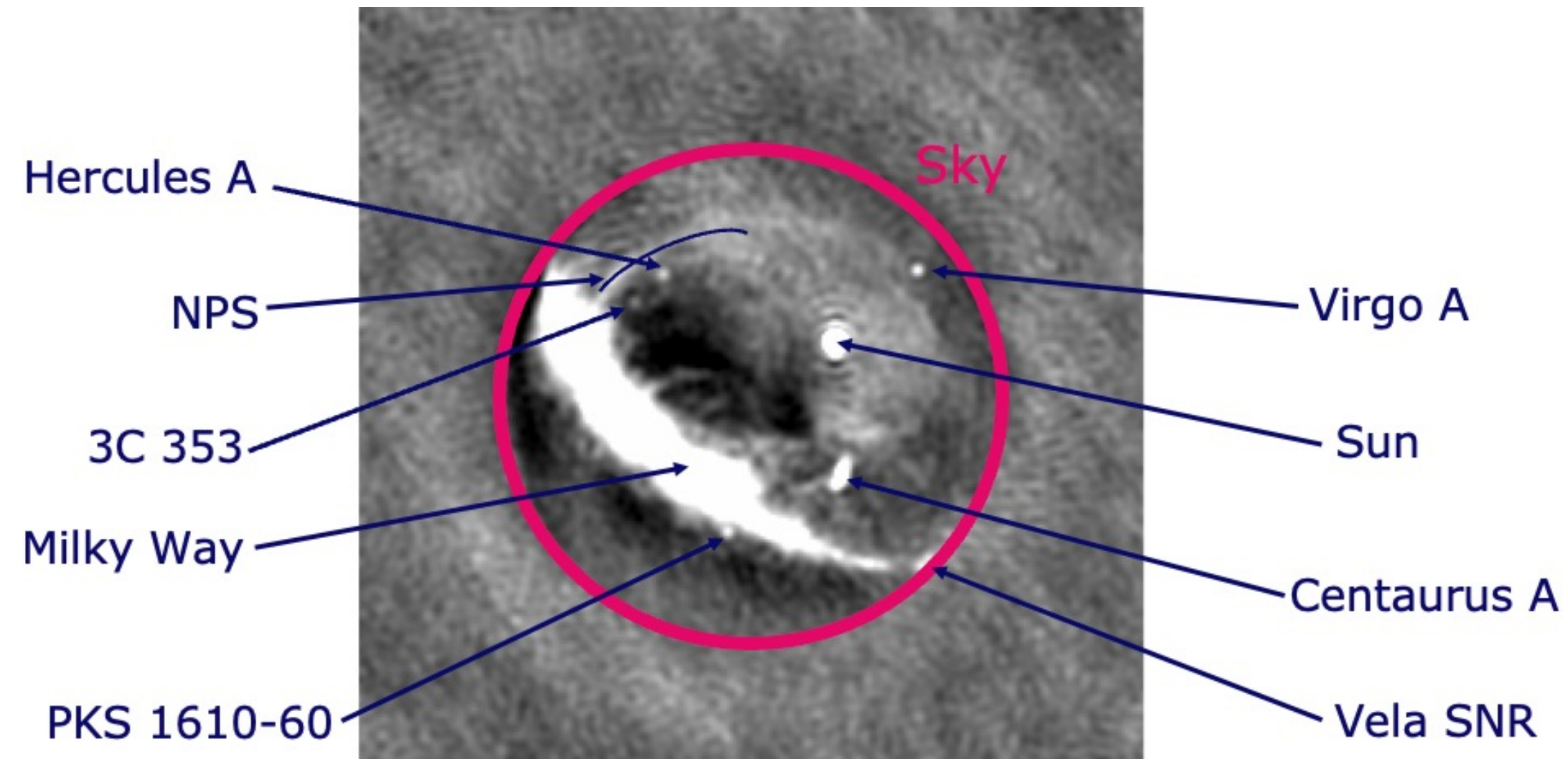


- **Fully deployed (256 antennas) and on schedule.**



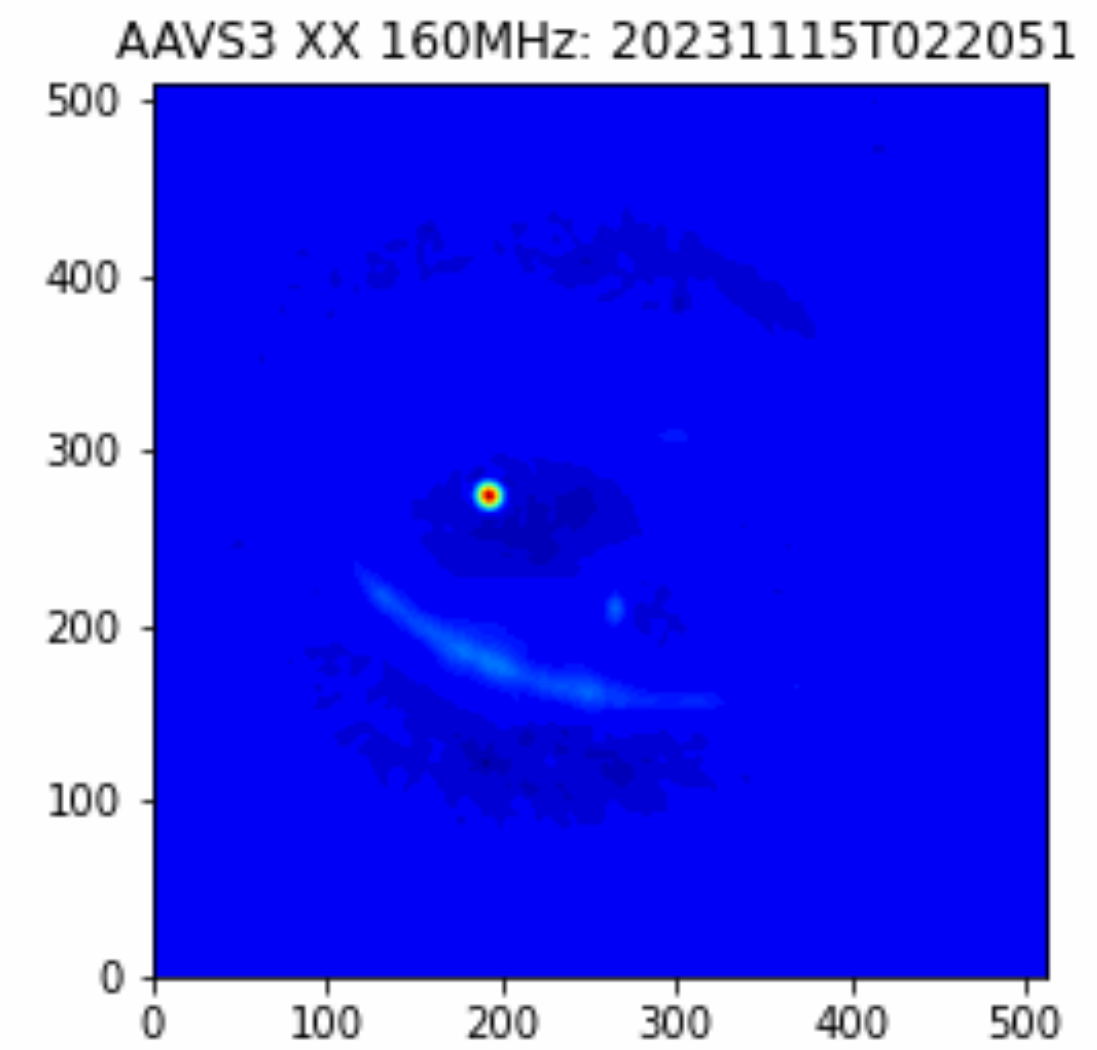


# AAVS3 first light



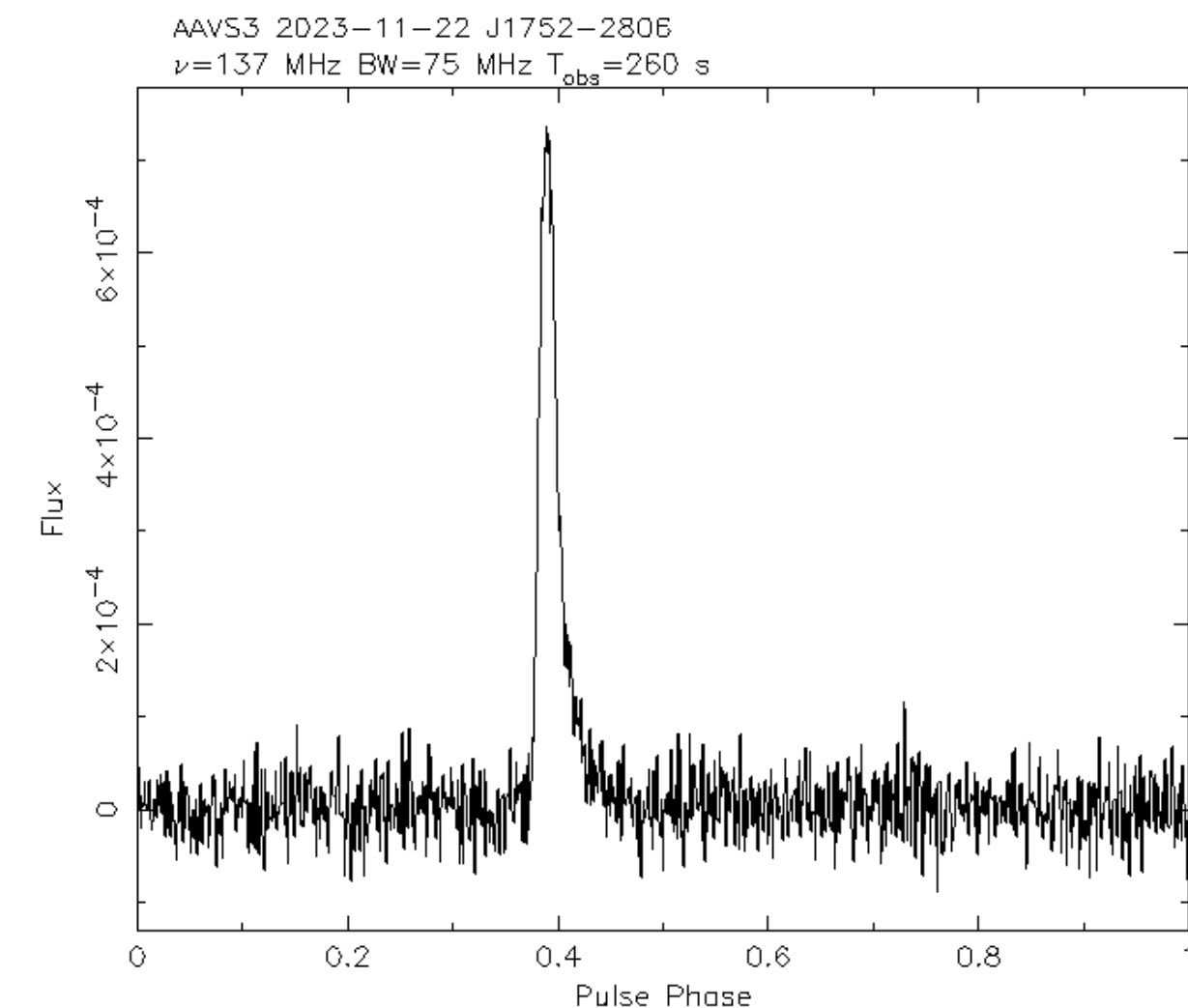
**First light:** all-sky image at 159 MHz. 800-kHz bandwidth, 5-min integration, calibrated with the Sun, CLEANed. Credit: Caiazzo, Wayth et al.

- **Currently in the engineering commissioning phase. Science commissioning to begin soon!**



**Above:** All-sky image movie with light CLEANing. Credit: Asayama et al.

**Below:** PSR J1752-2806. 137 MHz, 75-MHz bandwidth, 260-s integration. Credit: Serylak, Sobey et al.





Thank you!

*We recognise and acknowledge the  
Indigenous peoples and cultures that have  
traditionally lived on the lands on which  
our facilities are located.*

**SKAO**

[www.skao.int](http://www.skao.int)

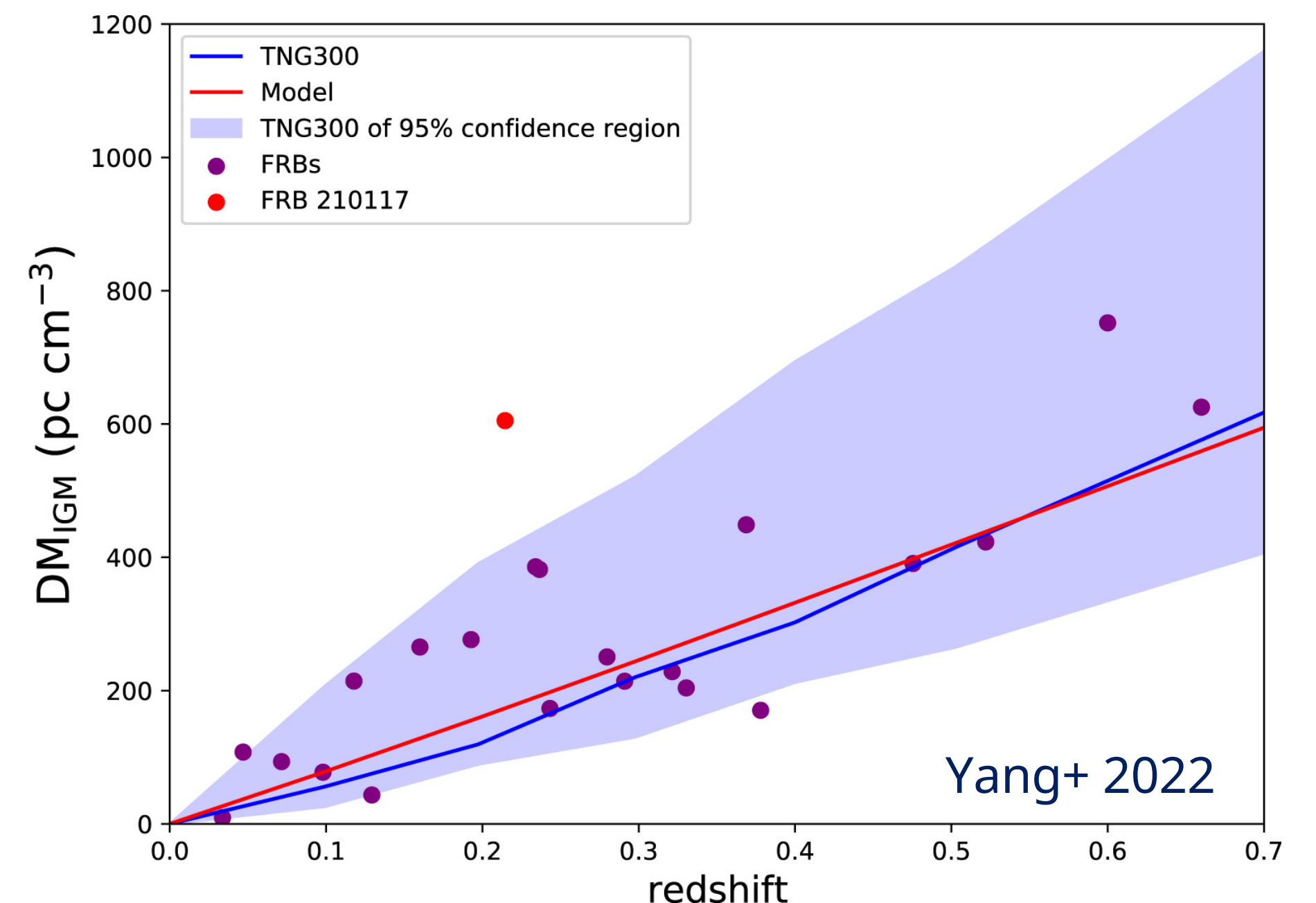
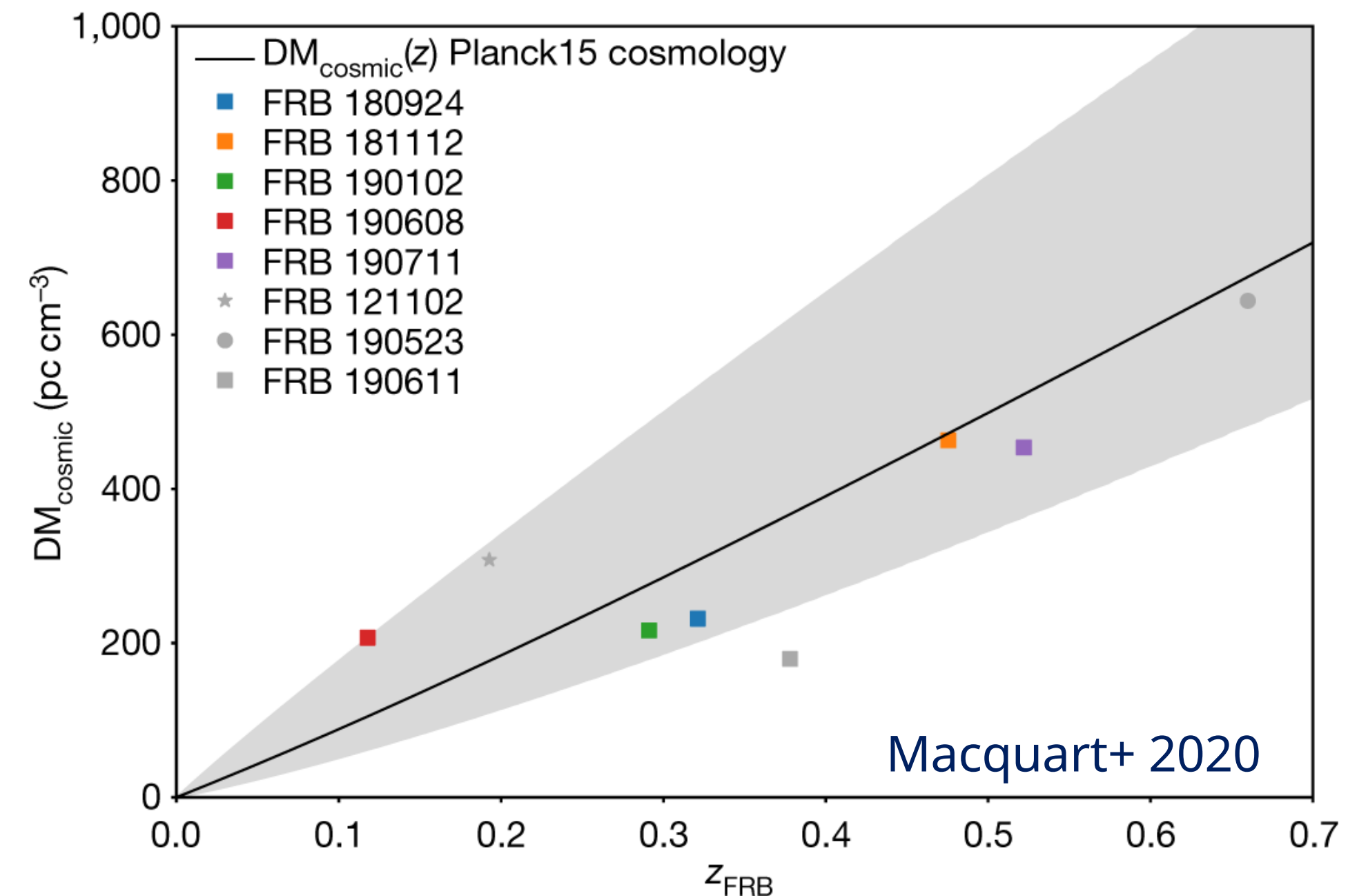


# Missing Baryon Question with FRBs

- Most (3/4) baryons difficult to detect
- Small fraction directly observed, rest are “invisible”
- FRBs sensitive to total electron column density, and hence the ionized baryon content
- FRBs lie at cosmological distances
- Use FRB DM to infer baryon content
  - (DM has MW+IGM+host+FRB: IGM dominant)

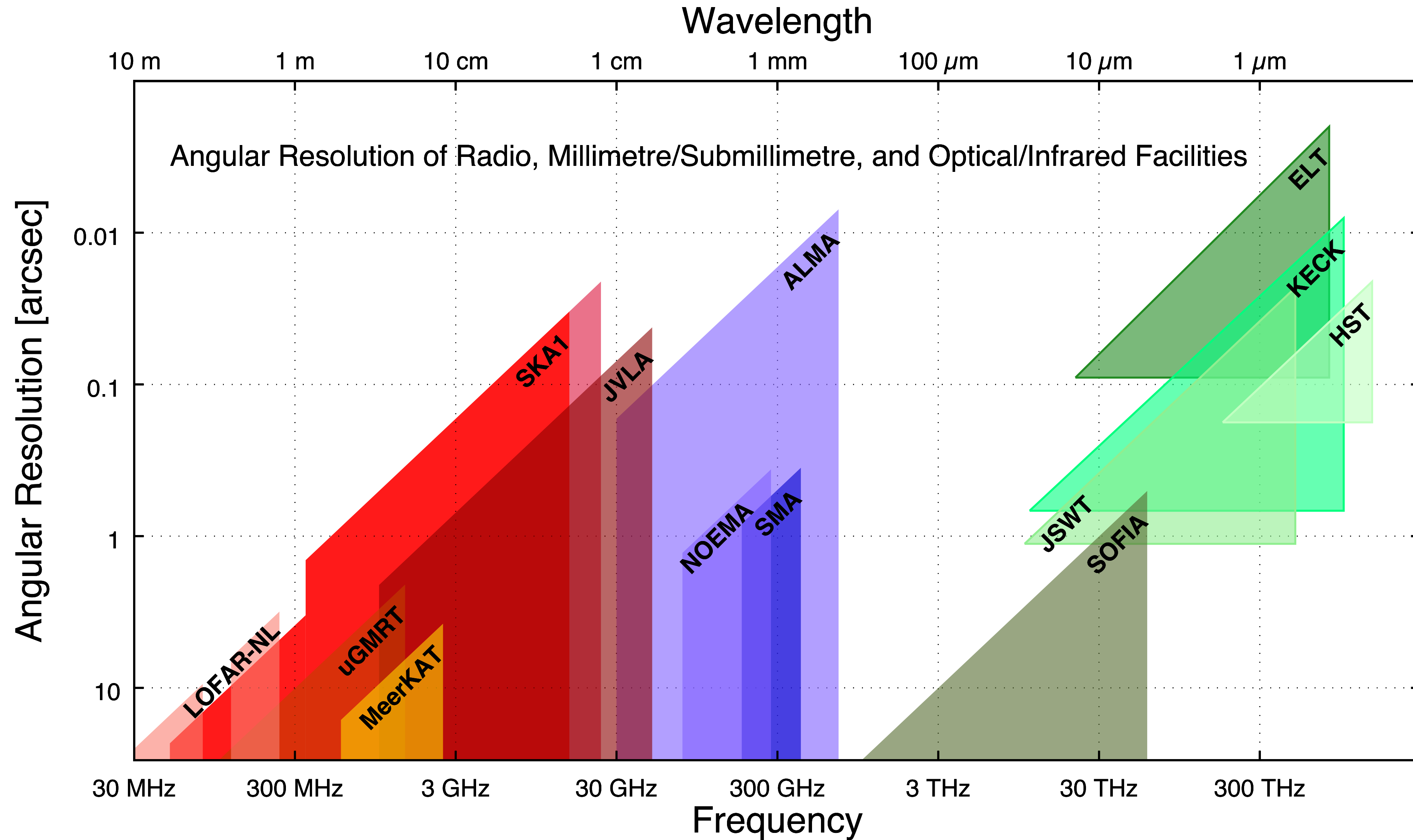
FRB localisation is difficult to date, due to small number of solid associations

Early results are consistent with CMB and Big Bang Nucleosynthesis





# Angular Resolution (without VLBI)





# Imaging Performance SKA-Mid

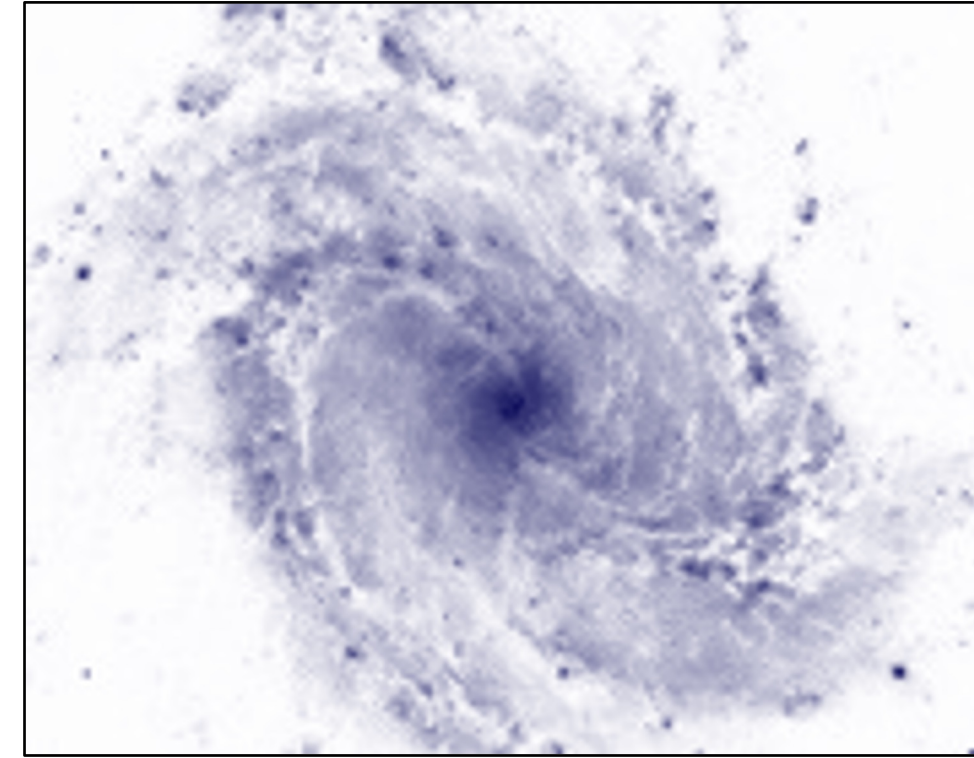
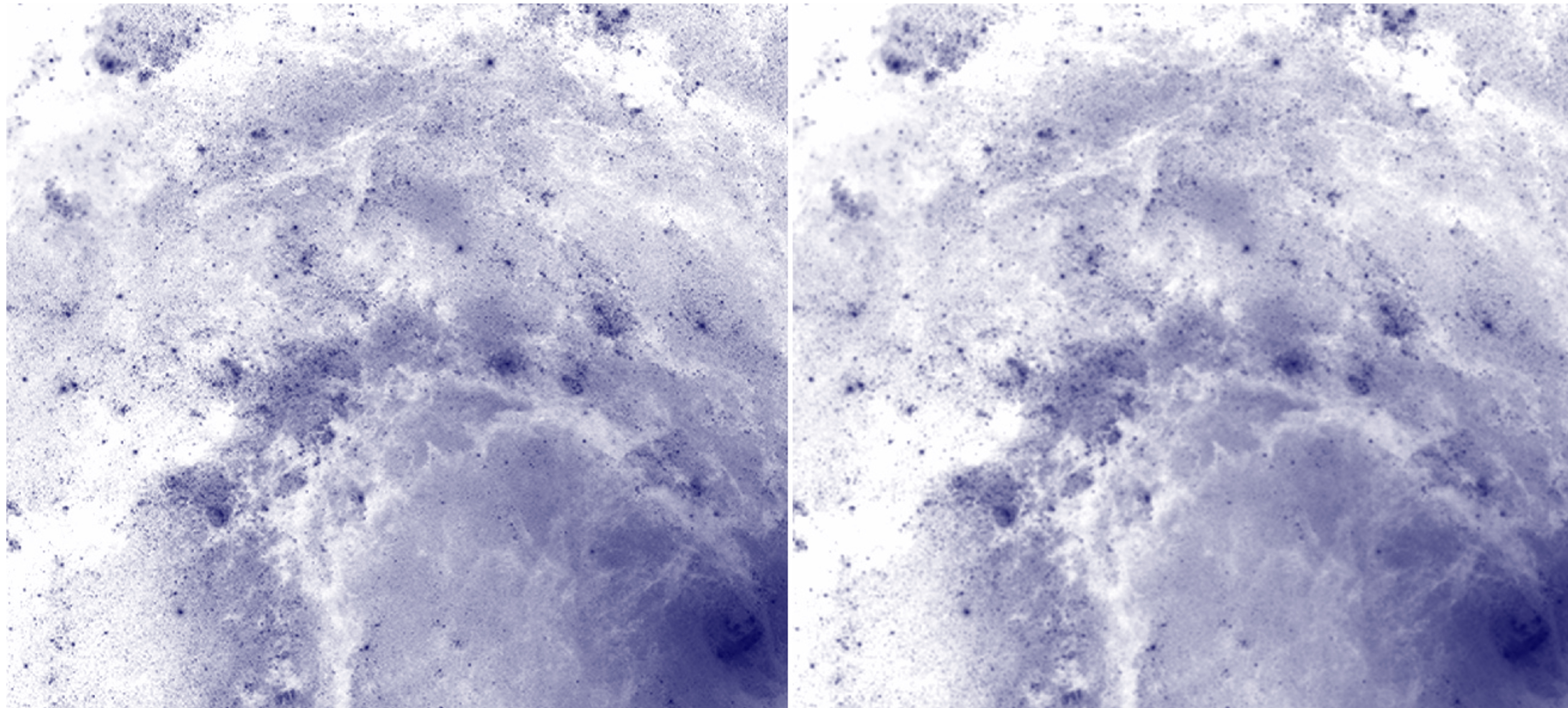


Image resample to SKA resolution  
~1" @ 1.4 GHz

Input Model Image  
(noiseless)

SKA-Mid, 8h track





# Imaging Performance SKA-Low

Input Model Image  
(noiseless)

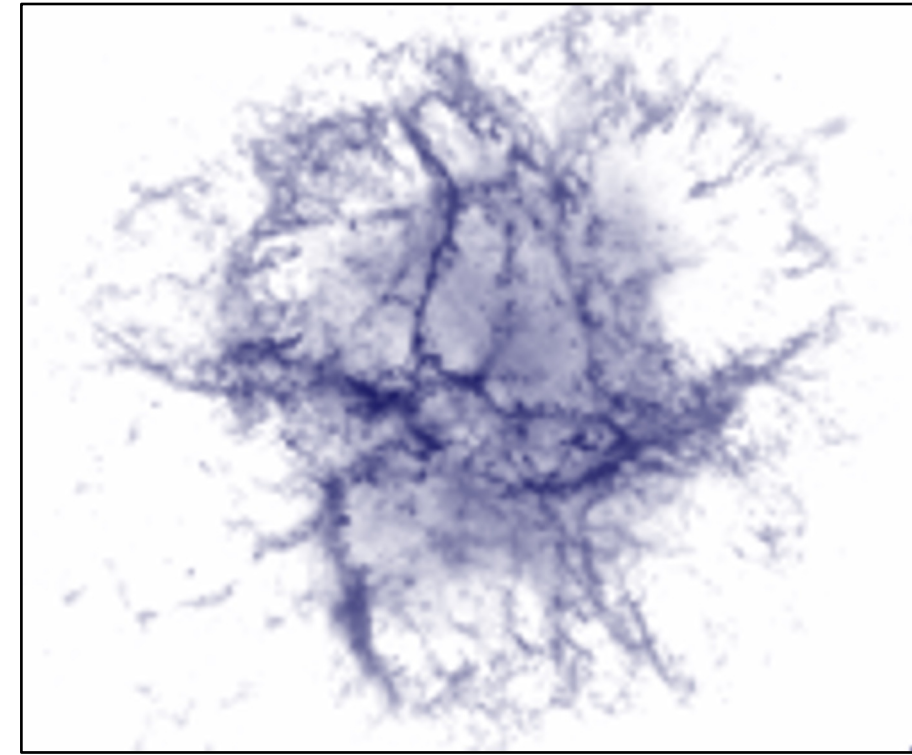
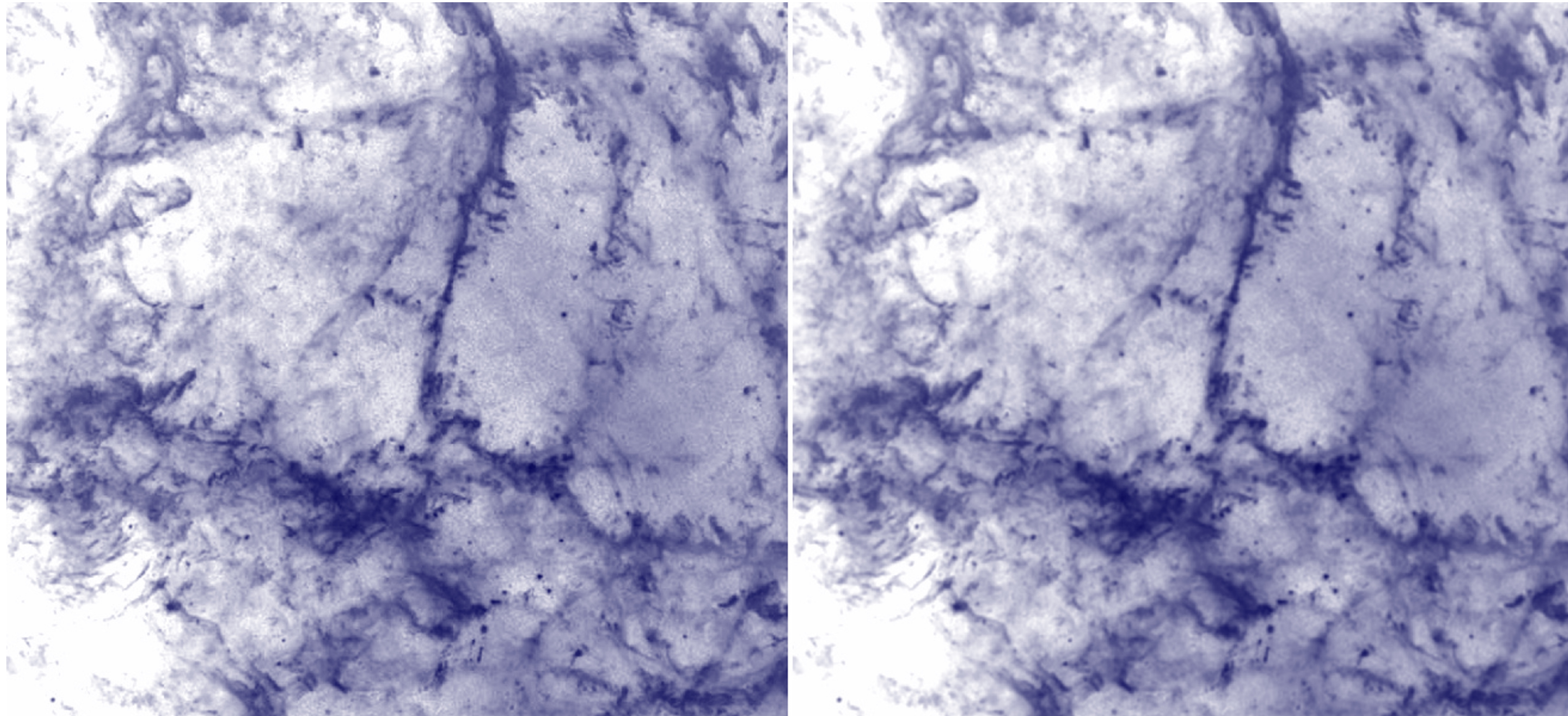


Image resample to SKA resolution  
10" @ 140 MHz

SKA-Low, 4h track





# The Road to Science – Proposal Types

## Key Science Projects (KSPs)

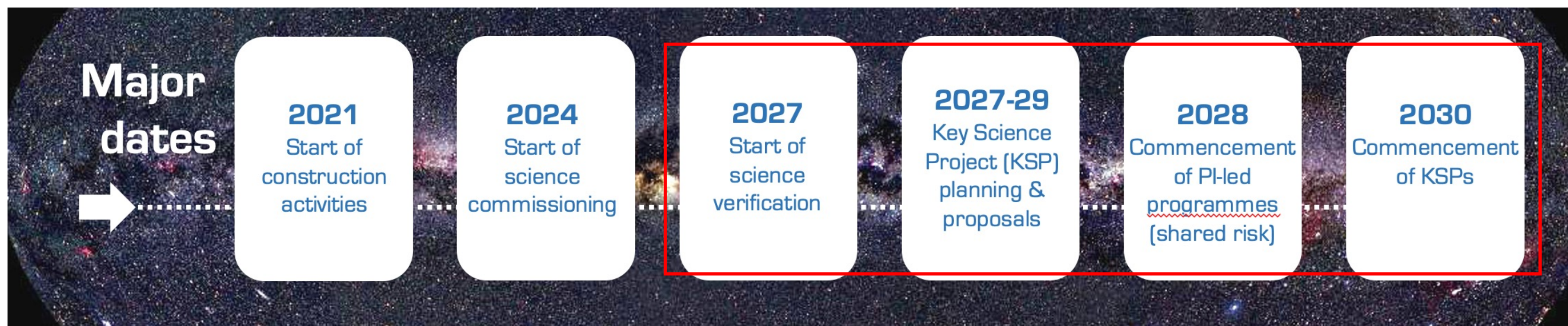
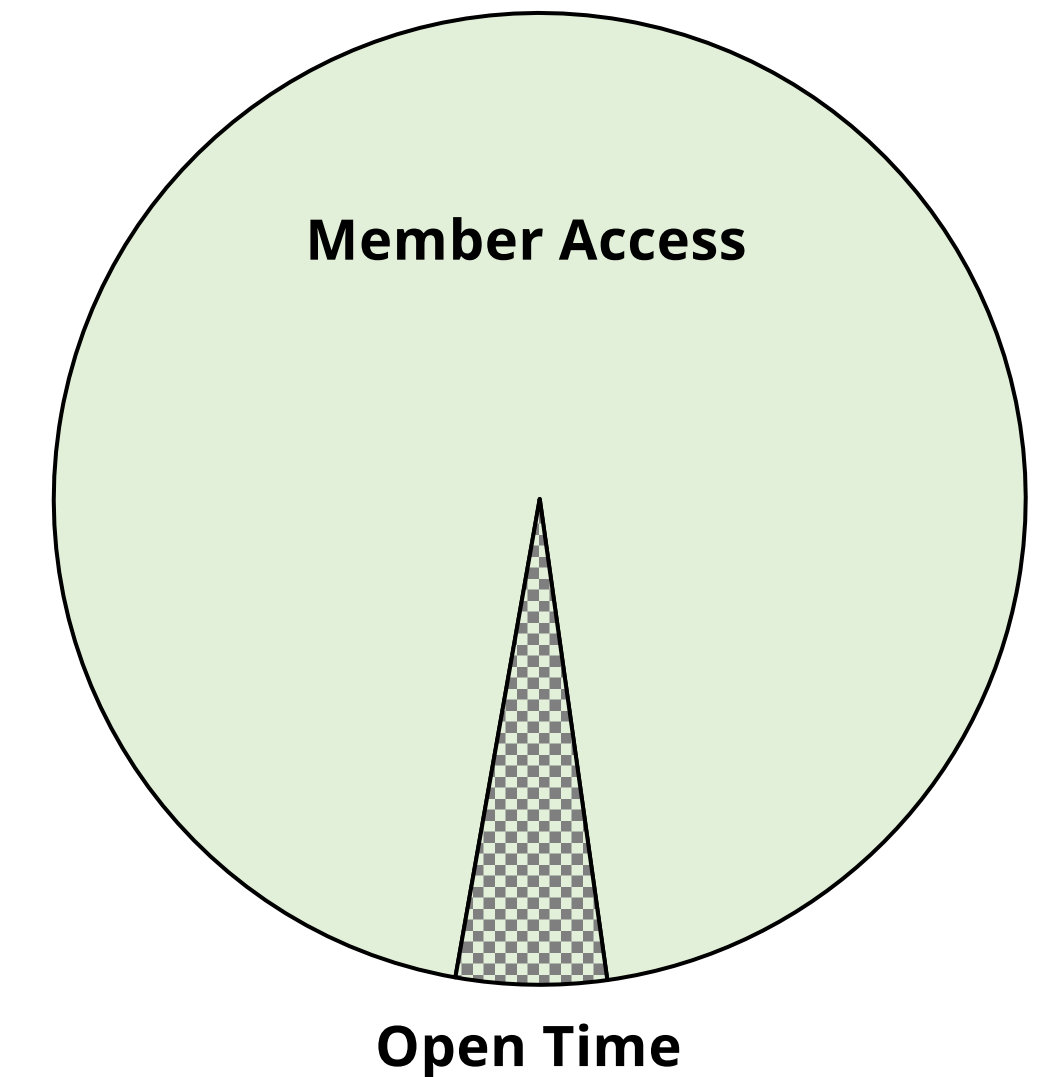
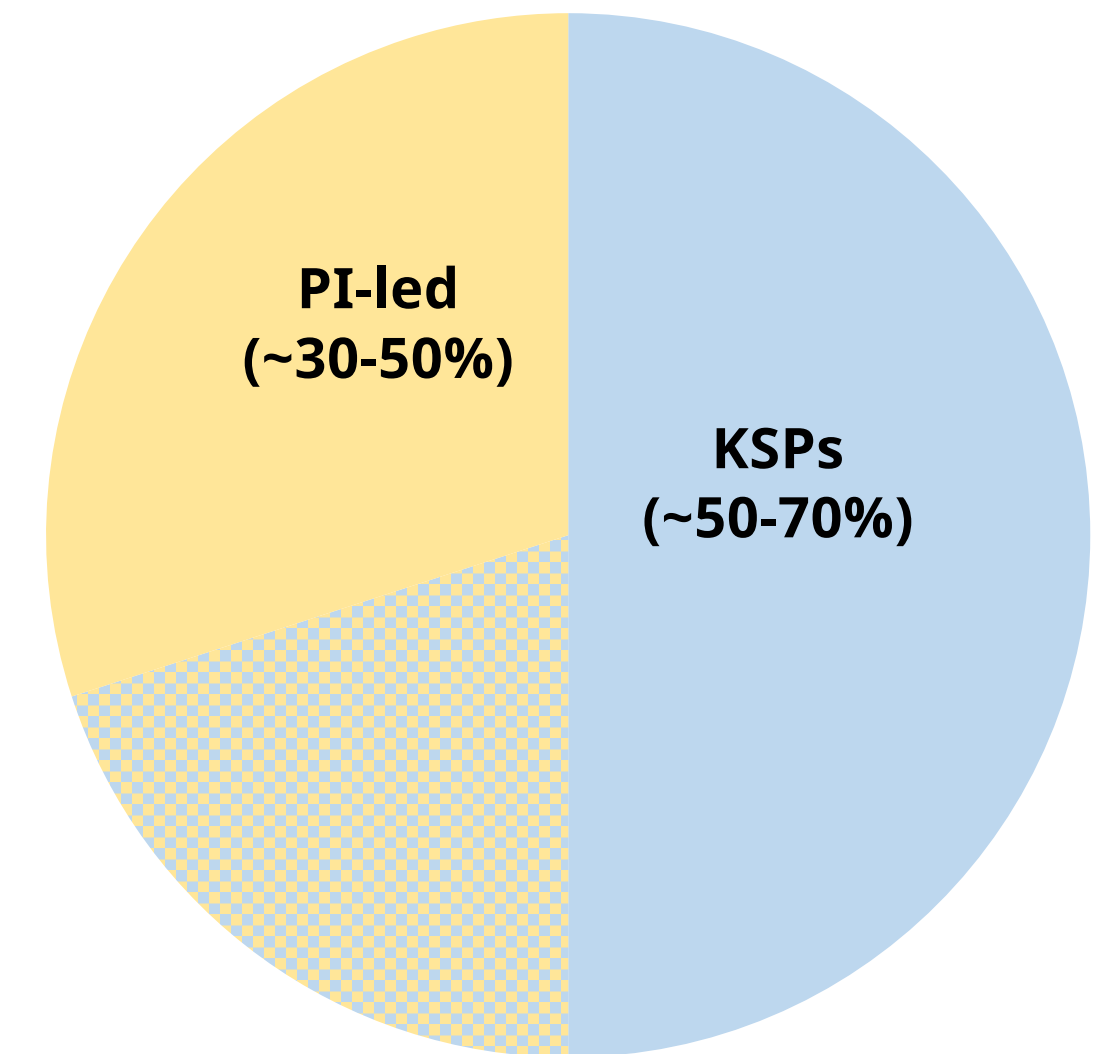
- Large programs performed over multiple cycles, requiring significant resources (e.g., observing time, computing)
- Leadership team from SKA-member countries; co-Is from any country (latter may be limited)
- Expected to provide added-value data products and tools back to SKAO
- Regular reviews to track progress toward goals

## Principal Investigator (PI) Projects

- Small programs typically performed within a single cycle (1 year)

## Access is proportional to member share

- e.g., UK's share currently ~15%





# Spectral resolution

Nominal Frequency	110 MHz	300 MHz	770 MHz	1.4 GHz	6.7 GHz	12.5 GHz
Range [GHz]	0.05-0.35	0.05-0.35	0.35-1.05	0.95-1.76	4.6-8.5	8.3-15.3
Channel width (uniform resolution across max. bandwidth) [kHz]	5.4	5.4	13.4	13.4	80.6	80.6
Channel width (uniform resolution across max. bandwidth) [km/s]	14.7	5.4	5.7	2.9	3.6	1.9
Spectral zoom windows X narrowest bandwidth [MHz]	4 X 3.9	4 X 3.9	4 X 3.1	4 X 3.1	4 X 3.1	4 X 3.1
Finest zoom channel width [Hz]	226	226	210	210	210	210
Finest zoom channel width [km/s]	0.62	0.22	0.09	0.04	0.01	0.004

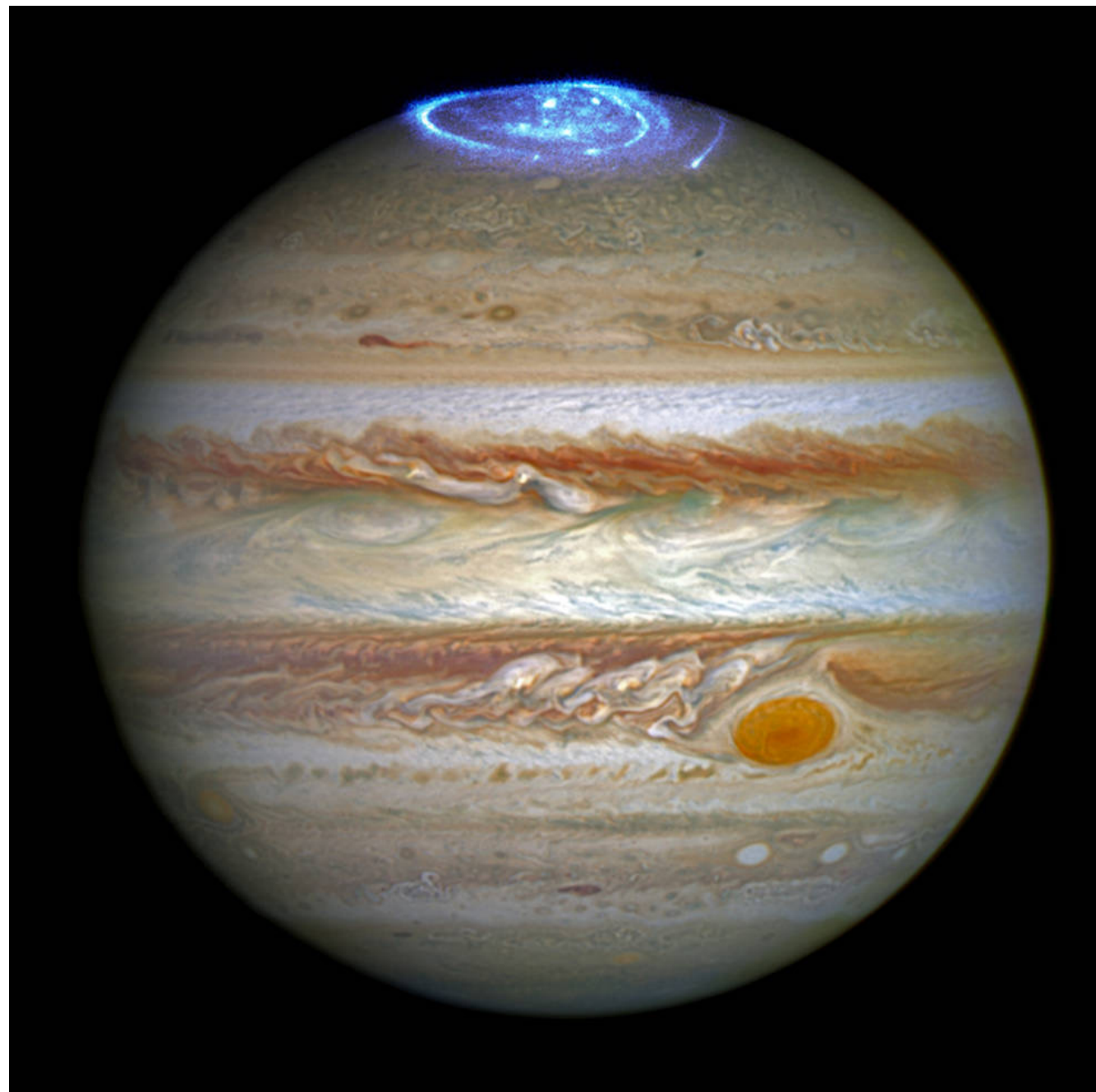
Anticipated Science Performance: <https://arxiv.org/abs/1912.12699>



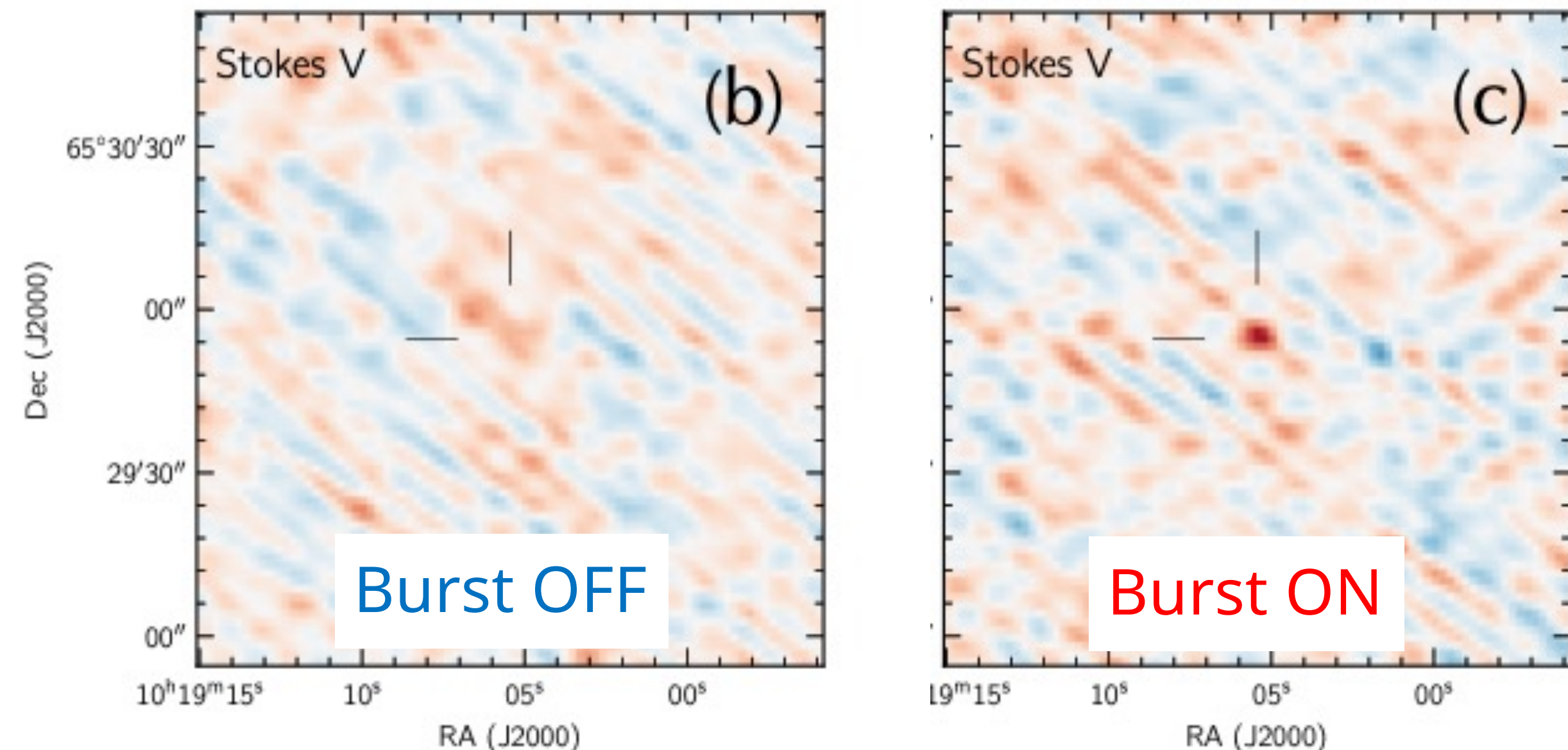


# Characterisation of exoplanets via direct detection

- Low frequency radio emissions from planetary aurora are very bright and **highly polarized**
- LOFAR detecting Brown Dwarfs – higher mass proxy (mass  $\sim 13\text{-}80 M_J$ ) for exoplanets ( $< 13 M_J$ )
- **SKA-Low will enable direct detection of exoplanets** (host star not polarized so not detected)
- Provides information on (i) internal structure, (ii) rotation rate, (iii) B field



Aurora on Jupiter (credit: NASA)



Circularly polarised images (Stokes V; 30s) of radio bursts from the Brown Dwarf WISEPA J101905.63+652954.2 observed with **LOFAR** at **144 MHz** (LoTSS) (Vedantham, Callingham, Zarka et al. submitted)

