Advancing Science with the SKA

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Overview

- Introductions
- What is the SKA?
- What kind of science is enabled by the SKA?
- Summary & conclusions

The Seven Sisters Dreaming, by Alma Nungarrayi Granites (courtesy Japingka Aboriginal Art)

Who am I?

- Professor at Department of Astronomy, Stockholm University.
- Research focus on Epoch of Reionization; developing and using simulation and interpretation tools.
- Member of LOFAR EoR since 2004.
- Involved in SKA since 2013.
- Member of the SKA Science & Engineering Advisory Committee since 2021.

What is the SKA?

- **1 Observatory, 2 Telescopes, 3 Sites**
- 2 telescopes:

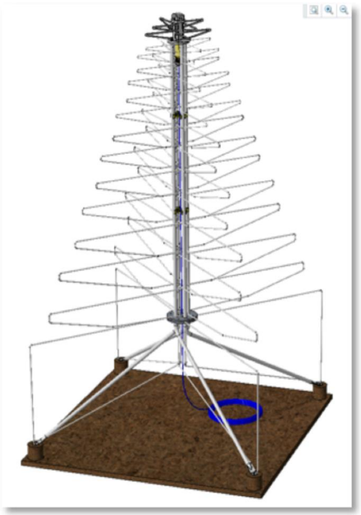

SKA-Low (50 – 350 MHz), Western Australia

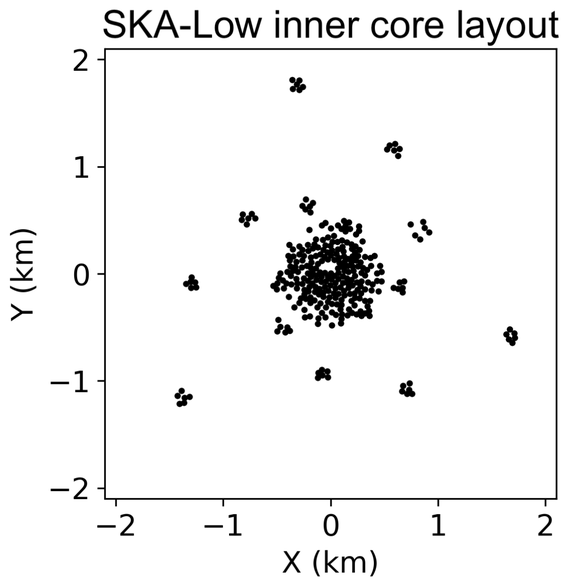

SKA-Mid (0.35 – 15.4 GHz), South Africa

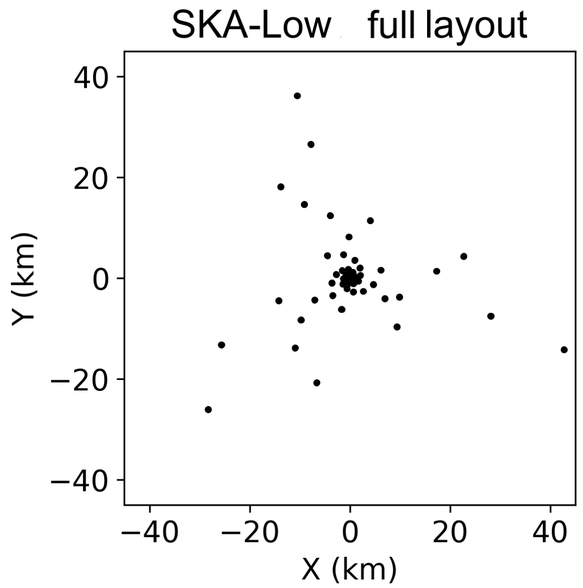
- 3 sites:
  - 2 telescope sites + Global Headquarters @ Jodrell Bank, UK

SKA-Low

- At Murchison Radio-Astronomy Observatory (Inyarrimanha Ilgari Bundara)
- Consists of stations made from 256 log-periodic antennae; initially 257, eventually 512.
- Dense core + three spiral arms

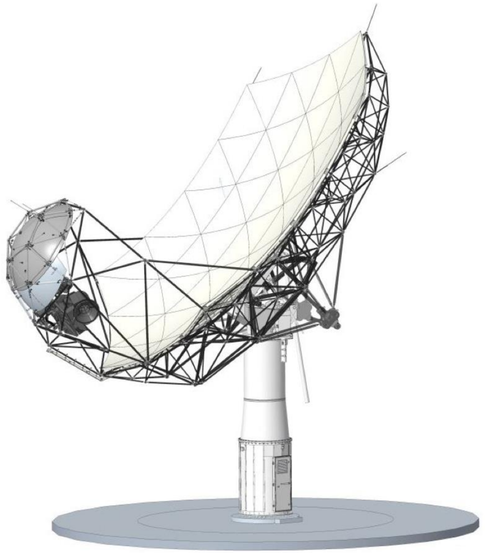


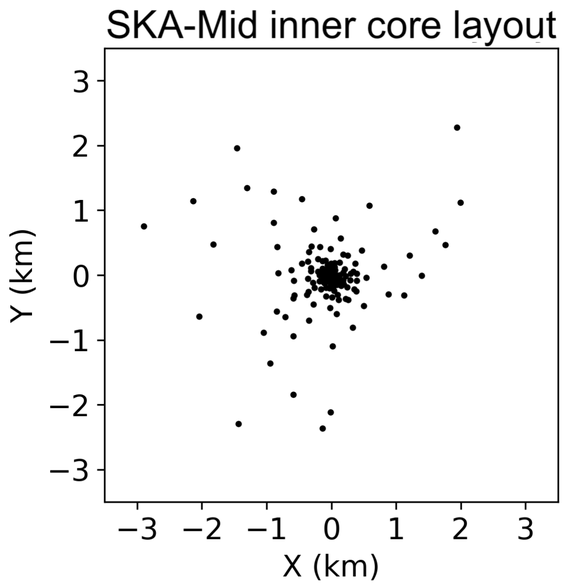


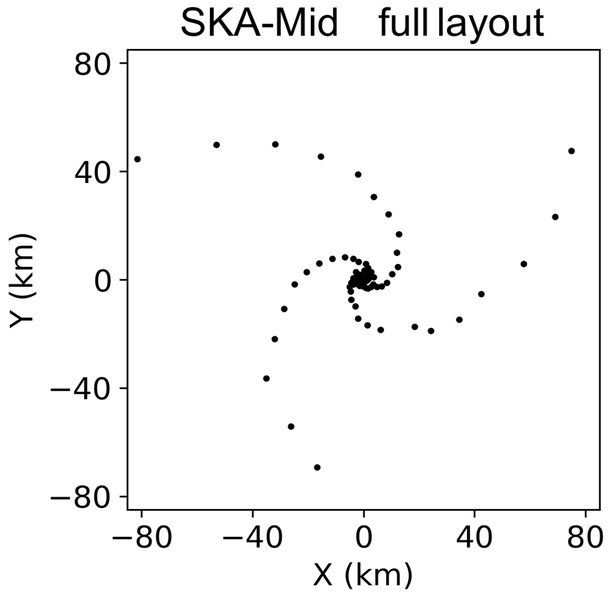


SKA-Mid

- At Karoo National Astronomy Reserve, Northern Cape, SA
- Consists of offset Gregorian dishes of 15m diameter, initially 144, eventually 197.
- Dense core + three spiral arms

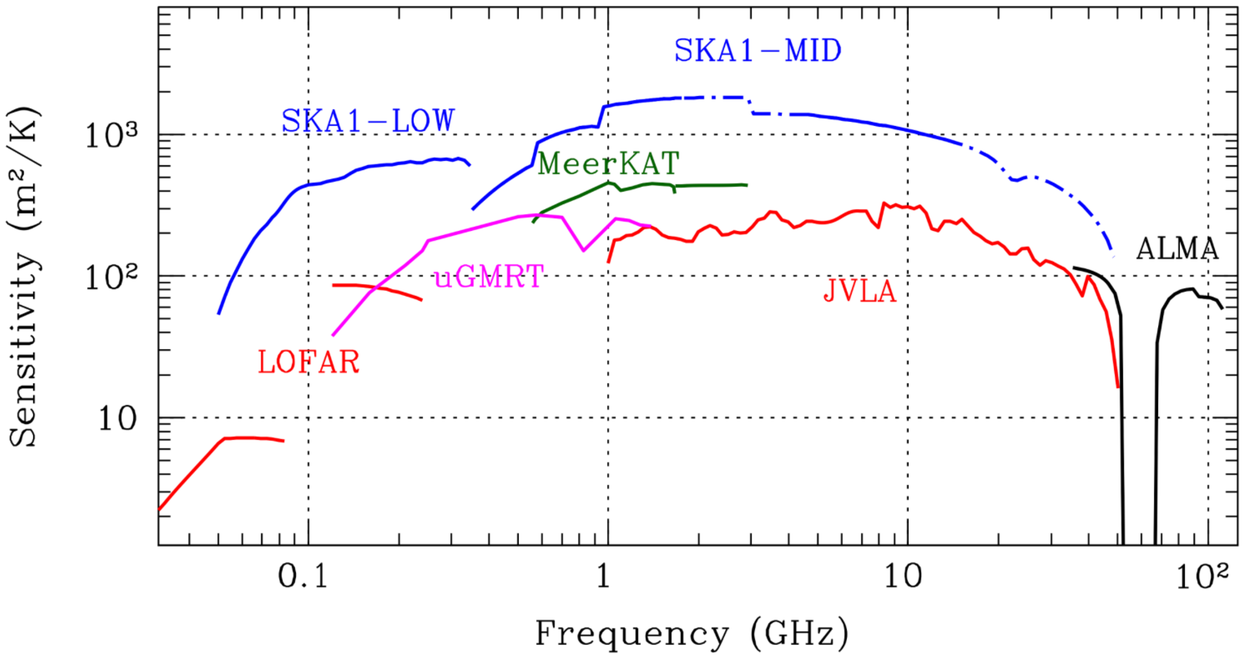






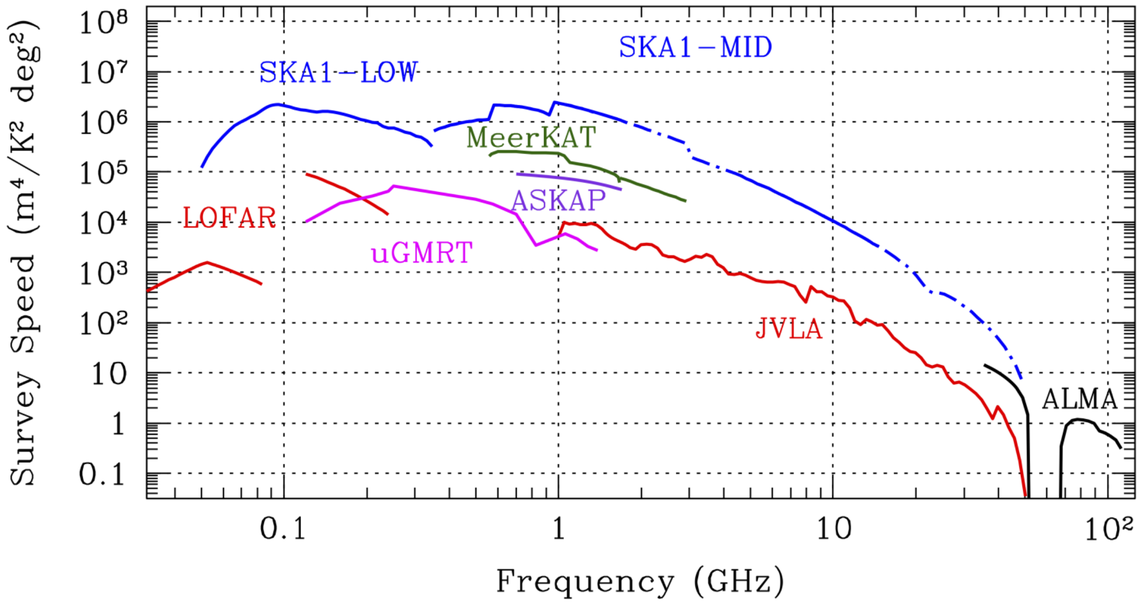
No longer artist’s impressions!

How do sensitivies compare?



Point source sensitivity

Survey speed



And: in the Southern Hemisphere!

SKA – Key Science Themes

Sun and Planets

Planet formation, SETI, Exoplanets, Complex Molecules, the Sun

The Cosmos

Cosmic Dawn and Reionization, Dark Matter, Dark energy, Large Scale Structure, Cosmic magnetism

Galaxies

Formation and evolution, Star-formation History, AGN, the role Magnetic Fields

Exploration of the Unknown

Formation and evolution of stars

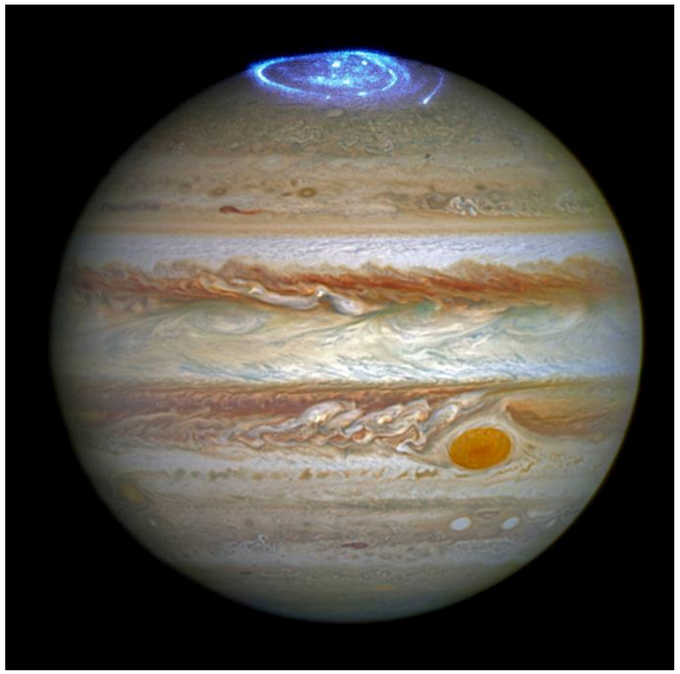
Star Birth & Death, Baryon Cycle, Interstellar Medium

The Extreme Universe

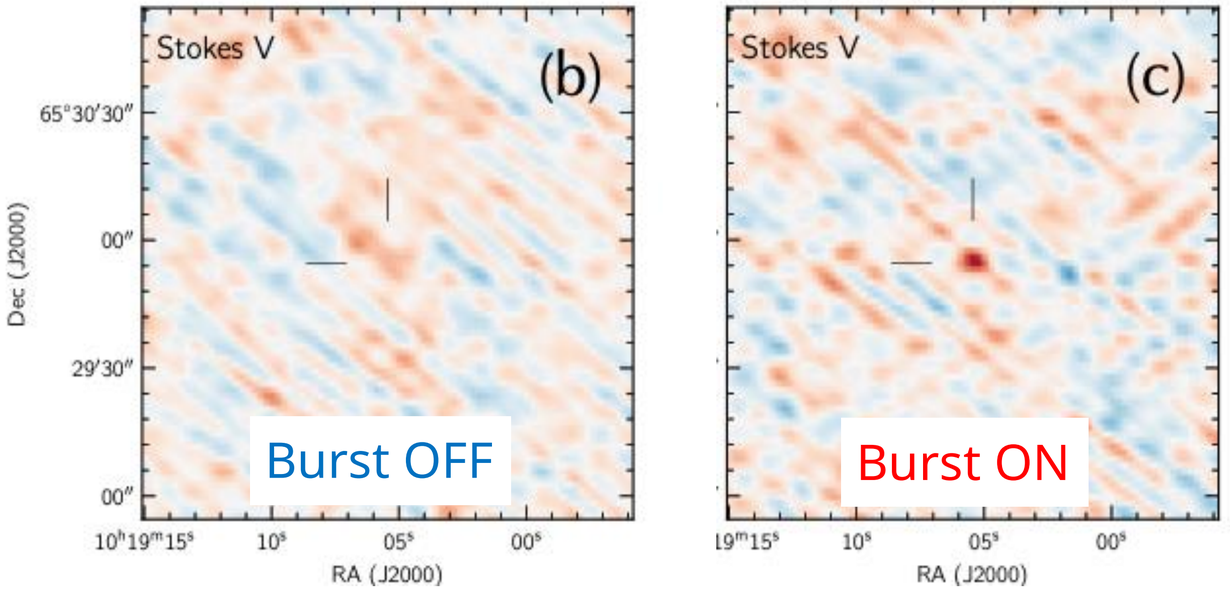
Testing General Relativity, Extreme Gravity, Gravitational Waves, Pulsars, Radio transients, Missing Baryons, Particle Physics

Sun, Planets: What are other planetary systems like?

- Low frequency (50-100 MHz) emission from planetary auroras are bright and highly polarized
- LOFAR detecting Brown Dwarfs – higher mass proxy (mass ~13-80 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+ 2020, 2022)

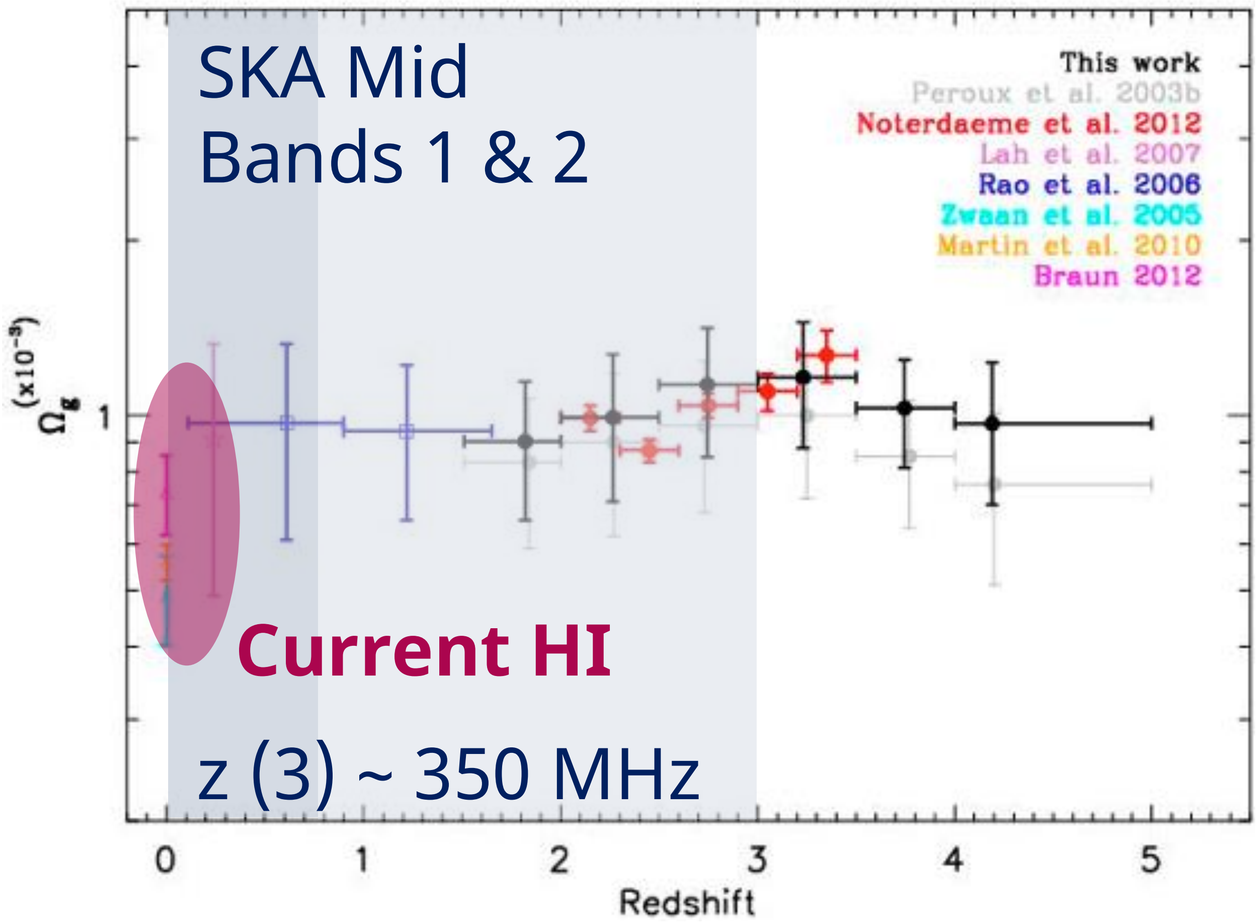
Galaxies: How do normal galaxies evolve? (Resolving nearby galaxies)

SKA will provide *sub-arcsecond* imaging with great point-source and low surface brightness sensitivity for good frequency coverage

- Resolves size scales down to a few pc in nearby galaxies with μJy sensitivity (“galactic-like” astronomy)
- Decompose source populations into:
  - ✓ compact HII regions
  - ✓ super star clusters
  - ✓ long-lived SNRs (detectable in all galaxies within a few 10s of Mpc)
- Separation of thermal and non-thermal components
  - ✓ SFRs on many size scales, dust free

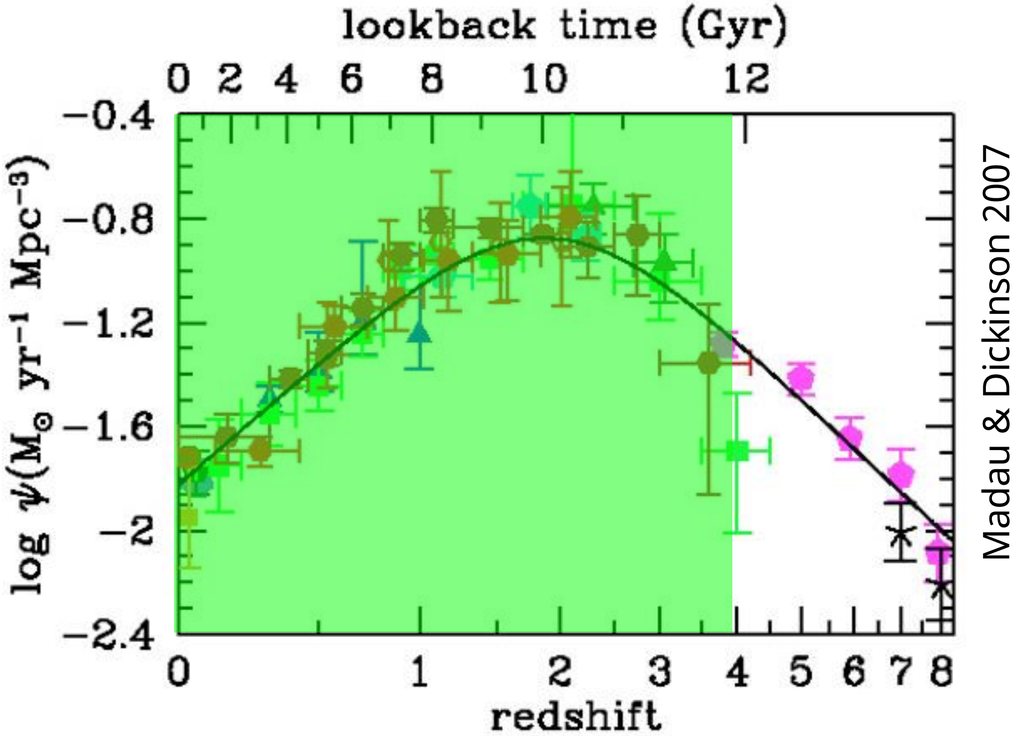
Central region of a nearby galaxy, as “observed” with SKA-Mid (MeerKAT Galactic Centre radio spectral index map – Heywood, Munoz-Mateos)

Galaxies: How do galaxies form and evolve? How does gas turn into stars?



HI/Continuum surveys deep & wide

Star Formation Rate Density

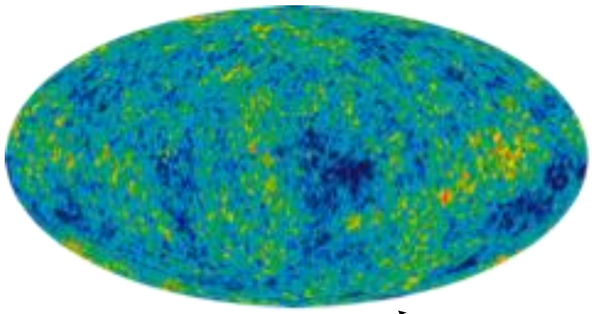


FUV and IR, many assumptions

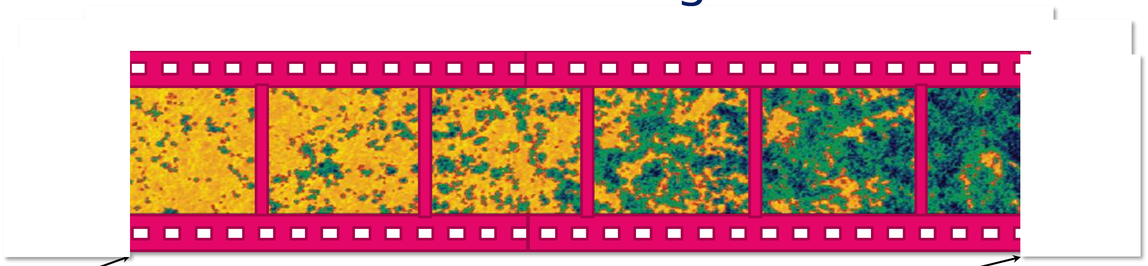
Multi-frequency continuum to separate non-thermal and thermal

The Cosmos: How did the first stars and galaxies form?

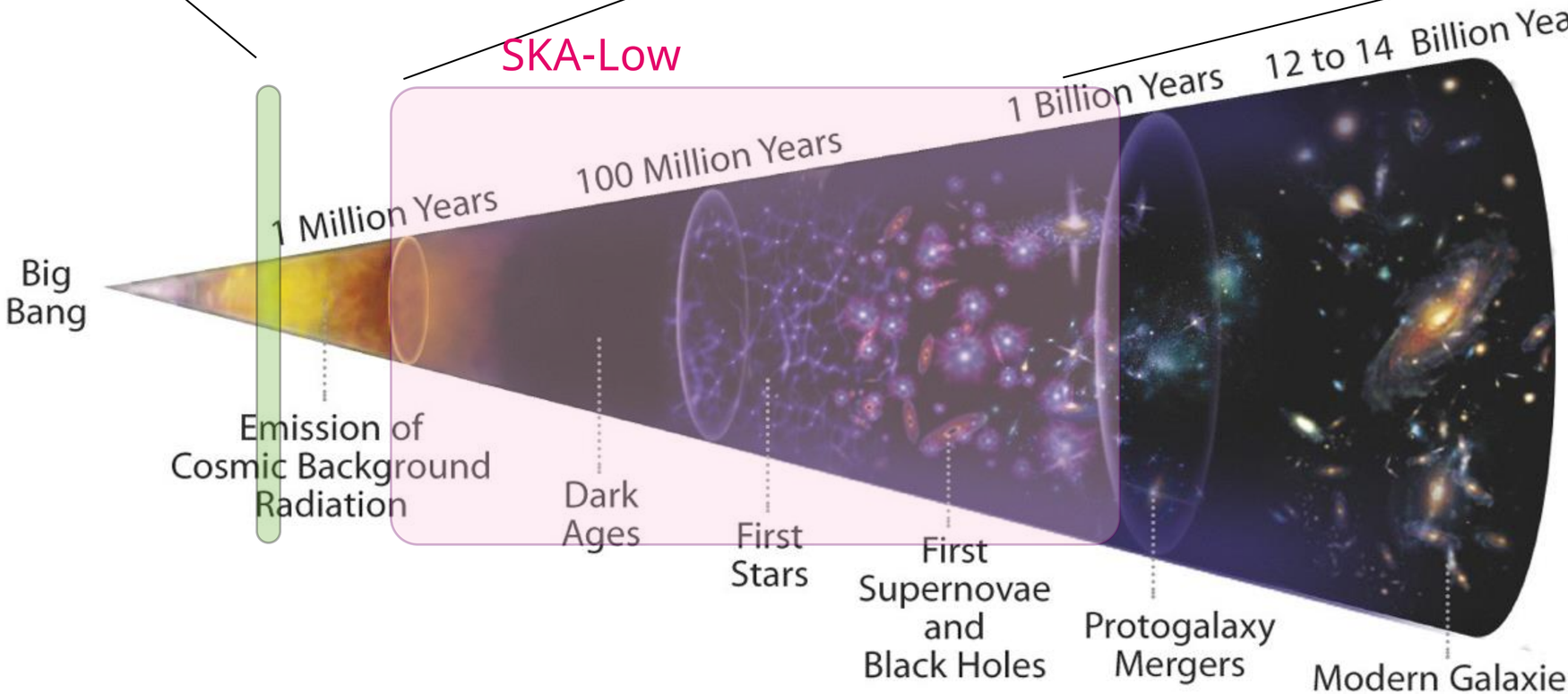
CMB snapshot at ~400,000 yrs



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

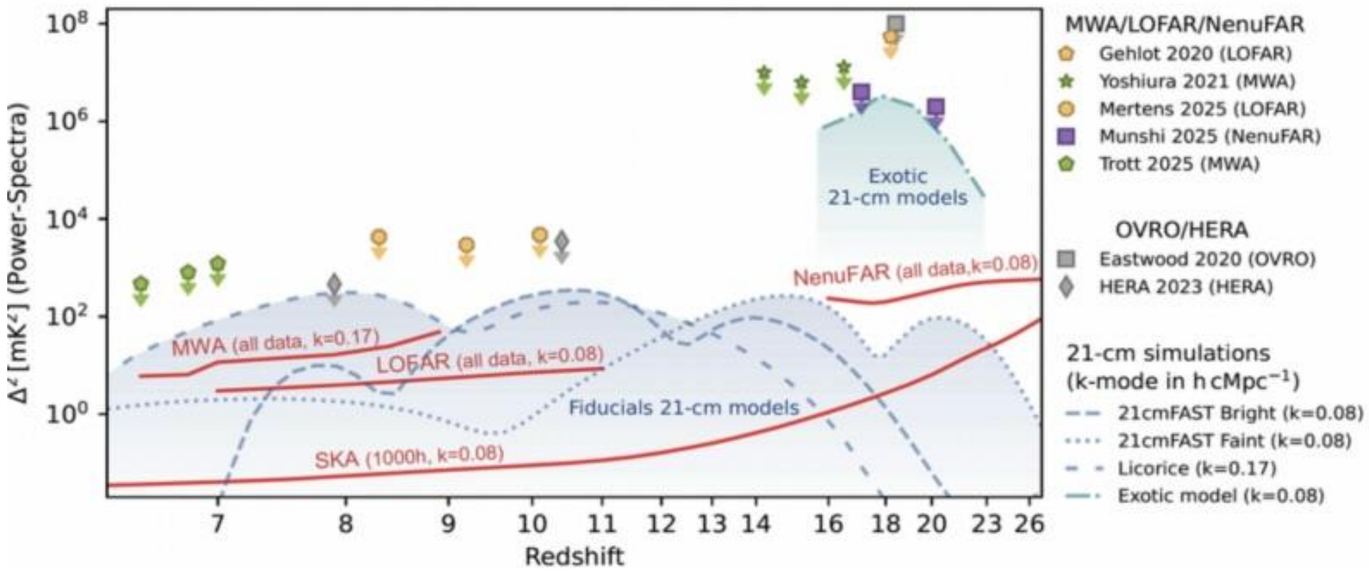


SKA-Low



The Cosmos: How did the first stars and galaxies form?

- Extremely challenging observations due to very bright foreground signals.
- Current focus on detecting the 21-cm power spectrum.
- Pathfinders LOFAR, MWA, HERA all yielding upper limits.
- SKA-Low has sensitivity to allow excellent calibration and power spectrum detection.



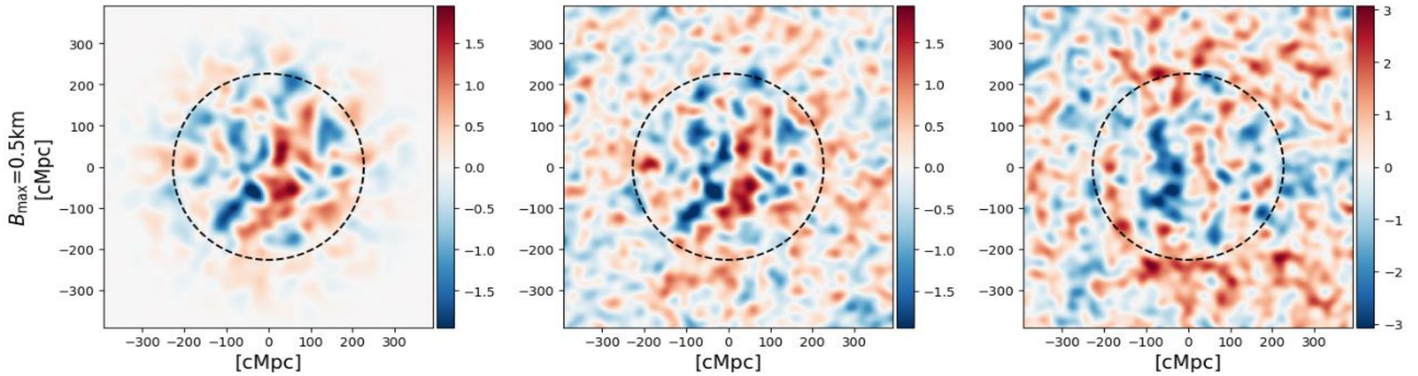
SKA-Low is even sensitive enough to produce images:

- Sizes and shapes of HII regions
- Connection to galaxy observations

Noise less 21-cm image (z=7; 60% ionized)

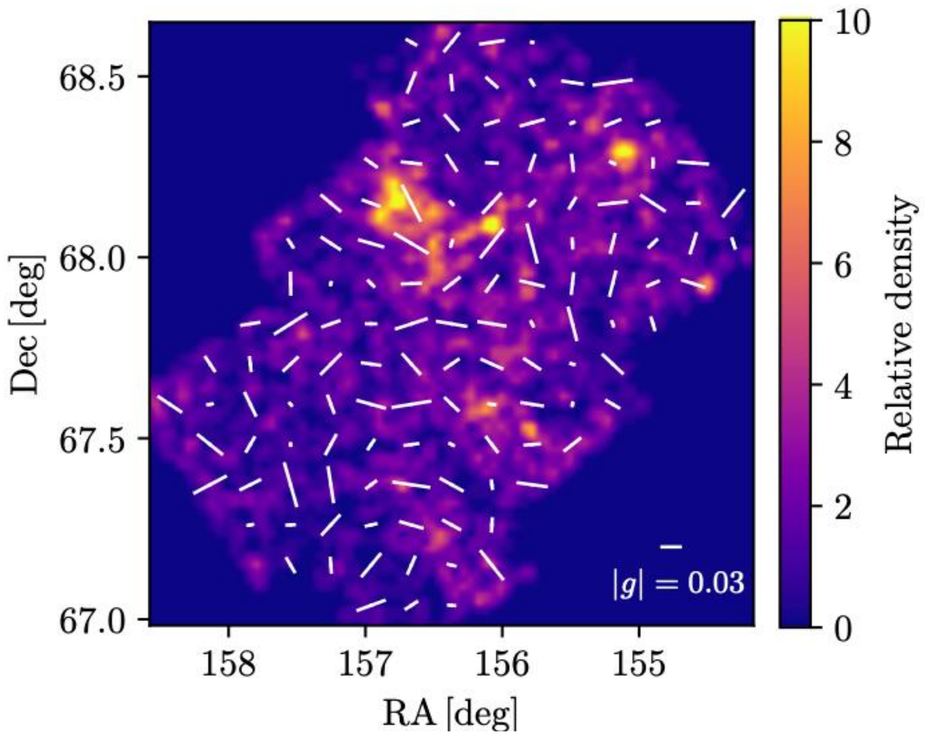
Same image with 1000h noise

Same image with 250h noise



Images by Sambit Giri

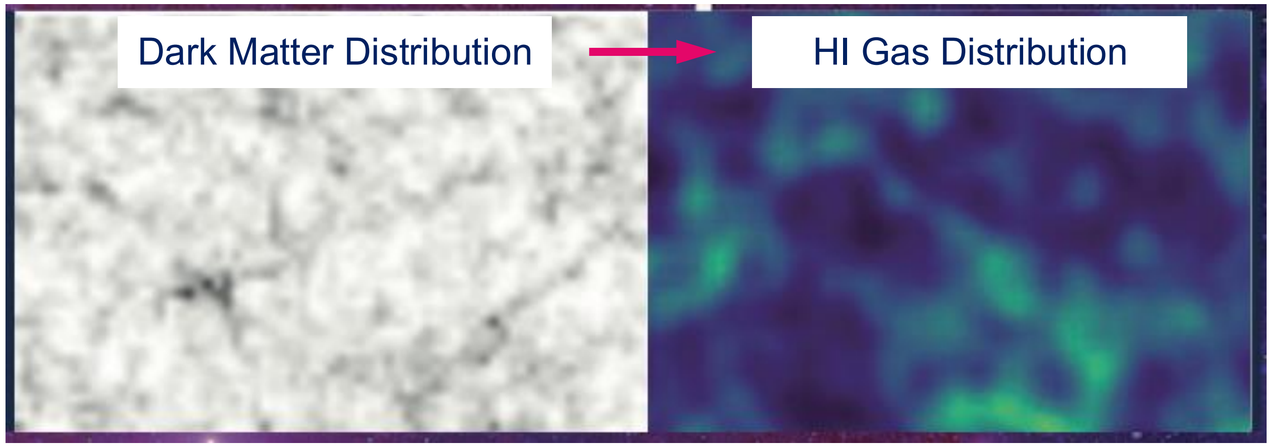
The Cosmos: What is the large-scale structure of the Universe?



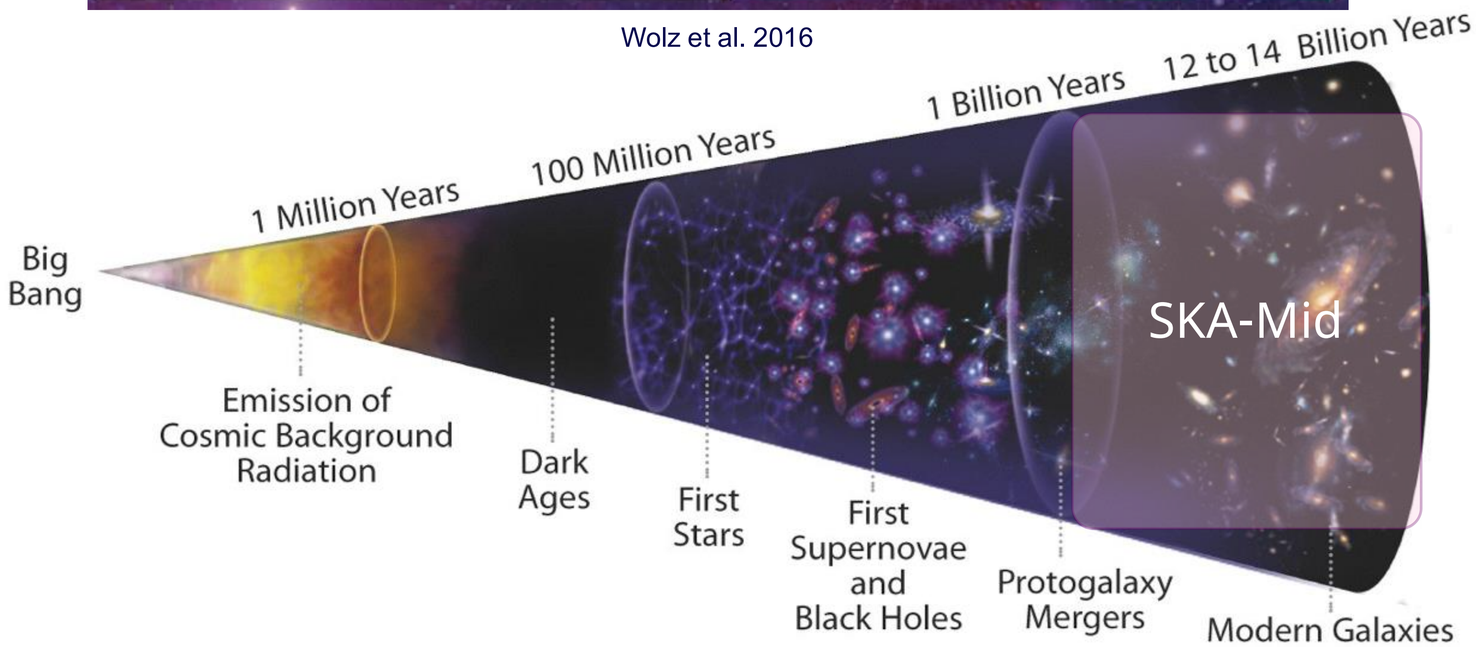
Big Bang

Over density of z~0.2 cluster galaxies (colour) and weak lensing signal (segments) from z~1 star forming galaxies in the SuperCLASS SKAO Pathfinder survey.

(Harrison et al. 2020; Battye et al. 2020)



Wolz et al. 2016



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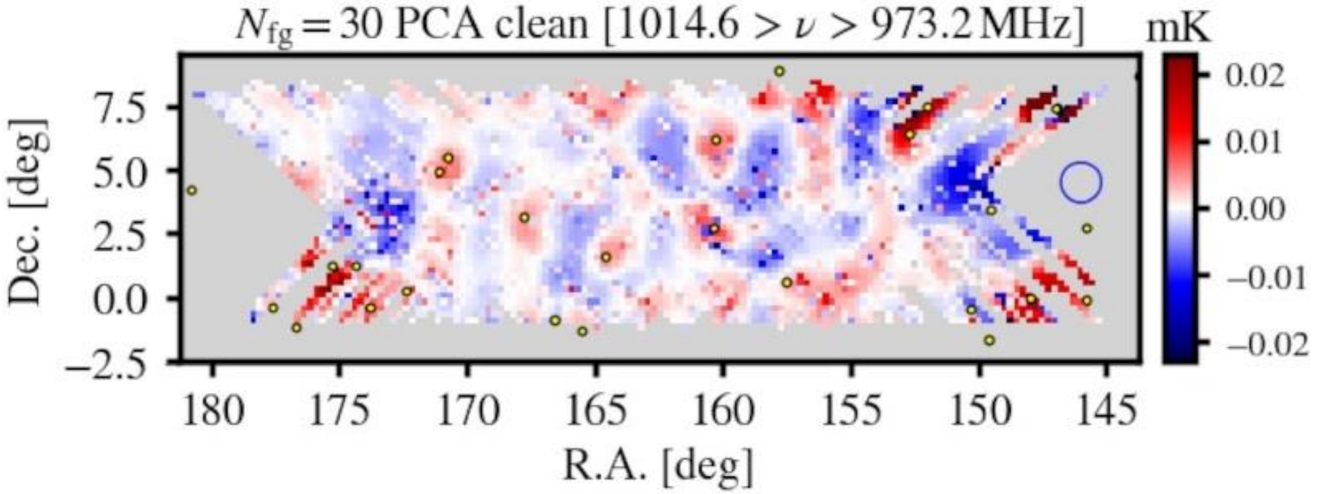
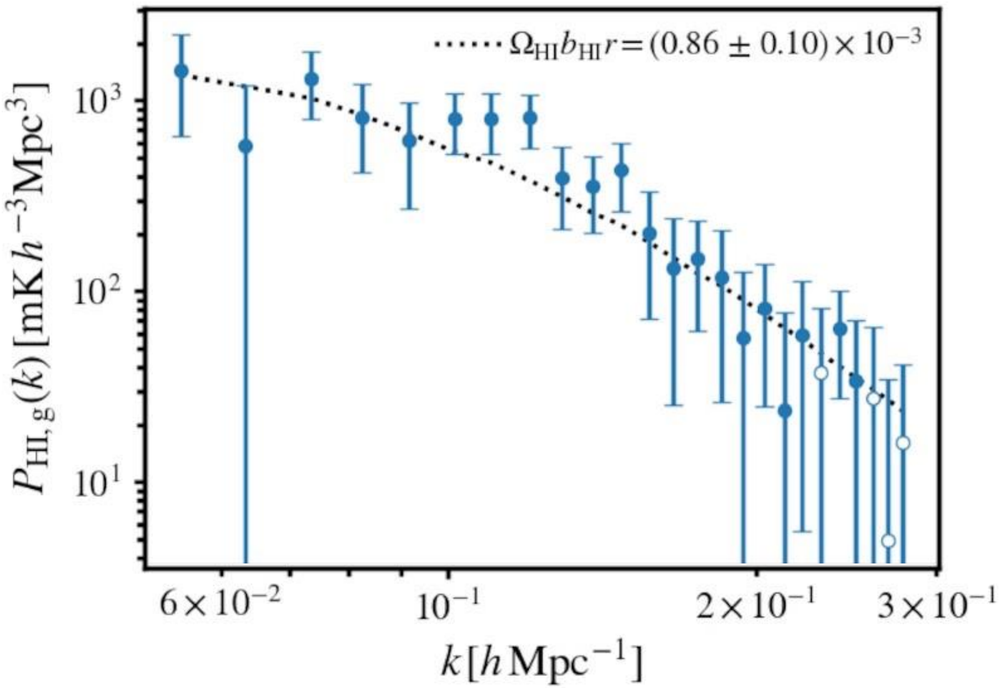


Intensity Map (IM) from MeerKAT's 10.5 h pilot observation (foreground cleaned)



Cross-correlation of the MeerKAT intensity map with the WiggleZ Dark Energy Survey (7.7σ detection)

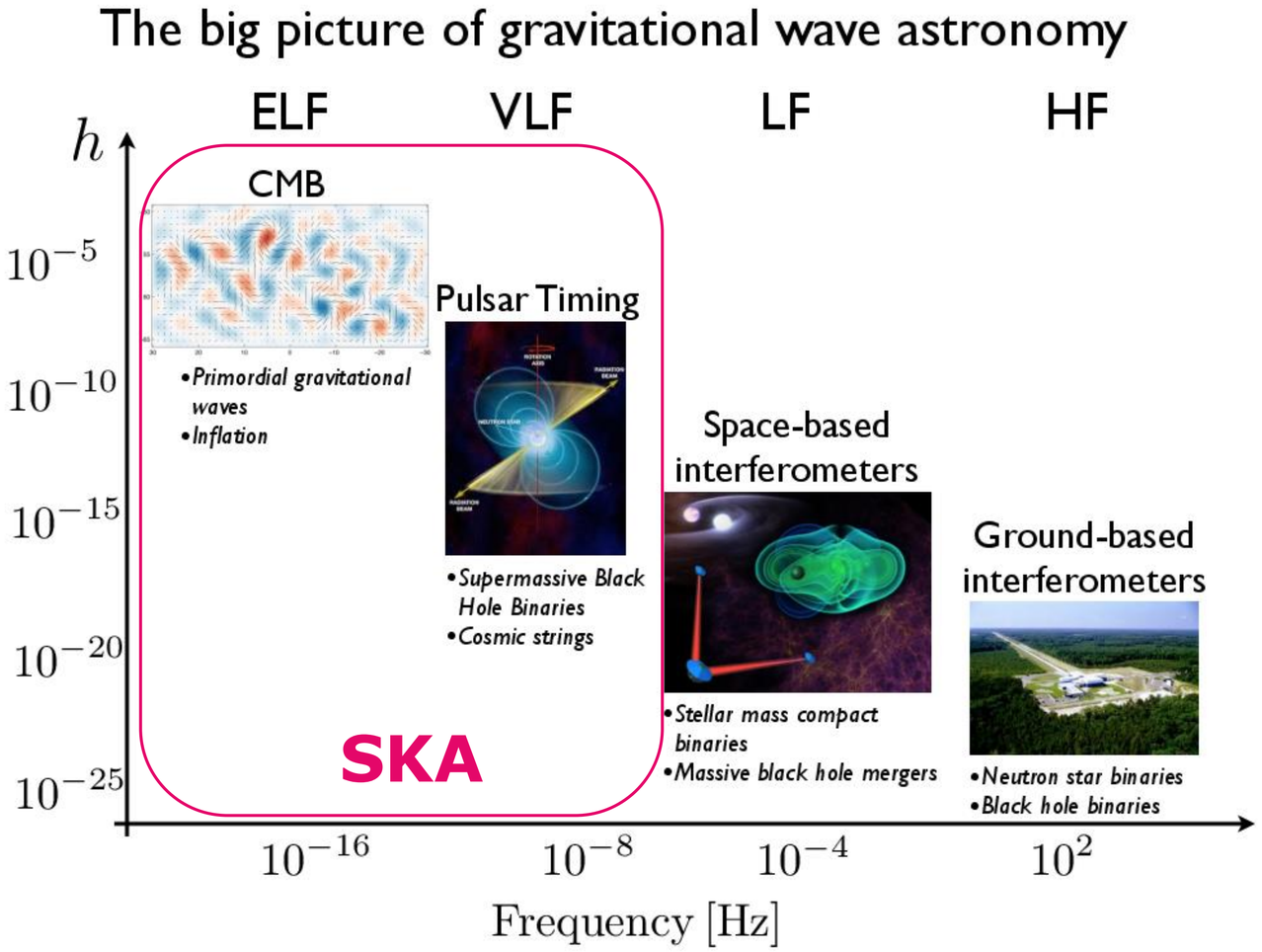
Cunnington et al. 2023

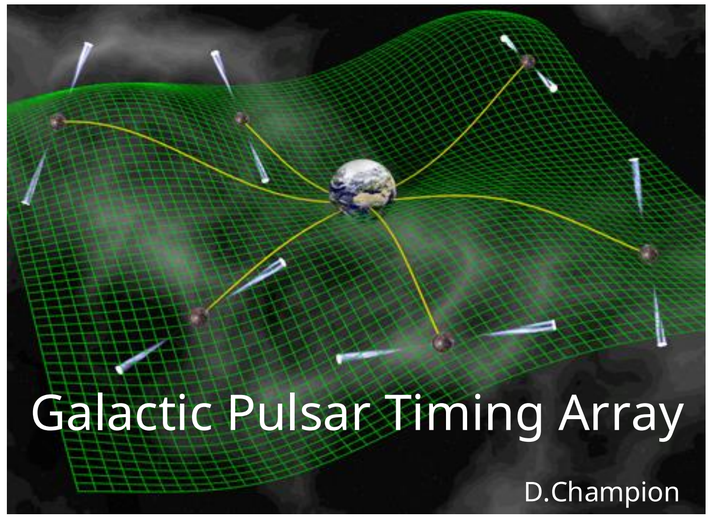
HI intensity mapping with MeerKAT

Positive correlation of intensity maps with overlapping galaxy survey at z~0.4

IM now shown to be effective!

Was Einstein right about gravity?
Gravitational Waves using Pulsars

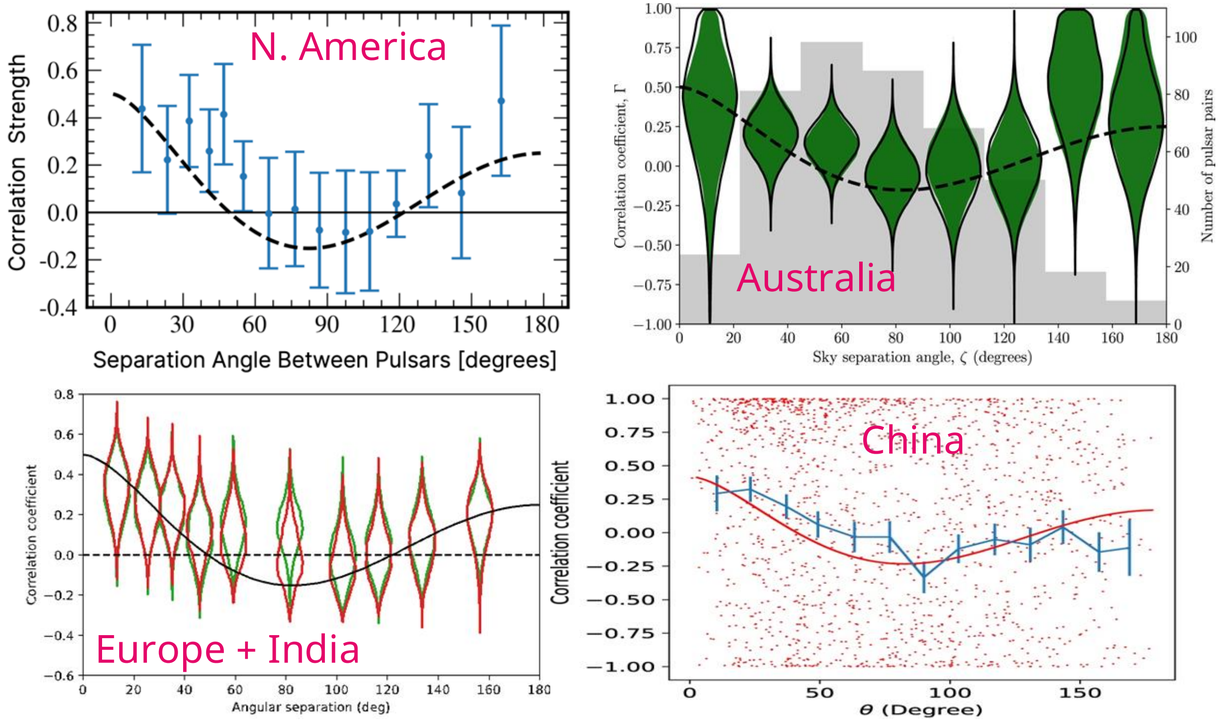


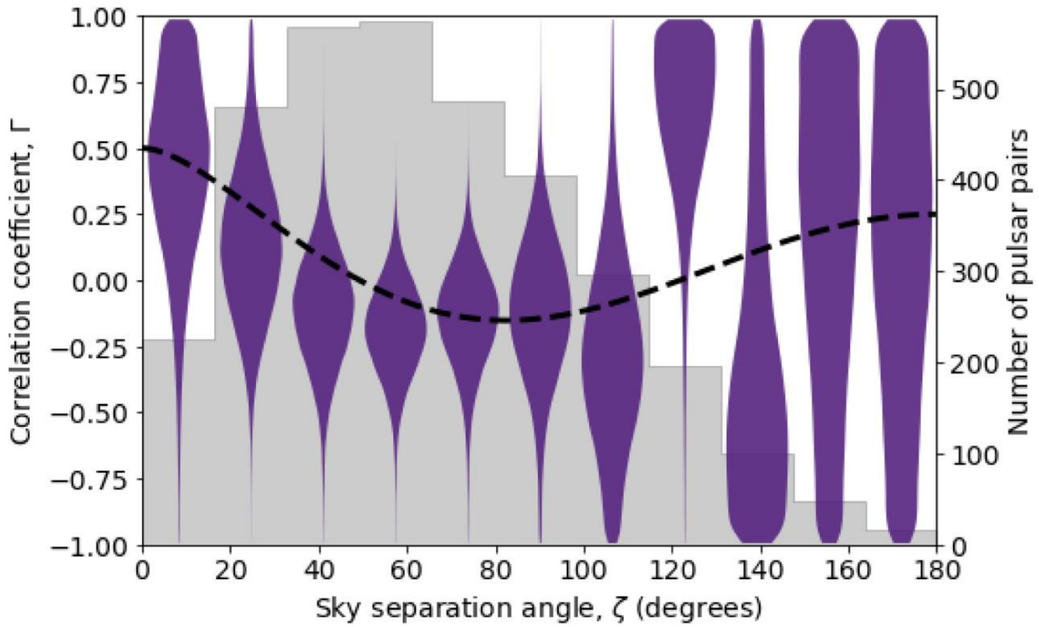


Was Einstein right about gravity?
Gravitational Waves using Pulsars

Revealing the Stochastic Background

PTAs: >10 years. MeerKAT: ~4 years



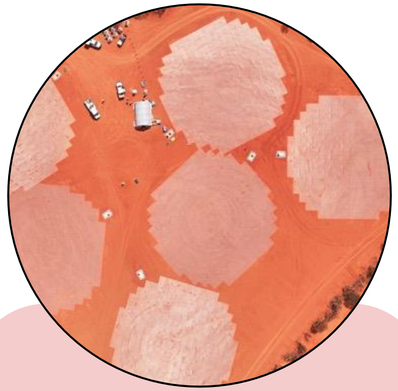


MeerKAT PTA – first 4.5 yrs of data (Miles et al. 2025)

SKAO timelines

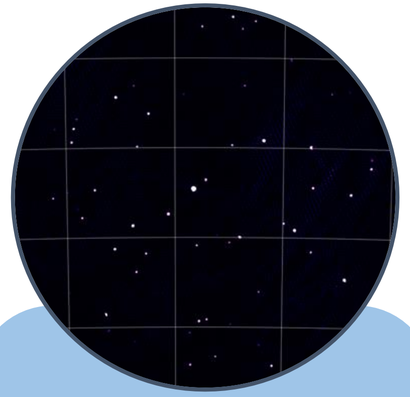
Community involvement starts

Credit: I. Heywood, SARAO



Construction

- Building antennas, dishes, roads etc!
- Followed by Assembly, Integration and Verification

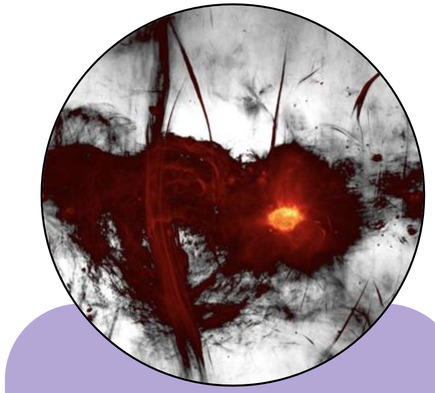


Commissioning

- SKAO activity
- Collaborative across system verification and science commissioning

Science Verification

- A dress rehearsal of the end-to-end process for every mode of operation
- The community will submit target ideas
- Once modes and pipelines are working, data will be publicly available for scrutiny
- Build trust and foster early science return



Cycle 0

- Shared-risk PI projects
- SRCNet resources ready for users
- Proprietary period applies

Now | Now | First half 2027 | First half 2029 | 2030

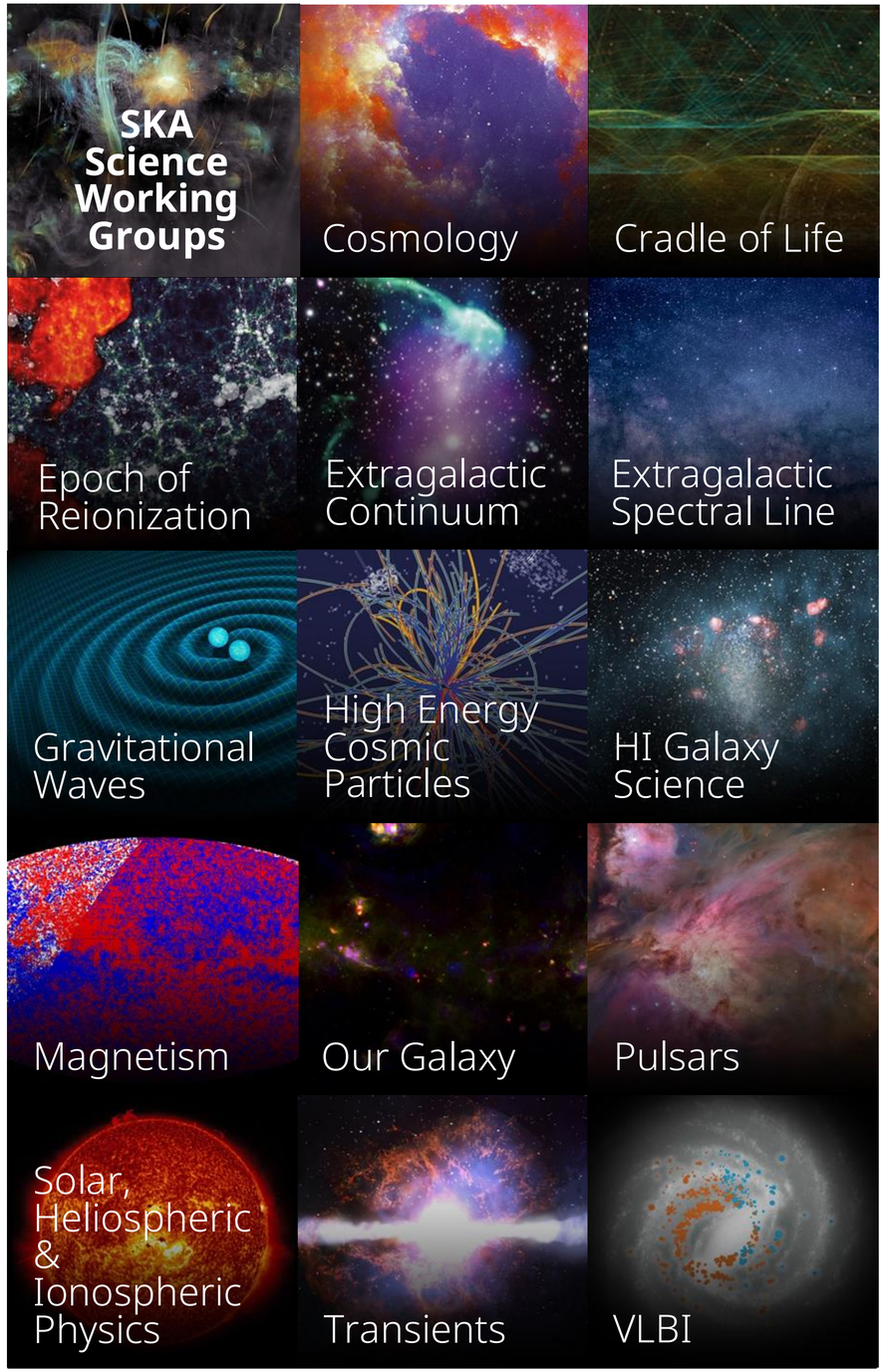
Now | Soon | First half 2029 | First half 2031 | 2032

Getting involved: SKA Science Working Groups

- provide a forum for discussion on possible SKA science projects, primarily the Key Science Projects (KSPs)
- are the best way to receive up-to-date information regarding the road to science and operations

Membership is open to any actively publishing researcher (see Terms of Reference), regardless of SKA-member status.

If you wish to join, fill in the online request form



Advancing Astrophysics with the SKA I & II

2015: first overview of SKA science cases

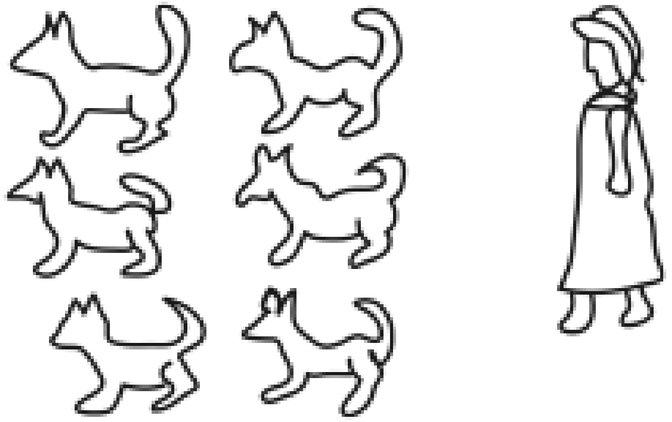
https://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=215

2026: thorough update of SKA science cases

https://www.skao.int/en/science-users/557/advancing-astrophysics-ii

Summary & Conclusion

- SKA delivers:
  - Sensitivity, resolution, frequency coverage, Low + Mid synergy
- SKA enables transformative science:
  - Exoplanets, galaxy evolution, gravity tests, transient Universe, Cosmic Dawn
- SKA builds on:
  - Global collaboration, transformative data science



The Pleiades as a woman with a pack of dogs, participating in the Great Hunt. From Sami mythology.

Questions?

SKAO

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

www.skao.int