

The SKA project

the promises of next-generation radio surveys

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Outline

I. The SKA Observatory

- Sites & Telescopes
- Performance
- Operational Model
- Timelines

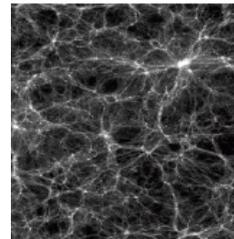


Dark matter

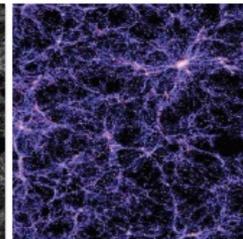
Visible matter

Neutral atomic hydrogen

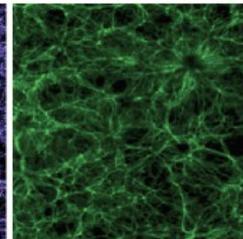
Credit: SKAO



DM haloes, merger trees



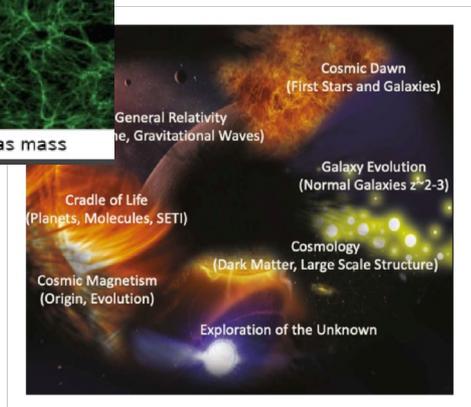
SFR, cold gas mass



HI from cold gas mass

II. SKA Science Drivers

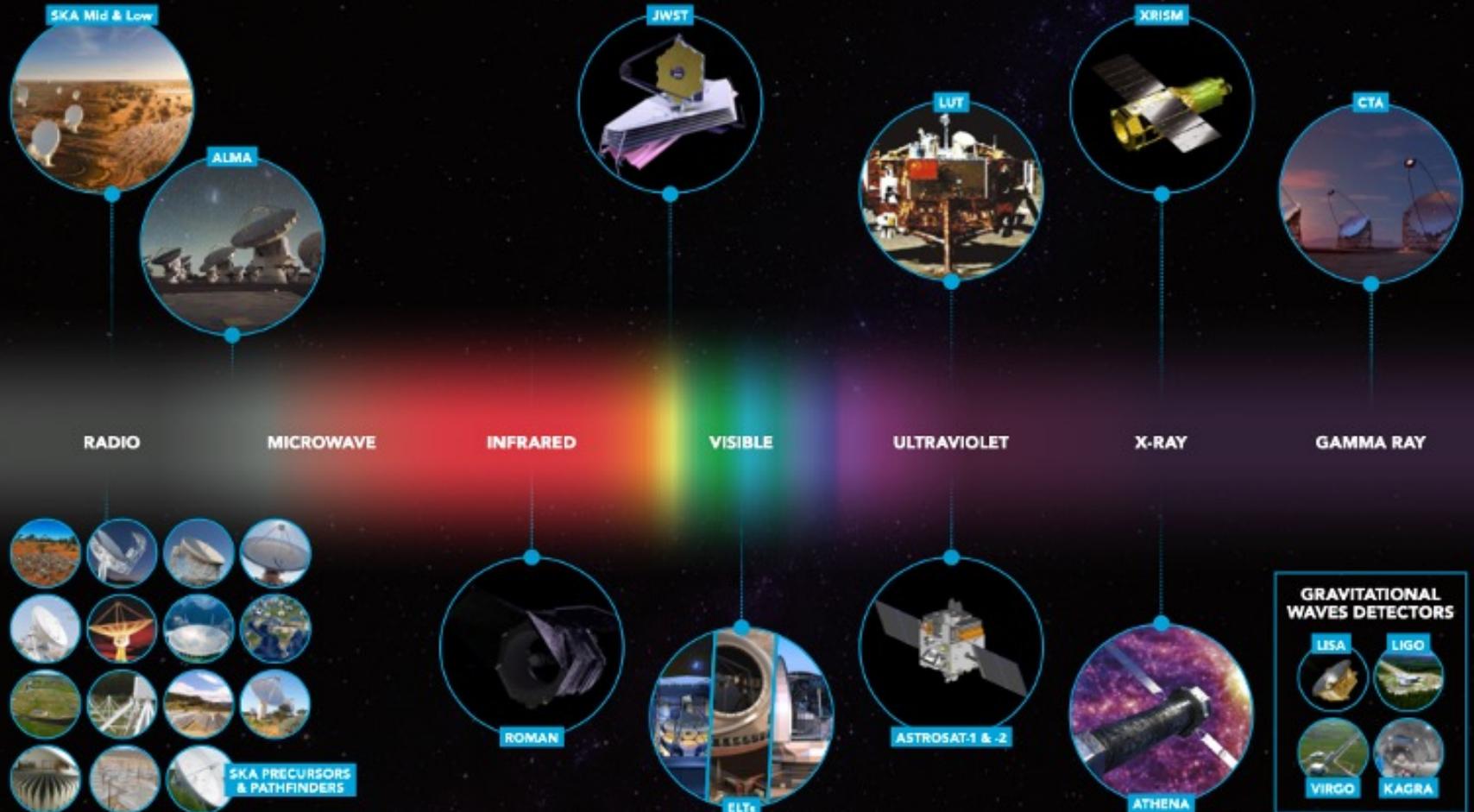
- Focus on cosmology
- Preliminary results from precursors



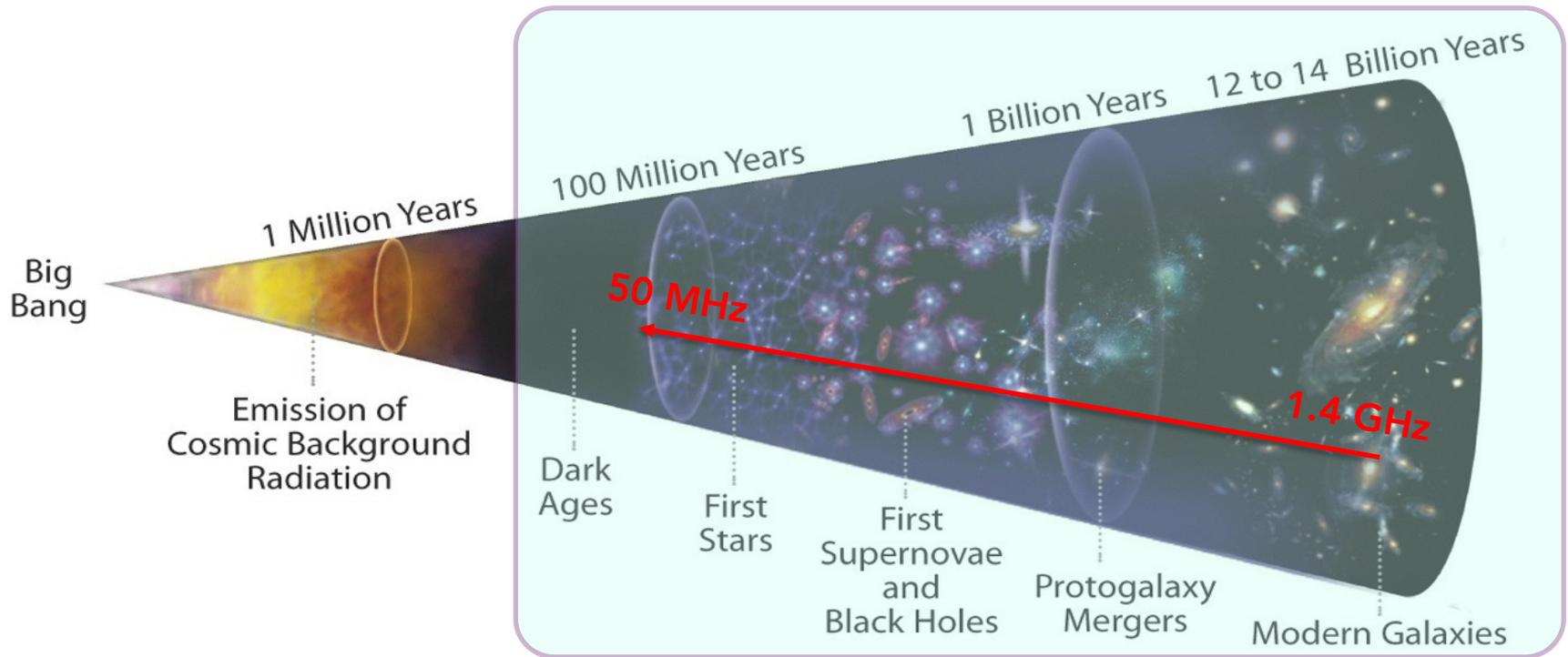
21st century astronomy

Credit: SKAO

As the world's largest radio-frequency interferometer, SKA will establish itself as the radio astronomy component of a suite of major facilities spanning the electromagnetic spectrum, on the ground and in space.



I - The SKA Concept



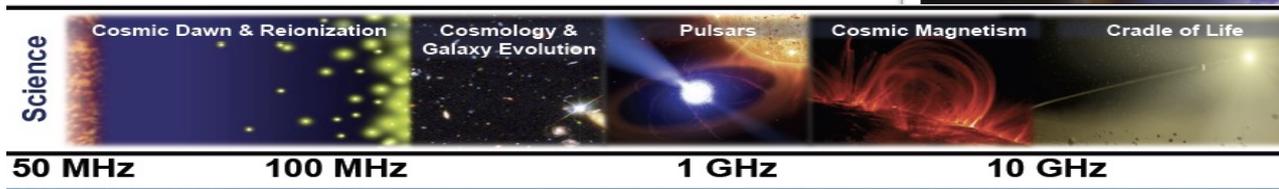
Original SKA Concept

Tracing the history of the Universe and of its constituents through Hydrogen
Mapping Hydrogen through cosmic time and on a wide range of scales
Super-sensitivity over wide range of frequencies and spatial resolutions

I – The SKA Science Framework

SKA Science Drivers

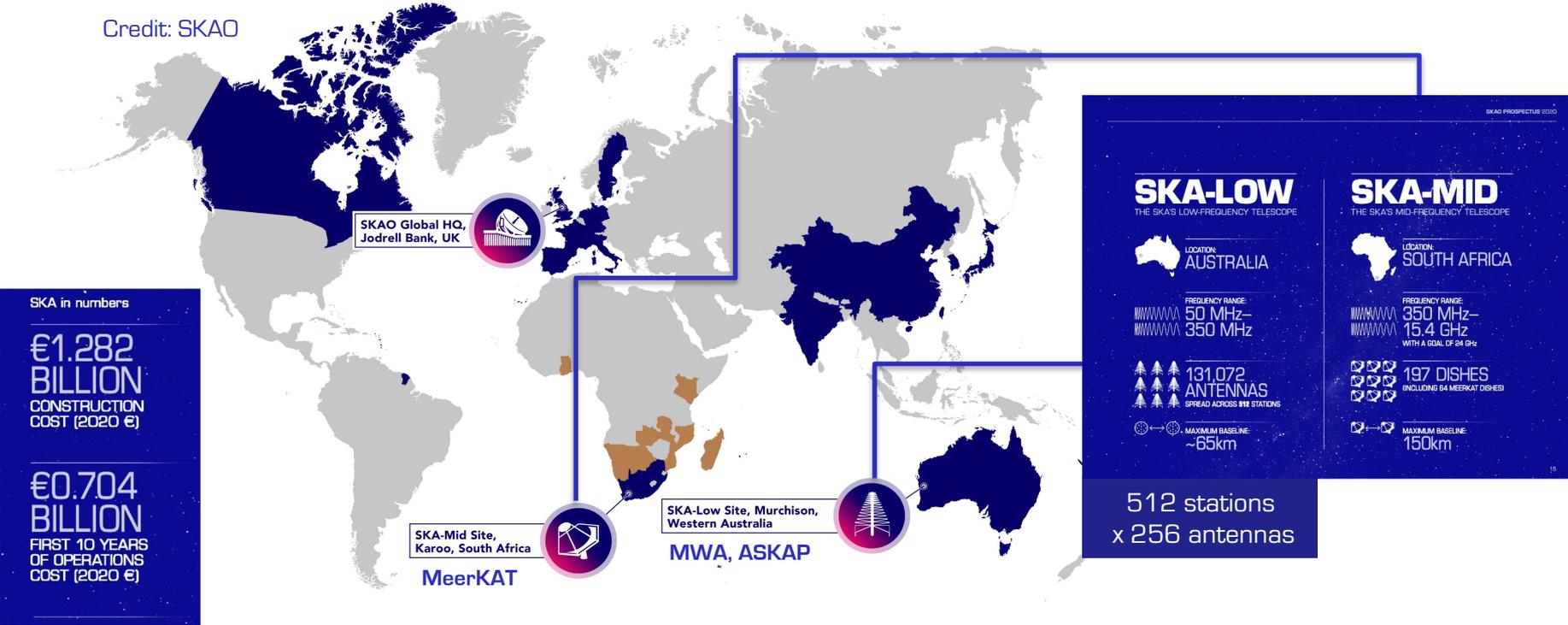
- **The Cradle of Life & Astrobiology**
 - *How do planets form? Are we alone?*
- **Strong-field Tests of Gravity with Pulsars and Black Holes**
 - *Was Einstein right with General Relativity?*
- **The Origin and Evolution of Cosmic Magnetism**
 - *What is the role of magnetism in galaxy evolution and the structure of the cosmic web?*
- **Galaxy Evolution probed by Neutral Hydrogen**
 - *How do normal galaxies form and grow?*
- **The Transient Radio Sky**
 - *What are Fast Radio Bursts? What haven't we discovered?*
- **Galaxy Evolution probed in the Radio Continuum**
 - *What is the star-formation history of normal galaxies?*
- **Cosmology & Dark Energy**
 - *What is dark matter? What is the large-scale structure of the Universe?*
- **Cosmic Dawn and the Epoch of Reionization**
 - *How and when did the first stars and galaxies form?*



Credit: SKAO

Broad science applicability through a combination of radio-continuum, polarization, HI and time domain surveys

I - The SKA Observatory in a nutshell



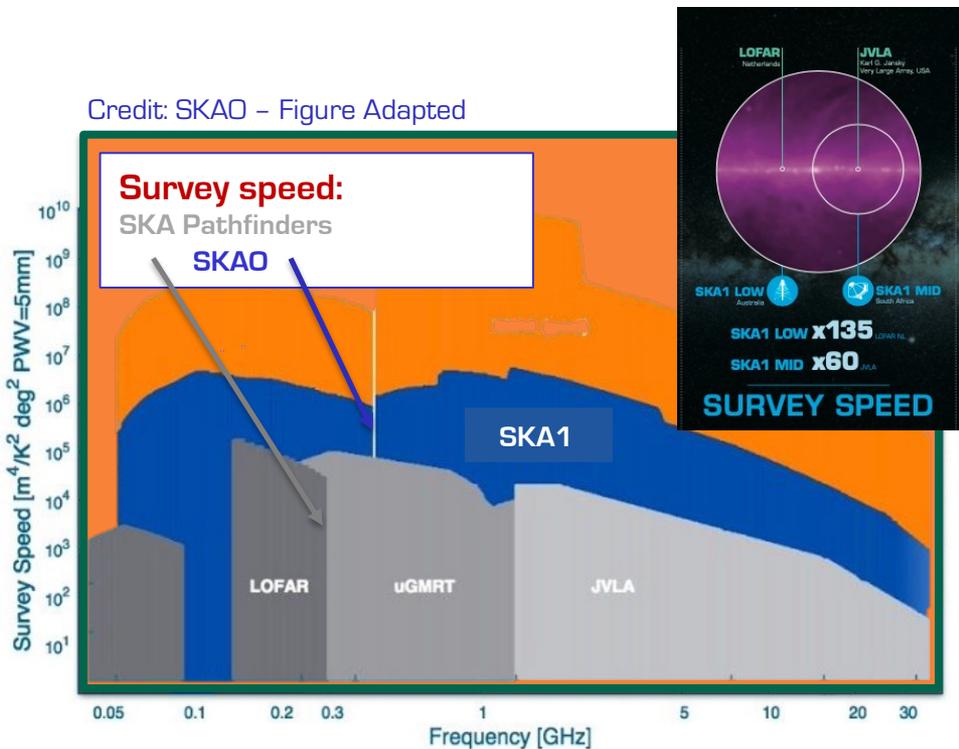
SKAO Partnership - includes SKAO Member States* and SKAO Observers (as of June 2022)

African Partner Countries



Full members (Updated June 2023): Aus, China, ITA, NL, Portugal, RSA, Spain, Switzerland, UK
Accession stage: Canada, France, Germany
Negotiations: India, Sweden - Early stages: Japan, South Korea

I – SKAO: A Multi-frequency Survey Infrastructure



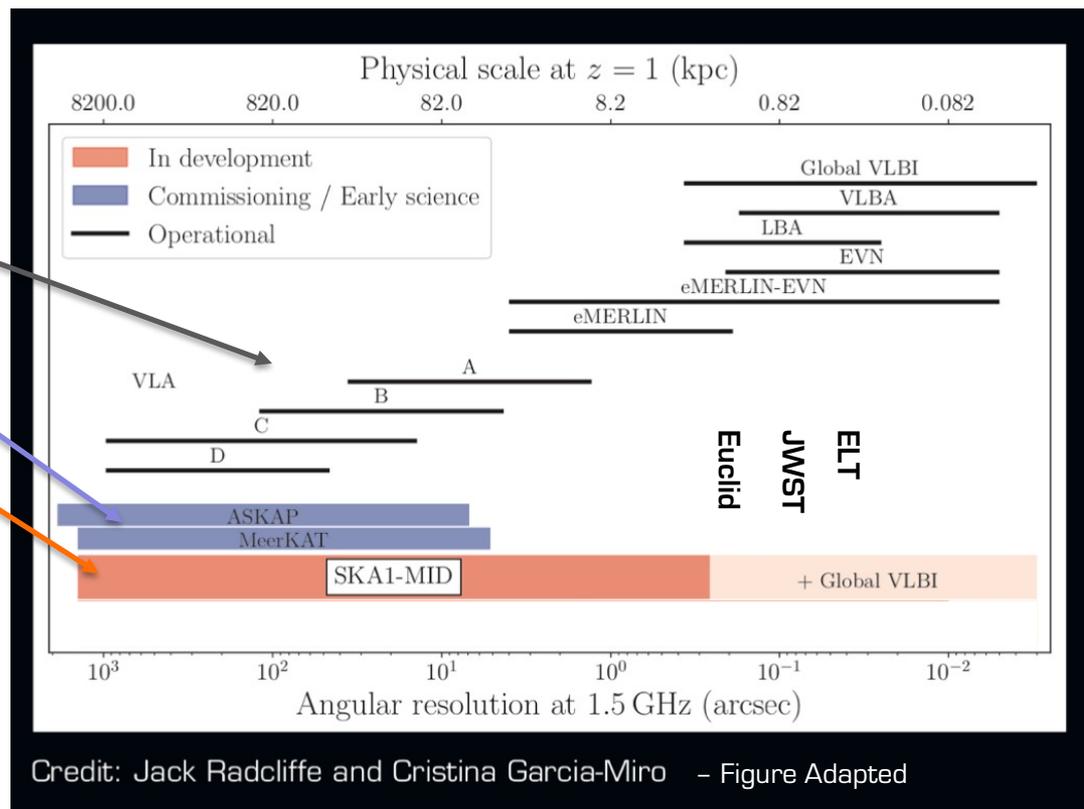
Telescope	Band	Frequency Range (MHz)
SKA1-Low	N/A	50 - 350
SKA1-Mid	1	350 - 1050
	2	950 - 1760
	3	1650 - 3050
	4	2800 - 5180
	5a	4600 - 8500
	5b	8300 - 15300
	6	~15000 – ~24000 (tbd)

50 MHz ← Frequency range → 15(24) GHz

I – SKAO: A Multi-resolution Survey Infrastructure

A multi-scale view of the radio Universe

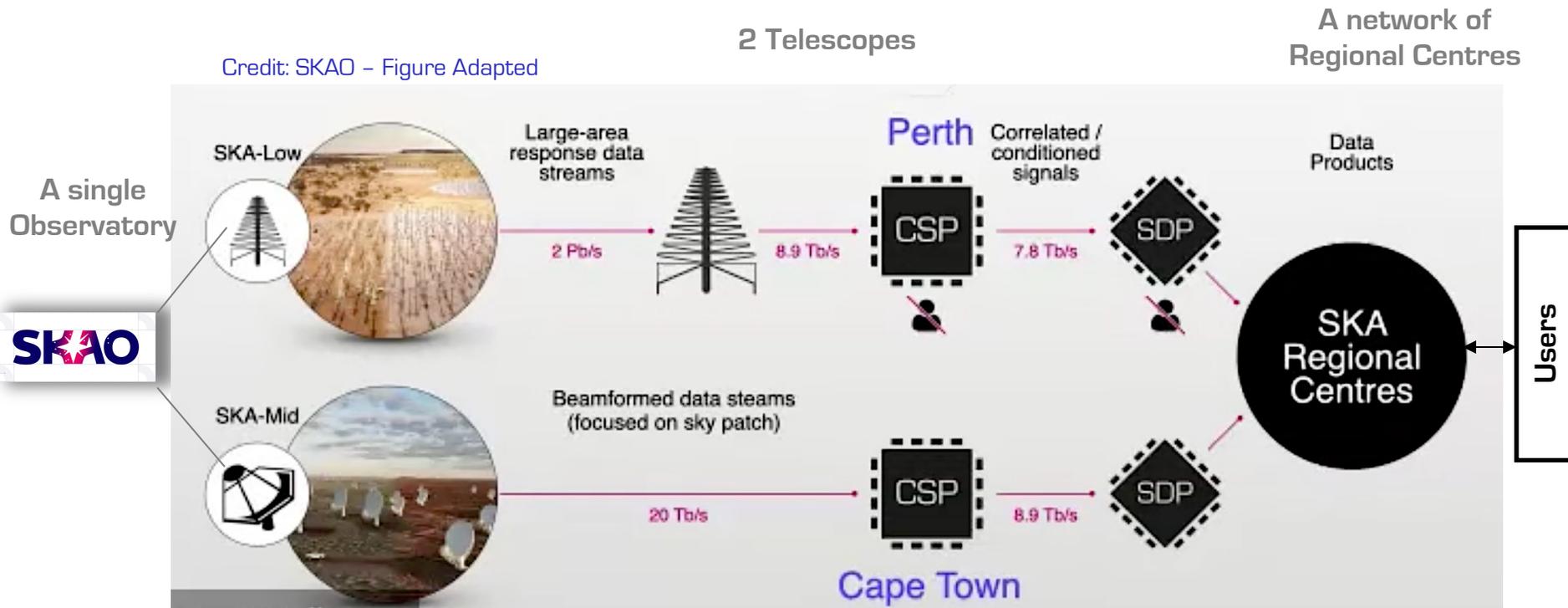
Angular resolution:
SKA Pathfinders
SKA precursors
SKA-MID



1000 arcsec ← Angular resolution → 0.01 arcsec

I - SKAO: Operational Model

Credit: SKAO – Figure Adapted



Volume

* Terabytes to Exabytes of data to process

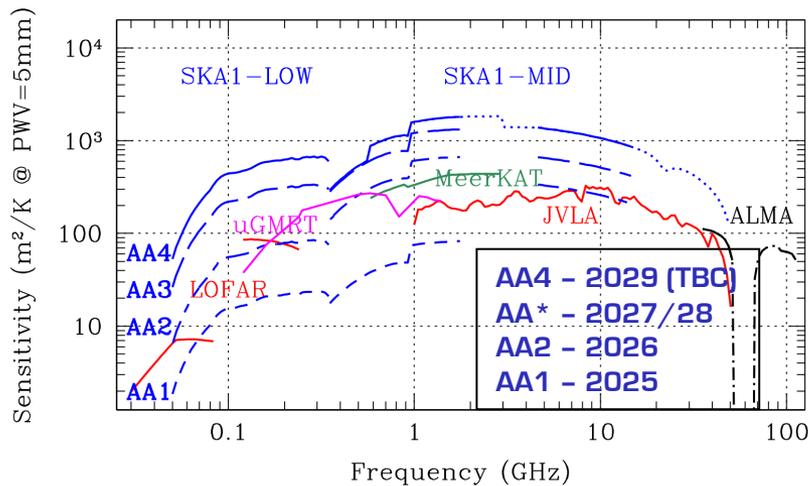
Velocity

* Streaming data requiring near real-time processing and responses

Only SKA Regional Centres will provide data access, data analysis, data archive, user support interfaces with the user community

I - SKAO: Construction Timeline

The ramp-up to full sensitivity



Target: baseline design
(see SKA Construction Proposal, 2021)

Credit: SKAO

Construction strategy: Staged delivery

- INFRA + Staged antenna deployment
- 5 Array Assembly (AA) phases
- AA0.5: demonstration of architecture & supply chain
- AA1, AA2
- AA* [formerly AA3] most sensitive array in the world
- AA4: full array

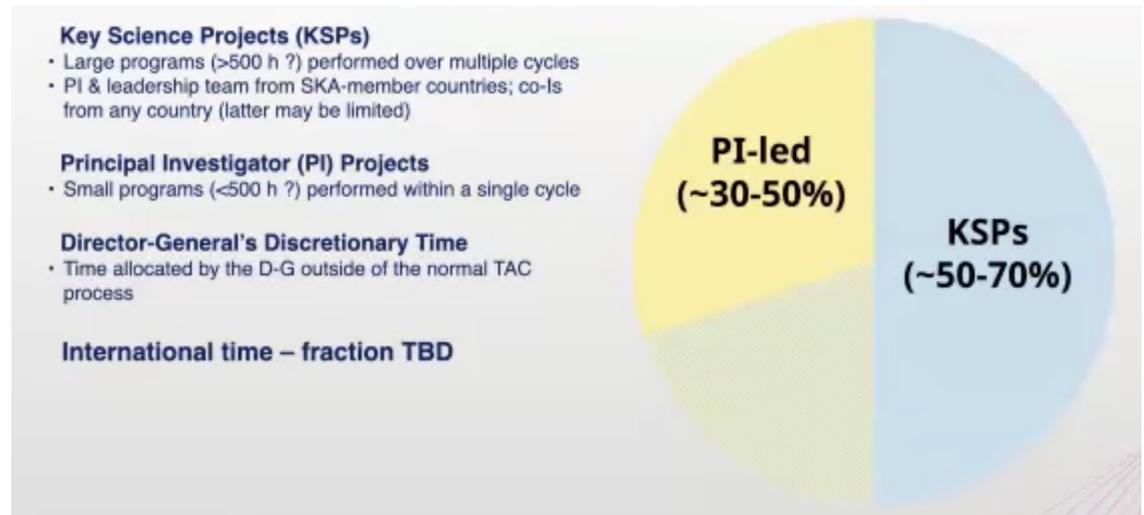
Milestone Event (earliest)		SKA-Mid (date)	SKA-Low (date)
AA0.5	4 dishes 6 stations	2024 Dec	2024 Aug
AA1	8 dishes 18 stations	2025 Nov	2025 Oct
AA2	64 dishes 64 stations	2026 Oct	2026 Sept
AA*	144 dishes 307 stations	2027 Aug	2028 Jan
Operations Readiness Review		2027 Nov	2028 Apr
End of Staged Delivery Programme		2028 Jul	2028 Jul
AA4	197 dishes 512 stations	TBD	TBD

I - SKAO: Scientific Timeline

Credit: SKAO

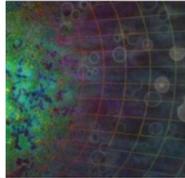
Telescope Access:

Science driven,
based on
contribution level



II – Science with the SKAO

Science Drivers

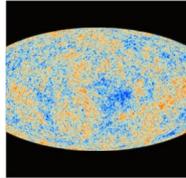


Cosmic Dawn and the epoch of reionisation

WHERE DID IT ALL BEGIN?

HOW AND WHEN DID THE FIRST STARS, GALAXIES AND BLACK HOLES FORM?

The SKA will uniquely enable the measurement of a complete time sequence



Cosmology and dark energy

CAN WE UNCOVER THE MYSTERIOUS NATURE OF DARK ENERGY?

HOW AND WHY HAS IT BECOME THE MAJOR PLAYER IN OUR UNIVERSE?

The SKA will fundamentally advance our understanding of the mysterious dark

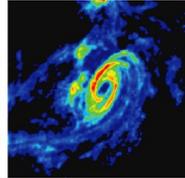


Forming stars through cosmic time

HOW AND WHEN WERE THE FIRST STARS BORN?

HOW HAS THE RATE OF STAR FORMATION CHANGED OVER TIME, AND WHY?

There is evidence that star formation

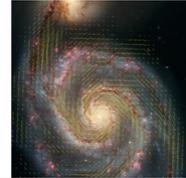


Galaxy evolution

WHAT IS THE LIFE-CYCLE OF A GALAXY?

WHERE DO THEY COME FROM, WHERE DO THEY GO?

WHAT ARE THE PROPERTIES OF THE MYSTERIOUS DARK ENERGY?



Cosmic magnetism

HOW DID THE UNIVERSE BECOME MAGNETIC?

WHERE AND WHEN DID MAGNETISM ORIGINATE?

HOW HAS IT EVOLVED?



The bursting sky

WHAT ARE THE COUNTERPARTS OF THE FAST AND FURIOUS BURSTS OF RADIO WAVES?

WHAT CAN THEY TELL US ABOUT THE CONSTITUENTS OF THE UNIVERSE?

SKA will enable us to investigate

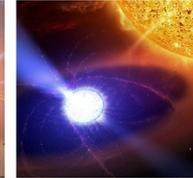


The cradle of life

HOW DO YOU MAKE A PLANET FROM SPACE PEBBLES?

ARE WE ALONE IN THE UNIVERSE?

The SKA will have sufficient resolution to watch the assembly of planets in Earth-like orbits about their parent stars.



Challenging Einstein: gravitational waves

WAS EINSTEIN RIGHT ABOUT GRAVITY?

CAN WE FIND AND UNDERSTAND WHERE GRAVITATIONAL WAVES COME FROM?

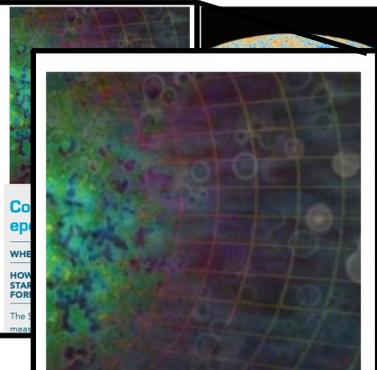
The SKA will use our entire galaxy to

Credit: SKAO

Focus today: Cosmology

II – Cosmic Dawn & Epoch of Reionization

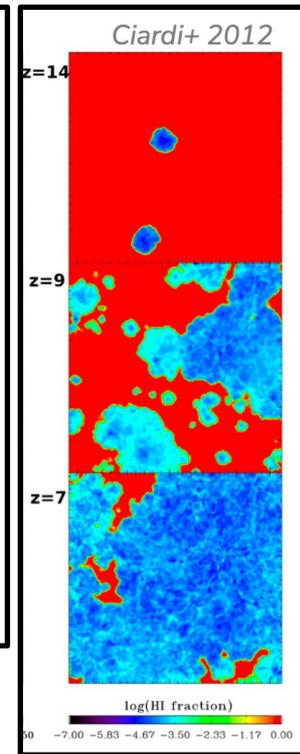
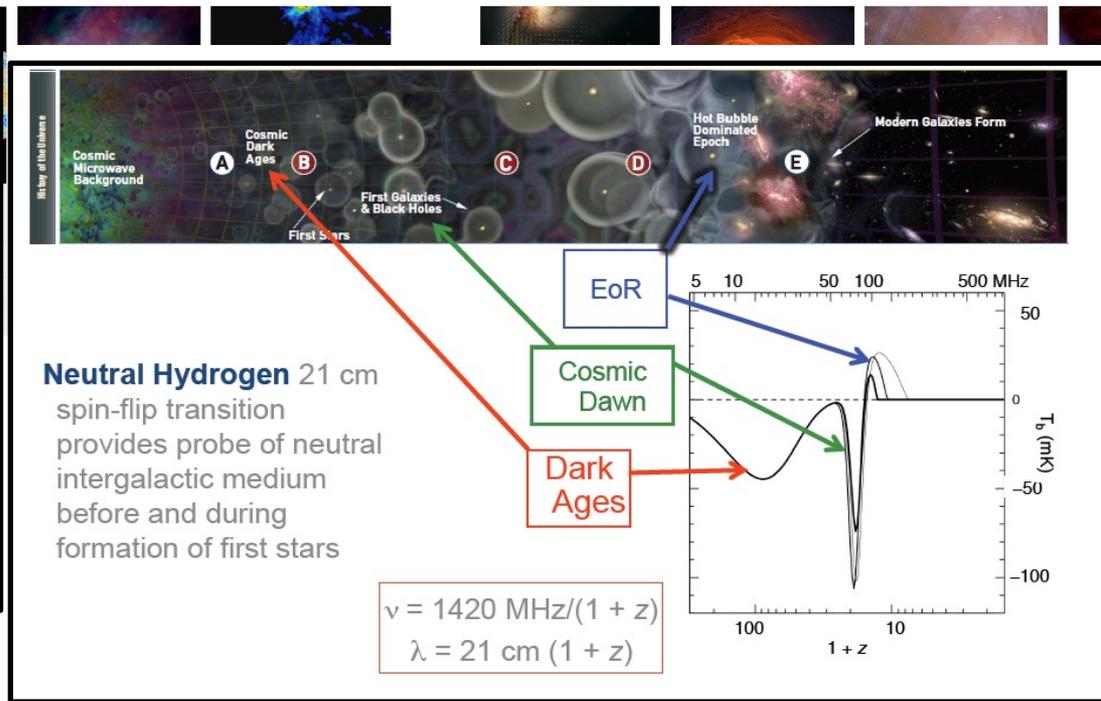
Science Drivers



Cosmic Dawn and the epoch of reionisation

WHERE DID IT ALL BEGIN?

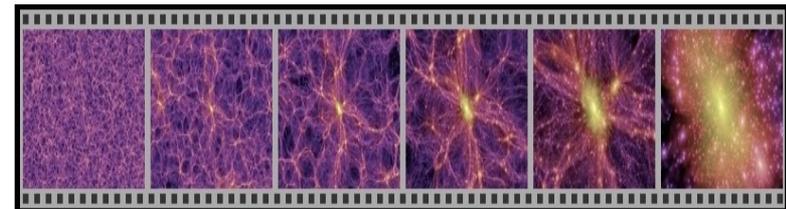
HOW AND WHEN DID THE FIRST STARS, GALAXIES AND BLACK HOLES FORM?



HI emission from the DA, CD & EoR traces evolving “movie” of baryonic and DM structure formation at $t_{\text{univ}} < 10^9$ years

Redshifted 21 cm signal:

- Astrophysics regulating formation of first stars, galaxies & AGN
- underlying fundamental physics & cosmological parameters



II – Cosmic Dawn & Epoch of Reionization

Science Drivers

Cosmic Dawn and the epoch of reionisation

WHERE DID IT ALL BEGIN?

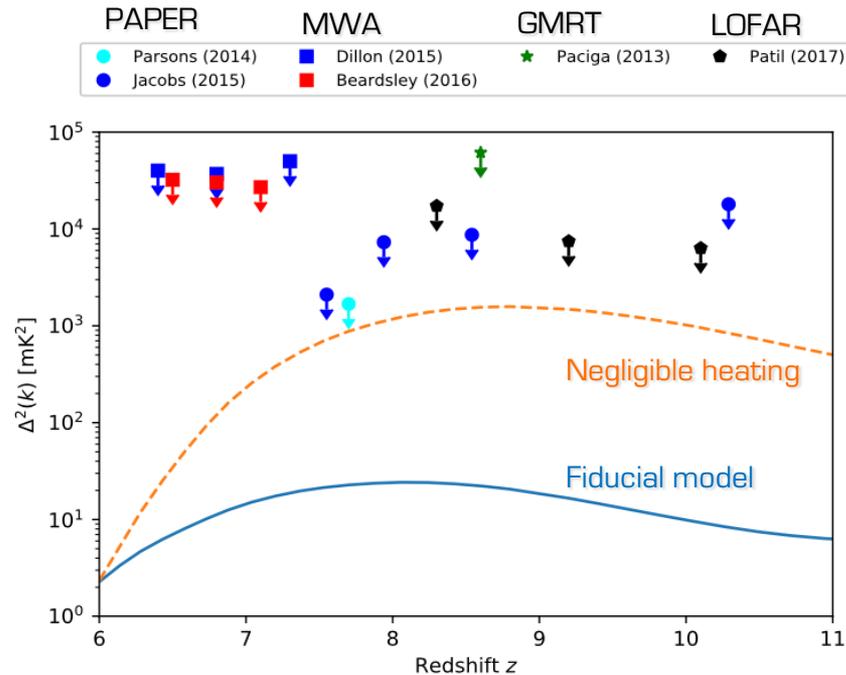
HOW AND WHEN DID THE FIRST STARS, GALAXIES AND BLACK HOLES FORM?

From Bull+2018

For more recent results see Li+2019; kolopanis+2019; Mertens+2020, Garsden+2021, HERA coll. 2022, Keller+2023

SKA objectives:

- 1) Statistical Detection (Power spectrum vs z)
- 2) Imaging of IGM transition vs z (Tomography)



II - Cosmology

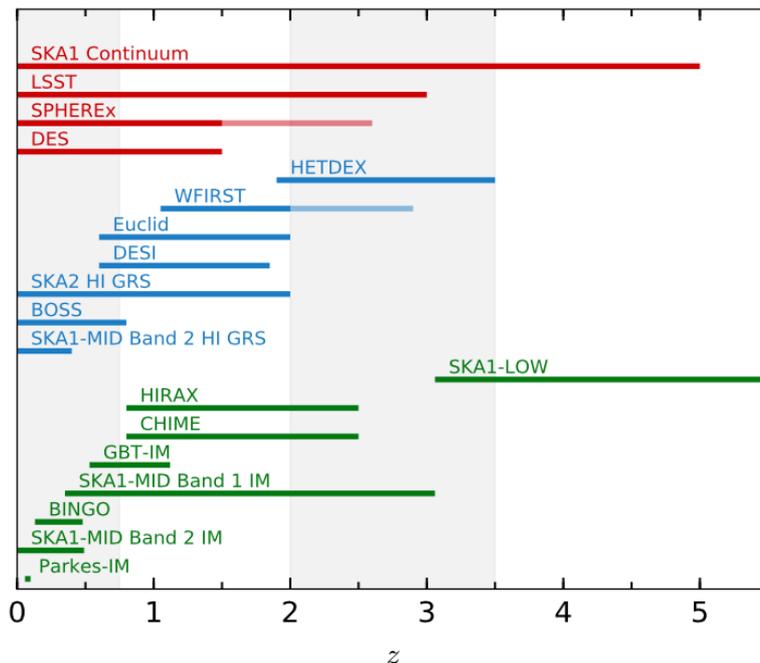
Science Drivers

Cosmic Microwave Background
WHERE DID IT COME FROM?
HOW AND WHEN DID STARS AND GALAXIES FORM?
The SKA will use its measurement of...

Cosmology and dark energy
CAN WE UNCOVER THE MYSTERIOUS NATURE OF DARK ENERGY?
HOW AND WHY HAS IT BECOME THE MAJOR PLAYER IN OUR UNIVERSE?

Bacon et al 2018: *Cosmology with SKA1 - Red Book*
Bull et al. 2018: *Fundamental Physics with the SKA*
Sprenger et al. 2019: *Cosmology in the era of Euclid and the SKA*

Cosmology surveys (Bacon et al. 2018)



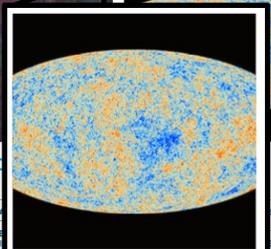
Continuum surveys:
weak lensing, galaxy clustering, Integrated SW Effect, Cosmic Dipole, etc.

Redshift surveys:
BAO, RSD, Voids, DM, etc.

HI Intensity Mapping:
HI Power Spectrum; BAO, RDS, Primordial non-Gaussianity, Neutrino masses, Nature of Dark Matter

II - Cosmology

Science Drivers

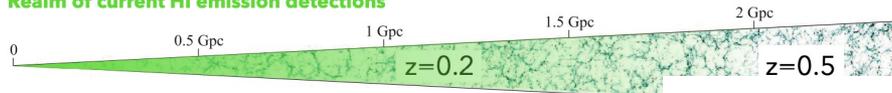


Cosmology and dark energy

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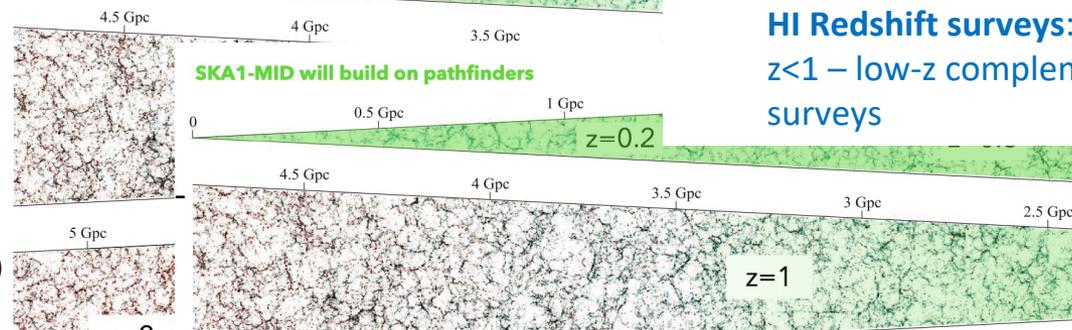
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Realm of current HI emission detections

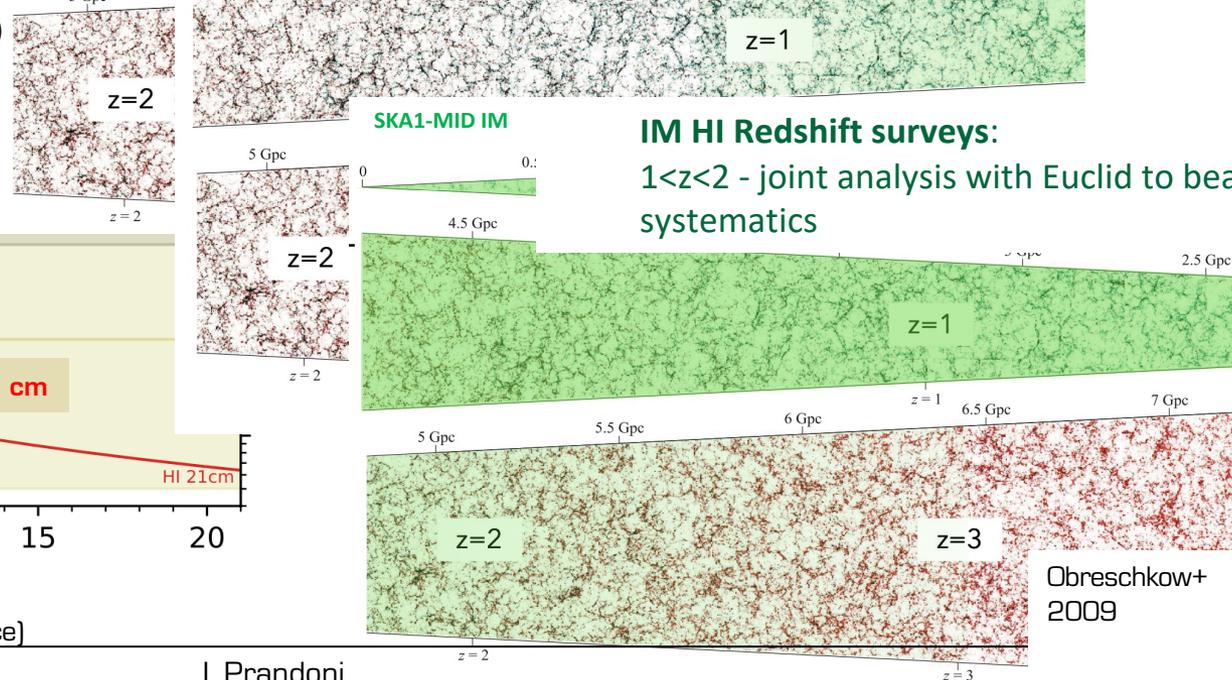


HI Redshift surveys:
z<1 – low-z complement to Euclid surveys

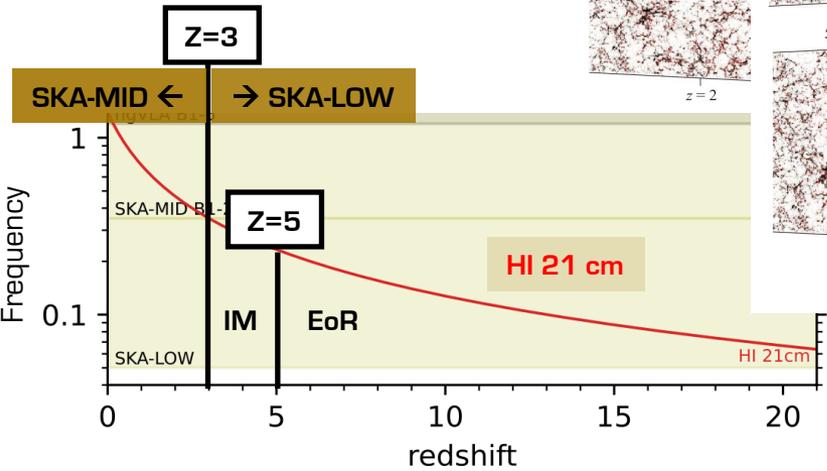
SKA1-MID will build on pathfinders



IM HI Redshift surveys:
1<z<2 - joint analysis with Euclid to beat systematics



Obreschkow+ 2009



Adapted from Boogaard (ngVLA/SKA conference)

II – Galaxy Formation & Evolution

Science Drivers

RC surveys

HI surveys

Galaxy evolution

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WHAT ARE THE PROPERTIES OF THE MYSTERIOUS DARK ENERGY?

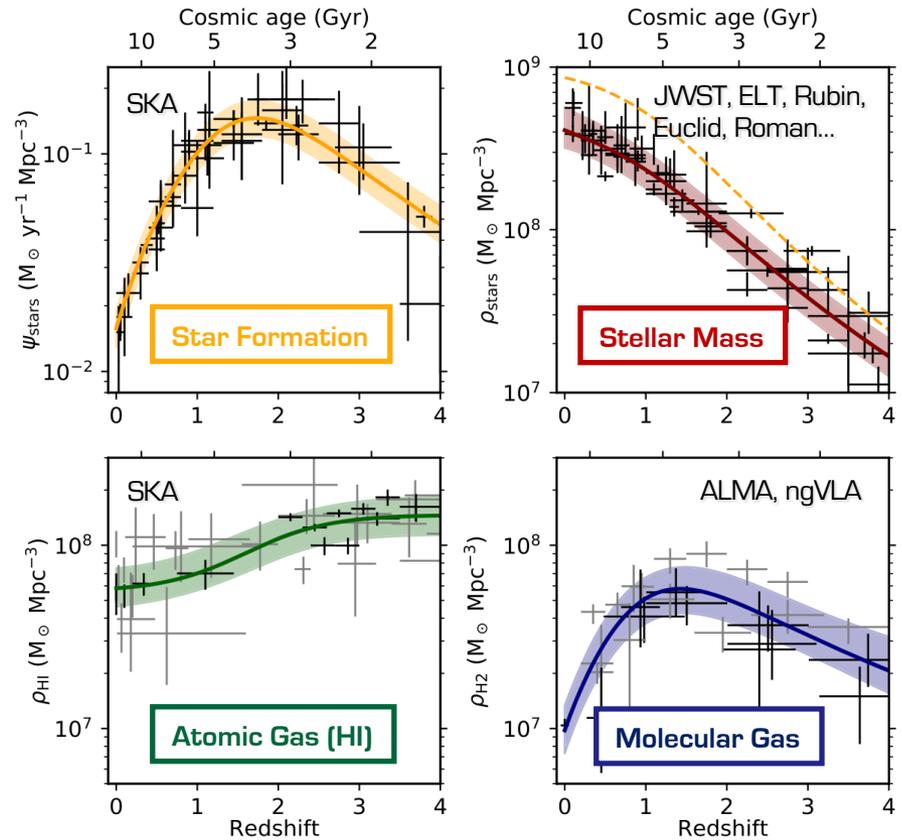
Forming stars through cosmic time

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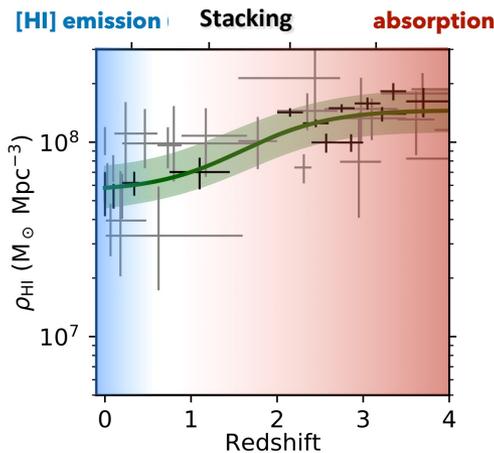
Madau & Dickinson 2014, Neelaman+2016, Walter+2020

Radio band:

- Reliable SFR
- HI

SKA:

- Cosmic noon and beyond



II - Magnetogenesis

Science Drivers



Magnetic fields permeate the Universe, but poorly constrained

- How they grow and propagate (amplification mechanisms, role of CRs)?
- How they affect galaxy evolution?

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A-Primordial Scenario:

Turbulent amplification and compression of weak cosmological fields (seed 10^{-9} G)

B-Astrophysical Scenario:

Magnetization by galactic winds and outflows powered by star formation feedback, SN, AGN (seed 10^{-11} G)

Magnetic fields in filaments should carry memory of the initial field

Upper limits from CMB temperature anisotropies:

$B < \text{few nG on Mpc scales}$

Lower limits from TeV γ -ray observations:

$B > 10^{-7}$ nG on Mpc scale

Cosmic magnetism

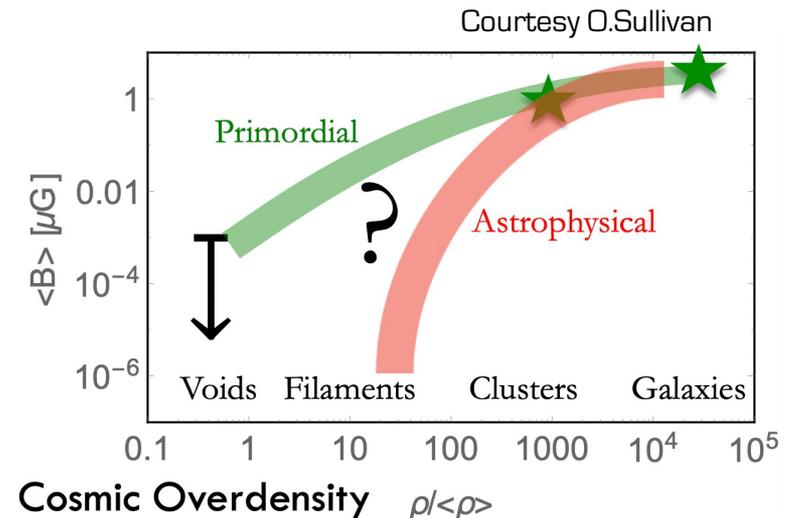
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Challenging Einstein: gravitational waves

WAS EINSTEIN RIGHT ABOUT GRAVITY?
CAN WE FIND AND UNDERSTAND WHERE GRAVITATIONAL WAVES COME FROM?
The SKA will use our entire galaxy to



II – Magnetogenesis

Science Drivers



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A-Primordial Scenario:

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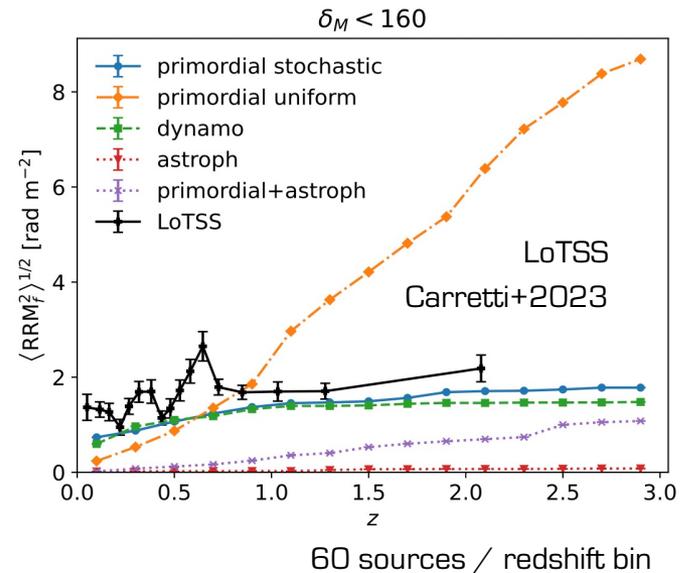
B-Astrophysical Scenario:

Magnetization by galactic winds and outflows powered by star formation feedback, SN, AGN (seed 10^{-11} G)

Magnetic fields in filaments and voids should carry memory of the initial field

All-sky RM/pol. surveys provide information on magnetic fields (B_{\parallel} and B_{\perp}) for all environments (MW, Galaxies/AGN, Clusters, Cosmic Web)

Precursors are providing first constraints on magnetic field evolution in filaments!



II – Magnetogenesis

Science Drivers



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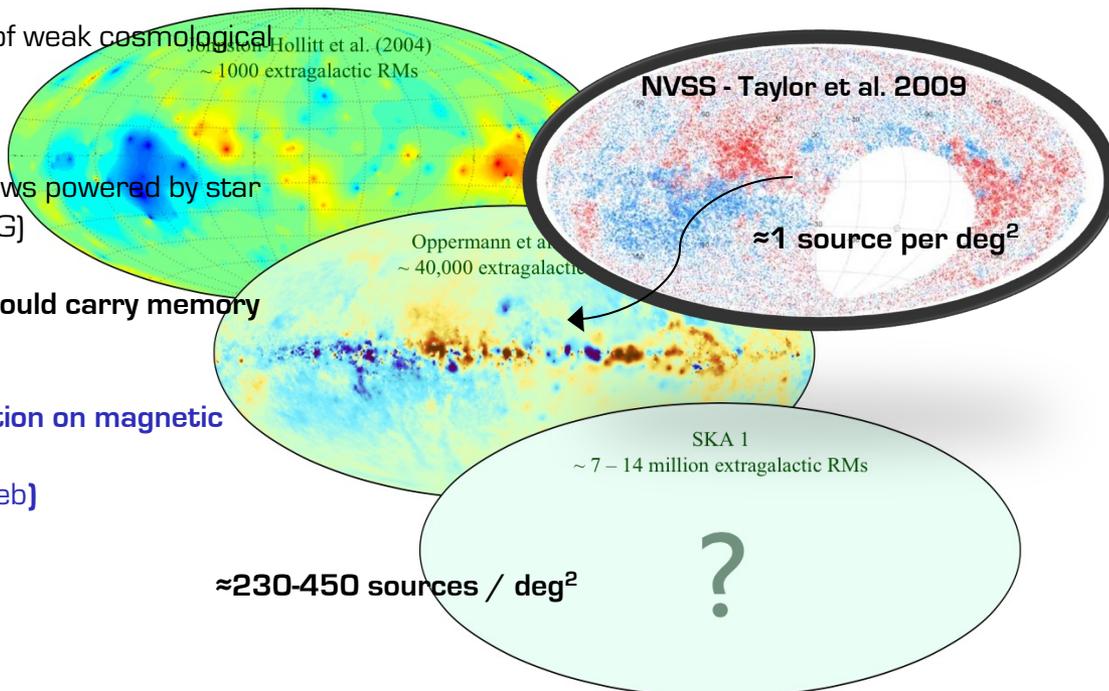
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Key requirement:

Dense RM grid \rightarrow better statistics



II – Magnetogenesis

Science Drivers



Magnetic fields permeate the Universe, but poorly constrained

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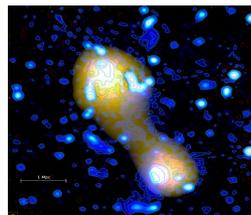
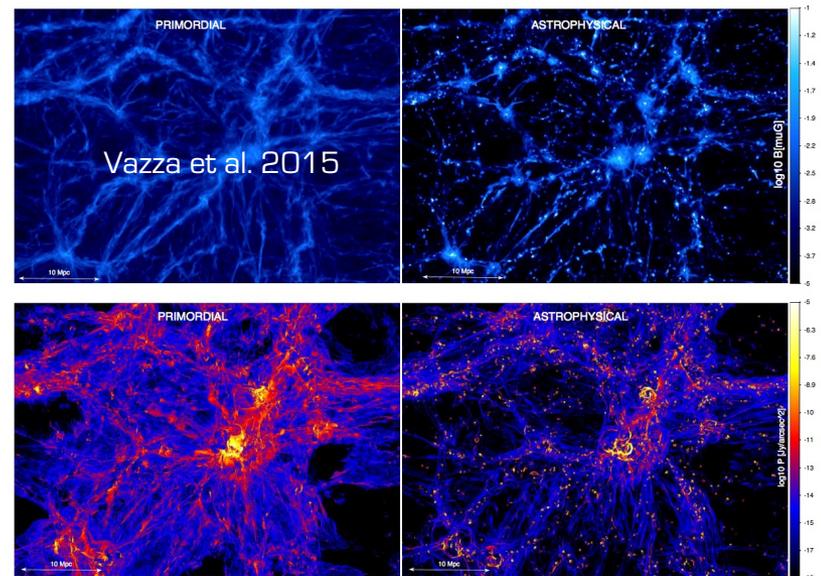
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Magnetic fields in filaments should carry memory of the initial field

Diffuse synchrotron radio emission from shocked WHIM can illuminate the cosmic web

Direct detection of “radio” filaments

Govoni+2019 (Science): radio ridge connecting two galaxy clusters in a filament of the Cosmic Web

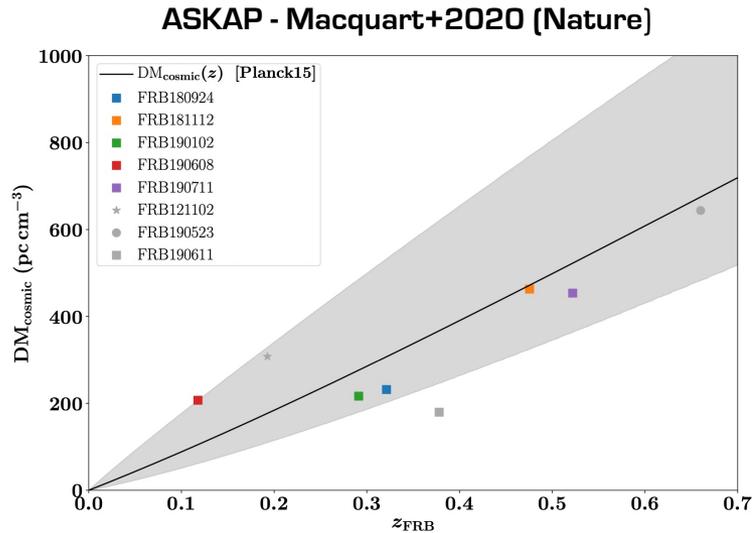



II – Cosmology with Fast Radio Bursts

Science Drivers



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James+2022

$$H_0 = 73^{+12}_{-8} \text{ km/s/Mpc}$$

Extragalactic Dispersion Measure – redshift (Macquart) relation

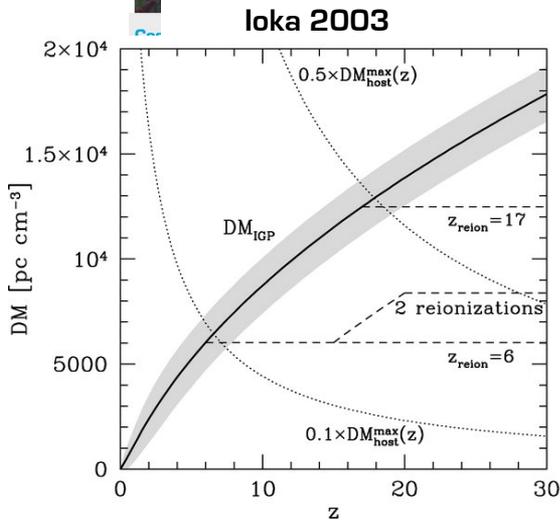
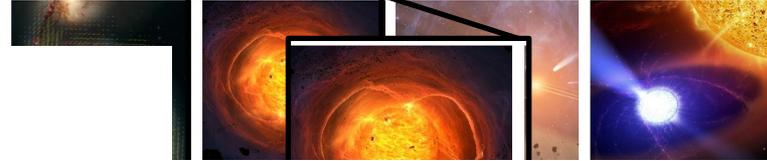
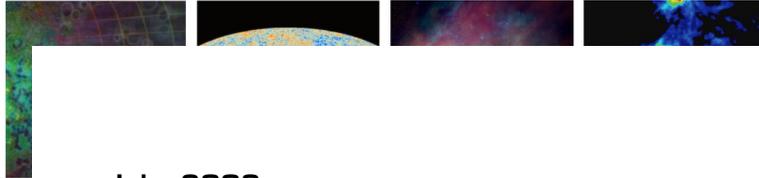
Independent measurement of baryon content for localized FRBs - consistent with CMB and Big Bang Nucleosynthesis values

DM measures the electron column density along each sight line and accounts for every ionised baryon

Next step: improve statistics at localized FRBs at low redshift

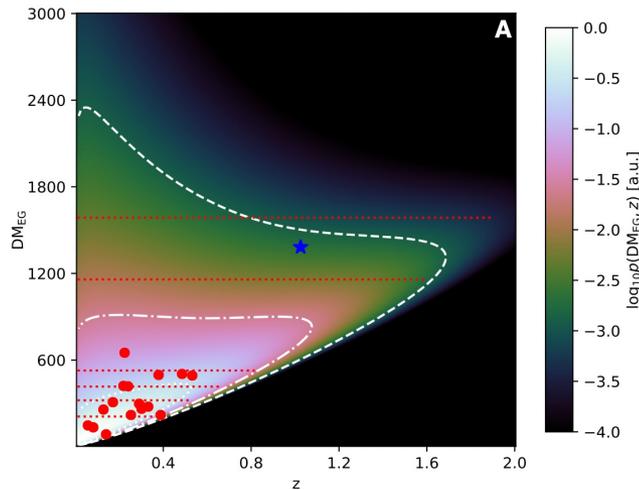
II – Cosmology with Fast Radio Bursts

Science Drivers

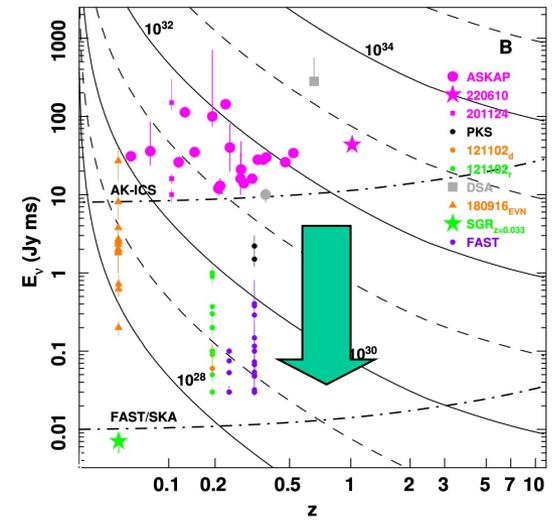


Next step:

Extend Macquart relation to higher z



Ryder+2023: Discovery of FRB at $z = 1.016 \pm 0.002$



Need sensitive interferometers like the SKA (lower fluence values + localization)

Prospects for fundamental contributions to cosmology with large samples (~ 1000) of spectroscopically identified FRBs out to $z \sim 2$ and beyond

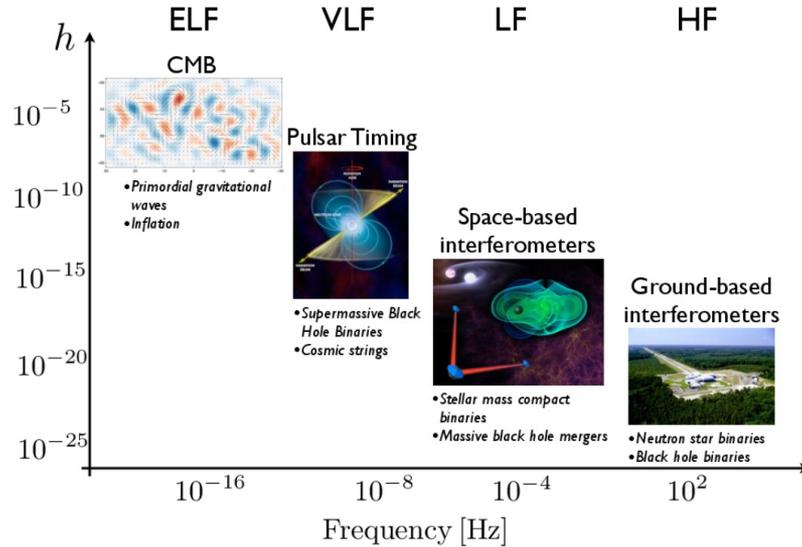
II – Cosmology with Gravitational Waves

Science Drivers



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The big picture of gravitational wave astronomy



The collage includes several text boxes:

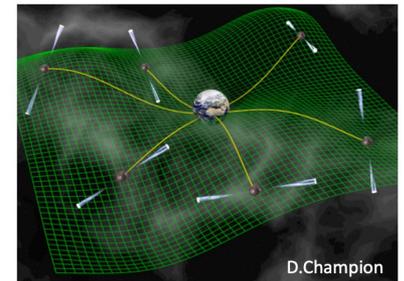
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- watch the ... like orbits ...**
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- ABOUT**
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- re galaxy to**
- WAS EINSTEIN RIGHT ABOUT GRAVITY?**
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- The SKA will use our entire galaxy to**

Pulsar Timing Arrays (PTA)

ultra precision (sub-microsec) pulsar timing from systematic monitoring of msec pulsars around the sky

PTA: search for the effects of GW passing near the Earth, looking for signature of GW in the residuals when fitting timing model

PTAs are sensitive to nHz GW from coalescing SMBH Binaries (complementary to CMB and interferometres)



D.Champion

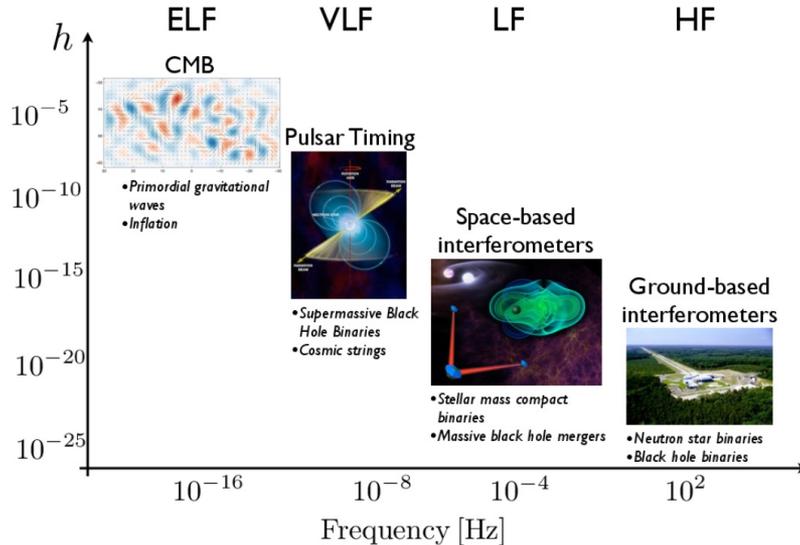
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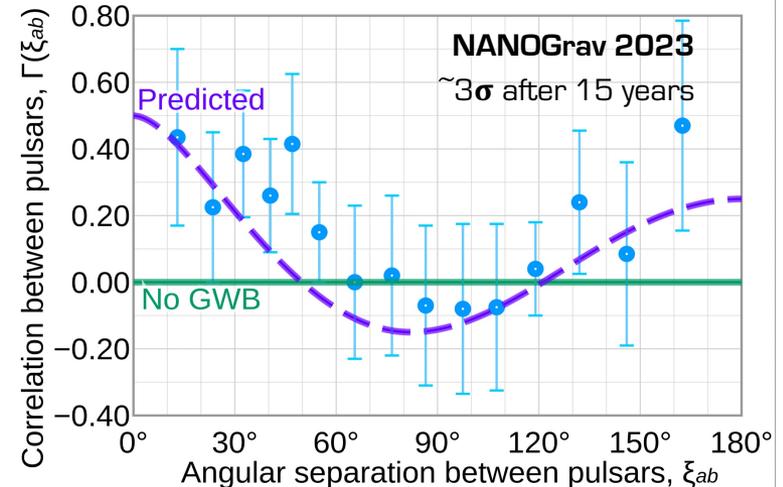
Cosmology
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The SKA will use our entire galaxy to



Main goal: measure amplitude of stochastic GW background, caused by SMBH mergers. Amplitudes can describe the history of how galaxies were formed.

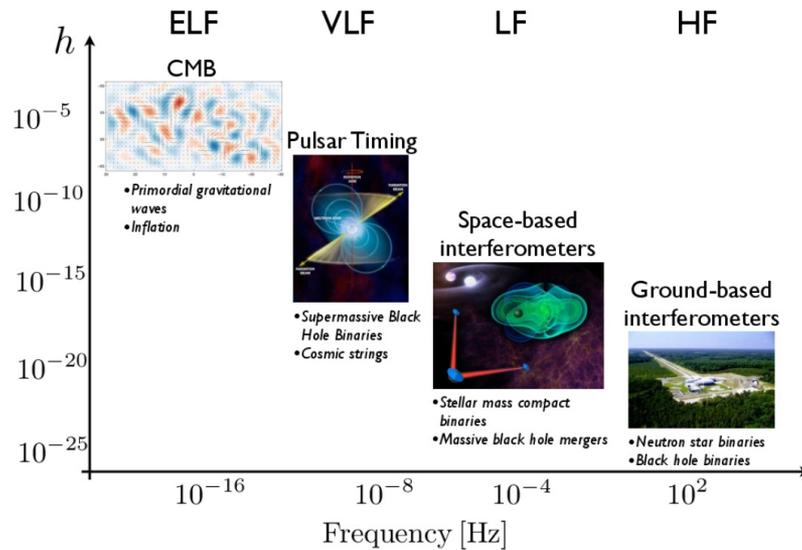
First tentative evidence of GW background announced on June 29th, 2023 - (NANOGrav, EPTA, PPTA, InPTA); See also CPTA (CPTA [FAST=500m]: 4.6σ after 41 months)

II - Cosmology with Gravitational Waves

Science Drivers



The big picture of gravitational wave astronomy



Cosmology
epoche
WHERE
HOW A
STARS
FORM?
The SKA
measur

The collage includes several text boxes:

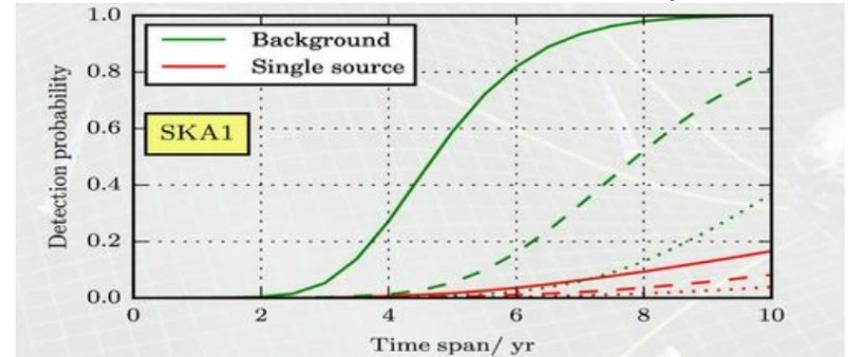
- The c...**
- HOW DO ... FROM SPA...**
- ARE WE A...**
- Challenging Einstein: gravitational waves**
- WAS EINSTEIN RIGHT ABOUT GRAVITY?**
- CAN WE FIND AND UNDERSTAND WHERE GRAVITATIONAL WAVES COME FROM?**
- The SKA will use our entire galaxy to**
- Einstein: waves**
- ABOUT**
- UNDERSTAND AL WAVES**
- ... galaxy to**

PTAs are sensitive to nHz GW from coalescing SMBH Binaries

SKA is expected to improve PTA sensitivity by >10x

SKA will be able to detect also single events

Courtesy Possenti



Take Home Message

Adapted from: SKAO Image

