The SKA project

the promises of next-generation radio surveys

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Outline

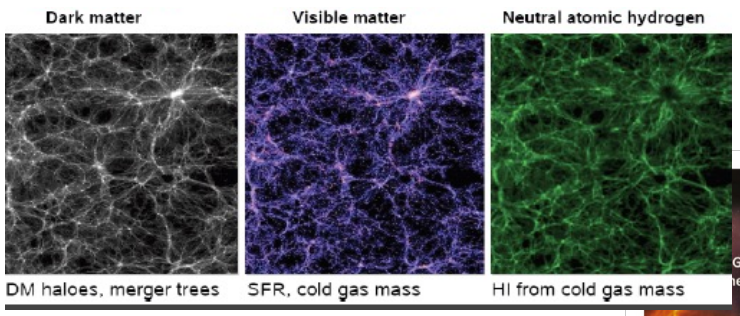
I. The SKA Observatory

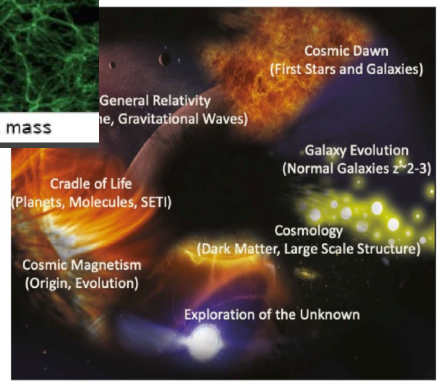
- Sites & Telescopes
- Performance
- Operational Model
- Timelines

II. SKA Science Drivers

- Focus on cosmology
- Preliminary results from precursors

Credit: SKAO

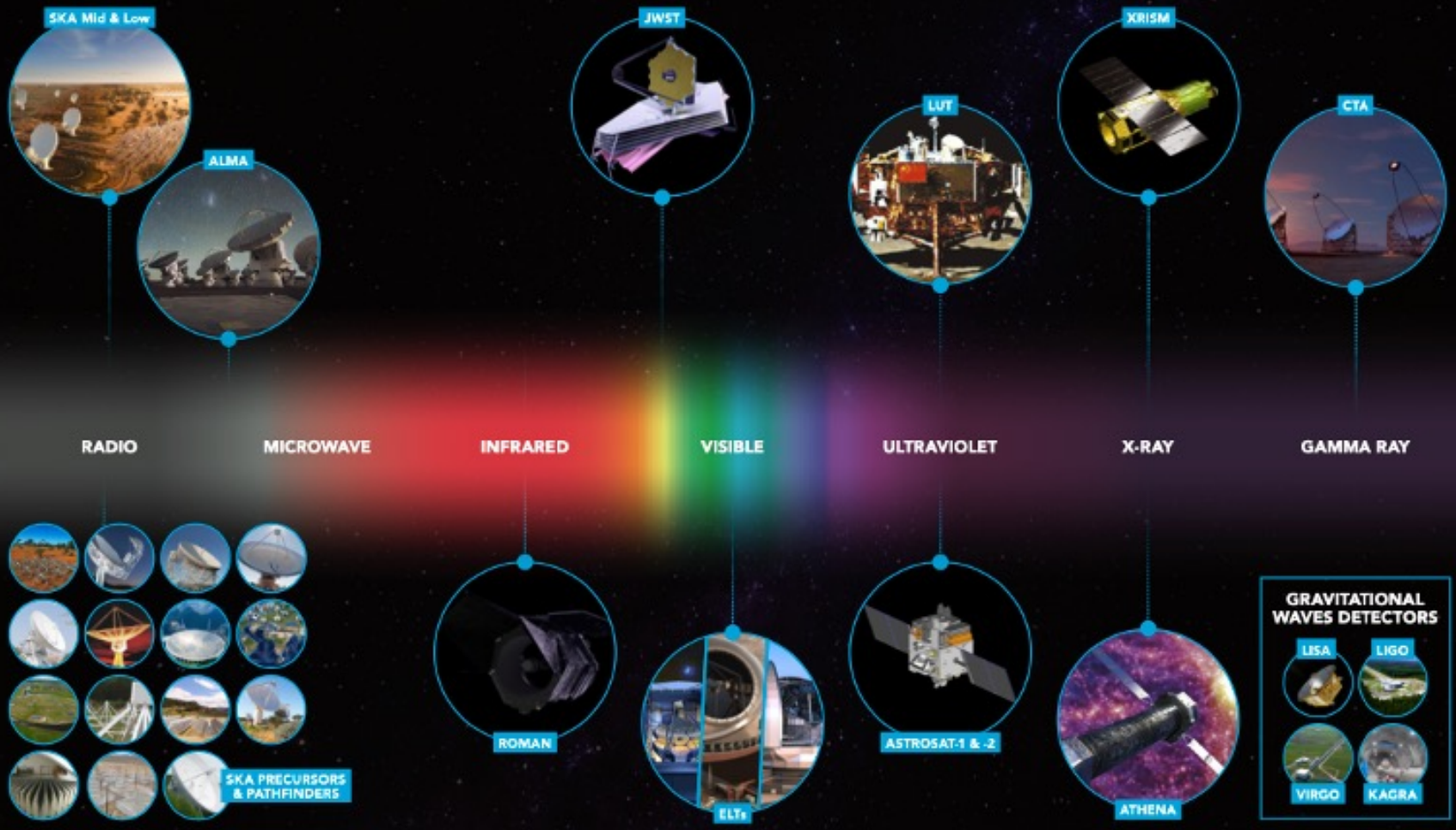




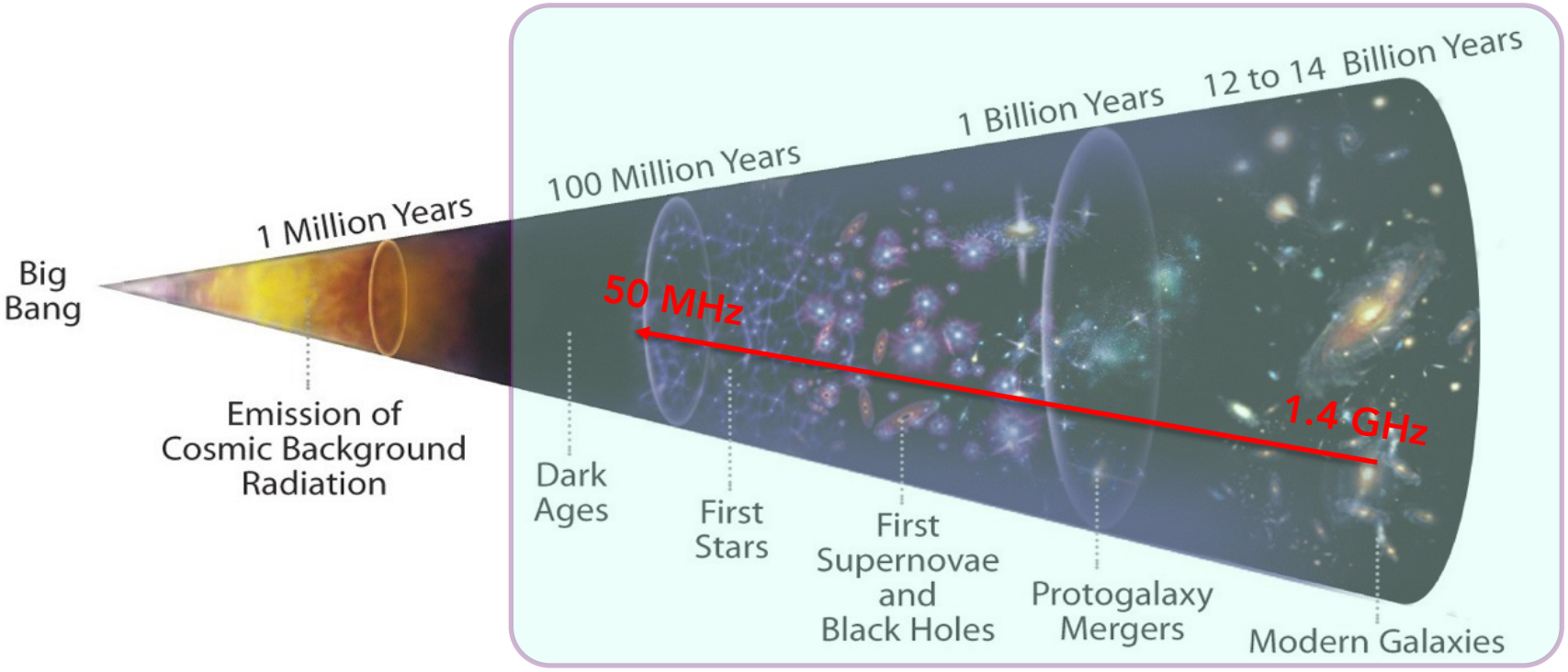
21st century astronomy

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

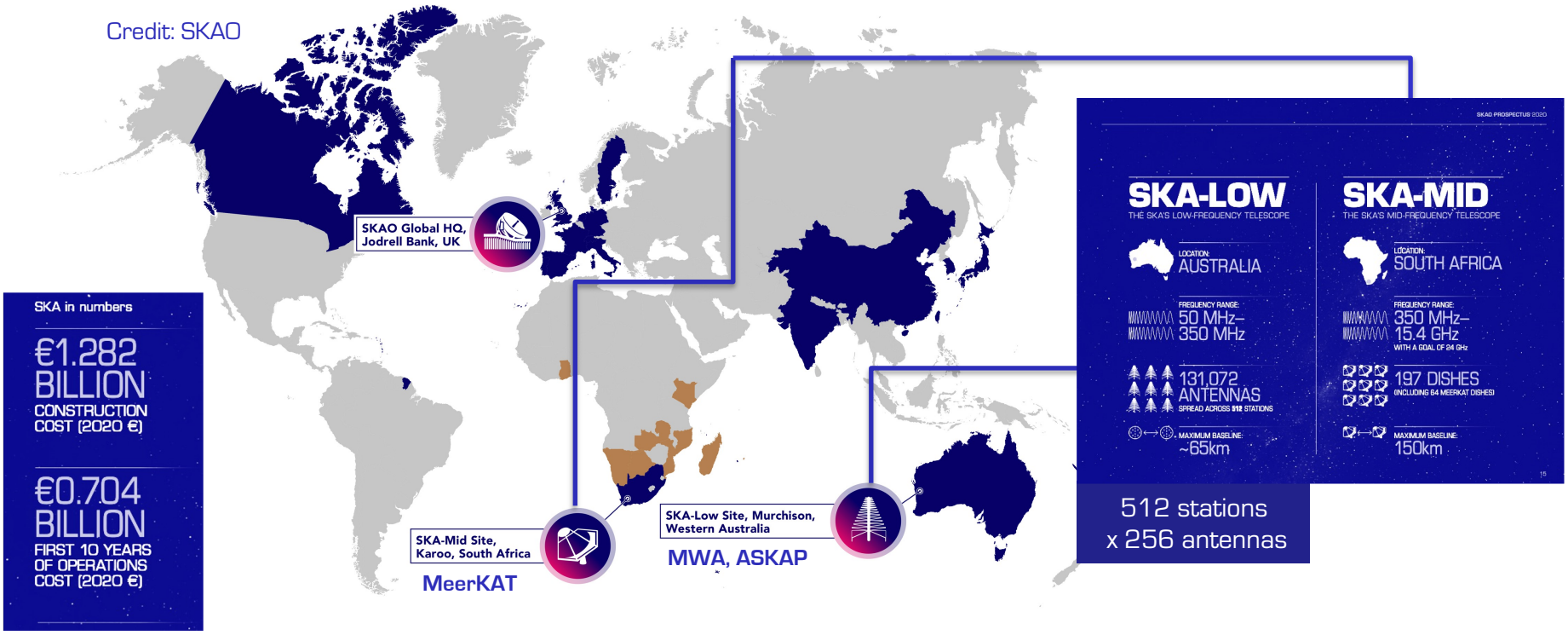
SKA Science Drivers

- **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



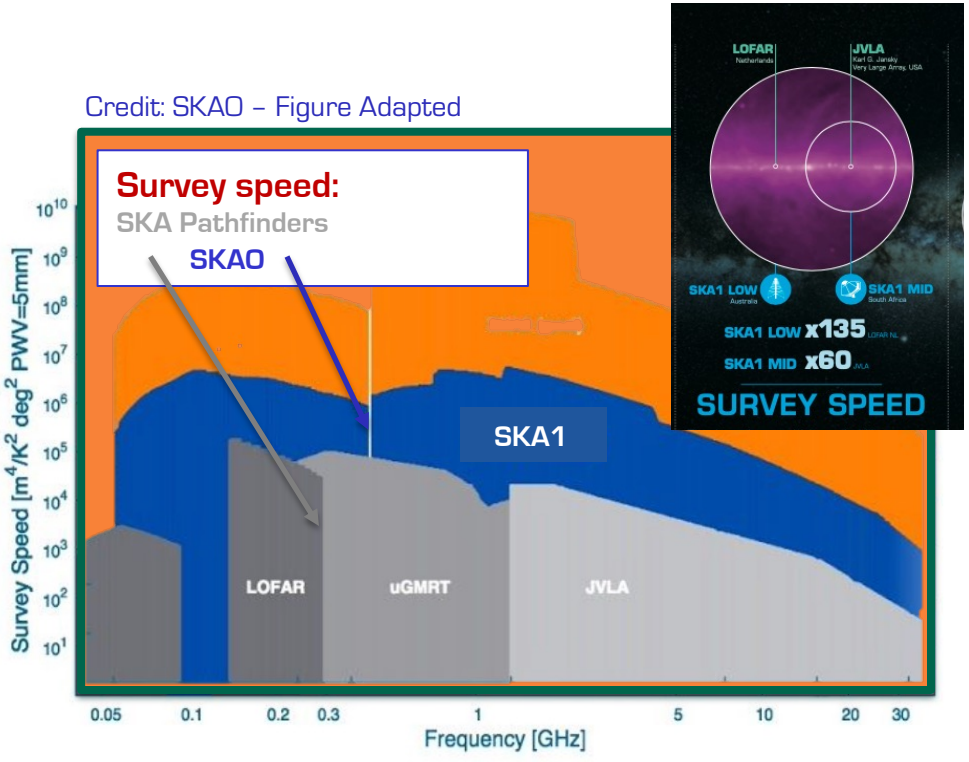
Full members (Updated June 2023): Aus, China, ITA, NL, Portugal, RSA, Spain, Switzerland, UK

Accession stage: Canada, France, Germany

Negotiations: India, Sweden - Early stages: Japan, South Corea

I – SKAO: A Multi-frequency Survey Infrastructure

Credit: SKAO – Figure Adapted



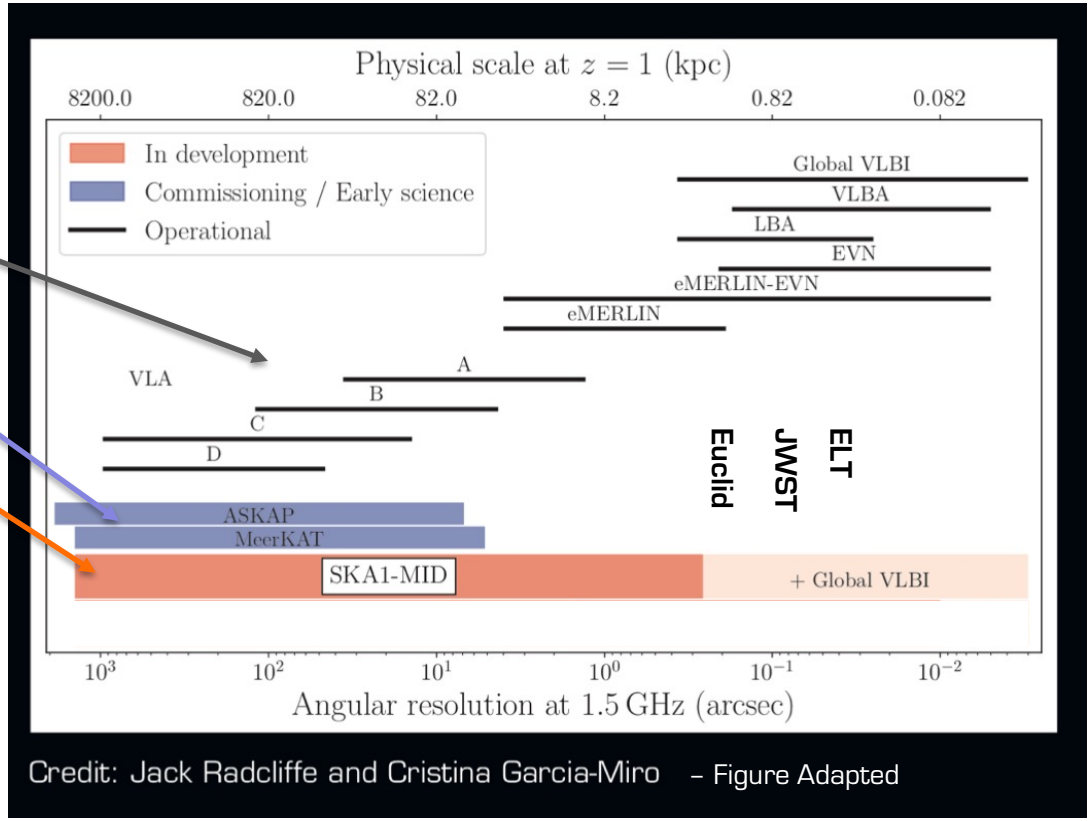
Telescope	Band	Frequency Range (MHz)
SKA1-Low	N/A	50 - 350
SKA1-Mid	1	350 - 1050
	2	950 - 1760
	3	1650 - 3050
	4	2800 - 5180
	5a	4600 - 8500
	5b	8300 - 15300
	6	~15000 – ~24000 (tbd)

50 MHz ← Frequency range → 15(24) GHz

I – SKAO: A Multi-resolution Survey Infrastructure

Angular resolution:
SKA Pathfinders
SKA precursors
SKA-MID

A multi-scale view of the radio Universe



1000 arcsec ← Angular resolution → 0.01 arcsec

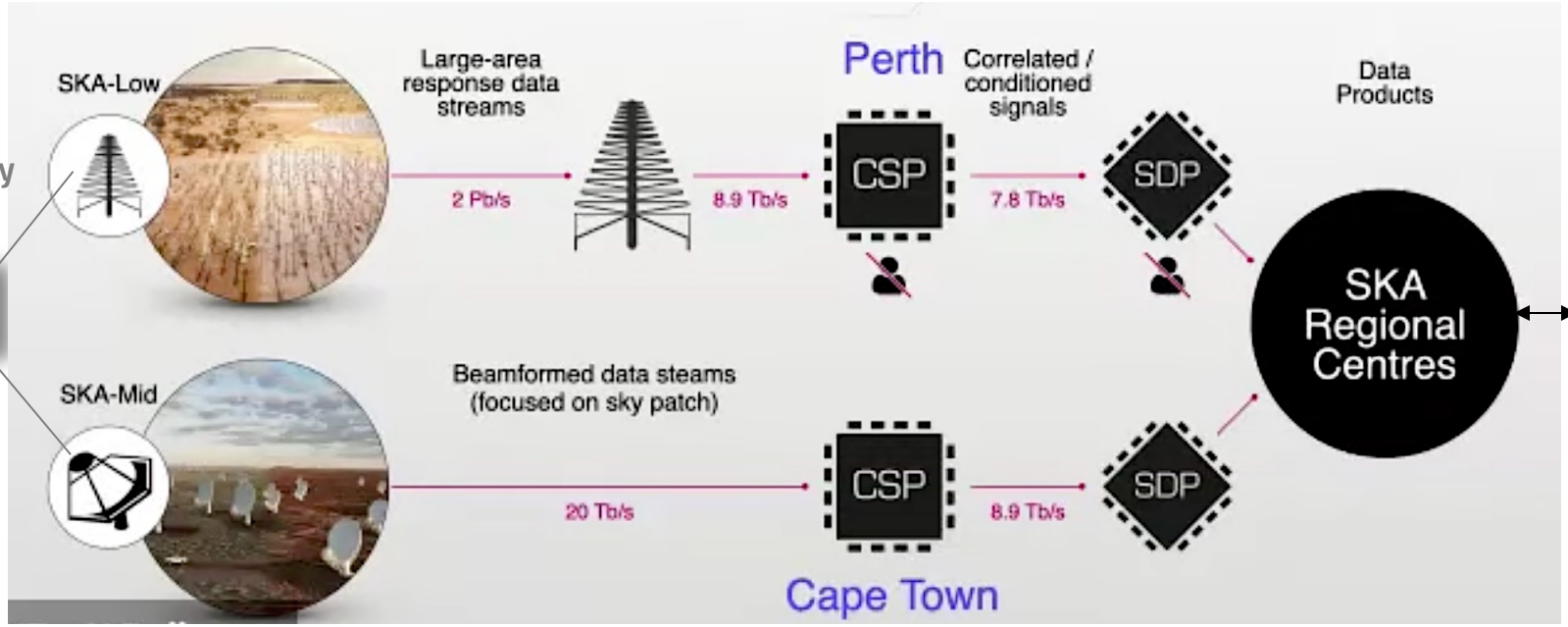
I - SKAO: Operational Model

A single Observatory

2 Telescopes

A network of Regional Centres

Credit: SKAO – Figure Adapted



Volume

- Terabytes to Exabytes of data to process

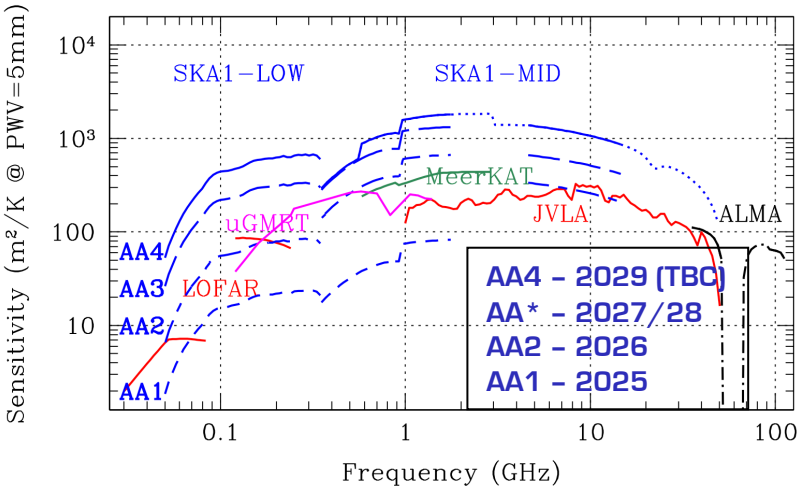
Velocity

- 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

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

Construction strategy: Staged delivery

- INFRA + Staged antenna deployment
- 5 Array Assembly (AA) phases

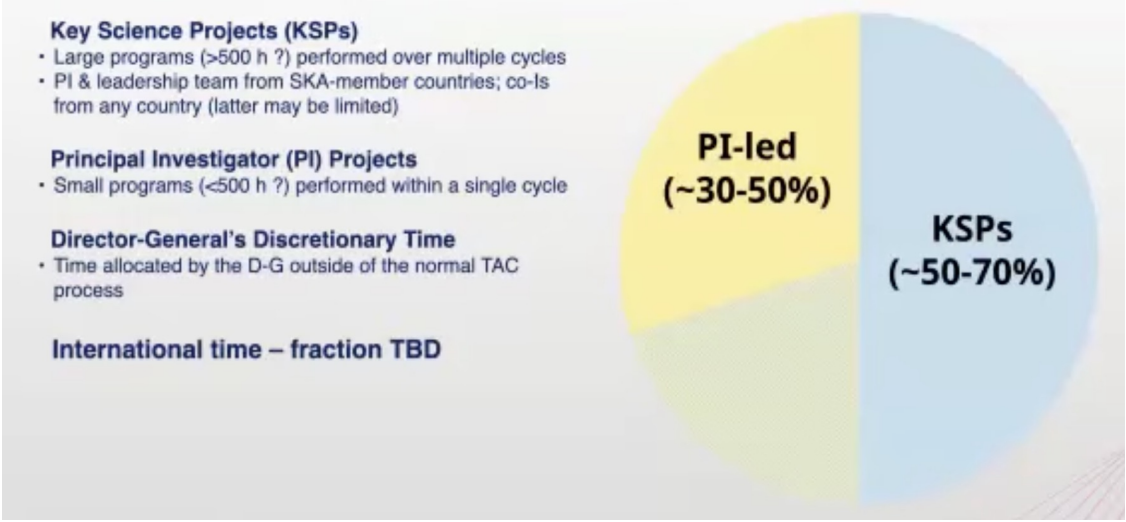
- AA0.5: demonstration of architecture & supply chain
- AA1, AA2
- AA* (formerly AA3) most sensitive array in the world
- AA4: full array

I - SKAO: Scientific Timeline

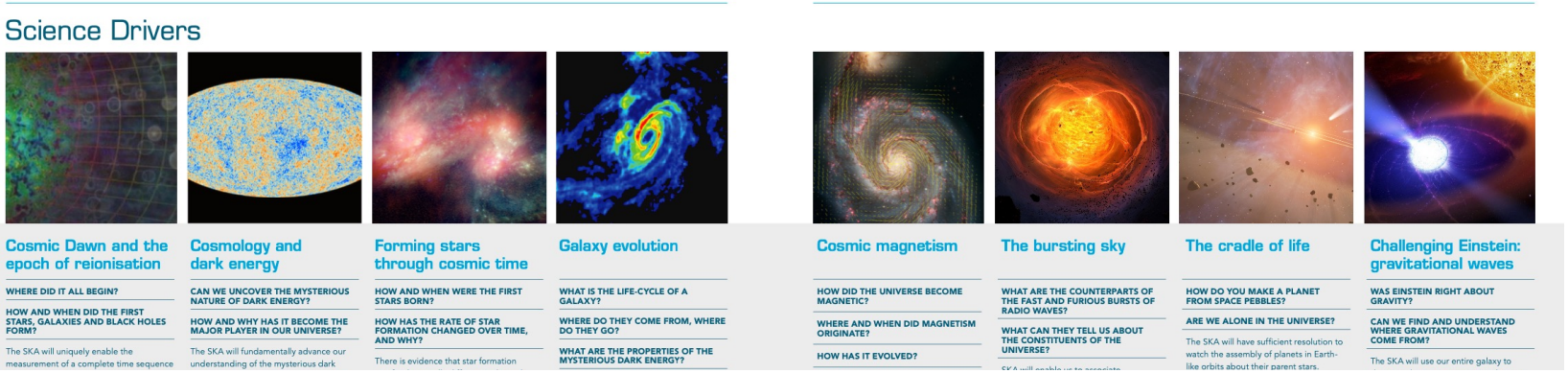
Telescope Access:

Science driven, based on contribution level

Credit: SKAO



II – Science with the SKAO

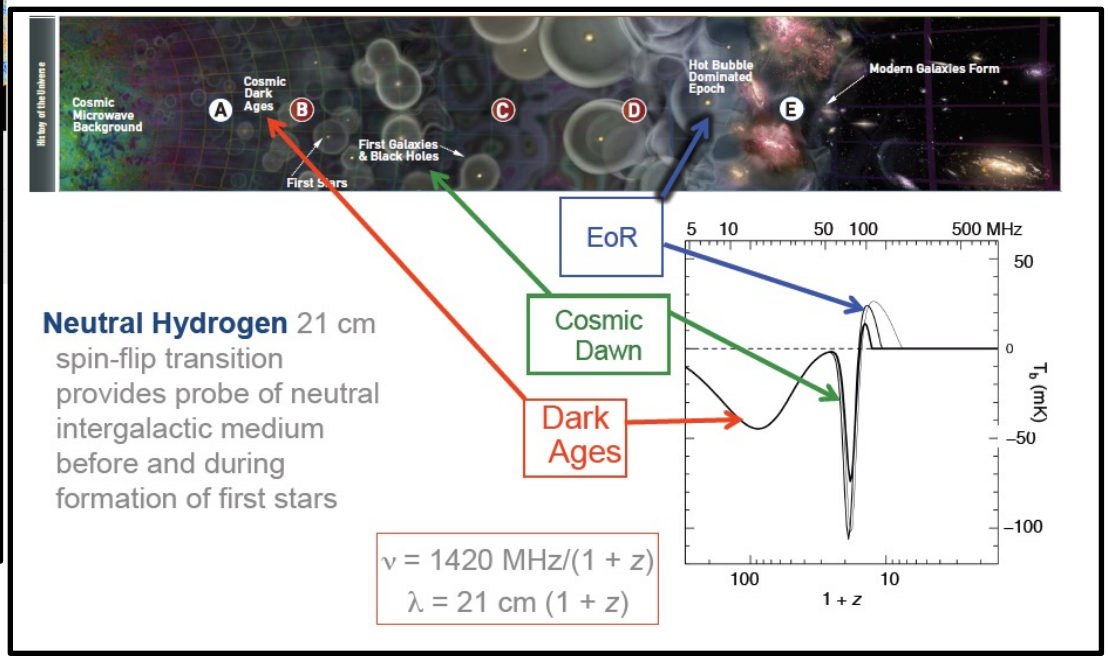


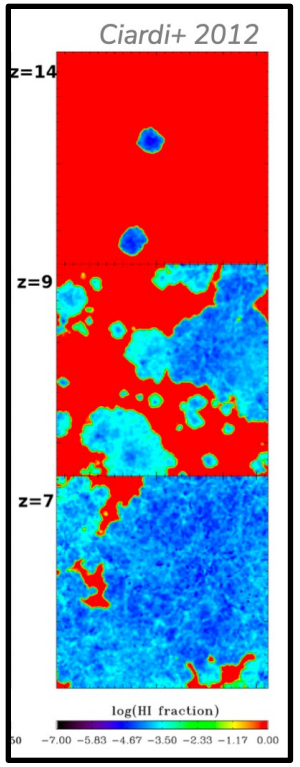
Credit: SKAO

Focus today: Cosmology

II – Cosmic Dawn & Epoch of Reionization

Science Drivers

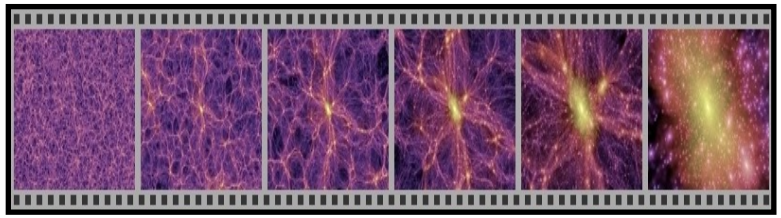




HI emission from the DA, CD & EoR traces evolving "movie" of baryonic and DM structure formation at $t_{univ}<10^9$ years

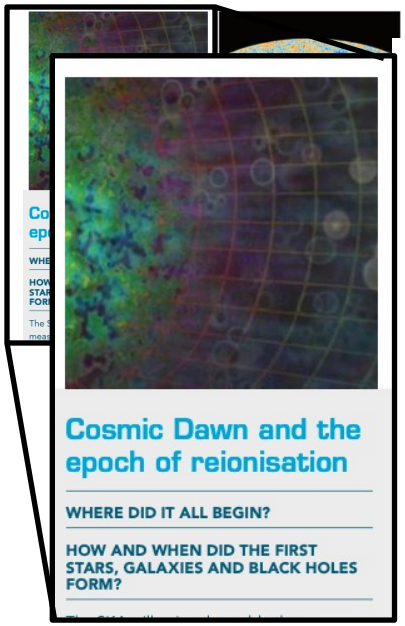
Redshifted 21cm signal:

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



II – Cosmic Dawn & Epoch of Reionization

Science Drivers



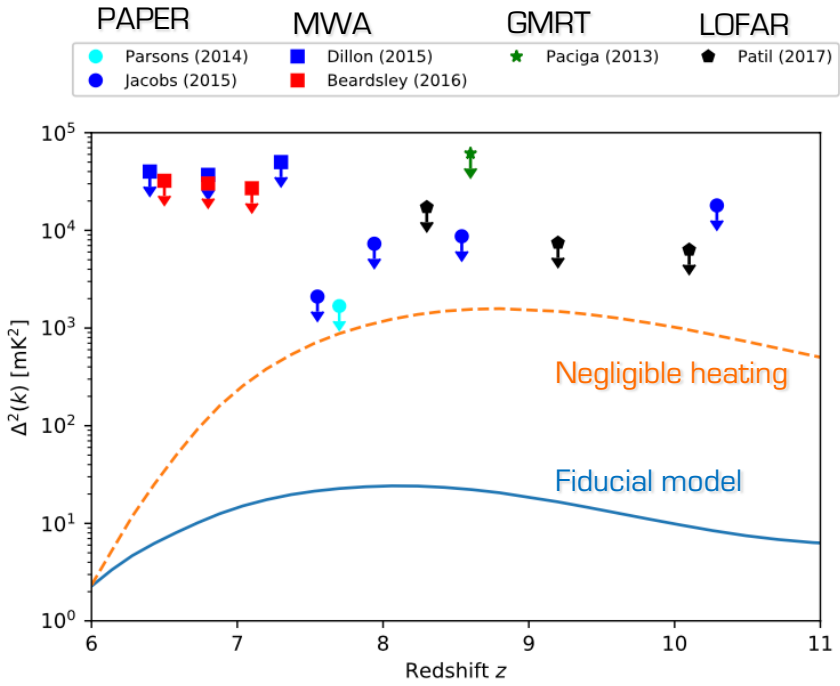
From Bull+2018

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

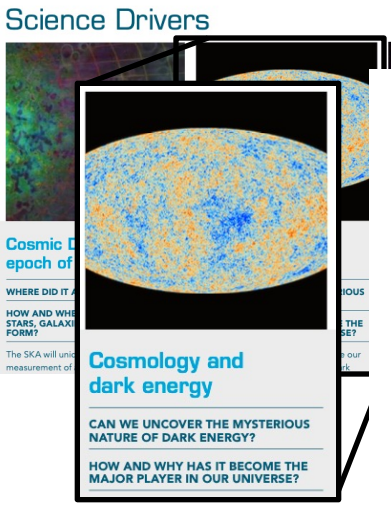
SKA objectives:

1) Statistical Detection (Power spectrum vs z)

2) Imaging of IGM transition vs z (Tomography)

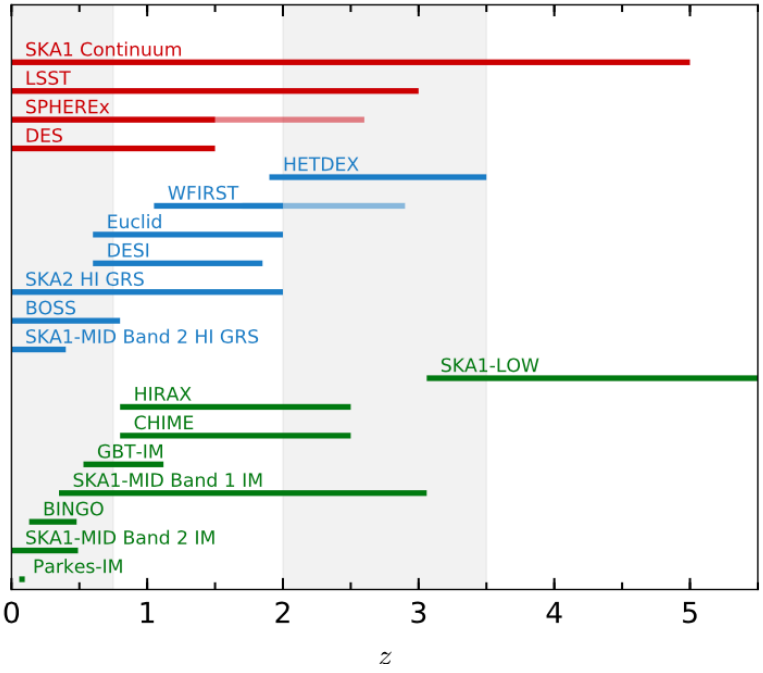


II – Cosmology



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)

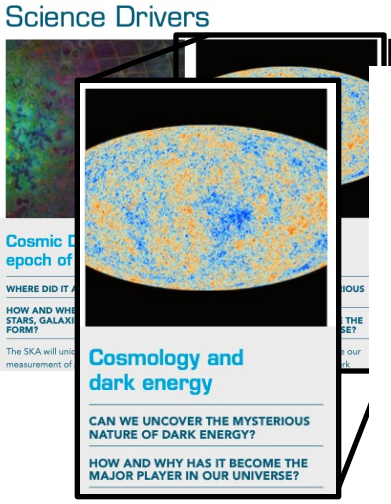


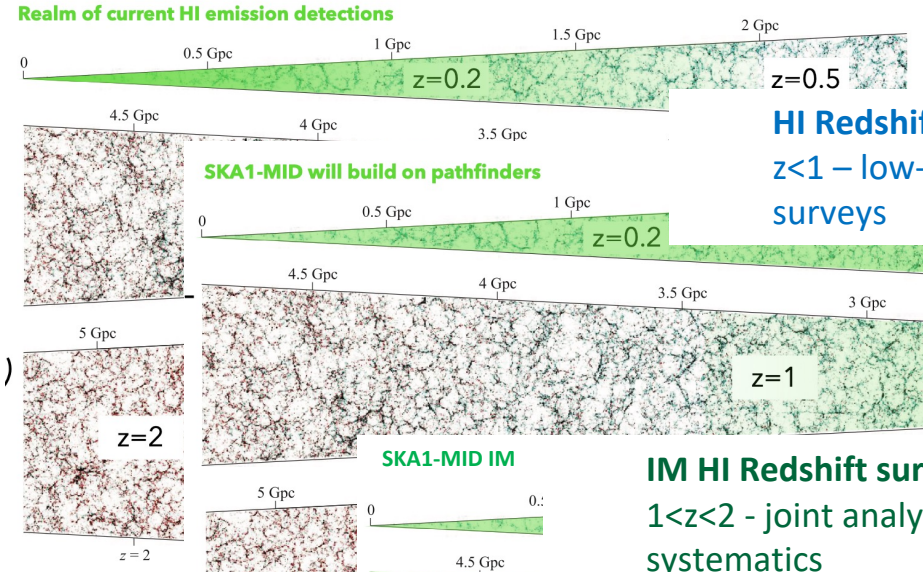
Continuum surveys:
weak lensing, galaxy clustering, Integrated SW Effect, Cosmic Dipole, etc.

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

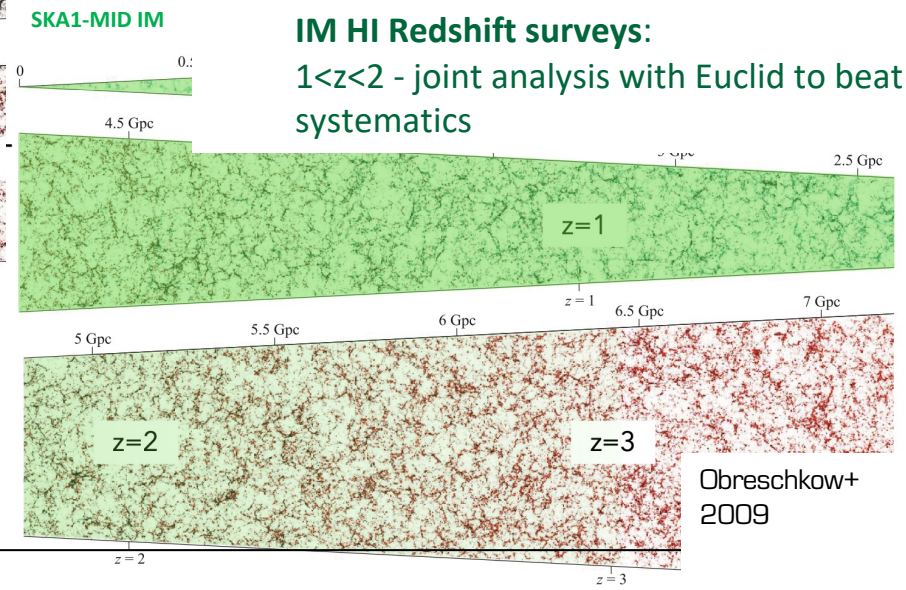
HI Intensity Mapping:
HI Power Spectrum; BAO, RDS, Primordial non-Gaussianity, Neutrino masses, Nature of Dark Matter

II – Cosmology



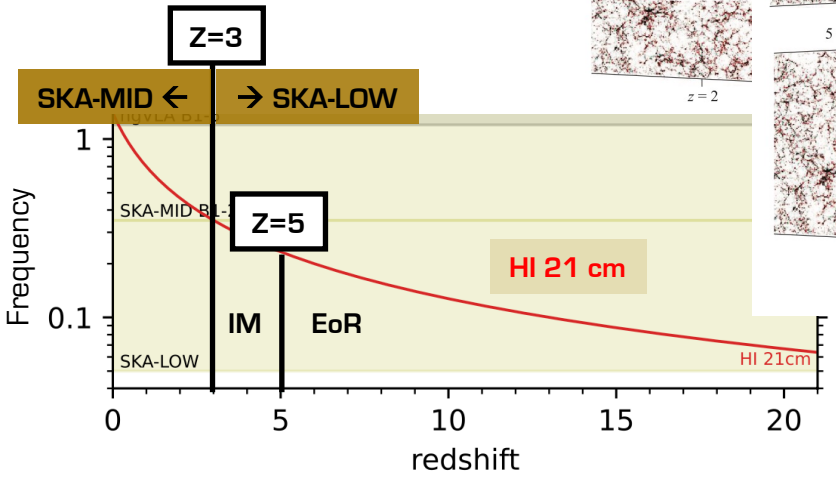


HI Redshift surveys:
z<1 – low-z complement to Euclid surveys



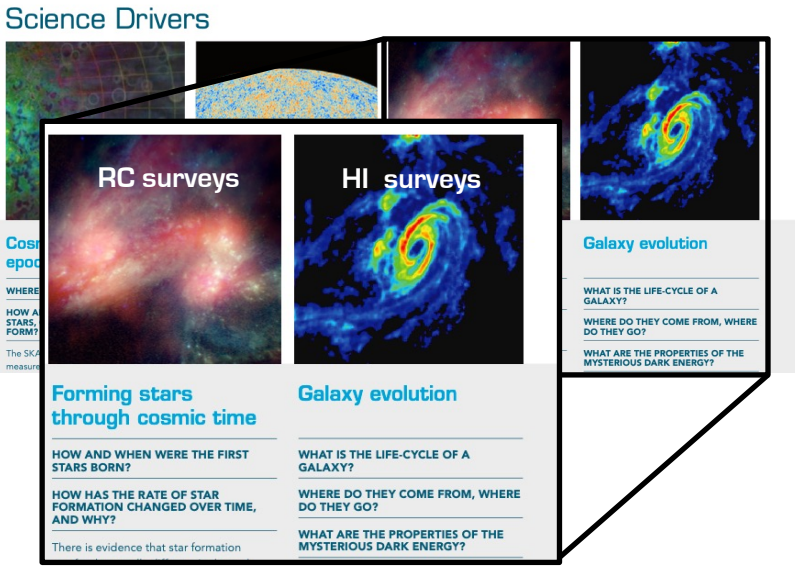
IM HI Redshift surveys:
1<z<2 - joint analysis with Euclid to beat systematics

Obreschkow+ 2009



Adapted from Boogaard (ngVLA/SKA conference)

II – Galaxy Formation & Evolution



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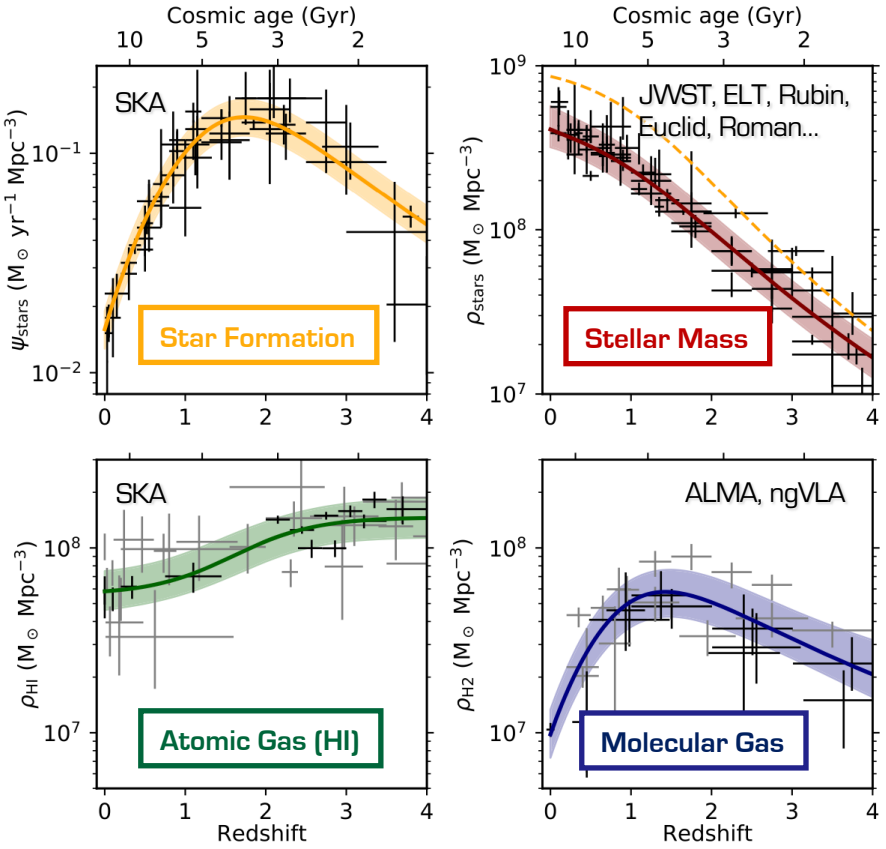


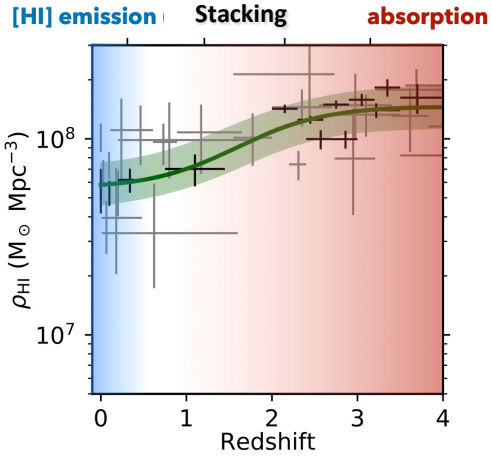
Madau & Dickinson 2014, Neelaman+2016, Walter+2020

Radio band:

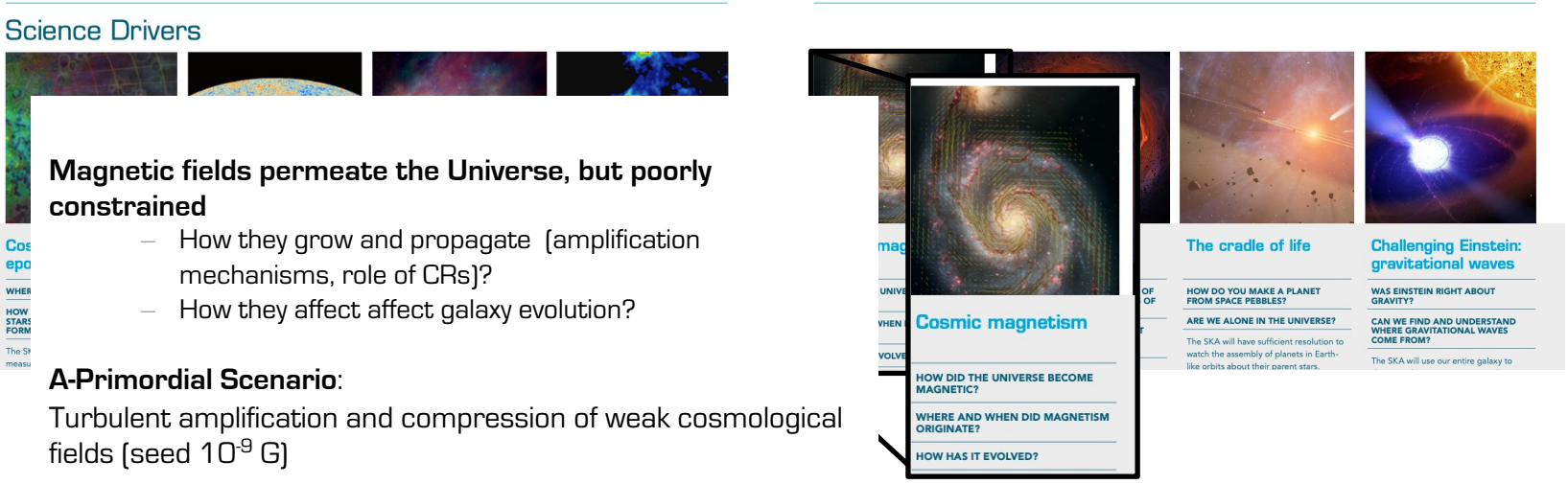
- **Reliable SFR**
- **HI**

SKA:

- **Cosmic noon and beyond**



II – Magnetogenesis



Magnetic fields permeate the Universe, but poorly constrained

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

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

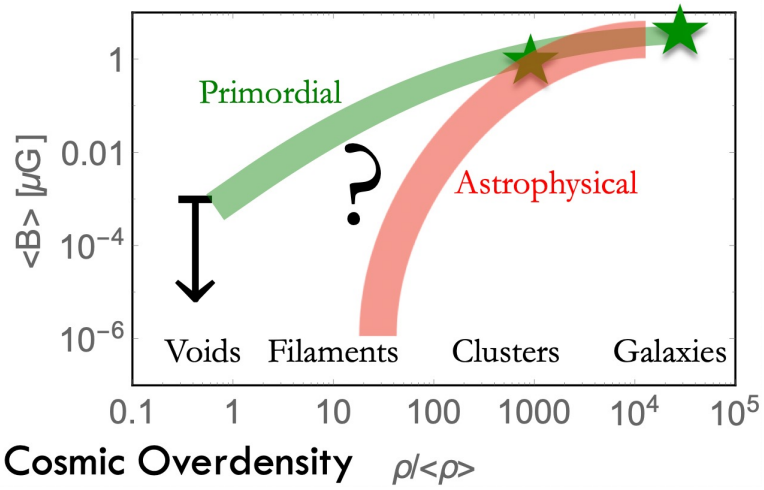
Upper limits from CMB temperature anisotropies:

B < few nG on Mpc scales

Lower limits from TeV γ-ray observations:

B > 10-7 nG on Mpc scale

Courtesy O.Sullivan



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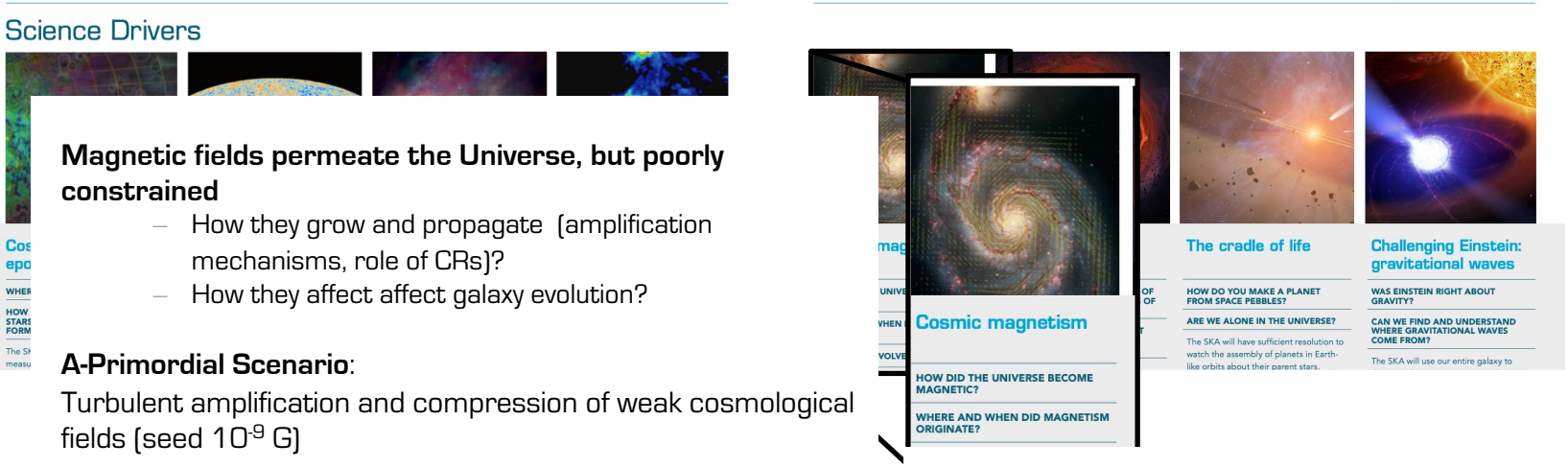

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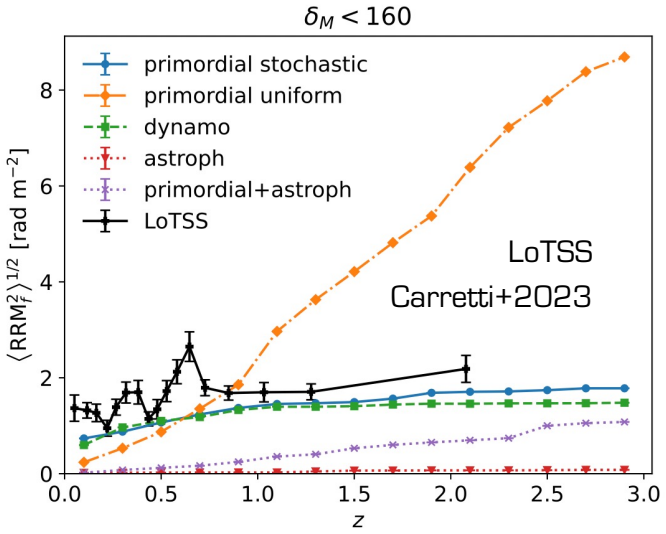
Magnetic fields in filaments and voids should carry memory of the initial field

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

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



60 sources / redshift bin

II – Magnetogenesis

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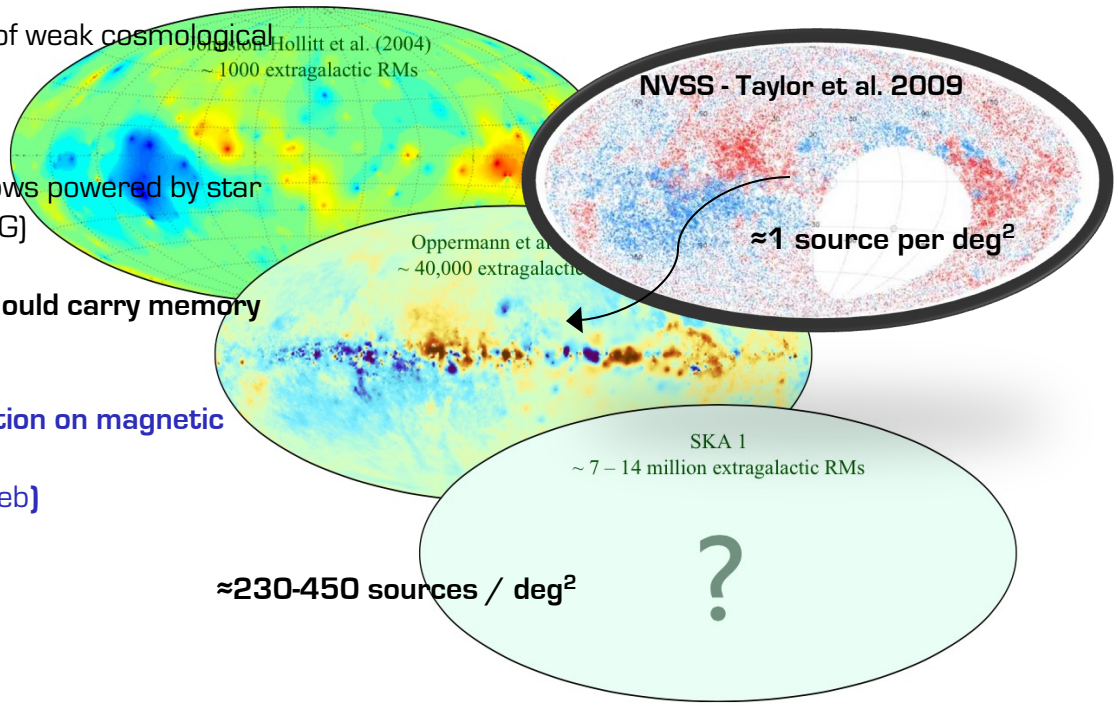
Key requirement:
Dense RM grid → better statistics



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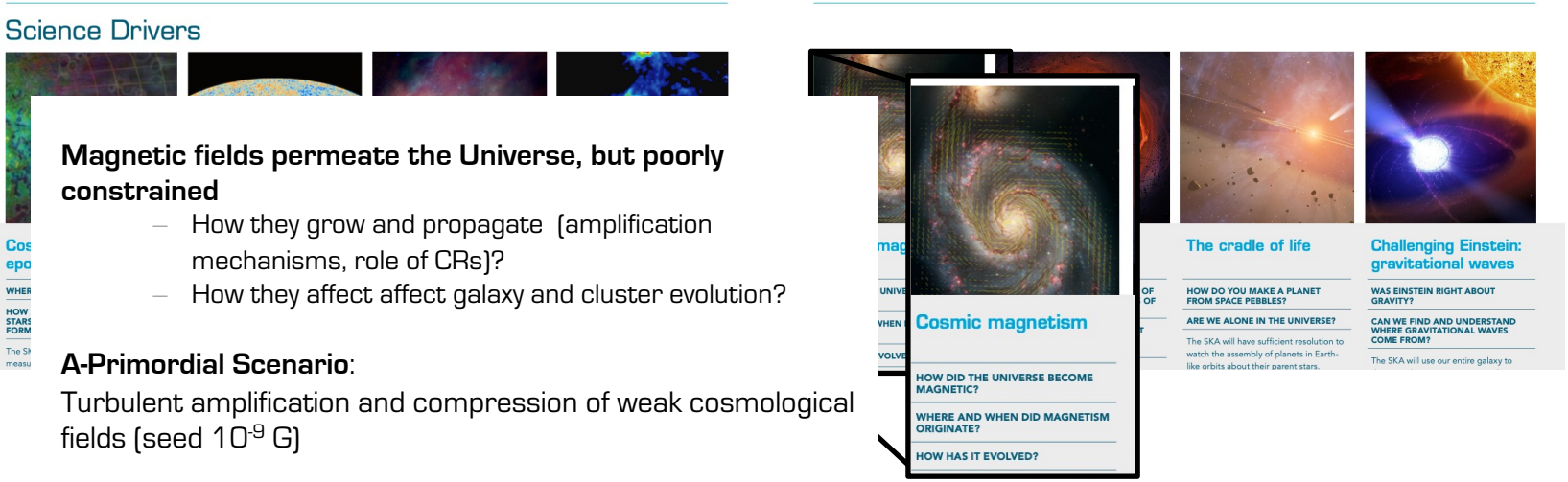

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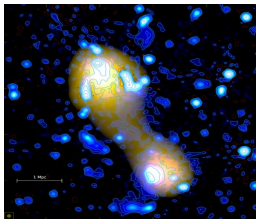
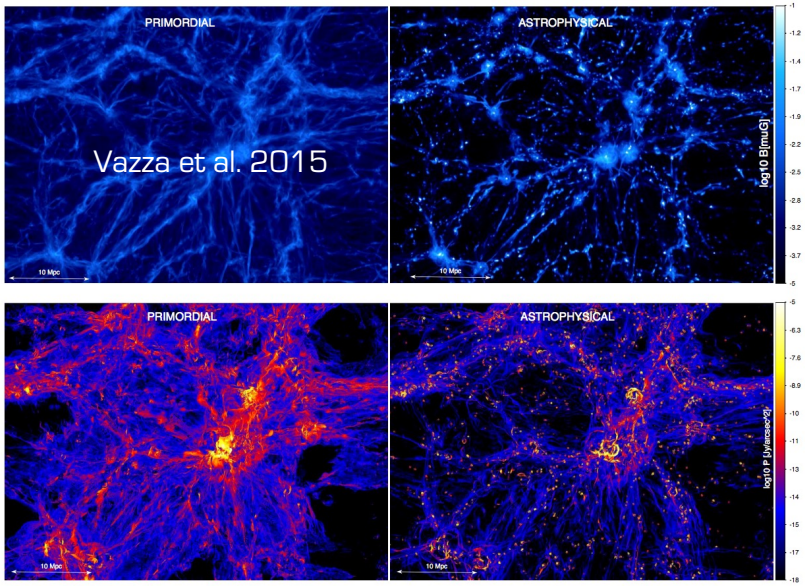
Magnetic fields in filaments should carry memory of the initial field

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

Direct detection of "radio" filaments

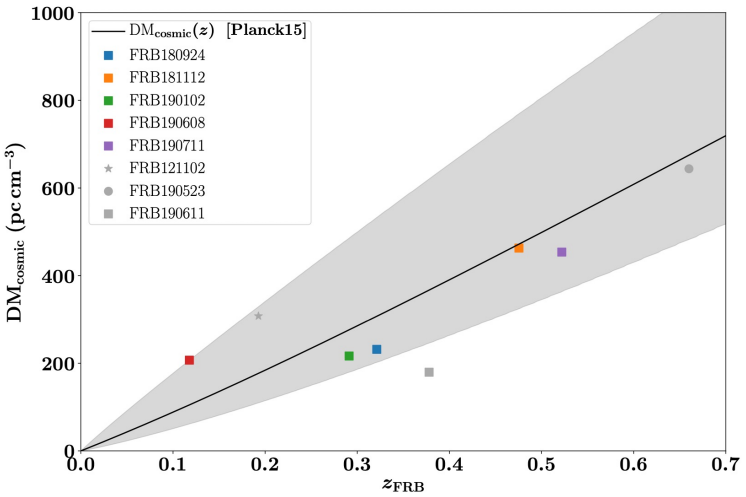
Govoni+2019 (Science): radio ridge connecting two galaxy clusters in a filament of the Cosmic Web





II – Cosmology with Fast Radio Bursts

ASKAP - Macquart+2020 (Nature)



James+2022

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

Extragalactic Dispersion Measure – redshift (Macquart) relation

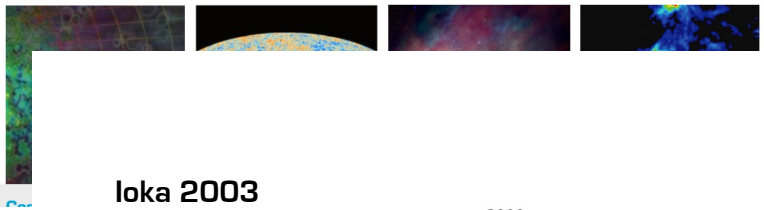
Indipendent meaurement of baryon content for localized FRBs - consistent with CMB and Big Bang Nucleosynthesis values

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

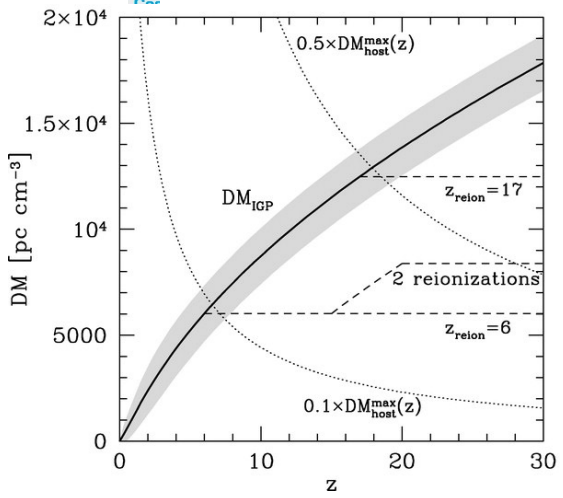
Next step: improve statistics at localized FRBs at low redshift

II – Cosmology with Fast Radio Bursts

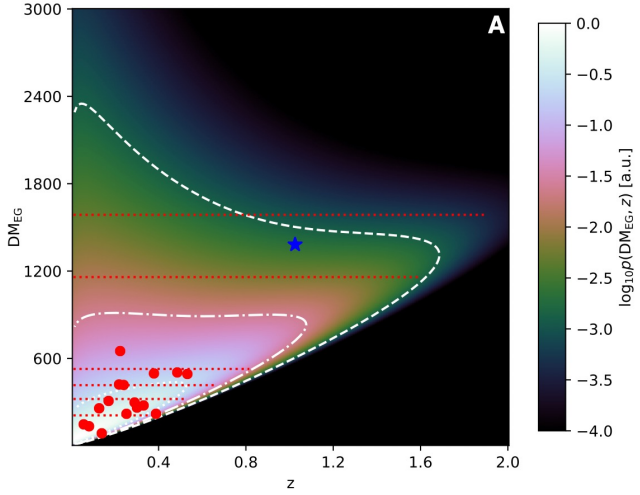
Science Drivers



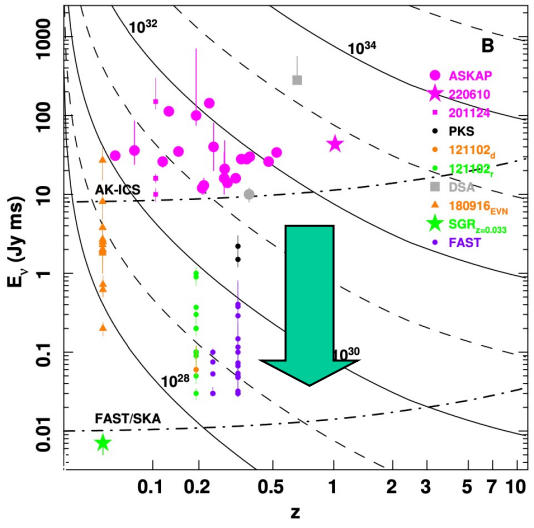
Ioka 2003



Next step:
Extend Macquart relation to higher z



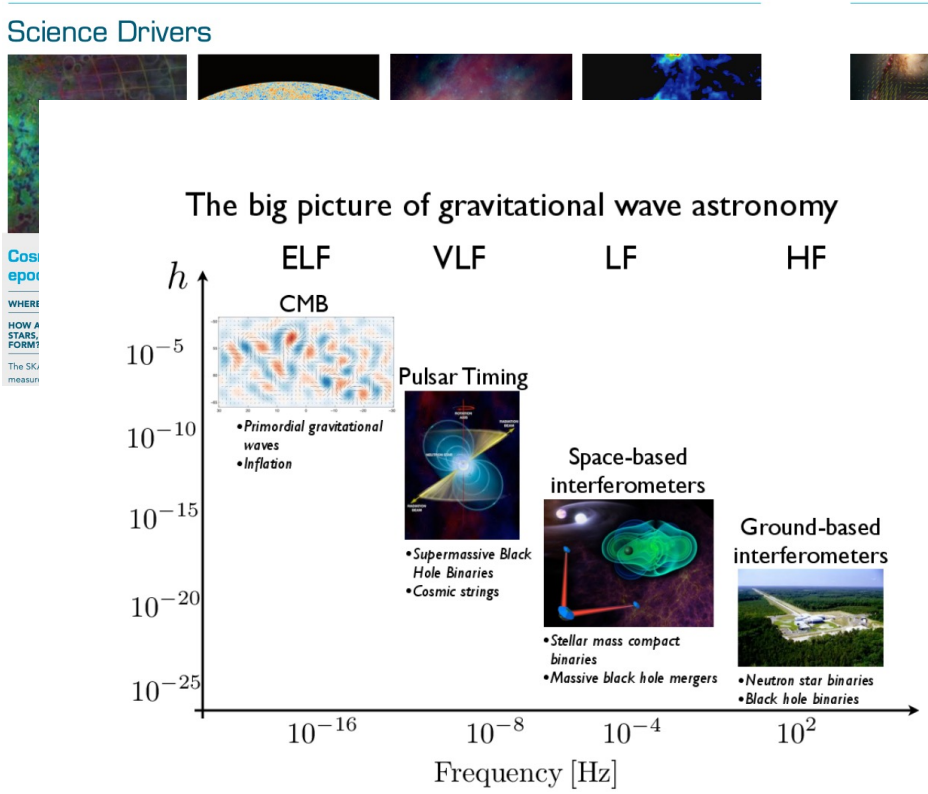
Ryder+2023: Discovery of FRB at z = 1.016 ± 0.002

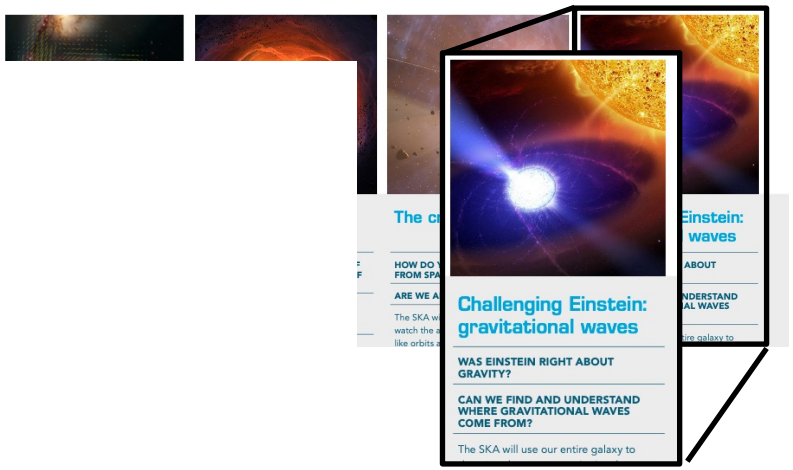


Need sensitive interferometers like the SKA
(lower fluence values + localization)

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

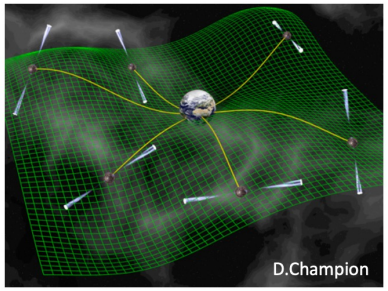
II – Cosmology with Gravitational Waves





Pulsar Timing Arrays (PTA)

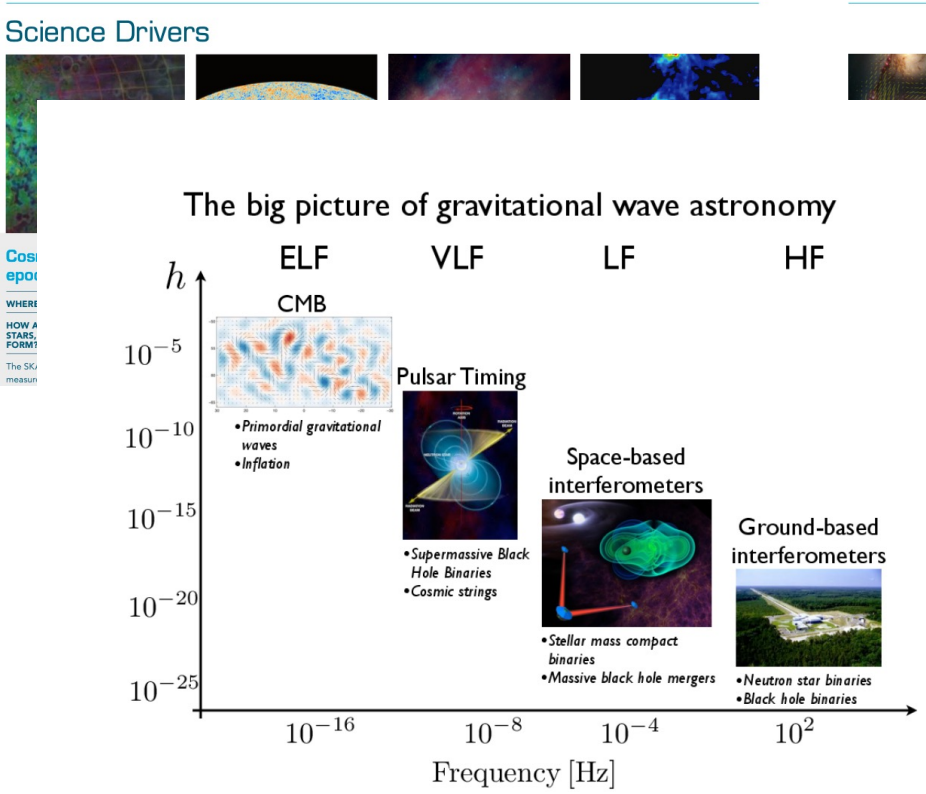
ultra precision (sub-microsec) pulsar timing from systematic monitoring of msec pulsars around the sky

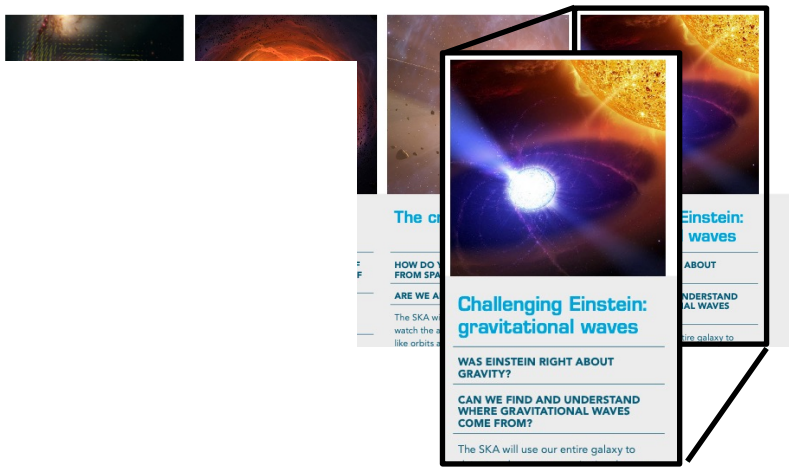


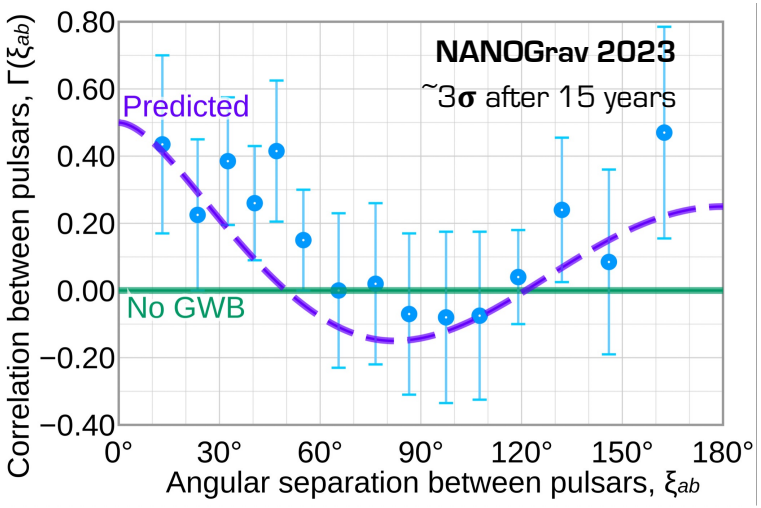
PTA: search for the effects of GW passing near the Earth, looking for signature of GW in the residuals when fitting timing model

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

II – Cosmology with Gravitational Waves



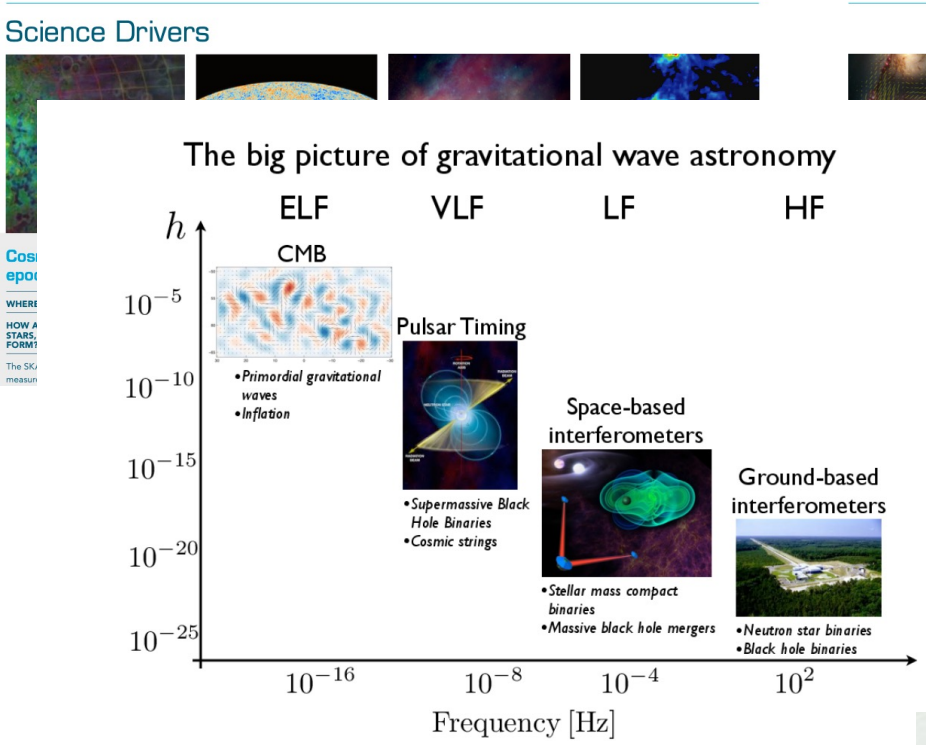


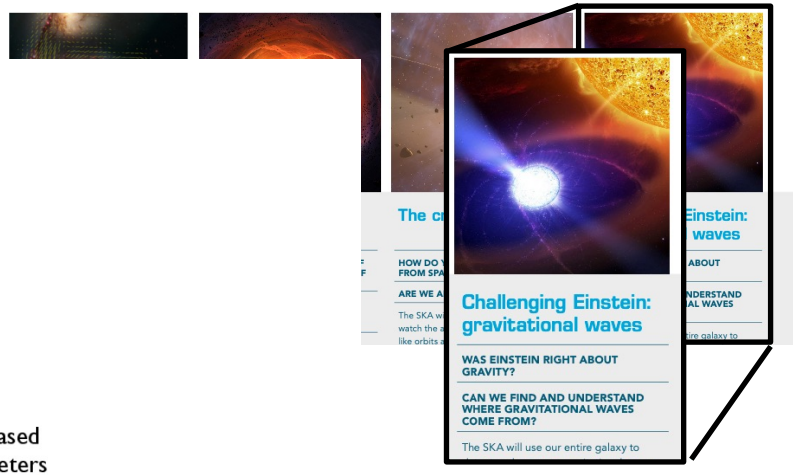


Main goal: measure amplitude of stochastic GW background, caused by SMBH mergers. Amplitudes can describe the history of how galaxies were formed.

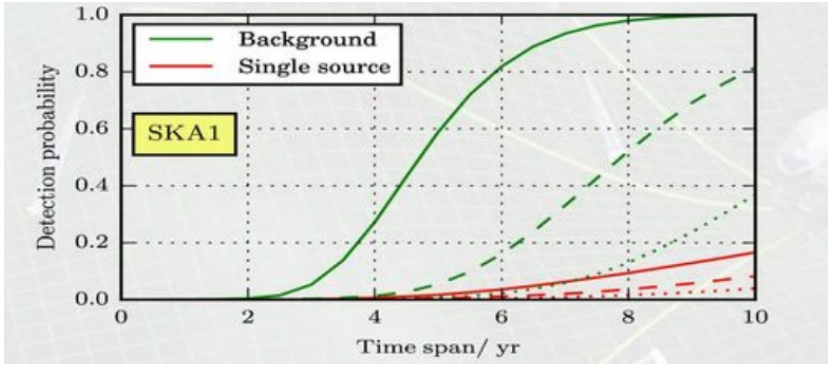
First tentative evidence of GW background announced on June 29th, 2023 – (NANOGrav, EPTA, PPTA, InPTA); See also CPTA **(**CPTA (FAST=500m): 4.6**σ** after 41 months)

II – Cosmology with Gravitational Waves





Courtesy Possenti



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

Take Home Message

Adapted from: SKAO Image