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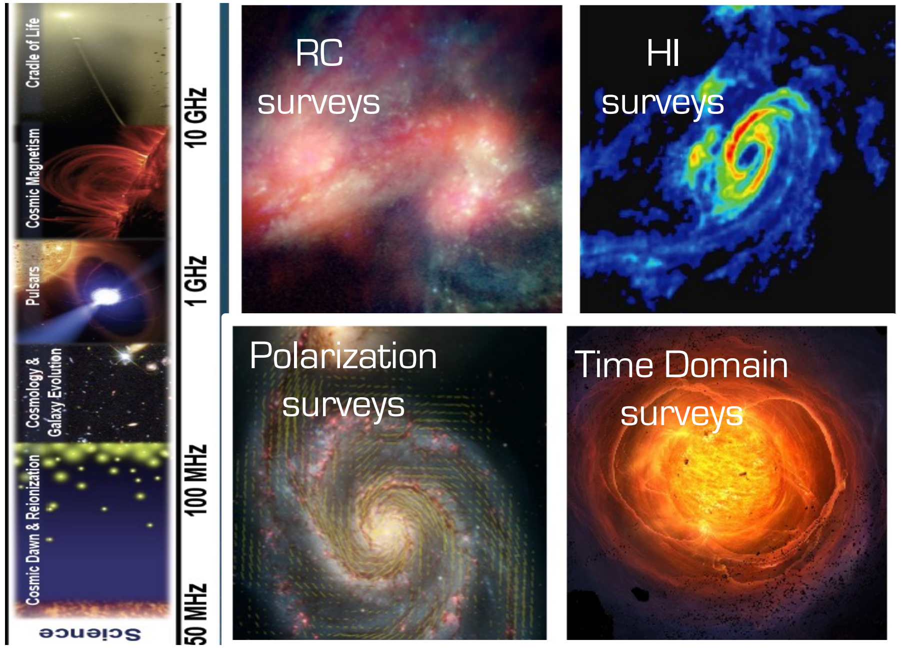


The SKA Observatory

SKAO

Perspectives and synergies with the Wide-field Spectroscopic Telescope

Isabella Prandoni – INAF - IRA

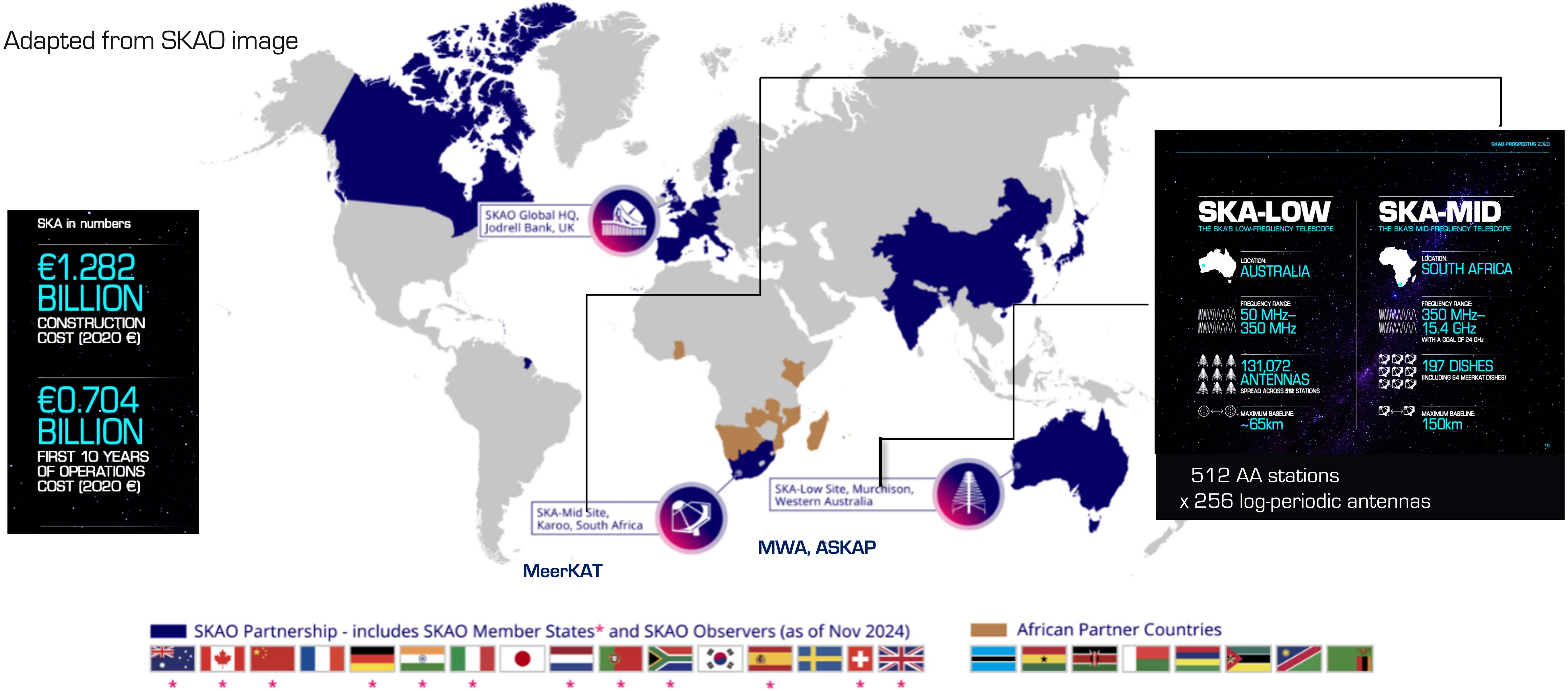
WST – Surveying the Universe in the 2040's and beyond
Napoli, 10-12 March 2025

PNRR
Missione 4 • Componente 2
Investimento 3.1
STILES – IR0000034
CUP C33C22000640006

SKAO

The SKA Observatory in a nutshell

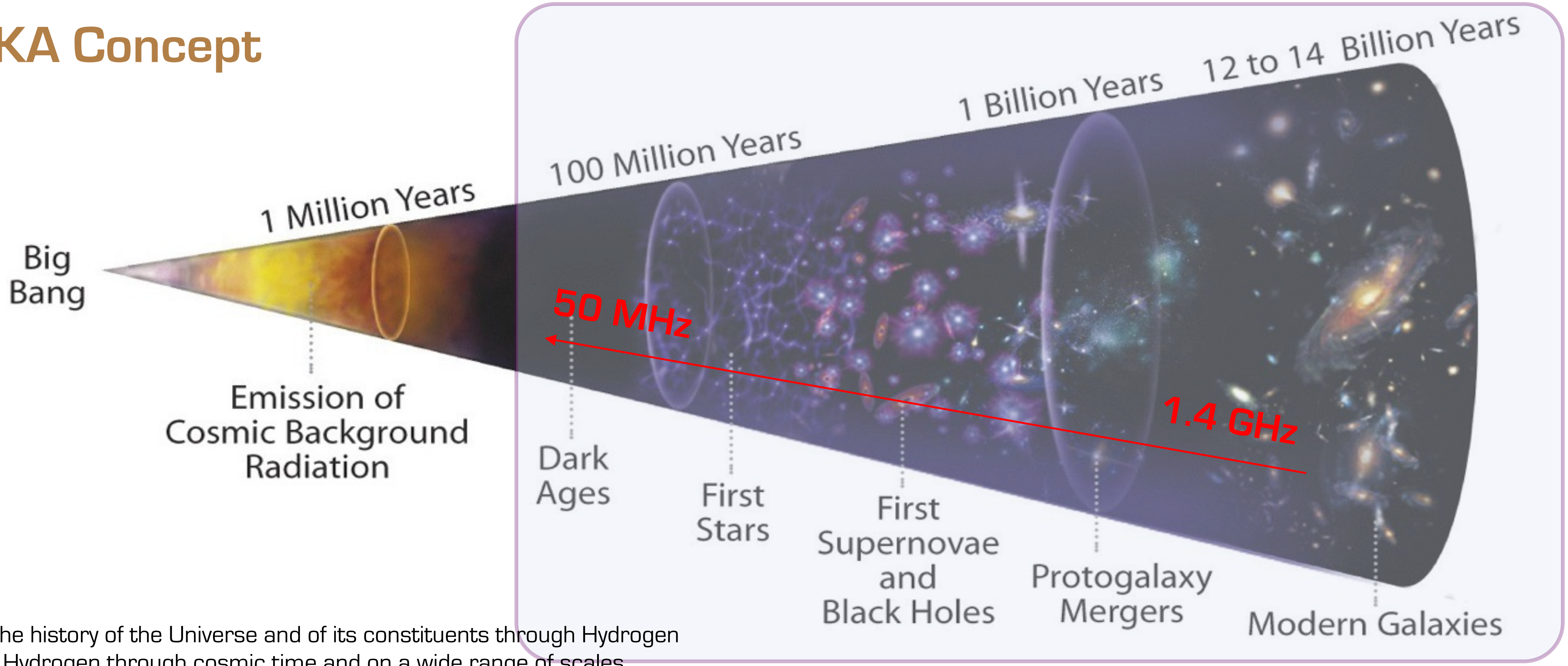
Adapted from SKAO image



Full members (Updated Nov 2024): Aus, Canada, China, Germany, India, ITA, NL, Portugal, RSA, Spain, Switzerland, UK

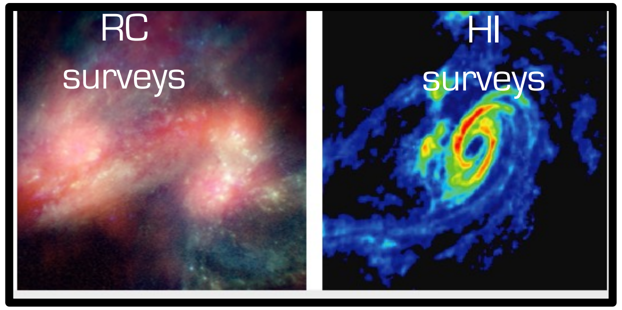
France, Japan, South Korea, Sweden on the path to join

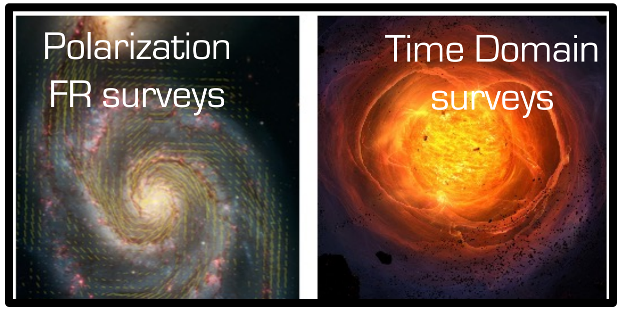
The SKA Concept



- 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**

The SKAO Science Case

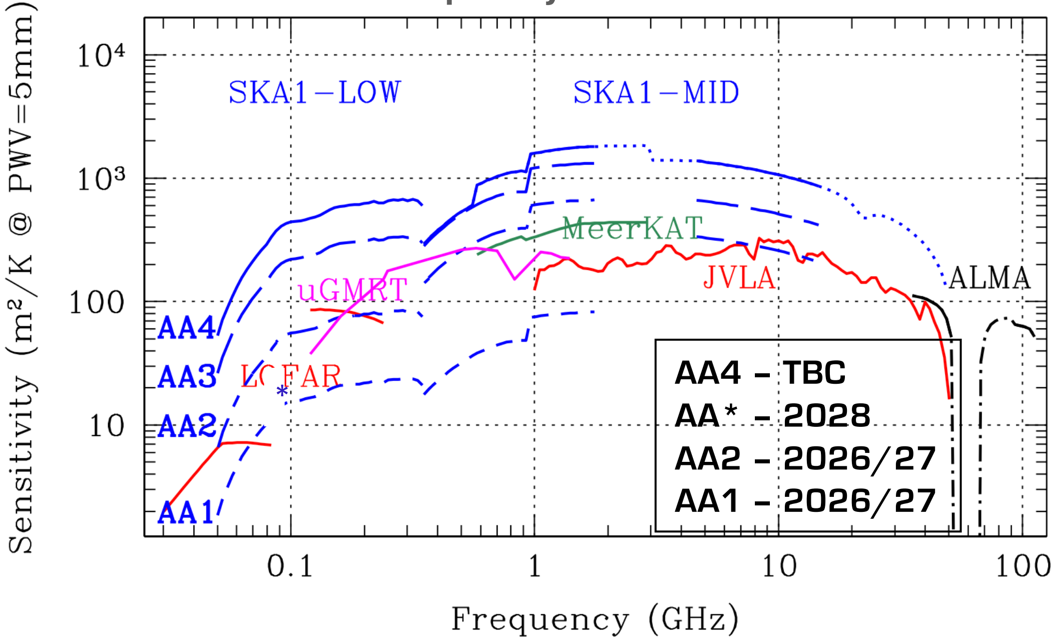




Multi-purpose Facility

The SKAO Timelines

Multi-frequency Infrastructure



Construction Strategy: Staged Delivery

5 Array Assembly (AA) phases

Milestone Event	Mid Dishes	Mid Date	Low Stations	Low Date
AA0.5	4 (4 SKA + 0 MeerKAT)	2026 Q2	4	2024 Q4
AA1	8 (8+0)	2027 Q1	16	2026 Q1
AA2	64 (64+0)	2027 Q4	68	2026 Q4
Science Verification begins 2027				
AA*	144 (80+64)	2028 Q3	307	2028 Q1
Operations Readiness Review		2029 Q1		2028 Q2
End of Staged Delivery		2029 Q1		2029 Q1
Early Operations begin 2029 (shared risk)				
AA4 (Full Design Baseline SKA1)	197 (133+64)	TBD	512	TBD

Updated November 2024. *Note that the construction schedule is updated each month at present, and the dates in this table reflect that schedule*. If the "updated" date is significantly different from today's date (i.e., > 3 months), then you may wish to request an updated schedule from us. Q1=Jan-Mar; Q2=Apr-Jun; Q3=Jul-Sep; Q4=Oct-Dec.

2021
Start of Construction activities

2024
Start of Science Commissioning

2027
Start of Science Verification **(AA2)**

2027/30
Key Science Projects (KSP) planning & proposals

2029
Shared risk + Start of PI-led programmes **(AA*)**

2031
Start of KSPs

II –Synergies with WST

Contributions from

E. Bianchi, S. Camera, A. Ingallinera, A. Mesinger, A. Possenti, P. Serra, G. Umana, V. Vacca

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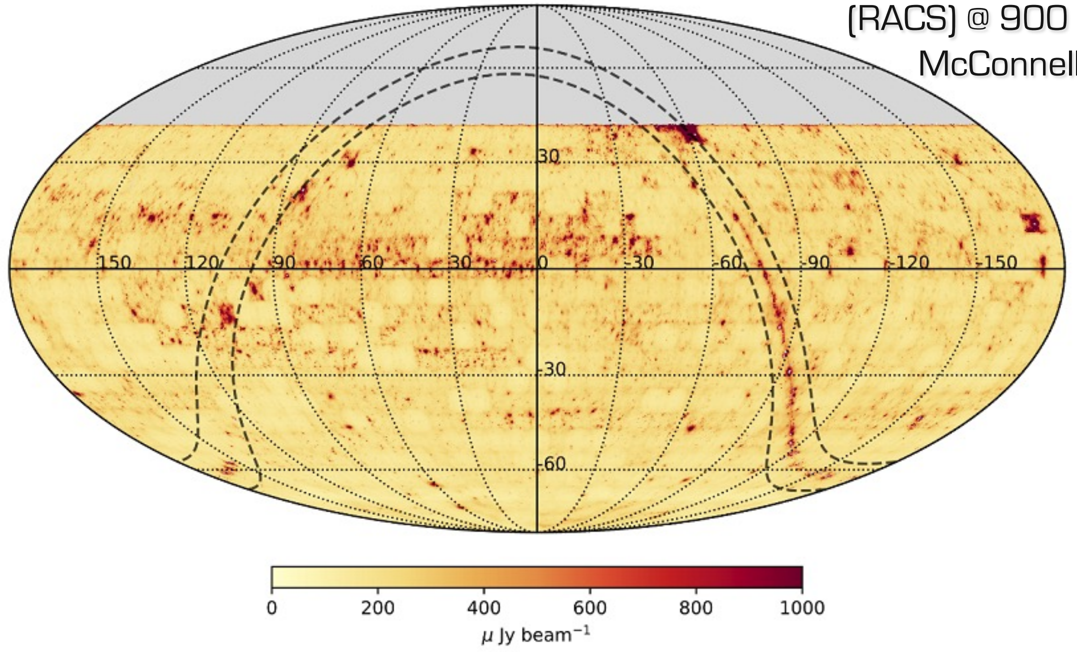
SKAO & WST: a complementary suite of surveys

SKAO: Multi-tier, Multi-frequency radio continuum and HI Surveys + time domain surveys

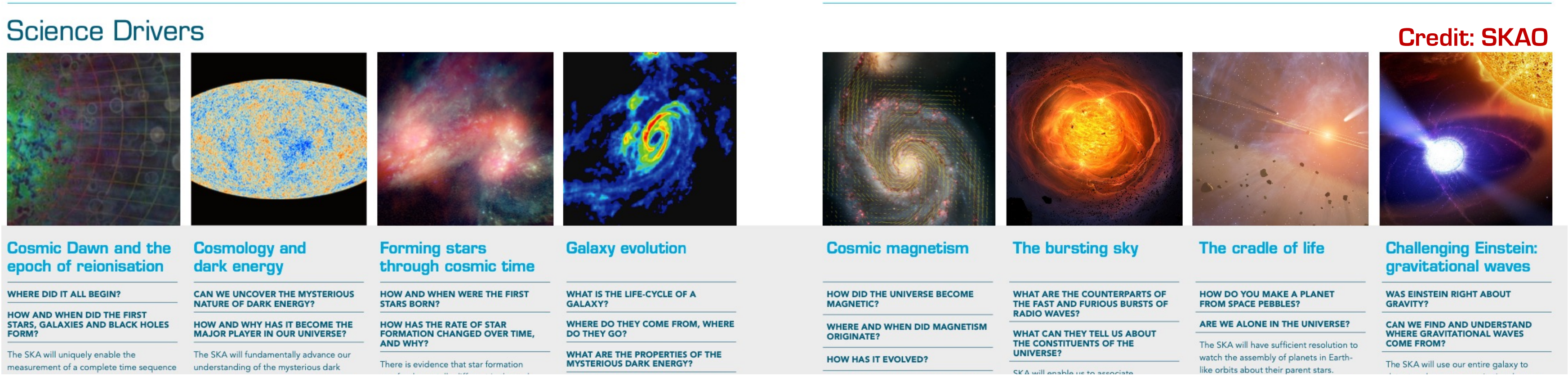
WST: wide-area deep optical spectroscopy (MOS+IFS)

- **WST & SKAO** will observe the **same sky**
- **WST**'s deployment schedule aligns with the full deployment of the **SKA** in its AA4 configuration
- **SKAO:** free-free and non-thermal processes, magnetic fields, SFR, HI gas mass & kinematics
- **WST:** redshifts & kinematics of stars and galaxies, line diagnostics, detailed chemical composition of stars

Rapid Askap Continuum Survey (RACS) @ 900 MHz McConnell+20



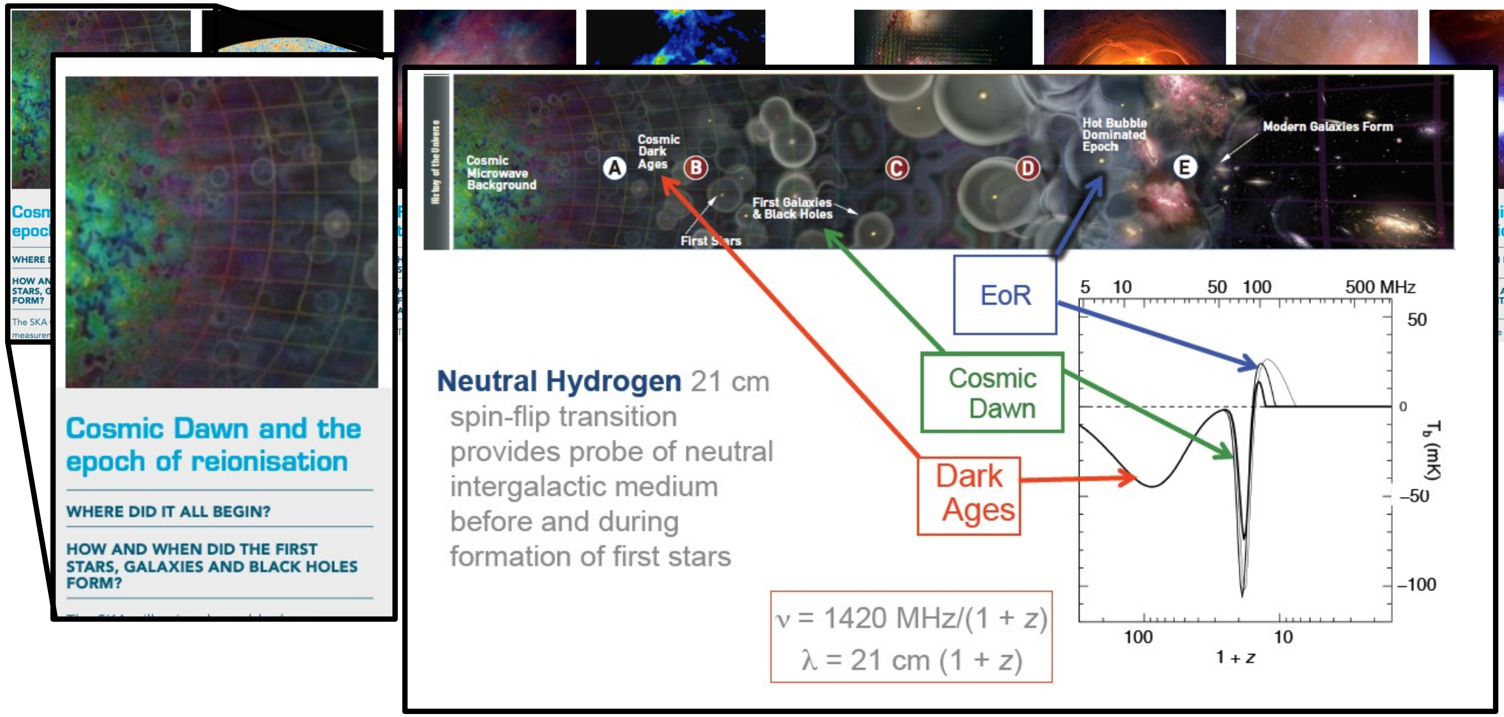
SKAO & WST: Science Drivers

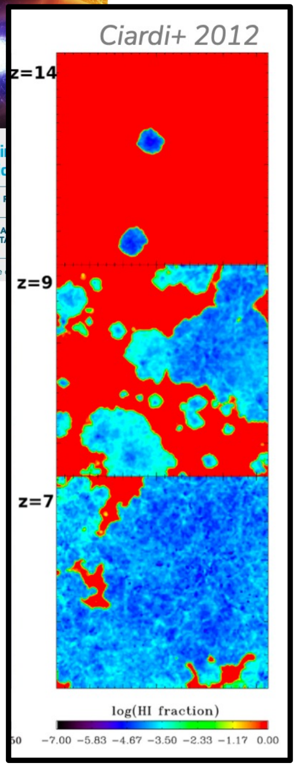


WST Science Drivers:

- Is the accelerated expansion of the Universe due to an unknown form of energy or to a modification of General Relativity on large scales?
- What is the interplay between dark, stellar, and gaseous material in galaxies and how does primordial and metal-enriched gas flow in and out of galaxies at various scales?
- What is the detailed formation history of our own Galaxy, the Milky Way and of its satellites?
- What is the origin of the various chemical elements that are crucial to trace galactic evolution?
- What are the conditions that drive the formation and evolution of extra-solar planets?
- What are the extreme physics conditions that govern transient events (explosions, eruptions, and disruptions)?
- What do gravitational waves tell us about neutron star physics, heavy element production, and cosmology?

Cosmic Dawn & EoR

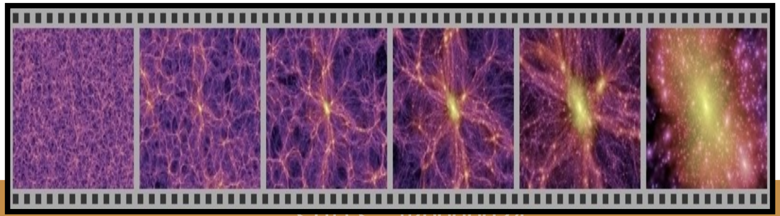




HI emission from the DA, CD & EoR traces evolving “movie” of baryonic and DM structure formation at $t_{univ} < 10^9$ years

Redshifted 21cm signal:

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



Epoch of Reionization

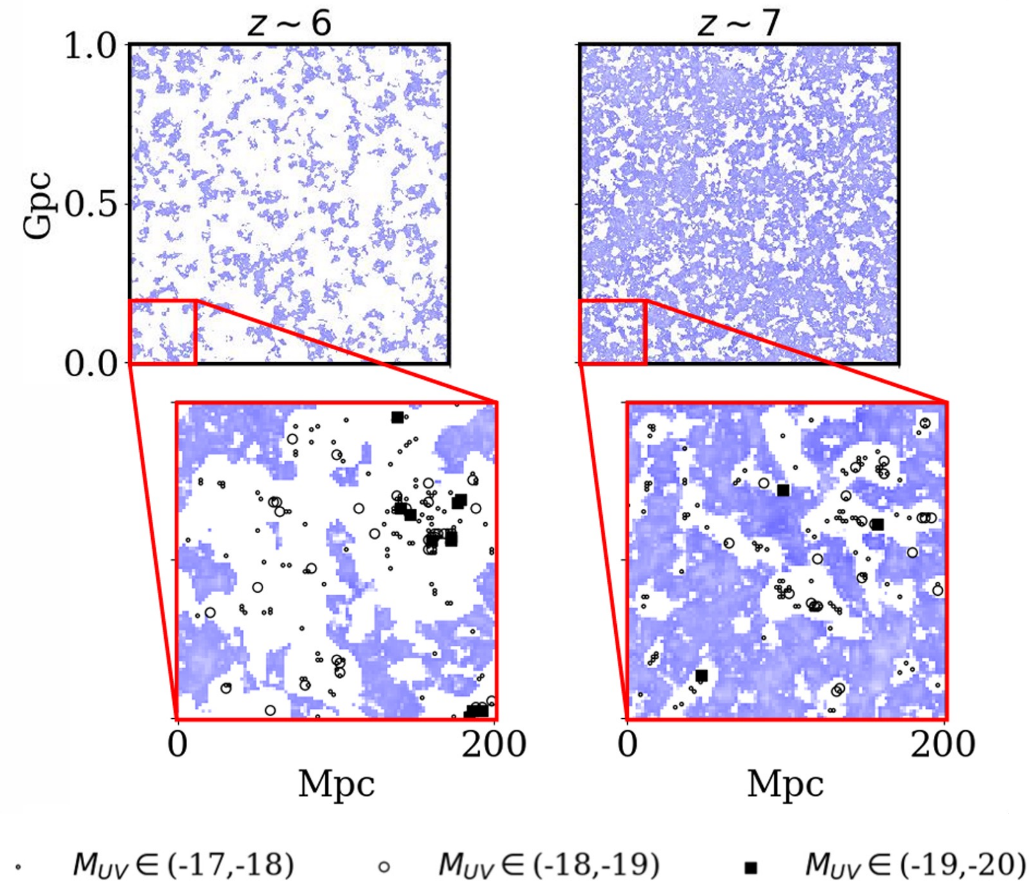
SKA-WST Synergy :
Galaxy –21cm cross correlation during Cosmic Reionization

Galaxies drive the epoch of reionization (EoR) → ***HI(21cm) and galaxies are anti-correlated on large scales***

Detecting this anti-correlation will

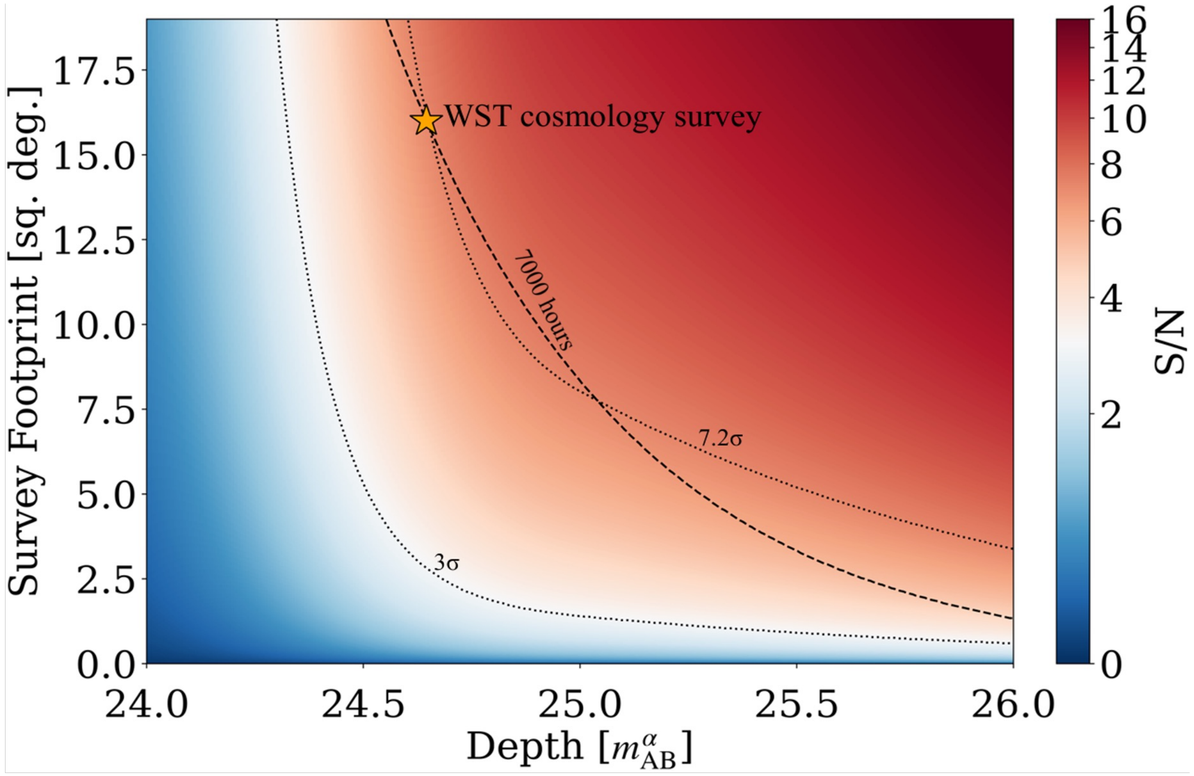
- **verify 21cm** detection claims (foregrounds are uncorrelated)
- **improve our understanding** of which galaxies drove EoR (>99.99% of EoR galaxies are too faint even for JWST)
- allow us to connect galaxies with their **local environment** (w. 21cm images)

Courtesy S. Gagnon-Hartman, A. Mesinger



Gagnon-Hartman+2025
https://arxiv.org/abs/2502.20447

Epoch of Reionization



WST + SKA AA4 cross-power detection

Galaxy cross-correlation with 21-cm requires at least two of:

1. Large survey footprint
2. Deep exposure
3. Low redshift uncertainty

WST has all three →

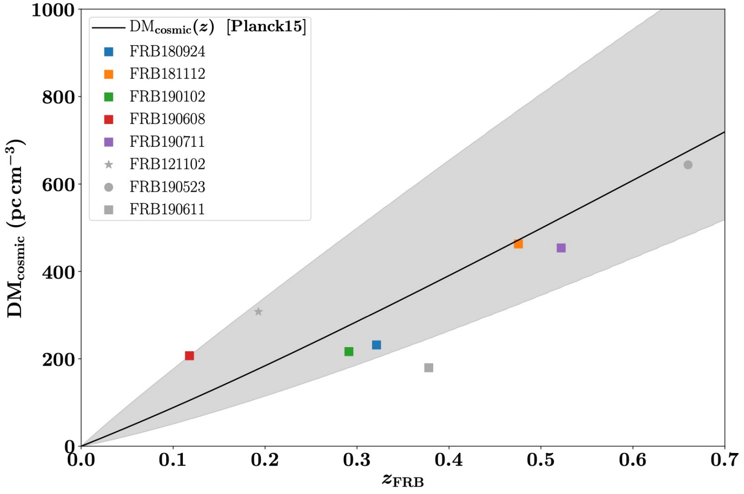
>7σ detection of the cross-power

Courtesy S. Gagnon-Hartman, A. Mesinger

Assuming moderate foregrounds, and combining 16 sq. deg. fields of 1k-hour SKA AA4 + 7k-hour WST IFU cosmology survey of Lyman alpha at z<7; **for simulation details see**: https://arxiv.org/abs/2502.20447

Fast Radio Bursts as cosmological probes

Science Drivers



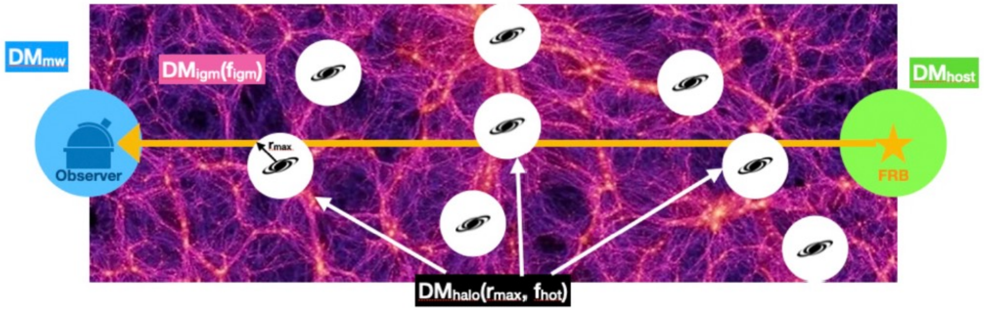
ASKAP
Macquart+2020 (Nature)

$DM = \int n_e(l)\ dl$

measures the electron column density along FRB line of sight

accounts for every ionised baryon

SKA will detect ~100 FRBs / day at z < 2 (Hashimoto+20)



Extragalactic Dispersion Measure – redshift (Macquart) **relation**
➔ Indipendent measurement of baryon content for localised FRBs (consistent with CMB and Big Bang Nucleosynthesis values)

→ **constraints the baryon distribution (CGM vs IGM) vs redshift**
→ **constraints on galaxy feedback models**

WST IFS + MOS: foreground LSS and intervening galaxies

See WST Science White Paper, Sect 6.5.5

Magnetogenesis

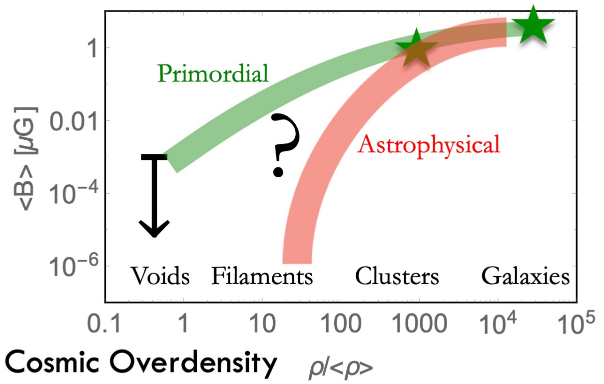
Magnetic fields permeate the Universe, but poorly constrained

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

Magnetic fields in filaments should carry memory of the initial field

SKA traces the magnetic fields through polarization / Rotation Measure (RM) grid surveys
WST traces the matter distribution in the Universe through MOS surveys
Caveat: photo-z uncertainties limit our ability to study weak magnetic fields, as those expected in the LSS

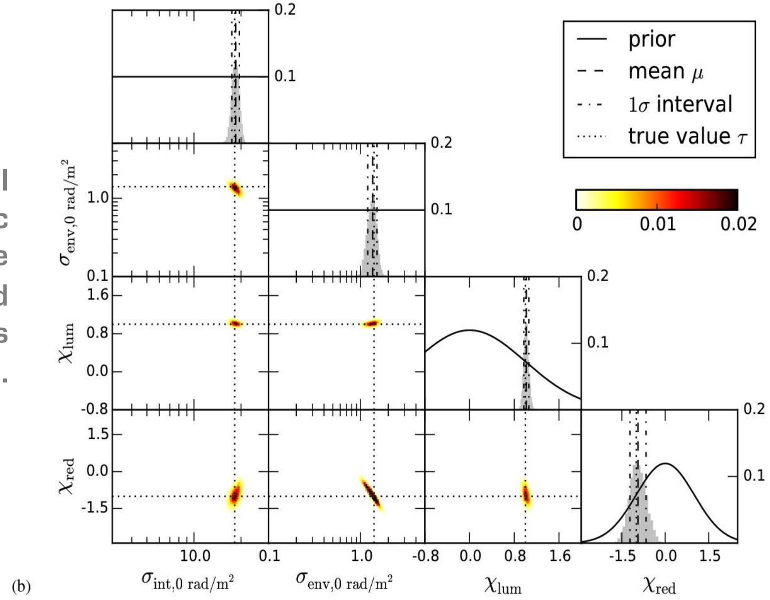
Courtesy O.Sullivan



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

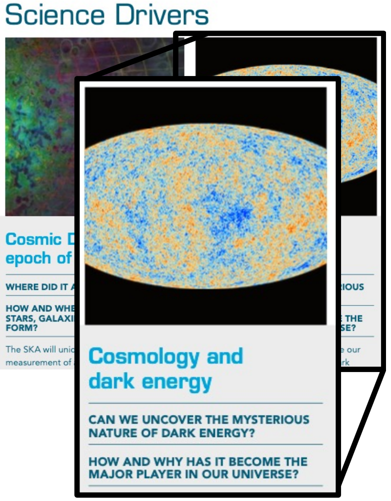
B-Astrophysical Scenario:
Magnetization by galactic winds and outflows powered by star formation feedback, SN, AGN (seed 10^{-11} G)

Expectations for statistical disentangling of extragalactic contributions to RM with the SKA RM grid and spectroscopic redshifts (Vacca et al. 2016).



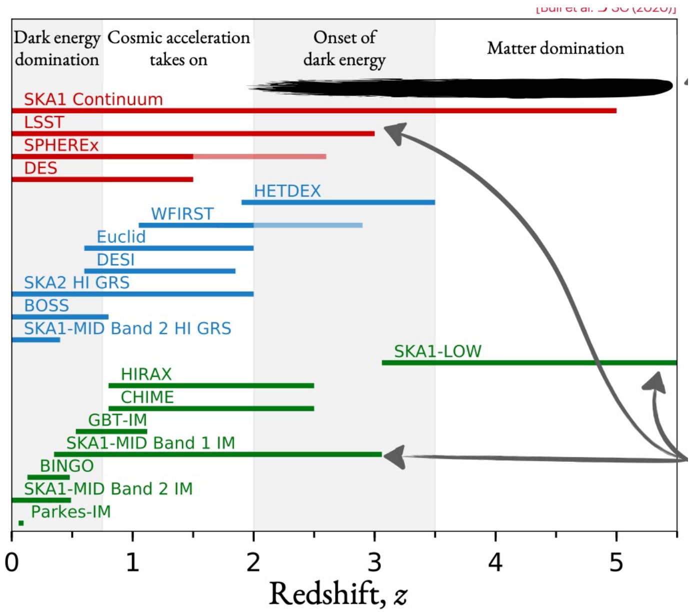
Adapted from V. Vacca

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. ⊃ SC 2020



Adapted from S. Camera

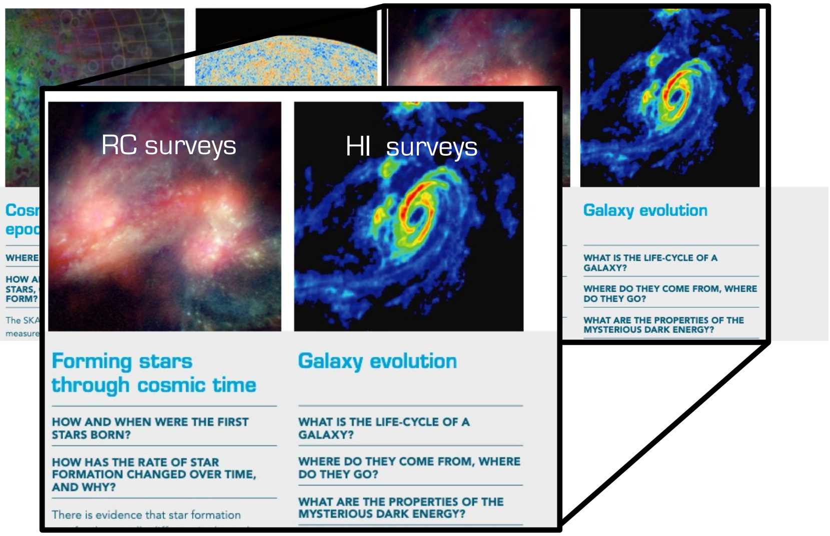
Continuum surveys:
weak lensing, galaxy clustering, Integrated SW Effect, Cosmic Dipole, etc.

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

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

Galaxy Formation & Evolution

Science Drivers



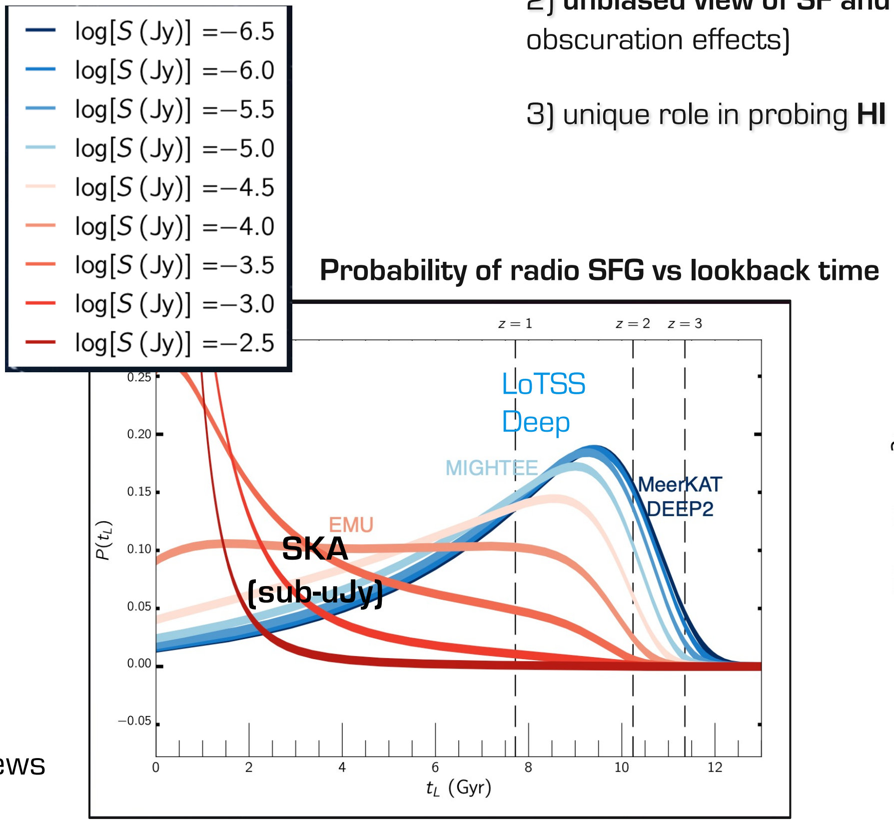
New generation Radio surveys:

1) unique role in **probing jetted AGN populations**

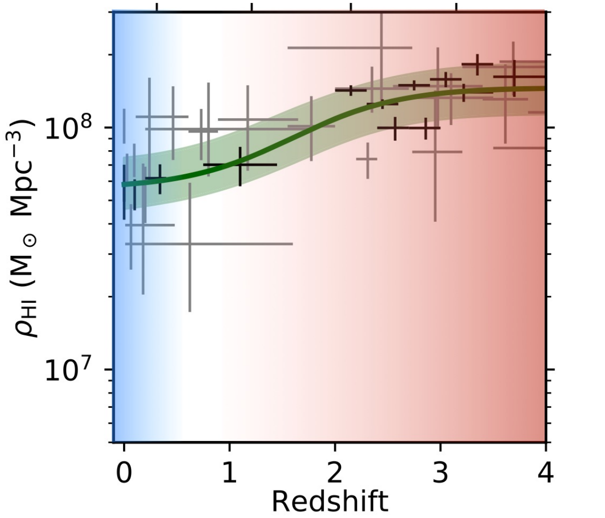
2) **unbiased view of SF and AGN populations** (no dust extinction/gas obscuration effects)

3) unique role in probing **HI properties of galaxies and AGN**

Probability of radio SFG vs lookback time



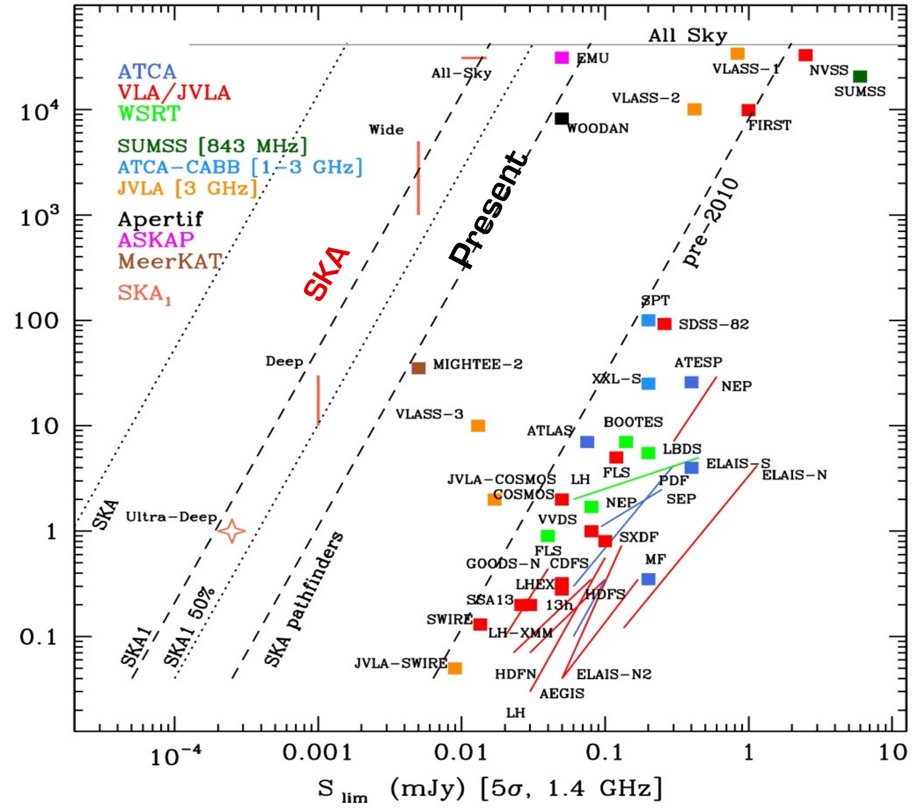
Courtesy A. Matthews



SKAO & WST working together

SKA Band 2 radio continuum extra-gal. surveys

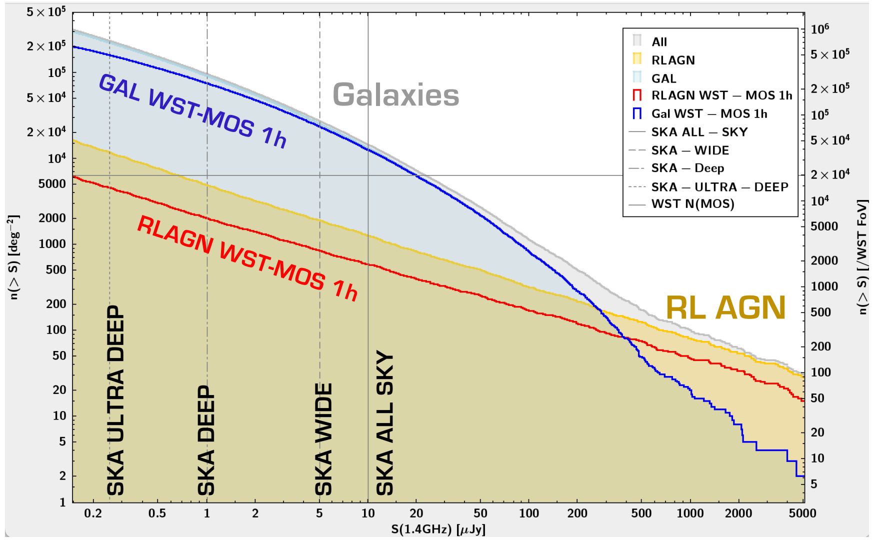
Prandoni & Seymour 2015



Optical/NIR spectroscopy

- ➔ source redshifts, line diagnostics (source classification, SFR, metallicity, etc.)
- ➔ **wider cosmological context (environment)**
- ➔ **IFS -** resolved multi-component (ionized gas, stars) studies on (sub-)galactic – CGM scale →

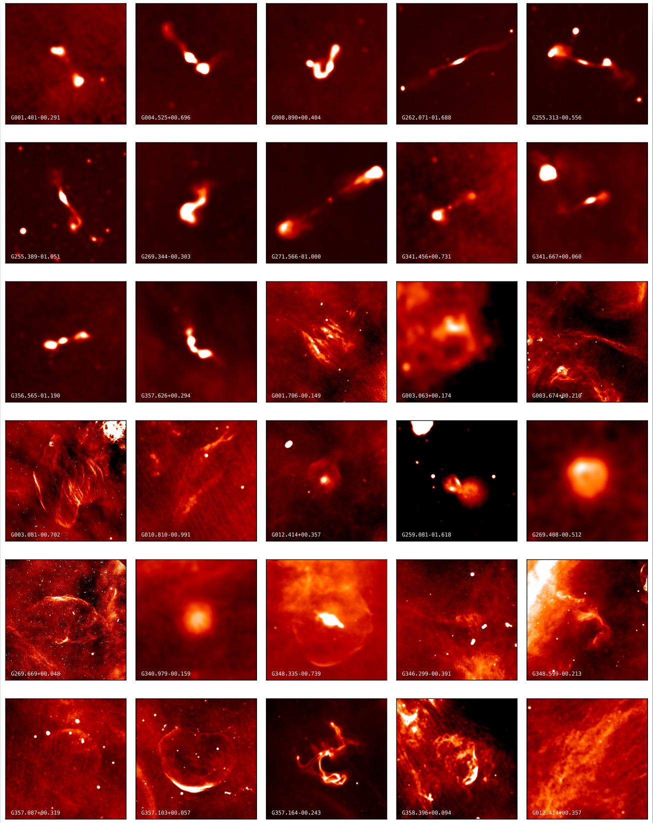
See talk by Filippo Maccagni



Adapted from Prandoni+24

Radio source cumulative distribution vs flux denisty

Galactic Science – Galactic Plane Surveys



Bordiu+24
Goedhart+24

Adapted from G. Umana

The SARAO MeerKAT Galactic Plane Survey catalogued **16487 extended sources**

- Only 24% known Galactic objects
- Many potentially new **SNR**s, giant **HII regions** or **evolved star candidates**
- Uncovering **new population of Planetary Nebulae**, particularly **at low galactic latitude**

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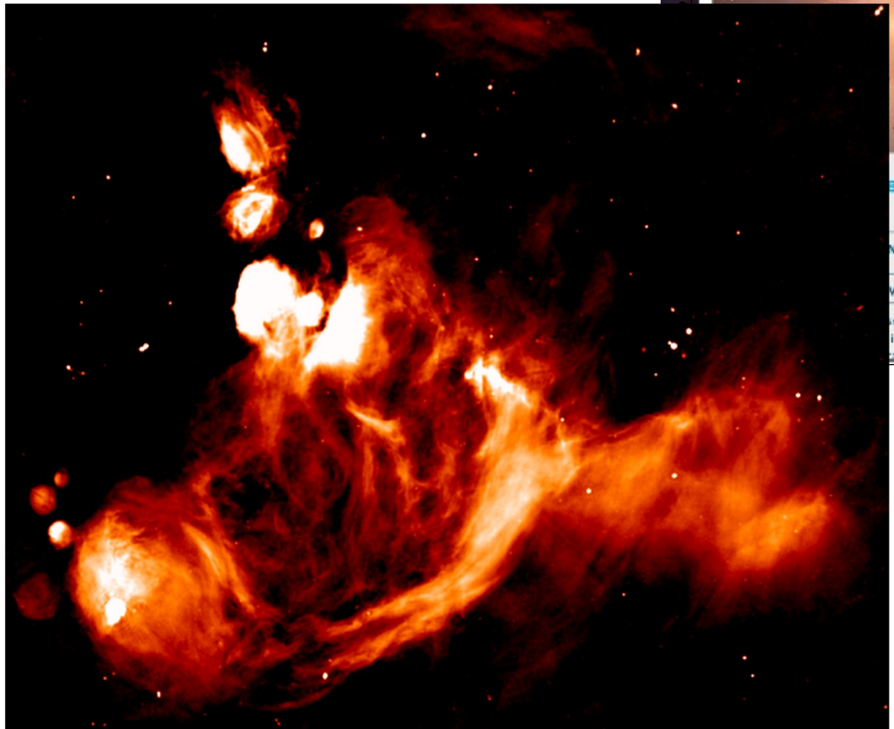
Galactic Science – HII Regions & PNs

WST will provide **kinematics** through detection of the **emission lines** in ionised nebulae, as **H II regions and Planetary nebulae**

SKA will provide information on:

- **Total ionised mass** through **radio continuum** (mostly free-free from thermal electrons)
- **Electron density and temperature** through **radio recombination lines**



An H II region observed with ASKAP (Umana et al. 2021)

Courtesy I. Ingallinera

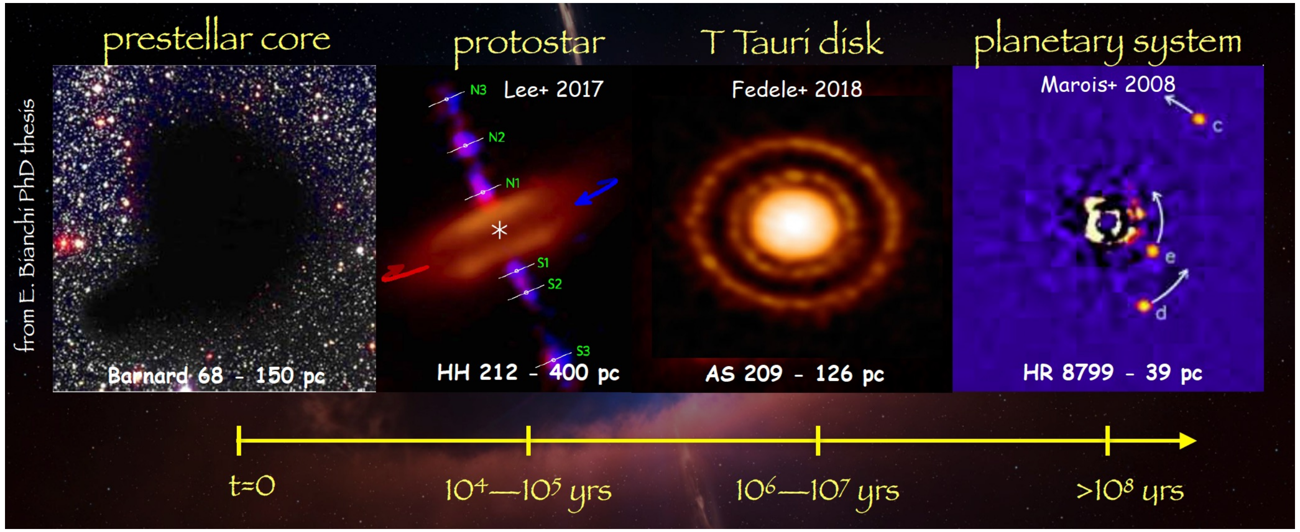
Galactic Science – Star and planet formation

High complementarity with WST

- **SKAO:** focus on proto-stellar embedded objects (10^4-10^5 yr) and their chemical properties through cm wavelength observations

Important to constrain the initial conditions of planet formation process

- Complex carbon chains and rings have their brightest transition < 50 GHz
- dust is optically thin at radio band
- SKA can resolve the small regions (<100 AU) where planetary systems are forming



Adapted from E. Bianchi

- **WST:** Stellar properties and accretion/ejection processes of young populations (pre-MS, I 1-10 Myr)

➔ **WST & SKAO together** will trace proto-stellar evolution and star formation in nearby galaxies and at the borders of our Galaxy

Take home messages:

- Radio future is bright! SKA in behind the corner and SKA precursors are already producing transformational results
- Strong case for joint SKA/WST studies
- Time to get engaged and establish collaborations