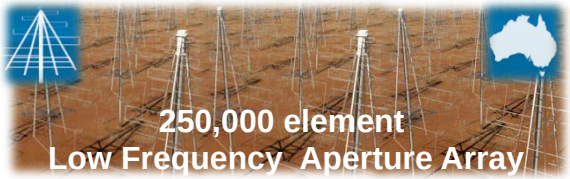
Square Kilometre Array – Design and Science Performance

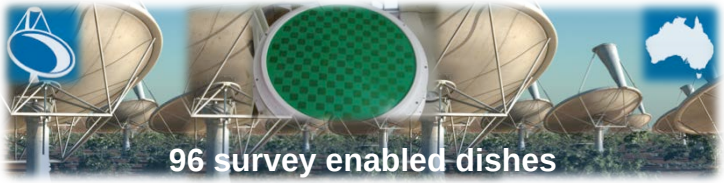
Robert Braun
SKA Science Director
13th November 2013

Exploring the Universe with the world's largest radio telescope

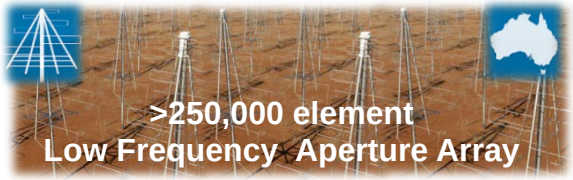
SKA
SQUARE KILOMETRE ARRAY

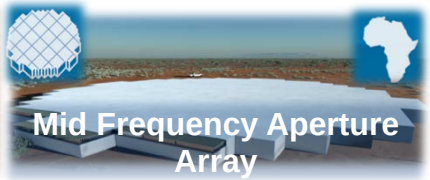
Phase I : 2020



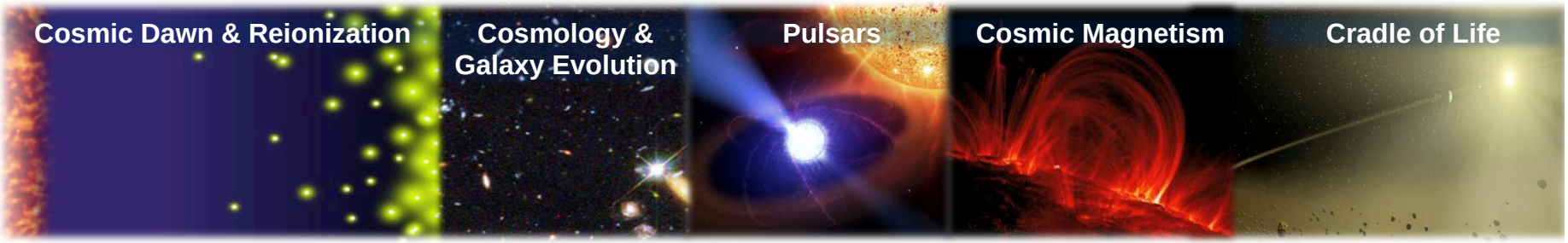


Phase II : 2024





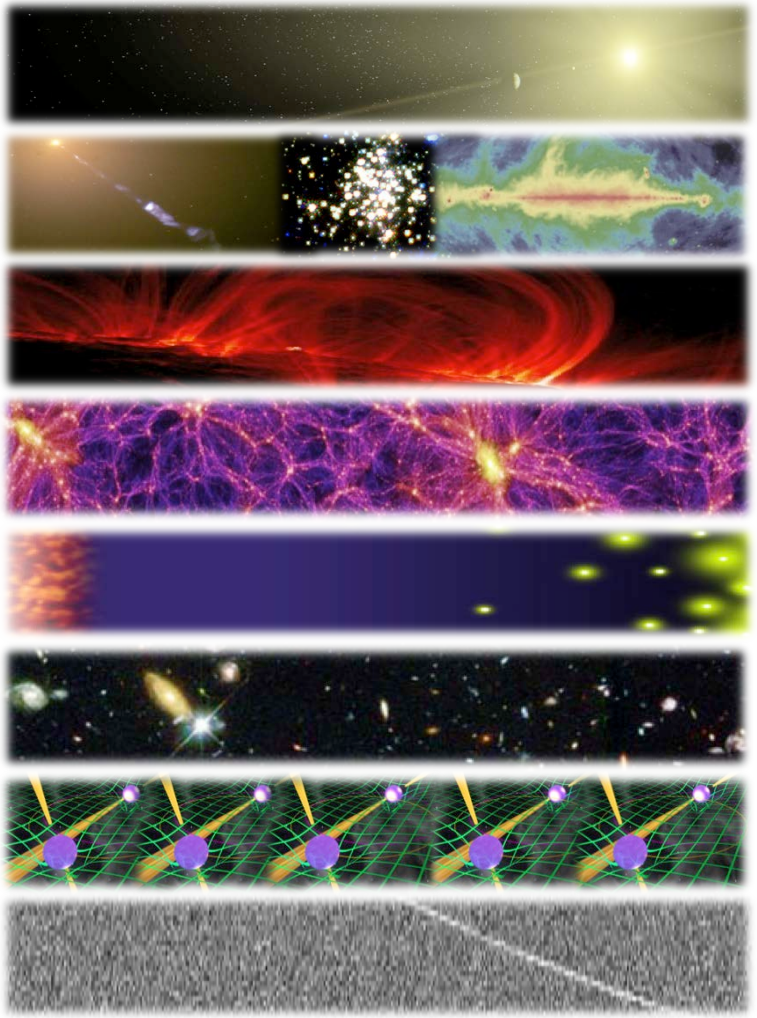
Science



50 MHz 100 MHz 1 GHz 10 GHz

The Science Working Groups

- **Astrobiology (“The Cradle of Life”)**
  - *Project Scientist:* Tyler Bourke
  - *Working Group Chair:* Melvin Hoare
- **Continuum**
  - *Project Scientist*: Jeff Wagg
  - *Working Group Chairs:* Nick Seymour & Isabella Prandoni
- **Cosmic Magnetism**
  - *Project Scientist:* Jimi Green
  - *Working Group Chairs:* Melanie Johnston-Hollitt & Federica Govoni
- **Cosmology**
  - *Project Scientist:* Jeff Wagg
  - *Working Group Chair:* Roy Maartens
- **Epoch of Reionisation & the Cosmic Dawn**
  - *Project Scientist:* Jeff Wagg
  - *Working Group Chair:* Leon Koopmans
- **HI Galaxies**
  - *Project Scientist:* Jimi Green
  - *Working Group Chairs:* Lister Staveley-Smith & Tom Osterloo
- **Pulsars (“Strong field tests of gravity”)**
  - *Project Scientist:* Jimi Green
  - *Working Group Chairs:* Ben Stappers & Michael Kramer
- **Transients**
  - *Project Scientist:* Tyler Bourke
  - *Working Group Chair:* Rob Fender



Exploring the Universe with the world’s largest radio telescope

The Work Package Consortia

Project Scientist: Jimi Green

Project Scientists: Jeff Wagg & Tyler Bourke

Project Scientist: Tyler Bourke

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Project Scientists: Jimi Green & Tyler Bourke

Project Scientist: Jimi Green

Project Scientist: Jimi Green

Project Scientist: Tyler Bourke

Project Scientist: Tyler Bourke

Project Scientist: Tyler Bourke

Project Scientists: Jeff Wagg & Tyler Bourke

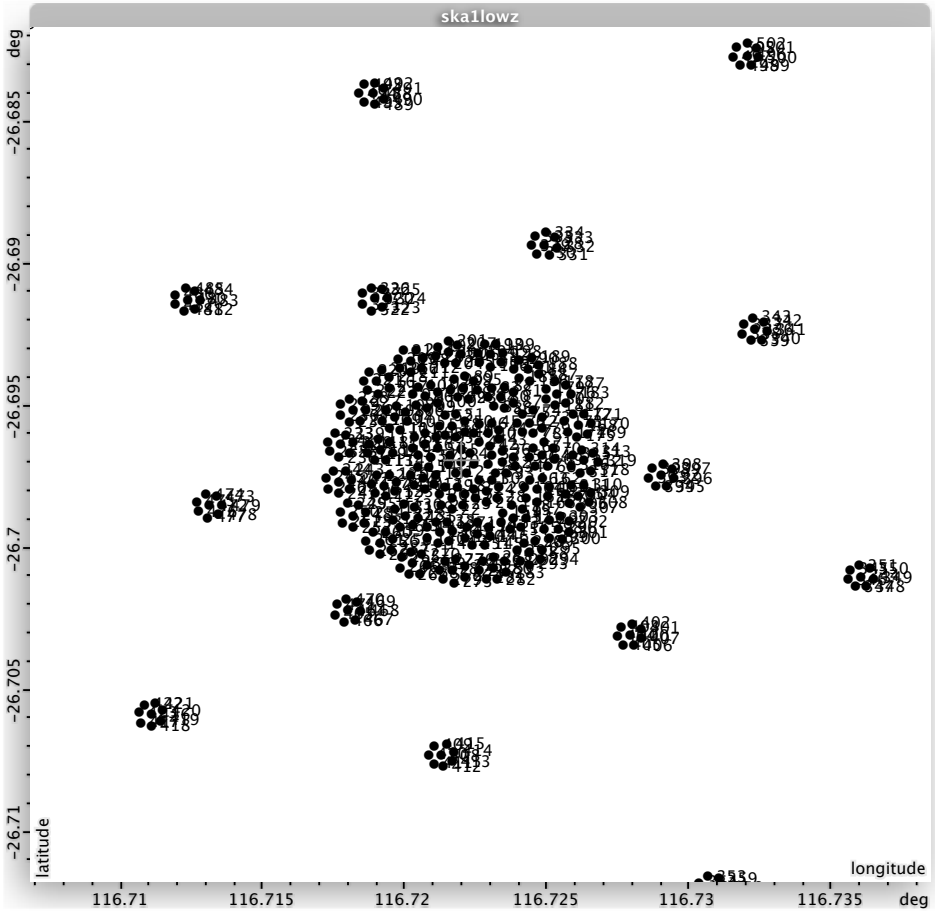
How does SKA1 baseline redefine state-of-art?

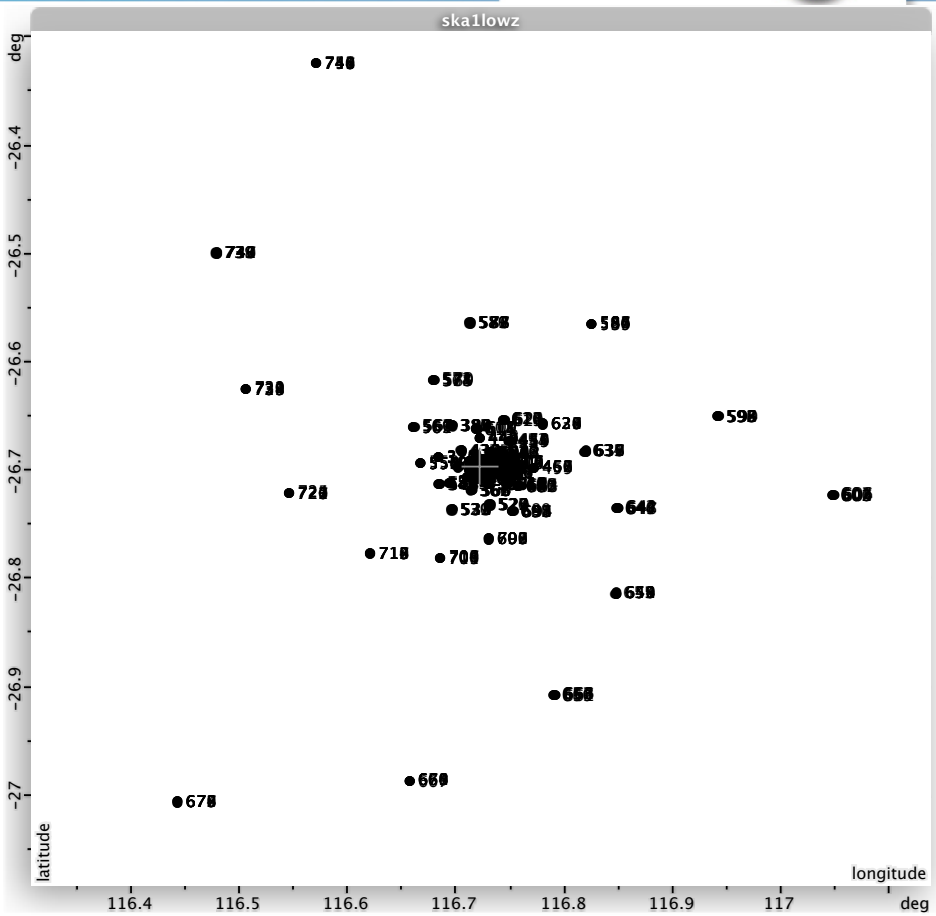
		JVLA	MeerKAT	SKA1-mid	ASKAP	SKA1-survey	LOFAR-NL	SKA1-low
Aeff/Tsys	m^2/K	265	321	1630	65	391	61	1000
Survey FoV	deg^2	0.14	0.48	0.39	30	18	6	6
Survey Speed FoM	$deg^2\ m^4\ K^{-2}$	0.98×10^4	5.0×10^4	1.0×10^6	1.3×10^5	2.8×10^6	2.2×10^4	6.0×10^6
Resolution	arcsec	1.4	11	0.22	7	0.9	5	11

A_{eff}/T_{sys}: 6xJVLA 6xASKAP 16xLOFAR

Survey Speed: 100x 22xASKAP 270x 280xJVLA

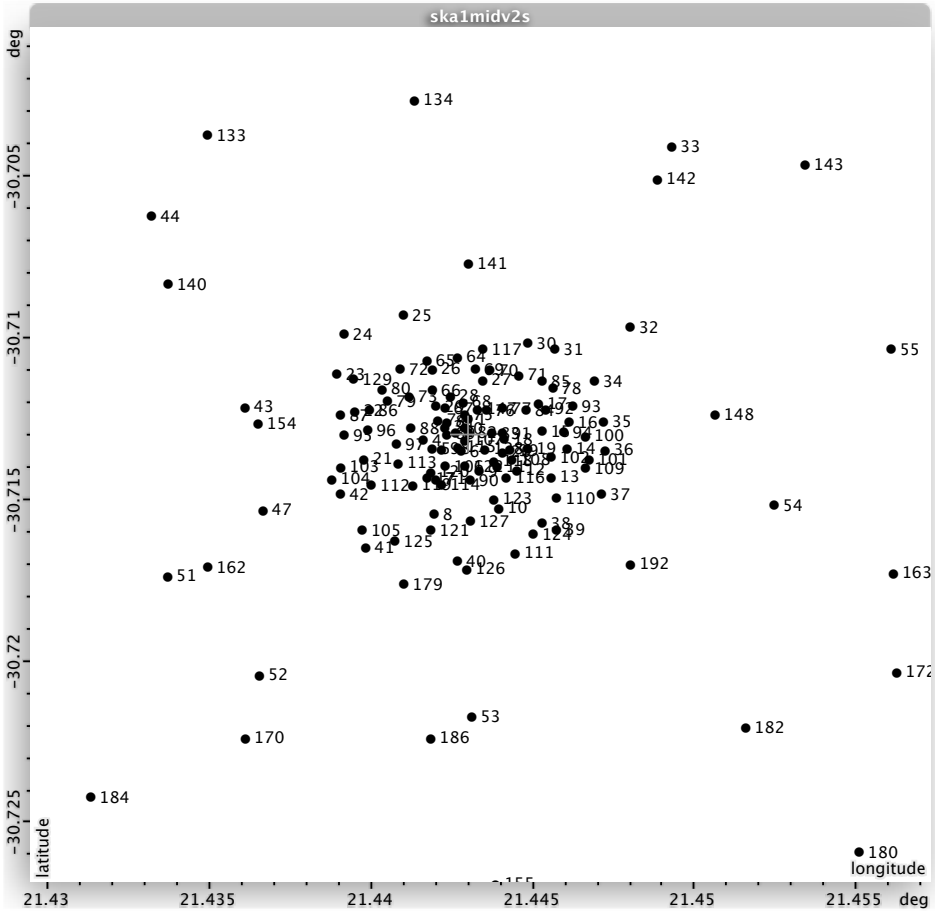
SKA1 “2nd generation” configurations

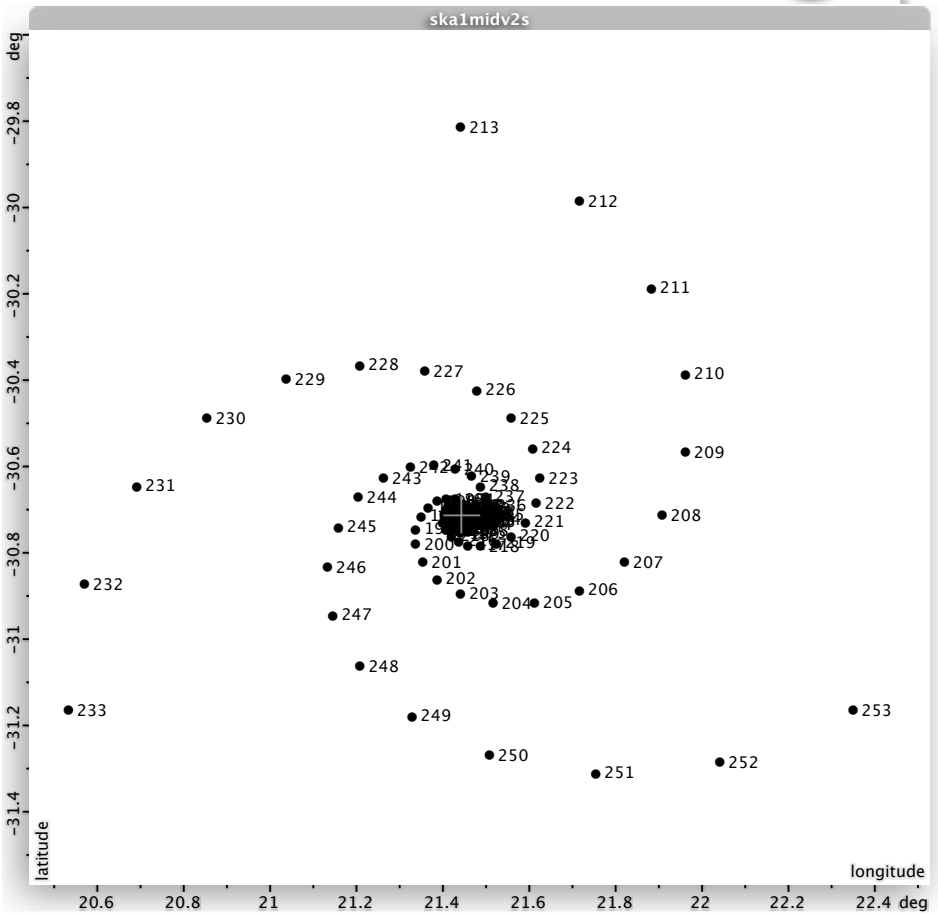




- SKA1-LOW possible configuration of core and remote spiral

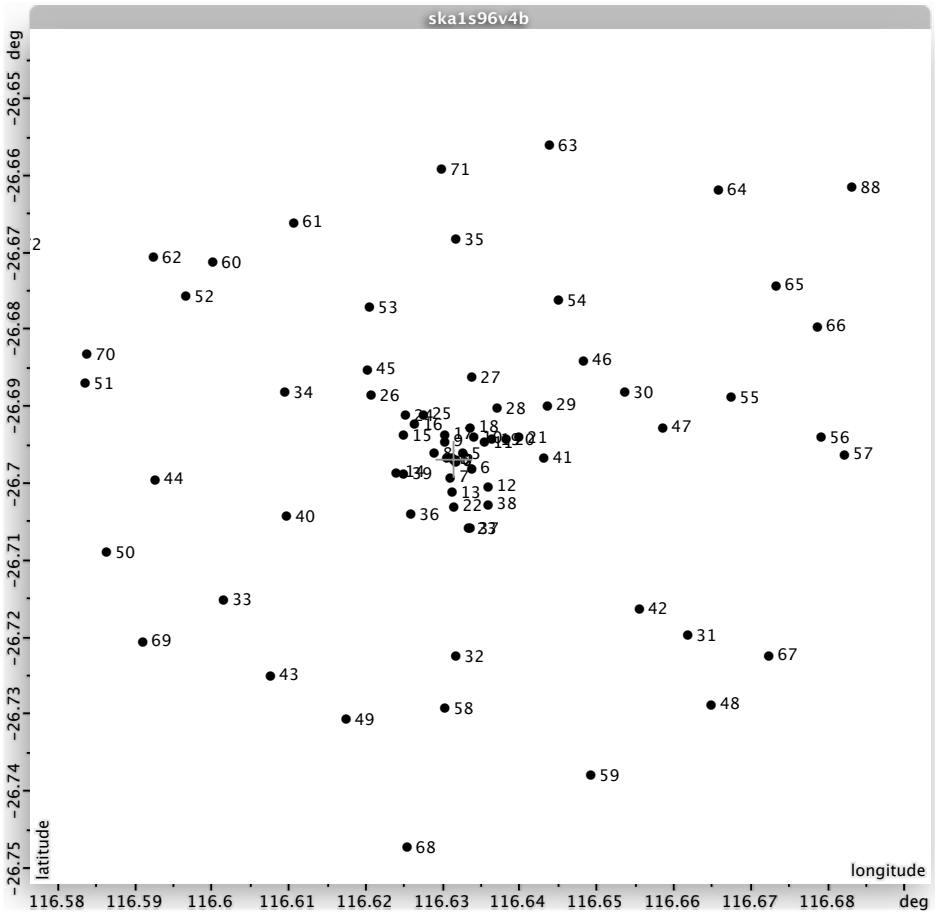
SKA1 "2nd generation" configurations

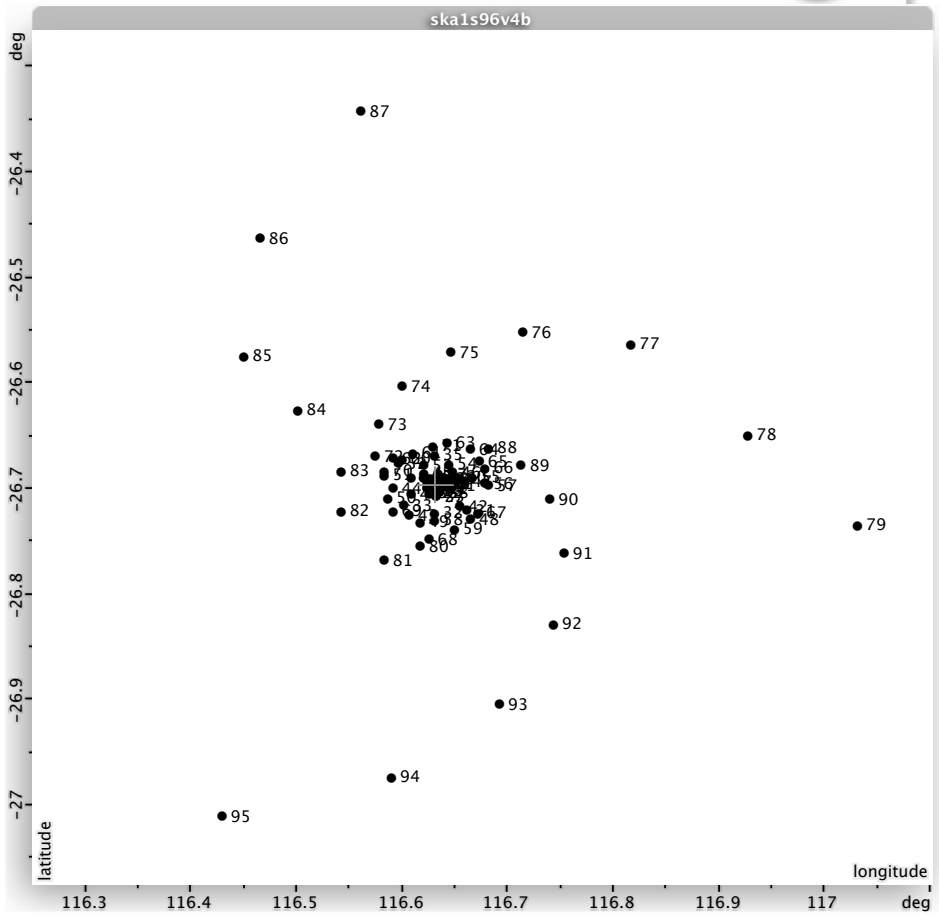




- SKA1-MID possible configuration of core and remote spiral

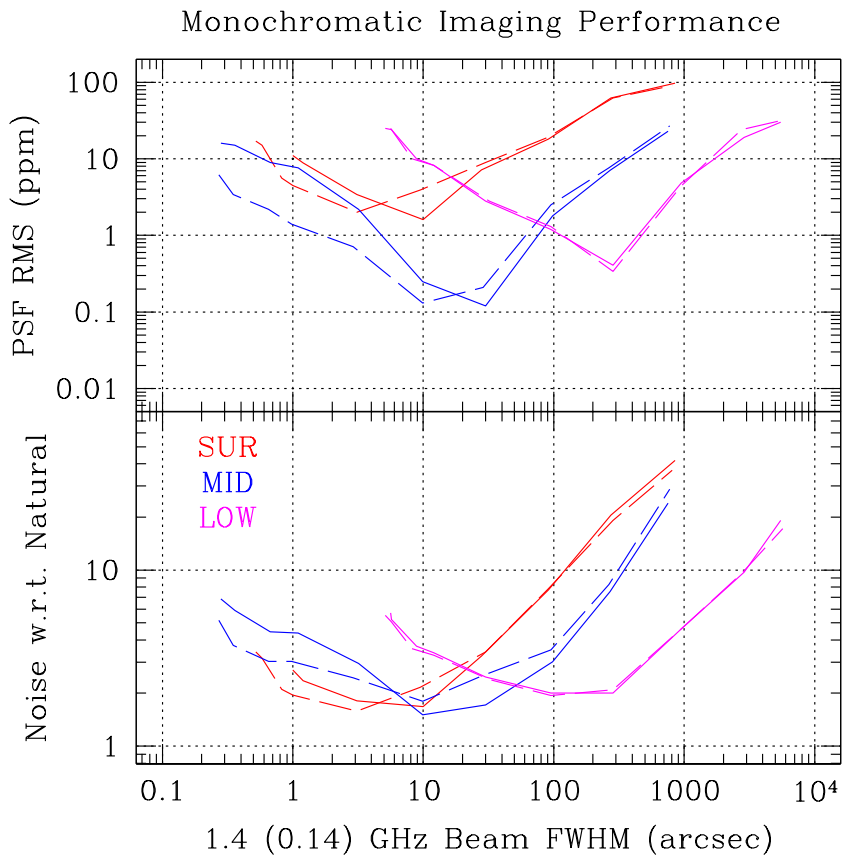
SKA1 “2nd generation” configurations

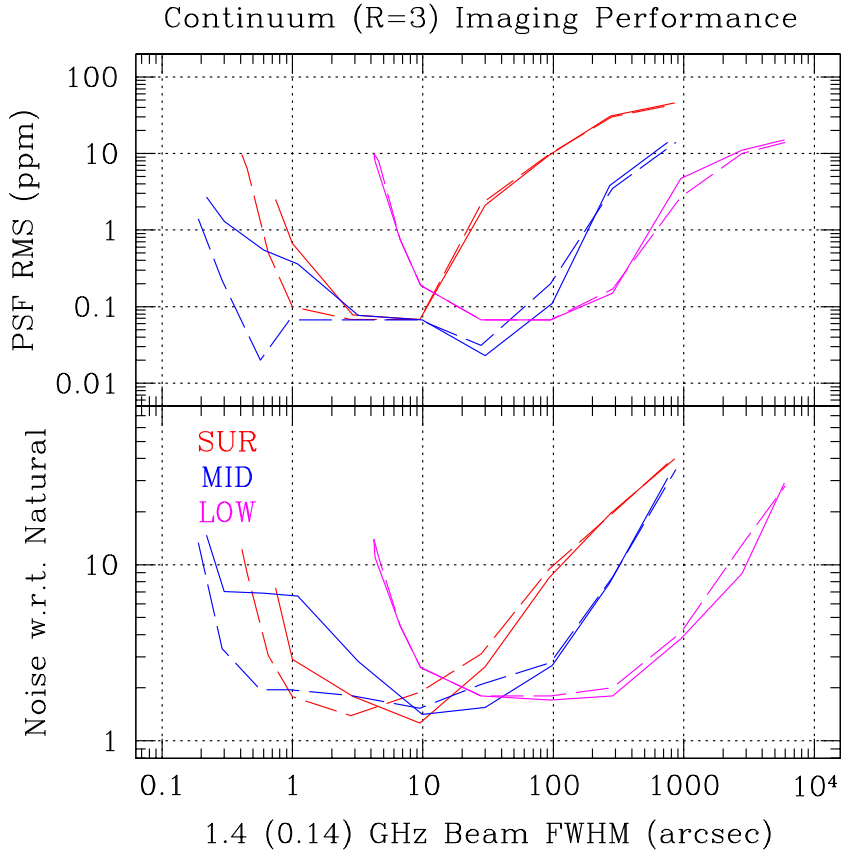




- SKA1-SUR possible configuration of core and remote spiral

SKA1 performance as function of scale





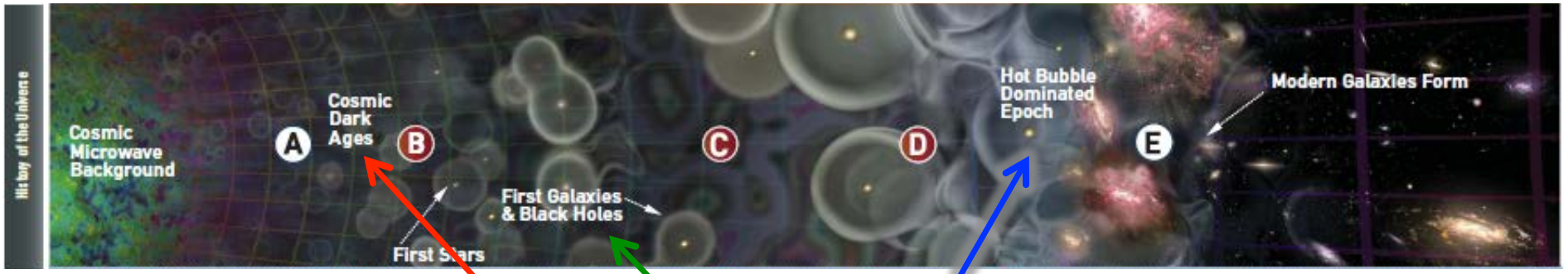
- Configuration optimisation for broad performance “sweet-spot”

SKA Key Science

- Strong-field Tests of Gravity with Pulsars and Black Holes
  Phase 1 headline science
- Galaxy Evolution, Cosmology, & Dark Energy
  Phase 1 headline science
- Emerging from the Dark Ages and the Epoch of Reionization
  Phase 1 headline science
- The Cradle of Life & Astrobiology
- The Origin and Evolution of Cosmic Magnetism

With design philosophy of *Exploration of the Unknown*

Cosmic Origins
Probing the early universe with the 21cm HI Line

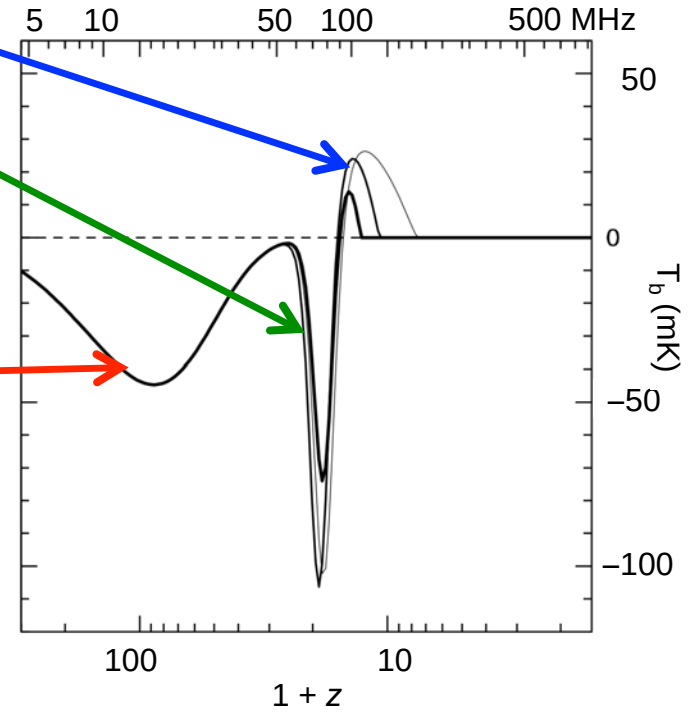


Neutral Hydrogen 21 cm spin-flip transition provides probe of neutral intergalactic medium before and during formation of first stars

EoR

Cosmic Dawn

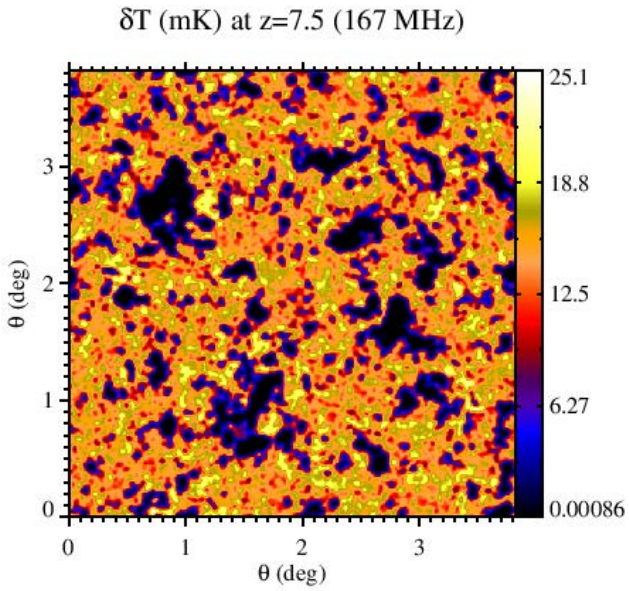
Dark Ages

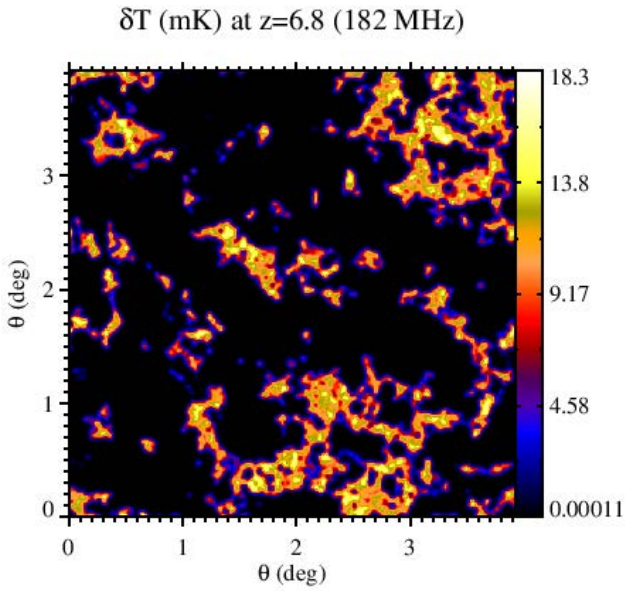


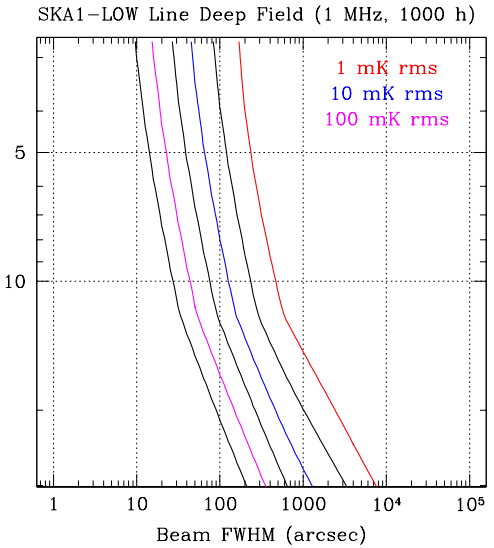
$\nu = 1420 \text{ MHz}/(1 + z)$

$\lambda = 21 \text{ cm } (1 + z)$

HI surveys of the EoR/Cosmic-Dawn Universe



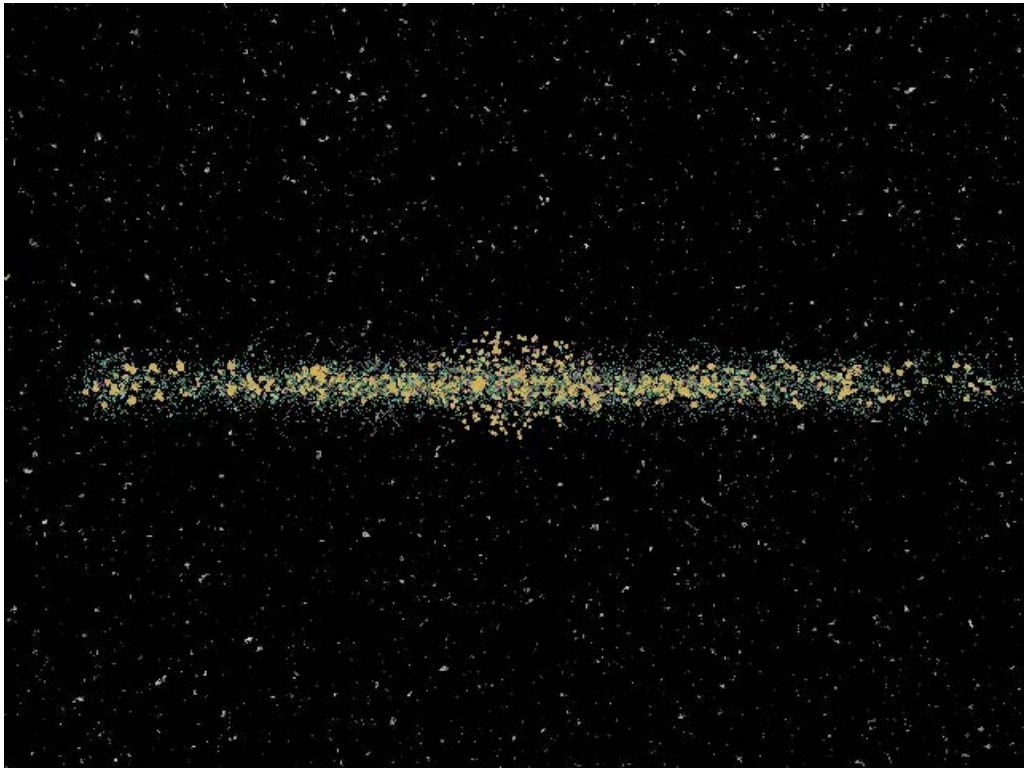


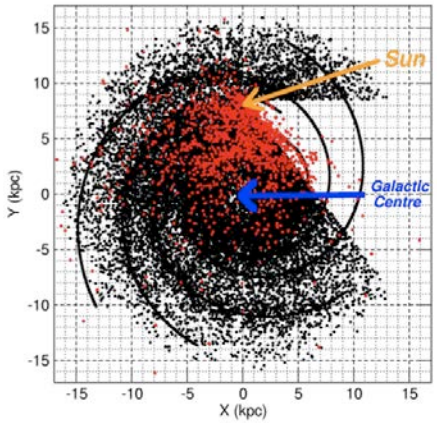


- **Detecting EoR structures in imaging mode (as distinct from statistically) on 5 arcmin scales with 1 mK RMS**
- **Probing the Cosmic Dawn statistically or possibly even imaging in ultra-deep**

Finding all pulsars in the Milky Way…

(Cordes et al. 2004, Kramer et al. 2004, Smits et al. 2008)



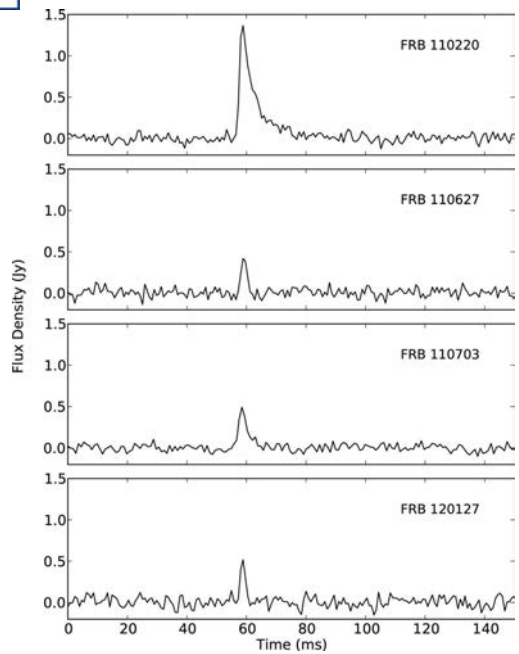


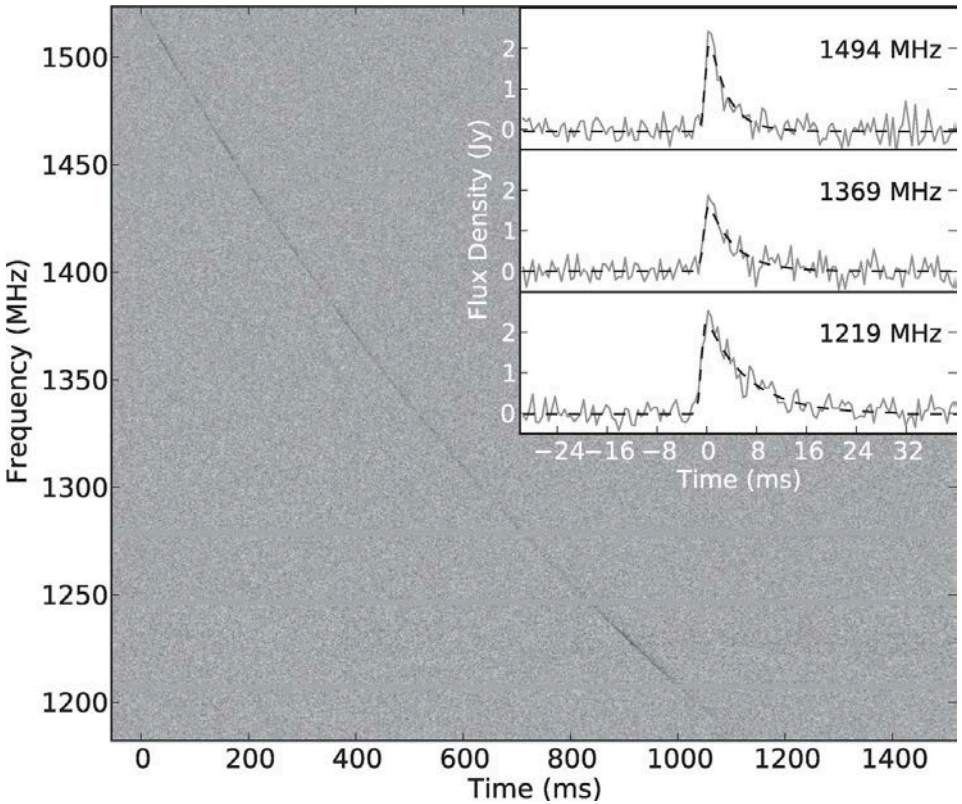
- ~30,000 normal pulsars
- ~2,000 millisecond psrs
- ~100 relativistic binaries
- first pulsars in Galactic Centre
- first extragalactic pulsars

- Timing precision is expected to increase by factor ~100
- Rare and exotic pulsars and binary systems: including PSR-BH systems!
- Testing cosmic censorship and no-hair theorem
- **Current estimates are that ~75% of entire Galactic population in reach of SKA1**

The transient radio sky

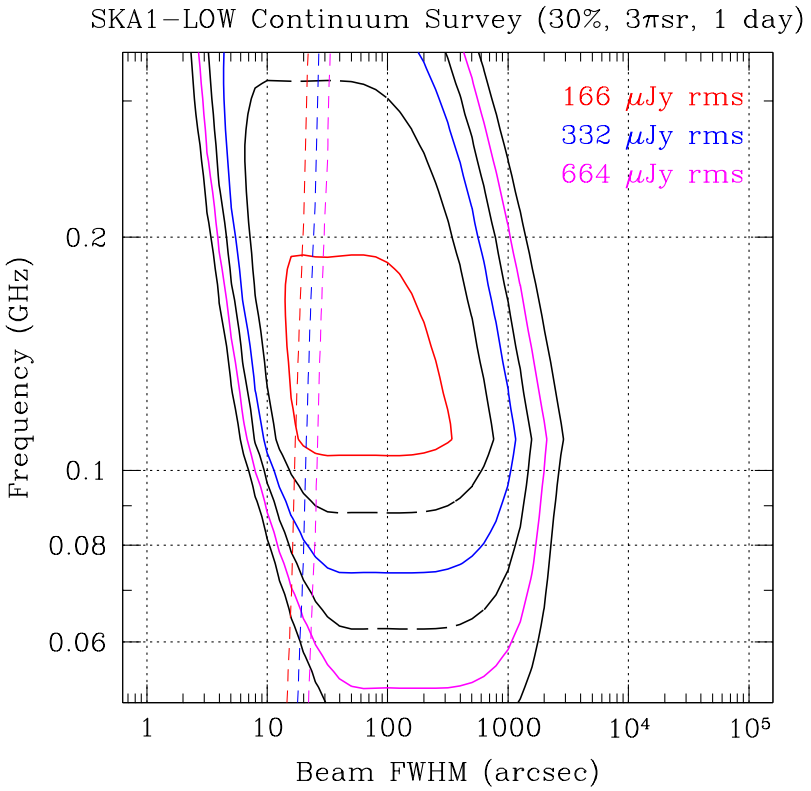
A Population of Fast Radio Bursts at Cosmological Distances
D. Thornton *et al.*
Science **341**, 53 (2013);
DOI: 10.1126/science.1236789

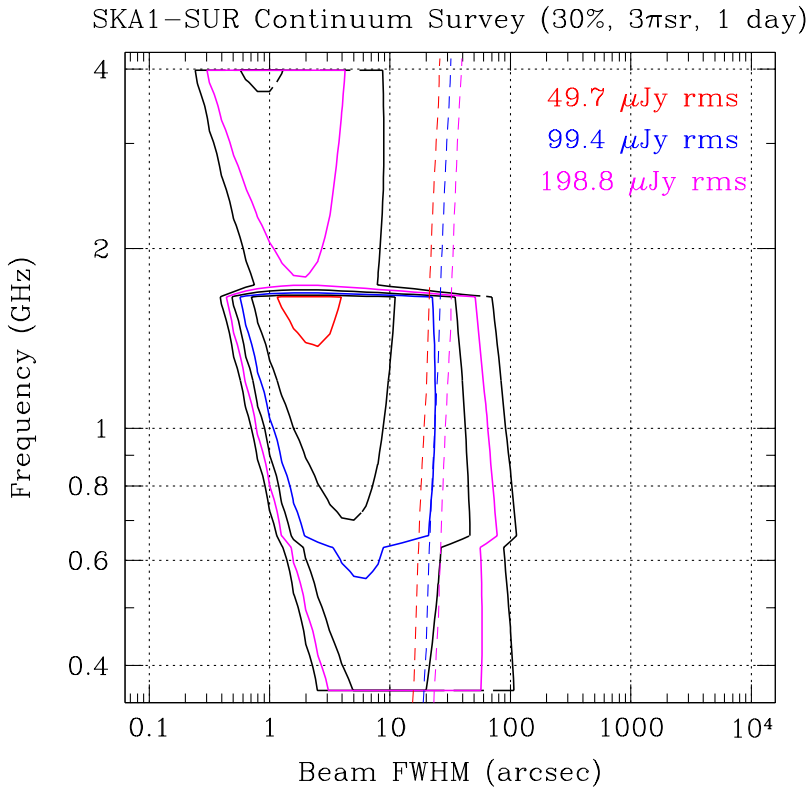




- Four celestial "FRB" events now detected (after first "Lorimer" burst):
  S = 0.5 – 1.3 Jy, Δt = 1 – 6 msec, DM = 550 – 1100 cm^{-3} pc
- Estimated event rate: $1x10^4$ sky^{-1} day^{-1}
- Completely unknown origin, possibly at cosmological distances

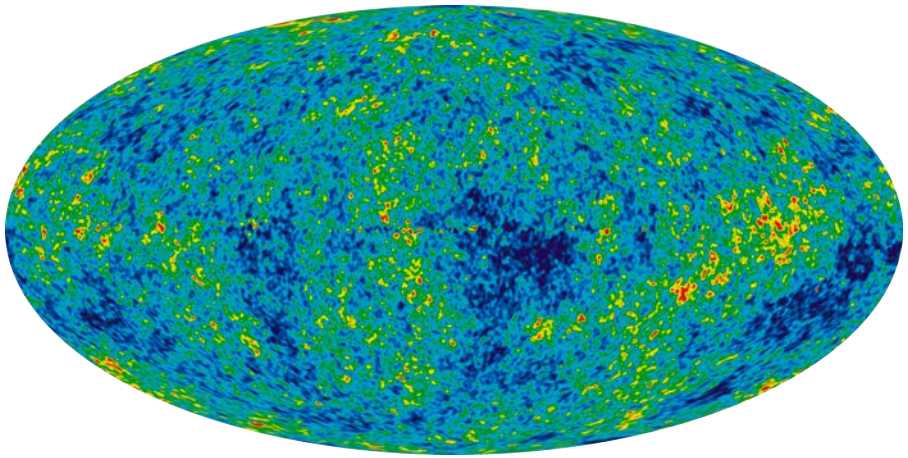
A daily SKA1 all-sky transient survey

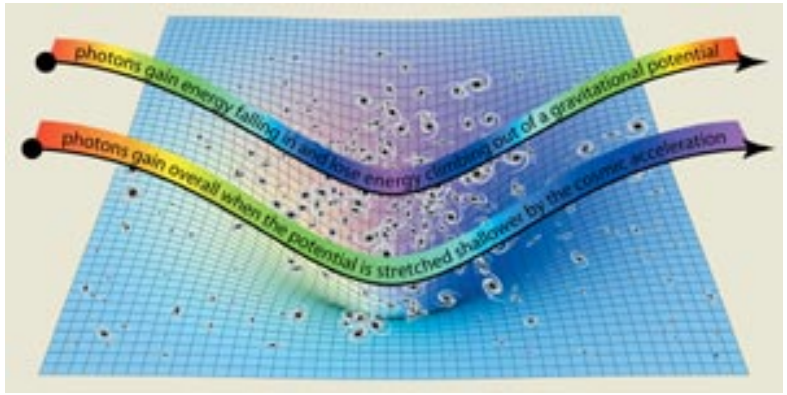




- Integration of ≈50 seconds per position
- Sensitivity for 2 msec bursts is 160x worse: 27 mJy, 8 mJy rms
- Computing strategy most still be developed for such a mode!
- **Predicted FRB detections: 5 per day, with localisation to a fraction of arcsec**

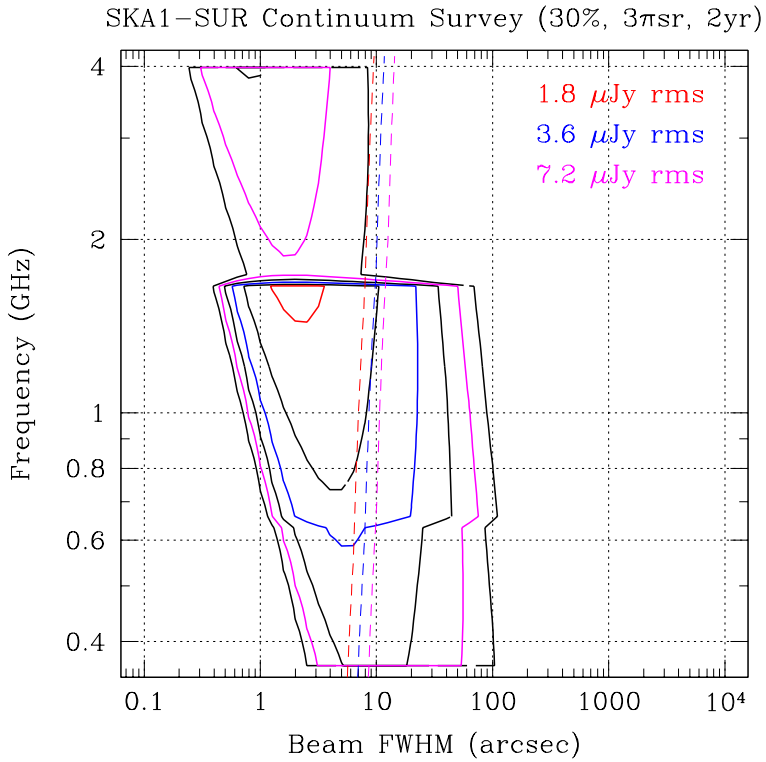
Cosmology with SKA1: Integrated Sachs-Wolfe effect

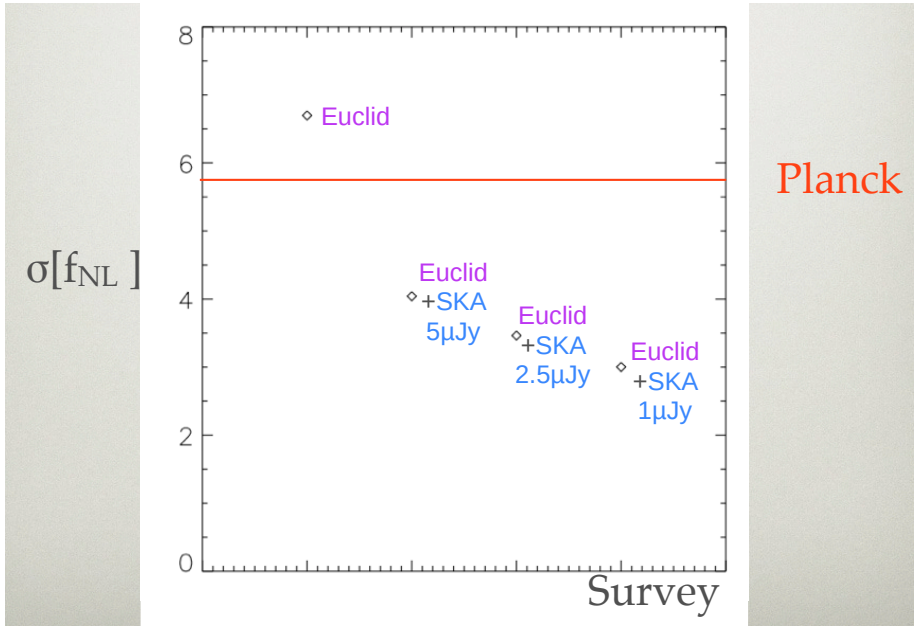




- Constraining non-Gaussianity of primordial fluctuations with the Integrated Sachs-Wolfe effect: correlation of foreground source populations with CMB structures

Cosmology with SKA1: Complementarity with Euclid

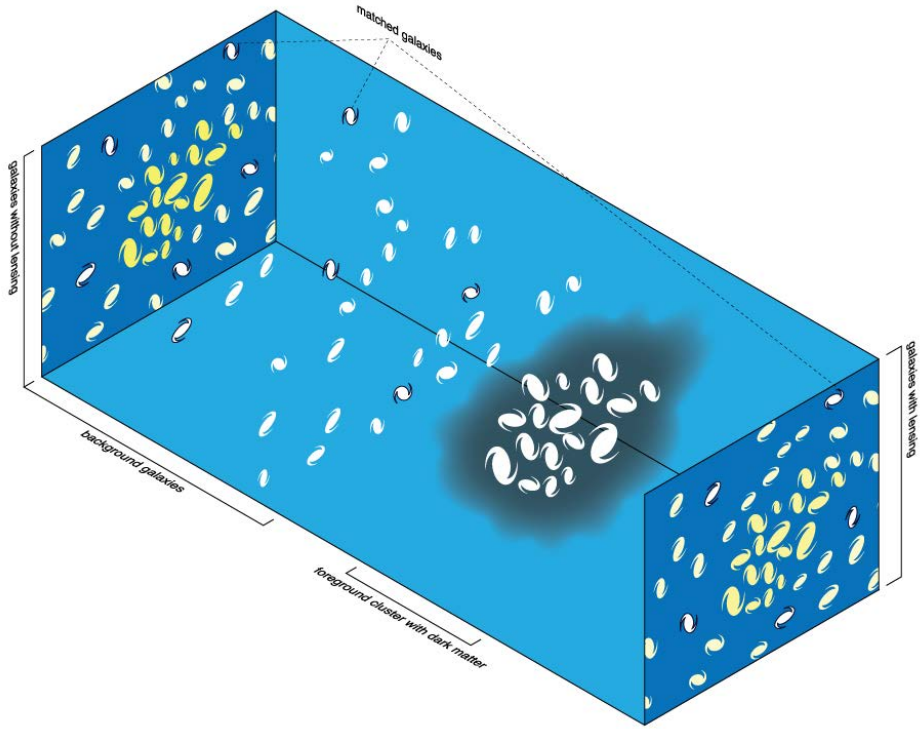




(Bacon 2013)

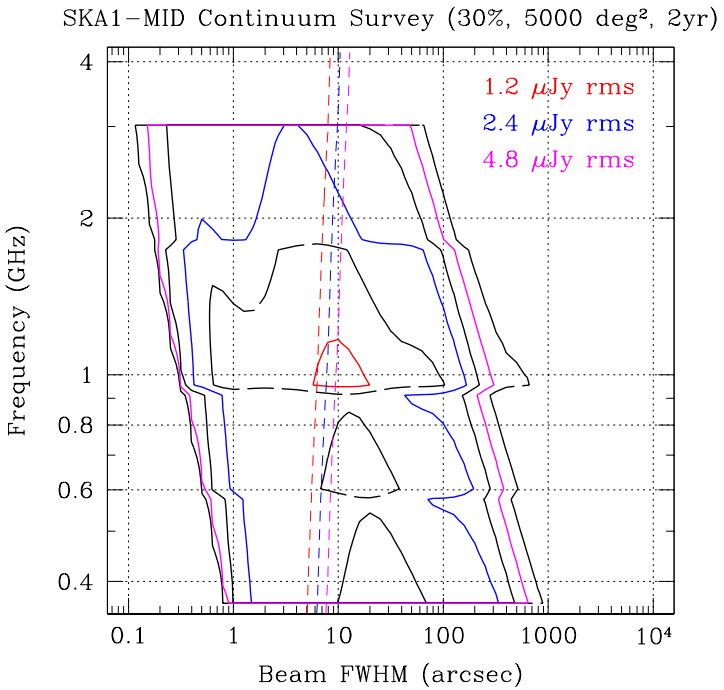
- Constraining non-Gaussianity of primordial fluctuations with the Integrated Sachs-Wolfe effect
- Achieving 2 μJy rms would provide ≈4 galaxies arcmin^{-2} (>10σ)
- Almost uniform sky coverage of 3π sr is exceptional
- **Major enhancement over Euclid alone**

Cosmology with SKA1: Weak Gravitational Lensing

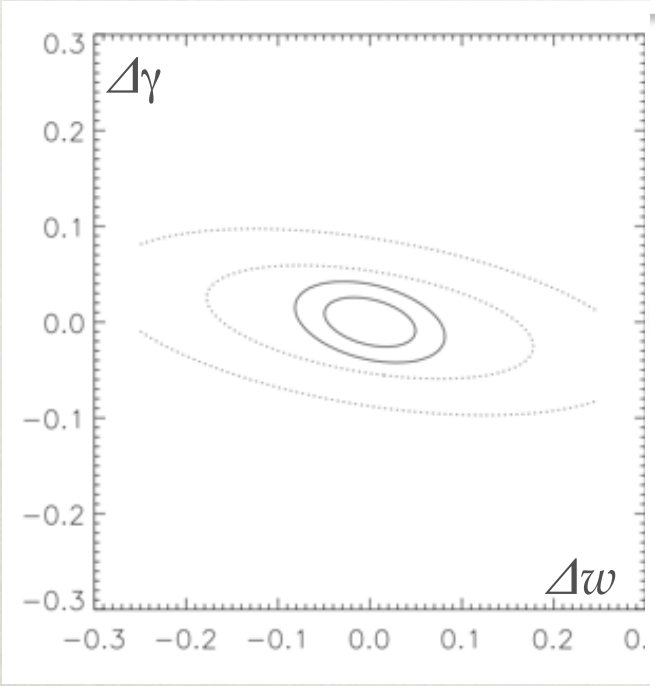


- Constraining the Dark Energy Equation of State with Weak Gravitational Lensing

Cosmology with SKA1: Complementarity with Euclid



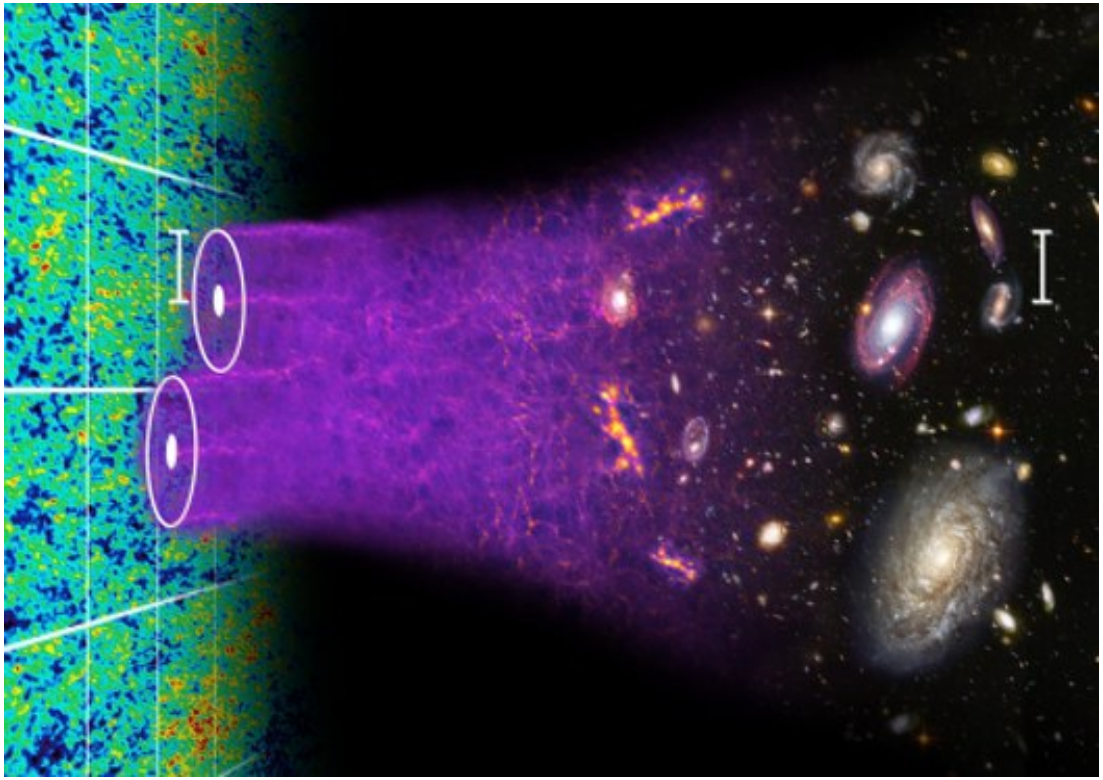
Euclid
+SKA1
lensing
σ_w=0.03
σ_γ=0.017



(Bacon 2013)

- Constraining the Dark Energy equation of state with a weak gravitational lensing measurement of cosmic shear
- Achieving 1 μJy rms would provide ≈6 galaxies arcmin^{-2} (>10σ)
- PSF is excellent quality circular Gaussian from about 0.6”
- **Major enhancement in DE Figure-of-Merit**

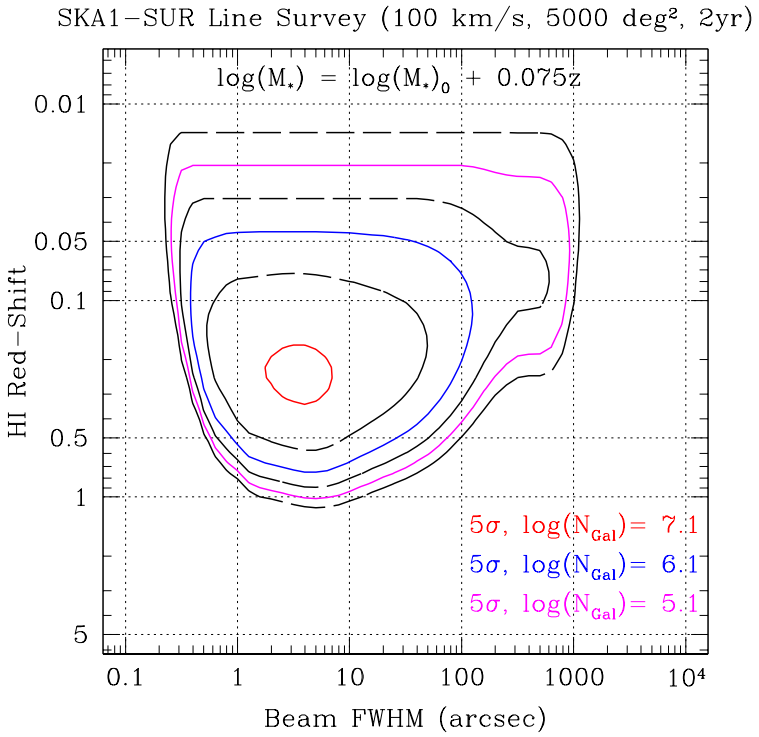
Cosmology with SKA1: Baryon Acoustic Oscillations

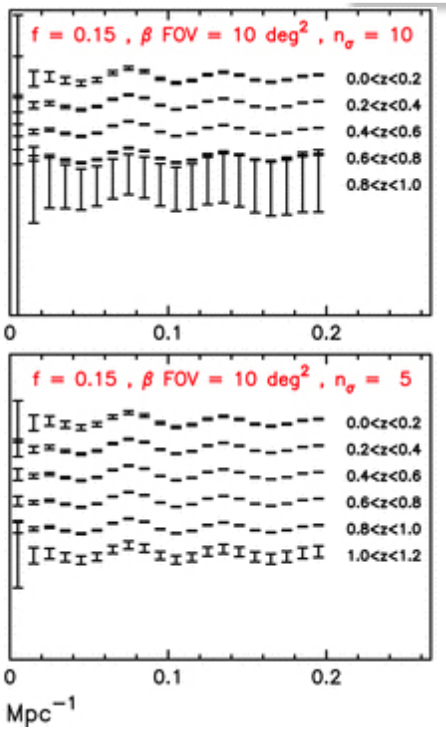


(Blake & Moorfield)

- Constraining Dark Energy models with redshift-resolved BAO measurements

A wide-field HI emission survey for BAO and $\Omega_{HI}(z)$

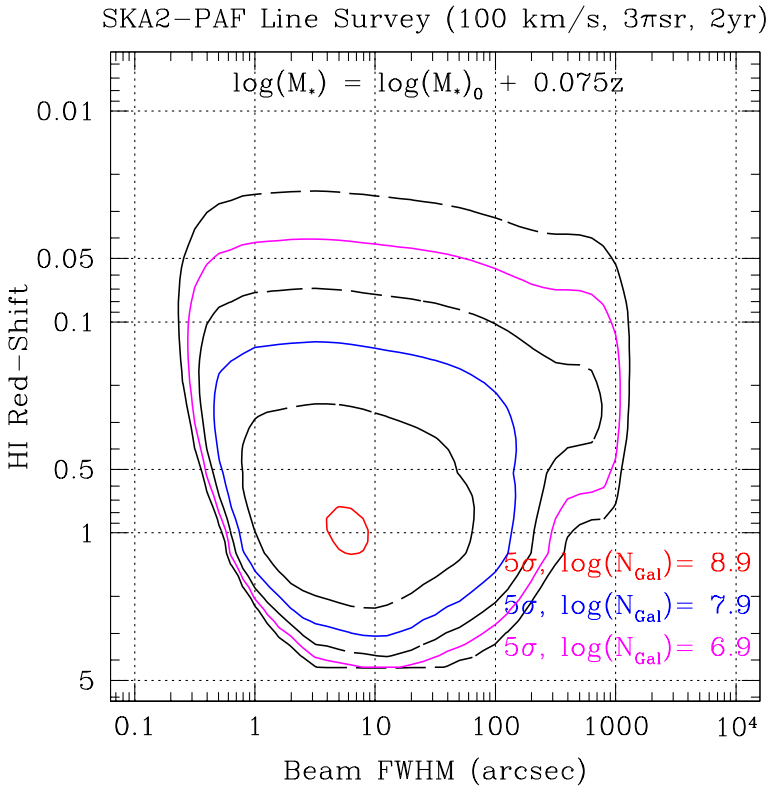




(Abdalla et al 2010)

- Detect $10^{7.1}$ galaxies <z> ≈ 0.3, $10^{5.1}$ galaxies <z> ≈ 1
- Density ≈ 2500 galaxies deg^{-2} , 1 arcmin^{-2}
- Compare SDSS: $10^{6.2}$ galaxies with <z> ≈ 0.1 over 15,000 deg^2
- Compare WigglesZ $10^{5.2}$ galaxies with <z> ≈ 0.6
- **Major contribution to BAO science, complementary systematics versus Opt/IR**

An SKA2 HI emission survey for precision Cosmology



- Detect $10^{8.9}$ galaxies with <z> ≈ 1, $10^{7.9}$ with <z> ≈ 2
- Compare Euclid target of 10^{8} spectra with <z> ≈ 1
- **SKA2 will provide an unrivaled capability for precision cosmology!**

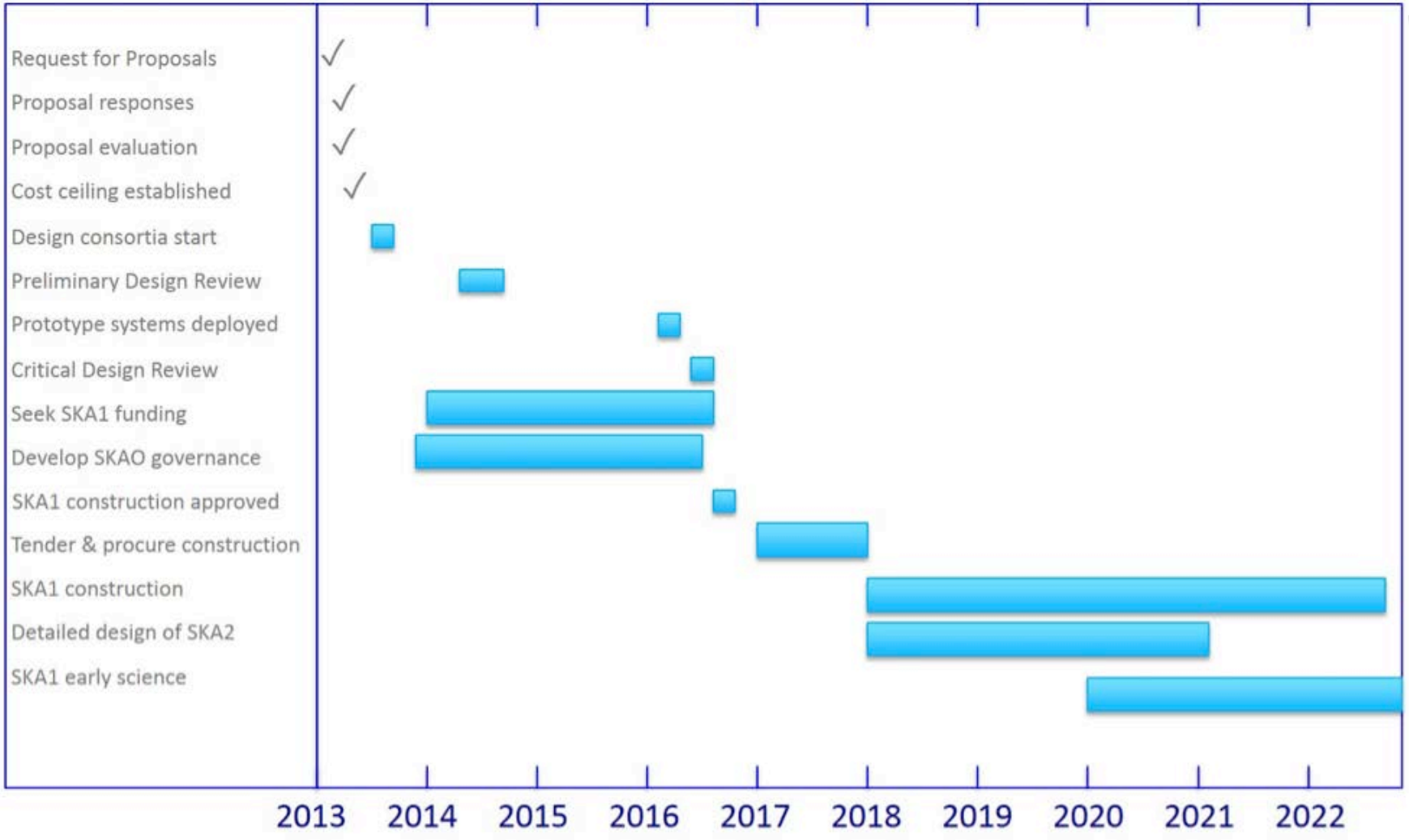
SKA Key Science

- Strong-field Tests of Gravity with Pulsars and Black Holes
  - **Unique GR constraints, major contributions in Phase 1 and Phase 2**
- Galaxy Evolution, Cosmology, & Dark Energy
  - **Cutting edge contributions in non-Gaussianity and Dark Energy**
  - **Complementarity to Euclid, LSST in Phase 1 (reduced systematics)**
  - **Unmatched performance in Phase 2 (Billion Galaxy Surveys)**
- Emerging from the Dark Ages and the Epoch of Reionization
  - **Unique EoR imaging capability in Phase 1**
  - **Reaching to Cosmic Dawn in Phase 2**
- The Cradle of Life & Astrobiology
- The Origin and Evolution of Cosmic Magnetism

With design philosophy of *Exploration of the Unknown*

Unmatched prospects (complement to LSST) in Phase 1 and Phase 2

Timeline


Request for Proposals
Proposal responses
Proposal evaluation
Cost ceiling established
Design consortia start
Preliminary Design Review
Prototype systems deployed
Critical Design Review
Seek SKA1 funding
Develop SKAO governance
SKA1 construction approved
Tender & procure construction
SKA1 construction
Detailed design of SKA2
SKA1 early science
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022

SKA1 Change Process

3 Engineering Change Proposal (ECP)

3.1 What is an ECP?

An ECP expresses the need for a permanent change of one or more Configuration Items. The rationale for a change could be one or more of the following:

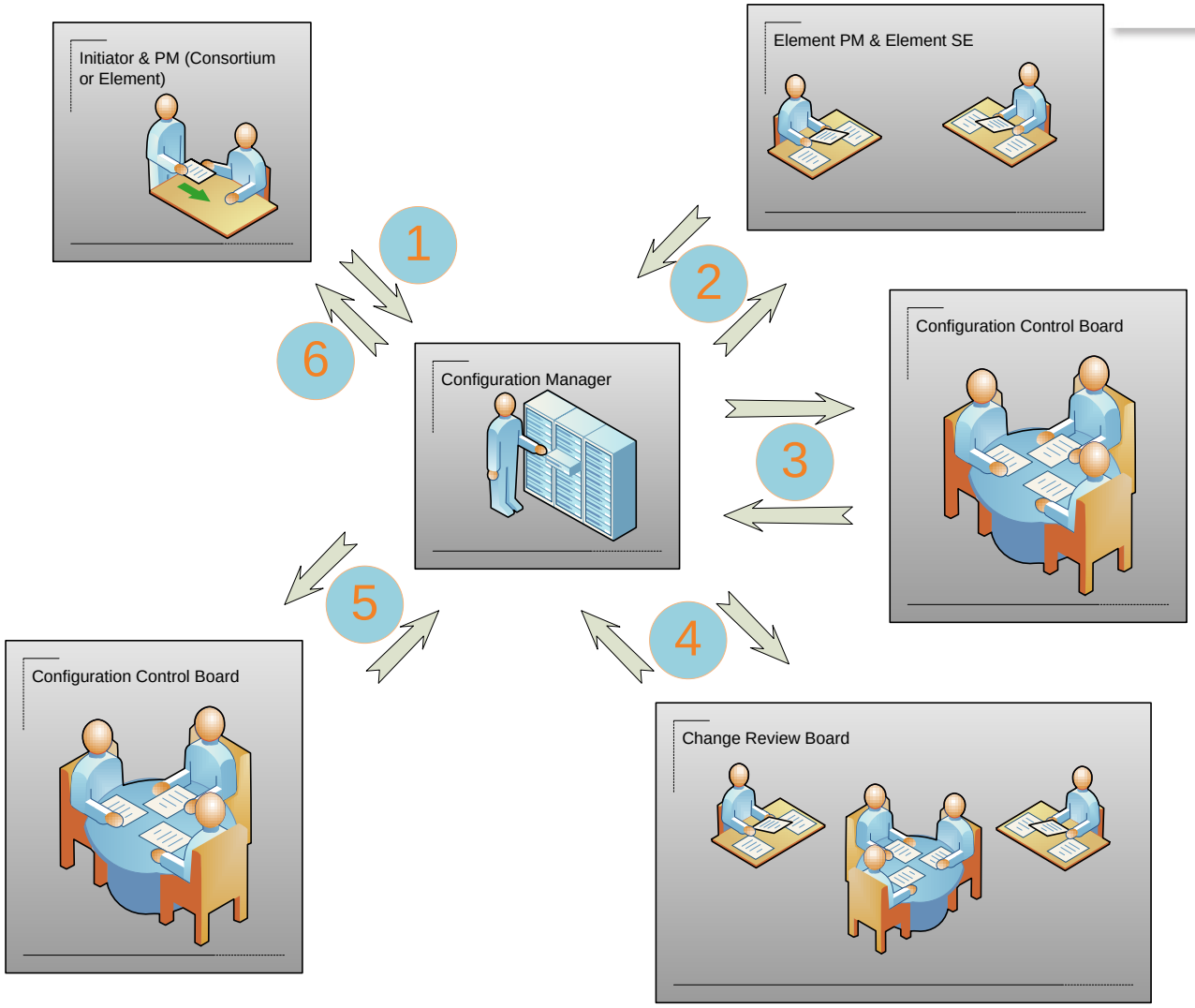
- Functional/Performance improvement or correction
- Change of interfaces
- New requirements
- A change in schedule and/or costs above a certain threshold (TBD)

The ECP process is the formal way to evaluate and to assess possible impacts that a proposed change will have on:

- Schedule,
- Performance,
- Full lifecycle cost,
- Interfaces to other Elements or the external world.

According to their impact, ECPs are classified as either Minor, Major or System Level, based on an evaluation by the SKA Chief System Engineer, SKA Architect & SKA Project Manager and following guidelines provided by the SKA Configuration Control Board (see below).

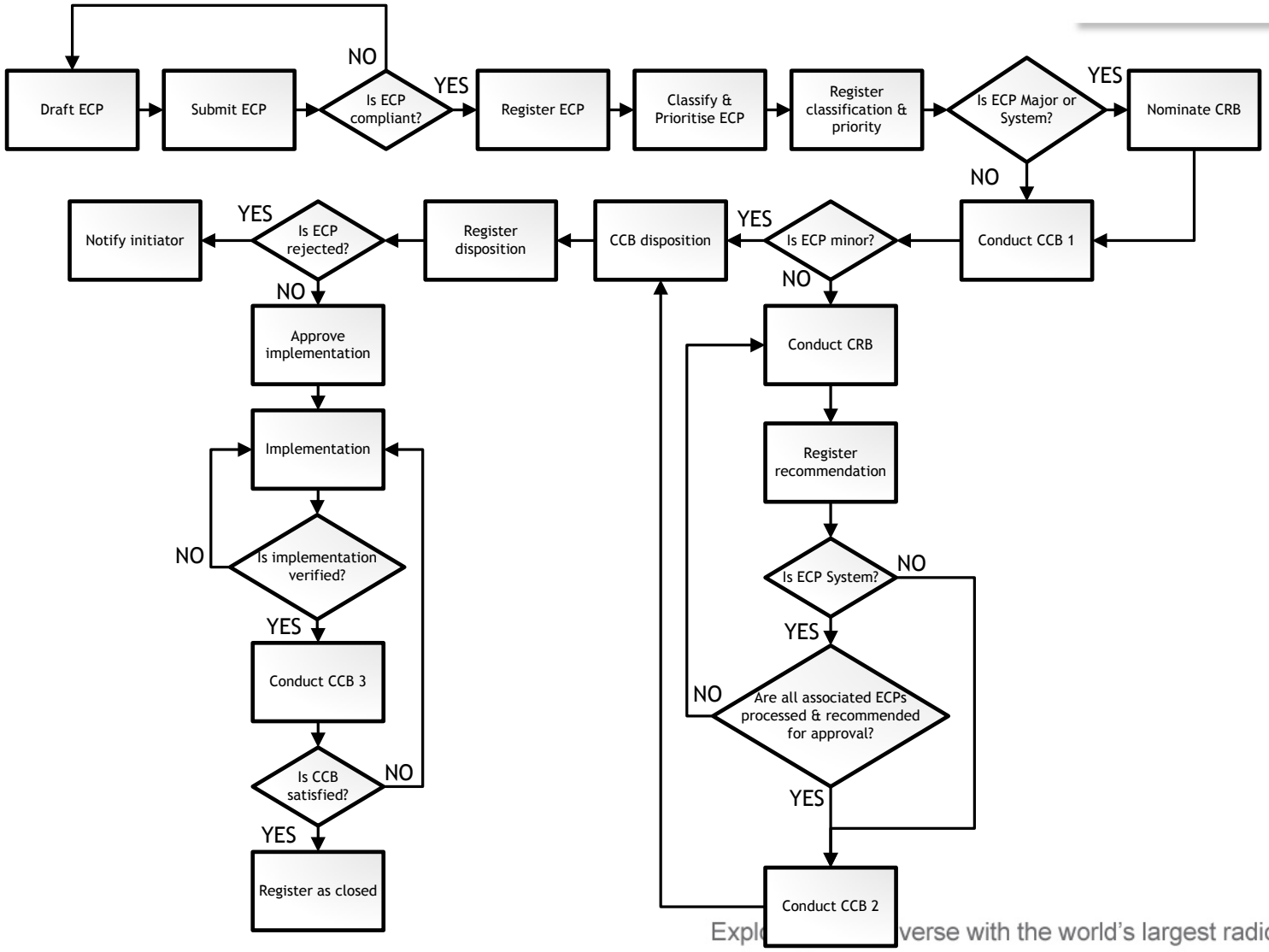
SKA1 Change Process



Exploring the Universe with the world's largest radio telescope

Figure 1: The normal ECP work flow**.**

SKA1 Change Process



Explo verse with the world's largest radio telescope

Figure 2: The ECP work flow diagram.

Thank you

www.skatelescope.org