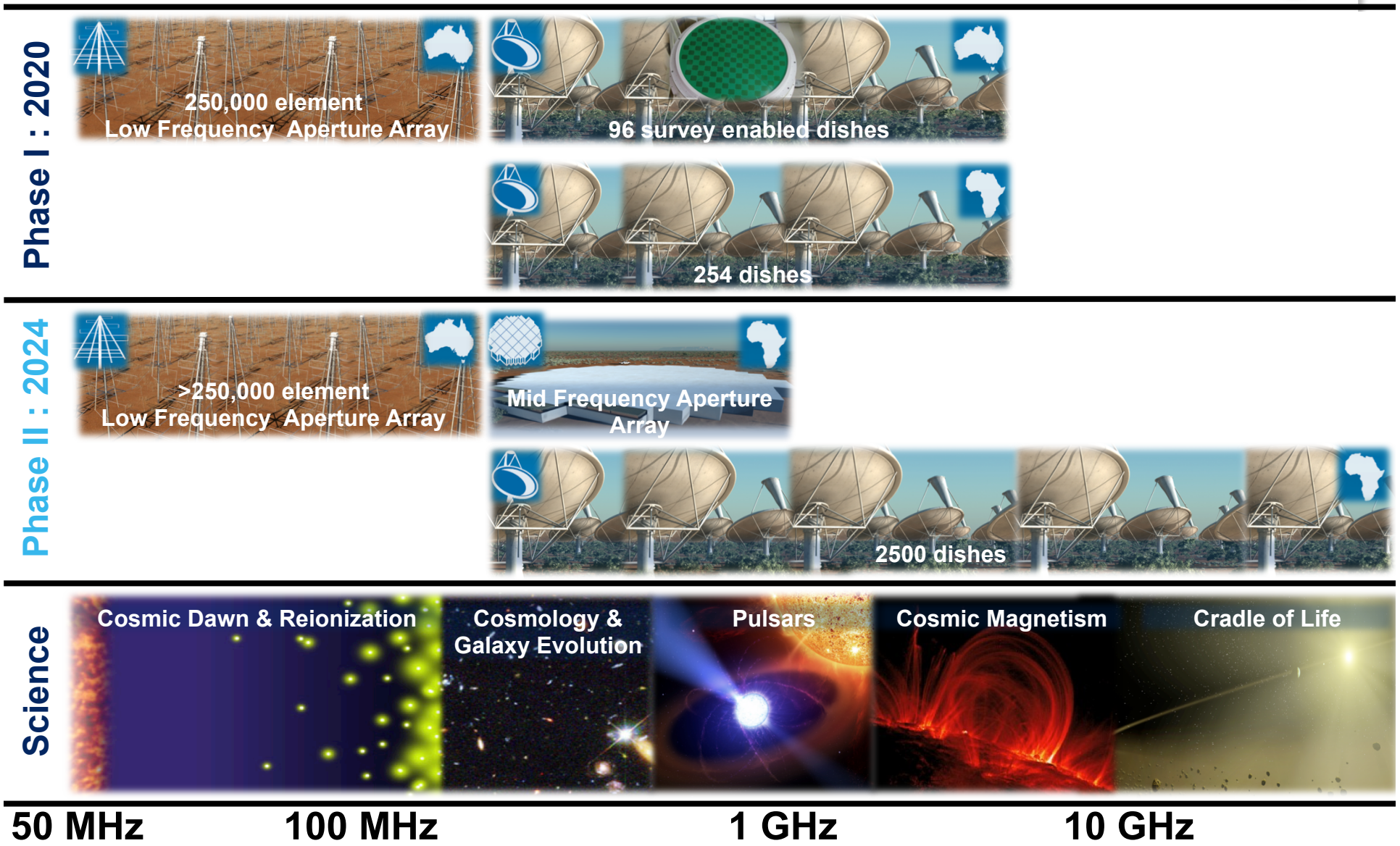
Square Kilometre Array – Design and Science Performance

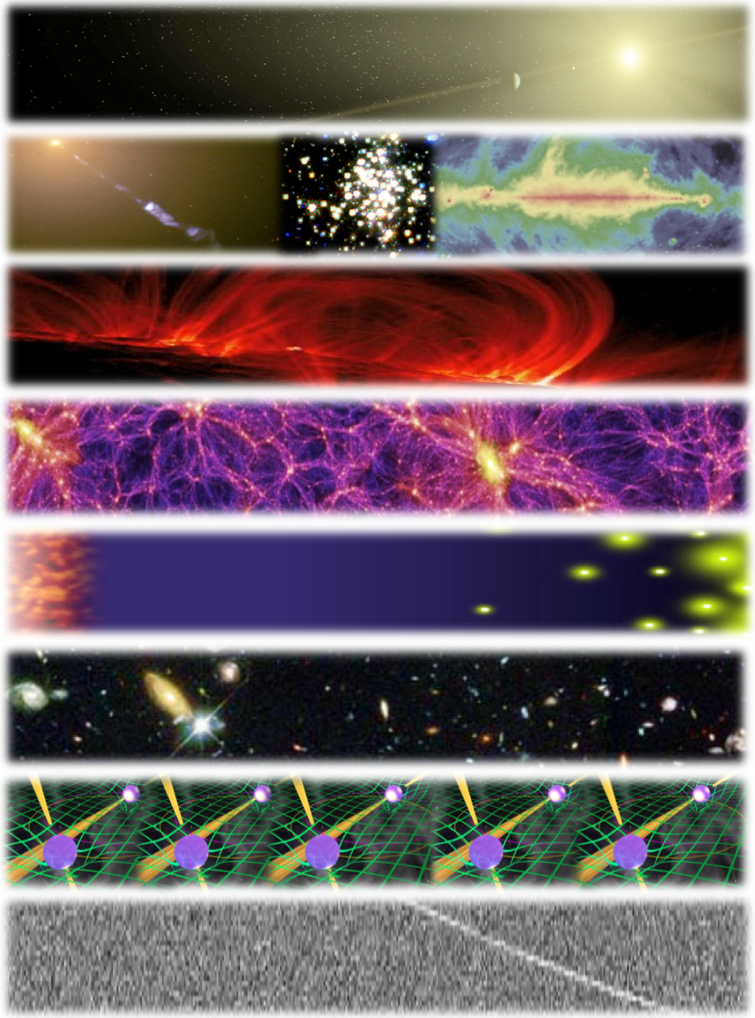
Robert Braun
SKA Science Director
6th November 2013

Exploring the Universe with the world's largest radio telescope



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

WIDE BAND SINGLE PIXEL FEEDS

Project Scientist: Jimi Green

SCIENCE DATA PROCESSOR

Project Scientists: Jeff Wagg & Tyler Bourke

ASSEMBLY, INTEGRATION & VERIFICATION

Project Scientist: Tyler Bourke

TELESCOPE MANAGER

Project Scientist: Jeff Wagg

DISH

Project Scientists: Jimi Green & Tyler Bourke

INFRASTRUCTURE AUSTRALIA

Project Scientist: Jimi Green

CENTRAL SIGNAL PROCESSOR

Project Scientist: Jimi Green

MID-FREQUENCY APERTURE ARRAY

Project Scientist: Tyler Bourke

INFRASTRUCTURE SOUTH AFRICA

Project Scientist: Tyler Bourke

SIGNAL AND DATA TRANSPORT

Project Scientist: Tyler Bourke

LOW-FREQUENCY APERTURE ARRAY

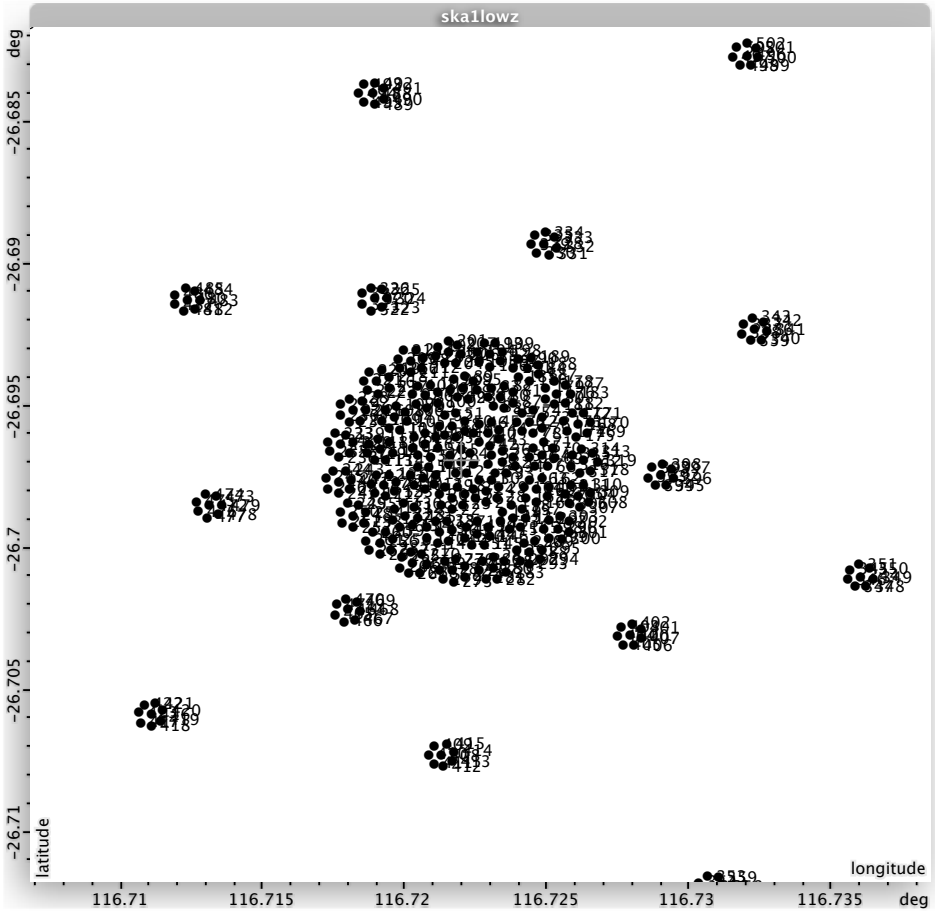
Project Scientists: Jeff Wagg & Tyler Bourke

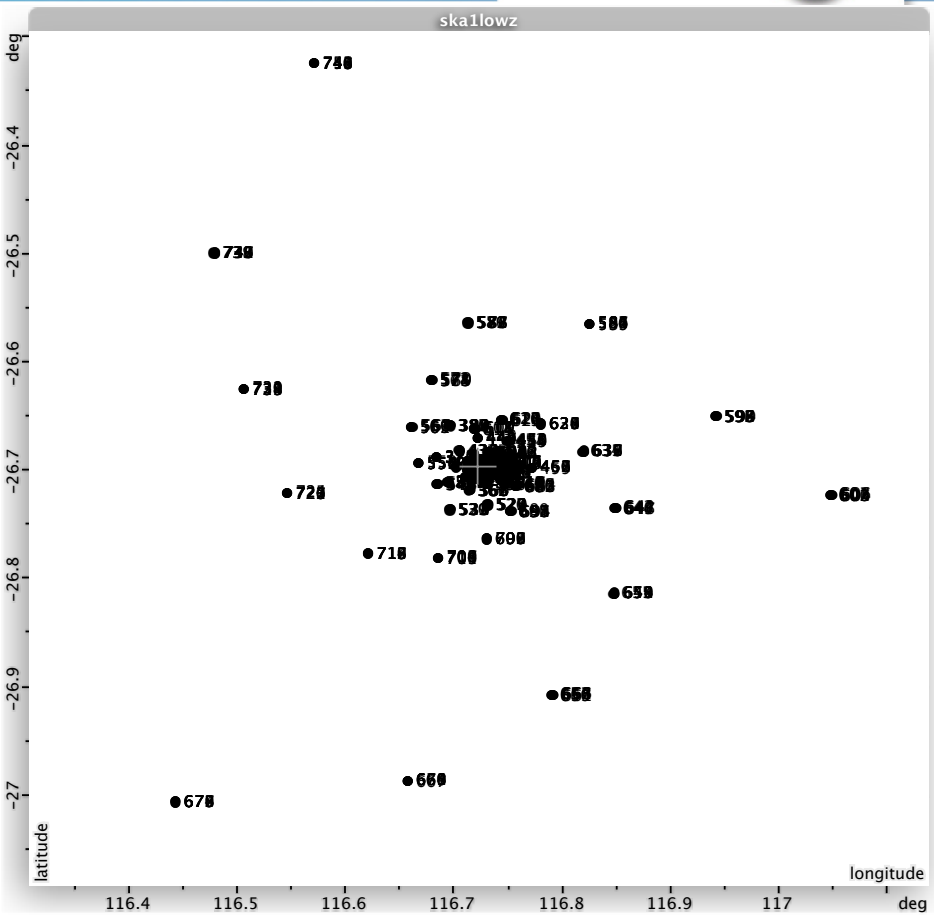
How does SKA1 baseline redefine state-of-art?

		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	22x	270x

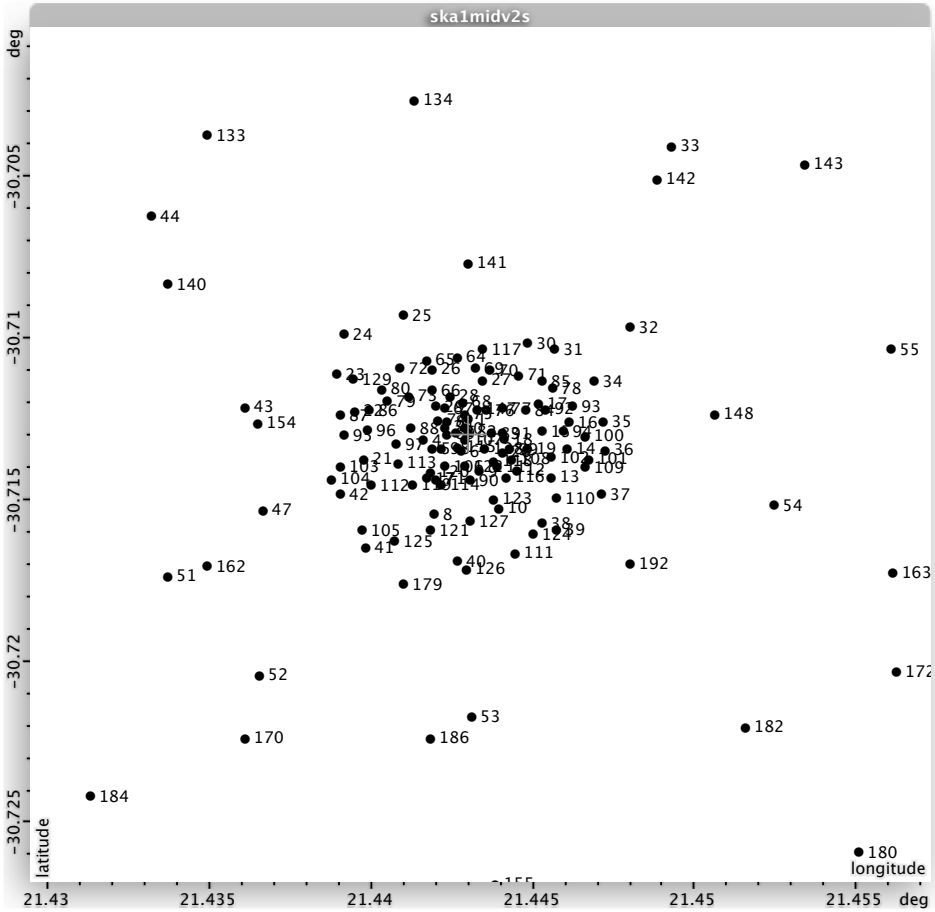
SKA1 “2nd generation” configurations

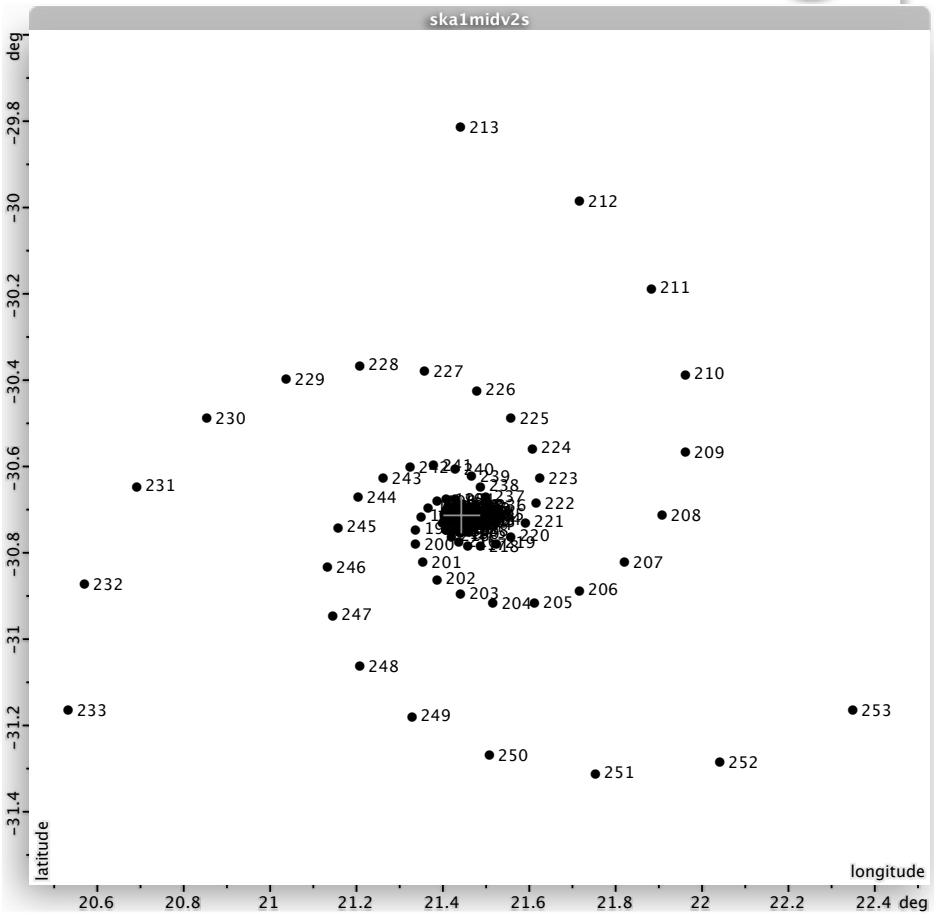




- SKA1-LOW possible configuration of core and remote spiral

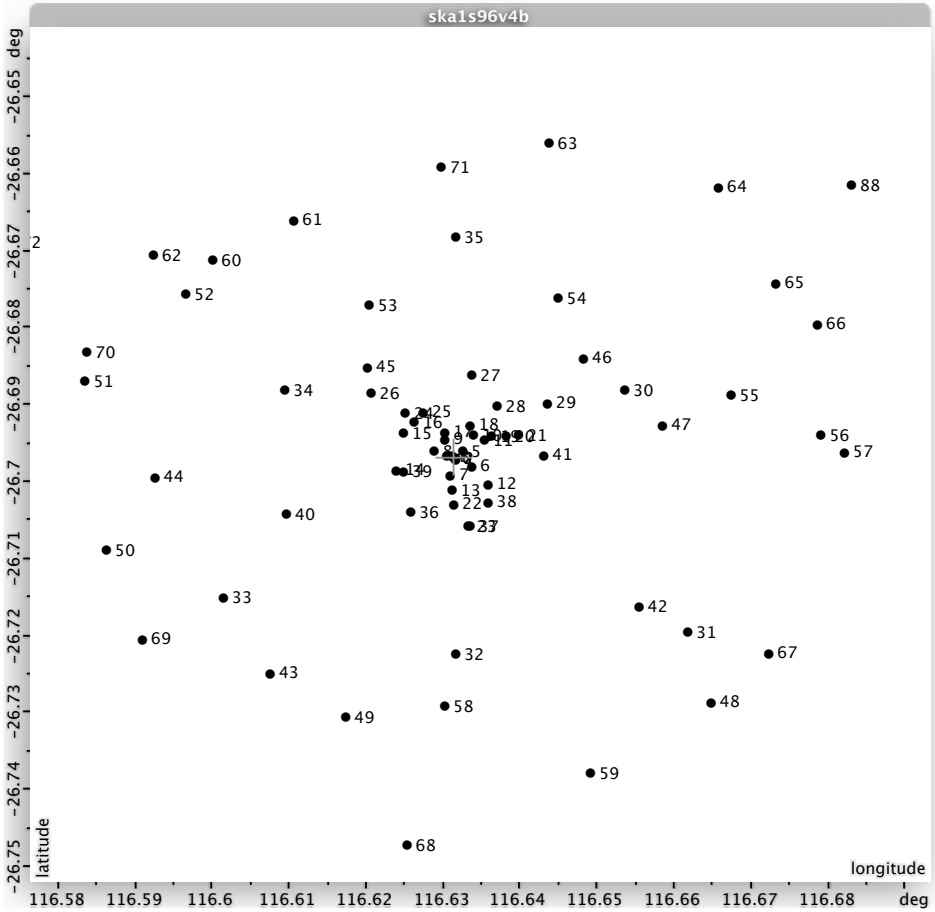
SKA1 “2nd generation” configurations

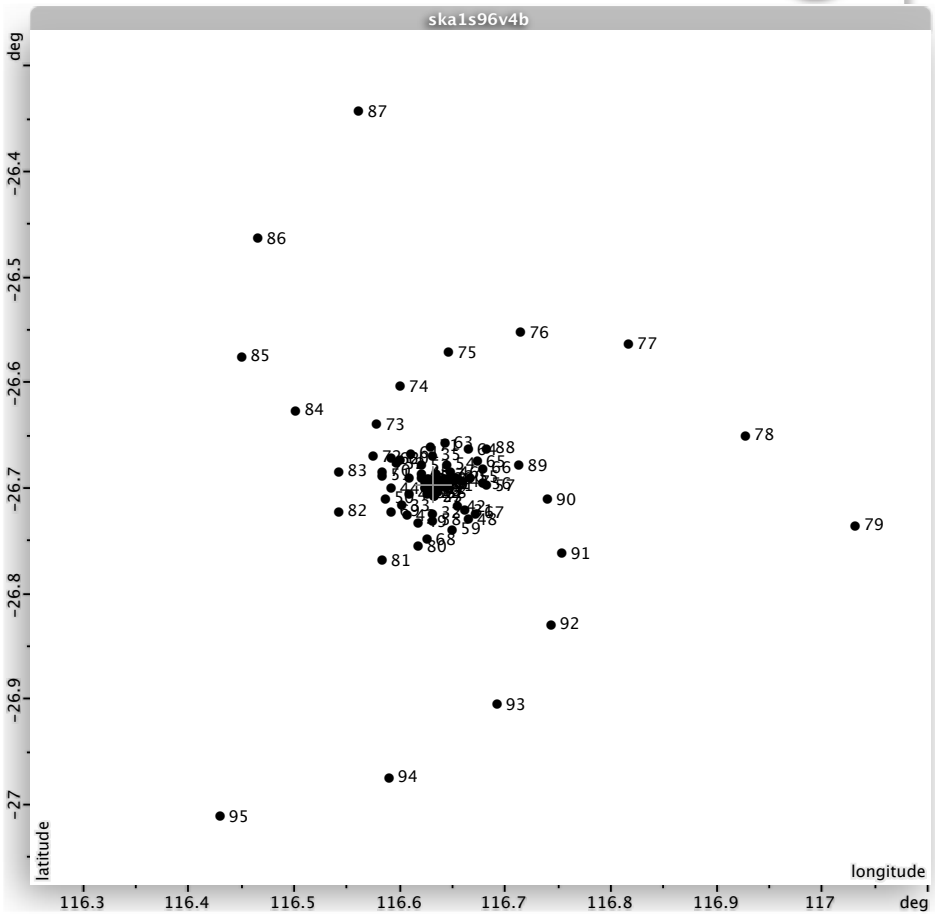




- SKA1-MID possible configuration of core and remote spiral

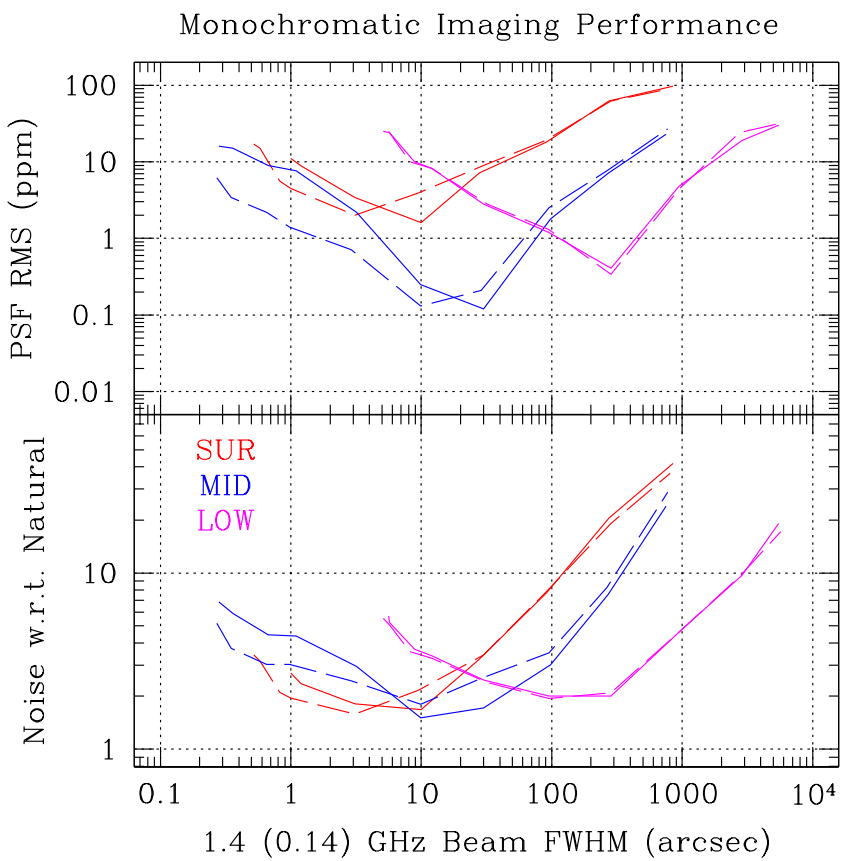
SKA1 “2nd generation” configurations

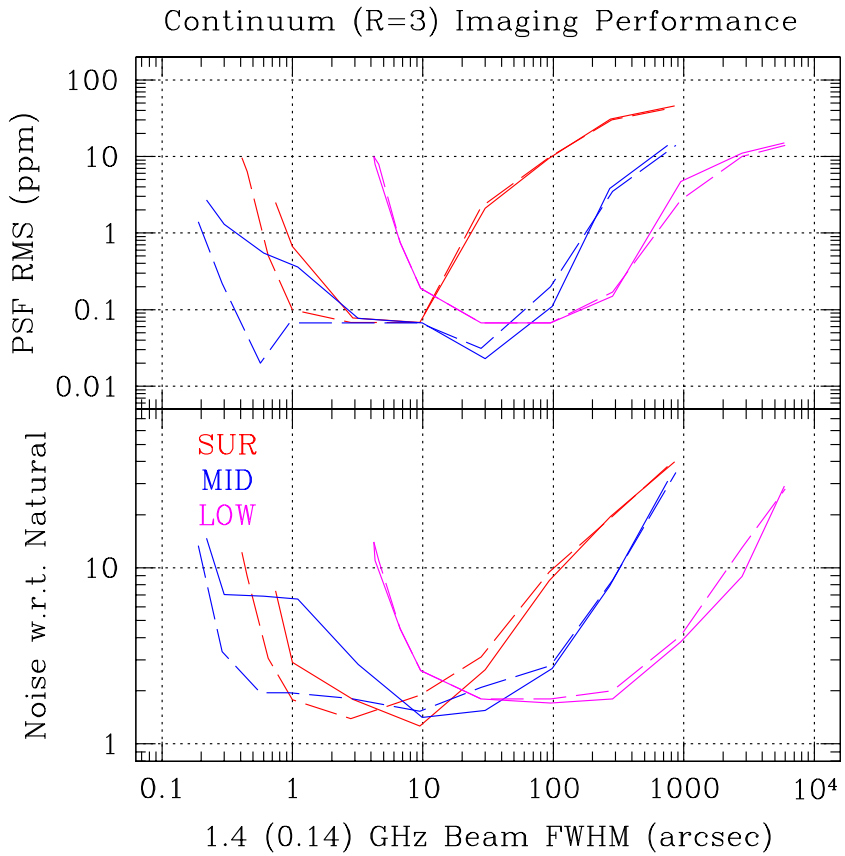




- SKA1-SUR possible configuration of core and remote spiral

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

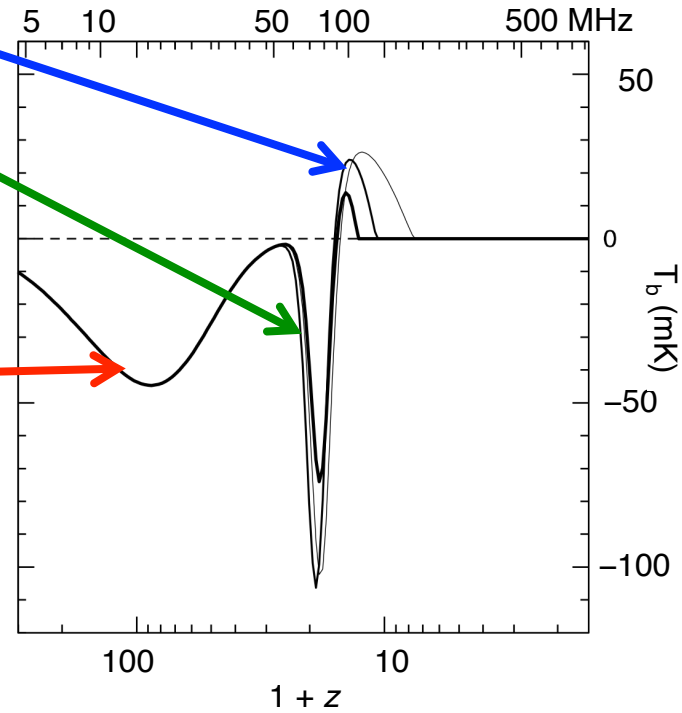
With design philosophy of *Exploration of the Unknown*

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

EoR

Cosmic Dawn

Dark Ages

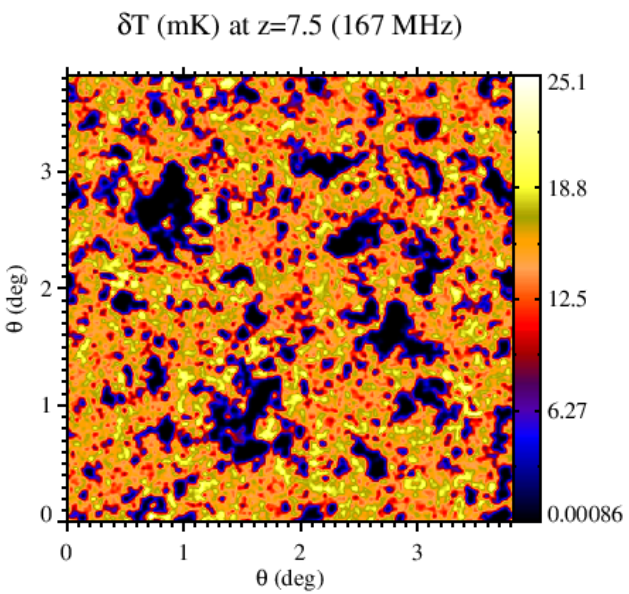


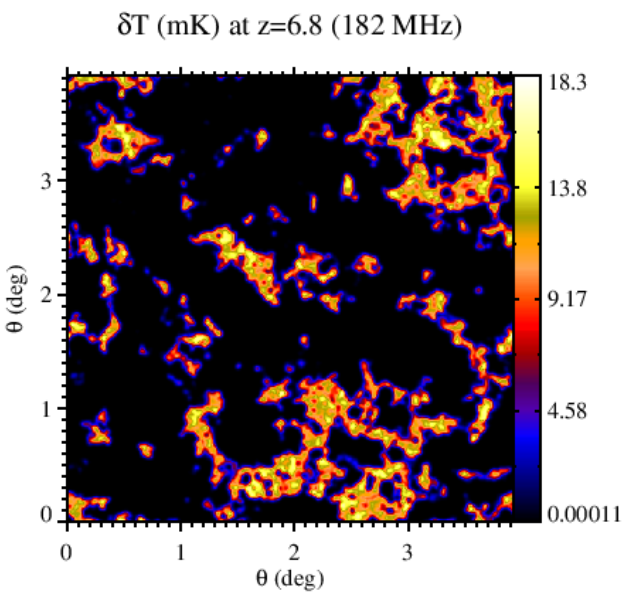
Neutral Hydrogen 21 cm spin-flip transition provides probe of neutral intergalactic medium before and during formation of first stars

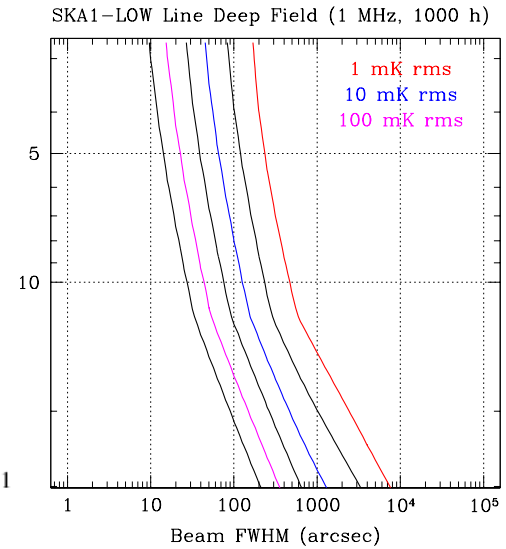
$\nu = 1420\ \mathrm{MHz}/(1 + z)$

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

HI surveys of the EoR/Cosmic-Dawn Universe



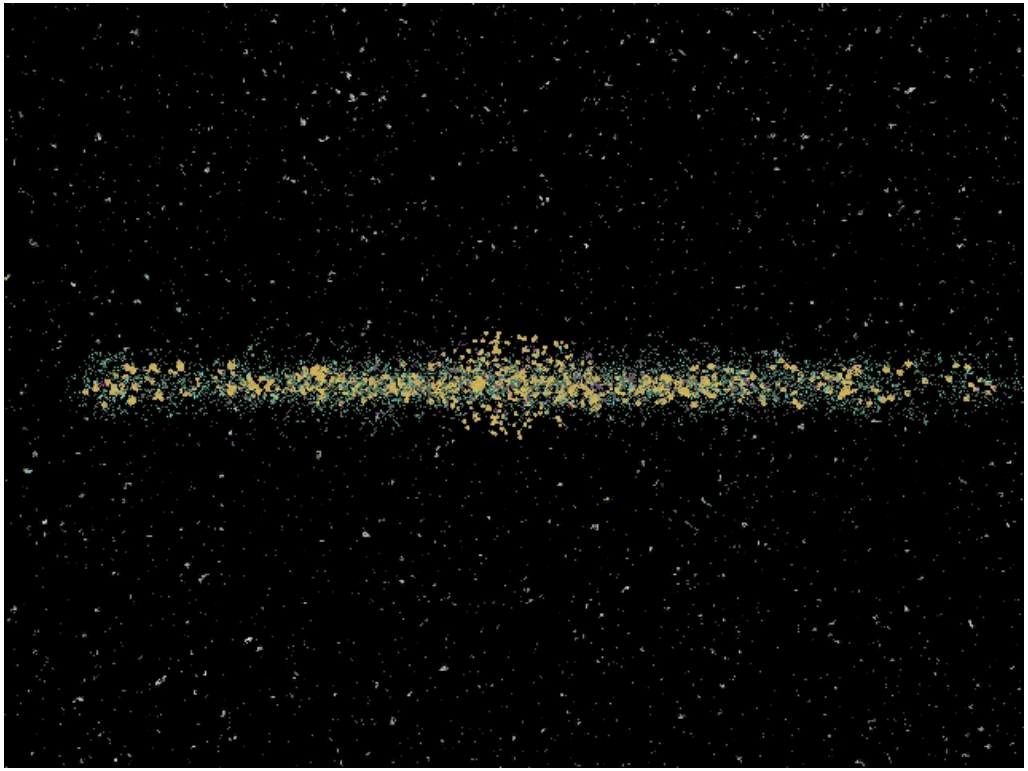


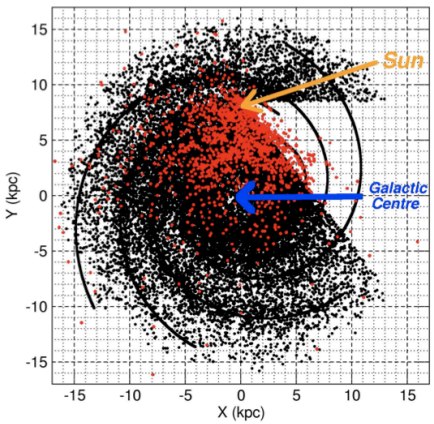


- **Detecting EoR structures in imaging mode (as distinct from statistically) on 5 arcmin scales with 1 mK RMS**
- **Probing the Cosmic Dawn statistically or possibly even imaging in ultra-deep**

Finding all pulsars in the Milky Way…

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



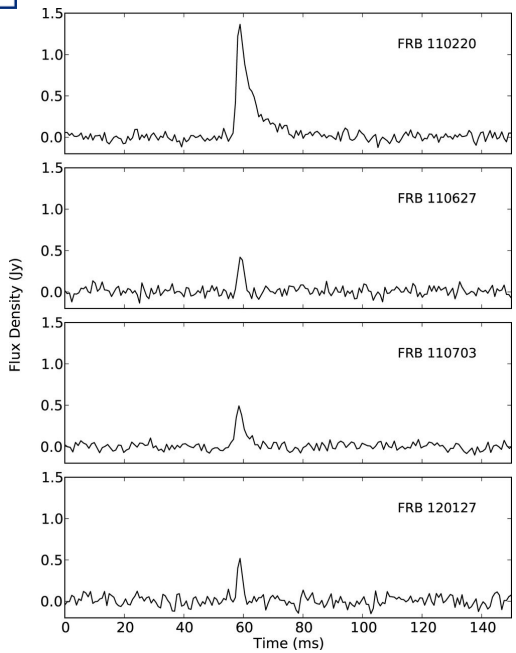


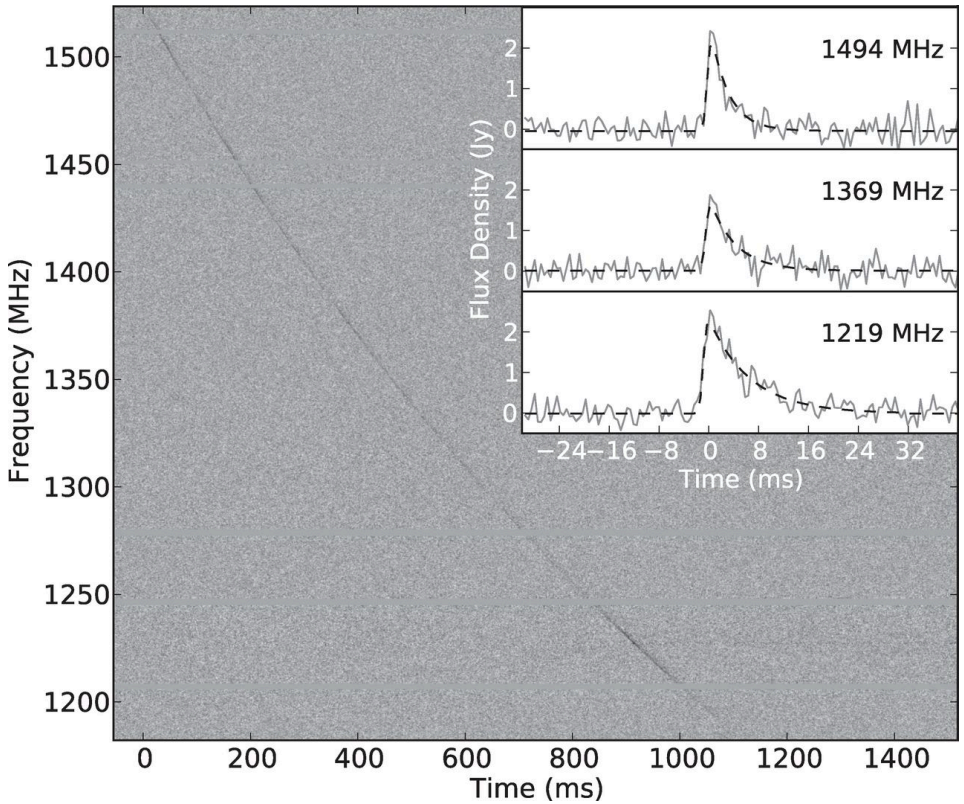
- ~30,000 normal pulsars
- ~2,000 millisecond psrs
- ~100 relativistic binaries
- first pulsars in Galactic Centre
- first extragalactic pulsars

- 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

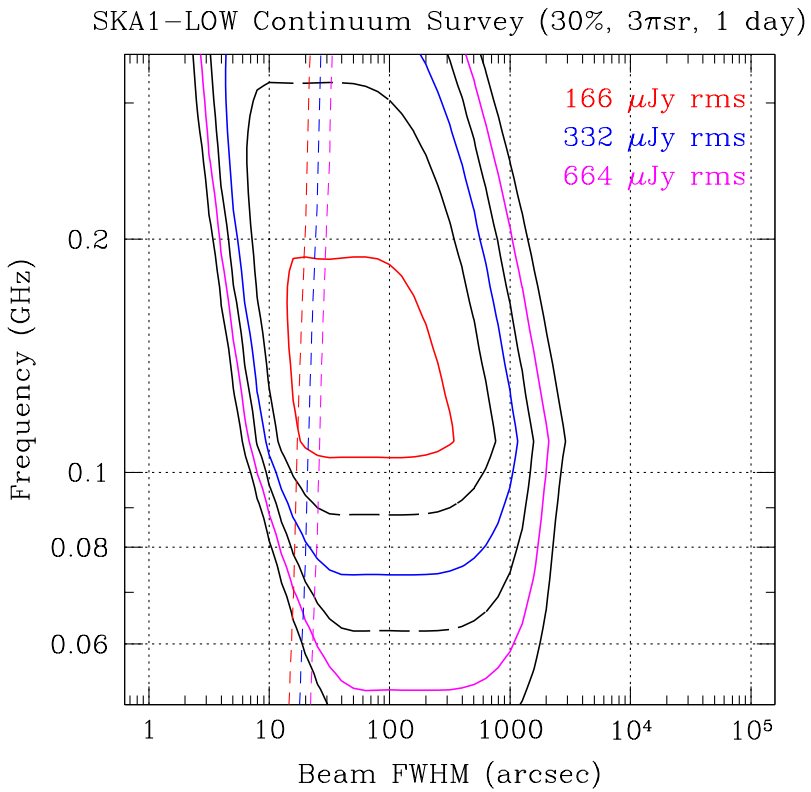
A Population of Fast Radio Bursts at Cosmological Distances
D. Thornton *et al.*
Science **341**, 53 (2013);
DOI: 10.1126/science.1236789

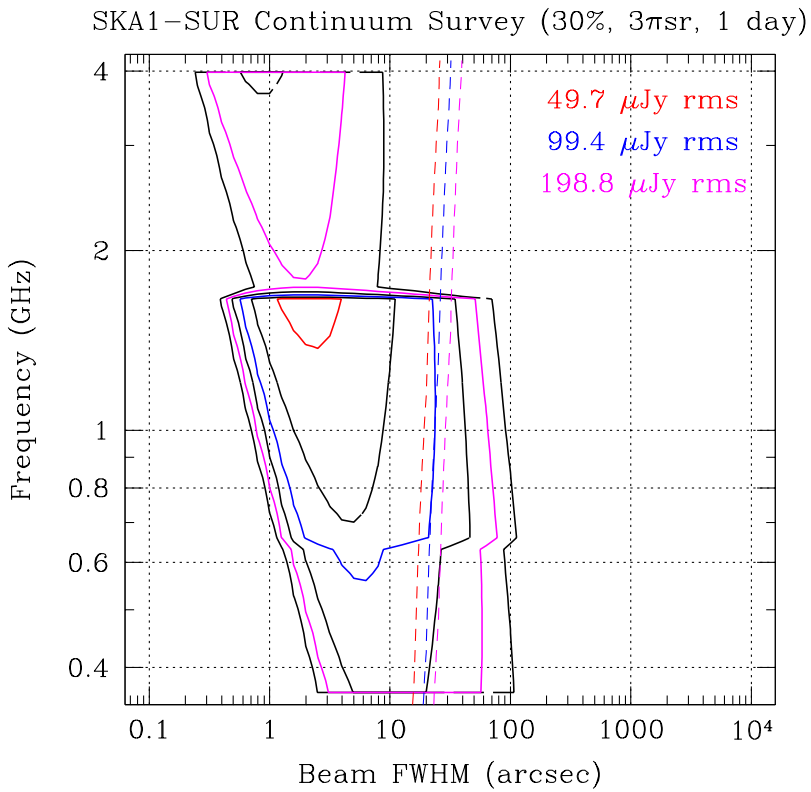




- Four celestial "FRB" events now detected (after first "Lorimer" burst):
  $S = 0.5 – 1.3$ Jy, $\Delta t = 1 – 6$ msec, DM = 550 – 1100 cm^{-3} pc
- Estimated event rate: 1×10^4 sky^{-1} day^{-1}
- Completely unknown origin, possibly at cosmological distances

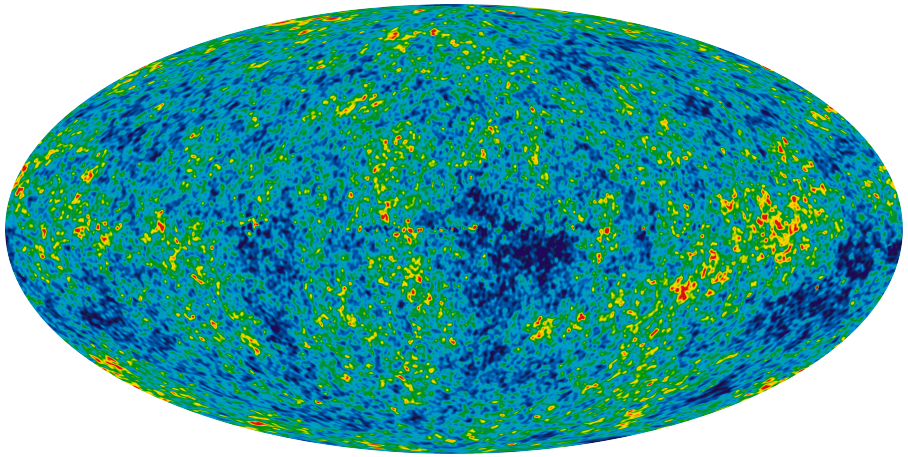
A daily SKA1 all-sky transient survey

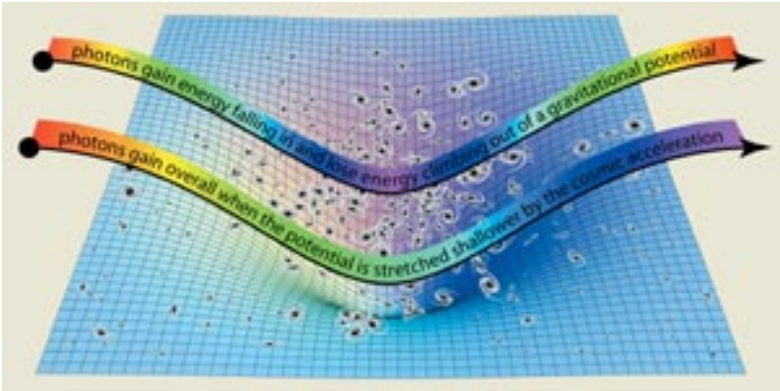




- Integration of ≈50 seconds per position
- Sensitivity for 2 msec bursts is 160x worse: 27 mJy, 8 mJy rms
- Computing strategy most still be developed for such a mode!
- **Predicted FRB detections: 5 per day, with localisation to a fraction of arcsec**

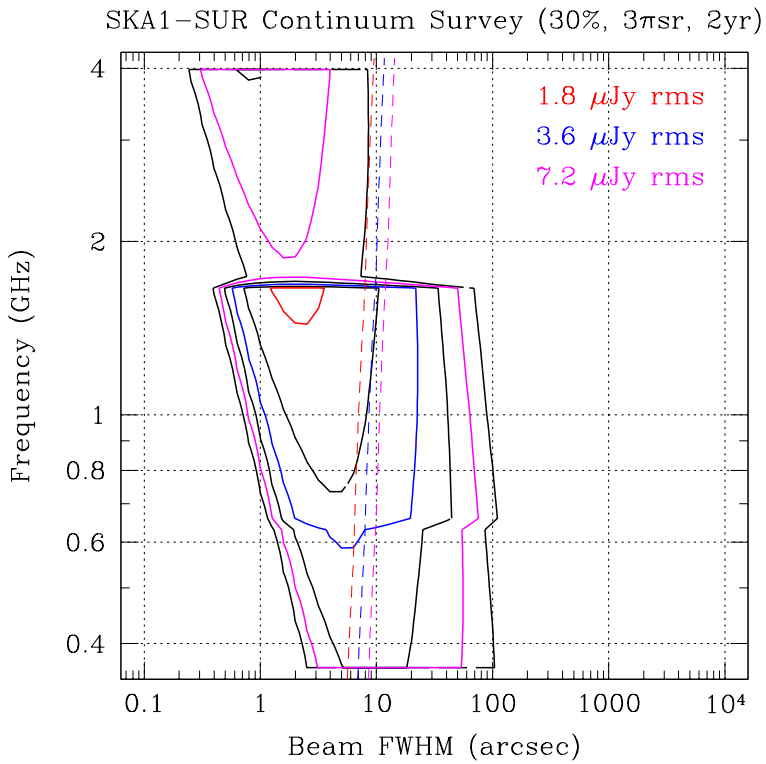
Cosmology with SKA1: Integrated Sachs-Wolfe effect

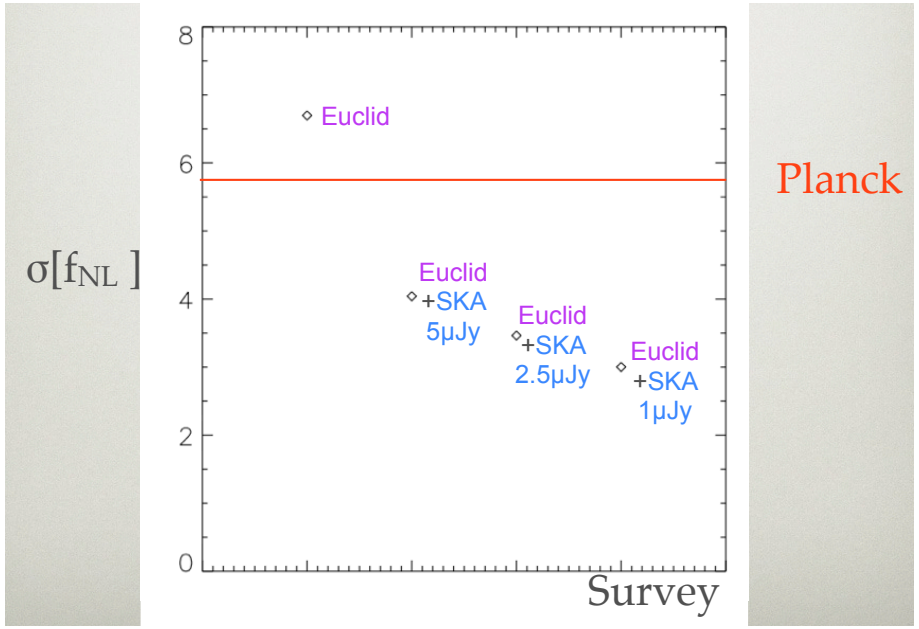




- Constraining non-Gaussianity of primordial fluctuations with the Integrated Sachs-Wolfe effect: correlation of foreground source populations with CMB structures

Cosmology with SKA1: Complementarity with Euclid

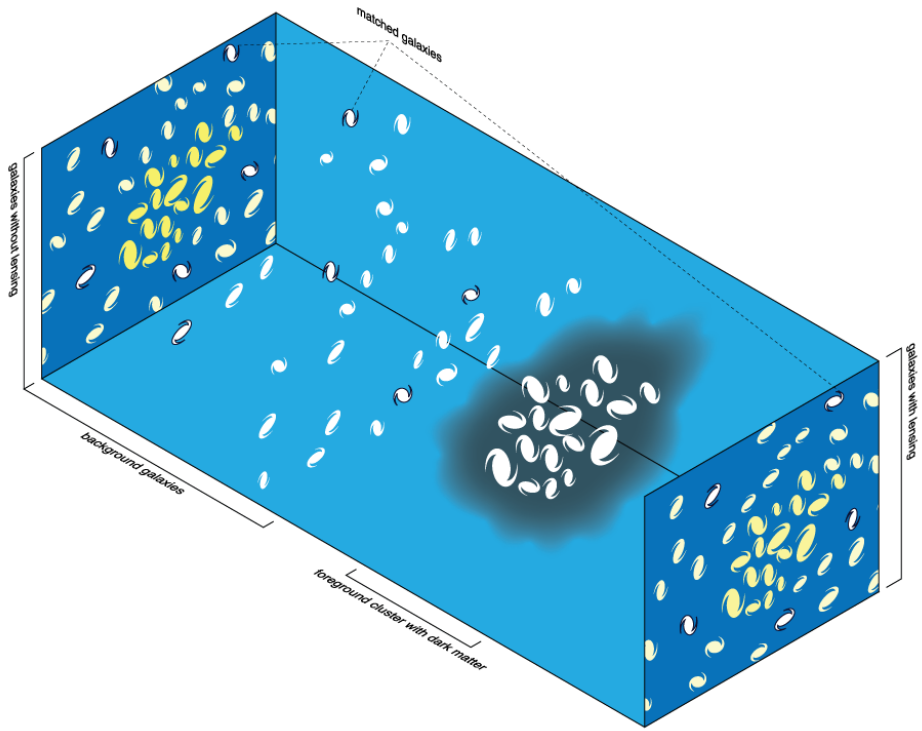




(Bacon 2013)

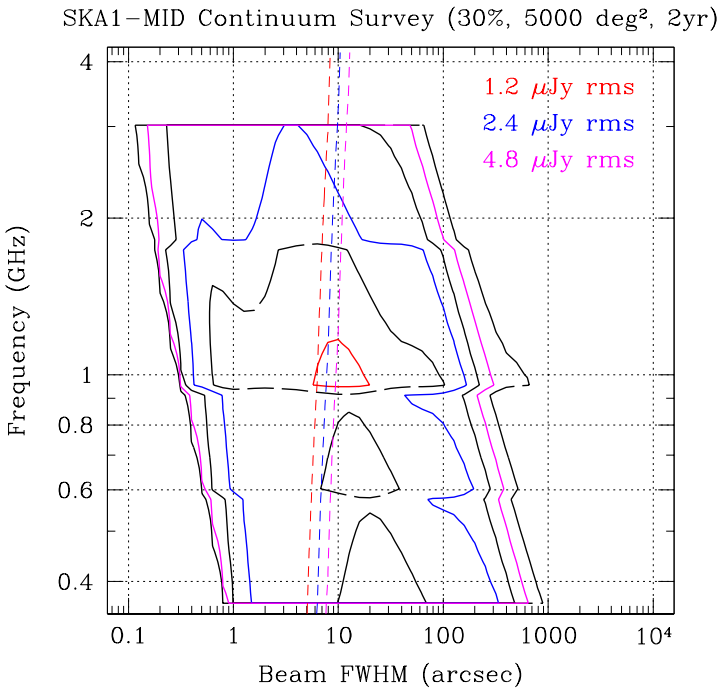
- Constraining non-Gaussianity of primordial fluctuations with the Integrated Sachs-Wolfe effect
- Achieving 2 μJy rms would provide ≈4 galaxies arcmin^{-2} (>10σ)
- Almost uniform sky coverage of 3π sr is exceptional
- **Major enhancement over Euclid alone**

Cosmology with SKA1: Weak Gravitational Lensing

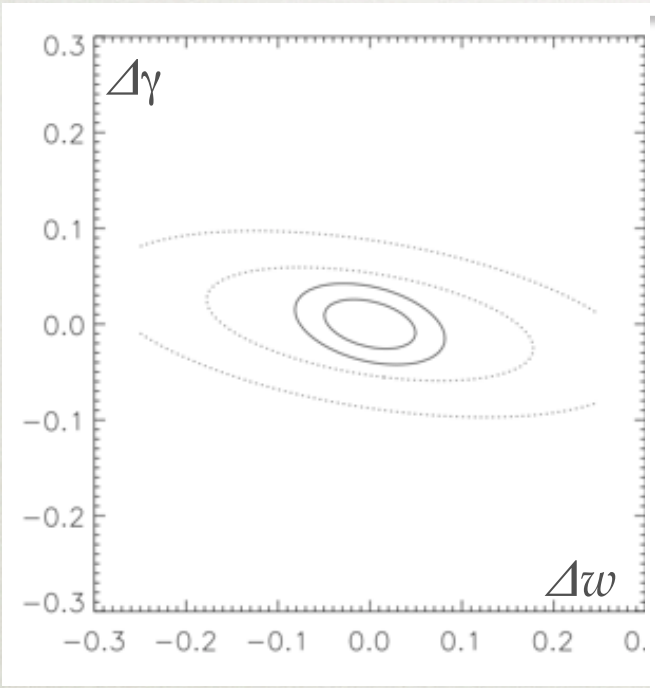


- Constraining the Dark Energy Equation of State with Weak Gravitational Lensing

Cosmology with SKA1: Complementarity with Euclid



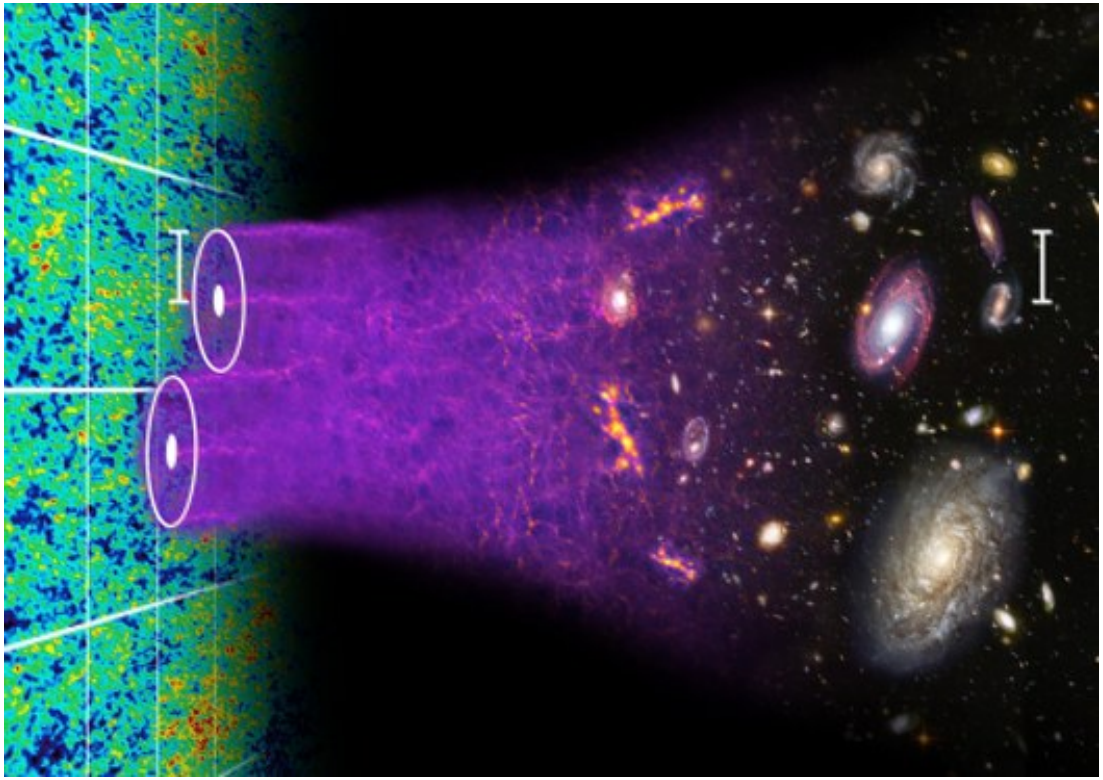
Euclid
+SKA1
lensing
σ_w=0.03
σ_γ=0.017



(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**

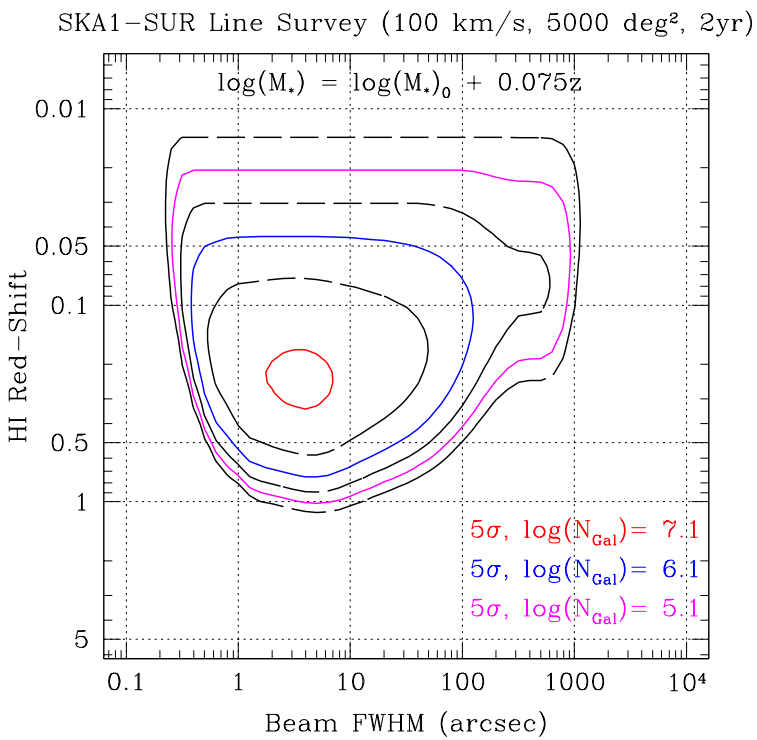
Cosmology with SKA1: Baryon Acoustic Oscillations

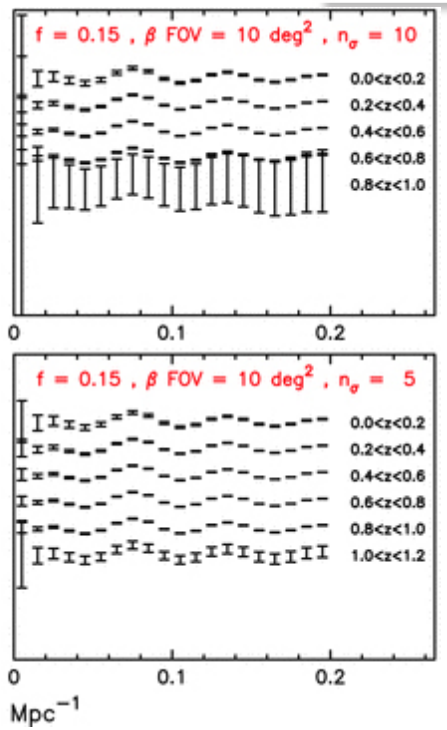


(Blake & Moorfield)

- Constraining Dark Energy models with redshift-resolved BAO measurements

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

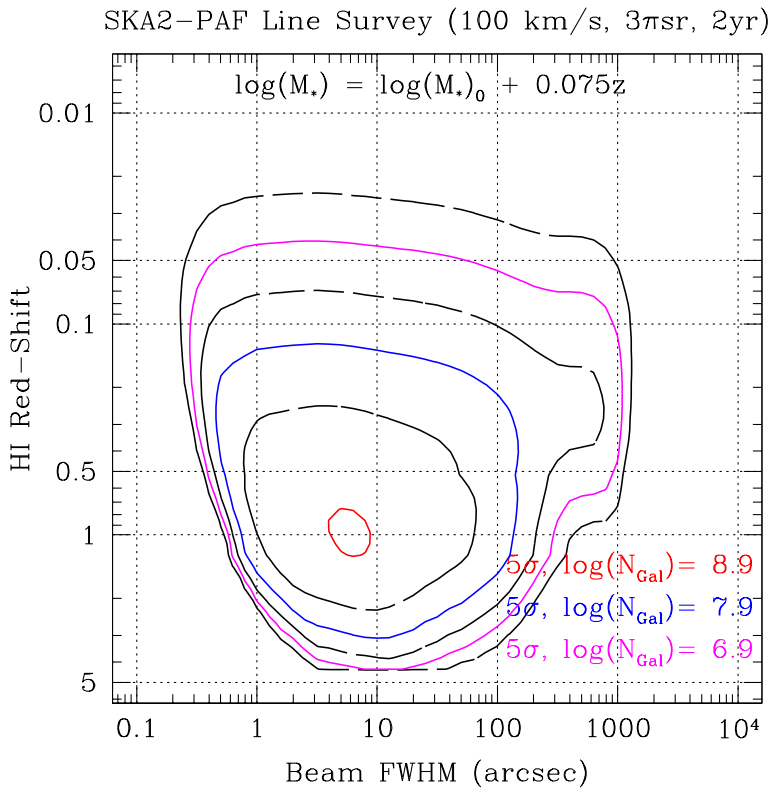




(Abdalla et al 2010)

- 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!**

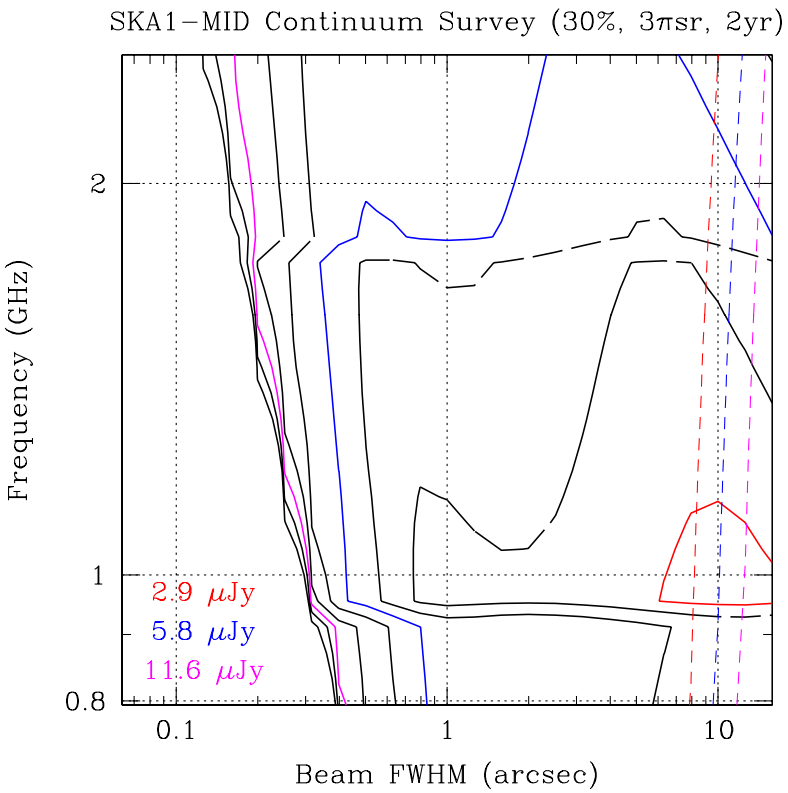
SKA Key Science

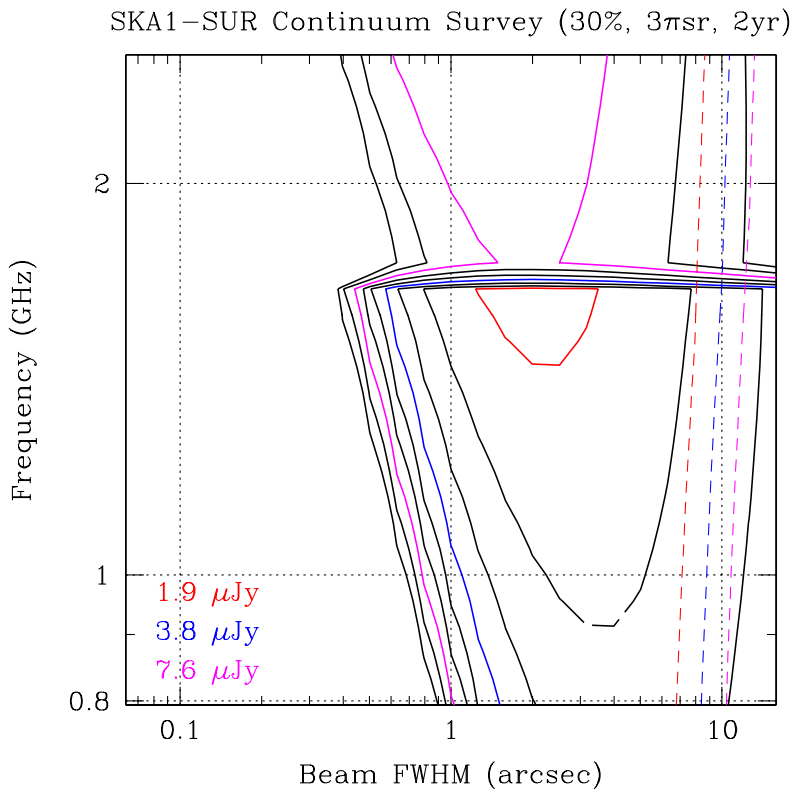
- Strong-field Tests of Gravity with Pulsars and Black Holes
  - **Unique GR constraints, major contributions in Phase 1 and Phase 2**
- Galaxy Evolution, Cosmology, & Dark Energy
  - **Cutting edge contributions in non-Gaussianity and Dark Energy**
  - **Complementarity to Euclid, LSST in Phase 1 (reduced 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

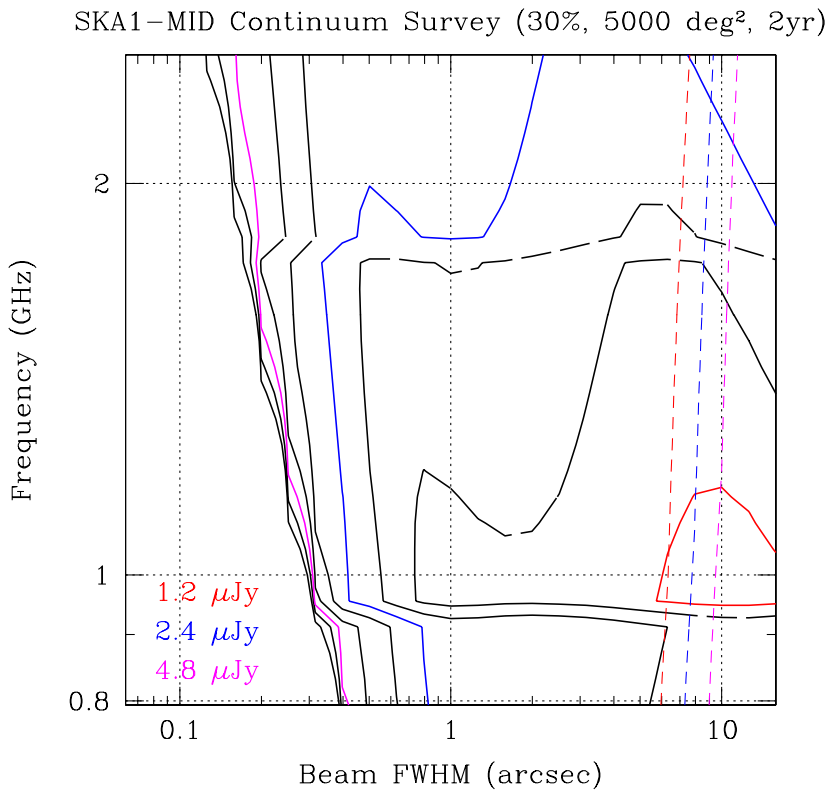
Continuum Surveys with SKA1:

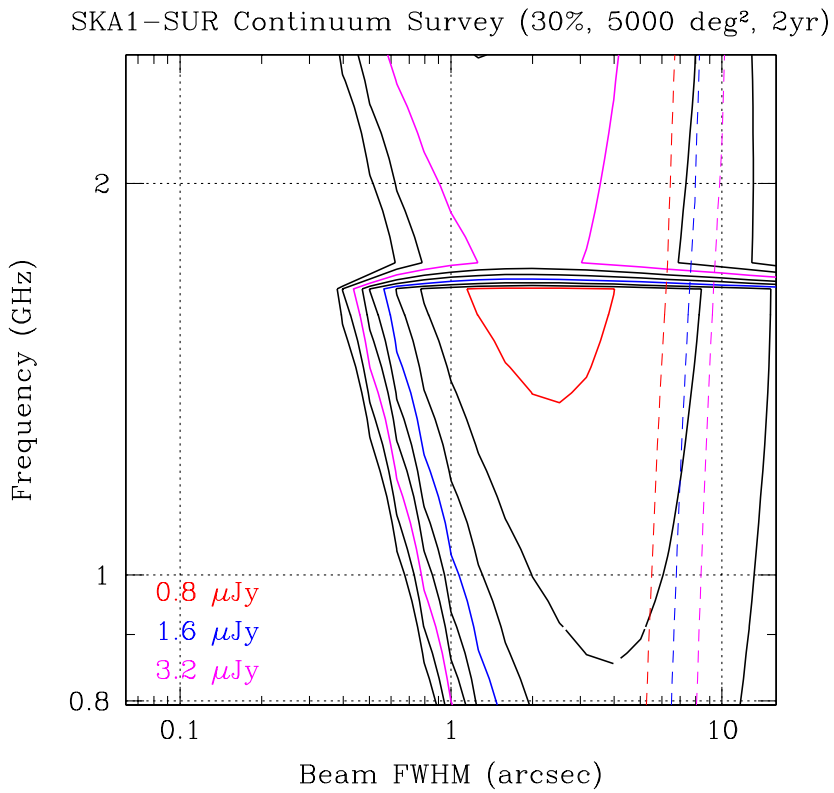




- All-sky surveys for Integrated Sachs-Wolfe, magnetism, Galactic sources, local Universe

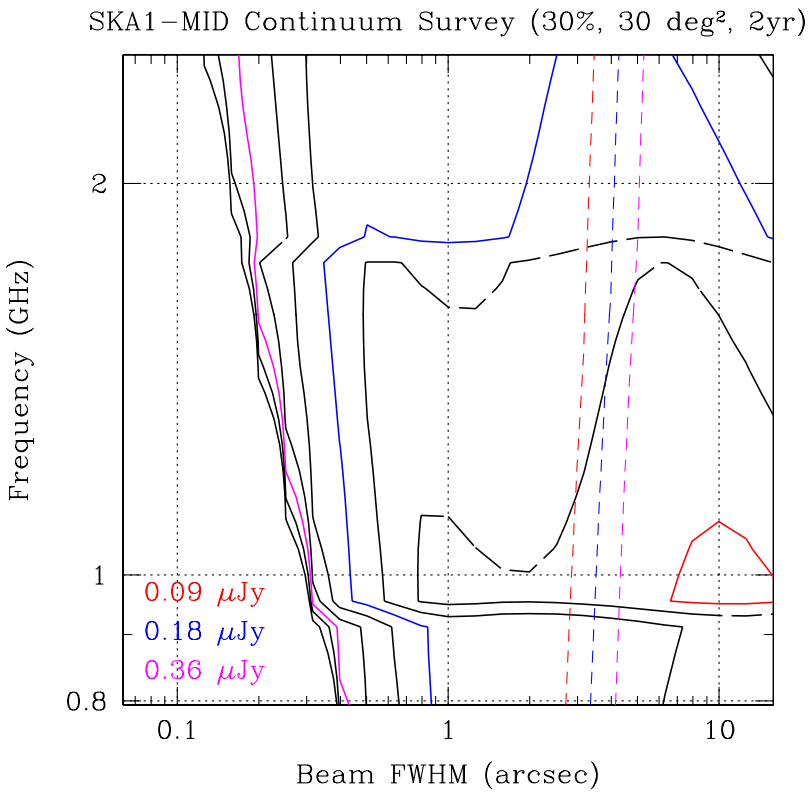
Continuum Surveys with SKA1:

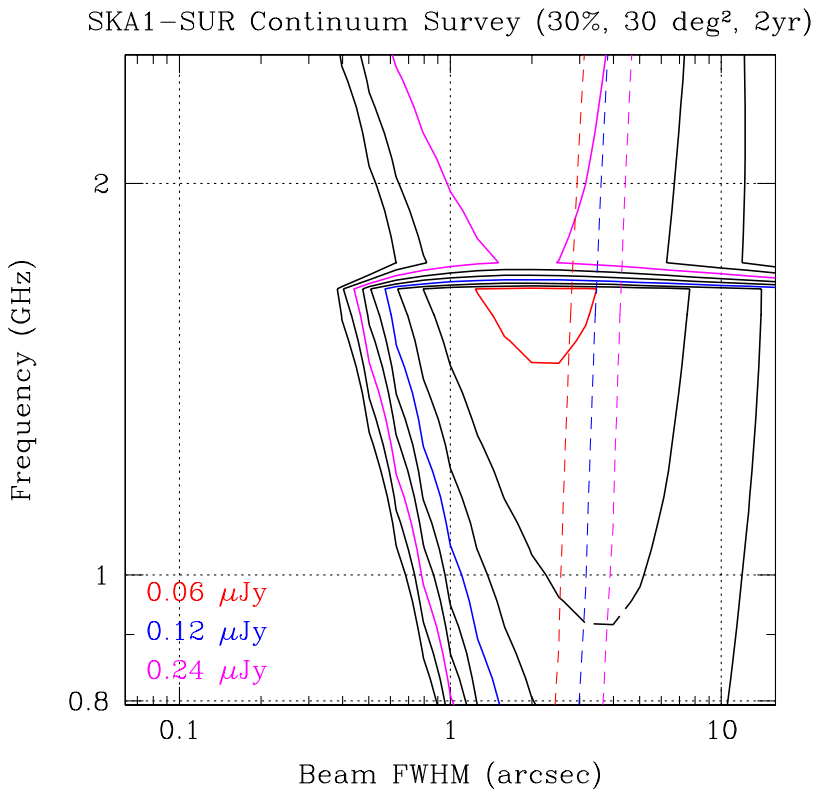




- Medium-wide surveys for weak lensing, galaxy evolution z < 1

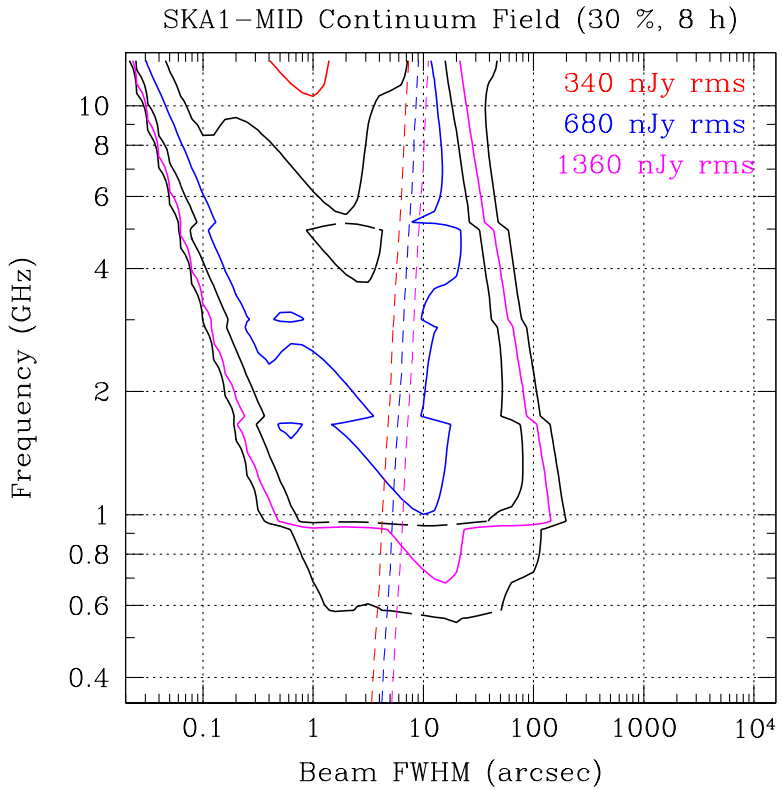
Continuum Surveys with SKA1:

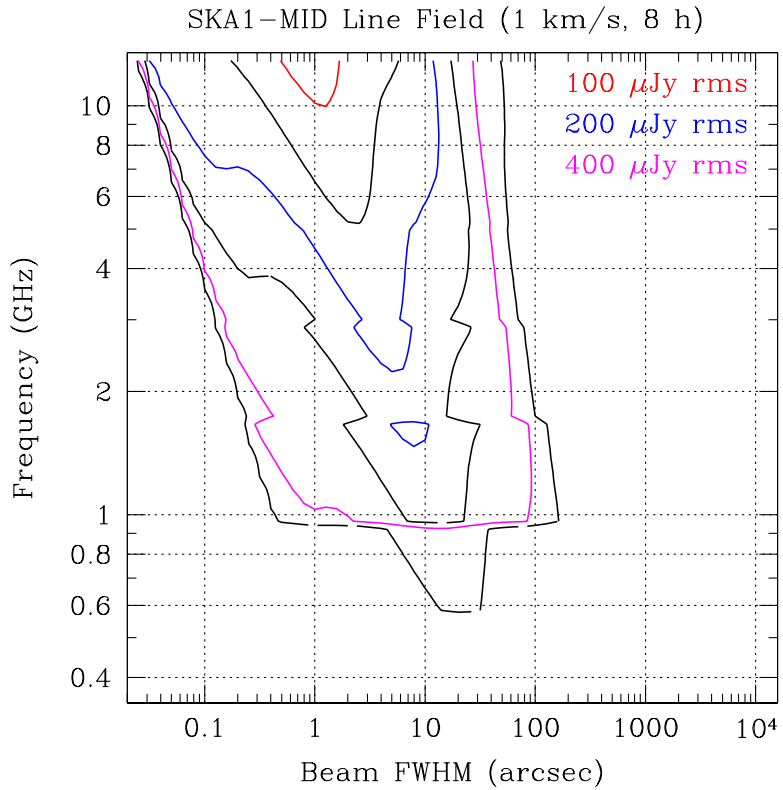




- Deep surveys for resolved morphology of z > 1 galaxies

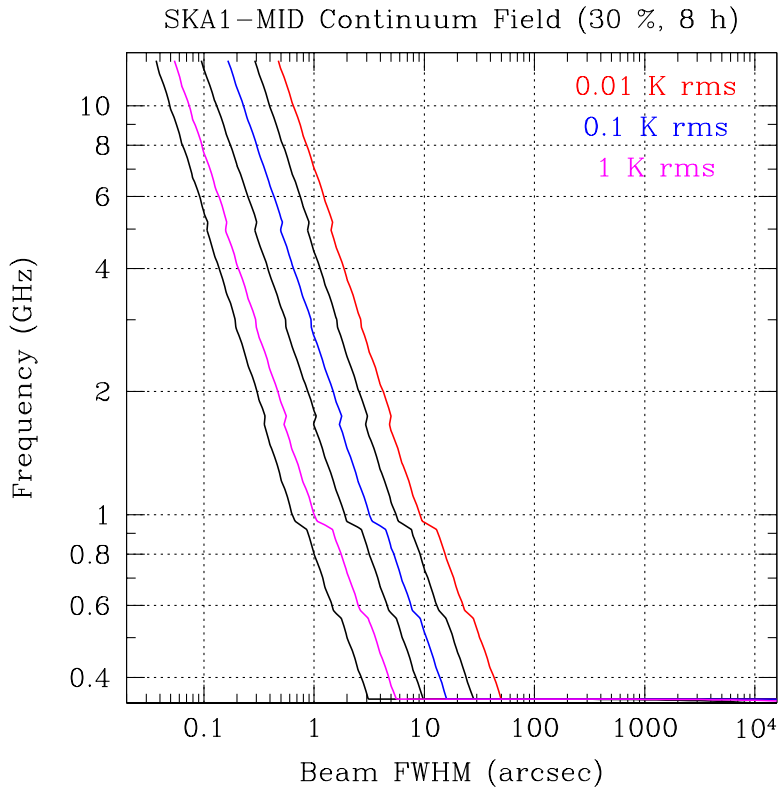
High Frequency Imaging with SKA1:

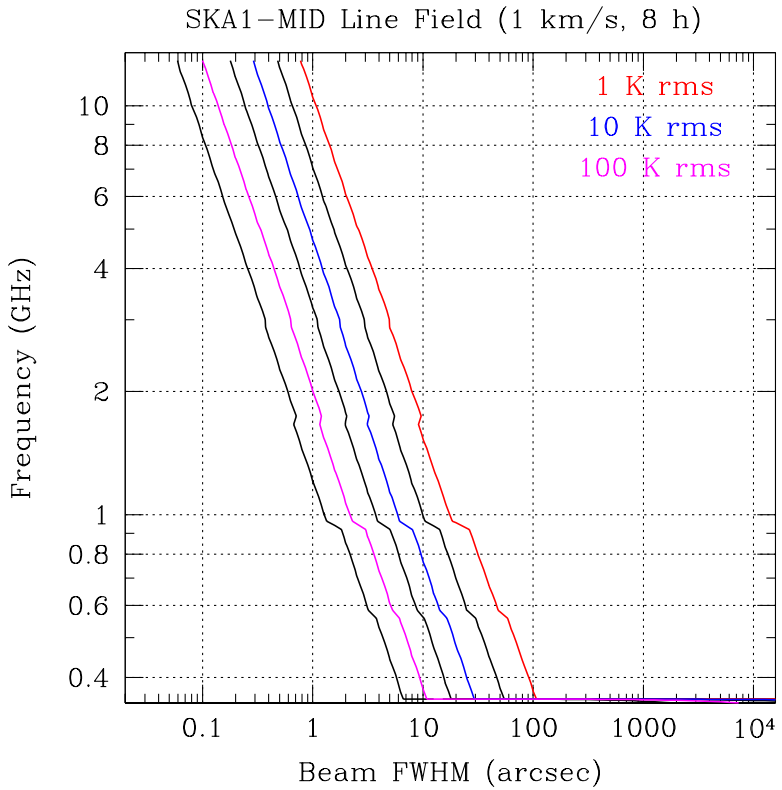




- Targeted imaging of line and continuum fields

High Frequency Imaging with SKA1:





- Targeted imaging of line and continuum fields