



Square Kilometre Array – Instrument and Science Overview

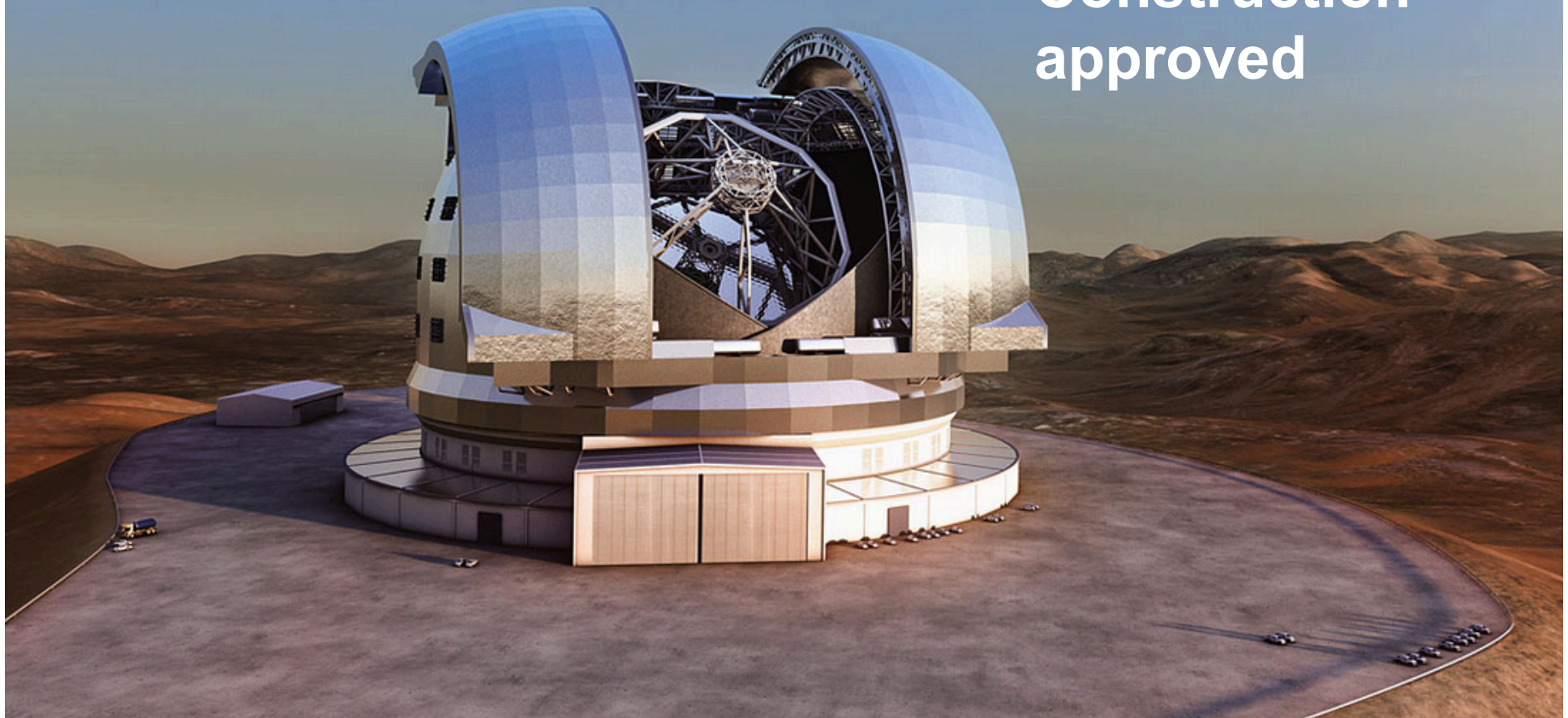
Robert Braun
SKA Science Director
9th January 2014

Great Observatories for the coming decades



E-ELT optical/IR

Construction
approved



Great Observatories for the coming decades

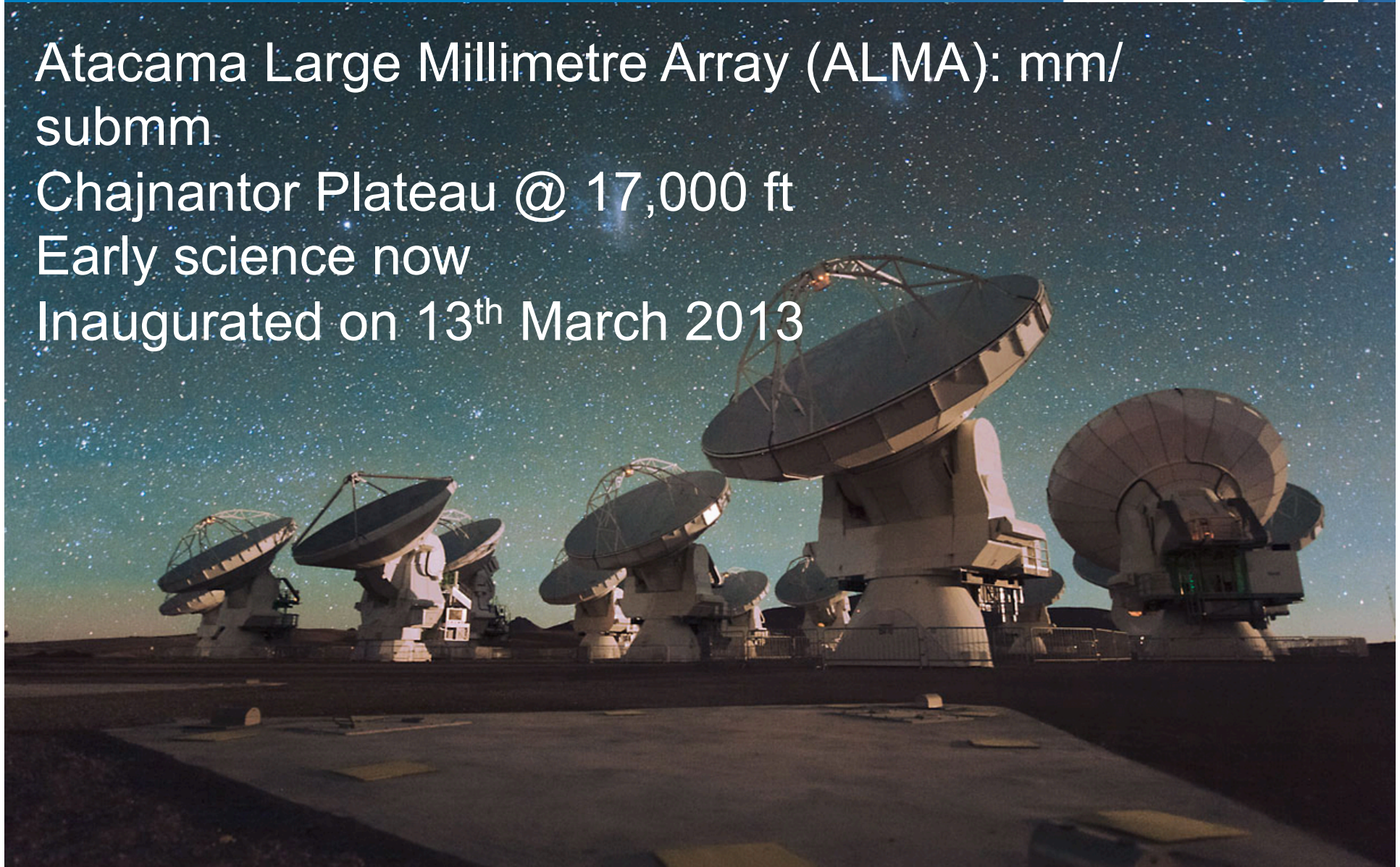


Atacama Large Millimetre Array (ALMA): mm/
submm

Chajnantor Plateau @ 17,000 ft

Early science now

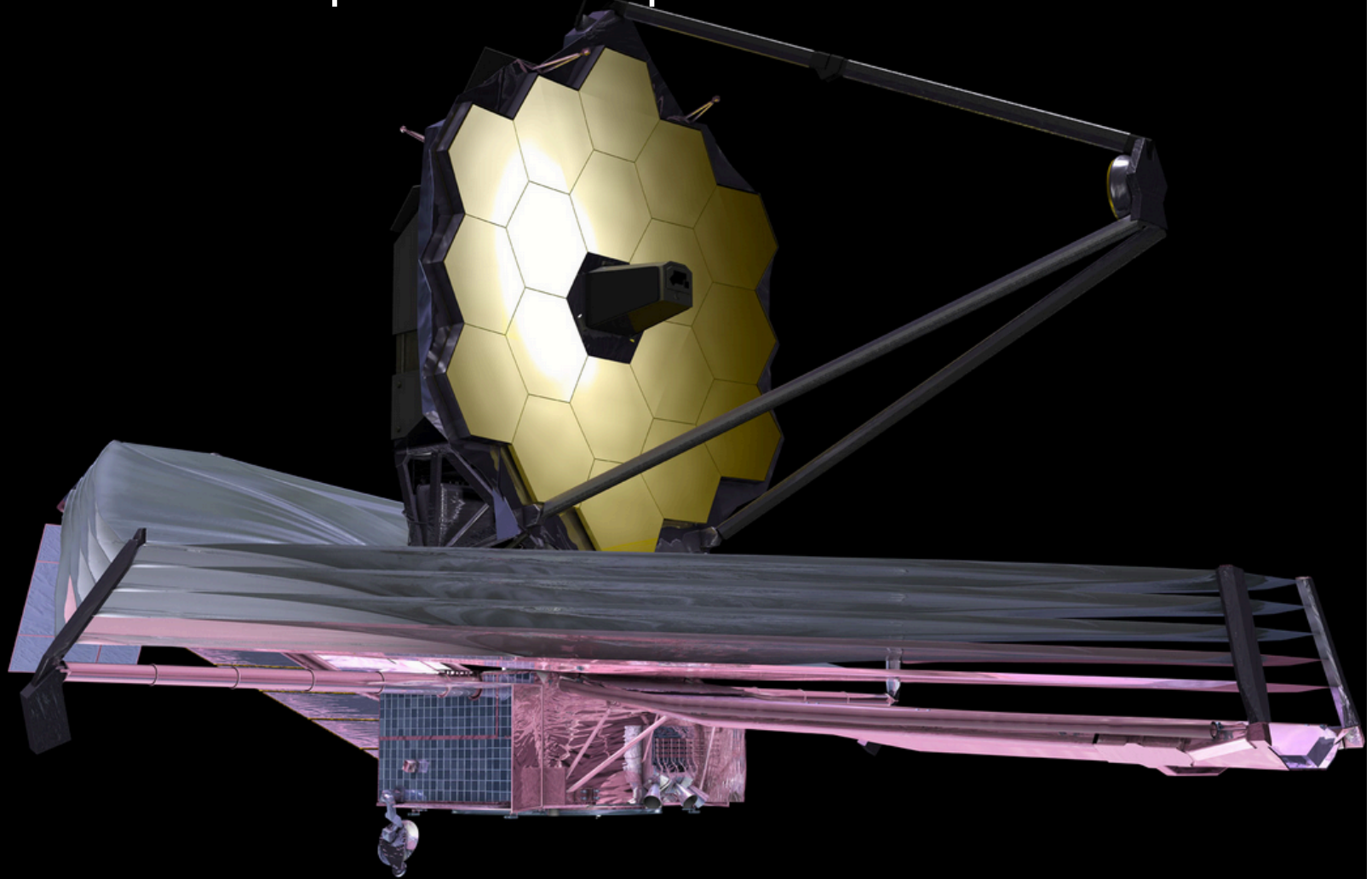
Inaugurated on 13th March 2013



Great Observatories for the coming decades



James Webb Space Telescope: due for launch in 2018



Great Observatories for the coming decades



Square Kilometre Array: radio
Construction start 2017/18

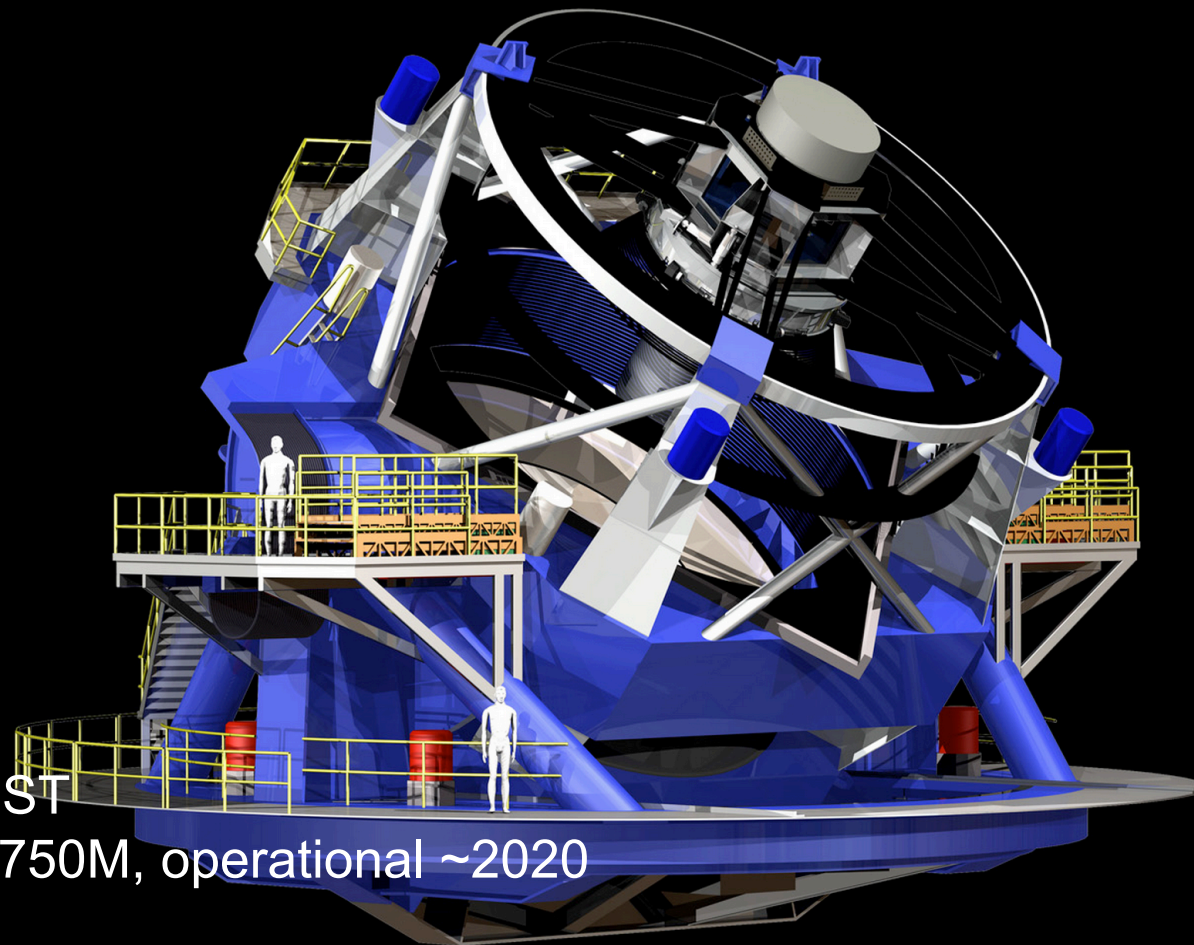
Specialised “experiments”



EUCLID:
~€1B, lau

LSST
~\$750M, operational ~2020

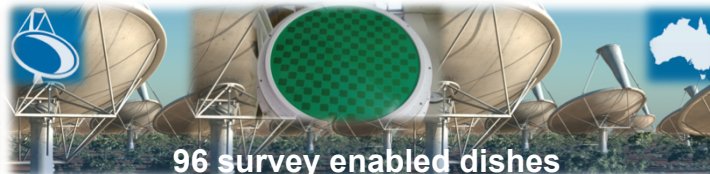
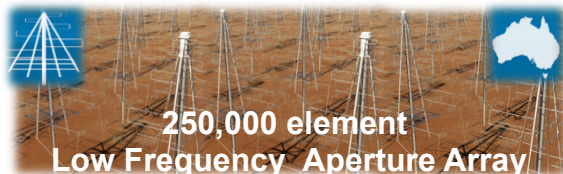
telescope



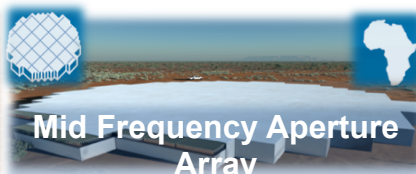
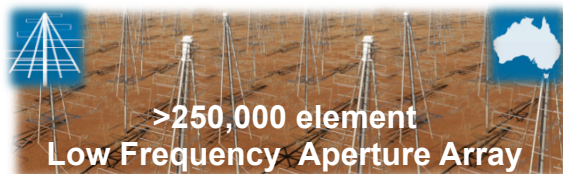
Exploring the Universe with the world's largest radio telescope



Phase I : 2020



Phase II : 2024



Science

Cosmic Dawn & Reionization

Cosmology &
Galaxy Evolution

Pulsars

Cosmic Magnetism

Cradle of Life

50 MHz

100 MHz

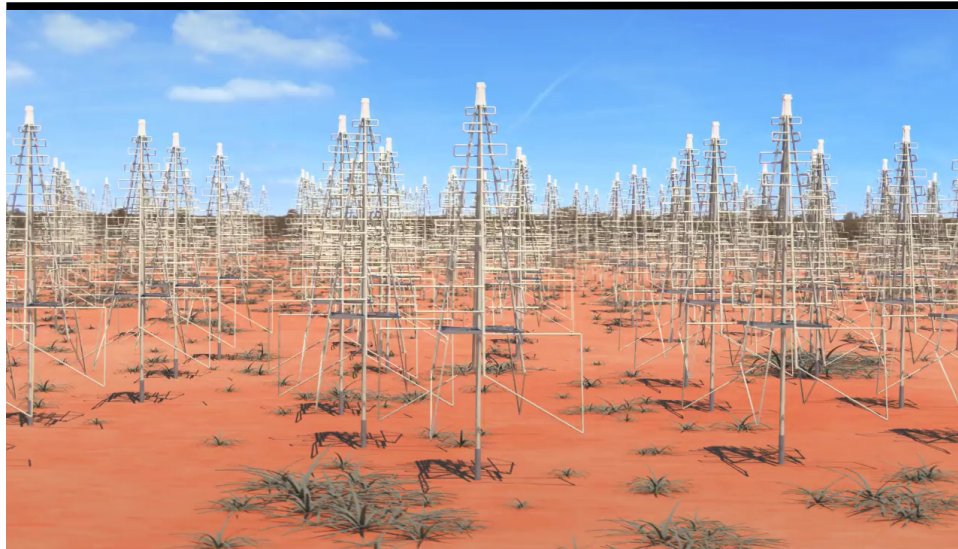
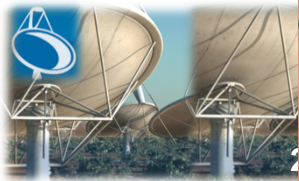
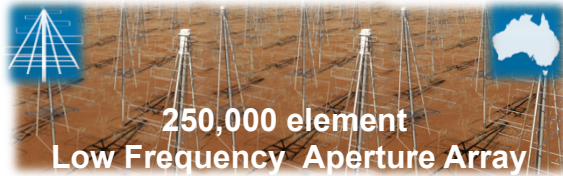
1 GHz

10 GHz

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Phase I : 2020



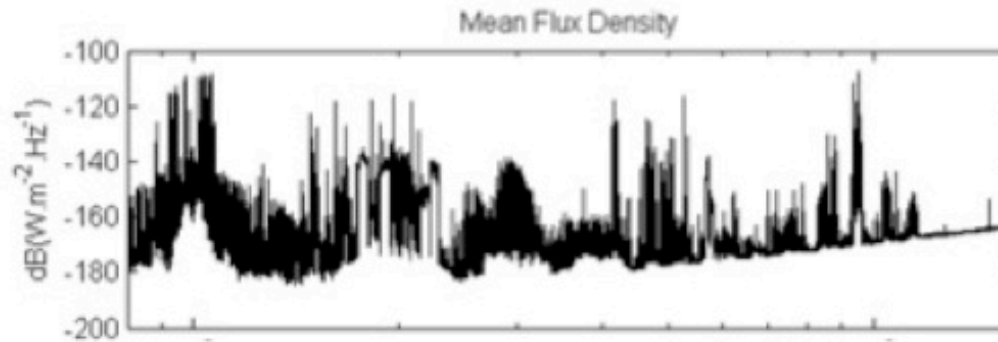
50 MHz

100 MHz

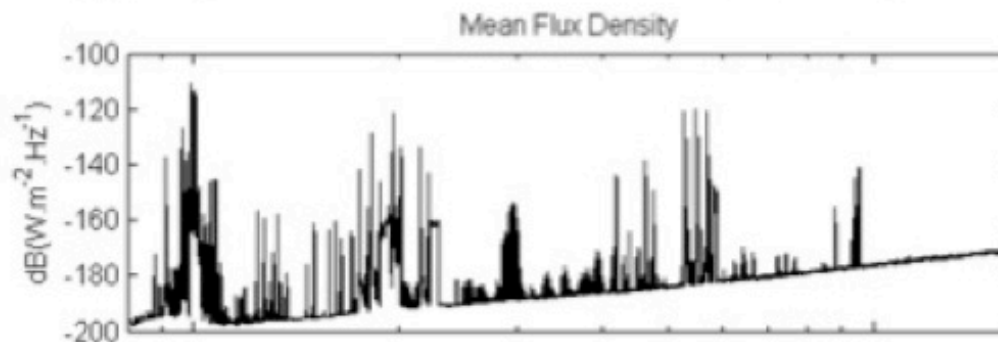
1 GHz

10 GHz

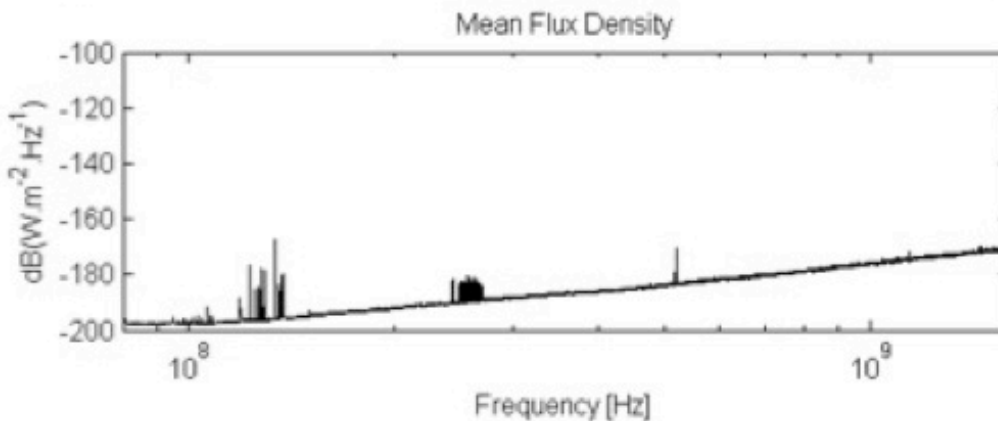
How did we choose the site?



Sydney:
population 4 million

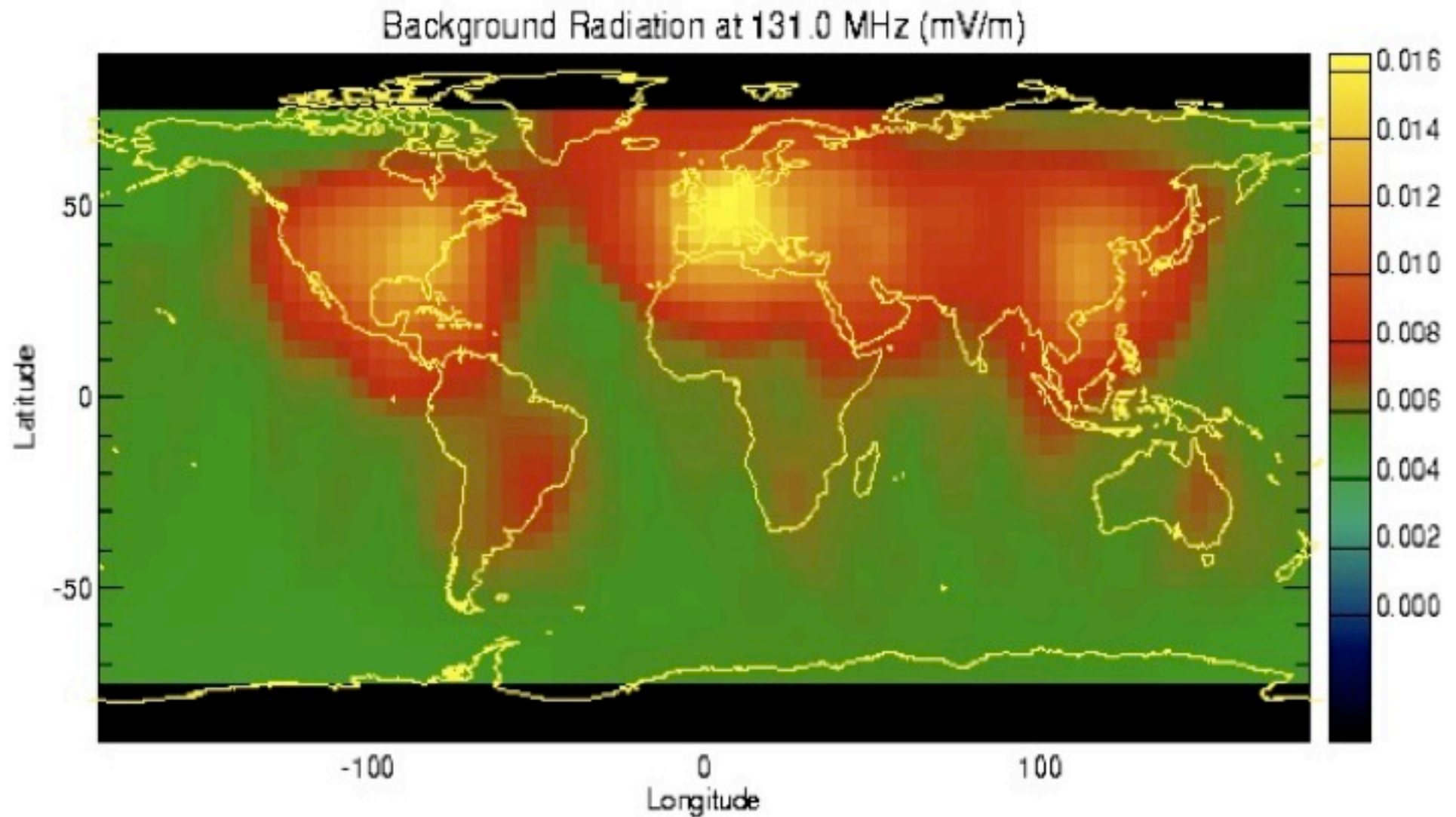


Narrabri:
population 4000



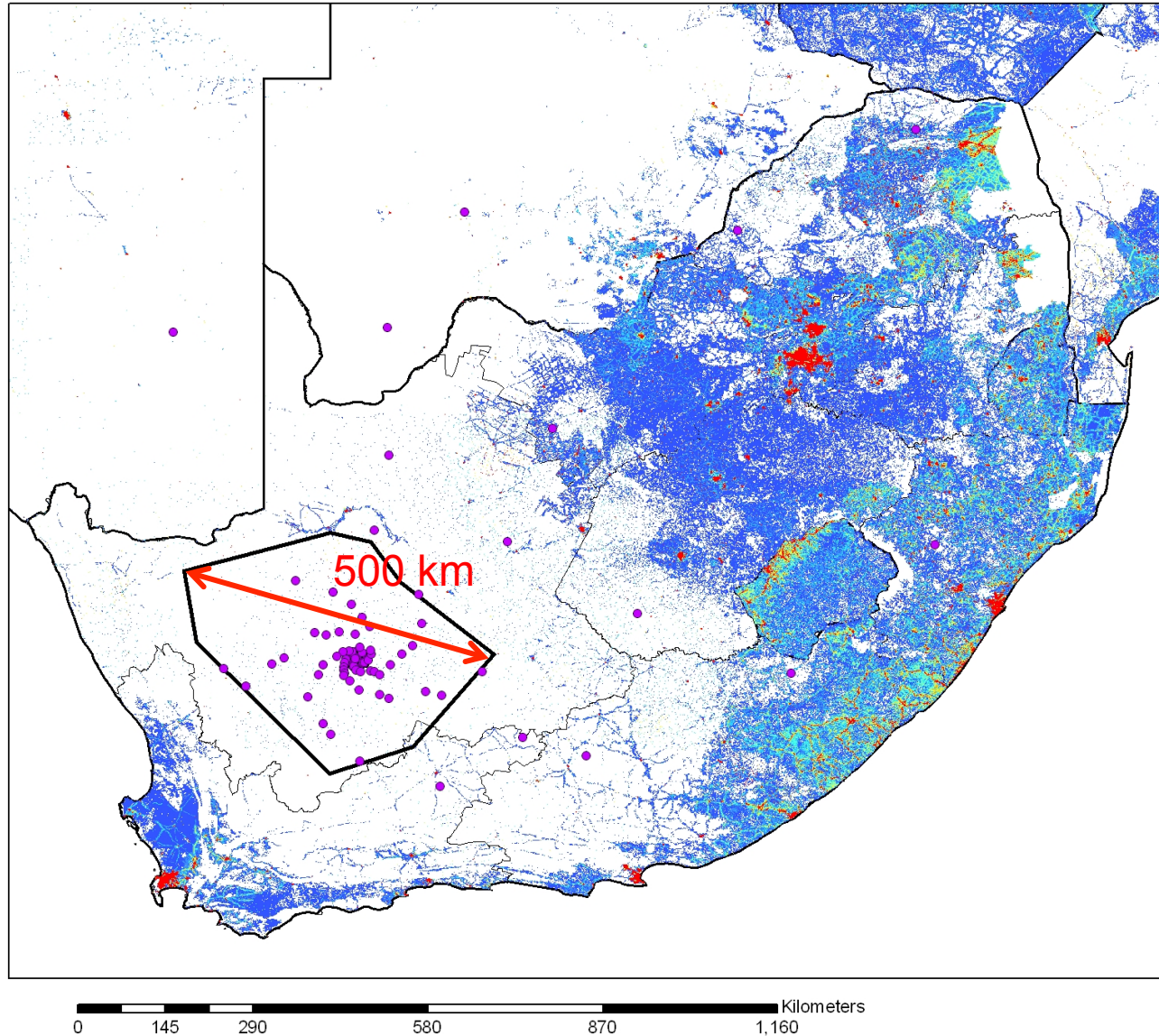
Mileura:
population 4

How did we choose the site?



Exploring the Universe with the world's largest radio telescope

Karoo Radio Astronomy Research



Legend

- SKA_Configuration_SPDO_Dish_Full
- AA1_SPDO_Version1
- AA2_SPDO_Version2
- KCAAA1

Population (per sq km)

Value

- 0 - 4
- 4.000000001 - 14
- 14.000000001 - 29
- 29.000000001 - 47
- 47.000000001 - 68
- 68.000000001 - 91
- 91.000000001 - 116
- 116.000000001 - 142
- 142.000000001 - 169
- 169.000000001 - 197
- 197.000000001 - 225
- 225.000000001 - 255

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Email: atiplady@ska.ac.za

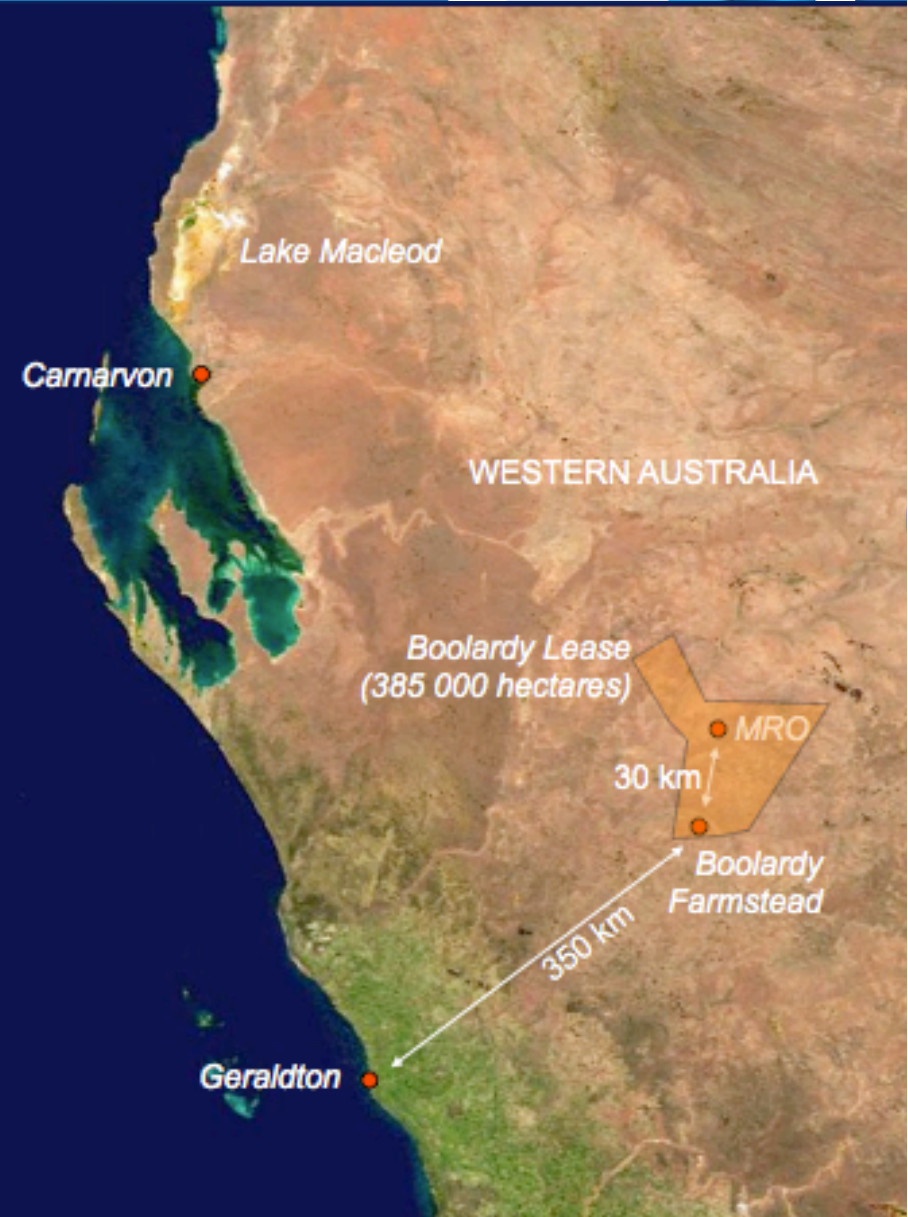


Murchison Radio Astronomy Observatory



Shire of Murchison:

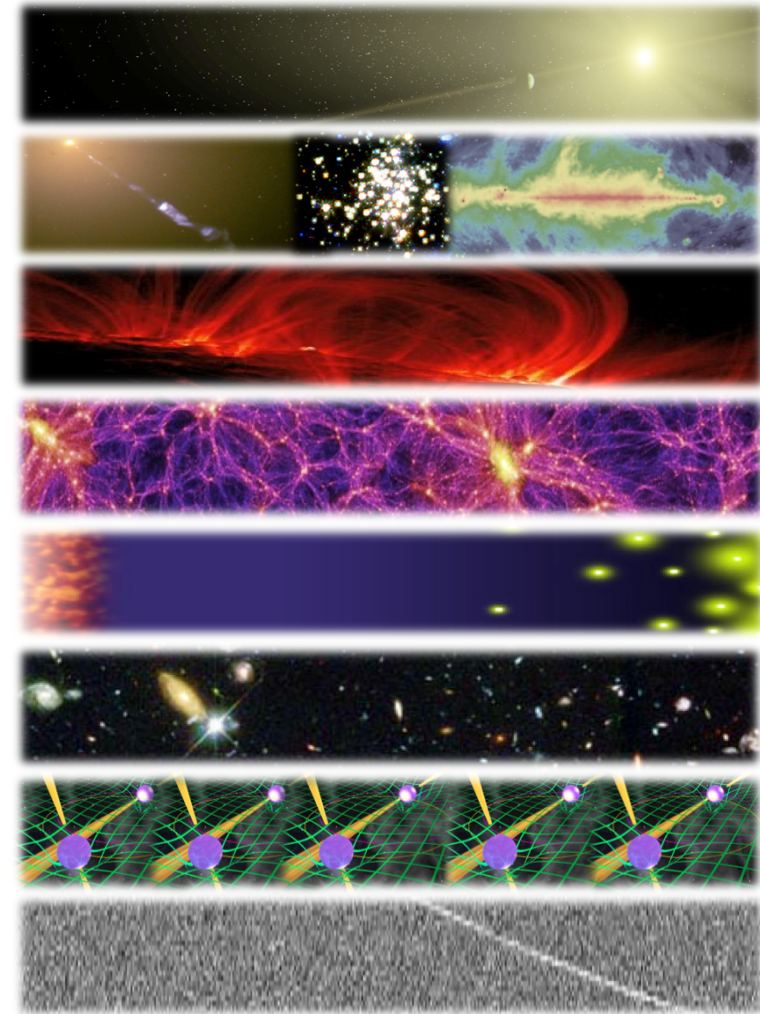
- 50,000 km² ; size of the Netherlands
- 0 gazetted towns
- 29 sheep/cattle stations
- 110 population $\Rightarrow$ 0.002 km⁻²



The Science Working Groups



- **Astrobiology (“The Cradle of Life”)**
 - *Project Scientist:* Tyler Bourke
 - *Working Group Chair:* Melvin Hoare
- **Galaxy Evolution – 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
- **Galaxy Evolution – HI**
 - *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

How does SKA1 baseline redefine state-of-art?



		JVLA	MeerKAT	SKA1-mid	ASKAP	SKA1-survey	LOFAR-NL	SKA1-low
A_{eff}/T_{sys}	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}:

Survey Speed:

6xJVLA

100x

6xASKAP

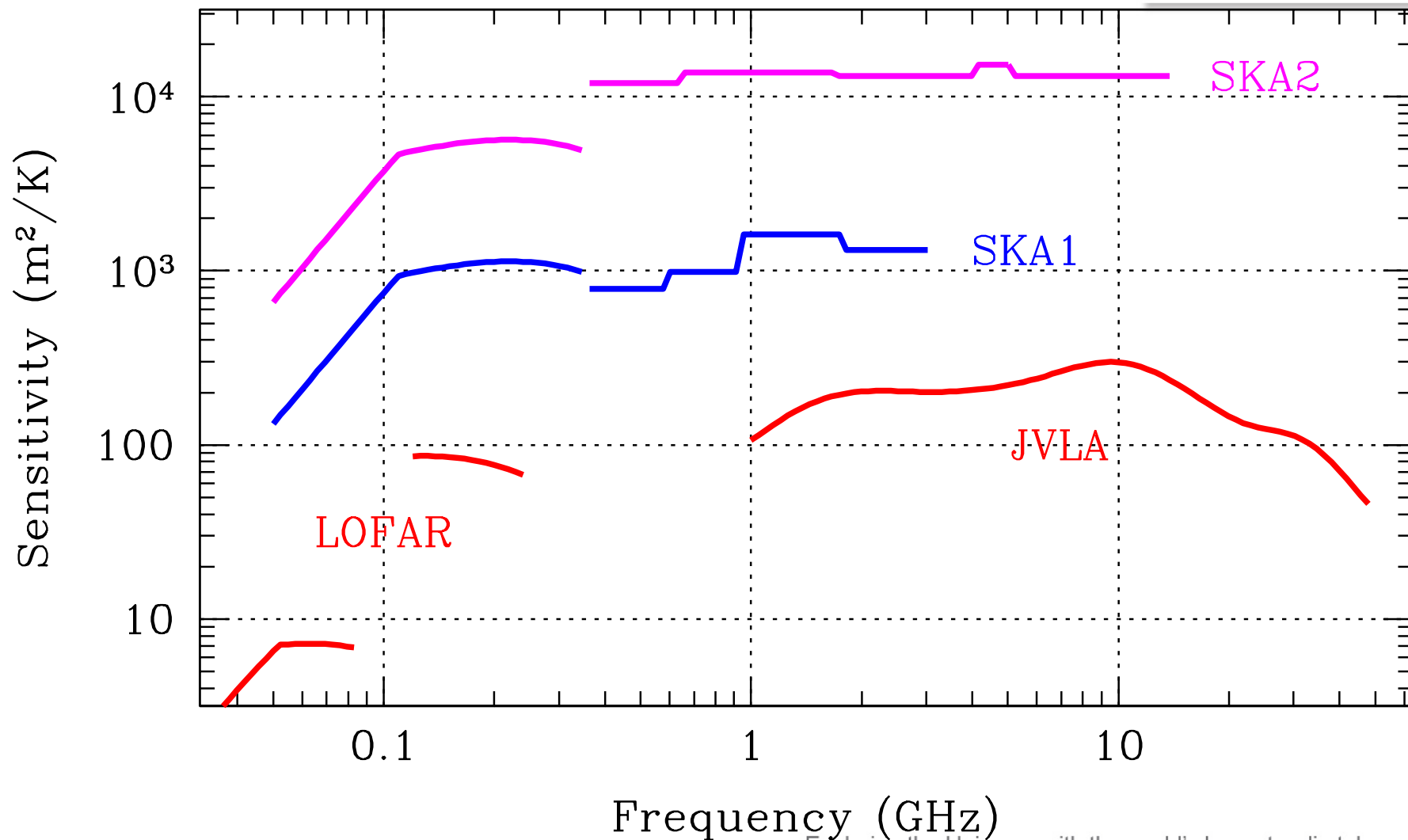
22xASKAP

280xJVLA

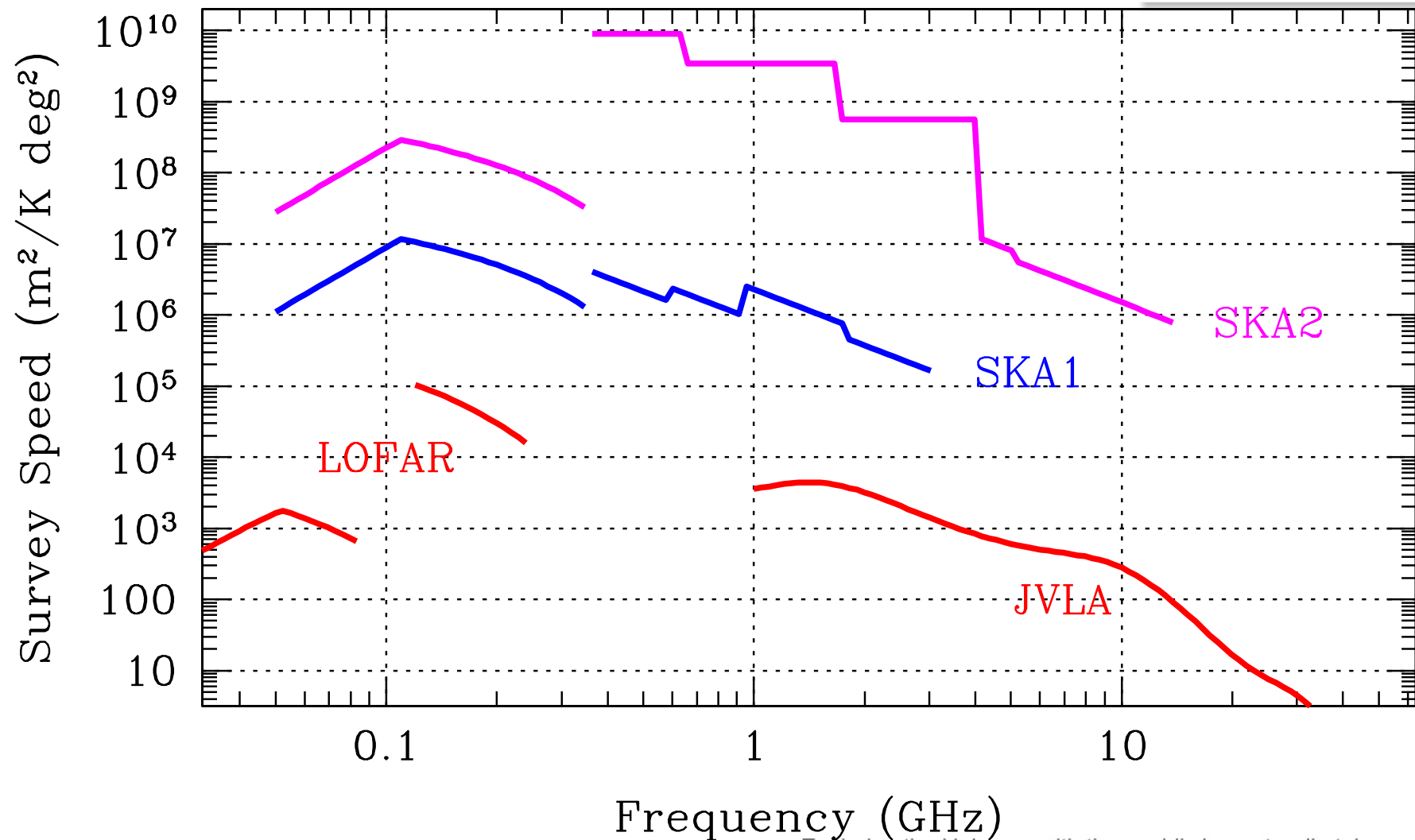
16xLOFAR

270x

Sensitivity comparison



Survey speed comparison

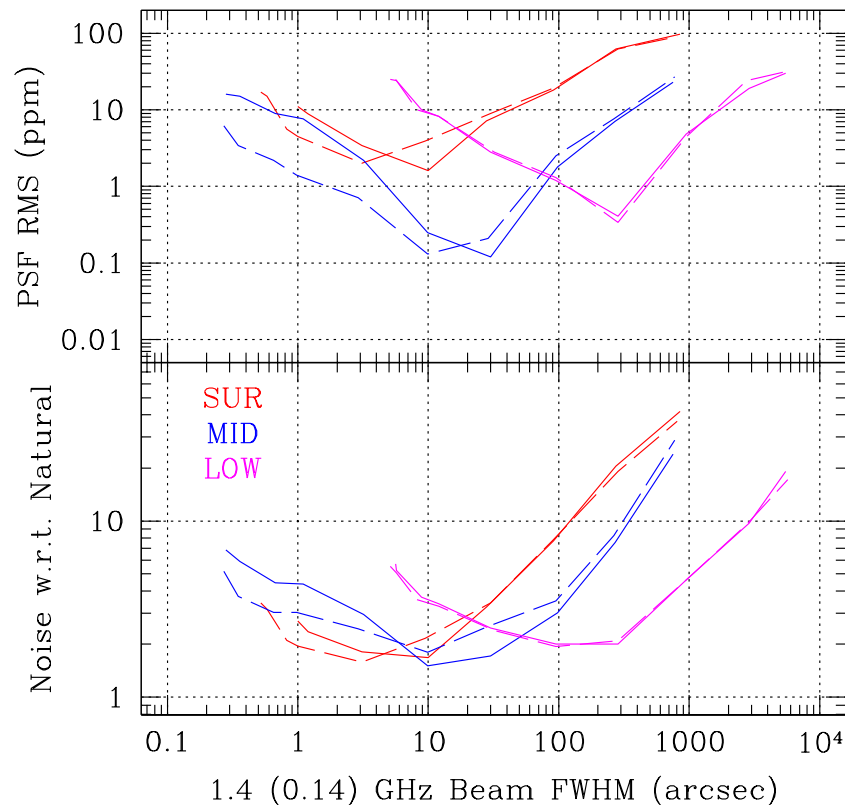


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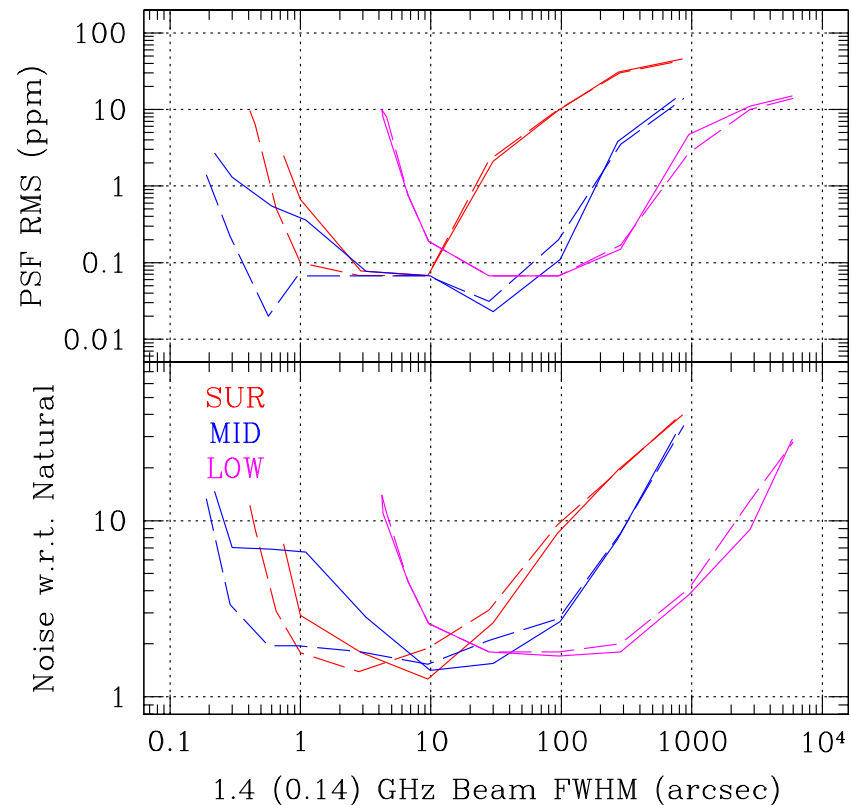
SKA1: facility versus “experiment”



Monochromatic Imaging Performance

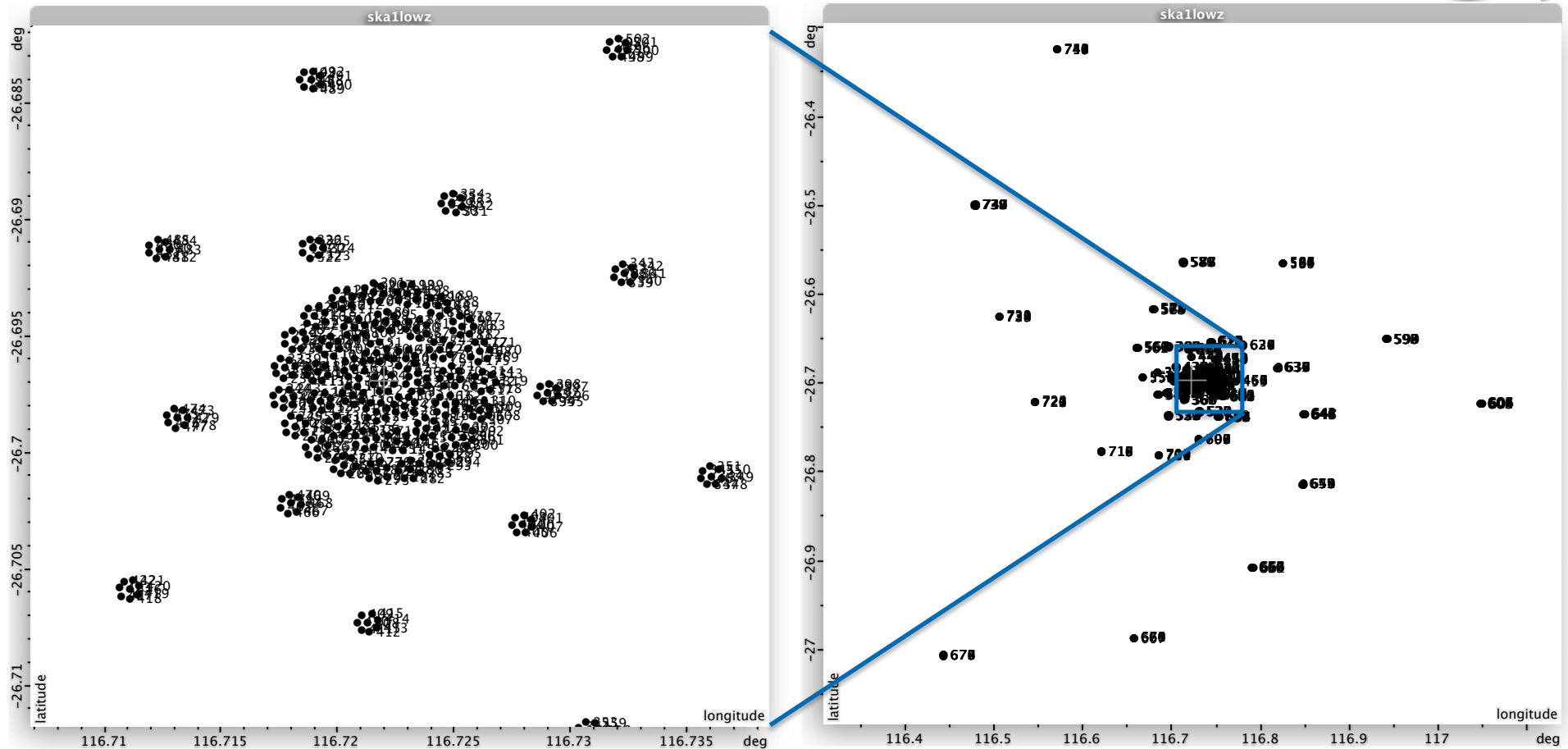


Continuum (R=3) Imaging Performance



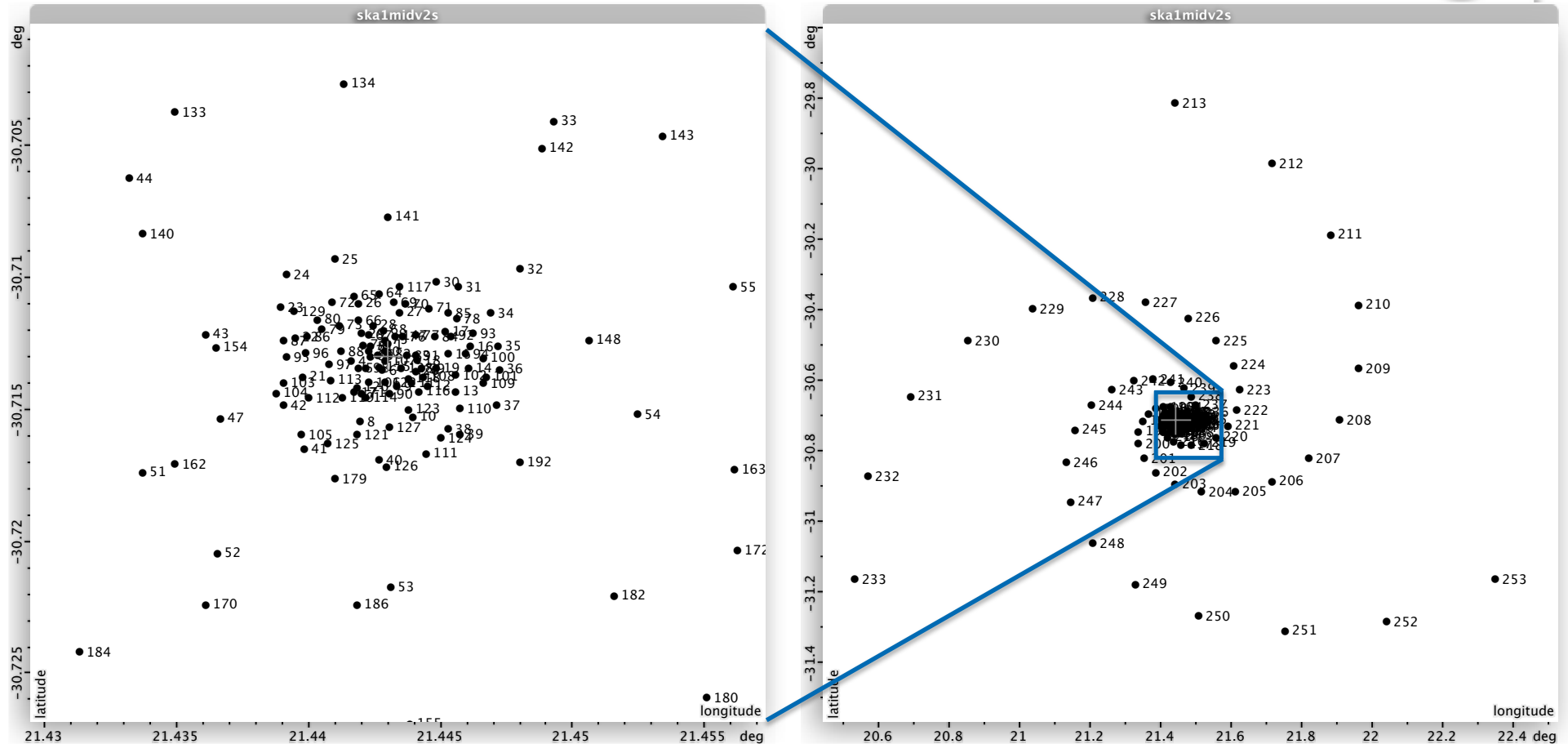
- Configuration optimisation for broad performance “sweet-spot”

SKA1 configurations



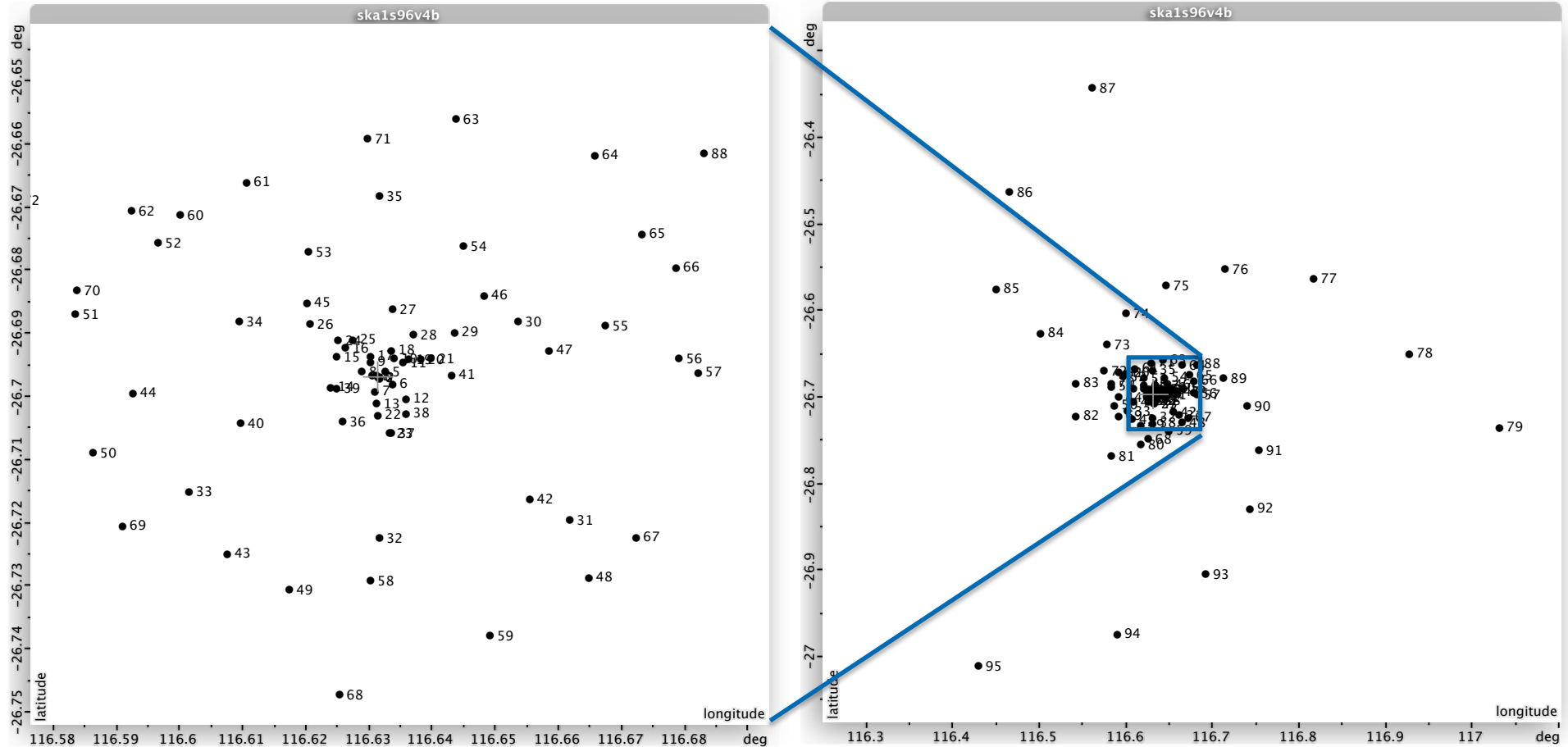
- SKA1-LOW possible configuration of core and remote spiral

SKA1 configurations



- SKA1-MID possible configuration of core and remote spiral

SKA1 configurations



- SKA1-SUR possible configuration of core and remote spiral

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

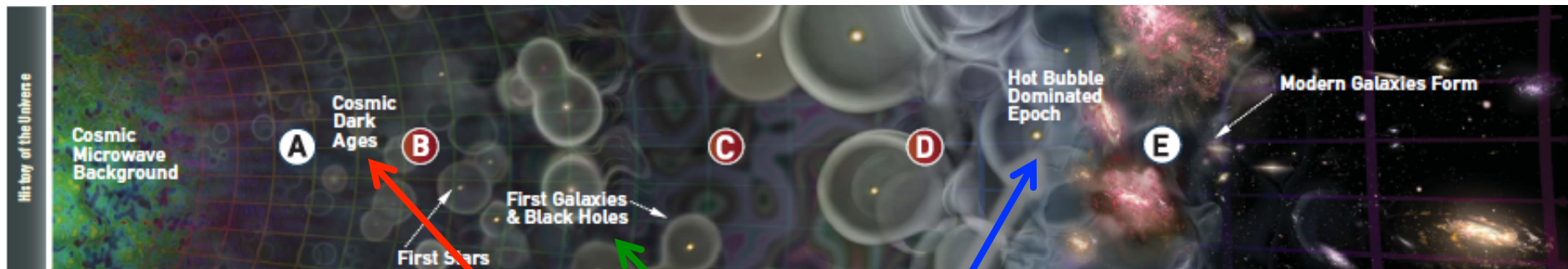
- The Cradle of Life & Astrobiology

- 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

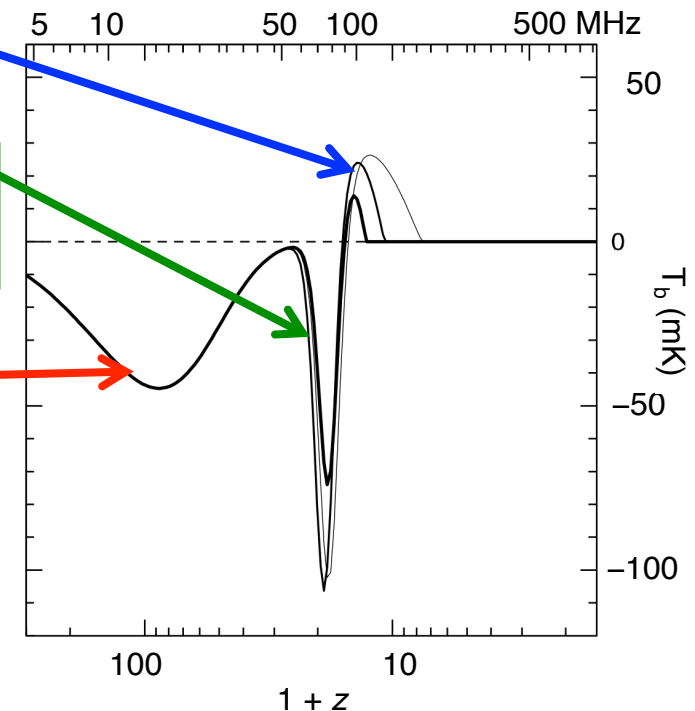
EoR

Cosmic
Dawn

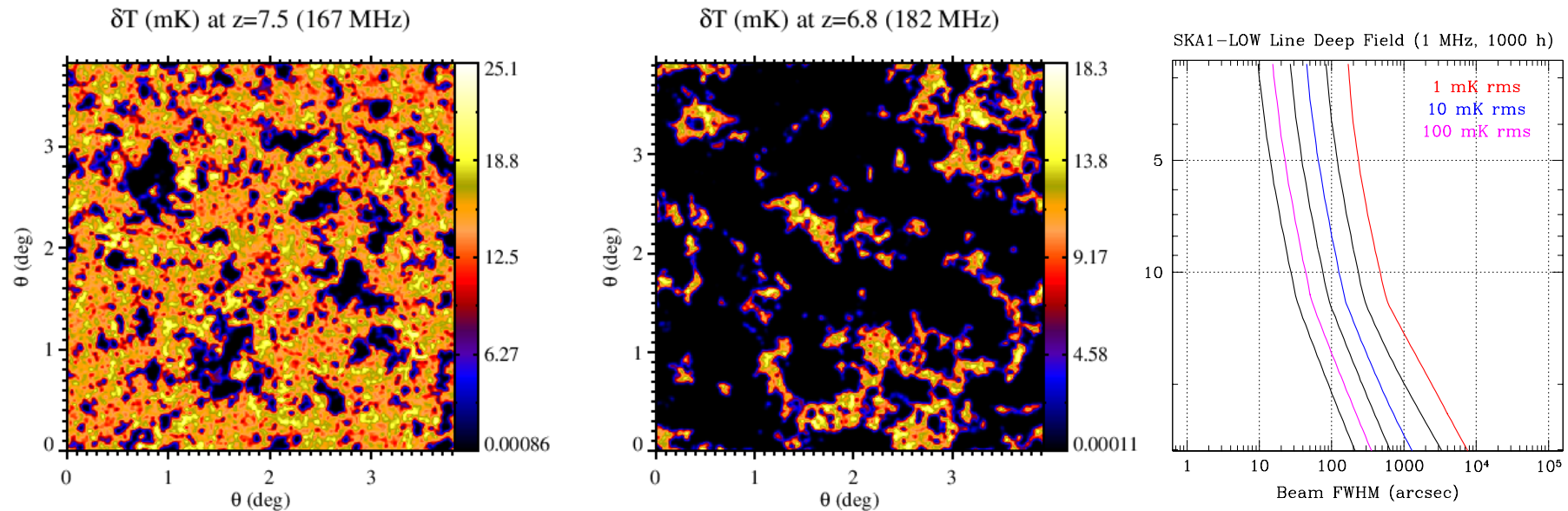
Dark
Ages

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

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



HI surveys of the EoR/Cosmic-Dawn Universe

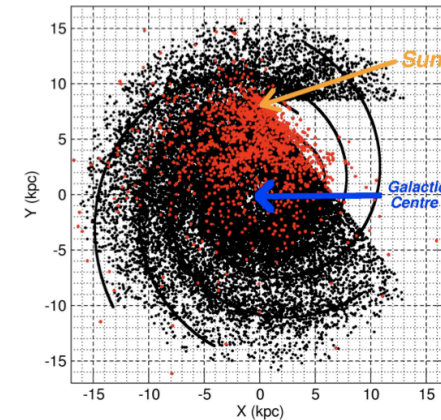
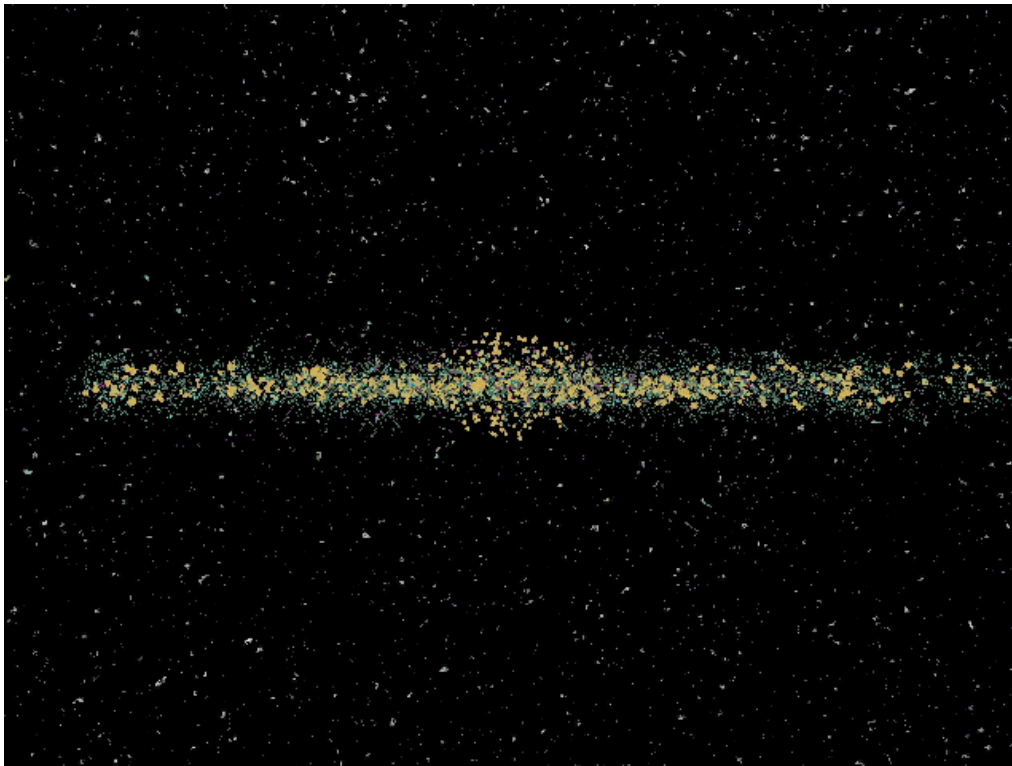


- Detecting EoR structures in imaging mode (as distinct from statistically) on 5 arcmin scales with 1 mK RMS
- Probing the Cosmic Dawn statistically or possibly even imaging in ultra-deep

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 ~50% of entire Galactic population in reach of SKA1**

The transient radio sky

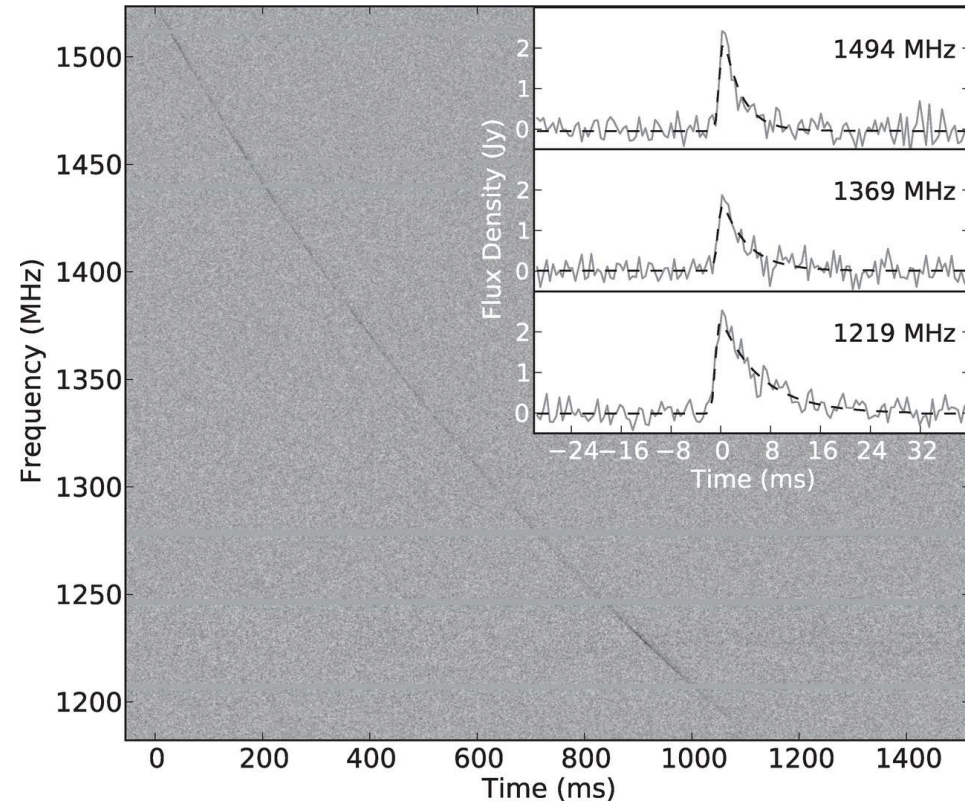
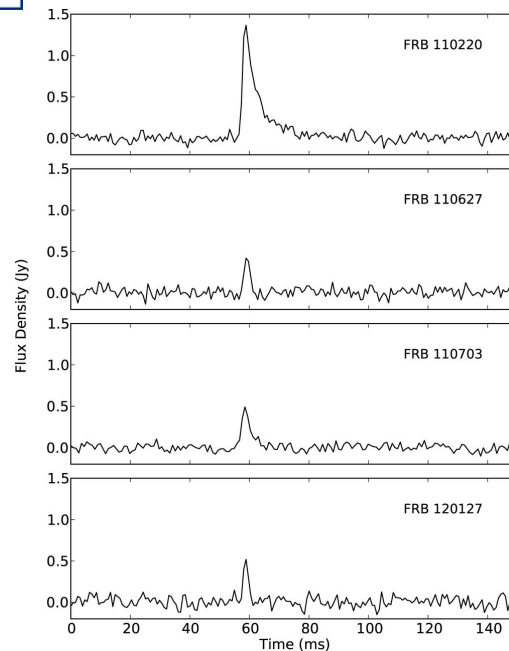


A Population of Fast Radio Bursts at Cosmological Distances

D. Thornton *et al.*

Science **341**, 53 (2013);

DOI: 10.1126/science.1236789



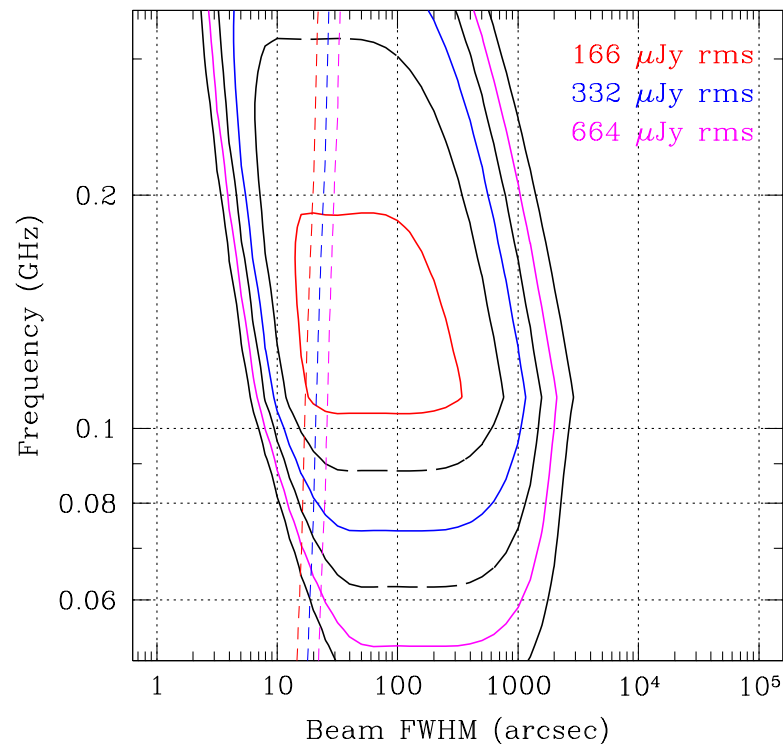
- Four celestial “FRB” events now detected (after first “Lorimer” burst):
 $S = 0.5 - 1.3 \text{ Jy}$, $\Delta t = 1 - 6 \text{ msec}$, $DM = 550 - 1100 \text{ cm}^{-3} \text{ pc}$
- Estimated event rate: $1 \times 10^4 \text{ sky}^{-1} \text{ day}^{-1}$
- Completely unknown origin, possibly at cosmological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

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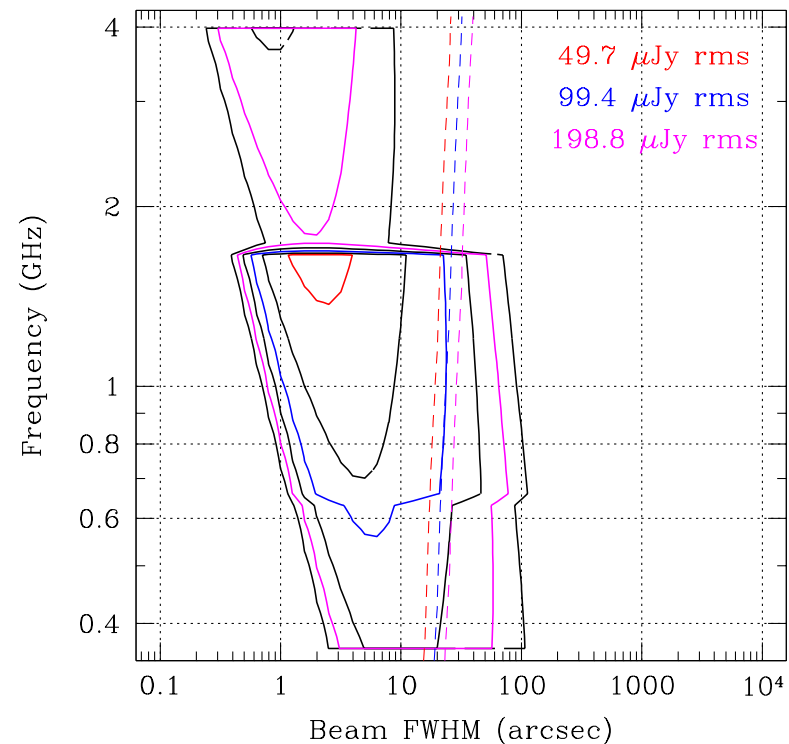
A daily SKA1 all-sky transient survey



SKA1–LOW Continuum Survey (30%, 3π sr, 1 day)

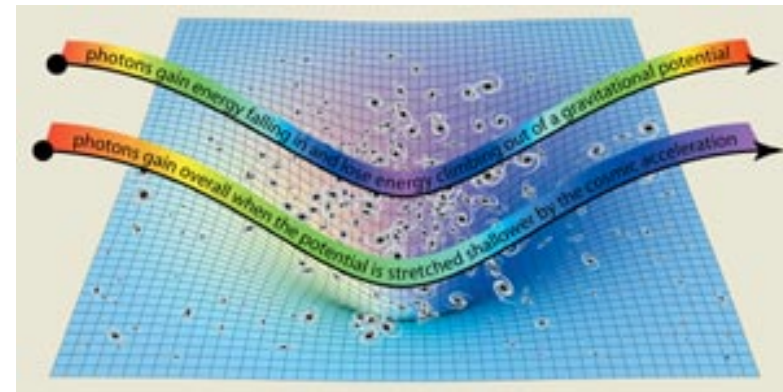
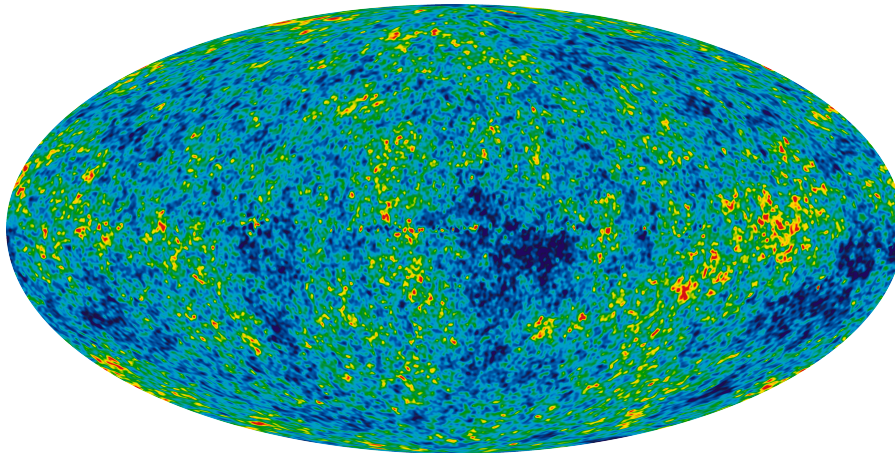


SKA1–SUR Continuum Survey (30%, 3π sr, 1 day)



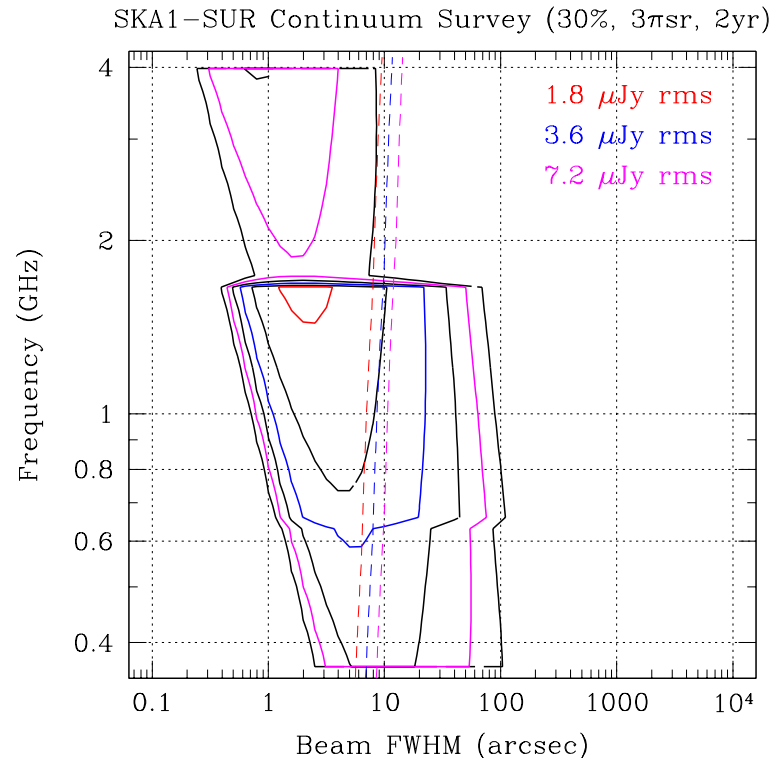
- Integration of ≈ 50 seconds per position
- Sensitivity for 2 msec bursts is 160x worse: 27 mJy, 8 mJy rms
- Computing strategy most still be developed for such a mode!
- **Predicted FRB detections: 5 per day, with localisation to a fraction of arcsec**

Cosmology with SKA1: Integrated Sachs-Wolfe effect

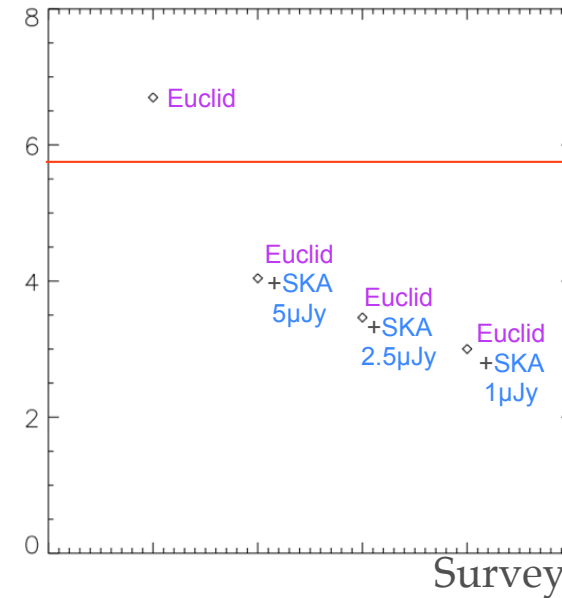


- Constraining non-Gaussianity of primordial fluctuations with the Integrated Sachs-Wolfe effect: correlation of foreground source populations with CMB structures

Cosmology with SKA1: Complementarity with Euclid



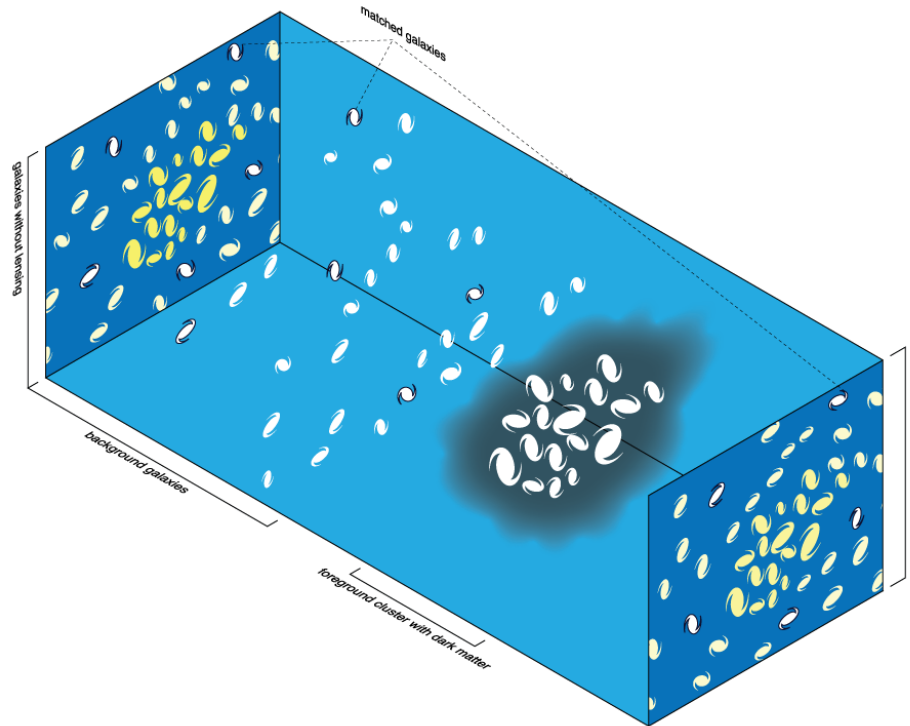
$\sigma[f_{\text{NL}}]$



(Bacon 2013)

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

Cosmology with SKA1: Weak Gravitational Lensing

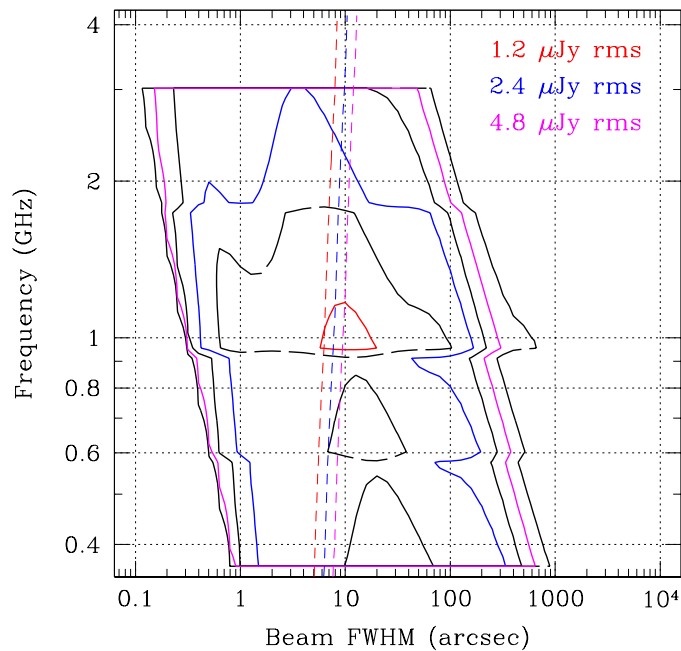


- Constraining the Dark Energy Equation of State with Weak Gravitational Lensing

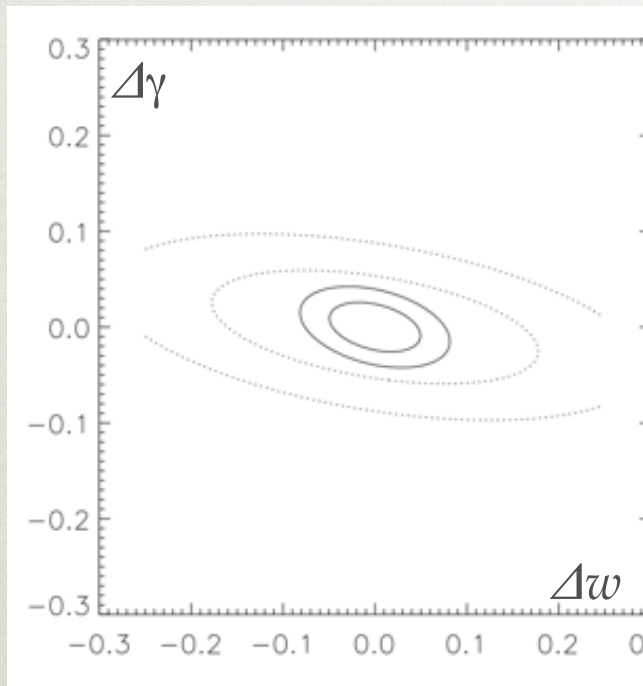
Cosmology with SKA1: Complementarity with Euclid



SKA1-MID Continuum Survey (30%, 5000 deg², 2yr)



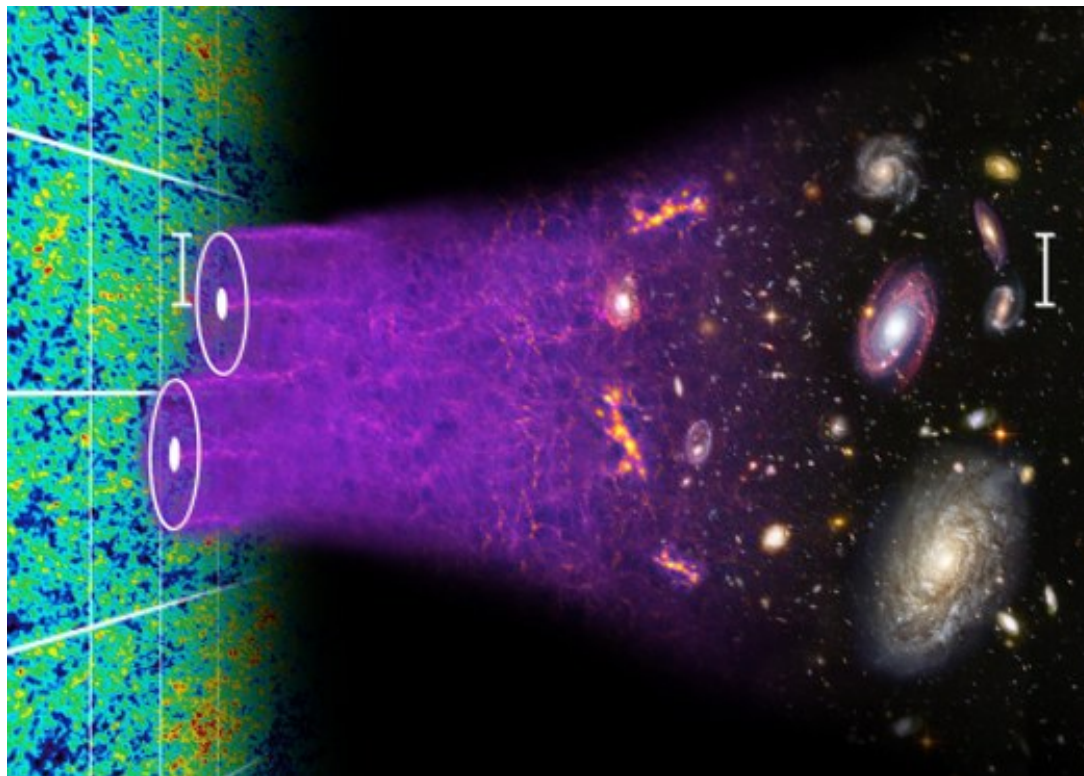
Euclid
+ SKA1
lensing
 $\sigma_w = 0.03$
 $\sigma_\gamma = 0.017$



(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 ($>10\sigma$)
- PSF is excellent quality circular Gaussian from about 0.6''
- **Major enhancement in DE Figure-of-Merit**

Cosmology with SKA1: Baryon Acoustic Oscillations



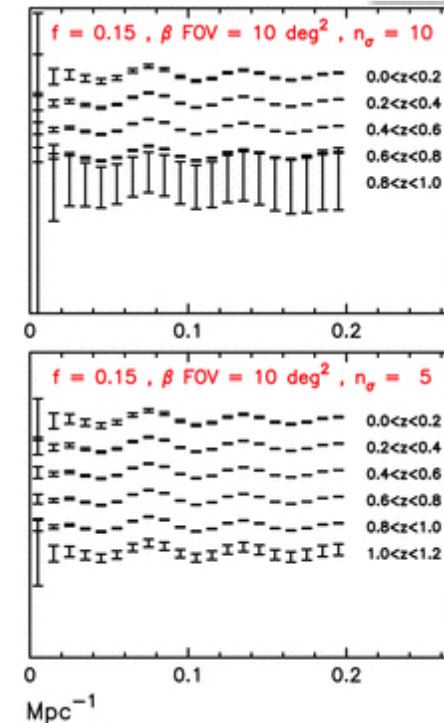
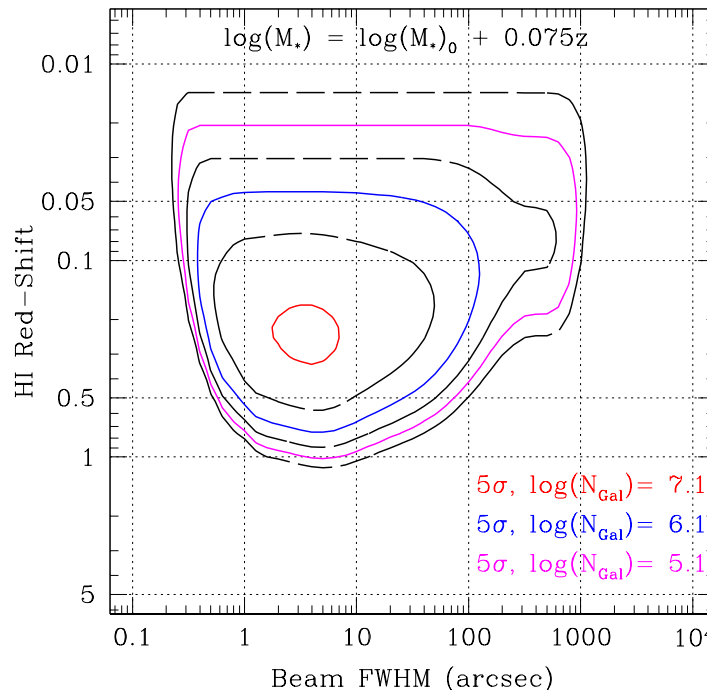
(Blake & Moorfield)

- Constraining Dark Energy models with redshift-resolved BAO measurements

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



SKA1-SUR Line Survey (100 km/s, 5000 deg², 2yr)

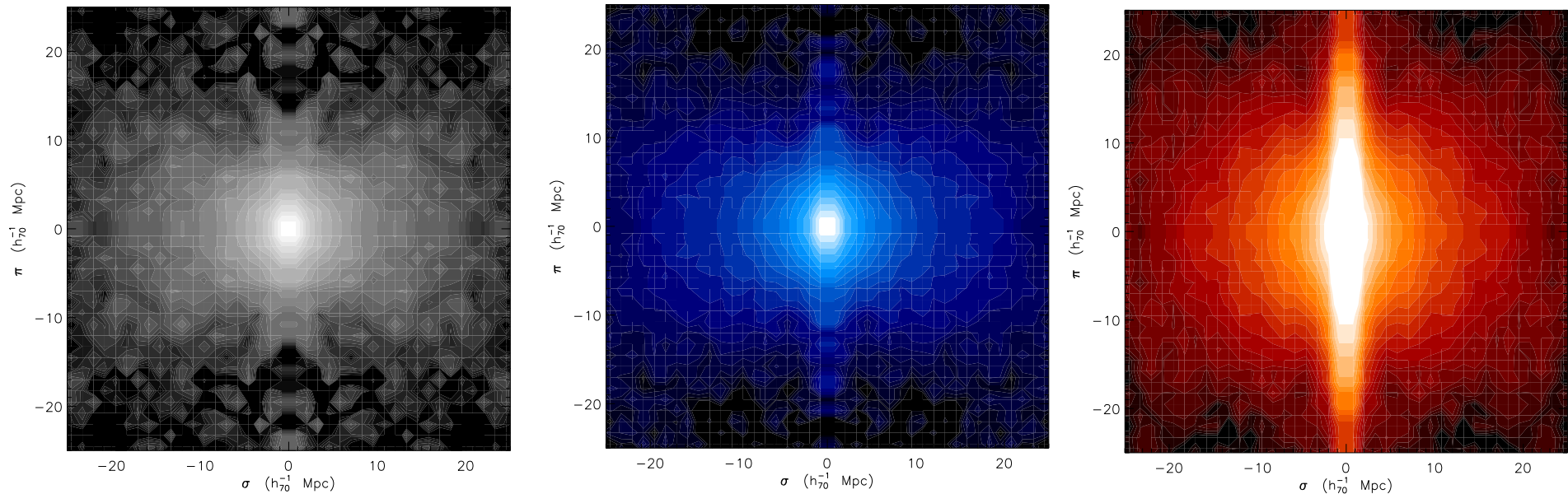


(Abdalla et al 2010)

- Detect $10^{7.1}$ galaxies $\langle z \rangle \approx 0.3$, $10^{5.1}$ galaxies $\langle z \rangle \approx 1$
- Density ≈ 2500 galaxies deg⁻², 1 arcmin⁻²
- Compare SDSS: $10^{6.2}$ galaxies with $\langle z \rangle \approx 0.1$ over 15,000 deg²
- Compare WigglesZ $10^{5.2}$ galaxies with $\langle z \rangle \approx 0.6$
- **Major contribution to BAO science, complementary systematics versus Opt/IR**

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Cosmology with SKA1: complementarity with optical



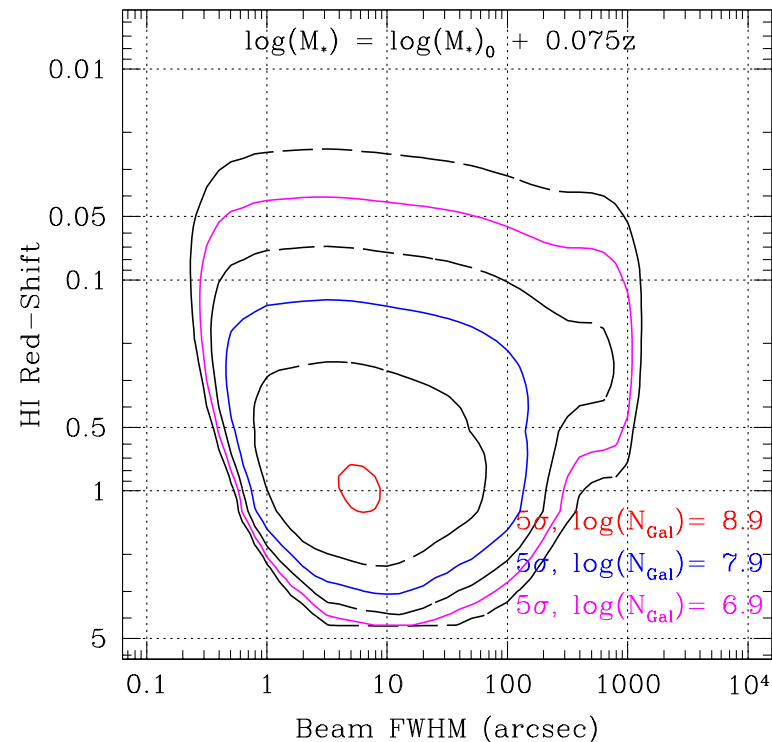
(Papasterigis et al. 2013) ALFALFA HI versus SDSS blue and red samples

- Correlation functions of HI detections demonstrate much lower bias and excellent prospects for Redshift-space distortion measurements once interesting sample sizes are achieved with SKA1

An SKA2 HI emission survey for precision Cosmology



SKA2-PAF Line Survey (100 km/s, 3π sr, 2yr)



- Detect $10^{8.9}$ galaxies with $\langle z \rangle \approx 1$, $10^{7.9}$ with $\langle z \rangle \approx 2$
- Compare Euclid (2020+5?) target of 10^8 spectra with $\langle z \rangle \approx 1$
- **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



Thank you

www.skatelescope.org