Square Kilometre Array – Instrument and Science Overview

Robert Braun
SKA Science Director
14th 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

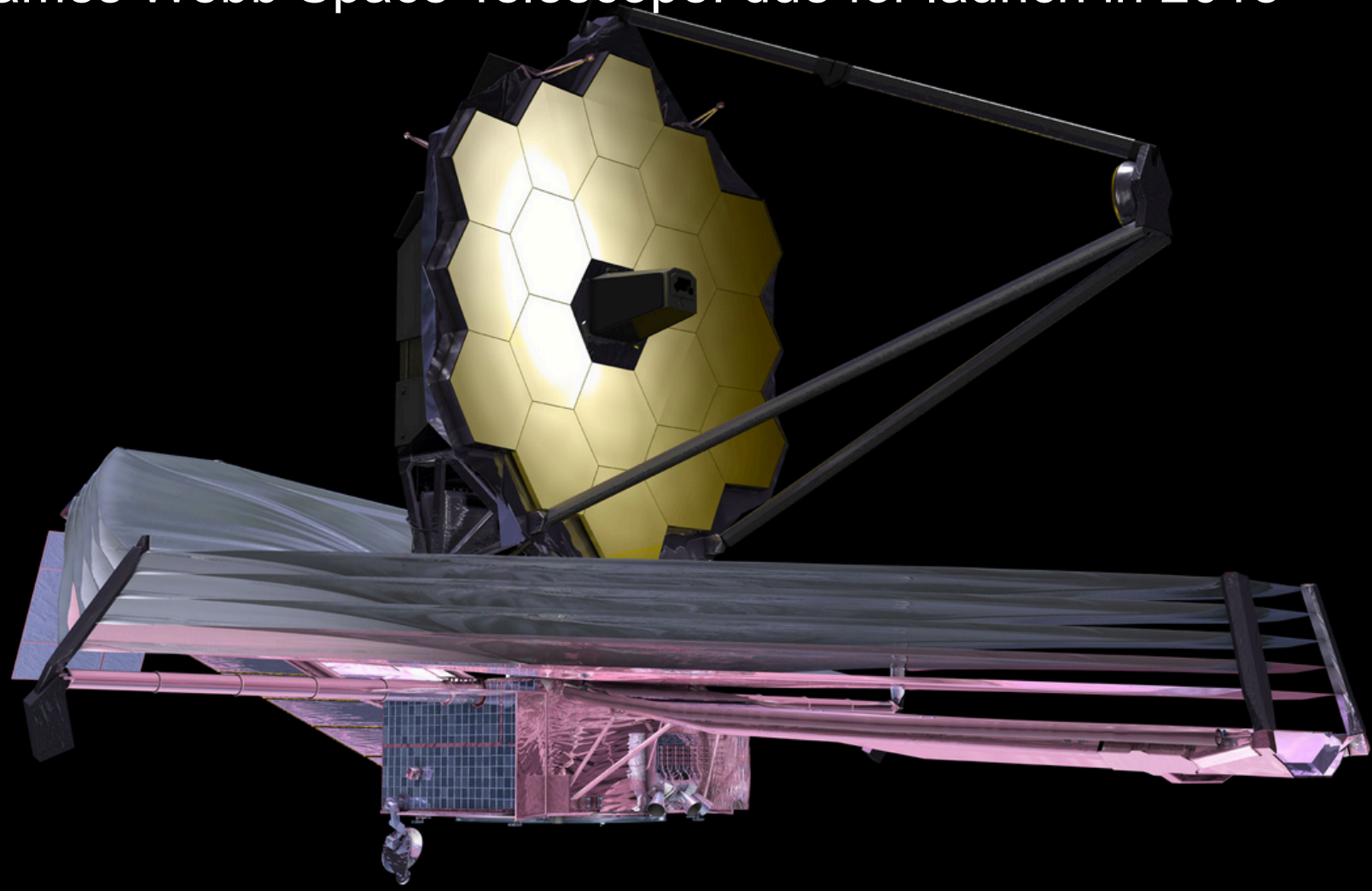
Chajnantor Plateau @ 17,000 ft

Early science now

Inaugurated on 13th March 2013

Great Observatories for the coming decades

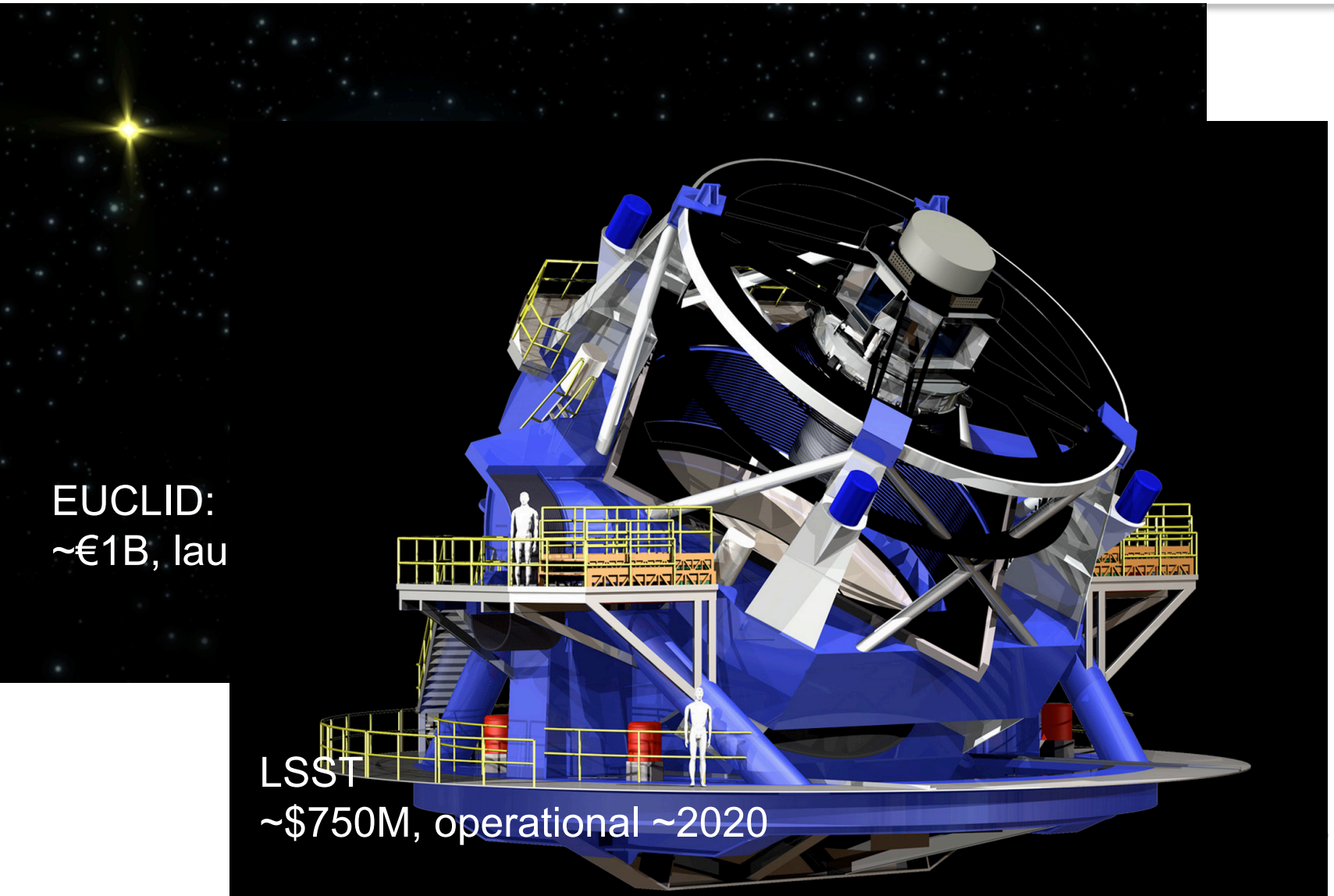
James Webb Space Telescope: due for launch in 2018



Great Observatories for the coming decades

Square Kilometre Array: radio
Construction start 2017/18

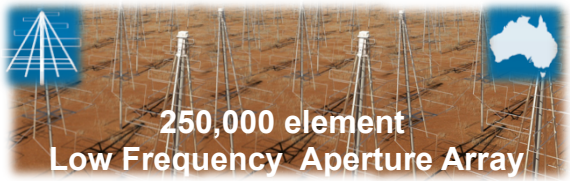
Specialised “experiments”

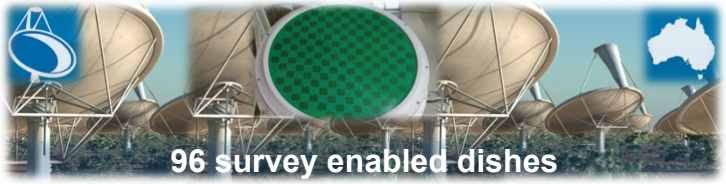


Exploring the Universe with the world's largest radio telescope

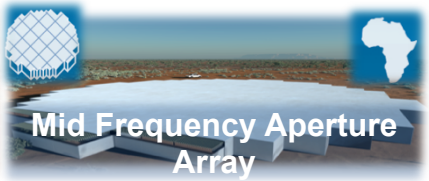
SKA SQUARE KILOMETRE ARRAY

Phase I : 2020

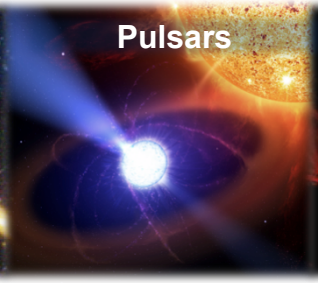


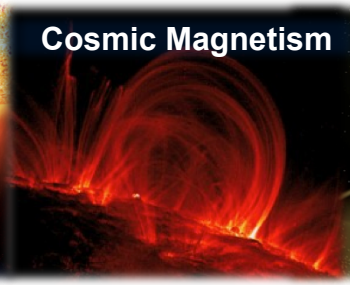


Phase II : 2024



Science



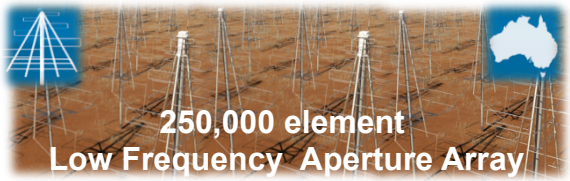


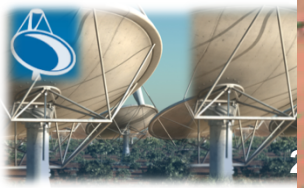
50 MHz **100 MHz** **1 GHz** **10 GHz**

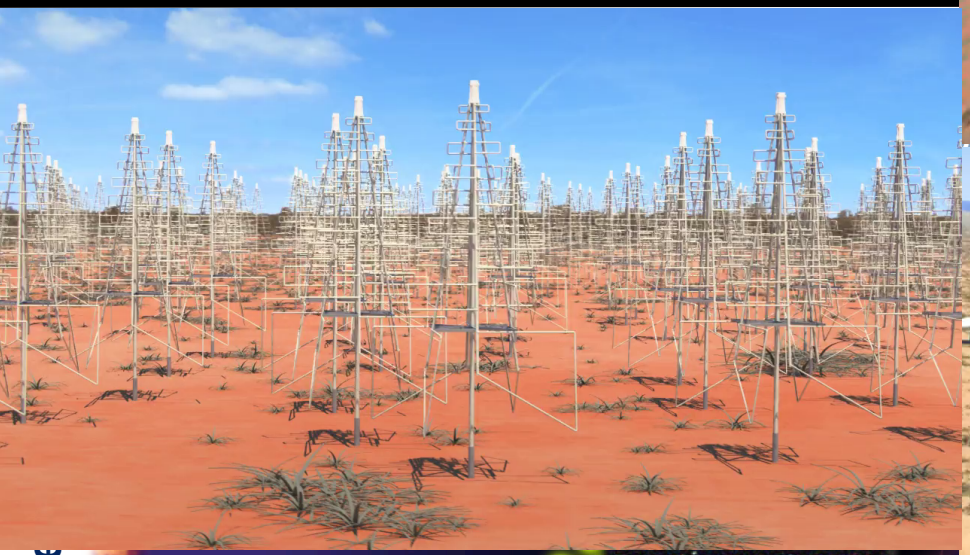
Exploring the Universe with the world's largest radio telescope

SKA
SQUARE KILOMETRE ARRAY

Phase I : 2020



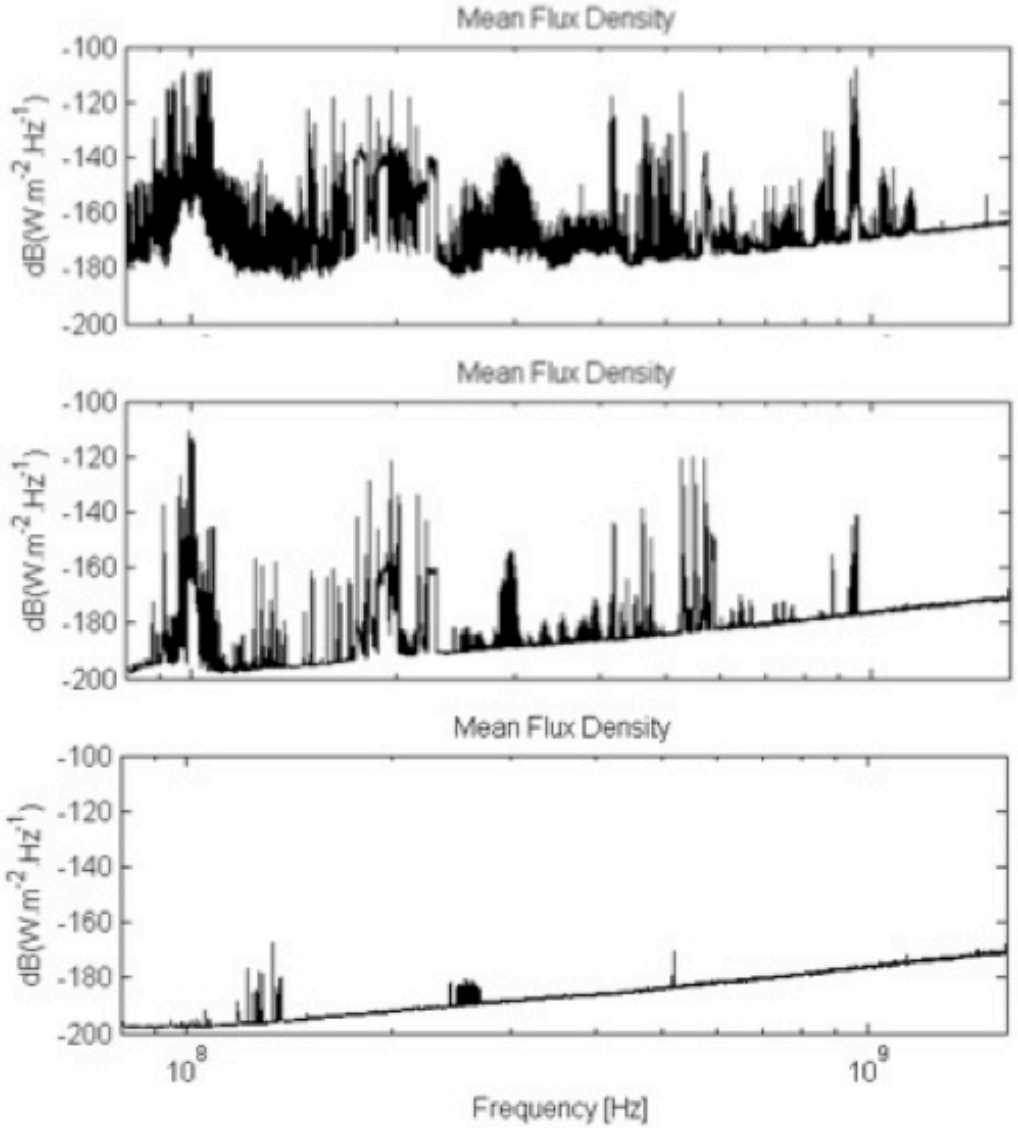




Scie

50 MHz 100 MHz 1 GHz 10 GHz

How did we choose the site?



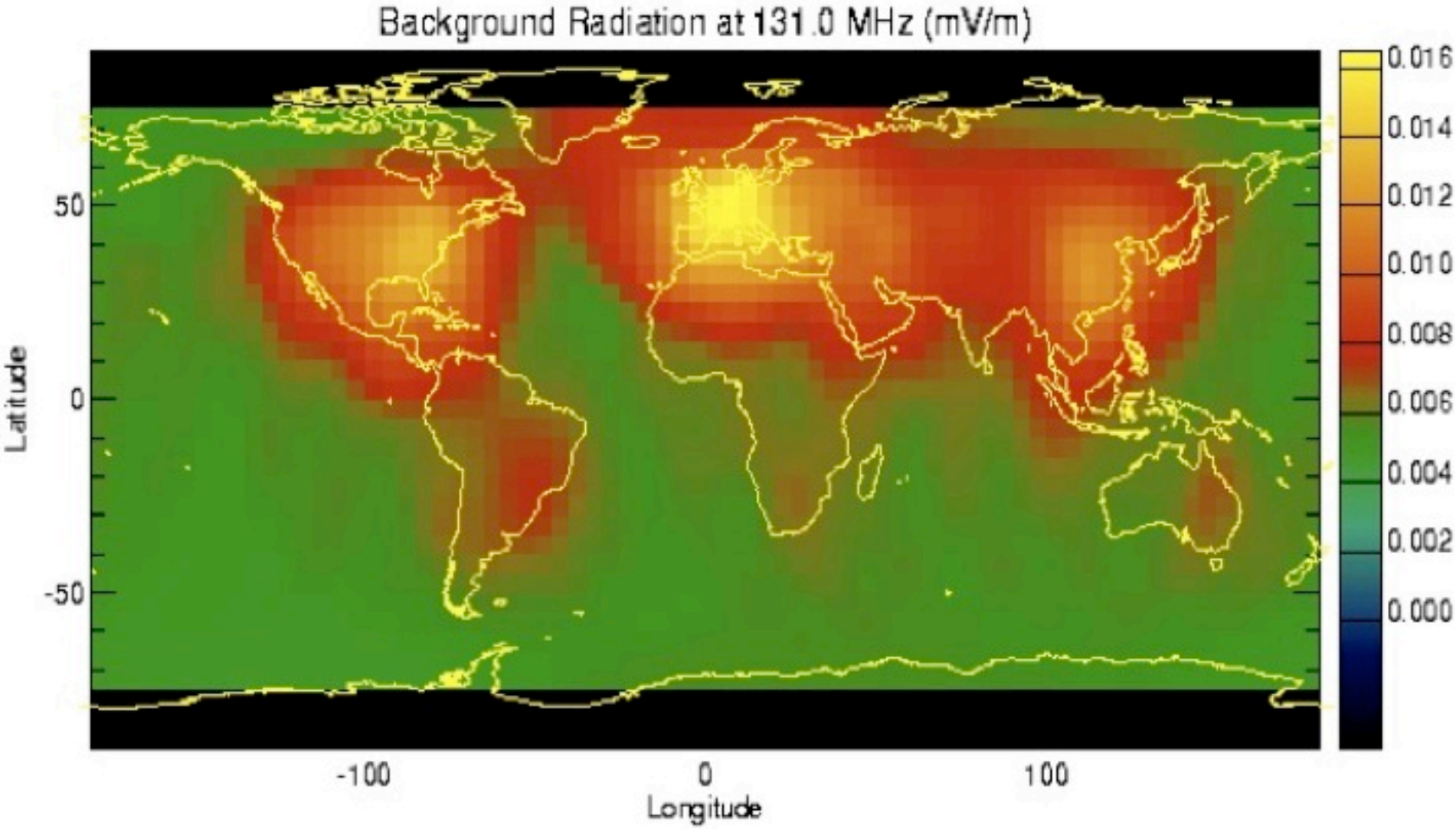
Sydney:
population 4 million

Narrabri:
population 4000

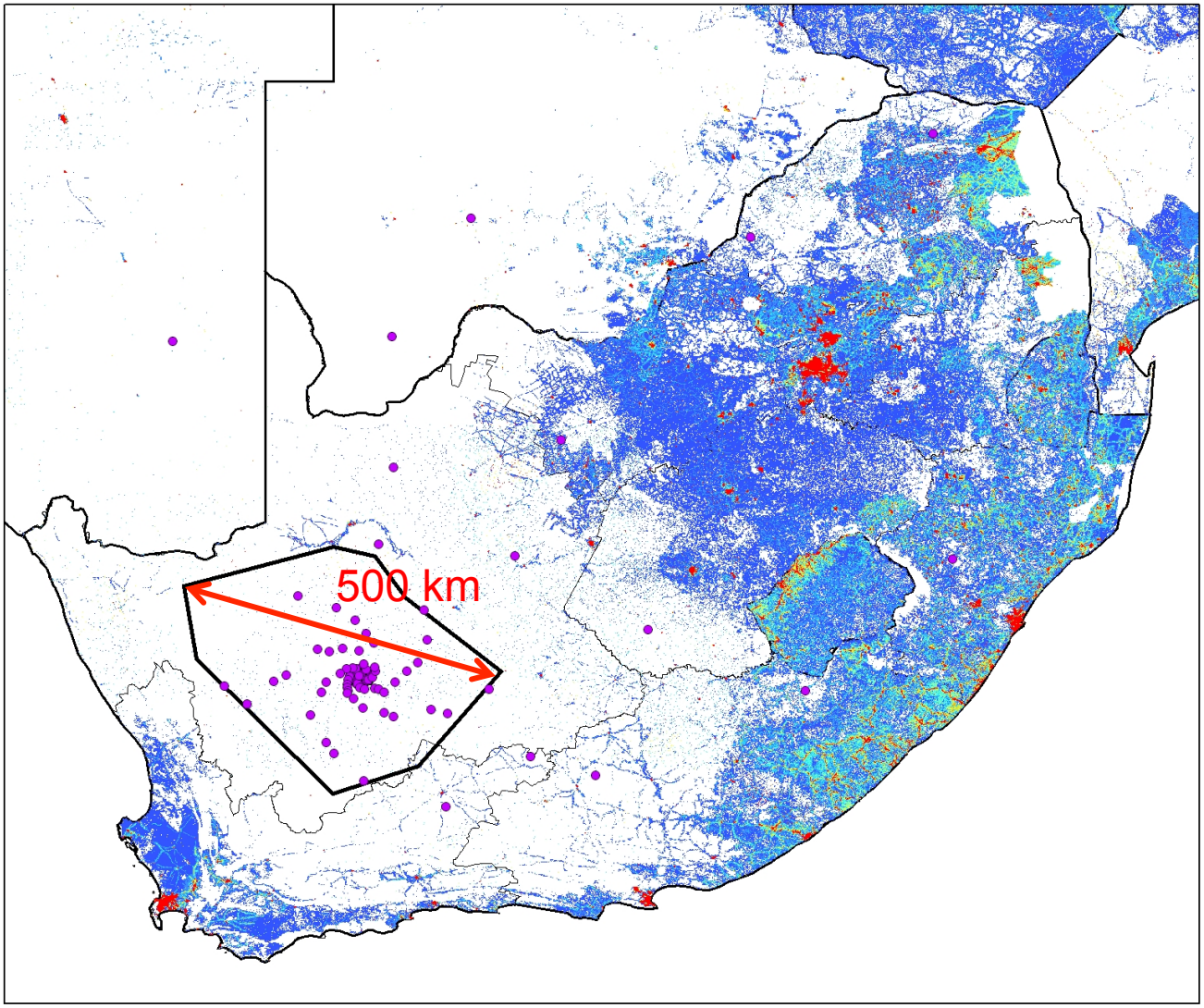
Mileura:
population 4

elescope

How did we choose the site?



Karoo Radio Astronomy Rese



Legend

- SKA_Configuration_SPDO_Dish_Full
- AA1_SPDO_Version1
- AA2_SPDO_Version2
- KCAAA1

Population (per sq km)

Value

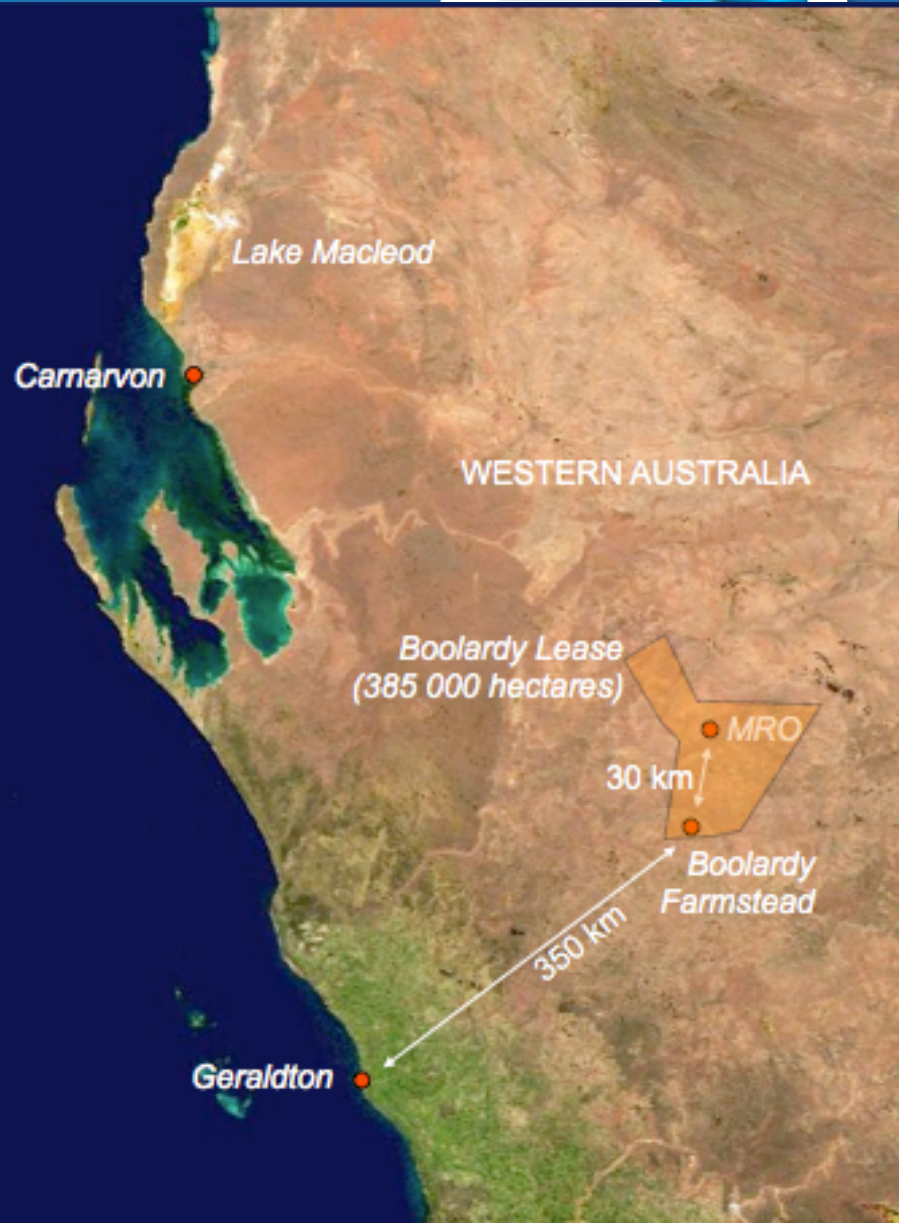
- 0 - 4
- 4.000000001 - 14
- 14.00000001 - 29
- 29.00000001 - 47
- 47.00000001 - 68
- 68.00000001 - 91
- 91.00000001 - 116
- 116.0000001 - 142
- 142.0000001 - 169
- 169.0000001 - 197
- 197.0000001 - 225
- 225.0000001 - 255

N

0 145 290 580 870 1,160 Kilometers

Contact:
Dr. Adrian Tiplady
SKA South Africa
17 Baker Street
Rosebank
2196
South Africa
Tel: +27 11 442 2434
Fax: +27 11 442 2454
Email: atiplady@ska.ac.za

Murchison Radio Astronomy Observatory

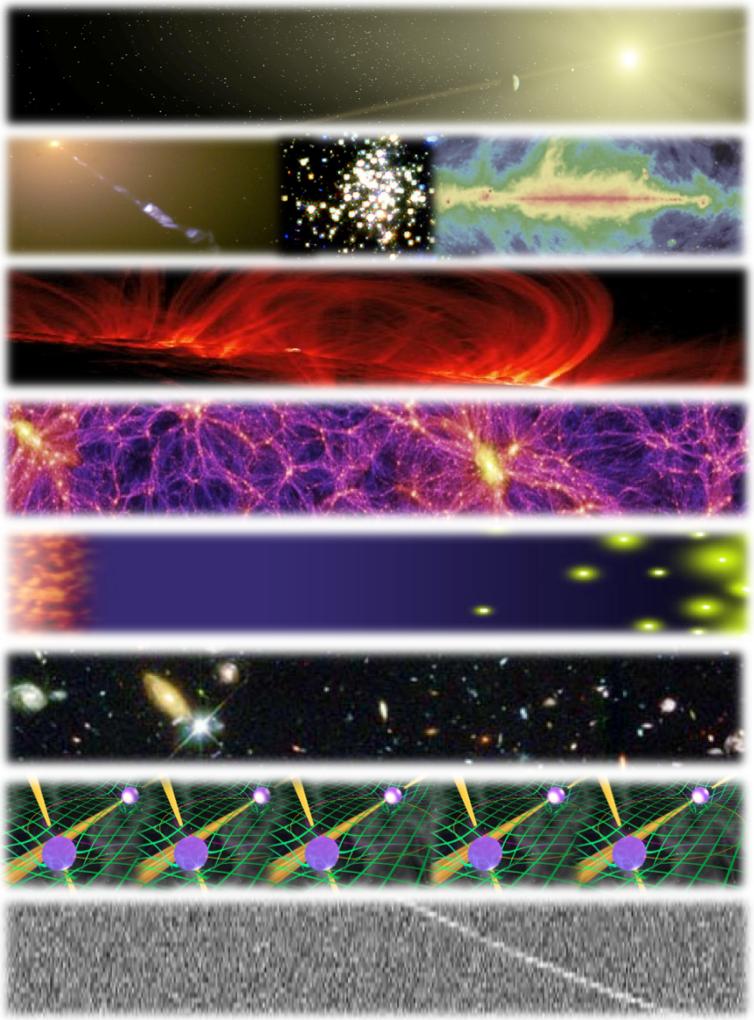


Shire of Murchison:

- 50,000 km² ; size of the Netherlands
- 0 gazetted towns
- 29 sheep/cattle stations
- 110 population => 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

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

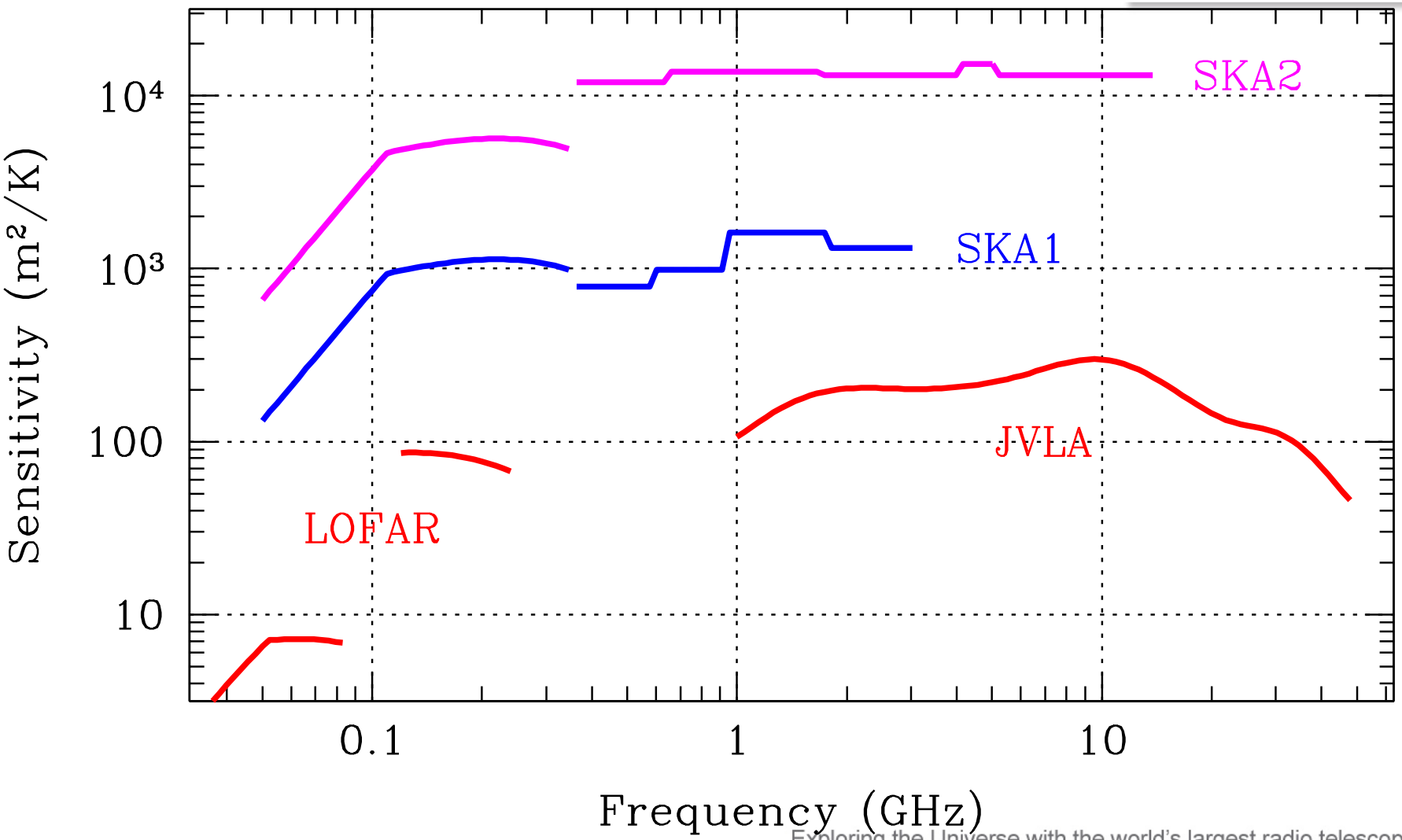
How does SKA1 baseline redefine state-of-art?

		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

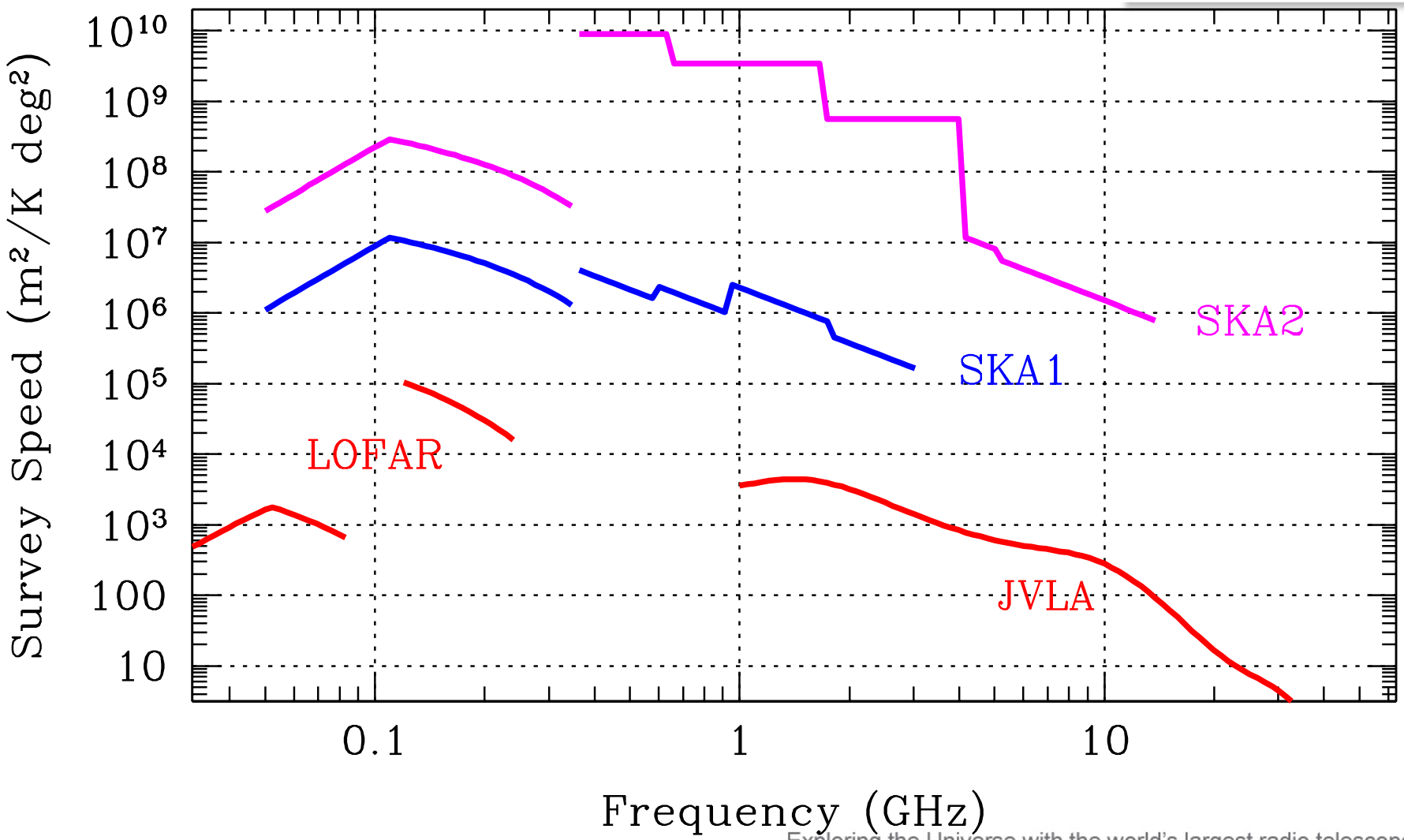
A_{eff}/T_{sys}: 6xJVLA 6xASKAP 16xLOFAR

Survey Speed: 100x 22xASKAP 270x 280xJVLA

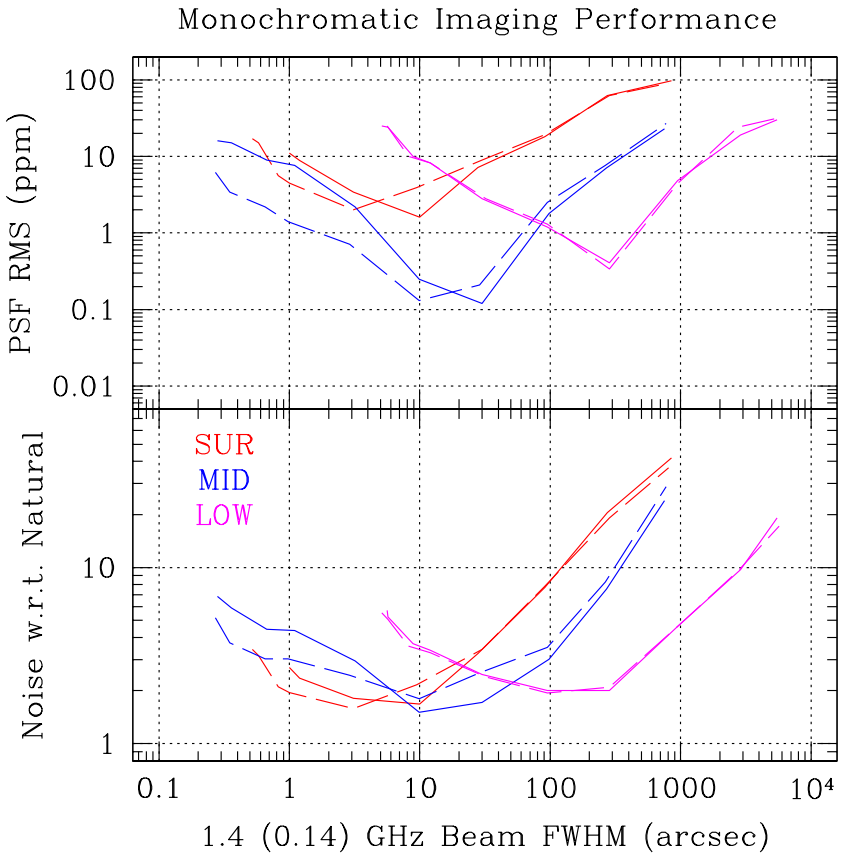
Sensitivity comparison

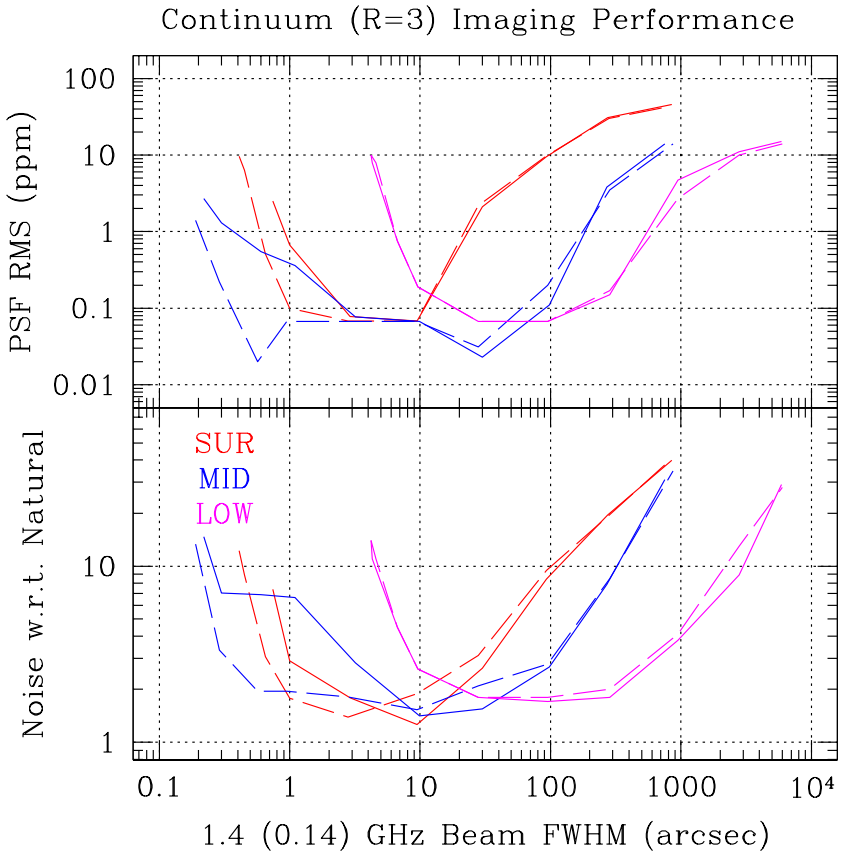


Survey speed comparison



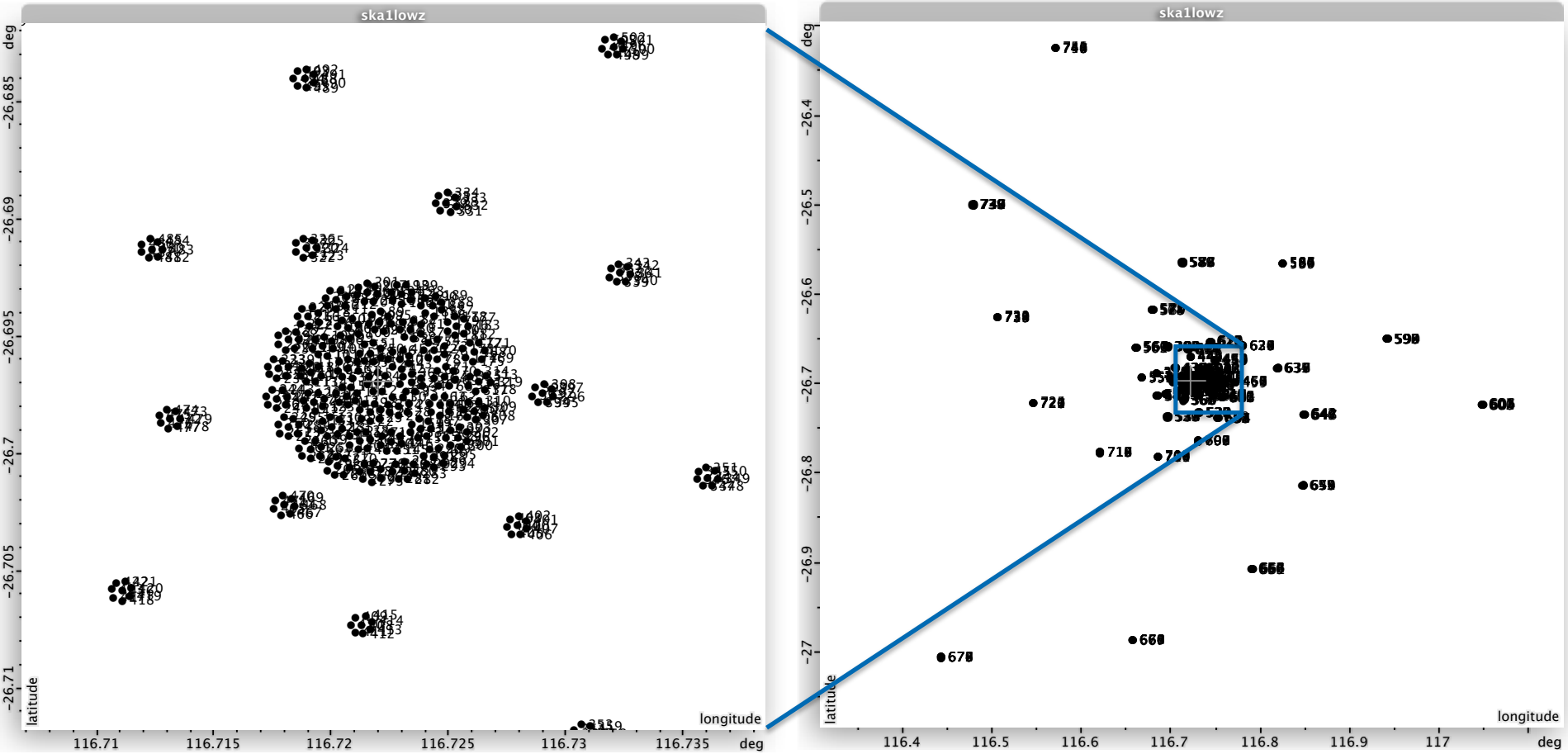
SKA1: facility versus "experiment"





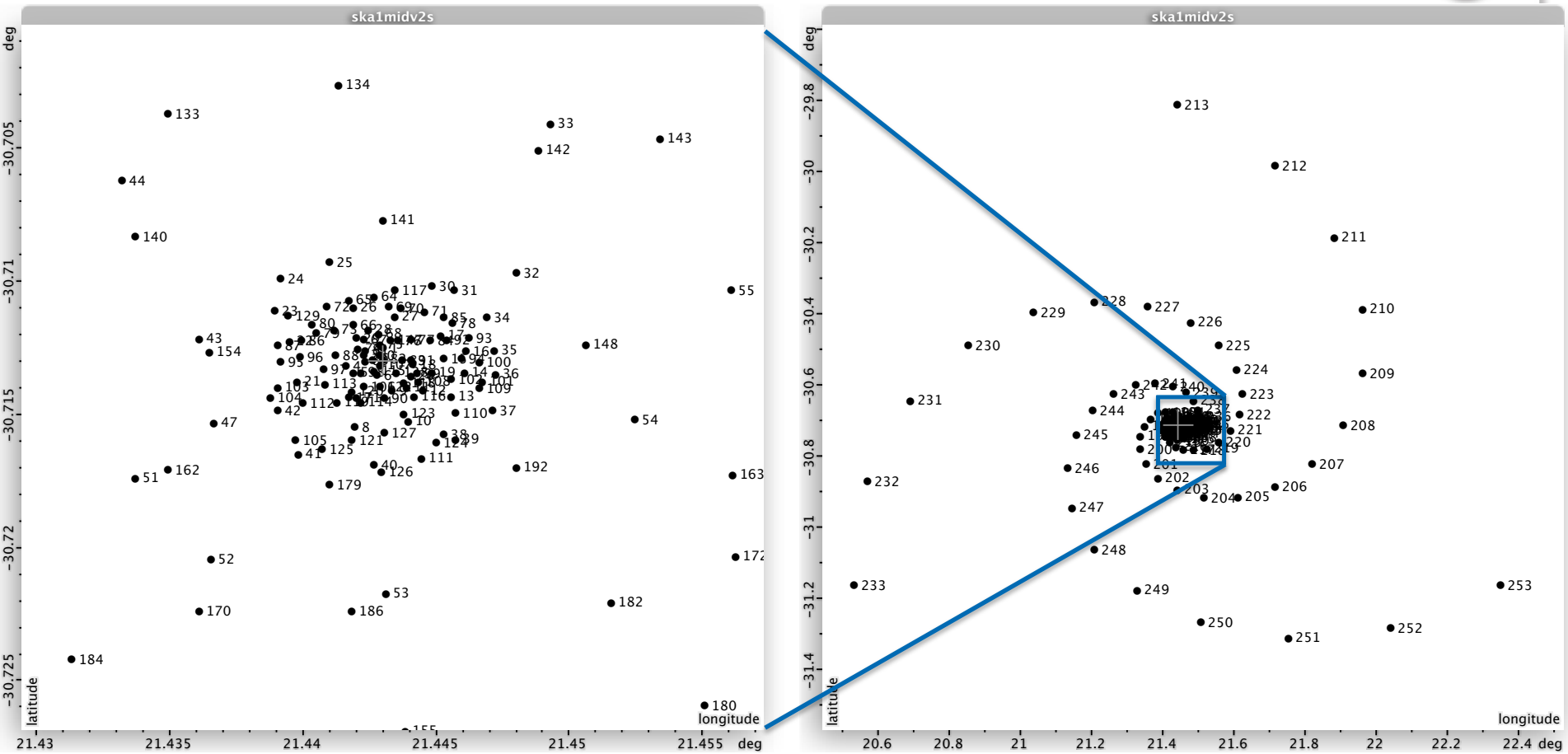
- Configuration optimisation for broad performance "sweet-spot"

SKA1 configurations



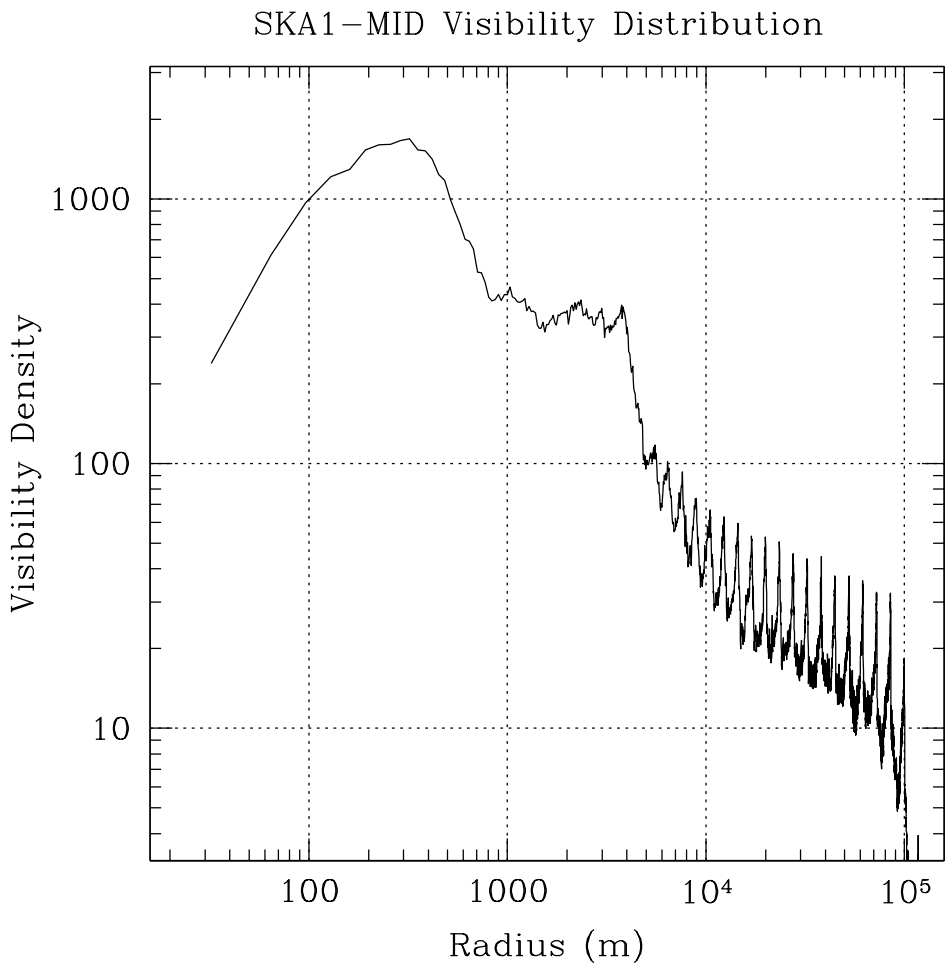
- SKA1-LOW possible configuration of core and remote spiral

SKA1 configurations



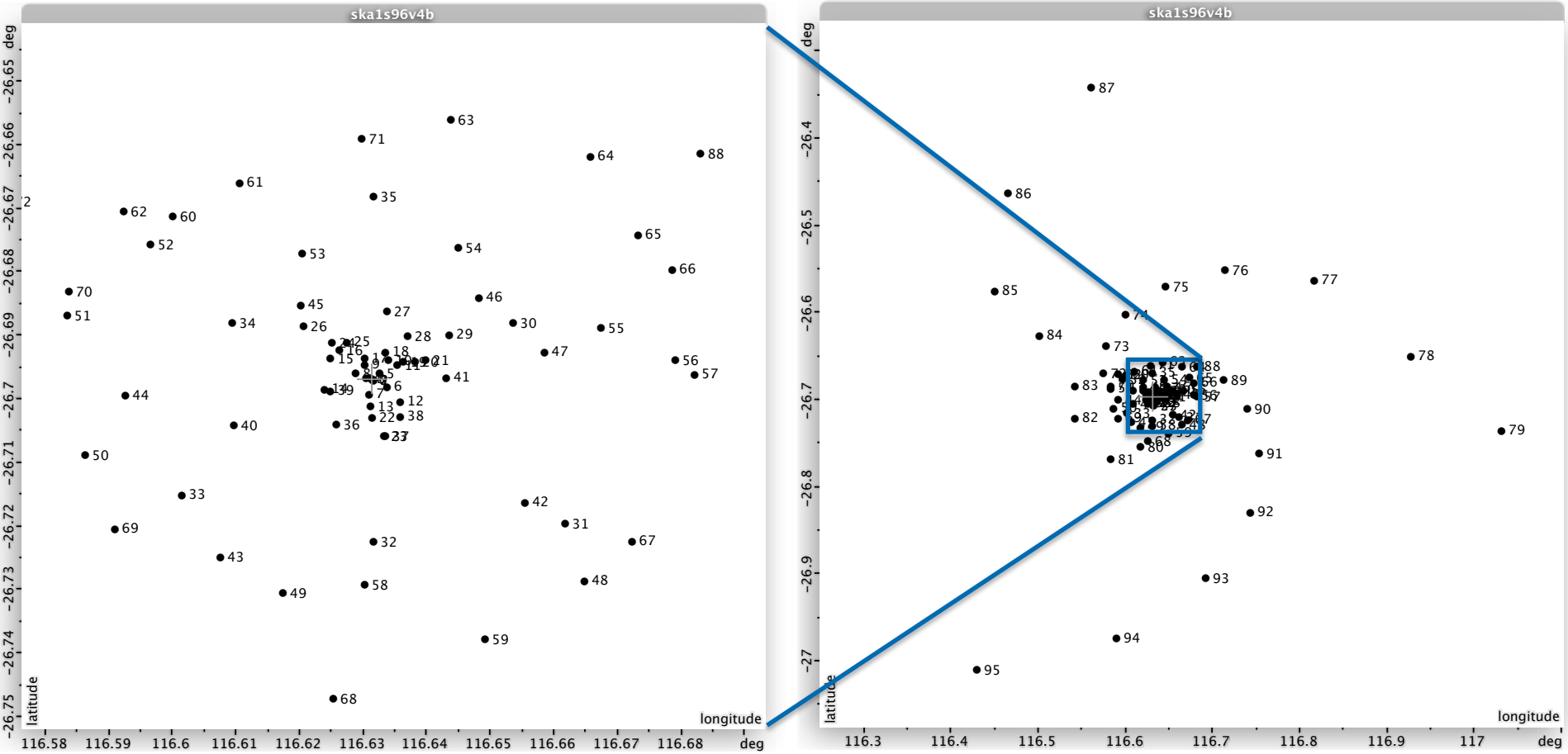
- SKA1-MID possible configuration of core and remote spiral

SKA1 configurations



- SKA1-MID configuration: still scope for adjustment of 3km -> 30+ km

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

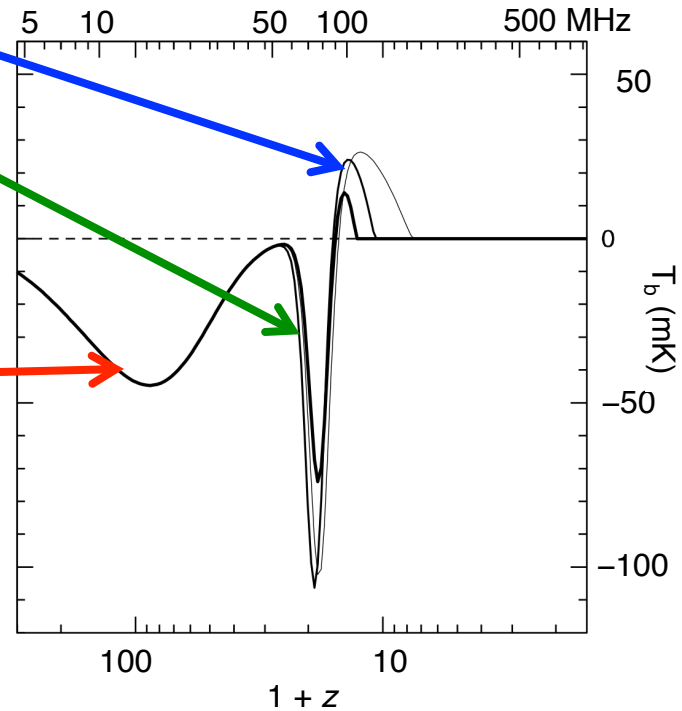
With design philosophy of *Exploration of the Unknown*

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

EoR

Cosmic Dawn

Dark Ages

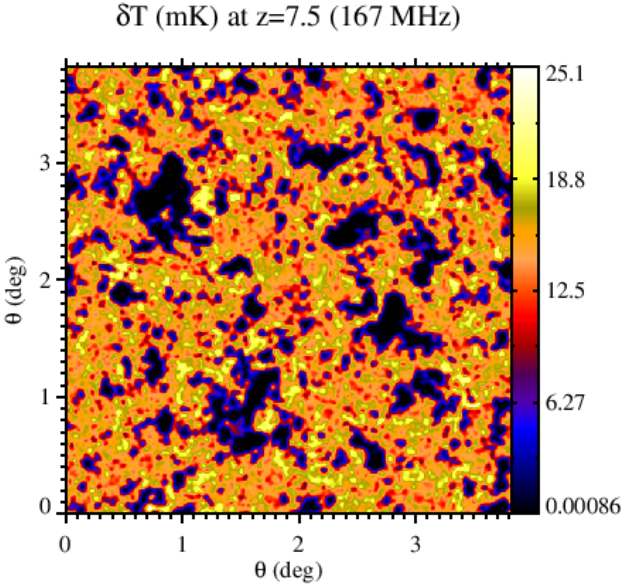


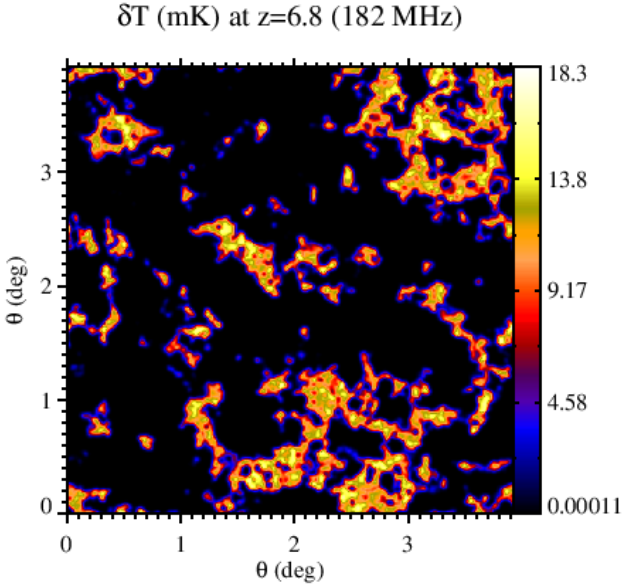
Neutral Hydrogen 21 cm spin-flip transition provides probe of neutral intergalactic medium before and during formation of first stars

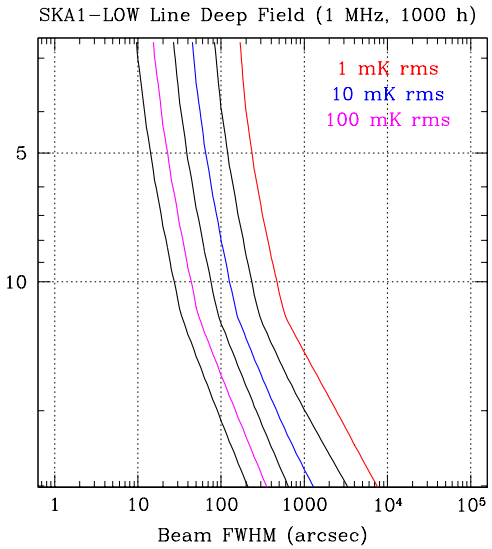
$\nu = 1420\ \mathrm{MHz}/(1 + z)$

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

HI surveys of the EoR/Cosmic-Dawn Universe



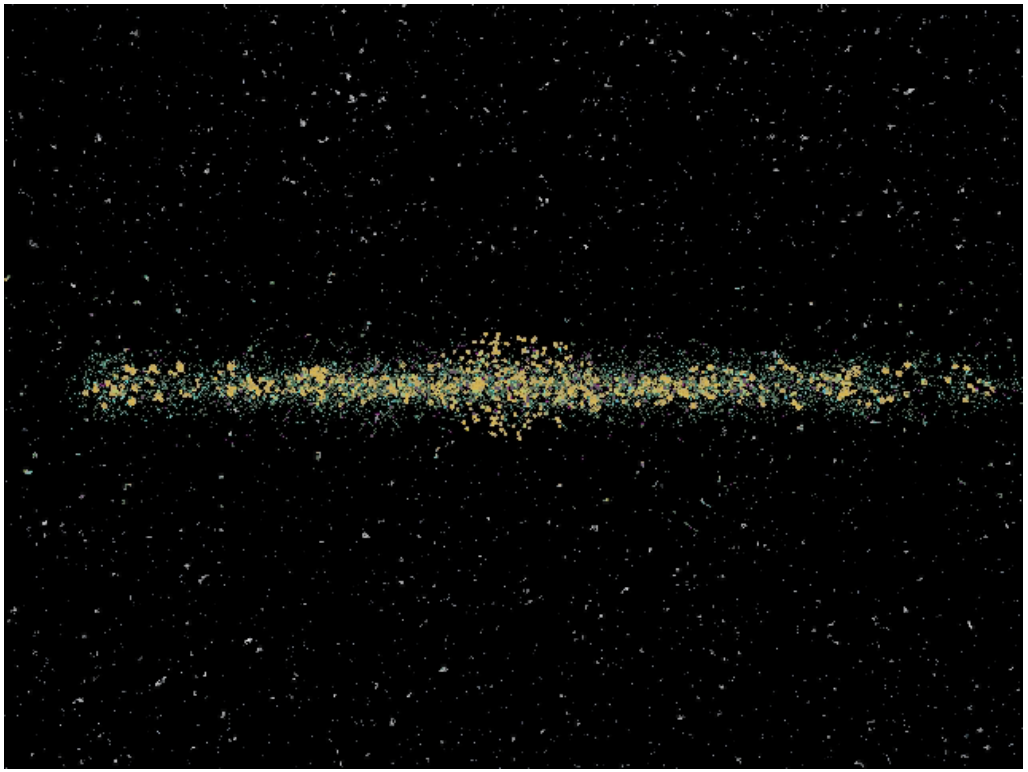


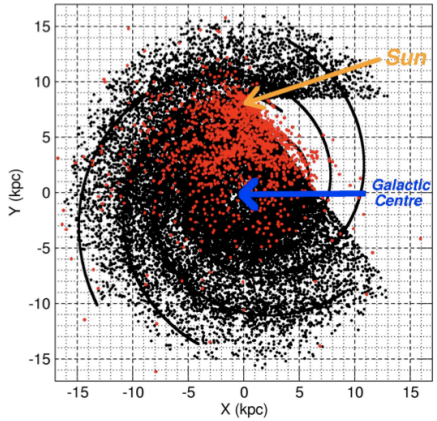


- Detecting EoR structures in imaging mode (as distinct from statistically) on 5 arcmin scales with 1 mK RMS
- Probing the Cosmic Dawn statistically or possibly even imaging in ultra-deep

Finding all pulsars in the Milky Way…

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



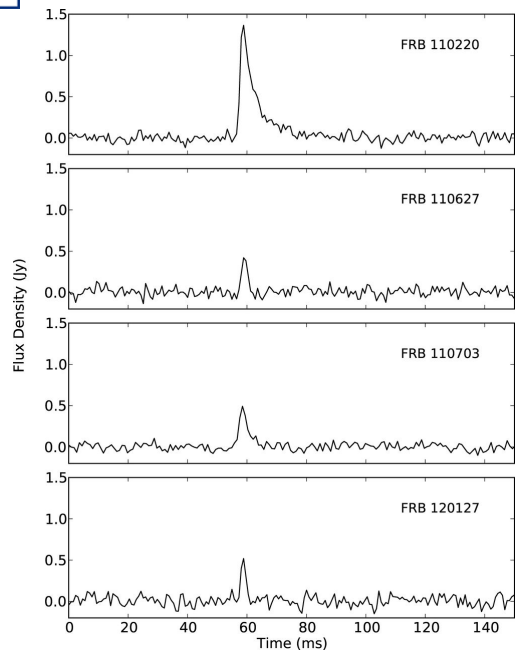


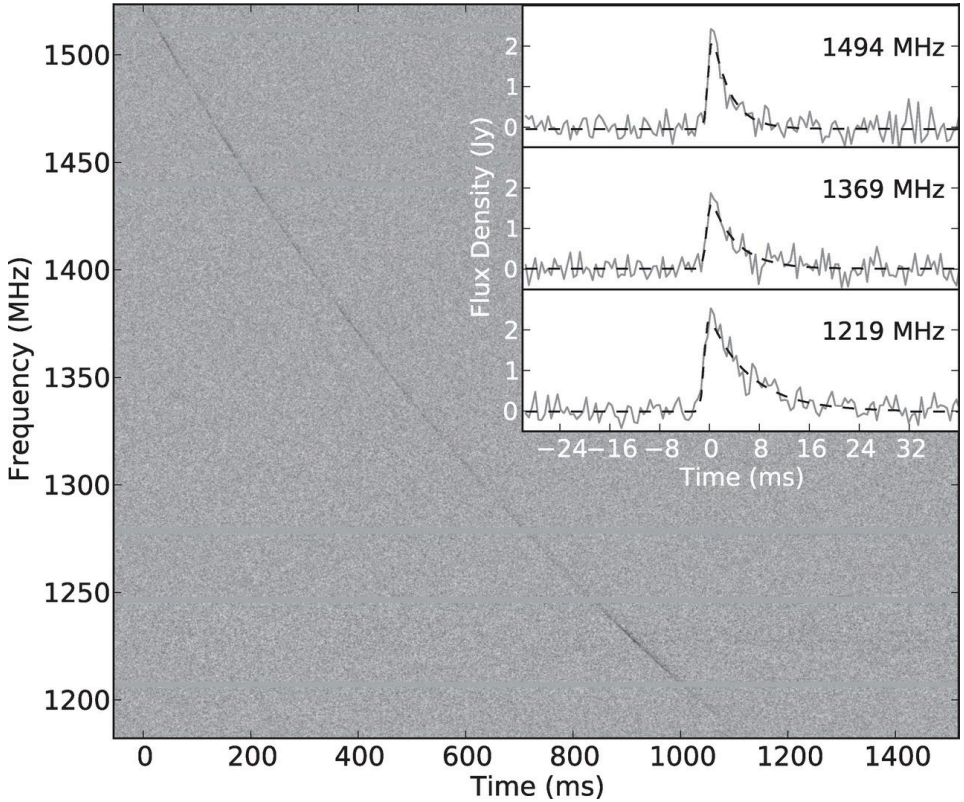
- ~30,000 normal pulsars
- ~2,000 millisecond psrs
- ~100 relativistic binaries
- first pulsars in Galactic Centre
- first extragalactic pulsars

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

The transient radio sky

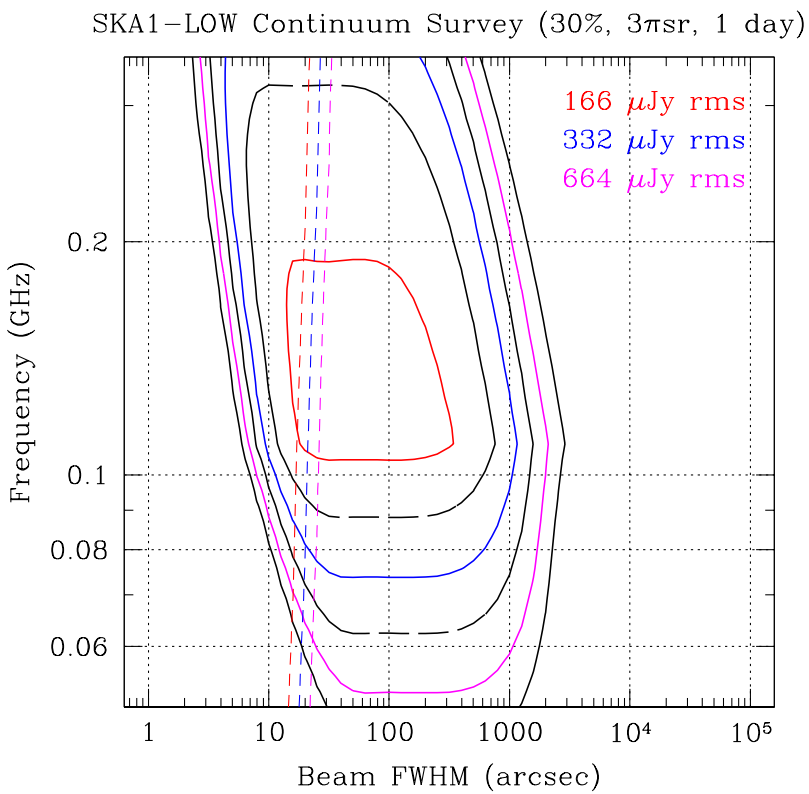
A Population of Fast Radio Bursts at Cosmological Distances
D. Thornton *et al.*
Science **341**, 53 (2013);
DOI: 10.1126/science.1236789

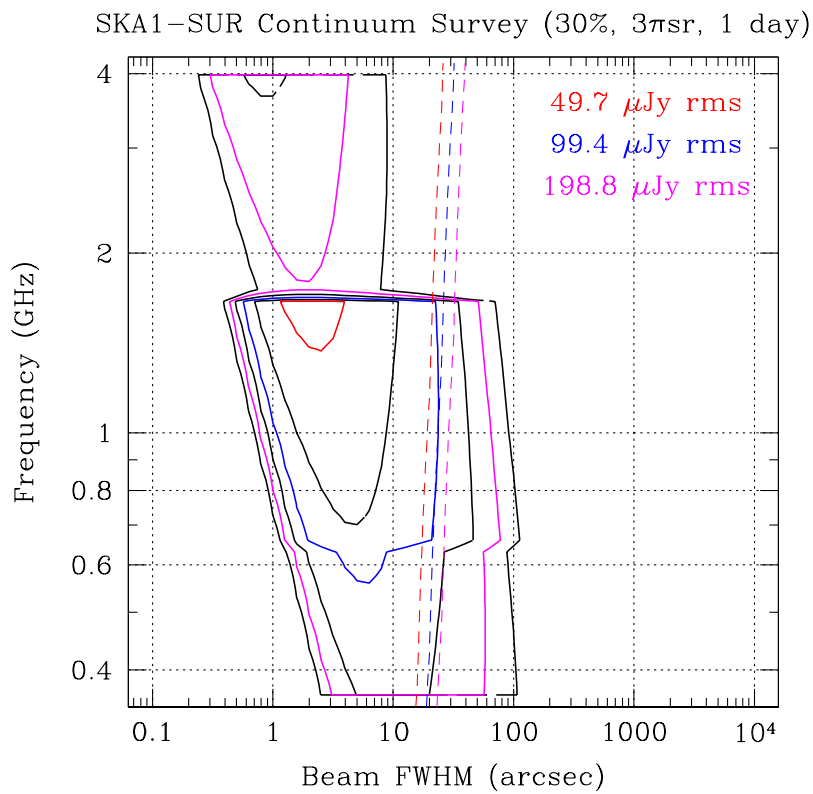




- Four celestial "FRB" events now detected (after first "Lorimer" burst):
  $S = 0.5 – 1.3$ Jy, $\Delta t = 1 – 6$ msec, DM = 550 – 1100 cm^{-3} pc
- Estimated event rate: 1×10^4 sky^{-1} day^{-1}
- Completely unknown origin, possibly at cosmological distances

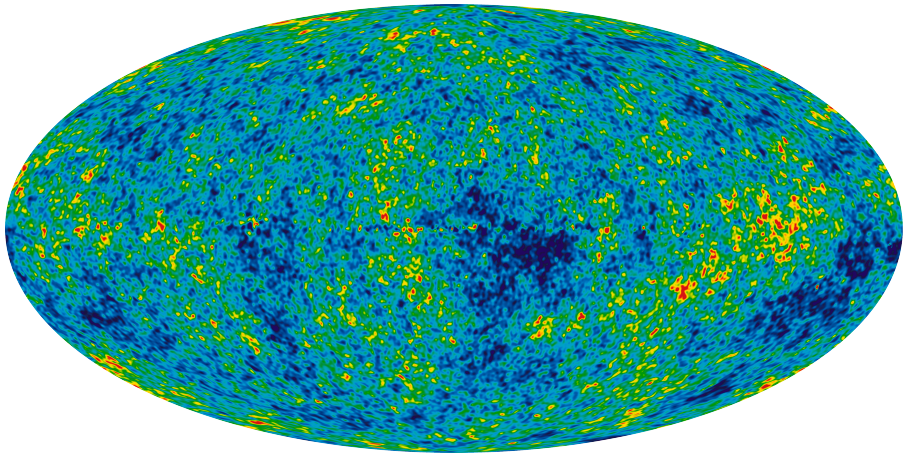
A daily SKA1 all-sky transient survey

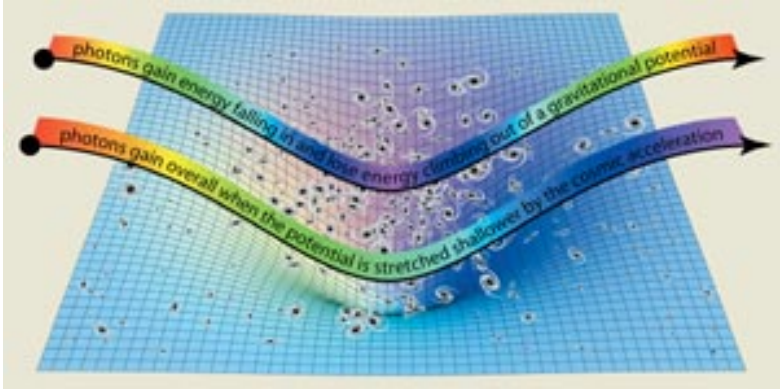




- Integration of ≈50 seconds per position
- Sensitivity for 2 msec bursts is 160x worse: 27 mJy, 8 mJy rms
- Computing strategy most still be developed for such a mode!
- **Predicted FRB detections: 5 per day, with localisation to a fraction of arcsec**

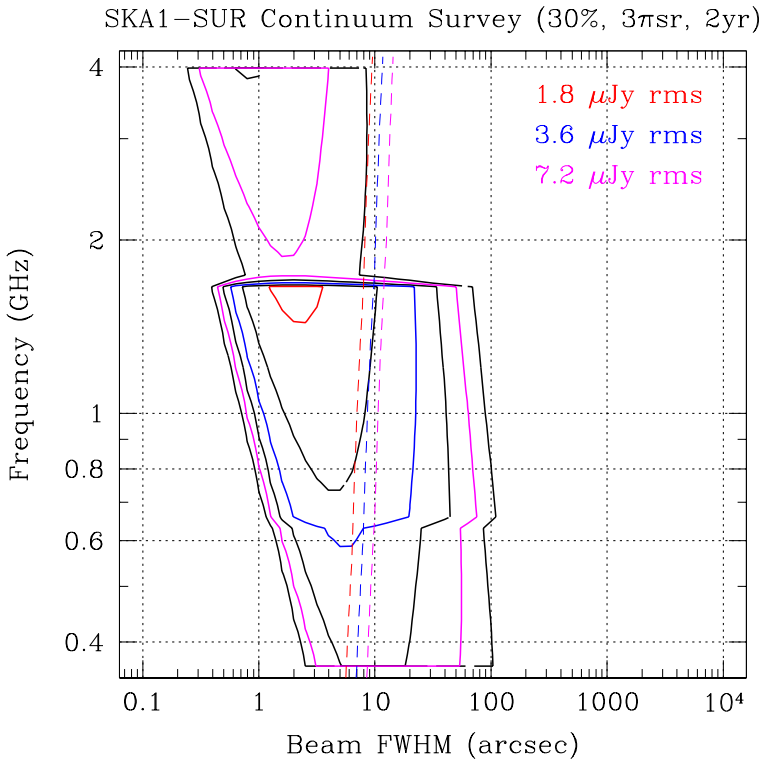
Cosmology with SKA1: Integrated Sachs-Wolfe effect

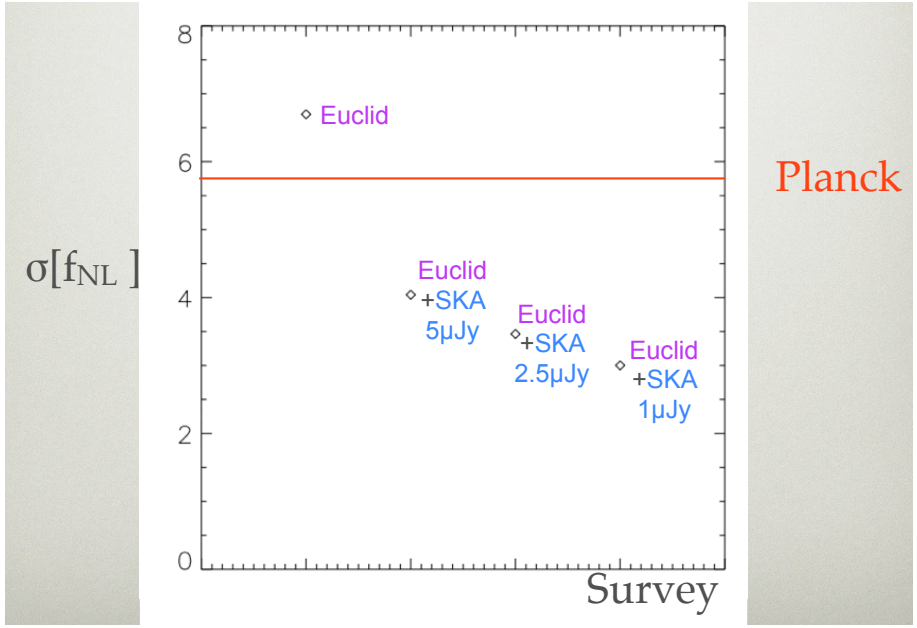




- Constraining non-Gaussianity of primordial fluctuations with the Integrated Sachs-Wolfe effect: correlation of foreground source populations with CMB structures

Cosmology with SKA1: Complementarity with Euclid

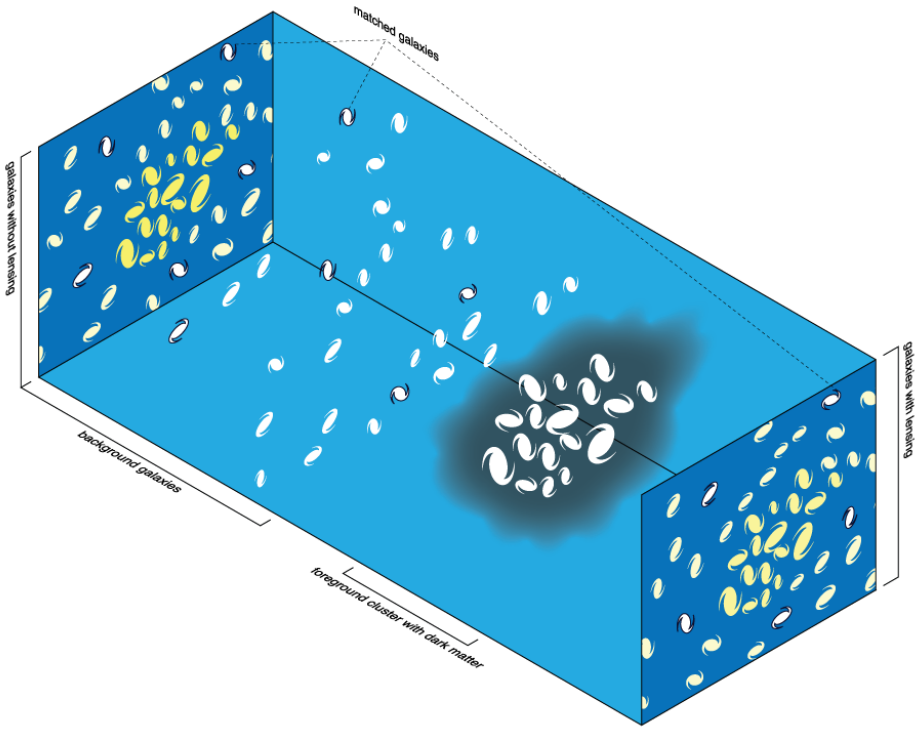




(Bacon 2013)

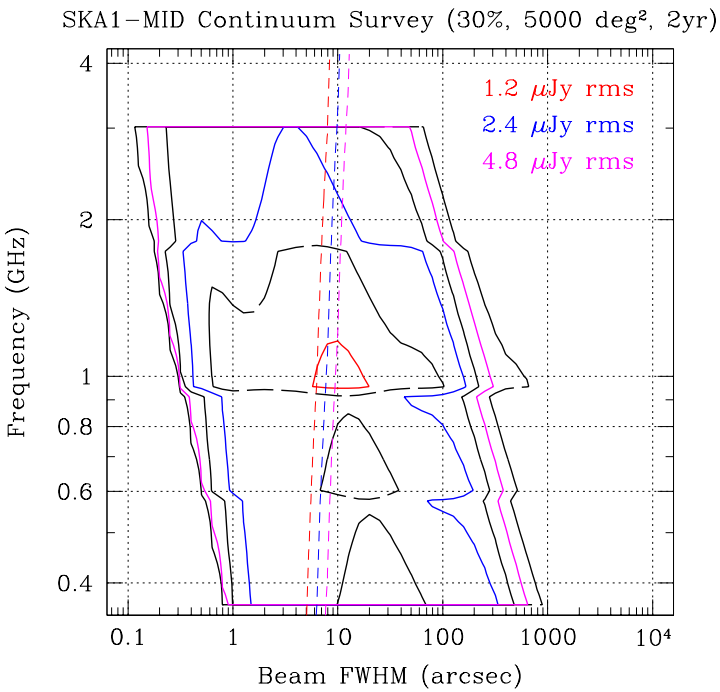
- Constraining non-Gaussianity of primordial fluctuations with the Integrated Sachs-Wolfe effect
- Achieving 2 μJy rms would provide ≈4 galaxies arcmin^{-2} (>10σ)
- Almost uniform sky coverage of 3π sr is exceptional
- **Major enhancement over Euclid alone**

Cosmology with SKA1: Weak Gravitational Lensing

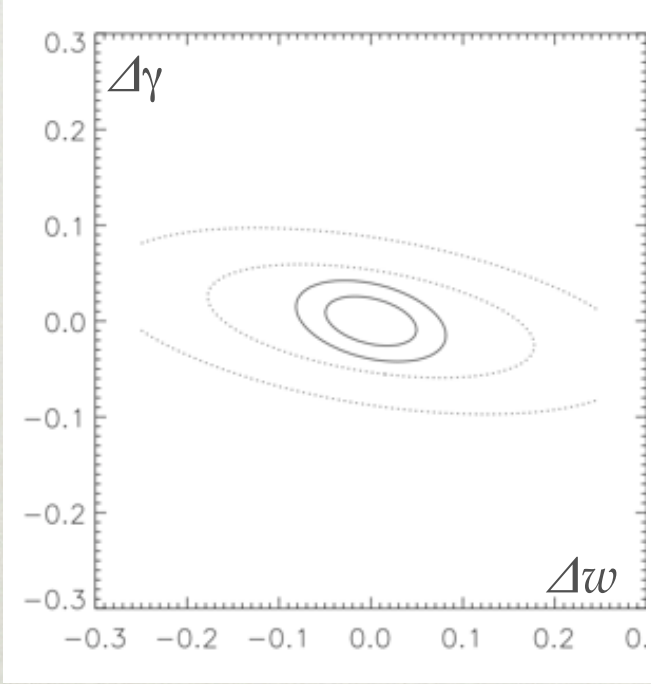


- Constraining the Dark Energy Equation of State with Weak Gravitational Lensing

Cosmology with SKA1: Complementarity with Euclid



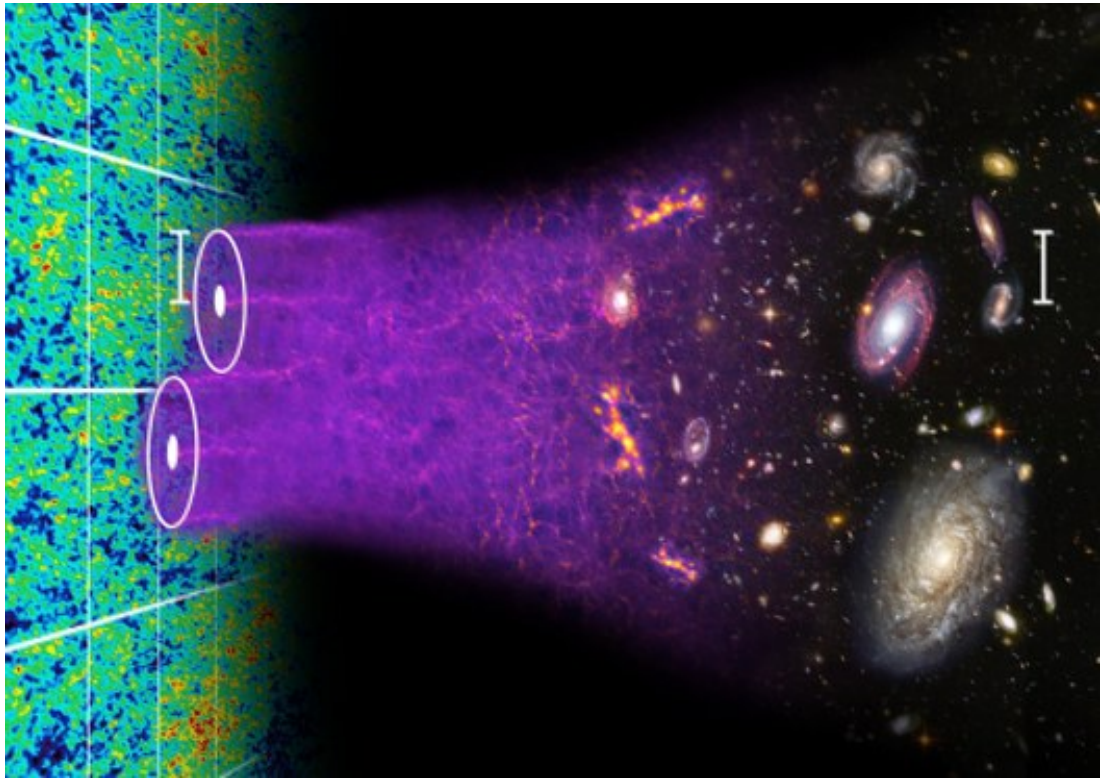
Euclid
+SKA1
lensing
σ_w=0.03
σ_γ=0.017



(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**

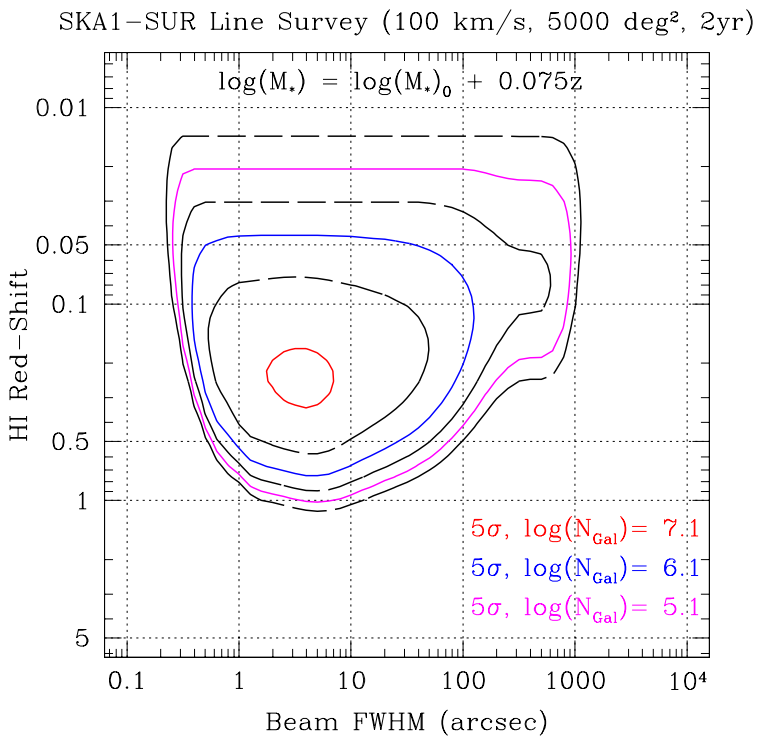
Cosmology with SKA1: Baryon Acoustic Oscillations

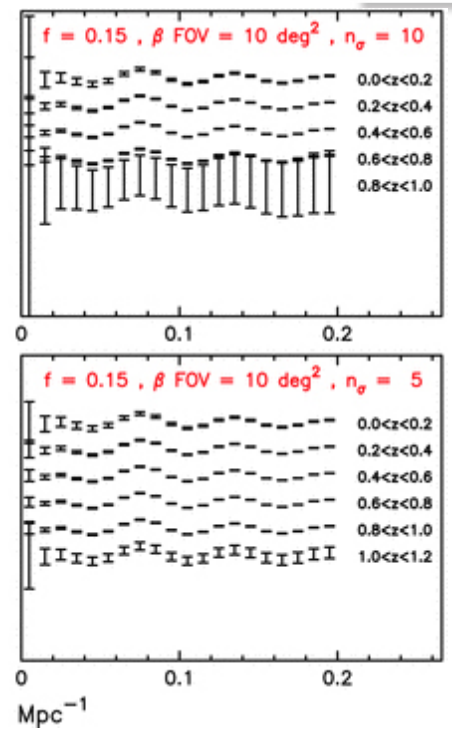


(Blake & Moorfield)

- Constraining Dark Energy models with redshift-resolved BAO measurements

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

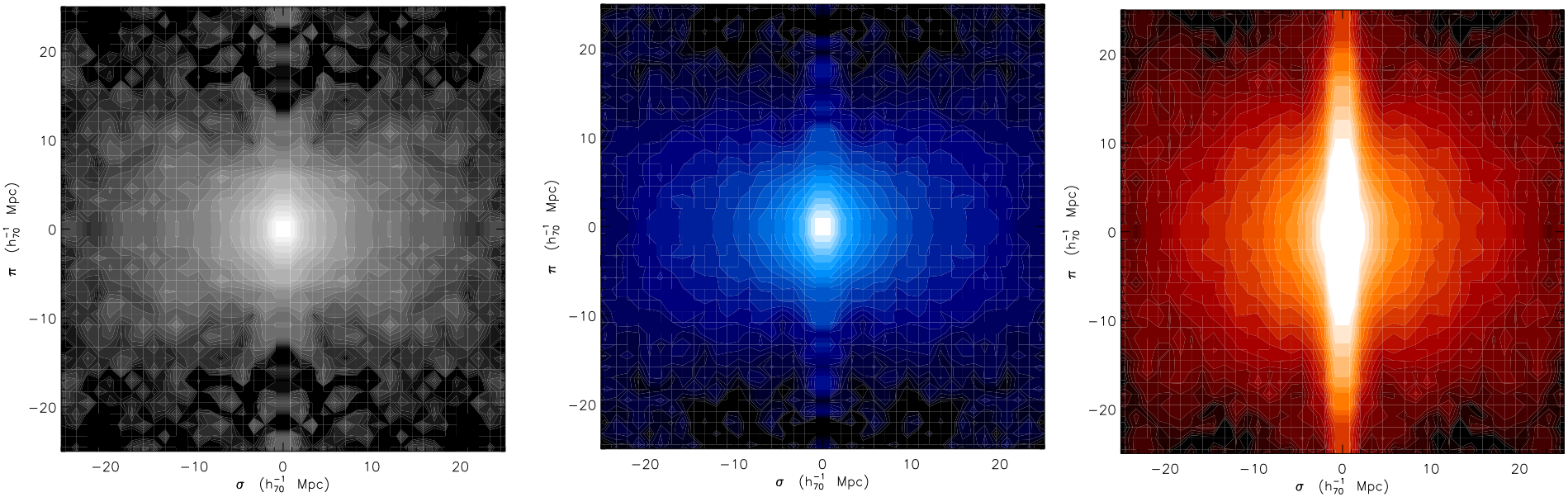




(Abdalla et al 2010)

- 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**

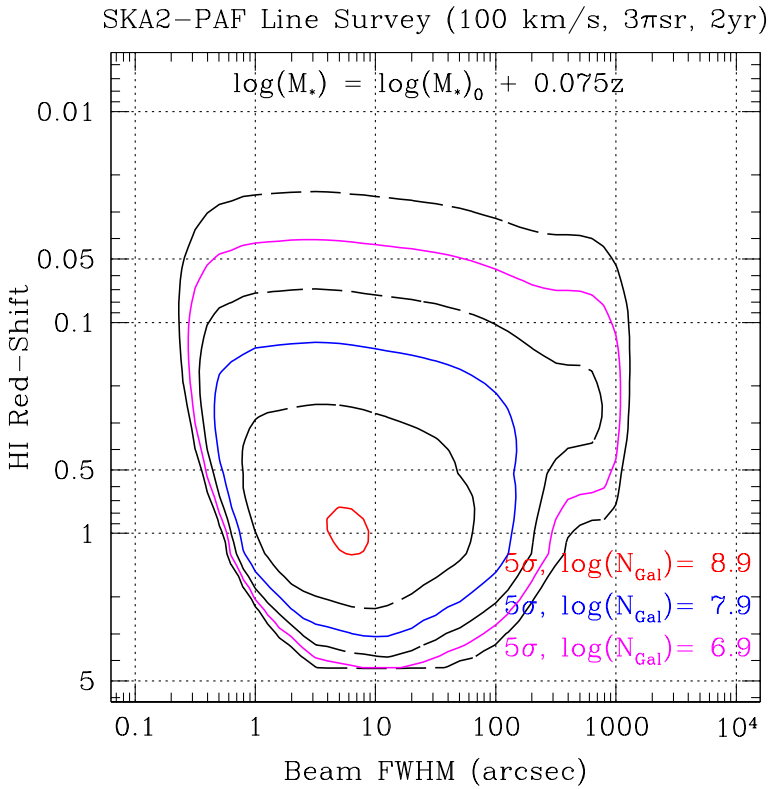
Cosmology with SKA1: complementarity with optical



(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



- Detect $10^{8.9}$ galaxies with <z> ≈ 1, $10^{7.9}$ with <z> ≈ 2
- Compare Euclid (2020+5?) target of 10^8 spectra with <z> ≈ 1
- **SKA2 will provide an unrivaled capability for precision cosmology!**

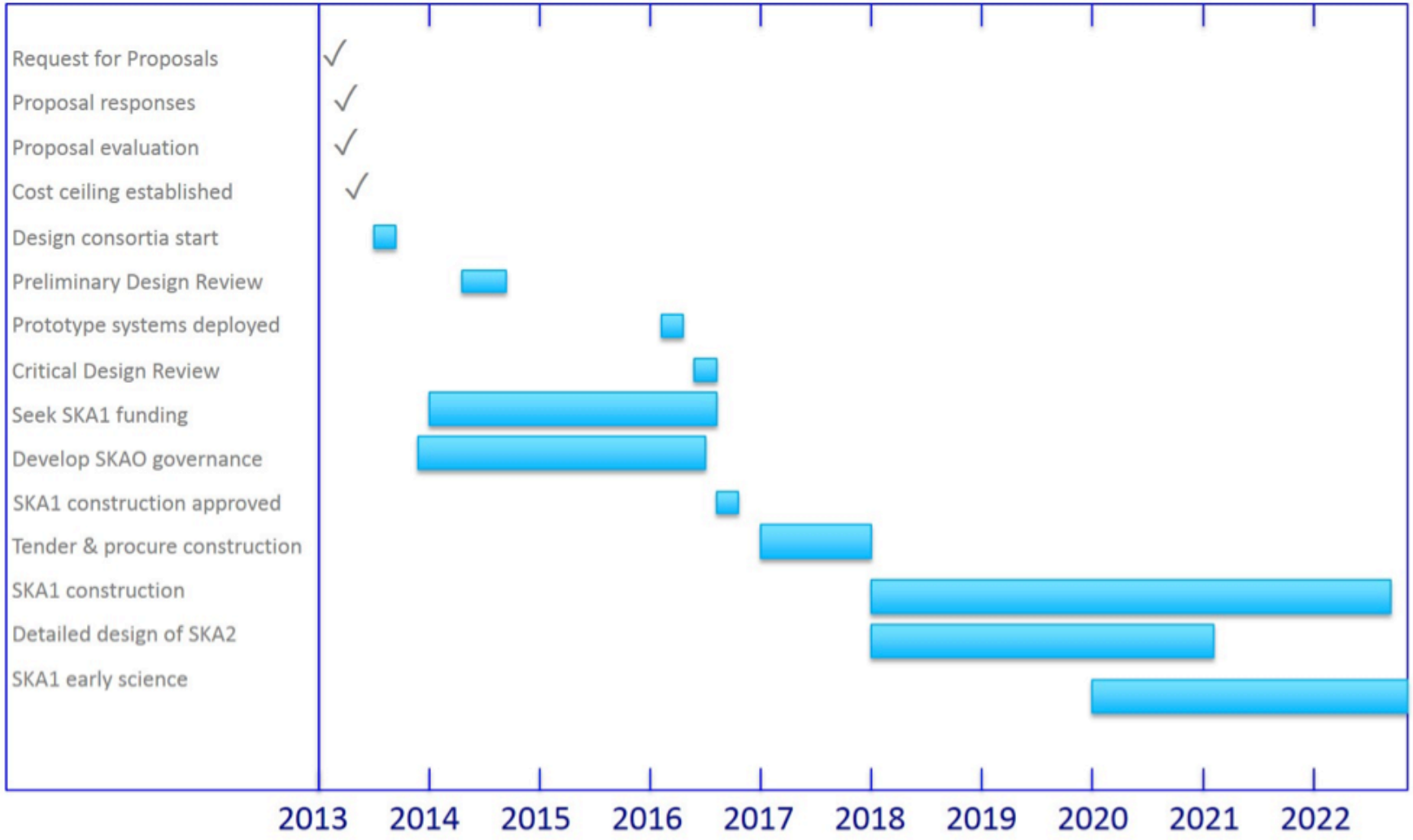
SKA Key Science

- 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:

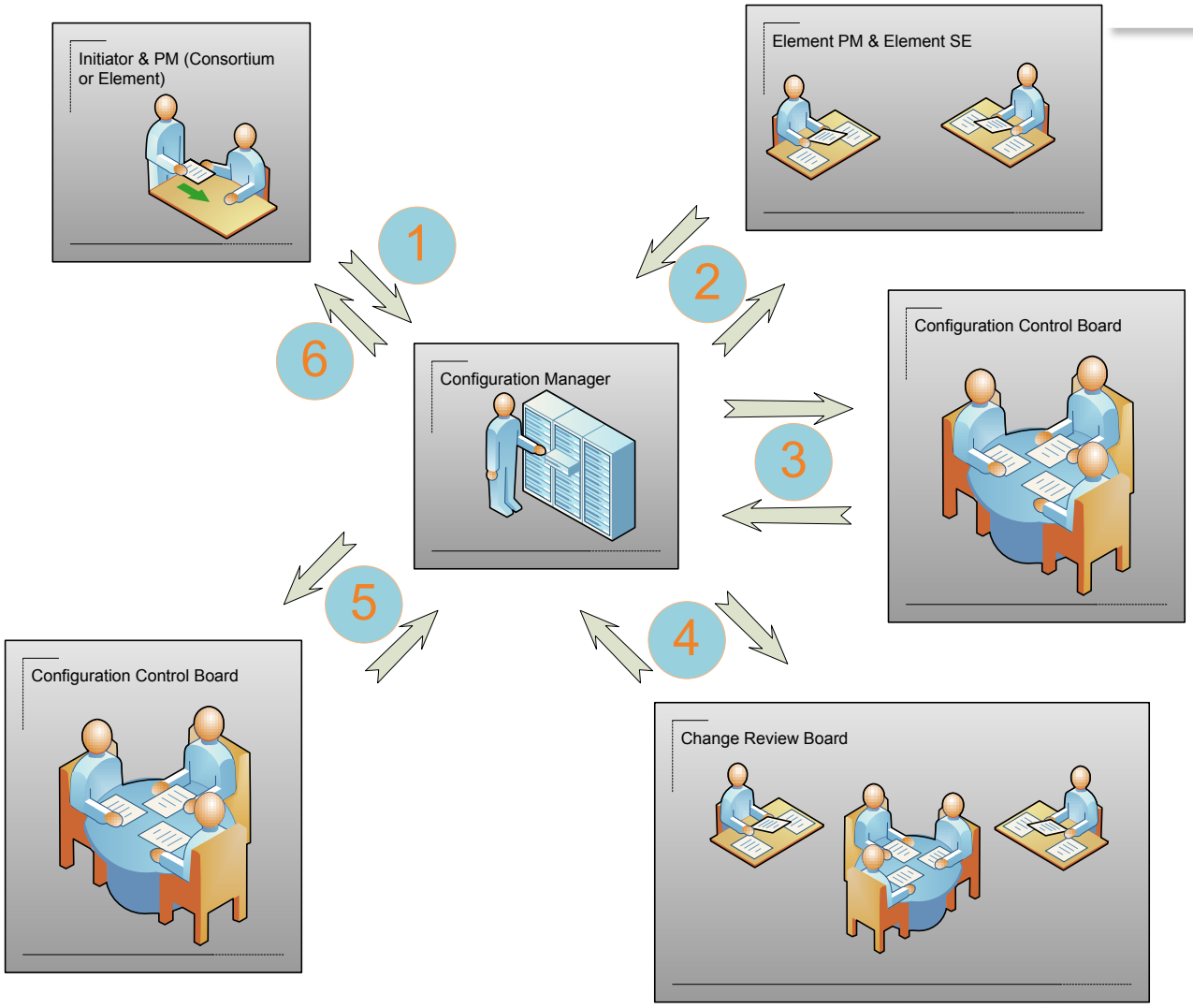
- Functional/Performance improvement or correction
- Change of interfaces
- New requirements
- A change in schedule and/or costs above a certain threshold (TBD)

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

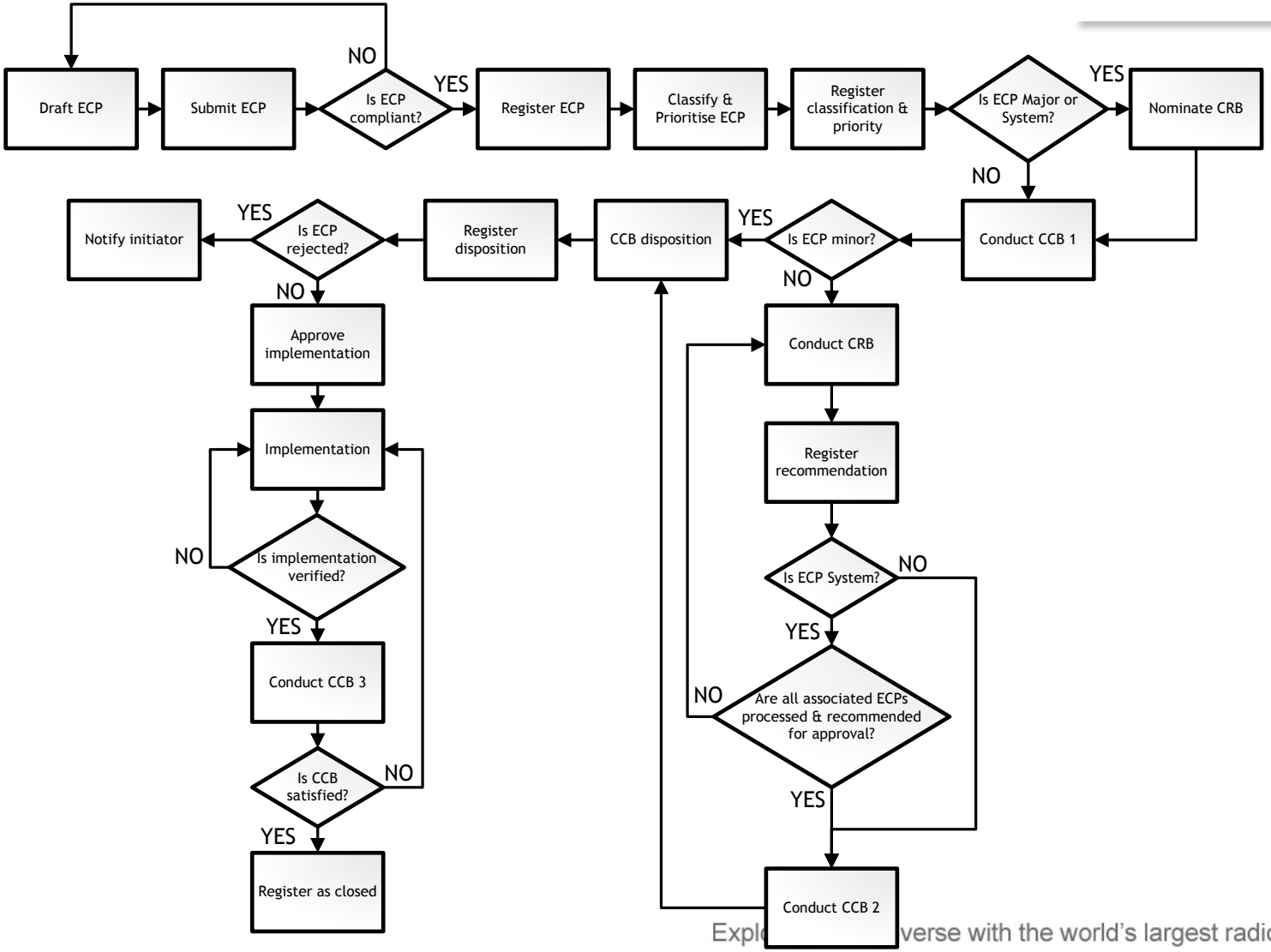


Figure 2: The ECP work flow diagram.

Thank you

www.skatelescope.org