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SKA SQUARE KILOMETRE ARRAY

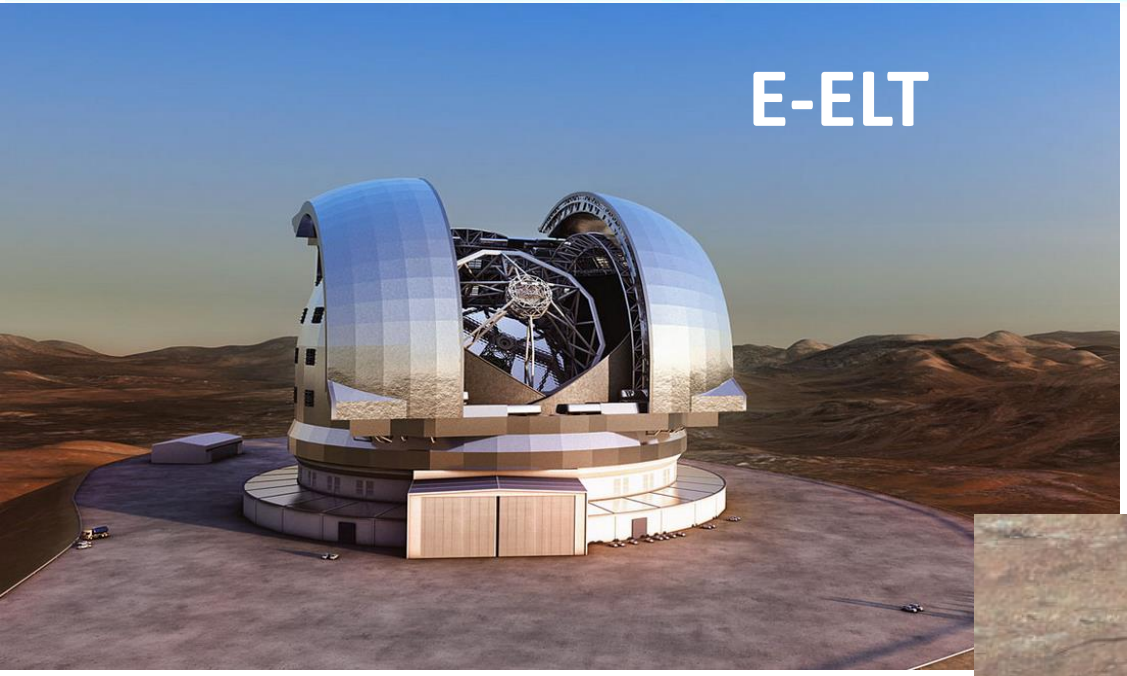
The Square Kilometre Array

Richard Schilizzi
University of Manchester

GerFeest, Groningen, 7Nov13

(with slides from Peter Dewdney, Phil Diamond and Robert Braun)

Great Observatories for the coming decades

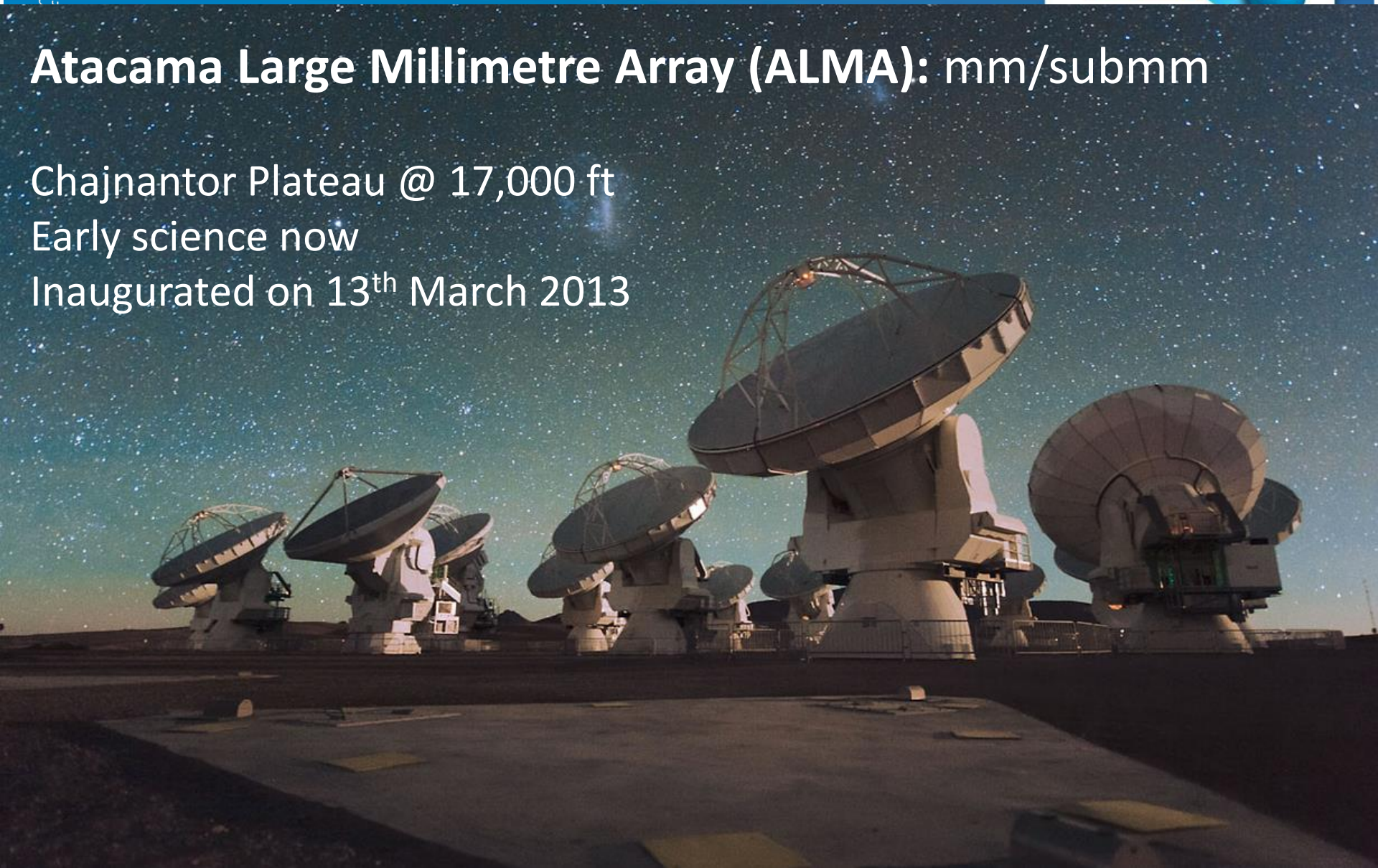


optical/IR

Great Observatories for the coming decades

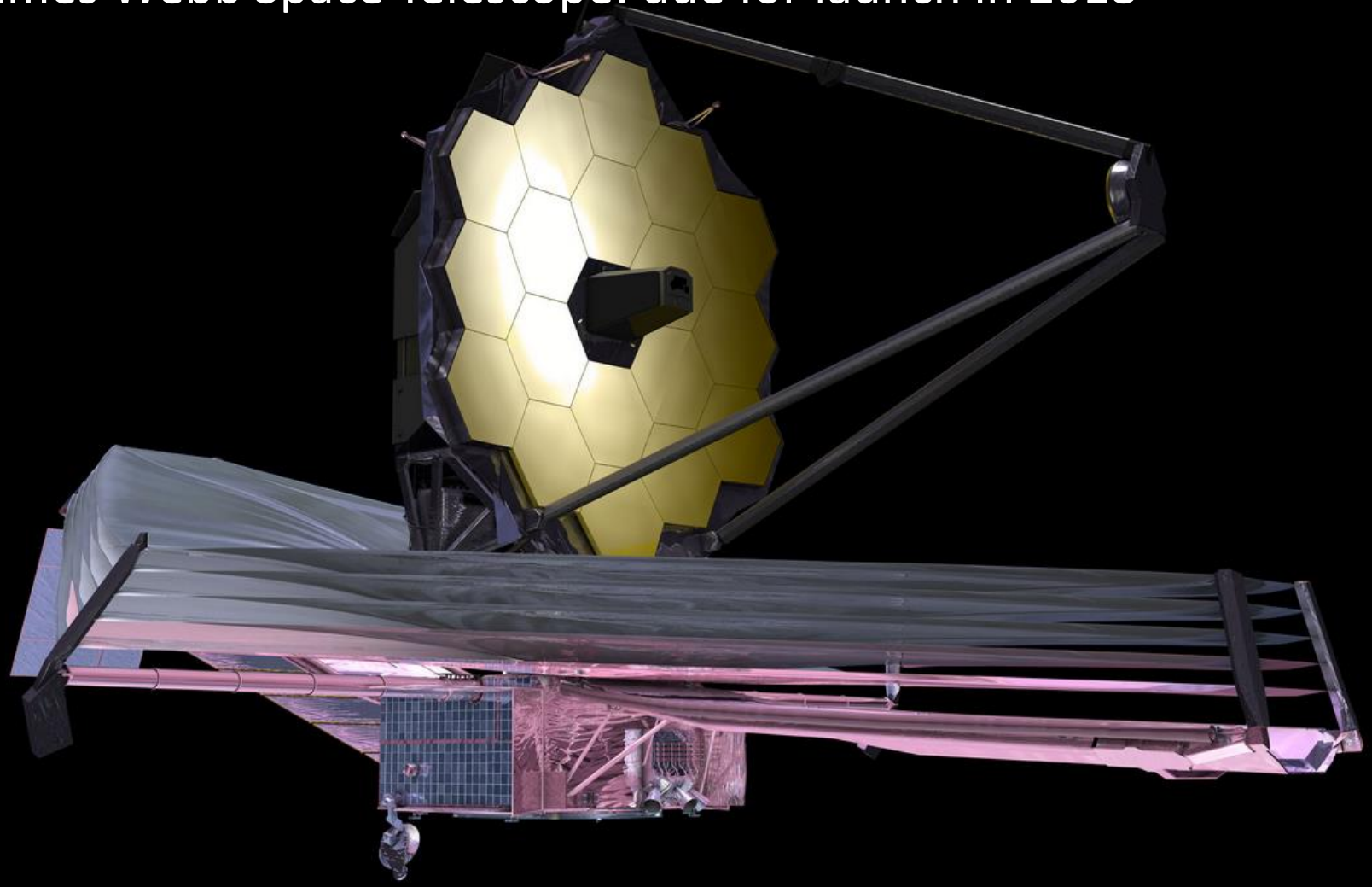
Atacama Large Millimetre Array (ALMA): mm/submm

Chajnantor Plateau @ 17,000 ft
Early science now
Inaugurated on 13th March 2013

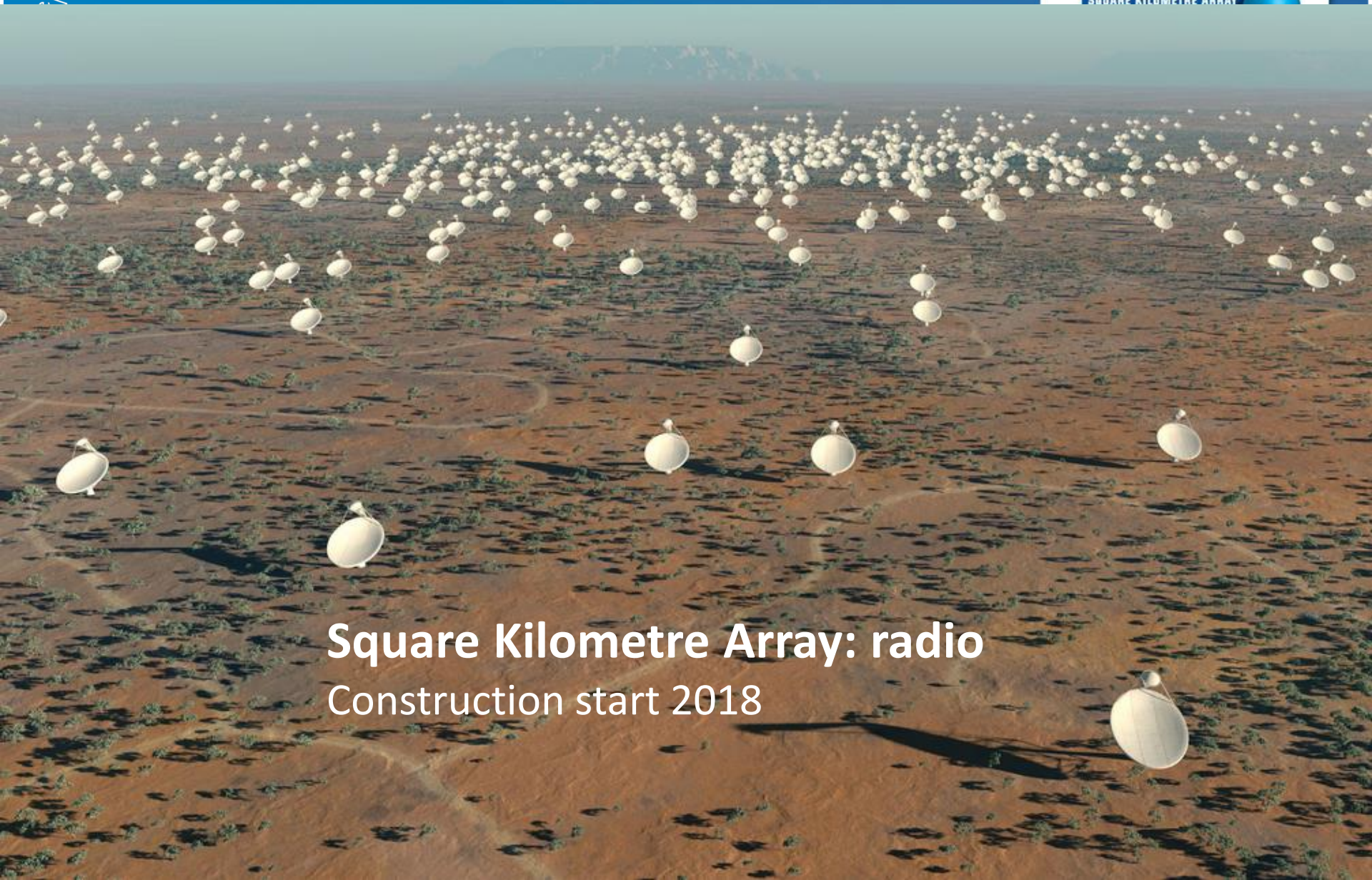


Great Observatories for the coming decades

James Webb Space Telescope: due for launch in 2018



Great Observatories for the coming decades



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But how did the SKA get started?

SKA SQUARE KILOMETRE ARRAY

EUR0 16: PROPOSAL FOR AN ARRAY OF 16 LOW COST 100 METER RADIO TELESCOPES

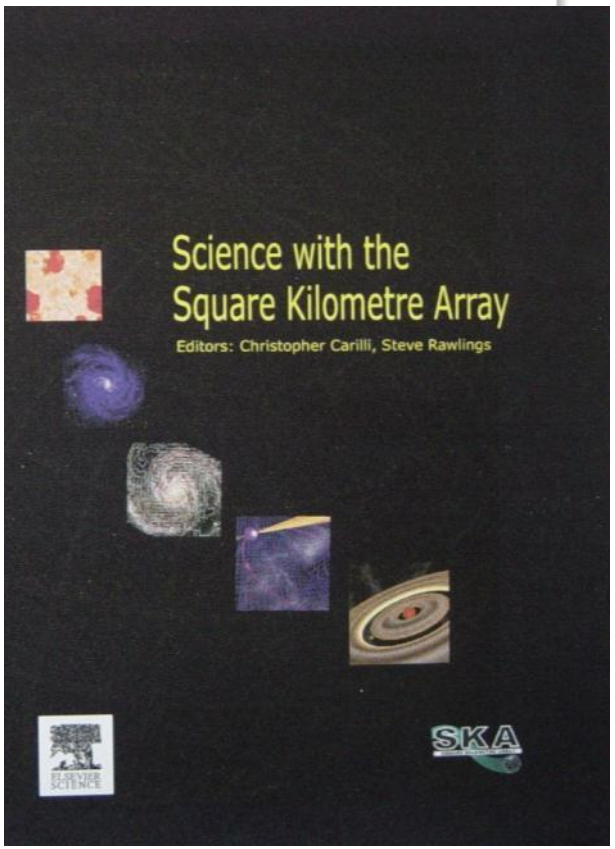
J.E.Noordam, R.Braun, A.G.de Bruyn

August 13, 1991

Summary: The next big step forward in radio astronomy will require a massive increase in collecting area. Ultimately, one square km will be needed for the imaging of individual galaxies in HI at high redshifts. However, there is already a very strong scientific case (outlined here) for an array with 16 telescopes of 100m diameter. a maximum baseline of 15-20 km, and a minimum operating wavelength of 20 cm. This "EUR016" (Early Universe Radio Observatory) array could be funded nationally, provided the mechanical part of a 100m telescope, with limited surface accuracy and steerability, could be built at a cost of a few MECU. A number of more or less promising designs are given here. Depending on the scientific enthusiasm of the Dutch community, NFRA could do a more extensive feasibility study in the near future.

SKA2 Key Science Drivers

- ORIGINS
  - Neutral Hydrogen in the Universe from the Epoch of Re-ionisation to now
    - When did the first stars and galaxies form?
    - How did galaxies evolve?
    - Dark Energy, Dark Matter
  - Cradle of Life and Astro-biology
    - Planetary formation
    - Complex molecules
- FUNDAMENTAL FORCES
  - Pulsars, General Relativity and gravitational waves
  - Origin and evolution of cosmic magnetism
- TRANSIENTS (new phenomena)



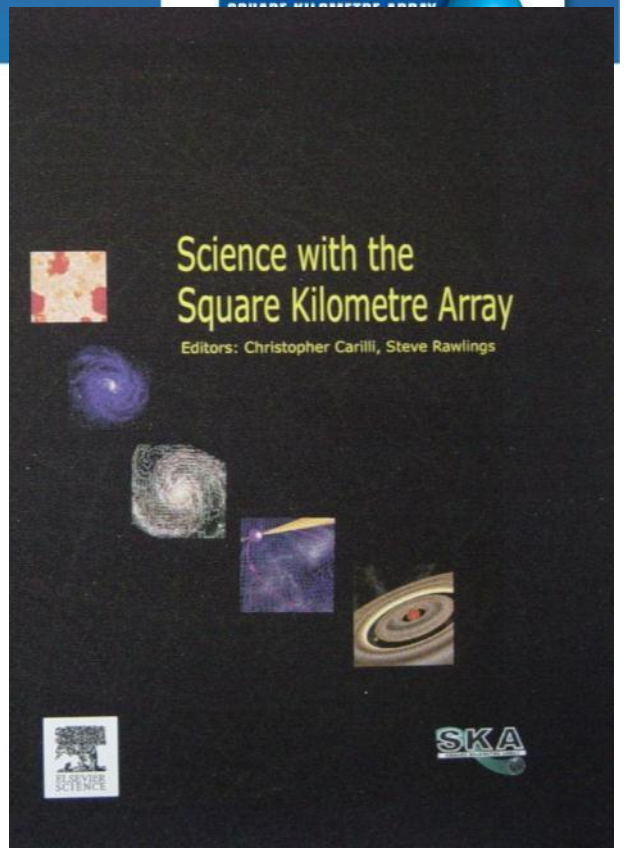
Science with the Square Kilometre Array

(2004, eds. C. Carilli & S. Rawlings, *New Astron. Rev.*, **48**)

SKA1 Defining Science

- ORIGINS
  - Neutral Hydrogen in the Universe from the Epoch of Re-ionisation to now
    - When did the first stars and galaxies form?
    - How did galaxies evolve?
    - Dark Energy, Dark Matter

- FUNDAMENTAL FORCES
  - Pulsars, General Relativity and gravitational waves



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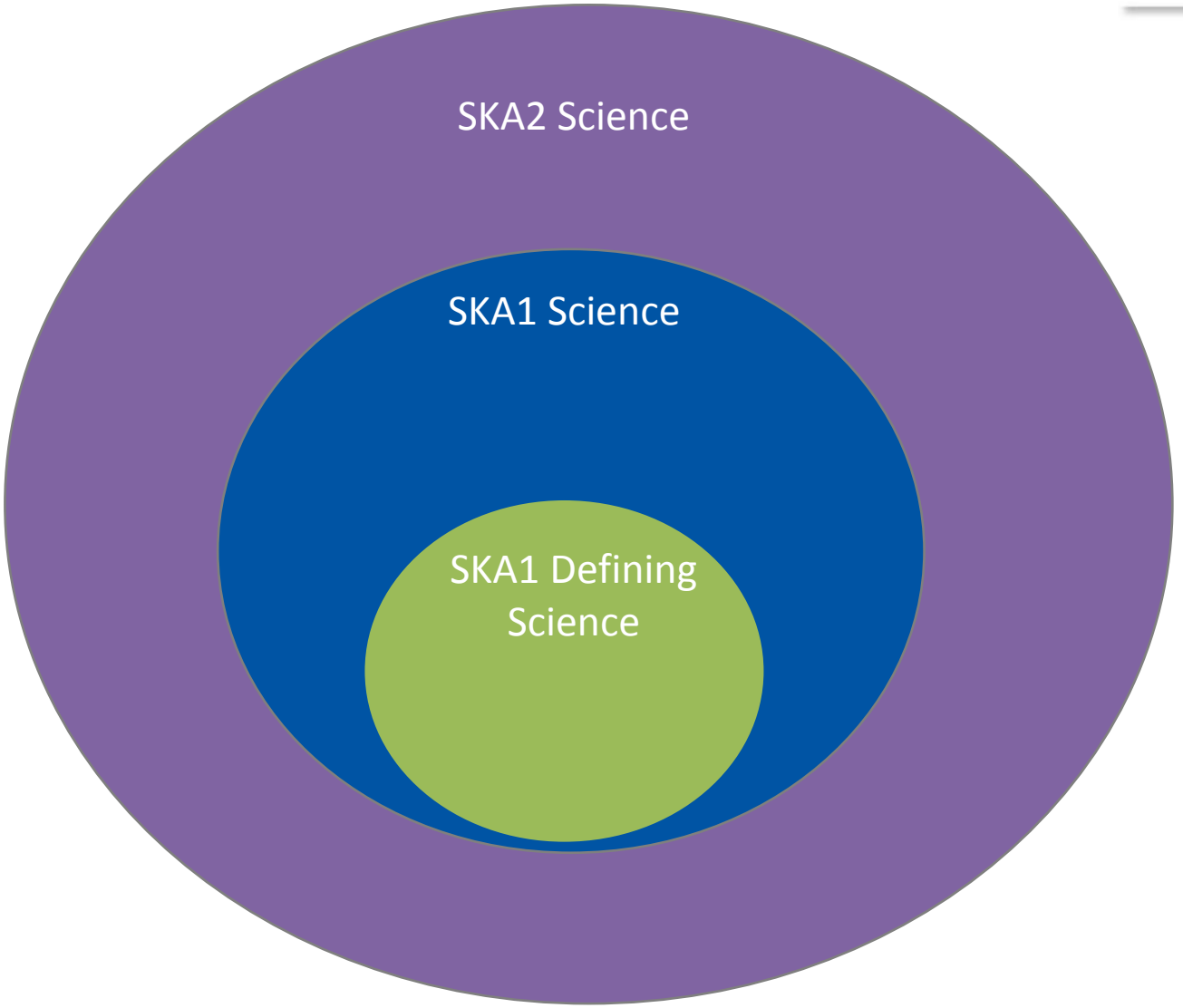
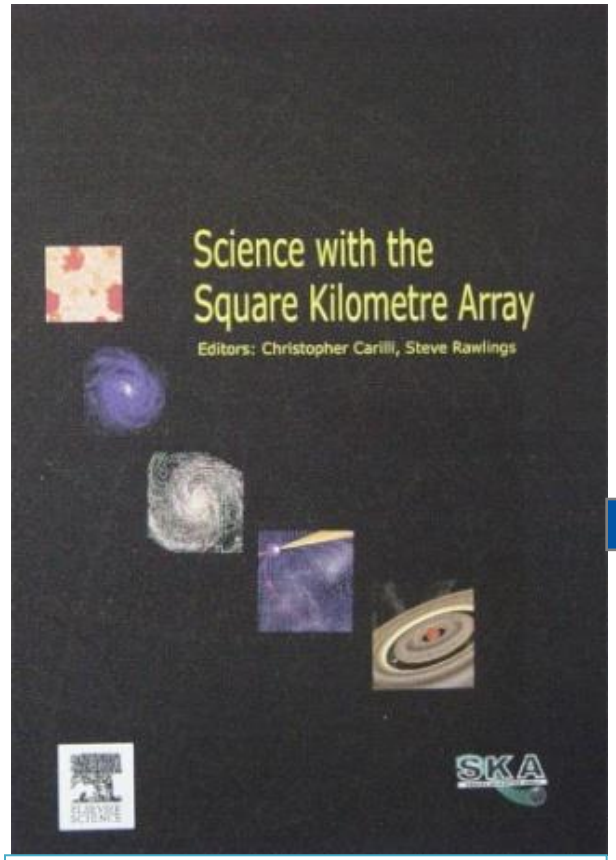
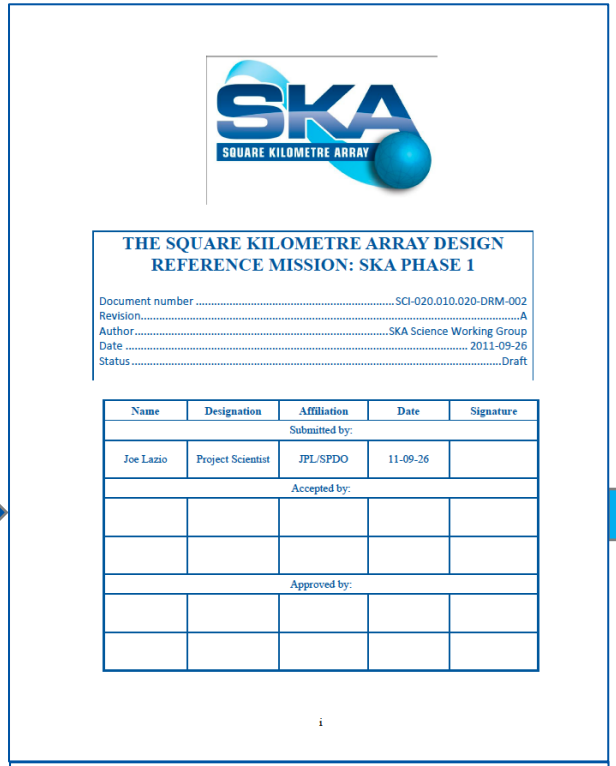

SKA2 Science
SKA1 Science
SKA1 Defining Science

Science Case, DRM, Requirements, and Baseline Design



Science Case

Lays out **overarching** goals, full suite of science



THE SQUARE KILOMETRE ARRAY DESIGN REFERENCE MISSION: SKA PHASE 1

Document number SCI-020.010.020-DRM-002
Revision ..... A
Author ..... SKA Science Working Group
Date 2011-09-26
Status ..... Draft

Name	Designation	Affiliation	Date	Signature
Submitted by:				
Joe Lazio	Project Scientist	JPL/SPDO	11-09-26	
Accepted by:				
Approved by:				

i

Design Reference Mission

Set of science observations to set **envelope** of science requirements

SCI-SYSR-0010
SCI-SYSR-0020
…
SCI-S-REQ-0110
SCI-S-REQ-0[illegible]

Baseline Design!

Requirements Document

Input from science, but from other areas as well

Baseline design: boundary conditions

- Site decision May 2012:

  SKA Observatory with two sites
  - SKA1-low – Australia
  - SKA1-survey – Australia
  - SKA1-mid – South Africa
- Incorporate precursors on the sites to re-use as much existing infrastructure as possible
- SKA Board has set a cost-cap of €650M for SKA1 construction

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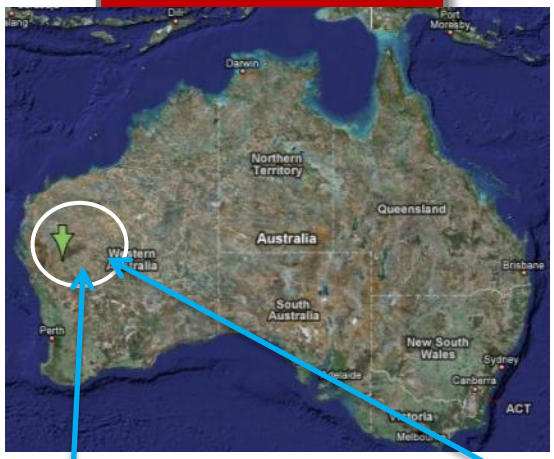
SKA Phase 1 (SKA1)
Cost €650M, construction start 2018

SQUARE KILOMETRE ARRAY

Southern Africa

SKA1_MID
254 Dishes including:
64 x MeerKAT dishes
190 x SKA dishes

Australia

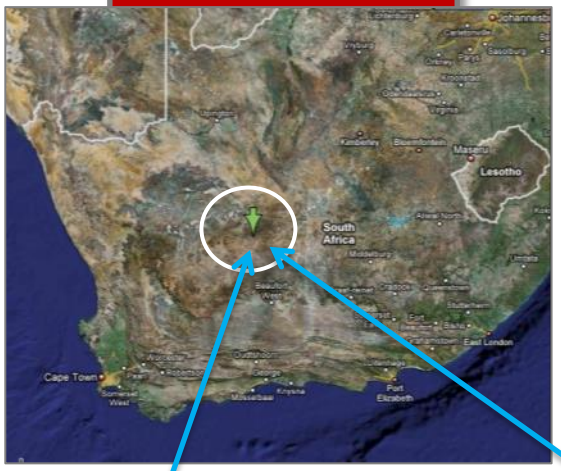


SKA1_LOW
Low Frequency Aperture Array Stations
250000 antennas

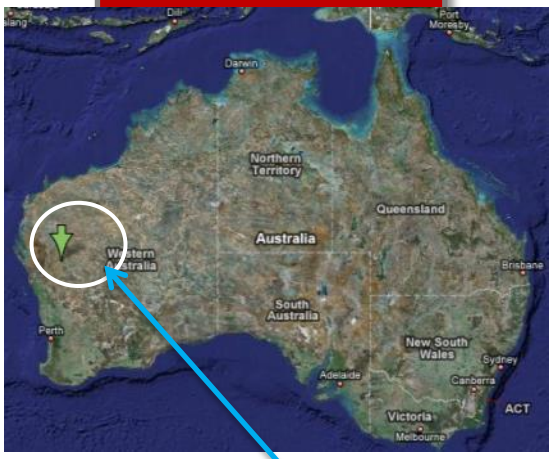
SKA1_SURVEY
96 Dishes including:
36 x ASKAP
60 x SKA dishes

SKA Phase 2 (SKA2)
Cost > €1.5B; construction start 2022

Southern Africa



Australia



SKA2_MID
2500 Dishes

SKA2_AA
Mid Frequency Aperture Array Stations (N=250)
30 million individual elements

SKA2_LOW
Low Frequency Aperture Array Stations
3 million antennas

SKA1 Design Time-line

- 2013 start of preliminary design (4 November)
- 2014 complete preliminary design;
  re-baseline the Baseline Design
- 2016 complete detailed design
- 2017 initiate procurement/ pre-production runs
- 2018 start construction

Today's Comparable Telescopes (L-band)

		JVLA	MeerKAT	SKA-mid	ASKAP	SKA1-survey	LOFAR	SKA1-low
Aeff/Tsys	m^2/K	265	321	1630	65	391	61	1000
FoV	deg^2	0.25	0.86	0.49	30	18	14	27
Survey Speed FoM	$deg^2\ m^4\ K^{-2}$	1.76×10^4	8.86×10^4	1.30×10^6	1.27×10^5	2.75×10^6	5.21×10^4	2.70×10^7
Resolution	arcsec	1.4 - 44	11	0.22	7	0.9	5	11

SKA1 Ae/Tsys	6.2 x JVLA	6.0 x ASKAP	16 x LOFAR
SKA1 Survey Speed FoM	74x	22x	520x

SKA1-MID headline science

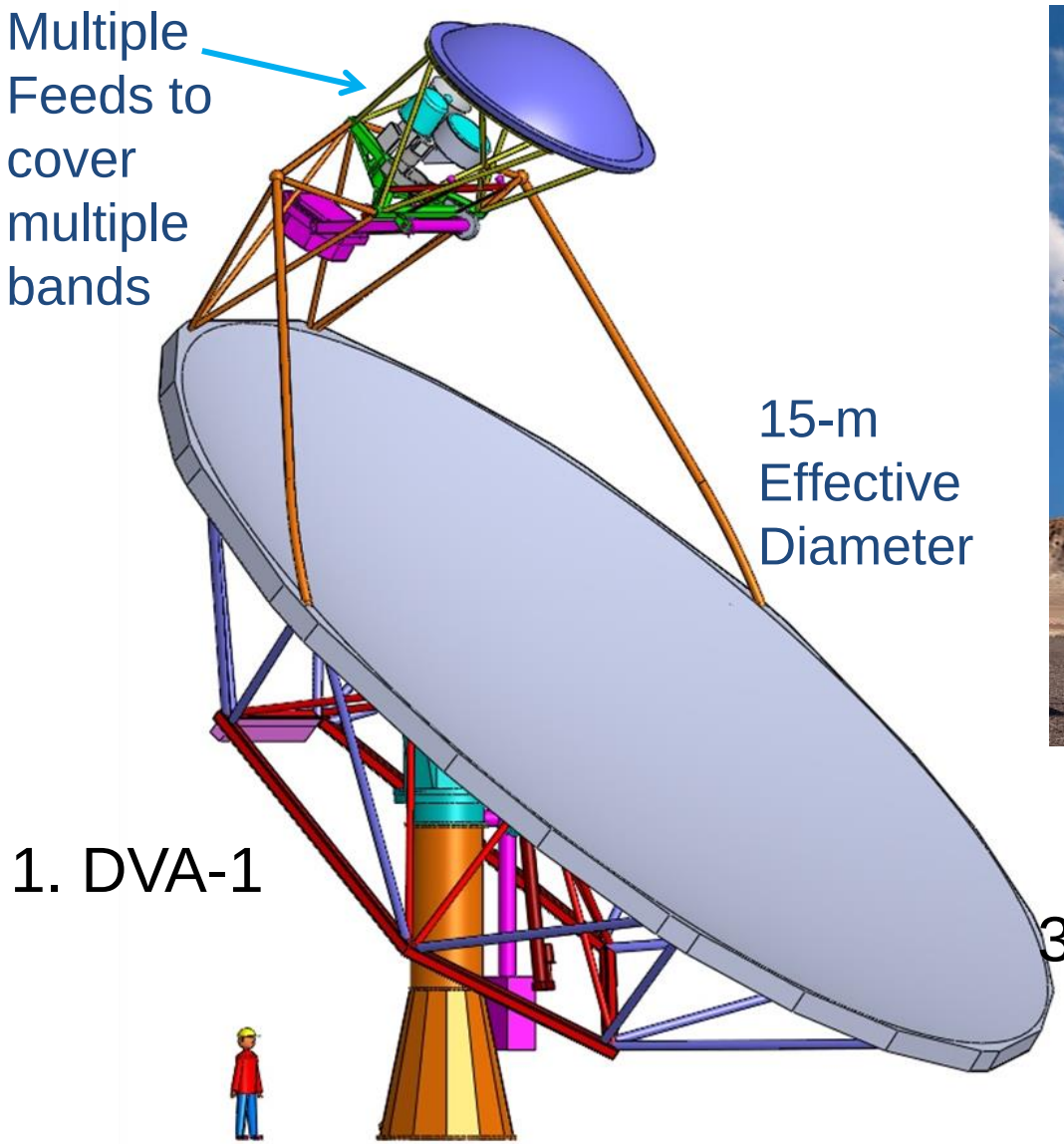
- HI-line from local Universe, to moderate redshifts
- Radio pulsars
- High sensitivity continuum
  - Polarisation: magnetized plasmas, Galactic & Extragalactic
  - potentially proto-planetary disks, if high frequency receivers enabled
- Other spectral lines (e.g. OH-lines)
- Some classes of radio transients

SKA1-MID Baseline Design

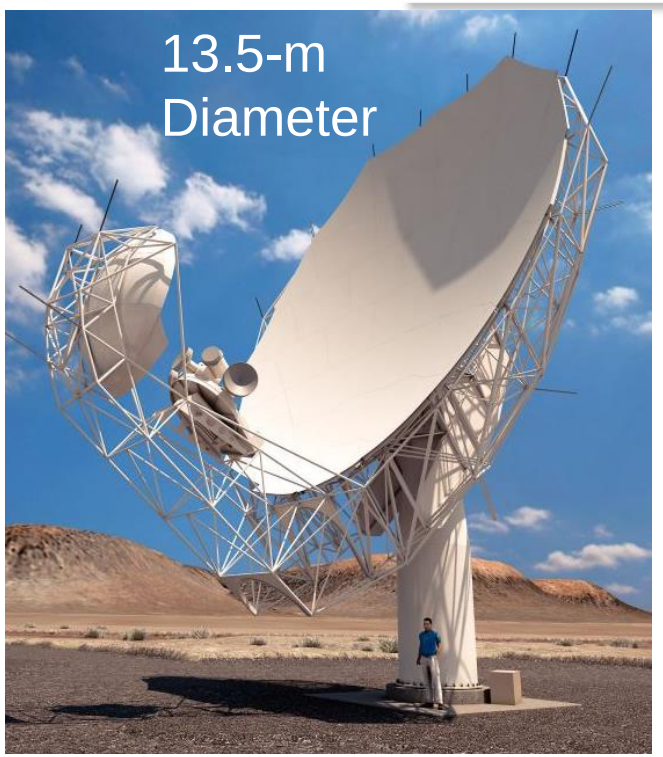
- Mixed Dish array
  - 190x15-m SKA1 dishes
  - 64x13.5-m diameter dishes from the MeerKAT array
  - Equipped with receivers from .350 to 3.0 GHz for SKA1 (dishes capable of 5 receiver packages up to 20 GHz)
- Configuration
  - Compact core with a diameter of ~1 km, built on the MeerKAT array centre
  - Further 2-D array of randomly placed dishes out to ~3 km radius, thinning at the edges
  - Three spiral arms, a subset of the 5 equally spaced arms reserved for SKA2, extending to ~100 km from the centre
  - Array to be expanded to a much larger SKA2 array (by “density matching”)
- Sensitivity
  - SKA1 sensitivity: ~6.9 m^2/K
  - System Equivalent Flux Density (SEFD): ~1.7 Jy

Offset-Optics Antenna Design

3 prototypes



1. DVA-1



2. MeerKAT dish design

3. Design from China (DVA-C)

Traditional back-up structure and single surface (no illustration available).

DVA1 Prototype Construction

DVA1 Main Reflector Layup

Note scale

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DVA1 Main Reflector Move

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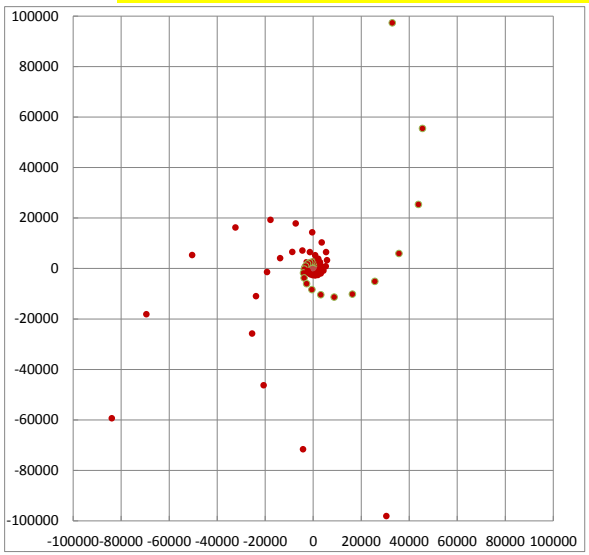
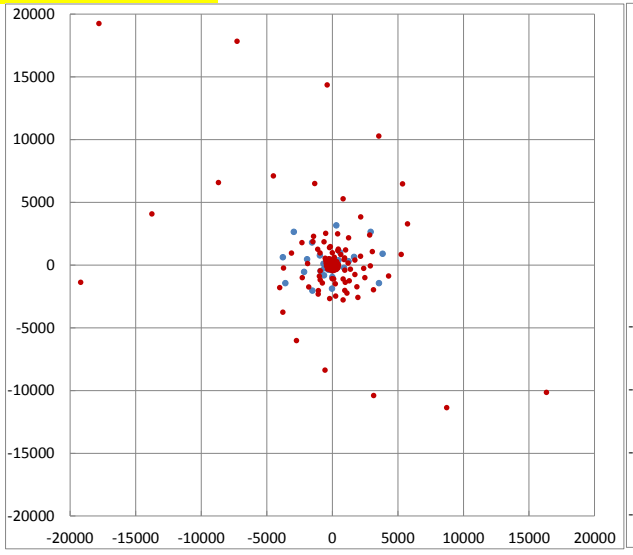
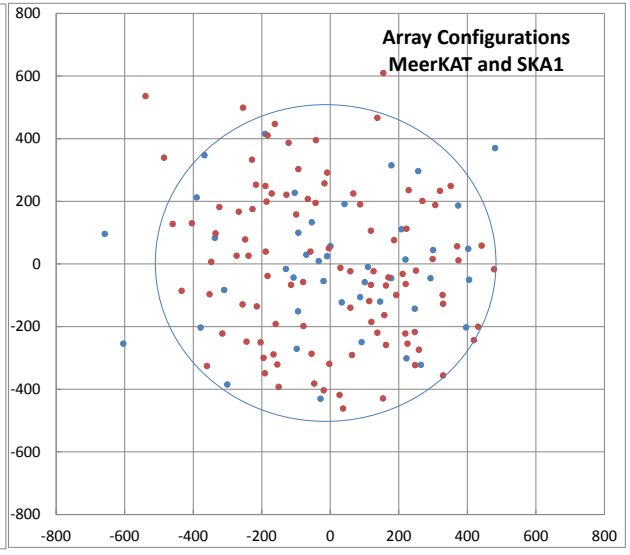
SKA1-MID Array Configuration



200 km



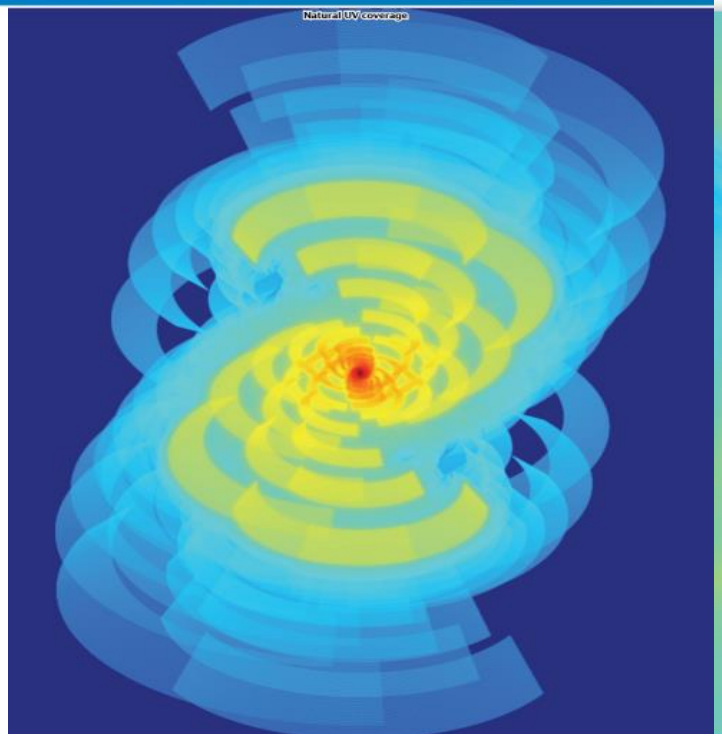
40 km



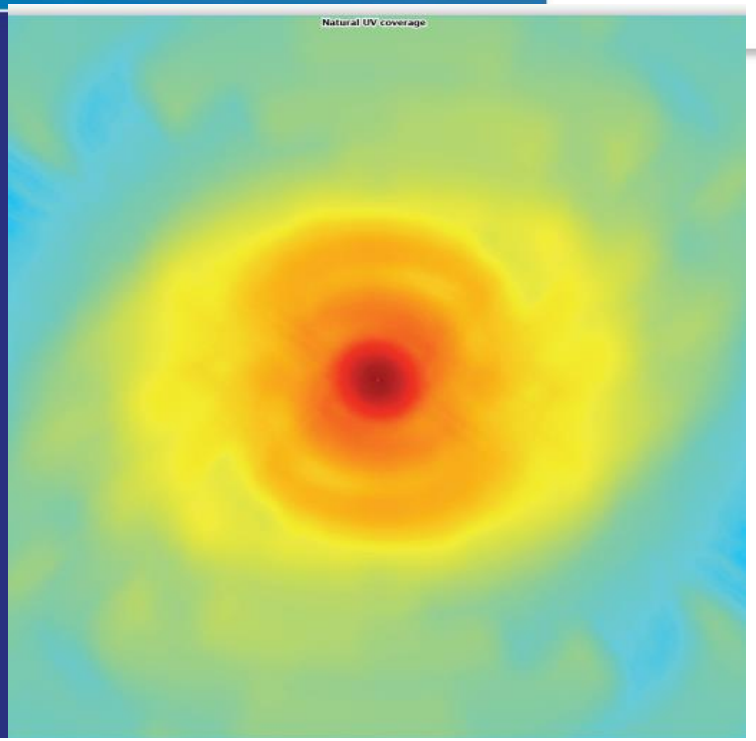
1.6 km

u-v Coverage SKA 1-MID

400 km



320 km



12 km

13 km

- *u-v* coverage with a 20% fractional bandwidth in 8 hr observation.
  - Strong emphasis on core density enables sensitive pulsar survey but also generates patchy *u-v* coverage elsewhere. Bandwidth helps for continuum.
  - Right box shows excellent coverage at shorter spacings.

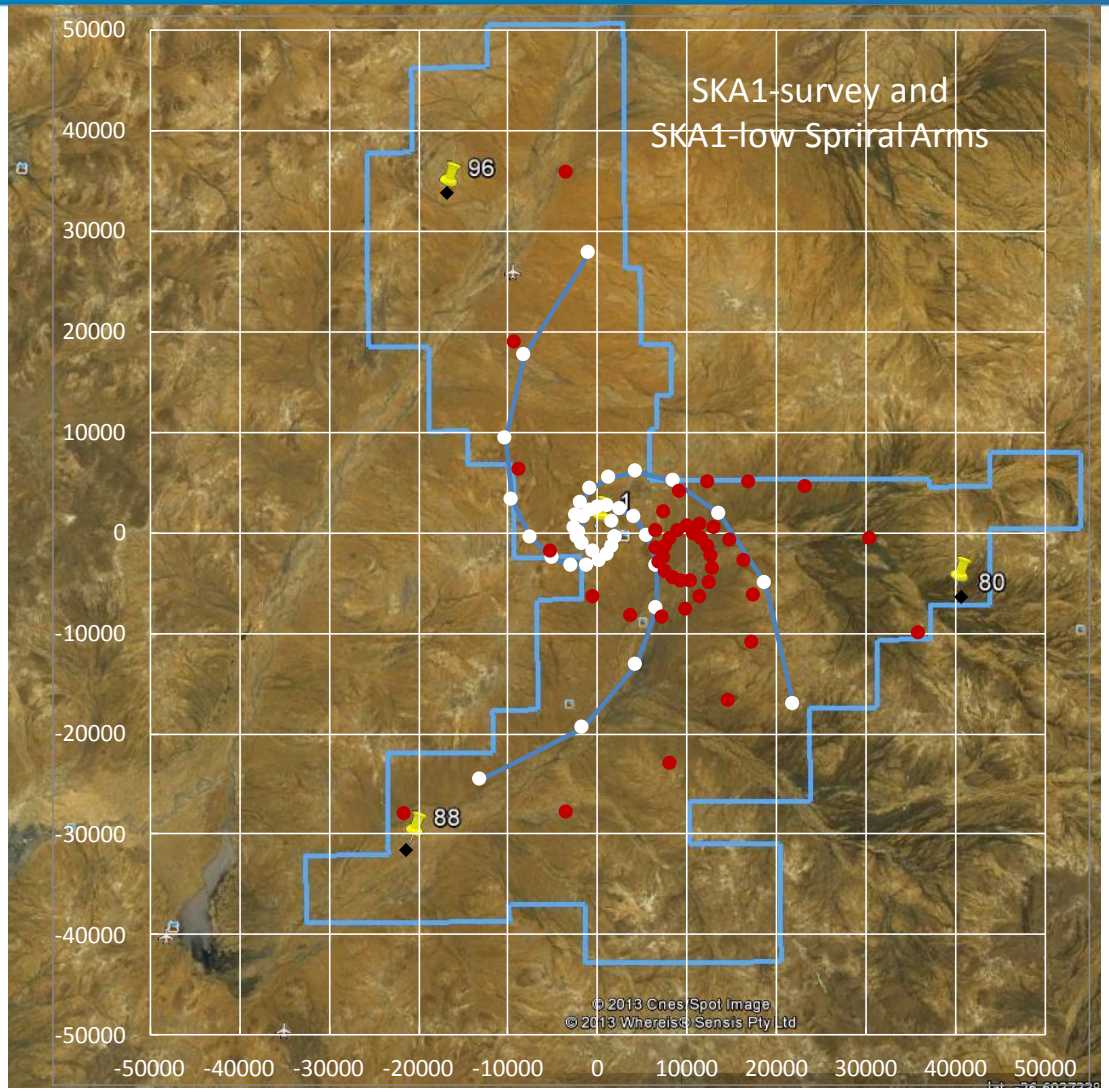
SKA1-LOW headline science

- Highly red-shifted HI line (emission and absorption) from Epoch of Re-ionisation and earlier
- High sensitivity continuum
- Potentially low-frequency pulsar surveys, radio recombination lines

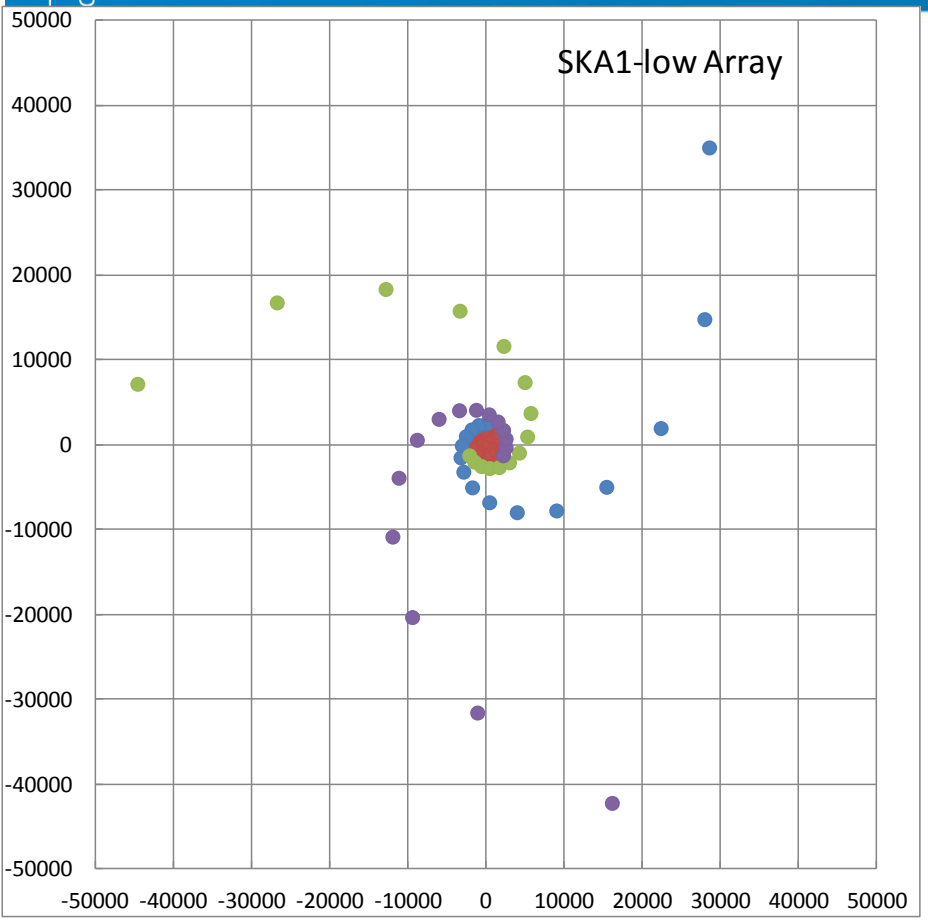
SKA1-LOW Baseline Design

- Configuration (911 35-m diameter stations; 866 in “core”)
  - Consist of an array of ~250,000 log-periodic dual-polarised antenna elements.
  - 866 stations arranged in a very compact configuration (the ‘core’) with a diameter of ~1 km.
  - Outer stations configured in three spiral arms.
  - Radius of the configuration is ~45 km (max baseline ~80 km).
- Frequency range: 50 MHz to ~350 MHz.
- Sensitivity
  - ~1000 m^2 / K above 110 MHz at the zenith above transition frequency of ~110 MHz.
  - Brightness temperature sensitivity ~1 mK with core at the zenith above transition frequency.
- Beamforming
  - Elements will be coarse channelised and beam-formed to expose a field-of-view of ~20 deg^2 in a single smooth beam.
  - Possibilities exist for more elaborate beamformers in the core, if needed.

SKA1-Low & SKA1-survey Baseline Design Array Configurations



SKA1-LOW Array Configuration

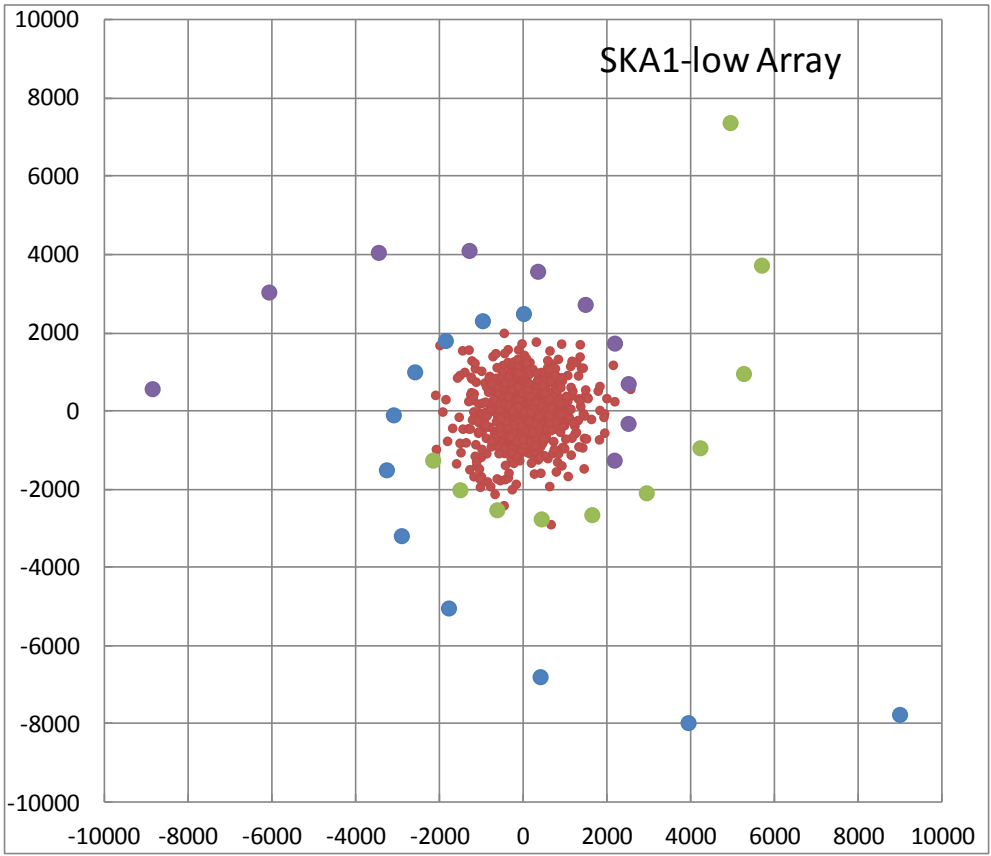


100 km

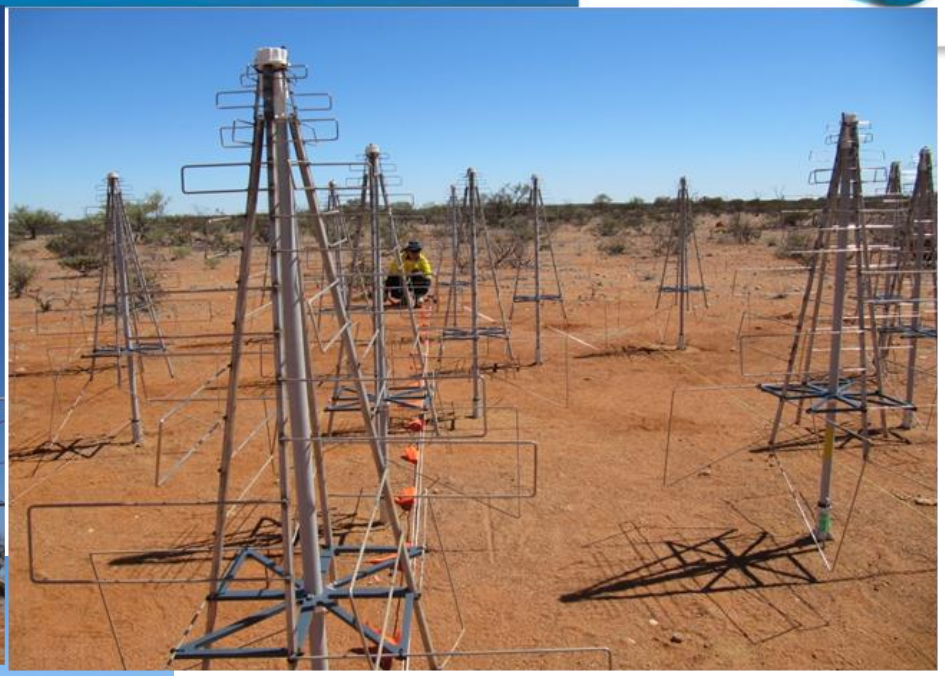
Dimensions in meters

Full Extent

20 km



Log-Periodic Test Array in Australia



Cambridge-ASTRON-ICRAR & industrial partners

- 16 log periodic dipole antenna array
- Configured as an MWA station

SKA1-LOW
Antenna Element Selection

- Antenna technology choices
  1. Arrays of low-gain antennas (droopy dipoles, LOFAR style)
     - Frequency range may require two arrays, but only one has been included so far
     - Mature technology – LOFAR in operation for some time.
  2. Higher-gain antenna elements (log-periodic)
     - Higher gain => fewer elements, lower cost
     - *Potential issue: Smooth frequency and spatial response*
     - Less sky coverage
     - Better frequency coverage individually
       - Array will be very sparse at high frequencies
       - Less sky coverage
       - Better frequency coverage
     - 8 dBi gain chosen => ~250,000 antenna elements

SKA1-SURVEY headline Science

- Surveys of large fractions of the sky
- Spectral line and continuum
- HI-line observations: Galaxy to moderate redshifts
- Continuum: total and polarised intensity

SKA1-SURVEY Baseline Design

- Mixed array
  - 60 x15-m SKA1 dishes equipped with a PAF (room for 3 PAFs in 3 bands)
  - 36 x12-m diameter dishes from the ASKAP array
- Frequency coverage
  - 650 to 1670 MHz in a single dual-polarised PAF
  - 500 MHz wide instantaneous bandwidth
- Configuration
  - “Densified” ASKAP core with diameter ~2 km
  - Three spiral arms to a radius of ~25 km from the centre
- Sensitivity
  - aperture efficiency of ~80%
  - system temperatures of ~30 K
  - Constant Field-of-View with frequency:
    - ~18 deg^2 (36 beams at the highest frequency)
  - Survey Speed Figure-of-Merit (SSFoM)
    - ~10^6 m^4 K^{-2} deg^2

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ASKAP Phased Array Feed

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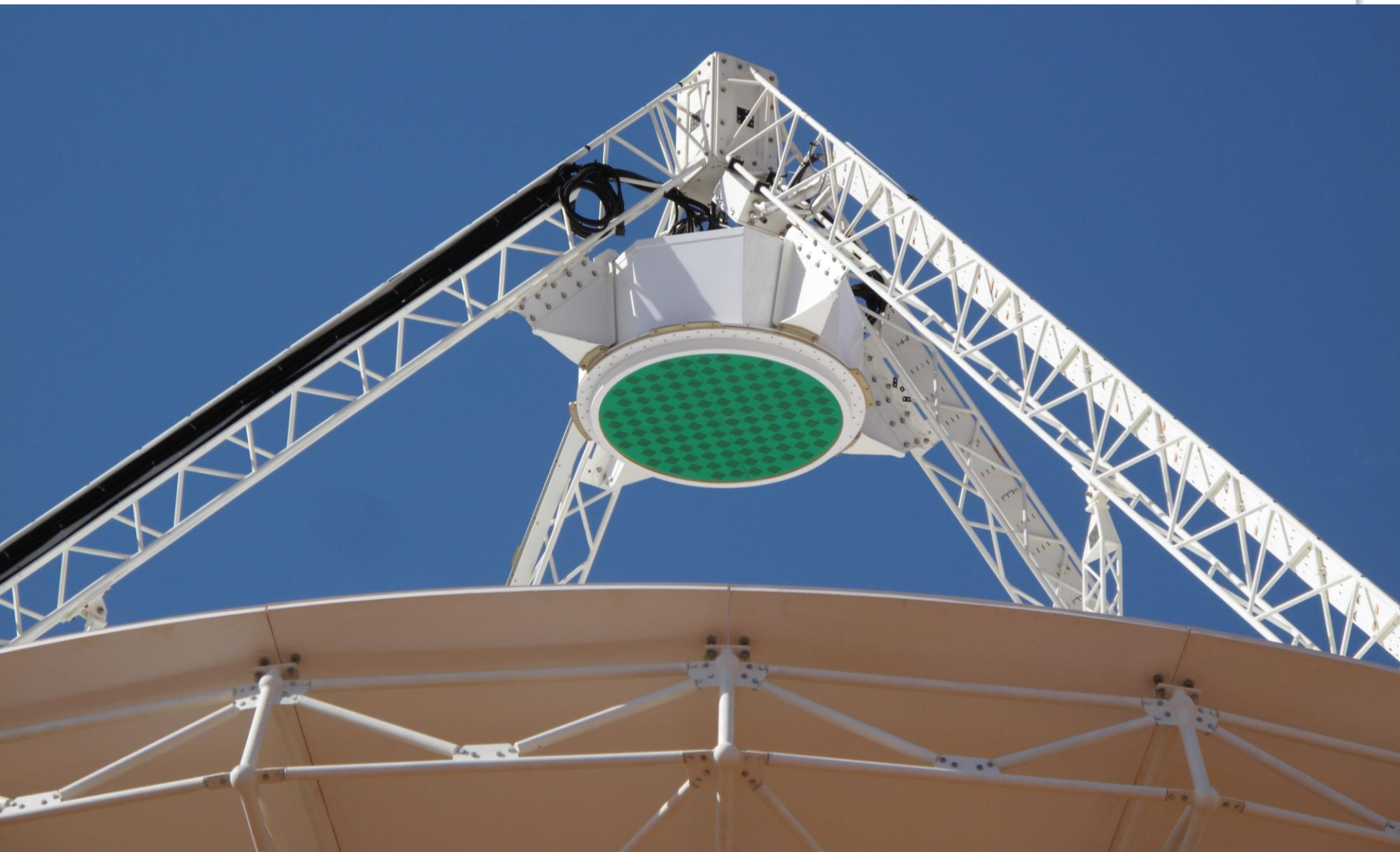
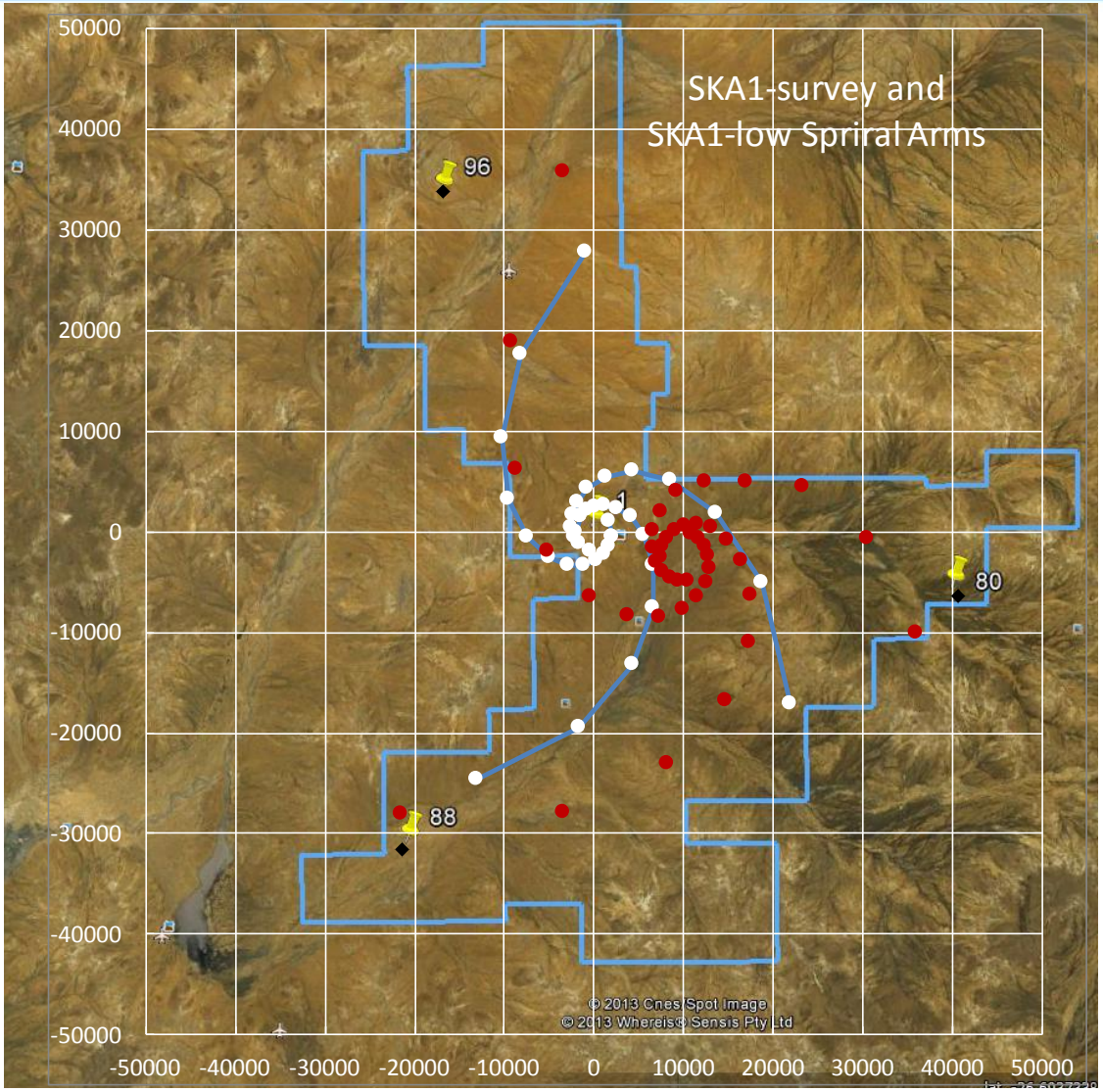


SKA1-Low & SKA1-survey BD Array Configurations

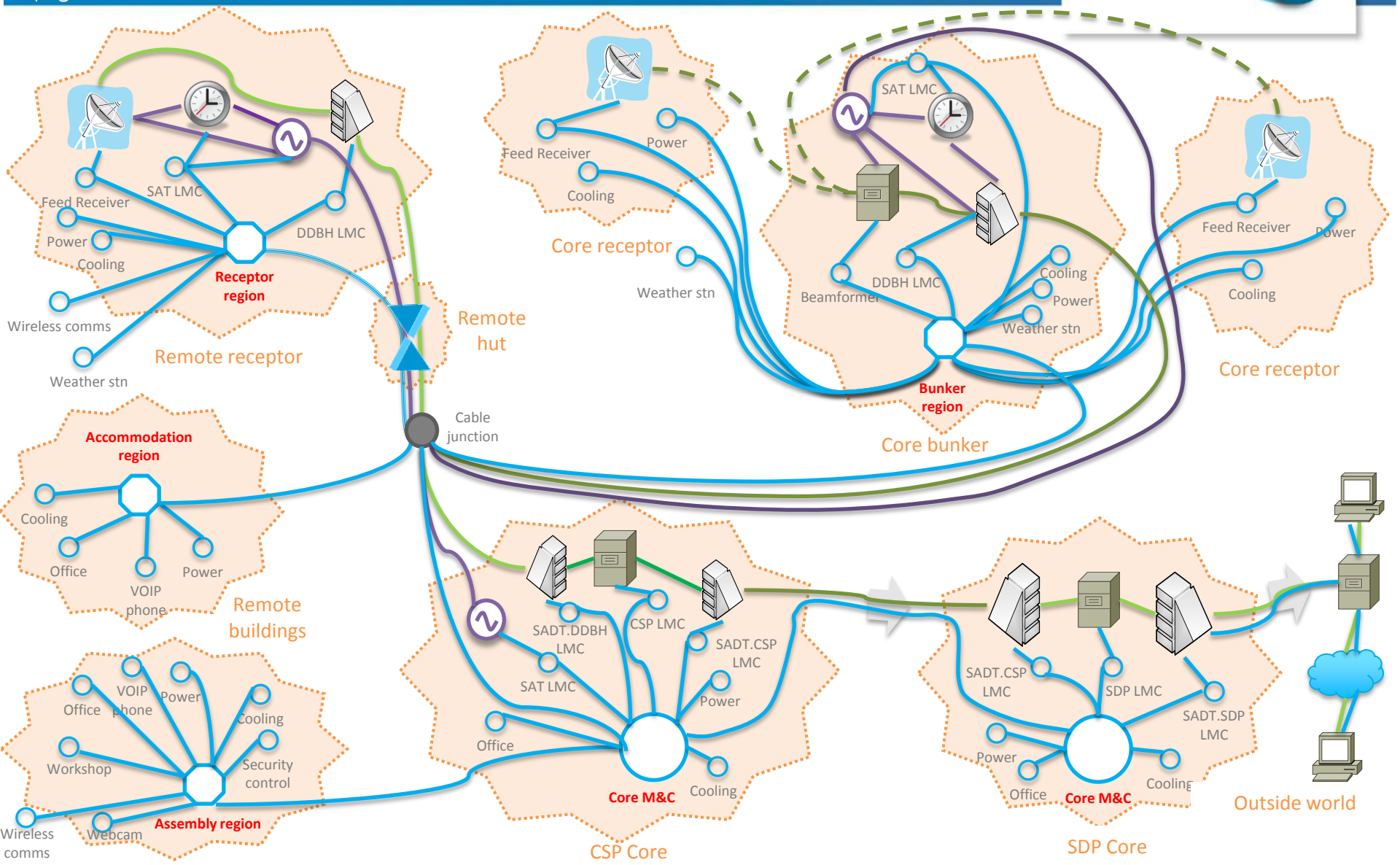


100 km

Data rates

Data network architecture

M&C
Sci Data
SAT



SKA1 System Sizing

SKA1 LOW / SURVEY (36 beams):

- Data rate into correlator:
  - 36Tb/s (SURVEY remote stations)
  - 450 Gb/s (LOW remote stations)
- Data rate out of correlator:
  - 4670 GB/s (SURVEY)
  - 842 GB/s (LOW)
- Max data rate into SDP: 995 GB/s
- Max computing load (flops/s): 32 Pflops
- Max UV buffer: 14 PB
- Data rate to the outside world: 100 Gb/s

SKA1 MID:

- Data rate into correlator: 22.8 Tb/s
- Data rate out of correlator: 1800 GB/s
- Max data rate into SDP: 255 GB/s
- Max computing load: 10.0 Pflops/s
- Max UV buffer: 11.0 PB
- Data rate to the outside world: 100 Gb/s

SKA Organisation

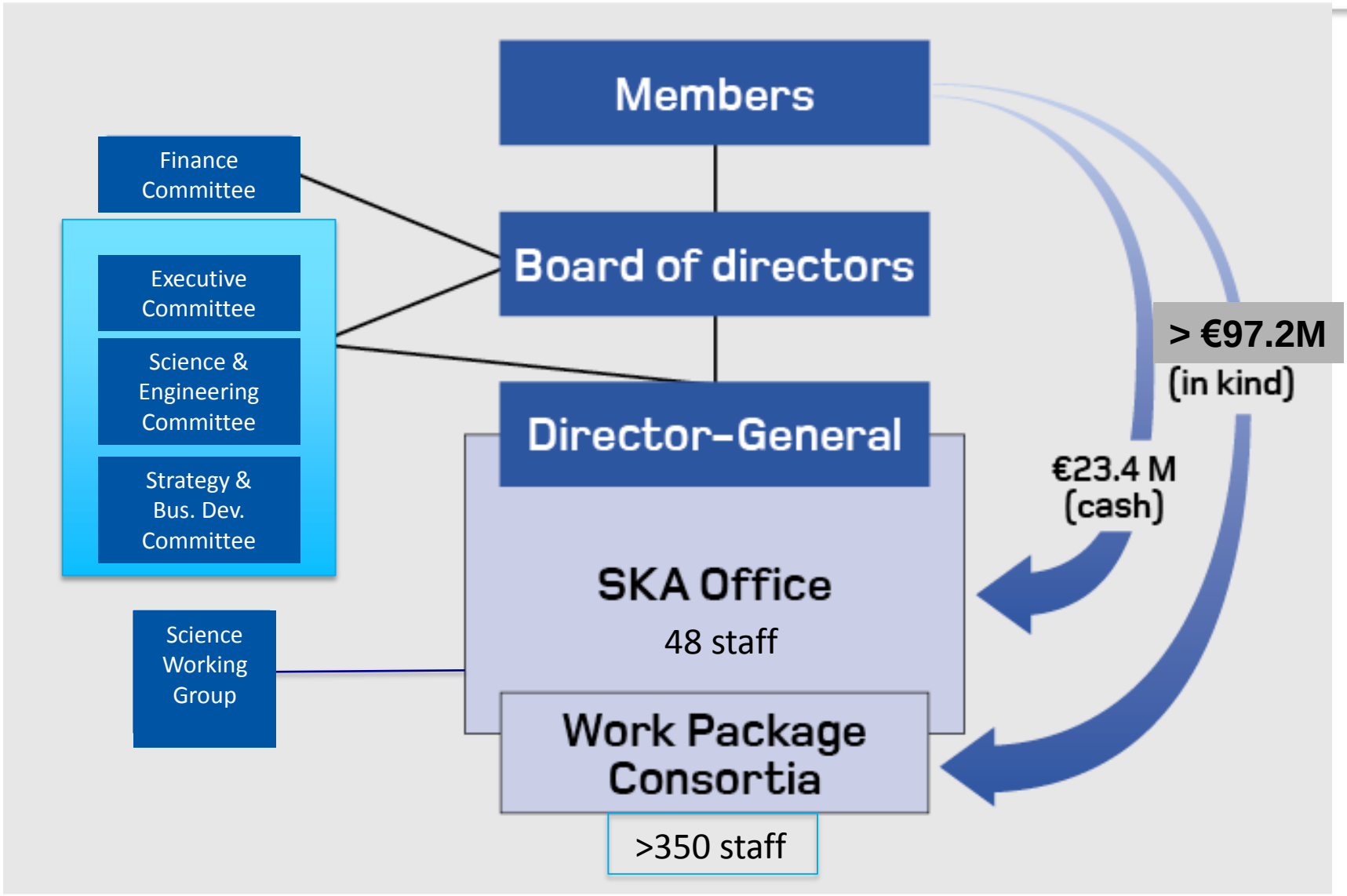
SKA Members and Governance

Australia (DIISRTE)
China (MOST)
Italy (INAF)
New Zealand (MED)
Sweden (Chalmers)
India (Tata/DAE)

Canada (NRC-Herzberg)
Germany (BMBF)
Netherlands (NWO)
South Africa (DST)
UK (STFC)

- UK Company Limited by Guarantee
- (Expedient solution to enable SKA project to proceed; long-term governance structure under review)

SKA Members and Governance



Work Packages

- **Led by SKA Office**
  - Management
  - Science
  - System Design and system engineering
  - Maintenance & Support and Operations
- **Carried out by Work Package Consortia**
  - Dish Array **(Australia)**
  - Aperture Arrays **(Netherlands)**
  - Signal and Data Transport (including synchronisation and timing) **(UK)**
  - Central Signal Processor **(Canada)**
  - Science Data Processor **(UK)**
  - Telescope Manager **(India)**
  - Infrastructure, including power **(South Africa and Australia)**
  - Assembly, Integration and Verification **(South Africa)**
- **Advanced Instrumentation Programmes (to be integrated with Dish & AA WPs)**
  - Mid Frequency Aperture Array **(Netherlands)**
  - Wide Band Single Pixel Feeds **(Sweden)**

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Timeline

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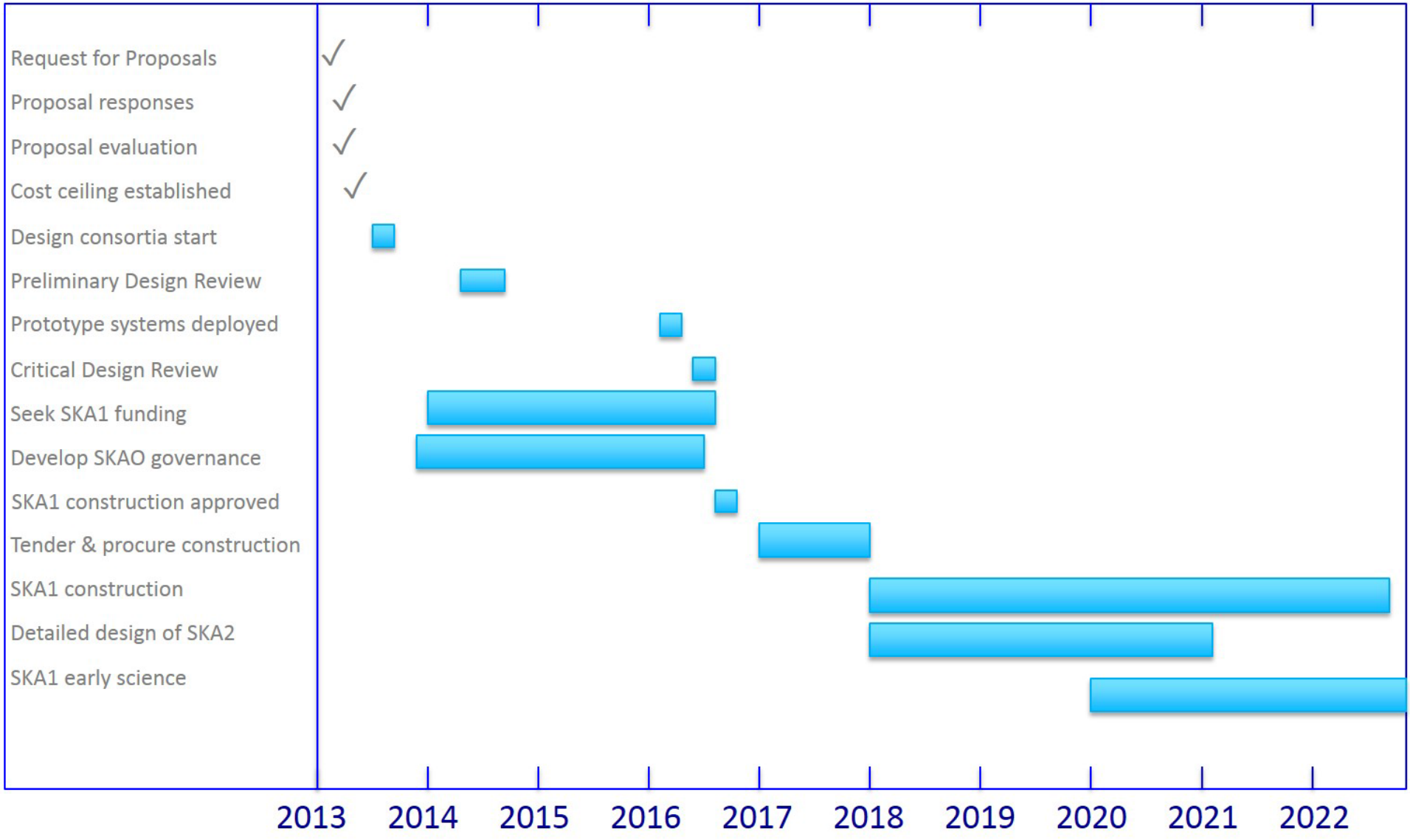

Thanks Ger!

It's been a really great conference.

(And we all look forward to your talk…)