one observatory
two telescopes
three continents

SKA, yesterday, today and tomorrow

Swiss SKA days

Catherine Cesarsky, SKAO Council Chairperson

7 September 2021

SKA– Key Science Drivers: The history of the Universe

Cosmic Dawn
(First Stars and Galaxies)

Testing General Relativity
(Strong Regime, Gravitational Waves)

Galaxy Evolution
(Normal Galaxies z~2-3)

Cradle of Life
(Planets, Molecules, SETI)

Cosmology
(Dark Matter, Large Scale Structure)

Cosmic Magnetism
(Origin, Evolution)

Exploration of the Unknown

Broadest range of science of any observatory

A short history of SKA

- A 30-year journey from early concepts
- 20 years of technology exploration
- 12 years since first, tentative steps towards an IGO
- 10 years since SKA Organisation established

3.1 The objects for which the SKA Organisation is established are:

3.1.1 to carry out the Business Plan;

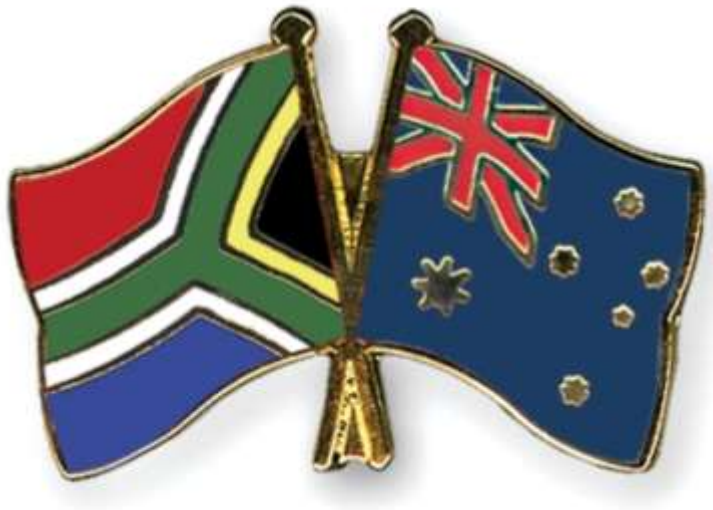
3.1.2 to select a preferred site for the SKA Facility in accordance with these Articles;

3.1.3 to develop an organisational framework for the construction and operation of the SKA Facility; and

A short history of SKA

- A 30-year journey from early concepts
- 20 years of technology exploration
- 12 years since first, tentative steps towards an IGO
- 10 years since SKA Organisation established
- 9 years since the site decision

The two sites which will host the core of the SKA Telescope are Australia and South Africa, whilst the SKA Organisation Headquarters is in the UK.



This decision (Link to PDF) to co-locate the telescopes in two sites came after careful consideration of all of the science goals, industry goals and suitability in terms of location, sustainability, local considerations and factors relating to economics and the site infrastructure.

View the members' statement on the teleconference of 14th November 2012.

View the members' statement on the meeting of 25th May 2012.

A short history of SKA

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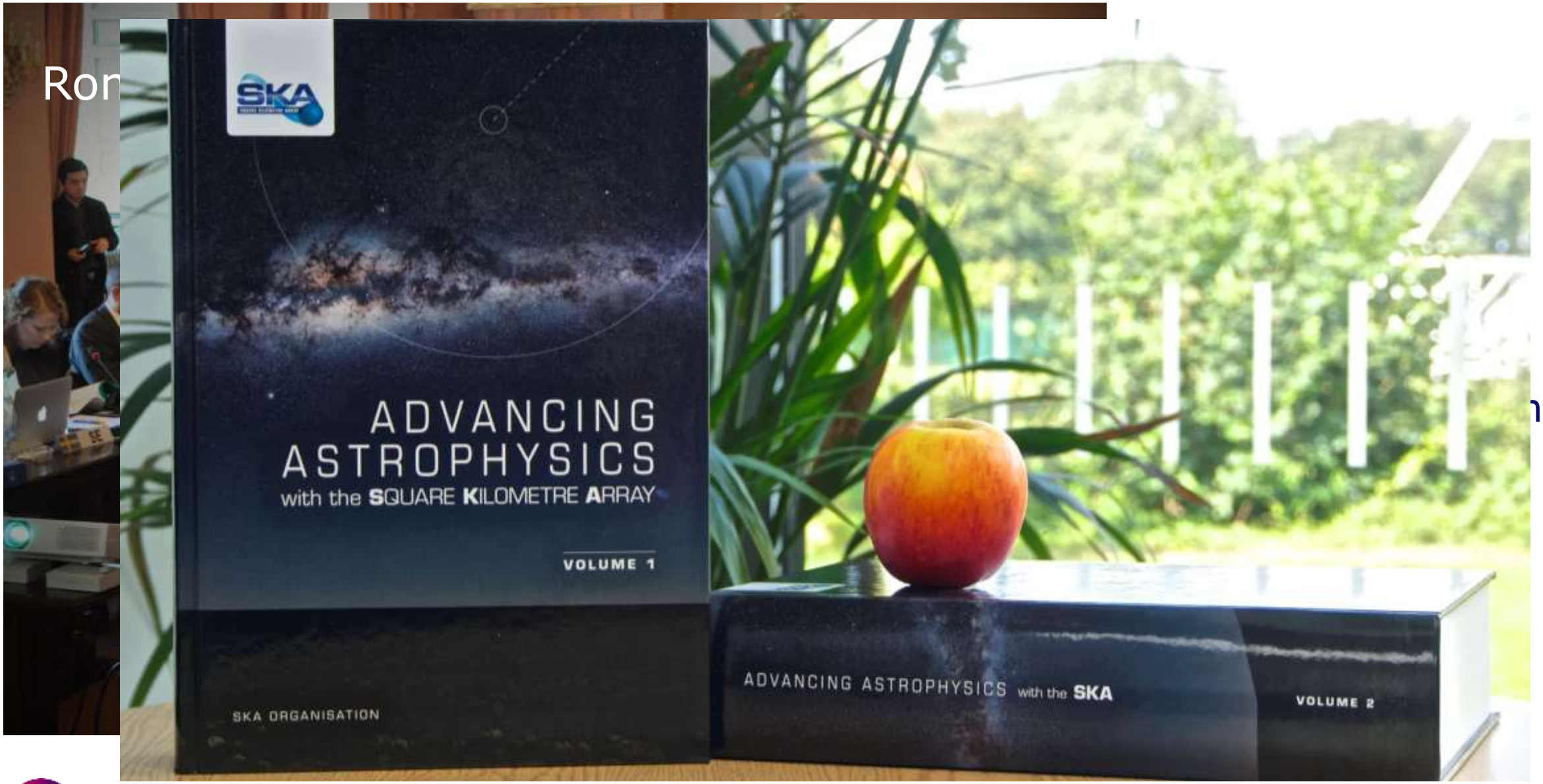
A short history of SKA



SKA Design Development; Construction & Operations

2015 - 2016 Element Preliminary Design Reviews

Consortia presented detailed proposals for assessment by an expert panel from the SKA and external organisations.

2016 System Preliminary Design Review

External experts assessed the SKA's system design, ensuring it was mature enough to enable the start of detailed design work.

2018 - 2019 Element Critical Design Reviews

The proposed design for each element was assessed against the project's tough engineering requirements.

December 2019 System Critical Design Review

An independent panel of external reviewers endorsed the SKA's overall design, including how all parts of the SKA will work and interact with one another.

Early 2020 Independent Cost Review

An independent review by consulting firm Arup concluded that the schedule and approach to construction follows logic and evidences good practice across both SKA-Low and SKA-Mid.

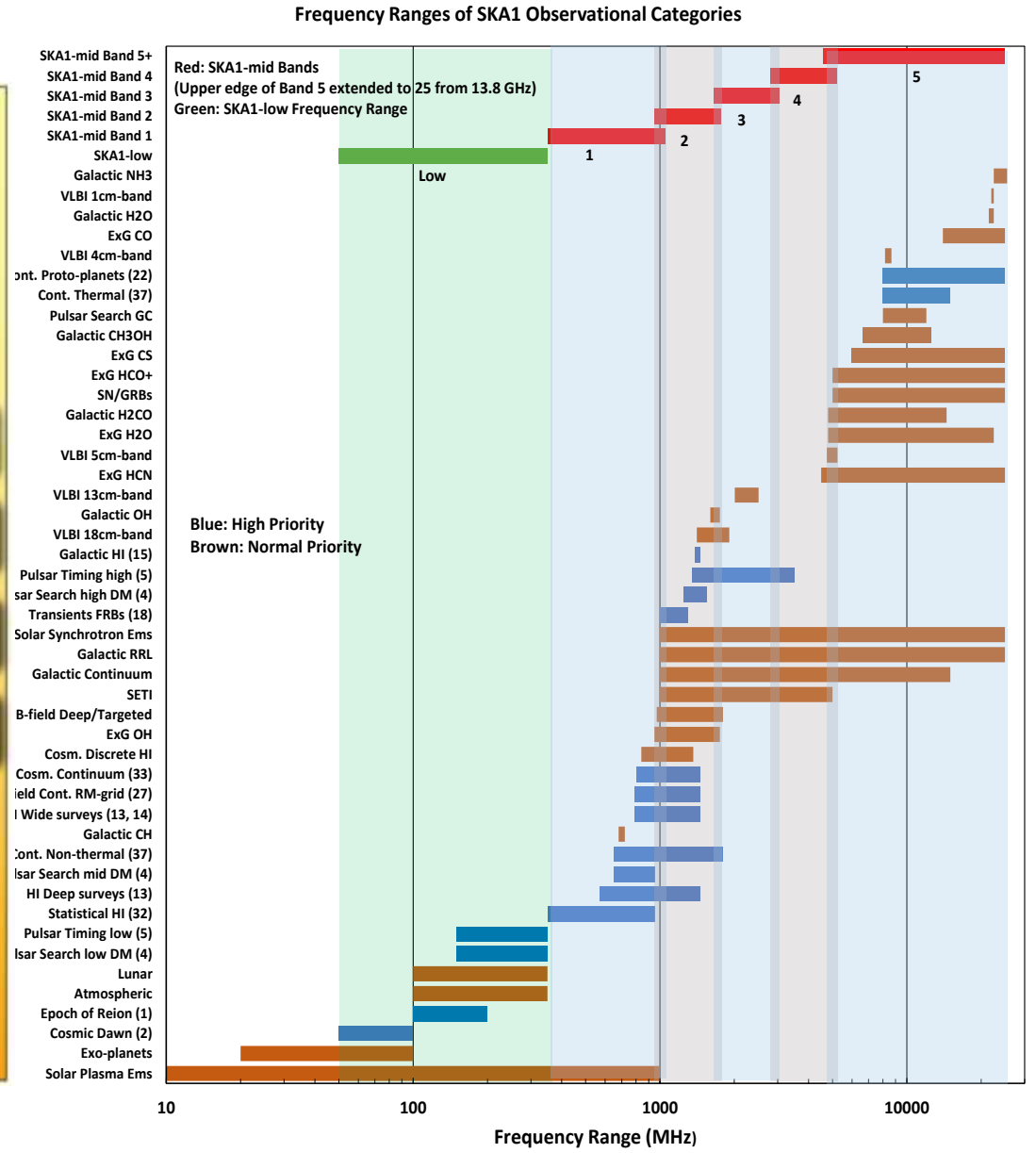
Mid 2020 Operations Reviews

Independent reviews of both the array operations and the business-enabling functions were successfully concluded in the first half of 2020.


SKA– Key Science Drivers:
The history of the Universe
Cosmic Dawn
(First Stars and Galaxies)
Testing General Relativity
(Strong Regime, Gravitational Waves)
Assembled Requirements Drive the Engineering Design
Galaxy Evolution
(Normal Galaxies z~2-3)
Cradle of Life
(Planets, Molecules, SETI)
Cosmology
(Dark Matter, Large Scale Structure)
Cosmic Magnetism
(Origin, Evolution)
Exploration of the Unknown

Science Drivers and Requirements

Cradle of Life	Cosmology and the Cosmic Dawn/EOR	Evolution of Galaxies	Strong-field tests of gravity; transient radio sky	Exploring the unknown
High Spatial, Spectral & Temporal Resolution				
Imaging, Spectral Sensitivity, Speed (Pulsar Timing)				
Polarimetry				
Broad Frequency Coverage				
IMPACT • Understand how rocky planets form • Understand the origins of life • Understand exoplanet characteristics	**IMPACT** • Understand the first 700 M years of the universe • Understand when the first stars formed	**IMPACT** • Understand how galaxies replenish their gas • Understand relationship between HI and AGN	**IMPACT** • Understand gravity in extreme environments • Understand multi-messenger astrophysics	**IMPACT** • Open new radio science windows • Provide next generation radio telescope



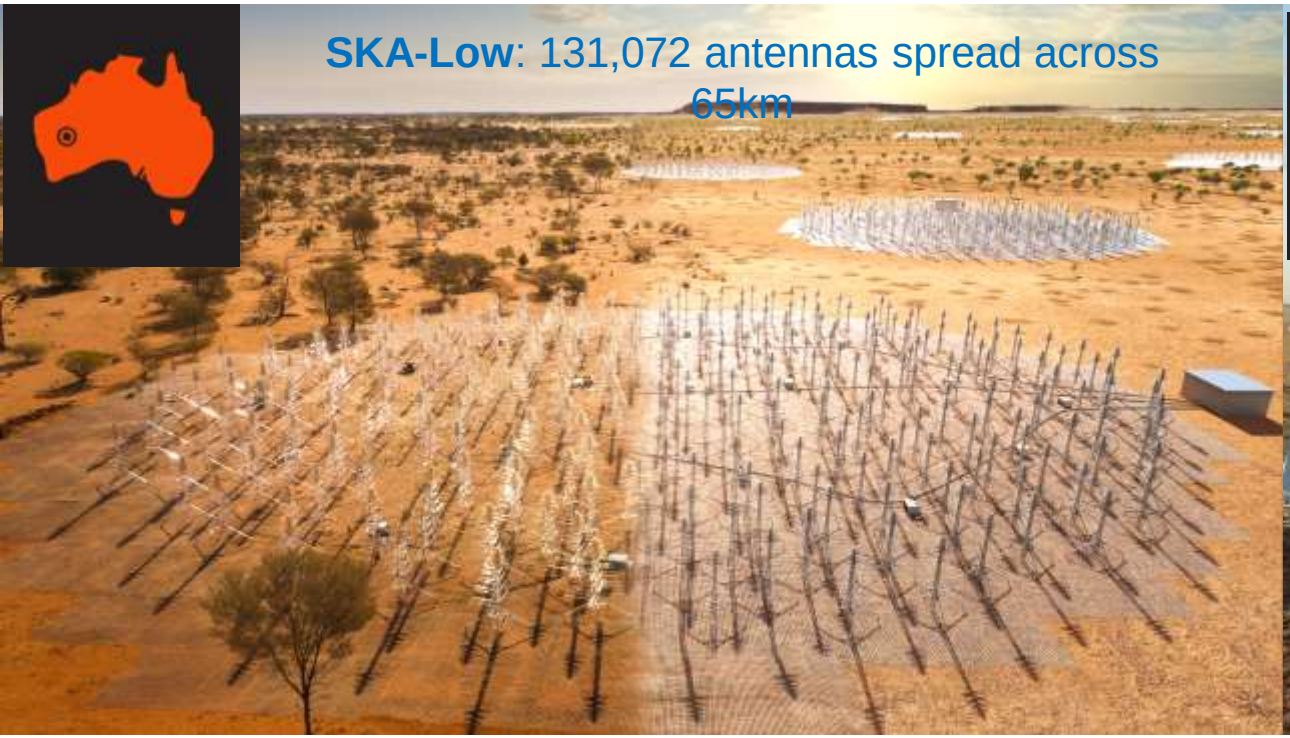
A short history of SKA

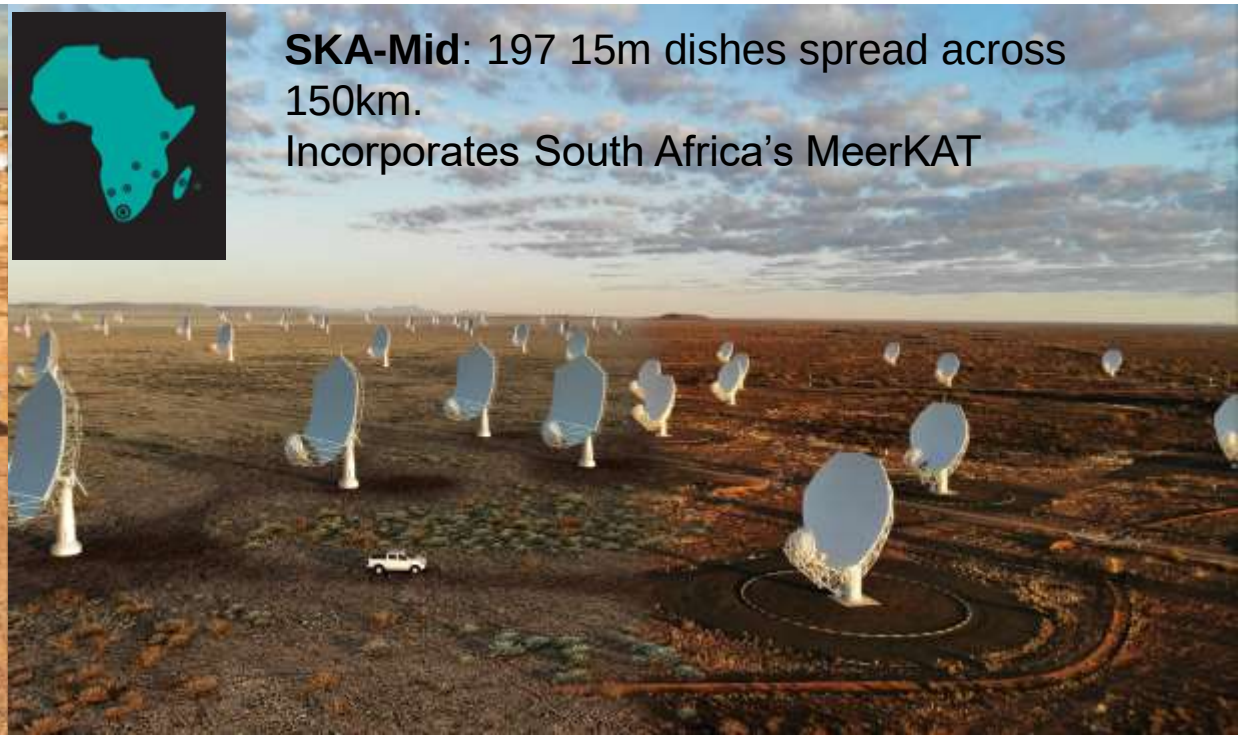
- A 30-year journey from early concepts
- 20 years of technology exploration
- 12 years since first, tentative steps towards an IGO
- 10 years since SKA Organisation established
- 9 years since the site decision
- 8 years since detailed design process began
- 6 years since IGO negotiations began in Rome, and Science Book published
- 5 years from System PDR
- 2 years from Element CDRs and signing of Convention, first ratification
- 1 year from System CDR & Operations Review
- 2020 – 2021: Ratifications, Entry into Force, SKAO born, Transition……

Birth of SKAO on February 4 2021

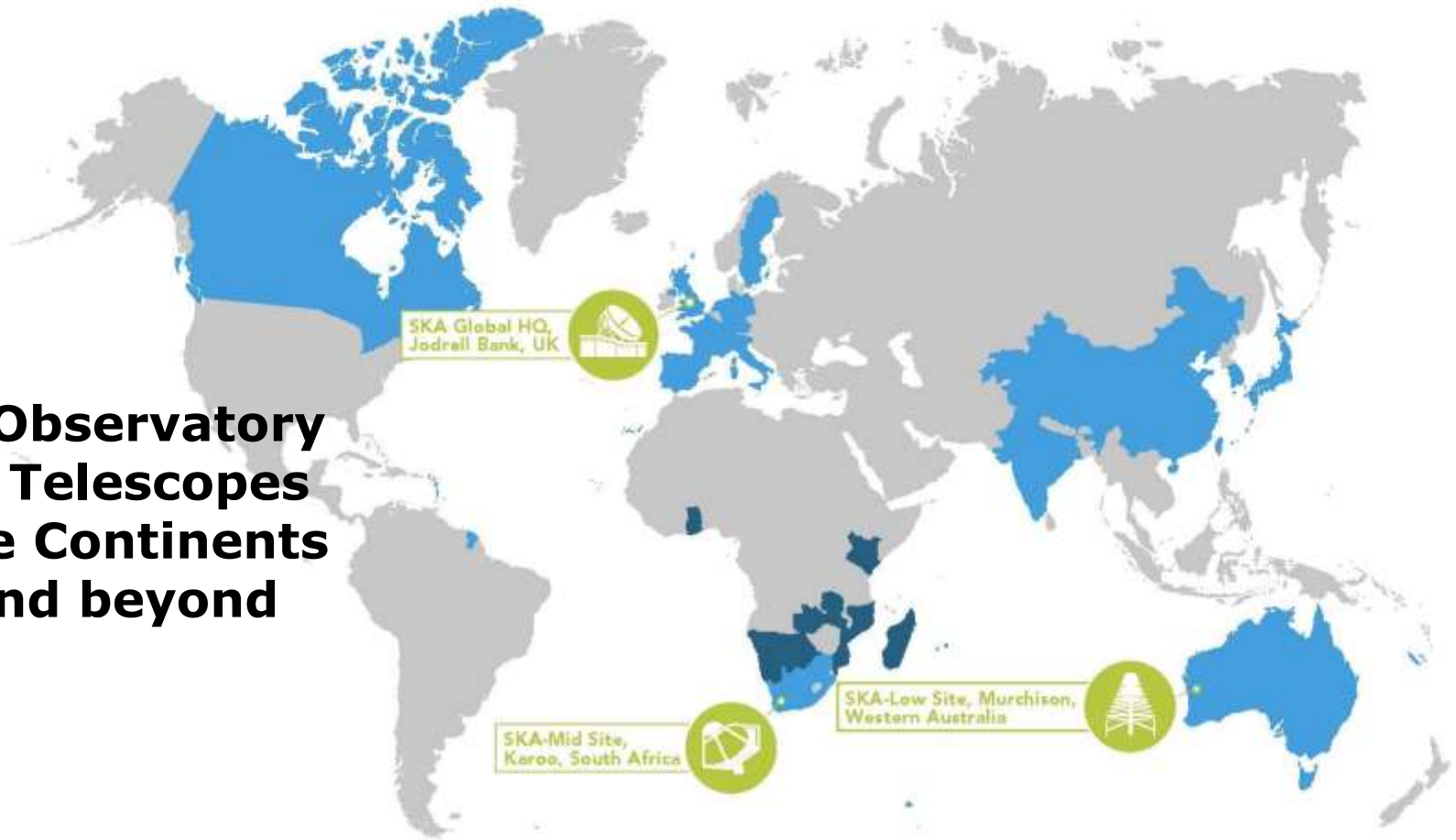
- A global collaboration of 16 countries (at present, 7 members completed ratification) which will build and operate the next-generation radio astronomy observatory
- SKA Observatory (SKAO), a new Inter-Governmental Organisation governed by a treaty, was born on 4 February 2021.
- Headquartered at Jodrell Bank (nr Manchester) in the United Kingdom
- Will be supported by a global network of SKA Regional Centres providing access to SKAO data

- 8 year construction schedule. Cost ~€2B (2020 euros) for first 10 years





One Observatory
Two Telescopes
Three Continents
…and beyond



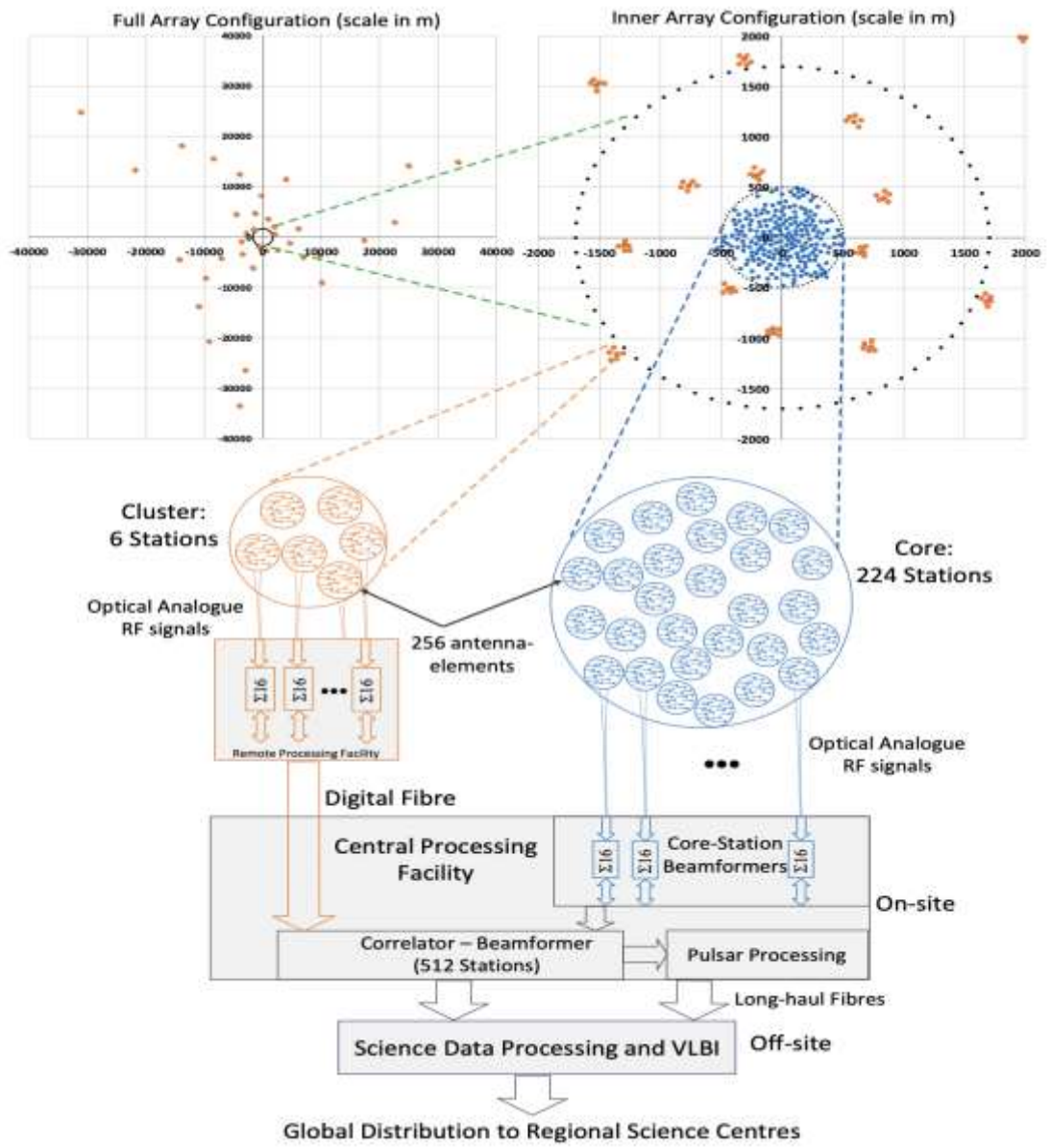
SKA Partners – includes Members of the SKA Organisation – precursor to the SKAO –, current SKAO Member States*, and SKAO Observers (as of June 2021)

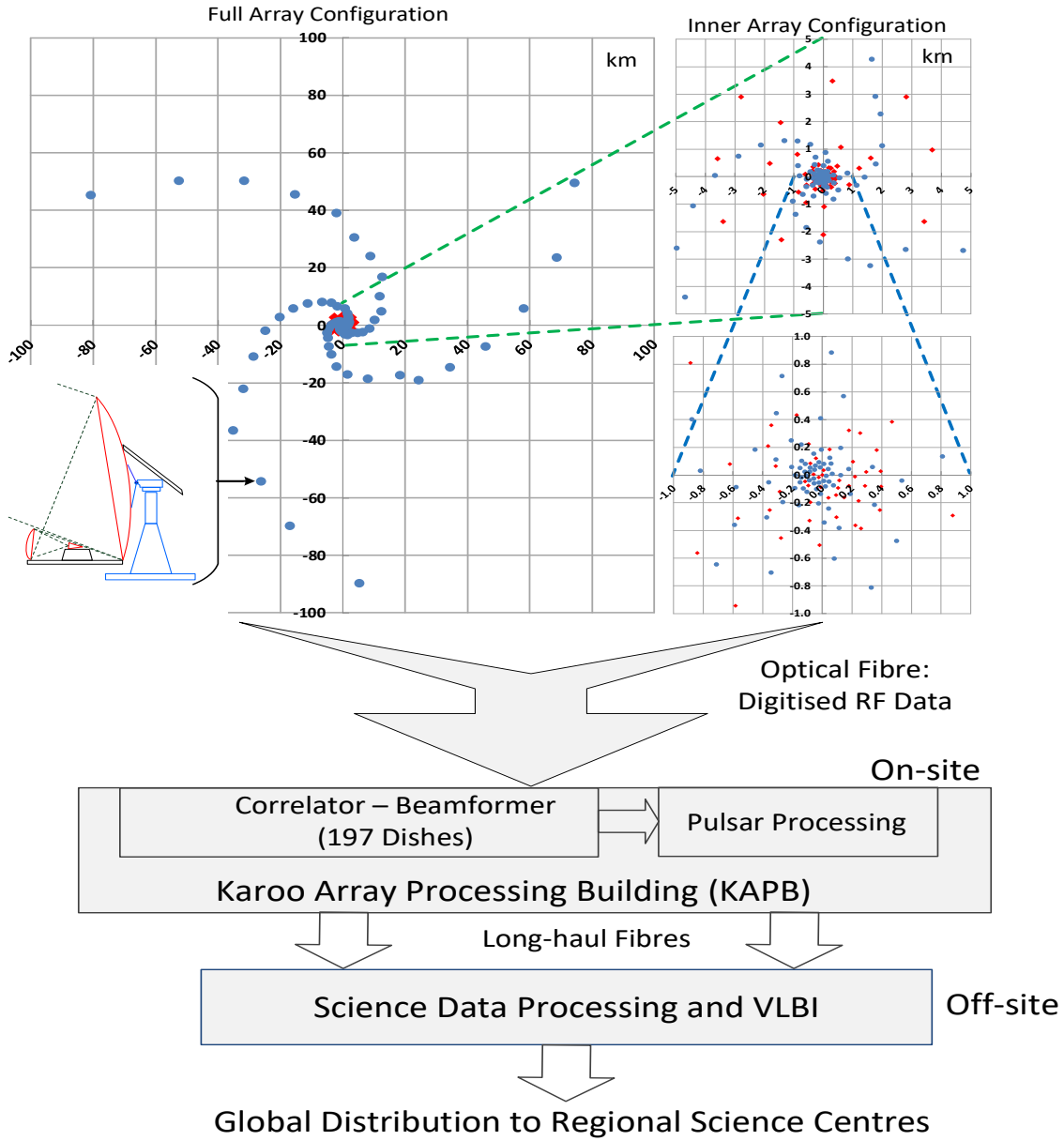
* * * * * * *

SKAO HQ: Jodrell Bank, UK

HQ of one of the world’s largest scientific facilities.
Acts as a nexus for world radio astronomy

SKA Low & Mid


Full Array Configuration (scale in m)
Inner Array Configuration (scale in m)
Cluster:
6 Stations
Optical Analogue
RF signals
256 antenna-
elements
Core:
224 Stations
Optical Analogue
RF signals
Digital Fibre
Central Processing
Facility
Core-Station
Beamformers
On-site
Correlator – Beamformer
(512 Stations)
Pulsar Processing
Long-haul Fibres
Science Data Processing and VLBI
Off-site
Global Distribution to Regional Science Centres


Full Array Configuration
km
Inner Array Configuration
km
Optical Fibre:
Digitised RF Data
On-site
Correlator – Beamformer
(197 Dishes)
Pulsar Processing
Karoo Array Processing Building (KAPB)
Long-haul Fibres
Science Data Processing and VLBI
Off-site
Global Distribution to Regional Science Centres

SKA Low & Mid Key Performance

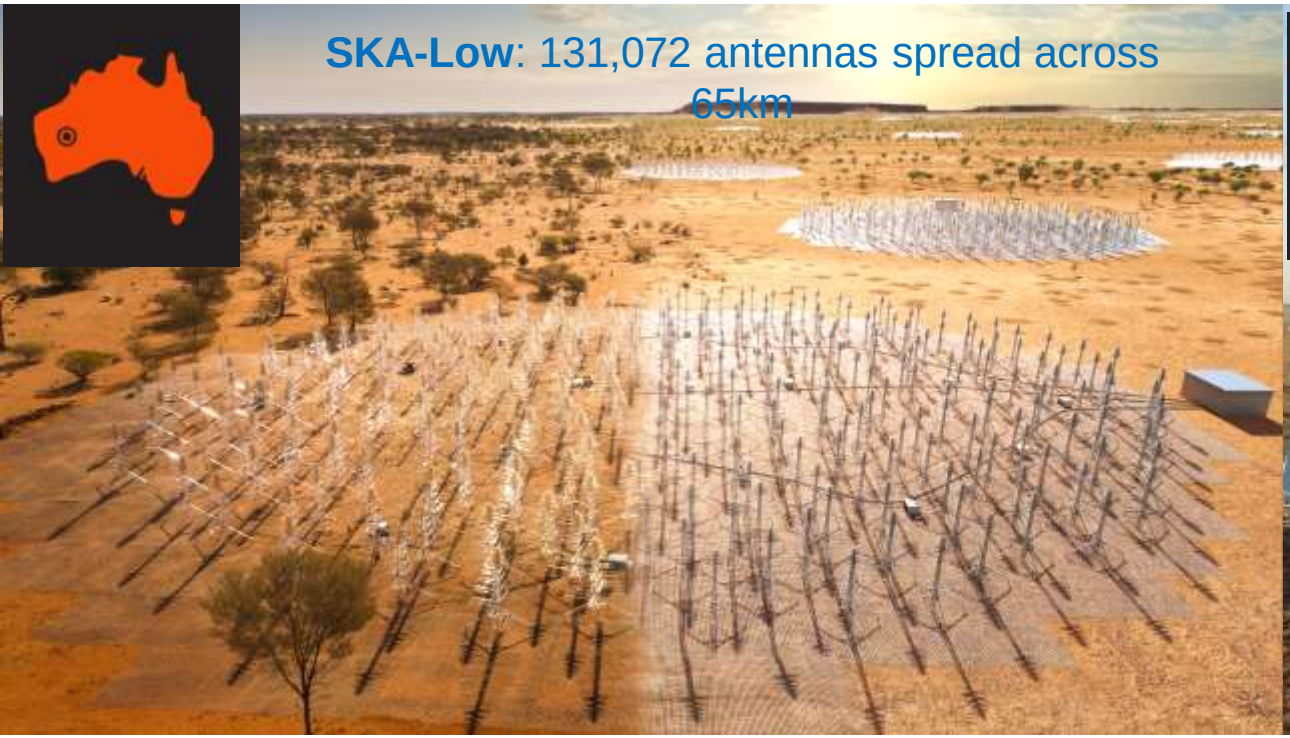
Table C-1: Selected SKA1-LOW performance parameters.		
Aperture Arrays		
Lower Frequency	50 MHz	Each antenna element covering full range
Upper Frequency	350 MHz	Dual pol'n
Number of antennas per station	256	Log-Periodic-Dipole antennas
Station Effective Diameter*	38 m	
Number of stations	512	
Total physical aperture	5.8 x 10^5 m^2	
Dense/Sparse Transition**	~94 MHz	
Array Configuration		
Core (radius <500 m)	224 stations	See Figure
Inner (radius <1700 m)	278 stations	〃
Spiral Arms	234 stations	〃
Station Beam Forming		
Number of beams***	1 – 384	Each with dual polarisation.
Max. bandwidth per beam	300 MHz	Each polarisation.
Max. no. of antennas per beam	256	
Signal Processing System		
Max. no. frequency channels	55296	
Standard Frequency Resolution	5.4 kHz	300 MHz/55296 = 5.4 kHz
Max. Frequency Resolution	226 Hz	Zoom mode
Complex Correlations****	2.9 x 10^{10}	(512·513/2) baselines x (1) beams x 4 pol'n prod's x 55296 chans
Integration Time	0.9 s	Reduceable to 0.3 s for a limited number of sub-stations
Array Beam Former		
Full beamformer	512 stations	
Within 20-km Array Diameter	404 stations	
Maximum number of beams		
Pulsar Search	500	Independently steerable; 2 pol'n
Pulsar Timing	16	〃
VLBI	4	〃
Max. Total Bandwidth		
Pulsar Search	118 MHz	Per beam; 2 pol'n
Pulsar Timing	300	〃
VLBI	300	〃

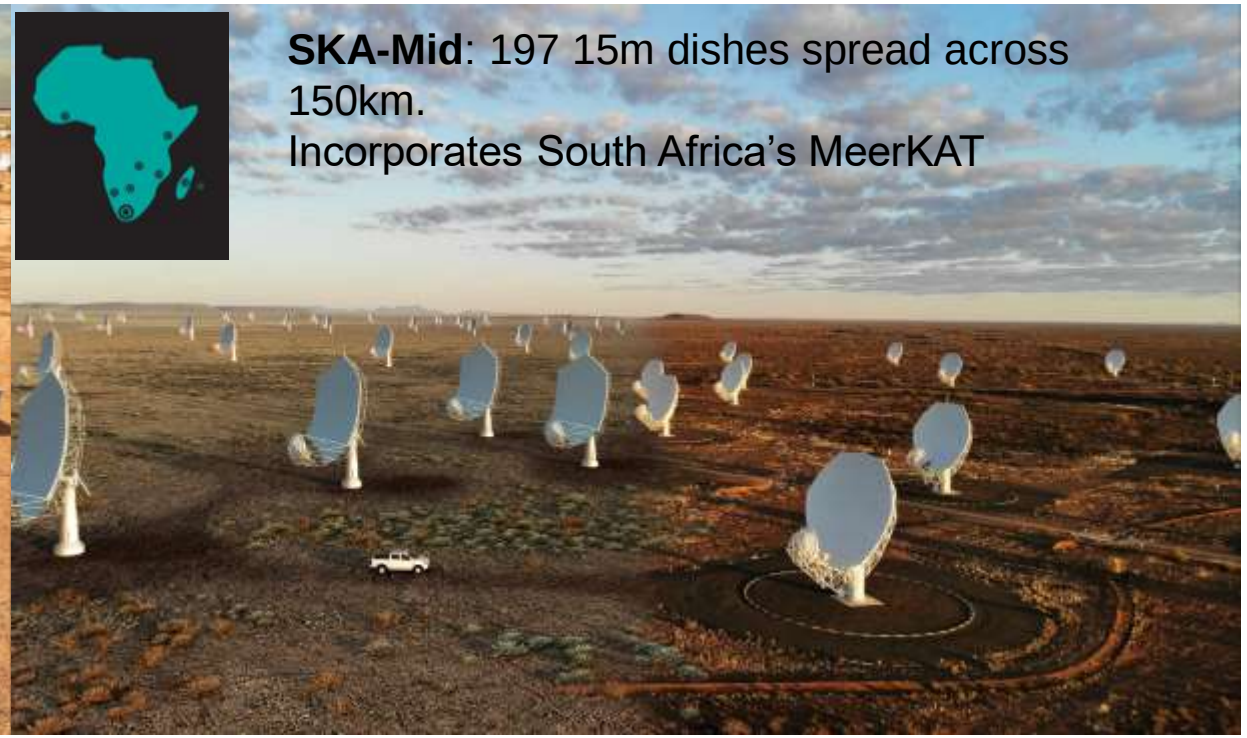
Table B-1: Selected SKA1-MID performance parameters[53]		
Aperture	m^2	133 x 15-m (equiv. dia.) offset Gregorian reflectors Plus 64 x 13.5-m (equiv. dia.) offset Gregorian reflectors
Total physical aperture	33306	
Total Available aperture	31641	Availability 95%
Minimum Elevation Angle	15 deg	All Azimuths – 270° wrap
Array Configuration	Antenna	Filling factor %
radius <~400 m	80 (41%)	2.67
~400 m < radius < ~1000 m	35 (18%)	0.22
~1000 m < radius < 2500 m	23 (12%)	0.023
~2500 m < radius < 4000 m	13 (6.6%)	7.04E-03
~4000 m < radius < 10000 m	13(6.6%)	8.53E-04
10000 m < radius < 30000 m	15 (7.6%)	1.05E-04
~30000 m < radius < 100000 m	18 (9.1%)	1.11E-05
Antenna RF System		
Frequency Range	GHz	
Band 1 (high) + UHF Band	0.58 – 1.015	Dual pol'n. Shared Frequency Range
Band 2 + L-band	0.95 – 1.67	〃
Band 3 Note 1	1.65 – 3.05	Dual pol'n. SKA antennas only
Band 4 Note 1	2.80 – 5.18	〃
Band 5a	4.60 – 8.50	〃
Band 5b	8.30 – 15.4	〃
Band 5c Note 1	15.0 – 26	〃
Continuum Sensitivity		
SEFD (available antennas, Stokes I)	Jy	Equivalent A_e/T_{sys} (m^2/K)
Band 1 (high) + UHF Band	2.85	967
Band 2 + L-band	1.55	1784
Band 3	2.50	1102
Band 4	3.49	792
Band 5a	2.38	1161 (Max. Sampled Bandwidth 2 x 2.5 GHz)
Band 5b	2.77	998 (Max. Sampled Bandwidth 2 x 2.5 GHz)
Min. detectable flux (rms) (ΔS_{min})	$\mu Jy\ s^{-1/2}$	
Band 1 (high) + UHF Band	99.8	Average over RF bands
Band 2 + L-band	42.1	〃
Band 3	48.9	〃
Band 4	53.1	〃
Band 5a	25.3	〃
Band 5b	29.4	〃
Signal Processing System		
Correlator		
Freq. chans (widest sampled BW)	65536	
Full Bandwidth Velocity Resolution	$km\text{-}s^{-1}$	
Band 1 (high) + UHF Band	~5	Non-Zoom, all available frequency channels
Band 2 + L-band	~5	〃
Max. Frequency Resolution	0.21 kHz	$13.440 \cdot 2^{-n}$ $n \in (0,..,6)$ kHz in Zoom mode
Standard Frequency Resolution	13.44 kHz	220.200960 / 16384
Complex Correlations	5.1 x 10^9	(197^2/2) baselines x 4 pol'n prod's x 65536 chans
Minimum Integration Time	0.14 s	Interface Control Document
Transient Capture Buffer Size	72 – 288 s	For 330 MHz BW, scaling with 2-8 bits sample width
Pulsar Search Array Beam Former		
Full beamformer	197 antennas	Any Front-end band.
No. Antennas in 20 km array diameter	164	Typical Beam-forming Sub-array

Start of SKA construction on July 1 2021

- A global collaboration of 16 countries which will build and operate the next-generation radio astronomy observatory
- SKA Observatory (SKAO), an Inter-Governmental Organisation governed by a treaty.
- One telescope in Australia, one telescope in South Africa
- Headquartered at Jodrell Bank (nr Manchester) in the United Kingdom
- Will be supported by a global network of SKA Regional Centres providing access to SKAO data

- 8 year construction schedule. Cost ~€2B (2020 euros) for first 10 years





SKA1 Low Roll-out Plan

	SKA-Low	SKA-Mid
Start of construction (T0)	1ST JULY **2021**	1ST JULY **2021**
Earliest start of major contracts (C0)	AUGUST **2021**	AUGUST **2021**
Array Assembly 0.5 finish (AA0.5) SKA-Low = 6-station array SKA-Mid = 4-dish array	FEBRUARY **2024**	MARCH **2024**
Array Assembly 1 finish (AA1) SKA-Low = 18-station array SKA-Mid = 8-dish array	FEBRUARY **2025**	FEBRUARY **2025**
Array Assembly 2 finish (AA2) SKA-Low = 64-station array SKA-Mid = 64-dish array, baselines mostly <20km	FEBRUARY **2026**	DECEMBER **2025**
Array Assembly 3 finish (AA3) SKA-Low = 256-station array, including long baselines SKA-Mid = 133-dish array, including long baselines	JANUARY **2027**	SEPTEMBER **2026**
Array Assembly 4 finish (AA4) SKA-Low = full Low array SKA-Mid = full Mid array, including MeerKAT dishes	NOVEMBER **2027**	JUNE **2027**
Operations Readiness Review (ORR)	JANUARY **2028**	DECEMBER **2027**
End of construction	JULY **2029**	JULY **2029**

	# Stations	Imaging	Pulsar Timing	Pulsar Search	Dynamic Spectrum	Transient Capture	VLBI
AA0.5	6	✓ • Basic Continuum and Spectral Line imaging • Standard Channelization • 75 MHz bandwidth					
AA1	18	✓ • Basic Continuum and Spectral Line imaging • Standard Channelization 75 MHz bandwidth					
AA2	64	✓ • Basic Continuum and Spectral Line imaging • Standard Channelization • 0.9 and 1.8KHz zooms • 75 MHz bandwidth	✓ • 4 beams		✓ • Supported by PST		
AA3	256	✓ • Basic Continuum and Spectral Line imaging • Standard Channelization • 0.2, 0.45, 0.9, 1.8KHz zooms • 150 MHz bandwidth	✓ • 8 beams	✓ • 125 beams • Pulsar de-dispersion and acceleration processing	✓ • Supported by PST	✓ • Transient response and commensal observing	
AA4	512	✓ • Basic Continuum and Spectral Line imaging • Standard Channelization • All zooms • 300 MHz bandwidth	✓ • 16 beams	✓ • 500 beams • Pulsar de-dispersion and acceleration processing	✓ • Supported by PST	✓ • Transient response and commensal observing	✓ • Full capabilities

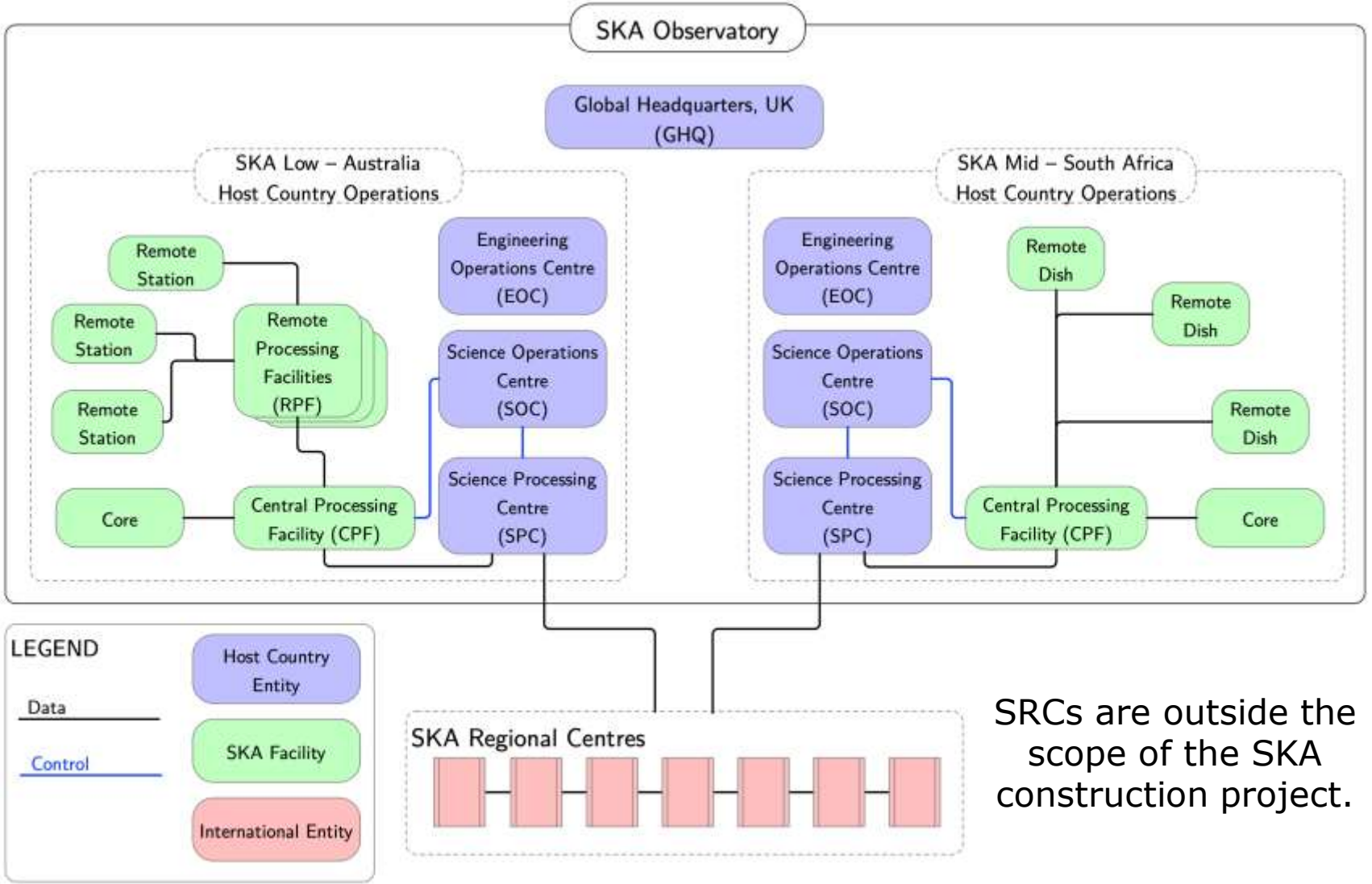
SKA Mid Roll-out Plan

	SKA-Low	SKA-Mid
Start of construction (T0)	1ST JULY **2021**	1ST JULY **2021**
Earliest start of major contracts (C0)	AUGUST **2021**	AUGUST **2021**
Array Assembly 0.5 finish (AA0.5) SKA-Low = 6-station array SKA-Mid = 4-dish array	FEBRUARY **2024**	MARCH **2024**
Array Assembly 1 finish (AA1) SKA-Low = 18-station array SKA-Mid = 8-dish array	FEBRUARY **2025**	FEBRUARY **2025**
Array Assembly 2 finish (AA2) SKA-Low = 64-station array SKA-Mid = 64-dish array, baselines mostly <20km	FEBRUARY **2026**	DECEMBER **2025**
Array Assembly 3 finish (AA3) SKA-Low = 256-station array, including long baselines SKA-Mid = 133-dish array, including long baselines	JANUARY **2027**	SEPTEMBER **2026**
Array Assembly 4 finish (AA4) SKA-Low = full Low array SKA-Mid = full Mid array, including MeerKAT dishes	NOVEMBER **2027**	JUNE **2027**
Operations Readiness Review (ORR)	JANUARY **2028**	DECEMBER **2027**
End of construction	JULY **2029**	JULY **2029**

	# Dishes	Frequency Bands	Imaging	Pulsar Timing	Dynamic Spectrum	Pulsar Search	Transient Capture	VLBI
AA0.5	4	Band 1 Band 2 Band 5: goal on 4 Dishes, but may not be supported by correlator	✓ • Basic Continuum and Spectral Line imaging • Using CASA • 16k channels • 800 MHz bandwidth					
AA1	8	Band 1 Band 2 Band 5: on 2 Dishes, goal on 4	✓ • Basic Continuum and Spectral Line imaging • Using CASA • 16k channels • 800 MHz bandwidth	✓ • Basic • 1 boresight non-steerable beam • 400 MHz bandwidth				
AA2	64	Band 1 Band 2 Band 5: on 32 Dishes	✓ • Basic Continuum and Spectral Line imaging • Using CASA • 16k channels • 800 MHz bandwidth	✓ • 6 steerable beams • With de-dispersion • 800 MHz bandwidth		✓ • 16 steerable beams • Not fully pipelined • Non-real time operation • Full bandwidth		
AA3	121 Includes 8 MeerKAT Dishes	Band 1 Band 2 Band 5: on 64 Dishes	✓ • Continuum and Spectral Line imaging pipelines • 64k channels • Zoom mode • 5200 MHz bandwidth	✓ • 16 steerable beams • With de-dispersion • Full bandwidth	? • Maybe	✓ • 128 steerable beams • Not fully pipelined • Non-real time operation • Full bandwidth	? • Maybe	
AA4	197 Includes all MeerKAT Dishes	Band 1 Band 2 Band 5	✓ • Full Continuum and Spectral Line imaging pipelines • 64k channels • Zoom mode • Full bandwidth	✓ • 16 steerable beams • With de-dispersion • Full bandwidth	✓ • Supported by PST	✓ • 1500 steerable beams • Fully pipelined • Real time operation • Full bandwidth	✓	✓ • 4 beams

✓ Functionality is partially implemented
✓ Functionality is fully implemented
? Not sure if functionality will be implemented

Operations: Functional Structure



SRCs are outside the scope of the SKA construction project.

Two Telescopes

Sarah Pearce
SKA Low Telescope Director

Lindsay Magnus
SKA Mid Telescope Director

One Observatory

- Single coordinated cycle of Calls for Proposals
- Proposals to use SKA-Low, SKA-Mid, or both
- Unified “SKA Science Programme”

- SKAO Data Products delivered to SKA users (public after the proprietary period)

- Users will interact with SKAO (not with SKA-Low or SKA-Mid)

SKA Regional Centre (SRC) Network

- SKA Members are expected to pool the resources necessary to exploit the data products provided by the Observatory
- SKA users will interact with the “SKA Science Archive” hosted by this SRC Network
- The SRCs will provide resources for further processing and analysis
- SRC resource requirements will be considered when building the science programme
- The SKA Science Archive will host both the primary SKAO data products and the “advanced data products” generated by the science community
- The Archive, associated tools and processing systems will be a valuable resource for a much broader range of users than those applying for observing time

SKA Access Policy

- Tier 2 document, Council Approved
- Single proposal submission, assessment & ranking process
  - Scientific merit and technical feasibility
- Key Science Projects
  - Significant observing time over more than one cycle
- PI Projects
  - Competitive allocation, not KSP
- Director’s Discretionary Time
- Fractions TBD by Council

Why am I excited about SKA science?
Radio range: Complementary or unique information on a wide range of astrophysical phenomena , e. g.

- H0 controversy: SKA can measure masers at various z
- Dark matter, dark energy: useful complement to LSST, EUCLID, baryon acoustic oscillations and weak lensing
- The history of HI, from EoR to the replenishment of galaxies and clusters at later times
- Measurements of magnetic field strength and direction at small, medium and large scales

Thank you

SKAO

The SKA Observatory (SKAO) recognises and acknowledges the indigenous peoples and cultures that have traditionally lived on the lands on which the SKAO facilities are located

www.skao.int