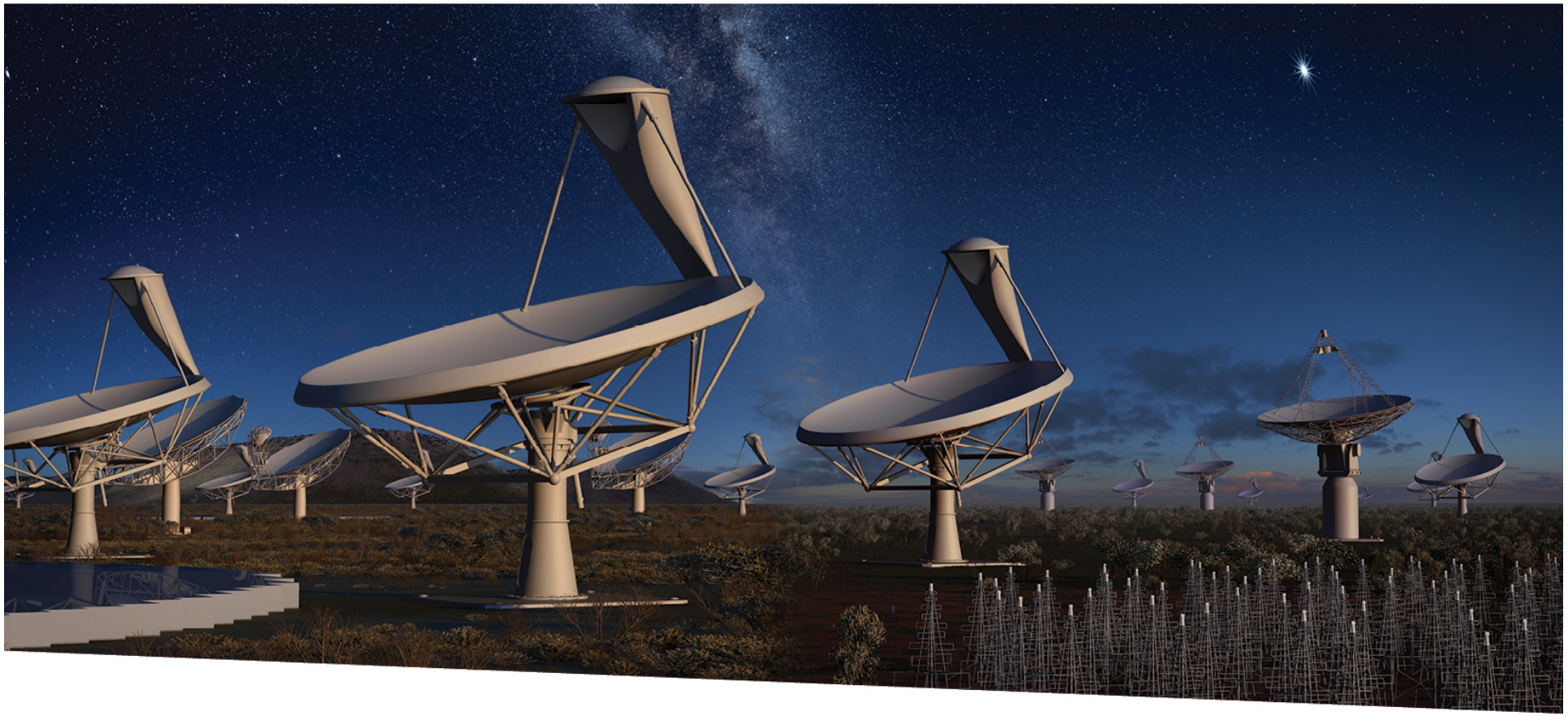
SKA Status and Continuum Surveys



SQUARE KILOMETRE ARRAY

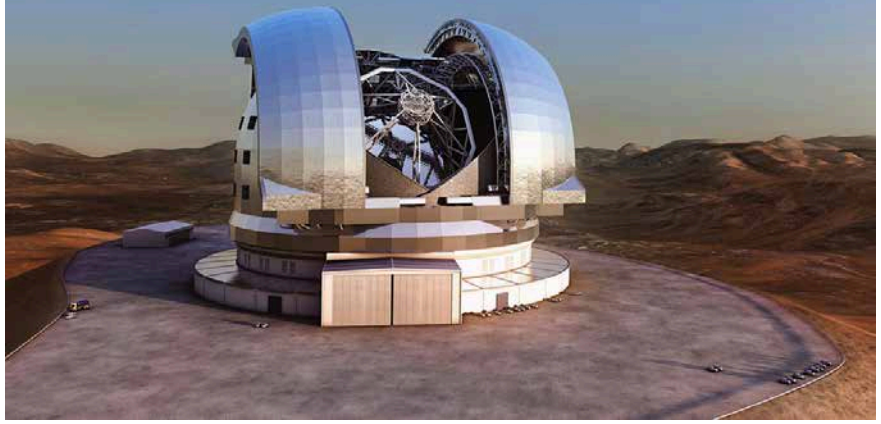
Exploring the Universe with the world's largest radio telescope

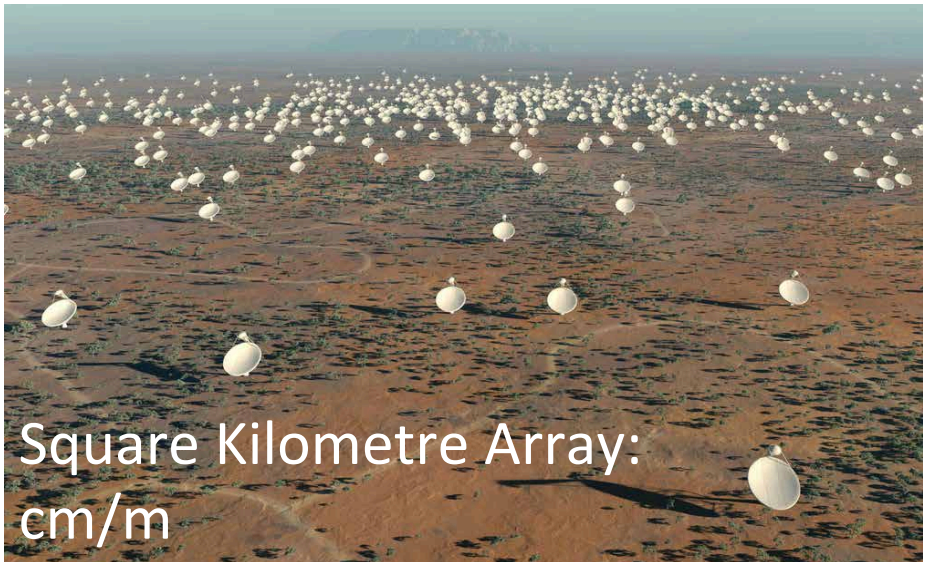
Robert Braun, Science Director

21 October 2015

Great Observatories for the coming decades

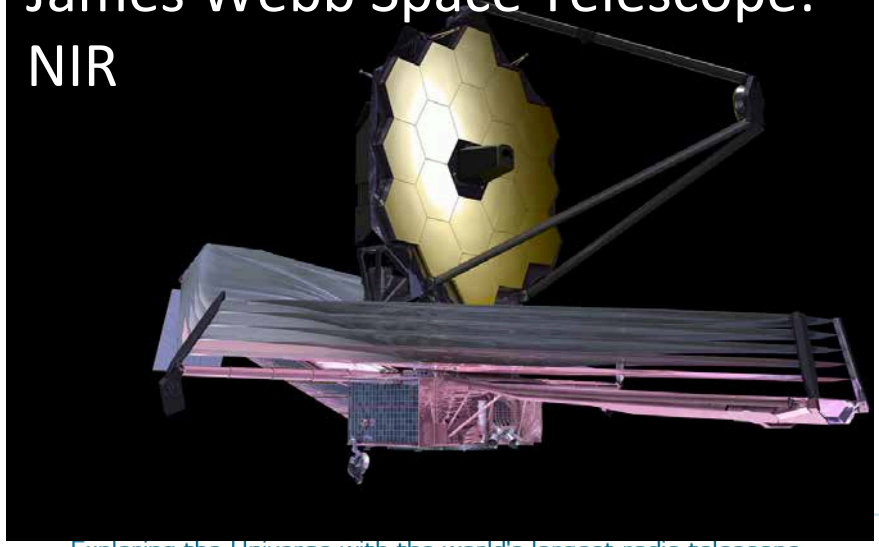
E-ELT/TMT/GMT: optical/IR





Square Kilometre Array: cm/m

James Webb Space Telescope: NIR



Atacama Large Millimetre Array (ALMA): mm/submm

SKA Science

- SKA: will be one of the great physics machines of 21st Century and, when complete, one of the world's engineering marvels.
- Science goals:
  - Fundamental physics: Gravity, Dark Energy, Cosmic Magnetism
  - Astrophysics: Cosmic Dawn, First galaxies, galaxy assembly and evolution; proto-planetary discs, biomolecules, SETI + much more
  - The unknown: transients; +…????

Advancing Astrophysics

with the Square Kilometre Array

9-13 June 2014, Giardini Naxos, Italy

#skascicon14

2014 marks 10 years since the publication of the comprehensive **'Science with the Square Kilometre Array'** book and 15 years since the first such volume appeared in 1999. In that time numerous and unexpected advances have been made in the fields of astronomy and physics relevant to the capabilities of the Square Kilometre Array (SKA). This meeting will facilitate the publication of a new, updated science book, which will be relevant to the current astrophysical context.

Scientific Organising Committee

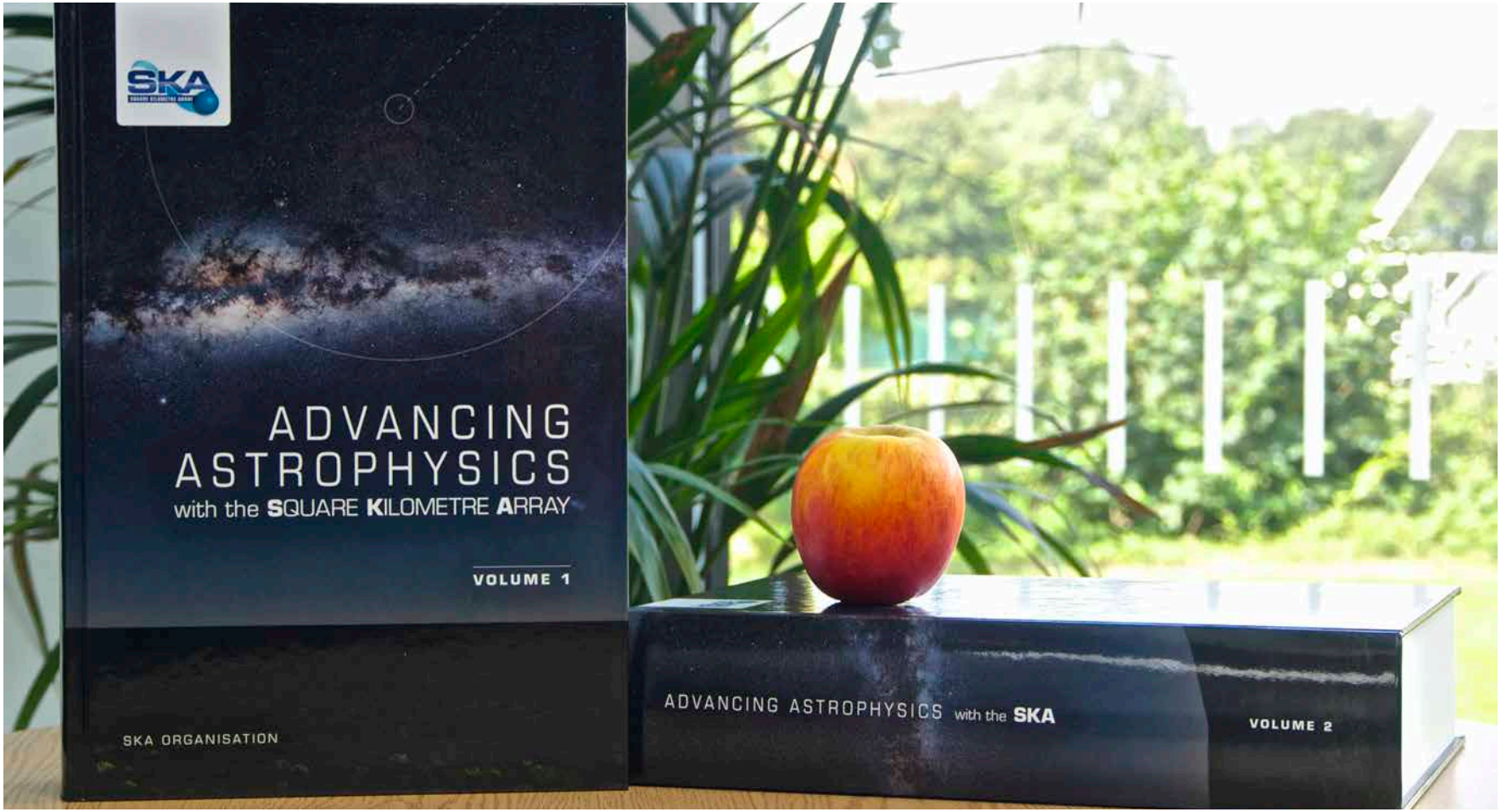
Robert Braun (SKAO) – co-Chair
Grazia Umana (INAF-OACt) – co-Chair
Tyler Bourke (SKAO)
Rob Fender (Oxford)
Federica Govoni (INAF–OA Cagliari)
Jimi Green (SKAO)
Melvin Hoare (Leeds)
Melanie Johnston-Hollitt (Victoria Univ. Wellington)
Leon Koopmans (Kapteyn Astronomical Institute)
Michael Kramer (MPIfR)
Roy Maartens (Univ. Western Cape)
Tom Oosterloo (ASTRON)
Isabella Prandoni (INAF–IRA)
Nicholas Seymour (CASS)
Ben Stappers (Manchester)
Lister Staveley-Smith (ICRAR)
Wen Wu Tian (NAOC)
Jeff Wagg (SKAO)

Enquiries: ska-june14@skatelescope.org
or visit: indico.skatelescope.org/event/AdvancingAstrophysics2014

SKA Science Book:

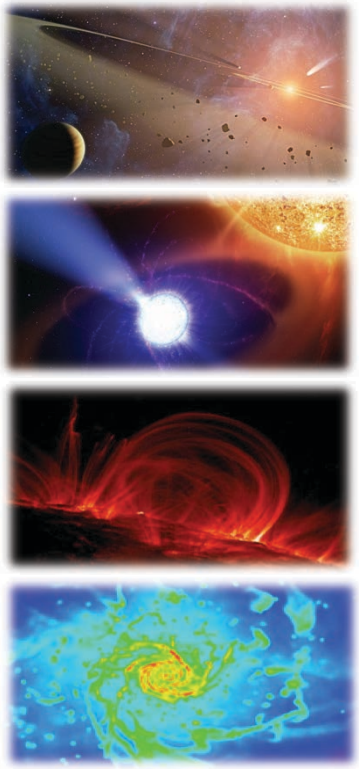
- Meeting Program based on advanced Chapter drafts
- 135 self-contained chapters with 1200 contributors
- Published electronically in PoS May 2015
- Printed Book ~2000 pages, in 2 volumes now out
  - Weighs in at 8.8 kg!

SKA Science Book 2015



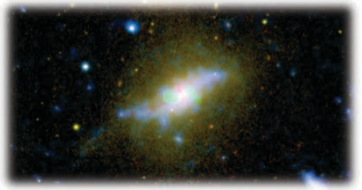
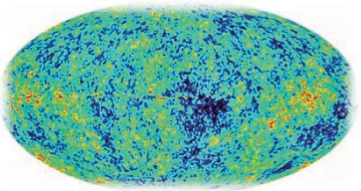
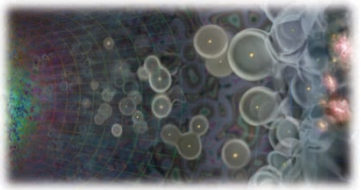
Headline Science with SKA1 and SKA2

	SKA1	SKA2
The Cradle of Life & Astrobiology	Proto-planetary disks; imaging inside the snow/ice line (@ < 100pc), Searches for amino acids.	Proto-planetary disks; sub-AU imaging (@ < 150 pc), Studies of amino acids.
	Targeted SETI: airport radar 10^4 nearby stars.	Ultra-sensitive SETI: airport radar 10^5 nearby star, TV ~10 stars.
Strong-field Tests of Gravity with Pulsars and Black Holes	1st detection of nHz-stochastic gravitational wave background.	Gravitational wave astronomy of discrete sources: constraining galaxy evolution, cosmological GWs and cosmic strings.
	Discover and use NS-NS and PSR-BH binaries to provide the best tests of gravity theories and General Relativity.	Find all ~40,000 visible pulsars in the Galaxy, use the most relativistic systems to test cosmic censorship and the no-hair theorem.
The Origin and Evolution of Cosmic Magnetism	The role of magnetism from sub-galactic to Cosmic Web scales, the RM-grid @ 300/deg2.	The origin and amplification of cosmic magnetic fields, the RM-grid @ 5000/deg2.
	Faraday tomography of extended sources, 100pc resolution at 14Mpc, 1 kpc @ z ≈ 0.04.	Faraday tomography of extended sources, 100pc resolution at 50Mpc, 1 kpc @ z ≈ 0.13.
Galaxy Evolution probed by Neutral Hydrogen	Gas properties of 10^7 galaxies, <z> ≈ 0.3, evolution to z ≈ 1, BAO complement to Euclid.	Gas properties of 10^9 galaxies, <z> ≈ 1, evolution to z ≈ 5, world-class precision cosmology.
	Detailed interstellar medium of nearby galaxies (3 Mpc) at 50pc resolution, diffuse IGM down to N_H < 10^17 at 1 kpc.	Detailed interstellar medium of nearby galaxies (10 Mpc) at 50pc resolution, diffuse IGM down to N_H < 10^17 at 1 kpc.



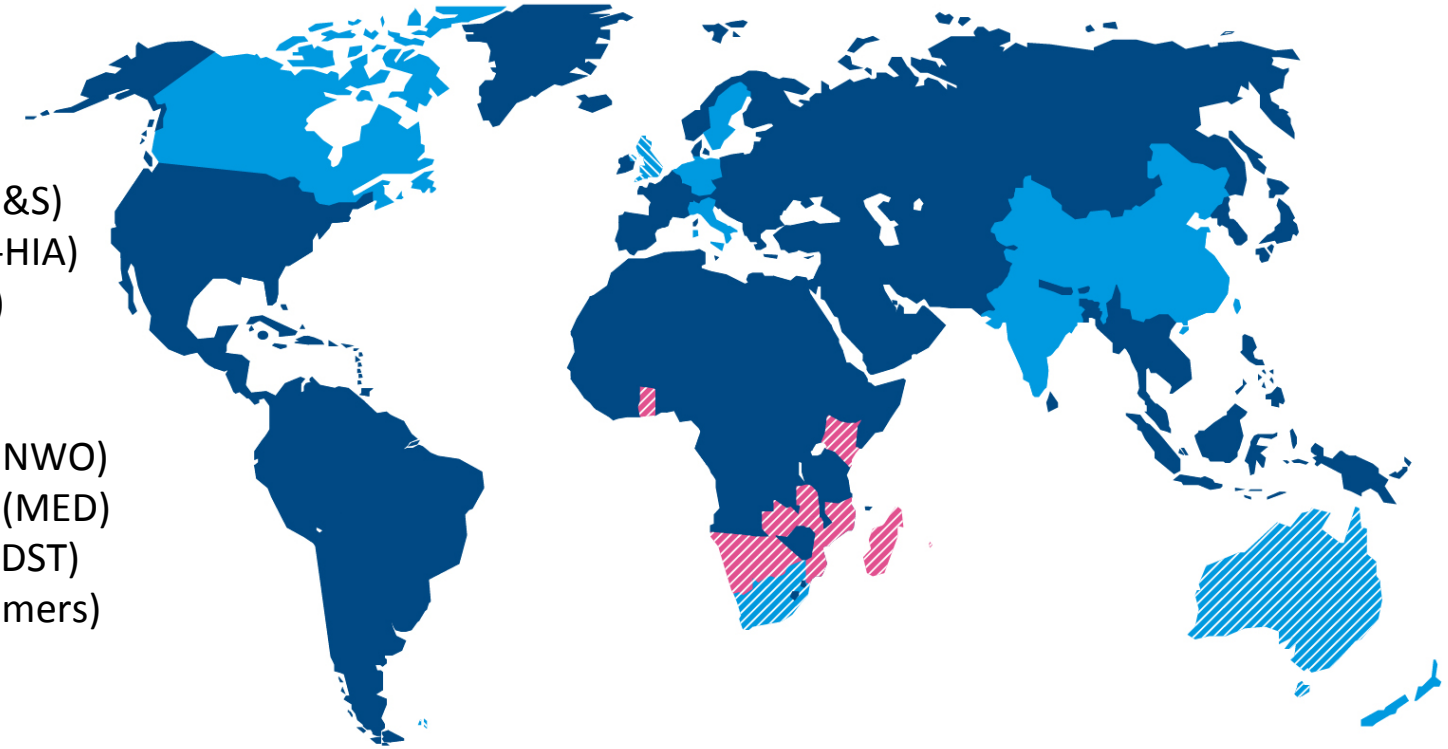
Headline Science with SKA1 and SKA2

	SKA1	SKA2
The Transient Radio Sky	Use fast radio bursts to uncover the missing "normal" matter in the universe.	Fast radio bursts as unique probes of fundamental cosmological parameters and intergalactic magnetic fields.
	Study feedback from the most energetic cosmic explosions and the disruption of stars by super-massive black holes.	Exploring the unknown: new exotic astrophysical phenomena in discovery phase space.
Galaxy Evolution probed in the Radio Continuum	Star formation rates (10 M_Sun/yr to z ~ 4).	Star formation rates (10 M_Sun/yr to z ~ 10).
	Resolved star formation astrophysics (sub-kpc active regions at z ~ 1).	Resolved star formation astrophysics (sub-kpc active regions at z ~ 6).
Cosmology & Dark Energy	Constraints on DE, modified gravity, the distribution & evolution of matter on super-horizon scales: competitive to Euclid.	Constraints on DE, modified gravity, the distribution & evolution of matter on super-horizon scales: redefines state-of-art.
	Primordial non-Gaussianity and the matter dipole: 2x Euclid.	Primordial non-Gaussianity and the matter dipole: 10x Euclid.
Cosmic Dawn and the Epoch of Reionization	Direct imaging of EoR structures (z = 6 - 12).	Direct imaging of Cosmic Dawn structures (z = 12 - 30).
	Power spectra of Cosmic Dawn down to arcmin scales, possible imaging at 10 arcmin.	First glimpse of the Dark Ages (z > 30).

SKA Organisation: 10 countries, more to join

Australia (DoI&S)
Canada (NRC-HIA)
China (MOST)
India (DAE)
Italy (INAF)
Netherlands (NWO)
New Zealand (MED)
South Africa (DST)
Sweden (Chalmers)
UK (STFC)



Full members

SKA Headquarters host country

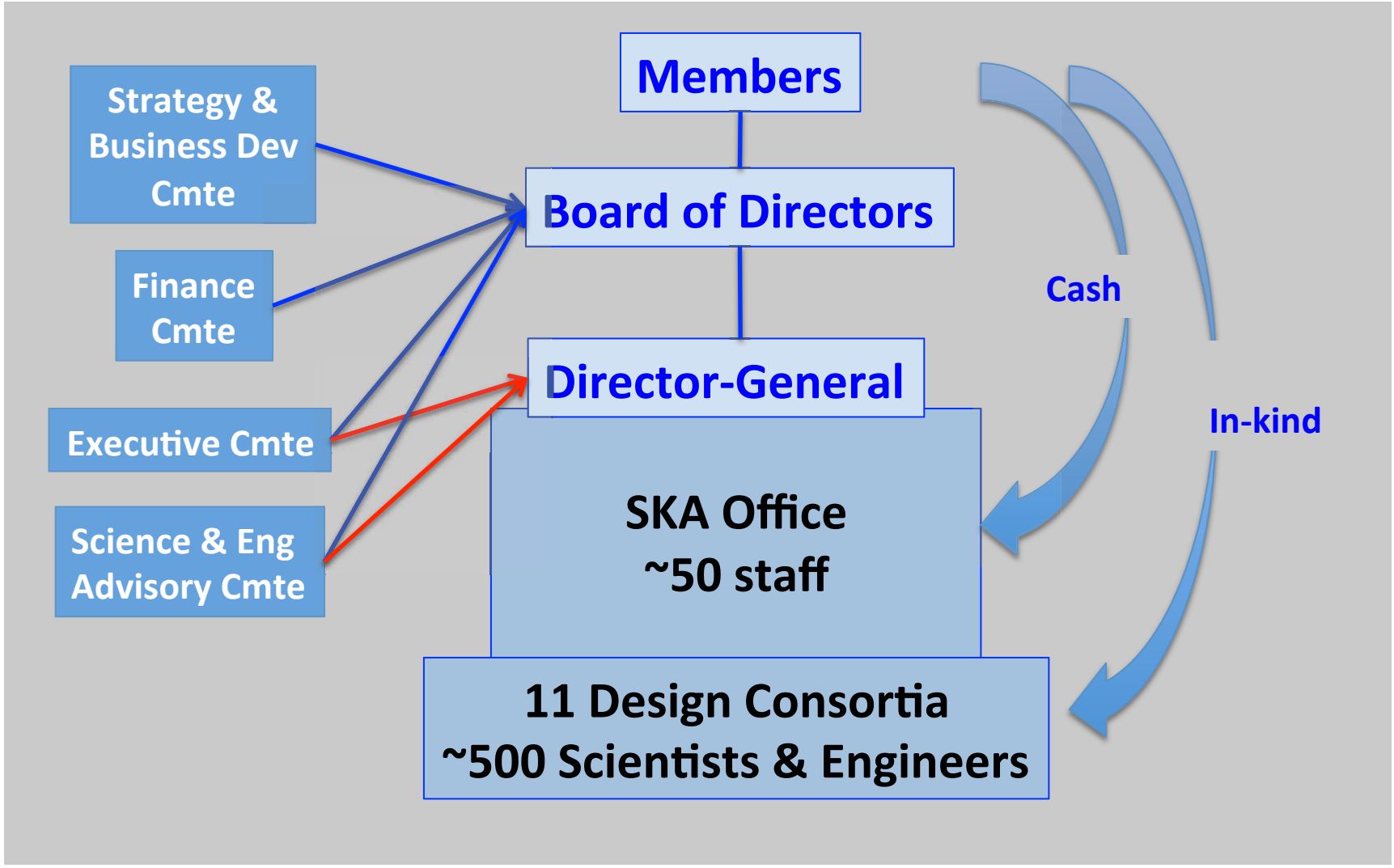
SKA Phase 1 and Phase 2 host countries

Exploring

African partner countries
(non-member SKA Phase 2 host countries)

This map is intended for reference only and is not meant to represent legal borders

SKA Governance + current funding



International Design Teams

- Project Management and System Engineering based at Jodrell Bank, Manchester, UK
- ~500 scientists & engineers in institutes and industry in 11 Member countries of the SKA

€150M design effort – fully funded

SKA1 Scope: Members decision 05/03/2015

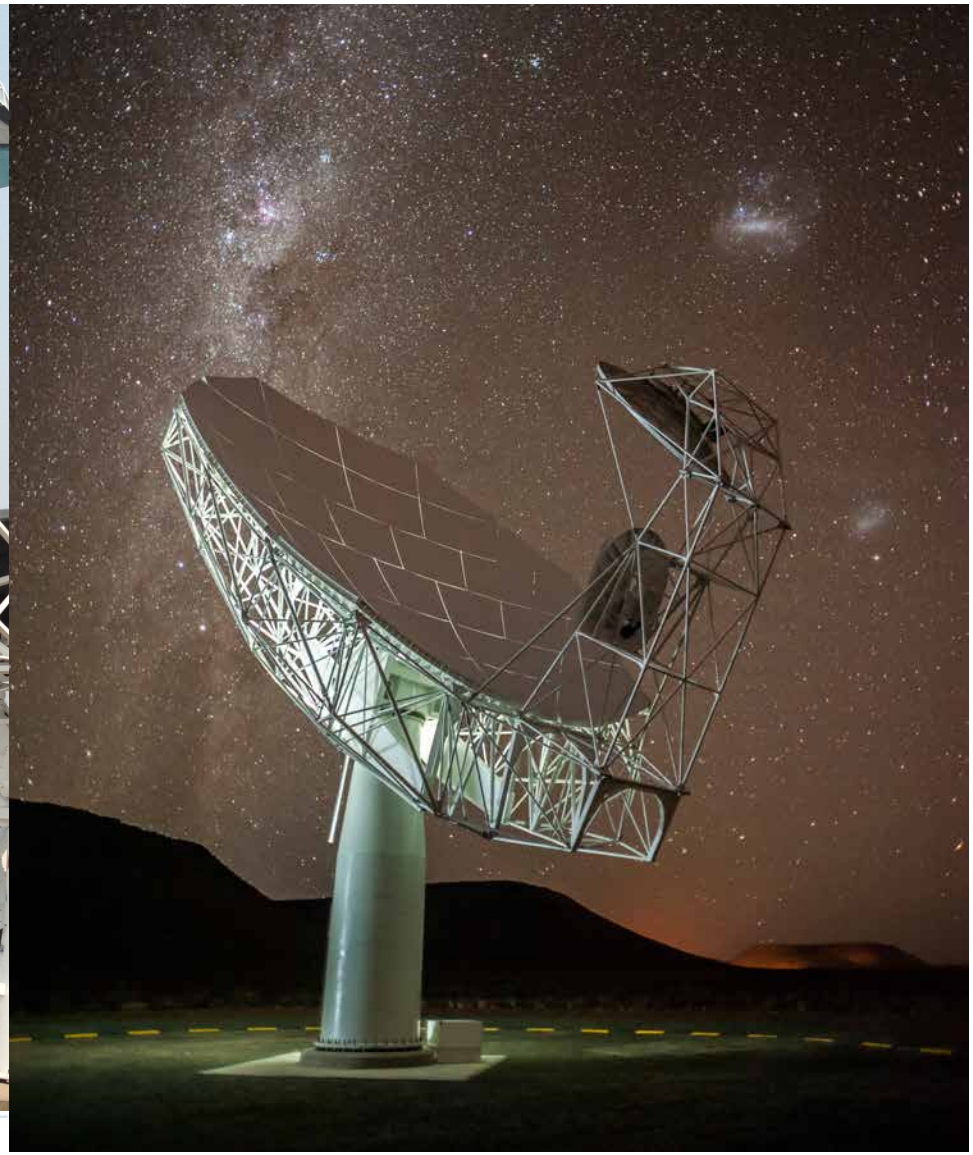
- SKA1-MID
  - 133x15m SKA1 dishes
  - Integration of MeerKAT, ie. 64x13.5m
  - Deployment of SPF2, SPF5 and SPF1
  - B_{max} ~ 150km (with 120km fall-back)
- SKA1-LOW
  - 131,000 x LPD Antennas
  - B_{max} ~ 65km
  - Pulsar search and timing capability
- Advanced Instrumentation Program
  - Highlighting PAF development
- Negotiate ASKAP integration into SKAO

SKA1-MID, Karoo, South Africa:

133 SKA1 + 64 MeerKAT dishes. Max baseline ~150km

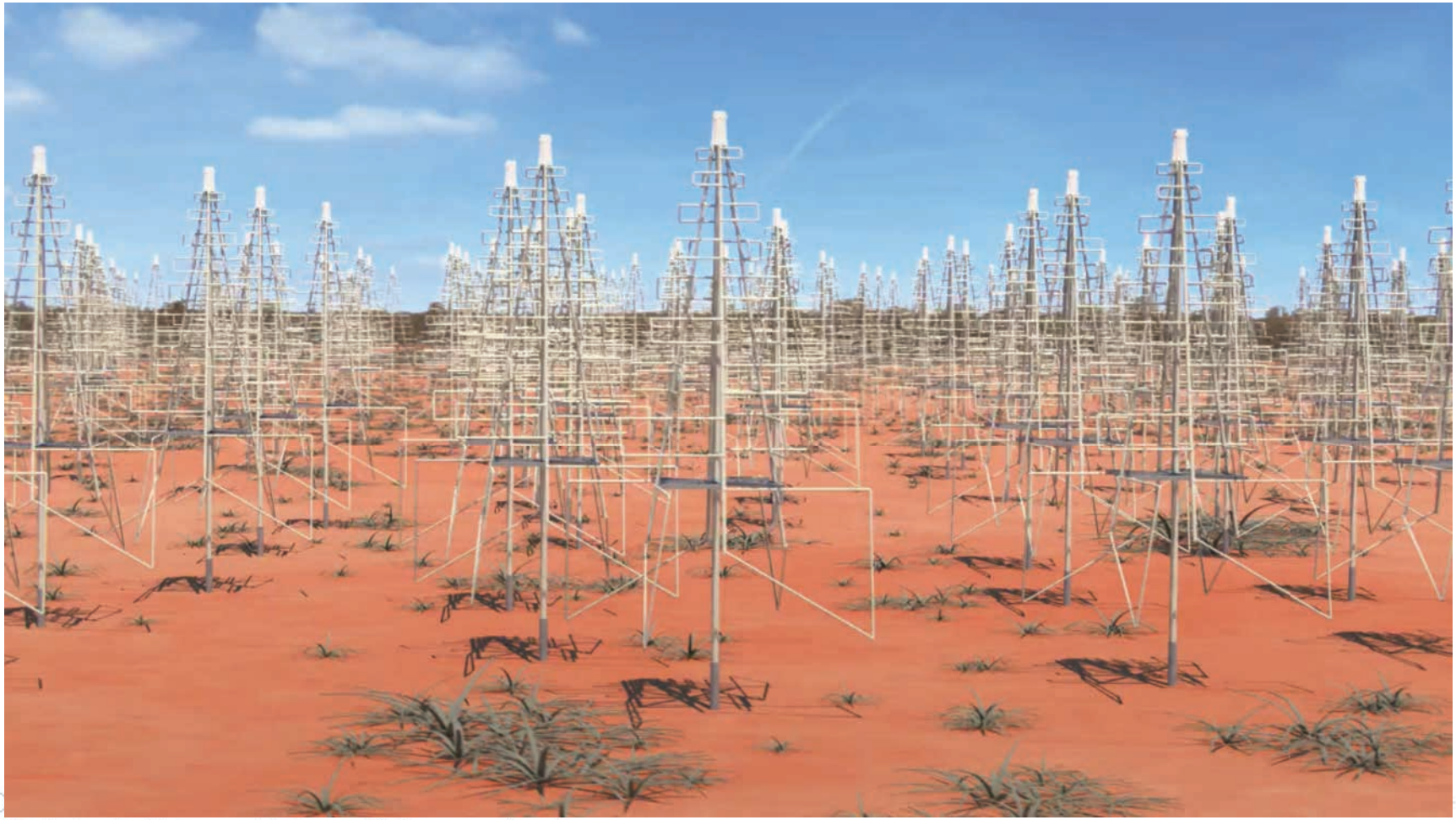
Bands: 2 (0.95–1.76 GHz), 5 (4.6–14(24) GHz), 1 (0.35–1.1 GHz)

3 dish prototypes all in testing



SKA1-LOW, Murchison, Australia:

130,000 dipoles (512 stations x 256 antennas); 50–350 MHz
~80km baselines; large areal concentration in core



First LFAA prototype now in testing

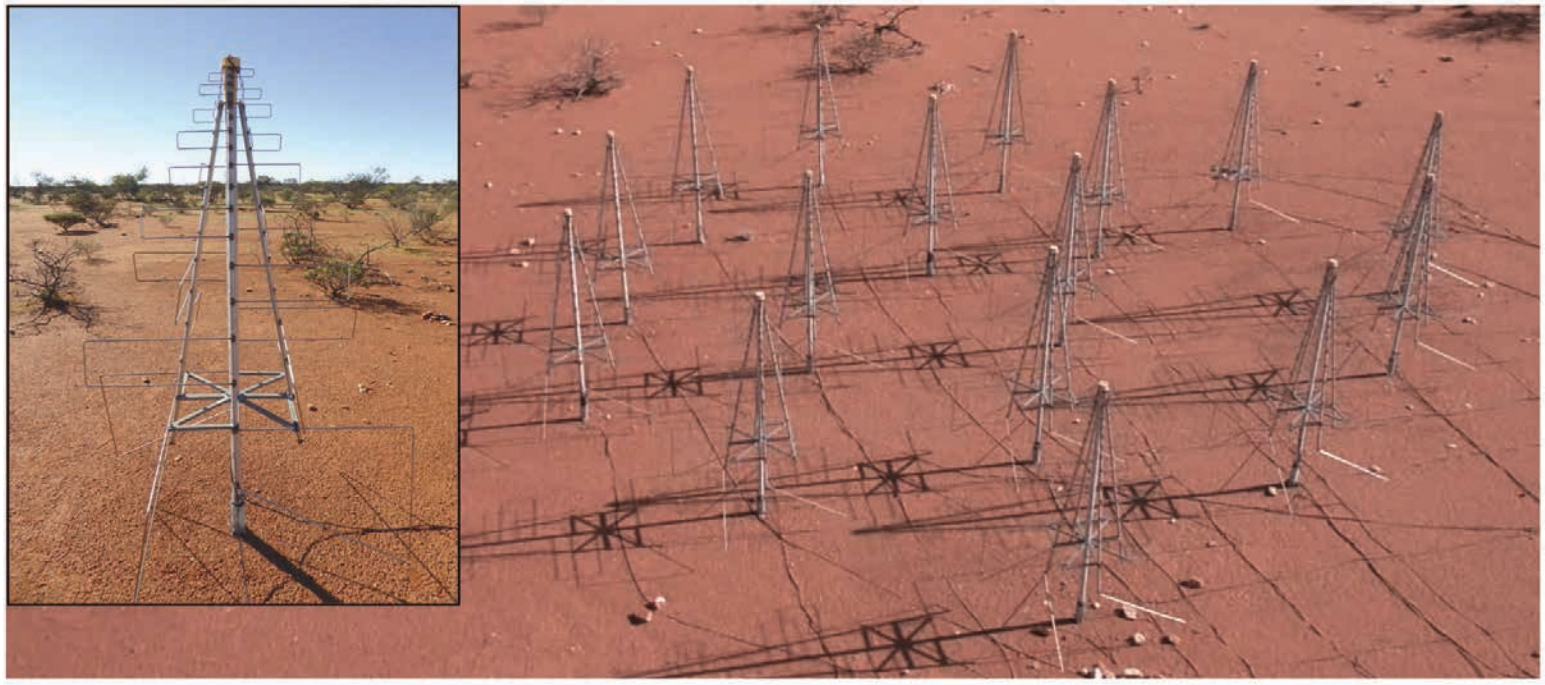
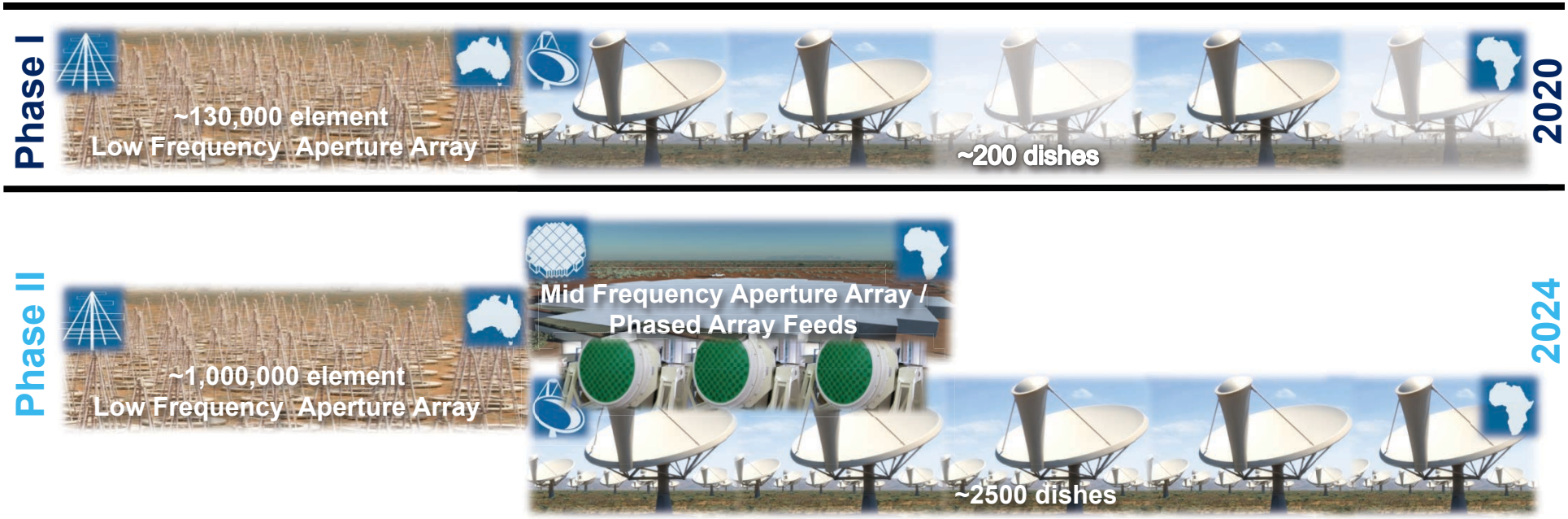
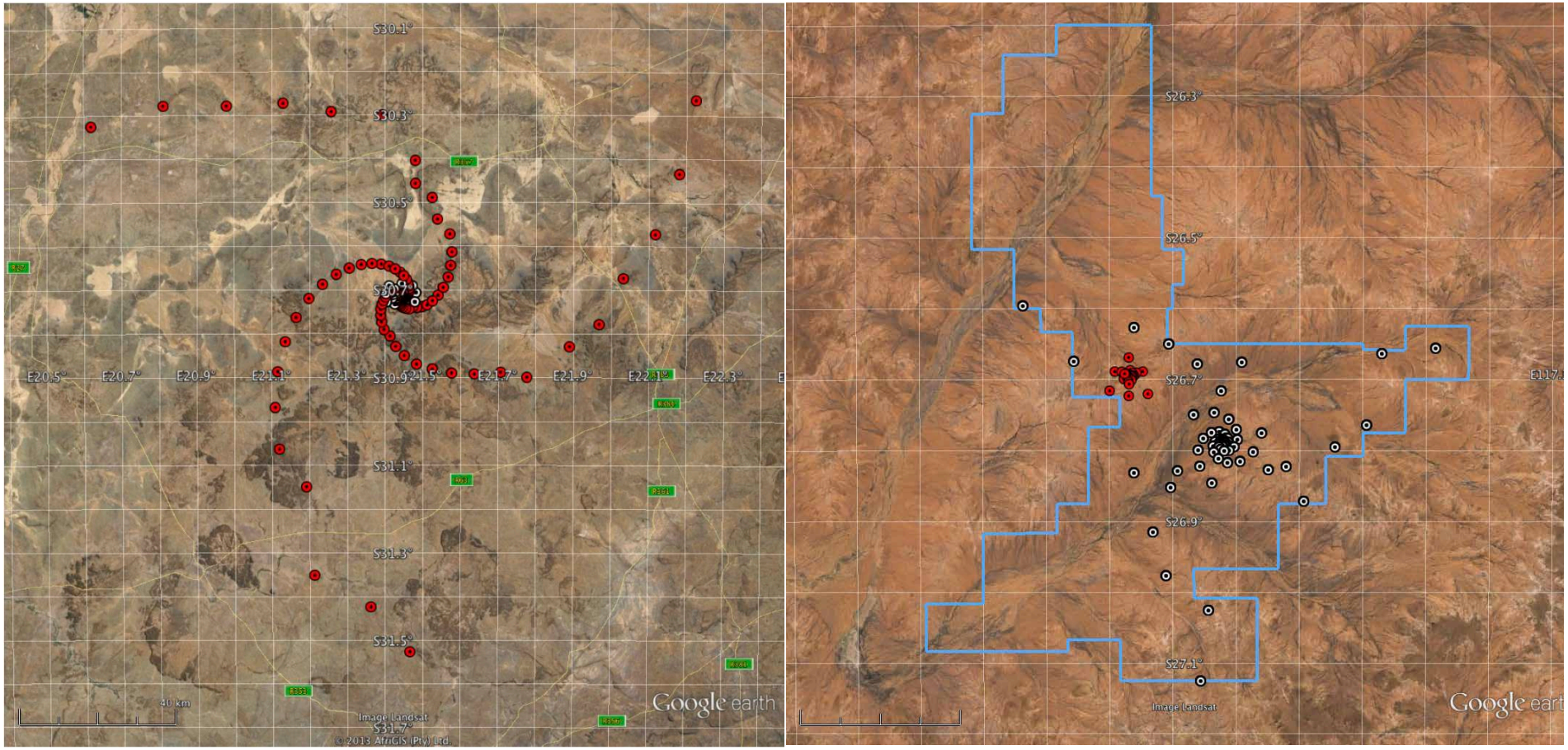


Figure 1. The AAVS0.5 is an array of 16 dual-polarized SKALA antennas (inset) pseudo-randomly placed in an 8 m diameter circle. In current implementation, the antennas are mounted over soil without a groundplane.

What is the SKA?

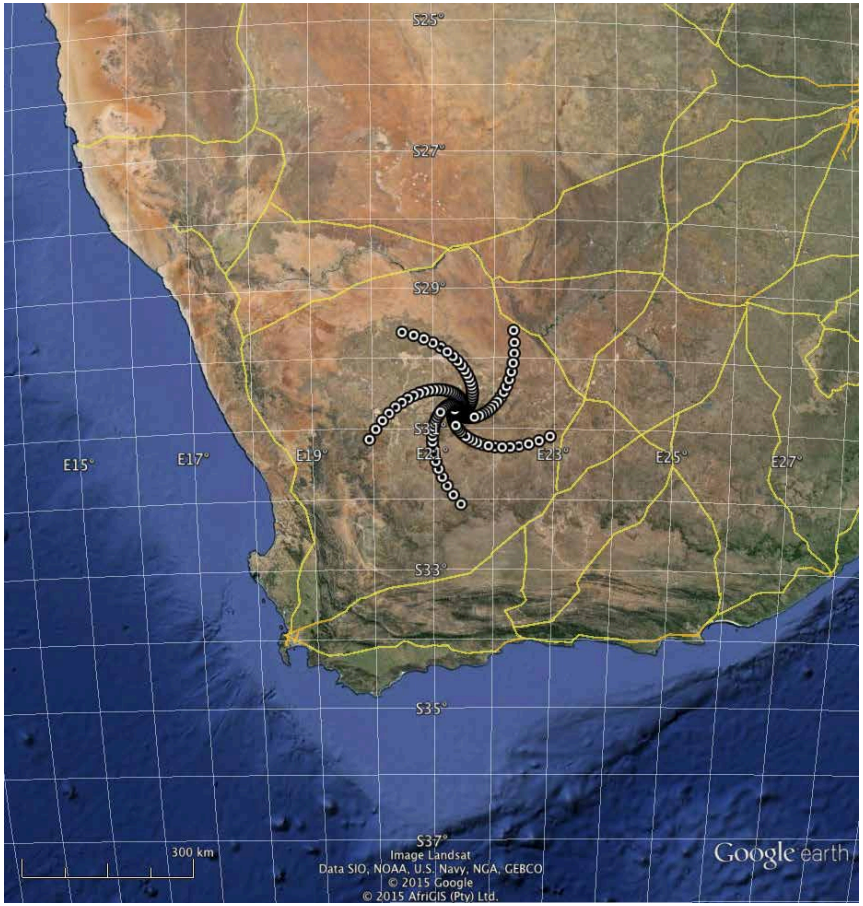


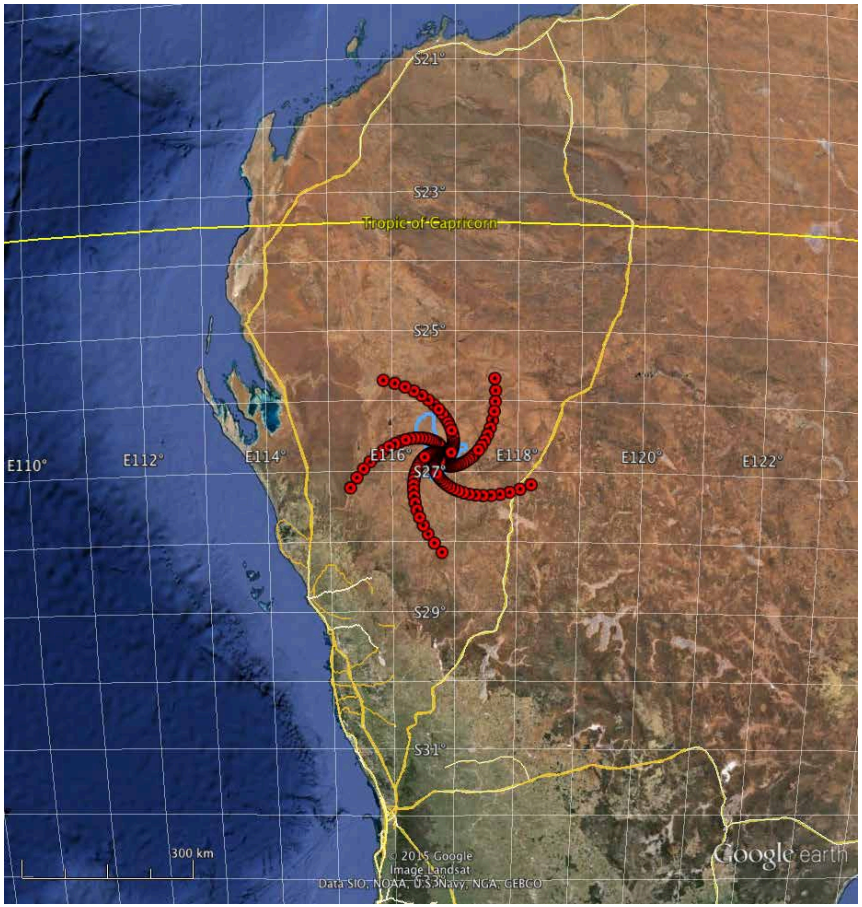
SKA1 Configurations



- SKA1–MID, –LOW: B_{Max} = 156, 65 km

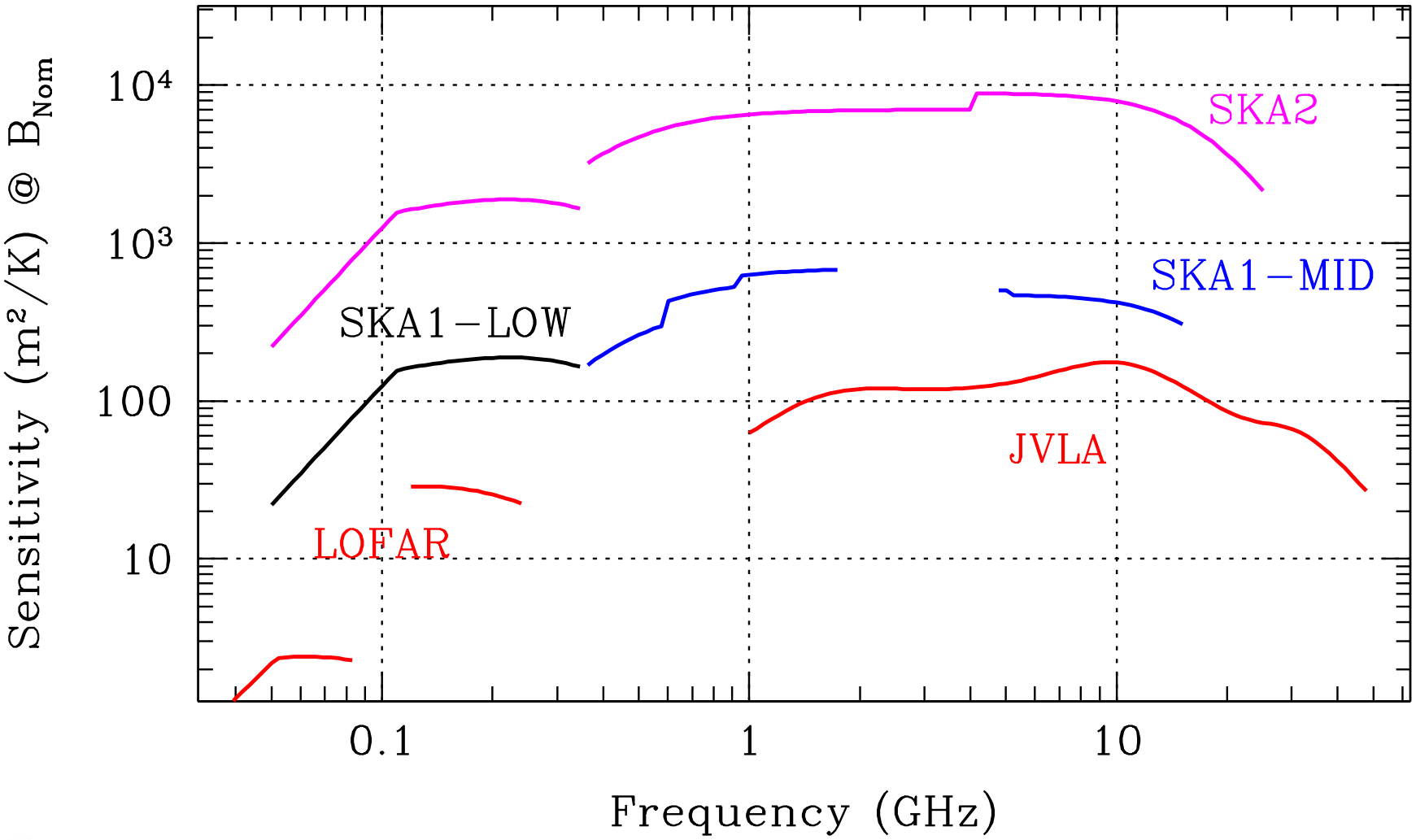
SKA2 Configurations



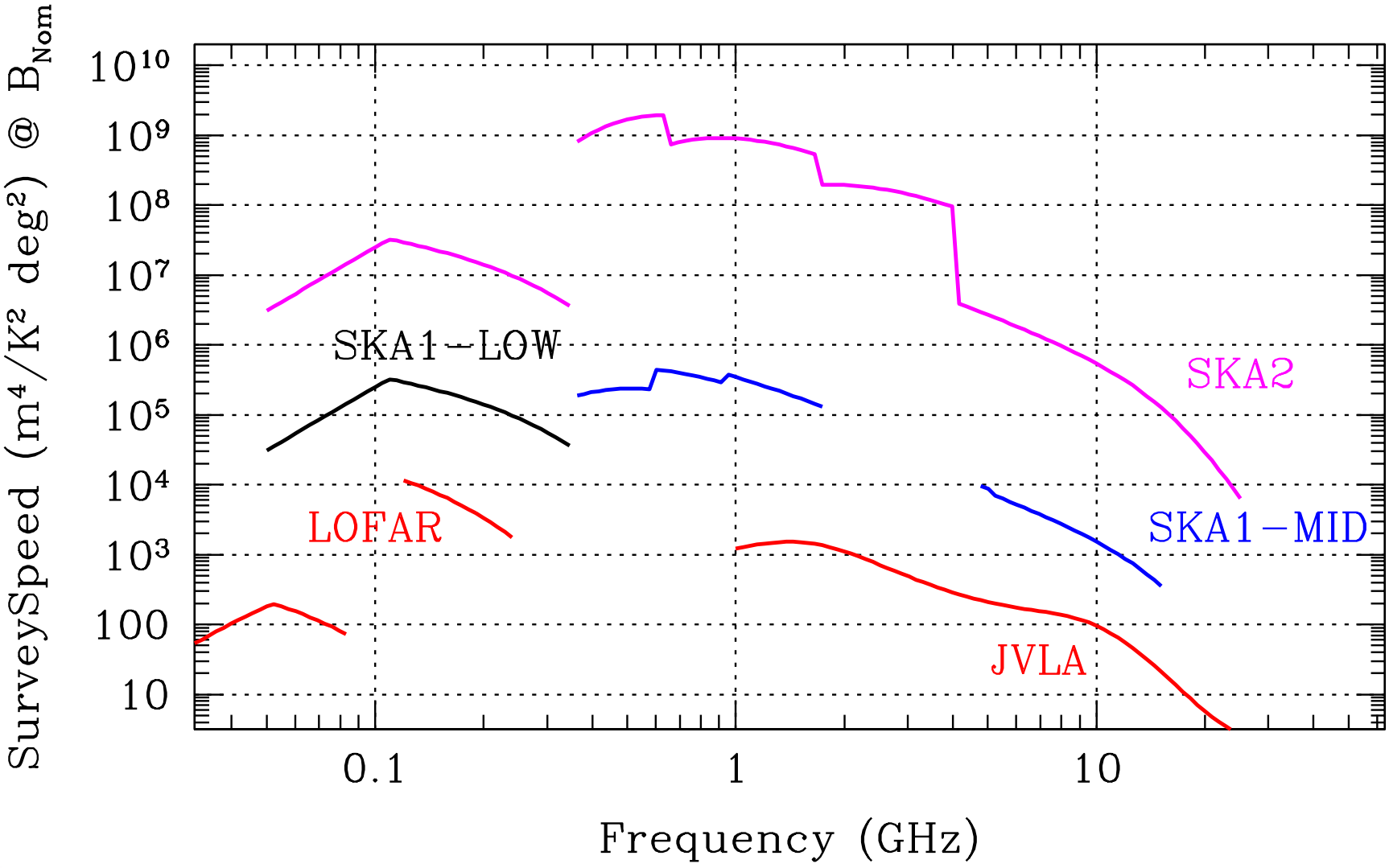


- SKA2–Dish, –LOW: B_{max} ≈ 300 km “core”, ≈3000+ km remote

Sensitivity Comparison



Survey Speed Comparison



Resolution Comparison

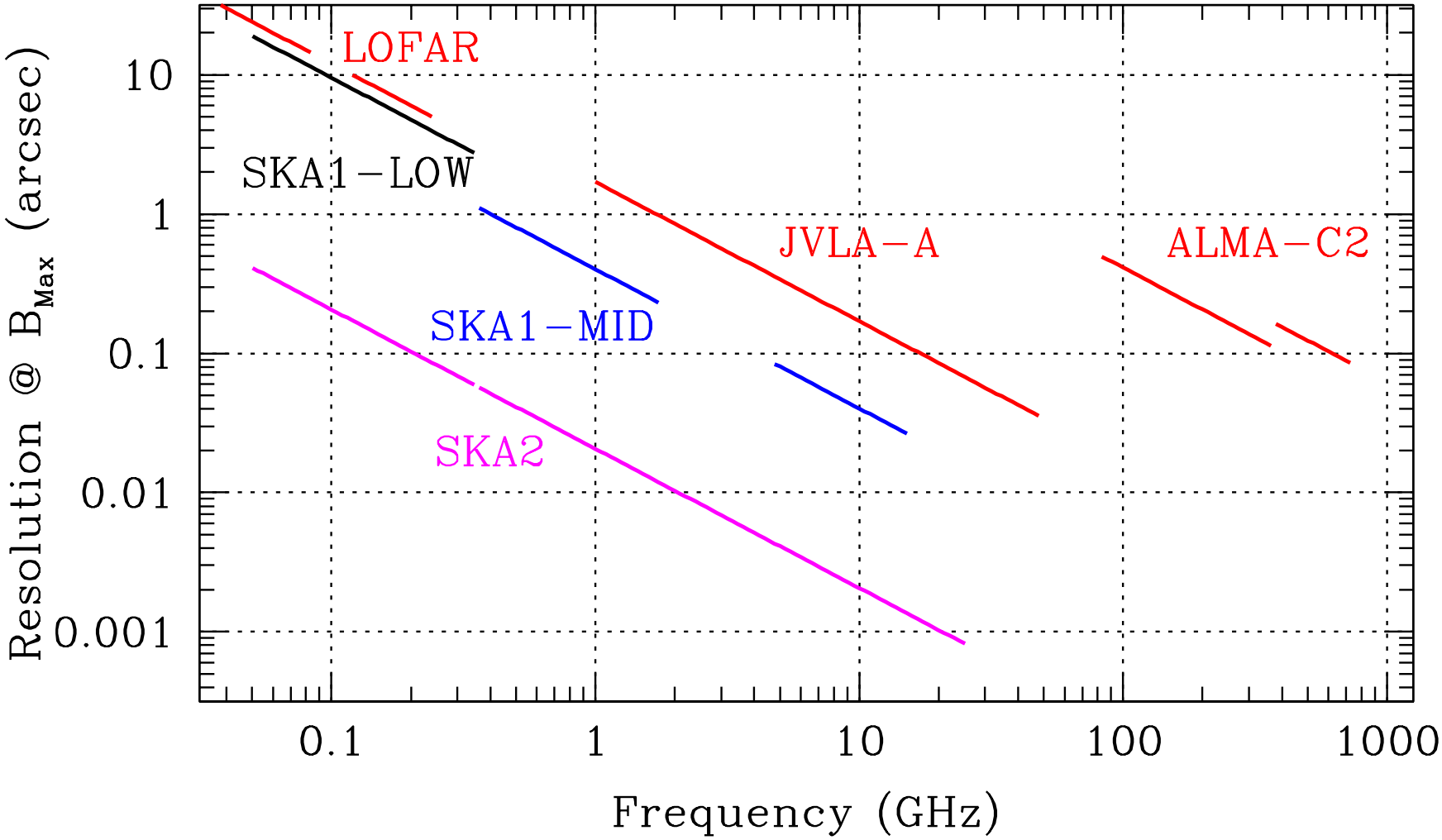
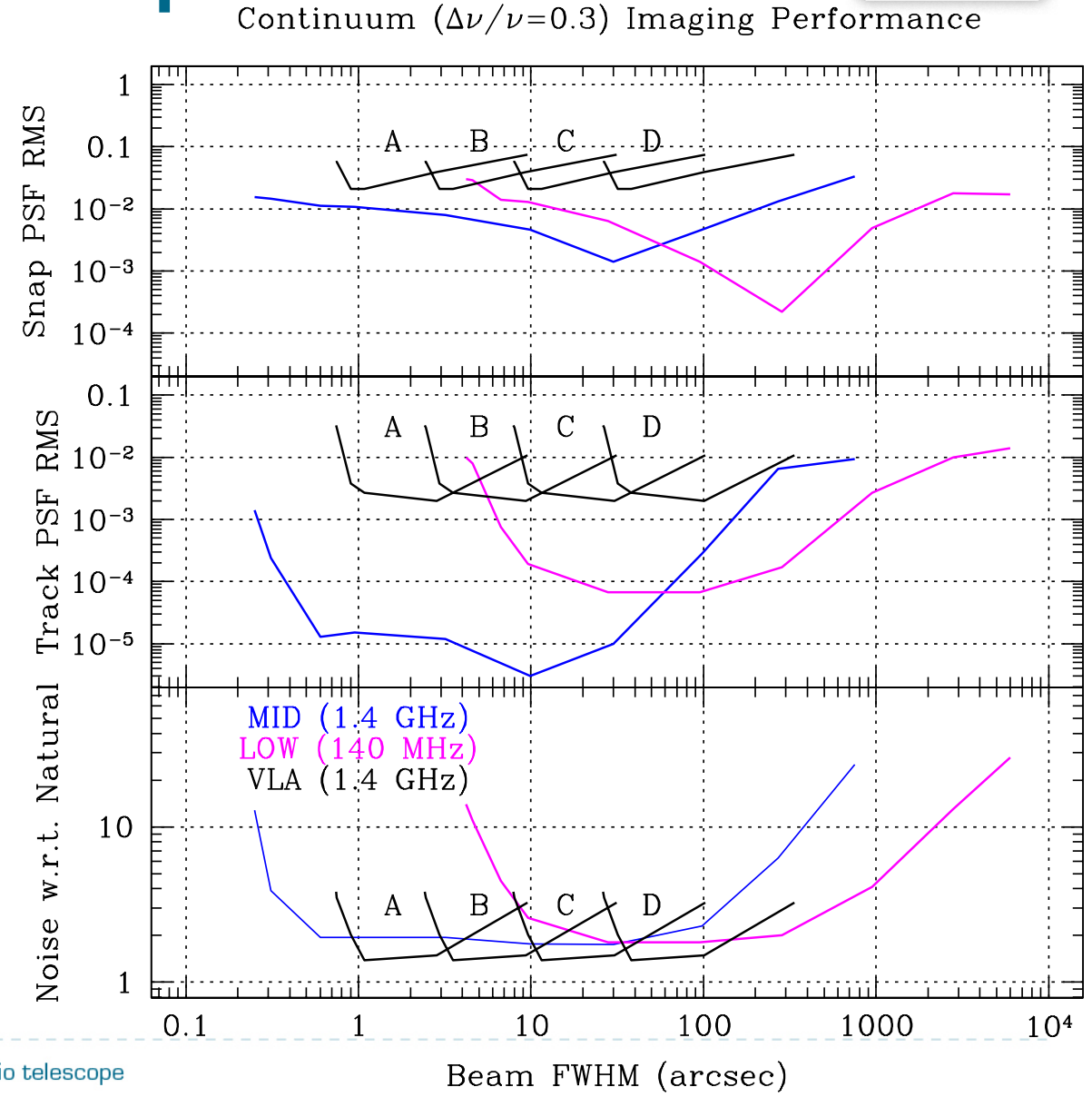


Image Quality Comparison

- Single SKA1 track equivalent to VLA A+B+C+D + **E+A$^+$**
- "Structural" dynamic range of ~1000:1 rather than ~3:1 per track
- Beam quality ~100 times better than VLA



Key Science Projects:

- **Notional** package of Key Science Projects in Q1 2015 based on the highest priority science objectives that have been recommended by our science community that will be:
  - Consistent with capabilities of the SKA1 design
  - Consistent with a realistic observing schedule filled at approximately 50% for the first 5 years of scientific operations
- Adopt KSP policy
  - Only scientists from SKA member countries may lead a KSP
  - KSP Leadership is guaranteed to be distributed amongst SKA members in proportion to their financial contribution
  - KSP participation (at the non-Leader level) is guaranteed to be distributed amongst SKA members in proportion to their financial contribution
  - KSP participation (at the non-Leader level) of SKA non-members is capped at the value defined in the Access Policy

A Package of Notional SKA1 Key Science Projects

SWG	Objective
CD/EoR	Physics of the early universe IGM - I. Imaging
CD/EoR	Physics of the early universe IGM - II. Power spectrum
Pulsars	Reveal pulsar population and MSPs for gravity tests and Gravitational Wave detection
Pulsars	High precision timing for testing gravity and GW detection
HI	Resolved HI kinematics and morphology of ~10^10 M_sol mass galaxies out to z~0.8
HI	High spatial resolution studies of the ISM in the nearby Universe.
HI	Multi-resolution mapping studies of the ISM in our Galaxy
Transients	Solve missing baryon problem at z~2 and determine the Dark Energy Equation of State
Cradle of Life	Map dust grain growth in the terrestrial planet forming zones at a distance of 100 pc
Magnetism	The resolved all-Sky characterisation of the interstellar and intergalactic magnetic fields
Cosmology	Constraints on primordial non-Gaussianity and tests of gravity on super-horizon scales.
Cosmology	Angular correlation functions to probe non-Gaussianity and the matter dipole
Continuum	Star formation history of the Universe (SFHU) – I+II. Non-thermal + Thermal processes

- Outcome of well-documented SKA1 science prioritisation process
  - All objectives originate with the science community
  - Review and strong endorsement by advisory bodies (SRP, SEAC)
- Should be viewed as ***representative*** package of high-impact science deliverables for the first five years of science operations

“Continuum” Key Science Project Ideas

Science Objective	SWG	High Priority Science Objective Number	SKA1 Component	Band	Mode	Frequency			Sensitivity			Observing Area					Integration				
						Range Low - High	Resolution Initial:Cal:Final	Spectral Dynamic Range (I_max/ I_min)	RMS Noise Min:Max @ Beam @ Bandwidth	Brightness Dynamic Range (I_max/ I_min)	Polarisation Dynamic Range (I_max/ P_min)	Total Area	Area of Single Pointing/ Beam	Angular Resolution Min:Max	Targets/ Beams	Tracking	Total	Per Pointing	Dump Rate / Temporal Resolution	# Sessions per Interval	Time per Session
Magnetism - RM-grid AASKA14:092	Magnetism	27	**SKA1-MID**	**SPF2**	**Imaging**	1000 - 1700 MHz	10:1000 kHz	30 dB	7 µJy/Beam @ 2 arcsec Cont	45 dB	30 dB	31000 deg2	0.38 deg2	2 arcsec	81600 Pointings	Sidereal	10000 hr	7.4 mn	0.15 s	1250	8 hr
Cosmology - ISW, Dipole AASKA14:018, 032	Cosmology	33	**SKA1-MID**	**SPF2**	**Imaging**	1000 - 1700 MHz	10:1000 kHz	30 dB	7 µJy/Beam @ 2 arcsec Cont	45 dB	30 dB	31000 deg2	0.38 deg2	2 arcsec	81600 Pointings	Sidereal	10000 hr	7.4 mn	0.15 s	1250	8 hr
Continuum - SFR(z) AASKA14:067	Continuum	37 + 38	**SKA1-MID**	**SPF2**	**Imaging**	1000 - 1700 MHz	10:1000 kHz	30 dB	1.3 µJy/Beam @ 0.5 arcsec Cont	**60 dB**	30 dB	1000 deg2	0.38 deg2	0.5:1 arcsec	2600 Pointings	Sidereal	10000 hr	3.8 hr	0.15 s	1250	8 hr
			SKA1-MID	**SPF2**	**Imaging**	1000 - 1700 MHz	10:10:1000 kHz	30 dB	0.25 µJy/Beam @ 0.5 arcsec Cont	**60 dB**	30 dB	7.8 deg2	0.38 deg2	0.5:1 arcsec	21 Pointings	Sidereal	2000 hr	95 hr	0.15 s	250	8 hr
			SKA1-MID	**SPF2**	**Imaging**	1000 - 1700 MHz	10:10:1000 kHz	30 dB	65 nJy/Beam @ 0.5 arcsec Cont	**60 dB**	30 dB	0.38 deg2	0.38 deg2	0.5:1 arcsec	1 Pointings	Sidereal	2000 hr	2000 hr	0.15 s	250	8 hr
			SKA1-MID	**SPF5**	**Imaging**	**7 - 11 GHz**	80:80:4000 kHz	25 dB	400 nJy/Beam @ 0.05 arcsec Cont	45 dB	30 dB	0.5 deg2	30 arcmin2	0.05:1 arcsec	61 Pointings	Sidereal	1000 hr	16.4 hr	0.15 s	125	8 hr
			SKA1-MID	**SPF5**	**Imaging**	**7 - 11 GHz**	80:80:4000 kHz	25 dB	50 nJy/Beam @ 0.05 arcsec Cont	45 dB	30 dB	30 arcmin2	30 arcmin2	0.05:1 arcsec	1 Pointing	Sidereal	1000 hr	1000 hr	0.15 s	125	8 hr

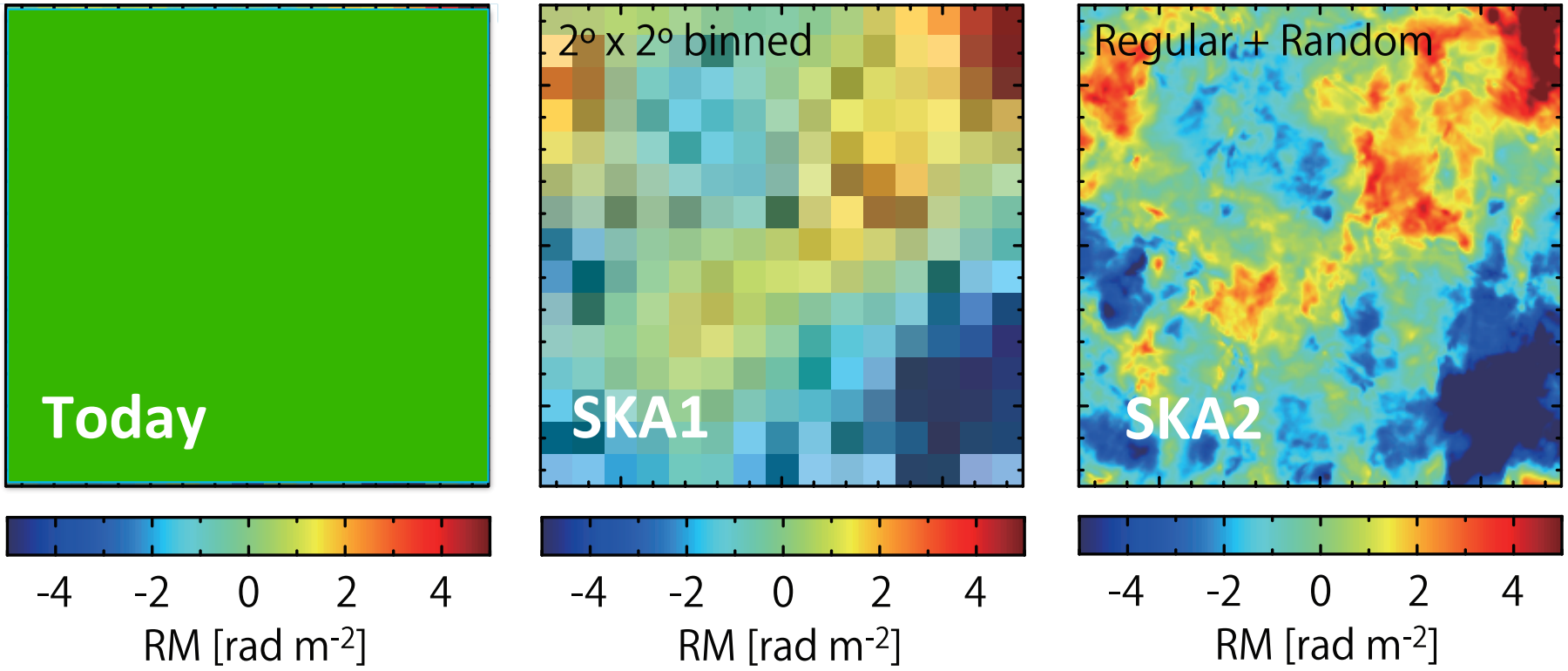
- HPSOs distilled from much broader package of survey ideas and goals

“Continuum” Key Science Project Ideas

Science Objective	SWG	High Priority Science Objective Number	SKA1 Component	Band	Mode	Frequency	Sensitivity	Observing Area		Integration
						Range Low - High	RMS Noise Min:Max @ Beam @ Bandwidth	Total Area	Angular Resolution Min:Max	Total
Magnetism - RM-grid AASKA14:092	Magnetism	27	**SKA1-MID**	**SPF2**	**Imaging**	1000 - 1700 MHz	7 µJy/Beam @ 2 arcsec Cont	31000 deg2	2 arcsec	10000 hr
Cosmology - ISW, Dipole AASKA14:018, 032	Cosmology	33	**SKA1-MID**	**SPF2**	**Imaging**	1000 - 1700 MHz	7 µJy/Beam @ 2 arcsec Cont	31000 deg2	2 arcsec	10000 hr
Continuum - SFR(z) AASKA14:067	Continuum	37 + 38	**SKA1-MID**	**SPF2**	**Imaging**	1000 - 1700 MHz	1.3 µJy/Beam @ 0.5 arcsec Cont	1000 deg2	0.5:1 arcsec	10000 hr
			SKA1-MID	**SPF2**	**Imaging**	1000 - 1700 MHz	0.25 µJy/Beam @ 0.5 arcsec Cont	7.8 deg2	0.5:1 arcsec	2000 hr
			SKA1-MID	**SPF2**	**Imaging**	1000 - 1700 MHz	65 nJy/Beam @ 0.5 arcsec Cont	0.38 deg2	0.5:1 arcsec	2000 hr
			SKA1-MID	**SPF5**	**Imaging**	**7 - 11 GHz**	400 nJy/Beam @ 0.05 arcsec Cont	0.5 deg2	0.05:1 arcsec	1000 hr
			SKA1-MID	**SPF5**	**Imaging**	**7 - 11 GHz**	50 nJy/Beam @ 0.05 arcsec Cont	30 arcmin2	0.05:1 arcsec	1000 hr

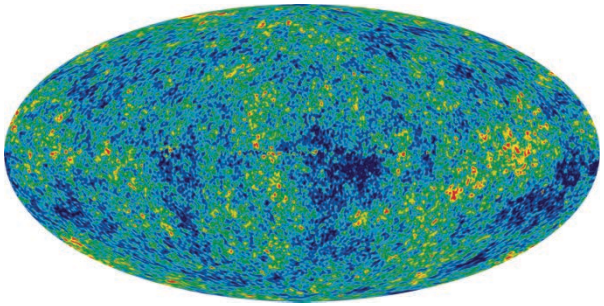
- HPSOs distilled from much broader package of survey ideas and goals

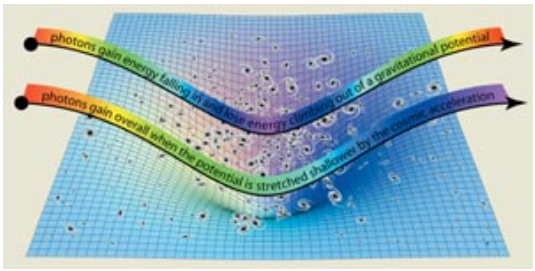
The “all-sky” RM grid

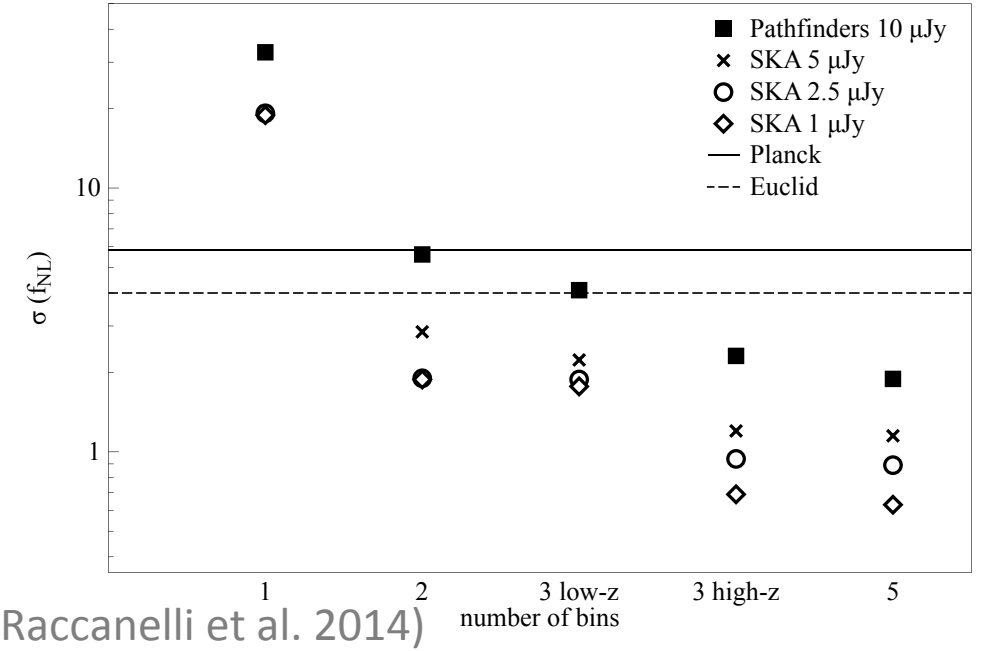


- 3D magnetic tomography of the Galaxy and distant universe; from current 1 RM deg^{-2}, SKA1: 300 deg^{-2} to SKA2: 5000 deg^{-2}

Cosmology with SKA: Integrated Sachs-Wolfe effect



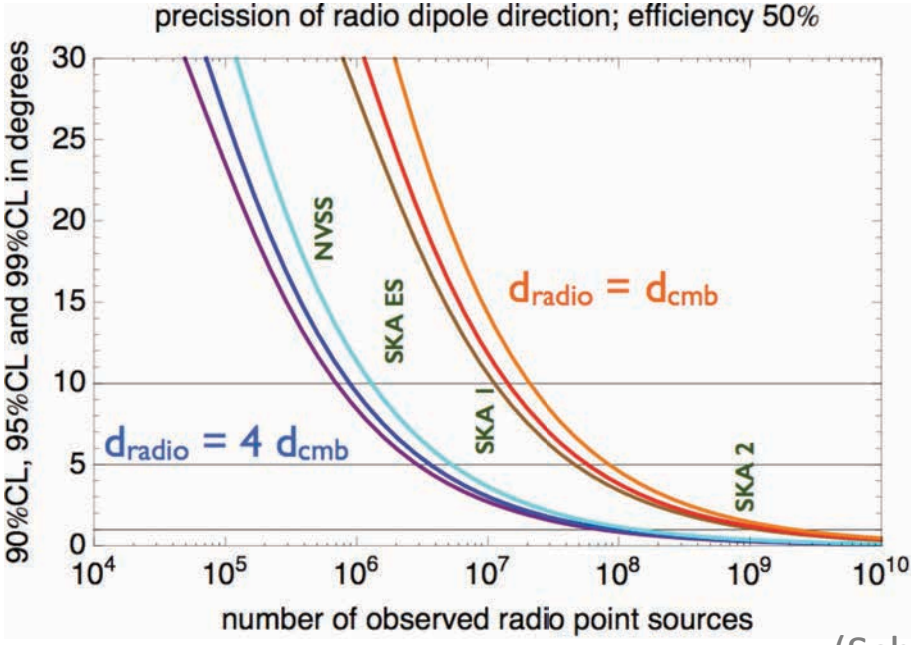


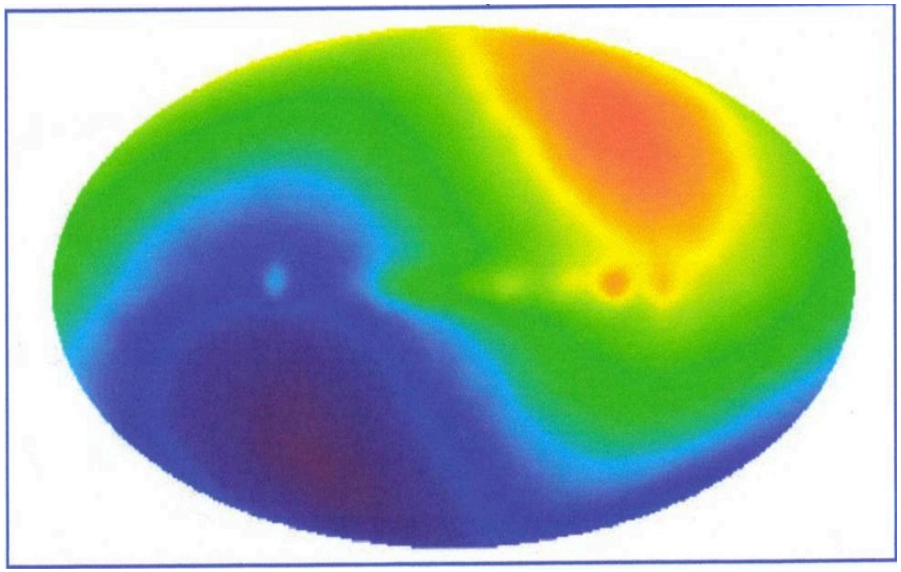


(Raccanelli et al. 2014)

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

Cosmology with SKA: Matter Dipole versus CMB Dipole

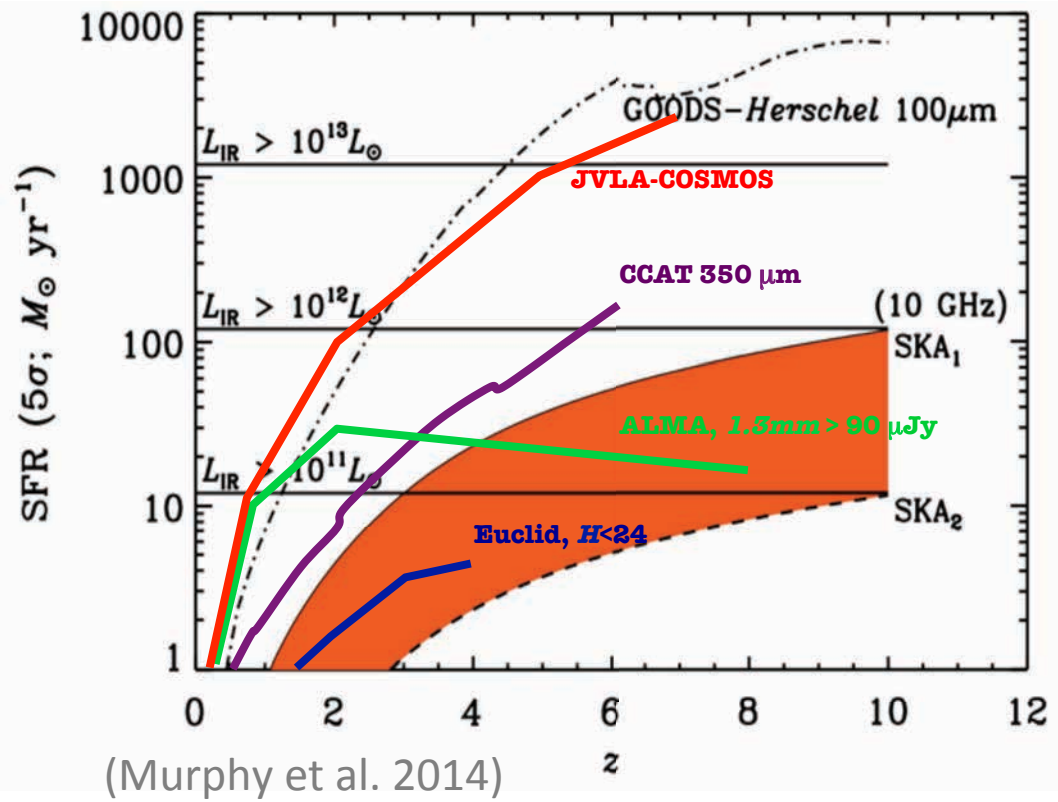




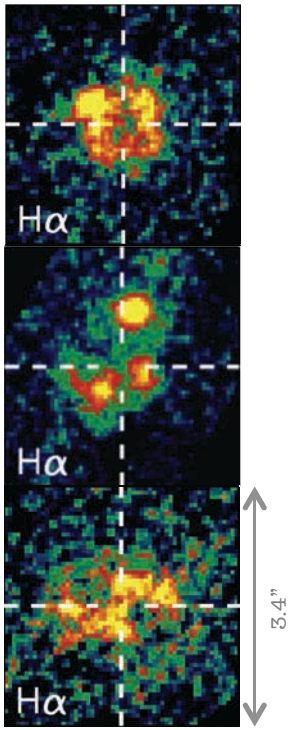
(Schwarz et al. 2014)

- Sensitive constraints on isotropy and homogeneity
  - Unique tests of isotropy at z ~ 1
  - Measure cosmic matter dipole with high precision

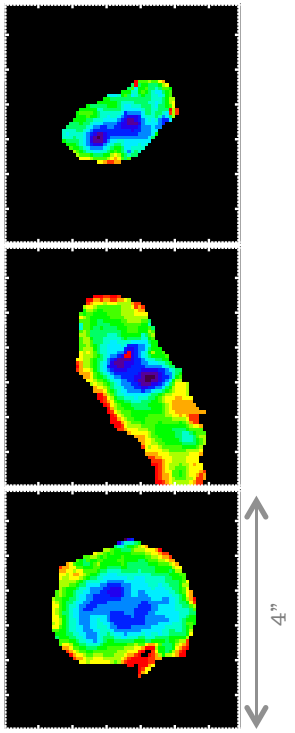
Galaxy Evolution Studies in the Radio Continuum: Understanding the Star Formation History of the Universe



(Murphy et al. 2014)



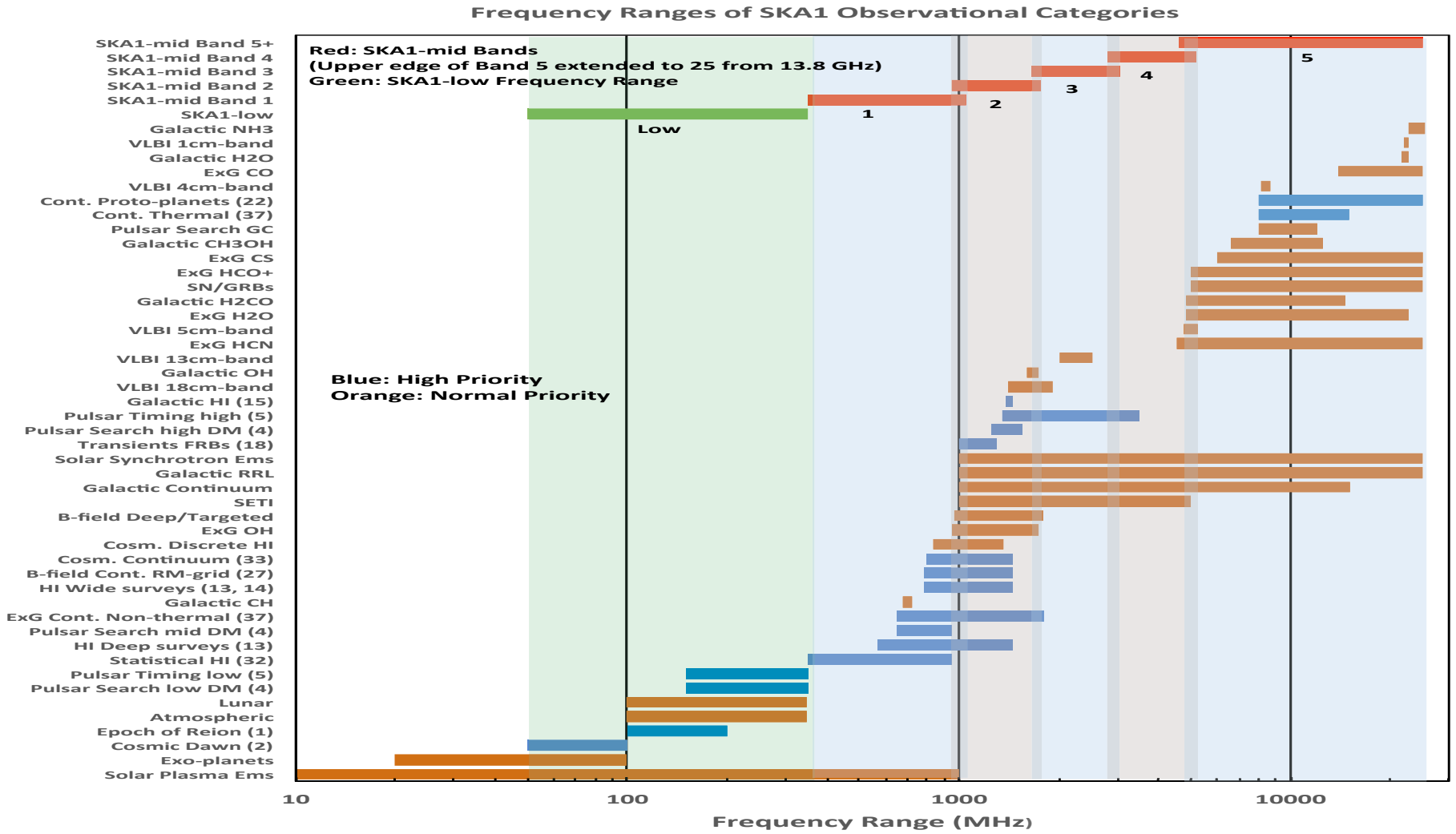
Wuyts et al 2013, **z~1**
Hα–based SFR-maps



Cibinel et al 2014, **z~2**
UV-based SFR-maps

- Unmatched sensitivity to star formation rates (10 $M_\odot$/yr) out to z ~ 4
- Resolved (sub-kpc) imaging of star forming disks out to z ~ 1

A Package of Notional SKA1 Key Science Projects



- HPSOs distilled from much broader package of survey ideas and goals

“Continuum” Science Project Ideas

Science Goal	SWG	Objective	SWG Rank
27	*Magnetism*	The resolved all-Sky characterisation of the interstellar and intergalactic magnetic fields	1/5
28	*Magnetism*	Determine origin, maintenance and amplification of magnetic fields at high redshifts - I.	2/5
29	*Magnetism*	Detection of polarised emission in Cosmic Web filaments	3/5
30	*Magnetism*	Determine origin, maintenance and amplification of magnetic fields at high redshifts - II.	4/5
31	*Magnetism*	Intrinsic properties of polarised sources	5/5
33	*Cosmology*	Angular correlation functions to probe non-Gaussianity and the matter dipole	2/5
34	*Cosmology*	Map the dark Universe with a completely new kind of weak lensing survey - in the radio.	3/5
37	*Continuum*	Measure the Star formation history of the Universe (SFHU) - I. Non-thermal processes	1/8
38	*Continuum*	Measure the Star formation history of the Universe (SFHU) - II. Thermal processes	2/8
39	*Continuum*	Probe the role of black holes in galaxy evolution - I.	3/8
40	*Continuum*	Probe the role of black holes in galaxy evolution - II.	4/8
41	*Continuum*	Probe cosmic rays and magnetic fields in ICM and cosmic filaments.	5/8
42	*Continuum*	Study the detailed astrophysics of star-formation and accretion processes - I.	6/8
43	*Continuum*	Probing dark matter and the high redshift Universe with strong gravitational lensing.	7/8
44	*Continuum*	Legacy/Serendipity/Rare.	8/8

- HPSOs distilled from much broader package of survey ideas and goals

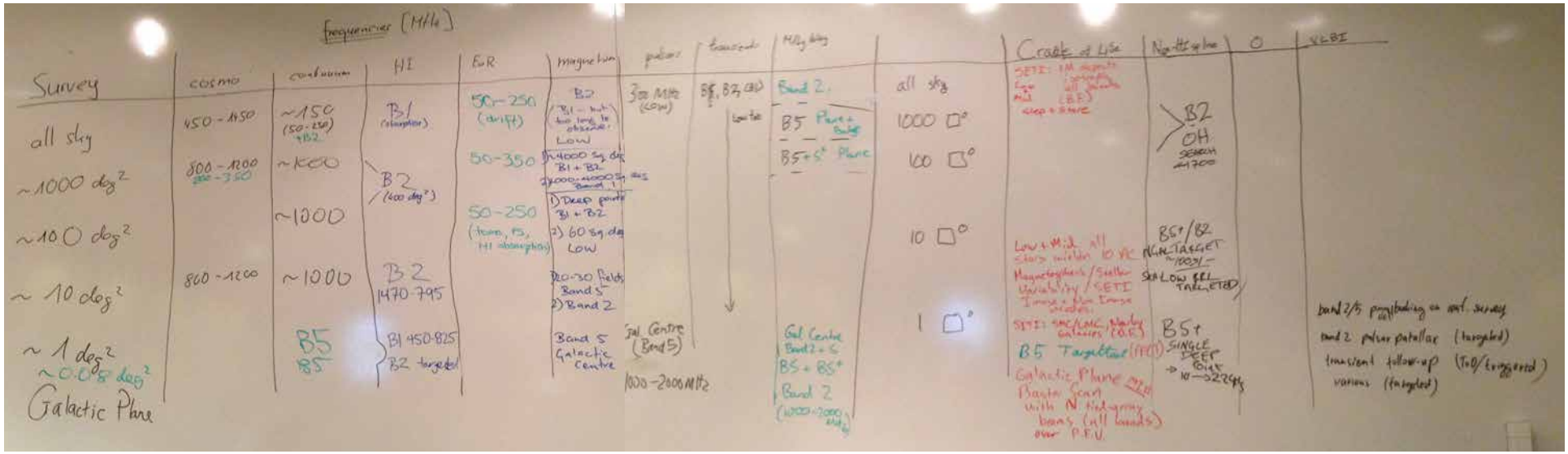
KSPs: 2015 Stockholm Workshop Aims

- Further develop KSP concepts
  - A notional KSP list has emerged from the SKA1 Science prioritization process, but this is only a representative placeholder, and will be continually reviewed.
    - This workshop aims to provide a forum for open discussion of KSP concepts, reviewing the notional list and identifying missing concepts.
- Support development of potential KSP collaborations
  - There will ultimately be a competitive process of KSP proposal submission, evaluation and allocation, implying that all discussions at this stage are informal and come with no guarantees.
    - This workshop aims to provide a forum for the key areas of interest of particular communities to be presented, leadership aspirations to begin to be identified and resourcing strategies to begin development.
- Maximizing commensality
  - It is likely that the same data stream will serve multiple KSP or PI-led groups, each with limited data rights to address specific scientific objectives.
    - This workshop aims to provide a forum for early discussion of support for such commensal programs, including the development of efficient survey strategies intending to maximise the scientific return of the KSP package.

KSPs: 2015 Stockholm Workshop Outcomes

- Further develop KSP concepts
  - Good progress as documented in the Working Group summaries (posted on web).
- Support development of potential KSP collaborations
  - Feedback has been positive.
- Maximizing commensality
  - Exploring definition of handful of “generic” surveys.
- Documenting science match to frequency bands
  - Document now ready for web posting.

KSPs: 2015 Stockholm Workshop



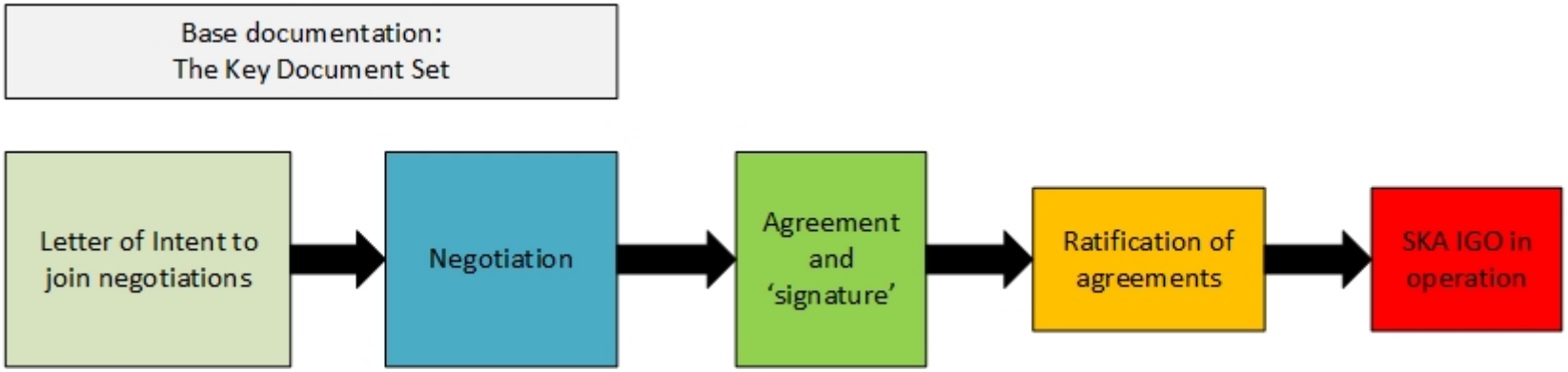
- Maximizing commensality
  - Exploring definition of handful of “generic” surveys.

Key events in last 12 months

- Dec 2014: Portugal releases its national research infrastructure roadmap: SKA included
- Dec 2014: Italian government passes legislation, includes €30M for industrial astronomy – SKA/CTA
- Dec 2014: UK releases its 10-year Science and Technology strategy – SKA prominent (UK construction funding £100M (€130M) for SKA1 construction already committed in March 2014)
- March 2015: SKA1 re-baselining
- April 2015: SKA HQ decision
- August 2015: First SKA1 KSP Workshop in Stockholm
- October 2015: India membership transferred to DAE
- October 2015: Formal IGO negotiations begin in Rome

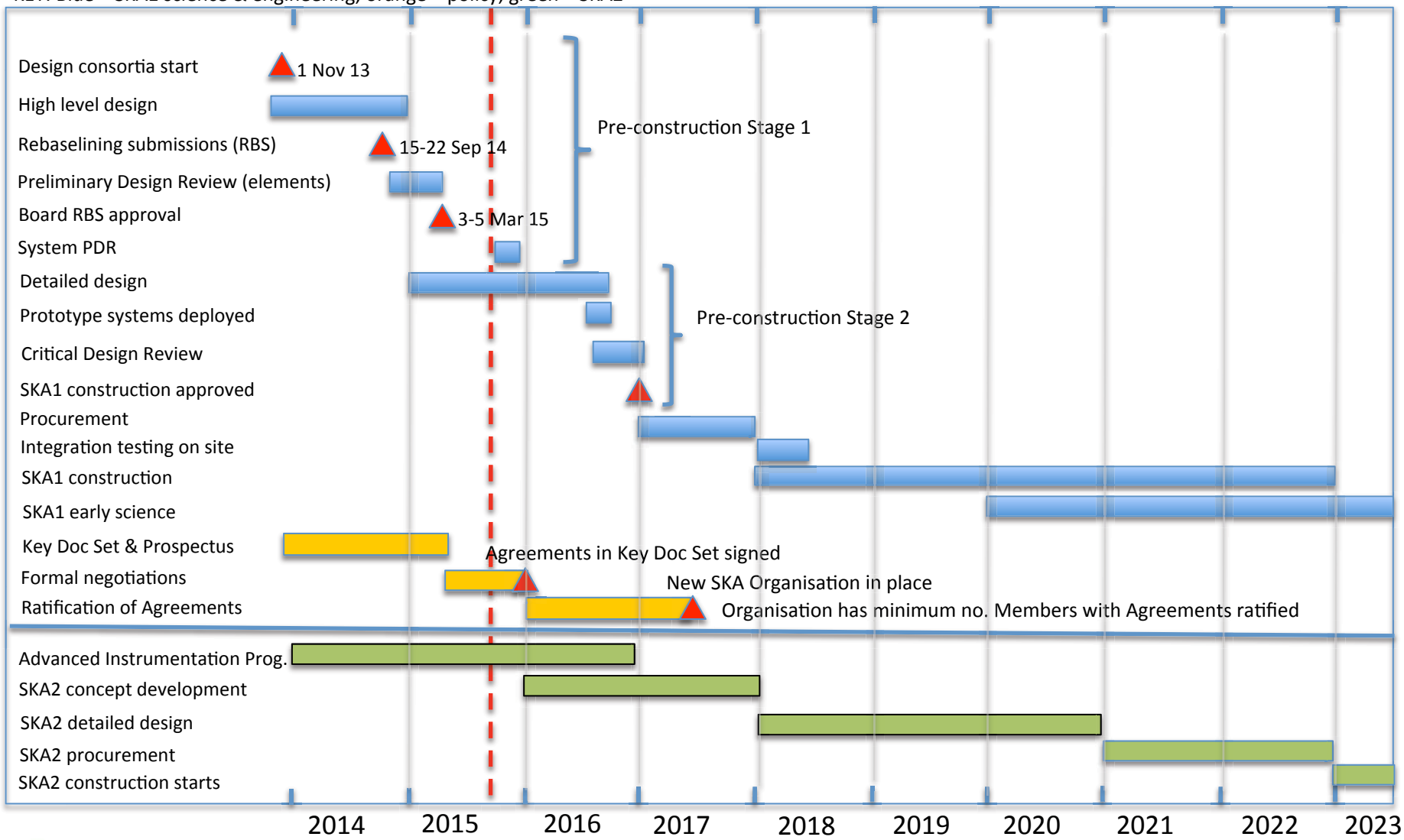
Governance/organisational structure

- Evolution planned to an SKA Inter-Governmental Organisation: a structure like ESO/ESA/ITER/EMBL/ CERN
- Rationale:
  - Government commitment: Long-term political stability, funding stability
  - Availability of 'concessions' through Privileges and Immunities from members



High-level SKA Schedule

KEY: Blue = SKA1 science & engineering; orange = policy; green = SKA2



SQUARE KILOMETRE ARRAY

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