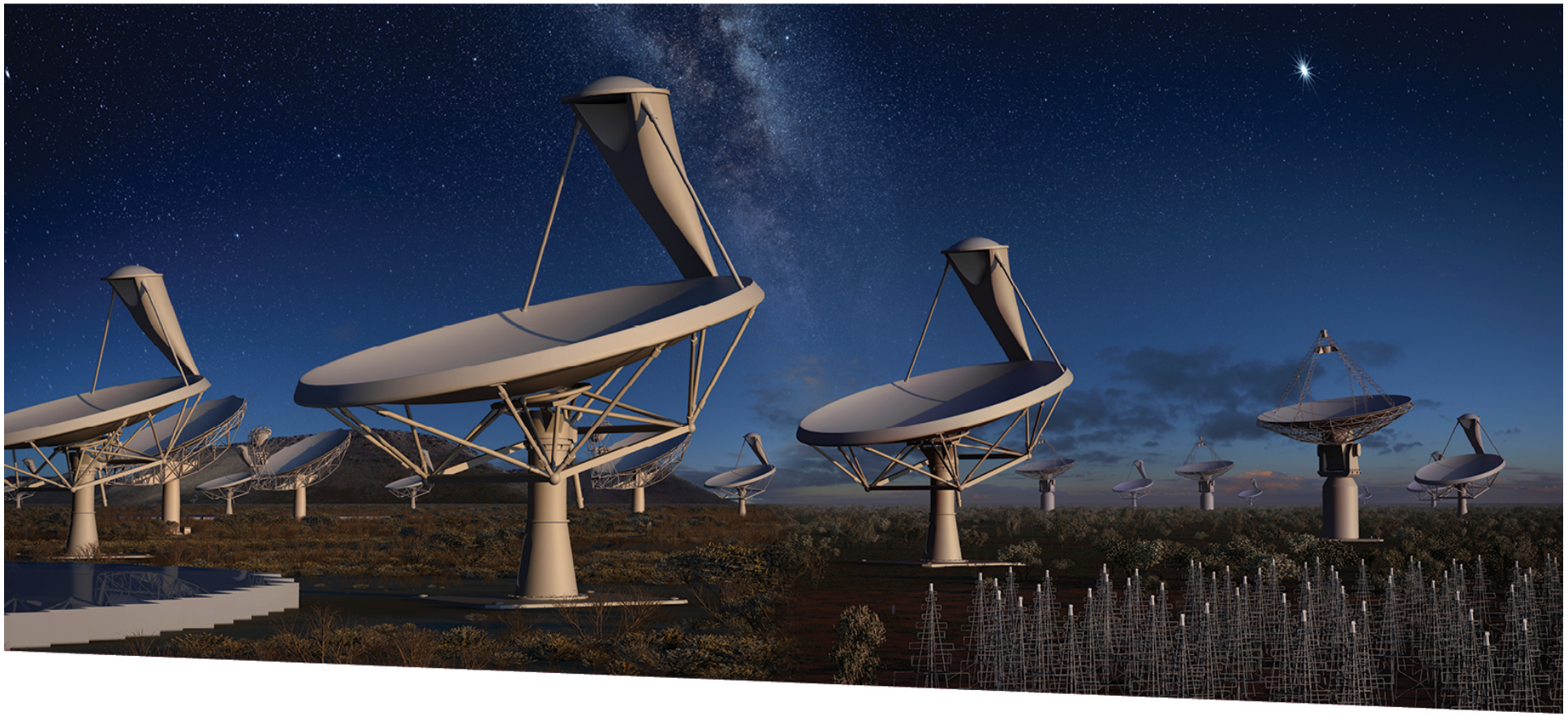
SKA Update



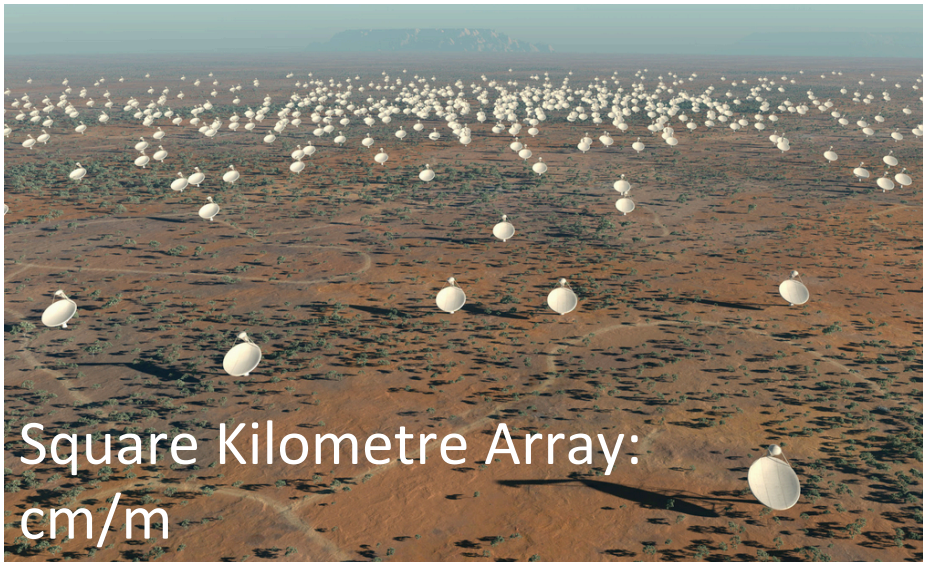
SQUARE KILOMETRE ARRAY

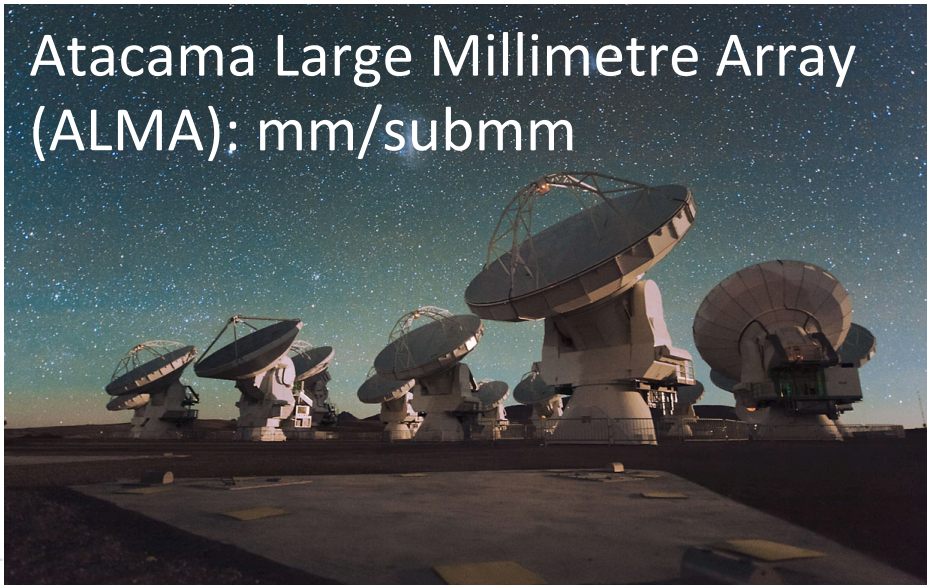
Exploring the Universe with the world's largest radio telescope

Robert Braun

5 May 2015

Great Observatories for the coming decades





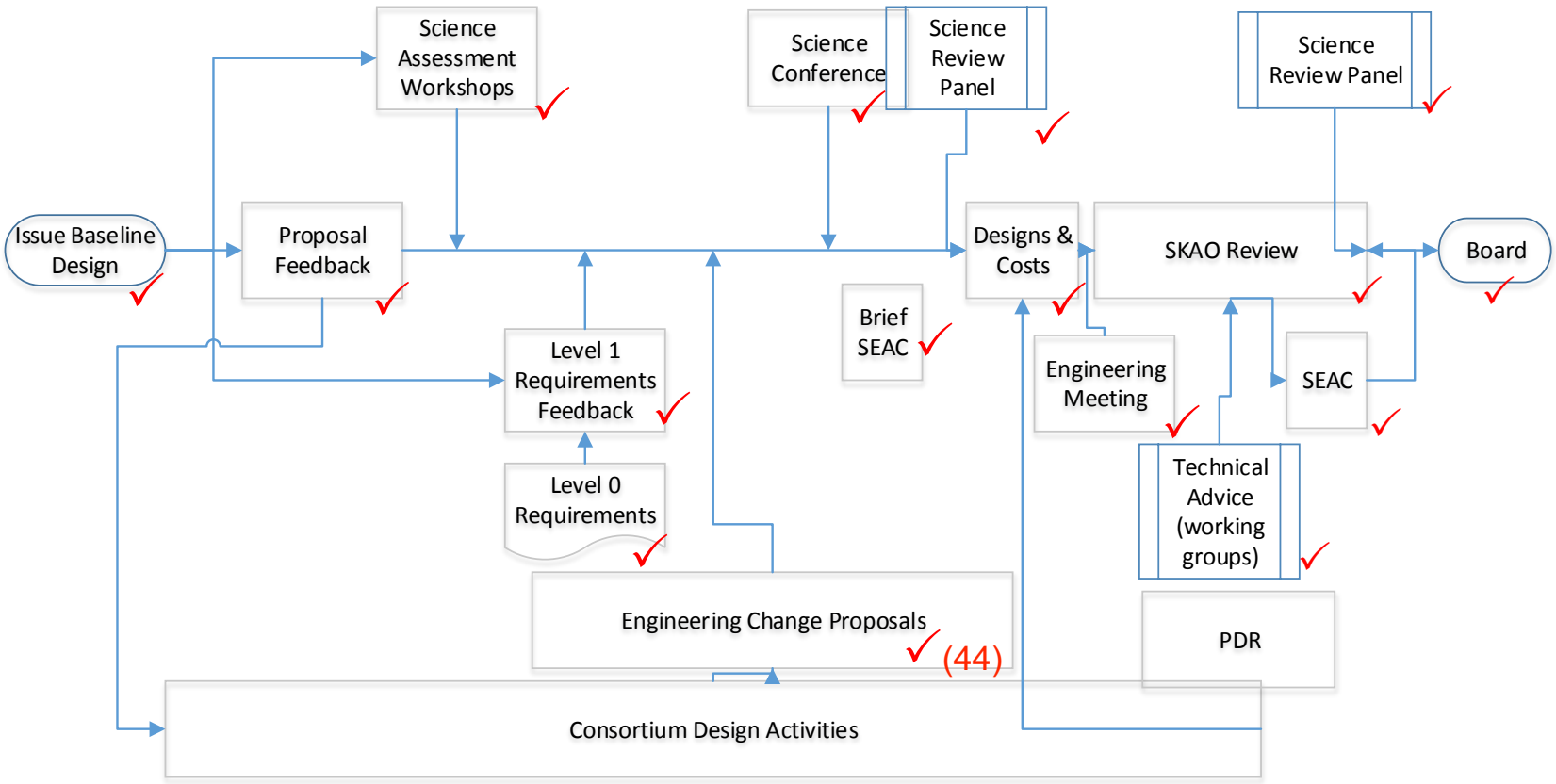
SKA Science

- 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; +…????

Re-baselining

- Re-baselining: ‘the act of generating a new baseline design, evolving from the existing baseline design’
  - ALMA: significant re-baselining
  - E-ELT: (100m) → 42m → 39m → phased deployment
  - LOFAR: reduced collecting area by 75%, reduced number of stations by 50%

Re-baselining Process



SKA1 Scope: Members decision 05/03/2015

- SKA1-MID
  - 70% of planned SKA1 dishes, ie. 133x15m
  - Integration of MeerKAT, ie. 64x13.5m
  - Deployment of SPF2, SPF5 and SPF1
  - B_{max} ~ 150km (with 120km fall-back)
  - 50% savings on non-image-processing
- SKA1-LOW
  - 50% of planned LPDs, ie. 131,000 x Antennas
  - B_{max} ~ 65km
  - Pulsar search and timing capability
- Advanced Instrumentation Program
  - Highlighting PAF development
- Negotiate ASKAP integration into SKAO

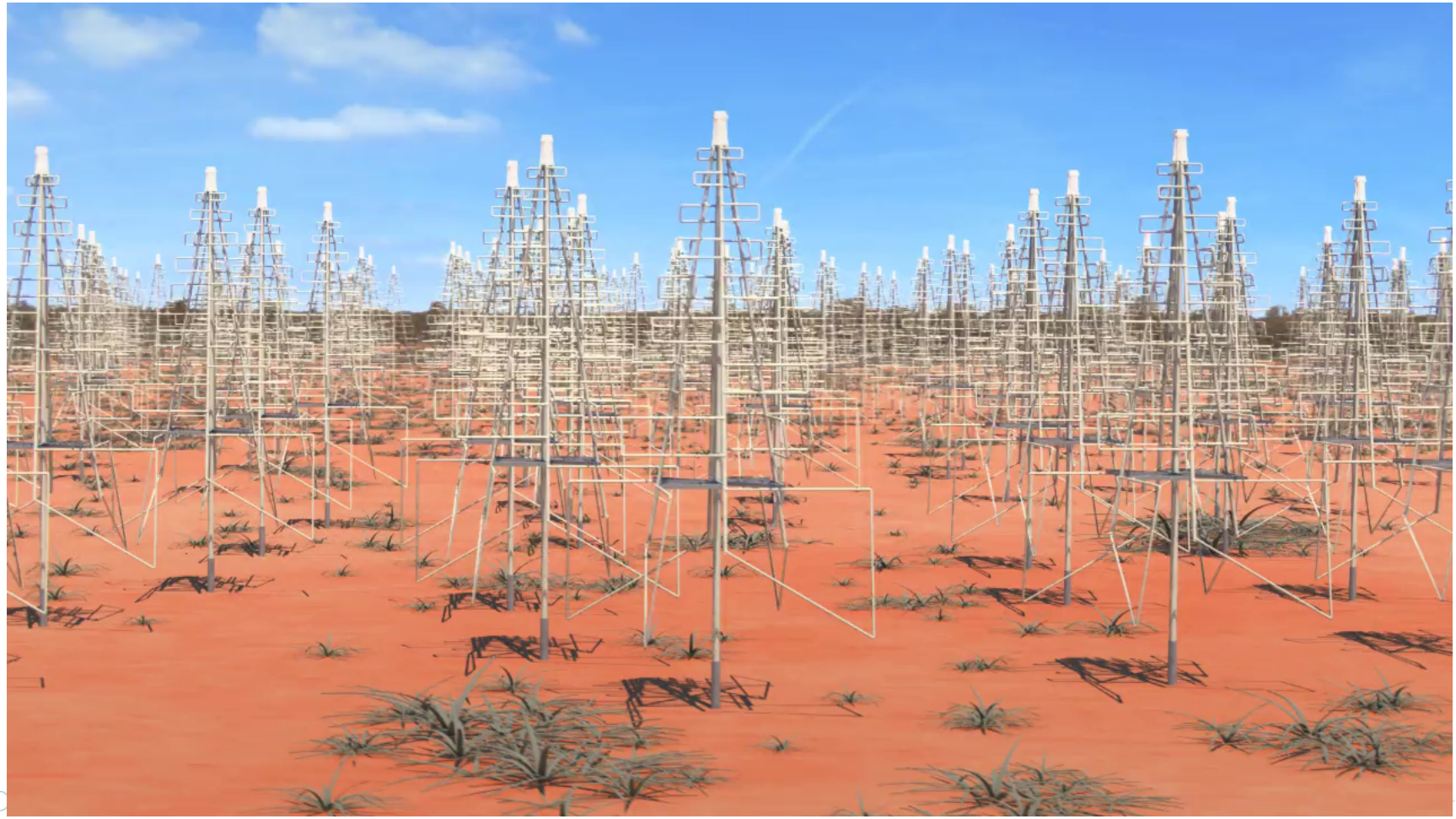
SKA1-MID, Karoo, South Africa:

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

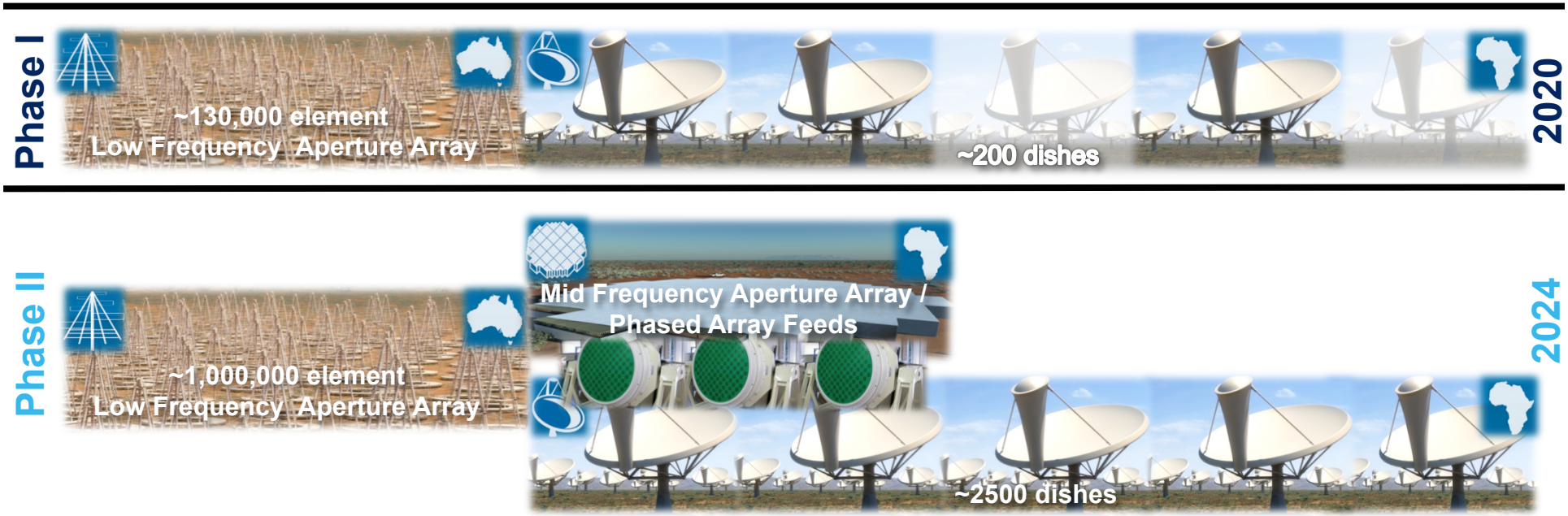
Bands: 2 (0.95–1.76 GHz), 5 (4.6–13.8 GHz), 1 (0.35–1.05 GHz)

SKA1-LOW, Murchison, Australia:

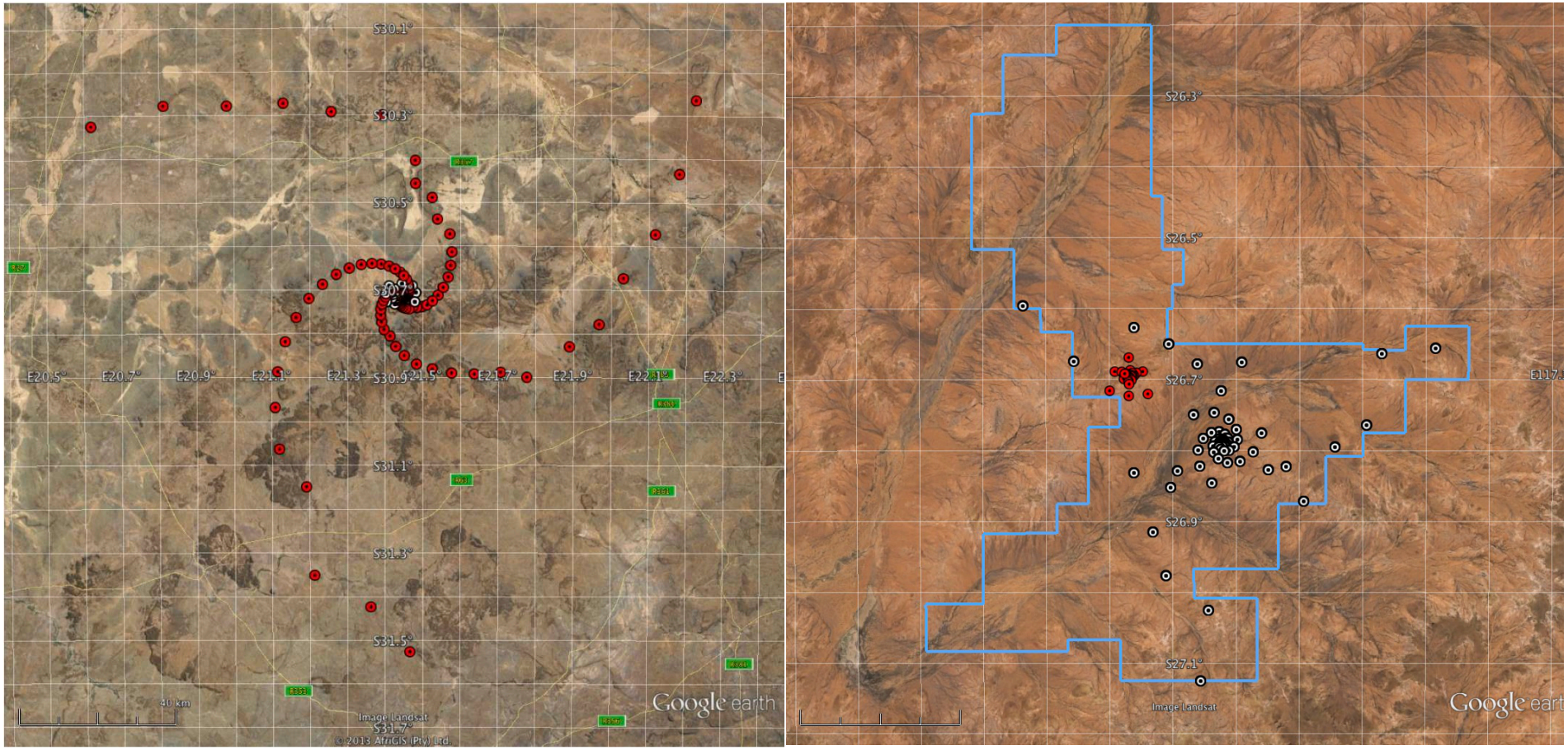
130,000 dipoles (512 stations x 256 antennas); 50–350 MHz
~80km baselines; large areal concentration in core



What is the SKA?

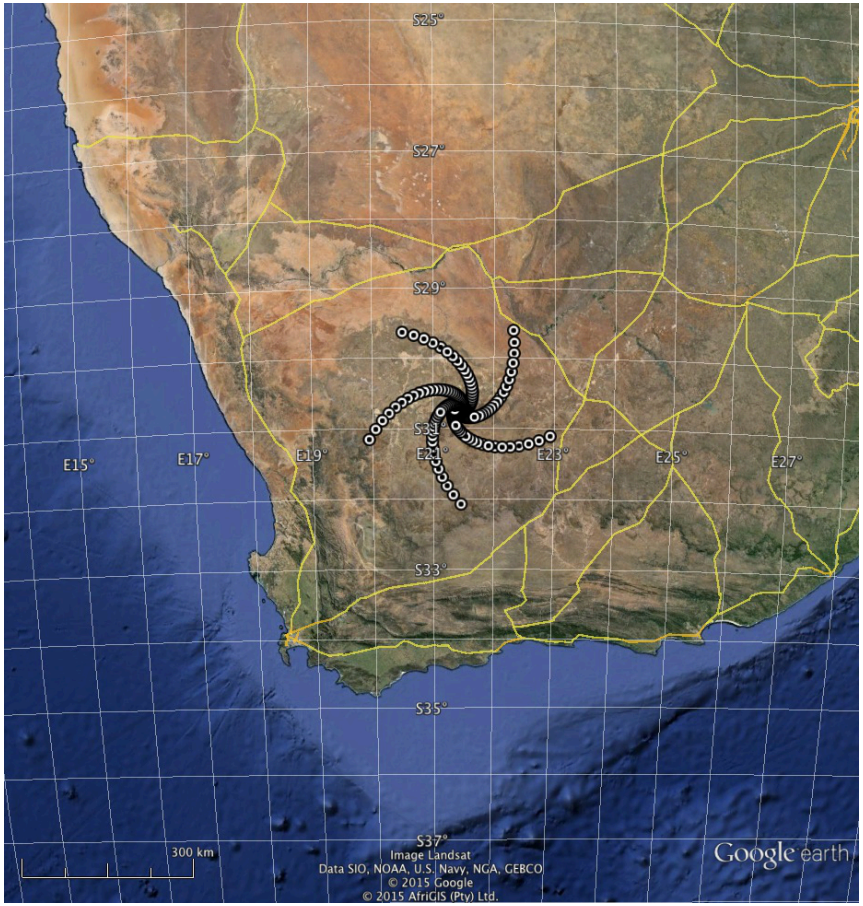


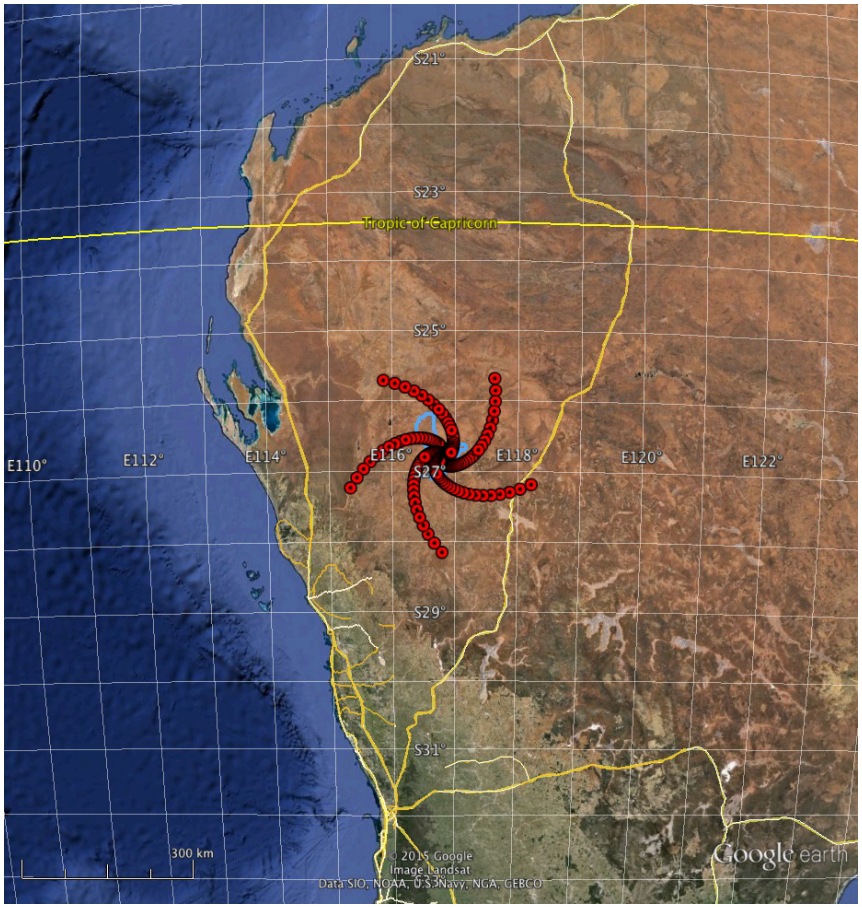
SKA1 Configurations



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

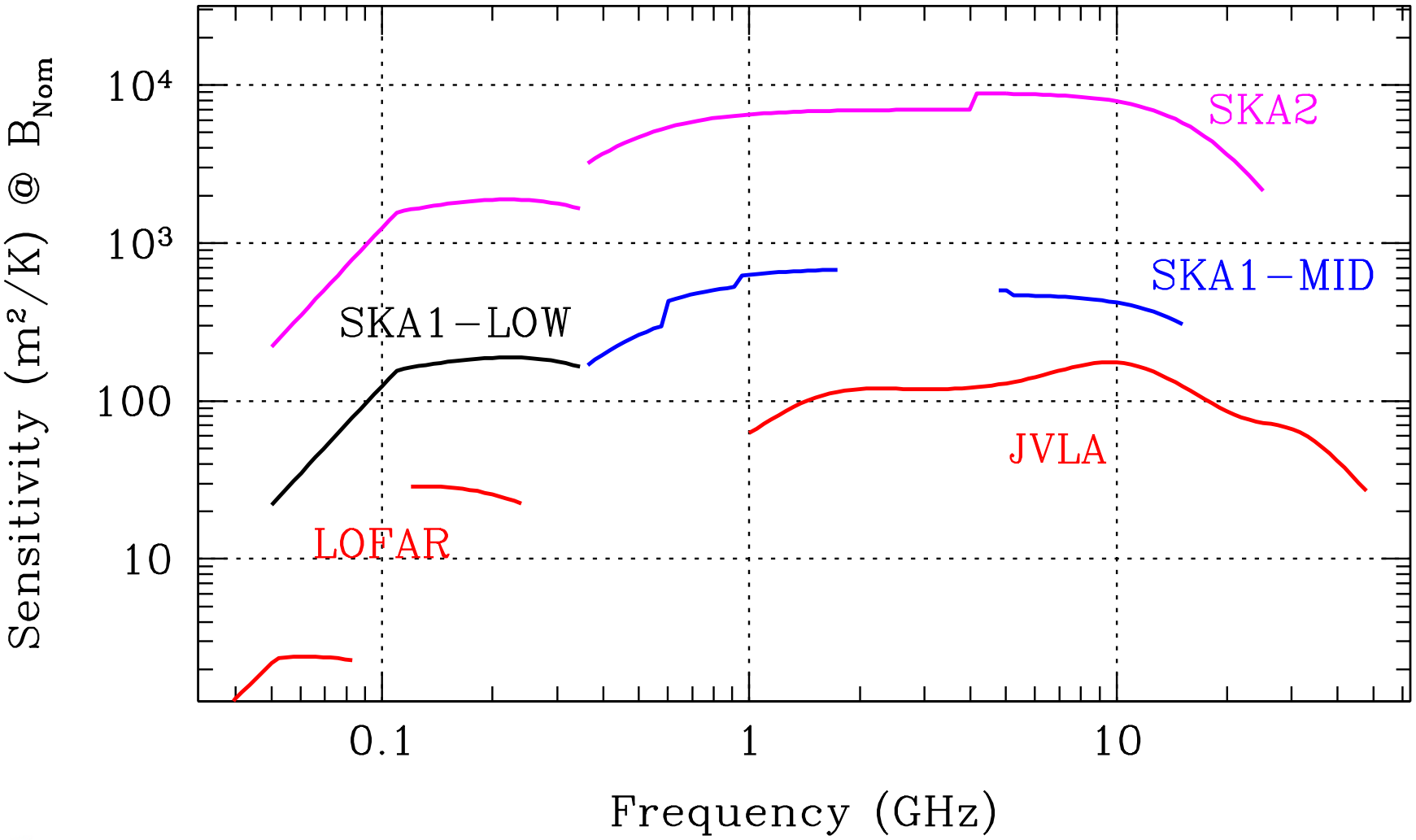
SKA2 Configurations



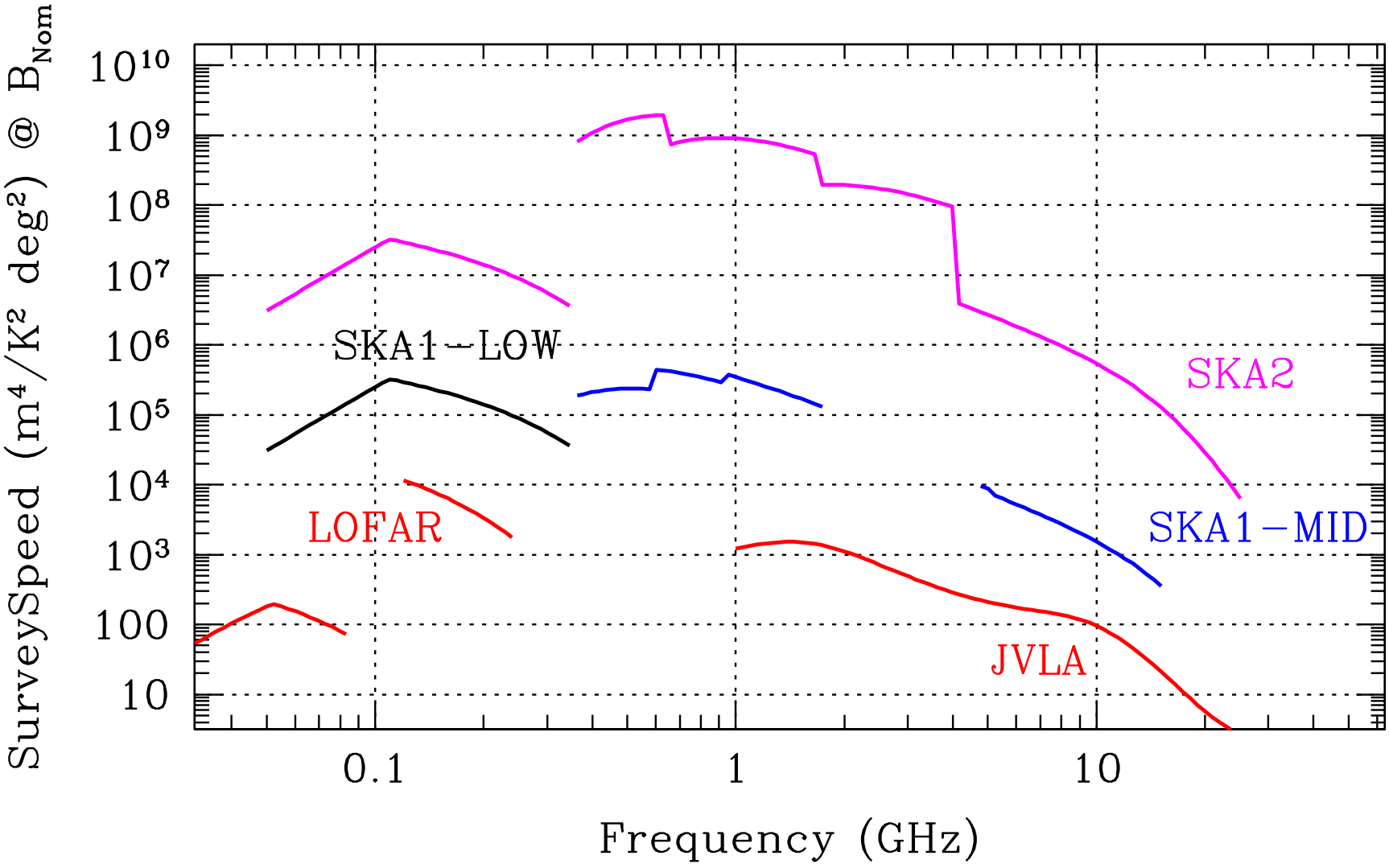


- SKA2–Dish, –LOW: B_{max} ≈ 300 km “core”, ≈3000+ km remote

Sensitivity Comparison



Survey Speed Comparison



Resolution Comparison

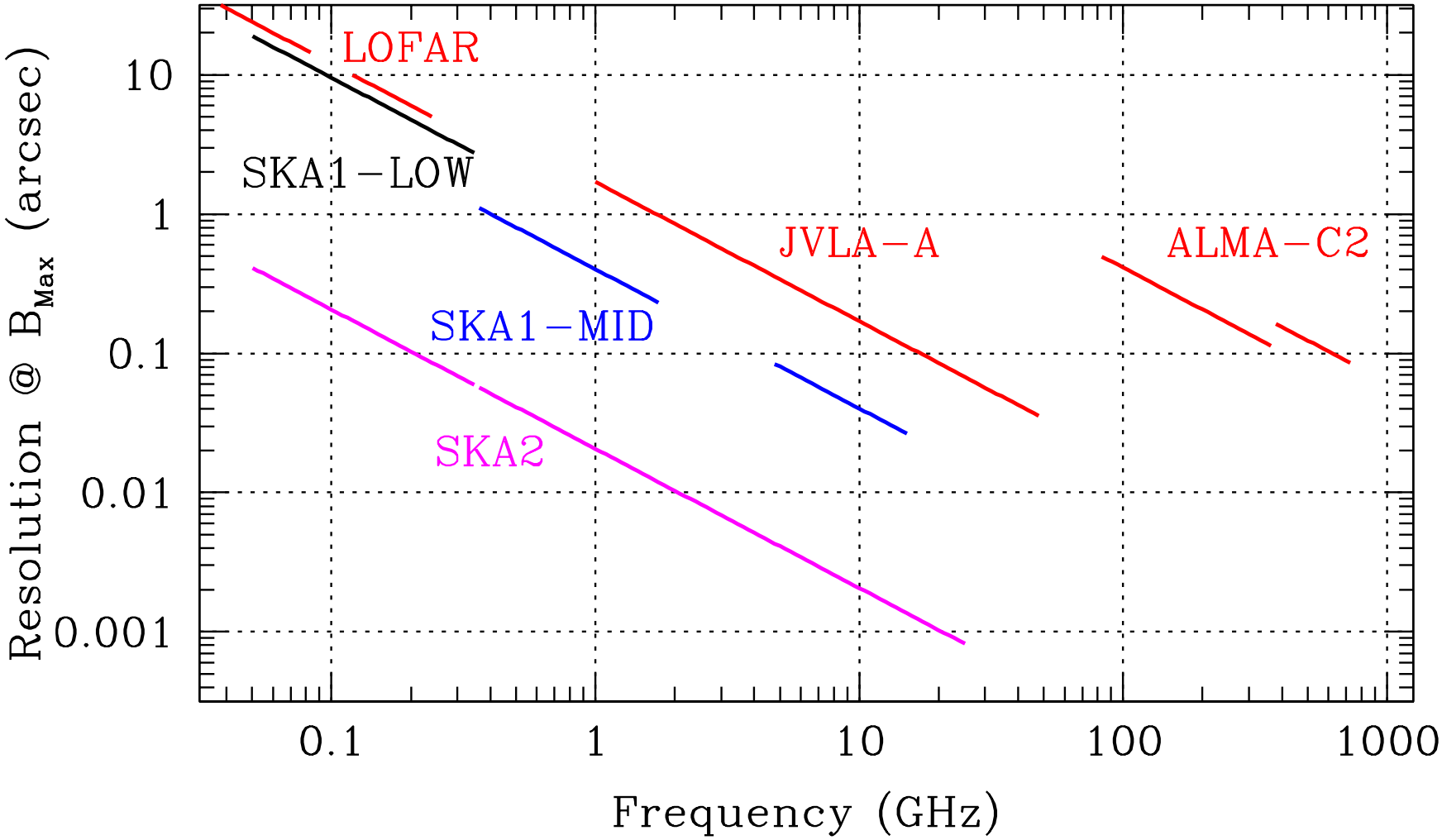
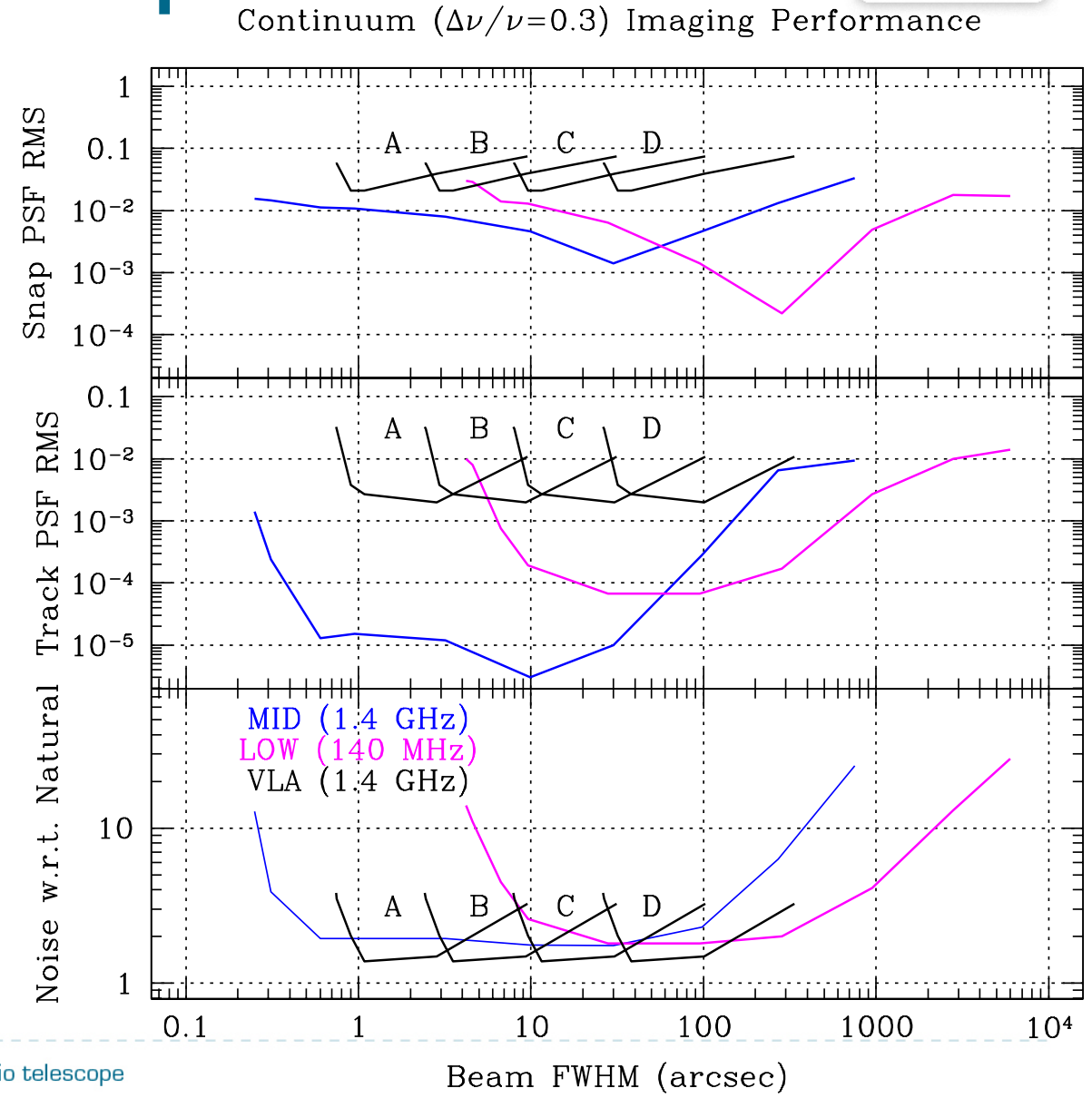


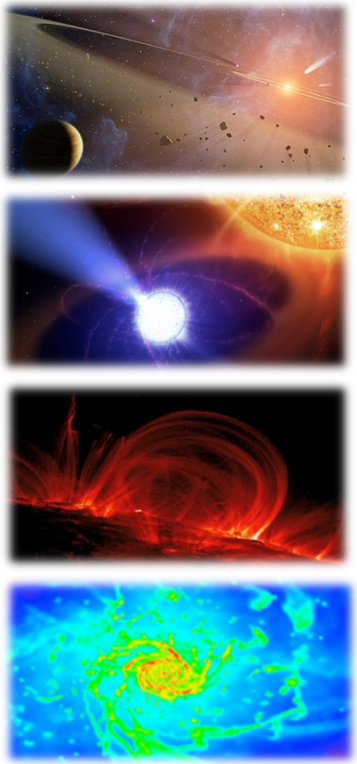
Image Quality Comparison

- 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



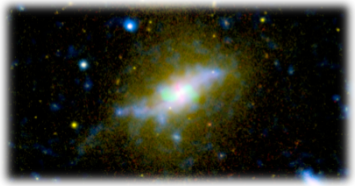
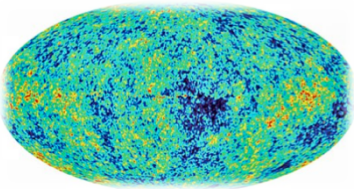
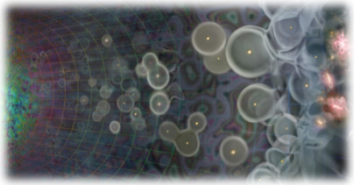
Headline Science with SKA1 and SKA2

	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).

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

Key Science Projects:

- Issue Call for KSP Letters of Intent (circa 2018)
  - Provides opportunity to coordinate appropriate balance of prospective SKA member teams and science topic coverage
- Issue Call for full KSP proposals
- Proposal assessment criteria:
  - Scientific merit
  - Technical feasibility
  - Plans and capabilities for data analysis
  - Publication and derived data product release arrangements
  - Collaboration policies and management arrangements
  - Consistency with science aims expressed in the set of notional KSPs

Key Science Projects:

- Resourcing
  - KSP teams can propose and receive dedicated SKA resources
  - General expectation that teams bring significant additional resourcing
- Data rights
  - Primary data rights remain with the SKA Observatory
  - Data rights are granted to KSP teams for specific objectives
  - Commensal programs can be granted data rights for complementary objectives
- Ongoing review
  - Satisfactory progress against project plan, including timely public release of agreed data products is condition for further allocations

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

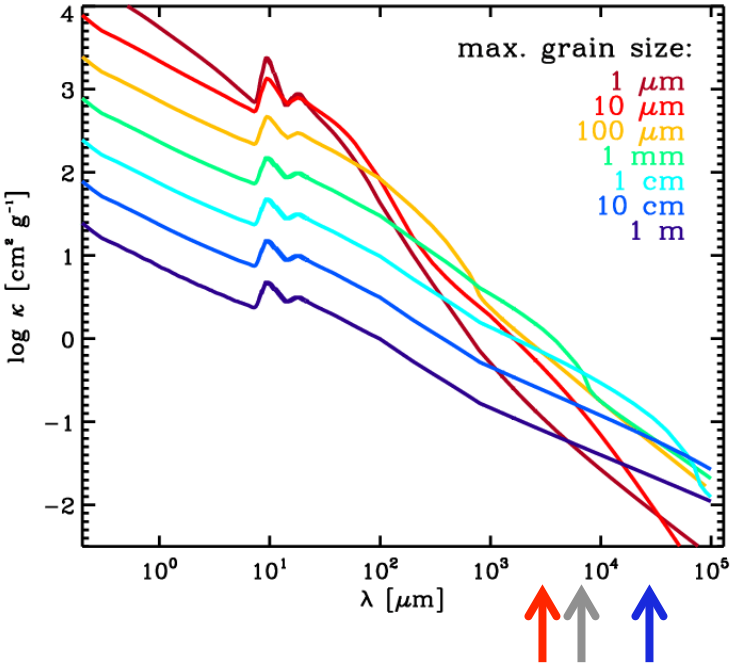
Key Science Projects:

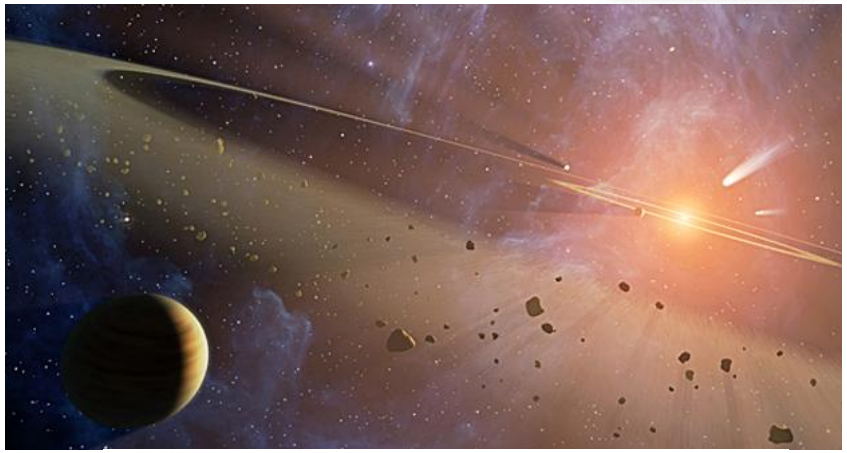
- Some areas of feed-back/concern and their clarification:
  - ***Notional*** KSPs versus ***actual*** KSPs
    - Need to stress that the current list is representative and not final
    - KSP process must allow for best new ideas and not be frozen too early
  - KSP ***proposals*** versus KSP ***programs***
    - Need to clarify that KSPs are large but otherwise normal observing proposals
    - KSPs are not blanket allocations of science areas to specific groups
  - ***Limited*** versus ***general*** data rights
    - KSPs only granted limited data rights for specific science objectives and well-motivated proprietary period
    - Same data stream may well serve multiple KSPs, each with limited objectives
  - ***Global*** versus ***project*** member balance
    - Member balance would only be imposed globally on entire KSP package
    - Letter of Intent phase to gauge national aspirations and membership projections

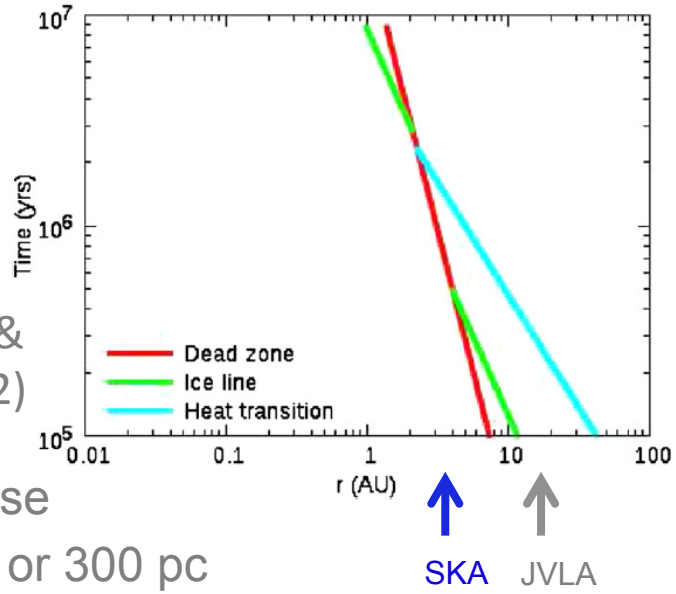
KSPs: Next step, 2015 Stockholm Workshop

- 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.

The Cradle of Life:
Understanding planet formation



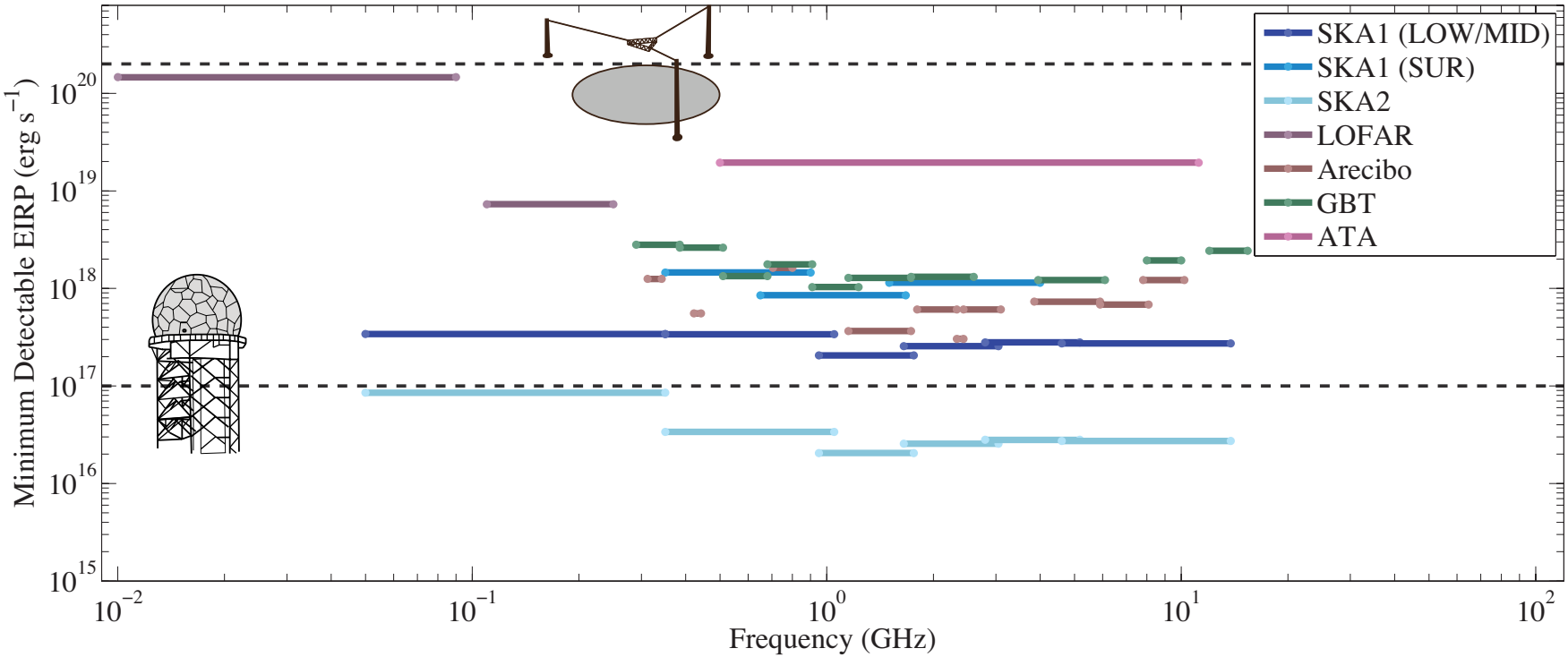




(Hasegawa & Pudritz 2012)

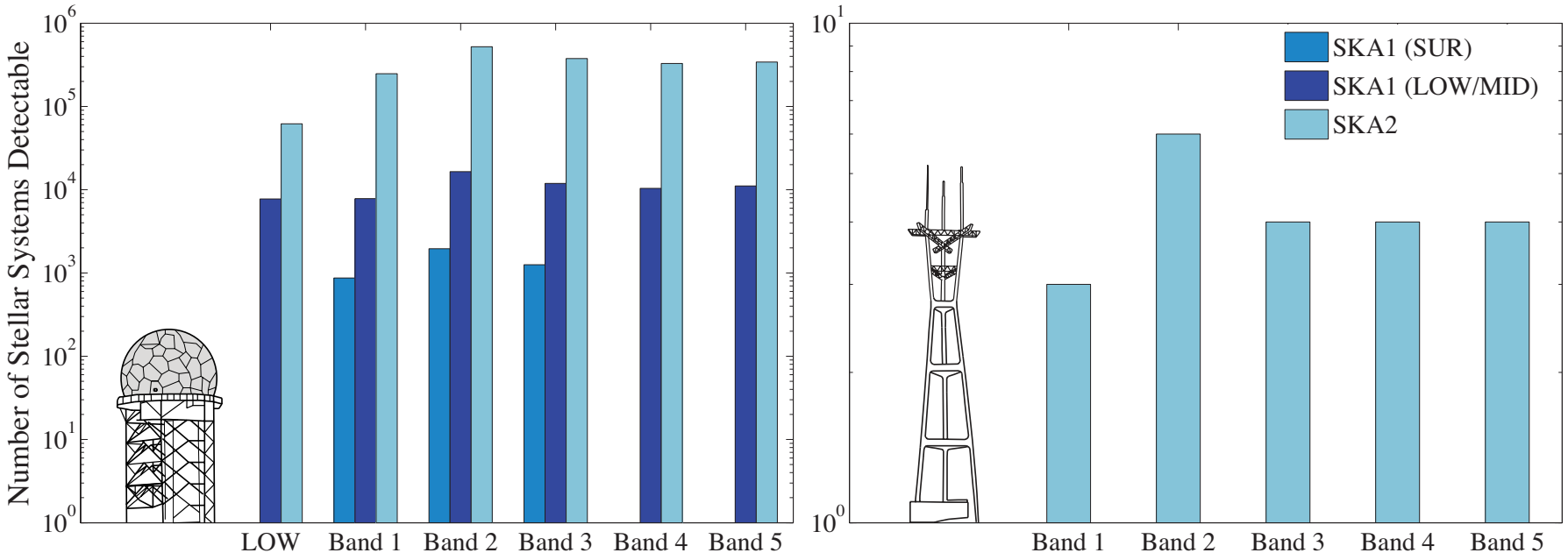
- Measuring grain growth through planetesimal phase
- Resolving proto-planetary disks at 100 pc (SKA1) or 300 pc (SKA2) inside the snow/ice line, sub-AU scales with SKA2

Headline SETI Science



- Detection thresholds for planetary and airport radars at 15 pc

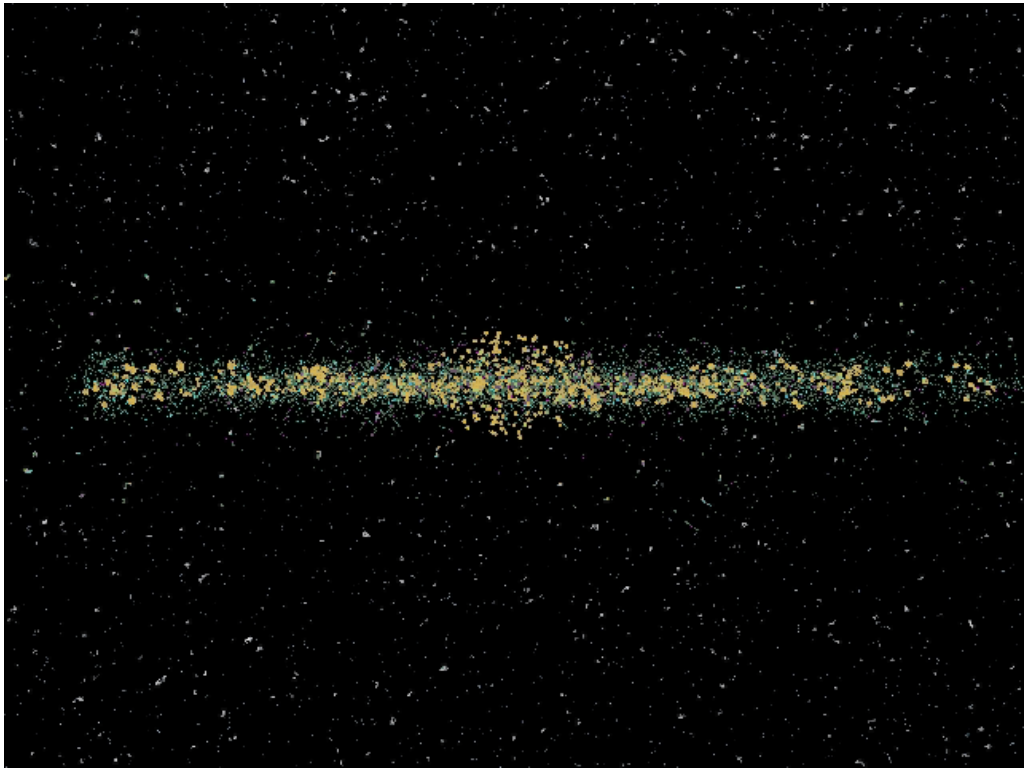
Headline SETI Science

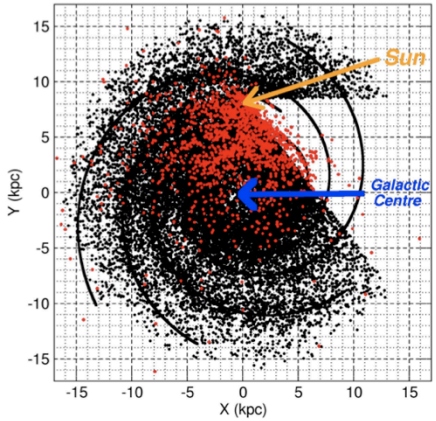


- Detectable stars with airport radar power ~ 10^4 with SKA1
- Detectable stars with TV transmitter power ~10 with SKA2

Finding all the pulsars in the Milky Way…

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

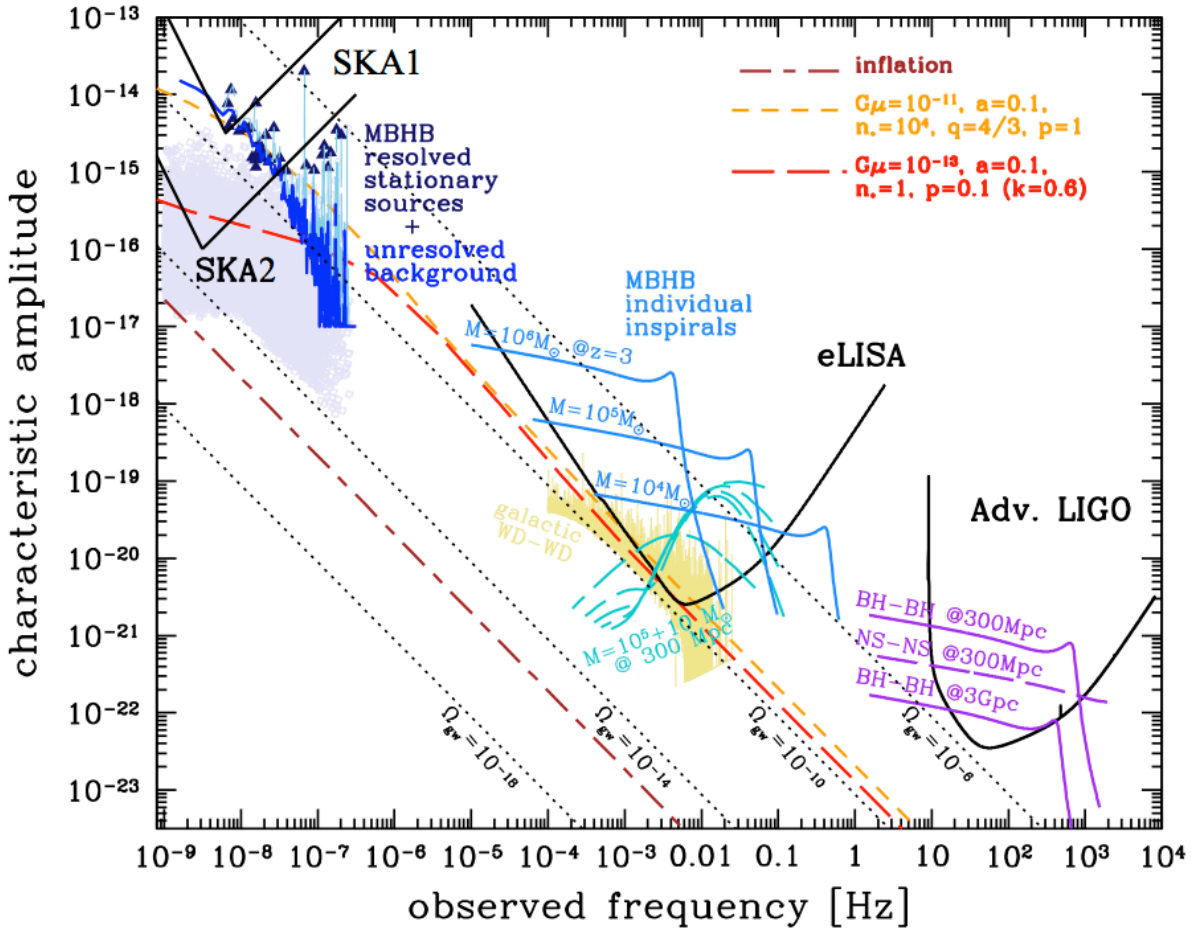




- ~40,000 normal pulsars
- ~2,000 millisecond psrs
- ~100 relativistic binaries
- first pulsars in Galactic Centre
- first extragalactic pulsars

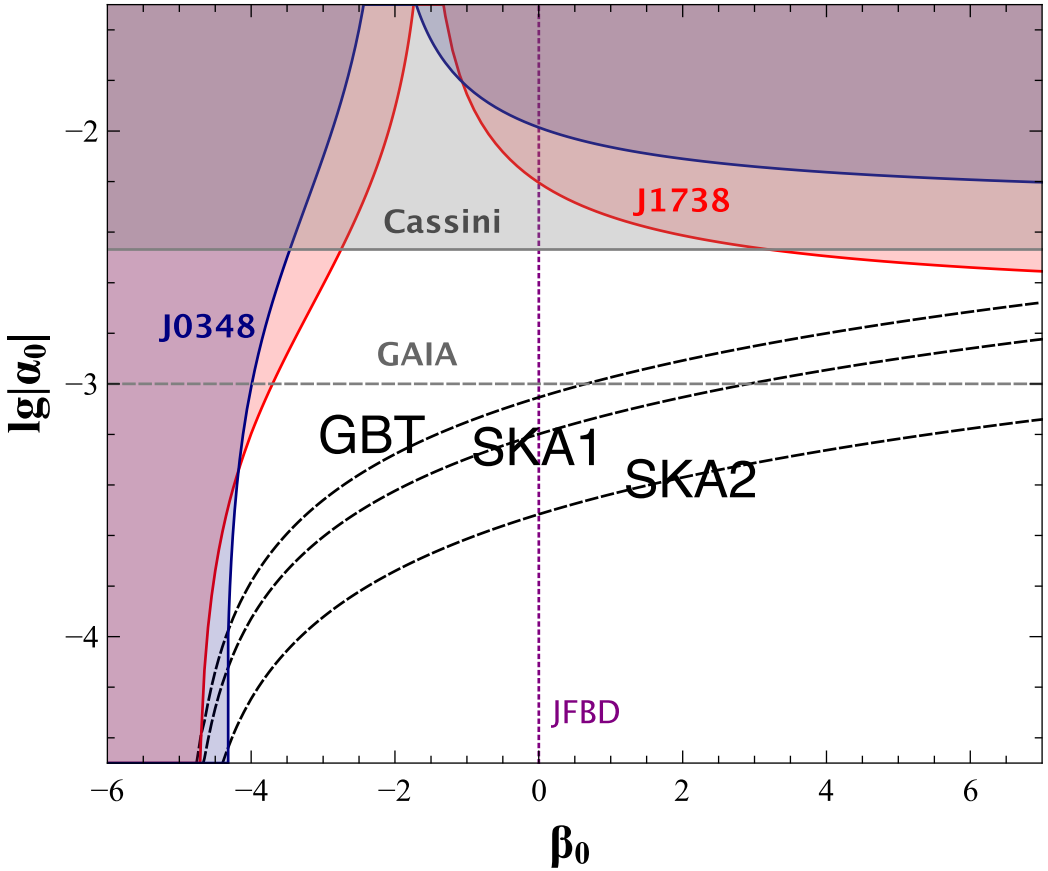
- Timing precision is expected to increase by factor ~100
- Rare and exotic pulsars and binary systems: including PSR-BH systems!
- Testing cosmic censorship and no-hair theorem
- **Current estimates are ~50% of population with SKA1, 100% with SKA2**

Headline Pulsar Science



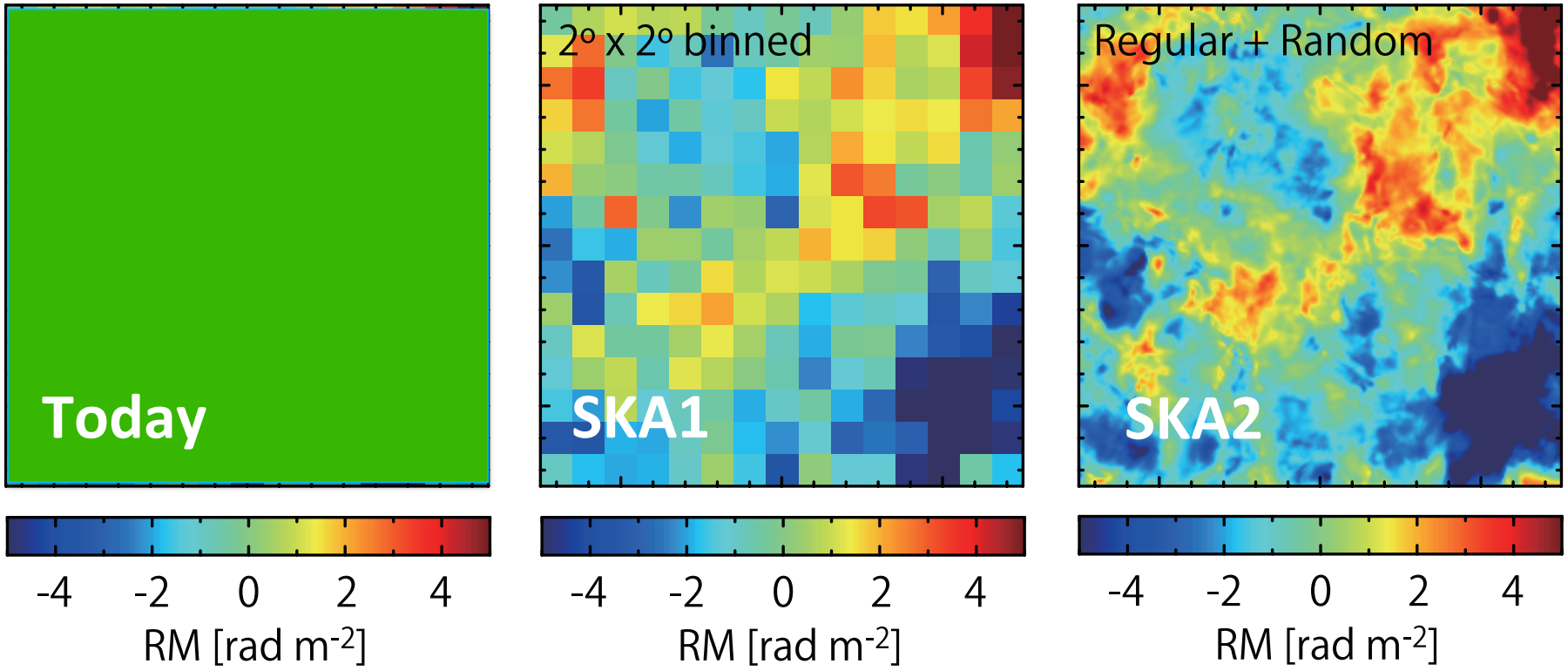
- Detection thresholds for discrete GW source detection; the first discoveries with SKA1, “GW astronomy” with SKA2

Headline Pulsar Science



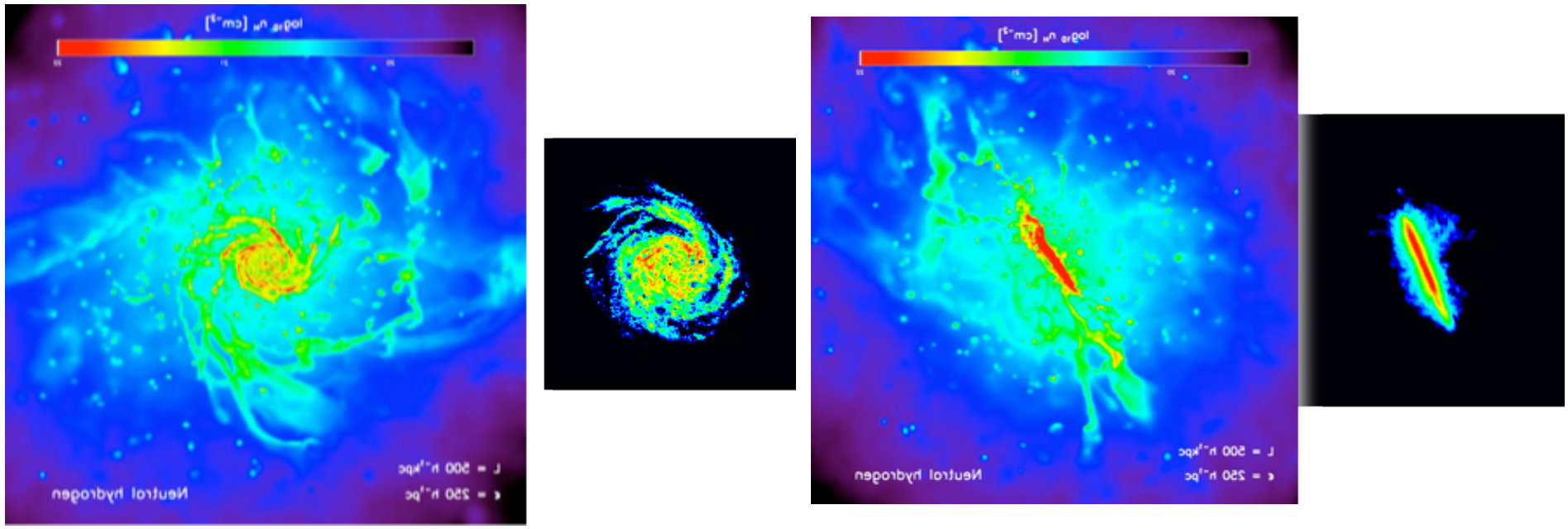
- Pulsar 5 year timing constraints from a MSP-BH binary (1.4, 10 $M_\odot$) on scalar-tensor theories of gravity

Headline Magnetism Science



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

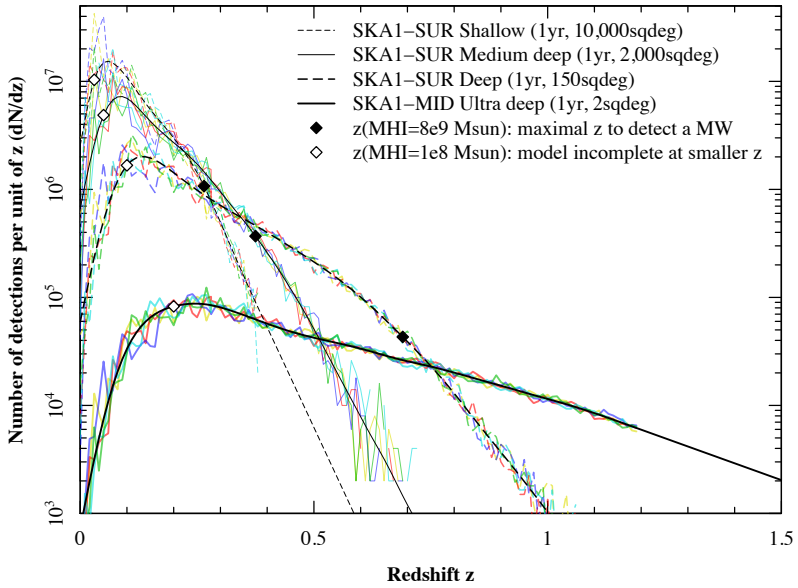
Galaxy HI Evolution:
out to z ~ 1 with SKA1 and z ~ 5 with SKA2

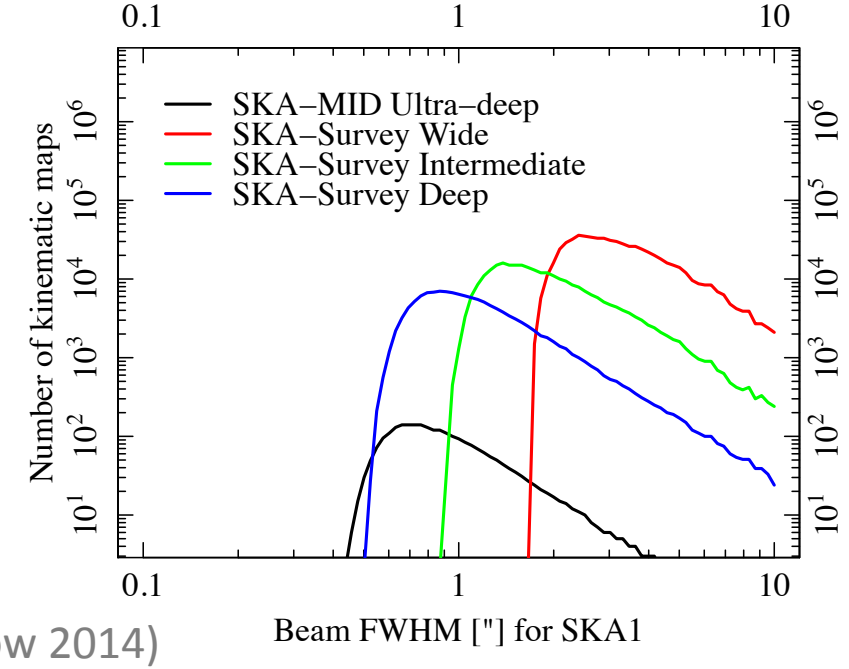


(Simulations: Schaye et al. 2010, Images: Oosterloo 2014)

- Understanding galaxy assembly and the baryon cycle
  - Determine the impact of galaxy environments
  - Probe gas inflow and removal, diffuse gas $N_{HI} < 10^{17}$ cm^{-2}
  - Measure angular momentum build-up

Galaxy HI Evolution: out to z ~ 1 with SKA1 and z ~ 5 with SKA2

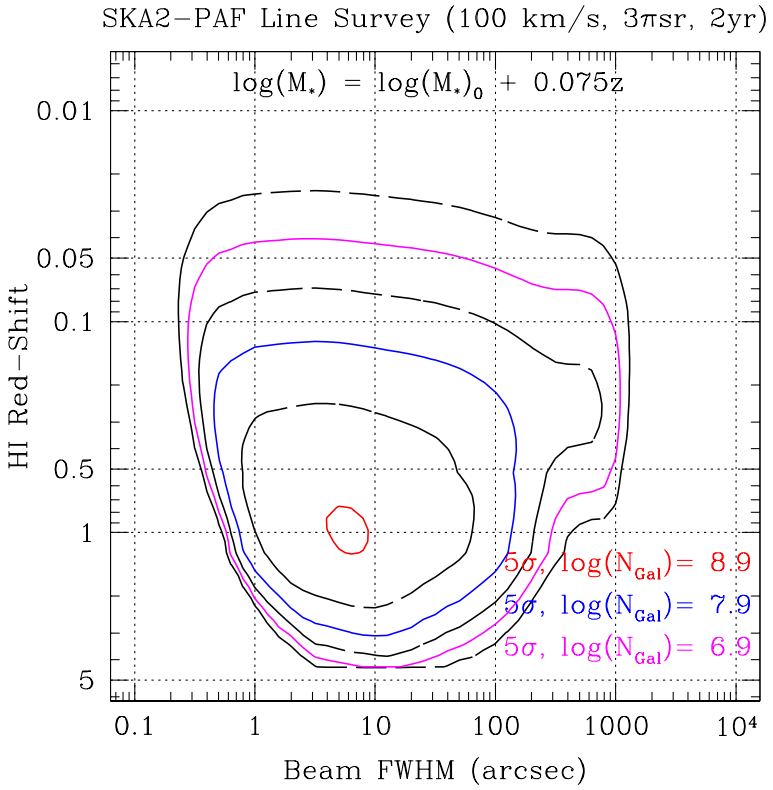




(Obreschkow 2014)

- Understanding galaxy assembly and the baryon cycle
  - Determine the impact of galaxy environments
  - Probe gas inflow and removal, diffuse gas $N_{HI} < 10^{17}$ cm^{-2}
  - Measure angular momentum build-up

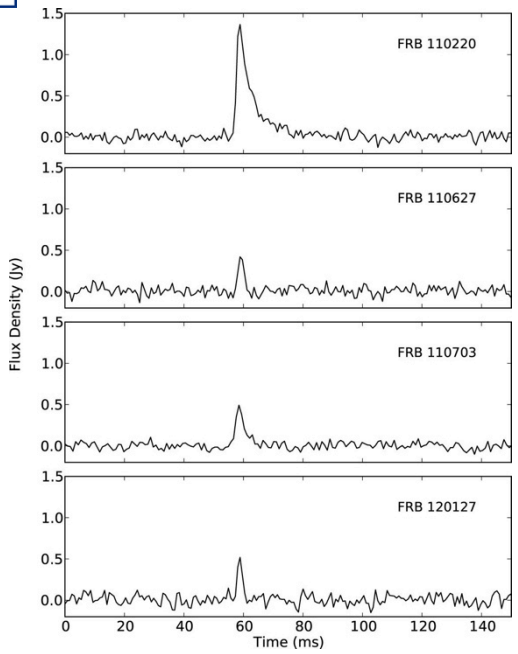
Precision Cosmology with SKA2 HI

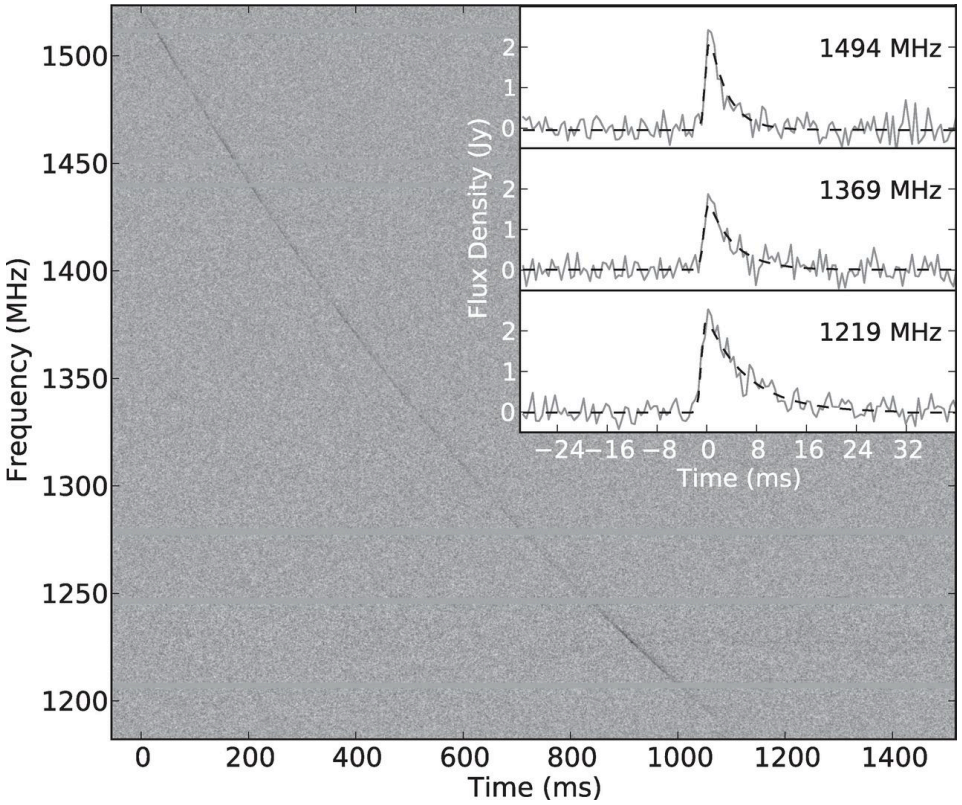


- Detect $10^{8.9}$ galaxies with <z> ≈ 1, $10^{7.9}$ with <z> ≈ 2
- Compare Euclid (2020+5?) target of 10^{8} spectra with <z> ≈ 1
- **SKA2 will provide an unrivaled capability for precision cosmology!**

The Transient radio sky

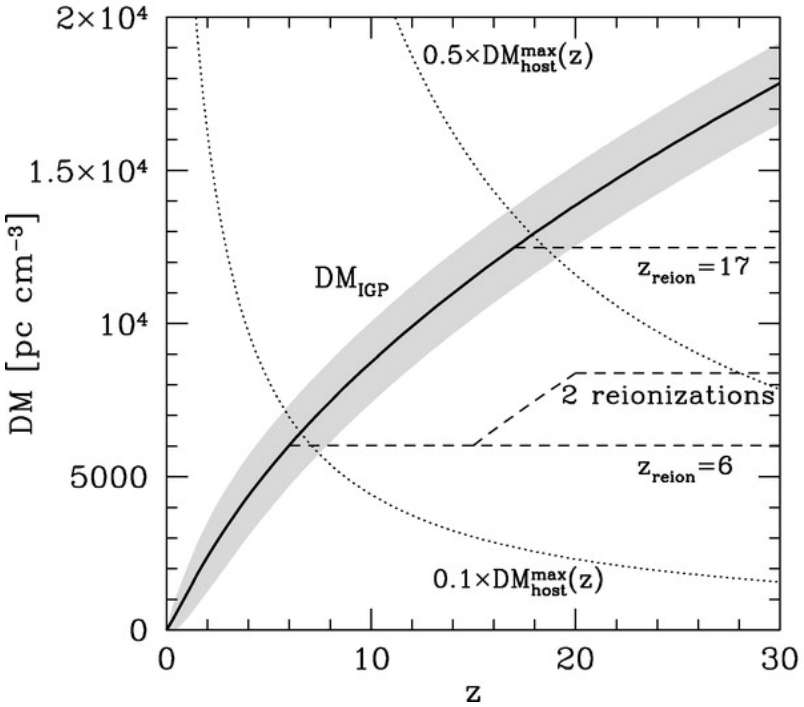
A Population of Fast Radio Bursts at Cosmological Distances
D. Thornton *et al.*
Science **341**, 53 (2013);
DOI: 10.1126/science.1236789



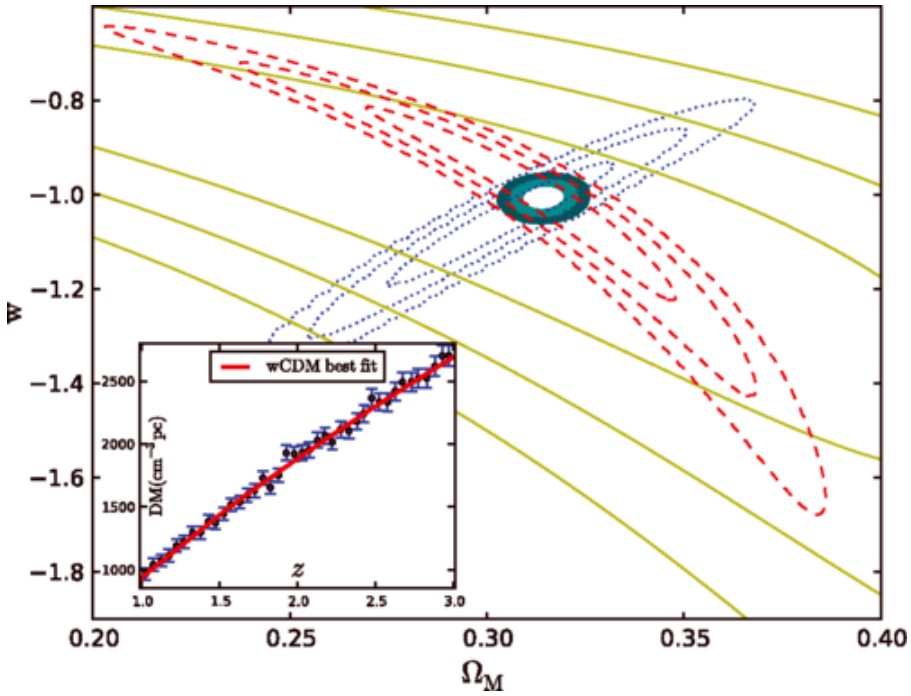


- Four celestial “FRB” events now detected (after first “Lorimer” burst):
  S = 0.5 – 1.3 Jy, Δt = 1 – 6 msec, DM = 550 – 1100 cm^{-3} pc
- Estimated event rate: $1x10^4$ sky^{-1} day^{-1}
- Completely unknown origin, possibly at cosmological distances

Transients headline science: Fast Radio Bursts as a cosmological probe



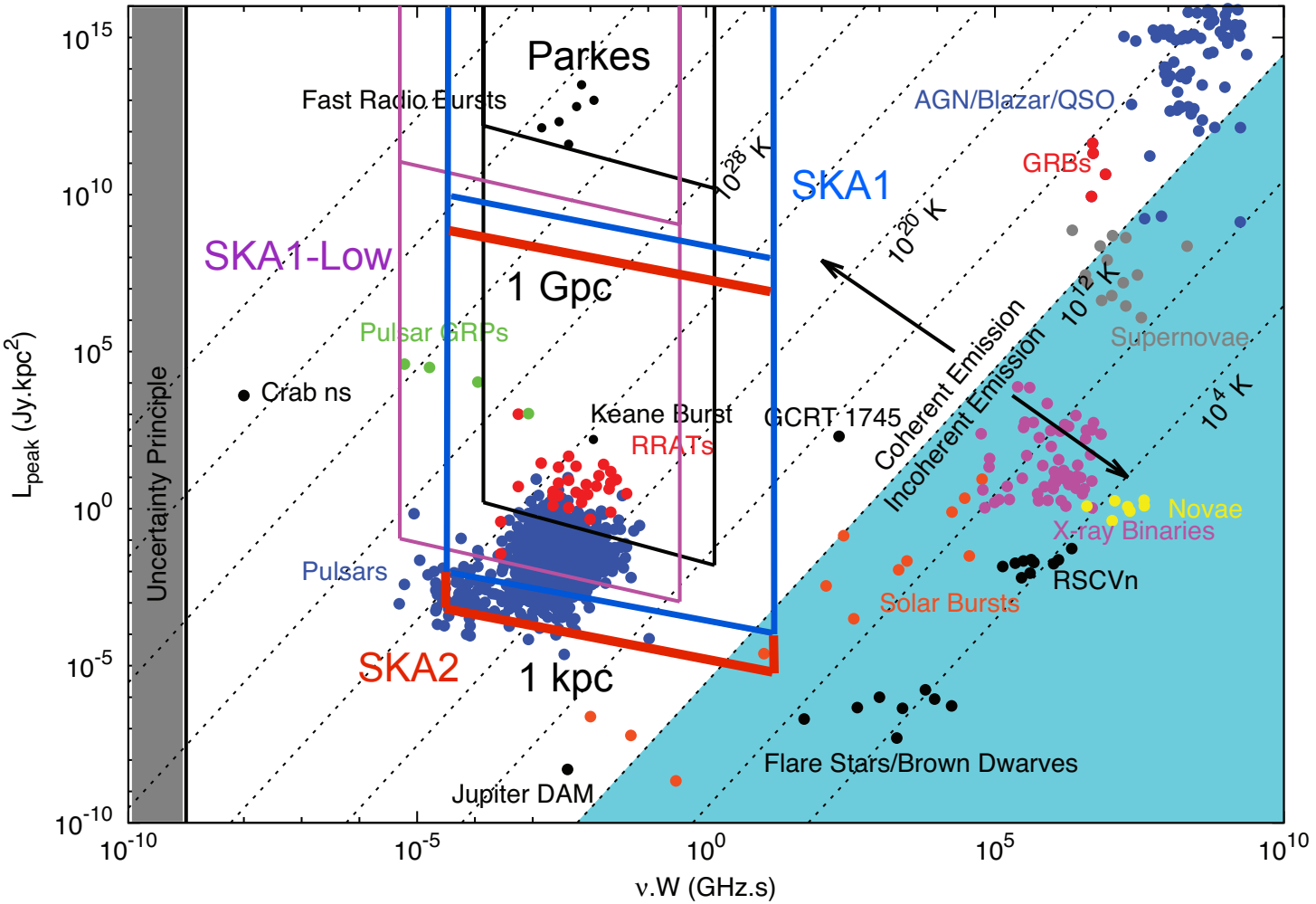
(Ioka 2003)



(Zhou et al. 2014)

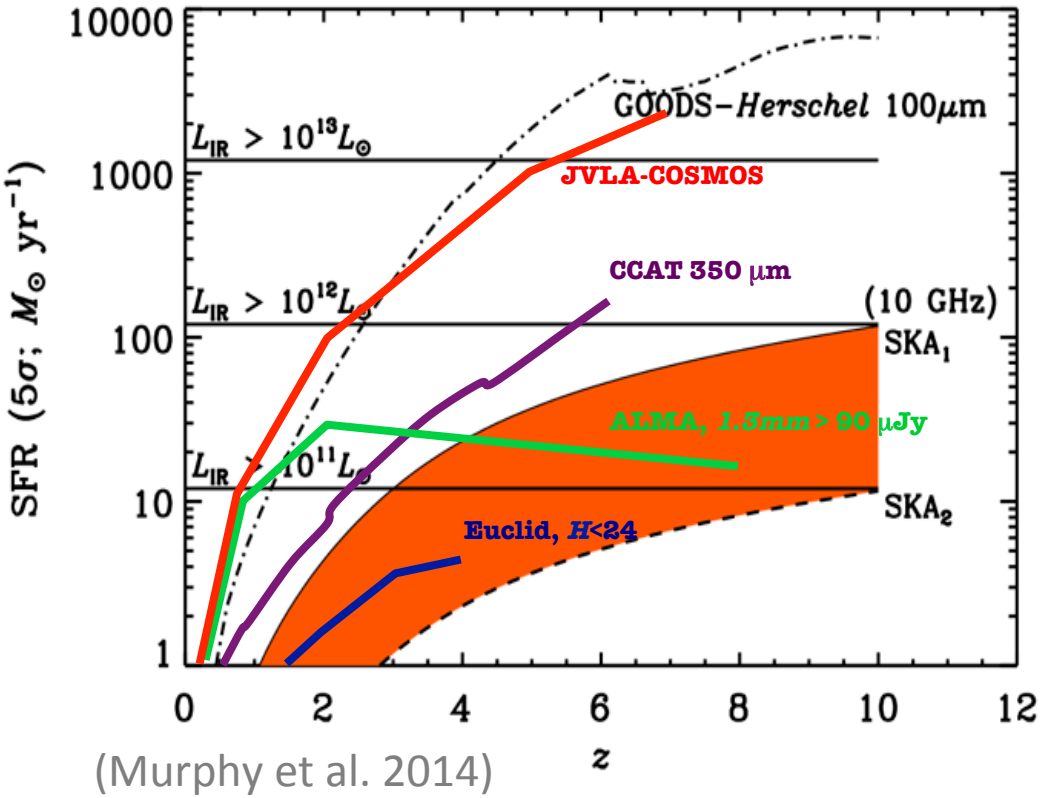
- Prospects for fundamental contributions to cosmology with large samples (~1000) of spectroscopically identified FRBs out to z ~ 2 with SKA1 and z ~ 5 with SKA2

Transients headline science: Untapped discovery space

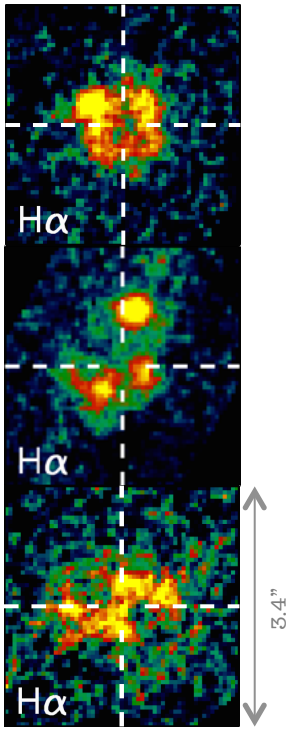


- Prospects for entirely new classes of transient phenomena

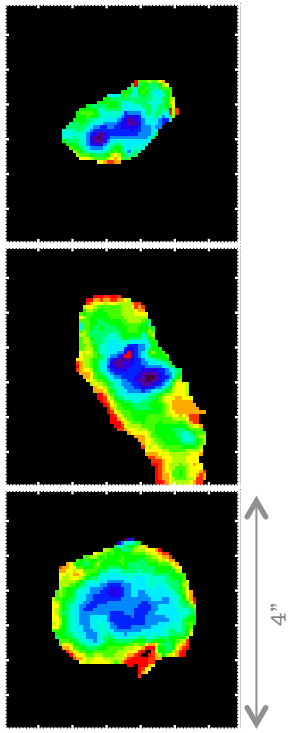
Galaxy Evolution Studies in the Radio Continuum: Understanding the Star Formation History of the Universe



(Murphy et al. 2014)



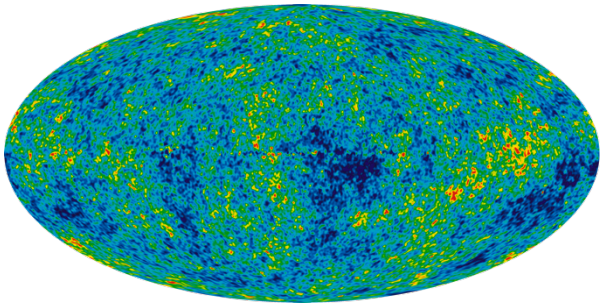
Wuyts et al 2013, **z~1**
Hα–based SFR-maps

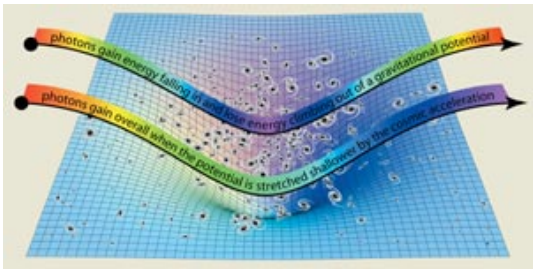


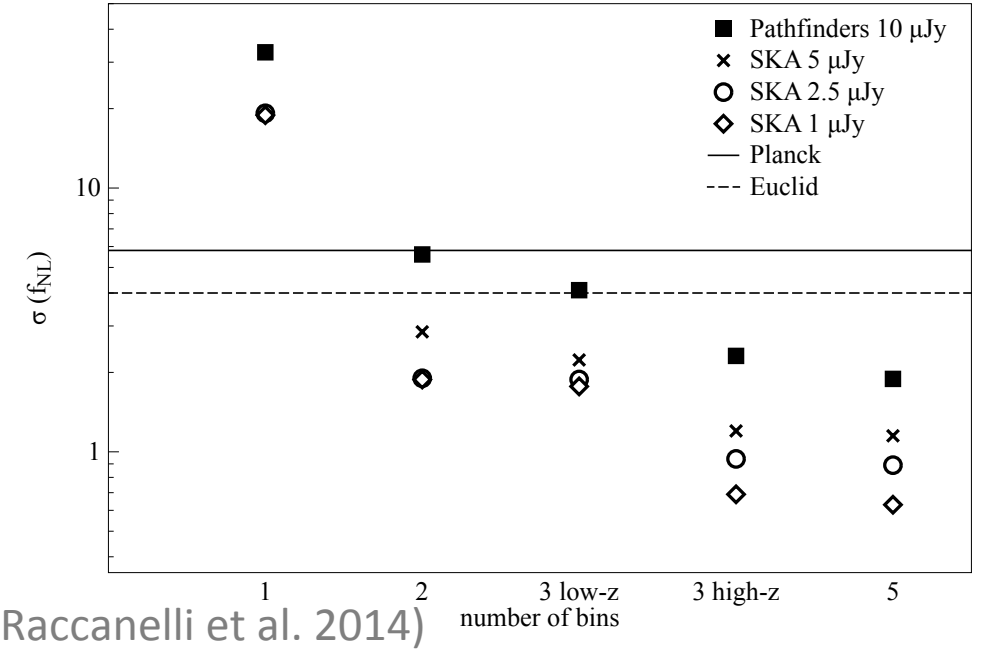
Cibinel et al 2014, **z~2**
UV-based SFR-maps

- Unmatched sensitivity to star formation rates (10 $M_\odot$/yr) out to z ~ 4 with SKA1 and z ~ 10 with SKA2
- Resolved (sub-kpc) imaging of star forming disks out to z ~ 1 with SKA1 and z ~ 6 with SKA2

Cosmology with SKA: Integrated Sachs-Wolfe effect



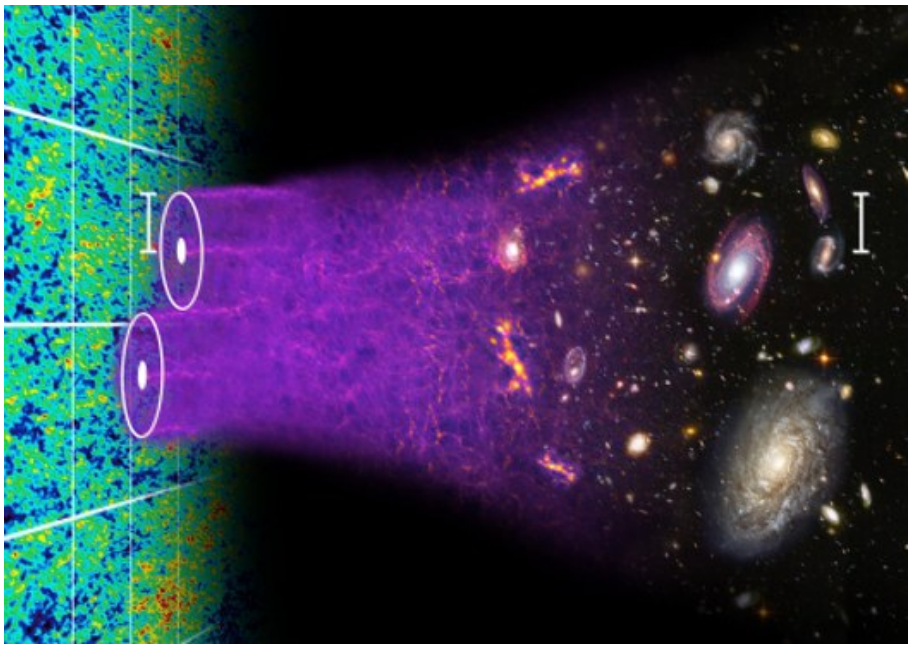




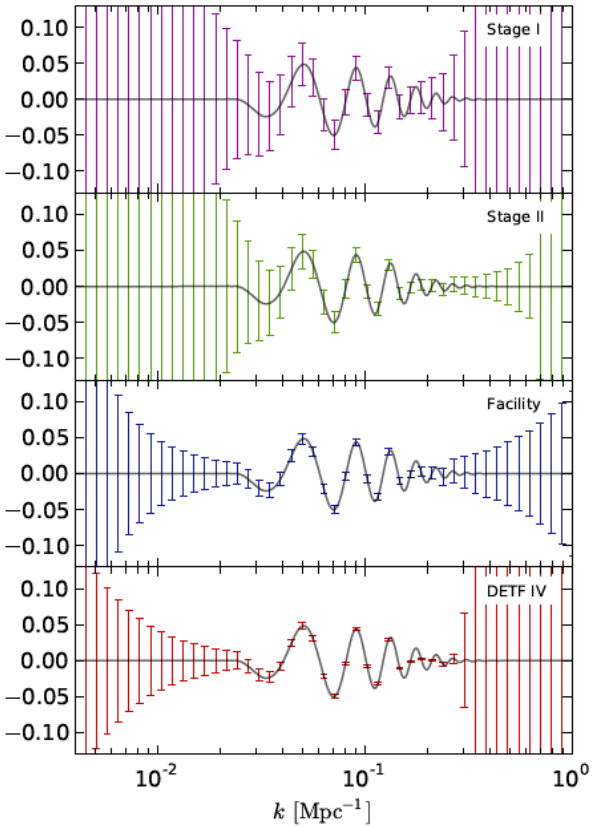
(Raccanelli et al. 2014)

- 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: Baryon Acoustic Oscillations

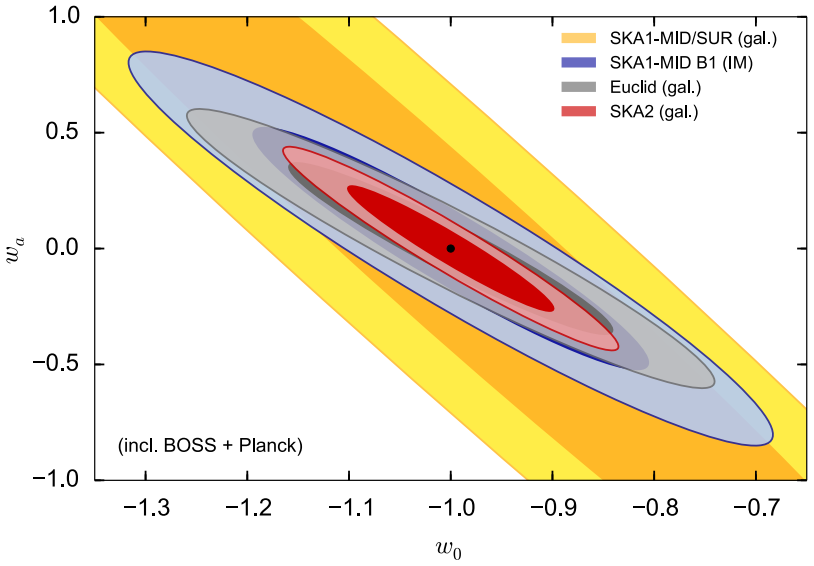


(Blake & Moorfield)

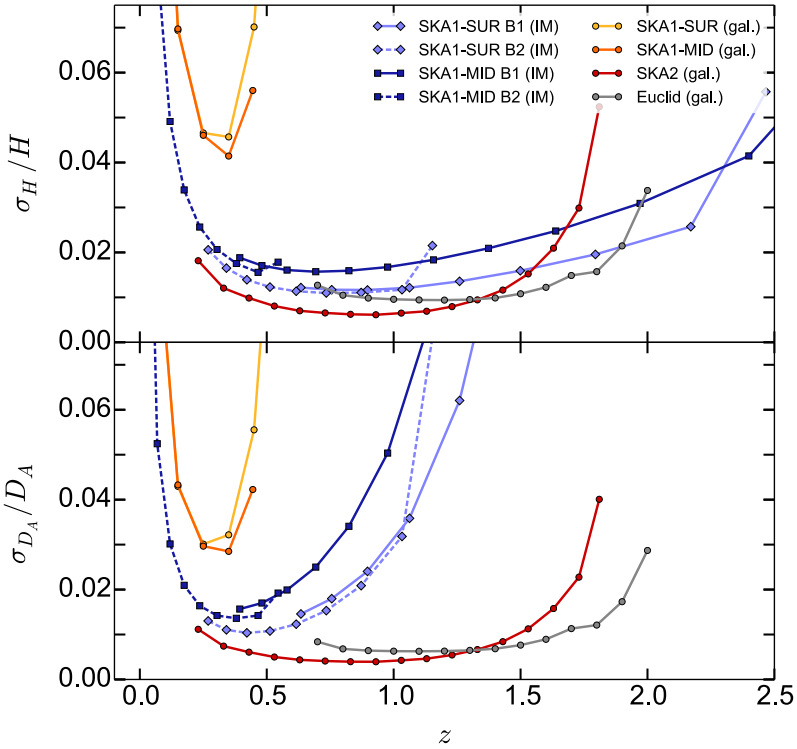


- Constraining Dark Energy models with redshift-resolved BAO measurements
  - Discrete detection is complementary with SKA1, cutting edge in SKA2
  - Intensity mapping is higher risk but world-class, even with SKA1

Cosmology with SKA: Baryon Acoustic Oscillations



(Bull et al 2014)



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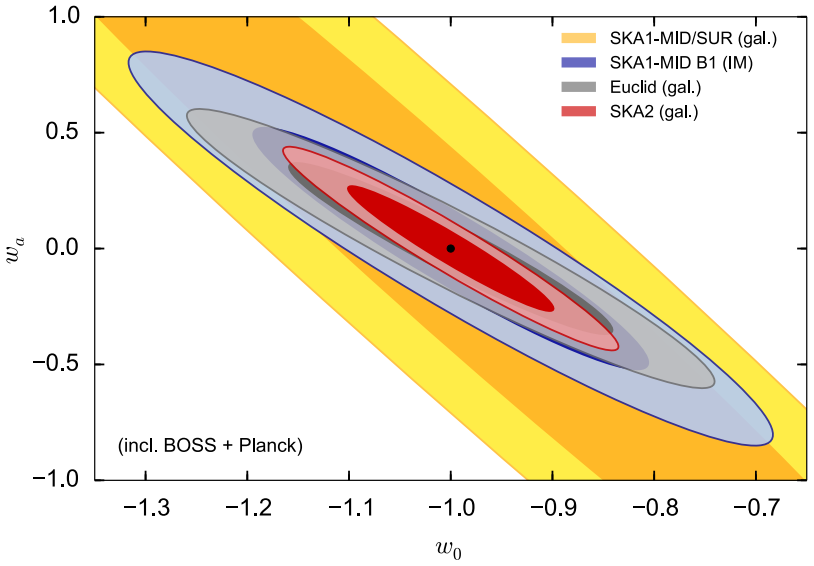
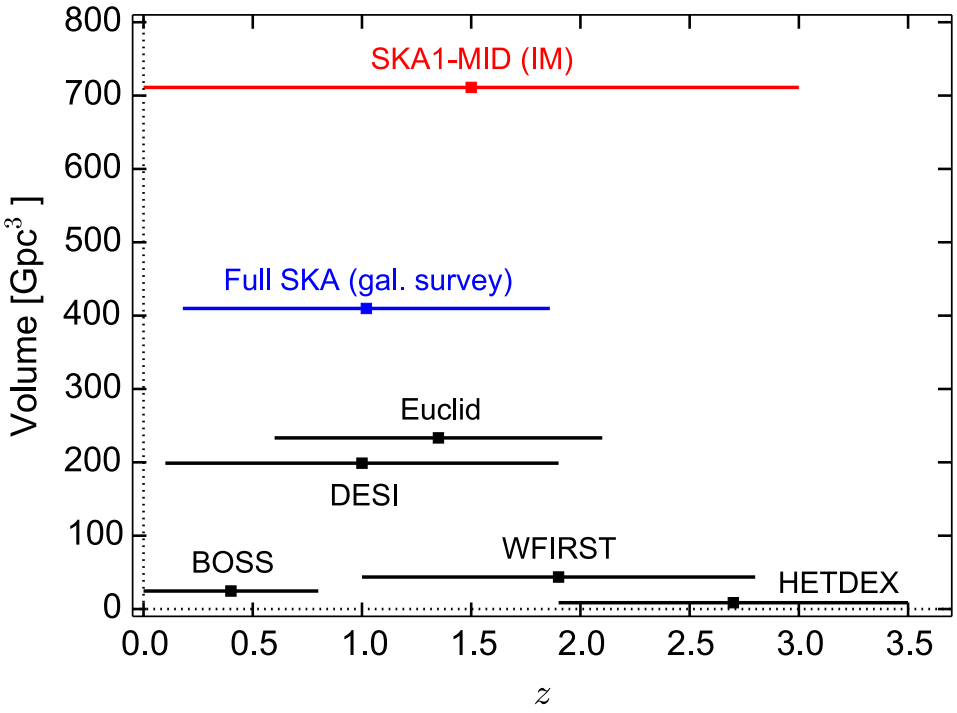
Cosmology with SKA: Baryon Acoustic Oscillations

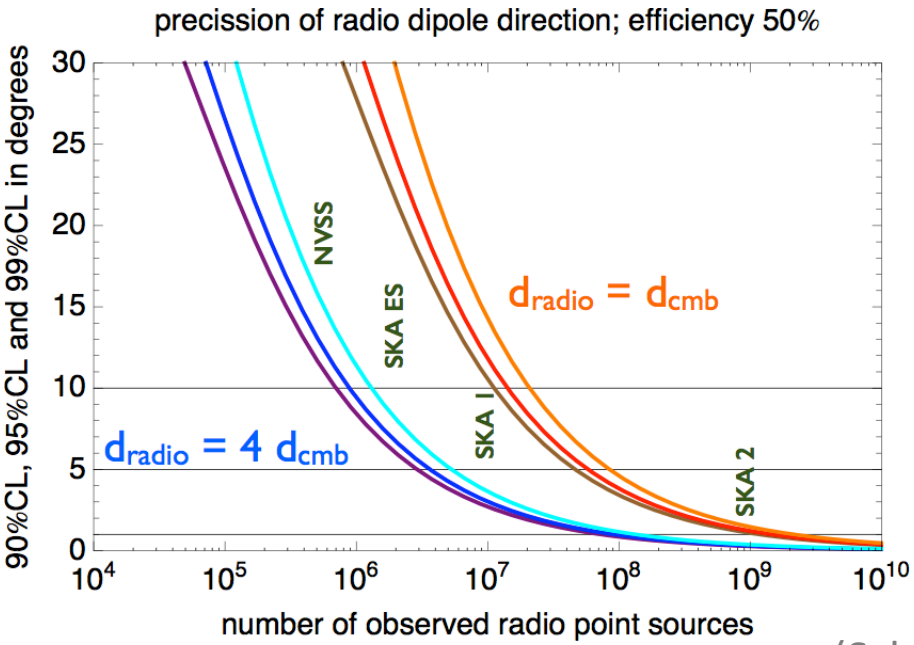


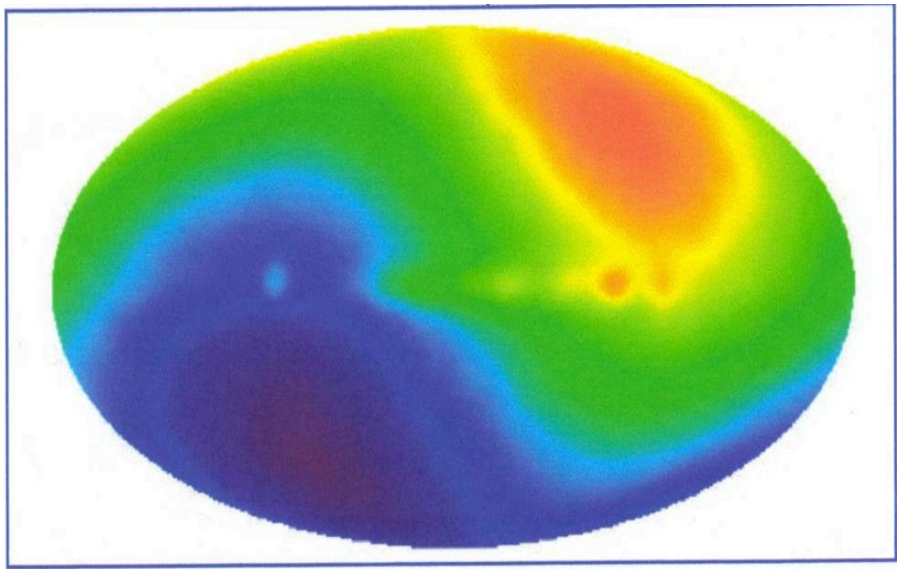


(Bull et al 2014)

- Constraining Dark Energy models with redshift-resolved BAO measurements
  - Discrete detection is complementary with SKA1, cutting edge in SKA2
  - Intensity mapping is higher risk but world-class, even with SKA1

Cosmology with SKA: Matter Dipole versus CMB Dipole

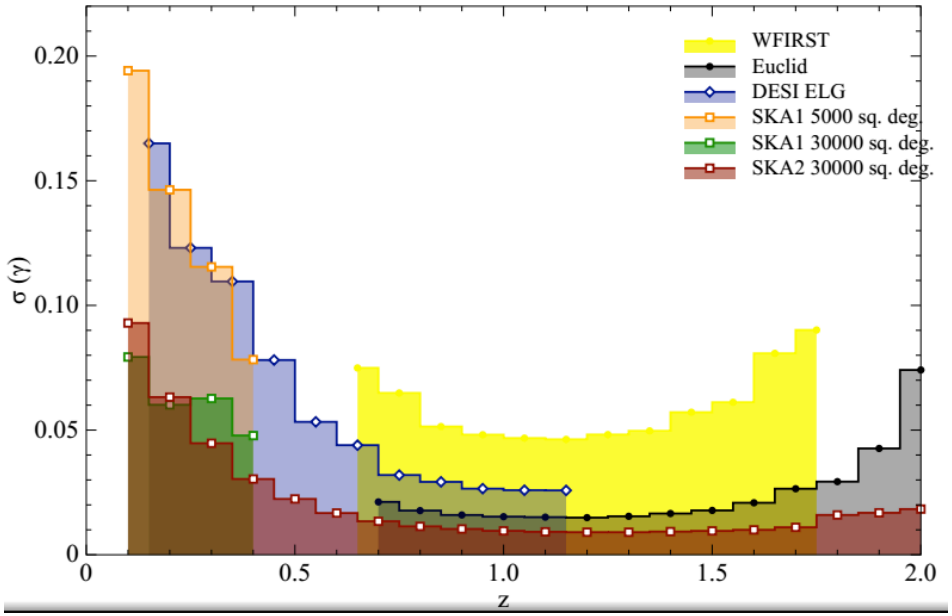




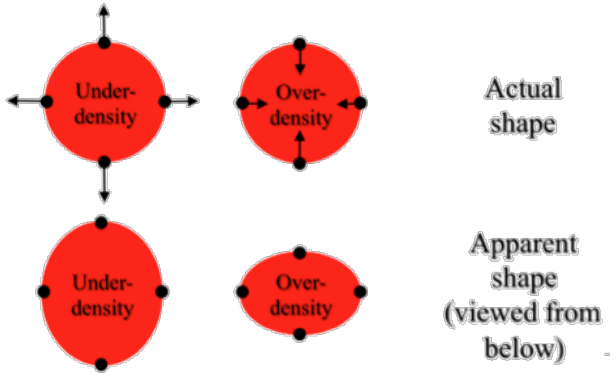
(Schwarz et al. 2014)

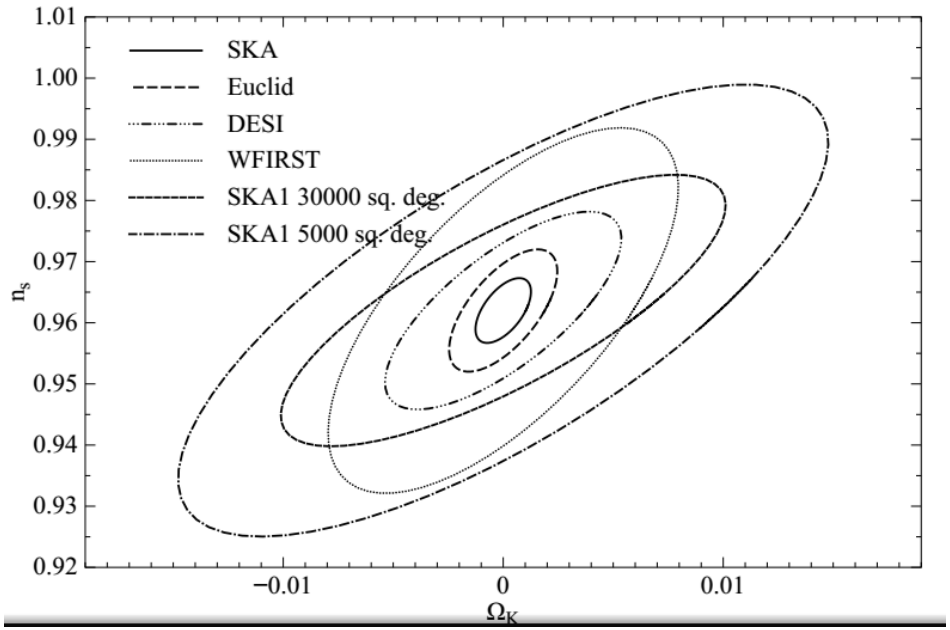
- Sensitive constraints on isotropy and homogeneity
  - Unique tests of isotropy at z ~ 1
  - Measure cosmic matter dipole with high precision

Cosmology with SKA: Redshift space distortions



Modified Gravity

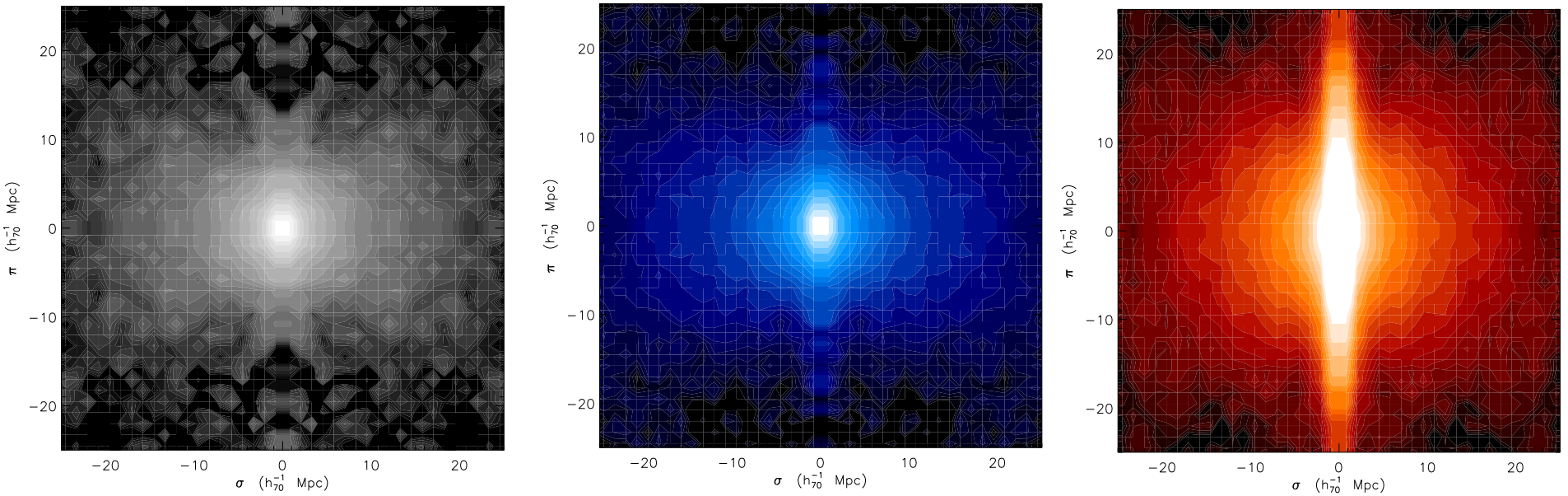




Curvature

- Constraining modified gravity and curvature with discrete HI galaxy surveys
  - Discrete detection is complementary with SKA1, cutting edge with SKA2

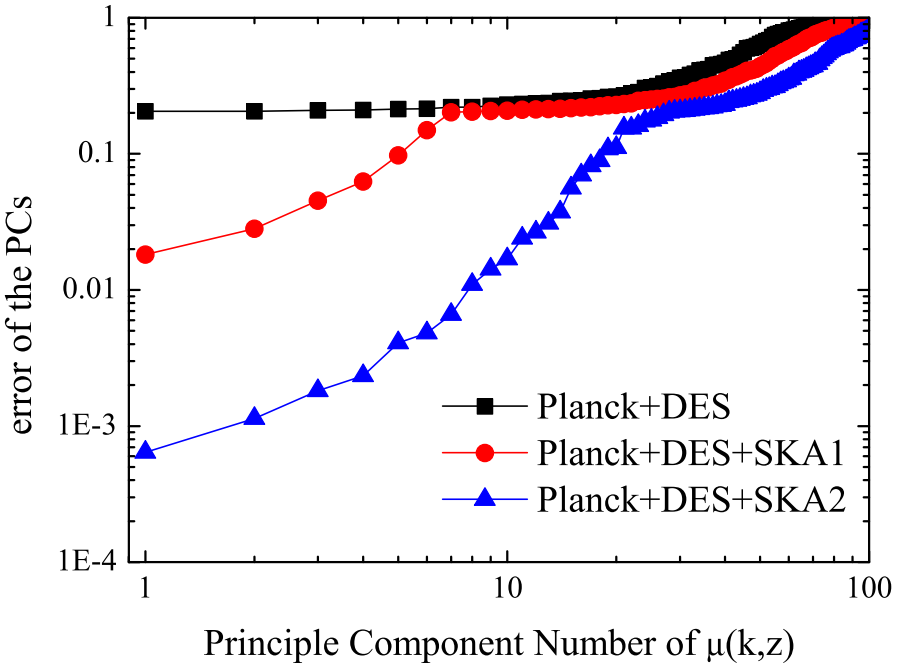
Cosmology with SKA: complementarity with optical

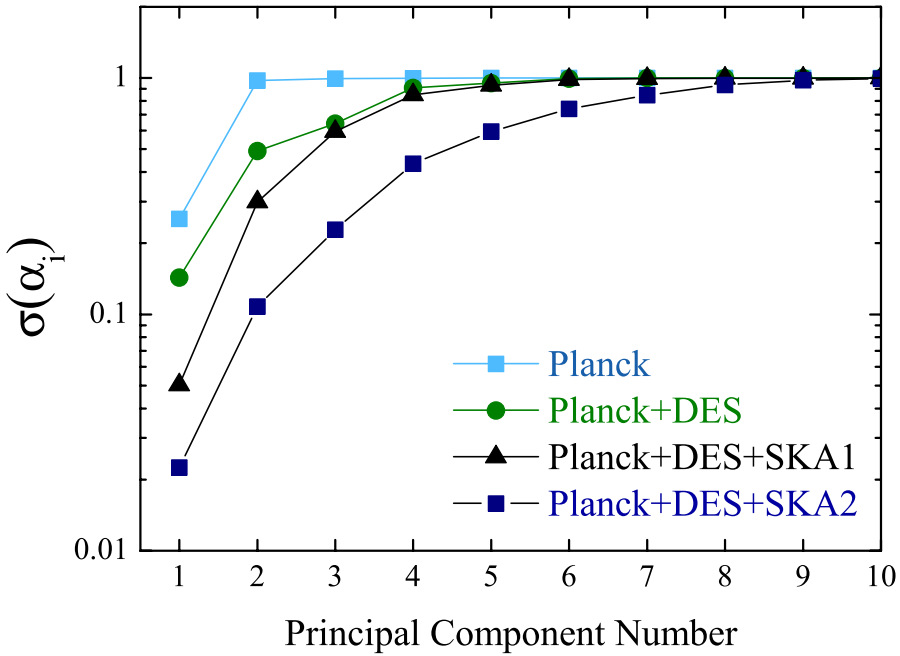


(Papasterigis et al. 2013) ALFALFA HI versus SDSS blue and red samples

- Correlation functions of HI detections demonstrate much lower bias for Redshift-space distortion measurements

Cosmology with SKA:
Modified Gravity & Dark Energy EoS w(z)



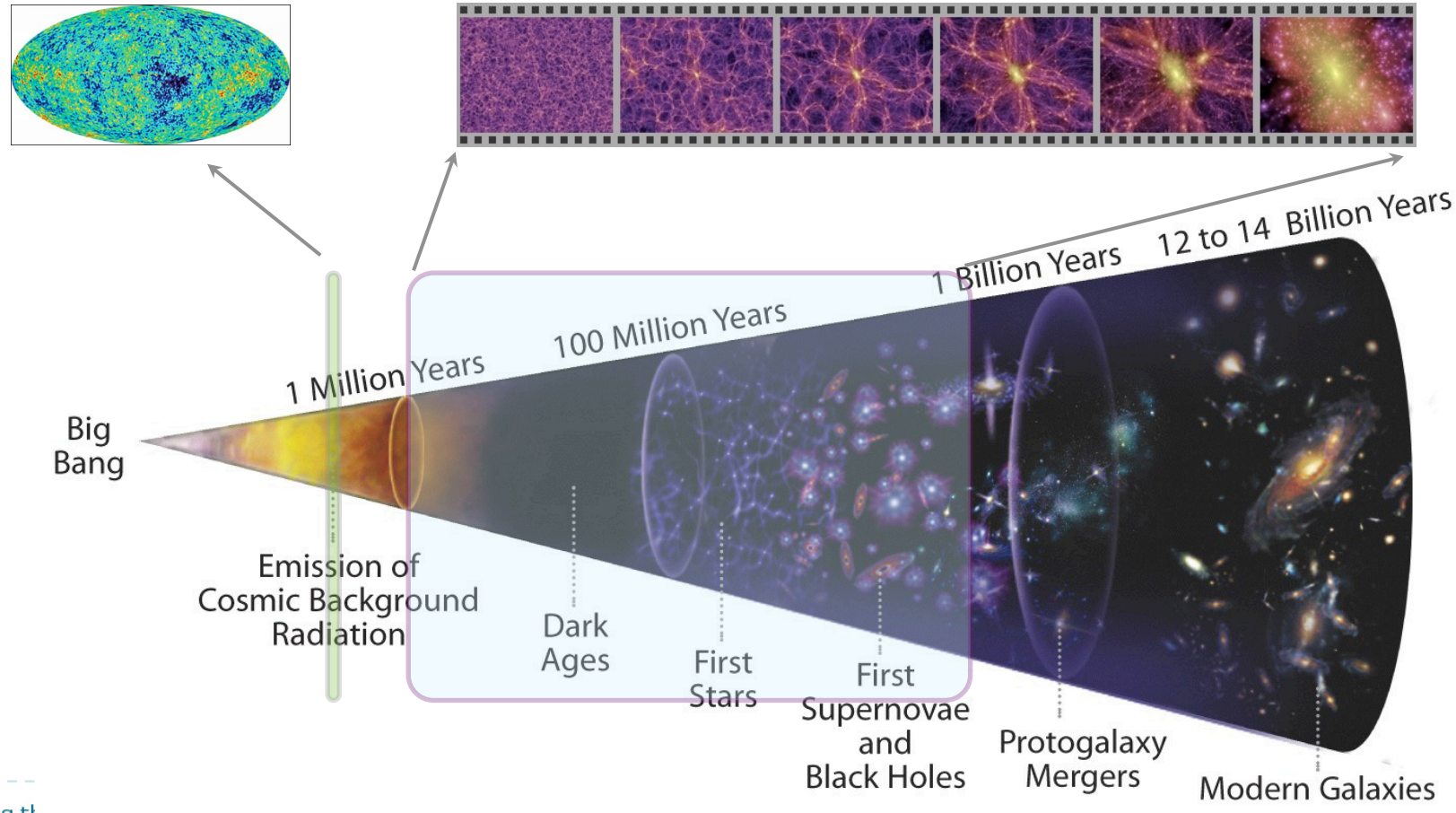


- Precision cosmology by enabling meaningful multi-parameter representations of new physics models with explicit red-shift evolution

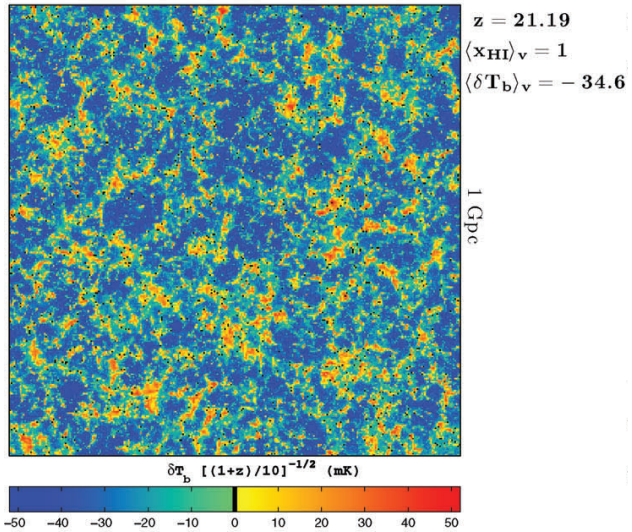
HI surveys of the EoR, Cosmic-Dawn & Dark Ages

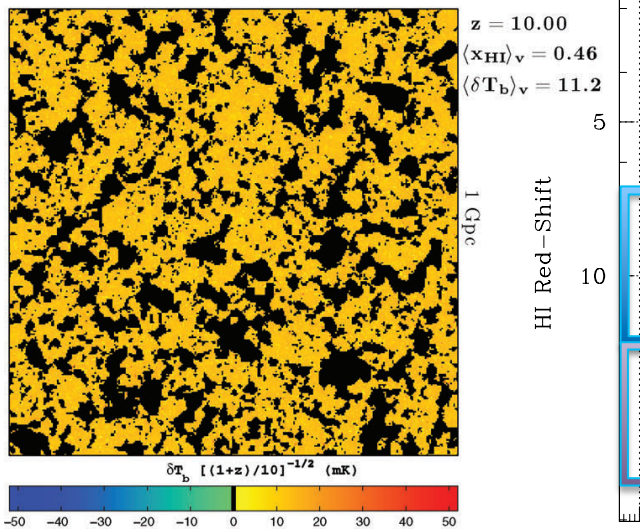
CMB displays a single moment of the Universe. Its initial conditions at ~400,000 yrs

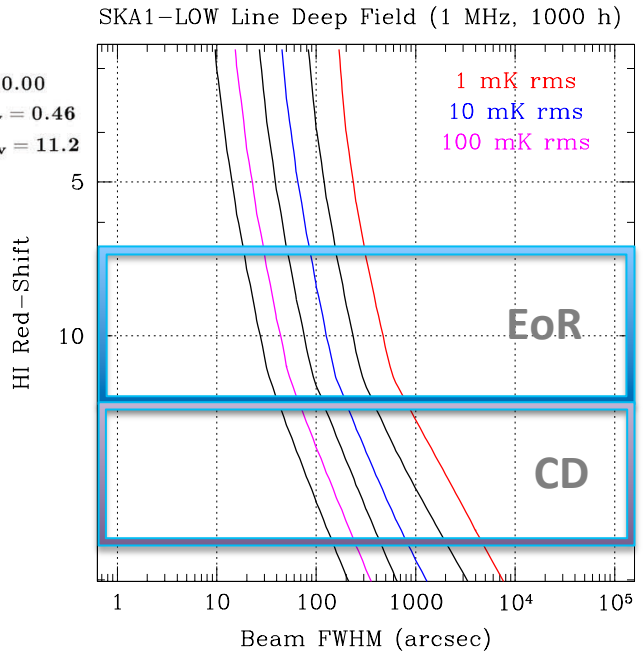
HI emission from the Dark Ages, Cosmic Dawn & EoR traces an evolving "movie" of baryonic and DM structure formation at $t_{univ}<10^9$ years.



SKA1 surveys of the EoR (& Cosmic-Dawn)



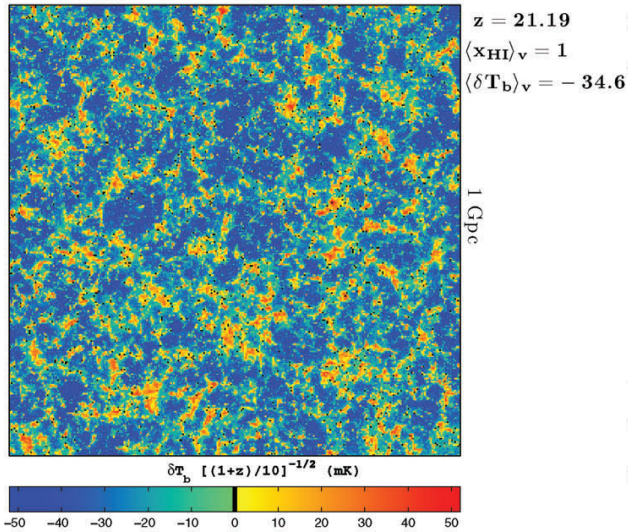


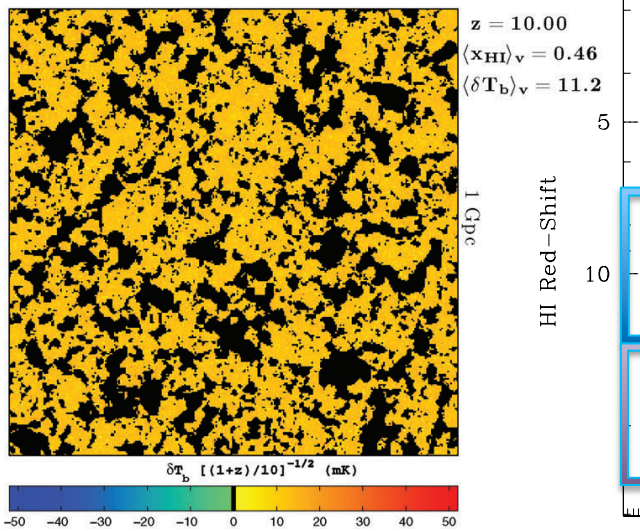


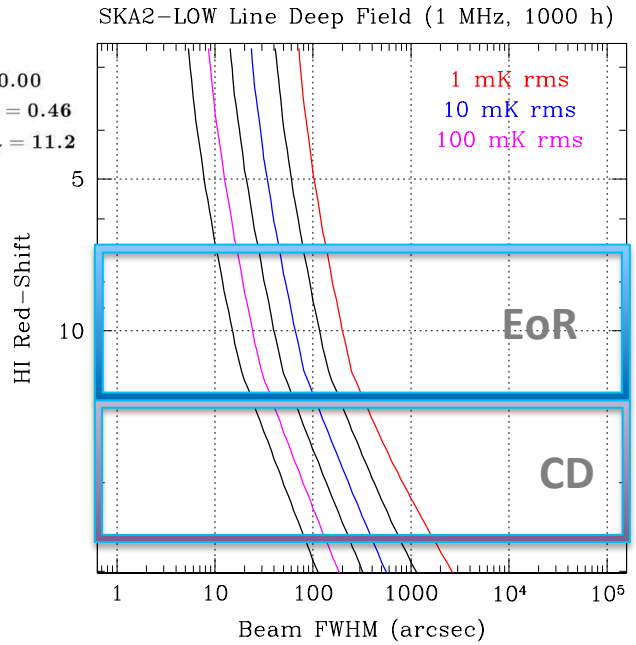
(Mesinger et al 2011)

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

SKA2 surveys of the Cosmic-Dawn (& Dark Ages)







(Mesinger et al 2011)

- Detecting Cosmic Dawn structures in imaging mode (as distinct from statistically) on 5 arcmin scales with 1 mK RMS
- Probing the Dark Ages statistically (for v_{Min} < 50 MHz)

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
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Rob Fender (Oxford)
Federica Govoni (INAF–OA Cagliari)
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Melanie Johnston-Hollitt (Victoria Univ. Wellington)
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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

BBC

Mount Etna eruption closes airport

16 June 2014 Last updated at 13:40 BST

A new eruption at Mount Etna eruption has forced the closure of Catania Airport in Sicily.

Footage shows boiling lava and ash spewing from the southern crater of Europe's most active volcano on Sunday.

And to celebrate completion of a very successful meeting …

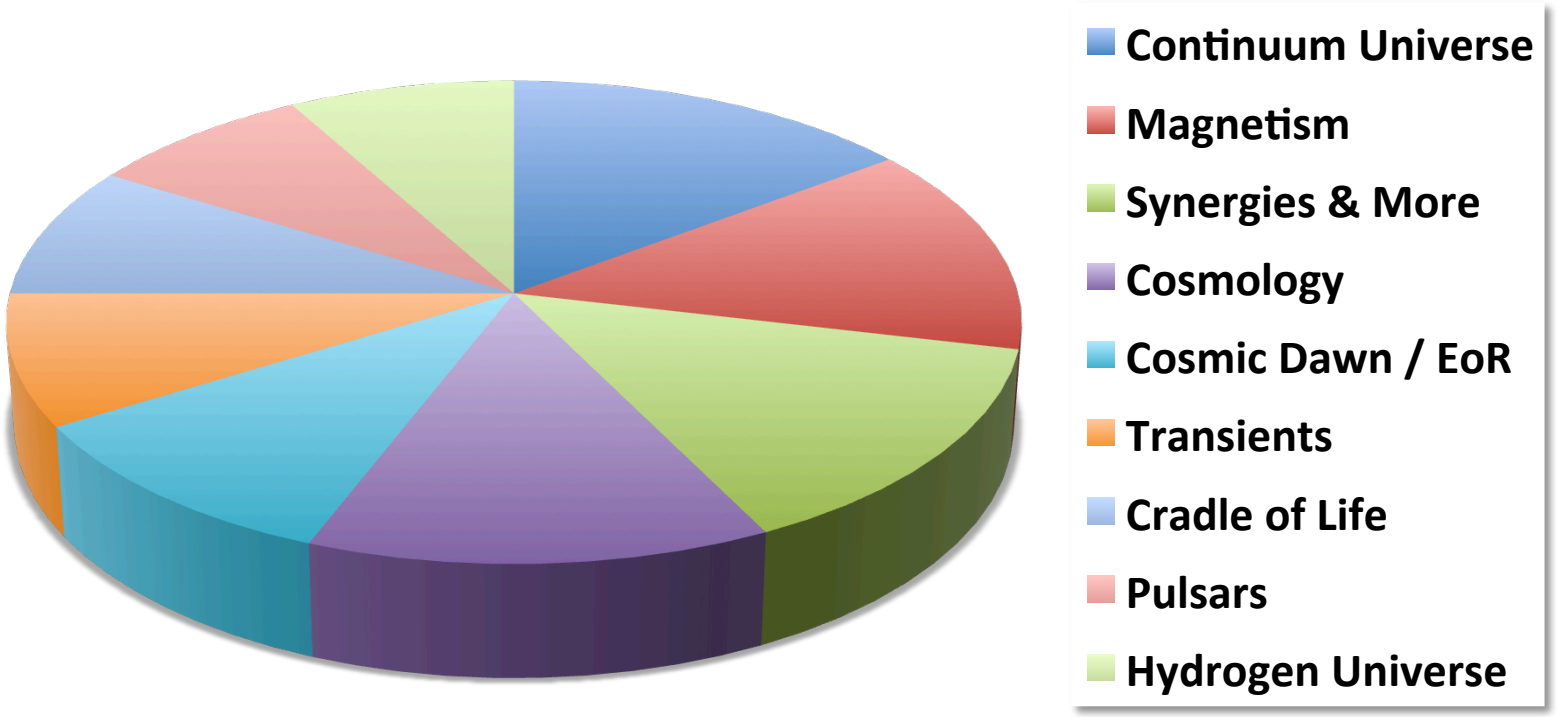
SKA 2014 Science Meeting

SKA Science Book:

- Meeting Program based on advanced Chapter drafts
- Contributions matched to instrumental capabilities:
  1. SKA1, early deployment phase (50% and up)
  2. Fully specified SKA1
  3. Fully specified SKA2
- 140 self-contained chapters, most now on arXiv
- Publication in 2015 Q2

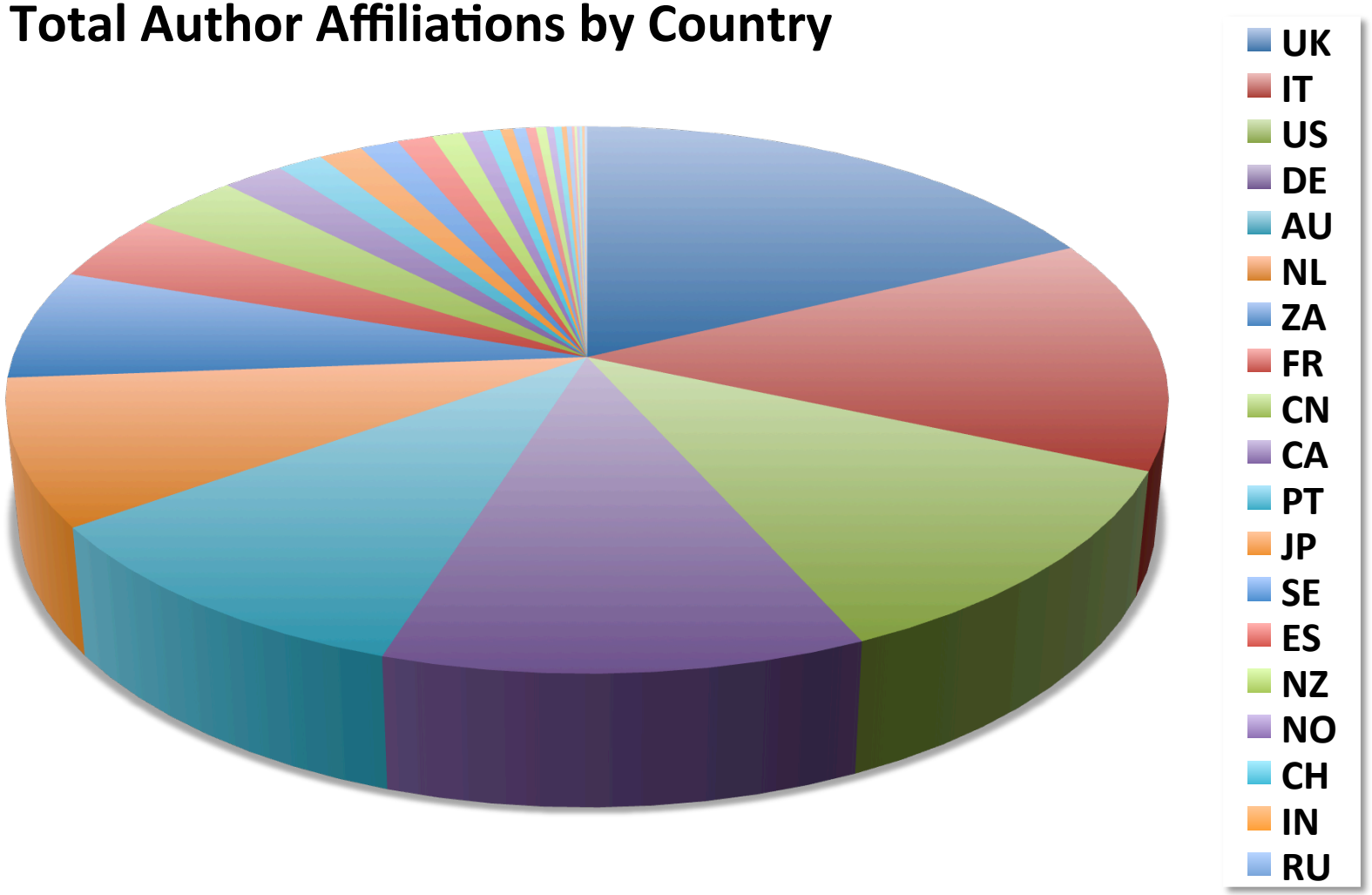
SKA Science Book:

Chapters by Category



SKA Science Book:

Total Author Affiliations by Country



Status

3 dish prototypes all in testing

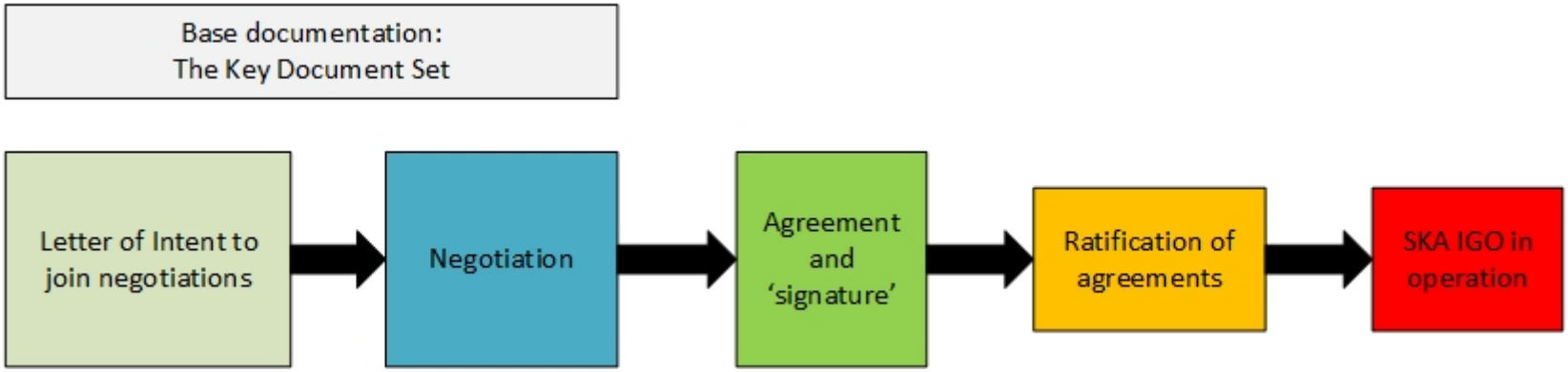
Key events in last 12 months

- March 2014: UK Science Minister announces £100M (€130M) for SKA1 construction
- May 2014: BMBF announces Germany's intention to withdraw by June 2015
- August 2014: India becomes Full Member of SKAO
- Sept 2014: SKA rated as top priority new project in French 5-year astronomy infrastructure planning.
- 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.
- March 2015: SKA1 re-baselining
- April 2015: SKA HQ decision

SKA HQ selection: decision 29 April

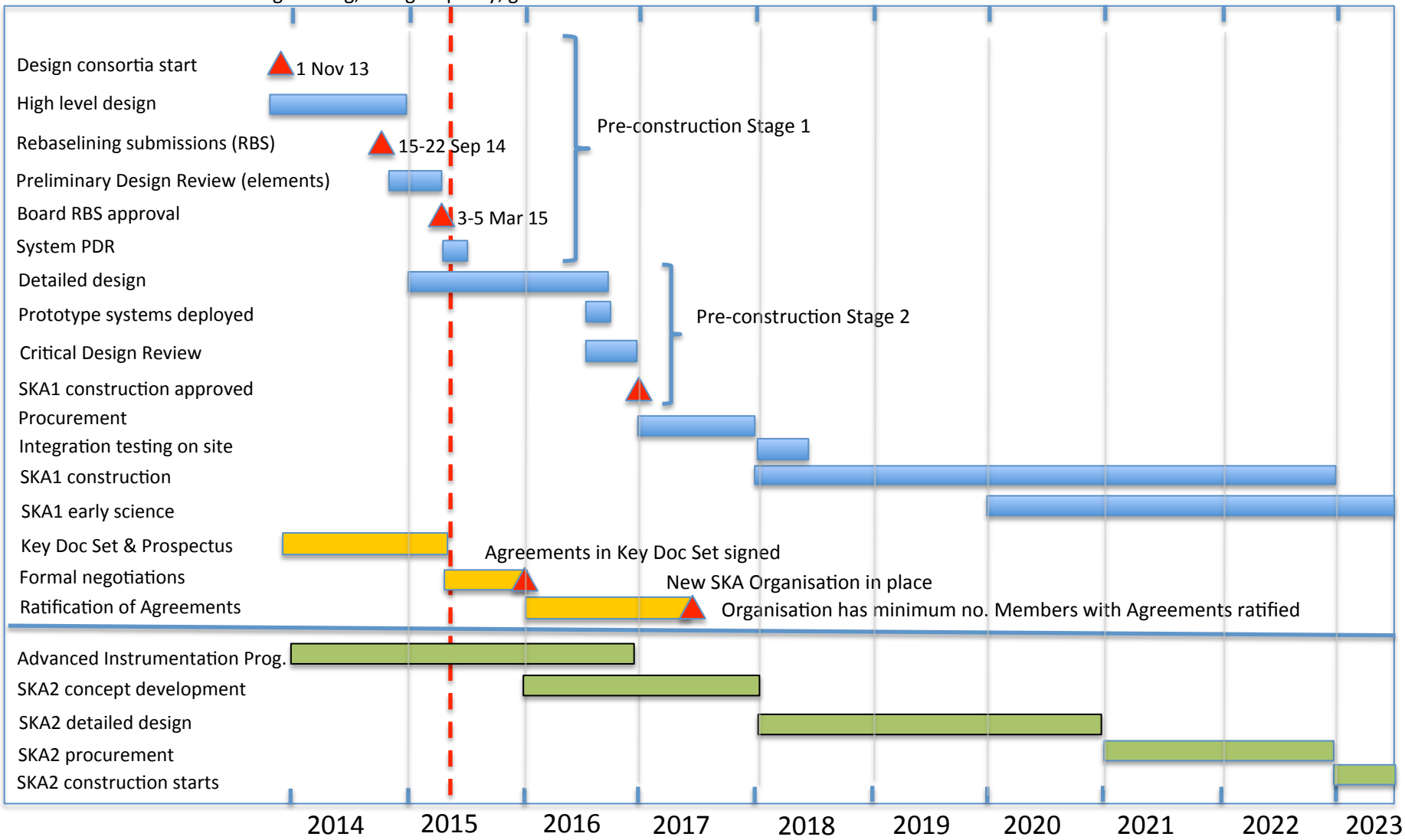
Governance/organisational structure

- 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
  - 'Freedom to operate', specifically through procurement process



High-level SKA Schedule

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



SQUARE KILOMETRE ARRAY

Exploring the Universe with the world's largest radio telescope

www.skatelescope.org