Phasing of SKA science: Design Reference Mission for SKA1

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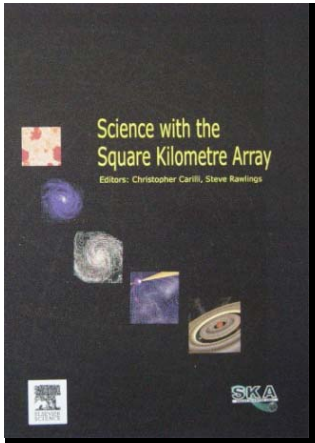
System Delta CoDR

Feb. 23, 2011



21st Century Astrophysics

20th Century: We discovered our place in the Universe

21st Century: We understand the Universe we inhabit

Cosmology & Fundamental Physics

- Gravity
  - Can we observe strong gravity in action?
  - What is dark matter and dark energy? (dark energy and BAOs with H I galaxies)
- Magnetism
- Strong force

  Nuclear equation of state

Galaxies Across Cosmic Time, The Galactic Neighborhood, Stellar and Planetary Formation

- Galaxies and the Universe
  - How did the Universe emerge from its Dark Ages?
  - How did the structure of the cosmic web evolve?
  - Where are most of the metals throughout cosmic time?
  - How were galaxies assembled?
- Stars, Planets, and Life
  - How do planetary systems form and evolve?
  - What is the life-cycle of the interstellar medium and stars? (biomolecules)
  - Is there evidence for life on exoplanets? (SETI)

The Square Kilometre Array

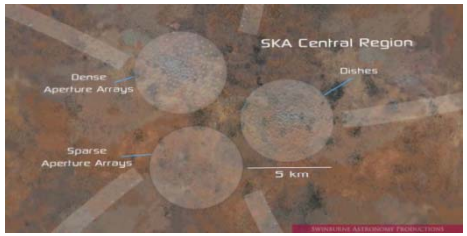
SPDO

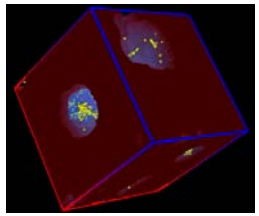
The Global Radio Wavelength Observatory

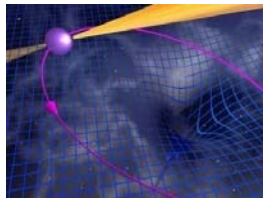
- Originally: “Hydrogen telescope”
  - Detect H I 21-cm emission from Milky Way-like galaxy at $z \sim 1$
- SKA science much broader
  - $\Rightarrow$ Multi-wavelength, multi-messenger
- On-going technical development

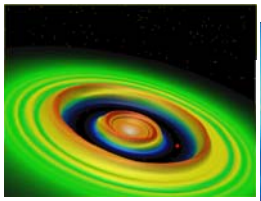
Wide-field, wide-band systems

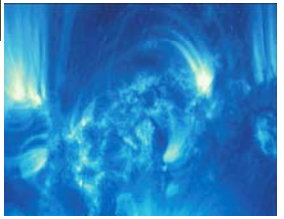
- International participation











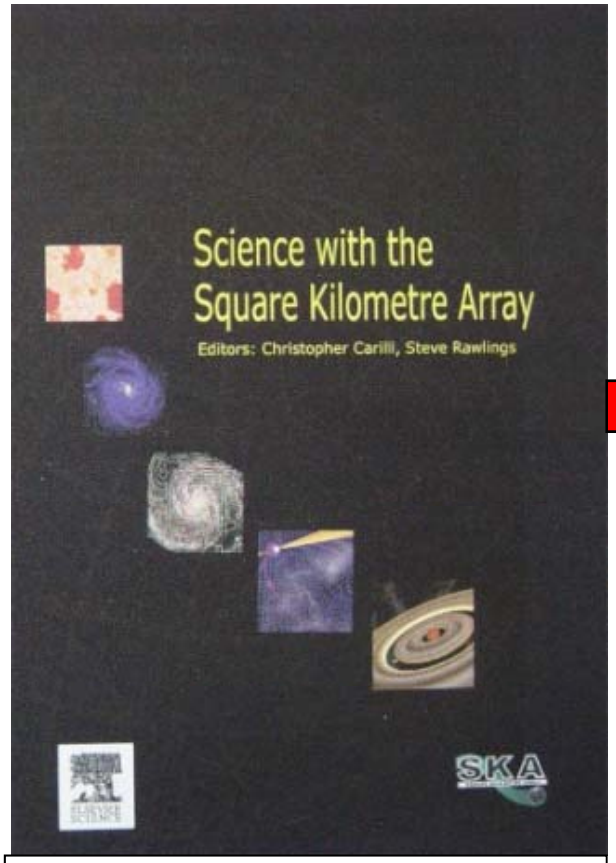
THE VISION HAS NOT CHANGED

Design Reference Mission

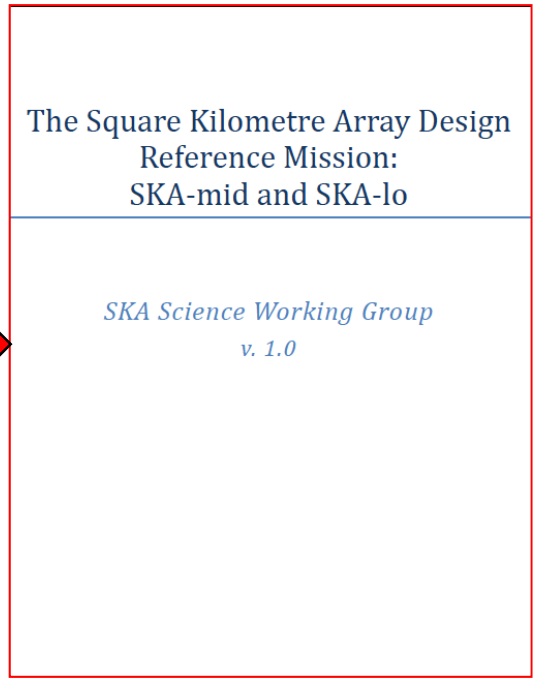
- Not another science case.
  - Does not include all science.
  - Includes all key science as a minimum.
  - May contain priorities and/or options.
- Assembly of science case studies that can be used to define the technical requirements of the telescope.
  - Defines an “envelope” of science requirements so that the SPDO engineering group can put together a technical requirements document.
- Coverage.
  - If the science requirements are not completely described, critical aspects may not be present in the telescope.
- DRM must be seen to be well justified, and traceable to the primary science case.
- Technology decisions must be traceable as well.
  - Technical progress will be much quicker if the DRM is complete.

Science Case, Design Reference Mission,

SPDO

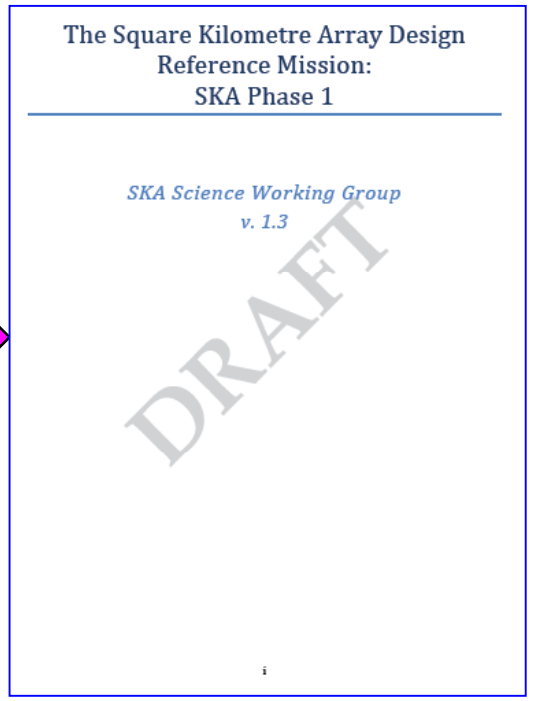


Science Case
Lays out overarching goals, full suite of science


The Square Kilometre Array Design Reference Mission:
SKA-mid and SKA-lo

SKA Science Working Group
v. 1.0

SKA2
Design Reference Mission
Defining set of science observations, science input to requirements


The Square Kilometre Array Design Reference Mission:
SKA Phase 1

SKA Science Working Group
v. 1.3

DRAFT

SKA1
Design Reference Mission
Scaled down version of SKA2 DRM.

SKA1 “Essential” Science Objectives

- From Memo 125: A Concept Design for SKA Phase 1 (SKA1)
  - Garrett et al.
- “Major science themes for SKA1”
  - (i) Understanding the history and role of neutral Hydrogen in the Universe from the dark ages to the present-day, and
  - (ii) Detecting and timing binary pulsars and spin-stable millisecond pulsars in order to test theories of gravity (including General Relativity and quantum gravity), to discover gravitational waves from cosmological sources, and to determine the equation of state of nuclear matter.

DRM2 => DRM1

SPDO

[X] = DRM1 Chapter

1. Resolving AGN and Star Formation in Galaxies
2. Pre-biotic molecules in and around Protoplanetary Disks
3. Cosmic Magnetism Deep Field
4. Galactic and Intergalactic Magnetic Fields: Wide Field Survey
5. Wide-Field Polarimetry
6. Tracking Cosmic Star Formation: Continuum Deep Field
7. Neutral Gas in Galaxies: Deep H I Field.
8. **Epoch of Reionization H I Imaging Tomography. [2]**

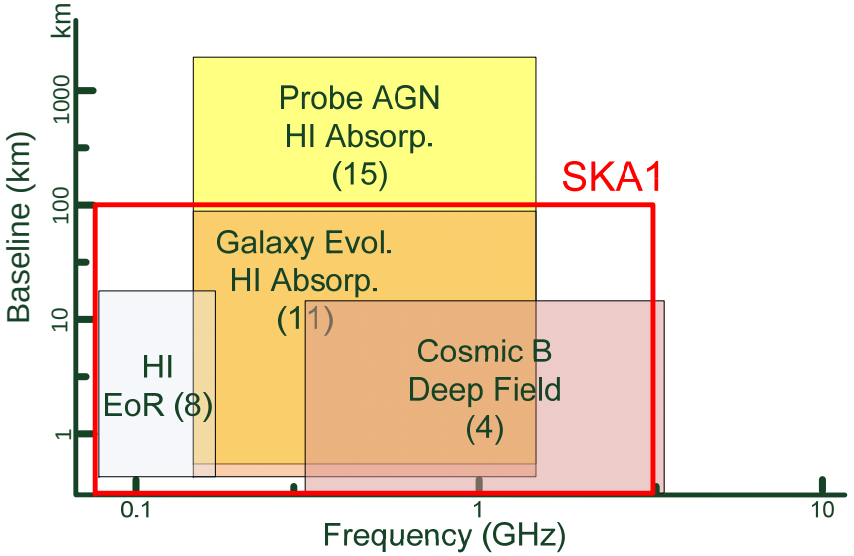
8a. **Probing the EoR Using the 21-cm Forest. [4]**

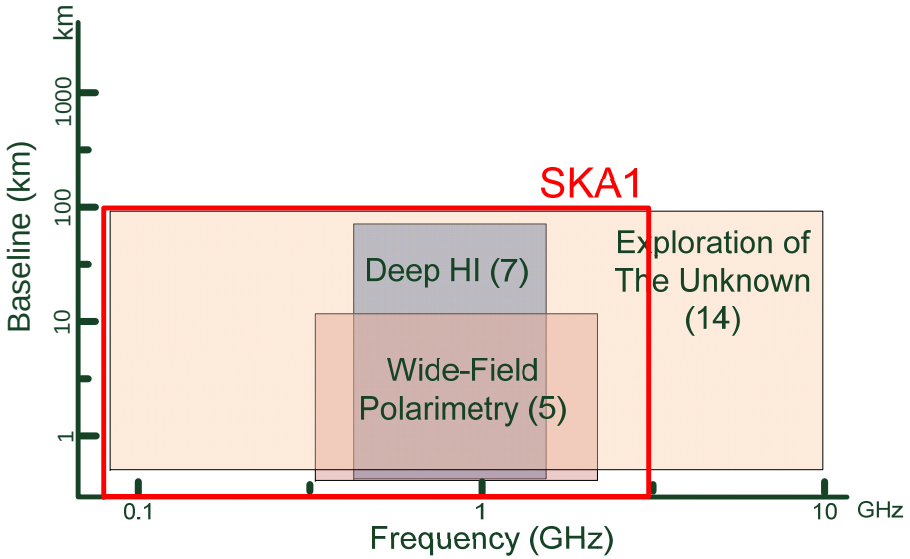
9. Probing Gravity, Dark Matter, & Stellar Populations in the Galactic Center with Radio Pulsars
10. Not used.
11. **Tracking Gal. Evolution over Cosmic Time via HI Absorption? [3]**
12. H I Baryon Acoustic Oscillations.
13. Not used.
14. Exploration of the Unknown: The Transient Radio Sky.
15. Probing AGN Environments via HI Absorption
16. **Pulsar Surveys with the SKA. [5]**
17. **Pulsar Timing with the SKA. [6]**

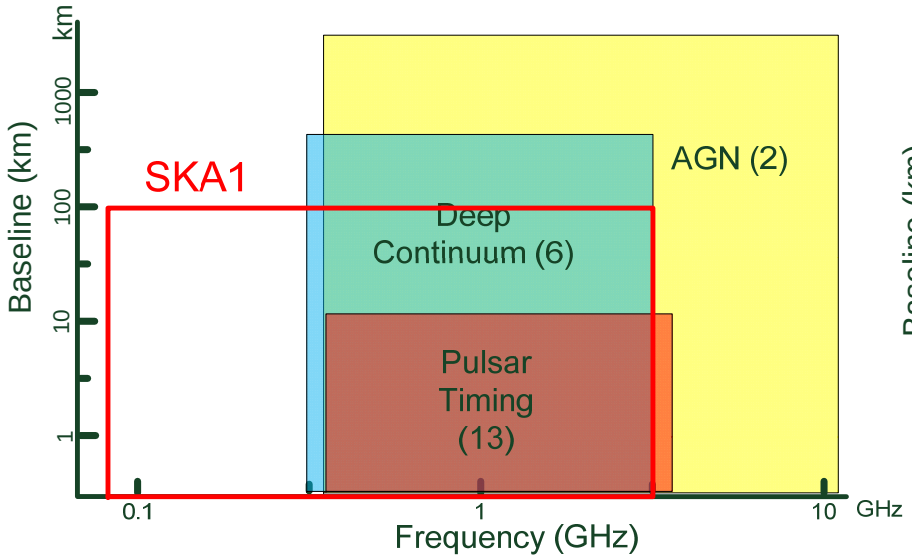
“Power Science Parameters”

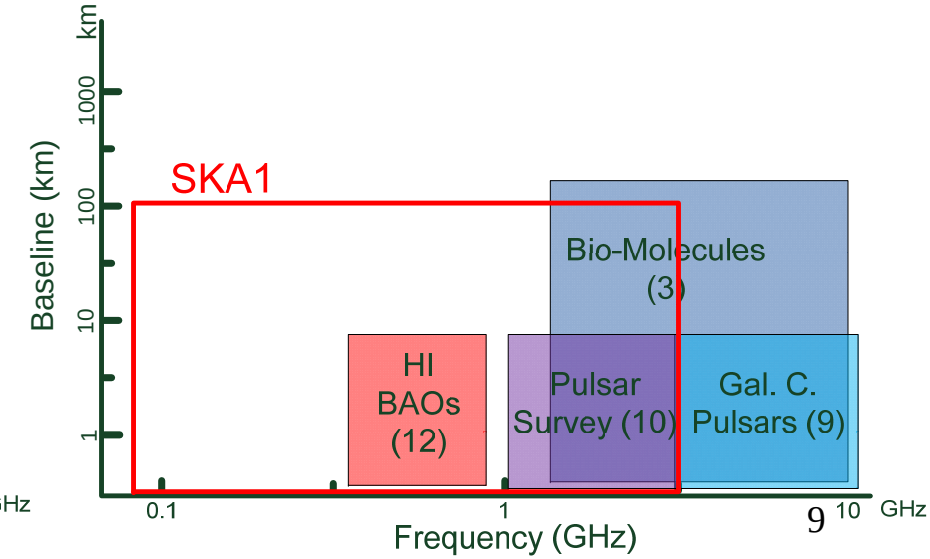
- Frequency range
- Maximum baseline
  - (determines resolution)
- Sensitivity
  - A_e / T_{sys}
  - Survey Speed $[(A_e / T_{sys})^2 \ \Omega]$

DRM Components

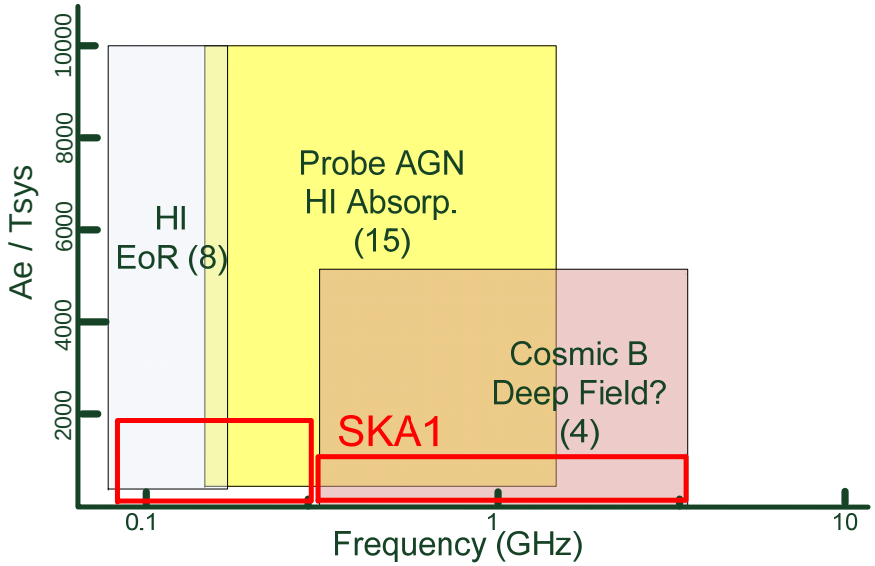


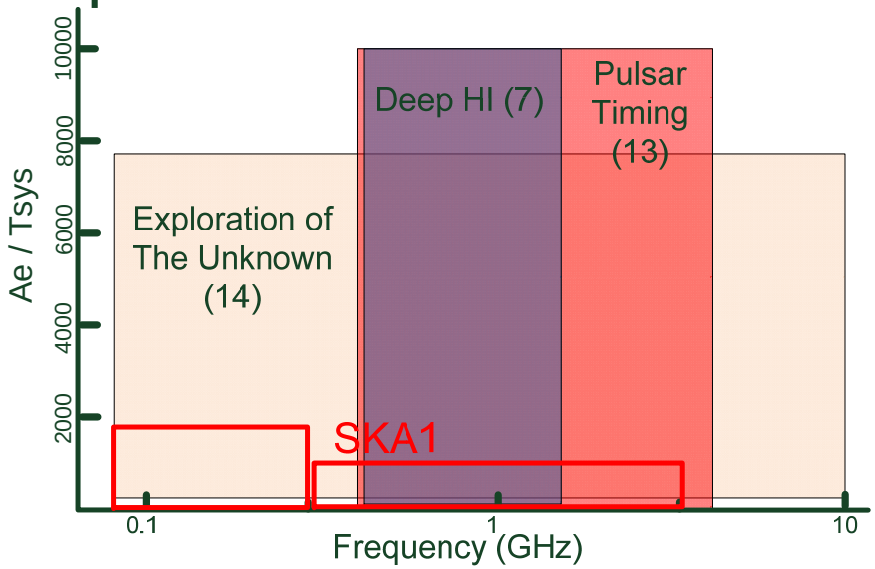


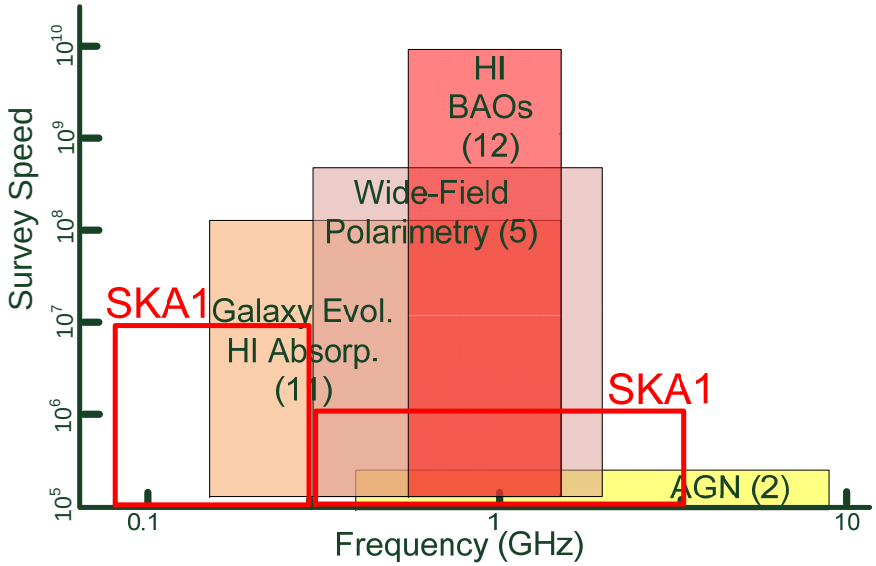


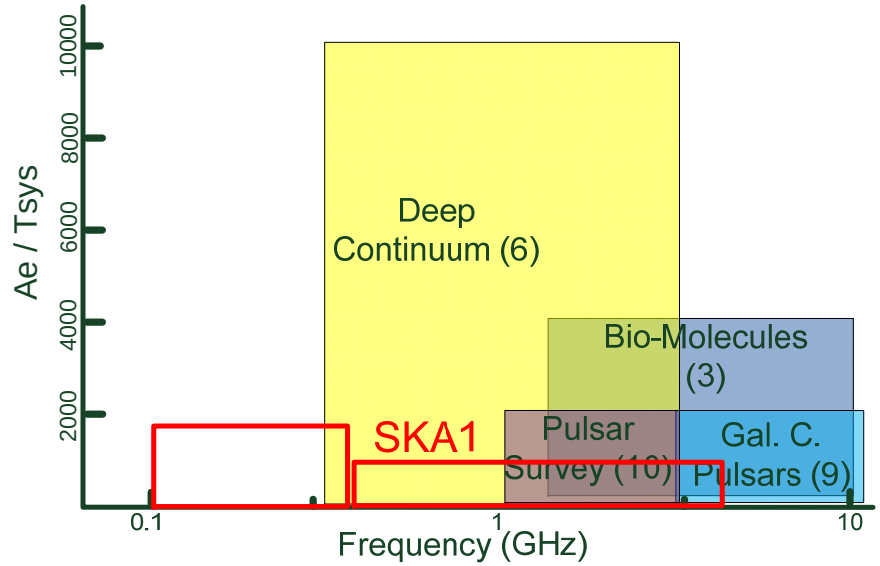


DRM Components









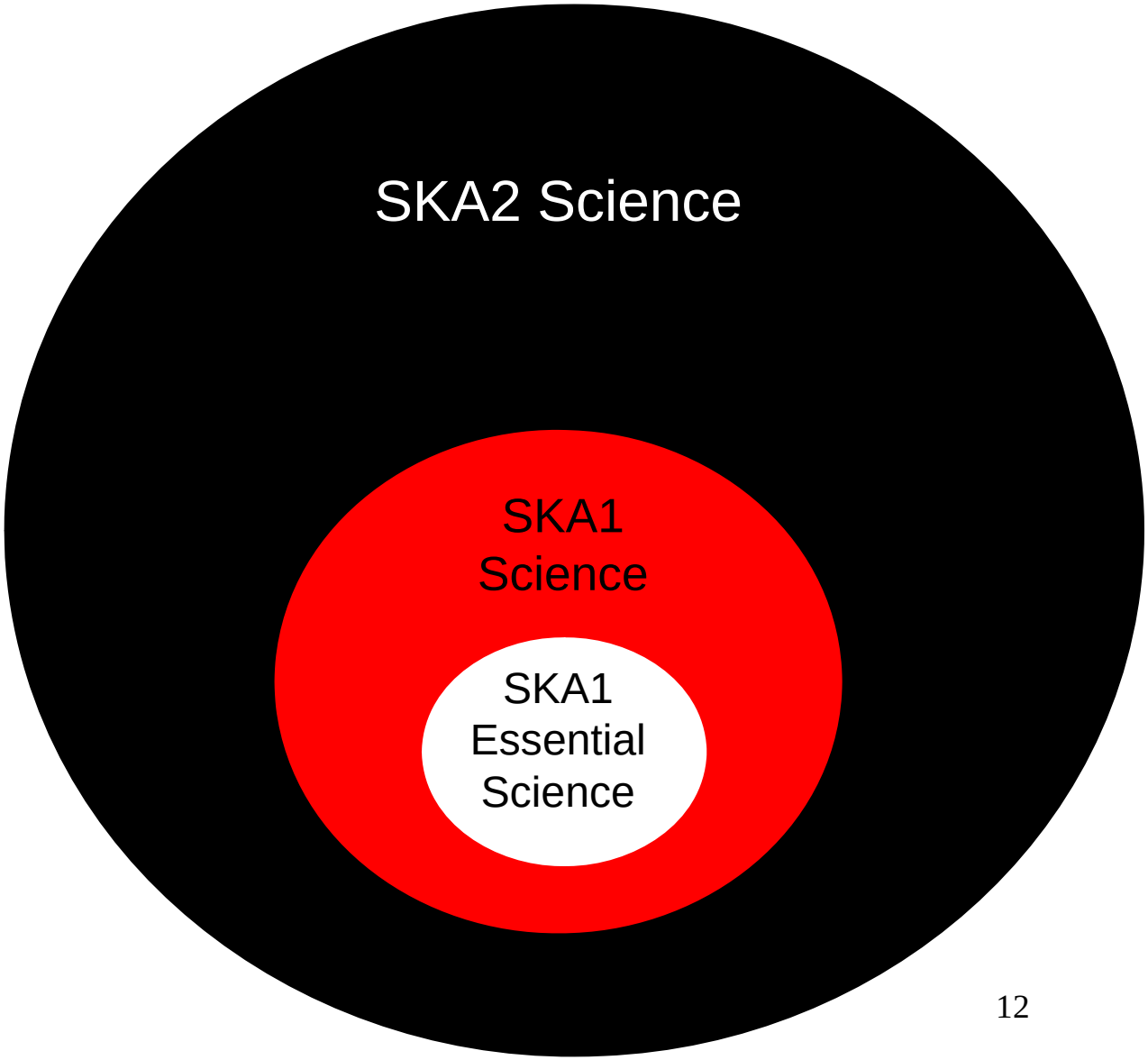
SKA1 DRM (DRM1)

SPDO

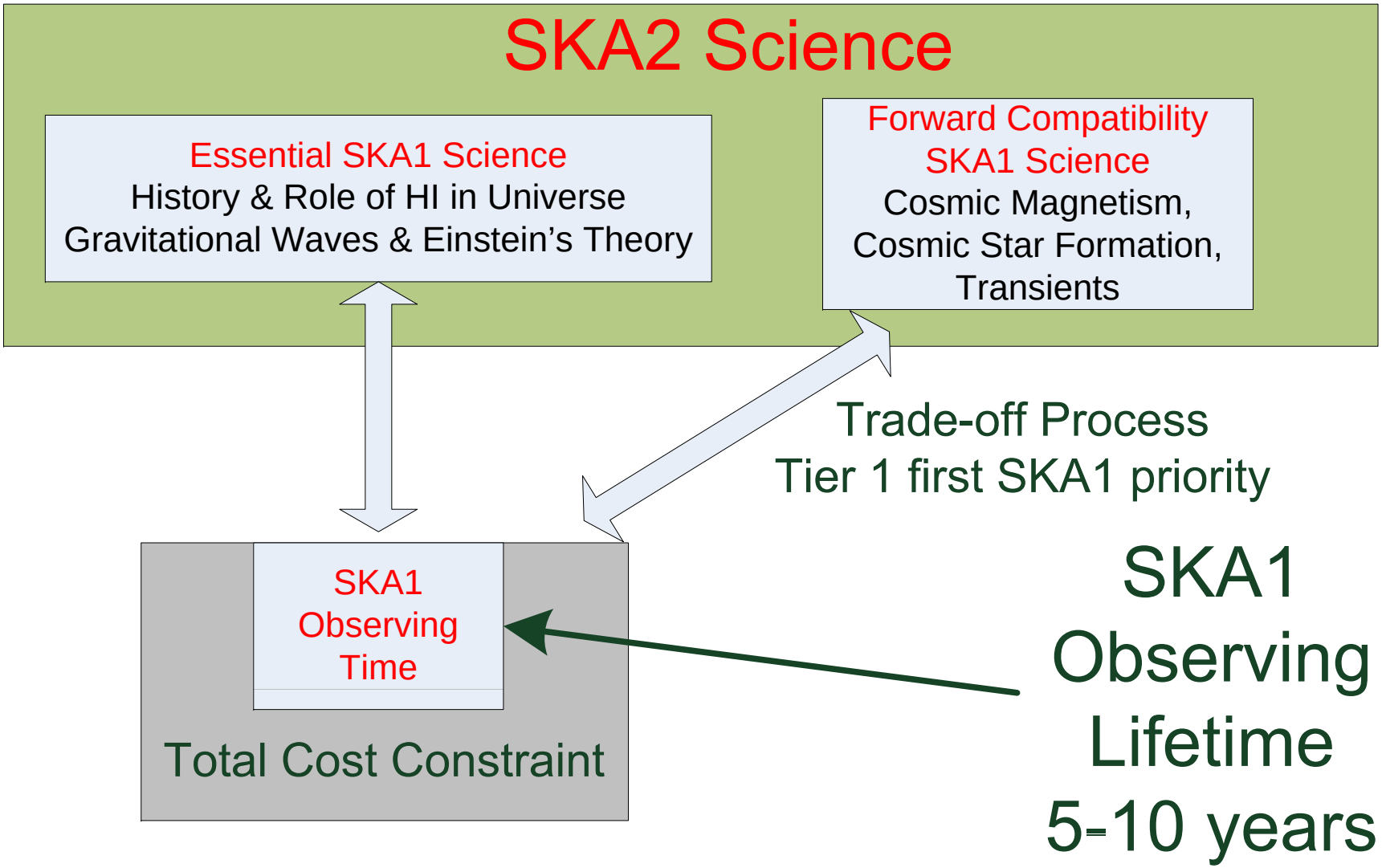
Chapter	Title	Frequency Range (MHz)	Survey Speed (m^4 K^-2 deg^2)	Ae/Tsys (m^2 K^-1)	Frequency Resolution (kHz)	Temporal resolution (s)	polarisation purity	Imaging dynamic range (dB)	Spectral Dynamic Range (dB)	Observation type	Key Science Case Ref	Notes
2	Probing the Neutral Intergalactic Medium during the Epoch of Reionization	70-240	N/A	1000	100	SL	full	N/A	N/A	Line	Probing the Dark Ages	
3	Tracking Galaxy Evolution over Cosmic Time via HI absorption	200-1400	1.0E+07	N/A	5	SL	N/A	35	43	Line	Galaxy Evolution, Large-Scale	possible technology change
4	Probing the Epoch of Reionization with the 21-cm Forest	70-240	N/A	N/A	0.2	SL	N/A	N/A	61	Line	Probing the Dark Ages	
5	Pulsar Surveys with the SKA1	400-3000	N/A	1000	10	5.00E-05	N/A	N/C	N/C	Time Domain	Strong Field Tests of Gravity Using Pulsars and Black Holes	non-imaging data required
6	Pulsar Timing with the S	800-3000	N/A	1000			40 dB	N/C	N/C	Time Domain	Strong Field Tests of Gravity Using Pulsars and Black Holes	high frequency agility required, non-imaging data required, polarization purity likely needs to be achieved only on-axis, post-calibration
7	Additional Telescope Considerations	70-10,000					full-field capability	74 dB capable			multiple	"forward capatibility"

SKA2 and SKA1 Science

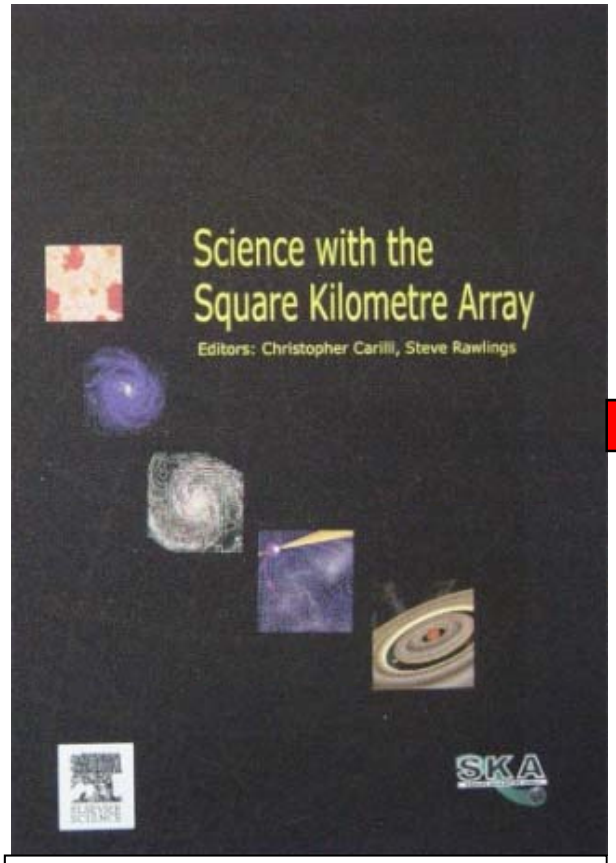
SKA1 is a modest step compared with SKA2, but a large step compared with existing capabilities.



SKA1 Science as a Subset



Way Forward with DRM - Requirements



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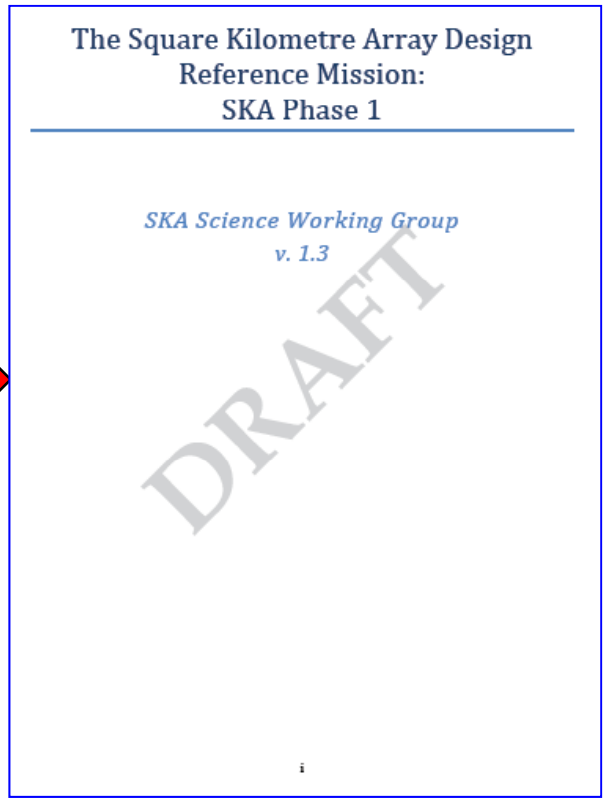


SKA1
Design Reference Mission.

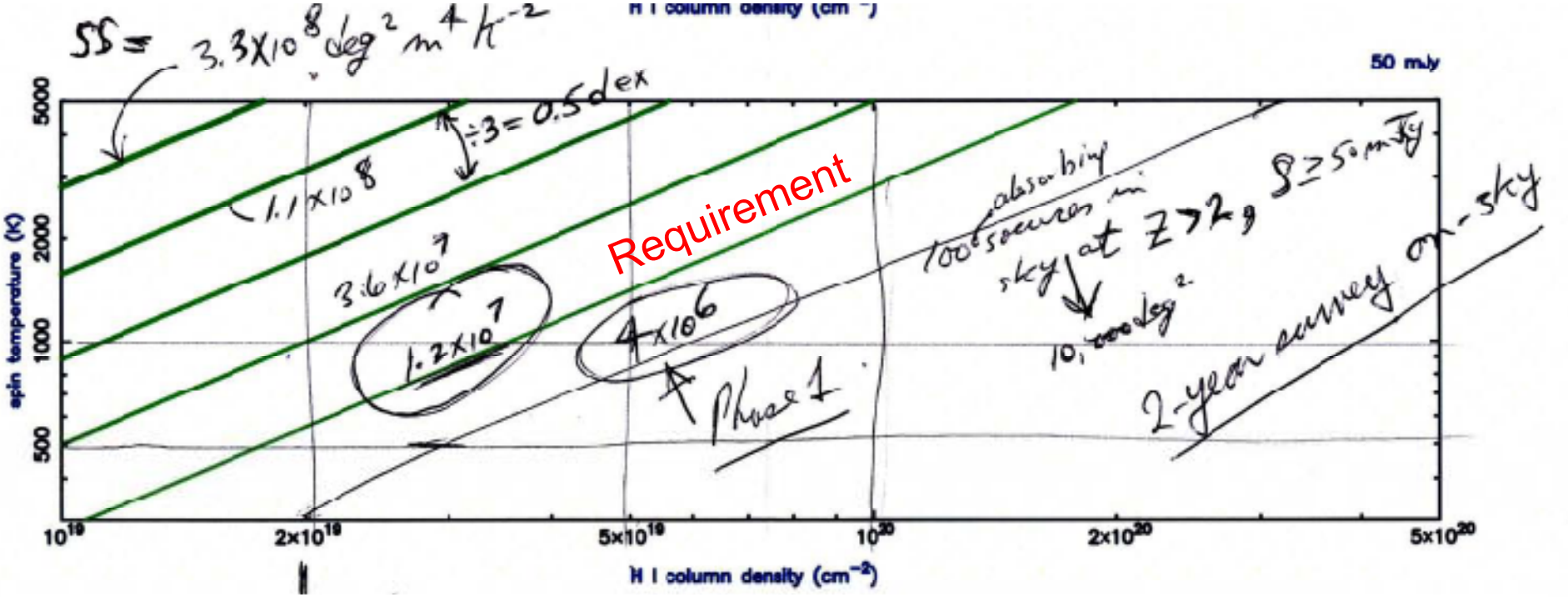
```
Requirement #1
Requirement #2
Requirement #3
Requirement #4
Requirement #5
Requirement #6
Requirement #7
Requirement #8
Requirement #9
Requirement #10
Requirement #11
Requirement #12
Requirement #13
Requirement #14
Requirement #15
…
Requirement #N
```

Requirements Document
Incorporates input from science, but other inputs as well

Science Requirements from DRM

- Still a work in progress – will continue for a while.
- Distil to “atomic statements” that can be tested.
  - e.g. Carry out a mock pulsar search.
    - Detect and time a set of known pulsars.
  - small-scale HI absorption survey and low z.
  - high-z mock absorption survey against known continuum sources.
    - Show that residuals are small enough that HI would have been detected.
- Requirements should be technology-independent.
  - Requirements need to be testable.
    - Tests related to the requirement must be proposed at various levels of the system.
- Need to “back-project” on to the original science case.
  - Are there inadvertent restrictions imposed.
- Examine for completeness.

Hydrogen Absorption – Pathfinder Work



- Tau = 0.01
- Background source = 50 mJy.
- Number of sources for S>50 mJy at high z???
  - Luminosity must be very high.
  - ASKAP and MeerKAT will do exploratory work on “deep” HI fields out to z~1.
- Is this a really a wide-field experiment?

Instrumental Pol'n at EoR Frequencies

- AA-low
  - Instrumental polarisation is likely to be large,
  - Varies in field of view,
  - Varies with pointing direction,
  - Rotates on the sky.
- Sky
  - diffuse Galactic foreground is intrinsically highly polarized
    - T_b ~10^5 times expected signal on large angular scales.
  - power on small angular scales (sources) in linear polarization few K at 150 MHz.
  - The EoR observations should therefore target one, possible several, windows of low (polarized) Galactic foreground emission, the choice of which will be guided by the pathfinders.
- Calibration << 0.1% (-30 dB? – not in DRM1 as a requirement).
  - residual instrumental pol'n of 0.01% = few mK (comparable to the EoR signal).
  - frequency dependent on a scale of a few MHz (mimic spectral signature?).
- "EoR observations should therefore target one, possible several, windows of low (polarized) Galactic foreground emission, the choice of which will be guided by the pathfinders." LOFAR, MWA, PAPER, are needed to fix this!

End