SKA
SQUARE KILOMETRE ARRAY

Refining the DRM & Deriving Technical Requirements

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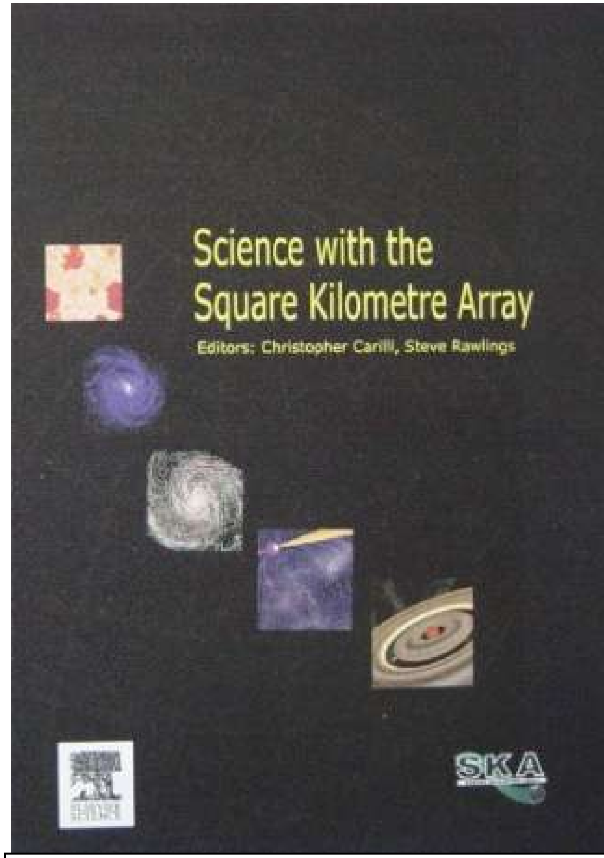
Science Case, Design Reference Mission, Requirements

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

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

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

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.

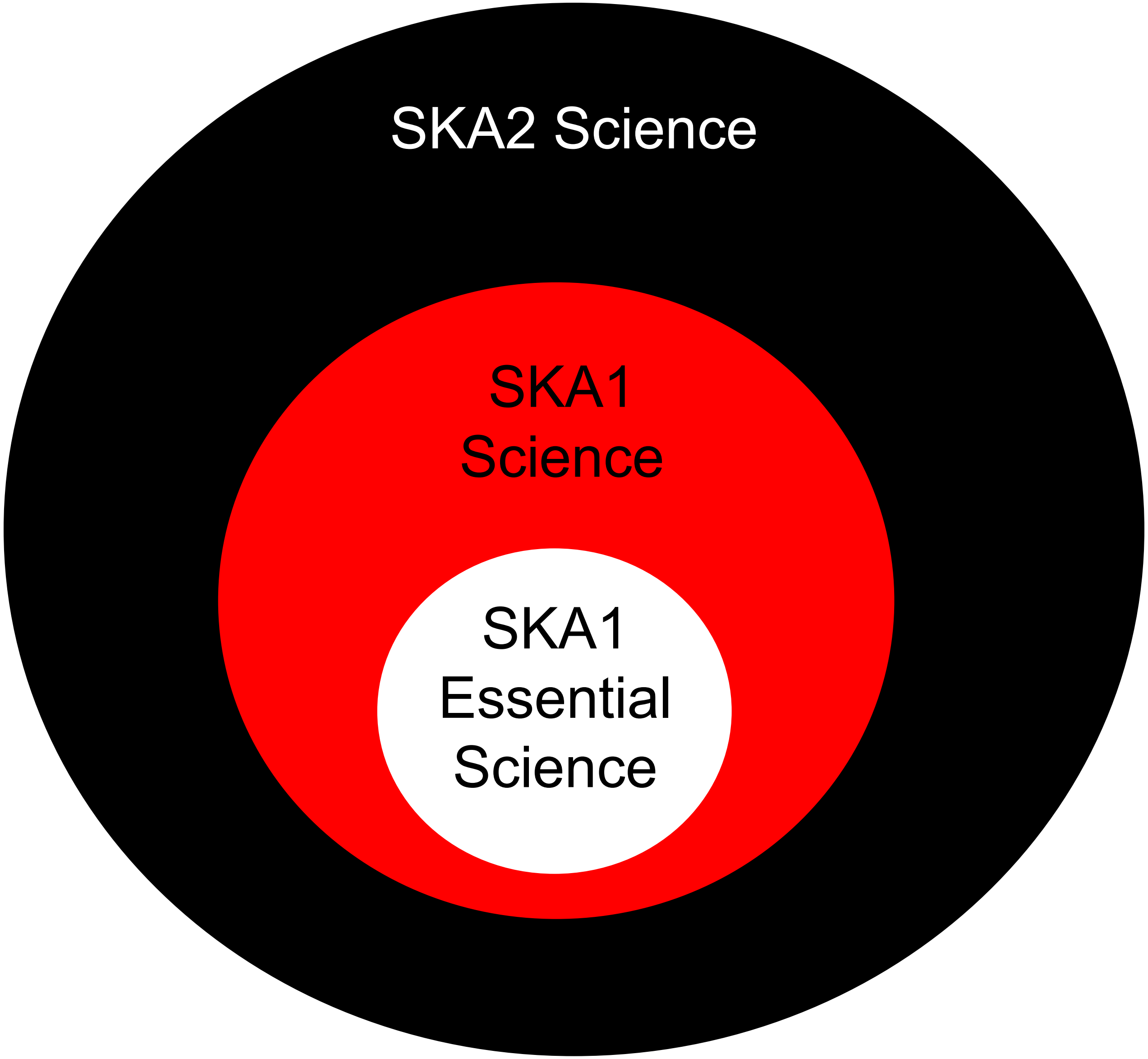
SKA1 "Essential" Science Objectives

- From Memo 125: A Concept Design for SKA Phase 1 (SKA1)
  - Garrett et al.
- "Major science goals which drive the technical specifications for the 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.

"Forward Compatibility" Science Objectives

- Forward compatibility indicates that some aspects of the system will have to support these key science components in SKA2.
- A wide variety of different studies will be enabled:
  - e.g. detecting and imaging radio continuum emission from galaxies and active galactic nuclei to trace the evolution of galaxies, black holes, star formation and magnetism from the dawn of galaxies to the present era.
- Large HI galaxy surveys for cosmology and dark energy may also be conducted, in addition to transient searches (including SETI).
- In particular, the advances that SKA1 represents in terms of its sensitivity, survey speed, time domain sampling and image fidelity will open up new regions of discovery space.

SKA2 and SKA1 Science



DRM Refinement

- DRM is a font of information ... but a bit of a mixture.
- Contains
  - Essential information (astronomical goals, science-based information to support the goals).
  - Some extraneous information (e.g. Frequency resolution based on RFI considerations).
- Some essential information is missing (e.g. general statement on spectral baseline fluctuations, but specific requirement for different cases may be needed).

DRM Refinement

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- Goal is to extract and supplement the DRM science information:
  - Distil to "atomic statements" that can be formally entered in system design software and traceable throughout the system design process.
    - e.g. Observe all the spectral lines in the 1-3 GHz band in the TMC down to a specified brightness temperature.)
    - Test: Detect and identify the spectral line of CH_3CHO (A ~ 10-10 s-1 ; N ~ 1014 cm-– these are guesses) in the Taurus molecular cloud in 50 hr of integration.
    - Example chosen because it is an SKA2 requirement, but will still affect the design of SKA1.
- Requirements should technology-independent.
  - Don't limit the solution space!
  - Requirements need to be testable.
    - Tests related to the requirement must be proposed at various levels of the system.
- Cross-check with original science case. How much of the original science can be done as a result of the set of science requirements ("backproject" requirements)? Are we building the right thing?
- Examine for completeness.

Need for Formal System Design Approach: SKA Complexity

- SKA scale is large by current standards in radio astronomy.
- Wide international participation, complex financing & procurement.
- Moderately complex technology.
- Remote Site.
- Construction & observations to co-exist for many years (Progressive Rollout).
- RFI to be minimized.
- Large operational site.
- Large power requirement where there are now few services.

Characteristics of Requirements

- Science requirements are not specific technologies for science
  - Not solutions looking for a problem.
- Only some requirements are derived from science
  - Many other sources – see Wallace Turner talk.
  - Most other requirements affect cost, but a whole category affects operations.
- Can build a telescope without getting requirements but,
  - performance will be uncertain,
  - final cost may never be known (continually correcting things) and you can’t trace why,
  - may deliver something that was never intended or wanted,
  - project may actually run out of funds without being finished.
    - Even “finished” may not be defined.

Examples: ALMA, LSST

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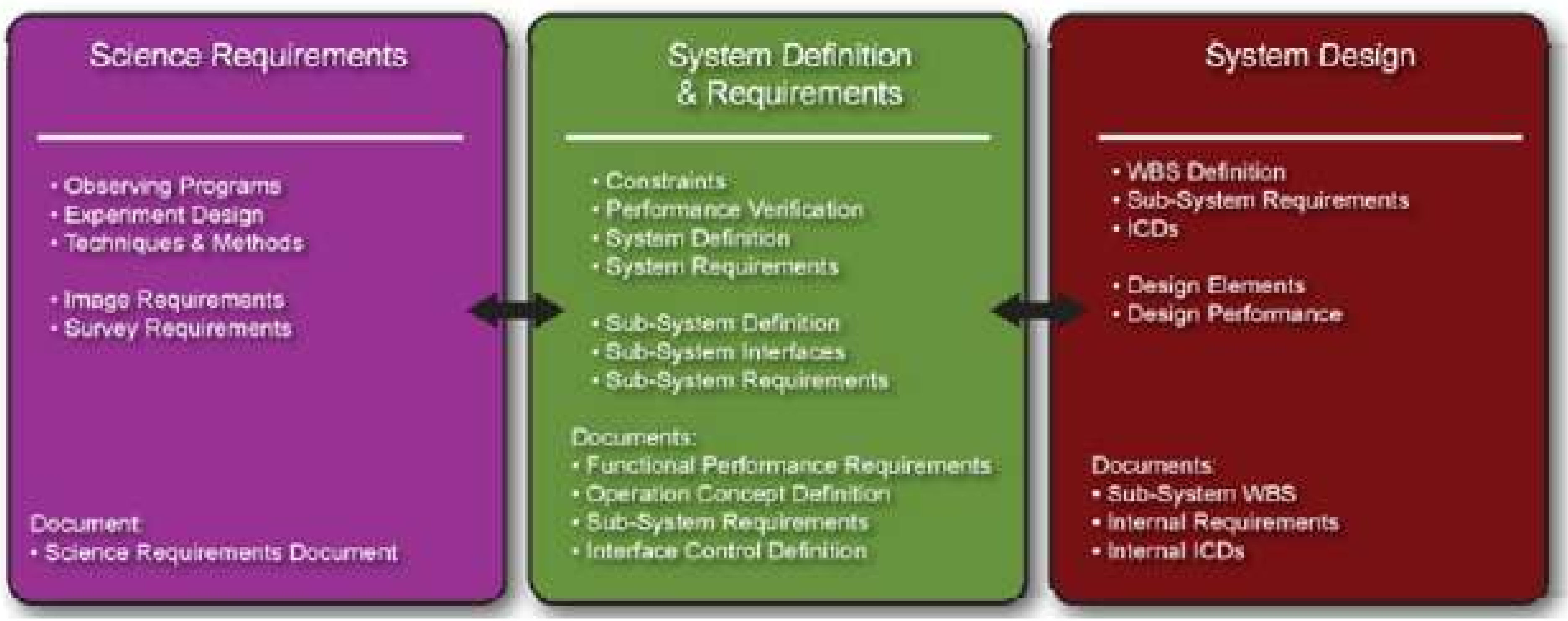
- System engineering did not figure strongly in ALMA.
  - Recently added system engineering capability.
  - Needed to address system issues that have arisen later in the design.
- LSST (http://www.lsst.org/lsst/science/system_design)
  - Appears to be playing a strong role.



SKA1 Requirements Gathering Process

- Elicit requirements in the following classes (already been done with the DRM):
  - SKA2 Science
  - SKA1 “essential” Science
  - SKA1 “forward compatibility” Science
- Elicit Other Requirements
  - Non-functional requirements, operations requirements, environment, etc.
- Develop SKA1 system design
  - A number of technology options available.
  - Phase 2 extensibility constraints.
  - Obtain cost estimates.
- Cost is a constraint.
- Iteration: trading requirements against cost.
  - Observing time is a tradable commodity – nominal available ~10 yrs.

Process, Emphasising SKA1

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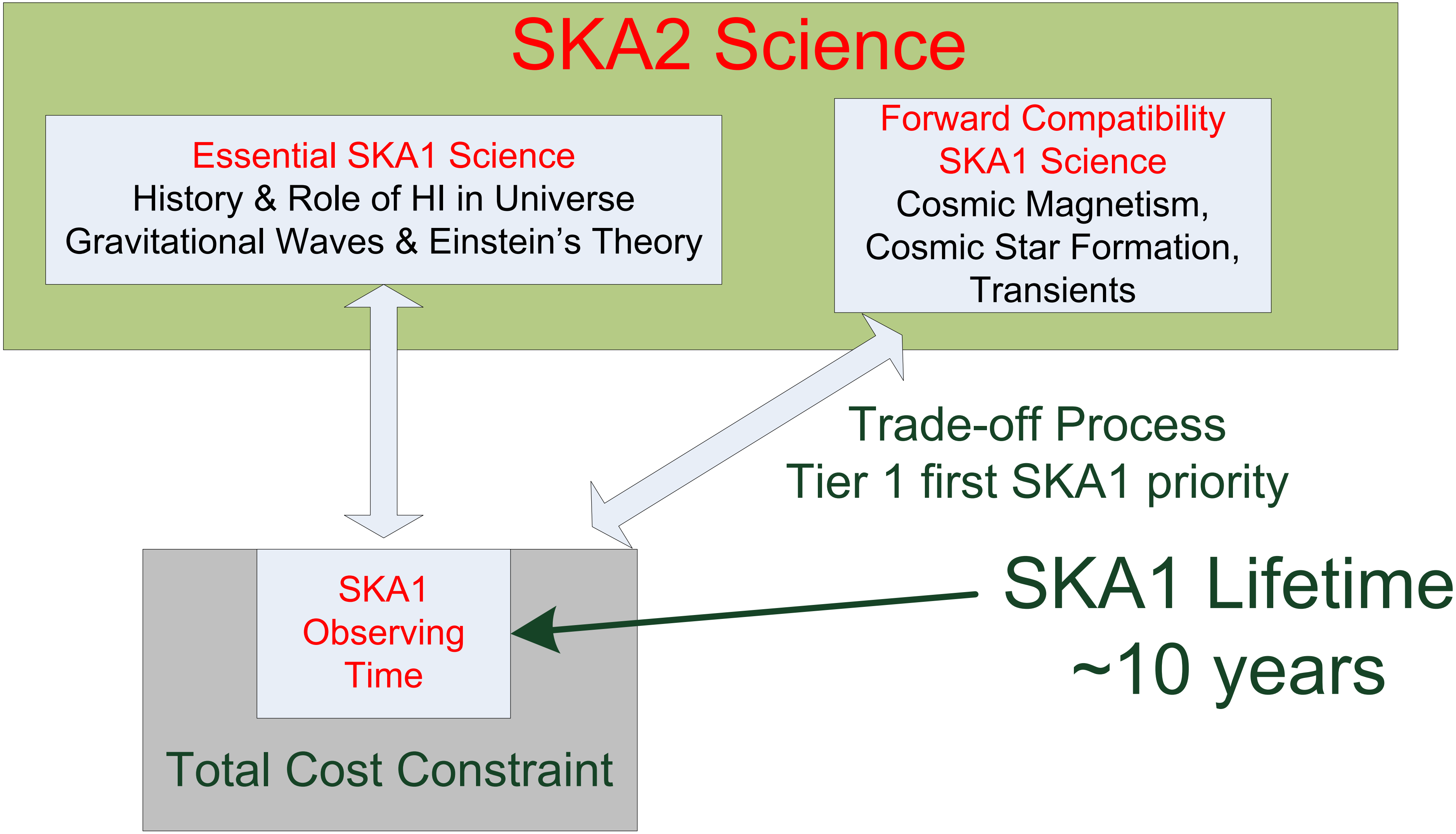
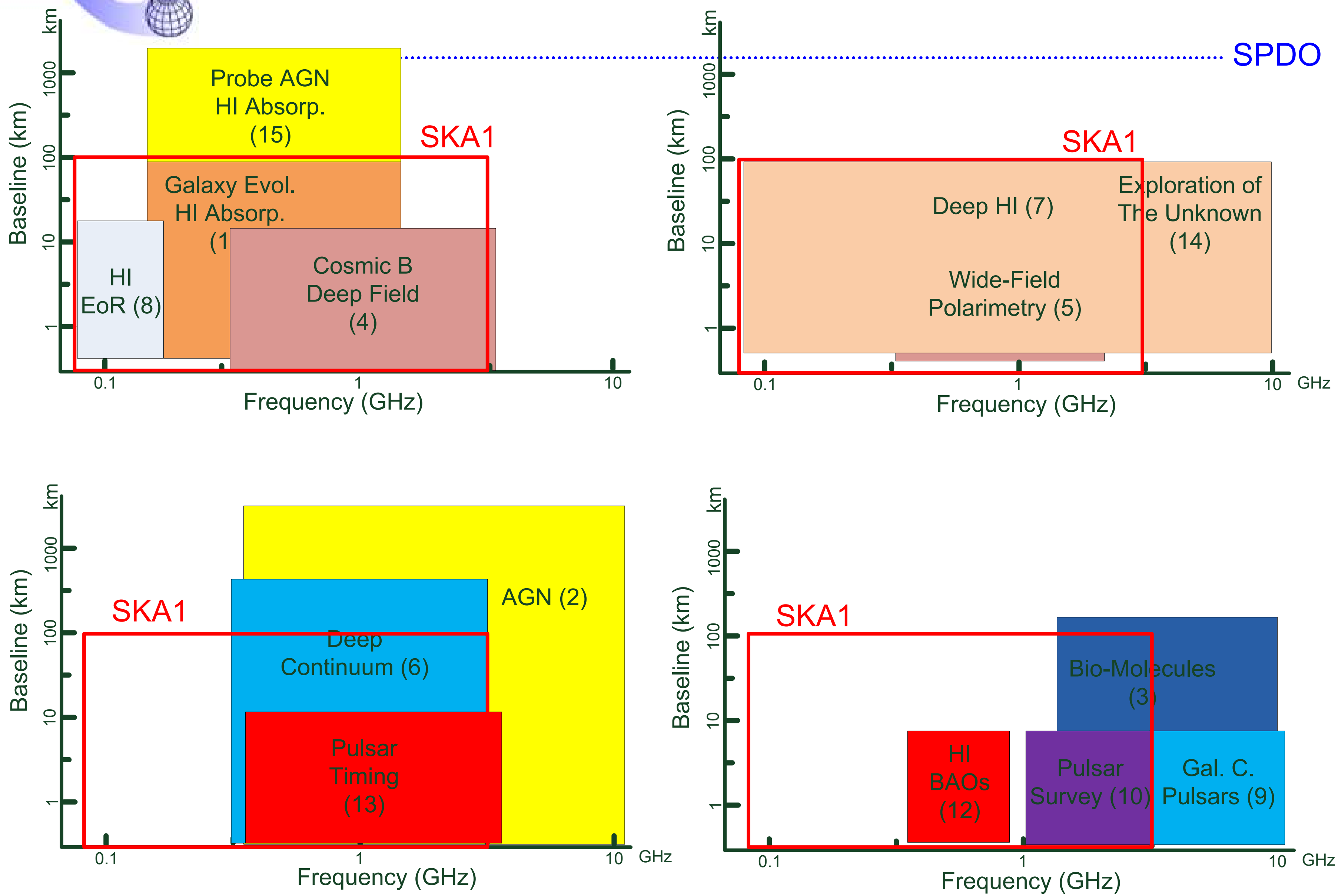


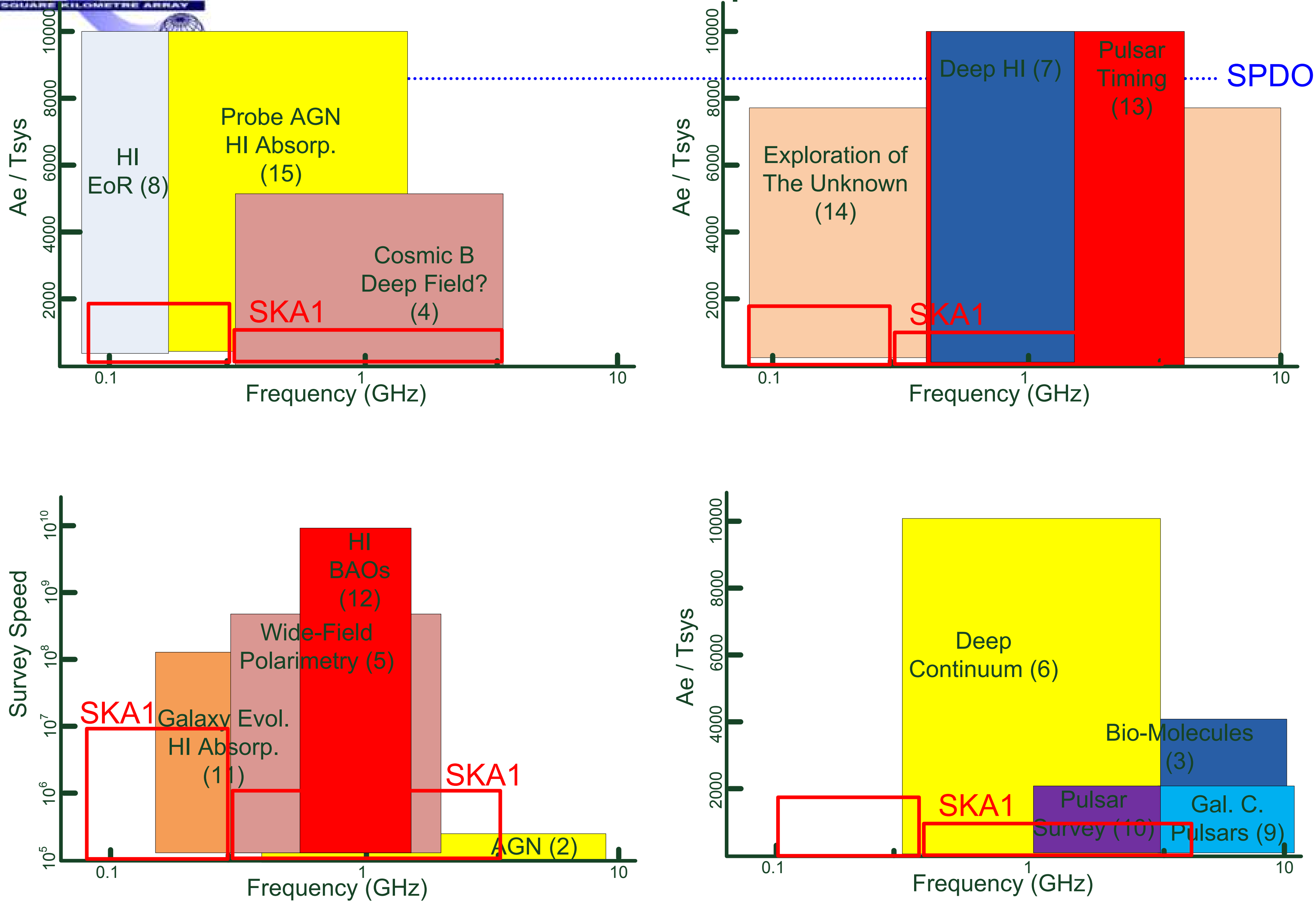
SKA1 Design Reference Mission

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.**
9. Probing Gravity, Dark Matter, & Stellar Populations in the Galactic Center with Radio Pulsars
10. Not used.
11. **Tracking Galaxy Evolution over Cosmic Time via H I Absorption?**
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.**
17. **Pulsar Timing with the SKA.**

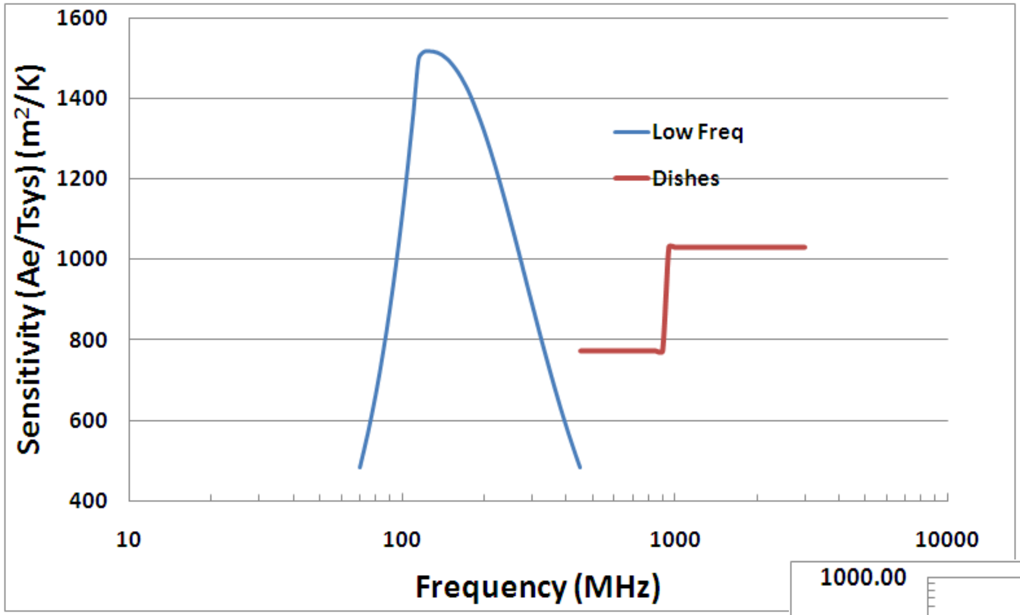
DRM Components



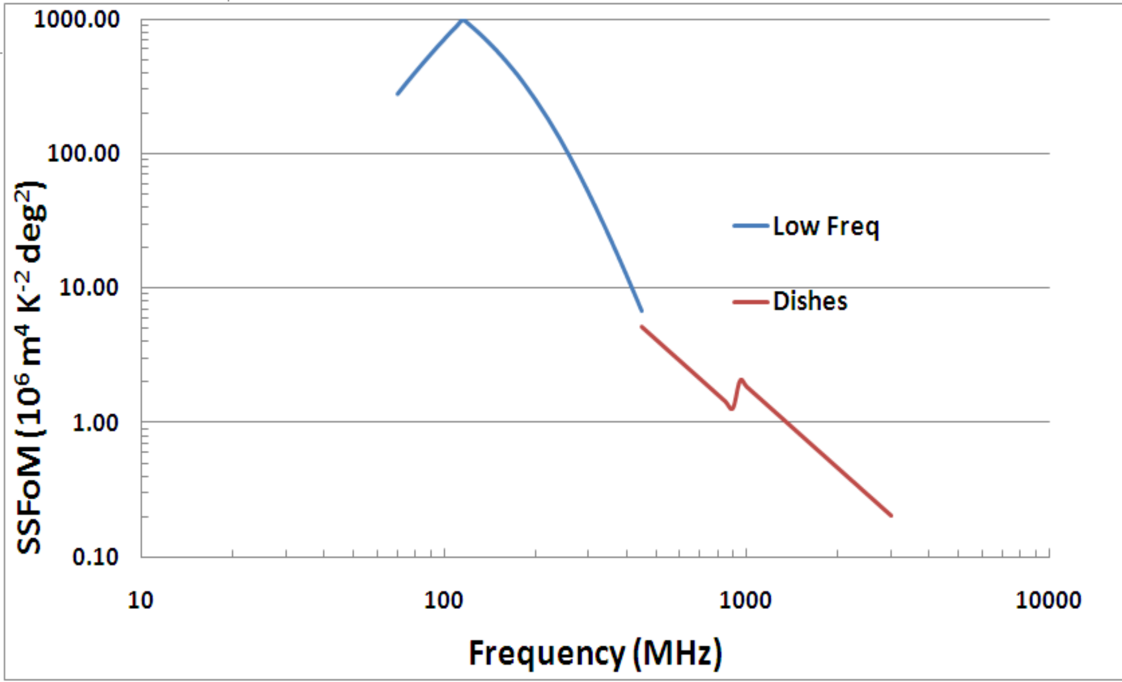
DRM Components



Potential SKA1 Sensitivity



These are not given. Cost is unknown but could easily be >> the constraint (€300M).



Example: High-level Science Requirement

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- Objective: Test theories of gravity
- Needed: additional ultra-relativistic binaries.
- Implies: Blind Survey: low- and moderate Galactic latitude for binaries.
- Frequency: 1.4 GHz (and ~ 2 GHz?)
- Flux limit: 1 μJy time average at 1.4 GHz?
- Timing resolution: 50 μs?
- Frequency resolution: 10 kHz?
- Leads to DM_{max} ~ 1600 cm-3 pc, Number of DM trials ~ 36000
- Area of sky to be covered: l = ± 45 deg; b = ± 5 deg. (900 deg^2)?
- Nominal available observing time: 2 x 10^4 hr (2 yr, possibly traded up or down).

- Needed: higher precision timing of known and future ultra-relativistic binaries.
- Implies: pointed observations toward "timers"
- Signal to noise: typical pulsar ~0.1 to 3 mJy, σ(TOA) < 100 ns
- Frequency range: 0.4 GHz to 3 GHz
- Polarization purity: 40 dB
- Timing resolution: 100 ns
- Frequency agility: need 3 to 4 quasi-simultaneous bands across 0.4 to 3 GHz.
- 40-100 pulsars to be timed at ~1 month cadence.

With assistance from Minh Hyunh.

Examples: Technical Requirements

- System: post calibration polarisation purity is 10^{-4}.
  - Only required during timing observations.
  - Polarisation error budget to be developed (absolute errors & drift rates):
    - Receptors at beam center, RF-chains, A/D converters, drift rates, calibration intervals, calibration residuals, etc.
  - Each of the element/sub-system/assemblies inherits a piece of the budget as a requirement.
  - The system level keeps track of the total.
  - Tests at system level and lower levels are proposed, done and recorded.
- System survey throughput: cover required parameter space in 2 years (sky area, flux limit, period range, acceleration trials, DM trials, etc.).
  - Survey speed balancing “budget”: sensitivity per beam, N beams, bandwidth, DSP processing throughput limits (N_{chan}, N_{DM}, L_{FFT}, etc).
  - These items must be in balance.
  - System level keeps track of the balance and other competing requirements.
  - Tests proposed, done and recorded (system and lower).

End