


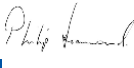




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LIST OF ABBREVIATIONS

BD	SKA1 Baseline Design
EMI	Electromagnetic Interference
EoR	Epoch of Reionisation
FWHM	Full Width Half Maximum
HPSO	High Priority Science Objective
ISW	Integrated Sachs Wolfe effect
NIP	Non-image Processing
PSF	Point Spread Function
RFI.....	Radio Frequency Interference
RMS	Root Mean Square
SEFD.....	System Equivalent Flux Density
SKA	Square Kilometre Array
SKAO	SKA Organisation
SCI_REQ-	Specification number in this document

1 Introduction

1.1 Purpose of the document

This document serves as a vehicle to communicate the scientific goals of the SKA Phase 1 Observatory in the form of specific requirements. The requirements are derived from the key reference documents, in particular the SKA Science Book [RD1] that captures the breadth of science that the community wishes to address with the facility as well as the more focused subset of high priority science objectives [RD2] that emerged from the SKA1 science prioritisation process, together with the Science Use Cases [RD3] that continue to be developed by the SKA Science Working Groups to demonstrate indicative observing strategies to address those objectives. The science requirements provide a high level description of the capabilities desired to achieve the scientific goals of the SKA Observatory.

There is a fundamental difference between the Level 0 (Science) requirements and the Level 1 (System) requirements [RD4]. The Level 0 requirements convey the scientific goals of the facility, while the Level 1 requirements convey the technical specifications that the project proposes to deliver to address those goals. Neither is formally “applicable to”, although both are “informed by”, the other. All of the engineering design work is tied to meeting the System requirements. The Science requirements provide the scientific context and motivation for understanding the System requirements. There is a natural tension between these two requirement sets and there are recognised areas of potential inconsistency. For example, there is a scientific desire to achieve an instrumental reconfiguration response to triggers of significant variable events (as outlined in Sec. 3.10 and expressed in SCI_REQ-53 and SCI_REQ-54) with a latency of less than 5 seconds, while the Level 1 requirements (SYS_REQ-2681) stipulate a mode switching time of less than 30 seconds. The System requirement represents a considered balance of the anticipated cost of achieving a more rapid reconfiguration with the scientific prioritisation of this capability. The Science requirement demonstrates the utility of delivering performance that exceeds the L1 specification. If that can be achieved at no additional construction or operational cost, then it is advantageous.

There is a similar relationship between the Level 0 requirements and the Observatory requirements [RD5]. The Observatory requirements have been informed by both the scientific goals (L0) and the specific technical specifications (L1) proposed to address them. These requirements are the basis for an operations concept [RD6], a calibration plan [RD7], detailed data product definitions [RD8] and a commissioning plan [RD9]. The commissioning plan defines the method by which the scientific performance of the facility is established. The scientific performance is tested against the goals laid out in the (L0) Science requirements.

The Level 1 requirements capture the current balance that has been adopted to maximise the scientific capabilities within a constrained construction and operational budget through delivery of specific technical specifications. Changes to the Level 1 requirements only occur on the recommendation of the Configuration Control Board (CCB), the design authority that safeguards the Science, System and Observatory requirements. It is the CCB that has responsibility for assessing all Engineering Change Proposals (ECPs) against the Level 0 and Observatory requirements in the context of all budgetary implications when considering any modification of the Level 1 requirements.

1.2 Scope of the document

This document establishes the Top Level (or Level 0) Science Requirements of the SKA Observatory in its Phase 1 deployment. The motivation for groups of requirements is provided in the “Context” subsection that precedes each group of specifications. The linkage to specific scientific objectives is

provided in the statement of each specification where appropriate. A summary of specification linkages of Science requirements to scientific objectives is provided in the final row of Tables 1 and 2. A summary of linkages between the L0 and the L1 requirements is given in the Requirements Linkage Document [RD10].

The relationship of this document with other key documents has been summarised in Sec. 1.1 above and is depicted in graphical form in Figure 1.

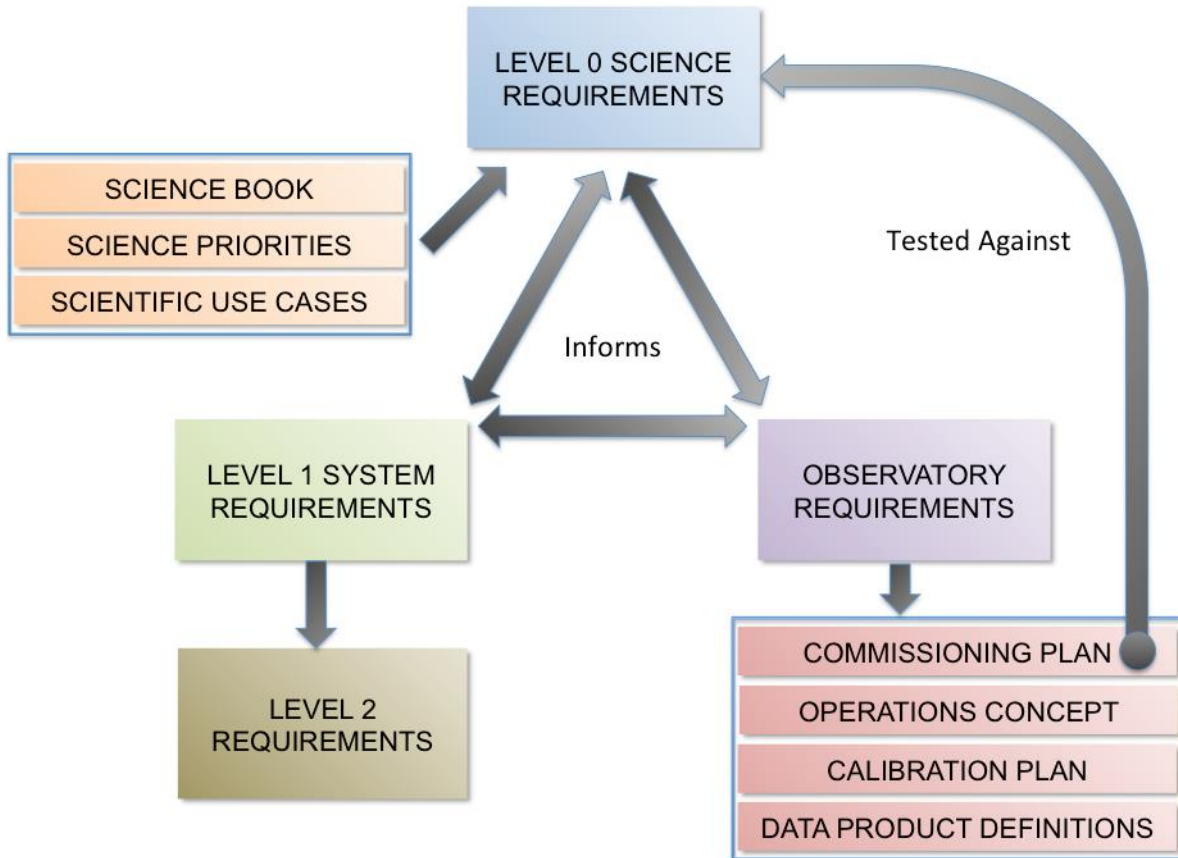


Figure 1. Relationships between the Level 0 requirements and other key documents.

2 References

2.1 Applicable documents

The following documents are applicable to the extent stated herein. In the event of conflict between the contents of the applicable documents and this document, **the applicable documents** shall take precedence.

2.2 Reference documents

The following documents are referenced in this document. In the event of conflict between the contents of the referenced documents and this document, **this document** shall take precedence.

- [RD1] Advancing Astrophysics with the SKA, R. Braun et al. eds., 2015
- [RD2] SKA-SCI-PRI-002-Appendix A, SKA1 Science Priority Outcomes
- [RD3] SKA-TEL-SKO-0000015_SKA1_Science_Use_Cases, Rev 03
- [RD4] SKA-TEL-SKO-0000008_SKA1_Phase_1_System_(Level 1)_Requirement_Specification
- [RD5] SKA-TEL-SKO-0000311, SKA Phase 1 Observatory Requirements (currently being drafted)
- [RD6] SKA-TEL-SKO-0000312, Operations Plan (currently being drafted)
- [RD7] SKA-TEL-SKO-0000313, Calibration Plan (currently being drafted)
- [RD8] SKA-TEL-SKO-0000314, Data Product Definitions (currently being drafted)
- [RD9] SKA-TEL-SKO-0000315, Commissioning Plan (currently being drafted)
- [RD10] SKA-TEL-SKO-0000316, Requirements Linkage Document (currently being drafted)
- [RD11] SKA-OFF.AG.CNF-SKO-TN-001-1, SKA1 Configurations
- [RD12] Radio Source Confusion Document, Condon et. al. 2012, ApJ 758, 23.

3 Requirements

3.1 General Science Performance and Siting

3.1.1 Context

It is anticipated that during its 50-year operational lifetime the SKA Observatory will ultimately be equipped for observations at all radio frequencies between the ionospheric cut-off of about 20 MHz, to beyond the atmospheric water absorption feature to about 24 GHz, enabling the full range of scientific outcomes described in the SKA Science Book [RD1]. The 24 GHz upper limit for the SKA frequency range has emerged from the ongoing dialogue between designers and scientists as a viable, if challenging, goal for the adopted technology. It is widely understood, and captured in the System requirements, that high performance will only be specified below 20 GHz. The expectation is that a graceful decline of performance be available above that frequency. A staged deployment strategy has been adopted whereby a subset of the full capabilities, in terms of frequency coverage, sensitivity and survey speed are delivered, consistent with the available resources and the scientific priorities. For the Phase 1 deployment, both a budgetary cap and a set of Scientific Priorities [RD2] have been approved by the SKA Board. The SKA1 deployment plan calls for two distinct components, SKA1-LOW sited in Australia and SKA1-MID sited in South Africa, to provide capabilities in the “LOW” and “MID” portions of the radio spectrum as defined in more detail below.

The quality of scientific outcomes of the Observatory is measured against the SKA1 science priorities [RD2] together with the more general science objectives identified in the SKA Science Book [RD1]. The set of highest priority science objectives for SKA1 is shown in Table 1 and 2 of Appendix A, together with an indicative observational strategy for their delivery. Key specifications that must be met to enable these outcomes are also listed in the Table, where they are linked by number designation to specific requirements.

It is acknowledged that while specific scientific objectives must be defined and enabled, it is also vital to provide the broader capabilities of a well-rounded observatory. History has demonstrated that it is often the unanticipated discoveries that have proven the most fundamental legacy of astronomical observatories.

3.1.2 Specifications

- | | |
|------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SCI_REQ-01 | SKA1-LOW shall have its scientific performance measured against the SKA1 science priorities [RD2] as well as broader objectives defined in the SKA Science Book [RD1]. |
| SCI_REQ-02 | SKA1-MID shall have its scientific performance measured against the SKA1 science priorities [RD2] as well as broader objectives defined in the SKA Science Book [RD1]. |
| SCI_REQ-03 | If not mentioned otherwise and applicable, the L0 requirements shall be met at the start of scientific operations. If this timescale is not met for a given requirement, then an upgrade path shall be defined. |
| SCI_REQ-04 | SKA1-LOW shall be sited at the locations detailed in [RD10] in the Murchison Shire of Western Australia, as decided by the SKA Members. |
| SCI_REQ-05 | SKA1-MID shall be sited at locations detailed in [RD11] in the Karoo Region of South Africa, as decided by the SKA Members. |

3.2 Key Definitions

3.2.1 Context

The key attributes of final data products are defined and specified here. It should be noted that the specifications pertain to fully calibrated and deconvolved or beam-formed data products, following the procedures documented in RD7, and not to earlier products within the data flow. The calibration, beam-forming and imaging strategy must be sufficiently robust that an effective noise level within all data products is degraded by no more than 10% from the thermal noise associated with the net integration time over at least 95% of the effective data volume. These requirements apply to data products that are not in the “source confusion regime” as described in RD12. It is acknowledged that there may be a greater level of noise degradation in the immediate vicinity of bright sources. What is indicated below in Sec 3.2.2 are the most extreme requirements extracted from the full requirements matrix (shown in Table 1 and 2) listing the High Priority Science Objectives (HPSOs, following reference RD2). It should be noted that the requirements apply to specific contexts, such as angular and spectral resolution for a specific frequency band, as provided by the detailed entries in Tables 1 and 2. Accuracies are defined in the high signal-to-noise regime, where thermal noise fluctuations contribute less than 10% to the error budget of these quantities. Verification of all specifications will be demonstrated as documented in RD9.

- **Image fidelity** is defined here as the anticipated fractional error in the image brightness, $\Delta I/I$, relative to a matched resolution reference image. It is generally acknowledged that this quantity is exceedingly difficult to estimate in practise, since only well-understood effects can be included in a simulation, while it’s likely that poorly understood effects may dominate.
- **Photometric accuracy** is defined here as the fractional error in the flux scale, $\Delta S/S$, relative to an adopted celestial flux standard for the integrated brightness of compact objects (smaller than the PSF FWHM).
- **Astrometric accuracy** is defined here as the fractional error in the position, $\Delta p/\Delta\theta$, for the centroid of compact objects (smaller in size than the PSF FWHM, $\Delta\theta$) relative to the adopted celestial reference frame.
- **Frequency accuracy** is defined here as the fractional error in the frequency, $\Delta\nu/\nu$, relative to an adopted frequency standard over a specified time interval. One of the instances in which frequency accuracy is vital is in a measurement of the time evolution of cosmological redshifts (as documented RD1) which yields a 0.1 Hz frequency shift at 1 GHz over 10 years.
- **Timing accuracy** is defined here as the time error, $\Delta\tau$, relative to an adopted time standard over an indicated time interval. Timing accuracy is of particular importance in the context of enabling precision pulsar timing.
- **Brightness dynamic range** is defined here as the ratio of peak to RMS brightness, $I/\Delta I$, where the RMS fluctuation level is measured within the entire primary beam of the dish or station, but may exclude an area of 5x5 PSF FWHM centred on the brightness peak. It is generally acknowledged that there may be elevated noise levels in the immediate vicinity of bright sources, particularly when partially resolved by the PSF, due to residual calibration errors.
- **Polarisation dynamic range** is defined here as the ratio of peak Stokes I brightness to the residual instrumental polarised response, $I/\Delta P$, at the source location. Specified values apply to both the target pointing direction as well as everywhere within the half power point of the dish or station beam.
- **Spectral dynamic range** is defined here as the ratio of peak brightness to the residual instrumental spectral response, $I/\Delta I$, at the source location over a specified spectral interval. Specified values apply to both the target pointing direction as well as everywhere within the half power point of the dish or station beam.

- **Bandpass stability** is defined here as the residual fractional error in the brightness, Δ/I , as a function of frequency for a specified frequency interval over a specified time. Sufficient bandpass stability must be realised to permit a calibration strategy that provides the specified Spectral Dynamic Range.
- **Spurious spectral features** level is defined here as the fractional amplitude, Δ/I , of residual spurious features that are a consequence of a spectral signal of strength I . Spurious spectral feature levels must be low enough to satisfy the Spectral Dynamic Range specification.

3.2.2 Specifications

SCI_REQ-06	SKA1-LOW shall provide an effective noise level within all final data products that is degraded by no more than 10% from the thermal noise associated with the net integration time over at least 95% of the effective data volume when not limited by image source confusion. All applications using SKA1-LOW (e.g. HPSO 1 – 5) are otherwise negatively impacted.
SCI_REQ-07	SKA1-MID shall provide an effective noise level within all final data products that is degraded by no more than 10% from the thermal noise associated with the net integration time over at least 95% of the effective data volume when not limited by image source confusion. All applications using SKA1-MID (e.g. HPSO 4 – 38) are otherwise negatively impacted.
SCI_REQ-08	SKA1-LOW shall provide image fidelity of at least 10%. All applications using SKA1-LOW (e.g. HPSO 1 – 5) are otherwise negatively impacted, but particularly the foreground subtraction required for the EoR applications (HPSO 1 and 2).
SCI_REQ-09	SKA1-MID shall provide image fidelity of at least 10%. All applications using SKA1-MID (e.g. HPSO 4 – 38) are otherwise negatively impacted, but particularly the deep continuum imaging (HPSO 37+38).
SCI_REQ-10	SKA1-LOW shall provide photometric accuracy of at least 2%. All applications using SKA1-LOW (e.g. HPSO 1 – 5) are otherwise negatively impacted, but particularly the EoR imaging and power spectra applications (HPSO 1 and 2).
SCI_REQ-11	SKA1-MID shall provide photometric accuracy of at least 1%. All applications using SKA1-MID (e.g. HPSO 4 – 38) are otherwise negatively impacted, but particularly deep continuum imaging (HPSO 37+38).
SCI_REQ-12	SKA1-LOW shall provide astrometric accuracy of at least 1%. All applications using SKA1-LOW (e.g. HPSO 1 – 5) are otherwise negatively impacted, but particularly the EoR imaging (HPSO 1).
SCI_REQ-13	SKA1-MID shall provide astrometric accuracy of at least 1%. All applications using SKA1-MID (e.g. HPSO 4 – 38) are otherwise negatively impacted, but particularly deep continuum imaging (HPSO 37+38).

SCI_REQ-14	SKA1-LOW shall provide frequency accuracy of at least 10^{-11} over a 10 year interval. All applications using SKA1-LOW (e.g. HPSO 1 – 5) are otherwise negatively impacted, but particularly a measurement of the time evolution of cosmological red-shifts (RD1).
SCI_REQ-15	SKA1-MID shall provide frequency accuracy of at least 10^{-11} over a 10 year interval. All applications using SKA1-MID (e.g. HPSO 4 – 38) are otherwise negatively impacted, but particularly a measurement of the time evolution of cosmological red-shifts (RD1).
SCI_REQ-16	SKA1-LOW shall provide timing accuracy of at least 10 nsec over a 10 year time year interval to enable precision pulsar timing at 150 – 350 MHz (HPSO 5).
SCI_REQ-17	SKA1-MID shall provide timing accuracy of at least 10 nsec over a 10 year time year interval to enable precision pulsar timing at 950 – 1760 MHz (HPSO 5).
SCI_REQ-18	SKA1-LOW shall provide 50 dB brightness dynamic range at 300 arcsec spatial and 1 MHz spectral resolution to enable EoR imaging and power spectra generation at 50 – 200 MHz (HPSO 1 and 2).
SCI_REQ-19	SKA1-MID shall provide 60 dB brightness dynamic range at 0.5 arcsec spatial and 1 MHz spectral resolution to enable deep continuum imaging at GHz frequencies at 1000 – 1700 MHz (HPSO 37+38).
SCI_REQ-20	SKA1-LOW shall provide 45 dB polarisation dynamic range at 300 arcsec spatial and 1 MHz spectral resolution to enable EoR imaging at 50 – 200 MHz (HPSO 1).
SCI_REQ-21	SKA1-MID shall provide 40 dB polarisation dynamic range at 7 arcsec spatial and 75 kHz spectral resolution to enable precision pulsar timing at 950 – 1760 MHz (HPSO 5) and sensitive intensity mapping at 350 – 1050 MHz (HPSO 32).
SCI_REQ-22	SKA1-LOW shall provide 50 dB spectral dynamic range at 300 arcsec spatial and 1 MHz spectral resolution to enable EoR imaging at 50 – 200 MHz (HPSO 1).
SCI_REQ-23	SKA1-MID shall provide 45 dB spectral dynamic range at auto-correlation spatial and 300 kHz spectral resolution to enable sensitive intensity mapping at 350 – 1050 MHz (HPSO 32).

3.3 Frequency coverage, instantaneous bandwidth and sampling

3.3.1 Context

The ultimate limiting frequencies of the SKAO, 20 MHz – 24 GHz, are of particular relevance for long-term protection of the RFI environment of the two Observatory sites as well as future-proofing the design of all on-site equipment from an EMI perspective. The observing capability in specific frequency bands will be deployed in a staged fashion determined by scientific priorities and budgetary limitations. Although the first SKA deployment phase calls for deployment of a low frequency capability in Australia and a higher frequency capability in South Africa, this does not imply that the long-term RFI or EMI considerations may be similarly restricted in frequency coverage. Rather, it is vital to retain the flexibility to deploy frequency coverage throughout the full range of 20 MHz – 24 GHz at both sites.

Access to the largest possible instantaneous bandwidth is desired for many applications that require either high continuum sensitivity or broad spectral sampling (see references RD1, RD2); limited only, when practical, to the nominal band-pass of the feed system itself. The perpendicular polarisation states of the signal must be measured and the system designed to permit their suitably precise calibration (see reference RD2 and Table 1 and 2) both toward a tracking centre and out to the half power point of the effective field of view. Multiple pointing directions will normally be used to extend the total field over which some sensitivity and polarisation precision is desired.

In the case of the aperture array station beams of SKA1-LOW, there are many applications (see references RD1, RD2) that benefit from forming several simultaneous station beams that may be pointed independently, each provided with a fraction of the total processed bandwidth. A particular case of interest occurs when only a portion of the accessible spectral range of the SKA1-LOW antennas, for example 100 – 150 MHz, is desired for an application. In such cases it is often desired to observe with multiple station beams that each sample the same portion of the spectrum.

The desired spectral sampling within final data products varies widely with the specific application (see reference RD2 and Table 1 and 2). Relatively fine spectral sampling is often required early in the processing, for example to allow for filtering of narrow band RFI signals or spectral calibration, while somewhat coarser sampling is often sufficient in final data products. While some applications require extremely high spectral resolution in their output data products, it is understood that this will normally come at the expense of total bandwidth. In such cases, it is desirable to preserve the maximum number of available spectral channels and apply these over a smaller output bandwidth, either in one contiguous segment or distributed over multiple segments constrained by the total instantaneous bandwidth.

3.3.2 Specifications

- SCI_REQ-24 SKA1-LOW shall provide frequency coverage of both perpendicular polarisation states at 50 – 350 MHz to enable EoR imaging and power spectra generation (HPSO 1 and 2), as well as pulsar searching and timing (HPSO 4 and 5).
- SCI_REQ-25 SKA1-MID shall provide frequency coverage of both perpendicular polarisation states at 0.35 – 1.76 GHz and 4.6 – 13.8 GHz to enable the highest priority mid-frequency science objectives to be realised (HPSOs 4 to 38). As a goal, frequency coverage of both perpendicular polarisation states will be continuous from 0.35 GHz to 24 GHz.
- SCI_REQ-26 SKA1-LOW shall provide a maximum instantaneous bandwidth for each of four polarisation products of 300 MHz in the 50 – 350 MHz range, sampled by a maximum number of spectral channels within output data products of 65,536.
- SCI_REQ-27 SKA1-LOW shall provide the capability for up to 8 simultaneous station beams, N_{Bm} , each of four polarisation products of $300/N_{Bm}$ MHz maximum bandwidth and a number of spectral channels per station beam within output data products of $65,536/N_{Bm}$.
- SCI_REQ-28 SKA1-MID shall provide a maximum instantaneous bandwidth for each of four polarisation products of 1 GHz in the 0.35 – 1.76 GHz range and 2x2.5 GHz in the 4.6 – 13.8 (or 24) GHz range, sampled by a maximum number of spectral channels within output data products of 65,536.

- SCI_REQ-29 SKA1-LOW shall provide the capability to distribute the maximum number of available spectral channels, N_{Max} , over up to 4 spectral windows, each with up to $N_{Max}/4$ spectral channels. The minimum spectral window width shall be 4 MHz and the maximum spectral window width shall be the total bandwidth divided by the spectral window number.
- SCI_REQ-30 SKA1-MID shall provide the capability to distribute the maximum number of available spectral channels, N_{Max} , over up to 4 spectral windows, each with up to $N_{Max}/4$ spectral channels. The minimum spectral window width shall be 4 MHz and the maximum spectral window width shall be the total bandwidth divided by the spectral window number.

3.4 Accessible sky

3.4.1 Context

In general, the most complete possible accessibility to the 2π steradians above the local horizon is desirable. This enables the longest duration tracking of celestial sources and provides access to the largest possible range of Declinations. These considerations are of particular importance in the context of VLBI observations involving other observatories that are widely distributed geographically by maximising the duration of joint source visibility. Limitations on sky accessibility to less than 2π steradians will only be adopted when associated with significant cost savings. In the case of mechanically pointed dishes, there is a need to access the full range of azimuthal angles (0 – 360 deg) as well as to allow wrapping to provide an efficient source tracking capability. In the case of aperture array stations there is a desire for a pointing capability that extends below the local horizon (elevations less than zero) to permit data acquisition toward ground-based transmitters.

The noise performance of radio telescope systems will generally vary with the local pointing direction due to a combination of environmental factors and engineering design choices. Degradation of noise performance with local pointing direction due to engineering choices will generally only be adopted when associated with significant cost savings.

3.4.2 Specifications

- SCI_REQ-31 SKA1-LOW shall provide access to all local azimuthal angles, 0 – 360 deg and all local elevation angles, -5 – +90 deg.
- SCI_REQ-32 SKA1-MID shall provide access to all local azimuthal angles, -270 – +270 deg (relative to North = 0 deg) and local elevation angles, +15 – +95 deg.
- SCI_REQ-33 SKA1-LOW shall provide nominal noise performance at all local azimuthal angles, 0 – 360 deg and a degradation of peak performance of less than 30% at local elevation angle of 60 deg and less than 50% degradation at local elevation angle of 45 deg.
- SCI_REQ-34 SKA1-MID shall provide nominal noise performance at all local azimuthal angles, -270 – +270 deg (relative to North = 0 deg) and a degradation of peak performance of less than 5% at local elevation angle of 55 deg and less than 15% degradation at local elevation angle of 20 deg.

3.5 Sensitivity and synthesized PSF quality as function of angular resolution

3.5.1 Context

The sensitivity and synthesized point spread function (PSF) quality at a specified angular resolution are determined by the total system equivalent flux density (SEFD), the array configuration, the duration of source tracking, the fractional bandwidth being sampled as well as the method of visibility data weighting employed in imaging. These quantities will vary with the central observing frequency. Current zenith performance estimates of the 131,072 antennas planned for deployment within the SKA1-LOW array are shown in Figure 2. Also shown in Figure 2 are the current performance estimates for each of the 133x15m diameter SKA1 dishes that are planned for deployment in SKA1-MID, to be used in conjunction with the 64x13.5m diameter MeerKAT dishes.

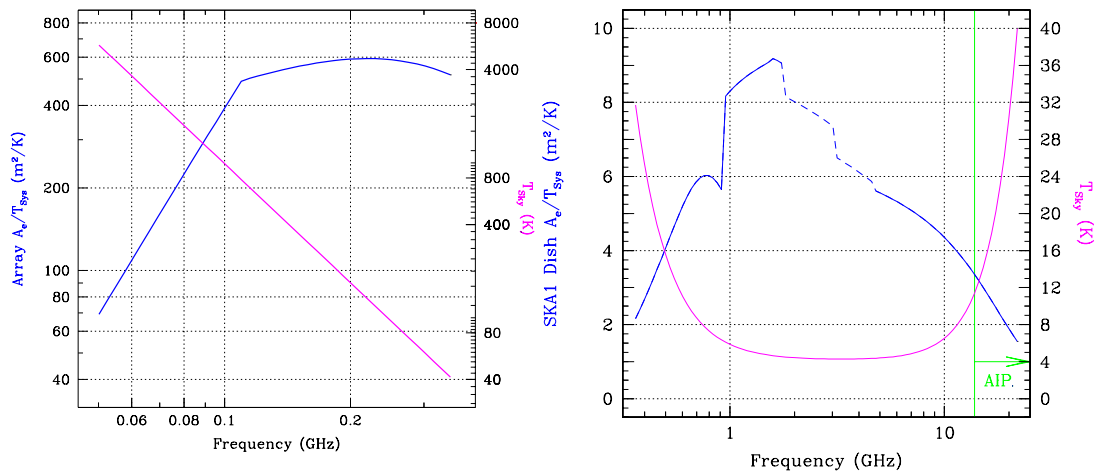


Figure 2. The full array sensitivity at zenith of SKA1-LOW (left) and the zenith sensitivity of each SKA1-MID dish (right). The blue curves show estimated sensitivity in terms of the left hand axis labels, while the magenta curve shows the typical assumed sky temperature using the right hand axis labels. The dashed blue curve depicts bands not yet scheduled for deployment, while the frequency interval above 13.8 GHz is under investigation in the context of the Advanced Instrumentation Program (AIP).

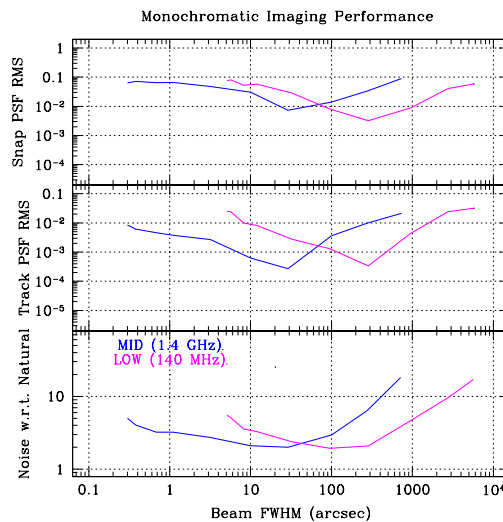


Figure 3. Monochromatic image noise relative to the total array SEFD (bottom) as well as PSF near-in sidelobe levels for snap-shot (top) and full-track (middle) observations of the SKA1 configurations as function of required beam size.

Some of the dependencies on angular resolution at a fixed nominal observing frequency are illustrated below for the specific example of the array configurations specified here (in reference RD11) for both the case of narrow-band (Figure 3) and broad-band (Figure 4) observations. The visibility data weighting method employed for this illustration is so-called “uniform” weighting, followed by a Gaussian visibility taper to yield the specified PSF FWHM diameter.

A relevant PSF quality metric is the RMS side-lobe level in the central 10x10 beam areas of the “dirty” PSF; this is shown for both “snap-shot” observations (containing only a single time sample) occurring at zenith and “full-track” observations of 8 hour (for SKA1-MID) or 4 hour (for SKA1-LOW) duration for a source at a typical -30 deg Declination. The maximum nominal track duration depends on how the array sensitivity varies with elevation. In the case of steerable dishes operating between 350 MHz and 24 GHz the nominal track duration of 8 hours will often be appropriate. In the case of an aperture array station employing moderate gain log periodic antennas the nominal track duration of 4 hours is more likely to be appropriate. The reasons for the shorter track duration for aperture arrays are both the degraded system performance and the anticipated increase in calibration complexity at significant zenith angles.

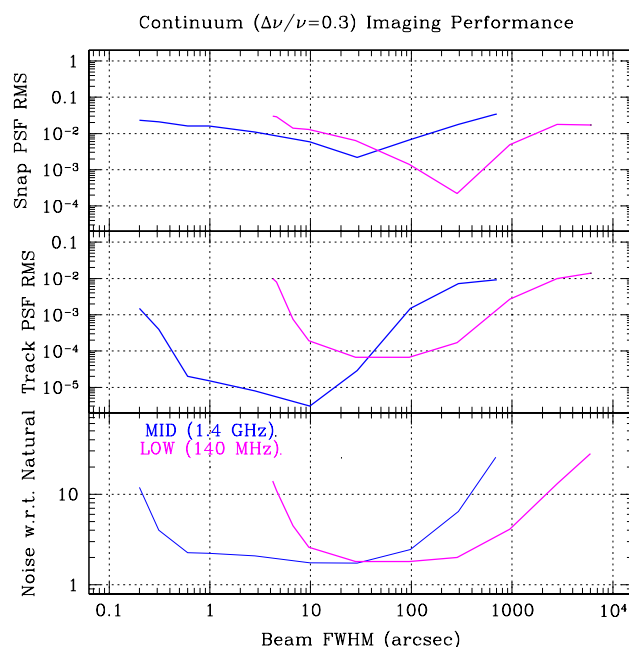


Figure 4. Continuum mode (for 30% fractional bandwidth) image noise relative to the total array SEFD (bottom) as well as PSF near-in sidelobe levels for snapshot (top) and full-track (middle) observations of the SKA1 configurations as function of the required beam size.

The array configurations are constrained by two primary drivers: (1) the need to deliver sensitivity at particular angular scales, and (2) sufficient instantaneous and long-track visibility sampling to allow for successful calibration and imaging. As noted previously, the maximum duration of long-track observations might be about 8 hours for SKA1-MID and 4 hours for SKA1-LOW. For both SKA1-LOW and SKA1-MID there are high priority scientific requirements for achieving exceptional brightness sensitivity, as outlined in RD2. This leads to configurations that have a very high areal filling factor within a dense core region. Both components also have high priority requirements for providing high angular resolution: better than about 0.5 arcsec at 1.4 GHz in the case of SKA1-MID and better than about 10 arcsec at 140 MHz in the case of SKA1-LOW (see reference RD1, RD2). The maximum required angular resolution (at a specific frequency) constrains the maximum physical extent of the configuration; $B_{Max} \approx 150$ km in the case of SKA1-MID and $B_{Max} \approx 65$ km in the case of SKA1-LOW as

illustrated in Figures 3 and 4 above. Providing sensitivity to an extremely broad range of angular scales is most effectively achieved with a logarithmic variation of antenna density as function of radius from the dense core. The optimum distribution of antennas in an azimuthal sense is the most diverse sampling possible, within the constraints imposed by the finite antenna number and the cost of antenna connectivity infrastructure. A practical implementation (see reference RD11) calls for a modified three-arm logarithmic spiral using the tightest possible spiral winding consistent with the site layout. Previous studies have indicated that a tightly wound five-arm logarithmic spiral might form the basis for the more extensive antenna deployments envisaged for SKA2. Indicative plots of accumulated collecting areas as function of radius from the core are shown in Figure 5 below.

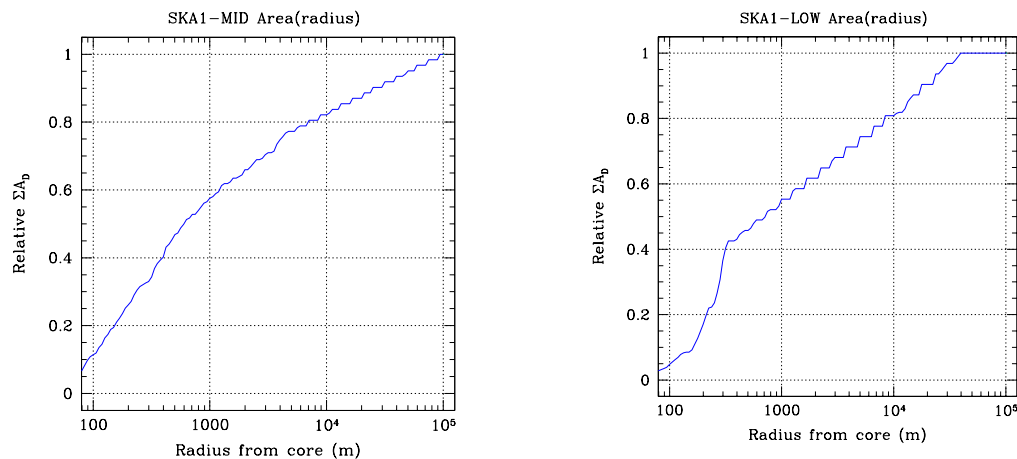


Figure 5. The SKA1-MID (left) and SKA1-LOW (right): cumulated collecting area as function of radius.

3.5.2 Specifications

- SCI_REQ-35 SKA1-LOW shall provide a total array sensitivity as function of frequency at least as high as shown in Figure 2.
- SCI_REQ-36 SKA1-MID shall provide a dish sensitivity as function of frequency at least as high as shown in Figure 2.
- SCI_REQ-37 SKA1-LOW shall provide a relative collecting area as function of radius as shown in Figure 5.
- SCI_REQ-38 SKA1-MID shall provide a relative collecting area as function of radius as shown in Figure 5.
- SCI_REQ-39 SKA1-LOW shall provide a PSF quality for zenith snapshot observations at least as good as shown in Figures 3 and 4.
- SCI_REQ-40 SKA1-MID shall provide a PSF quality for zenith snapshot observations at least as good as shown in Figures 3 and 4.
- SCI_REQ-41 SKA1-LOW shall provide a PSF quality for a 4-hour tracking observation at nominal declination at least as good as shown in Figures 3 and 4.
- SCI_REQ-42 SKA1-MID shall provide a PSF quality for an 8-hour tracking observation at nominal declination at least as good as shown in Figures 3 and 4.

3.6 Survey speed and deep-field performance

3.6.1 Context

Survey speed and deep-field performance are determined by the combination of array SEFD and configuration together with the instantaneous field-of-view. *Indicative* pictorial representations of these capabilities are given in Figures 6 for SKA1-LOW and 7 for SKA1-MID. The RMS sensitivity, expressed in units of Jansky per beam, is shown in these Figures for two *indicative* types of experiment; a wide-field survey covering 3π sr utilising two calendar years of net integration time and a deep pointed observation that accumulates 1000 hours of net integration on a single field.

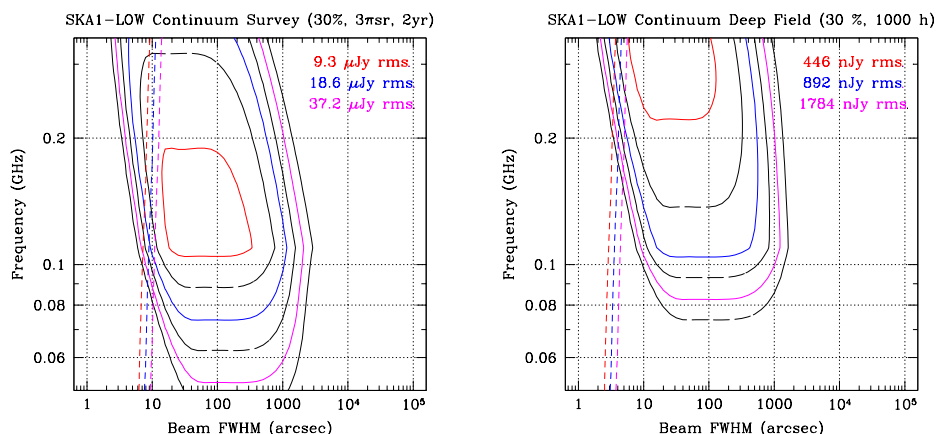


Figure 6. The all-sky survey and deep-field sensitivity performance of SKA1-LOW as function of angular scale and centre frequency. Source confusion levels for continuum observations are indicated by the diagonal dashed contours.

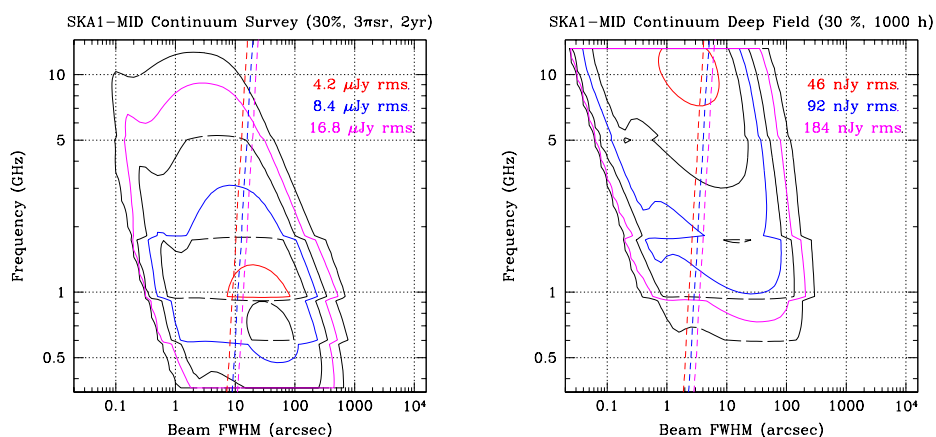


Figure 7. The all-sky survey and deep-field sensitivity performance of SKA1-MID as function of angular scale and centre frequency. Source confusion levels for continuum observations are indicated by the diagonal dashed contours.

The indicative RMS noise performance is shown for wide-band continuum applications that utilise, in this example, a 30% fractional bandwidth at each centre frequency (noting that the requirement is for the availability of up to 100% as applicable: see specifications SCI_REQ-25 and SCI_REQ-26). The noise performance is shown as function of both the centre frequency and the FWHM of a Gaussian PSF within image data products, under the assumption that the thermal noise level is achieved. Contours

of RMS noise levels are drawn at intervals of $\sqrt{2}$, beginning at 110% of the minimum RMS noise. Odd contours are drawn in colours that match the numerical labels. The anticipated FWHM beam-size above which source confusion noise is greater than the labelled numerical values (following reference RD12) is drawn in the figures as a dashed line of the same colour. Although the following deep-field specifications are stated for 1000 hour durations this is not a limitation on observation length, merely a timescale for a given performance.

3.6.2 Specifications

- SCI_REQ-43 SKA1-LOW shall provide a survey speed as function of frequency and beam-size at least as good as shown in Figure 6.
- SCI_REQ-44 SKA1-MID shall provide a survey speed as function of frequency and beam-size at least as good as shown in Figure 7.
- SCI_REQ-45 SKA1-LOW shall provide a survey depth in integrations of 1000 hour duration as function of frequency and beam-size at least as good as shown in Figure 6.
- SCI_REQ-46 SKA1-MID shall provide a survey depth in integrations of 1000 hour duration as function of frequency and beam-size at least as good as shown in Figure 7.

3.7 Local Imaging modes

3.7.1 Context

A wide range of observational modes must be supported to enable the scientific goals of the observatory to be achieved. The most common mode is anticipated to be “local imaging”, whereby data is acquired and images are generated over a range of frequencies based on the correlation of voltage data from the configuration of stations or dishes of the SKA1 observatory. Within this category there will be a variety of observational strategies:

- **Single pointing**
 - Sidereal tracking observations of variable total duration will be required, ranging from a single correlator dump time up to 24 hours (e.g. for a circum-polar target).
 - Multiple distinct “snap-shot” images will at times need to be generated at a moderately high sustainable rate of about 1 Hz. One of the applications driving this rapid imaging mode is detection of “slow” radio transients with variability timescales of seconds to hours.
 - Multiple repeats of tracking observations must be accommodated to allow accumulation of 2500 hours or more (e.g. deep high red-shift HI fields) of net integration time per distinct pointing direction.
 - Non-sidereal tracking observations with drive rates up to 17 times sidereal will at times be required to permit observation of targets with non-sidereal ephemerides that in the most extreme cases may extend down to Low Earth Orbital distances.

- **Multi-pointing**
 - Sidereal tracking observations of variable total sky coverage will be required, ranging from as few as two distinct pointings to coverage of the entire 3π steradians visible from the telescope site. Data acquisition of the total sky coverage would be distributed over a time interval of up to 36 months (e.g. wide-field polarimetric or

neutral hydrogen surveys) and a variable inter-pointing spacing would be utilised to achieve some desired degree of uniformity to the net sensitivity pattern.

- Drift-scan (fixed pointing direction in local azimuth and elevation) observations of variable total duration from a single correlator dump time to 24 hours.
- Driven-scan observations with of variable drive rate and total duration from a single correlator dump time up to 24 hours. This will be particularly relevant for possible survey observations targeting 3π steradians of sky coverage in a 24 hour time interval.

Data products for local imaging observations would typically include fully calibrated, de-convolved ($\alpha, \delta, \text{Stokes}, v$) or ($\alpha, \delta, \text{Stokes}, v, t$) image cubes with a resolution and sampling matched to the particular application (see reference RD3) and optionally with broad-band continuum emission removed. Data products for local mode imaging observations are documented in RD8.

3.7.2 Specifications

SCI_REQ-47 SKA1-LOW shall provide single pointing and multi-pointing local imaging modes.

SCI_REQ-48 SKA1-MID shall provide single pointing and multi-pointing local imaging modes.

3.8 Non-Imaging modes

3.8.1 Context

In addition to local imaging, there is a wide range of applications that requires the formation of one or more “tied-array-beams”, each utilising some subset of all dishes or stations of the array configuration. Real-time calibration must be determined and applied to maximise the coherent tied-array-beam gain as well as its polarisation purity while counteracting possible ionospheric position jitter (as described in RD7). The time series data streams are then either processed by a dedicated SKAO non-image-processing (NIP) capability or exported in a format appropriate for non-SKAO analysis. Some specific examples of such modes are:

- Multiple tied-array-beam “real-time” **SEARCH** mode, is the typical pulsar and single burst transient search mode utilising the SKAO NIP capability, whereby many tied-array-beams are used to tile a large fraction of the dish or station beam and these time series are analysed on-site with low latency to detect new pulsars and transient bursts. The detection of suitable events may result in the triggering of a data buffer freeze and dump operation to permit imaging of the correlated visibilities pertaining to the relevant time interval of a detected event. Typically a large fraction of the core configuration is used for each of the tied-array-beams so as to provide the highest possible sensitivity while keeping the tied-array-beam as broad as possible.
- Multiple tied-array-beam “real-time” **TIMING** mode, is the typical pulsar timing mode used to acquire a higher precision timing solution for up to 16 targets of known location simultaneously utilising the SKAO NIP capability. This mode is also of interest for application to other time variable phenomena, including SETI.
- Multiple tied-array-beam **ARCHIVE** mode, is used for special targeted campaigns for up to 16 targets of known location simultaneously, whereby the acquired time series is not processed by SKAO NIP resources in real time, but is exported in a suitable format for non-SKAO NIP analysis.

- Multiple tied-array-beam **VLBI** mode, with up to 4 tied-array-beams, with data exported through the VLBI terminal for correlation outside of the SKA Observatory. Note this mode is conceptually equivalent to the previous.

Of particular relevance to the SKAO NIP pulsar search mode is the ability to undertake Doppler acceleration searches over a range of about -350 to 350 m/s/s and Dispersion measure searches over the range of about 0 – 3000 cm⁻³ pc.

Data products for non-imaging mode observations are documented in RD8.

3.8.2 Specifications

SCI_REQ-49 SKA1-LOW shall provide (search, timing, archive and VLBI) non-imaging observation modes.

SCI_REQ-50 SKA1-MID shall provide (search, timing, archive and VLBI) non-imaging observation modes.

3.9 Commensal modes

3.9.1 Context

There are many instances when the SKA components will be used to simultaneously address multiple scientific objectives [RD1]. Some specific examples of such modes are, in accord with [RD6]:

- **Multi-pipeline.** It will often be the case that an observing campaign will be used to provide a number of distinct data products based on the same data stream. These might include image cubes that are suitable for continuum imaging, polarimetric imaging, spectral imaging of red-shifted neutral hydrogen and high time cadence imaging to search for “slow” transients to name a few.
- **Multi-Sub-array.** There are circumstances in which only a portion of the array configuration would be used for a particular observing campaign, while other portions of the array would be scheduled in a completely independent program. A particular operational instance might be a maintenance sub-array that is involved in commissioning or testing, while the remainder of the facility is involved with scientific data acquisition. A more scientifically motivated case involves the precision timing of multiple pulsars that are widely separated on the sky which are bright enough that only a fraction of the dishes or stations are required to achieve the requisite signal-to-noise, but which each require a long duration (20 minute) observation to provide sufficient averaging over pulse periods to stabilise the pulse profile. An upper bound on the number of sub-arrays that might be effectively employed simultaneously is anticipated to be 16.
- **Image/non-image.** There are many cases where it will be desirable to provide the ability to provide local imaging of correlated visibilities at the same time that tied-array-beam non-imaging modes are active.
- **Coordinated** observations are campaigns of simultaneous or sequential data acquisition involving two or more observatories. These may be scheduled in advance or arise in response to appropriate external triggers.

Data products for commensal mode observations are documented in RD8.

3.9.2 Specifications

SCI_REQ-51 SKA1-LOW shall provide (multi-pipeline, multi-sub-array, image/non-image and coordinated) commensal mode observations.

SCI_REQ-52 SKA1-MID shall provide (multi-pipeline, multi-sub-array, image/non-image and coordinated) commensal mode observations.

3.10 Mode Changes

3.10.1 Context

It is anticipated that the SKA telescopes will often be undertaking scheduled observations that are planned some hours or days in advance. The sequence of distinct observations may well involve a transition of the observing mode from one of the imaging, non-imaging or commensal modes defined in Secs. 3.7 – 3.9, to another. Such transitions may also involve changes to the observing band (for SKA1-MID) and its sampling as discussed in Sec 3.3. There will also be a need to support more “dynamic” scheduling to make the most efficient use of changing environmental conditions. The most routine of these are varying atmospheric transparency at high frequencies (> 5 GHz) and varying ionospheric phase stability at low frequencies (< 350 MHz). Particularly good or poor environmental conditions would motivate a real-time adjustment of the schedule based on pre-defined criteria. Neither of these circumstances of mode/band changes places particularly strong constraints on the speed needed to implement the change. As long as the mode transition time is a small fraction of the typical mode/band duration, of perhaps 1 hour, then the overall observing efficiency is not unduly impacted.

Another category of changing conditions arises when the observatory receives a “trigger”. This may be generated internally to the observatory or arise from external sources in response to detection of a significant time variable phenomenon. Anticipated latencies of trigger reception to relevant events may be about 1 second. If appropriate authority had been granted in advance, such triggers could initiate an over-ride of the active observing schedule, which would typically involve a change in the pointing and tracking direction, and might also involve a change of the observing mode and band. Minimisation of latency prior to useful data acquisition in the new requested mode will be crucial to the scientific success of the triggered observation for rapidly variable targets.

3.10.2 Specifications

SCI_REQ-53 SKA1-LOW shall provide the capability to change observing modes within less than 5 seconds.

SCI_REQ-54 SKA1-MID shall provide the capability to change observing modes and/or bands within less than 5 seconds.

4 Appendix A

Table 1. Indicative survey strategies and requirements of SKA1 High Priority Science Objectives as identified in reference RD2. The ordering and numbering of objectives in the table is arbitrary. The “Cont” and “Line” designations in the Sensitivity column are used to indicate an assumed fractional bandwidth, $\Delta\nu/\nu = 0.3$ and 10^{-4} respectively. The LO requirements that pertain to specific needs of the science objectives are listed in the final row of the table. The bold-faced entry in each column is the one providing the strongest constraint.

Science Objective	SWG	High Priority Science Objective Number	SKA1 Component	Band	Mode	Frequency			Sensitivity		
						Range Low - High	Resolution Initial:Cal:Final	Spectral Dynamic Range (L_max/L_min)	RMS Noise Min:Max @ Beam @ Bandwidth	Brightness Dynamic Range (L_max/L_min)	Polarisation Dynamic Range (L_max/P_min)
EoR - Imaging AASKA14:001	CD/EoR	1	SKA1-LOW	N/A	Imaging	50 - 200 MHz	4:4:1000 kHz	50 dB	1.4:100 mK @ 300 arcsec @ 1 MHz	50 dB	45 dB
EoR - Power Spectra AASKA14:001	CD/EoR	2	SKA1-LOW	N/A	imaging/Power Spectrum	50 - 200 MHz	4:4:1000 kHz	50 dB	4.6:330 mK @ 300 arcsec @ 1 MHz	50 dB	40 dB
			SKA1-LOW	N/A	imaging/Power Spectrum	50 - 200 MHz	4:4:1000 kHz	50 dB	14:1000 mK @ 300 arcsec @ 1 MHz	50 dB	35 dB
Pulsar Searching AASKA14:040	Pulsars	4	SKA1-LOW	N/A	Non-Imaging	150 - 350 MHz	20:20:75 kHz	30 dB	20 μ Jy/Beam @ 145 arcsec Cont	30 dB	25 dB
			SKA1-MID	SPF1	Non-Imaging	650 - 950 MHz	20:20:75 kHz	30 dB	13 μ Jy/Beam @ 65 arcsec Cont	30 dB	25 dB
			SKA1-MID	SPF2	Non-Imaging	1250 - 1550 MHz	20:20:75 kHz	30 dB	7 μ Jy/Beam @ 45 arcsec Cont	30 dB	25 dB
Pulsar Timing AASKA14:037	Pulsars	5	SKA1-LOW	N/A	Non-Imaging	150 - 350 MHz	20:20:75 kHz	30 dB	10 μ Jy/Beam @ 8 arcsec Cont	30 dB	40 dB
			SKA1-MID	SPF2	Non-Imaging	950 - 1760 MHz	20:20:75 kHz	30 dB	3 μ Jy/Beam @ 7 arcsec Cont	30 dB	40 dB
HI - High z AASKA14:128	HI	13	SKA1-MID	SPF1	Imaging	790 - 950 MHz	4:50 kHz	30 dB	16 μ Jy/Beam @ 2-10 arcsec Line	50 dB	35 dB
HI - Low z AASKA14:129	HI	14	SKA1-MID	SPF2	Imaging	1300 - 1400 MHz	4:15:20 kHz	30 dB	14 μ Jy/Beam @ 2-10 arcsec Line	50 dB	30 dB
HI - Galaxy AASKA14:130	HI	15	SKA1-MID	SPF2	Imaging	1415 - 1425 MHz	0.5:4 kHz	30 dB	75 μ Jy/Beam @ 2-10 arcsec Line	45 dB	30 dB
Transients - FRB AASKA14:055	Transients	18	SKA1-MID	SPF1	Non-imaging/Commensal	650 - 950 MHz	20:20:75 kHz	30 dB	7 mJy/Beam @ 65 arcsec Cont	30 dB	25 dB
CoL - Planet formation AASKA14:117	Cradle of Life	22	SKA1-MID	SPF5	Imaging	8 - 12 GHz	80:80:4000 kHz	30 dB	80 nJy/Beam @ 0.04 arcsec Cont	40 dB	25 dB
Magnetism - RM-grid AASKA14:092	Magnetism	27	SKA1-MID	SPF2	Imaging	1000 - 1700 MHz	10:1000 kHz	30 dB	7 μ Jy/Beam @ 2 arcsec Cont	45 dB	30 dB
Cosmology - High z IM AASKA14:019	Cosmology	32	SKA1-MID	SPF1	Auto-correlations	350 - 1050 MHz	10:300 kHz	45 dB	3.3 mJy/Beam @ 1.7 deg Line	40 dB	40 dB
Cosmology - ISW, Dipole AASKA14:018, 032	Cosmology	33	SKA1-MID	SPF2	Imaging	1000 - 1700 MHz	10:1000 kHz	30 dB	7 μ Jy/Beam @ 2 arcsec Cont	45 dB	30 dB
Continuum - SFR(z) AASKA14:067	Continuum	37 + 38	SKA1-MID	SPF2	Imaging	1000 - 1700 MHz	10:1000 kHz	30 dB	1.3 μ Jy/Beam @ 0.5 arcsec Cont	60 dB	30 dB
			SKA1-MID	SPF2	Imaging	1000 - 1700 MHz	10:10:1000 kHz	30 dB	0.25 μ Jy/Beam @ 0.5 arcsec Cont	60 dB	30 dB
			SKA1-MID	SPF2	Imaging	1000 - 1700 MHz	10:10:1000 kHz	30 dB	65 nJy/Beam @ 0.5 arcsec Cont	60 dB	30 dB
			SKA1-MID	SPF5	Imaging	7 - 11 GHz	80:80:4000 kHz	25 dB	400 nJy/Beam @ 0.05 arcsec Cont	45 dB	30 dB
			SKA1-MID	SPF5	Imaging	7 - 11 GHz	80:80:4000 kHz	25 dB	50 nJy/Beam @ 0.05 arcsec Cont	45 dB	30 dB
LO Requirements			001, 002, 004, 005		047, 048, 049, 050, 051, 052	024, 025, 026, 028	026, 028	022, 023	003, 006, 007, 008, 009, 010, 011, 012, 013, 014, 015, 033, 034, 035, 036, 037, 038, 043, 044, 045, 046	018, 019, 039, 040, 041, 042	020, 021

Table 2. Indicative survey strategies and requirements of SKA1 High Priority Science Objectives (continued).

Science Objective	SWG	High Priority Science Objective Number	Observing Area					Integration						
			Total Area	Area of Single Pointing/ Beam	Angular Resolution Min:Max	Targets/ Beams	Tracking	Total	Per Pointing	Dump Rate / Temporal Resolution	Epochs	Cadence Min:Max	# Sessions per Interval	Time per Session
EoR - Imaging AASKA14:001	CD/EoR	1	100 deg2	20 deg2	10:1000 arcsec	5 Fields/ 2 StationBeams	Sidereal	5000 hr	2000 hr	0.4 s			1000	5 hr
EoR - Power Spectra AASKA14:001	CD/EoR	2	1000 deg2	20 deg2	10:1000 arcsec	50 Fields/ 2 StationBeams	Sidereal	5000 hr	200 hr	0.4 s			1000	5 hr
			10000 deg2	20 deg2	10:1000 arcsec	500 Fields/ 2 StationBeams	Drift	5000 hr	20 hr	0.4 s			1000	5 hr
Pulsar Searching AASKA14:040	Pulsars	4	30000 deg2	11.3 arcmin2	320 arcsec	1 Target/ 500 Tied-Array Beams	Sidereal	12750 hr	40 mn	50 μs			3200	4 hr
			2400 deg2	1.2 arcmin2	105 arcsec	1 Target/ 1500 Tied-Array Beams	Sidereal	800 hr	10 mn	50 μs			100	8 hr
			2400 deg2	0.39 arcmin2	60 arcsec	1 Target/ 1500 Tied-Array Beams	Sidereal	2400 hr	10 mn	50 μs			300	8 hr
Pulsar Timing AASKA14:037	Pulsars	5	0.9 arcmin2	65 arcsec2	8 arcsec	50 Targets/ 1 Tied-Array Beam	Sidereal	4300 hr	40 mn	100 ns	130	2 wks	1075	4 hr
			0.7 arcmin2	50 arcsec2	7 arcsec	50 Targets/ 1 Tied-Array Beam	Sidereal	1600 hr	15 mn	100 ns	130	2 wks	200	8 hr
HI - High z AASKA14:128	HI	13	5.4 deg2	1.1 deg2	3:5 arcsec	5 Fields	Sidereal	5000 hr	1000 hr	0.15 s			625	8 hr
HI - Low z AASKA14:129	HI	14	3.8 deg2	0.38 deg2	3:5 arcsec	10 Targets	Sidereal	2000 hr	200 hr	0.15 s			250	8 hr
HI - Galaxy AASKA14:130	HI	15	1080 deg2	0.38 deg2	5:60 arcsec	2840 Pointings	Sidereal	12600 hr	4.4 hr	0.15 s			1575	8 hr
Transients - FRB AASKA14:055	Transients	18	30000 deg2	1.2 arcmin2	105 arcsec	1 Target/ 1500 Tied-Array Beams	Sidereal	10000 hr	2 msec	50 μs	1.20E+06	2 msec	1250	8 hr
CoL - Planet formation AASKA14:117	Cradle of Life	22	0.05 deg2	0.005 deg2	0.04:1 arcsec	10 Targets	Sidereal	6000 hr	600 hr	0.15 s			750	8 hr
Magnetism - RM-grid AASKA14:092	Magnetism	27	31000 deg2	0.38 deg2	2 arcsec	81600 Pointings	Sidereal	10000 hr	7.4 mn	0.15 s			1250	8 hr
Cosmology - High z IM AASKA14:019	Cosmology	32	30000 deg2	1.4 deg2	1.7 deg	21500 Pointings	Drift	10000 hr	2.2 hr @ 190 Dishes	0.15 s			1250	8 hr
Cosmology - ISW, Dipole AASKA14:018, 032	Cosmology	33	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	1000 deg2	0.38 deg2	0.5:1 arcsec	2600 Pointings	Sidereal	10000 hr	3.8 hr	0.15 s			1250	8 hr
			7.8 deg2	0.38 deg2	0.5:1 arcsec	21 Pointings	Sidereal	2000 hr	95 hr	0.15 s			250	8 hr
			0.38 deg2	0.38 deg2	0.5:1 arcsec	1 Pointings	Sidereal	2000 hr	2000 hr	0.15 s			250	8 hr
			0.5 deg2	30 arcmin2	0.05:1 arcsec	61 Pointings	Sidereal	1000 hr	16.4 hr	0.15 s			125	8 hr
			30 arcmin2	30 arcmin2	0.05:1 arcsec	1 Pointing	Sidereal	1000 hr	1000 hr	0.15 s			125	8 hr
LO Requirements			043, 044		037, 038	27, 031, 032		043, 044	045, 046		016, 017	016, 017		031, 032, 033, 034