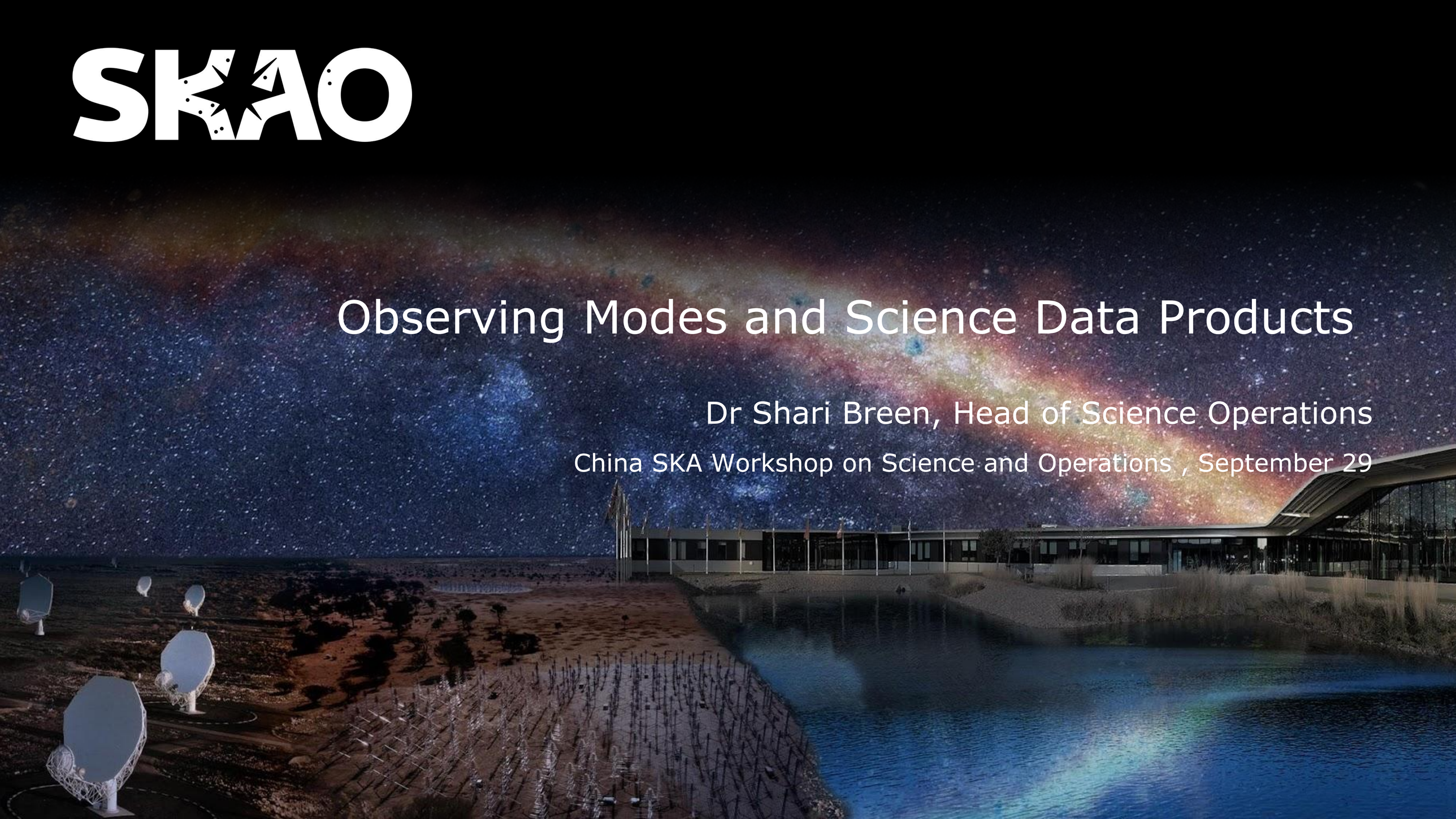


Observing Modes and Science Data Products

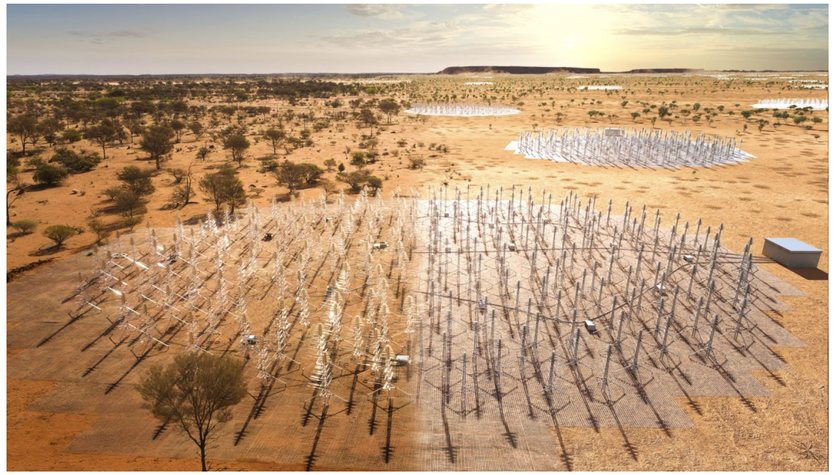
Dr Shari Breen, Head of Science Operations

China SKA Workshop on Science and Operations , September 29

Observing modes (frequencies, subarrays and CBFs!)

(Thanks to Sarrvesh and Tom for their help with these slides)

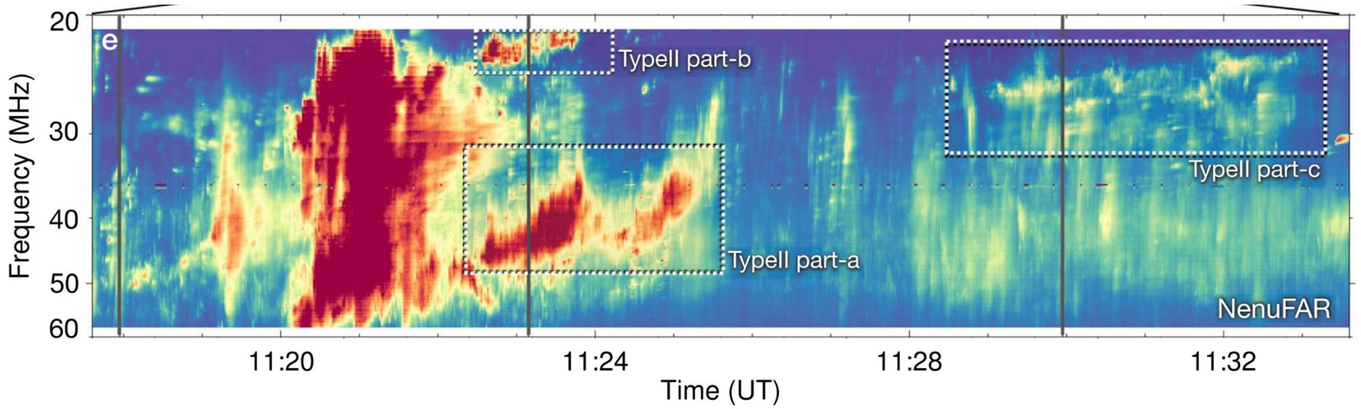
Lots of observing parameters: frequency, correlator, subarrays….



- Like any telescope, users will have to made decisions about what mode they need for their science
- Frequency/band, correlator, beamforming etc
- Subarrays
  - SKA will use subarrays, both for engineering test and for science
  - Templates will be offered to the community
  - Expect majority of science cases will use full array, but science cases requiring a fraction of the array have been identified
    - E.g. Pulsars might use the core of Mid but Cradle of life (imaging of dusty disks around stars) might want to use mostly the extended antennas
    - **Defining scientifically useful subarrays will require interaction with members of the community!**

Observing modes

- Both imaging and non-imaging modes supported
  - Continuum imaging - standard broad-band mode, high sensitivity
  - Spectral/zoom window imaging - usually used for spectral line observations
  - Pulsar and transient search
  - Pulsar timing
  - Dynamic spectrum
  - VLBI

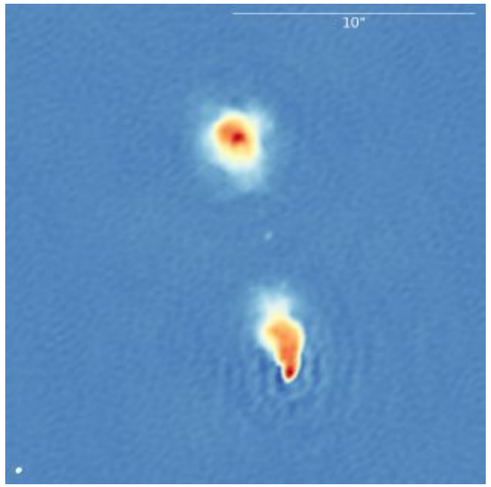


Telescope tracking modes

- Four tracking modes offered to allow the efficient delivery of the breadth of science
  - Sidereal tracking: observe target position by tracking at sidereal speed
  - Non-sidereal tracking: tracking at speeds different from the sidereal rate for, e.g. solar system observation
  - Wide area scanning: large area, shallow integration. Scans defined in RA,Dec, Az, El or Gal coords
  - Drift scanning: tracking fixed position relative to earth, rather than the sky. Sky moves across the beam at the sidereal rate.

Continuum imaging

- Broad bandwidth observations
  - Continuum data can be taken for the full bandwidth of all SKA receivers with the exception of Mid 5b where the bandwidth is largest (2 x 2.5 GHz bands)
  - Native spectral resolutions from 5.4 kHz (Low) and 13.4 kHz (Mid)
  - Minimum integration time 0.85 seconds for Low
  - Correlated visibilities + autocorrelations for intensity mapping
  - All 4 stokes parameters available for imaging
- Fast imaging available for slow transient (seconds to hours) detection. Detections recorded to transient catalogue (with optional triggering of the IVOA alerts



Band	Central freq. (MHz)	Bandwidth (MHz)
Low	200	300
1	700	700
2	1355	810
3	2350	1400
4	3990	2380
5a	6550	3900
5b	11850	2 x 2500

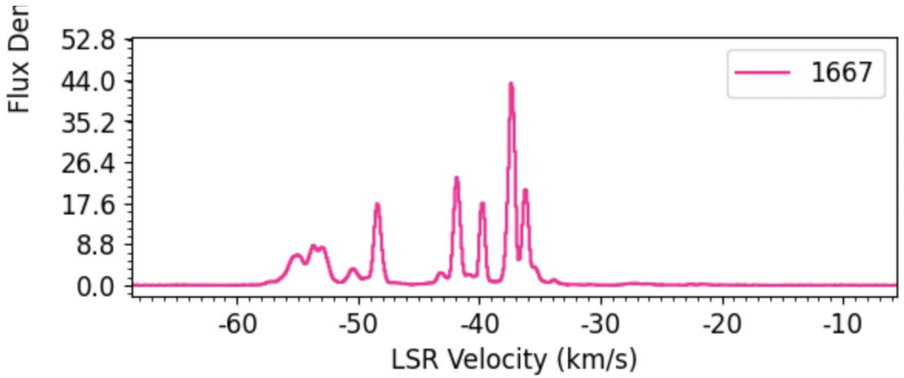
Spectral line imaging

Low

Zoom mode	Freq. res (Hz)	Bandwidth
1	14.1	24 kHz
2	28.2	48 kHz
3	56.4	97 kHz
4	113	195 kHz
5	226	390 kHz
6	452	780 kHz
7	904	1.16 MHz
8	1808	3.12 MHz

Mid

Zoom mode	Freq. res (kHz)	Bandwidth (MHz)
1	0.21	3.125
2	0.42	6.25
3	0.84	12.5
4	1.68	25
5	3.36	50
6	6.72	100
7	13.44	200



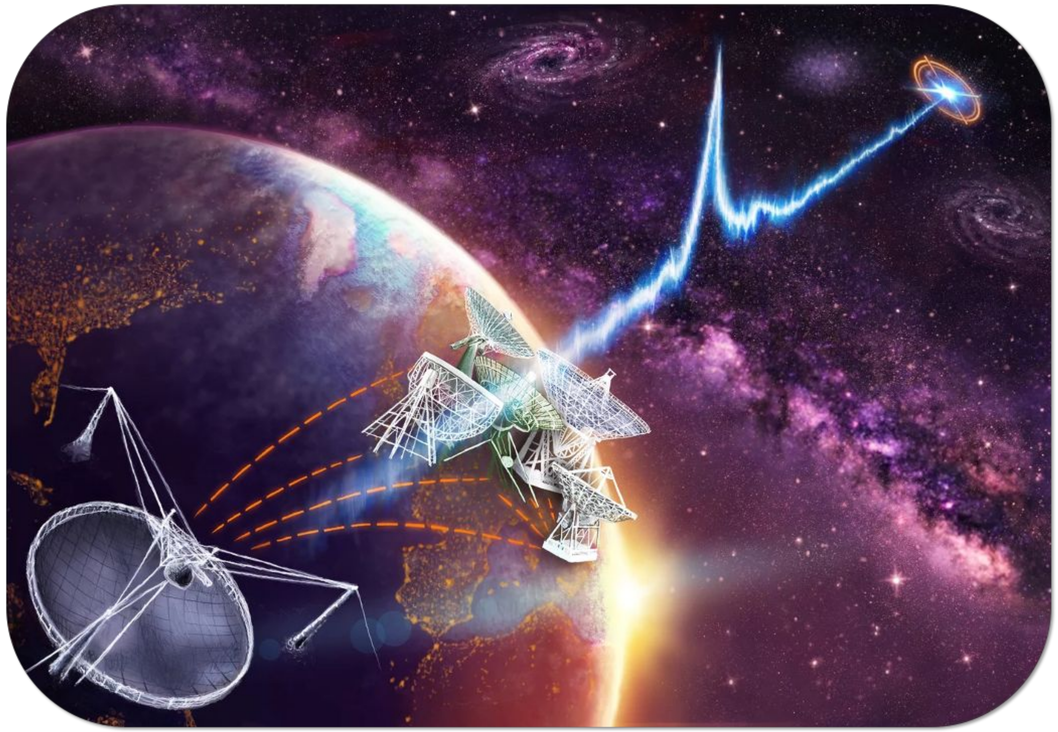
- Flexibility of zooms placement within band
- Number of zooms limited by resources, both in the correlator and the ability of SDP to take on the channels.
- Correlated visibilities + autocorrelations for intensity mapping
- All 4 stokes parameters available for imaging

Line at 200 MHz would have:
vel BW of 35 km/s and vel res of 0.042 km/s in zoom 1
Vel BW of 4600 km/s and 2.6 km/s in zoom 8

Line at 1420 MHz would have:
vel BW of 658km/s and vel res of 0.088 km/s in zoom 1
Vel BW of 36000 km/s and 5.6 km/s in zoom 7

Pulsar and transient Search

- Search mode for periodic pulses across range of DMs, including acceleration searches for highly relativistic pulsars
- Capable of identifying single pulses
- Pipeline identifies candidates and generates a catalogue
- New single pulse detections may trigger IVOA alerts and dump of the transient buffer (raw voltage data, dual pol)
- Uses a large number of tied array beams to search the sky (limited to 501 for Low)
- Time resolution of 69.12 μs for Low and 12.4 μs for Mid
- Complex voltage data available



Pulsar timing

- Converts tied-array dual-polarisation voltage beams into folded integrated pulse profiles
- Accurately measure ToA
- These are used to generate a timing model for the pulsars
- Can process up to 16 dual-pol, independent, beamformed voltage streams simultaneously
- Formed from up to 16 subarrays
- Time resolution of 207.36 μs for Low and 18.60 μs for Mid

Dynamic spectrum

- Broad range of science applications for a high time resolution, dynamic spectrum
- Time versus frequency spectrum, configurable time resolutions
- All stokes parameters are available

VLBI

- SKA can provide a super sensitive element to VLBI arrays at milli-arc sec resolution
- Can also provide shortest “VLBI” baselines with our own distant antennas to participate with a phased up core
- At least four dual-polarisation VLBI beams can be formed from one or more subarray
- Polarisation corrected and RFI-masked tied array beam voltage data will be recorded in VDIF (VLBI Data Interchange Format), compatible with VLBI correlators
- Jumping JIVE presented an SKA VLBI operational model that we are refining into our plan

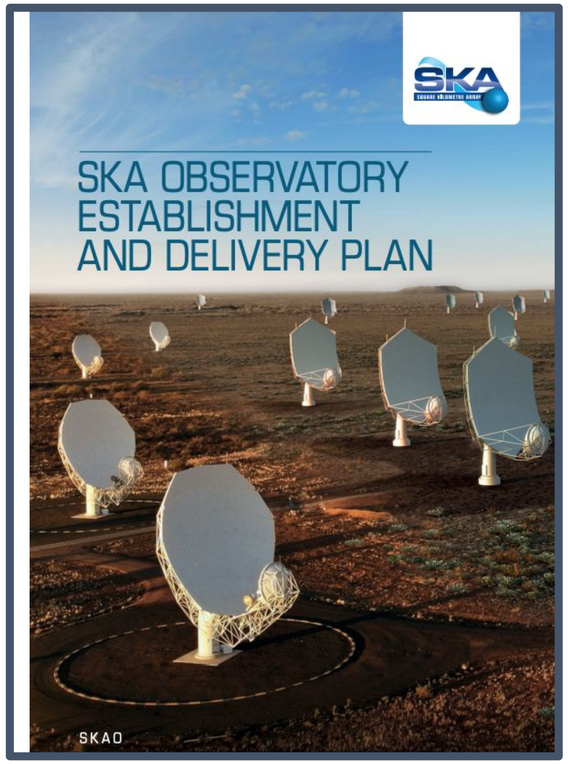
Commensality of modes

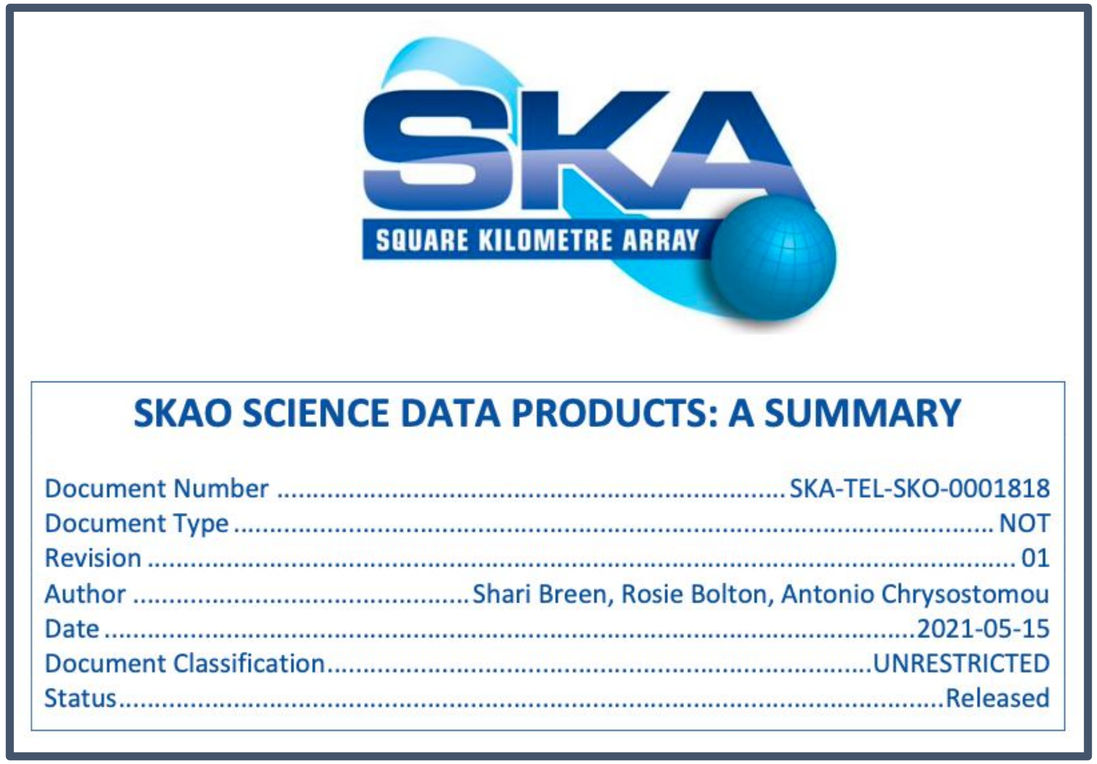
- Both Mid and Low are flexible, allowing modes to be observed commensally, with subarrays, only limited by resources (both CBF and SDP)
- This makes it fairly complex to concisely describe their limitations (especially because some details are changing as our knowledge is advancing)
- Document describing the particulars the scientists are interested in are being developed now, hopefully for release to the community in the next 6-12 months

Science data products

More details on SKA data products

- High level plans can be found in the Observatory Establishment and Delivery Plan
- Focused information in the “SKAO Science data products: A summary” document





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Available on indico

SKA Data Products: Three types of data products in two categories

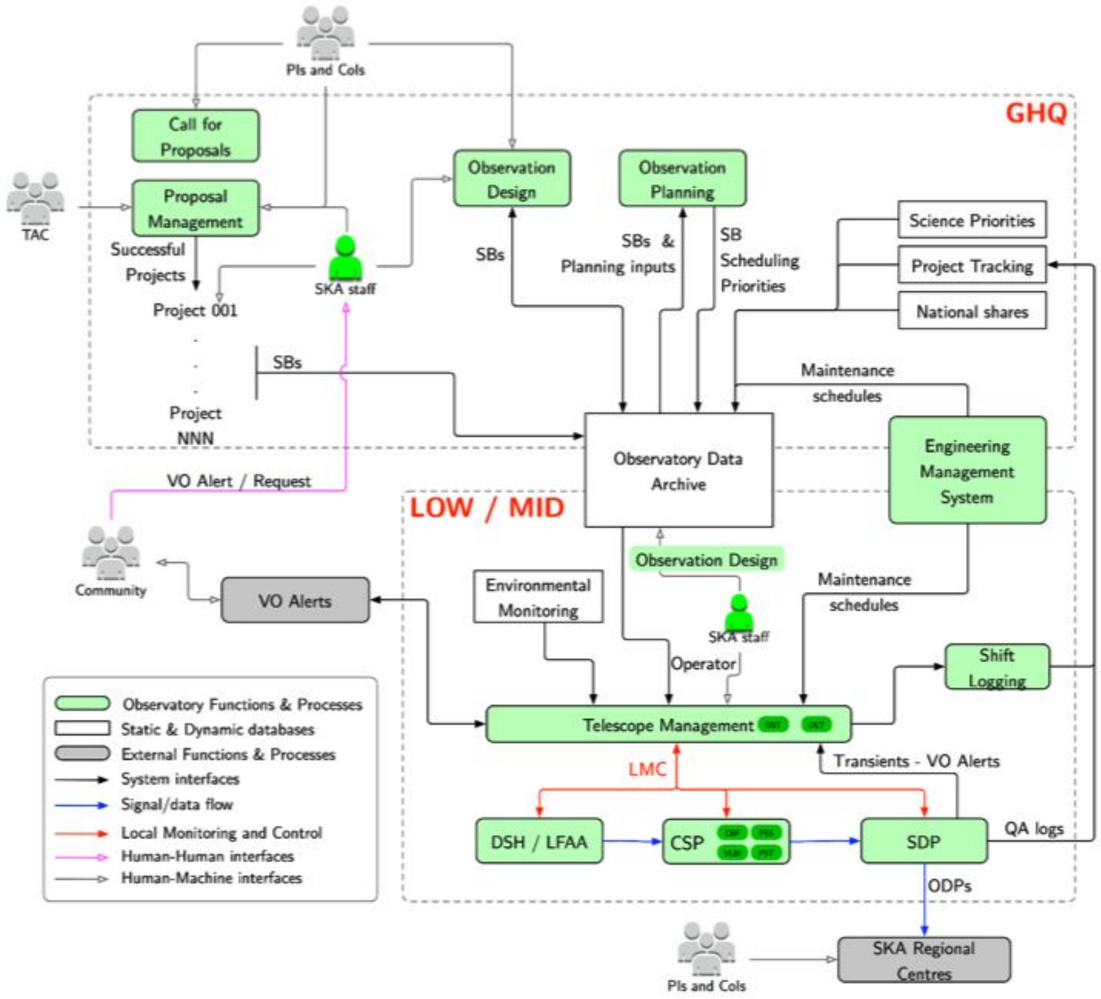
- Observatory Data products (SKAO responsibility), come with all Quality Assessment information
  - (1) Observation level-data products (OLDPs) - calibrated data products generated by SDP workflows, based on a single execution of a scheduling block
  - (2) Project-level data products (PLDPs) - generated by combining several, related, OLDPs. Created within the SRCNet using SDP workflows

- Advanced Data products (ADPs) - user generated products produced through rigorous within the SRCNet (a series of template workflows will be offered to streamline the generation of common ADPs)

All 3 types of data products will be made publicly available following the conclusion of the appropriate proprietary period (1 year)

The user experience: up to the point of data delivery

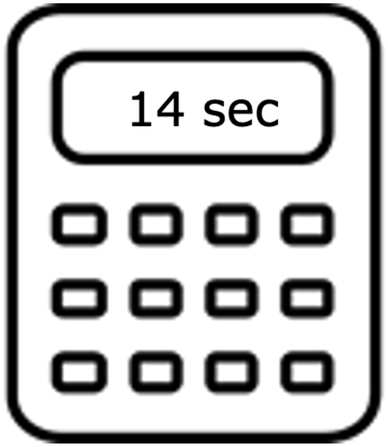
- SKA Users will request observations AND data products at the proposal stage
  - Science Data Processor (SDP) is a schedulable part of the telescope
  - There will be no interaction with Science Data Processor (SDP), except in a small number of cases
    - E.g. large projects might need to interact with and amend chosen SDP pipelines and parameters after a small amount of data has been taken
    - This interaction will be facilitated through the SRCNet, where data products and calibrated visibilities can be delivered for consideration



The user experience: up to the point of data delivery

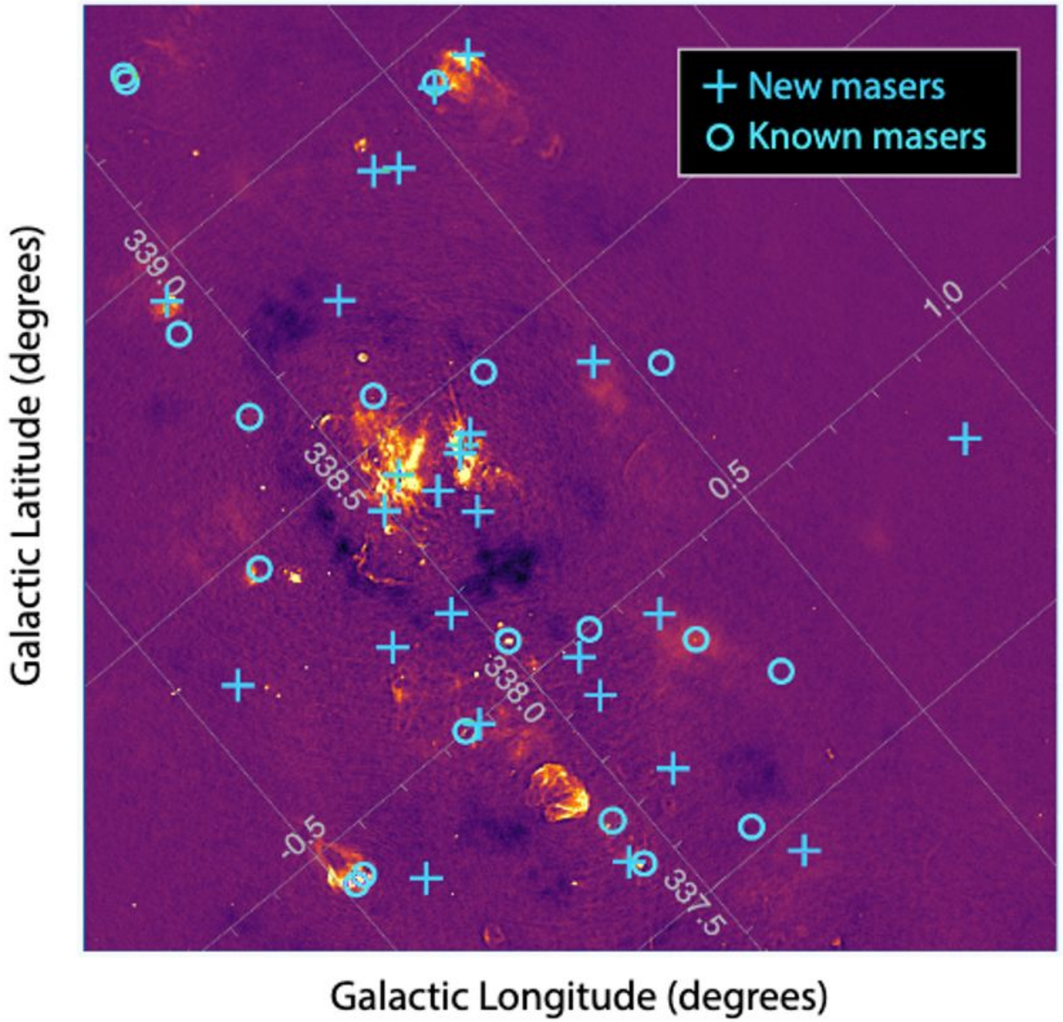
Preparing proposals:

- Users will have access to all of the information and planning tools to accurately determine their requirements
  - These requirements will include frequency, subarray, observing mode, data products and all of the processing parameters
    - Mid sensitivity calculator first release **is out now** (thanks to the buttons team OMC train). Feedback sought from some members of the community.
    - Low calculator development starting soon!



The data product lifecycle

- Once taken, data could sit in the SDP for up to ~2 weeks before processing (exact timescales will be prototyped and analysed)
  - Once data products have passed Quality Assessment the raw data (and any intermediate products) will be deleted.
- Moved to the SKA long term preservation system for safe keeping and queued for delivery to the SRCNet



OLDPs SDP will generate (assumes polarisation and autocorrelation data)

- Image cubes:
  - continuum, cleaned restored Taylor term images
    - In the case of slow transient detection (“fast imaging”) maps are expected to be made, searched and discarded
    - Residual continuum images (i.e. residuals post CLEAN)
    - Clean component image (or table)
  - Spectral line cubes (optionally with continuum subtraction)
    - Residual spectral line image
  - Representative PSF for the observation
- Uv Grids
- Calibrated visibilities*
- LSM Catalogue
- Imaging transient search catalogue
- Pulsar timing solutions
- Transient buffer Data
- Sieved Pulsar and transit candidates
- Science Alert Catalogue
- Science Product catalogue

* a null calibration table could be applied to allow access to raw visibilities in exceptional circumstances

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*****Multiple data products can be be produced by the same observation, limited only by scientific justification and resource availability*****

* a null calibration table could be applied to allow access to raw visibilities in exceptional circumstances

The question of raw data (with/without averaging and calibration)

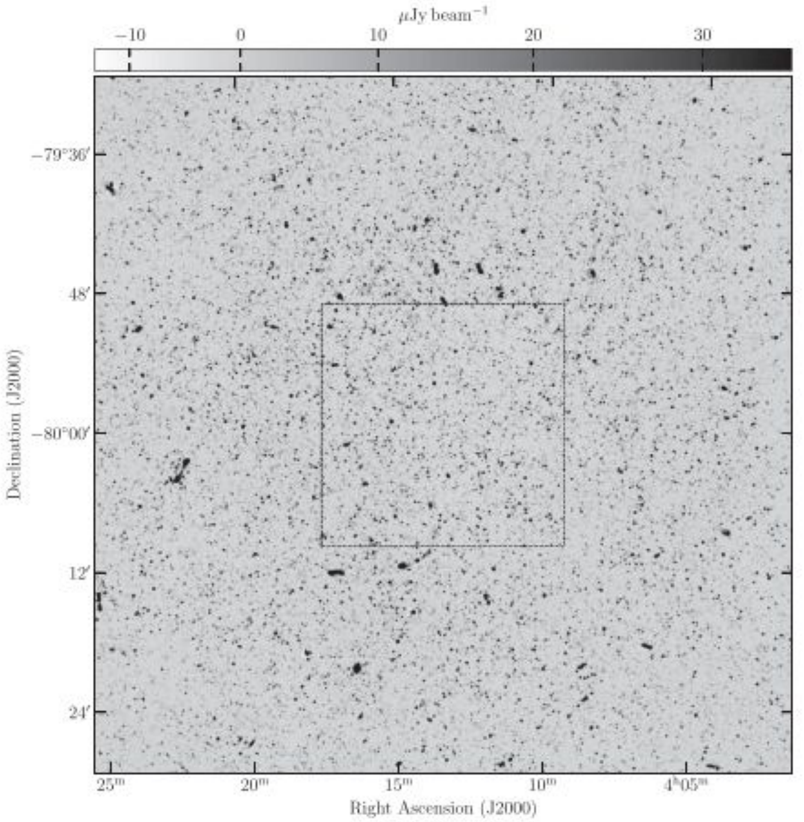
- Technically possible, likely to be necessary for limited cases in early Operations in order to develop robust pipelines
- **BUT** in steady state Operations the SKAO is responsible for the delivery of calibrated data products
  - Proposals requesting raw visibilities are expected to be an exception and will require a detailed plan for calibration and the generation of data products (less than 1% of projects!).

PLDPs generated by SDP workflows using SRCNet resource

- Combination of multiple OLDPs to fulfil the science goals outlined in an Observing Proposal
- Limited capacity of the SDP means that PLDPs will be generated on the SRCNet resources, but remain a responsibility of the SKAO
- Created using SDP workflows, come with all the same QA information as OLDPs
- Users will have access to both the PLDPs and the OLDPs that were combined to create them

Examples:

- Deep integrations requiring multiple epochs of observations
- Stitched mosaics



MeeKAT DEEP2 image; Mauch et al. (2020)

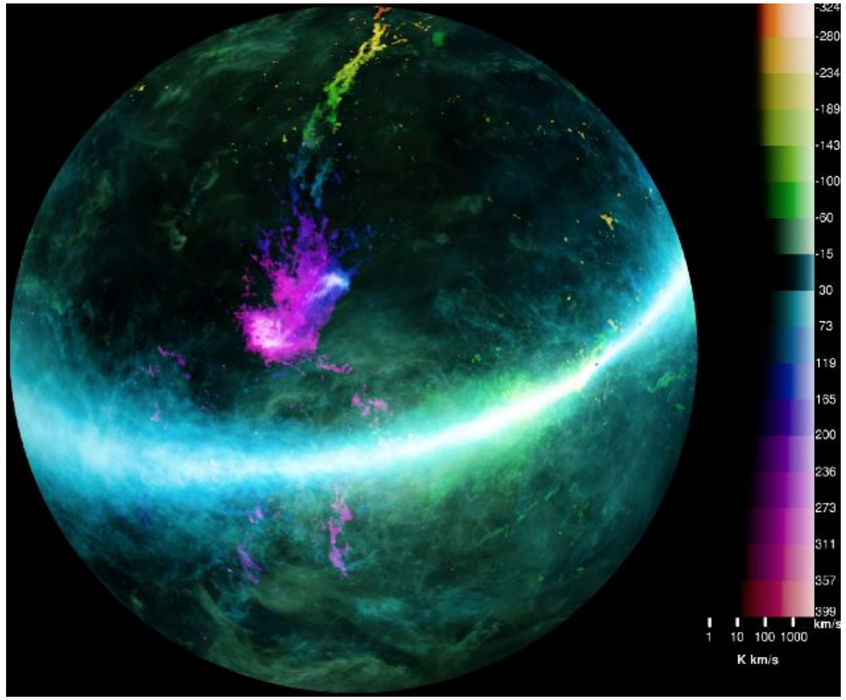
OLDPs and PLDPs Quality Assessment

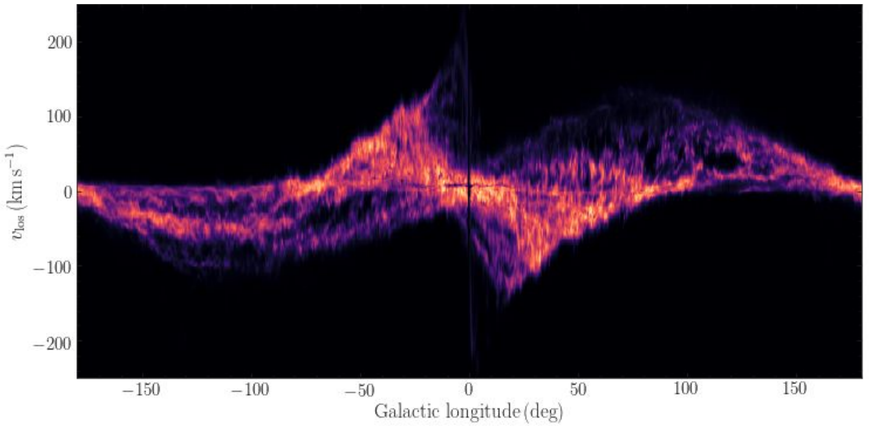
- All SKA data products will need to pass Quality Assessment metrics before they are released to proposers (failures will be repeated)!
- All information will be provided with the data products

- Both OLDPs and PLDPs will come with an associated Quality Assessment log from the entire SKA processing chain
  - Contain information chiefly from SDP
    - Astrometry (source positions)
    - Photometry (source fluxes)
    - Radiometry (image statistics)
    - Polarimetry (polarisation fluxes and angles)
    - Spectrometry (emission line fluxes and moments)
  - But also other information from Central Signal Processor (for PSS and PST) and other monitoring, control and calibration systems.

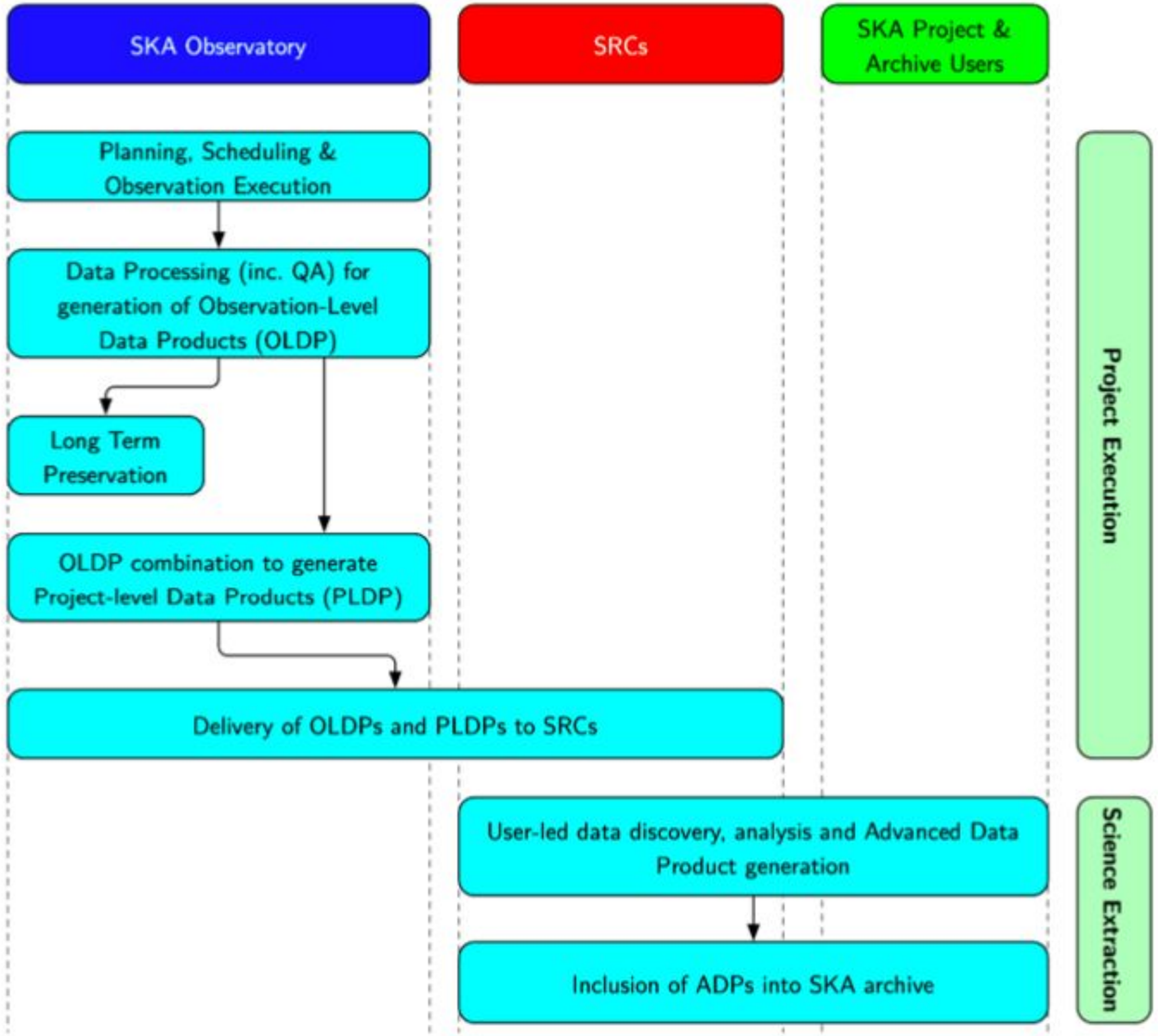
ADP Examples

- Anything that the user generates and wants to publish
  - RM synth products (extraction, models)
  - Source catalogues
    - Parameter extraction
    - classification
  - Spectral index maps
  - Simulations
  - Power spectra
  - Spectral extraction and characteristics
  - Stacked images
  - Moment maps
  - PV diagrams
  - Electron density models based on DM
  - Magnetic field models/ Galactic, star formation, other galaxies etc)





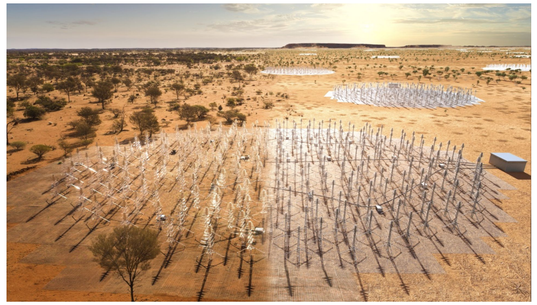
Summary of responsibilities in the generation of SKA science data products

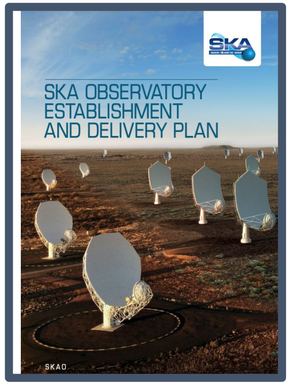


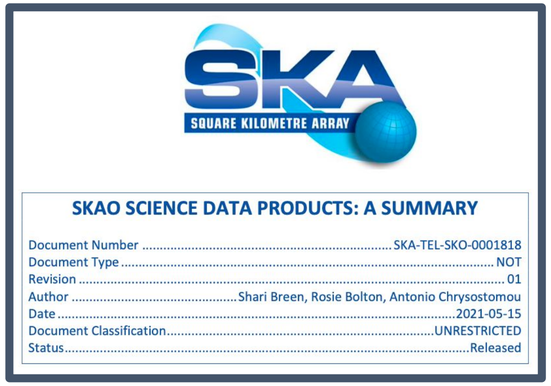
Summary

- **Observing modes:**
  - Subarrays, driven by science but yet to be defined, will need science user input!
  - Observing modes are driven by science priorities and can be executed commensally, limited only by resources in both the correlator and SDP
  - More detailed documentation of tradeoffs and limits of the CBFs forthcoming to allow planning

- **Data products:**
  - in steady state Operations the SKAO is responsible for the delivery of calibrated data products
  - All data products will need to have passed QA to be released to the Users and all information will be passed on







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Thank you!

Shari.Breen@skao.int

We recognise and acknowledge the Indigenous peoples and cultures that have traditionally lived on the lands on which our facilities are located.

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