SKA1 Baseline Design
Pulsars

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Intent of the Baseline Design

- Basic architecture: 3-telescope, 2-system model
  - SKA1-low, SKA-survey (Australia); SKA1-mid (South Africa).
- Produce a design that:
  - Emphasises capability to do key science.
  - Otherwise preserves flexibility for all types of observations
  - Architecturally bounded without being overly constrained.
- Appropriate “hooks” to permit extension to the full SKA.
  - Where feasible and within cost.
- Not the final design. Controlled changes permissible as a result of:
  - science assessments,
  - responses to the RfPs,
  - design work by the consortia during preconstruction.
- Major design changes will have to be extremely well motivated.
  - No immediate changes are contemplated.
- The final design based on cost analysis and these inputs.
  - well considered trade-offs.

SKA1 Key Pulsar Science

- Pithy summary of our understanding of the science (from Jim Cordes?):

1. Discover and time a sufficient set of MSP clocks to allow detection of, or put significant limits on, nano-Hz gravitational waves.
2. Discover and time a complete sample of relativistic binary pulsars with WD, NS, and BH companions to test the equivalence principle and GR in the strong-field regime; the sample should reach to sub-hour orbital periods.
3. ~~Discover and time a significant sample of pulsars orbiting Sgr A* to probe spacetime and plasma around the Milky Way's central black hole.~~

Pulsar Science Input

- Major decisions are of greatest interest at this point.
- Optimum frequency for pulsar survey
  - Baseline Design assumes frequencies in the SKA1-mid range.
  - Survey requires the largest equipment investment.
  - Probably not possible to have a large investment at both sites.
- Flexibility of processing
  - What are the core processing requirements?
  - Additional “nice-to-have”.
  - Trade-offs with efficiency, cost and power.
  - Transition of processing capability for SKA2.
  - Transients
- Science operations
  - Total time on sky (nominally 6.3 Ms = 2 yr) for survey.
  - Cadence, multiple passes.
  - What is the appropriate measure of survey completeness?
  - Ramp-up and maintenance of timing.
    - Does subsequent timing all need to be done by SKA?
- Competitive telescopes in SKA1 timeframe.
  - FAST: potentially comparable A/T and FoV depending on no of beams.
  - Others?

SKA-related Telescope Parameters + FAST

Parameters for SKA Related Telescopes							
		MeerKAT	**ASKAP**	**SKA1-survey**	**SKA1-low**	**SKA-mid**	**FAST**
A_{eff}/T_{sys}	m^2/K	321	65	391	1000	1630	1250
FoV	deg^2	0.86	30	18	27	0.49	0.0017
Receptor Size	m	13.5	12	15	35	15	300
Fiducial frequency	GHz	1.4	1.4	1.67	0.11	1.67	1.4
Survey Speed FoM	$deg^2\ m^4\ K^{-2}$	8.86×10^4	1.27×10^5	2.75×10^6	2.70×10^7	1.30×10^6	2.66×10^3
Resolution	arcsec	11	7	0.9	11	0.22	88
Resolution Calc.	arcsec	11.050	7.367	0.741	11.251	0.185	0.000
Baseline or Size	km	4	6	50	50	200	0.5
Frequency Range	GHz	0.7 - 2.5, 0.7 - 10	0.7-1.8	0.65-1.67	0.050 – 0.350	0.35-14	0.1 – 3
Bandwidth	MHz	1000	300	500	250	770	800
Cont. Sensitivity	$\mu Jy\text{-}hr^{-1/2}$	3.20	28.89	3.72	2.06	0.72	0.00
Sensitivity, 100 kHz	$\mu Jy\text{-}hr^{-1/2}$	320	1582	263	103	63	0
SEFD	Jy	8.6	42.5	7.1	2.8	1.7	0.0

Today's Comparable Telescopes (L-band)

		JVLA	MeerKAT	SKA-mid	ASKAP	SKA1-survey	LOFAR	SKA1-low
Aeff/Tsys	m^2/K	265	321	1630	65	391	61	1000
FoV	deg^2	0.25	0.86	0.49	30	18	14	27
Survey Speed FoM	$deg^2\ m^4\ K^{-2}$	1.76×10^4	8.86×10^4	1.30×10^6	1.27×10^5	2.75×10^6	5.21×10^4	2.70×10^7
Resolution	arcsec	1.4 - 44	11	0.22	7	0.9	5	11

~800 m^2 / K in core

SKA1-mid: Key Design Parameters

- *Array Configuration:*
  - constrained by the need to incorporate the MeerKAT antennas.
  - Must share the same core location
    - dual core array would produce an unusable synthesised beam.
  - in-fill with SKA1 antennas (i.e. a dual core array would produce an unusable synthesised beam).
  - array configuration can be accommodated under this constraint.
  - reasonable plan to expand to SKA2 available using the SKA1 antennas.
- *Frequency Range:*
  - link up in frequency range with SKA1-low.
  - capable of being extended to the highest frequency sustainable on the South African site for SKA2.
  - Emphasis for SKA1:
    - on the bands below 1420 MHz for redshifted HI.
    - bands best suited to pulsar detection and timing.

SKA1-mid: Key Design Parameters

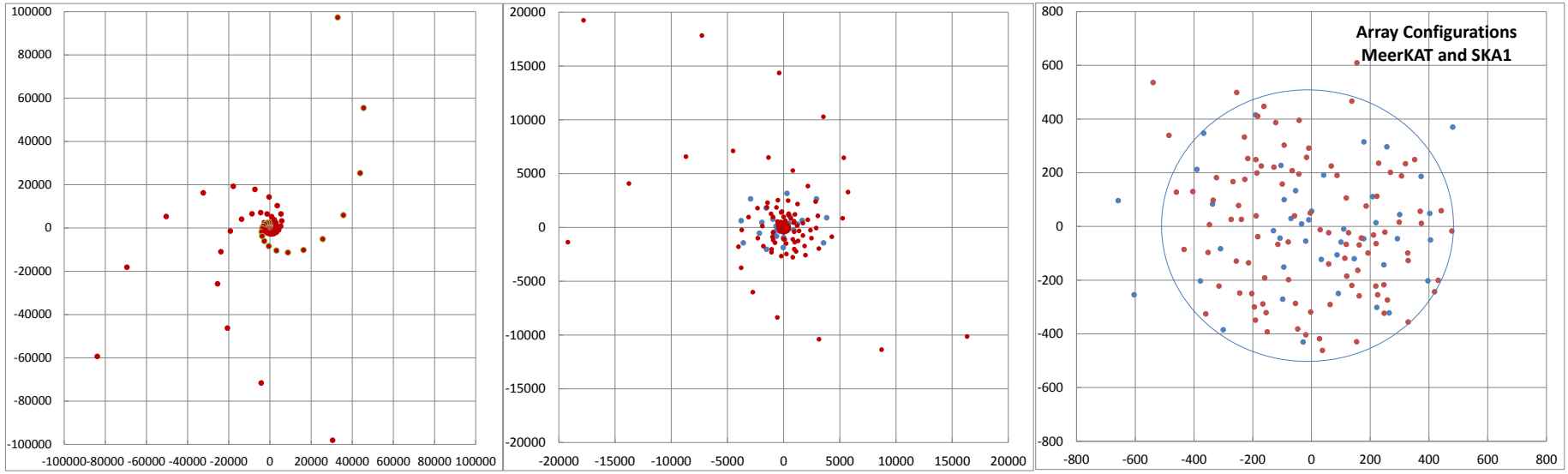
- *Sensitivity:*
  - Defined by the affordability of the system per dish.
  - Includes the incorporation of 64 MeerKAT dishes.
  - Baseline consists of 190 + 64 15-m diameter dishes.
  - Must remain globally competitive in the same frequency range.
  - Determined by sources of noise and receiver bandwidth.
    - subject to data transport and processing capability.
- *Polarisation capability*:
  - Essential to properly calibrate the telescope.
  - Fundamental to pulsar timing, at least at the field centre.
  - For imaging observations (continuum and spectral line)
    - instrumental polarization must be accurately characterized across the processed field-of-view.

SKA1-mid: Key Design Parameters

- *Sky Coverage:*
  - Depends upon the minimum elevation of the antennas and on "shadowing".
  - "soft" requirement,
    - desirable but not easily quantifiable.
    - Large air column at low elevations quickly erodes sensitivity at high frequencies.
    - the ionosphere produces a similar effect at low frequencies.
  - VLBI observations at near Earth-diameter baselines main beneficiaries.
- *Extension to SKA2:*
  - Extension of the core array configuration to SKA2.
  - Upgrade flexibility:
    - SKA1 dishes will not be equipped with a full suite of receivers.
    - Potential intermediate upgrade of SKA1 could include receivers.
    - In SKA2 additional receivers will be needed.
    - Receiver "slots" have been designed with this in mind
    - Nevertheless, receiver bands could be completely re-arranged for SKA2.

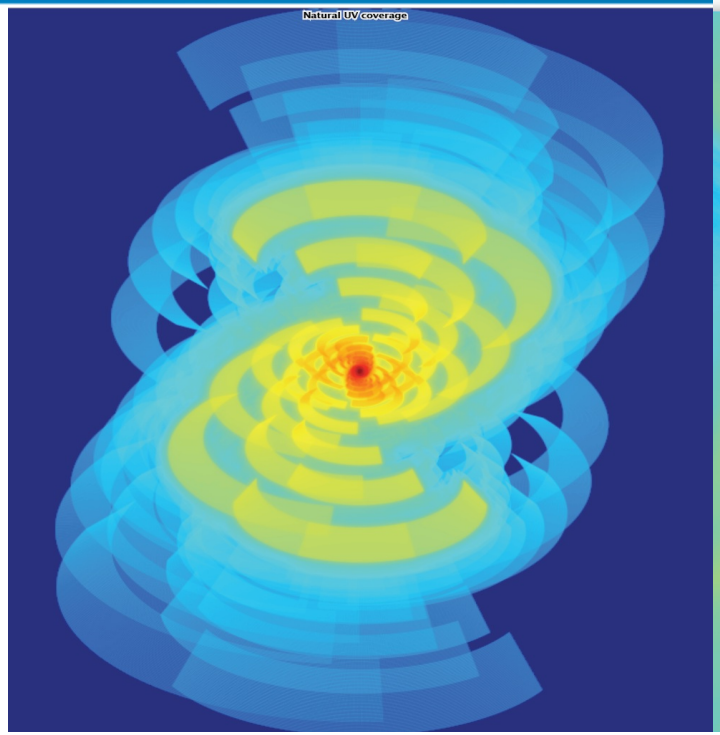
Array Configuration

- PreSKA configuration retained.
  - Result of working group.
  - Dominant core for pulsar work.
    - 133 dishes in the core (~1 km diameter) + most MeerKAT dishes.
  - “Thinned” in the core to approx. compensate for MeerKAT dishes.
  - Three spiral arms as a subset of five planned for SKA2.
    - 19 dishes each arm.
    - Clumped dishes in spiral arms re-distributed.

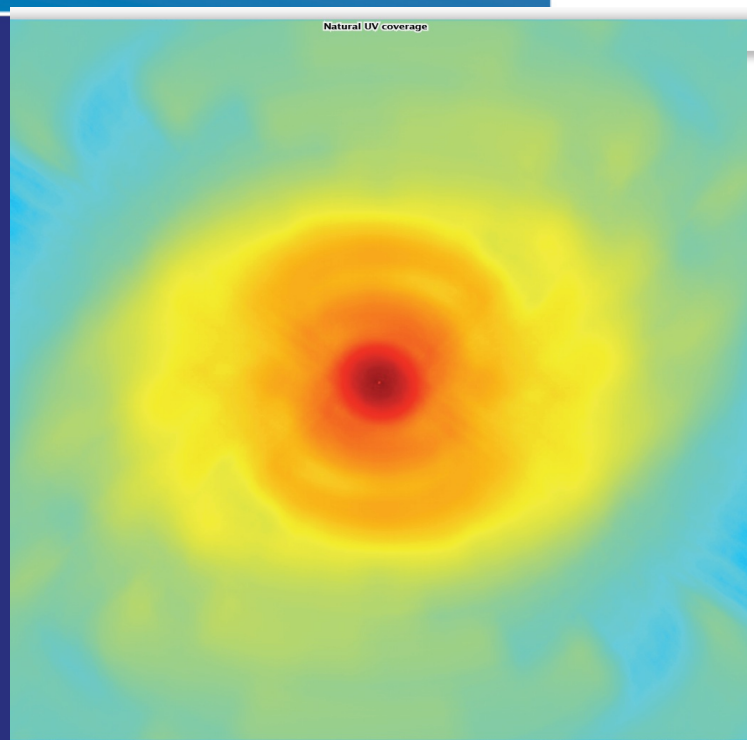


u-v Coverage SKA 1-mid

400 km



320 km

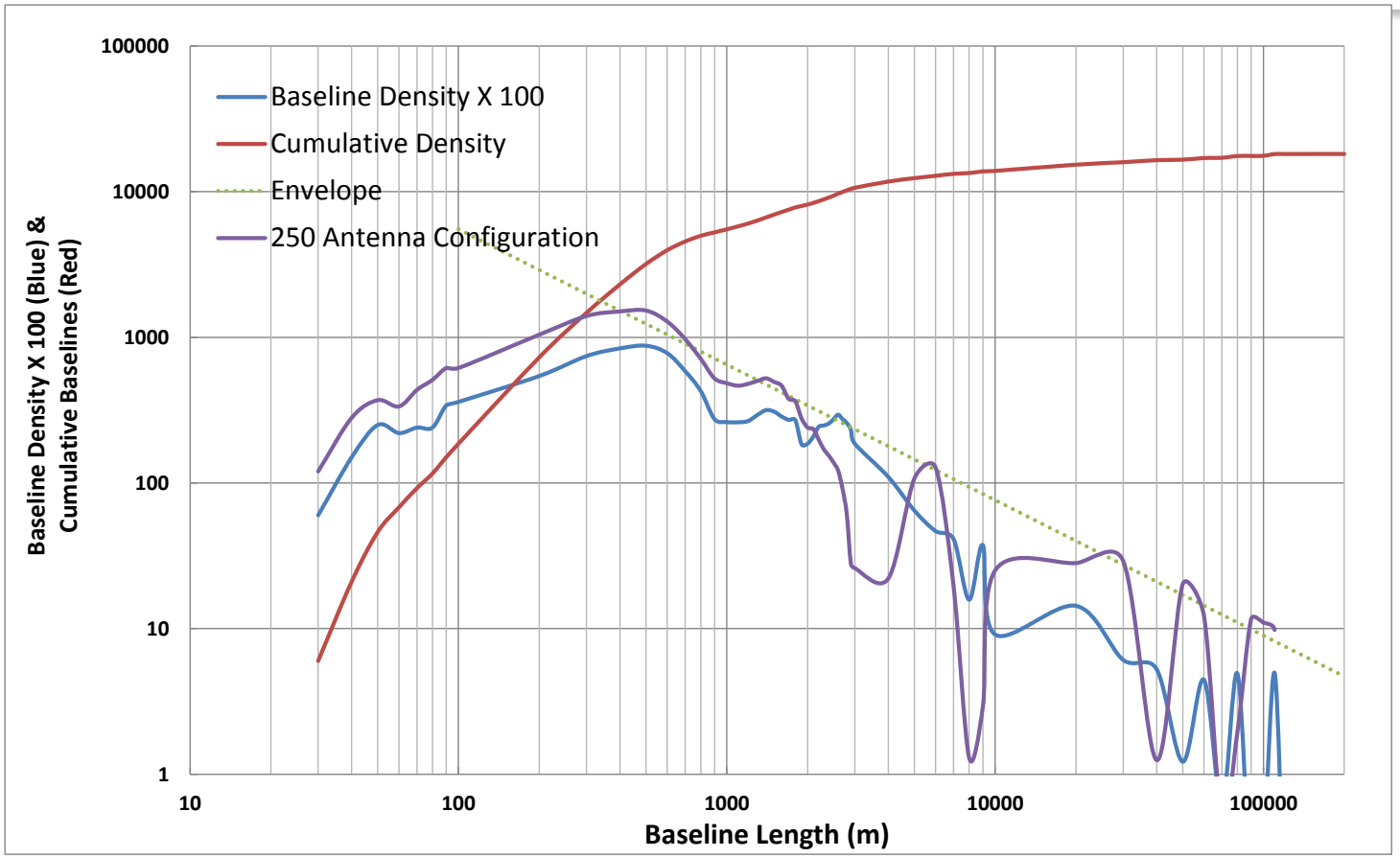


12 km

13 km

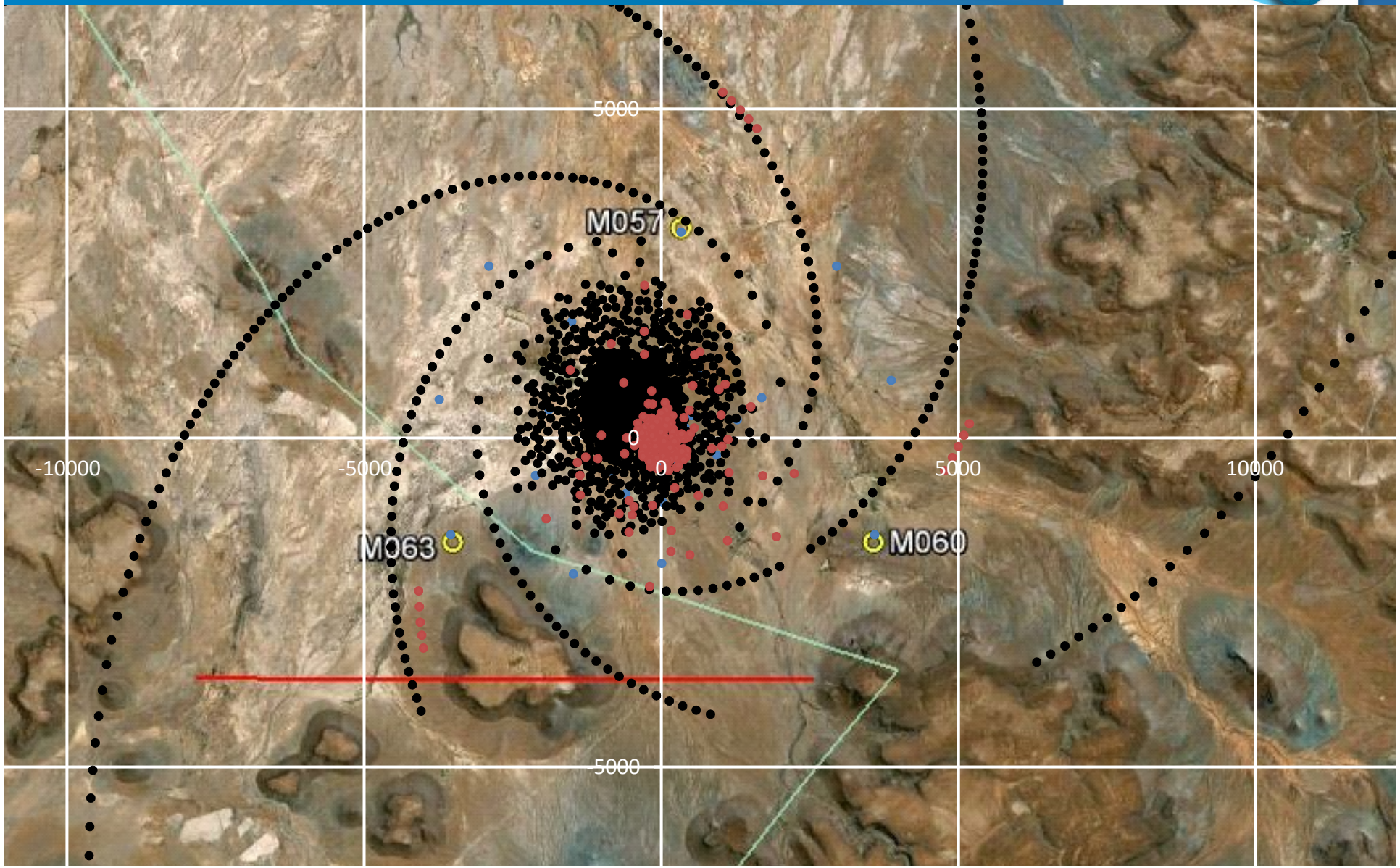
- *u-v* coverage with a 20% fractional bandwidth in 8 hr observation.
  - Strong emphasis on core density enables sensitive pulsar survey but also generates patchy *u-v* coverage elsewhere. Bandwidth helps for continuum.
  - Right box shows excellent coverage at shorter spacings.

Density of Max. Baseline Lengths

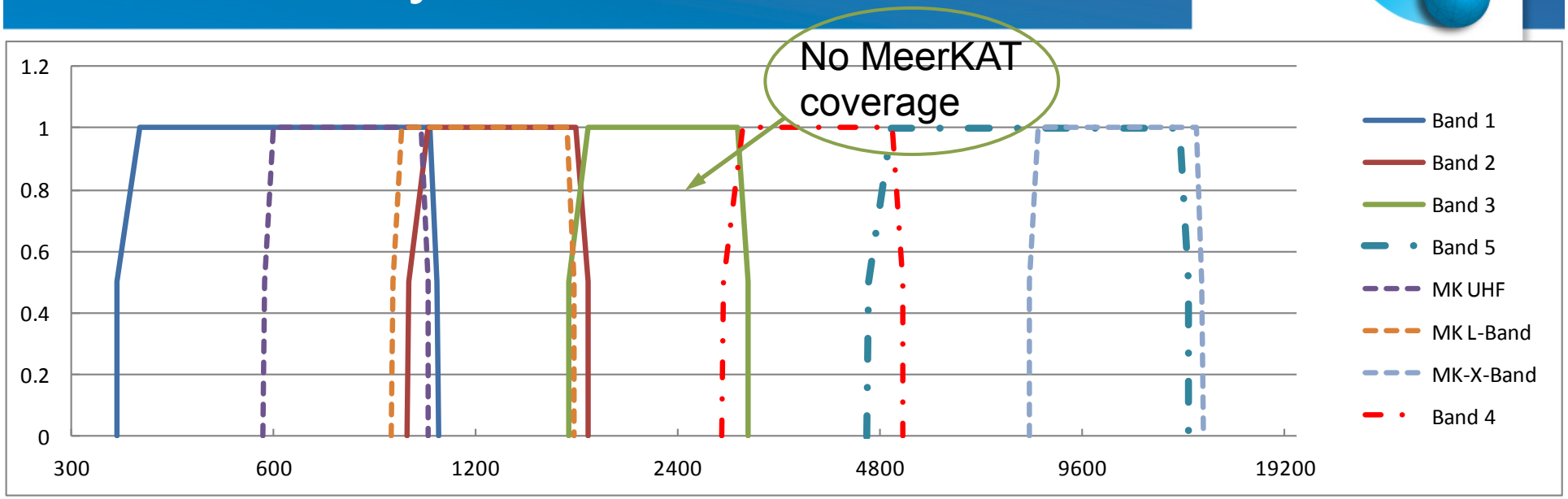


- Very approximately follows a power law (scale free)
  - Note envelope.
  - Coverage beyond ~1000 m is very sparse with gaps.

Central SKA2 South Africa Core Site – Potential Dish



SKA1-mid
Preliminary Dish Receiver Bands



Band	Sky Freq.	Sampled Bands	Streams x bits	Total per Antenna
Band 1	350 – 1050 MHz	1 x 1 GHz	2 x 8 bits	48 Gbit s^{-1} ←
Band 2	0.95 – 1.76 GHz	1 x 1 GHz	2 x 8 bits	48 ←
Band 3	1.65 – 3.05 GHz	1 x 2.5 GHz	2 x 8 bits	120 ←
Band 4	2.80 – 5.18 GHz	1 x 2.5 GHz	2 x 4 bits	60
Band 5	4.6 – 13.8 GHz	2 x 2.5 GHz	4 x 4 bits	120

← SKA1

Pulsar Search Frequencies

- What we understand at the moment …
- Ideal frequency range varies with
  - Dispersion (DM) (f^{-2})
  - Type of pulsar (millisecond or normal)
  - Interstellar scattering (~$DM^{3.5}$ f^{-4})
  - Spectrum ($f^{-1.6}$)
- Galactic plane frequencies centred at 800 MHz or ~1400 MHz.
- Key search parameters (f_{search}, Ω_{beam}, δt_{res}, BW, ΔDM, δf_{ch}) are not independent of each other.
  - Scope for load-leveling by trading Ω_{beam} for ΔDM, δt_{res}, etc. in different regions.
- Lower frequencies (~400-500 MHz) have potential for the higher latitude regions where DMs are lowest.
  - But actually centreing at even lower frequencies will mean using SKA1-low.
- Galactic centre region requires f > 10 GHz (scattering)
  - Size of the region is very small.
  - Not likely in scope for SKA1.

End