Technology Challenges of the SKA

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First National Meeting on Science and Technology with SKA: The Italian pathway to SKA

Rome

June 19-20, 2012

The SKA Concept

A large radio telescope for transformational science:

- ➢up to 1 million m^2 antenna collecting area distributed over a distance of 3000^+ km;
- ➢operating at frequencies from 70 MHz (wavelength = 3^+ m) to 10 GHz (~3 cm) with two or more detector technologies;
- ➢connected to a signal processor and high performance computing system by an optical fibre network.

providing

- ➢50 x sensitivity of current world's best radio interferometers, and
- ➢up to 1 million x survey speed

The Square Kilometre Array (SKA) will be the largest telescope in the cm-to-m range of wavelengths built to greatly surpass the current generation of telescopes in sensitivity and fields-of-view, and with sufficient resolution to address the foremost questions in astrophysics that are likely to dominate the field in the next generation.

THE GOAL HAS NOT CHANGED

Phased Construction

- Construction will proceed in two phases (SKA1 & SKA2).
  - Phase 1 will be a subset (~10%) of Phase 2.
  - SKA1 & SKA2 will be split between two sites along frequency lines.
    - Aperture arrays in Australia; Dishes in South Africa (and Australia for SKA1_SURVEY).

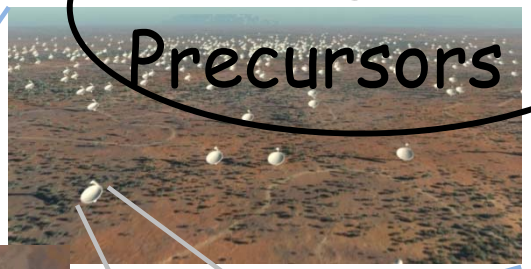
- Major science observations already possible with SKA1.

- Phased construction => parallel technology development for SKA2.

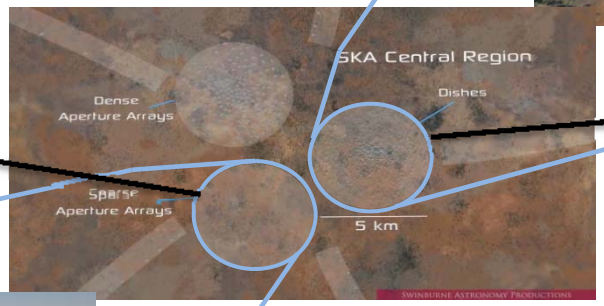
SKA1 Technologies

- Huge frequency range demands multiple technologies.
- Technologies mature enough to enter the design phase.

~250 Dishes + Precursors

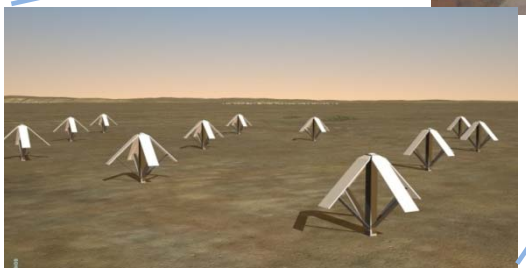


Central Region



Australia

Australia & South Africa



Single pixel feed

Sparse Aperture Arrays (SKA_low)

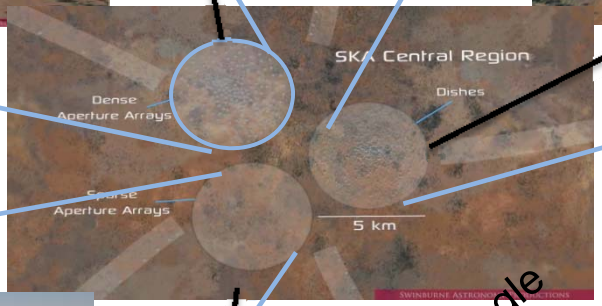
SKA2 Technologies

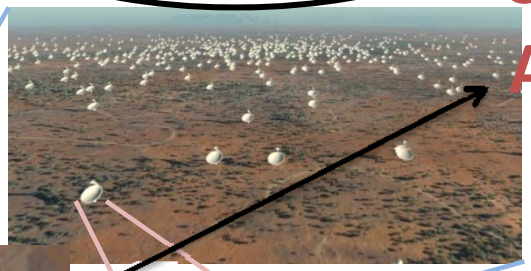
Dense Aperture Arrays

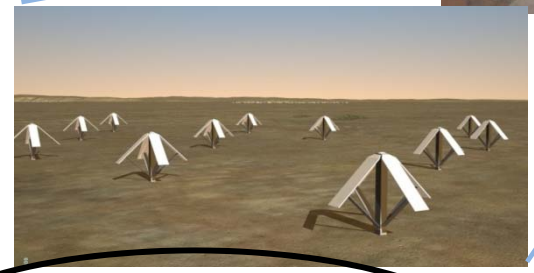
South Africa?

3000 Dishes

South Africa



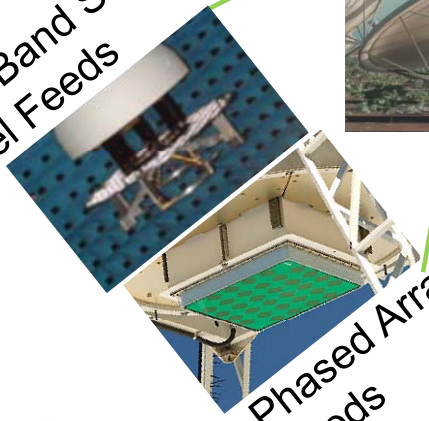




250 Sparse Aperture Arrays

Australia

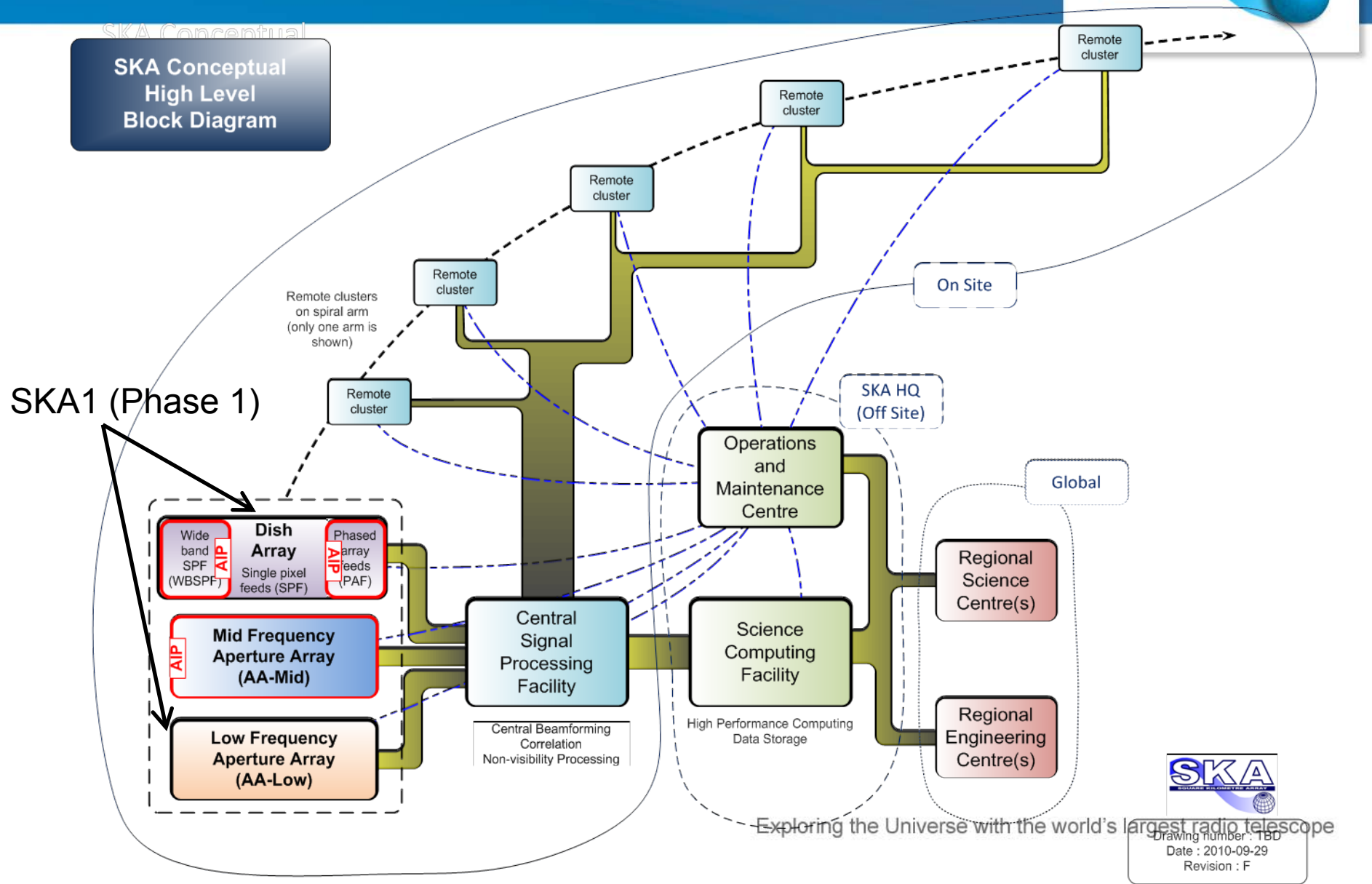
Wide Band Single Pixel Feeds



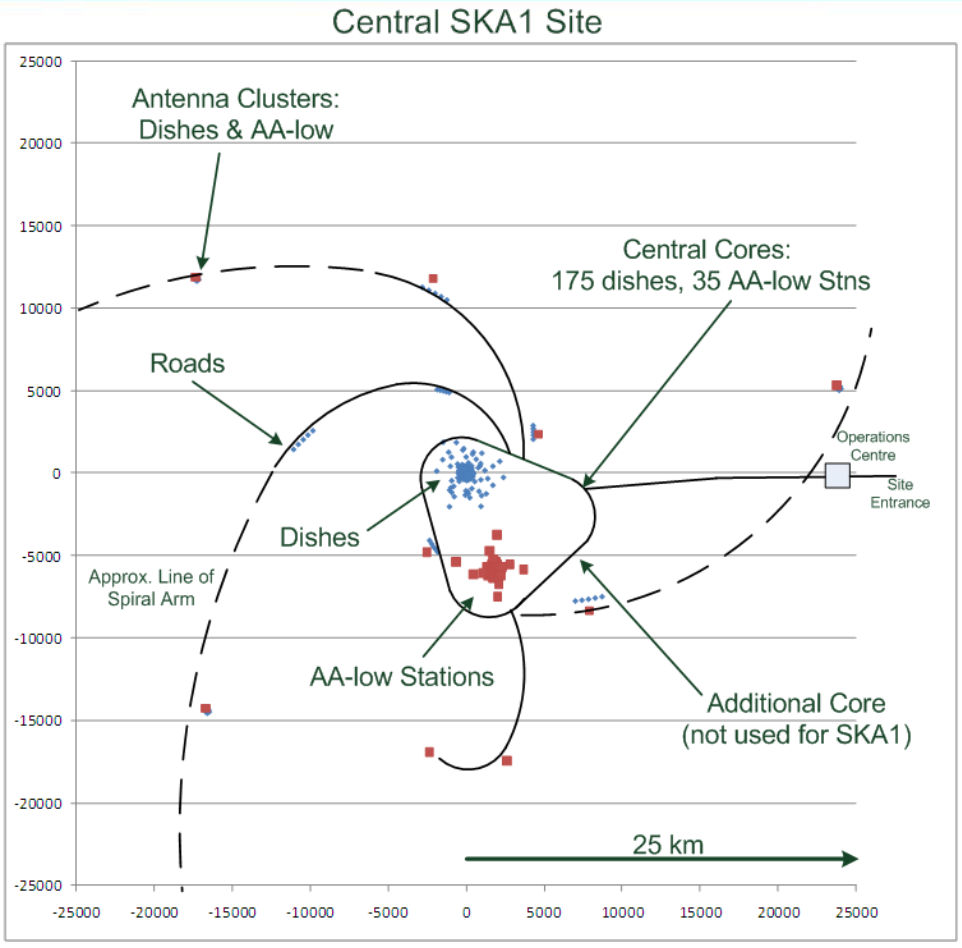
Phased Array Feeds

Artist renditions from Swinburne Astronomy Productions

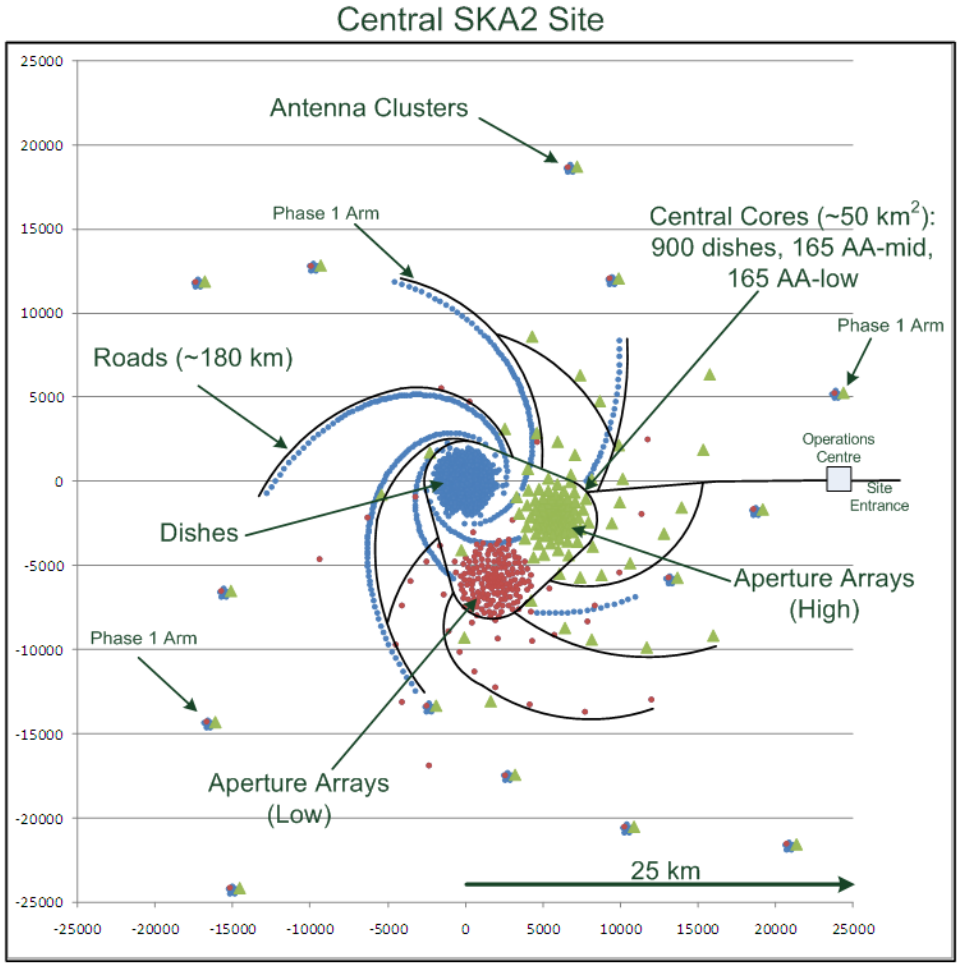
SKA System Diagram



Central SKA Site – two^{+} massive physical systems

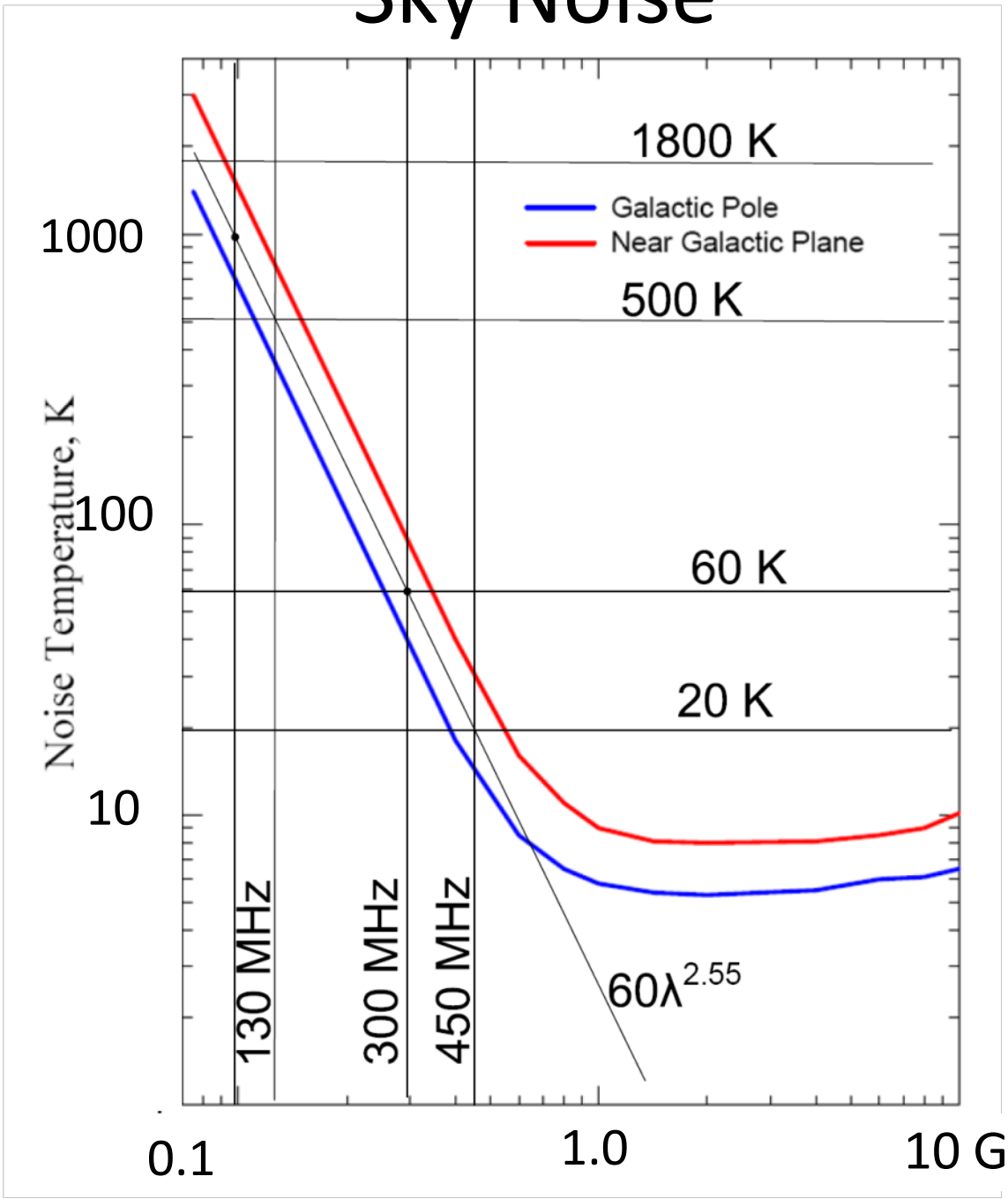


- **Site decision will change this diagram in ways that we are still working on.**



- SKA2 is ~10 x the collecting area of SKA1.

Sky Noise


1800 K
Galactic Pole
Near Galactic Plane
1000
500 K
Noise Temperature, K
100
60 K
20 K
10
130 MHz
300 MHz
450 MHz
60λ^2.55
0.1
1.0
10 GHz

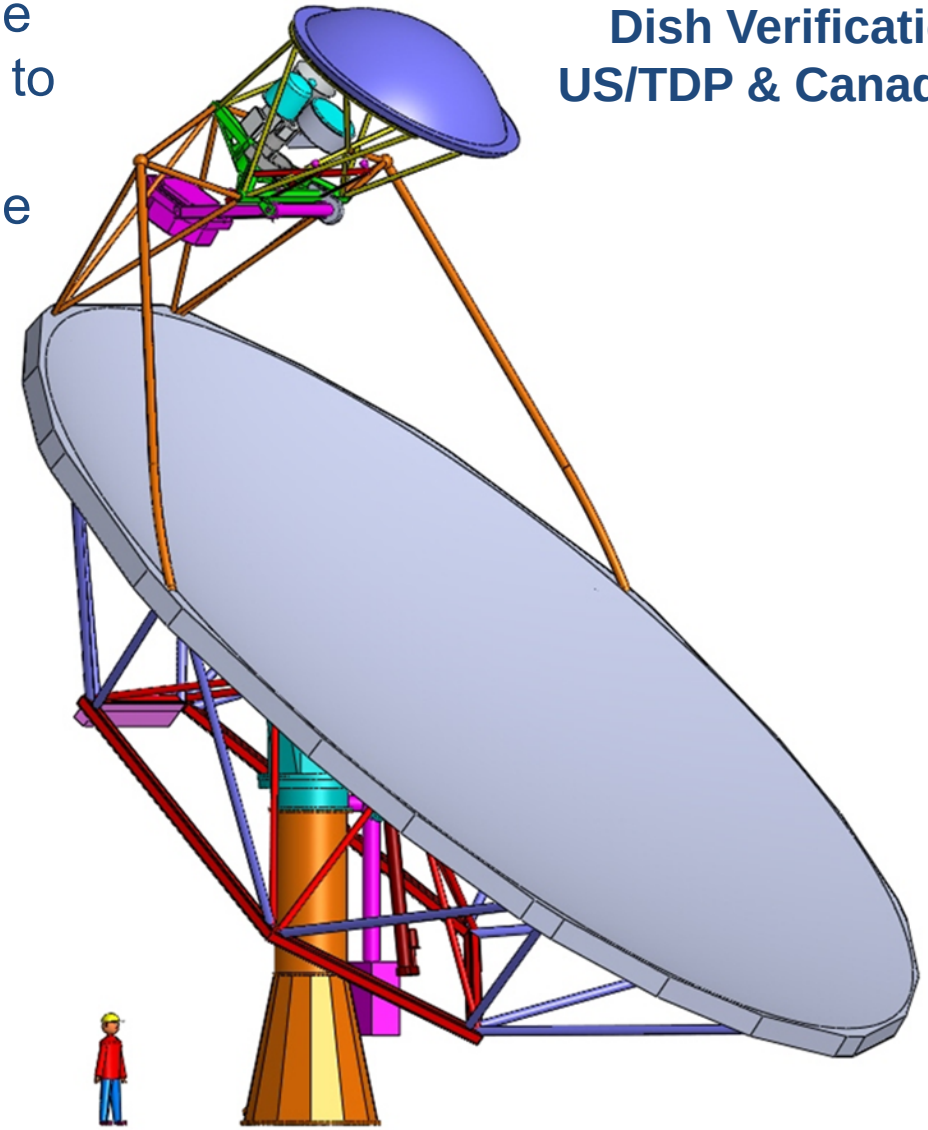
Low frequency aperture arrays

LOFAR (Netherlands et al)

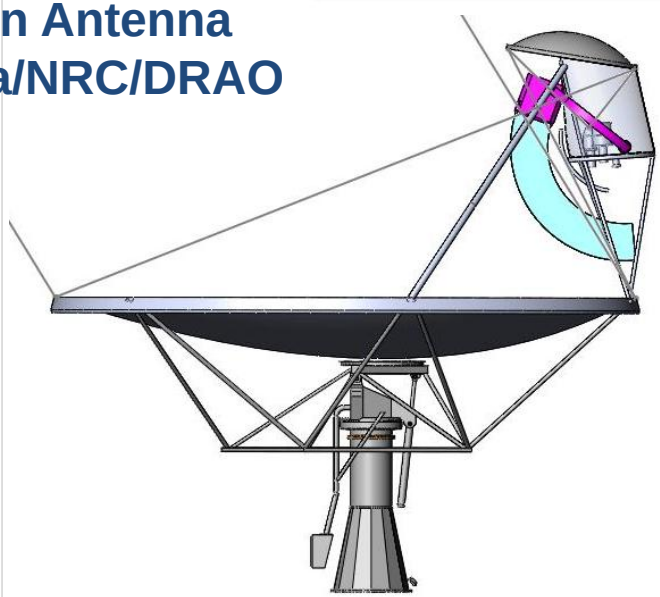
MWA (USA, Australia, India)

Offset-Optics Antenna Design

Multiple Feeds to cover multiple bands

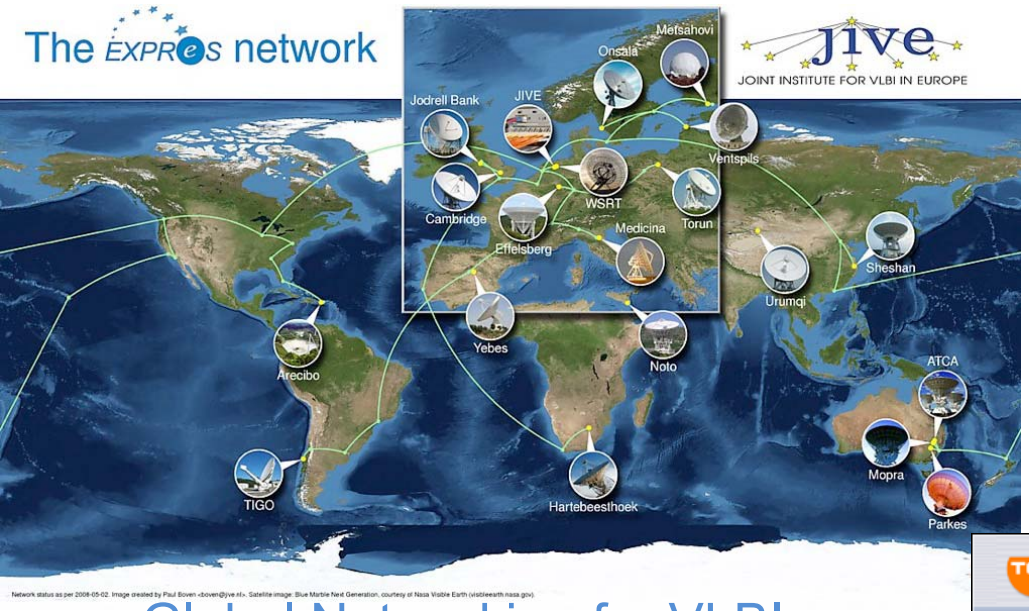


Dish Verification Antenna
US/TDP & Canada/NRC/DRAO



- Deployment of PAFs. at prime or secondary focus.
- Predicted $A_e/T_{sys} > 6\ m^2/K$ with cooled front end.

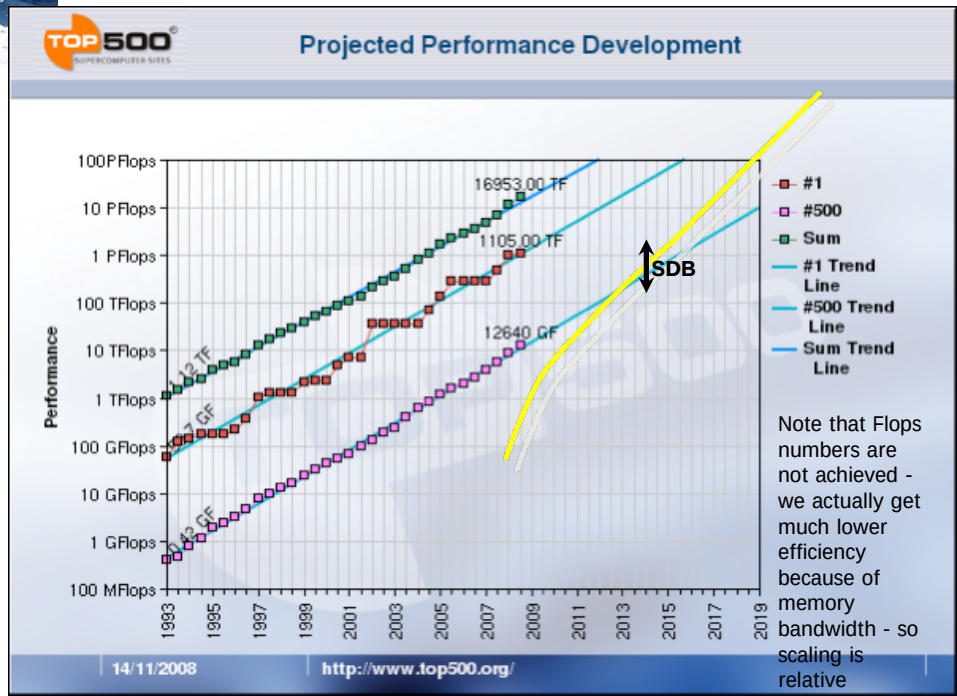
Signal transport, Image Processing



Global Networking for VLBI

Fiber optic transmission

HPC (Supercomputer) performance needed for high-through-put image formation.



Note that Flops numbers are not achieved - we actually get much lower efficiency because of memory bandwidth - so scaling is relative

Signal Processing

EVLA Correlator

170 KW power, and 120 tons of cooling
17308672 control/monitor bits
1473536 registers
24832 FPGAs
256 boards
16 racks
1 room

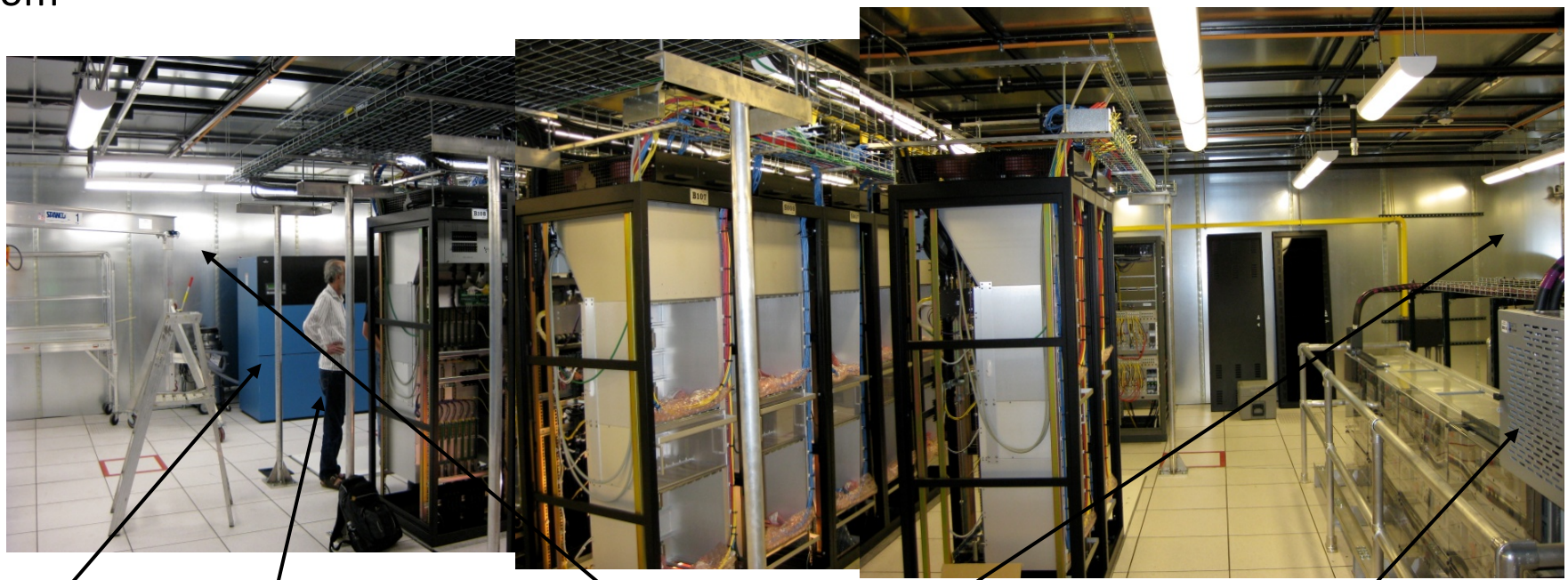
SKA1 Correlator

Completely different requirements.

Likely to be a staged approach, with several correlator generations.

Could be a software correlator initially.

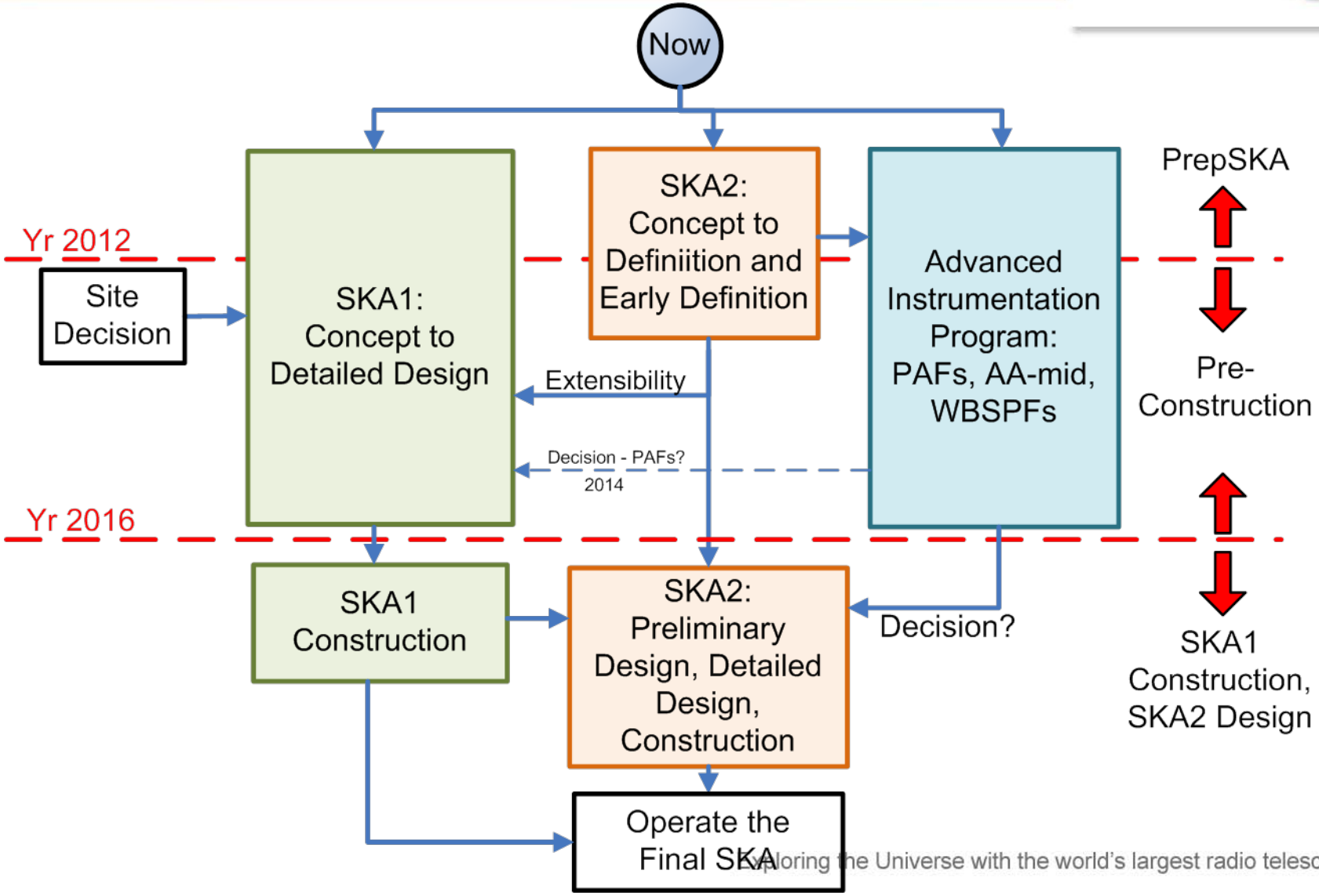
Each site will have at least one correlator.



SKA Phases

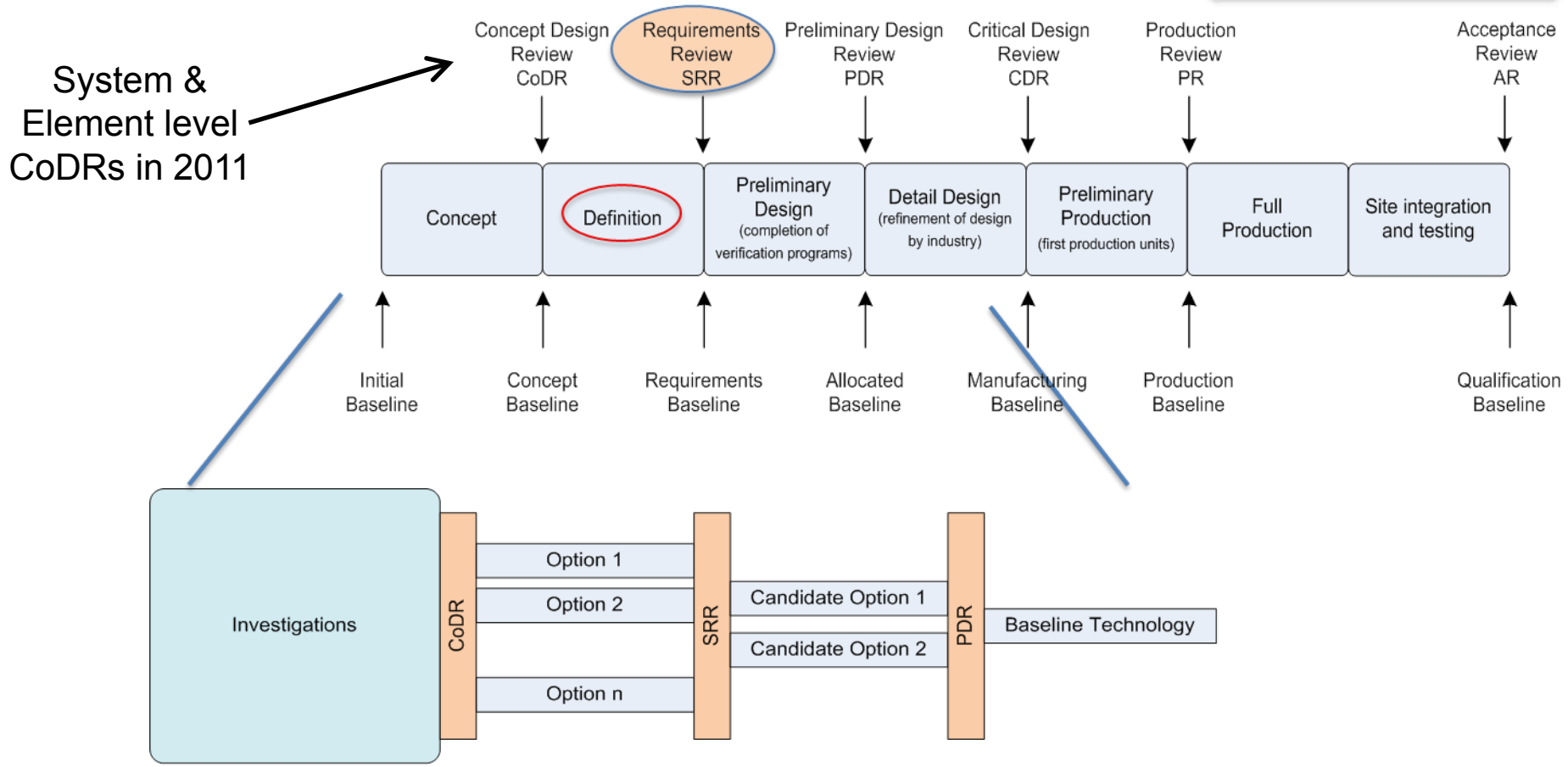
- Preparatory phase (now over)
- **Pre-construction phase (production readiness)**
- SKA1 construction, verification, commissioning, acceptance, integration & first science
- SKA2 construction, commissioning, acceptance, integration & first science
- SKA Operations

Approach to Technical Development



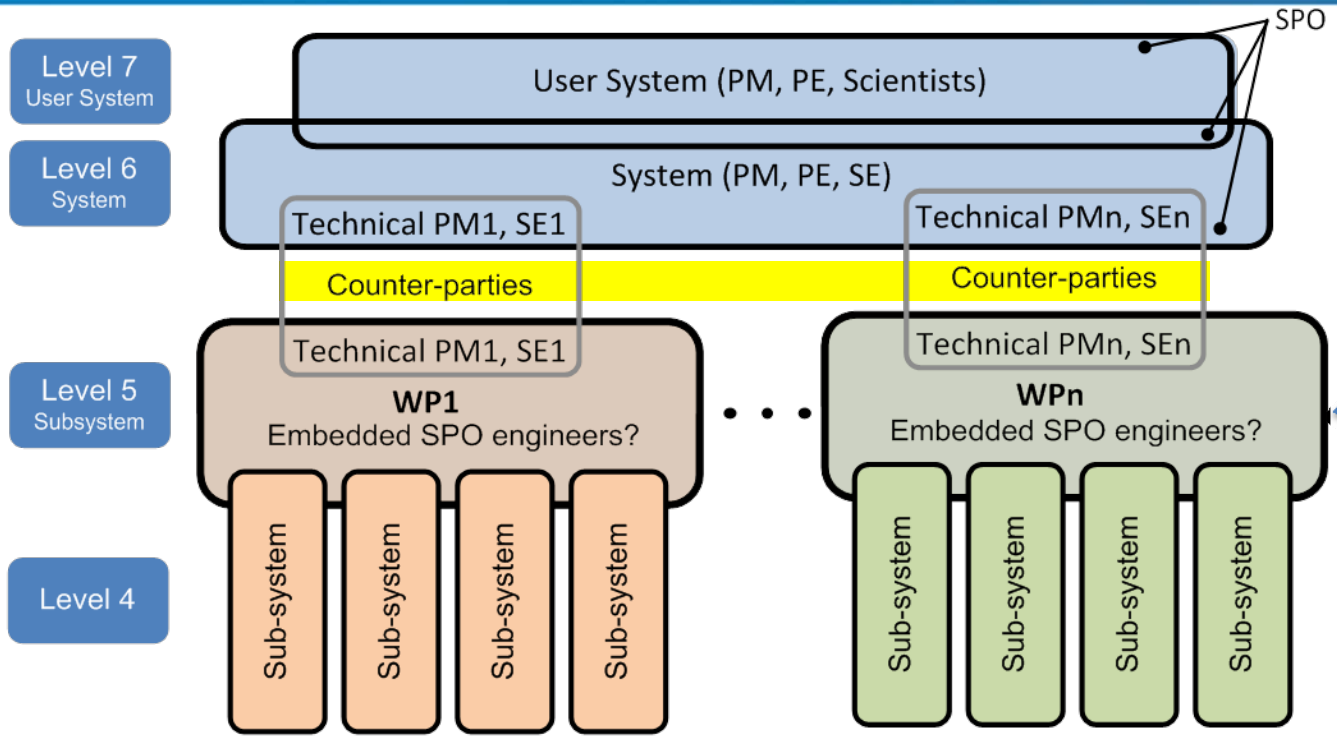
Design Review Series

System & Element level CoDRs in 2011



Industry Representation on Review Boards

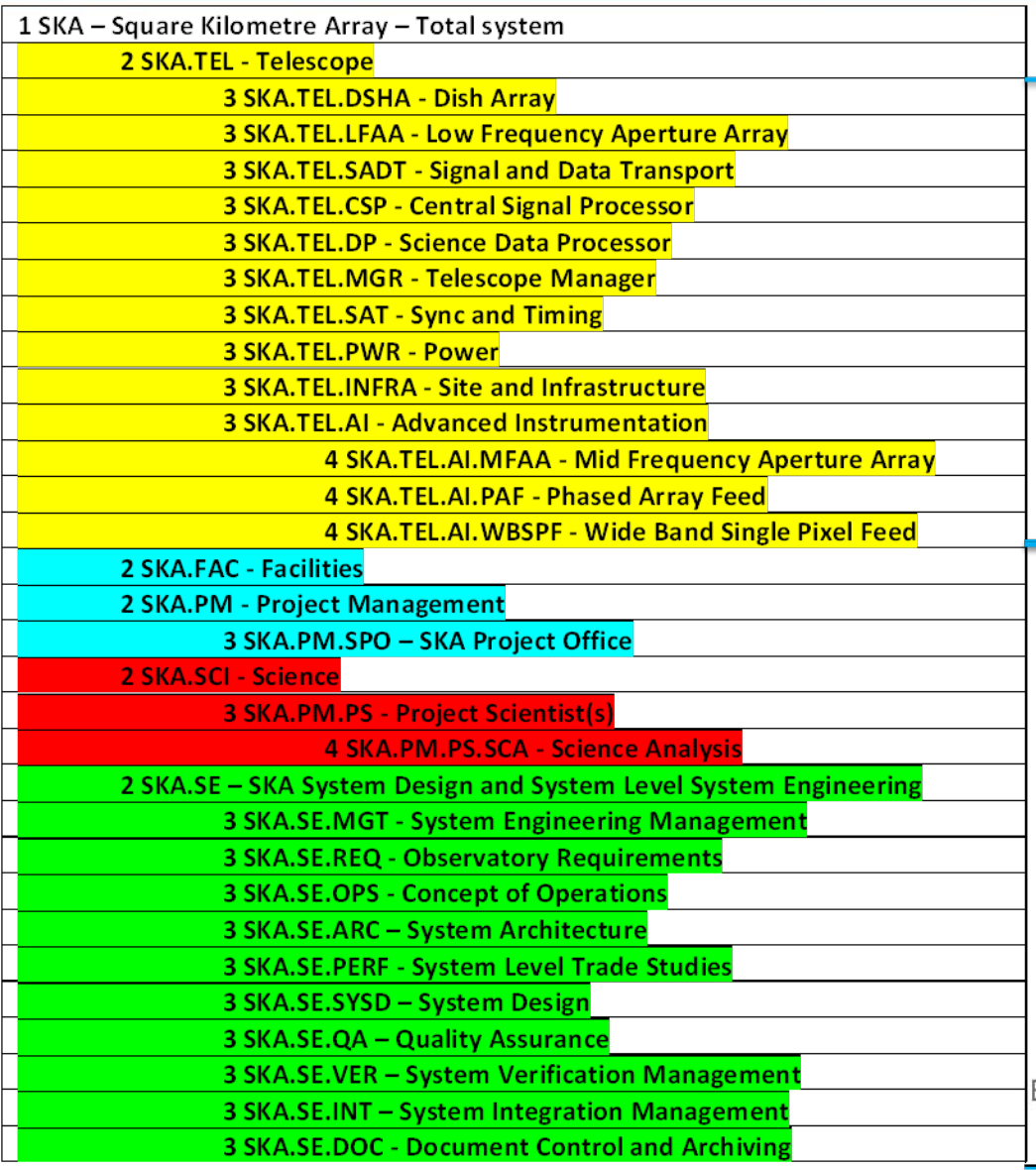
SPO-WPC Relationship



Similar Organization: But now may expect some WPs to capture similar work across two sites, and more than one telescope system

- SPO (as per PEP) contains a Technical Project Mgr and a System Engineer, devoted to each of five WPCs.
- Each WPC has a direct responsible counterparty (top WPC management and principal point of contact).

Overall Work Breakdown Structure (WBS)



WPCs

SPO

- **Expressions of Interest (EoI).**
- **>100 EoIs received.**
- **No gaps.**
- **Many from industry.**

- **Some revision will be required, but we don't know the details yet.**

Stage 1 at System Level

Science Requirements → Instrumental Requirements → System Requirements Review (SRR)

- Frequency range
- *u-v* coverage (max. Baseline)
  - (determines resolution)
- Sensitivity
  - A_e / T_{sys}
  - Survey Speed $[(A_e / T_{sys})^2 \ \Omega]$
- Non Functional requirements

Integrated Task Teams

1. SKA.TEL.ITT.SSP – System Science Performance
2. SKA.TEL.ITT.TRD – System Trades
3. SKA.TEL.ITT.OPS – Observatory Operations
4. SKA.TEL.ITT.CONF - SKA Array Configuration & Topology
5. SKA.TEL.ITT.SWE – Software Engineering
6. SKA.TEL.ITT.RFI – EMI and RFI Design Policies, Guidelines and Standards

- Carry out work that cuts across Element boundaries.
- Fundamentally associated with the System Level
- Take advantage of specialized expertise available within the community , or because the central office lacks the resources.
- Initiated, organized and coordinated by the SKA Office,
- Resourced by the Element work package consortia and the SKA Office.

Example Task: System Science Performance ITT

- Requirement from DRM Chapter 2 (EoR):

SCI-T-REQ-0040: The SKA Phase 1 shall provide full polarization capabilities.

SCI-T-REQ-0041: The SKA Phase 1 shall provide polarization calibration of better than TBD%.

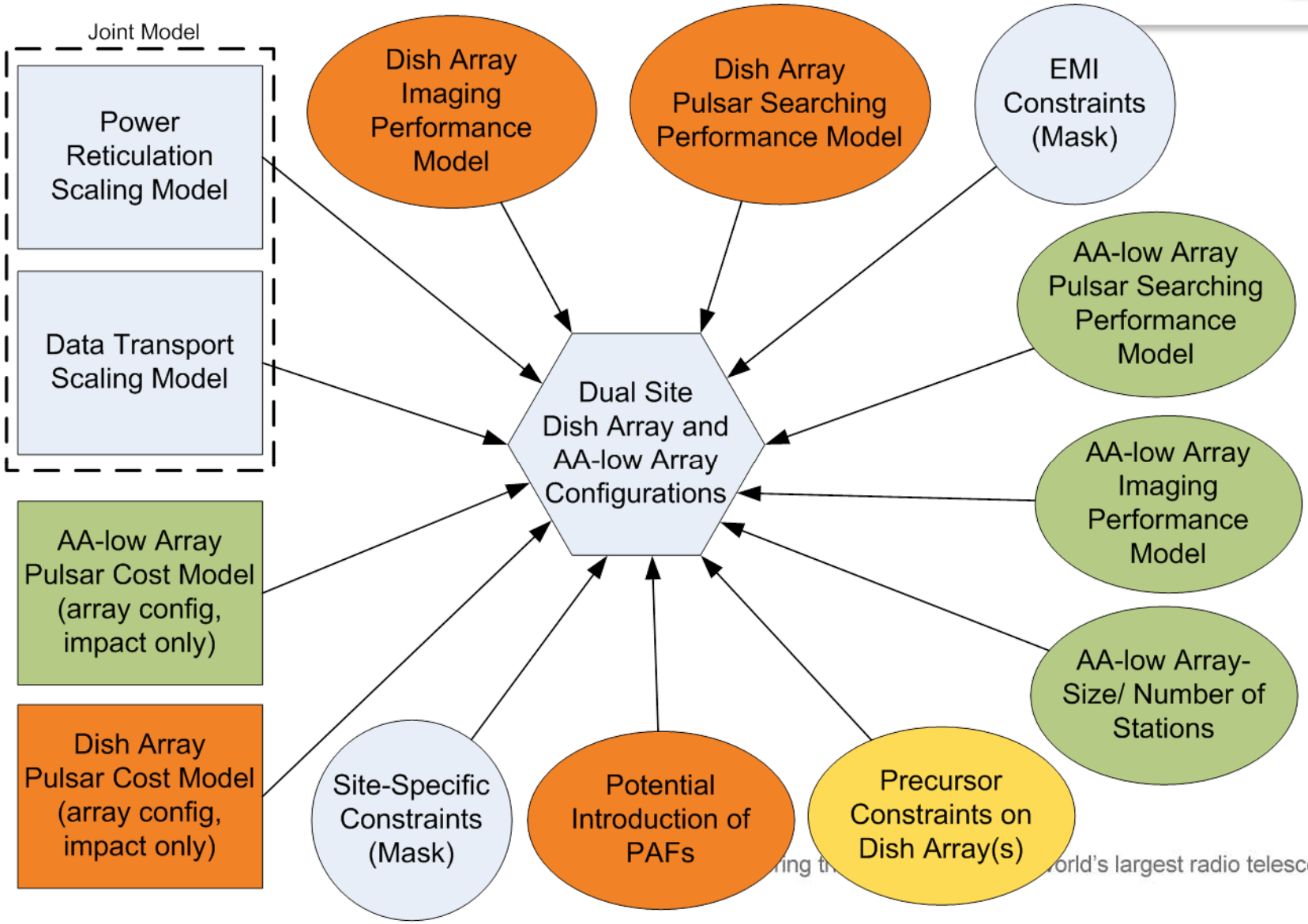
SCI-T-REQ-0042: The SKA Phase 1 shall provide a polarization separation of better than TBD dB.

- What is behind this assertion?
  - HI is unpolarized, so why worry about polarisation?
    - But the bright continuum Galactic foreground is strongly polarized. Also linear pol'n structure from Faraday screens.
  - Foreground scales are arcmin ⇔ degrees, similar to EoR HI scales.
    - But continuum can be subtracted from spectra, so it still doesn't matter.

Example Task: System Science Performance ITT (2)

- Uncalibrated instrumental pol'n will be frequency dependent.
  - This will result in a 'false signal' that could mimic an HI spectrum in either emission or absorption.
  - We need to set a limit on this => DRM says ~0.1%, which is the strength of the expected signal.
- This leads to a description of an ITT task on telescope modelling:
  - Need to begin with the pol'n properties of the array elements, then the stations, and then the all-sky station beam.
  - Essentially a 5-dimensional model: two angles within the beam (θ,ϕ), two pointing angles (Elevation, Azimuth), and frequency.
  - Need model sky for candidate regions.
  - Add perturbation parameters (e.g. Inter-element coupling, orientation of elements, imperfections in ground screen, etc.)
  - Model must be verified by experiment – how?

Array Configuration ITT: Context Diagram/Input Considerations



Array Configuration ITT (2)

Examples

- Trade Space
  - Core configuration: cost of power/data distribution vs science performance.
  - A_{core}/A_{total} vs observing time for large surveys (balance needed). Need explicit analysis. May be different for AA-low and dishes.
- Constrained Optimisation
  - A_{core}/A_{total} may change from SKA1 to SKA2.
    - e.g SKA1 core size and area for AAs should be optimised for SKA1 AA-low science. This may be a different optimisation from the AA-low science in SKA2.
  - Constraints: scale-free outside core, grouping of AA stations & dishes to reduce servicing costs, etc.
- Engineering modelling
  - No scaling model at present for power, although commercial availability of same is being investigated.
  - Partially developed model for data (SPDO & U. Cambridge) is available. Probably will need a joint power/data model.
- Science Assessment
  - Cross-check array configuration with original science case.

Array Configuration ITT (3)

- Dish-Related
  - Dish Array Imaging Performance Model
  - Dish Array Pulsar Searching Performance Model
  - Dish Array Pulsar Cost Model (array config, impact only)
- AA-low Related
  - AA-low Array Imaging Performance Model
  - AA-low Array Pulsar Searching Performance Model
  - AA-low Array Pulsar Cost Model (array config, impact only)
  - AA-low Array-Size/Number of Stations
- Power/Data Joint Model
  - Data Transport Scaling Model
  - Power Reticulation Scaling Model
- EMI Constraints (Mask)
- Site-Specific Constraints (Mask)
- Impact of AIP technologies on SKA2 Array Configurations
  - PAFs
  - AA-mid arrays

End