The SKA Project : Overview, Science, Pulsars and this Workshop

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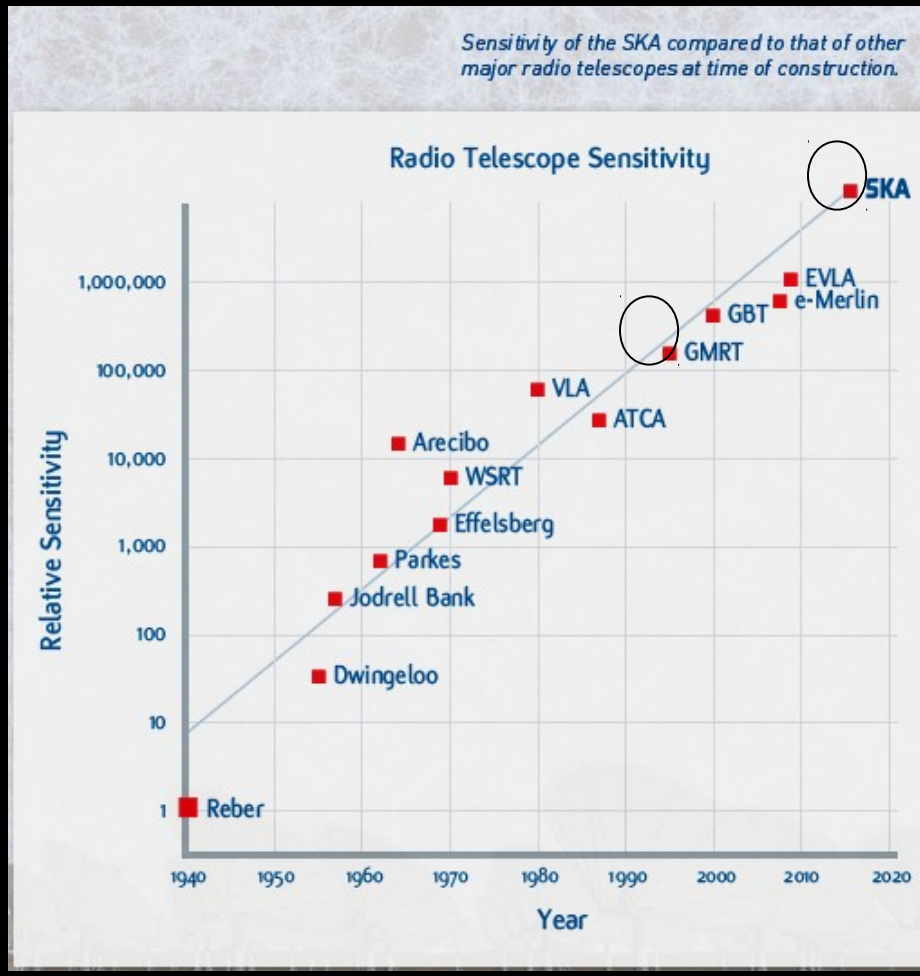
Setting the context for this Introductory Talk

- Main goals and plans for this talk are as follows :

- Science goals and possibilities with the SKA
- An introduction to the SKA : what is it, what is planned, what will it consist of...
- Indian participation in the SKA : current role, future plans & possibilities
- Pulsars with the SKA
- What we would like to address in this workshop

Background : what is the SKA ?

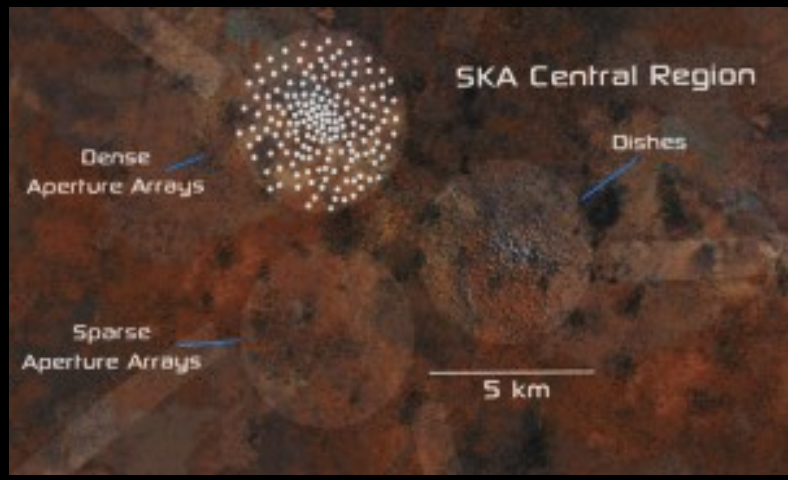
- The SKA is the most ambitious Radio Astronomy project ever attempted
- 1 square km (1,000,000 sq m) collecting area (~ 30 x GMRT !) ➔ ~ 3000 small sized antennas, with larger field of view
- High resolution ➔ antennas spread out over distances up to 3000 km, but connected in real-time (by optical fibre)
- Wide frequency range: 70 MHz - 10 GHz
- Location : Australia AND South Africa (radio quiet regions, far away from human habitat)
- Total estimated cost s for full SKA :
  Phase I : 650 M Euros
  Total : ~ 1.5 billion Euros (?)



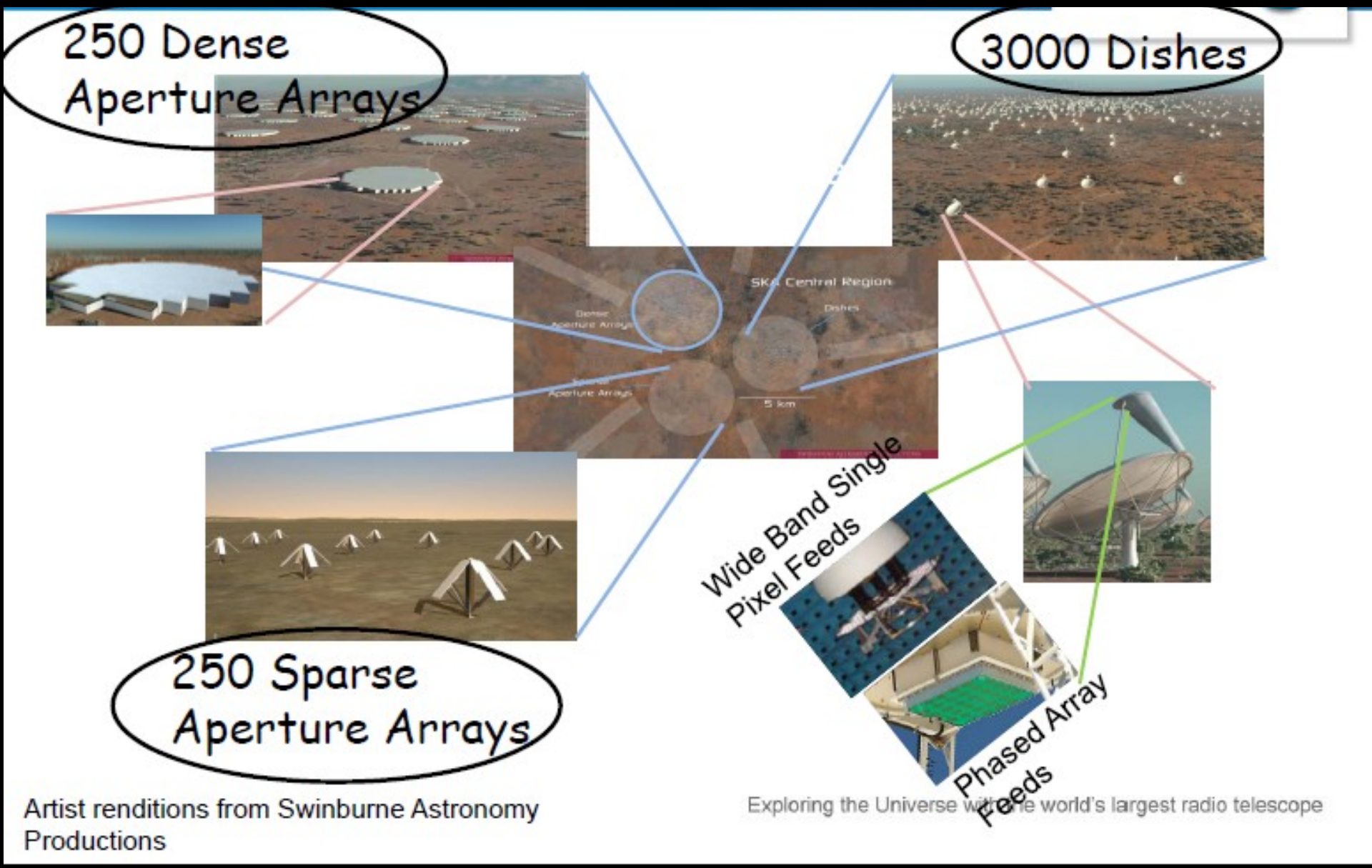
Radio telescope sensitivities over the years
SKA will be 50x better than today's best !

SKA Design & Technologies

- Receptor stations spread out over a region of 3000 km ; highly compact & dense central core region
- Multiple detector technologies to cover the large frequency range : dishes (high frequency), sparse & dense aperture arrays (low & mid frequencies)
- Extensive optical fibre network (petabits/sec) : > total internet traffic)
- State of the art low noise electronics & real-time signal processing
- Supercomputing capability (petaflops) for post processing requirements
- Complex telescope management structure



Full SKA : Reference Design Layout



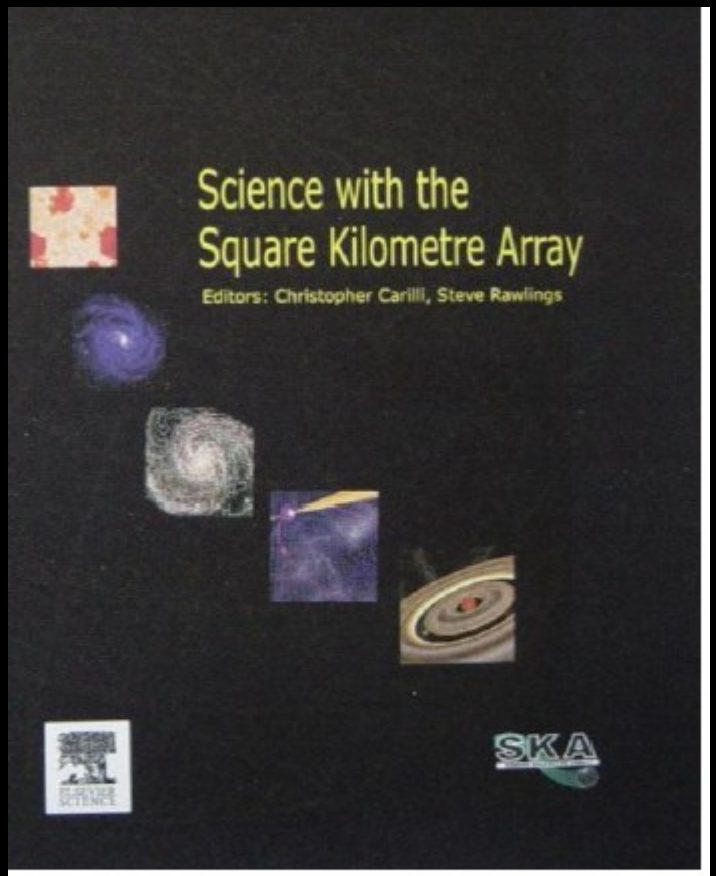
Artist renditions from Swinburne Astronomy Productions

Science with the SKA

- Frontline Science with the SKA : (courtesy R. Braun at SKA Engg Meet 2014)
  1. Cosmic Dawn and EoR – direct imaging of the earliest structures
  2. Cosmology & Dark Energy – primordial non-Gaussianity, super-horizon scales and the matter dipole
  3. Galaxy Evolution probed via Radio Continuum – star formation rates and resolved disks
  4. Galaxy Evolution probed via Neutral Hydrogen – resolved gaseous disks and angular momentum growth
  5. The Origin and Evolution of Cosmic Magnetism – what generates the magnetic fields in space? ; the role of magnetism in galaxy evolution
  6. The Transient Radio Sky – Fast Radio Bursts as cosmological probes
  7. Strong-field Tests of Gravity with Pulsars & Black Holes – gravity waves and fundamental physics; was Einstein right ?
  8. The Cradle of Life & Astrobiology -- detecting proto-planetary disks, search for complex molecules (building blocks of life), SETI

Serendipitous science : the power and sophistication of the SKA will provide plenty of opportunities for new, unexpected discoveries !

Science with the SKA



Science with the Square Kilometre Array
(2004, eds. C. Carilli & S. Rawlings, *New Astron. Rev.*, **48**)

Now being updated with a new & more comprehensive version following the SKA Science meeting in Italy in June 2014.

SKA Science Working Groups

Astrobiology / Cradle of Life
Hoare (UK)

Galaxy Evolution / Continuum
Prandoni (IT), Seymour (AU)

Cosmic Magnetism
Govoni (IT), Johnston-Hollitt (NZ)

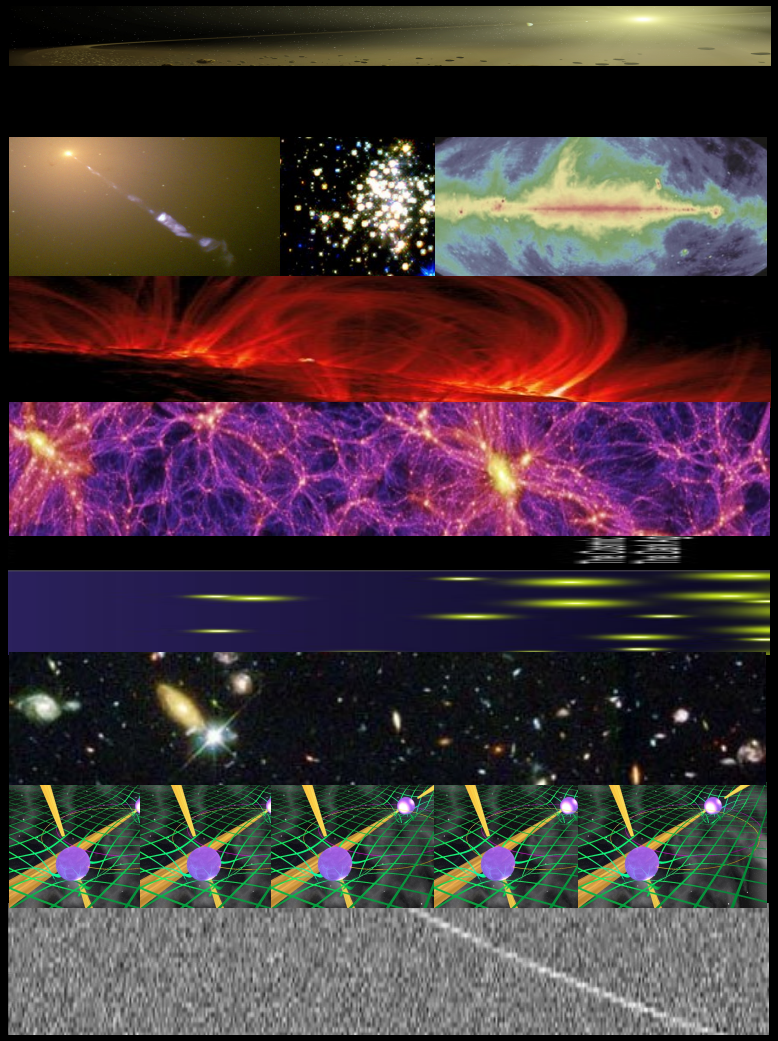
Cosmology
Maartens (ZA)

Epoch of Reionisation / Cosmic Dawn
Koopmans (NL)

Galaxy Evolution / Neutral Hydrogen
Staveley-Smith (AU), Oosterloo (NL)

Pulsars / Strong field tests of gravity
Stappers (UK), Kramer (DE)

Transients
Fender (UK), MacQuart (AU)



Courtesy : Robert Braun

SKA Phase I

- Full SKA is a very ambitious project; for ease of implementation, it has been split into phases

- SKA Phase I :
  - ~ 10% of full SKA
  - Frequency coverage : 70 MHz to 3 (10) GHz
  - Max baseline : 200 km
  - 2 key science goals : EoR ; Pulsars & Gravity (+ minor goals)
  - All infrastructure and designs to keep in mind the full SKA
  - Total cost estimate : ~ 650 M Euro (Rs. 4550 cr)
  - Selection of site has happened (May 2012) and the project will be located in Australia and South Africa
  - 3 part telescope : SKA-LOW, SKA-MID & SKA-SURVEY
  - Detailed design & definition phase : 2012 -- 2016 (~ 90 M Euros)
  - Construction phase : 2017 – 2022 (~ 550 M Euros)

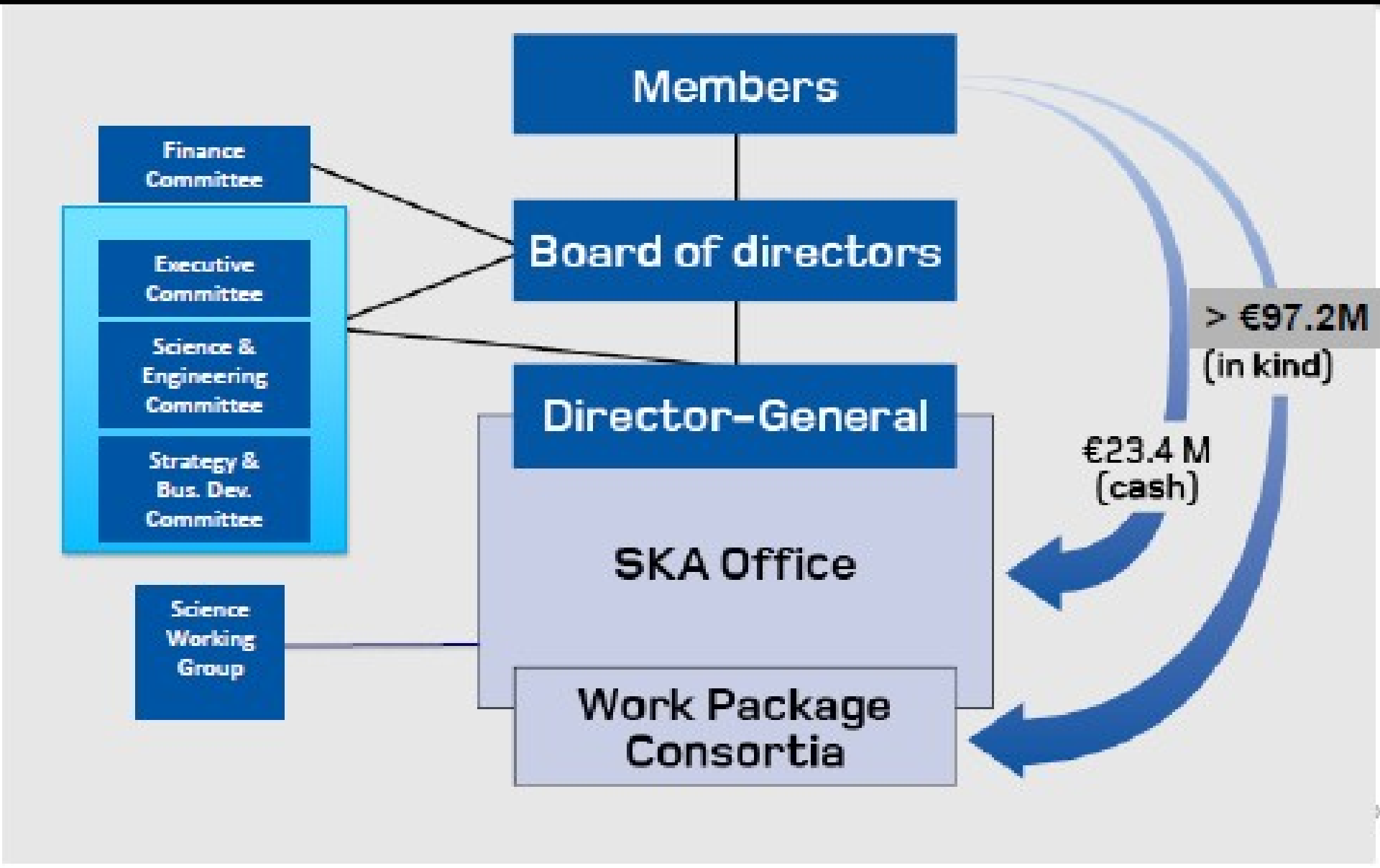
Realisation Plans for SKA-I

SKA1_MID
254 Dishes including:
64 x MeerKAT dishes
190 x SKA dishes

SKA1_LOW
Low Frequency Aperture Array Stations

SKA1_SURVEY
96 Dishes including:
36 x ASKAP
60 x SKA dishes

SKA : Governance & Management



SKA-I : Management Structure

- Present management structure (2012 onwards) is as follows:
  - The SKA Project Office (HQ in Manchester, UK) coordinates all the technical activities
  - The work is divided into work packages for different elements of the SKA telescope
  - At a higher level, the affairs are managed & guided by the SKA Organisation : Board of Directors, representatives from scientific community and funding agencies of each member nation; Full Members vs Associate Members
  - Presently : Ten nations with Full Membership -- Australia, Canada, China, Germany, Italy, The Netherlands, New Zealand, South Africa, Sweden, UK.
  - Till recently, India was an Associate Member. At present, NCRA is a Full Member; shortly be going to Full Membership for India.

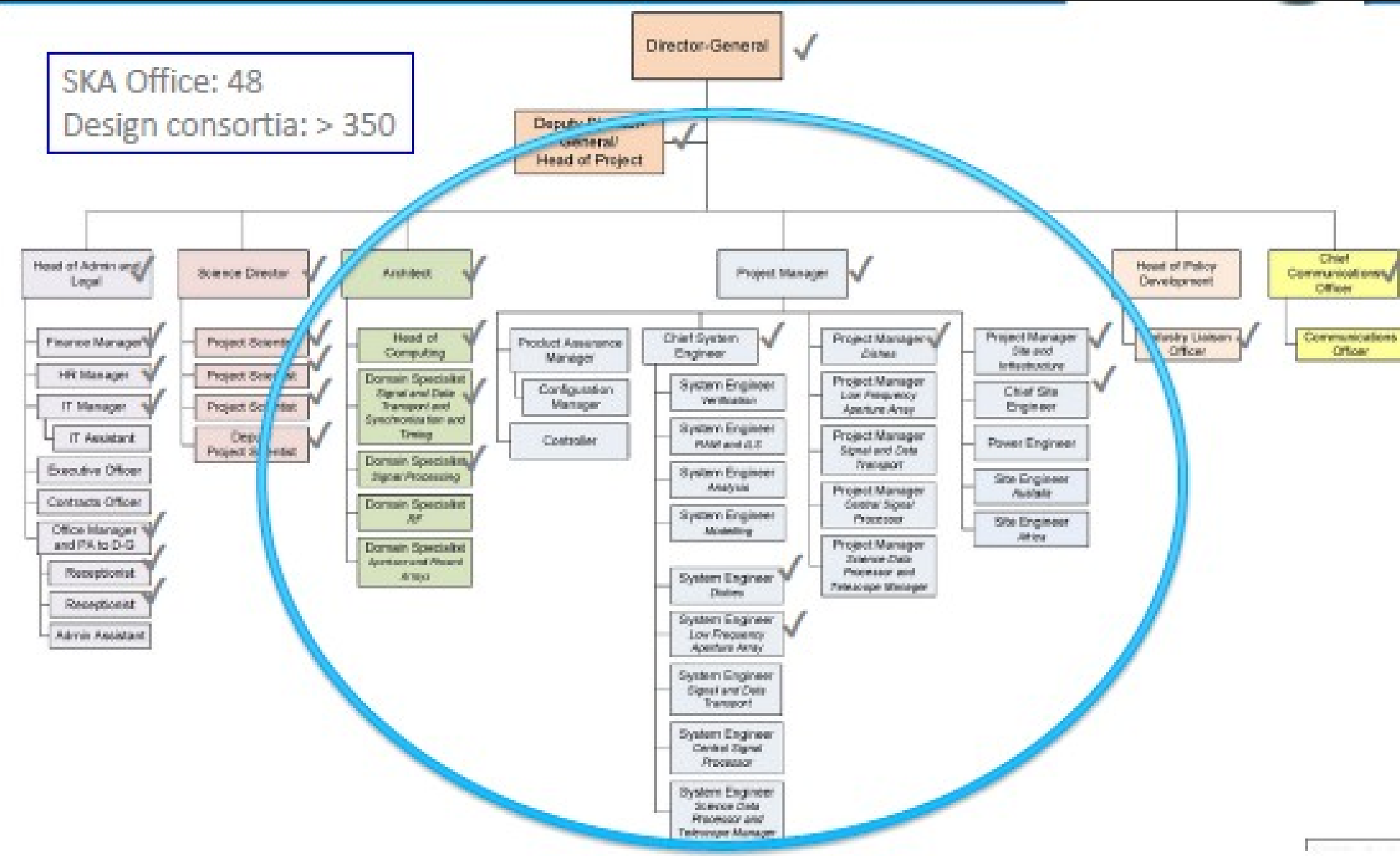
SKA-I : Design Process

- Design of the SKA is being undertaken by global consortia, acting as contractors to the central SKA Office.
- SKA Office has direct control of the system engineering process, receiving and reviewing designs from consortia, monitor progress, analysing and allocating Earned Value etc.
- SKA Office issued a baseline conceptual design to serve as starting point for design, based on previous work and CoDRs.
- 10 consortia formed to undertake the design.
- First major target is the Preliminary Design Review (PDR) scheduled at the end of 2014 / early 2015.
- Inputs from the design and cost estimates from the work by the consortia will be used to rebaseline the design – by March 2015.
- SKA Office holds the design authority for the project.

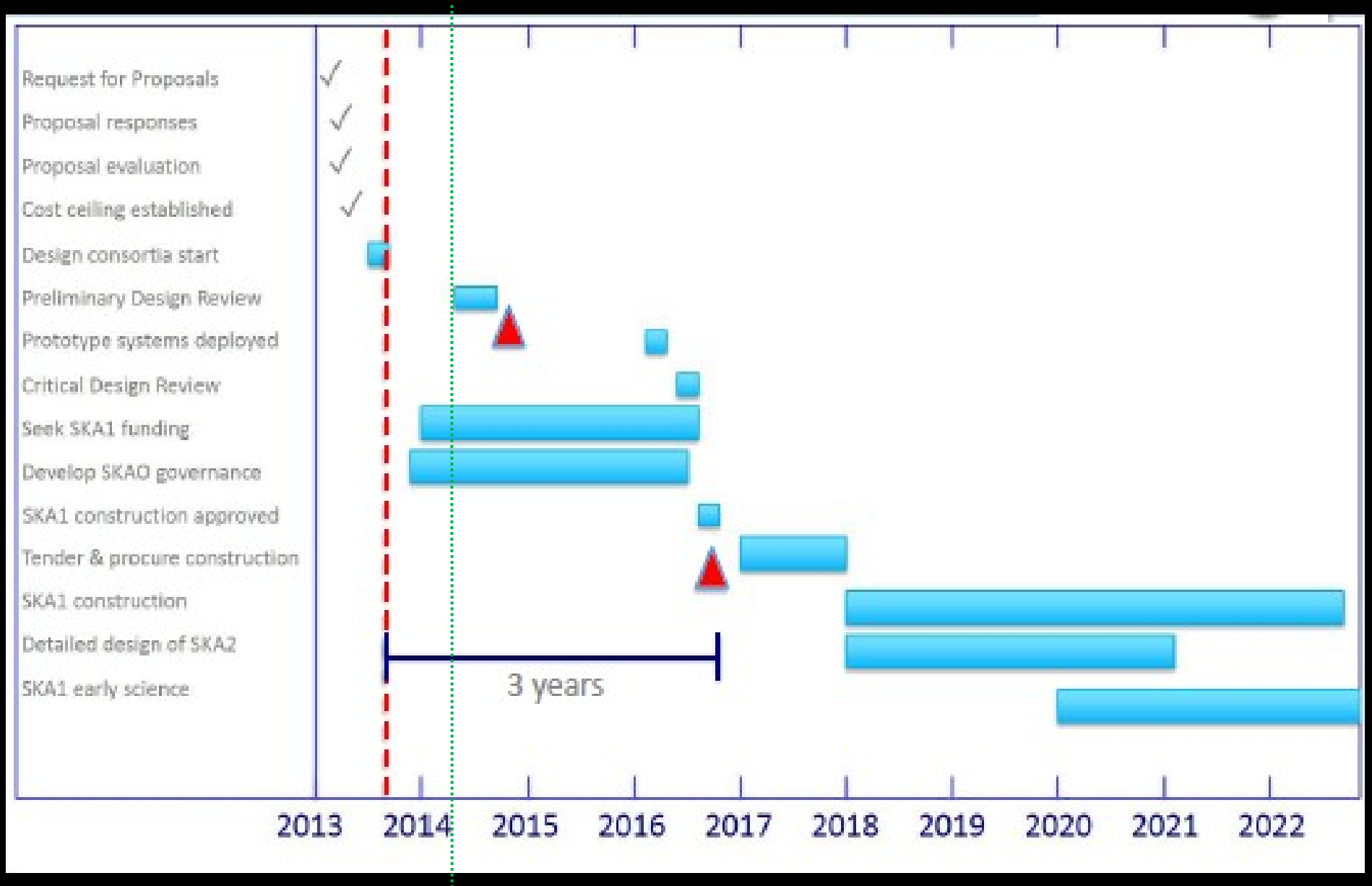
SKA-I : Work Packages

- Following are led by SKA Office :
  - Management
  - Science
  - System Design and system engineering
  - Maintenance & Support and Operations
- Following are carried out by Work Package Consortia :
  - Dish Array
  - Aperture Arrays
  - Signal and Data Transport (including synchronisation and timing)
  - Central Signal Processor
  - Science Data Processor
  - Telescope Manager
  - Infrastructure, including power
  - Assembly, Integration and Verification
- Additional packages on Advanced Instrumentation Programmes (to be integrated with Dish & AA WPs) by WP Consortia :
  - Mid Frequency Aperture Array
  - Wide Band Single Pixel Feeds

SKA : Governance & Management



SKA : Timelines



Indian Participation in SKA : overview

- India has been part of SKA from the beginning & member of the formal organisation bodies (Associate Member of the present "SKA Organisation")
- Indian astronomers have been active participants in various SKA committees
- With 3% of full SKA collecting area, the GMRT project is an important low frequency radio telescope -- provides useful test-bed for SKA work
- Presently ongoing upgrade activities at GMRT provide for natural overlap & synergy with SKA efforts ; e.g. monitor and control systems with industry collaboration, development of next-gen signal processing platforms
- RRI's involvement in the MWA pathfinder project provides valued experience
- Both main science goals of SKA Phase I are active areas of research in India
- NCRA, working with partners from software research groups & industry, has taken a lead role in some of the work packages of the SKA design phase

Indian Participation in SKA : benefits

Participation in the SKA will be beneficial for India in many ways :

- Provide opportunity for research organisations and industry to contribute at the highest levels of technological development in the field : antennas, electronics, signal transport, signal processing, computing, software, data archiving.

- Drive development of latest technologies in the country, with scope for both research organisations and industry to benefit : structural, electronics, computing, software, process control etc.

- Feedback from SKA design work into improvements in Indian facilities, including GMRT.

- Development of a vibrant & internationally competitive community of astronomers with convenient and priority access to next generation facilities.

Present involvement of India : Leadership role in Telescope Manager System for the SKA

- NCRA is heavily involved in the monitor & control (M&C) system of the SKA – the nerve centre of the telescope : in late 2010, Indian team took the lead institution role for CoDR stage of M&C work for SKA Phase-I
- Partners : TRDDC, PSL, ECM (software research groups / companies)
- CoDR for the M&C system in October 2011 in Pune, with international review panel & SPO participants – was immensely successful !
- Since then, the Indian group has been the leader for the formation of an international consortium for the Telescope Manager work package : South Africa, Canada, Italy, Australia, New Zealand + others as partners.
- From October 2013, this India led team has been working on the Detailed Design for the Telescope Manager – the Preliminary Design Review is due to be completed by early 2015 (design docs submitted 10 days ago!)
- In addition, NCRA is also involved at lower levels in the Signal & Data Transport Consortium and the Central Signal Processing Consortium

TM Consortium : Partners & Roles

LMC (INAF, Italy)

Observation Management (UKATC , UK)

Telescope Management (NCRA , India)

Infrastructure (Engage SKA Consortium , Portugal)

Project Management (NCRA, India)

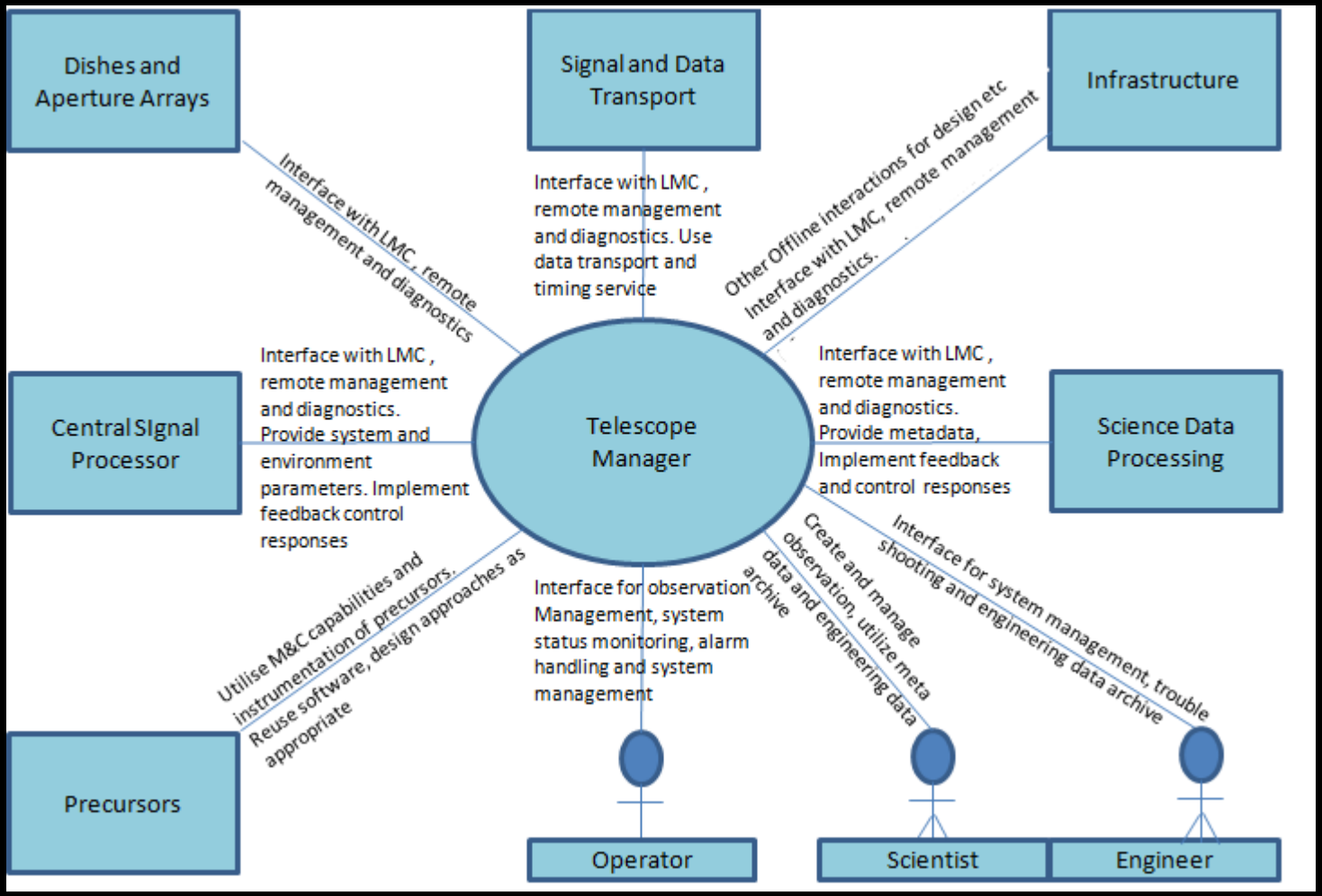
System Engineering (SKA SA, South Africa)

Prototyping (NCRA , India)

Review, support (CSIRO , Australia ; NRC-HIA, Canada)

The Telescope Manager Consortium is led by the Indian team (NCRA + partners from research institutes & industry) and includes members from 7 other countries. Each member plays a specific role in the consortium, contributing to one or more of the major activities.

Telescope Manager for the SKA



The Telescope Manager is the central brain + nervous system of the SKA telescope : it interacts with and controls every element of the observatory and plays the central role in carrying out the observations and managing the observatory resources.

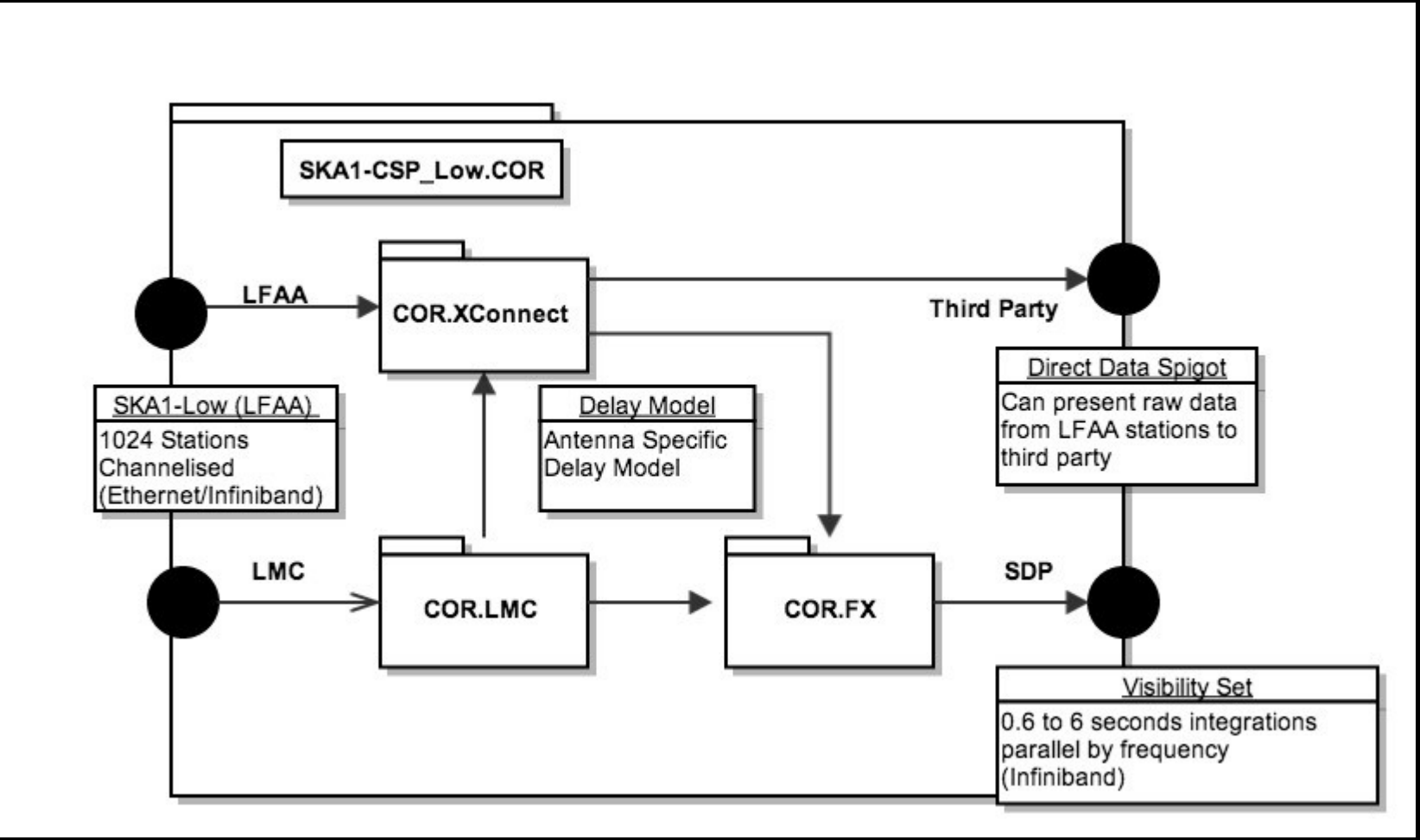
Telescope Manager : Deliverables

Start	Intermediate Deliverables	Owner	Status
29-Jan-14	LMC Interface Guidelines v1	TELMGT	Delivered
29-Jan-14	LMC Scope and Responsibility v1	TELMGT	Delivered
23-Apr-14	Architectural Analysis Report v1	SE	Delivered
02-May-14	Proposal Mgt & Observation Preparation v1	OBSMGT	Delivered
Start	**Input to Rebaselining Deliverables**	**Owner**	**Status**
12-May-14	Architectural Analysis Report v1	SE	Delivered
09-Jul-14	Trade-Off Options Document	SE	Delivered
01-Aug-14	Cost Model Spreadsheet	SE	Delivered
08-Aug-14	Risk Register V1	SE	Delivered

The Telescope Manager consortium has already been active for more than one year and has completed several important delivery milestones and is working on the PDR deliverables due end of October.

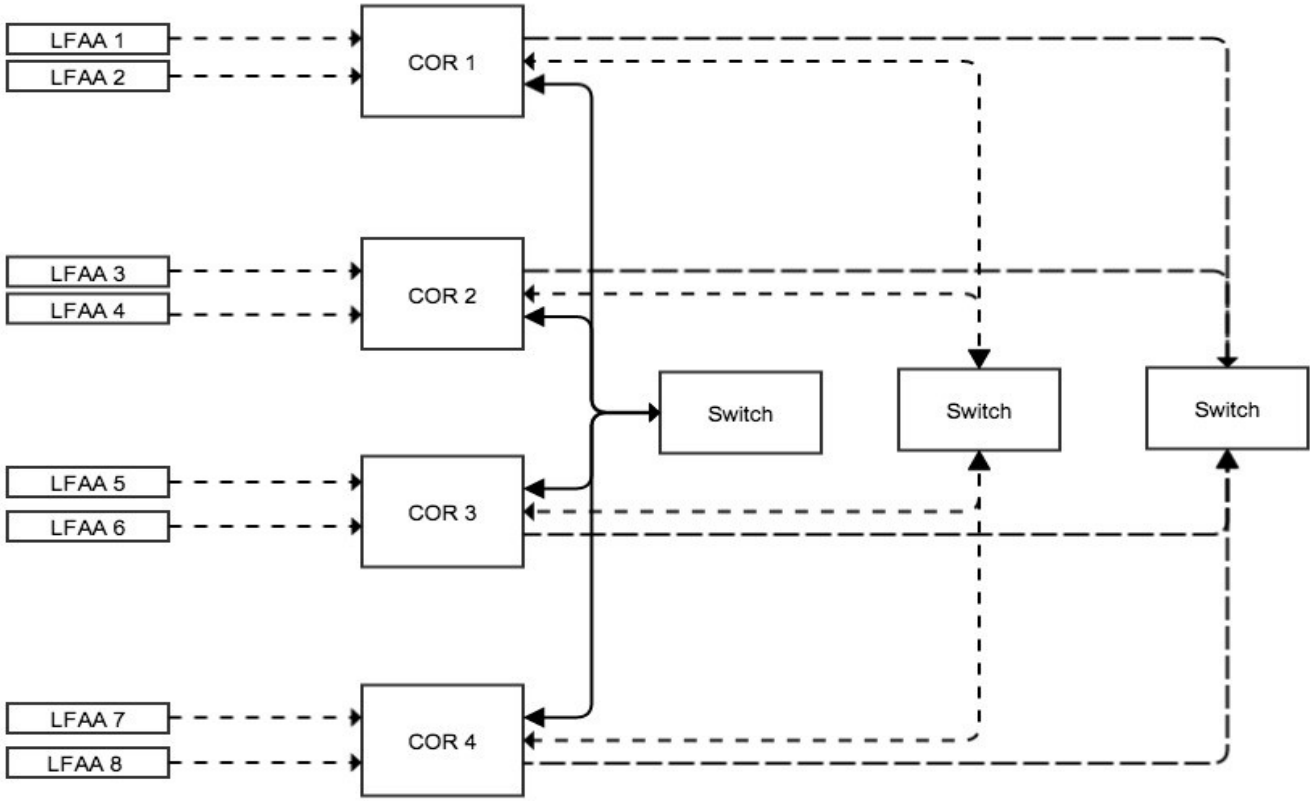
Start	Ext Review	PDR Deliverables	Owner	Status
01-Aug-14	31-Oct-14	TM Design Report v1	SE	Submitted
08-Aug-14	31-Oct-14	TELMGT Design Report v1	TELMGT	Submitted
08-Aug-14	31-Oct-14	OBSMGT Design Report v1	OBSMGT	Submitted
29-Aug-14	31-Oct-14	LINFRA Design Report v1	LINFRA	Submitted
18-Aug-14	31-Oct-14	LMC Design Report v1	LMC	Submitted
01-Aug-14	31-Oct-14	TM EMC/RFI Analysis Report v1	SE	Submitted
08-Aug-14	31-Oct-14	TM Hazard & Safety Analysis Report v1	SE	Submitted
08-Aug-14	31-Oct-14	Cost Analysis Report v1	MGT	Submitted
08-Aug-14	31-Oct-14	TM Construction Plan	SE	Submitted
13-Oct-14	31-Oct-14	TM Configuration Item List v1	SE	Submitted
08-Aug-14	31-Oct-14	TM Maintenance Plan v1	SE	Submitted
08-Aug-14	31-Oct-14	TM Verification Plan v1	SE	Submitted
08-Aug-14	31-Oct-14	TM Risk Register v1	SE	Submitted
08-May-14	31-Oct-14	TM Requirements Specification v1	SE	submitted
20-May-14	31-Oct-14	TELMGT Requirement Specification v1	TELMGT	Submitted
30-Jun-14	31-Oct-14	OBSMGT Requirement Specification v1	OBSMGT	Submitted
29-Apr-14	31-Oct-14	LINFRA Requirement Specification v1	LINFRA	Submitted
30-Apr-14	31-Oct-14	LMC Requirement Specification v1	LMC	Submitted
18-Aug-14	31-Oct-14	Internal ICDs v1	SE	Submitted

Correlator design for SKA-low



Functional description of a correlator design for the SKA-low telescope where there is Indian participation in the design effort

Correlator design for SKA-low



Schematic block diagram for a GPU-based software correlator design for the SKA-low that follows an architecture having close synergy with the design for the upgraded GMRT

Indian Participation in SKA : ongoing plans & activities

- Formation of "SKA India Consortium" involving interested astronomy & technical research organizations -- to oversee the overall Indian participation in SKA (both technical and science areas) : this is targeted to be formed by March 2015.

- Close interaction with Indian industry for SKA related work : formation of "SKA India Industry Cluster" : TCS, PSL, Intel, NI etc.

- Develop a larger and stronger user community that is interested in SKA science : simulations, projections, science working groups, interactions with the SKA design teams etc.

Formation of Science Working Groups : during the SKA meeting at the time of ASI 2014 in Mohali, 6 different SWGs were identified and these are in various stages of activation.

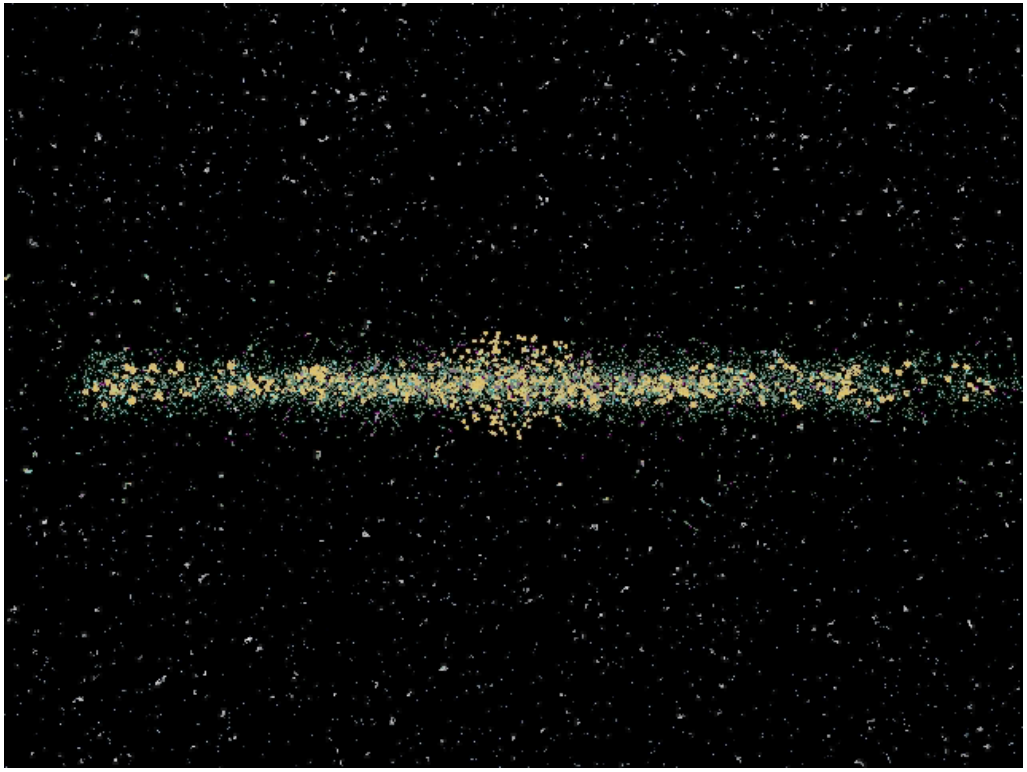
We are gathered here for this workshop to brain storm ideas for the Indian SKA Pulsar SWG.

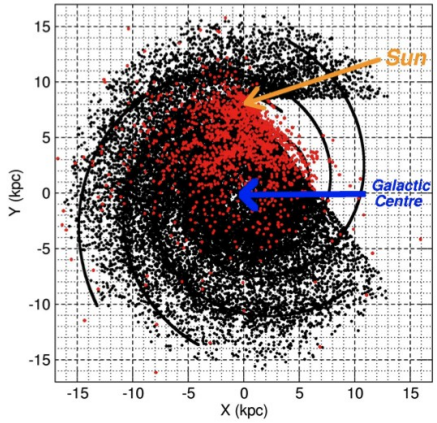
The SKA : Pulsar Science

- The SKA as described (even Phase-1), should be able to do everything than anybody today can think about !
  - Searches : complete census in the Milky Way, extragalactic pulsars, exotic objects…
  - High Precision Timing : Gravitation waves, Strong field tests of gravity, Extreme dense matter physics…
  - Studying individual pulsars in exquisite detail : emission mechanism
  - + many other applications…

Finding all the pulsars in the Milky Way…

(Cordes et al. 2004, Kramer et al. 2004, Smits et al. 2008)





- ~30,000 normal pulsars
- ~2,000 millisecond psrs
- ~100 relativistic binaries
- first pulsars in Galactic Centre
- first extragalactic pulsars

- Timing precision is expected to increase by factor ~100
- Rare and exotic pulsars and binary systems: including PSR-BH systems!
- Testing cosmic censorship and no-hair theorem
- **Current estimates : ~50% of entire Galactic population in reach of SKA1**

SKA Case Study : Pulsar Search

- Pulsar search with central 1-km core, 30 mins integration time :
  - Around 14,000 normal pulsars and 6,000 millisecond pulsars
  - Computational requirements for beam forming of full FoV of single-pixel feed for this : 2.2×10^15 operations per second
  - Corresponding data rate from such a pulsar survey : 4.7×10^11 bytes per second
  - Required computational power for a deep real time analysis estimated to be 1.2×10^16 operations per second.

Smits et al SKA Memo 105 (2008)

SKA Pulsar Science and Us

- A few points and ideas to keep in mind :
  - We have good expertise in the country : both in theory and observations
  - Need to get more familiar with the SKA pulsar science case
  - Work out areas of participation and identify roles
  - Put down out thoughts and ideas in documents
  - Increase presence and participation in the mian SKA Pulsar Science Working Group
  - More active use of instruments like the GMRT for building up observation capabilities
  - Reach out to more researchers and students
  - ...

Summary

- The SKA is the future of Radio Astronomy : promises revolutionary science ; requires next-gen, cutting-edge technology
- For neturon stars and pulsars : there is a huge potential with the SKA
- The SKA is now entering the detailed design phase ; being run by the SKA Organisation; Ten countries are already Full Members
- India needs to build up its engagement with the SKA : both technical and science aspect : skilled manpower base; international class facilities in the country; significant interest in various SKA science cases
- On technical front, we have already established leadership roles in some areas
- Need to ramp-up participation of Indian astronomers in SKA science areas & grow the user community to make best use of SKA when it gets ready for science.
- For neturon star science : work out priority areas of participation; identify roles; use facilities like the GMRT for developing expertise in pulsar observations; attract more students and researchers to the fold...

Thank You for your attention !