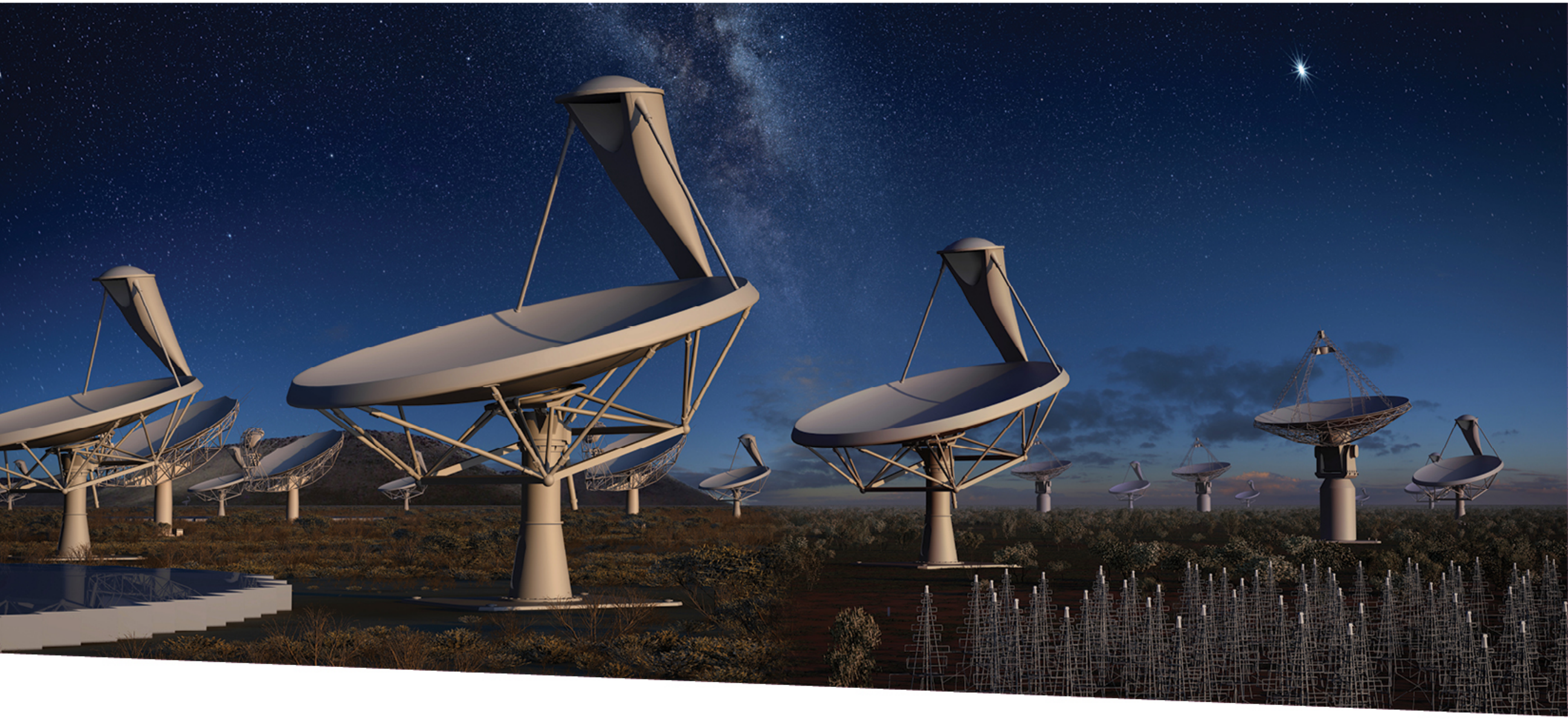
AADC all-hands…Bologna Italy

9 – 13 May 2016



SQUARE KILOMETRE ARRAY

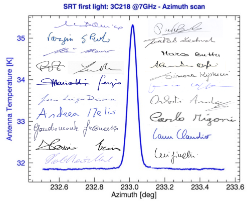
Exploring the Universe with the world's largest radio telescope

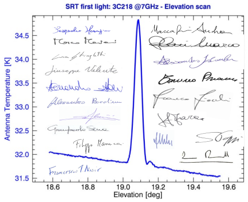
LFAA IET

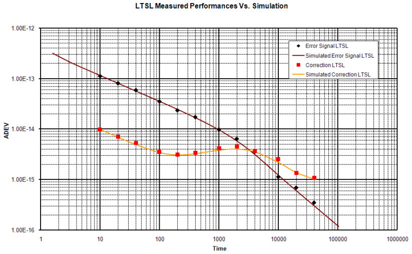
9 – 13 May 2016

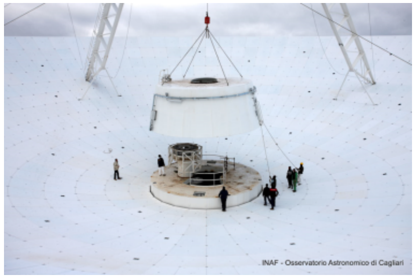
Outline

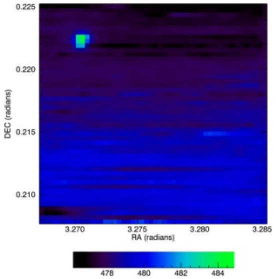
- Luca Stringhetti Introduction
- LFAA Integrated Element Team
- Operations/HQ
- Schedule
- System Review (outcomes)
- Low Frequency Science with SKA1 (Jeff)
- TT-Low/Performance Budgets/Configuration (Mark)
- SKA1 Low System (Maria Grazia)

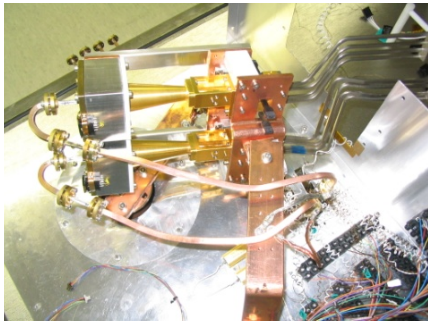

SRT first light: 3C218 @7GHz - Azimuth scan
Antenna Temperature [K]
Azimuth [deg]

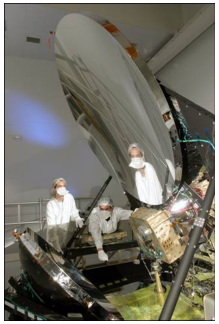

SRT first light: 3C218 @7GHz - Elevation scan
Antenna Temperature [K]
Elevation [deg]

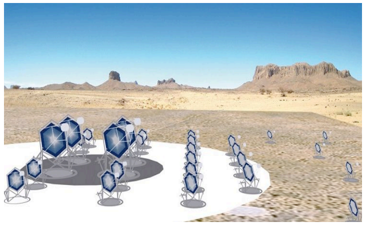

LTSL Measured Performances Vs. Simulation
Error Signal LTSL
Simulated Error Signal LTSL
Correction LTSL
Simulated Correction LTSL
ADEV
Time

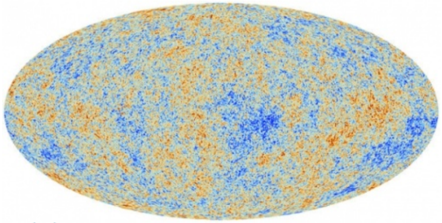

INAF - Osservatorio Astronomico di Cagliari


DEC (radians)
RA (radians)

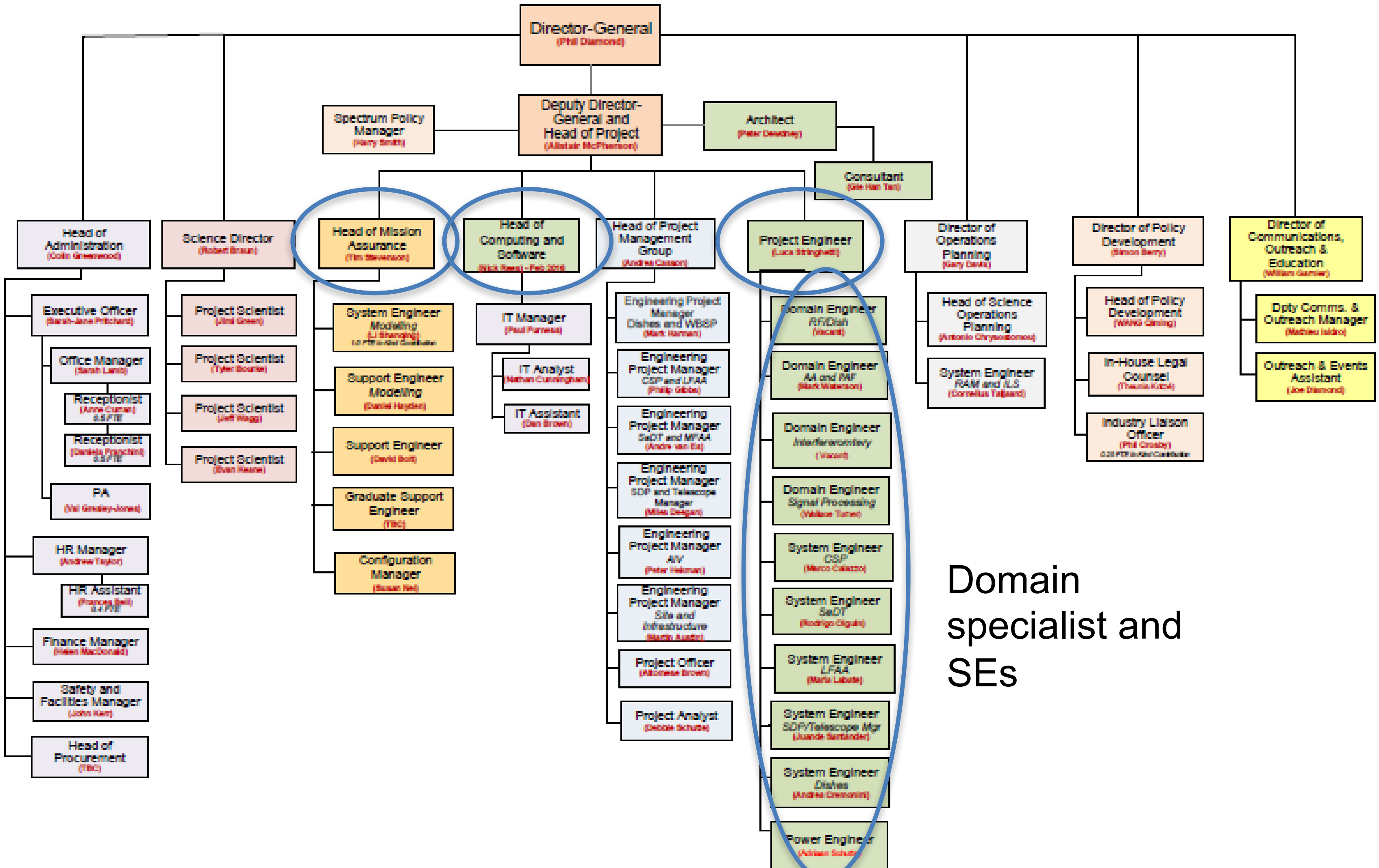








New Organization Chart



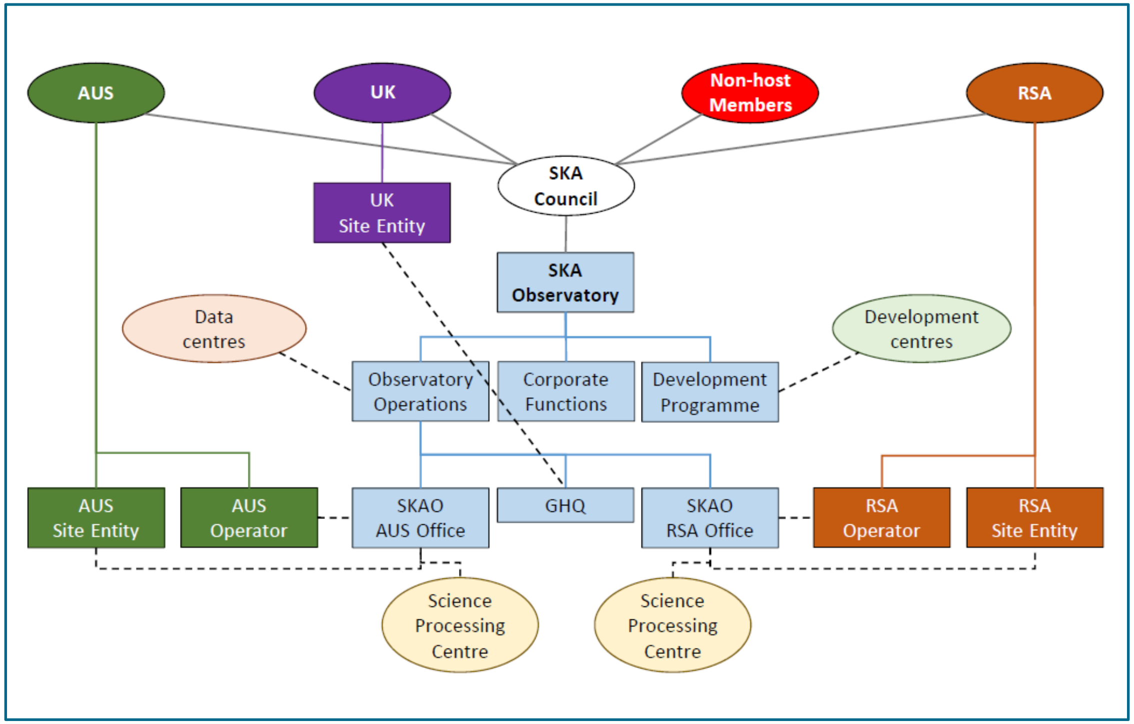
Domain specialist and SEs

Integrated Element Team (IET)…

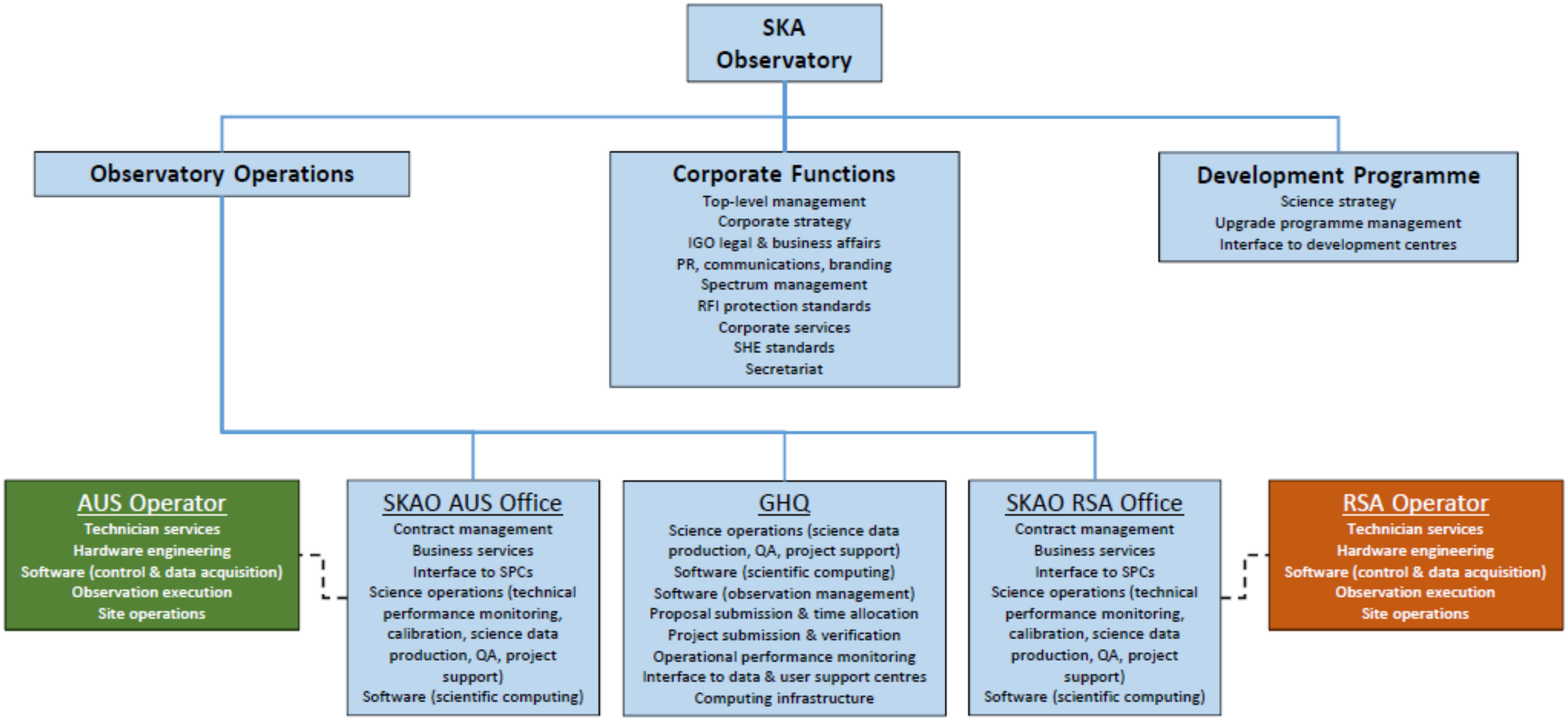
- Philip Gibbs (Engineering Project Manager)
  - Provide PM processes, tools and techniques to achieve project objectives.
- Mark Waterson (Domain Engineer)
  - Specialist in Aperture Arrays and RF Engineering.
- Maria Grazia Labate (System Engineer)
  - Specialist in Aperture Array Synthesis and Electromagnetics.
- Jeff Wagg (Project Scientist)…interface between SKA science and Engineering communities
  - Specialist in EOR, Extragalactic Continuum and Cosmology.
- Evan Keane (Project Scientist)…interface between SKA science and Engineering communities
  - Specialist in Pulsars and Transients.
- Gary Davis (Operations)
  - Director of Operations Planning.

Operations / HQ…

- Operations concept review successfully completed
- Ops requirements to be included in Rev 8 of L1 Requirements



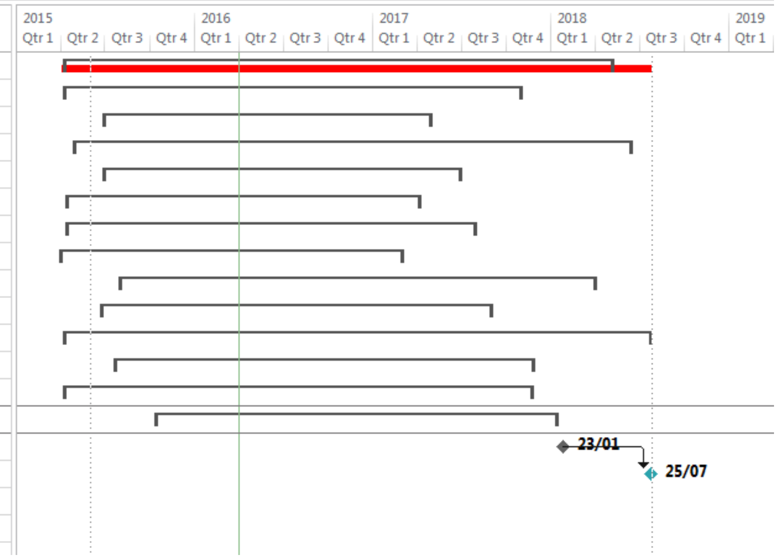
Operations / HQ…



Schedule…SKAO

- “Integrated” schedule is on community confluence under Precon PM.

ID	Task Name	Duration	Start	Finish	Predecessors
1	Stage 2 milestones	802 days	Thu 09/04/15	Mon 07/05/18	
2	AIV	668 days	Thu 09/04/15	Tue 31/10/17	
19	CSP	477 days	Tue 30/06/15	Fri 28/04/17	
33	DSH (not confirmed)	815 days	Thu 30/04/15	Thu 14/06/18	
69	INAU	523 days	Tue 30/06/15	Fri 30/06/17	
91	INSA	517 days	Wed 15/04/15	Fri 07/04/17	
117	LFAA	598 days	Wed 15/04/15	Sun 30/07/17	
131	SaDT (not confirmed)	500 days	Wed 01/04/15	Tue 28/02/17	
150	SDP	695 days	Fri 31/07/15	Fri 30/03/18	
162	TM	569 days	Fri 26/06/15	Thu 31/08/17	
181	Project Stage 2 key milestones	859 days?	Thu 09/04/15	Wed 25/07/18	
182	Governance	613 days	Wed 22/07/15	Fri 24/11/17	
191	Reviews	684 days?	Thu 09/04/15	Tue 21/11/17	
252	IGO set up	587 days	Wed 14/10/15	Fri 12/01/18	
257	Construction proposal submitted	0 days	Tue 23/01/18	Tue 23/01/18	251FS+9 wks
258	Construction proposal approved	0 days	Wed 25/07/18	Wed 25/07/18	257FS+26 wks

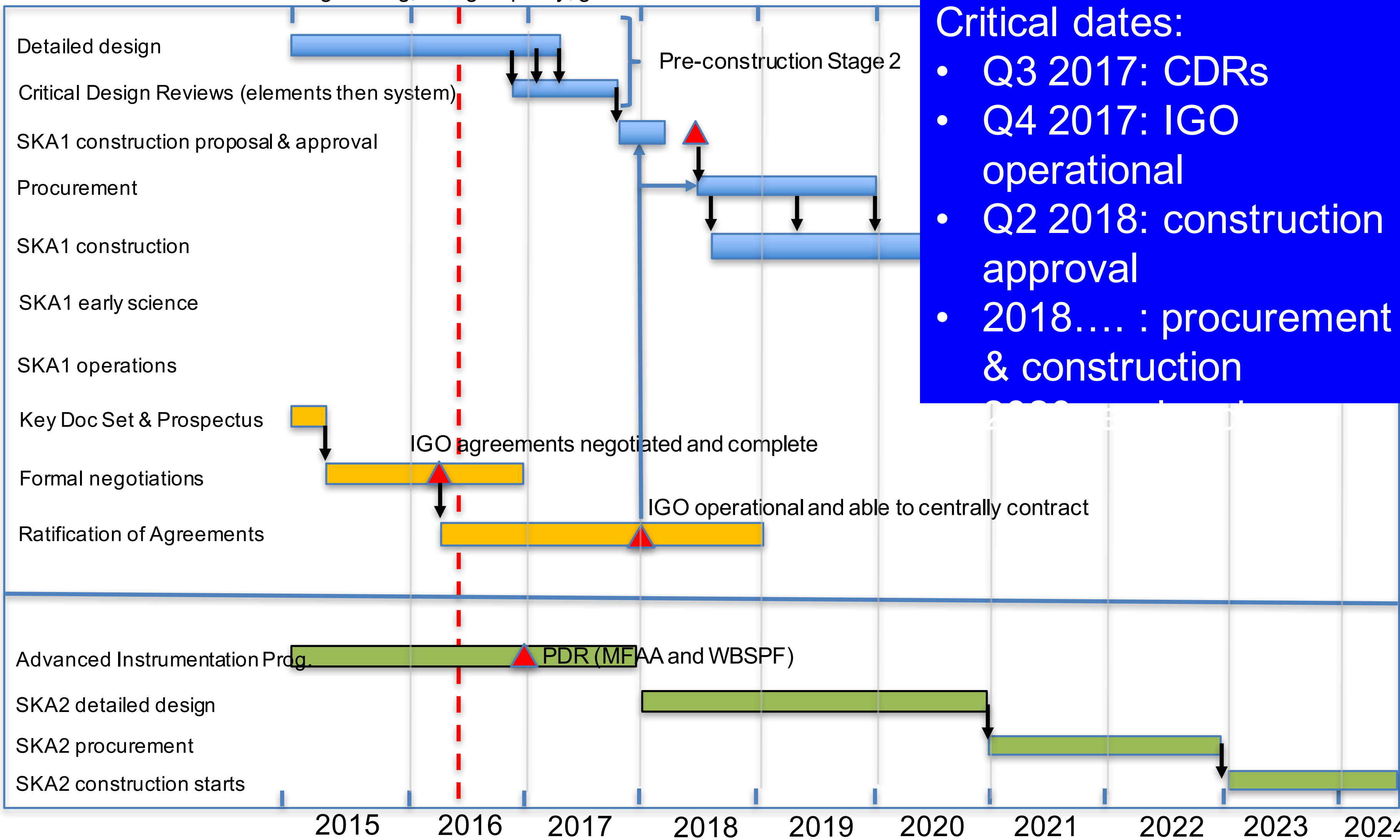


High-level SKA Schedule

KEY: Blue = SKA1 science & engineering; orange = policy; green = SKA2

Critical dates:

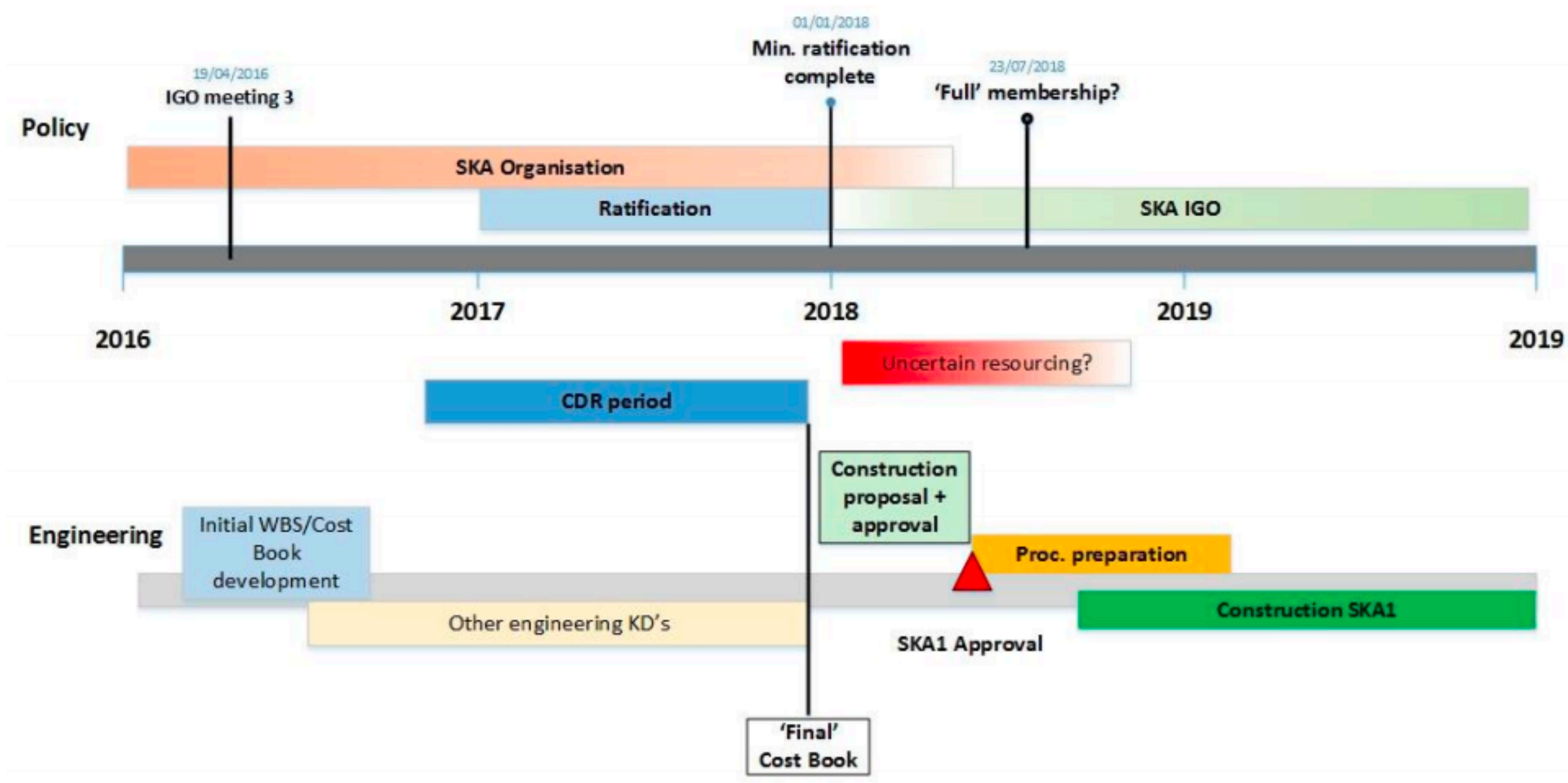
- Q3 2017: CDRs
- Q4 2017: IGO operational
- Q2 2018: construction approval
- 2018…. : procurement & construction



Major events in Q1/Q2 2016

- March 9-10: StratCom, Beijing
- March 15: SKA Finance Committee, SKA HQ
- March 16-17: Science and Engineering Advisory Committee, SKA HQ
- March 22-23: SKA1 System Review, SKA HQ
- April 4-6: 20th SKA Board Meeting, Pune, India
- April 19-21: 3rd IGO Meeting, Rome
- May 11-13: HPC/SDP Meeting, Shanghai
- May 23-25: SKA Management Review, SKA HQ
- June 3: Cost Reviews all consortia

Schedule…IGO



System Review…

Summary of Panel feedback:
- Panel believes the project is several months away from reaching PDR readiness
- Costing appears immature at this stage

Recommendations:
- Complete L1 requirements
- Operational Concepts and Calibration Requirements to be flowed down to L1
- Release all Technical Budgets with allocation down to L2
- Complete the release all System ICDs
- Coherence of Integrated System Design with Overall Architecture, ICDs etc.
- L1 requirements meet Science Goals
- PM – need for schedule, WBS, from now to CDR
- System PDR is held before work progress in the Element CDRs

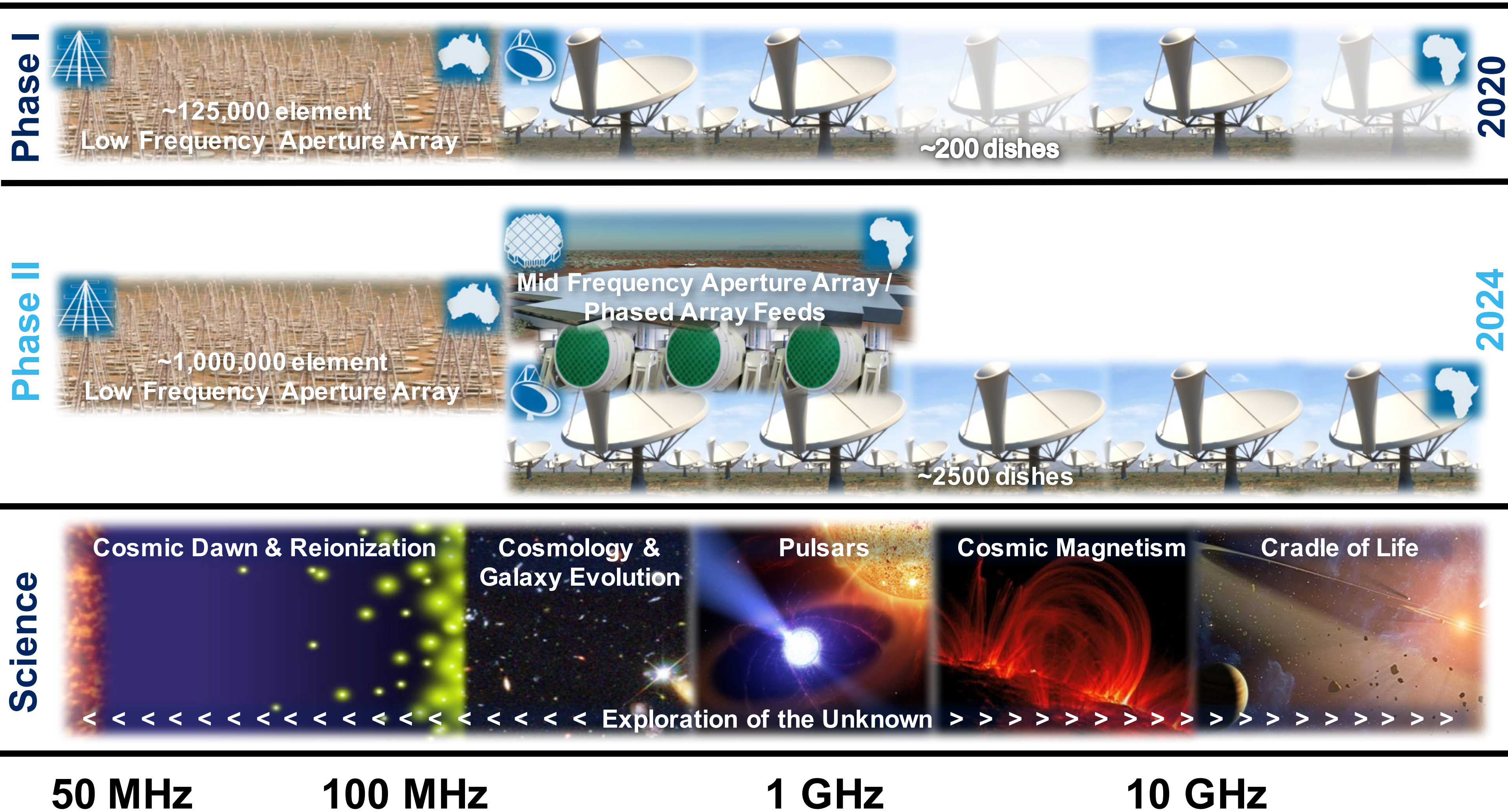
What does this all mean?
- SKAO will be working through the recommendations made by the panel
- Formulating a plan of action (how to proceed)

Low frequency science with SKA1

Jeff Wagg
SKAO
UK

Robert Braun, Tyler Bourke, Evan Keane, Anna Bonaldi
LFAA all-hands meeting, Bologna
May 9, 2016

Overview of the SKA



Outline

- Update on recent SKAO (science) activities
- SKA1-LOW science objectives
- SKA1-LOW design considerations

Update on SKAO science activities

- August, 2015: “SKA Key Science Workshop”, Stockholm, Sweden
    - more than 130 participants
    - Begin collaborations that may evolve into future KSP teams
    - Generic surveys with SKA1?
- October, 2015: Level 0 requirements published
    - Scientific desires for the telescopes
    - NOT requirements for consortia, design is based on the Level 1s
- October, 2015: Observing bands: scientific context document
    - Frequency ranges required for SKA1 science objectives

Update on SKAO science activities

- Dec., 2015: baselining of station positions for SKA1-LOW
  - Positions defined in 'V4A' calibration memo
  - Calibration assessed and risks deemed to be sufficiently low to proceed for environmental site surveys
- April, 2016: Level 1 version 7 requirements published
  - post-rebaselining requirements
  - implementation of recently accepted ECPs
- May, 2016: publication of SKA1-LOW station positions
  - core of pseudo-random stations in the core with spiral arms of (6 stations per group) extending out to 65km
  - concept of virtual sub-station presented
- Upcoming:
  - new project scientist Anna Bonaldi, Sept., 2016
  - "SKA2016: Science for the SKA Generation", Goa, India, November 7 – 11th, 2016

The early history of structure formation in the Universe

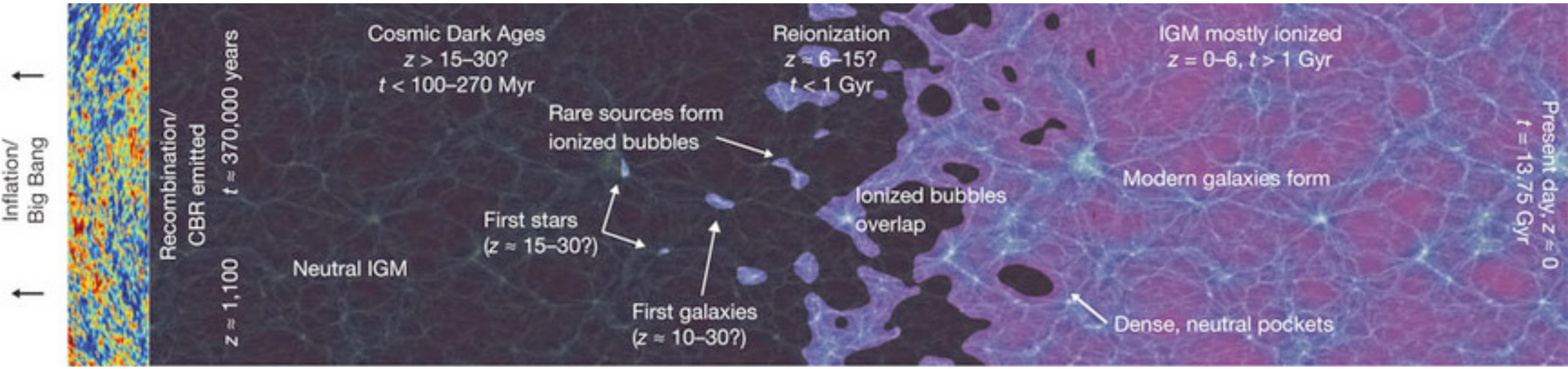
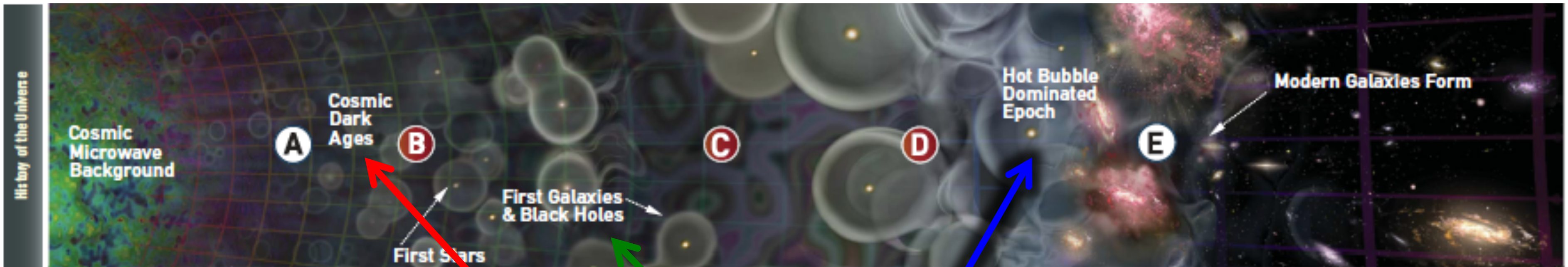


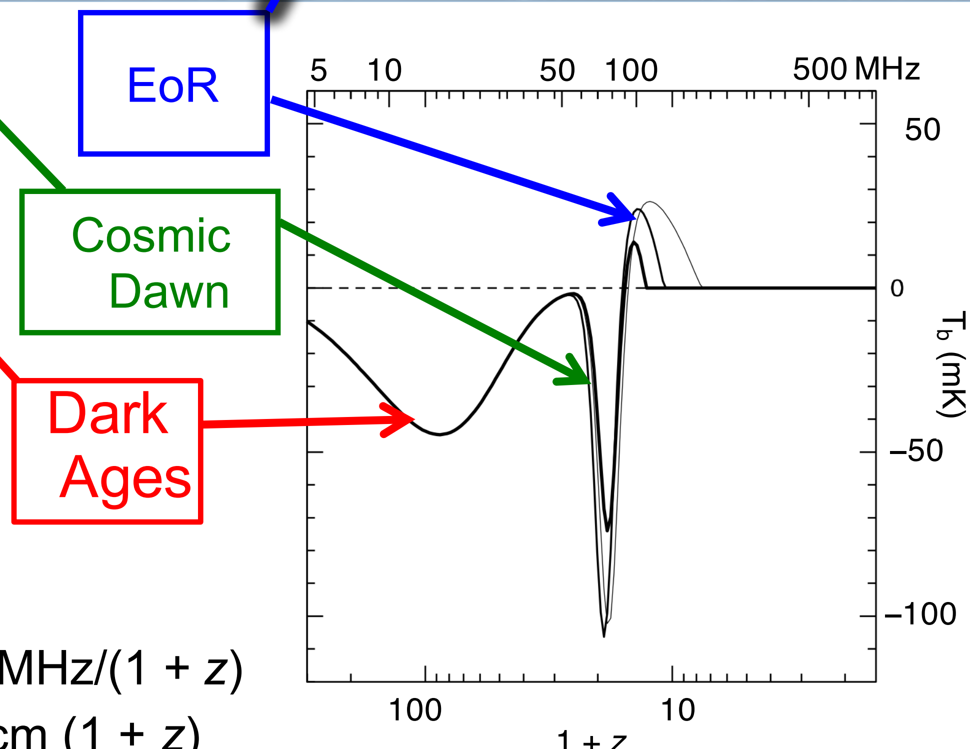
Figure from Robertson et al. 2010

- When did the Universe emerge from the Dark Ages?
- How did cosmic (re)ionization proceed?
- What was the neutral fraction of the IGM as a function of redshift?

Probing the early universe with the 21cm line



Neutral Hydrogen 21 cm spin-flip transition provides probe of neutral intergalactic medium before and during formation of first stars

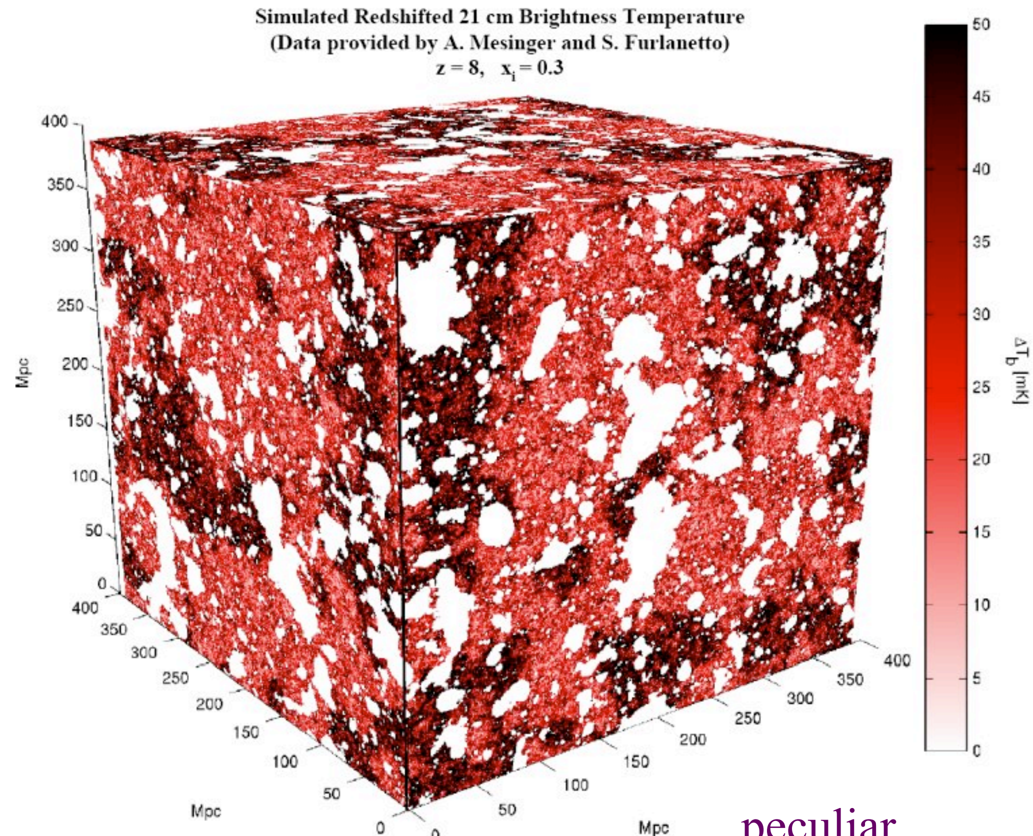


ν = 1420 MHz/(1 + z)

λ = 21 cm (1 + z)

eg Pritchard & Loeb

Physics of the 21cm HI line in the early Universe



21cm spin temperature set by:

- radiative transitions (CMB)
- collisions
- Wouthysen-Field effect (resonant scattering of Lyα)

brightness temperature:

$$T_b = 27\, x_{\mathrm{HI}}\, (1 + \delta_{\mathrm{b}})\, \left(1 - \frac{T\gamma}{T_s}\right) \left(\frac{1+z}{10}\right)^{1/2} \left(\frac{\delta v/\delta r}{(1+z)\, H(z)}\right)^{-1} \ \mathrm{mK}$$

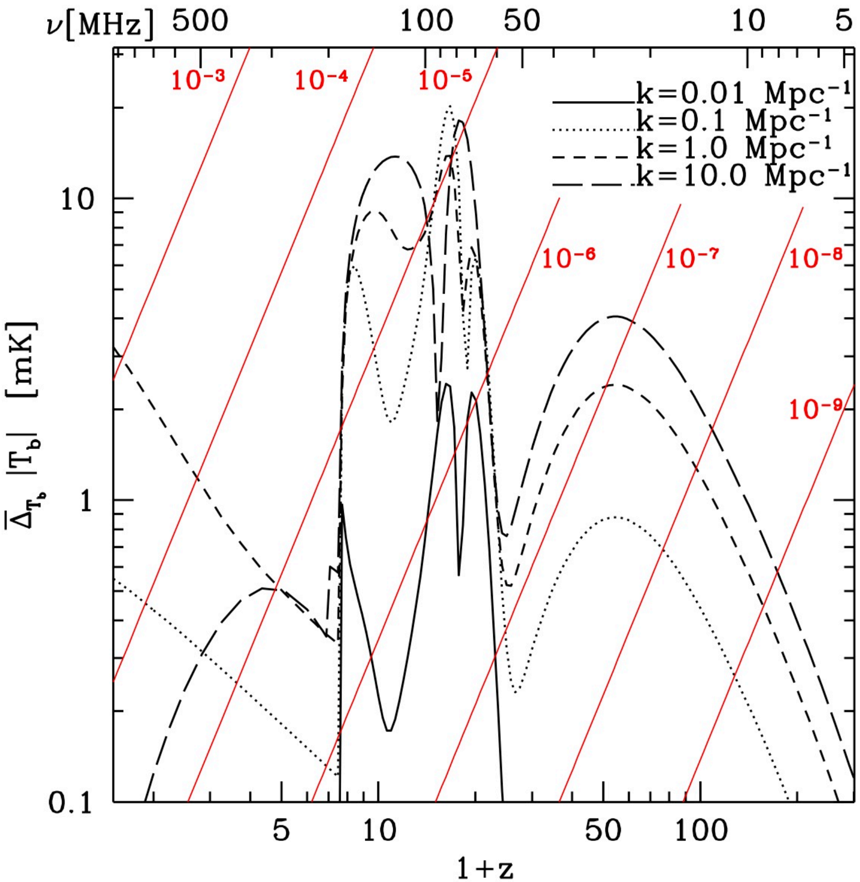
neutral fraction

baryon density

spin temperature

peculiar velocities

Power spectrum of 21cm fluctuations during the EoR and Cosmic-Dawn



eg Pritchard and Loeb 2008, 2010

SKA1: Koopmans et al. 2015

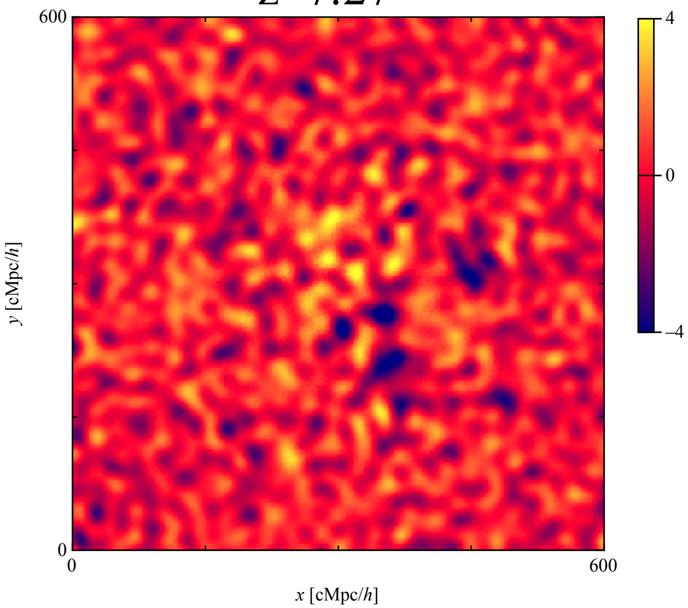
Probing the EoR and Cosmic Dawn statistically (to z < 27) through fluctuations in the power spectrum. Sensitive to:

- Density of baryons (cosmology)
- Peculiar velocities (cosmology)
- Neutral fraction (reionization)
- Gas temperature (X-ray heating)
- Lyman Alpha flux (Lyα sources)

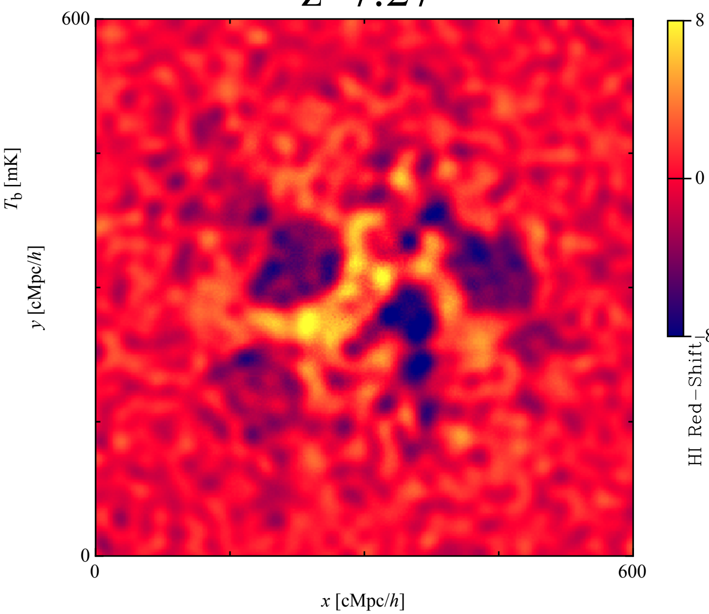
Current EoR facilities:
MWA: Tingay et al. 2013
LOFAR: van Haarlem et al. 2013
PAPER/HERA: Parsons et al. 2010

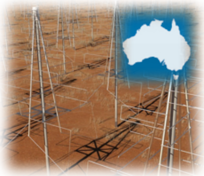
SKA1 21cm HI tomography of ionized bubbles

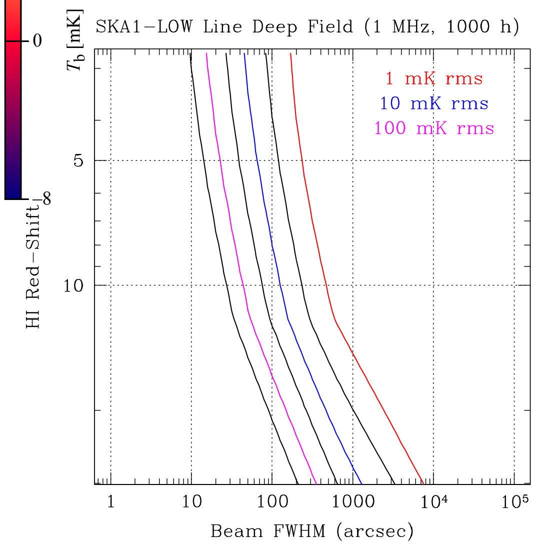
no strong SNe feedback
z=7.27



efficient SNe feedback
z=7.27





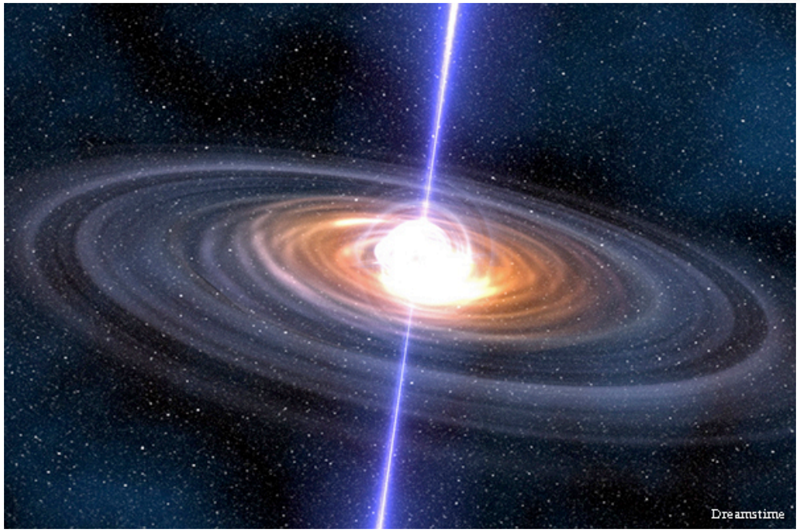


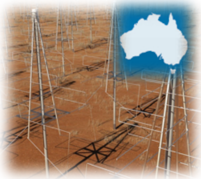
eg Mellema ea; Wyithe ea, SKA science book

- Detecting EoR structures in imaging mode (as distinct from statistically) on 5 arcmin scales with 1 mK RMS
- Possibly imaging during the Cosmic Dawn (most likely PS)

Pulsar surveys and timing

- cosmic lighthouses
- masses: ~1.4 $M_{\odot}$ within 20km
- $B \sim 4.4 \times 10^{13}$ Gauss
- periods: 1.4ms to 8.5s





- ~16,000 normal psrs (7000 LOW)
- ~2,300 ms psrs (900 LOW)
- ~100 relativistic binaries
- first pulsars in Galactic Centre
- first extragalactic pulsars

<u>SKA1-LOW: <350 MHz</u>

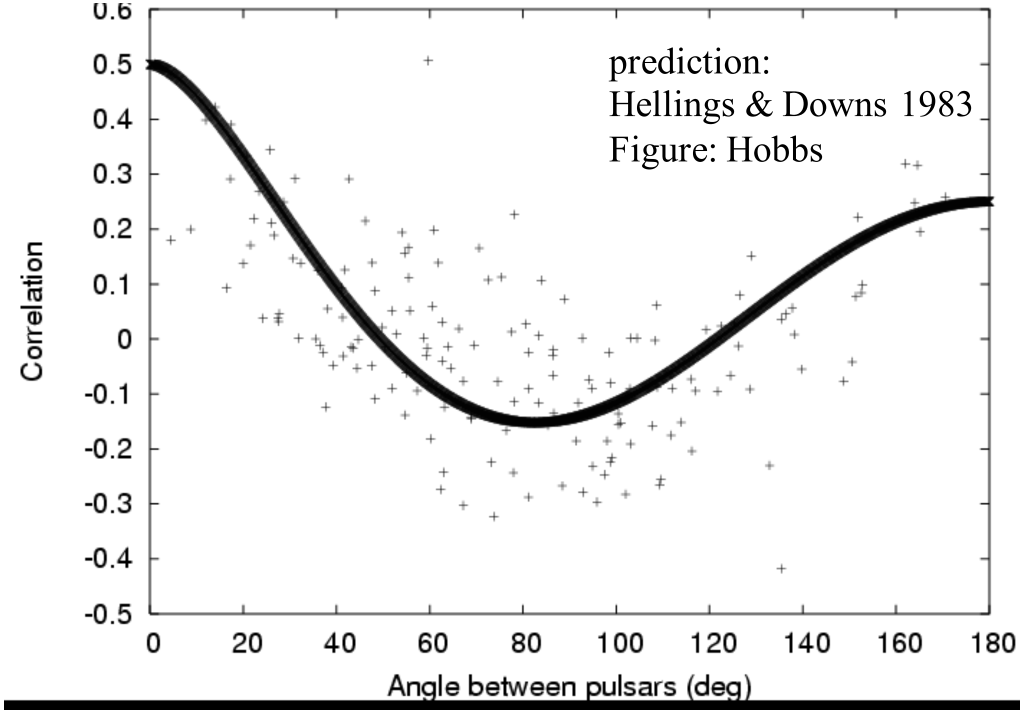
- Surveys for pulsars out of the Galactic plane
- discovery of exotic pulsars and binaries: PSR-BH

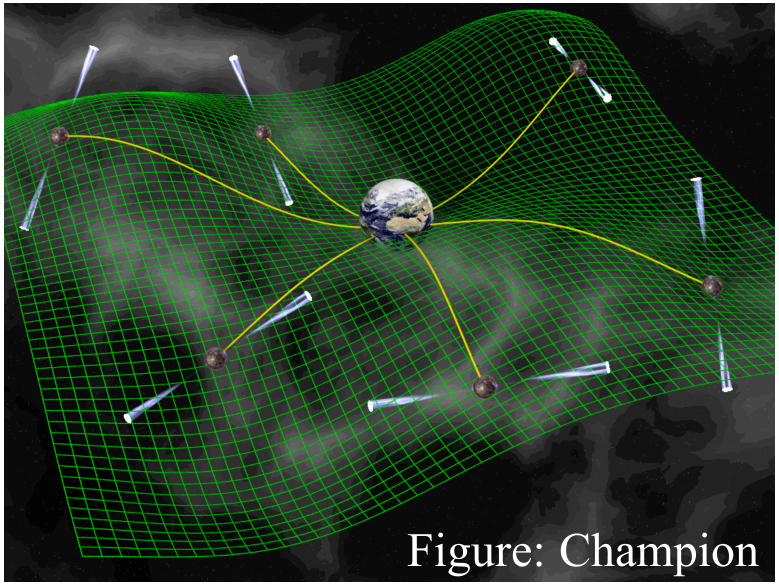
Current estimates are that 50% of the Galactic population will accessible with SKA1

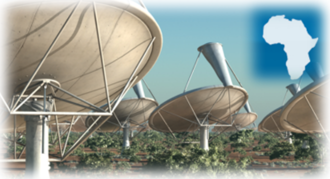
(Cordes et al. 2004; Smits et al. 2009; Kramer & Stappers 2015; Keane et al. 2015; Pulsar SWG)

Pulsar surveys and timing: testing general relativity

correlation between msp timing residuals





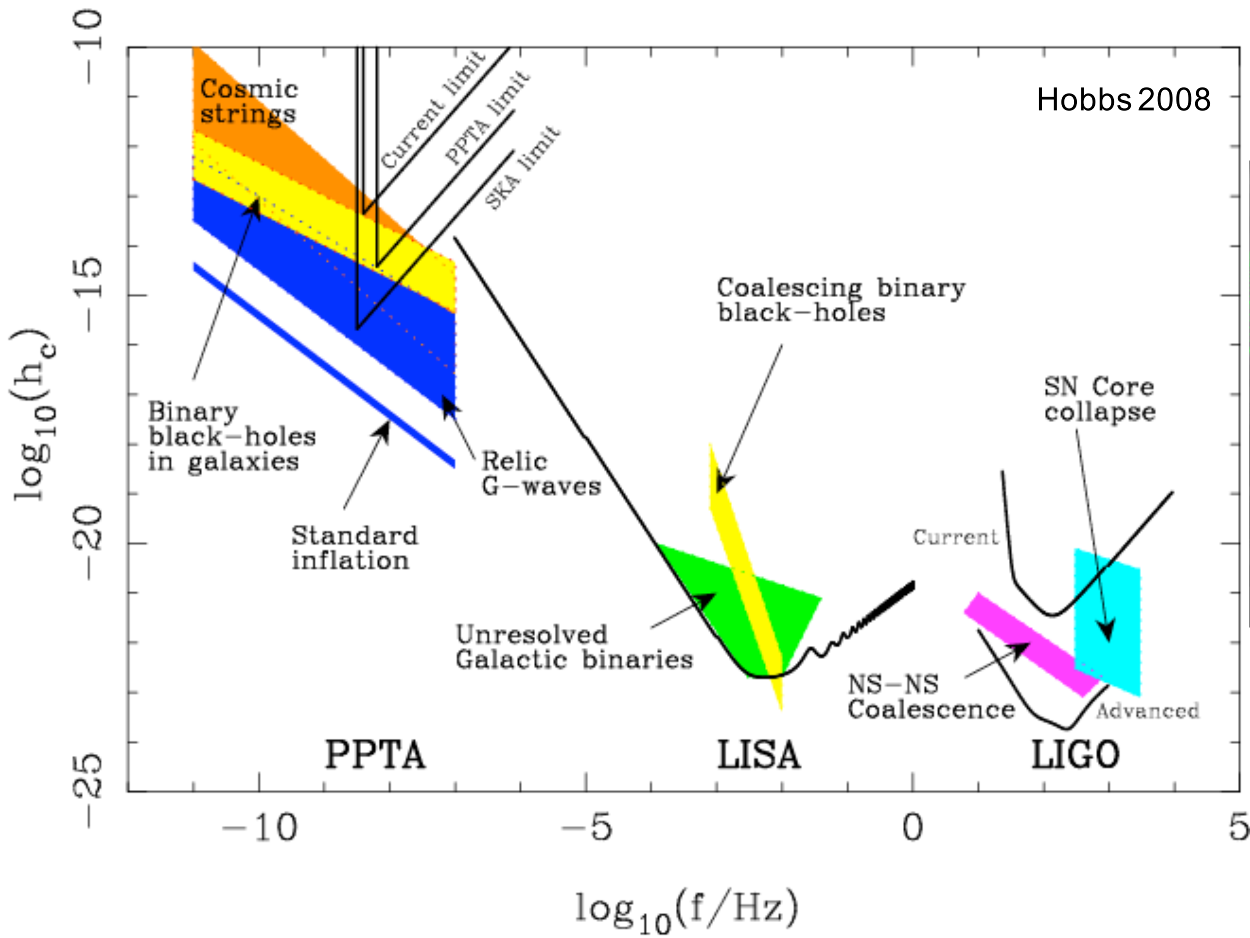


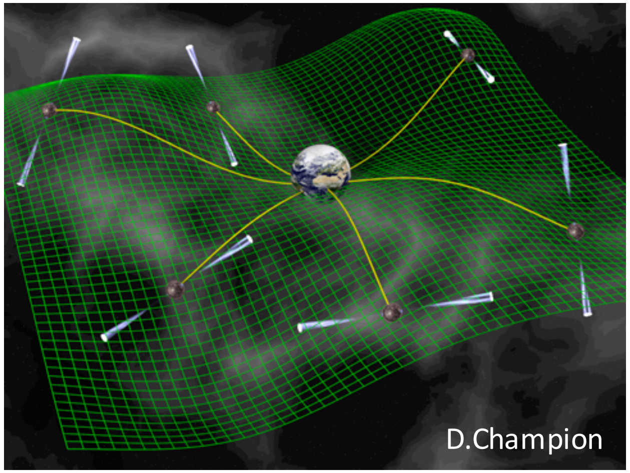
- millisecond pulsars can be very precise astrophysical clocks, eg:

PSR B1937+21, period = 1.5578064688197945 +/- 0.0000000000000004 ms

- Timing residuals between ms pulsars can be used to directly detect the gravitational wave background (SMBH mergers)

Gravitational Waves with pulsar timing



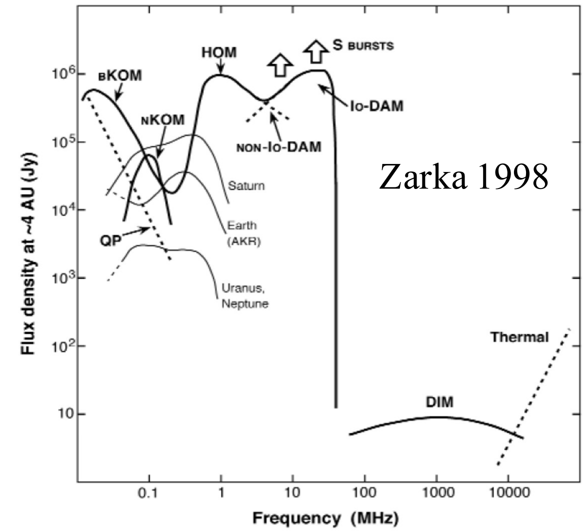


Discoveries with SKA1 (SMBH mergers, Primordial GWs)

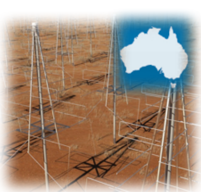
“GW astronomy” with SKA2 (discrete sources)

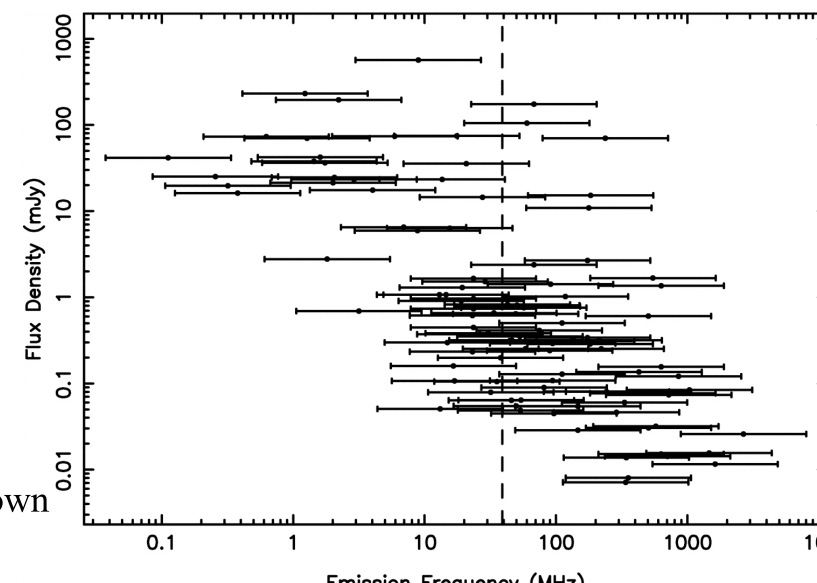
The Cradle of Life: exoplanets


from Gregg Hallinan



- At SKA1-low frequencies (<100MHz), we will be sensitive to radio burst emission from hot Jupiters out to 10 pc: ***measure rotation periods*** (Zarka ea, SKA science book)



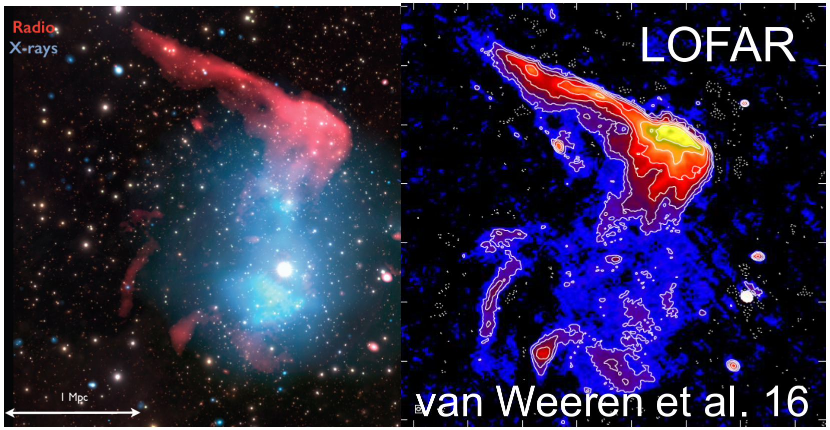


Predicted radio emission from known exoplanets (Lazio et al 2004)

SKA1-LOW: Extragalactic continuum science

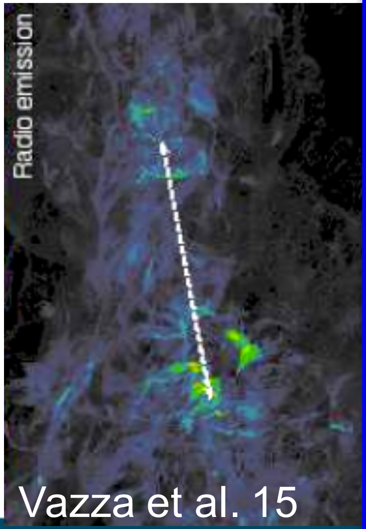
DIFFUSE RELATIVISTIC PLASMAS IN THE UNIVERSE

Galaxy Clusters: Halos, Relics,…

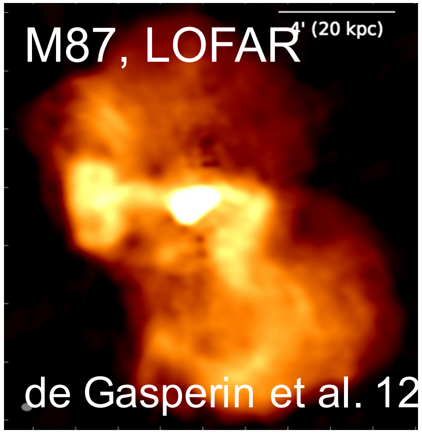


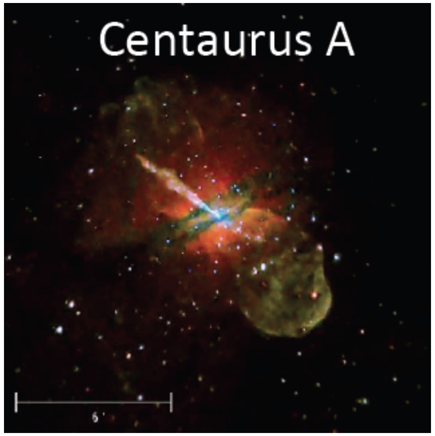
Cosmic Filaments

-Origin of NT-components
-Impact of NT-comp. on the ICM microphysics and cluster dynamics
-first detection of shocked WHIM



Radio Loud AGN (radio galaxies and RL quasars)

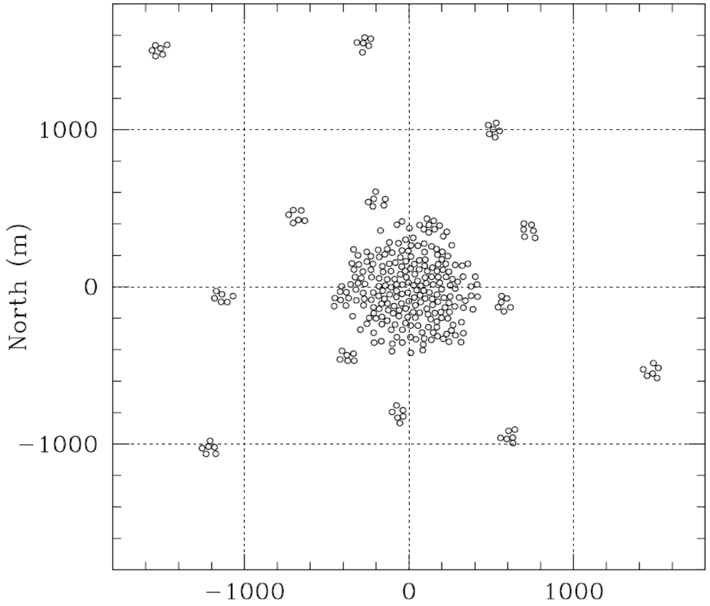


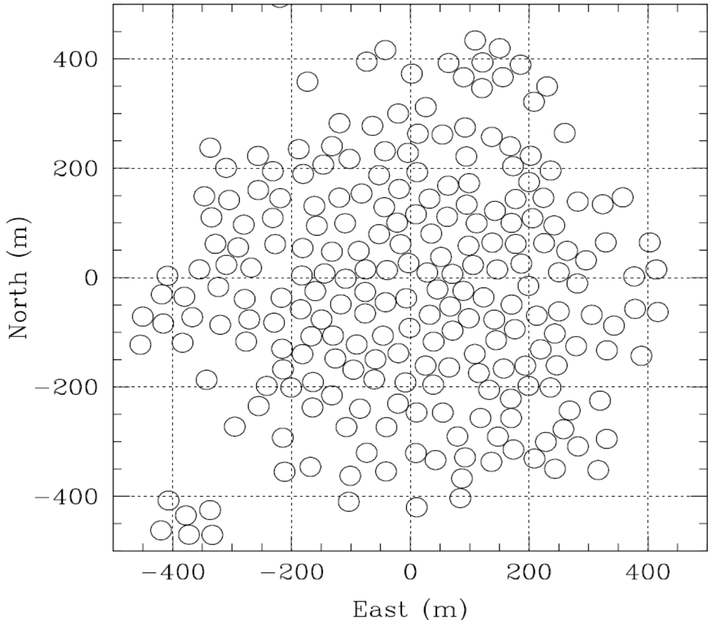


- Life-cycle (birth, life, death) of radio galaxies
-Physics of radio emitting regions: jets, lobes..
-high-z AGN, low accretion-rate AGN
-AGN "feedback" and galaxy formation & evolution

Cassano and Ferrari
Third SKA1-LOW calibration consultation

Design considerations for LFAA: configuration

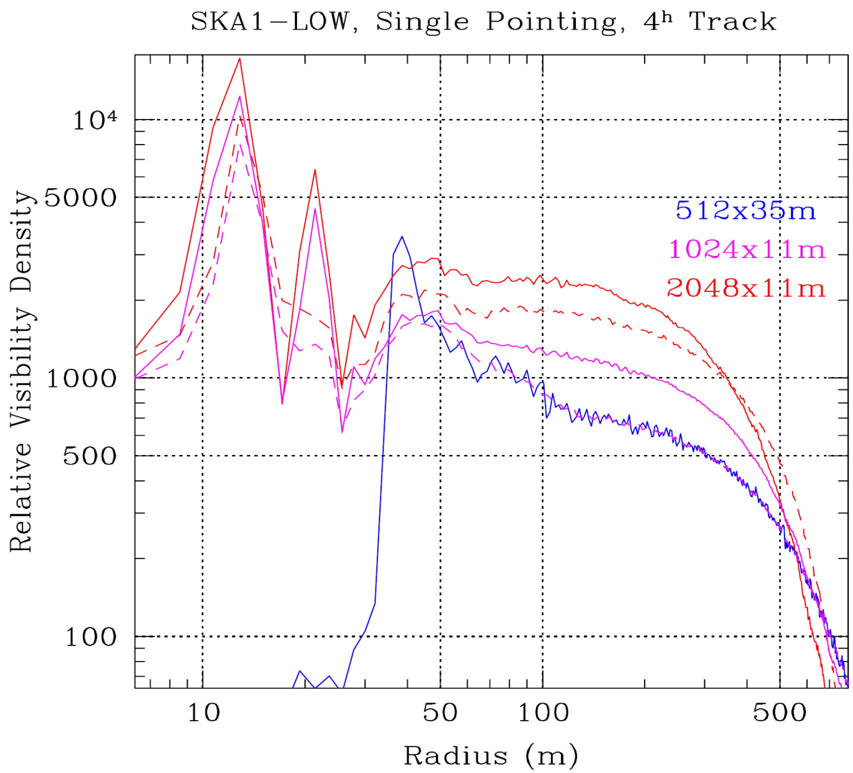




- Outcome of three calibration consultations and input from wide range of scientific, low frequency calibration and engineering input
- Pseudo-random core distribution of (~35m diameter) stations in a compact configuration
- Groups of six stations extending out to 65km diameter
- Supports the concept of virtual (~10m diameter) sub-stations for a limited number of correlations – cost neutral

Dewdney et al 2016

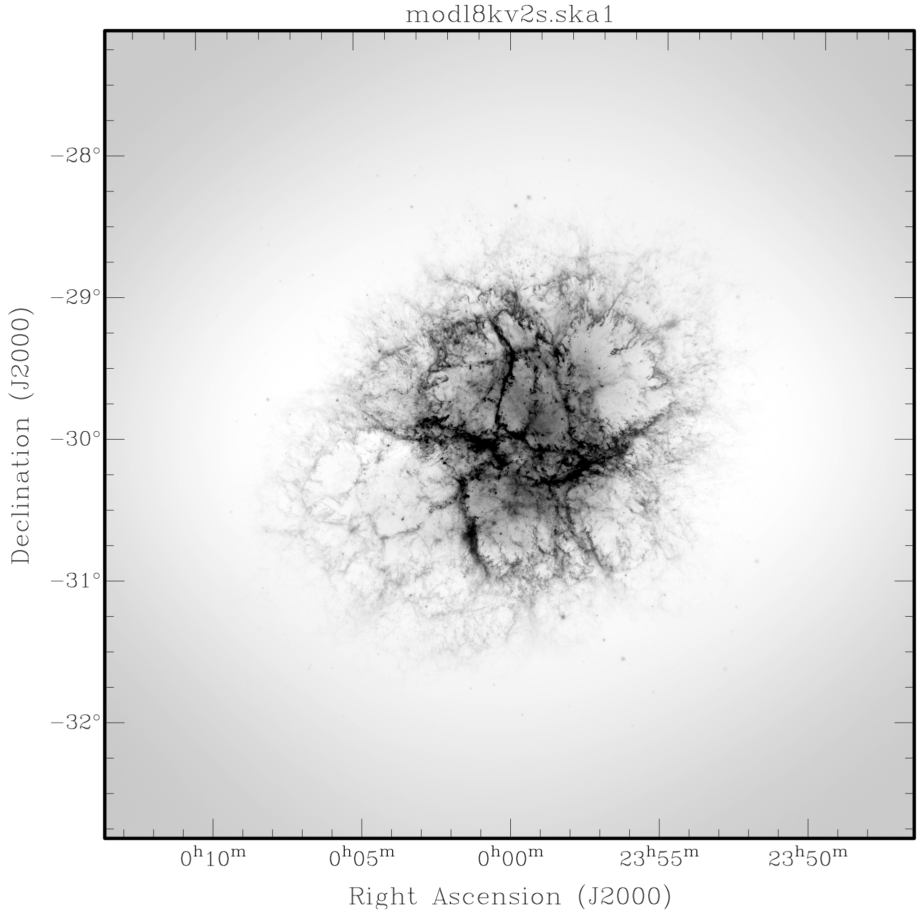
Design considerations for LFAA: configuration

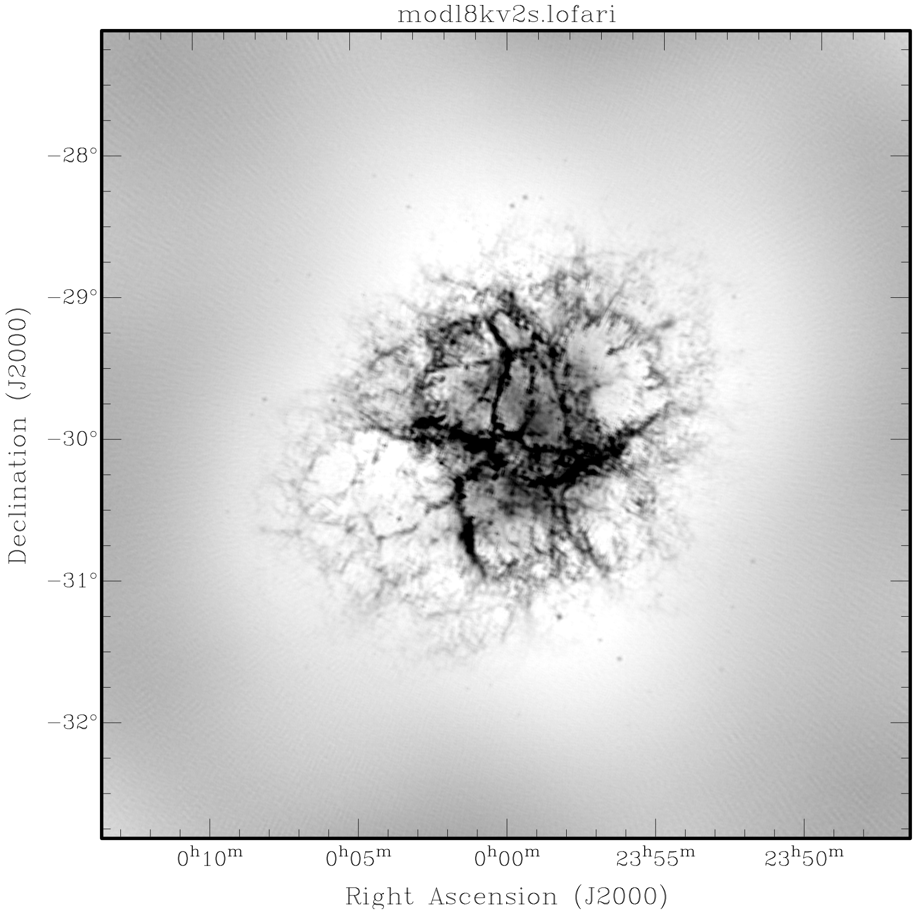


- Outcome of three calibration consultations and input from wide range of scientific, low frequency calibration and engineering input
- Pseudo-random core distribution of (~35m diameter) stations in a compact configuration
- Groups of six stations extending out to 65km diameter
- Supports the concept of virtual (~11m diameter) sub-stations for a limited number of correlations – cost neutral

Dewdney et al 2016

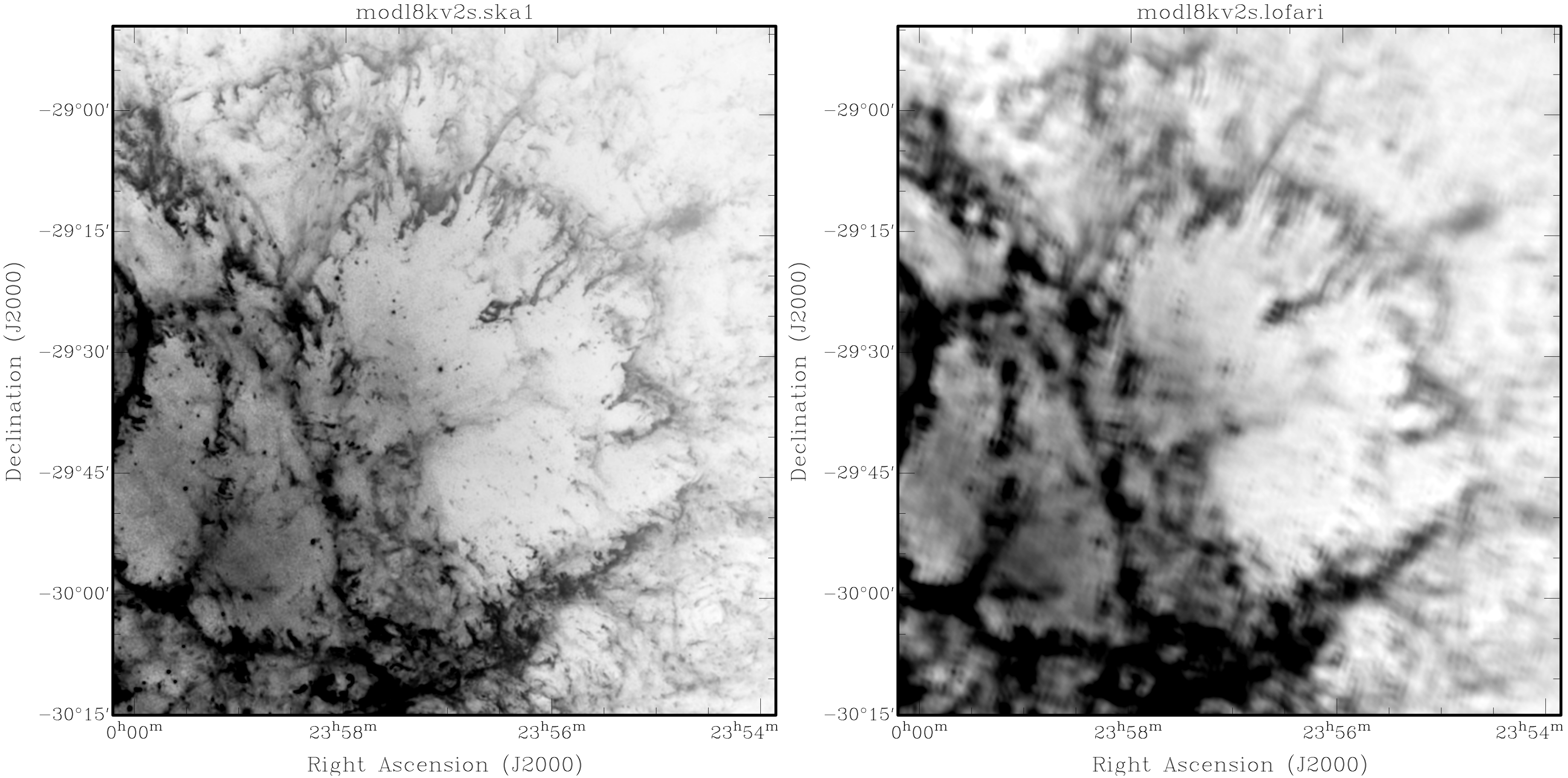
SKA1-LOW image quality





- Single SKA1-LOW track compared to LOFAR-INTL (natural weighting)

SKA1-LOW image quality



- Single SKA1-LOW track compared to LOFAR-INTL (natural weighting)

Summary

- Excellent progress made in defining SKA1-LOW telescope – driven by scientific and calibration considerations

- Configuration station positions defined and released for use in the next costing

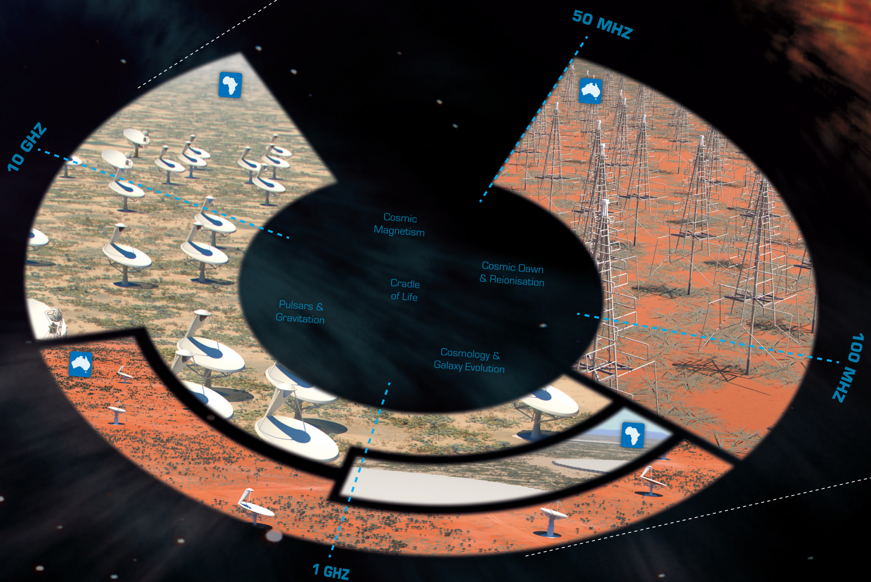
- Concept of virtual sub-station (~11m diameter) defined which vastly improves the 21cm power spectrum sensitivity on large scales

- Progress in defining requirements on spectral bandpass shape – should discuss this week

SKA Science

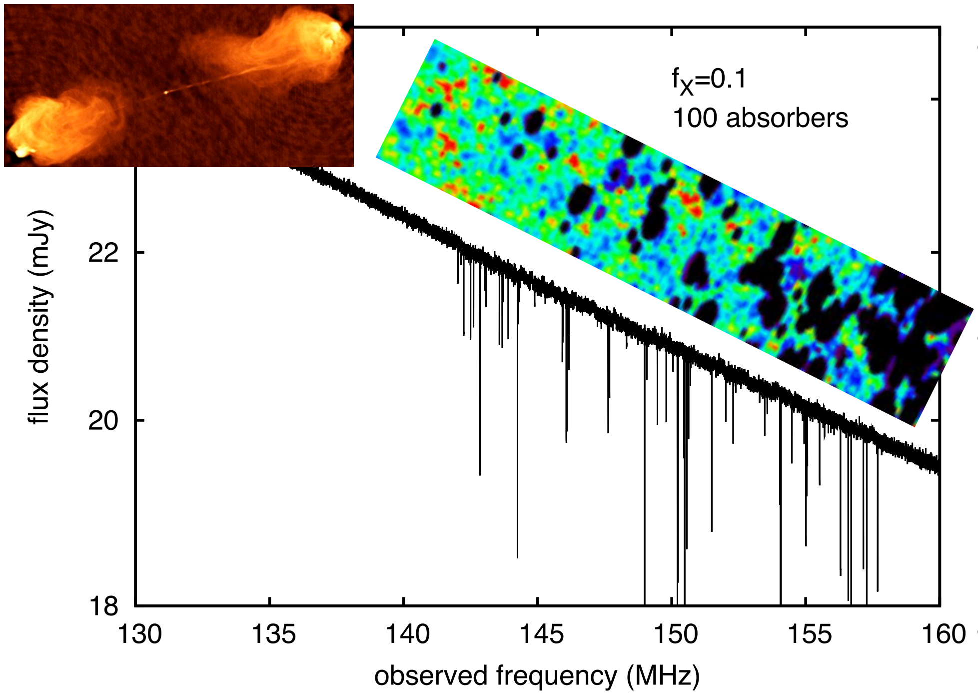
The SKA will revolutionise our understanding of the Universe and the laws of fundamental physics

http://astronomers.skatelescope.org/



Credits and acknowledgements: Djorgovski et al, (Caltech) (EoR image); Casey Reed (Pulsar image); NASA/JPL-Caltech/SSC (Galaxy evolution image-NGC 3190 Field); NASA/Stanford-Lockheed Institute for Space Research's TRACE Team (Cosmic Magnetism image-Sun's Corona); NASA/JPL-Caltech (Cradle of life image)

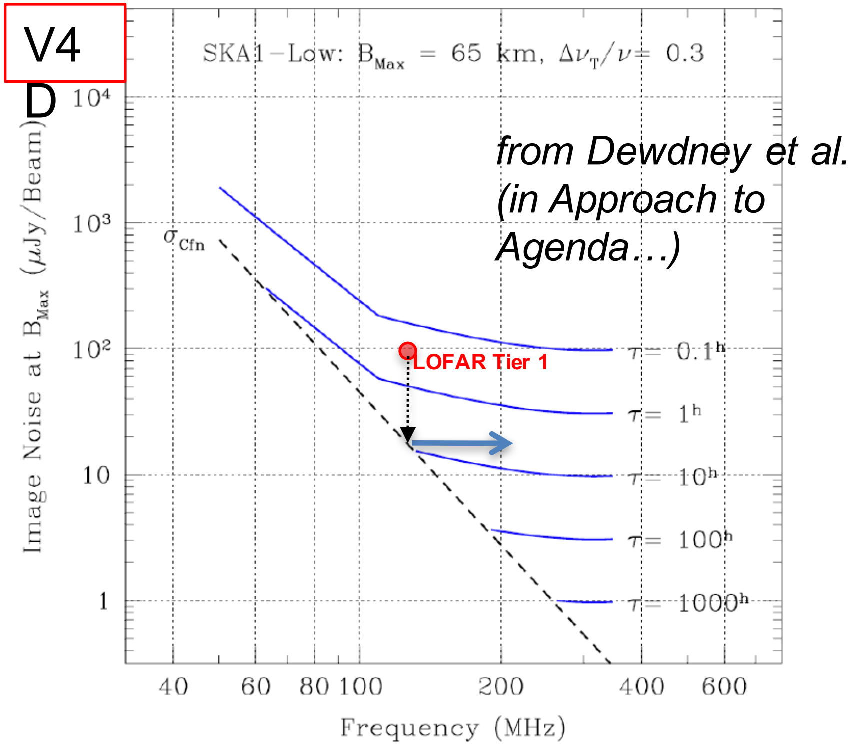
The 21cm forest: minihaloes and the IGM

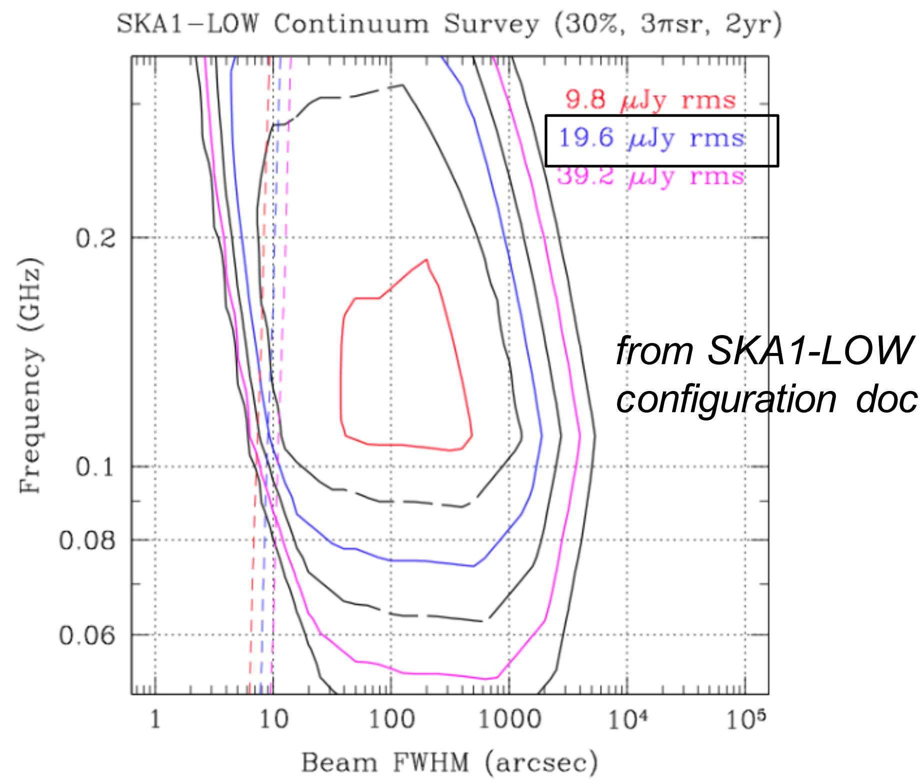


- absorption by cool neutral gas along the LOS associated with diffuse IGM or overdense clumps
- Sensitive to X-ray heating -> possible to distinguish between different IGM heating histories
- Requires the existence of radio loud sources well within the reionization epoch

eg Carilli ea 2002; Furlanetto & Loeb 2002; Mack et al. 2012; Ciardi ea 2015

$$S_{min} = 10.3 \left(\frac{S/N}{5}\right)\left(\frac{0.01}{e^{-\tau IGM} - e^{-\tau}}\right)\left(\frac{5\ \mathrm{kHz}}{\Delta\nu}\right)^{1/2}\left(\frac{1000\ \mathrm{m^2K^{-1}}}{A/T_{sys}}\right)\left(\frac{1000\ \mathrm{hr}}{t_{int}}\right)^{1/2}\ \mathrm{mJy}$$





- (30% BW, 3π sr, 2 yr) continuum surveys at 120-150 MHz will reach almost the confusion noise, rms~20 µJy/beam at a resolution of ~10”. To get rid of confusion one needs to move at > 200 MHz, reaching a noise of 10 µJy/beam (which is above the expected confusion level of 3 µJy/b).

- deeper imaging with longer integration time, i.e., 100-1000 hours per field is almost prohibitive below ~200-250 MHz, even at the longest baselines.

Outline

- TT-Low activity
- System Error Analysis (performance budgets)
- Configuration & costing guidance…

TT-Low

LOW Telescope Team Home

Created by Stevenson, Tim, last modified by Waterson, Mark on Apr 28, 2016

LOW Telescope meetings

LOW Telescope Team (Notes and agendas)

Current (last) meeting: Agenda for TT-LOW April 28th

April 28th (room **23** SKAO) at 08:00 UTC

(09:00 UK, 10:00 CET)

Minutes of previous TT-LOW Meeting: 2016-04-14 Meeting notes

Further scheduled meetings:

May 12th/13 (f2f in Bologna)

June 15th

Issues Stats:

Issue	Nr.	%
Total Number of Issues	21	100
Active Issues	12	57
Deferred/Watch Issues	5	24
On Hold	0	0
Not assigned Issues	0	0
Closed Issues	4	19

Click here for: Issues Template

TT Terms of Reference: Telescope_Teams_Terms_of_Reference_v10.docx

Current Low_TT members:

- @Mark Waterson - Chair
- @Jan Geralt bij de Vaate - Co-Chair
- @André van Es - PM
- @Maria Grazia Labate - SE, LFAA
- @Jeff Wagg - PS
- @Wallace Turner - Requirements
- @Corrie Taljaard - RAMS
- @Andrew Faulkner - LFAA
- @Rosie Bolton - SDP
- @Ben Stappers / @Grant Hampson - CSP
- @Alan Bridger - TM
- @Richard Oberland - SaDT
- @Abeywickrema, Shandip - INFRA-AUS
- @Michael Hayes / @Adam MacLeod - AIV
- @Peter Dewdney - AG
- @Alistair McPherson - HoP

Top Level Issue Log

Issue status 1-3

Issue Nr	Issue Name	Issue Description	Identified by	Assigned to	Progress	Priority	Expected Completion Date	Current Status	Closure Date	Closing Remarks
1	Calibration & Configuration	The calibration approach for SKA-LOW is still undefined and subject to ongoing work. Convergence on this work is urgently needed,however, the Configuration of the LOW-telescope is a function of the calibratability. The unclarity has impact on a number of design parameters such as: Infrastructure, RFi-mask, Station boundaries, etc. Issue 04, Issue 05, Issue 08 added to this RT, see background info on issue page.	MW	ALL	The approach will be to gather constraints/driving factors of the TT-LOW calibration & configuration approach on short notice. The TT-exec team will gather all these in a paper, define an approach and assign Resolution Teams before the end of October. Issue 04, 05 and Issue 08 are merged into this issue. Next step is workshop on SKA1 Low Station Configuration Feb. 24,25 2016	**Extreme**	First stage finished on: 22 December 2015 Second stage Early March	Open		
2	CSP Relocation	Relocation of CSP to Perth could result in cost reductions	SO	SO	Item is moved to watch list.	**Hold**	(November 2015)			
3	Synchronised Telescope Network Time	NTP time server location. As the timing of telescope data is well defined the location of a server providing telescope time to the supporting functions is unknown.	RO	MW/RO	A small RT of TM and SaDT was set up to adress this issue and come up with a solution (this will also impact Mid)	**Norm**	January 2016	Closed	17Mar2016	Final report SKAO to prepare ECP for implementation.

Issues 4-5

4	Station Lay Out	To synthesize and clarify the overall requirements applicable to station size • A different lay-out of the antennas in the station could be needed for smoother station beam shape • sensitivity at 50MHz • station self-cal must be possible			Moved to Issue 01	**High**	December 10th	Closed	28 Jan 2016	Added to Issue 01 RT
5	Array Lay-out	Considerations: • The array beam model should change as little as practical between successive pointings (and the resulting beam should satisfy the beam-error requirements). • Collecting area ratio between core and arms • Infra/network/power costs minimized Both station-size and antenna lay-out could change. This work shall start after the calibration discussion.	TT-LOW team meeting		Moved to Issue 01	**Norm**		Closed	28 Jan 2016	Added to Issue 01 RT

Issues 6-9

6	Sub-arraying	A similar workgroup is working on this topic in TT-Mid. It makes sense to start a similar workgroup to deal with the particular problems for the LOW-telescope.	AvE	JW	An RT of scientists is requested to make a list with science cases applicable for sub-arraying.	Norm		Open		
7	LOW Construction Phasing	Alignment of Construction with AIV. What milestones need to be defined to obtain an achievable AIV plan.			Waits on outcome of AIV discussion during CL-meeting in Feb.	**Hold**				
8	Sub/Super Stations	Will the elements (LFAA, CSP, SDP) have designs which that are capable of supporting either of these concepts? What are the limits for what the whole telescope can do cost-effectively? (bandwidth,control,imaging). This needs to be evaluated			Moved to Issue 01	Norm		Closed	28 Jan 2016	Added to Issue 01 RT
9	Performance Budgets	Placeholder. We will need a RT for each performance budget.	TBD	All	Names for this RT to be provided Info here: Low System Budget Work TT-LOW team requested to comment on doc.	Norm				

Issues 10-12

10	Low Network Architecture	(initialization) This is an issue resulting from assumptions regarding assignment of traffic to diferent networks and requirements on the networks. An RT is needed to assess the implications of a revised architecture to the element designs and requirements. The office will address and scope the changes first.	SKAO(AvE), LFAA, SaDT, TM	All	SKAO internal working group discussing scope & breakdown of issue (March 2016).	**High**		Pending scope		
11	Collecting data for RAMS on AAVS1	Identify what are the key risks that can be mitigated by using AAVS1 as a test and data-gathering platform. Outcome: Test plan based on inventory of risks	All	CT	Group discussion agreed to establish RT/working group. Initial work to set up RAMS risk register and canvass mitigation aproaches, identifying what can be studied with AAVS, precursors.	**Norm**				
12	Cost reduction working group	Any proposals for cost reductions can/should be discussed across consortia, and further ideas may come out of this	JGvdB	JGbdV	All elements are invited to enter cost reductions in the table on the RT page: Issue 12: Cost Reduction					

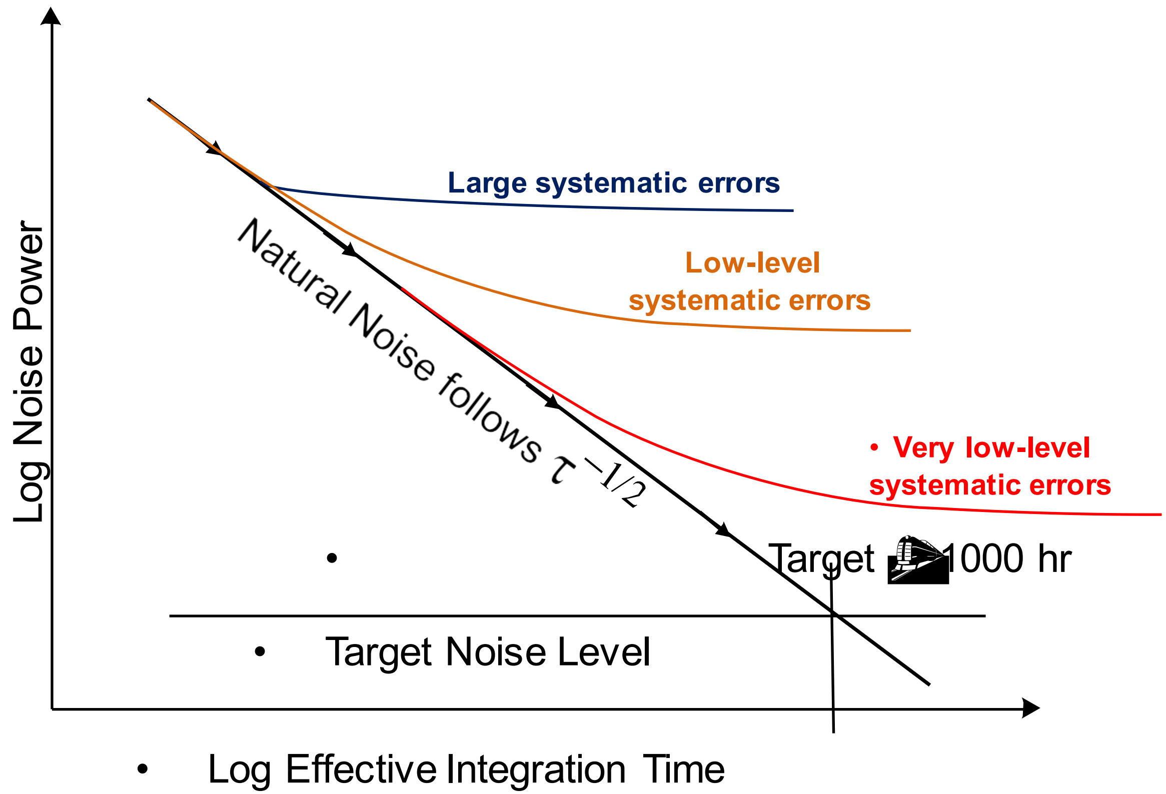
System Error Analysis

- Extract from High-level (sys review) presentation
- Plan for doing it
- Next steps

A Fundamental Requirement for Scientific Success

- Basic assumption behind some of the most important SKA observations:
  - ability to integrate for at least 1000 hours, limited in sensitivity only by uncontrollable, natural noise over the full field-of-view at all spatial resolutions.
- Note the combinations of high sensitivity, all resolutions and long integrations:
  - previously had ‘high resolution’ rather than all resolutions, recognising that reaching high brightness temperature sensitivity in long integrations will be equally challenging.
- The 1000-hr requirement is most difficult to reach at low frequencies (<3 GHz) in both line and continuum imaging observations.
  - These represent 16-24% of the high-priority science, depending on where on the HDR cutoff taken.
  - At these frequencies the sky is bright, and so so-called High Dynamic Range imaging is required to meet the 1000-hr limit.
  - Systematic Errors will tend to “redirect” flux from bright backgrounds into the science data to create ‘noise’ at low levels that does not decrease with longer integrations.
- At high frequencies other effects will limit long-term integrations, so HDR is not primary, per se.
- Caveat: Not all the important science projects require 1000-hr integrations.

Systematic Error Effect on Deep Integrations



- High-level systematic errors will be relatively easy to track down and remove;
- Low-level errors may take considerable experience with the system;
- Extremely low-level errors may take a very long time or may never be found.
  - The low and very low levels are the most 'dangerous' when considering how to best meet the extreme integration time requirement.
  - Such errors may appear noise-like in short integrations but fail to 'average down' in long integrations because they are not actually random.

Models, Calibration, Residuals and Stability

- In principle:
  - Effects that are understood can be modelled.
  - Typically models contain parameters that must be measured by calibration.
  - After calibration has been applied => residual uncertainty that affects the final result.
  - Also calibrations cannot be applied continuously:
    - system must remain sufficiently stable between cals for residuals to be controlled.
  - The balance between system (or sub-system) stability and the residuals are key design factors for the SKA telescopes.
- In practice the foregoing is very complex:
  - understanding subtle effects takes time and effort,
  - systematic errors interact so that calibrations may have to be carried out iteratively,
  - incorporating knowledge and techniques from sub-systems into the whole system may not scale,
  - some calibration schemes may require too many resources to be practical.

Error Contributions and Budgeting

Individual instrumental effects.

What the astronomer cares about*.

Mid / Common / Low

Telescope Performance Measures \ Sub-System Effects	Dish Pointing	Dish Optical	Alignment Dish	Displacements	Noise-source	Stability Troposphere …	u-v	Coverage	ADC Errors	Correlator	Truncations Weak	RFI	Strong RFI	Deconvolution	Residuals	Signal-chain Complex	Gain Array Geometry …	Timing Errors	Frequency/Time Antenna/Element	Smearing Response Array Filling	Factor	Station Filling Factor	RF-over-Fibre Transfer	Function Ionosphere …
Imagin																								
Sensitivity Loss g	X	X								X										X		X		
Synthesised Beam-Shape																								
Quality Antenna Beam-Shape																								
Quality Antenna Beam-Shape																								
Stability Polarisation Errors																								
Response to Near-in																								
Sidelobes Response to Far																								
Sidelobes Closure Errors																								
Wide-band Spectral																								
Smoothness BandShape																								
Stability & Flatness																								
Spectral-channel Bandshape																								
Spectral-channel Rejection																								
Non-linearity																								
Spectrum																								
Loss Data																								
Loss																								
Direction-Dependent																								
Errors Flux Density																								
Scale																								
Track-mode Observing Time																								
Domain Efficiency Array Scan-mode Beam-																								
Shape Observing Quality Efficiency Spectral-																								
channel Resolution																								
Spectral-channel Impulse Response																								
De-dispersion Errors (incoherent &																								
coherent) Polarisation Errors																								
Othe r																								
Spatial/Spectral Power Spectra (Eor /																								
CD) VLBI Capability																								

Mid Error Budget

Low Error Budget

* Should be as general as possible, short, but complete.

Proposal for a Process

- Agree on a set of performance parameters.
  - Define them in a document.
- First Step:
  - Create headings across the top of the matrix, applicable to sub-system designs.
  - Define the headings.
  - Fill in the boxes.
  - For each ‘X’, provide:
    - a model description,
    - a calibration method (if available),
    - a residual estimate
    - an impact statement on system performance.
- Second Step:
  - roll up the contributions;
  - Provide allocations (error budgets) for all items in which multiple ‘X’s appear in the rolled up version of the table.

So – first the “budgets”:

Table 1: Science-Budget Mapping

1	**Science Case**	**Attribute / class**	**System Timing Budget**	**Time-domain stability**	**Noise / Tsys Budget[A1]**	**Linearity Budget**	**Dynamic Range**	**Spectral performance**	**Polarization performance**
2	EoR/CD								
3		Spatial /spectral frequency domains	x	x	x	x	x	x	x
4		spectral cube image domain		x	x	x	x	Affects	x
5		brightness temperature sensitivity			Affects	Affects	Affects		
6	pulsar search								
7		DM range		x				x	
8		search area		x	x				
9	pulsar timing								
10		timing accuracy	x	x	x				
11		system clock and clock derivatives	x						
12	standard imaging								
13		continuum	x	x	x	x	x	x	x
14		spectral line cubes			x	x	x	x	
15	transients		x	x	x				

Budget definition

5.6 Time-domain stability

Created by Waterson, Mark on Apr 19, 2016

Description:

This refers to the temporal stability of the system parameters against environmental effects. The various calibration loops apply feedback corrections to their terms in order to maintain errors at a sufficiently low level, and the update rates of these loops must be set based on the expected time scales of the driving effects.

Reference Documents:

Relevant Level-1 Requirements:

SKA1-SYS_REQ-2621	The spectral stability, on a time scale of 600 seconds or less, of the station beam bandpass, post station calibration and RFI-mitigation, shall be within 1.3 %, 0.4 %, 0.6 % and 1.1 % at 50 MHz, 100 MHz, 160 MHz, and 220 MHz respectively compared to the full polarization, parameterized beam model.
SKA1-SYS_REQ-2629	Station beam stability. The difference between the parameterized station beam model and the actual station beam shall remain smaller than 1.3 %, 0.4 %, 0.6 % and 1.1 % relative to the main beam peak power, after calibration, at 50 MHz, 100 MHz, 160 MHZ and 220 MHz respectively

Analysis Method:

Calibration steps and effects:

Source Errors (see Table 2):

To the contributors:

Low System Error-Effect Mapping

Created by Waterson, Mark, last modified on Apr 24, 2016

The following table maps the effects resulting from each individual element of the signal chain to the respective performance budgets. In each cell, an "X" indicates a value which should be calculated (those whose contribution is less clear are marked "?"), and implies an analysis report. In addition, parameterization by environmental effect is shown where appropriate. Going forward, each entry will be replaced by an allocation to the design consortium responsible, and a calculated value provided into the budget column for management. The sum of the error values in a budget can be compared against the limits set by the applicable requirements and the resultant margin traded among the contributing factors.

Table 2: Attribute-Effect-Budget Mapping

Attribute/effect definition list	Budgets/Planes affected

1	Owner /Consortia	Product Item Number	Component	Attribute/class	Attribute	Effect	Parameterized by:	Calibration loop	-	Clock & Timing Budget	Signal Chain stability	Noise/Tsys (sensitivity?)	Linearity
2			Antenna Element										
3				beamshape		Structure of individual antenna sensitivity pattern	phi, theta, freq	Station cal			X	X	X
4				sensitivity		Peak sensitivity of element at zenith	frequency	Station cal			X	X	X
5				coupling to neighbours	embedded, edge	modifies beamshape C depending on location in station	X,Y in station	Station cal			X	?	
6				coupling to neighbours	edge			Station cal			X		
7				external influences	soil, reflecting	should be included in	static	Station cal			X	X	

…not even half of it…

Table 2: Attribute-Effect-Budget Mapping

Attribute/effect definition list	Budgets/Planes affected

1	Owner /Consortia	Product Item Number	Component	Attribute/class	Attribute	Effect	Parameterized by:	Calibration loop	-	Clock & Timing Budget	Signal Chain stability	Noise/Tsys (sensitivity?)	Linearity	Dynamic Range	Spectral performance	Polarization
2			Antenna Element													
3				beamshape		Structure of individual antenna sensitivity pattern	phi, theta, freq	Station cal			X	X	X	X	X	X
4				sensitivity		Peak sensitivity of element at zenith	frequency	Station cal			X	X	X	X	X	X
5				coupling to neighbours	embedded, edge	modifies beamshape C depending on location in station	X,Y in station	Station cal			X	?		X	?	X
6				coupling to neighbours	edge			Station cal			X			X	?	
7				external influences	soil, reflecting screen	should be included in C,D	static	Station cal			X	X		?	?	?
8					wind (vibration)	modifies antenna performance on fast/short time scales	time (wind)	Station cal			X			?		X
9					rain	changes dielectric constant of soil, affects both C&D. should be eliminated by ground screen	Time (slow)	Station cal			X	?		?	?	?
10				frequency behaviour (sensitivity)		frequency dependence of sensitivity (D)	frequency	Station cal							X	X
11				polarisation separation		IxR of antenna pair, may be modified by E	frequency	Station cal							?	X
12				instrumental polarisation		Net effect of K on station performance?		Station cal							?	X
13				errors in position and orientation		affects Station beam & sensitivity, modifying C&D	static (dynamic term part of H)	Station cal				?		X		X
14					Aeff	Calculated fig of merit - not error term		Station cal								
15					Tsky	Input, model of frequency-dependent signal	RA, Dec, time, frequency	Station cal				Src		Src	Src	Src
16					T_LNA	Intrinsic noise of LNA transistor	Frequency, time	Station cal				X		X		
17					T_rec	Product of all antenna, electronics - Fig of Merit for Reciever, not error		Station cal								X
18			analogue signal chain					Station cal								
19				complex gain		Overall net gain of receiver chain - compensated at channel level by calibration	Freq (channel), time, internal settings (attenuation)	Station cal			X	X	X	X	X	X
20				time behaviour		stability of analogue components (LNA, RFoF, ASC components)	Time, Frequency	Station cal		?	X	X	X	X	X	-
21				frequency behaviour		frequency-dependent behaviour of analog components (LNA, RFoF, ASC components)	Frequency (time)	Station cal			X	x	X	X	X	-
22				RF channel isolation		Inter-channel crosstalk (both x-y and between antennas)	frequency, possibly position in TPM	Station cal			X	X	X	X		X
23				Out-of-Band leakage/aliasing		Rx-level band-pass filter performance	Frequency, time	Station cal				X	X	X	X	
24				linearity		effect of large input signals on power spectrum	input level, frequency (time)	Station cal					X	X		
25			Station digital signal chain													
26				quantisation		introduces finite dynamic range and linearity limits at individual signal level	static	-		?		X	X	X	X	?
27				bandpass shape/smoothness		post-calibration figure-of-merit		Station Cal						X	X	
28				Coarse channel filter shape & aliasing		Out-of-channel power leakage, Effect of finite scale of channelization filter, word-length	frequency	Design				X		X	X	
29			station beamformer													
30				finite-word-size/truncation		assume negligable if correctly designed						X	X	X	X	
31				digital gain/bit selection		changes "bit-statistics" of noise signal	gain setting, frequency channel	??				X	X	X	X	
32				clock and clock distribution		Effects digitization, characterized as phase-noise, sample # offset	time			X		X		?	X	
33			Station beam behaviour			Effects on beam-formed/summed antenna pattern & sensitivity										
34				Beam Shape model		Drives pointing gain/phase coefficients		Station Cal								
35				embedded in core												
36					number of elements											
37					variable											
38					fixed											
39					distribution of elements											
40					shared											
41					not shared											
42					beamshape											
43					sensitivity											
44					frequency behaviour											
45					time behaviour											

Next:

- Review, revise, agree on error source contributors
- Allocate to consortia & products
- Identify priority contributors
- Extract analysis from design reports
- Populate tables…
- Sum the errors & write reports (!)

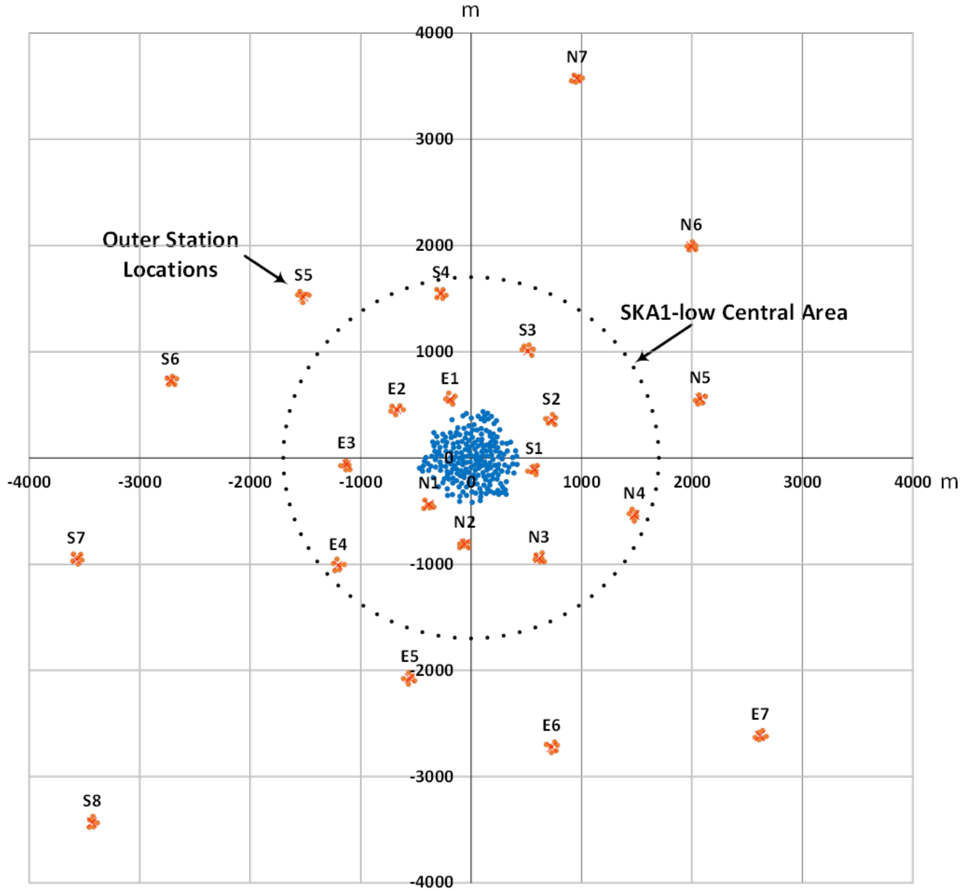
Budgets

- SKAO “owns” budgets and targets at L1
- Consortia own/provide/support error contributions
- Budgets “add-up” contributions against L1 targets
- Residual headroom = margins
- Allocation/trades occur as needed to achieve targets in cost-effective manner

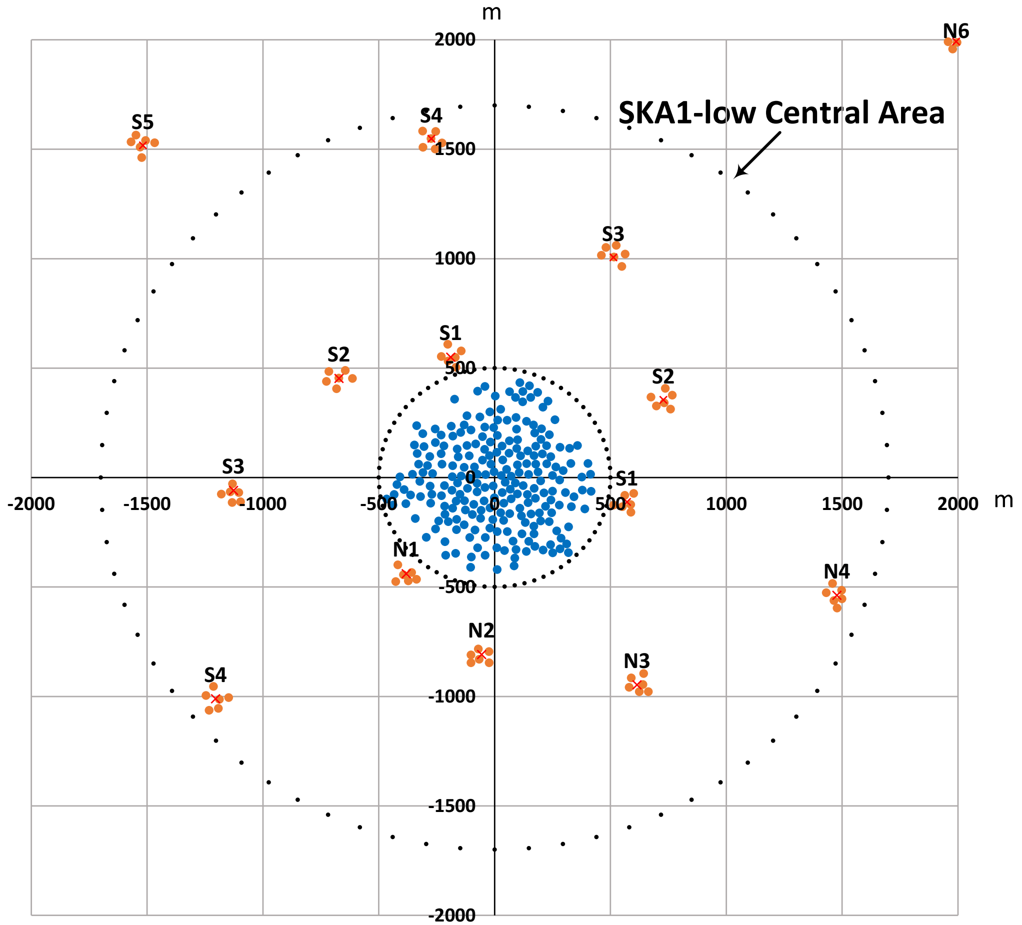
Array Configuration

- Just released the “final” version of the doc
- Supporting analysis is nearly out
- ECP to formalize changes is in process
- Topology should now be sufficient & stable for costing.
- Will only change IF clear reasons to change it are revealed after design & cost analysis progress, and then only after full ECP process.

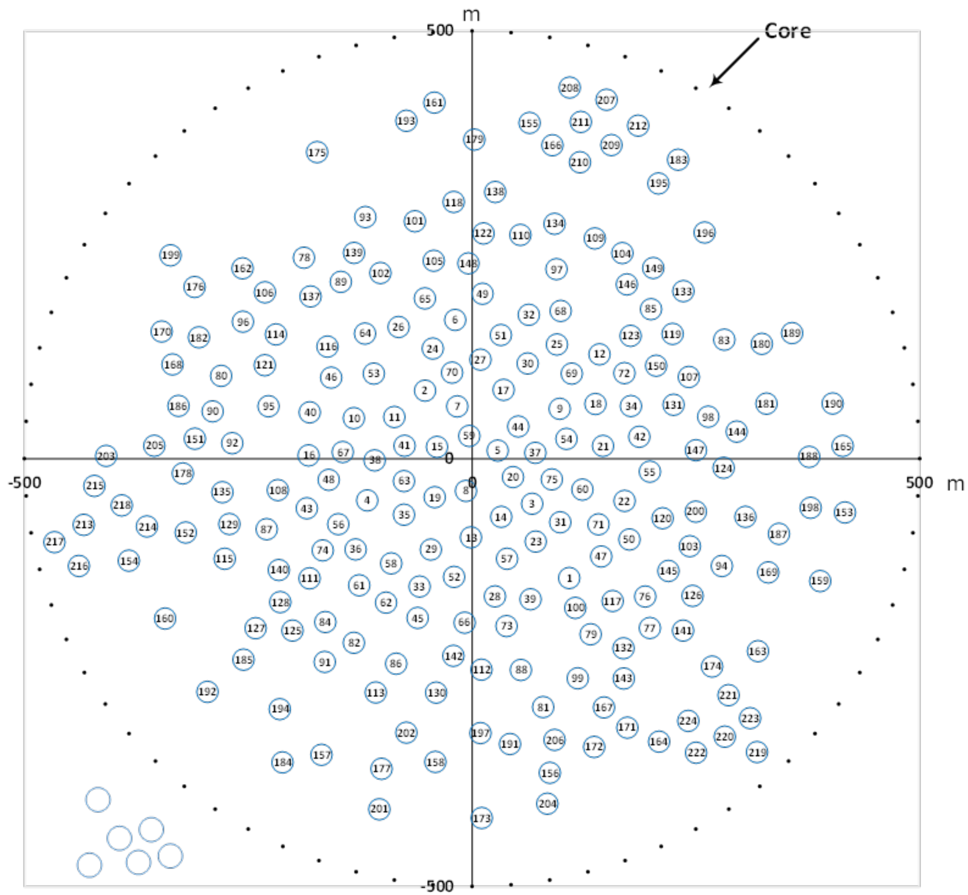
Entire array



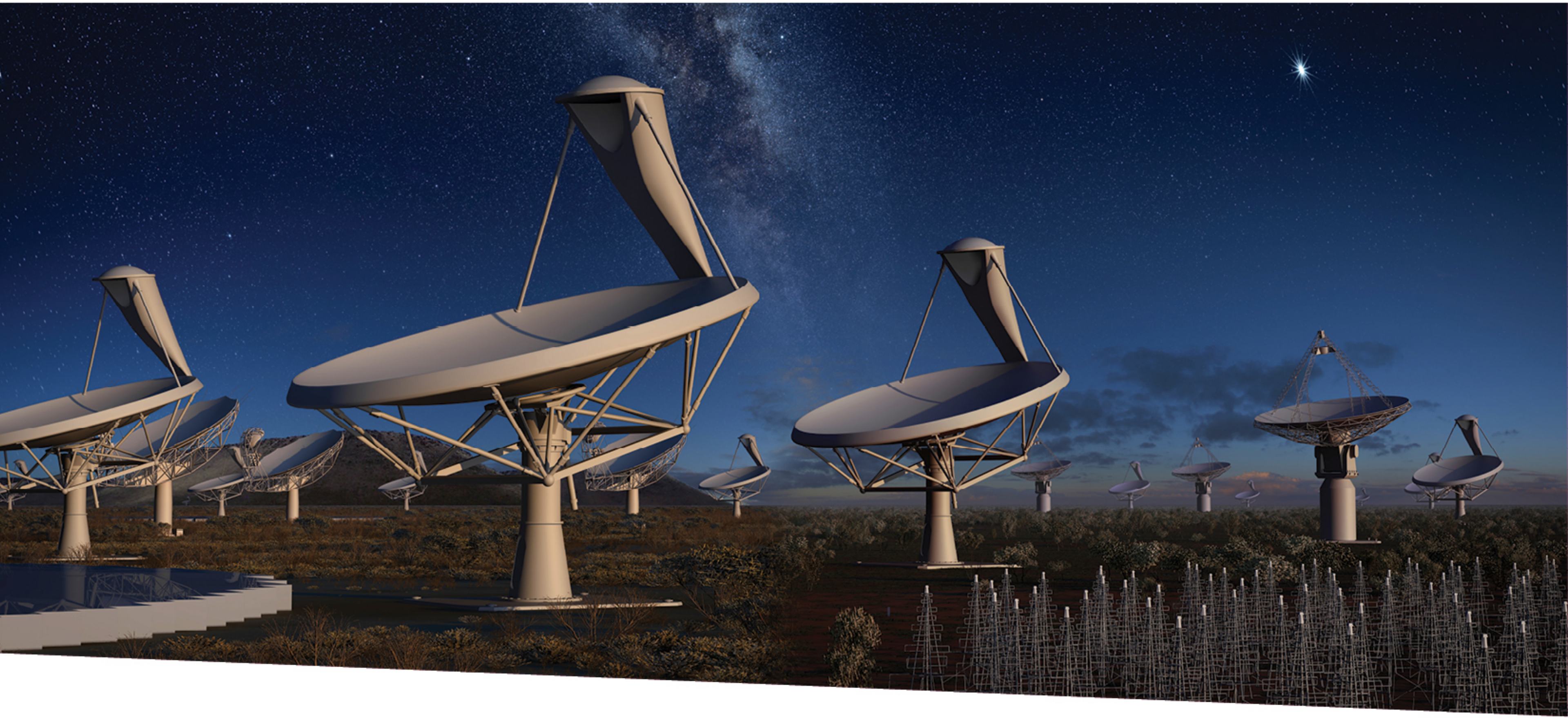
Central region



Core



SKA1 Low System: What is going on



SQUARE KILOMETRE ARRAY

Exploring the Universe with the world's largest radio telescope

Maria Grazia Labate

Bologna, 9th May 2016

What happened?

- Our latest all-hands meeting?

- Back in time

3-5 December 2013,
Dwingeloo

- T0 ->SKA1: L0 and L1 Req.

When the AADC Consortium Leader was 2.5 years younger

T0 → SKA1:
L0 and L1 Requirements

Dec 3, 2013

Maria Grazia Labate
System Engineer (Aperture Array)
SKA Office

AADC Consortium Meeting, 3-5 December 2013, ASTRON -

Overview

- SKAO support
- L0 requirements generation
- T0 documentation
- L1 requirements review approach

Level 1 documentation (1/5)

- Cover Letter
- Concept of Operations
- Model (SysML) description
- MagicDraw file
- A few corrections to the Baseline Design
- Addenda to the Baseline Design
- Level 1 requirements

Other documents will be produced in the future to provide more detail to the ConOps and Baseline Design.

When the AADC Consortium Leader was 2.5 years younger

Aperture Array Design and Construction Consortium: AADC

of the

Low Frequency Aperture Array Eleme

All-hands meeting
3-5th December

Jan Geralt Bij de Vaate

Dec 2013 Low Frequency Aperture Array

Negotations with SKA Office

	Date	Nominal date	Deliverable
1.	T0	1st Nov 2013	Bid preparation and OSKAO delivery of Level 1 requirements
2.	T0+12 weeks	1st Feb 2014	TBD and TBC agreed and closed for Level 1 requirements
3.	T0+25 weeks	1st May 2014	Preliminary report on RFoF cost and performance
4.	T0+34 weeks	1st July 2014	Preliminary installation plan (including demonstration plan)
5.	T0+38 weeks	1st August 2014	Preliminary power design report
6.	T0+46 weeks	Mid Sept 2014	System Requirements Review and associated documents (see SEP)
7.	T0+50 weeks	End of Oct 2014	Preliminary Design Review and associated documents (see SEP)
8.	T0+68 weeks	1st March 2015	Closure of Stage 1
		Total	

Table 1: List of deliverables for Stage 1

tions with SKA Office

		inal date	Deliverable
		arch 2015	Kick-off Stage 2
		pril 2015	AA Verification System 1 (AAVS1) Detaile
3.	T0+85 weeks	1st July 2015	Installation plan includin
4.	T0+99 weeks	1st Oct 2015	Demonstr
5.	T0+112 weeks	31st Dec 2	
6.	T0+140 weeks	1st July 20	
7.	T0+148 weeks	1st Sept 20	
8.	T0+156 weeks	1st Nov 20	of Stage 2
		Total	

Table 2: List of deliverables for Stage 2

updated

1) Milestone 1 Kick- off of stage 2: Not accepted yet (waiting for closure of stage
2) Milestone 2 (AAVS1 DDR review report): Accepted by SKAO
3) Milestone 3.1 (Installation plan for field node): Accepted by SKAO
4) Milestone 9 (Update of technical compliance matrix and antenna design): 50% delivered (LFAA station design report not delivered yet due to relevant input documents from SKAO not yet delivered)
5) Milestone 10: (Updates PMP and SEMP): Accepted by SKAO.
6) Milestone 11 (RAM report, INFRA.AUS-LFAA and CSP-LFAA external ICDs, updated costs and Risk register): Partially (80%) accepted by SKAO (ILS report not delivered yet due to relevant input documents from SKAO not yet delivered)

When the AADC Consortium Leader was 2.5 years younger

- ✓ Perth, Sept 2014 (face-to-face progress meeting with all the WP Leaders).
- ✓ LFAA PDR, 2015
- ✓ AAVS1 face-to-face meetings (Malta, DDR in Dwingeloo), 2015.

- ✓ Architecture Review
- ✓ System Review

Only a few

- Product Breakdown Structure
- Interfaces and ICDs
- LMC Harmonisation
- Functional Analysis
- Modelling
- Level 1 requirements

Product Breakdown Structure

LFAA example:

PDR submission: more focused on WPs

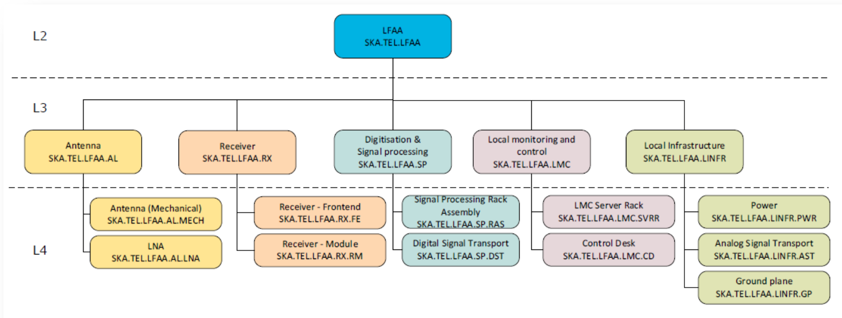


Figure 1: Product Tree overview

More focus on actual products

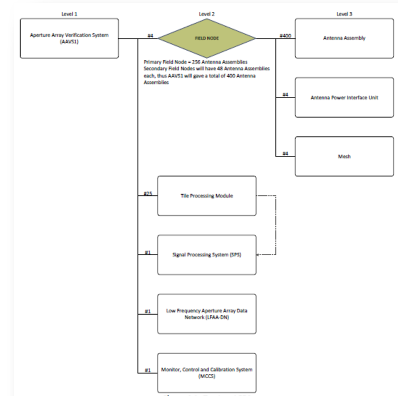


Figure 4-1 Top Level PBS

Product Breakdown Structure

LFAA example:

PDR submission: more focused on WPs

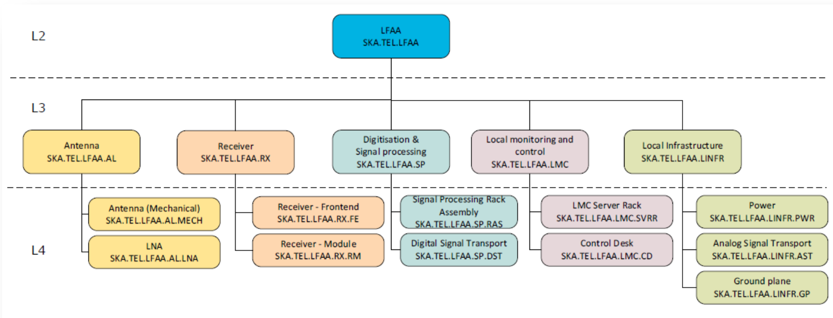


Figure 1: Product Tree overview

More focus on actual products

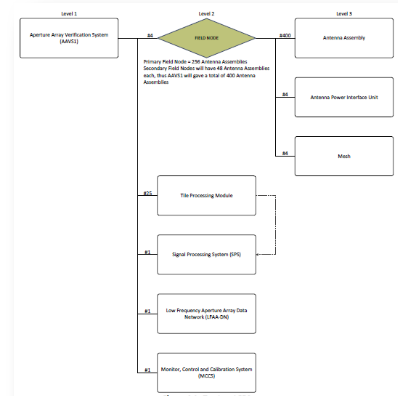
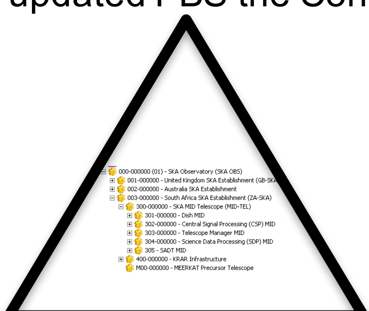
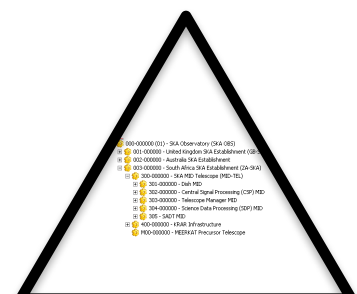


Figure 4-1 Top Level PBS

To reflect the updated PBS the Consortia are working on

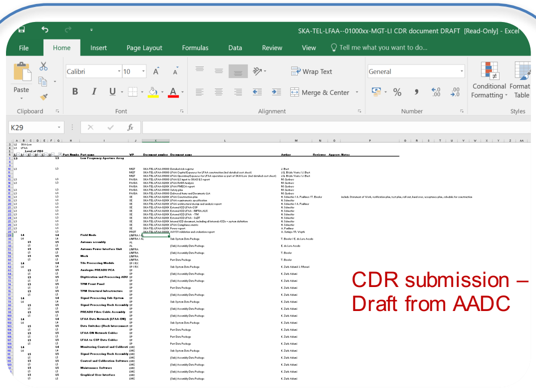




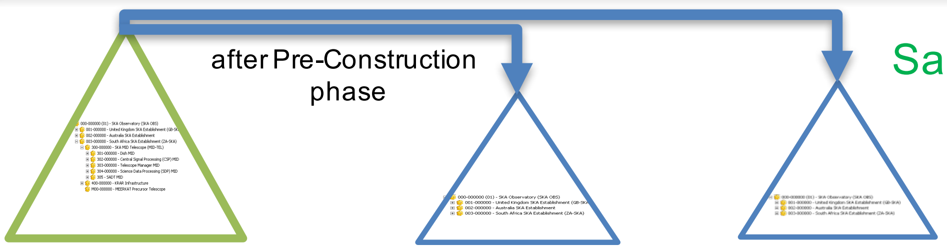
SKA Telescope PBS

Product Breakdown Structure

- What is now under formal management and CM control is the Development PBS (or SKA Telescope PBS)
- Documents are then generated in context of the Development PBS.



CDR submission – Draft from AADC



after Pre-Construction phase

Same products of the SKA Telescope PBS

Possible *views* that we will generate and use <u>at the office</u> to prepare for construction

SKA Telescope PBS

Construction **<u>View</u>**

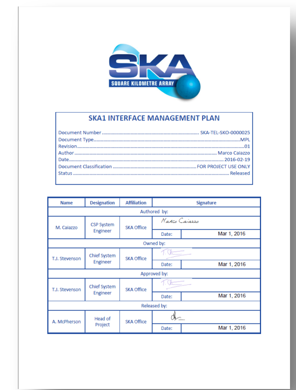
Operations **<u>View</u>**

Interfaces

- Architecture Review OAR: mapping between interfaces identified in the architecture and in which ICDs these interfaces are defined.

- Identification of the interfaces between products and mapping to ICDs

LOW Functional Analysis → LOW Model in Cameo →



SKA1 INTERFACE MANAGEMENT PLAN

Document Number SKA-TEL-SKO-0000025
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Revision 01
Author .... Marco Caiazzo
Date 2016-02-19
Document Classification .... FOR PROJECT USE ONLY
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Name	Designation	Affiliation	Signature	
Authored by:				
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Owned by:				
T.J. Stevenson	Chief System Engineer	SKA Office		
			Date:	Mar 1, 2016
Approved by:				
T.J. Stevenson	Chief System Engineer	SKA Office		
			Date:	Mar 1, 2016
Released by:				
A. McPherson	Head of Project	SKA Office		
			Date:	Mar 1, 2016

- Inter-Element and Intra-Element

Between Elements

Internal to an Element

Cross-checks – something to update in the IMP

ICD Dashboard

ELEMENT	**CSP**	CSP	LFAA	DISH	SDP		
	SADT	AIVMEERKAT	SADT	SADT	SADT	SADT	
	TM	TM	TM	TM	SDP	CSP	TM
	INFRA SA	AIV MEERKAT	-	DISH	SDP	CSP	SADT	TM
	INFRA AUS	-	LFAA	-	SDP	CSP	SADT	TM
		AIV MEERKAT	**LFAA**	**DISH**	**SDP**	**CSP**	**SADT**	**TM**
	ELEMENT							

focus on LOW

ELEMENT	**CSP**	~~CSP~~	LFAA	~~DISH~~	SDP		
	SADT	~~AIVMEERKAT~~	SADT	~~SADT~~	SADT	SADT	
	TM	~~TM~~	TM	~~TM~~	SDP	CSP	TM
	~~**INFRA SA**~~	~~AIV MEERKAT~~	-	~~DISH~~	~~SDP~~	~~CSP~~	~~SADT~~	~~TM~~
	INFRA AUS	-	LFAA	-	SDP	CSP	SADT	TM
		~~**AIV MEERKAT**~~	**LFAA**	~~**DISH**~~	**SDP**	**CSP**	**SADT**	**TM**
	ELEMENT							

ICD Dashboard

ELEMENT							
CSP	CSP	LFAA	DISH	SDP			
SADT	AIVMEERKAT	SADT	SADT	SADT	SADT		
TM	TM	TM	TM	SDP	CSP	TM	
INFRA SA	AIV MEERKAT	-	DISH	SDP	CSP	SADT	TM
INFRA AUS	-	LFAA	-	SDP	CSP	SADT	TM
	AIV MEERKAT	**LFAA**	**DISH**	**SDP**	**CSP**	**SADT**	**TM**
	ELEMENT						

Interface	Doc. no.	Status
CSP - TM	100-000000-021	Signed
CSP - INFRA AUS	100-000000-020	In progress
SADT - CSP	100-000000-023	In progress
SADT – INFRA AUS	100-000000-024	Signed
SADT – SDP	100-000000-025	In progress
SADT – LFAA	100-000000-026	Signed
TM – INFRA AUS	100-000000-022	Signed
TM – SADT	100-000000-027	In progress
TM – LFAA	100-000000-028	In progress
SDP – CSP	100-000000-002	Signed
SDP – TM	100-000000-029	Under signature
LFAA – INFRA AUS	100-000000-003	Signed
LFAA - CSP	100-000000-004	Signed

ICD Dashboard

ELEMENT							
CSP	~~CSP~~	LFAA	~~DISH~~	SDP			
SADT	~~AIV MEERKAT~~	SADT	~~SADT~~	SADT	SADT		
TM	~~TM~~	TM	~~TM~~	SDP	CSP	TM	
~~INFRA SA~~	~~AIV MEERKAT~~	-	~~DISH~~	~~SDP~~	~~CSP~~	~~SADT~~	~~TM~~
INFRA AUS	-	LFAA	-	SDP	CSP	SADT	TM
	~~AIV MEERKAT~~	LFAA	~~DISH~~	SDP	CSP	SADT	TM
	ELEMENT						

Hermine, Alan Bridger et al. working on this

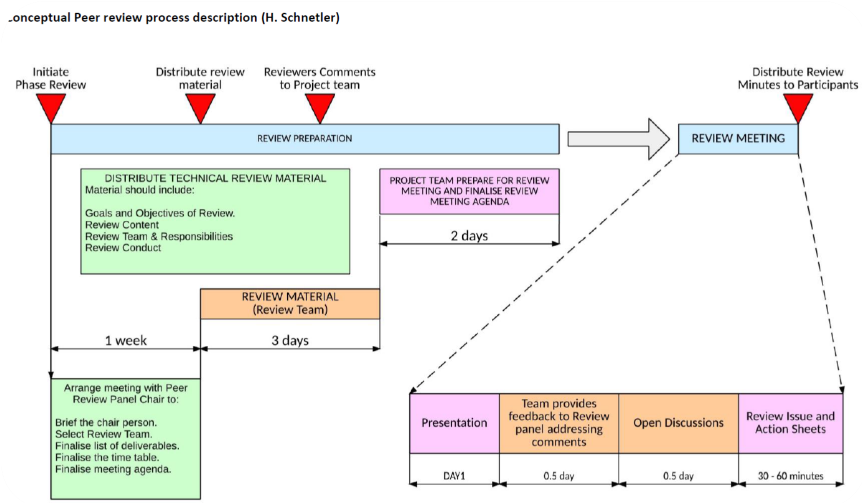
Interface	Doc. no.	Status
CSP - TM	100-000000-021	Signed
CSP - INFRA AUS	100-000000-020	In progress
SADT - CSP	100-000000-023	In progress
SADT – INFRA AUS	100-000000-024	Signed
SADT – SDP	100-000000-025	In progress
SADT – LFAA	100-000000-026	Signed
TM – INFRA AUS	100-000000-022	Signed
TM – SADT	100-000000-027	In progress
TM – LFAA	100-000000-028	In progress
SDP – CSP	100-000000-002	Signed
SDP – TM	100-000000-029	Under signature
LFAA – INFRA AUS	100-000000-003	Signed
LFAA - CSP	100-000000-004	Signed

LMC Harmonisation

- Each Element responsible to provide monitoring and control capabilities
- TM implements the higher level telescope functionalities and coordinate the activities of the telescopes.
- Non-homogeneous implementations.
- Harmonisation process aiming to bring out possible inconsistencies in the TANGO implementation for SKA, by exploiting previous experiences in different application fields.
- LMC peer-review sessions

Date	Venue	Element under reviewed
11-13/4/16	Madrid (After CSP TIM#5)	MID.CSP.LMC MID.DSH.LMC
4-6/7/16	Edinburgh (After SPIE 2016)	LFAA LMC SADT.NMGR
2-6/10/16	Stellenbosch (During SKA Engineering Meeting)	LOW.TM.LMC MID.TM.LMC SAT.LMC Harmonization status
jan/feb 2017	TBD	SDP.LMC AIV.LMC INFRA.LMC

LFAA: Hermine Schnetler, Andrea De Marco, Kris Zarb Adami

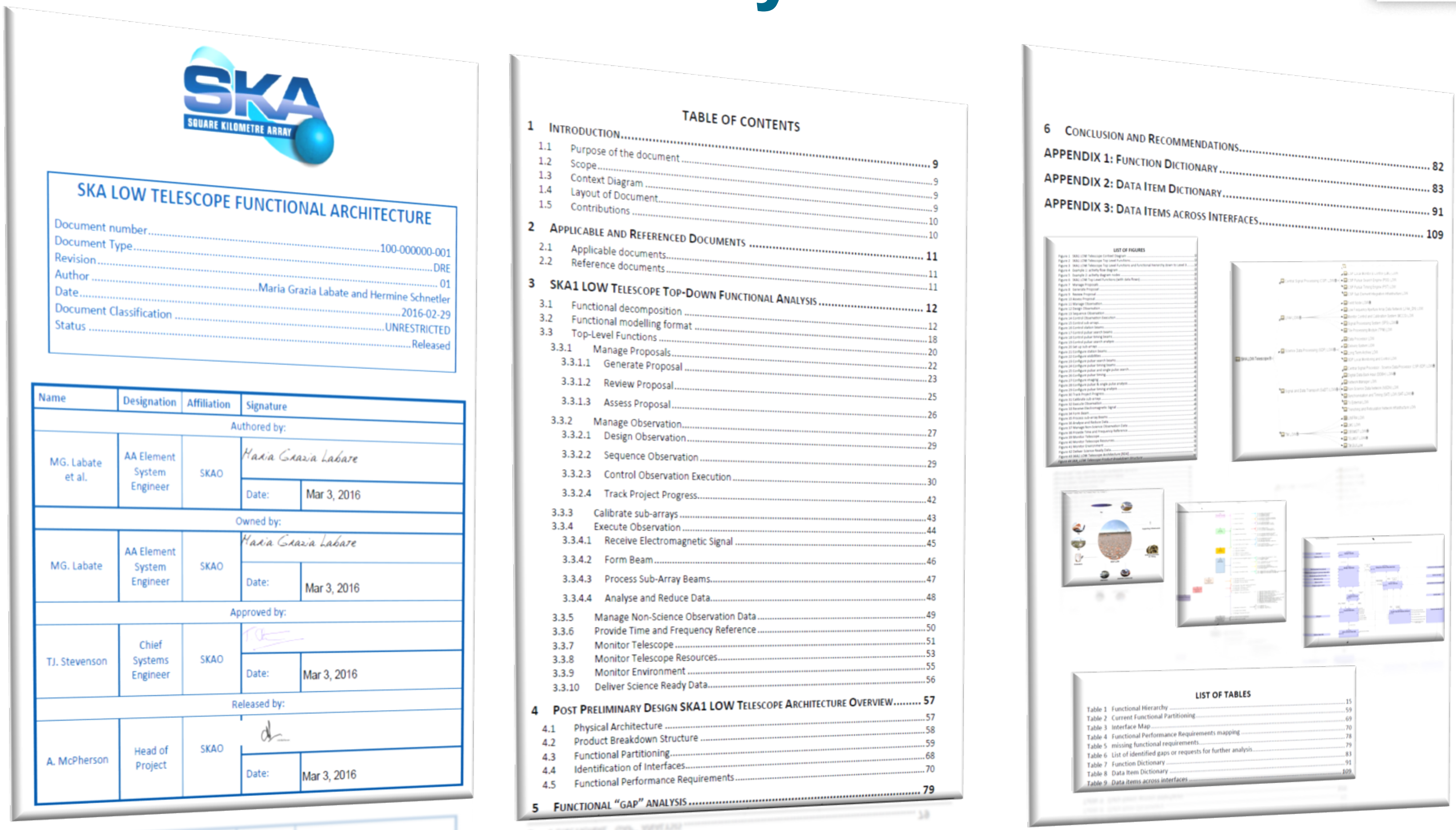


Functional Analysis

- "What" a system has to do to achieve the system's objectives

a) Identification and a description of the primary mission **end-to-end system level functions**.
b) A description of the **data flow** through the system that is required to support these top-level functions.
c) A **cross-check** of which functions have been implemented by which system elements.
d) The identification of functions that are not implemented as yet and the **allocation** of these as work elements to the most appropriate design consortia for further development.
e) Evaluate the architectural design of the Low Telescope and where appropriate optimise the design.
f) Prepare an N-squared diagram to ensure **100% coverage of identified internal and external interfaces**.

LOW Functional Analysis



SKA LOW TELESCOPE FUNCTIONAL ARCHITECTURE

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Author .... Maria Grazia Labate and Hermine Schnetler
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Name	Designation	Affiliation	Signature	
Authored by:				
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Owned by:				
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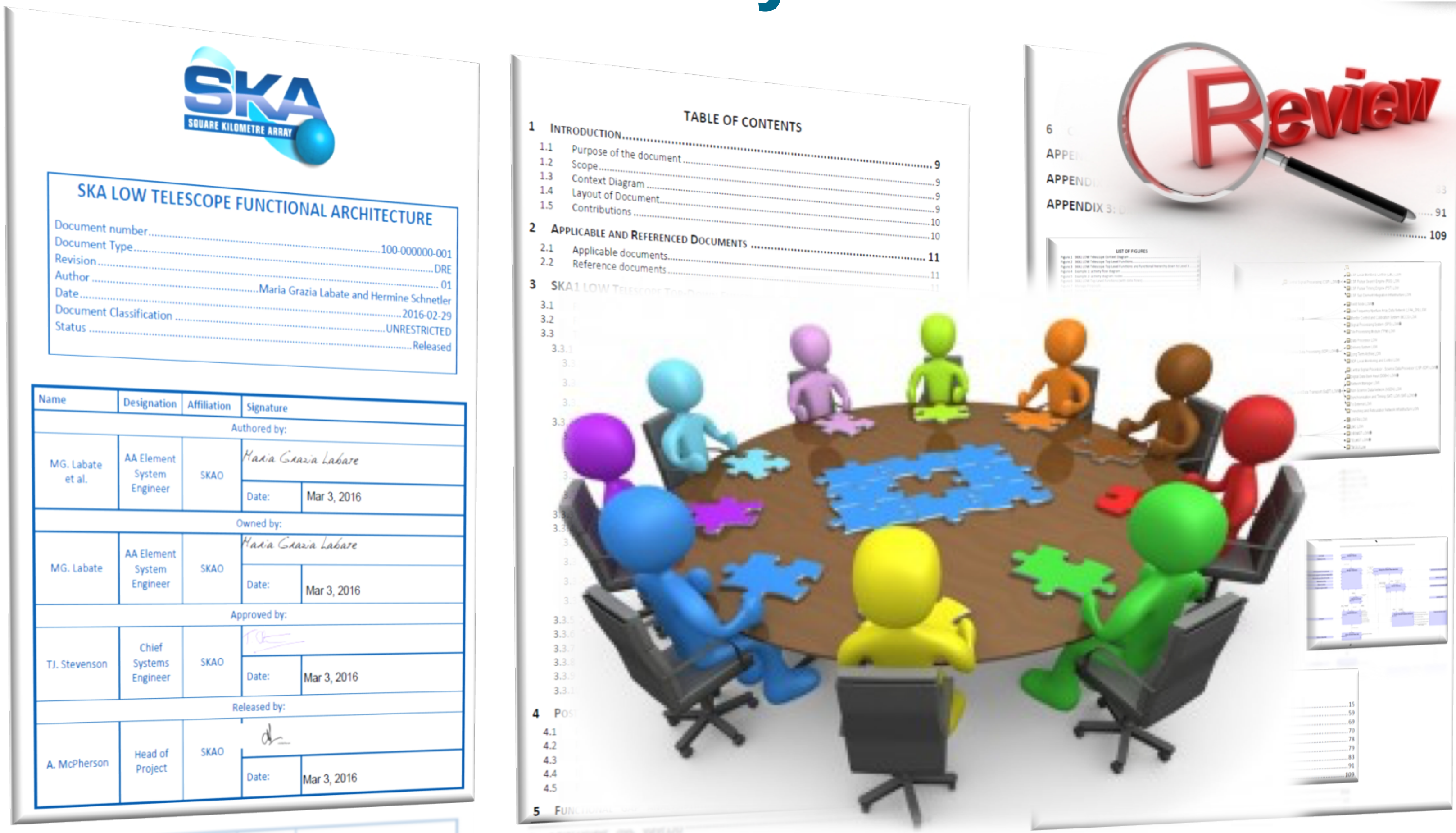
			Date:	Mar 3, 2016
Approved by:				
TJ. Stevenson	Chief Systems Engineer	SKAO		
			Date:	Mar 3, 2016
Released by:				
A. McPherson	Head of Project	SKAO		
			Date:	Mar 3, 2016

TABLE OF CONTENTS

LIST OF TABLES

- ✓ Functional decomposition (135 functions at the moment)
- ✓ Identification of the data flow
- ✓ Descriptions of functions and data flows
- ✓ Functional Requirement Mapping
- ✓ Function to Products
- ✓ Interfaces to products
- ✓ Data items across Interfaces
- ✓ Identification of Gaps

LOW Functional Analysis



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- ✓ Data items across Interfaces
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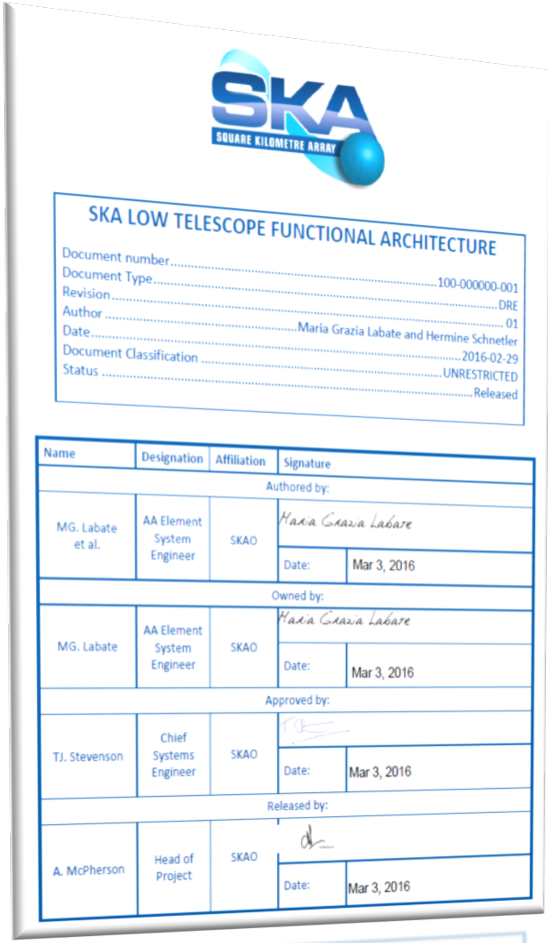
LOW – MID FA Harmonisation



SKA LOW TELESCOPE FUNCTIONAL ARCHITECTURE

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Author .... Maria Grazia Labate and Hermine Schnetler
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MG. Labate et al.	AA Element System Engineer	SKAO	Maria Grazia Labate Date: Mar 3, 2016
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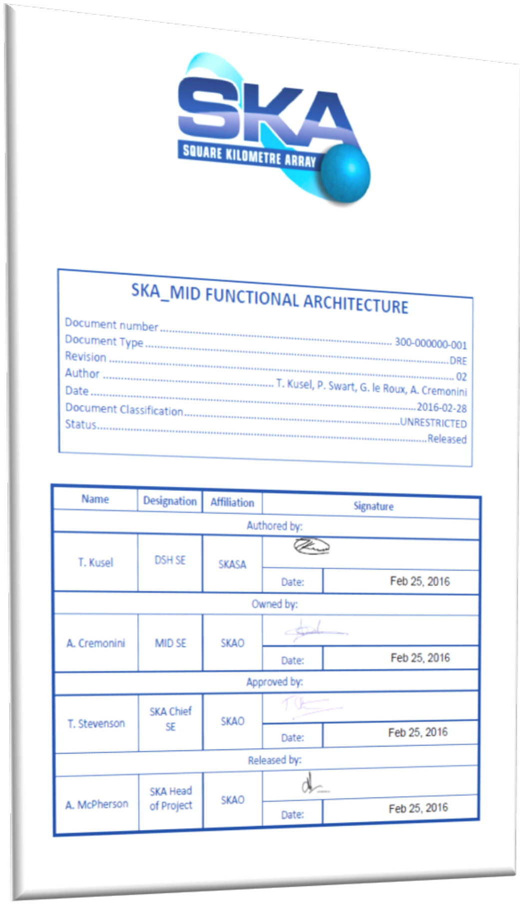
MG. Labate	AA Element System Engineer	SKAO	Maria Grazia Labate Date: Mar 3, 2016
Approved by:			
TJ. Stevenson	Chief Systems Engineer	SKAO	Date: Mar 3, 2016
Released by:			
A. McPherson	Head of Project	SKAO	Date: Mar 3, 2016

LOW



SKA_MID FUNCTIONAL ARCHITECTURE

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Name	Designation	Affiliation	Signature
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Approved by:			
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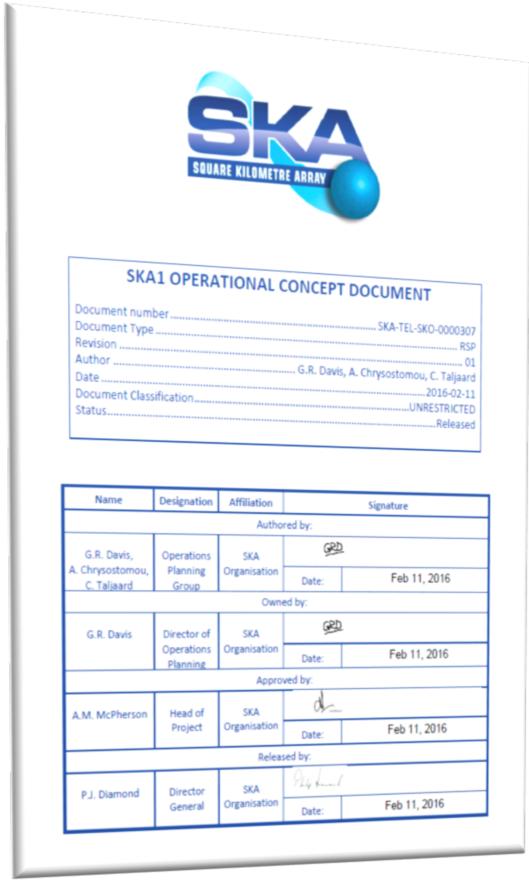
Released by:			
A. McPherson	SKA Head of Project	SKAO	Date: Feb 25, 2016

MID



SKA1 OPERATIONAL CONCEPT DOCUMENT

Document number SKA-TEL-SKO-0000307
Document Type .... RSP
Revision 01
Author .... G.R. Davis, A. Chrysostomou, C. Taljaard
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Authored by:			
G.R. Davis, A. Chrysostomou, C. Taljaard	Operations Planning Group	SKA Organisation	GRD Date: Feb 11, 2016
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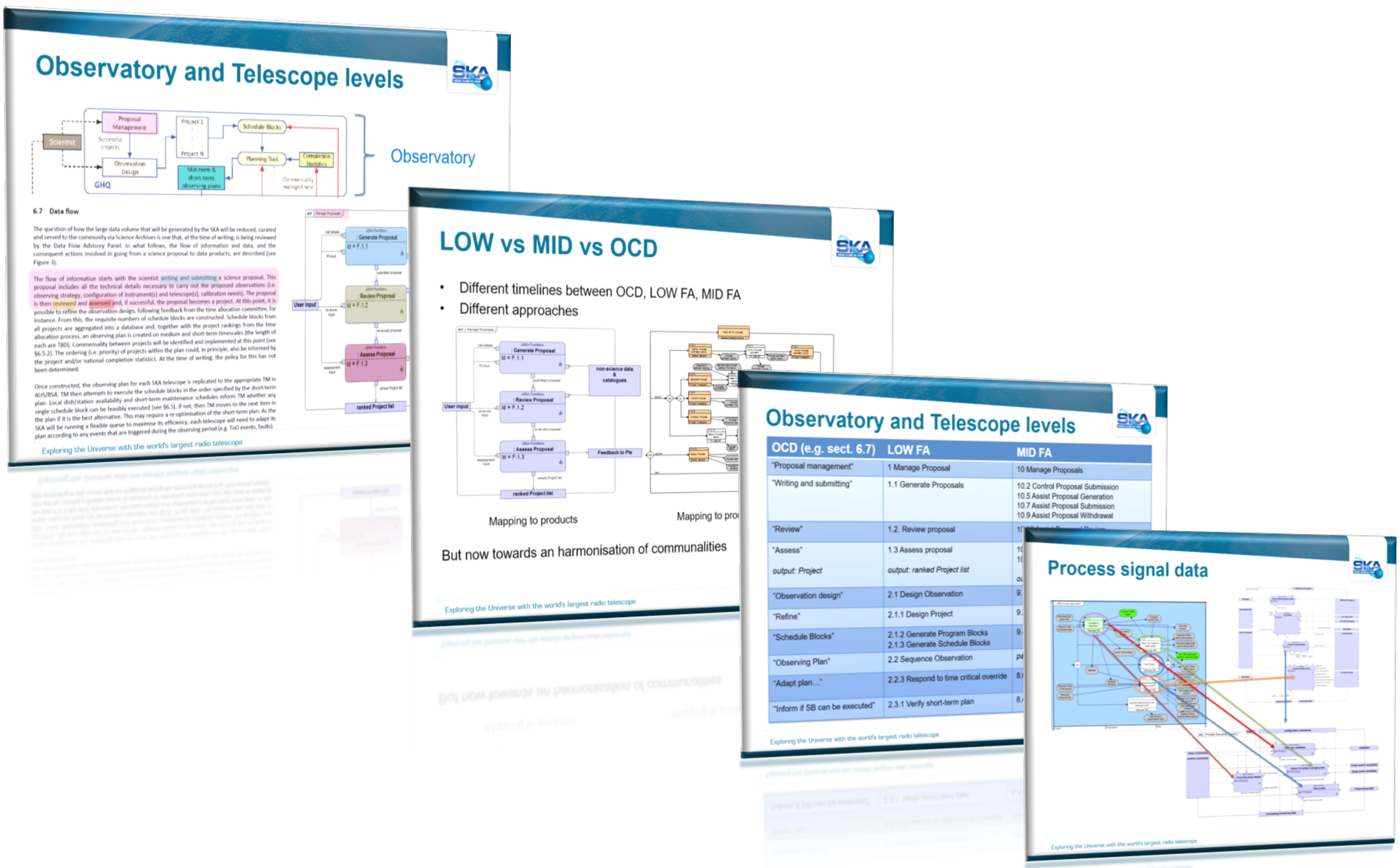
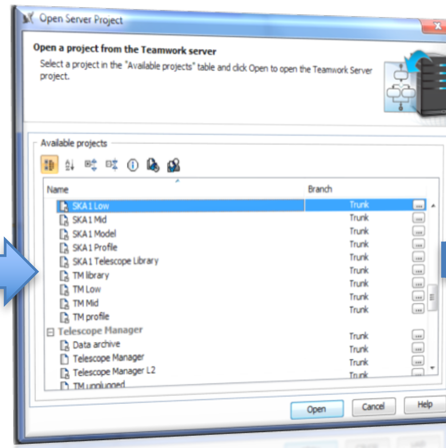
Approved by:			
A.M. McPherson	Head of Project	SKA Organisation	Date: Feb 11, 2016
Released by:			
P.J. Diamond	Director General	SKA Organisation	Date: Feb 11, 2016

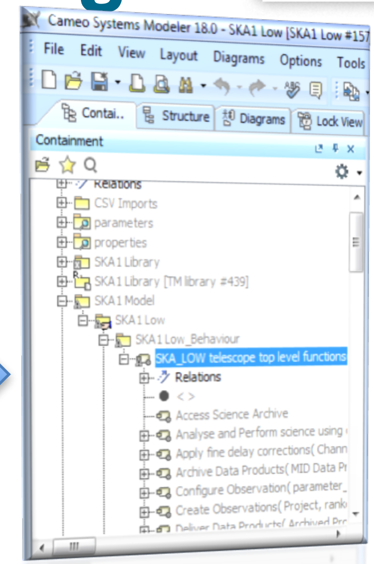
OCD

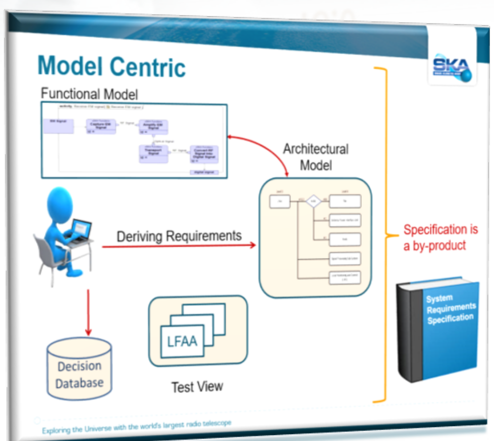
LOW – MID FA Harmonisation

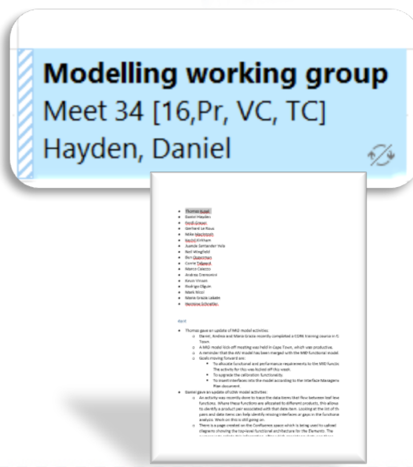


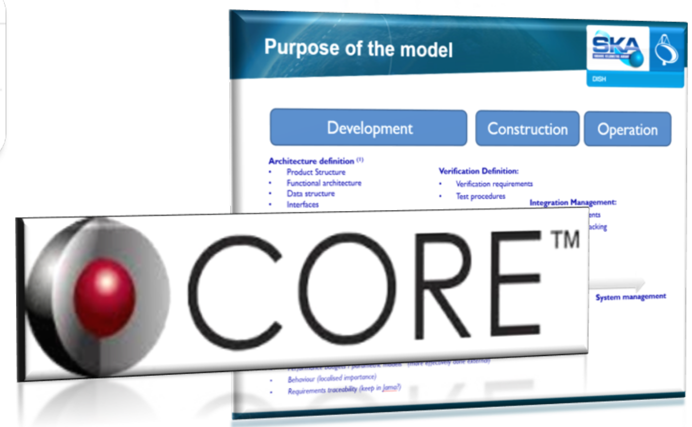
Model Based Systems Engineering











L1 Requirements and statistics

Release of Version 7 of the SKA PHASE 1 SYSTEM REQUIREMENTS SPECIFICATION

Jama

Baseline to Baseline Comparison Report

Baseline 1 - SKA-TEL-SKO-0000008-AG-REQ-SRS-Rev07 01/03/16

Created by Wallace Turner on Mar 1, 2016

Baseline 2 - SKA-TEL-SKO-0000008-AG-REQ-SRS-Rev06B-06/27/2015

Created by Wallace Turner on Jun 27, 2015

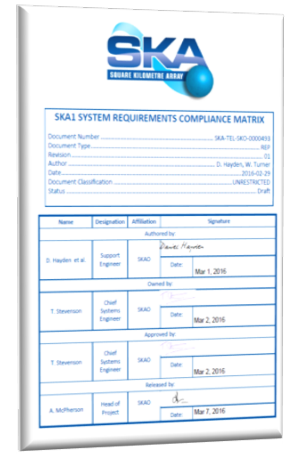


Table 4: Mapping between consortia levels of compliance and SKAO levels of compliance

Consortia level of compliance	Mapping to SKAO level of compliance	Text added to Compliance Rationale column
Yes/Y	Yes	
No/N	No	
N/A	No	Not applicable
TBD	TBD	
Intend to comply – low risk	TBD	Intend to comply – low risk
Intend to comply – high risk	TBD	Intend to comply – high risk
Partial	Partial	

Element	# of L2 reqs	# of Orphans L2	Ratio	# of L3 reqs	# of Orphans L3	Ratio
SDP	132	0	0	0	0	NA
INFRA AUS	122	0	0	0	0	NA
LFAA	100	0	0	0	0	NA
INFRA SA	291	174	0.597938144	0	0	NA
TM	246	73	0.296747967	289	0	0
SADT	128	0	0	727	0	0
DSH	284	181	0.637323944	569	42	0.073813708
CSP	469	81	0.172707889	1228	12	0.009771987

Traceability of Level 3 requirements to Level 2 requirements for each Element of the SKA1 system, and an indication of which Level 2 requirements do not trace directly to Level 1 requirements. The requirements presented are confined to those that are aligned to revision 6C of the Level 1 requirements, and that were received by the consortia on request of such requirements.

Thank you…Questions?