**Summary of the First SKA Design Convergence Workshop, 13 January 2004**

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This document summarises the main points of the workshop held in Cape Town on 13 January 2004 to discuss the desirability and options for combined or hybrid technical designs for the SKA. It is not a set of minutes and does not ascribe individual comments to individuals at the meeting, but attempts to draw together the various strands of discussion that took place at different times during the meeting.The Workshop programme is included as Annex 1.

The purpose of the workshop was to explore the parameter space of combined designs and narrow down the possibilities to a small number that can be focussed on in the future. In addition, the workshop held a discussion about how to continue to engage the community in the pre-SKA era. Input material to the Workshop included a number of papers outlining possible combined concepts and ideas on how individual engineering groups in the world could contribute to the alternative concepts. These papers can be found in the international SKA Memo series as memo 49.

## Introduction

1) In its meeting in January 2003 the ISSC defined the options for selecting the SKA design concept as being

- mutual convergence to a single cooperative design concept
- down-selection amongst cooperative designs including combinations of two or more concepts
- down-selection amongst individual concept proposals

The top-level selection criteria for the design concept are:

- it captures a significant fraction of the science of the Key Science Projects
- it has demonstrated engineering feasibility and compatibility with the site choice
- it is maintainable at a reasonable cost
- it is upgradable
- it is within the nominal cost envelope of 1 B€/USD

The timescale to concept selection and beyond is currently foreseen to be:

- 2004-7 demonstrator development including a major external review in 2006, submit funding proposals for a 5% SKA demonstrator
- 2008 selection of technical design, start construction of the 5% demonstrator on chosen site (SKA phase 1)
- 2009 submit funding proposals for full array
- 2012 start construction

2) Why talk about convergence? The trigger for this workshop was the clear ISSC preference to encourage thinking towards a mutually agreed single concept that is inclusive and engages the global community. This preference is based on the following considerations:

- It is not clear that any of the individual design concepts can, by itself, cover the wide range of science goals proposed for the SKA.
- The SKA is only affordable through a global collaboration, so it makes sense to engage the global community as fully as possible in the final design.

3) Five different types of hybrids can be identified (see SKA memo 48, *Veidt et al*):

- *frequency hybrids*, such as aperture arrays + the LNSD parabolas

- *complementary hybrids* such as one or more LARs at the centre of the compact core + small parabolas in the outer regions
- *technology hybrids*, of which the cylinder concept is an example
- *risk hybrids* eg LNSD (relatively safe) + cylinders or AA/LL/LAR (more risk)
- *site hybrids*, one telescope - 2 sites; a high frequency site and a low frequency site
- *poitical hybrids*, in which political funding considerations (juste retour) play a role

The general goals for hybrid concepts for the SKA are that the cost should not exceed the 1 B€/$ goal and must not compromise the science goals. In practical terms, the study of hybrids must be part of the overall engineering demonstration process, not a separate effort; we need to match the scientifically interesting hybrids to this process.

The workshop only considered hybrids that covered all or most of the frequency range specified in the SKA Science Requirements document. Other options providing a restricted frequency coverage and reduced cost (eg pre-loaded parabolic dishes or aperture arrays on their own) were not considered.

**Hybrid proposals considered**

| | Advantages | Disadvantages |
|---|---|---|
| LNSD+aperture arrays<br><br>AA <1.5 GHz; LNSD>1.5 GHz | Covers full frequency range; multi-fielding in low band for fast all-sky surveying and multiple users; symmetric LNSD design possible → cost savings | Duplication of central core infrastructure needed for high and low freq science |
| LNSD+cylinders<br><br>cyl <1.5 GHz; LNSD>1.5 GHz | Covers full frequency range; large FOV <1.5 GHz for fast all-sky surveying; symmetric LNSD design possible → cost savings;cylinder collecting area is releatively cheap | Duplication of central core infrastructure needed for high and low freq science; |
| LNSD+LAR<br><br>LAR(s) in central core; small parabolas in intermediate and outer parts of array | Excellent surface brightness temp sensitivity; matched FOV across the full frequency range | FOV too small for fast all-sky surveying for dark energy; multi-fielding impossible |
| LNSD+Luneberg Lenses<br><br>LL <1.5 GHz; LNSD >1.5 GHz | Covers full frequency range; multi-fielding in low band for fast all-sky surveying and multiple users; symmetric LNSD design possible → cost savings | Large diameter lenses needed at the lowest frequencies (weight, cost?); duplication of central core infrastructure needed for high and low freq science |
| Aperture arrays+Luneberg Lenses<br><br>AA<1.5 GHz; LL 1-22 GHz | Multi-fielding from 100 MHz to 22 GHz for fast all-sky surveying and multiple users | Poor sensitivity for freq > 10 GHz; many components |
| LAR+other large N concepts<br><br>LAR(s) in central core; AA/cyl/LL in intermediate and outer parts of array | Excellent surface brightness temp sensitivity | Unmatched FOV; FOV (LAR) too small for fast all-sky surveying for dark energy |
| LNSD+focal plane array | Large FOV possible for fast all-sky surveying including dark energy project | Extra mechanical structure to swing FPA away for high freq ops; requires separate beam-former |

| | | |
|---|---|---|
| LNSD+log-periodic antennas mounted on back of secondary reflector | Shares hardware and infrastructure | Mechanical stresses incrase mount requirements and cost; poor $A_{eff}/T_{sys}$ |
| LNSD (inner 6m) + mesh (outer 6m) | | Mechanical costs increased; no multiple-FOV possible |
| LNSD+existing large single dishes | Uses existing and future large collecting area infrastructure (in northern hemisphere); reduces data transport costs using existing fibre networks | Shared use with other users of non-SKA telescopes; different telescope types to be integrated; no multiple FOV |
| Elements consisting of four 2-3 m diameter solid parabolas mounted on a single azimuthal frame | Reduces pointing requirements at high frequencies; simpler mass production | Not enumerated |
| LNSD+LOFAR+<br><br>LOFAR 10-240 MHz; LNSD >250 MHz | Augmenting LOFAR collecting area (LOFAR+) a cheaper option to cover low end of the frequency range | Reduced sensitivity 200-800 MHz; insufficient sensitivity for dark energy project |
| LNSD+AA+LOFAR+ | Covers the full frequency range | Not enumerated |
| LL+AA+LOFAR+ | A multi-fielding instrument across a wide ffrequency range | Not enumerated |
| LAR+LOFAR+ | Not enumerated | Not enumerated |
| LNSD+CYL+LOFAR+ | Not enumerated | Not enumerated |
| LL+CYL+LOFAR+ | Not enumerated | Not enumerated |

Rough estimates of costs for LNSD+Aperture Array Tiles was $B 1.5, and $B 1.1-1.3 for LNSD+Cyl. No cost estimates were available for other possible hybrid concepts.

It was also noted that LOFAR in northern Europe does not allow SKA +LOFAR+ combinations since Europe is not a candidate for the SKA site.

**Pathfinders for the SKA**

The following instruments were noted as being pathfinders or niche-science instruments for the SKA:
EVLA (phase 1 funded, phase 2 proposal submitted, phase 2 expected to be completed 2012); ATA (partially funded, to be completed 2008); LOFAR (funded, to be completed 2008); eMERLIN (funded, to be completed 2007); eEVN (partially funded, to be completed in 2005-7) SKAMP (funded, to be completed 2007); FAST; CLAR; HIFAR.

The FAST, CLAR and HIFAR concepts are all very large collecting areas targeted on low surface brightness temperature science and surveys (HI and pulsars). FAST (500 m diameter) would cost about USD 60M, CLAR (300 m diameter) about USD 30M, and HIFAR (200000 $m^2$ ) about USD 60M. FAST has been proposed to the Chinese Academy of Sciences and there is hope that construction could start in 2006. CLAR and HIFAR have not yet been proposed for funding; the earliest start is 2006.

**Comments by the IEMT on the concept selection process**

1) there is a need to make sensible optimisations, and modify our ambitions where necessary. Magic is unlikely to play a role in the SKA development.

2) The continuing focus on demonstrators is important to determine the viability of the various constituent concepts
3) Concept costs need updating, in particular for the aperture array. The initial HIFAR costs may be optimistic. The engineering cost/performance simulator in preparation should help.
4) Need to assess the scale and cost of post-processing for imaging and non-imaging applications for all concepts, including hybrids. This may be significantly helped by the new simulation and software engineering efforts, and may be a major factor in concept selection.
5) Experimental verification of the engineering simulations by demonstrators is essential.
6) Need to share knowledge on non-antenna areas of the SKA – workshops at URSI ae a possibility.
7) Dynamic range and fidelity issues, large N vs small N, affect data processing and software, and ultimately the concept choice.
8) Issues to be considered for hybrids:

- Are there advantages in sharing infrastructure; do they justify keeping the SKA in one site and as one project? 20-25 % of the cost of the array is in non-concept-specfic infrastructure.
- Can we use one backend to do all the signal processing for the different parts of the hybrid?
- The role of LOFAR in meeting the low-frequency goals of the SKA (SKA-low or LOFAR+)

**Comments on the hybrid concepts by the ISAC**

1) the $A_{eff}$/Tsys vs frequency must remain the most important parameter, do not want a factor of 2 lower as compromise for full frequency coverage
2) Multi-fielding across the full frequency range needs further investigation for its scientific benefits; the “week in the life of the SKA” (see Hall and Chippendale in SKA Memo 48) is a means of coming to grips with this question.
3) The polarisation purity of hybrids needs investigation
4) Can non-hybrids do the key science projects better than hybrids?
5) Operational modelling of the use of the SKA may show that it is desirable to give preference to particular key science projects and delay others. Are people prepared to wait? Need a “Year in the life of the SKA” expanding on the “week” included in the Hall and Chippebdale document.
6) Some frequency overlap is necessary between the antenna concepts in hybrids, for calibration, but this does not need to be large.
7) Flexibility in design should include the use of distributed computing. Software should take account of Moore’s Law

**Discussion**

**What is the best strategy for optimising the chances of funding the full SKA?**
Three options were discussed, all of which found support amongst the Workshop participants:

1) *form a global cooperation from 2008 onwards on a hybrid concept.*
   But are we not trying to prove that 1+1=1? Can we build a hybrid which maintains the broad science case for 1 B$?

2) *concentrate on a single concept after 2008 providing either low frequencies or high frequencies in order to keep costs within the nominal limit*.
   A hybrid would not be needed in this case.

Restricting the frequency range to frequencies 100 MHz-1.5 GHz would mean that the AA, Cyl, KARST, LAR, PLPD concepts remain in contention; restricting the frequency range to 1-25 GHz would mean that the LNSD and LAR concepts remain in contention.

This requires the ISSC to assign weights to the key science projects

3) *build a number of 5-10% SKA pathfinders from 2008 onwards that are major science and technology demonstrators in their own right and that at the same time build up the national and regional radio astronomy communities.*

It is clear that with as broad and frequency-dependent a science case as we have for the SKA, it is inevitable that proposals for niche-science or SKA pathfinder insturments will be made, to be realised on shorter timescales than the SKA. Examples are HIFAR and CLAR. Whether niche-science instruments can be regarded as SKA pathfinders depends on whether the technology is that chosen for the full SKA and whether the timescales for realisation are sufficiently short not to delay proposals for full SKA funding.

The concern was raised that manpower resources for the SKA will be absorbed by the pathfinders. One can argue that the SKA community needs to keep its eye on the goal of building a single instrument, and not get too caught up in advocating local designs. “Ask not what SKA can do for you, but what you can do for the SKA.”

**Hybrids selected for further analysis**

At the end of the discussion, a small number of hybrids were selected for further analysis (see table). These included LNSD+AA, LNSD+CYL, LL+AA, and LL+CYL, while the LAR was recognised as a frequency hybrid in itself since it will cover the full frequency range. Additional information will be requested from the proponents of the four non-LAR hybrid concepts.

| | AA | CYL | KAR | LAR | LNSD | LL | PLPD |
|---|---|---|---|---|---|---|---|
| AA | | | | | | | |
| CYL | | | | | | | |
| KAR | | | | | | | |
| LAR | | | | X | | | |
| LNSD | X | X | | | | | |
| LL | X | X | | | | | |
| PLPD | | | | | | | |

**Preliminary inventory of technological expertise around the world**

The workshop considered the contributions that could be made to the various design concepts from the different groups around the world. A number of possibilities were highlighted, for example, the mechatronic expertise in China developed for the FAST focal platform control is applicable to the LAR concept and vice versa. The following table summarises current expertise in a number of areas of importance to the SKA project, and should be viewed as a first attempt to capture this information.

| | Australia | Canada | China | Europe | India | USA |
|---|---|---|---|---|---|---|
| | | | | | | |
| Science | x | x | x | x | x | x |
| Antennas/feeds | x | x | x | x | x | x |
| Receivers | x | x | x | x | x | x |
| Feed transport | | x | x | | | |
| Calibration | x | x | x | x | x | x |
| Phased arrays | x | x | x | x | | |
| Data transport | x | | x | x | | x |
| Configuration | x | | x | x | | x |
| Simulations | x | | | x | | x |
| Imaging techniques | x | | | x | | x |
| Survey techniques | x | x | x | x | | x |
| RFI mitigation | x | | x | x | x | x |
| Correlation | x | x | | x | | x |
| Computing | | x | | x | | x |
| Software | x | x | x | x | x | x |
| Systems analysis | x | x | x | x | x | x |
| Construction/infrastructure | x | | x | | | x |
| Operations | x | | x | x | | x |
| Site characterisation | x | | x | | x | x |
| Siting | x | | x | x | | x |
| Education and public outreach | x | x | x | x | x | x |

**Timescale for the convergence process**

*Jan 04*: first workshop at Cape Town
June 04: assessment of the feasibility, cost and science benefit of the propose hybrid concepts by ISAC and IEMT. Draft report on options for international collaboration.
*July 04*: second convergence workshop at Penticton to refine and narrow the list of hybrid concepts
*Oct 04*: global teams report interest in supporting hybrid options
*Nov 04*: report on status of possible hybrid approaches
*Jan05*: third convergence workshop in GuiYang. Define international hybrid concepts to be pursued/proposed.

**Discussion on engaging the radio astronomy community in the pre-SKA era**
*Comments made:*

- With EVLA, ALMA, eMERLIN, LOFAR, eVLBI, ATA all in the pipeline, there is no danger that the astronomical community will disengage from radio astronomy in the pre-SKA era.
- None of these instruments attack the SKA key science projects; one can argue for SKA niche-science instruments to be built to attract young people into the SKA project early on.
- The upgrades all miss the scale and scope of the SKA, eg EVLA will not do HI science in the way the CLAR and HIFAR will.
- We should be looking to engage the entire electromagnetic community in radio astronomy and the way to do that is build a niche-science instrument that attacks one or more of the current big issues in astronomy.
- ATA, EVLA and LOFAR are not fully funded yet, so one shouldn't muddy the waters with new proposals.
- A pathfinder/ niche-science instrument is a distraction unless it is Phase 1 of the SKA.
- Aperture arrays is a winning technology on the longer term; is there any way of accelerating its development

This debate will clearly continue!

**Annex 1.** **Convergence Workshop Programme**

**Capetown, 13 January 2004**

| | | |
|---|---|---|
| **09:00** | 1. | Scope and purpose of the workshop (Richard Schilizzi) |
| | 2. | Short presentations on potential hybrid solutions ($10^m$ talk, $10^m$ discussion) |
| **09:15** | 2.1 | SKA Hybrids using the US LNSD Concept (Joe Lazio) |
| **09:35** | 2.2 | Hybrid solutions – A European perspective (Peter Wilkinson/Arnold van Ardenne) |
| **09:55** | 2.3 | Hybrid solutions for the Square Kilometre Array: perspectives from the LAR (Bruce Veidt) |
| **10:15** | 2.4 | A cylinder plus 12-m dish hybrid (Ron Ekers/John Bunton) |
| **10:35** | **Coffee/tea** | |
| **11:00** | 2.5 | A multi-fielding SKA covering the range 100 MHz to 22 GHz (Peter Hall/Aaron Chippendale) |
| **11:20** | 2.6 | Potential combined concepts with KARST (Bo Peng) |
| **11:40** | 2.7 | HIFAR (Brian Boyle) |
| **12:00** | 3. | Contributions from design teams to other concepts if their design is not chosen (please come prepared!) |
| **12:30** | **lunch** | |
| **13:30** | 4. | Comments on feasibility of hybrid concepts (IEMT)<br>Preliminary costing (Peter Hall)<br>Scientific utility of the hybrids (Steve Rawlings) |
| **14:30** | 5. | Discussion |
| | 5.1 | Open discussion of feasibility and scientific utility of proposed hybrid concepts, and their place in the engineering demonstration process |
| | 5.2 | Activities and schedule leading toward convergence |
| **15:30** | **Coffee/tea** | |
| **16:00** | 6. | Open discussion on how to maintain the continuity of the radio astronomy communities around the world in the pre-SKA and SKA eras |
| **17:00** | 7. | Presentation from Rudolph Gouws on “The strategic and economic future of South Africa” (part of the “Industry Day” programme from the day before) |
| **17:30** | **End** | |

**Annex 2: Documents included in SKA Memo 48**

J. Lazio “SKA Hybrids using the US LNSD Concept”
P. Wilkinson “Hybrid solutions – A European perspective”
B. Veidt “Hybrid solutions for the Square Kilometre Array: perspectives from the LAR”
R. Ekers, J. Bunton “A cylinder plus 12-m dish hybrid”
P. Hall, A. Chippendale “A multi-fielding SKA covering the range 100 MHz to 22 GHz”
B. Peng “Potential combined concepts with KARST”
B. Boyle “HIFAR”
A. Van Ardenne “Hybrids; a combined concentrator for high frequency observing”
A. R. Thompson and B. Veidt “Comments on Hybrid-System Documents”