
The SKA Story: Prequel, Episodes 1 and 2

Richard Schilizzi, Ron Ekers and
Peter Hall

Innovation and Discovery in Radio Astronomy
16 September 2016

Running title: “The History of the SKA. Volume 1: 1993-2011”

Authors: RTS, RDE, PJH

Contents

Preface

1. Introduction
2. Pre-history
3. SKA science
4. SKA design
5. Global collaboration on science and technology
6. Project politics and funding
7. Site selection
8. Industry engagement
9. SKA as a mega-science project

The Prequel

- early ideas and realisations of large collecting area telescopes
- key meeting in Socorro in October 1990
- formation of URSI Working Group on Large Telescopes in August 1993

Episode 1: 1993 – 2005 “Born global - doing it our way”

- From URSI LTWG to active Funding Agency involvement
 - science drivers
 - engineering challenges
 - organisation

Episode 2: 2006 – 2012 “Growing pains – shaping the SKA”

- living with the Funding Agencies
- design decisions and engineering processes
- competitions for telescope and HQ sites
- establishment of the SKA Organisation as a legal entity and initial funding

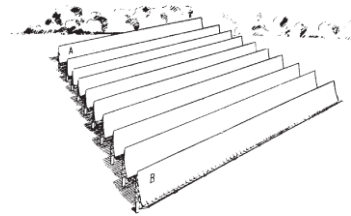
Episode 3 is still being written

- **Human memory is a leaky storage device**
Digital memory is also not perfect
- **This is a work in progress, and is not at all complete**

Prequel: big telescopes

1962 “Future large telescopes”, Bracewell, Swarup, Seeger

~ 1 sq km



An array of parabolic cylinders like a venetian blind

1963 Arecibo

Bill Gordon

~0.07 sq km



1958-1964 Benelux Cross

Jan Oort

100 x 30m dishes →

0.1 sq km



Big telescopes

1971 Project Cyclops

Barney Oliver

100x100m dishes over a few sq km →
1000x100m dishes over 10 sq km

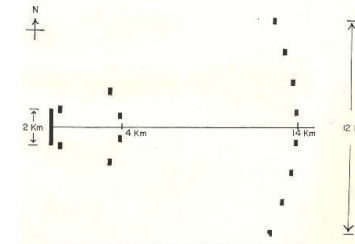
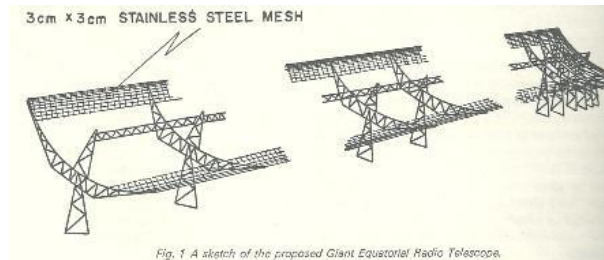


SETI

1977 Giant Equatorial Radio Telescope

Swarup

2 km x 50m cylinders +
14 cylinder segments
~0.2 sq km



1984 GMRT proposal

Swarup

30 x 45m
antennas
Funded 1989
Completed 1995
~0.05 sq km



The Socorro meeting in 1990

Govind
Swarup



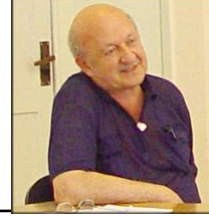
Peter
Wilkinson



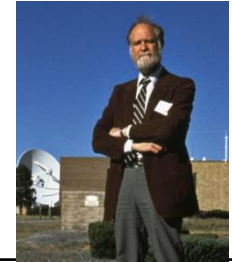
Jan
Noordam



Yuri
Parijskij



Ron Ekers



Key players converging on Socorro, October 1990 for the SKA epiphany at IAU Colloquium 131

And like many historical epiphanies, nobody paid it much attention for a while....

The SKA: Good ideas have many fathers...

Govind
Swarup



Peter
Wilkinson



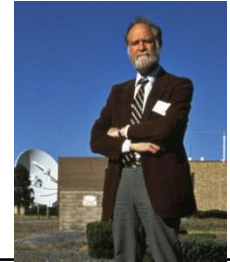
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Ron Ekers



1981 GERT
proposal

1984 GMRT
proposal

1989 GMRT
funded

HI at high redshift
included in
science case

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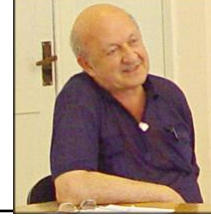
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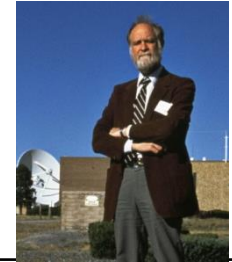
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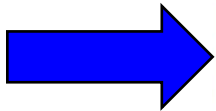
1985 note on
Large Radio Flux
Collector

The 1985 Note

Paper written for U.K. Committee (R.A.S. & Royal Society) inquiring into "future plans for U.K. astronomy" before I learnt about the CfA.R.T. 5 July 1985
 A LARGE COLLECTING AREA RW

of the
 Many recent discoveries from radio astronomy have been as a result of the improved imaging and resolution afforded by new nested-element arrays, and VLBI, in the centi- and decimetre wavelength regimes. Currently there is a world-wide effort and opening up the ^(sub) millimetre regime with many telescopes and ~~four~~ ^{newer} arrays either recently operational or just about to come on. There is one aspect of radio astronomical technique, that of raw sensitivity, which has not been improved since the advent of the Arecibo telescope ~20 years ago. The evident success of Arecibo in astronomical terms, despite its restricted imaging capability, is a testament to the fact that its collecting area is roughly ten times that of the largest steerable paraboloids. If we could construct a radio telescope with ten times larger collecting area still we could confidently expect to garner a rich harvest of new, and unexpected, discoveries. It is financially out of the question to array a large number (100 MTA's!) of ~~large~~ ^{fully steerable} paraboloids to obtain this collecting area and so clearly one must give up the ^{flexibility} offered by ~~such~~ ^{expensive} elements. I therefore suggest we restrict the telescope's operation to the wavelength range ~18 to ~23 cm. The design principles are still ~~not~~ ^{under discussion} (!) but phased mini-arrays of yagi antennas cylinders/troughs arranged in a "Y" are possibilities. Assuming that such an antenna could be constructed for a cost of a very large (eg. ~150m) paraboloid what would it do? Its primary goal would be imaging/detecting and hence determining the velocity and column density of ^{atomic} neutral hydrogen, which comprises ~90% of the ^(observable) matter in the universe. Very sensitive redshift surveys would vastly improve our kinematical picture of the nearby universe; Fisher-Tully surveys would make a major contribution to our

"The evident success of Arecibo in astronomical terms, despite its restricted pointing capability, is a testament to the fact that its collecting area is roughly ten times that of the largest steerable paraboloids. If we could construct a radio telescope with ten times larger collecting area still, we could confidently expect to garner a rich harvest of new, and unexpected, discoveries."



The SKA: Good ideas have many fathers...

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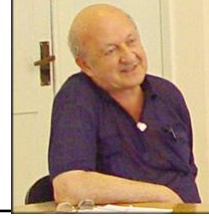
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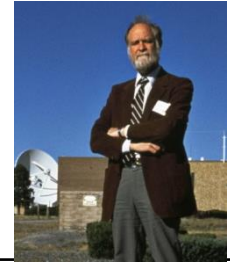
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Priorities for
British Astronomy

From the RAS-RS Report on the Priorities for British Astronomy, 1986

(iii) Large Radio Flux Collector

The sensitivity of many fundamental radio astronomical observations is limited by the collecting area of the radio telescopes involved. An array of reflector telescopes, possibly using cylindrical paraboloids, could provide a large collecting area for comparatively long radio wavelengths, including particularly the 21-cm hydrogen line. A total area of several hectares would provide new prospects in several areas of radio astronomy.

The main difficulty in proposing such an array is to find a site reasonably free of radio interference. Cooperation between European radio astronomers may lead to a suitable proposal. A similar large radio telescope will soon be constructed in India. The costs of this proposal have not been estimated.

The SKA: Good ideas have many fathers...

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Swarup



Peter
Wilkinson



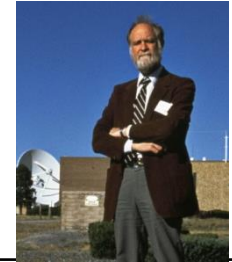
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1987? Robert and
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sensitivity and HI

1989 discussions
in Dwingeloo on
large collecting
area concepts and
science case

Director of
RATAN-600

The SKA: Good ideas have many fathers...

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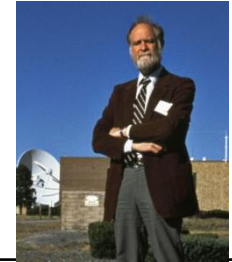
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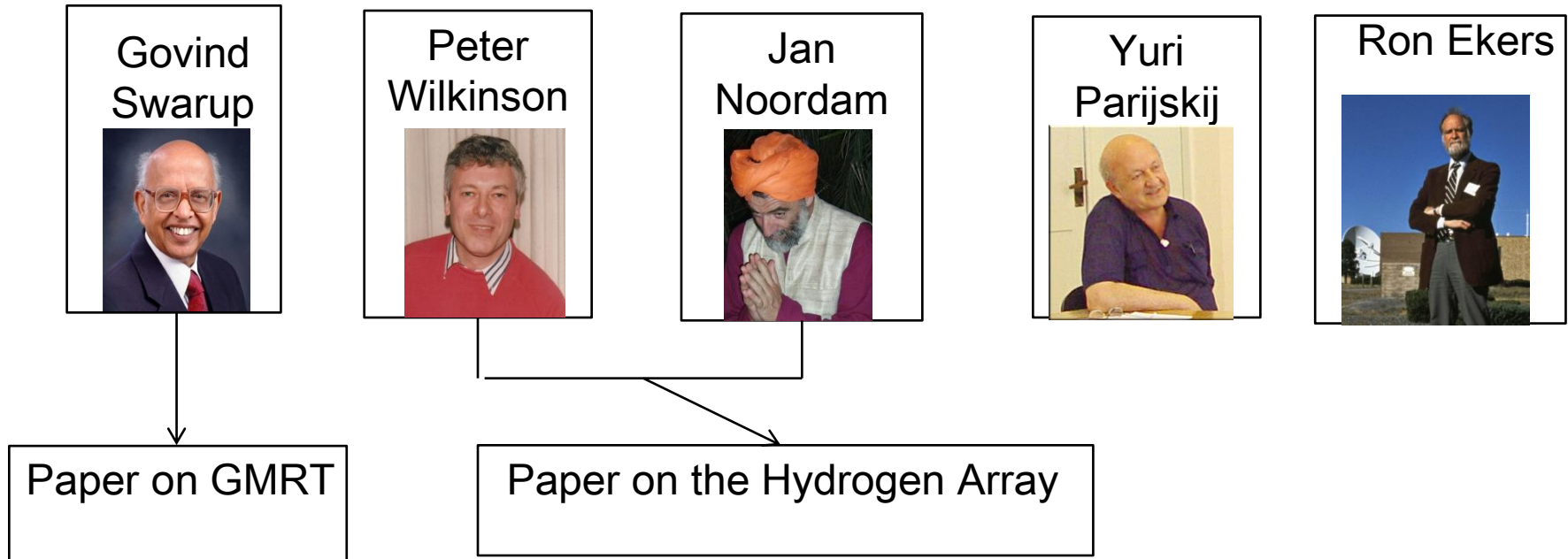
Director of
RATAN-600

Ex-VLA Director

ATNF Director

Chair URSI Comm J

The Socorro meeting in 1990



Hydrogen Array

Imaging HI at $<1''$ resolution needs 100x sensitivity of VLA

→ 1 sq km

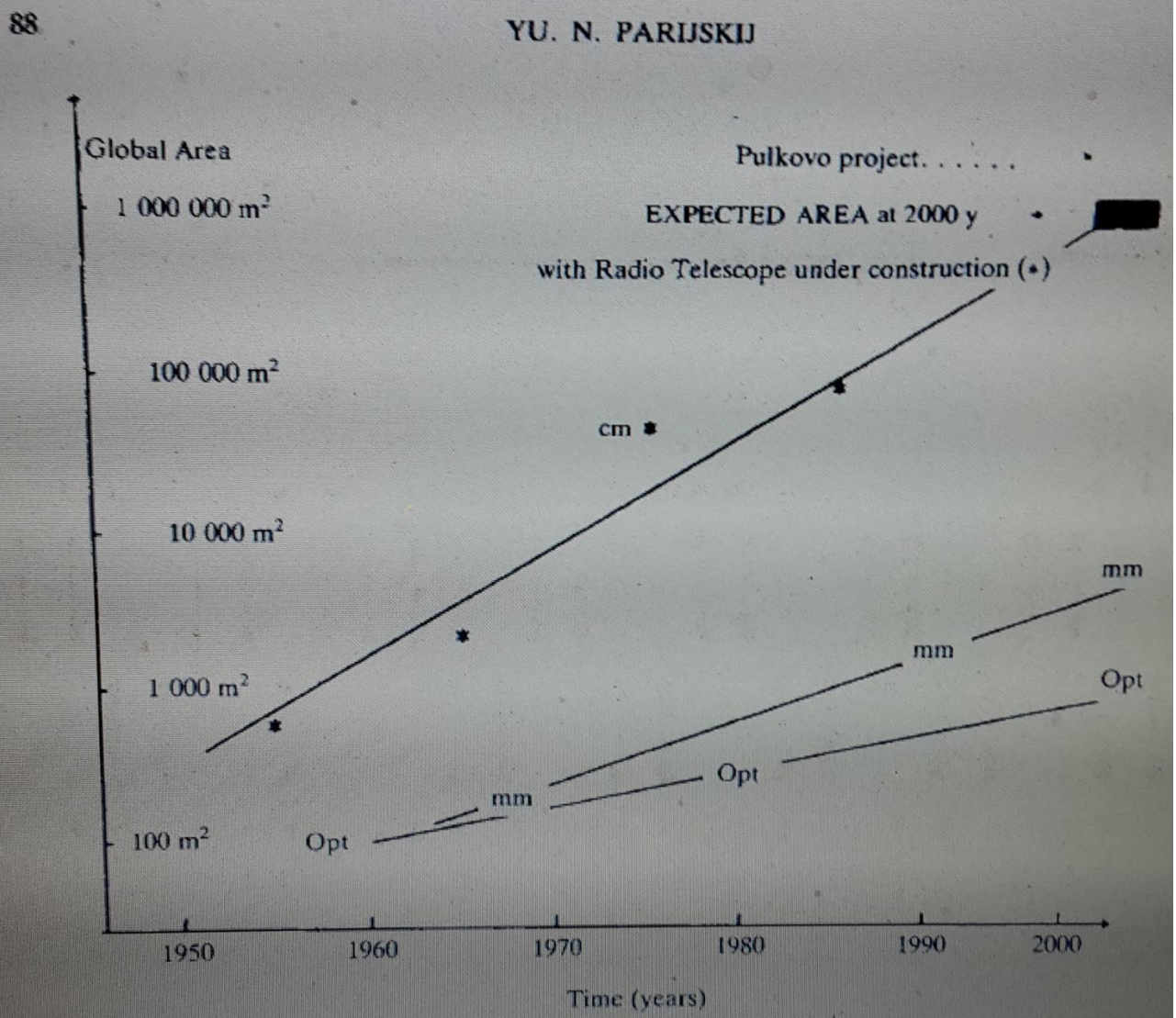


Figure 3 Growth of the collecting area of Radio Telescopes.

Govind
Swarup



Robert Braun
Jan Noordam
Ger de Bruyn



Yuri
Parijskij



Papers on Hydrogen Array,
GMRT

→ Noordam et al, EURO16
1991; Swarup papers
on ITRA, 1991, SETI
1992; Parijskij 1992

Govind Swarup



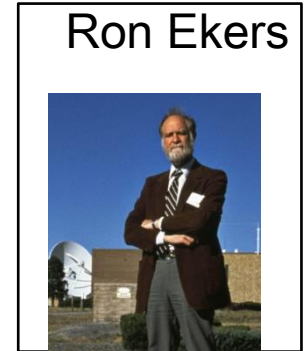
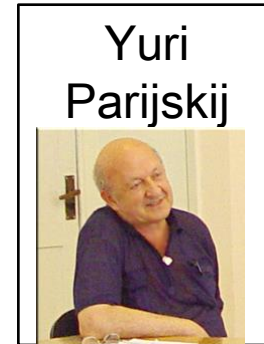
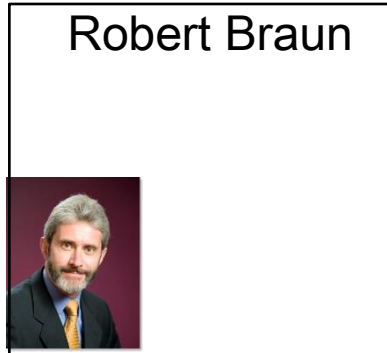
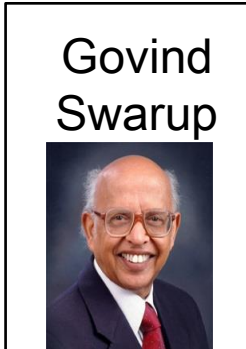
Ron Ekers



IAU Colloquium 131
Papers on Hydrogen Array, GMRT

Noordam et al, EURO16
1991, Swarup et al papers
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Parijskij 1992

March 1993 ESA Symposium on
Frontiers of Astronomy



Oct 1990, IAU Colloquium 131
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OECD contact with
Ron

Aug 1993 URSI Large Telescope
WG formed
(Chair: Robert Braun)

Start of SKA and End of Prequel

- How the global effort organised itself and raised its profile
- Science development and review
- Telescope design and review
- Site selection
- First interaction with the Funding Agencies

1993-2005: global organization

- 1993** URSI Resolution leading to the formation of the URSI LTWG – start of SKA
 - 1994** IAU WG on Large Scale Facilities formed (Butcher, Praderie, Ekers and Ishiguro);
LTWG also became a joint URSI - IAU WG
 - 1996** MoU to Cooperate in a Technology Study Program Leading to a Future Very Large Radio Telescope (led by Harvey Butcher)
 - 1999** US SKA Consortium formed, UCB, MIT, SETI, CIT, Cornell, OSU; chair Jackie Hewitt
- First meeting of a “self-appointed” SKA Steering Committee under Ron’s leadership

1999 meeting of SKA Steering Committee

3. Tentative Sequence of the Events for the international project.
- a. refine specifications.
 - b. reduce choice of technology to one or two.
 - c. construct one or two prototypes.
 - d. operate and refine prototypes, write proposal and make selection.
 - e. full construction.
- Full construction should begin around 2010. The timeline for this and the other items to be discussed at the next meeting.

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- 2000** European SKA Consortium formed (NL, UK, IT, FR, DE, ES), chair Harvey Butcher.

MoU on ISSC signed at IAU GA in Manchester, Chair: Ron, vice-Chairs: Jill Tarter and Harvey Butcher

SKA International Organization

- International SKA Steering Committee
 - 18 members representing 11 countries
 - 6 European (UK, Germany, Netherlands, Sweden, Italy, Poland)
 - 6 United States
 - 2 Canada
 - 2 Australia
 - 1 China
 - 1 India
 - 2 at large members
- MOU signed IAU Manchester August 2000



**Square Kilometre Array
Steering Committee
Signing Ceremony
Manchester
10 August 2000**



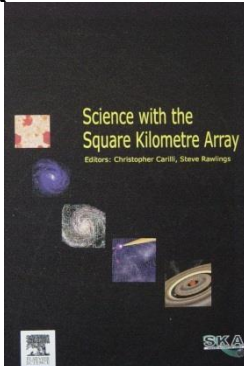
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 - 2000 European SKA Consortium formed (NL, UK, IT, FR, DE, ES), chair Harvey Butcher
MoU on ISSC signed at IAU GA in Manchester, Chair: Ron, vice-Chairs: Jill Tarter and Harvey Butcher
 - 2003** International SKA Project Office established in Dwingeloo, first full-time staff member
 - 2004** ISSC decision to stage SKA construction as Phase 1, Phase 2 and Phase 3
 - 2005** Funding Agencies first discuss the SKA

1993-2005: science development and review

Meetings

- 1995 IAU175 Bologna, Extragalactic radio sources. Scientifically relevant but not dedicated to SKA science;
IAF Congress, Ron's SETI and SKA talks
- 1997 *Oort Workshop, Leiden "Next Generation Radio Telescopes";
Amsterdam, "The most distant radio galaxies". Not SKA specific;
*1kT/SKA technical workshop, Sydney. Jointly with the URSI LTWG, included one full day on science.
- 1998 *Calgary, "The Square Kilometre Array", Science focus. (Proceedings)
- 1999 *Amsterdam, Perspectives on Radio Astronomy (Proceedings)
- 2002 *Bologna
- 2003 *Leiden, dedicated to writing chapters of the SKA Science Book
- 2004 *publication of the Science Book edited by Carilli and Rawlings
- 2003-4 *Development of Key Science Projects led by Bryan Gaensler; adopted at Pune ISSC meeting in 2005



Progression in the science case

1991 (Wilkinson IAU131)

Neutral Hydrogen Observations at $z=0$ to $z=10$ (Zel'dovich pancakes, but no EoR)

Pulsar searches and timing

Continuum sources

SETI

Mega-masers

1999 (US Consortium MoU)

Cosmology - the Universe on the Largest Scale

High Energy Astrophysics - The Radio-X-ray-Gamma-ray connection

Cosmogony - Origins, Evolution

Fundamental Physics

Constituents of the Universe

2003: SKA Key Science Drivers

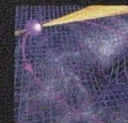
- **Probing the Dark Ages**
When & how were the first stars formed?
- **Cosmology and Galaxy Evolution**
Galaxies, Dark Energy and Dark Matter
- **Strong-field tests of General Relativity**
Was Einstein correct?
- **Origin & Evolution of Cosmic Magnetism**
Where does magnetism come from?
- **Cradle of Life**
What and where are the conditions for life?

plus **The Exploration of the Unknown as an underlying philosophy for design & costing**



Science with the Square Kilometre Array

Editors: Christopher Carilli, Steve Rawlings



1993-2005: telescope design

1995 1kT workshop in Sydney, first dedicated science and engineering meeting
Yearly technology workshops thereafter in Australia, Canada, Netherlands

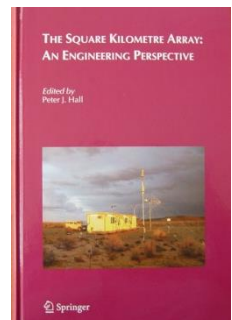


1995 -2005 National funding for technology research and prototyping

- **Aperture Arrays** in NL led by Arnold van Ardenne, first international SKA R&D
- **KARST** in China led by Nan Rendong
- **Large Aperture Radio** telescope in Canada led by Peter Dewdney
- **1hT** in the USA led by John Dreher, Sandy Weinreb → ATA
- **Luneberg Lenses** in Australia (MNRF) led by Peter Hall
- **Pre-Loaded parabolic dishes** in India led by Govind Swarup
- **Cylinders** in Australia led by John Bunton

2001 -2004 IEMT meetings to solicit and review White Papers and comment on technology developments

2005 Engineering book published; SKADS started in Europe with EC funding



1995-2005 telescope design

Artist's
impressions



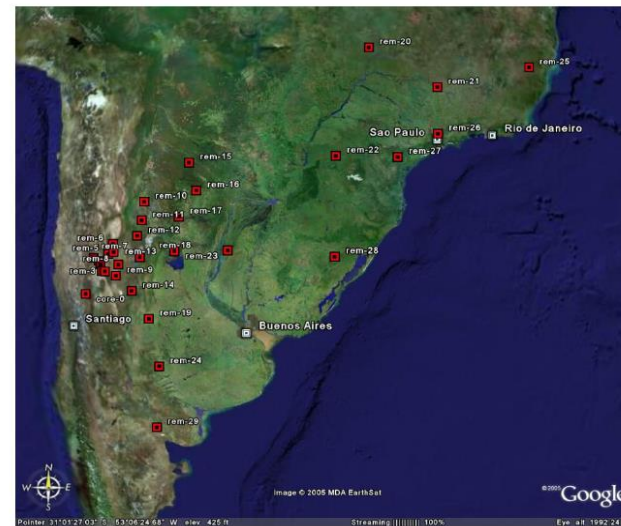
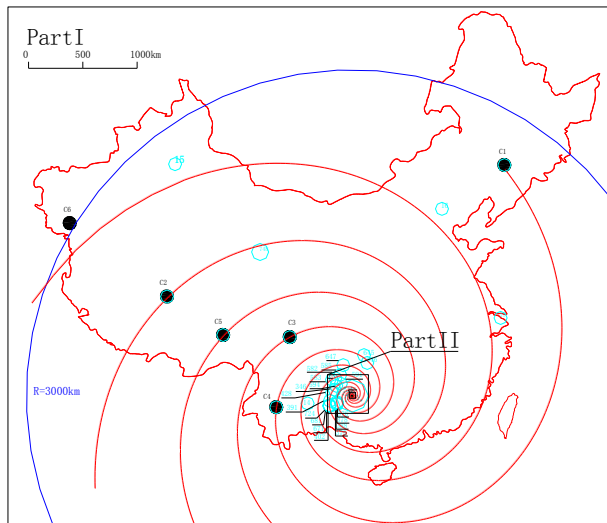
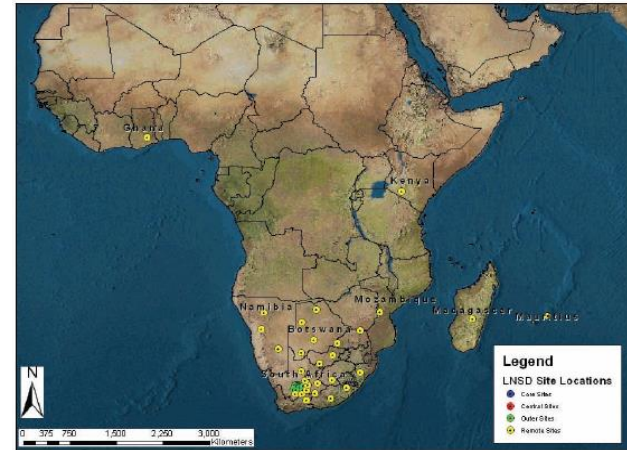
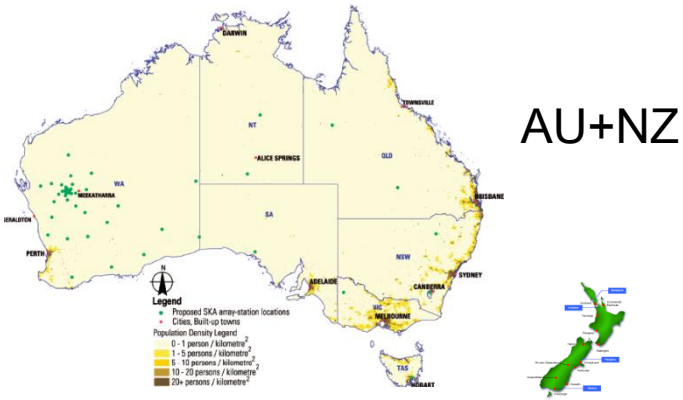
Prototypes



1993-2005: site selection

- 2002 Open request to global radio astronomy community for Expressions of Interest in siting SKA
- 2003 Call for Initial Site Analyses from Australia, South Africa, Argentina/Brazil, China, USA
- 2004 Call for Proposals to Host the SKA
USA did not respond
- 2005 RFI measurements at the four competing sites
- 2005 Deadline for submission of Proposals (December)

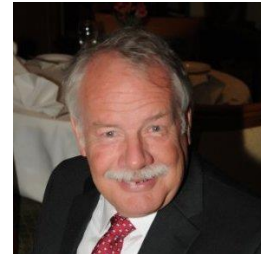
The site contenders in 2006



First meeting on SKA at Heathrow airport in June 2005

- PPARC (UK) initiative
- ELT in the morning, SKA in the afternoon

Richard Wade, chair (PPARC Programme Manager and Deputy CEO)



Wayne van Citters, vice-chair (NSF Director of Astronomy Division)

Formal reaction

- The science case for SKA is seen as being strong;
- The ELT is currently regarded as being ahead of the SKA in terms of technological readiness and priority within funding agencies;
- The **SKA technological readiness appears immature** due to the variety of concepts under consideration;
- A **site selection in September 2006 [by the ISSC] was seen as premature**, given the current state of the project and need to engage agencies in the site decision making process;
- The global nature of the SKA has both a positive and negative impact. Within the USA there is no prospect of serious funding until at least 2010, although the NSF recognises the strength of the science case and wishes US scientists to remain involved in the planning;
- **The agencies do not want to take “ownership” of the SKA yet because the project is not sufficiently mature.**

Informal comment

- “the trouble with radio astronomers is that you always collaborate, it would be much better if you were fighting each other like optical astronomers.”

- **New possibilities for radio astronomy**
 - Interferometer as an “array of detector arrays”, enabled by the IC revolution
 - Individual sensors no longer restricted to single pixel on the sky
 - » phased arrays of receivers in the focal planes of parabolic dishes
 - » phased arrays as direct receptors of incoming radiation
 - » simultaneous independent fields of view - multiplex advantage
 - Sensors no longer restricted to bandwidths of 10% observing frequency
 - Far higher data rates and processing power, enabled by the IT revolution
 - » faster and cheaper data processors enabled by programmable multi-purpose chips replacing hard-wired component systems
 - » SKA is a “software telescope”

- **We have all the technology necessary to build the SKA. The challenge is to build it at an affordable cost.**

- **Many opportunities to exploit close synergy with industry for our and industry’s benefit**



End of Episode 1

Overview

- 2006 Funding Agencies Working Group formed
- Site short list: Australia and Southern Africa
- Large precursor projects begin on the two short-listed sites, ASKAP, MeerKAT

Some of the FA interventions

1) [Site short-listing](#). Feb 2006

- ISSC ranking of the four candidate sites not approved
- short list of two required → negotiations and “blood on the floor” (Richard Wade)

2) [Open Skies](#). Oct 2007

“Concern was expressed about the implications of this policy whereby non-contributors from countries with active astronomical programs might obtain “free” access to the instrument. Members noted that open skies or its equivalent is not the norm in international programs.”

3) [SKA Phase 1](#), Oct 2007

“The SKA Forum stated that the abandonment of the Phase 1 milestone and associated science case would have a profound impact on FAs’ ability to fund the project.”

The intervention on site shortlisting raised the stakes through the competition and the high level interventions by the protagonist governments. Without this national competition, and the greatly increased profile, it's not clear that the project would have made the progress that it has.

What might have been the consequences of a single site choice in 2006? Topic for the book?

Overview

- 2006 Funding Agencies Working Group formed
Site short list: Australia and Southern Africa
Large precursor projects begin on the two short-listed sites, ASKAP, MeerKAT
- 2006 Inclusion as an ESFRI Research Infrastructure in Europe
- 2007 SKA Office HQ competition: Dwingeloo → Manchester
- 2008 New funding for technology development (€60M)
Europe (PrepSKA), USA (TDP), Australia, Canada, China
- 2008 ISSC→SSEC; ISPO→SPDO
OECD as banker for annual contributions to SPDO (except USA)

2006-2012: overview

2010 Engineering Reviews of Conceptual Designs for SKA system and sub-systems

Science KSP down-select as a result of a System CoDR Panel recommendation (SKA Memo 125)

2010: Key Science for SKA1

ORIGINS

- Neutral hydrogen in the universe from the Epoch of Re-ionisation to now

When did the first stars and galaxies form?
How did galaxies evolve?
Dark Energy, dark matter

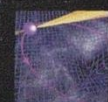
FUNDAMENTAL FORCES

- Pulsars, General Relativity & gravitational waves



Science with the
Square Kilometre Array

Editors: Christopher Carilli, Steve Rawlings



*Science with the
Square Kilometre
Array*

(2004, eds. C. Carilli &
S. Rawlings, *New
Astron. Rev.*, 48)

Episode2: overview

- 2010 Engineering Reviews of Conceptual Designs for SKA system and sub-systems
Science KSP down-select as a result of a System CoDR Panel recommendation (SKA Memo 125)
- 2011 External review of Project Execution Plan
SKAO HQ competition → Manchester selected
SKAO established as a “Company limited by Guarantee” in the UK
- 2011 US Decadal Review outcome → US withdrawal from the global SKA project
- 2011-2012 Site Selection → Dual site decision

Ron and the international SKA

- Discussed telescopes needed for HI with Robert Braun and Leo Blitz at the VLA in the 1980s when he was VLA Director
- Took part in discussions with Jan N and Peter W in Socorro at IAU131 in 1990
- Planned the formation of the URSI LTWG with Govind Swarup in March 1993 in his capacity as Chair of URSI Commission J on Radio Astronomy
- During Ron's term as Oort lecturer in Leiden in 1997, he chose the topic for the Oort Workshop "Workshop on Scientific Drivers for the Next Generation Radio Telescope". This triggered George Miley to come up with the LOFAR concept
- Was first chair of the ISSC

- Led and contributed to many science, engineering and political discussions on the SKA at national and international level
- Made many presentations on the SKA and radio astronomy around the world
- Ron's inclusive, collegial and collaborative style encouraged astronomers and engineers to interact freely and resulted in particularly productive meetings in the early years
- Ron was the enabler of a great deal of the early SKA activity as well as being international spokesperson for the SKA

Book research in progress



Happy Birthday, Ron!

and happy writing....