Birth of ASKAP

A personal view

John Bunton | 25 May 2023

Australia's National Science Agency

Birth of ASKAP

- International SKA innovation Circa 2002
- CSIRO developments 1998 to 2002
- 2003 a change of paradigm
- 2004 a time of flux
- 2005 ASKAP

SKA Concepts

- 1990s SKA is born brainstorming
- By 2002 we had as well as
  - Standard dish array – super VLAs, and
  - Super LOFARs at low frequencies
- There were a number of more left field proposals
- Category 1 large reflectors – sensitive, small field of view
  - LAR – Canada (Aerostat bought and section of reflector built)
  - KARST – China (One aperture built – FAST!)
- Category 2 *aperture re-use* – multiple independent observations
  - Dense aperture arrays – Netherlands (Embrace demonstrator)
  - Luneburg Lens – CSIRO (0.9 m prototype)
- Category 3 Low cost aperture, Large field of view – fast observing
  - Cylindrical Reflectors – CSIRO (No funding 1/2 engineer - me)

Large Adaptive Reflector – LAR, Canada

- Large f/D reflector
  - Fairly flat on ground
  - Moveable feed to change focus point
- Fairly narrow beam to illuminate dish
  - Beam changes with time
  - (large) Phased array at focus
- Aerostat needed to position feed
  - Problem feed and positioning

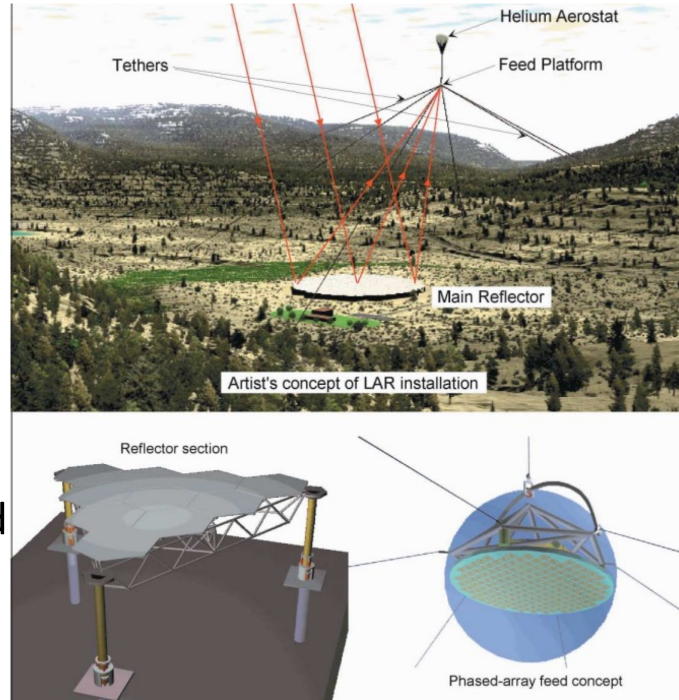


Figure 1. An artist's concept of a complete 200-m diameter LAR installation. The installation includes the main reflector, the multi-tethered aerostat system, the feed platform at focal length of 500 m. Details of a main reflector section and the prime-focus phased-array feed concept are shown at the bottom of the figure. The phased-array feed contains pointing and stabilization mechanics, phasing networks, and cryogenic coolers.

Kilometre-square Area Radio Synthesis Telescope (KARST) - China

- Multiple FAST telescopes
- In the KARST region of China
- One is enough to do great science FAST

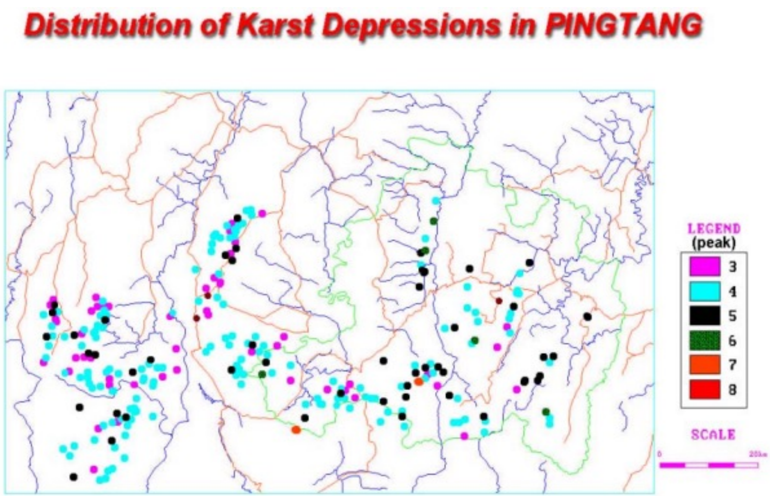


Fig. 1-2 Candidate karst depressions for the Chinese SKA, KARST

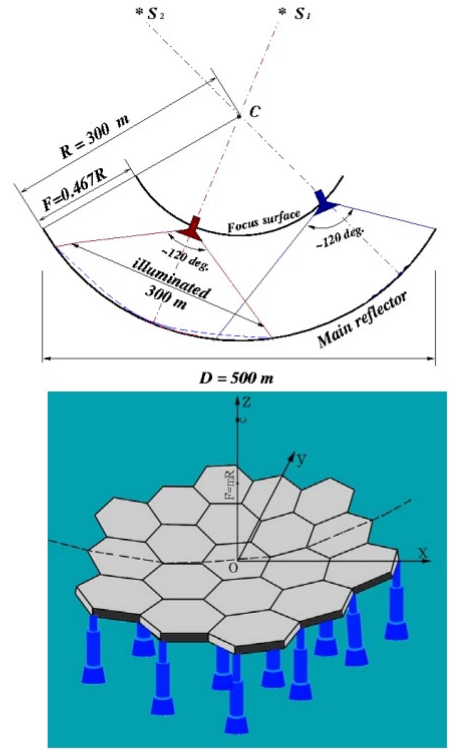
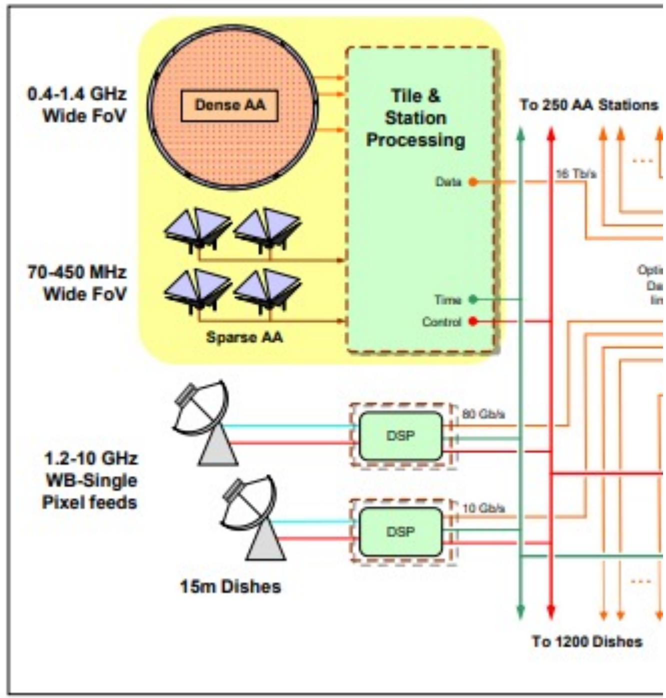


Fig.1-1 FAST concept and its geometrical configuration

Aperture Arrays –SKADS - ASTRON

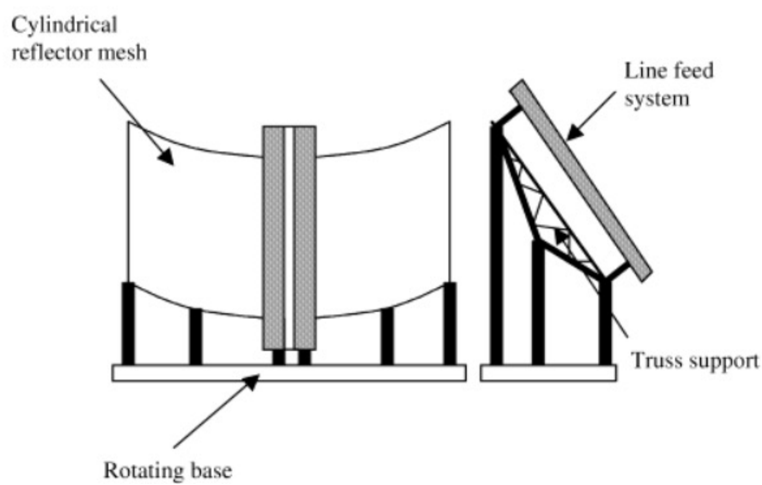
- Sparse AA to 450MHz
  - Now SKA Low
- Also proposed Dense AA to 1.4GHz
  - Problem cost is proportional to $\propto \sim fmax^{2-3}$
    – #elements and bandwidth
  - Dual RF beamformers to reduce cost – two independent observations



The Doublet

- Low-Cost Cylindrical Reflector for the Square Kilometre Array, G.James & A.Parfitt, Perspectives on Radio Astronomy: Technologies for Large Antenna Arrays, ed Smoulders and Harrlem at ASTRON April 1999
- I liked the idea but CSIRO by August (Toronto meeting) was discussing Luneburg Lens

- But I concluded
    - Cost of foundations Expensive as only a fraction used at a time
    - But one like Monlonglo ….



Luneburg Lens – CSIRO

- **Aperture re-use**
  - Multi-fielding
- Same lens
  - Multiple feeds
  - All independent
- One built 0.9 m
  - Used the NTD funding whose aim was an SKA demonstrator.

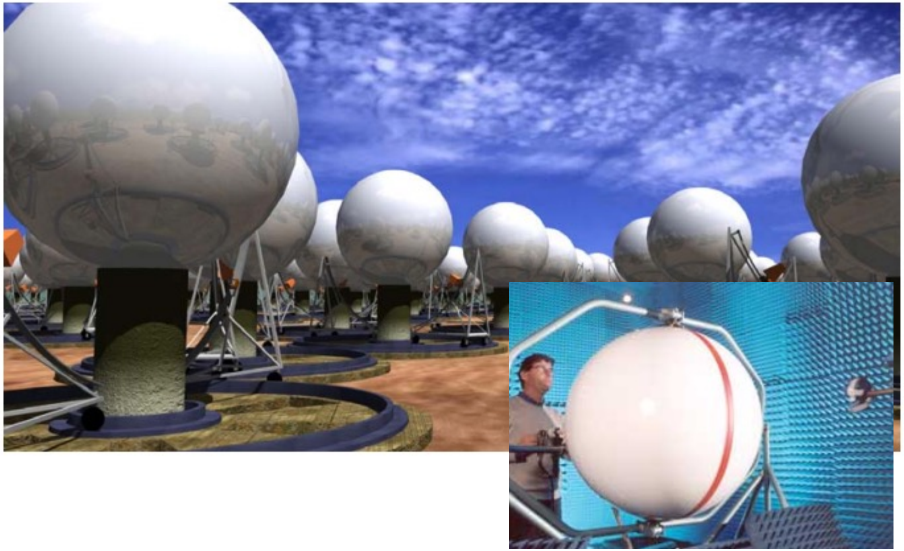


Fig. 6-3. Views of an array station (about 250 m across) composed of 176 seven-metre diameter Luneburg lens antennas.

"Large radio telescopes of the future will be driven to aperture re-use through multibeaming for both scientific and economic reasons." Eyes on the Sky, SKA white paper 2002, ed. Peter Hall

Cylindrical Reflector CSIRO

- Proposal 600 single axis reflectors 111x15m = 1 square kilometre
  - Negligible funding, Staffing – just me and Elaine Sadler and Carol Jackson for Science
- Low cost area, 100Mz to 9GHz
- https://www.skatelescope.org/uploaded/17698_23_memo_Bunton.pdf

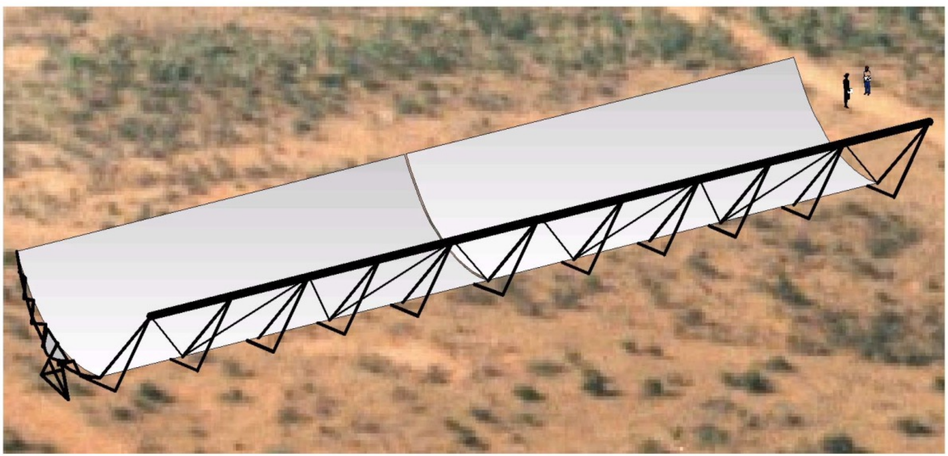
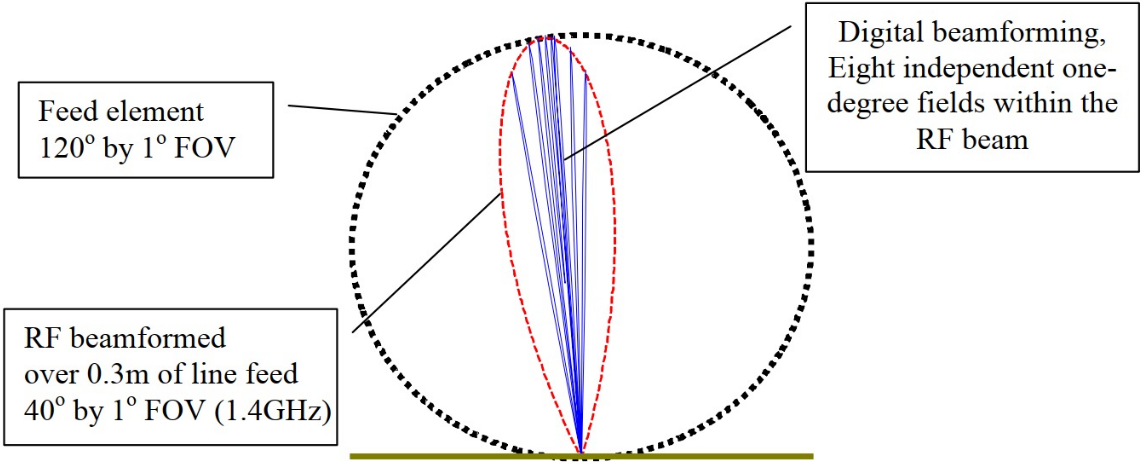


Figure 1 Cylindrical reflector antenna

Beamforming for a Cylindrical Reflector

- Full digital would blow out cost
- Initial beamforming RF (similar to dense aperture arrays)
  - Beyond 1GHz backend electronics scale the same as dishes
- Problem - Calibration



Why Cylindrical reflector (2002)

- Low cost reflector – only one axis of mechanical rotation
  - Molongolo and Parkes had similar cost
    - Parkes ~3000m^2, Molonglo ~40,000m^2
- Electronic cost ~1% of dense aperture array at 1.4GHz
  - Similar to PAF (1m^2 per receptor), less with RF beamforming
- Multibeam capability – widefield of view
  - But not the true aperture re-use of dense aperture array and Luneburg
    - Beams not independent
  - Electronic costly at 9GHz mainly due to the 4.5GHz bandwidth that was specified at that time but still viable

2003 Luneburg Lens falling out of favour

- Material needed not by square metre but cubic metre
  - ~10 million cubic metres
- Design predicated on dielectric lens being lightweight
  - Density needed similar to Styrofoam
  - Materials division found dielectric with required properties but too dense - approaching 1 ton per cubic metre
  - Would be too costly
- High loss at 10GHz – up to 7m through dielectric
- Analysis showed cost per observation not going down as number of feeds increased (Aaron Chippendale) – aperture re-use not free

FOV – Bandwidth trade-off

- Full bandwidth of 4.9 GHz not always needed
  - Particularly at lower frequencies
- 1.5 GHz nominal bandwidth is 0.8GHz
- Can fit of six (6) 0.8GHz signals in place of a single full bandwidth signal
- Increases number of beams and FOV by 6
  - Imaging FOV = 48 deg^2 at 1.4GHz
- Doubling the bandwidth to 1.6 GHz gives
  - Imaging FOV = 1.9 deg^2 at 5GHz
- Product of FOV and bandwidth constant

2003 Aperture reuse to large field of view

- Start of 2003 New Technology Demonstrator (NTD) money going to Luneburg lenses in CSIRO but
- Cost and weight blowouts and analysis that second field of view not really low cost
- Luneburg Lens falling out of favour
- CSIRO had Cylindrical Reflectors as a fallback proposal now with large field of view
- OK large field of view – rather than aperture re-use what do you get
  - Daily all sky?
    - RACS 230hours and Cylindrical Reflector SKA 100 times more sensitive
  - at z=3 FOV 500 deg^2 used commensally during normal GHz and above observing
    - whole sky @ 10μJy (5σ) at 20 km/s
  - …….
  - Looks interesting – NTD to build three 50x15m prototypes in WA

2004 HIFAR/HYFAR HYdrogen Frequency ARray

- The ambition 120 antennas 111x15m = 200,000m^2, 0.1 to 1.4GHz
  - Had money for three – estimated full hardware cost $100M
  - Just think what sort of FRB machine it would have been (25 CHIMEs, 50 ASKAPs)!

- February 2004 HIFAR An Array of Cylindrical Reflectors for Precision Cosmology, Workshop on Applications of Radio Science (WARS'04); Hobart, Tas

- June 2004, Norris, R. The Australian Ska New Technology Demonstrator Program. *Exp Astron* **17**, 79–85 which says the change was in recognition of:

  • **the scientific importance of a wide field-of-view;**

  • the scientific importance of low frequencies, especially for cosmological studies;

  • the advantages of extremely radio-quiet sites *(Mileura, WA),* both in permitting new types of science to be done,

Wars'2004 poster

HIFAR : An Array of Cylindrical Reflectors for Precision Cosmology

John D. Bunton, *CSIRO ICT Centre,* **Frank H. Brigs** *ANU* **and J. Chris Blades** *UNSW*

CSIRO

Introduction

Much effort has been put into developing designs for the proposed Square Kilometre Array SKA. One of the concepts, the cylindrical reflector, is not only low cost but also expands the parameter space available because of it large field of view. Using this technology it is proposed that a 20% prototype HIFAR be built that covers the frequencies up to 1.4 GHz.

In one year HIFAR can detect millions of galaxies by there neutral hydrogen emission at a redshift of z=1 allowing the instrument to probe the dark energy in the universe.

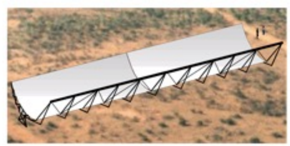
HIFAR Concept

The great advantage of cylindrical reflector is that they have single axis of mechanical rotation which greatly reduces the cost of mounting and moving the reflector. This makes cylindrical reflector low cost as the mount on parabolic reflectors can comprise more than half the cost. Steering orthogonal to the mechanical rotation is achieved by placing a phased array (line feed) at the focus of the parabolic cylinder. For a 15m wide reflector 120° by 1° of sky is accessible. With the continuing reduction in electronics cost it is now economically possible to form beams over this full area.

In HIFAR it is proposed that three adjacent line feeds be used with some RF signal aggregation giving a 17° by 6° field of view. To achieve the required sensitivity 120 cylindrical reflector each 110m by 15m will be arrayed over a 10 km area for a cost of $50M for the reflector and $50 for the electronics.

The Cosmological Question

Our best cosmological model for the Universe's geometry has the Universe slowing in its expansion -- as predicted by the gravitational attraction -- during roughly the first half of the age of the Universe; but surprisingly, the Universe subsequently exhibits a re-acceleration, apparently due to an additional pressure, the "dark energy". However the current data does not significantly constrain the possible cosmological models that explain the re-acceleration. The models are characterised by the parameter w(z) which is the ratio of the "dark energy pressure to its density. Note this parameter may be a function of redshift z.



Proposed cylindrical reflector antenna as described in SKA memo 23

Other Astronomy

HIFAR will not only answer a major cosmological question it will also.

- observe the evolution of galaxies throughout the second half of the age of the Universe.
- With operation down to 100 MHz it will observer the Era of re-ionization cause by the first stars at z~13
- Detect galaxies in absorption at redshifts z=2 – 5
- Survey pulsar 1000 time faster than present
- Provide detailed source counts of the weakest radio sources

Standard Rods

The cosmic background radiation and the matter in the universe has structure with the dominant angular scale being 0.5 degrees, as is seen by the clustering of local galaxies, Figure 2. This can be used as a standard rod to determine w as a function z. By detecting millions of galaxies HIFAR will measure the standard rod for redshift up to one. The improvement possible with one years operation of HIFAR is shown in Figure 3.

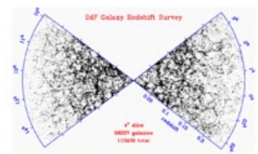


Figure 2. Large-scale structure in the nearby Universe for 56,237 2dF galaxies[3]. A distance of 100 Mpc corresponds to an increment of redshift of $\Delta z \sim 0.025$.

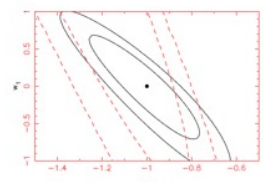
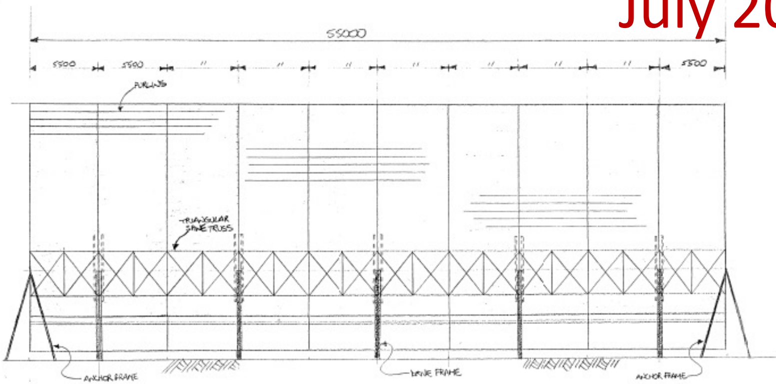


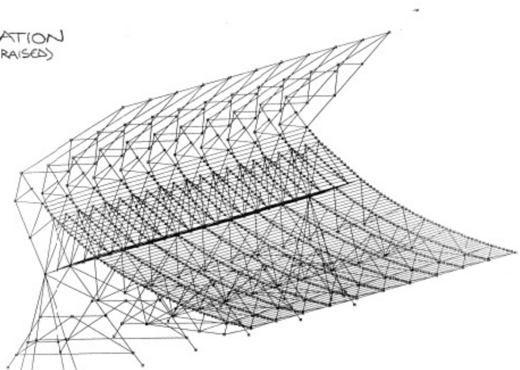
Figure 3. Error ellipses for a HIFAR (black ovals) measurement of w_0 (constant with z) and w_1 (linear with z). Current constraints (dashed ovals) extend far outside the boundaries of the plot.

A3

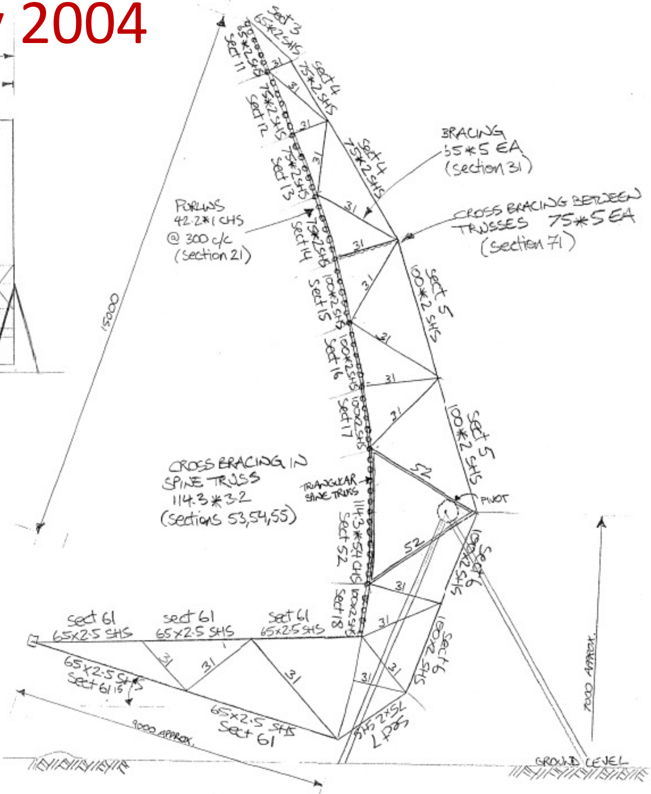
July 2004



ELEVATION
(FULLY RAISED)



3D VIEW
("FLAT" POSITION)



MEMBER SIZES

No.	Date	Revision Details	By	Ver.	App.

Connell Wagner

Connell Wagner Pty Ltd ABN 54 005 139 873
116 Military Road (PO Box 538) Neutral Bay
New South Wales 2089 Australia
Telephone: +61 2 9465 5599
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Email: cwsyd@conwag.com

Client: CSIRO AUSTRALIA TELESCOPE NATIONAL FACILITY

Project: HYFAR SKA TECHNOLOGY DEMONSTRATOR

Drawn	Signed	Date
Designed	Signed	Date
Verified	Signed	Date
Approved	Signed	Date

Drawing Title: PRELIMINARY CONCEPT "S-DRIVE" OPTION

CW Project No.

Scale

Drawing No.

Rev.

20 10 0 10 20 30 40 50mm

Move to PAFs

- But Jan 2004 Ron Ekers went to South Africa and presented a talk on a cylindrical reflector – dish hybrid
  - Increased sensitivity below 5GHz by a factor of 1.5 to 3.7 (plus larger field of view) compared to dishes
  - Found no support for cylindrical reflectors – **politically difficult**
- What to DO?
- Mid 2004 looking at three wide field-of-view options
  - Cylindrical reflectors
  - Big Gulp (Tim Cornwell) - small diameter dish array.
  - Phased array feeds on standard dishes.

A time of flux

- Big Gulp appealing in terms of hardware but
  - Correlator grows as FoV^2 and imaging at $\sim FOV^3$
  - For cylinders and PAF on dish both are linear with FoV.
- For PAFs - Rick Fisher and Canadian LAR had been working on "Focal Plane Arrays" FPA at focus of a dish – not a new
- Many FPA sceptics, but dishes politically OK
- Phase Array Feeds give 10s of deg^2 field of view

- Late 2004 main option cylinders and PAFs
  - Norris " Early decision on concentrator configuration (cylinder/parabola, no. of elements in focal-plane array." in paper submitted Aug. 2004

2005 ASKAP Concept born

- Late 2004 early 2005 decision to go with PAFs on dishes
- Feb 2005 draft design of 100 (Dutch) Vivaldi, single polarisation beamformer
- June 2005 Hayman paper on encircled power
- August hardware in hand for a 24 input beamform based on existing PAF hardware from ASTRON
- October white paper on Single Dish – Focal Plane Array in preparation

- 2005 -2006 called xNTD, 2007 Milera International Radio Array (MIRA which became MIRANdA, MIRA Large N small d Array, 2008 ASKAP

Hindsight

- Move to PAF on a dish was a good decision
- ASKAP beams are stable with time
  - Brilliant decision to include 3rd axis, beams do not rotate
  - Even so, has been a long process to understand the beams
  - There are still some problems but we have high quality imaging.
- Cylindrical reflector
  - Beams change in size, shape and angle on the sky as a source is track
  - Also feed reflector interaction can be large – proposal was offset fed to counter this – but this adds to polarisation cal problems.
- Could we solve the beam cal problem for cylindrical reflector?
  - MAYBE but much harder than ASKAP.
  - CHIME is known to have calibration problems and beams are fixed.
    – Compounded by being centre feed (did not listen to me)

Summary

- Cylindrical Reflector SKA concepts from 1998
  - But CSIRO favoured APERTURE RE-USE – no resources for Cylinder
  - 2002 problems emerging for Luneburg Lens
- July 2003, FOV – Bandwidth Trade-off generates excitement
  - Thank you to the astronomers who helped science cases – eg All Sky
  - Thinking changes from APERTURE RE-USE --> WIDE FIELD of VIEW
- For about 15 months the Cylindrical Reflector concept HIFAR/HYFAR was supported by CSIRO
- Early 2004 concept of PAF on dishes introduced
- End of 2004/start of 2005 have moved to PAF on dish concept
  - Birth of ASKAP - Australian SKA Pathfinder

Postscript

- For a time a third leg to SKA was approved
  - Survey telescope – ASKAP on steroids –separate to MID – in Australia
  - But was cut when money became tight and
- KAST had a single dish built – FAST
  - Did the Chinese use an international project to raise political capital for FAST?
- Fermilab was looking for new direction after LHC
  - Maybe astronomy?
  - Cylindrical Reflector to search for Baryon Acoustic Oscillations
  - John makes two trips to Fermilab
  - Idea taken up by Canadians -> CHIME
    - – But did not take the recommendation for offset fed.

Thank you

Astronomy and Space Science
John Bunton
Birth of ASKAP

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