Cylindrical Reflector SKA Update

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Overview

- Concept
- Linefeed
- Costs
- Fields of view
- Applications

Making the desert bloom -

With Cylindrical Reflectors

SKA compact core?

Solar energy collection using cylindrical reflectors. Collecting area over 1 km^2

Confirms original reflector estimates for cylindrical concept: ~\$235m^2 at 6 GHz Includes foundations

Comparable 12 m (preloaded) ~\$530m^2

Philosophy

- Paraboloids best at high frequencies, Maximises the area of each detector/feed
  - At least 4400 feeds in the SKA
- Cylindrical Reflector
  - Single axis reflector cheaper than two axis
  - large FOV compared to paraboloids
  - Reduced feed count compared to phased arrays
- Phased arrays good at low frequencies, feeds are cheap and large effective area, large FOV
  - No. of feeds increases quadratically with frequency

History

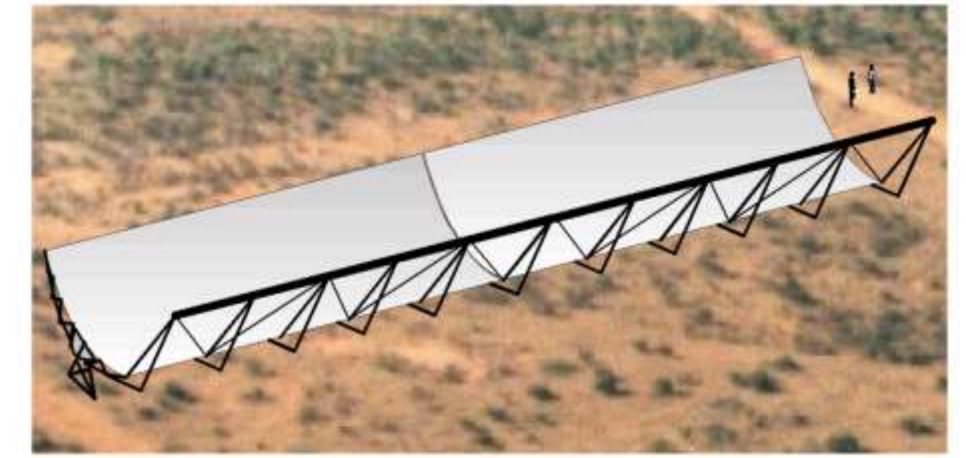
- Cylindrical Reflector (64m dish = 3,200 m^2)
  - 1958 - 178MHz, Radio Star Interfer. 10,000 m^2,
  - 1967 ~400MHz
    - Northern Cross 31,000 m^2
    - Ooty 16,000 m^2
    - Molonglo 40,000 m^2
  - 1980 - 843 MHz, MOST 19,000 m^2
- Extrapolating to 2010 we could have a university instrument with 20,000 m^2 at 6 GHz
- Electronics cost and LNA noise the problem

Today

- LNA problem is being solved
  - Simple SiGe LNA uncooled,   47K at 2 GHz
  - All concepts have multiple receiver
    - No longer just a problem for cylinders
- Electronics cost keeps on coming down
  - E.g. 4560 baseline correlator ~$4k
  - Moore’s Law should continue to 2010
  - Full digital beamforming possible
    - Solves the problem of meridian distance steering
- Cylindrical reflectors again become a viable solution

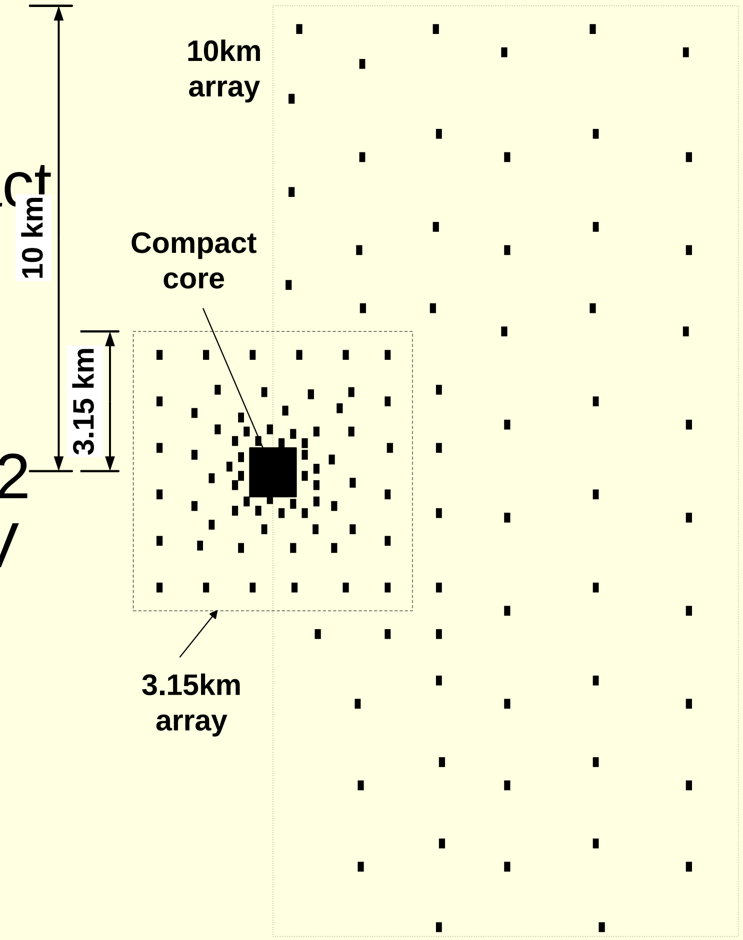
Cylindrical Reflector Concept

- Original white paper 2002, Update presented here
- Offset fed cylindrical reflector
  - Low cost collecting area
  - 111 by 15 metres (1650 m^2)
- Multiple Line feeds in the focal plane
  - Each 3:1 in frequency
- Low spillover for central part of linefeed
  - Linefeed 100m
    - reduced spillover
  - Aperture efficiency ~69%
  - Spillover 3-4K



Array Concept

- 1 km compact core filling factor ~0.3, UV filling ~100%
- 3 km doubly replicate compact core, min UV filling ~50%
- 10 km array asymmetric to save cabling. 1 km compact core replicated within any 2x2 km area of UV space. 4% UV filling of remaining 75%.
- 31 km array –UV filling instantaneously greater than .4% in any 1km^2



Odds and Ends

- Sub 10s response time with three sub-arrays
- Antenna - 4 section each independently steerable
  - End sections, one observes before transit and the other after. Middle sections close to transit.
  - Accessible sky ~200 deg^2 at 1.4 GHz - 4 independent meridian angles (declinations)
  - Also sub-arrays of antenna stations
- Tied arrays probably only central core
  - 100 to 400 pencil beams (bandwidth 4.9GHz)
- Sampling time after first filterbanks - 0.6 to 5μs

Linefeed

- Focal area of offset fed cylinder is large – multiple linefeeds (James and Parfitt)
- Use Aperture tile array technology for focal plane array (5 elements wide by n long)
  - Allows reasonable field match
  - Resulting in good efficiency and polarisation
- Mitigate residual polarisation errors by aligning feeds at 45^{o} to the axis of the cylinder
  - Plus calibration

Multiple Linefeeds

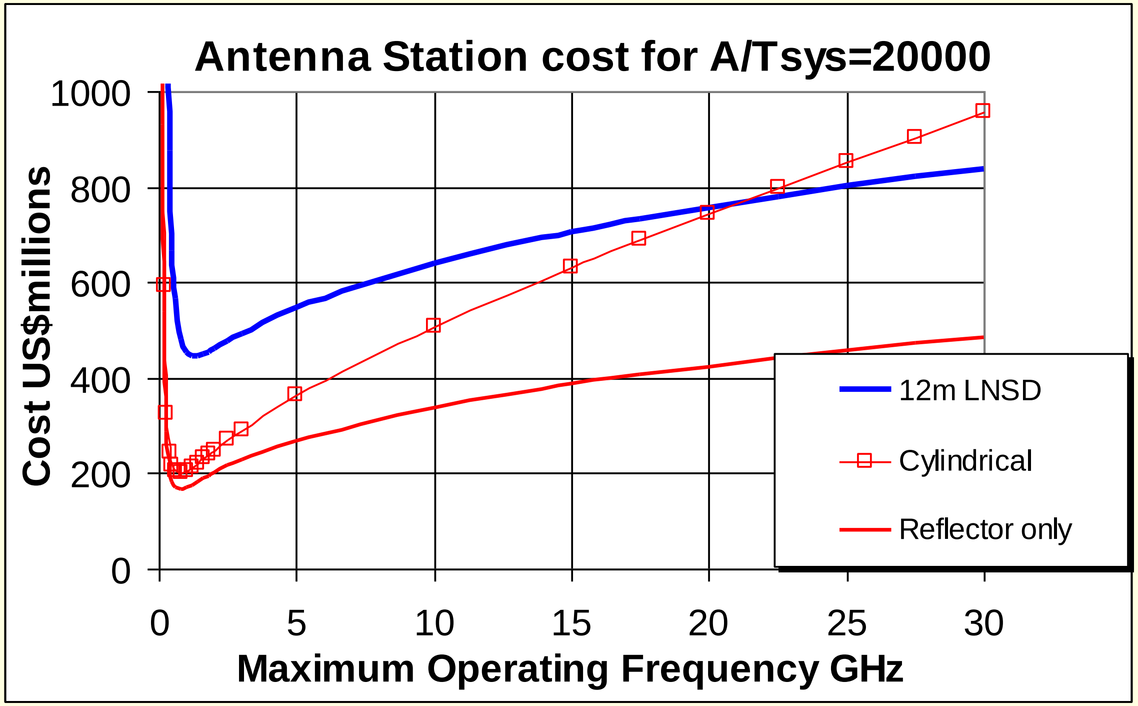
- Need multiple line feeds to cover full frequency range (each at ~3:1)
- Will have three or more line feeds in the focal plane at any one time. However fields of view may not overlap. (more linefeed work needed here)
- Can divide beamforming and signal transmission resources between the individual IFs from all linefeeds.

Linefeed cost reduction

- Increased bandwidth from 2:1 to 3:1
  - Reduces number of linefeeds - save 25%
- Linefeed cost broken down into hardware and electronics.
  - Hardware cost increases slowly with frequency
  - Reduced cost at high frequencies
- As foreshadowed in white paper use ASICs instead of FPGA
  - Five times cost reduction of electronics

Antenna station costs

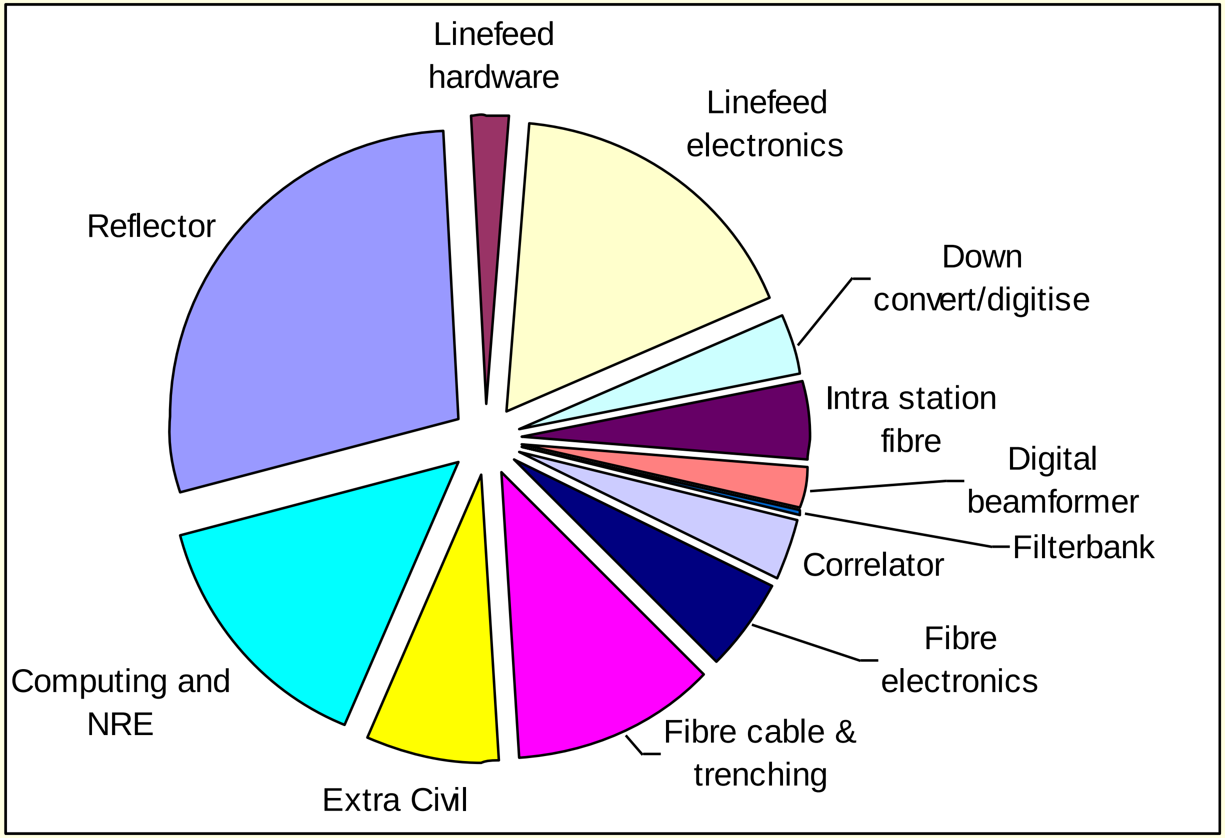
- Competitive to 20 GHz+
- Station electronics and fibre, (linefeed & beamformer) half the cost
- Cheapest solution below 10 GHz



- See poster for other concepts

Cylindrical Cost Breakdown

- 22 GHz cylindrical $760M for antenna stations
- Total cost ~$1.3 billion



Hybrid SKA

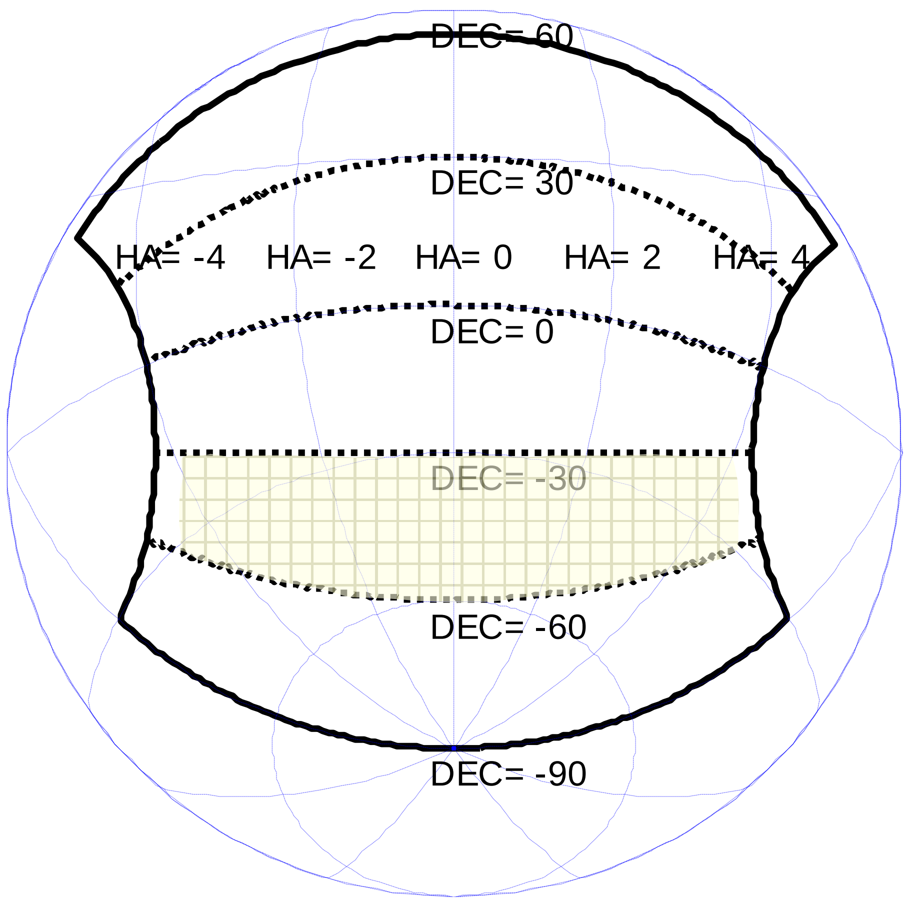
- 500 MHz cylindrical reflector \$150m 1km^2
- + 3 GHz cylindrical reflector \$290M 1km^2
- + 34 GHz hydroformed \$400M 0.25km^2
- Antenna station cost \$840M
- Total cost similar to 22 GHz cylinder
- Area 2 km^2 below 500 MHz

- A/Tsys = 10,000 m^2/K 0.25 GHz
- A/Tsys = 30,000 m^2/K 0.5 to 3 GHz
- A/Tsys = 10,000 m^2/K above 3 GHz.

Element Field of View

- This the FOV of a single feed element.
- In one directions same as phased arrays
  - ~120 degrees (electronic beamwidth)
  - but sensitivity proportional to cos(MD)
    - FOV increases with MD   (MD ~ HA)
- Constrained by the reflector in orthogonal direction (reflector beamwidth)
  - 1.4/v degrees (v in GHz) for 15m reflector

Element FOV on the sky



FOV covers large range of MD (~HA)

Adjacent beams approximately sidereal at transit

Beams rotate at large HAs giving access to large areas of sky

Example – Hatched area available during 10 hour observation of a source at DEC -30°

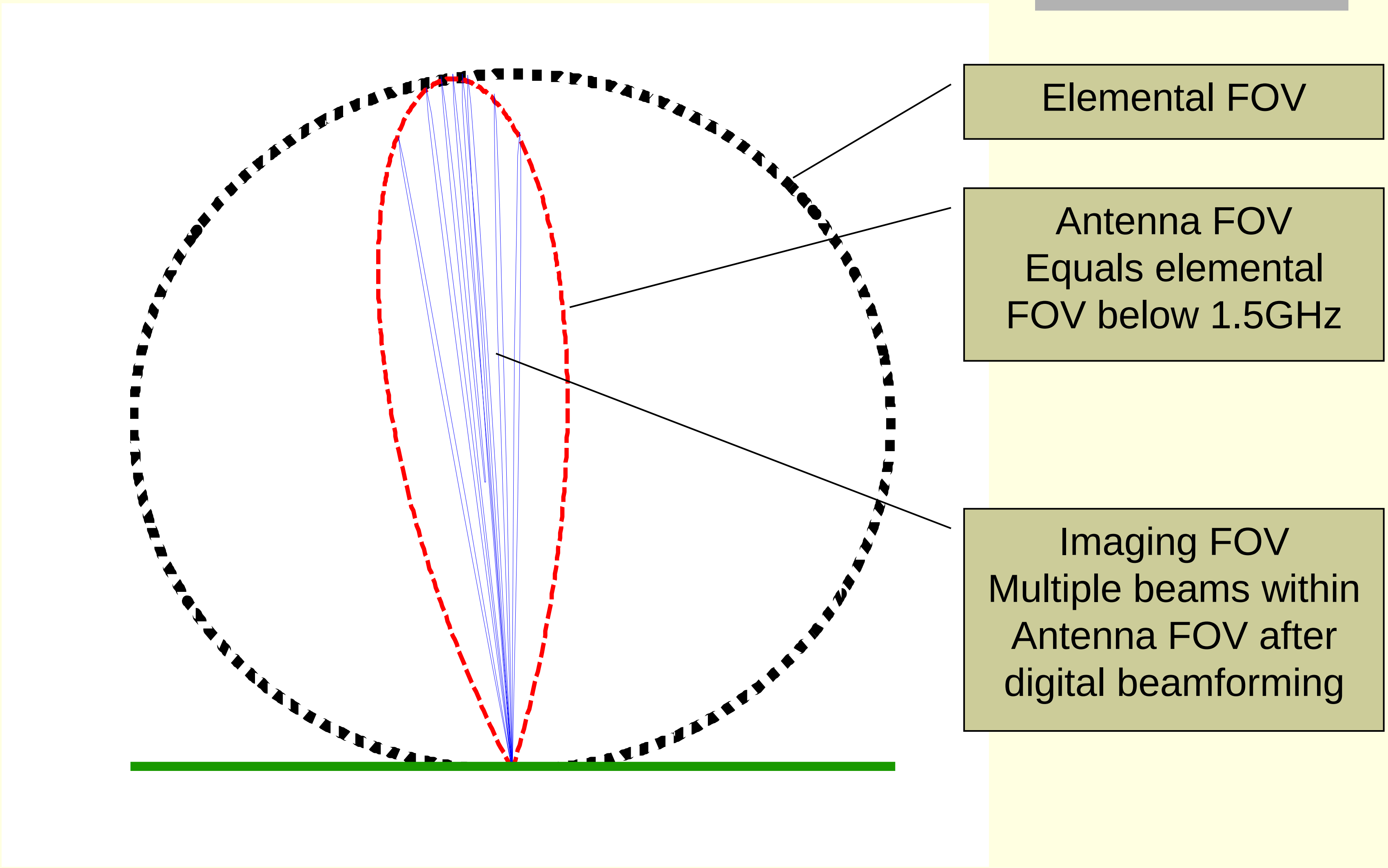
Antenna Field of View

- Field of view defined by RF beamformer
- As frequency increases must limit front end electronics.
  - RF beamforming
- For SKA
  - 120^o below 1.5GHz = elemental FOV
  - 170^o/ ν for frequencies from 1.5 to 7GHz
  - 51^o/ ν for frequencies above 7GHz
- E.g. at 10GHZ the antenna FOV is 5^o x .14^o
  - 30 times larger than a 12m paraboloid

Imaging Field of View

- Field of view defined by signal from antenna station
- Have fixed total bandwidth from antenna.
- For SKA 64 full bandwidth signals (core antennas)
- Allows 8 circular beams or 64 fanbeams
- With 64 full bandwidth fanbeams
  - All beams can be imaged
  - Their total area is the imaging FOV

Field of View in MD



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

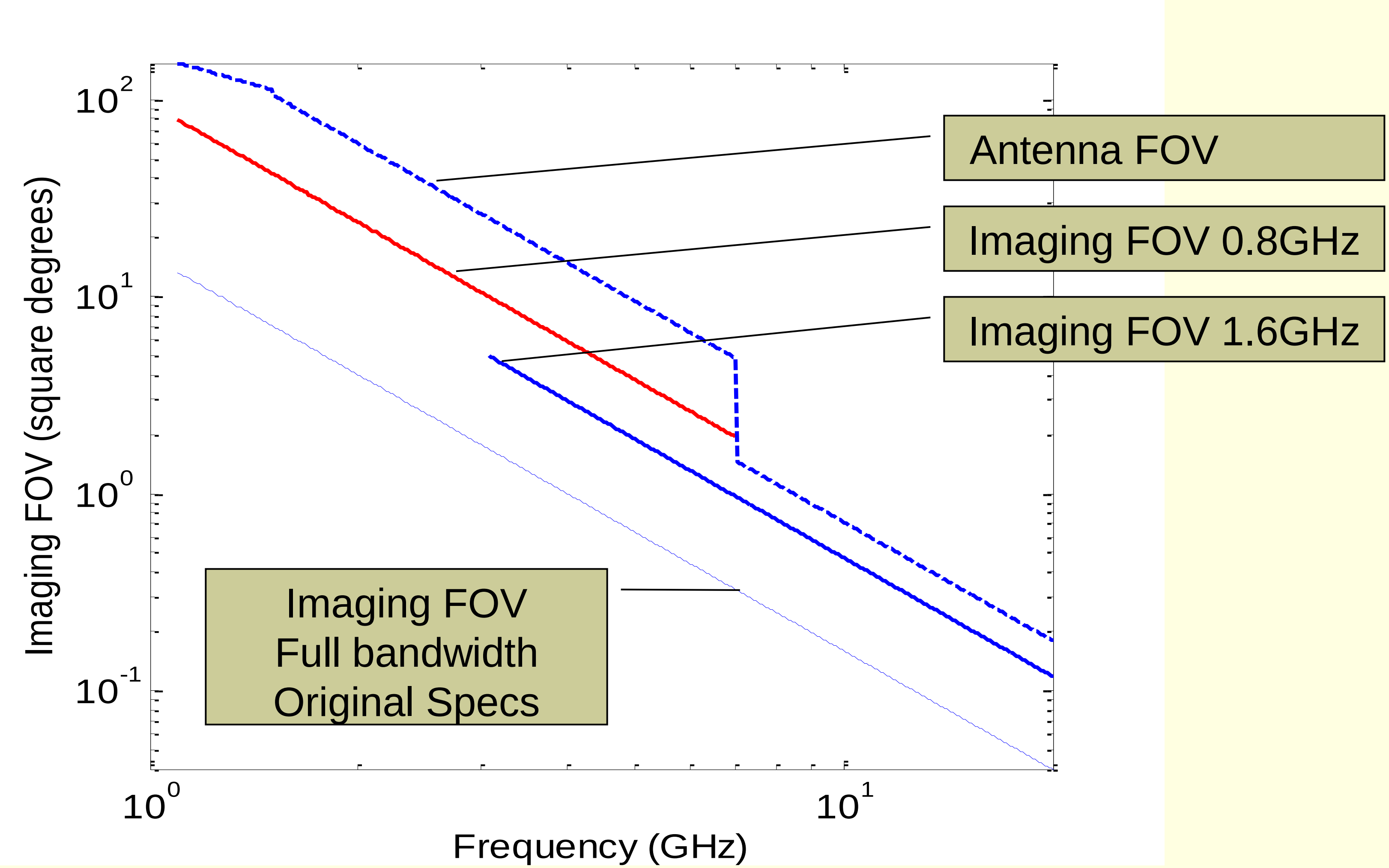
48 Square Degrees???

- Correlator efficiency proportional to size of filled aperture
  - Cylindrical reflector aperture 15 times greater than 12m Paraboloid
- Bandwidth trade-off gives a factor of 6
  - Not possible unless Antenna FOV>Imaging FOV
- But cylindrical has Tsys twice as great as 12 m paraboloid with cooled LNA
  - Increases correlator size by factor of 4
- Cylindrical Correlator gives a 15*6/4 = 22.5 greater imaging area at 1.4 GHz per $/watt/MIP

SKAMP – SKA Molonglo Demonstrator

- see posters for details on correlator and update
- Continuum correlator
  - New 4560 baselines using 18m sections
  - Old system 64 fanbeams, two 800 m sections
  - More correlation because of smaller sections
  - And will give greater dynamic range
- Spectral Line correlator
- Wideband line feed
  - Work has started

Field of View – reduced BW

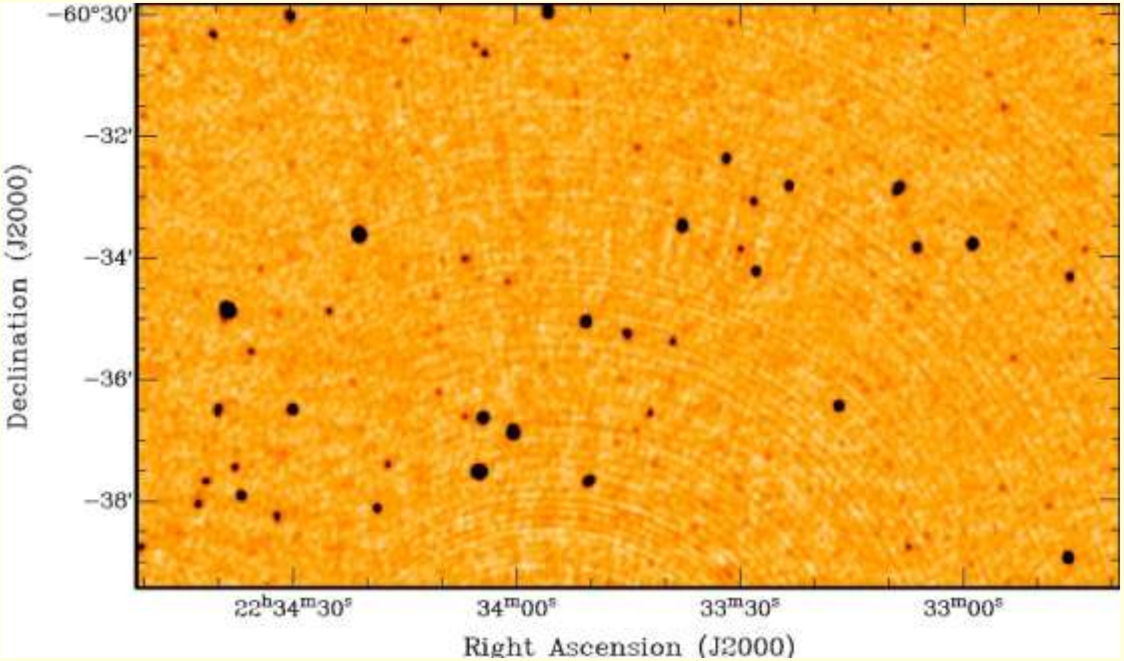


Daily All Sky Monitoring

- At 1.4 GHz and a bandwidth of 400MHz
  - Image 96 deg^2 with one minute integration
- Time to image 30,000 deg^2 is 5.3 hours
- Observe in ~1.5 hour sessions 4 times a day
- Resolution 1 arcsec with 10^5 dynamic range
- Sensitivity 6μJy (5σ)
- Compute power to generate images
  - Wait for Moore’s law or
  - Build FPGA/ASIC compute engine

Daily All Sky Monitoring

- Daily monitoring and detection of
  - AGN variability
  - Star Burst galaxies
  - Supernova
  - GRB
  - IDV
  - ESE ….
  - See poster



Minh Huynh (ANU) et al.], noise 11μJy

Simultaneous Best Effort

- Many programs do not use all resources
  - E.g. target observing of compact sources
- Antenna FOV is large
  - 120 deg^2 @1.4 GHz,   0.7 deg^2 @ 10 GHz
- List all non-time critical observations
- If observations is with antenna FOV and bandwidth resources available then proceed
- System will make “Best Effort” get your observing program done. Target leftover fields
- Can maximise use of SKA resources
  - Correlator, transmission bandwidth

Simultaneous HI survey

- For z=3 antenna FOV is large - 500 deg^2
- Choose 100 uniformly distributed field centres
- At least one is in the antenna FOV all the time
  - Independent of targeted observing
- Allocate 8 beams for circular FOV - 8 deg^2
- After five years av. 400 hours on each field
  - 10μJy (5σ) at 20 km/s velocity resolution
- Redshift for 100s million galaxies
- Directly trace the large scale structure of the Universe.

SKA speed

- Fast surveys and simultaneous “best effort” observing
  - Instrument has very high observing throughput
- Surveys an order of magnitude faster.
- Other observing modes 2 to 5 times faster

- If average speed is 4 times faster
  - Equivalent to two times increase in sensitivity for non-transient sources.
  - A/Tsys ≡ 40,000 m^2/K

Conclusion

A cylindrical reflector offers the unique combination of

- High frequency operation to 22 GHz+
- Large imaging FOV
  - Fastest survey speeds
  - Daily all sky 1.4 GHz surveys
- Large antenna FOV
  - Multiple simultaneous observation
  - Example piggy back deep z=3 HI survey
- High speed equivalent to higher sensitivity

Thank you