EVLA Low-Frequency Extension

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Science at Low Frequencies

- Contrary to the opinions of some*, there IS good science below 1 GHz …
  - HI emission from galaxies at redshifts up to ~ 0.4
  - Absorption studies against strong background objects, to z ~ 1, and higher.
  - Polarization and RM studies (galactic, extra-galactic).
  - Steep-spectrum, low-frequency synchrotron emission studies.
  - Pulsars
  - EOR (E-config. preferred).
- Indeed – the numerous arrays being planned or built at low frequencies is clear testimony.
- Should we – and can we – install a sensitive, wide-band optimally efficient, low-frequency capability on the EVLA?

*A former senior NRAO administrator, now retired.

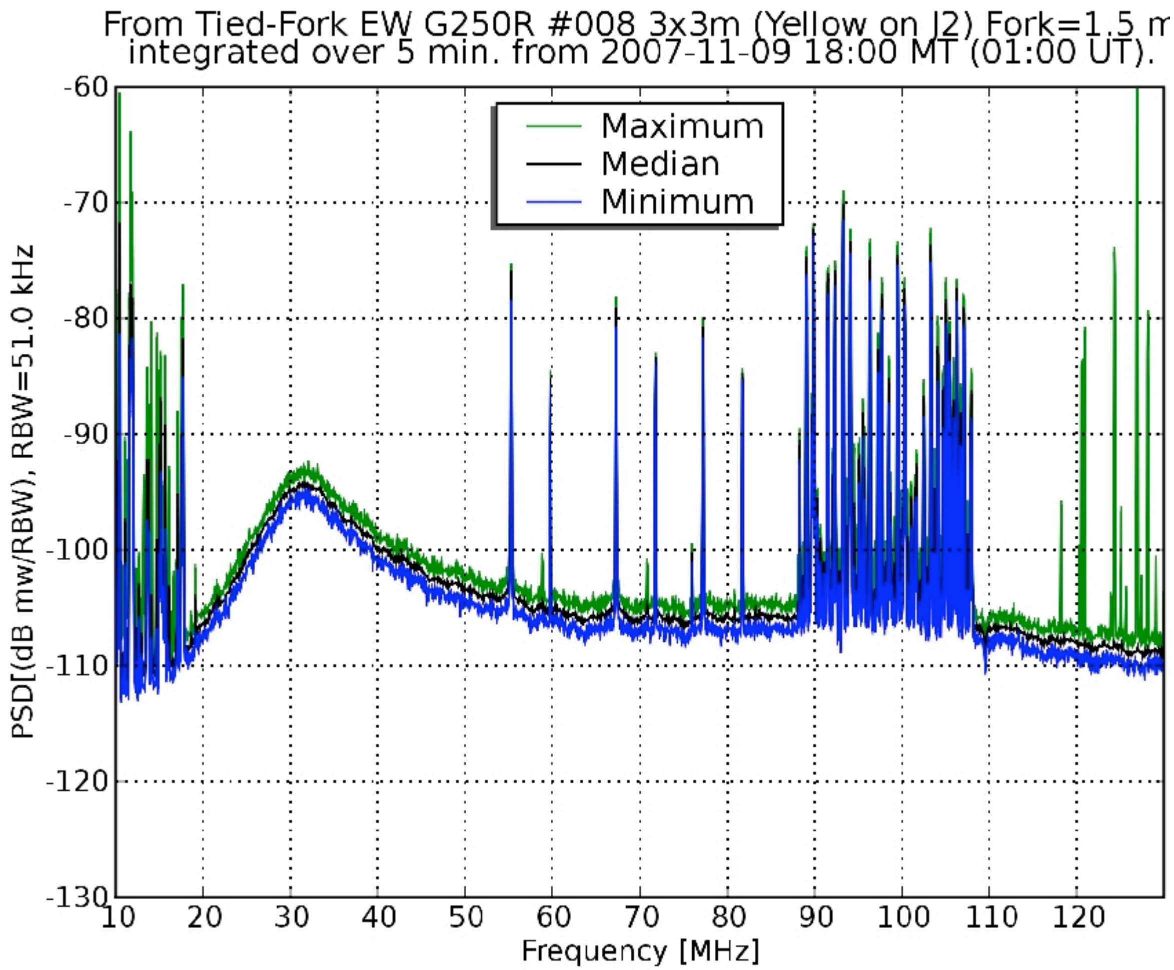
Clear Skies?

Before committing to new wide-band capabilities, we should check the spectral content.

- Spectrum, from LWA, 10 – 130 MHz.

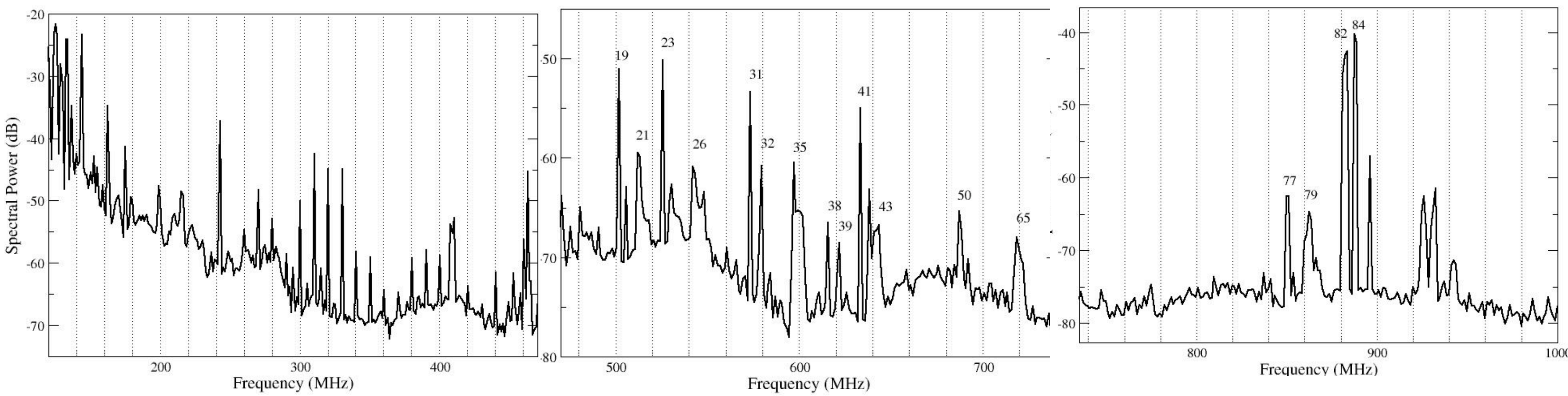
- TV allocations:

Channels	Frequency
2 – 4	54 – 72
5 – 6	76 – 88
7 – 13	174 – 216
14 – 83	470 -- 890



120 – 1000 MHz

- From Dan Mertely's monitoring – 5 minute peak hold.

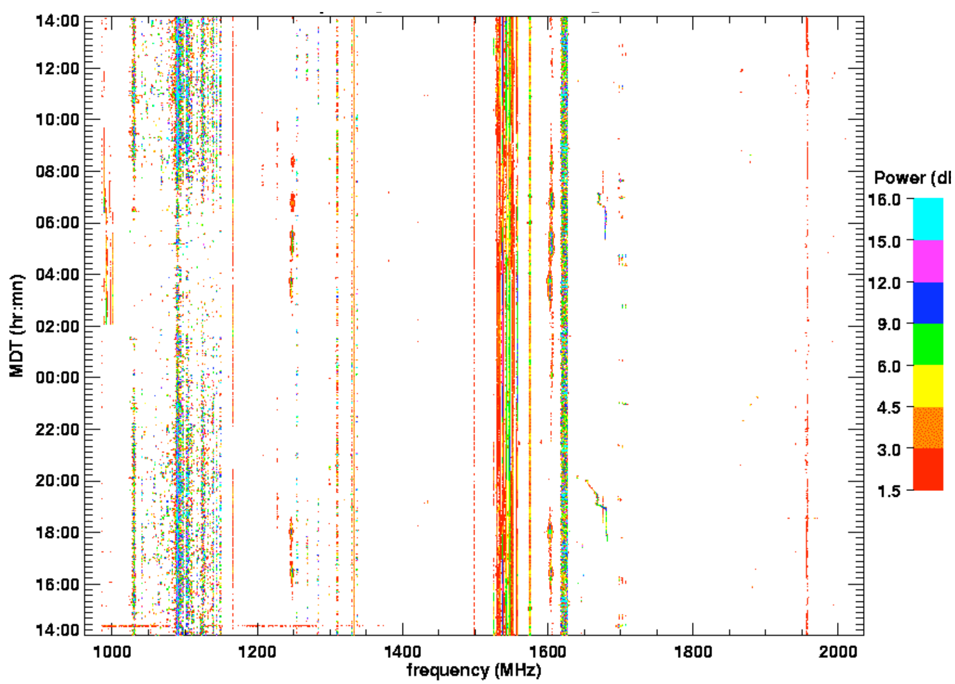


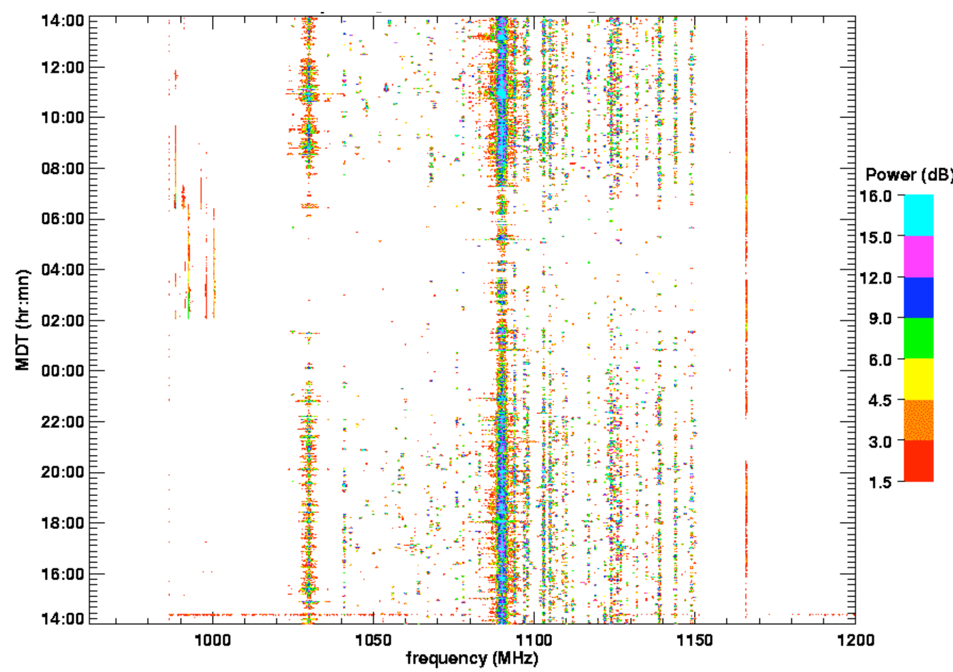
- Above ~650 MHz, spectrum fairly clean.
- TV stations a problem from 500 – 650 MHz.

Channels	Frequency
2 – 4	54 – 72
5 – 6	76 – 88
7 – 13	174 – 216
14 – 83	470 -- 890

RFI and Interferometers

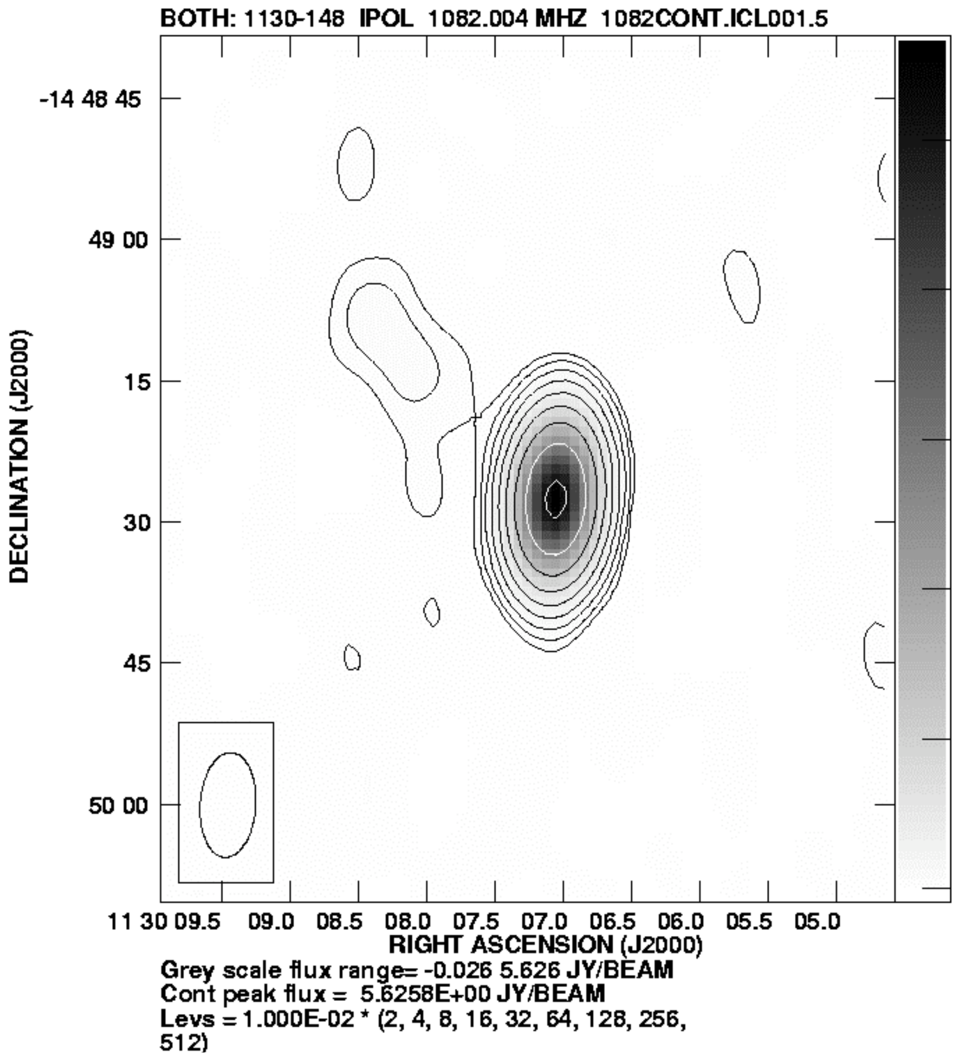
- Interferometers have considerable immunity against RFI – 10 to 60 dB, depending on frequency and resolution.
- Immunity even better against pulsed emission – notably DMEs, where the pulses, although strong, are only ~3km wide, and occupy 0.1% of the time.

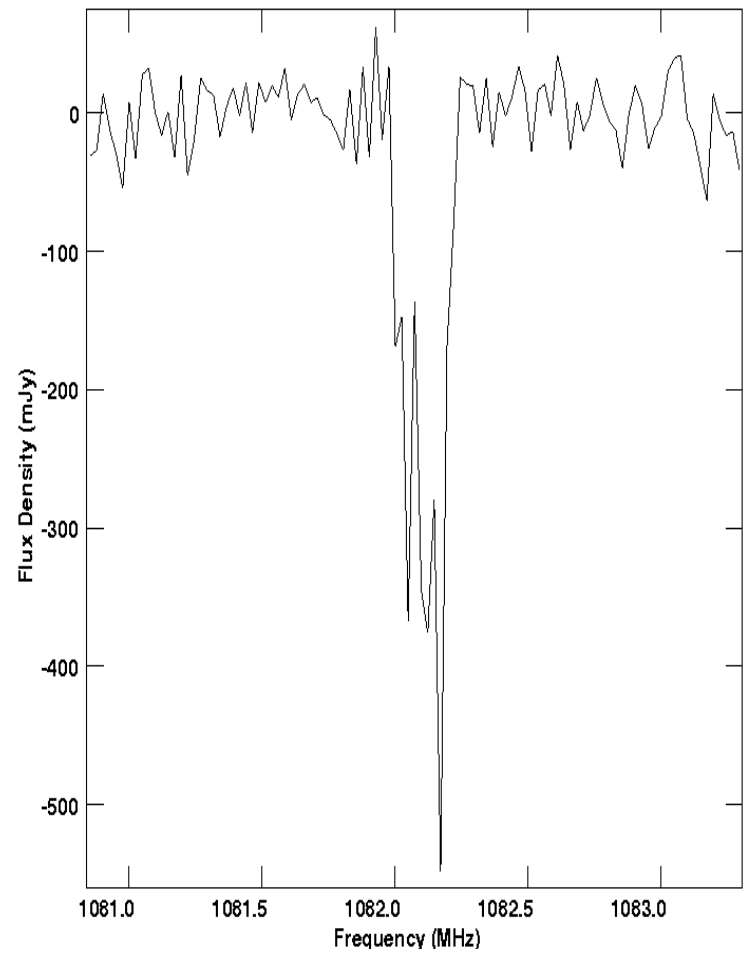




Despite it all – clean images!

PKS 1127-145: z = 0.3127. 1 hour, at 2AM, B-Config.





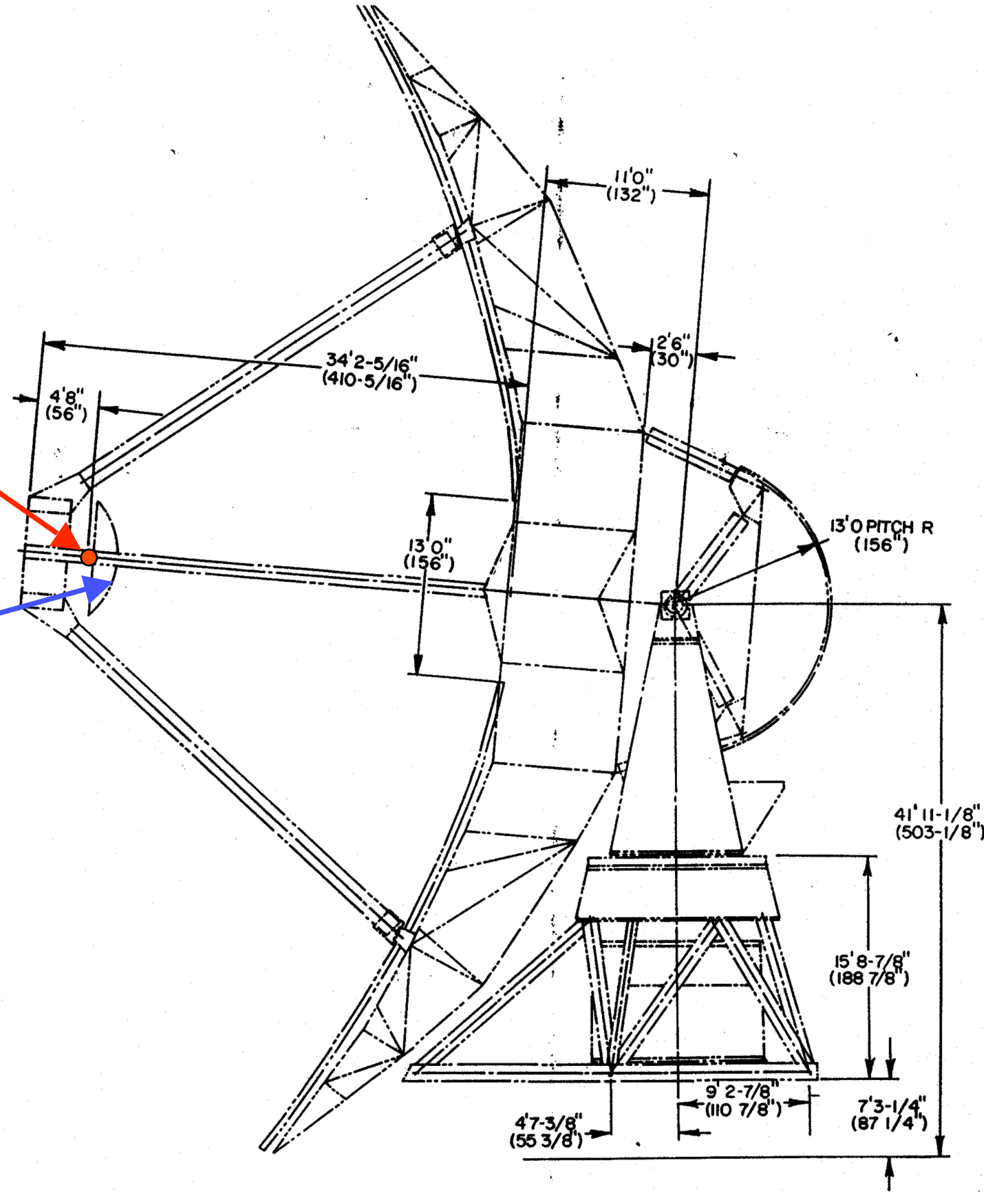
E. Momjian

The Problem with the VLA, in a nutshell

- The VLA's antennas work well down to a frequency of ~100 MHz.
- **But,** the small subreflector requires ~7λ feed!
  - A 6-meter horn for 327 MHz operation just won't fit!
- **Thus,** sub-1GHz operation requires a prime focus system.
- **Sadly,** the existing subreflector mount does not permit access to prime focus. (About 50 cm short).
- **So,** how can we get efficient, broad-band coverage below 1 GHz?

VLA Antenna

- The focus lies behind the subreflector.
- Subreflector cannot be moved back far enough to expose PF.



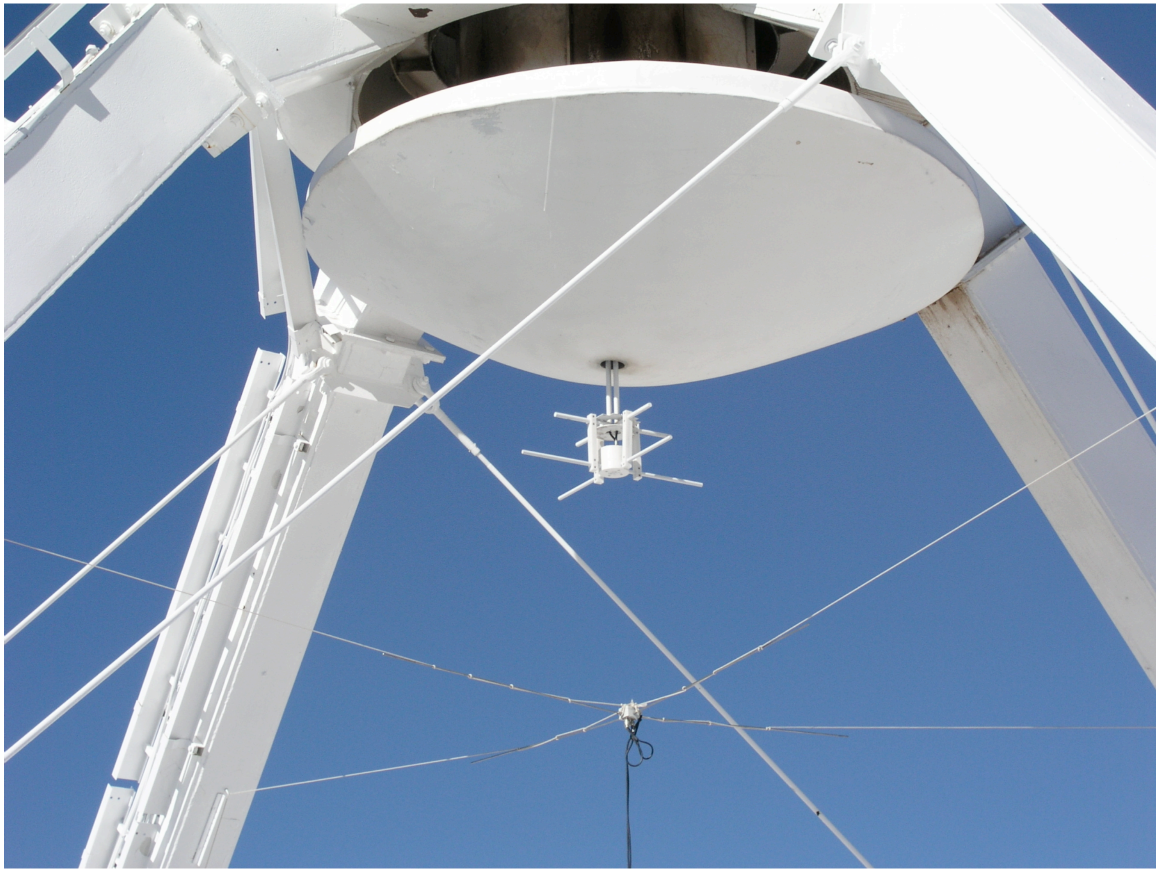
How to do Low-Frequencies with/at the VLA?

- We look at four proposed approaches
  1. Improving the current system
  2. Off-focus Phased Focal Plane Array
  3. New FR mount to remove subreflector, giving access to the PF.
  4. A new, dedicated, array.

Approach #1: Improving the current system.

The present system employs X-dipoles, using the subreflector as a backplane. 74 MHz system is a truly floppy dipole.

- One could imagine:
  - Improving amplifiers.
  - Designing wider-band feed.
  - A rigid mount for 74 MHz?
  - Possibly a deployable system?
- However, any such system will remain at least 55 cm out of focus.



Focus Error causes Loss of Gain!

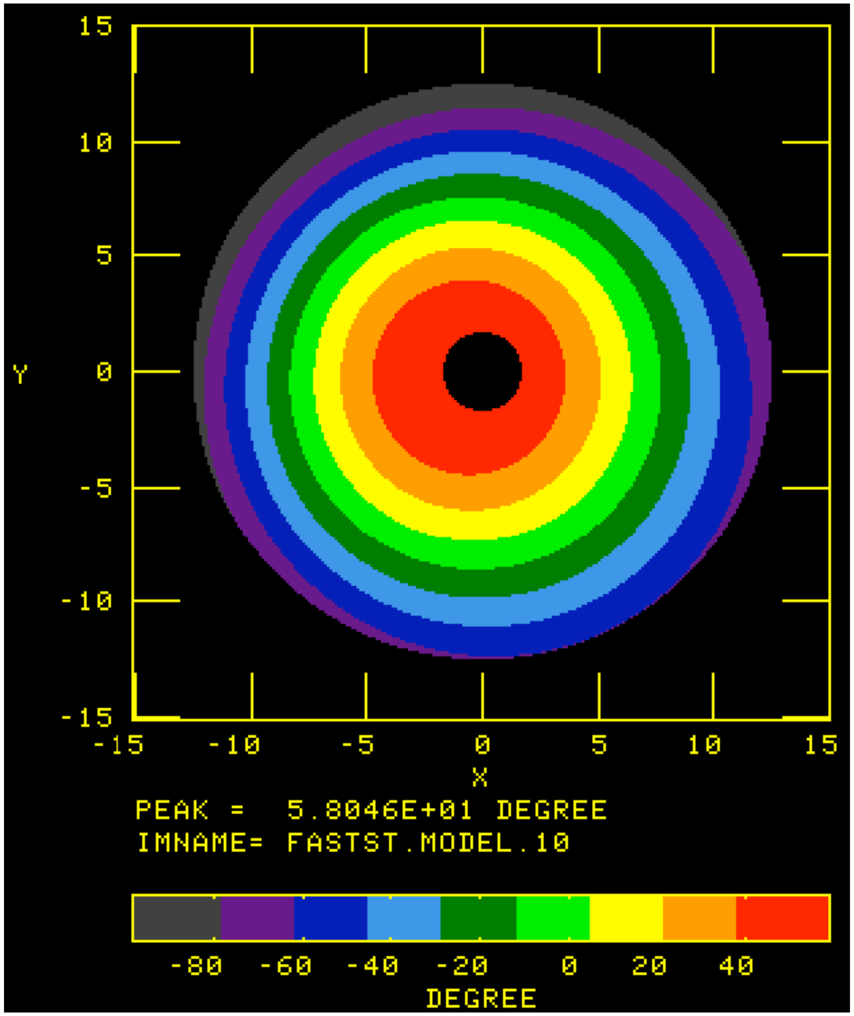
- According to Ruze (1969), a focus error of Δ causes a loss in forward gain by a factor

$$\frac{G}{G_0} \sim 1 - \mathrm{K}\frac{[\Delta/\lambda]^2}{[f/D]^4}$$

- For the VLA, $\Delta = 55$ cm, causing a loss by about 40% for 90cm band.
- The measured efficiency is about 0.32.
- This is an unavoidable loss – and gets much worse at higher frequencies.
- The antenna beam is broadened, with a broad plateau.

Focus Phase Error

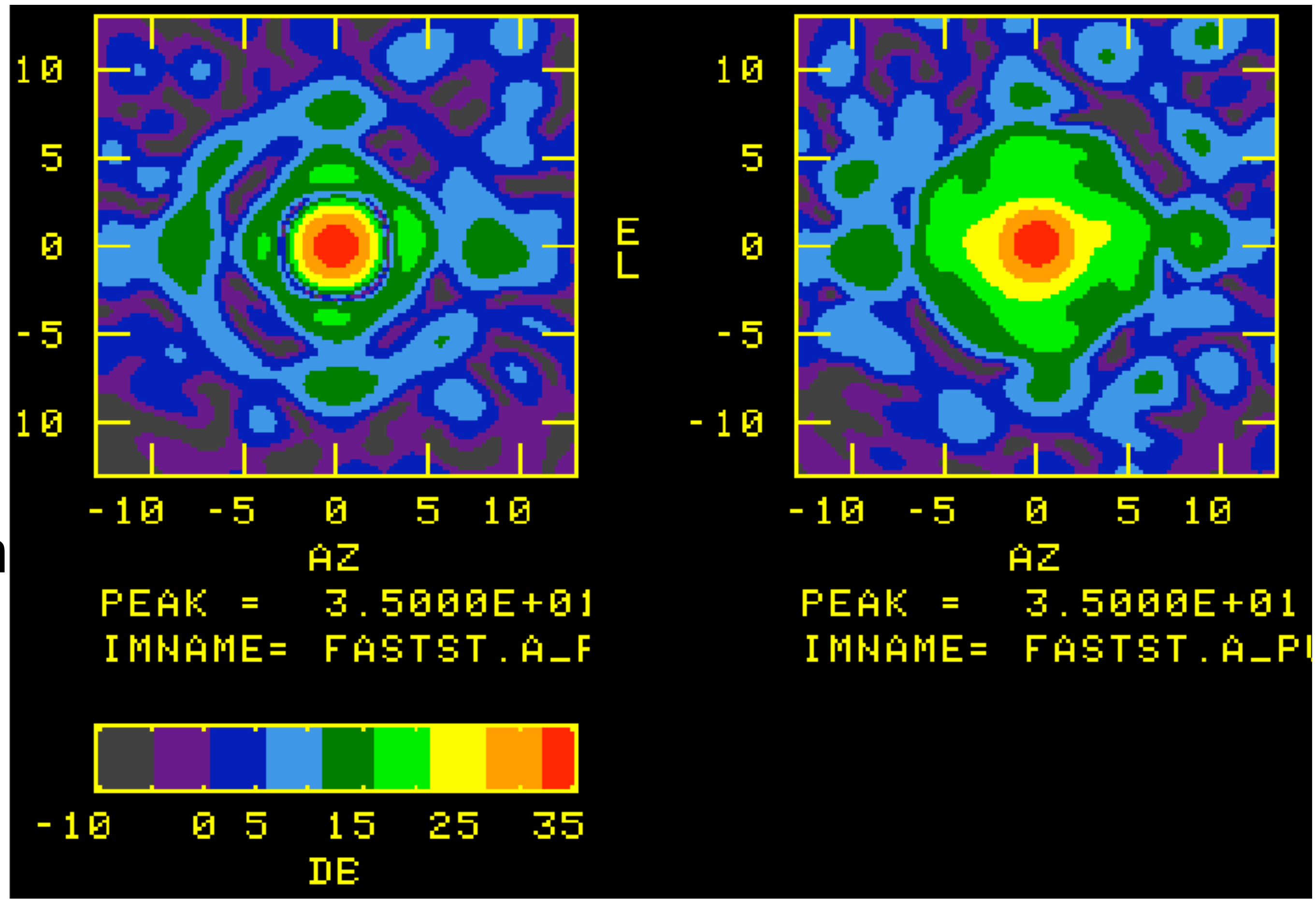
- Holography nicely shows the effect of the focus error.
- The ~55 cm effective offset introduces a ~160 degree parabolic phase across the antenna surface.
- The loss of forward gain is by nearly 2 dB.



P-Band Beam – with/without focus error

- The 55 cm focus error causes a broad plateau to form.
- The P-band beam sits on top.
- Power through plateau nearly equal to main beam.!

In-Focus **Actual**



Option 1 Discussion

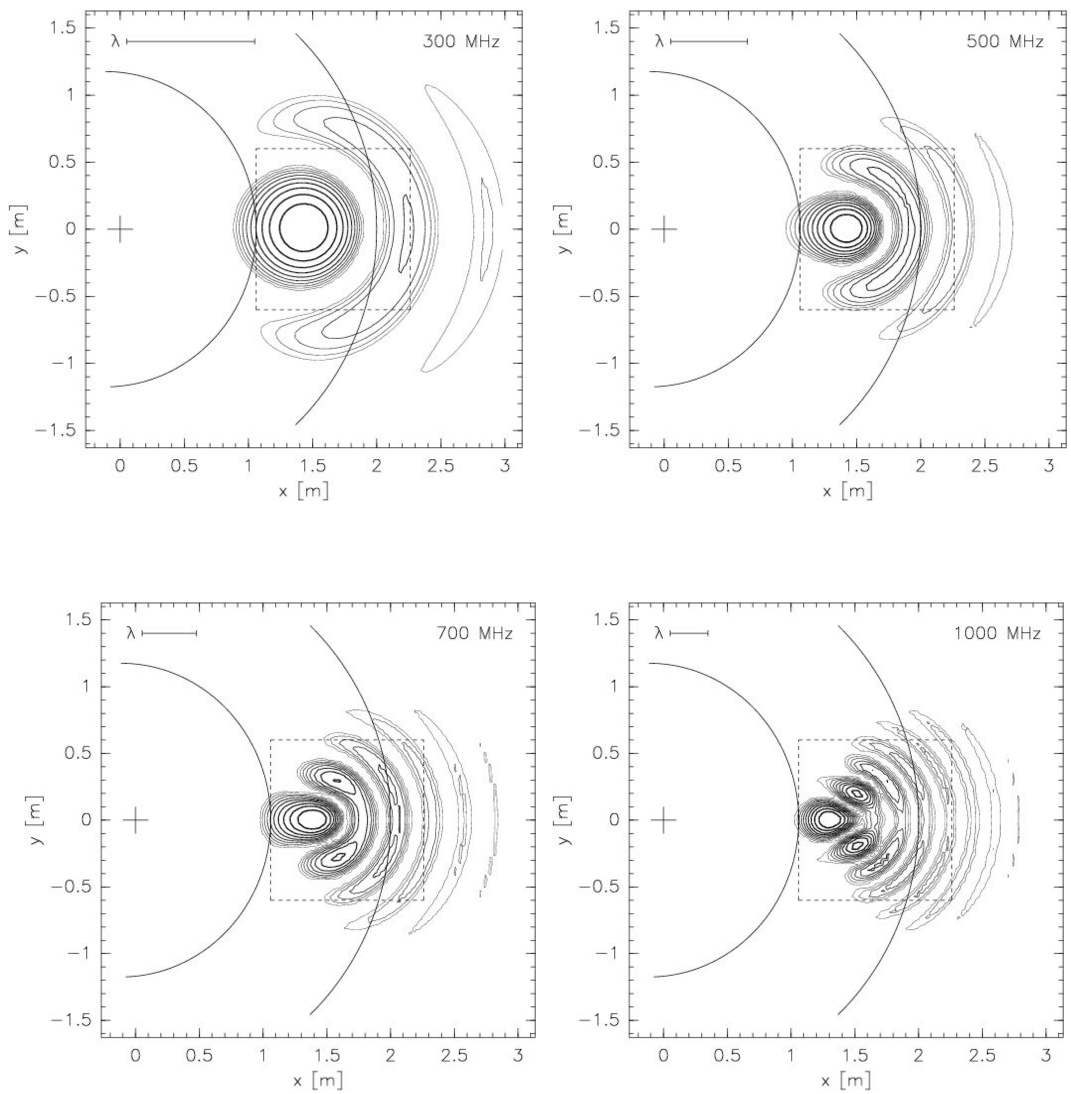
- Advantages:
  - Much faster, cheaper than other approaches.
- Disadvantages:
  - Cannot recover from defocussing loss.
  - Strong likelihood of interfering with higher frequency performance – particularly L band.
- Nevertheless – simply modernizing the P-band amplifiers, and utilizing a wider-band feed would be very useful.

Option 2 – Phased FPA

- Phased FPAs are ‘all the rage’ these days.
- If they work as advertised, one can imagine feeding the EVLA antenna with a PFPA positioned near the subreflector.
- If in front of subreflector, a PFPA must be both large (~3 meters!) and deployable. Messy.
- Perhaps on the side? Walter Brisken looked at this …

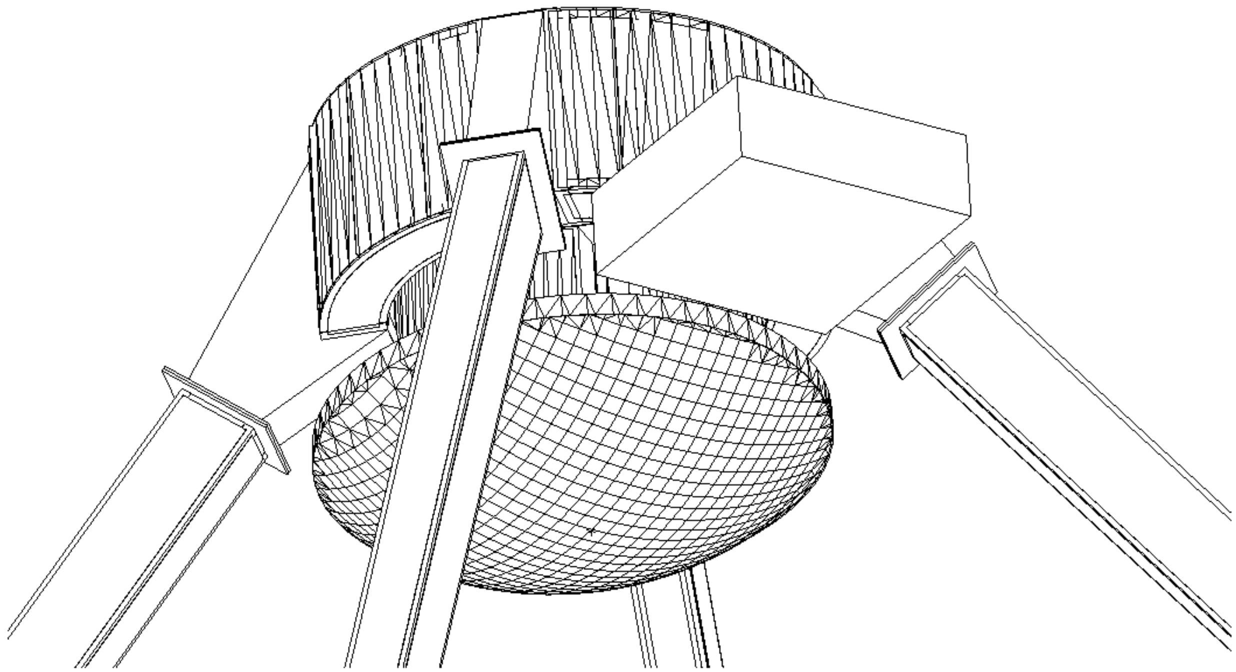
Off-Axis Airy Patterns

- Showing the distribution of EM flux for an off-axis source, at four frequencies.
- Effects of subreflector, legs, and struts are NOT included.
- Dotted rectangle shows a 1.2-meter FFPA.
- Very difficult to obtain good efficiency and to form a good circular beam.



Option Two: Phased Focal Plane Array

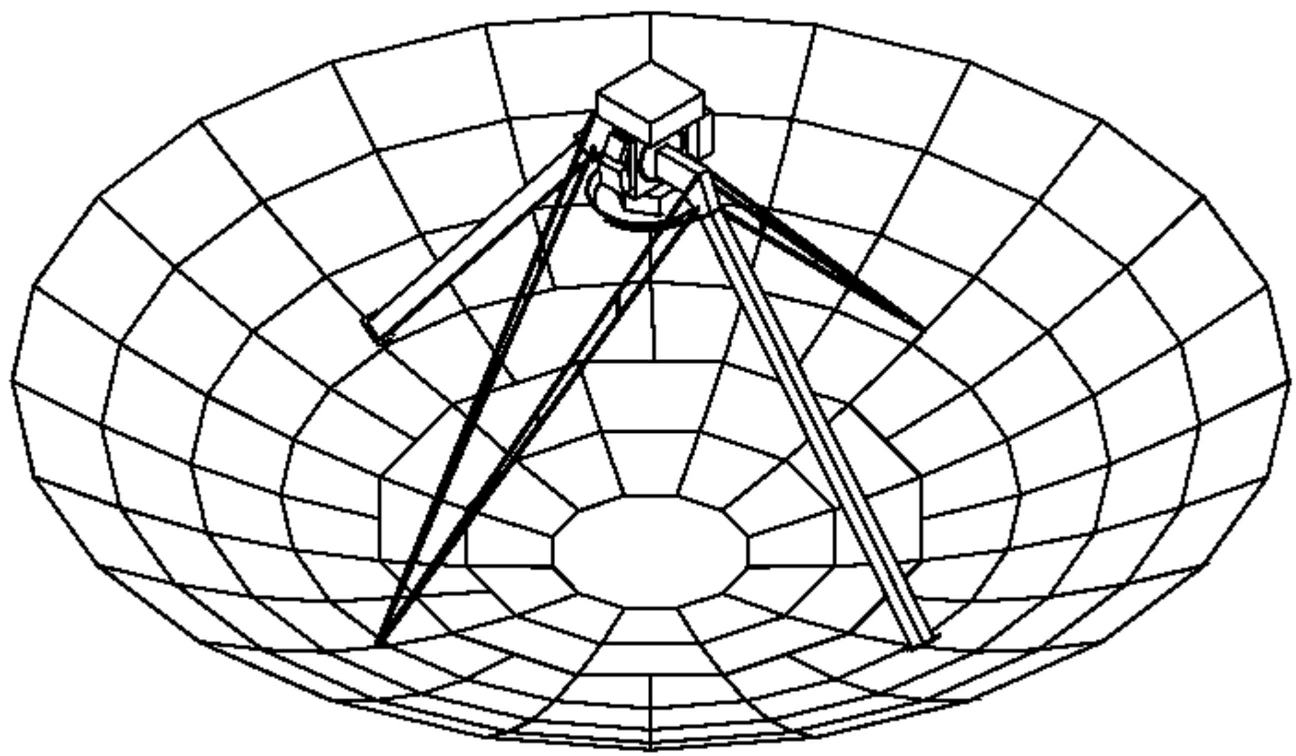
- **Advantages:**
  - Multiple beams possible
  - Higher efficiency
  - No major surgery
- **Disadvantages**
  - Non-circular beam
  - Limited frequency coverage
  - A different PFPA for each frequency band
  - Higher Tsys
  - Extra weight.
  - Likely to need retractable system.
  - Will it work at all?



This approach rejected in Phase II study.

Option Three: New FRRM

- Horizontal legs replaced with rigid rods.
- FRM replaced with new mount (the FRRM)
- Subreflector can be rotated out of way, permitting PF access by up to three feeds.



More on Option 3

- **Advantages**
  - If feasible, solves the problem at once and for all.
  - Minimizes weight, optimizes gain.
  - Modest cooling should be enabled.
  - Phased FPA (if feasible) can be employed on-axis for multiple beams and higher sensitivity.
- **Disadvantages**
  - Lengthy D&D needed.
  - Implementation slow
  - Pricey.
  - Weight is apparently not an issue – Jim Ruff believes the extra mass is offset by removal of the ‘doughnut’.

Performance

- To give an idea of likely performance, I've defined three bands, and made up some best guesses.
- Values shown are for A-configuration.

Freq.	BW	Eff.	Tsys	SEFD	Res'n	CPSS	Conf.	CBTS	LPSS	LBTS
GHz	MHz		K	Jy	arcsec	μJy	μJy/b	K	mJy	K
.12 - .25	100	0.5	200	2810	10	137	17	57	54	22500
.25 - .50	200	0.6	70	650	5.0	22	2.6	9.2	9	3750
.5 – 1	400	0.5	40	450	2.5	11	0.4	3.0	4	1700

Acronym Key

CPSS: Continuum Point Source Sensitivity (1-σ, 1 Hr, Stokes I)
CBTS: Continuum Brightness Temperature Sensitivity
LPSS: Line Point Source Sensitivity (1-σ, 1 Hr, Stokes I, 1 km/sec)
LBTS: Line Brightness Temperature Sensitivity

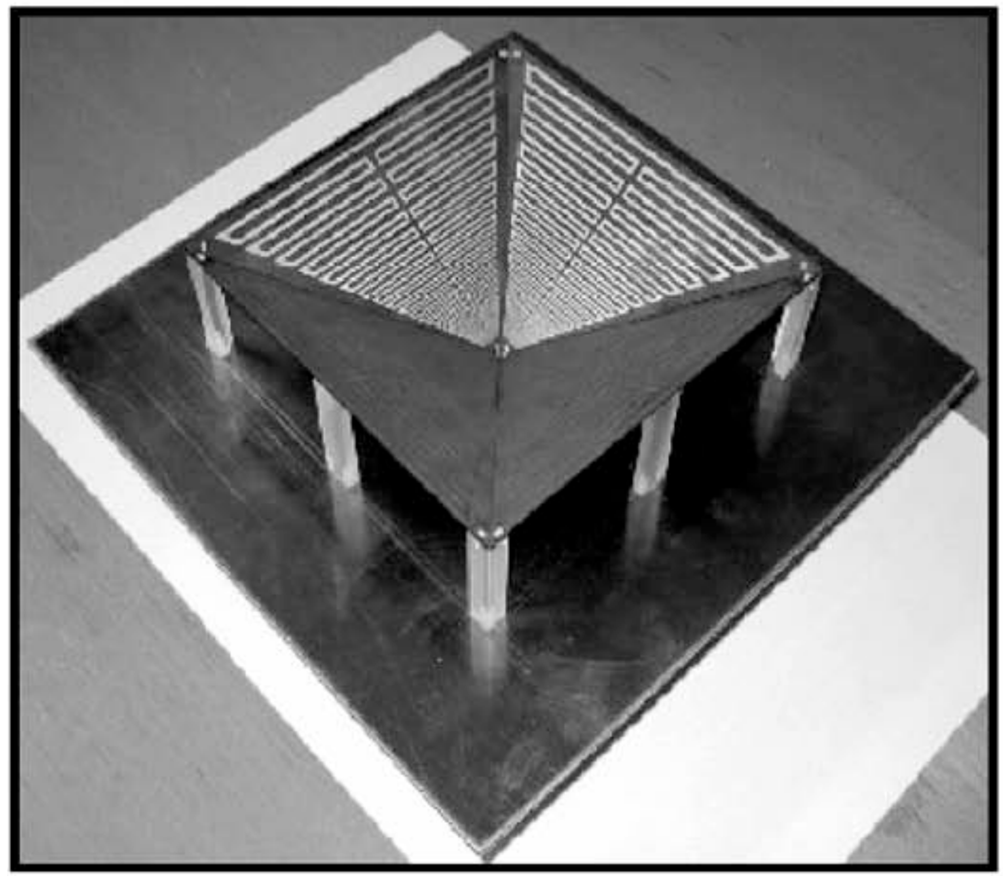
Low Frequency Wide-band Feeds

- Good performance is essential, especially for the highest frequency band.
- Pictured is a 2:1 BWR corrugated feed horn, developed by P.S. Kildal, modified by S. Weinreb.

Frequency	Cryo?	Feed	Polarizer
500 – 1000	Yes	Corrugated Circular Horn	Quad-Ridge OMT + circular WG + hybrid
250 – 500	No	Quad-ridge Horn	hybrid
125 -- 250	No	Cavity Dipole	hybrid

One Feed for All?

- 10:1 BWR feeds are available.
- Something like the ATA feed may suffice – but cooling, and polarization are issues.
- Compact Low-profile Decade BW Dual Polarized Feed (pictured), has been developed by Sandy Weinreb.



Timescale

- This is a significant engineering effort!
- 6m – 1 yr for FEM analysis.
- 6m – 1 yr for detailed design.
  - Can partly be done in parallel with FEM.
- 2.5 years needed for design and testing feed/receiver.
  - Concurrent with antenna design.
- 6m testing on first antenna.
- Implementation rate: 6 antennas/year.
  - Is compatible with antenna maintenance schedule.
- Start time: No sooner than end of 2010, following completion of EVLA retrofits.
- Completion time: Near the end of next decade!

Cost

- D&D: $1M
- Implementation: $0.5M/antenna
- Receivers: $2.7M
- Labor $1.5M
- Total: $19M.

Option 4: A Whole New Array?

- The final option is to build a new array, comprising antennas designed for good low-frequency performance at fixed locations.
- Electronics similar to what is proposed for Option 3.
- Advantages: Standalone, thus full-time observing would be possible. Can be engineered for optimal performance.
- Disadvantages: No reconfigurability. New correlator probably required. Long development and construction time.

Cost, for GMRT-like antennas.

- Swarup (1990) provides the following cost equation:

$$C = \$14M\left(\frac{N}{30}\right)\left(\frac{D}{45}\right)^{2.5}\left(\frac{\nu}{\nu_0}\right)^{2} * (1+i)^{20}$$

- If we take i = .05, and adopt the same maximum wind tolerance as the GMRT (140 km/hr), then

$$C = \$37M\left(\frac{N}{30}\right)\left(\frac{D}{45}\right)^{2.5}$$

- For 25-meter antennas, this comes to a modest $9M.
- Adding in D&D, and electronics, plus a correlator, will likely bring the total to ~$15M.

Some Conclusions (?)

- There is an abundance of science below 1 GHz.
- Option 1 should give quick return, and is probably the most cost-effective.
- Option 2, pending a breakthrough in PFPA technology, looks very unlikely.
- Option 3 is the best if we want it all in one array, and have the resources and time.
- Option 4 is the best match for high sensitivity, long-integration observations, but also requires much development, time, resources.