EVLA System Commissioning Results

EVLA Advisory Committee Meeting, March 19-20, 2009

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Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

NRAO

Project Requirements

- EVLA Project Book, Chapter 2, contains the EVLA Project system performance requirements.

- Demonstrating that these requirements are met necessitates a wide suite of tests, both on the bench and on the sky.

- I give here results from system performance testing for key project requirements.

System Sensitivity

- There are band-dependent requirements for:
  - Antenna Efficiency -- ε
  - Antenna System Temperature -- T_{sys}
- The key sensitivity parameter is their ratio:
  - the 'effective system temperature': T_{sys}/ε, or
  - 'System Equivalent Flux Density': $S_E = 5.62 * T_{sys}/\varepsilon$.
- We have determined good values for all bands except L, X, and Ku, which are still under development.
- The noise-limited array sensitivity, per correlation, is given by:

$$\sigma = \frac{S_E}{\eta_c N \sqrt{BT}}$$

Efficiency and Tsys Results

	Band (GHz)	Tsys		Aperture Effic.	
		Req'd	Actual#	Req'd	Actual#
L	1 – 2	26	TBD	.45	0.40 – 0.45
S	2 – 4	26	24 – 28*	.62	~0.52*
C	4 – 8	26	24 -- 31	.56	.53 -- .61
X	8 -- 12	30	TBD	.56	TBD
Ku	12 -- 18	37	TBD	.54	TBD
K	18 -- 26.5	59	36 -- 42	.51	.57 -- .48
Ka	26.5 -- 40	53	40 -- 50	.39	.48 -- .36
Q	40 -- 50	74 -- 116	55 -- 100	.34	.37 -- .28

Blue = System tested and in place, or under installation.

Red = Prototypes to be tested in 2009

* Preliminary result

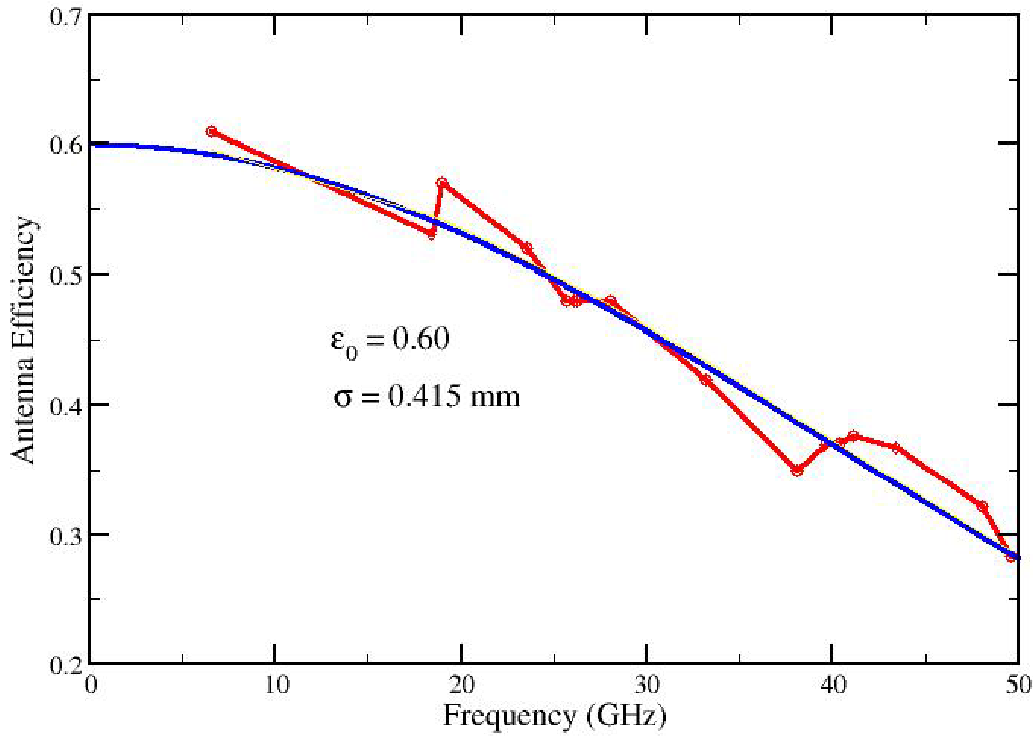
\# Range over the band

Antenna Efficiency and Ruze's Law

- For randomly distributed panel errors, Ruze showed that the efficiency should decline as:

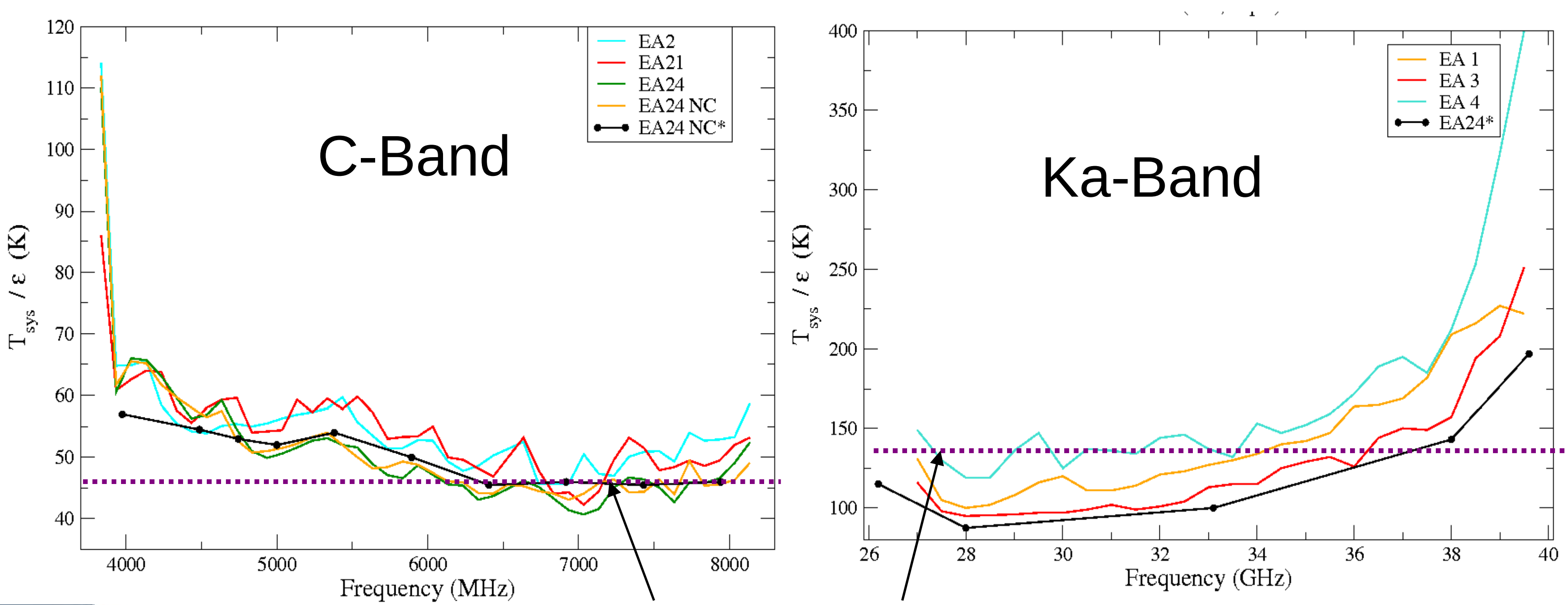
$$\varepsilon = \varepsilon_0 e^{-(4\pi\sigma/\lambda)^2}$$

- Our efficiency results are in excellent agreement, with $\varepsilon_0 = 0.60$.



C and Ka Band Sensitivity Detail

- Sensitivity as a function of frequency:
  - Colored lines are derived via correlation coefficients
  - Black line with dots are from direct antenna measurements.



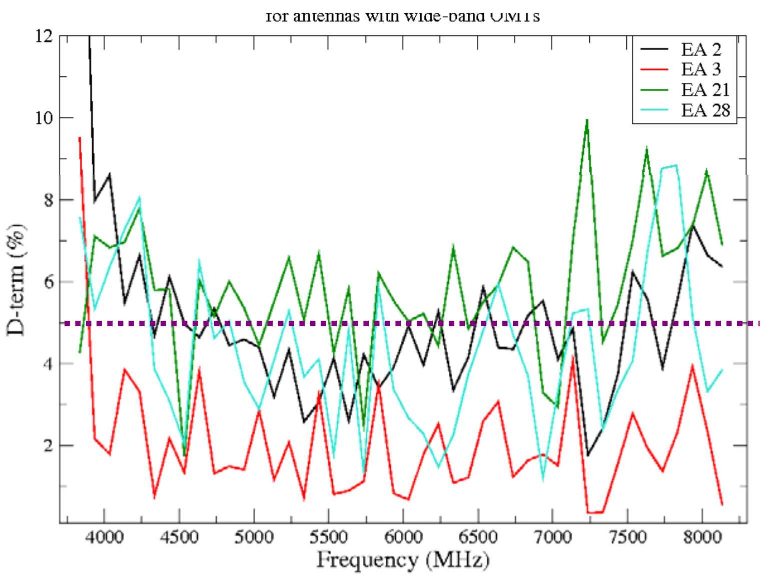
Project Requirement

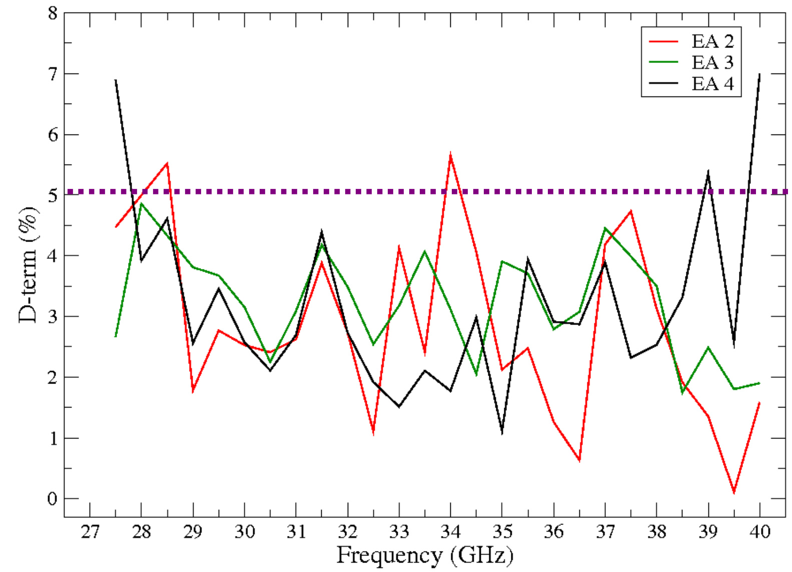
Polarization

- Polarization purity (D-term)
  - Less than 5% leakage of total intensity into ‘RL’ and ‘LR’ cross-products.
- Cross-polarization (‘D’ term) stability
  - Stable to 0.1% in leakage.
- Beam squint stability
  - Separation of ‘R’ and ‘L’ beams constant to 6”, over 8 hours.
- Note: Although polarization purity (small ‘D’-term) is useful and desirable, the stability of the cross-polarization is critical for accurate polarimetry.
  - A 1% stability is sufficient to determine fractional linear polarization with an accuracy ~0.1%.
  - The 0.1% stability is required to achieve noise-limited performance in the presence of a strong unpolarized source.

C and Ka-Band Cross-Polarization

- Antenna 'D-Term' polarization with the new OMT design close to the specs at C-band.
- Ka-band polarization, with waveguide OMT meets specs, except at the band edges.





Cross-Polarization Stability

- Low antenna cross-polarization is desirable, but is not as critical as stability.
- Extensive testing show the polarizers are stable.
- Best demonstration of this is in the imaging.
- Examples:
  - C-band imaging of NGC7027, an optically thin thermal source (PN) with no polarization.
  - L-band imaging of 3C147, whose linear polarization is known to be less than 0.1%.

C-Band Imaging of N7027

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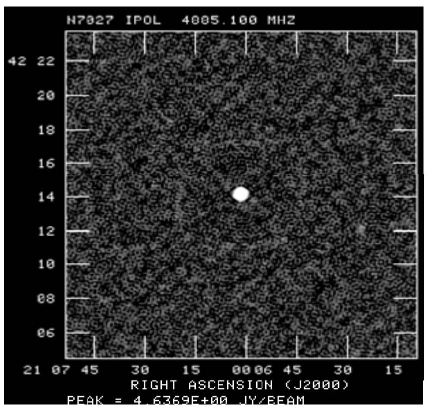
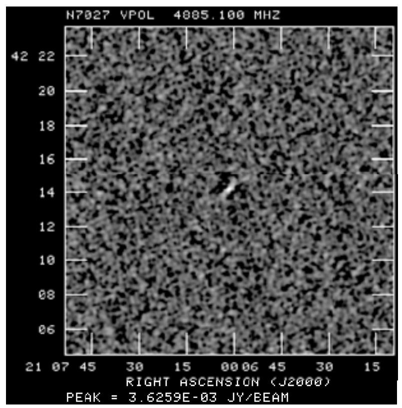
- N7027 is a planetary nebula – no polarization is expected.
- D-Configuration. 4885 MHz. Data taken in pieces over 16 days.
- Phase self-calibration, flat amplitude calibration. Single polarization solution.

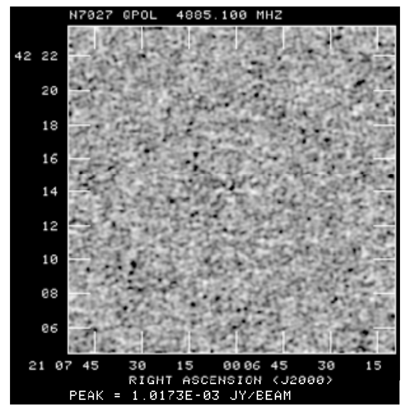
I



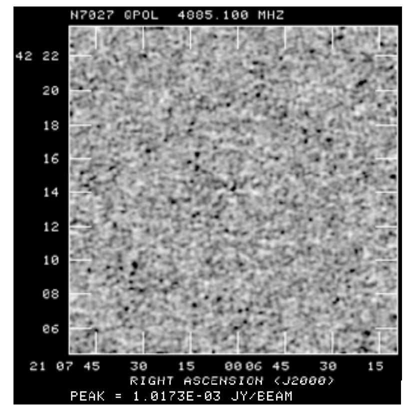
V



Q



U



	I	V	Q	U
Peak	4637 mJy	3.6 mJy	1.01 mJy	1.02 mJy
Pk/I		.07 %	.025%	.025%

Polarization images are (nearly) noise-limited!

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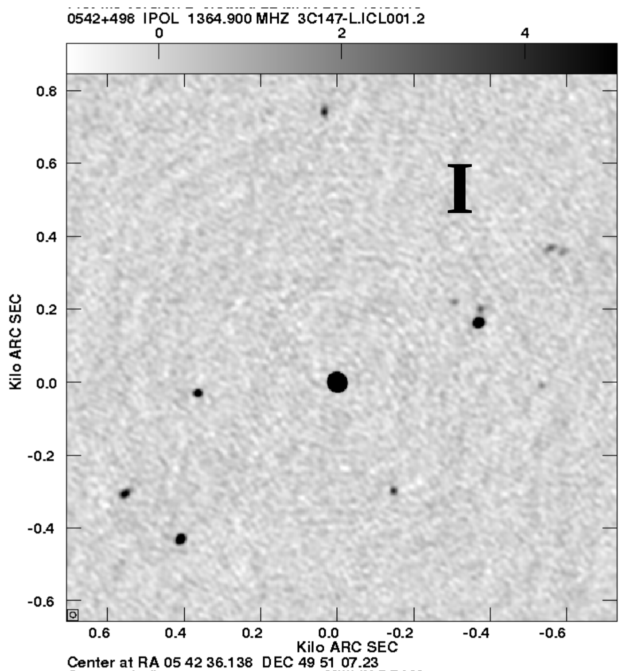
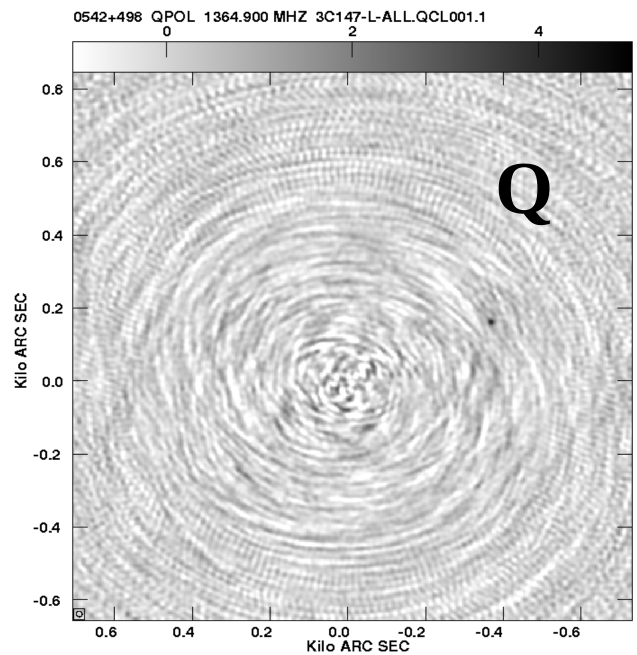
3C147, an Unpolarized Source, at 1485 MHz

- Noise-limited polarimetry in the field of a very bright source imposes much more demanding requirements on polarizer stability.
- Shown are images with 6 hours' data, with interim L-band polarizers.





Peak = 21241 mJy, σ = 0.21 mJy

Max background object = 24 mJy

Peak = 4 mJy, σ = 0.8 mJy

Peak at 0.02% level – but not noise limited!

3C147, an Unpolarized Source, at 1485 MHz

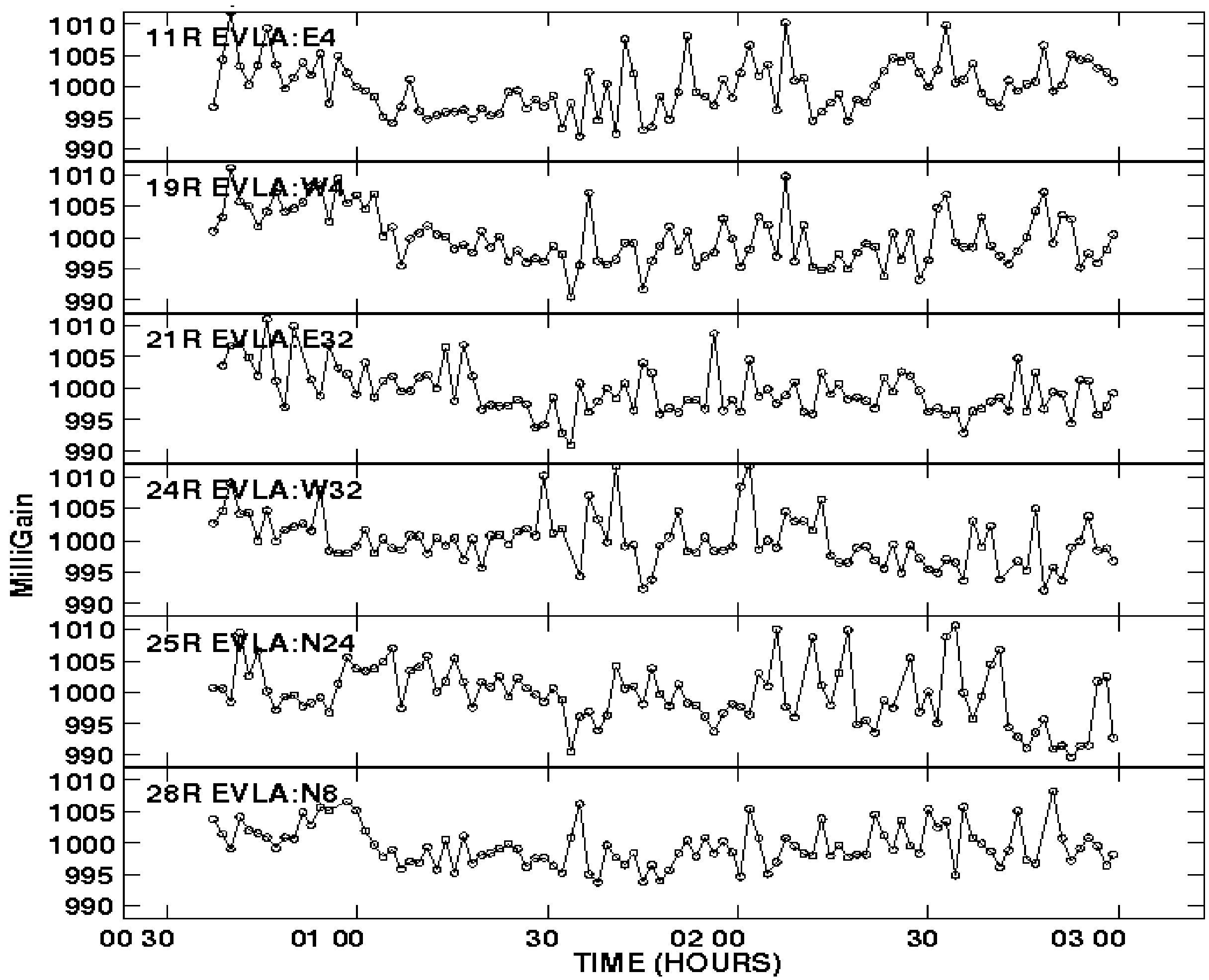
- The ‘structure’ in the polarization images clearly shows the effects of a slowly changing cross-polarization error.
- Although the polarization field is not noise limited, we are confident that we will do much better, as:
  - The ‘interim’ L-band polarizers were utilized in this test – they have 5 – 15% cross polarization.
  - The experiment was done in continuum, with no correction for the ‘closure errors’ that must affect the cross-polarization correlations.
  - Second-order terms in the polarization calibration were not utilized.
  - The solution utilized was time-independent.

Antenna Gain Determination

- The overall goal is to be able to determine the source spectral flux density, relative to an established standard, with an accuracy of
  - 0.5% for non-solar observations, and
  - 2% for solar observations.
- These place requirements on:
  - Correlator linearity
  - Stability and linearity of system temperature determination (switched power)
  - Accuracy of correction for antenna elevation gain dependence
  - Accuracy of correction for atmospheric absorption (at higher frequencies).

Amplitude Transfer Stability

- Two northern sources, observed alternately 1 minute each, at C-band.
- Separation of a few degrees.
- (Almost) no editing.
- Flat calibration.
- Peak deviations ~1% in amplitude.
- These antennas meet requirements.

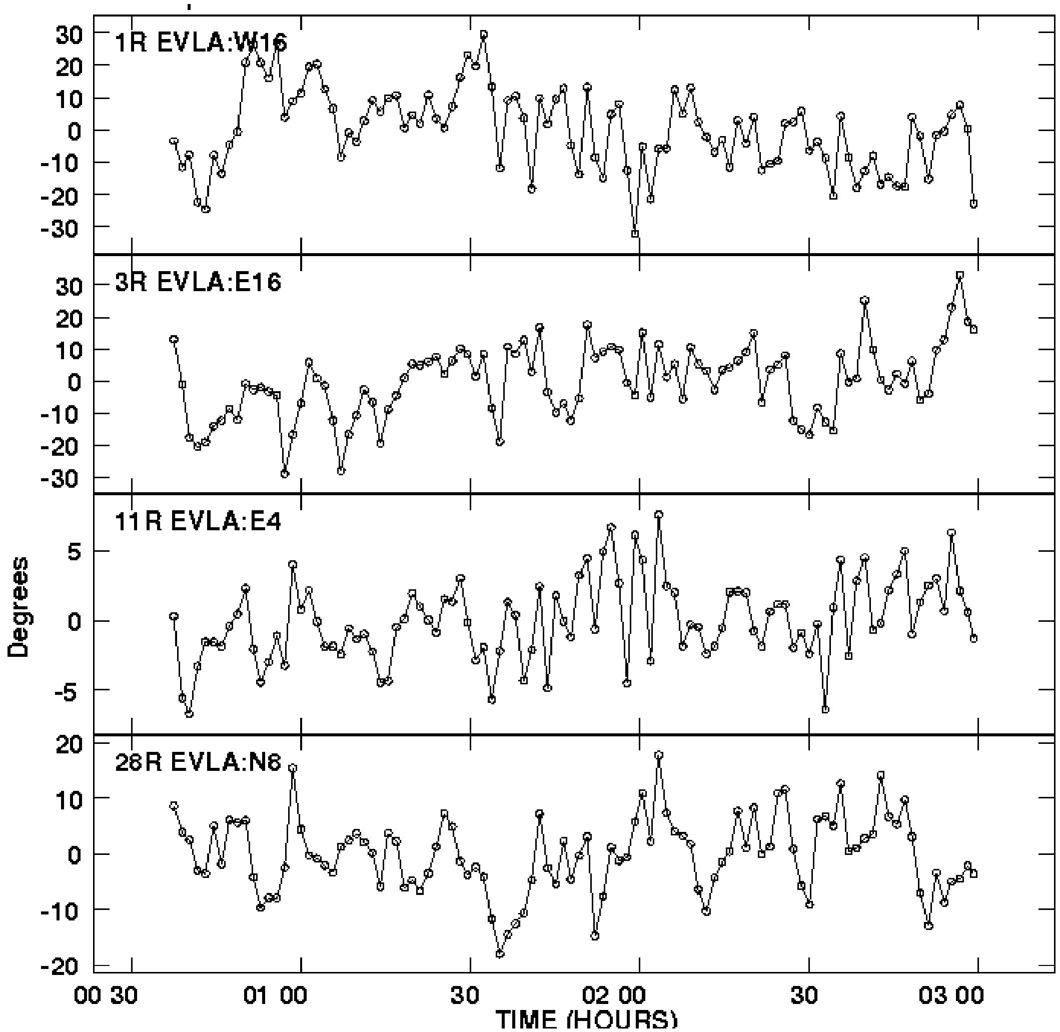


System Phase Stability

- A detailed list of requirements on different time and angular scales (all at 50 GHz):
  - 1-second rms phase jitter < 10 degrees.
  - Phase change over 30 minutes < 100 degrees
  - Fluctuations about mean slope over 30 minutes < 30 degrees.
  - Phase change upon source change < 15 degrees.
- Results
  - Short-term phase jitter requirement met (via lab measurements)
  - Medium term and spatial variations:
    - on-sky observations show these requirements are met for most antennas.
    - Residual drifts are understood, and being addressed.

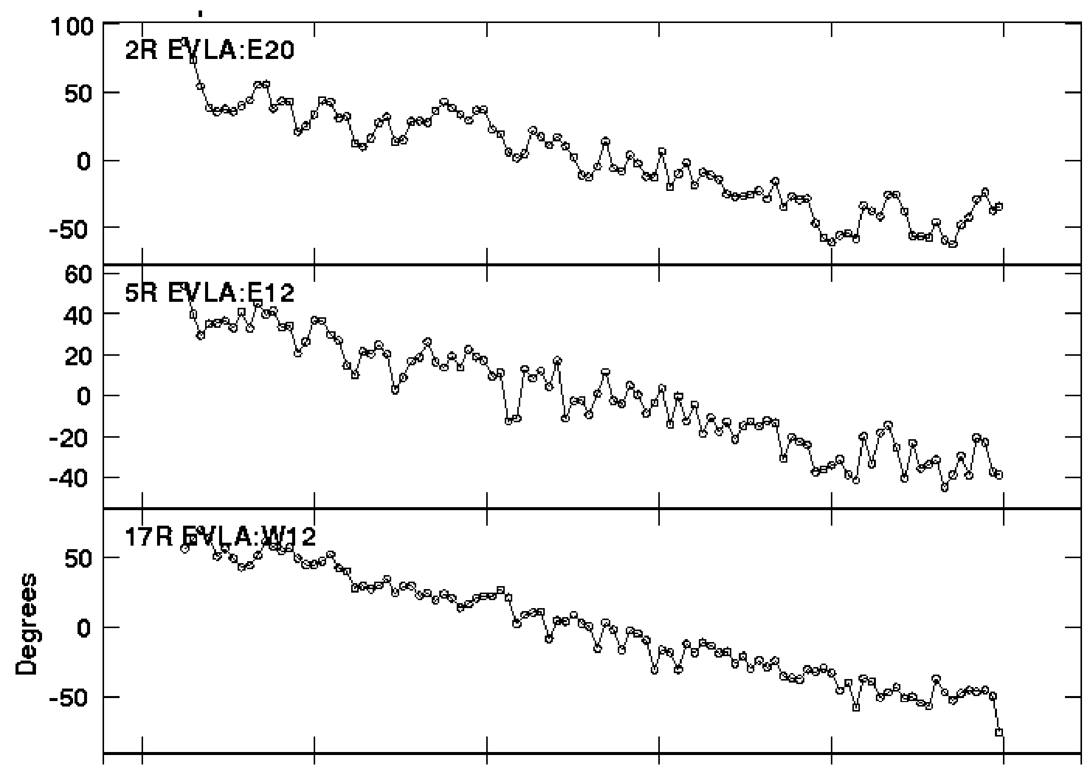
System Phase Stability

- Same pair of sources.
- B-configuration (so atmosphere dominates on most baselines).
- Same flat calibration – no trends removed.
- B-configuration @ 6 cm
- No phase transfer problems for these antennas.



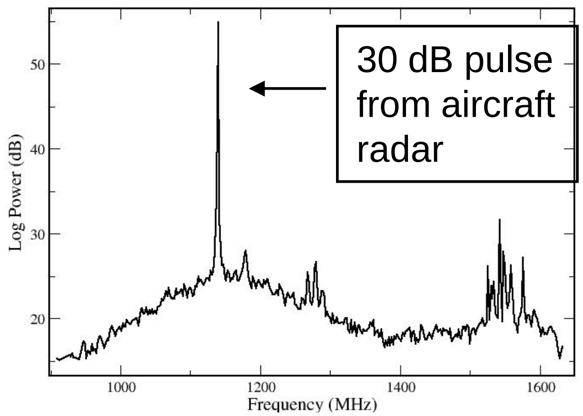
System Phase Stability

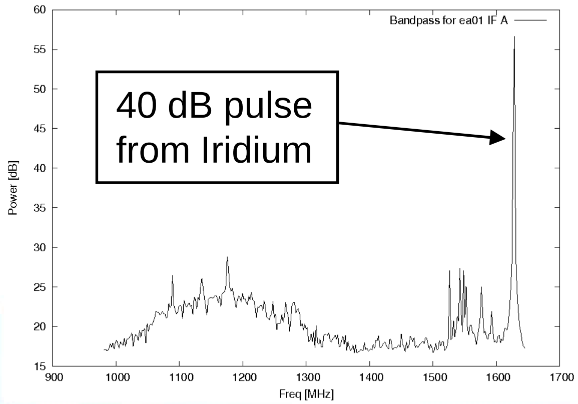
- Some antennas do show slow drifts.
- Drift exceeds system requirements at 50 GHz
- The origins of these slow trends are understood.
- Corrections are underway.
- These do not affect regular, local calibration.
- No science impact.

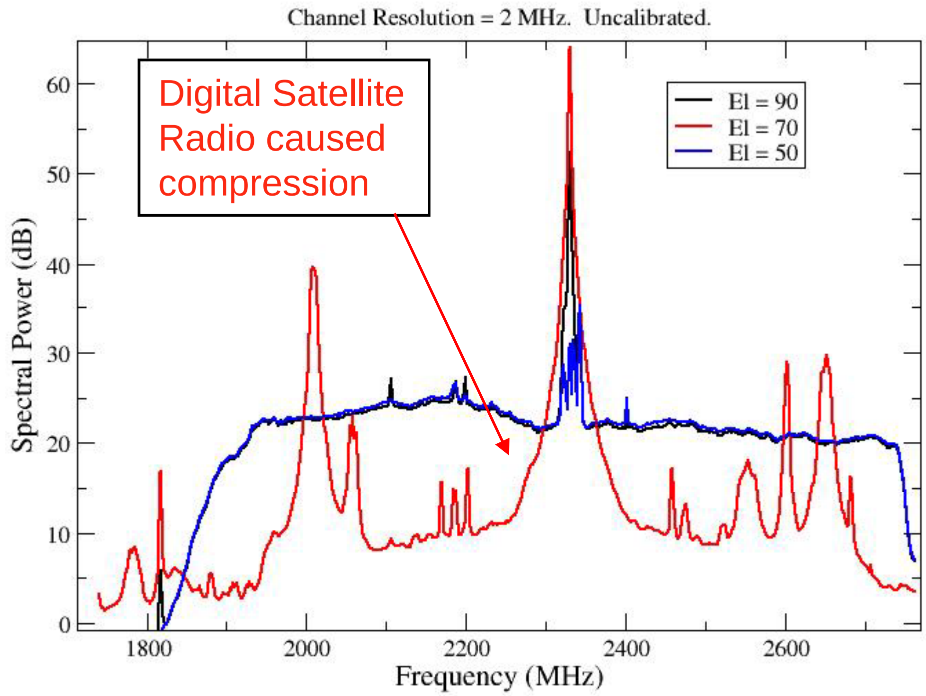


RFI Tolerance

- It's a rough world out there for radio astronomy.
- RFI can increase total system power by many orders of magnitude.
- Show are examples at L and S bands.







RFI Tolerance Requirements

- Strong external signals will cause saturation of the electronics, giving spectral ringing and distortion.

- ‘Headroom’ is the ratio of RFI power to system noise power which causes the electronics to go into gain compression to a given level.

- To minimize distortions, high ‘headroom’ requirements have been set for both the RF and IF.

- For the RF, the headroom, in dB, which causes 1 dB compression:

Band	L	S	C	X	U	K	A	Q
Headroom	47	48	43	42	40	33	35	27

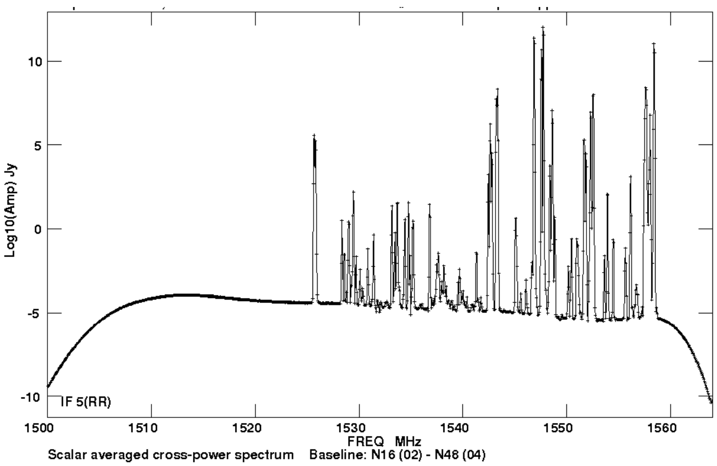
- For the IF electronics, the headroom requirement is set at 32 dB to 1 dB compression.

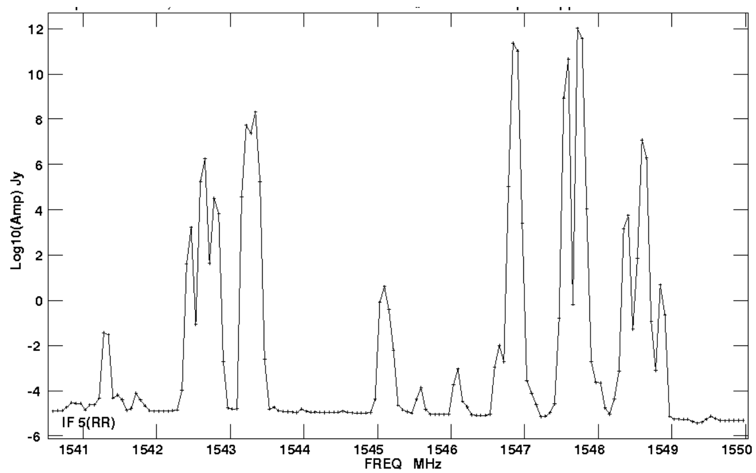
RFI Tolerance Results

- All electronics are designed to meet the requirements.
- On-sky examples of amplifier compression hard to find! No specific tests have been conducted yet.
- Antenna 14 is outfitted with prototype wideband OMT:
  - This antenna ‘sees’ all DME aircraft signals, as well as Inmarsat, Iridium, GPS, Glonass, etc.
  - No evidence for any degradation in performance from this antenna.
  - If saturation is occurring, it is rare.
- Careful study will be needed when the new S and L band systems come on line.

Correlator Linearity

- The correlator needs to have high linearity too.
- WIDAR designed to provide more than 50 dB linearity.
- Early tests with the PTC are very encouraging:





- Left: Scalar averaged spectrum of 3C84, showing INMARSAT
- Right: Closeup, showing astronomical signal between emissions.
- There is no sign of correlator saturation, at a level 40 dB below the peak signal strength.

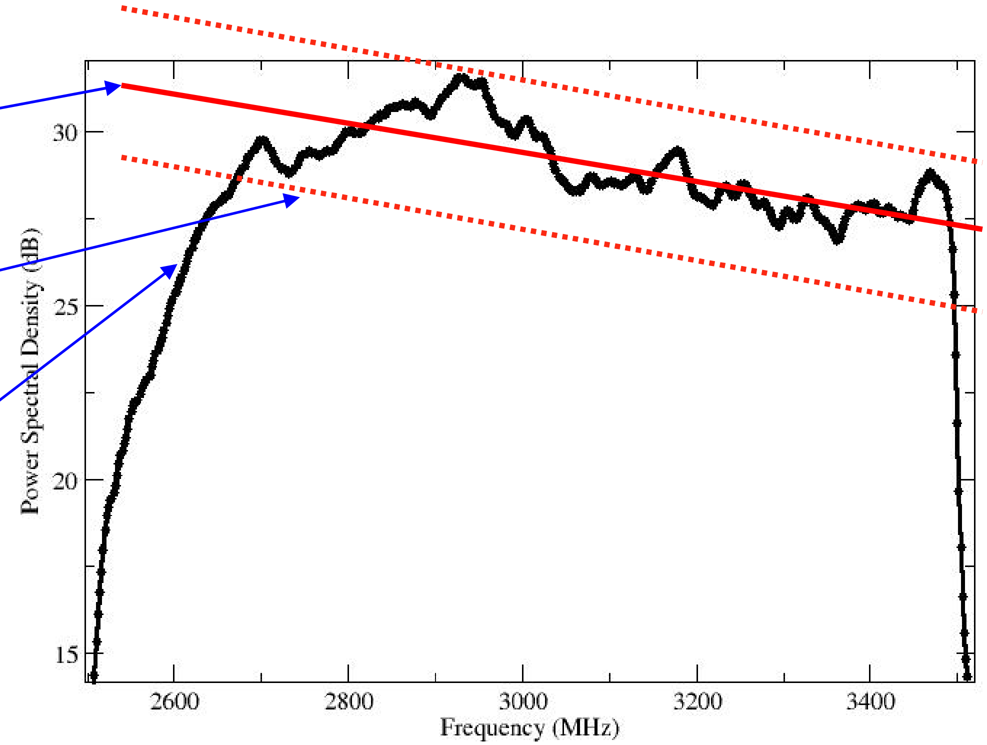
Bandpass Requirements

- Gain (power) slope and ripple limitations
  - Spectral power density slope to 3-bit digitizer < 3 dB over 2 GHz.
  - Fluctuations about this slope < 4 dB
- Amplitude Stability (in frequency and time)
  - Amplitude bandpass stable to 0.01%, over 1 hour, over frequency span of 0.1% of frequency.
- Phase Stability (in frequency and time)
  - Variations less than 6 milli-degrees (over same span as above)

Results: Spectral Power Slope/Fluctuations

- Results: Need 3-bit digitizers to test the 2-GHz path.
- Example (from S-band) shown below.

- Slope will be reduced by gain equalization filters (in 2 GHz path).
- Variations about the mean slope meet requirements.
- Low-frequency roll-off applies only to 8-bit path.



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Bandpass Phase and Amplitude Stability

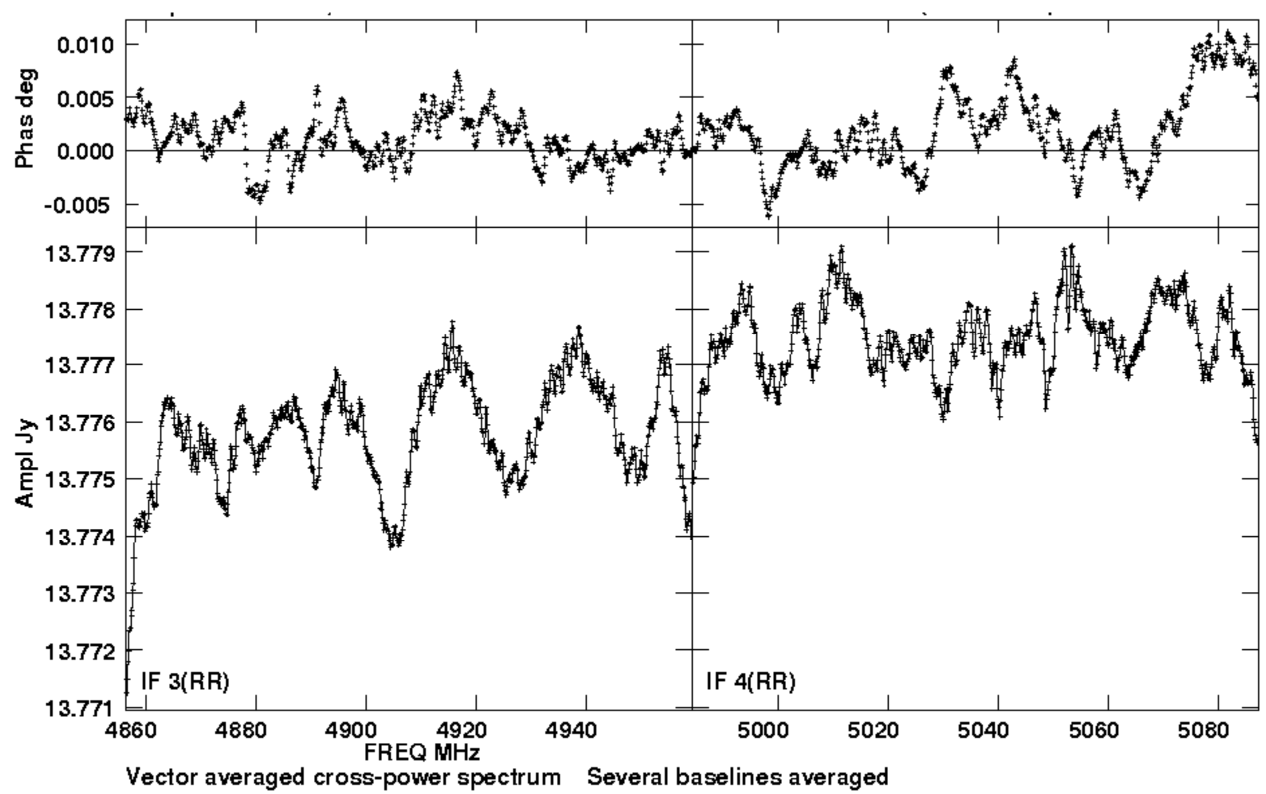
- From the prototype correlator, observations at 6cm of 3C84 – a strong calibrator – with four antennas.
- Residual ripple in vector sum meets requirements.

Observations made hourly, each 20 minutes long.

Bandpass calibration done each 10 minutes.

Vector averaged spectrum shown.

Edge channels not shown.



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Summary

- Intensive testing is being conducted regularly to demonstrate that the antennas and electronics are performing at the required level.
- Many of the requirements need the full system (completed receivers and WIDAR correlator) before final testing can be done.
- Work done so far indicates we will meet all, or nearly all, system performance requirements.