Observing Strategies at Millimetre Wavelengths

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Narrabri Synthesis Workshop

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Current 3mm System

- **3 antennas (CA02, CA03, CA04) with dual polarisation receivers.**
- **2 freq bands: 84.9-87.3 and 88.5-91.3 GHz.**
- **Up to 128 MHz bandwidth in each of 2 frequencies (both must be in same band).**

86243.442	SiO 2-1 v=1 (maser)
86846.998	SiO 2-1 v=0 (thermal)
88631.8473	HCN 1-0
89188.518	HCO^+ 1-0
90663.543	HNC 1-0

Current 12mm System

- **6 antennas with dual polarisation receivers.**
- **2 freq bands: 16.1-18.8 and 20.1-22.4 GHz.**
- **If observing 2 frequencies, both must be in same band.**

18154.887	SiS 1-0
18196.218	HC_3N 2-1 F=2-1
18638.617	HC_5N 7-6
22235.120	H_2O maser
22344.033	C_2S 2_1-1_0

Pending 12mm System

- 6 antennas with dual polarisation receivers.
- 2 overlapping frequency bands: 16.0-22.4 and 20.0-26.0 GHz (ammonia!).
- For dual-frequency operation, both freqs must be in same band, and separated by <2.7 GHz (lower band) or <2.3 GHz (upper band).
- Available from end of May!

Millimetre interferometry

Millimetre interferometry poses special challenges:

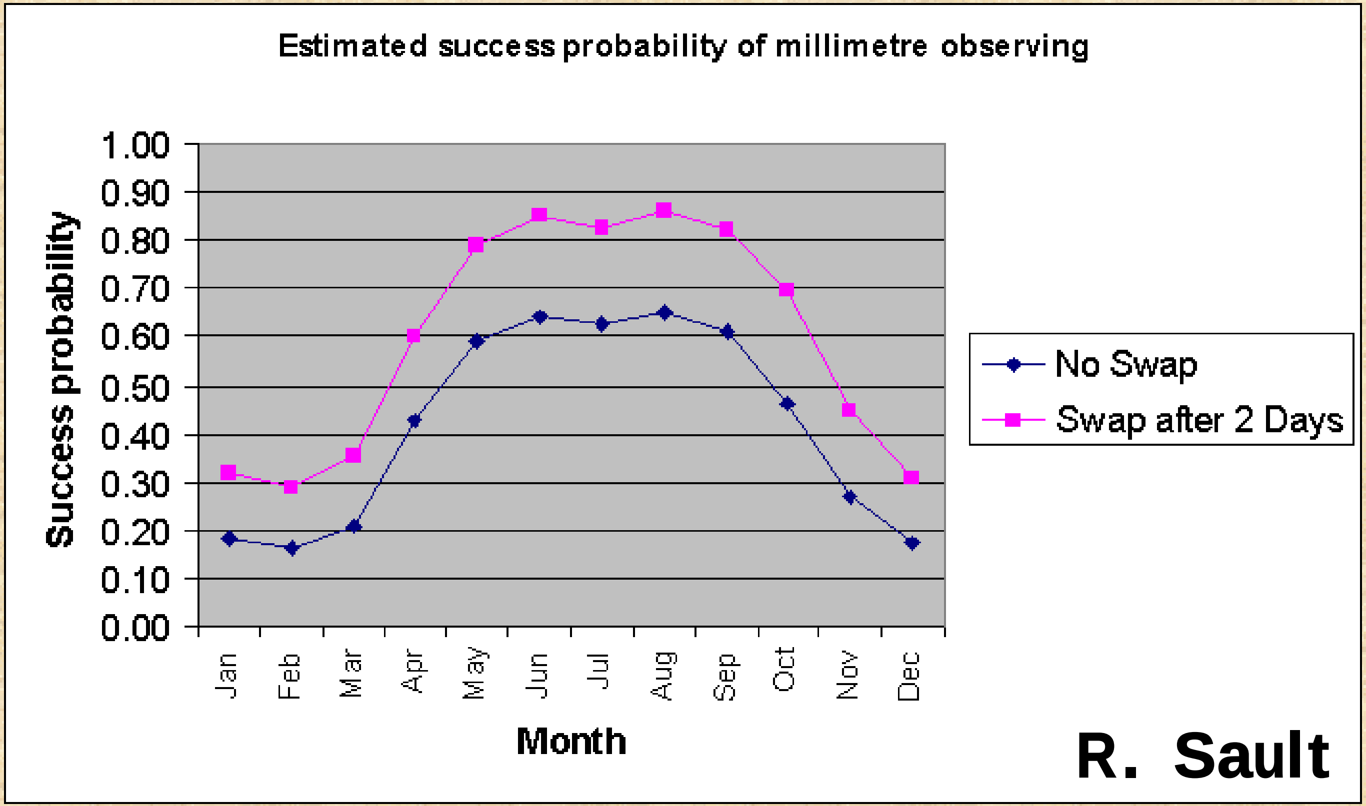
1. Significant atmospheric opacity, much of which is due to H_2O vapor (and is hence variable).
2. Fluctuations in H_2O vapor content above the antennas produce atmospheric phase noise that increases with baseline length & with frequency.
3. Instrumental requirements (e.g. surface, pointing, baseline accuracy) become more severe.
4. Need more bandwidth to cover same velocity range:

$$1 \text{ MHz} \approx \lambda_{mm} \text{ km s}^{-1}$$

When to Observe

The mm observing season is April to October.

Observations outside this period are unlikely to succeed.



Atmospheric Opacity

$$T_{sys} \approx T_{rec} + T_{sky} = T_{rec} + T_{atm}(1-e^{-\tau})$$

$$T_{sys,eff} = T_{sys}\, e^{\tau} = T_{rec}e^{\tau} + T_{atm}(e^{\tau}-1)$$

$$T_{rms} \propto T_{sys,eff}\, (n_{bas}Bt)^{-0.5}$$

The variable component of atmospheric opacity τ (due to precipitable H_2O vapor) is minimised in cold, clear conditions.

To try to make optimum use of the array, each mm project is typically assigned a cm "swap" partner. The "swap" is made if the weather during the mm slot is poor.

Phase Stability

- Effect of phase noise on a visibility measurement can be expressed as

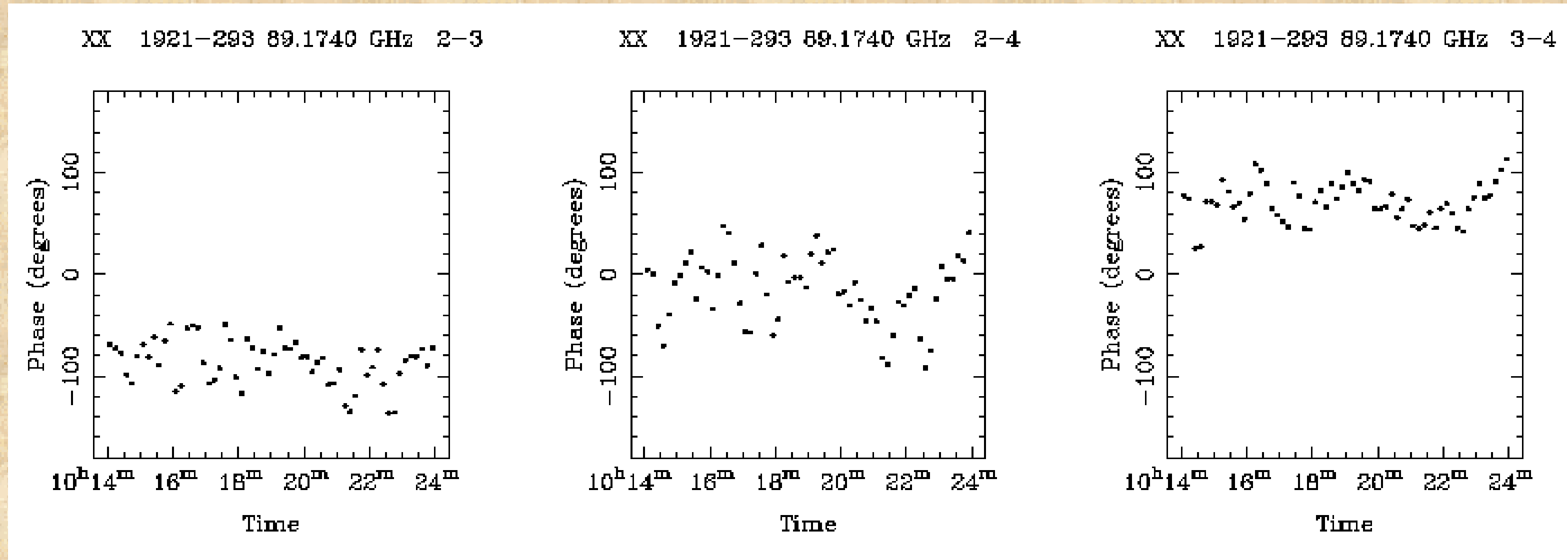
$$\langle V \rangle / V_0 = \exp\left(-\, \phi_{rms}^{2} / 2\right)$$

where ϕ_{rms} is the RMS phase variation during the averaging time, and V_0 is the true amplitude.

- For ϕ_{rms}=30° (280 μm), $\langle V \rangle / V_0 = 0.87$ and the visibility amplitude will be reduced by 13% due to phase noise (also called decorrelation).
- ϕ_{rms} is a function of weather, frequency, and baseline length:

$$\phi_{rms} \approx K \nu b^{0.8}$$

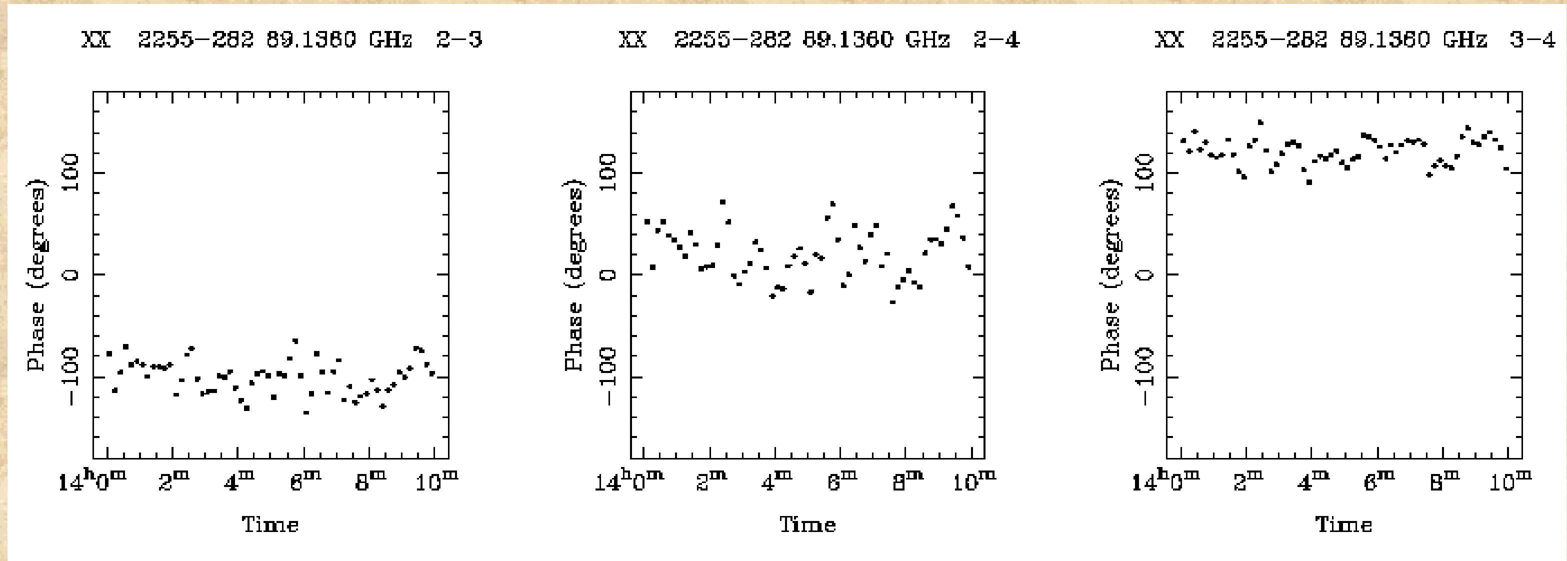
Clear Night, 8pm local time



b: 75m 120m 45m

ϕ_{rms}**:** 22° 34° 19°

4 hours later (midnight)



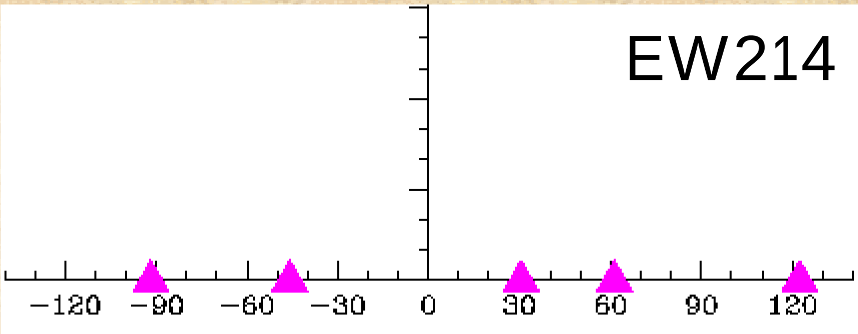
b:	75m	120m	45m
ϕ_{rms}:	22°	34°	19°
ϕ_{rms}:	16°	24°	13°

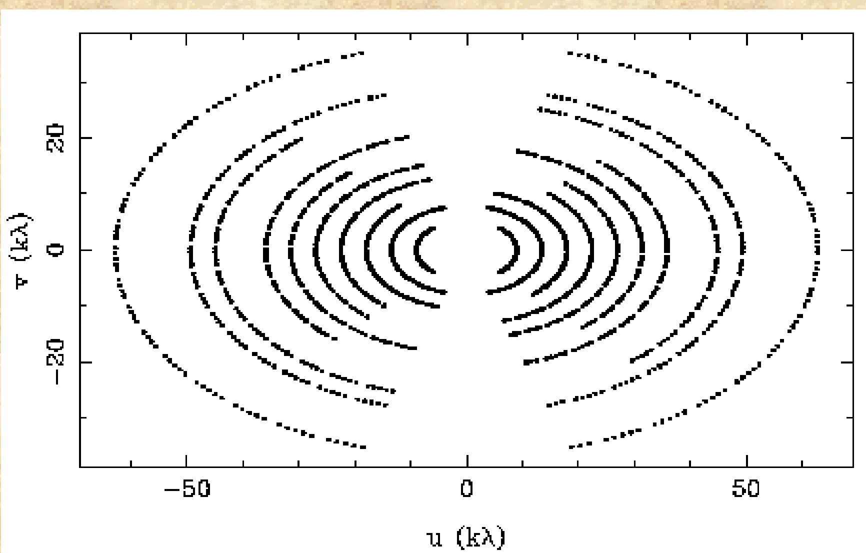
Advice on Day vs. Night

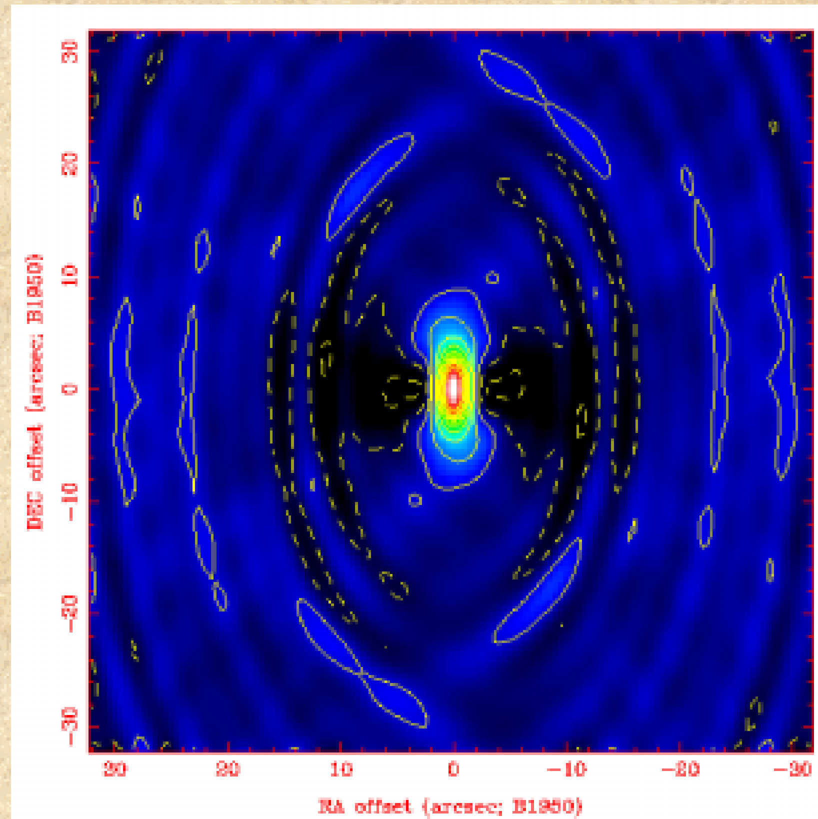
- There is a very strong diurnal effect: phase stability is much better at night, with a few hours' latency (2 hr after sunrise is much better than 2 hr after sunset).
- If phase stability is important (i.e. extended arrays) then may be better to observe in morning or evening during "shoulder" season (Apr-May, Sep-Oct) than during afternoon in "peak" season.
- Better statistics will be available once a phase monitor is in operation.

Array Configurations

- **E-W configurations not always ideal for mm obs, which must be done at low airmass (elev > 30°).**



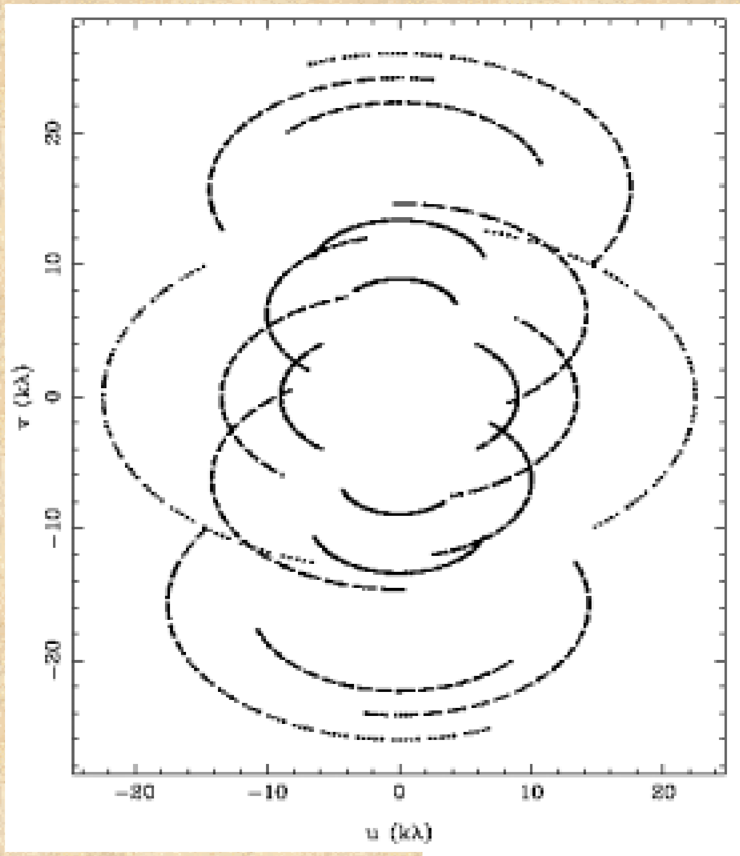


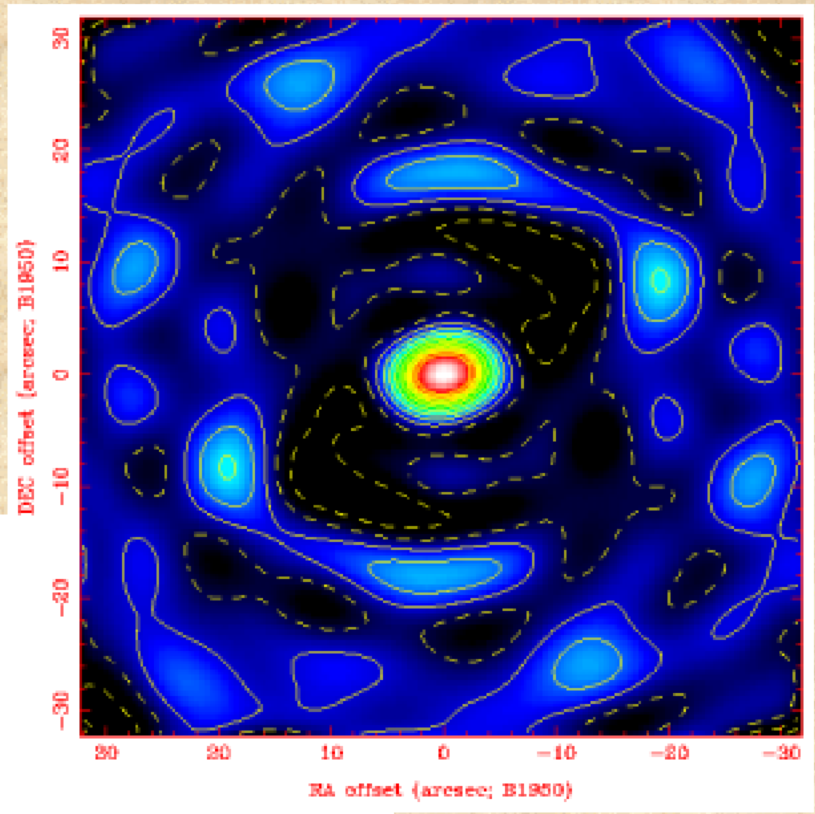


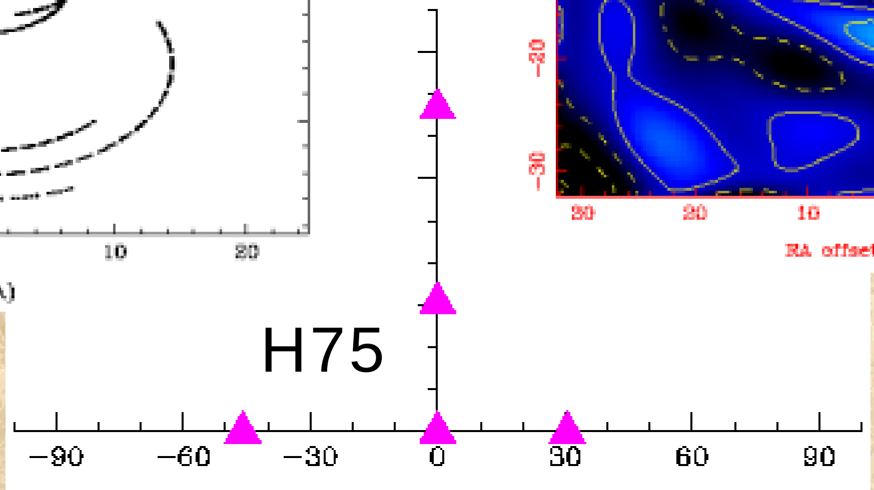
δ=-35º, beam=7.7” x 2.7”

Array Configurations

- **N-S or hybrid arrays may improve u-v coverage.**



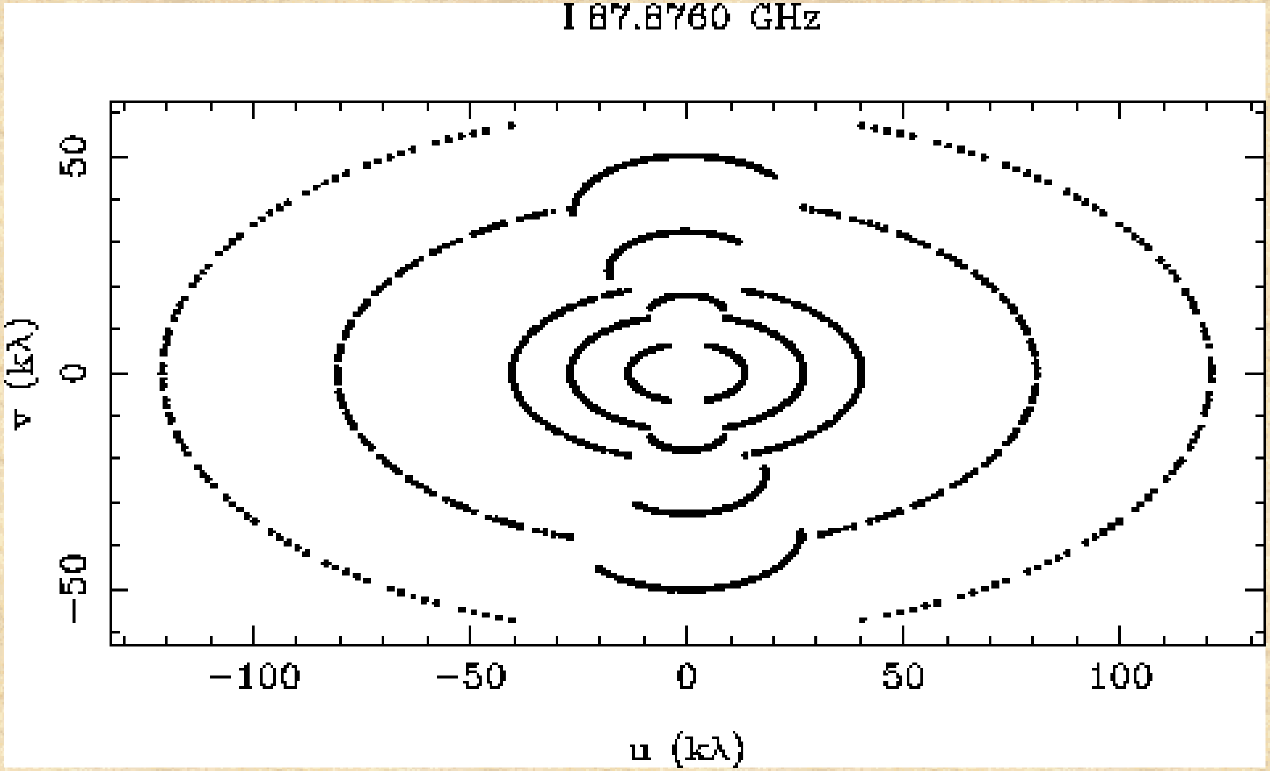




beam=6.6” x 4.9”

Array Configurations

- **Example of combining E-W and N-S arrays.**

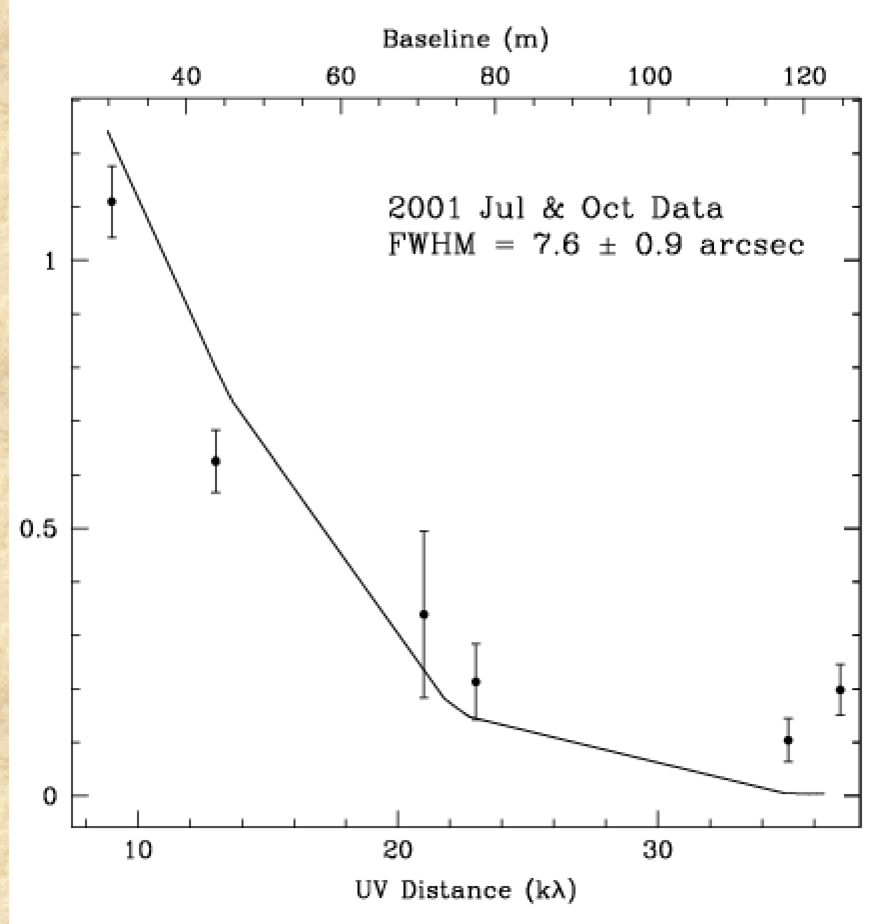


EW367 + 750A + H168

beam=3.3” x 2.8”

Advice on Configurations

- **Simulate your PSF before writing your proposal. Be sure to include shadowing!**
- **If the emission is likely to be extended, be sure to include short baselines.**



- **Shorter baselines also easier to calibrate.**

Gain calibration

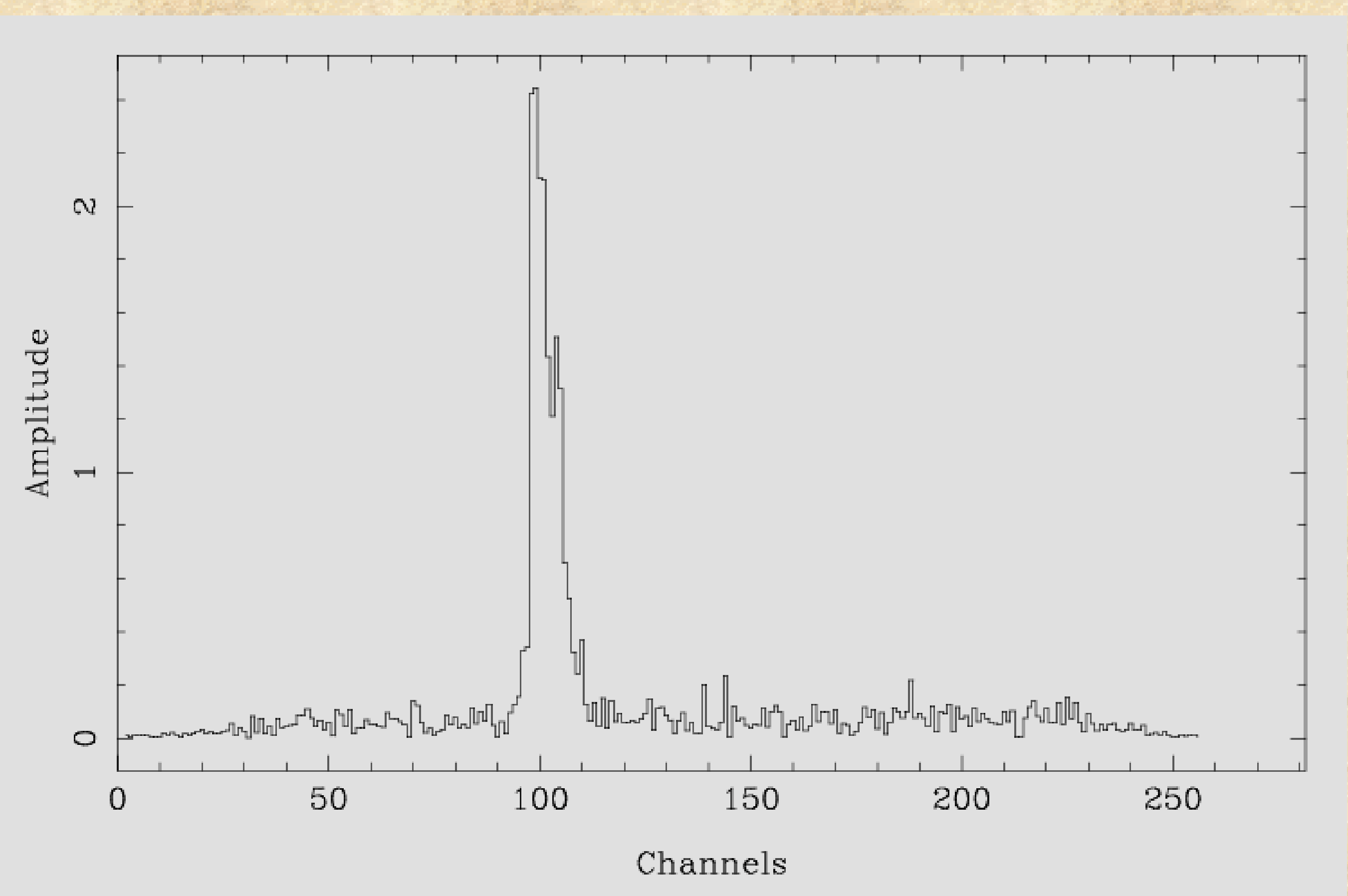
- Involves observing a bright point source at a known position (e.g., maser or quasar).
- Important for tracking phase drifts due to instrumental and large-scale atmospheric effects.
- For a quasar, use the maximum possible bandwidth (128 MHz at ATCA).

$$T_{\mathrm{rms}} \propto T_{\mathrm{sys,eff}} \, (n_{\mathrm{bas}} B t)^{-0.5}$$

- Rather than using different correlator config for source vs. cal, employ dual frequency mode (wide & narrow).

Gain calibration

- **For a maser, use a bandwidth that gives you adequate freq resolution to resolve the line.**



Choosing your calibrator

Calibrators near 16:50:51,-56:35:23

The following table gives calibrator sources near 16:50:51,-56:35:23. **Note** that the presence of a source in this table does not necessarily mean it is a good calibrator for your purposes. Please click on the link of a prospective calibrator to check its suitability.

Distance	Source	20cm flux	13cm flux	6cm flux	3cm flux	12mm flux	3mm flux
4.99°	1613-586	3.82	4.17	3.98	3.45	2.68	2
9.31°	1718-649	3.62	4.68	4.64	3.64	2.1	0.61
18.38°	1831-711	1.70	2.13	2.51	2.50	2.0	1.17

Flux densities should be taken as a guide only. The fluxes are taken from a variety of sources of differing accuracy. Calibrator fluxes are often variable, perhaps significantly so.

A good calibrator is within 15º of your target source and has a flux in the ATCA catalogue of >1 Jy.

Choosing your calibrator

The reasons for these guidelines are:

1. **Catalogued mm fluxes unreliable, and sources <1 Jy are often <<1 Jy.**
2. **If the calibrator is more than 15º away, you may be observing it through a very different H_2O column, and will be more susceptible to antenna position (baseline) errors.**

Holdaway (1992 ALMA memo) estimates that the mean distance between a source and calibrator at 115 GHz will be $7^{\circ} \times S^{0.75}$, where S is the flux cutoff in Jy.

How often and how long?

Don't want to spend too much time calibrating!

Need to find compromise between:

1. **Errors in gain solution due to S/N on cal**
2. **Errors due to atmospheric changes**
3. **Time lost due to calibrator observations**

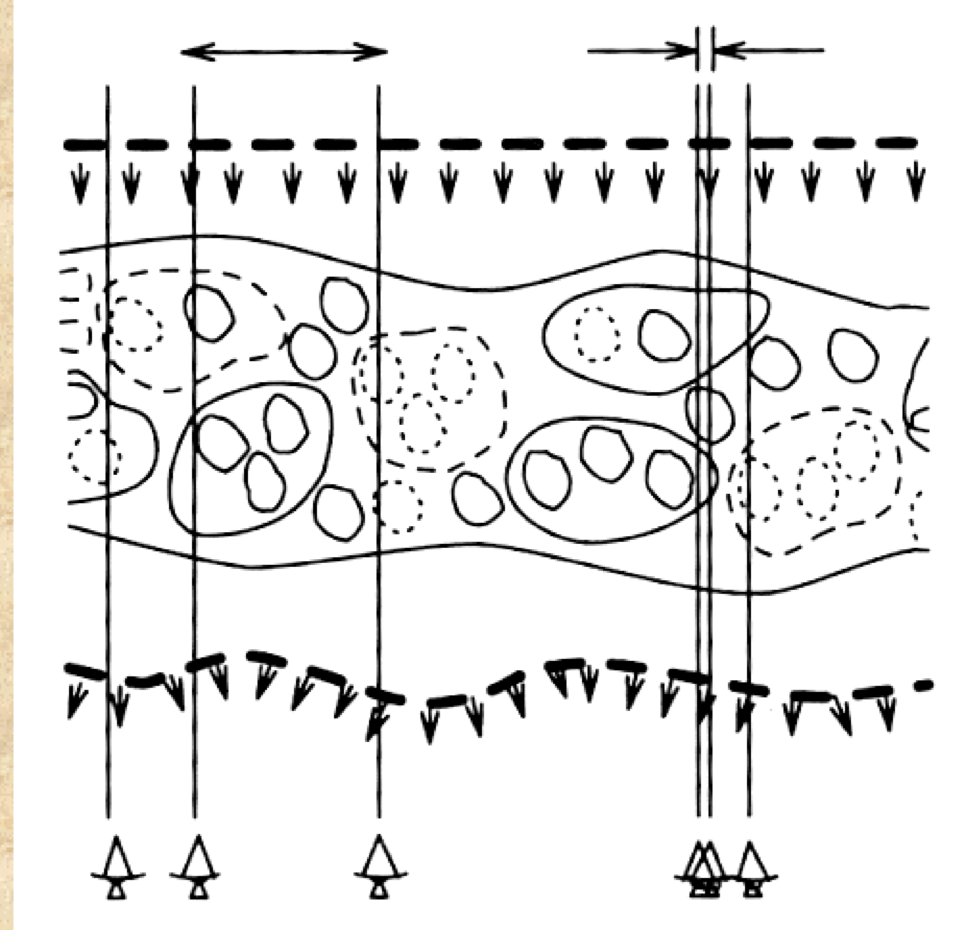
Usually calibrating every 20-30 minutes is adequate for baselines < 100m.

For a 1 Jy source, to achieve a S/N of 10 in each baseline and polarisation requires just 1 minute's integration in good weather.

How often and how long?

Ideally, we'd like to calibrate faster than troposphere moves across the array.

But with typical wind speeds of ~10 m/s, this would require calibrating every 20s for a 100m baseline!

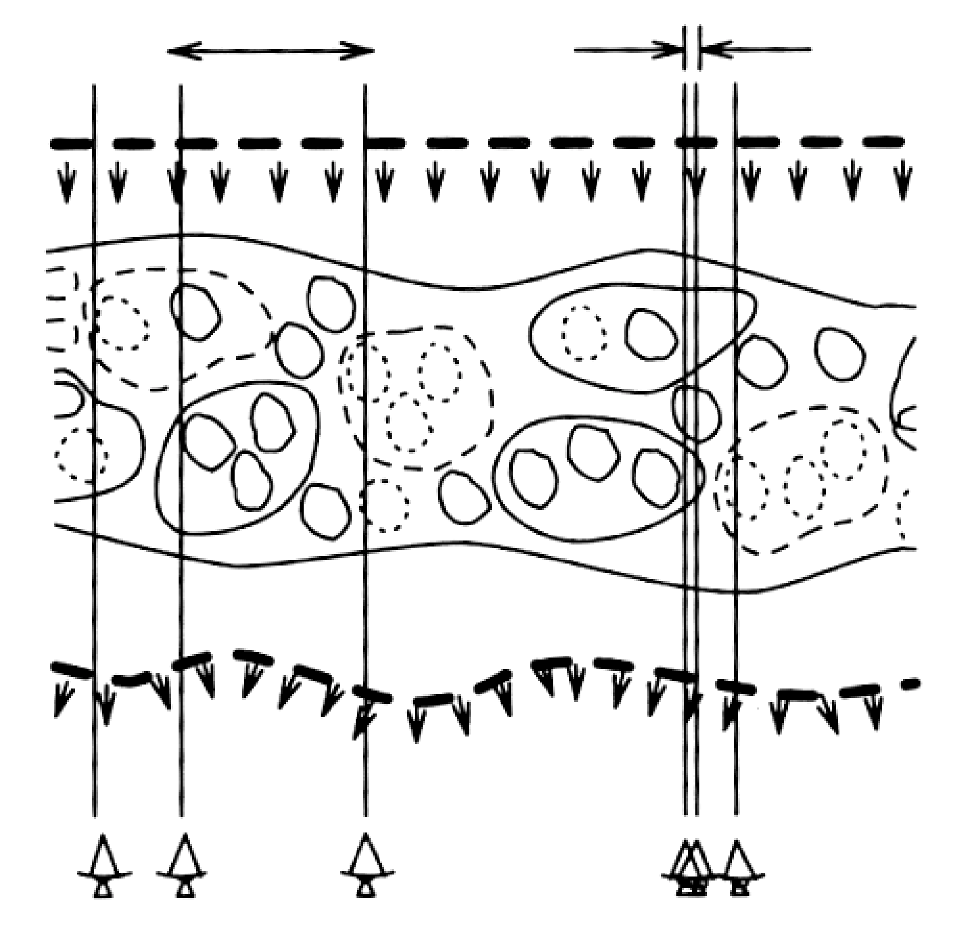


Desai 1998

How often and how long?

Less frequent calibration still useful: removes fluctuations with size scales $> b_{eff} \sim v_a t_{cyc}/2 \sim 300\text{m} \times (t_{cyc}/\text{min})$.

Rule of thumb: for baselines twice as long, calibrate the phase twice as often.



Desai 1998

Observing a test calibrator

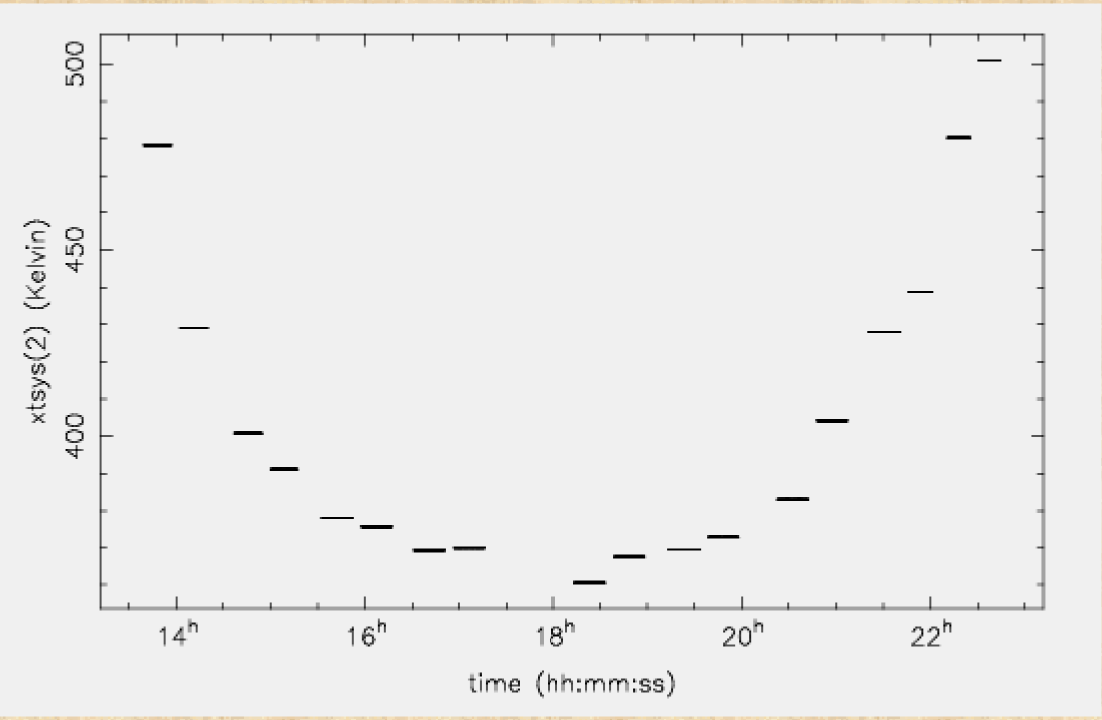
In poor weather or when using long baselines, it may be unclear whether a non-detection is due to source weakness or to atmospheric phase decorrelation.

Procedure: observe a weaker (but detectable) "test" quasar near your source, in addition to a stronger quasar as the phase calibrator.

If phase gains applied to the test quasar yield a good detection, your phase calibration is probably adequate.

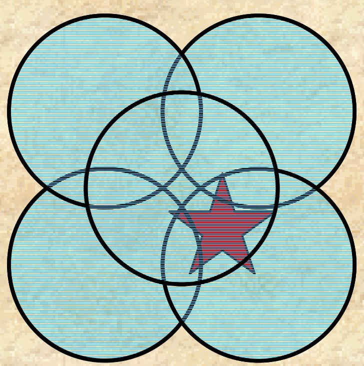
Other required calibrations

Paddle (vane) calibration: measures $T_{sys,eff}$. Changes quickly during rise & set or in cloudy weather (repeat every **~15 min**), more slowly near transit (**~30 min**).



Other required calibrations

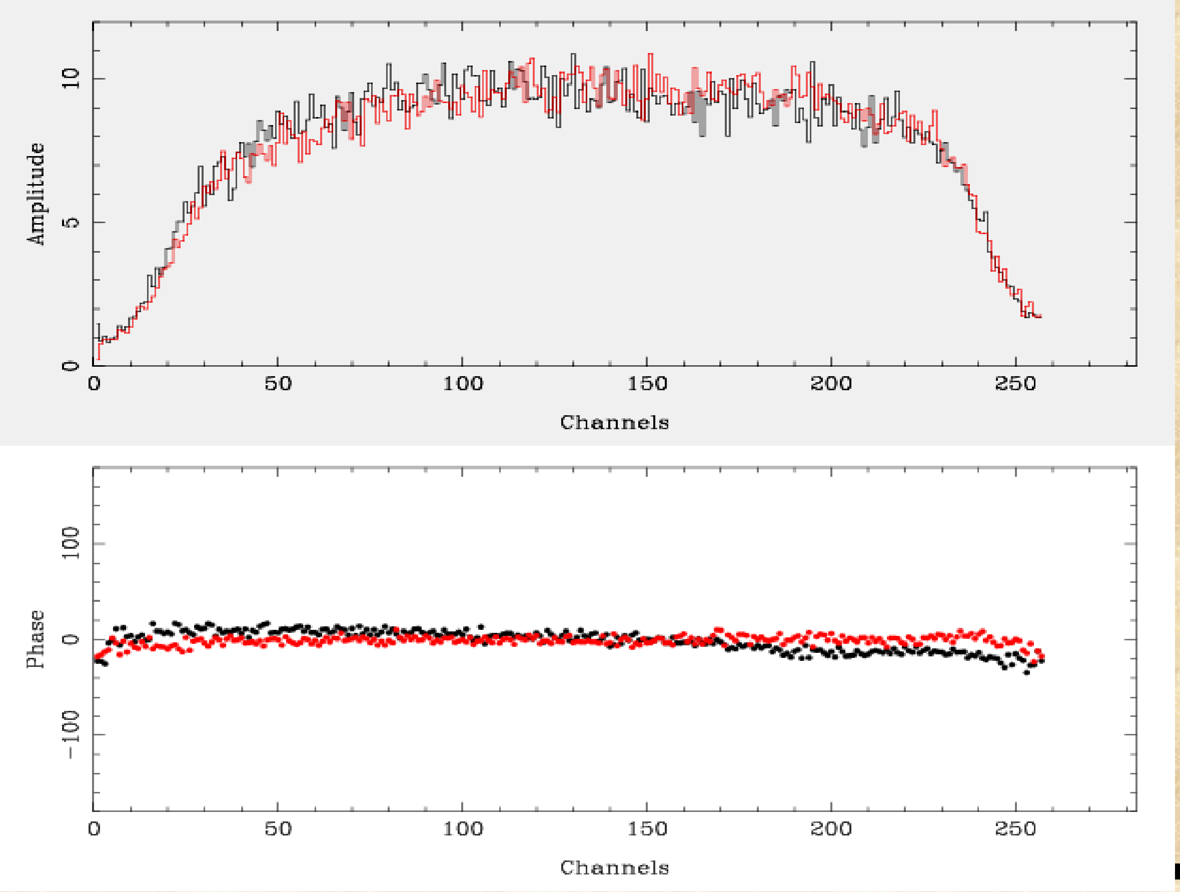
Pointing calibration: refines antenna pointing by doing a "cross" pattern around a bright source. At least **once an hour** or when moving to a different part of sky.



- Primary beam FWHM is only **36"** at 86 GHz!
- A **10°** shift in elevation can produce a **~5"** shift in pointing: must choose a nearby source!

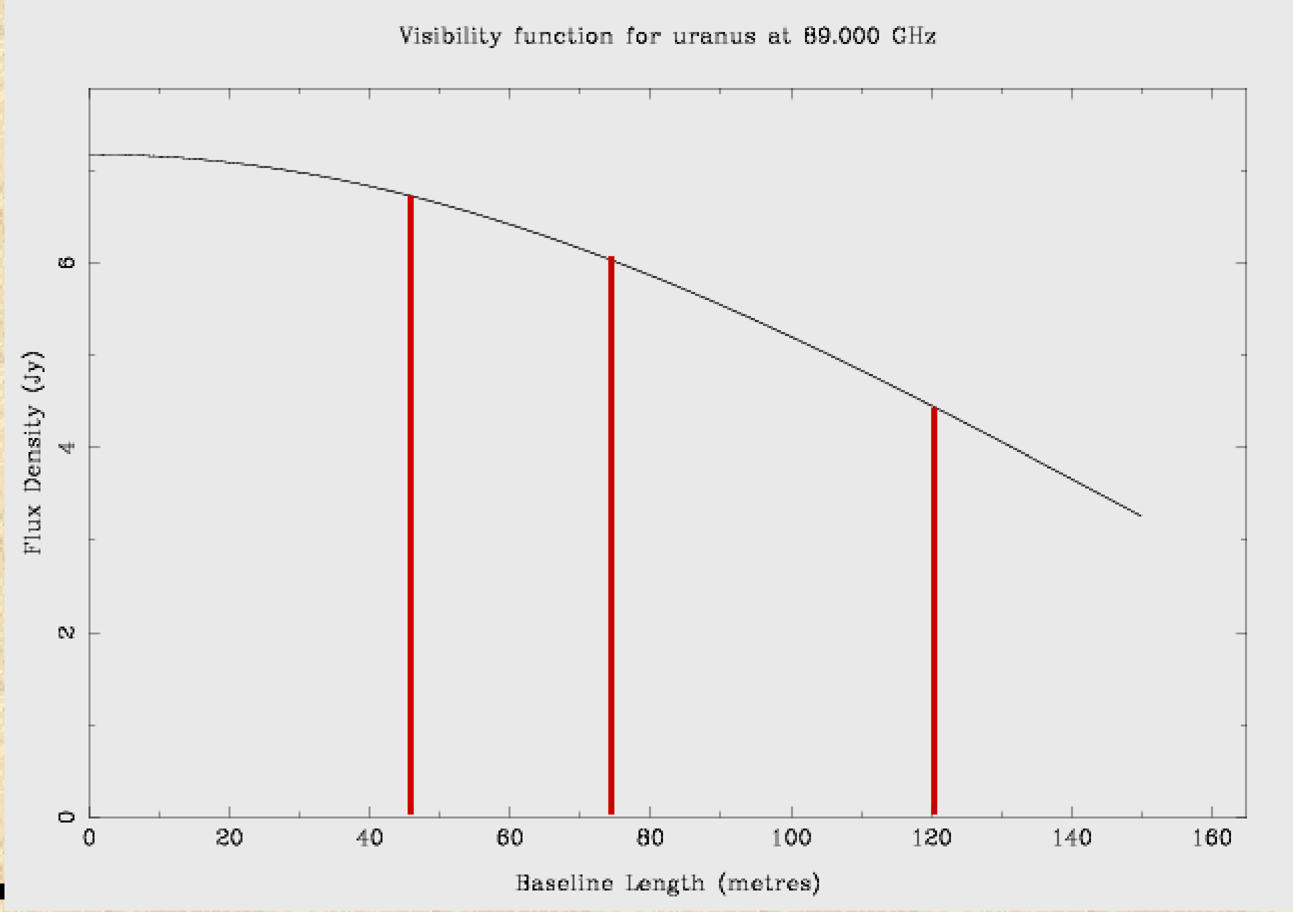
Other required calibrations

Bandpass calibration: determines amplitude and phase on a strong point source as a function of frequency (once during project).



Other required calibrations

Flux calibration: **observe thermal continuum emission from an unresolved planet once during project, to set absolute flux scale.**

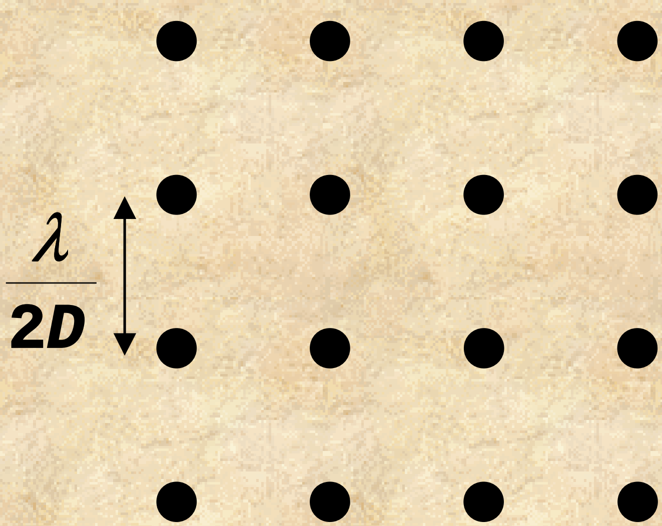


MIRIAD task plplt

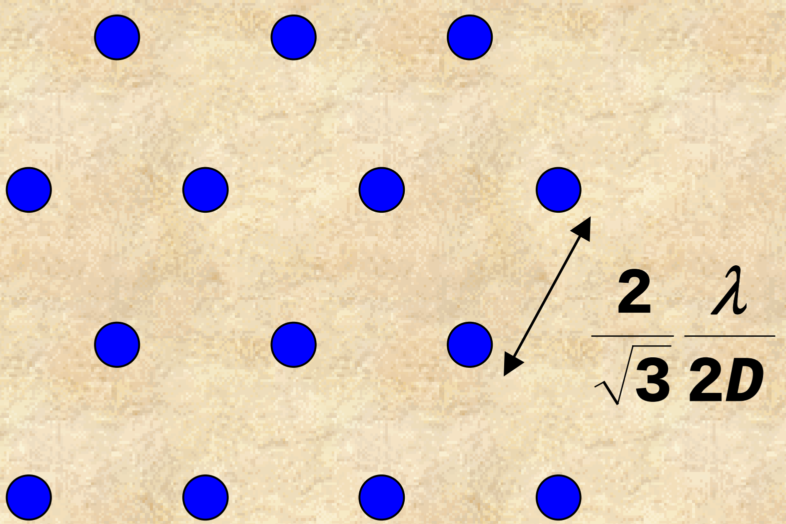
Multi-field imaging

Due to the small size of the ATCA beam at mm wavelengths, it will often be desirable to combine several fields (mosaic).

But, pointing errors and uncertainties in the beam shape make this difficult at present.



Rectangular grid



Hexagonal grid

Parting Thoughts

- **Best to observe sources that you believe will be detectable in 4 hours or less integration time.**
- ***Time flies when you're stuffing around*** **– don't modify your observing strategy midway unless there's an obvious mistake.**
- **Use loops when possible: have a sequence of pointing, calibration, and on-source scans that can be repeated many times.**
- **Keep an eye on slew times and shadowing (even by idle antennas!). Don't observe at elevations >85º.**
- **Especially at 3mm, record T_{sys} and pointing offsets in log – useful to diagnose problems in reduction.**