ATCA – Calibration at mm wavelengths

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Topics:

- Basics of interferometry
- The atmosphere
- Amplitude & phase calibration
- Atmospheric & instrumental effects
- Antenna effects

ATCA Bands

Band	λ cm	GHz	mJy/b	beam
L	20	1.5	0.19	33
S	13	2.3	0.24	22
C	6	5.6	0.22	10
X	3	8.6	0.21	5
K	1.2	20.5	0.53	2
W	0.35	87.5	2.70	0.6

A few definitions

Brightness $B = 2k\,T_B/\lambda^2$ W/Hz m² Ω

Flux density $S = \int B\, d\Omega$ W/Hz m^{-2}

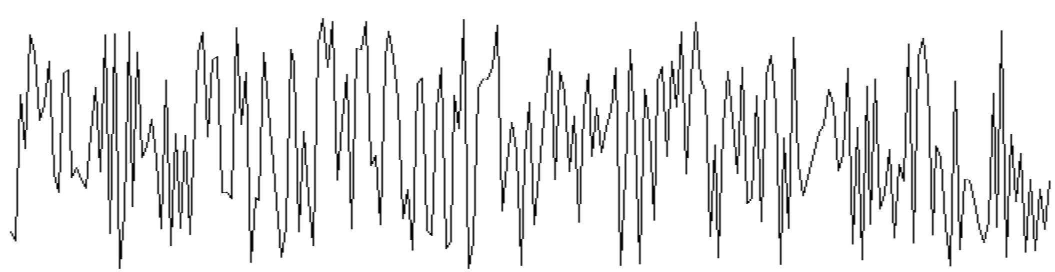
Effective area $A_{eff} = \eta\pi D^2$ m^2

Received power $V_A{}^2 = A_{eff}\, S\, \Delta\nu$ Watts

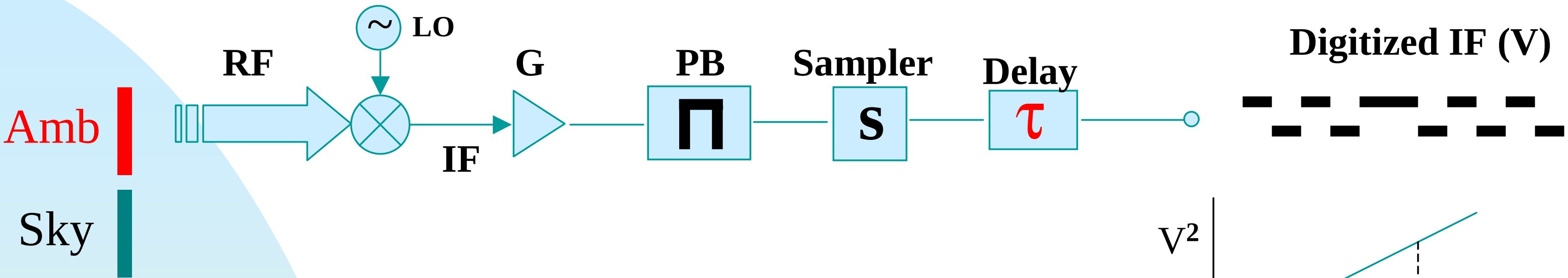
Janskys/K $S/T_A = 3510/\eta D^2$ Jy/K

V^2 or the total output power
is $T_{SYS} = T_R + T_{SKY} + T_A$ K
(100+200+.04 K)

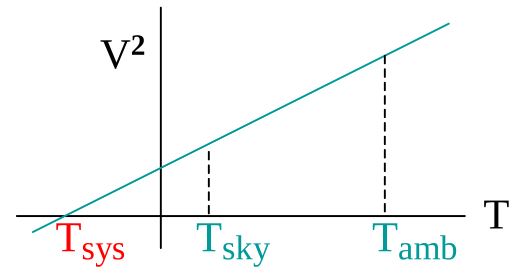
V
(volts)



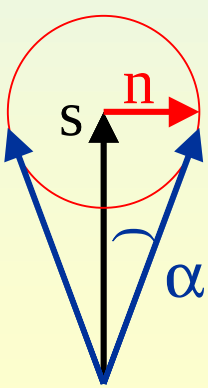
Tsys – ‘Paddle’ or Chopper Wheel method



$$T_{sys} = \left(\frac{T_{amb} - T_{sky}}{V^2_{amb} - V^2_{sky}} \right) V^2_{sky} - T_{sky}$$



Tsys sets the flux scale and the noise level!



$\alpha = \sin^{-1}(n/s)$

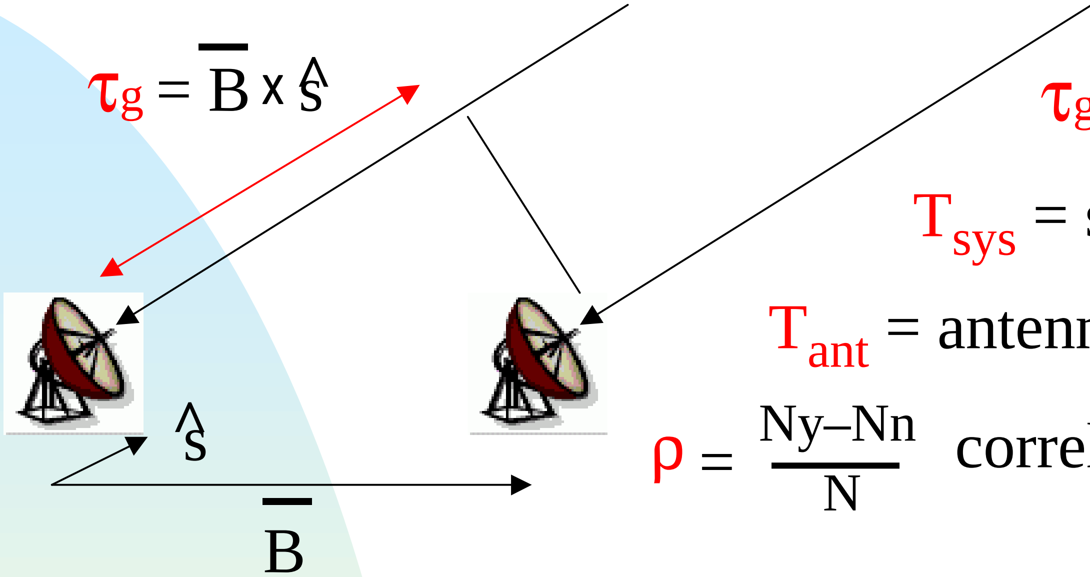
$$n = \frac{2\,k\,T_{sys}}{A\,\eta\,\sqrt{bw \bullet t}} \text{ Jy}$$

k=1380 Jy m²/K
Tsys=300 K
A=380 m²
η=0.3
bw=128 MHz
t=10 sec

$\alpha = \sin^{-1}(0.2) \sim 12^o$

n=0.2 Jy

Basic Interferometry



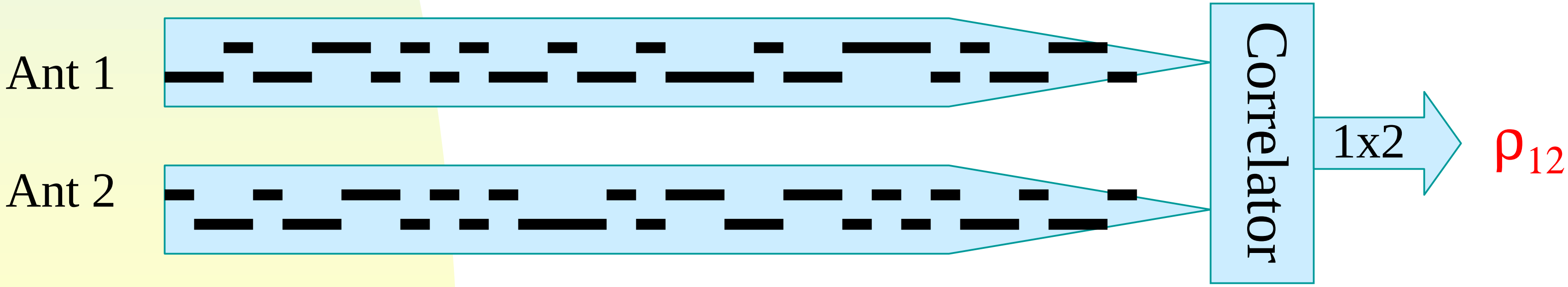
τ_g = geometrical delay

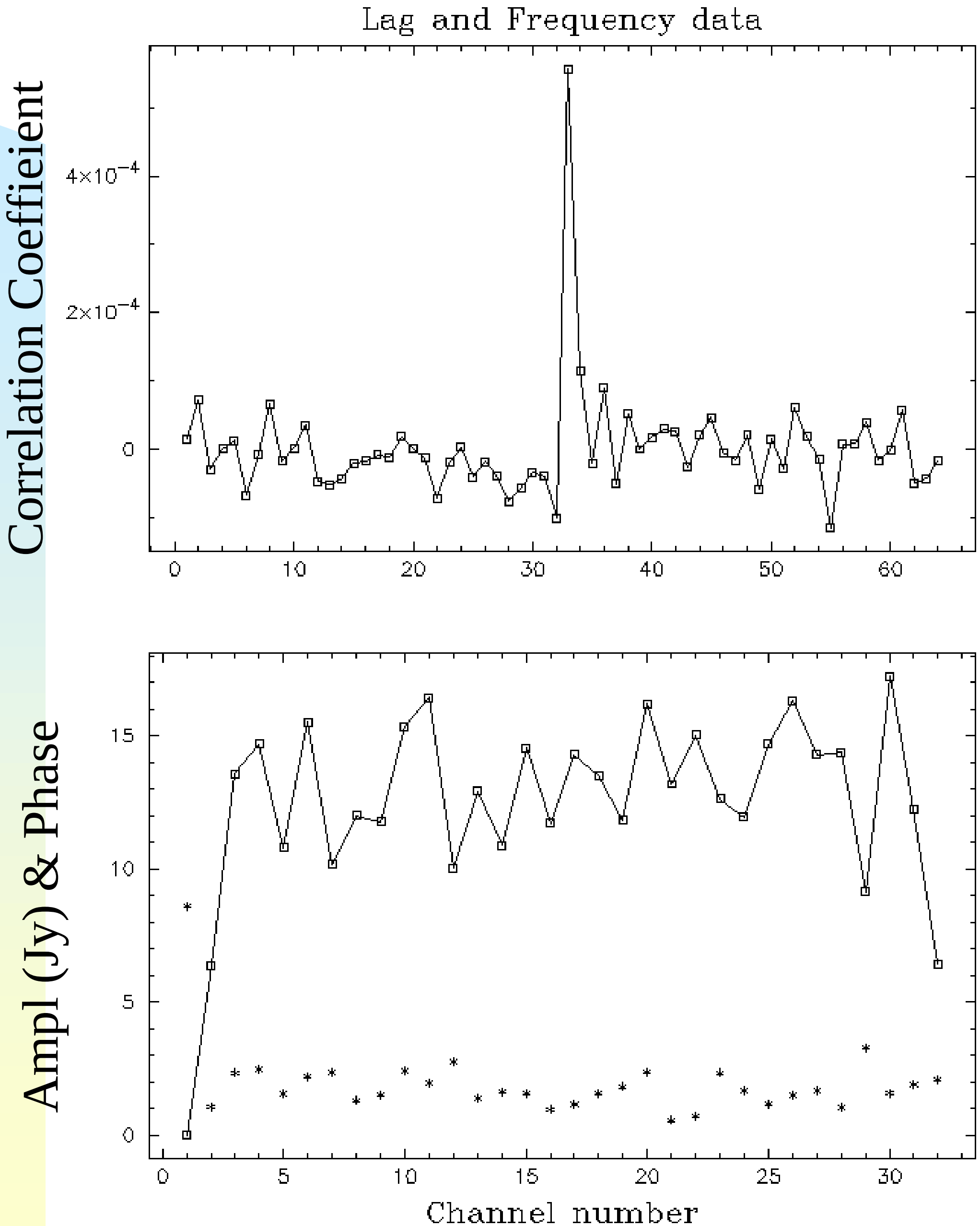
T_{sys} = system temperature

T_{ant} = antenna temperature

$\rho = \dfrac{Ny - Nn}{N}$ correlation coefficient

Digitized IF from two antennas





Correlation Function

64 lag channels (+/- 32)

Fourier Transform

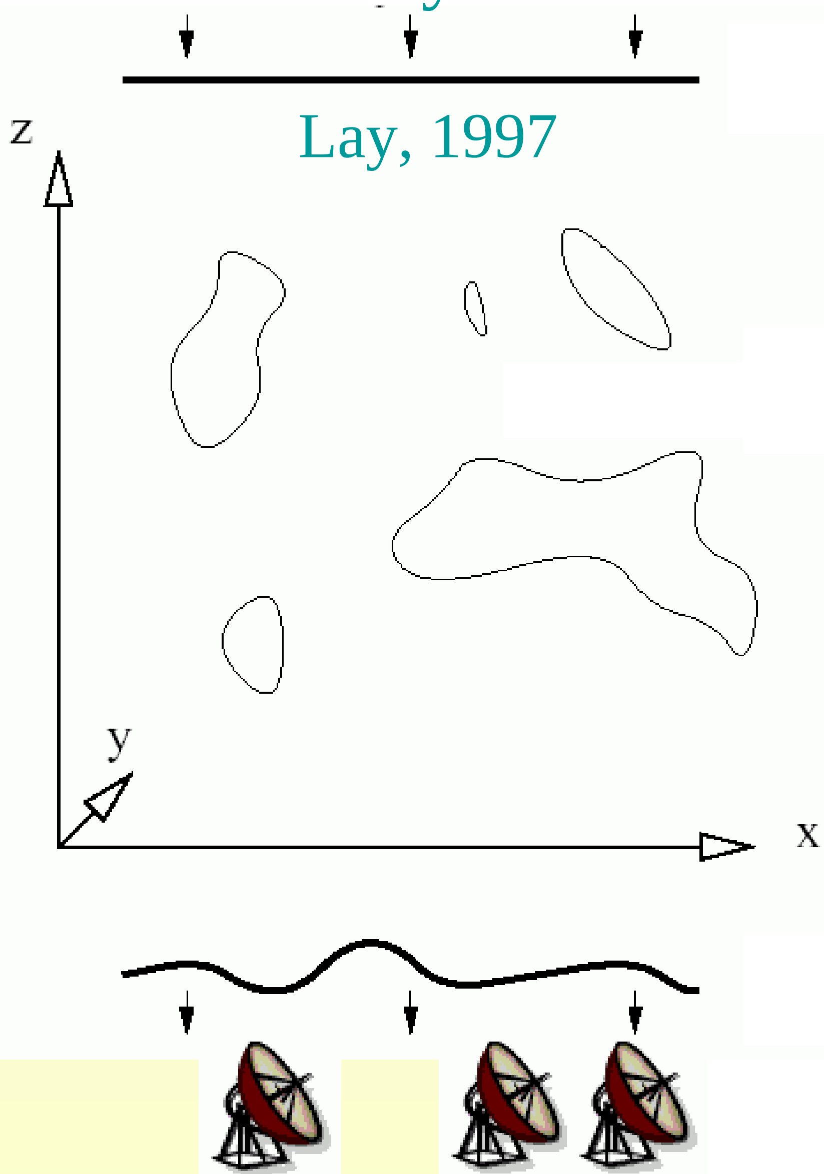
32 freq channels (amp & pha)

Visibility

$\boldsymbol{V} = Ae^{i\phi}$

Atmosphere

delay



absorption

$$T_A = T_{sou} (e^{-\tau})$$

$$T_{sky} = T_{atm} (1-e^{-\tau})$$

$$T_{sys} = T_R+T_{sky}+T_A$$

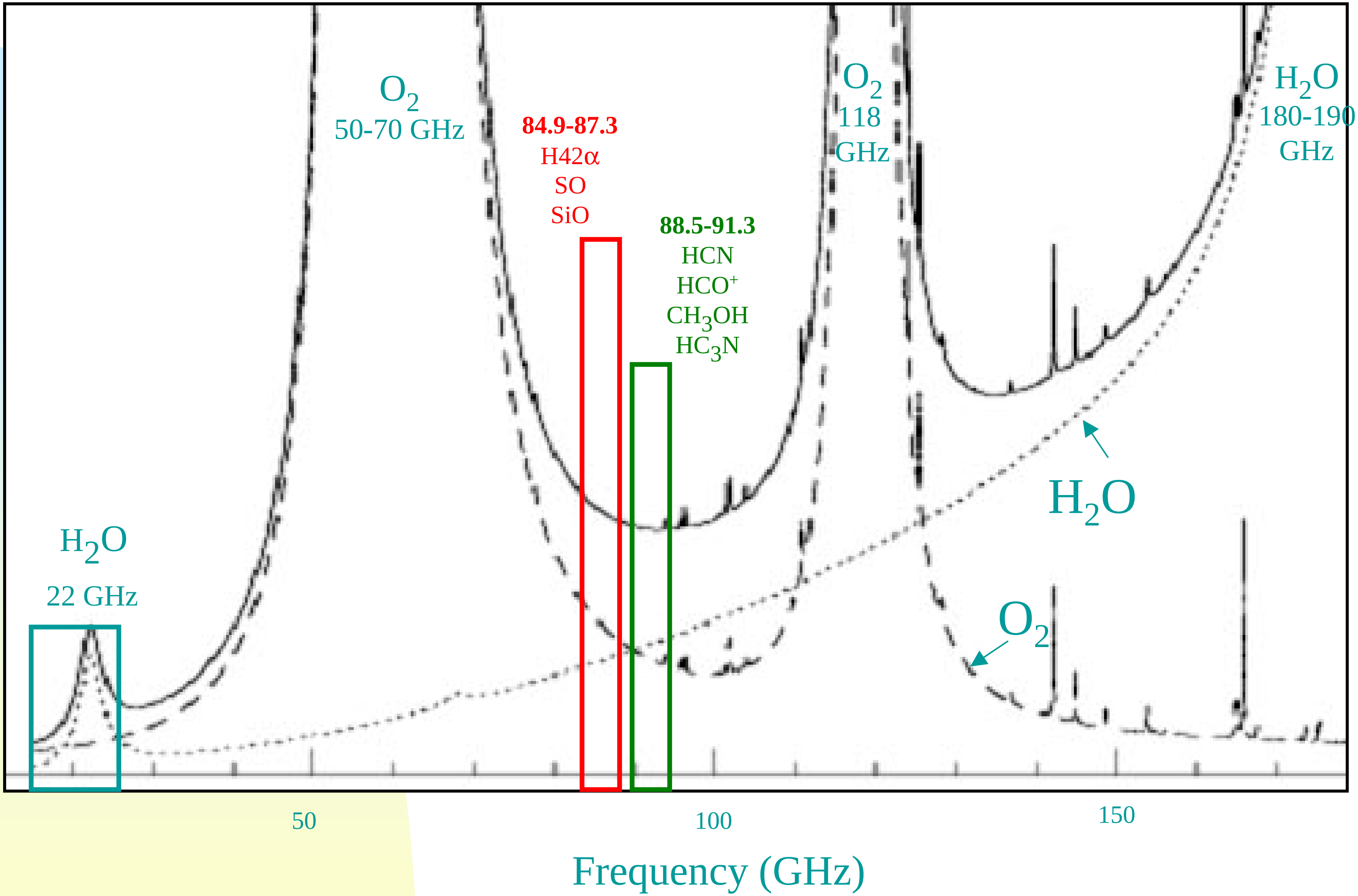
$$T_{sys} = T_R+T_{atm}(1-e^{-\tau})+T_{sou}(e^{-\tau})$$

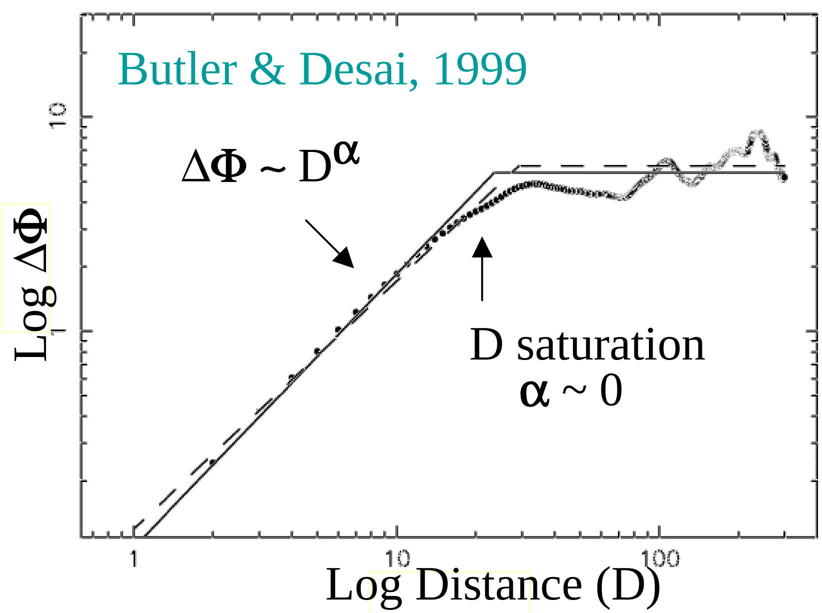
$$T'_{sys} = T_R e^{\tau} +T_{atm}(e^{\tau} -1)+T_{sou}$$

$$T'_{sys} = T_{sys}e^{\tau}$$

for $\tau = 1$, $e^{\tau} = 2.7$

Opacity of the Atmosphere – O_2 & H_2O



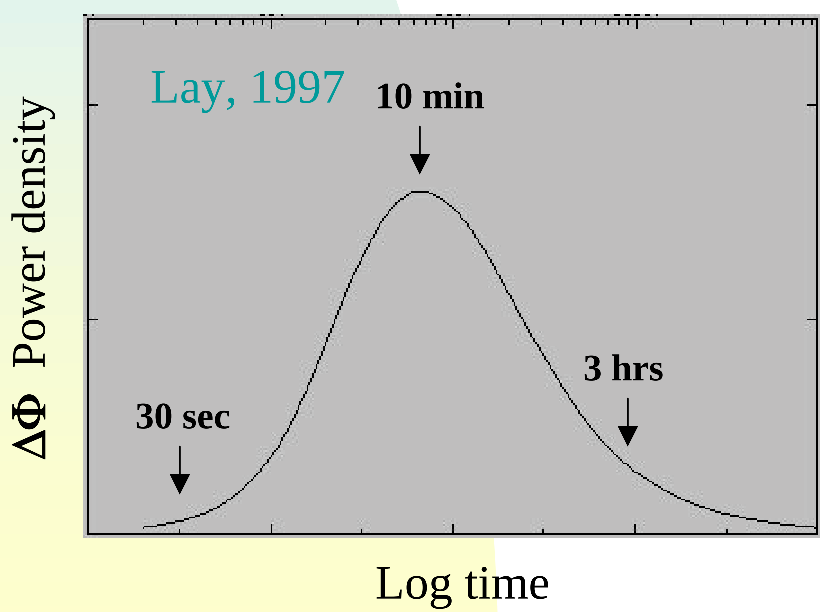


Structure Function (ΔΦ vs D)

α = 1.0 (Gaussian)

α = 5/6 (Kolmogorov)

α = 1/2 (Lorentzian)



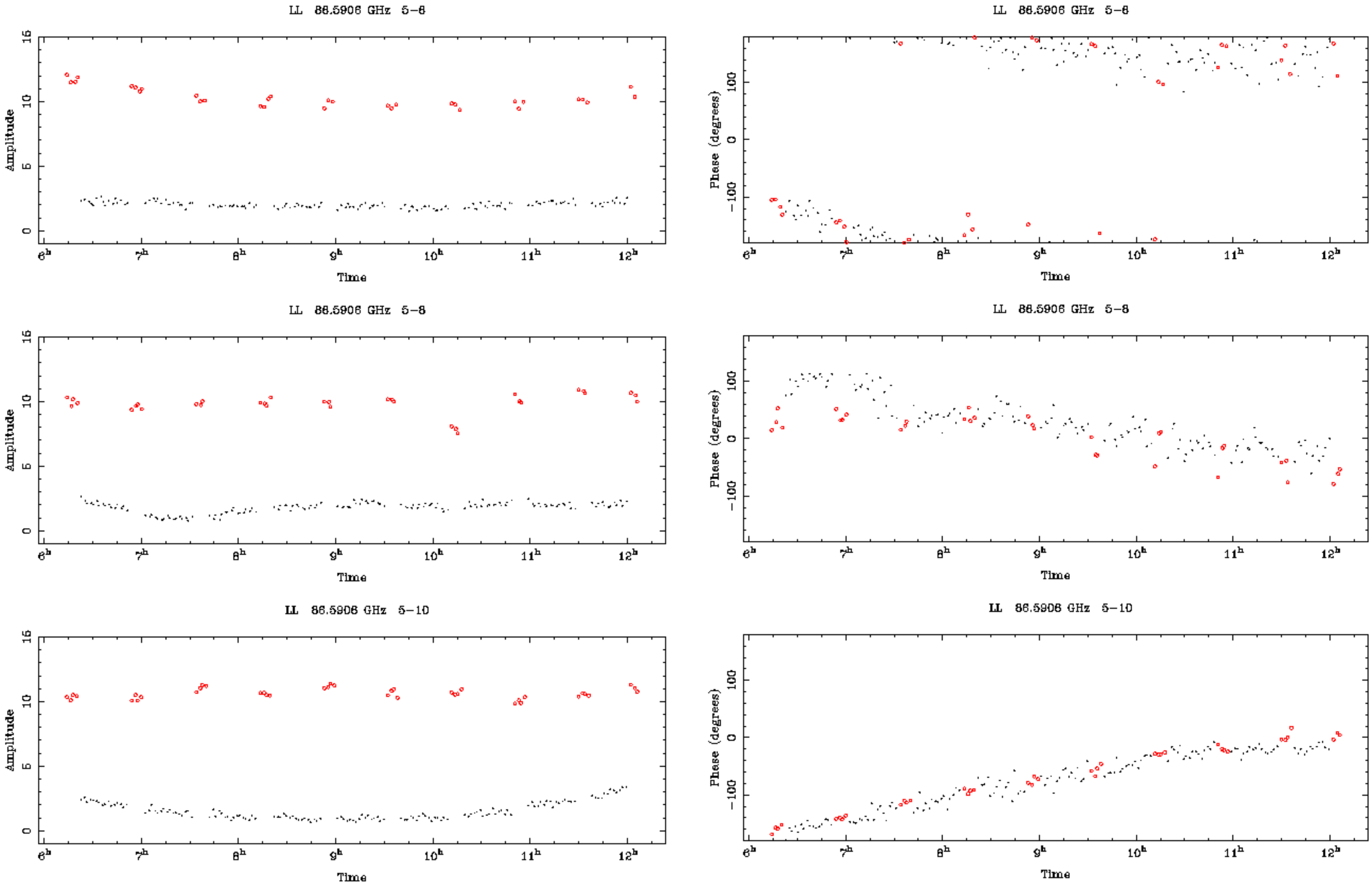
"Frozen Turbulence" Model (ΔΦ power vs t)

α = 5/6, 1km layer, 5km/s wind, 500m D

Longer baselines shifts peak right
Stronger winds shifts peak left

M87 data calibrated with 3C273

Amplitude | Phase



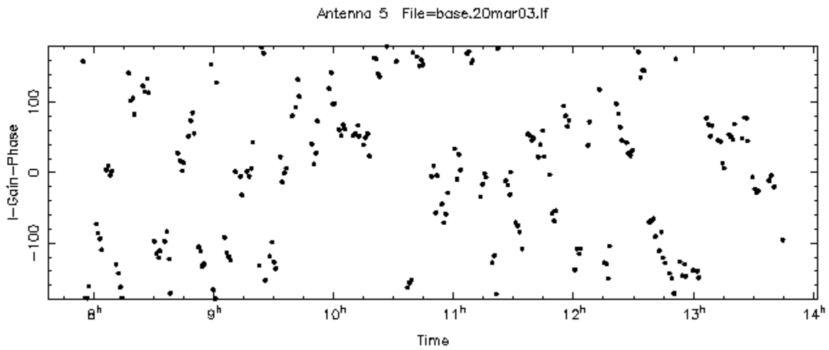
80m

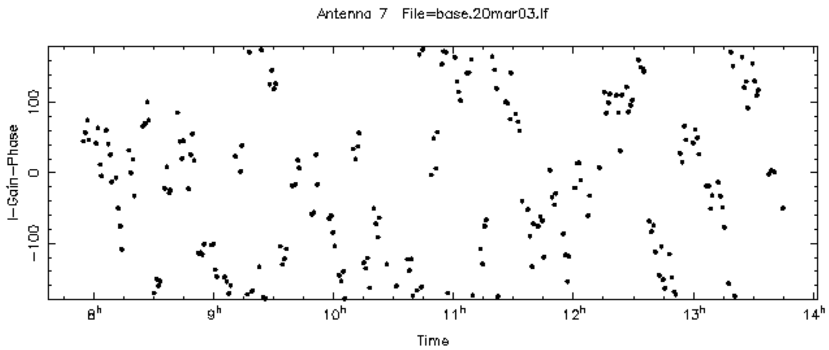
45m

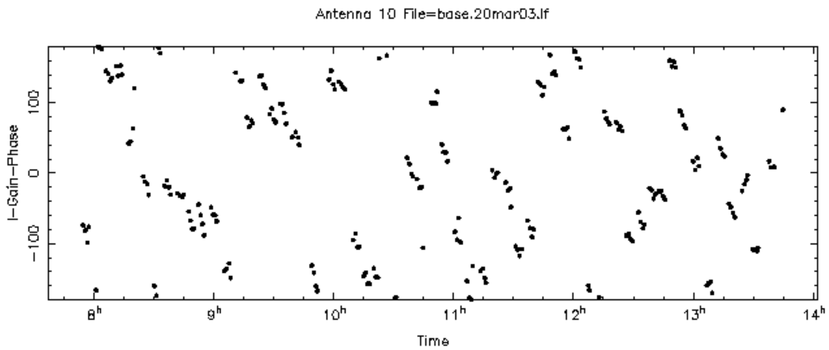
15m

Baseline Solution – C-array, March 2003

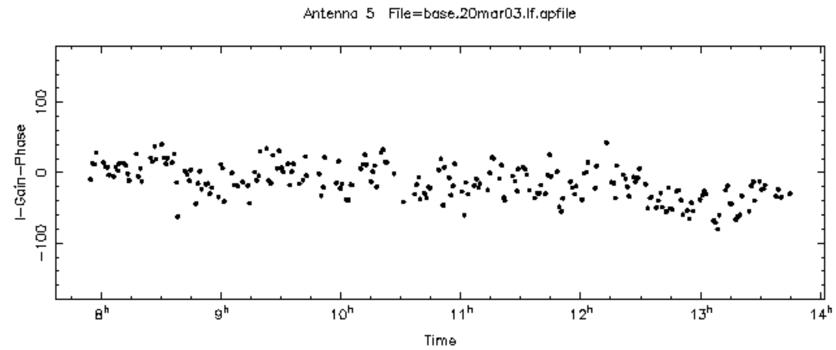
Phases BEFORE Correction

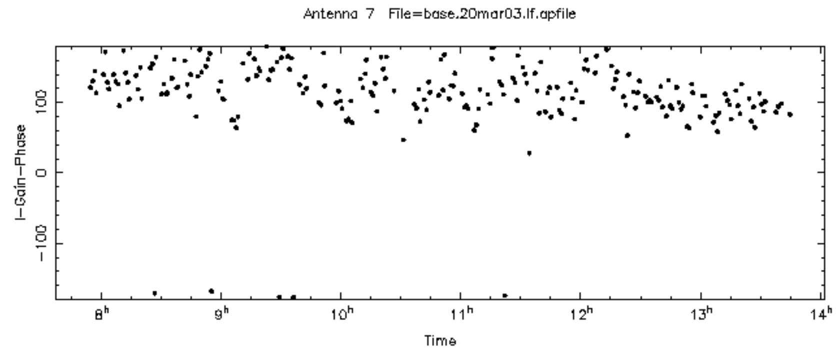


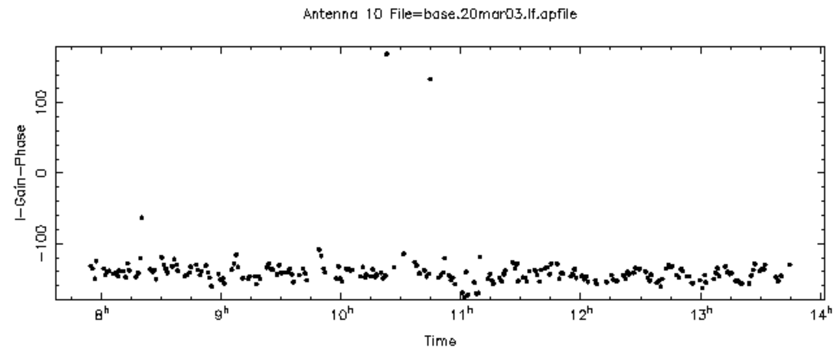


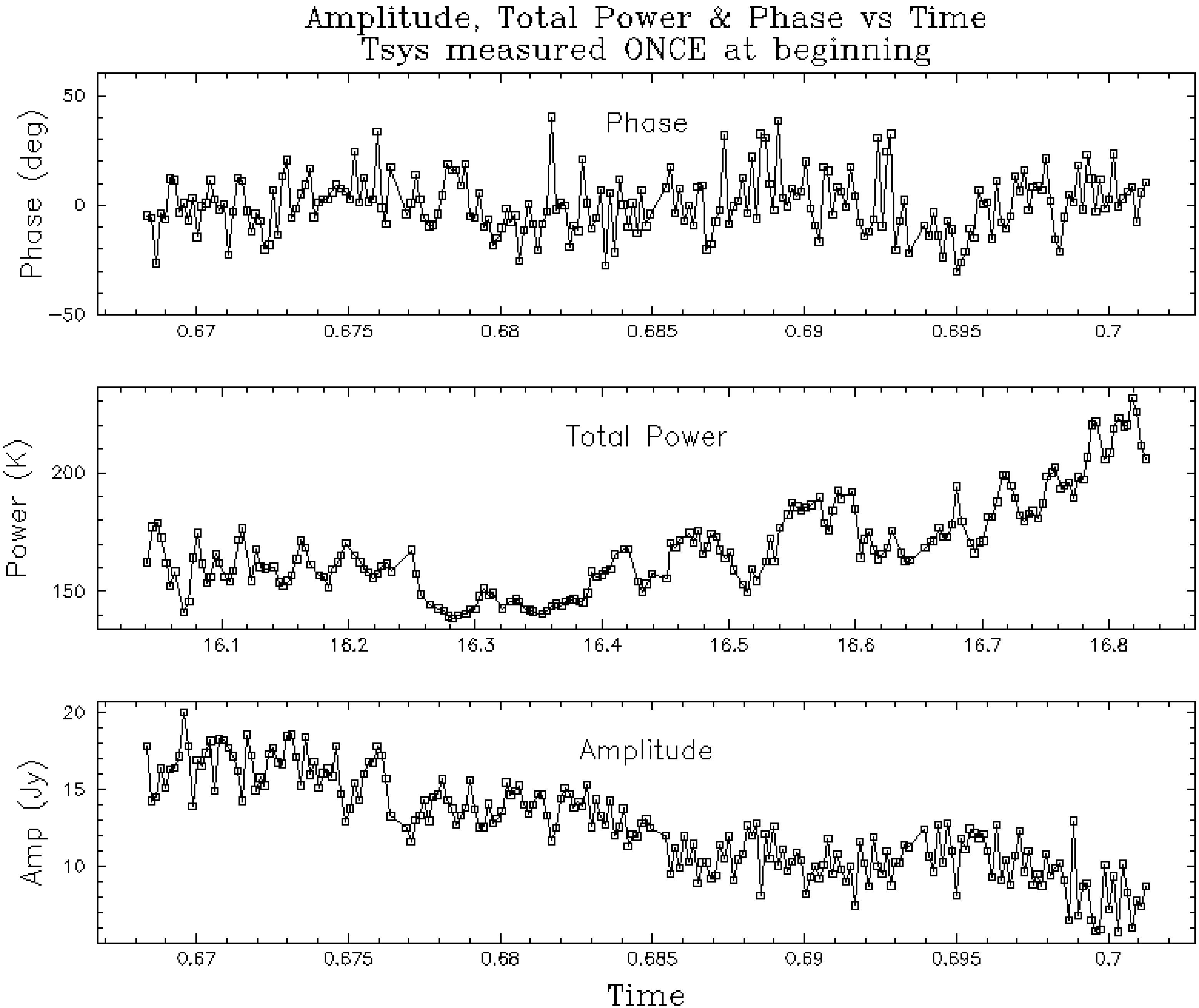


Phases AFTER Correction

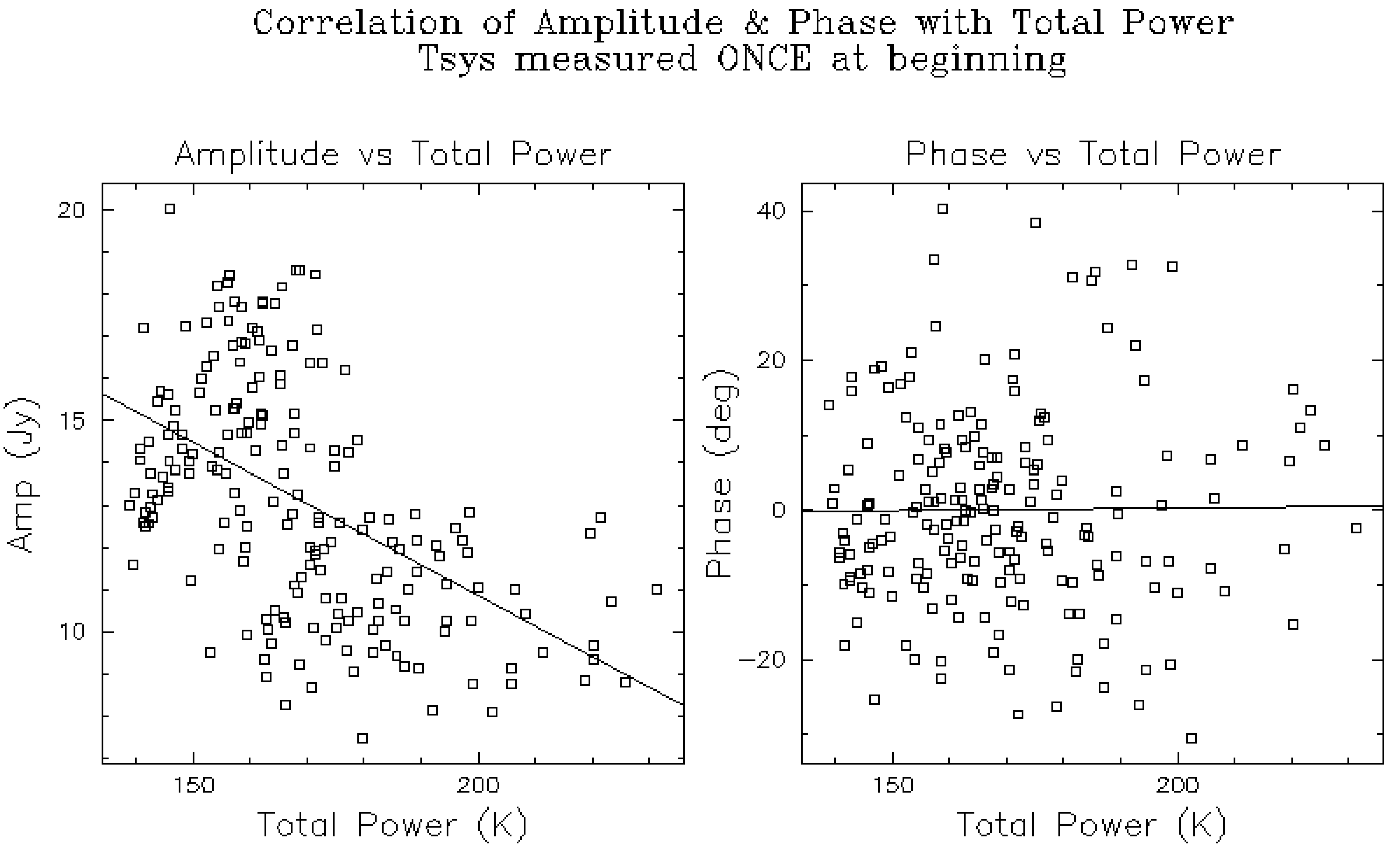


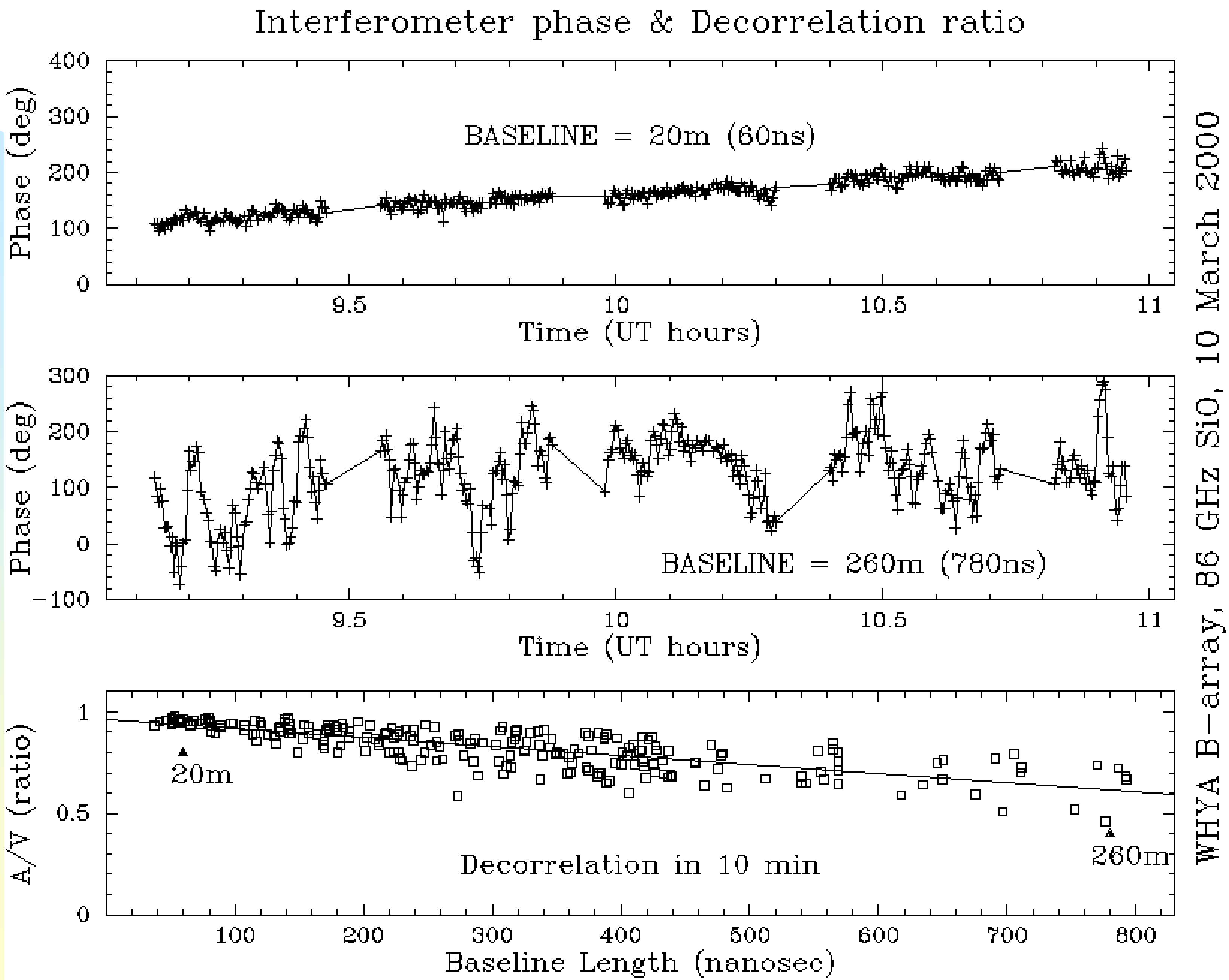




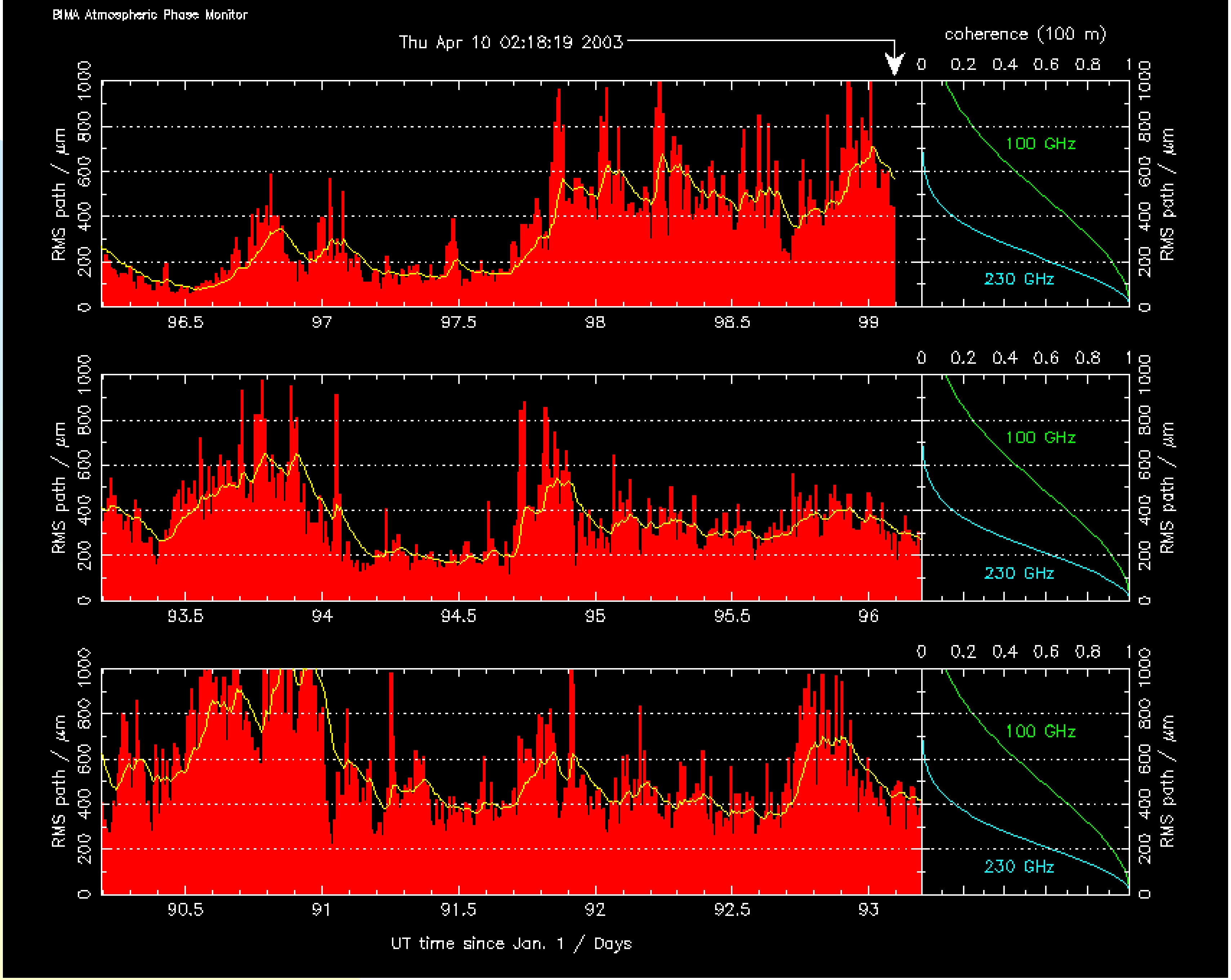


Amplitude, Total Power & Phase vs Time
Tsys measured ONCE at beginning
Phase
Phase (deg)
50
0
−50
0.67
0.675
0.68
0.685
0.69
0.695
0.7
Total Power
Power (K)
200
150
16.1
16.2
16.3
16.4
16.5
16.6
16.7
16.8
Amplitude
Amp (Jy)
20
15
10
0.67
0.675
0.68
0.685
0.69
0.695
0.7
Time

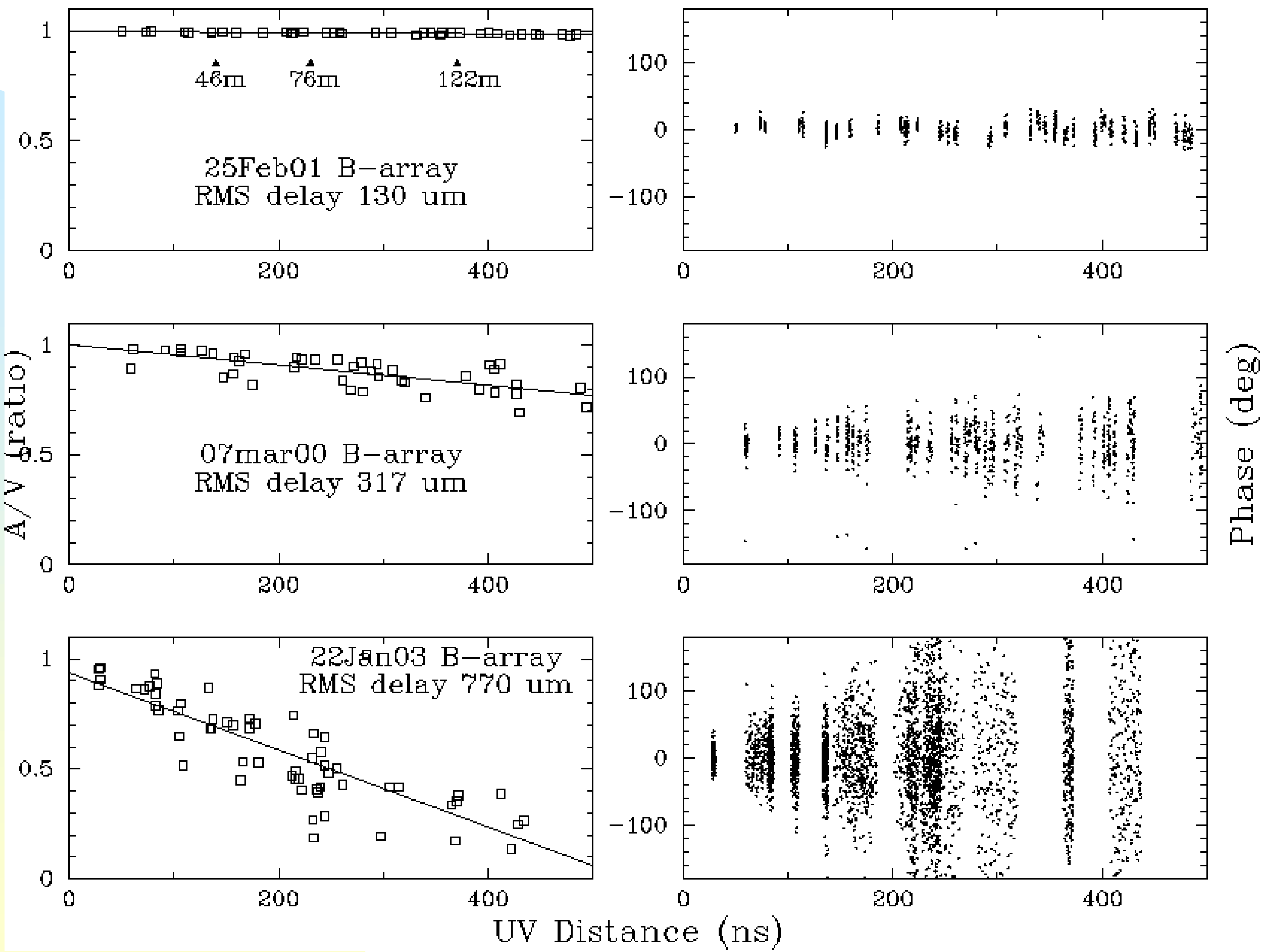

Correlation of Amplitude & Phase with Total Power
Tsys measured ONCE at beginning
Amplitude vs Total Power
Phase vs Total Power
Amp (Jy)
Phase (deg)
Total Power (K)
Total Power (K)
20
15
10
150
200
40
20
0
−20
150
200



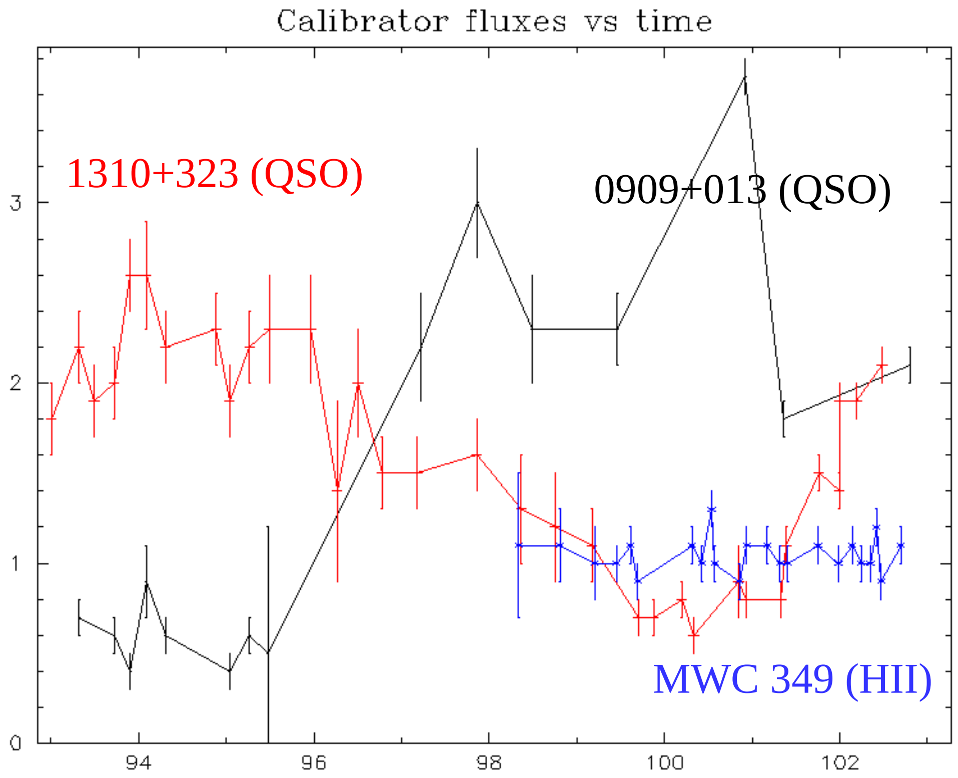
Interferometer phase & Decorrelation ratio
Phase (deg)
BASELINE = 20m (60ns)
Time (UT hours)
Phase (deg)
BASELINE = 260m (780ns)
Time (UT hours)
A/V (ratio)
20m
260m
Decorrelation in 10 min
Baseline Length (nanosec)
WHYA B–array, 86 GHz SiO, 10 March 2000


BIMA Atmospheric Phase Monitor
Thu Apr 10 02:18:19 2003
coherence (100 m)
100 GHz
230 GHz
RMS path / μm
UT time since Jan. 1 / Days

Decorrelation and Phase scatter vs Baseline length

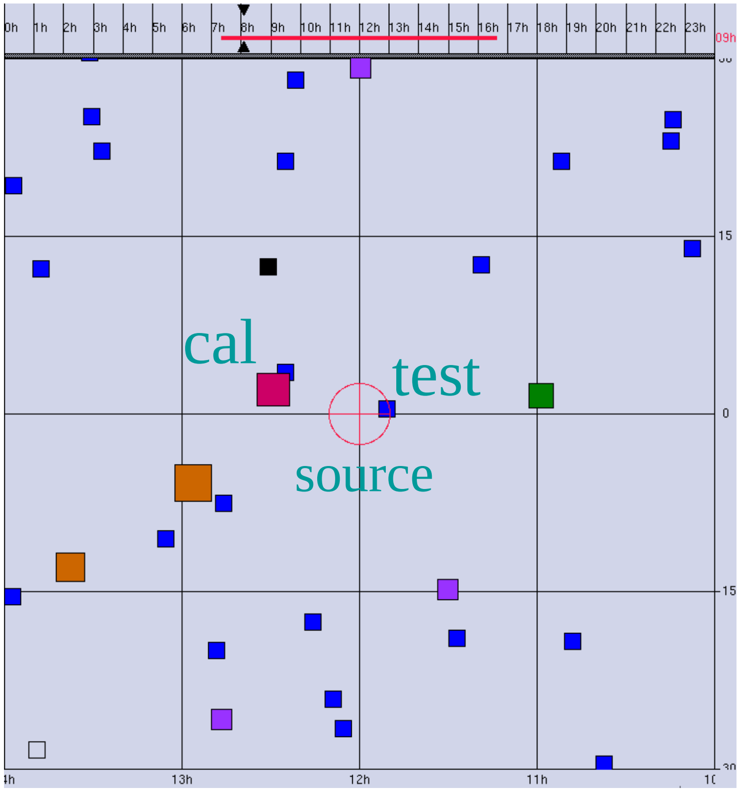


Absolute flux calibration

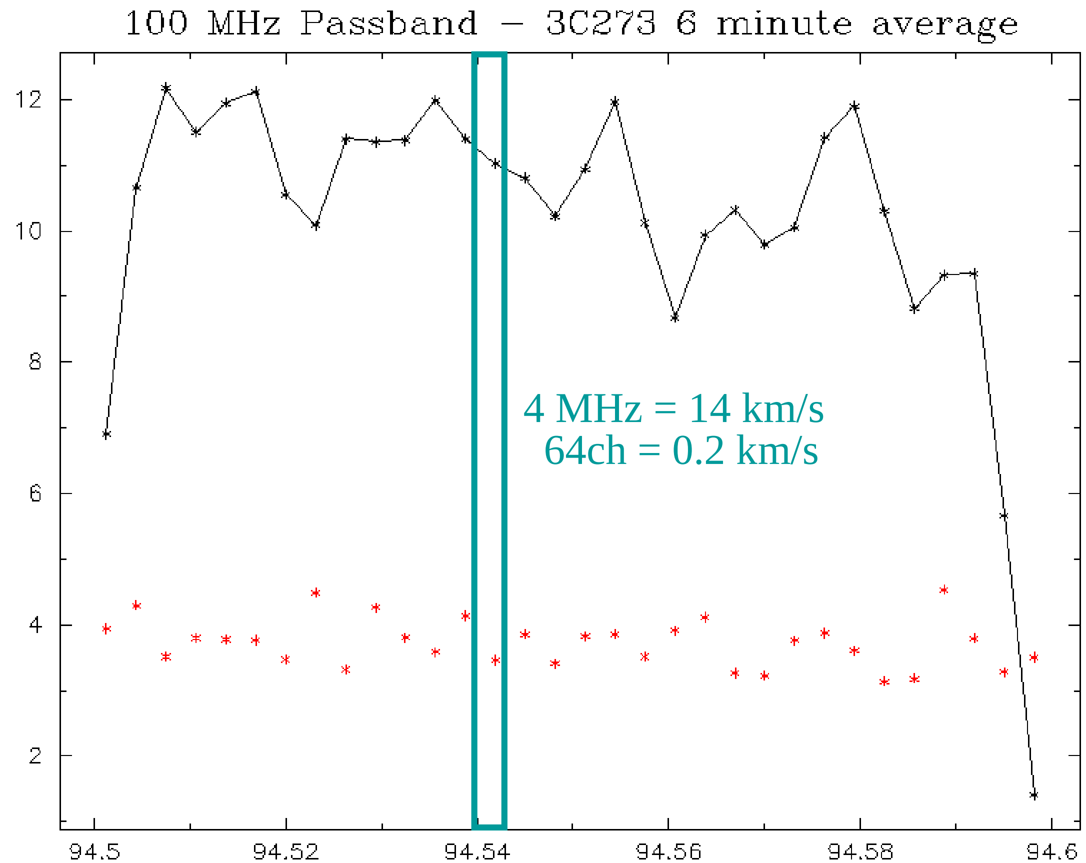


Use a primary flux calibrator (planet or HII region) to check the value of Jy/K. Use your phase calibrator to monitor temporal gain changes.

Test source



Use a test source to help quantify the effects of atmospheric decorrelation in the image plane.



Passband – 32 visibility channels over 100 MHz
Channel BW = 3.125 MHz (~11 km/s)

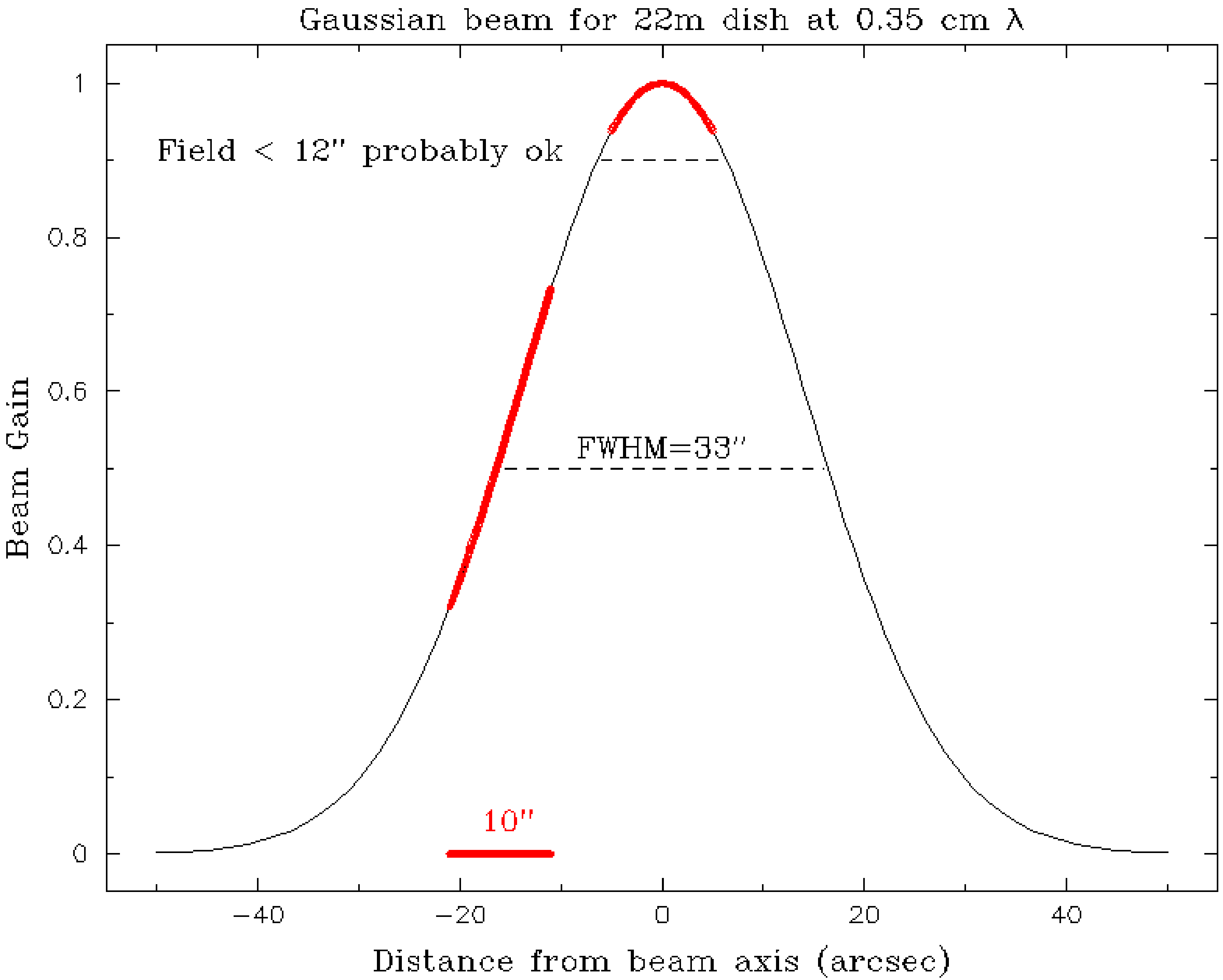
n = 2.6 Jy (each 11 km/s channel)

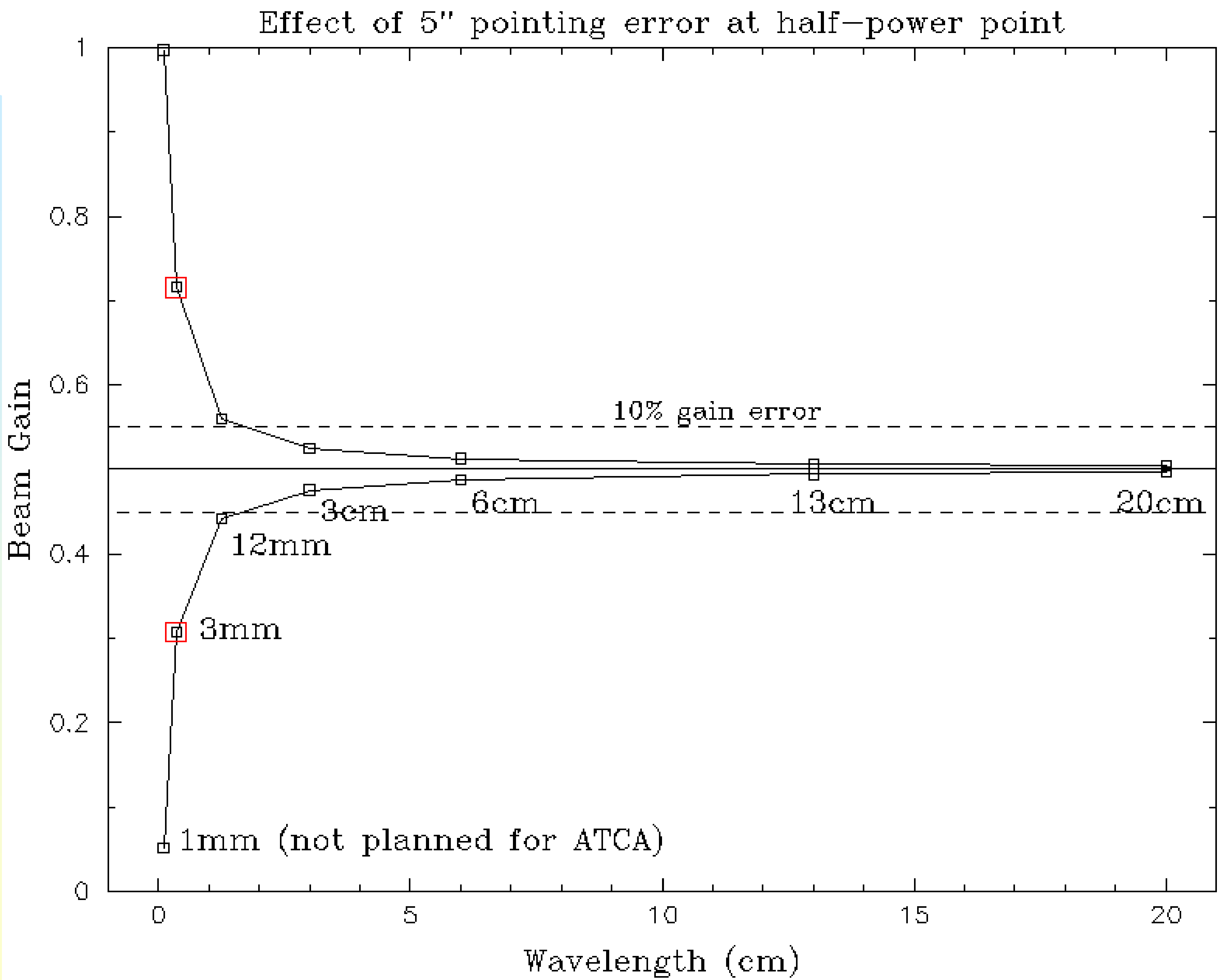
s/n = 12/2.6 ~ 4.6
phase noise ~ 11 deg
(ave 100 MHz ~ 6 times better)

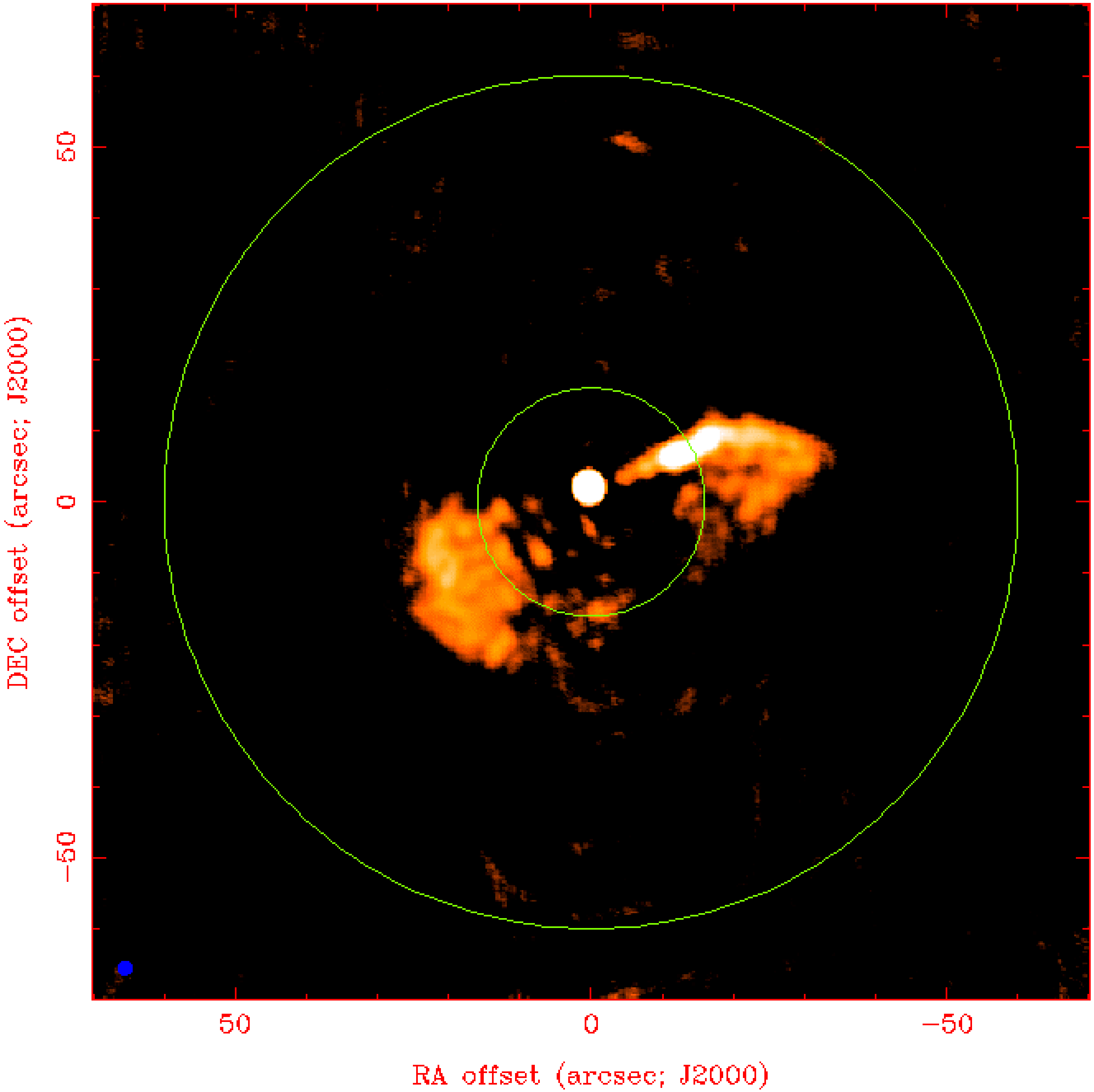
At 0.2 km/s channel
n = 8x2.6 ~ 21 Jy

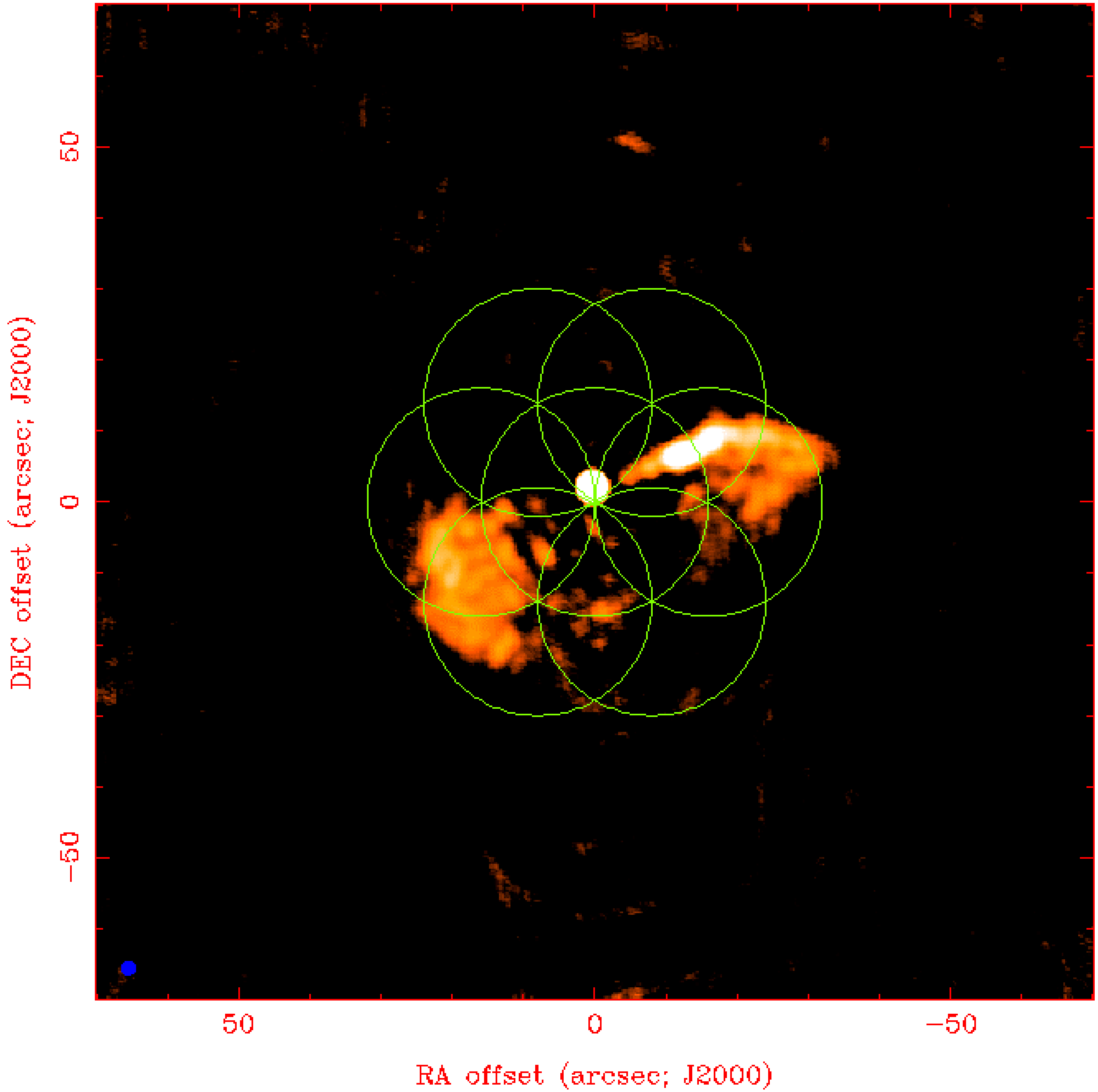
k = 1380 Jy m^2/K
Tsys = 560 K
A = 28 m^2
$\eta = \eta_a \eta_c = .70 \times .88 = .61$
bw = 100/32 = 3.125 MHz
t = 6m = 360 s

$$n = \frac{2\,k\,T_{sys}}{A\,\eta\sqrt{bw \bullet t}}\ \text{Jy}$$


Gaussian beam for 22m dish at 0.35 cm λ
Field < 12" probably ok
FWHM=33"
10"
Beam Gain
1
0.8
0.6
0.4
0.2
0
−40
−20
0
20
40
Distance from beam axis (arcsec)

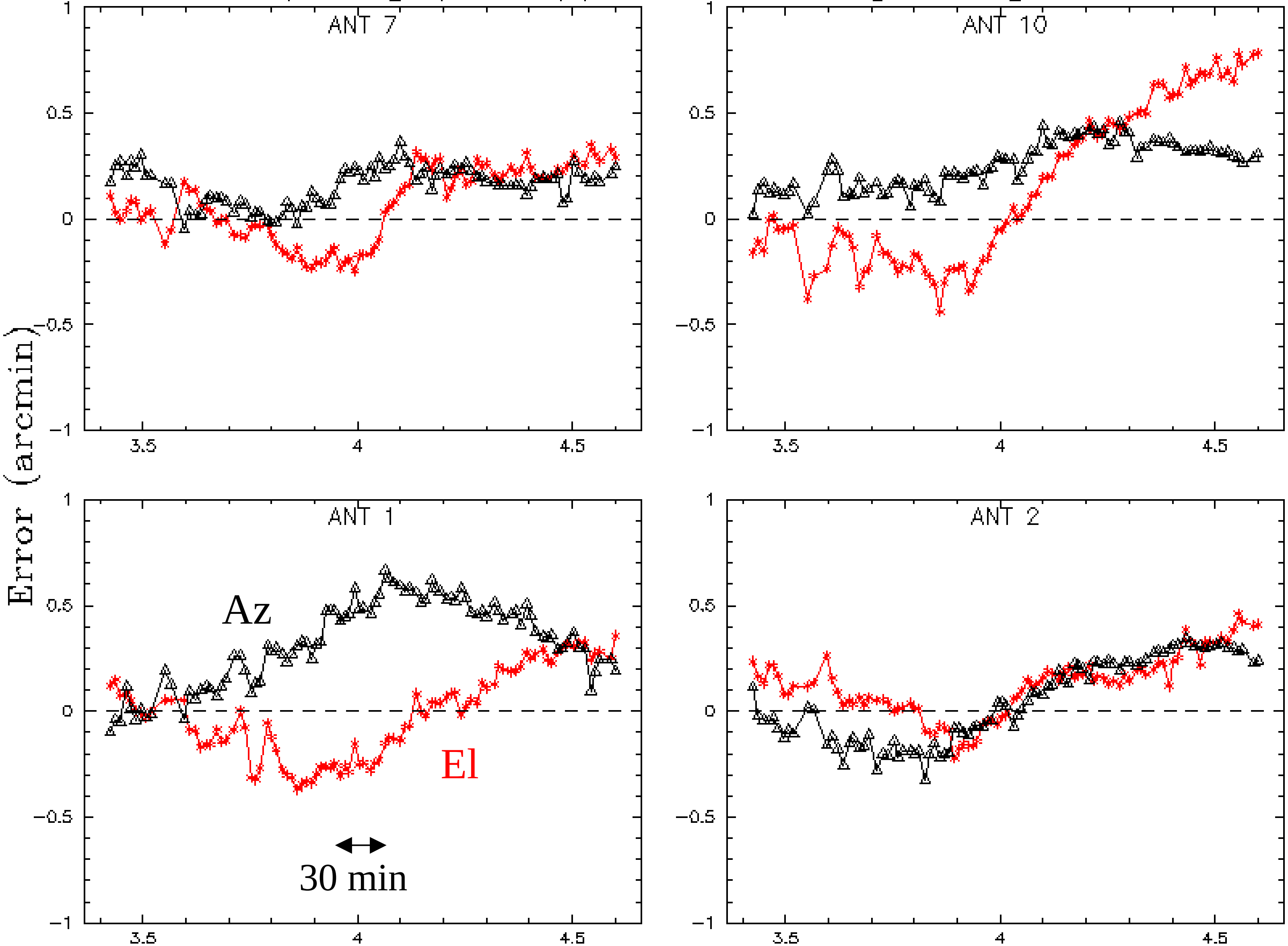

Effect of 5" pointing error at half-power point
Beam Gain
Wavelength (cm)
10% gain error
1mm (not planned for ATCA)
3mm
12mm
3cm
6cm
13cm
20cm
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20


50
0
−50
DEC offset (arcsec; J2000)
50
0
−50
RA offset (arcsec; J2000)


50
0
−50
50
0
−50
DEC offset (arcsec; J2000)
RA offset (arcsec; J2000)

0237+288 – 12 July, 2000

DAZ(triangle), DEL(*) BIMA sunrise pointing errors



Time – 6am to 10:30am

A few final suggestions

- ✓ Calibrate Tsys often
- ✓ Check Jy/K on a flux cal
- ✓ Mosaic sources larger than ½ fwhm
- ✓ Use offset pointing for extended sources
- ✓ In a pinch total power correction might help
- ✓ Choose nearby calibrator if baseline is uncertain
- ✓ Choose integration time so S/N > 5 on calibrator
- ✓ Use a guest calibrator to gauge atmospheric effects
- ✓ Don't push your observations beyond the seeing limit
- ✓ Avoid unnecessary PB calibration, & check sensitivity
- ✓ Monitor the atmosphere – **abort 3mm** in severe conditions
- ✓ Fast-switching might be worth a try in reasonable conditions

9.62+0.19 (OH009)