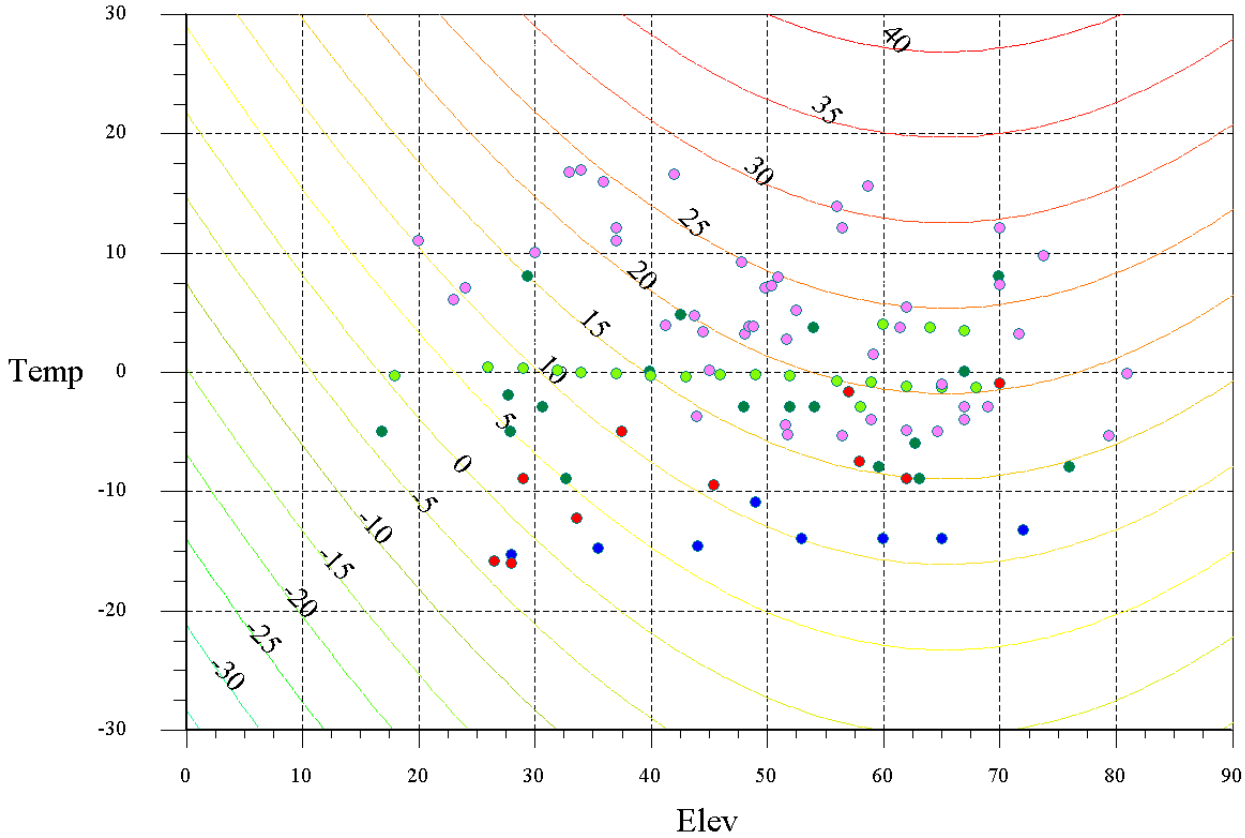
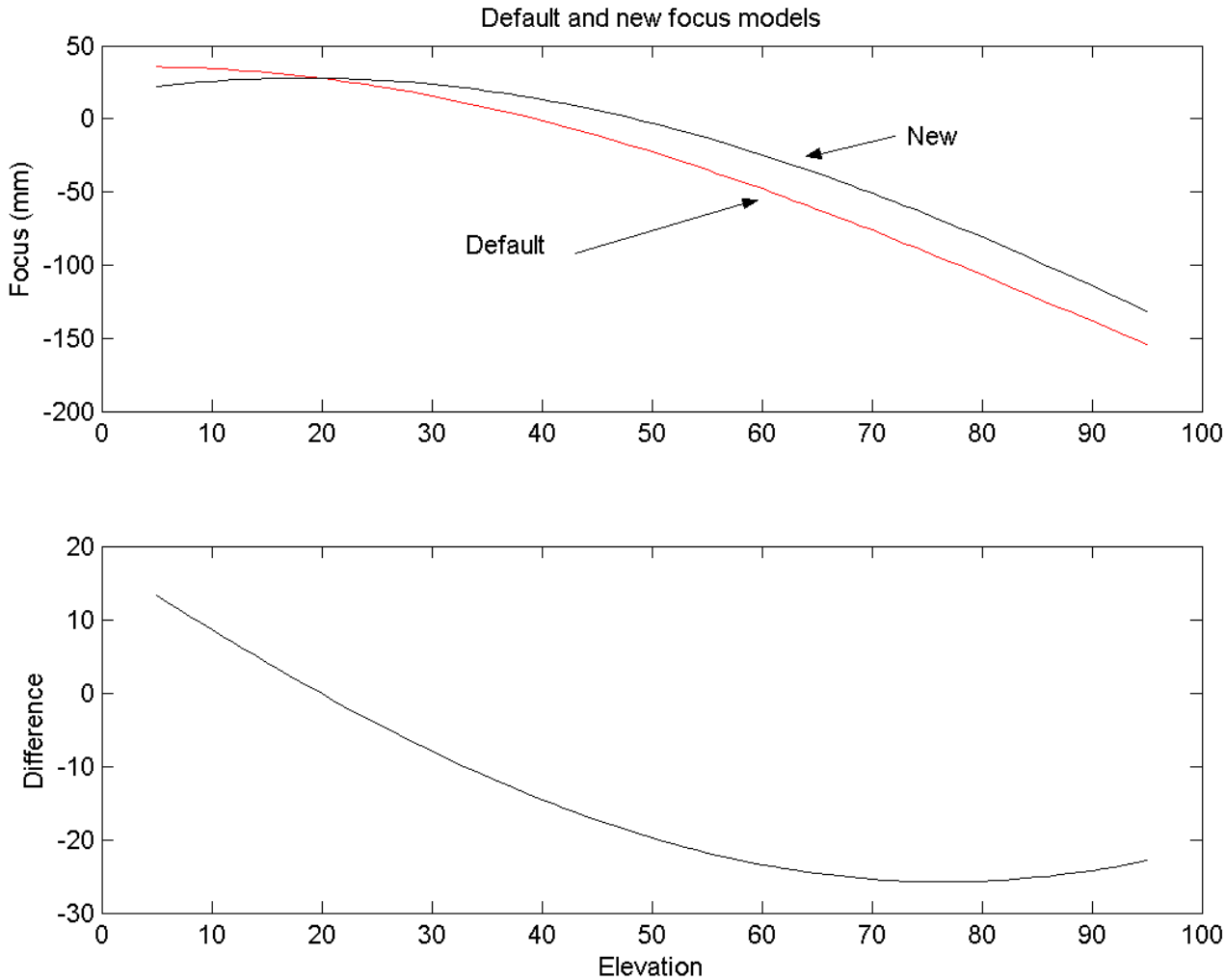
The Details….

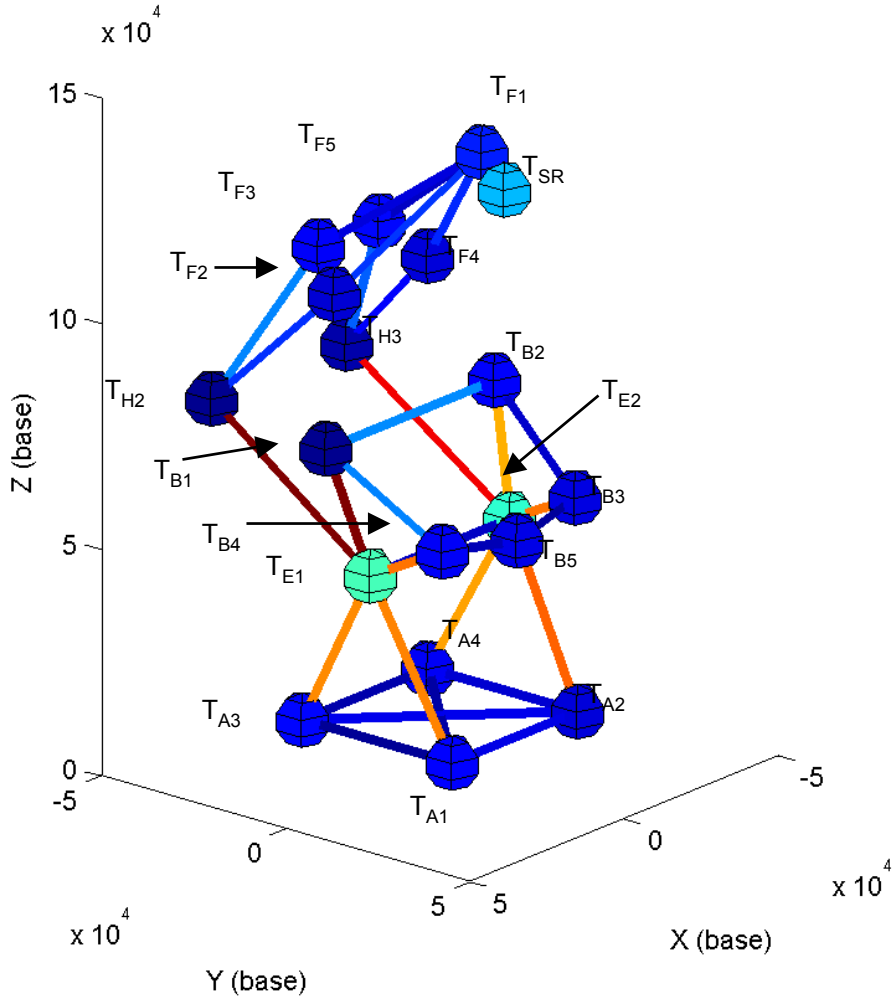
Previous Focus Tracking Curves



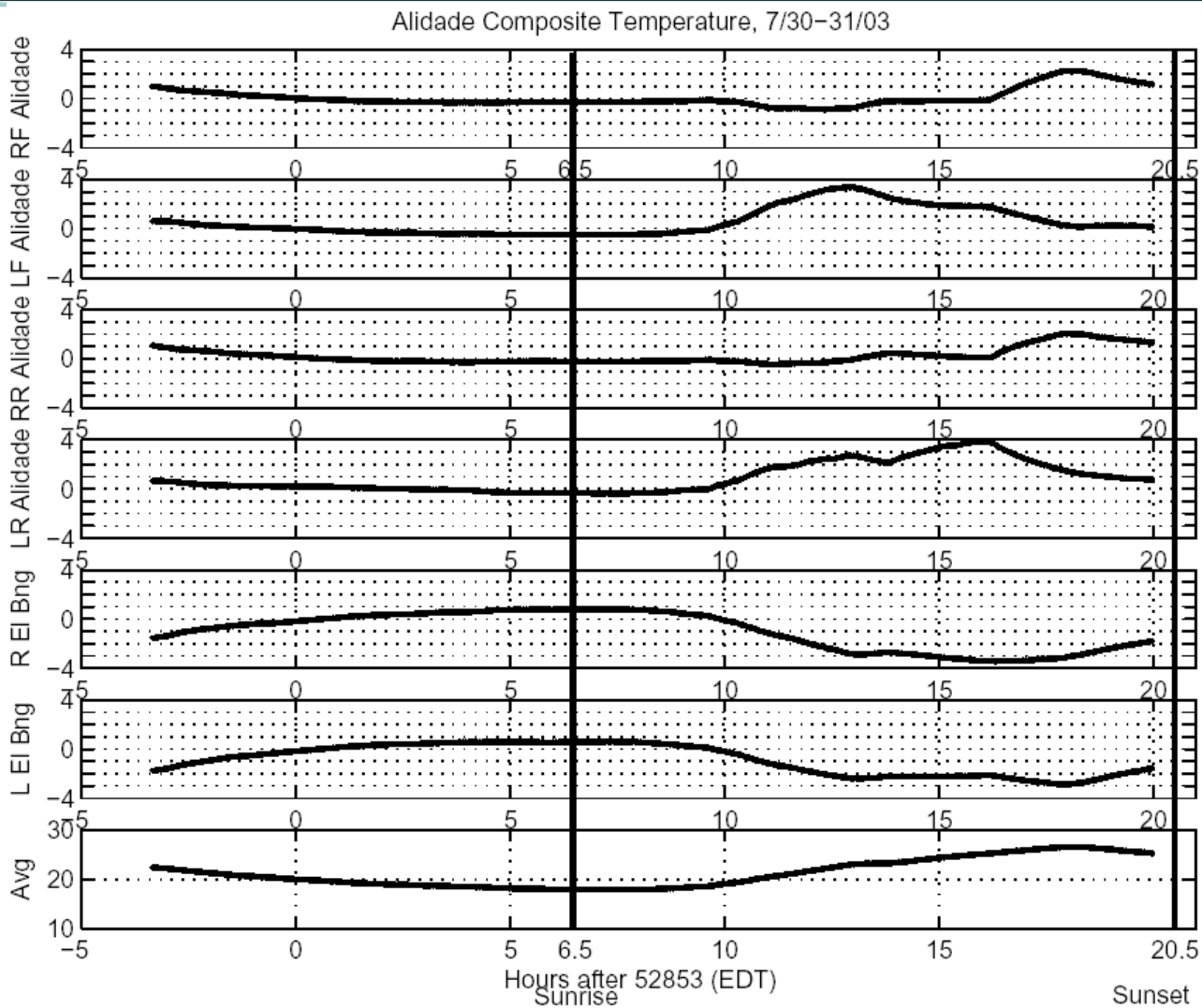
Previous Focus Tracking Curves



Temperature Sensor Locations



Structural Temperatures



Focus Model

- *Gravity*
- *SR-Primary*
- *VFA-Primary*
- *HFA*
- *BUS*

$$\Delta F = a_1 + a_2 \sin(\phi) + a_3 \cos(\phi),$$

$$T_1^{(f)} = T_{SR} - \frac{T_{B1} + T_{B2} + T_{B3} + T_{B4} + T_{B5}}{5}.$$

$$T_2^{(f)} = \frac{T_{F1} + T_{F2} + T_{F3} + T_{F4} + T_{F5}}{5} - \frac{T_{B1} + T_{B2} + T_{B3} + T_{B4} + T_{B5}}{5}.$$

$$T_3^{(f)} = \frac{T_{H2} - T_{E1} + T_{H1} - T_{E2}}{2}$$

$$T_4^{(f)} = \frac{T_{B1} + T_{B2}}{2} - T_{B5}$$

$$T_5^{(f)} = \frac{T_{B1} + T_{B2}}{2} - \frac{T_{E1} + T_{E2}}{2}.$$

$$T_6^{(f)} = \frac{T_{B3} + T_{B4} + T_{B5}}{3} - \frac{T_{E1} + T_{E2}}{2}.$$

Elevation Model

- *Gravity*

$$\Delta E = -(IE) - (AW)\sin(\theta) + (AN)\cos(\theta) + (HZCZ)\sin(\phi) + (HZSZ)\cos(\phi)$$

- *BUS*

$$T_1^{(e)} = \frac{T_{B3} + T_{B4} + T_{B5}}{3} - \frac{T_{B1} + T_{B2}}{2}$$

- *HFA*

$$T_2^{(e)} = \frac{T_{H2} - T_{E1} + T_{H1} - T_{E2}}{2}$$

- *VFA*

$$T_3^{(e)} = \frac{T_{F2} + T_{F4}}{2} - \frac{T_{F3} + T_{F5}}{2}.$$

- *Alidade*

$$T_4^{(e)} = \frac{T_{A1} + T_{A2}}{2} - \frac{T_{A3} + T_{A4}}{2}.$$

Azimuth Model

- *Gravity*

$$\Delta A = (CA) + (NPAE)\sin(\phi) + (IA)\cos(\phi) + (AW)\cos(\theta)\sin(\phi) + (AN)\sin(\theta)\sin(\phi)$$

- *Alidade*

$$T_1^{(a)} = \sin(\phi)\left[\frac{T_{A1} + T_{A3}}{2} - T_{E1} - \frac{T_{A2} + T_{A4}}{2} + T_{E1}\right].$$

- *HFA*

$$T_2^{(a)} = \frac{T_{H2} - T_{E1} - T_{H1} + T_{E2}}{2}.$$

- *BUS*

$$T_3^{(a)} = \frac{T_{B1} + T_{B4}}{2} - T_{E1} - \frac{T_{B2} + T_{B3}}{2} + T_{E2}.$$

- *VFA*

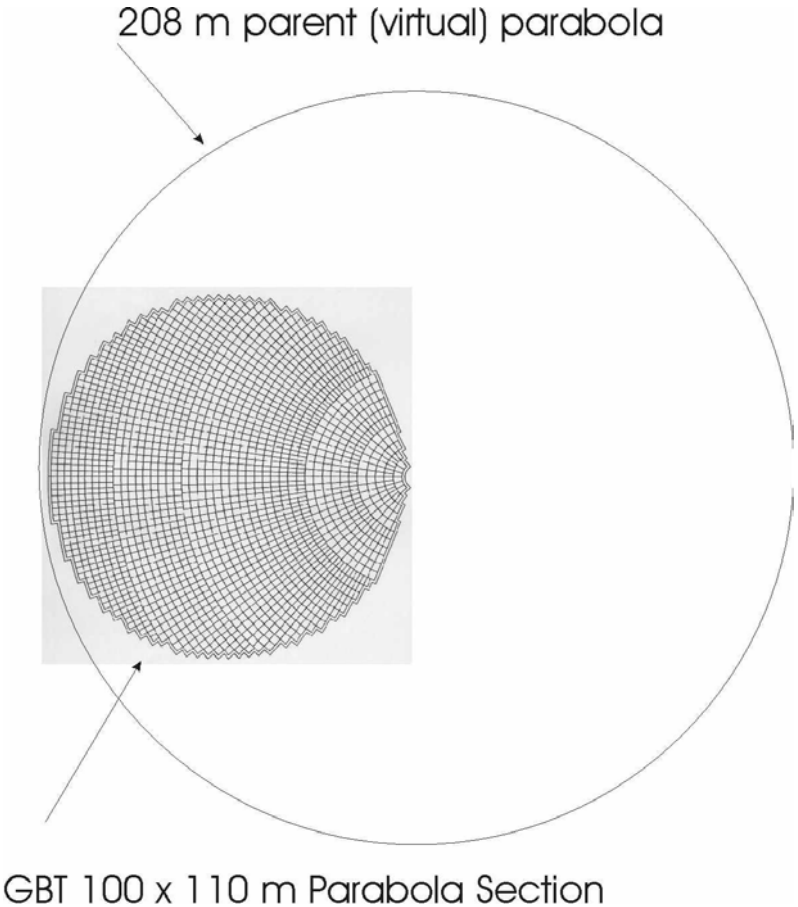
$$T_4^{(a)} = \frac{T_{F2} + T_{F3}}{2} - \frac{T_{F4} + T_{F5}}{2}$$

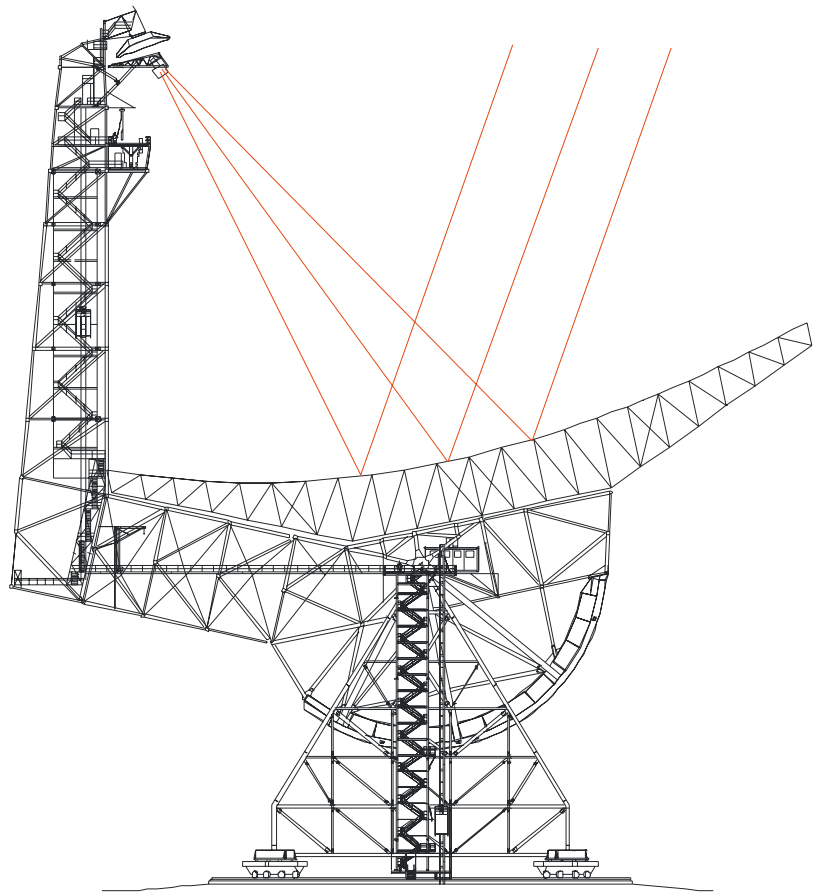
Optimization

- *Focus optimization using pseudo-inverse for LSE solution*
- *Coupled Az and El gravity models (AN, AW constraint)*
  - *Gradient descent*

Unblocked Aperture

- 100 x 110 m section of a parent parabola 208 m in diameter
- Cantilevered feed arm is at focus of the parent parabola





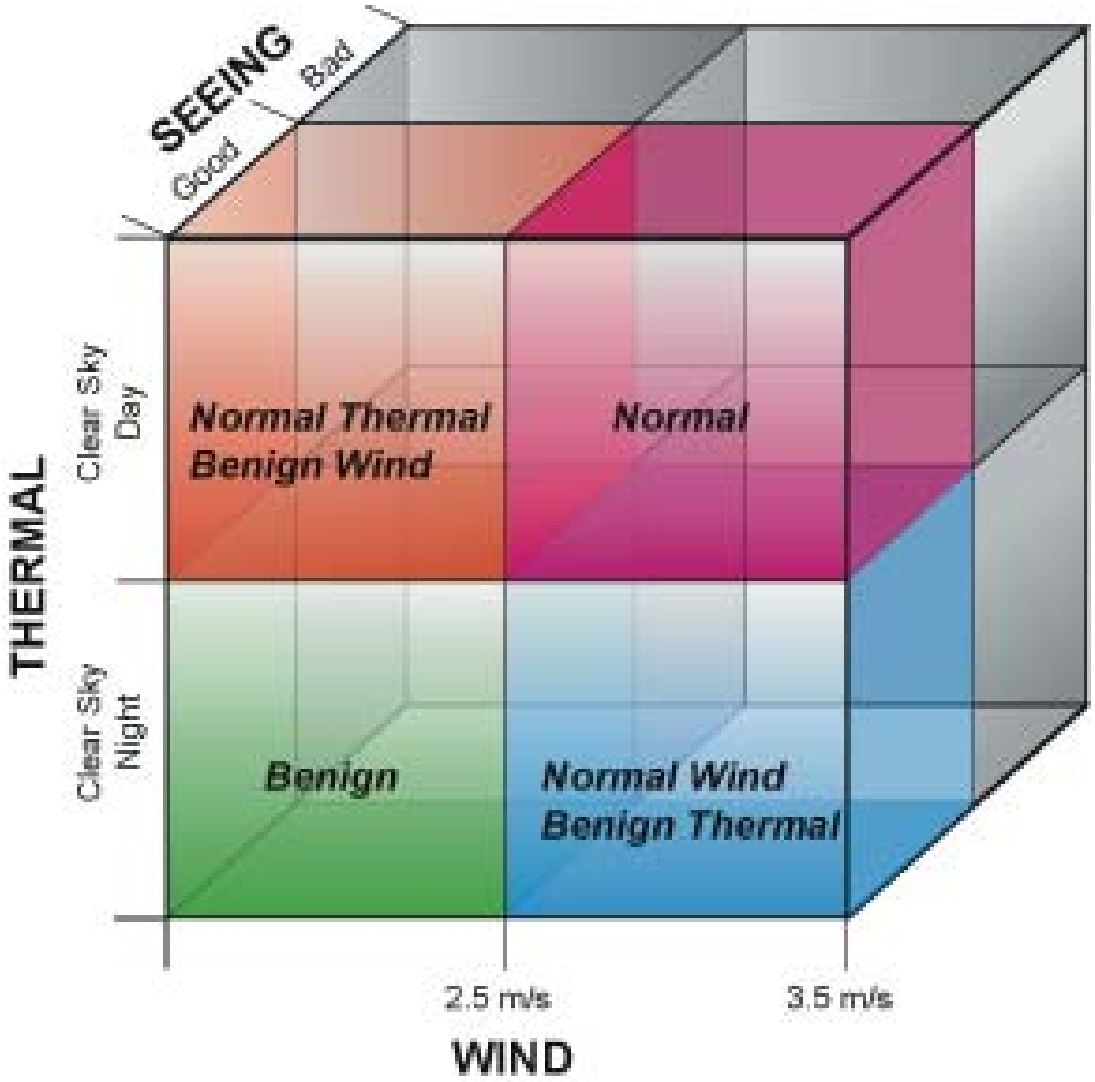
Telescope Structure and Optics

Development Phases

Table 1.1: GBT Telescope Commissioning Phases

Phase 1:	Frequencies <= 15 GHz.	Passive surface (surface actuators fixed)
Phase 2:	Frequencies <= 50 GHz.	Active surface in open loop
Phase 3:	Frequencies <= 100+ GHz.	Active surface in closed loop with laser metrology system

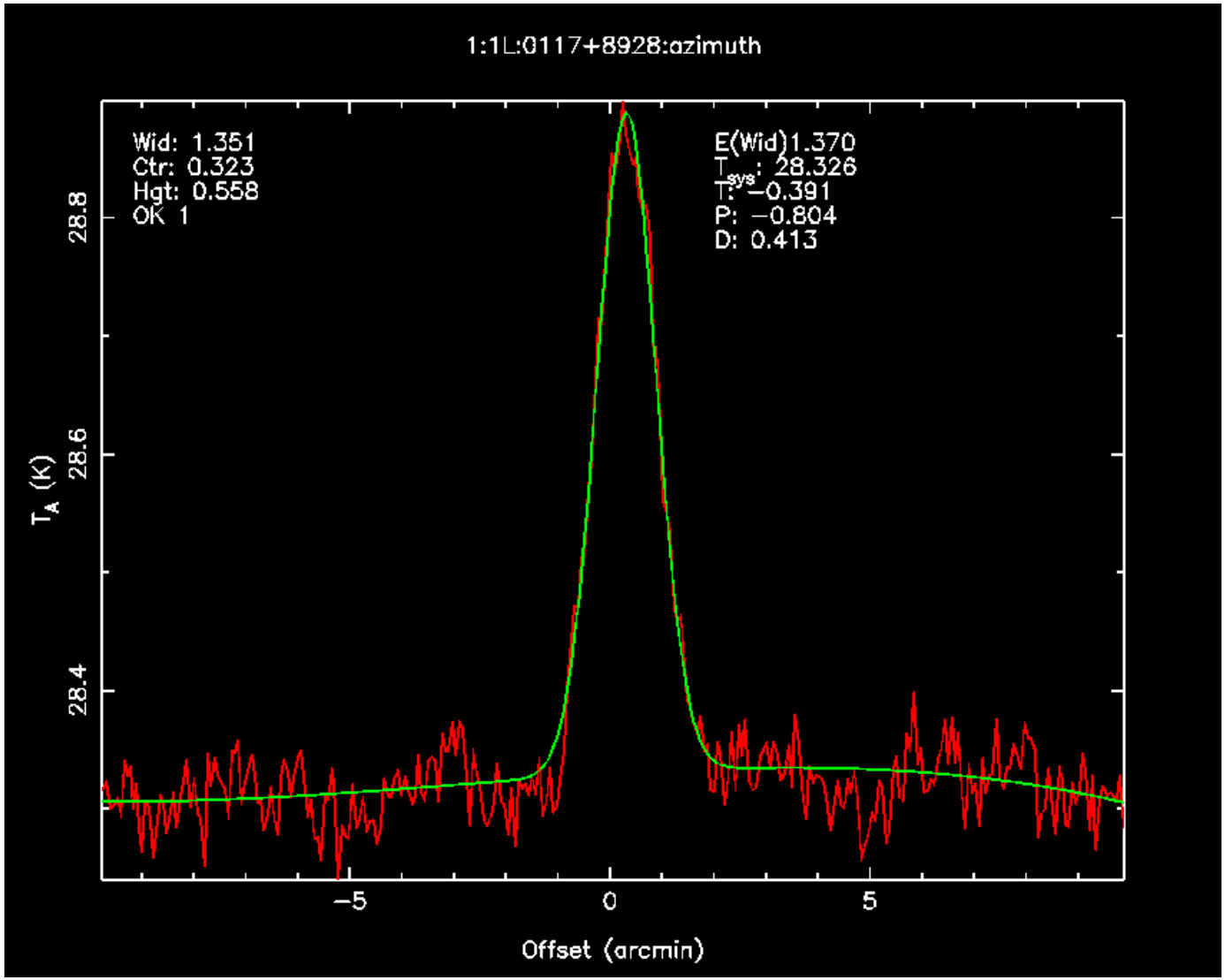
High Frequency Environmental Envelope



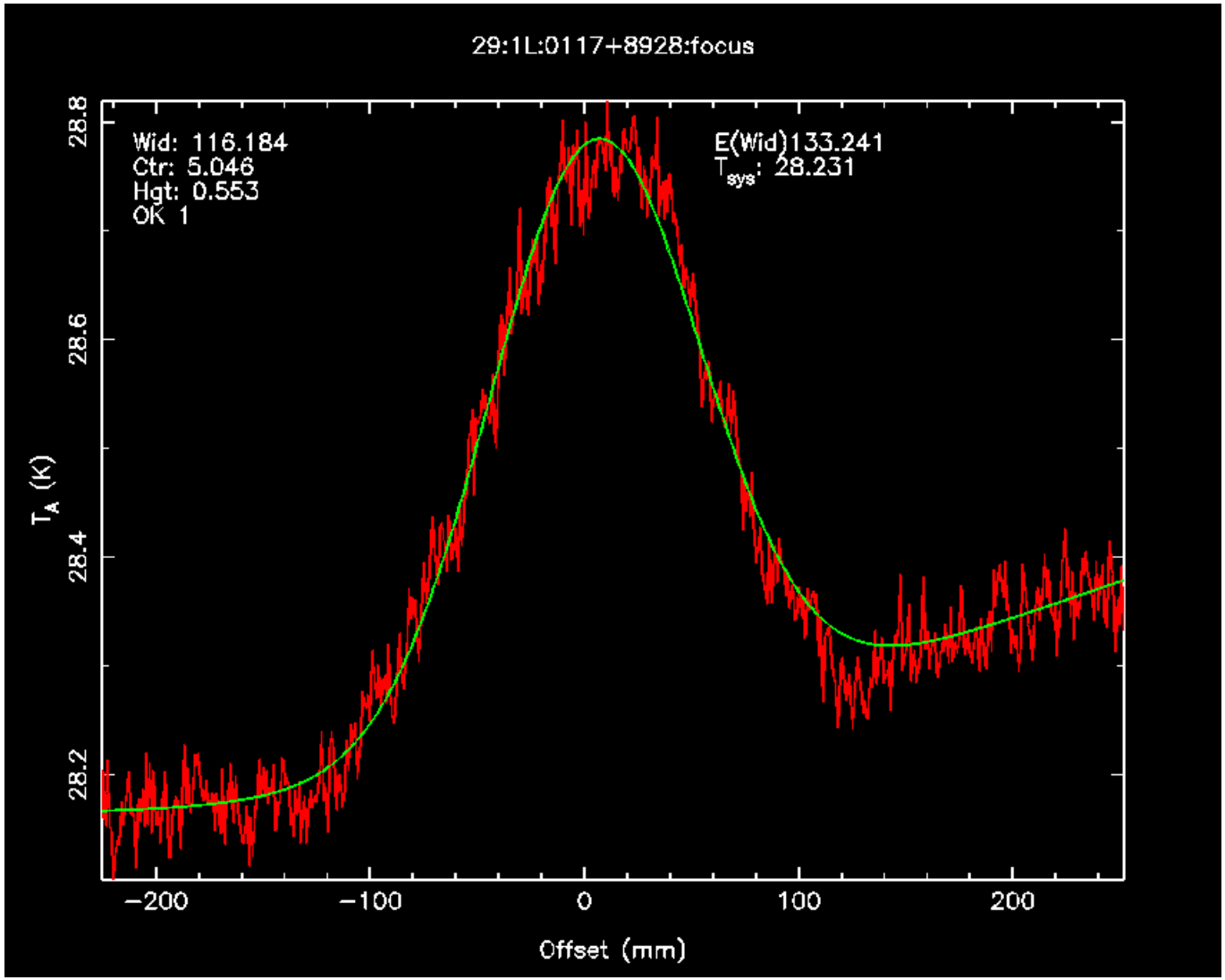
Pointing Accuracy, 5° C Gradient, 5° El

Loral Tech Memo 52 Table 2-20		El=5, ΔT=5,V_w=0,Sun Az=180		
Error Sources	**El Errors (arcsec)**		**X-El Errors (arcsec)**	
	Repeatable	**Nonrepeatable**	**Repeatable**	**Nonrepeatable**
Mechanical Alignments				
RF/El Axes Orthogonality	0.0		0.0	
El/Az Axes Orthogonality	0.0		5.2	
Az Axis Verticality	5.0		0.4	
Structural Deformations				
Reflector				
Wind				
Thermal Gradient		0.3		
Alidade				
Wind				
Thermal Gradient		11.5		
Servo and Drive		0.9		0.3
Miscellaneous				
El Bearing Wobble	1.0	0.4	0.1	0.0
Az Bearing Wobble	1.0	0.4	0.1	0.0
Encoder Accuracy		1.2		1.2
Encoder Coupling		1.8		2.1
Encoder Referencing	10.0		10.0	
RSS Subtotals	11.3	12.1	11.3	2.4

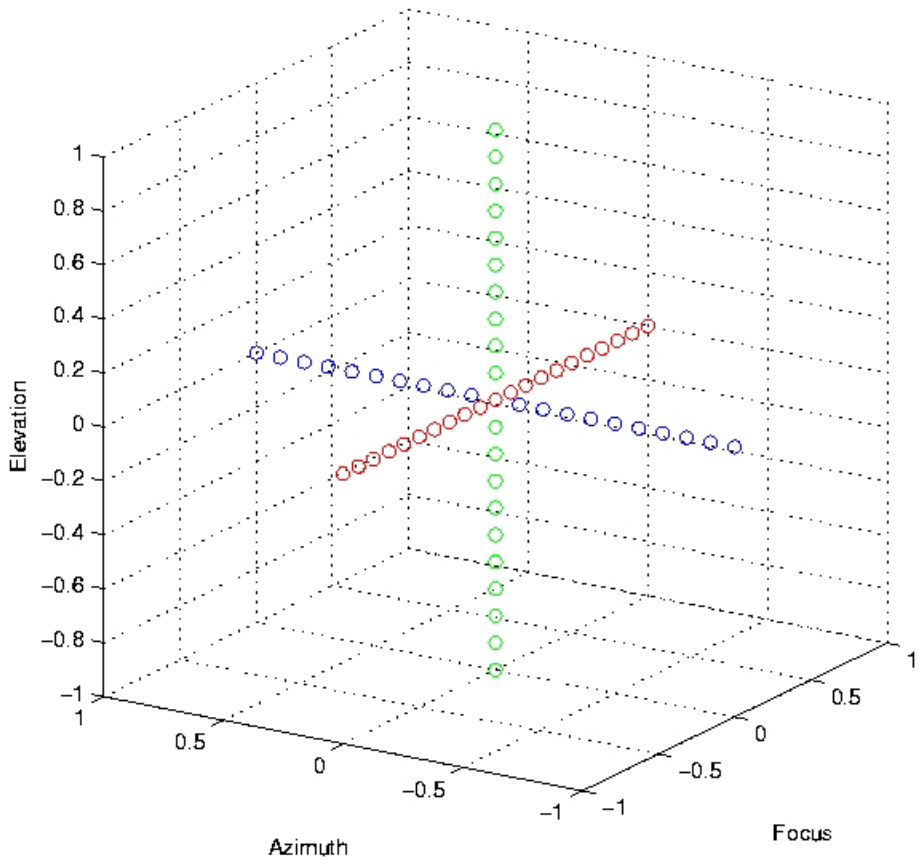
Pointing


1:1L:0117+8928:azimuth
Wid: 1.351
Ctr: 0.323
Hgt: 0.558
OK 1
E(Wid)1.370
T_{sys}: 28.326
T: −0.391
P: −0.804
D: 0.413
28.8
28.6
28.4
T_A (K)
−5
0
5
Offset (arcmin)

Focus


29:1L:0117+8928:focus
Wid: 116.184
Ctr: 5.046
Hgt: 0.553
OK 1
E(Wid)133.241
T_{sys}: 28.231
28.8
28.6
28.4
28.2
T_A (K)
−200
−100
0
100
200
Offset (mm)

Data Quality



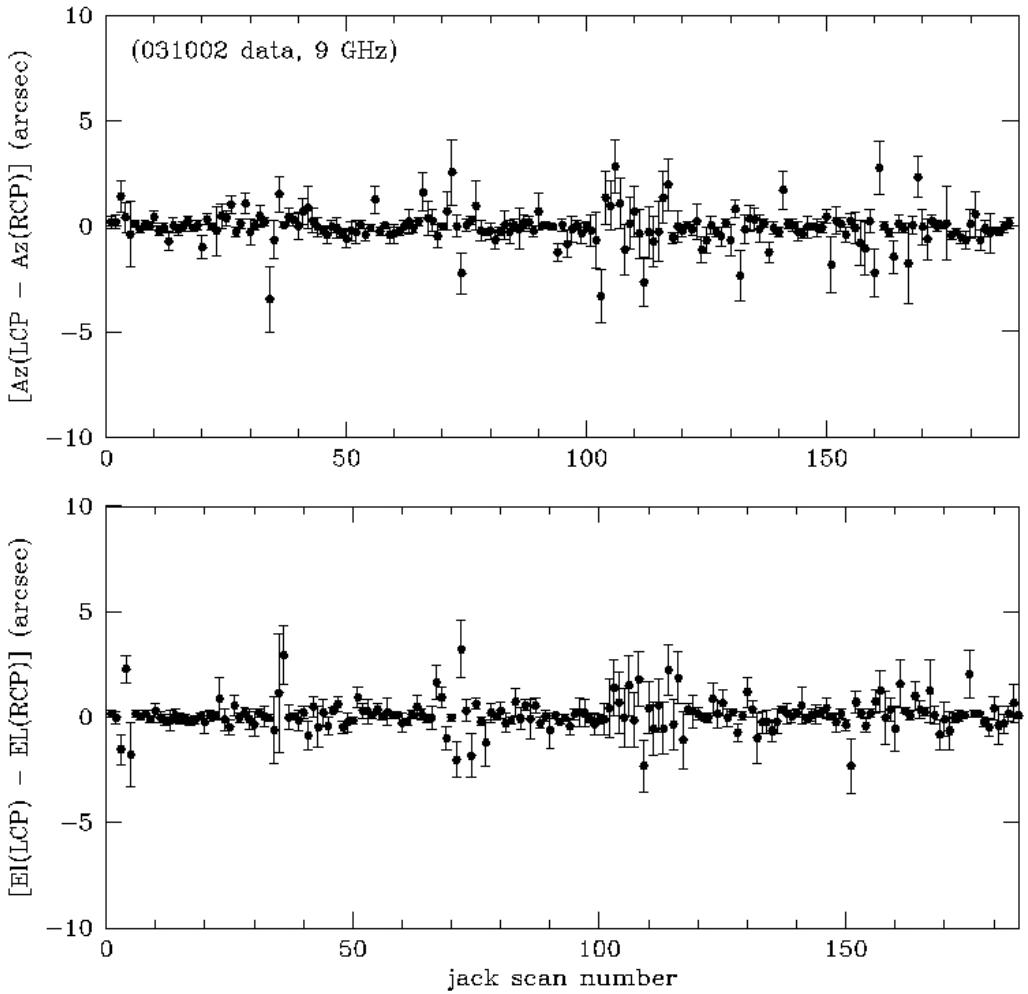
Jack Scan

Gaussian Fits (Az, El, Focus)

Polarization (LCP – RCP)

Direction (Forward – Backward)

Data Quality: Pointing (LCP – RCP)

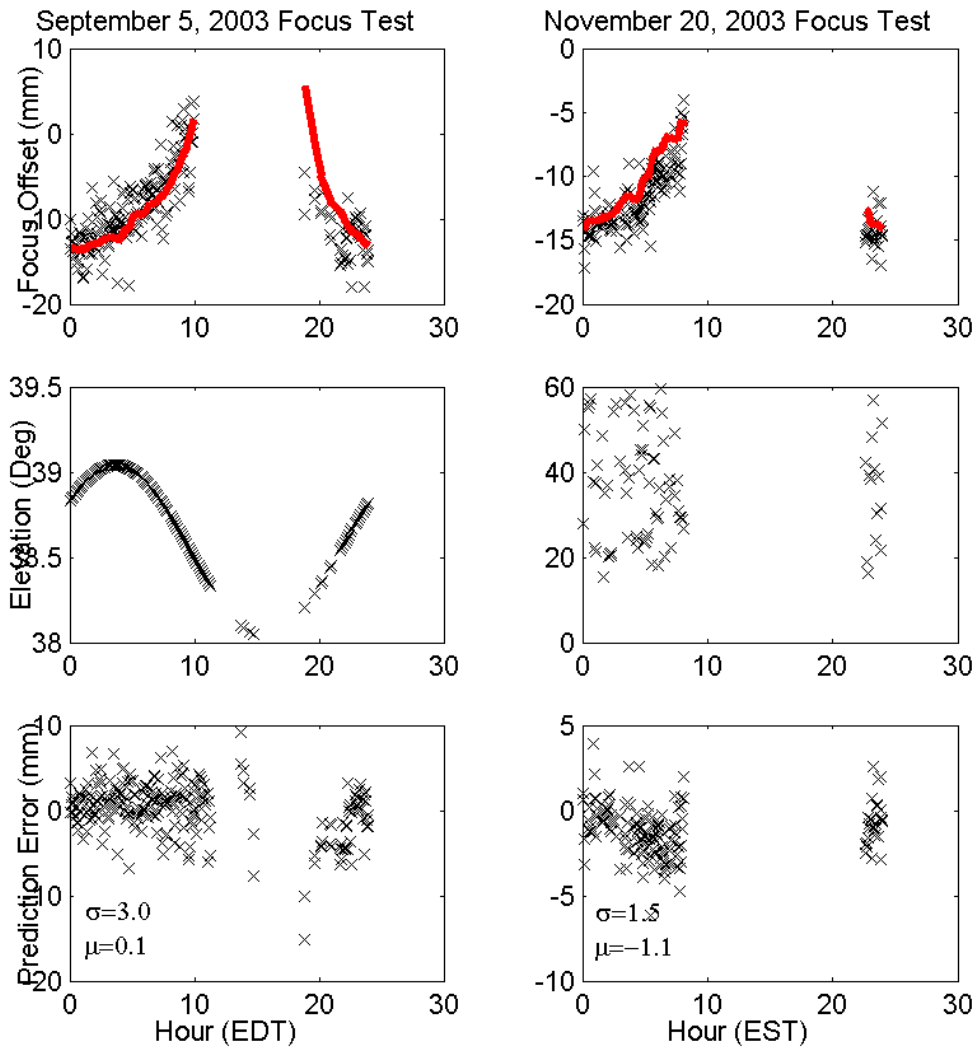


Structural Temperature Sensors

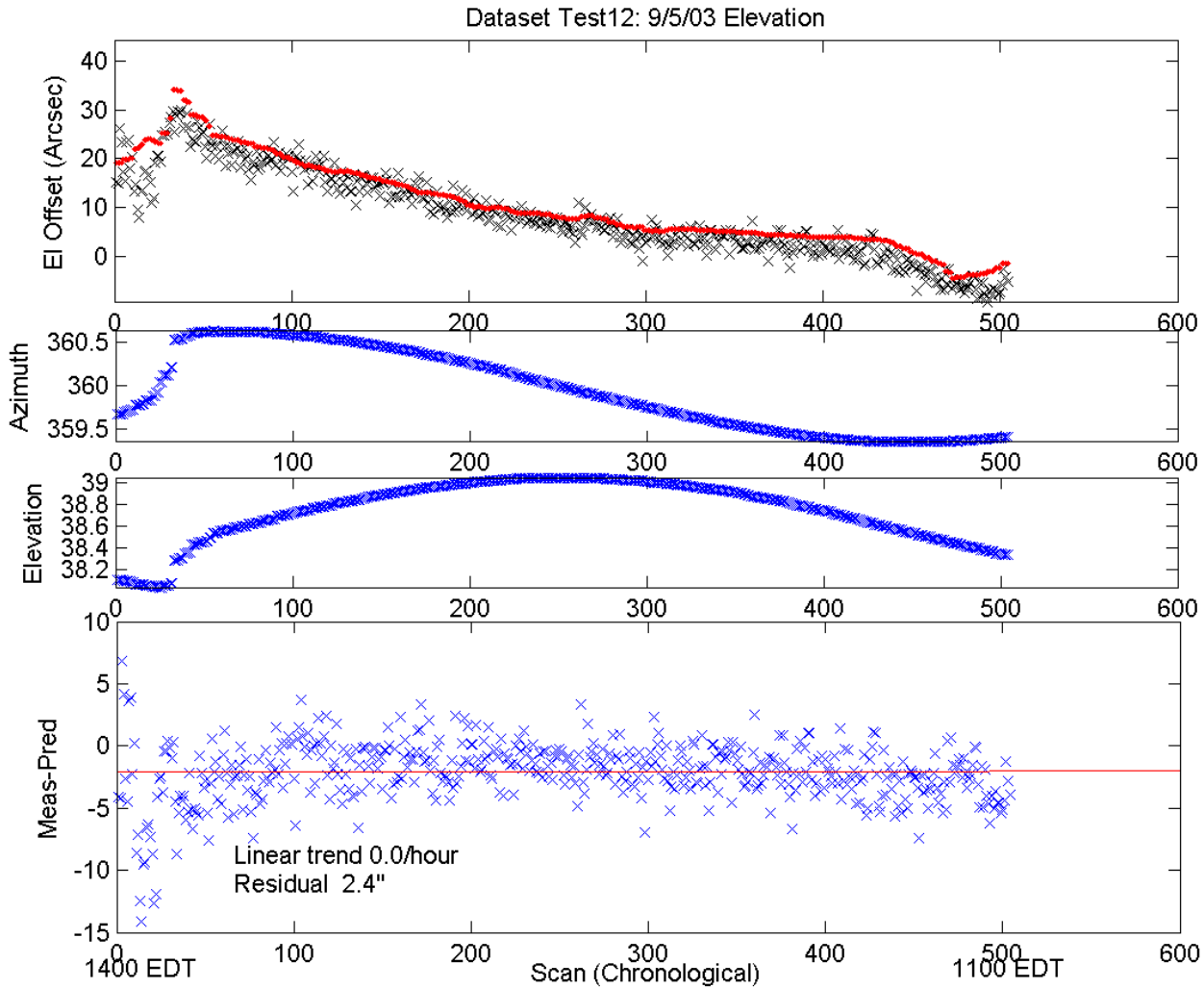
- *19 locations, 0.2C interchangeable accuracy, 0.01C resolution, 1Hz, range –35 to 40C. (actual accuracy is ~0.1C, temp control of conversion elex)*
- *Design documentation:*
  - *PTCS Wiki (AntennaInstrumentation)*
  - *PTCS Project Note PTCS/PN12*
- *Accuracy tested in lab:*
  - *Solar/convective loading*
  - *Selected unit-to-unit accuracy, repeatability*
  - *Electronics temperature range*
- *RFI mitigated, ESD protected*
- *Two thermistor failures, forensics with YSI*
- *Integrated into M&C*
- *First cut pointing, focus predictive algorithms tested*

Focus Model Tests

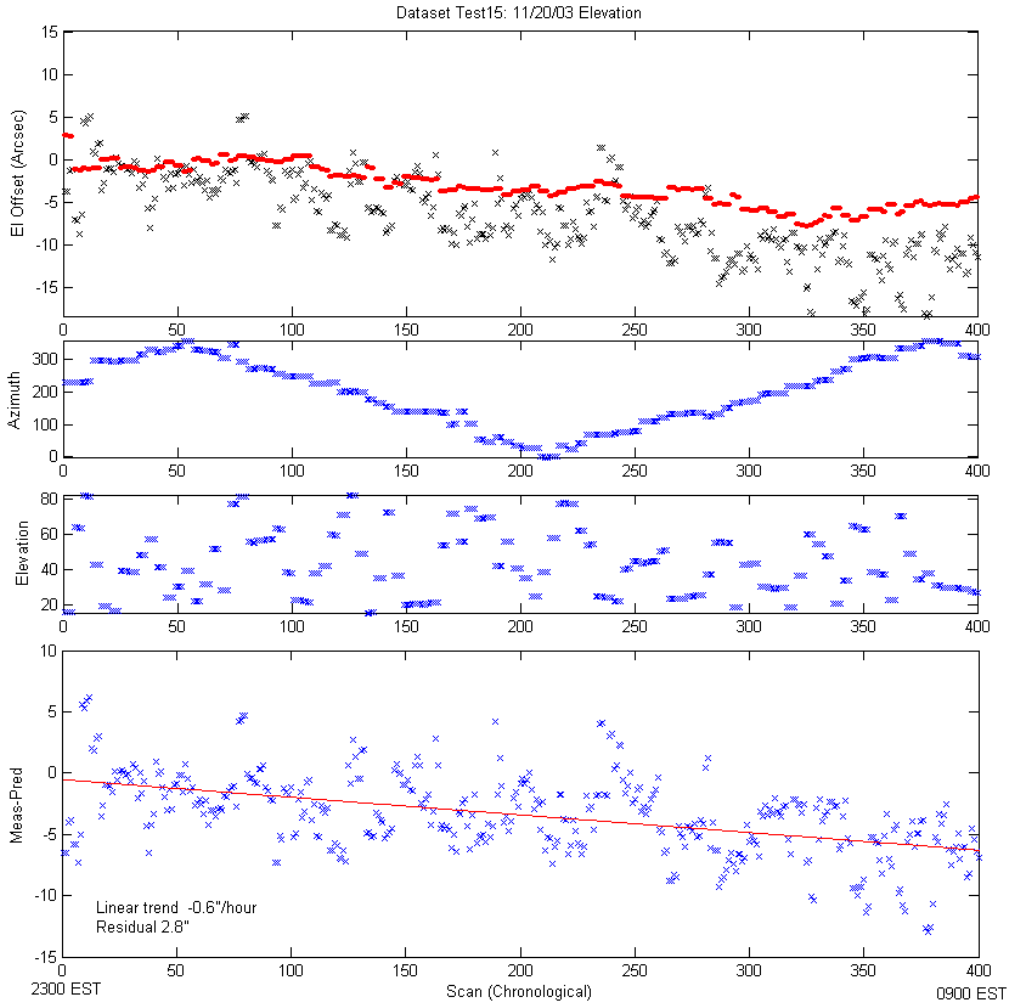
- *Wind < 2.5 m/s*
- *15° < elevation < 85°*
- *9/5 is NCP*
- *11/20 is all-sky*
- *Excludes 1000-1800*
- *Graphs show thermal contributions only*



Elevation Model Test



Elevation Model Test

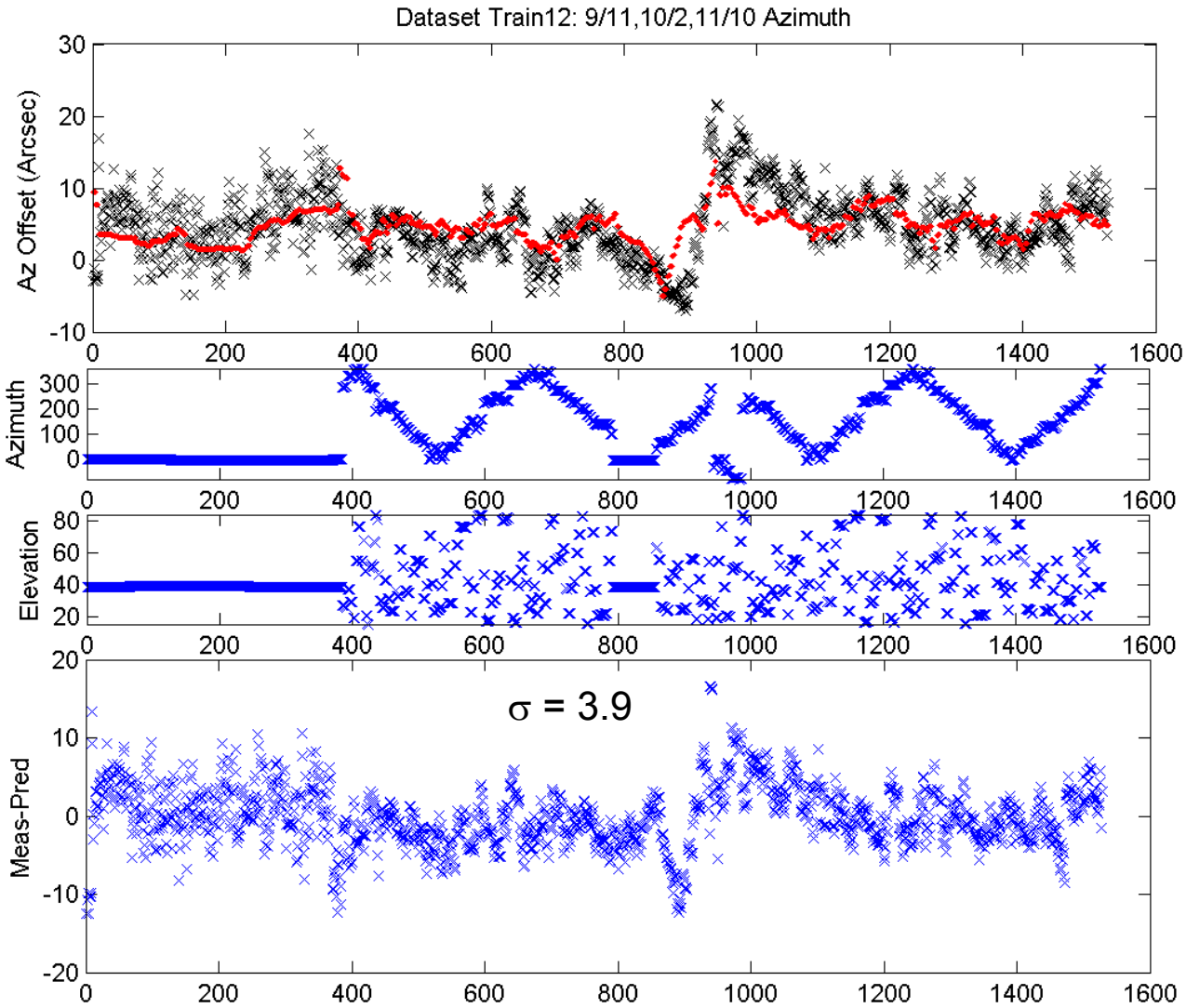


Azimuth Model

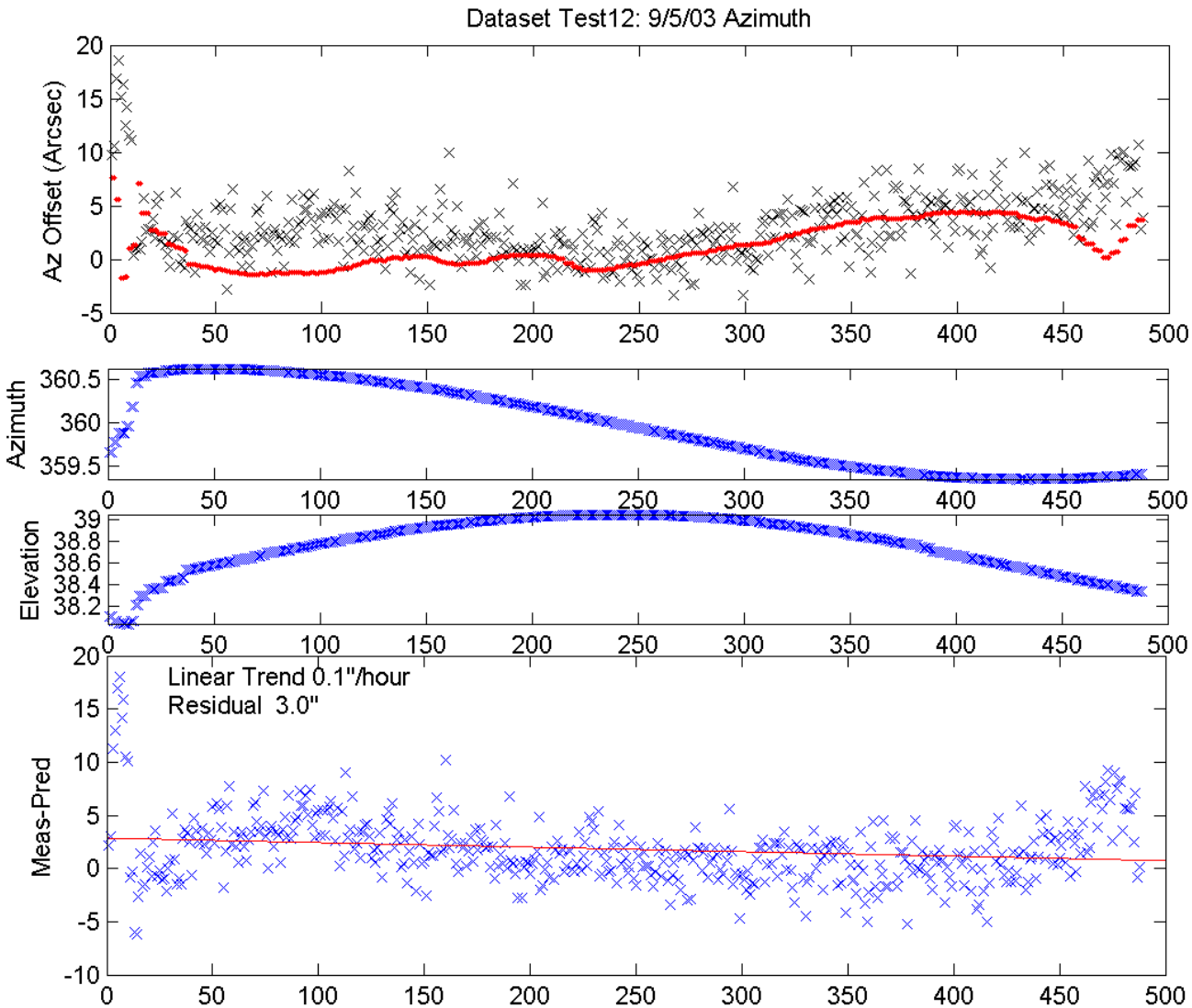
$$\Delta M\left(\phi,\theta,T_i^{(a)}\right) = M^{(e)} \times \begin{bmatrix} T_1^{(a)} \\ \cdot \\ \cdot \\ \cdot \\ T_4^{(a)} \\ 1 \\ \sin(\phi) \\ \cos(\phi) \\ \cos(\theta)\sin(\phi) \\ \sin(\theta)\sin(\phi) \end{bmatrix} = M^{(a)} \times T^{(a)}.$$

Term	Coefficient	Min-Max	Significance	Parameter
M_1	5.5862	4.0	22.4	Alidade
M_2	-8.0331	2.7	21.3	HFA
M_3	-1.6289	2.4	3.8	BUS
M_4	1.3683	2.0	2.8	VFA
M_5	3.4124	0.0	0.0	CA, d(0,0)
M_6	1.3223	0.7	1.0	NPAE, b(0,1)
M_7	3.5152	0.9	3.0	IA, d(0,1)
M_8	-2.4960	1.9	4.8	AW, b(1,1)
M_9	-1.3360	1.8	2.5	AN, a(1,1)

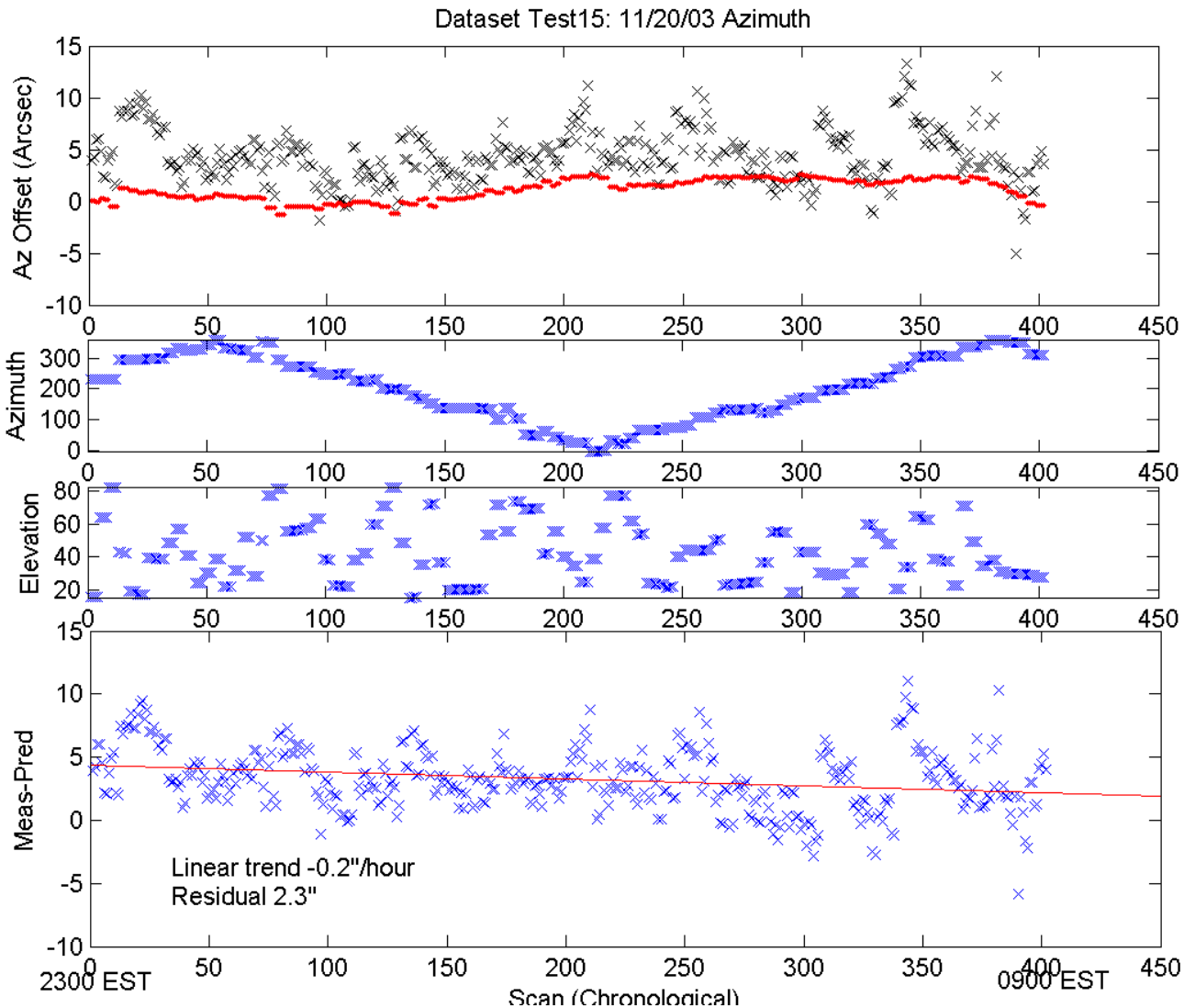
Azimuth Model Estimation



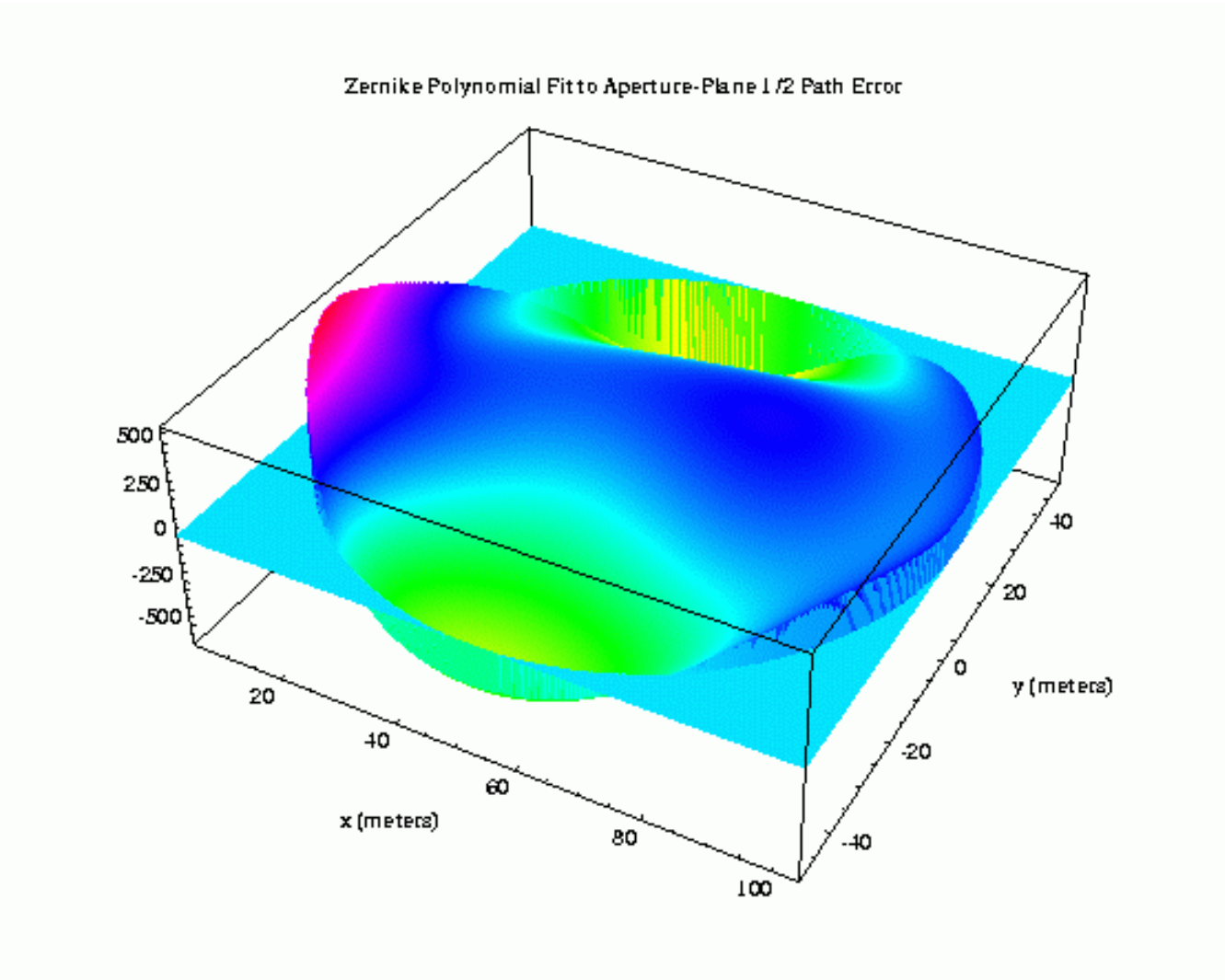
Azimuth Model Test



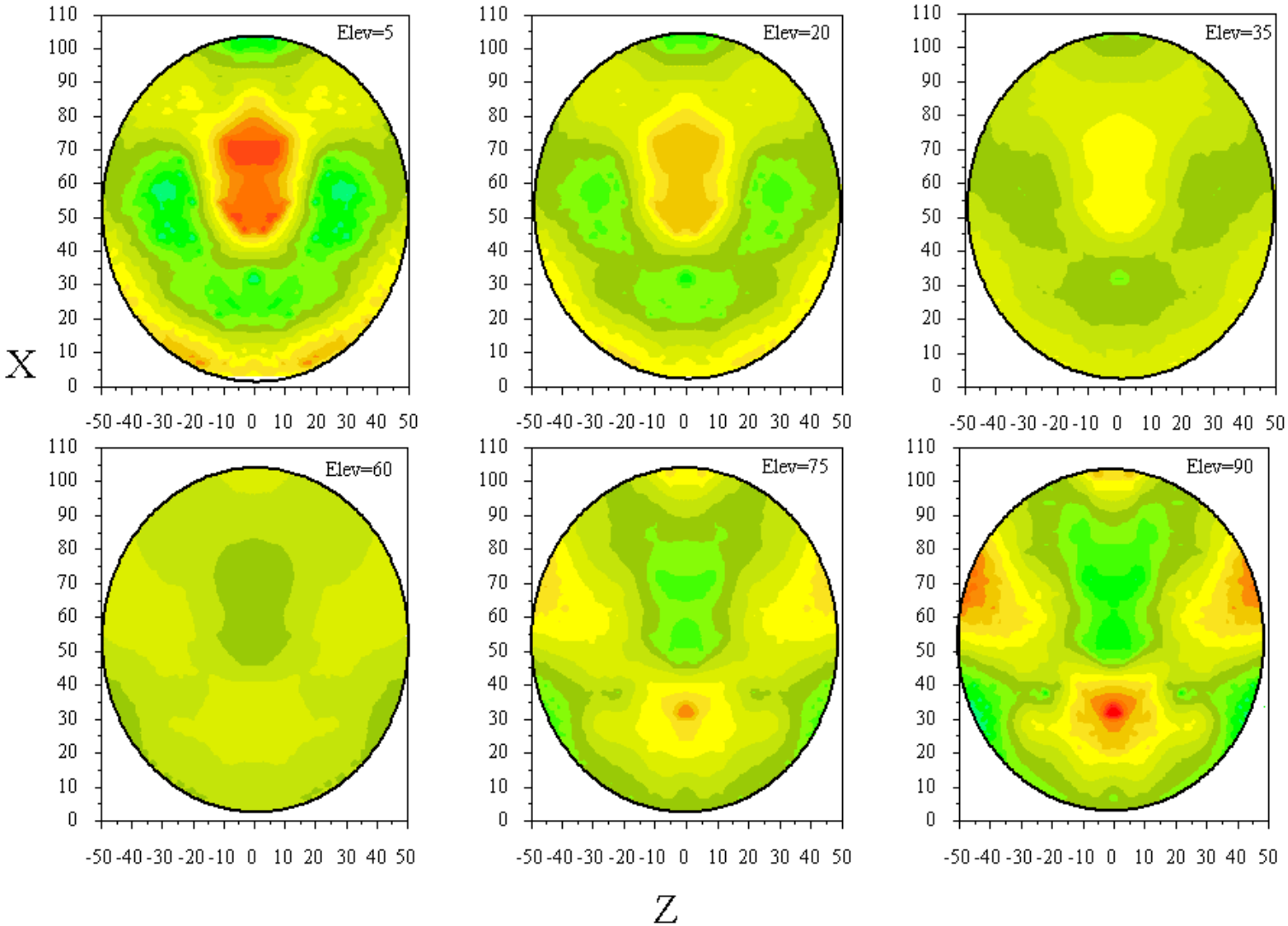
Azimuth Model Test



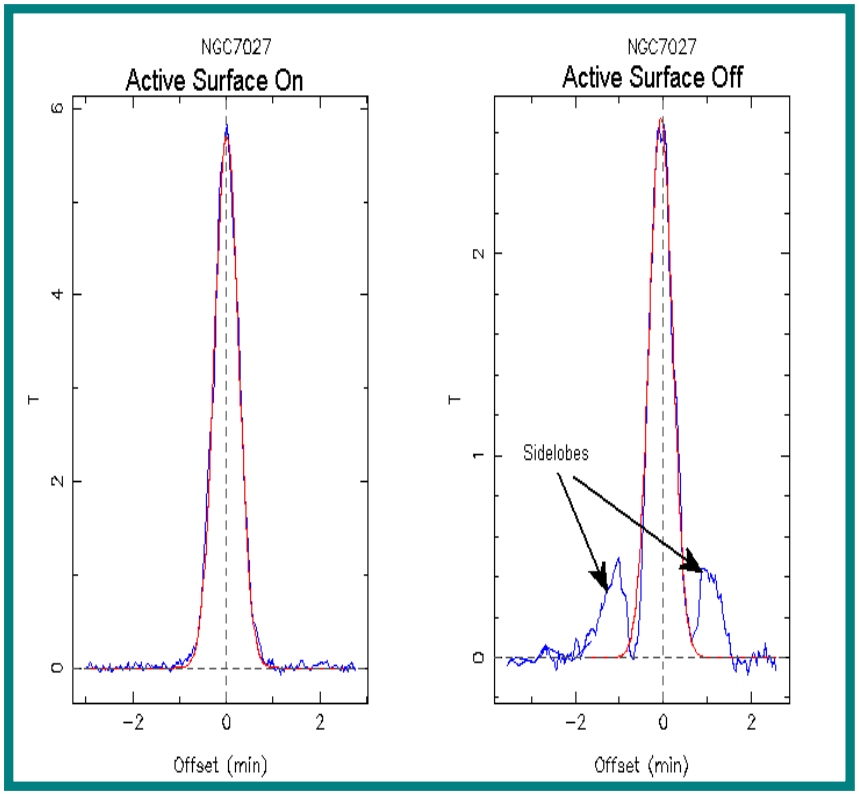
Holography Results

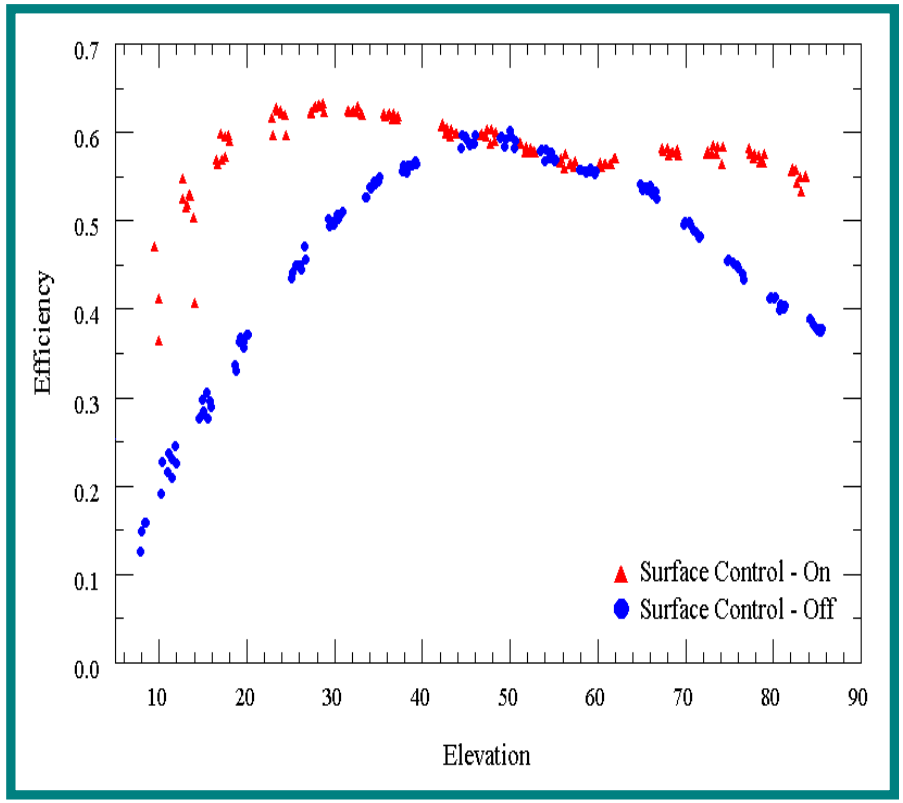


Finite Element Model Predictions



Efficiency and Beam Shape





Requirements for high-frequency observing

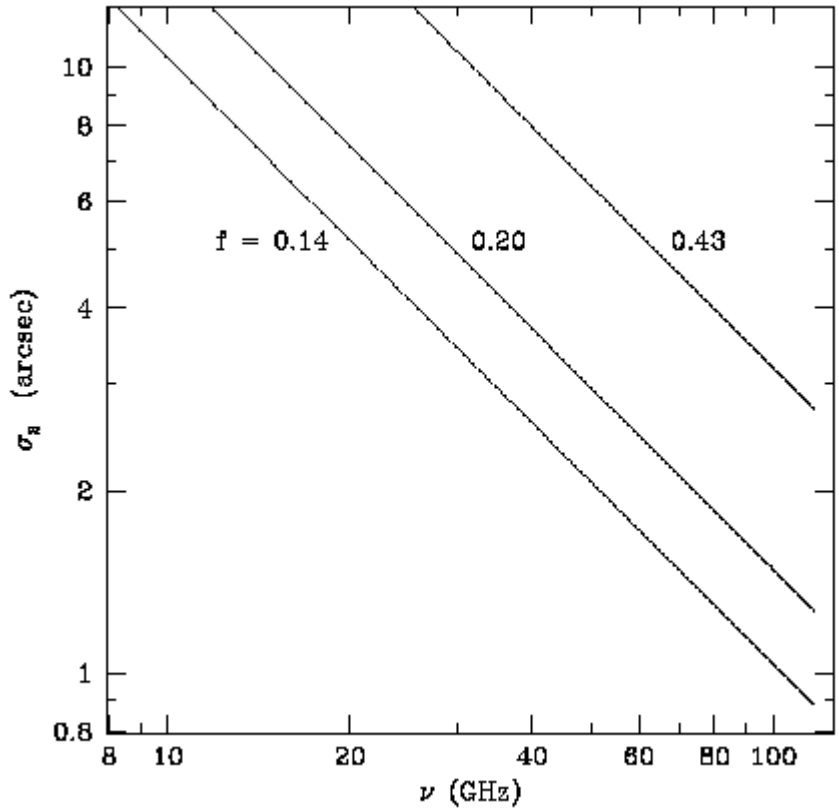


Fig. 7.— The rms pointing errors σ_2 needed for accurate tracking ($f = 0.14$), adequate tracking ($f = 0.20$), and blind pointing ($f = 0.43$) with the GBT are shown as functions of frequency. Abscissa: Frequency (GHz) Ordinate: RMS pointing error σ_2 (arcsec)

Requirements for high-frequency observing

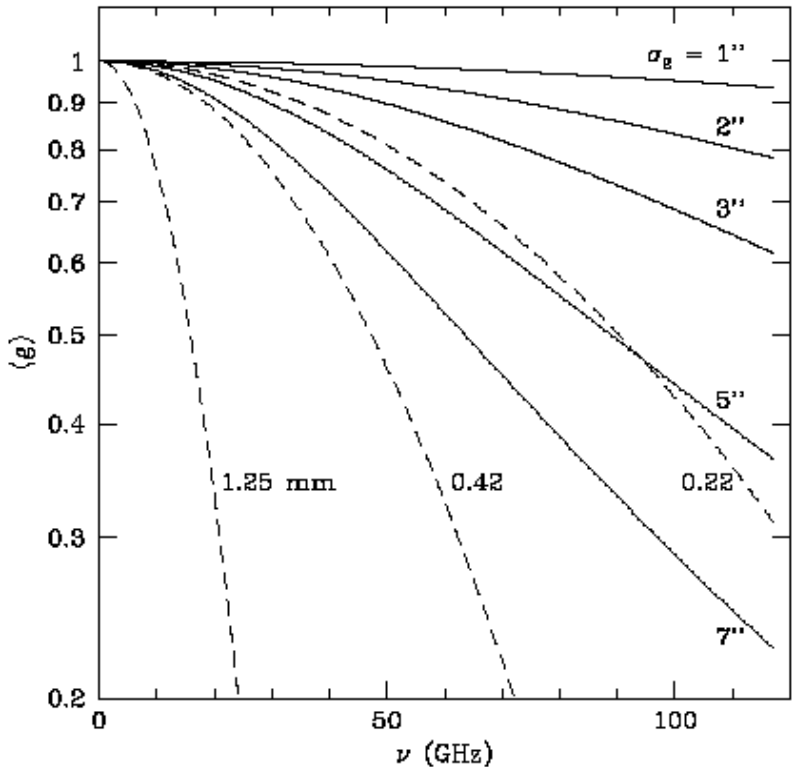


Fig. 6.— Tracking errors reduce the average on-source gain $\langle g \rangle$ of the GBT. The solid curves show $\langle g \rangle$ as a function of frequency for several values of the rms tracking error σ_2. For comparison, the dashed curves show the surface efficiency η as a function of frequency for several values of the rms surface error—1.25 mm, 0.42 mm and 0.22 mm correspond to the Phase I, II, and III expected errors (Hall et al. 1993). It appears that surface errors will have a much larger effect than pointing errors on the average on-source gain of the GBT. Abscissa: Frequency (GHz) Ordinates: Relative gain (dimensionless)

Pointing Accuracy, 6 m/s wind

Error Sources	El Errors (arcsec)		X-El Errors (arcsec)	
	Repeatable	Nonrepeatable	Repeatable	Nonrepeatable
Mechanical Alignments				
RF/El Axes Orthogonality	0.0		0.0	
El/Az Axes Orthogonality	0.0		35.3	
Az Axis Verticality	5.0		2.9	
Structural Deformations				
Reflector				
Wind		10.5		
Thermal Gradient				
Alidade				
Wind		1.5		
Thermal Gradient				
Servo and Drive		0.9		0.3
Miscellaneous				
El Bearing Wobble	1.0	0.4	0.6	0.2
Az Bearing Wobble	1.0	0.4	0.6	0.2
Encoder Accuracy		1.2		1.2
Encoder Coupling		1.8		1.7
Encoder Referencing	10.0		8.1	
RSS Subtotals	11.3	12.3	36.4	2.1

Architecture of current GBT Observing System

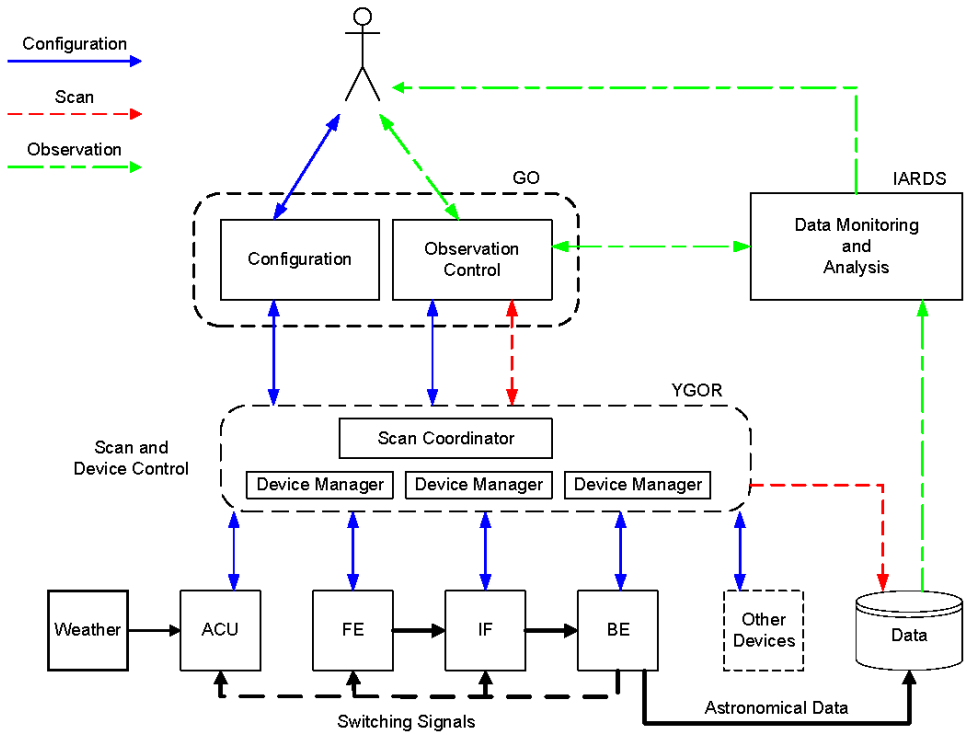


Figure 1: The GBT observing system

Architecture of HFOS

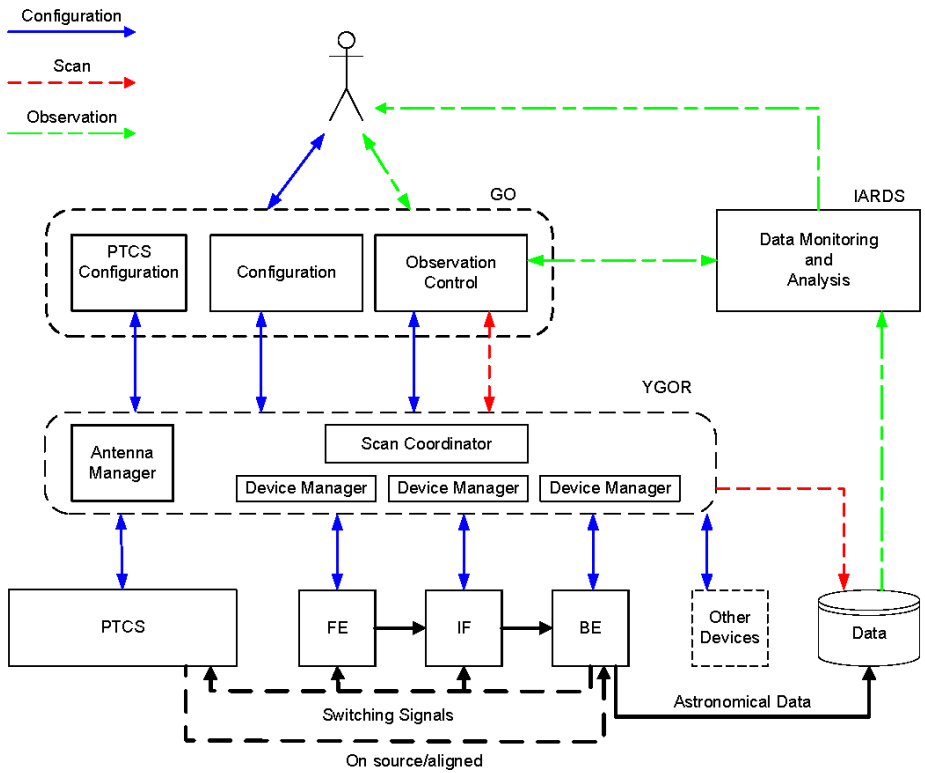
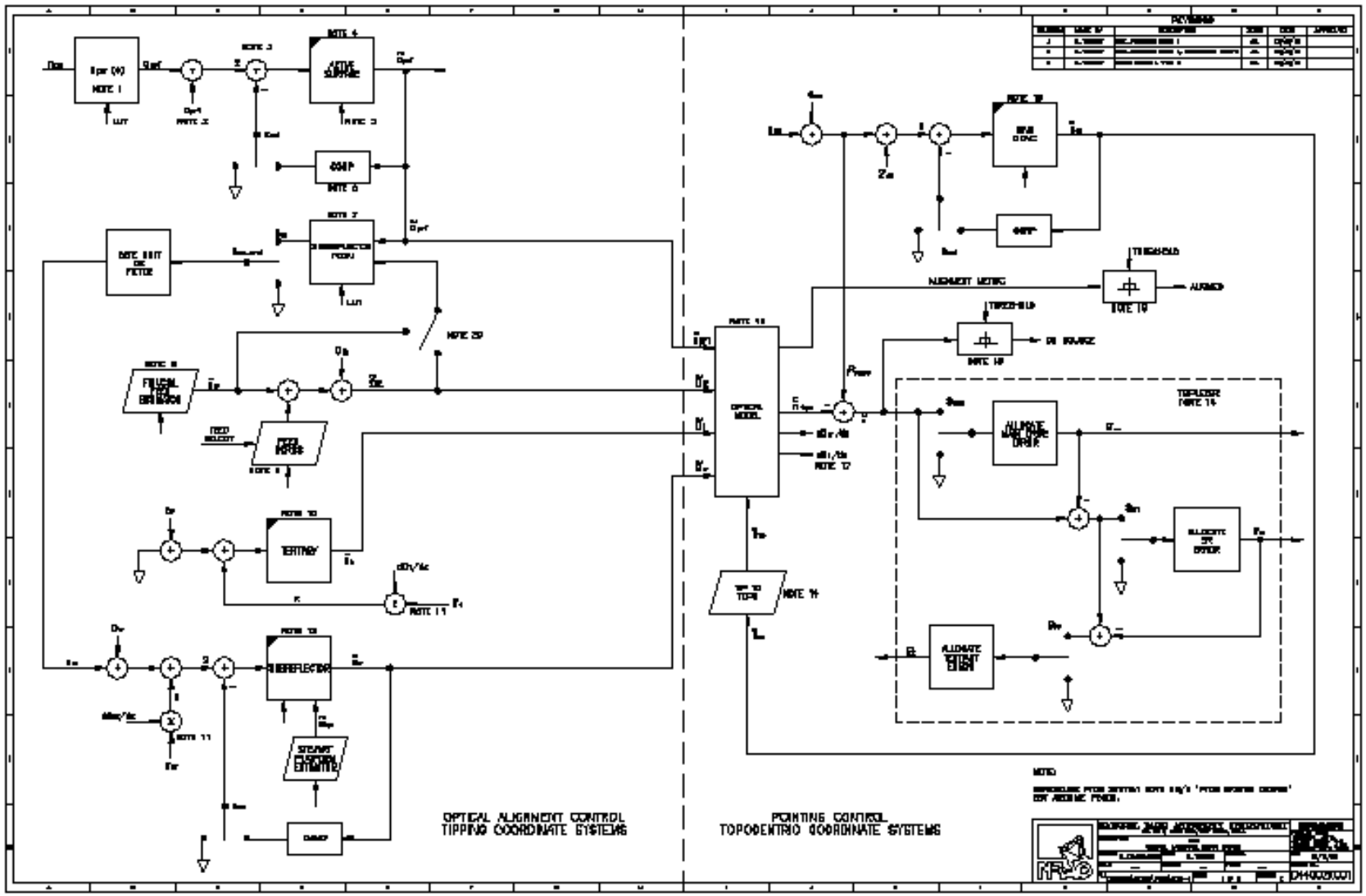


Figure 3: Upgraded Observing System

Architecture of PCS



Telescope Structure and Optics

- Optics: 110 m x 100 m of a 208 m parent paraboloid
  - Effective diameter: 100 m
  - Offaxis feedarm
- Elevation Limit: 5 degrees
- Slew Rates: Azimuth – 40deg/min; Elevation – 20deg/min
- Main Reflector: 2209 actuated panels with 68 μm rms.
  - Total surface: rms 400 μm
- FWHM Beamwidth: 740"/f(Ghz)
- Prime Focus: Retractable boom
- Gregorian Focus:
  - 8-m subreflector with 6-degrees of freedom
  - Rotating Turret with 8 receiver bays