The Measurements and Calibrations for Large Radio Telescope
(Tian ma 65m & SKA-P 15m)

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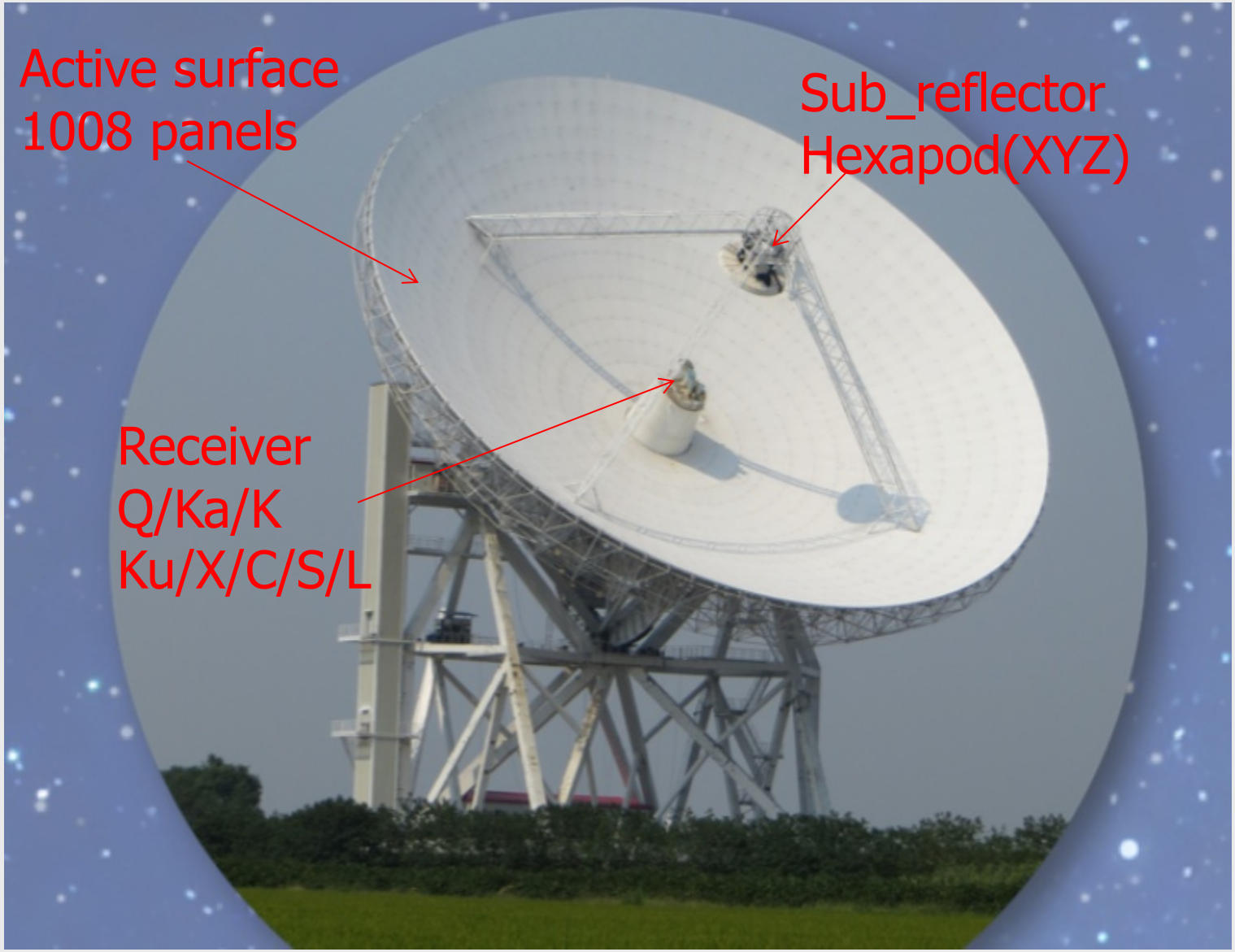
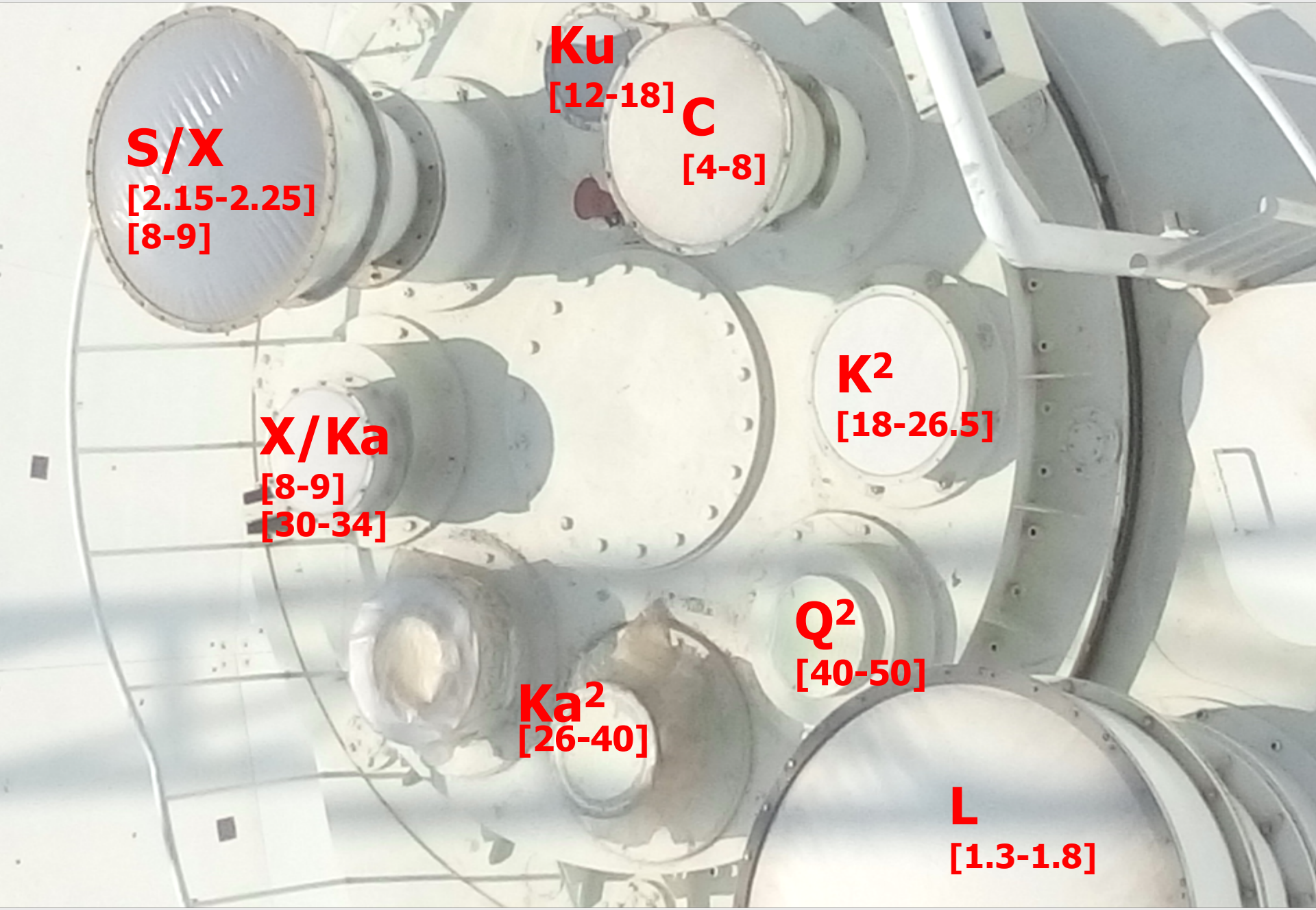
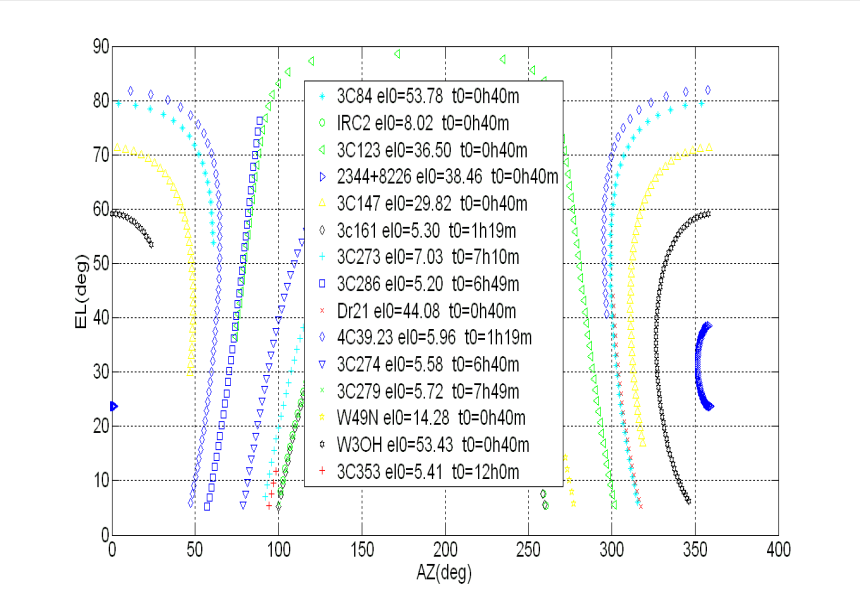
Shanghai SKA Meeting 2019

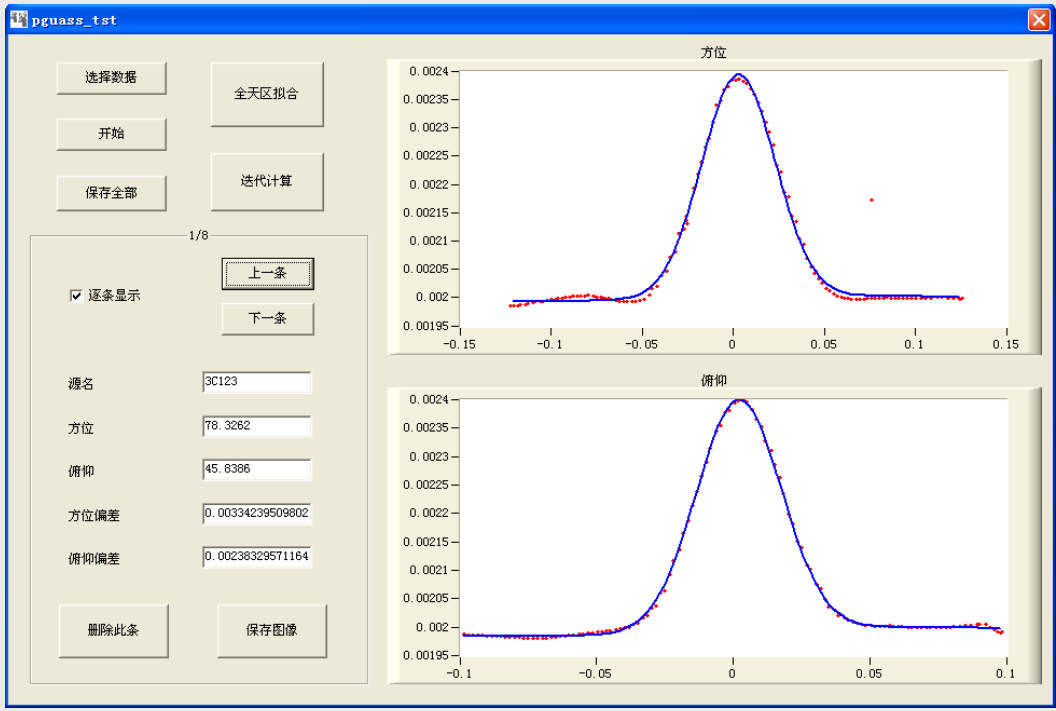
- Pointing model & seperation
- Sub_reflector model by amplitude method
- Antenna performance measurement
- Surface measurement by holography

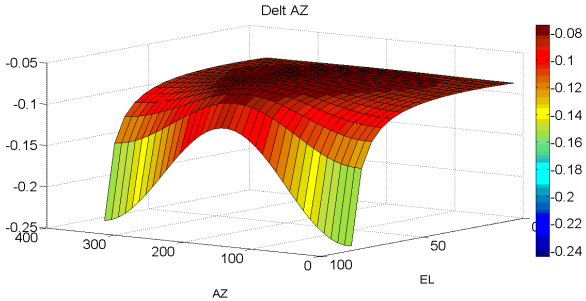

Active surface
1008 panels
Sub_reflector
Hexapod(XYZ)
Receiver
Q/Ka/K
Ku/X/C/S/L

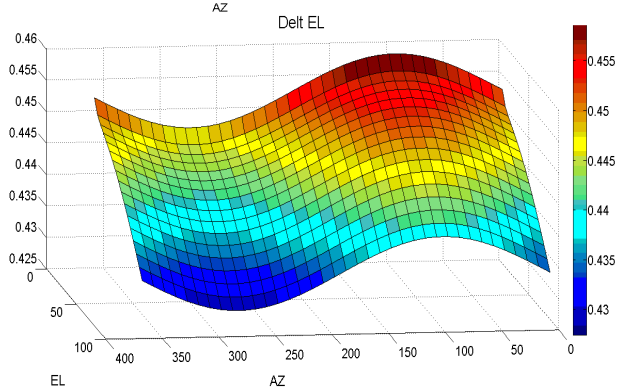

Ku
[12-18]
C
[4-8]
S/X
[2.15-2.25]
[8-9]
K2
[18-26.5]
X/Ka
[8-9]
[30-34]
Q2
[40-50]
Ka2
[26-40]
L
[1.3-1.8]

Pointing Model Measurement



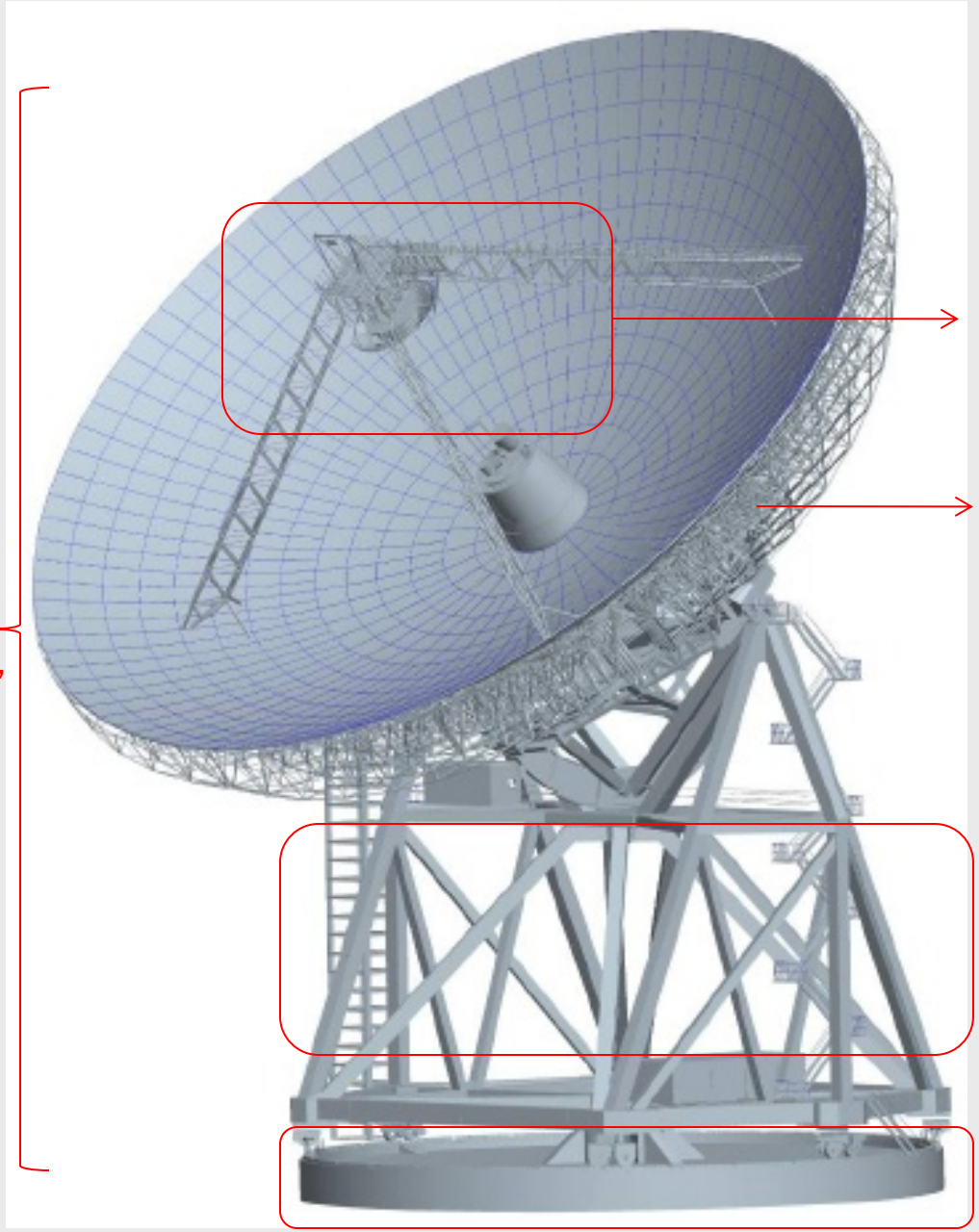






Delt_AZ= C1+ tan(E0)*cos(A0)*C3 + tan(E0)*sin(A0)*C4 + tan(E0)*C5-1/cos(E0)*C6

Delt_EL= C2- sin(A0)*C3+ cos(A0)*C4+ cos(E0)*C7+ C8/tan(E0)



Sub-reflector:
PSD+temperature sensor

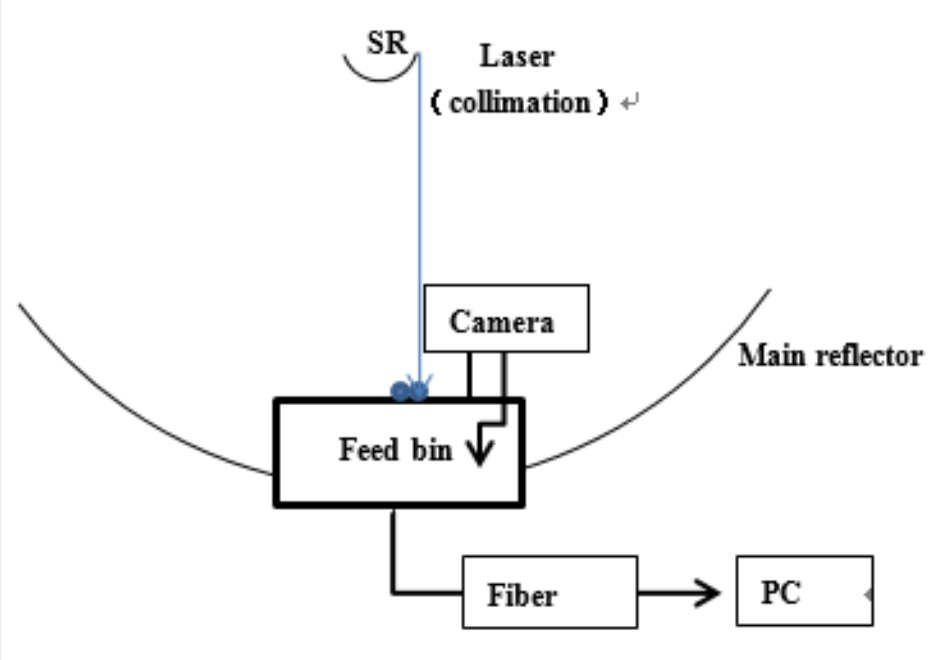
Backup structure:
Gravity model+
temperature sensor

Half-power
tracking,
Cross scan,
Five point

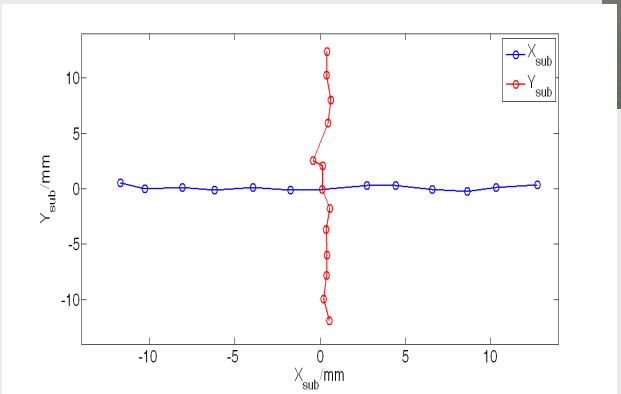
Frame:
Tiltermeter +
temperature sensor

Track:
tiltermeter

Pointing error caused by sub-reflector

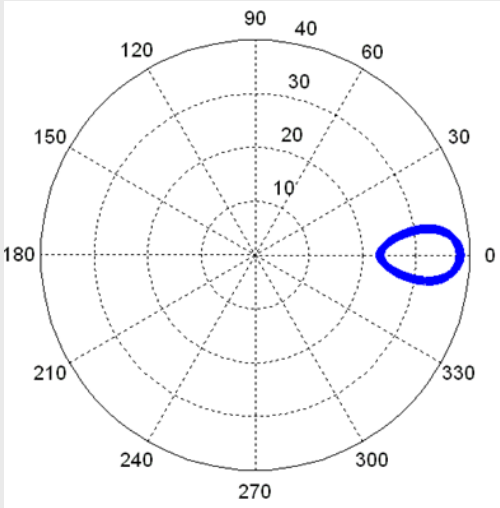


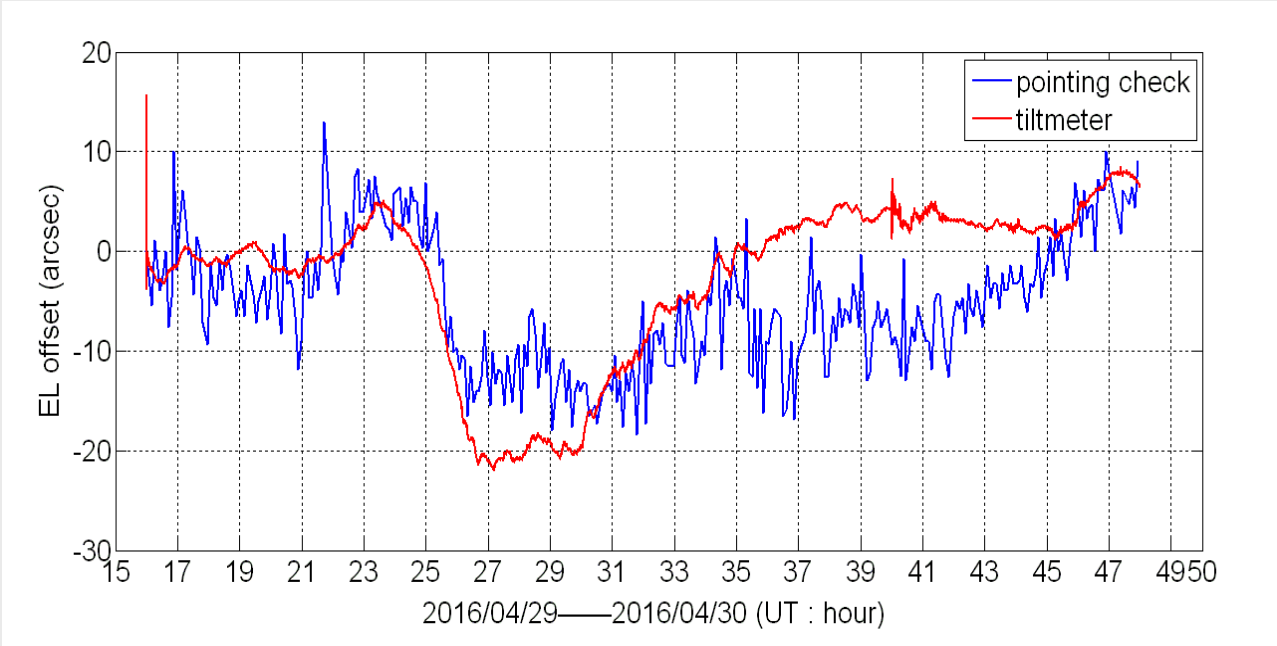
$$\begin{pmatrix} X_{sub} \\ Y_{sub} \end{pmatrix} = \begin{pmatrix} \alpha & 1 \\ 1 & \beta \end{pmatrix} \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} 1 & k \\ 0 & 1 \end{pmatrix} \begin{pmatrix} X_{PSD} \\ Y_{PSD} \end{pmatrix} - \begin{pmatrix} X_{offset} \\ Y_{offset} \end{pmatrix}$$

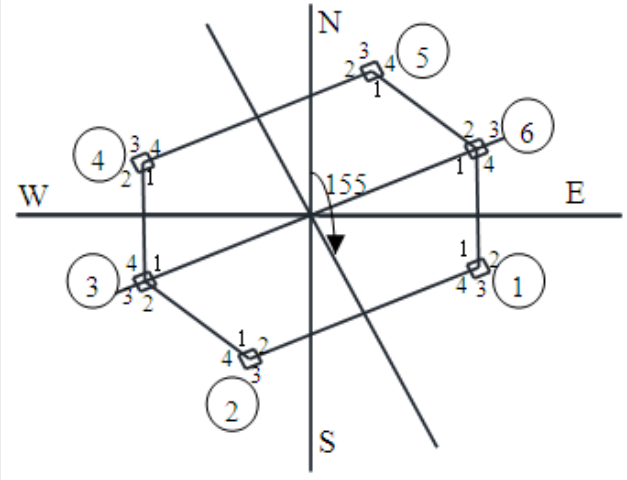


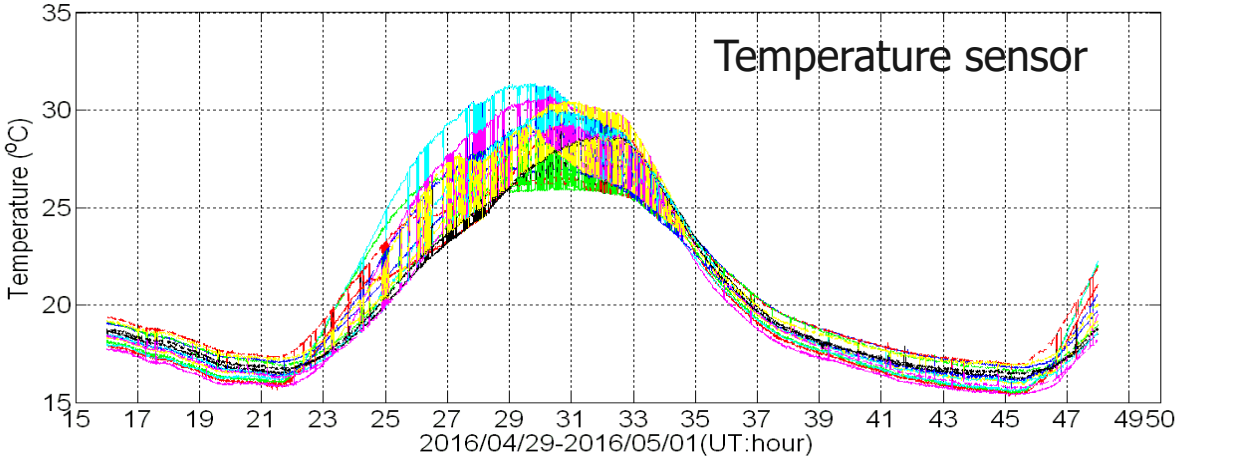
Pointing error caused by frame temperature

Source: 2344+8226



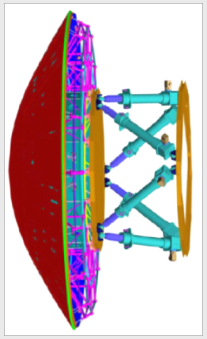


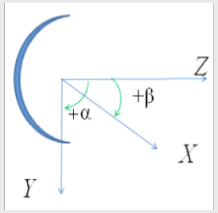


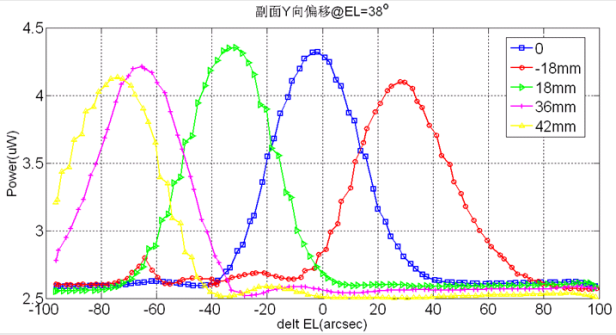


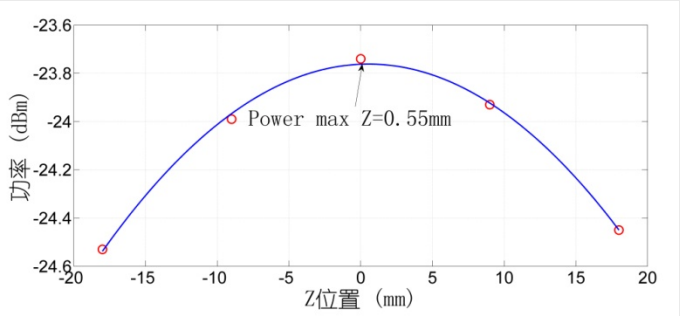
Sub_reflector Model

- Amplitude sweep(active sub-reflector)
- Aperture phase(holography)

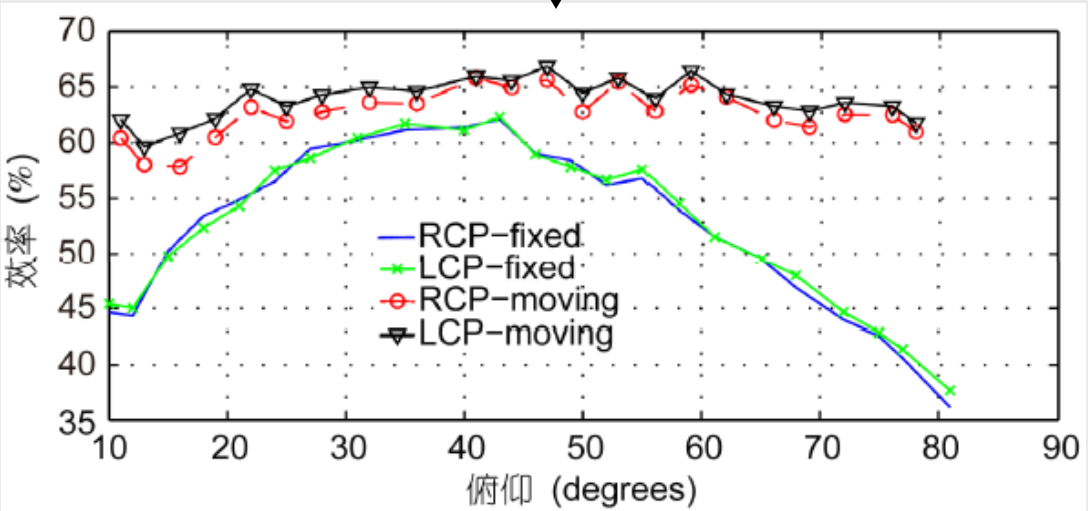








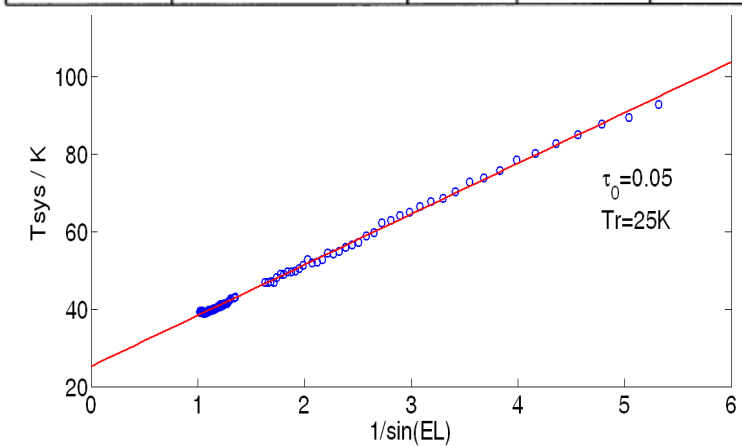
X 方向位移(mm)	$dX=A+B*\cos(\omega_x*el)+C*\sin(\omega_x*el)$	$\omega_x=3.797$
Y 方向位移（mm）	$dY=D+E*\cos(\omega_y*el)+F*\sin(\omega_y*el)$	$\omega_y=3.032$
Z 方向位移（mm）	$dZ=G+H\sin(el)$	

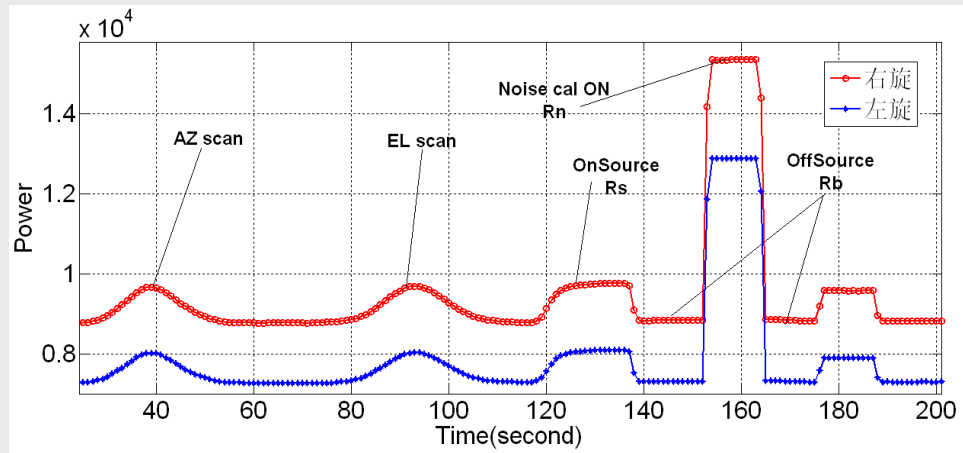


Antenna performance measurement
Method: calibrated radio source + noise diode

$$\log S\,[\mathrm{Jy}] = a + b * \log \nu\,[\mathrm{MHz}] + c * \log^2 \nu\,[\mathrm{MHz}]$$

source	range [MHz] from	to	a	b	c
3C48	1408	23780	2.465	−0.004	−0.1251
3C123	1408	23780	2.525	+0.246	−0.1638
3C147	1408	23780	2.806	-0.140	−0.1031
3C161	1408	10550	1.250	+0.726	−0.2286
3C218	1408	10550	4.729	−1.025	+0.0130
3C227	1408	4750	6.757	−2.801	+0.2969
3C249.1	1408	4750	2.537	−0.565	−0.0404
VirA	1408	10550	4.484	−0.603	−0.0280
3C286	1408	43200	0.956	+0.584	−0.1644
3C295	1408	32000	1.490	+0.756	−0.2545
3C309.1	1408	32000	2.617	−0.437	−0.0373
3C348	1408	10550	3.852	−0.361	−0.1053
3C353	1408	10550	3.148	−0.157	−0.0911
CygA	4750	10550	8.360	−1.565	—
NGC7027	10550	43200	1.322	−0.134	—





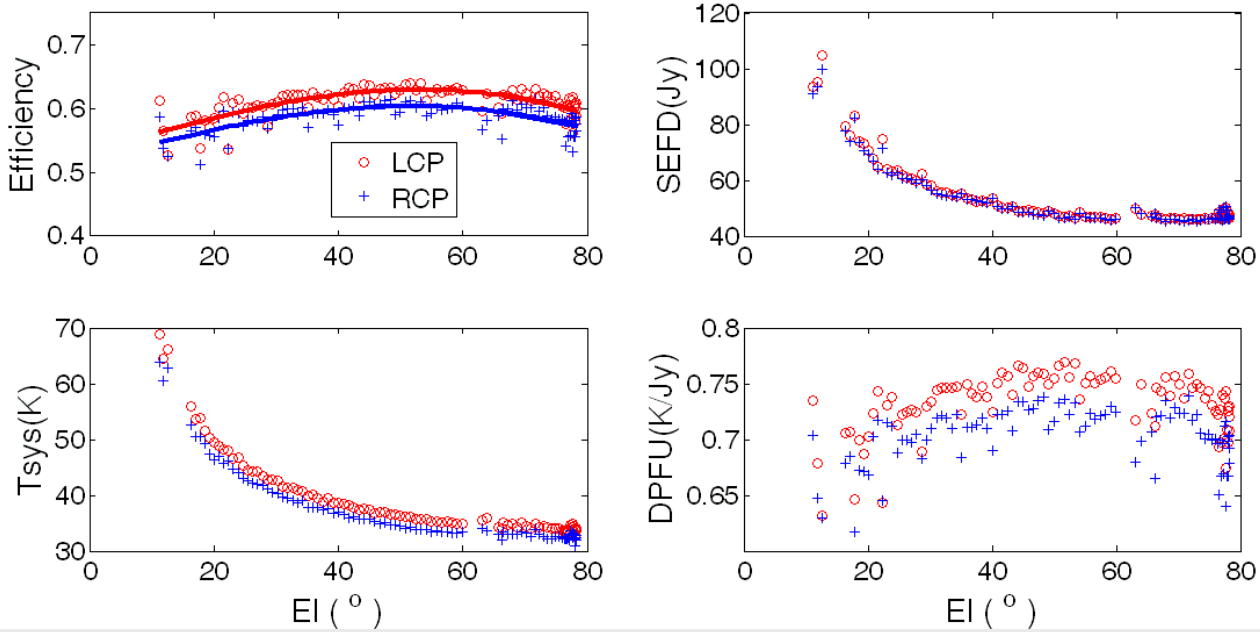
$$\eta(\varphi) = \frac{2kT_{as}(\varphi)K_1K_2K_3K_4K_5}{SA_g}$$

$$K_1 = \exp(\tau_0/\sin El)$$

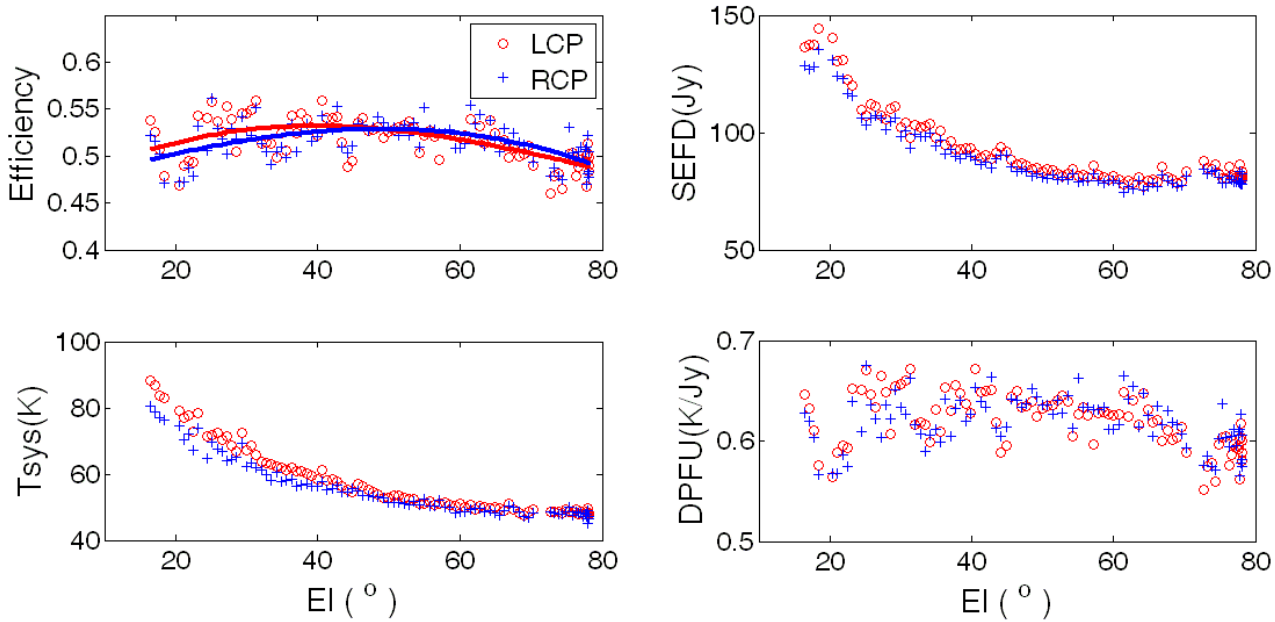
$$T_{as} = \frac{(R_S - R_b)}{R_N - R_b}T_{cal}$$

$$T_{sys} = \frac{R_b - R_0}{R_N - R_b}T_{cal}$$

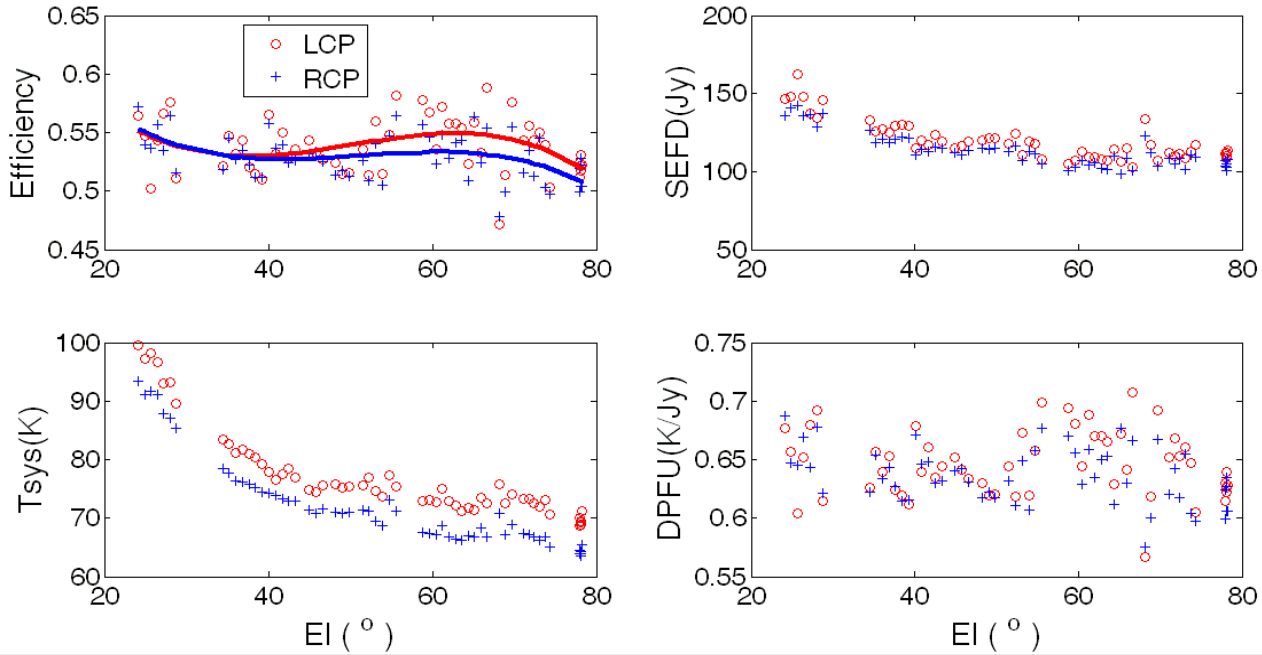
Ku band（15.6GHz）



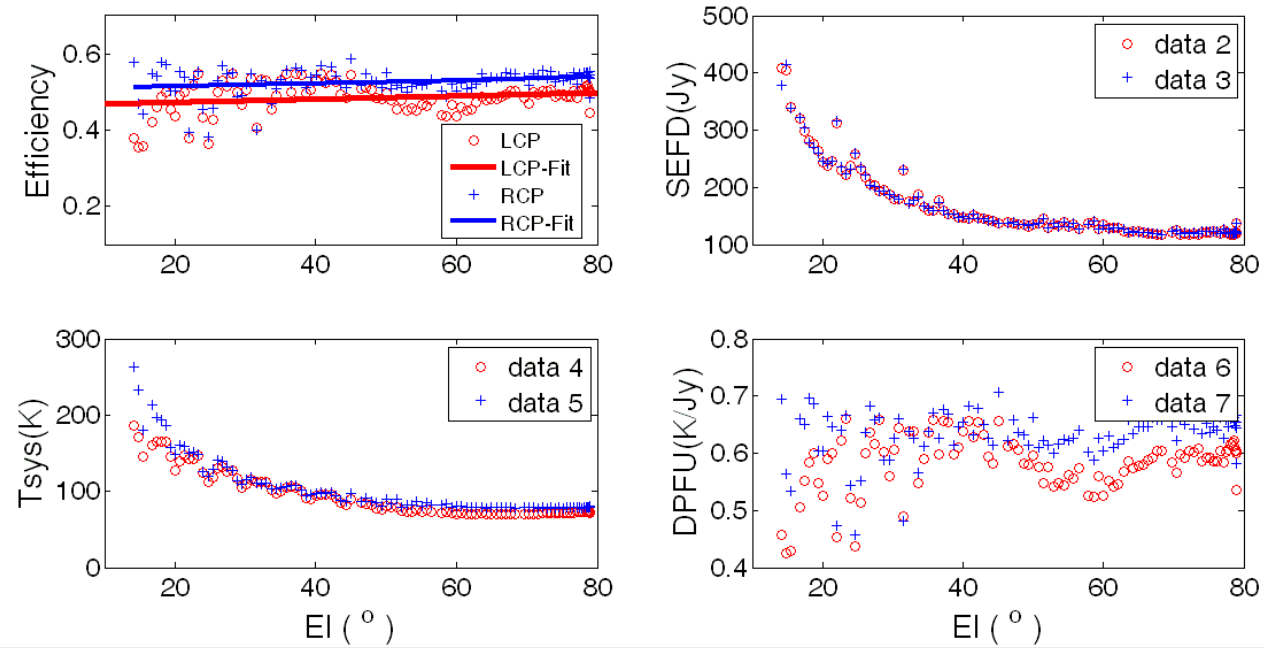
K band（22GHz）



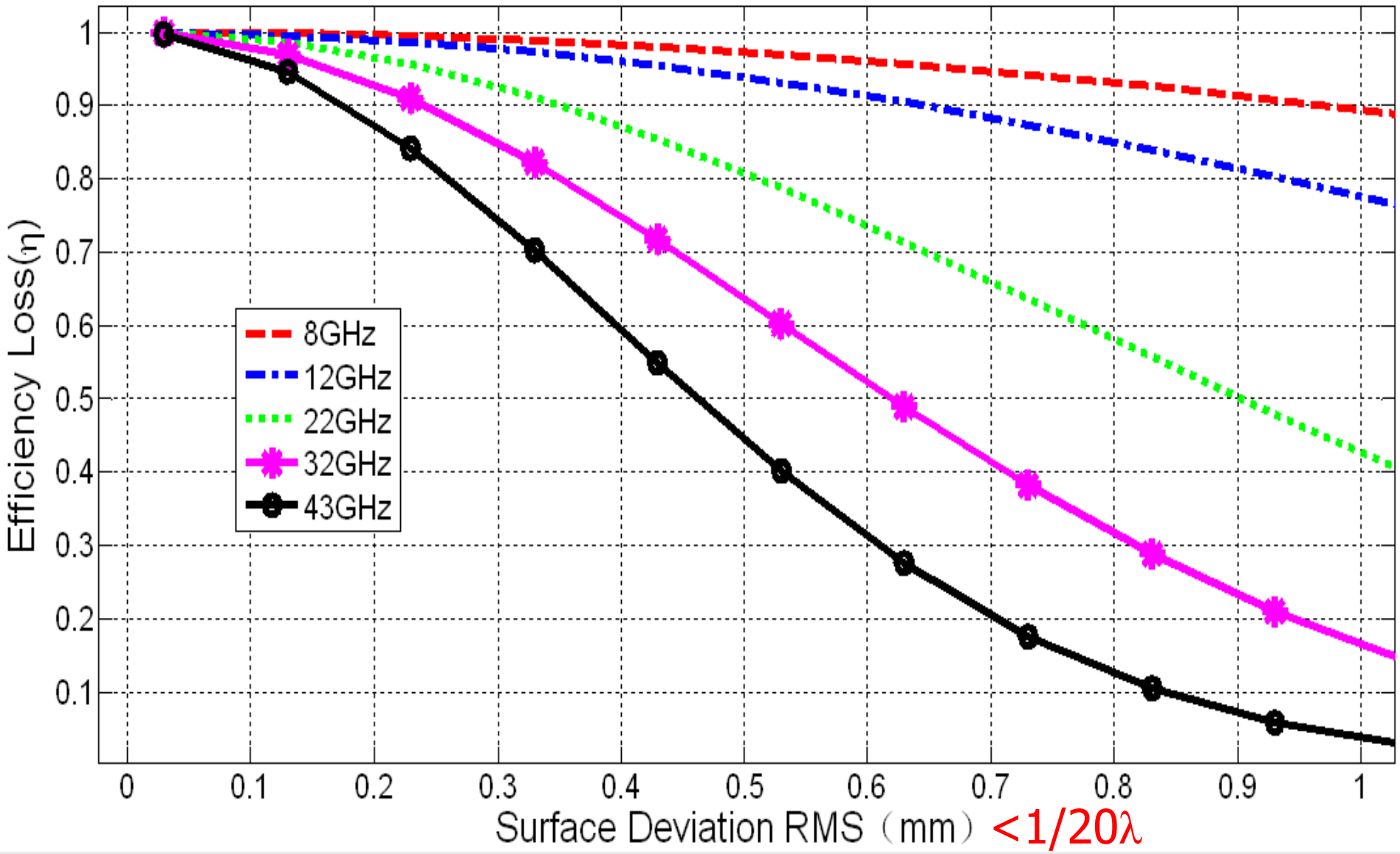
Ka band（31.1GHz）

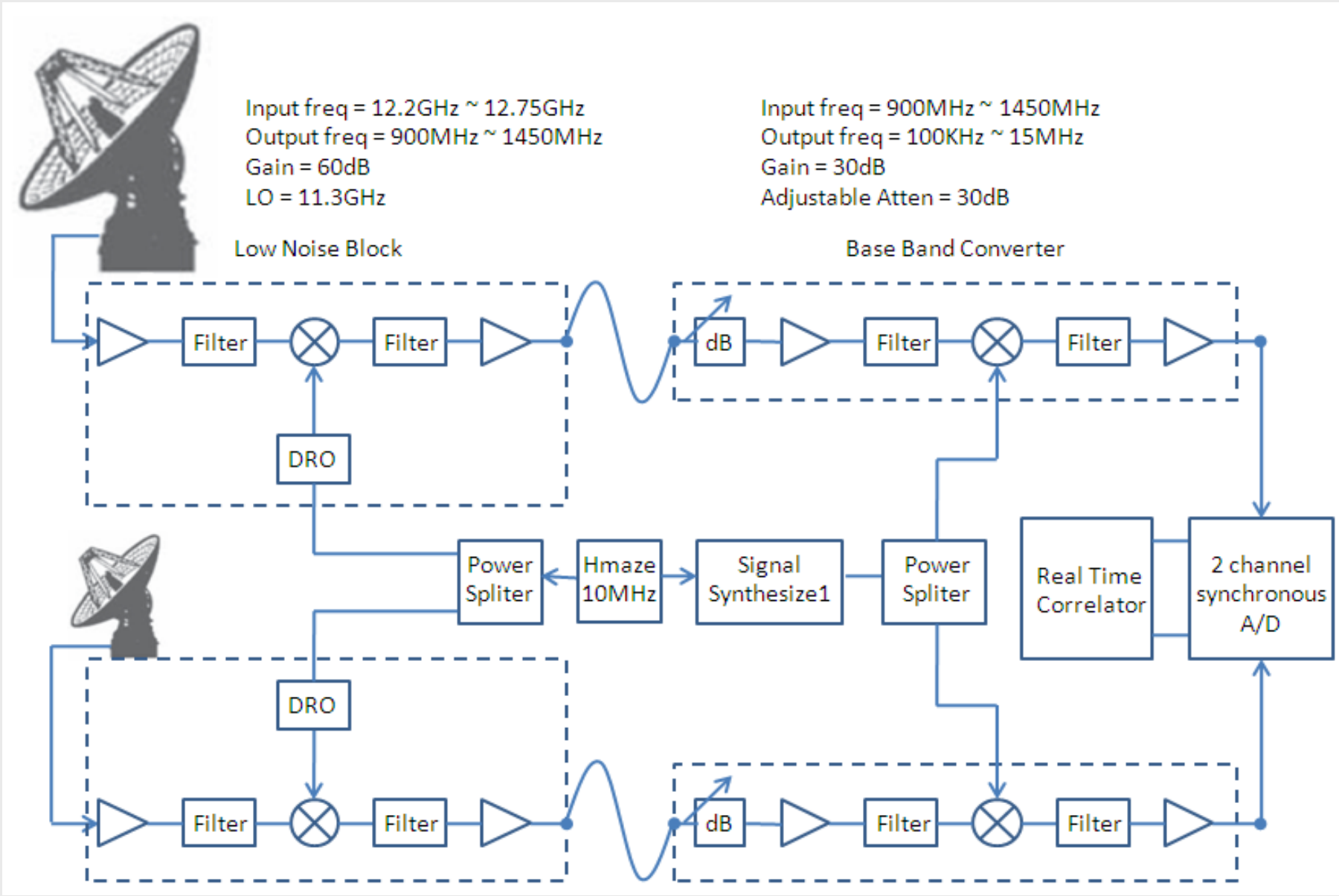


Q band（43GHz）



Microwave holography for surface accuracy measurement

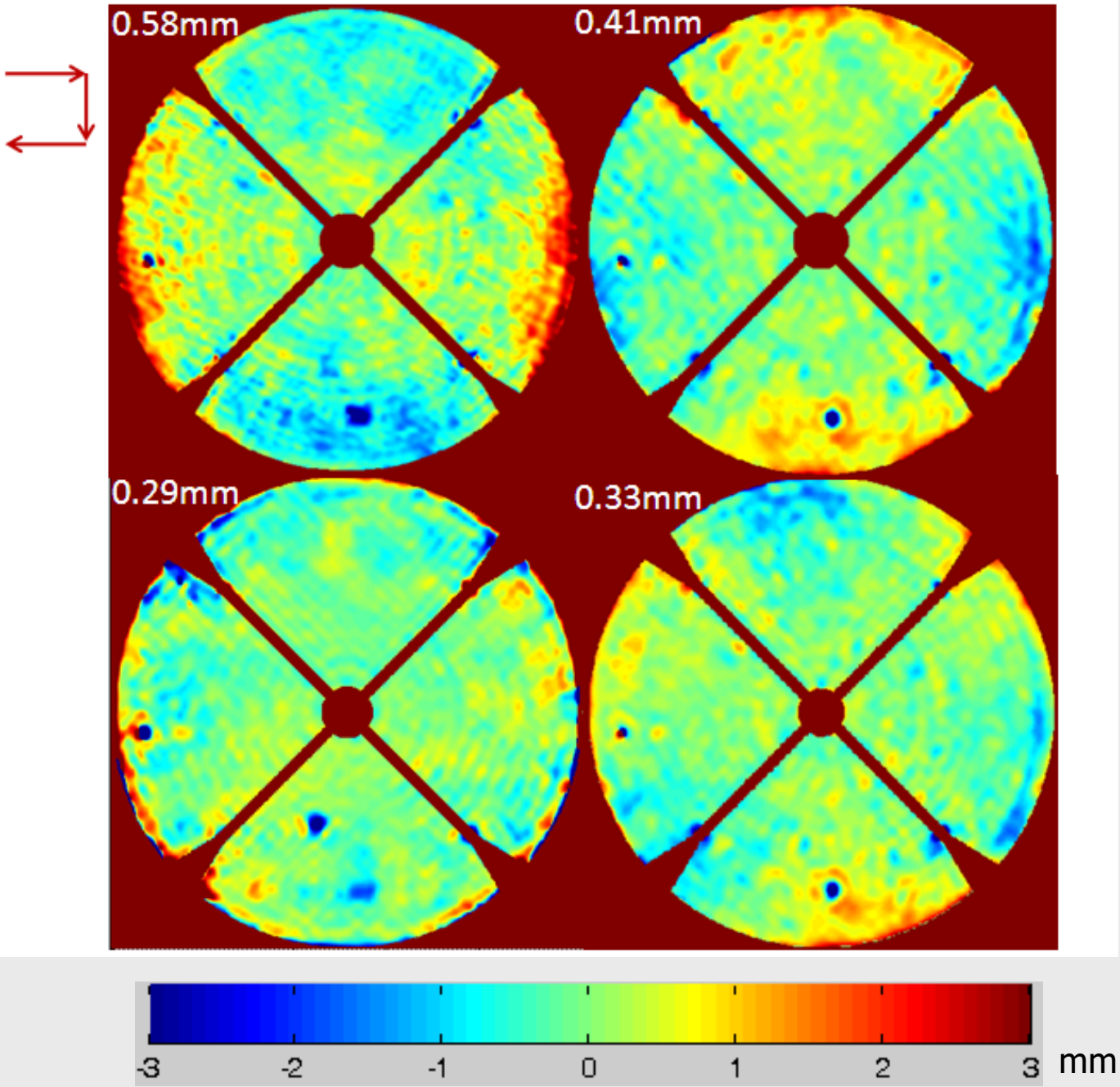


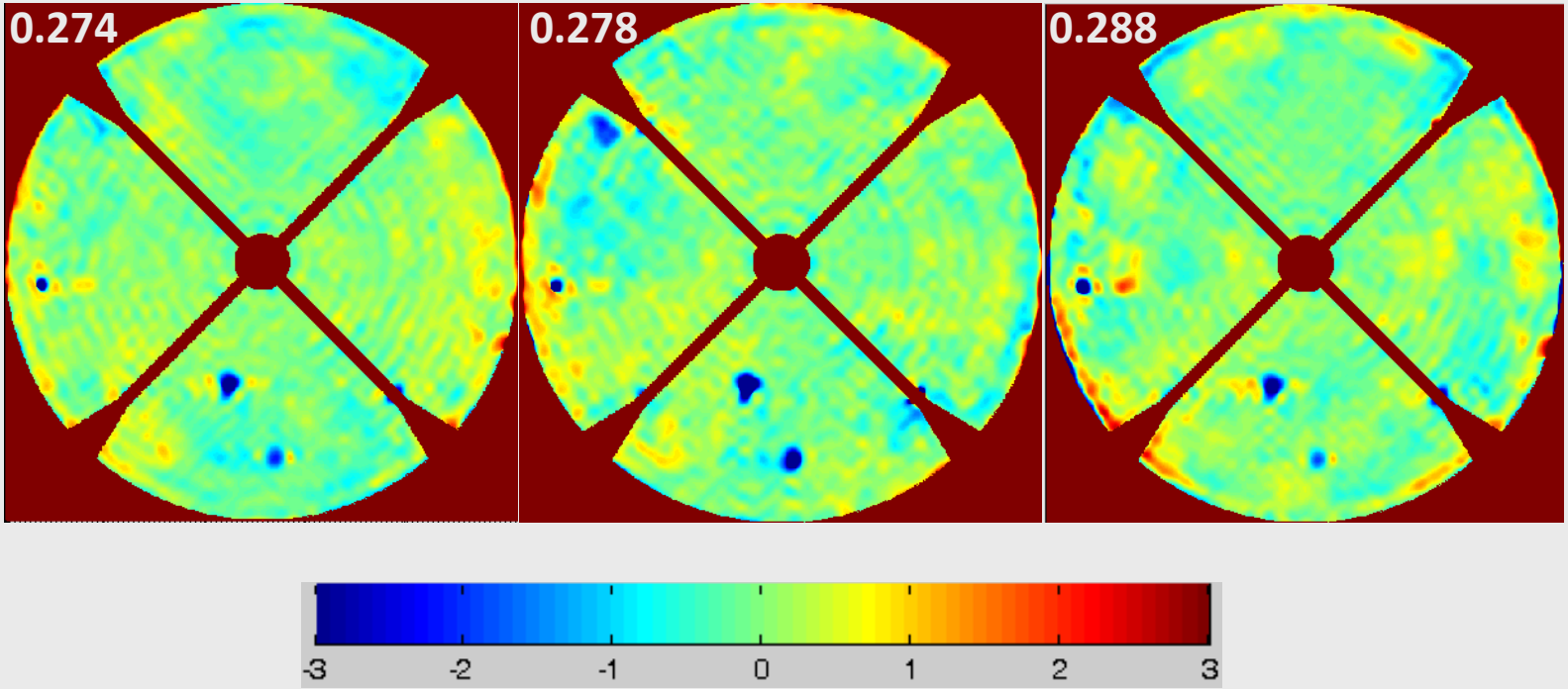

Input freq = 12.2GHz ~ 12.75GHz
Output freq = 900MHz ~ 1450MHz
Gain = 60dB
LO = 11.3GHz
Low Noise Block
Input freq = 900MHz ~ 1450MHz
Output freq = 100KHz ~ 15MHz
Gain = 30dB
Adjustable Atten = 30dB
Base Band Converter
Filter
Filter
DRO
dB
Filter
Filter
Power Spliter
Hmaze 10MHz
Signal Synthesize1
Power Spliter
Real Time Correlator
2 channel synchronous A/D
DRO
Filter
Filter
dB
Filter
Filter


65m Ku LNB


Reference
antenna

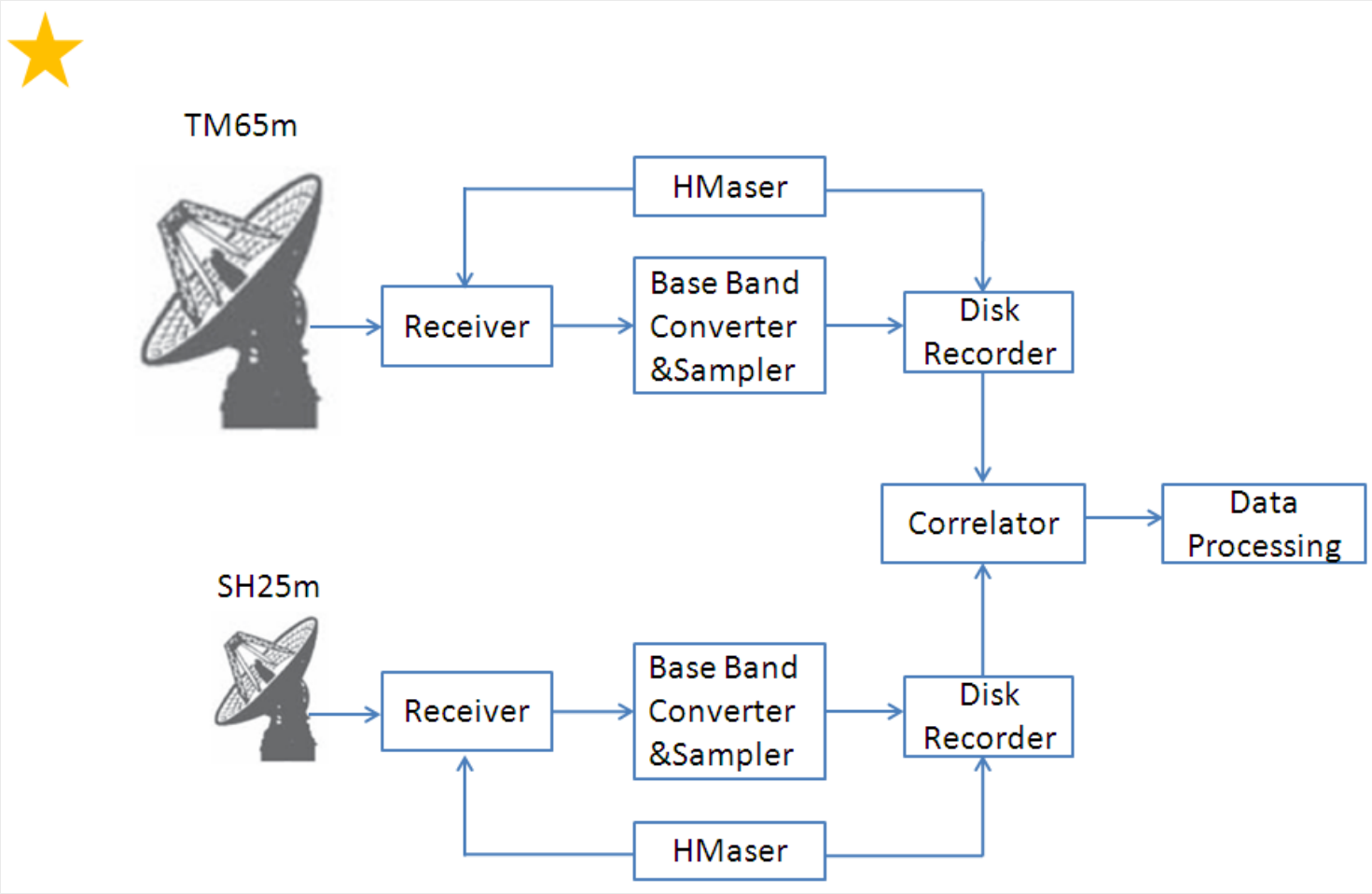

双通道基带变换器
Base Band
Converter
上海天文台
Real- time
correlator
SUPERMICRO
100MHz-distributor
100MHZ分配单元
中国科学院上海天文台


0.58mm
0.41mm
0.29mm
0.33mm
-3
-2
-1
0
1
2
3
mm



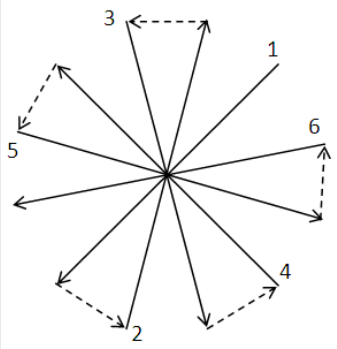
D(m)	65	63	60	58	56
RMS(mm)	0.274	0.267	0.257	0.251	0.243
	0.278	0.270	0.263	0.260	0.255
	0.288	0.281	0.273	0.263	0.256

Main Surface Gravity Model Measurment by Short Baseline(~6km) VLBI

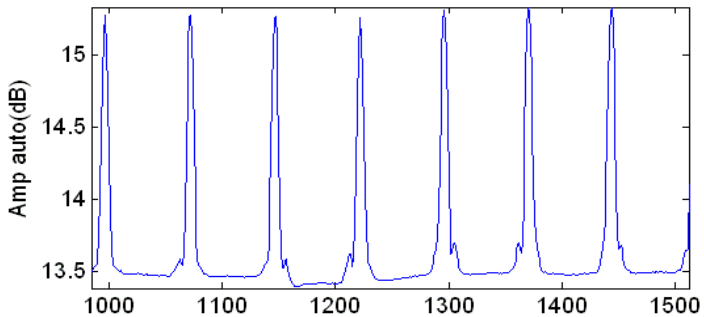


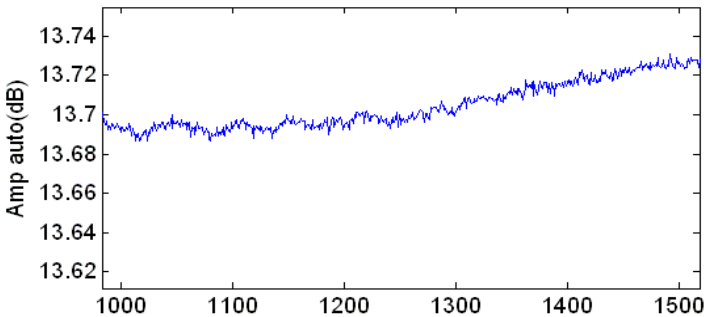
Radial sweep and correlation

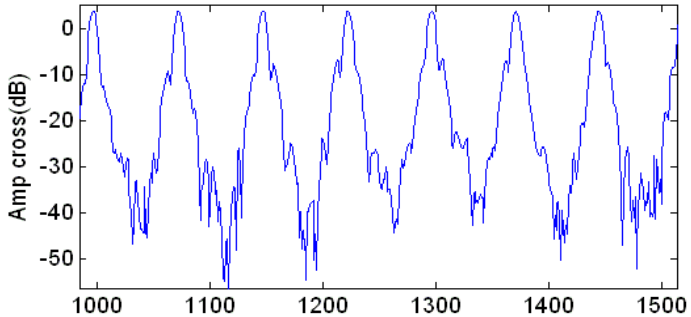
Radial sweep

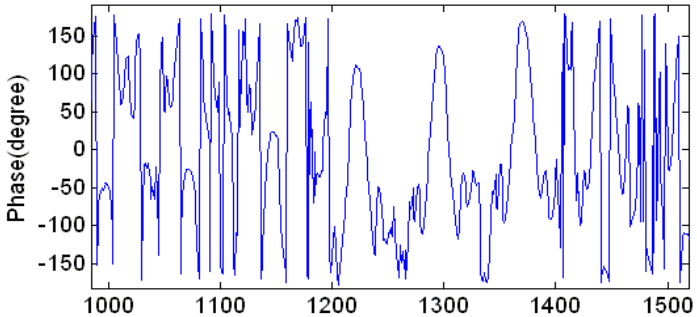


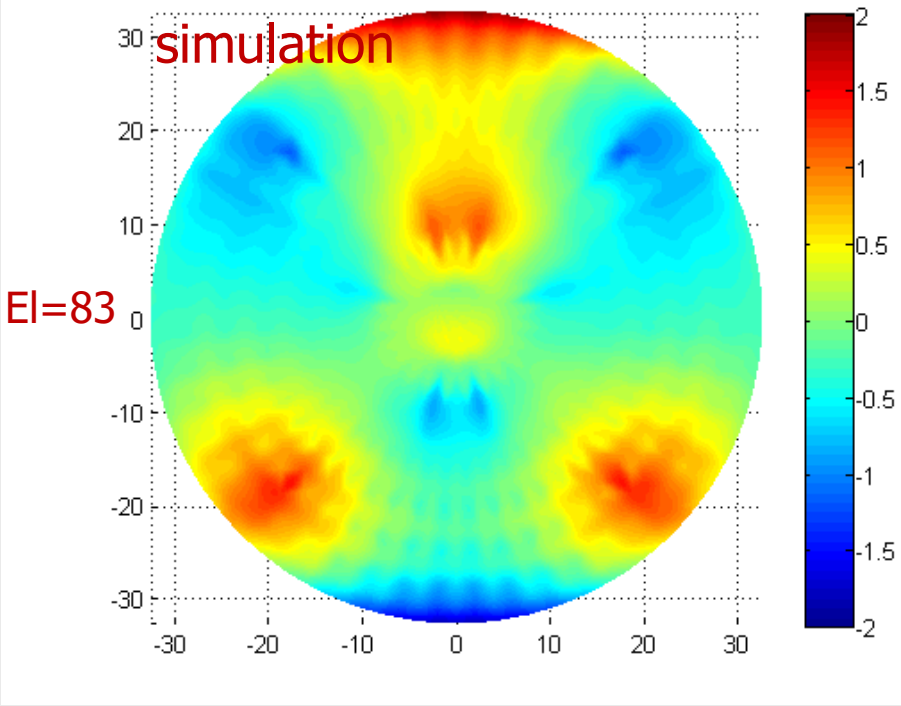
One pattern:~20minutes
Resolusion:~3m
Meaure error:~0.17mm
Radio source:3C84
Integeration time:1second
Freq&Bandwidth:8.4GHz&16MHz

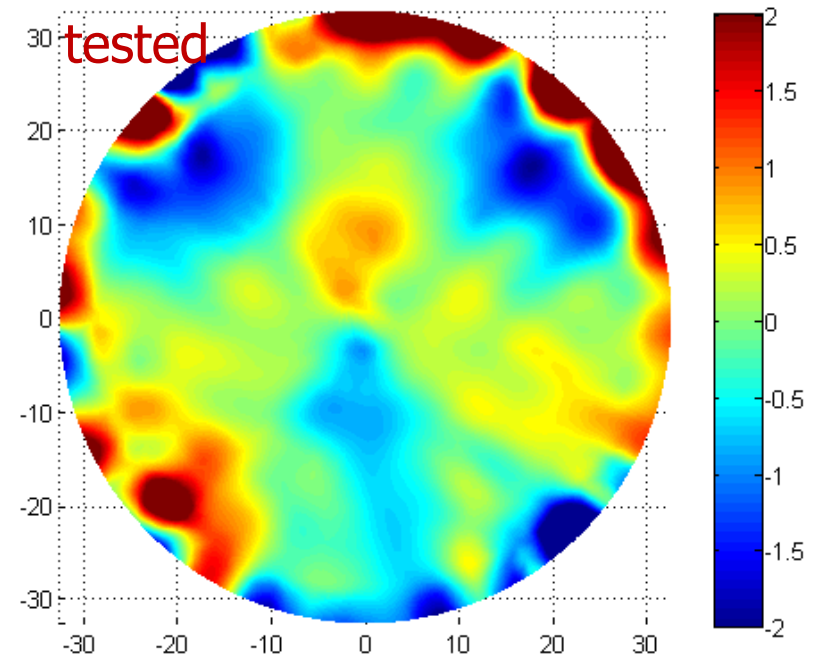


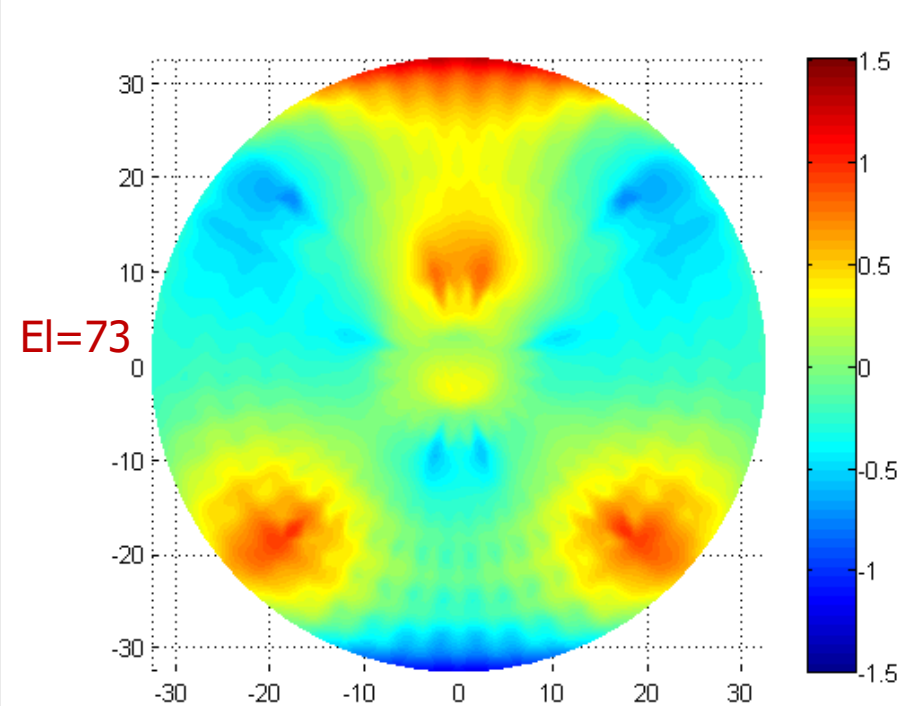


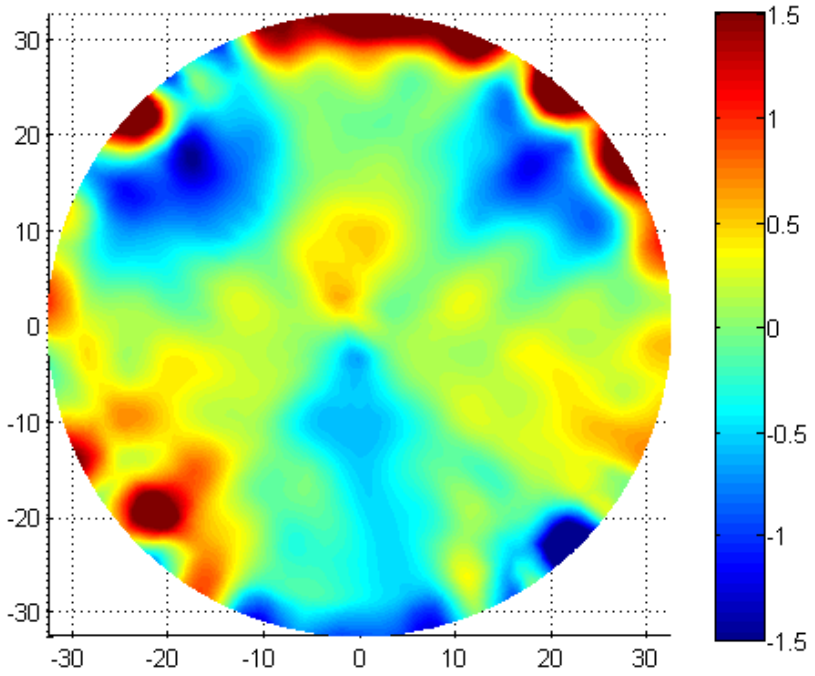


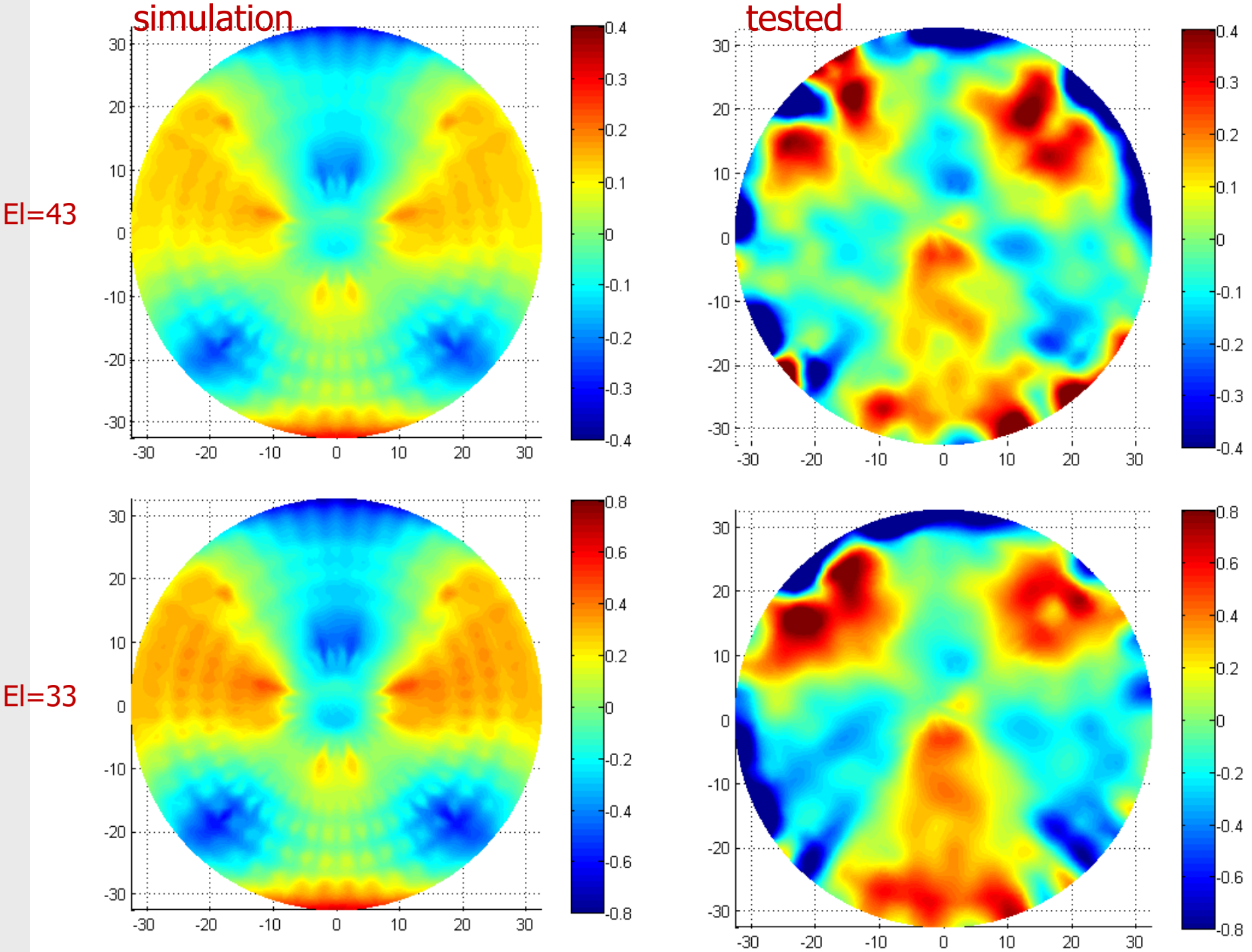



simulation
El=83
30
20
10
0
-10
-20
-30
-30 -20 -10 0 10 20 30
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2

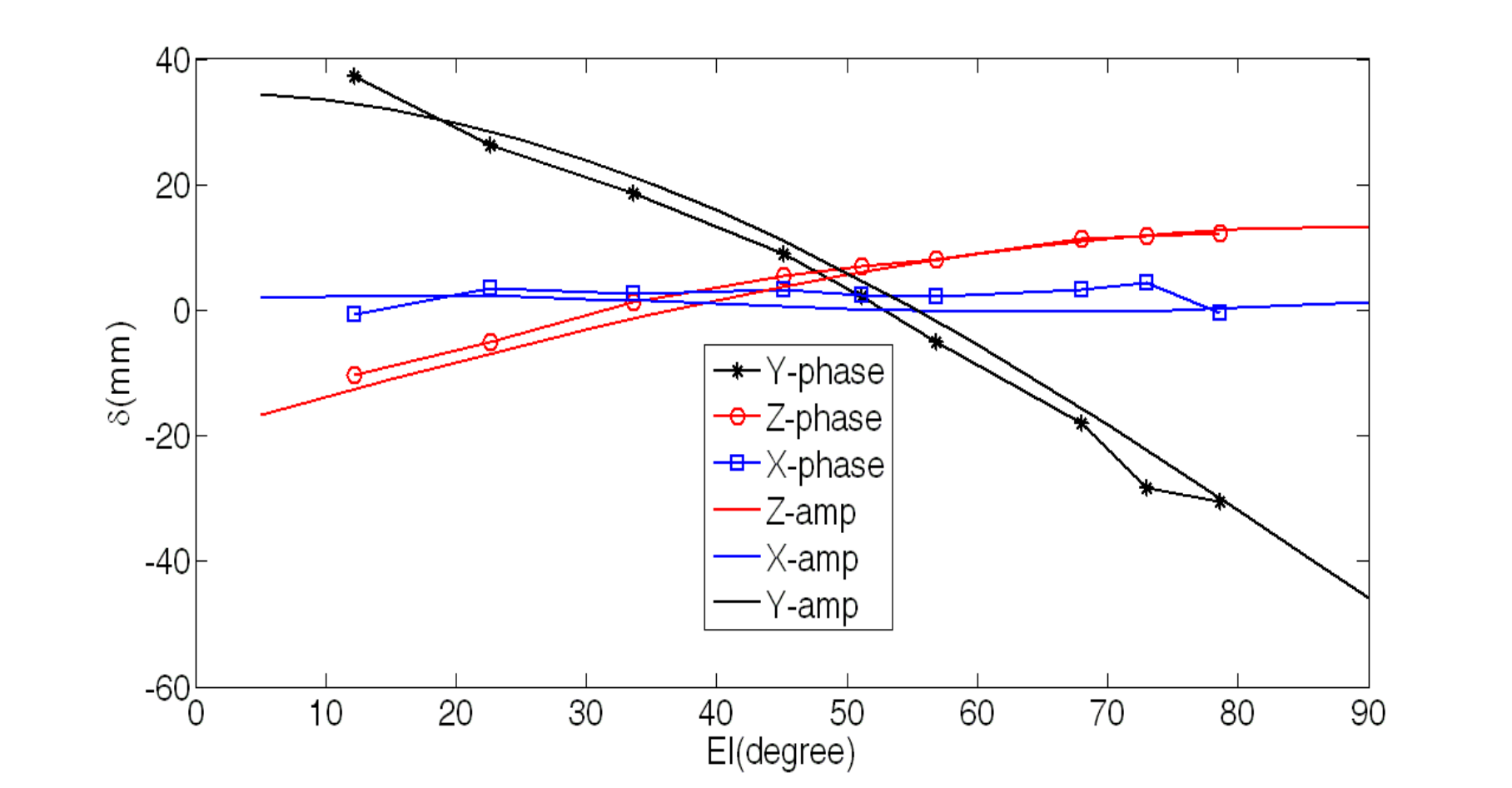

tested
30
20
10
0
-10
-20
-30
-30 -20 -10 0 10 20 30
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2


El=73
30
20
10
0
-10
-20
-30
-30 -20 -10 0 10 20 30
1.5
1
0.5
0
-0.5
-1
-1.5


30
20
10
0
-10
-20
-30
-30 -20 -10 0 10 20 30
1.5
1
0.5
0
-0.5
-1
-1.5


simulation
tested
El=43
El=33
30
20
10
0
-10
-20
-30
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8

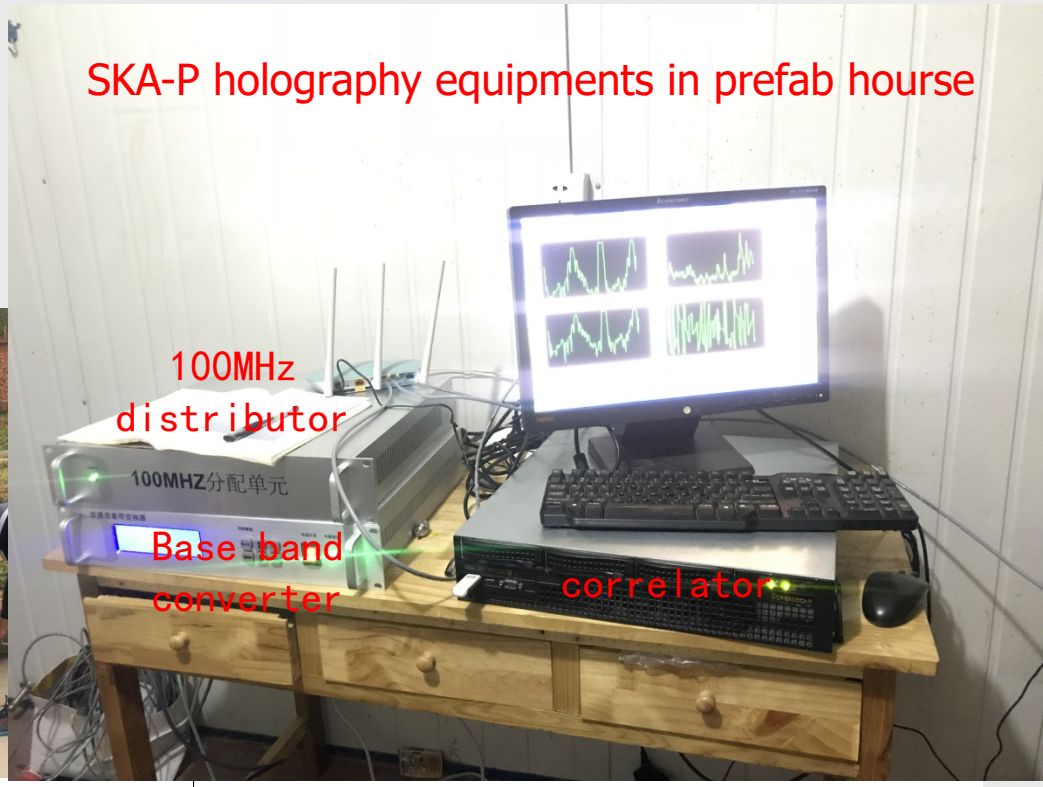
Sub-reflector XYZ position derived from holography aperture phase VS the sub-reflector model constructed from amplitude sweep

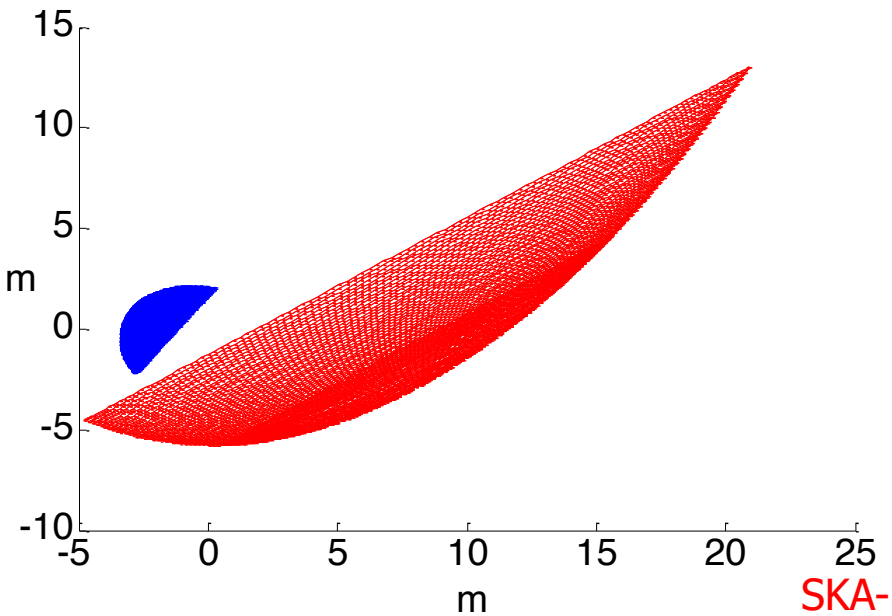


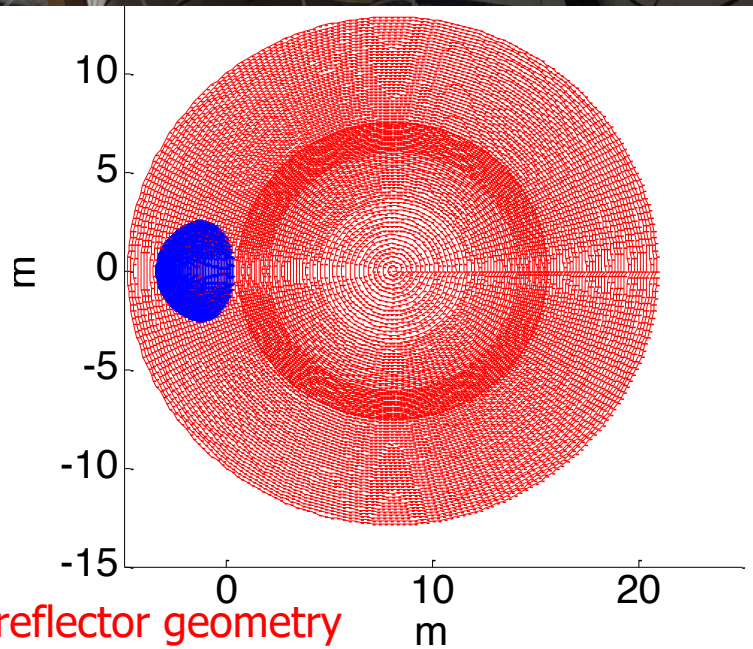
SKA-P Satellite Holography

- Satellite Asia 4 @ 12.25GHz ,Elevation is about 45degrees
- Aperture resolution 0.5m (31 scans in elevation)
- 50minutes for every measurement
- Energy taper is about -10dB at the edge. And the beam seems nice
- Surface error is about 0.3mm RMS
- Several datasets are collected, all results are relible and repeatable(~30um)

Ref antenna

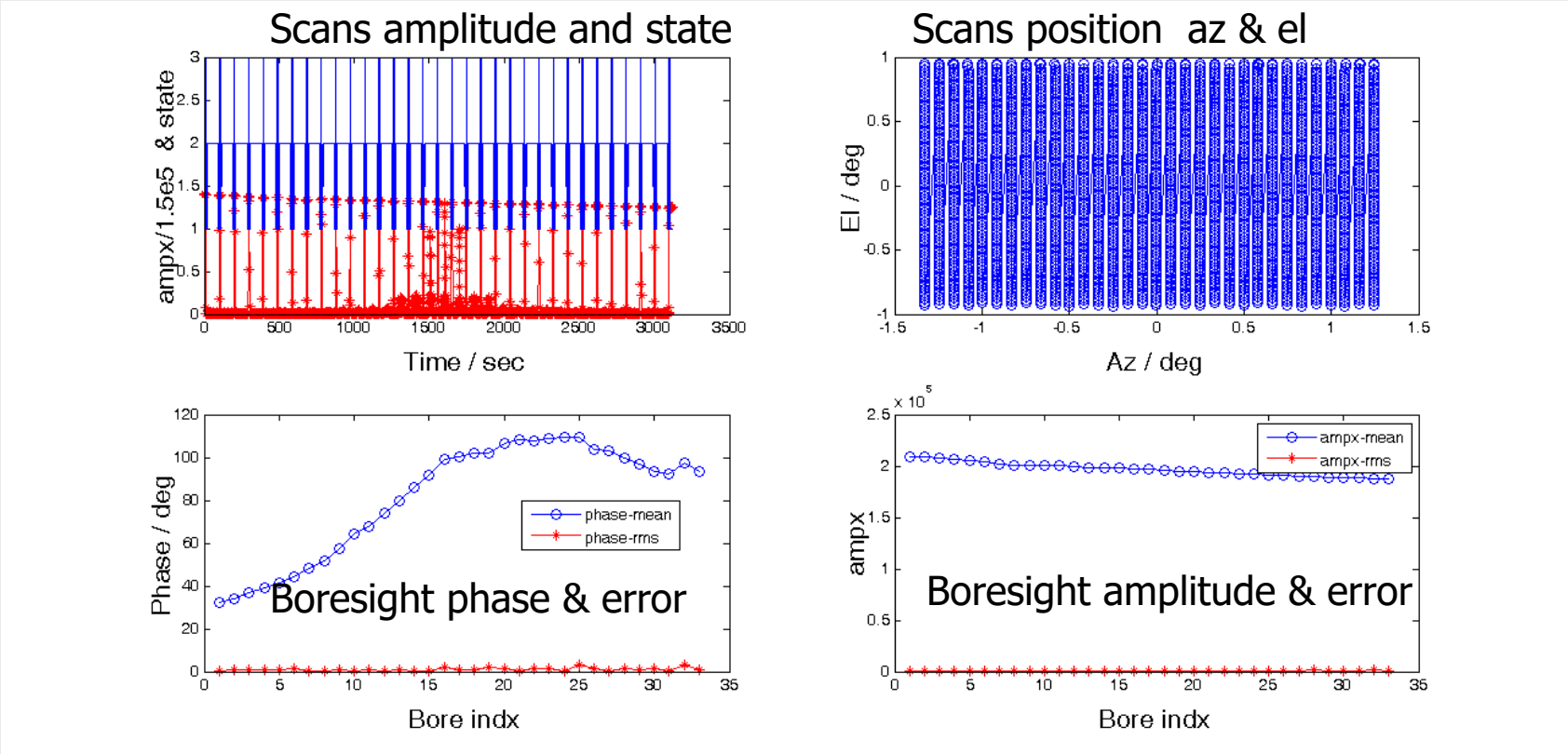


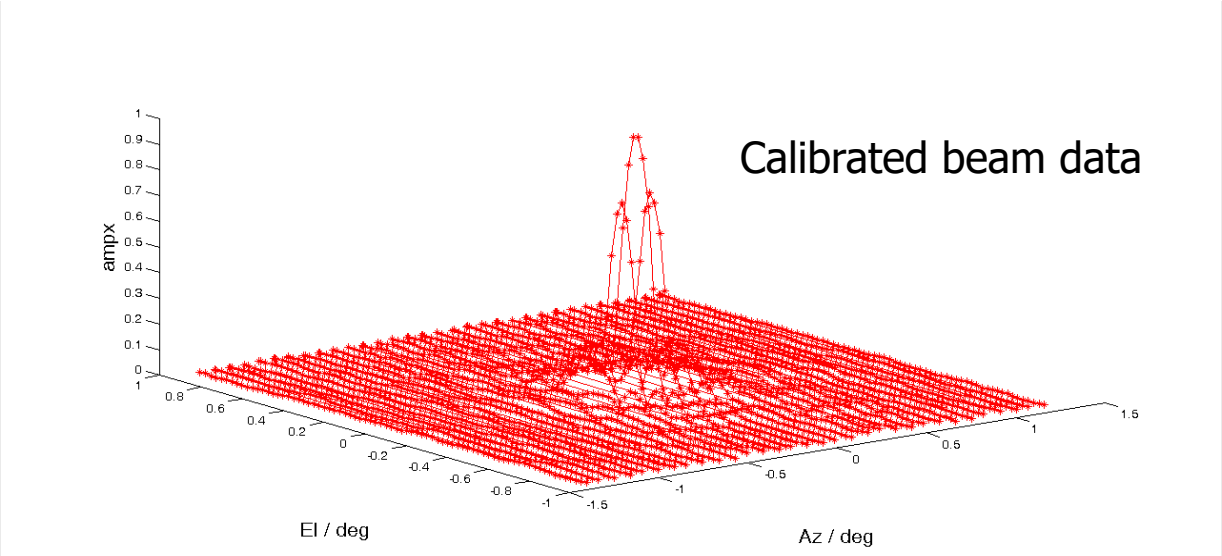


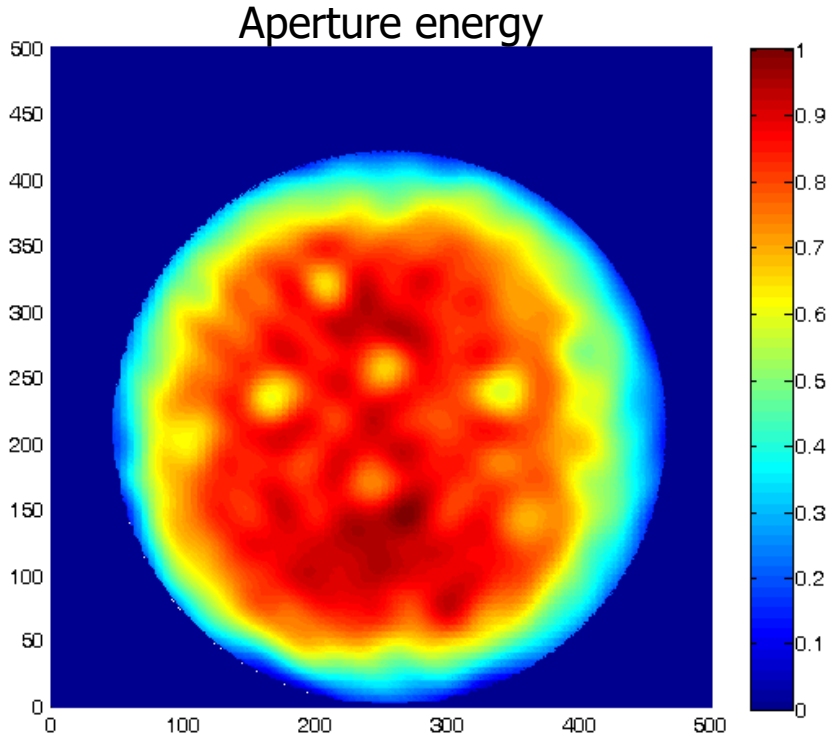


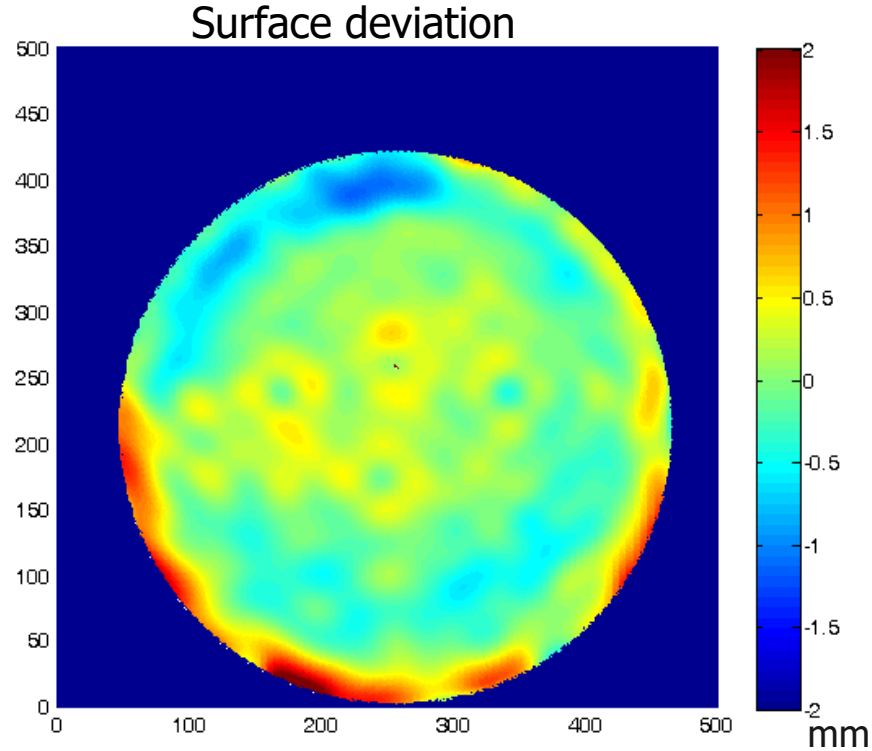
SKA-P reflector geometry

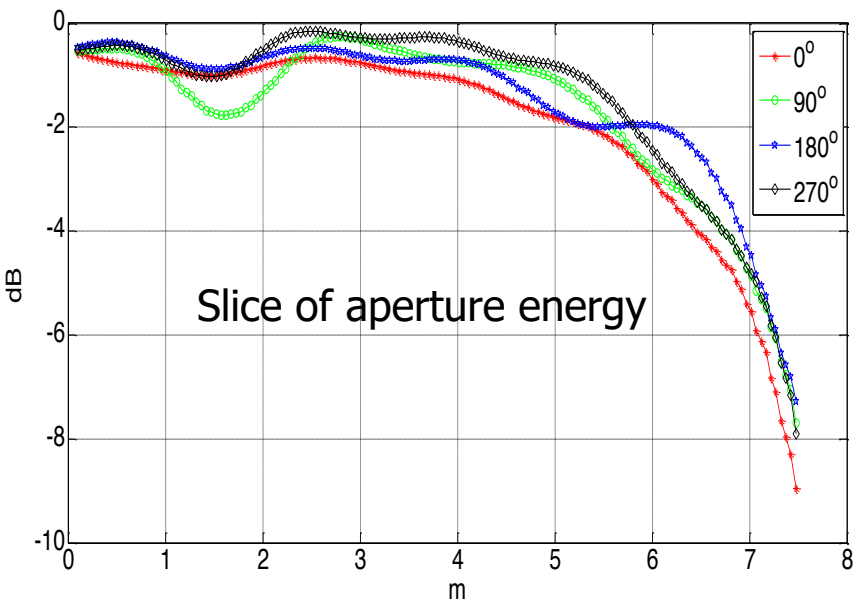
SKA-P holography data calibration

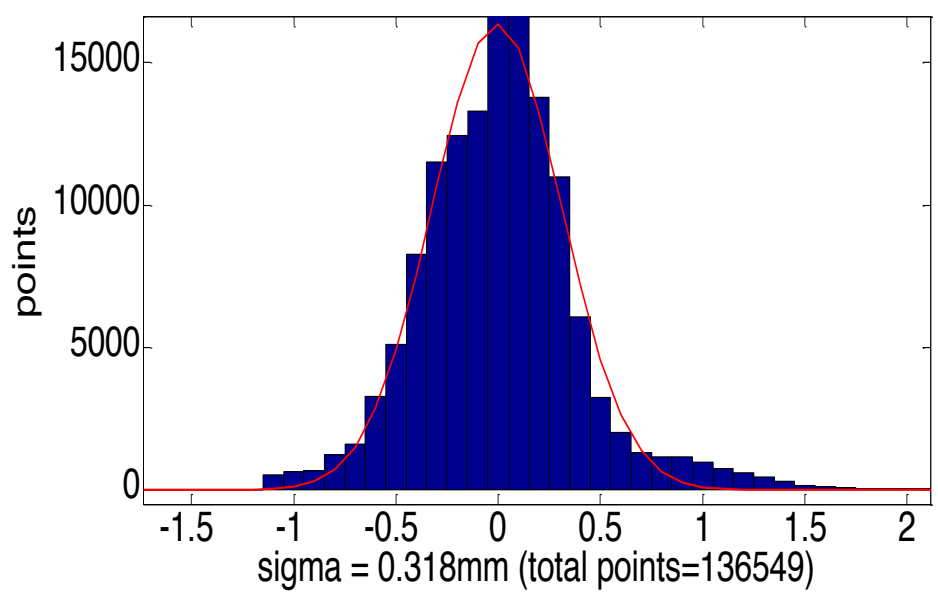





Aperture energy
500
450
400
350
300
250
200
150
100
50
0
0
100
200
300
400
500
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0


Surface deviation
500
450
400
350
300
250
200
150
100
50
0
0
100
200
300
400
500
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
mm


Slice of aperture energy
0°
90°
180°
270°
dB
0
-2
-4
-6
-8
-10
0
1
2
3
4
5
6
7
8
m


points
15000
10000
5000
0
-1.5
-1
-0.5
0
0.5
1
1.5
2
sigma = 0.318mm (total points=136549)

SKA holography and outputs information

Holography steps:

1)Geostationary satellite holography at best elevation for panels setting better than 0.3mm rms (room temperature receiver,early time)

2)CE4 Ralay star(Earth moon 2nd Lagrange point) holography for entire elevation gravity deformantion,the star will be on service more than 10years (room temperature receiver,early time)

3)Strong radio source holography for entire elevation gravity deformantion (cooled receiver installed)

Holography outputs:

1)Surface accuracy: **panel setting**

2)Gravity deformation model: design evaluation

3)Sub-reflector best position model: **sub-reflector position adjustment**

4)Elevation axis offset: design evaluation

5)Gain and efficiency estimate: design evaluation

Summary

- Pointing model & seperation:

  industrial metrology applied,such as PSD,temperature sensor,tiltermeter,etc.

- Sub_reflector position model:

  based on amplitude detection method

- Antenna performance measurment:

  based on calibrated noise diode

- Surface measurement by holography:

  surface error,gravity deformaiton moded,sub-reflector position model base on aperture phase


Kunming40m


Miyun50m


Sheshan25m


Tianma65m


Seshan13m


Tianma13m


SKA-P 15m
SKA-P


Thanks for your attention!