



中国科学院新疆天文台

Xinjiang Astronomical Observatory, Chinese Academy of Sciences



# Some surface measurement work in XAO and high precision surface challenges on QTT

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- Conclusion



# Nanshan 25m telescope

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## ➤ Upgrade plan

- Mar. – Oct. , 2014, Antenna structure, reflector, servo control...
- May – Oct. , 2015, Antenna rail

New Nanshan 26m





July 28, 2014











May 27, 2015





# Photogrammetry at Nanshan 25m

➤ Aug. 9 – Aug. 31 , 2014



➤ Chenway Technology Inc. & CETC 39 Institute

➤ Measurement system

- Dedicated camera, retro reflector, reference meter, directional gauge, image processing software

















# Photogrammetry at Nanshan 25m

- 6 measurement and 5 adjustment before feed cabin installation
  - RMS : 5.504 → 8 → 0.847 → 0.451 → 0.271 → 0.177 (mm)
- 2 measurement and 1 adjustment after feed cabin installation
  - RMS : 0.202 → 0.173 (mm)
- RMS under different Elevation

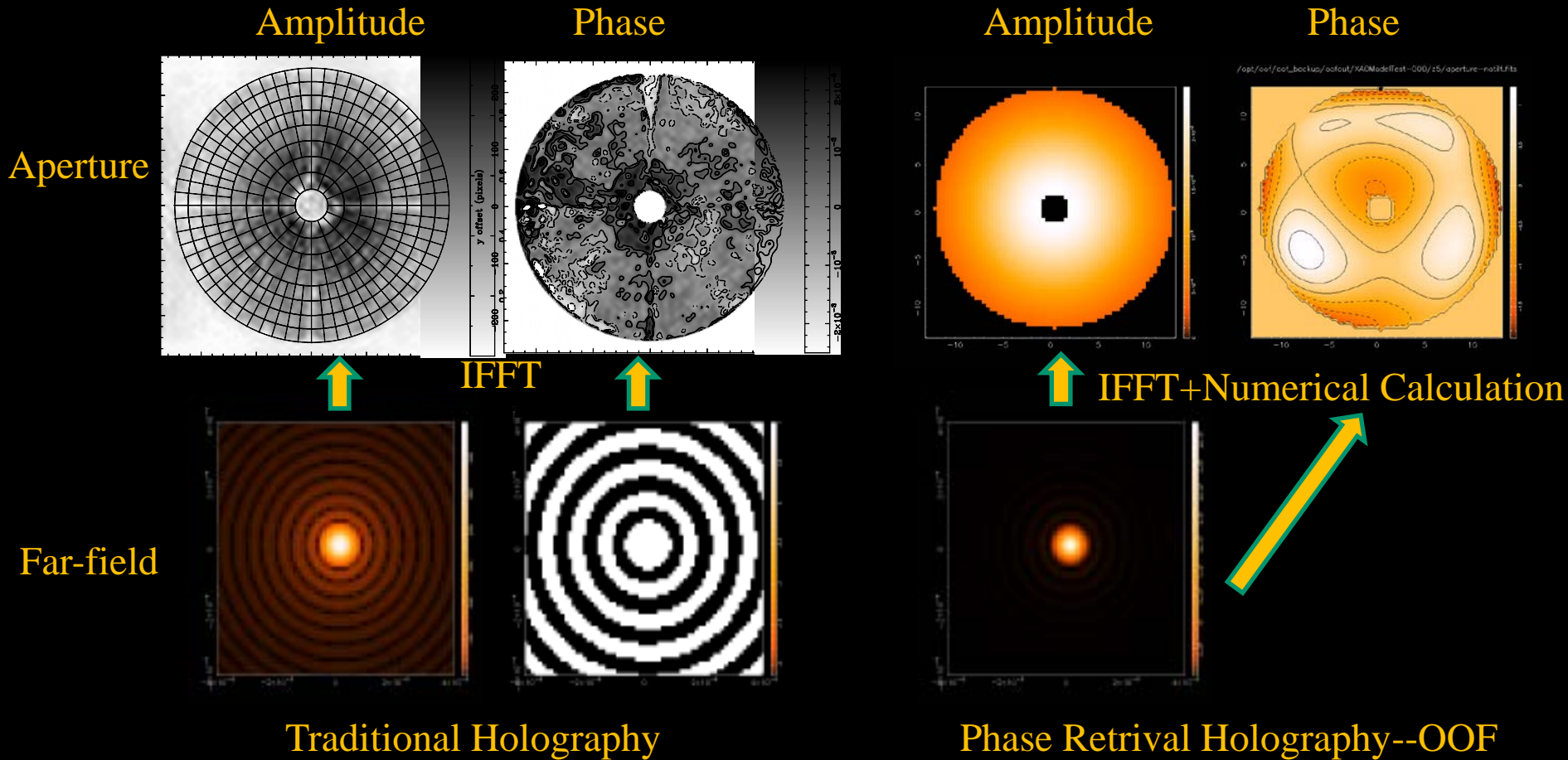
EL	RMS (mm)
90°	0.536
38°	0.173
20°	0.489
6°	0.561

The surface deformation is a little larger due to gravitational effect!



# Microwave Holography at Nanshan 25m Telescope

- With Phase Holography(Traditional)
- Phase Retrieval Holography(Out Of Focus)





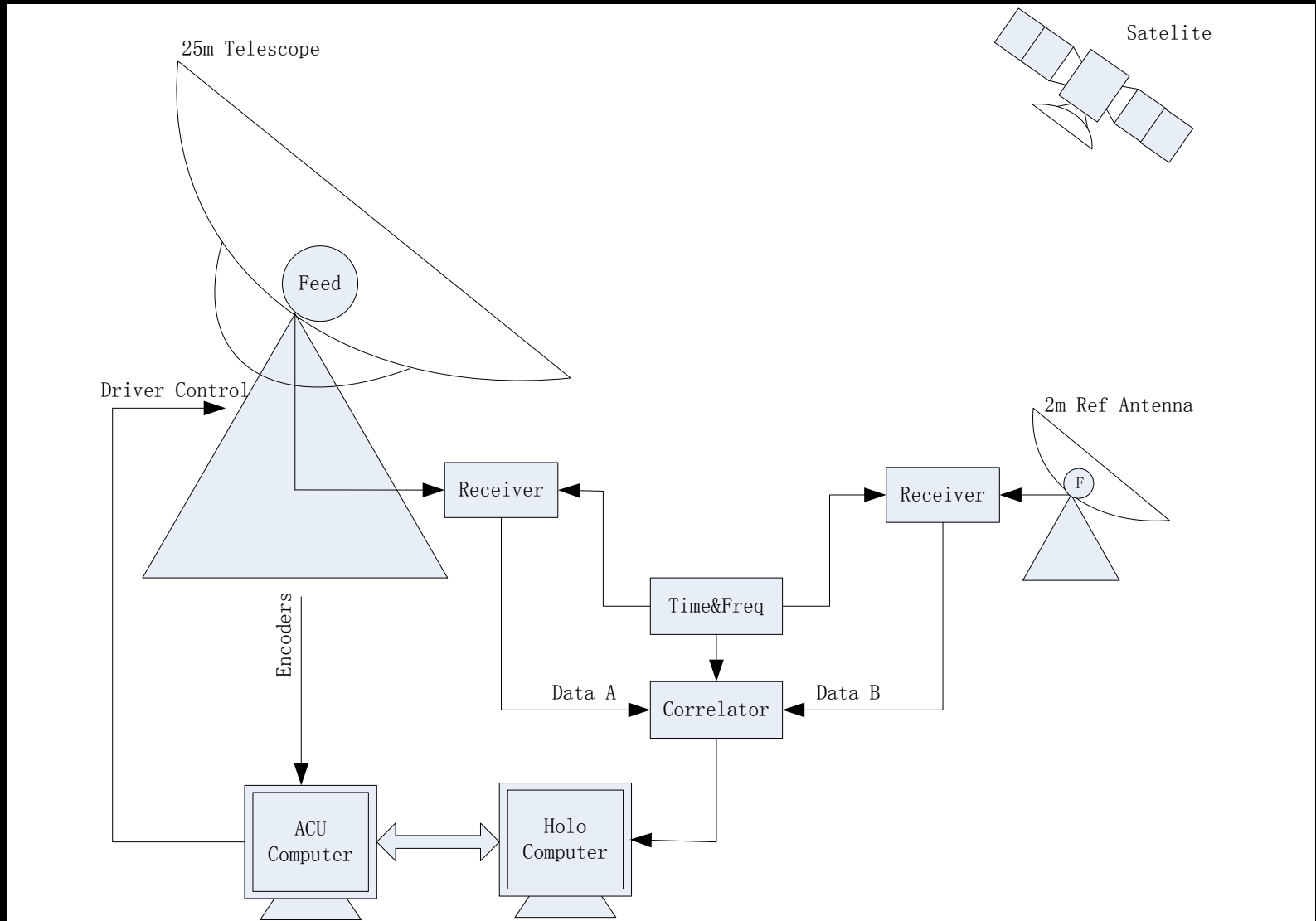


# The Difference between Traditional Holography and OOF

	Traditional Holography	OOF
Measured data	Amplitude + Phase	Amplitude
Measurement error	~100 $\mu$ m, <b>10<math>\mu</math>m</b> (ALMA)	$\lambda/100$ (SNR:200:1) For 1.3cm: ~130 $\mu$ m
Resolution	D/N, High, <b>Single panel</b>	Low, for large scale deformation
Time consumption	~2hours	<b>&lt;20mins</b>
Source	Geostationary satellites	<b>Radio sources</b>
Observed elevation	Fixed	<b>Full range</b>
Observed Band	Ku, Ka...	K, Ka, Q... <b>arbitrarily</b>
Software	<b>Simple</b>	Complex
Hardware	Reference antenna and receiver + Correlator	<b>Removeable sub-reflector</b>



# Traditional Holography System Design

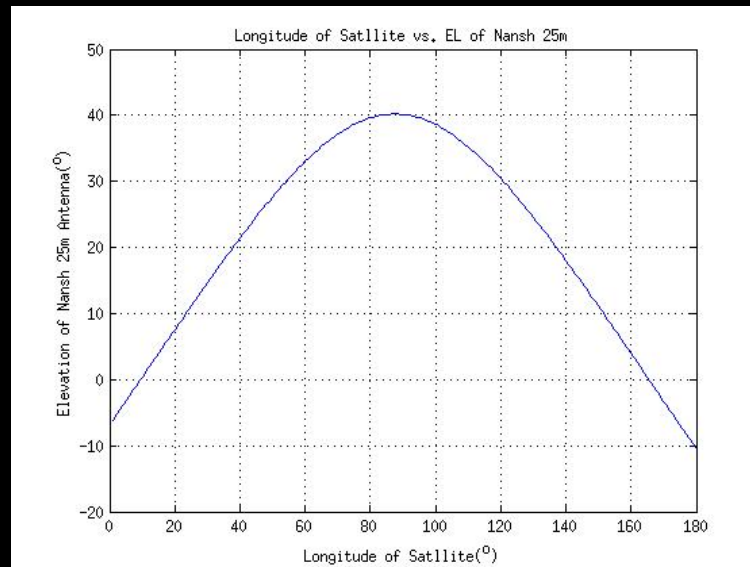




# Satellite Select



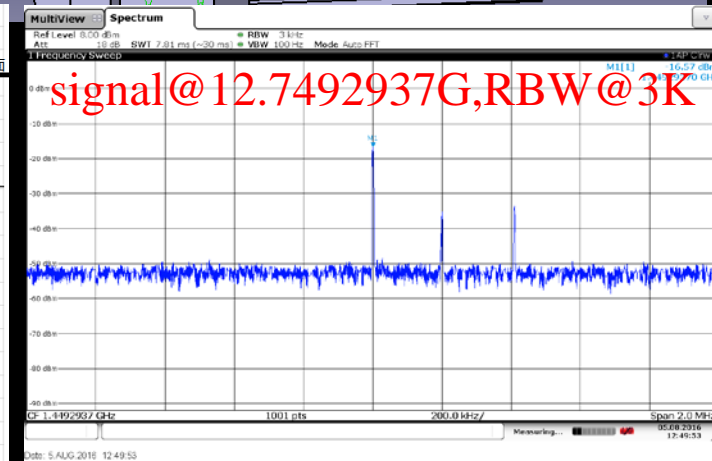
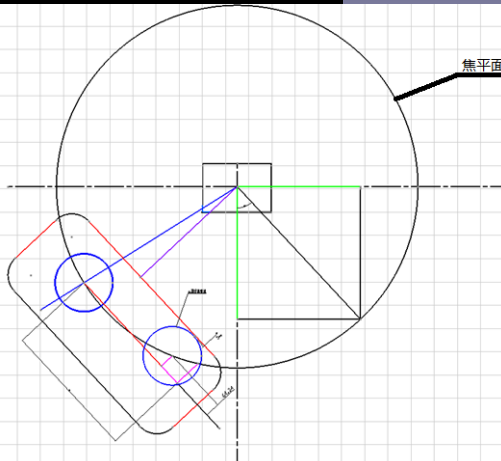
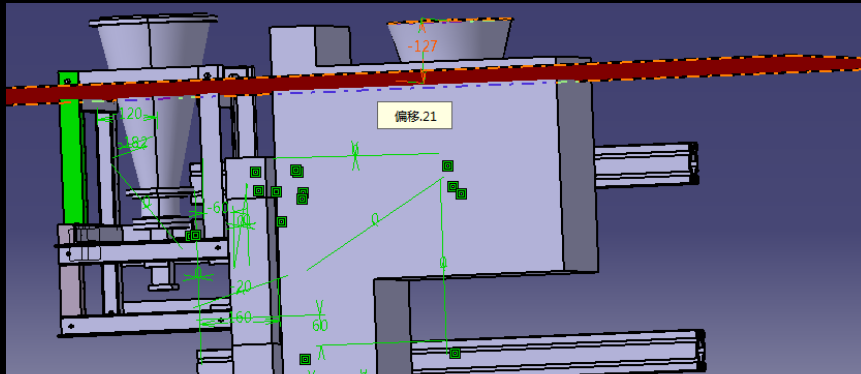
Satellite Name	Orbital Position/ ° E	Ku band beacon/MHz	Az, El of Nanshan 25m	EIRP /dBW
		Horizontal		
ChinaSat 10#	110.5	12745	148.2, 35	46
ChinaStar-1	87.5	12749.5	180, 40.2	45
AsiaSat-3	105.5	12749	154.6, 37	44
AsiaPasific-2R	76.5	12749	195.8, 39	45





# Feed Installation

- Using back shelf of K-band receiver, can move along three dimension, very easy to installation, adjust and remove

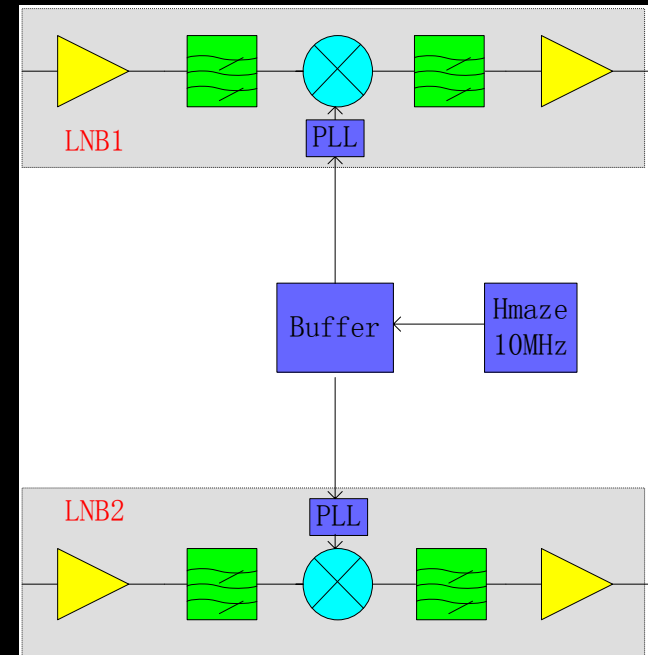
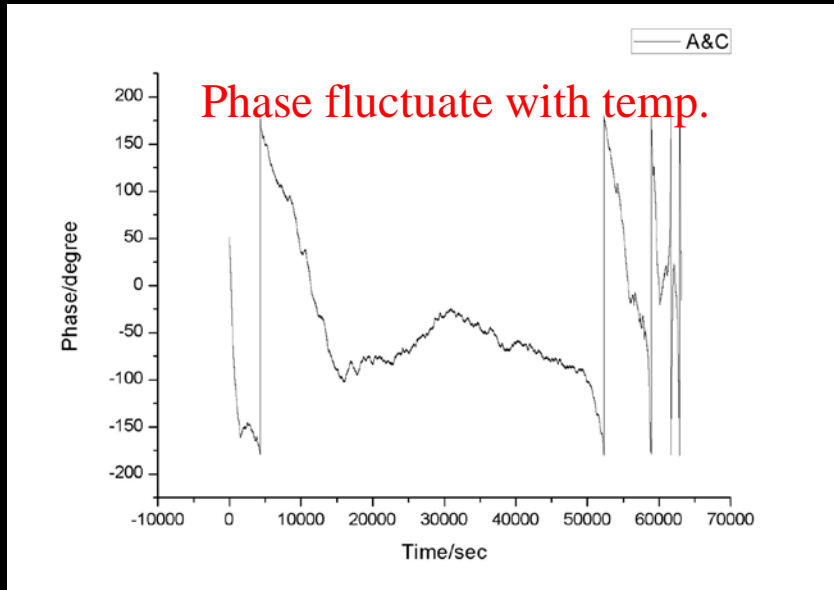






# Receiver

- First plan: Norsat LNB, 1007XHBN
  - pro's: Internal 11.3GHz LO, just need a ext. 10M ref.
  - con's: bad phase stability



Low Noise Block

Input freq : 12.25GHz~12.75GHz

Output freq : 950MHz~1450MHz

Gain : 60dB

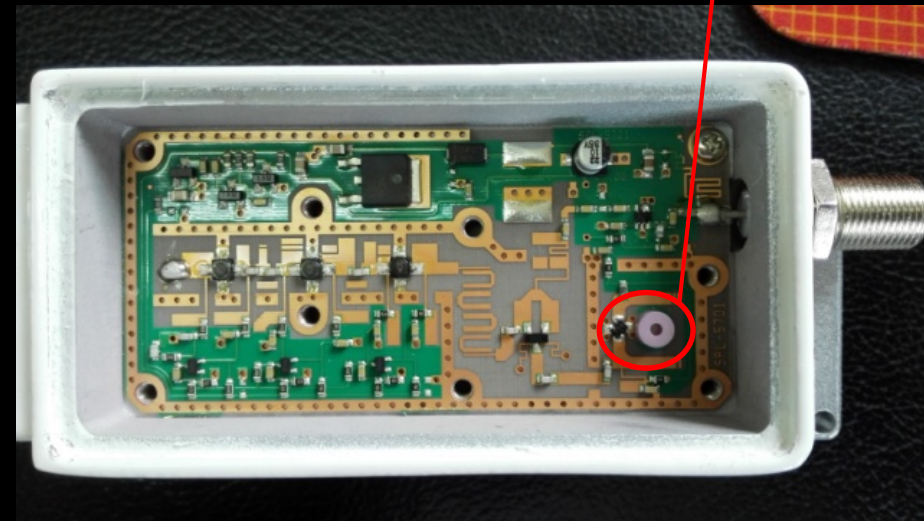
LO : 11.3GHz



# Receiver

## ➤ Revised plan

- Ext. 11.3GHz PDRO
  - KRATOS CTI
- Atron LNB
- Very good phase stability
  - 2.5h test, STDEVP about 1.68deg

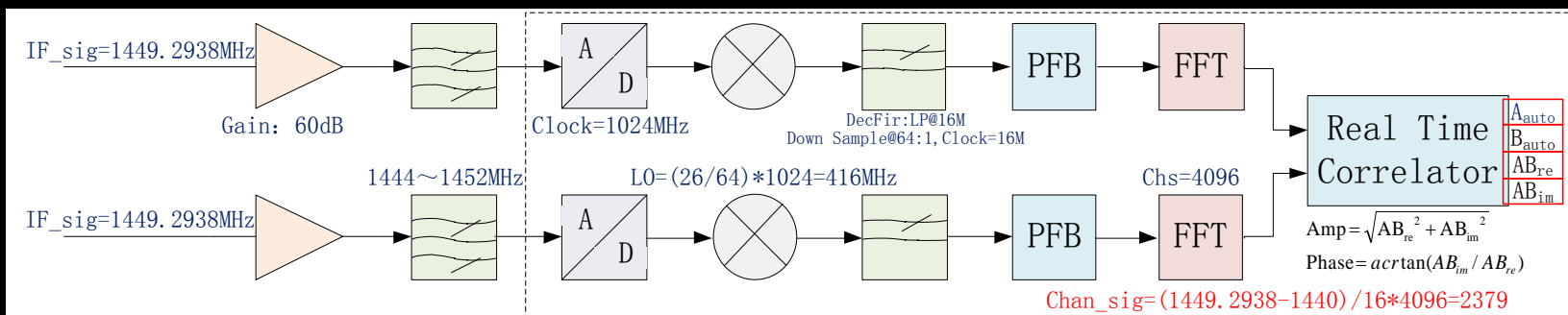





# Correlator



- ROACH2 board + CASPER library
- Dual channel, 2G, 8bit sampling
  - band pass sampling—needn't base band converter
  - digital mixer and filter—bandwidth adjustable
  - high precision, good stability



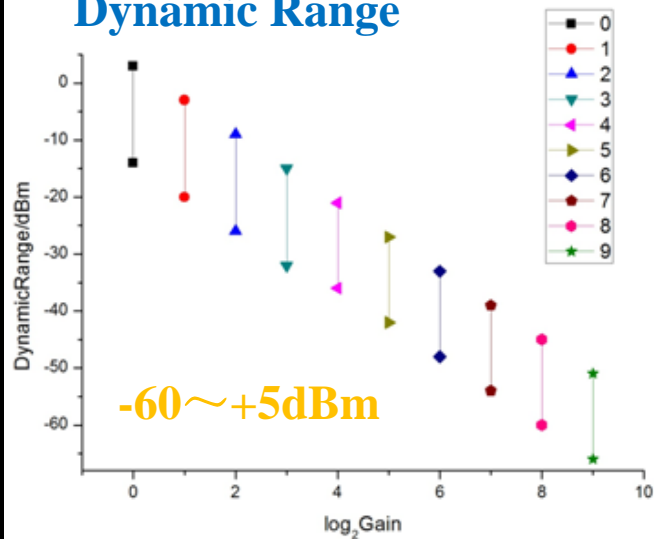
## ROACH2 Correlator Performance

Dynamic range : -54dBm~-15dBm  
Band Width : 16MHz  
A/D Sampling : 1024MHz  
Points of FFT : 4096  
Sampling bits : 8 bit  
Integration time : 1 sec  
Spectrum resolution : 3.9kHz  
Nyquist Zone:3(1024~1536MHz)  
Bandpass BW: 1440~1456MHz

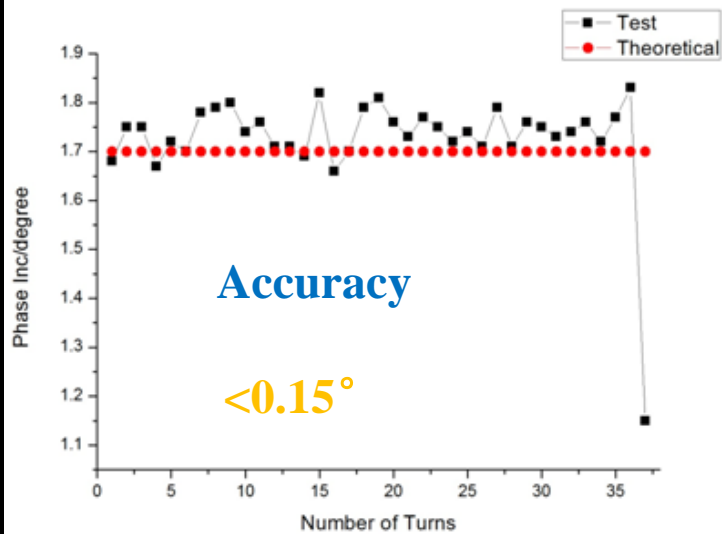
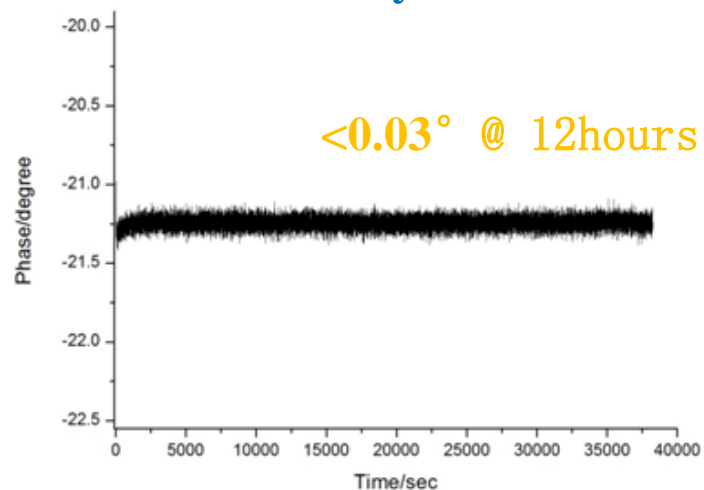


# Correlator Test Result

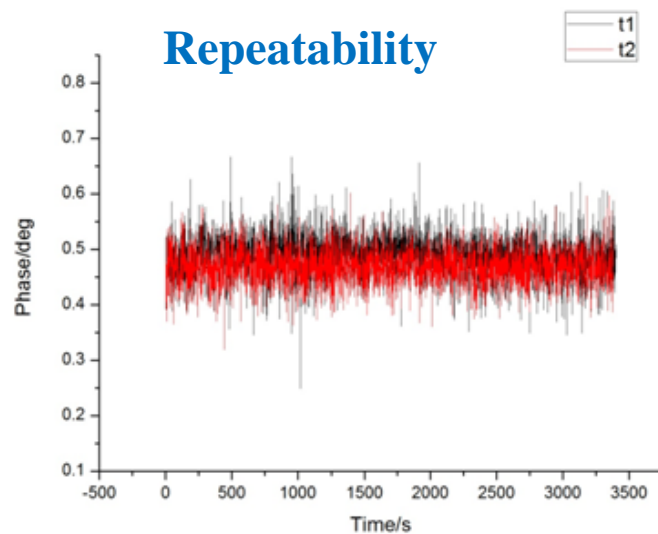
## Dynamic Range



## Stability



## Repeatability



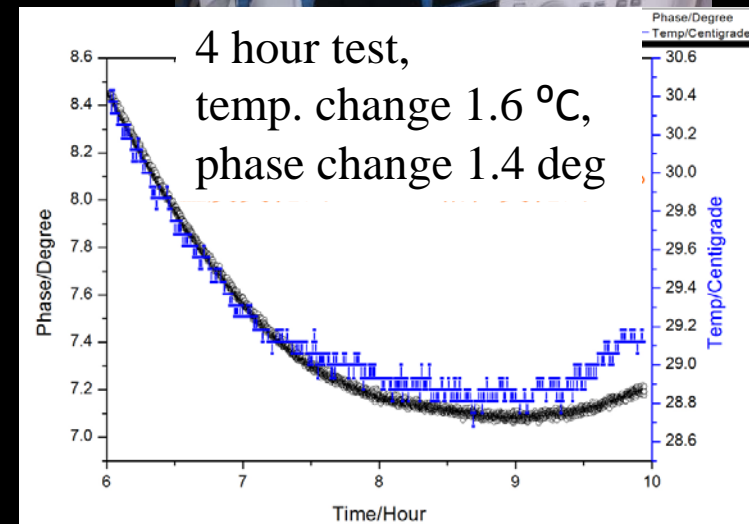
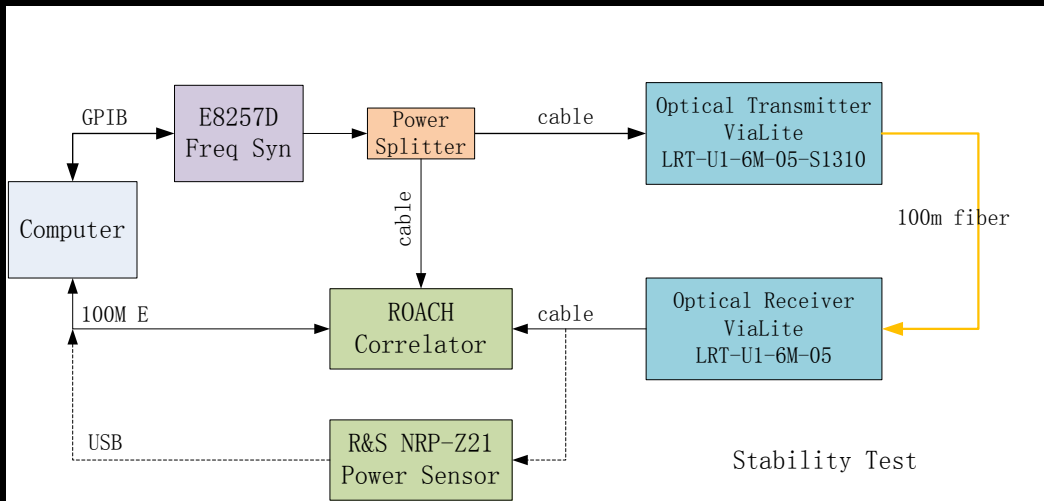
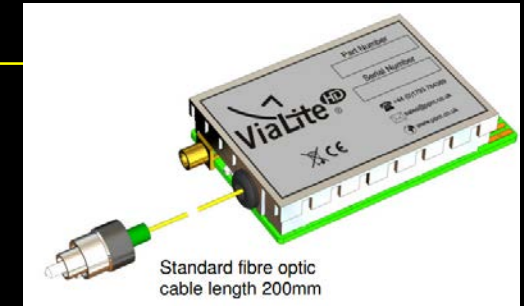




# Transmission Link

## ➤ First plan: fiber optic transmission

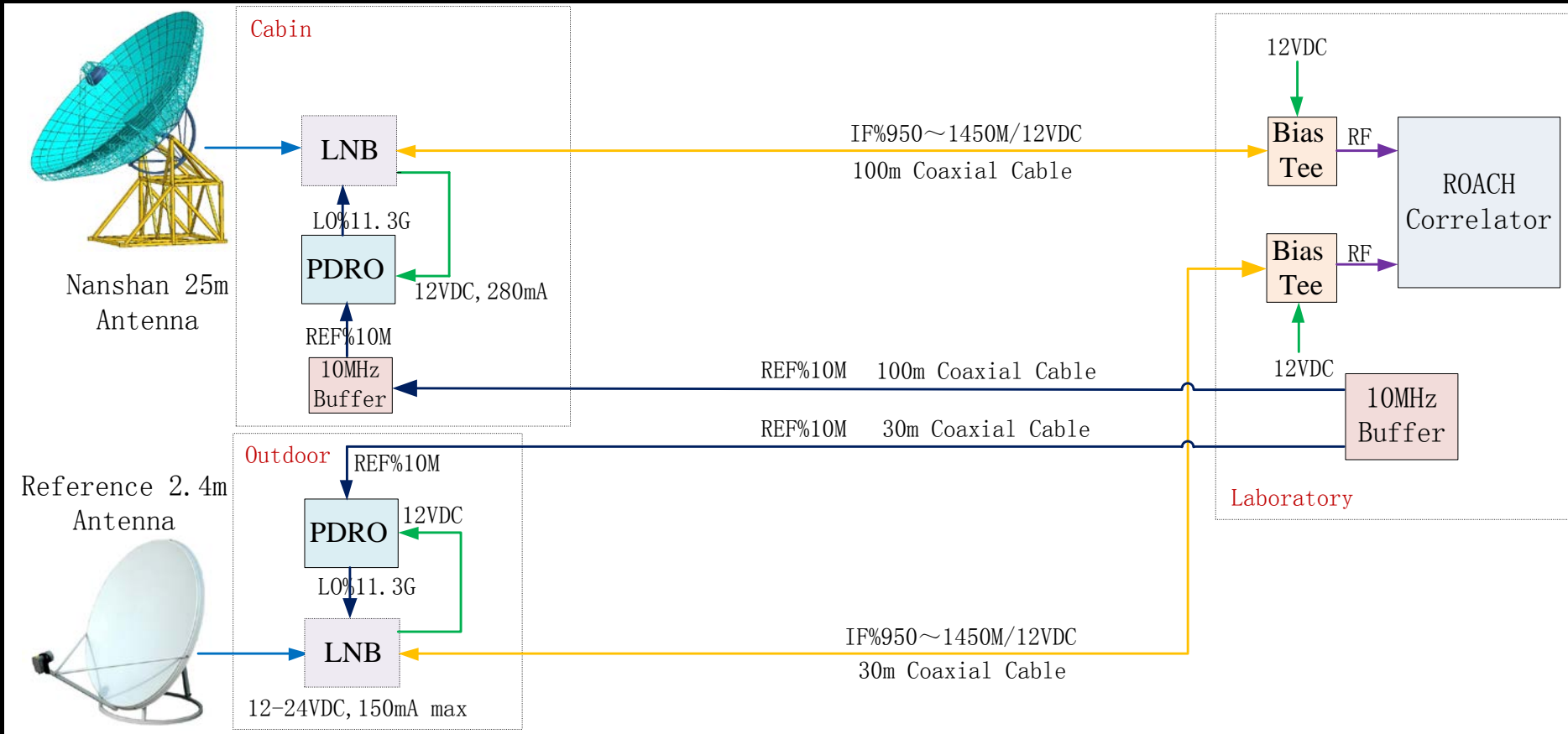
- pro's: good phase stability
- con's: bad phase stability due to optical receiver and transmitter temp. variation





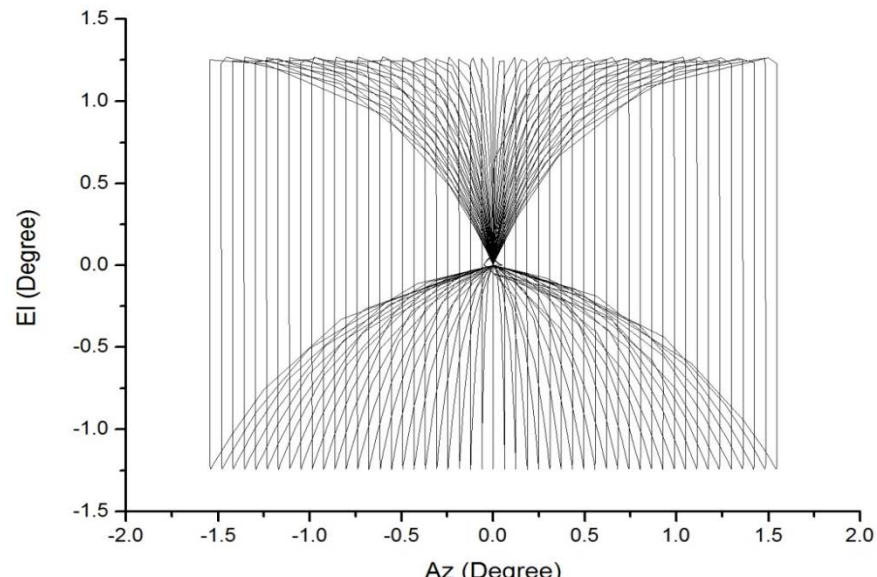
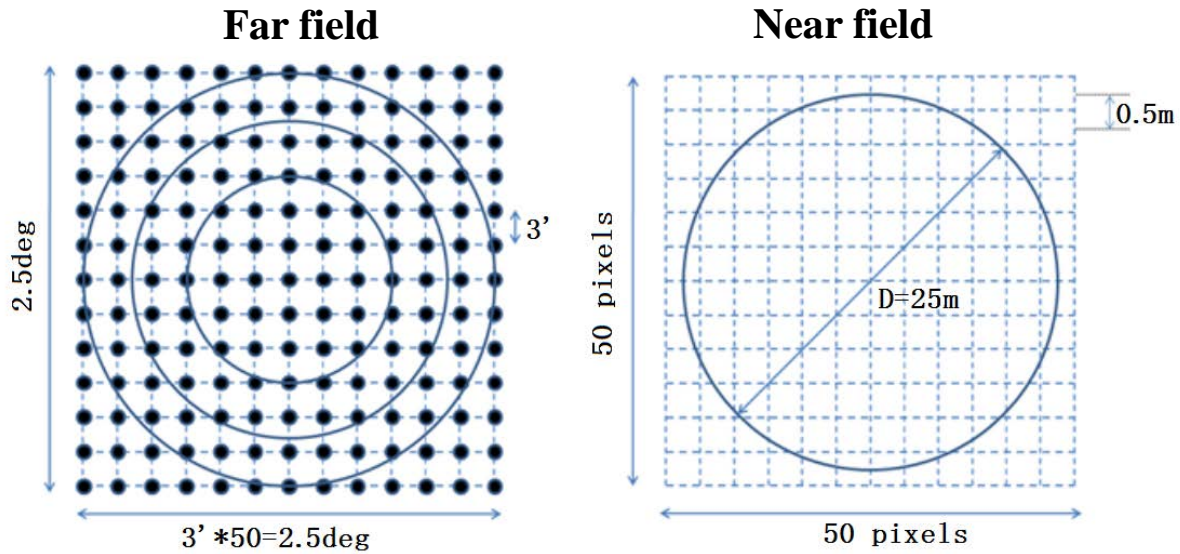
# Transmission Link

➤ Currently used: coaxial cable



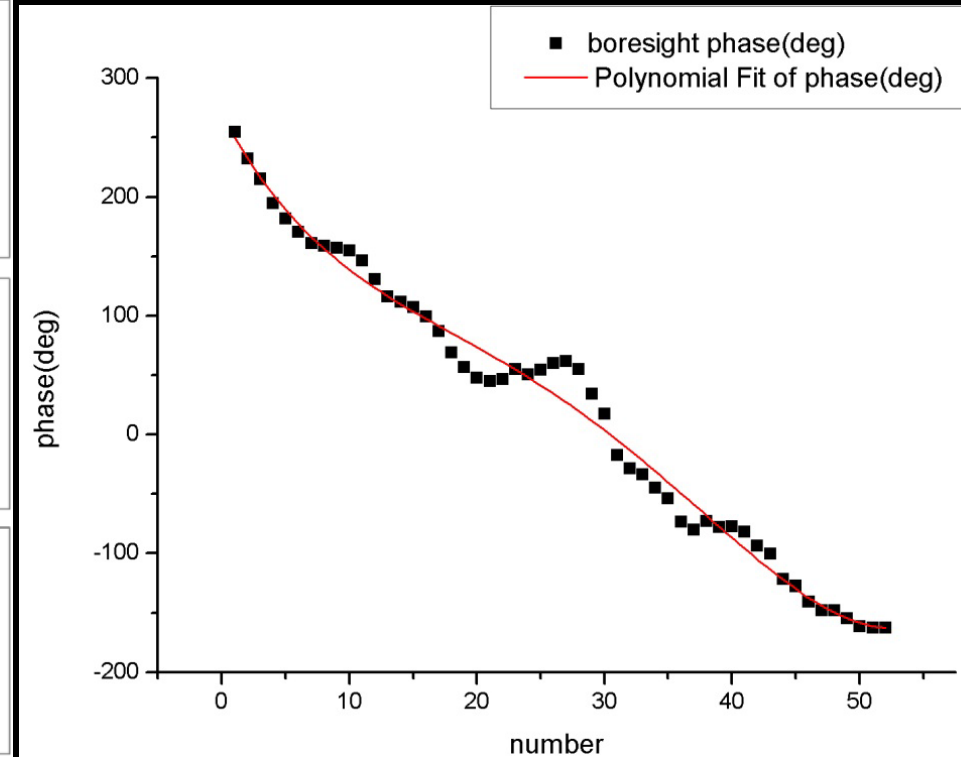
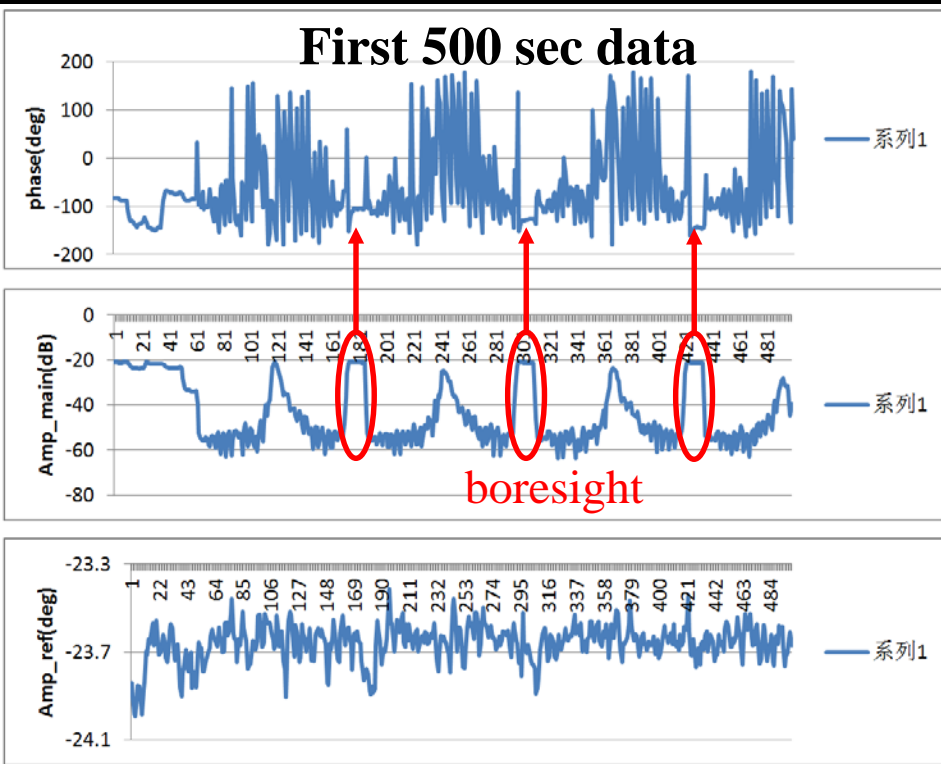


# Scan control





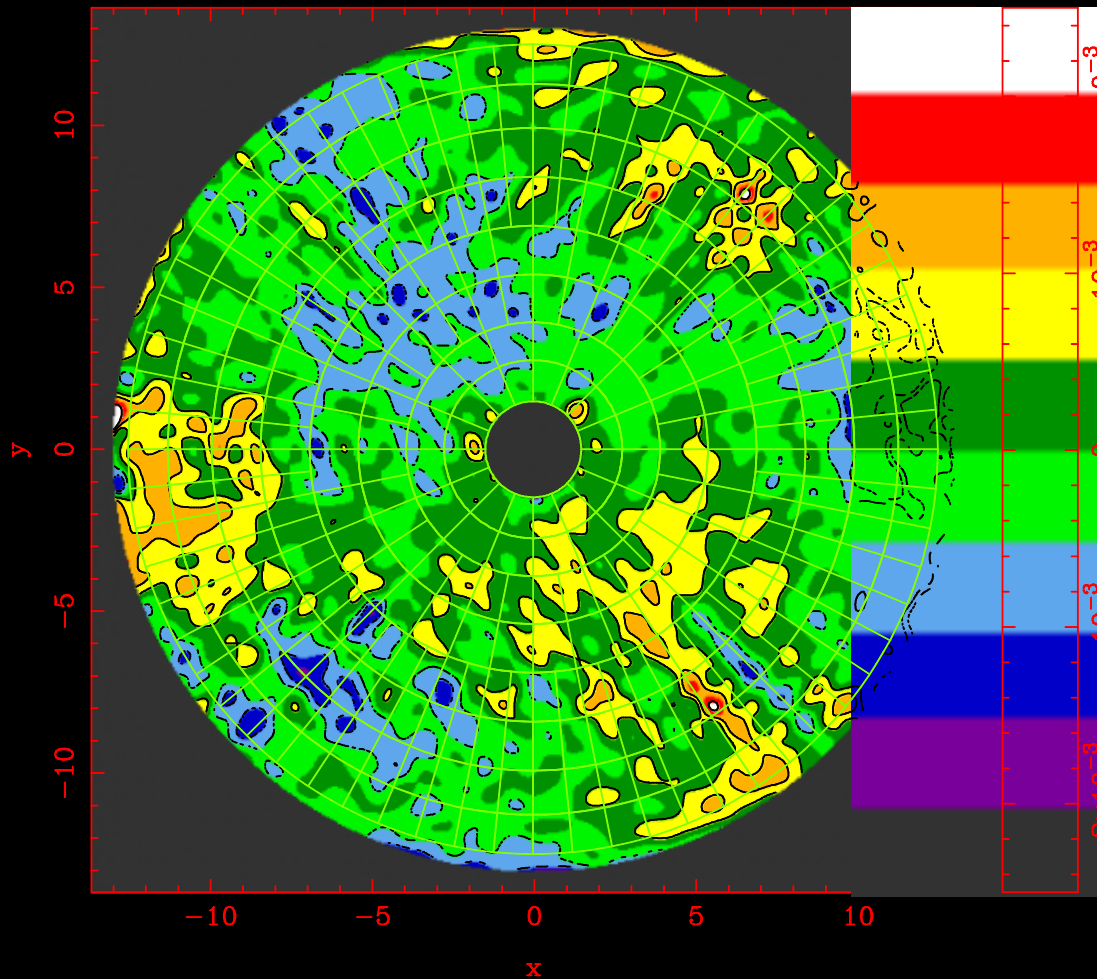
# Holo Test result





# Holo Test result

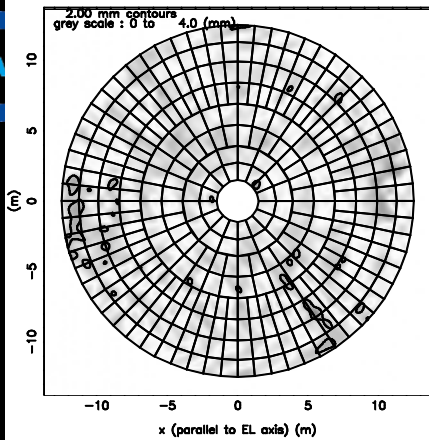
## ➤ Surface error distribution



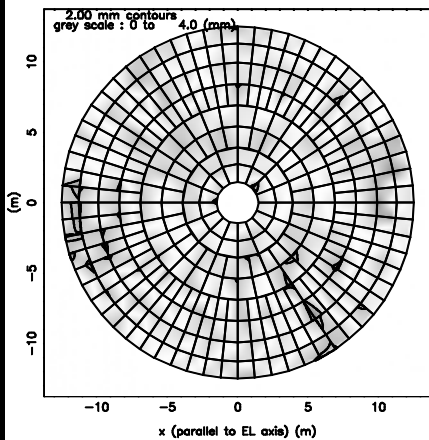


raw data - rms : 0.49 mm

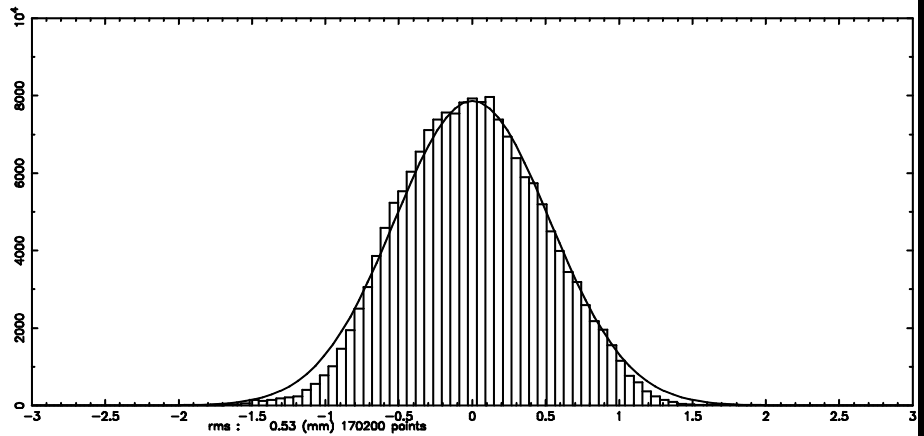
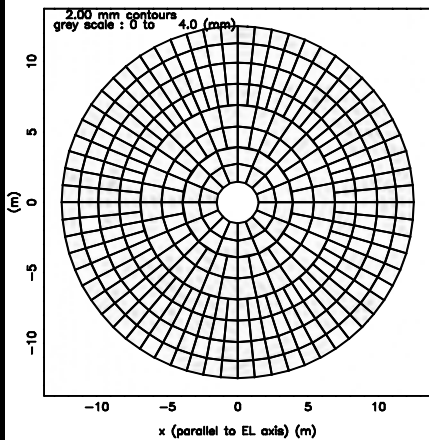
./px\_holo/20160806/fake\_data2r.V\_DEV/



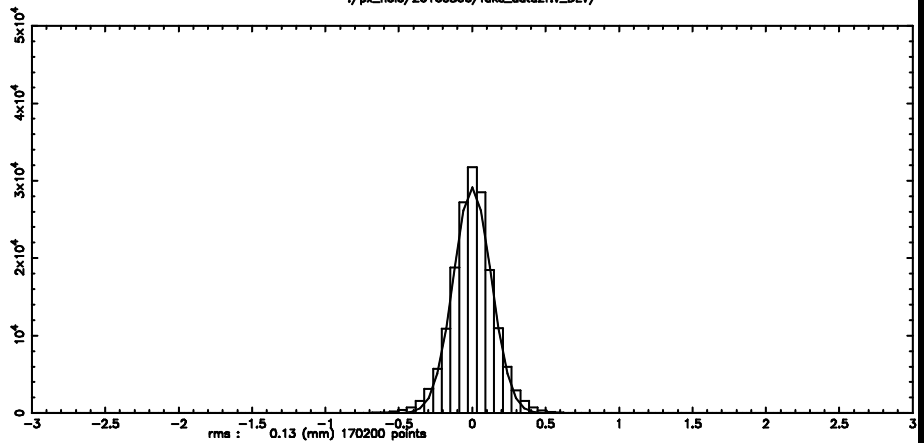
Adjustment map - Fit : Flexible panel



residuals - rms : 0.15 mm. Fit : Flexible panel



./px\_holo/20160806/fake\_data2r.V\_DEV/



Before adj(RMS): 0.49mm  
After adj(RMS): 0.15mm



# OOF Technique

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- 2003, Bojan Nikolic, University of Cambridge, U.K.
- Phase retrieval , measure power only of far-field beam pattern on bright astronomical calibrator
- Make three beam maps, one in focus, two in defocus
  - Parametrisation of surface errors -- Zernike polynomials
  - Solver algorithm -- Levenberg-Marquardt maximum-likelihood
- Adjust coefficients to minimize difference between model and actual beam maps
  - Correction for residual gravitational deformations , and "real-time" thermal deformations
- For closure active surface control system



# Advantages

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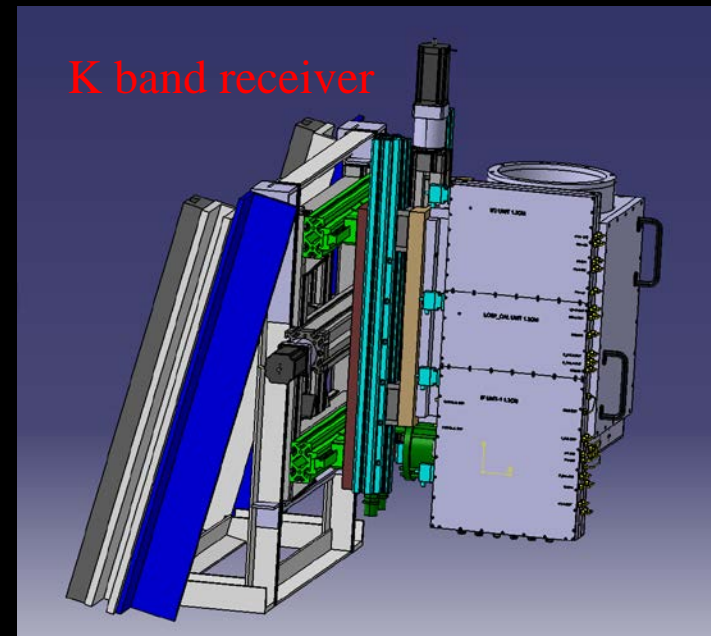
- Measure the complete optical aberrations
  - Surface errors + mis-collimation + receiver optics...
- Fast
  - Several minutes
  - “Near real-time” closure active surface control system
  - Faster when using multi-beam or focal-plane array
- As a function of elevation, time of day, etc
  - Measure the effect of gravity
  - Measure the thermal deformation
- Without extra equipment
  - Makes it easy to interleave with science observations
  - (Zero materials cost)





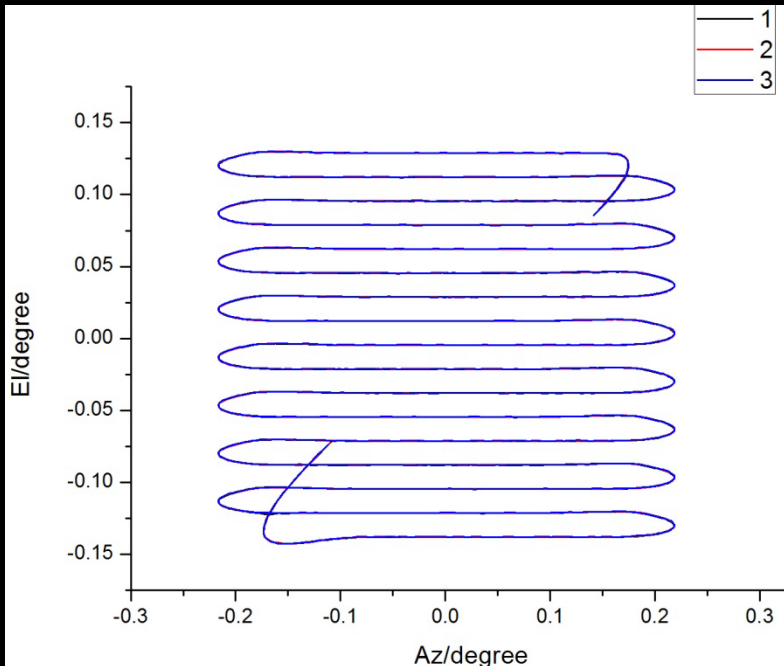
# Out Of Focus Holography at Nanshan 25m

- Feb., 2013, Old 25m system, K band
- BW: 500MHz
- Beam: 2.18'
- Defocus:  $\pm 70\text{mm}$
- Moving pattern: moving back shelf vertically
- Sources: 3C84
- Tsys: 40K
- SNR: 100:1
- Az Length: 30'
- El Length:  $1' * 16 = 16'$
- Scanning speed: 3'/s at Az  
(Max Az Speed: 60'/s, Max El Speed: 30'/s)
- Integration Time: 32ms/64ms
- Sampling Time: 32ms/64ms





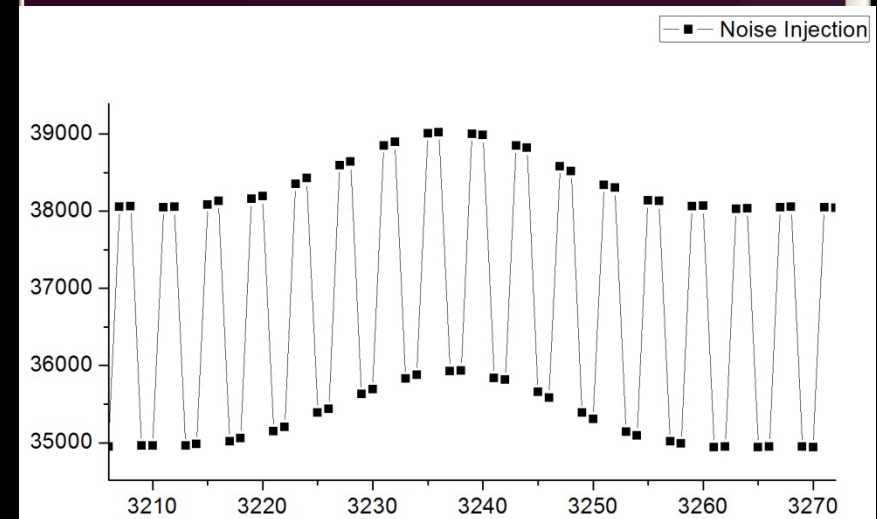
- Antenna control software(set scan mode and trajectory)
- Data acquisition software
- Noise injection
- OOF software installation(from Bojan)



```
root@ubuntu: /usr/local/bin
File Edit View Terminal Tabs Help

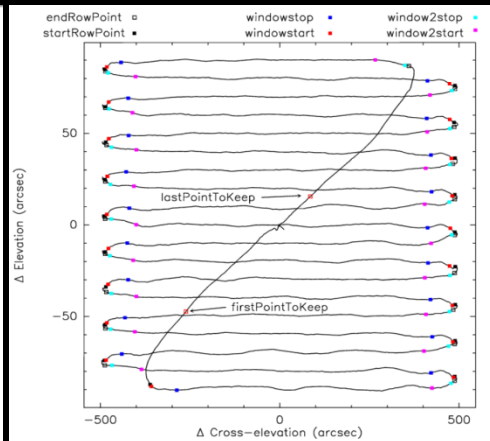
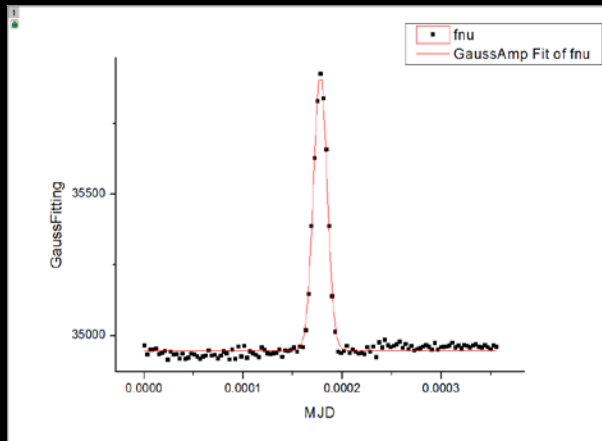
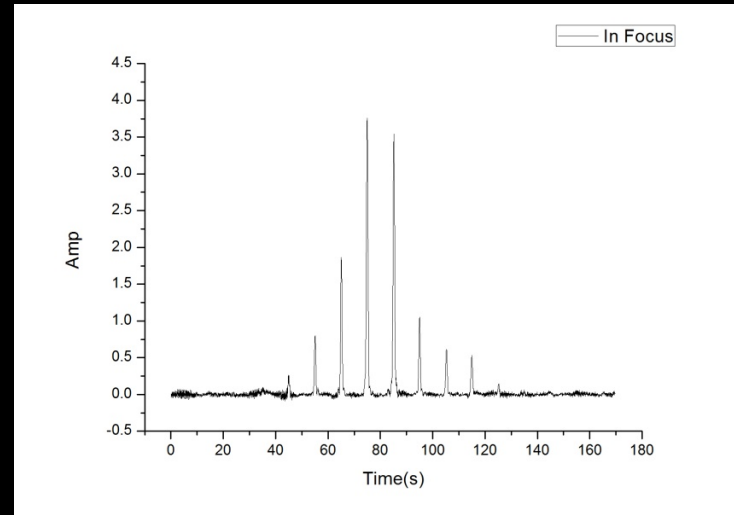
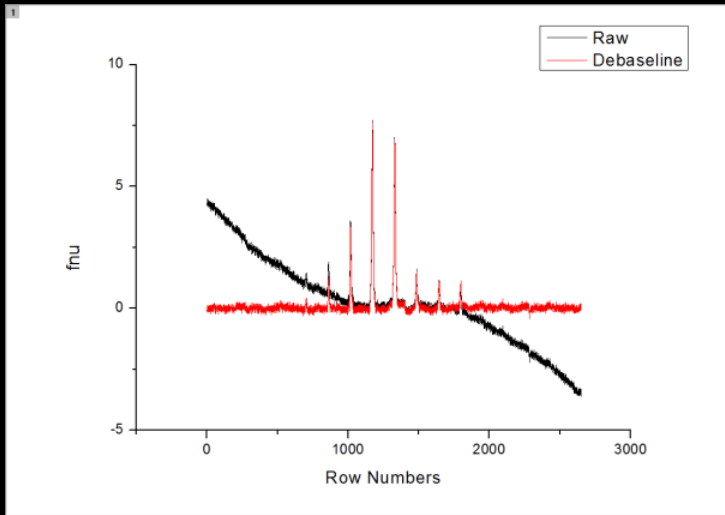
root@ubuntu: /mn... x root@ubuntu: /mn... x root@ubuntu: /usr/... x administrator@ub... x

root@ubuntu: /usr/local/bin# ls
bnfitsutils.py      gsl-histogram      nestedgauss        pybnmin1.py
bnmin1io.py         gsl-randist        oofcol.py          pybnmin1.pyc
bnmin1io.pyc        implot.py          oofcol.pyc         pyoof.py
bnmin1nested.py    implot.pyc         oofdataio.py       pyoof.pyc
bnmin1utils.py     iofits4.py         ooffitconv.py      pyplot.py
bnmin1utils.pyc   iofits4.pyc        oofplot.py         pyplot.pyc
ccache-swig        kernel3dutils.py   oofplot.pyc        swig
django-admin.py    kolmogorovutils.py oofreduce.py       t_minim
fftw-wisdom        kvolume            oofreduce.pyc     t_minim
fftw-wisdom-to-conf libpng15-config    pybnfits.py        t_unit
gsl-config         libpng-config      pybnlib.py         t_units
root@ubuntu: /usr/local/bin#
```





- Data pre-processing
- FITS file data
- Debaseline



fv: Binary Table of newbump.fits[1] in /home/px/Downloads/

Select	DX	DY	f <sub>nu</sub>	UFHU	TIME
All	radians	radians	E	E	E
Invert	Modify	Modify	Modify	Modify	Modify
1	-6.073639E-04	-2.356243E-04	4.780521E-03	5.121715E-03	5.024754E-05
2	-6.272015E-04	-2.428558E-04	1.87427E-03	5.121715E-03	5.092594E-05
3	-6.467761E-04	-2.500912E-04	-1.917839E-03	5.121715E-03	5.150466E-05
4	-6.657842E-04	-2.573285E-04	-2.35072E-03	5.121715E-03	5.208252E-05
5	-6.842404E-04	-2.645638E-04	-6.783340E-04	5.121715E-03	5.266222E-05
6	-7.026908E-04	-2.717985E-04	-8.867979E-04	5.121715E-03	5.324073E-05
7	-7.211463E-04	-2.790217E-04	-6.070822E-03	5.121715E-03	5.381944E-05
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9	-7.591838E-04	-2.935445E-04	1.458984E-03	5.121715E-03	5.497704E-05
10	-7.790295E-04	-2.999722E-04	3.209289E-03	5.121715E-03	5.555579E-05
11	-7.990549E-04	-3.057044E-04	-1.364946E-04	5.121715E-03	5.613430E-05
12	-8.182293E-04	-3.122184E-04	-3.359079E-04	5.121715E-03	5.671384E-05
13	-8.385673E-04	-3.194528E-04	-7.815261E-04	5.121715E-03	5.729225E-05
14	-8.590200E-04	-3.266831E-04	3.343748E-03	5.121715E-03	5.787050E-05
15	-8.695394E-04	-3.339183E-04	2.826810E-03	5.121715E-03	5.844921E-05
16	-8.892616E-04	-3.403985E-04	-1.474261E-03	5.121715E-03	5.902801E-05
17	-8.989806E-04	-3.461855E-04	-1.492143E-03	5.121715E-03	5.960672E-05
18	-9.149077E-04	-3.526256E-04	2.600789E-03	5.121715E-03	6.018519E-05
19	-9.305680E-04	-3.599605E-04	8.210540E-03	5.121715E-03	6.076390E-05
20	-9.454758E-04	-3.670978E-04	7.954858E-03	5.121715E-03	6.134279E-05



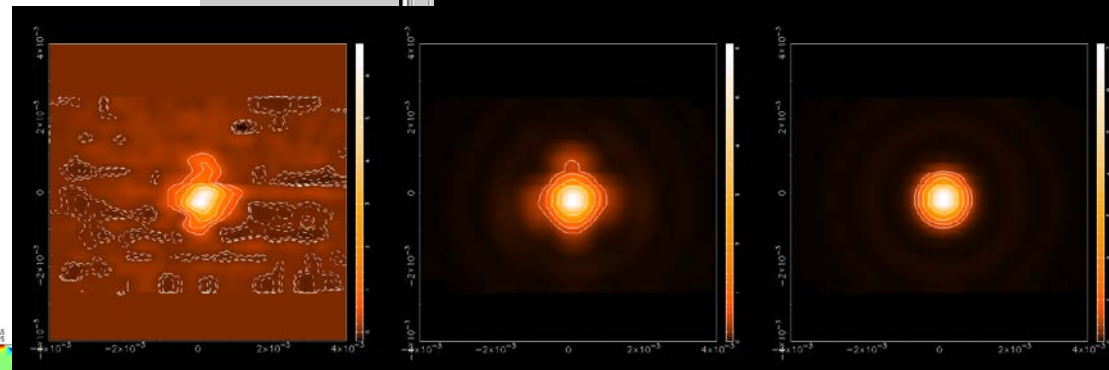
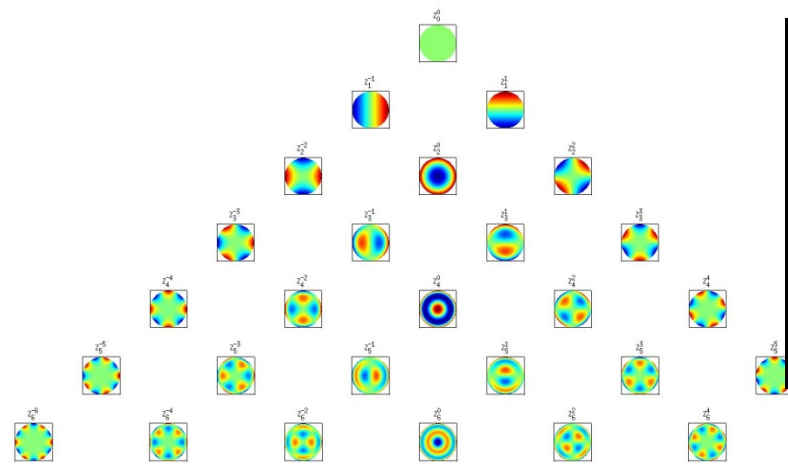
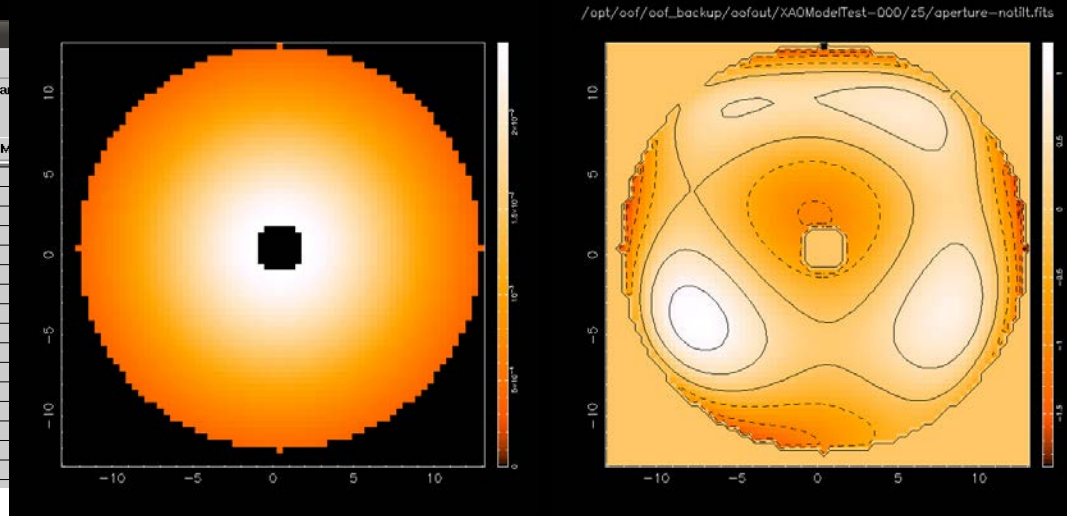
# OOF Maps of Nanshan 25m

## Zernike polynomials

fv: Binary Table of fitpars.fits[1] in /home/px/Downloads/oofout/s114-l-db-001/z5/

Select	ParName	ParValue	DoFit
<input type="checkbox"/>	30A	E	I
<input type="checkbox"/>	All		
Invert	Modify	Modify	Modify
1	amp	9.132390E-04	1
2	sigma	3.000000E-01	0
3	x0	0.000000E+00	0
4	y0	0.000000E+00	0
5	z0	0.000000E+00	0
6	z1	-1.226602E-01	1
7	z2	-6.266849E+00	1
8	z3	1.081935E-01	1
9	z4	-9.170491E-02	1
10	z5	1.864050E-01	1
11	z6	-1.951748E-02	1
12	z7	-1.095982E-01	1
13	z8	-6.867645E-02	1
14	z9	3.466250E-02	1
15	z10	-6.291842E-02	1
16	z11	-1.557280E-02	1
17	z12	4.442498E-03	1

## Aperture phase and amplitude distribution



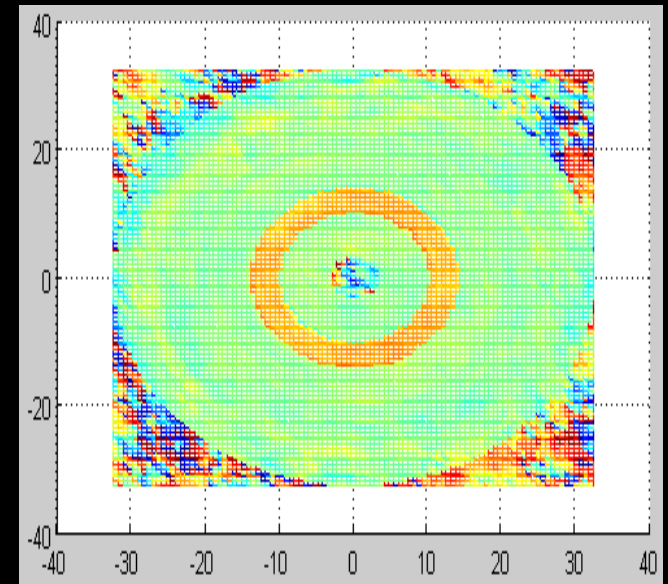
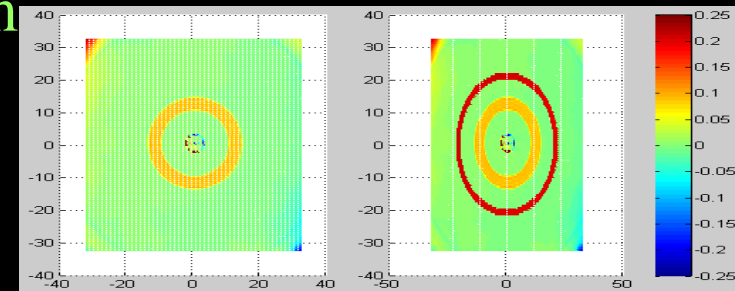
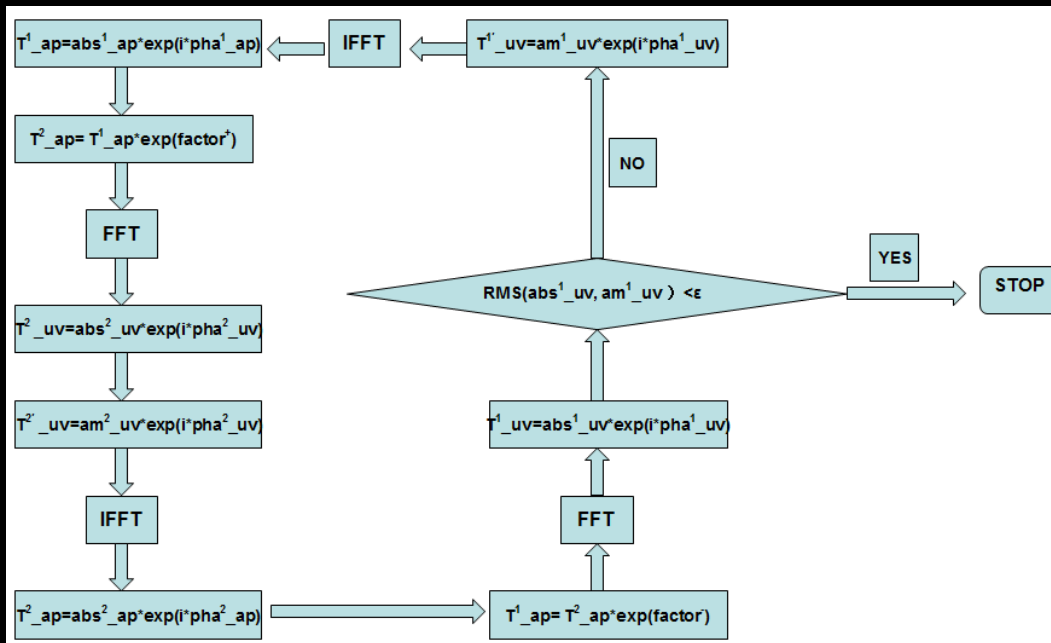
Beam maps





# Other methods research

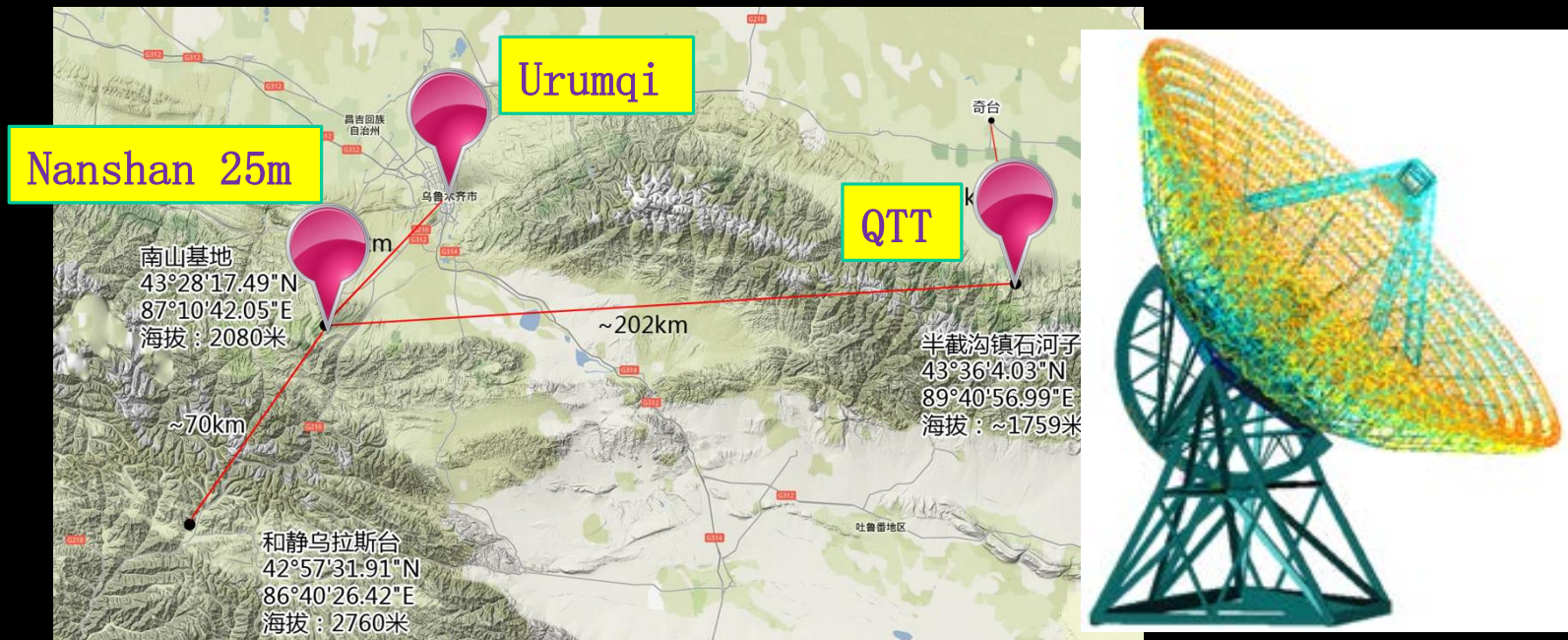
- Active surface de-focus algorithm
  - A sort of phase retrieval algorithm
  - move main surface for de-focus
  - Add a ring error in main surface





# Qi Tai radio Telescope(QTT)

- 260km from Urumqi, 202km baseline from Nanshan
- 110m , fully moveable, 150M~117GHz,Active reflector
- Surface accuracy RMS: <math><0.2\text{mm}</math>
- Blind pointing error: <math><5''</math>





# Key Point for QTT High Precision Surface

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## ➤ Design

- Decrease geometric approximate error, homology, partitioning, gravity and thermal effect simulation

## ➤ Machining

- Promote machining precision, technology and machine, factory testing

## ➤ Installation

- 3 step, theodolite coarse adjust → photogrammetry tiny adjust → holography fine adjustment

## ➤ Compensation

- closed loop control active surface system, FEM model, real time surface measurement, active sub-reflector...



# Conclusion

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- Some surface measurement methods were researched, experimented in XAO for QTT pre-research
- System is easy to build, but hard to get high measurement precision
- Real time surface measurement challenge and chance
  - Very fast, Any elevation
  - Low resolution, for large scale deformation
  - Feedback, for closed loop active surface compensation
  - Collaboration on the new methods research



**Thank you !**

