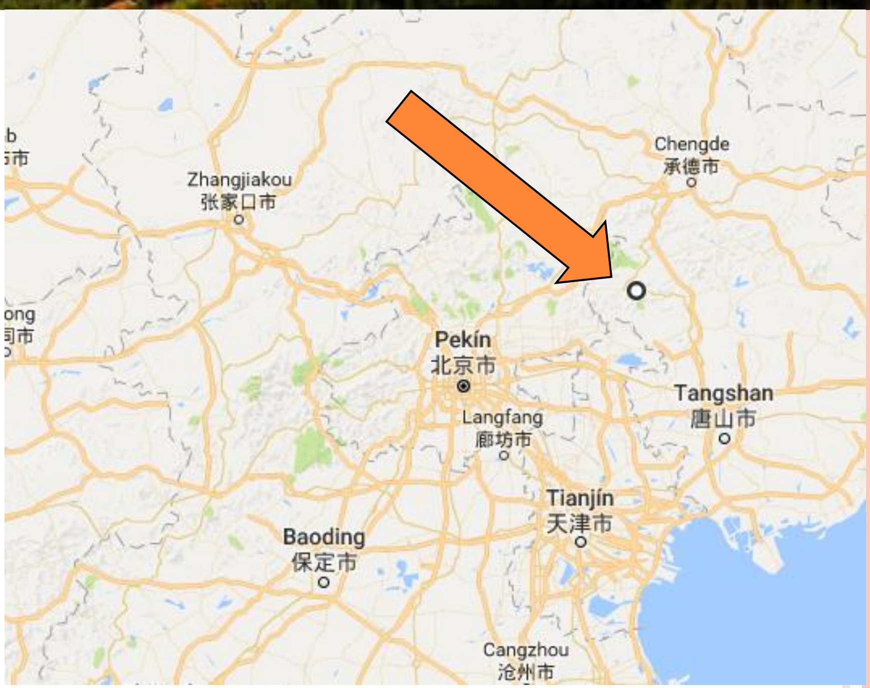
中国科学院国家天文台
NATIONAL ASTRONOMICAL OBSERVATORIES ,CHINESE ACADEMY OF SCIENCES

Comparison of baffle and vanes in open truss telescope: stray light control and airflow analysis

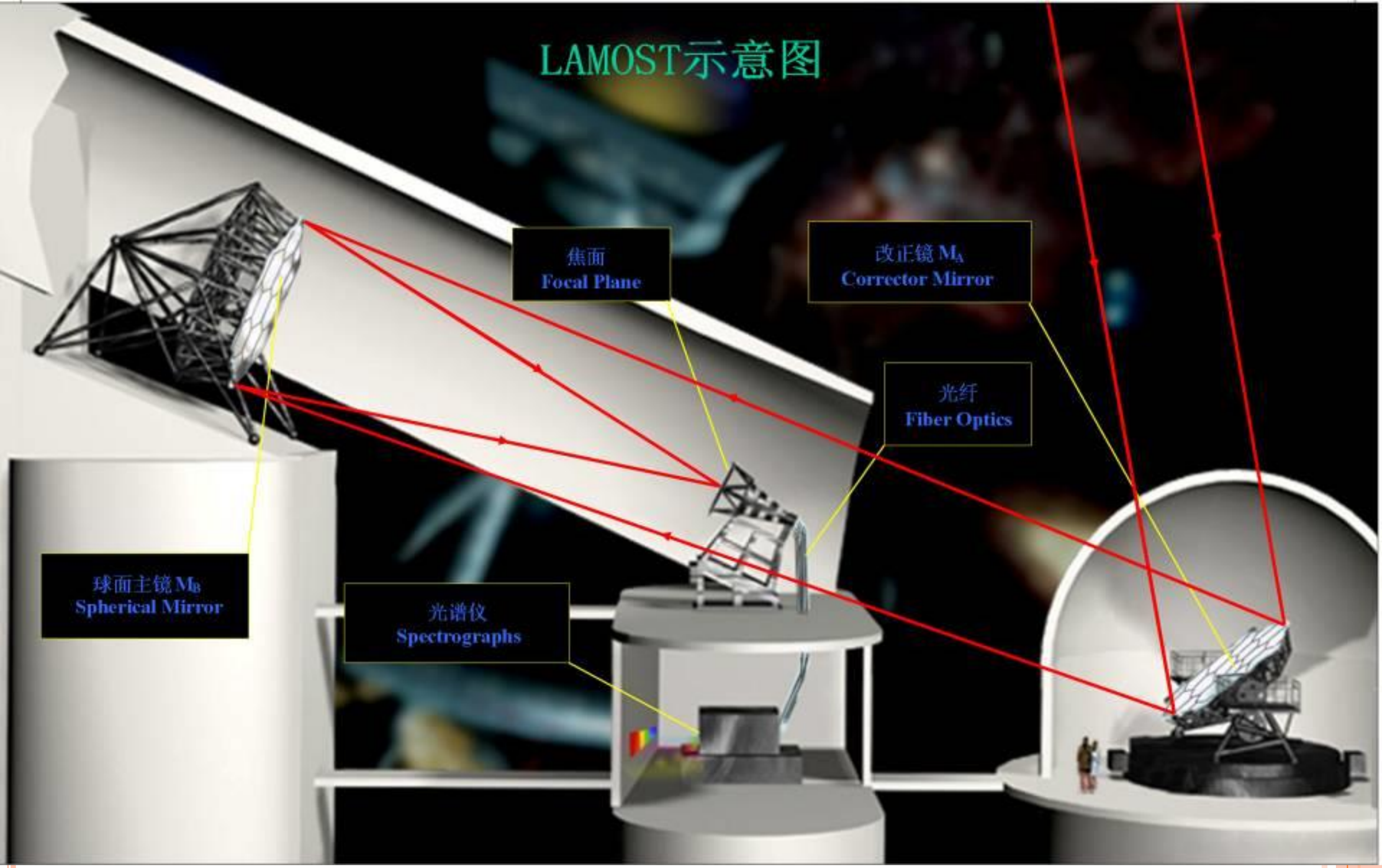
Taoran Li

National Astronomical Observatories, Chinese Academy of Sciences

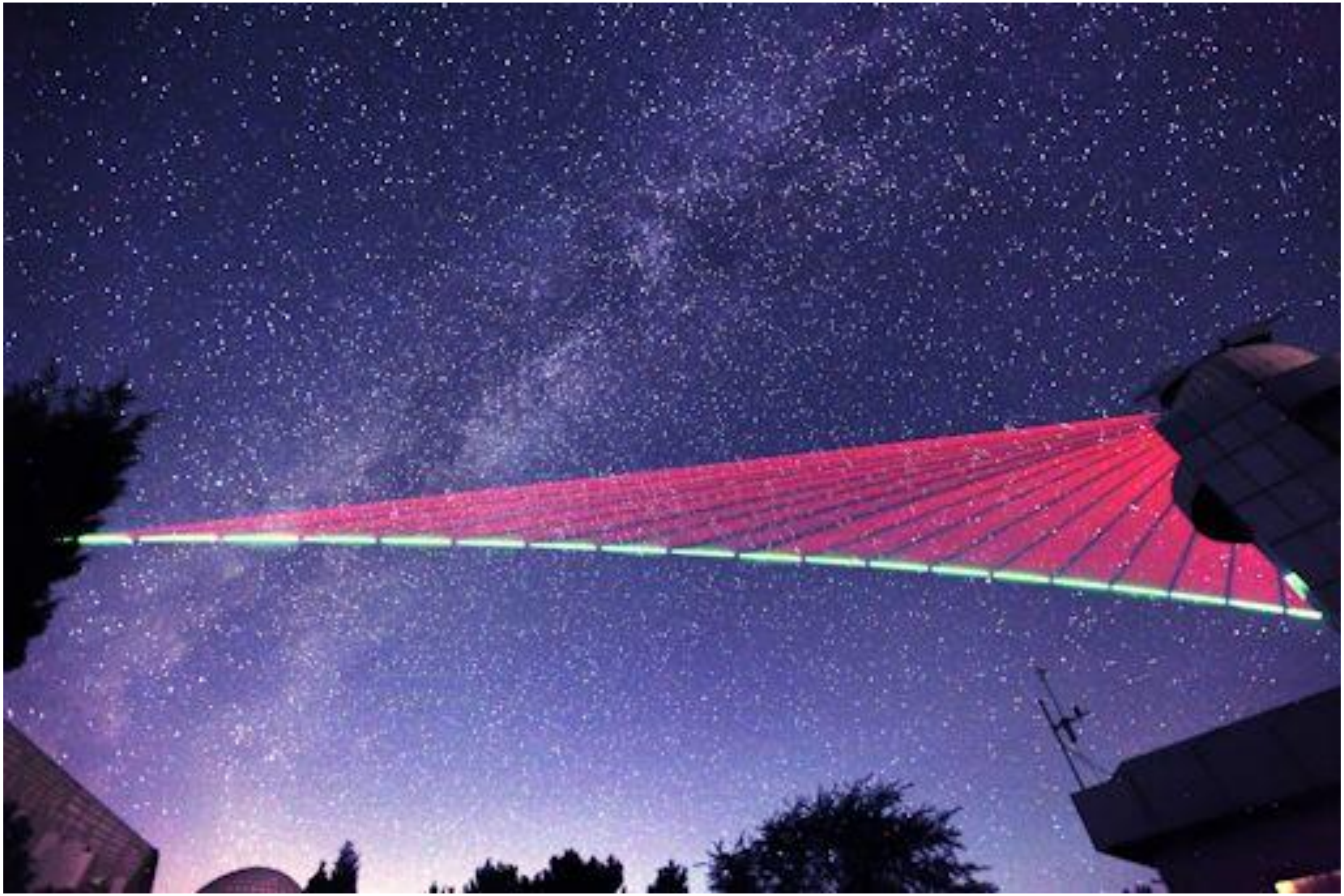
- Built in 1968
- 9 telescopes



Xinglong Station, 2005



Quantum Science satellite---Micius



Content

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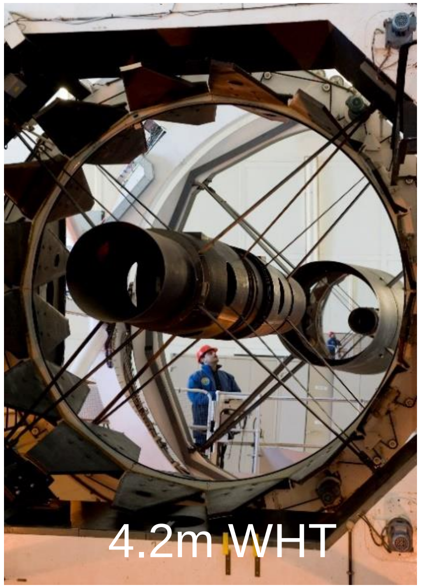
- Baffle turbulence
- Design and test about the stray light control equipments
- Summary

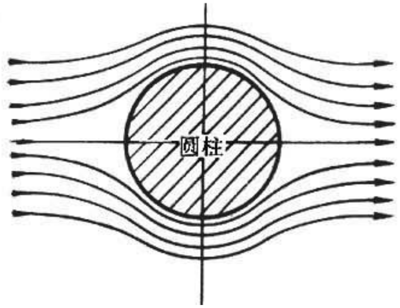
Introduction

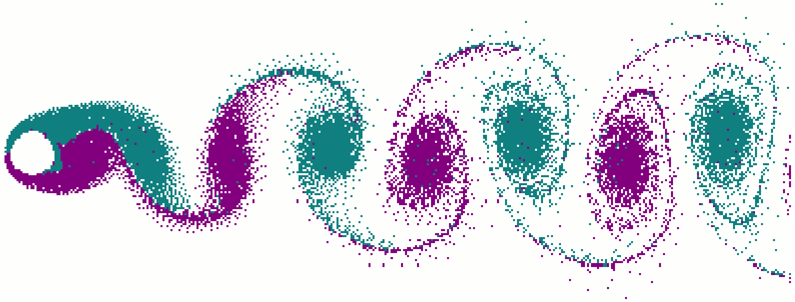
Stray light control methods

- Baffle



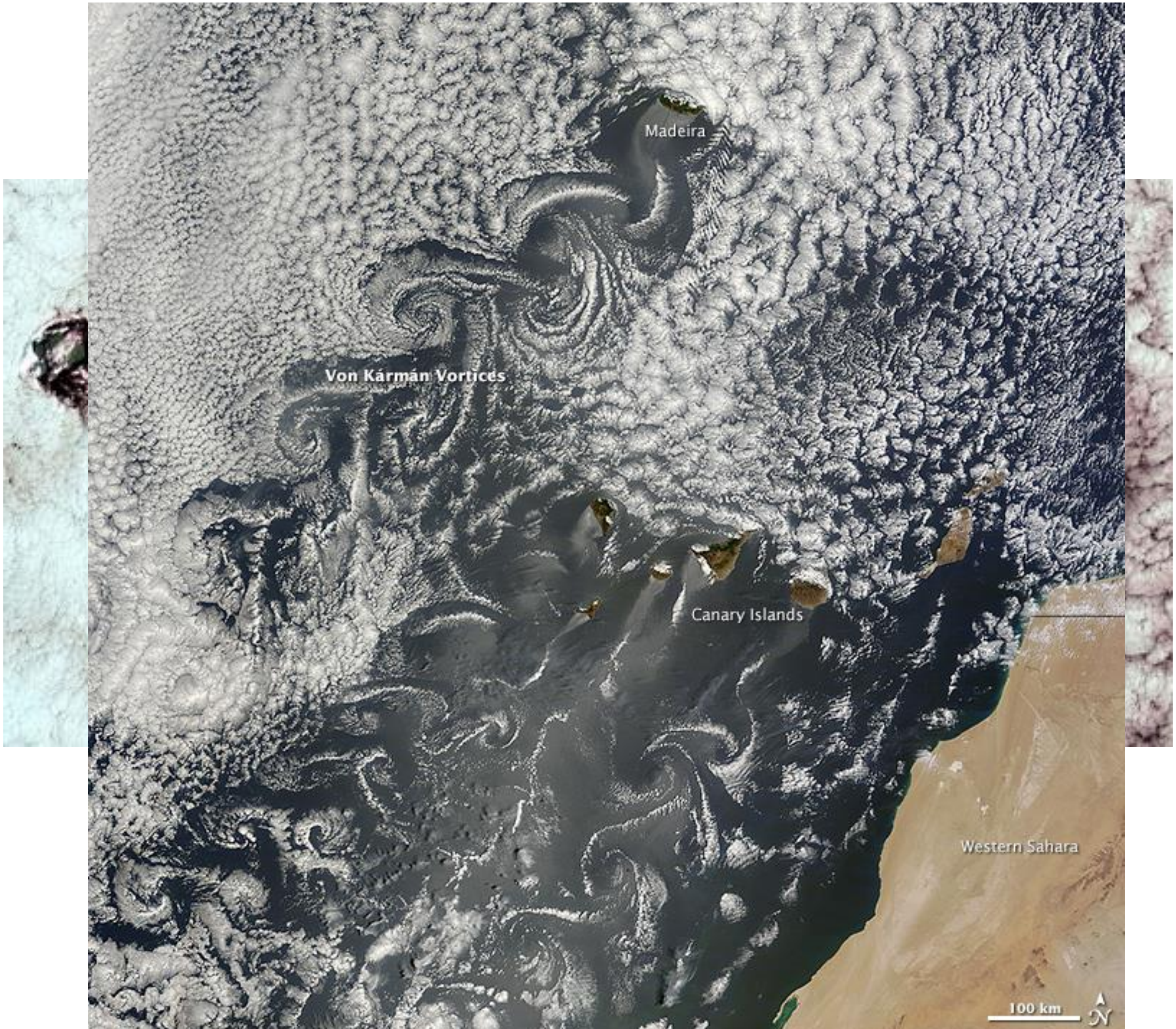
- Circular cylinder—Kármán vortex street





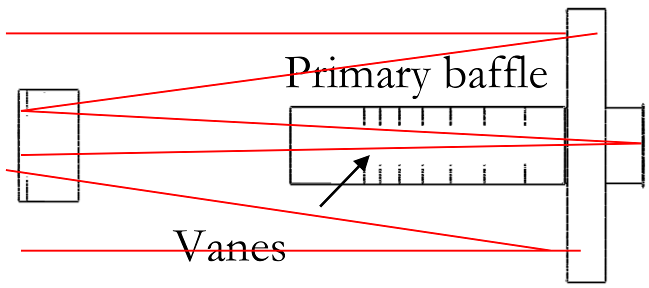
When does Kármán vortex street happen?

- Typically above a limiting *Re* value of about 90
- *Re*=Reynolds number
- $Re = \frac{D \cdot V}{\upsilon} = \begin{cases} < 2000 \ \ laminar\ flow \\ 2000 \sim 4000\ laminar/turbulent \\ > 4000\ turbulent\ flow \end{cases}$
  - D = the diameter of the cylinder (or some other suitable measure of width of non-circular bodies) about which the fluid is flowing.
  - V = the steady velocity of the flow upstream of the cylinder.
  - υ = the kinematic viscosity of the fluid. For air, $\upsilon = 13.27 mm^2/s$
  -
  - ie. D=30cm,V=1m/s, *Re*=22607
- For telescope, almost always turbulent!


Madeira
Von Kármán Vortices
Canary Islands
Western Sahara
100 km
N

Research status

- Normally stray light control methods：
  - Baffle and vanes；
  - Aperture stops、Field stops、Lyot stops；
  - High absorptivity coating



- Stray light control research：
  - No particular study on comparing the capability of baffle and vanes；
  - Lack of test；
  - No study on air turbulence above the mirror affected by baffle

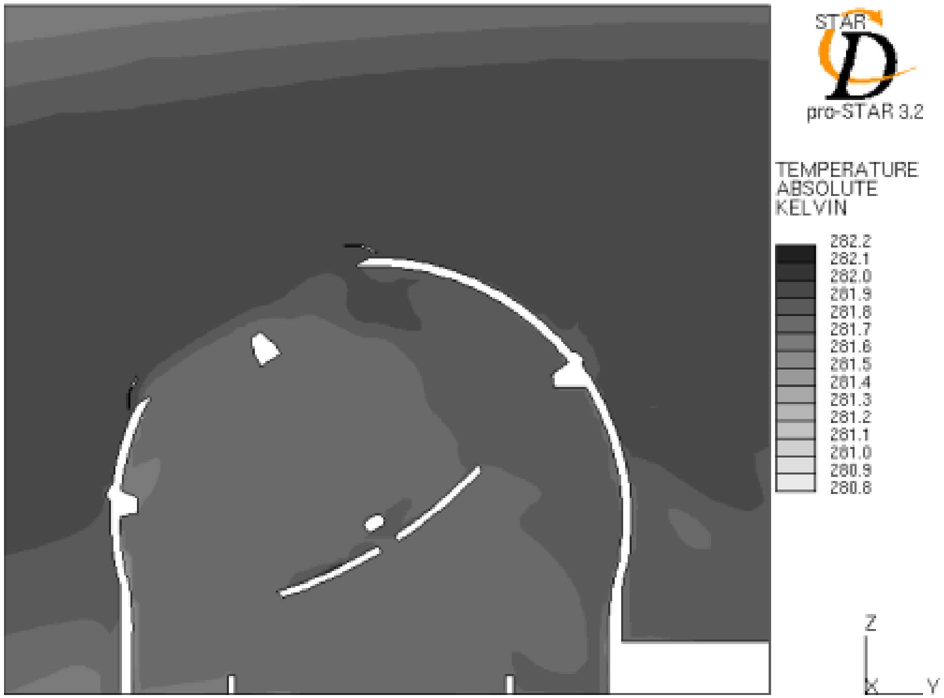
My research includes

1. Stray light analysis and control about reflection optical telescope
   - Focus on comparing baffle with vanes
   - Example :50cm Binocular Network(50BiN) and

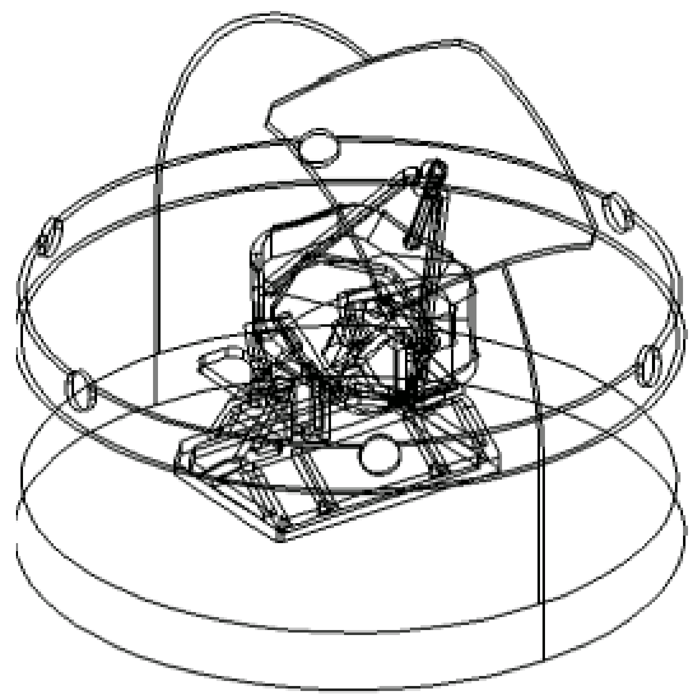
     Xinglong 50cm telescope

2. Air flow analysis about the stray light control equipment
   - Computational Fluid Dynamics, CFD
   - Focus on comparing baffle with vanes

- CFD in ongoing telescopes, TMT, E-ELT...



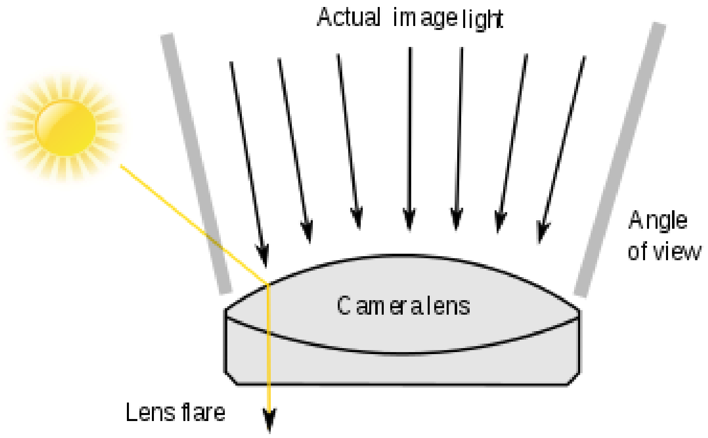
Telescope zenith angle 32, azimuith 90, vents closed, external wind 10m/s



Stray light analysis

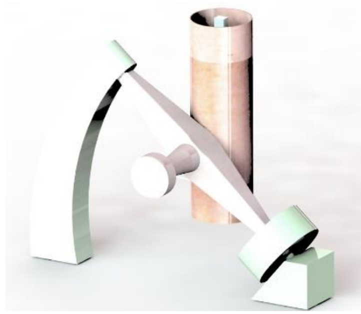
What is Stray light?

- Stray light is defined as unwanted light that reaches the focal plane of an optical system.
- It is one of the most important factors that influence the high-accuracy photometry of optical astronomical telescopes, which would reduce the signal to noise ratio of astronomical objects.

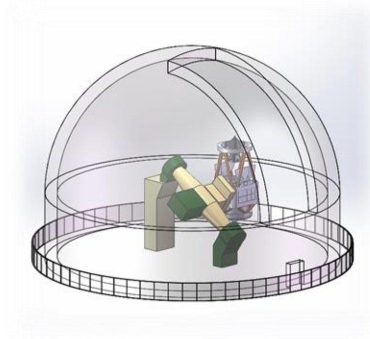


Model of telescopes

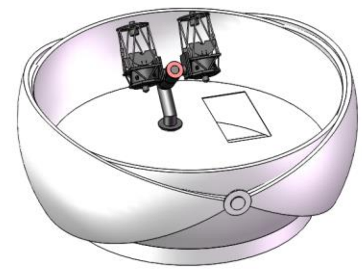
50cm cassergrain focus



85cm prime focus



2.16m *classical* dome

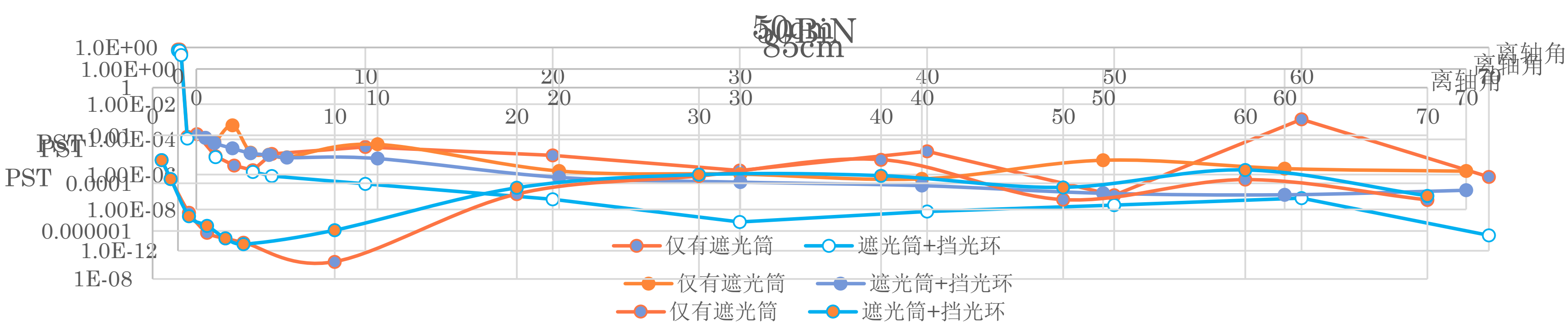


50BiN *clamshell* dome

Many simulations about stray light:

Comparison between baffle and vanes

PST(Point Source Transmission)=E(focal plane)/E(entrance)



50BiN stray light analysis

SONG （Stellar Observations Network Group-SONG）

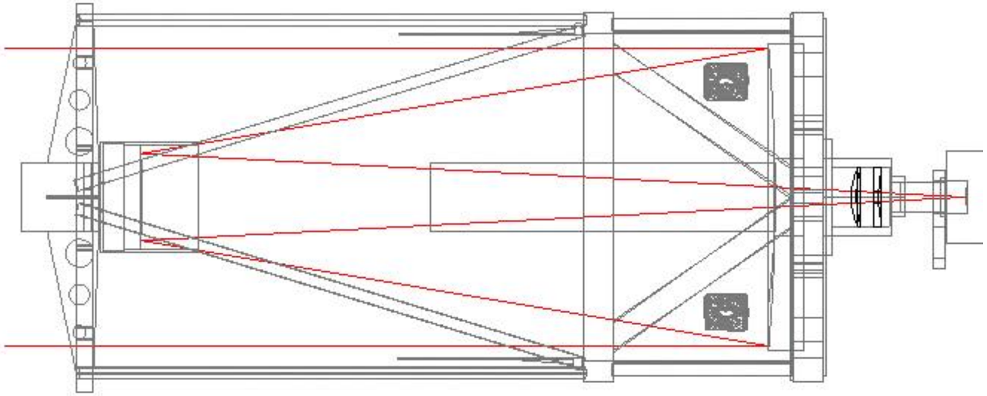
- 8 sites(4 north, 4 south)
- Two completed

50BiN （50cm Binocular Network-50BiN）

- Share the sites with SONG(north)
- Chinese proposal
- One completed

50BiN details

- Aperture: 500mm
- Focal ratio: 9.5
- Open-truss, R-C system
- Two identical telescopes

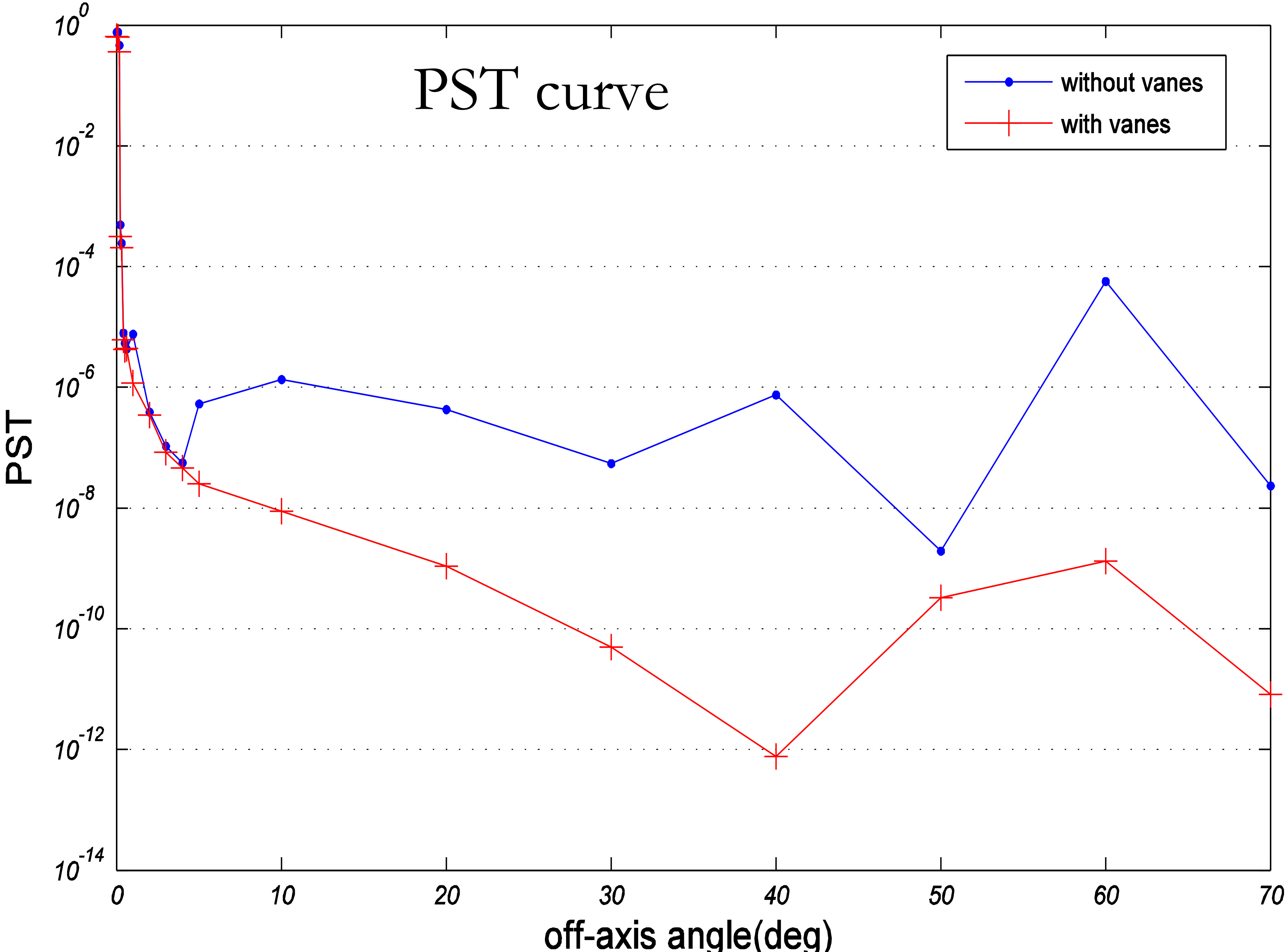


TracePro

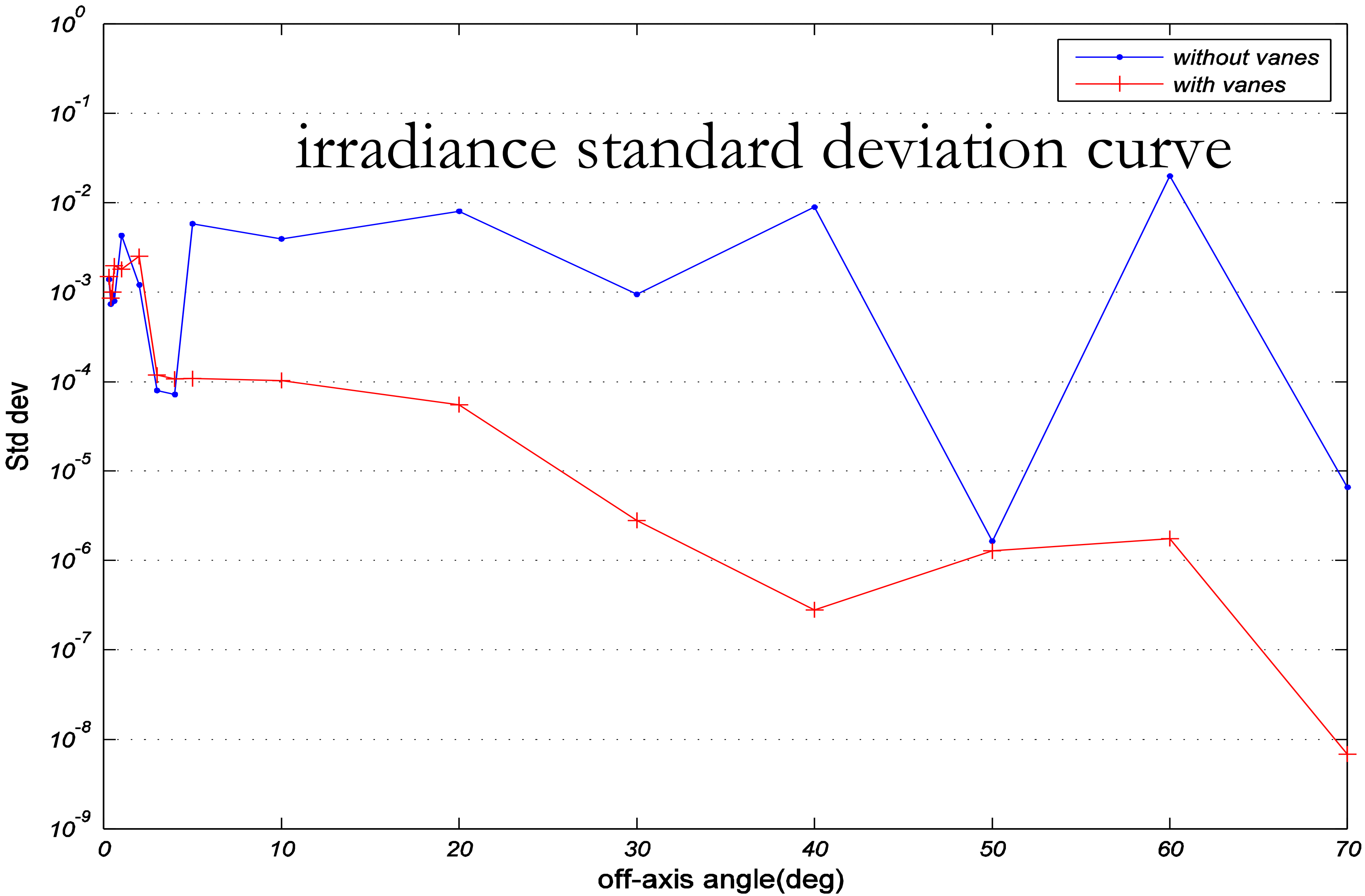
- Input parameters：

1. Light source
2. Incident angle
3. Rays number
4. BRDF
5. Threshold
6. 。。。。

50BiN stray light simulation-1



50BiN stray light simulation-2



50BiN stray light simulation-3

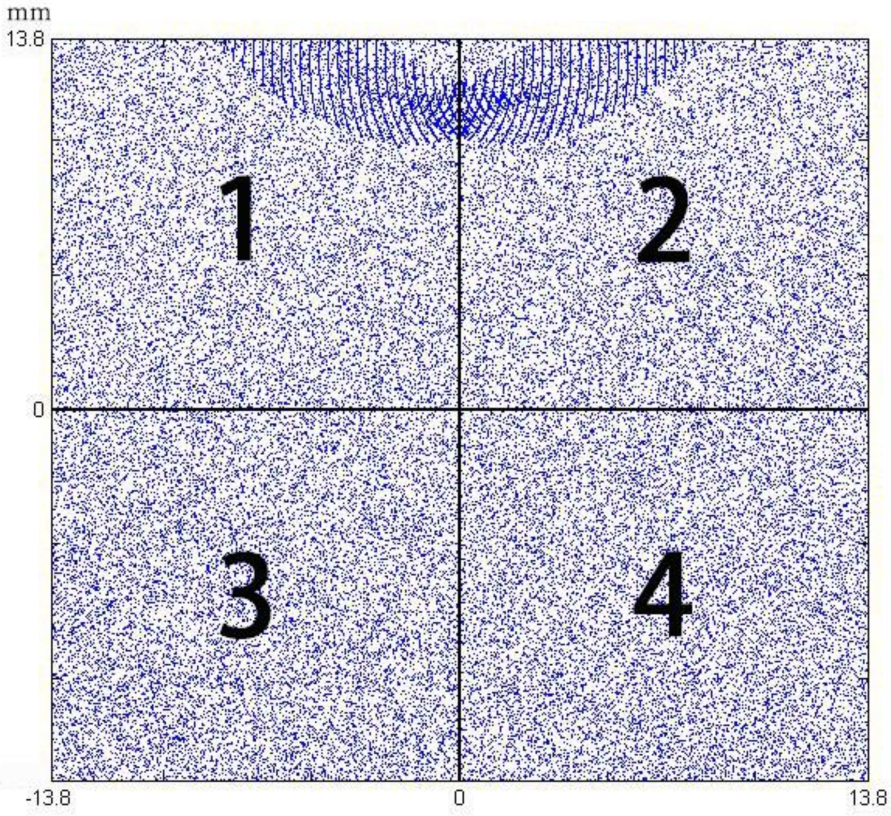
- For convenient, split the CCD plane into 4 areas, record all the coordinate and irradiance value of every incident angles.

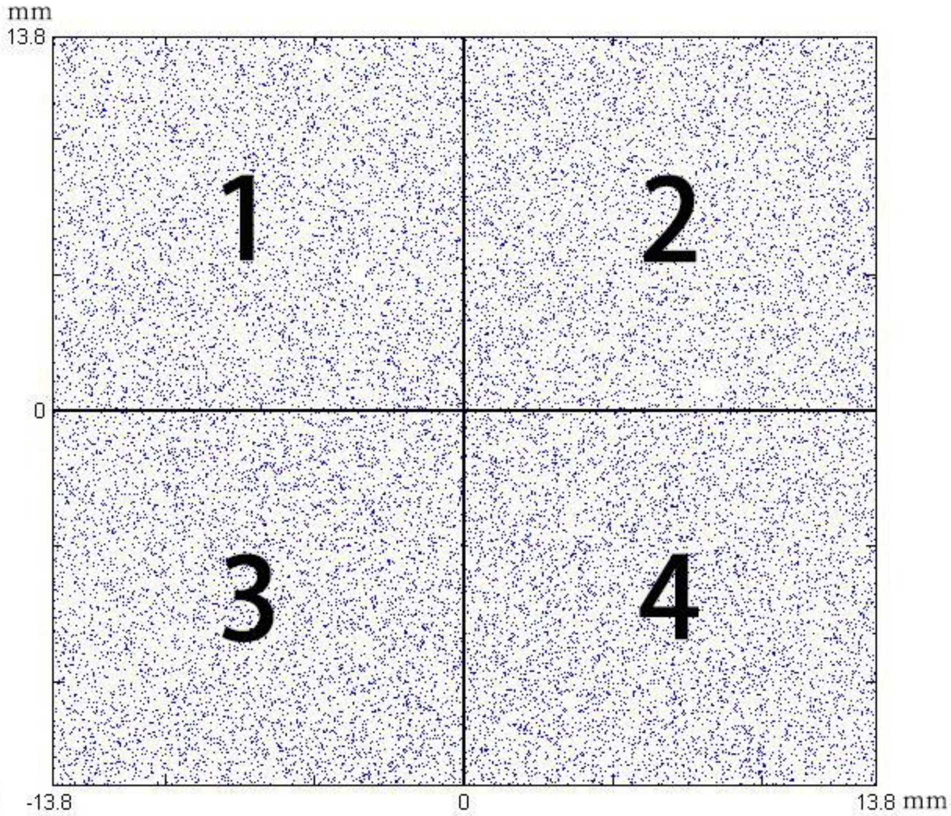
	Without vanes		With vanes	
Area	Number of rays	Irradiance(%)	Number of rays	Irradiance(%)
1	147258	22.2	91051	19.9
2	146761	22.2	90755	18.8
3	139391	33.9	103572	30.5
4	138941	21.7	103422	30.8
Total rays	572351		388800（-32.1%）	
Standard deviation	1.5‰		1.4‰	

50BiN stray light simulation-4

- Import the TracePro data to MATLAB
- Incident angle : 0.5 degree

Stray light distribution, without vanes(left), with vanes(right)

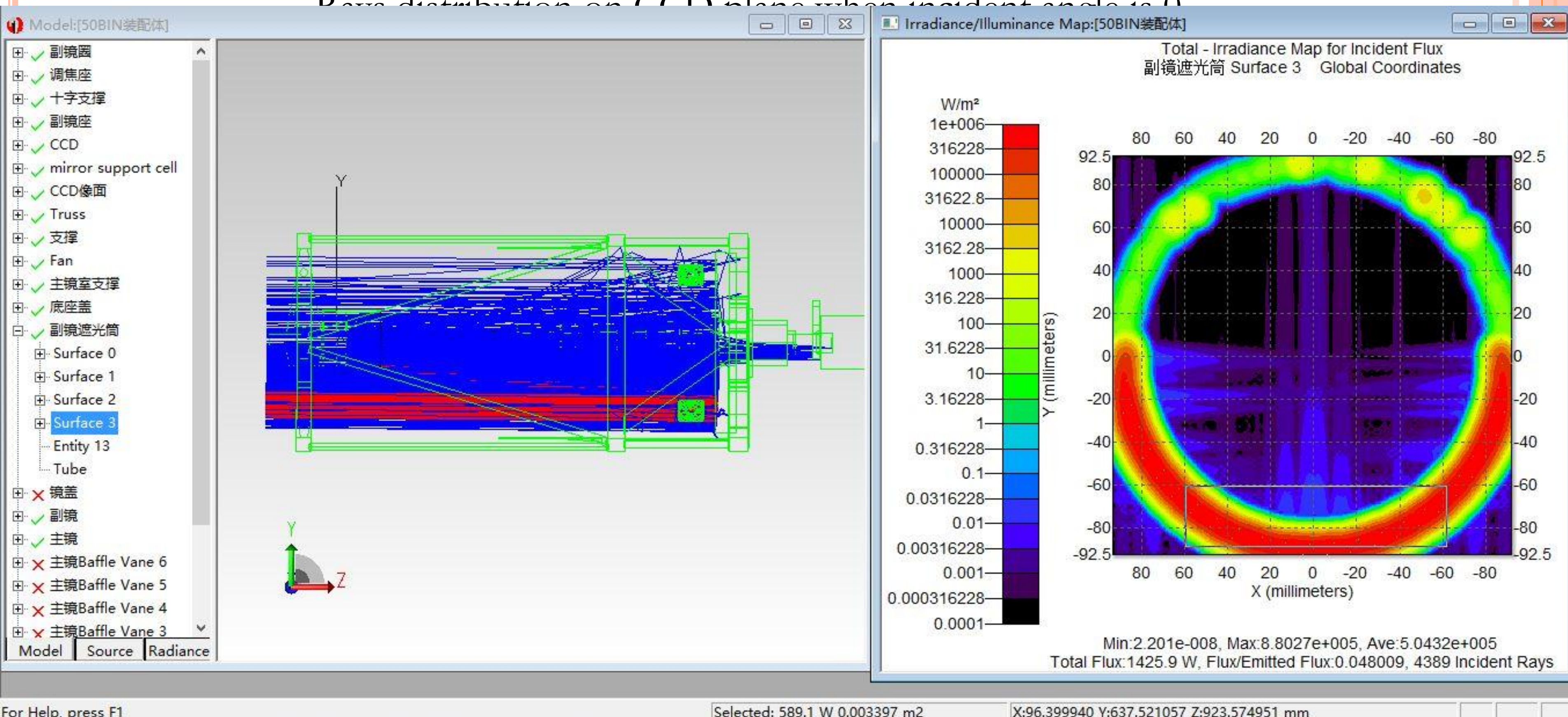


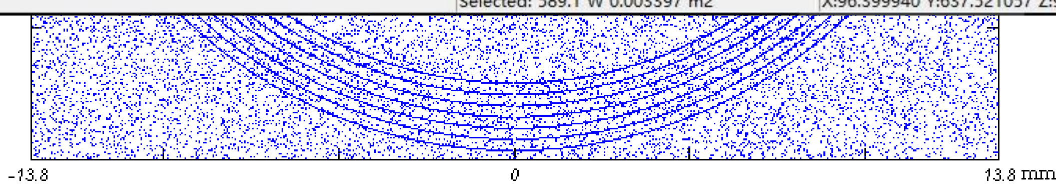


50BiN stray light simulation-5

- Primary mirror-secondary baffle edge-inner surface primary baffle-CCD plane

Rays distribution on CCD plane when incident angle is 0



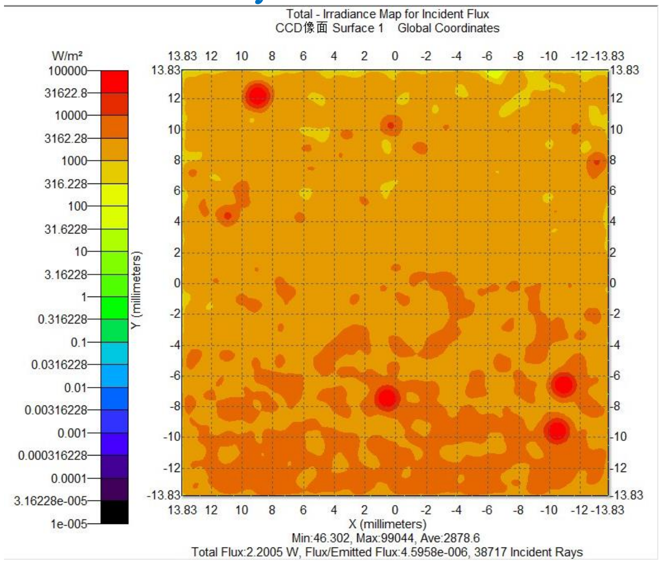


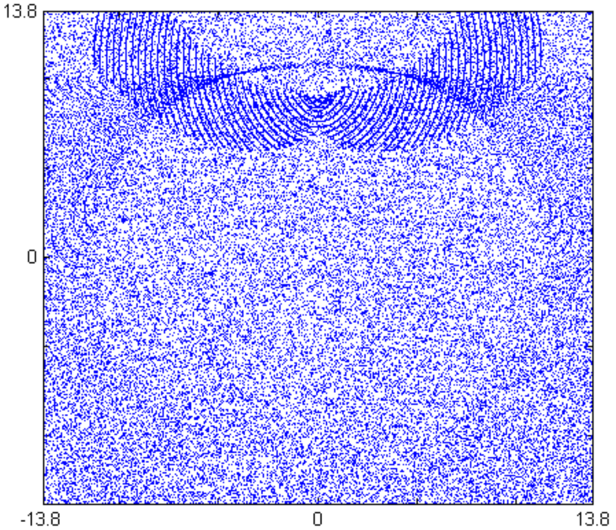
50BiN stray light simulation-6

- Incident angle =0.4 , TracePro vs Matlab

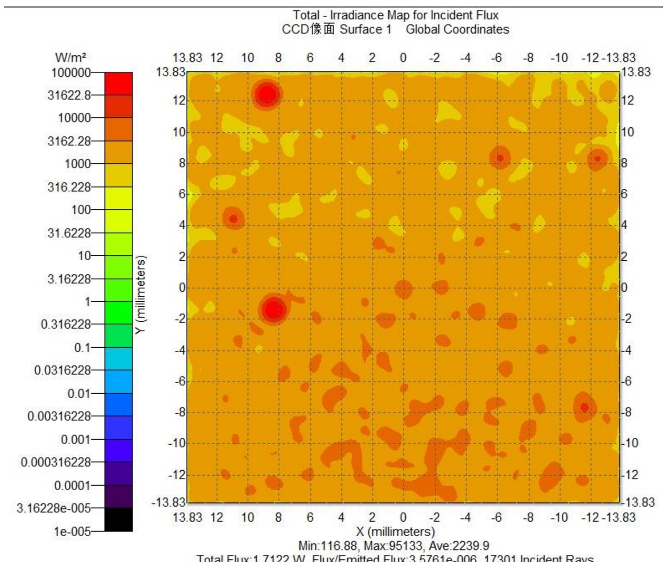
intensity distribution | location distribution

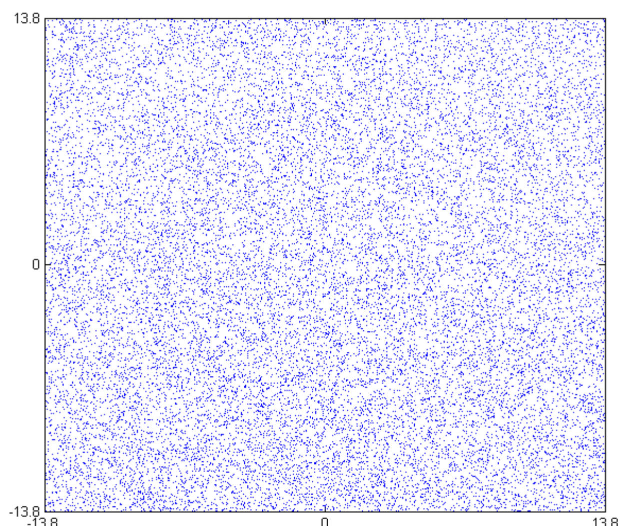
Without vanes





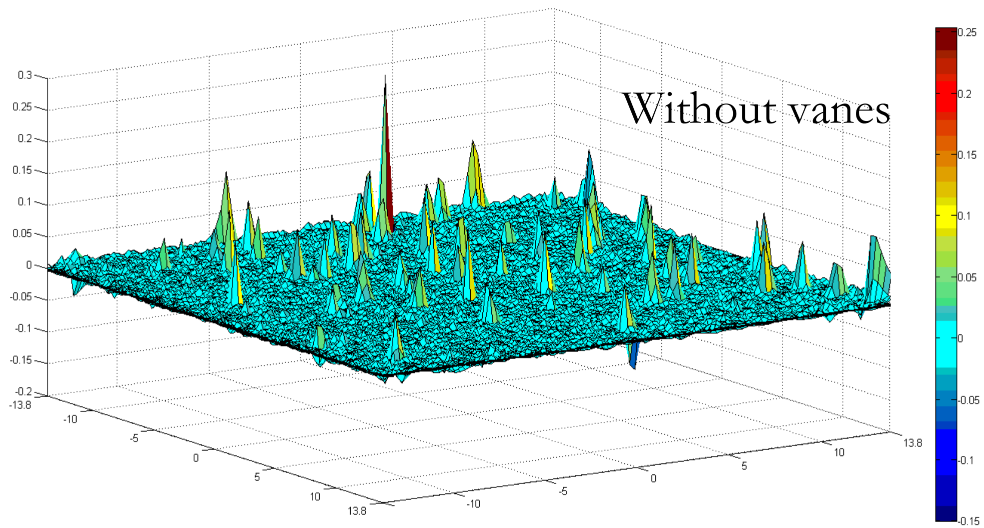
With vanes

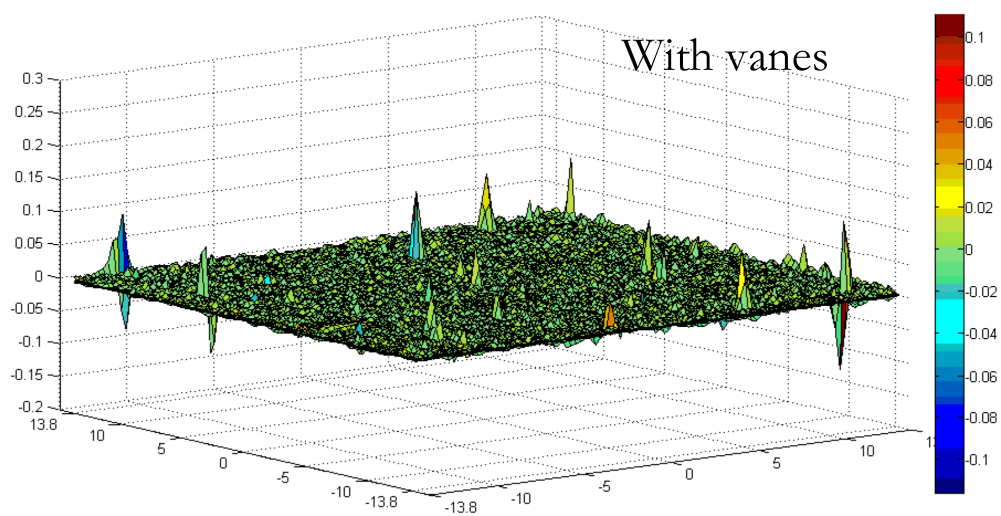




50BiN stray light simulation-7

3D distribution





Disadvantage

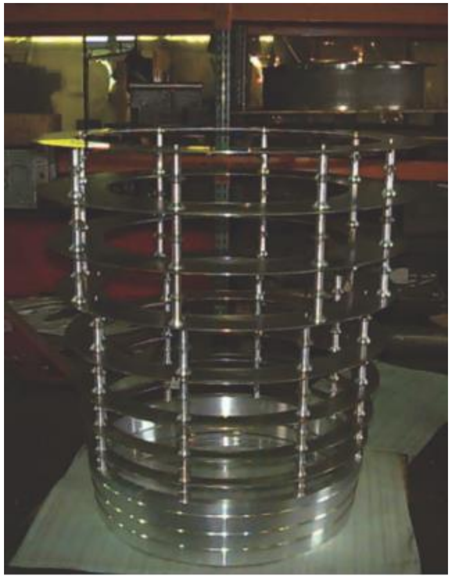
1. TracePro needs so much CPU and memory that we can not simulate all the incident angle one time. We can only simulate some angles and combine them. Therefore, it is only a qualitative research.
2. The software uses randomized algorithm. We have to choose the right number of incident rays.
3. Too much time.

Baffle turbulence

Baffle turbulence -1

- Background

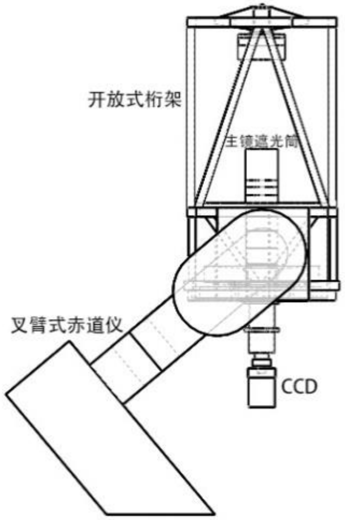
SDSS--Sloan Digital Sky Survey

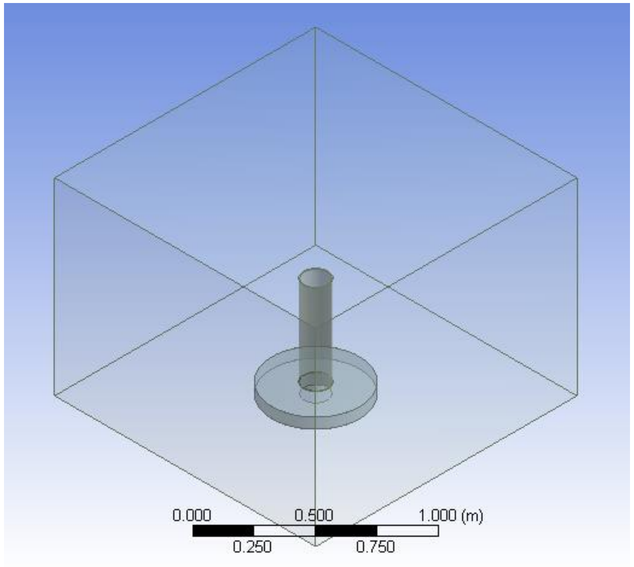


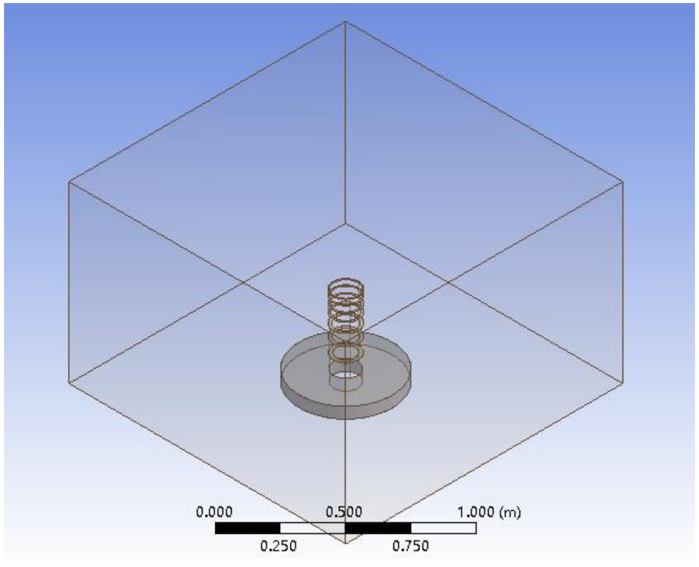

LCOGT--Las Cumbres Observatory Global Telescope Network


Baffle turbulence -3

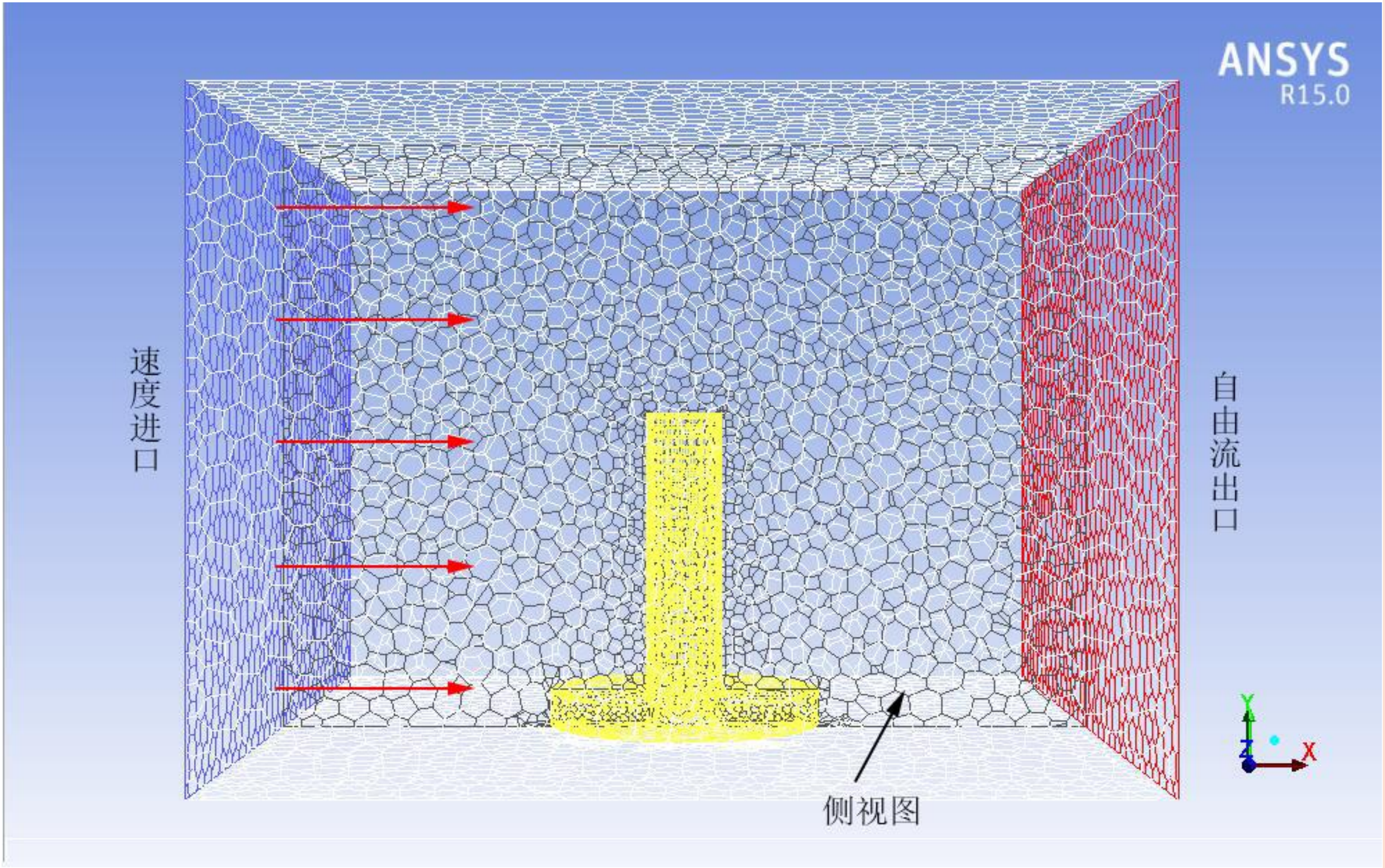
- Comparison between baffle and vanes
- Velocity=1m/s, initial ambient temperature=273K, initial mirror temperature=278K







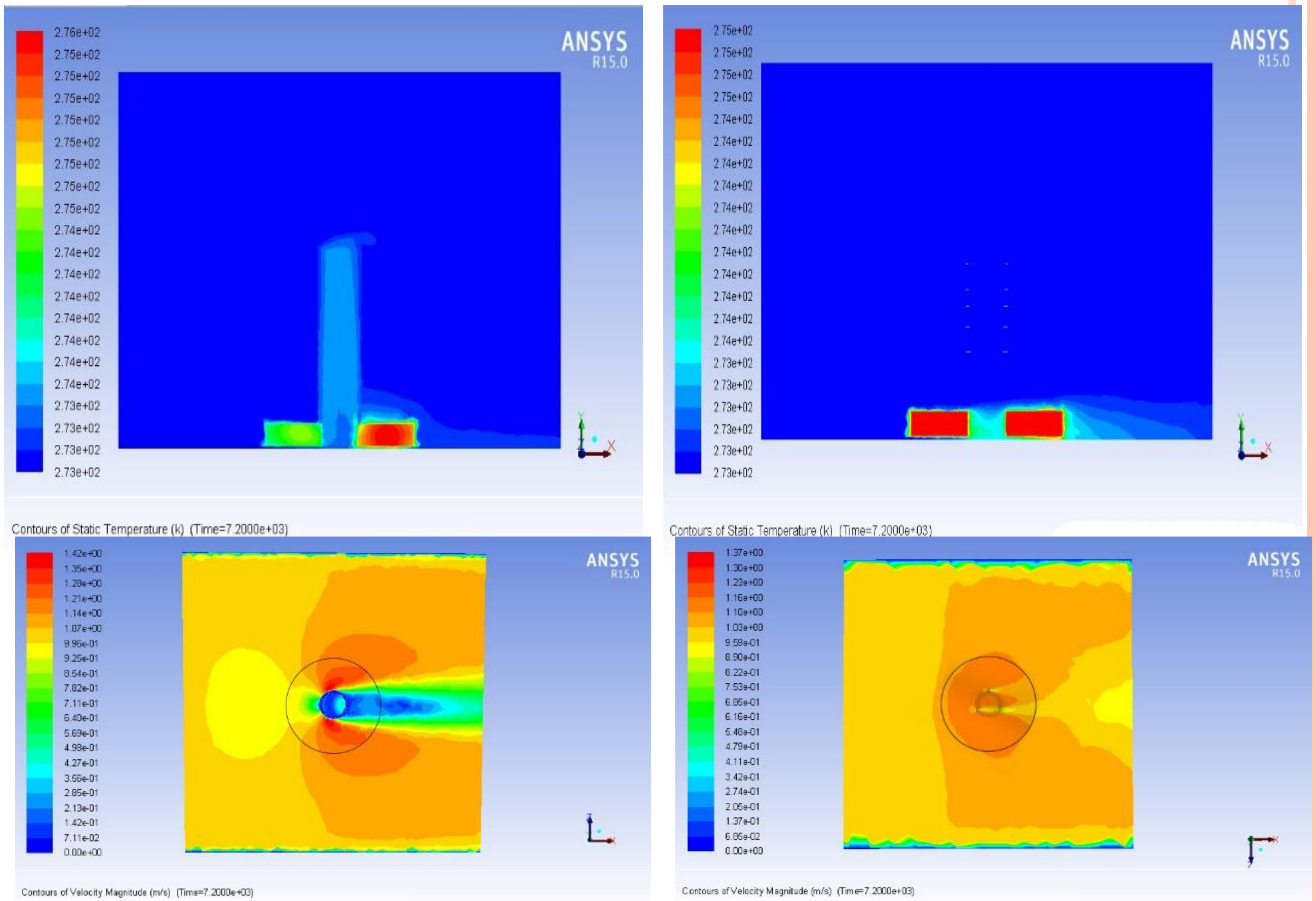
Baffle turbulence -4



Baffle turbulence -5

- Disadvantage of baffle :

1. Mirror cooling and temperature inside the baffle;
2. Turbulence behind the baffle, Kármán vortex street



Mirror seeing

- Seeing formulas：

$$\begin{cases} \theta = 0.975863\dfrac{\lambda}{r_0} \\ r_0 = \left[0.423\left(\dfrac{2\pi}{\lambda}\right)^2 (cos\gamma)^{-1}\displaystyle\int_{Vertical} C_N^2(z)dz\right]^{-3/5} \\ \theta = 1.0854\times 10^6\lambda^{-\frac{1}{5}}\left[(cos\gamma)^{-1}\displaystyle\int_H C_N^2(z)dz\right]^{\frac{3}{5}} \\ C_N^2 = C_T^2\left[77.6\times 10^{-6}(1+7.52\times 10^{-3}\lambda^{-2})\dfrac{P}{T^2}\right]^2 \end{cases}$$

For Xinglong Station, altitude =960m, P=901mb；

In case of $\lambda = 500nm$：

$$\theta = \frac{8.418\times 10^5}{T^{2.4}}\left[\int_H C_T^2(z)dz\right]^{\frac{3}{5}}$$

With baffle $\theta = 0.15''$, without baffle $\theta = 0.04''$

Design and test about the stray light control equipments

Vanes installation

1. Punching

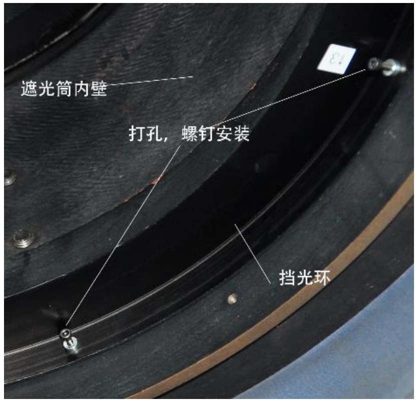
For big diameter of baffle

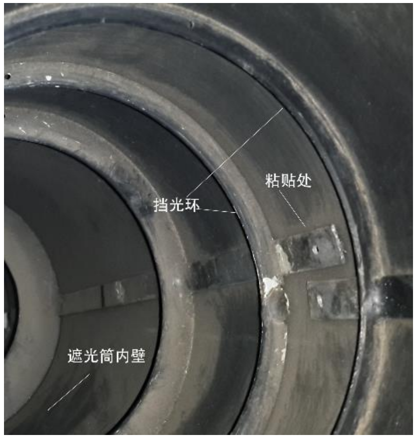
2. Pasting

Each vanes pasted on a long plate, then pasted on the inside surface of the baffle

3. One Batch Forming

For spiral pitch, like baffle of digital camera





Independent vanes

Advantages:

- Easy to adjust the interval;
- Contribute to air flow;
- Low cost;
- Easy to install and maintain;
- Easy to switch baffle/vanes, convenient to the following experiments

- The outer diameter of the vanes is equal to the inner diameter of the baffle.

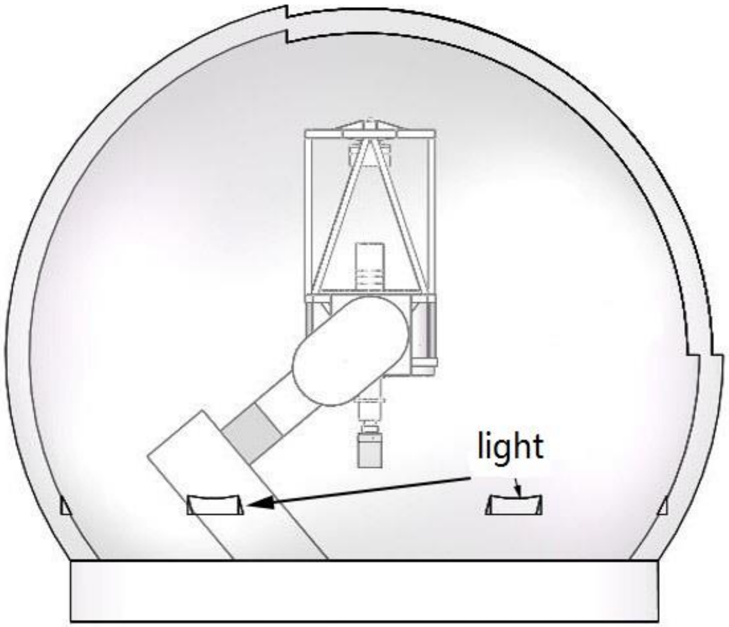
Experiments about baffle and vanes

- Off sky(inside the dome)experiments
  - No vanes and baffle
  - Only vanes, no baffle
  - Baffle+vanes
- On sky experiments
  - Only vanes, no baffle
  - Baffle+vanes
- Why on small open truss telescope?
  - It is convenient and quick to change the baffle and vane on small open truss telescope.

Off sky experiments-1

3 circumstances：

- No vanes and baffle
- Only vanes, no baffle
- Baffle+vanes



Methods：

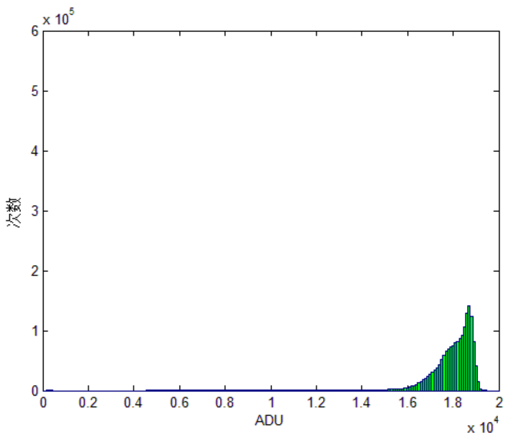
- Close the dome, park telescope to zenith；
- Turn on the light
- Exp-time: 1s

Off sky experiments-2

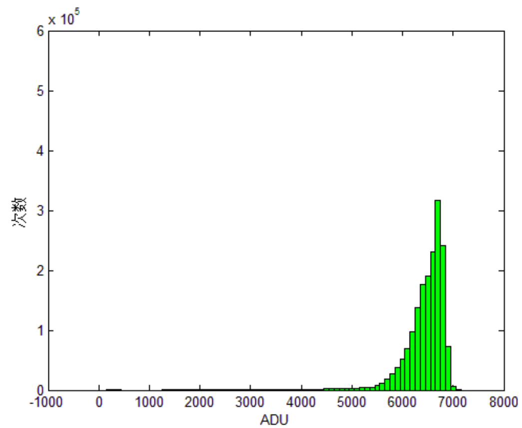
- Import the image(fit) to MATLAB;

ADU	Max	Median	Std.dev
No vanes and baffle	19429	18187	1269
Only vanes, no baffle	7102	6549	494
Baffle+vanes	4360	4024	314

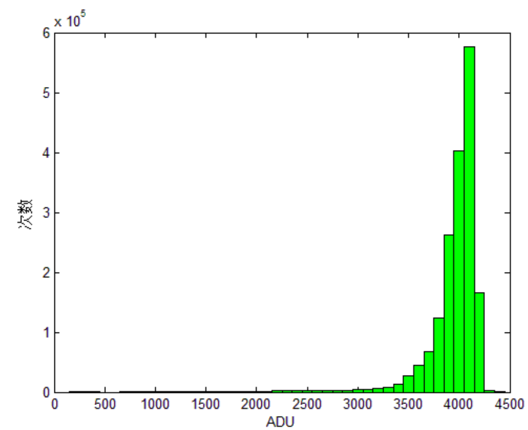
- Histogram



No vanes and baffle(left)



Only vanes(middle)

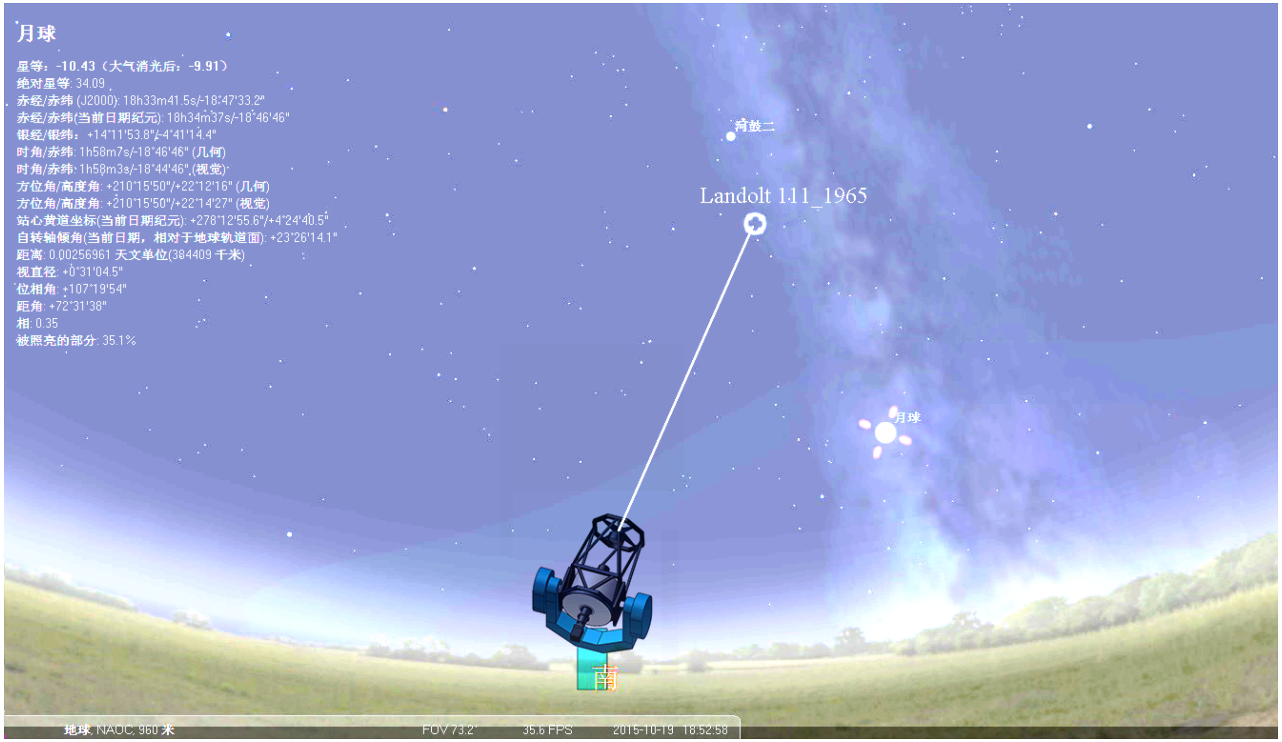


Baffle+vanes(right)

	ADU range	Frequency	Percentage
No vanes and baffle	18700-18800	141736	8.14%
Only vanes, no baffle	6700-6800	317133	18.21%
Baffle+vanes	4000-4100	576913	33.12%

On sky experiments-photometry

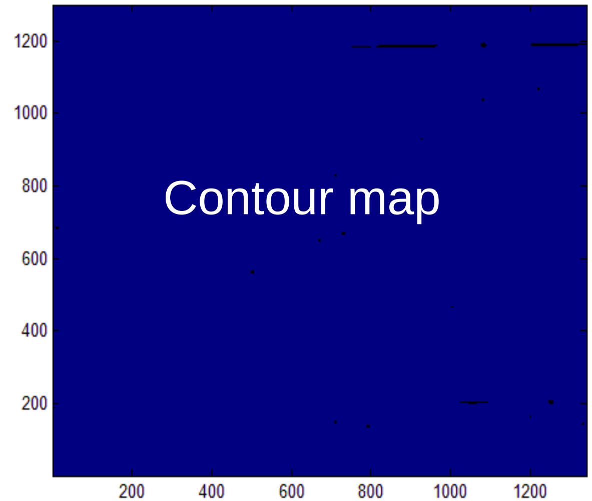
- Landolt 111_1965， moon phase 35%， about 26 degrees between moon



IRAF==unit：counts		Msky	Mag
111_1965	Baffle+vanes	2053.56	11.33
	Only vanes	2054.36	11.26
111_1969	Baffle+vanes	2061.51	9.79
	Only vanes	2074.50	9.78

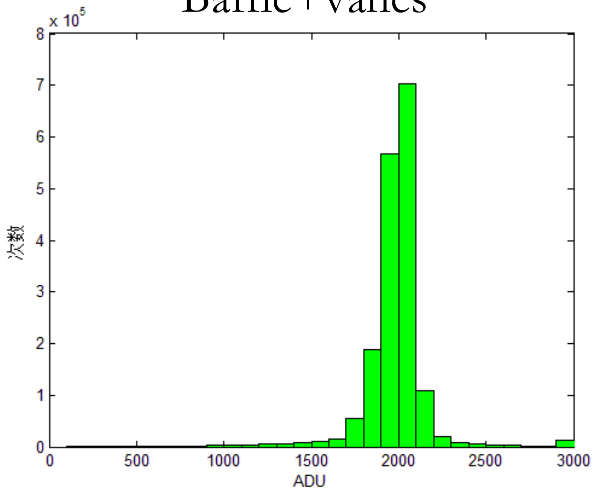
On sky experiments-background value

- Background value—stray light uniformity

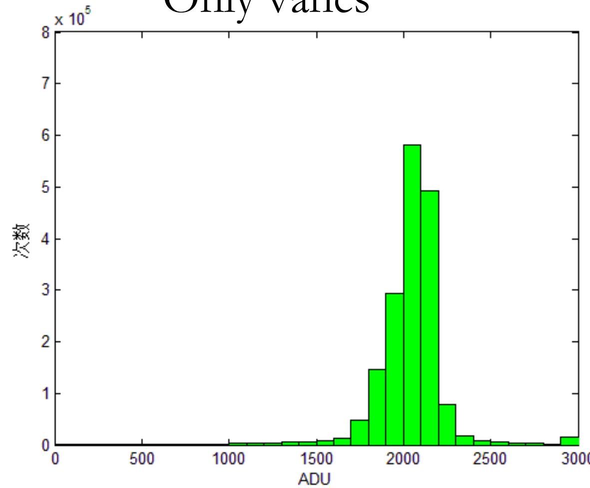


- Histogram, determine the ADU range

Baffle+vanes



Only vanes

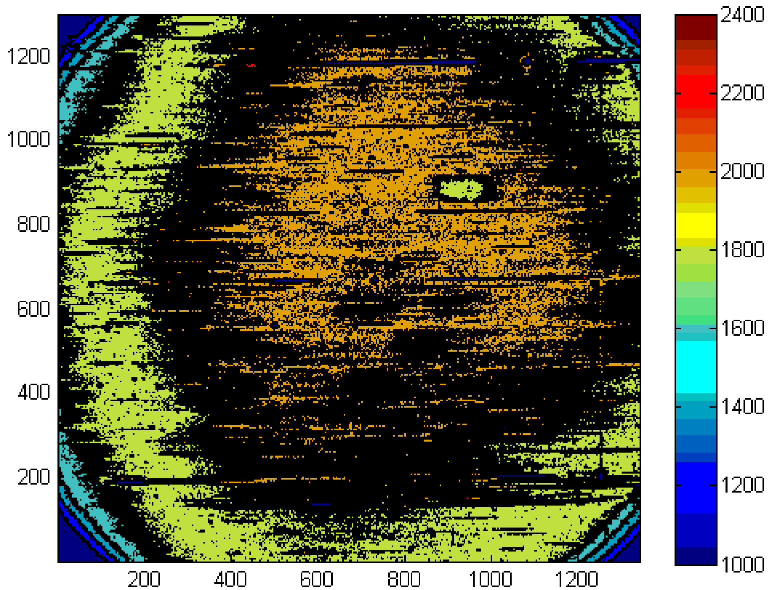


On sky experiments-background value

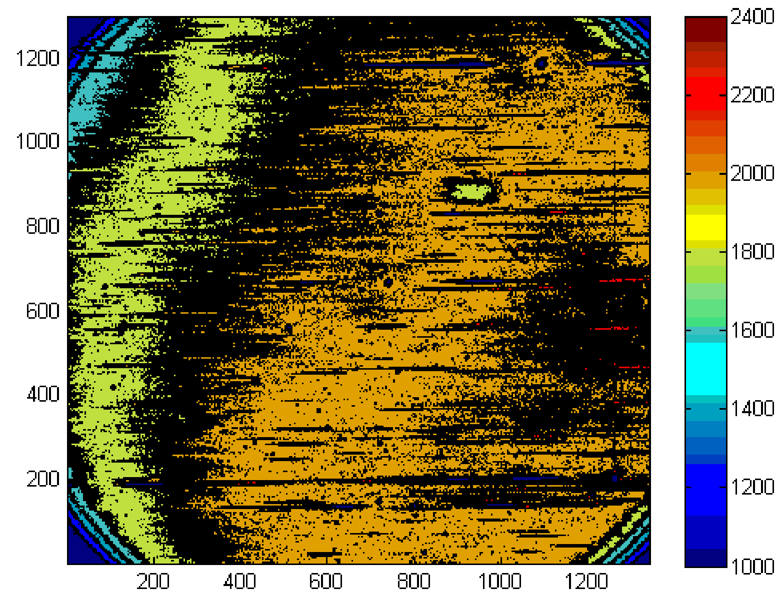
- ADU(ADU>2500)=1000

	Median	Std.dev	ADU range	Percentage
Baffle+vanes	2000	673	2000-2100	40.35%
Only vanes	2064	712	2000-2100	33.34%

Baffle+vanes

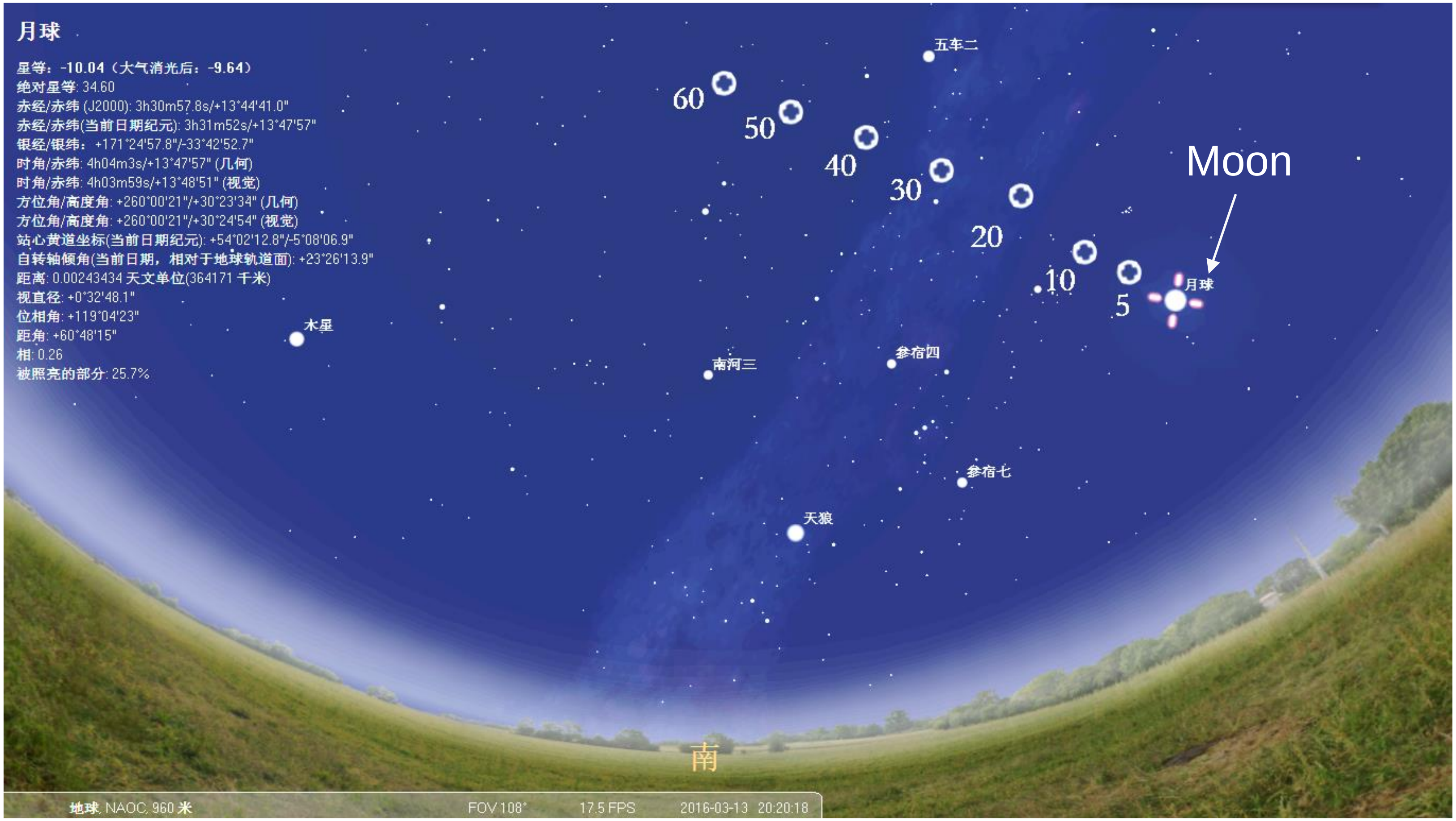


Only vanes



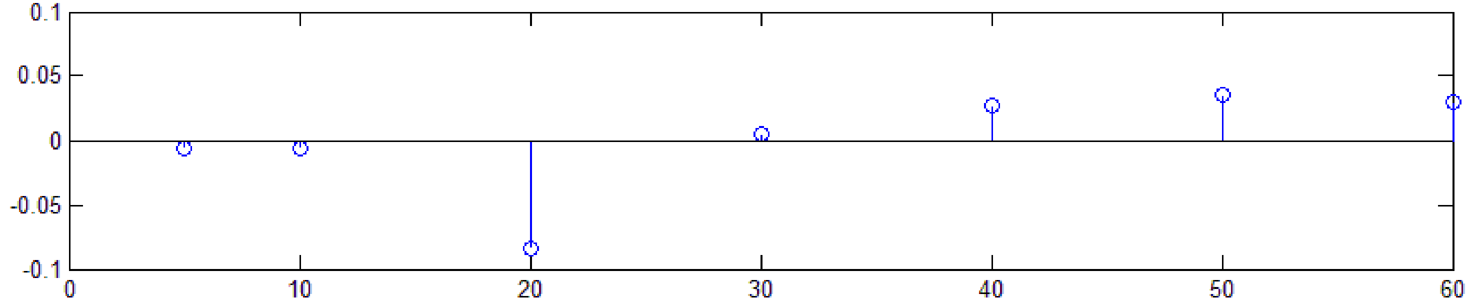
On sky experiments-stray light source changing

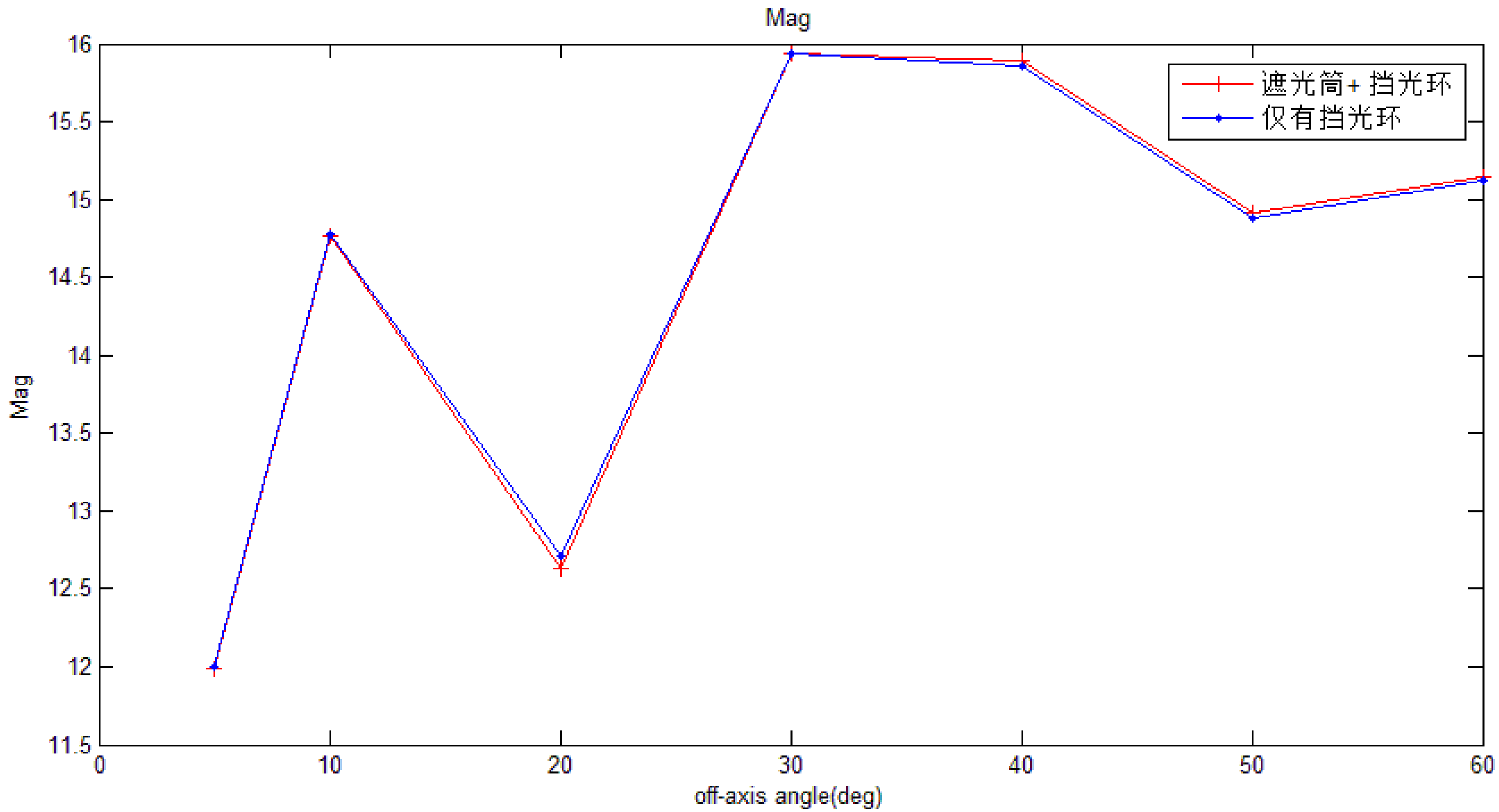
- Moon phase: 26%
- The telescope pointed to the sky areas which were 5, 10, 20, 30, 40, 50, 60 degrees to the moon.



On sky experiments-stray light source changing

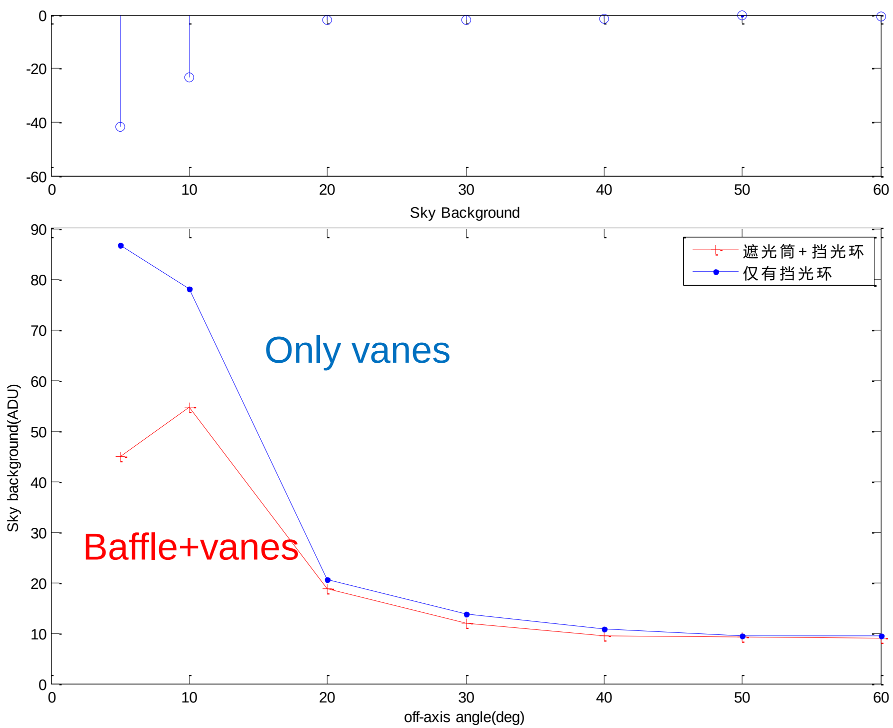
- Photometrical magnitude(baffle+vanes vs only vanes)

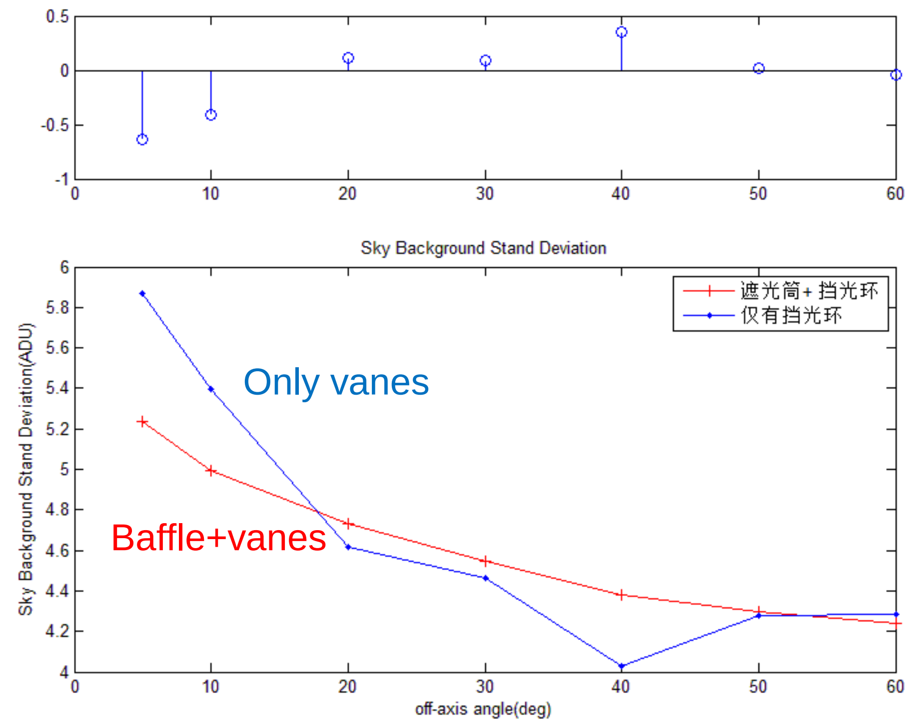




On sky experiments-stray light source changing

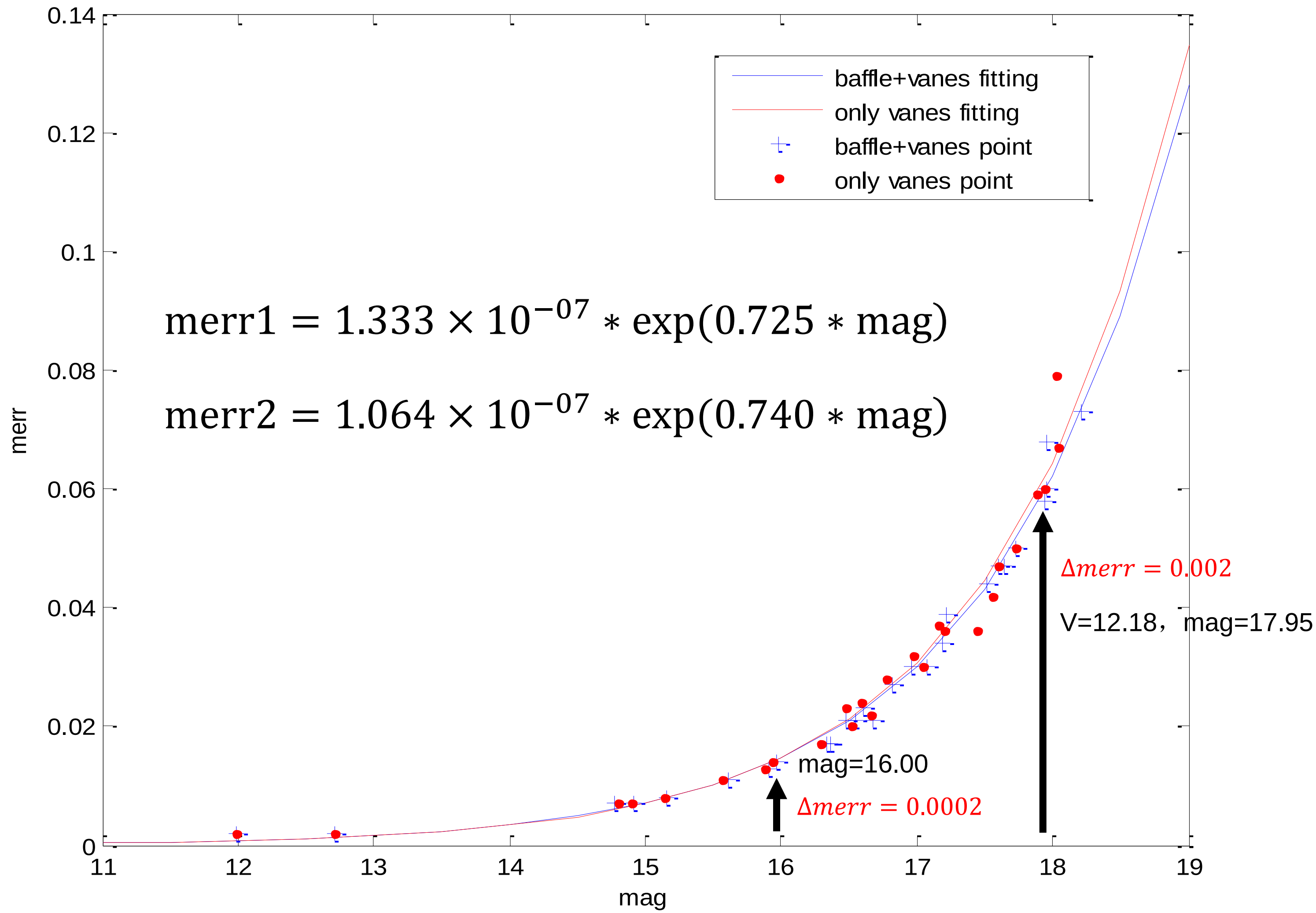
- Sky background value(left) and standard deviation(right),
- Msky and Std in IRAF results





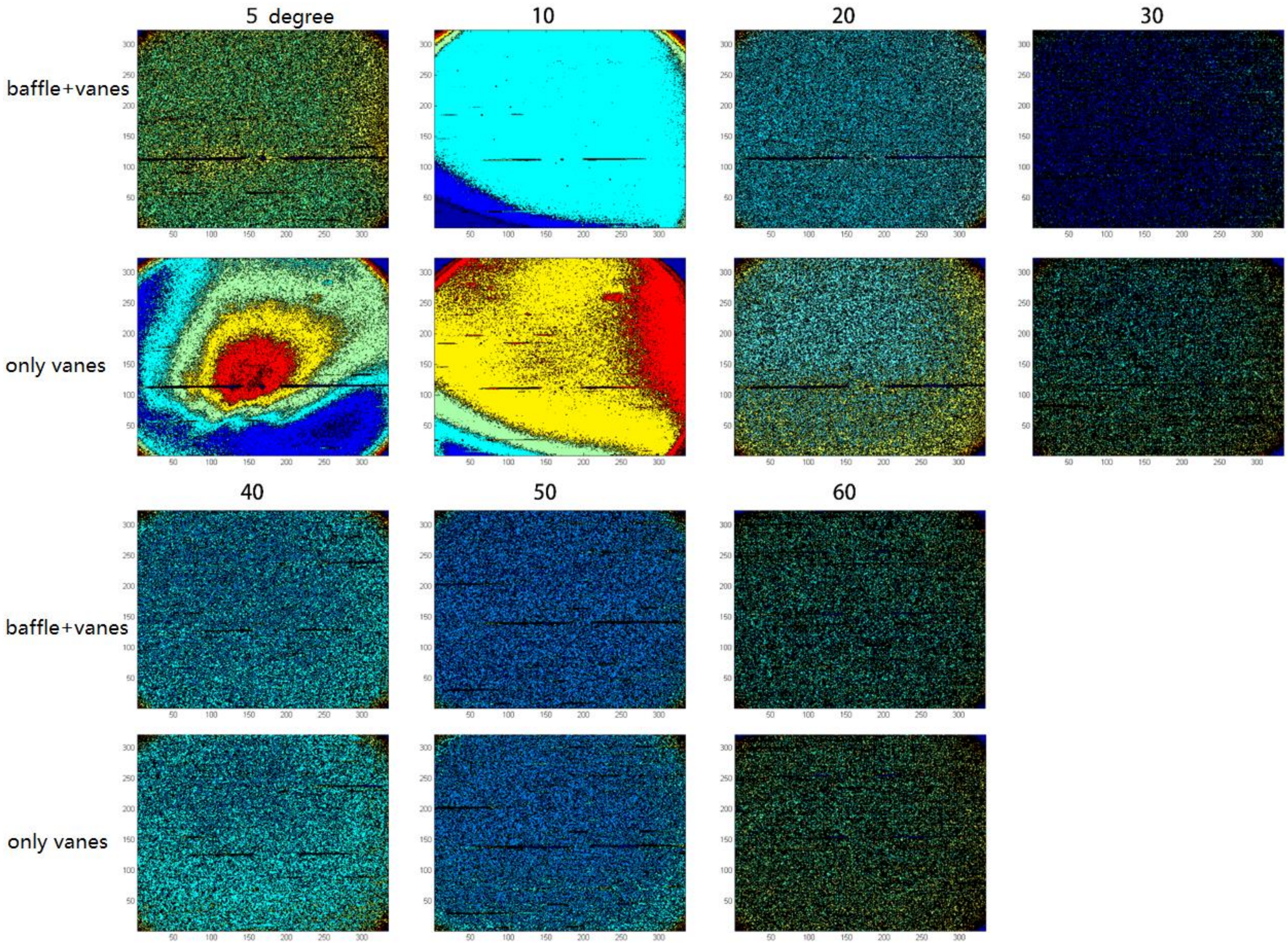
On sky experiments-stray light source changing

- Error curves



On sky experiments-stray light source changing

Contour on CCD focal plane



Summary

1. Stray light analysis and control

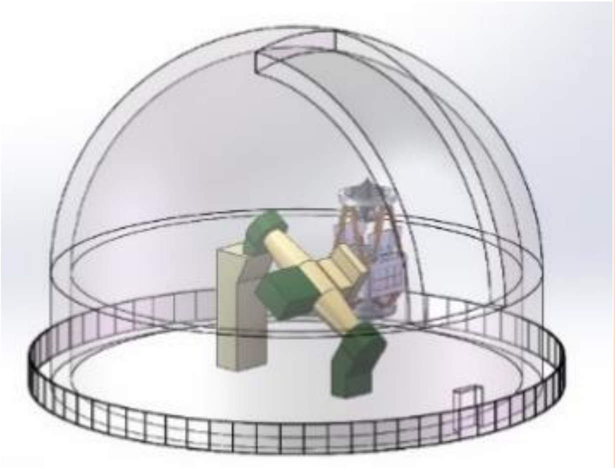
- Combine TracePro with MATLAB, analyze the distribution of stray light intuitively
- The independent vanes, design and experiments

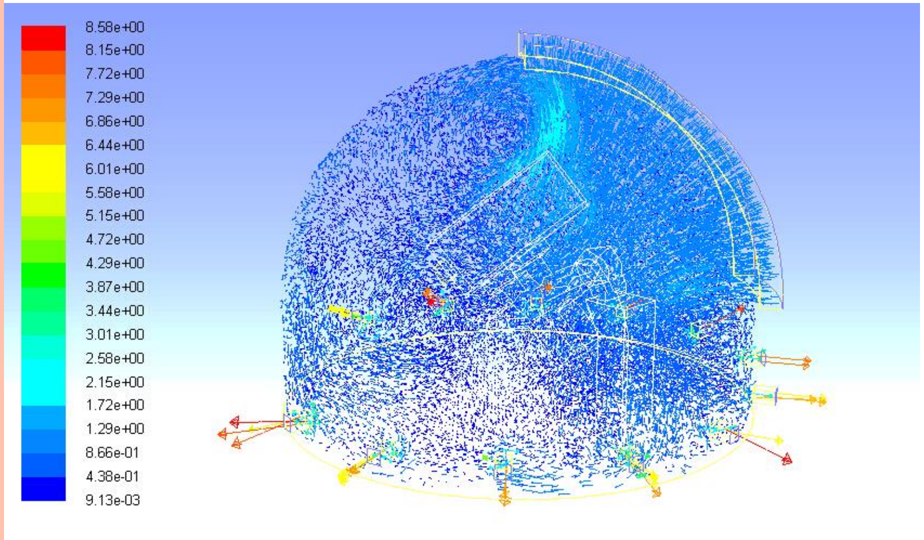
2. Turbulence analysis

- The independent vanes works better in mirror cooling and air circulation.
- CFD methods to compute mirror seeing

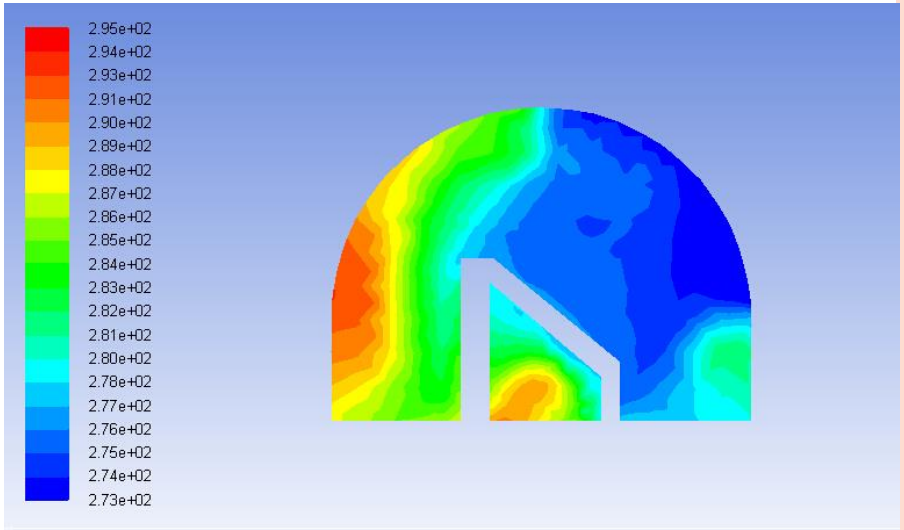
Future work

- Experiment vs CFD
- Air flow in dome





Velocity Vectors Colored By Velocity Magnitude (m/s) (Time=3.6000e+03)



Contours of Static Temperature (k) (Time=1.0000e+02)

Thank you!