The preliminary analysis of stray light for AST3-3 Near-infared Camera

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NIAOT

Content

- **Stray light issues**
- **The ghost analysis**
- **The issue of suppressing the lunar light**
- **The self-radiation analysis**

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Stray light issues

- **what?**

 The "unwanted" radiation on focal plane

- **which?**

 Sky background, moon, bright stars in/out field of view, self-radiation (for the infared system)

- **why?**

a)The reflection or scattering from the surfaces of non-optical components

b)Contamination or roughness of optical elements

c)The reflection or scattering from the surfaces of lens

d)Self-radiation(only for infared system)

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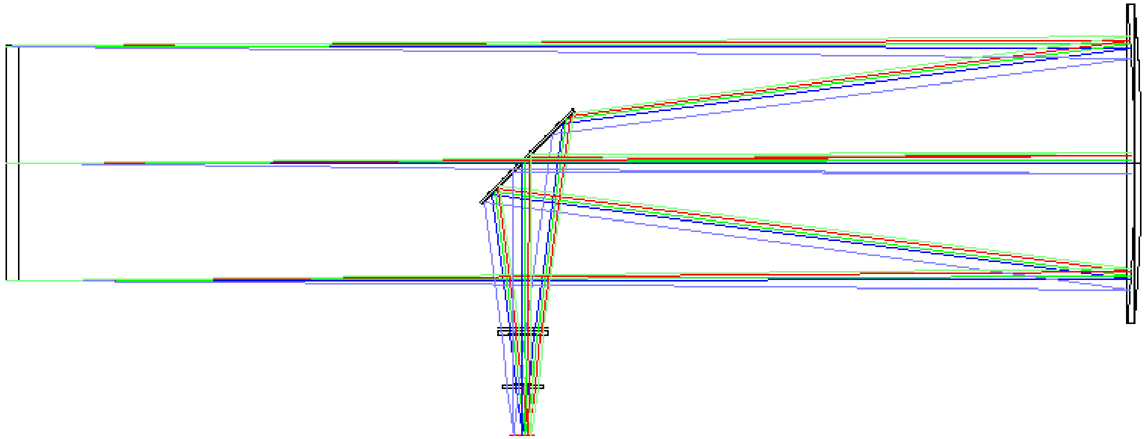
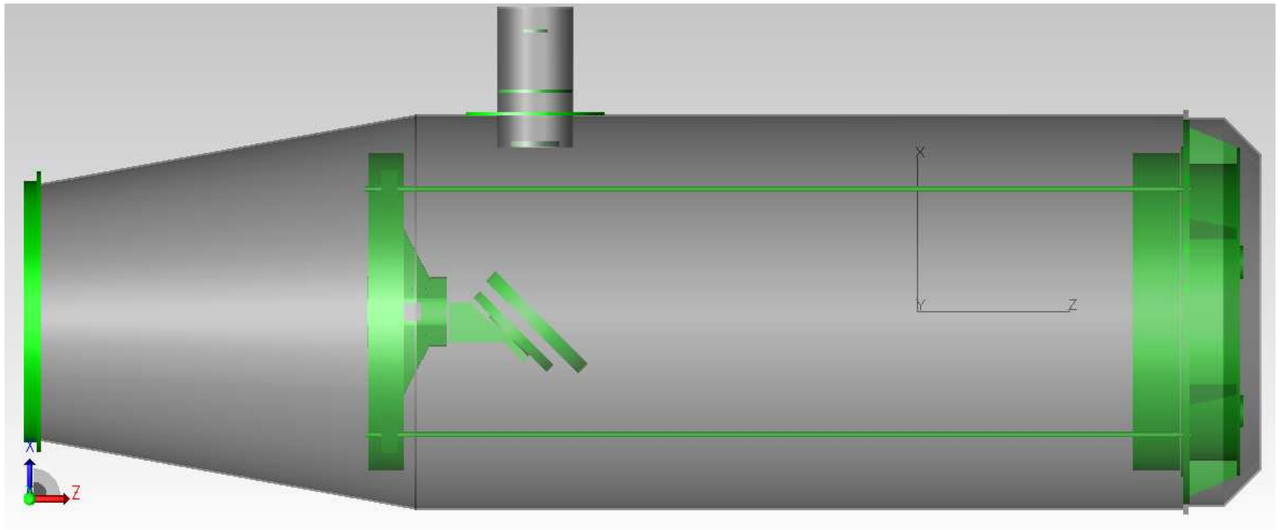
The model of AST3-3



The optical system of AST3 Near-infared telescope



The model of the whole system in the software Tracepro

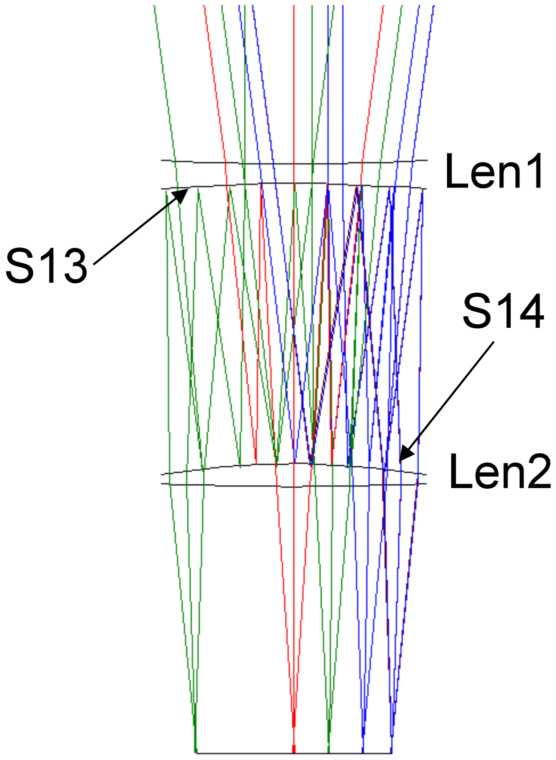
The ghost analysis

- DBFL – Delta Back Focal Length - the distance from the primary image plane (not the paraxial focal plane) to the reflected image.
- EFL – Effective Focal Length - the focal length of the system including the two extraneous reflections
- DISC – the semi-diameter of the reflected beam (from an on-axis object point) at the primary image plane
- PUPIL RATIO – the maximum ratio of the first order reflected ray heights at the stop surface to the stop semi-diameter
- MAGNIFICATION – the size of the reflected image at the image plane indicated by DBFL relative to the size of the primary image

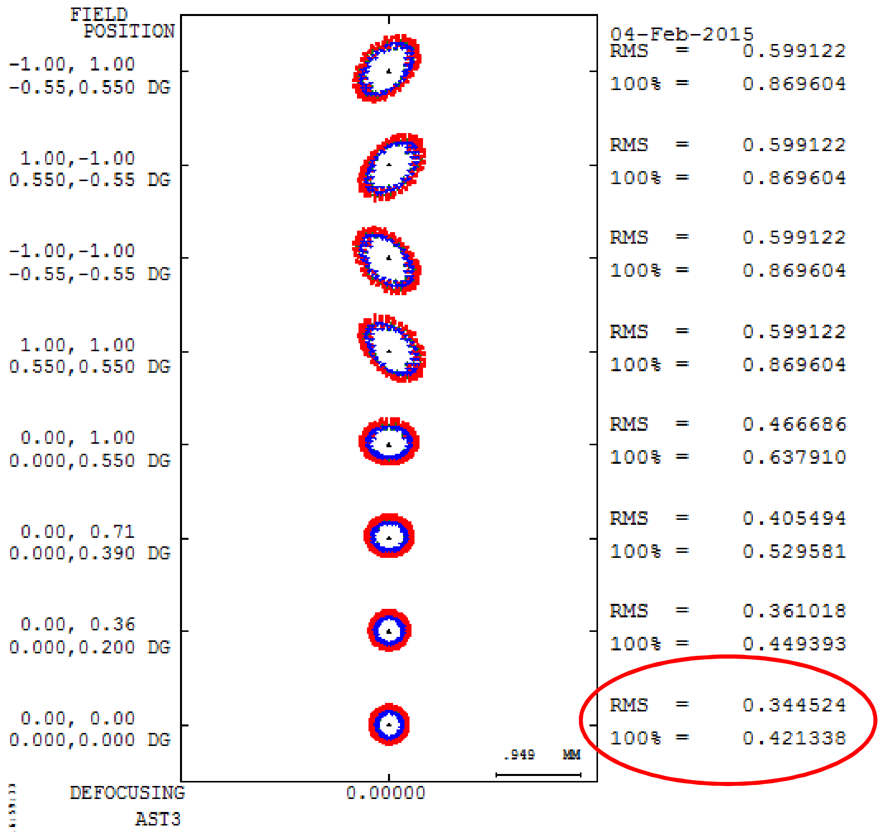
REFL 1	REFL 2	DBFL	EFL	DISC	PUPIL RATIO	MAGNIFICATION
3	2	-57.088191	2028.397361	-7.036120	1.000000	1.061362
7	2	821.383725	-812.326306	-252.787494	1.000000	-0.425051
9	2	477.863139	-805.844588	-148.249162	1.159241	-0.421660
12	2	245.222540	-988.836813	-61.997727	1.425718	-0.517411
13	2	728.305543	-6895.114416	-26.406579	1.000000	-3.607880
14	2	670.480026	-12779.417647	-13.116404	1.000000	-6.686852
15	2	133.407746	-1150.955136	-28.977616	1.423520	-0.602239
7	3	828.618634	-813.228041	-254.731327	1.000000	-0.425523
9	3	492.553789	-787.480453	-156.370163	1.000000	-0.412050
12	3	273.929982	-950.928978	-72.016415	1.000000	-0.497575
13	3	735.947771	-6857.328610	-26.830702	1.000000	-3.588109
14	3	678.987244	-12657.620259	-13.410642	1.000000	-6.623121
15	3	171.308593	-1098.432967	-38.989314	1.000000	-0.574757
9	7	1623.068191	-1618.348437	-250.729100	1.000000	-0.846804
12	7	1207.042589	-880.518404	-342.707939	1.000000	-0.460733
13	7	-1251.572167	39409.088716	-7.939616	1.000000	20.620873
14	7	-18119.833597	652239.279028	-6.945240	1.000000	341.285314
15	7	1137.095204	-808.568459	-351.576663	1.000000	-0.423085
12	9	-2895.841006	5190.130288	-139.487876	1.000000	2.715745
13	9	885.861967	10283.797139	21.535381	1.000000	5.381014
14	9	745.176663	20846.264736	8.936573	1.000000	10.907844
15	9	-10284.507176	14490.105114	-177.440175	1.000000	7.581972
13	12	-3416.935068	-25234.449035	33.851889	1.000000	-13.203968
14	12	-4601.857459	-71553.206061	16.078446	1.000000	-37.440337
15	12	-308.521079	1643.245833	-46.937755	1.000000	0.859831
14	13	-4.826883	3861.863120	-0.312471	1.000000	2.020726
15	13	-308.519429	2153.644304	-35.813647	1.000000	1.126898
15	14	-62.813964	900.363703	-17.441275	1.000000	0.471117

The ghost analysis in Code V software

The ghost analysis



non-sequential ray-trace



spot diagram

The ghost analysis

The ratio of ghost intensity to scene image intensity is

$$\frac{E_{Ghost}}{E_{Target}} = R_1 \times R_2 \times \left\{ \frac{1}{\pi} \times \left(\frac{A \times F}{R \times D} \right)^2 \right\} \times \frac{H}{B}$$

$$\frac{H}{B} = 10^{\frac{m_T - m_g}{2.5}}$$

A	=	Lens entrance pupil diameter (lens units)
F	=	F-number of lens
B	=	Brightness of extended object (energy/unit area)
R	=	PUPIL RATIO from ghost analysis
D	=	DISC semi-diameter from ghost analysis (lens units)
H	=	Irradiance on pupil from point object (energy/unit area)
R_1	=	Reflectivity of the first surface of the ghost pair
R_2	=	Reflectivity of the second surface of the ghost pair

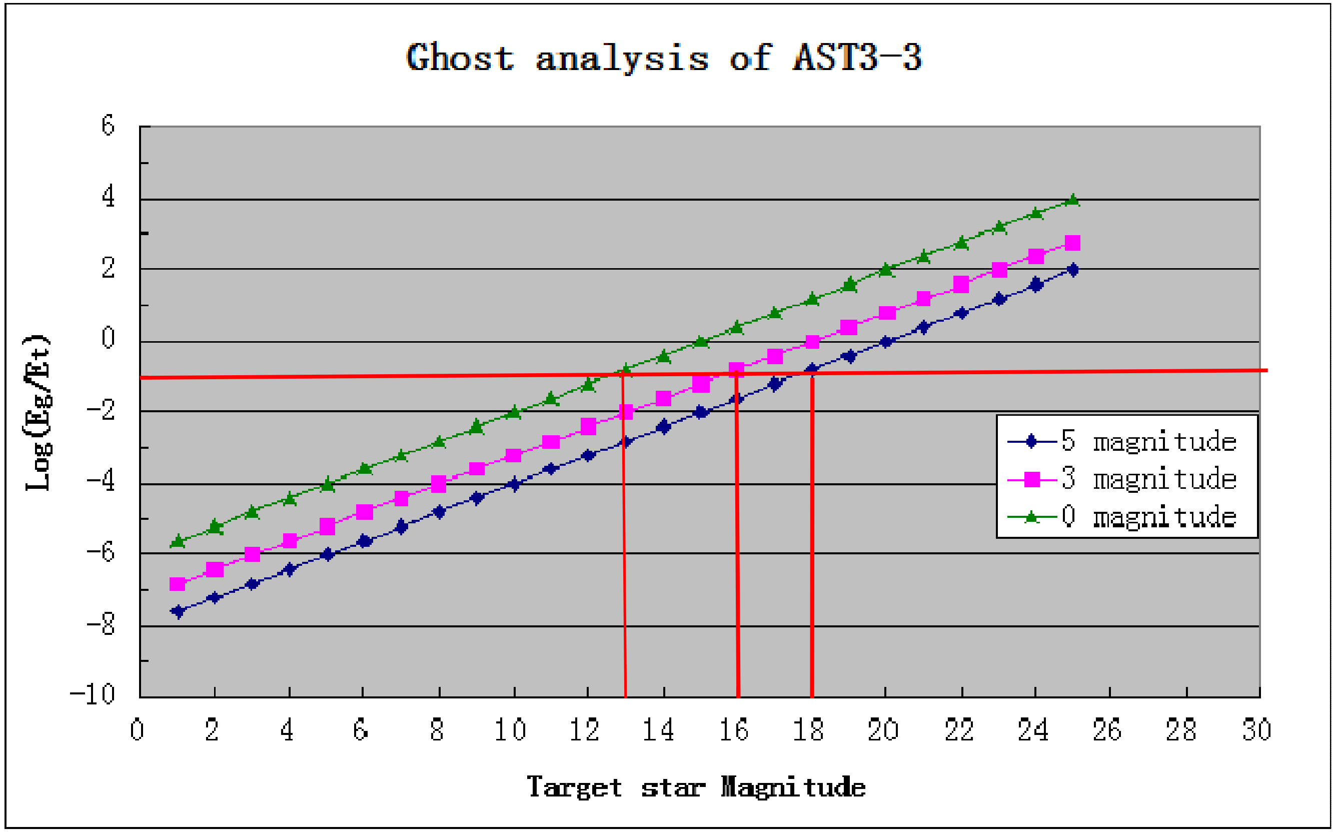
m_T: the magnitude of target star

m_g: the magnitude of the bright star

The ghost analysis

The semi_diameter of the ghost is 0.3mm

The semi_diameter of the target star on focus plane is 18 um (1 pixel)



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- The self-radiation analysis

Suppressing the external sorce: Moon

- For the infared system,Two parts from the moon: 1) the self-radiation of the moon;2) reflected solar energy
- At daytime ,the temperatur of the lunar surface is 127 degrees centigrade ,but at nighttime that is minus-183 degrees centigrade
- The self-radiation of the moon

Plank's formula：

$$M_m = \varepsilon \times \int_{\lambda_1}^{\lambda_2} \frac{c_1}{\lambda^5} \times \frac{1}{\exp\left(c_2 / \lambda T_m \right) - 1} d\lambda \quad W/m^2$$

c_1=2*pi*h*c^2; c_2=hc/k

The illuminance on the earth'surface: $E_{m-e} = \dfrac{M_m}{\left(D_{m-e} / R_m \right)^2}$

Suppressing the external sorce: Moon

- Reflected solar energy by the moon surface

the reflectance of the moon surface：0.12（infared-band）

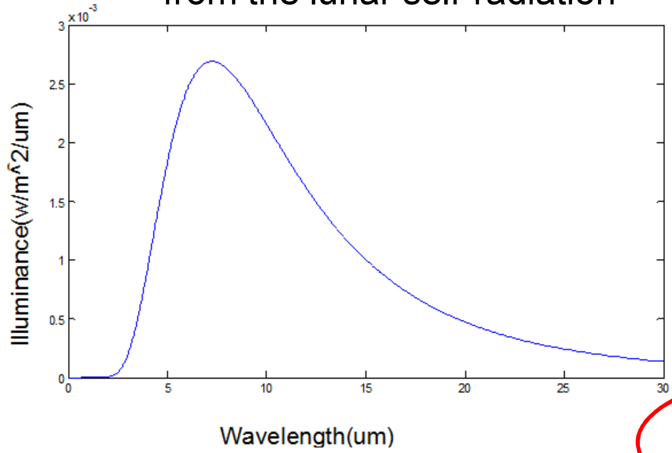
$$M_{sun} = \int_{\lambda_1}^{\lambda_2} \frac{c_1}{\lambda^5} \bullet \frac{1}{\exp\left({c_2}/{\lambda T_{sun}} \right) - 1} d\lambda$$

$$E_{sun-m} = \frac{M_{sun}}{\left({R_{sun-m}}/{R_{sun}} \right)^2}$$

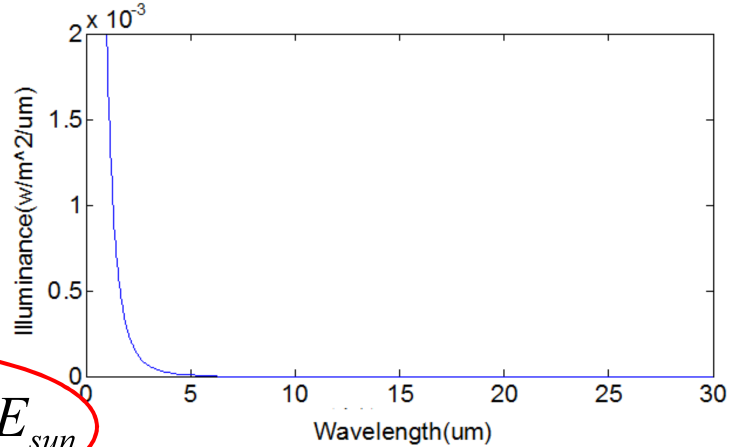
$$E_{e-sun-m} = \rho \times \frac{E_{sun-m}}{\left({R_{m-e}}/{R_m} \right)^2}$$

Suppressing the external sorce: Moon

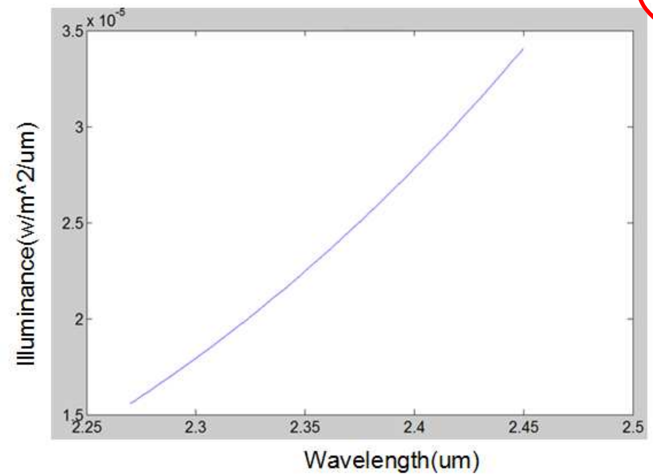
The illuminance on the earth from the lunar self-radiation

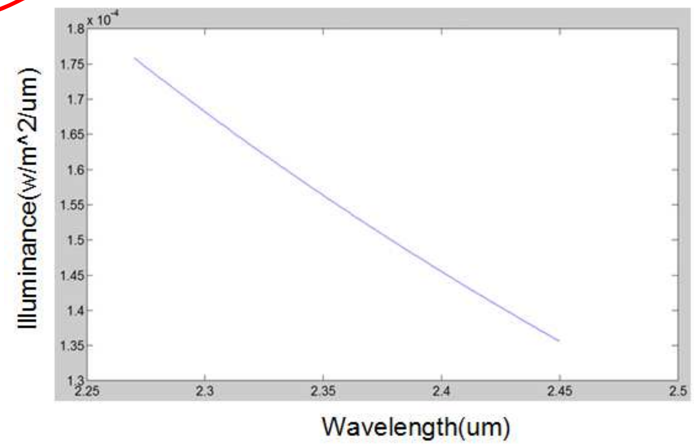


The illuminance on the earth from the reflected solar-radiation by the moon



$$E_{total} = E_{moon} + E_{sun}$$





At K_{dark}-Band， E_{moon}= 3.78e-06W/m^2； E_{sun} =2.78e-05W/m^2;

E_{total}=3.16e-05W/m^2

Point Source Transmission(PST)

Defining the system stray light performance as a function of off-axis angle. It is a standard for the stray light rejection .

$$PST(\theta) = \frac{E_{\mathrm{i}}(\theta)}{E_{\mathrm{e}}(\theta)}$$

$E_{\mathrm{e}}(\theta)$ ： the energy of the radiation entering the entrance of the telescope

$E_{\mathrm{i}}(\theta)$ ： the energy of the radiation on focal plane

Suppressing the external sorce: Moon

The sky spectral brightness in the near infrared K_{dark} window at the South Pole has been determined from analysis of data collected by the Near Infrared Sky Monitor over the 2001 winter. It is found that the average winter-time sky flux is ~ 220 μJy.arcsec^{-2}. This falls to 80 μJy.arcsec^{-2} for the best 25% of conditions. These values compare well with those

Observations of the Antarctic infrared sky spectral brightness

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- According to the brightness of the sky background at K_{dark}-band at South Pole(9.1×10-7w/m^2/sr) ,the illuminance on the focus plane of the telecope is 3.4e-8w/m^2 (if the efficiency of the system is 0.7)
- If the requirement of suppressing the moon is that the illuminance of lunar light on the focus plane is supposed to be about 5 times lower than that of the sky background,then the requirement of the PST for the moon is

$$PST \le \frac{1}{5} \times \frac{E_{B\_i}}{E_{total}}$$

***PST*≦2.2e-4**

The surface property

Surface Type	Abbreviation	Absorptance	Specular reflectance	Integrated BRDF	BRDF A	BRDF B	BRDF g	Specular transmission	Integrated BTDF	BTDF A	BTDF B	BTDF g
Perfect Absorber	PA	1	0	0	0	0.1	0	0	0	0	0.1	0
Perfect Mirror	PM	0	1	0	0	0.1	0	0	0	0	0.1	0
Perfect Transmitter	PT	0	0	0	0	0.1	0	1	0	0	0.1	0
Anti Reflect	AR	0.001	0.015	.0001324	.00001	0.015	2	0.984	7.53e-5	.00001	0.1	2
Dusty AR	DAR	0.01	0.015	0.0132	0.001	0.015	2	0.962	0	0	0.1	0
Aluminium	Al	0.03	0.956	0.0145	0.001	0.01	2	0	0	0	0.1	0
Dusty Aluminium	DAl	0.04	0.946	0.0145	0.001	0.01	2	0	0	0	0.1	0
Nextel	N	0.95	.00001	0.0500	.031825	1	0	0	0	0	0.1	0

Lens → Anti Reflect

Mirror → Aluminium

Black paint → Nextel

Analysis of Scattered Light for VISTA

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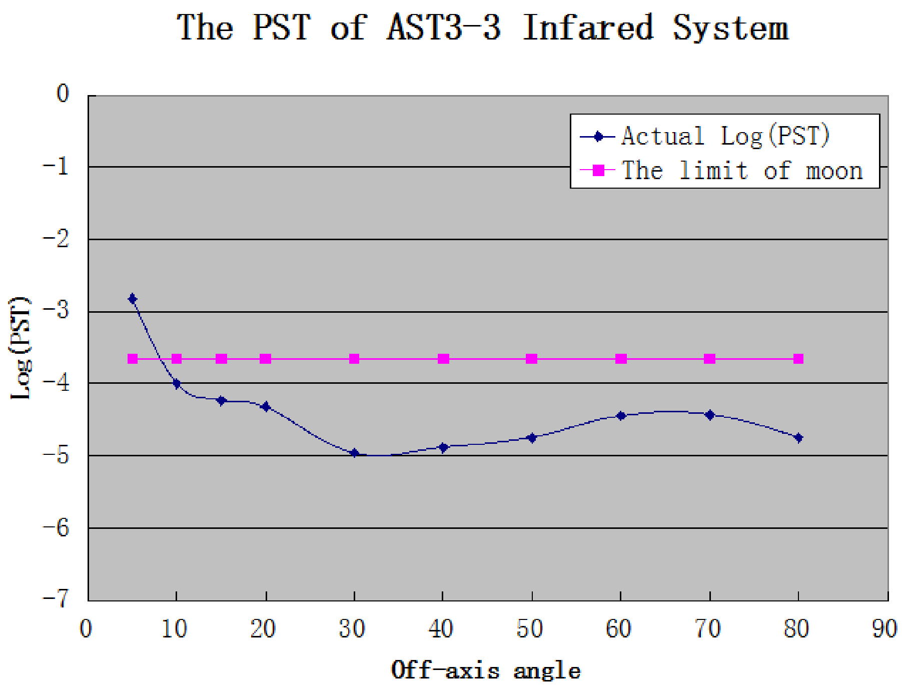
PST of the AST3-3

off-axis angle(+Y)	PST
5	1.5e-3
10	1.0e-4
15	5.8e-5
20	4.8e-5
30	1.1e-5
40	1.3e-5
50	1.8e-5
60	3.6e-5
70	3.7E-5
80	1.8E-5



The telescope can suppress the moon above 10 degree.

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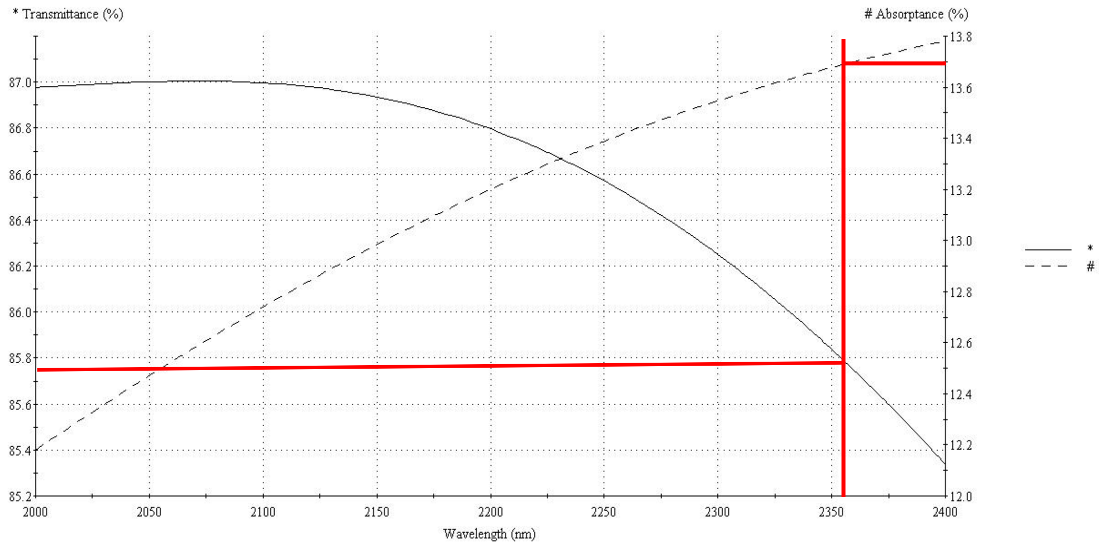
Self-radiation of the infared system

The emissivity is a important parameter in self-radiation analysis

Kirchhoff's law: the emissivity is equal to the absorptance



ITO 'contrivable transmittance curve

Surfaces	Emissivity (k-band)
ITO	0.138
Anti Reflect	0.002
Aluminium	0.03
Nextel	0.95

Self-radiation of the infared system

- The condition：the ambient temperature is -50 ℃，the tempreture in the dewar is -100℃。the wavelength range of Kdark-band is 2.27~2.45μm

- The illuminance of the self-radiation of the whole system on the imaging plane is 4.08e-8w/m^2 。

Objects	Temperature
Window	-47℃
Dewar	-100℃
Others	-50℃

Lens in dewar

If the telescope will work at minus 50 degrees centigrade ,the self-radiation dominates over the sky background,according to the illuminance of the sky background on the imaging plane (3.4e-8w/m^2)

Self-radiation of the infared system

- The condition：the ambient temperature is minus 60 degrees centigrade，the tempreture in the dewar is -100℃。the wavelength range of Kdark-band is 2.27~2.45μm

- The illuminance of the self-radiation of the whole system on the imaging plane is 1.2e-8w/m^2。it is three times lower than the background

Objects	Temperature
Window	-57℃
Dewar	-100℃
Others	-60℃

The Near-infared camera can play the best performance when the ambient tempreture is below minus 60 degrees centigrade

The next steps

- Verify some parameters(the brightness of sky background at dome A , the temperature in dewar , the actual optical property ,Etc)
- Design the structure of the baffles in dewar
- Compute PST in the other direction
- Analysis the self-radiation in detail
- Analysis the limit of magnitude of the AST3-3 Near-infared camera
- Design the relay-lens,compare the stray-light suppressing ability of the telescope with cold stop and that of the system without the cold stop

The end

Thank you
for your attention and advice!