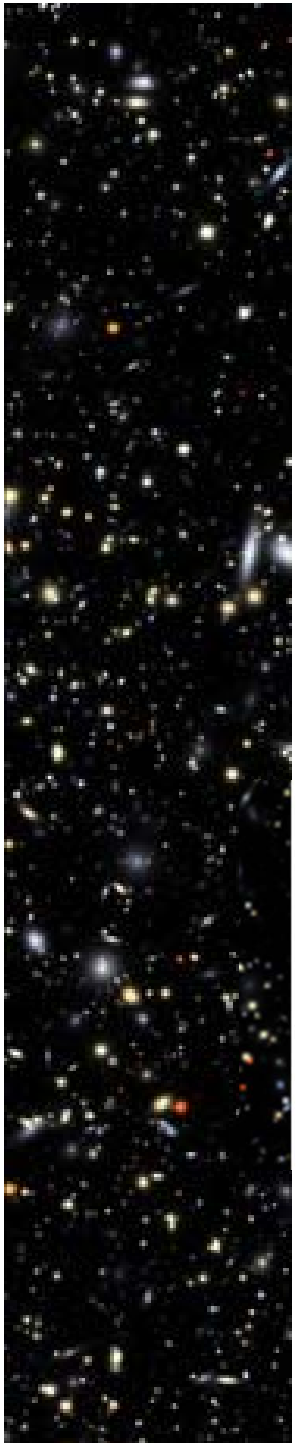


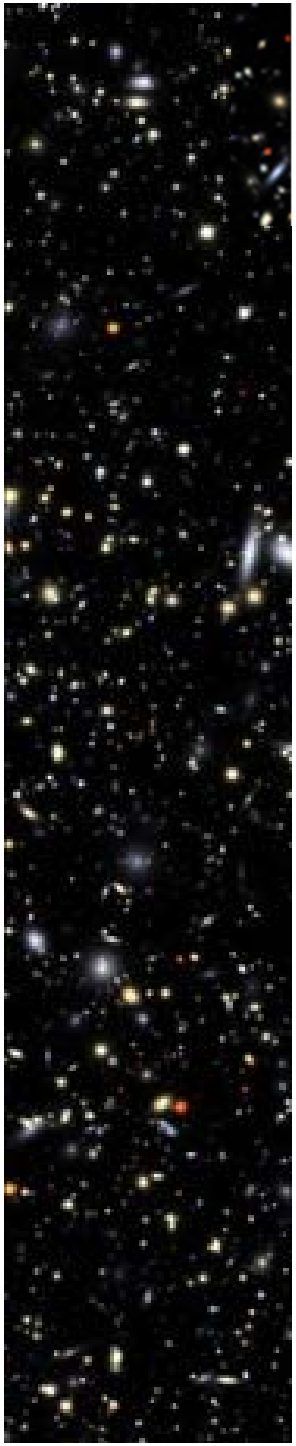
Modeling Subaru through the LSST Simulator

By Mary Ann Hodge, Murray State University

Advised by Professor Peterson

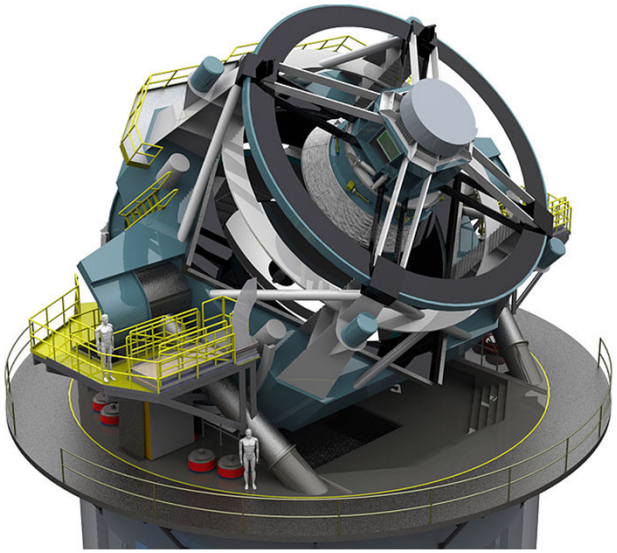
The Subaru Telescope

- ✧Located at the top of Mauna Kea in Hawaii
- ✧Finished construction in 1998
- ✧8.2m primary mirror
- ✧Instruments include Subaru Prime Focus Camera (Suprime-Cam)

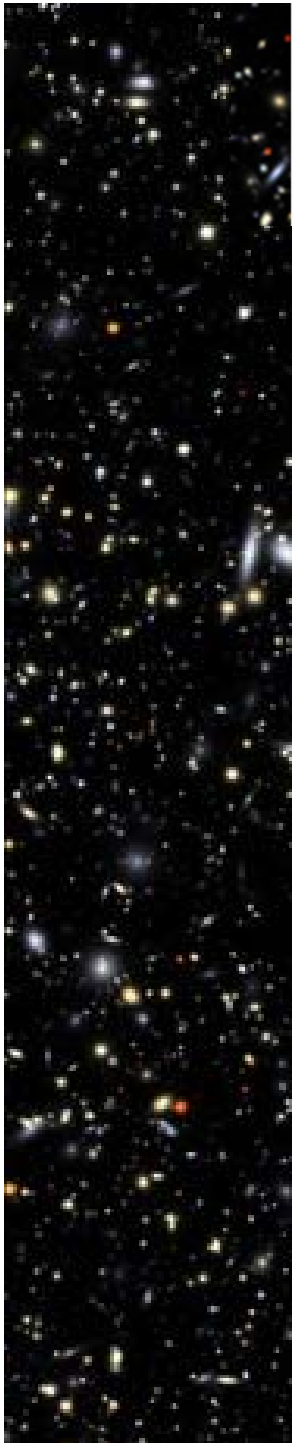


The LSST

Large Synoptic Survey Telescope



- “Large Synoptic Survey Telescope”
- Will be located in northern Chile
- Will start operations in 2019/2020
- 8.4m primary mirror
- Optical Telescope



The LSST Image Simulator

✧The simulator samples sky data and uses Snell's Law to track photons through the atmosphere and telescope

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✧The images produced reflect what the pictures taken with the completed telescope should look like

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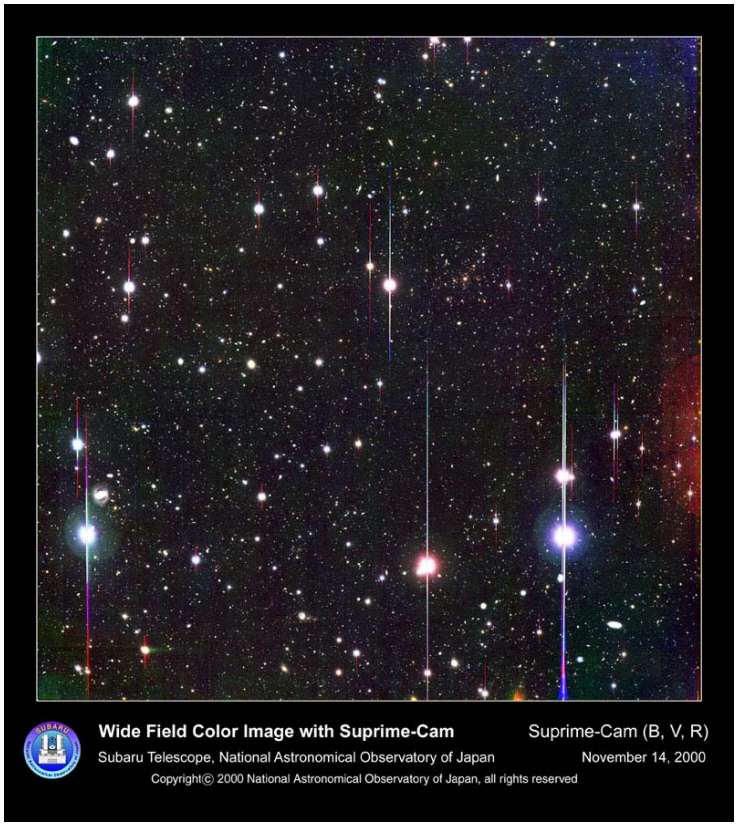
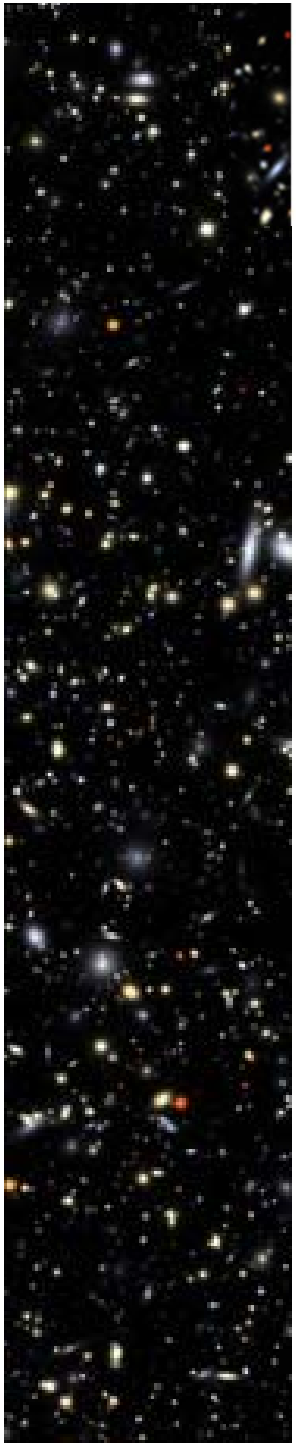
✧Finds errors in the system before the telescope is built, and helps our understanding of the atmosphere

Project

By making alterations to model another telescope that has already taken real images (Subaru), the simulator can be validated or improved

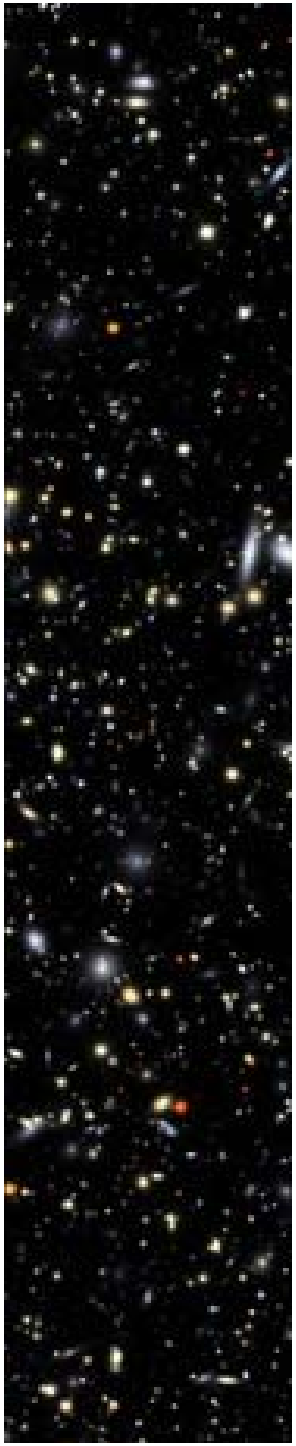




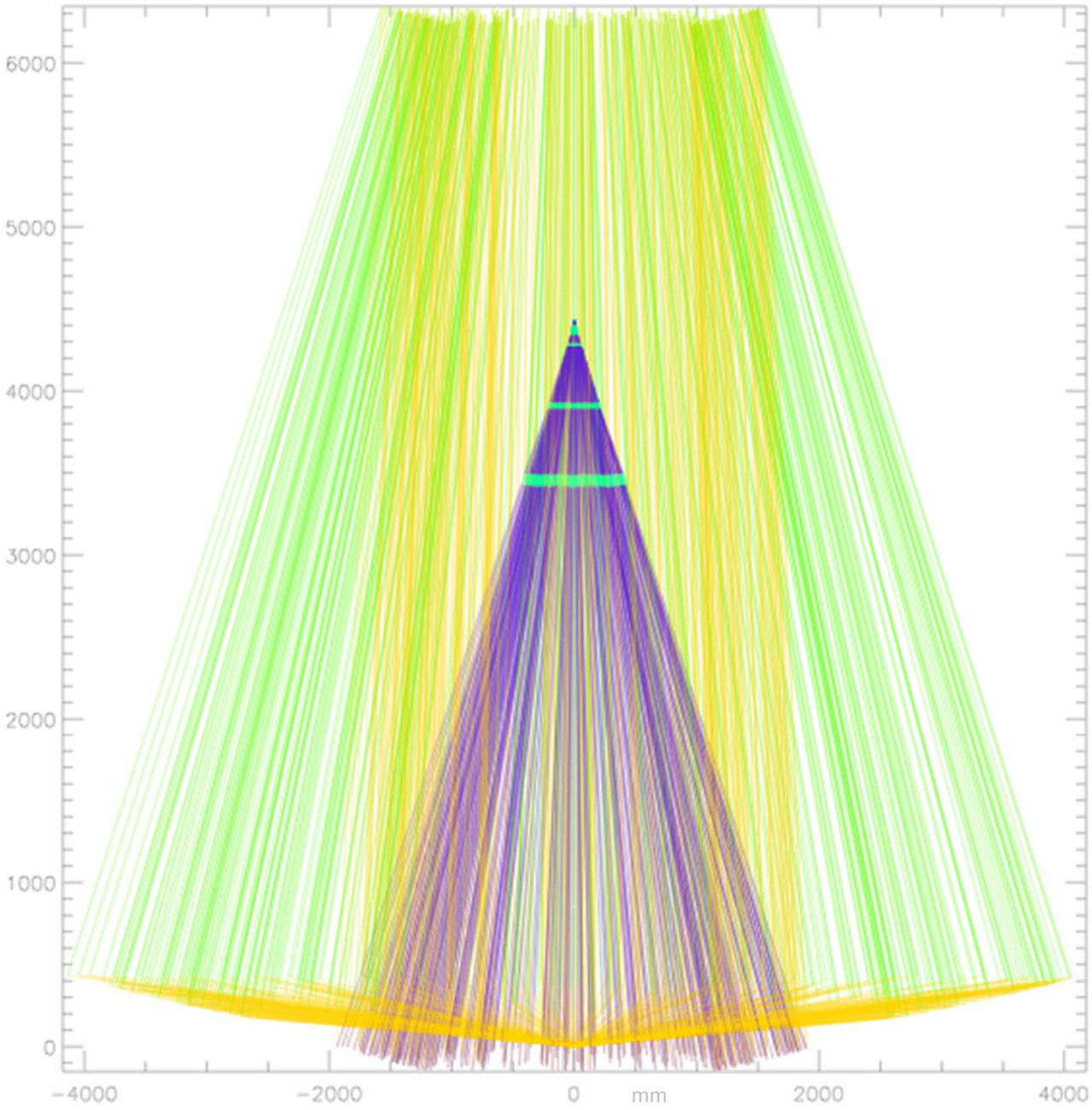
First Step – Creating Optics File

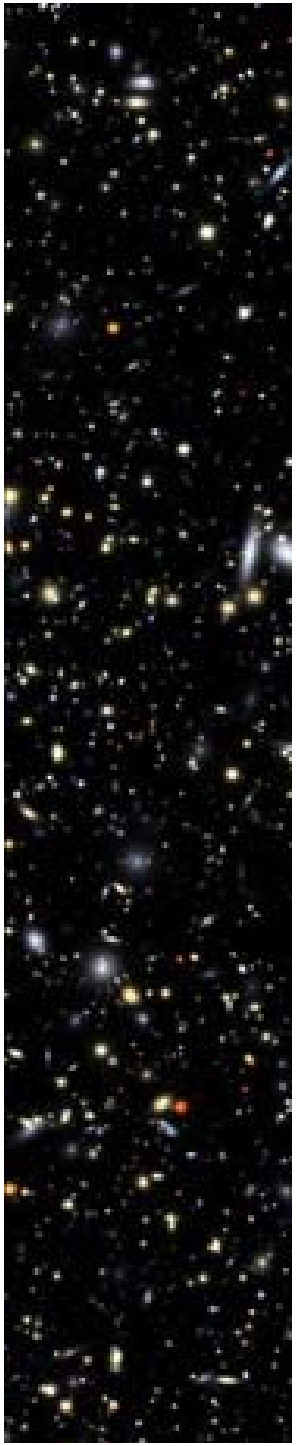
- The optics file contains the list of surfaces, such as mirrors and lenses
- Replace LSST file with one for Subaru
- Run raytrace, the part of the simulator that computes photon paths
- Use a program to show the photons

Name	Type	Rad. of Curv.	Thickness	Semi-Diam	Conic
M1	mirror	30000	0.0	4100	-1.00835

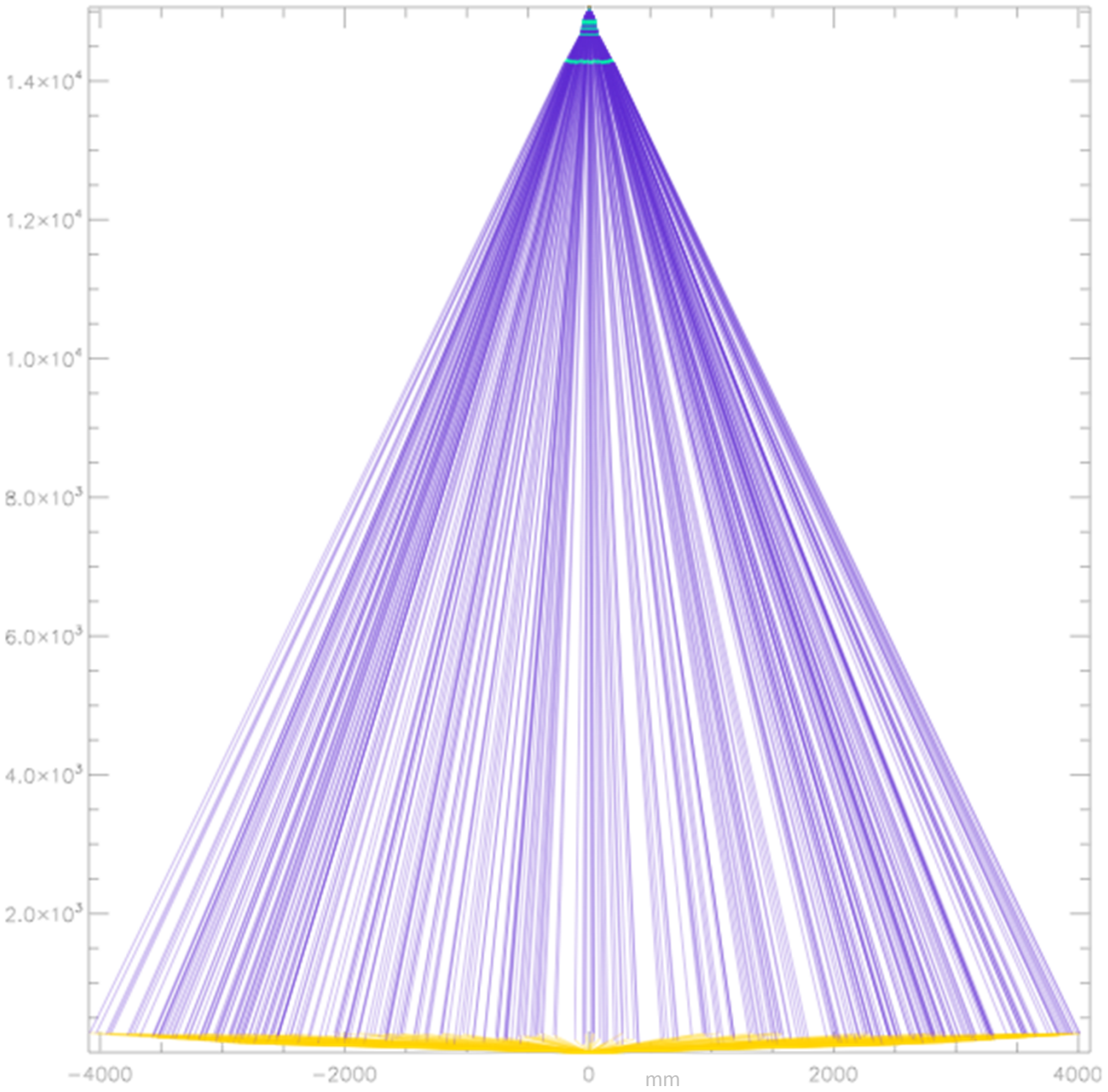


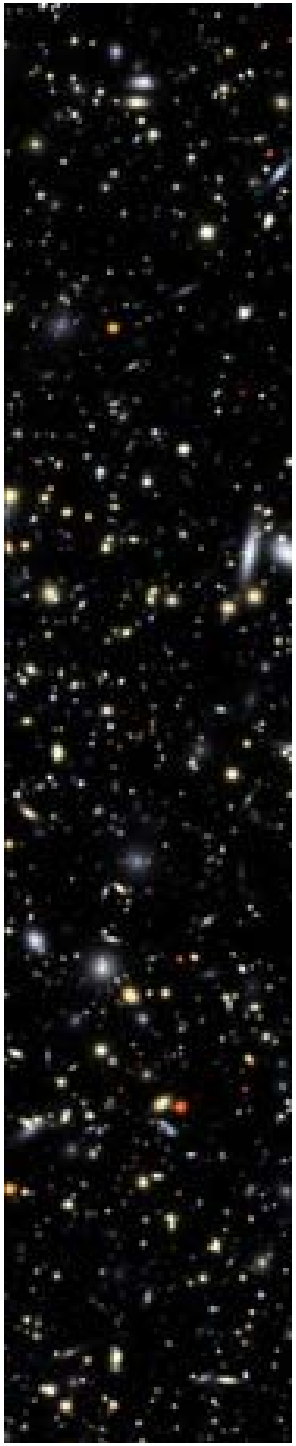
LSST



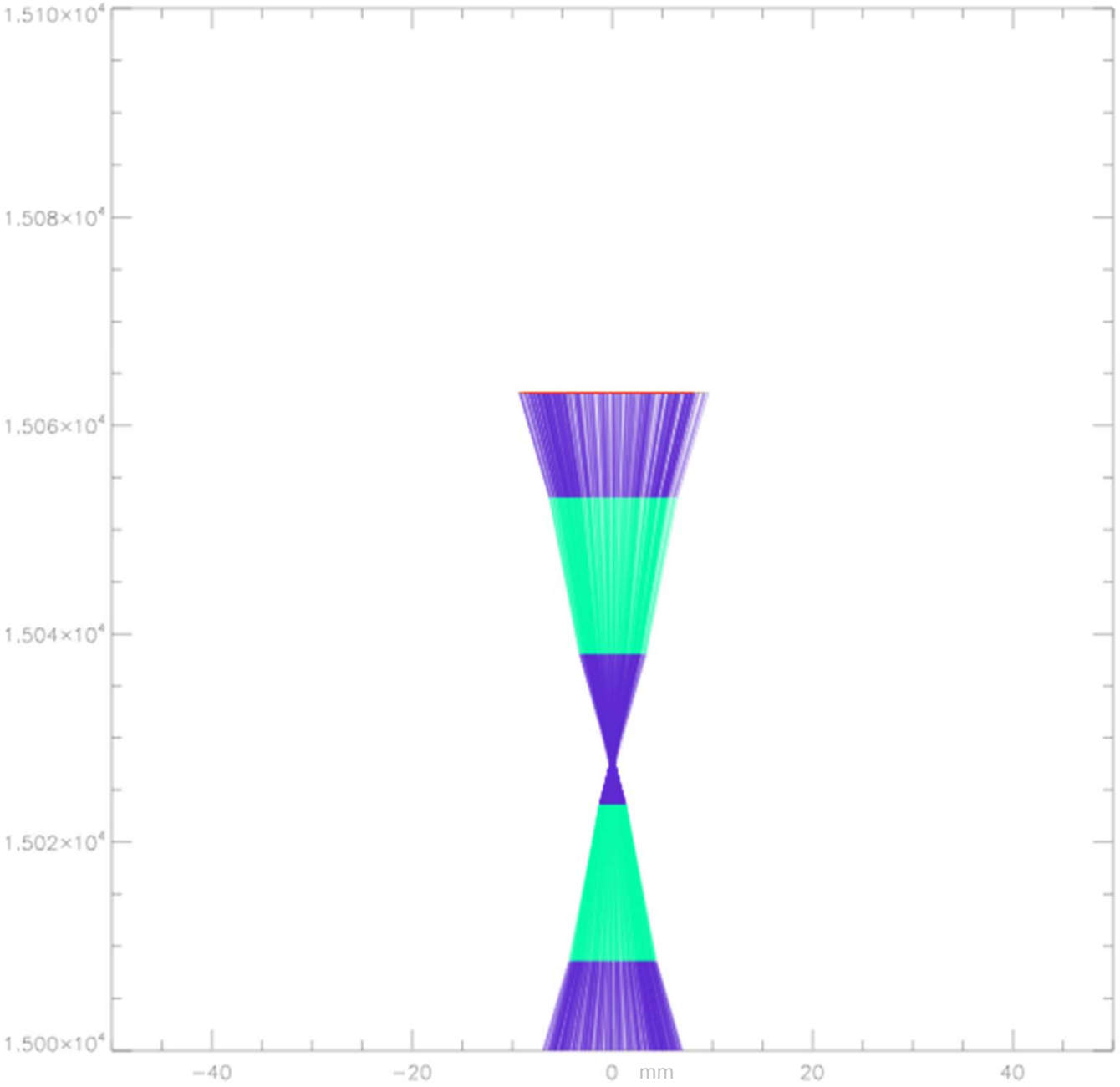


Subaru


1.4×10⁴
1.2×10⁴
1.0×10⁴
8.0×10³
6.0×10³
4.0×10³
2.0×10³
−4000
−2000
0
mm
2000
4000

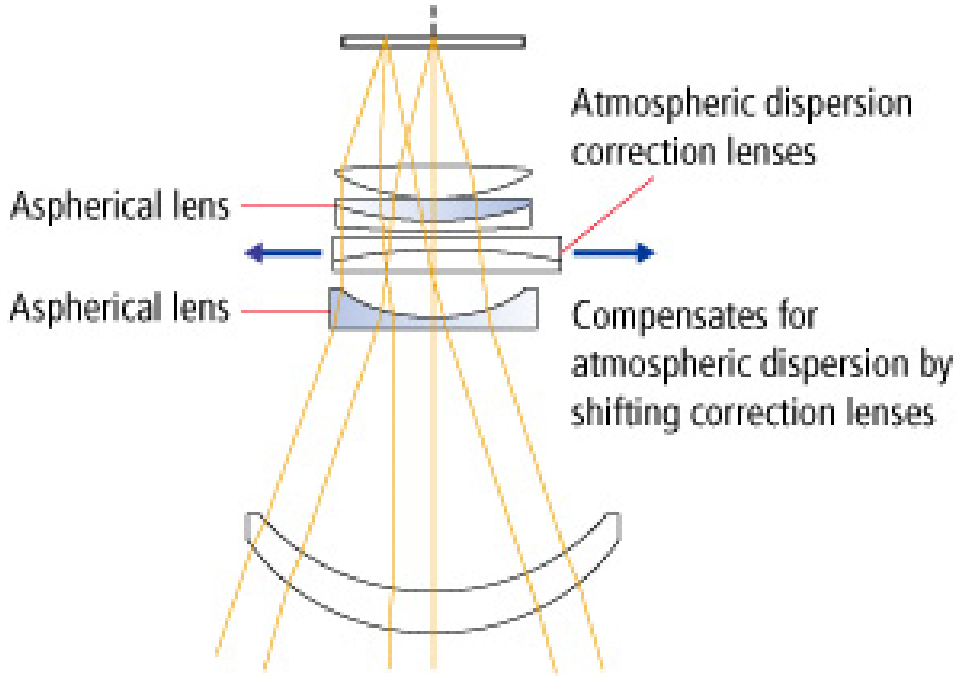


Problem


1.510×10⁴
1.508×10⁴
1.506×10⁴
1.504×10⁴
1.502×10⁴
1.500×10⁴
−40
−20
0
mm
20
40

Possible Causes for Error

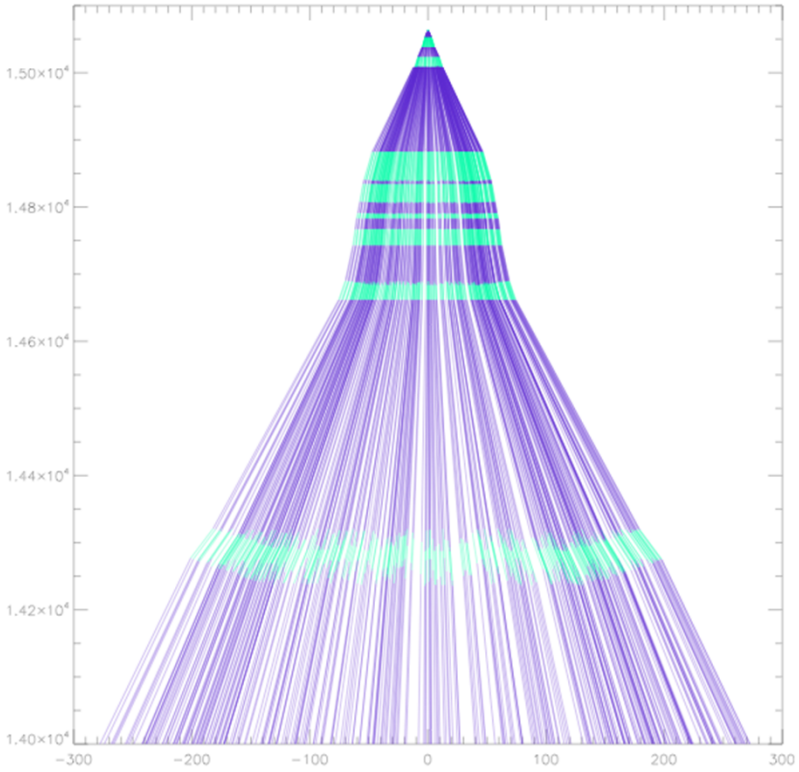
- ✧ Switched negatives
- ✧ Incorrect surfaces
- ✧ Aspherical coefficients
- ✧ Glass indexes of refractions

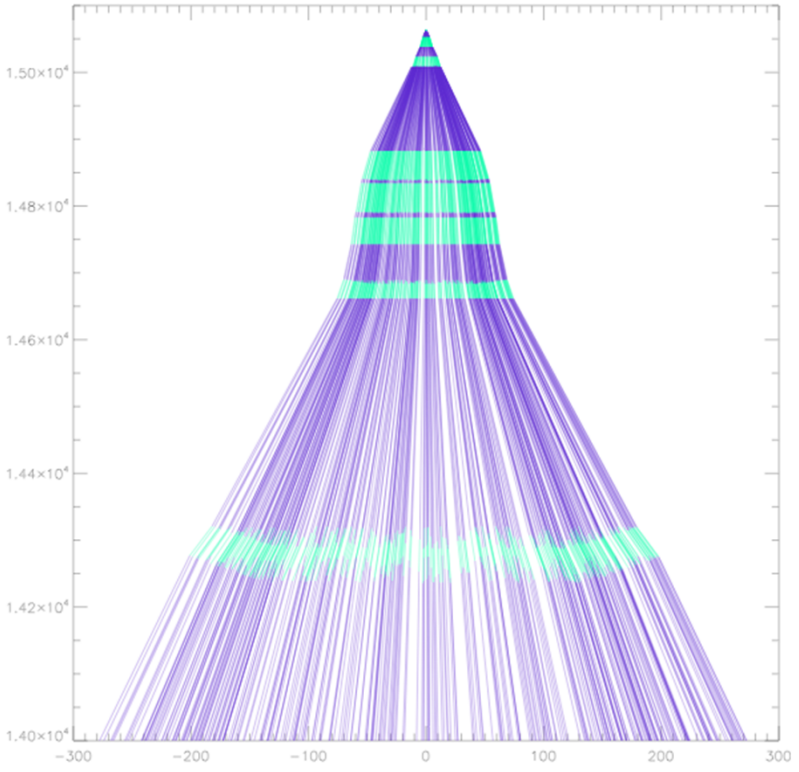


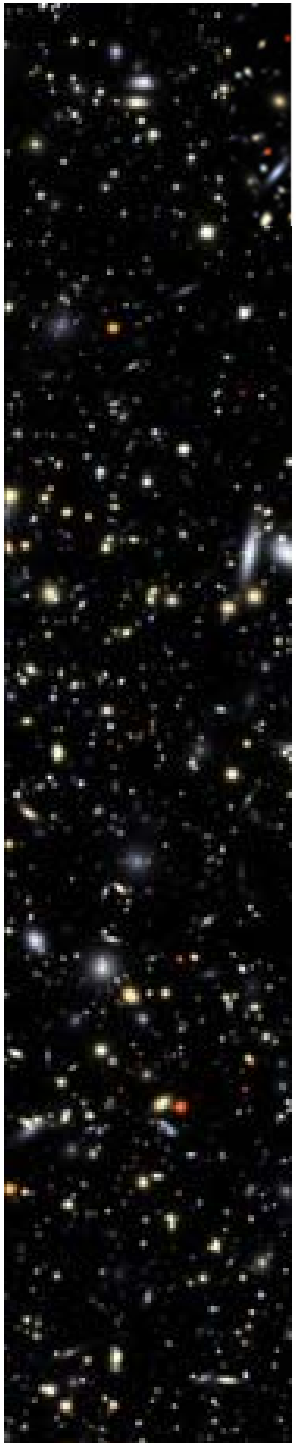
Changes Due to ADC

Name	Rad. of Curv.	Thickness
L3E	-897.65	26
L4	0.0	14

L3E	-897.65	26
L4	-897.65	0
L4E	0.0	14







Aspherical Lens Formula

$$z(r) = \frac{r^2}{R\left(1+\sqrt{1-(1+\kappa)\frac{r^2}{R^2}}\right)} + \alpha_1 r^2 + \alpha_2 r^4 + \alpha_3 r^6 + \cdots,$$

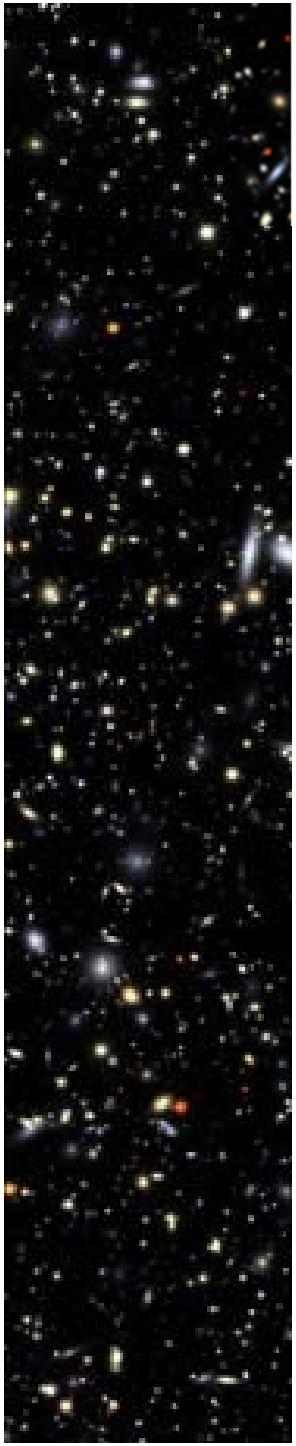
z=sag

R=radius of curvature

r=radius

K=conic constant

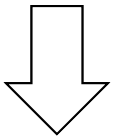
α=coefficients of terms with even powers



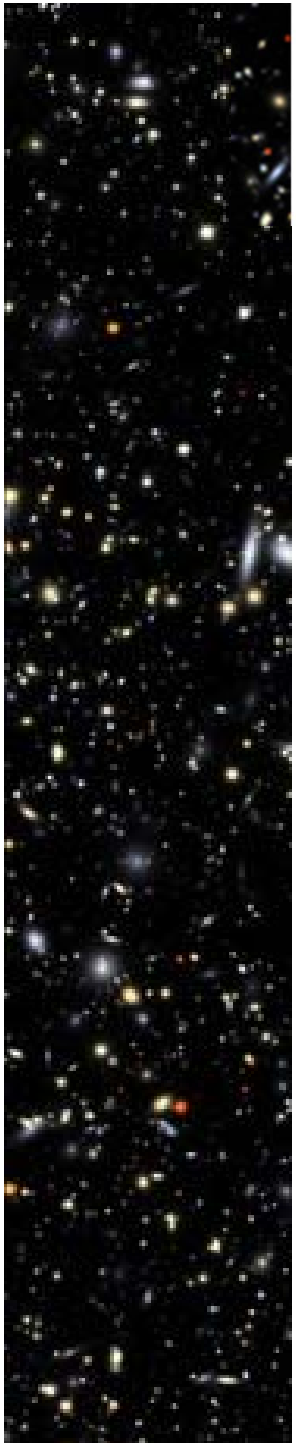
Aspheric Lens

- Subaru – L2, L4E
- LSST – M1, M2, M3, L2E

Name	6th	8th
Subaru L2	8.363e-17	-2.038e-21
Subaru L4E	5.389e-17	6.67e-21

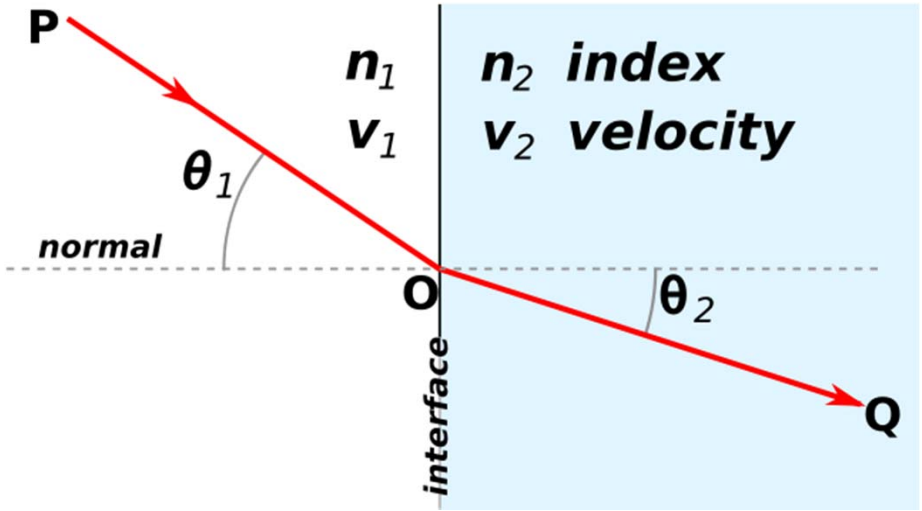


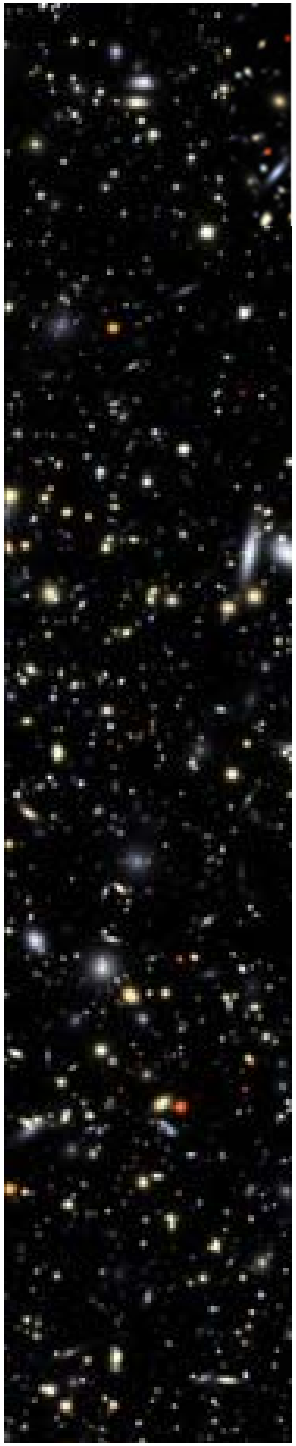
Name	6th	7th	8th	9th
Subaru L2	8.363e-17	0.0	-2.038e-21	1.338e-26
Subaru L4E	5.389e-17	0.0	6.67e-21	6.942e-23



Index of Refraction

- Silica indexes are the default for LSST surfaces
- Subaru is designed with 5 other types of glasses

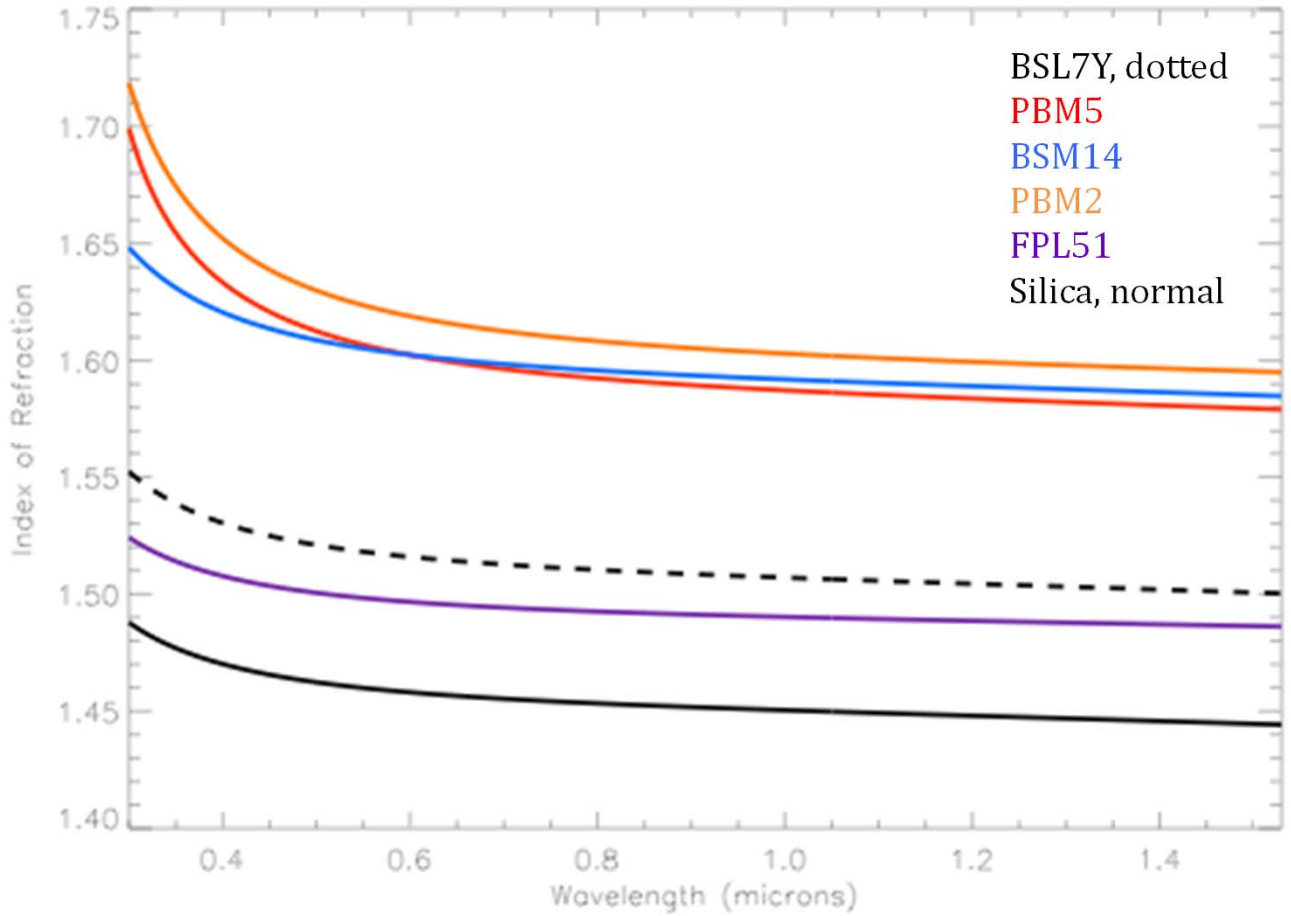




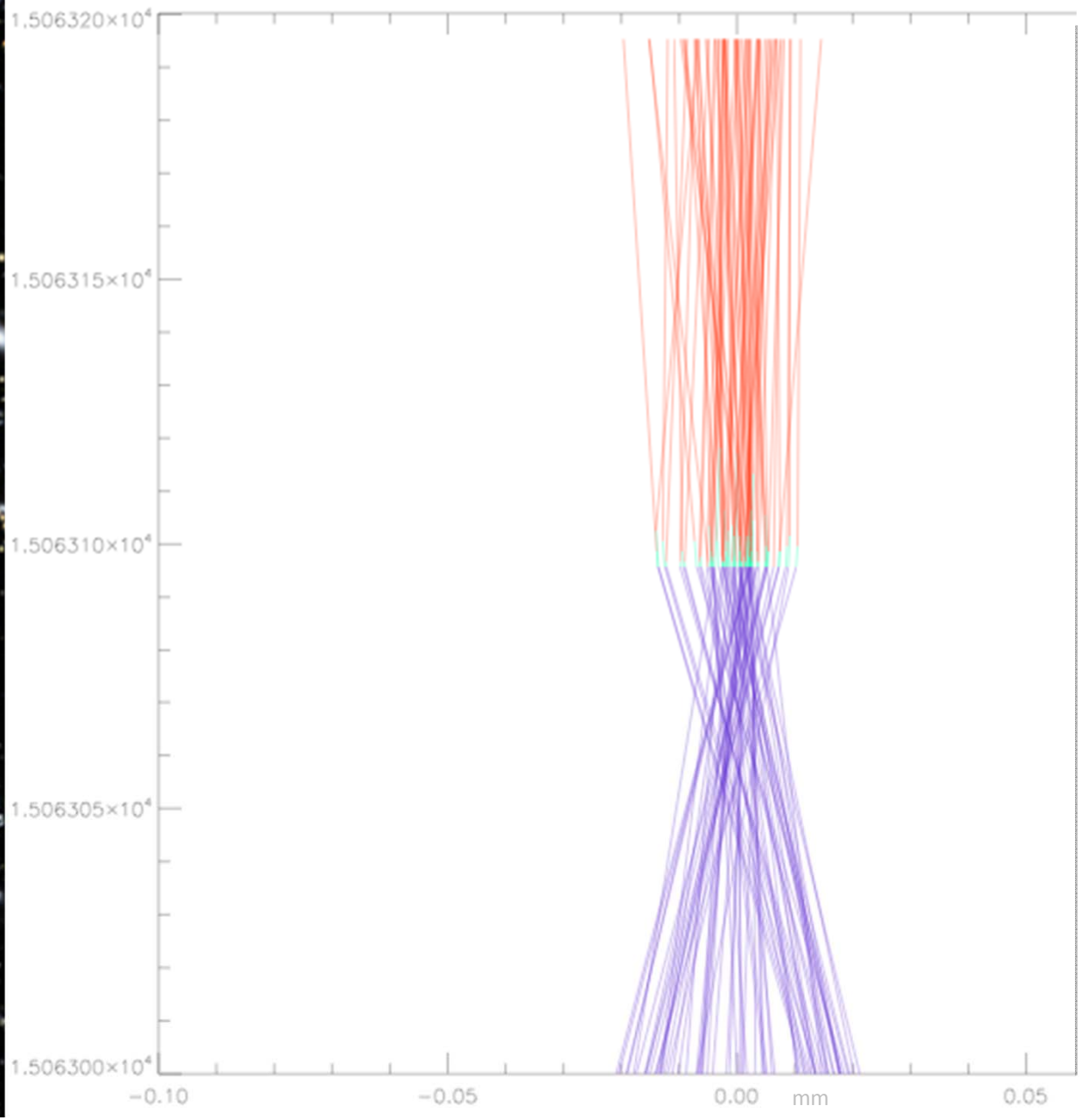
The Sellmeier Equation

$$n^2(\lambda) = 1 + \frac{B_1\lambda^2}{\lambda^2 - C_1} + \frac{B_2\lambda^2}{\lambda^2 - C_2} + \frac{B_3\lambda^2}{\lambda^2 - C_3},$$

n=index of refraction
λ=wavelength
B, C=coefficients



Acceptable Error



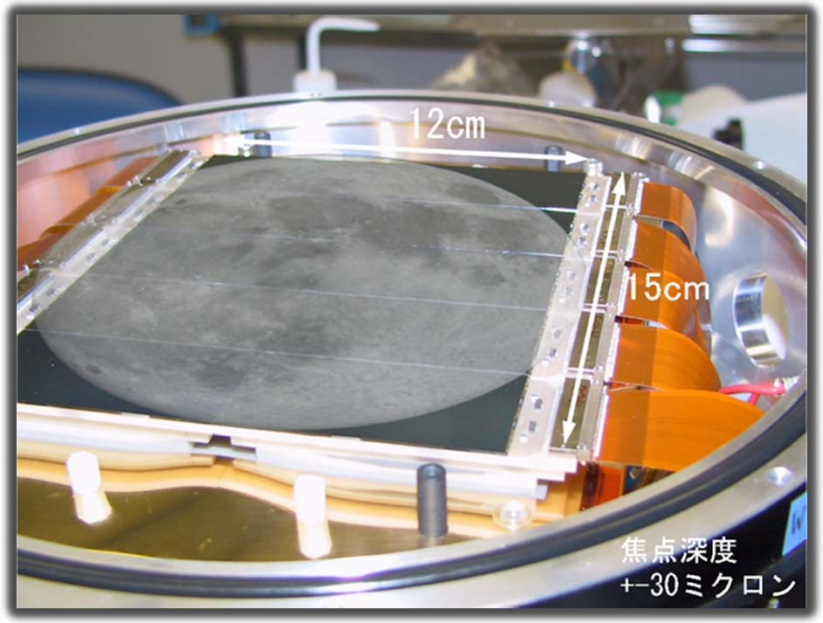
CCD

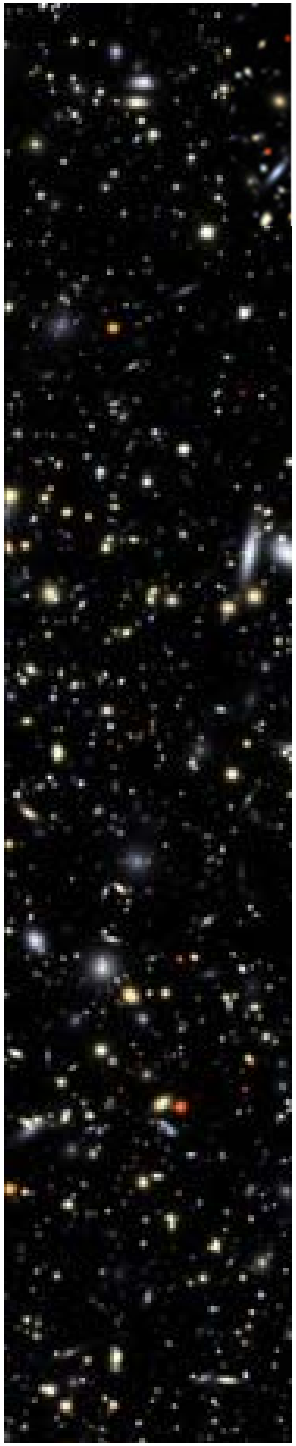
- ✧Subaru – 10 CCDs, LSST – 189 CCDS
- ✧Changes focal plane layout

Name	xpos (µm)	ypos (µm)	x pixels	y pixels
R00_S12	-254000	-212750	4000	4072

⇩

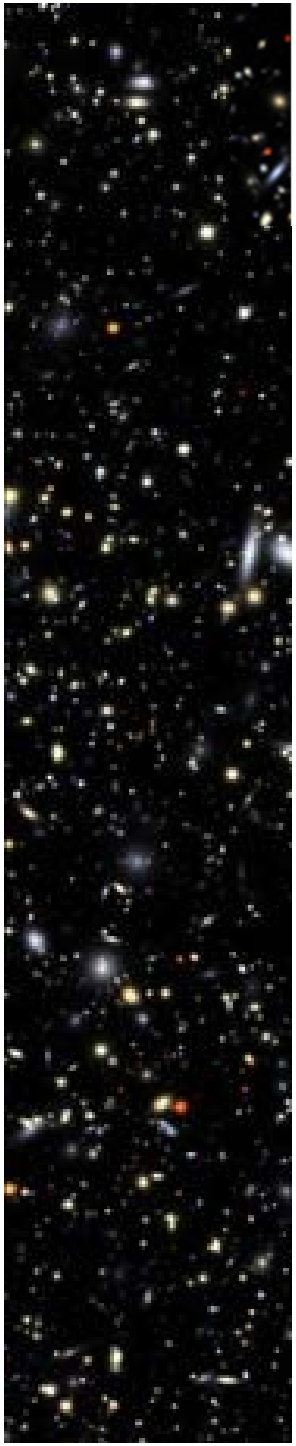
Ponyo	-60000	-30000	2048	4096





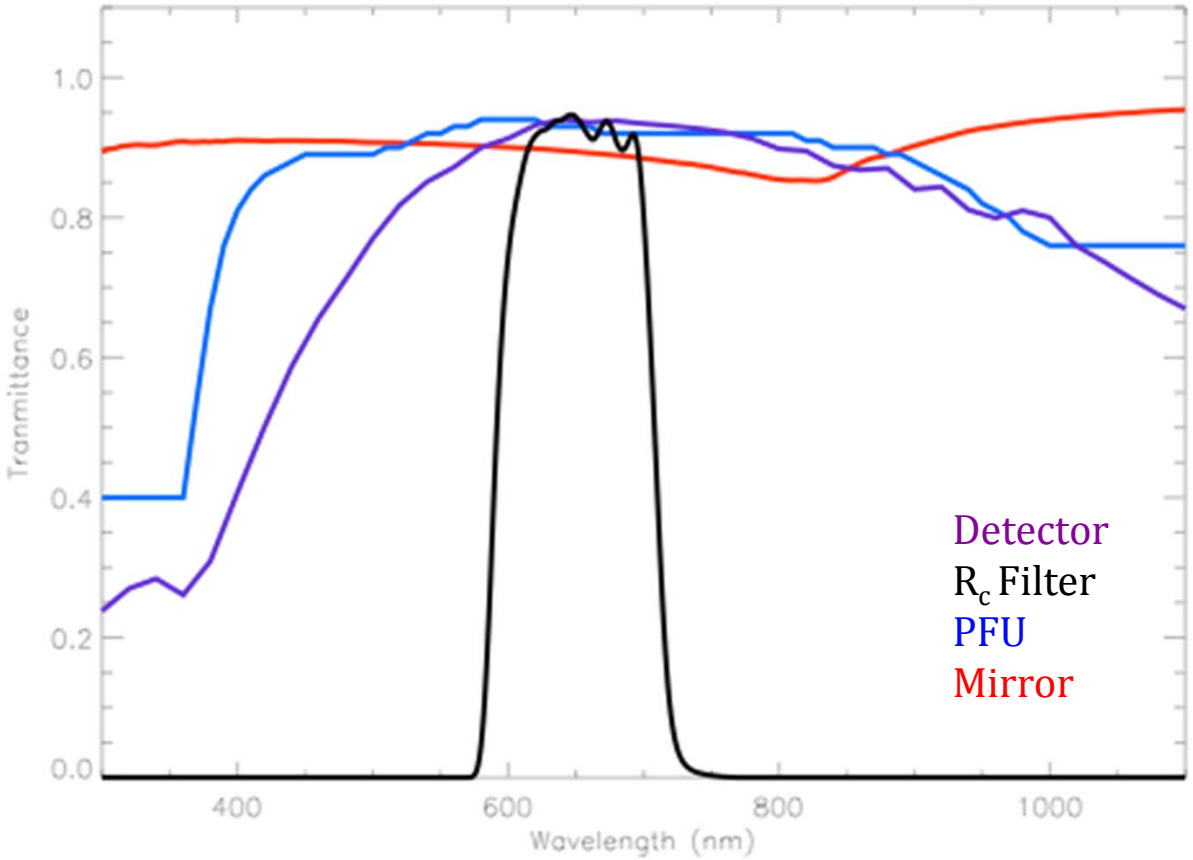
Detector Settings

- ✧Back bias voltage increased from 35 to 50V
- ✧Silicone layer increased to 200µm
- ✧Pixel size increased from 10 to 15µm
- ✧Aperture radius maximum of 4100mm, minimum of 480mm



Reflectivity/Transmittance

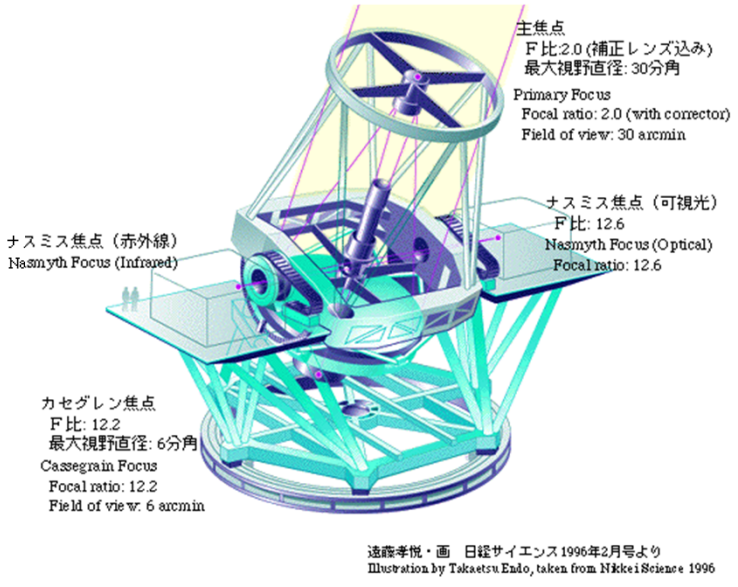
✧Coating files determine which wavelengths pass through a surface

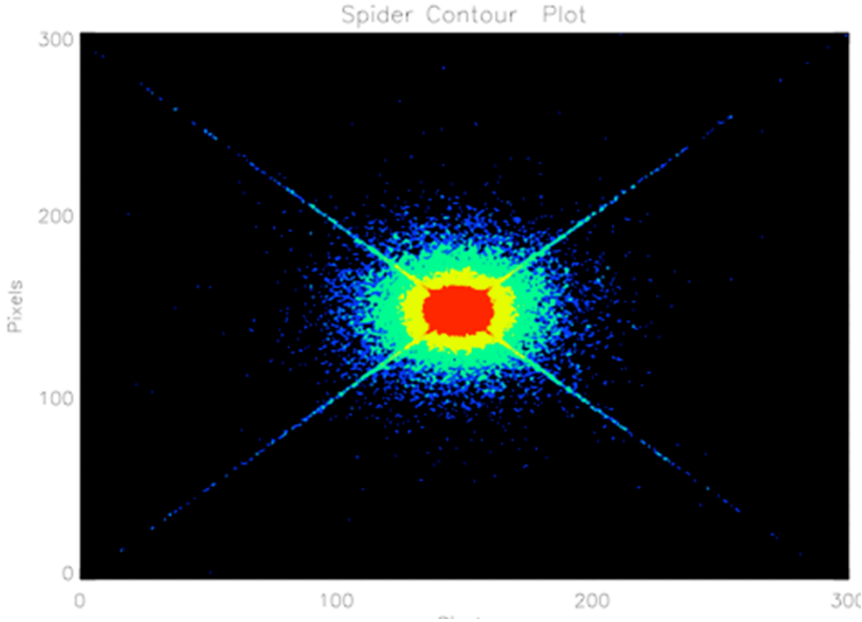


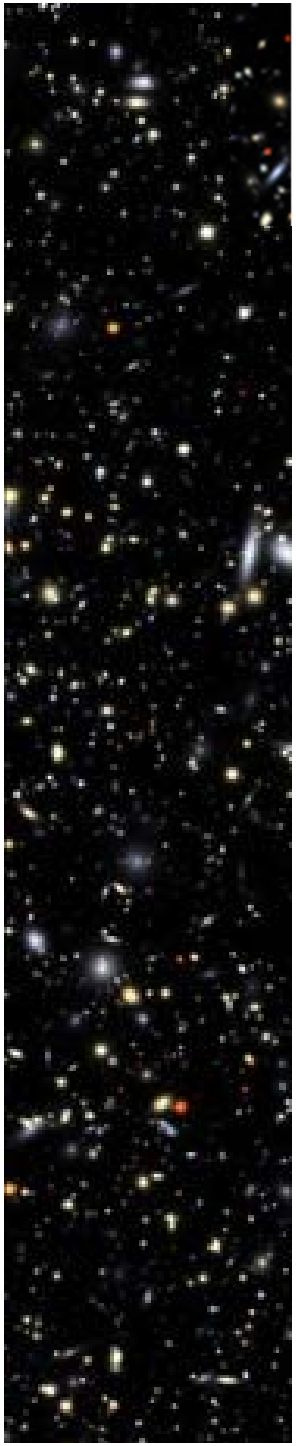
Spider

✧Size affects the light that reaches the mirror

Type	Height	Thickness	X-Position	Y-Position
outerring	16100	4100	0	0
cross	16100	224	0	0
outerring	1550	4100	0	0
cross	1550	224	0	0







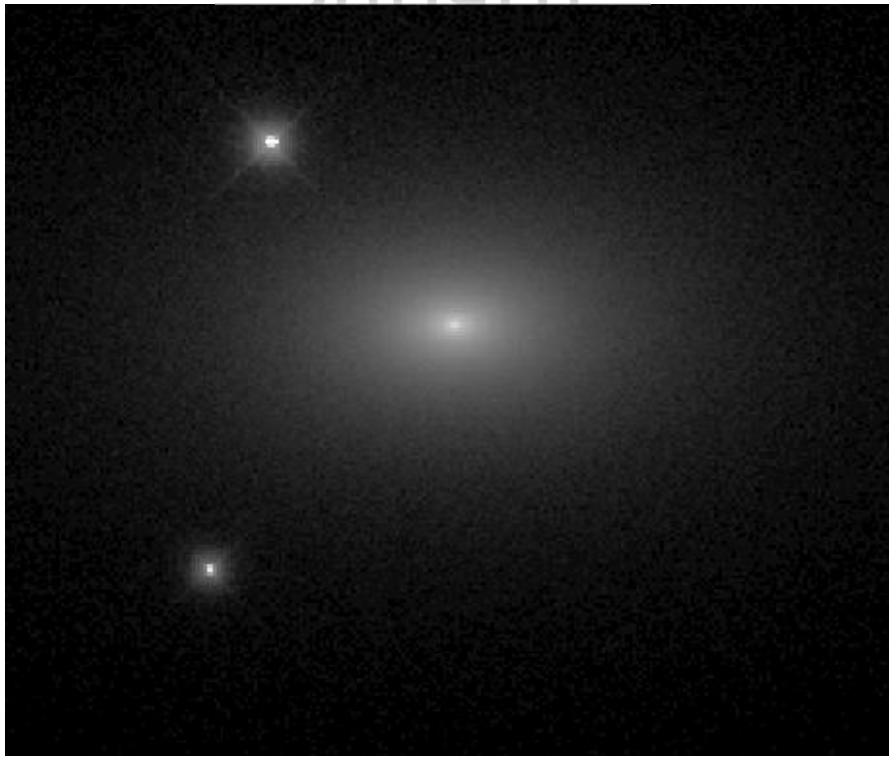
Control

✧Accounts for slight movement of surfaces in the telescope due to wind or other factors

Object	Displacement Type	Mean	Sigma	Distribution	Affected Surface Number
M1	phi, psi	0	6.28	uniform	0
M1	theta	2.47e-7	0	gaussian	0
M1	xdis, ydis, zdis	1.14e-3	0	gaussian	0
M1	z4, z5, z6, z7, z8, z9	4.18e-5	0	gaussian	0
M1	z10, z11, z12, z13, z14, z15	2.166e-5	0	gaussian	0
M1	z16, z17, z18	1.4e-5	0	gaussian	0
M1	z19, z20, z21	1e-5	0	gaussian	0
camera	phi, psi	0	6.28	uniform	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
camera	theta	1.67e-5	0	gaussian	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
camera	xdis, ydis, zdis	3.4e-3	0	gaussian	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

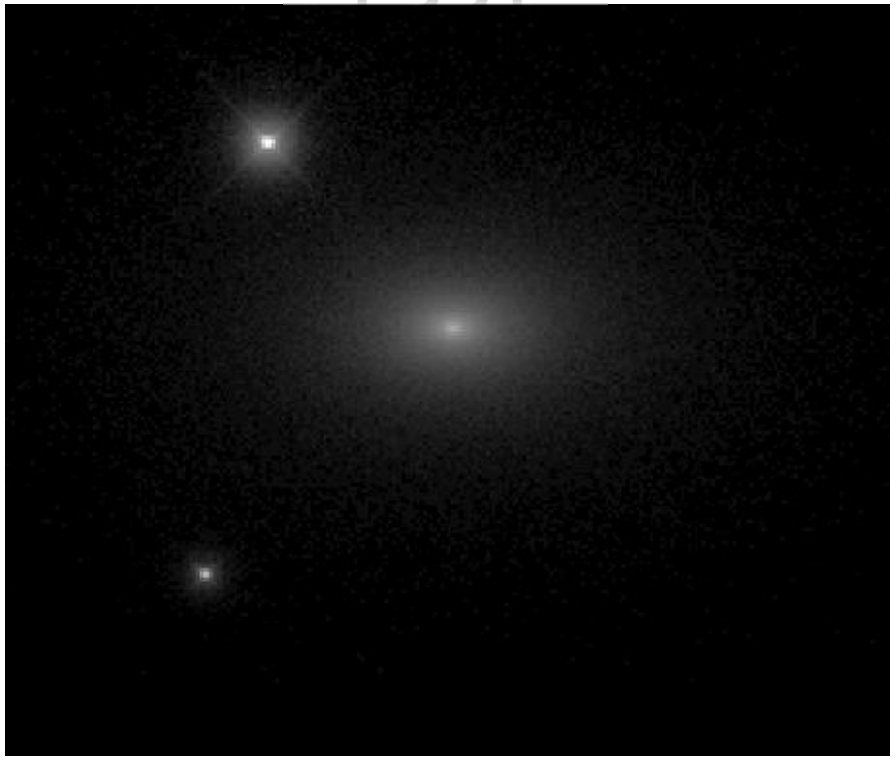
Final Results

Subaru



Pixels

LSST



Pixels

✧Actual Subaru pictures have not yet been compared, but differences between simulated images are realistic.

Sources

- Miyazaki, S., et al. 2002, *Subaru Prime Focus Camera - Suprime-Cam*, PASJ, 54, 833
- Satoshi Miyazaki, e-mail to John Peterson, Sept 2010
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- Yukiko Kamata, Satoshi Miyazaki, Hidehiko Nakaya, Takeshi Go Tsuru, Shin-ichiro Takagi, Hiroshi Tsunemi, Emi Miyata, Masaharu Muramatsu, Hisanori Suzuki and Kazuhisa Miyaguchi, "Recent results of the fully-depleted back-illuminated CCD developed by Hamamatsu", Proc. SPIE 6276, 62761U (2006); doi:10.1117/12.672628
- Julien Lozi, Frantz Martinache, and Olivier Guyon. "*Phase-Induced Amplitude Apodization on Centrally Obscured Pupils: Design and First Laboratory Demonstration for the Subaru Telescope Pupil*." ASP, 121, Nov. 2009, pp. 1232-1244.

✧ The LSST Image Simulation Team