The EUV Normal-Incident Telescope with an Adaptive Optics

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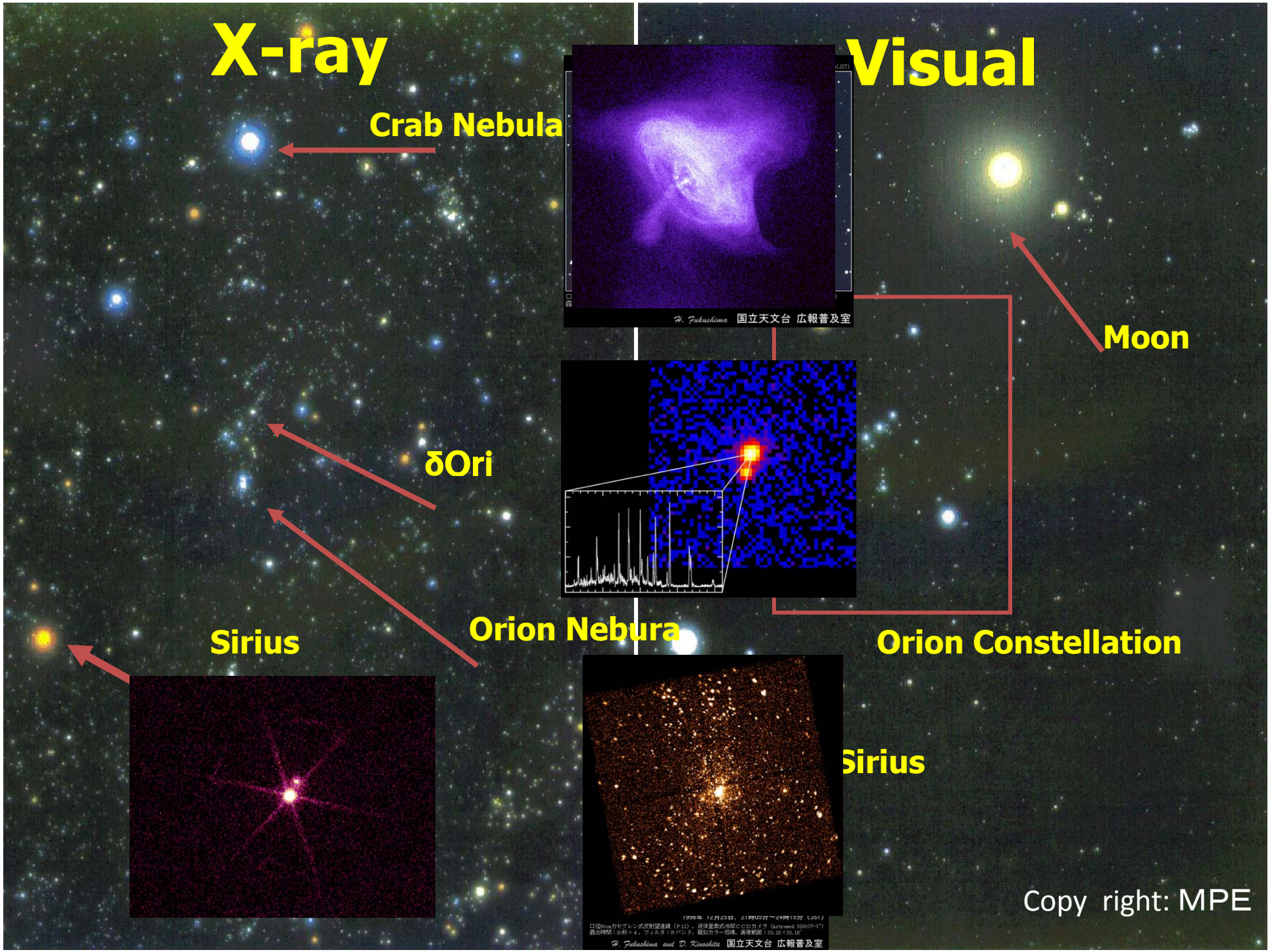
ABSTRACT

- We report some experimental results of our normal-incident EUV telescope tuned to a 13.5 nm band, with an adaptive optics.

- We confirmed the validity of our control and performed a 2.1 arc-sec resolution by both optical light and EUV.

Outline

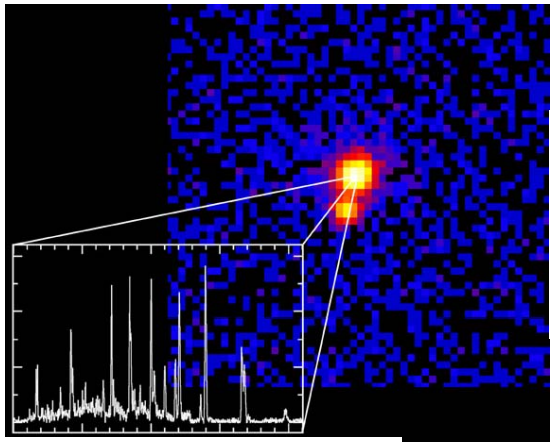
- 1. Introduction
- 2. Telescope Design
- 3. AO System
- 4. Experiment
- 5 Summary


X-ray
Visual
Crab Nebula
Moon
δOri
Orion Nebura
Orion Constellation
Sirius
Sirius
Copy right: MPE

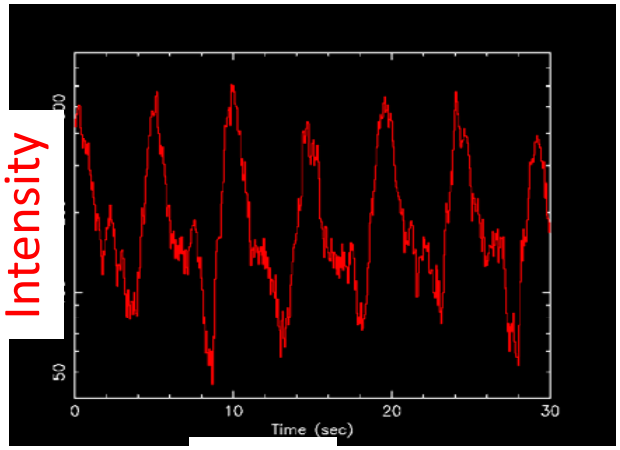
1.Introduction

In X-ray Astronomy, we can investigate
very-hot objects and
non-thermal energetic phenomena
by taking

Energy Spectra, Time Variations and **Images.**



O-type Star δ Ori（CXO）
From Chandra Photo Album



X-ray Pulsar Cen X-3
(Kohmura etal. 2001)

Radio Galaxy Cen A (CXO)
From Chandra Photo Album

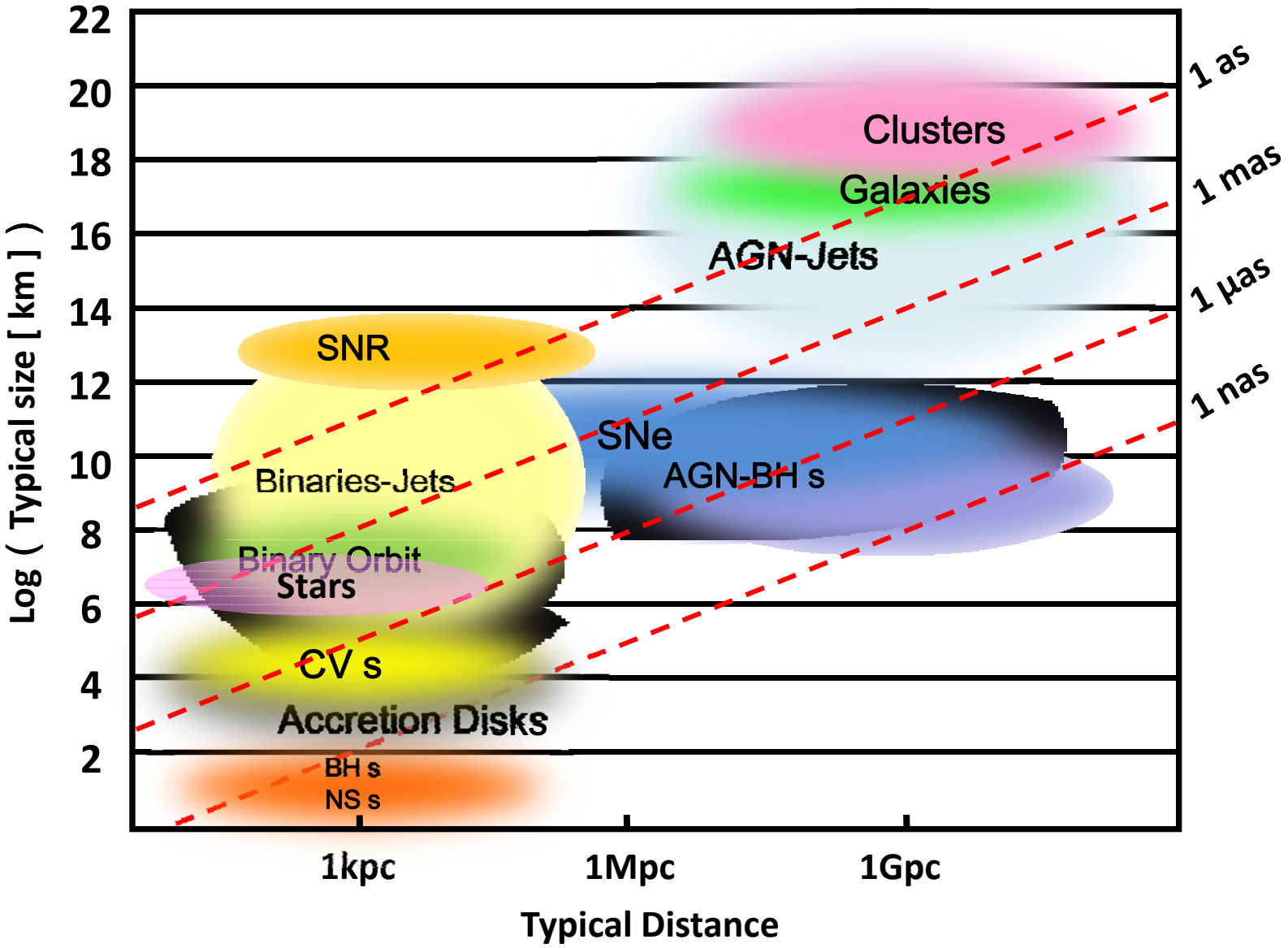
1. Introduction

- X-ray Astronomy Satellite "*Chandara*" was launched in July 1999 and it has ~0.5 arc-sec resolution. Thisis the best telescope in the world.

- *Chandra* is providing us wonderful X-ray images and we are enjoying lots of science.

- However, the current achievement of the image quality is still far from the theoretical diffraction limit!

Celestial Objects



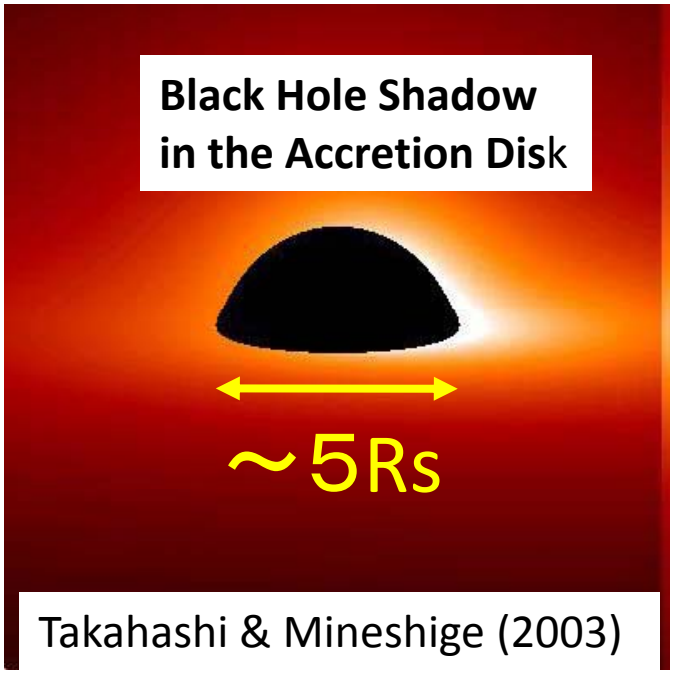
Angular-sizes of BHs

	Mass (Msun)	D (kpc)	(m)	Rs (au)	(μ as)	Shadow Size (μ as)
StellarBH@pc	1.00E+00	0.001	2.95E+03	1.97E-08	0.02	0.10
M82	1.00E+06	3700	2.95E+09	1.97E-02	0.01	0.03
SgrA*@GC	2.60E+06	8	7.67E+09	5.11E-02	6.39	31.96
SgrA*@GC	3.70E+06	8	1.09E+10	7.28E-02	9.10	45.48
M31	3.50E+07	800	1.03E+11	6.88E-01	0.86	4.30
NGC4258	3.90E+07	7200	1.15E+11	7.67E-01	0.11	0.53
M87	3.20E+09	16100	9.44E+12	6.29E+01	3.91	19.54

Ultimate objective is a BH-imaging.

1 μ-arc sec resolution is required.

This is currently almost impossible.

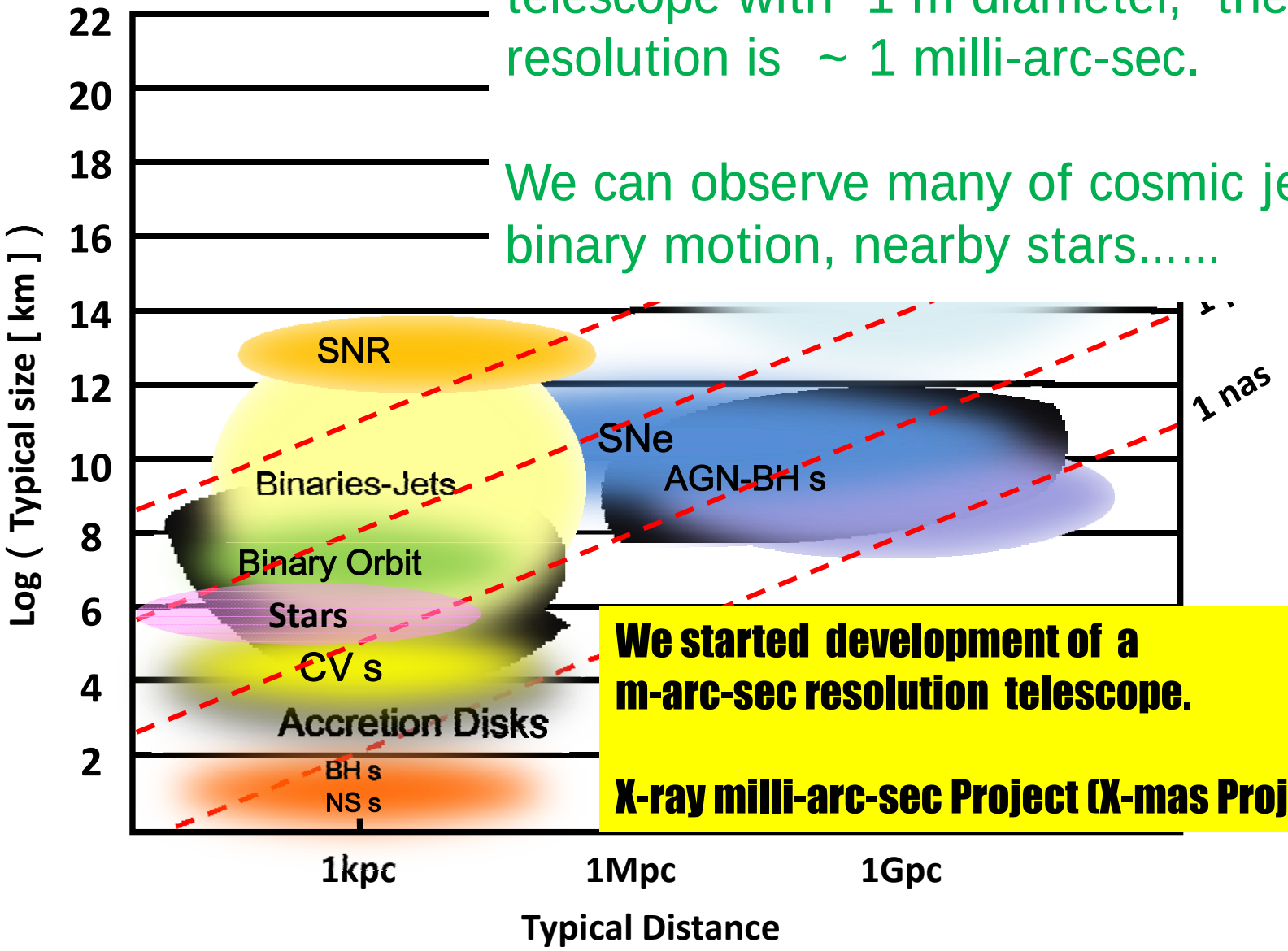


Takahashi & Mineshige (2003)

Celestial Objec

Without mentioning the BH imaging,
if we have a diffraction limit X-ray telescope with 1 m diameter, the resolution is ~ 1 milli-arc-sec.

We can observe many of cosmic jets, binary motion, nearby stars.....



We started development of a m-arc-sec resolution telescope.

X-ray milli-arc-sec Project (X-mas Project).

2.Telescope Design : What is the problem?

Requirement of Small-scale Roughness : several Å — **Easy**

Requirement of Large-scale Figure Error: ~1 nm — **Difficult**

We must correct only large scale figure error by thermal and gravitational distortion. This requires only slow control.
This is not a case of ground base AO telescopes.
They need to correct the atmospheric and need very fast control. — **relatively easy**

We are applying two ideas.

[1] continuous monitoring of the figure error

[2] adaptive optics system

2.Telescope Design : Technical Consideration

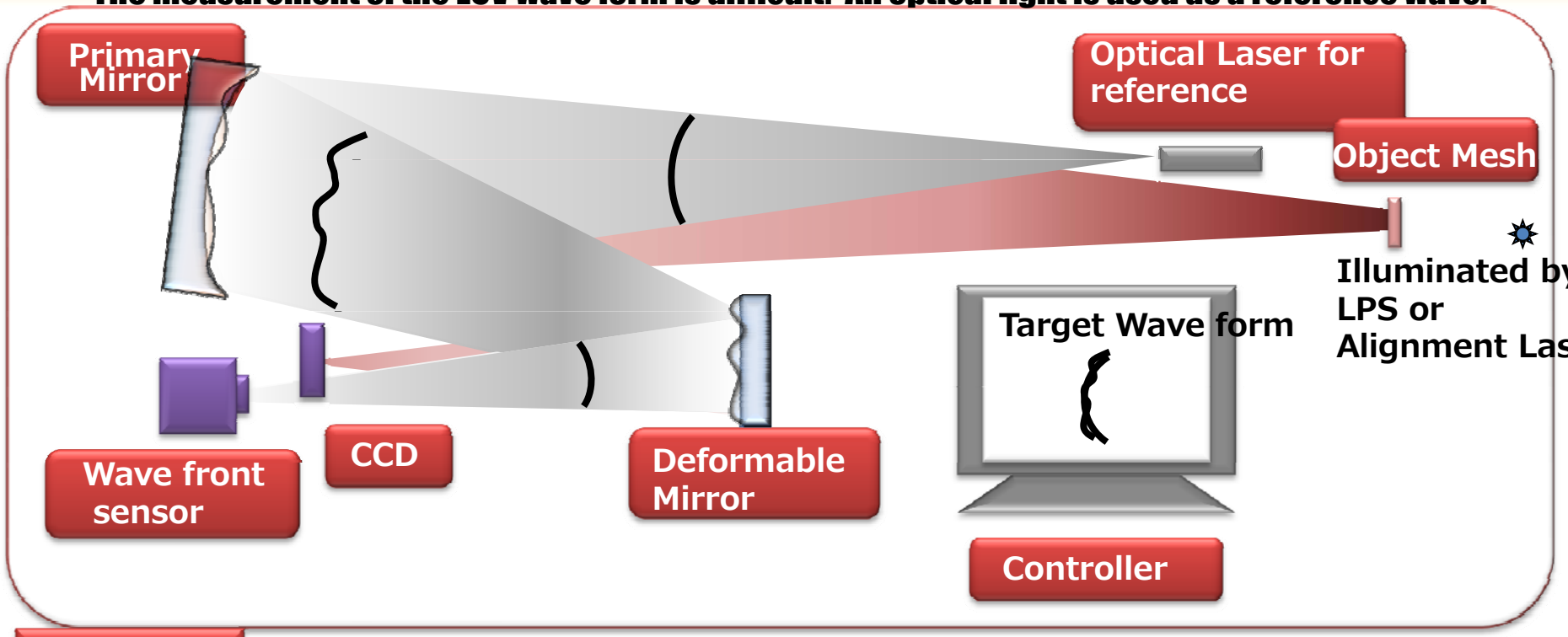
- A normal incident telescope is easier than the grazing incident telescope on a fabrication point of view, and on having a large effective area.
- Possible precision of a simple shape measurement is ~ nm.

13.5nm band is currently best choice.

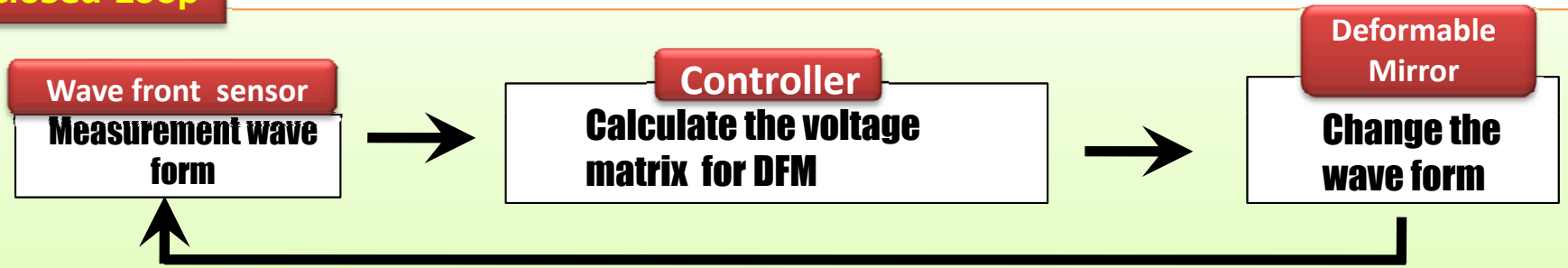
Because Mo/Si Multi-Layers has more than 70% reflectivity for the normal incident mirror.

3. AO System

The measurement of the EUV wave form is difficult. An optical light is used as a reference wave.

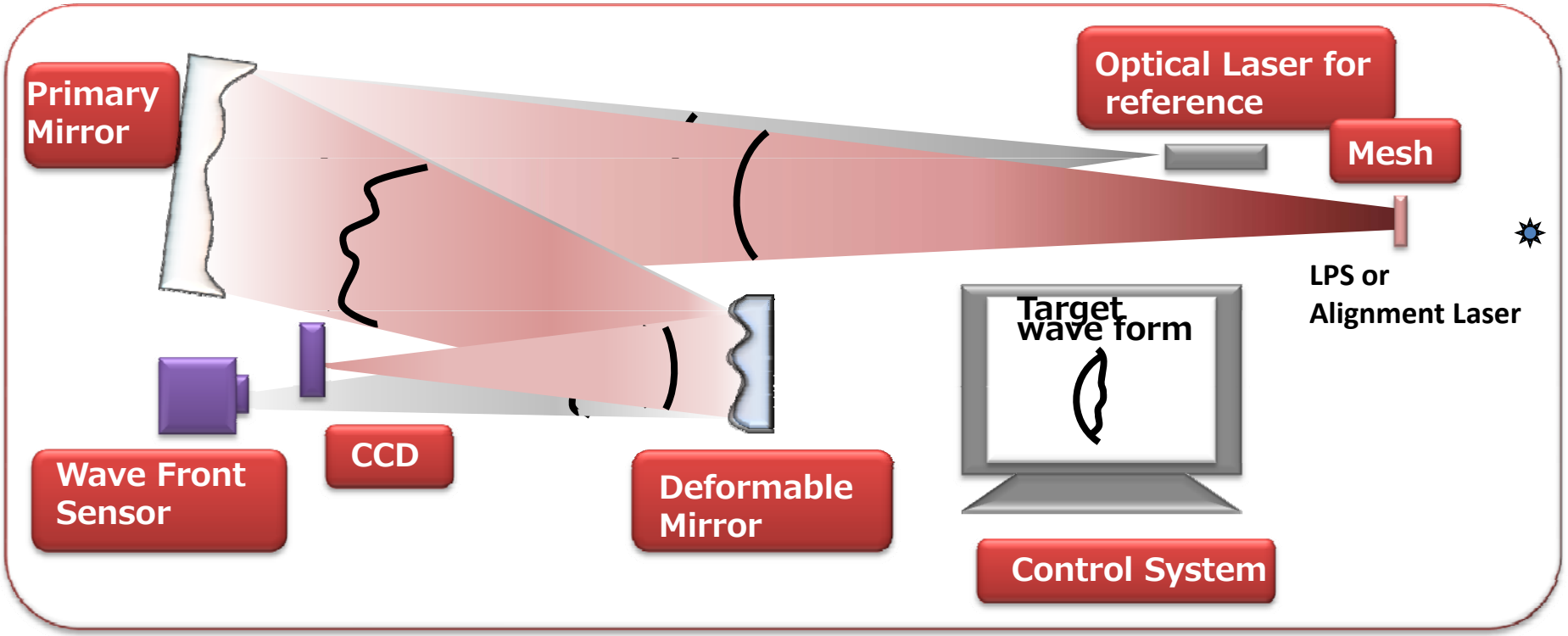


Closed Loop



Correction of the wave form as approaching to a target wave form.

3. AO System : Effect of the light path



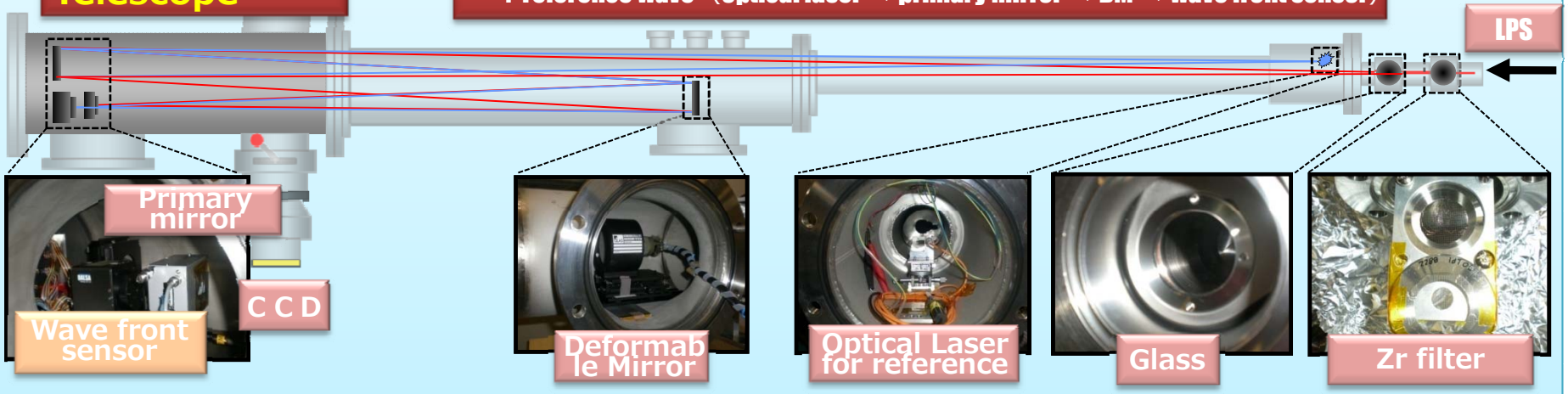
- The paths of the reference light and the EUV are different from each other.
- We modify the target wave form
- Optimum target wave from is derived and control the system to have a good image for EUV.

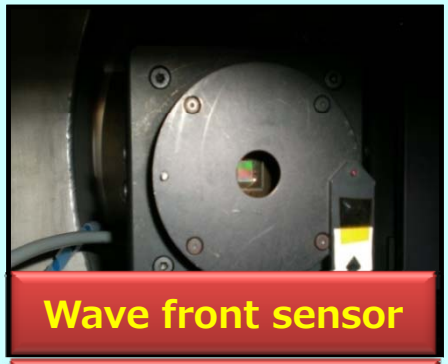
4.Experiment : Telescope

The measurement of the EUV wave form is difficult. An optical light is used as a reference wave.

Xmas Telescope

— : Optical Light or EUV （LPS → Primary Mirror → DM → CCD）
— : reference wave （optical laser → primary mirror → DM → wave front sensor）





Wave front sensor

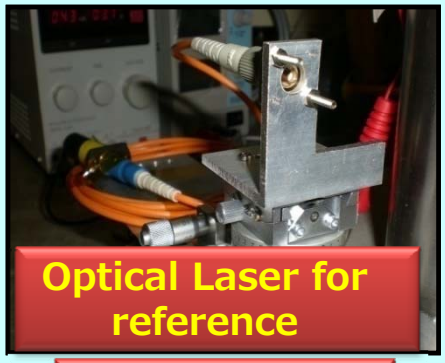
HASO32 Shack-Haltmann
32×32 mirocr-lenses
512×512 CCD

Zr filter

Thickness : 150nm
Transmission : ~60%@13.5nm
Transmission : ~0.01%@Optical
Supported by a mesh with
interval : 332μm Thickness : 31μm

glass

Thickness : ~1 mm
Optically transparent
X-ray opaque



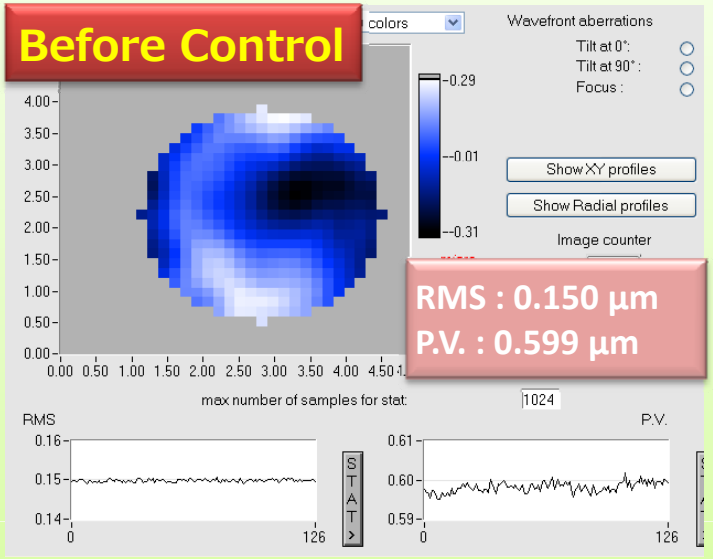
Optical Laser for reference

Wave length : 6 6 3 nm
Spot size : 1μm

4. Experiment : Set up

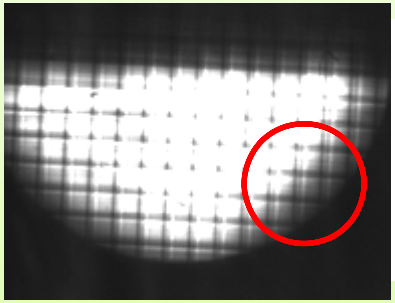
4. Experiment : Closed Loop Control with Optical Light

Before Control



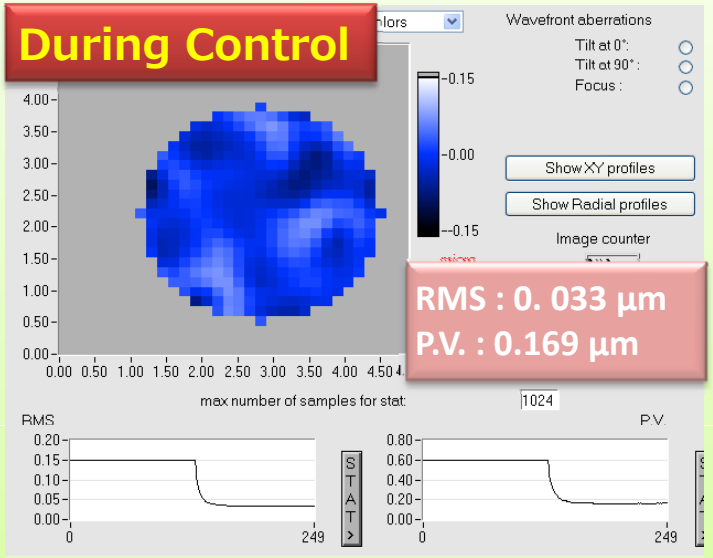
RMS : 0.150 μm
P.V. : 0.599 μm

Alignment Laser （663 nm）



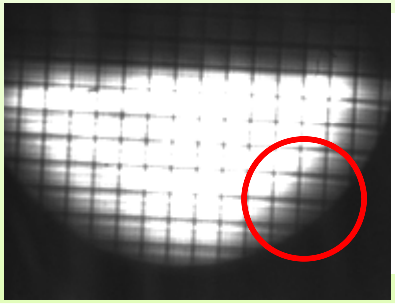
resolution : ~4.44 arcsec
(Reyleigh Criterion)

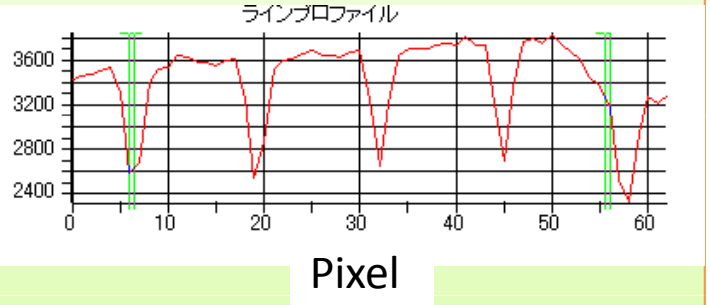
During Control



RMS : 0. 033 μm
P.V. : 0.169 μm

Alignment Laser（663 nm）





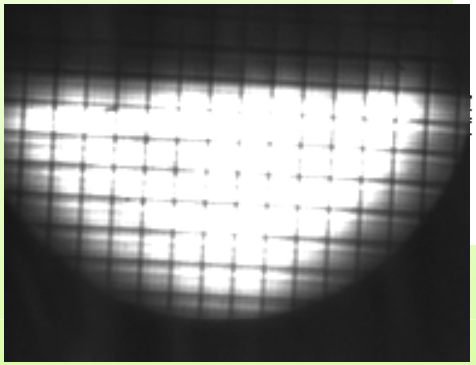
resolution : ~2.67 arcsec

4. Experiment : Modify target wave form

Target Wave Form

収差名	係数 [um]
tilt at 0°	-16.45
tilt at 90°	-1.96
focus	-4.466
astigmatism at 0°	0
astigmatism at 45°	0
coma at 0°	0
coma at 90°	0
spherical	0
etc・・・	0

Alignment Laser（663 nm）

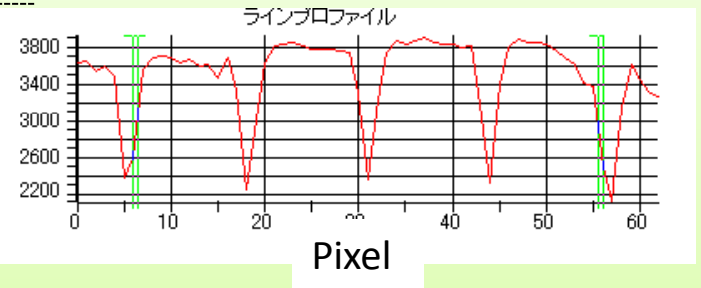


Resolution : ~2.67arcsec

Target Wave Form (taking into account the light path difference)

収差名	係数 [um]
tilt at 0°	-16.45
tilt at 90°	-1.96
focus	-4.466

Alignment Laser（663 nm）



By modifying the target wave form, the resolution becomes better. The resolution is roughly consistent with the diffraction limit of the optical light.

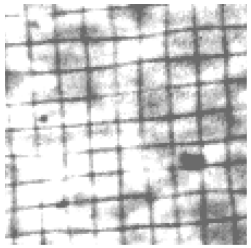
$$1.22\frac{663nm}{80mm} = 2.09arc\sec$$

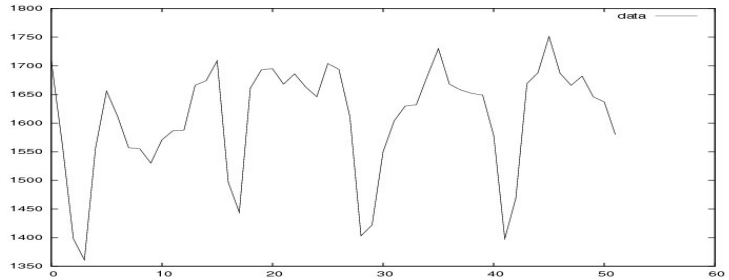
Resolution :~2.13arcsec

4. Experiment : Imaging Experiment with EUV

LPS -EUV(13.5nm) Diffraction Limit : 0.042arc-sec

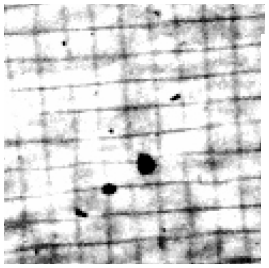
With spherical target wave form

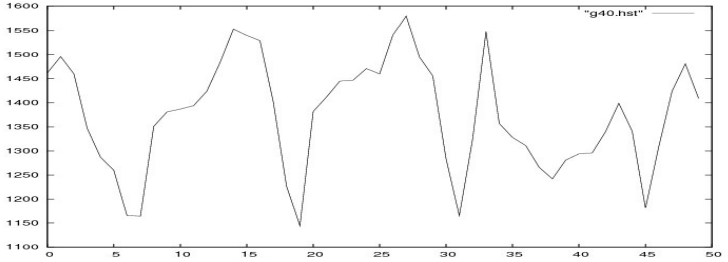




2.59arc-sec

With modified target wave form





2.08arc-sec

A little improvement but not enough performance

5. Summary : Result

Visual(532nm)	No.A.O.	A.O. with Spherical target	A.O. with Modified target	Diffraction limit
Angular Resolution(arc-sec)	5.69	2.7	2.1	2.09
EUV(13.5nm)	**No.A.O.**	**A.O. with Spherical target**	**A.O. with Modified target**	**Diffraction limit**
Angular Resolution(arc-sec)	3.10	2.6	2.1	0.04

Expanded Image

Possible Cause of the poor performance

1. More precise plimary mirror
   => Now we are polishing a new mirror.
2. Too large pixel size of the CCD
   ＝＞We ordered a new small pixel CCD

5.Summary

- An EUV AO-telescope is working now in our laboratory.
- We applied a closed Loop control using modified target, taking into account of the light path difference.
- The best resolution of the optical light is ~2.1 arc sec, which is roughly diffraction limit.
- In the EUV experiment, the resolution is still far from the diffraction limit, and further improvement is going on.