Subaru Telescope, LGSAO, & TMT

Masanori Iye（NAOJ）

1) Subaru Telescope
2) Laser Guide Star Adaptive Optics
3) 30m telescope TMT

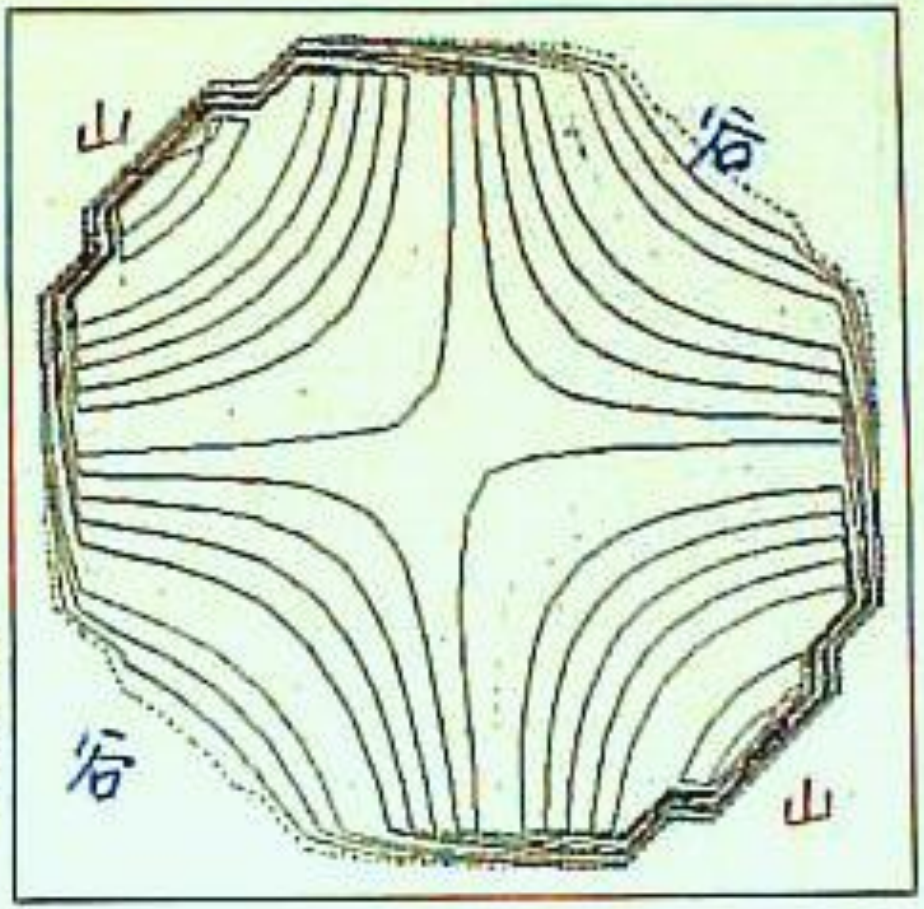
Subaru Telescope, its Science Achievements

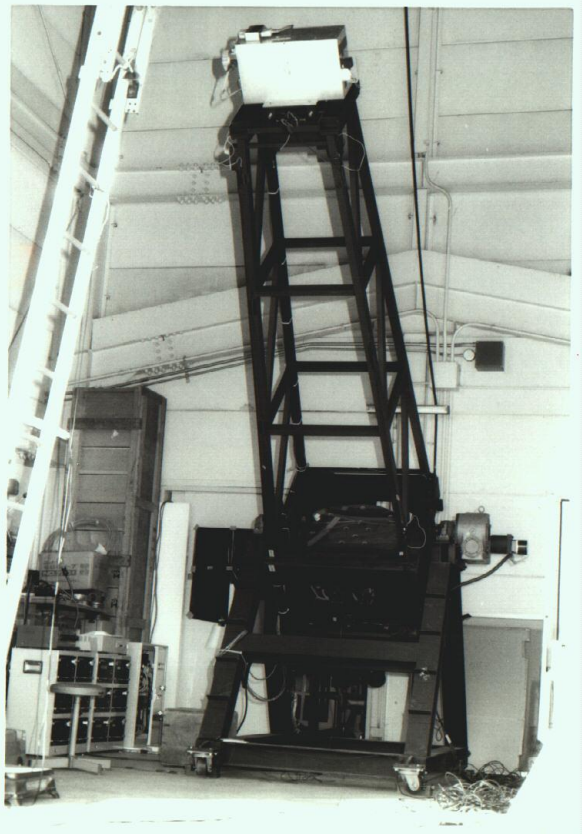

Enclosure Φ40m, H42m, 2500ton
400M$, 16yr for prep+construction, completion in1999

1989年10月14日

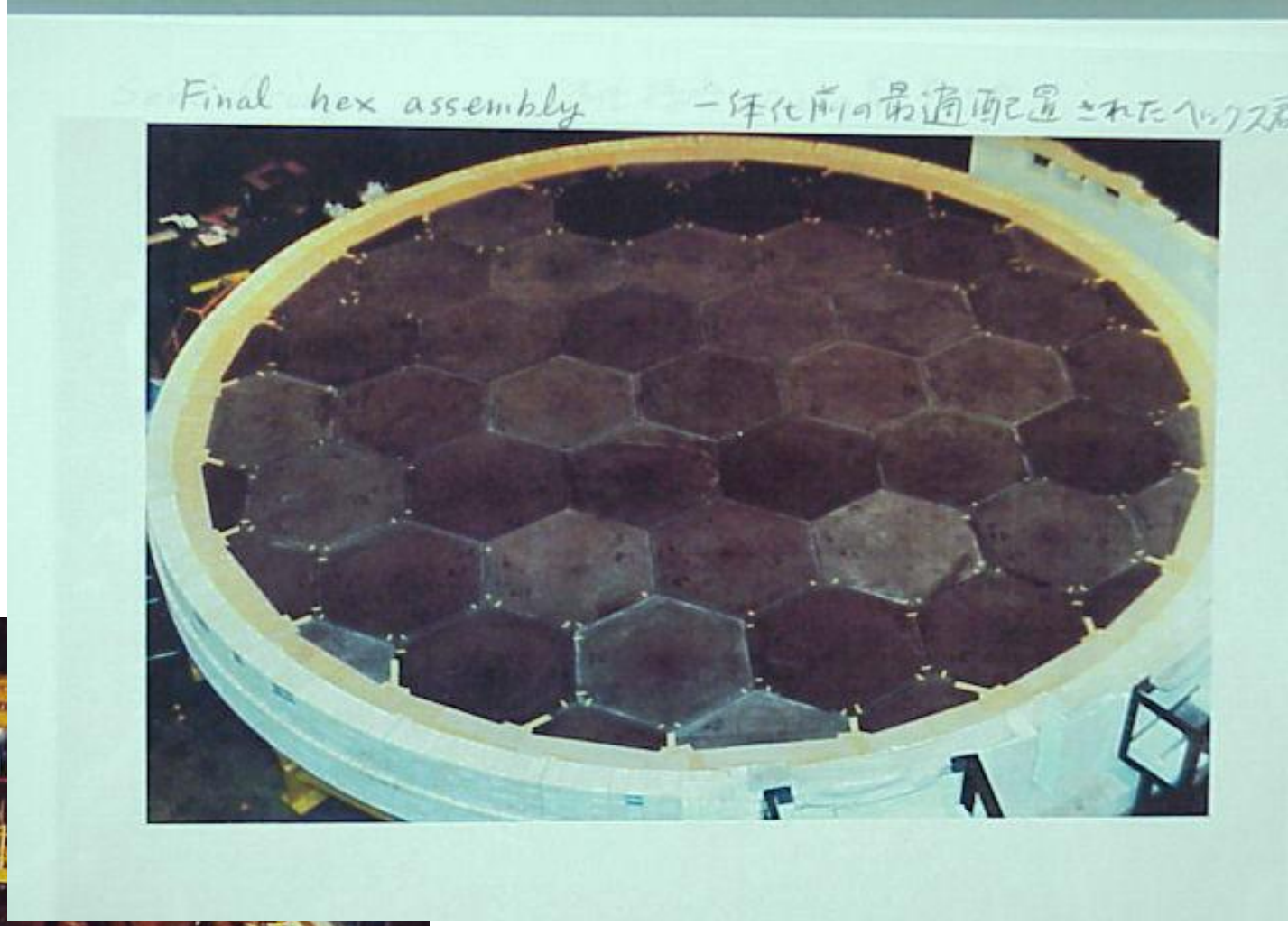
Active mirror control experiment on a 62cm mirror supported by 12 actuators

```
le  = coeffD.088
90T23CT+12V05   62cmB22=3
ame 88 - 15
it in nano-meter
n Z=  -653  Max Z=   659
0=     0 A40=  -9 A60=  -2
1=     0 A31= -14 A51=   2
1=     0 B31=  14 B51=  -7
2=    27 A42=  -0 A62=  -9
2=  -779 B42=  49 B62= -11
3=     9 A53=  -0
3=     6 B53=   3
4=    -8 A64=   8
4=    10 B64=  -8
5=     9
5=    14
5=   -13
5=    -2              EL=     0
=  -117 02=  -107 03=  -129
=   116 05=   262 06=   229
=    45 08=  -377 09=  -152
=   124 11=  -160 12=   278
ntour pitch =    66
ntour lines =    20
```



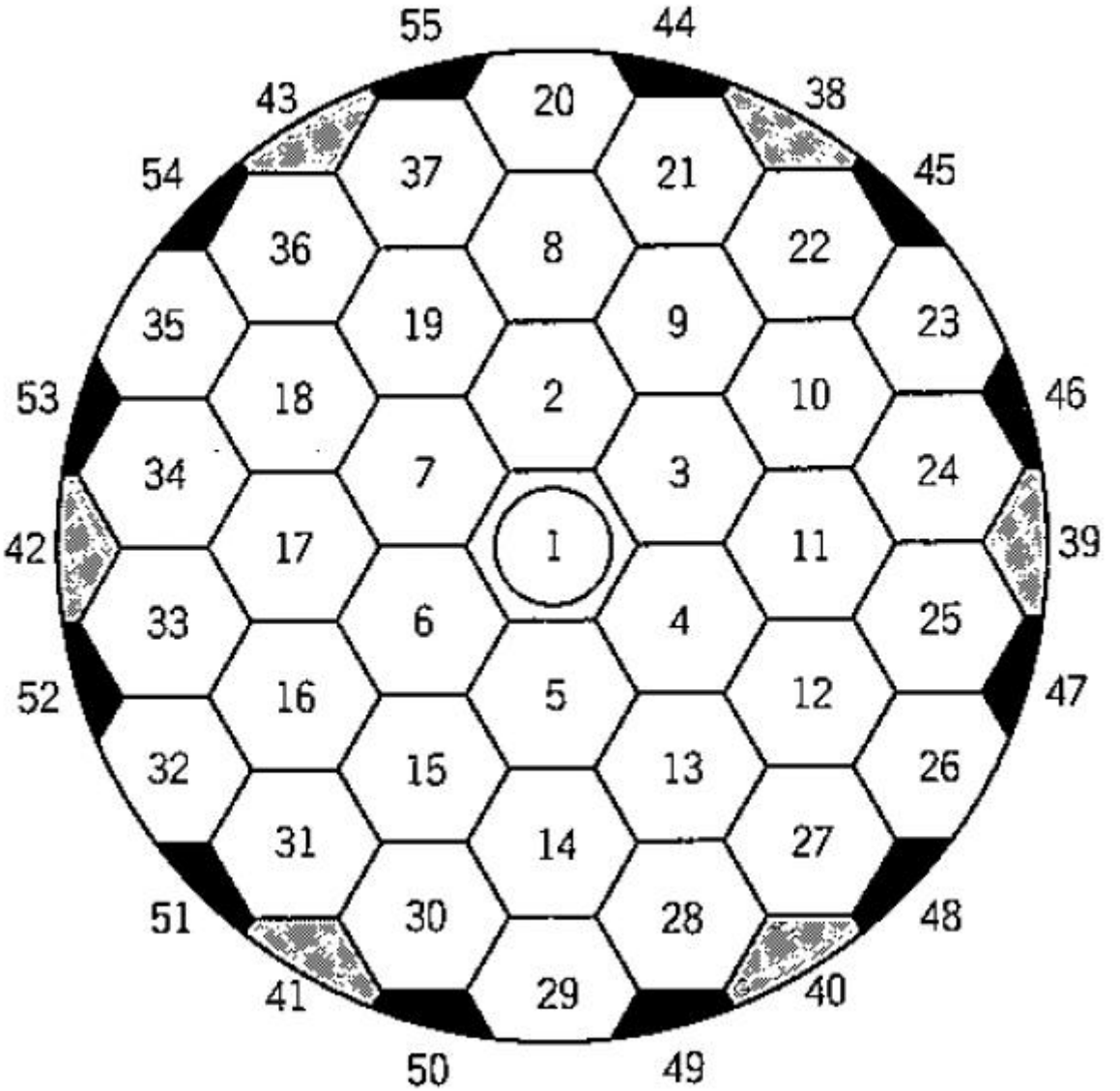


Corning ULE



First mathematical problem :
Find the best configuration to distribute 55 segments with different CTE to form a monolithic mirror with minimum thermal deformation

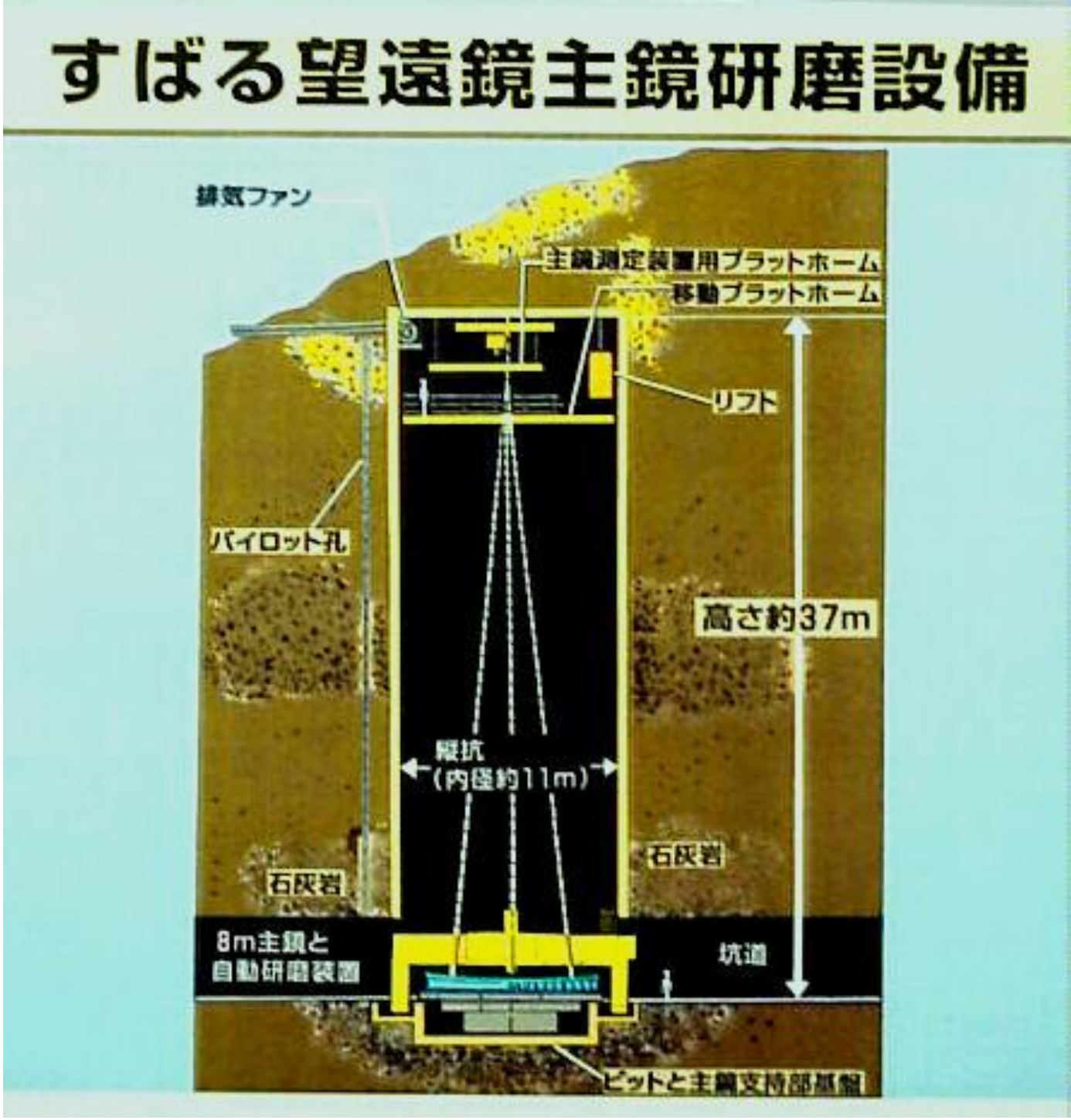
~ 55! combinations to examine.



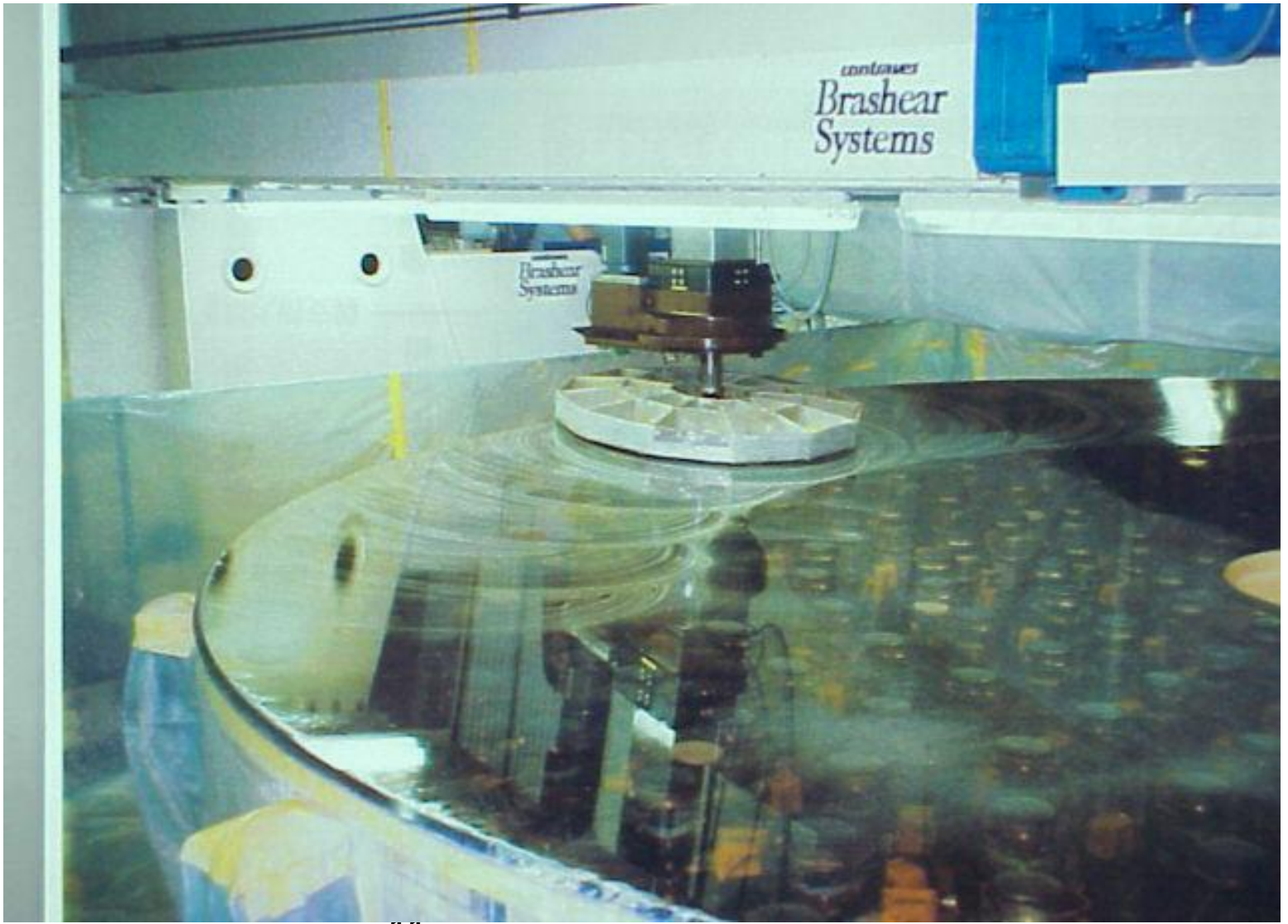
Glass transportation to Pittsburgh

Contraves underground optics facility needed 30m span

no wind shake
no diurnal tilt
no traffic vibration



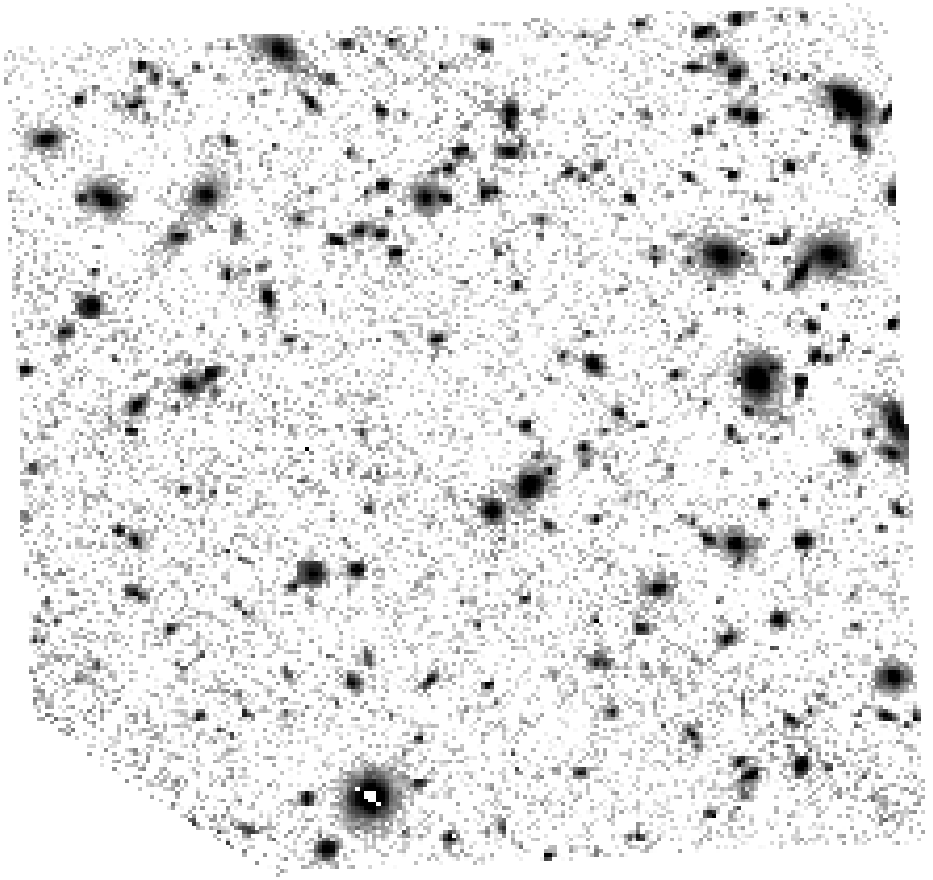
Four years of patient polishing




Aug.1998
13nm rms figure error achieved

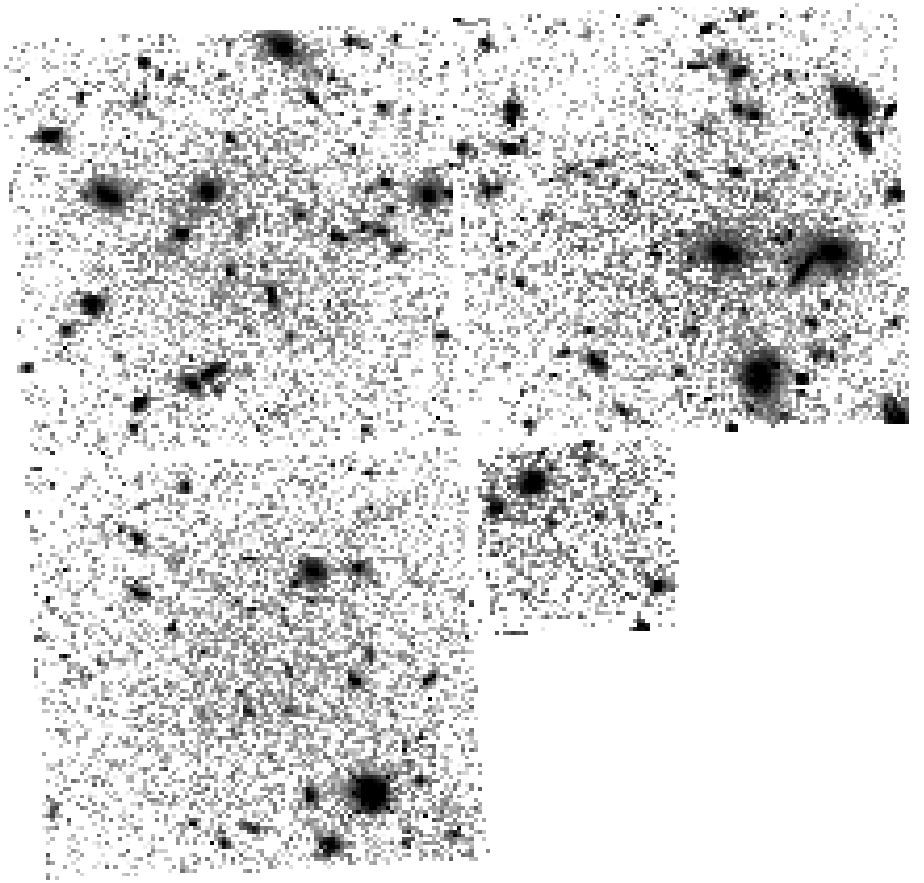
First light sensitivity comparison

Subaru R
3600 s



すばる　60分, 28等級

HST F702W
4200 s

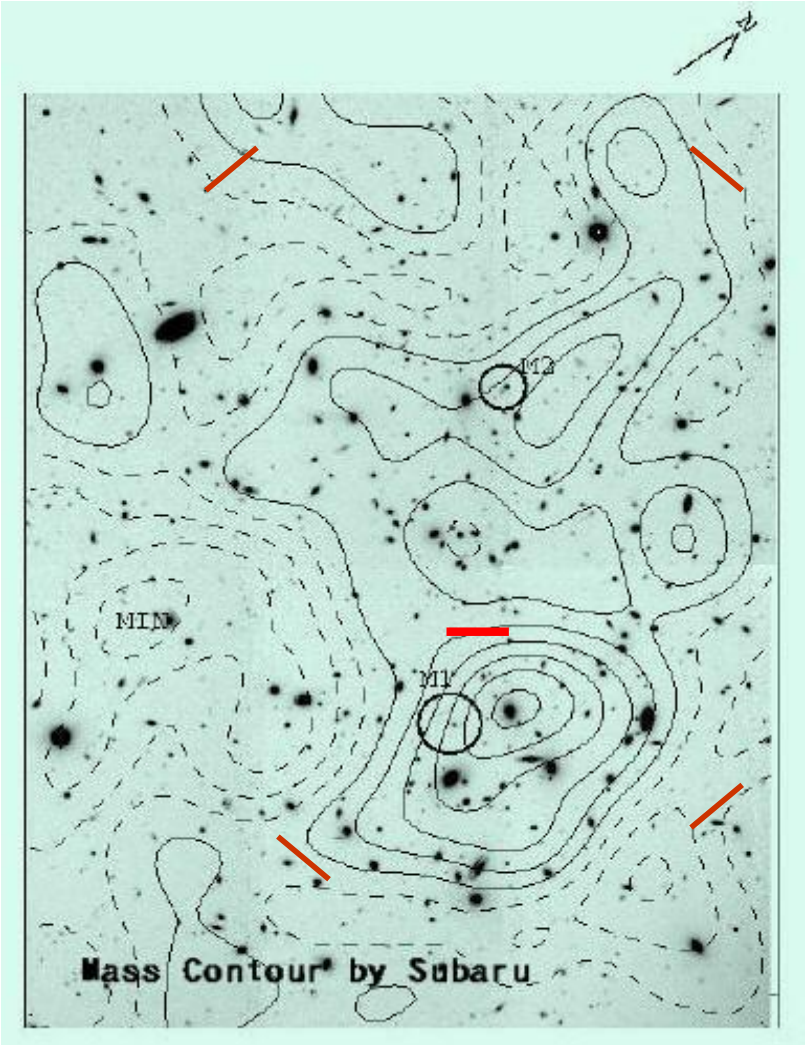


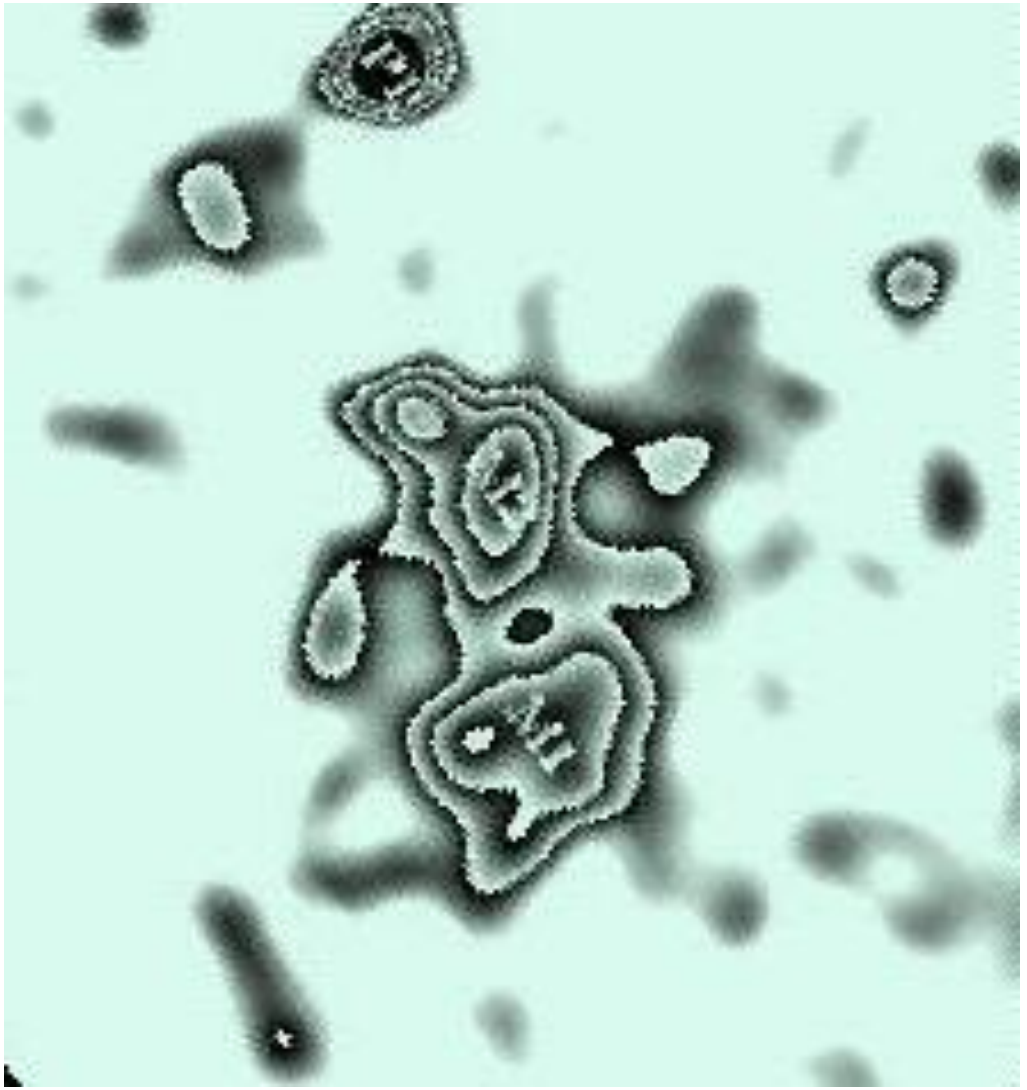
ハッブル 70分 28等級

勝負は引き分け

Weak lensing by a cluster of galaxies

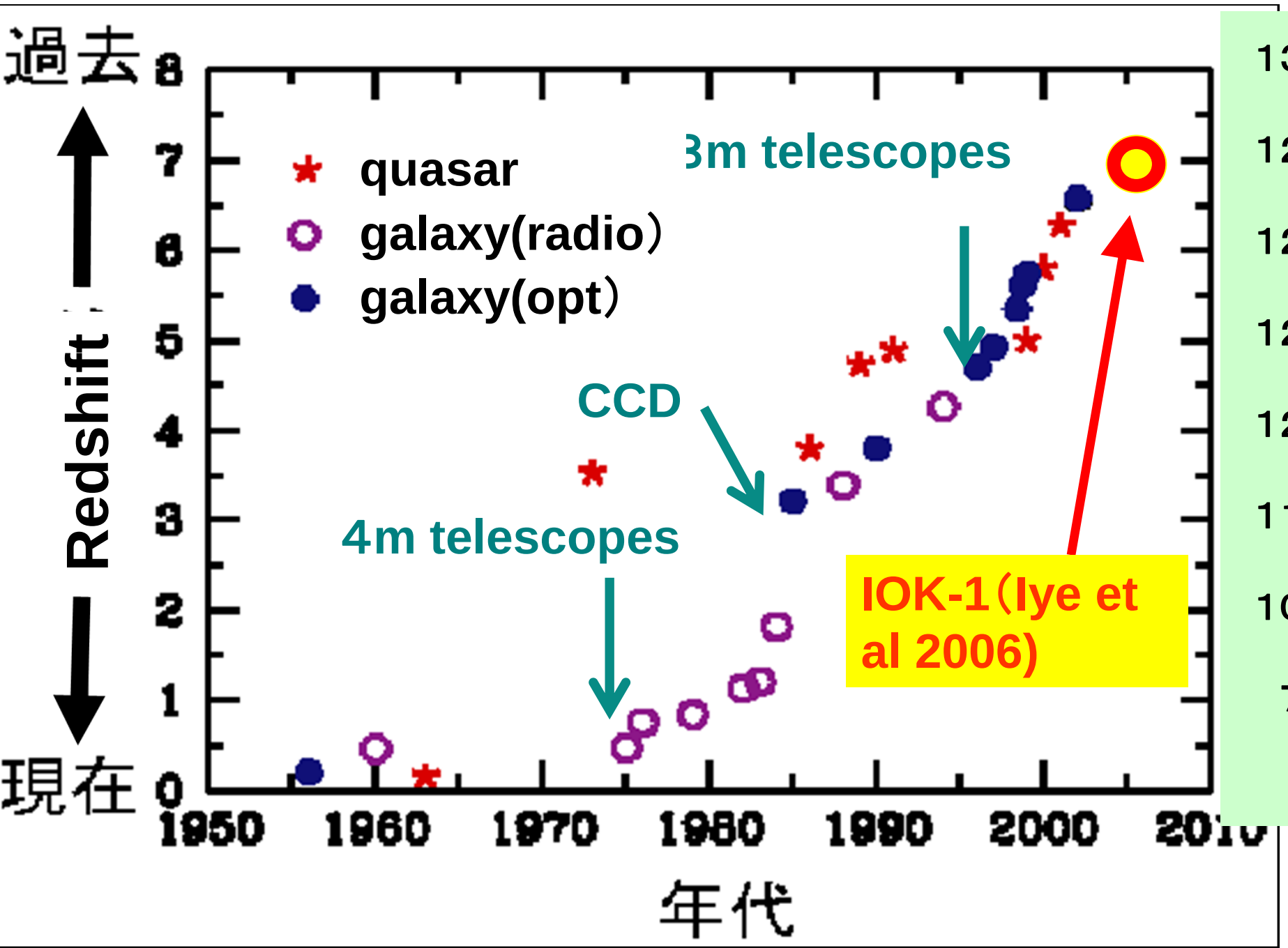
Miyazaki in Iye et al.(2000)



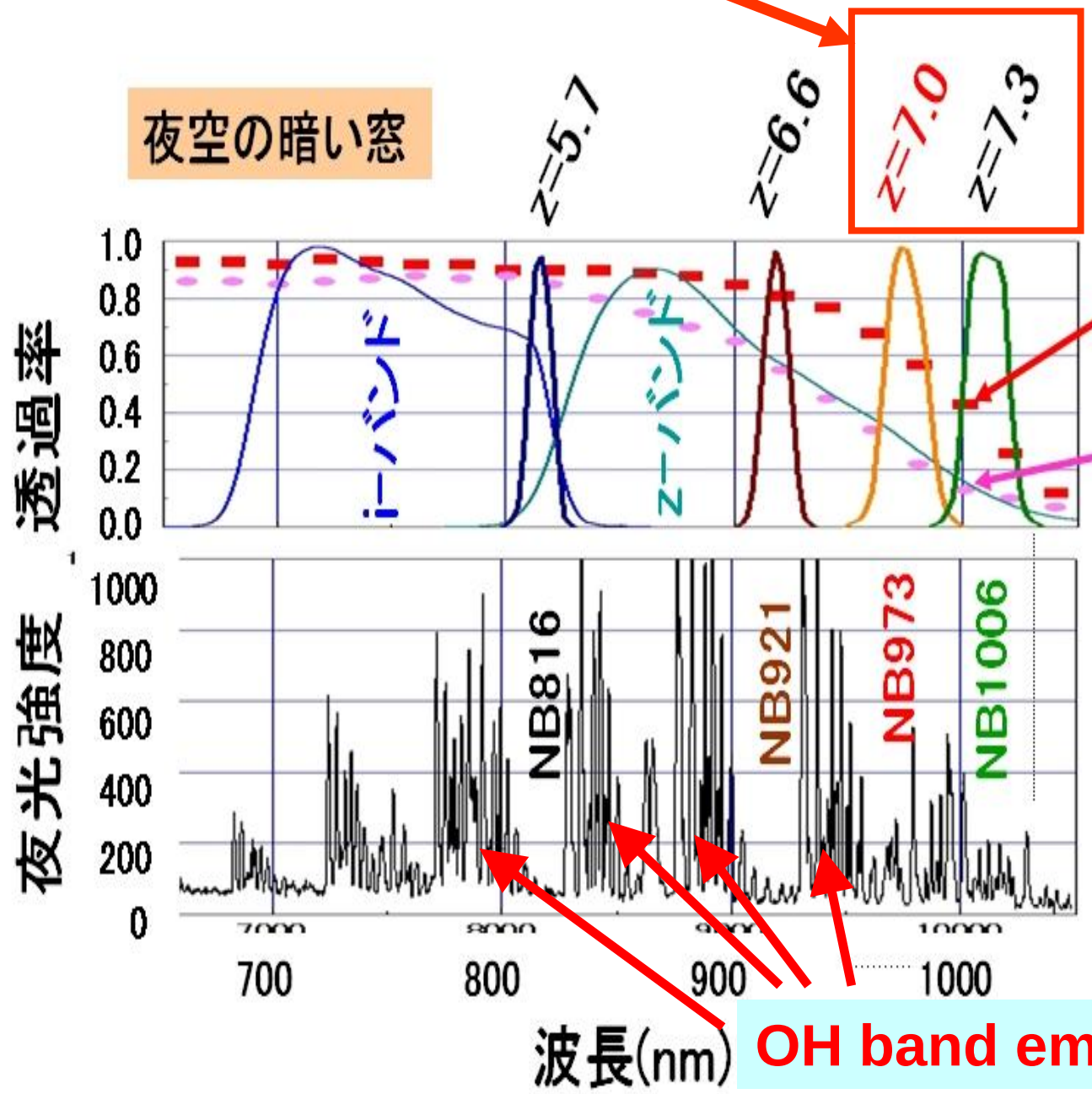


- Looking far is looking back in time

Most distant galaxies in history

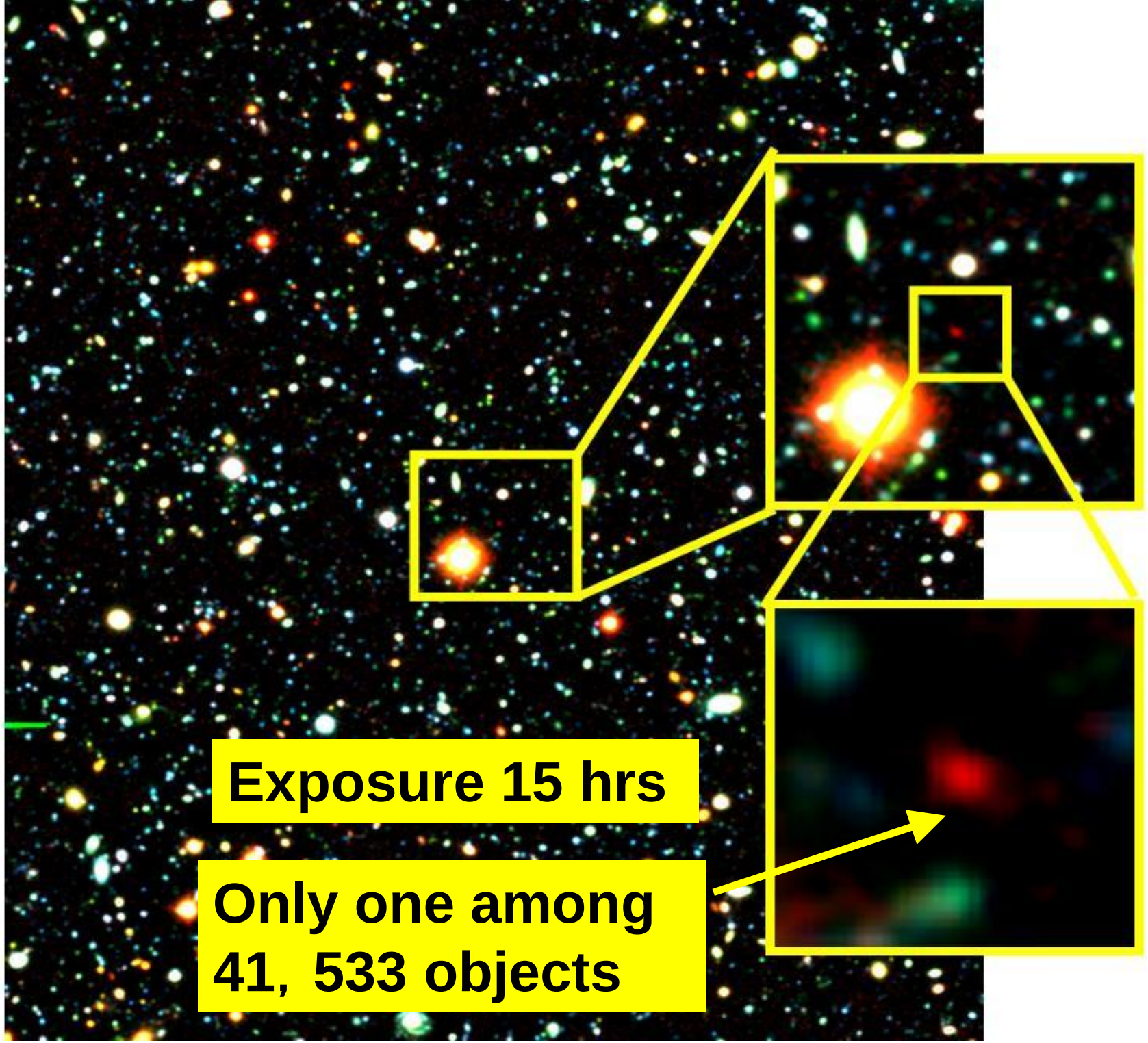


NB filters for SuprimeCam

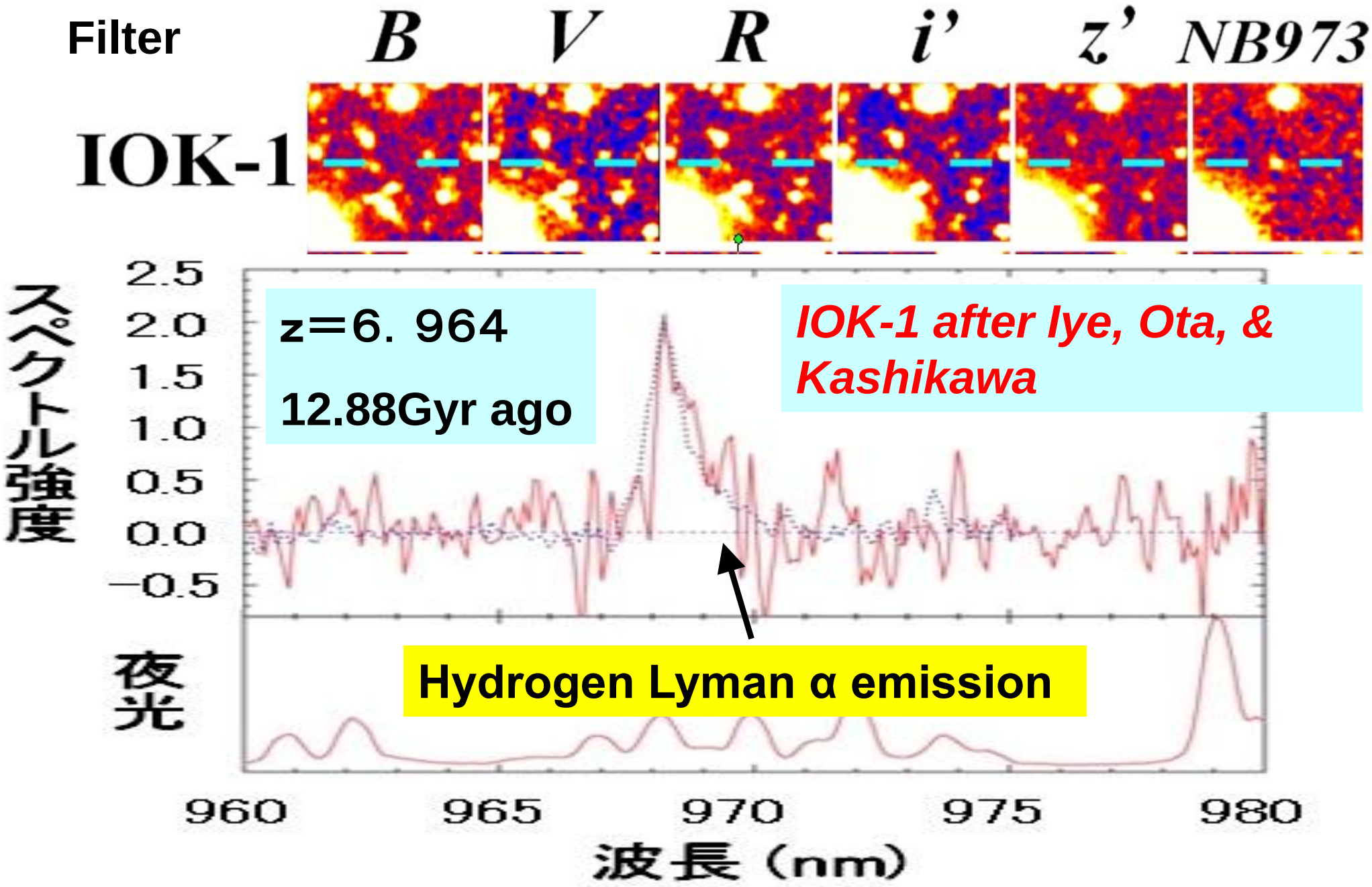


NB973

OH band emission


Exposure 15 hrs
Only one among
41, 533 objects

The most distant galaxy at 12.88Glyr IOK-1



High-z galaxy list

10/21で1498日目

Table 1: 赤方偏移が確定した最遠銀河ベスト 12(2009 年 10 月 1 日時点).

順位	銀河名	座標	赤方偏移	億年 #	論文	出版日
1	IOK-1	J132359.8+272456	6.964	128.8	家ほか	2006 年 9 月 14 日
2	SDF ID1004	J132522.3+273520	6.597	128.2	谷口ほか	2005 年 2 月 25 日
3	SDF ID1018	J132520.4+273459	6.596	128.2	柏川ほか	2006 年 4 月 25 日
4	SXDF Himiko		6.595	128.2	大内ほか	2008 年 7 月 25 日
5	SDF ID1030	J132357.1+272448	6.589	128.2	柏川ほか	2006 年 4 月 25 日
6	SDF ID91163	J132343.4+272954.5	6.587	128.2	柏川ほか	2009 年 2 月
6	SDF ID91988	J132342.2+272644.5	6.587	128.2	柏川ほか	2009 年 2 月
6	SDF ID71101	J132450.7+272159.7	6.587	128.2	柏川ほか	2009 年 2 月
9	SDF ID1					年 2 月 25 日
10	SDF ID1					年 2 月 25 日
11	SDF ID1					年 4 月 25 日
12	SDF ID157057	J132419.3+274124.8	6.568	128.2	柏川ほか	2009 年 2 月
13	HCM-6A	J023954.7-013332	6.560	128.2	Hu ほか	2002 年 4 月 1 日

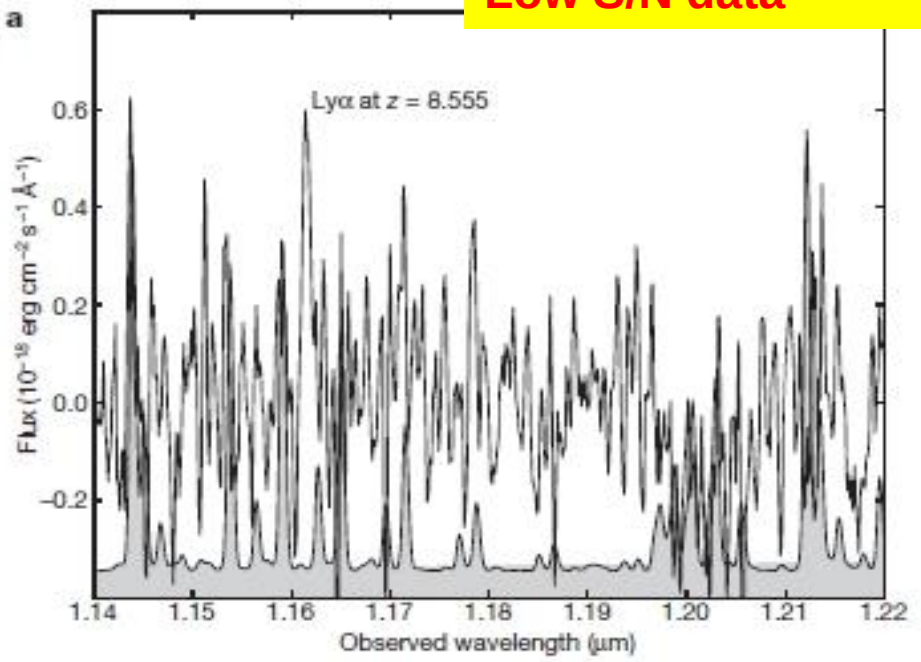
年齢は宇宙年齢が 136.6 億年となるモデルに基づいて算出.

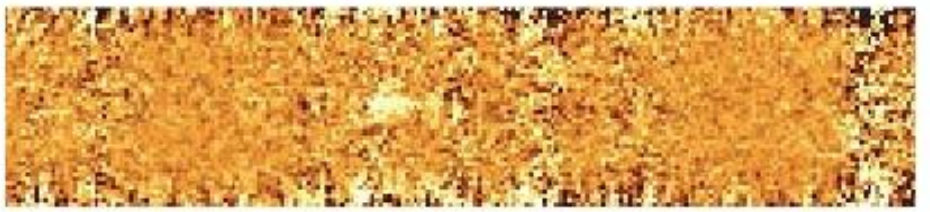
Tens of LAE at z=6.6 but only one LAE at z= 7.0.

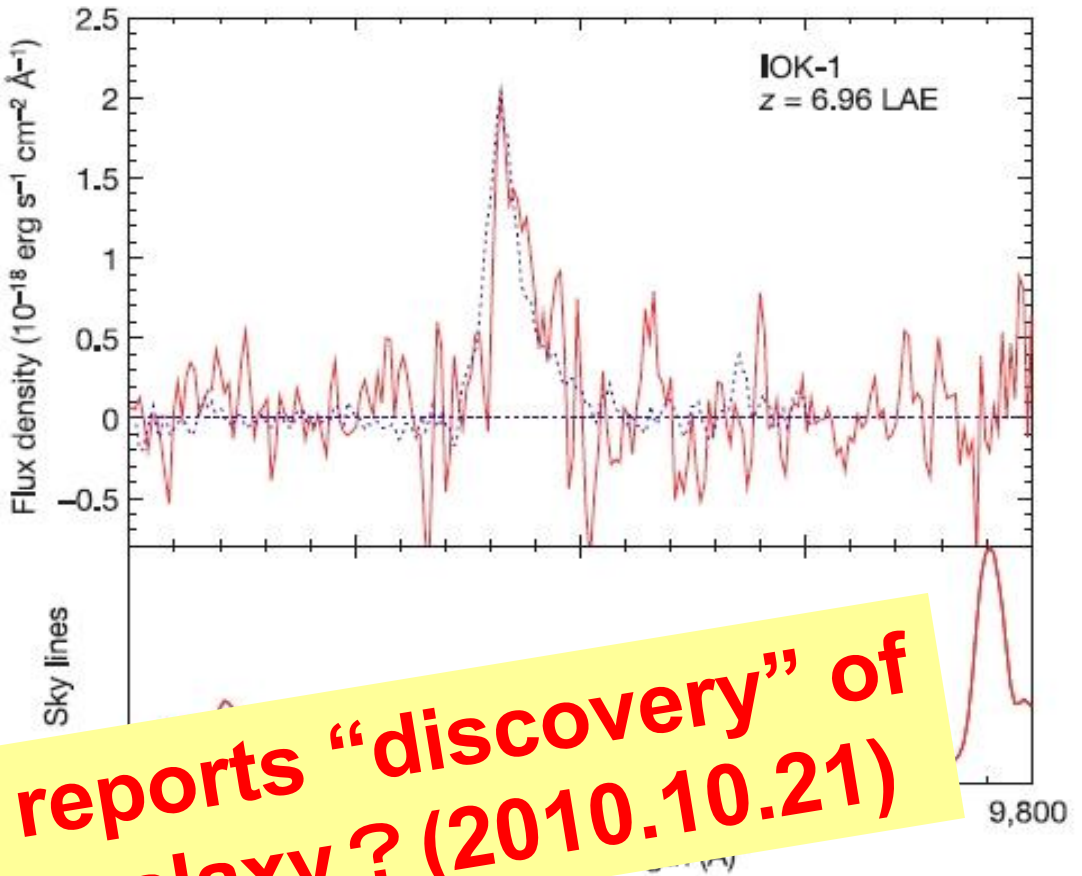
Lehnert et al.(2010) z=8.55?
UDFy-38135539

Iye et al.(2006) z=6.96
IOK-1

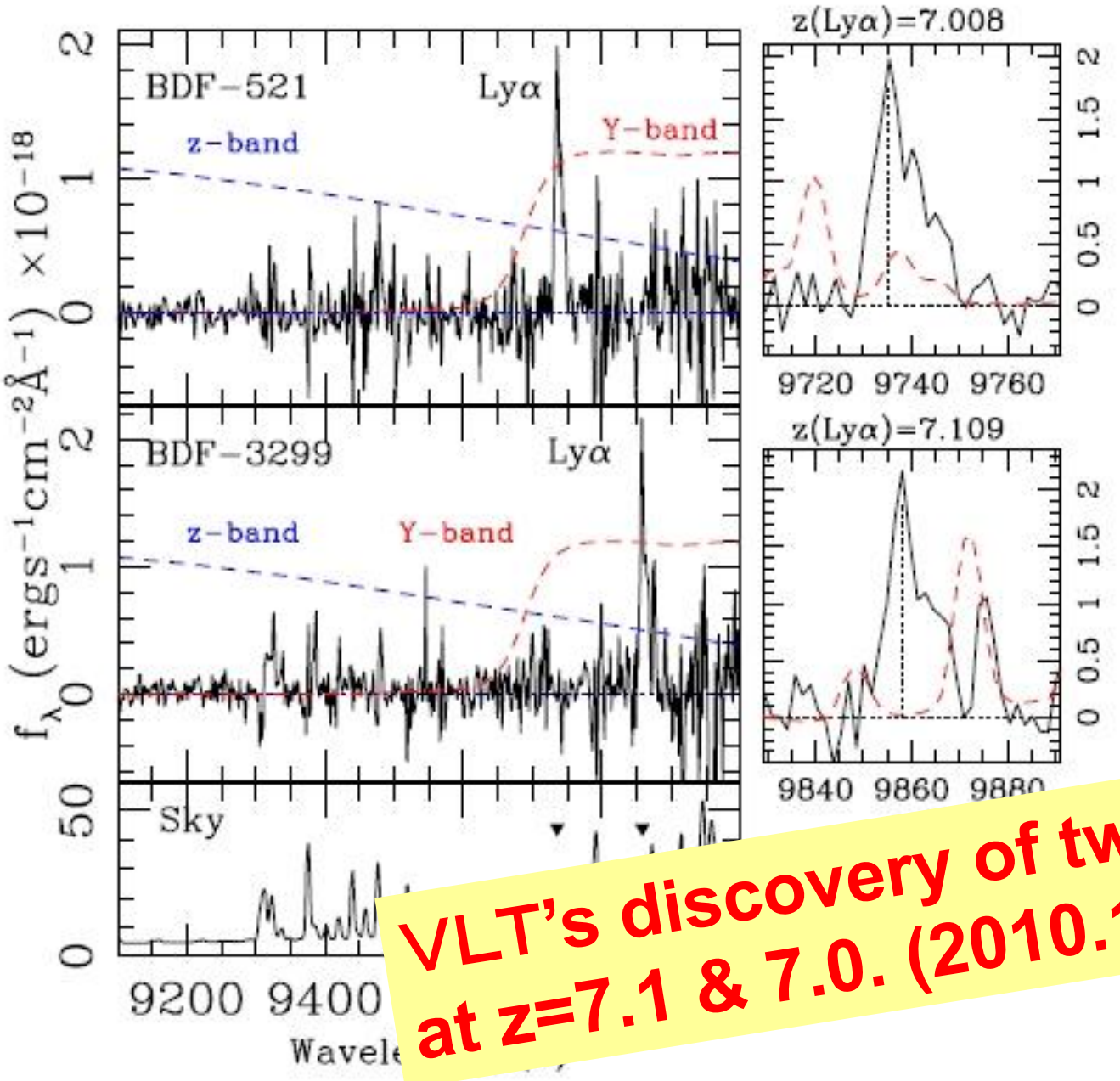
Low S/N data







VLT reports "discovery" of z=8.6 galaxy ? (2010.10.21)



VLT's discovery of two LAEs at z=7.1 & 7.0. (2010.11.30)

High redshift galaxies

Table 1: Top 10 most distant galaxies with measured redshift(Dec 9 2010)

Rank	ID	Coordinates	Redshift	0.1Gyr	Paper	Date
?	UDFy-38135539	J033237.79-274600.0	8.555?	128.29	Lehnert et al.	Oct.21, 2010
1	BDF-3299	J222846.0-350959	7.109	128.29	Vanzella et al.	Nov.24 2010
2	BDF-521	J222746.6-350707	7.008	128.29	Vanzella et al.	Nov.24 2010
3	IOK-1	J132359.8+272456	6.964	128.85	Iye et al.	Sep. 14, 2006
4	SXDF N-71598	J021844.7-043637	6.621	128.29	Ouchi et al.	in preparation
5	SXDF W-30717	J021654.6-045557	6.617	128.28	Ouchi et al.	in preparation
6	SDF ID1004	J132522.3+273520	6.597	128.25	Taniguchi et al.	Feb. 25, 2005
7	SDF ID1018	J132520.4+273459	6.596	128.25	Kashikawa et al.	Apr. 25, 2006
8	SXDF Himiko	J021757.6-050844	6.595	128.25	Ouchi et al.	Jul. 25, 2008
9	SXDF w-31790	J021653.9-050601	6.590	128.24	Ouchi et al.	in preparation
10	SDF ID1030	J132357.1+272448	6.589	128.24	Kashikawa et al.	Apr. 25, 2006
11	SXDF C-106098	J021703.5-045619	6.589	128.24	Ouchi et al.	in preparation
12	SDF ID91163	J132343.4+272954.5	6.587	128.23	Kashikawa et al.	Feb. 2009
13	SDF ID91988	J132342.2+272644.5	6.587	128.23	Kashikawa et al.	Feb. 2009
14	SDF ID71101	J132450.7+272159.7	6.587	128.23	Kashikawa et al.	Feb. 2009
15	SXDF W-36217	J021650.4-050545	6.586	128.23	Ouchi et al.	in preparation
16	SDF ID1007	J132432.5+271647	6.580	128.22	Taniguchi et al.	Feb. 25, 2005
17	SDF ID1008	J132518.8+273043	6.578	128.22	Taniguchi et al.	Feb. 25, 2005
18	SDF ID1001	J132418.3+271455	6.578	128.22	Kodaira et al.	Apr. 25, 2003
19	SXDF C-22057	J021820.7-051110	6.575	128.21	Ouchi et al.	in preparation
20	SXDF W-25755	J021658.3-045557	6.573	128.21	Ouchi et al.	in preparation
21	SDF ID157057	J132419.3+274124.8	6.568	128.20	Kashikawa et al.	Feb. 2009
22	SXDF C-34609	J021819.4-050901	6.563	128.19	Ouchi et al.	in preparation
23*	HCM-6A	J023954.7-013332	6.560	128.19	Hu et al.	Apr. 1, 2002

Many brilliant Japanese Supernovae burst in Early Universe Studies

- N.Kashikawa
- M.Ouchi
- K.Shimasaku
- K.Ota

- N.Yoshida
- K.Omukai
- A.Inoue
- M.Kobayashi

Japan Strategy

Subaru SuprimeCam

V

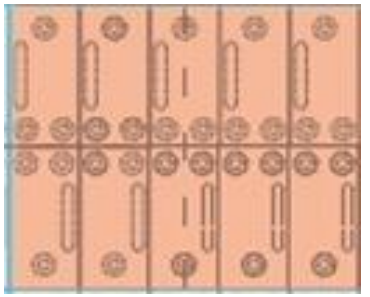
HyperSuprimeCam

V

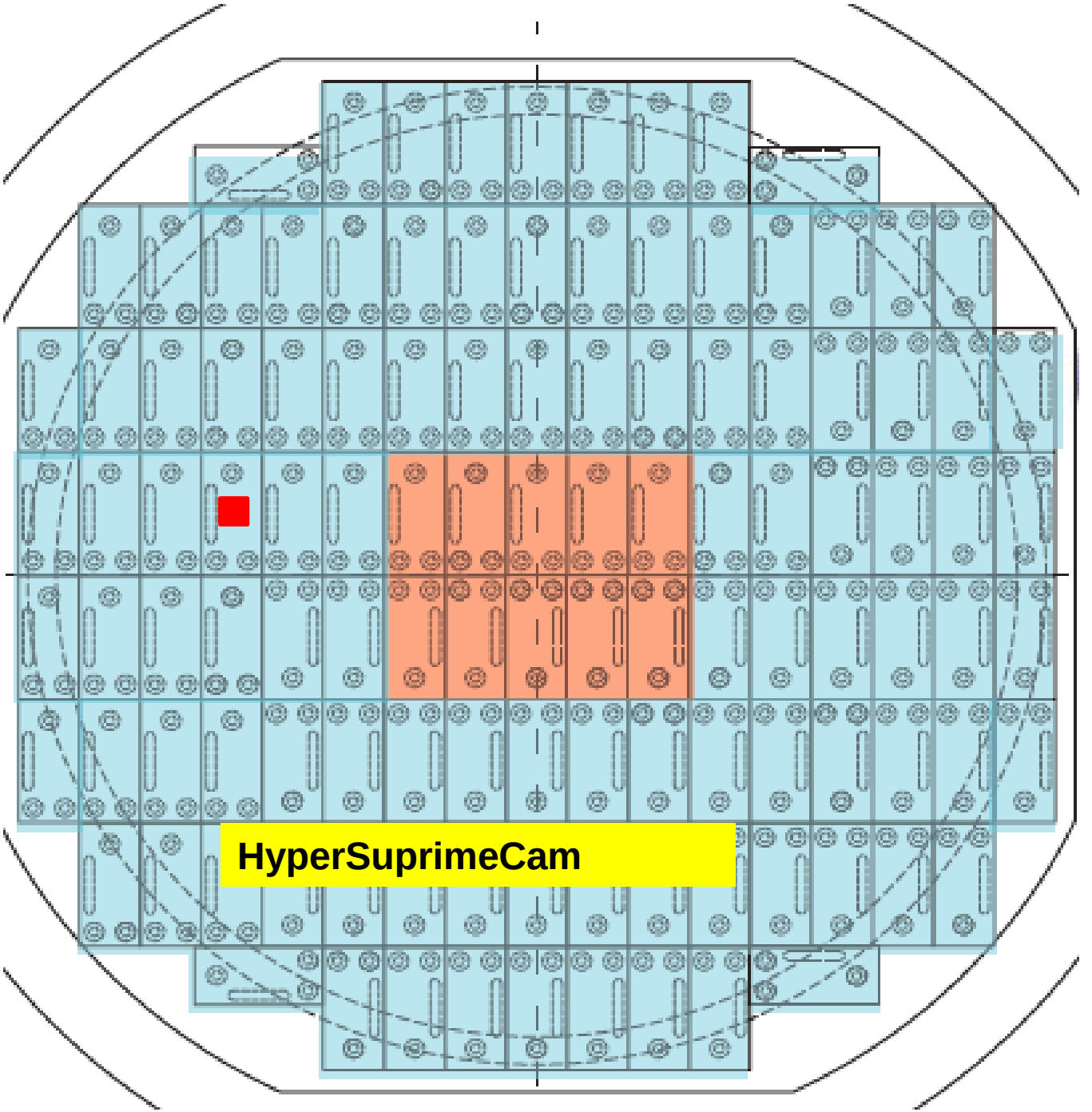
TMT

視野比べ

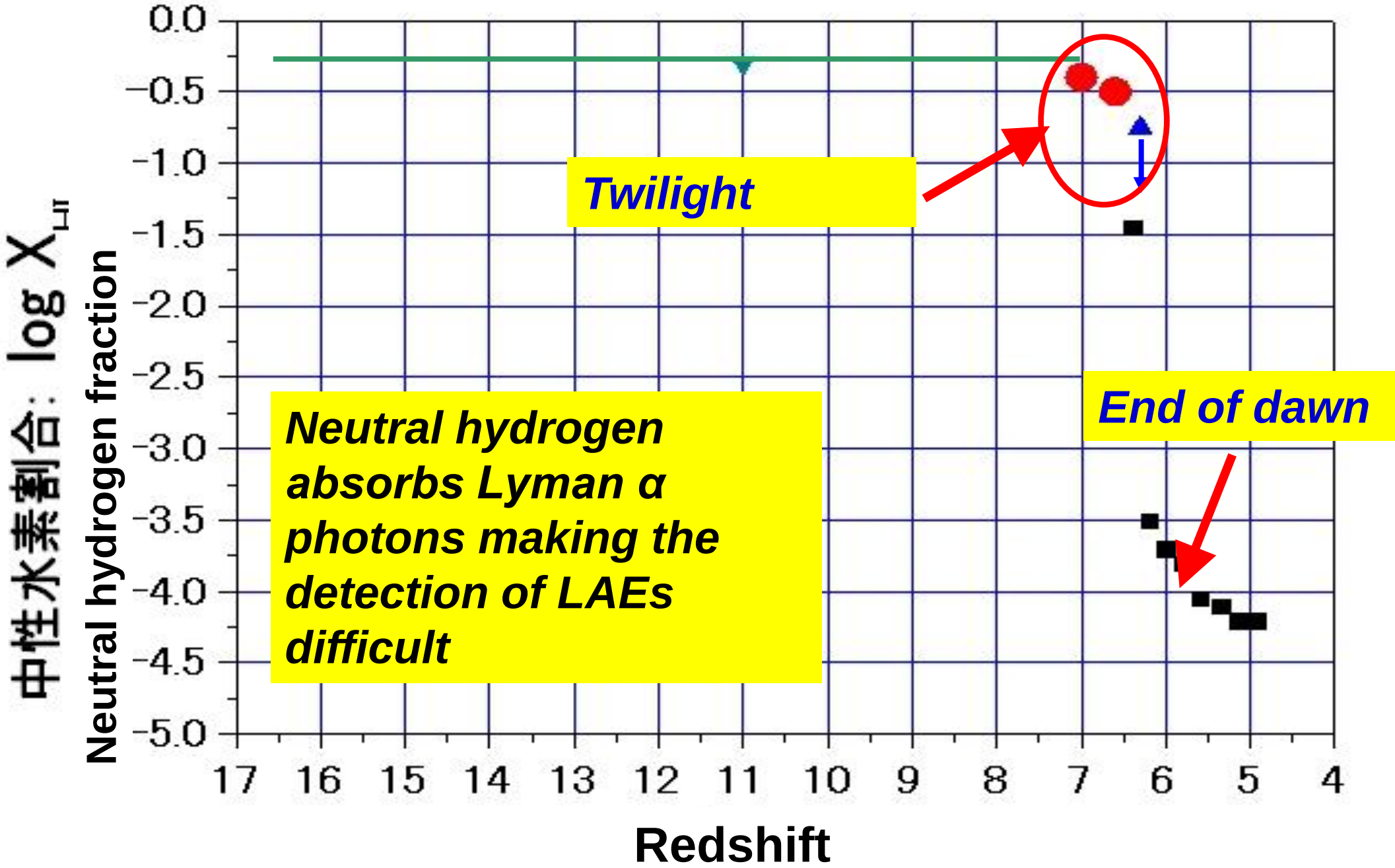
HST WFC3



SuprimeCam



Cosmic Reionization History



Looking at Cosmic Dawn

Hot → Cool → *Reionzed by stars* → Warm

Recombination (0.38My, z=1000)

Primordial galaxies (2Gy, z~20?)

Cosmic Dawn (0.8Gy,z~7)

Present (13.7Gy,z=0)

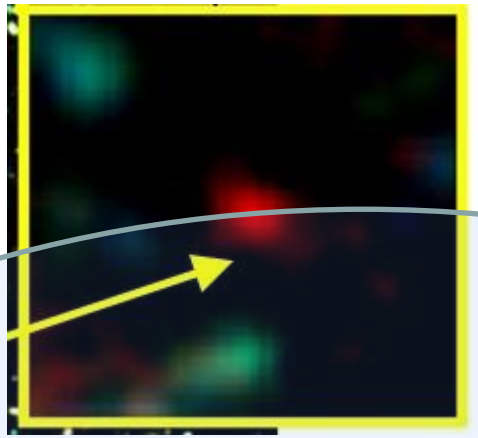
Big Bang

CMB

Subaru studies

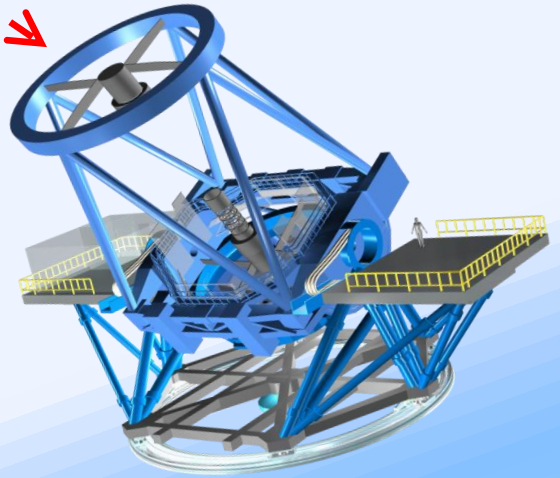
Laser guide star Adaptive Optics

光子
（photon）

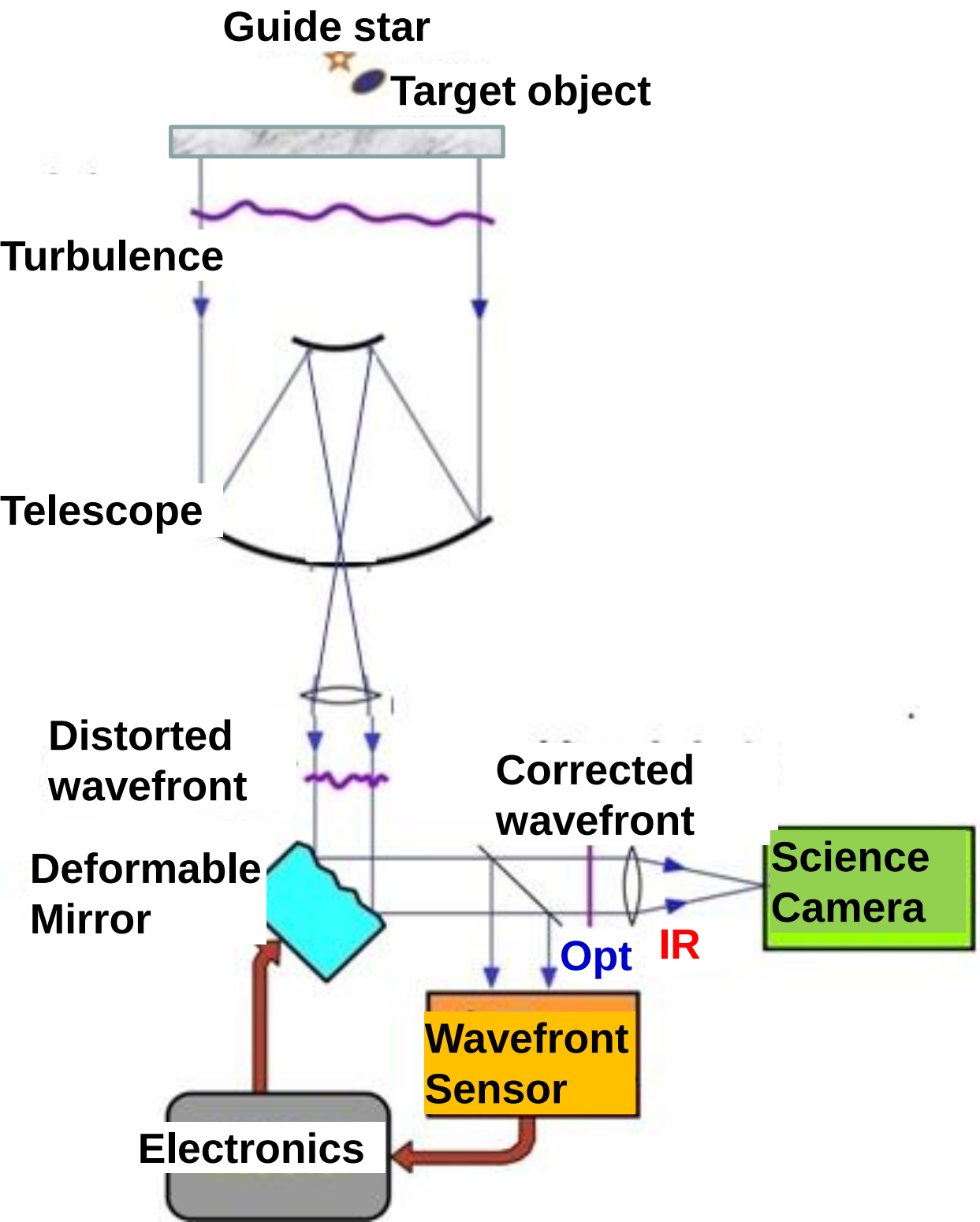


12.9 Gyr
＝40，0000，0000，0000，0000sec

Last 0．001sec



The last milli second of photon’s long journey blurs its beauty

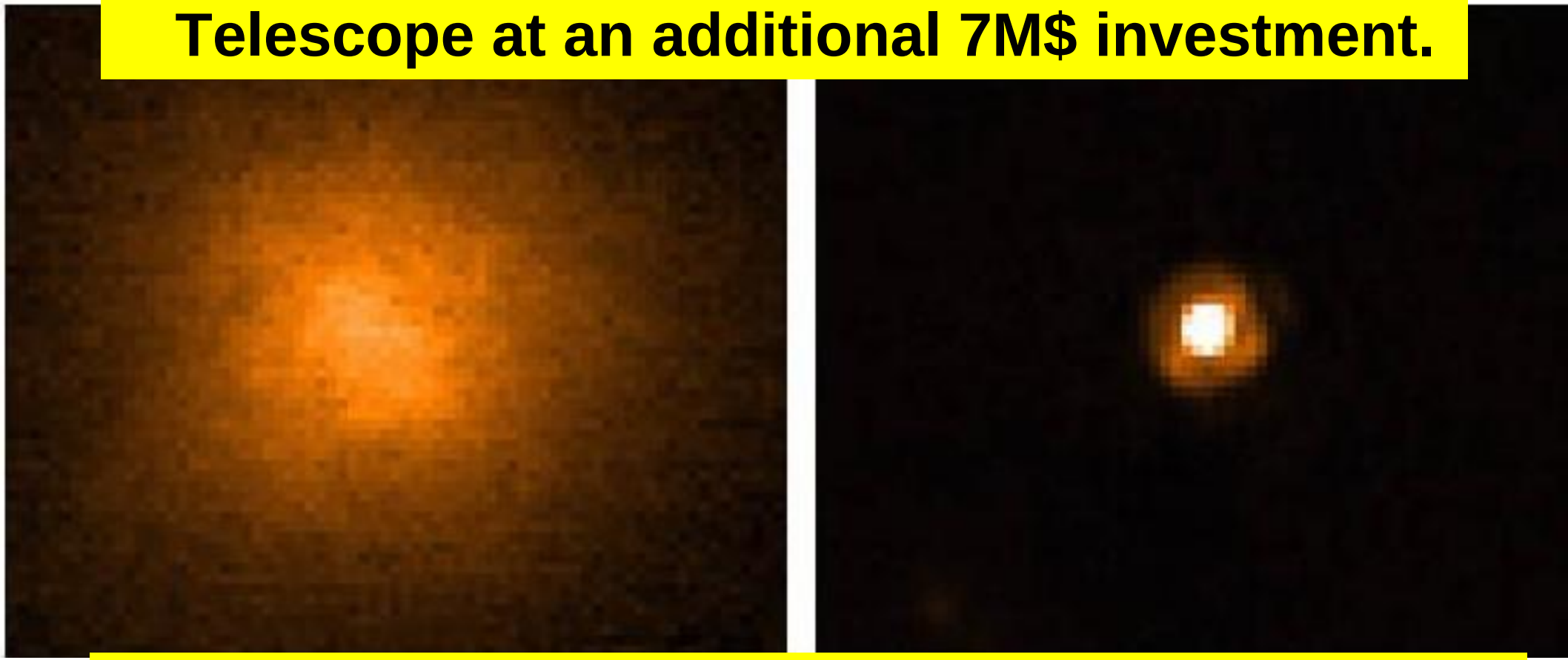


Adaptive Optics

Wavefront sensor
Deformable mirror
Real time control

First light of AO188(2006/10/9)

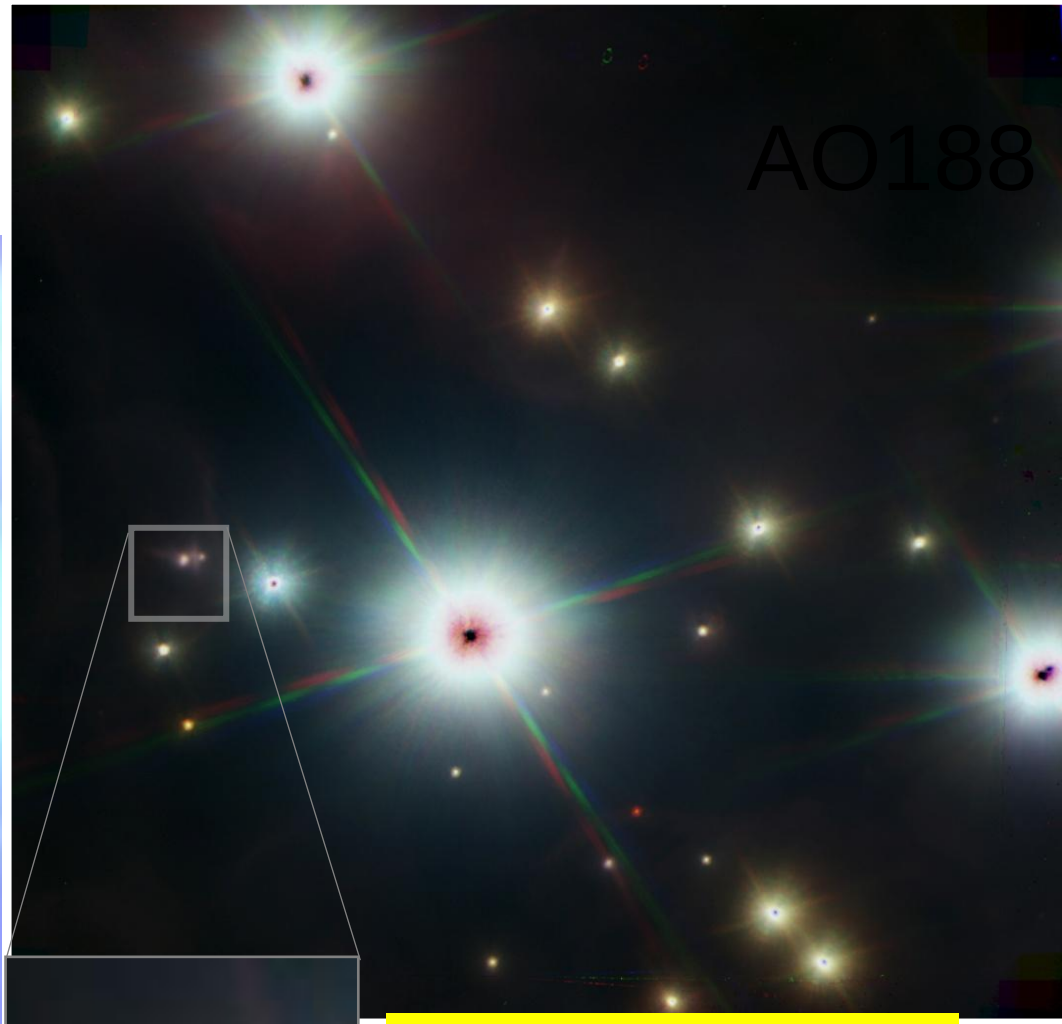
AO188 improved the PSF of 400M$ Subaru Telescope at an additional 7M$ investment.



AO off (0.6arcsec）　　2.2μm　　AO on (0.063arcsec）

Orion Trapezium

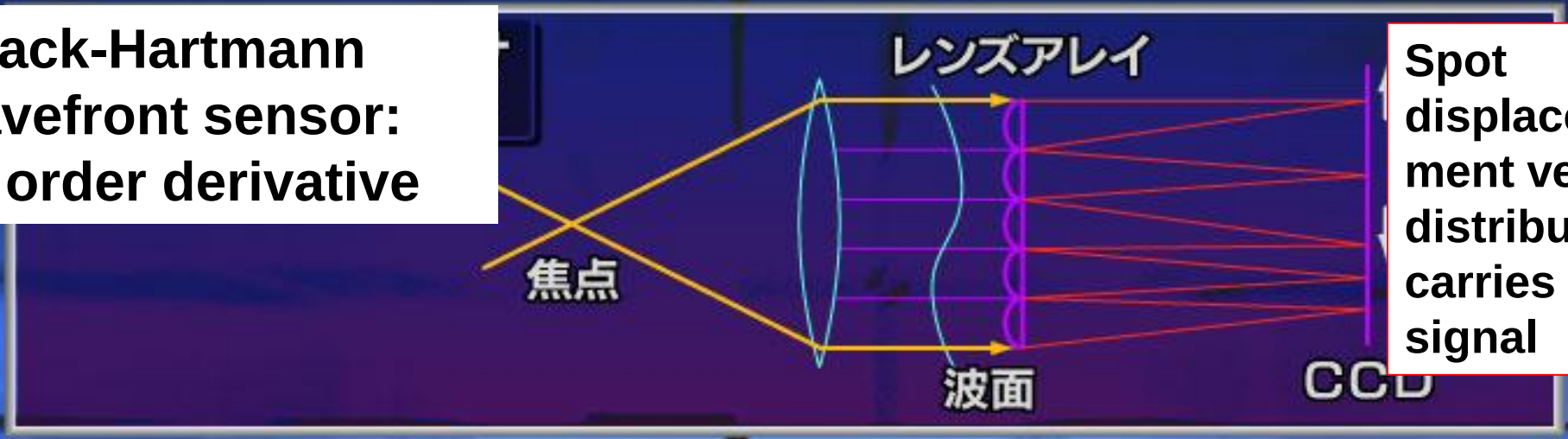
Without AO (1999)



With AO188 (2006)

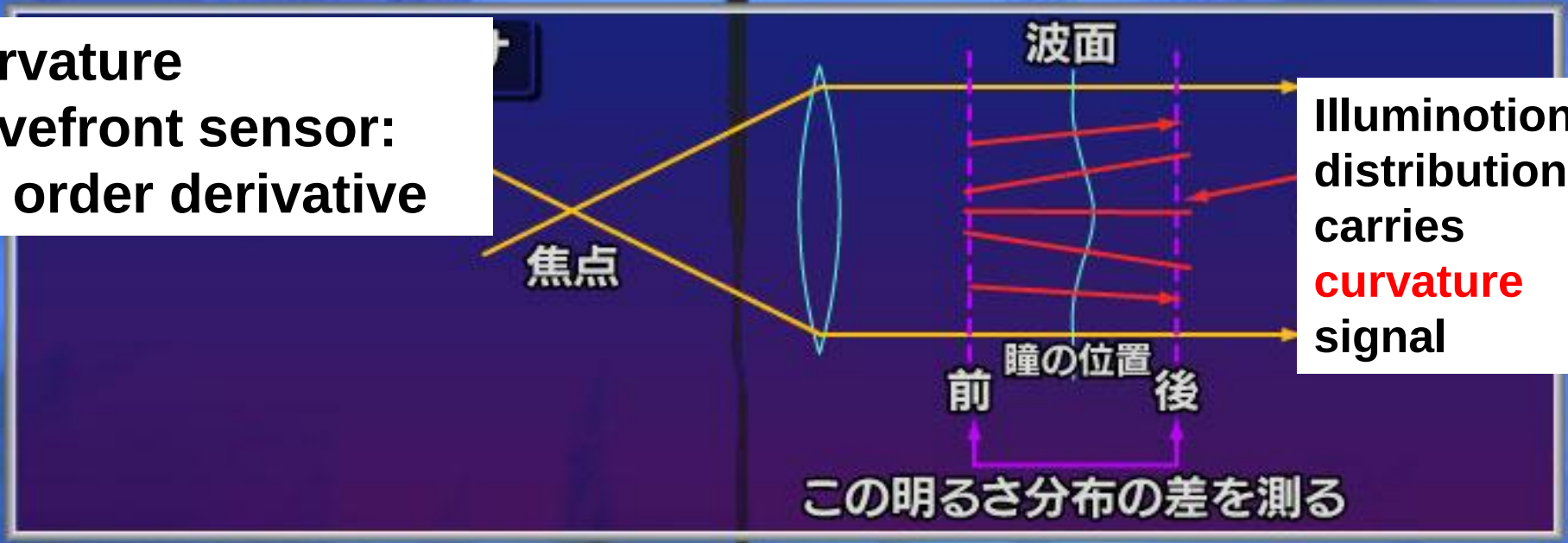
Wavefront sensors

Shack-Hartmann wavefront sensor: 1st order derivative



Spot displace-ment vector distribution carries tilt signal

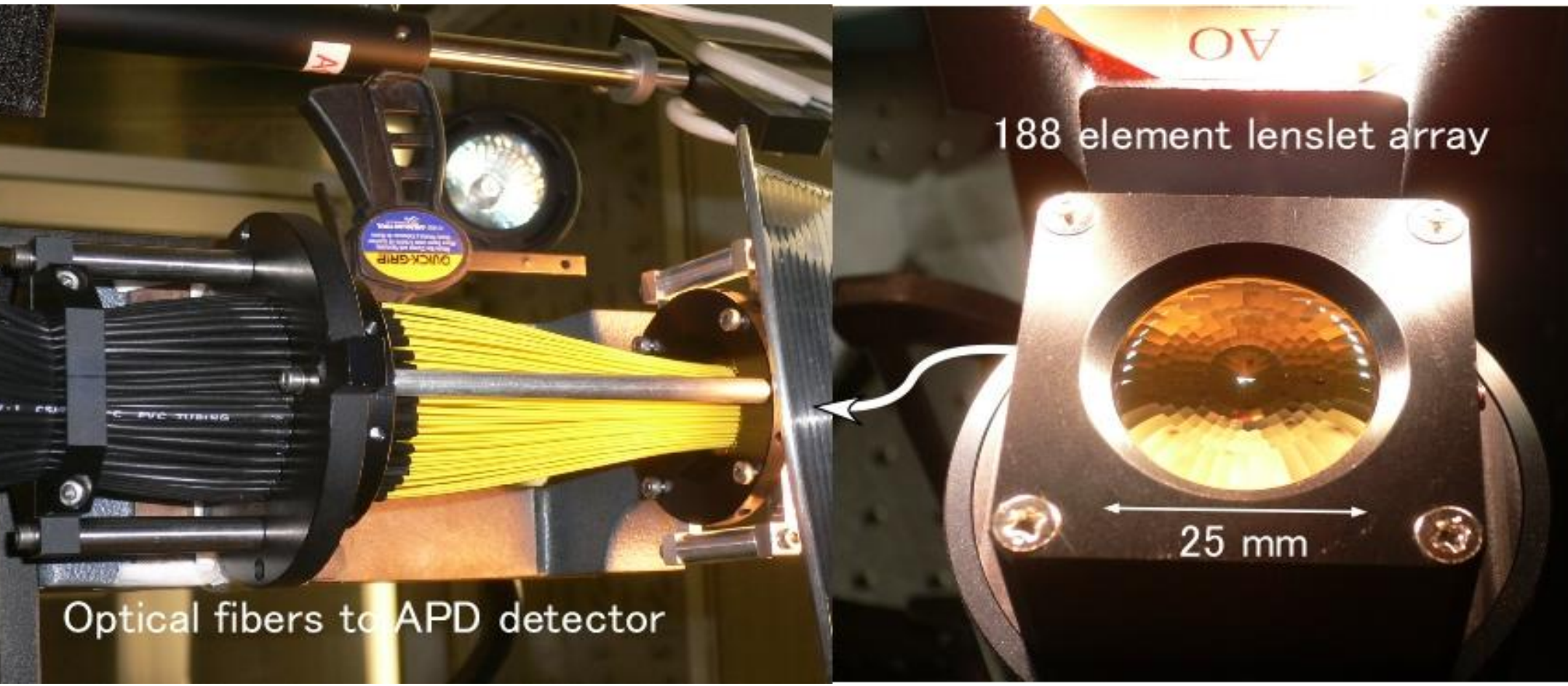
Curvature wavefront sensor: 2nd order derivative



Illuminotion distribution carries curvature signal

Wavefront sensor

wavefront sensing at 188 subapertures



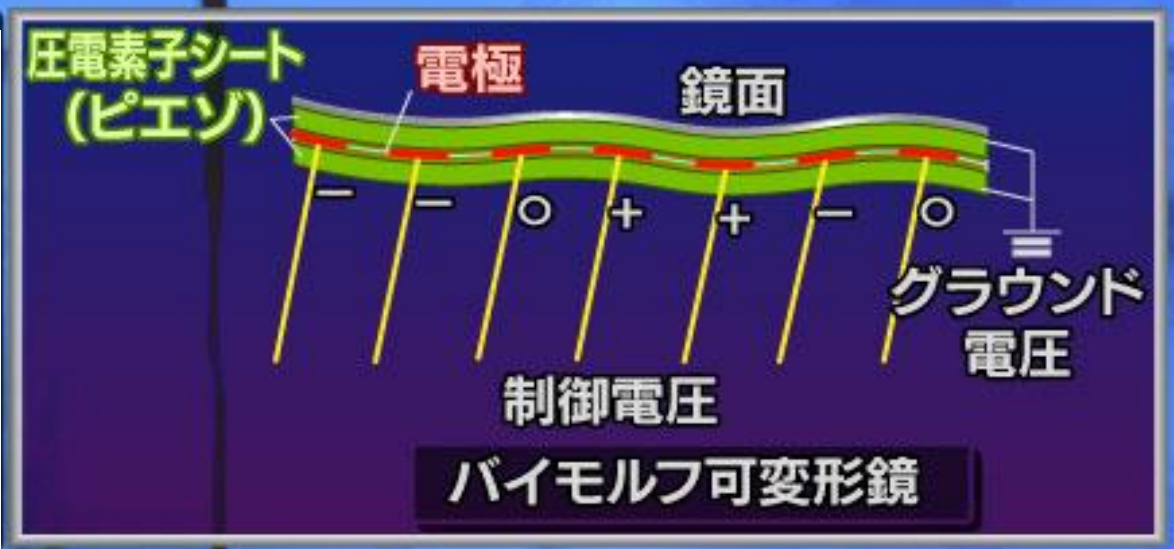
Functioning Principles of Deformable mirrors

Stacked piezo rods:

Used with Shack-Hartmann sensor for high order correction

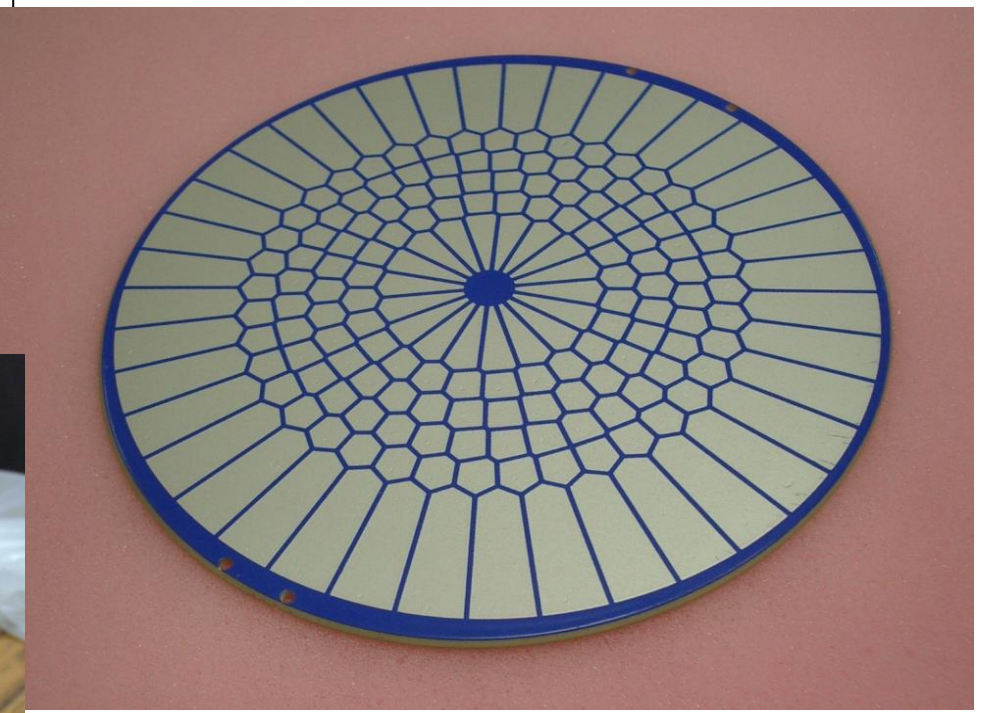
Bi-morph piezo sheet :

Used with curvature sensor for medium/low order correction



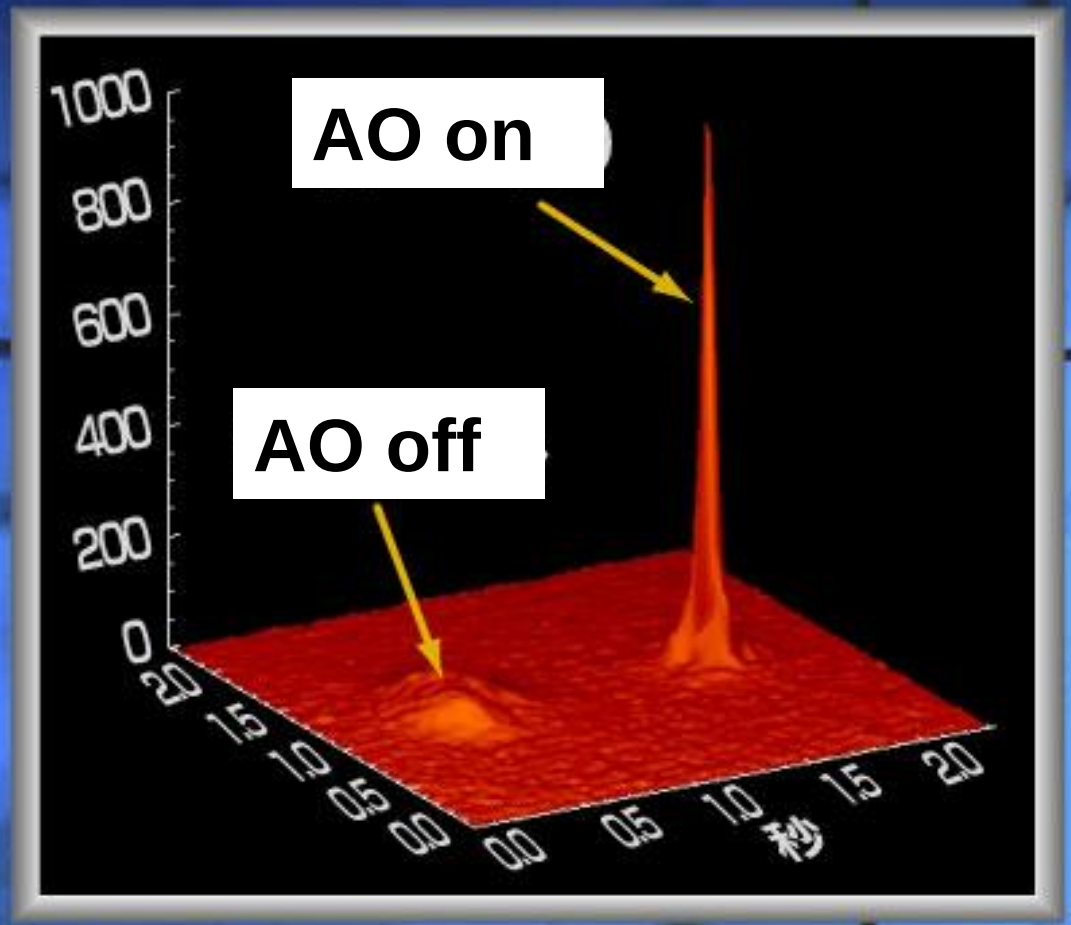
Deformable mirror with 188 electrodes.

Diameter : 90 mm
Speed :200Hz
Price : 200k$ (CILAS)



188 Electrode distribution
Designed by NAOJ

Image improvement in the AO188 fisrt light (2006)

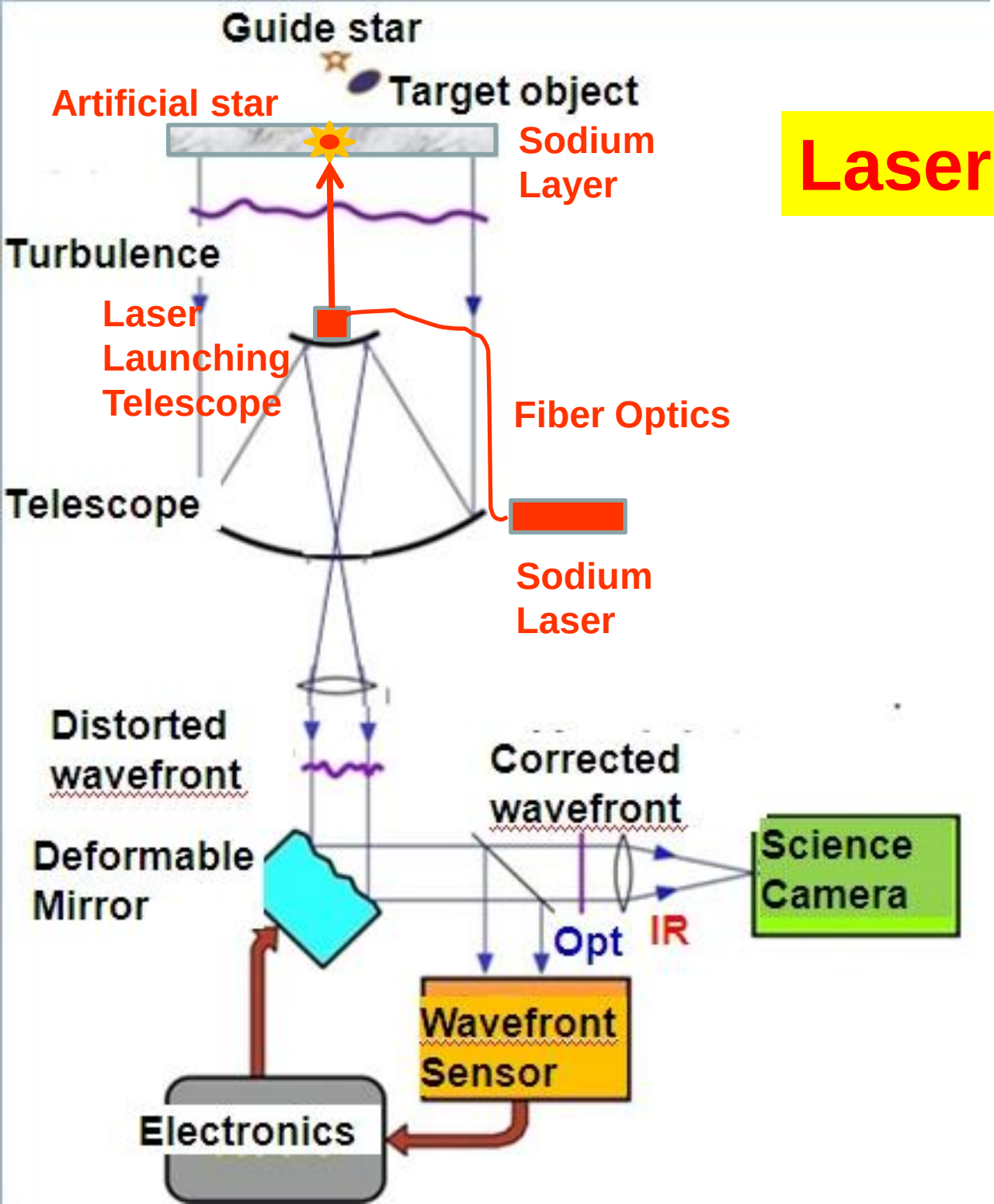


Band : 2.2miron

Seeing : 0.4 arcsec

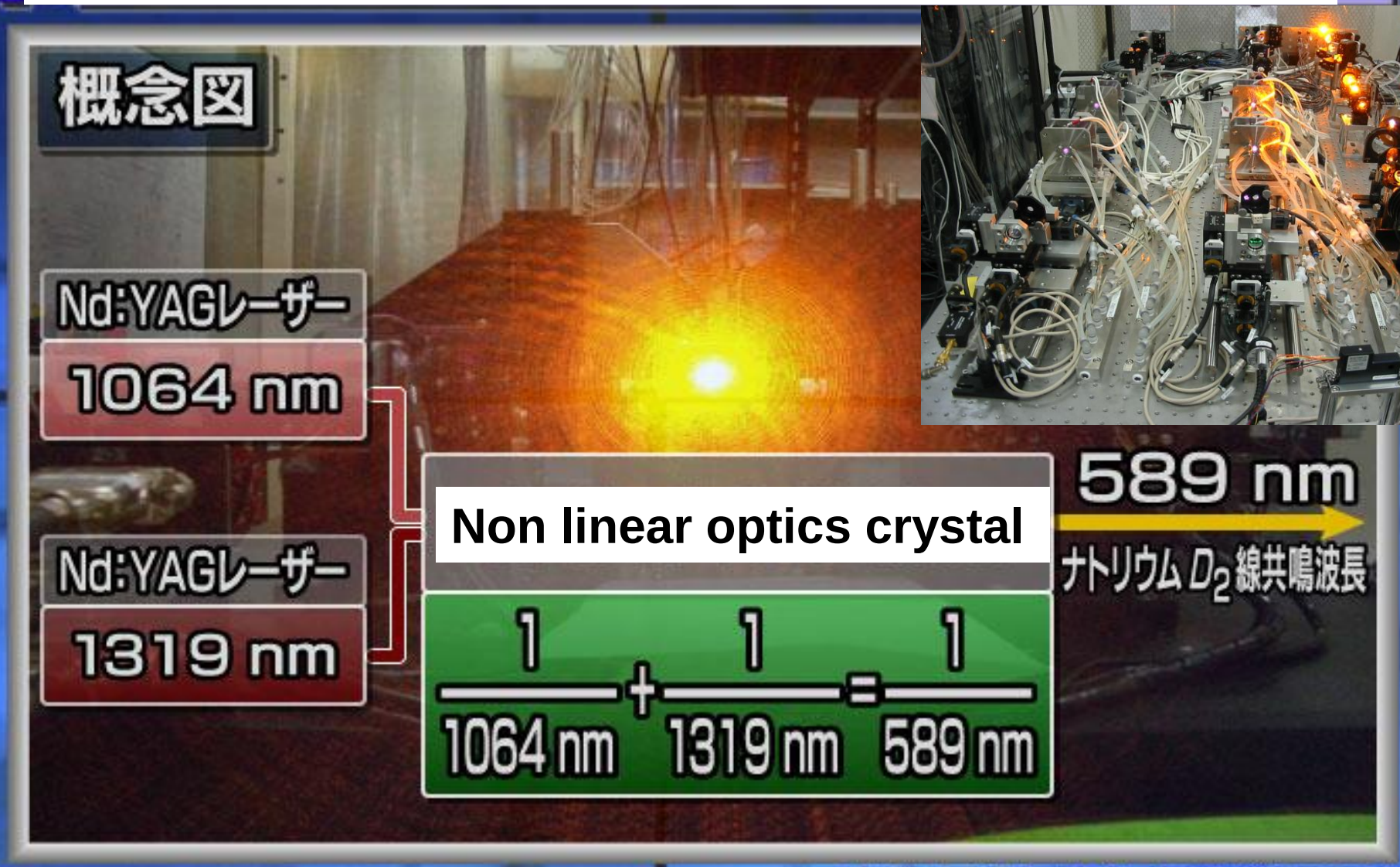
Corrected Image : 0.07 arcsec

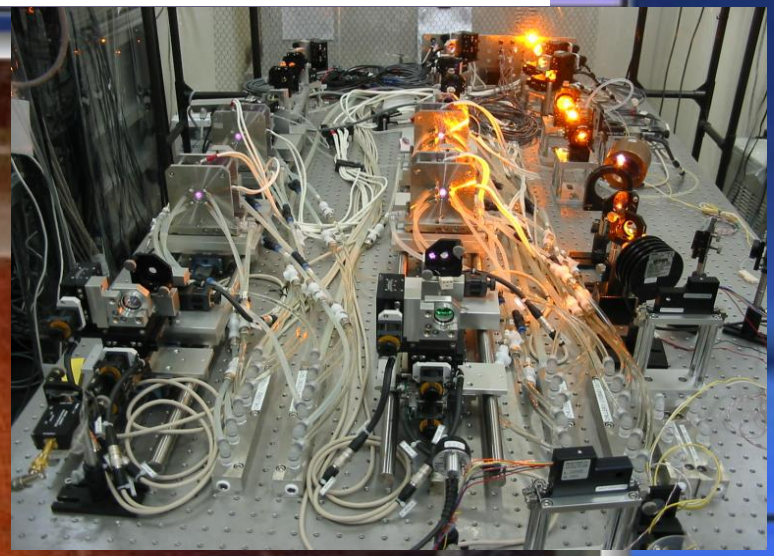
Laser guide AO system



Generate an artificial guide star by illuminating the sodium layer at 90km height using a special 6W laser shining at 589nm.

Sum frequency sodium laser



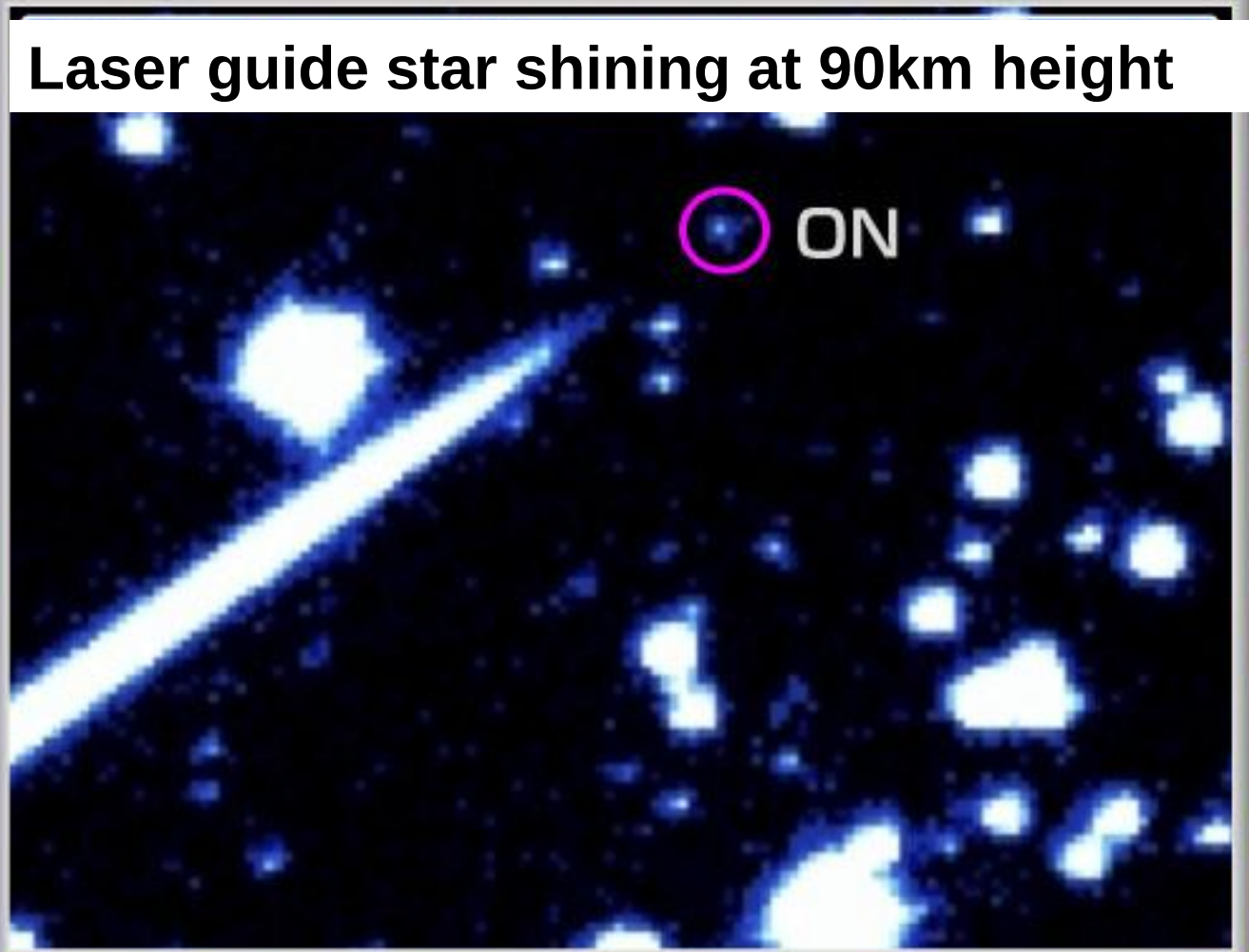


RIKEN/NAOJ

GS Generation Verification Experiment(Oct 2005)

e tuning the frequency to sodium D2 line at 0.1ppm level

Laser guide star shining at 90km height

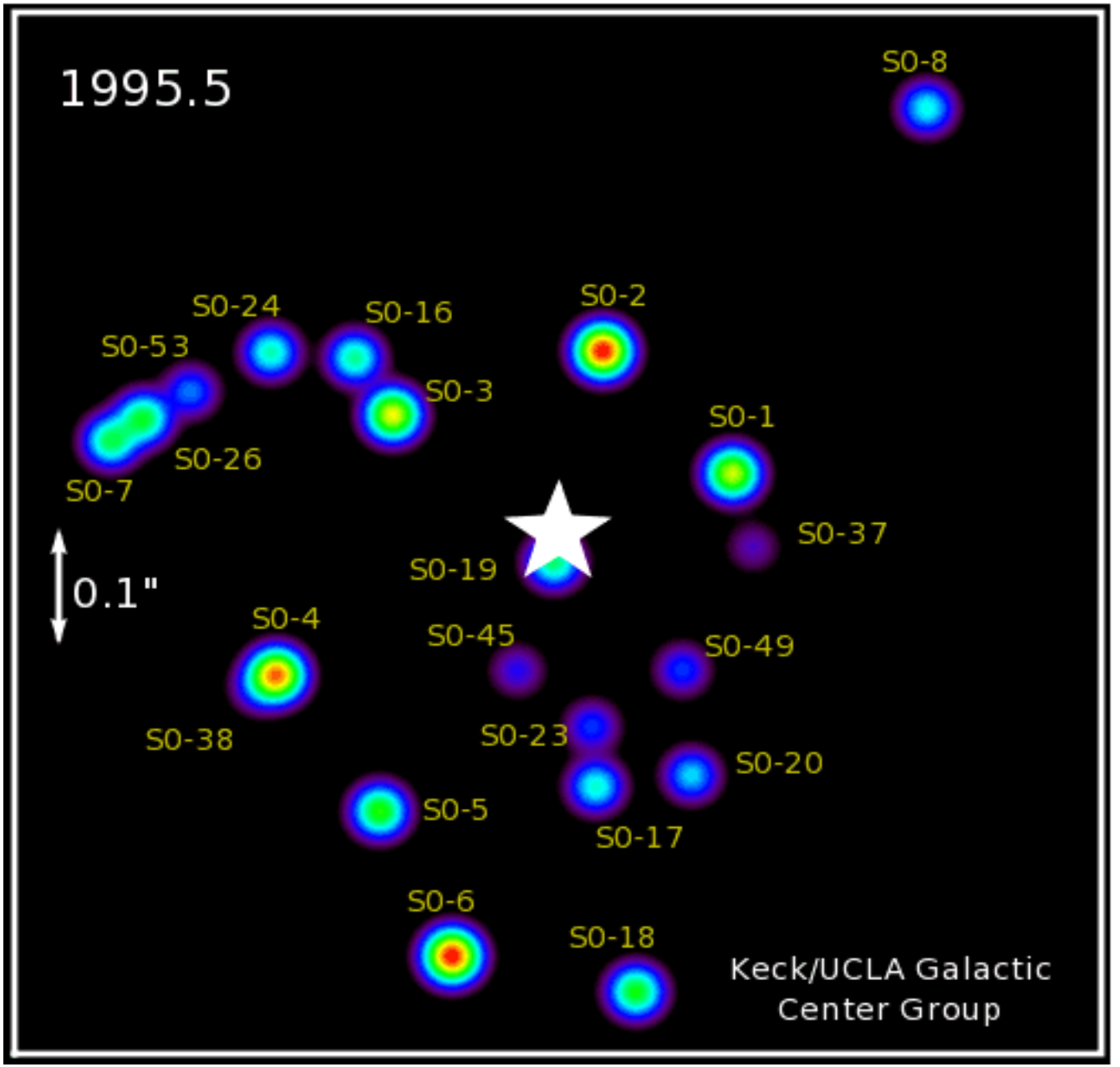


No star wars.

T.Fuse 2009

Orbits of stars around SMBH in GC

Orbital motion of stars around Sgr A* indicates a BH of about million times the mass of the Sun

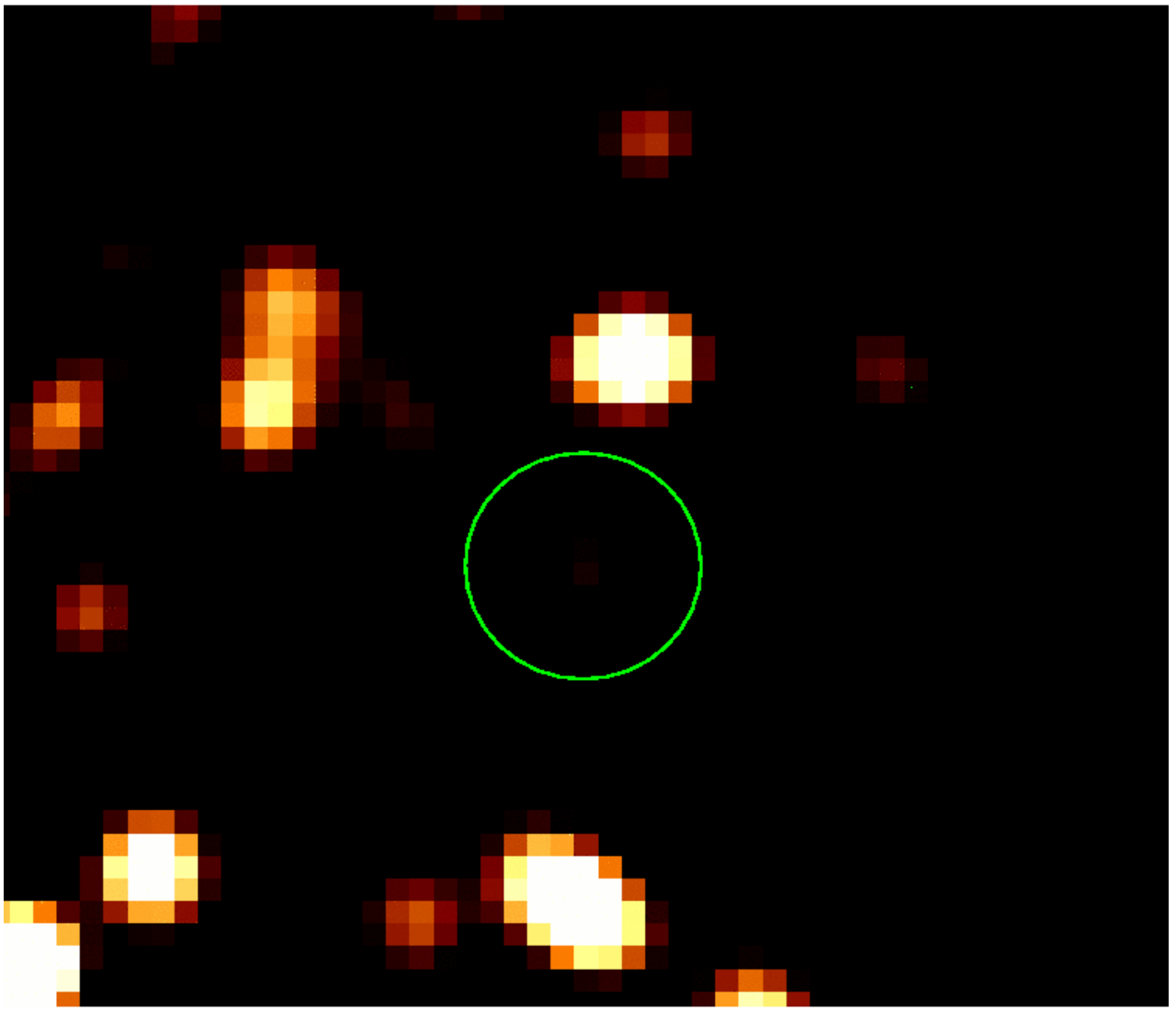


Flickering of infalling gas onto BH in the GC

Subaru AO36

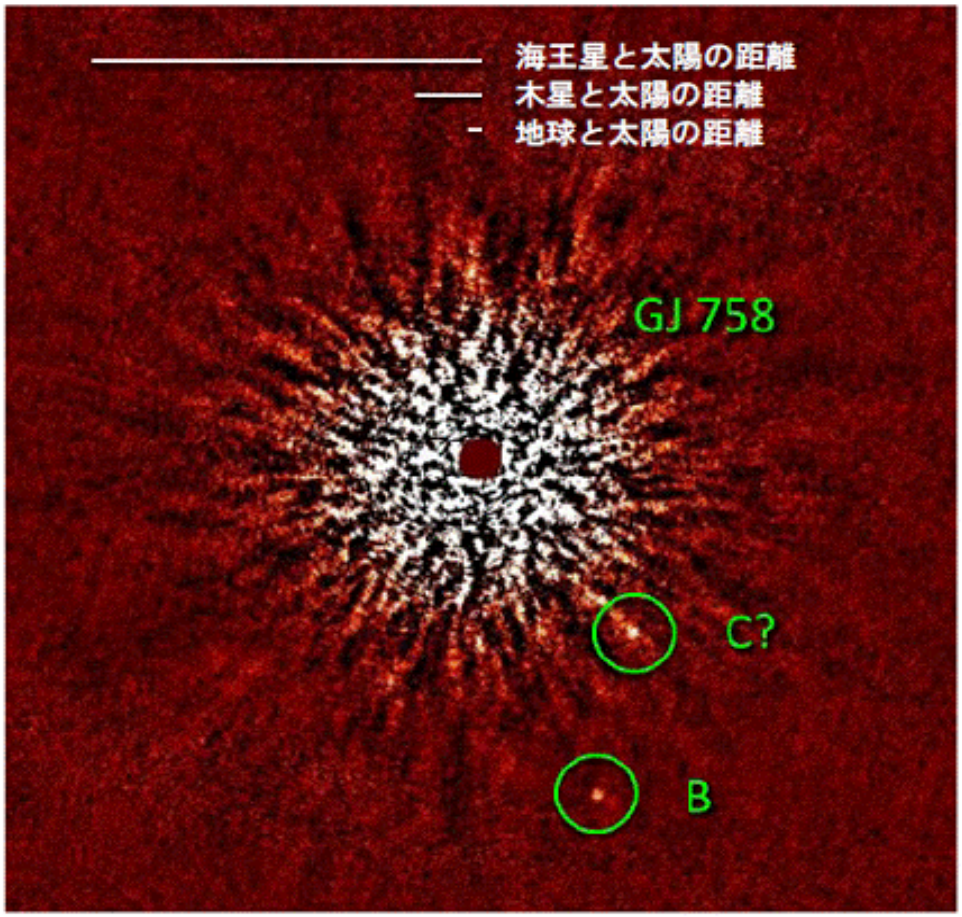
2008 May 28

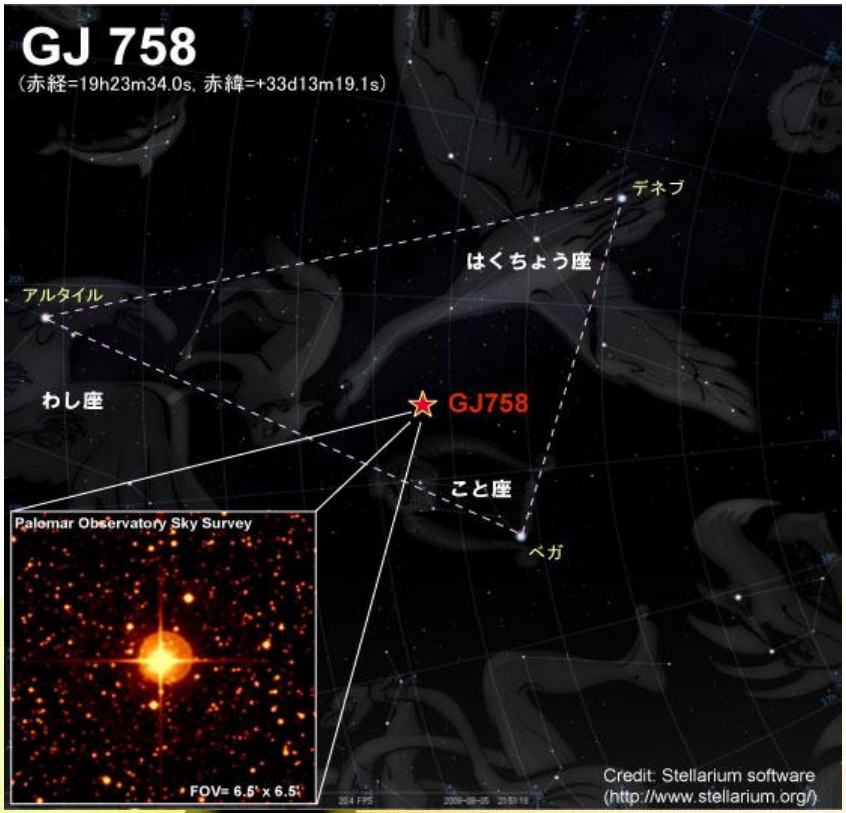
Nishiyama et al.（2009)

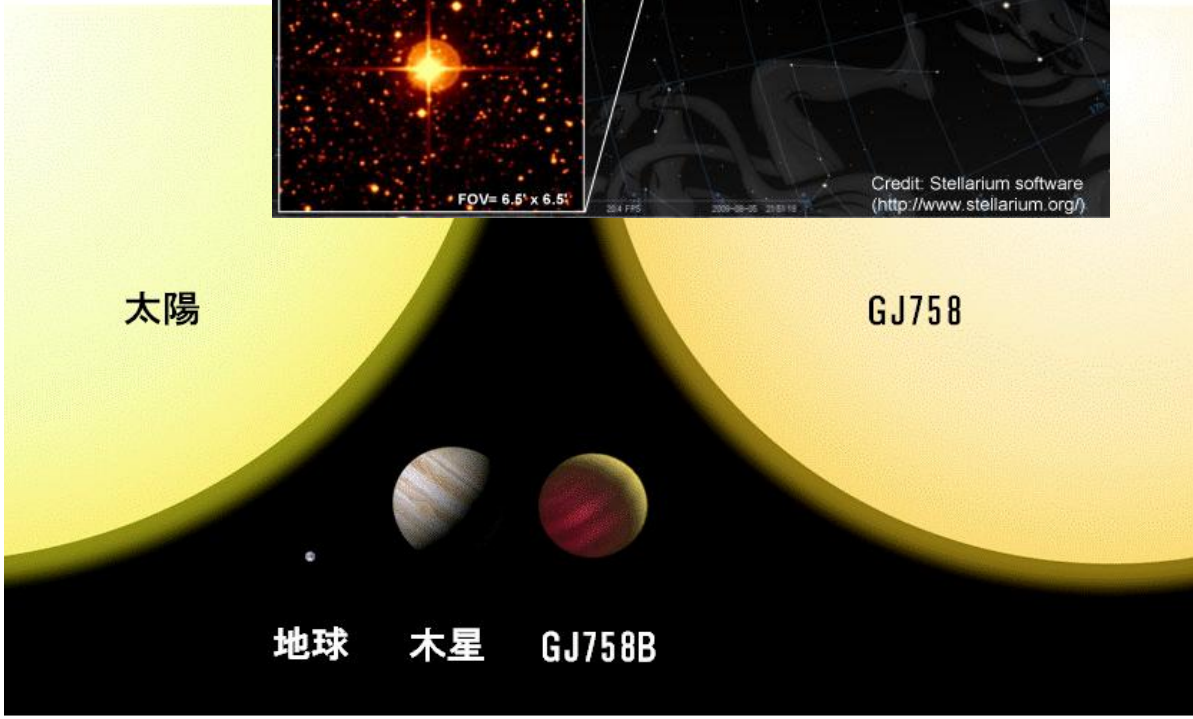


Exoplanet candidates GJ758B,C

- Jupitor like planet around a sun like star

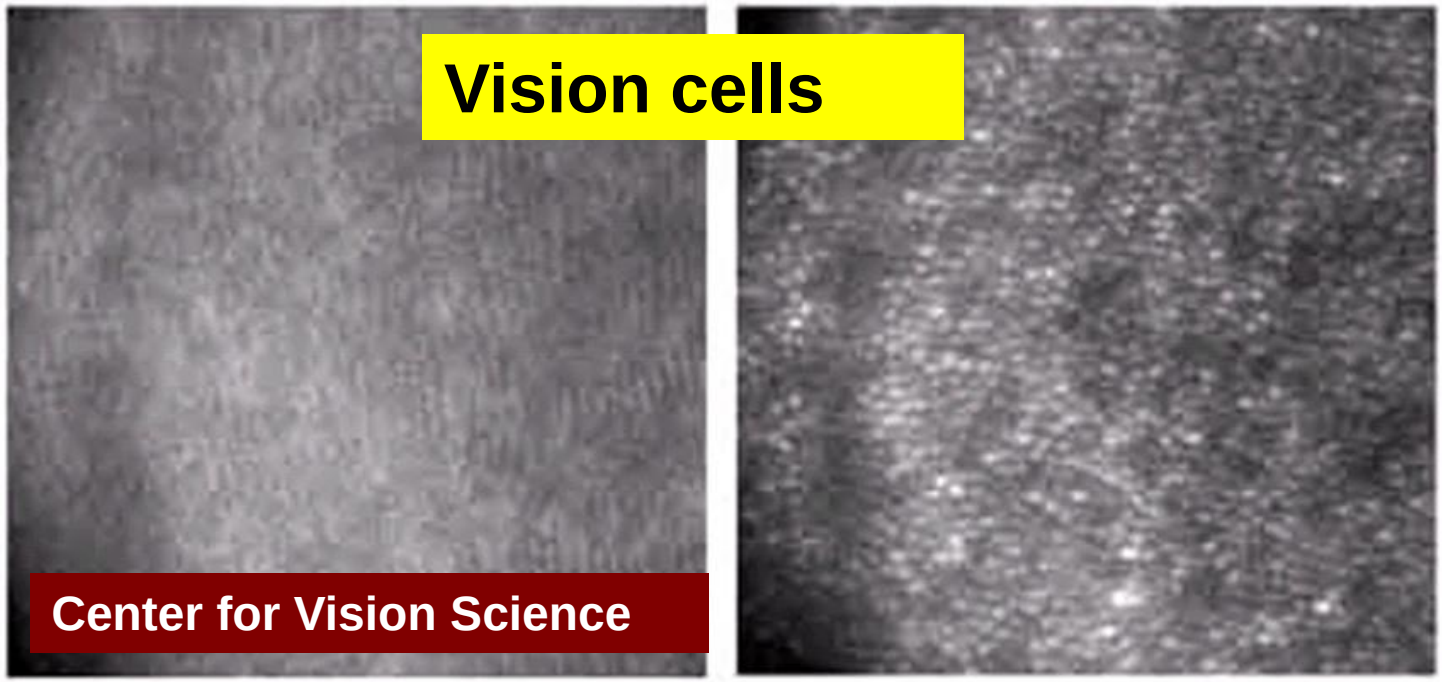






Other applications of AO

- Remote sensing
- Retinal imaging
- Laser surgery
- Laser Communication
- Laser cutter
- Laser nuclear fusion
- Guiding lightenin
- Purification of Uranium



w/o AO **w AO**

Thirty Meter Telescope

Thirty Meter Telescope

1.5m segments x 492

Construction 1.3B$

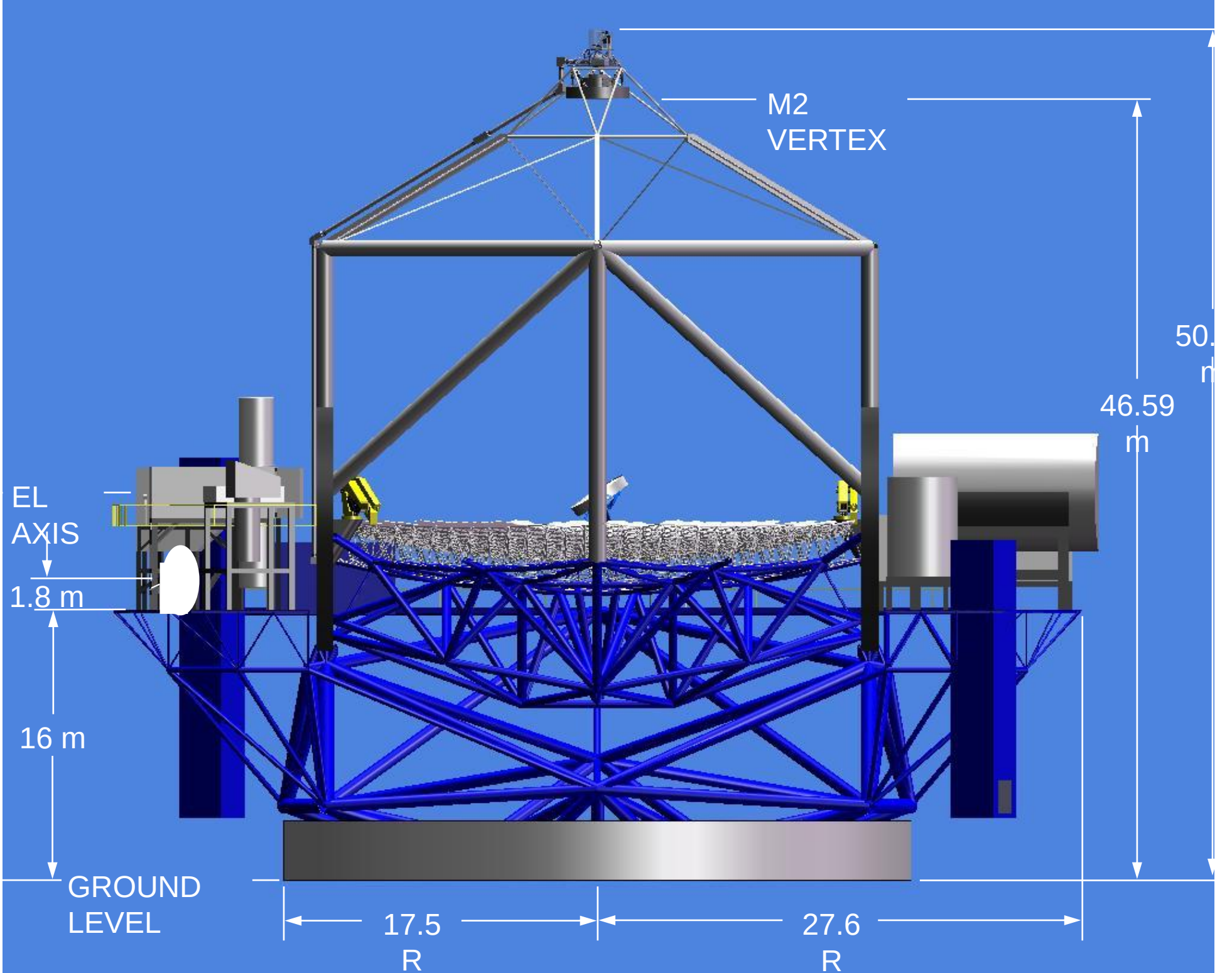
FL 2019 End?

First stars and cosmic dawn

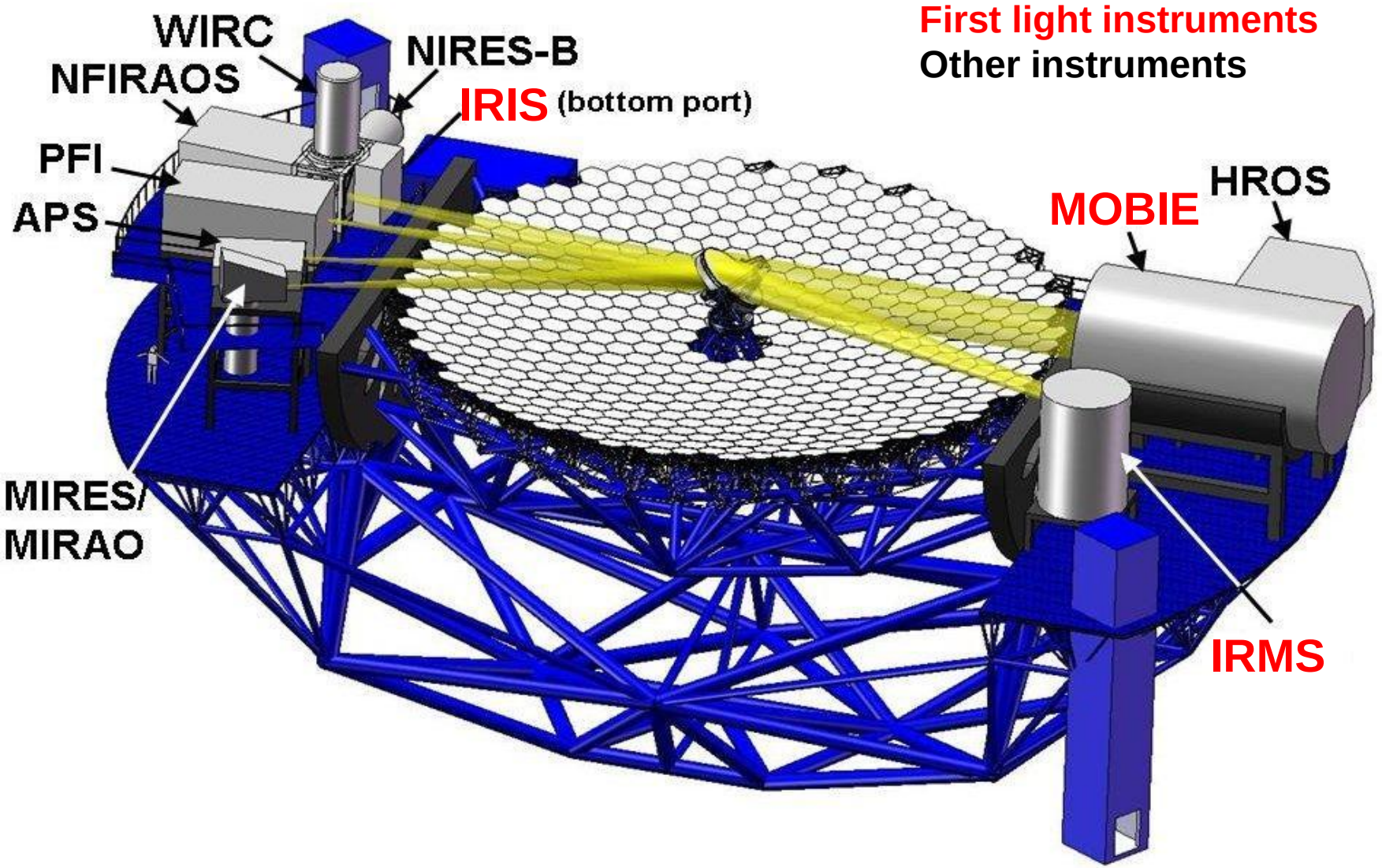
2nd Earth, Life in other planets

Dark energy, Cosmology constants

NAOJ, Caltech, Univ.California
ACURA, AURA, NAOC, India


M2
VERTEX
50.
m
46.59
m
EL
AXIS
1.8 m
16 m
GROUND
LEVEL
17.5
R
27.6
R

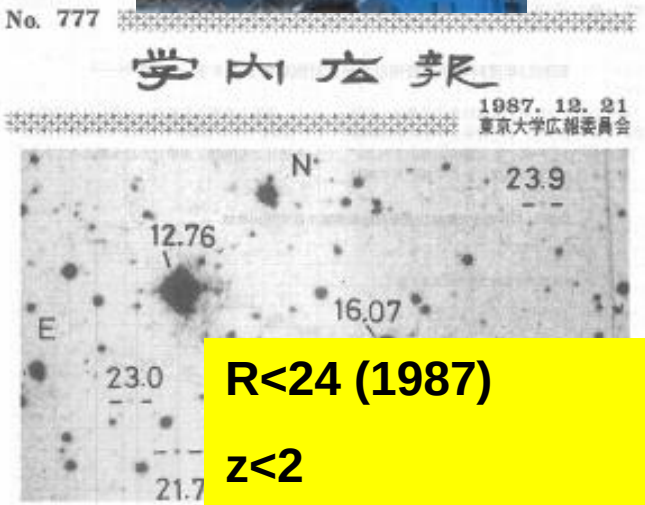
Instrument layout



Evolution of telescopes

Masanori Iye(NAOJ)

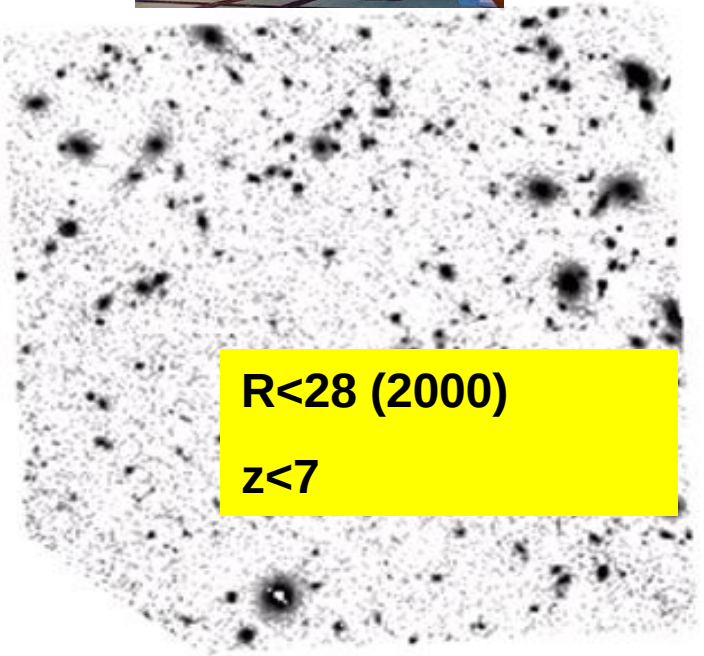
Okayama 1.88m



R<24 (1987)

z<2

8.2m Subaru



R<28 (2000)

z<7

Subaru/S-Cam 60min, R=28, 0".5

30m TMT

Light collecting power =x13

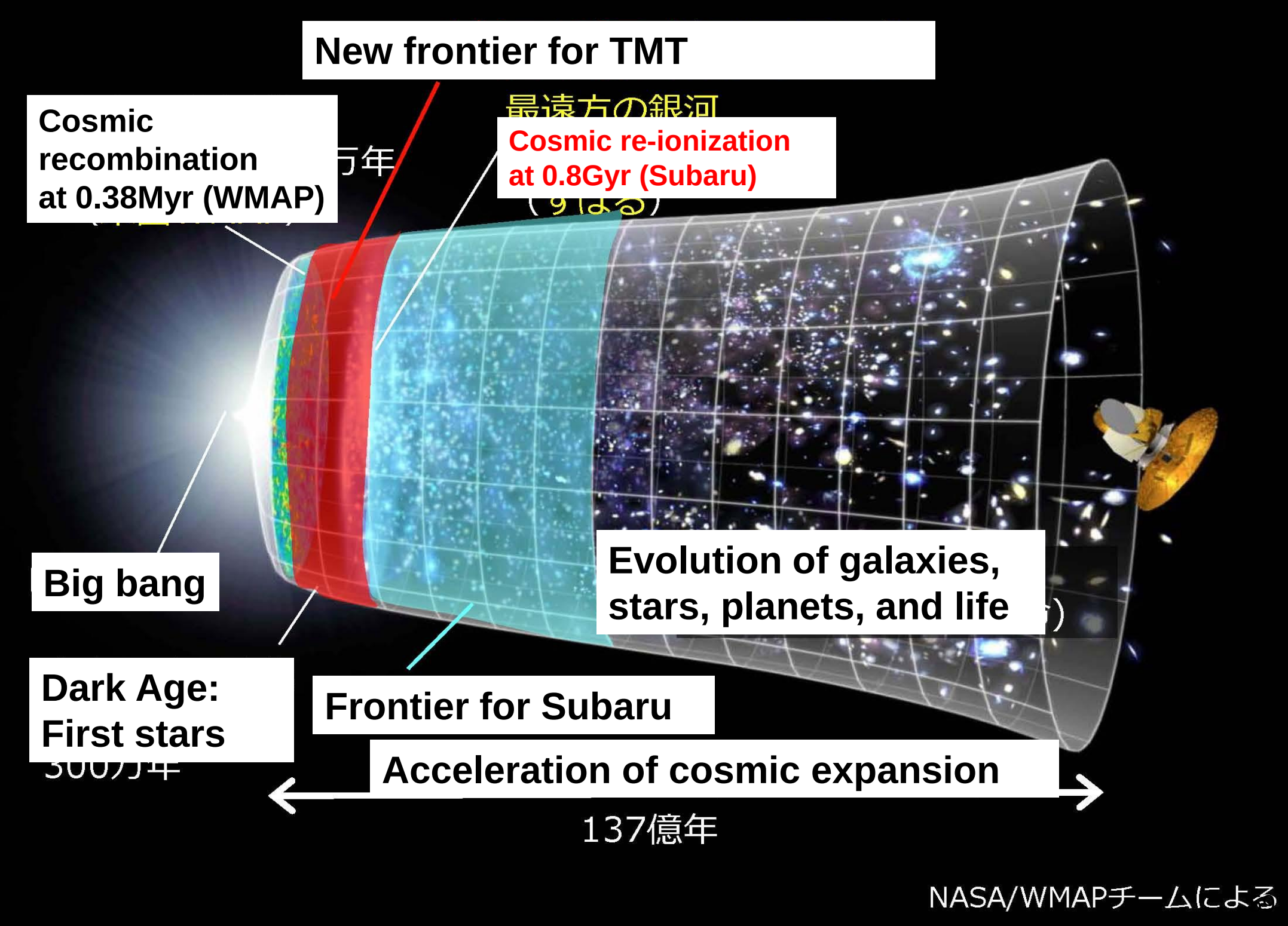
Spatial resol'n =x3.6

Efficiency =x180

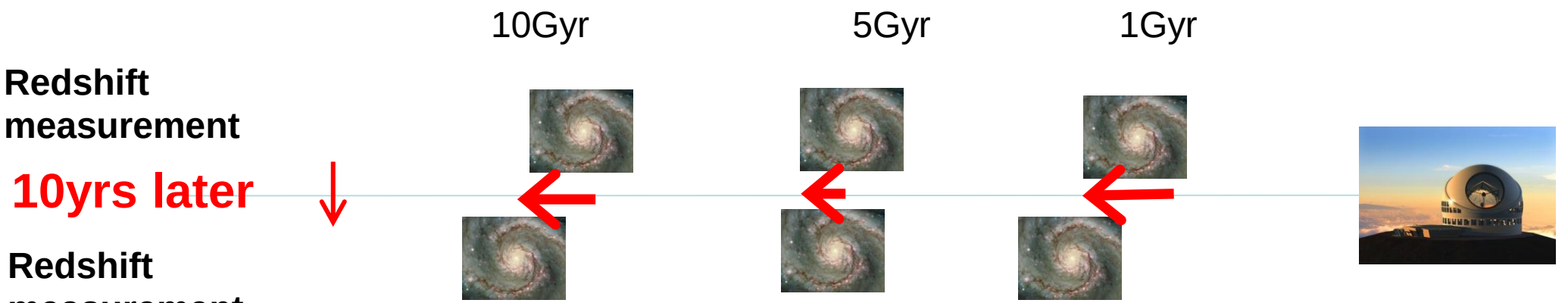
R<33? (2019?)

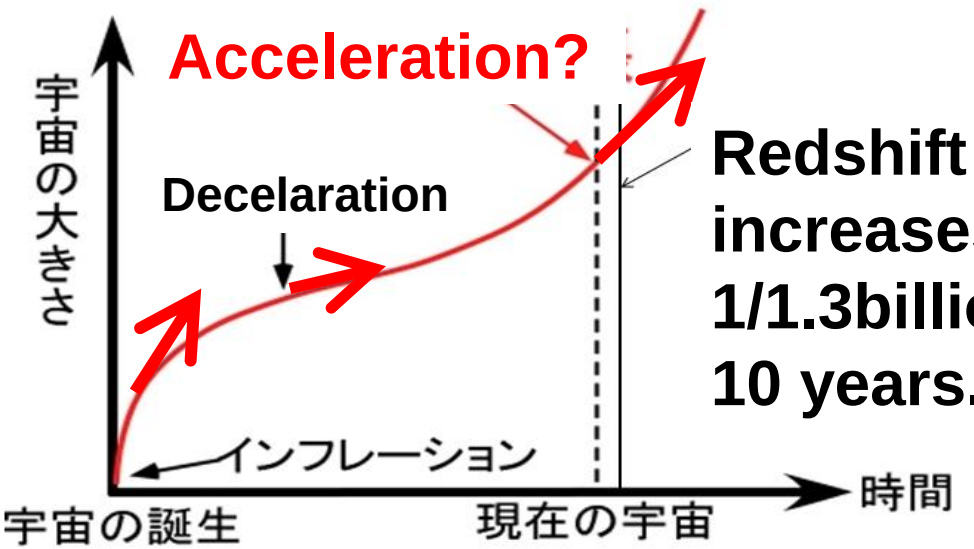
Z< 17 ?

R~33　A firefly on the dark side of the Moon.(~10mW), 1 hour exposure on TMT with LGSAO


New frontier for TMT
Cosmic recombination at 0.38Myr (WMAP)
Cosmic re-ionization at 0.8Gyr (Subaru)
Big bang
Evolution of galaxies, stars, planets, and life
Dark Age: First stars
Frontier for Subaru
Acceleration of cosmic expansion
137億年
NASA/WMAPチームによる

Direct measurement of cosmic expansion history to quantify the dark energy property



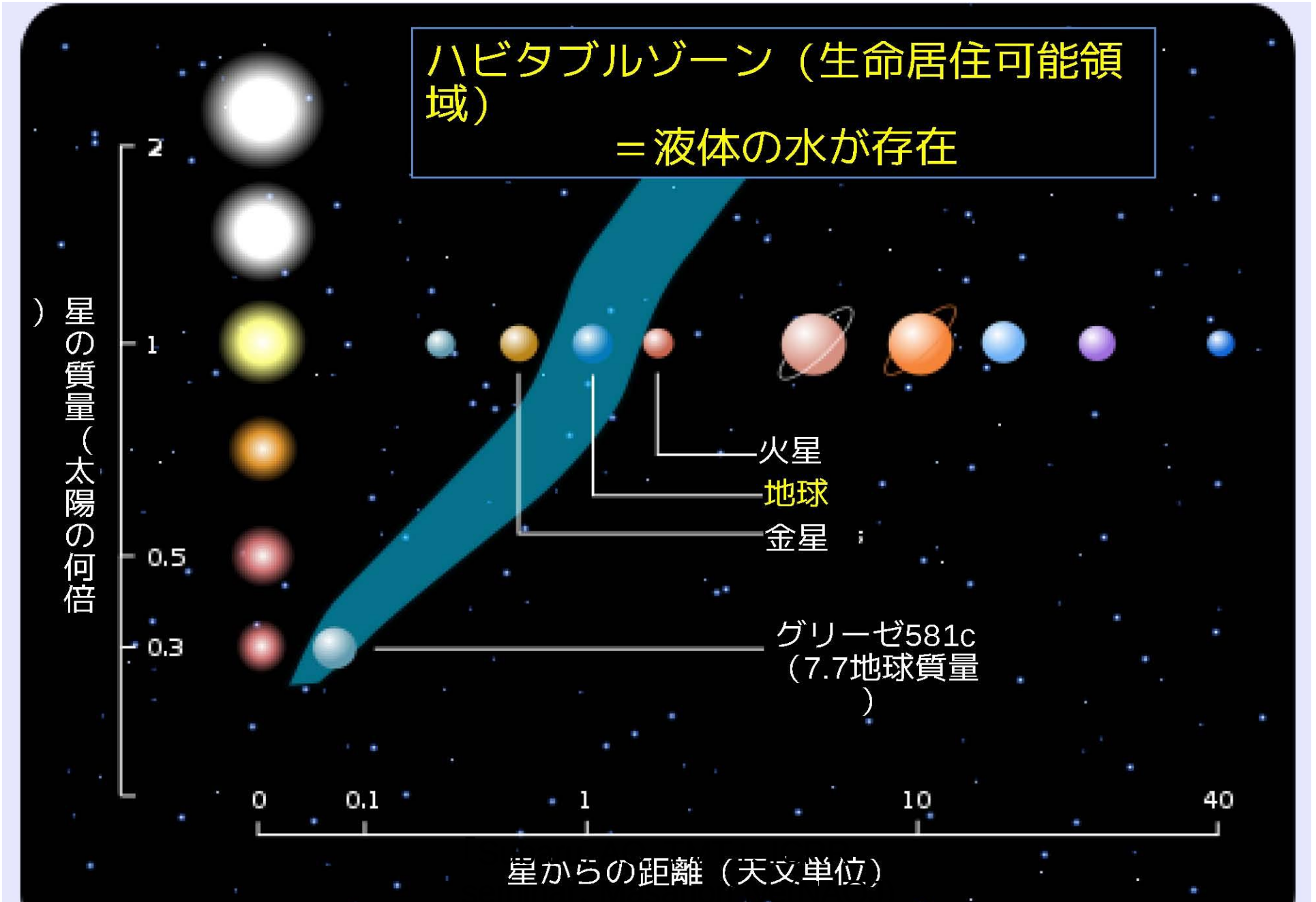


Needs precision at 1cm/sec

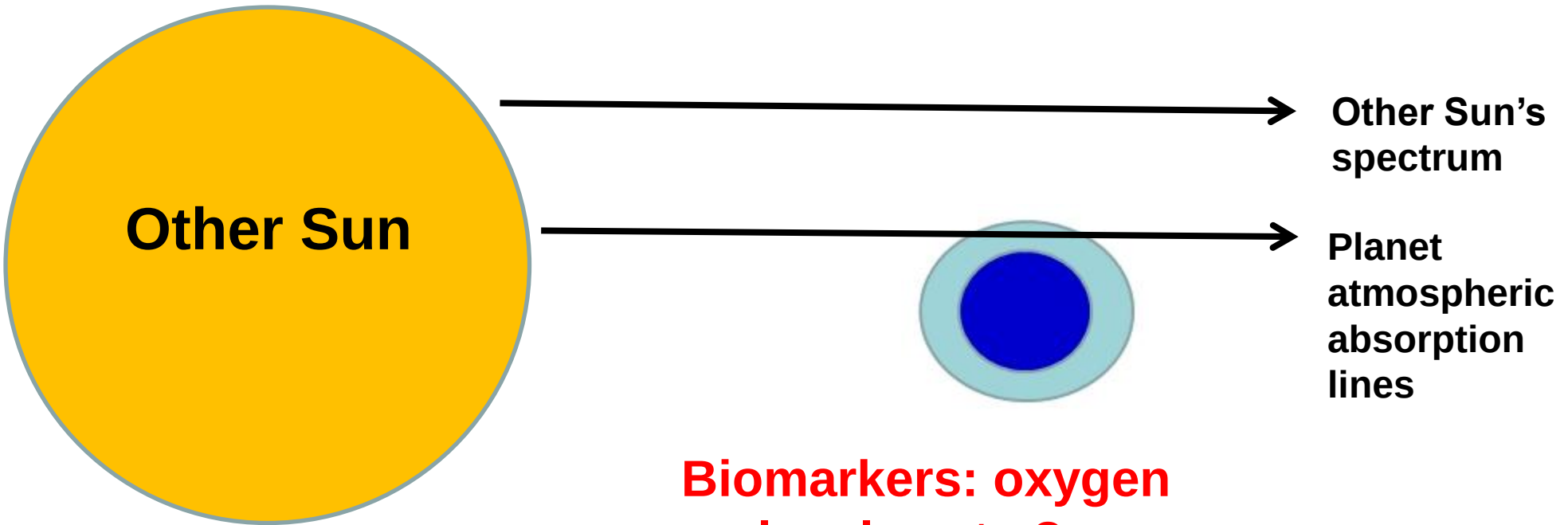
50cm/sec precision is becoming feasible for stellar Doppler measurement is

Redshift increases by 1/1.3billion in 10 years.

Planets in habitable zone
Search for biomarkers in the atmosphere



Composition analysis of atmosphere



Biomarkers: oxygen molecules etc.?

250M$
Gordon Moore（Intel）

All we need is money …, but
East Japan Earthquake & Disaster …

NAOJ donation site
from 10$