Instrument of the prime focus on the Subaru telescope

Masahiko Kimura

content

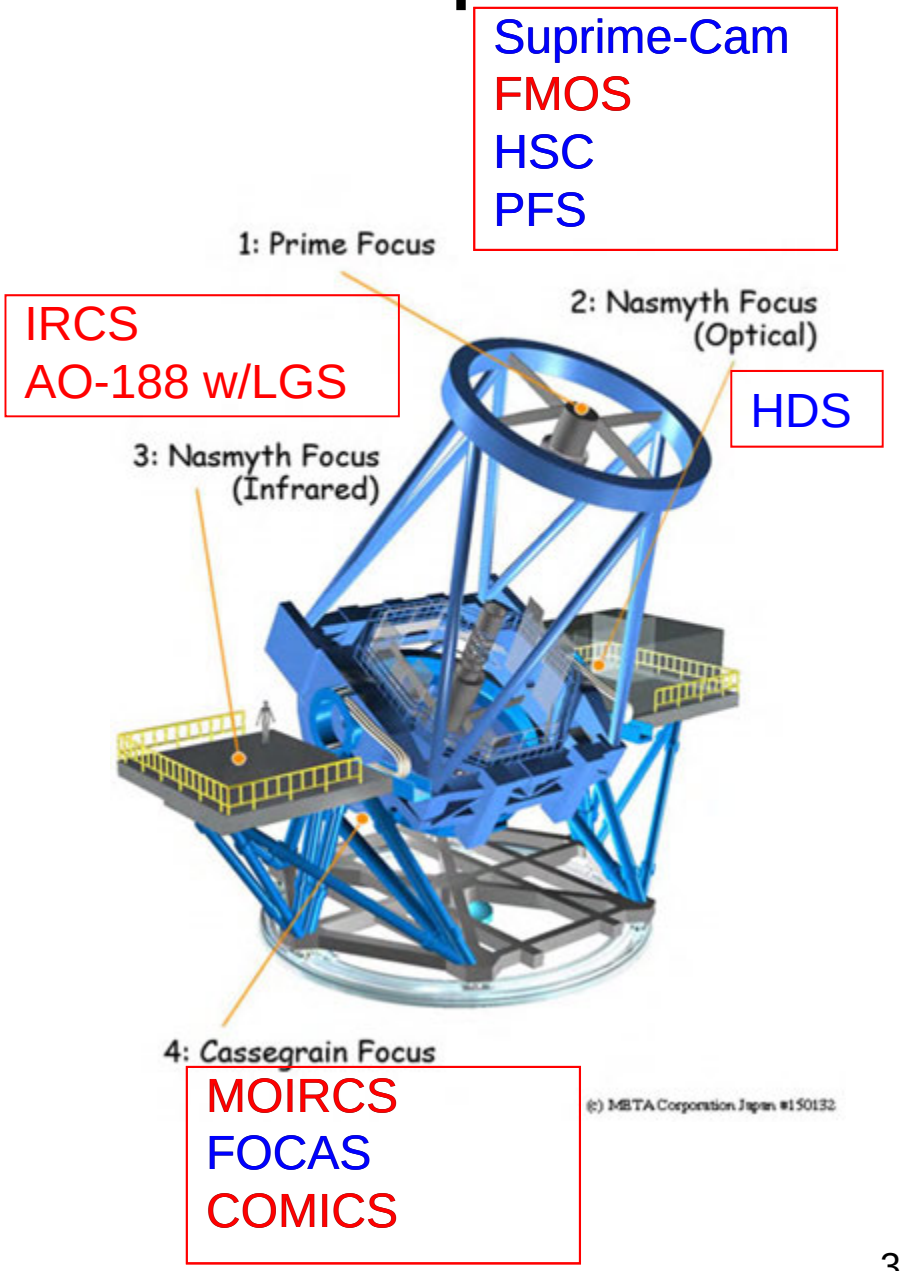
- What is Subaru telescope
- Why we use the prime focus?
  - merit vs. demerit
- Suprime-Cam
- FMOS (today's main talk)
- HSC
- PFS (today's sub-main talk)
- Summary/Conclusion

What is Subaru telescope

Primary Mirror
* Effective diameter: 8.2 m
* Thickness: 20 cm
* Active support: 261 actuators
* Weight: 22.8 tons
* Material: ULE (ultra-low thermal expansion glass)
* Mean Surface error: 12 nanometer
* Focal length: 15 m

Telescope Structure
* Mounting: altitude-azimuth (Alt-Az)
* Basic Optics: Ritchey-Chretian System
* Height: 22.2 m
* Maximum width: 27.2 m
* Weight: 555 tons
* Foci: Four

-Primary focus : F2.0 (with corrector lens)
-Cassegrain focus : F12.2
-Nasmyth focus (optical) : F12.6
-Nasmyth focus (infrared) : F13.6



Instruments

AO188
- Subaru 188-elements Adaptive Optics system
- diffraction-limited images in the near-infrared

COMICS
- Cooled Mid-Infrared Camera and Spectrograph
- imaging and spectroscopy from 8-25 microns

FMOS
- Fibre Multi Object Spectrograph
- Multi-object spectroscopy from 0.9-1.8 microns

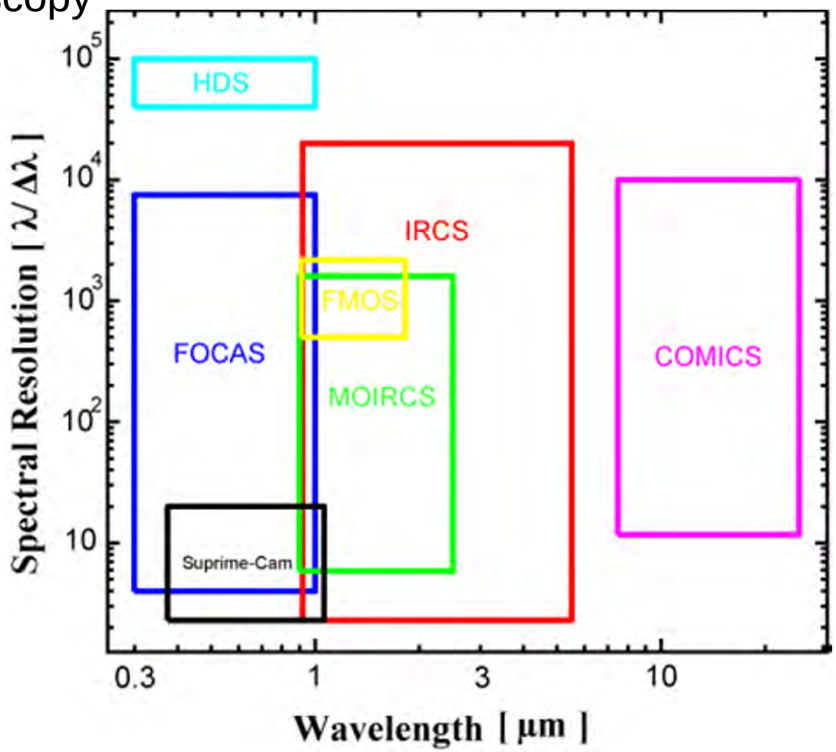
FOCAS
- Faint Object Camera And Spectrograph
- optical imaging and longslit and multi-slit spectroscopy

HDS
- High Dispersion Spectrograph
- extremely high-resolution optical spectroscopy.

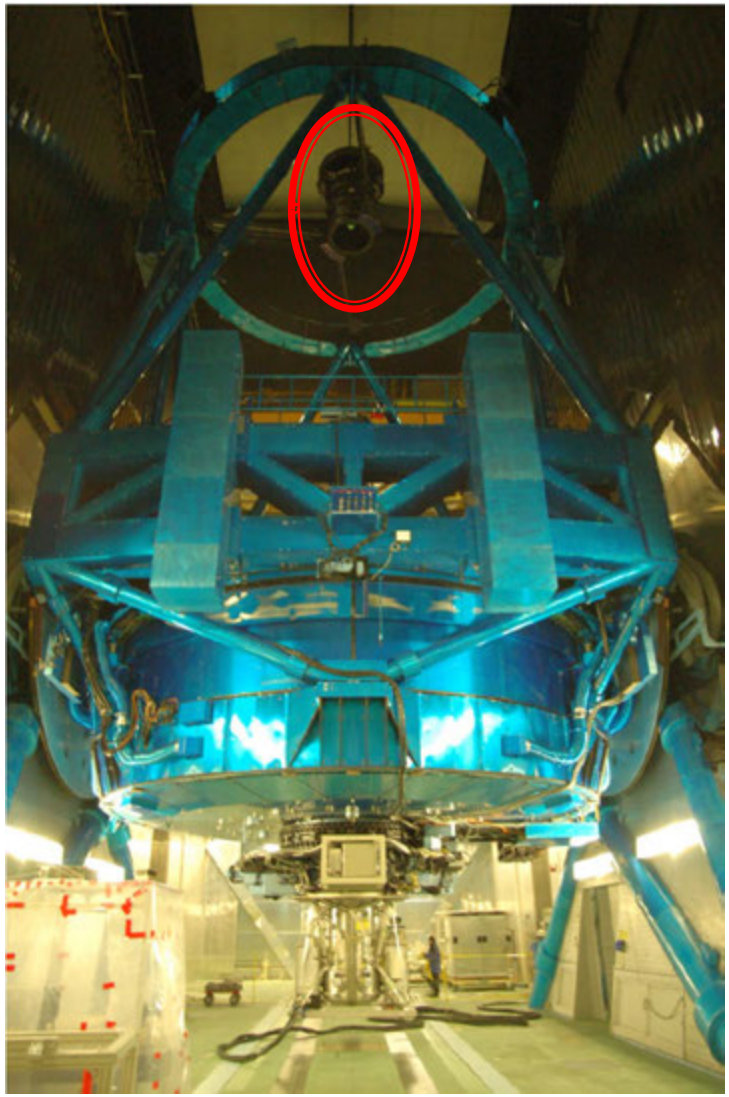
IRCS
- Infrared Camera and Spectrograph
- imaging from 0.9-5.5 microns
- low-resolution and echelle spectroscopy

MOIRCS
- Multi-Object Infrared Camera and Spectrograph
- imaging and low-resolution spectroscopy from 0.9-2.5 microns, 4* 7 arcmin field of view.

Suprime-Cam
- Subaru Prime Focus Camera
- optical imaging, 30 arcmin field of view



Prime focus



3 secondary mirror
3 prime focus units

Merit vs. Demerit

using the prime focus.

Merit	Demerit
a small number of the focal ratio	a severe limit of the weight of the prime focus instrument
a wide field of view, suitable for the survey observations.	a laborious work
	a risk of giving a serious damage to the main mirror by falling items from the instrument

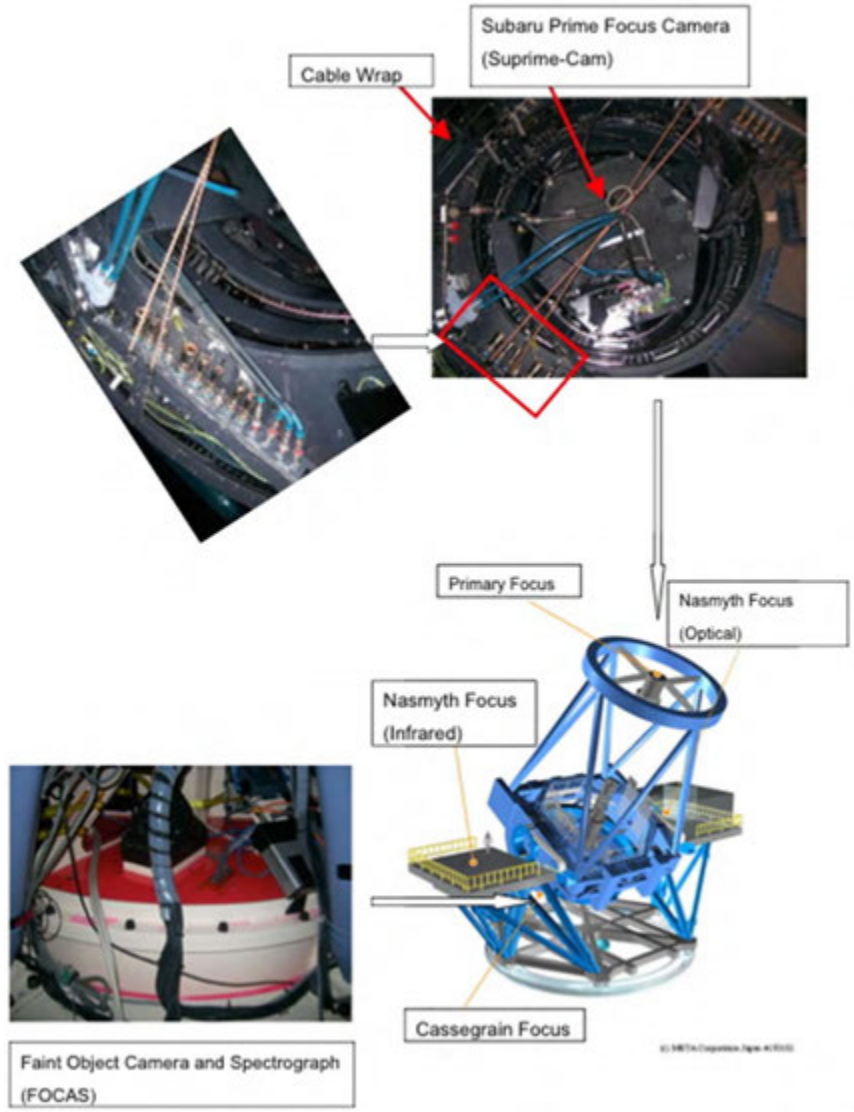
a laborious work,
a risk of giving a serious damage to the main mirror

Serious Hardware Incident with the Subaru Telescope (Suprime-Cam) Interrupts Its Operation

While shutting down the observation system at the end of the night shift during the early morning of Saturday, 2nd, July 2011, the telescope operator detected an error signal from the top unit of the telescope.

@ Subaru Web page

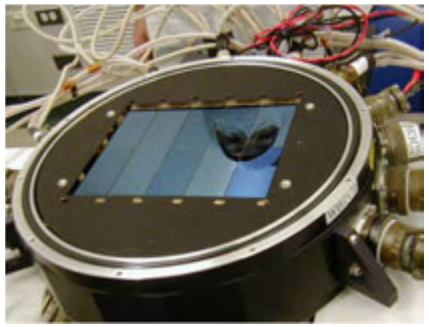
We need to consider risks of giving a serious damage to the telescope and instruments.



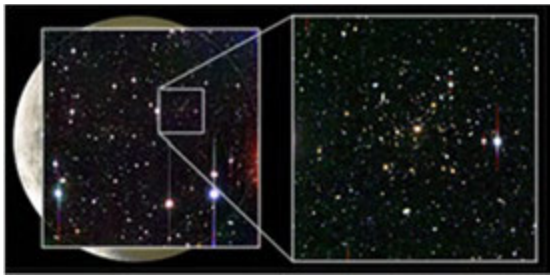
But, invaluable advantage

a small number of the focal ratio

a wide field of view, suitable for the survey observations.

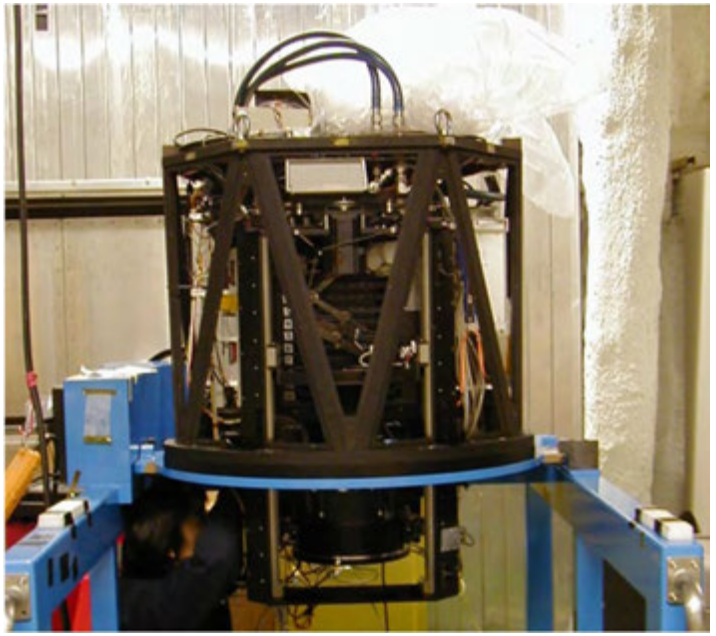


Suprime-Cam



- mosaic camera
  - ten - 2048 x 4096 CCDs
- 34' x 27' field of view
  - a pixel scale of 0.20".
- Pixel size 15 um
- Gain 2.5-3.7 e-/ADU
- Read noise 10 e-
- Readout time 18 s

- hold 10 filters at a time
- Filter exchange time 300 s



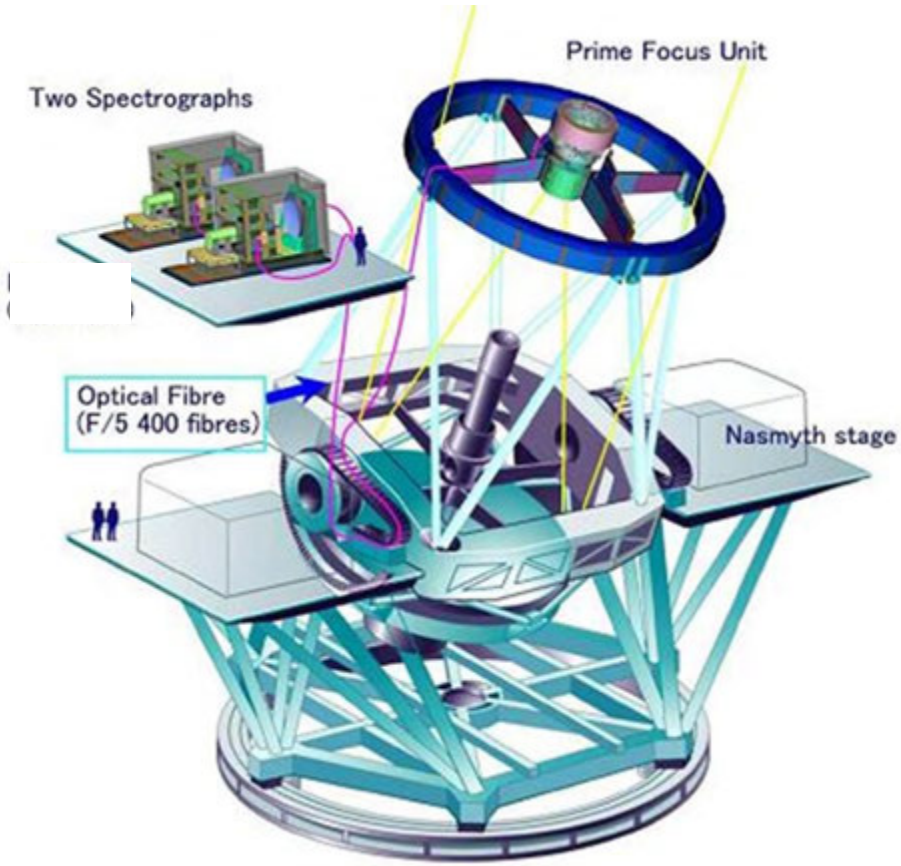
Filter			Sensitivity		mag for 1 e⁻/s
Name	Plot	List	(mag)	(mag/arcsec^2)	
B	✓	✓	27.6	26.2	28.5
V	✓	✓	27.4	25.9	28.7
R_c	✓	✓	27.0	25.5	28.7
I_c	✓	✓	26.0	24.5	27.7
g'	✓	✓	27.5	26.0	28.9
r'	✓	✓	27.2	25.8	28.9
i'	✓	✓	26.8	25.4	29.1
z'	✓	✓	25.8	24.4	28.5
Y	✓	✓	24.7	23.3	26.8

Filter			Sensitivity		mag for 1 e⁻/s
Name	Plot	List	(mag)	(mag/arcsec^2)	
NA656	✓	✓	25.4	24.0	25.7
NB711	✓	✓	25.2	23.6	25.6
NB816	✓	✓	25.2	23.6	25.8
NB921	✓	✓	25.4	23.9	25.8

Condition:
S/N=5, 1 hour exp.
good (0.5") seeing
a moderately dark sky
(3 days from New Moon)

FMOS

- Fibre Multi-Object Spectrograph
- 400 fibres on the prime focus
  - 30’ diameter FoV
- Each fibre (100 μm core)
  ~ 1”.2 on the sky.
- wavelength coverage
  - 0.9 – 1.8 um
- 2 spectrographs (200 spectra x 2)
  - operated at T= - 50 deg.
  - OH– airglow suppression
- two spectral resolution modes :
  - Low R: R~500 (one exposure)
  - High R: R ~ 2200 (any ~ 0.2 μm)
- FMOS consist of
  - Prime Focus unit
  - Echidna fibre positioner & fibre cables and connector
  - Two cooled spectrographs

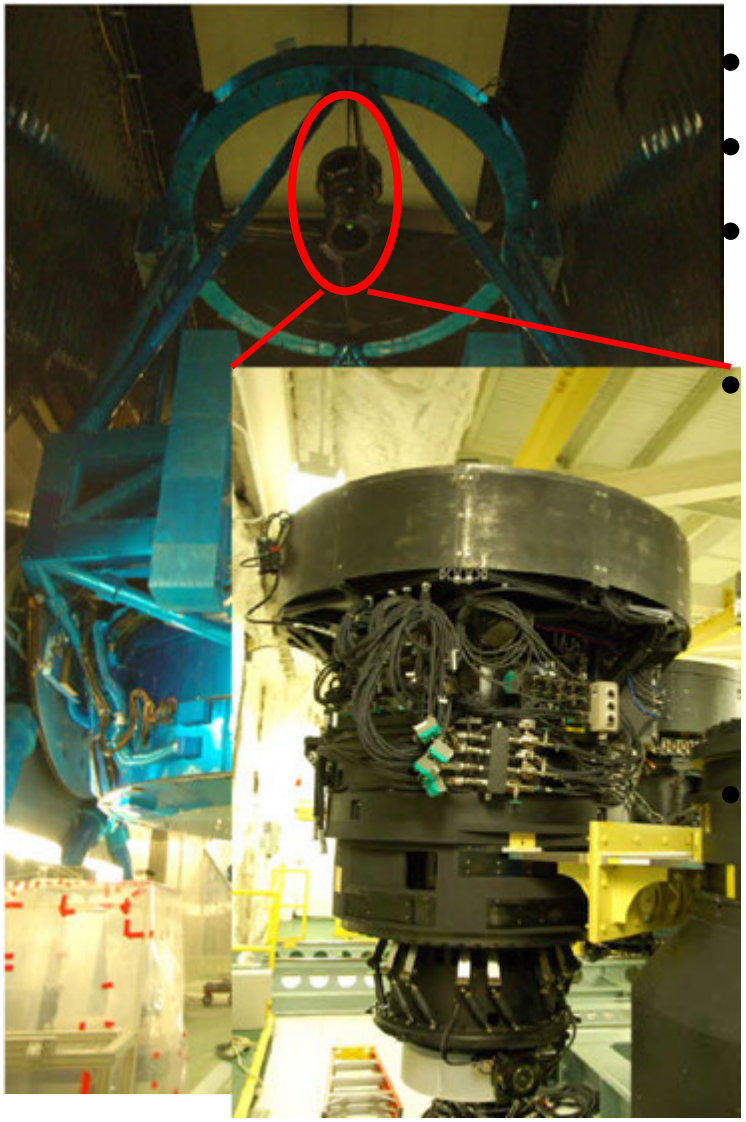


FMOS instrument team

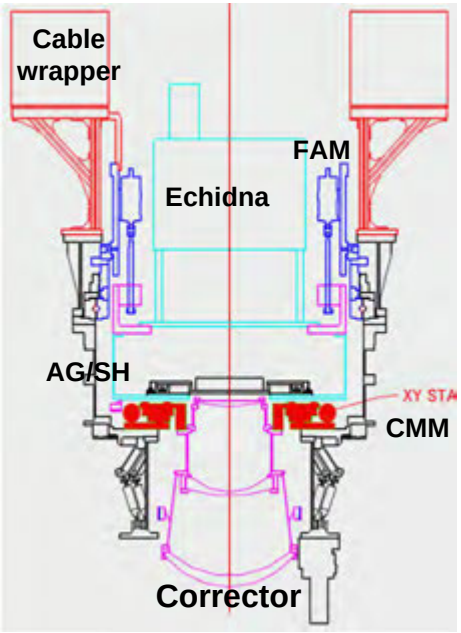
- Kyoto
  - Instrument PI (Toshinori Maihara)
  - Prime focus instrument bay
  - One OHS spectrograph
  - Observation software
- Oxford/RAL
  - Spectrograph Design
  - One OHS spectrograph
  - Fibre back-illumination system
- Durham
  - Fibre cables
  - Top end fibre connector
  - Slit assemblies
- AAO
  - ECHIDNA fibre positioner & software
  - Prime Focus Corrector
- Subaru
  - New floor to house spectrographs

- Mechanical/Optical structures of FMOS
  - Prime focus unit for IR
  - Fibre Positioner “Echidna” and Fibre connectors
  - Two cooled spectrographs
- Results
- Conclusion

Prime focus unit for IR



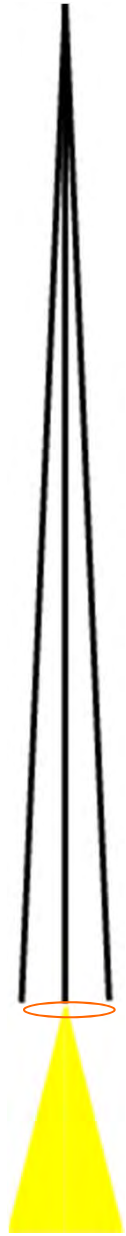
- Fibre positioner “Echidna”
- Wide-field corrector lens
- Instrument rotator with Cable wrapper
- Optical adjustment mechanism
  - Focus adjustment mechanism (FAM)
  - Corrector movement mechanism (CMM)
- Optical measurement systems
  - Auto-guide system using fibre bundles
  - Shack Hartmann system



Fiber positioner

Major fibre spectrograph

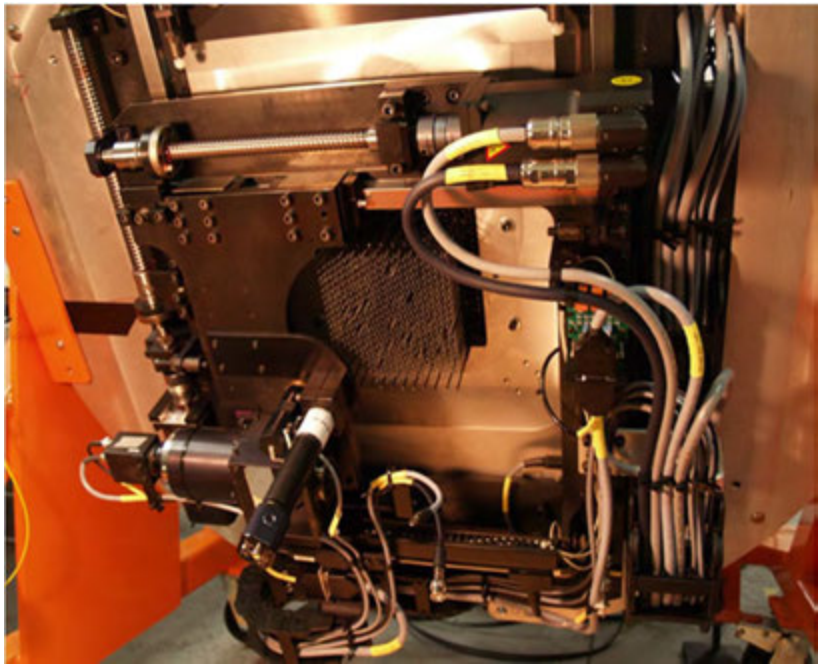
- FMOS is mounted the prime focus of the telescope. And there is not enough space in the prime focus unit.
- So, we developed new type of fibre positioning.
  - Spine type fibre positioner!



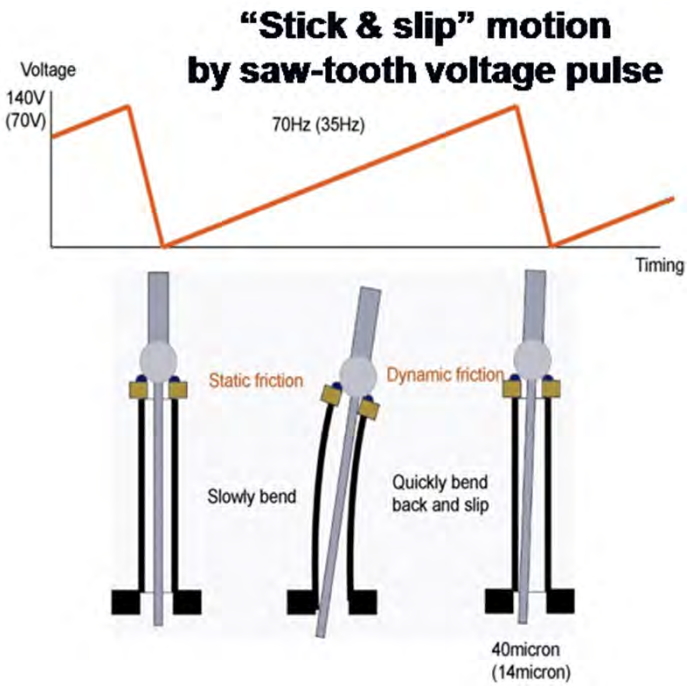
The patrol area of each fibre is φ7mm diameter.

The spacing between neighboring spines is 7mm.

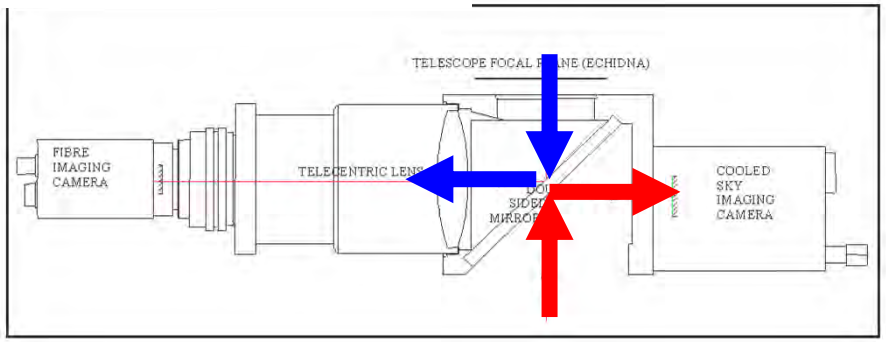
Fibre positioner “Echidna”



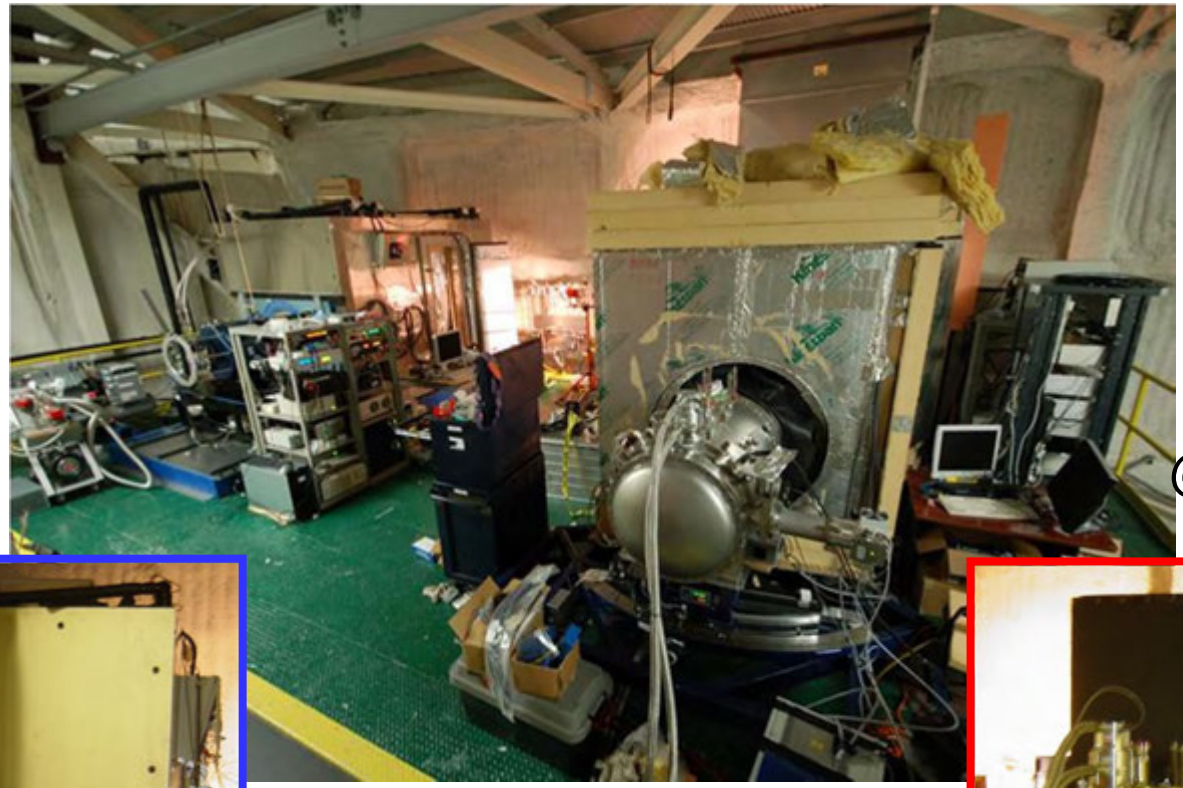
Echidna



Focal Plane imager

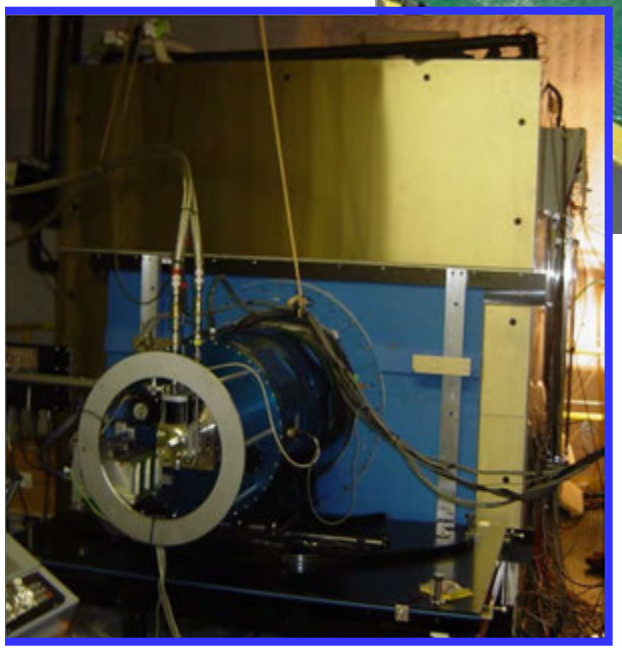


Two Spectrographs



Size
~ 2.5m x 3m x 2.5m

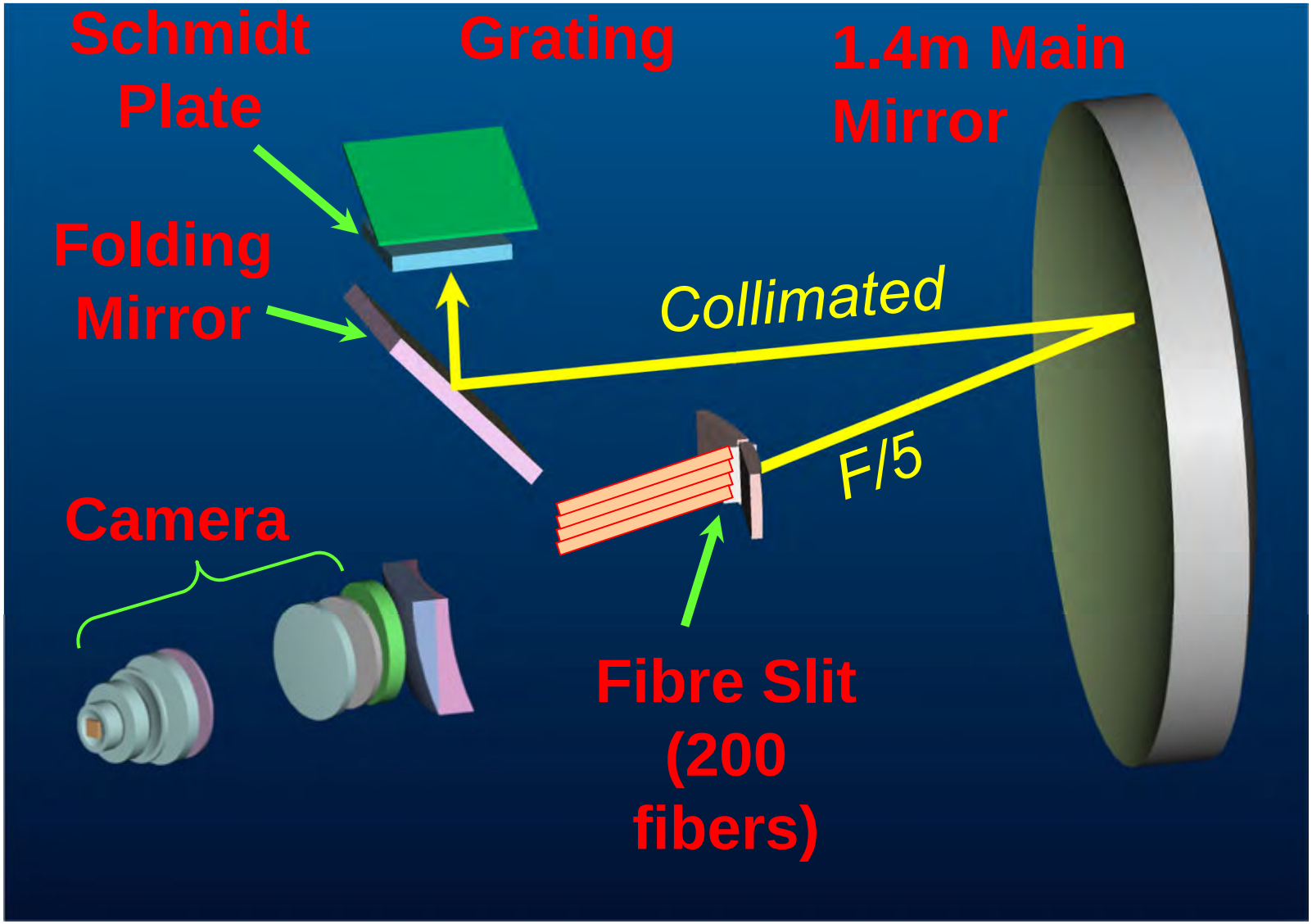
IRS1
@Kyoto Univ.



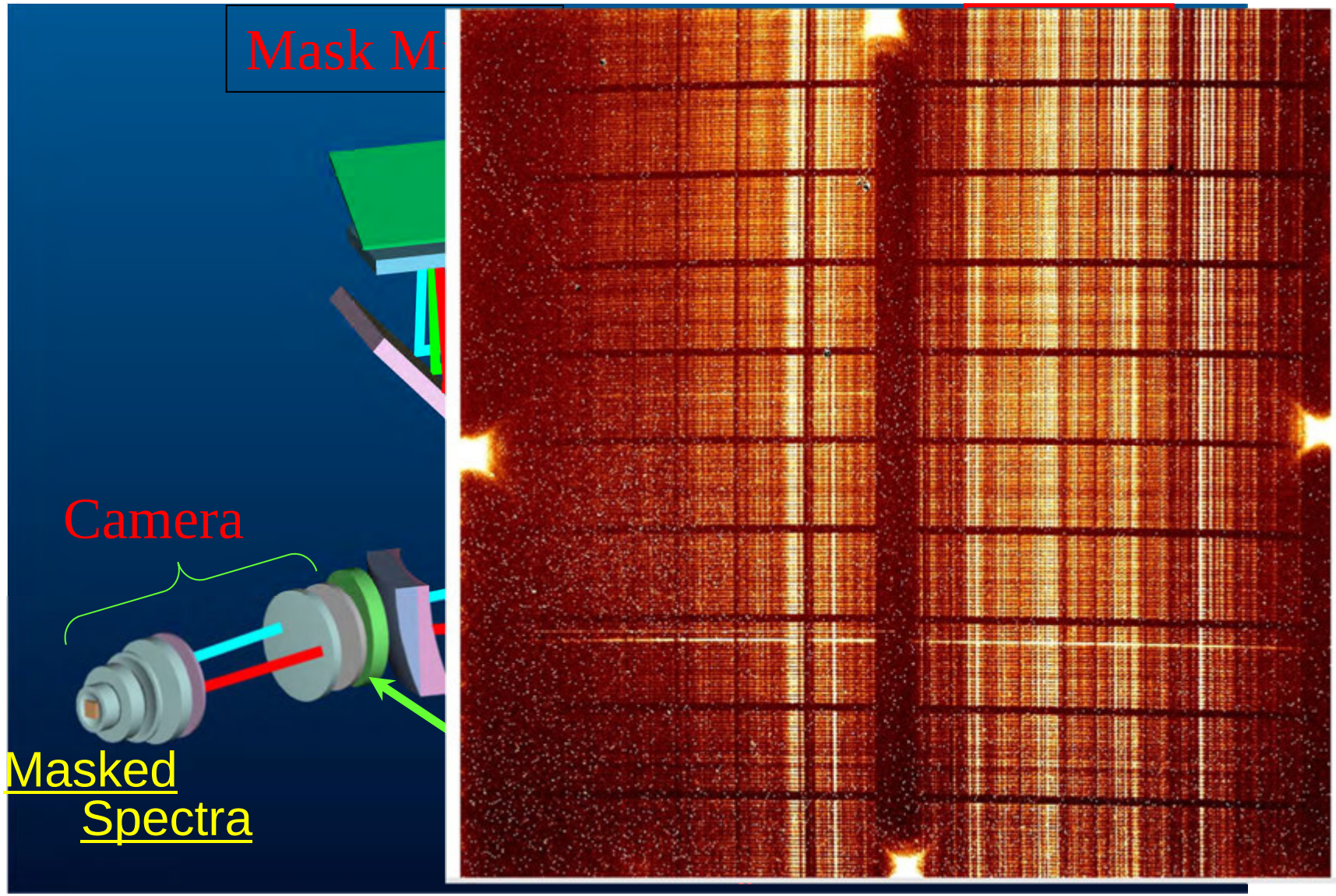
Optically identical

IRS2
@Oxford Univ. & RAL

Two Spectrographs



Two Spectrographs

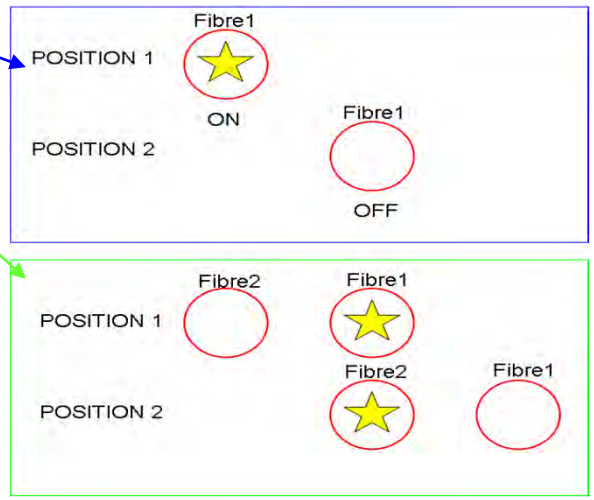


content

- Mechanical/Optical parts of FMOS
- Results
  - How to observe?
  - Previous commissioning/common use observations
  - Fibre Auto guiding
  - Echidna accuracy
  - Spectrum image
  - Performance
- Conclusion

Planning Observation

1. Prepare a source list of science targets
   1. Astrometry
   2. Guide star
   3. Coordinate calibration stars
2. Fibre allocation
   1. Field centre
   2. Position angle
   3. Observation method (sky background subtraction)
      1. Normal beam switching
      2. Cross beam switching
3. Spectrographs
   1. Low/high resolution mode
   2. Exposure time
   3. Calibration data



Observation Procedure

1. Pointing the telescope & allocating fibres (include focusing)
   1. Iterative process: Measure fibre positions and move spines.
      (back-illumination light + spine camera)

      Need 7 iteration (~15min.) > ~10um(0”.12)
   2. Check field

      Filed check using coordinate calibration star, offset-pointing and rotation angle
2. Star auto guide **~20 min.**
3. Start exposure
4. Re-configuration every 30 min. (~11min.)

   On-source 3 hour exposure:

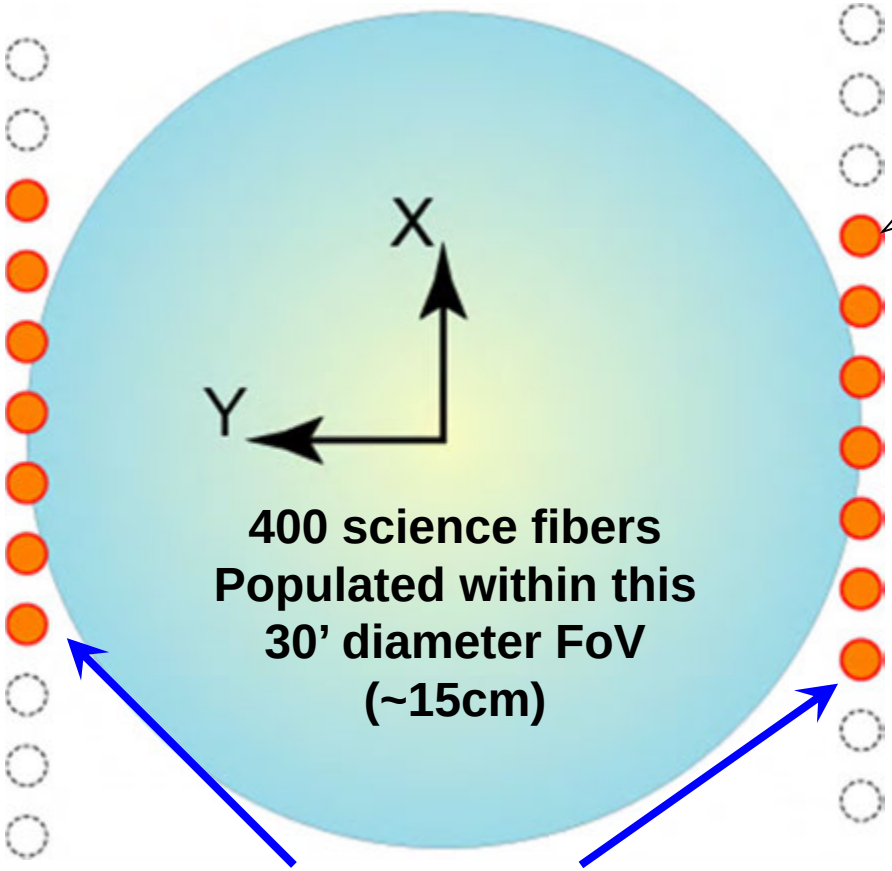
   20min + (30 + 11)min x 6 = 266min

   overhead = (266 – 180) ÷ 266 x 100 = 32.3 %
4. Data acquisition for flat-fielding and wavelength calibration

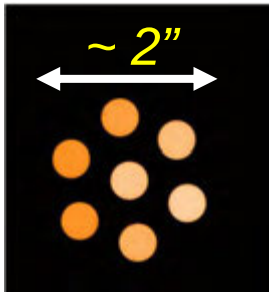
Previous observations

- FMOS project started from 1999?
- Assembling started from 2005/May at Subaru telescope site
- Engineering first light @ 2008/May
- Scientific engineering observation start form 2009/Dec
- Scientific observation start from 2010/May/28.
- Open-use observation start from 2010/May/29.

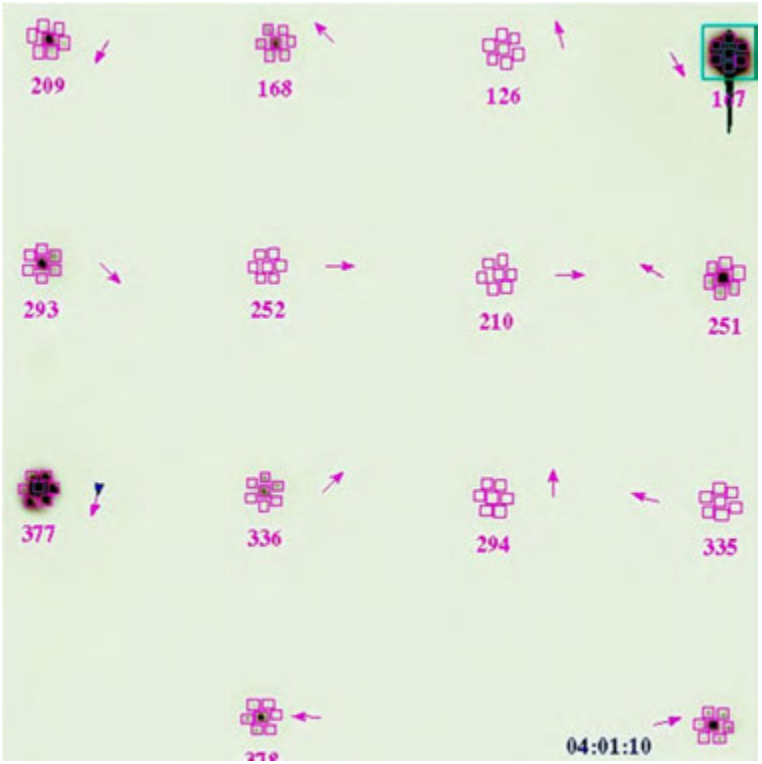
Fibre Auto Guide



14 fibre bundles
For Auto-Guide

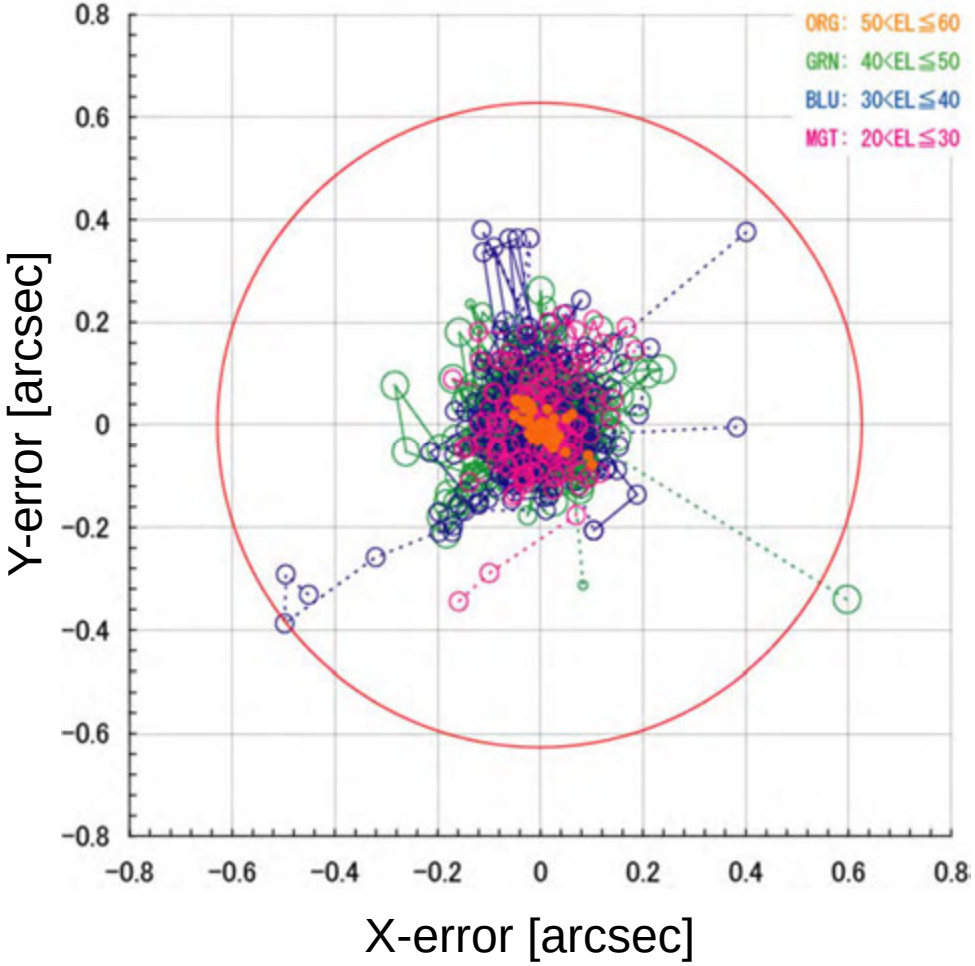


A guide fibre bundle
= 0".6 x 7 fibres
R =16-17 mag stars
worked for AG

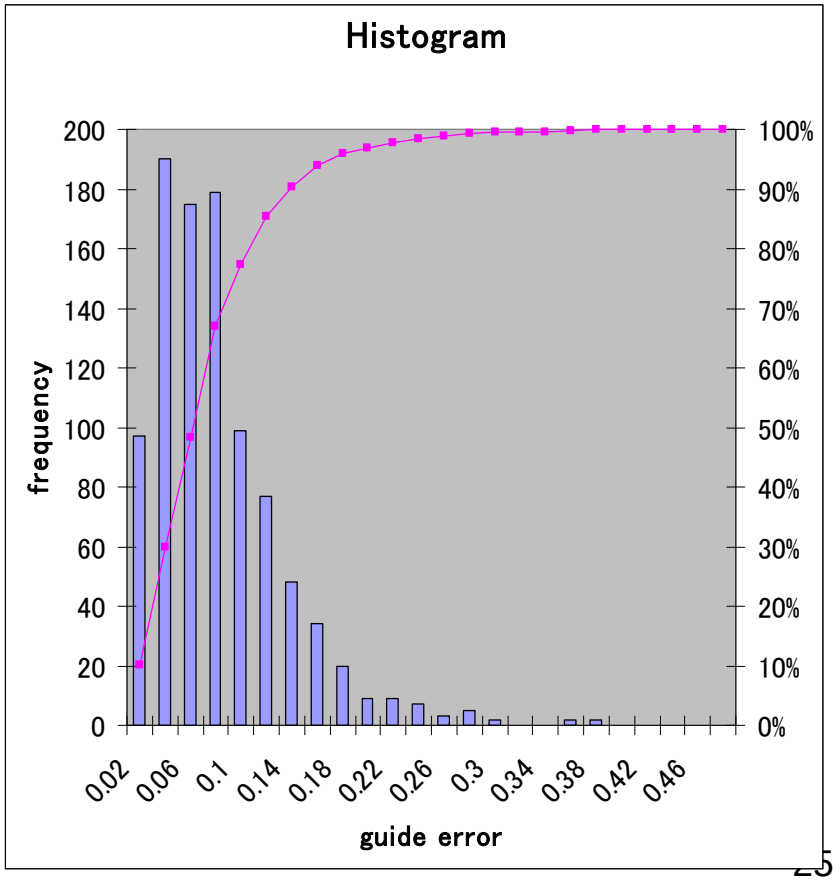


Fibre Auto Guide

Median AG2-error ~ 0”.063
90%value ~ 0”.139 , 95%value ~ 0”.173



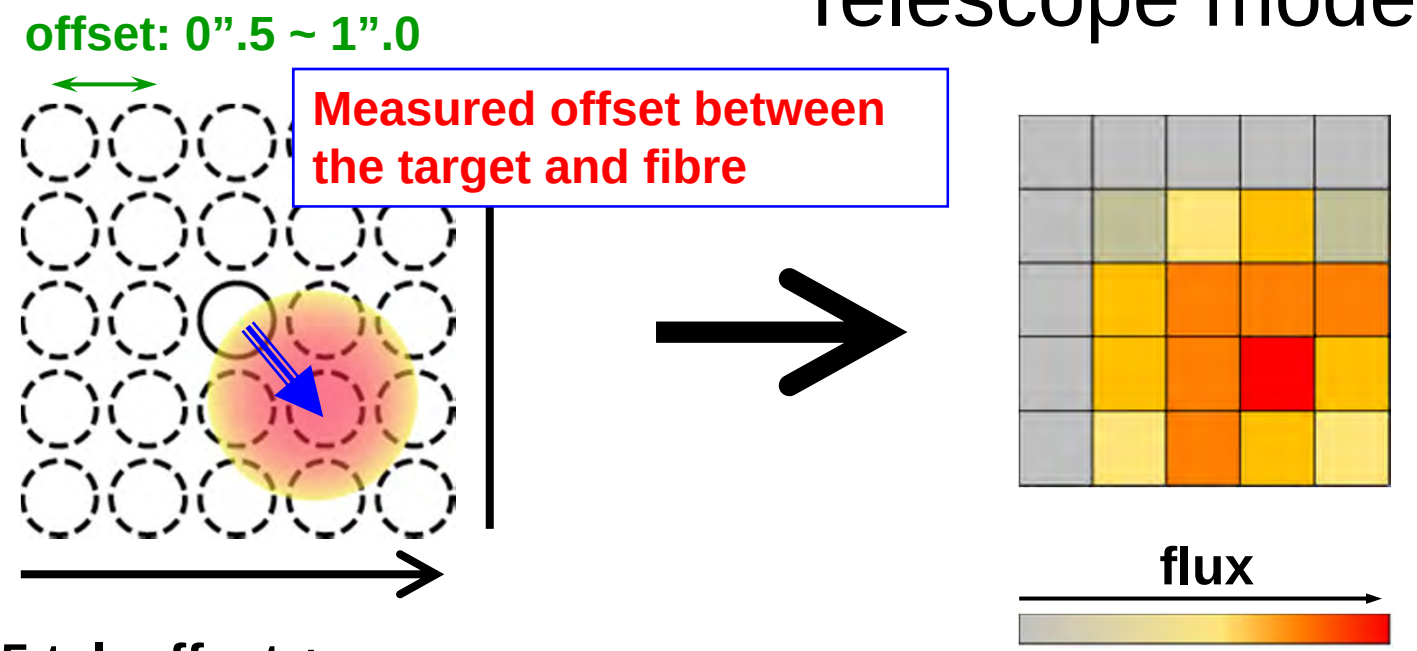
Sky condition :
21/Apr/2010 night log
MASS ~ 0”.24±0”.12
@CFHT WX Tower seeing



Echidna's allocation error

Fibre allocation ⇒ using catalogs

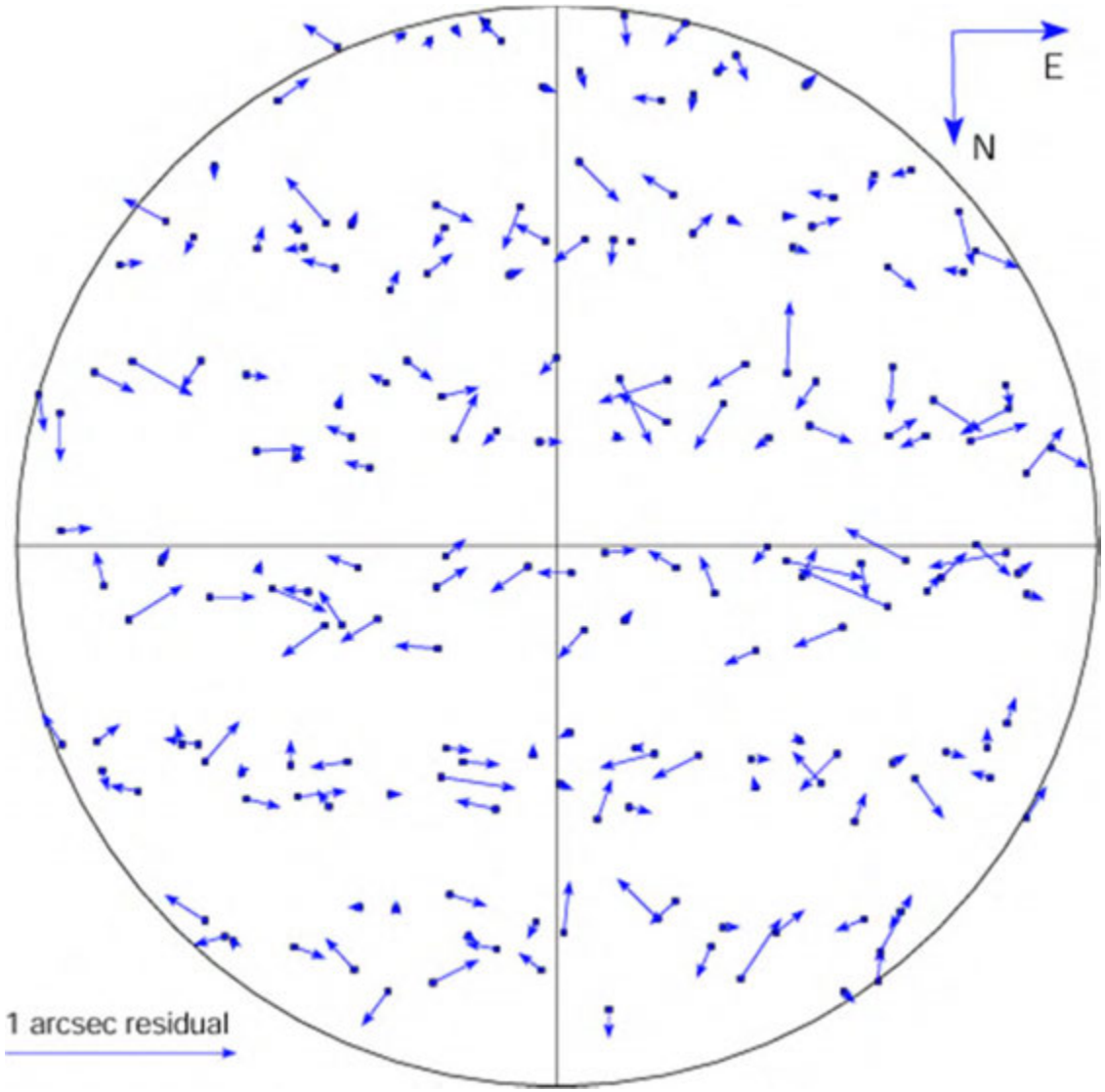
On-sky fibre position ⇒ Telescope pointing
Telescope model ,,,



5 x 5 tel. offset + exposure
→ 2D map of flux (spectrographs)
→ Centroid of star

Compare flux at each position

Positing accuracy of Echidna



Fine-tune telescope model with "rastering"
Configure spines based on the above telescope model, and acquire spectra of 400 fibers by "rastering" telescope.
Position offset between the targets and science fibres
~ 0".15 in rms

Observation !

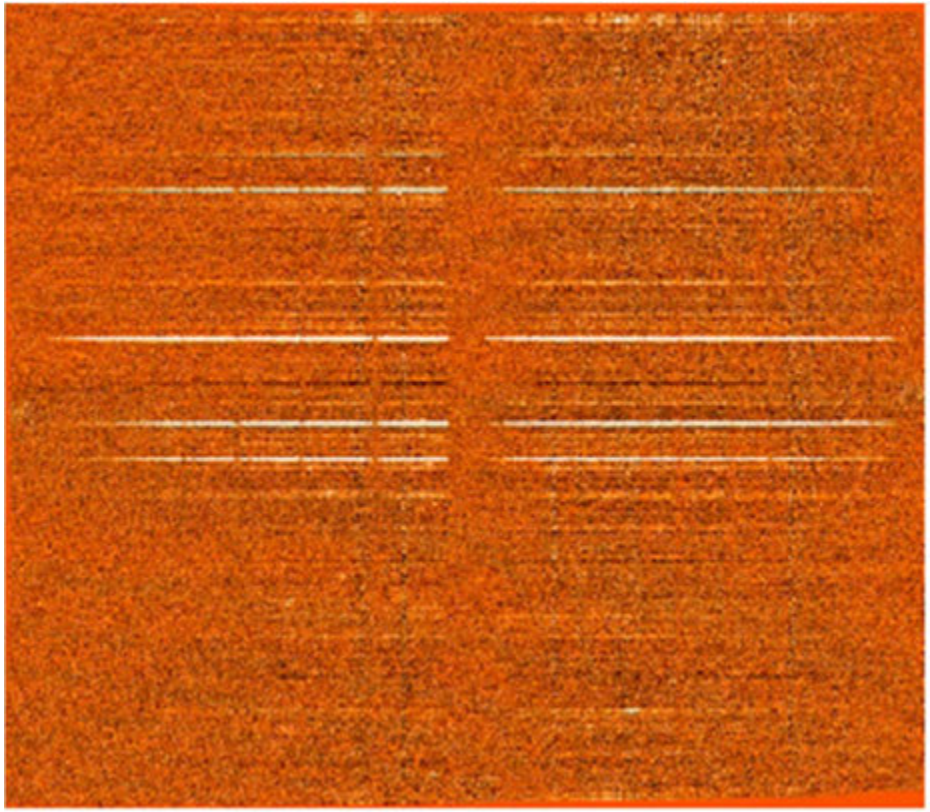
- Data sets @from Dec 2009
  - SXDF field: 120 min exp time
  - Lockman Hole: 90 min exp time
  - And 5 other fields
- Data analysis:
  - Estimate continuum flux by 5-ord Polynomial smoothing
  - Estimate emission line flux by Gaussian-fitting
  - Only use data in J-band (λ=1.1-1.35) & H-band (λ=1.4-1.7)
  - Estimate noise by using 1d-spectra

Detector image

Ramp sampling image at 15min exp . time

J-band **H-band**

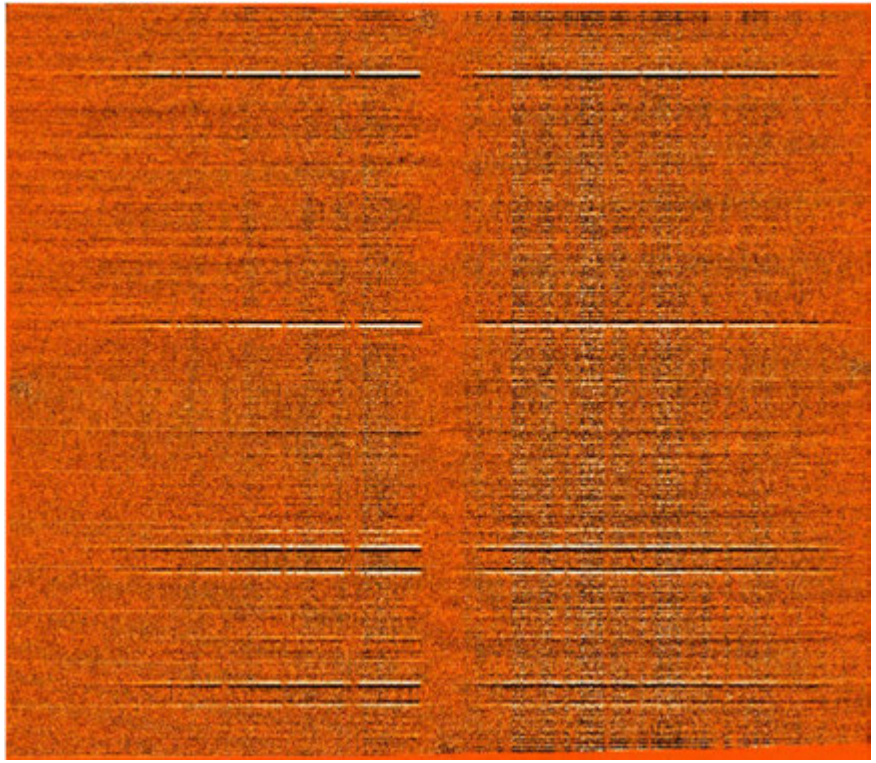
Object – Sky



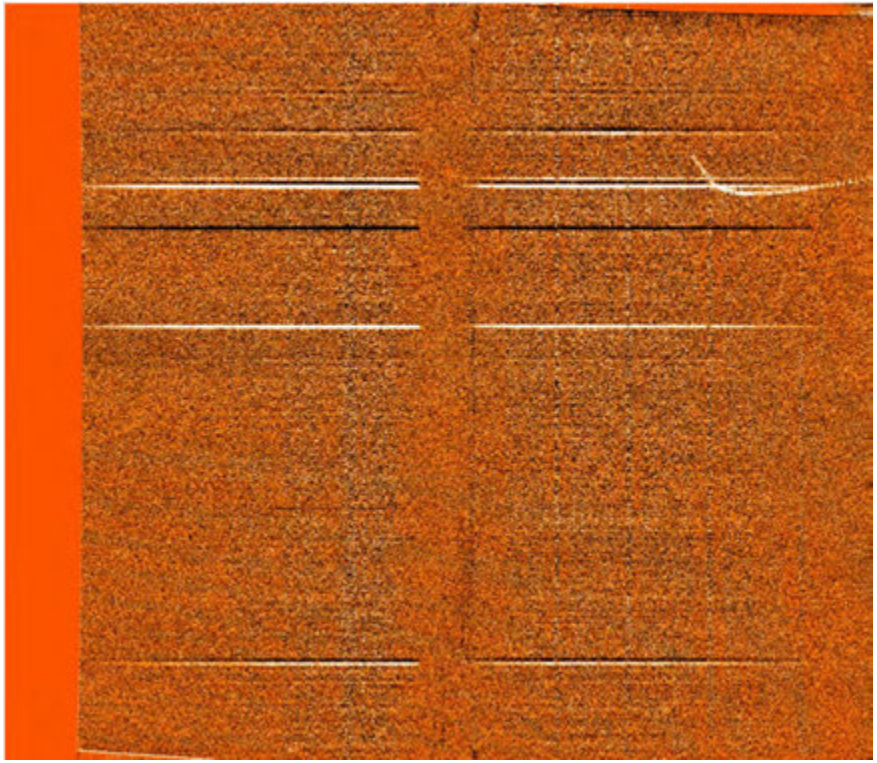
Reduction

Detector Image

IRS1 vs. IRS2

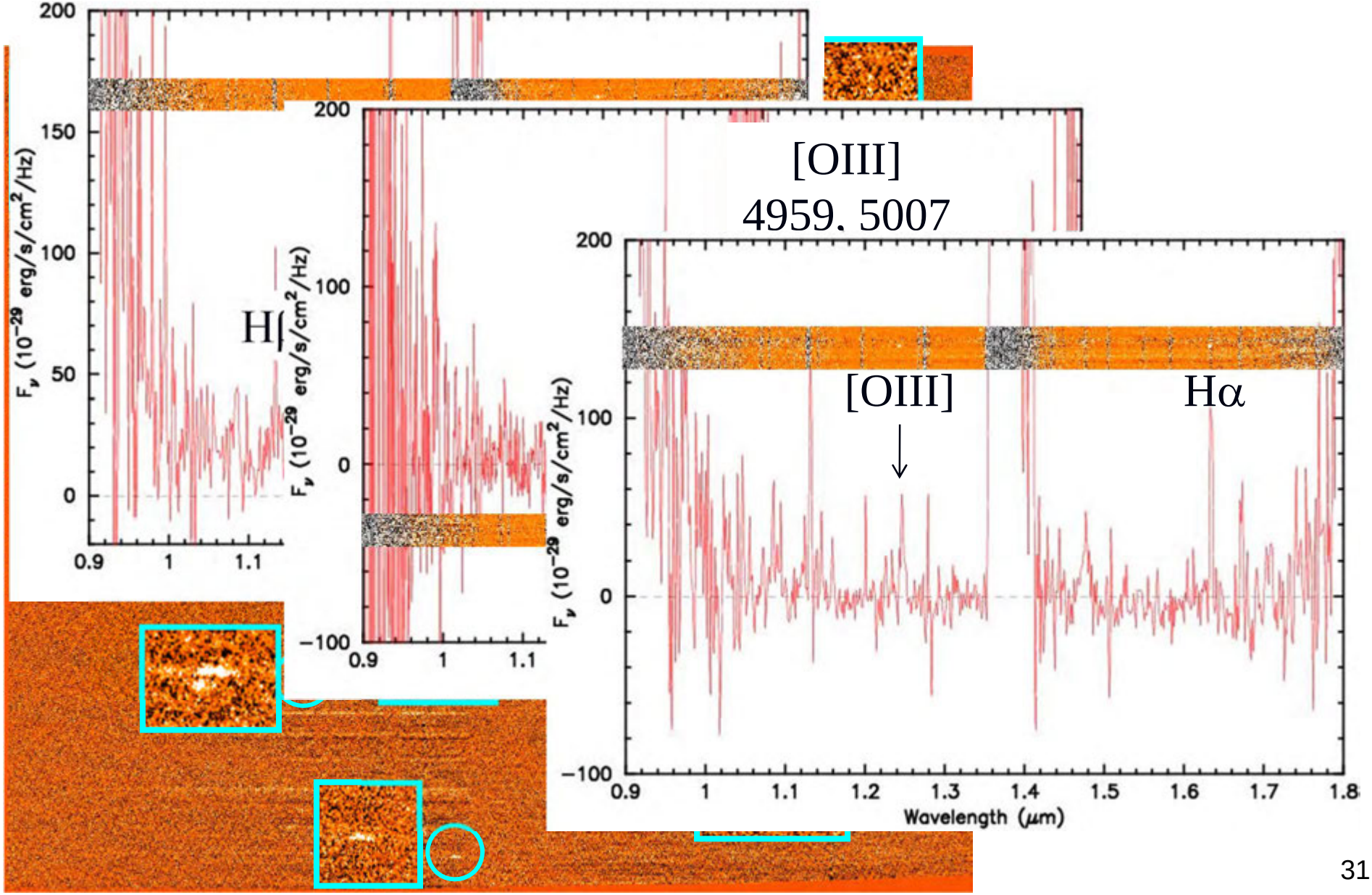


irs1_ELAIS_N1_SEabc_lrxpb.gif

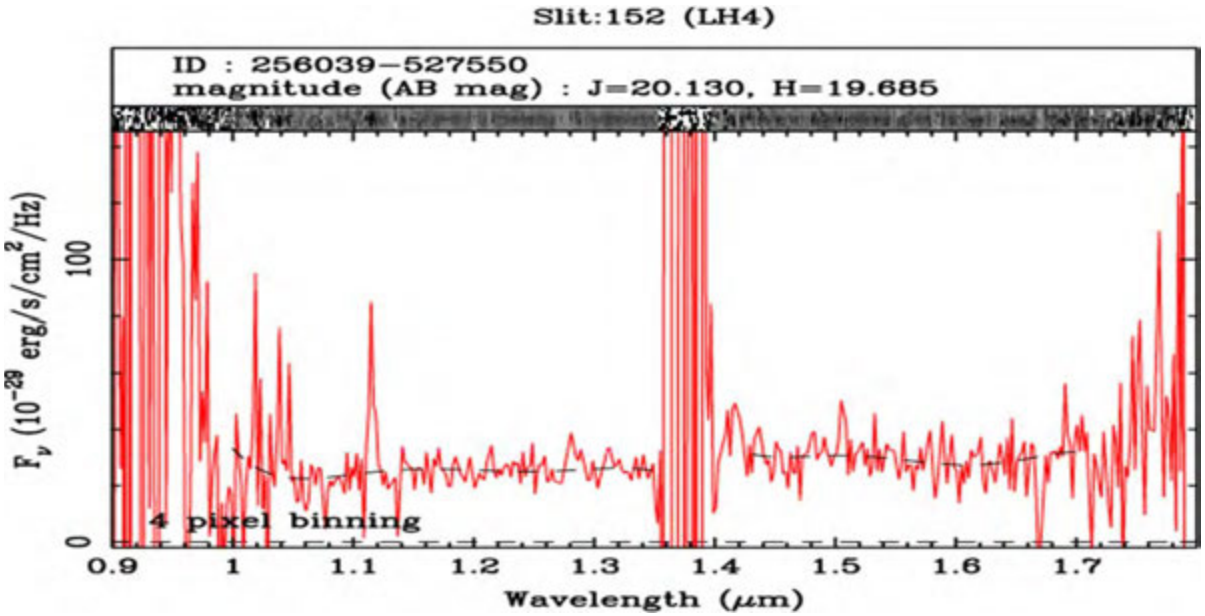


irs2_ELAIS_N1_SEabc_lrxpb.gif

Reduction image



Continuum flux sensitivity

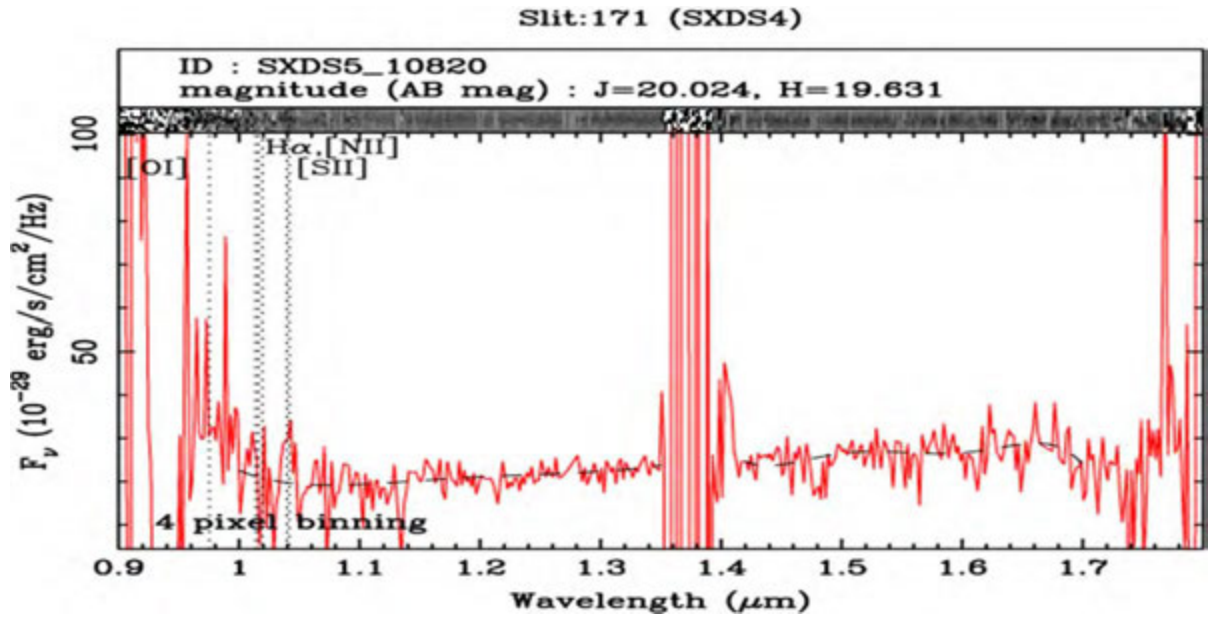


A low resolution spectrum

❖CBS mode
1.5 hrs exp. Time

J = 20.1 mag., H = 19.7 mag

S/N = 4.9 @J-band,
4.5 @H-band

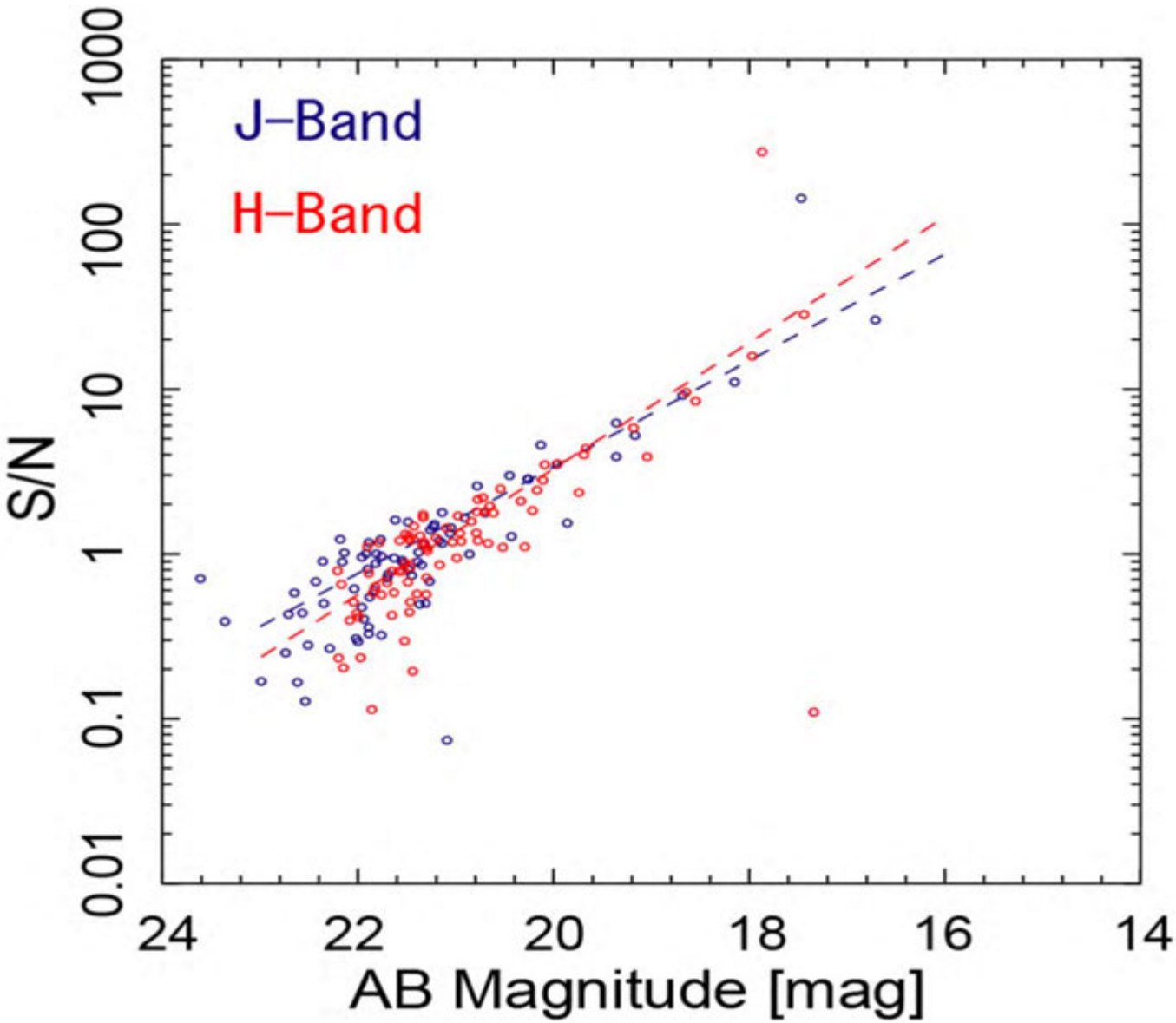


❖ CBS mode
2hrs exp.time

J = 20.0 mag., H = 19.6 mag

S/N = 5.9 @J-band,
6.4 @H-band

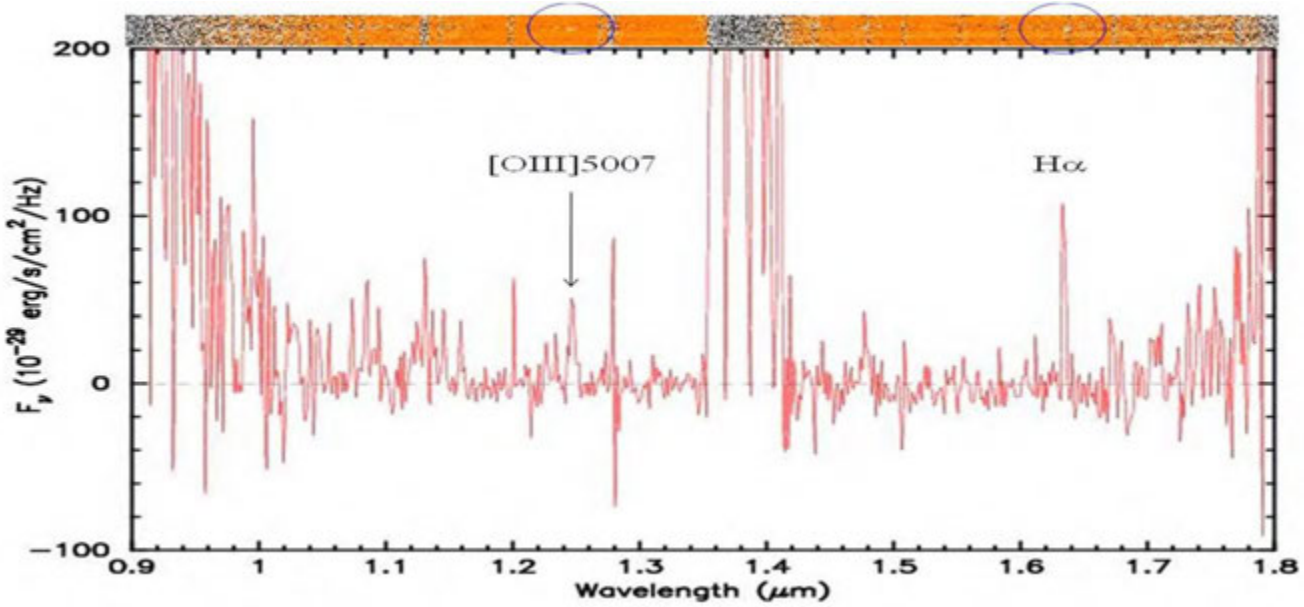
Continuum flux sensitivity



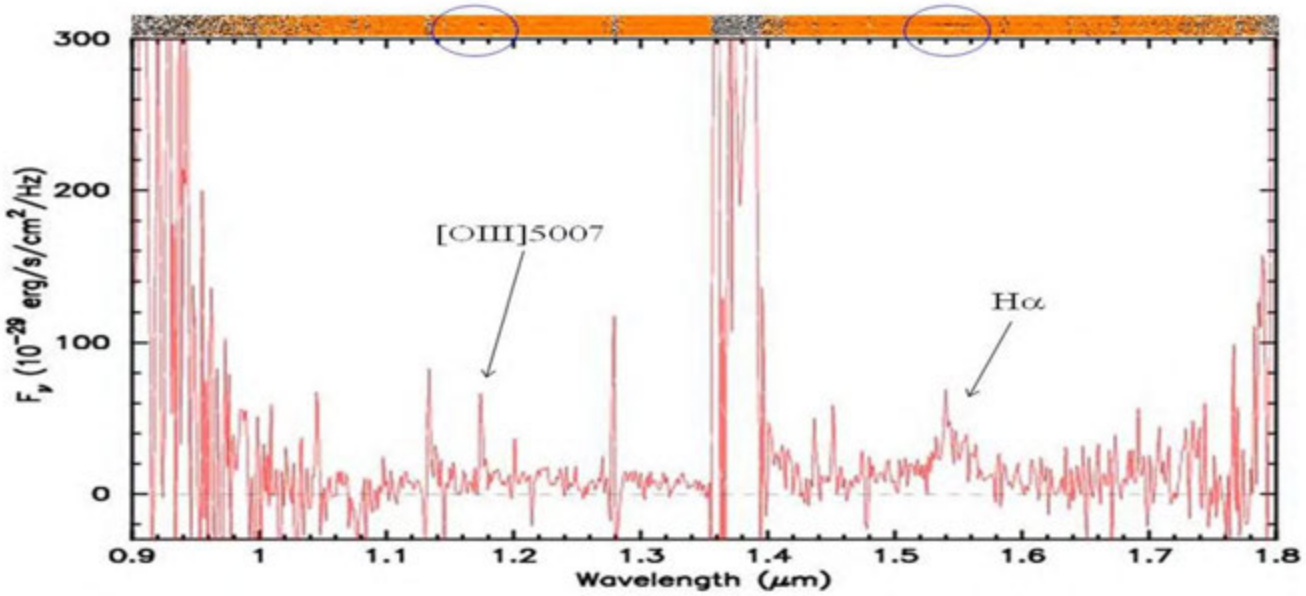
Lockman Hole field
CBS mode
1.5 hrs epx. time

Results:
J-band ~20.1 mag
H-band ~19.8mag
@ 1hrs, S/N=5

Emission line sensitivity

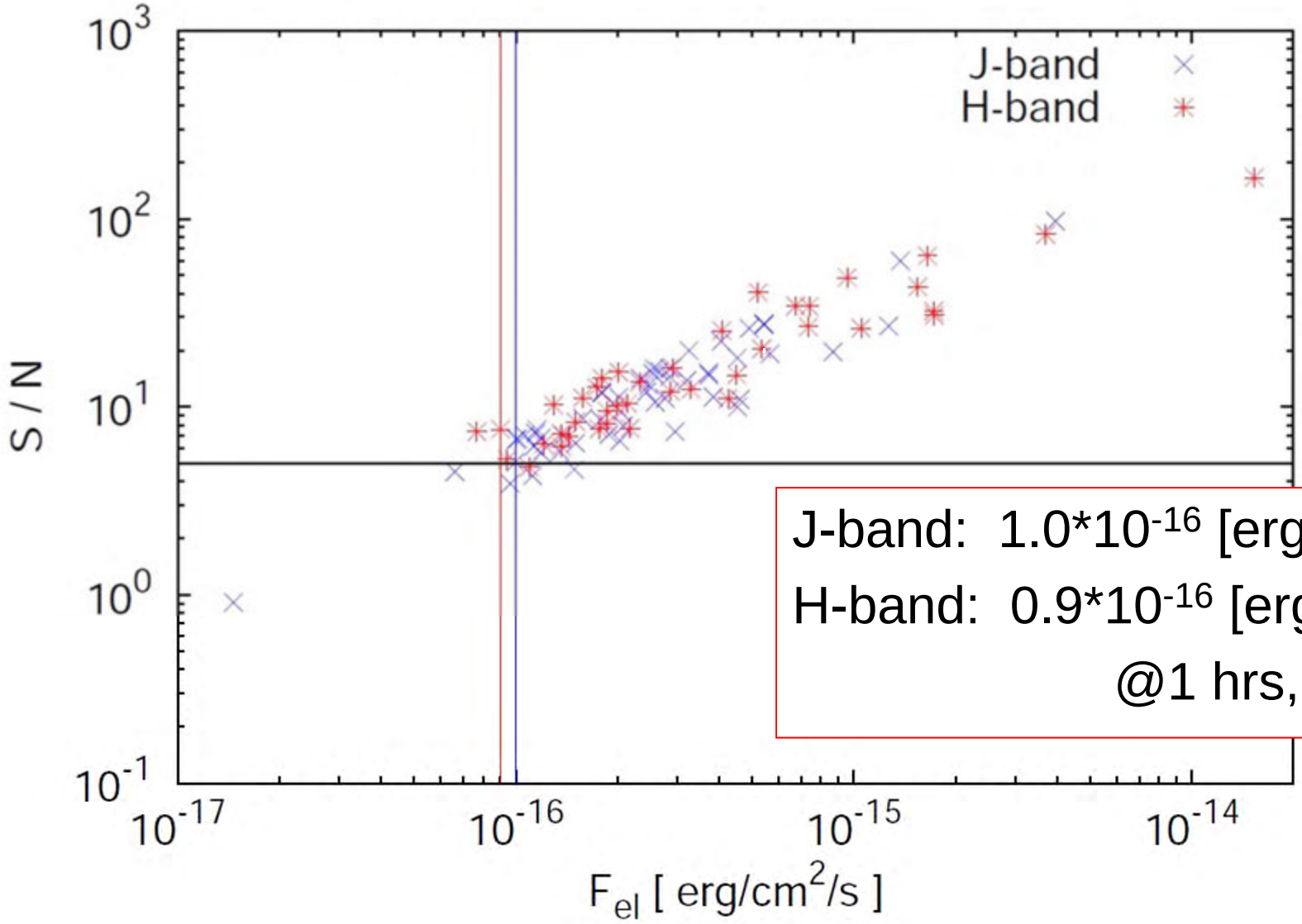


An emission line galaxy at z=1.5. [OIII]5007 emission is detected with S/N~24, of which flux is estimated to be ~5.4 x 10-16 erg cm-2 s-1.



An AGN at z=1.35. the narrow [OIII]5007 emission is detected with S/N~5, of which flux is estimated to be ~8 x 10-17 erg cm-2 s-1.

Emission line sensitivity



J-band: $1.0*10^{-16}$ [erg/cm2/s]

H-band: $0.9*10^{-16}$ [erg/cm2/s]

@1 hrs, S/N=5

Conclusion of FMOS

- Open-use observation begin in May 2010.
- Allocate fibres (include focusing)
  need 7 iteration (~15min.) within 10um(0”.12)
- Need re-configuration every 30 min.
  On-source 3 hour exposure:
  20min + (30 + 11)min x 6 = 266min
  overhead = (266 – 180) ÷ 266 x 100 = 32.3 %
- Median AG2-error ~ 0”.063 @ MASS ~ 0”.24±0”.12
- Continuum flux @ 1hr, S/N=5
  – J-band =20.1 mag & H-band = 19.8 mag
- Emission line sensitivity @1 hrs, S/N=5
  – J-band = $1.0*10^{-16}$ [erg/cm2/s]
  H-band = $0.9*10^{-16}$ [erg/cm2/s]

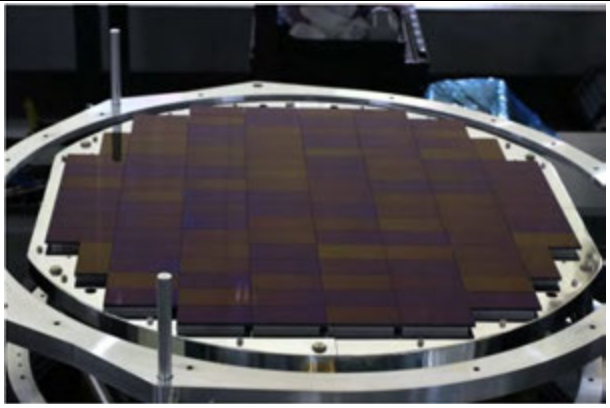
SuMIRe Project
--- HSC and PFS ---

History of HSC project

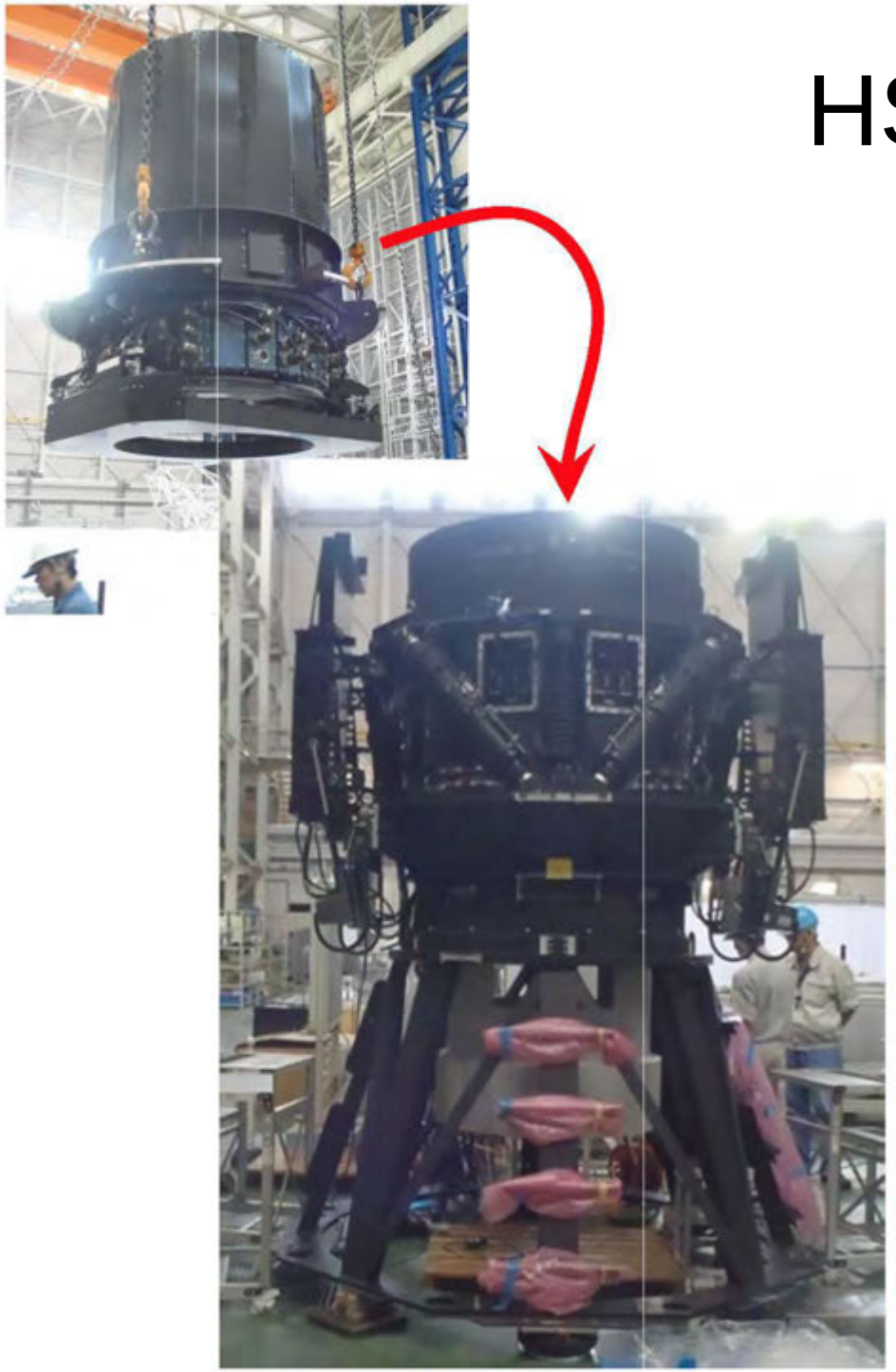
Year	Milestone, Progress	Budget, Organization	People	Org.
2002	Conceptual study of new lens	Subaru R&D (Miyazaki+)	3	1
2003~	CCD development, Mechanics concept study	Grants-in-Aid(Miyazaki+)	6	1
2005		ASIAA participation	10	2
2006~	CCD production, Lens, Mechanics detail design	Grants-in-Aid (Karoji+)	33	4
2007		Princeton participation	~40	5
2008		NAOJ Subaru HSC project established	~40	5
2009	Design Review		~40	5
2010~		Stimulus Package (Murayama+)	~40	5
2012	Lens and PFU completed Camera completed (?)		~40	5
2012 ?	First Light (planned)		~40	5

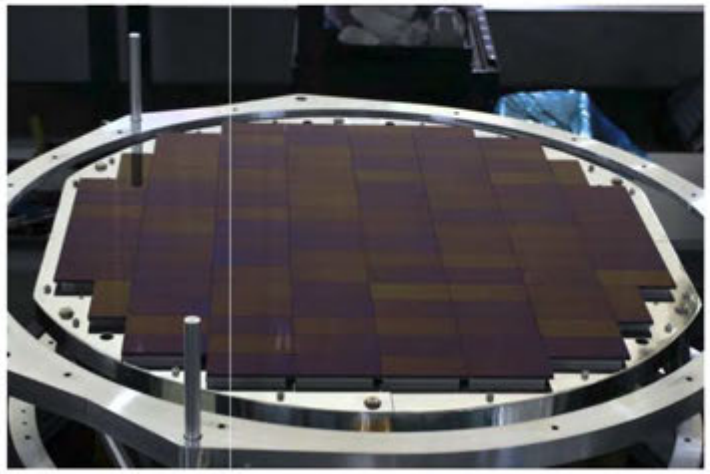
HSC

	Suprime-Cam	HSC
CCD Make and model	Hamamatsu S10892-01	Hamamatsu S10892-02
Number of CCDs	10	104 + AutoGuide4 + AutoFocus 8
Pixel	15 micron square (0.2 arc-sec)	15 micron square (0.17 arc-sec)
Field of	View34 arcmin x 27 arcmin	90 arcmin daiameter
Readout time	18 sec	20 sec
Number of filter	10	6
Filter exchange time	300 sec	600 sec (900sec while commissioning)

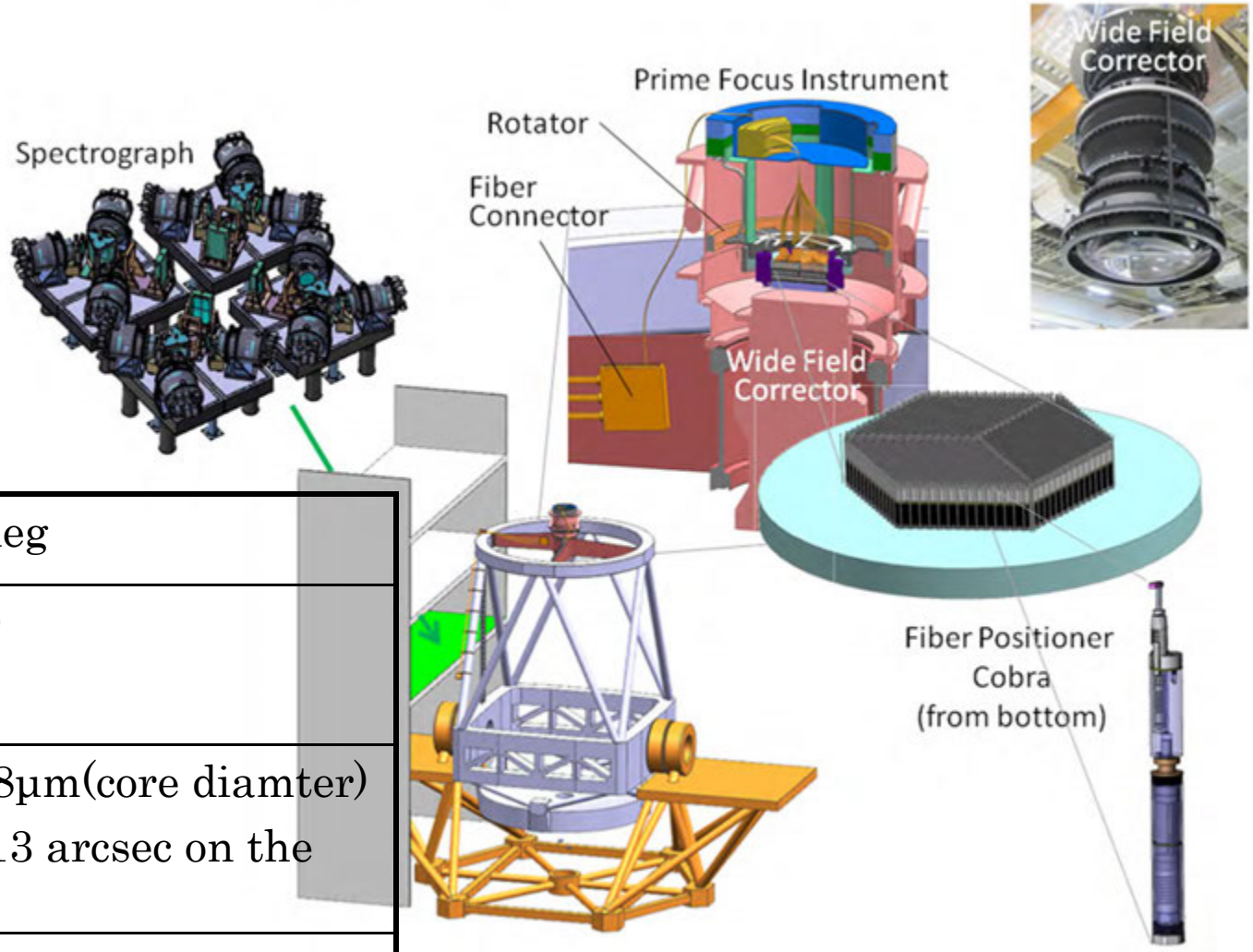


HSC



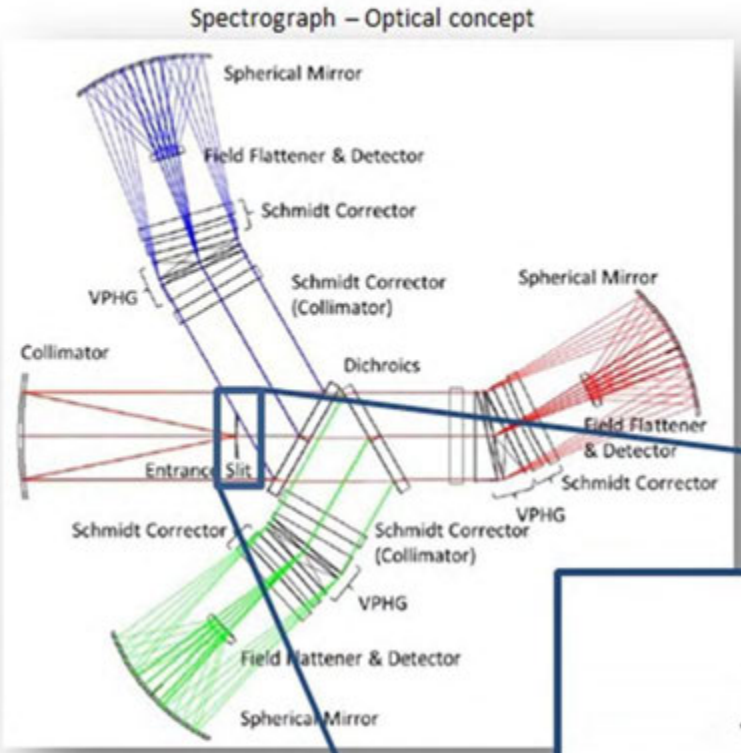


PFS

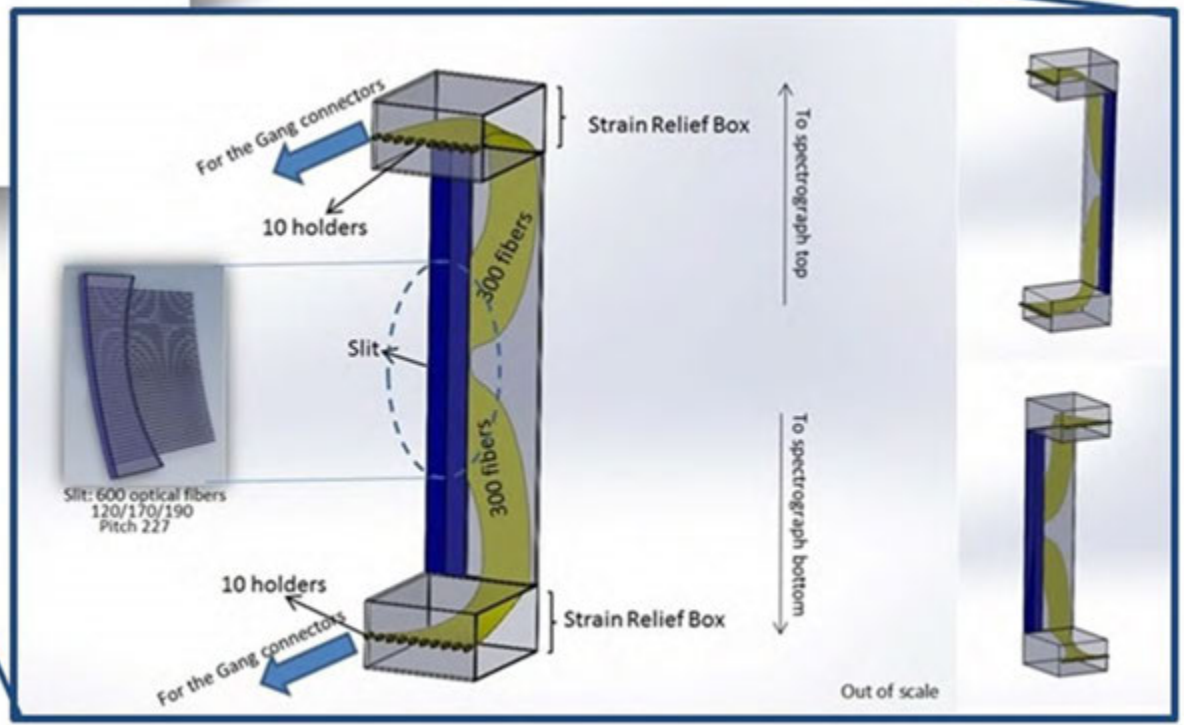


Field of View	1.3 deg
Number of fibres	2400
fibre	Φ128μm(core diamter) →1.13 arcsec on the sky
Spectrograph	3-arm design, 4 sets 0.38-1.3μm

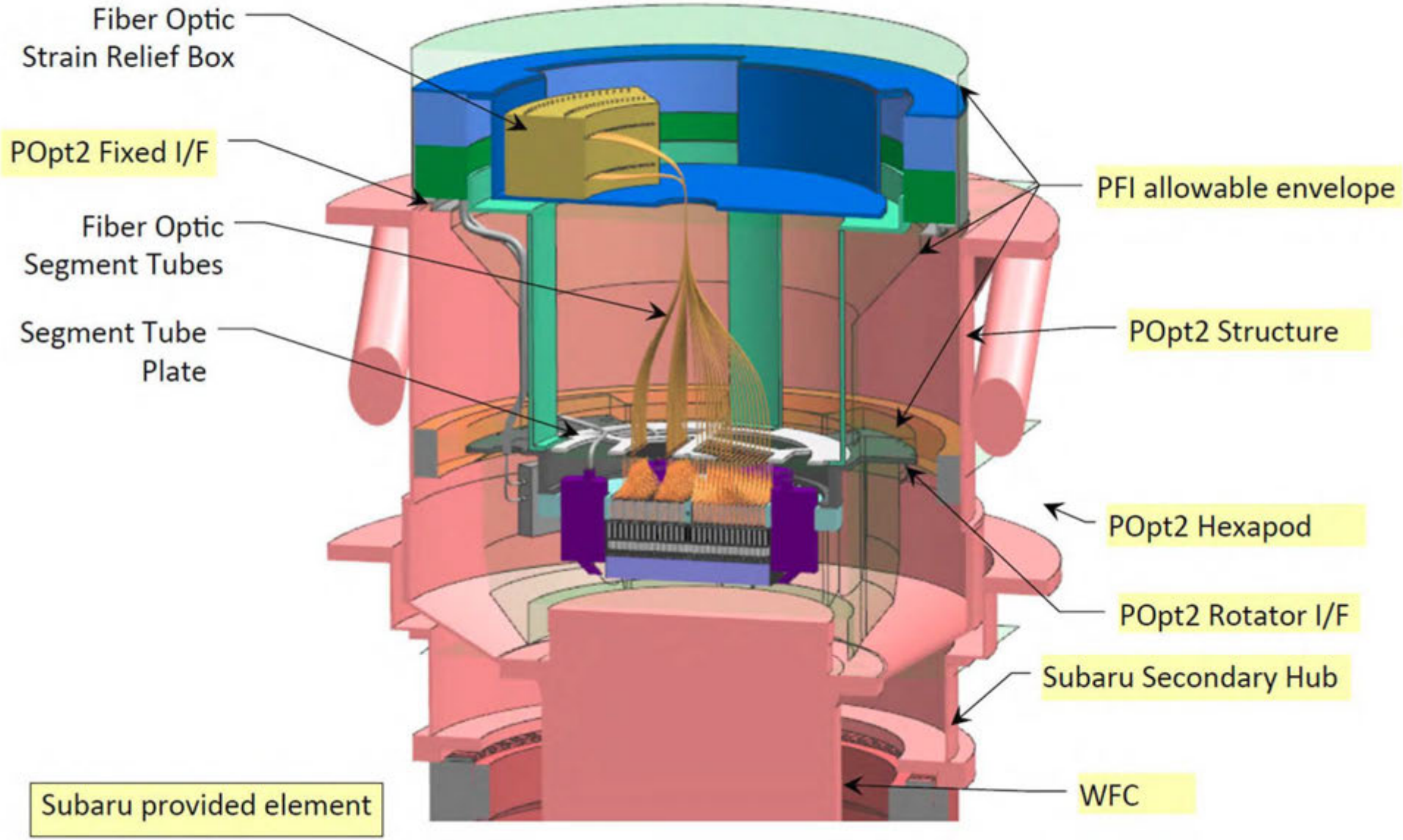
4-sets of Spectrograph



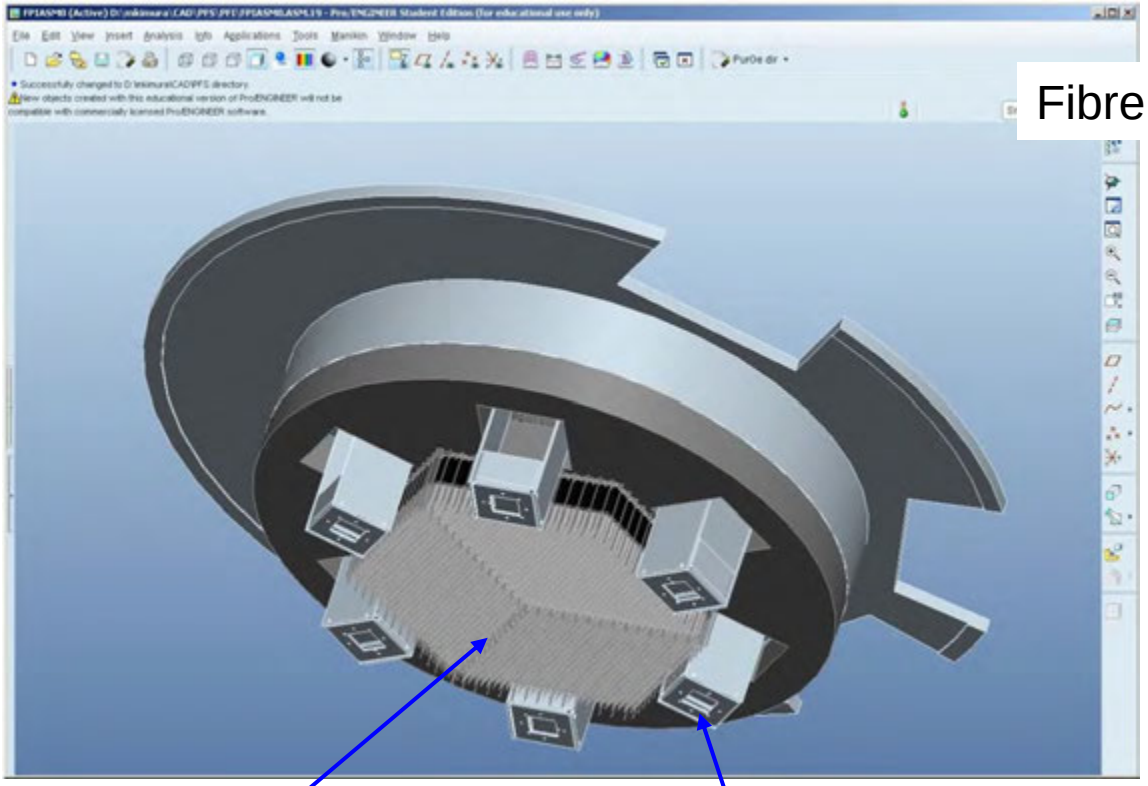
3-arm	Coverage [A],	Resolution [λ/Δλ] Field
Blue	3800-6700	2200
Red	6500-10000	3500
IR	9700-13000	4500



Prime focus instrument for PFS



Fibre Positioning system



2400 Cobra
Fibre positioners

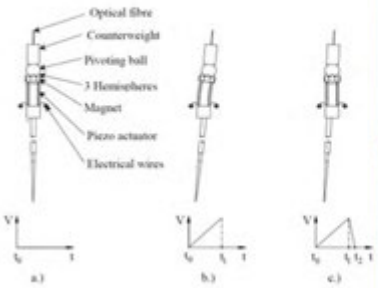
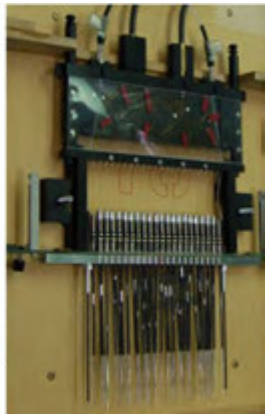
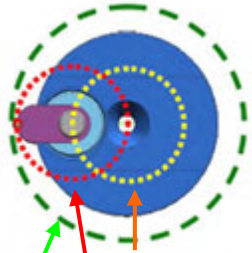
6 Auto guide
cameras

Fibre stage

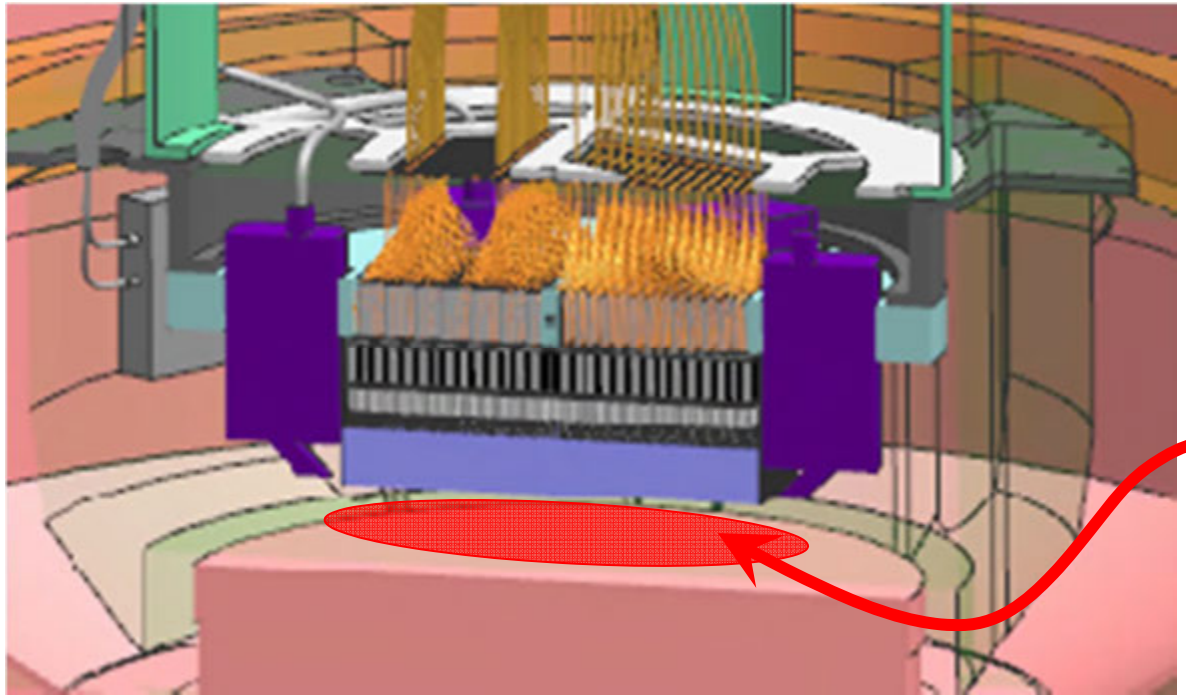
Fibre arm

http://www.newscaletech.com/app_notes/Cobra-JPL-article.html

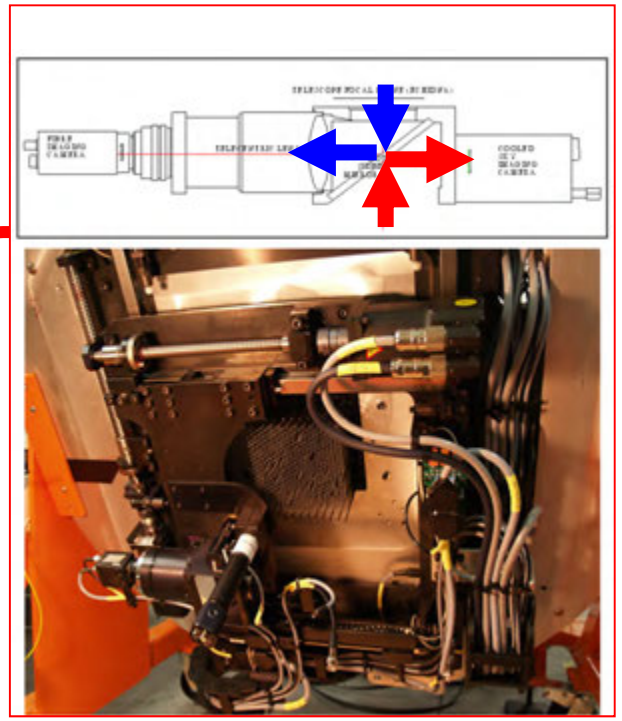
Fibre positioner

Instrument	FMOS	PFS
Nickname	Echidna (针鼹) 	COBRA (眼镜蛇) 
Type	Tubular piezo actuator	2-axis picomotor
Driving method	Tilt  	Rotation   
control	○	○
Twisted fibre	○	×
Defocus	×	○

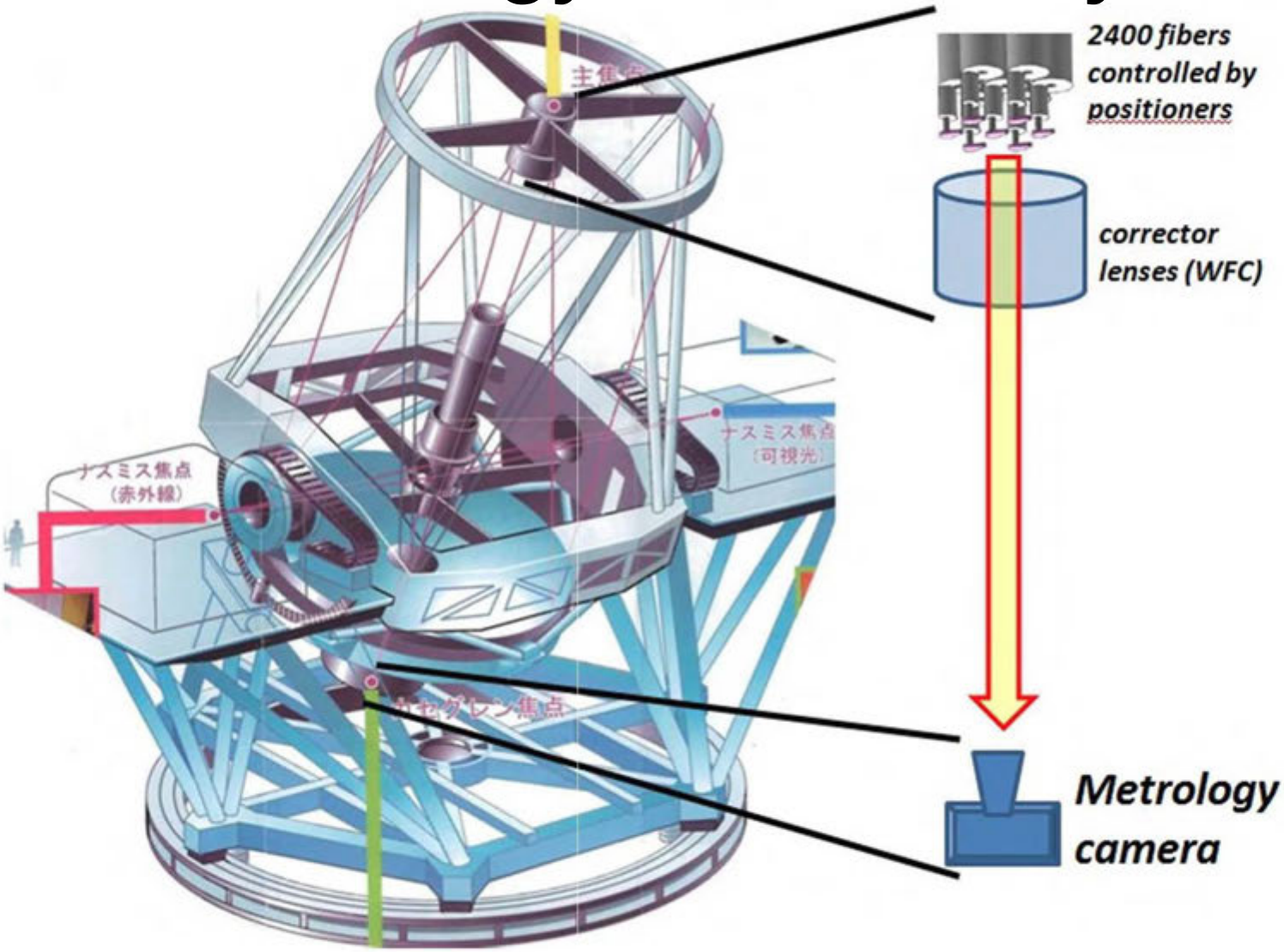
Measurement of the position and Auto guide



Not enough space

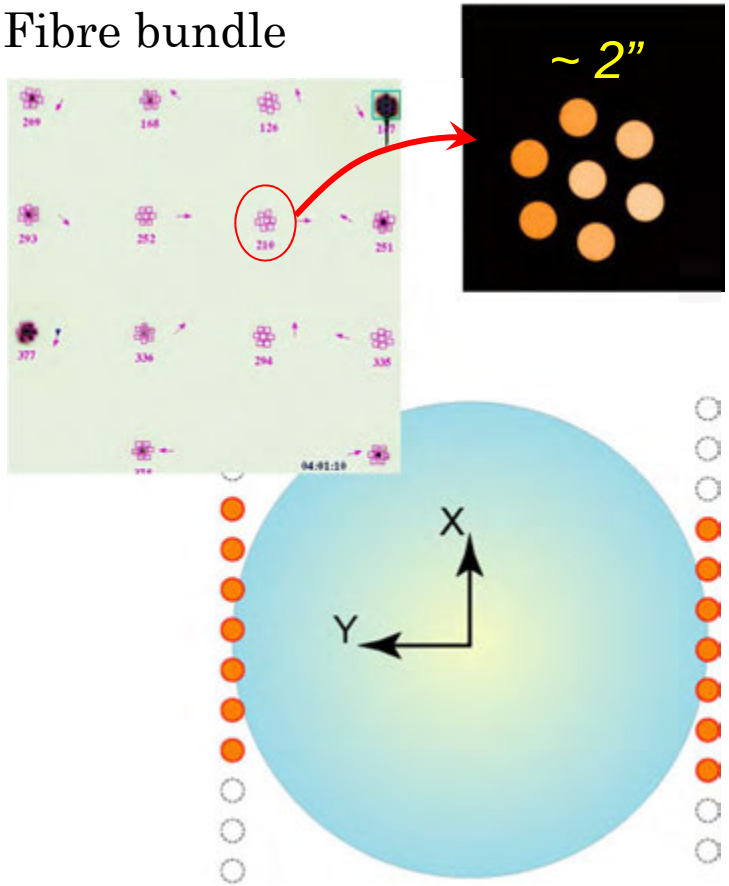
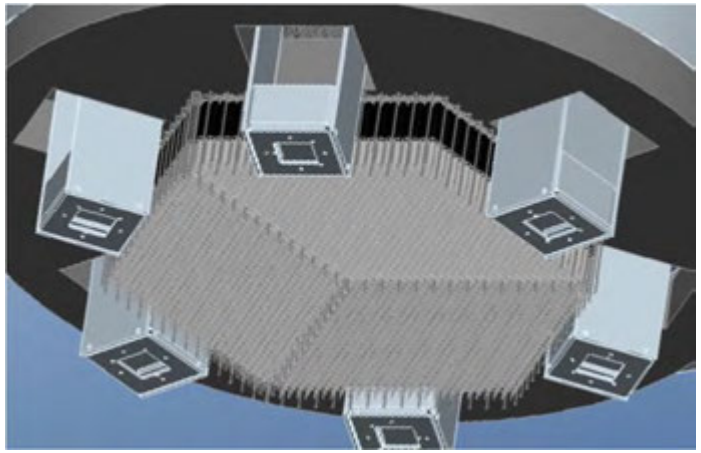


Metrology Camera System

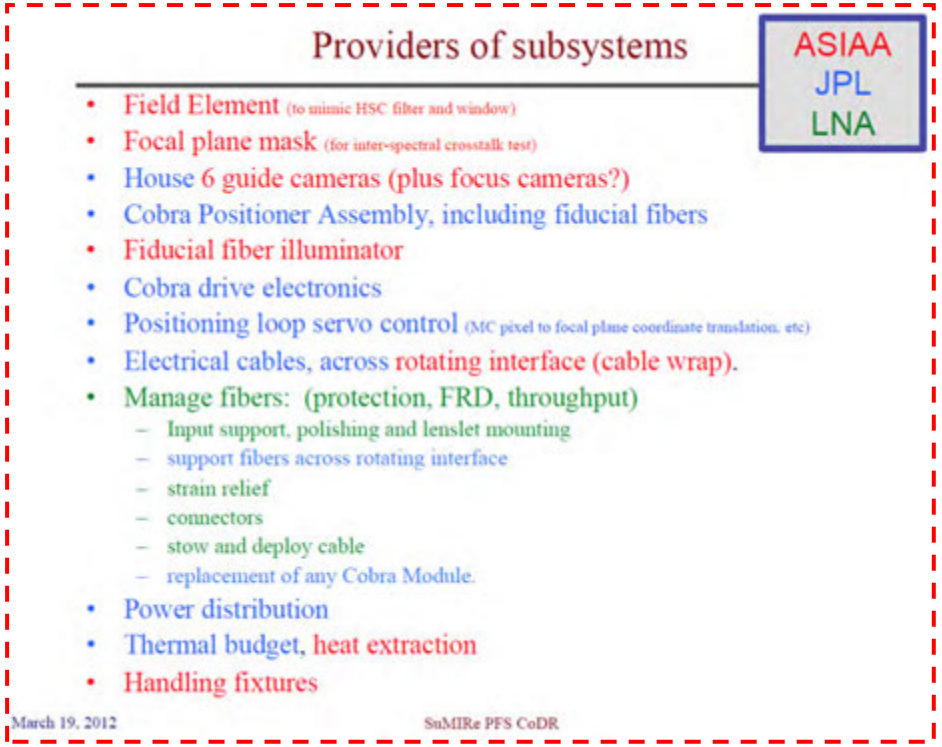


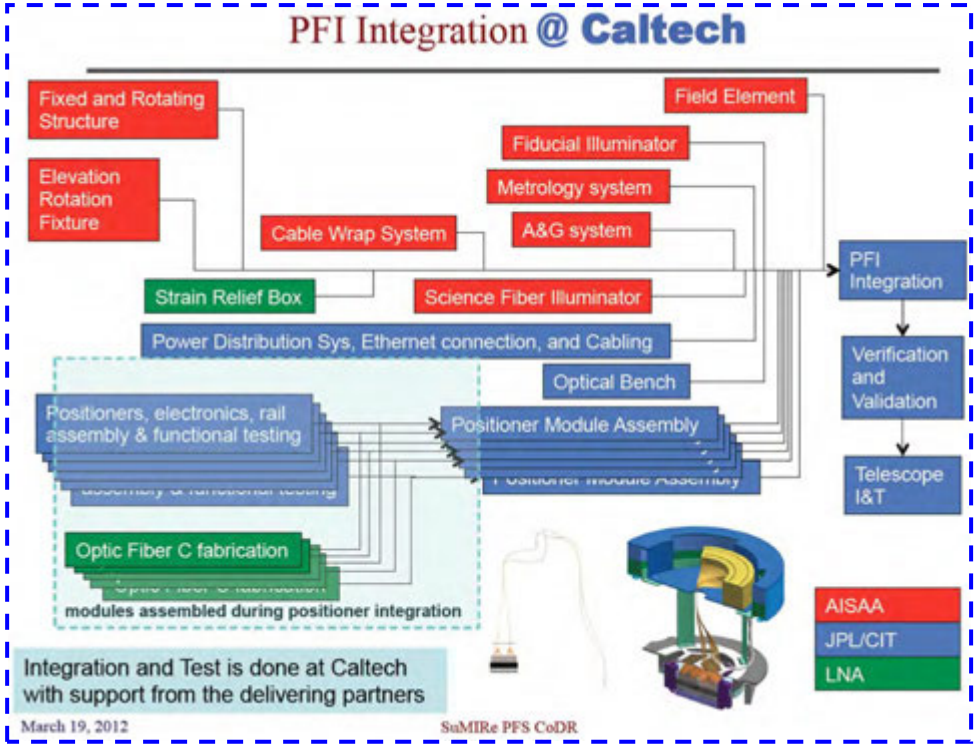
in-plane position of each fibre tip within an error of 5 μm
the centroid of all imaged fibre tips in less than 3s

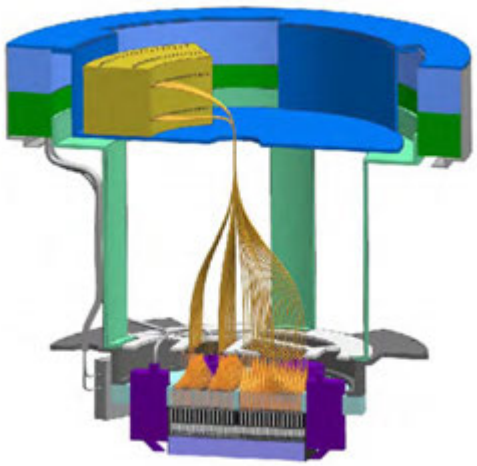
Auto guide

Instrument	FMOS	PFS
Type	Fibre bundle 	Direct image (CCD camera) 
merit	Small space	Direct image, known seeing condition, focal plane distortion

What to do in ASIAA?







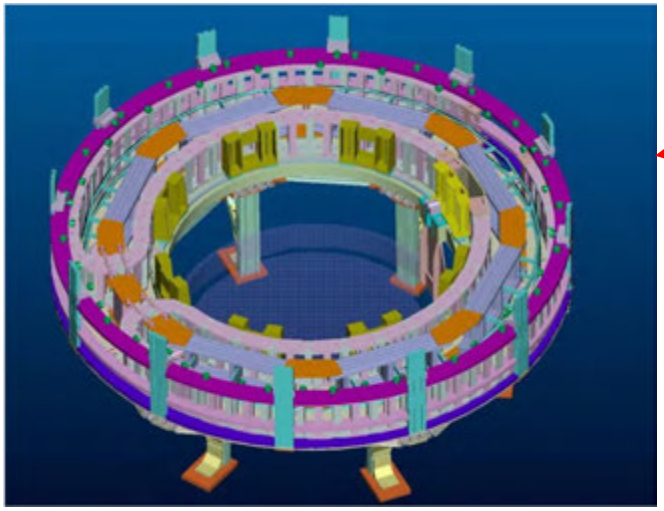
- Configuration, preliminary design and preliminary analysis will be by JPL
- Detailed design, analysis, fabrication, ***handling fixtures*** and test will by ASIAA

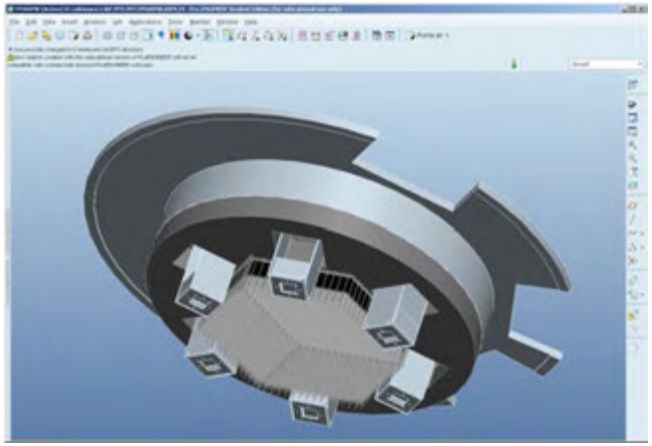
↓

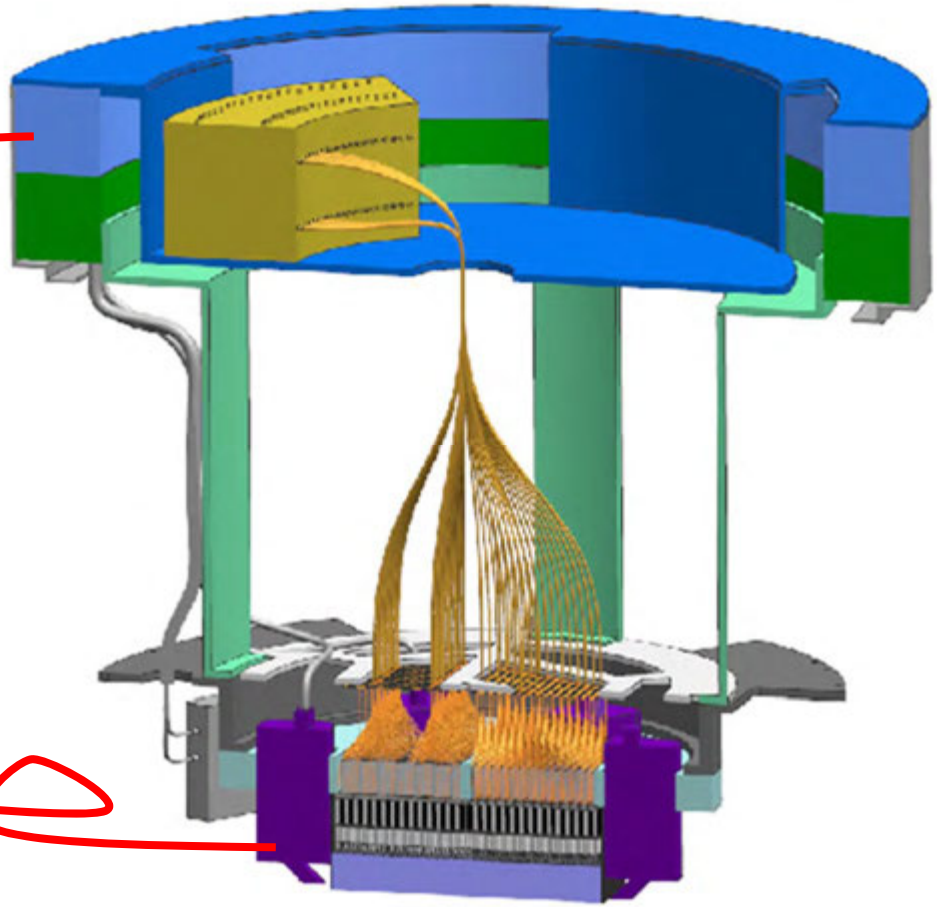
almost ALL!

Conclusion

- We start a realistic design for the prime focus instrument.







Question and answer

Question:

How do you suppress OH airglow lines?

Answer:

We use a mask mirror. The mask is made of a thin (0.2mm in thickness) stainless-steel plate at the positions of the strong OH-airglow lines, and blackened to absorb the OH light.

More detail:

- http://subarutelescope.org/Introduction/instrument/OHS.html
- "The Fibre Multi-Object Spectrograph (FMOS) for Subaru Telescope" Kimura, M., et al. 2010, PASJ, Vol. 62, 1135.

Question and answer

Question:

Number density?

Answer:

The targets are randomly scattered over the field. FMOS use 400 spine type fibres with 7mm pitch. So, the number density of spines is 0.57 / arcmin^2., which is suitable for objects like Extremely-Red Objects, Submm-bright sources, Lyman Break Galaxies, and so on.