Subaru fiber multi-object spectroscopy

~ Current & future instruments for large census in astronomy ~

Naoyuki TAMURA

Subaru Instrument Astronomer

(Subaru Telescope, NAOJ)

Talk outline

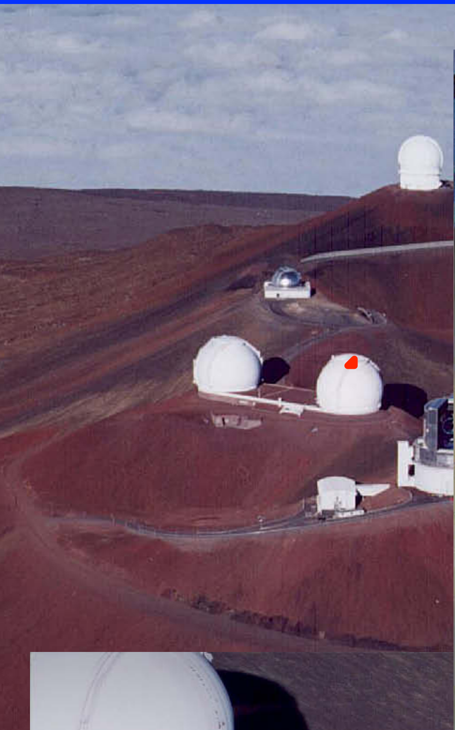
1. Introductions
   - Subaru telescope
   - “Instrument Astronomer” in the Subaru operation
   - Personal history & research interests

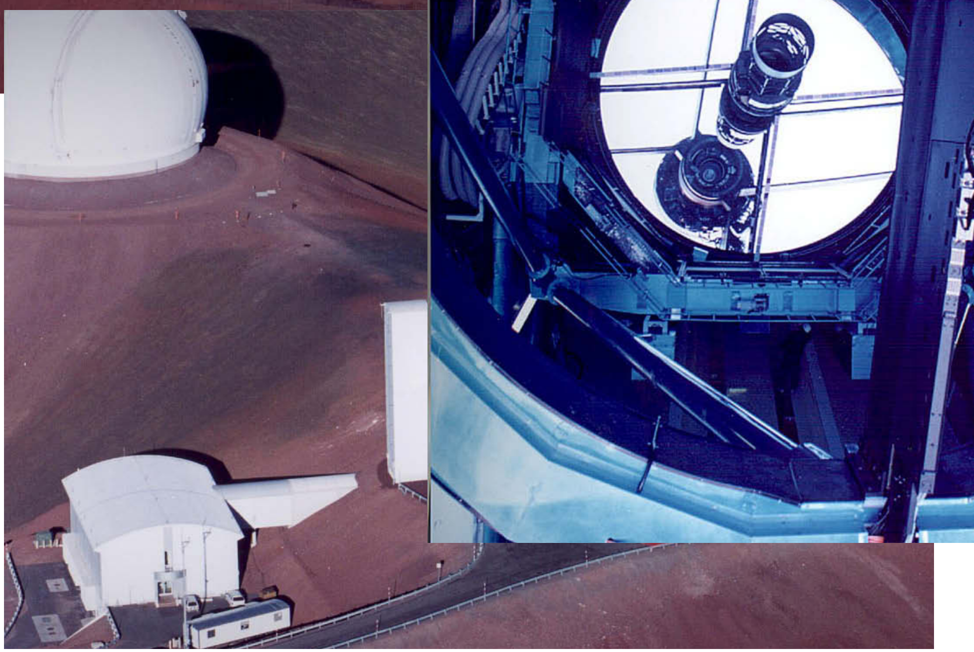
2. Subaru “FMOS” (Fiber Multi Object Spectrograph)
   - Background
   - Instrument overview & highlighting subsystems
     [Fiber positioner, fiber system, spectrograph & camera]
   - Data example
   - On-going & future programs

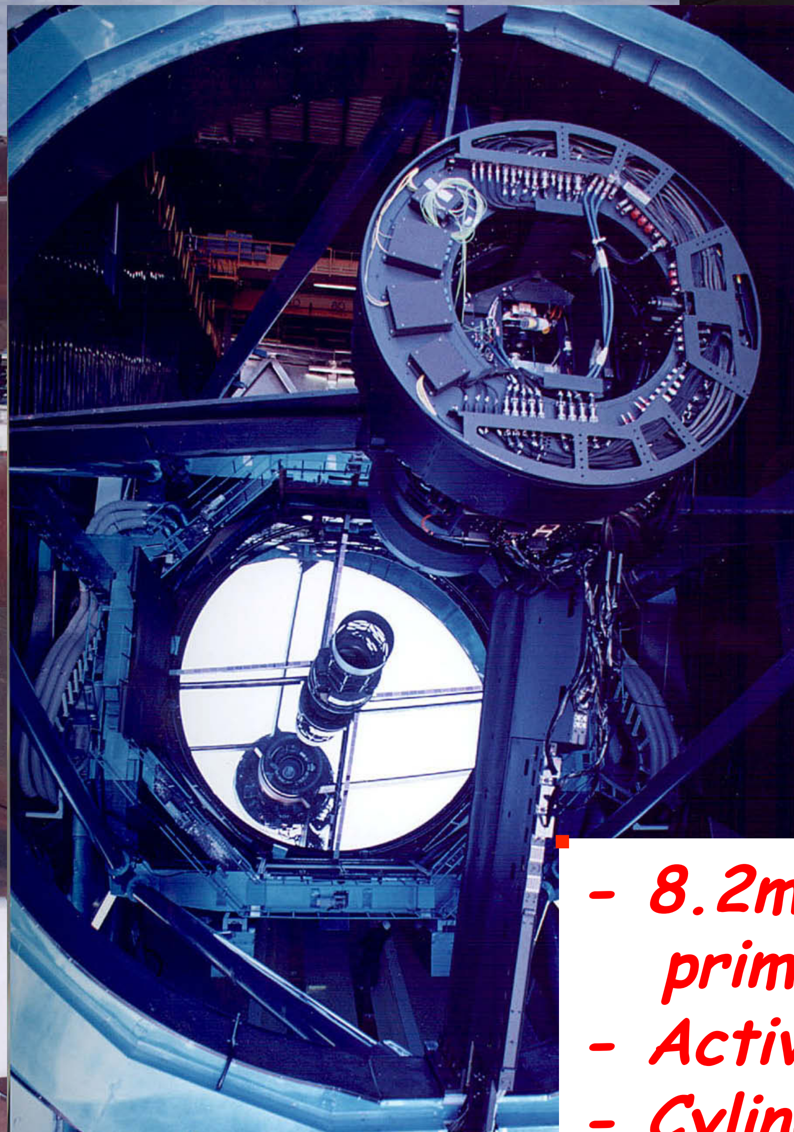
3. Future instruments
   - SuMIRe/PFS – A new challenge centered by IPMU.
   - SuFAIFS – Flexibly addressable integral field spectrograph

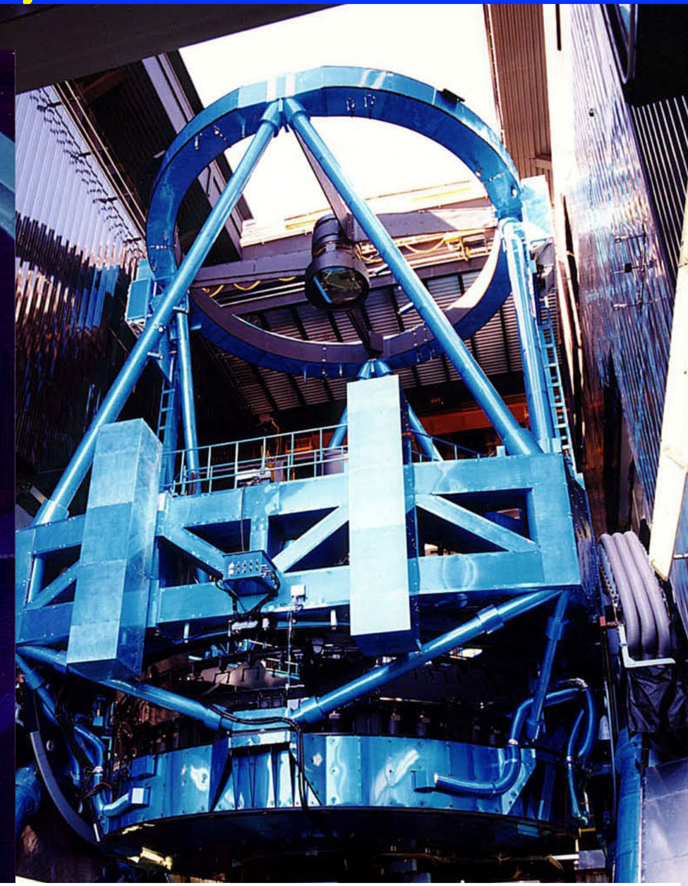
4. Summary & some remarks on future

Subaru Telescope









- 8.2m diameter monolithic primary mirror
- Active mirror support
- Cylindrical enclosure
- In operation for ~13 yrs

Subaru colleagues

Hilo base

Summit

~ 100 staffs

(~ 60% are Japanese)

Subaru instrument operation

SA Suprime-Cam

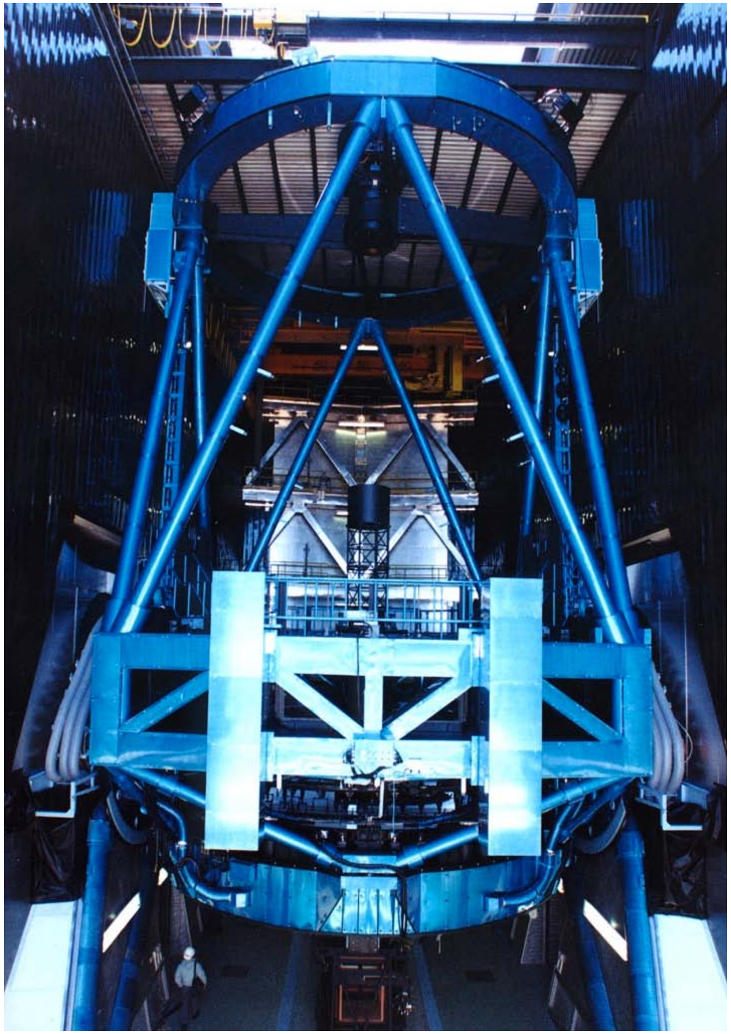
Prime focus

FMOS

1st gen

2nd gen

Visiting



"IR"-side Nasmyth

SA IRCS

HiCIAO

LGS

SA AO188

"Opt"-side Nasmyth

HDS SA

Decommissioned

CIAO

OHS/CISCO

AO36

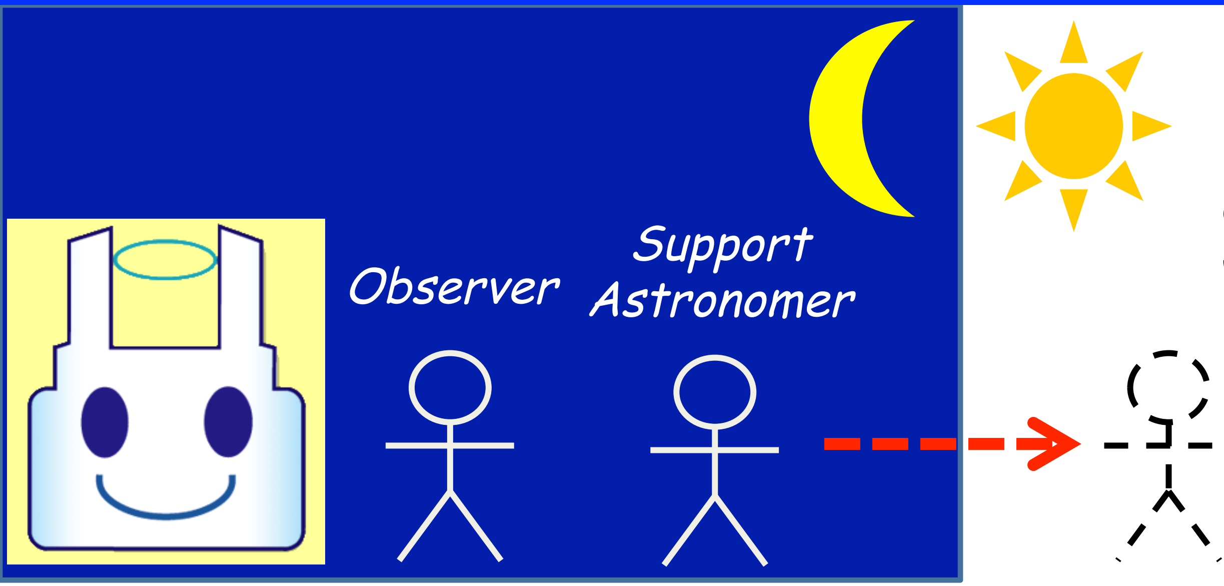
SA SA Cassegrain focus SA

FOCAS COMICS MOIRCS K3D-II

Subaru instrument operation

Earlier ...

S. A. was the only expert of the instrument, so had to work day & night if needed ...

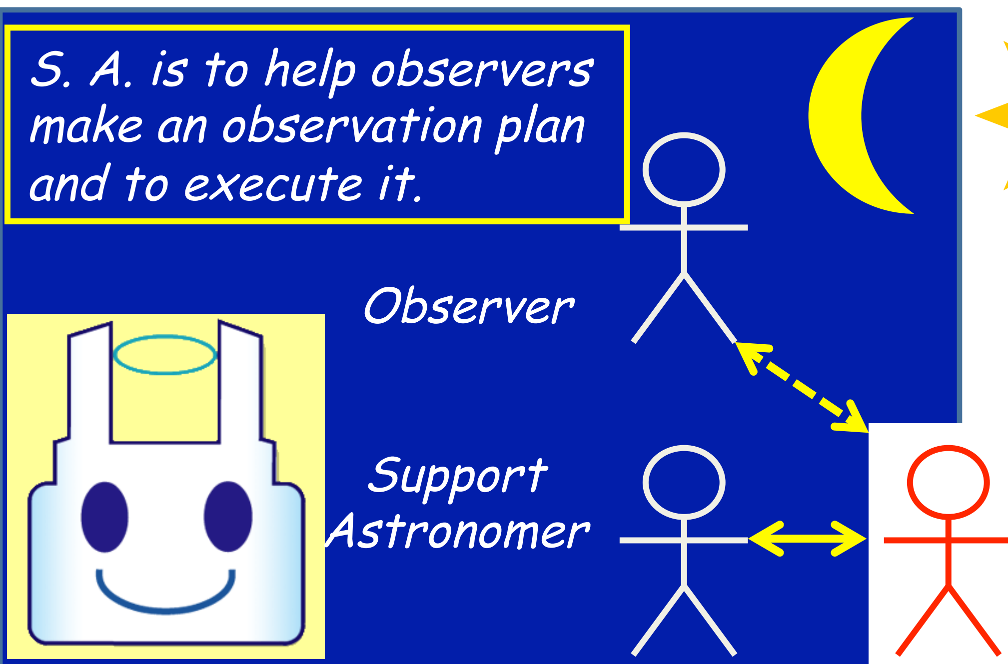


Engineers

Technicians

Recently ...

I. A. is an interface between day & night, in charge of commissioning, stabilization, instrument setup for obs, trouble shooting, upgrade, etc.



Instrument Astronomer	Instrument Group

Telescope division

Personal history & research interests

1997-2002: Graduate School of Science, Kyoto University, Japan
[Supervisor: Prof. K. Ohta]

- Doctoral thesis titled: "Origin of color gradients in elliptical galaxies and implications for formation processes"

Tamura+ 00,Tamura & Ohta01,03,04

- *Started being interested in spectroscopic follow-up of faint red galaxies (e.g. ERO) and joined the FMOS development team [PI: Prof. Maihara in Kyoto]*
  (Optical design of WFC & IRS, measurements of optical fibers characteristics)

2002-2005: Durham University, UK

"fibre" "fiber"

[Main collaborators: R. Sharples, J. Allington-Smith, G. Murray]

- *Development of fiber system for Subaru FMOS*
- *Cryogenic test of Volume Phase Holographic (VPH) grating*
- Globular cluster populations in luminous elliptical galaxies
- FMOS feasibility study, development of spectrum simulator
- Planning high-redshift (z=1-3) galaxy surveys for FMOS GTO & SSP

Tamura+ 03,05,06

Tamura+ 06a,b

2005/12- Present: Subaru Telescope, NAOJ

- *FMOS integration, commissioning & stabilization* (working on high-z galaxies, globular clusters, VP

A few papers in prep …

History of FMOS development

- 1996?: Project started.
- 1997: Tamura joined the project.

  …

- Dec 2005: Tamura moved to Subaru.

- Late 2005: Delivery & integration started.
- Late 2006: Echidna commissioning started.
- Nov 2007: Fiber cables installed on the telescope.
- Dec 2007: Engineering observation started.
- May 2008: Engineering first light.
- Mar 2009: Performance verification started.
- May 2010: Open use started (IRS1 LR only).
- Feb 2011: IRS2 LR has joined open use.
- ~~Sep 2011: IRS1 HR has become available.~~ *Due to mechanical trouble*
- Feb-Mar 2012: IRS1 & IRS2 HR will join.

"Multi-phase" epoch in 2009-2011

"Commissioning"

- Performance verification and instrument optimization
- IRS2 & High Res. mode

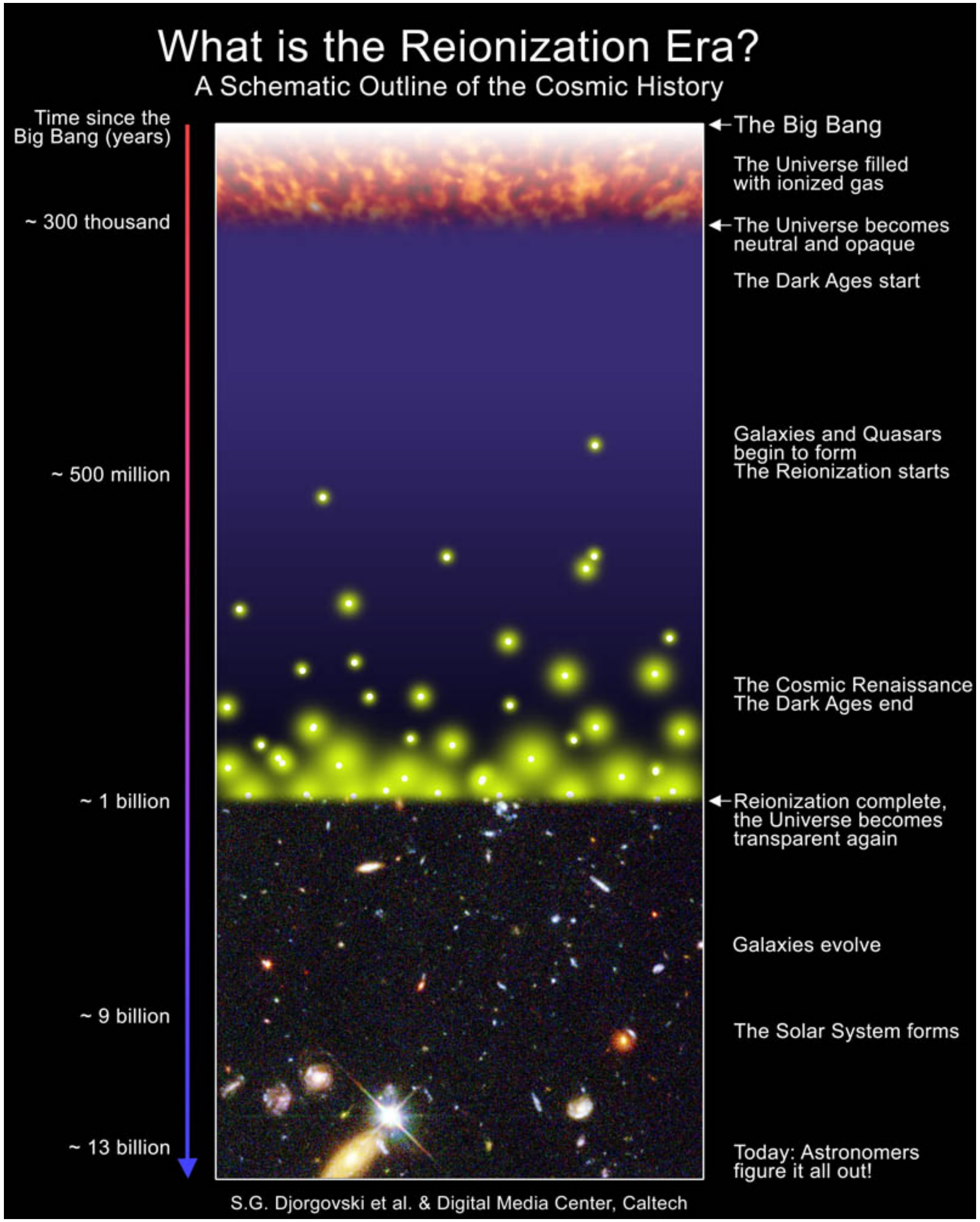
"Operation" (Open use & GTO from S10A)

- User support (day & night)
- Support of support astronomer

"Stabilization"

- Trouble shooting & maintenance
- Clean-up
- Upgrade of hardware & software

Galaxy evolution: A motivation for FMOS



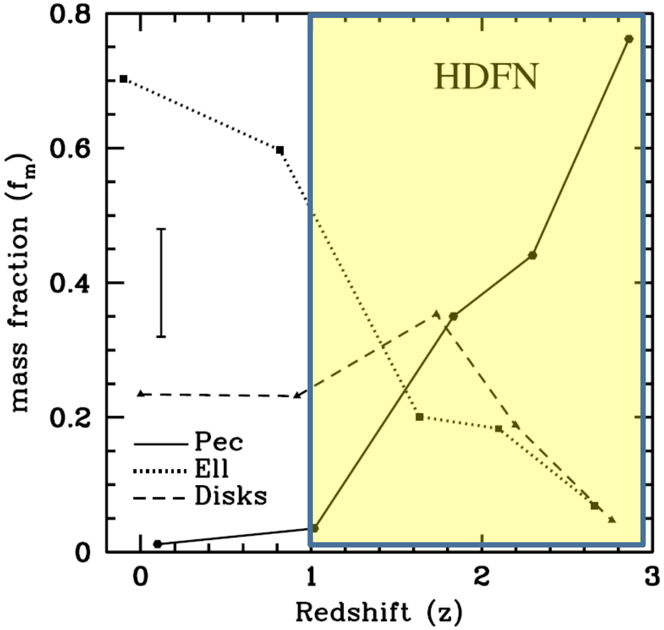
Galaxy evolution can be investigated by studying the “statistical” properties of galaxies as a function of time.

Spectroscopy is essential not only to locate galaxies in the redshift (= time) space but also characterize them.

Star-forming activity, AGN activity, abundance, dust, stellar age, etc

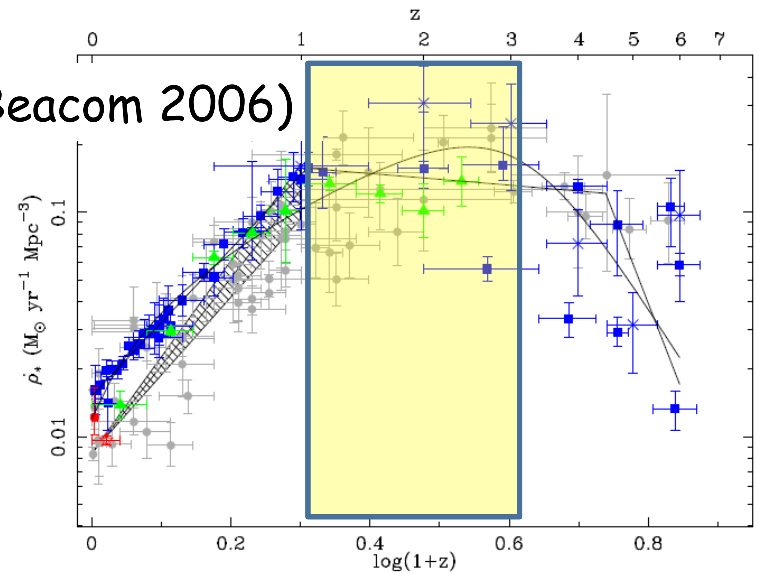
Access to z>1 is important.

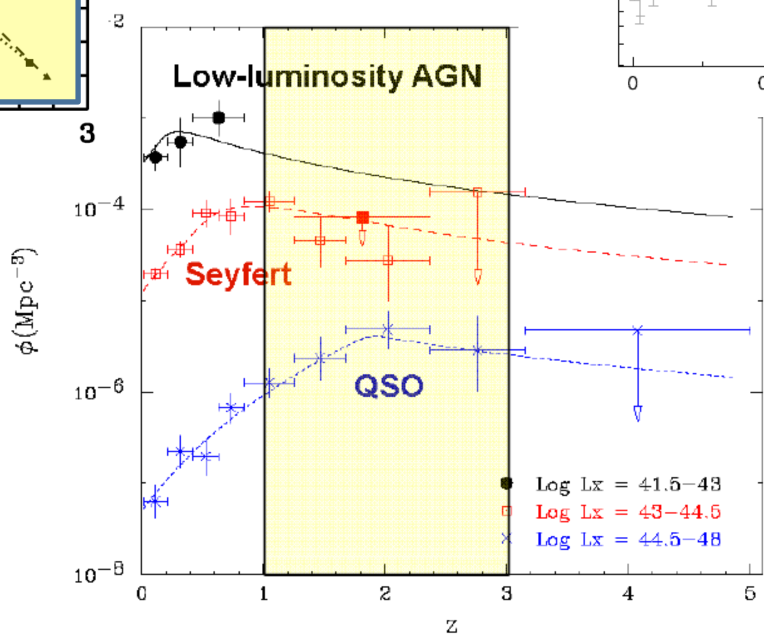
Properties of galaxies & AGNs are found “different” at high redshift in various aspects, especially at 1<z, from those at z=0.



(Conselice et al. 2003)

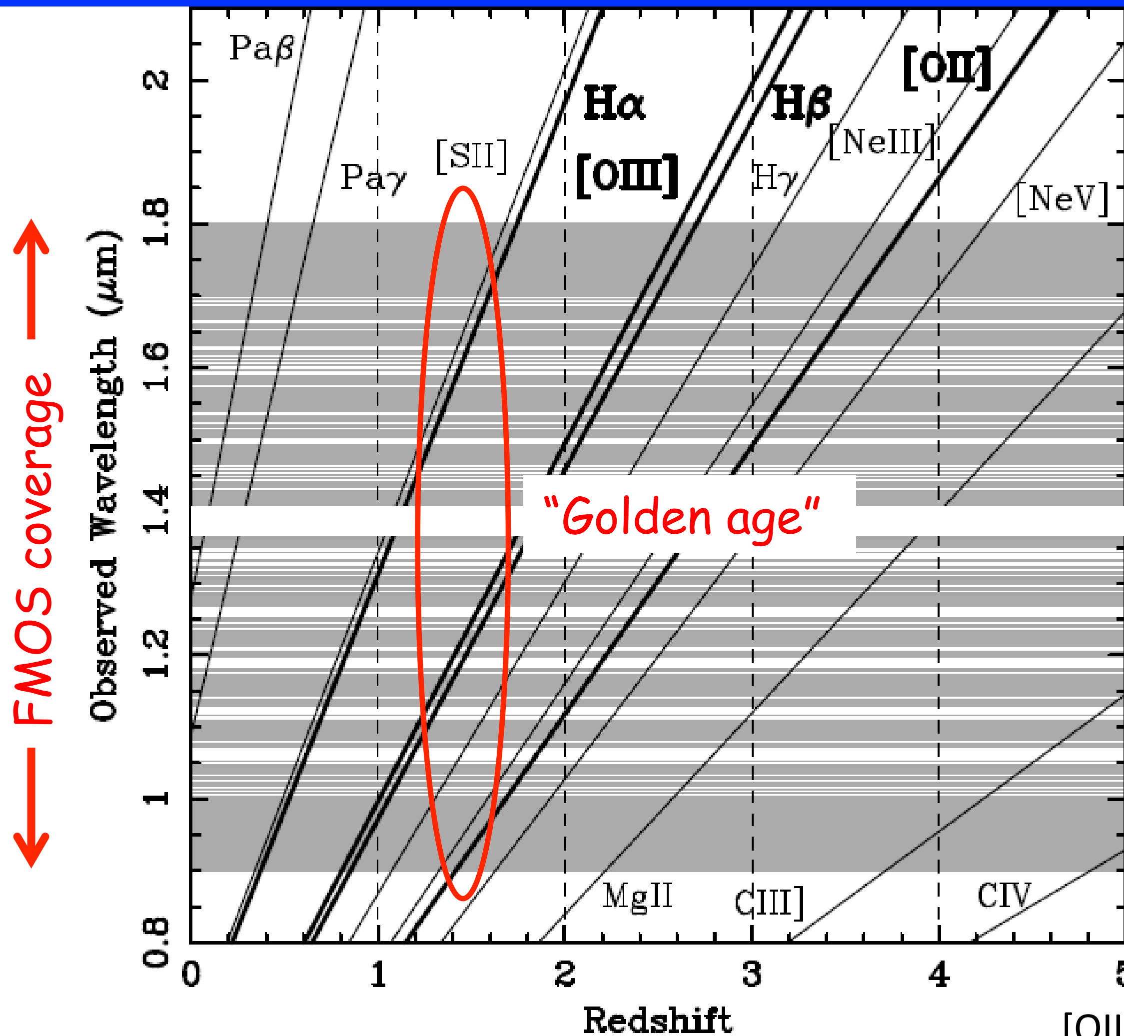
(Hopkins & Beacom 2006)





(Ueda et al. 2003)

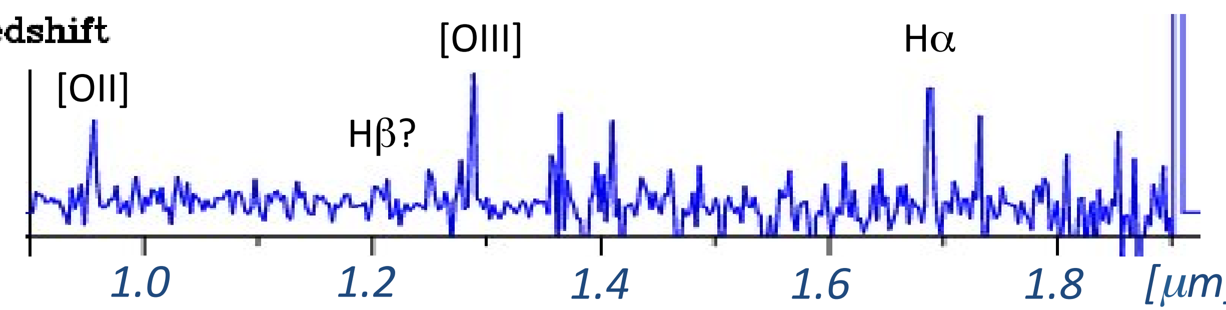
FMOS to scrutinize galaxies & AGN at z>1



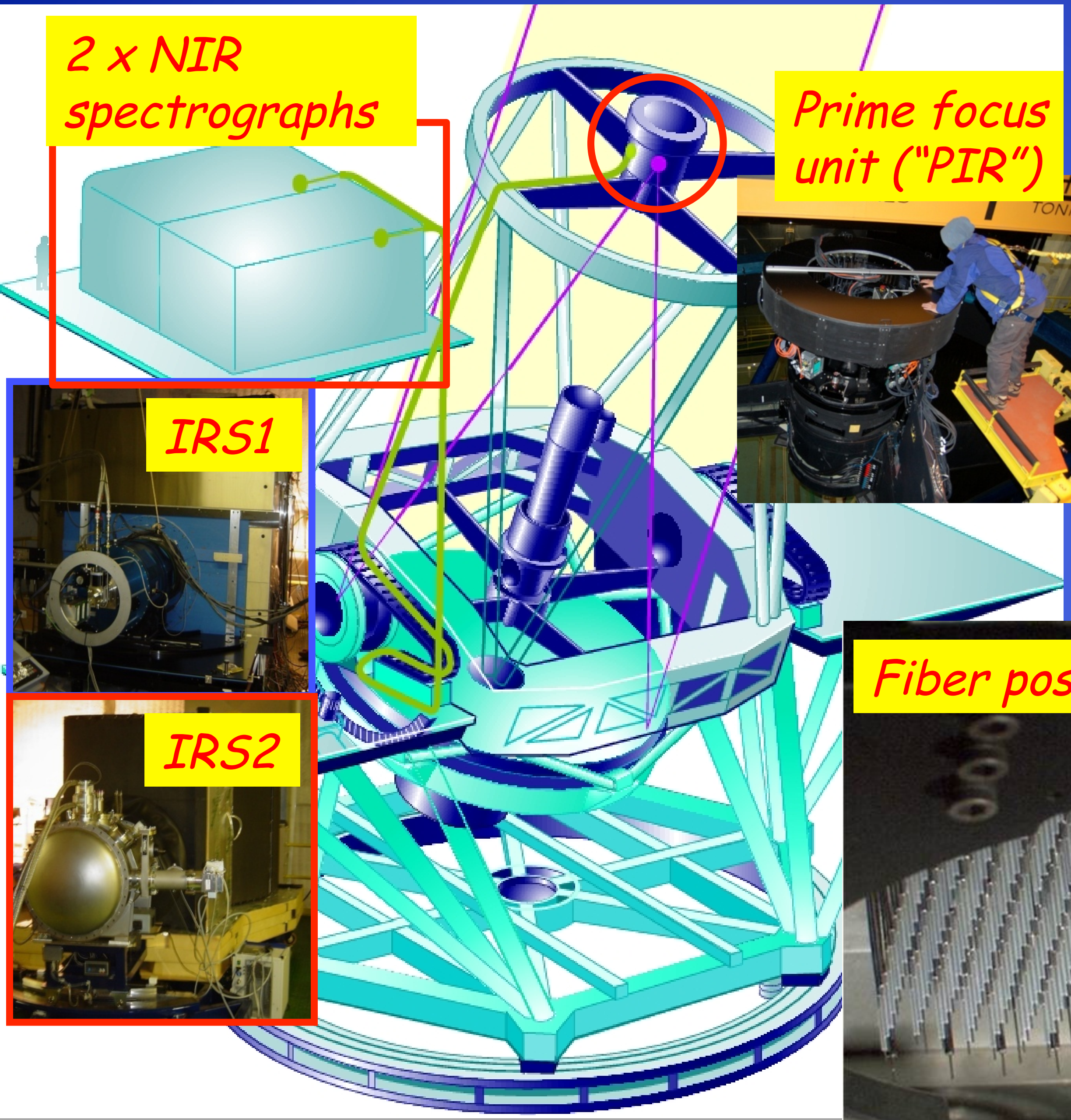
NIR spectroscopy is important to observe redshifted rest-frame optical spectral features.

High multiplicity & wide-field of view are keys to enhance observing efficiency, achieve good statistics, & study cosmic variance & environmental effects on galaxies.

sBzK, K=19.5, z(spec) = 1.54 by Subaru/MOIRCS zJ500 (Tamura+ in prep)



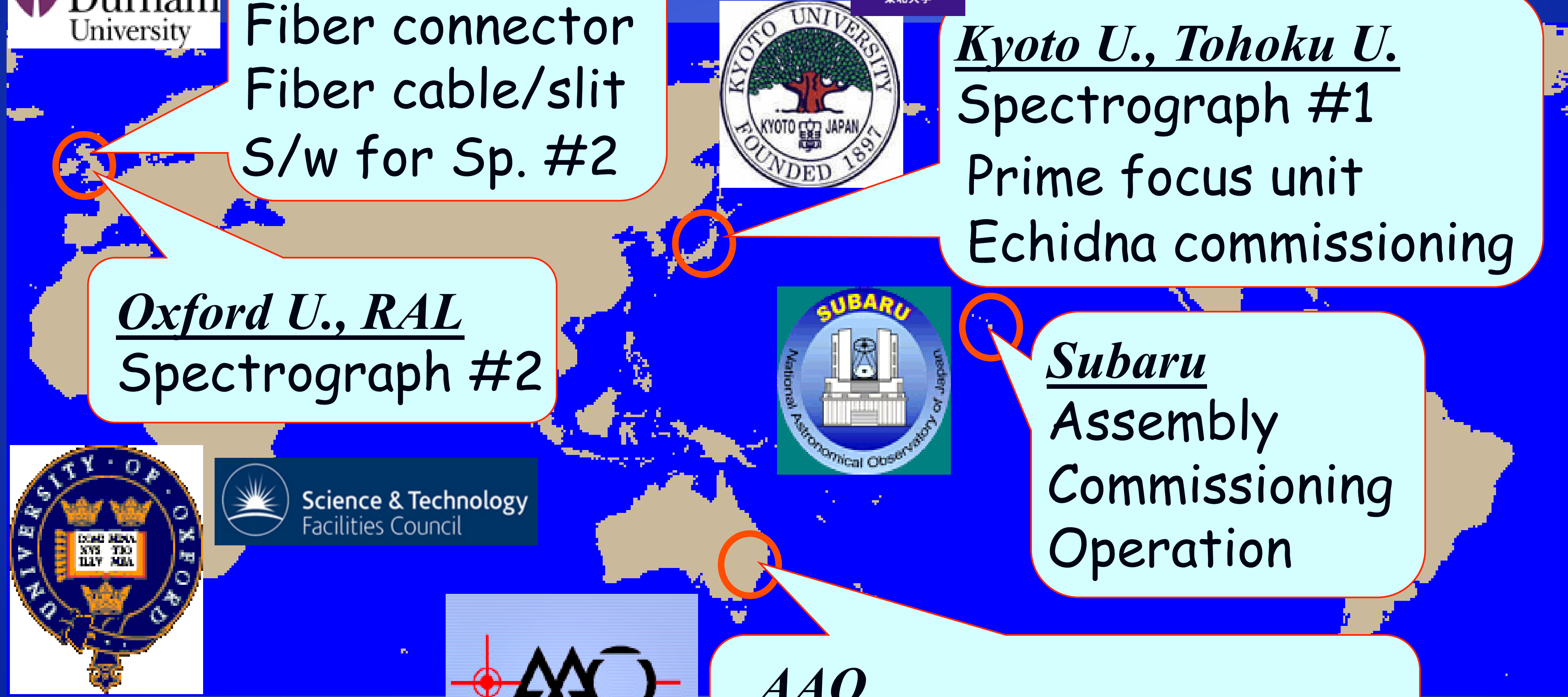
"*FMOS*": Fiber Multi Object Spectrograph



- ★ Subaru M1 8.2m
- ★ 400 fibers in the 30′ diameter FoV
- ★ NIR (0.9-1.8μm) spectroscopy

Unique combination as a multi-object spectrograph

International collaboration to FMOS



Durham U.
Fiber connector
Fiber cable/slit
S/w for Sp. #2

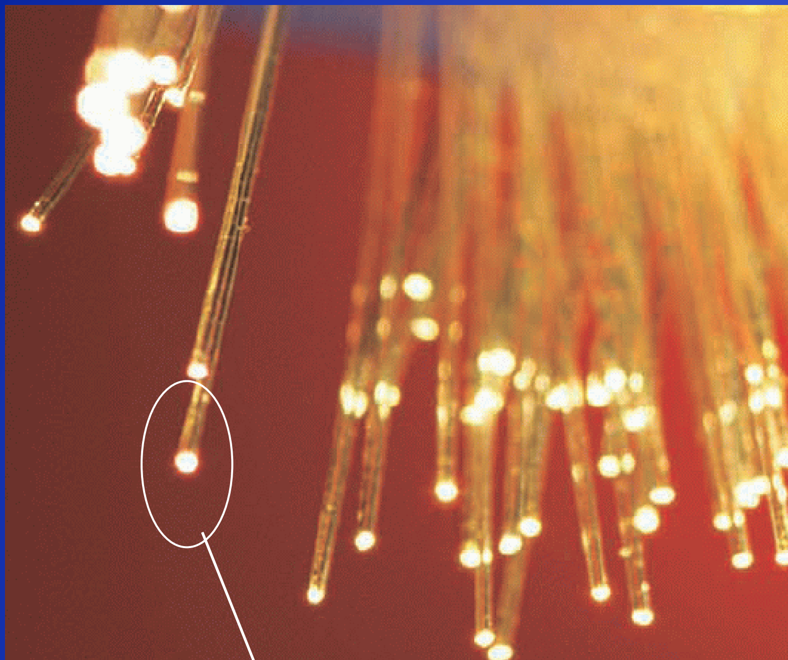
Kyoto U., Tohoku U.
Spectrograph #1
Prime focus unit
Echidna commissioning

Oxford U., RAL
Spectrograph #2

Subaru
Assembly
Commissioning
Operation

AAO
Fiber positioner "Echidna"
Wide-field corrector

Fiber spectroscopy



Position fiber tips on objects & feed them to spectrographs.

Light travels in a fiber with a high throughput.

Flexibility to spectrograph design is significantly increased.

Fiber positioner "*Echidna*"

↑ Echidna unit on the test jig on the "TUE" floor in the telescope dome where top units stand by.

- Designed, developed & manufactured by AAO.

- Shipped to Hilo in 2007.

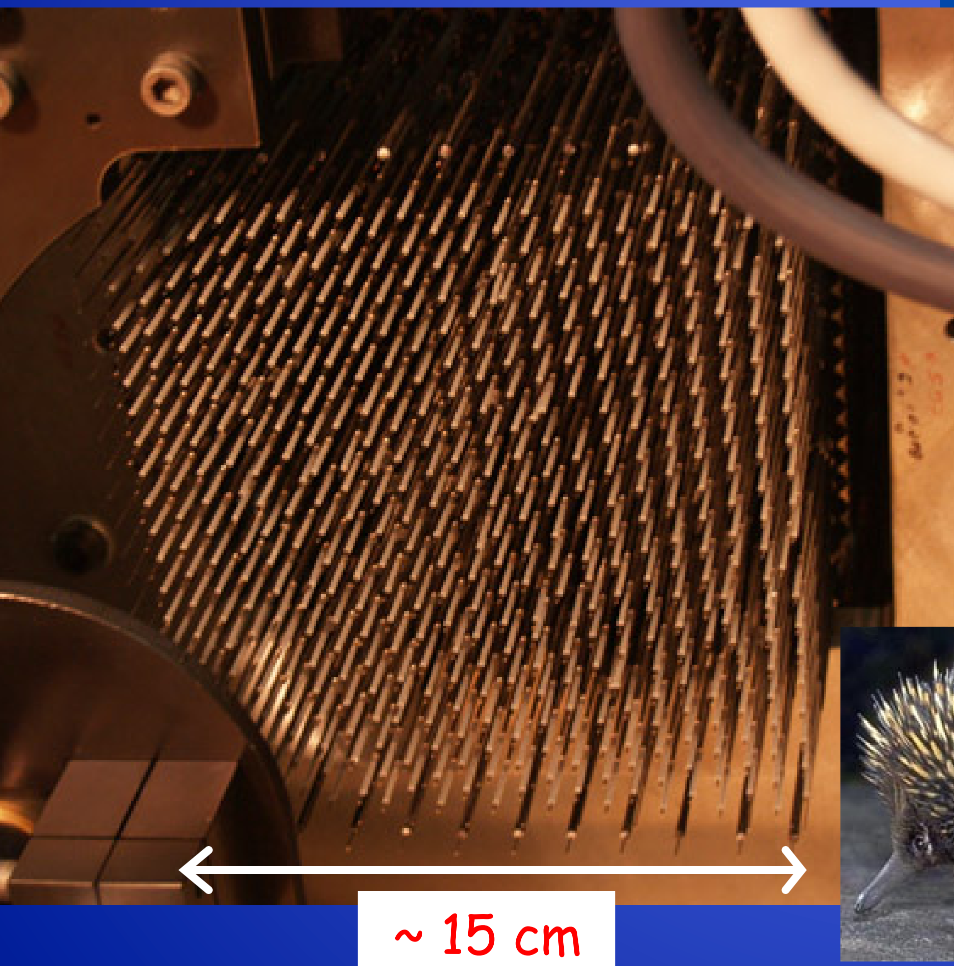
- After reassembled and tested, transferred to the summit.

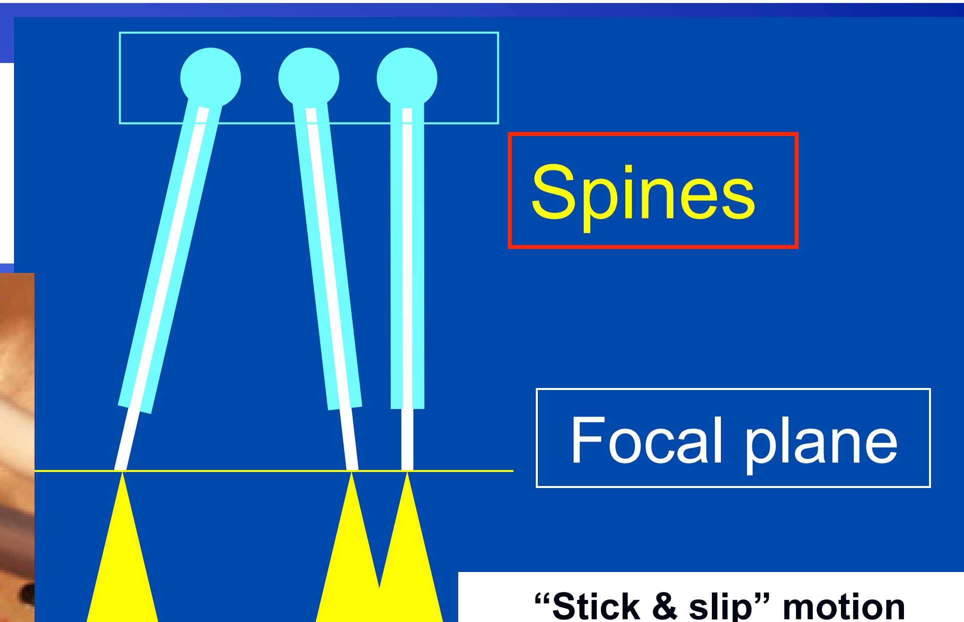
Ref.
- Akiyama et al. (2008, SPIE, Vol. 7018, p. 26)
- Brzeski et al. (2004, SPIE, Vol. 5492, p. 1228)

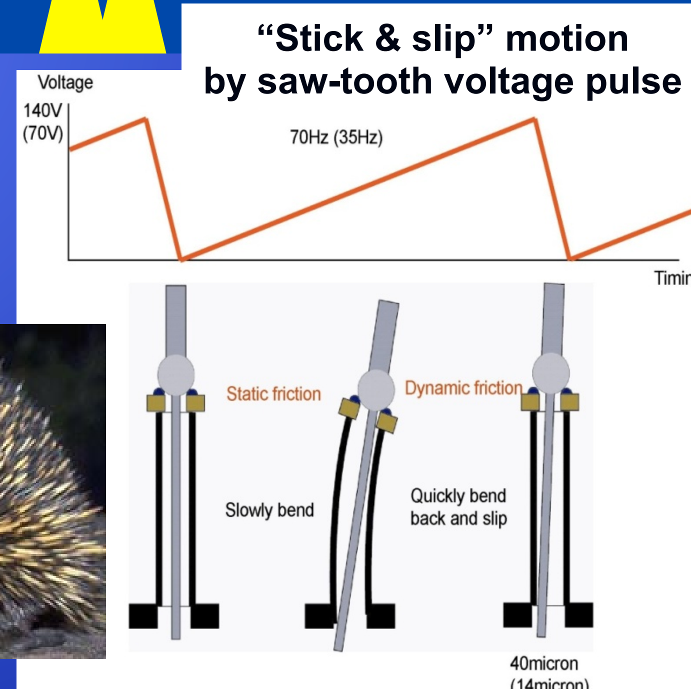
... etc

Fiber positioner "*Echidna*"

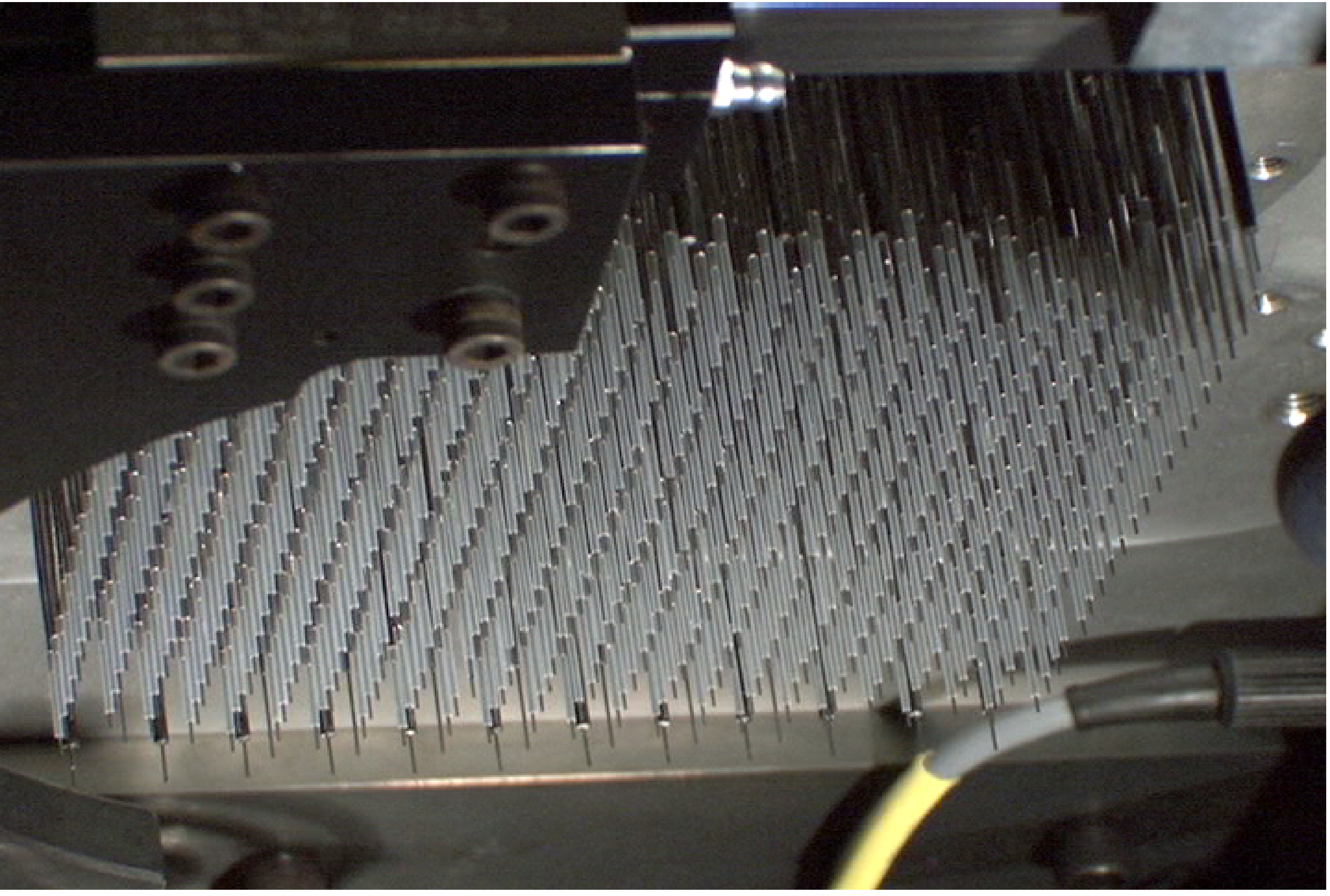
400 fibers
in the 30'φ FoV







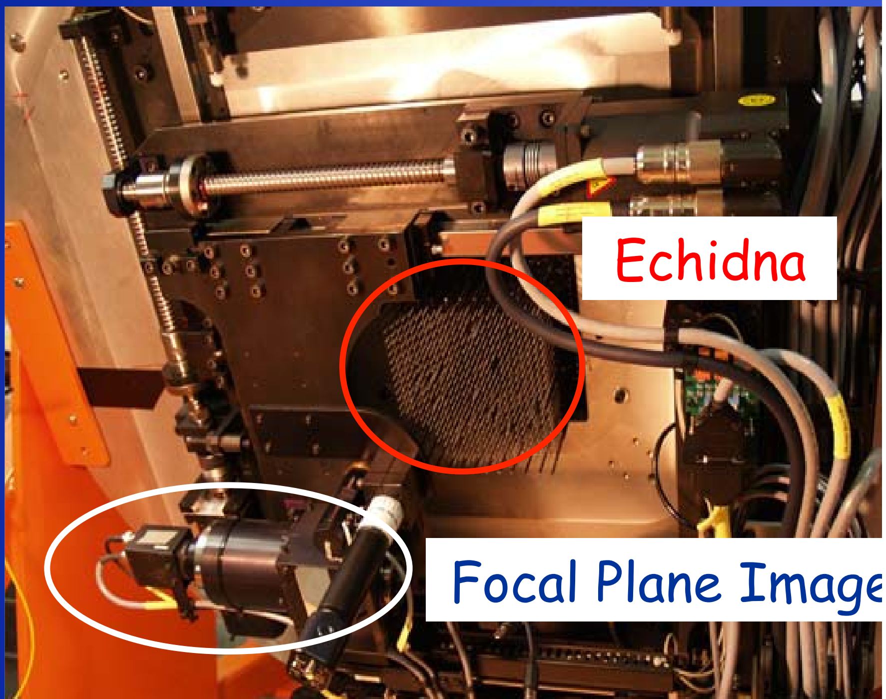
Fiber positioning

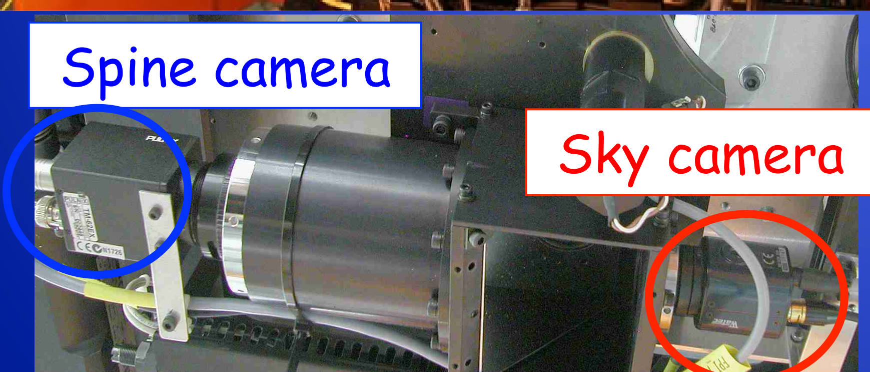


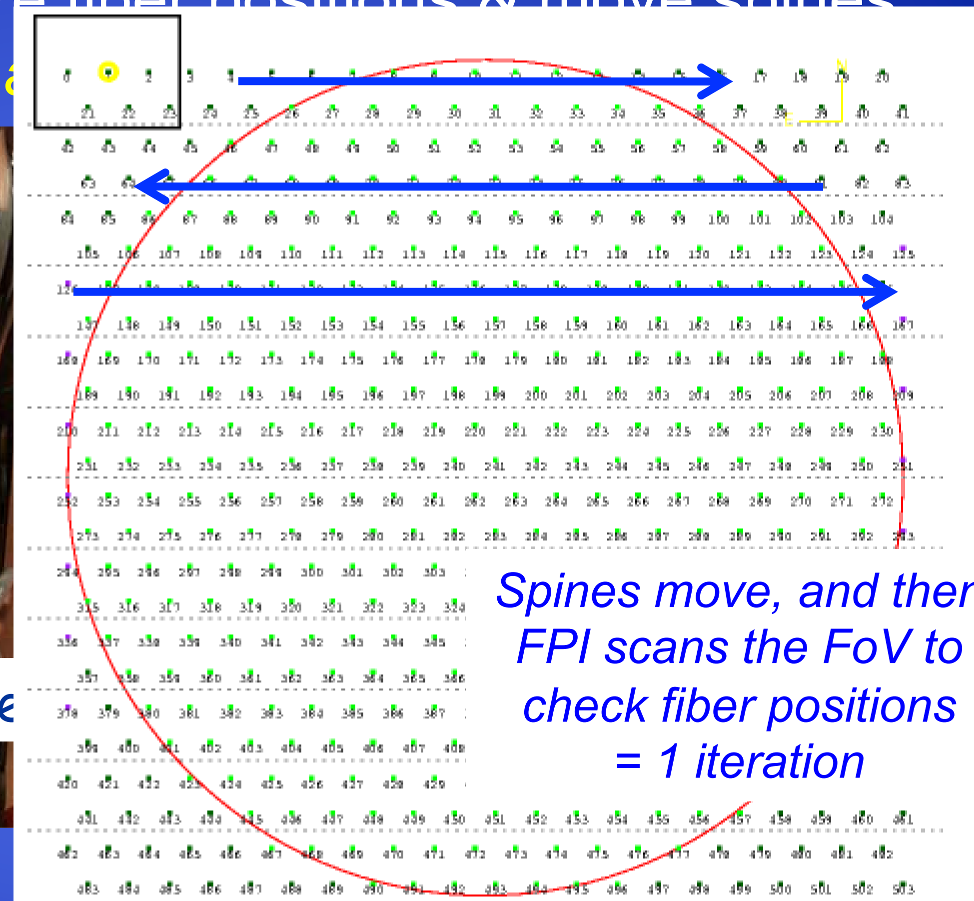
Fiber positioning

Iterative process: Measure fiber positions & move spines

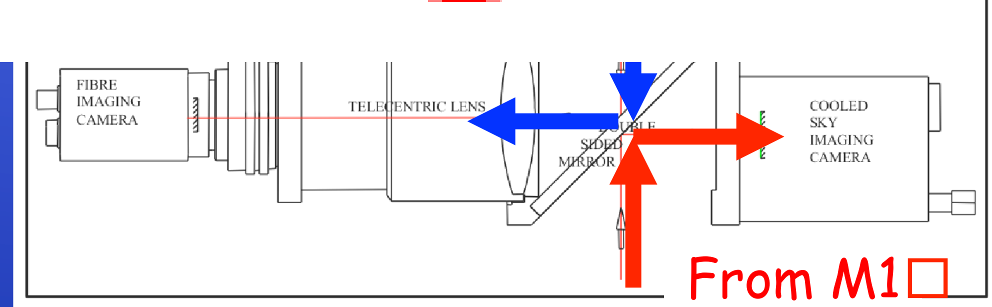
Back-illuminated fibers a





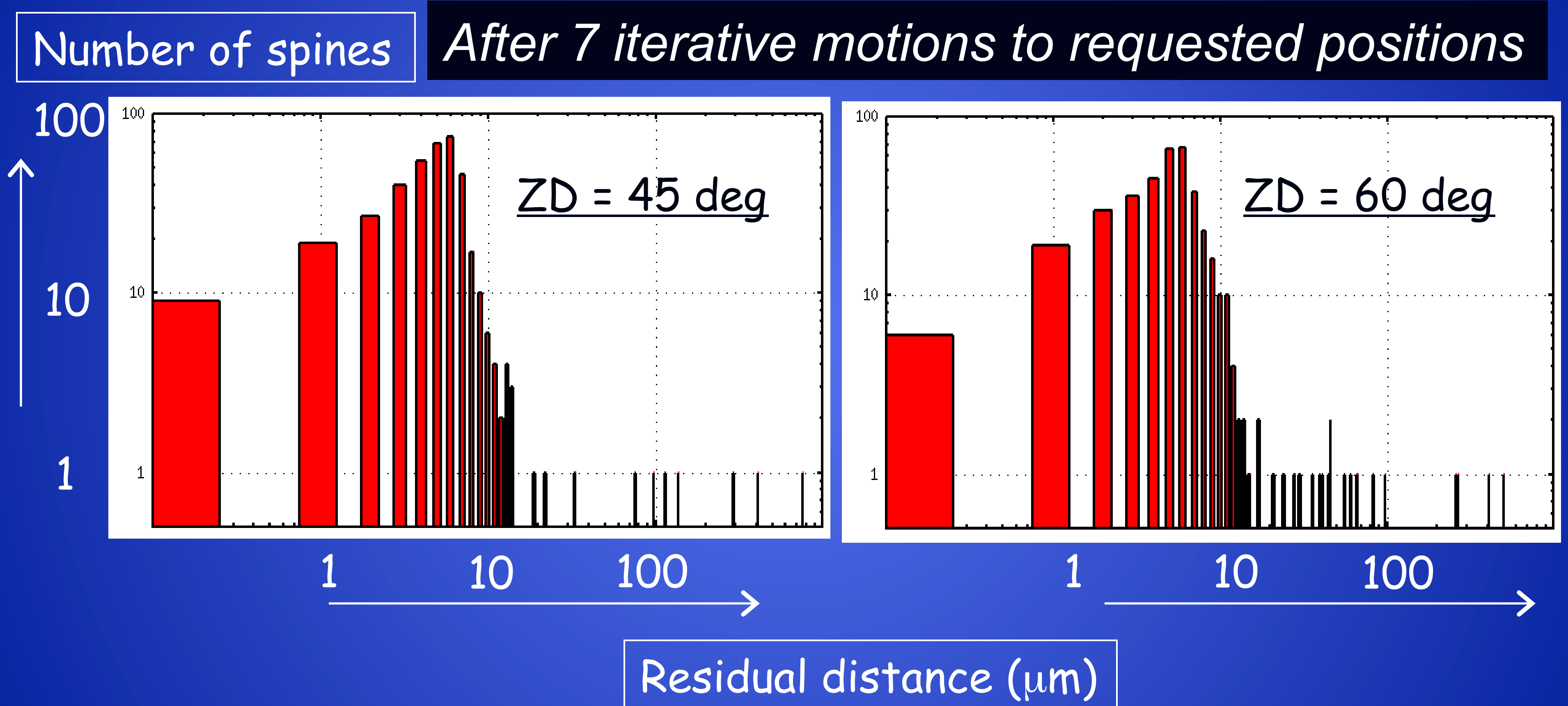


Spines move, and then FPI scans the FoV to check fiber positions = 1 iteration



Positioning accuracy & required time

(Test results at a lab)

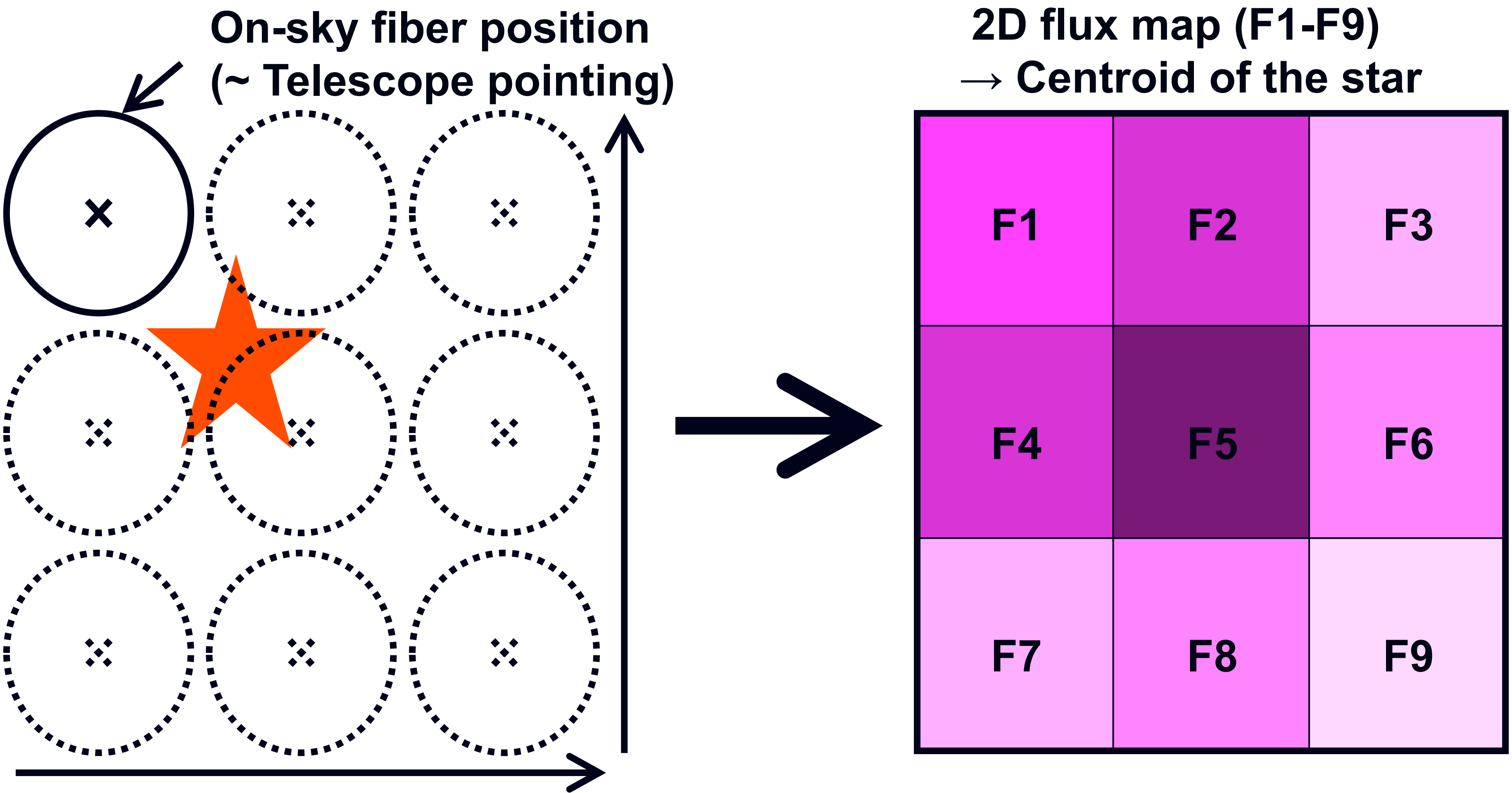


~ 95% of the spines are positioned with < 12 μm accuracy (~0".1) in 7 iterations (~13 minutes) at ZD < 60 deg.

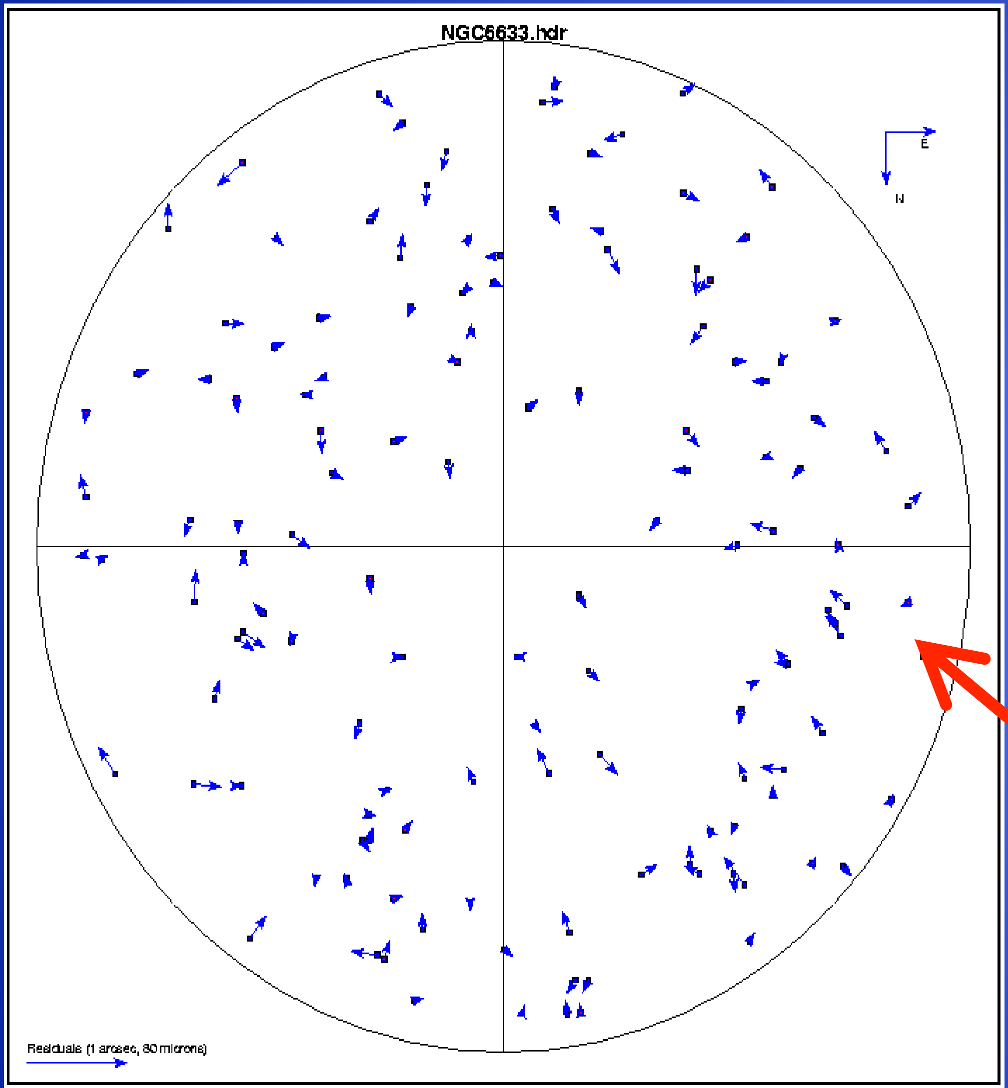
Focal plane map: (α, δ) → (x, y)

Telescope pointing, position angle, field distortion, atmospheric dispersion, differential atmospheric refraction, misalignment of rotator axis & M1 axis, difference of wavelength between fiber and guide camera … etc.

<u>Final refinement was made by telescope raster scan.</u>



Fiber positioning: Residuals on sky



Open cluster NGC 6633 (α, δ ← UCAC3)

Error

$(\alpha, \delta) \longrightarrow (x, y)$

Model

Error

Echidna spine goes to a requested position.

RMS ~ 0".15

was achieved in Oct 2008.

An important upgrade in fiber positioning: Metrology camera [PI: Tamura]

FMOS fiber positioning takes time to scan 400 fibers with FPI …

A "metrology camera" system to image 400 back-illuminated fibers at once.

↓

<u>Overhead: 30-40% → ~10%</u>

The concept has been present for a while, but none has been applied yet to the operation of an actual instrument (as far as we know … ?).

- Moore & McGrath (2004, a prime-focus MOS on an ELT)
- WFMOS
- SuMIRe/PFS

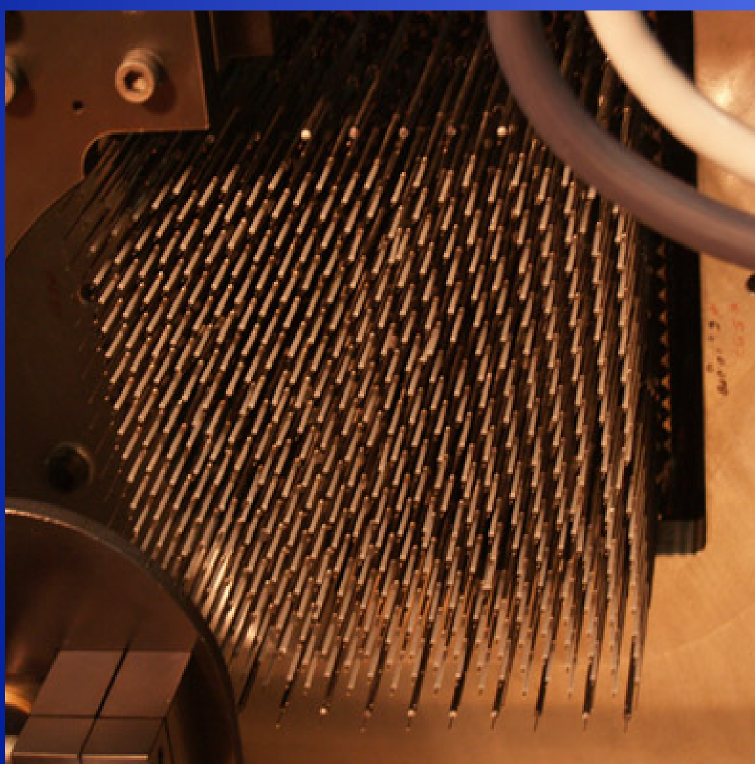
Collaboration with the SuMIRe/PFS team in ASIAA
→ Upgrade for FMOS and verification for PFS

FMOS fibre cables

~ Not just cables however ! ~

F/2 → *F/# conversion* → *F/5*

Echidna@Prime focus



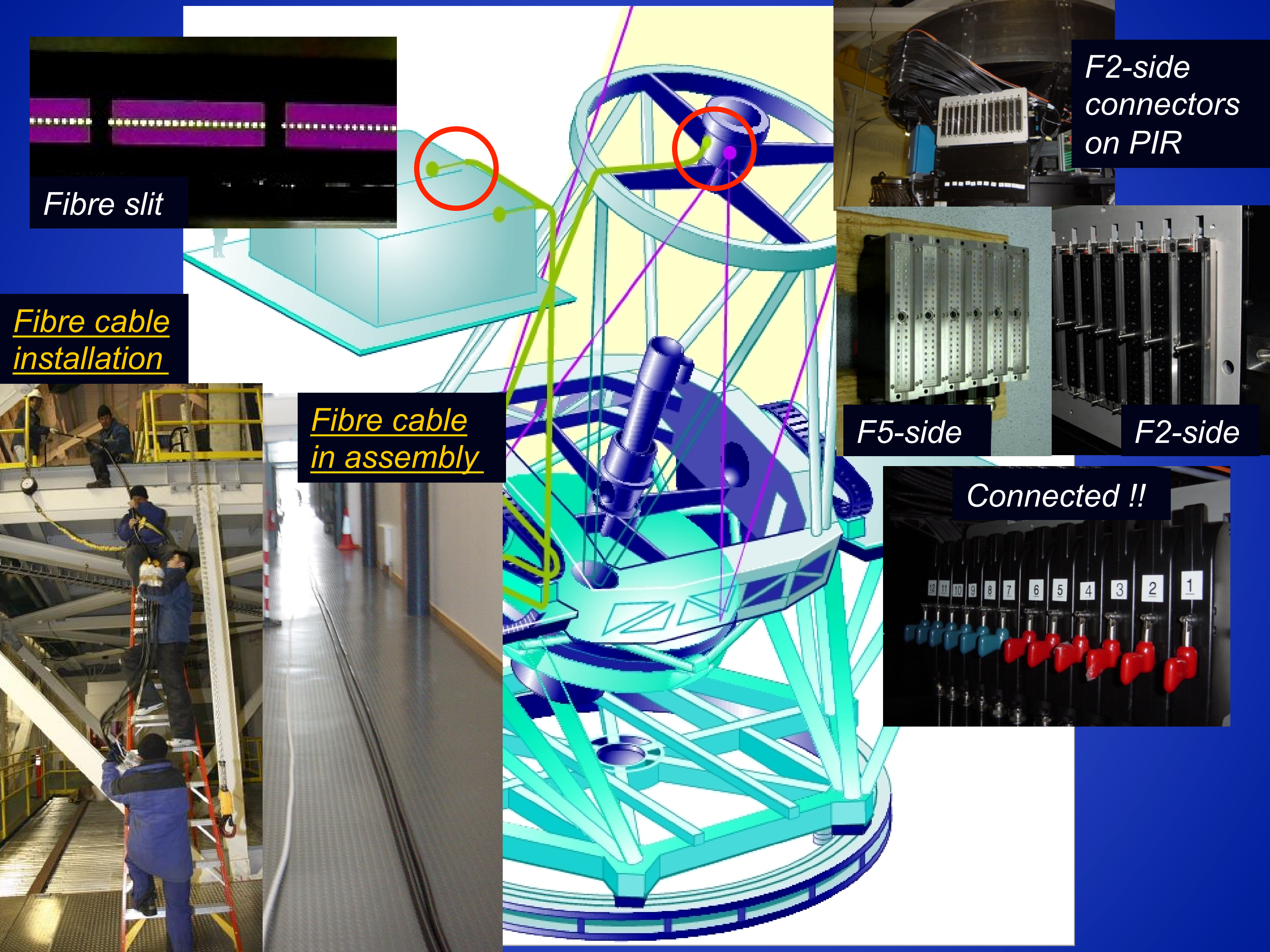
Optical link

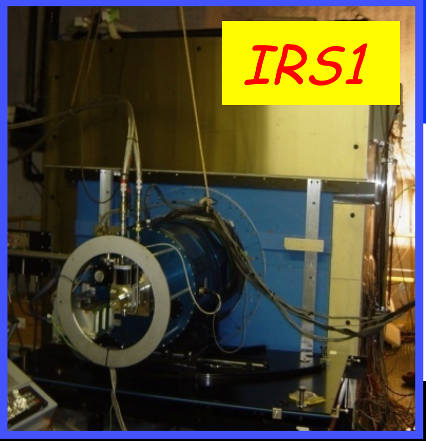
Spectrographs @Dome

Fibre connectors

"Back"-illumination

Fibre slits

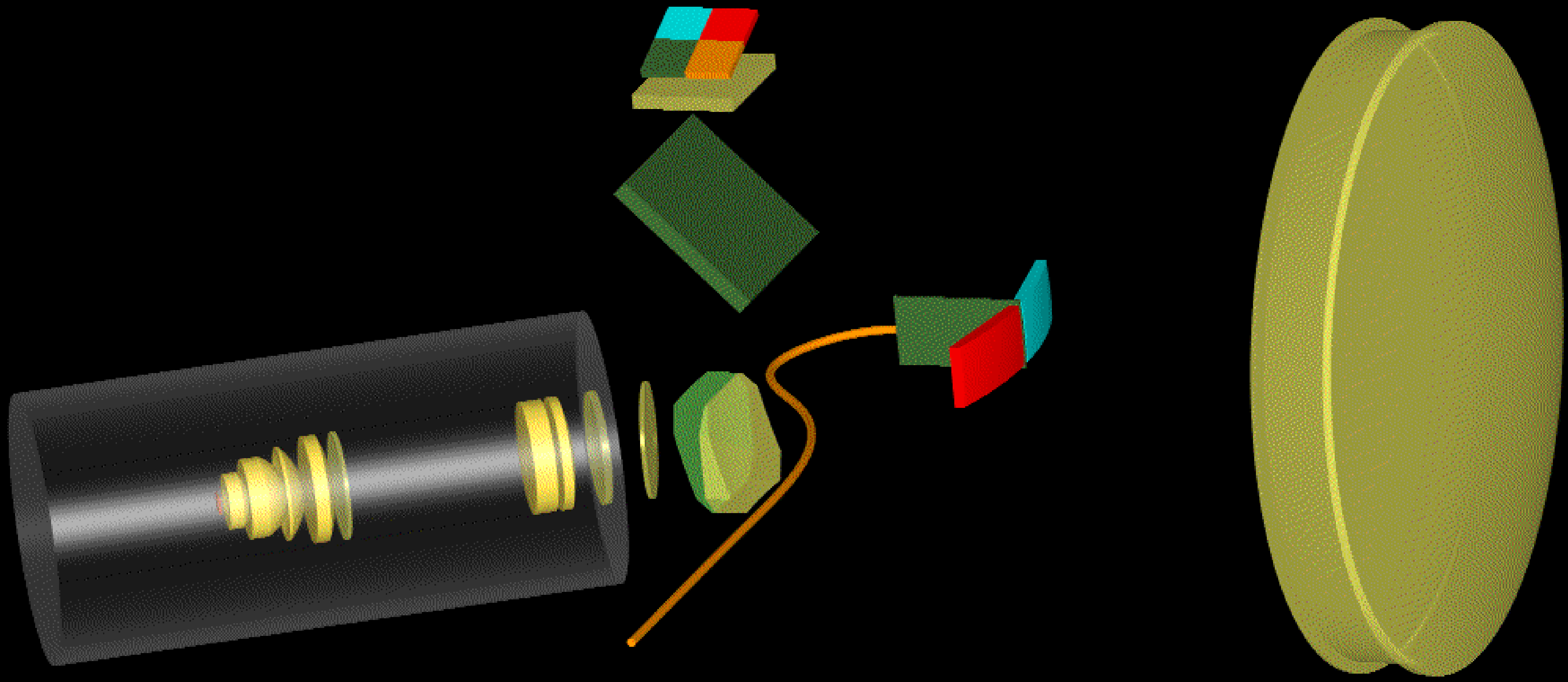

Fibre slit
F2-side connectors on PIR
Fibre cable installation
Fibre cable in assembly
F5-side
F2-side
Connected !!



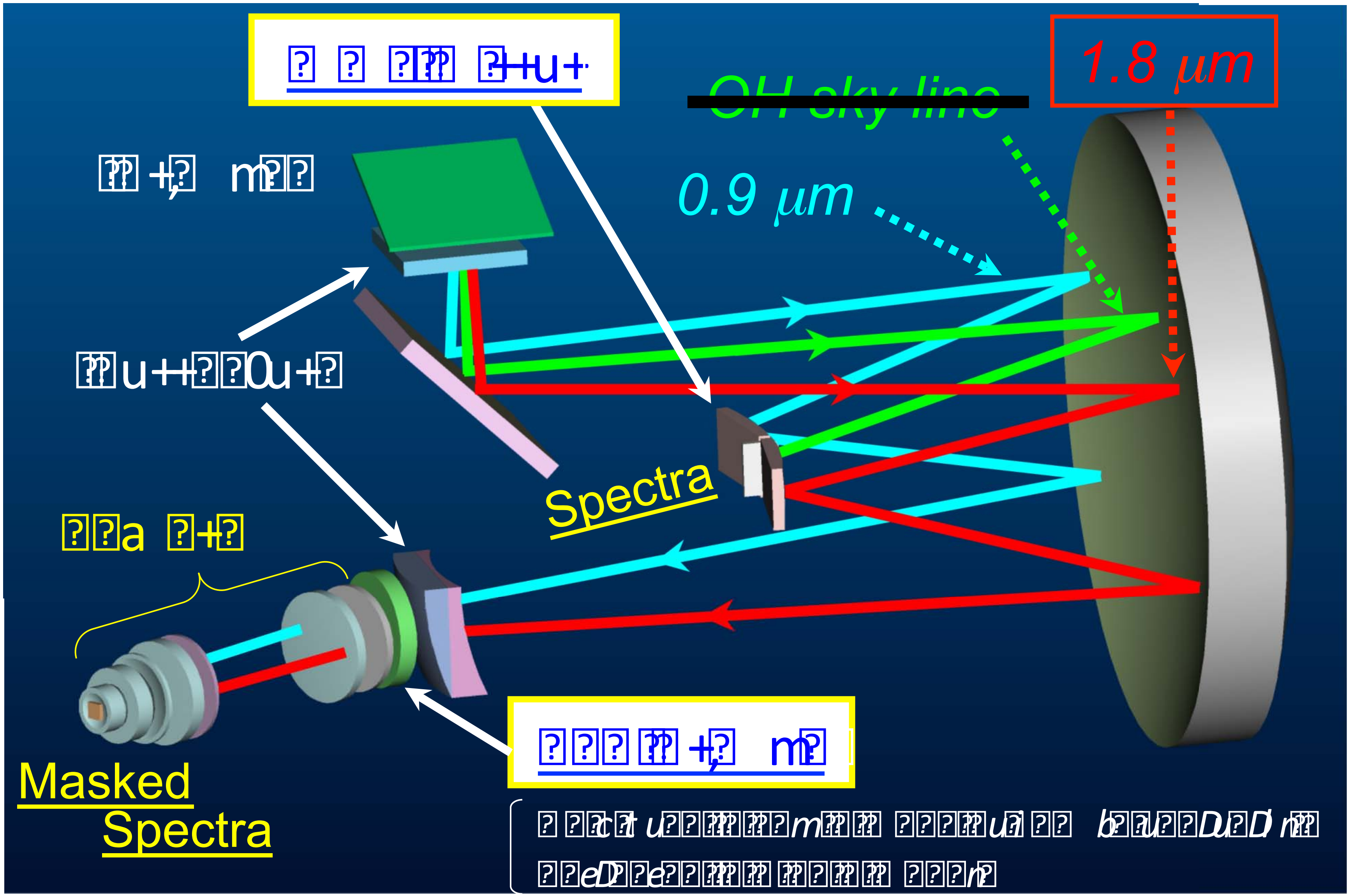
InfraRed Spectrographs

200 fibers go to each of IRS1 & IRS2.
Cooled down to -55 deg.
OH suppression by the mask mirror

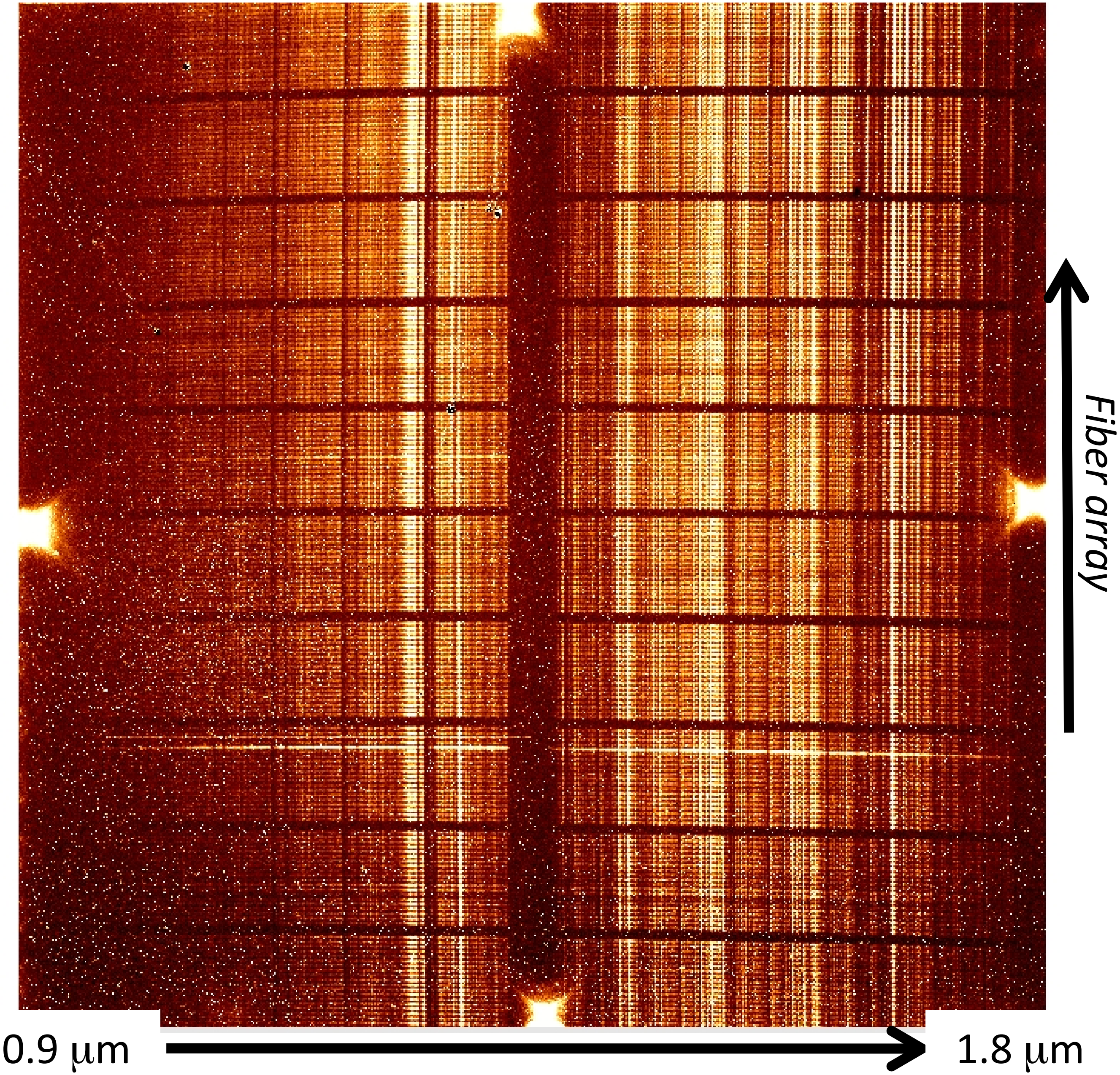
“Low Res.”: R~600 (w/ VPH), “High Res.”: R~2200 (w/o VPH)



InfraRed Spectrographs



Data example

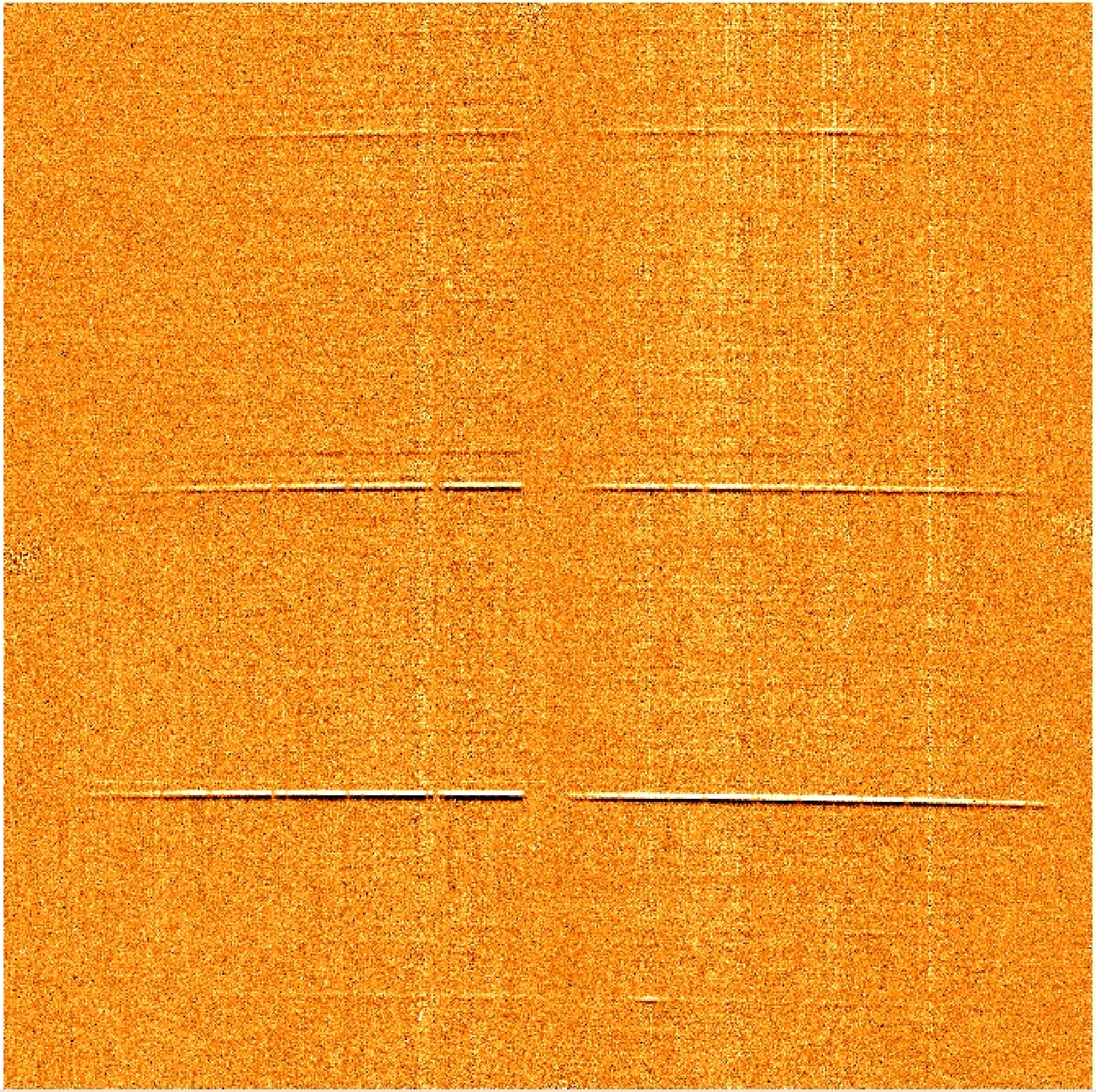


A 15 min exposure ramp sampling image by IRS1 in Low Resolution.

Left: J-band
Right: H-band
The gap in between is due to fiber slit (no light comes through).

There are 4 glows at the readout ports.

Data example



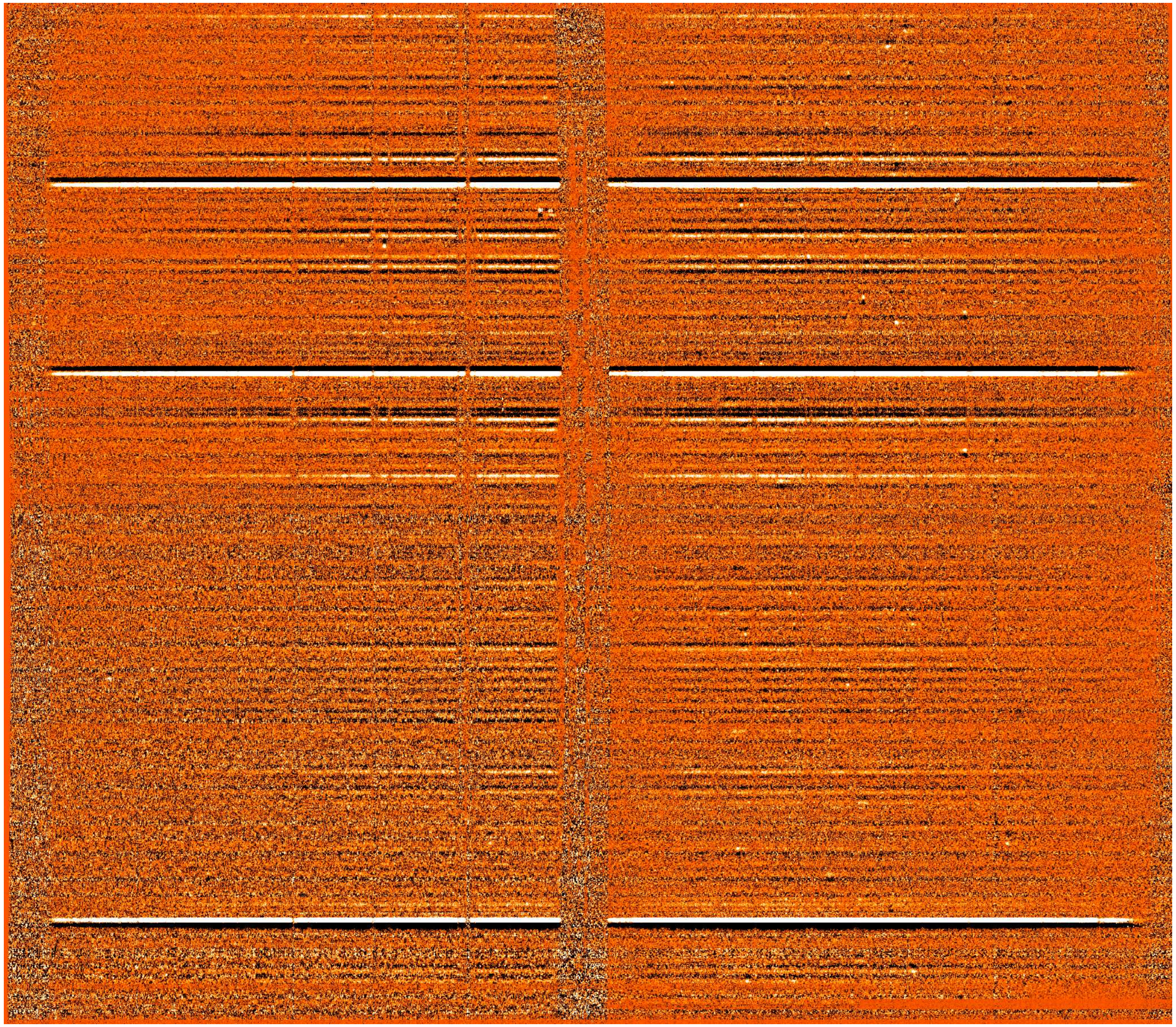
2 frames taken with the same exp. time & the telescope dithered and one is subtracted from another. This data is an image after this subtraction.

Since this is from Cross Beam Switching, a few pairs of positive and negative spectra from single bright objects are visible.

Residual sky is subtracted by a way like “skysub” for long-slit data after fiber extraction.

Data example

SXDS, Cross beam switching, 8 hr on-source with IRS1 LR [GTO, Oct 2011]
Targets: Star-forming galaxy candidates w/ z(phot)~1.4 (Yabe+ 2012, in prep.)



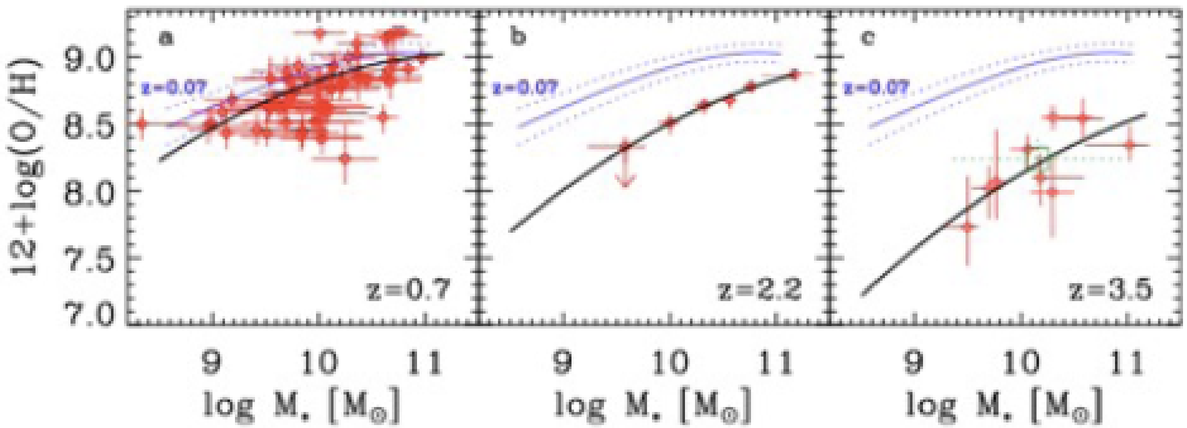
The image shown here is that after data reduction and stacking several frames (still flux-uncalibrated).

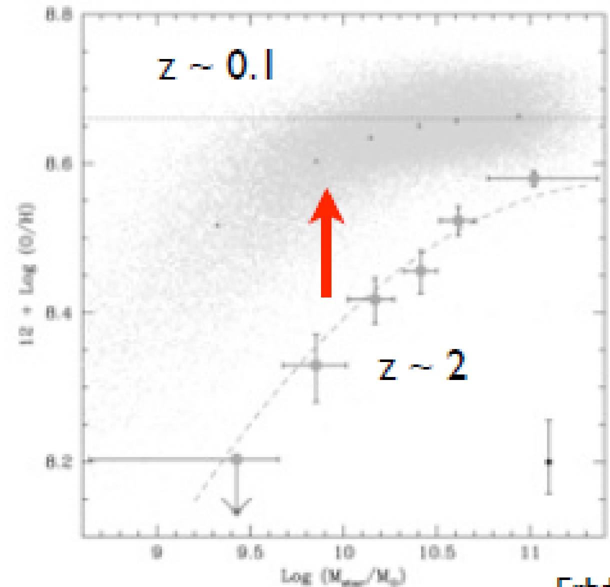
Data reduction & calibration is performed in parallel to the observation using a reduction package “FIBRE-pac” (Iwamuro et al. 2011, PASJ, in press).

Mass-metallicity (M-Z) relation at z>1

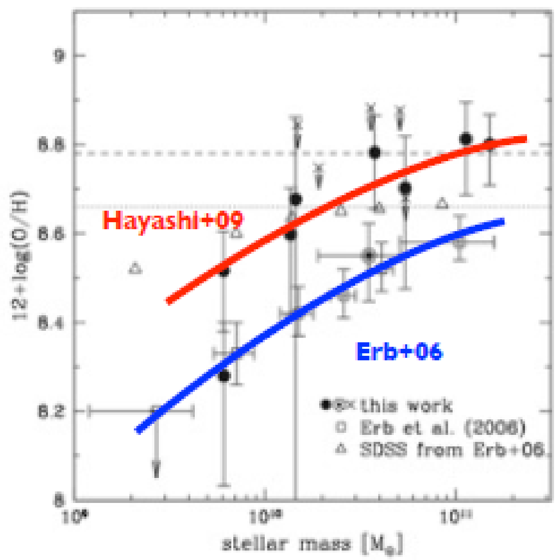
Simple trend or not - Larger samples should help to understand what are behind the sample dependency.

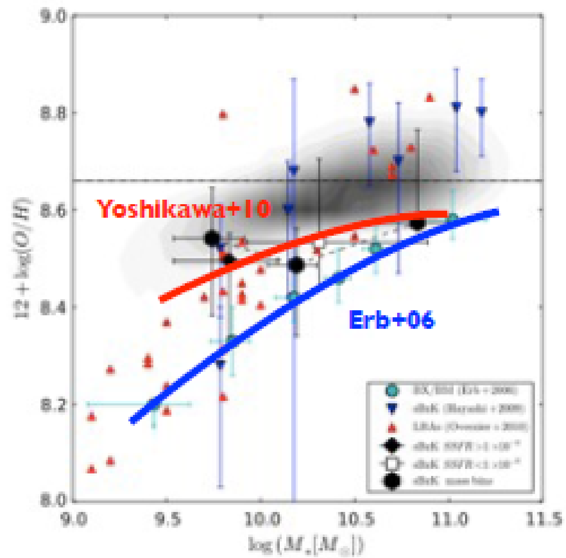
Maiolino+08

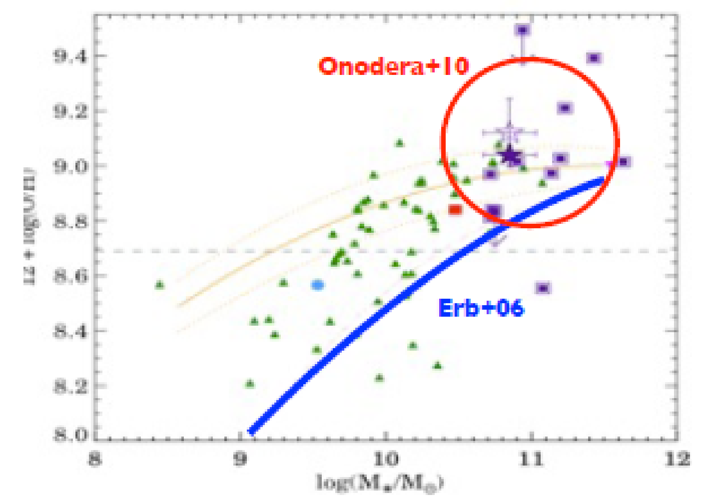




Erb+06







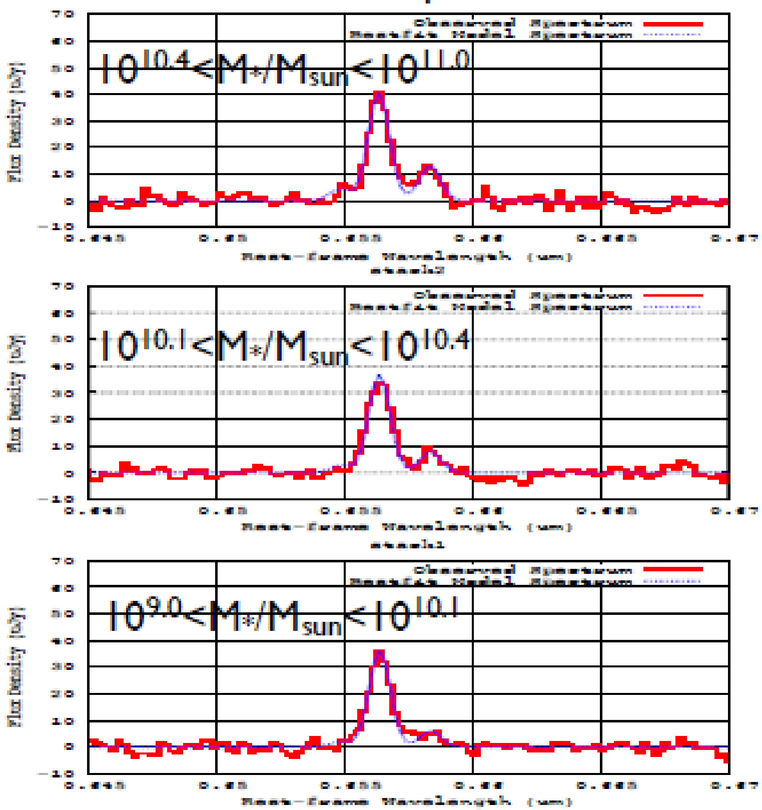
M-Z relation at z~1.4 by FMOS

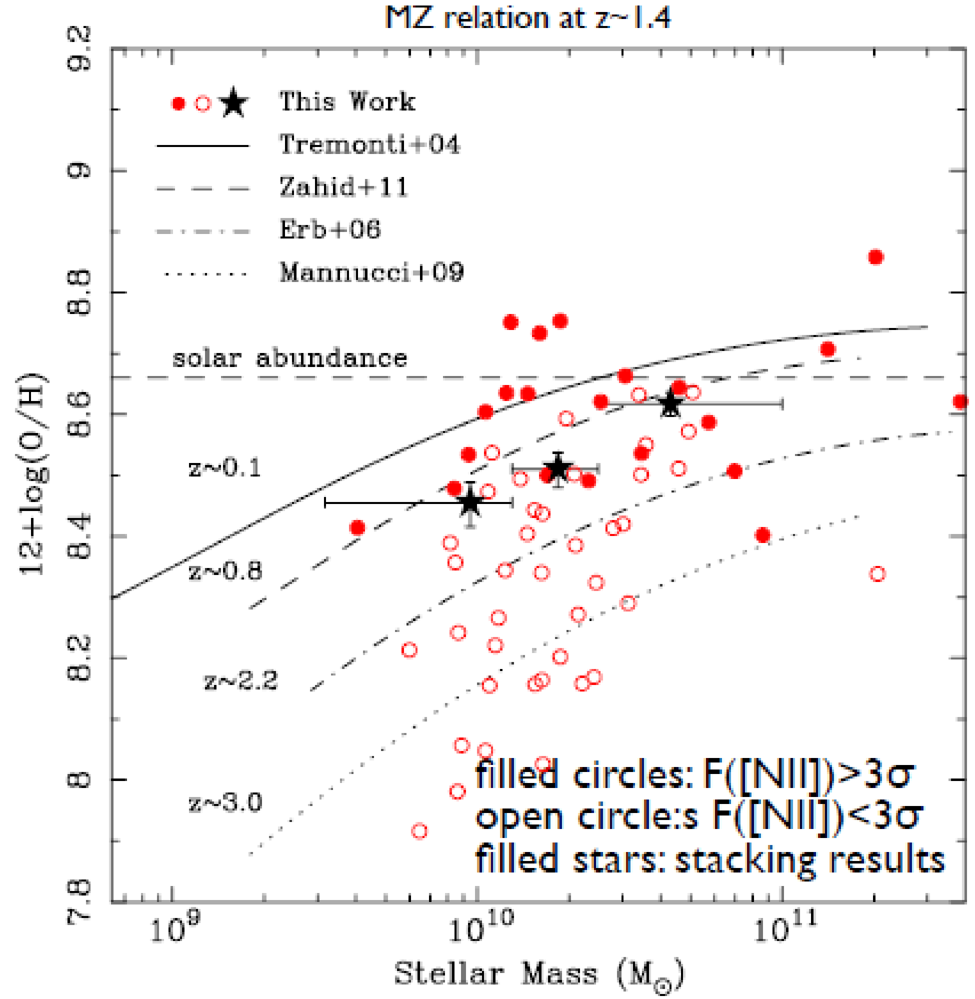
Star-forming galaxies at $1.2<z<1.6$ were observed. Metallicities of these objects are derived from [NII]/Hα flux ratios using the metallicity calibration by Pettini & Pagel (2004).

Resulting mass-metallicity relation (MZR) shows that the MZR at z~1.4 lies between the previous result at z~2.2 obtained by Erb+2006 and that at z~0.8 obtained by Zahid+2011.

<u>K. Yabe (Kyoto) et al. (2012), in prep.</u>

Stacked Spectra





Note: Possible AGNs are excluded

FMOS for cosmology at z>1

~ The “FastSound” project [PI: T. Totani (Kyoto Univ.)] ~

To understand the physical origin of cosmic acceleration:

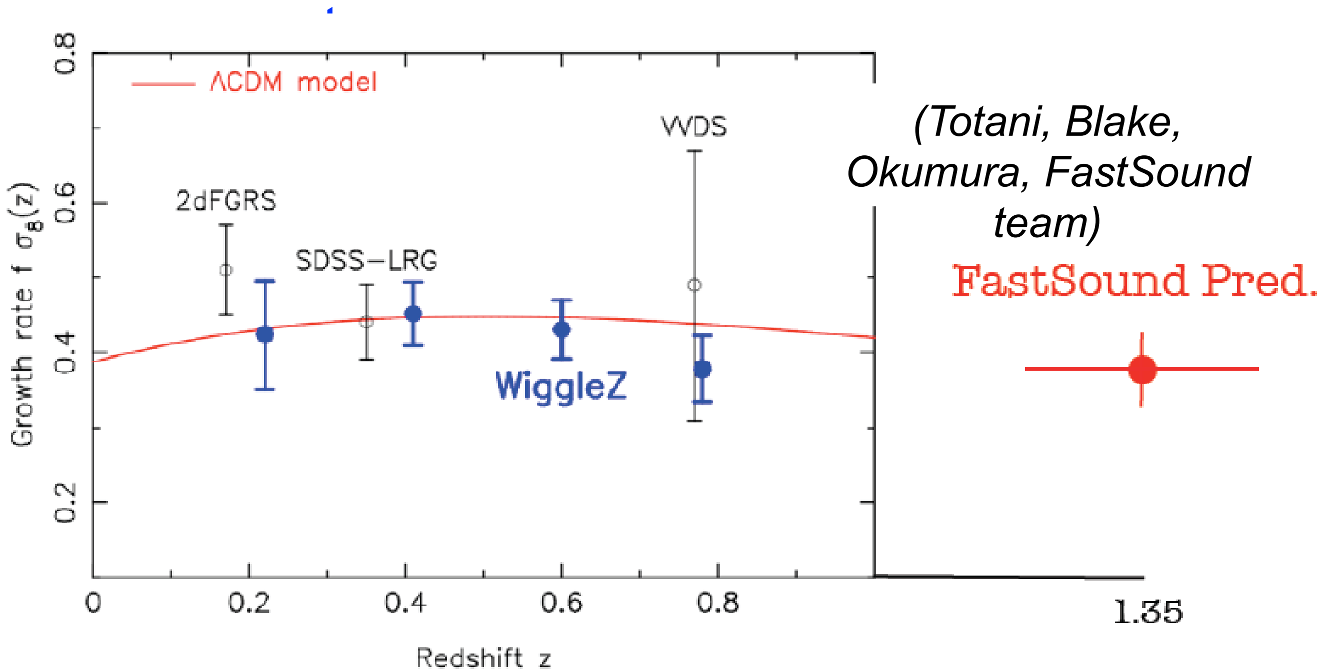
Dark Energy or else? (testing General Relativity)

Baryonic Acoustic Oscillation (BAO)
Redshift Space Distortion (RSD)

- Aiming at the 1st r
  of RSD at z>1 usi
- Redshift evolutior
  → Constraint on (

Survey Plan:

- Target: Hα emitter
  (~10,000 galaxies
- Field: CFHTLS W
  30deg², z<22.5



Now that FMOS is about to be fully operational(?), it's hopefully(!) time to quit being a "frequent traveller" to the Mauna Kea summit for engineering works & observations, and re-visit the motivations to have joined this FMOS project 10 years ago …

"SCDXT"

To get deeper spectra

Talk outline

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    - Subaru telescope
    - “Instrument Astronomer” in Subaru operation
    - Personal history & research interests

2. Subaru “FMOS” (Fiber Multi Object Spectrograph)
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    - Instrument overview & highlighting subsystems
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    - Data example
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3. Future instruments
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    - SuFAIFS – Flexibly addressable integral field spectrograph

4. Summary & some remarks on future

Summary

FMOS was developed as a common-use instrument on Subaru through the collaboration of Japan, UK, and Australia.

FMOS has been open to general observers since May 2010, after >10 years efforts since the project began, and it will be (hopefully) fully operational from early 2012.

Now is the time to move on to science using FMOS data & R&D activities for instrumentation (e.g. for SuFAIFS)(!?)

SuMIRe/PFS is more challenging in almost all aspects than FMOS, but now I strongly intend to make committements to make it, exploiting lessons & learns from FMOS.

Can IPMU be another base in Japan
for astronomical instrumentation?