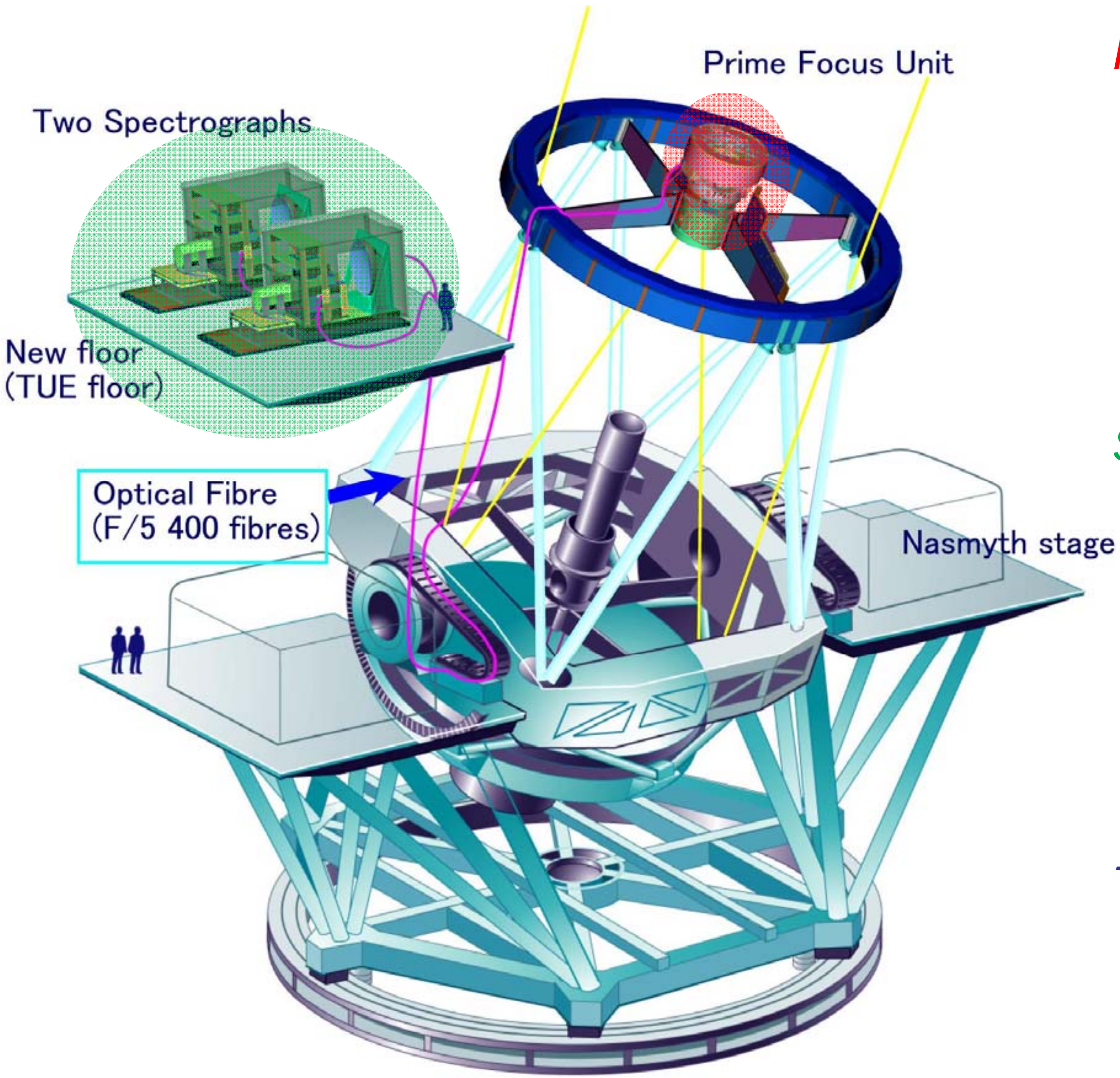
Overview of the Fiber Multi-Object Near-Infrared Spectrograph (FMOS) for the Subaru telescope

1. *Instrument overview*
2. *Strategic survey plan overview*

Masayuki Akiyama (Tohoku University)

FMOS overview



IR prime focus unit (PIR)

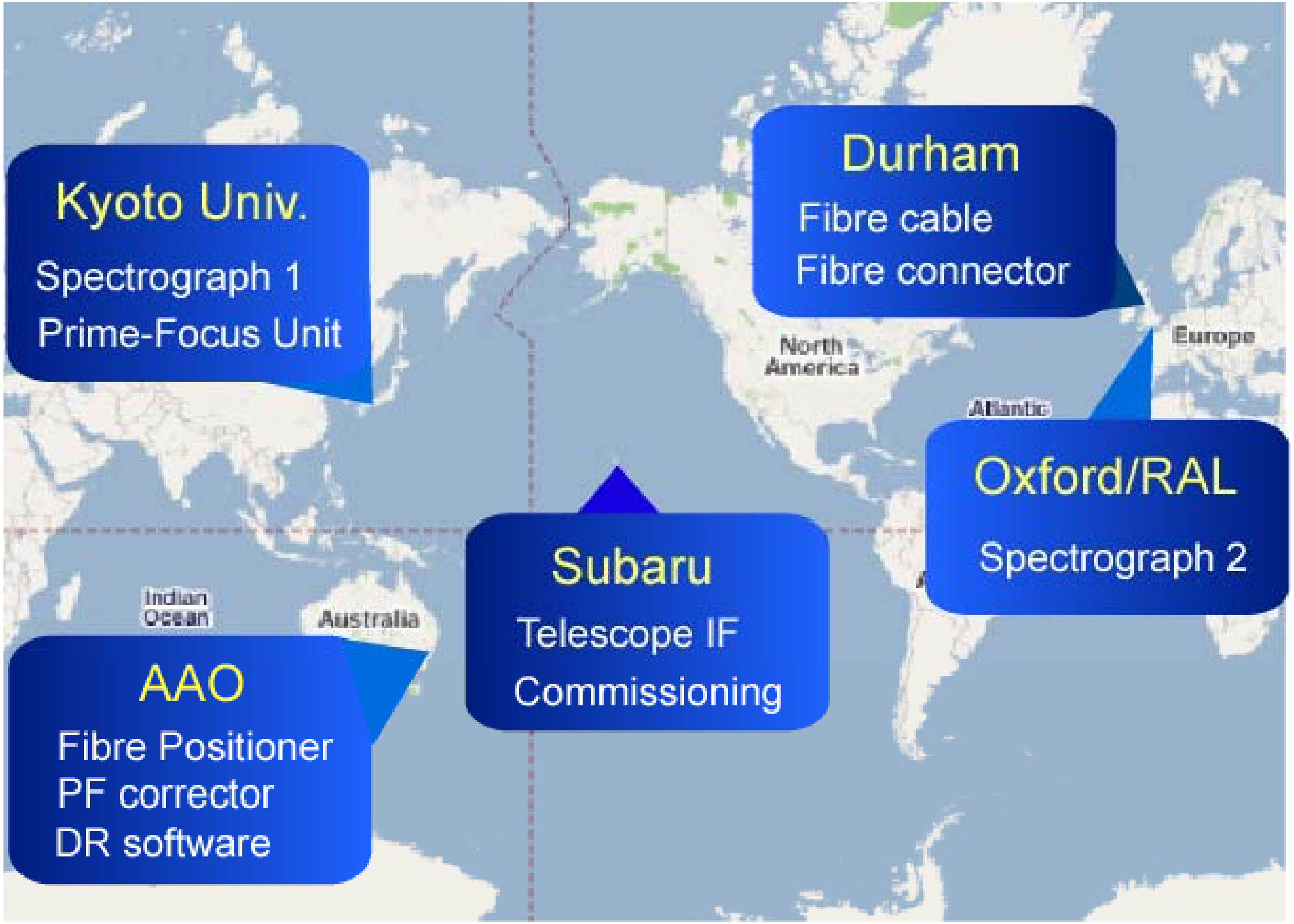
- *Three lens NIR prime-focus corrector makes 30arcmin diameter FoV.*
- *Fiber positioner is enclosed in the unit.*

Spectrograph unit:

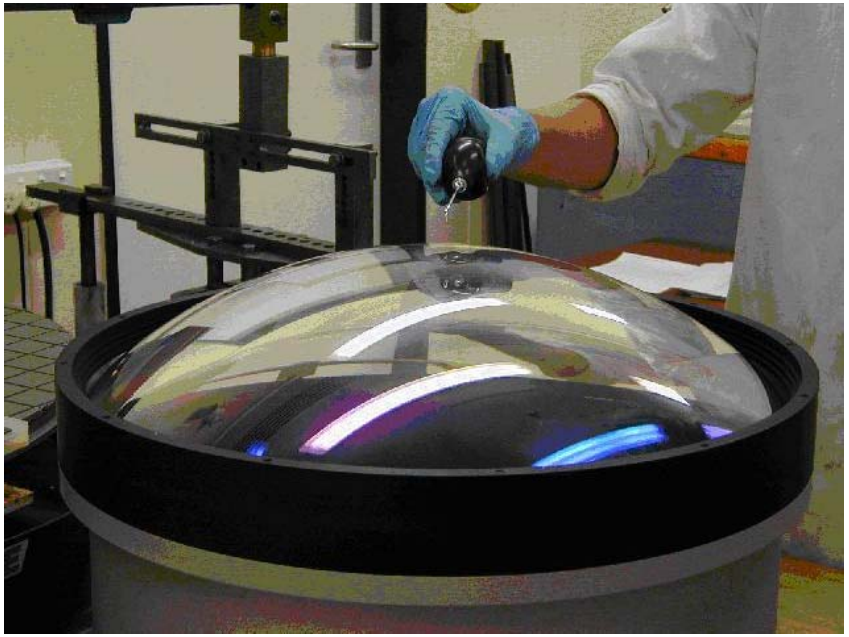
- *Each spectrograph covers 200 fibers.*
- *Covering 0.9-1.8um with spectral resolution of R=500,2200 and mechanical OH-line suppression with mask.*

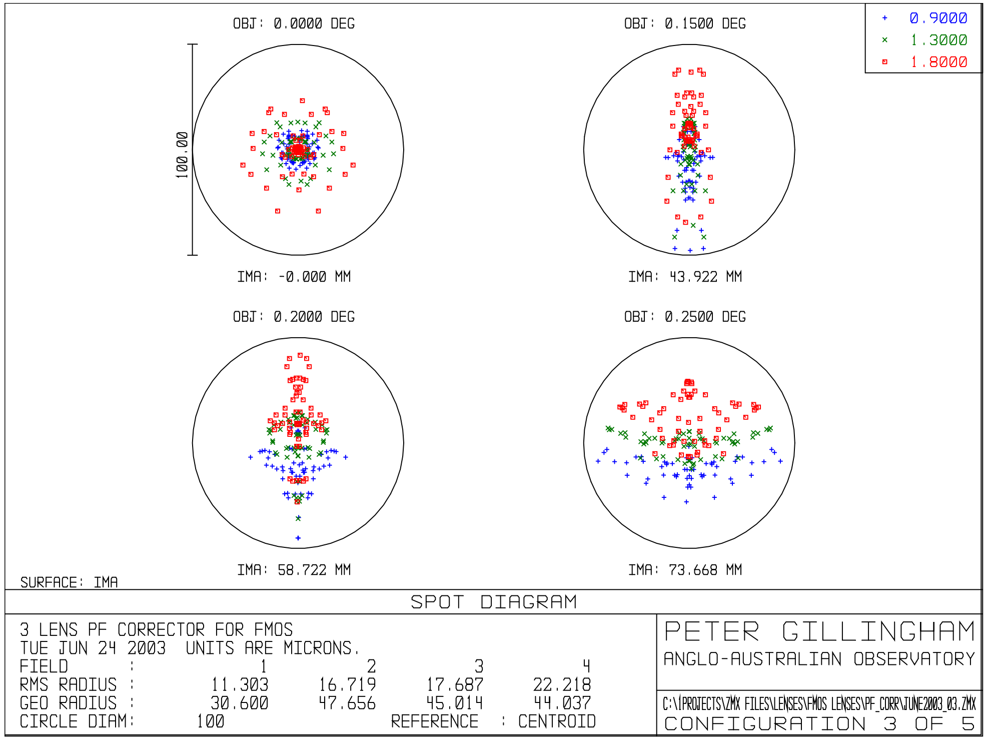
Two units are connected by fiber cable with a optical connector which also convert input F/2 light into F/5 spectrograph feeding light.

FMOS overview



FMOS in reality *3-lens corrector*

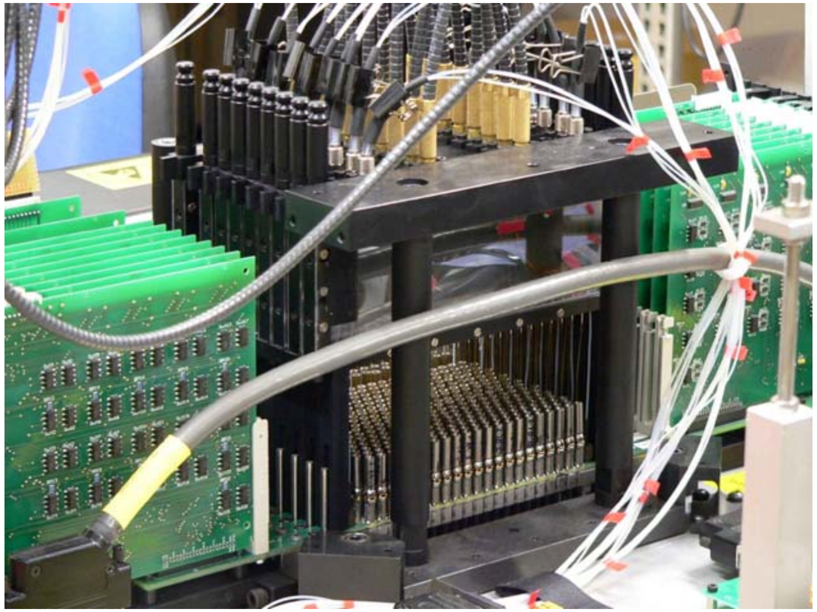


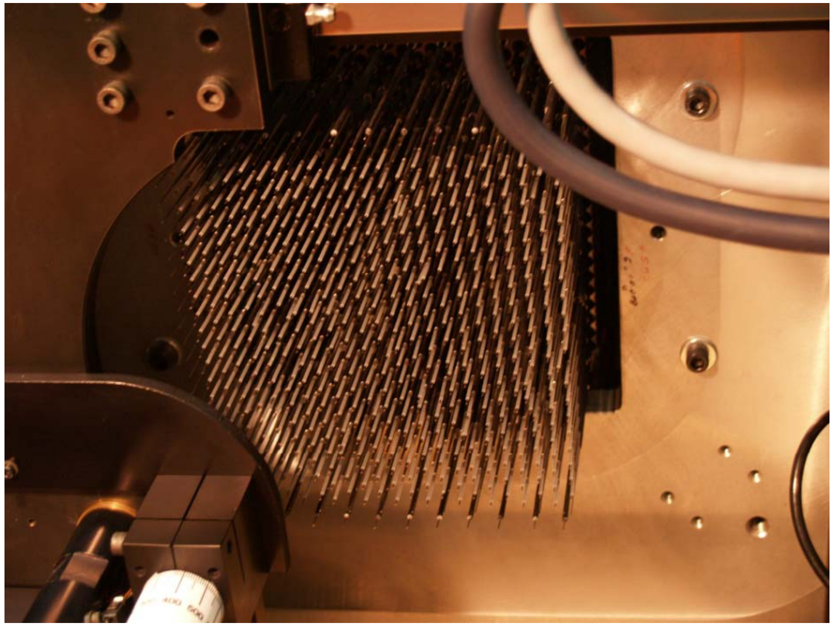


100um circles
0.9, 1.3, 1.8um (blue, green, red)
At 0.0 0.15 0.20 0.25deg from center
(from top-left to bottom-right)

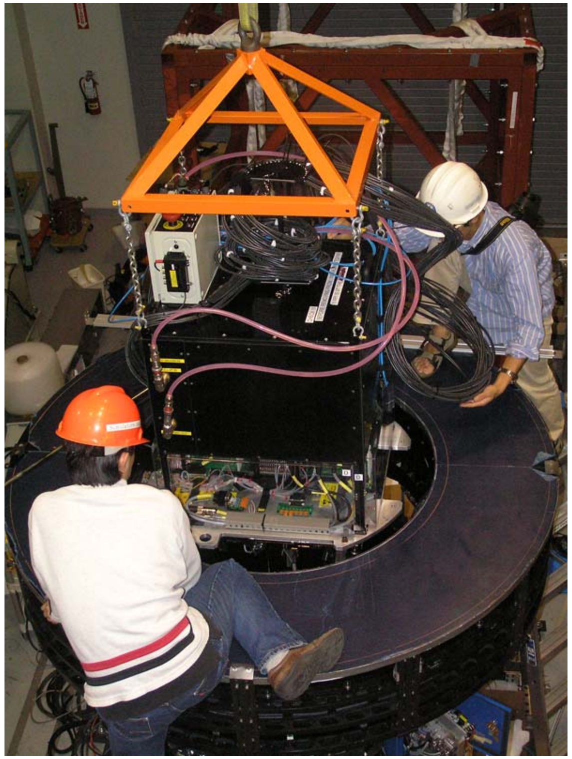
No ADC optics

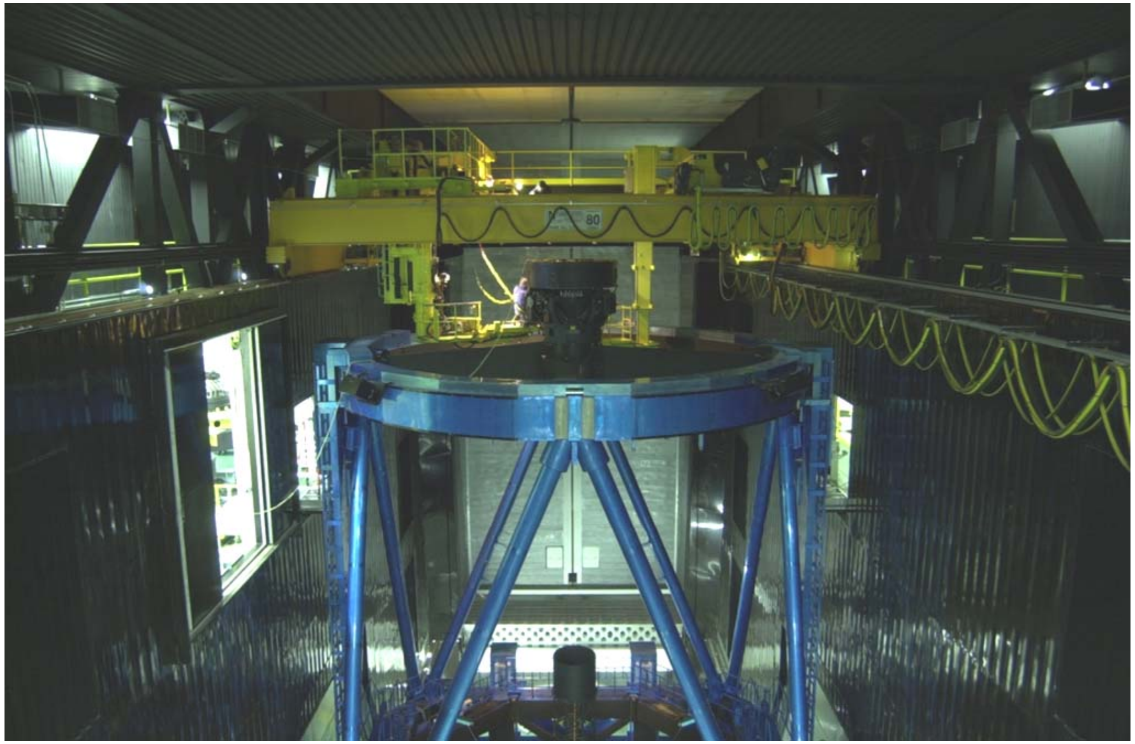
FMOS in reality   Fiber positioner (Echidna)



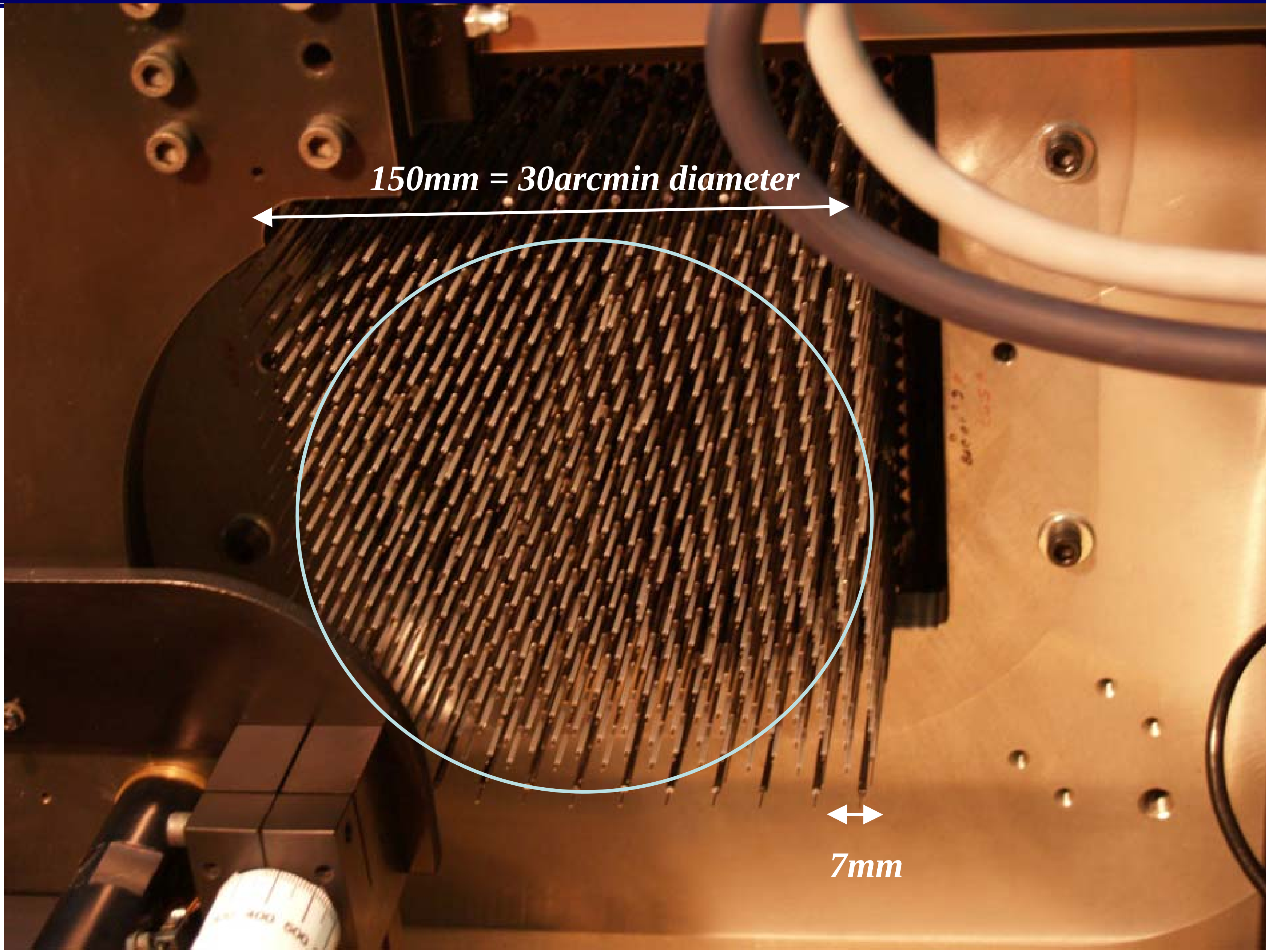


FMOS in reality   IR prime-focus unit (PIR)



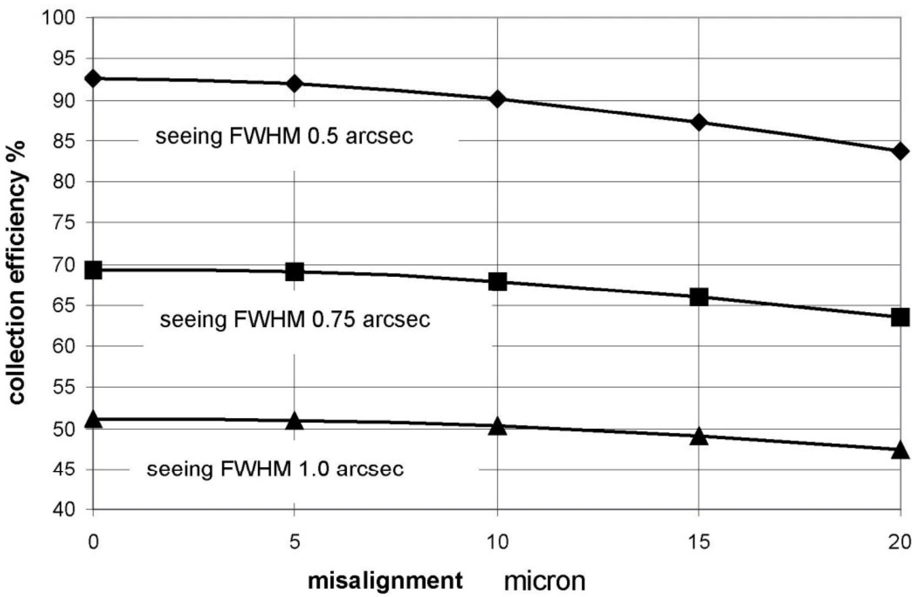


FMOS in reality   Fiber positioner (Echidna)



FMOS Echidna requirements for the positioner

• The optimal core size of the science-fibers was determined to be 1.2”, which corresponds to 100micron, maximizing the expected SN ratios of faint galaxies.

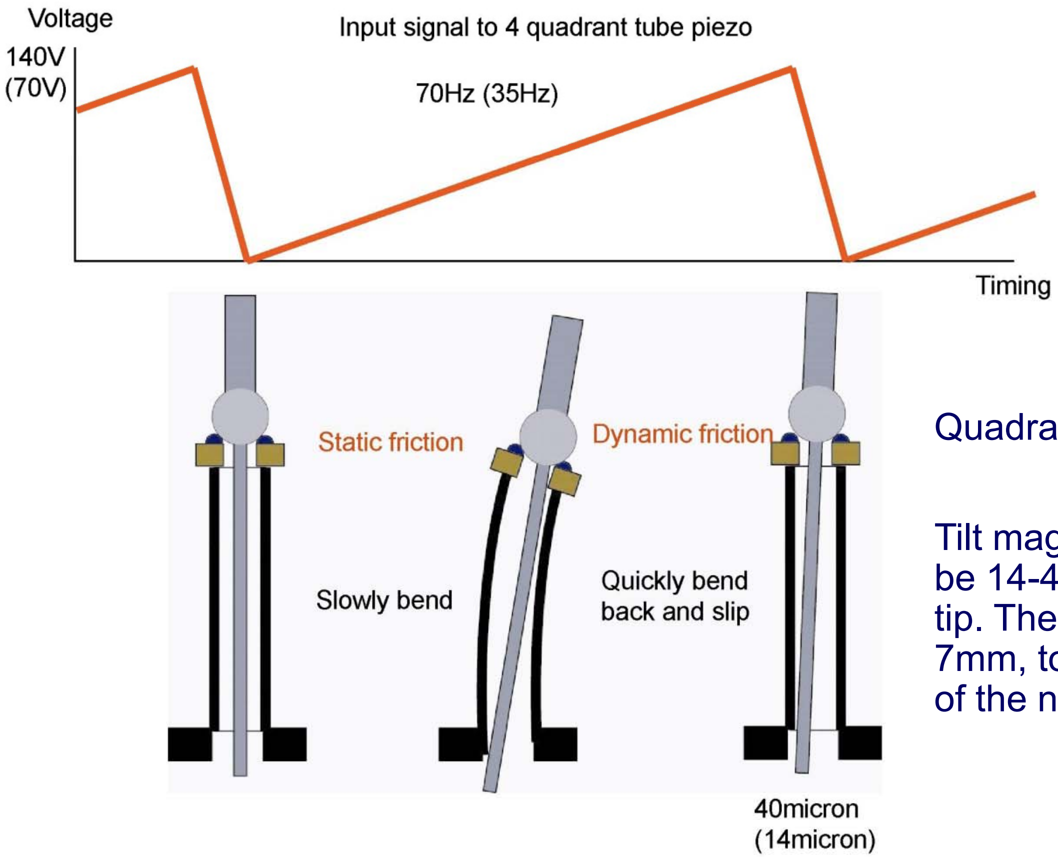


Coupling efficiency as a function of the misalignment of the fiber to the target. Stellar object is assumed

• For misalignment less than 20micron, the reduction of the coupling efficiency is less than 10%, even under a good seeing condition with FWHM=0.5”.

•Due to a number of physical effects, the repeatability of spine movement is not precise, thus iterations are required to achieve the required accuracy. Position the 400 fibers with the 20micron accuracy to targets within 15 minutes.

FMOS Echidna principle

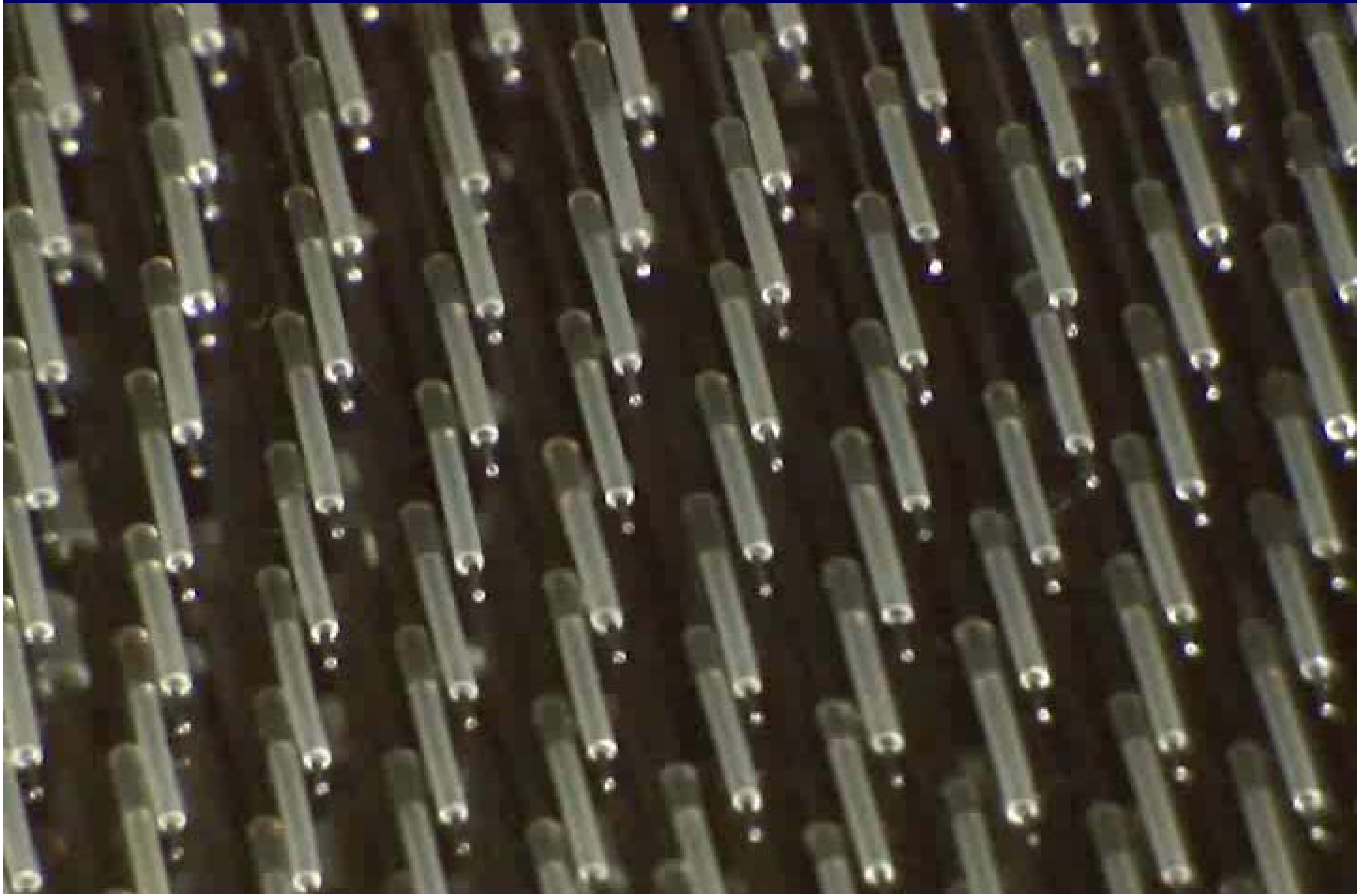


Quadrant tube piezo actuator

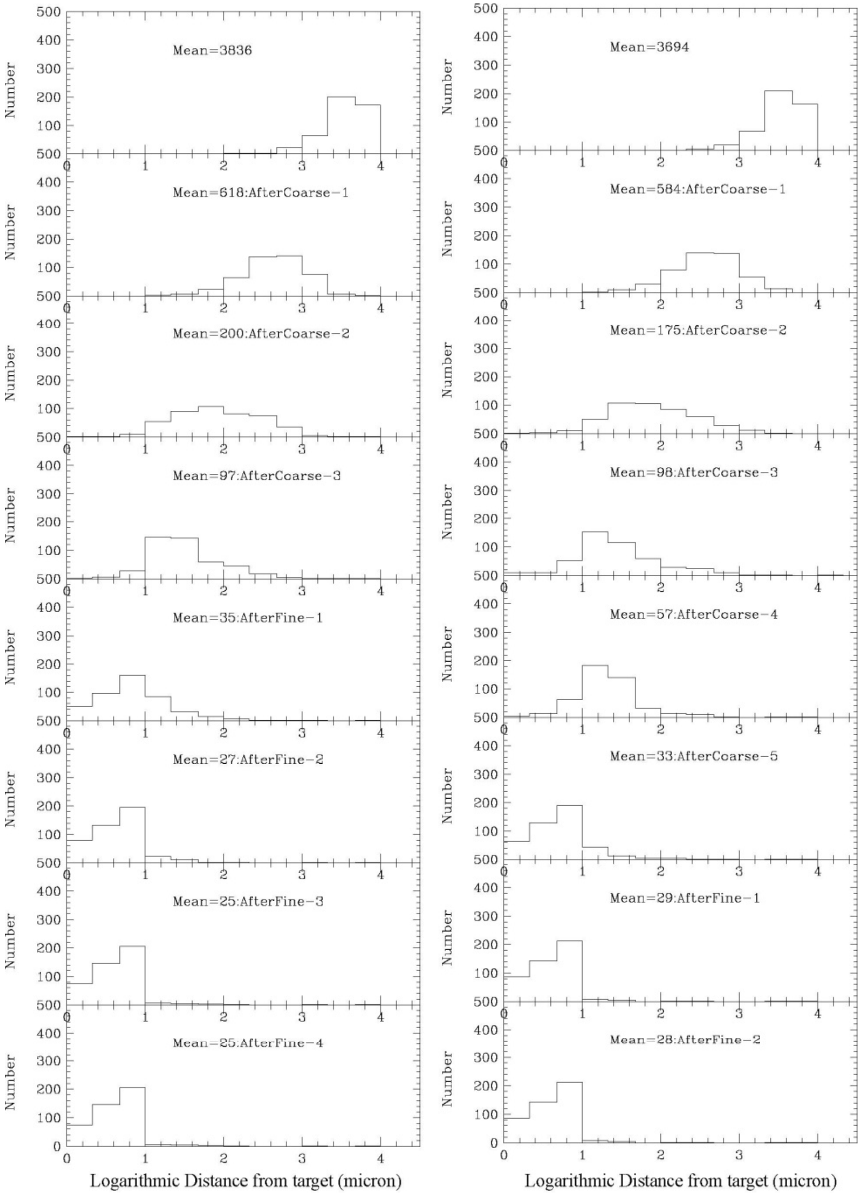
Tilt magnified, one step will be 14-40 micron at 160mm tip. The maximum tilt will be 7mm, to the home positions of the neighboring fibers.

- Slow bend and quick bend back of quadrant tube piezo actuator with the saw-tooth signal make the “stick and slip” movement of the pivot ball of the “spine”.
- For principle and prototype developments, see Gillingham et al. 2000 SPIE 4008, 1395, Moore et al. 2003 SPIE 4841, 1429, Gillingham et al. 2003 SPIE 4841, 985.

FMOS Echidna: "configure fibres" zoom-up



FMOS Echidna Fiber positioning tests



Intensive positioning tests have been done inside tilted prime-focus unit at various rotation angles.

At tilt angle<60deg., 95% of the spines reach target position within 12micron with 7 iterations. About 10 out of 395 fibres cannot reach the target positions.

At tilt angle=60deg. with some rotation angles, the performance degrades. ~20 out of 395 fibres cannot reach the target positions with 7 iterations.

With 7 iterations, the fibre configuration takes 13 minutes currently.

The bad positioning accuracy at ZD=60deg is some spines have difficulty with moving against the direction of the gravity in the current mode. This may be solved with different frequency and voltage signals to the fibre movement. The fine tuning of the frequency and voltage is still underway.

FMOS Echidna constructing "telescope model"

"Telescope model" describes conversion between (RA,DEC) <-> (FPI X, FPI Y)

Inputs for each fov

- Pointing center
- Observing time (telescope elevation + rotator angle), conditions (temperature=focus position, humidity, pressure)

Parameters need to be calibrated before hand (during engineering obs.)

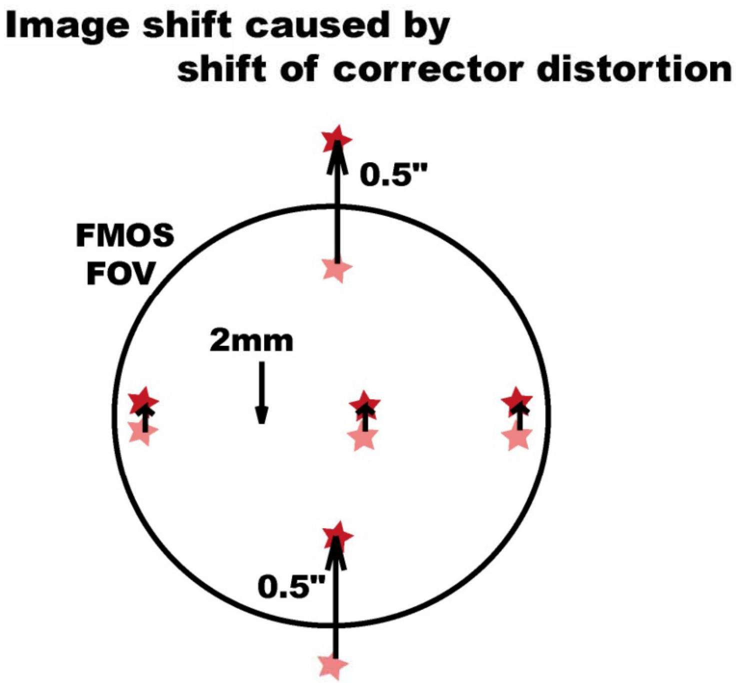
- Distortion pattern

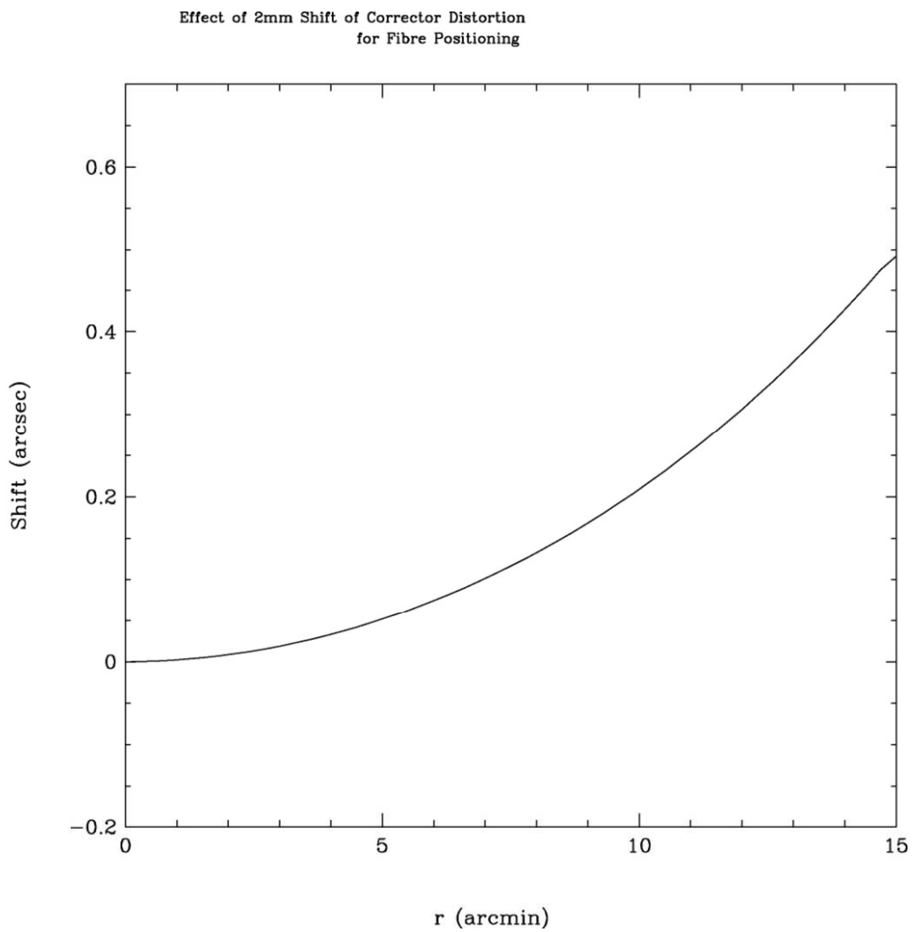
  a*r + b*r^3 + c*r^5 + d*r/lamda + e*(r/lamda)^2,

- Movement of the distortion pattern against focal plane (see next slide).

FMOS Echidna effect of distortion pattern center

Due to the mis-alignment between M1-axis (corrector-axis) and the PIR rotator axis, the distortion pattern move against the focal plane. For example if the corrector move 2mm against focal plane, the distance between a star at the FoV center and a star at the edge of FoV will change by 0.5".

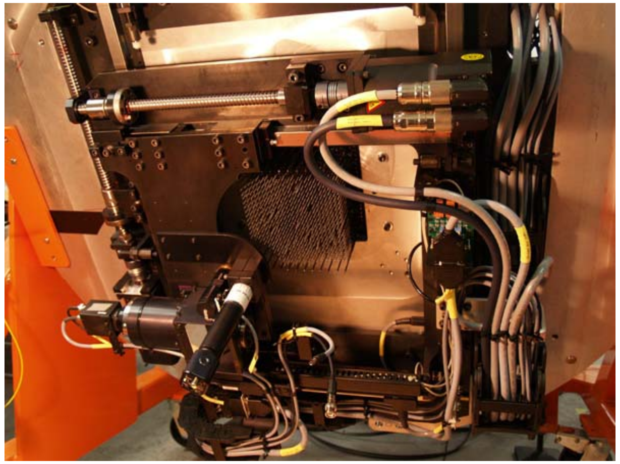




FMOS Echidna three steps

1) Focal plane mapping with the sky-camera

Measure positions of stars with the sky-camera, and determine the telescope model parameters (distortion pattern, distortion pattern offset).



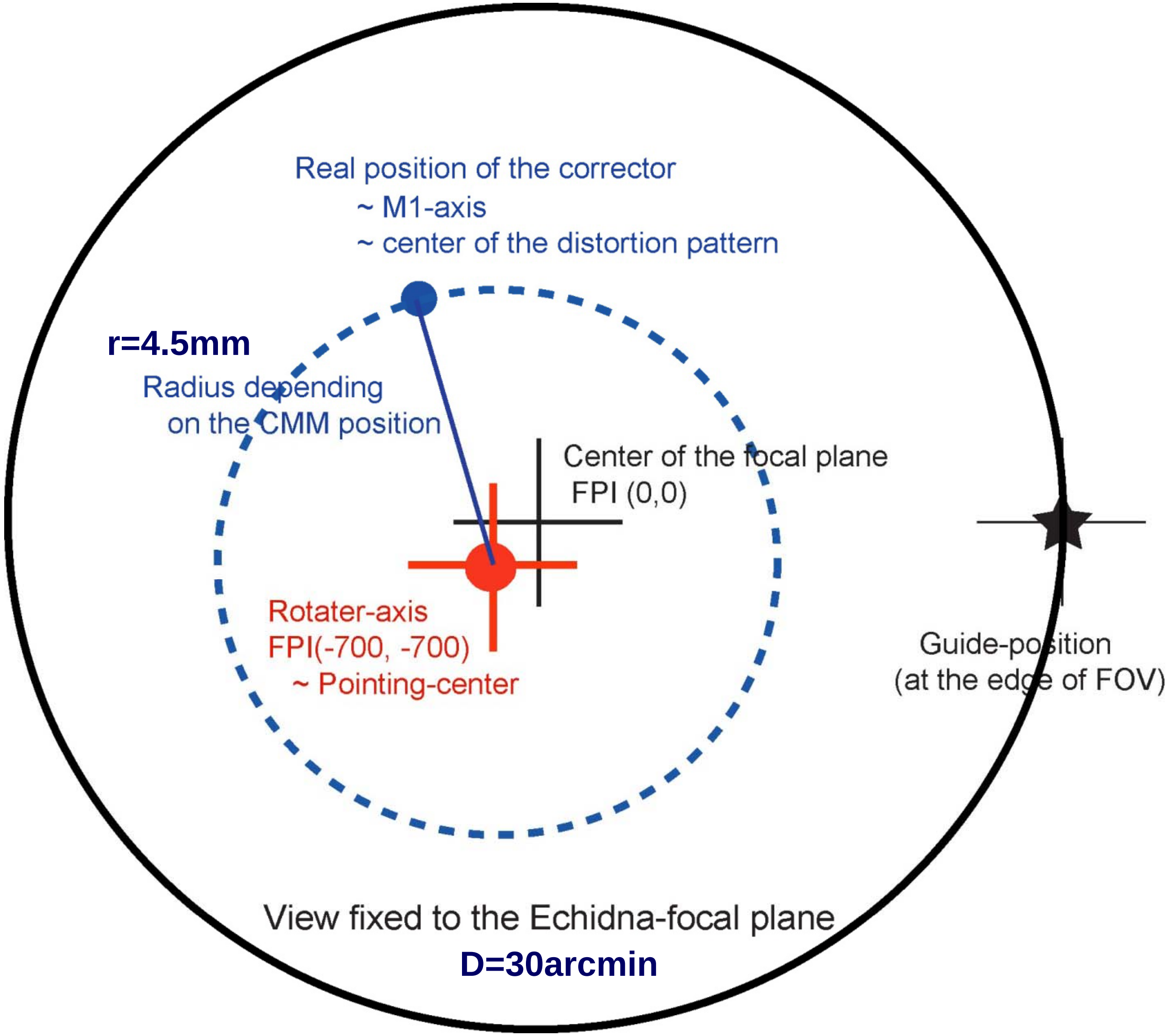
2) Checking the telescope model with the guide bandles

Configure spines based on the above telescope model, and acquire multiple guide stars. Confirm the telescope model and determine systematic offset.

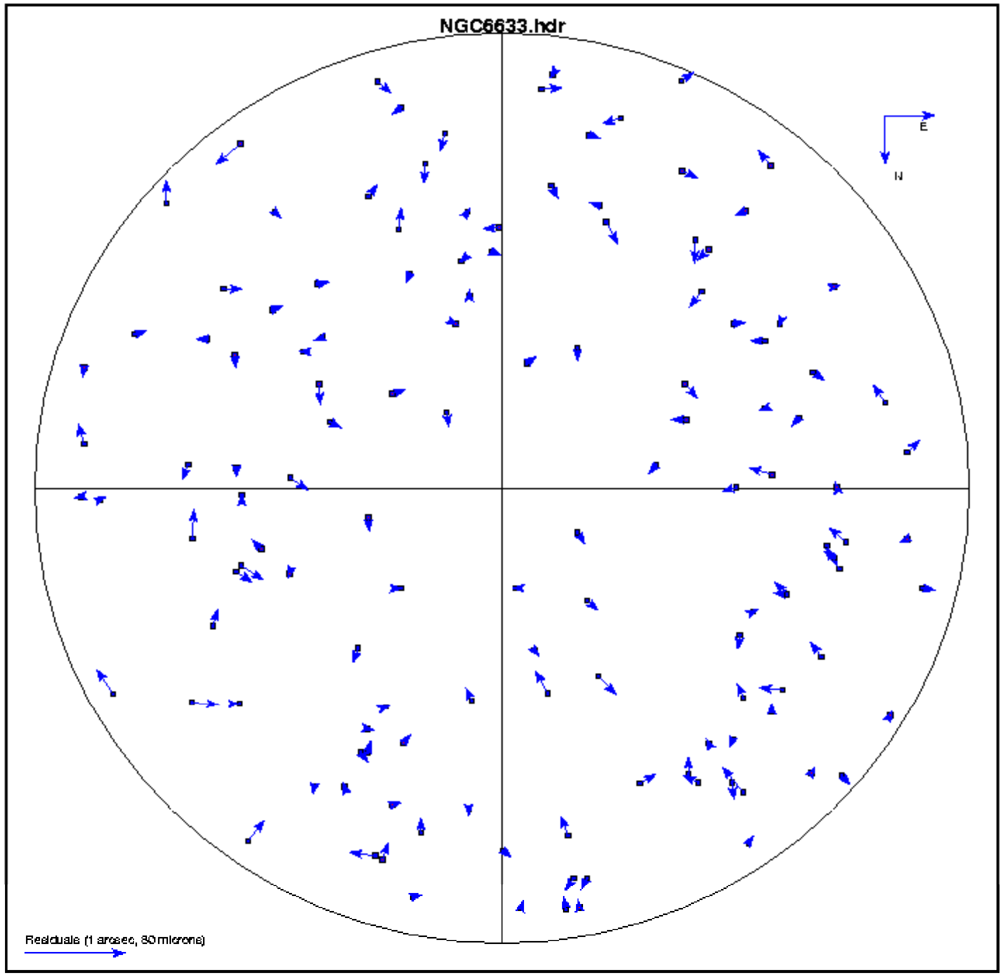
3) Fine-tune telescope model with “rastering” observations

Configure spines based on the above telescope model, and acquire spectra of 400 fibers by “rastering” telescope. Determine wavelength dependent parameter.

FMOS Echidna   focal plane schematics

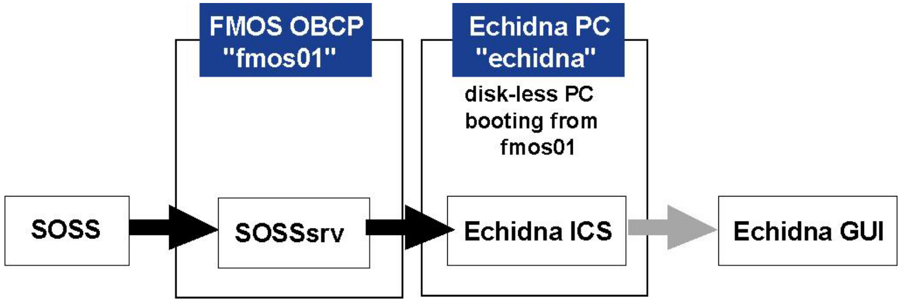


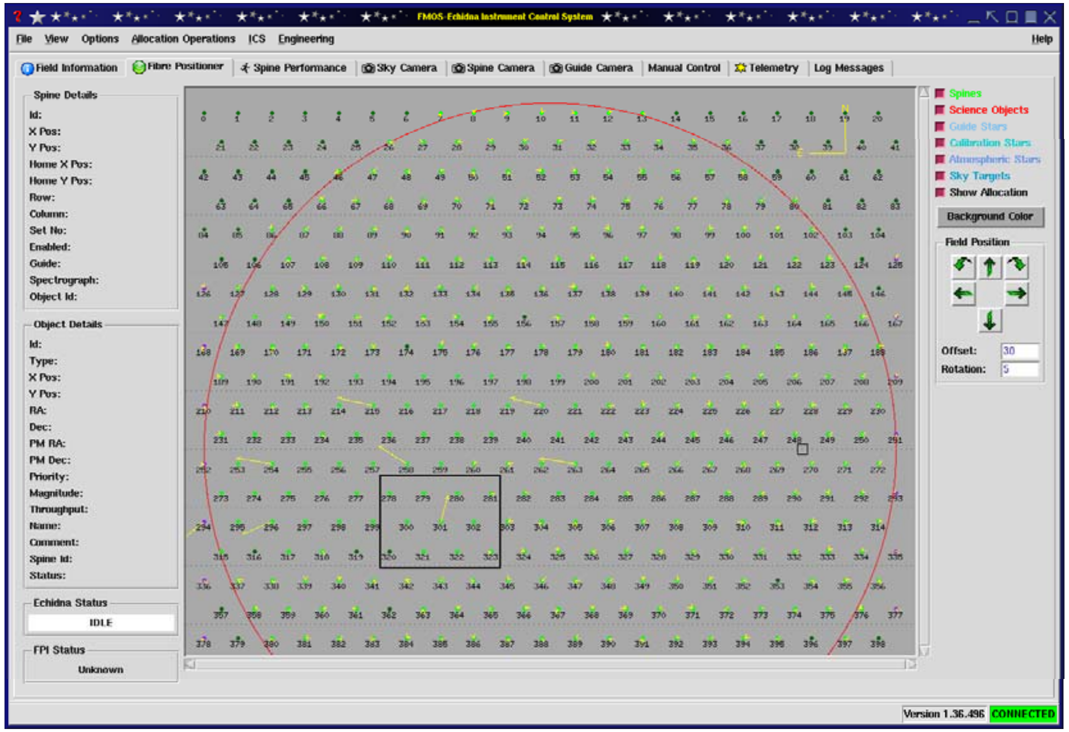
FMOS Echidna sky-camera mapping residual



RMS of 0.15arcsec is achieved already.

FMOS Echidna: control s/w and GUI





Echidna is controlled by the ICS s/w running on the "echidna" PC in the electronics enclosure of the unit. "echidna" PC is a disk-less PC booting using linux image on "fmos01".

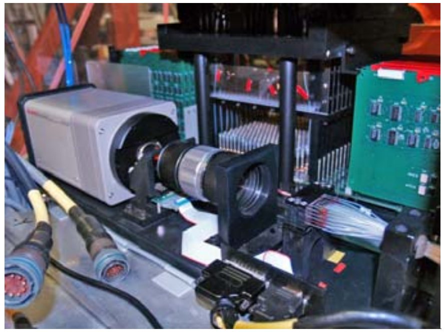
Observation catalog with targets' RA, DEC, priority etc. is fed to the fibre allocation s/w. Optimizing fibre assignment (observe higher priority targets, minimizing fibre tilt, etc.) the s/w determines the fibre allocation and store the data in .s2o file.

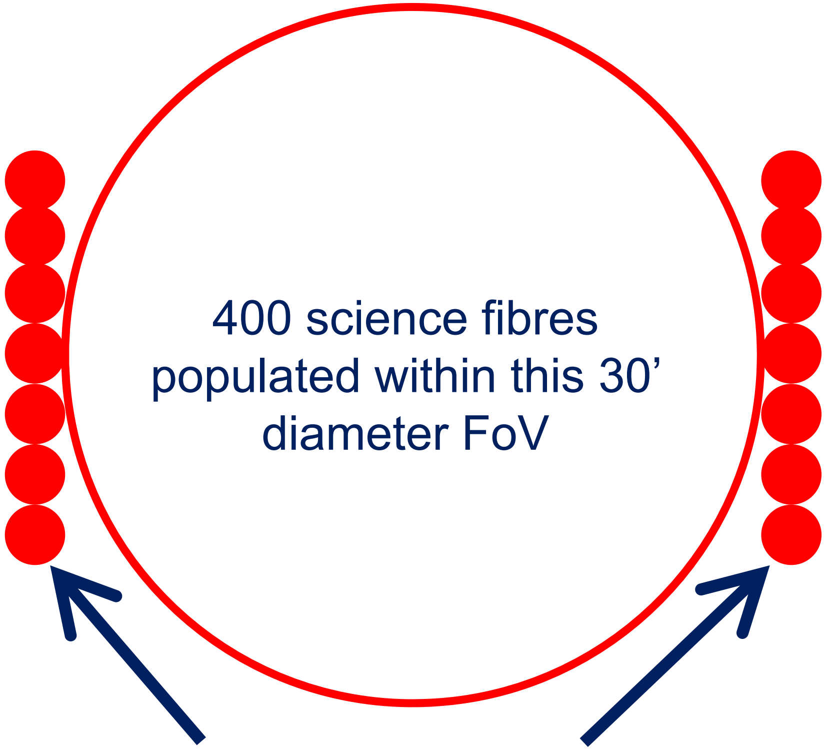
Based on the allocation, ICS s/w automatically configure fibres with several times (~7) iterations.

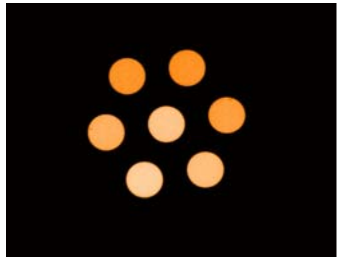
The results of the configuration will be stored in .efai file in the "fmos01" and fetched by the FITS creation software. The target information, configuration results are stored as ASCII extension header of the FITS images file.

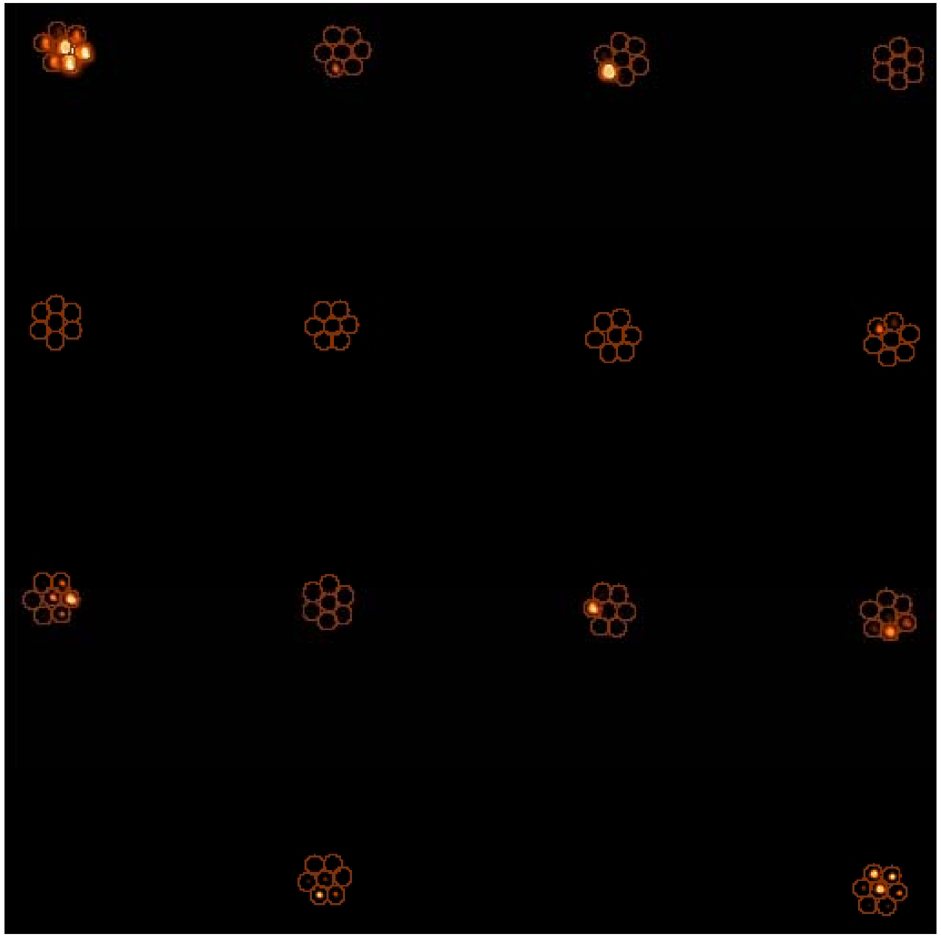
Engineering menus (for example calibrating fibre movement automatically) are also available from the GUI.

FMOS Echidna stars acquired with guide-bundles

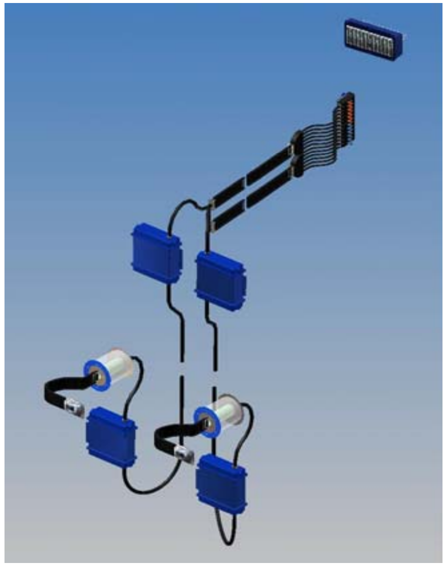






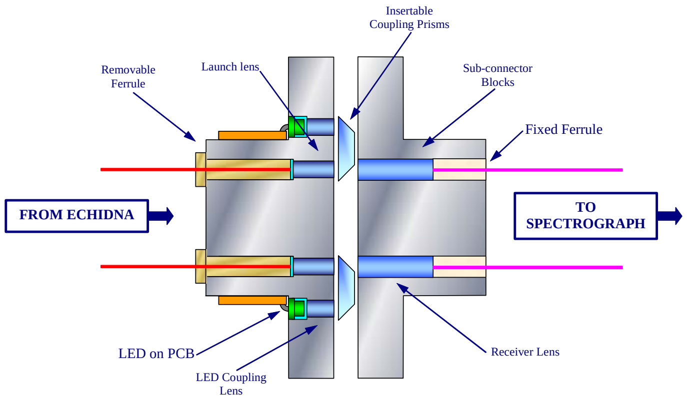


FMOS Fiber train with optical connector



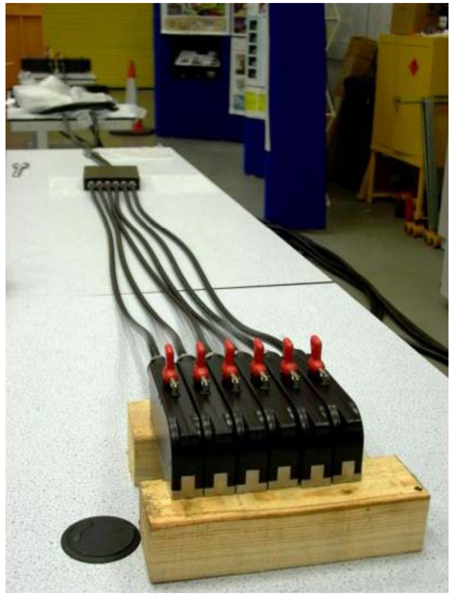
- Fibre trains with
  - 120mm 200 fibres slit
  - strain relief boxes
  - F2/F5 conversion air connector
  - fibre back illumination system

are disigned and fabricated in Durham.

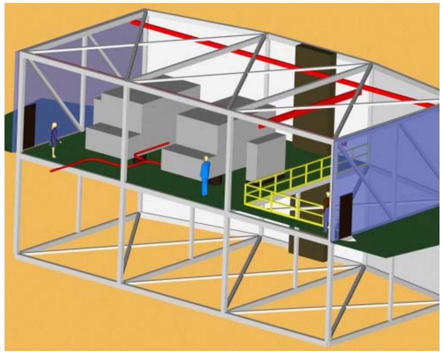


- F2-side fibre

- F5-side fibre

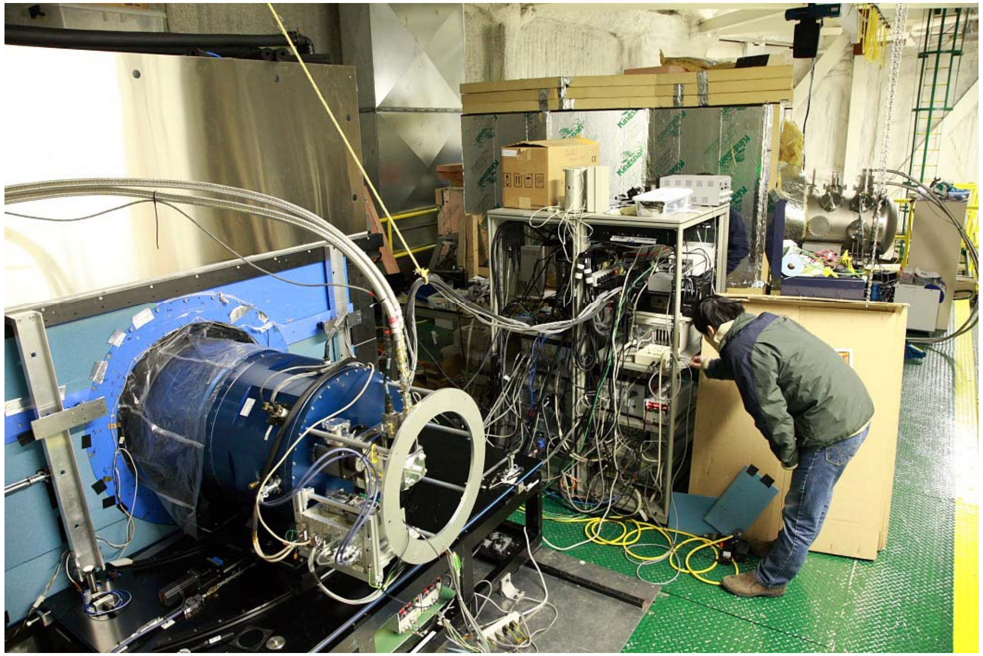


FMOS in reality: 2 cooled spectrographs (IRS1+IRS2)

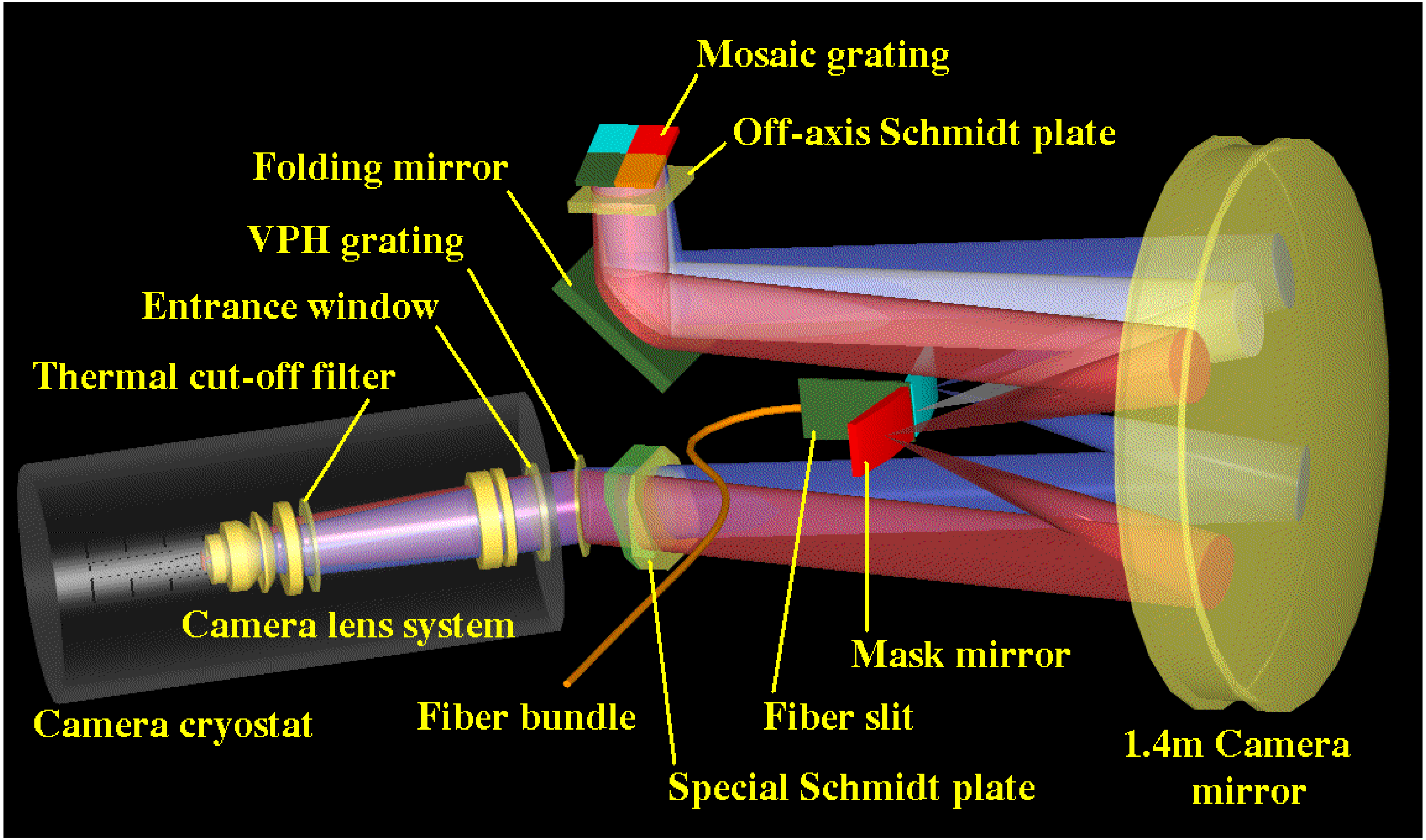


IRS1 Kyoto spectrograph

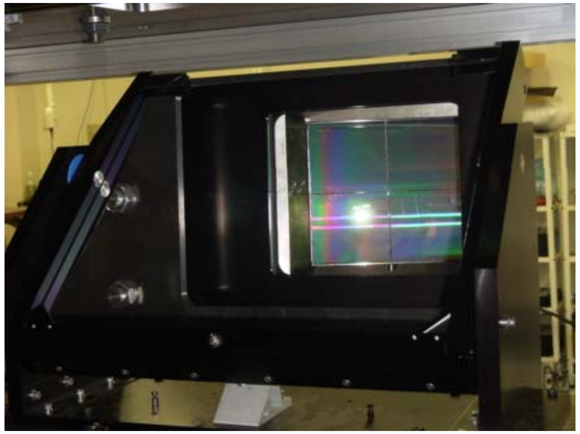
IRS2 UK spectrograph



FMOS in reality: 2 cooled spectrographs (IRS1+IRS2)

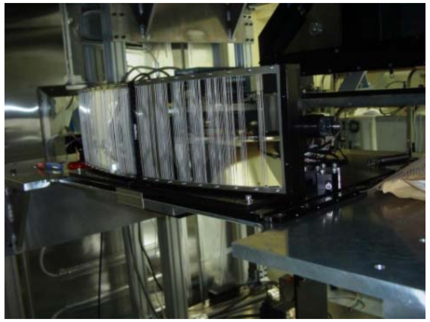


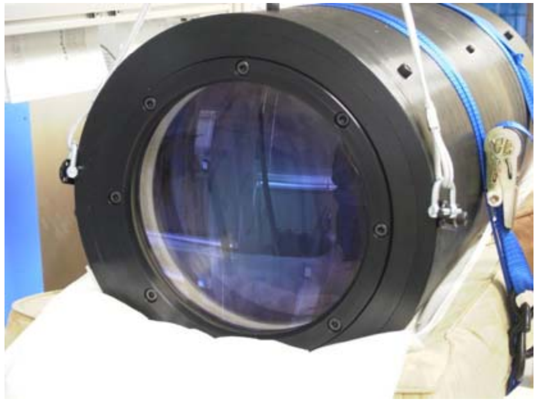
FMOS in reality: 2 cooled spectrographs (IRS1+IRS2)



Each component is huge.

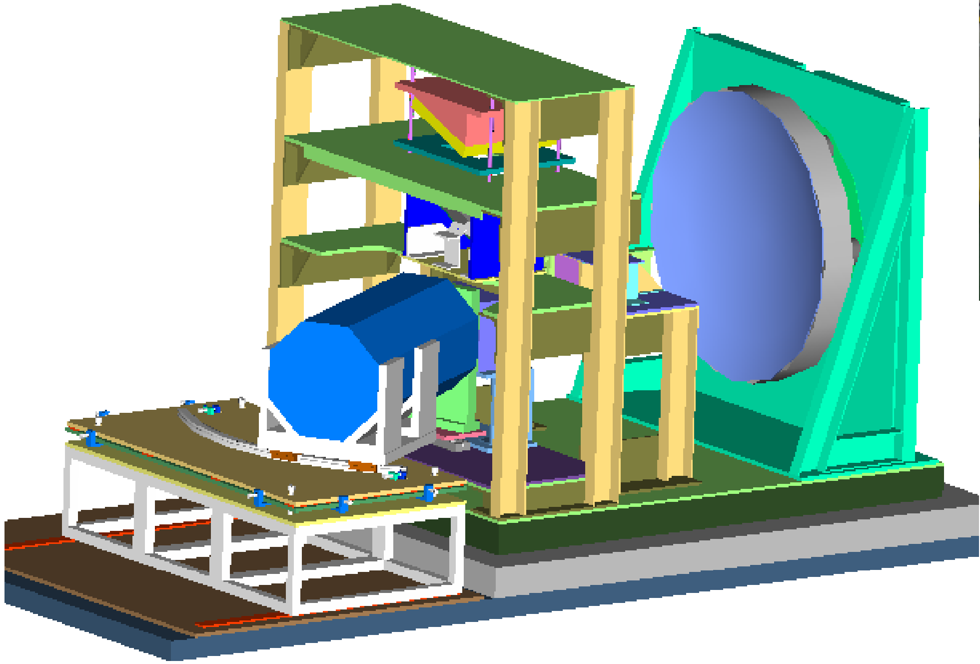
Mosaic grating, Special Schmidt plate, Camera lens system, OH-suppression mask, 1.4m primary mirror.

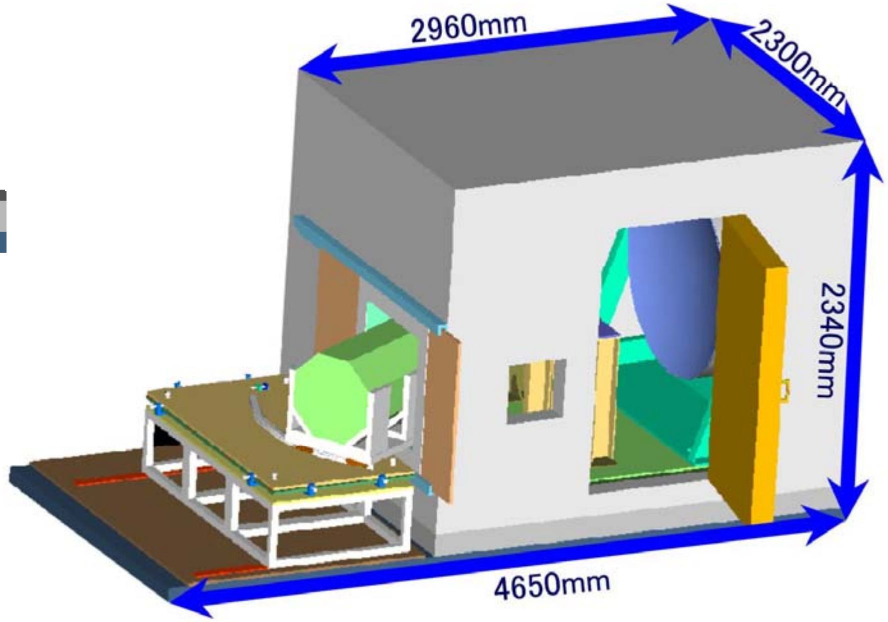




FMOS in reality: 2 cooled spectrographs (IRS1+IRS2)

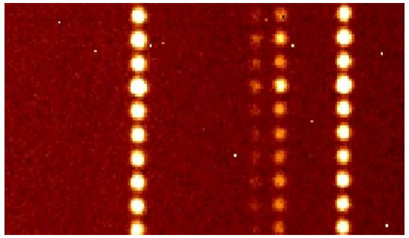
Spectrograph optics are enclosed in big refrigerators and cooled down to -50 – -70C.





FMOS IRS Calibration Frames

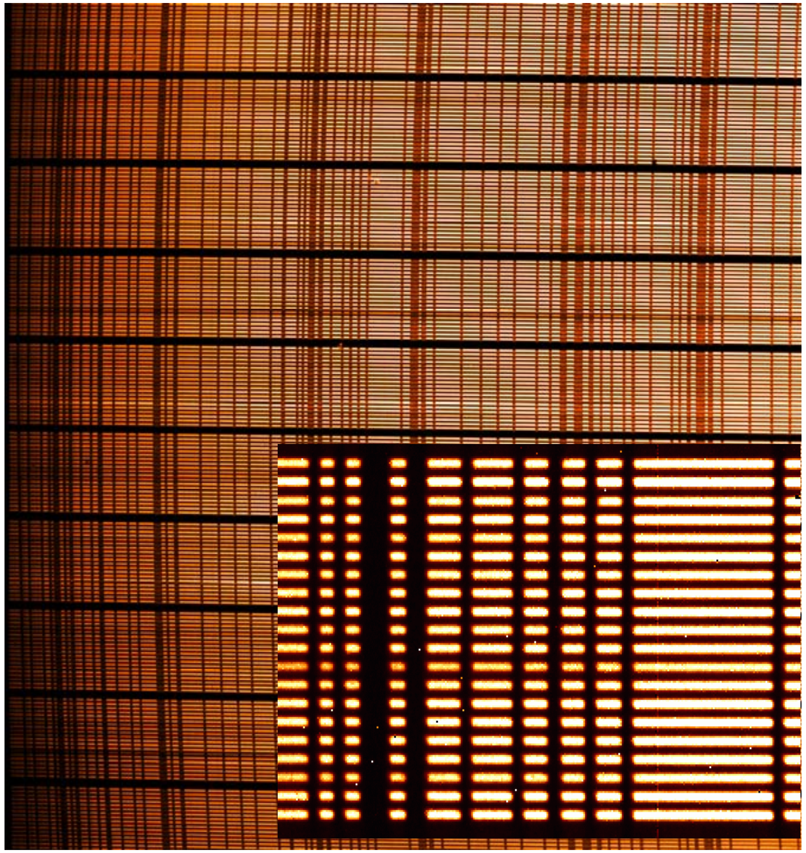
Optical alignment : FWHM = 4 - 5 pix at ~ -55 deg of T(IRS) as designed is achived.



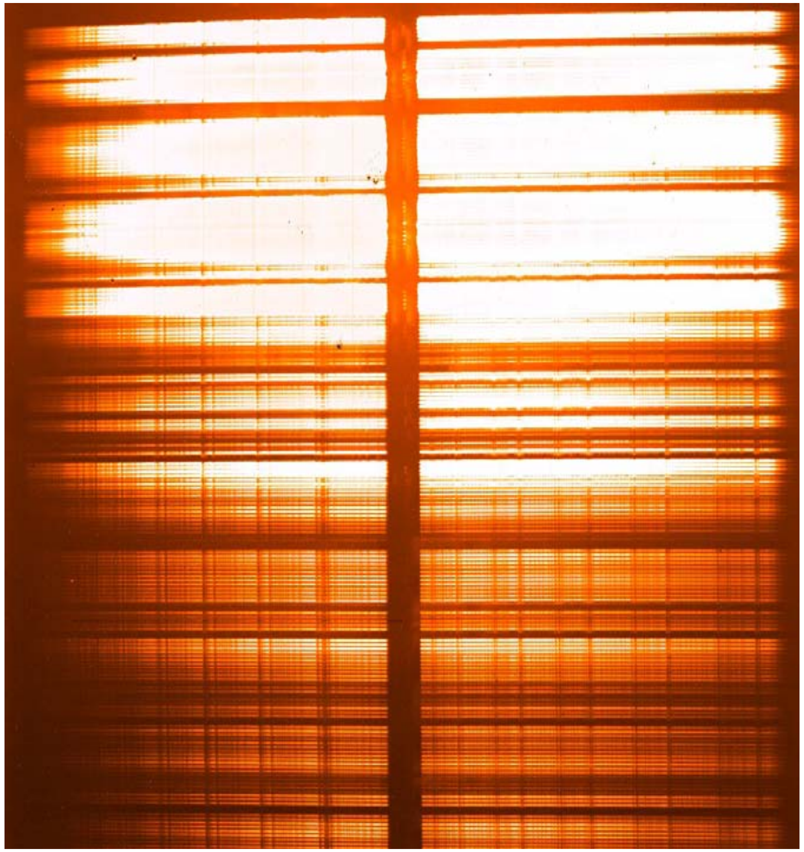
Ar lines images

Halogen lamp spectra

HighRes mode (R=2200, ¼ of 0.9-1./8um)

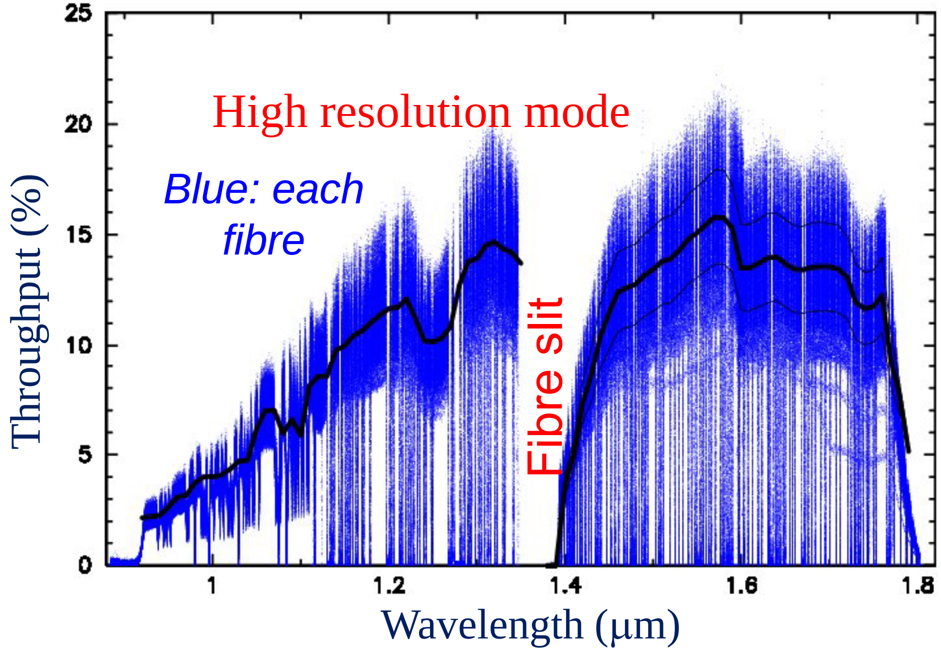


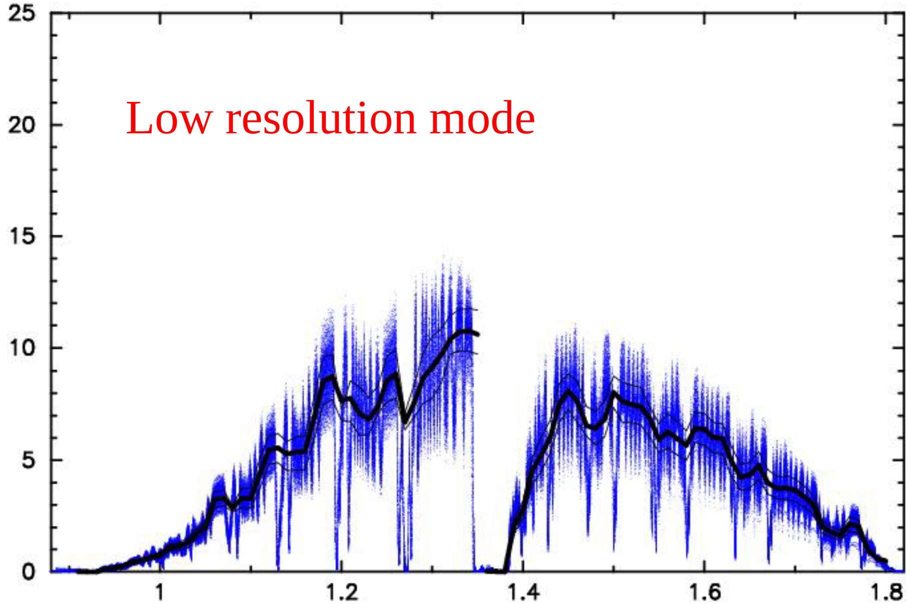
LowRes mode (R=500, 0.9-1.8um)



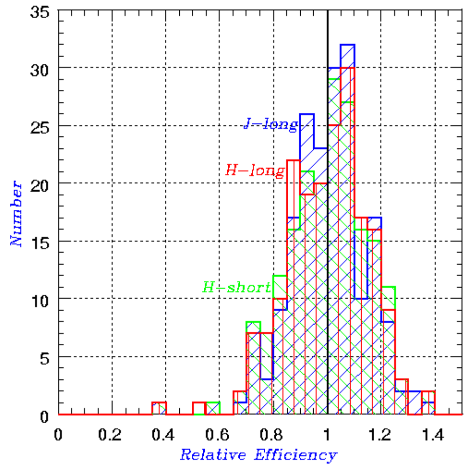
FMOS IRS System efficiency

Using a black-body radiation source, we determined the efficiency of the system. The results are basically consistent with what we expect from
PF corrector x Echidna x fibre x fibre connector x IRS x Cam x detector



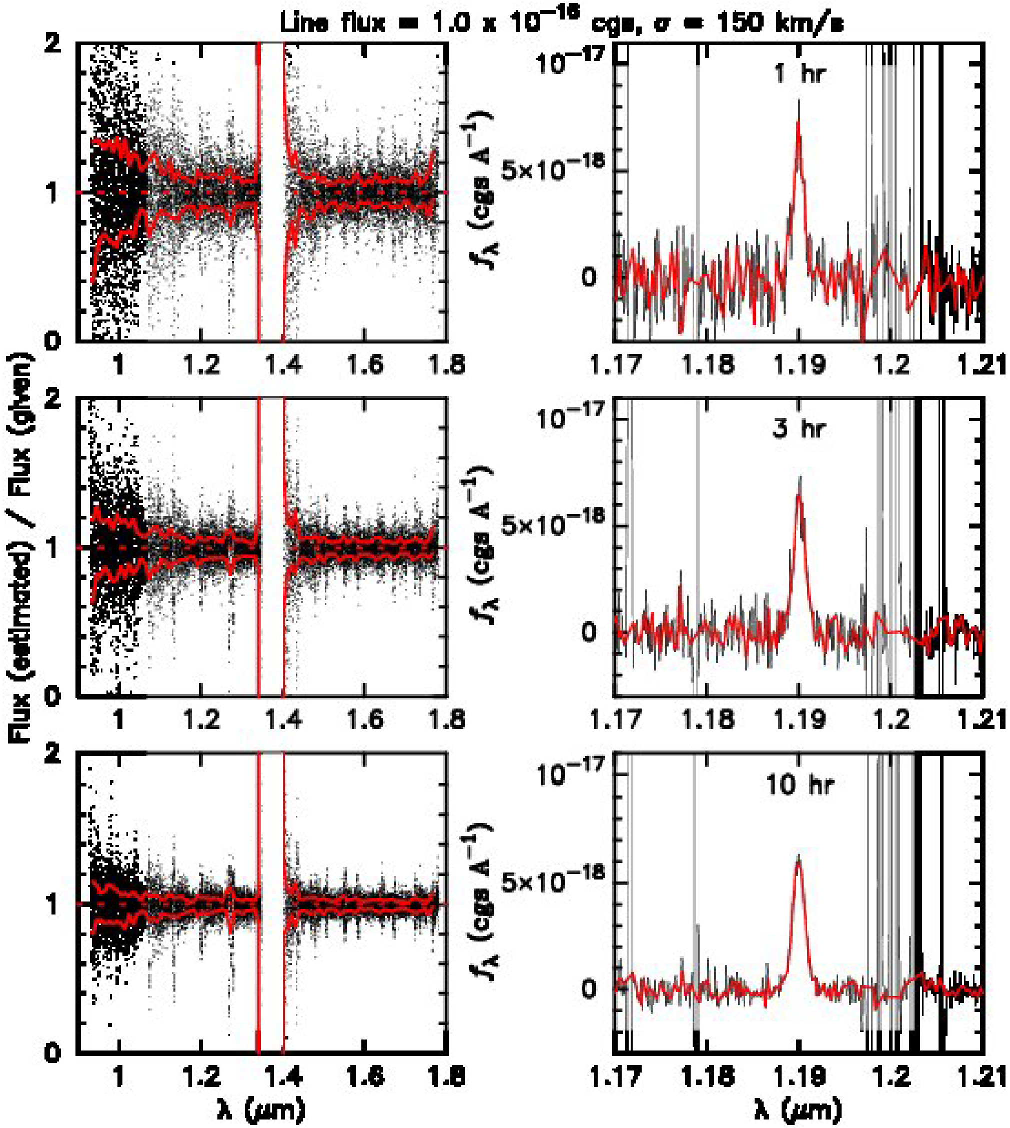


Fibre-to-fibre variation:
a factor of ~1.2 around med.



FMOS Expected performance

Measure the flux of a simulated emission line



Parameters given:

Line flux = 1x10^-16 cgs
Line width: σ=150 km/s
Obs mode: HR
3 cases of integration time:
1hr(top), 3hr(mid),& 10hr(bot)

What's been done:

Simulating an emission line at every angstrom and measure the flux. Repeat this 20 times.

Left panels:

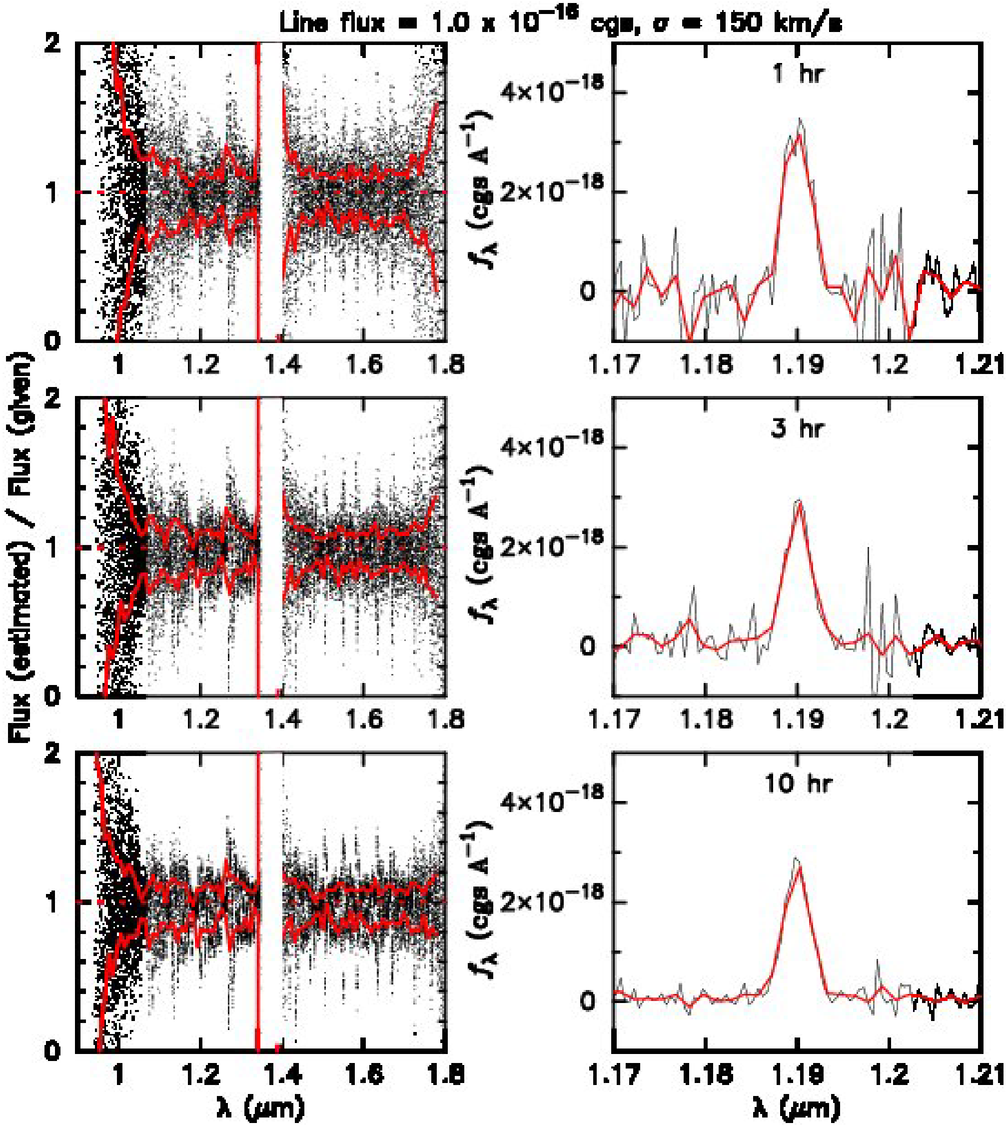
Measured flux vs. λ. Red lines show the 25 & 75 percentiles of the data distribution.

Right panels:

Examples of simulated lines.

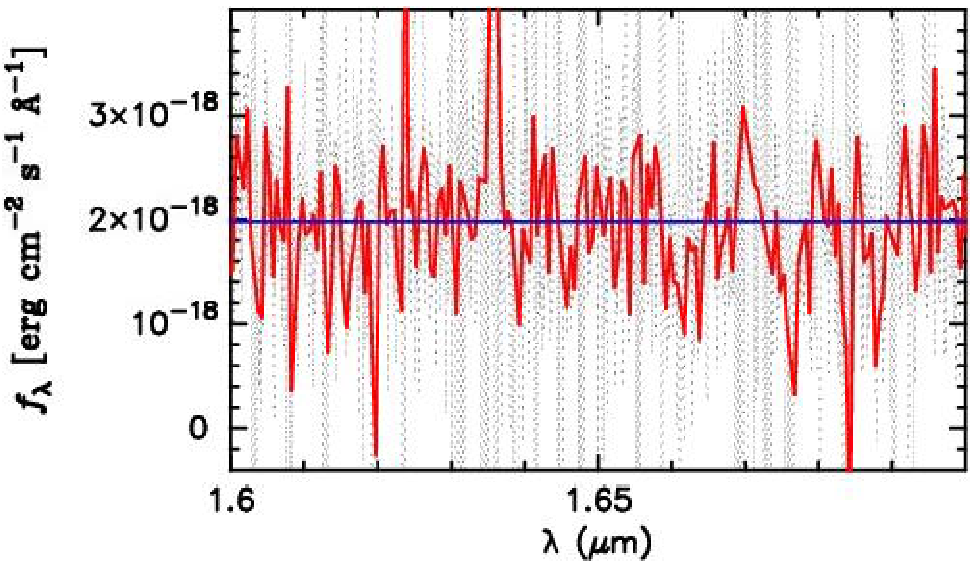
FMOS Expected performance

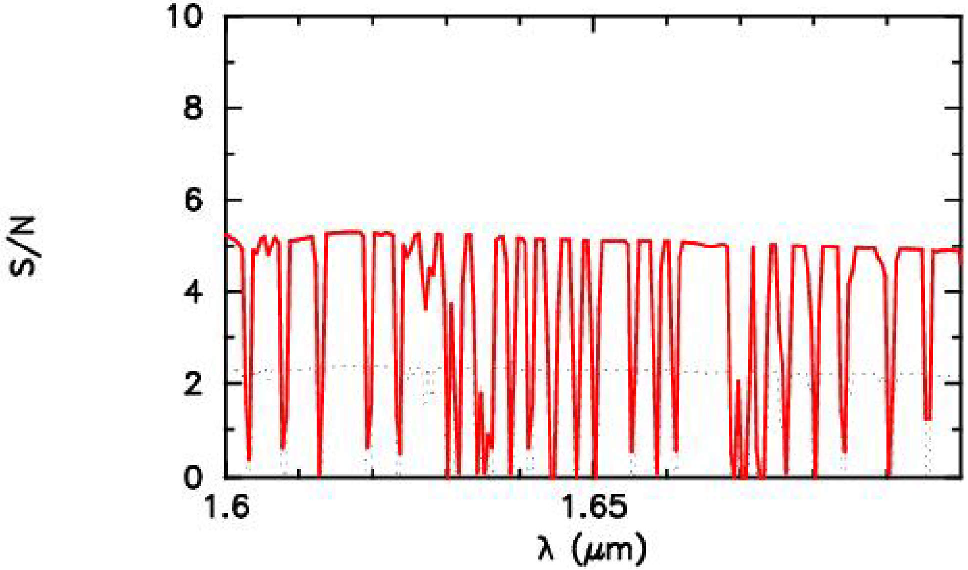
Measure the flux of a simulated emission line



Same as the last slide,
but for LR mode.

FMOS Expected performance





Simulation for continuum emission

(example, J-band High-Res)

Red solid (black dotted) line after (before) 5pix binning, respectively.

Magnitudes giving S/N = 5 with 1 hour exposure, per $\Delta\lambda$ (~5 pix):

HighRes Mode:

JAB=21.2 (Jvega=20.3)

HAB=20.8 (Hvega=19.4)

LowRes Mode:

JAB=21.8 (Jvega=20.9)

HAB=21.2 (Jvega=19.8)

FMOS commissioning in reality

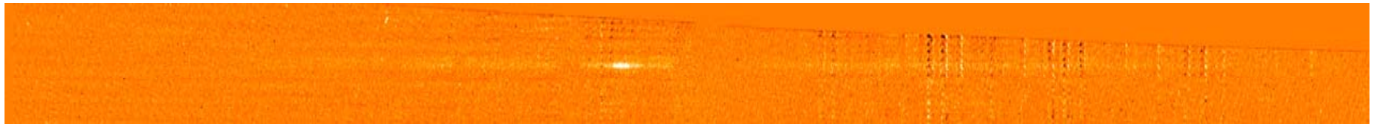
A must have item….cherry picker.

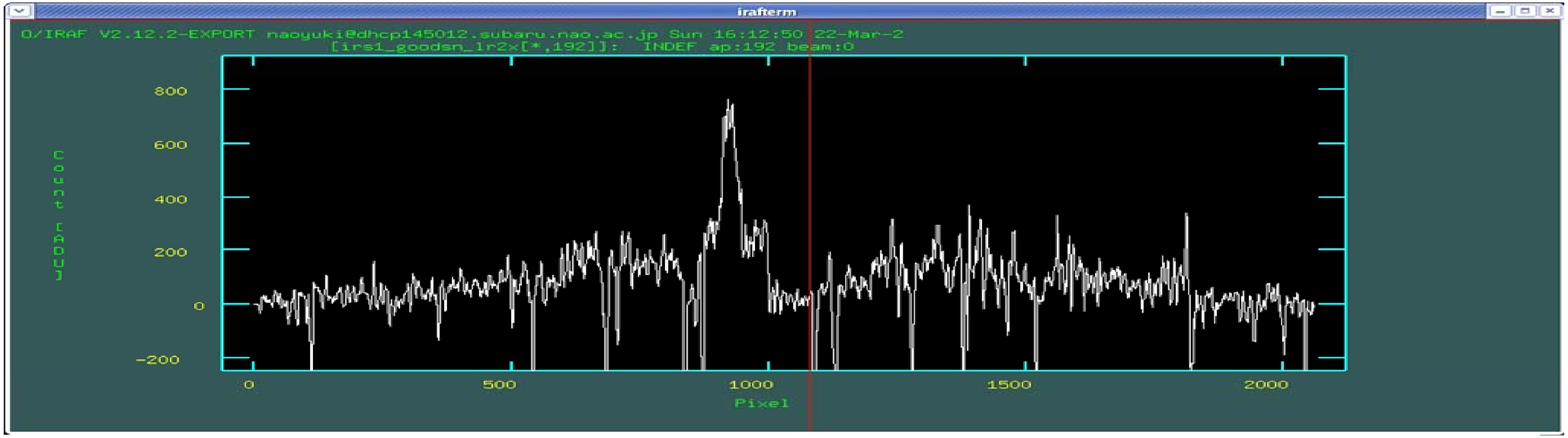
FMOS First Light (2009 Mar)

Long exposure of faint objects with fibre auto guiding

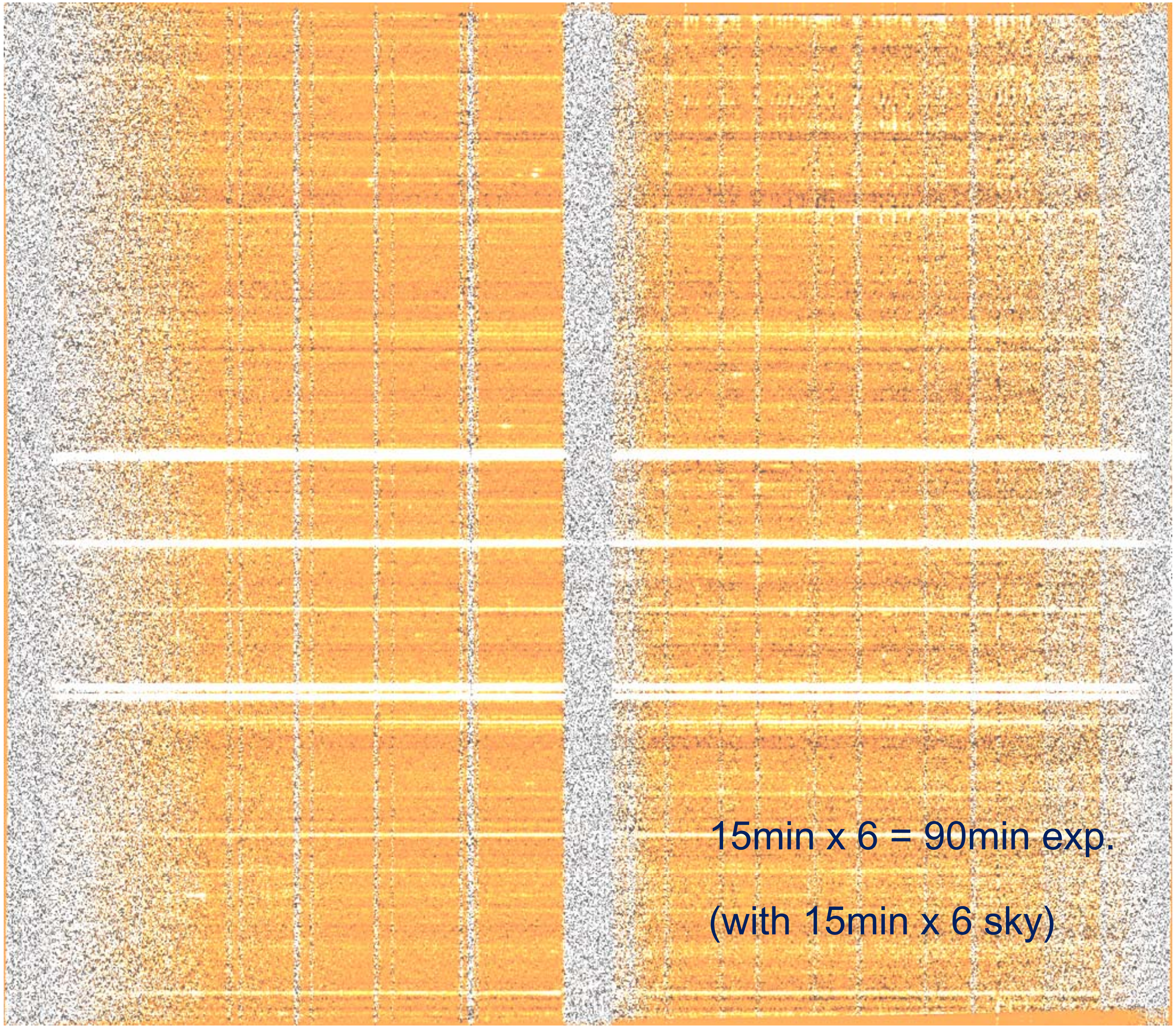
GOODS-N field, Low Res, 15 min “on” minus 15 min “off” x 3

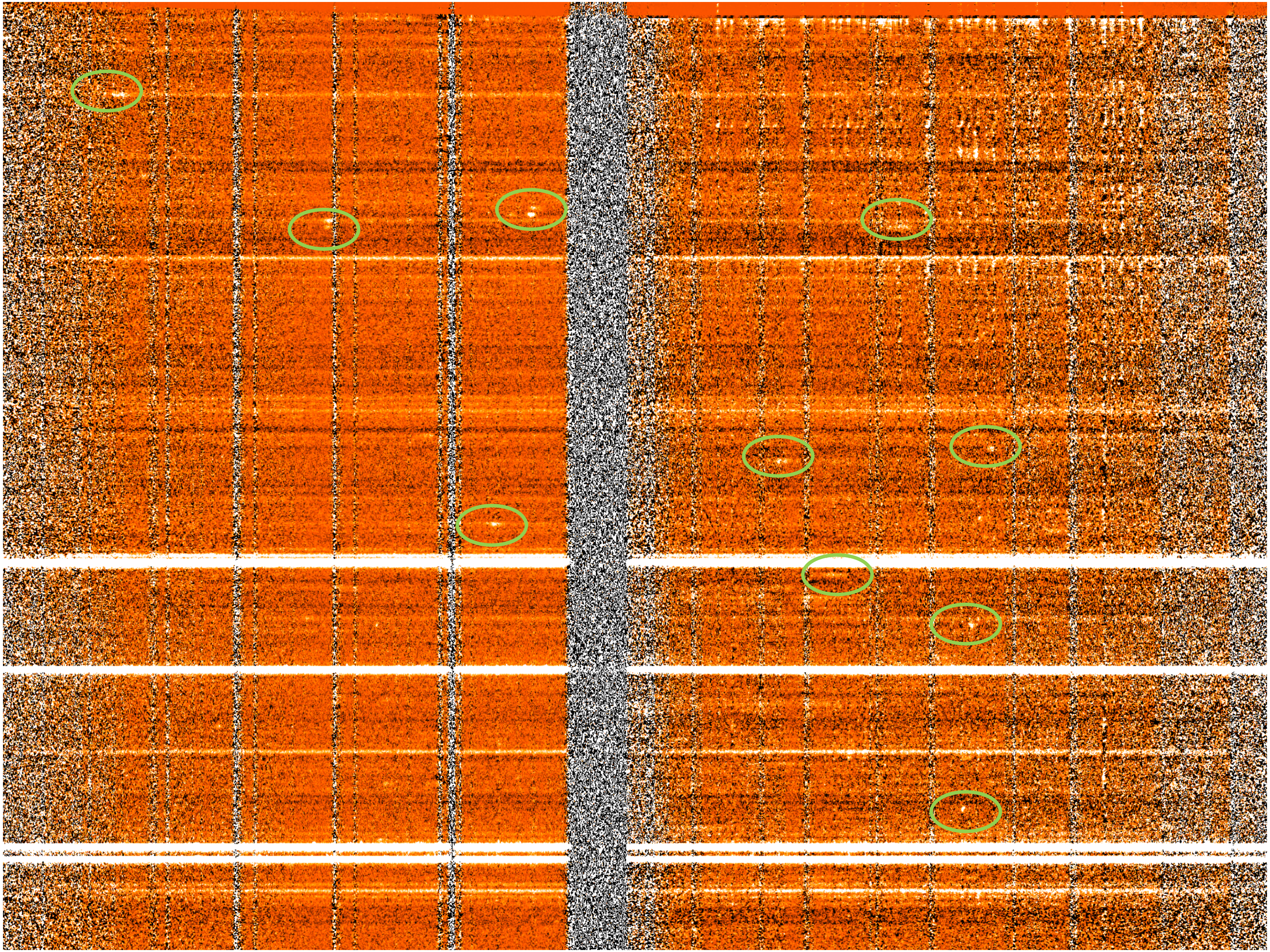
QSO@z=1 z’(AB)=18.9





FMOS First PV data taken ~10days ago





FMOS Schedule

2009 / 10, 12, 2010 / 02, 04 Engineering Observation (entering PV(-like) phase).

2010 / 06 Start open-use (and GT) observation with IRS1 low-resolution mode

- IRS2 UK spectrograph has detector readout issue, need to be finalized.

2010 / 09 Open-use with IRS1, IRS2 with high- and low-resolution modes

2010 / 2nd half ? Start Subaru strategic program (SSP) with FMOS

- Proposal finalization underway based on the feasibility revealed during the PV observations.

FMOS SSP H=20 galaxy evolution survey

Targeting galaxies at z=1-3 (H=20 corresponds to L* at z=2)

— 5 FoVs magnitude limit unbiased survey, 60 nights.

- Pre-selections with photometric redshifts (removing z<0.5 galaxies).
- One field per night
- Cross-beam switching mode with 200 objects + 200 sky at once and dither to 200 sky + 200 same objects.
- 1500+ galaxies in one FoV * 5
- Subaru XMM-Newton Deep Survey field (UKIDSS UDS, Spitzer SpUDS) + COSMOS field.

— Additional FoVs covering cluster region, complementary to the “field” observations.

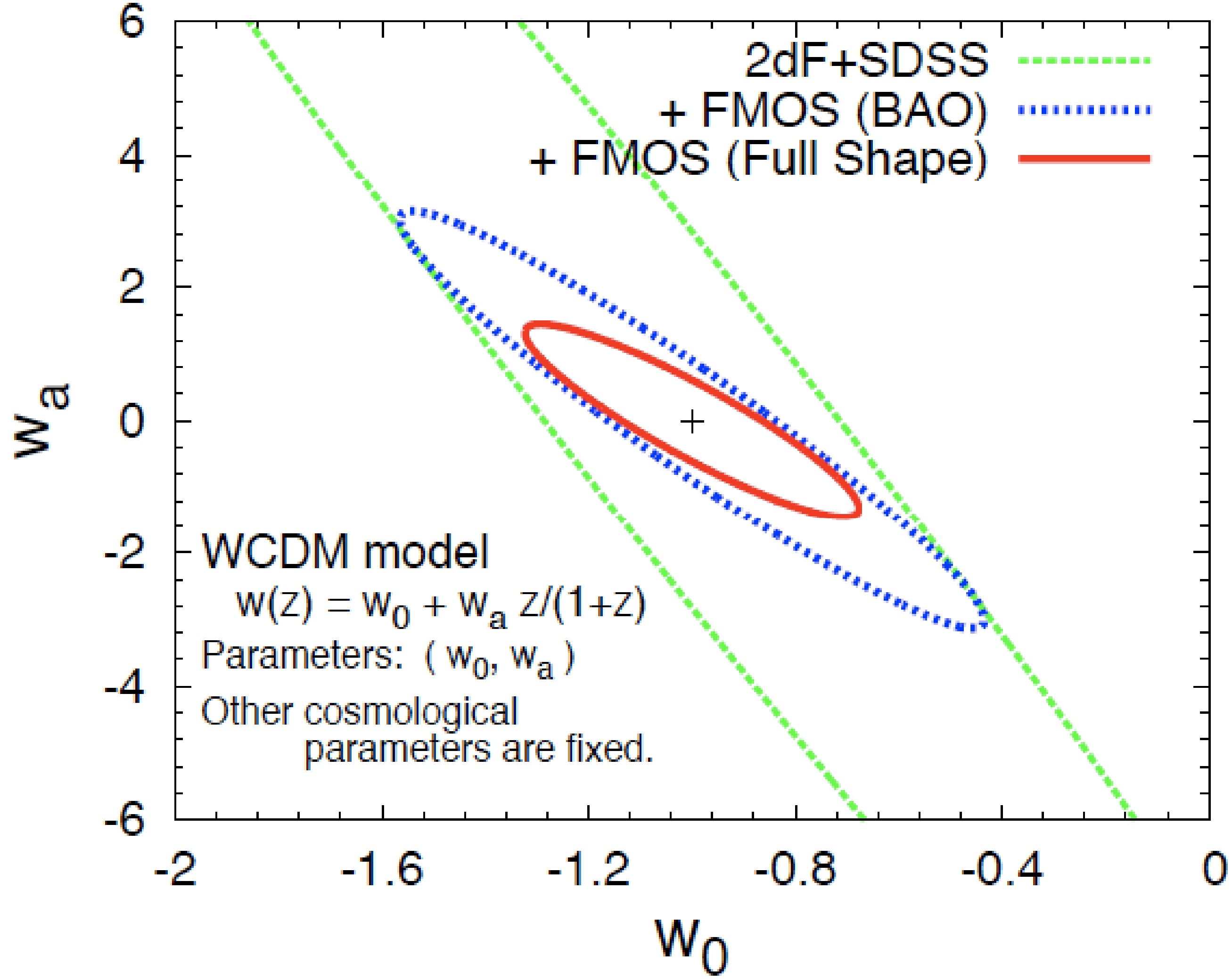
FMOS SSP BAO *FastSound*

- **FastSound**
  - Fast: **F**MOS **A**nkoku **S**hindou **T**ansa (= Dark Oscilaltion Survey "*in Japanese*")
  - Sound: **S**ubaru **O**bservation **U**nderstanding **N**ature of **D**ark energy
  - A BAO survey at $z\sim1$ using Hα by Subaru/FMOS
- **Purpose:**
  - Precise measurement of the geometry of the universe at z~1
  - Constraint on the nature of dark energy (w, dw/dt)
- Survey Area Candidates:
  - CFHTLS Wide: 170deg^2, ugriz, r=25.9 (deep, but a little small area)
  - RCS2: 830deg^2, grz, r=24.8 (shallow, but a large area)
  - Future Surveys:
    VST/VISTA, PanSTARRS, still others

In details, see Sumiyoshi's poster.

FMOS SSP BAO w-w' constraints

- 200-night survey, 500deg2, 0.5hours integration per FoV.
- 3% precise measurement of BAO distance at z~1 (BAO detection: S/N~3)



FMOS Summary

FMOS is now opening a new opportunity of wide-field NIR spectroscopic survey.

- NIR galaxy evolution survey
- BAO galaxy redshift survey
- YSO researches in star forming regions
- Galaxy archeology in NIR (bulge region?)
- etc etc.

Thank you for your attention.