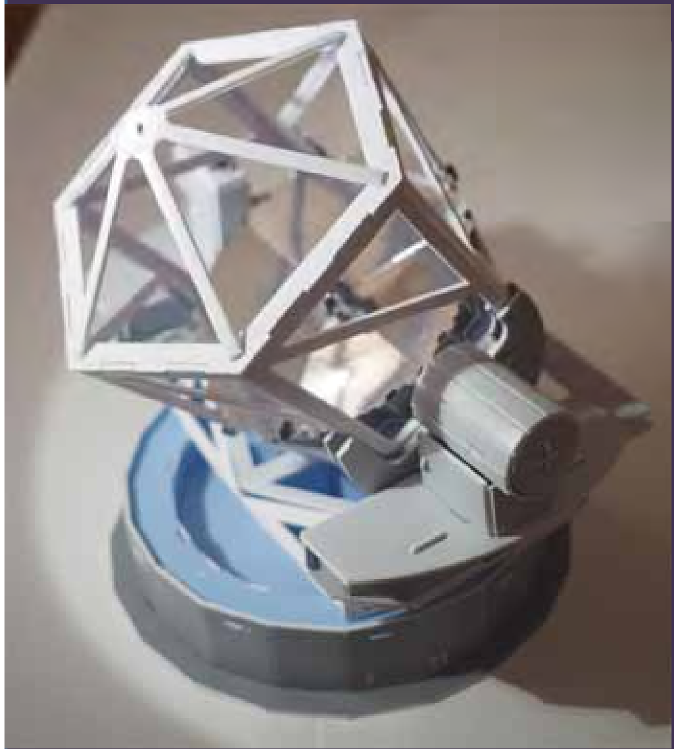


TMT-AGE:
TMT Analyzer for Galaxies in the Early universe

AO-assisted wide-field multi-object NIR spectrograph concept

Masayuki Akiyama (Tohoku Univ., Japan)
and TMT-AGE team

Three Science Drivers

1. How is the internal structure of local galaxies established ?

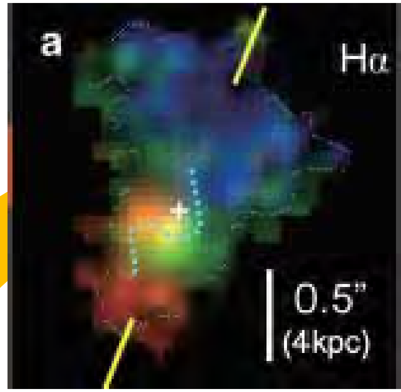
2. What is going on in galaxies in the early universe ?

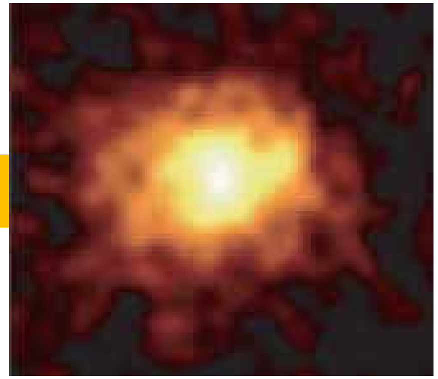
3. Hunting for galaxies/AGNs at z>8

Statistics is a key

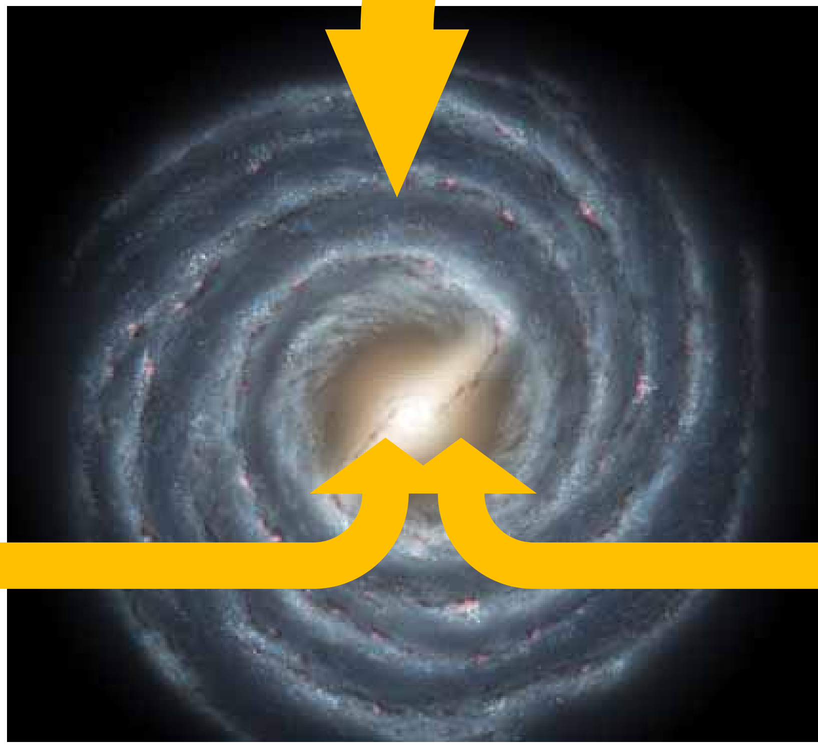
1. How is the internal structure of local galaxies established ?

Turbulent / High-density disks at high-z



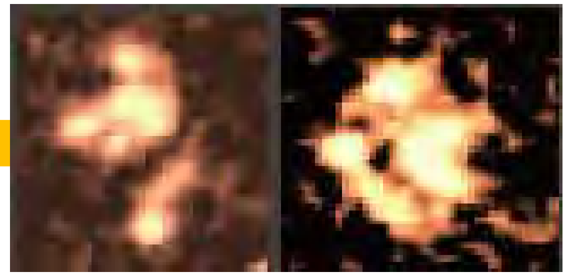


Typical galaxy seen in the local universe

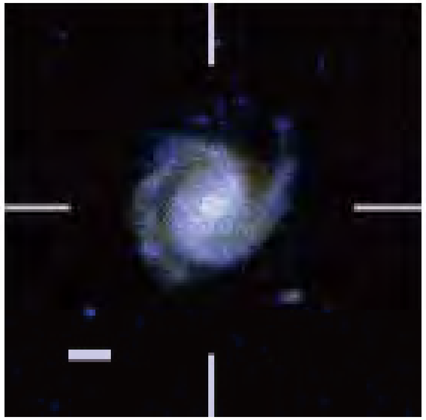


Very compact galaxies at high-z

Clumpy galaxies at high-z



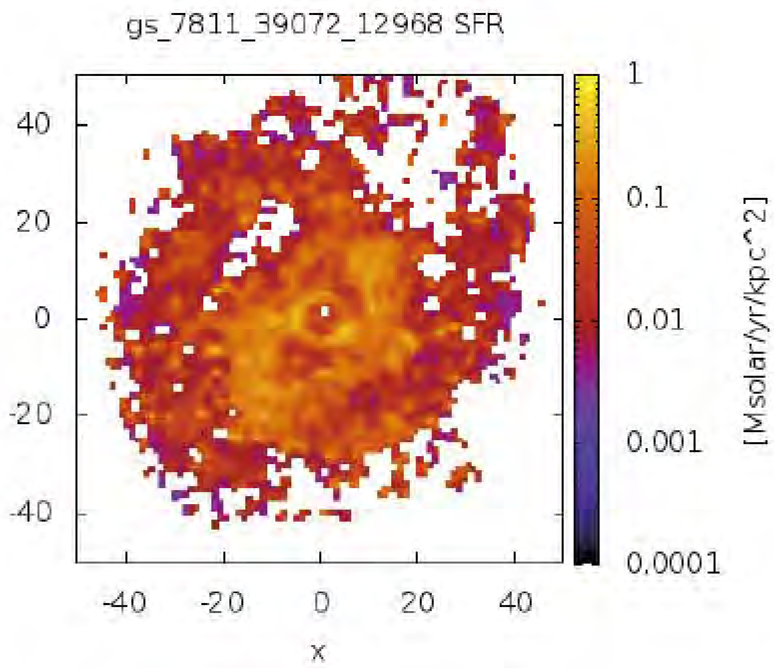
1. Galaxy "establishment" history



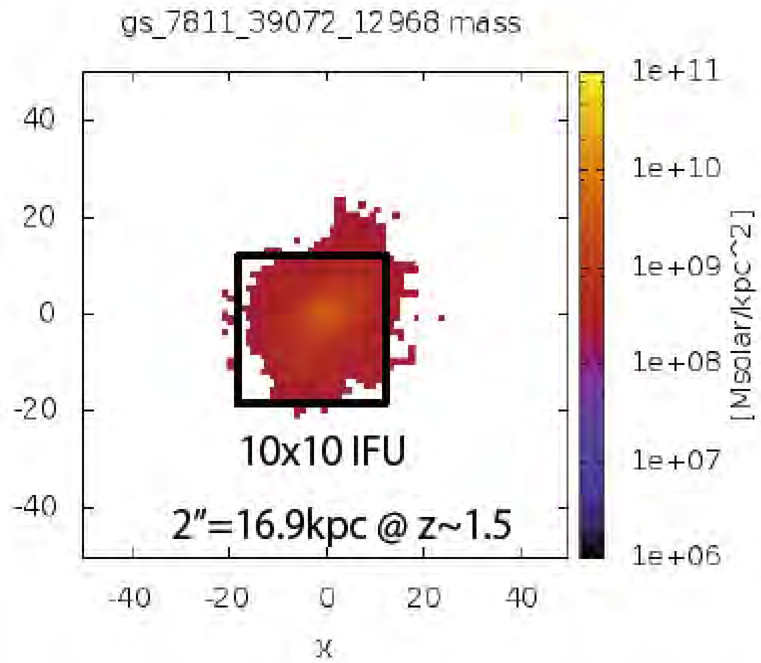
Example image of a massive galaxy at z=1.0

Even if we put this galaxy at z=1.5, TMT IFU spectroscopy can detect Ha-line / stellar continuum from the colored regions shown below.

Gas dynamics

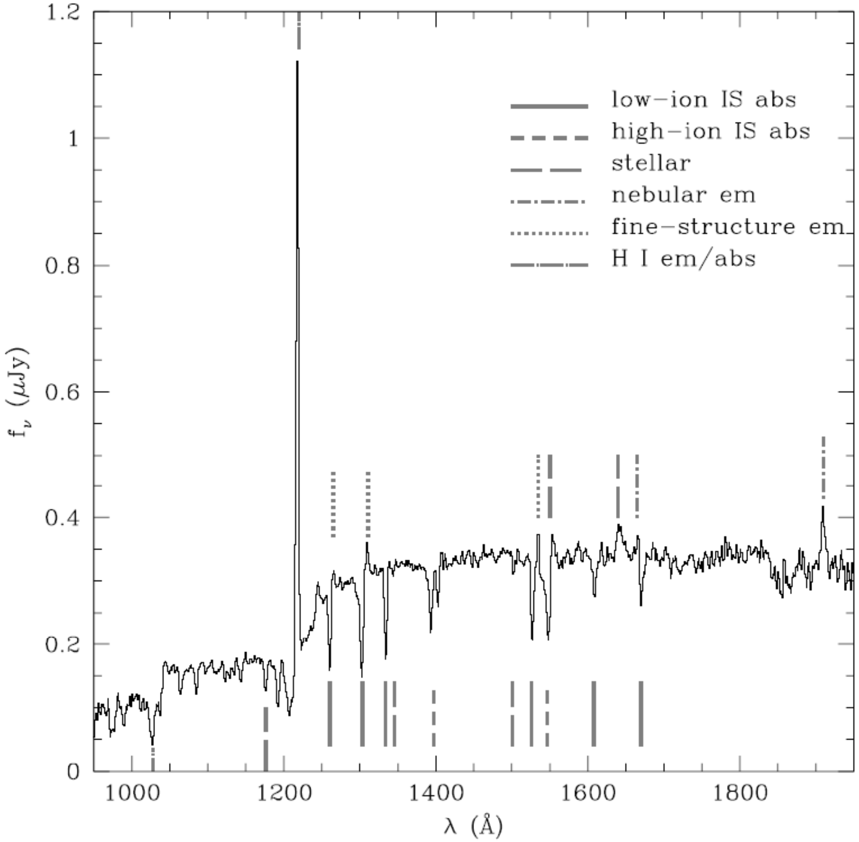


Stellar dynamics



2. What is going on in galaxies in the early universe ?

Average of rest-UV spectra of z~3 star-forming galaxies

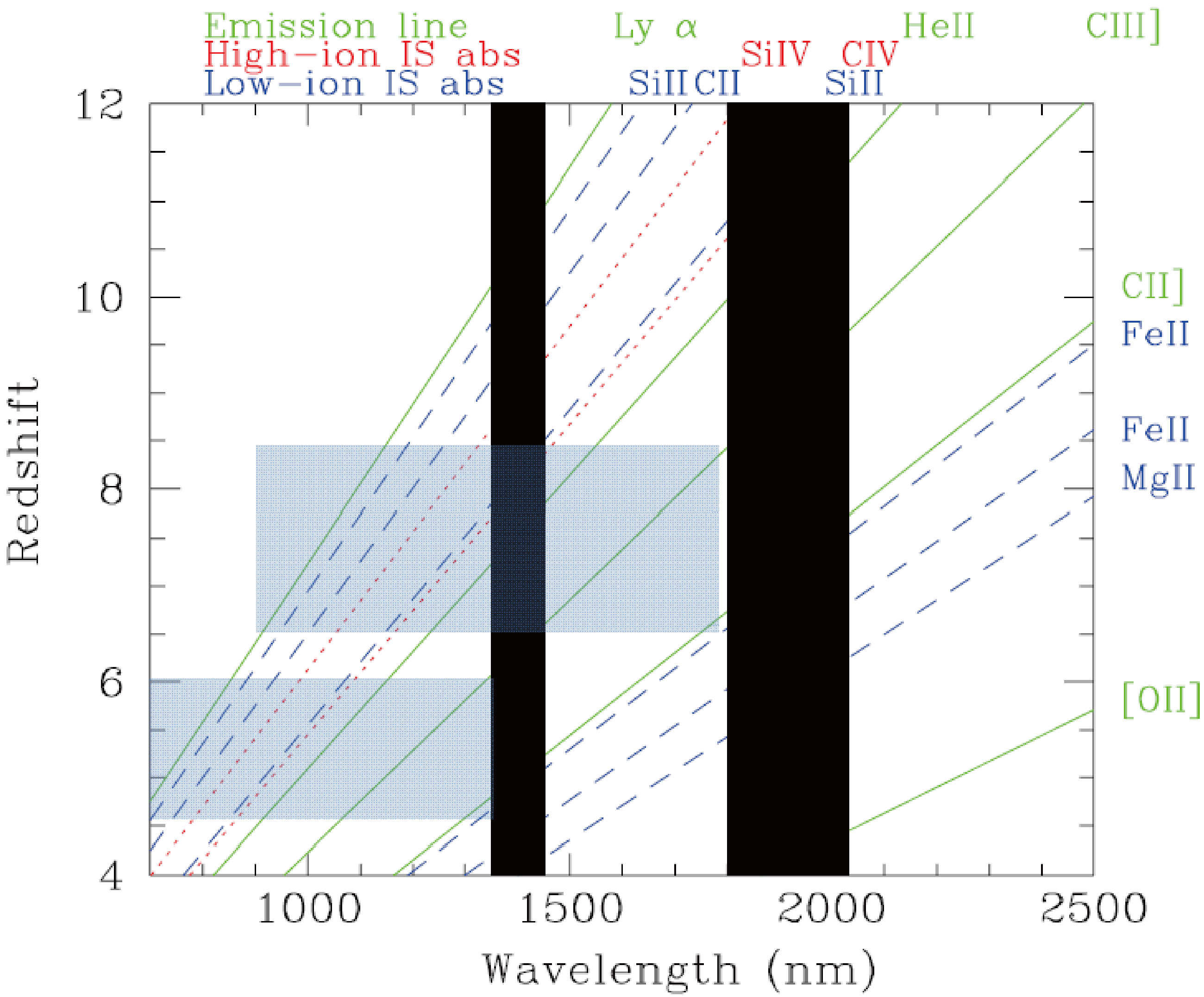


Shapley et al. 2003

- Rest-frame UV features of star-forming galaxies
  - Low-ion IS abs line:
    - ➢ Distribution and dynamics of neutral gas
  - High-ion IS abs line:
    - ➢ Distribution and dynamics of ionized gas
  - Stellar emission:
    - ➢ High-mass star contents
  - Nebular emission:
    - ➢ Galaxy rest-frame

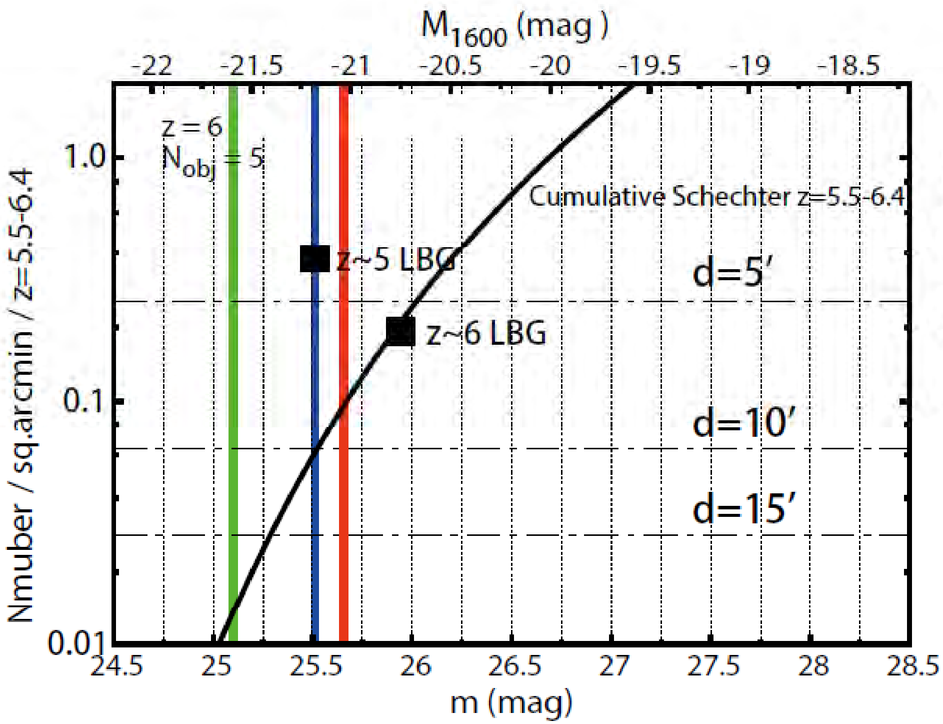
Diagnostic lines for high-z galaxies

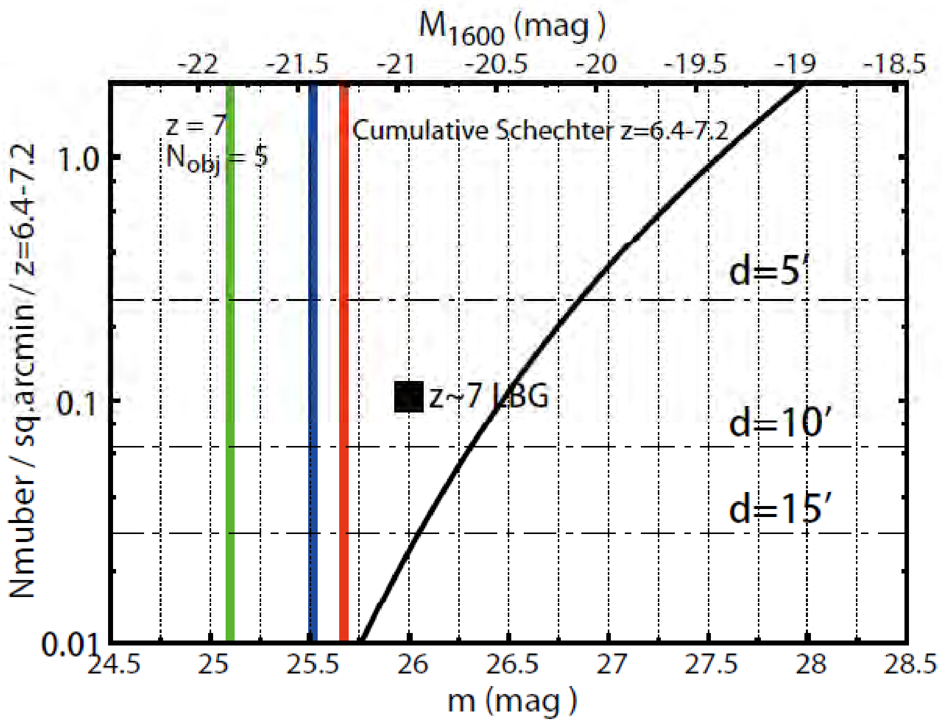
- Most of the redshifted UV diagnostic lines fall within 700-1800A for galaxies at z>5-9.



Number density

- Red (MOAO), blue (GLAO), green (seeing-limit) lines show the detection limits for each system.
- Number density of luminous z~6-7 LBGs is not so high.





Filled squares from Bouwens et al. 2014,
V-dropout for z~5, i-dropout for z~6, and Y-dropout for z~7

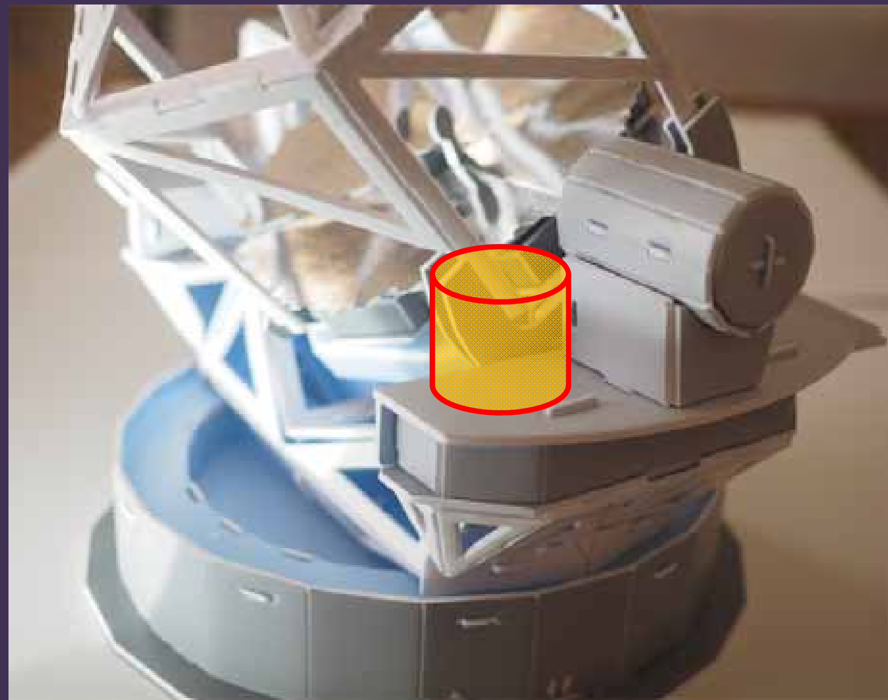
3. Hunting for galaxies/AGNs at z>8

- Follow-up spectroscopy of candidates of high-z galaxies / AGNs picked up by wide-field IR surveys (Euclid, WFIRST, SPICA,,,), and wide-field X-ray surveys (Athena, STARX,,,) from space.

Requirements

1. Spatially-resolved spectroscopy of z=1-5 galaxies.
   - High spatial and spectral resolution deployable multi-IFU spectrograph covering wide target field.
   - 0.05x0.05” sampling IFUs with 2” FoV
   - R=10,000 spectroscopy for v~30km/s

2. Integrated spectroscopy of z>5 galaxies.
3. Follow-up spectroscopy of candidates of z>8 galaxies
   - Wide-field high-sensitivity (moderate AO correction) multi-object spectrograph in short NIR wavelength range
   - 0.3x0.3” – 0.5”x0.5” aperture integrated spectroscopy
   - R=3,000 (5A resolution, 2A/pix) for absorption/emission lines with rest-frame EW of 1A.



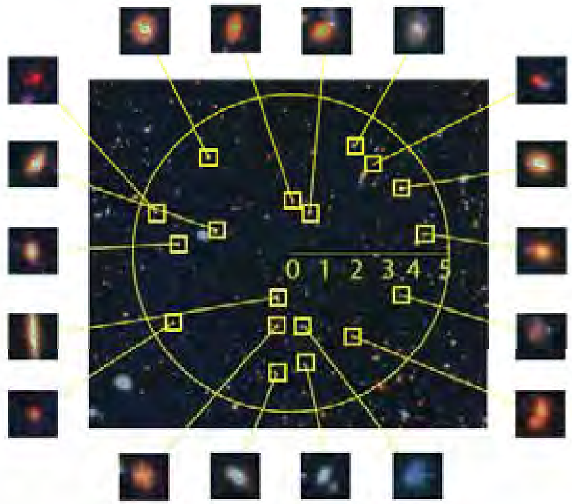
BASELINE DESIGN

AO-correction in wide field = GLAO+MOAO

TMT focal plane

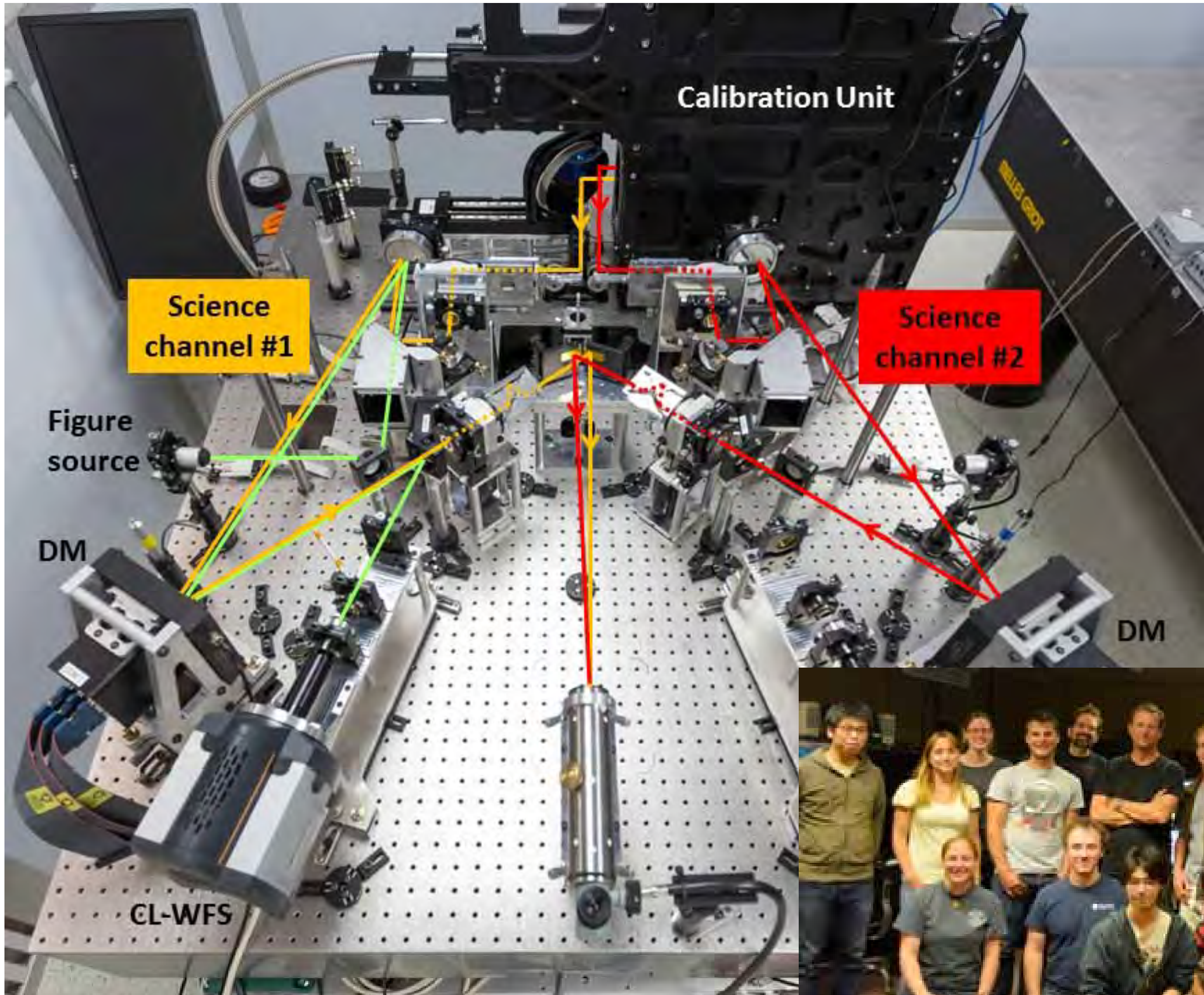
<u>Ground-Layer Adaptive Optics</u>
Correcting for common turbulence within d=10' FoV

R-theta pick-off opt-mechanics
for 20 objects in the corrected FoV



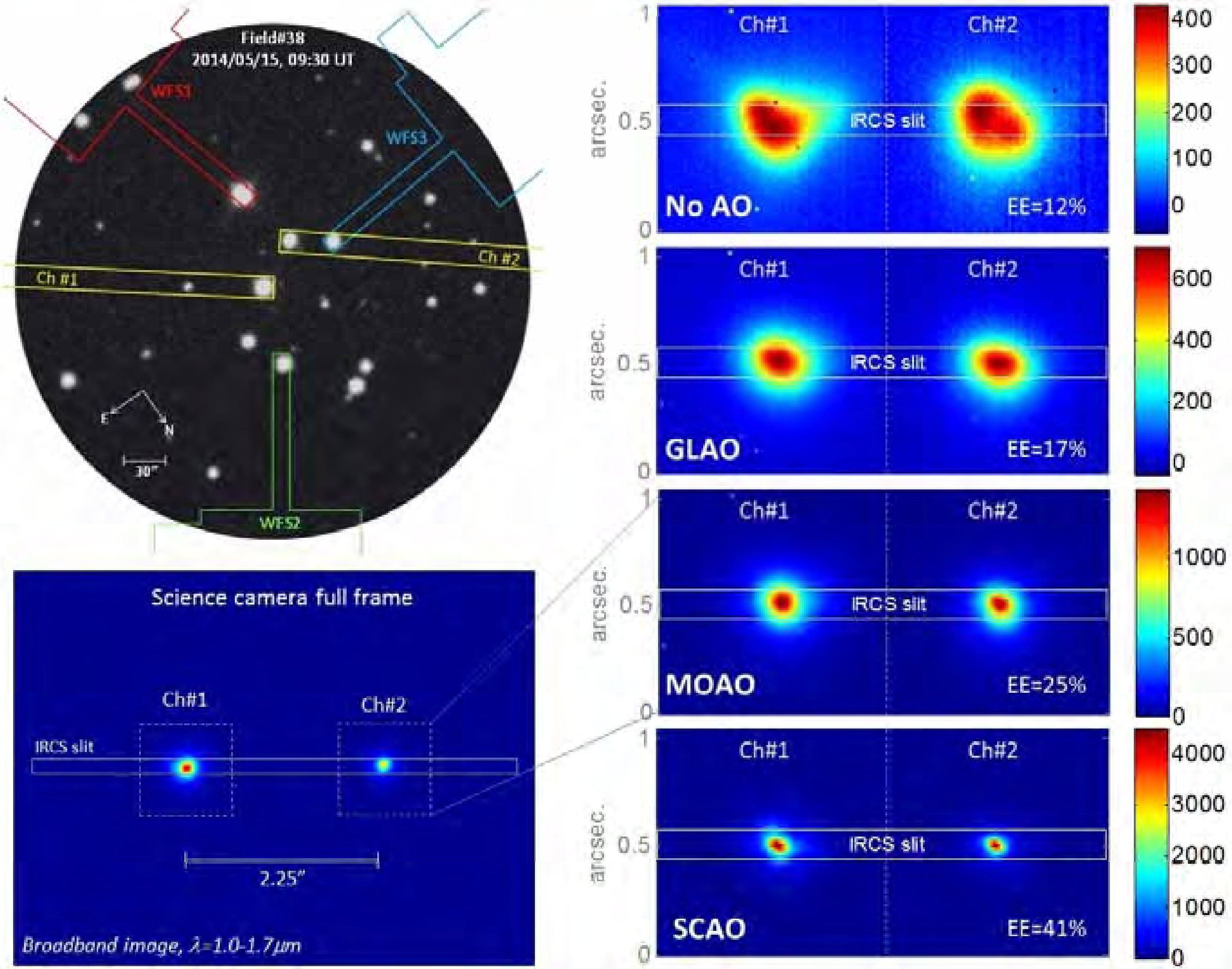
<u>Multi-Object AO correction</u>
for <u>each science path independently</u>

RAVEN: Subaru Multi-Object AO engineering and science demonstrator



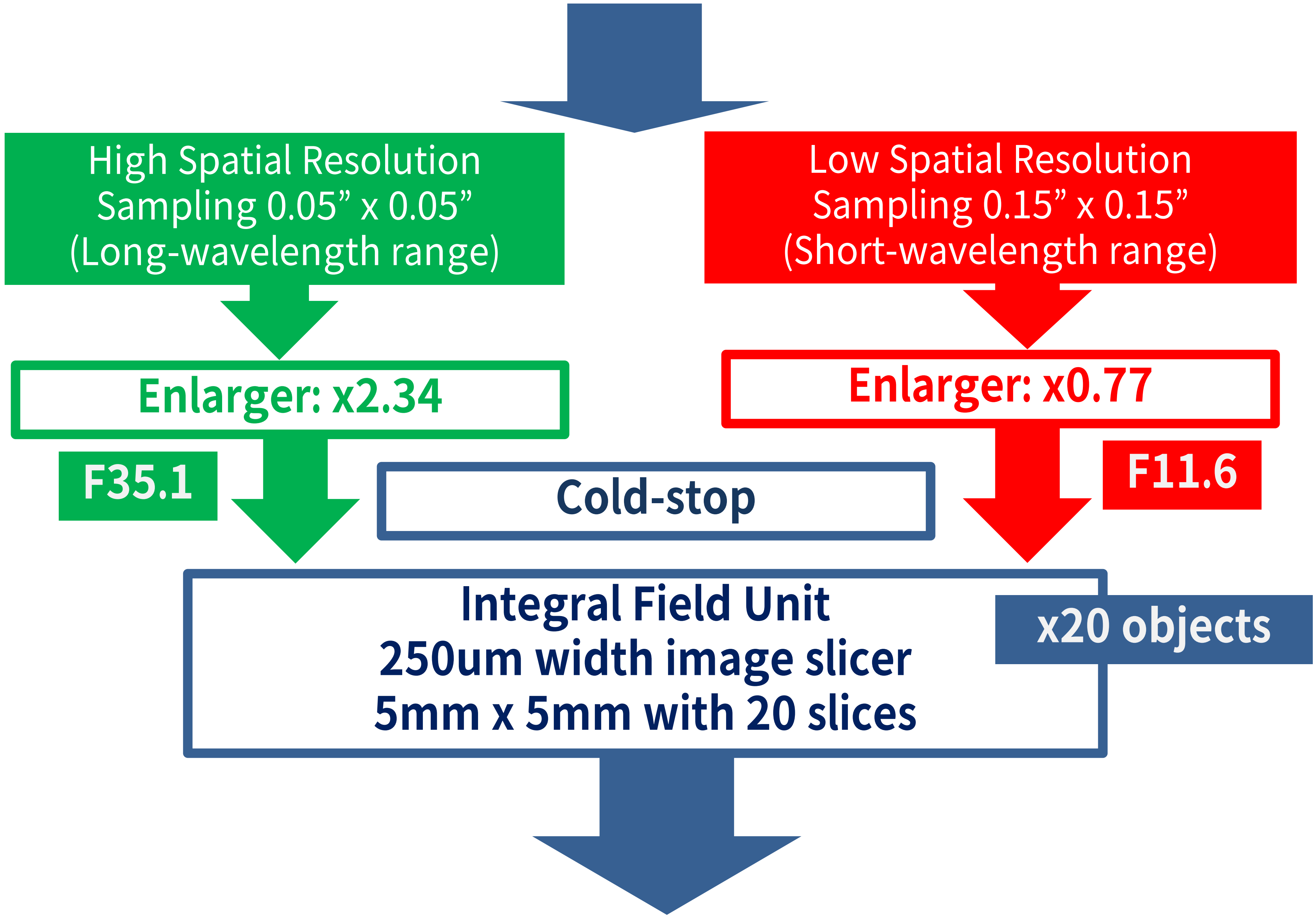
RAVEN : MOAO demonstration

- Simultaneous AO correction for two objects by tomography estimation with three NGSs within d=3' FoR.

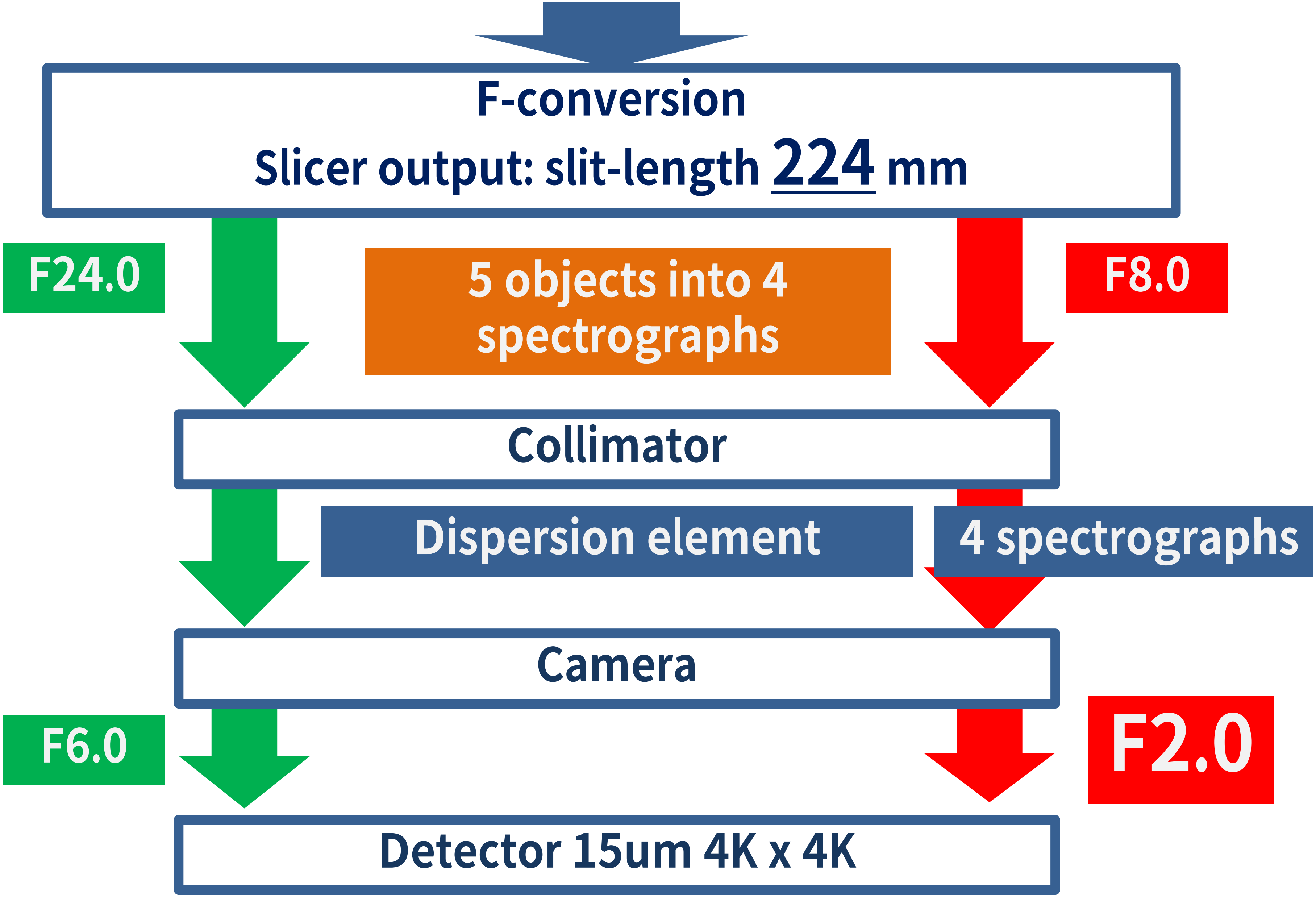


Lardiere et al. 2014

Overview of the optical path

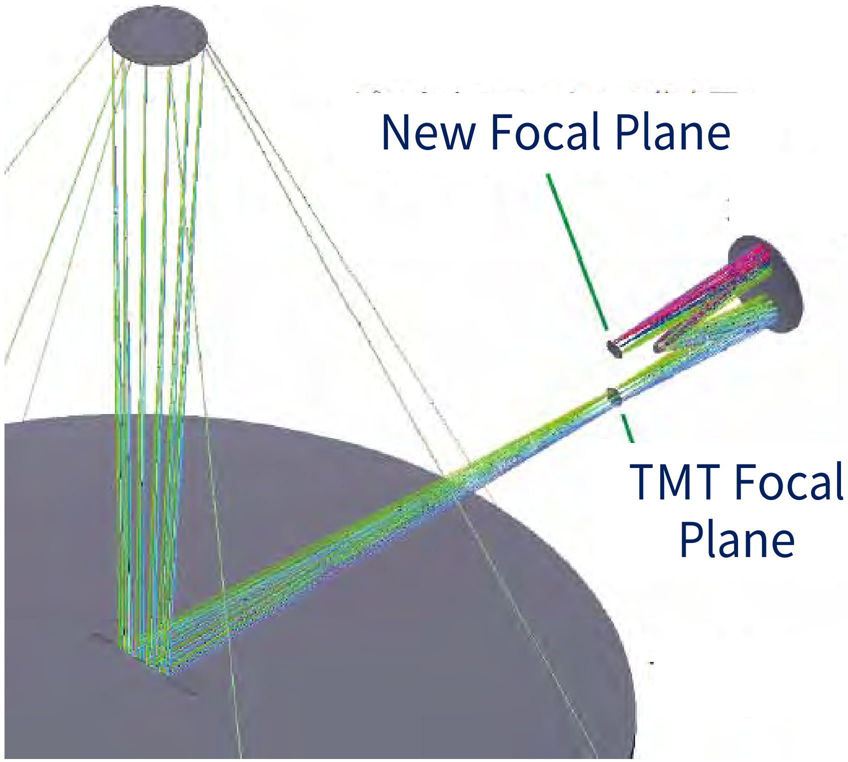


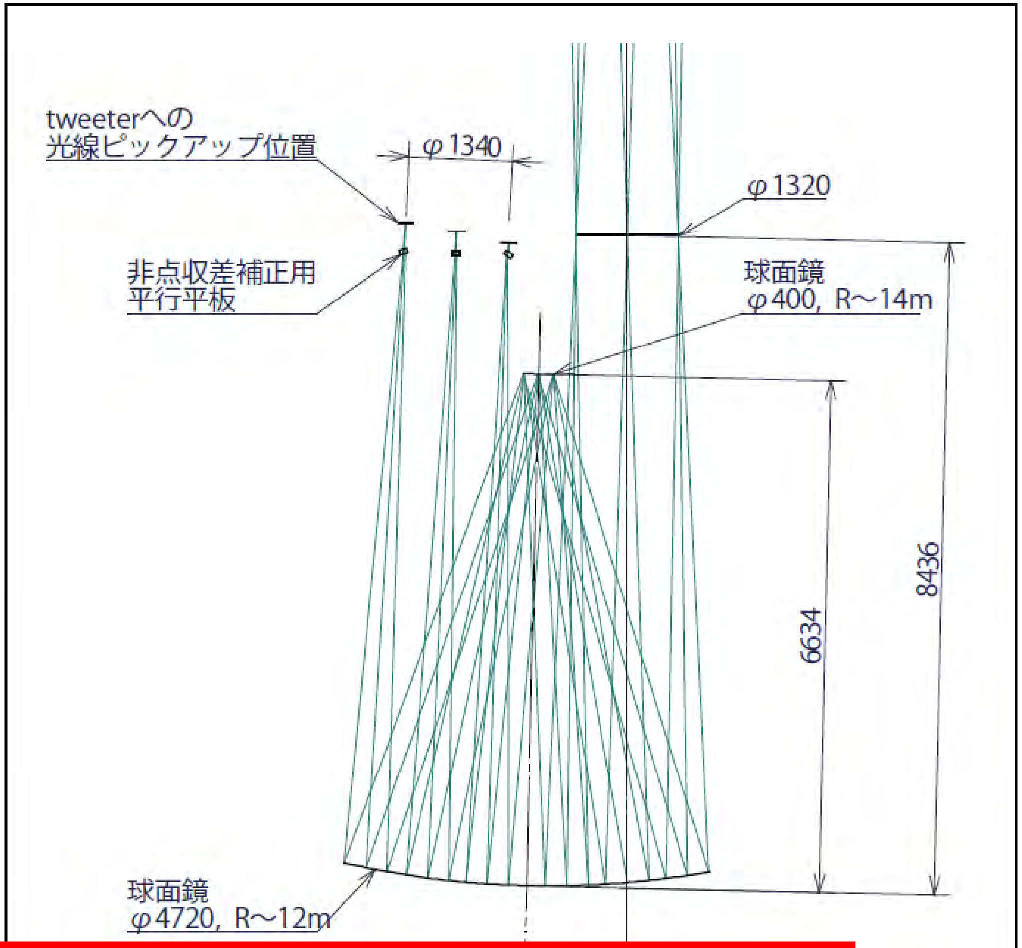
Overview of the optical path



Ground-layer AO optical design

- d=10’ FoV AO optical design.

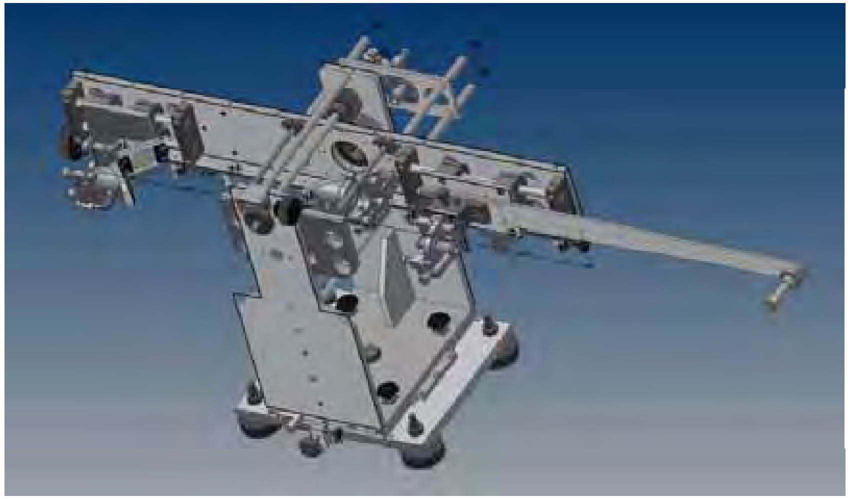


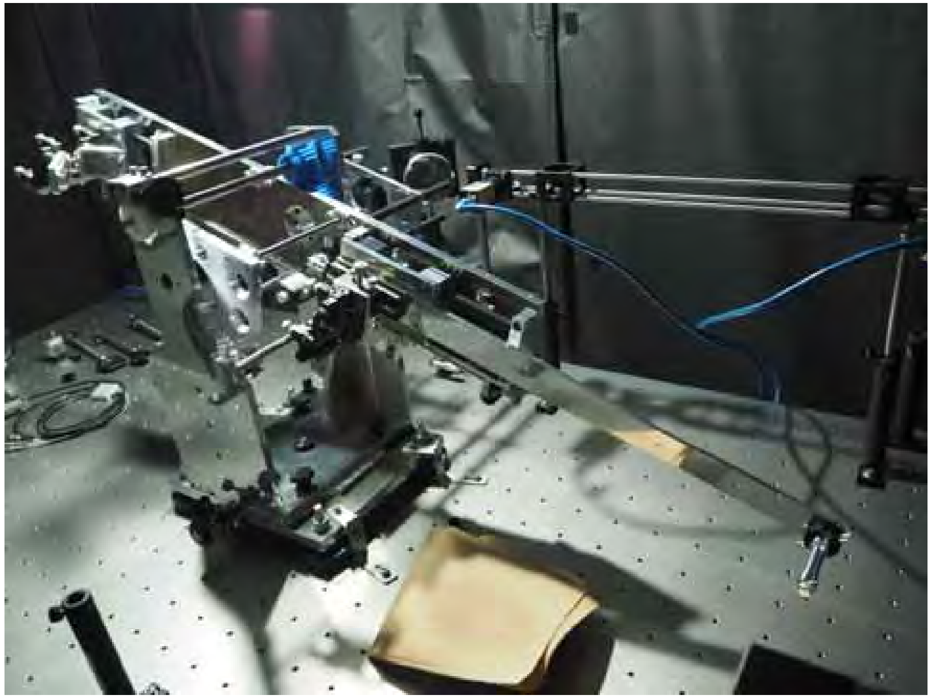


Pupil distortion needs to be small to be used as an AO system.

Pick-off Opt-mechanics Mock-up

- Classical r-theta pick-off arm system.
- 20 pick-off arms will be put around the corrected focal plane.

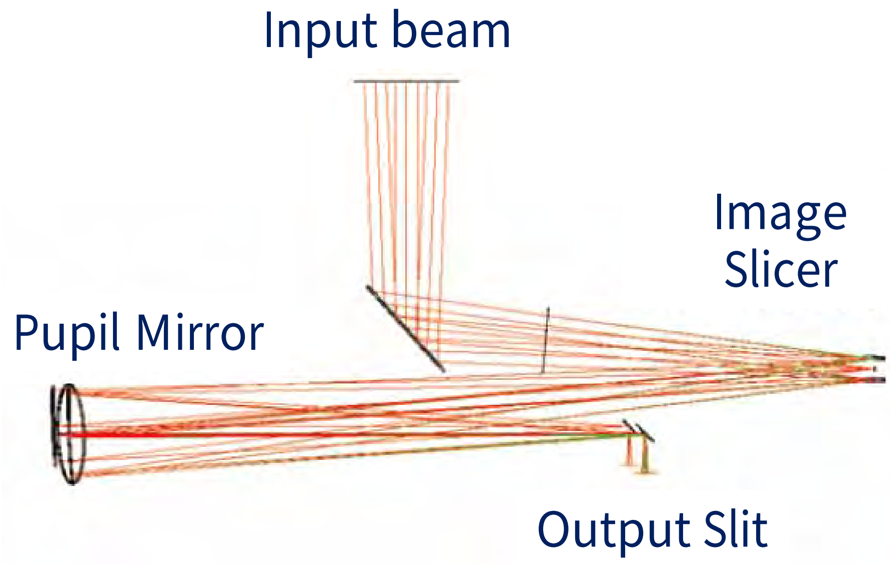


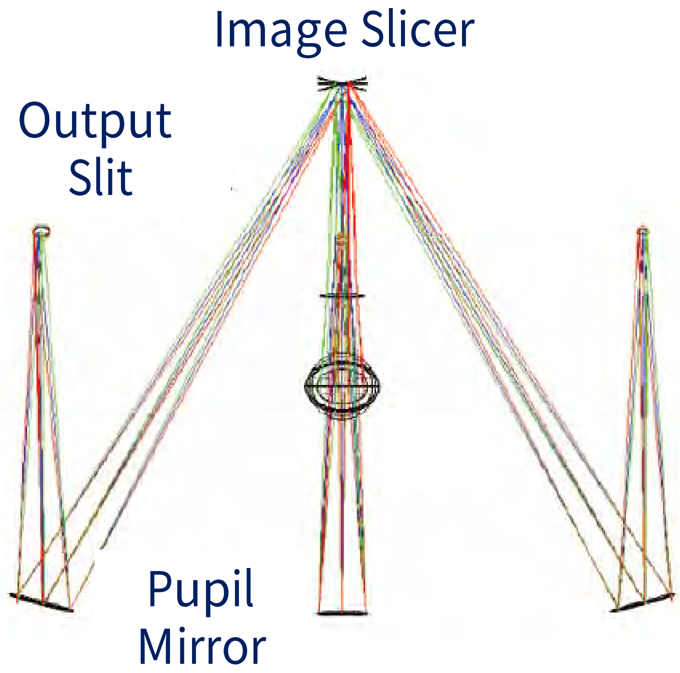


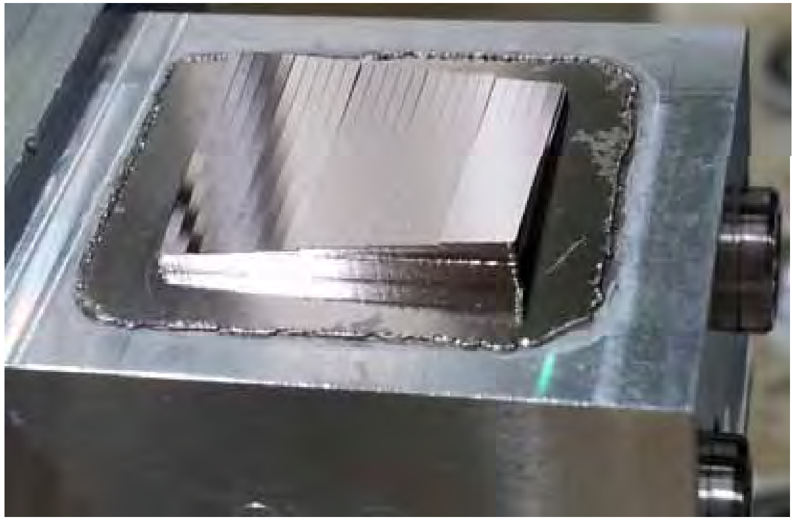
Optical alignment test is underway

Integral Field Unit optical design

- Optical design and prototyoing for the IFU by Yutaro Kitagawa.



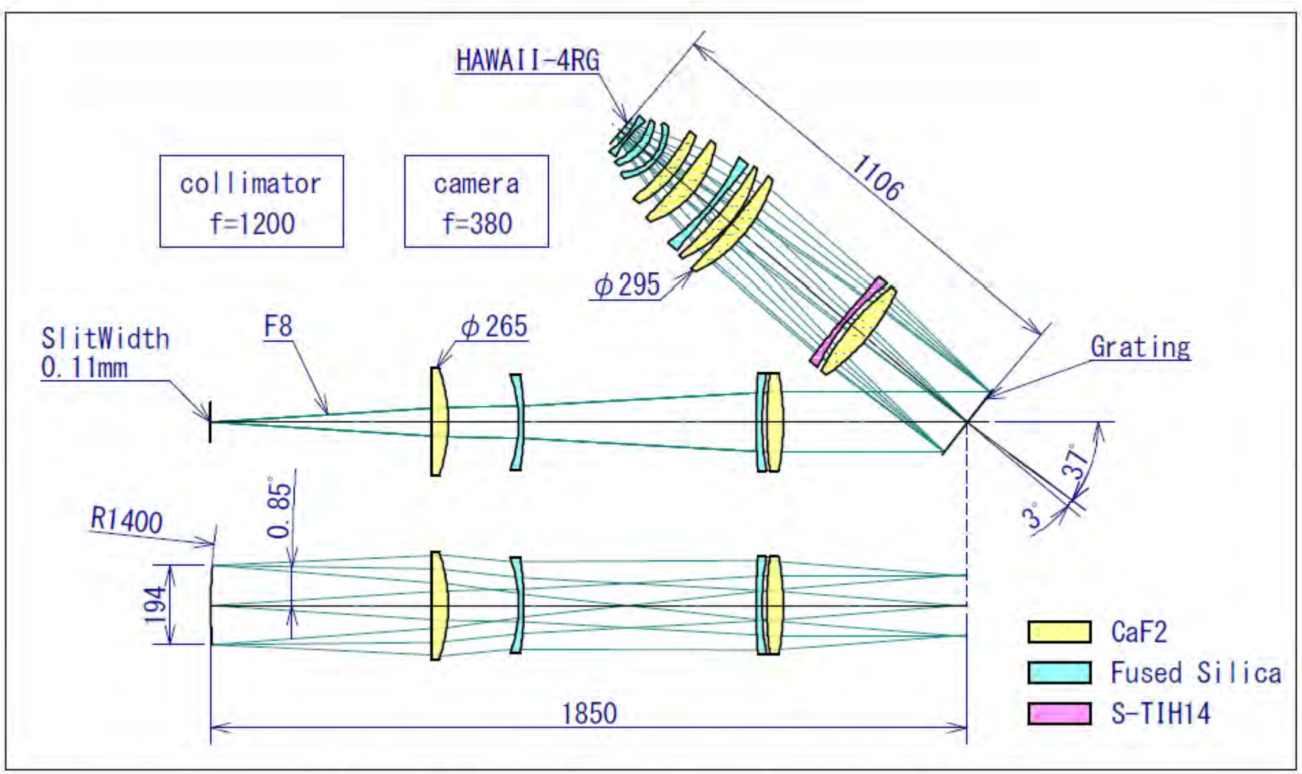




Prototype of the image slicer optics made by griding + coating + ultra-fine polishing. The unit will be used in TAO/SWIMS instrument.

IFU spectrograph optical design (F8/F2.5)

- Optical design studies for F8/F2.5 spectrograph by Optcraft.
- F2.5 output and slit length of 194mm are achieved.



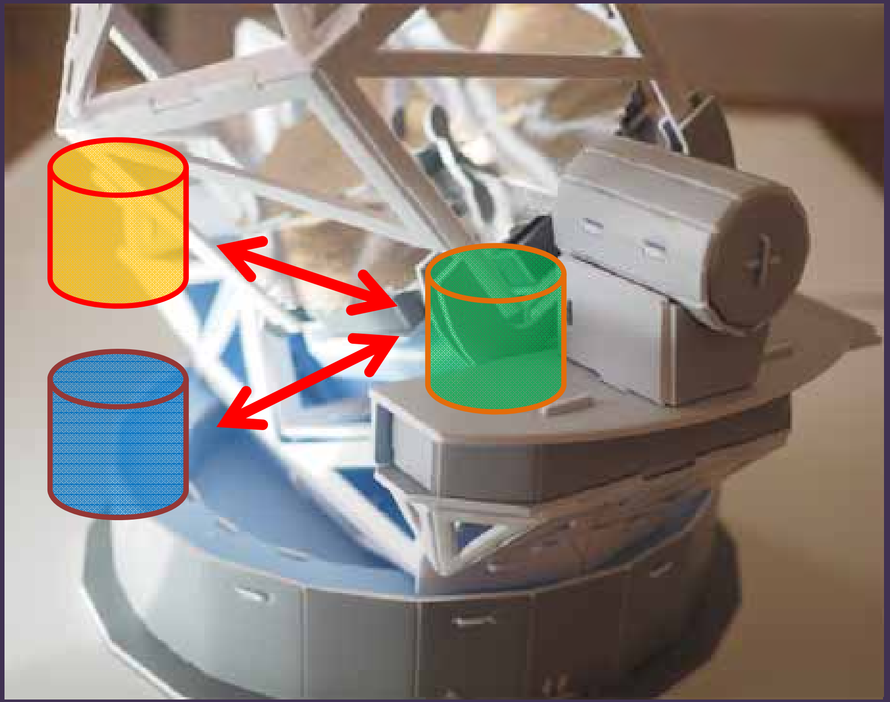
The camera system require 10 lenses including CaF2 lens with 295mm diameter.

Bottleneck of the baseline design

- Based on the feasibility study, we conclude in order to realize both of the low-resolution and high-resolution modes in one instruments, we require…

GLAO/MOAO with 4.7m mirror optical system
+ 4 spectrographs with 290mm CaF2 lenses

- Those are feasible, but highly challenging and expensive.

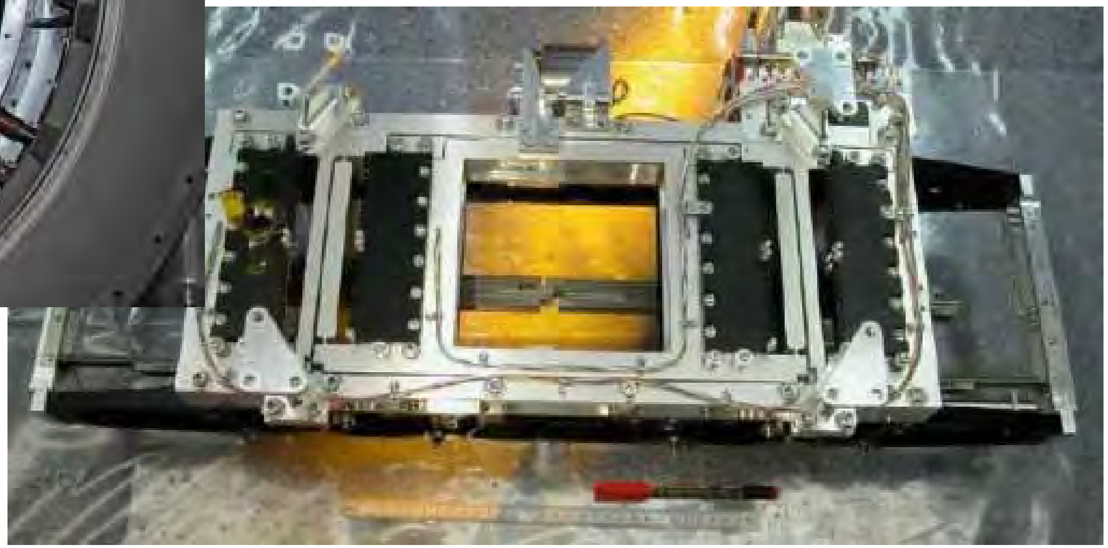


ALTERNATIVE IDEAS

Idea 1: Pick-off arms as “multi-slits”

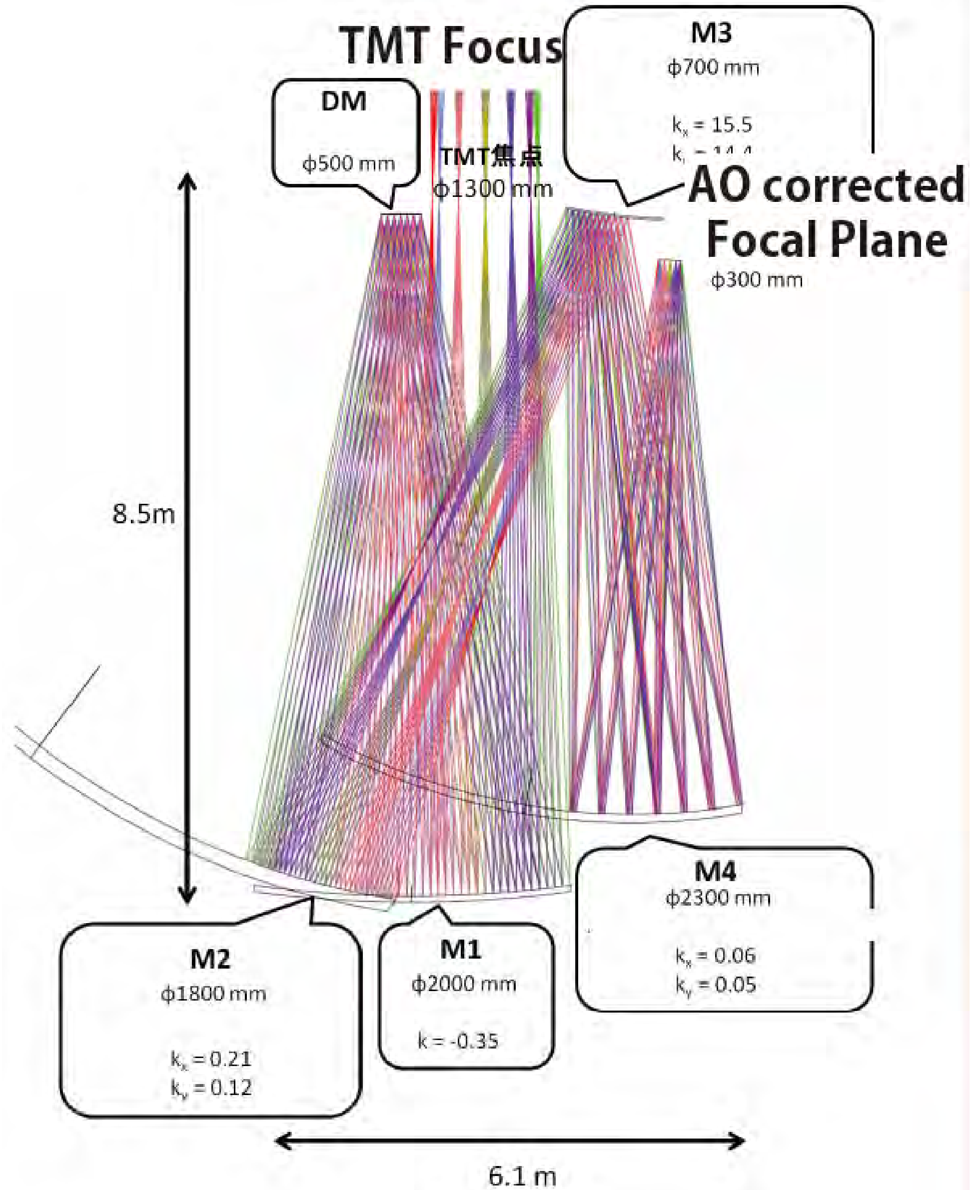
- Pick-off arms can be used as object picker same as multi-slits to conduct multi-object spectroscopy.
- If we consider d=10’ FoV, TMT focal plane is large (d=1320mm).

VLT/KMOS



Keck/MOSFIRE

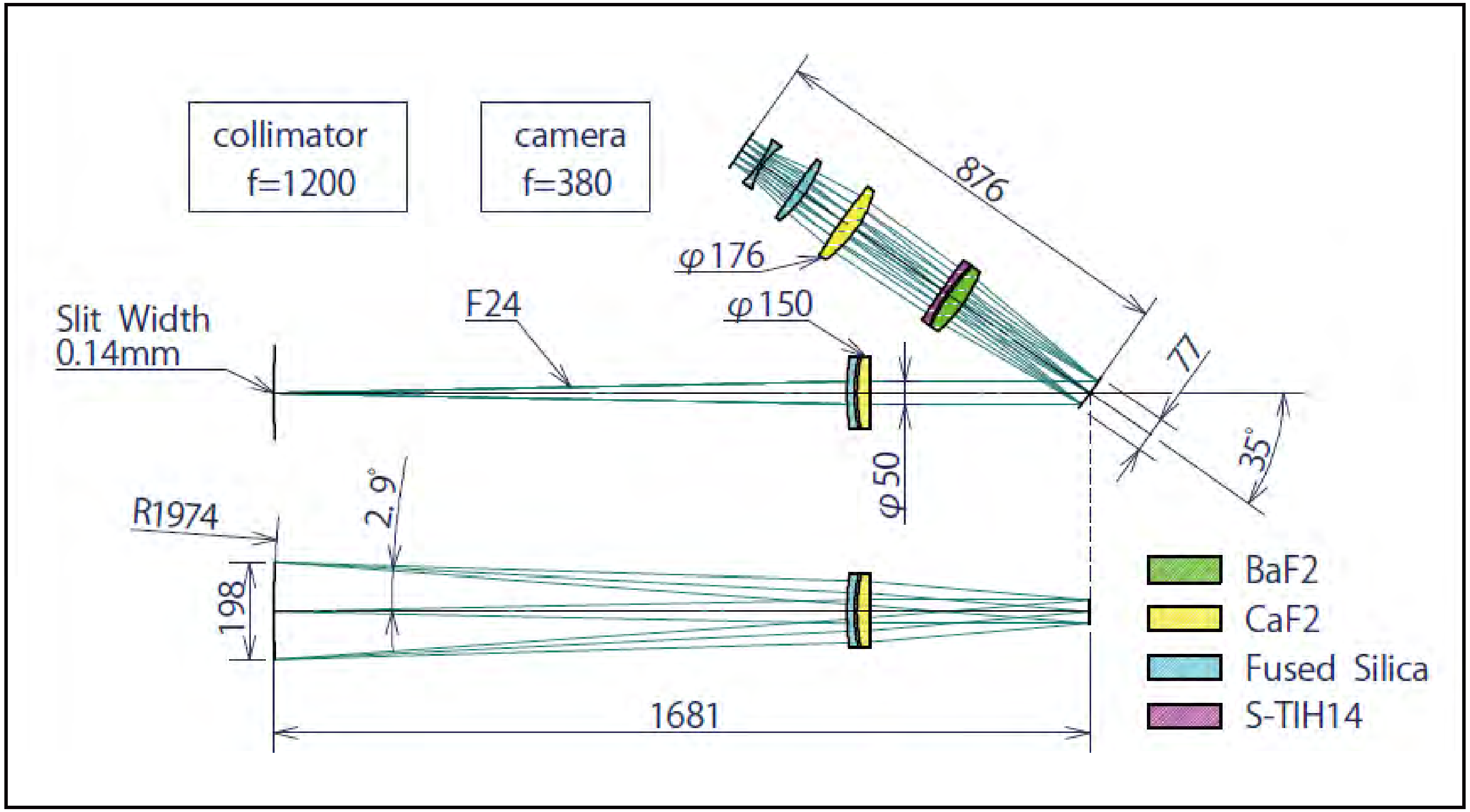
Idea 2: GLAO optical design with “shrinked” focal plane



- GLAO corrected focal plane is smaller (d=300mm) with faster F-ratio (F3.5).
- Imager / multi-slit MOS / fiber MOS can be put on the “shrincked” focal plane.

Idea 3: IFU spectrograph only with high-resolution mode (F24/F7.6)

- Compared to F8/F2.5 spectrograph design, the slow F-ratio design is much simpler and more feasible.



Three alternative specifications

1. d=10 arcmin multi-pickoff-arm MOS spectrograph with GLAO correction (w/o imaging capability)

2. d=10 arcmin imager / MOS instrument with GLAO correction with shrincked focal plane

3. d=5 arcmin multi-IFU (0.05” sampling) spectrograph with GLAO+MOAO correction with optimized spectrograph for high-spatial sampling mode.

Which configuration does your science prefer ?