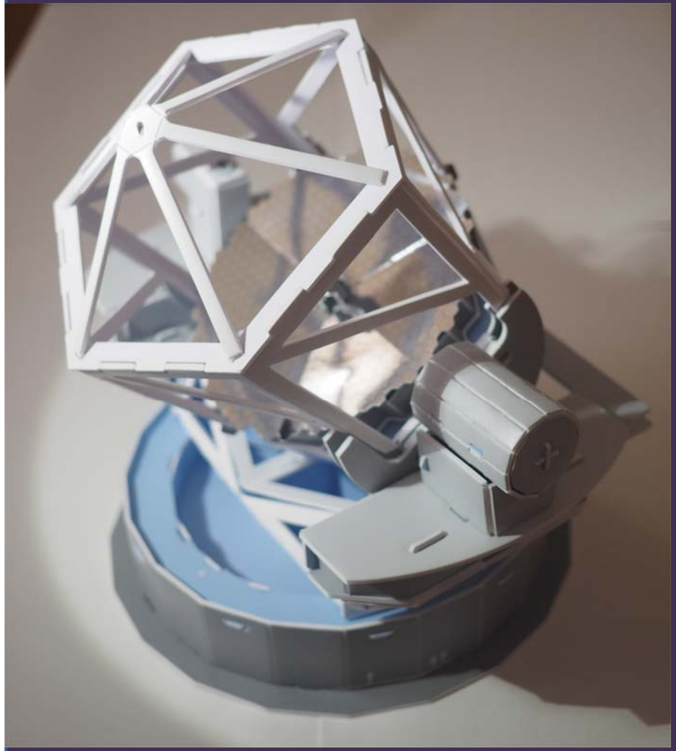


TMT-AGE:
TMT Analyzer for Galaxies in the Early universe

TMT 広視野多天体分光器の可能性

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

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.

Early-light 装置群との比較

- IRIS: 近赤外線での IFU (max 2.2” x 4.55”) と 34” 角の撮像装置。初期補償光学系 NFIRAOS で良く補償される領域をカバーする。

- IRMS: 近赤外線での多スリット分光装置。NFIRAOS で補償された 2’ x 0.6’ の視野をカバーする。Keck-MOSFIRE のクローン、ただし焦点距離の違いで視野は狭くなる。(分光は 2’ x 0.6’, 撮像は 2’ x 2’)

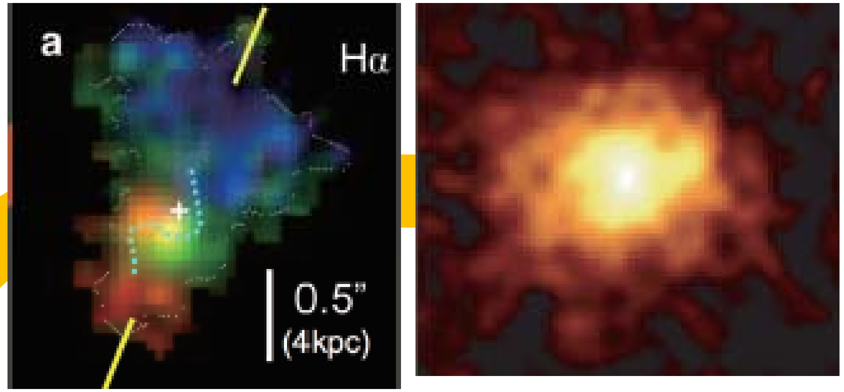
- TMT-AGE: 近赤外線での multi-IFU (~20個)での多天体分光装置。広視野 (直径 5’-10’ の領域) の補償光学系を新しく設置する。視野を広げる分、IRIS よりも補償性能は劣る。

Three Science Drivers

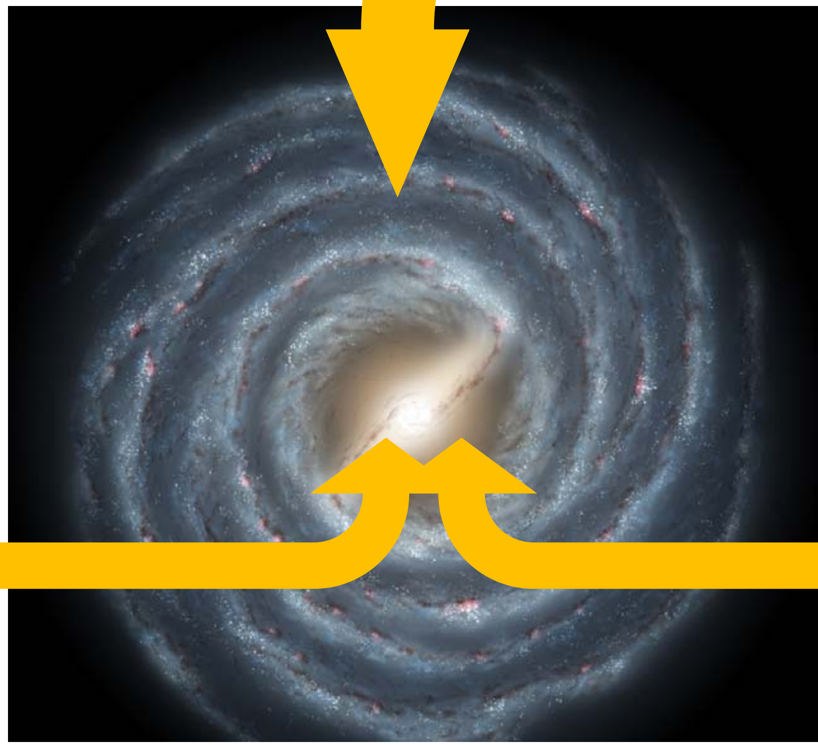
1. How is the internal structure of local galaxies established ?
2. What is going on in galaxies in the early universe ?
3. Hunting for galaxies/AGNs at z>8

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

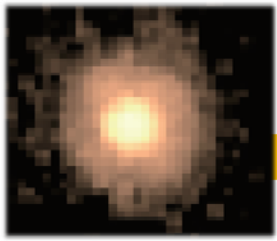
Turbulent / High-density disks at high-z



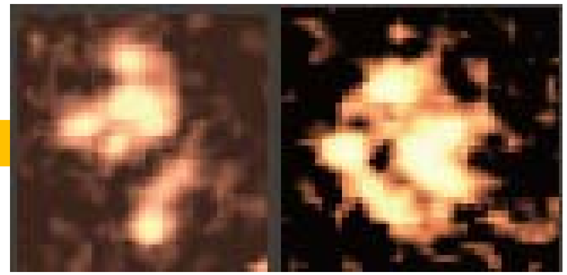
Typical galaxy seen in the local universe



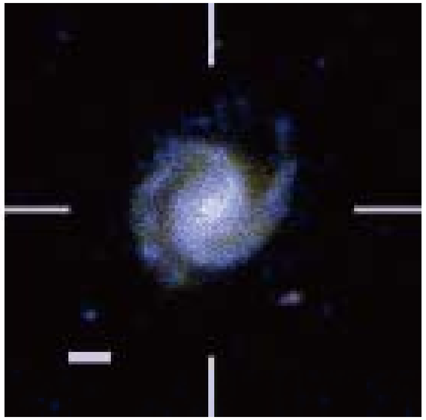
Very compact galaxies at high-z



Clumpy galaxies at high-z



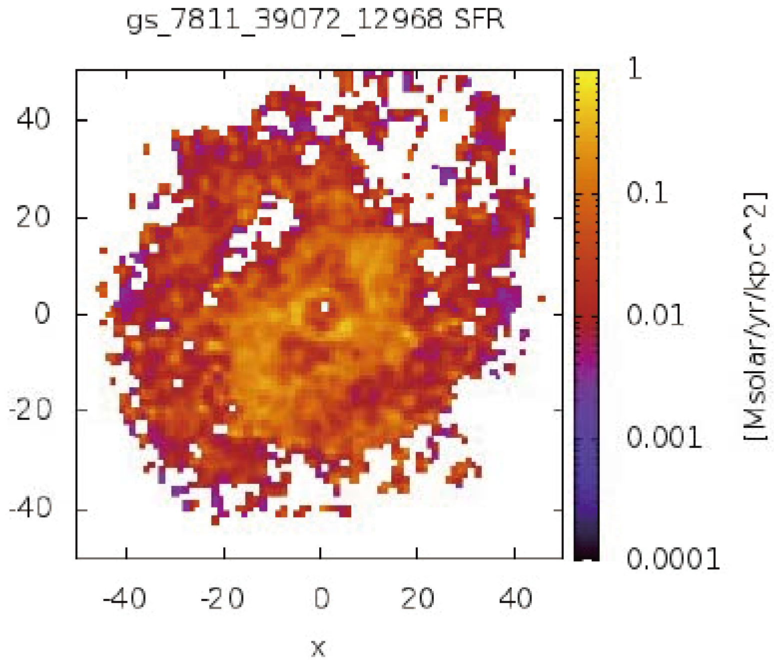
1. Galaxy "establishment" history



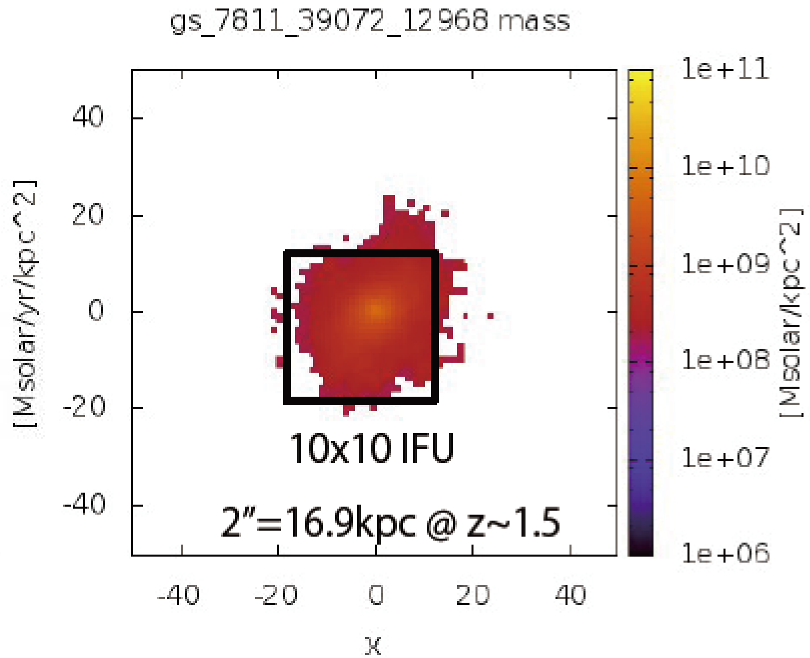
Example image of a massive galaxy at z=1.0

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 with 0.2" resolution

Gas dynamics with 0.2" resolution

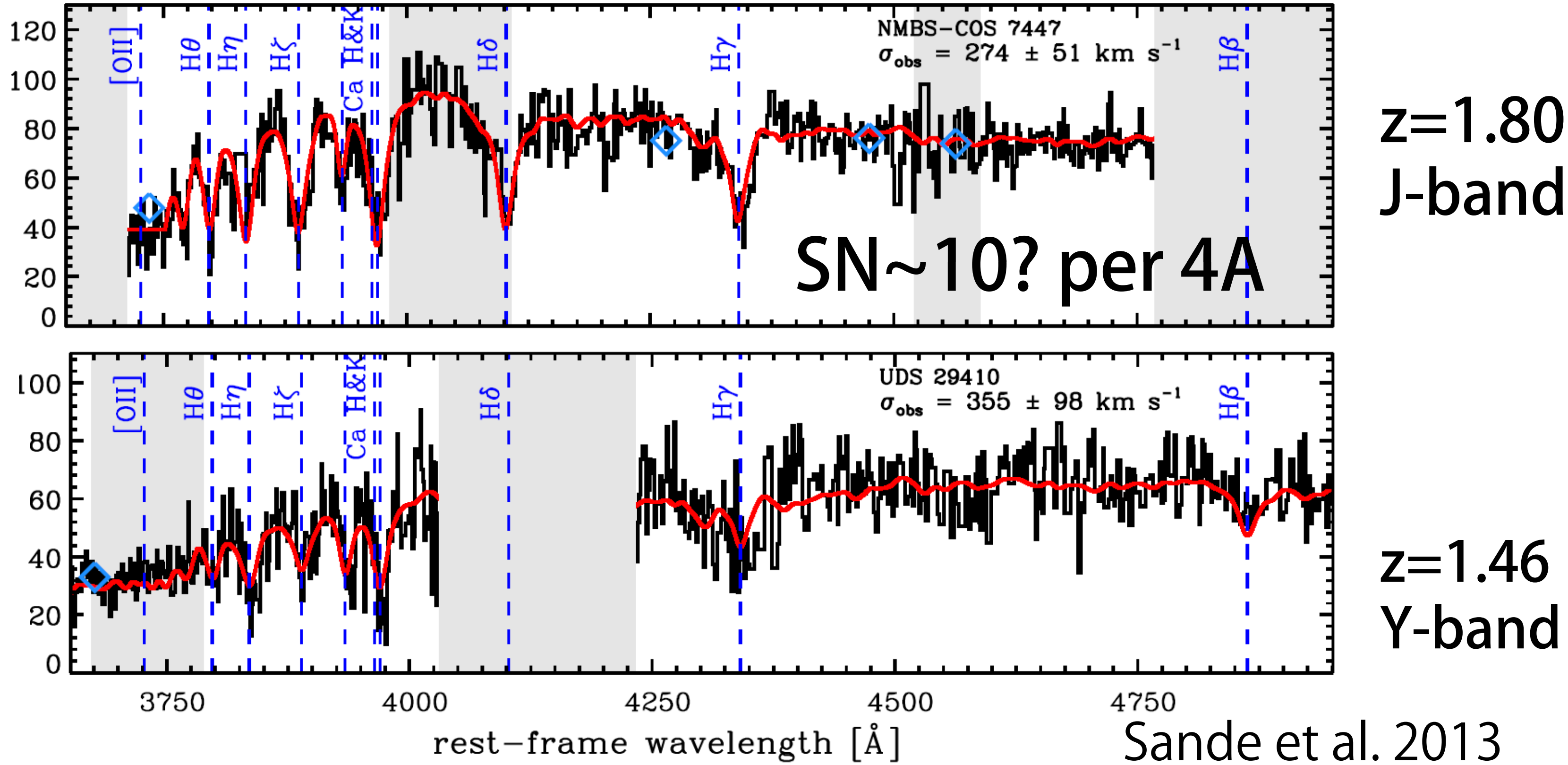


Stellar dynamics with 0.2" resolution



Stellar kinematics of z~2 quiescent massive galaxies

- Integrated stellar kinematics of quiescent massive galaxies at z~2.
- X-shooter 0.9" slit with R=5100 @ 1.4um, 2hour integ.
- Jap(1.75")=21.09 and Jap(1.75")=20.59 (Should be SN=15 with J=21.09 aperture loss of 0.50), SN=10 with J=21.9)

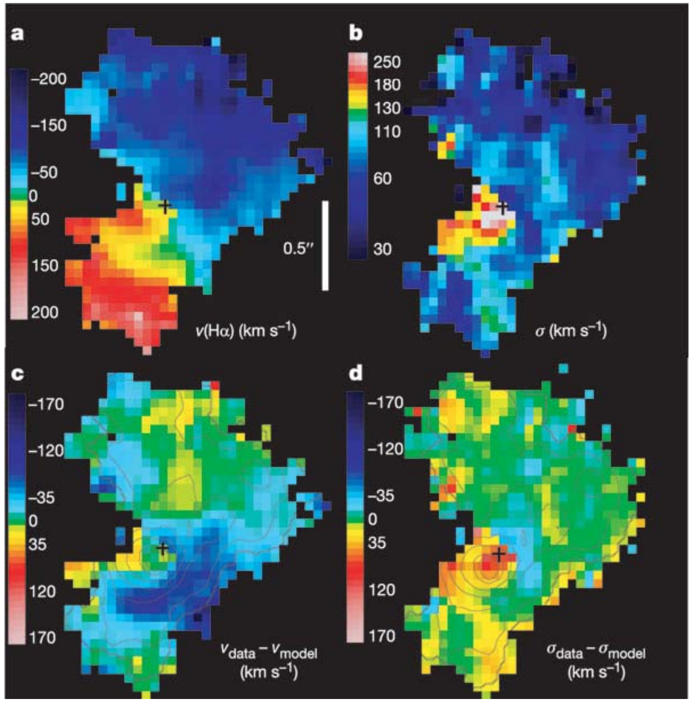


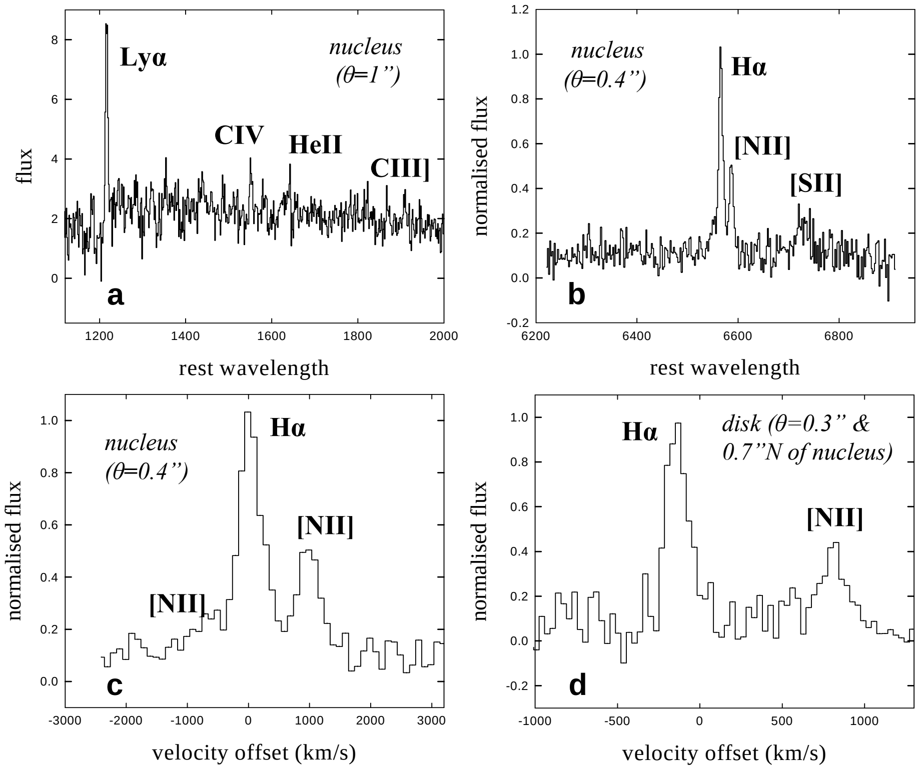
Sande et al. 2013

Figure 4. Rest-frame optical part of the spectrum focused on the Balmer break. As in Figure 3, the X-Shooter spectrum is shown in black, but this time in higher resolution (~4 Å observed, or ~100 km s^{-1} rest frame). The most prominent absorption and emission features are indicated by the blue dashed lines. The clear detection of absorption lines enables us to measure stellar velocity dispersions. We use pPXF to fit the best-fitting BC03 τ-model to the spectrum and find velocity dispersions that range from 275 to 435 km s^{-1}. The convolved best-fit BC03 template is shown in red.

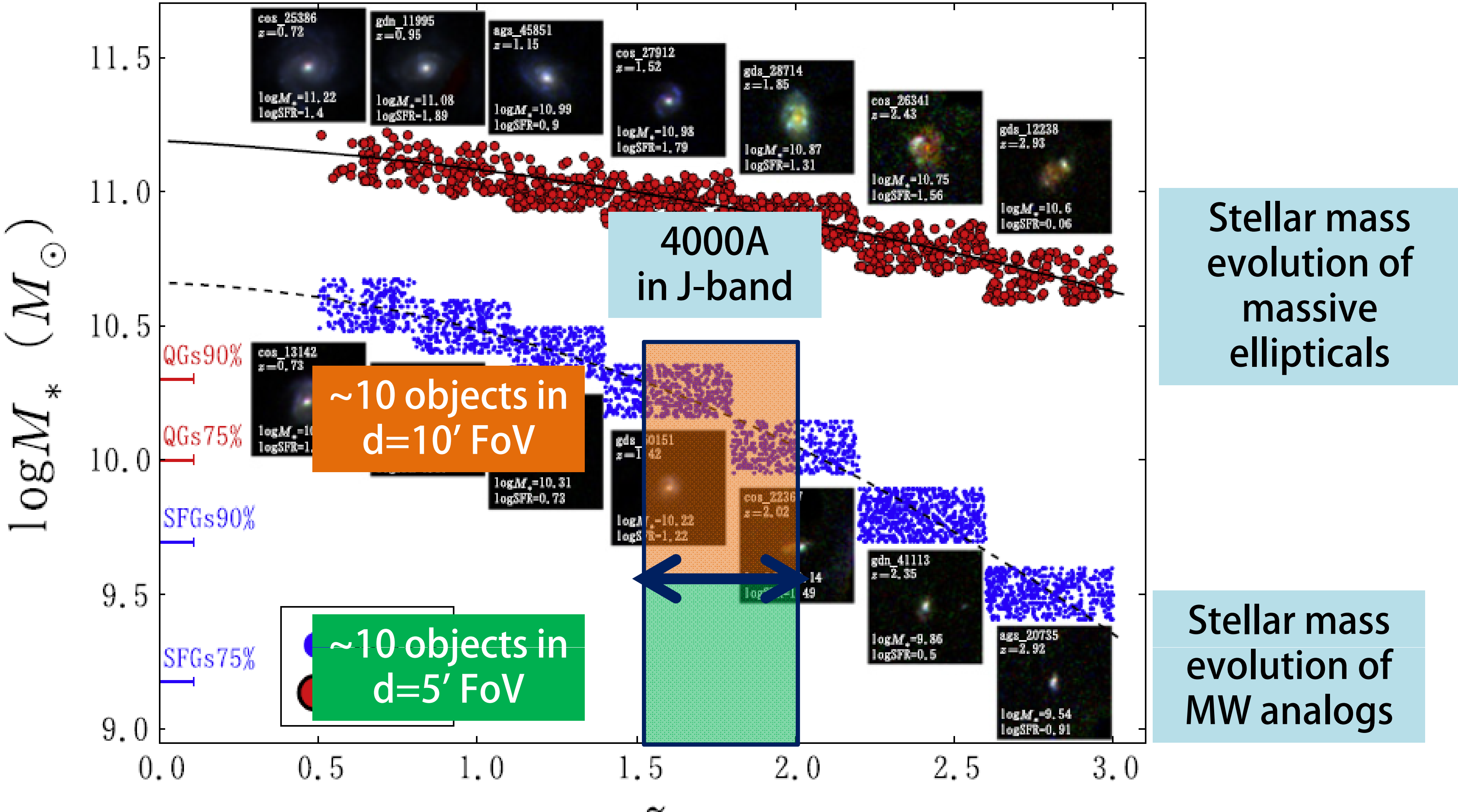
低光度 AGN の探査

補償光学＋面分光観測により明らかになった銀河中心核領域のAGN活動性　Genzel et al. 2006





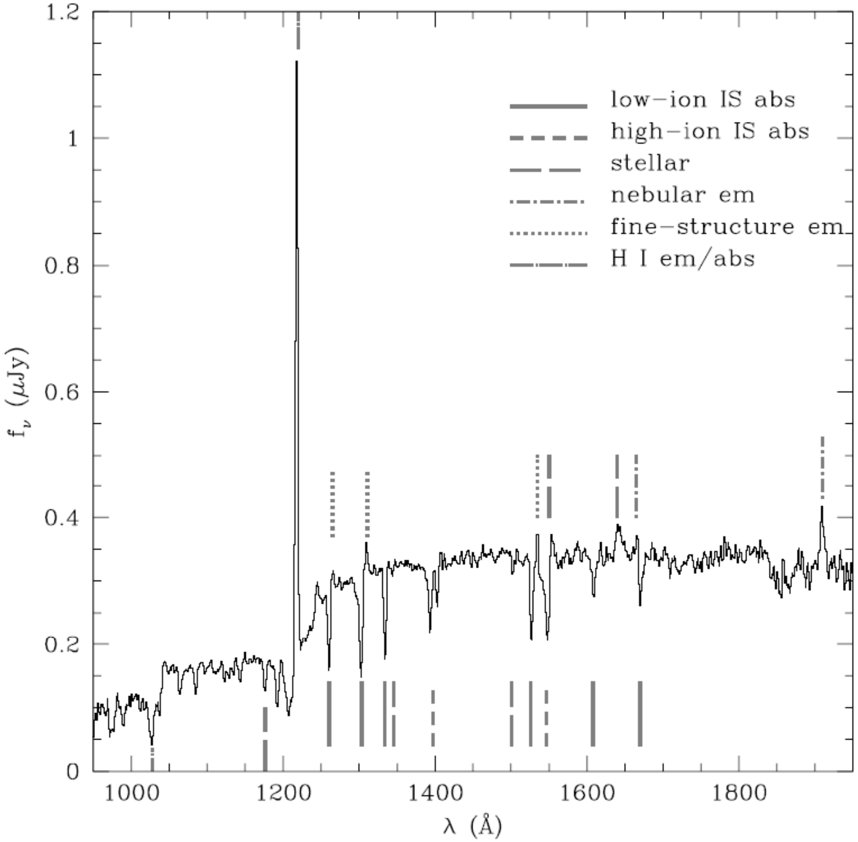
Targets of Multi-IFU Observations



Morishita et al. 2015
Number density from MOIRCS Deep Survey results

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

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

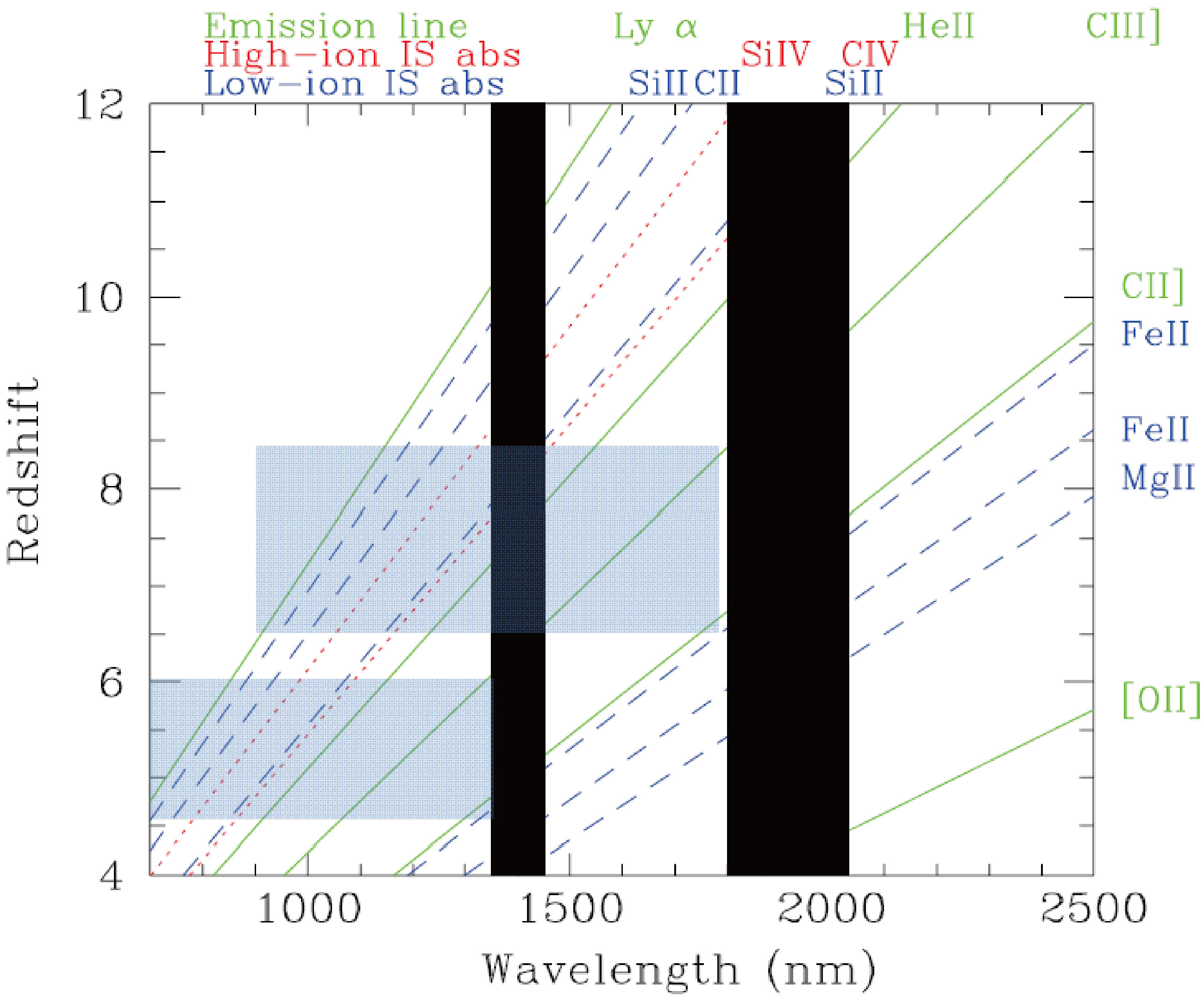


Shapley et al. 2003

- 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

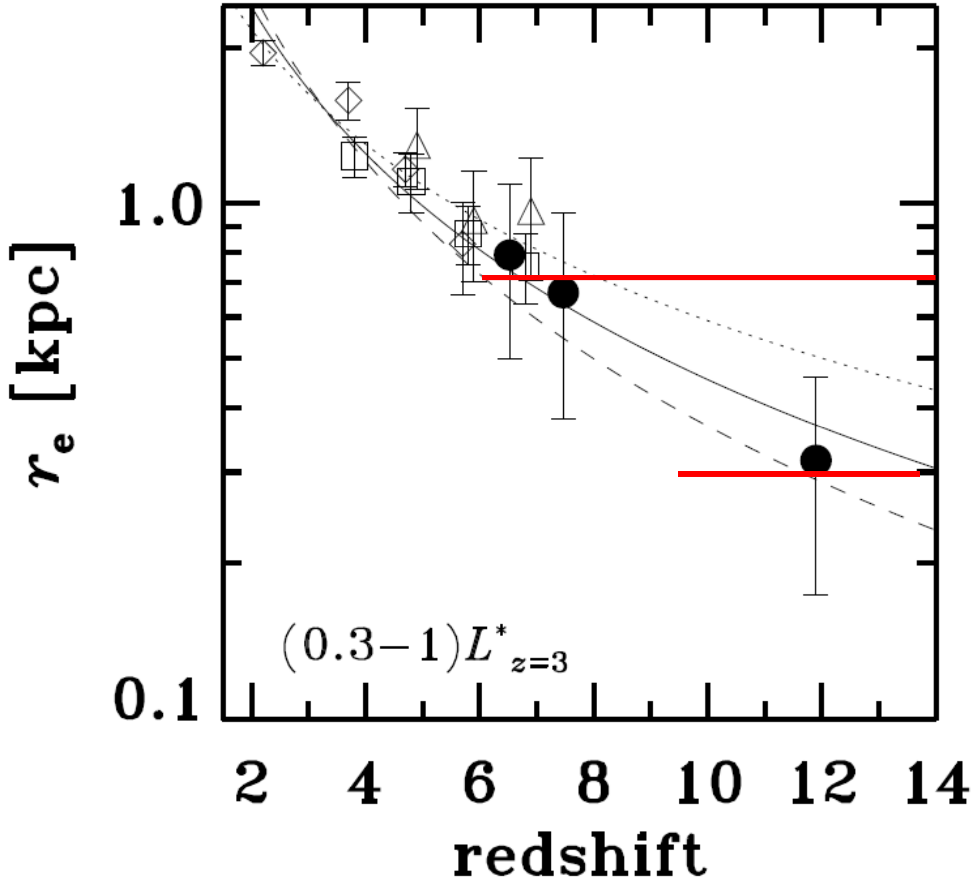
Diagnostic lines for high-z galaxies

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



Sizes of high-z galaxies

- z>5 galaxies are compact, but still extended compared with the diffraction-limit of TMT.

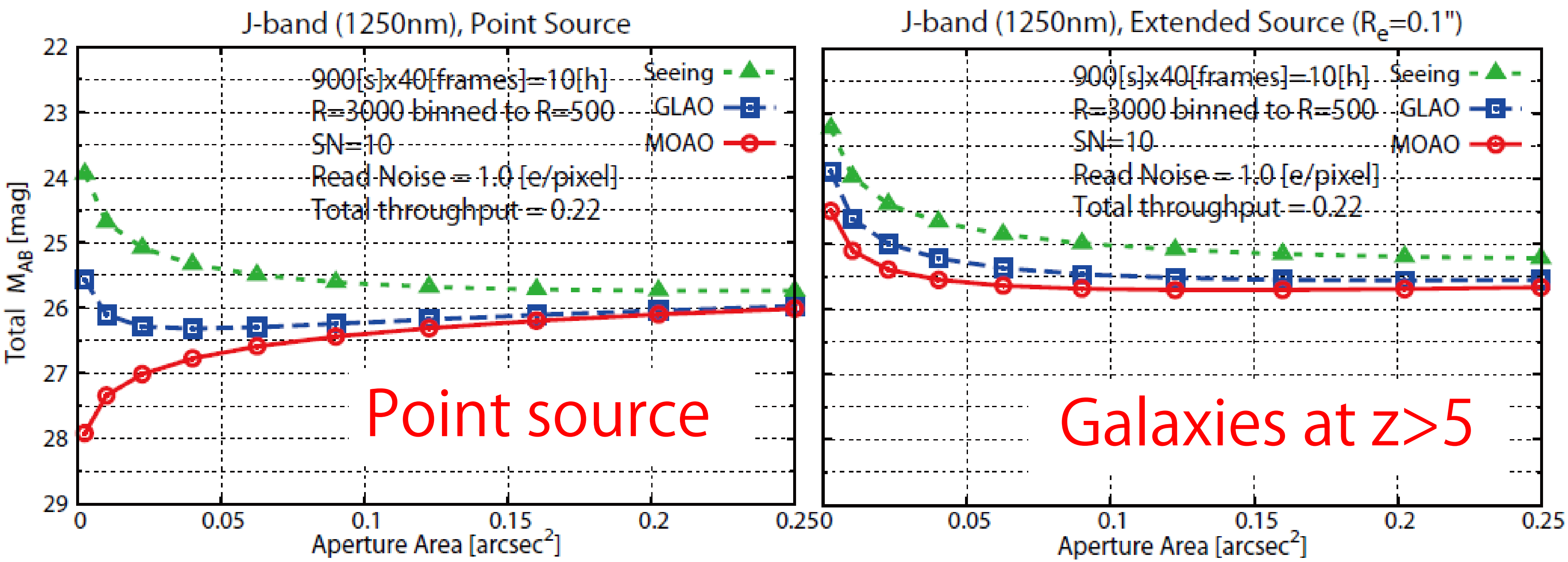


0.7 kpc = 0.13″ @z=7-8

0.3 kpc = 0.07″ @z=10

Ono et al. 2009

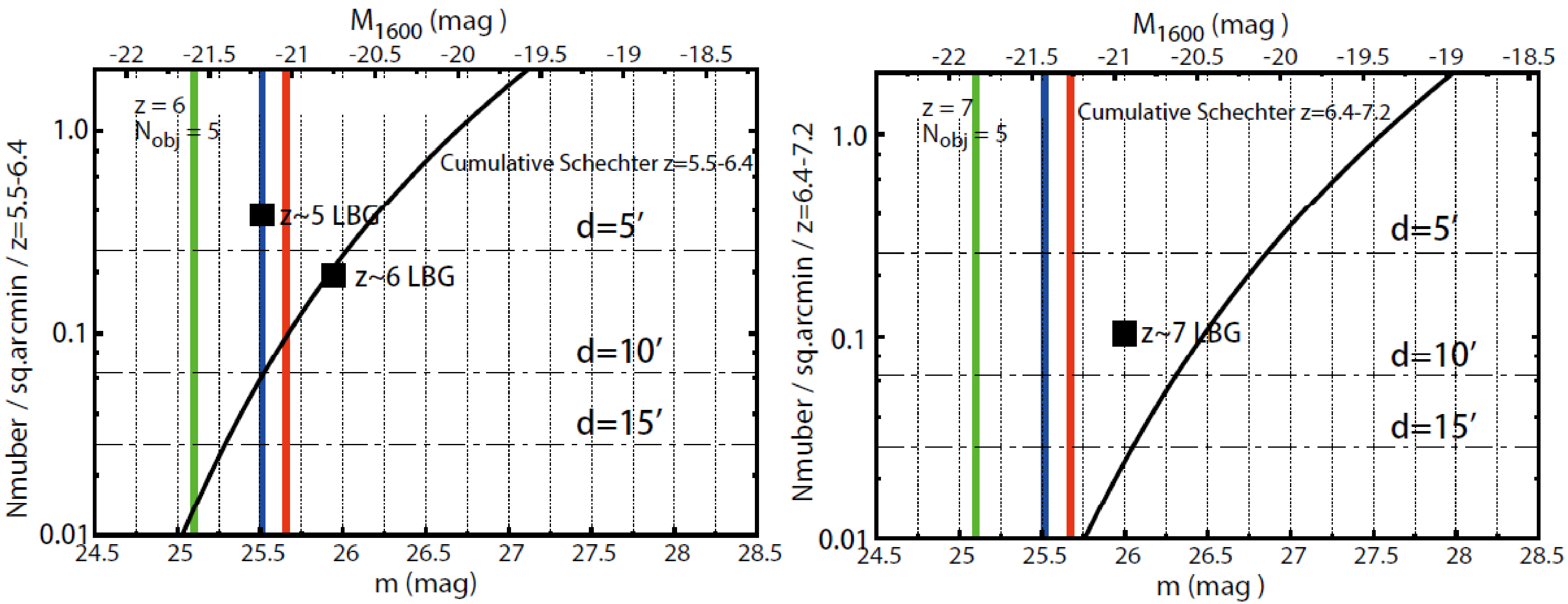
Baseline Detection limits – integrated J-band



– Red (MOAO), blue (GLAO), green (seeing-limit) lines show the detection limits for each system with different aperture size.
– SN=10 for continuum with 10h integration
– R=3,000 spectroscopy binned to R=500
– Typical size of z>5 galaxies: effective radius of 0.1”

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.



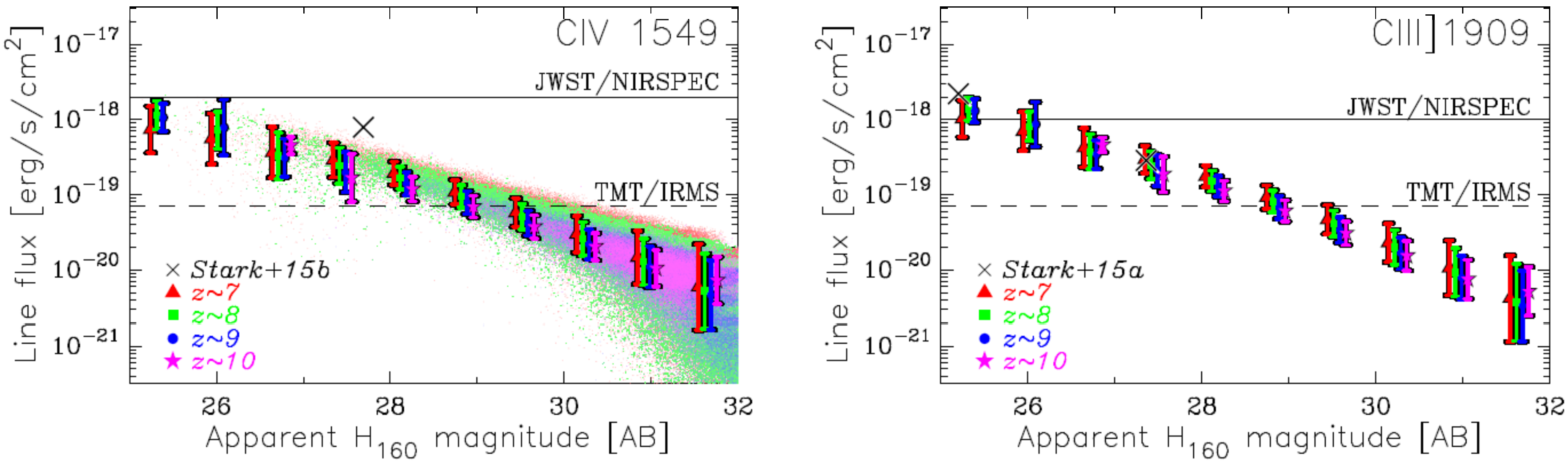
Filled squares from Bouwens et al. 2014,
V-dropout for z~5, i-dropout for z~6, and Y-dropout for z~7

3. Hunting for galaxies/AGNs at z>8

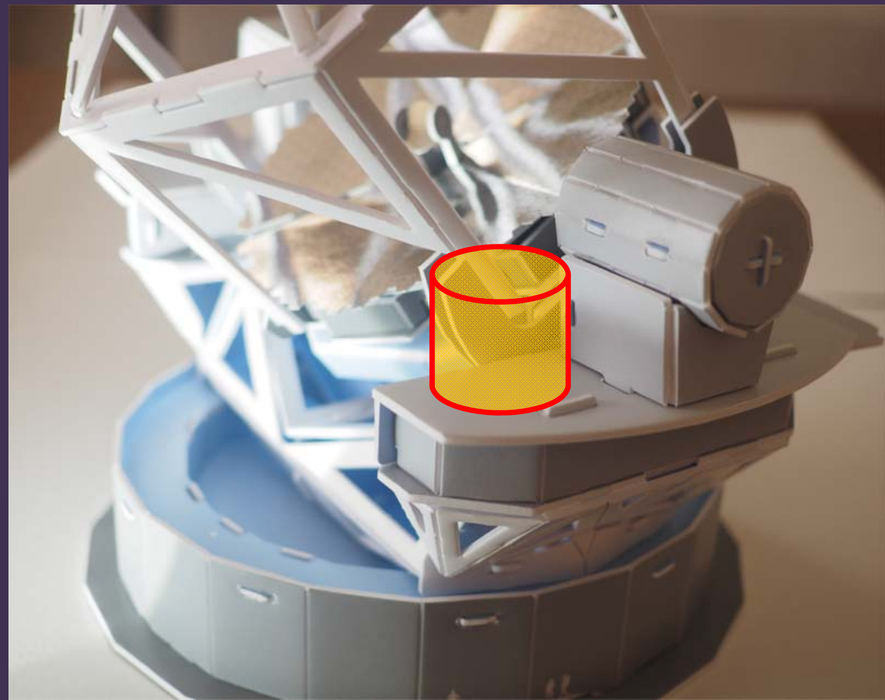
- Follow-up spectroscopy of candidates of high-z galaxies / AGNs picked up by wide-field IR surveys (Euclid, WFIRST, SPICA,,,), and wide-field X-ray surveys (Athena, STARX,,,) from space.

Nebular line emission

Estimated CIV, CIII] line flux for high-z galaxies



Shimizu et al. 2015



BASELINE DESIGN

広視野の補償光学系の実現が鍵

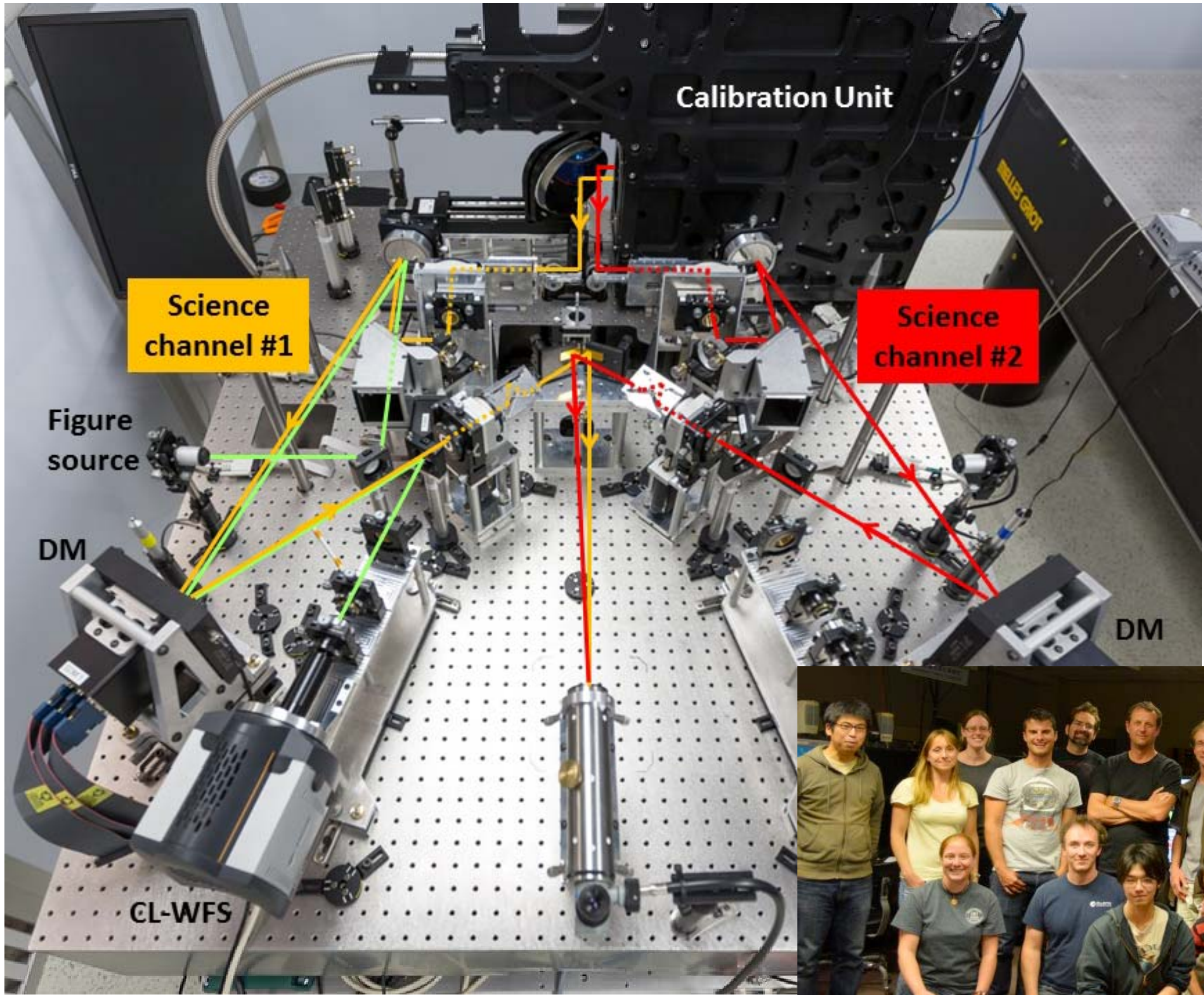
- <u>地表層補償光学系</u>：直径 10 分角程度の視野内で、共通の大気揺らぎを補償して、近赤外線で FWHM = 0.2 秒角程度の補償を実現する。

- <u>多天体補償光学系</u>：直径 5 分角程度の視野内で、それぞれの天体の方向に最適化した補償をして、近赤外線で FWHM = 0.05 秒角程度の補償を実現する。

TMT の初期補償光学系 NFIRAOS は、、、

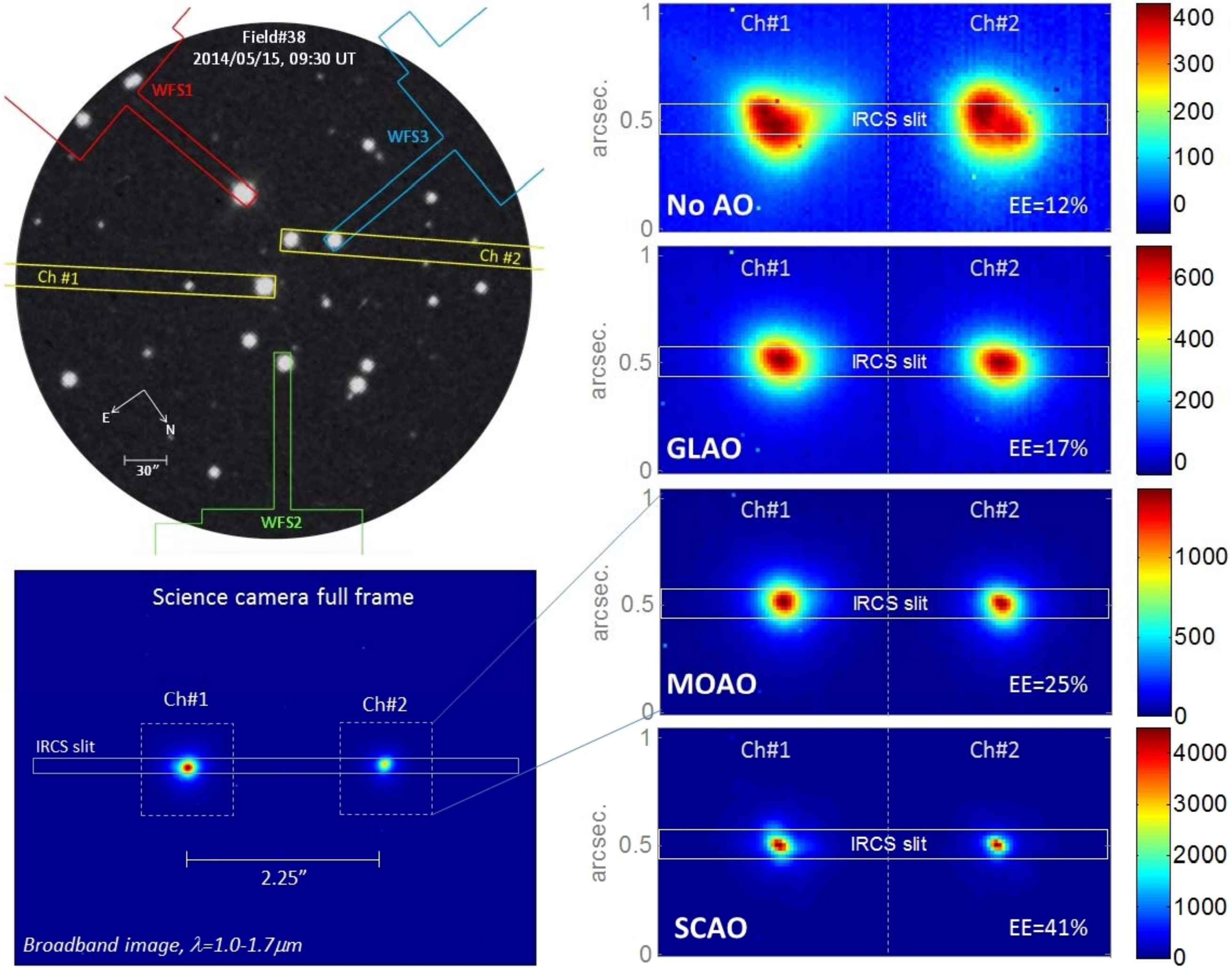
- <u>多層共役補償光学系</u>：直径 30 秒角程度の視野内で、複数の高さの大気揺らぎを補償して、近赤外線で FWHM = 0.02 秒角、TMT の回折限界の補償を実現する。

RAVEN: Subaru Multi-Object AO engineering and science demonstrator



RAVEN : MOAO demonstration

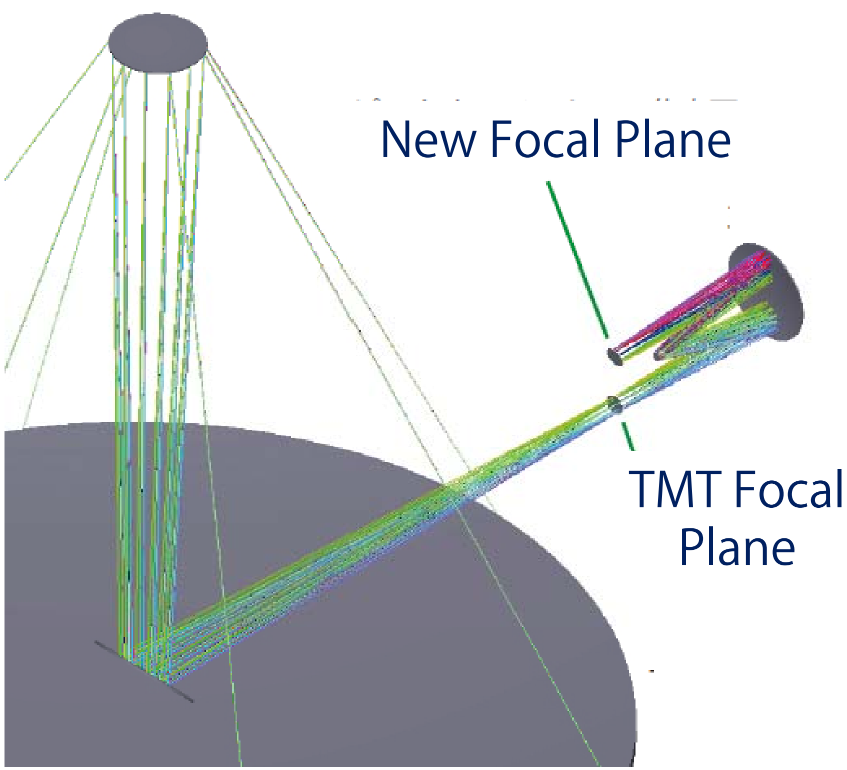
- Simultaneous AO correction for two objects by tomography estimation with three NGSs within d=3' FoR.

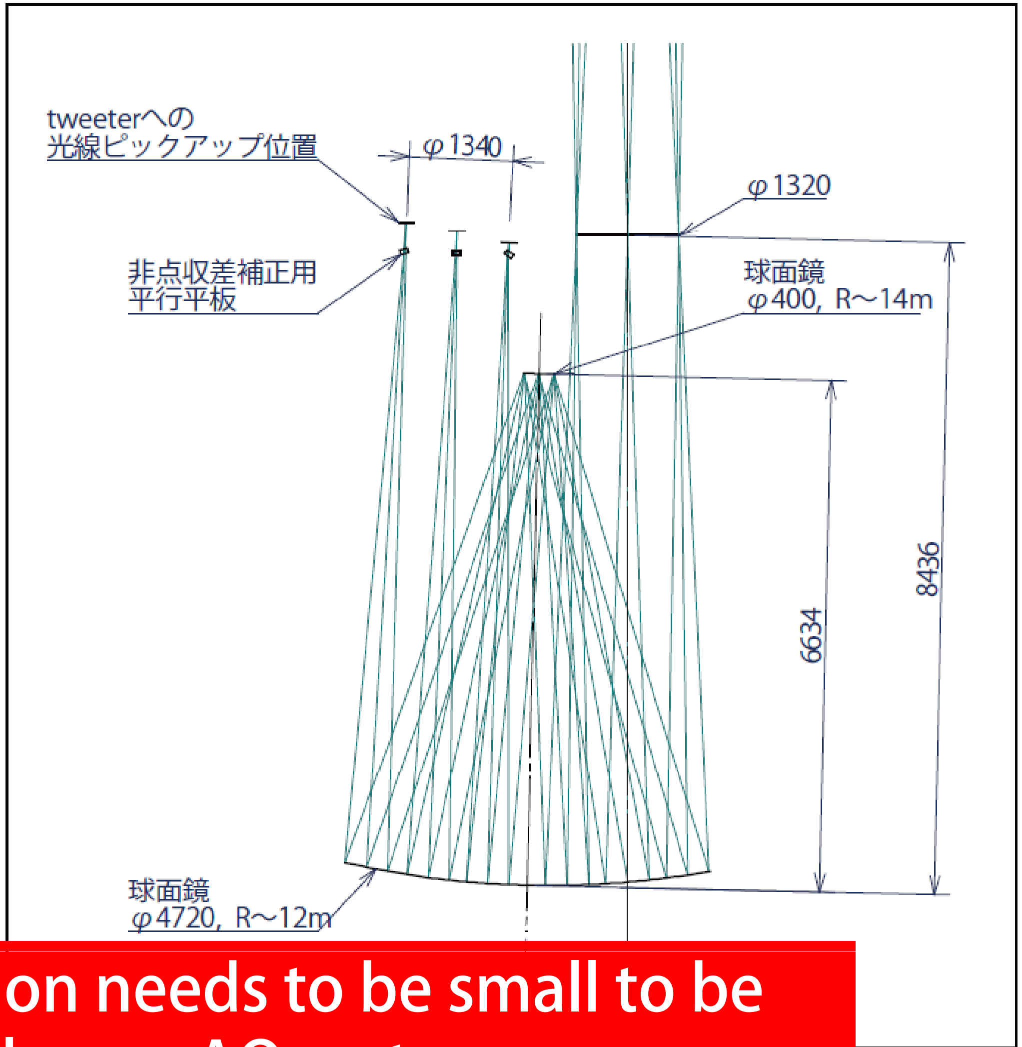


Lardiere et al. 2014

Ground-layer AO optical design

- d=10’ FoV AO optical design.

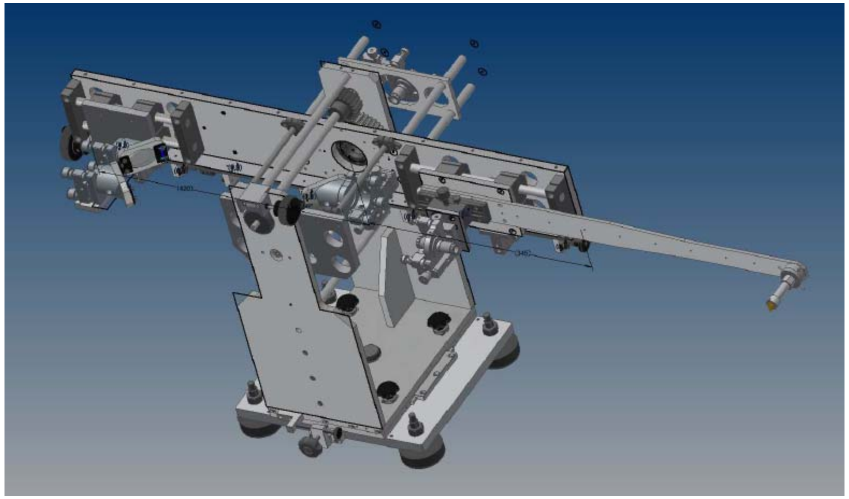


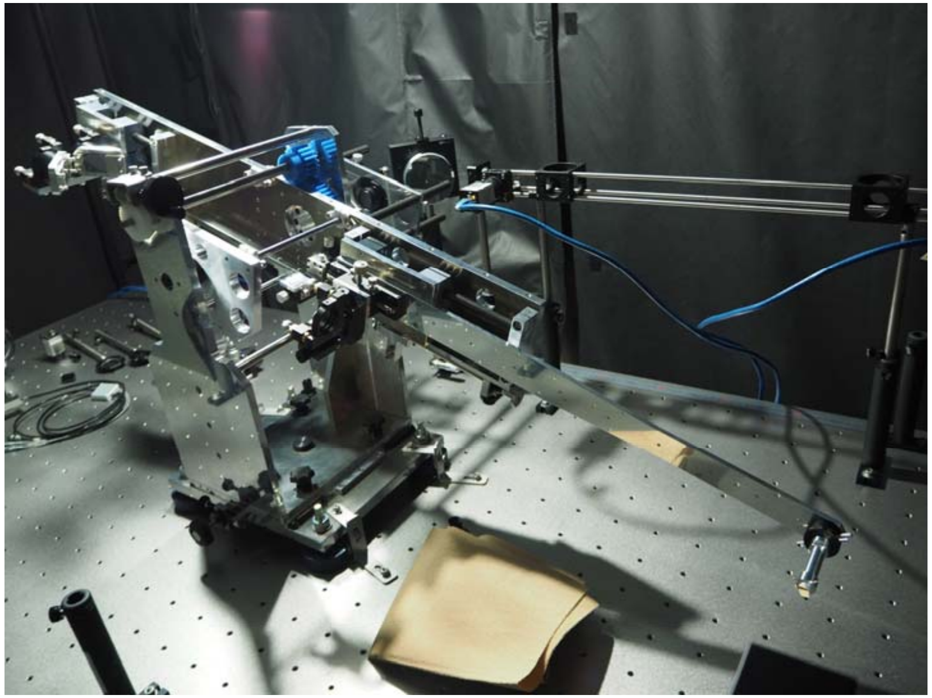


Pupil distortion needs to be small to be used as an AO system.

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.

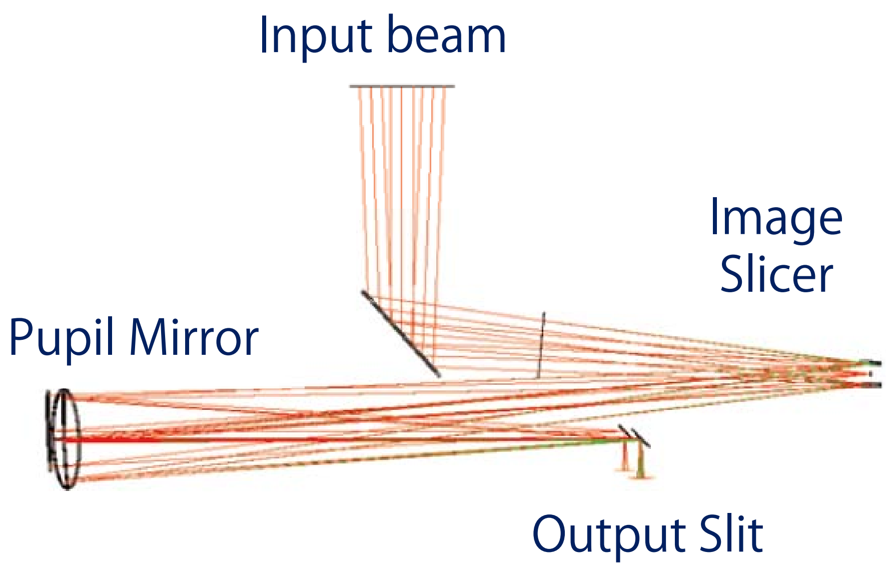


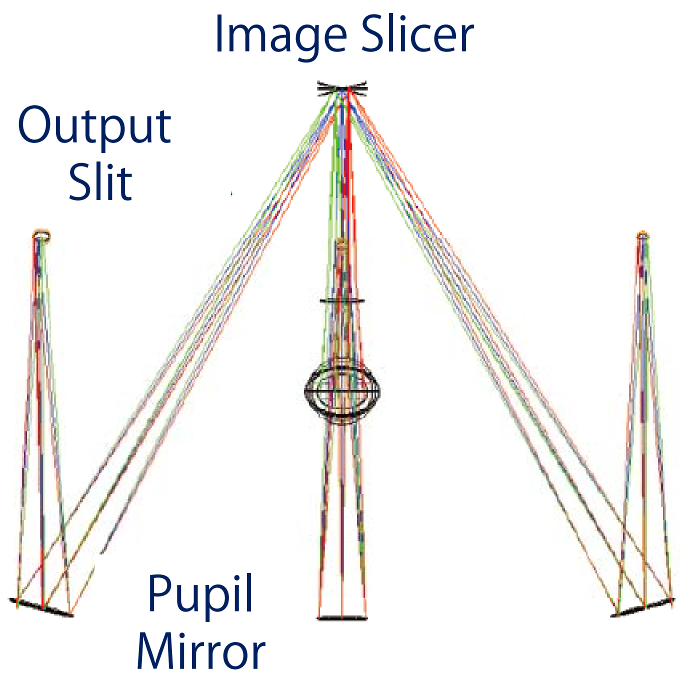


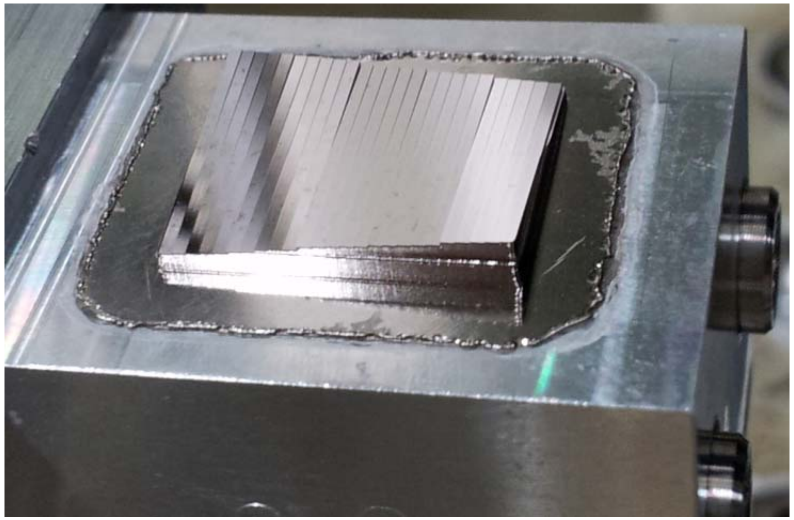
Optical alignment test is underway

Integral Field Unit optical design

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



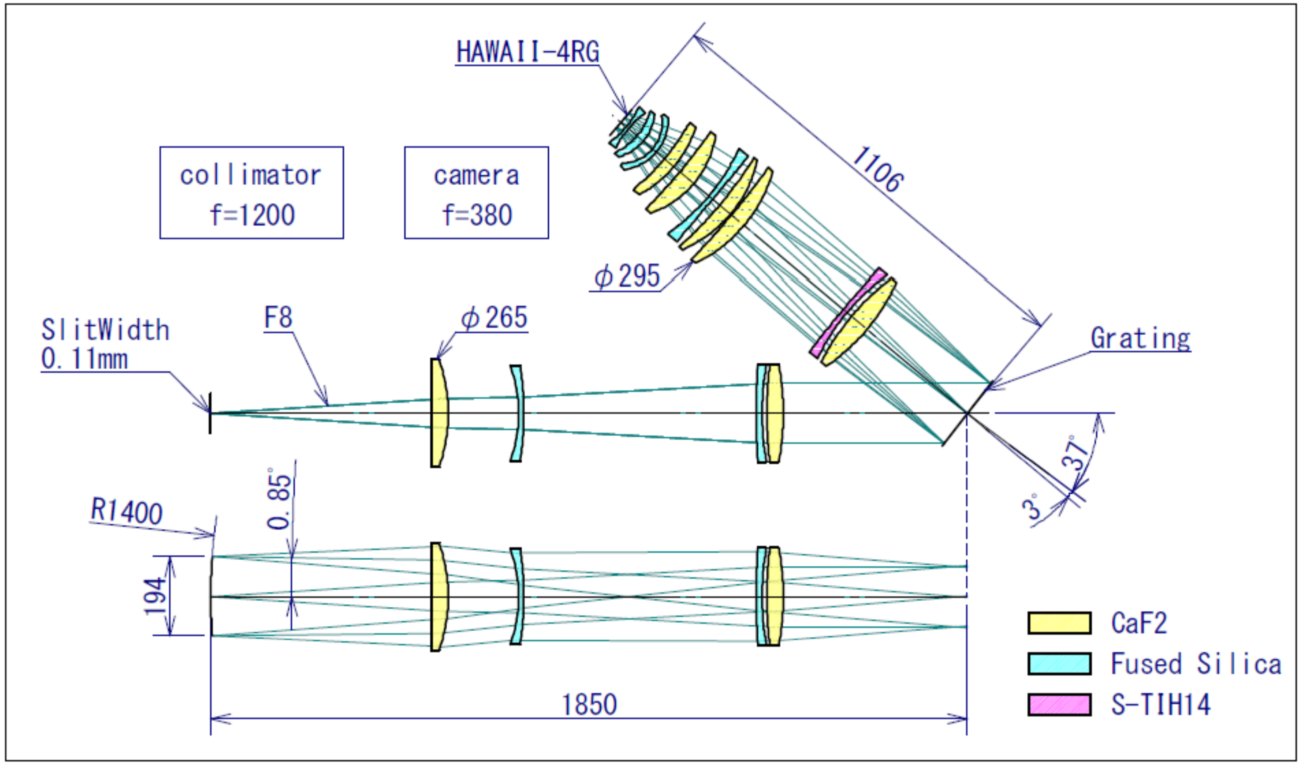




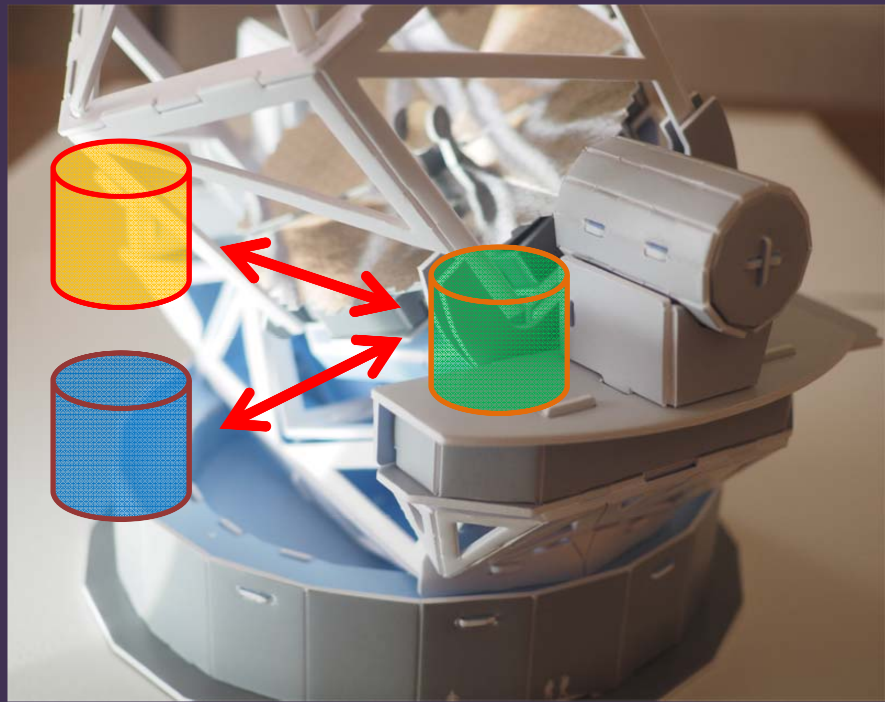
Prototype of the image slicer optics made by
griding + coating + ultra-fine polishing.
The unit will be used in TAO/SWIMS instrument.

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.



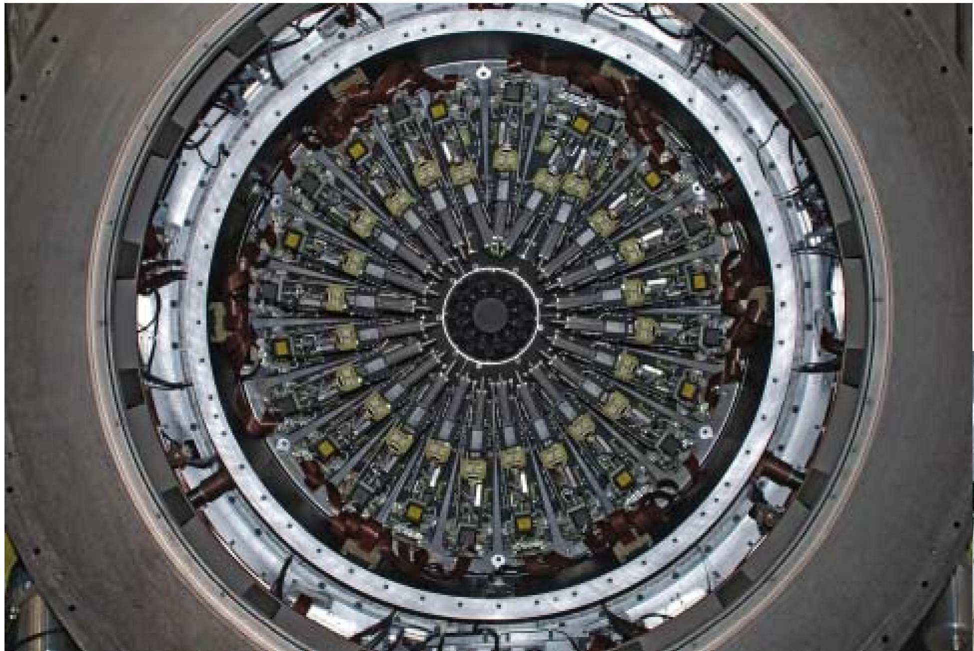
The camera system require 10 lenses including CaF2 lens with 295mm diameter.



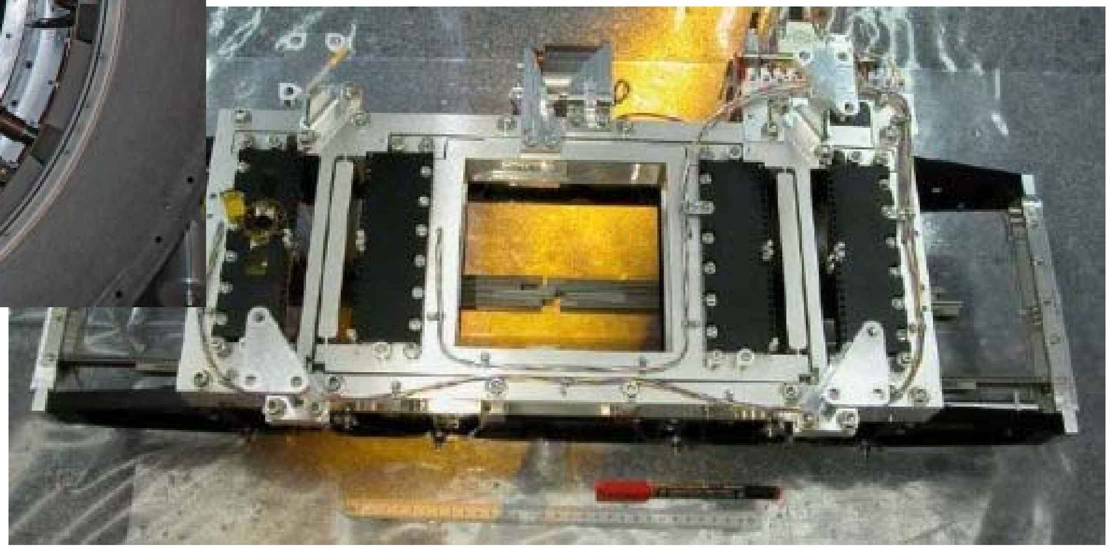
ALTERNATIVE IDEAS

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).

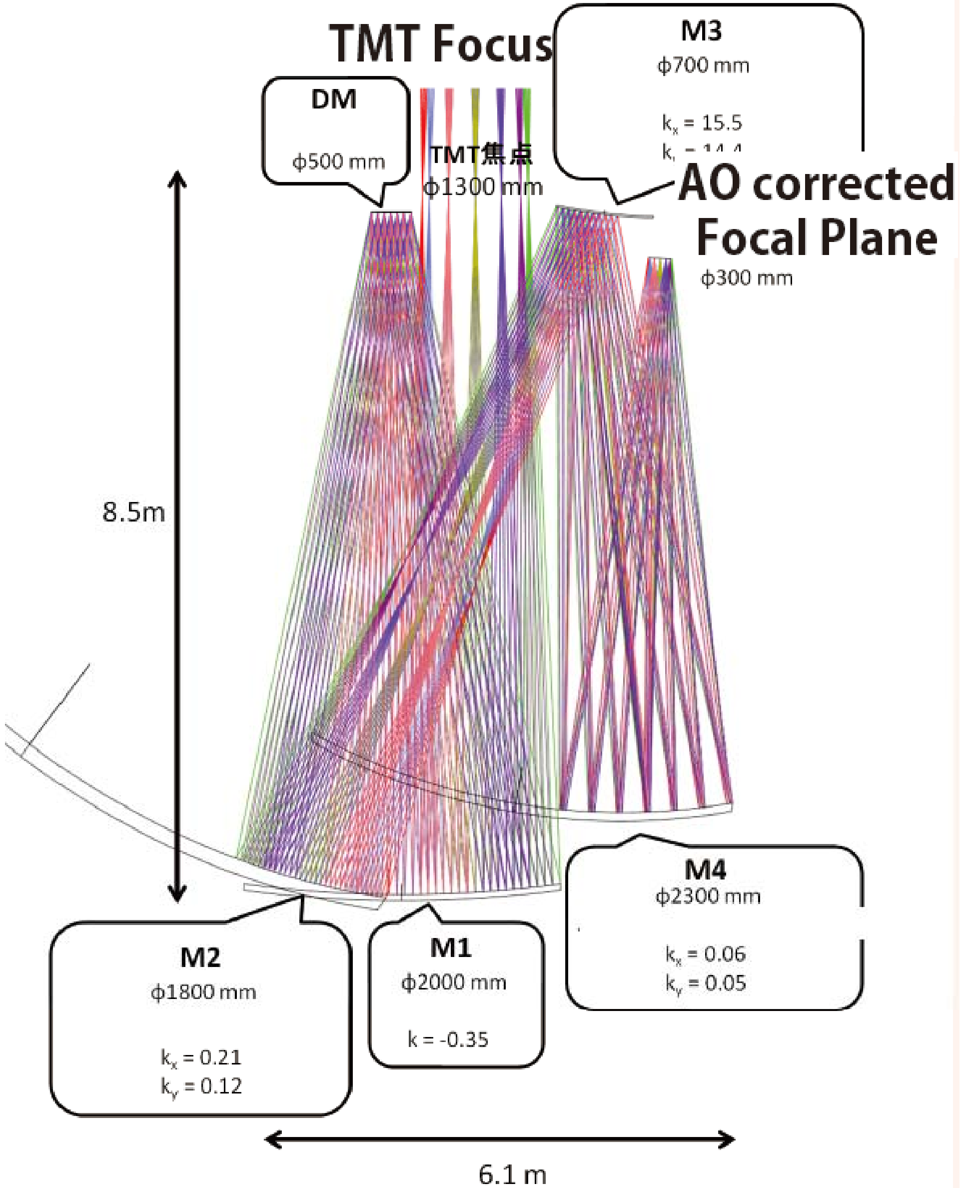


VLT/KMOS



Keck/MOSFIRE

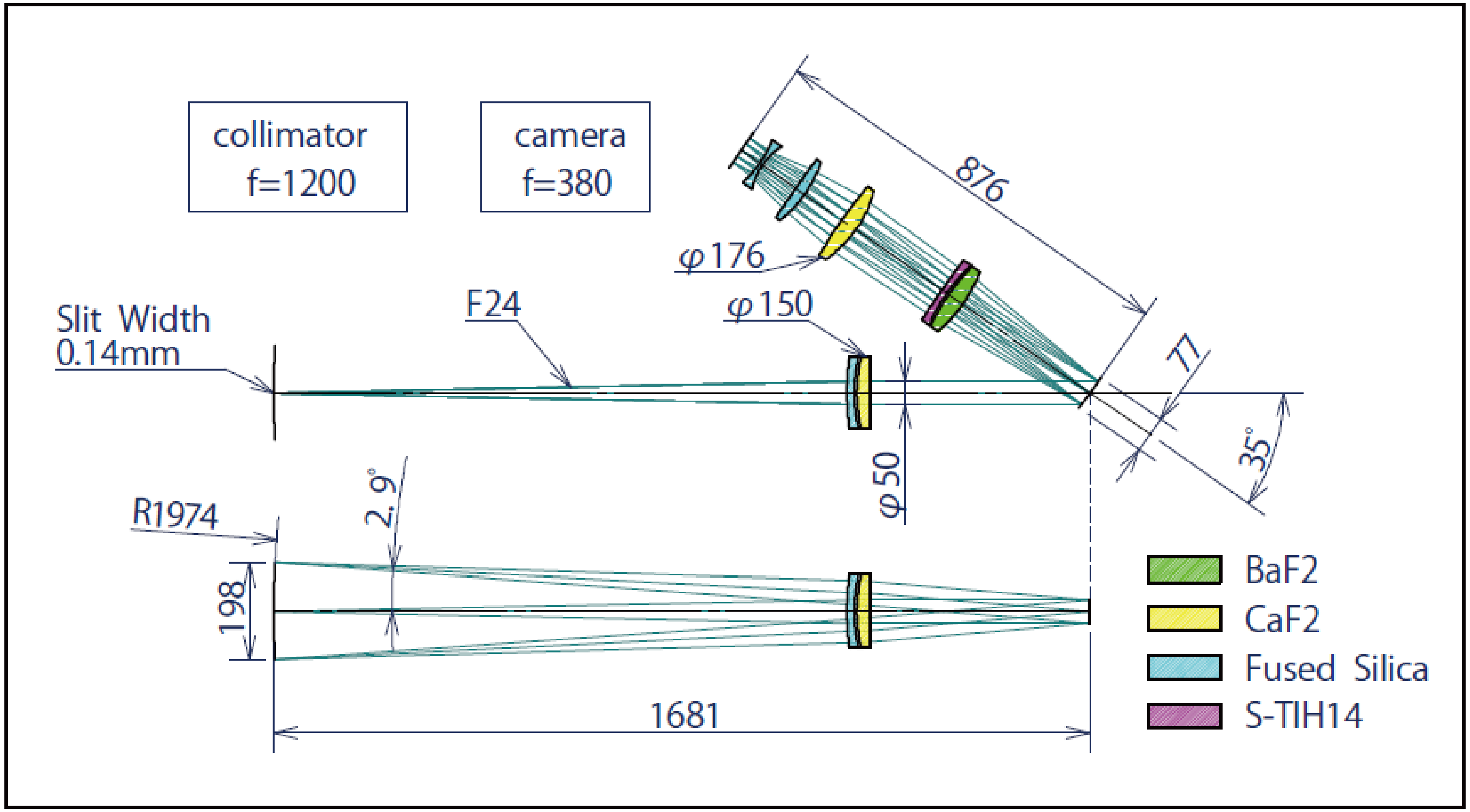
Idea 2: GLAO optical design with "shrinked" focal plane



- 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 "shrunk" 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

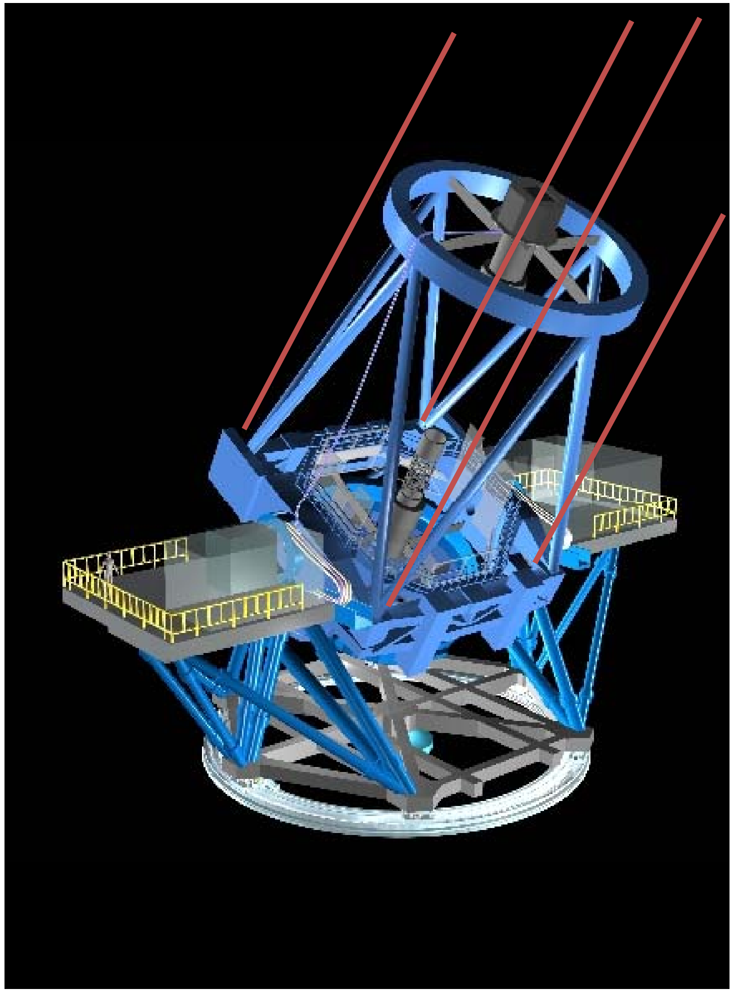
1. d=10 arcmin multi-pickoff-arm MOS spectrograph with GLAO correction (w/o imaging capability)

2. d=10 arcmin imager / MOS instrument with GLAO correction with shrunk 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 ?

ULTIMATE-Subaru



- 地表層補償光学によるすばる望遠鏡で10分角程度の広視野補償光学系を実現するプロジェクト。TMTの広視野補償光学の開発にもつながる。
- 6/16-6/17 ULTIMATE-Subaru Science workshop を国立天文台三鷹にて行います。詳しくは

http://www.naoj.org/Projects/newdev/ngao/201606_ULTIMATE_WS/

を参照ください。

議論

- z=1-3 の銀河内部構造を分解した分光探査から、どのような物理量を引き出すことが鍵になるか？
  - 星の系の速度分散、回転速度？
  - 中心核活動性 Seyfert-class？
- z>5 の銀河の分光探査観測から、どんな物理量を引き出すことが鍵になるか？
  - ガスの outflow / infall？
  - IMF？
- TMT を用いた wide-field (d=10’) narrow-band surveyer？

- FoV: TMT (d=15’-20’) vs. E-ELT (d=10’) vs. GMT (d=20’)