GLAO instrument specifications and sensitivities

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ULTIMATE-Subaru
Instrument Plan as of 2013

- Wide Field NIR imaging
  - Broad-band (BB) imaging
  - Narrow-band (NB) imaging
- Multi-Object Slit (MOS) spectroscopy
  - Emission line
  - Continuum
- KMOS type Multi-IFU spectroscopy
  - Emission line

Science cases with these instruments have been discussed at GLAO Science WS 2013 in Sapporo.

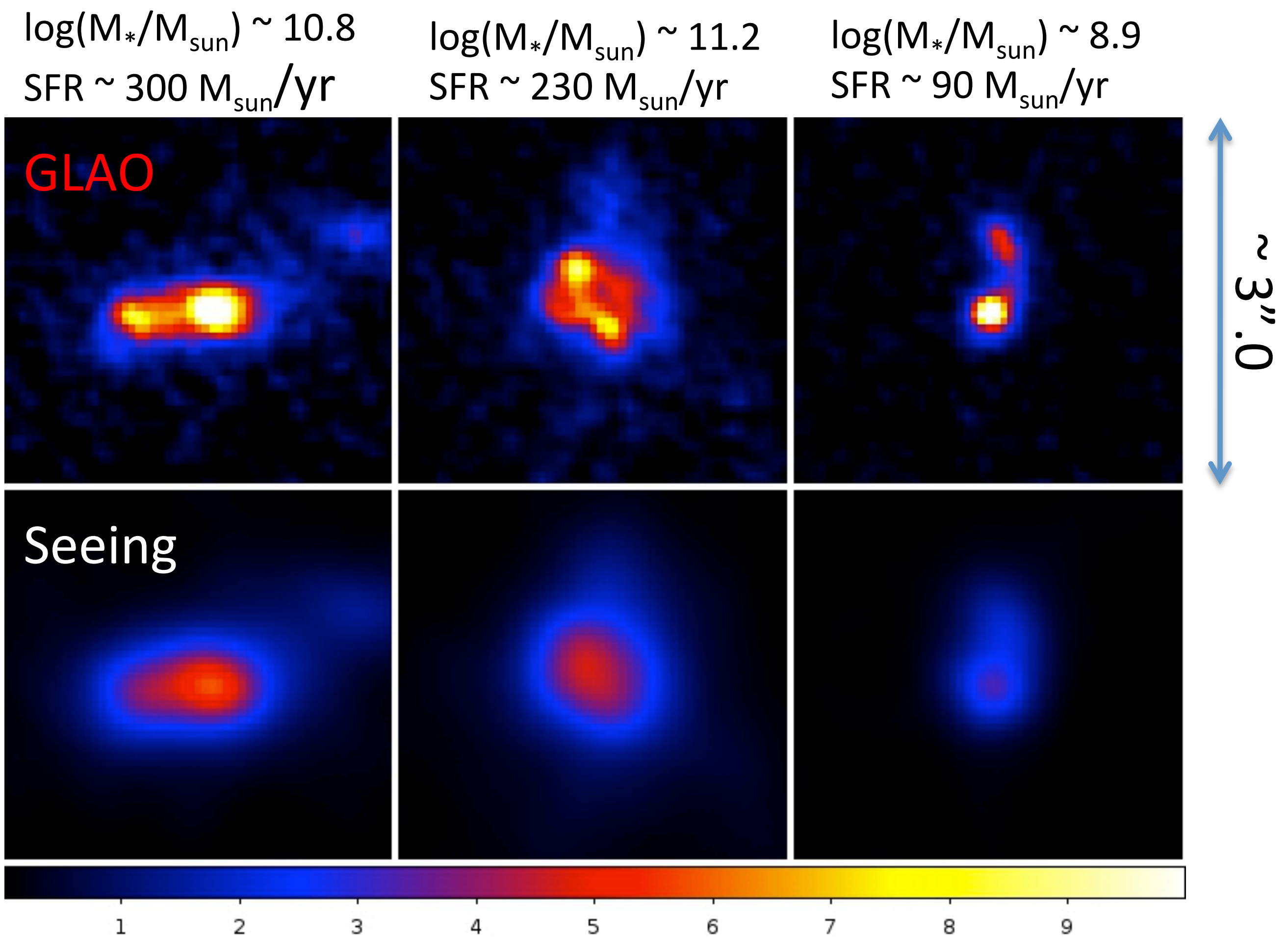
http://www.naoj.org/Projects/newdev/glaows13/index.html

ULTIMATE-Subaru
Baseline Instrument Specifications as of 2013

	Imager	MOS spectrograph	Multi-object IFU
Wavelength Coverage	0.9-2.5 μm		
Plate Scale	0.10 arcsec/pix		0”.125/spaxel
FOV	13’.6 x 13’.6		IFU: 1”.75x1”.75 Patrol Area: ϕ~13’
Filters	YJHK + NB filters		
Spectral Resolution	-	~3000	~3000
Multiplicity	-	100-150 slits	~24 IFUs (TBD)
Detectors	4 x H4RG (Teledyne)		3-4 H4RG (Teledyne)
Throughput (Atmosphere +Telescope +Instrument)	~60%(J,H), ~50%(K) (similar to VLT/HAWK-I)	~33%(J), ~35%(H,K) (similart to Keck/MOSFIRE)	~26%(J), ~30%(H,K) (similar to VLT/KMOS)

ULTIMATE-Subaru
performance simulation for z~2 galaxies

z~2 star-forming galaxies (Tadaki et al. 2013)



1kpc scale Clumpy structure of star-forming galaxies can be spatially resolved with GLAO

Comparison with Wide-Field AO instruments at 8-10m class telescope in 2020s

Instrument/Tel.	FOV	Multiplicity	λ(μm)	R	AO
Imager					
HAWK-I/VLT	7'.5x7'.5	-	0.9-2.5	-	GLAO(GRAAL),~0".2
FLAMINGOS2/Gemini-S	2'.0x2'.0	-	0.9-2.5	-	MCAO(GEMS), <0".1
ULTIMATE/Subaru	ϕ~13'.6	-	0.9-2.5	-	GLAO, ~0".2
Multi-Object Slit Spectrograph					
MOSFIRE/Keck	6'.1x6'.1	<46	0.9-2.5	~3500	NOAO,~0".5
FLAMINGOS2/Gemini-S	2'.0x2'.0	?	0.9-2.5	~3000	MCAO(GEMS),<0".1
ULTIMATE/Subaru	ϕ~13'.6	~100	0.9-2.5	~3000	GLAO, ~0".2
Multi-Object IFU Spectrograph					
KMOS/VLT	ϕ~7'.2	24	0.9-2.5	~4000	NOAO,~0".5
MUSE/VLT	1'x1'	1	0.46-0.93	~4000	GLAO(GRAAL),~0".3-0".4
ULTIMATE/Subaru	ϕ~13'.6	24	0.9-2.5	~3000	GLAO, ~0".2

- The most unique capability of ULTIMATE-Subaru is the widest FOV among the other AO instruments.

Comparison with TMT/Space instruments in 2020s

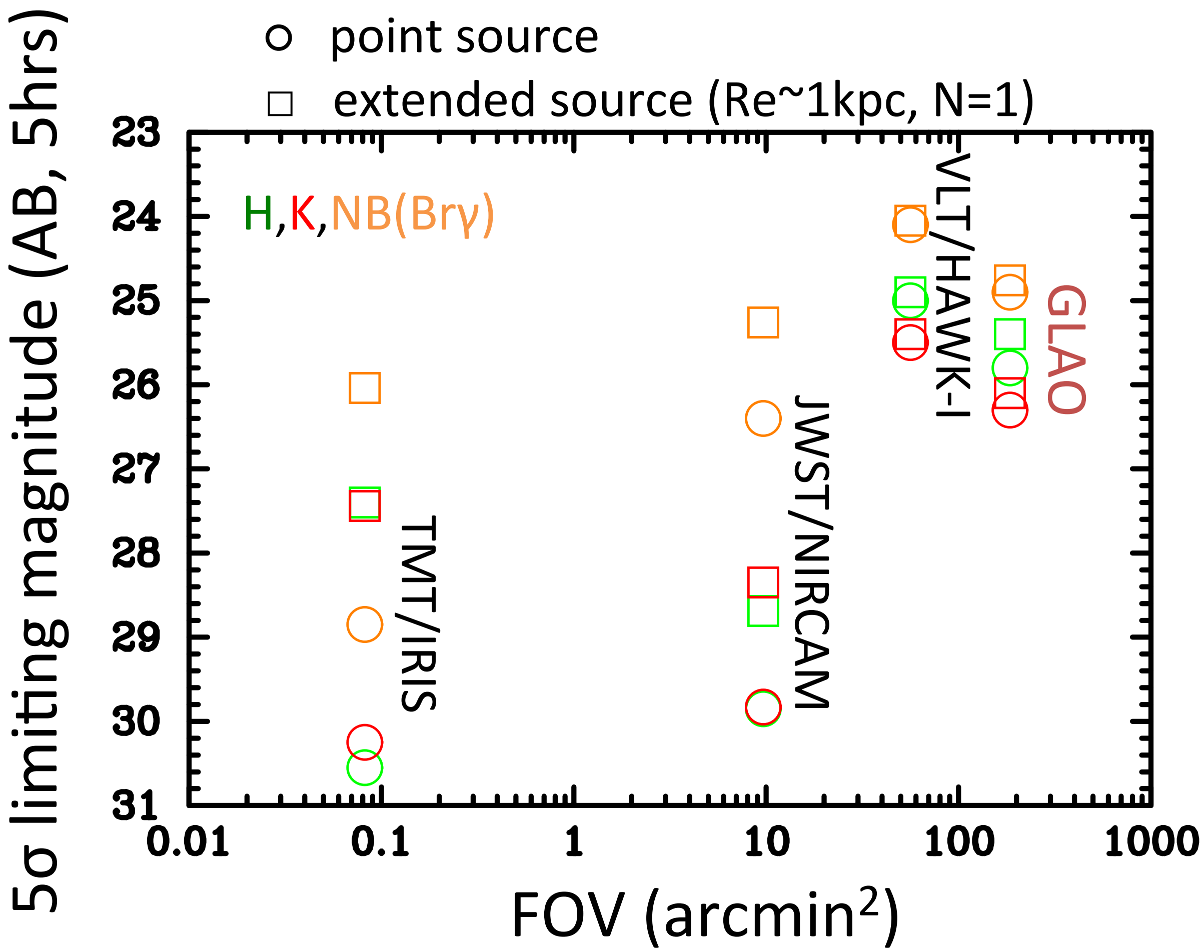
Instrument/Tel.	FOV	Multiplicity	λ(μm)	R	AO, FWHM
Imager					
IRIS/TMT	17”.2x17”.2	-	0.9-2.5	-	MCAO(NFIRAOS),~0”.01
NIRCam/JWST	2’.2x4’.4	-	0.5-5.5	-	Space, <0”.08
Euclid	0.5 deg^2	-	0.9-1.6	-	Space, ~0”.4
WFIRST	0.3deg^2	-	0.6-2.0	-	Space,~0”.2
WISH	0.23deg^2	-	0.9-5.0	-	Space, ~0”.3
ULTIMATE/Subaru	ϕ~13’.6	-	0.9-2.5	-	GLAO, ~0”.2
Multi-Object Slit Spectrograph					
TMT/IRMS	2’.1x2’.1	<46	0.9-2.5	5000	MCAO(NFIRAOS),~0”.01
NIRSPEC/JWST	3’.0x3’.0	>100	1.0-5.0	~2700	Space,<0”.08
ULTIMATE/Subaru	ϕ~13’.6	~100	0.9-2.5	~3000	GLAO, ~0”.2
Multi-Object IFU Spectrograph					
IRIS/TMT	<2”.2x4”.5	1	0.9-2.5	>4000	MCAO(NIFRAOS),~0”01
IRMOS/TMT	ϕ~5’.0	20(?)	0.9-2.5	>2000	MOAO, <0”.1
ULTIMATE/Subaru	ϕ~13’.6	24	0.9-2.5	~3000	GLAO, ~0”.2

- Survey type space telescope would be the best for imaging, but less flexible
- IFU is less competitive compared with TMT instruments

ULTIMATE-Subaru: performance

- Imaging sensitivity comparison

NB imaging survey of galaxies with the ULTIMATE-Subaru (GLAO) would be competitive or complementary to the TMT or JWST.

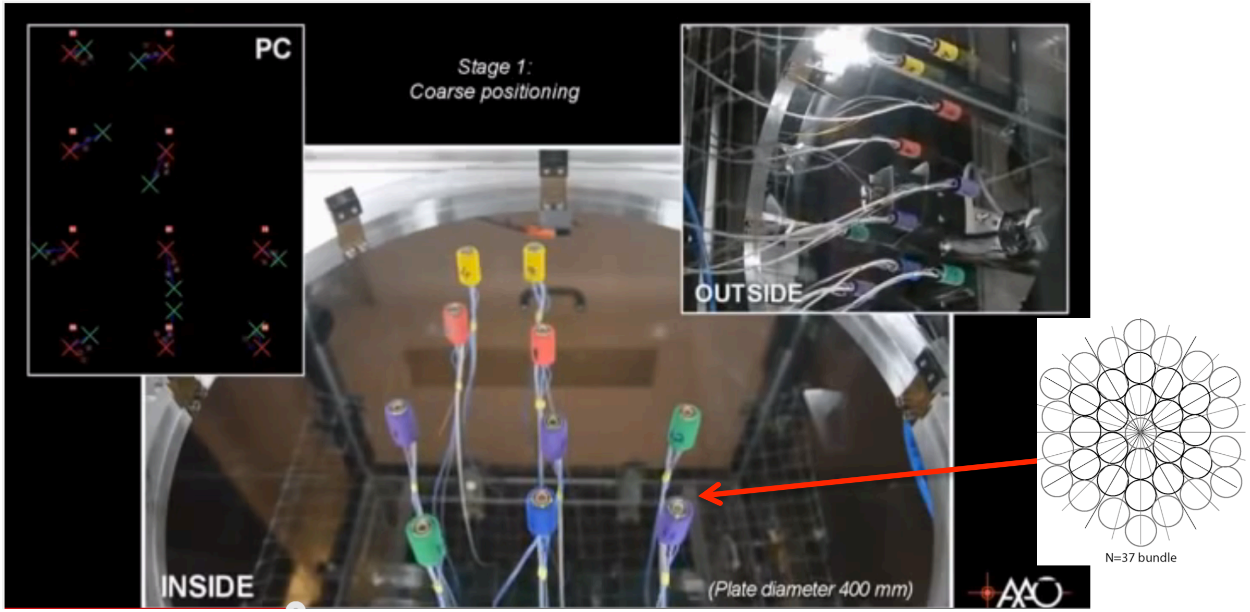


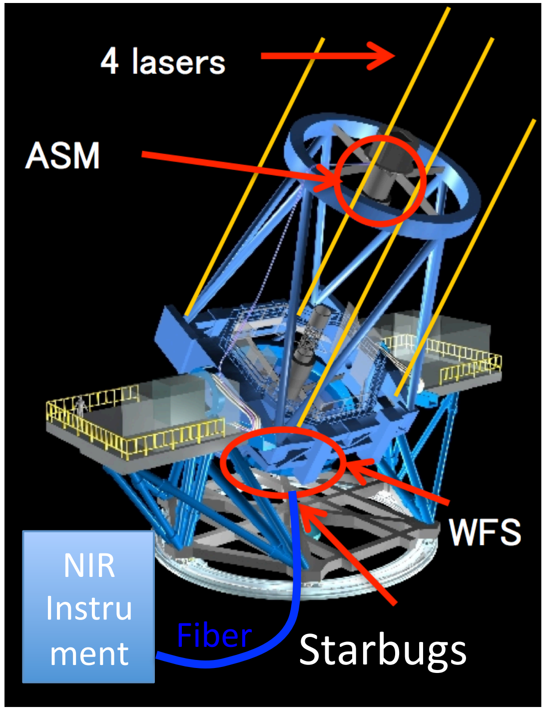
Summary from the workshop in 2013

- Imaging mode
  - Largest FOV in FWHM~0".2 resolution
  - NB wide field survey is competitive even compared with JWST instruments.
  - K'-band wide field imaging is also acceptable.
- Multi-Object Slit Spectroscopy
  - Combination with NB survey would be the best in terms of flexibility and long period compared.
- Multi-Object IFU spectroscopy
  - Provides more information than slit spectroscopy,
but number of IFU (~24) is not enough.
  - Can be replaced by NB imaging to some extent.

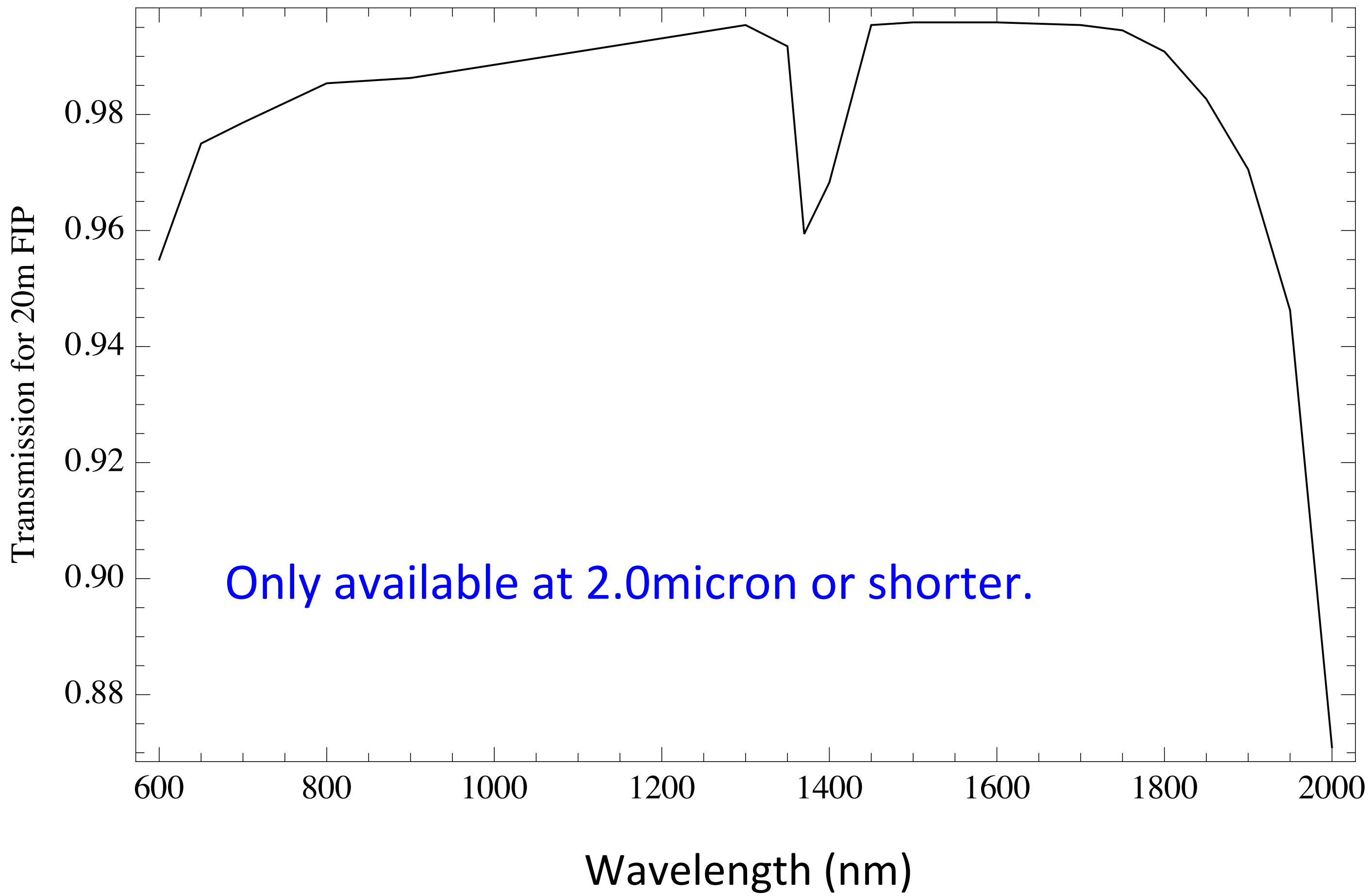
New Instrument Plan under Consideration

- Multi-object fiber IFU spectrograph
  - Fiber-bundle multi-IFU system
  - Utilize “Starbugs” developed by AAO
  - More multiplicity than KMOS-type IFU
  - Feed the light from the starbugs to the existing NIR instruments (e.g. MOIRCS)





Fibre throughput model
fibre only, no coupling losses or FRD



From: Andy Sheinis

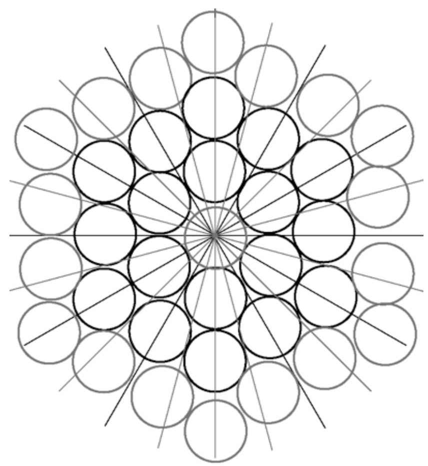
Instrument setup

- Starbugs unit will be attached to the Cassegrain focus
- Spectrograph will be placed at the observation floor and connected to the Starbugs with fibers.
  - F-conversion optics should be necessary to reduce the F# (12.4→→(e.g. 3.0) and avoid the effect of focal ratio degradation.
  - Throughput of the fiber will be (e.g. 90%@NIR).
- Fiber will be connected to the fiber slit in the focal plane module, which is placed in the cryogenic condition.
  - Minimum spacing in between fiber centers should be 4 pixels or larger and the minimum spacing between the 90% EE diameter of each adjacent fiber should be 1 pixel or larger to avoid significant cross-talk and ensure the accuracy of the sky subtraction (<0.5%? based on PFS study).
  - F-conv. optics in side of the FP module might be necessary to change the F# back to the original (12.4) or to the optimum number for the spectrograph.
- Total throughput including fiber and pre and post F-conversion optics would be 70-80%

→ Andy's talk for more detail

Fibre Bundle Configuration (1)

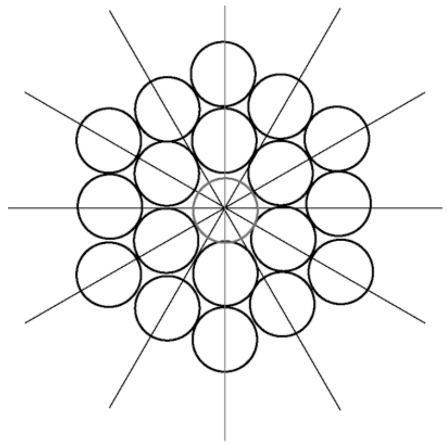
Number of fibres	37 (7 fibres on an axis)
Spatial sampling	0.2 arcsec / fibre
Bundle sky diameter	1.4 arcsec (point to pint)
Number of detector pixels per fiber	4
Number of pixels per bundle	148
Number of bundles per 2k detector	13 (1924 pixels; plus sky fibers?)
Object Multiplicity (MOIRCS)	26
Sky Fibres/detector	30 sky fibres with 1 fibre gap



N=37 bundle

Fibre Bundle Configuration (2)

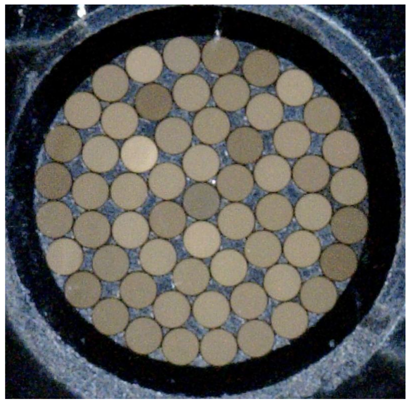
Number of fibres	19 (5 fibres on an axis)
Spatial sampling	0.2 arcsec / fibre
Bundle sky diameter	1.0 arcsec (point to pint)
Number of detector pixels per fiber	4
Number of pixels per bundle	76
Number of bundles per 2k detector	26 (1976 pixels; plus sky fibers?)
Object Multiplicity (MOIRCS)	52 (feasible??)
Sky fibres /detector	17 sky fibres with a 1 fibre gap



N=19 bundle

Fibre Bundle Configuration (3)

Number of fibres	61 (9 fibres on an axis)
Spatial sampling	0.2 arcsec / fibre
Bundle sky diameter	1.8 arcsec (point to point)
Number of detector pixels per fiber	4
Number of pixels per bundle	244
Number of bundles per 2k detector	8 (1952 pixels; plus sky fibers?)
Object Multiplicity (MOIRCS)	16
Sky fibres/detector	23 sky fibres plus 1 fibre gap

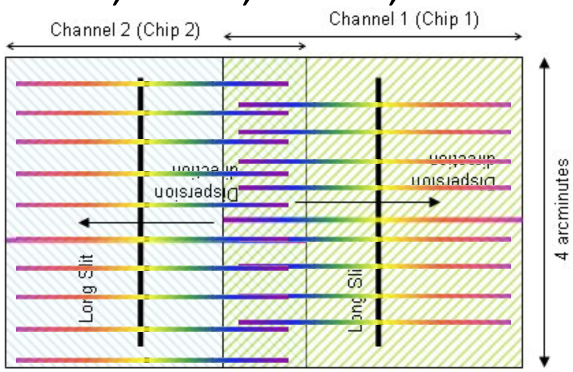


N=61 bundle (Bryant et al. 2014, MNRAS 438, 869)

Phase-I: Starbug + New MOIRCS

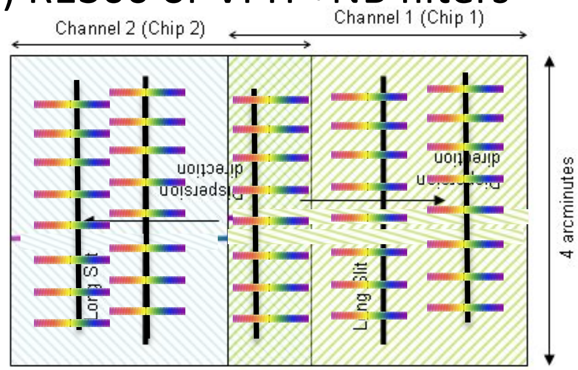
- First light instrument for GLAO
  - Commissioning obs. will start from around 2017 in the earliest case.
  - Observations with OH suppression might be be an option
- Number of bundles in ϕ~13.5 arcmin FOV:

(1) HK500, zJ500, R1300, VPH+BB(JH) filters



26 (config 1); 52 (config 2); 16 (config 3)

(2) R1300 or VPH +NB filters



78 (config 1); 156 (config 2); 48 (config 3)

- MOIRCS will be moved to the observation floor and connected to the Starbugs with fibers.

- Focal plane unit of MOIRCS will be modified so as to feed the light into slits from fibers.

Sensitivity comparison with MOSFIRE

	MOIRCS		MOSFIRE
	Current	New	
FOV	4'x7'		6'.1x6'.1
Imaging throughput (atm+Telescope+Instrument)	0.23(J), 0.34(H),0.30(K)		0.54(J),0.56(H),0.50(K)
Spectral resolution	500, 1300, ~3000(VPH)*		3500
Grating diffraction efficiency	HK500, zJ500: 0.8(J), 0.78(H), 0.65(K) R1300: 0.2(J), 0.3(H), 0.5(K) VPH: ~0.75(J), ~0.7(H) 0.80(K)		0.60(J), 0.65(H),0.70(K)
Spec. throughput (atm+Telescope+Instrument)	HK500, zJ500: 0.18(J), 0.26(H), 0.20(K) R1300: 0.05(J), 0.10(H), 0.15(K) VPH: ~0.15(J), ~0.20(H), ~0.26(K)		0.325(J), 0.361(H), 0.350(K)
Detector	HAWAII-2	HAWAII-2RG	HAWAII-2RG
QE	~80%(JHK)		~80%(JHK)
Read-out noise	15e rms (16NDR)	5e rms (16NDR)	5e rms (16NDR)

* For 0.5" slit. Using a fiber with 0.2" spatial sampling, resolutions are 2.5 times higher.

Sensitivity Improvement of MOIRCS

- HAWAII2 => H2RG
  - Readout noise: 15e- => 5e-
- Grism replacement
  - System throughput: 15%(R1300) => 25%(R2000)
- Spectral resolution will be more than 2 times higher than MOIRCS nominal value by using 0".2 fibers.
- Sharp and stable image with GLAO
- Improvement of emission line sensitivity
  - Point source: >1.2 mag. (>3x)
  - Extended source: ~0.5 mag. (~1.6x)

Sensitivity comparison with MOSFIRE

- Current MOIRCS sensitivity is 4~7 times lower than MOSFIRE (difference in the telescope diameter is not taken into account).

- If the new MOIRCS can successfully reduce the RO-noise down to 5e- and replace the grism, the sensitivity difference is about 1.4.

- This difference can not be reduced without changing the optical coating.
  - MOSFIRE has 31 surfaces with
    - Average throughput in each surface: ~0.992
    - Total throughput of the optical coating: ~0.78.
  - MOIRCS has 24 surfaces.
    - Average throughput of the coating: ~0.983.
    - Total throughput of the coating: ~0.64.

0.78 / 0.64 ~ 1.2

- Throughput of the Phase-I (Starbugs+new MOIRCS) will be around 50% of MOSFIRE/Keck (or 60-75% of KMOS/VLT)

Phase-II: Starbug +new dedicated instrument

- First light will be several years after GLAO commissioning
- Number of bundles:
  - 52 (config 1); 104 (config 2); 32 (config 3) for each spectrograph!
  - Φ13’.5 FOV
- Spectral Resolution: 3000-4000 (TBD)
- Sensitivity: 70-80% of MOSFIRE/Keck (or 90-100% of KMOS/VLT)
  - Sensitivity of the spectrograph should be same as or higher than MOSFIRE.
  - Only difference is throughput and emissivity due to the fibers.
- New instrument will be placed on the observation floor or Nasmyth platform and connected to the starbugs with fibers.

Items to be discussed in this WS

http://www.naoj.org/Projects/newdev/ngao/glaows14/files/questions.html

- Instrument Specifications
  1) Optimal sampling and FOV of the fiber bundle
     - Which configuration is the best for your science case?
  2) Number of fiber bundles (or multiplicity) in 13'.6 FOV
     - What is the minimum number of multiplicity to be still competitive in 2020s?
  3) Wavelength coverage
     - Please note that fiber IFU is currently available up to 2.0 micron.
     - Implementation of the K-band fiber requires R&D.
  4) Spectral resolution
  5) Sensitivity requirement
- Science Case
  6) Observation plan with Phase-I (Starbugs+new MOIRCS) instrument
  7) Uniqueness of the science case
     - Is it competitive or complementary to the science with 30m class or space telescope?
- Phase-II instrument
  8) Requirement to the Phase-II (Starbug + new spectrograph) instrument
- Uniqueness
  9) Fiber bundle multi-IFU is more unique than multi-object slit spectrograph?

Please answer these questions in your presentation and discuss in this WS!