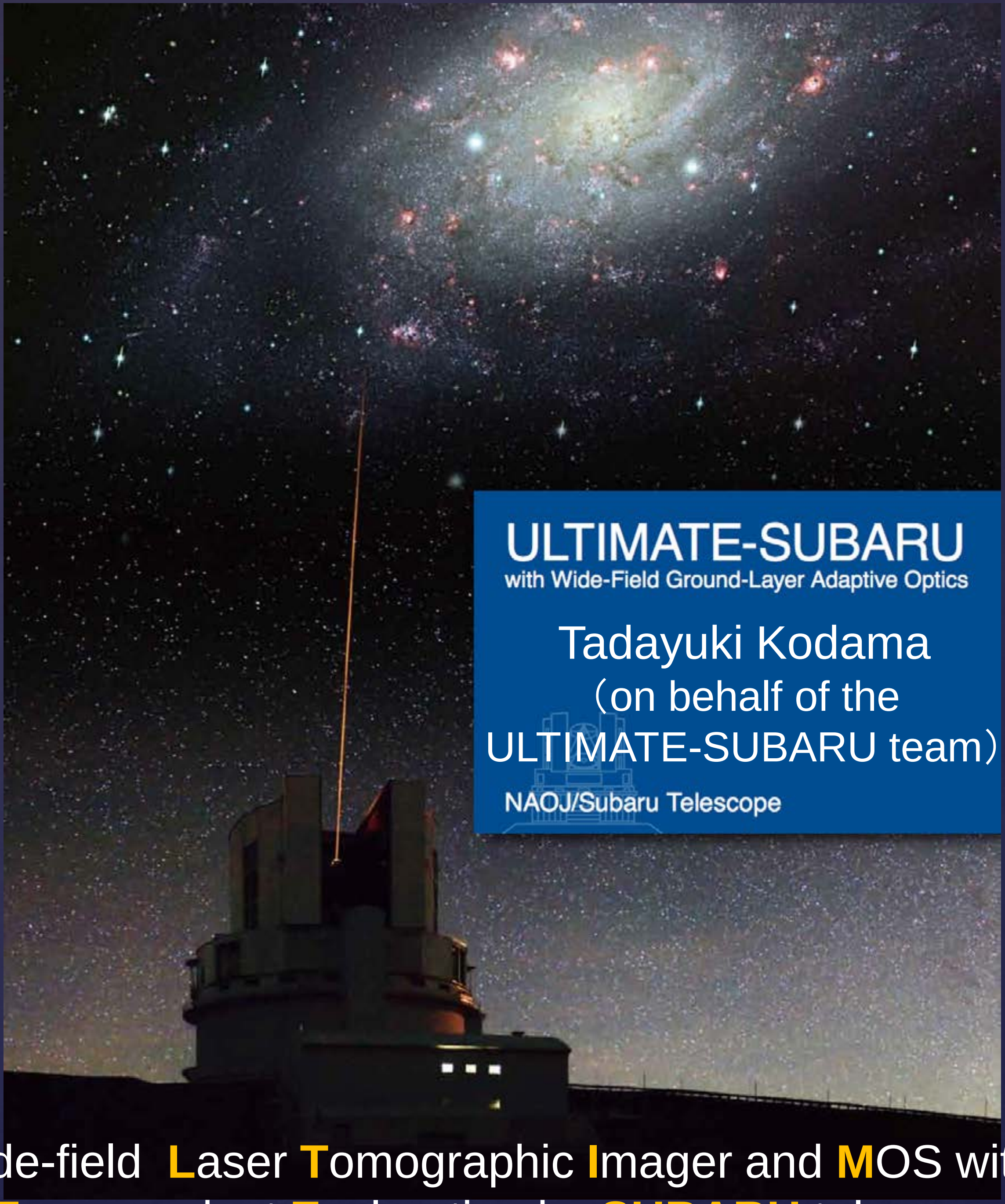


Ultra-wide-field **L**aser **T**omographic **I**mager and **M**OS with **A**O for **T**ranscendent **E**xploration by **SUBARU** telescope.

Future key instruments of Subaru Telescope

鼎(tripod pot)

ULTIMATE-SUBARU

1. **Ground Layer AO with Adaptive Secondary Mirror (4 LGSs)**

2. **Wide-field Near-IR Instrument (Imager, MOS or M-IFU)**

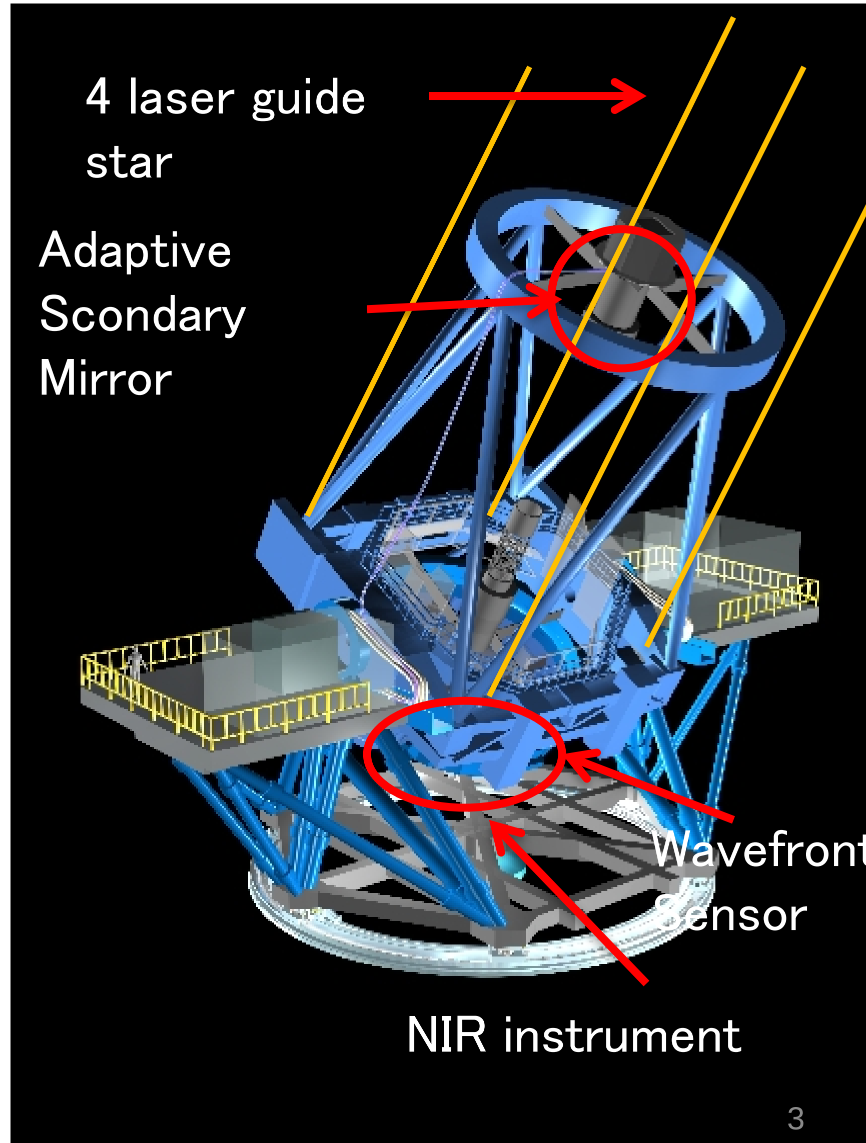
→ Seeing improvement
(FWHM 0.4”→0.2”) over FOV ~15’

Higher sensitivity equivalent to 2x telescope aperture[*1]

6 times wider FOV[*2]

~200 times wider FOV compared with AO188/LGS+IRCS

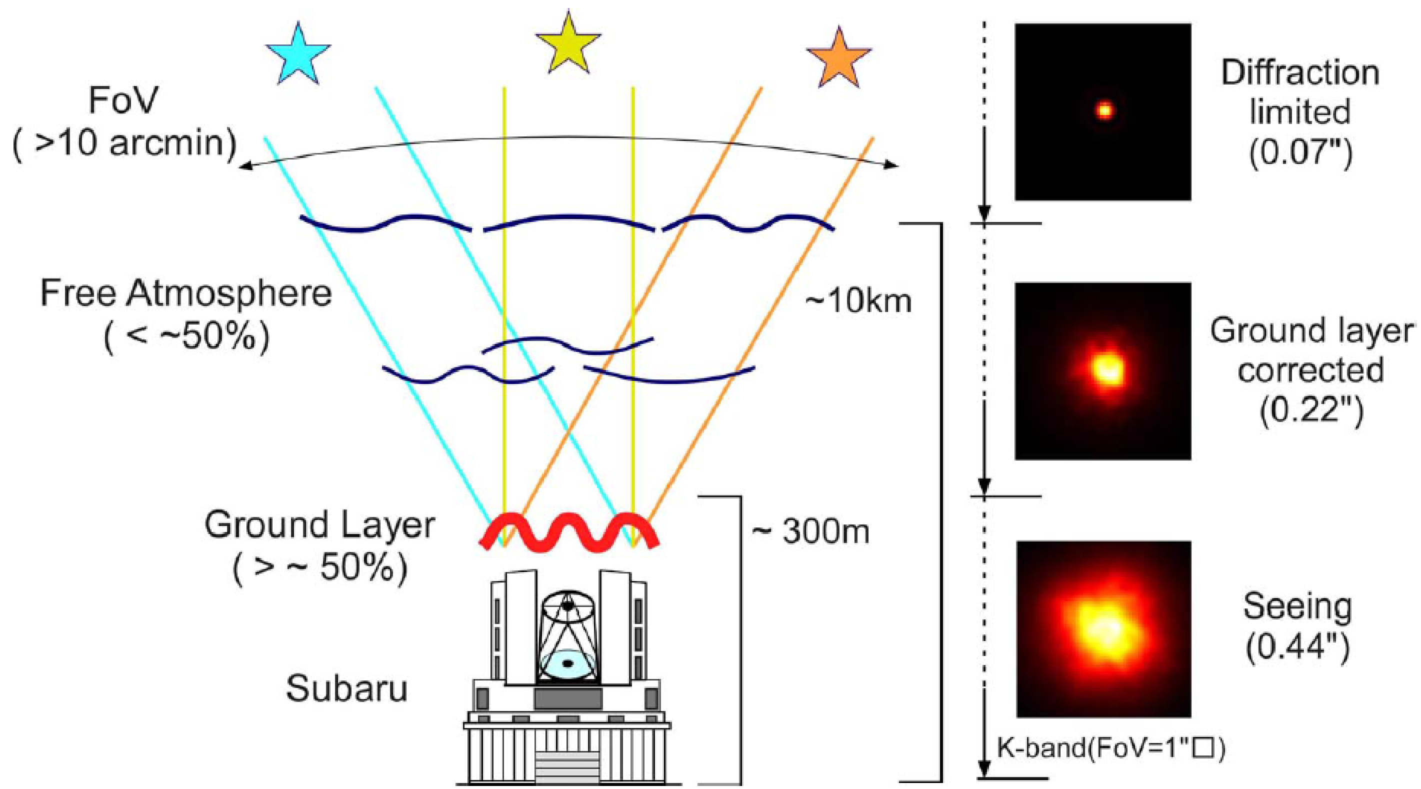
*1 For point sources.
*2 Relative to MOIRCS (seeing limited NIR instrument)



Basic idea of GLAO

- Corrects only turbulence close to the ground
- Improves seeing over wide-filed of view

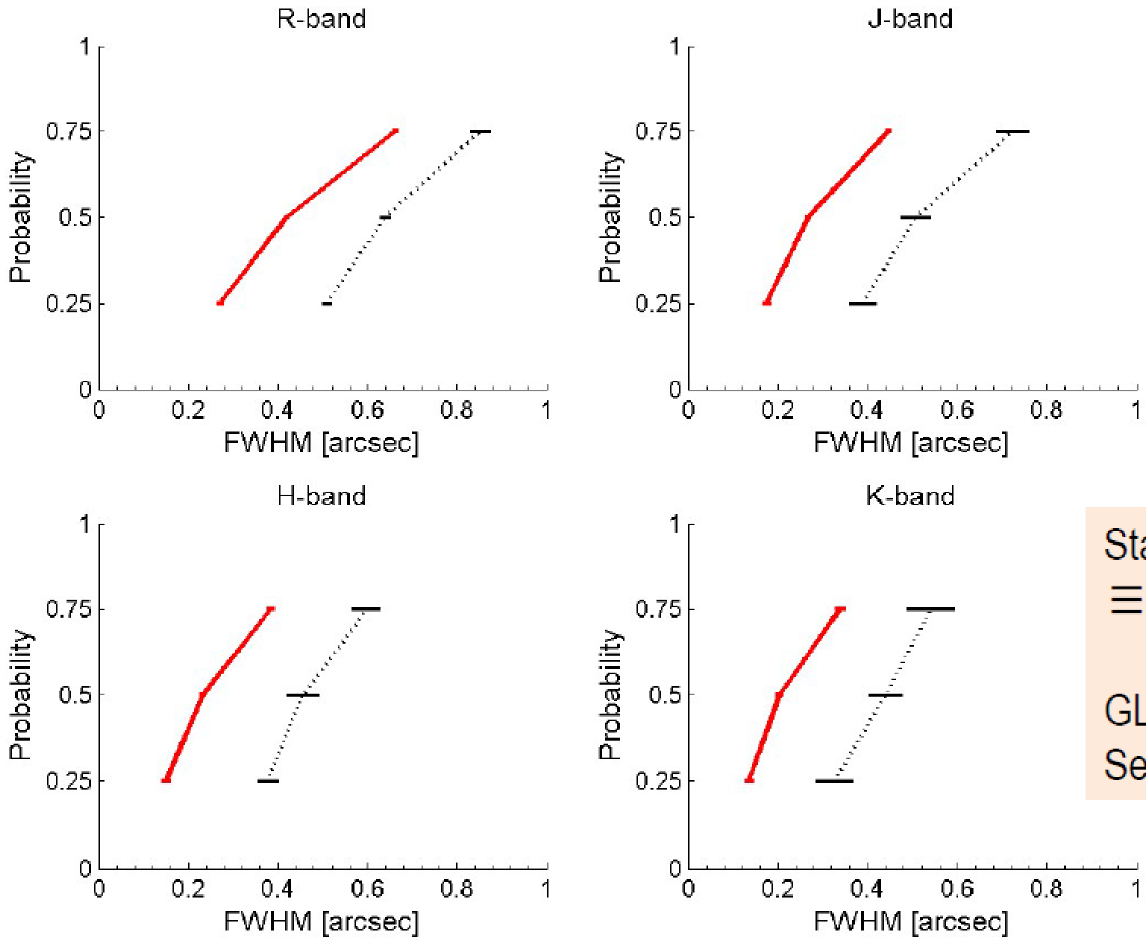
GLAO correction (simulation)



Effective for wide field of view

Seeing dependence of FWHM

@zenith



Stalibiy
≡ std / ave

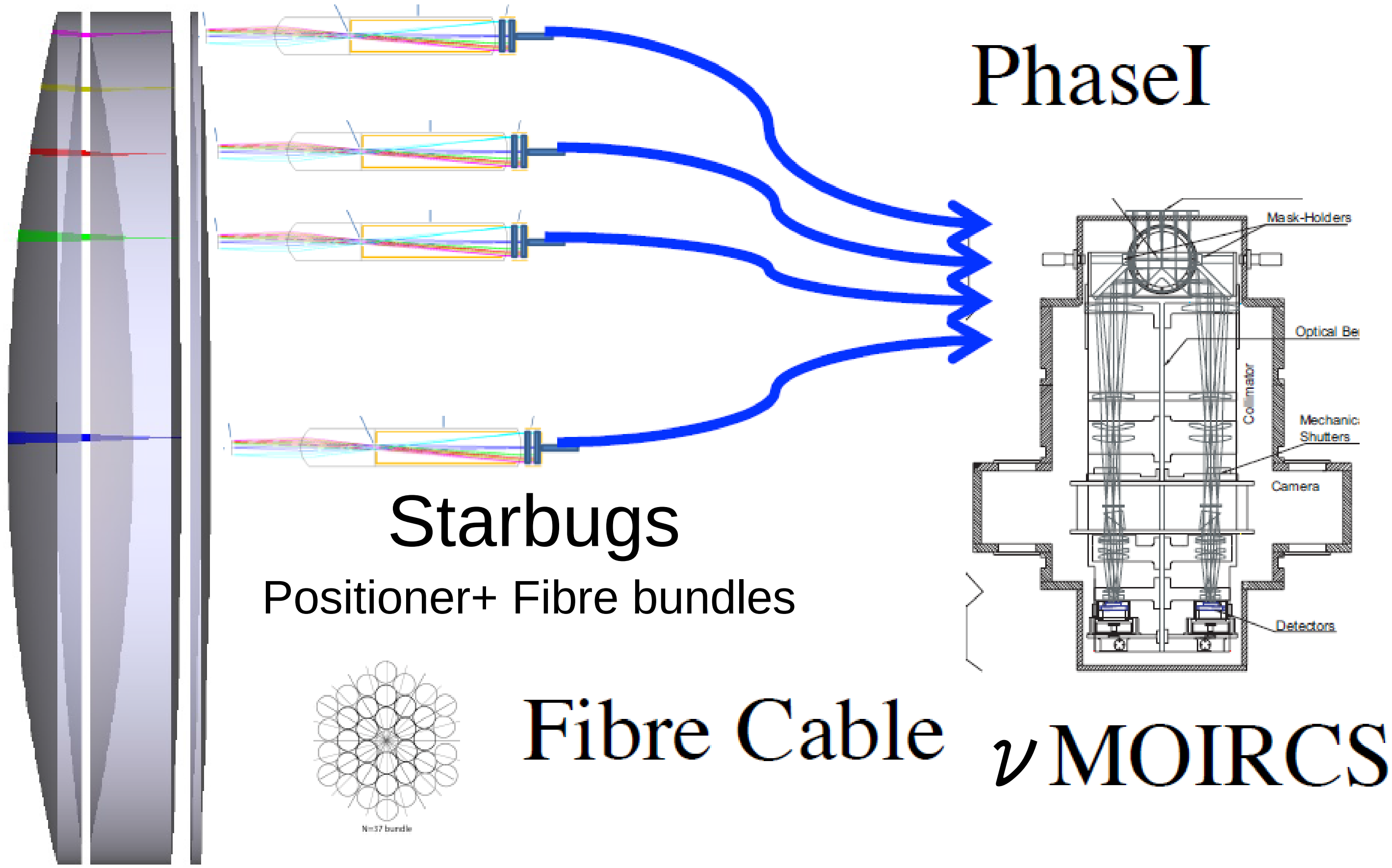
GLAO: 1~7%
Seeing: 2~10%

GLAO: solid , Seeing: dotted; error bars shows standard deviation along time axis

0.2” (~1.5kpc) at K-band

Starbugs + IFU

Fibre-based MOS for Ultimate

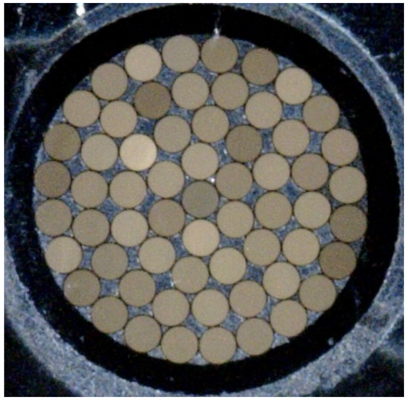


Wavelength range is limited to <2µm (no K-band)

Hα, [NII] limited to z<2, but [OIII], Hβ, [OII] to z~3

Fibre Bundle Configuration

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)

A phased approach for ULTIMATE-SUBARU

Phase 0.5 = Starbugs (+WFC/metrology camera) w/o GLAO
+ NuMoirics (new detectors and new grating)
+ Cassegrain modification (13’ x 8’)
(decommission of FOCAS, ADC, AGSH?)

基盤S + NAOJ (Cass改造)

Phase 1 = phase 0.5 + GLAO (adaptive secondary)

新学術 + NAOJ ?

Phase 2 = New dedicated NIR imager and spectrograph with more arrays and higher throughput + Wider Cass FoV (15’x15’)

特別推進?

Phase 3 = Phase 2 + OH suppression fibres + K fibres

Science Brainstorming

Subaru next generation AO workshop
(2011/9/8-9, Osaka Univ. Nakanoshima Center)
More general, including MOAO

↓

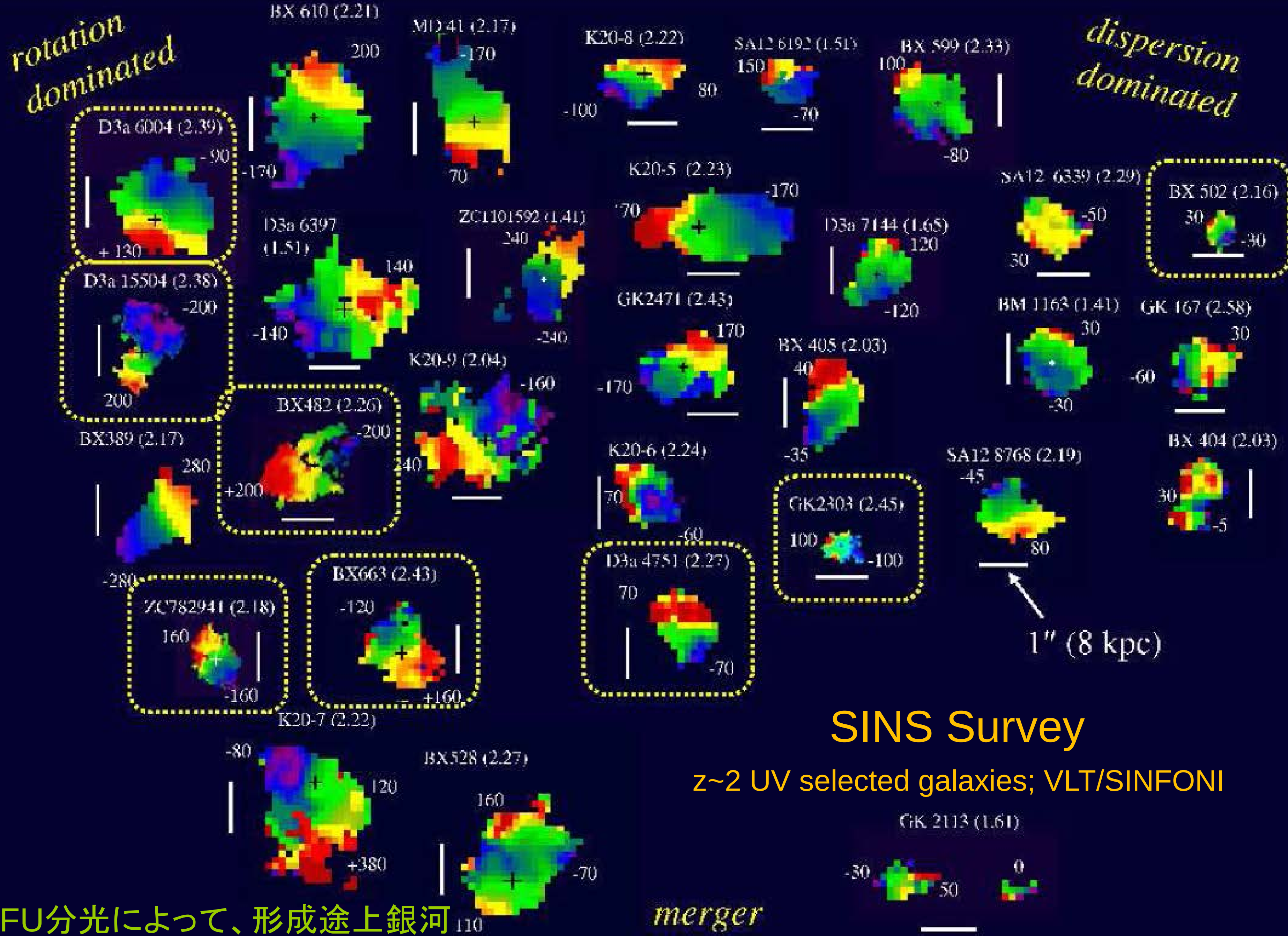
Subaru GLAO Science Workshop 2012
(2012/10/17-18, Subaru Hilo Office)
Kick-off meeting (invitation only)

↓

Subaru GLAO Science Workshop 2013
(2013/6/13-14, Hokkaido University)
wider community including Canadians, key science, imager/MOS

↓

ULTIMATE-Subaru Science Workshop 2014
(2014/7/28-29, NAOJ Mitaka)
wider community including Australians, starbug&IFU system



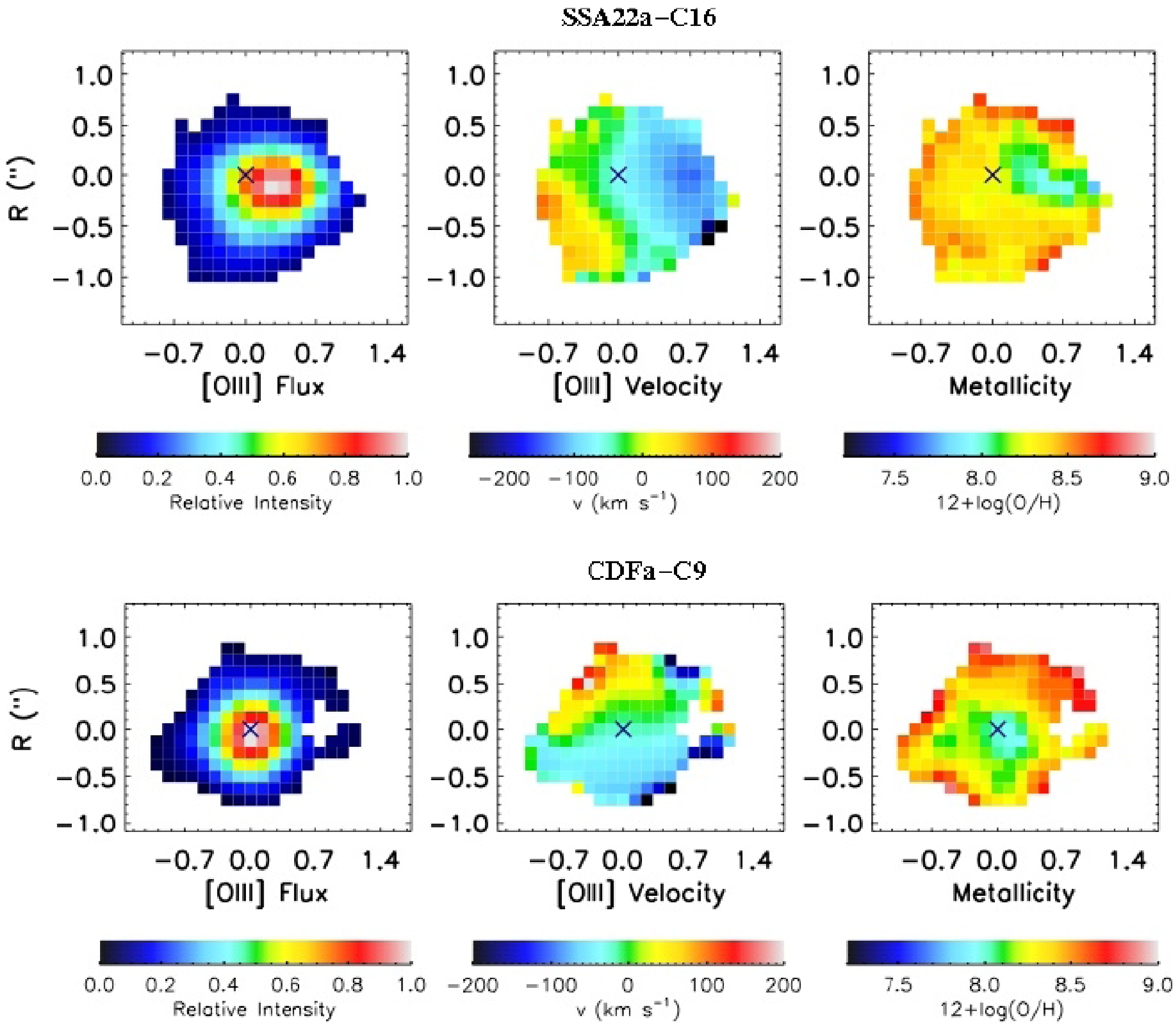
SINS Survey

z~2 UV selected galaxies; VLT/SINFONI

IFU分光によって、形成途上銀河
の内部運動や物理過程が詳細に分かる。

Foerster-Schreiber et al. (2009)

銀河内部の星形成マップや化学進化から、星形成の伝搬（中心バースト?inside-out?）やガスの流入（cold-stream?）を探る



2D map of line ratios (metallicity indicators) such as [OIII]/Hβ and [NII]/Hα

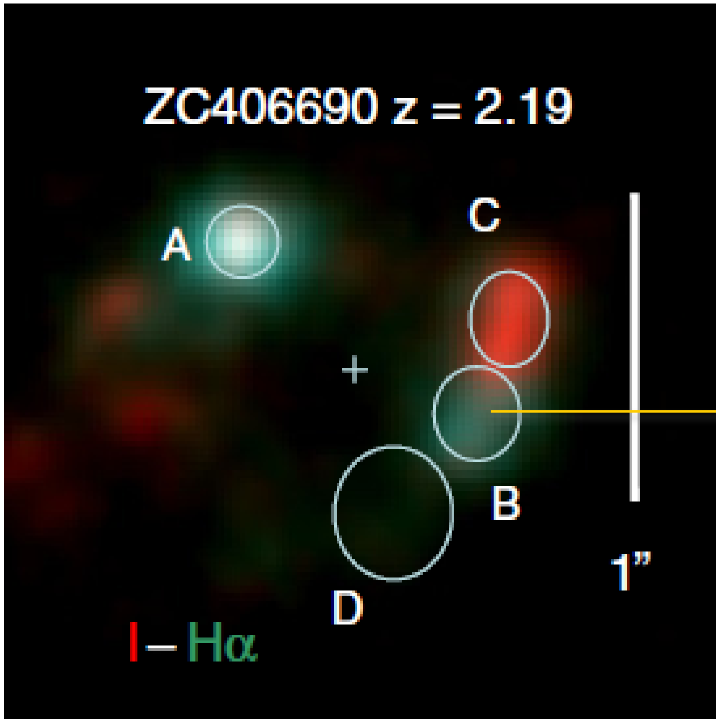
VLT/SINFONI

Cresci et al. (2010)

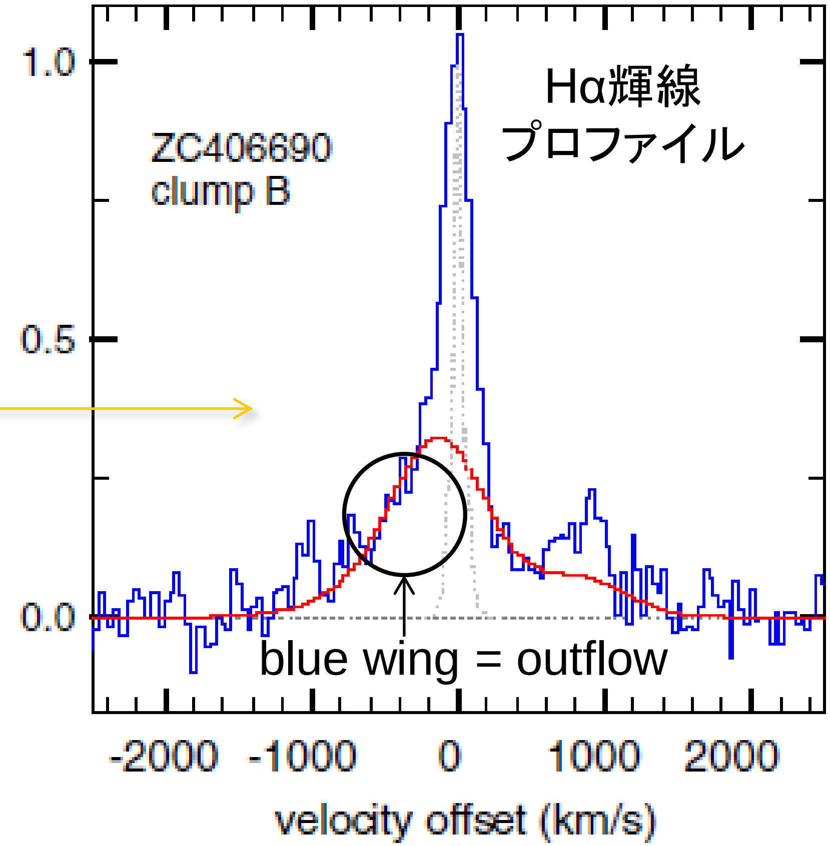
see also
Jones et al (2010)
With Keck2/OSIRIS

Lower metallicity at the center → Dilution by (almost) metal-free cold streams?

クランプ銀河からのガスのアウトフロー（フィードバックの現場）



Genzel et al. (2011)



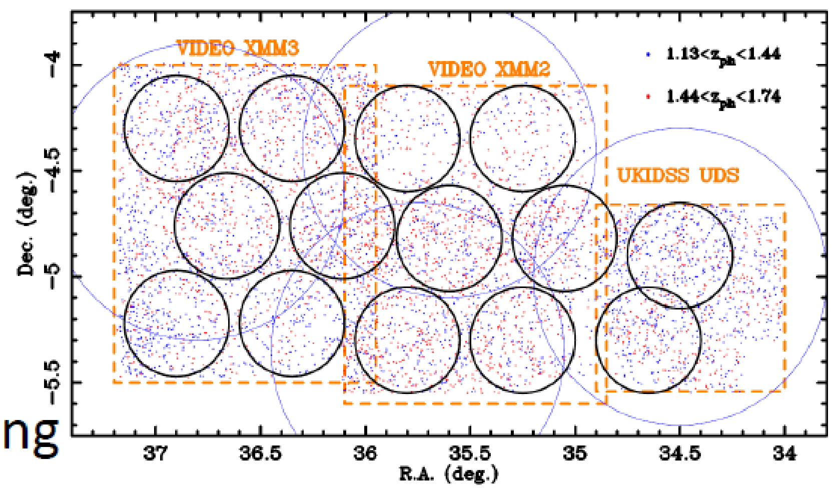
クランプBで起こっている星形成バーストによるガスのアウトフロー（~500km/s）

A possible ? survey (in phase I?)

- U<24 K>23 galaxies in CANDELS field
- GOODS-N, UDS(15’x10’), EGS(7’x25’), COSMOS(7’x20’)

  (GOODS-N, EGS: ALMA cannot access)
- => ~250 SF galaxies in UDS,EGS,COSMOS

- ~5000 galaxies in SXDS
- Before TMT



Possibility of HAE survey w/ pre-imaging

Ohta’s slide

波及効果

望遠鏡性能の一般的改善（主焦点装置以外）
可視（FOCAS）でもシーイング改善
熱背景光の低減（補償光学系のミラー枚数減）

Extreme-AO の開発
Laser-Tomography AOの開発

TMT時代に、日本の補償光学技術の維持、発展

Summary & Discussion

- Utilization of Subaru bright nights and reuse of existing instruments (e.g. MOIRCS)
- Killer science in the era of TMT?

  -Galaxy anatomy at $0<z<3$ (in e.g. CANDELS/3DHST)

  -Lyα blobs/haloes (detection/size/kinematics)

  -Clusters/Proto-clusters
- No K-band (<2μm)?

  -Hα, [NII] limited to $z<2$, but [OIII], Hβ, [OII] to $z\sim3$
- IFU or MOS? (K-band availability & multiplicity)

  -complex structure of high-z galaxies → IFU?

  -slit scan with MOS? (slit loss, seeing variation…)
- Decommission of ADC, AGSH, FOCAS ?

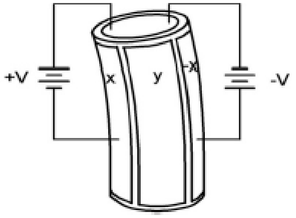
The END

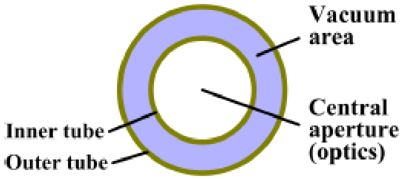
See http://www.naoj.org/Projects/newdev/ngao/glaows14/

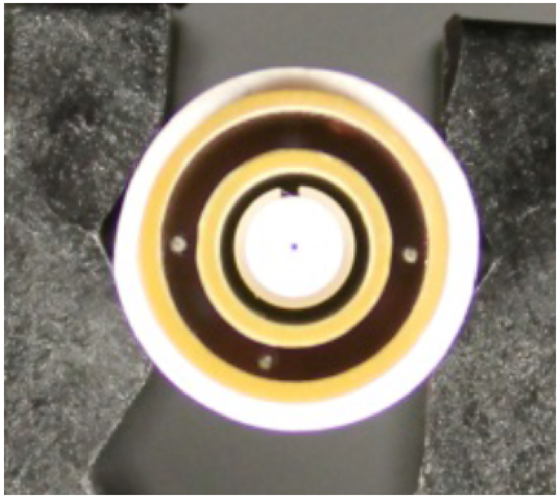
Backup slides

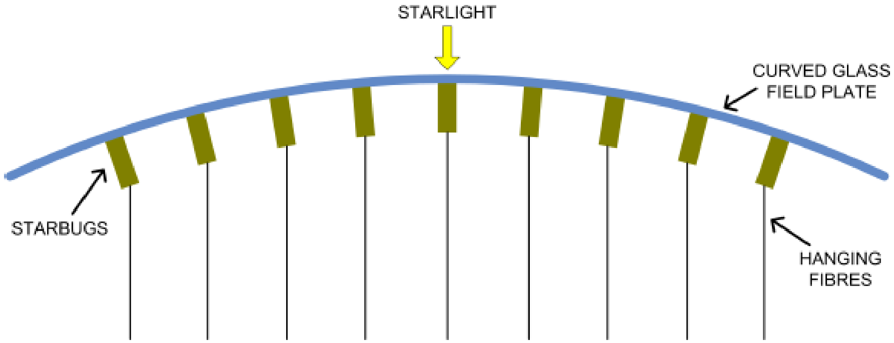
Starbugs

- Starbugs consist of co-axial piezoelectric tubes: stepping motion achieved by appropriate high-voltage waveforms sent the electrodes
- Optical payload (single fibre for TAIPAN) installed at centre of inner tube
- Back-illumination metrology fibres are mounted between the two tubes
- Vacuum is applied between tubes to hold Starbug onto glass field plate



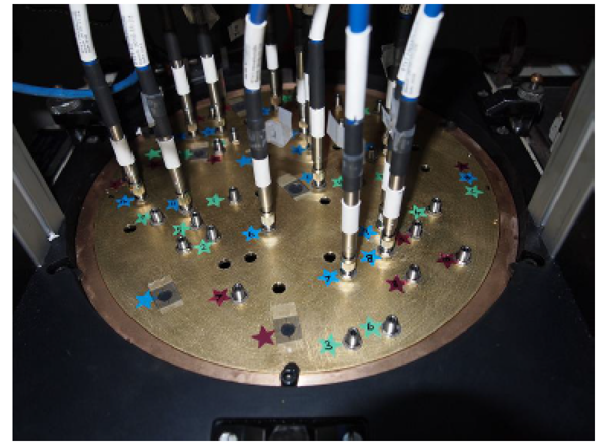


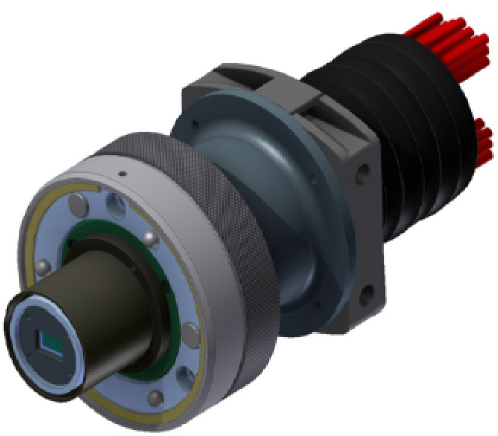


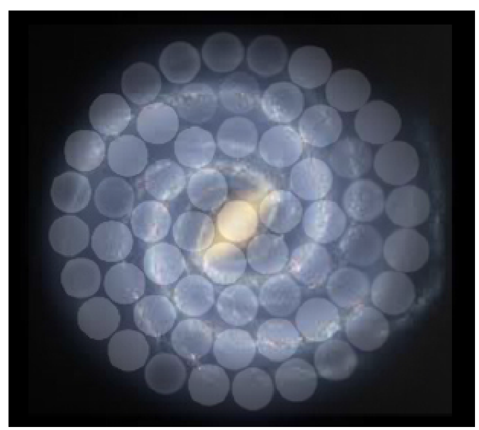


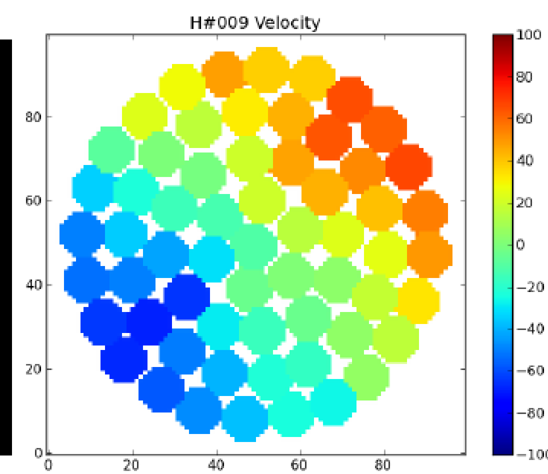
Integral Field Units

- Integral field unit (IFU) spectrographs collect both spatial and spectral information simultaneously
- Current approaches use lens arrays or slicing mirrors
- We have developed new "hexabundle" fibre IFU technology (61 core for SAMI) and lens array technology (1000 element for KOALA)



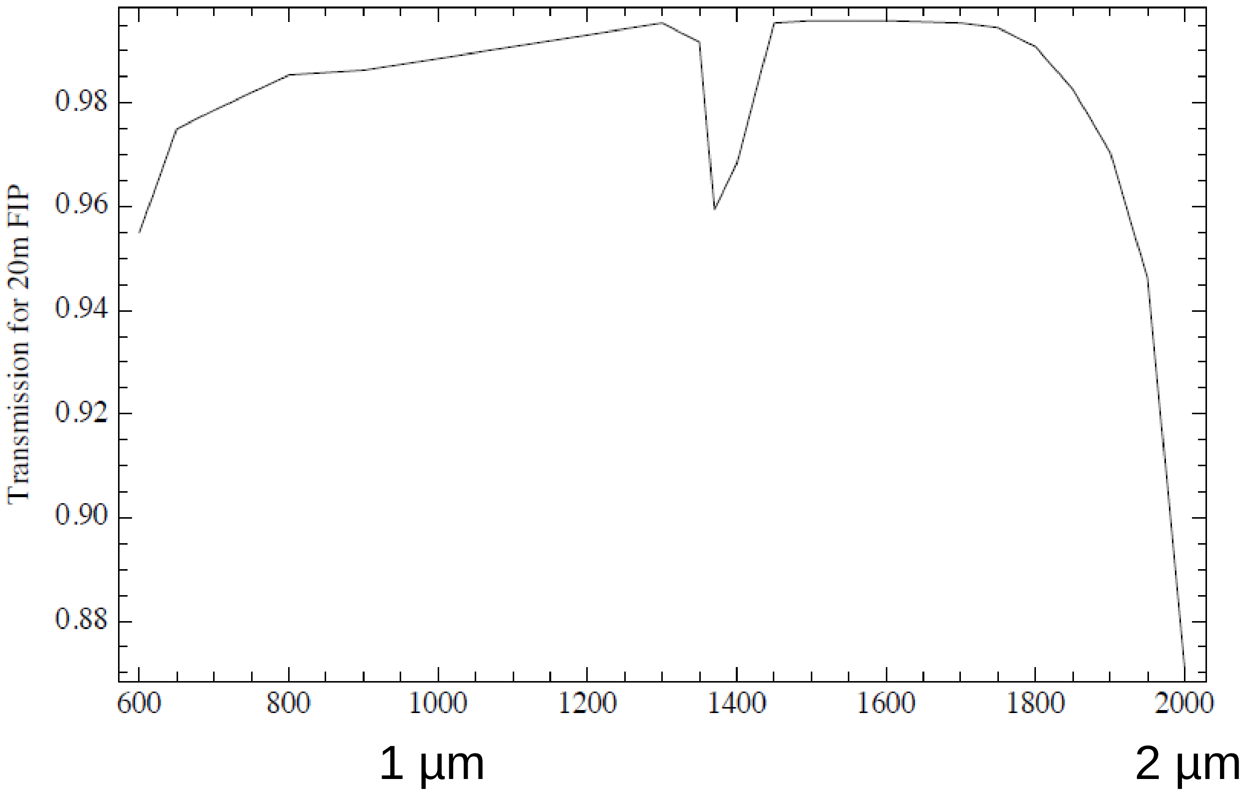






Fibre throughput model
fibre only, no coupling losses or FRD

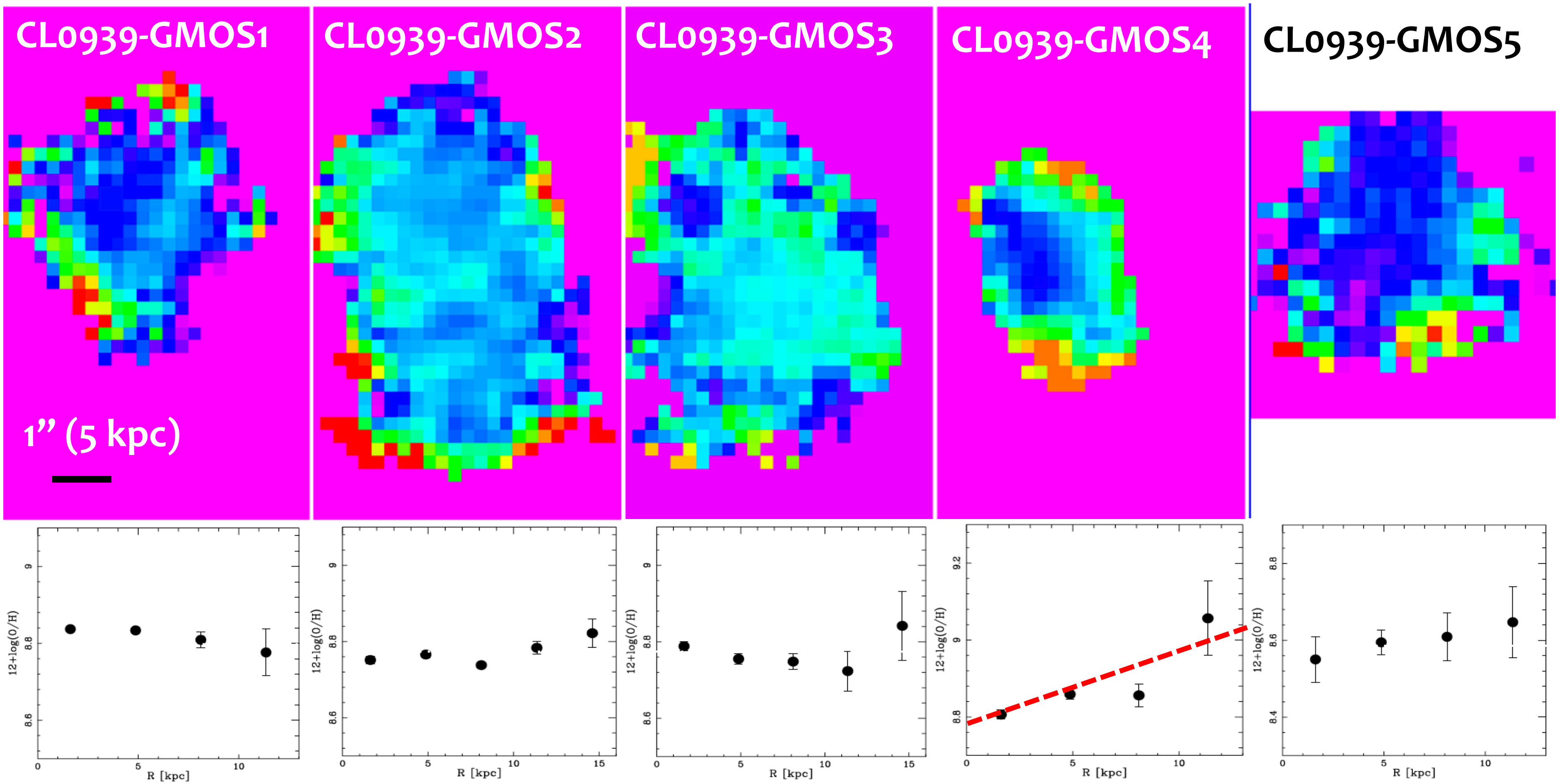
Wavelength range is limited to <2µm (no K-band)



Hα, [NII] limited to z<2, but [OIII], Hβ, [OII] to z~3

Metallicity gradient of red SF galaxies

Constant [NII]/Hα over the galaxies, but some hints of positive gradient?

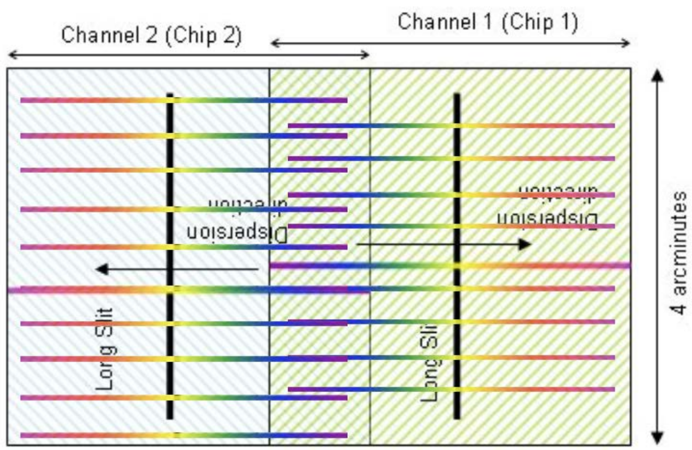


Koyama’s slide

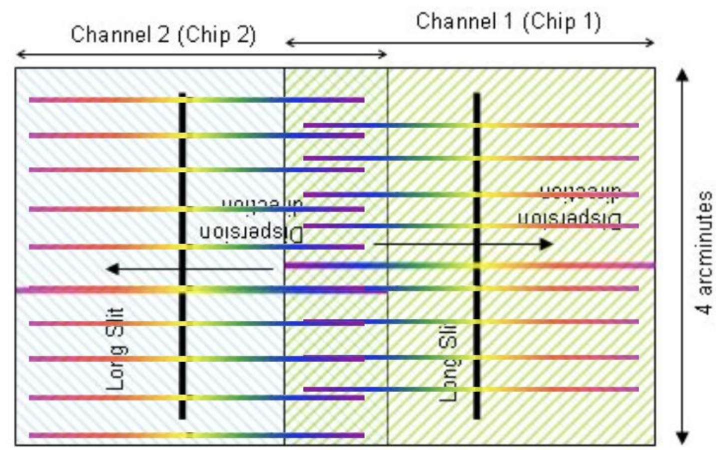
Phase-0.5: Starbug+ New-MOIRCS w/o GLAO
Phase-1 : w/ GLAO

- Number of bundles:
  - (1) HK500, zJ500, R1300+BB(JHK), VPH: 16
  - (2) R1300 or VPH + Narrow-band or Intermediate band filters: 48

(1)

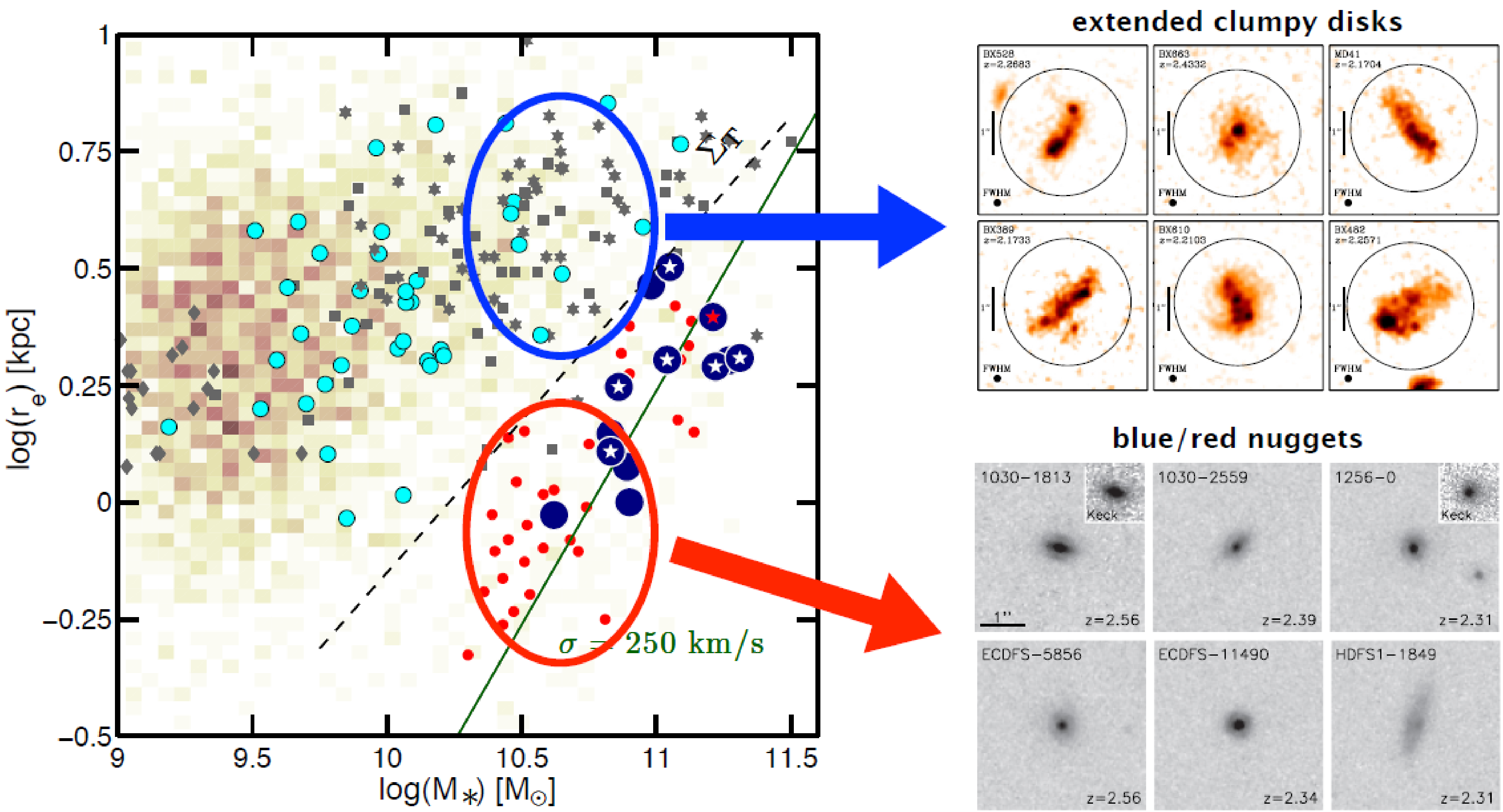


(1)



- Sensitivity: 60-70% of MOSFIRE/Keck (MOIRCS VPH only)
- Sensitivity: 75- 85% of KMOS/VLT (MOIRCS VPH only)
- Need to multiply by 70-80% efficency for fibre system
- MOIRCS will be moved to the observation floor or Nasmyth platform and connected to the starbugs with fibres.
- Focal plane unit of MOIRCS will be modified to feed the light into slits from fibres.

Blue/red nuggets



Barro+14, Forster Schreiber+11, van Dokkum+08

Tadaki's slide

Is ULTIMATE-S really ULTIMATE?

- Do we really want ULTIMATE-Subaru while TMT is coming along?

  - TMT-AGE/IRMOS will beat us?

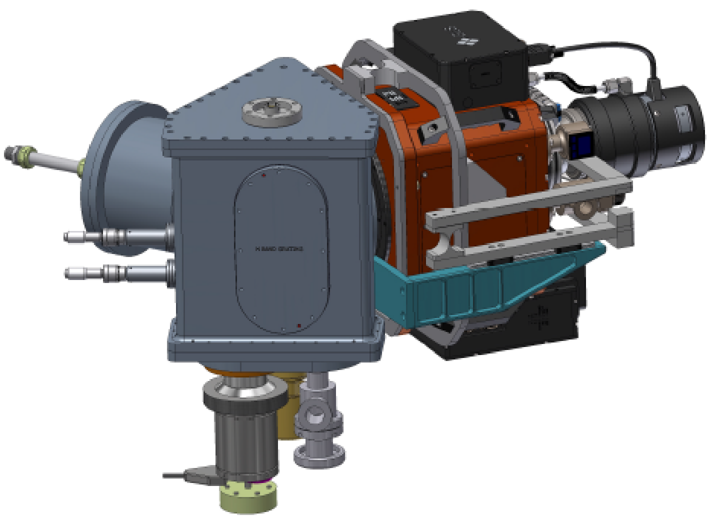
  - What is the future of Subaru-IR?

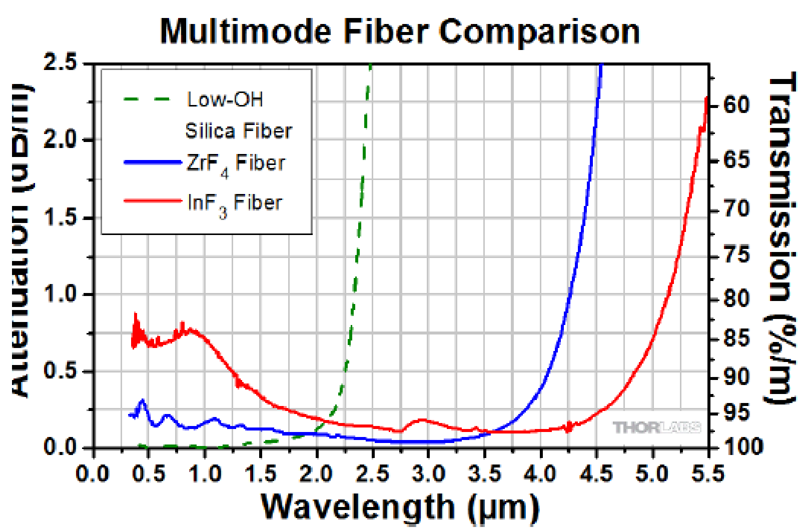
  - Excellent synergy with ALMA/JVLA (resolution, SFR depth…)?

  - Expansion of Keck/Gemini/VLT time exchange programmes?

Kband

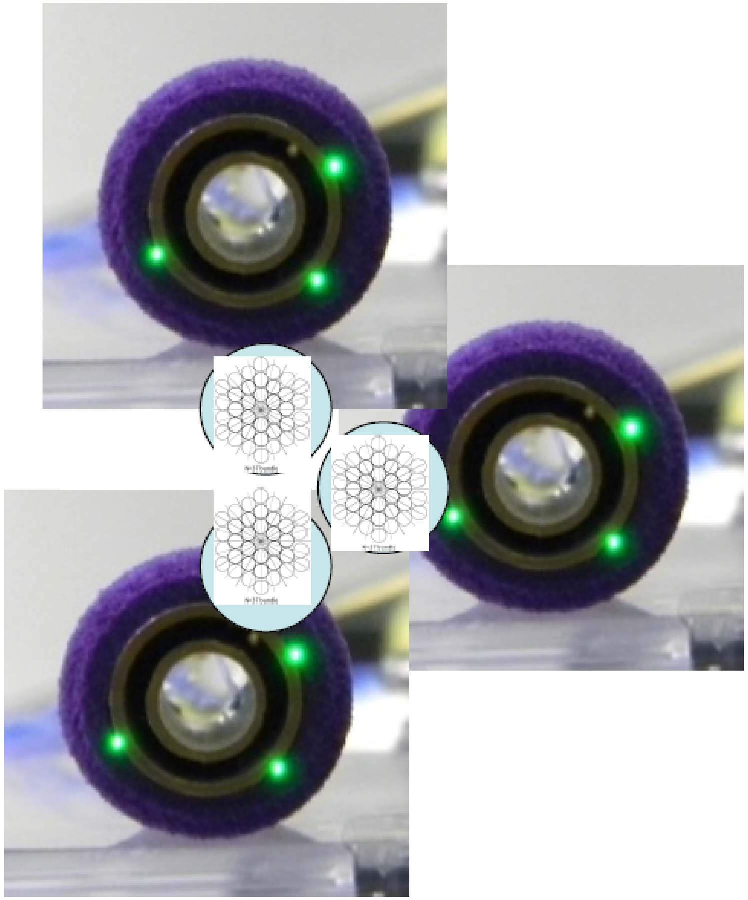
- Could proceed with a K-band experiment on AAT using Praxis in parallel on one or two fibers
- Look at self emission, losses, system issues etc…
- Measure SNR vs temperature, bends etc.…





Closest approach-1-5”

Use outboard IFU’s
Allows for 3 IFU’s to “contact”
Complicates targeting algorithm
Collision avoidance as well
No change to metrology
No change to stargbug drive/motion

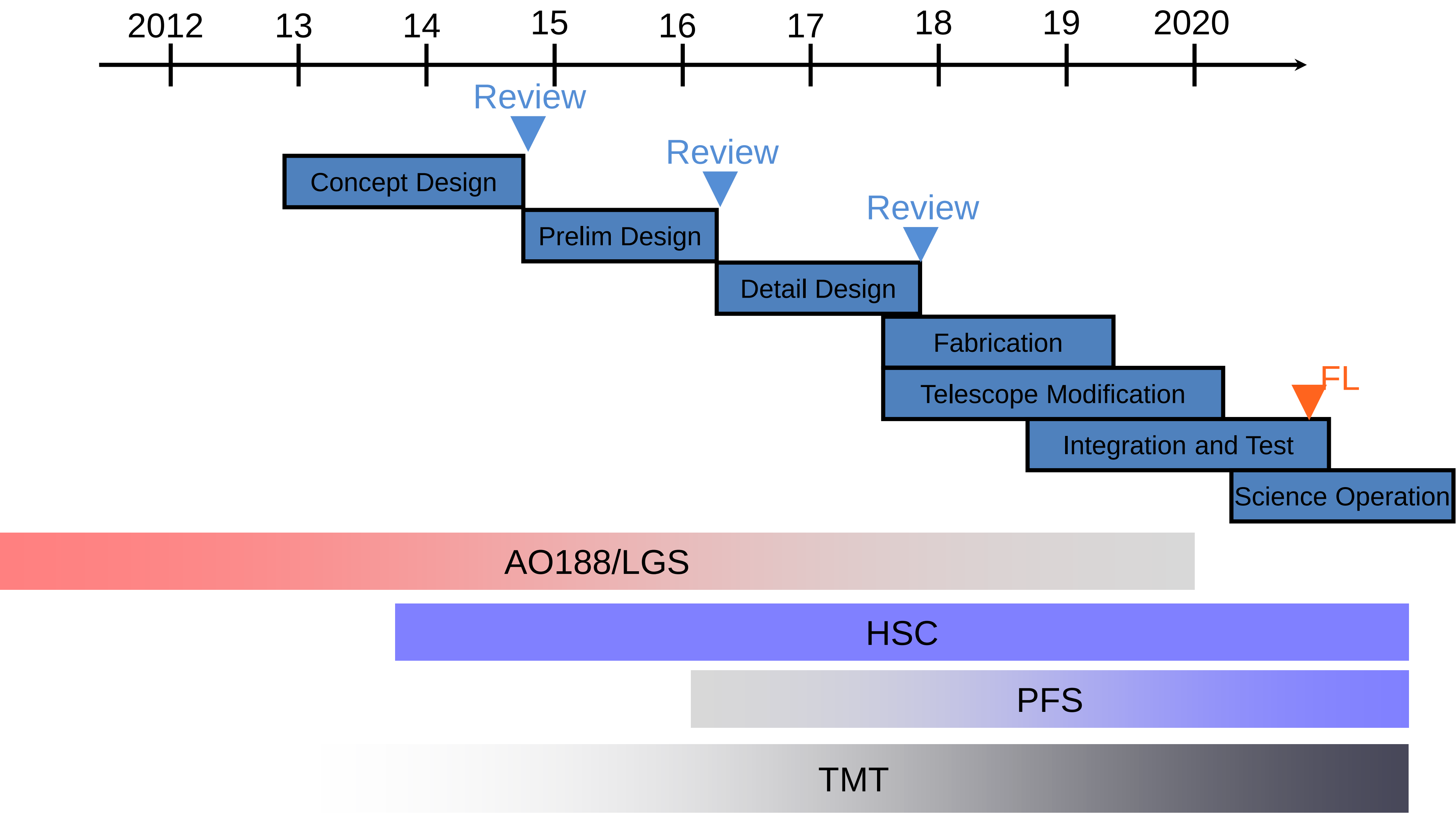


Cost estimation, budget

Items	Cost	Budget
ASM system	6 M	**Grant-in-aid Scientific Research, etc.**
Laser system	0.5 – 4 M	**Grant-in-aid Scientific Research, etc. (if Rayleight LGSs, cost is 1/10)**
Wavefront sensor unit	1 M	Grant-in-aid Scientific Research (International collaboration)
Realtime controller	0.5 M	Grant-in-aid Scientific Research, etc. (International collaboration)
Telescope modification	5 – 8 M	NAOJ budget
NIR instrument	0 – 10 M	Existing instrument at first. (MOIRCS or MOIRCS upgrade etc.)
Manpower	2 M	NAOJ budget and Grant-in-aid Scientific Research
Contingency	5 M	
Total	20 – 36.5 M	

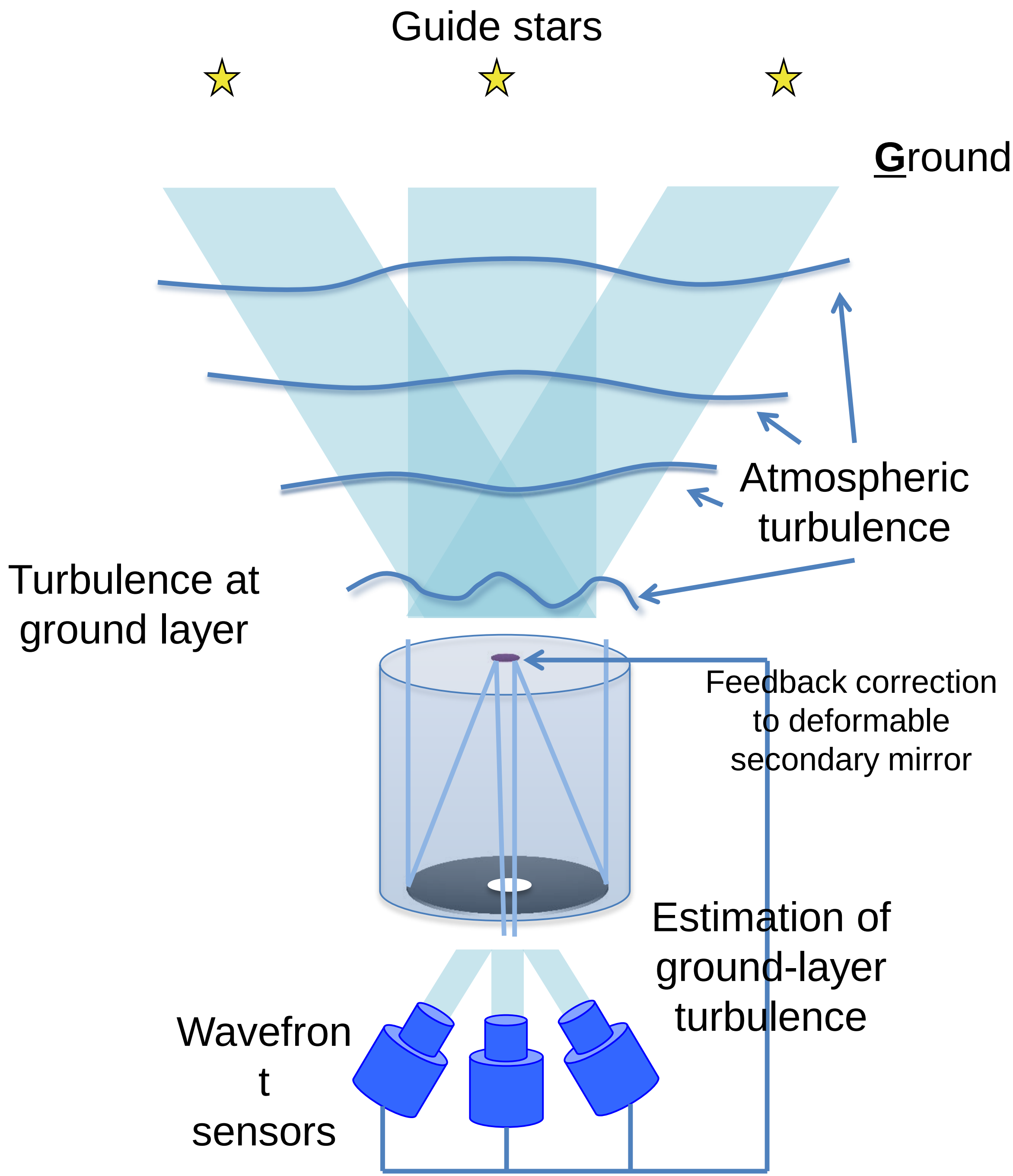
1. Grant-in-Aid for Scientific Research on Innovative Areas, 2015-2019
2. Grant-in-Aid for Specially Promoted Research, 2016-2020
3. Grant-in-Aid for Scientific Research (Category S), 2020-2024

Schedule


2012
13
14
15
16
17
18
19
2020
Review
Review
Review
Concept Design
Prelim Design
Detail Design
Fabrication
Telescope Modification
FL
Integration and Test
Science Operation
AO188/LGS
HSC
PFS
TMT

GLAO

Ground-**L**ayer **A**daptive **O**ptics



Resolving power and FoV of our facilities

Subaru+AO188

0.06-0.1”@2μm (~0.5-1kpc @z>1), 1 arcmin (FoV)

Subaru+GLAO

0.2” @2μm (~1.5kpc), 15 arcmin

JWST

0.05” @2μm (~0.5kpc), 3 arcmin

TMT+AO

0.015” @2μm (~0.1kpc), 15 arcsec

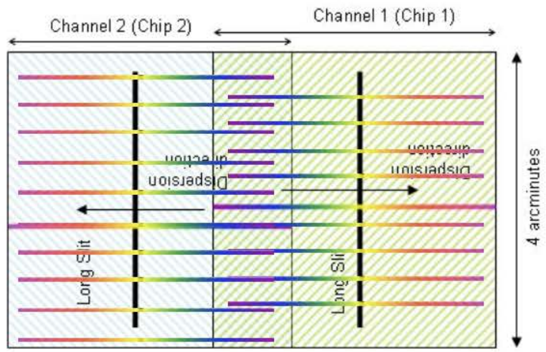
ALMA

0.01-0.1”@Submm (0.1-1kpc), 10arcsec-1arcmin
(0.08-0.6” in cycle-1)

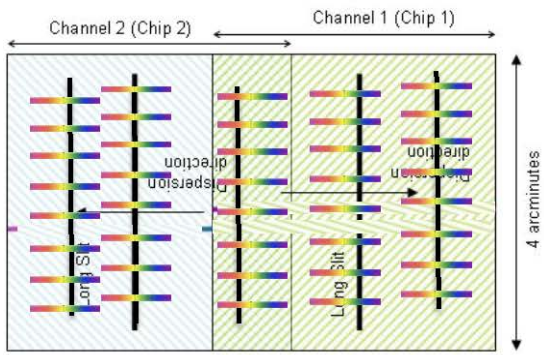
Phase-I: Starbug+ New MOIRCS

- First light instrument for GLAO
  - Commissioning obs. will start from around 2017?
  - Observations with OH suppression 2020?.
- Number of bundles:
  - (1) HK500, zJ500, R1300+BB(JHK), VPH: 26 (config 1); 52 (config 2); 16 (config 3)
  - (2) R1300 or VPH + Narrow-band or Intermediate band filters: 78 (config 1); 156 (config 2); 48 (config 3)

(1)



(2)



- Sensitivity: 60-70% of MOSFIRE/Keck (MOIRCS VPH only)
- Sensitivity: 75- 85% of KMOS/VLT (MOIRCS VPH only)
- Need to multiply by 70-80% efficency for fiber system
- MOIRCS will be moved to the observation floor or Nasmyth platform 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.

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

- Sensitivity: 70-80% of MOSFIRE/Keck
  - Sensitivity of the spectrograph should be same as or higher than MOSFIRE.
  - Only difference is throughput and emissivity due to the fibers.
  - Not including telescope diameter difference

- New instrument will be placed on the observation floor or Nasmyth platform and connected to the starbugs with 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

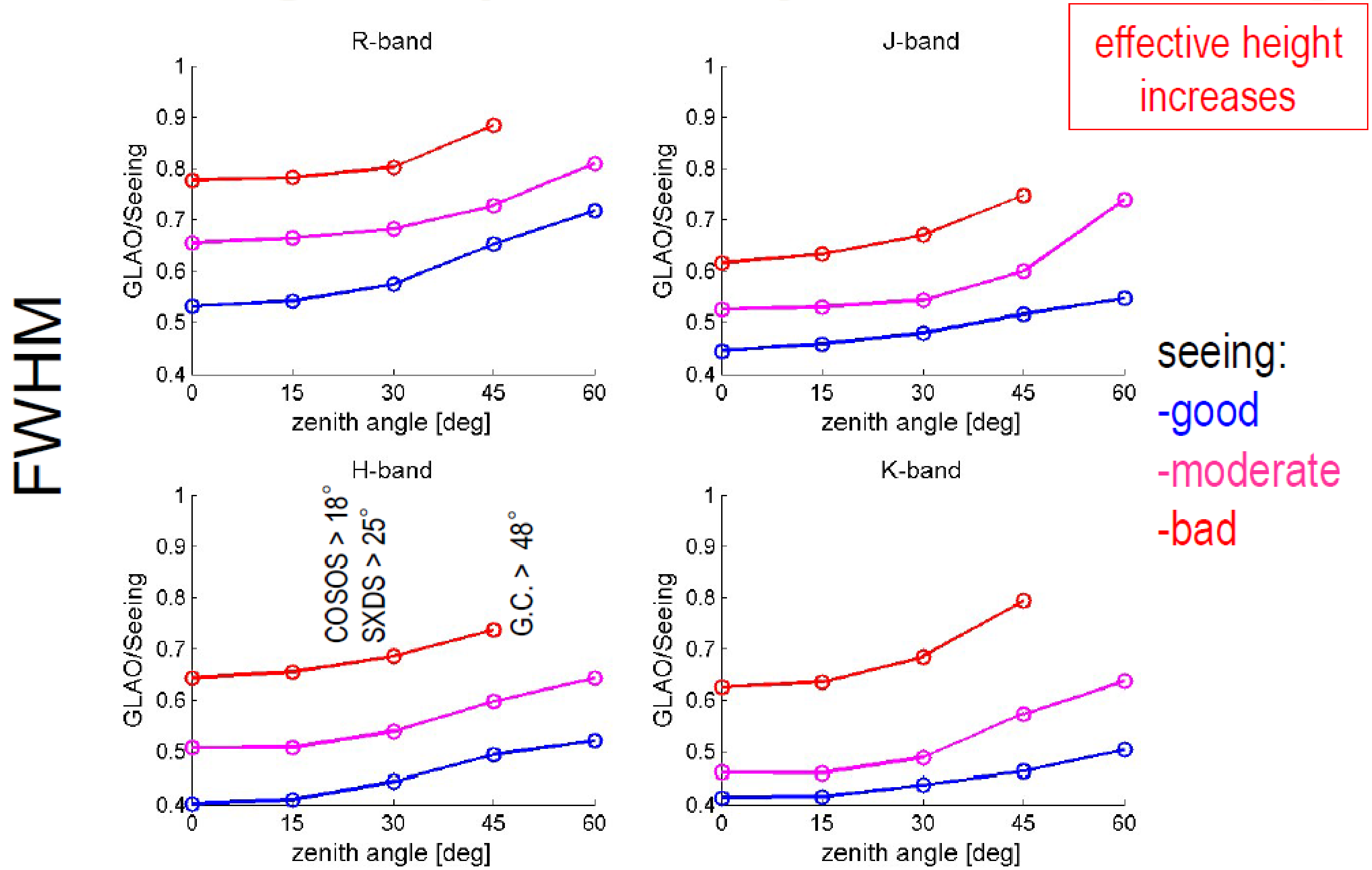
Sensitivity Improvement of MOIRCS

- HAWAII2 => H2RG
  - Readout noise: 15e- => 5e-
- Grism replacement
  - System throughput: 15%(R1300) => 25%(R2000)
- 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-, the sensitivity difference is about 1.4(VPH)~2.3(R1300).
- This difference can not be reduced without changing the optical coating.
  - MOSFIRE has 31 surfaces
  - Average throughput in each surface is about 0.992.
  - Total throughput of the optical coating is about 0.78
  - MOIRCS has 24 surfaces.
  - Average throughput of the coating is 0.983.
  - Total throughput of the coating is 0.64.

Zenith angle dependency: GLAO / Seeing



loss by 20% at 45°and 30% at 60°

Phase 1 = GLAO feeding fibre/IFU’s on NuMorics
Phase 2 = GLAO feeing new J,H,(K?) spectrograph (pupose-designed for this and OH-suppression fibres)
Phase 3 = same as Phase 2, but with OH suppression fibres.

There are a wide range of extragalactic science drivers. The main Australian driver is a follow-up to the SAMI survey at redshift > 1.0
NAOJ wishes to propose to the Kakehni grant in order to fund phase 0.5. This funding could be as much as $2M USD in addition to $200-300K in internal funds. Internal deadline is late September or early October, external deadline is November. To that end NAOJ would like AAO to produce a rough order of magnitude (ROM) schedule and budget to be included in this proposal. This budget will be broken out in terms of:

- Wide-field-corrector (which can possible be part of the telescope infrastructure and therefore eligible for internal funds)
- Starbugs IFU’s (16)
- Fibre cable
- Vacuum system
- Electronic control system
- Metrology system, including camera etc..
- Software packages for a) acquisition,b) control of starbugs c) metrology d) first order data-reduction

We are actively working on this and should have a reasonably accurate budget within 4-6 weeks.

- Vacuum system
- Electronic control system
- Metrology system, including camera etc..
- Software packages for a) acquisition,b) control of starbugs c) metrology d) first order data-reduction

We are actively working on this and should have a reasonably accurate budget within 4-6 weeks.

In addition, NAOJ would like to explore with AAO the possibility of K-band fibres. NAOJ has requested funds for a K-band fibre. AAO is happy to discuss how and when we could test this at AAO.

NAOJ also has a CoDR planned for end of this calendar year or early next year to present the status of the entire GLAO project. AAO would be happy to help prepare some materials on the fibre positioning system, IFU's. OH-suppression technology etc.. For this review.

There is the possibility that AAO can provide some internal labour funds for the project in the likely event that Phase 0.5 is more expensive than the funding available through Kakehni Grant. In that case it appears that while there is probably no guaranteed time for this project, there is precedent for collaborator time on the telescope on joint NAOJ/AAO projects. This should be spelled out in our MOU. In the meantime AAO is working on a science document describing our science project (SAMI at z>1) in detail, and querying the likely Australian Astronomers who would be part of this consortium.

AAO is excited and interested to work with NAOJ, as we have in the past with FMOS Echidna. This meeting has been an excellent first step in that process.

Program

Jul 28 (Mon)

13:00-13:40 Y. Hayano: Project Overview
13:40-14:00 S. Oya: GLAO performance simulation
14:00-14:30 Y. Minowa: Instrument specifications and sensitivities
14:30-15:15 A. Sheinis (AAO): IFUs with Starbug & fibre system
Break
15:30-16:00 Science-1: C. Lidman (AAO)
16:00-16:30 Science-2: M. Akiyama (Tohoku)
16:30-17:00 Science-3: K. Ohta (Kyoto)
17:00-17:30 Discussion
19:00- Banquet at Kichijoji (Shirubei), Odakyu bus #91 at 18:16 (or 18:04) at NAOJ

Jul 29 (Tue)

09:30-10:00 Science-4: K. Motohara (Tokyo)
10:00-10:30 Science-5: T. Shibuya (Tokyo)
10:30-11:00 Science-6: Y. Koyama (JAXA)
Break
11:30-12:00 Science-7: K. Tadaki (NAOJ)
12:00-12:30 Science-8: K. Kohno (Tokyo)
Lunch
14:00-14:30 Science-9: Y. Matsuda (NAOJ)
14:30-15:00 Science-10: D. Iono (NAOJ)
15:00-16:00 Discussion