galaxy science with GLAO

1 – GLAO: imaging vs spectroscopy

2 – galaxy science with GLAO

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GLAO サイエンスを考えるのが初めてなので、可能なサイエンスに至るまでの思考の筋道をまとめた、というのがほとんどの部分です。

あくまで個人的な意見ですので、ちょっと意地悪な考えがでてきても、怒らないでください。　悪意はありません。

1 – imaging vs spectroscopy

Is GLAO at Subaru competitive at all?

- How big is the difference between 0.2 and 0.5arcsec seeing?
- Can we compete with space-based missions?

  Main concern I have is the very high sky background for ground-based facilities.
- Can we compete with other ground-based facilities?

  LBT and VLT are also developing GLAO. Can we beat them?
- Can we do any interesting science with GLAO?


HST WFC3 F160W:
FWHM=0.2arcsec 0.06arcsec/pix


HST WFC3 F160W smoothed :
FWHM=0.5arcsec 0.06arcsec/pix

0”.2 vs. 0”.5

Does the 0”.2 seeing bring us to a new world? Need to be quantitative.

Minowa: gain in photometry, but we cannot easily do morphology.

- How big is the difference between 0.2 and 0.5arcsec seeing?
  → 0”.2 is of course better, but the difference is not huge.

- Can we compete with space-based missions?

  Main concern I have is the very high sky background for ground-based facilities.

- Can we compete with other ground-based facilities?

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- Can we do any interesting science with GLAO?

Can we compete with satellite missions?

The wide-field coverage of GLAO motivates us to do a survey-like observation. But, space-based 1-2m satellites have similar angular resolutions and they go very wide and deep. What satellite missions are out there?

WISH, JWST, EUCLID and WFIRST.

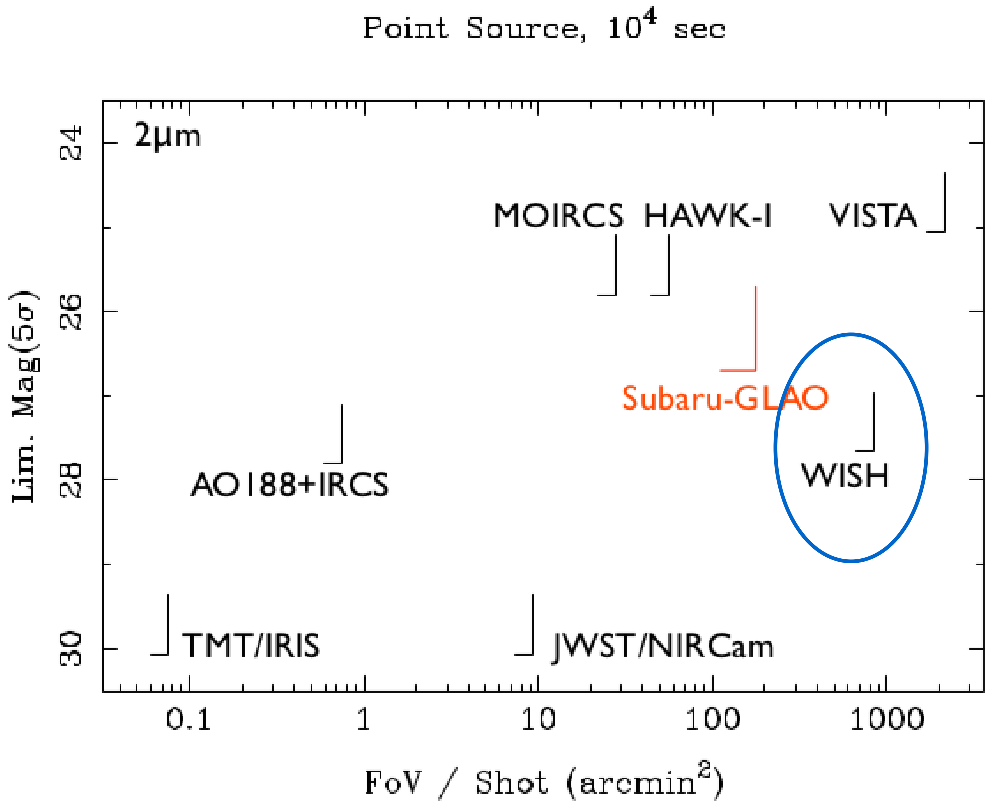
We also have to compete with other ground-based facilities including

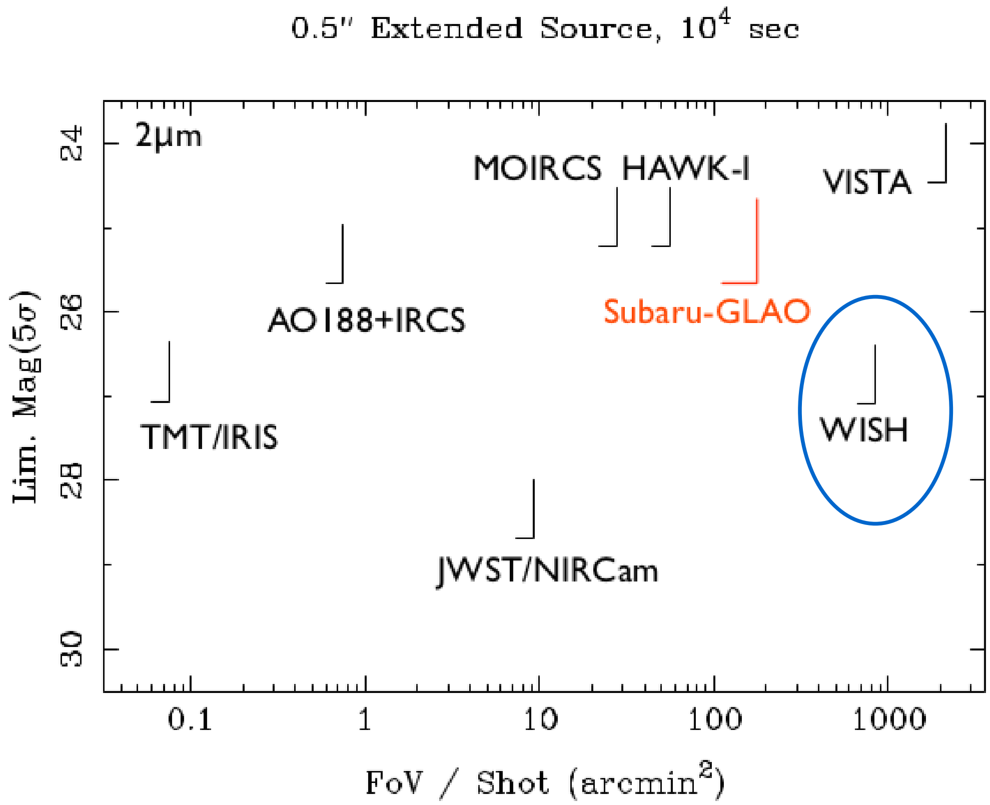
HAWK-I

Imaging

WISH

I think this plot from Iwata-san summarizes it all –





JWST

NIRCam Imaging Properties:

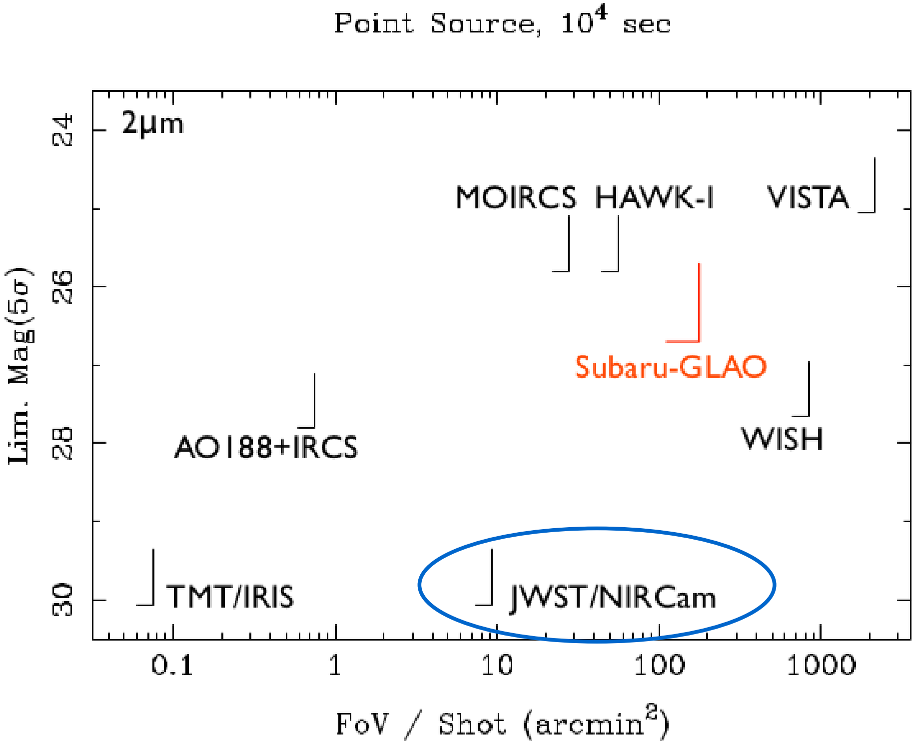
Wavelength range (μm)	0.6 to 2.3
	2.4 to 5
Nyquist λ (μm)	2/4
Pixel Format	4096^2 (short λ)
	2048^2(long λ)
Pixel Scale	0.032″ (short λ)
	0.065″ (long λ)
Field (arc min)	2.2 x 2.2 (one module)
Spectral Resolution	4,10,100

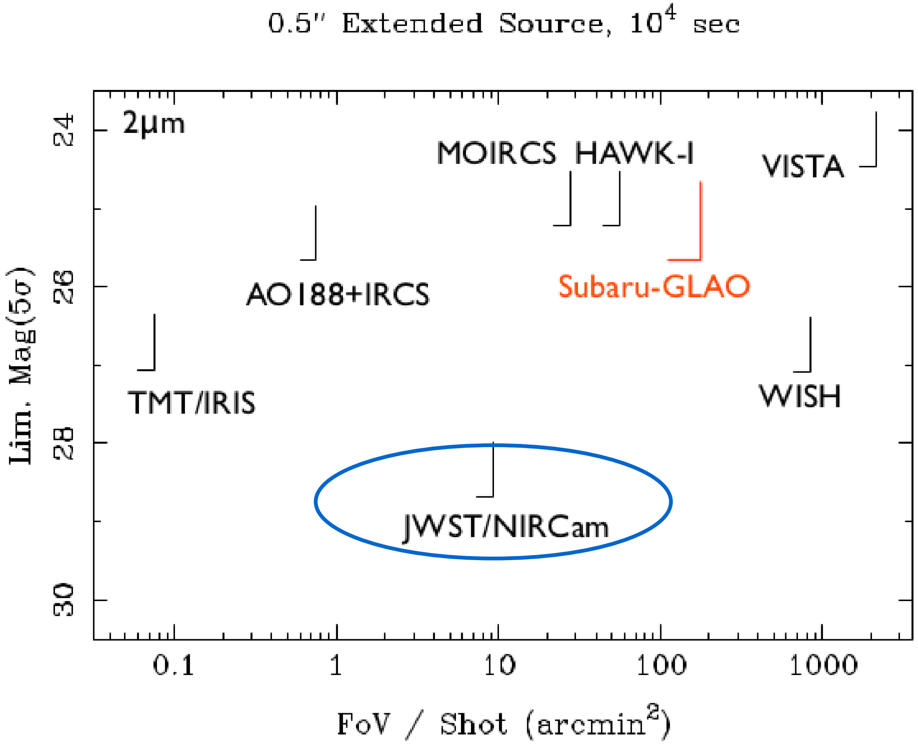
NIRCam Filters:

Short Wavelength Filter	Long Wavelength Filter
F070W	F277W
F090W	F356W
F115W	F444W
F150W	F250M
F200W	F300M
F140M	F335M
F162M	F360M
F182M	F410M
F210M	F430M
F164N	F460M
F187N	F480M
F212N	F323N
	F405N
	F466N
	F470N

4'.4 x 2'.2 in survey mode? Subaru+GLAO is still a factor of x40 larger.

JWST

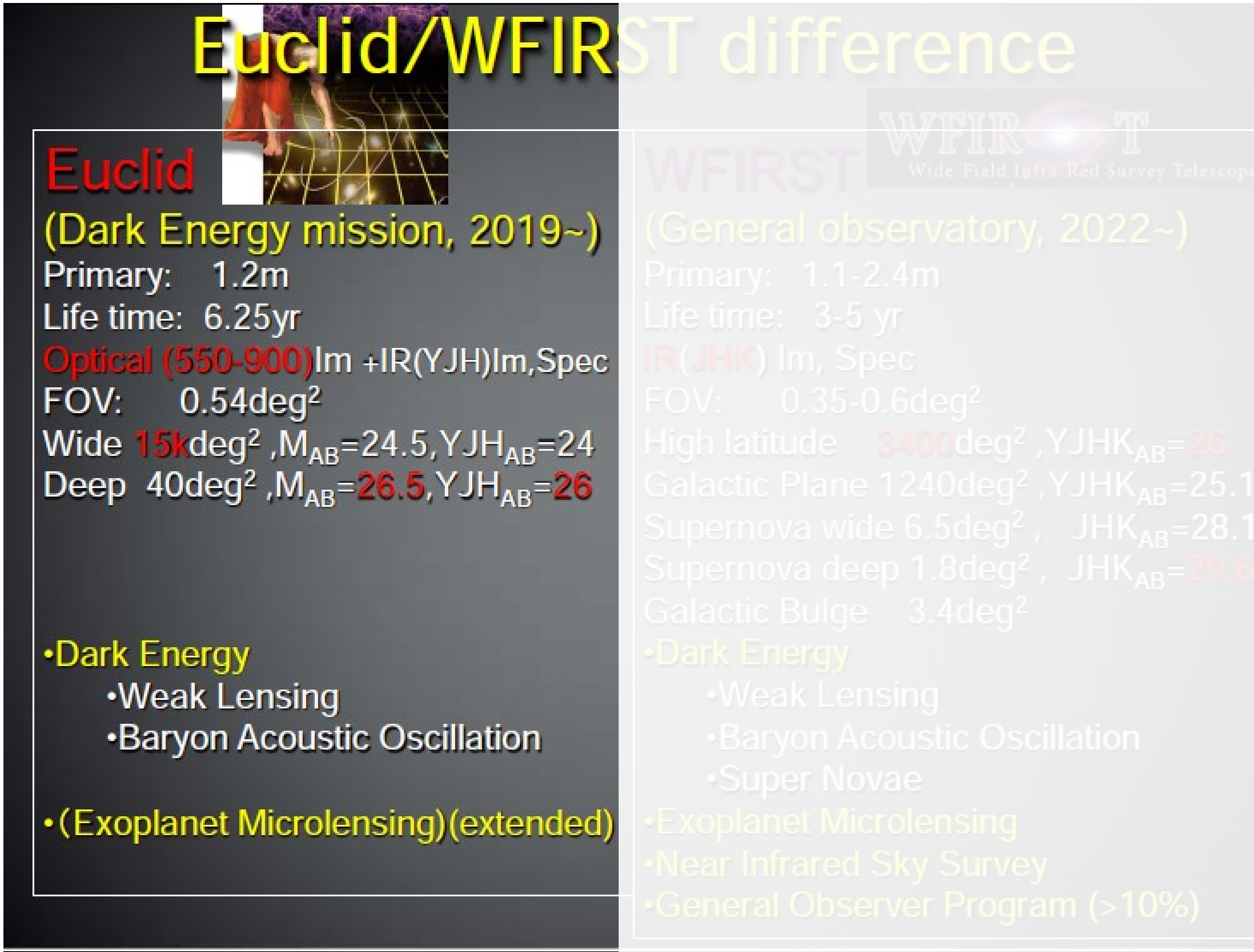




We could compete with JWST by going wider and shallower...?

But, the 3mag difference is huge.

EUCLID



From Sumi-san's talk

EUCLID

The Euclid Mission: baseline and options

Euclid Consortium

SURVEYS	In ~5.5 years	
	Area (deg2)	Description
Wide Survey	**15,000 deg^2**	Step and stare with 4 dither pointings per step.
Deep Survey	**40 deg^2**	In at least 2 patches of > 10 deg^2 2 magnitudes deeper than wide survey

PAYLOAD					
Telescope	1.2 m Korsch, 3 mirror anastigmat, f=24.5 m				
Instrument	VIS	NISP			
Field-of-View	0.787×0.709 deg^2	0.763×0.722 deg^2			
Capability	Visual Imaging	NIR Imaging Photometry			NIR Spectroscopy
Wavelength range	550– 900 nm	Y (920-1146nm),	J (1146-1372 nm)	H (1372-2000nm)	1100-2000 nm
Sensitivity	24.5 mag 10σ extended source	24 mag 5σ point source	24 mag 5σ point source	24 mag 5σ point source	3 10^{-16} erg cm-2 s-1 3.5σ unresolved line flux
	Shapes + Photo-z of n = 1.5 x10^9 galaxies ?			z of n=5x10^7 galaxies	
Detector Technology	36 arrays 4k×4k CCD	16 arrays 2k×2k NIR sensitive HgCdTe detectors			
Pixel Size Spectral resolution	0.1 arcsec	0.3 arcsec			0.3 arcsec R=250
Possibility to propose other surveys: SN and/or μ-lens surveys, Milky Way ?					

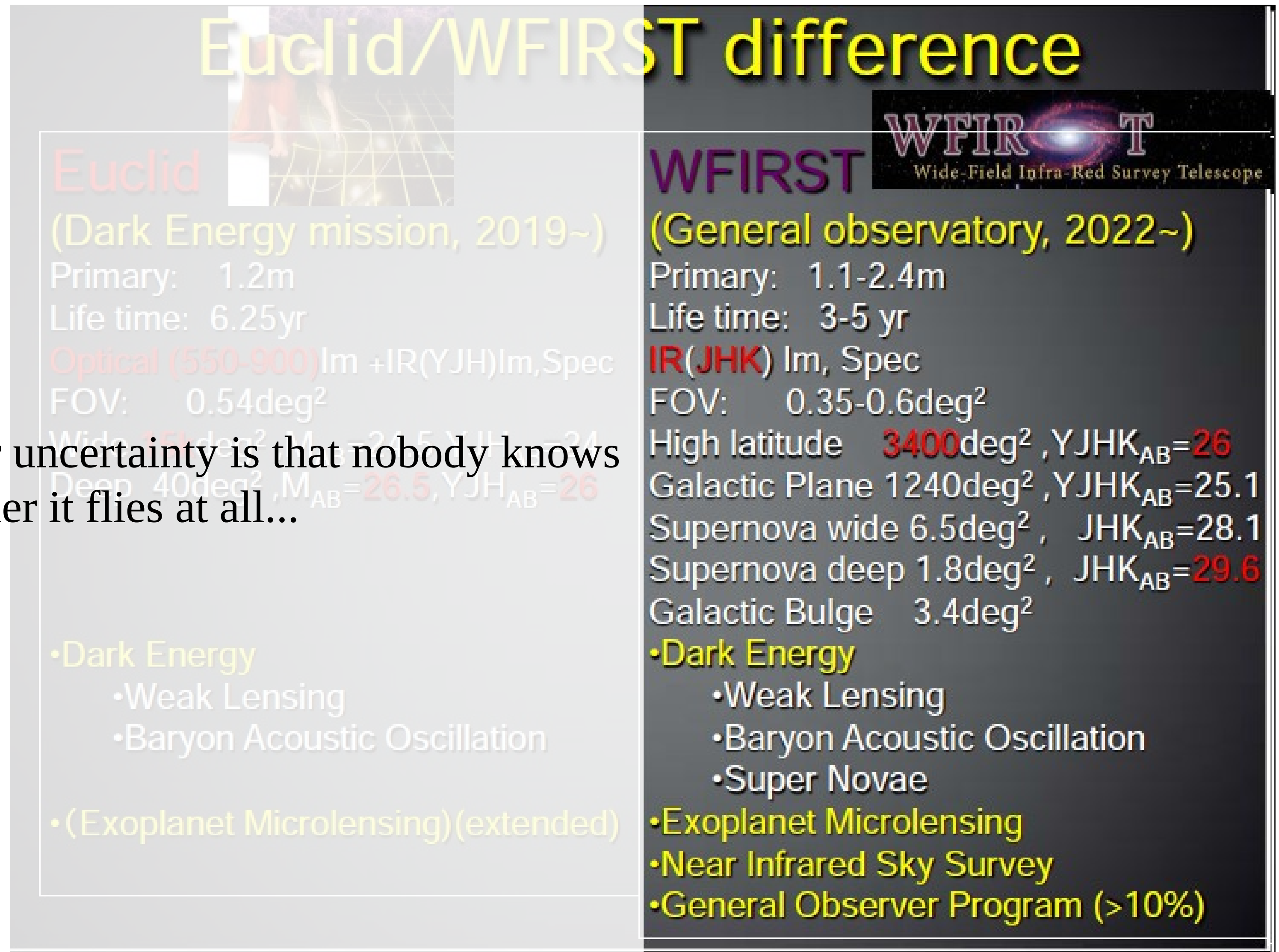
Ref: Euclid RB arXiv:1110.3193

Euclid IPMU June 1st 2012

Morphology analysis would be hard with EUCLID. We cannot do either.
Is there any science that can be done only in the K-band?

From Yannick's talk

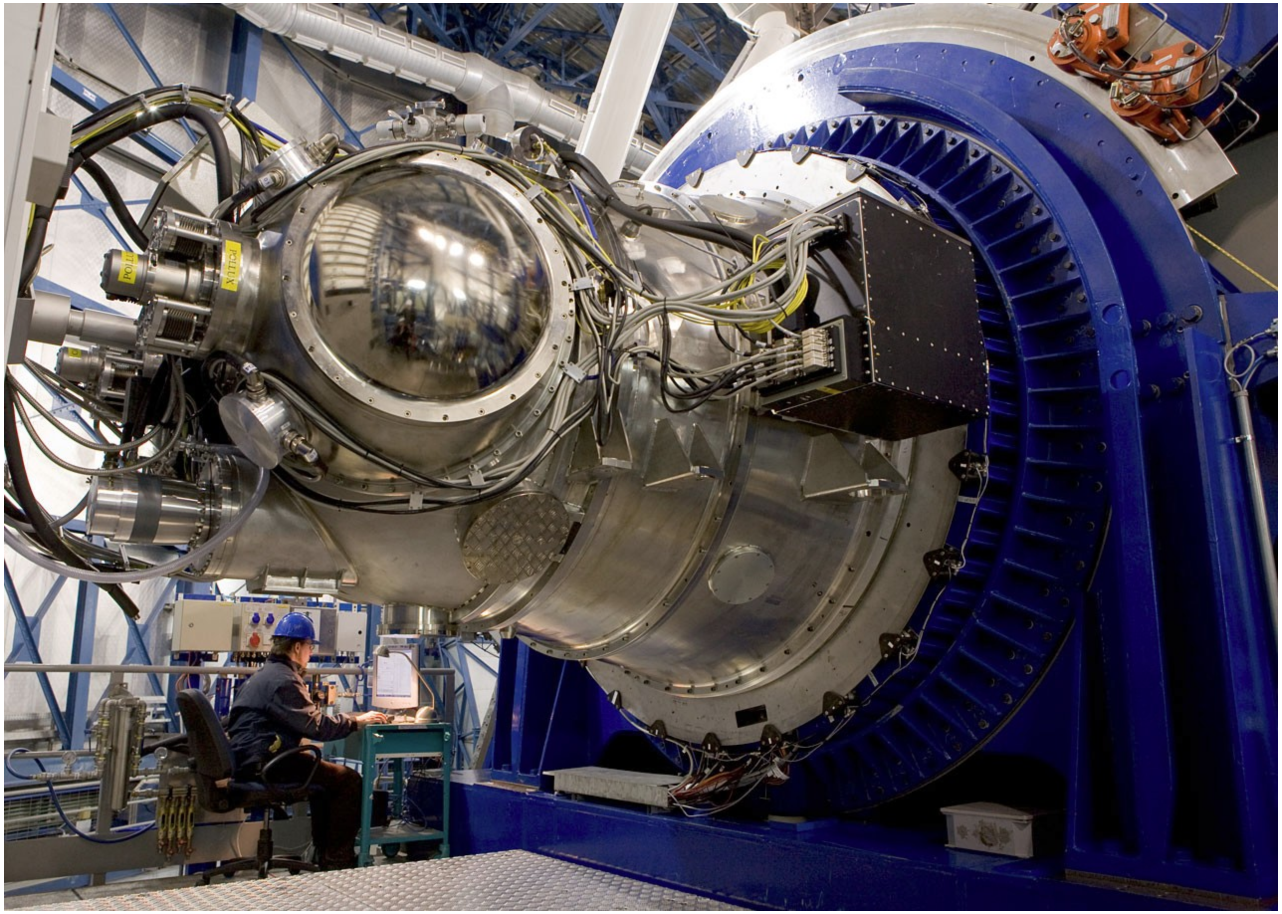
WFIRST



Major uncertainty is that nobody knows whether it flies at all...

From Sumi-san's talk

HAWK-I with GLAO



Fov is 7'.5 x 7'.5. So, the area is a quarter of the fiducial Subaru GLAO imager.

Is imaging with Subaru+GLAO competitive?

- If WISH flies, there is no way Subaru can compete with it.
- EUCLID will fly. Subaru+GLAO will go slightly deeper, but morphology is not easy even for us. Not sure if the K-band is really really essential to galaxy science.
- No one knows if WFIRST flies, but if it does, we can't compete with it.
- Subaru+GLAO is better than HAWK-I by a factor of 4. Is this a large factor?

Basically, the sky background is killing us in near-IR. A way to go around it would be to use NB filters.

U=23.0, B=22.3, V=21.6, Rc=21.0, Ic=20.2, J=16.5, H=14.7, K=15
(all in AB mag/arcsec^2)

Is imaging with Subaru+GLAO competitive?

Hard to compete with other facilities!
We are only x4 faster than HAWK-I.

	BB imaing	NB imaging
WISH	×	○
EUCLID	△	○
JWST	×	△
WFIRST	×	○
HAWK-I	○	○

We can observe emission line objects at very specific redshifts only.
Is that interesting enough so that we are willing to commit ourselves?
Is it interesting to study Ha emitters at z=2 when JWST is looking at those at z=6?
We need a very clever idea or unique targets for NB.

Spectroscopy

Spectroscopy

Space-based facilities have prism/grism spectroscopy or MOS mode. Let's go over JWST and EUCLID.

WISH and WFIRST may also have grism/prism mode, but I don't know the details.

HAWK-I doesn't have a spectroscopy mode.

JWST - NIRISS

Detector Characteristics

Array size	2048 x 2048 pixel HgCdTe array
Pixel size	18 µm x 18 µm
Dark rate	< 0.02 e-/s
Noise	23 e- (correlated double sample)
Gain	1.5 e-/ADU
Field of View (FOV)	2.2' x 2.2'
Plate scale in x	0.0654 arcsec/pixel
Plate scale in y	0.0658 arcsec/pixel

Observation Modes

Optical elements in the Pupil and Filter Wheel of NIRISS support 4 modes of observation:

Wide-Field Slitless Spectroscopy (WFSS), R~150; 1.0 – 2.5 microns; enabled by a matched pair of orthogonal grisms (GR150C and GR150R) in the Filter Wheel and a selection of blocking filters in the Pupil Wheel (F115W, F140M, F150W, F158M, F200W).

Single-Object Slitless Spectroscopy (SOSS), R~700; 0.6 – 2.5 microns; enabled by the grism GR700XD, which generates 3 orders of cross-dispersed (XD) spectra for a target placed at a reference point in the FOV.

Aperture Mask Interferometry (AMI), 3.8 – 4.8 microns; enabled by the non-redundant mask (NRM) in the Pupil Wheel and medium-band filters (F380M, F430M, F480M) in the Filter Wheel. The mask consists of 7 "holes" (apertures), which produce an interferogram that samples 21 unique ("non-redundant") baselines.

Imaging, 0.9 – 5.0 microns; enabled by wide-band filters F090W, F115W, F150W, F200W in the Pupil Wheel and F277W, F356W, F444W in the Filter Wheel.

JWST - NIRSpec

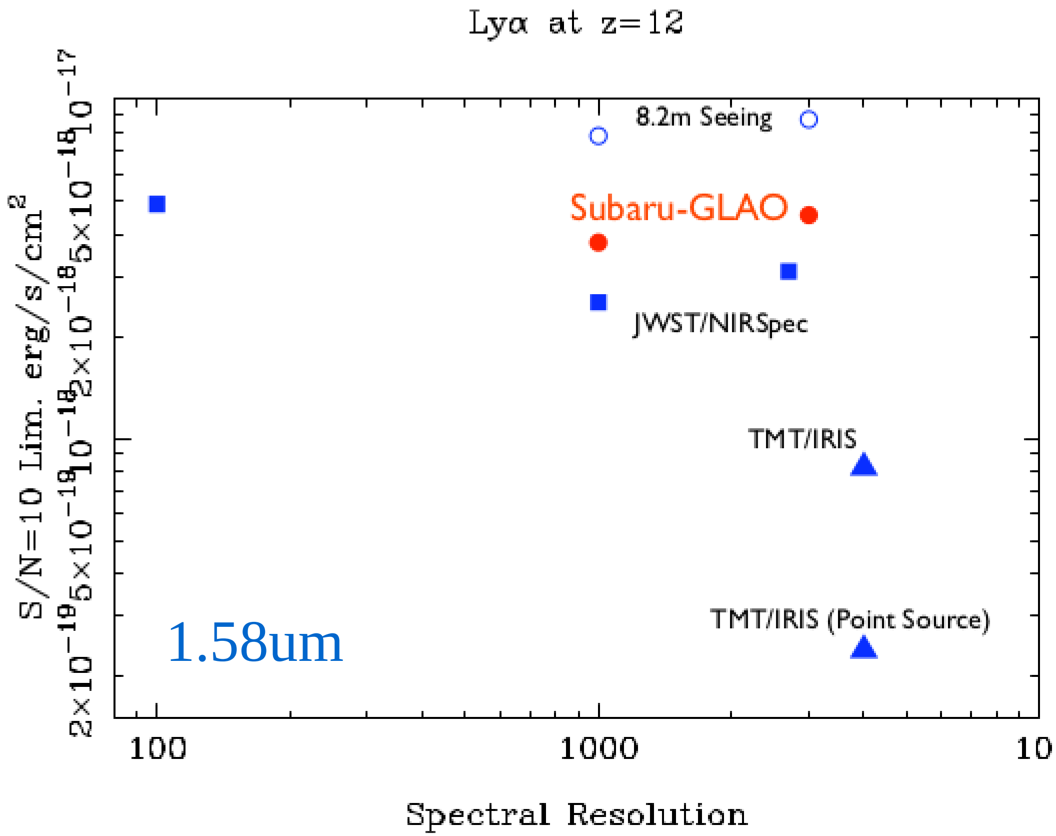
NIRSpec Features:

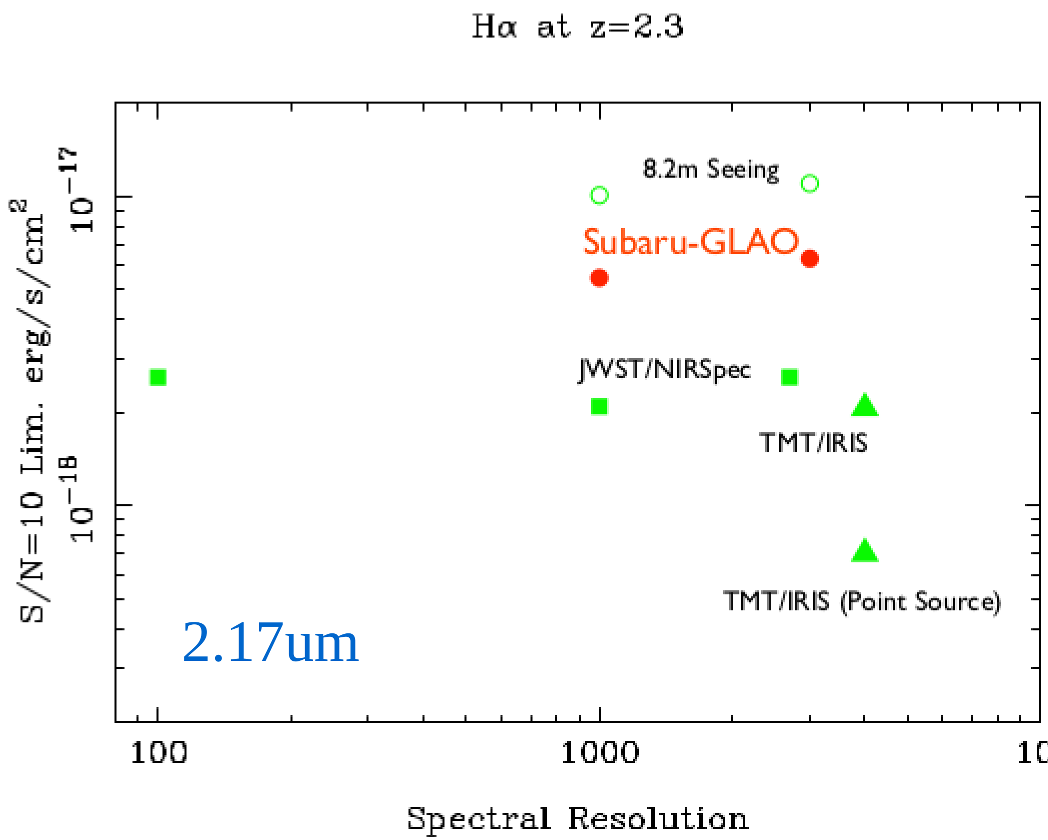
- All Reflective Optics
- 3.4′ x 3.6′ FOV (3' x 3' for Multi-object Spectroscopy)
- 200 mas nominal slit width
- 3 slit selection devices:
  - Micro-Shutter Array
  - Fixed slits
  - 3" x 3" Integral Field Unit
- 3 spectral resolutions:
  - R=100 (0.7 - 5.0 µm - single prism)
  - R=1000 (1.0 - 5.0 µm - 3 gratings)
  - R=2700 (1.0 - 5.0 µm - 3 gratings)
- 2 x 2k x 2k HgCdTe arrays

Sensitivity: The NIRSpec limiting sensitivity in 10,000 seconds for point source continuum at 3 µm for R=100 and at S/N=10 is AB=26.2. For the flux limit at 2m in 100,000 seconds is 5.2×10^{-19} erg cm^{-2}s^{-1}.

JWST - NIRSpec

Iwata-san's calculation





Need more quantitative estimate, but we are only <~1mag off from JWST if we work in between the sky lines!

EUCLID

The Euclid Mission: baseline and options

Euclid Consortium

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Ref: Euclid RB arXiv:1110.3193

From Yannick's talk

Subaru+GLAO spectroscopy

We can go fainter and higher resolution than EUCLID.

We cannot beat JWST in terms of depth, but we are only ~1 mag shallower.
We could be competitive if we go wide.

Space-based spectroscopic instruments are relatively simple.
I think an instrument with complicated mechanism/structure such as multi-object IFU and multi-object fiber spectrograph can compete with these space-based facilities.

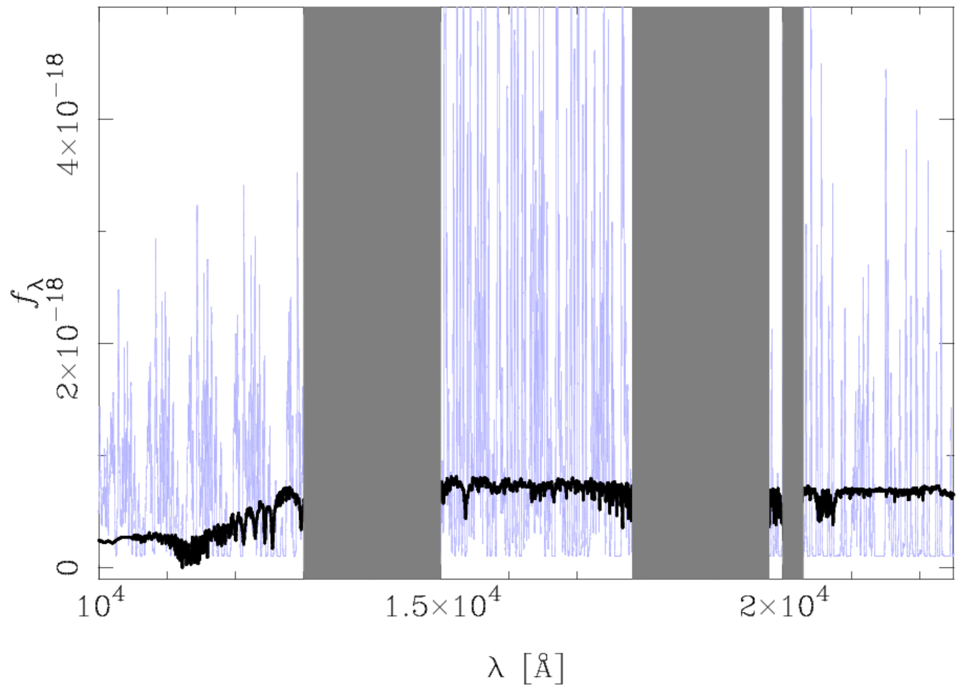
The key is to work in between the sky lines. Even if we work in between the sky lines, we can get not only emission lines, but continuum as well.

Spectroscopy is faster than imaging

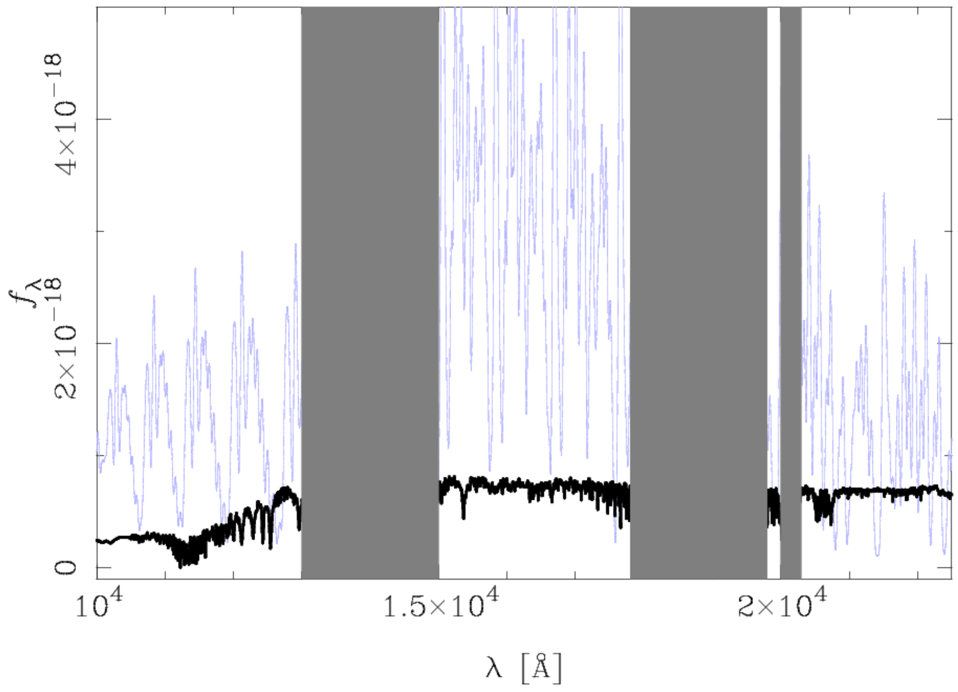
Sky emission is less of an issue (but still a major issue...) in spectroscopy because we can work in between the sky lines.

JEG : Spectroscopy is faster than imaging in near-IR.

R=2000



R=500



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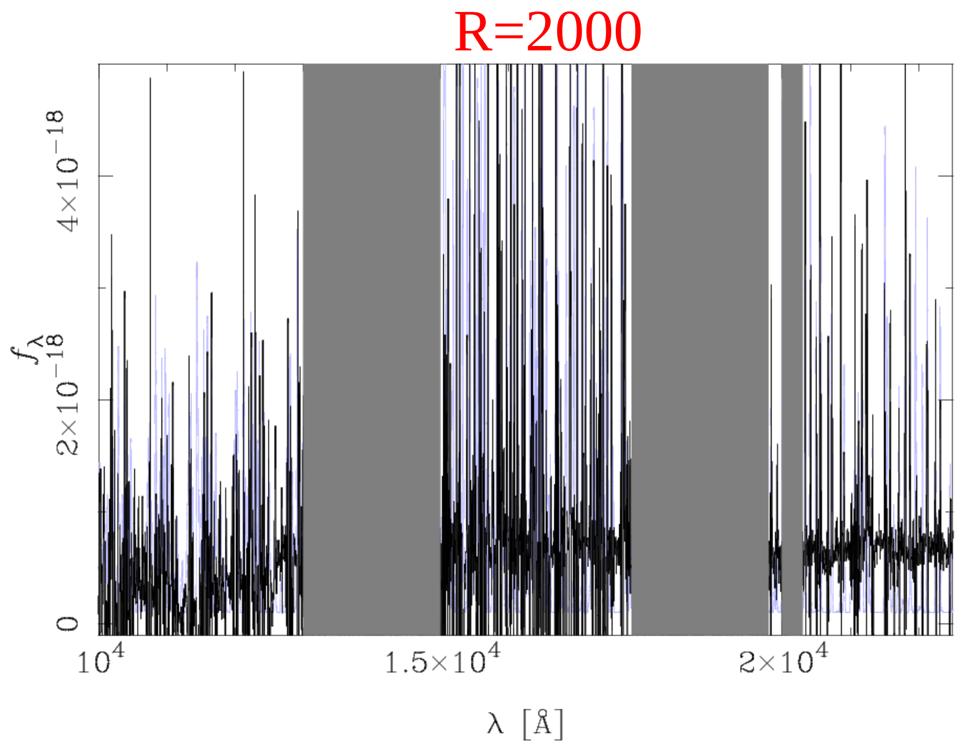

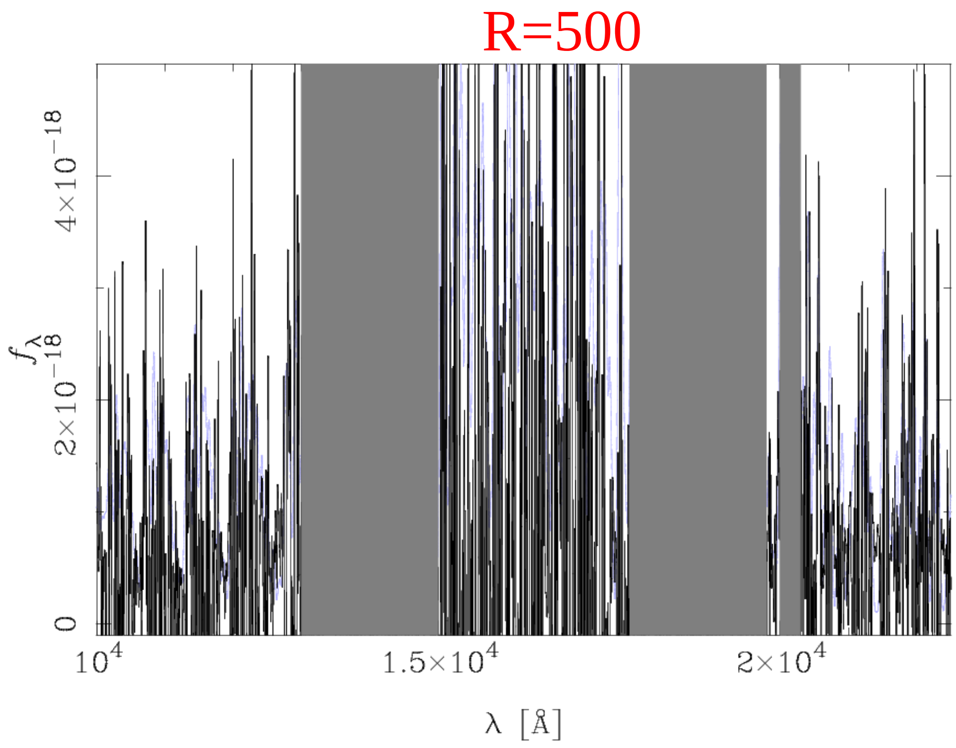

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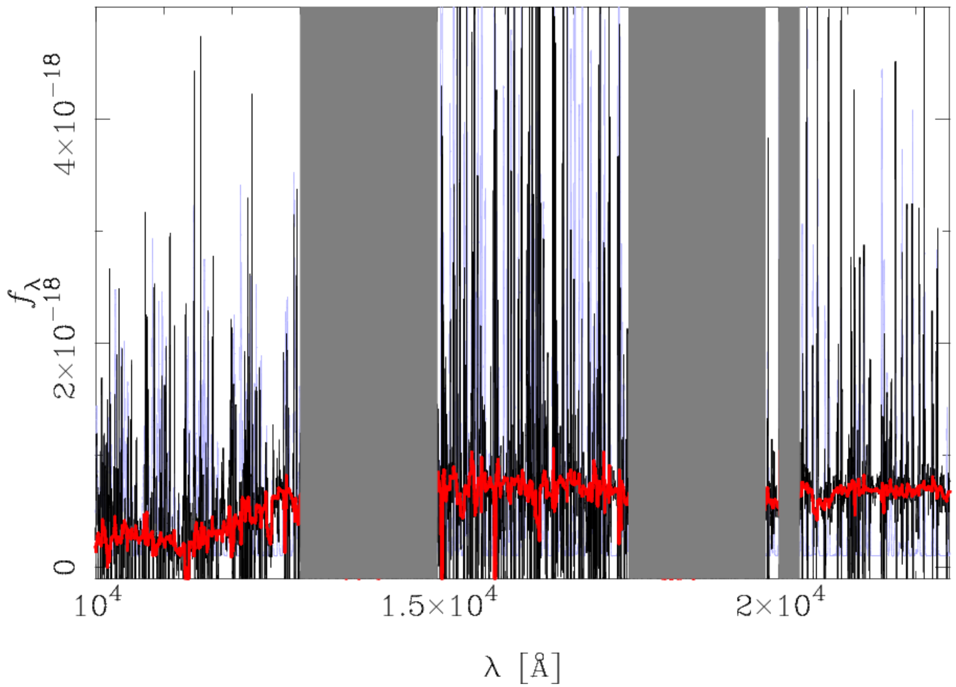
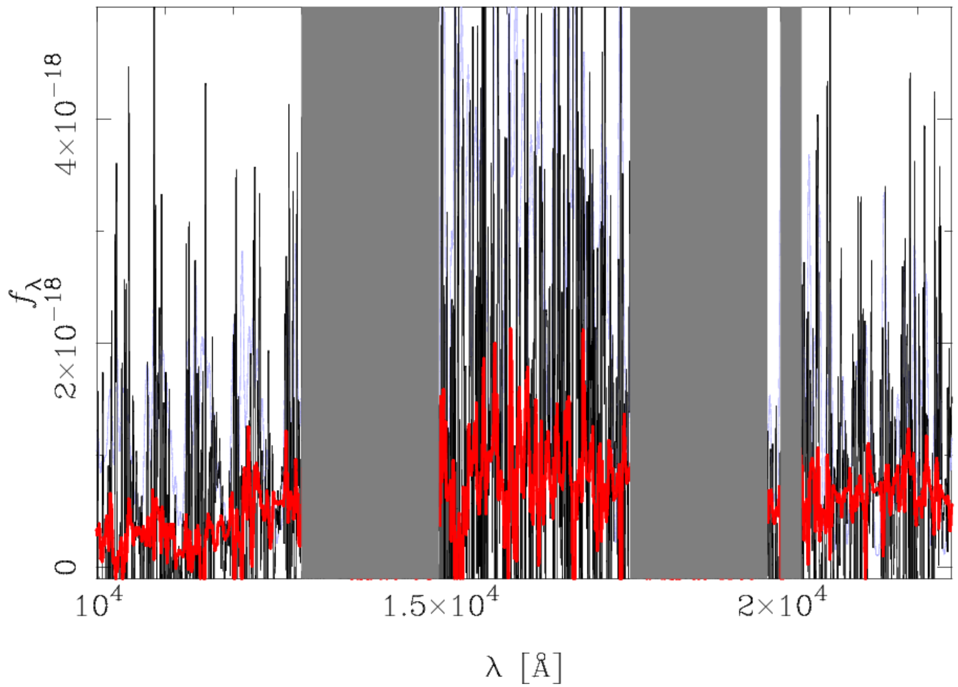


R=500



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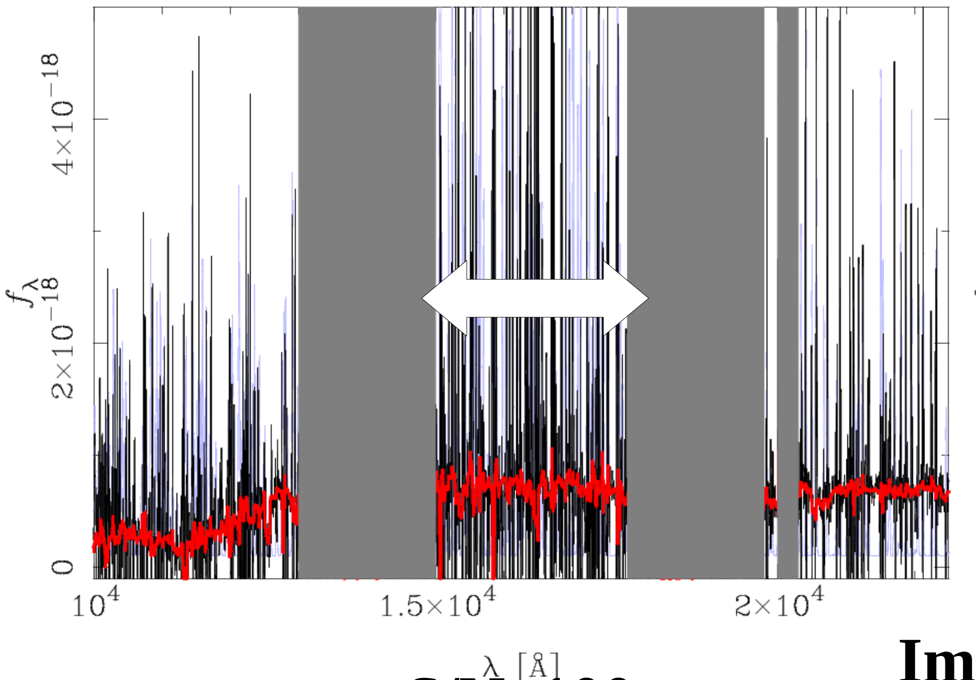
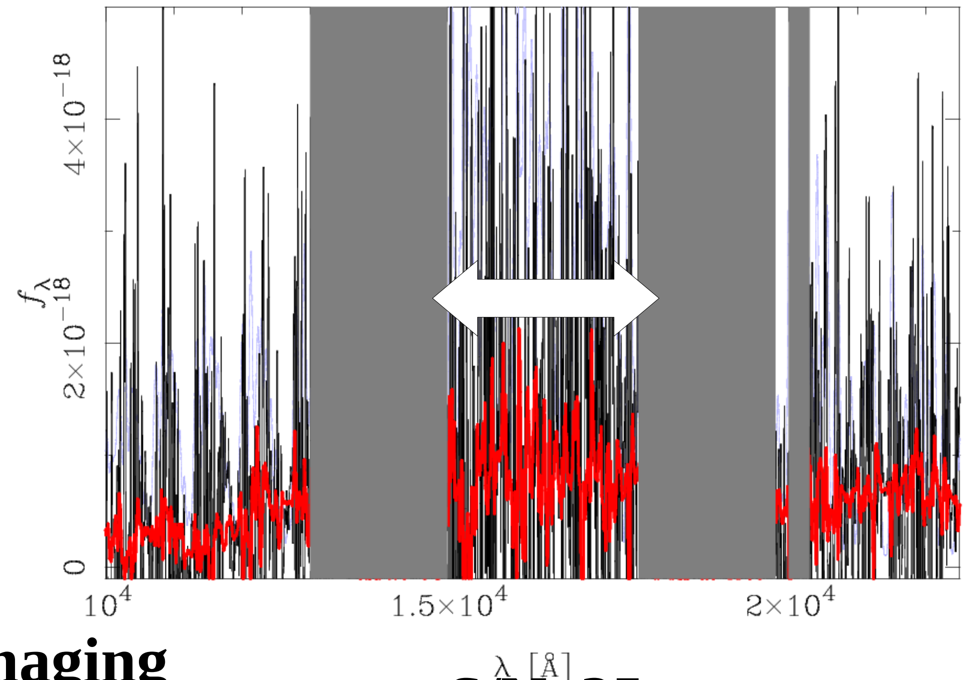


S/N~100

R=500



S/N~25

Imaging
S/N~15

Is spectroscopy with Subaru+GLAO competitive?

	BB imaing	NB imaging	Spectroscopy
WISH	×	○	–
EUCLID	△	○	○
JWST	△	○	△
WFIRST	×	○	–
HAWK-I	○	○	○

Spectroscopy is good not only for emission lines, but for continuum as well.
Unlike NB, we look at objects at all redshifts and we have low-res continuum.
So, more science.

- How big is the difference between 0.2 and 0.5arcsec seeing?
  - → 0”.2 is of course better, but the difference is not huge.
- Can we compete with space-based missions?

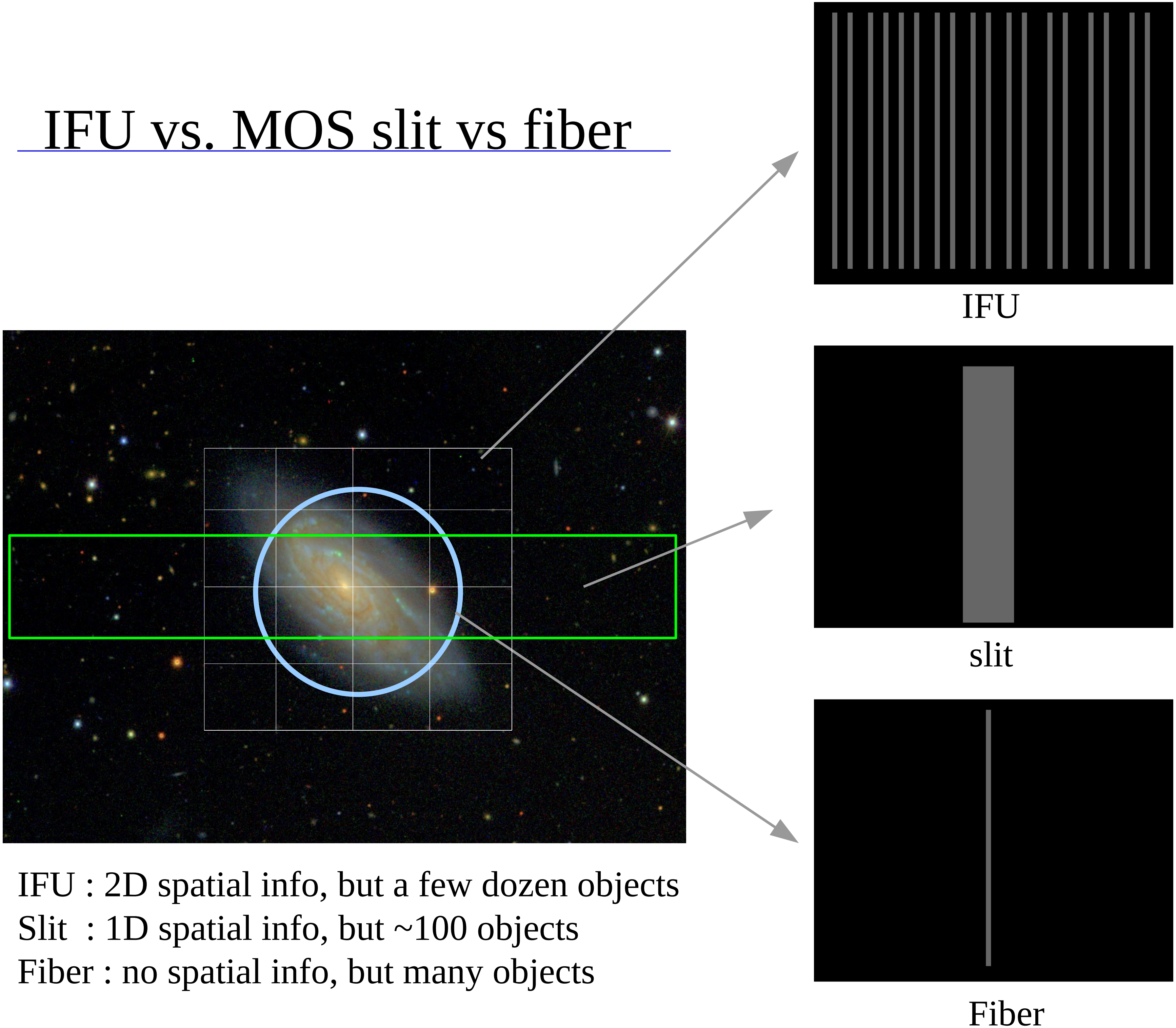
  Main concern I have is the very high sky background for ground-based facilities.
  - → I think we can compete with spectroscopy.
- Can we compete with other ground-based facilities?

  LBT and VLT are also developing GLAO. Can we beat them?
  - → Yes!
- Can we do any interesting science with GLAO?

	Imaging	Spectroscopy
Optical	HSC	PFS
Near-IR	WISH	GLAO+MOS

2 – galaxy science with fiber spectrograph

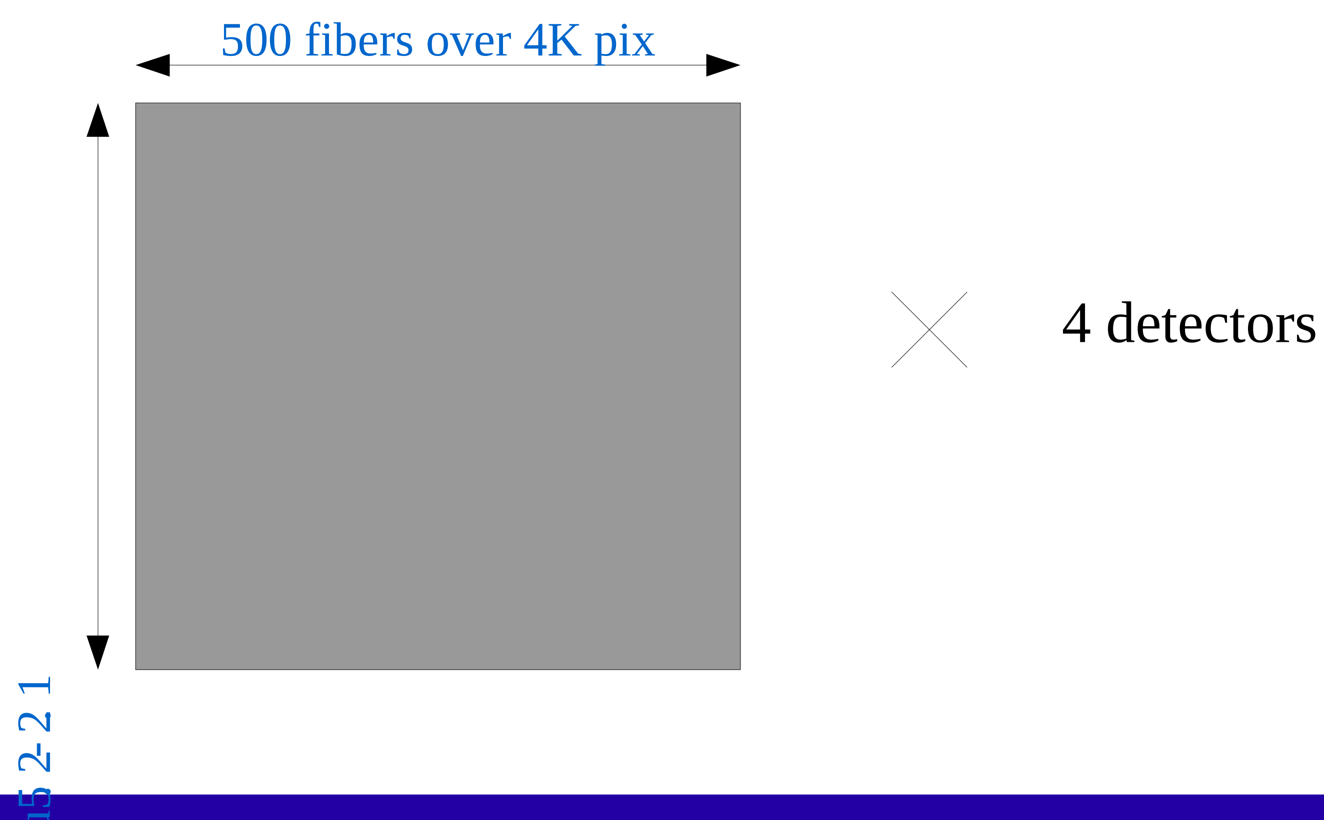
IFU vs. MOS slit vs fiber



IFU : 2D spatial info, but a few dozen objects
Slit : 1D spatial info, but ~100 objects
Fiber : no spatial info, but many objects

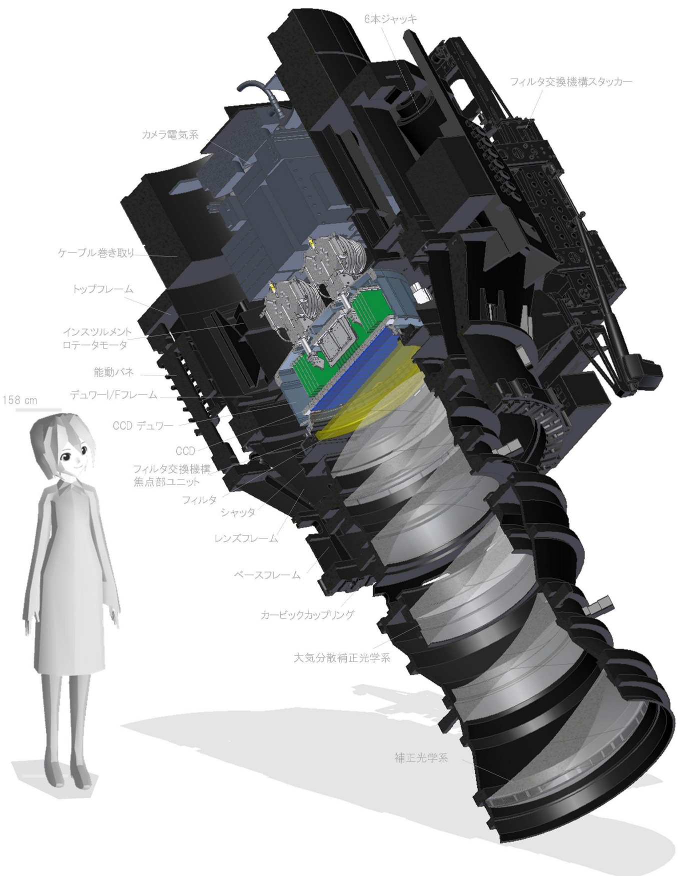
Multi-object fiber-fed spectrograph

- 2000 fibers (too dense??)
- 0”.5 aperture fibers (c.f. PFS is 1”.1)
- R~2000 (too low?)
- Wavelength coverage: 1.2-2.5um (K is challenging?)



Subaru's future galaxy survey

Hyper Suprime-Cam



Prime Focus Spectrograph

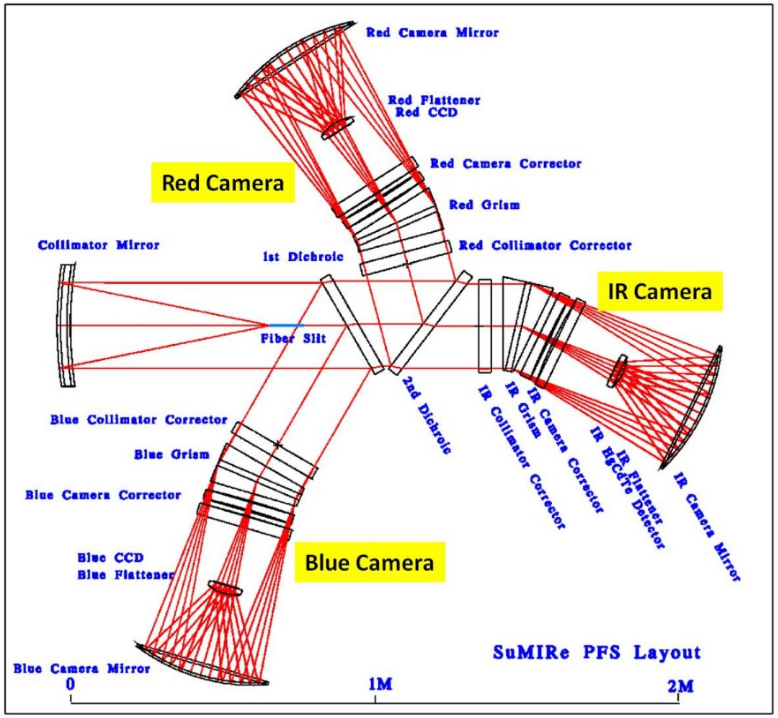


Fig. 2. Optical architecture of the 3-channel spectrograph

Obviously, we should build our survey upon HSC + PFS.

What GLAO adds to PFS

PFS survey plan is still not fixed yet at all. But the current baseline plan is

16sqdeg to J~23.5. 24k galaxies per sqdeg. 3 hours per galaxy.

Just to remind you, PFS has 2,400 fibers covering 0.38-1.3um over a 1.5deg diameter field of view. GLAO spectrograph will add the 1.3-2.5um coverage.

– Halpha at 1<z<2.5 (PFS has it only at z<1)
  SFR, AGN/SF separation, metallicity

– continuum shape of 2<z<4.5 in rest-frame optical
  Stellar populations through SED modelling.

A 10sqdeg survey with GLAO

One fiber configuration at each pointing. Source density is

2000 / 13.6^2 = 11 galaxies / arcmin^2

The current plan for PFS is about 60% of this. So, we can observe all the PFS galaxies, plus 40% of the fibers go to other targets. Let's aim at 10 sqdeg with 3 hours integration for each object.

10 / 0.05 * 3 = <u>600 hours ~ 100 nights</u>

We will have

- deep optical + near-IR photometric data + lots of other data
- deep spectra over 0.38-2.5um

for 240,000 galaxies at 0<z<5(?) over 10 sqdeg, plus 160,000 ancillary targets.

- How big is the difference between 0.2 and 0.5arcsec seeing?
  - ► 0”.2 is of course better, but the difference is not huge.

- Can we compete with space-based missions?

  Main concern I have is the very high sky background for ground-based facilities.
  - ► I think we can compete in spectroscoypy.

- Can we compete with other ground-based facilities?

  LBT and VLT are also developing GLAO. Can we beat them?
  - ► Yes!

- Can we do any interesting science with GLAO?
  - ► Maybe, but maybe not...

3 – Summary

Summary

Imaging – hard to compete with the satellite missions. We could do NB imaging, but is the science big enough so that we want to commit ourselves?

Spectroscopy – again hard to compete with satellites (esp. JWST). But, we can do complicated spectroscopy such as fiber MOS and multi-object IFU. I think the key is to work between the OH lines. Are there extremely exciting science opportunities with such an instrument? Maybe, but maybe not.