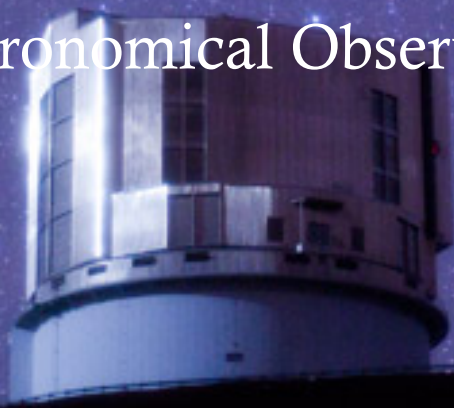


Future and International Collaboration of Subaru Telescope

Michitoshi Yoshida

Director, Subaru Telescope

National Astronomical Observatory of Japan





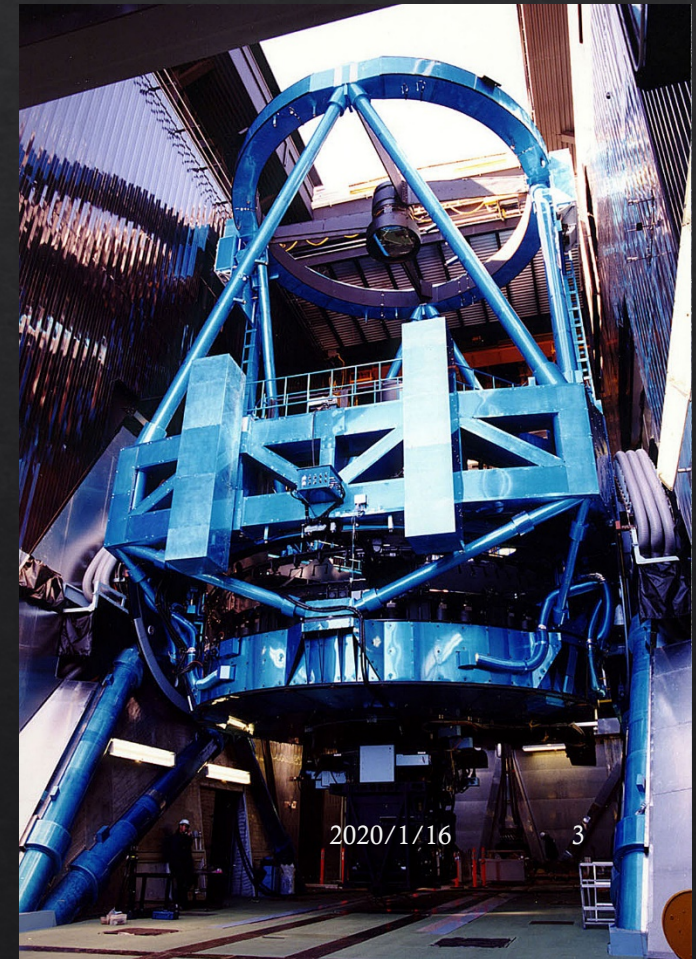
Subaru Telescope and Its Instruments



Subaru Telescope



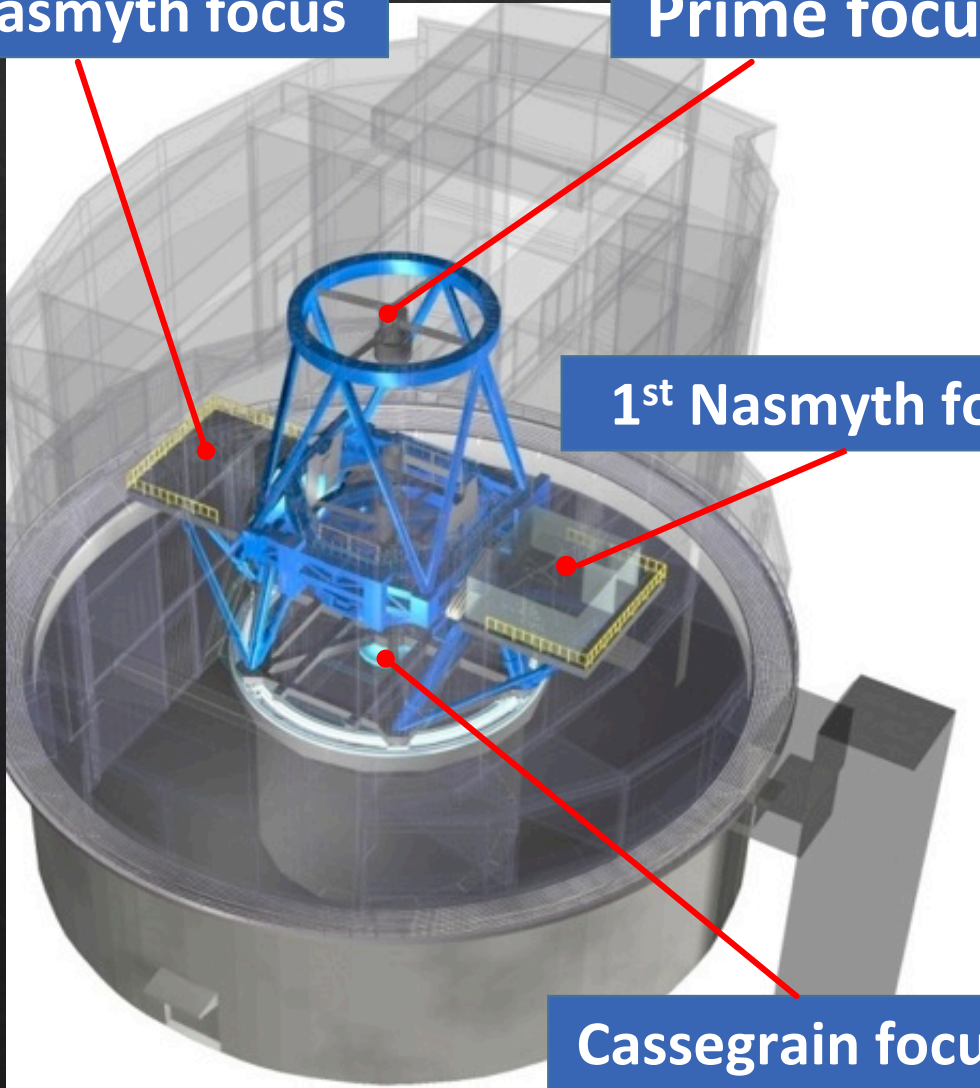
- ◇ 8.2m optical – infrared reflecting telescope operated by National Astronomical Observatory of Japan (NAOJ), National Institutes of Natural Sciences (NINS)
- ◇ Construction: 1991 - 1999
- ◇ Science operation: 2000 - present



Subaru has four foci

2nd Nasmyth focus

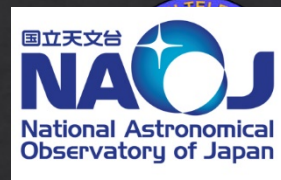
Prime focus



1st Nasmyth focus

Cassegrain focus

◇ Wide field observation capability using the prime focus is a unique point of Subaru.



Subaru has wide field observation capability

M31 image taken with HSC

Field-of-view of
Hyper Suprime-Cam
of Subaru

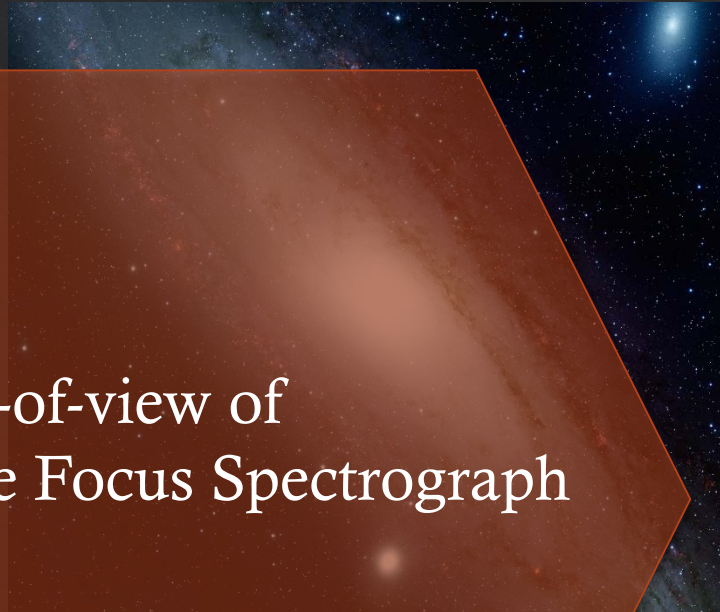
9 times as large as
the apparent size
of the moon



Field-of-view of TMT



Field-of-view of
Prime Focus Spectrograph



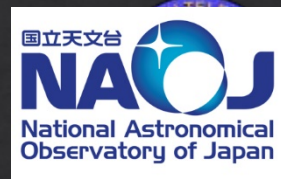
Field-of-view of
Keck DEIMOS



2020/1/16

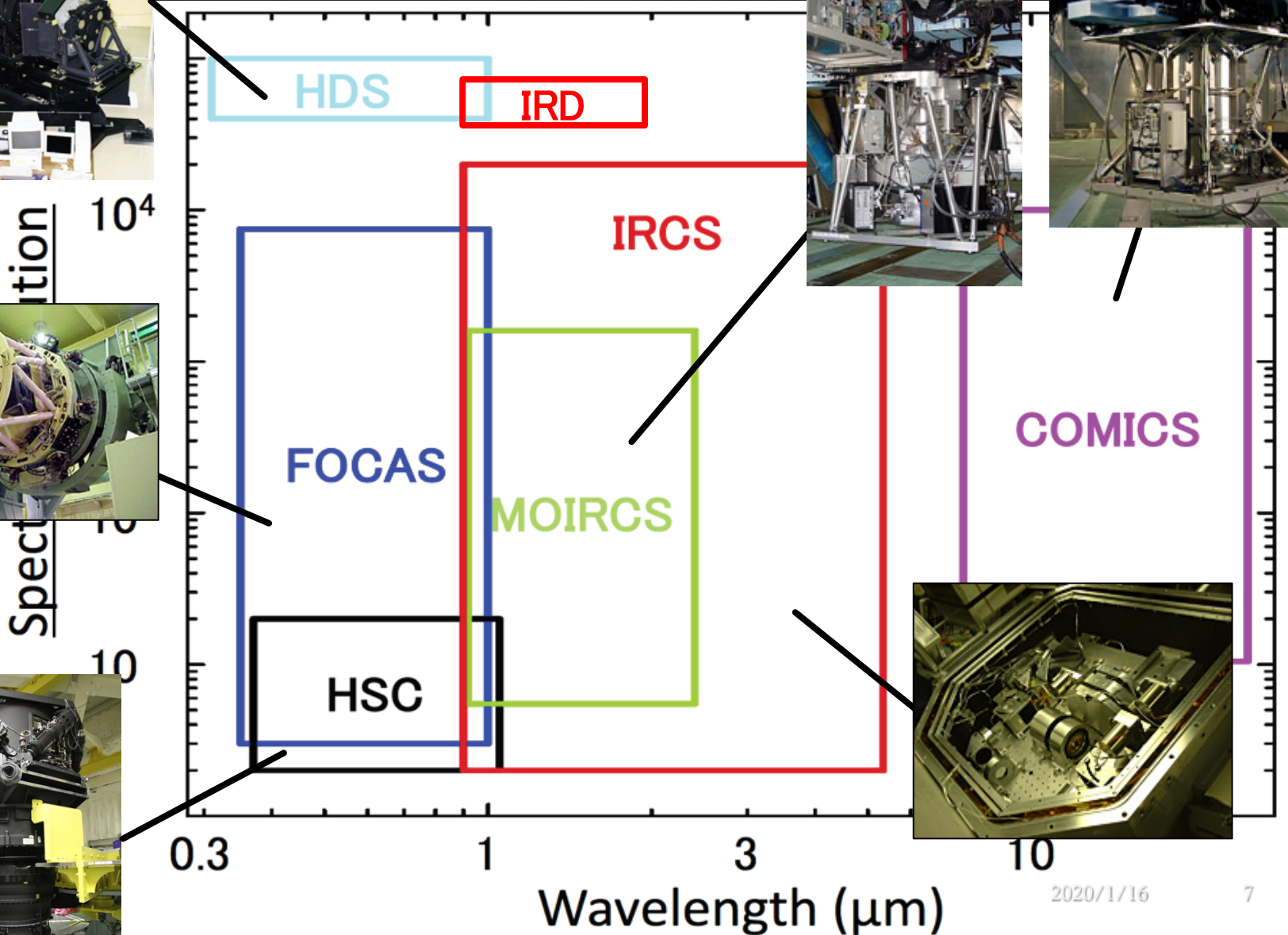
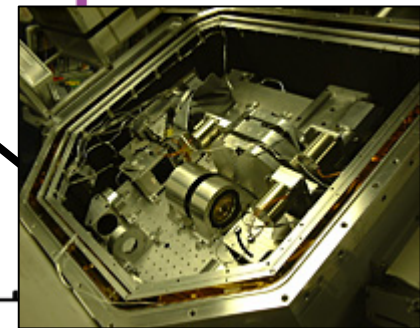
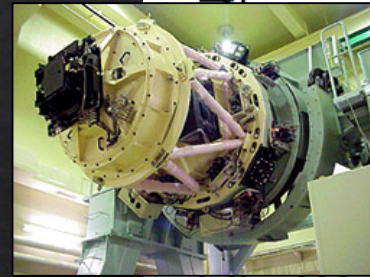
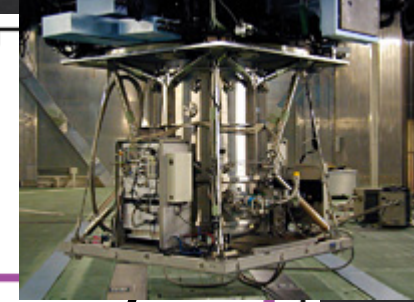


Instrument Suit of Subaru



- ◇ facility instruments
 - ◇ Optical wide field camera: HSC [Pr]
 - ◇ Optical camera and spectrograph: FOCAS [Cs]
 - ◇ Optical high dispersion spectrograph: HDS [Ns]
 - ◇ Near-infrared multi-object spectrograph: MOIRCS [Cs]
 - ◇ Near-infrared camera and spectrograph: IRCS [Ns]
 - ◇ Mid-infrared camera and spectrograph: COMICS [Cs]
- ◇ visiting instruments (PI-type)
 - ◇ Near-infrared high-dispersion spectrograph: IRD [Coude]
 - ◇ Coronagraphic High Angular Resolution Imaging Spectrograph (CHARIS) [Ns]
 - ◇ Extreme adaptive optics: SCExAO [Ns]
- ◇ adaptive optics
 - ◇ Adaptive optics system: AO188 [Ns]

Instruments of Subaru Telescope



← visible → ← near infrared → ← mid-infrared →

Hyper Suprime-Cam (HSC)

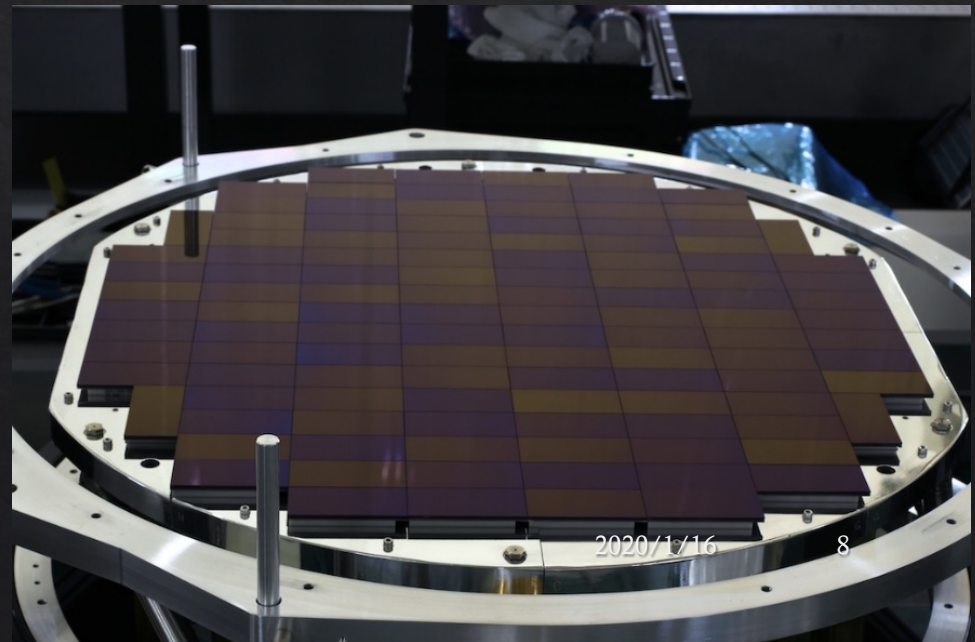


FOV: 1.7 degree^2

104 CCDs \rightarrow 830 million pixels

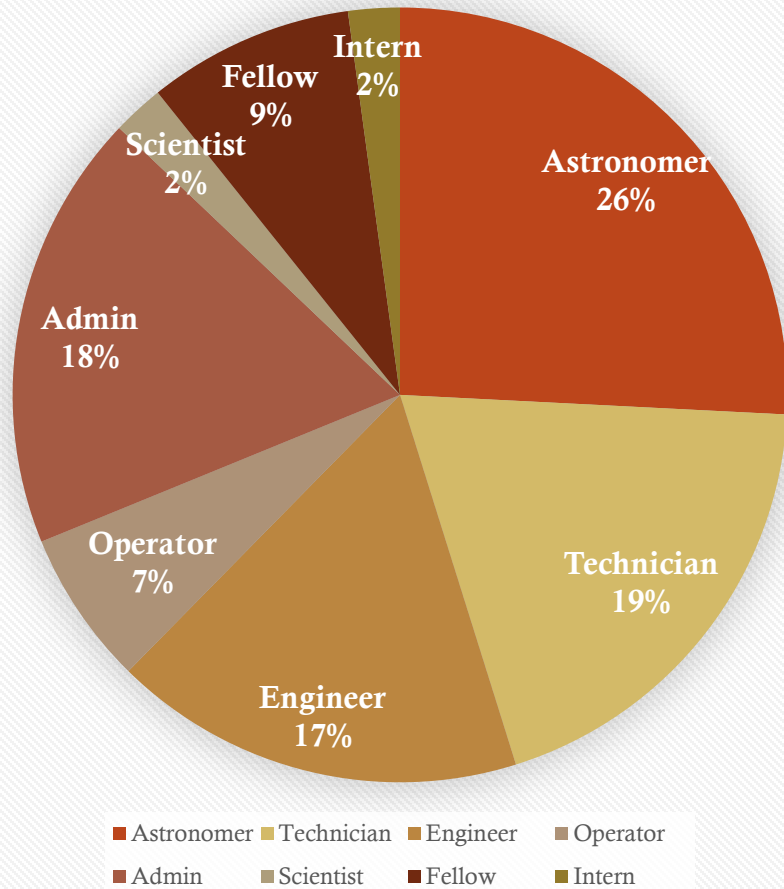
Pixel scale: 0.17 arcsec

Wavelength range: $0.4 - 1.0 \mu\text{m}$

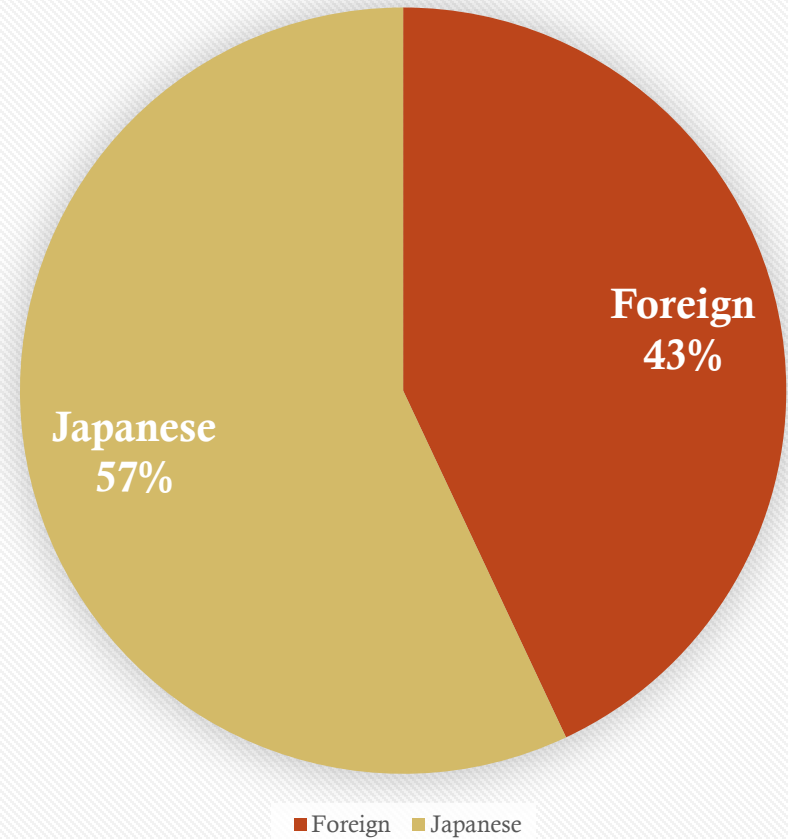


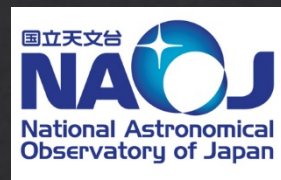
Employees of Subaru Telescope in Hawaii (88 employees) (+ 26 in Mitaka)

Job Title



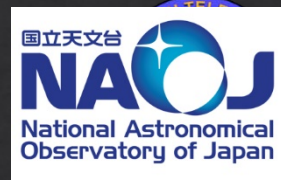
Foreign & Japanese



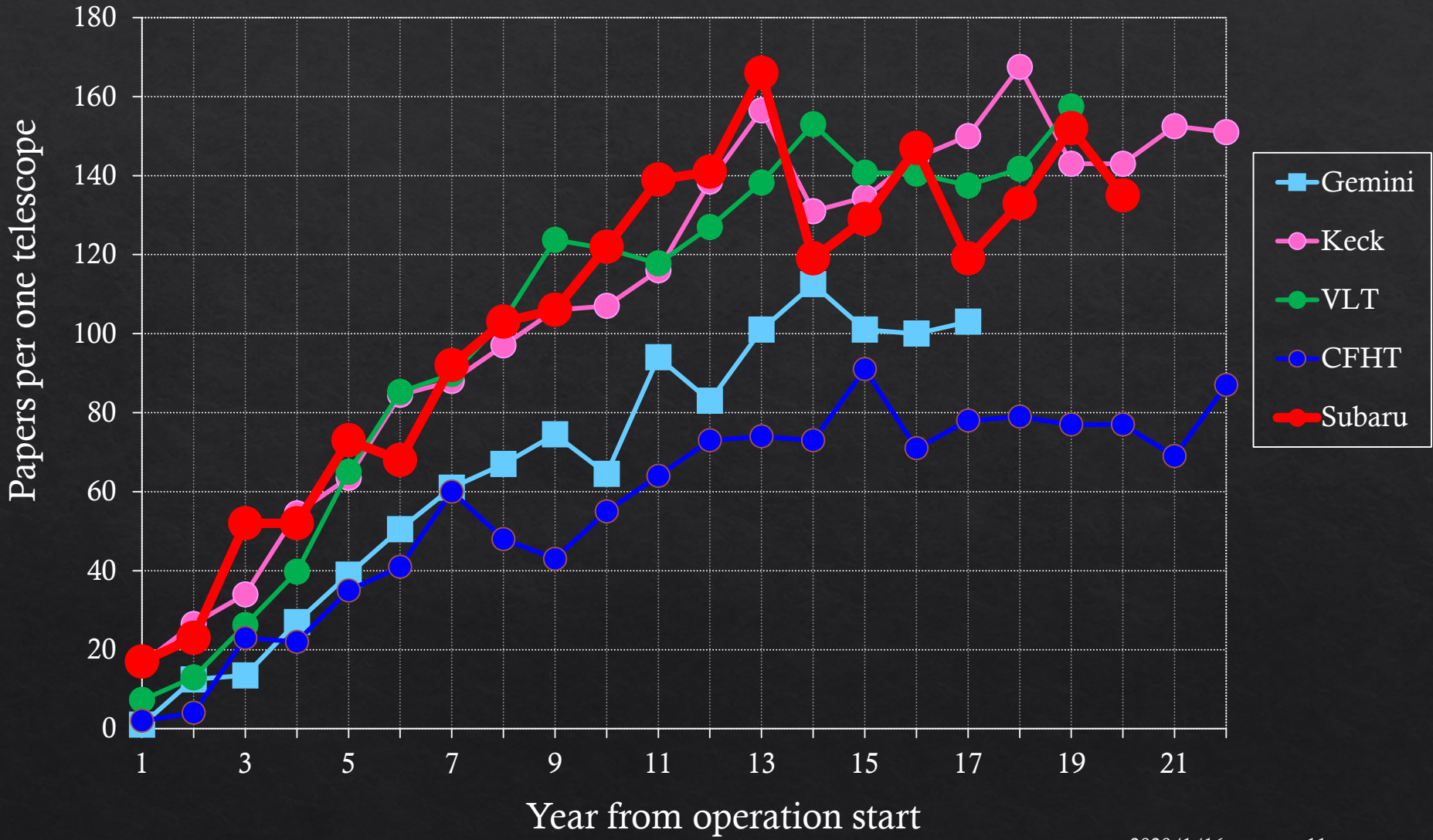


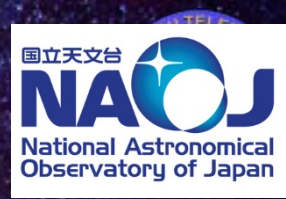
Subaru Strategic Programs

- ◇ Exceptionally large project using unique/expedient instruments of Subaru Telescope
- ◇ **HSC SSP (2014 - 2020) 300+30 nights ongoing**
 - ◇ “Wide-field imaging with **Hyper Suprime-Cam**: Cosmology and Galaxy Evolution”
- ◇ **IRD SSP (2019 - 2025) 70 (+100) nights ongoing**
 - ◇ “Search for Planets like Earth around Late-M Dwarfs: Precise Radial Velocity Survey with **IRD**”
- ◇ **PFS SSP (2022 - 2027?) 300 - 360 nights in preparation**
 - ◇ Large international **PFS** collaboration



Number of Publications





Instrumentation of Subaru

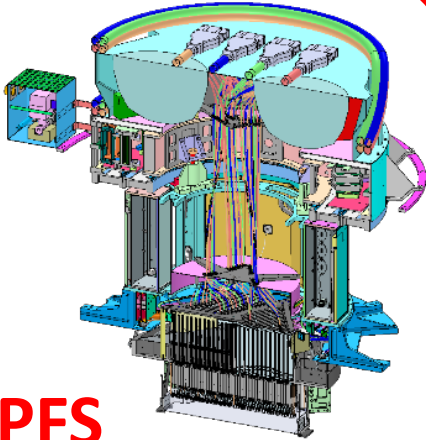
2020/1/16

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Subaru Instrumentation

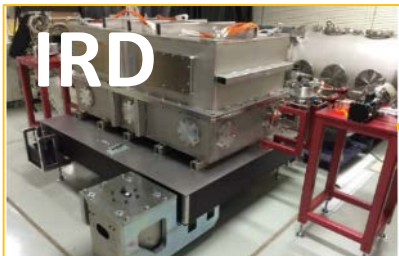


Wide field (1.5 deg) imaging



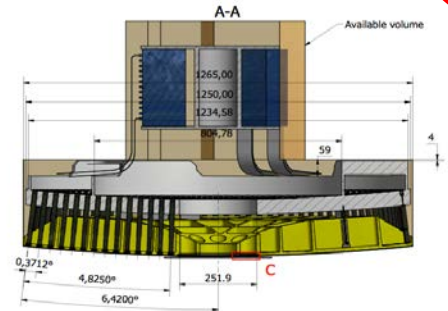
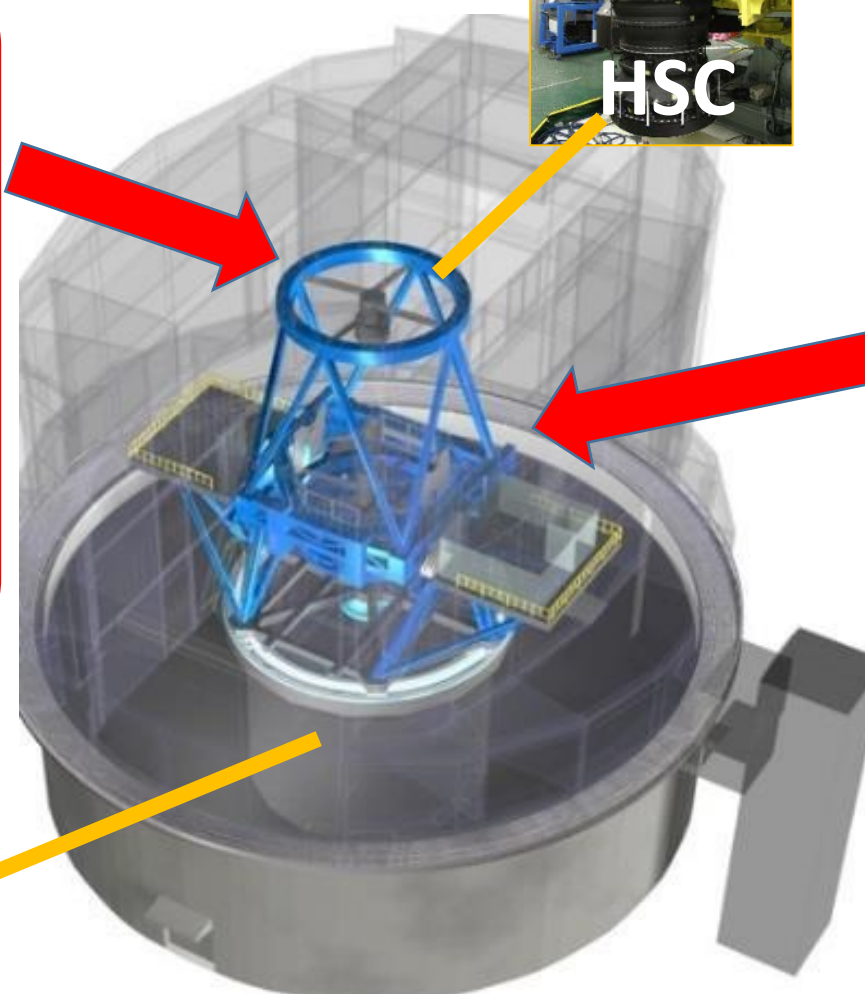
PFS

Wide field (1.3 deg) multi object (2,400) spectroscopy

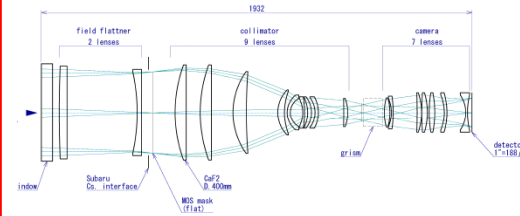


IRD

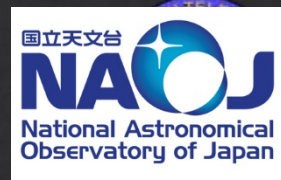
Precise radial velocity (2m/s) measurement



GLAO + Wide-field IR Instrument



ULTIMATE-Subaru
Wide field (20 arcmin) high spatial resolution (0.2 arcsec) Infrared observation



New Instrument

IRD (InfraRed Doppler spectrograph)

- ◇ A fiber fed **high-dispersion ($R=70,000$) NIR spectrograph** with laser frequency comb → precision of radial velocity measurement ~ 2 m/s in H-band
- ◇ Detection of earth-like mass planets around M-dwarfs
- ◇ Science operation started in S18B.
- ◇ SSP started in S19A.





PFS (Prime Focus Spectrograph)



(under development; science operation from 2022)

A fiber fed **multi-object spectrograph** attached to the prime focus of Subaru

2,400 fibers FOV: 1.25 deg^2

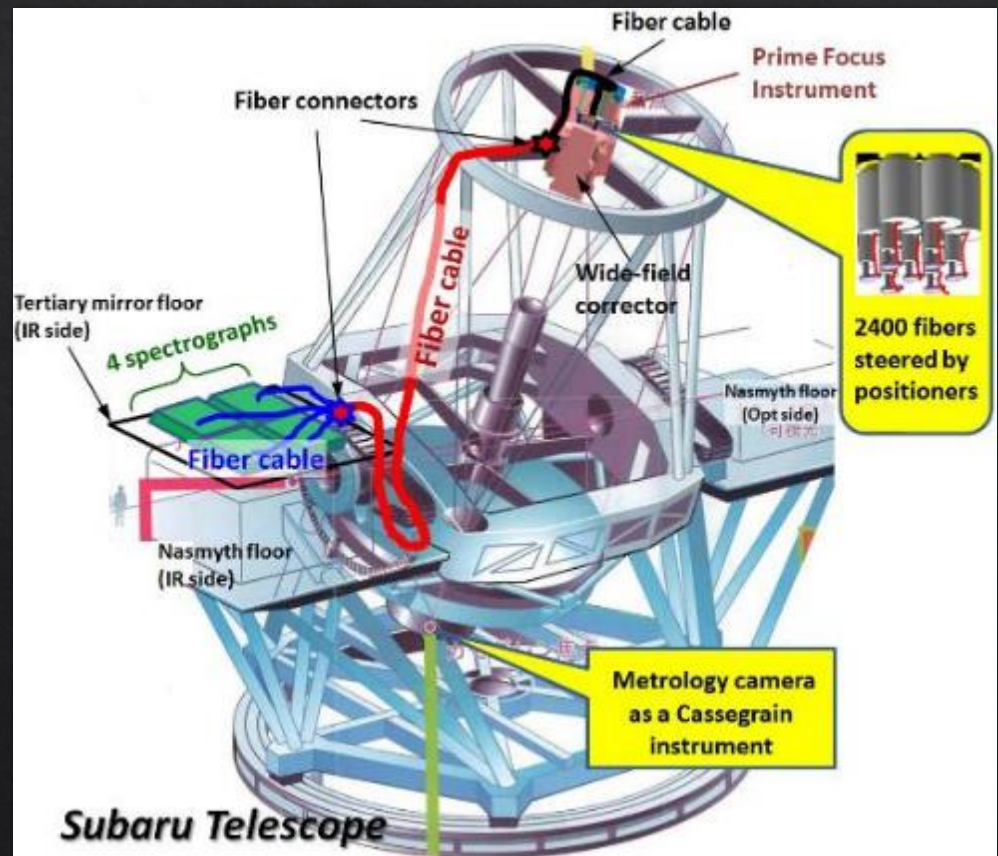
λ range: $0.38 - 1.26 \mu\text{m}$

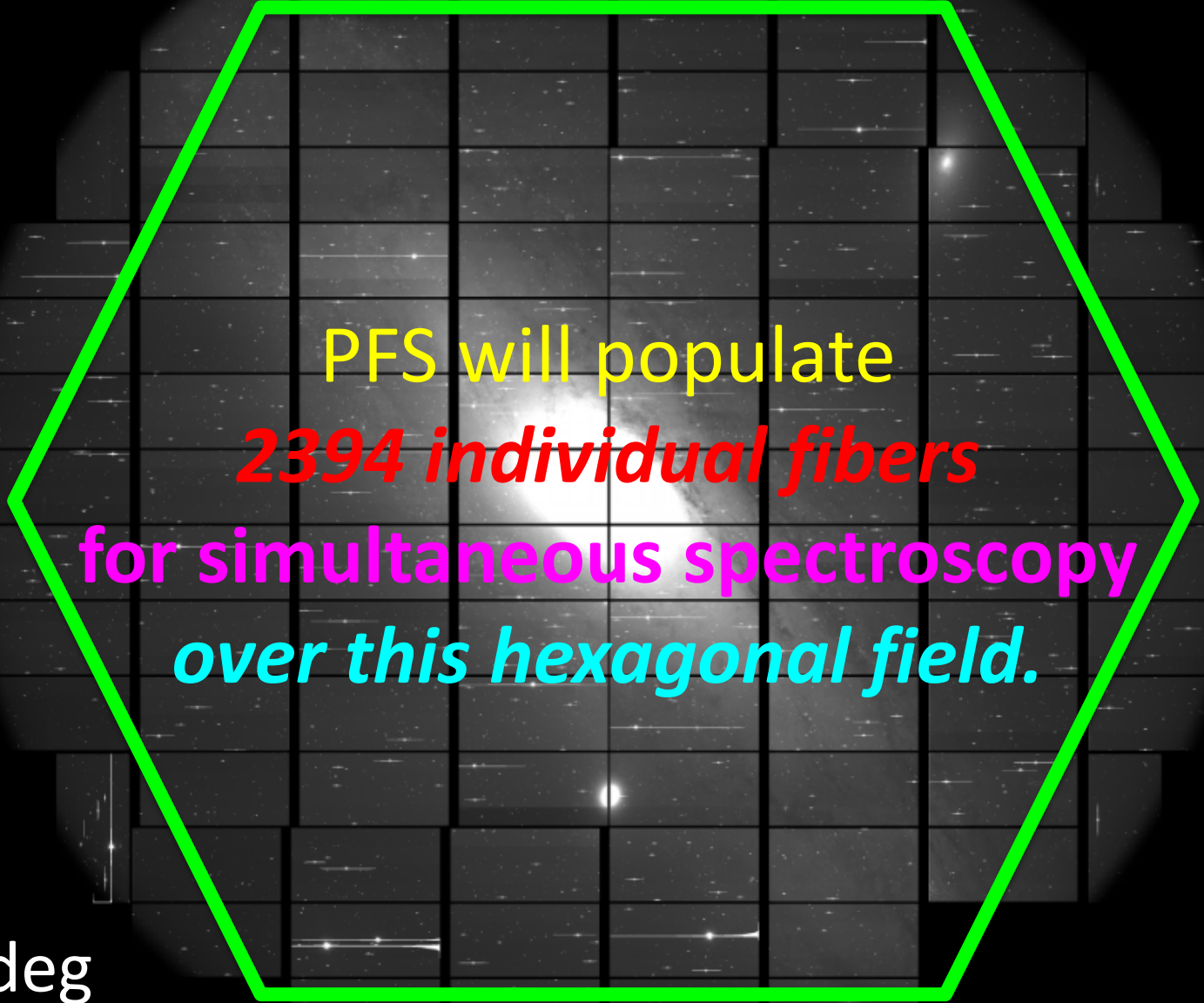
Spec. R: $2,300 - 5,000$

Sensitivity

Band	magnitude
Blue ($0.38 - 0.65 \mu\text{m}$)	22.5
Red ($0.65 - 0.97 \mu\text{m}$)	22.4
NIR ($0.97 - 1.26 \mu\text{m}$)	21.4

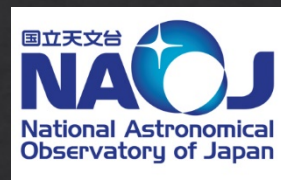
S/N = 5 @ 1 hour exposure





PFS will populate
2394 individual fibers
for simultaneous spectroscopy
over this hexagonal field.

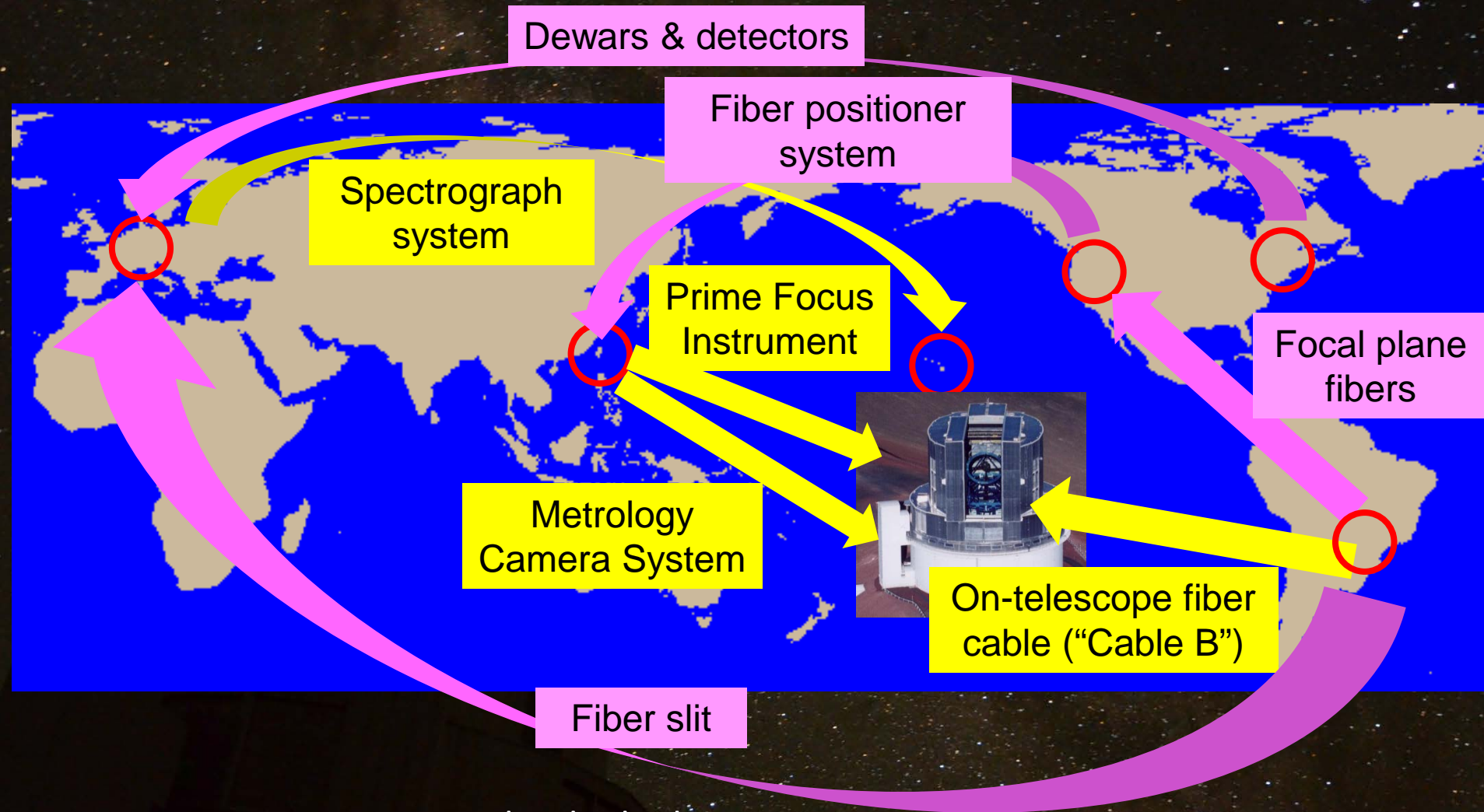
~1.5 deg



PFS collaboration

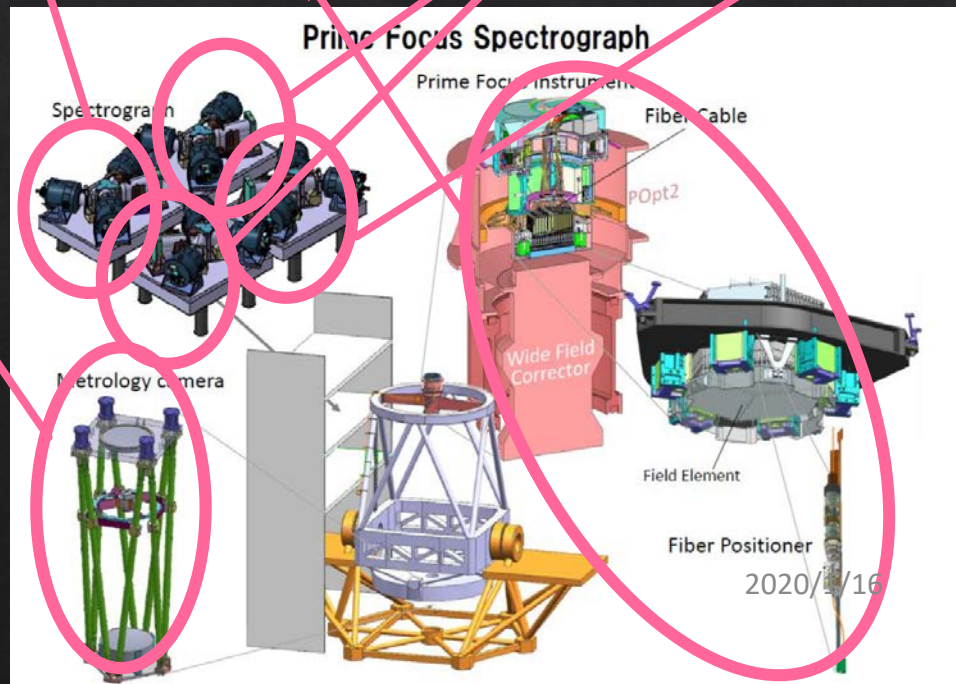
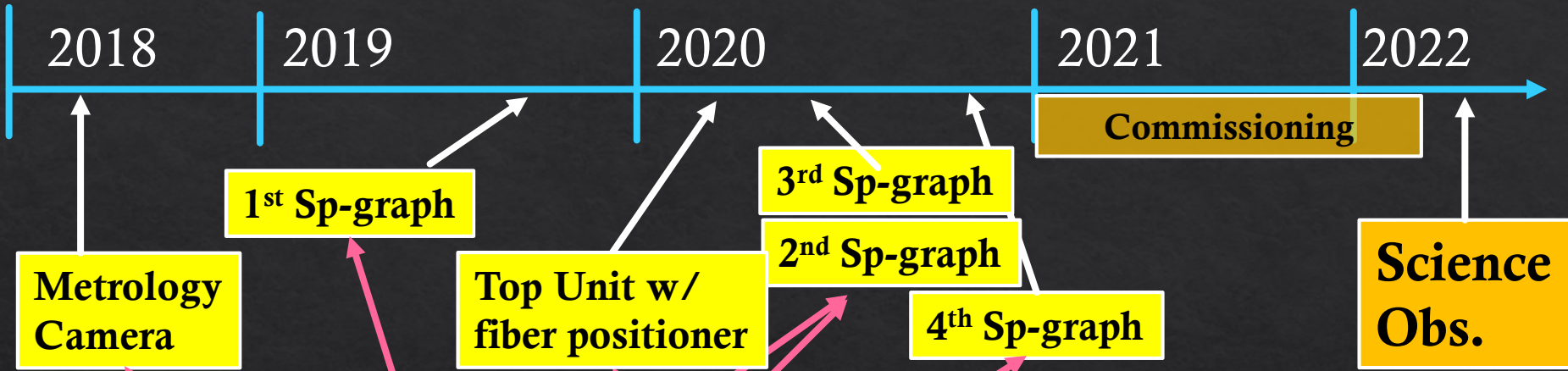
7 countries, 23 institutions





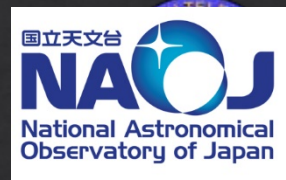
- Systems engineering is clearly the key.
- Parts/components/subsystem will be validated at each site before their delivery to other places for higher-level integration & finally to Subaru.

PFS Installation Timeline





ULTIMATE-Subaru



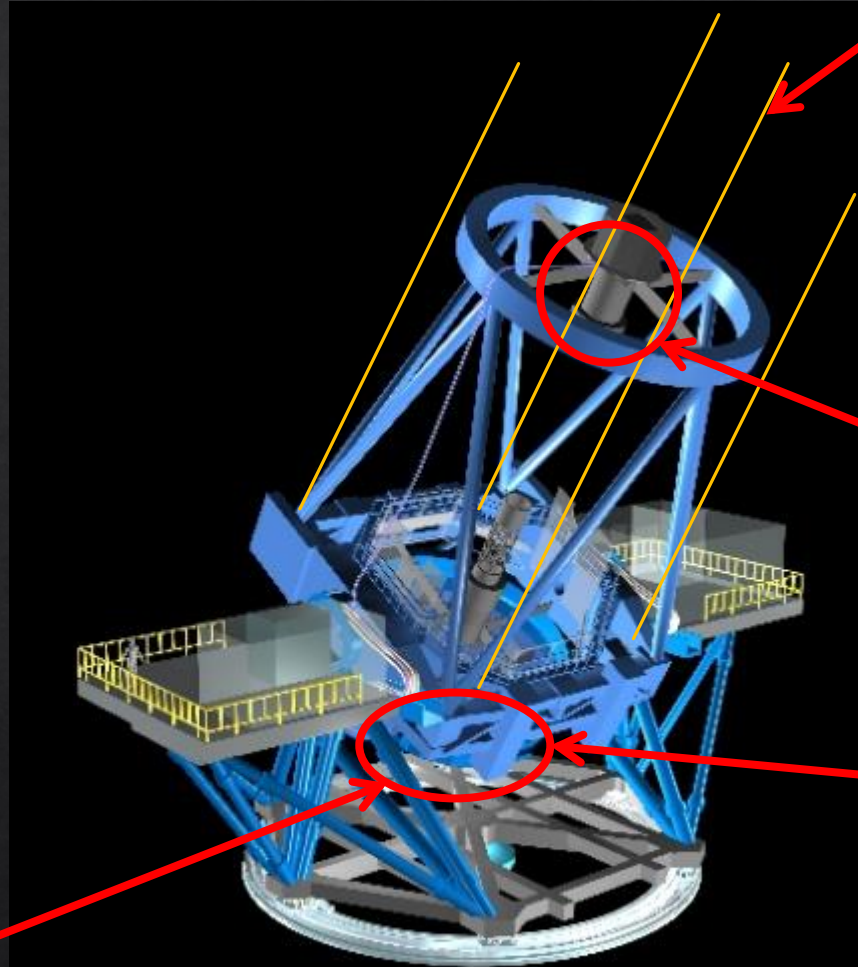
(preliminary design phase)

Wide field near-infrared observation facility using ground layer adaptive optics (GLAO) system

Science Operation: 2026

International Collab.:
Taiwan (ASIAA),
Australia (ANU),
(Canada (NCU))

Wide Field Near-infrared Instruments



4 Laser Guide Star System

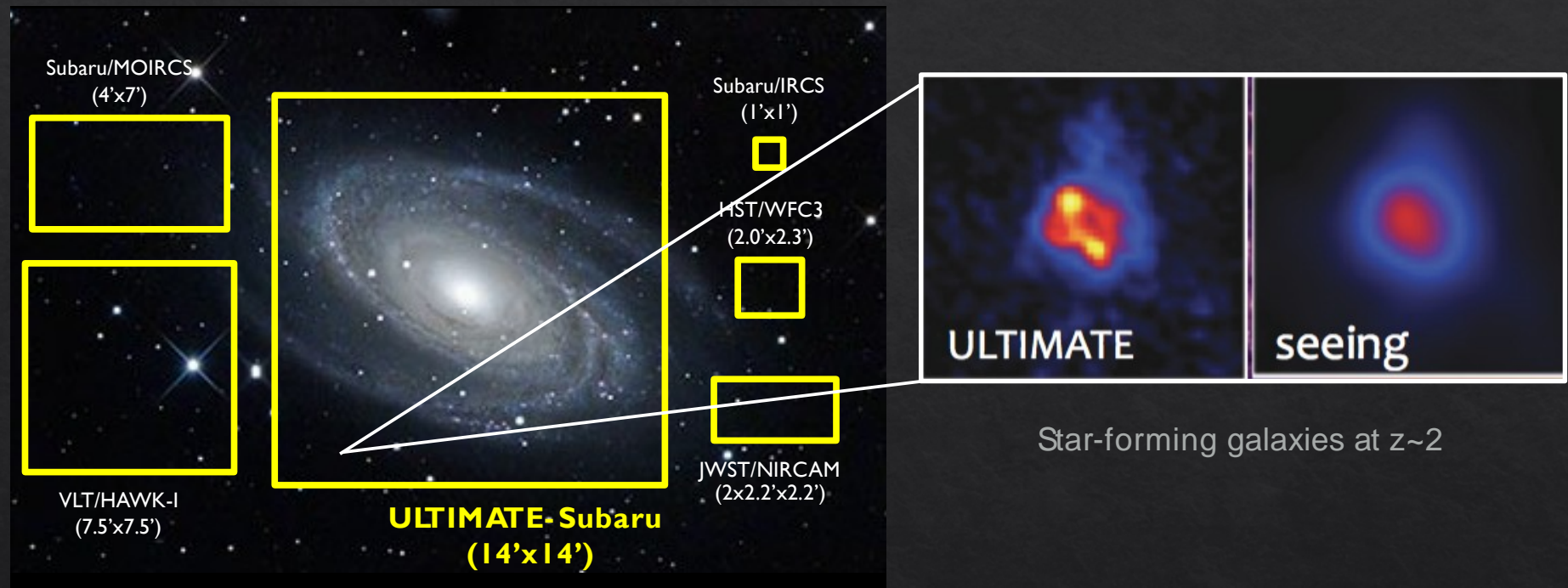
Deformable Secondary Mirror

Wavefront Sensors

2020/1/16

ULTIMATE-Subaru

High-Res “AND” Wide-Field NIR Capabilities



ULTIMATE-Subaru will deliver:

- ▶ Subaru’s original **High-redshift targets** to **follow-up with TMT**
- ▶ **Spatially-resolved** studies of the objects found by HSC/PFS
- ▶ **SDSS-like** comprehensive imaging/spec. survey for **high-redshift universe** ($z > 2$).
- ▶ Synergy with the future **surveys** by **wide-field space missions** (good synergy with **WFIRST**)

2020/1/16

Subaru wide-field capabilities in 2020s

HSC (operational)



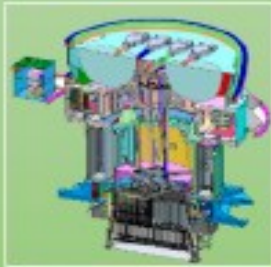
Optical
(0.38 – 1.1 μm)
FoV
1.7 deg²

Seeing limited
($> 0.4''$)
Imager

Limiting mag.
with 1h exp.

Band	mag
g	27.8
r	27.2
i	26.5
z	25.9

PFS (2022 -)



Optical – J-band
(0.38 – 1.26 μm)
FoV
1.3 deg²

2,400 fibers
1.05" ϕ
Multi-object sp.
0.38 – 1.26 μm

Limiting mag. with 1h exp.

Band	mag
Blue (0.38 – 0.65 μm)	22.5
Red (0.65 – 0.97 μm)	22.4
NIR (0.97 – 1.26 μm)	21.4

ULTIMATE (2026 -)

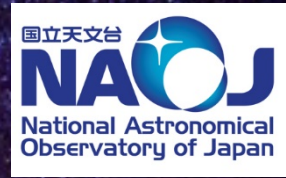


Near-Infrared
(0.9 – 2.5 μm)
FoV
20' ϕ

GLAO supported
0.2" resolution
(in K-band)
Imager (14'x14')
Multi-object sp.
(w/ MOIRCS)
IFU sp.

Limiting mag.
using GLAO
with 4h exp.

Band	mag
J	26.3
H	25.5
Ks	26.4
NB1340	26.1



International Collaboration

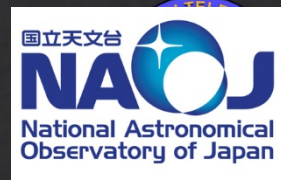
2020/1/16

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International collaboration on Subaru instrumentation

- ◇ Several collaborations on instrumentation
 - ◇ SCExAO : Japan, US, Australia, etc.
 - ◇ HSC : Japan, US, and Taiwan
 - ◇ PFS : Japan, US, France, Taiwan, Brazil, Germany, and China
 - ◇ IRD : Japan, US, Canada, Poland, Sweden, and Germany
 - ◇ ULTIMATE : Japan, Taiwan, Australia, and Canada



International Partnership

- ◇ It is getting more difficult for Subaru to financially sustain its operation even though the scientific value of the telescope is still very high.
 - ◇ It is required for Subaru to make its operation cost lower.
 - ◇ Japanese government has been asking Subaru to look for international partners who can operate the telescope together.
 - ◇ Discussions on international partnership with partner candidate countries are under way.
 - ◇ Partner candidates:
 - ◇ **India**
 - ◇ Canada
 - ◇ China
 - ◇ East Asian Observatories



Subaru – India Meeting on International Partnership

9/9 – 10 @Bangalore, India



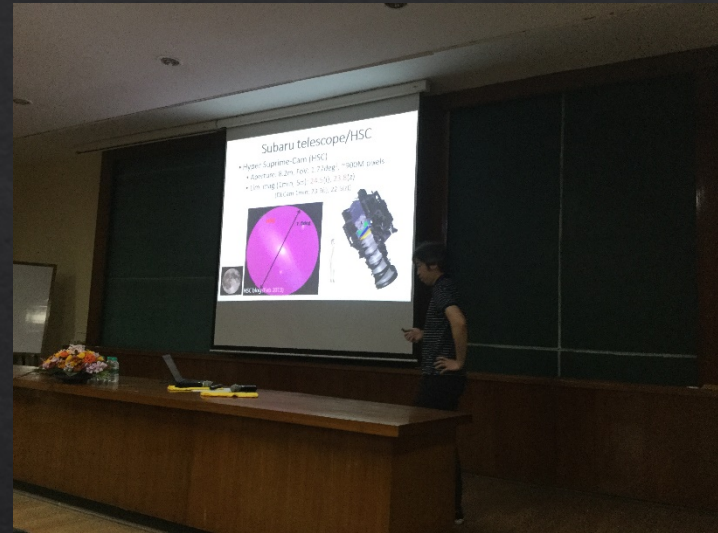
Agenda:

- Subaru Telescope Facility (Yoshida)
- HSC and ongoing planned projects at Subaru (Miyazaki)
- PFS, ULTIMATE, and instrument decommissioning plan (Yoshida & Miyazaki)
- Subaru Partnership (Sekiguchi)
- Discussion on plan & time scales from Indian side
- Discussion on the Subaru meeting @ TIFR in December 2019

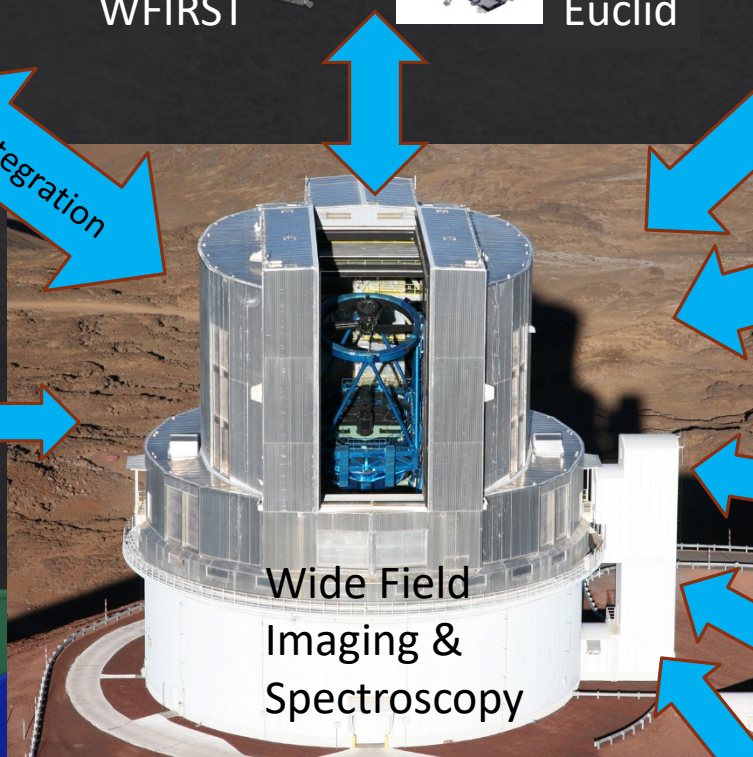


Science with Subaru – Indian perspective

12/18 – 20 @Mumbai, India



- ❖ Dec. 18 – 20 @ Tata Institute of Fundamental Research (TIFR), Mumbai, India
- ❖ About 75 people participated in the workshop
- ❖ Subaru – India partnership, Indian instrumentation for Subaru : Executive session between NAOJ representatives (DG, Sekiguchi, Miyazaki, Minowa, and Yoshida) and Directors of Indian astronomical institutions (8 institutes) was held.
- ❖ Science cases: cosmology, galaxy formation, nearby galaxies, Milky Way, time domain, star & planet formation, exoplanets, Solar system

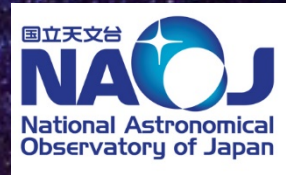


International Collaboration on Instrumentation (PFS, ULTIMATE, etc.)

Science Collaboration with Universities / Institutes

International Partnership for Subaru Operation and Science Promotion





Thank you