



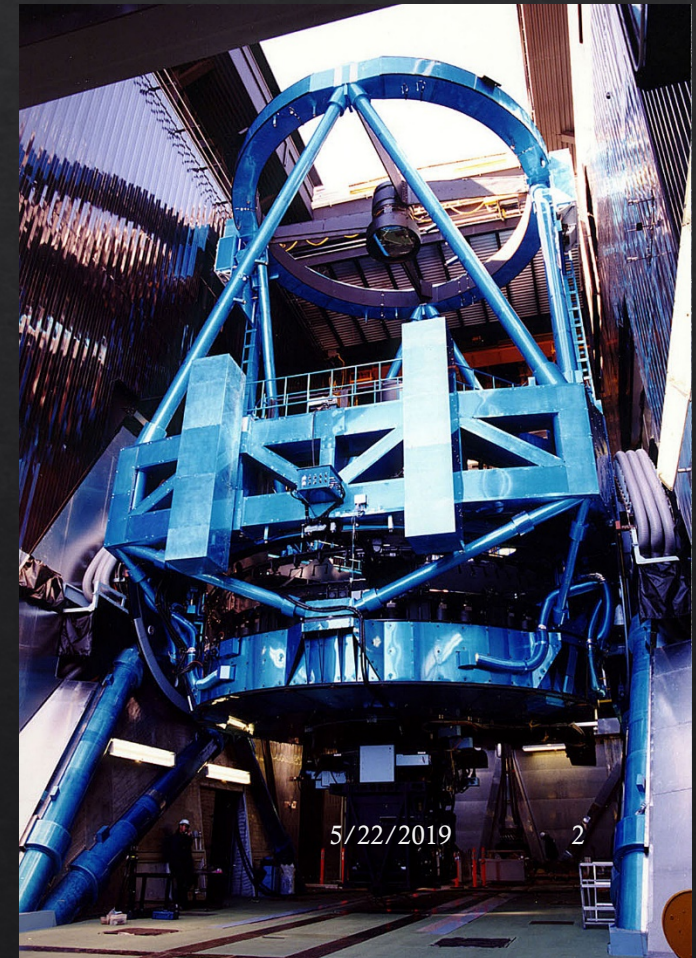
Current Status and Future of Subaru Telescope

Michitoshi Yoshida
Subaru Telescope, NAOJ



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





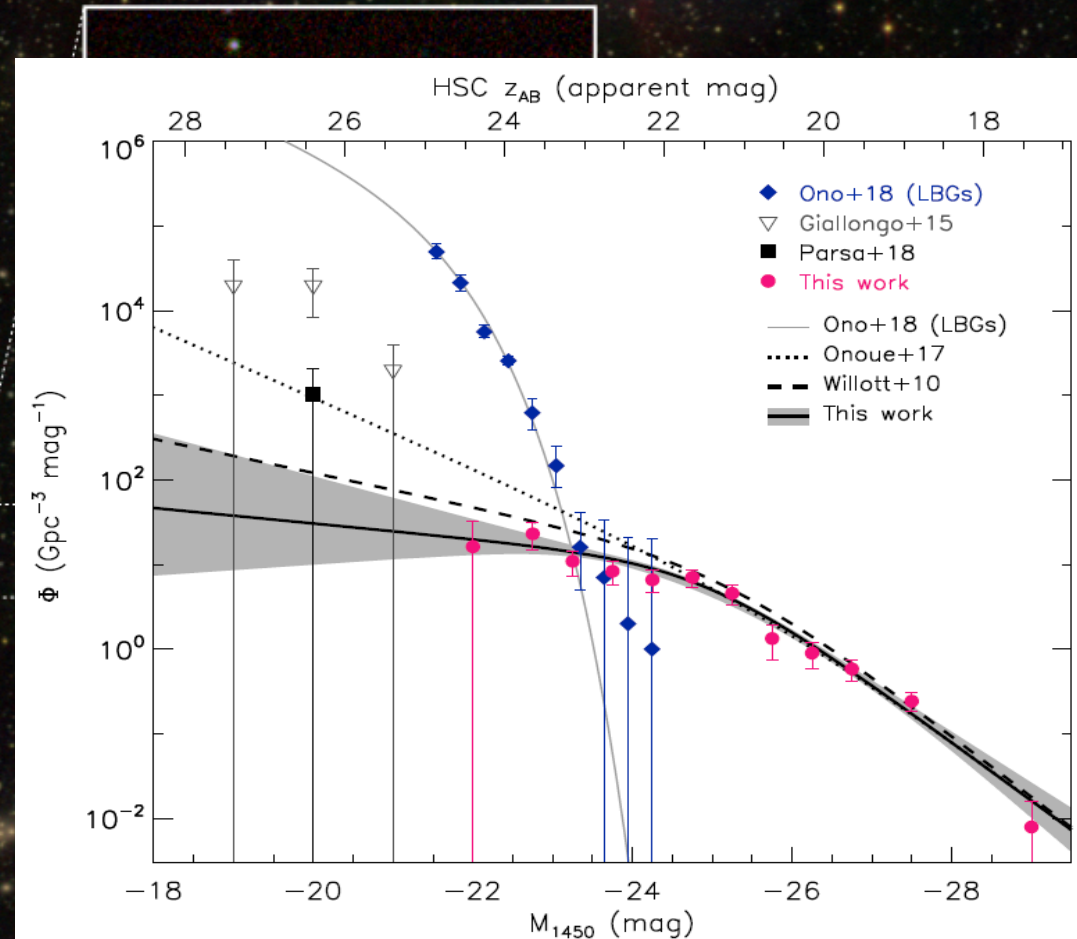
Recent Science Topics

Supermassive black holes in the early universe



Matsuoka et al. 2018

Matsuoka et al. discovered 83 quasars powered by supermassive black holes at $z \sim 6$ using Hyper Suprime-Cam (HSC) of the Subaru Telescope. The discovery increases the number of black holes known at that epoch considerably, and reveals, for the first time, how common SMBHs are early in the universe's history. In addition, it provides new insight into the effect of black holes on the reionization of the universe.



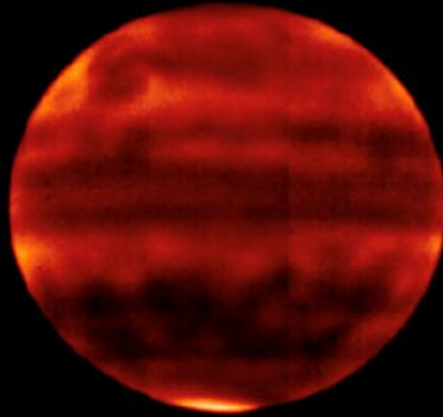
Jupiter's Atmosphere Heats Up Under Solar Wind

Sinclair et al. 2019

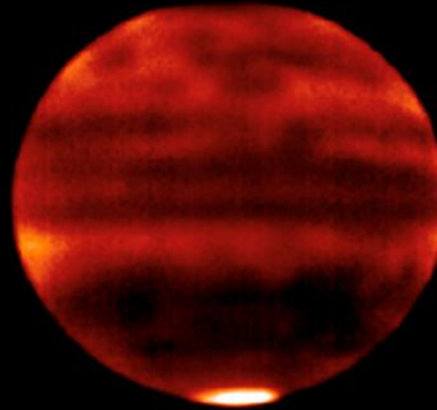


7.8 um CH₄ images of Jupiter taken with COMICS

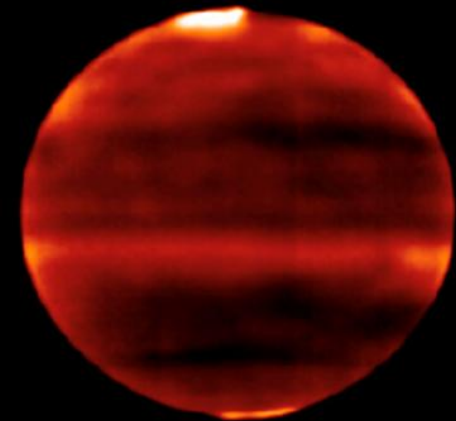
2017-Jan-11 15:50 UTC



2017-Jan-12 12:57 UTC



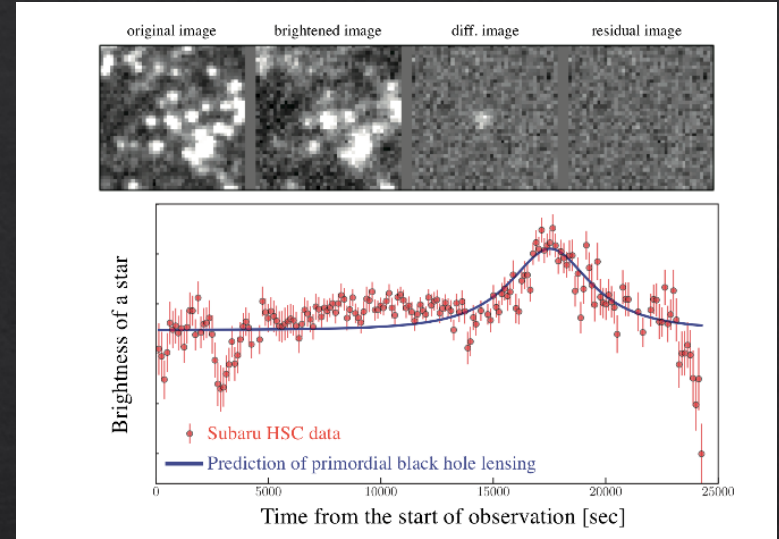
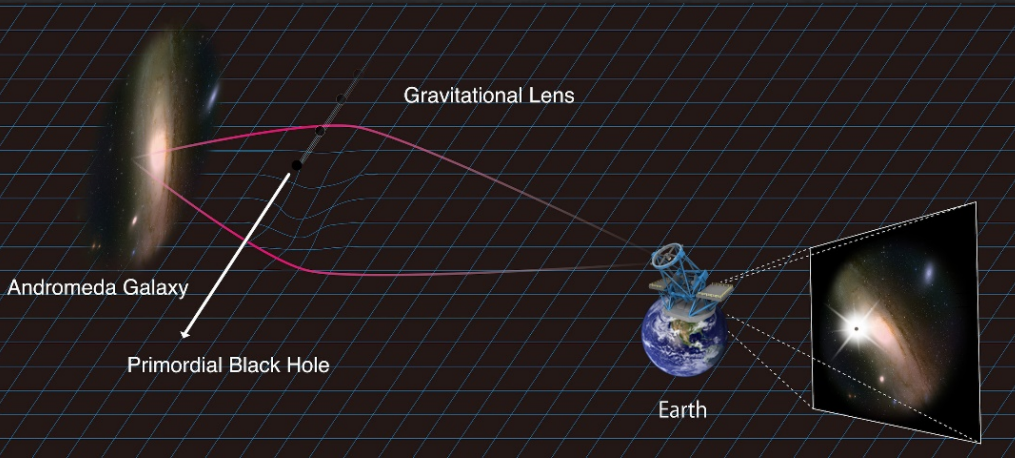
2017-Jan-12 16:13 UTC



Auroras at Jupiter's poles are heating the planet's atmosphere more deeply than previously thought. The heating occurs when the magnetosphere and the solar wind interact. Images illustrate how quickly the CH₄ emission from the stratosphere of Jupiter reacted to the impact of the solar winds onto Jupiter.

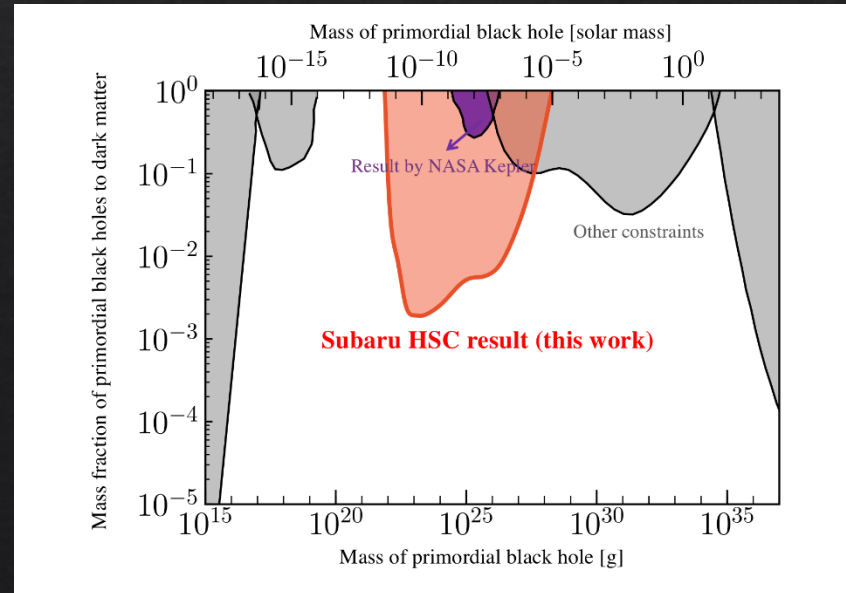
Subaru Telescope Helps Determine that Dark Matter is NOT Made Up of Tiny Primordial Black Holes

Niikura et al. 2019



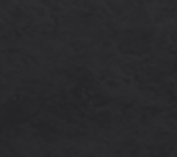
About 90 million stars of M31 were monitored with HSC for 1 night (time interval is 2 min.) to detect gravitational lensing effects by primordial BHs in the halo of M31. → Only 1 candidate event was detected.

The data ruled out the possibility that primordial black holes smaller than a tenth of a millimeter make up most of dark matter.





Open Use Status



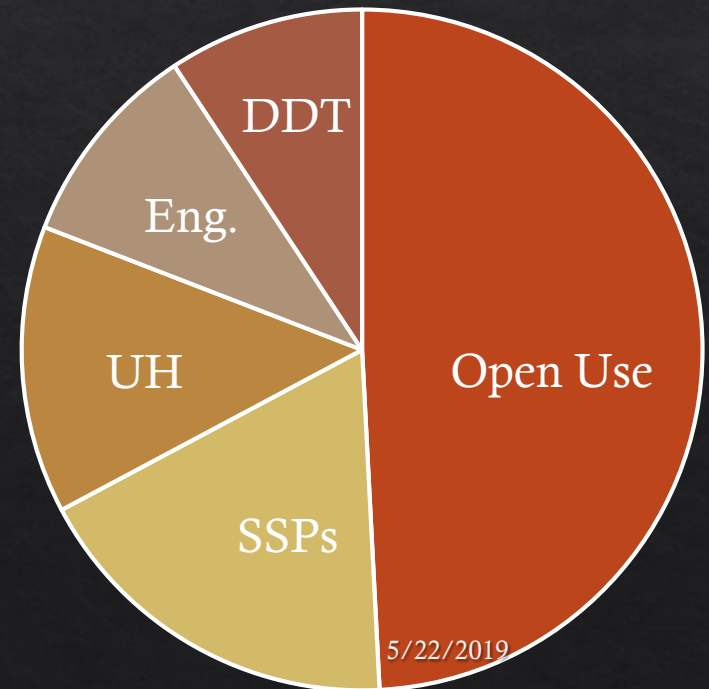


◆ Telescope time categories (nights/semester)

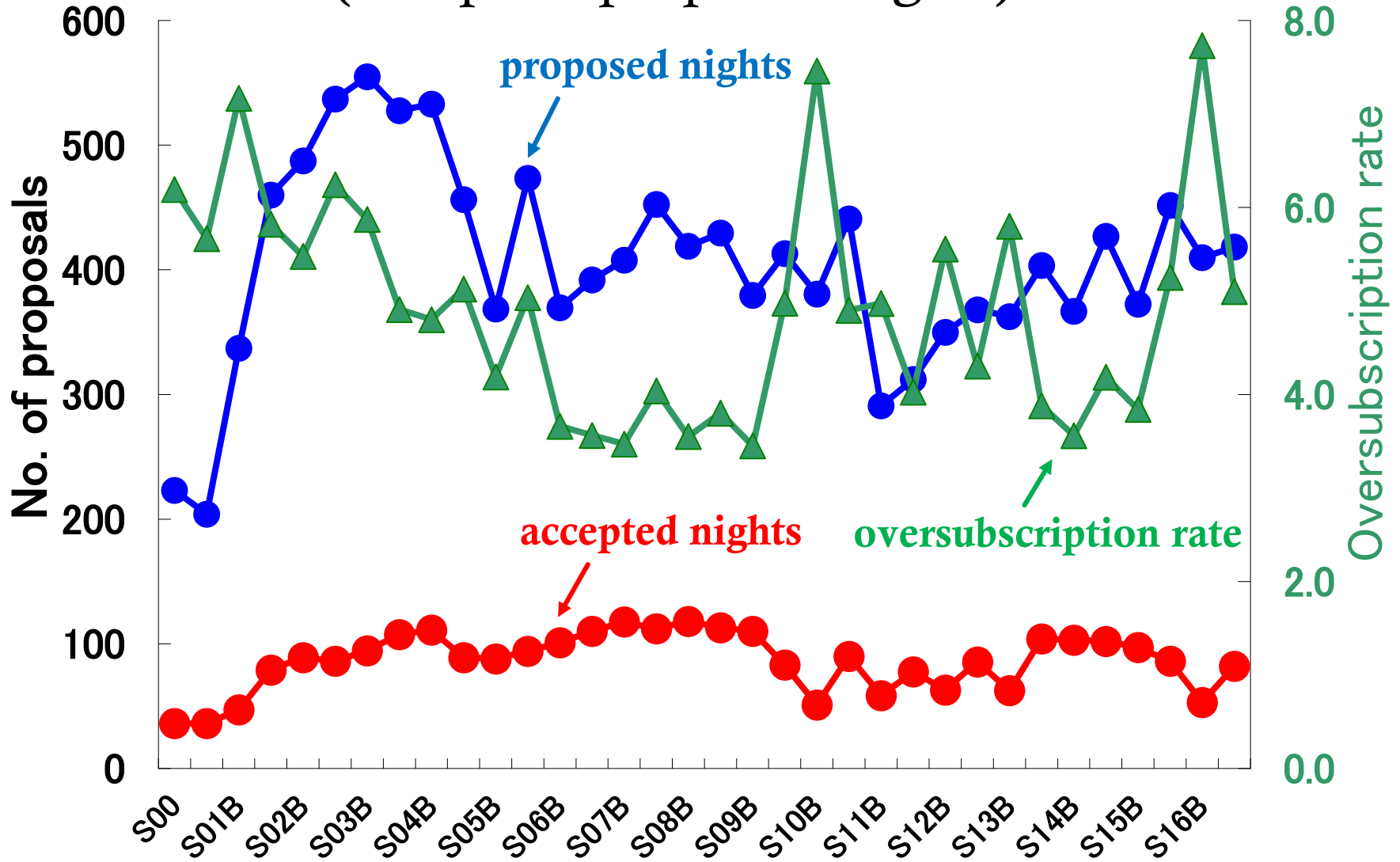
1. Regular Open-use Time (80 – 100 nights)
2. Subaru Strategic Programs (SSPs) (30 - 35 nights)
3. University of Hawaii (UH) Time (26 nights)
4. Engineering Time (18 nights)
5. Director's Discretionary Time (DDT)

(18 nights:

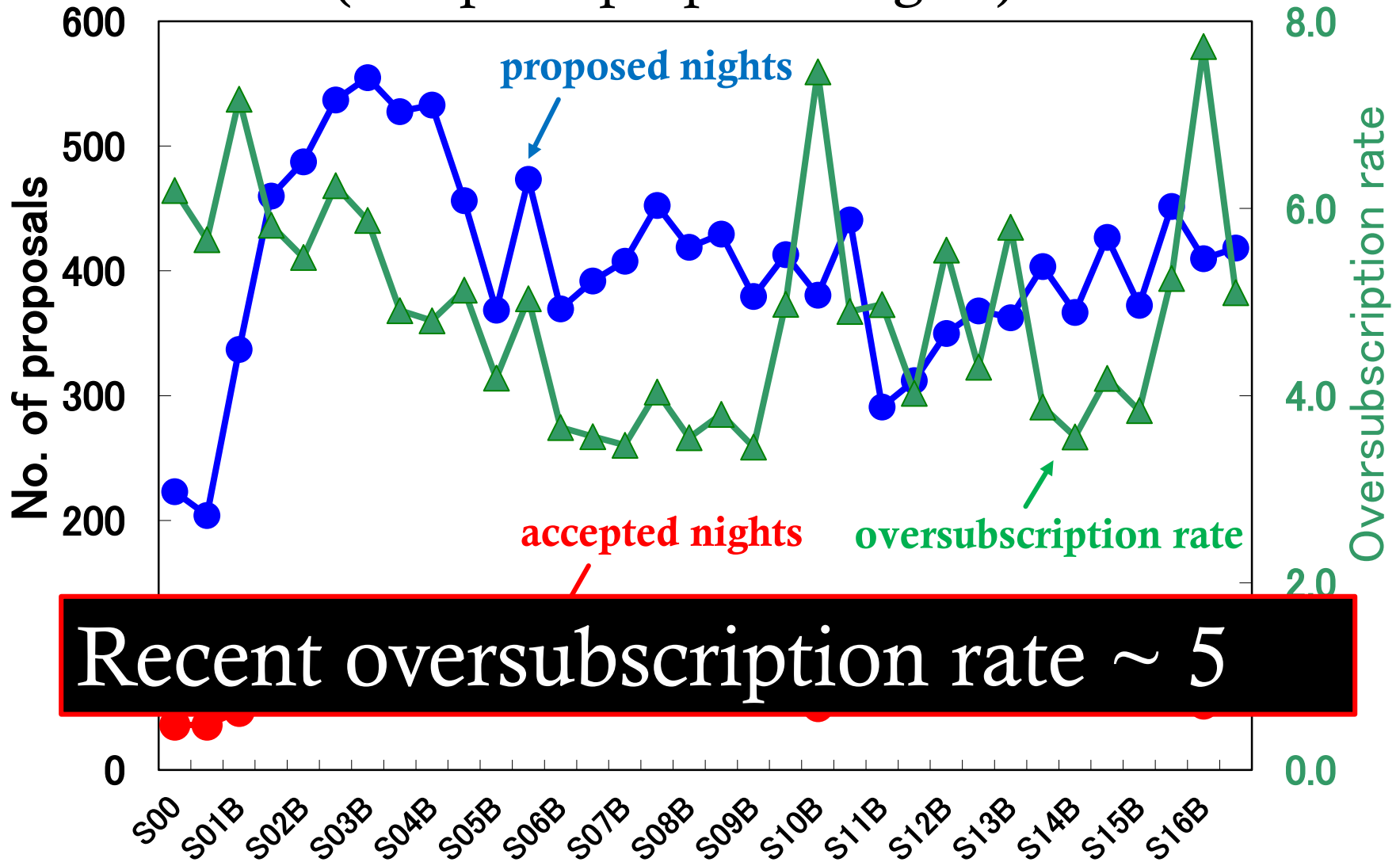
9 nights of which go to SSP)



Regular Open-use night statistics (accepted/proposed nights)



Regular Open-use night statistics (accepted/proposed nights)



Recent oversubscription rate ~ 5

Keck/Gemini Time Exchange

Gemini-N/S

minimum 5 nights / semester

Keck-I/II

5-8 nights / semester

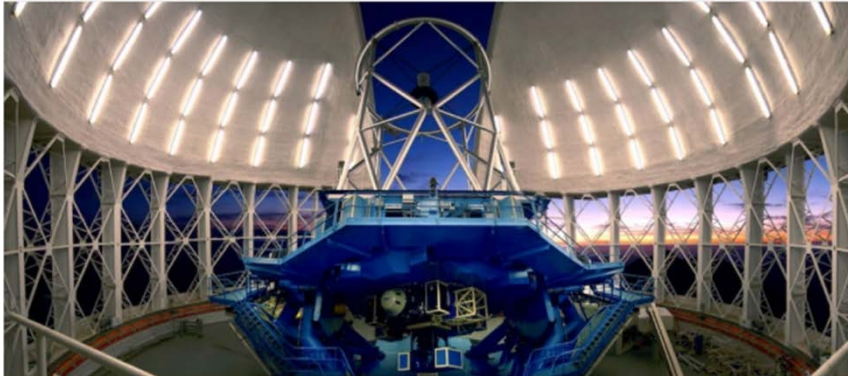
Astronomers set up telescope timeshare

Time swap between observatories points to closer collaboration among large telescopes.

Eric Hand

02 November 2012

Nature



Astronomers can now freely swap time on the Gemini telescopes (pictured) and Japan's Subaru telescope.





Subaru Strategic Programs

- ◇ **SEEDS (2009 - 2014)** 120 nights finished
 - ◇ “Subaru Strategic Exploration of Exoplanets and Disks with **HiCIAO/AO188** (SEEDS)”
- ◇ **Fastsound (2011 - 2014)** 40 nights finished
 - ◇ “Probing the Origin of the Cosmic Acceleration with the Subaru/**FMOS** Cosmological Redshift Survey”
- ◇ **HSC SSP (2014 - 2020)** 300 nights ongoing
 - ◇ “Wide-field imaging with **Hyper Suprime-Cam**: Cosmology and Galaxy Evolution”
 - ◇ Collaboration of Japan, Taiwan and Princeton.
- ◇ **IRD SSP (2019 - 2025)** 70 nights were approved as the 1st stage of the project
 - ◇ “Search for Planets like Earth around Late-M Dwarfs: Precise Radial Velocity Survey with **IRD**”
- ◇ **PFS SSP (2022? - 2027?)** 300? – 400? nights in preparation
 - ◇ Large international **PFS** collaboration

CFHT Users Meeting 2019

HSC SSP

Three layer survey

Wide: 1400 deg² g: 26.5, i: 25.9

Deep: 27 deg² g: 27.5 i: 26.8

Ultra Deep: 3.5 deg² g: 28.1 i: 27.4

300 nights are allocated from 2014 to 2020

2nd Public Data Release (May 2019)

<https://hsc-release.mtk.nao.ac.jp>

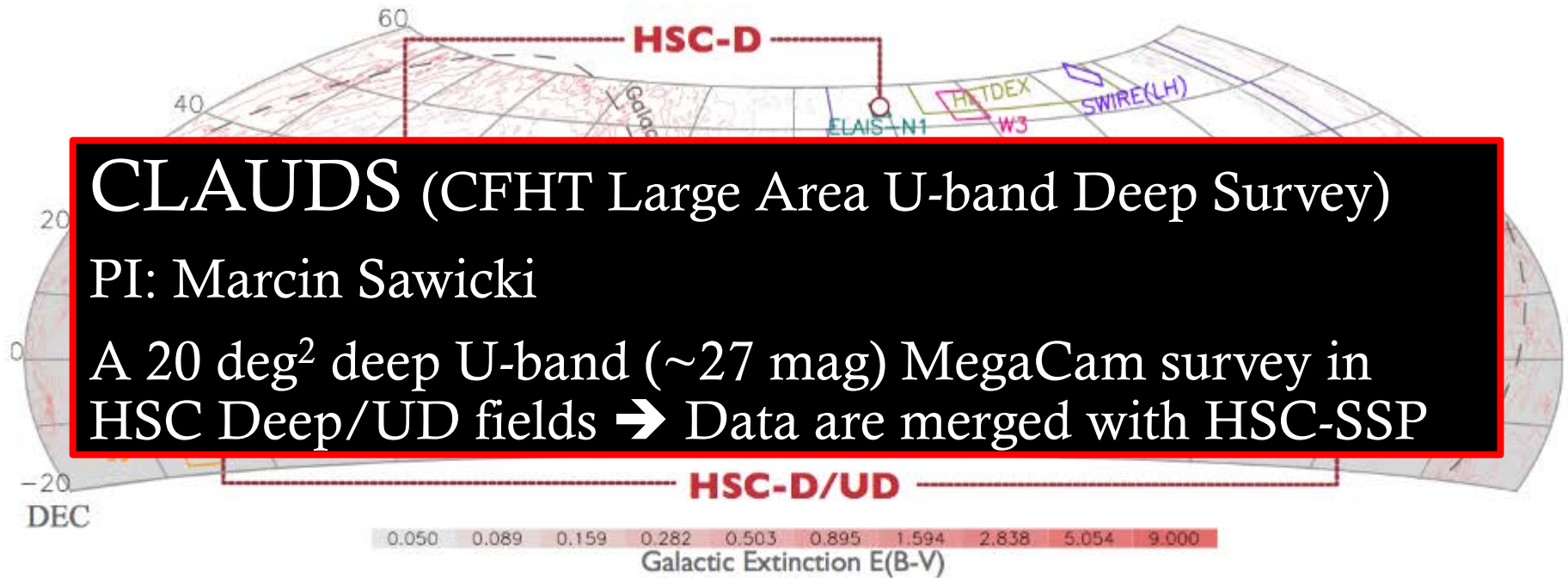


Figure 11: The location of the HSC-Wide, Deep (D) and Ultradeep (UD) fields on the sky in equatorial coordinates. A variety of external data sets and the Galactic dust extinction are also shown. The shaded region is the region accessible from the CMB polarization experiment, ACTPol, in Chile.

Number of publications

Number of Subaru publications





Instrumentation: now & future



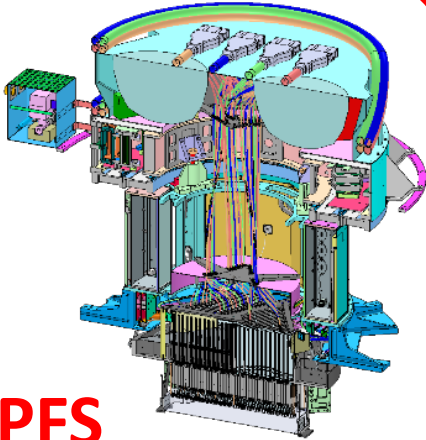
Instrument Lineup of Subaru

- ◇ 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]
- ◇ adaptive optics
 - ◇ Adaptive optics system: AO188 [Ns]
 - ◇ Extreme adaptive optics: SCExAO [Ns]

Subaru Instrumentation



Wide field (1.5 deg) imaging



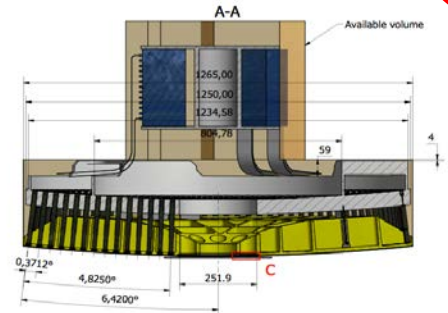
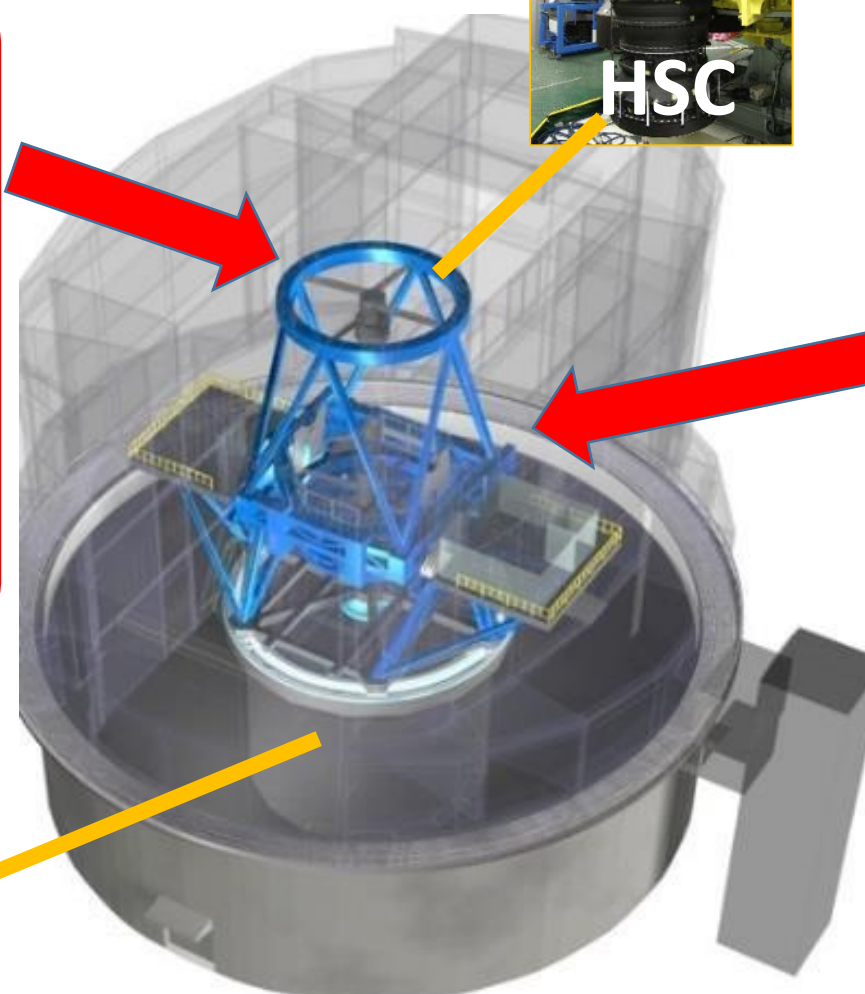
PFS

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

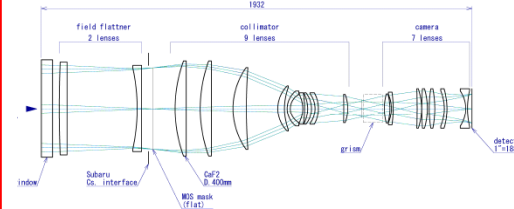


IRD

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 deg²

λ range: 0.38 – 1.26 μm

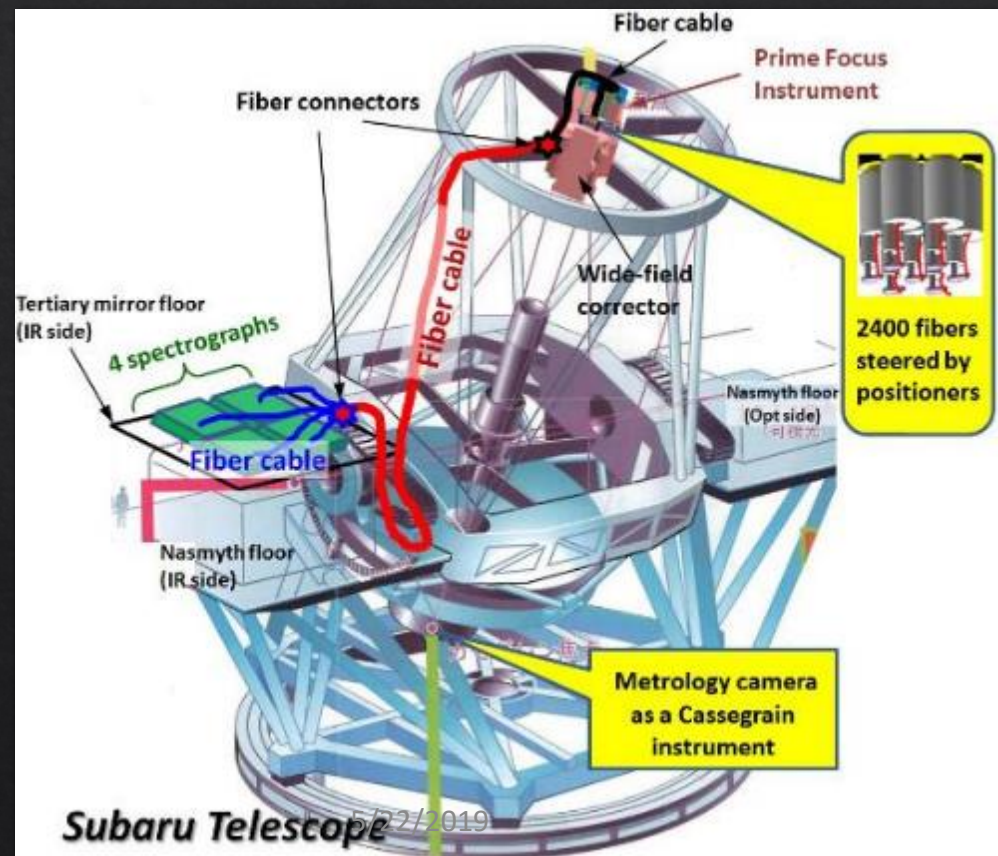
Spec. R: 2,300 – 5,000

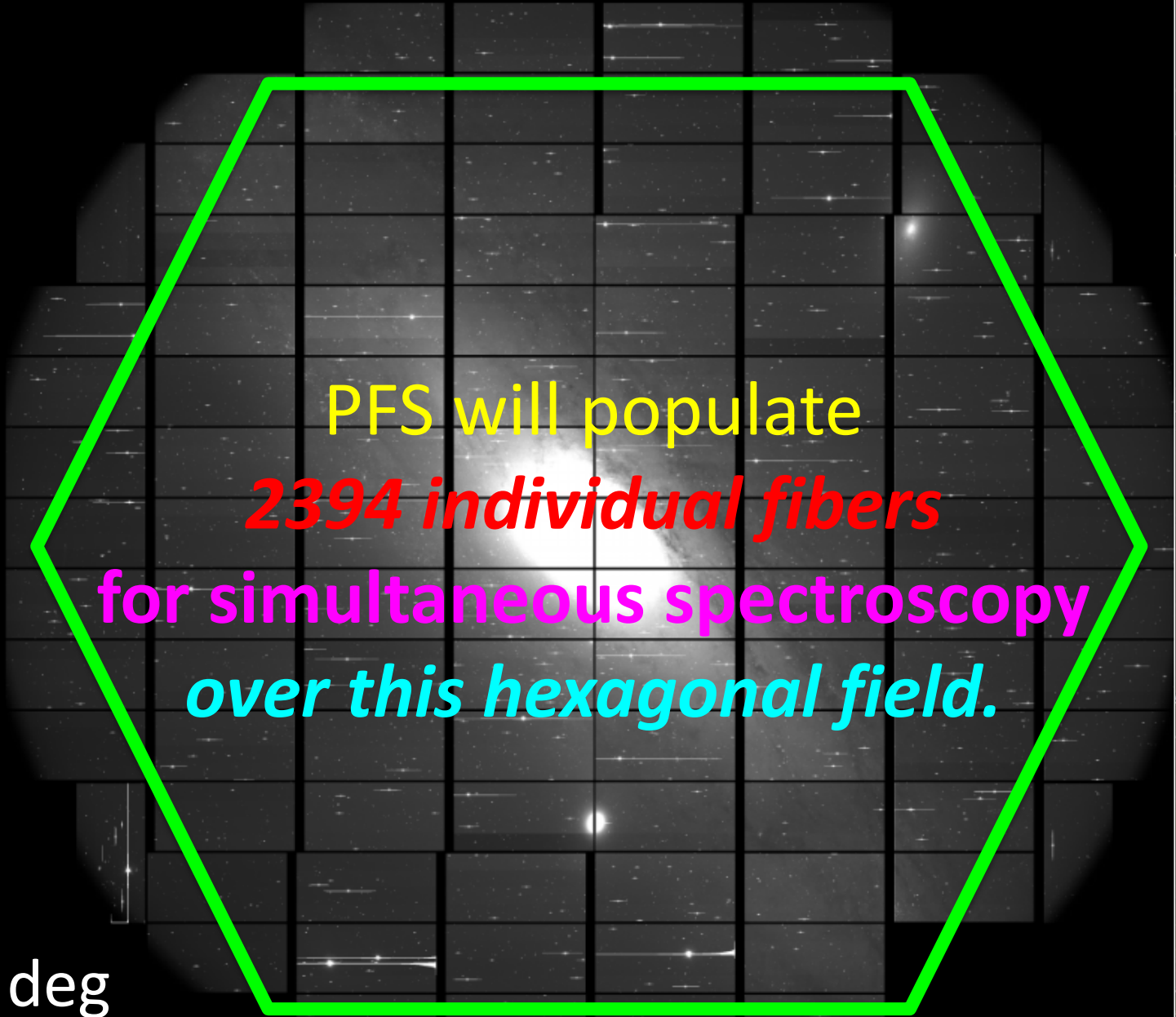
Sensitivity

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

S/N = 5 @ 1 hour exposure

CFHT Users Meeting 2019

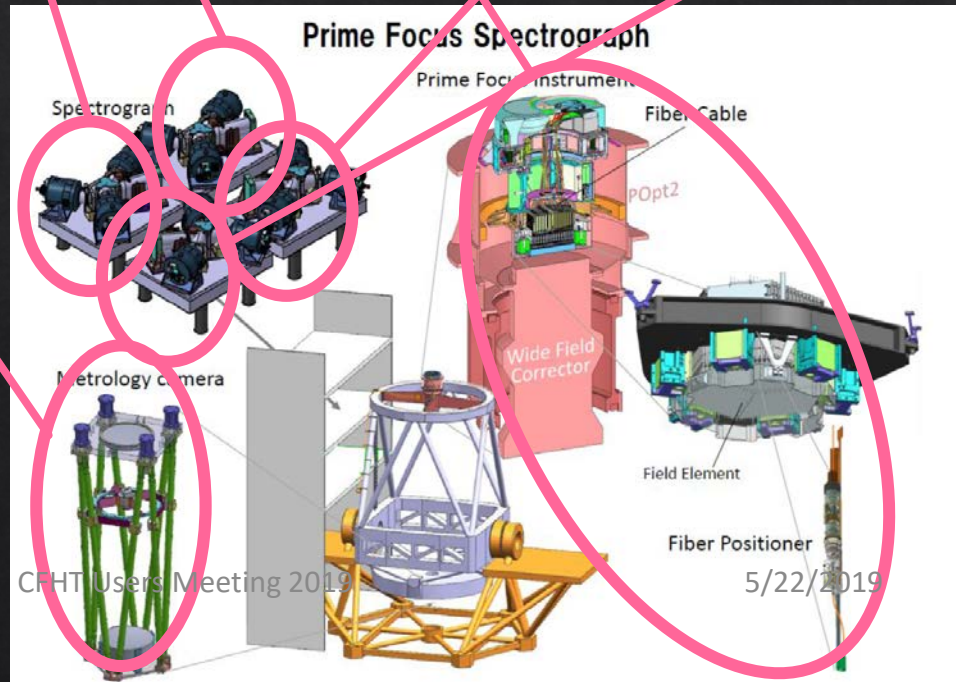
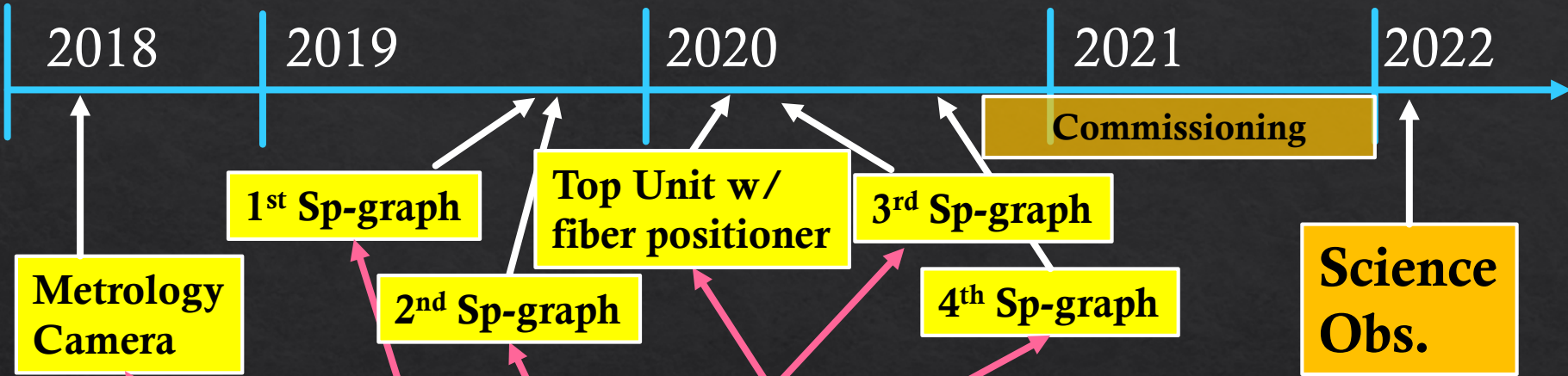




PFS will populate
2394 individual fibers
for simultaneous spectroscopy
over this hexagonal field.

~1.5 deg

PFS Installation Timeline



ULTIMATE-Subaru



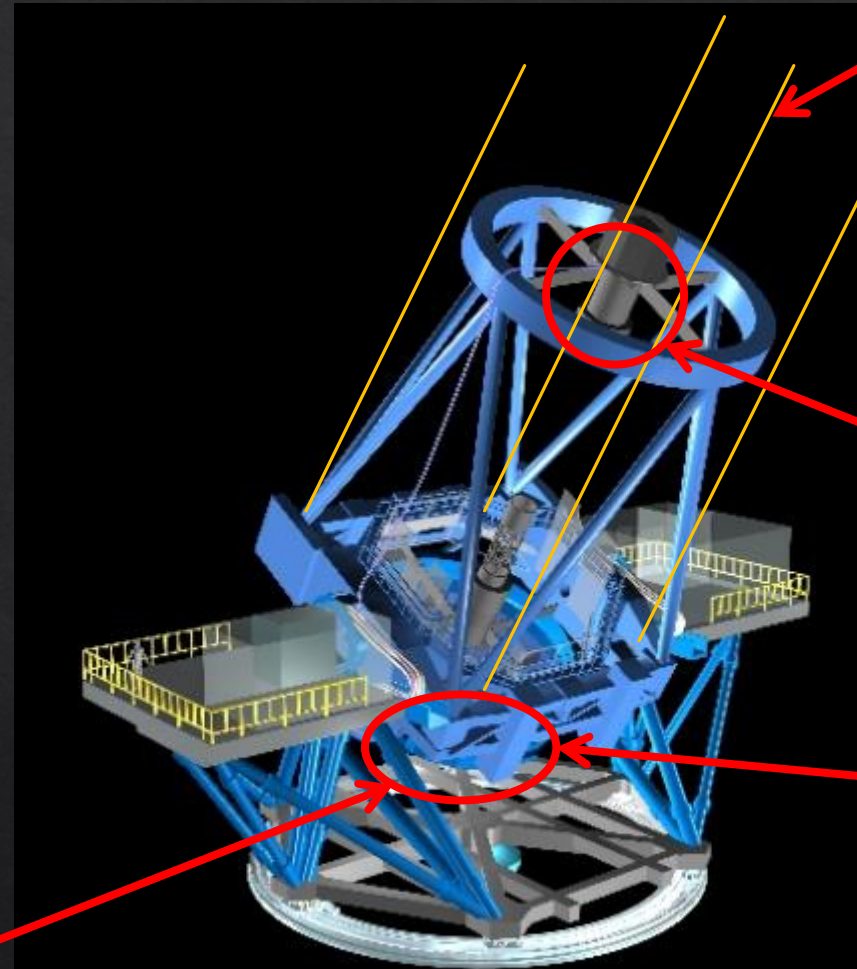
(preliminary design phase)

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

4 Laser Guide Star System

Deformable Secondary Mirror

Wavefront Sensors



Conceptual Design Review was done in Oct. 2018 !!

Science Operation: 2026

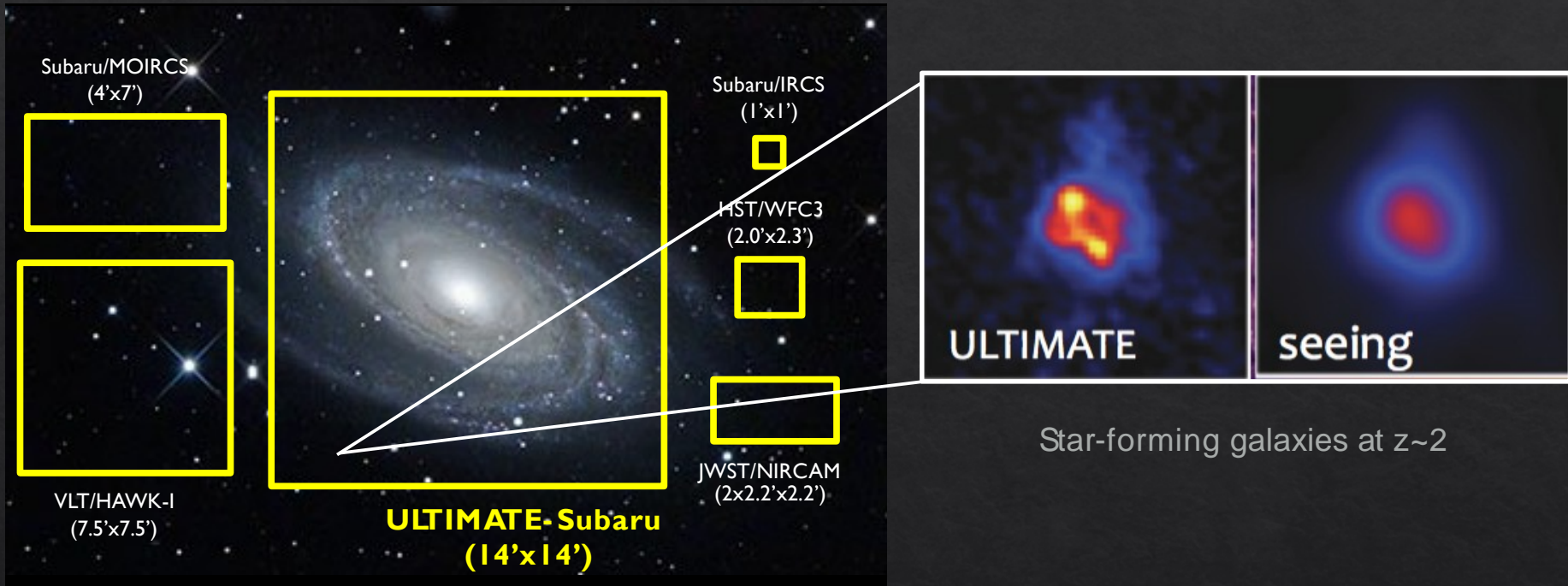
Wide Field Near-infrared Instruments

CFHT Users Meeting 2019

5/22/2019

ULTIMATE-Subaru

High-Res “AND” Wide-Field NIR Capabilities



ULTIMATE-Subaru will deliver:

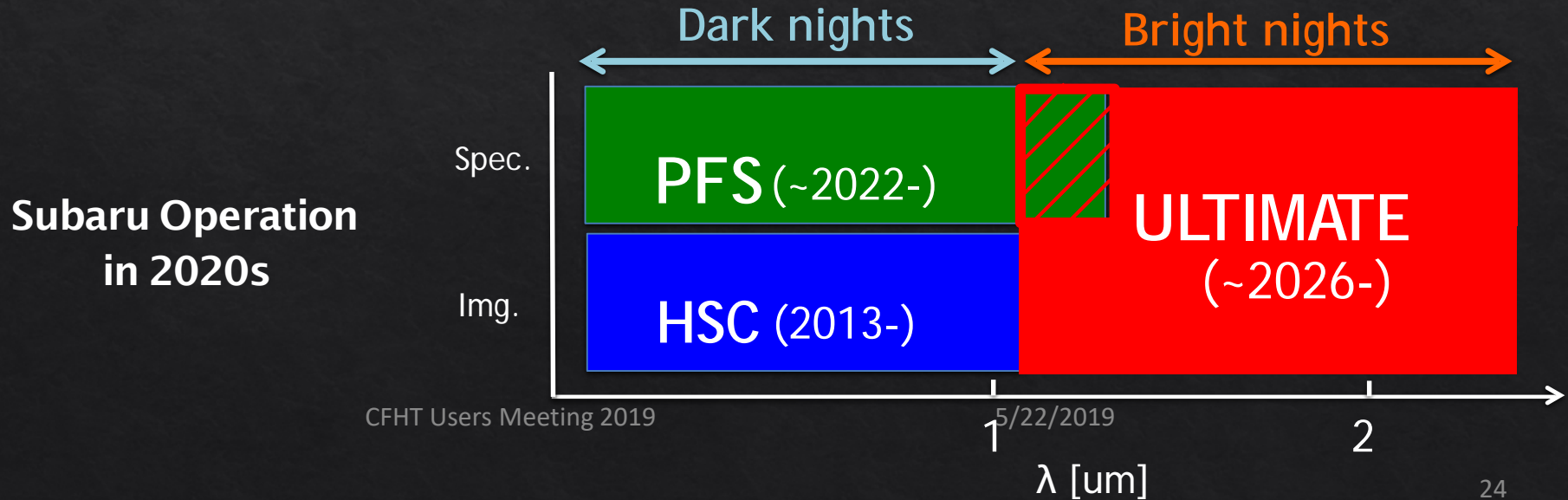
- ▶ Subaru’s original **High-redshift targets to follow-up with TMT**
- ▶ **Spatially-resolved** studies of the objects found by HSC/PFS
- ▶ **SDSS-like** comprehensive imaging/spec. survey for **high-redshift universe ($z > 2$)**.
- ▶ Synergy with the future surveys by **wide-field space missions**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

SUBARU'S Wide-Field Strategy in 2020s

- 1. very wide-field optical imager HSC (2014)
- 2. wide-field multi-object spectrograph PFS (2022)
- 3. wide-field near-infrared imager and MOS-spectrograph including AO-assisted IFU capability ULTIMATE (2026)

Subaru will provide “legacy data”

using **HSC**, **PFS** (in dark nights), and **ULTIMATE** (in bright nights)



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

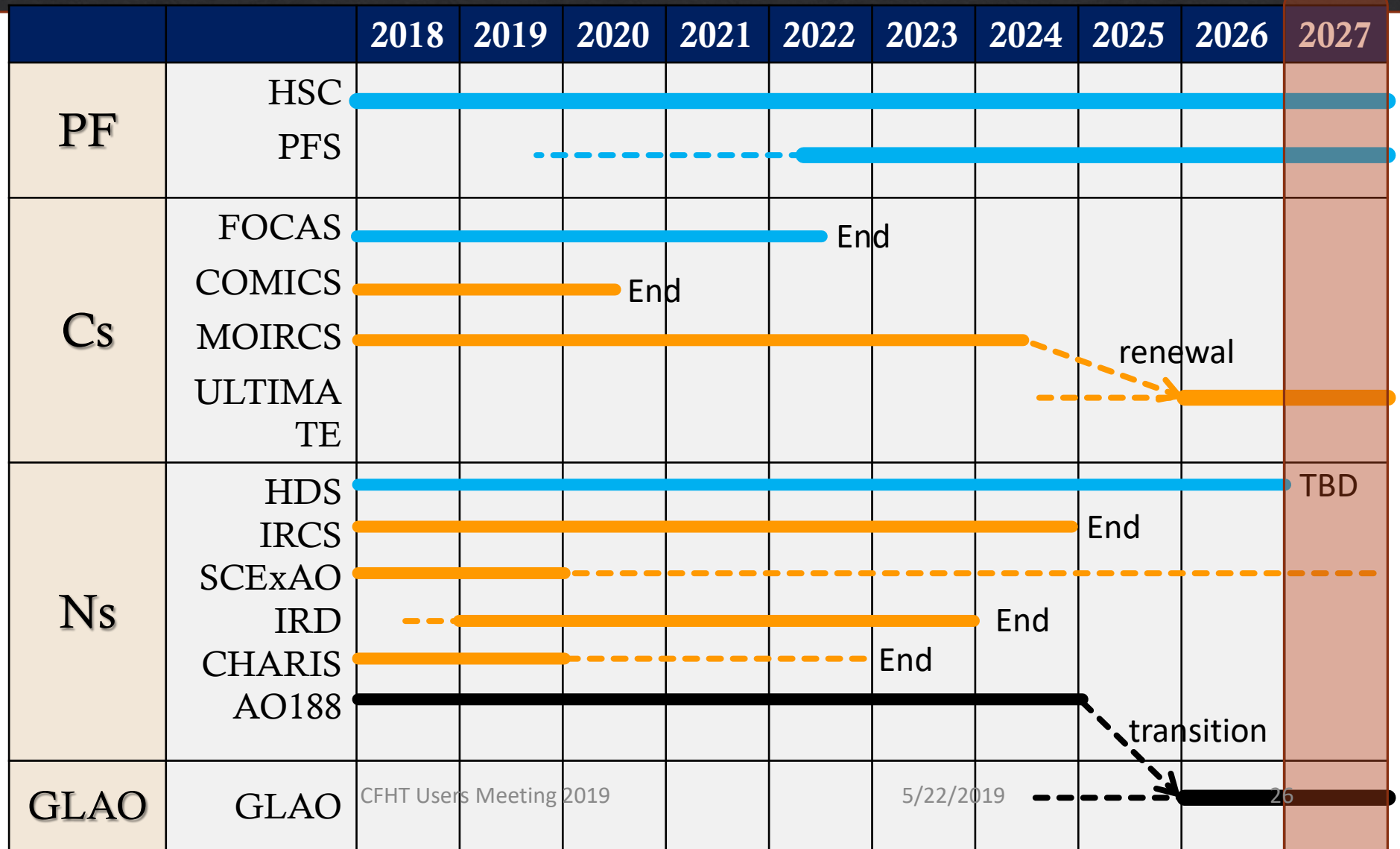
GLAO supported
0.2" resolution
(in K-band)
Imager (14'x14')
Multi-object sp.
(w/ MOIRCS)
IFU sp.

Limiting mag.
using GLAO
with 4h exp.

Band	mag
J	26.3
H	25.5
Ks	26.4
NB1340	26.1



Instrumentation Plan





Major science themes in 2020s and Subaru Telescope

The nature of dark matter and dark energy

Galaxy formation and evolution

Multi messenger astronomy

Extrasolar planet and biomarker

Wide Field Imaging and Spectroscopy

HSC
PFS

Wide Field Infrared Observation

ULTIMATE

High Resolution Infrared Observation

SCEXAO
IRD



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

Summary



- ◇ Subaru is one of the highest competitive telescopes in the world. The oversubscription rate of the proposals is about 5.
- ◇ Number of annual science publications is $\sim 120 - 150$ (140 in 2018).
- ◇ Two large programs (Subaru Strategic Programs) are running using HSC and IRD. HSC-SSP is allocated 300 nights from 2014 to 2020 and 70% of the project has been done. IRD SSP started from S19A and 70 nights are initially allocated to this project (finally, 170 nights may be allocated).
- ◇ Subaru is operating 6 facility instruments and 2 visiting instruments.
- ◇ Development of Prime Focus Spectrograph (PFS) is going well. Science observation of PFS will start in 2020.
- ◇ Conceptual design of the Wide field infrared observation facility, ULTIMATE, has been done successfully. The ULTIMATE project proceeds to preliminary design phase.
- ◇ Subaru is exploring international partners for sustainable operation of the telescope.

OPTICAL & INFRARED ASTRONOMY FOR THE NEXT DECADE

Keynote/Invited Speakers for Science Sessions

SOLAR SYSTEM

Mike Brown (Caltech)
David Tholen (UH-IfA)
Fumi Yoshida (CIT-PERC)
Glenn Orton (JPL)
Hideyo Kawakita (Kyoto Sangyo U.)
JJ Kavelaars (NRC-HIA)
Rosemary Pike (ASIAA)
Ruobing Dong (U. of Victoria)
Takafumi Ootsubo (JAXA)

EXOPLANET & STAR FORMATION

Motohide Tamura (U. of Tokyo)
Masahiro Ikoma (U. of Tokyo)
Mitsuhiro Honda (Kurume U.)
Olivier Guyon (Subaru/U. of Arizona)
Tyler D. Groff (Princeton U.)
Yumiko Oasa (Saitama U.)

LOCAL GROUP & NEARBY GALAXIES

Vasily Belokurov (U. of Cambridge)
Brent R. Tully (UH-IfA)
Eric Deng (DKU-KIAA)
Karoline Gilbert (STScI)
Kim Venn (Univ of Victoria)
Laura Ferrarese (GNRC-NRC)
Masashi Chiba (Tohoku U.)
Michael Rich (UCLA)

GALAXY FORMATION

Sandra Faber (UCSC/UCO Lick)
Annalisa Pillepich (MPIA)
Caitlin M. Casey (U. of Texas)
Camilla Pacifici (NASA Goddard)
David Sanders (UH-IfA)
Gwen Rudie (Carnegie Observatories)
Ivo Labbe (Swinburne U.)
Sirio Belli (MPE)
Taddy Kodama (Tohoku U.)
Takahiro Morishita (STScI)

SUPERMASSIVE BLACK HOLES

Masayuki Akiyama (Tohoku U.)
Jenny Greene (Princeton U.)
Kohei Ichikawa (Tohoku U.)
Luis Ho (DKU)
Xin Liu (U. of Illinois)
Chris Harrison (ESO)
Silvia Mateos (IFCA)
Stephanie La Massa (Yale U.)

TIME DOMAIN

Jeff Cooke (Swinburne U.)
Francisco Forster (U. Chile)
Marcelle Soares-Santos (Brandeis Univ)
Sigeru Yoshida (Chiba U.)
Takashi Moriya (NAOJ)

General Session
User's Meeting FY2019
International Partnerships
Synergies with WFIRST & TMT
WFIRST Special Session
Large & Intensive Programs
Subaru's Future Instrument (ULTIMATE)
and More!

SUBARU 20TH ANNIVERSARY

THE 5TH NAOJ SYMPOSIUM
THE 7TH SUBARU SCIENTIFIC
MEETING

IN HAWAII

November 17-22, 2019

Waikoloa Beach Marriott
Resort and Spa (HI, US)

Deadlines:

Abstract Submission
Due on June 15

Early Registration
Due on July 31

See details on the website



<https://subarutelescope.org/subaru20anniv>