SUBARU PRIME FOCUS SPECTROGRAPH

Updates of the next-gen facility instrument development

Coming to Its First Light

SuMIRe — Prime Focus Spectrograph (PFS)

- Introduction: Hardware delivered in the past
- Latest progress: New hardware deliveries and data processing
- Remaining risks & timeline
- Summary

Prime Focus Spectrograph

Naoyuki Tamura [Kavli IPMU]

On behalf of PFS collaboration

THE UNIVERSITY OF TOKYO

KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

Subaru Users Meeting FY2020 (online), Mar 3 2021

M31 on a single shot by HSC

PFS will configure

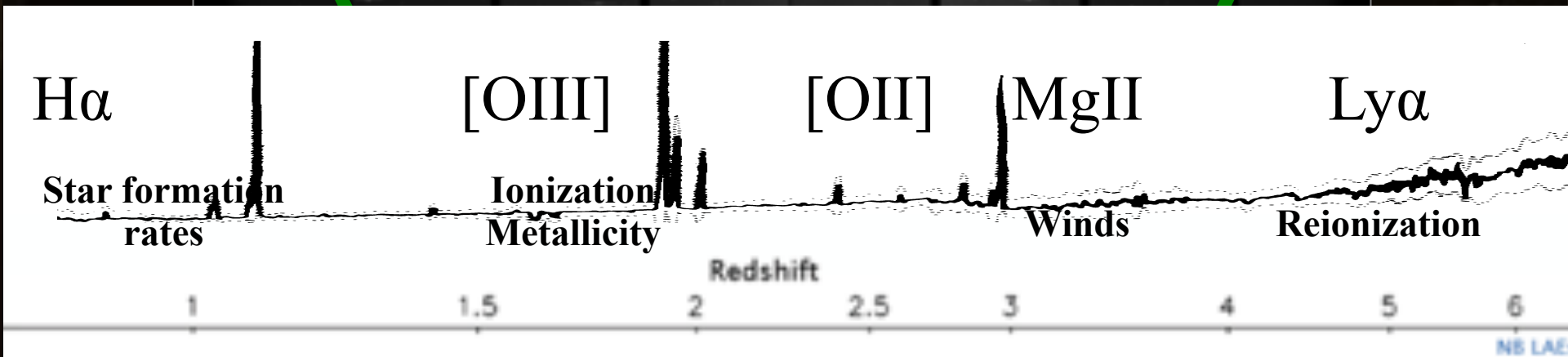
2394 individual fibers

for simultaneous spectroscopy

over this hexagonal field.

Wide in wavelength range too:

380—1260nm at once with 3 cameras



PFS subsystems distribution

Software system

Spectrograph system (SpS)

On the TUE floor

(IR side)

4 spectrographs

Fiber cable

Fiber connectors

Fiber cable

Prime Focus Instrument

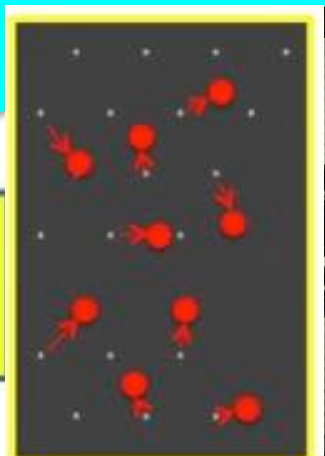
Wide-field corrector

… in Prime focus unit “POpt2” with Wide Field Corrector “WFC”.

Calibration system

This takes an image of the prime focus with the fibers “backlit” and measure their current positions*: Key part of iterative fiber positioning process.*

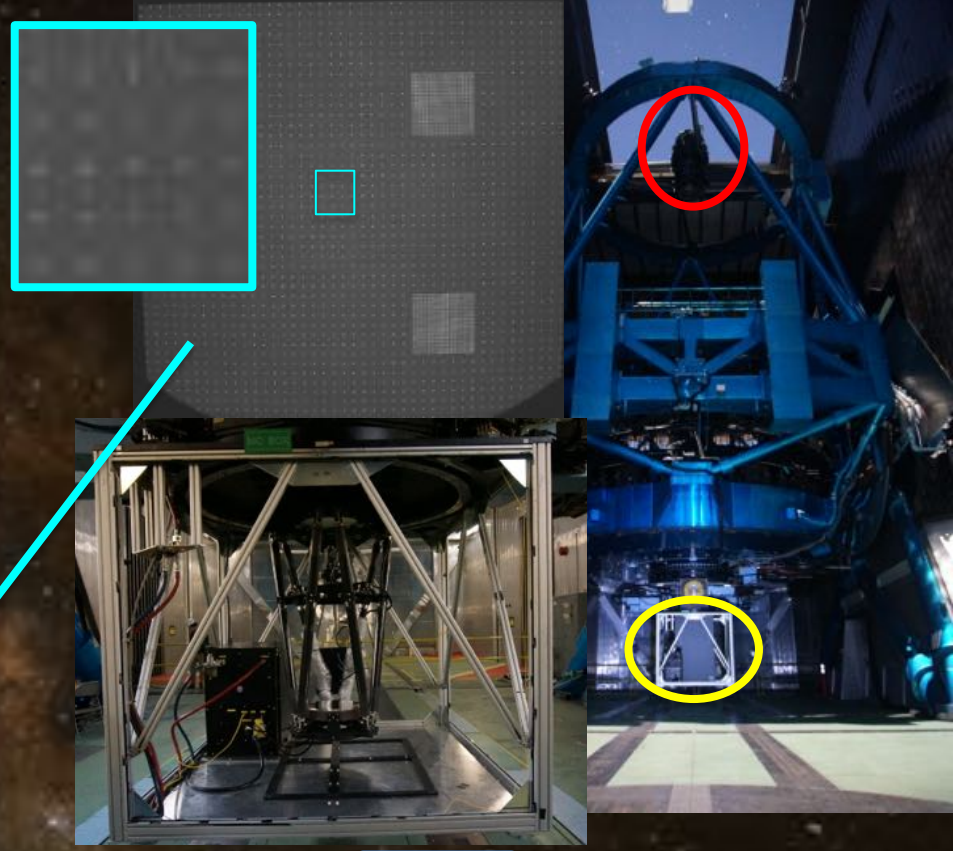
Metrology camera as a Cassegrain instrument

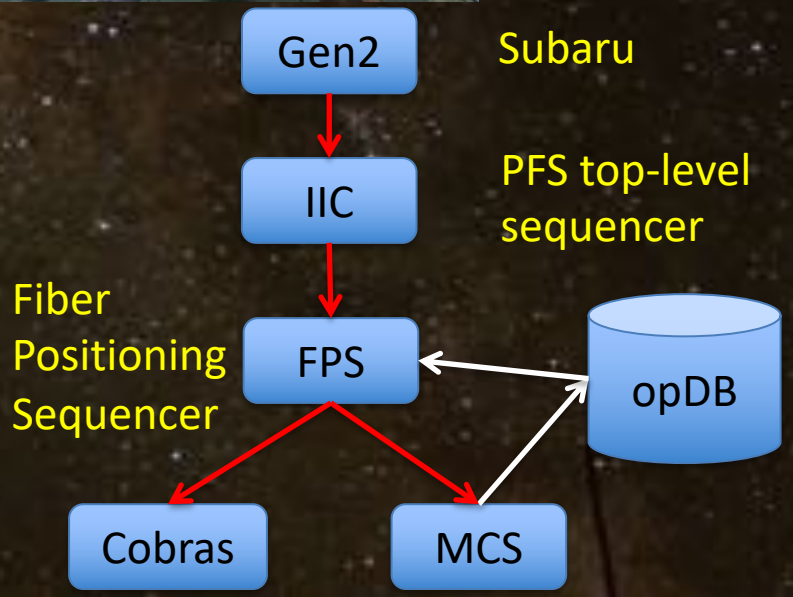


Subaru Telescope

Metrology Camera System (MCS)

- Delivered to Subaru in Apr 2018, and subsequently re-integrated and tested in May.
- On-telescope test in Oct 2018:
  - Imaged pinhole mask at Prime Focus that mimics backlit fibers.
- Re-tested in Aug 2019:
  - Upgraded the primary mirror support structure and re-aligned the optics.
  - Aligned MCS with the prime focus
  - Implemented and tested the upgraded routine of spot detection and centroiding
  - Simulated the command & data flow of fiber positioning sequence.





SM1 B+R is in operation at Subaru

- SM1 with blue and red cameras in the dedicated clean room at the Subaru summit.

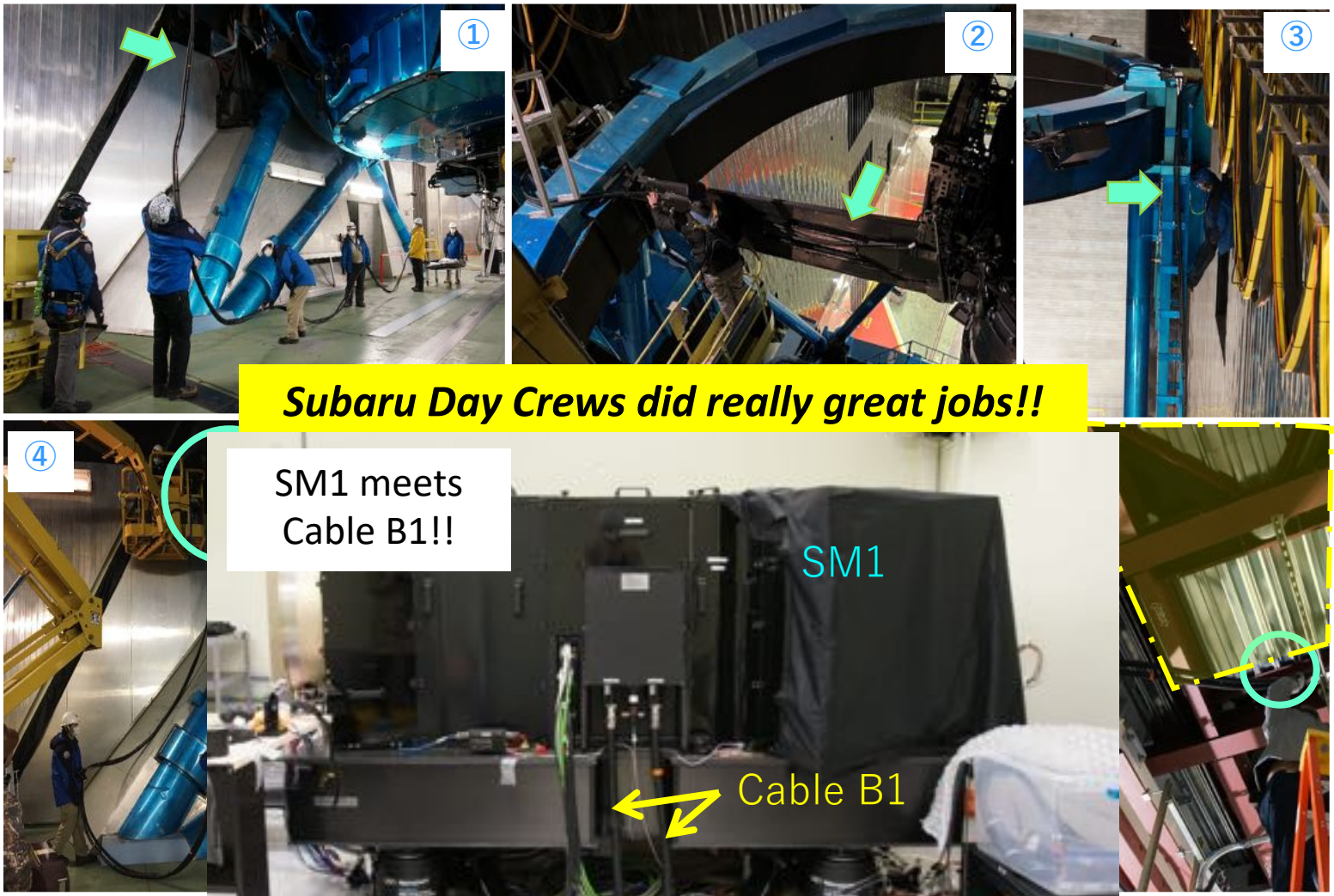
- Pre-ship review on ***Sep 25 2019***
- Arrived at Subaru on ***Nov 25 2019***.
- Reintegration, camera cooldown, and some data acquisition and analyses completed in ***Dec 2019***.
- Completed the major performance validation in ***Mar 2020***.
- Since then, continuing the operation and data acquisition for the characterization of the instrument & data stabilities and for data reduction pipeline development.

The 1st on-telescope fiber cable arrived!

- Pre-ship review on ***Oct 8 2020***
- Arrived at Subaru on ***Dec 22 2020***
- Optical re-tests & other prep works on the observation floor ***from mid Jan to Feb 7 2021.***
- Installation of the telescope side of the cable on ***Feb 8 2021***.
- Optical test (FRD monitoring) on ***Feb 9 2021***.
- Installation of the dome side on ***Feb 10 2021***.
- Post-installation optical tests and other wrap-ups by ***Feb 17 2021***.

Works by ~15 people from Subaru & IPMU

See the recent PFS blog post for details
https://pfs.ipmu.jp/blog/2021/02/p1785



Snapshots of installation. C
the cable on the side of the
from the bottom (6) to the
p of the telescope, (3) routed
y, (5) we pulled up the cable

Short pit stop (1)

- We already have a subset of PFS ready at the observatory:
  - Metrology Camera System (MCS)
  - 1st Spectrograph Module (SM1) w/ visible cameras
  - 1st on-telescope fiber cable
- So once ***Prime Focus Instrument (PFI)*** arrives, we will be able to start ***on-sky engineering observations*** in the partial configuration.

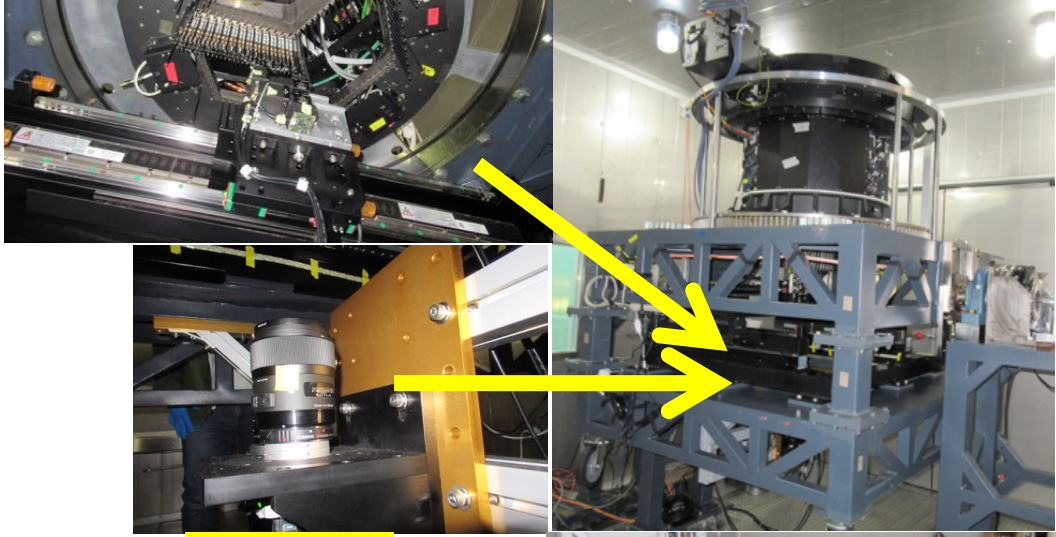
… Where are we about PFII?? 🤔

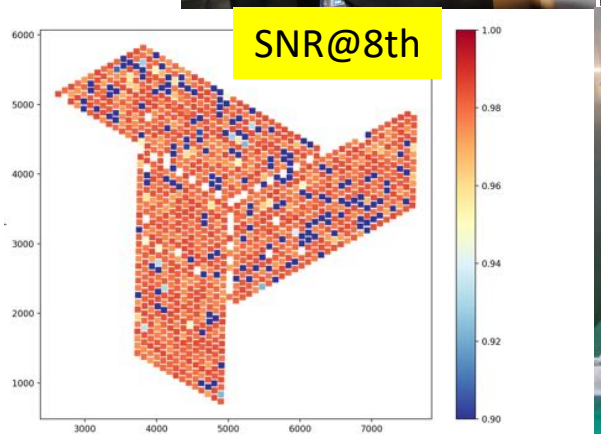
Cobra positioner → Module → PFI


Caltech
JPL
Jet Propulsion Laboratory
California Institute of Technology
LNA
LABORATÓRIO
NACIONAL DE ASTROFÍSICA
ASIAA
On Sep 2 2020, the PFI focal plane got populated
FULLY with ALL the 42 fiber positioner modules

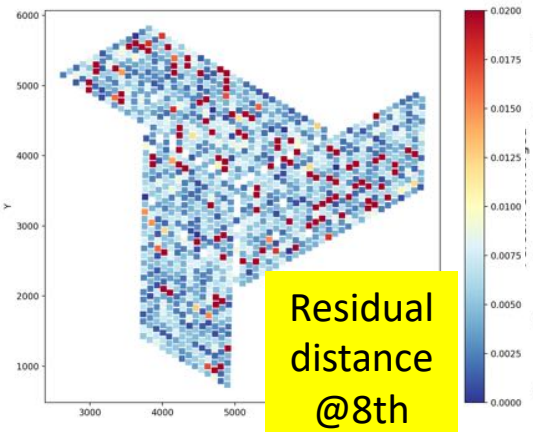
PFI AIT in Taiwan

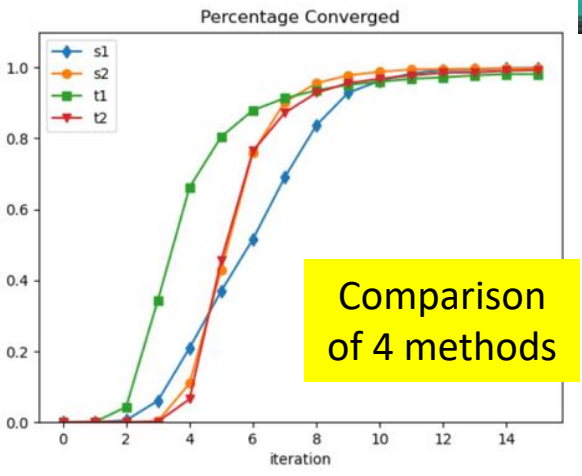
- All hardware is now in Taiwan and integration is well progressing.
- Detailed investigations of Cobra's characteristics and performance optimization are under way.
- Software development is also progressing in such a way as mimicking the real operation at the Subaru summit.
- The PFI fiber cable work is complete, and tests of 42 modules are ongoing.





2D convergence of 21 modules





Short pit stop (2)

- It will still take some time for PFI to be ready as part of PFS at the observatory.
  - Packing in May & shipping from Taiwan in June
  - Engineering works for a while after the delivery.

- However, it is the only missing piece to start observing the sky …

… Would we just wait then? ***No!*** 😙

SuNSS: Subaru Night Sky Spectrograph

PRINCETON UNIVERSITY

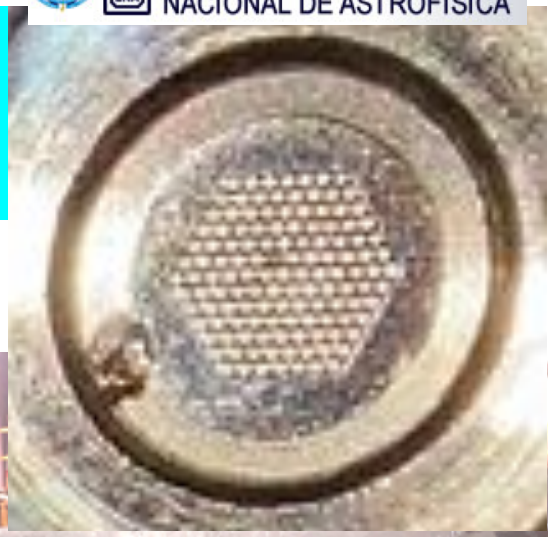
LNA LABORATÓRIO NACIONAL DE ASTROFÍSICA

Motivation and concept:

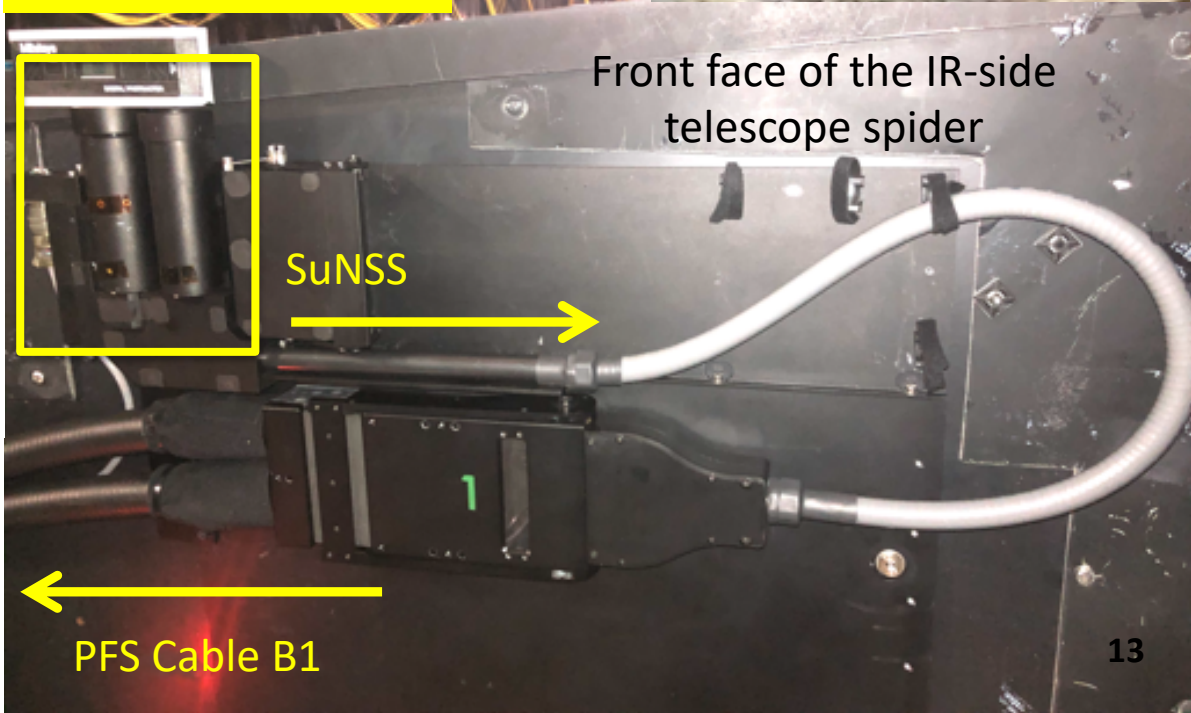
- Miniature (D~36mm) telescope permanently stays on the Subaru Telescope spider arm.
- Feeding night sky to Cable B and then one SM.
- ***"PFS observation" at any time when the dome is open w/o PFI (i.e. it can be started before PFI arrives).***
- Studies of sky spectra and development of 2D pipeline using quasi-real data in advance of formal engineering observation.

- **Installed on Feb 11, 2021.**
- **Data acquisition is continually underway.**

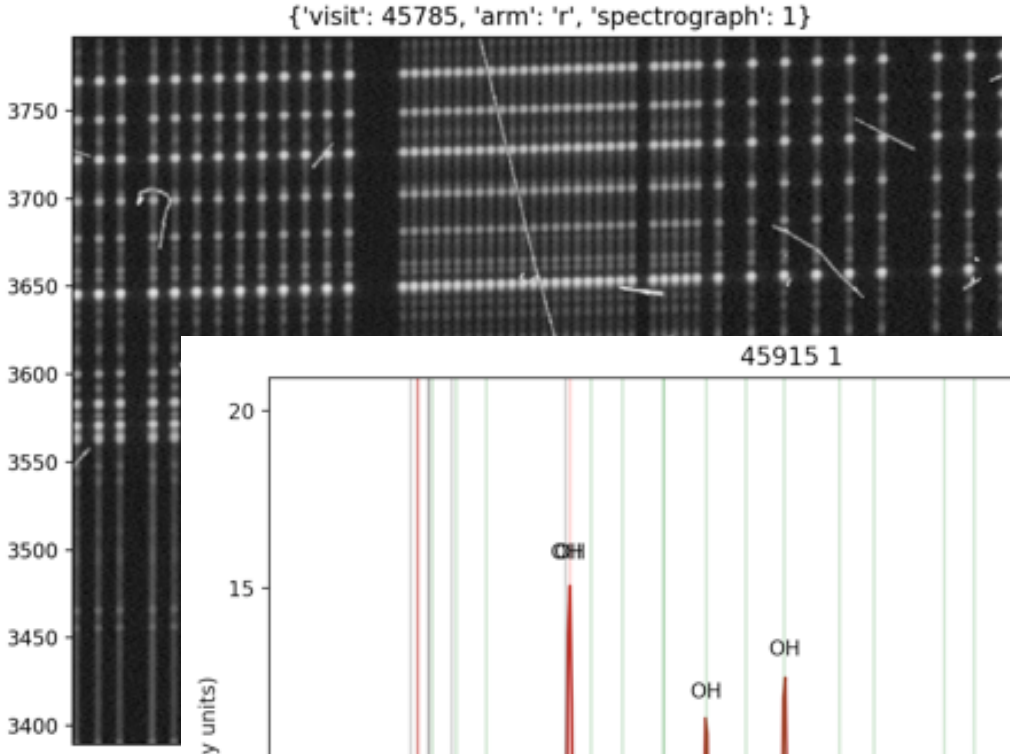
→ SuNSS focal plane by hex. fiber bundle (FoV D ~ 1.2 deg)

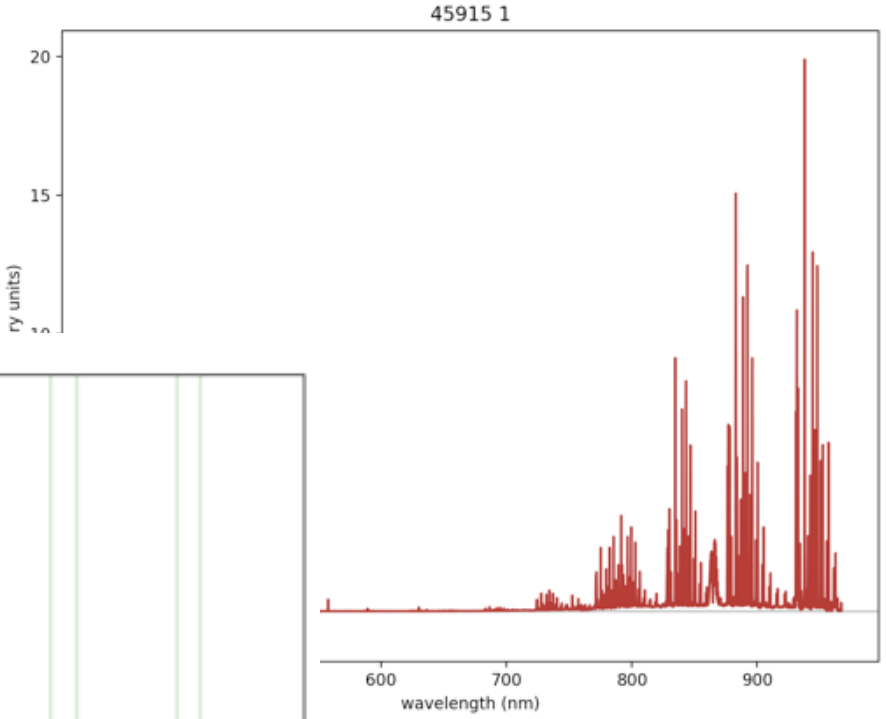


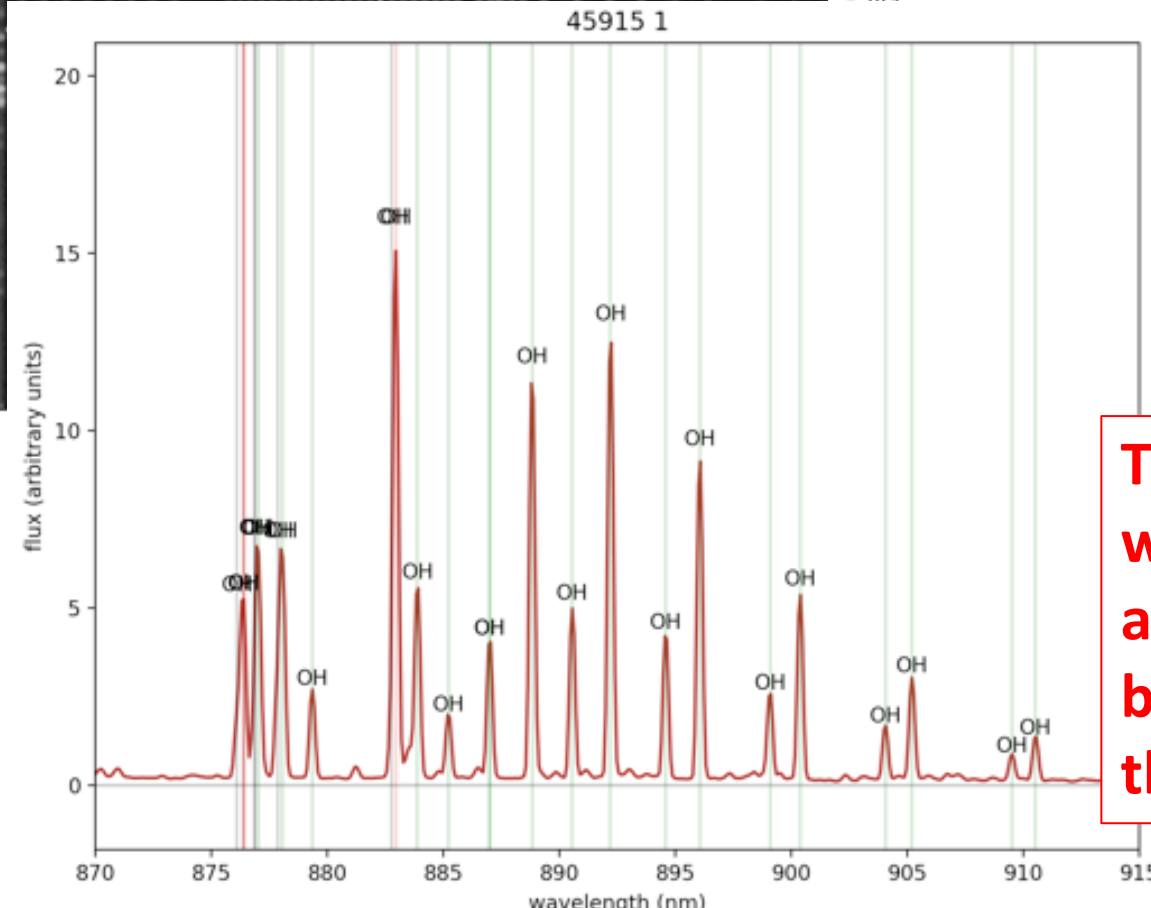
Two "telescopes"
1. IMAGING sky
2. DIFFUSE sky



Pipeline-processed sky via SuNSS + Cable B1 + SM1







The actual OH line wavelengths are accurately predicted by the solution from the arc lines.

2D Data Reduction Pipeline (2D DRP)

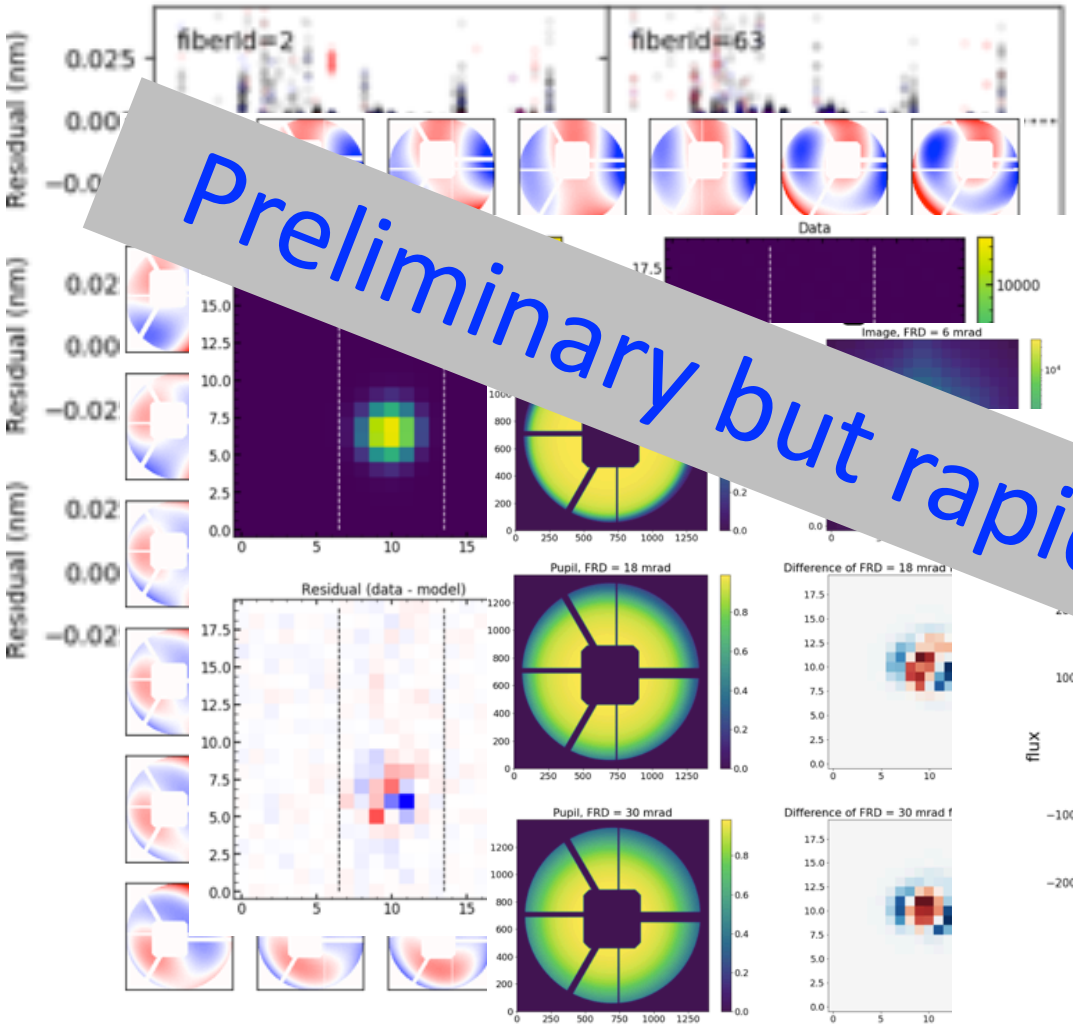
Price+ (Princeton): Accuracy of wavelength solution from SM1 data.

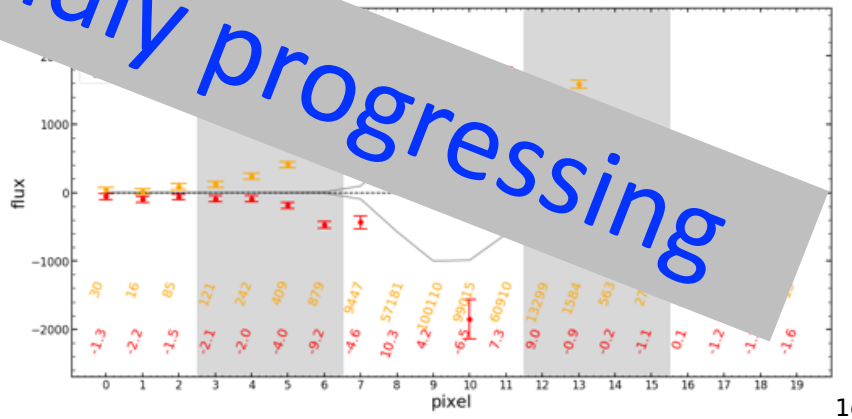
Caplar, Lupton, Gunn+ (Princeton), Belland (Caltech):

- Modeling SpS in 2D by defocused images
- Simulating in-focus images
- Considering how SpS is lit (e.g. FRD).

Preliminary but rapidly progressing

How well does this work for HgAr?

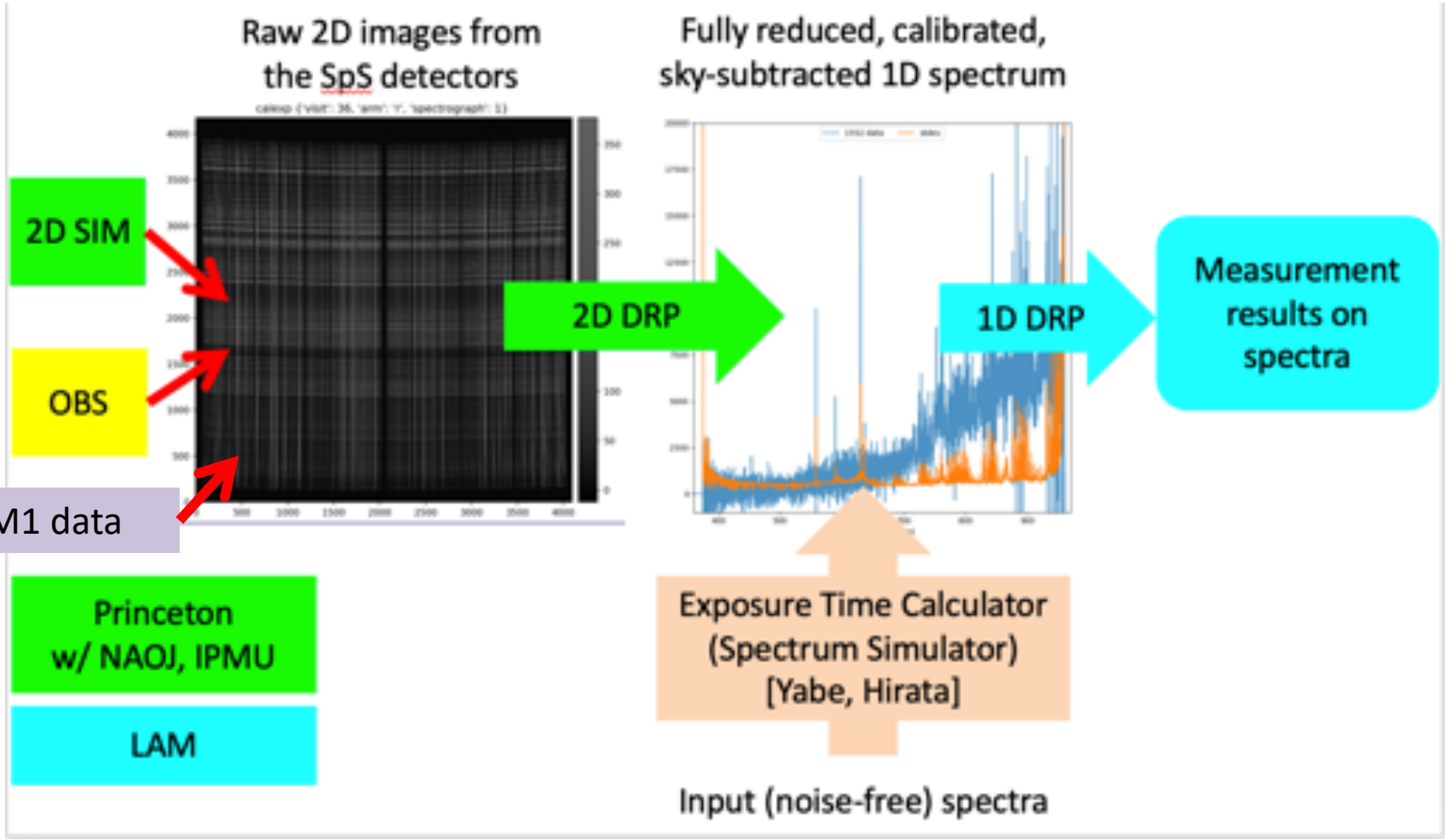




6 exposures back-to-back; 1 PSF model c. 80 OH lines

Data processing

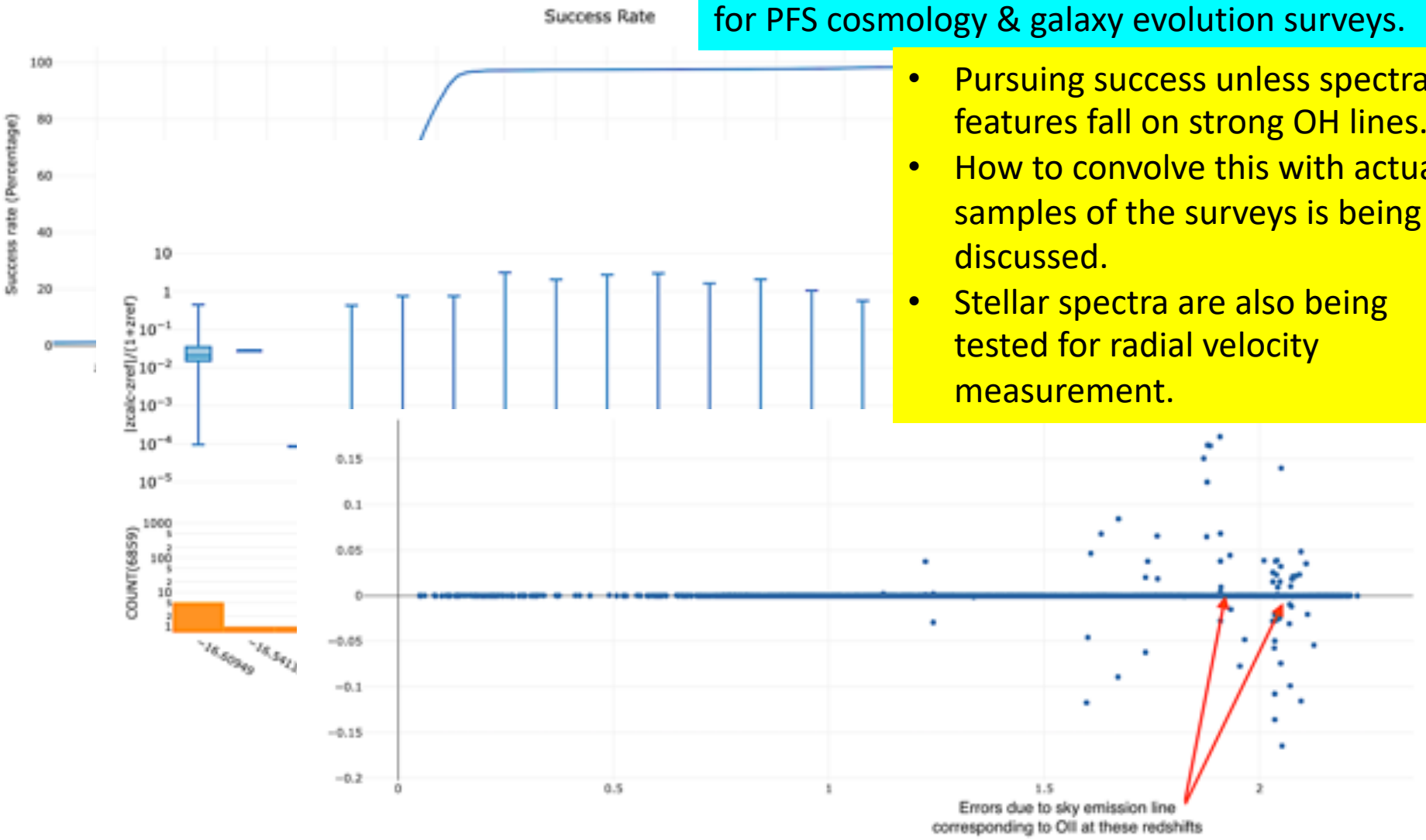
An schematic overview



1D Data Reduction Pipeline (1D DRP)

Le Brun+ (LAM); Simulated faint galaxy samples for PFS cosmology & galaxy evolution surveys.

- Pursuing success unless spectral features fall on strong OH lines.
- How to convolve this with actual samples of the surveys is being discussed.
- Stellar spectra are also being tested for radial velocity measurement.



Data processing

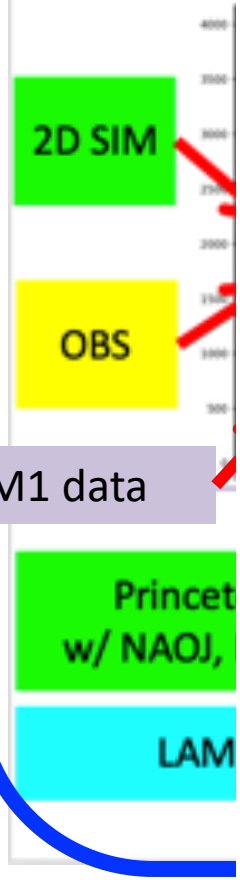
NAOJ National Astronomical Observatory of Japan

JOHNS HOPKINS UNIVERSITY

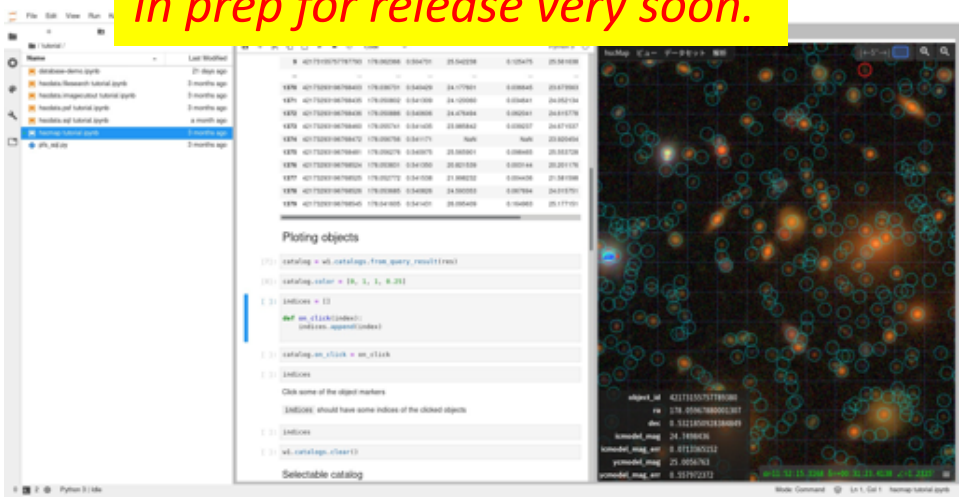
An schematic overview

Science DataBase (SciDB)

NAOJ &
JHU database team



Prototype Ver. 2.5
in prep for release very soon.



Offline tools:
Although Jupyter is the main environment as mentioned above, we also offer offline tools; users can download images, spectra, and catalogs to their local disks.
There is also an image browser that works just like googleMap. It is a very interactive tool and you can get, e.g., an image cutout in fits format, and query database (or upload a catalog) to display a table and mark objects. There is currently no tool to handle spectra, but it will be added in the future.

Jupyter:
This is an environment where you can open a notebook and make a Python script for data mining. A module to access the offline tools mentioned above is loaded by default, so that you can, e.g., talk to the database, and get an image cutout (or corresponding PSF image). A module to access hscMap is also loaded, and you can launch a new tab to display images. This can be controlled from your notebook; you can mark objects, and if you click an object, you can get its ID back in your notebook, for instance. Finally, we have a spectrum viewer, which allows you to browse a spectrum interactively.

Integration & detailed implementations of ***software***, infrastructure, and ***related procedures***

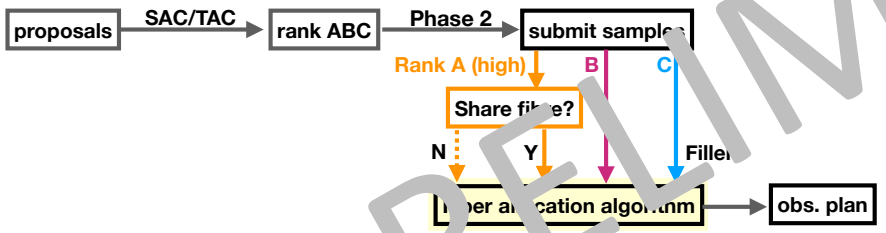
Discussions are underway mainly at the PFS Obs. Proc. WG chaired by M. Tanaka (NAOJ):

Phase 2 submission ← Our task is from this point on

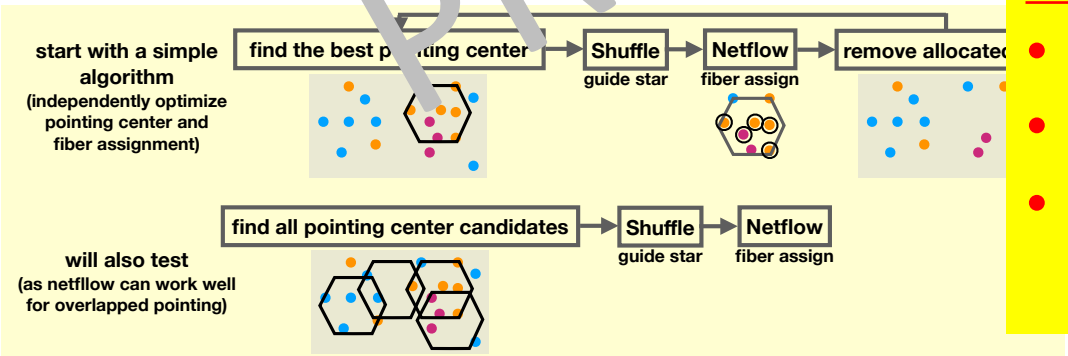
What should we collect from users?

- Object information: ID, R.A., Dec., internal priority
- Instrument config: LR or MR
- Exposure time: 7.5 or 15min, X visits
- Constraints: background level, throughput, reference arm or wavelength
- Anything else?

- **12.10 Meeting about observing process (Wanqiu He)**
- **new PD @NAOJ; will work on helping develop the PFS open-use framew**
- **a flow chart of Phase 2 procedure:**



- **GOAL: to establish a efficie t fi allo tion algorithm**



Phase 2 submission continued:

How should we collect the phase 2 material from users?

- I think the only option is user upload to a Subaru server (target list can be quite massive and we do not want to receive it by email).

We need an automated check script for the phase 2 submission. But, I am guessing that it is going to be super difficult.

Where should we store the target lists?

- The sentiment from the telecon the other day is to put them outside of opDB. Not sure if it is clever to have them in Queue DB as they can be quite massive. Maybe in a separate DB (targetDB)?
- There is a possibility to make the targetDB visible from opDB as a foreign table. Any technical considerations here?
- Should we have the SSP targets as well in the targetDB? I think yes, if open-use programs are going to share fibers with SSP. SAC formed a dedicated WG to discuss fiber sharing with SSP. Any updates from there?

process.

***Discussions (in Japanese) tomorrow afternoon*:**

- Queue operation of PFS
- Specific features
- Observation preparation procedure

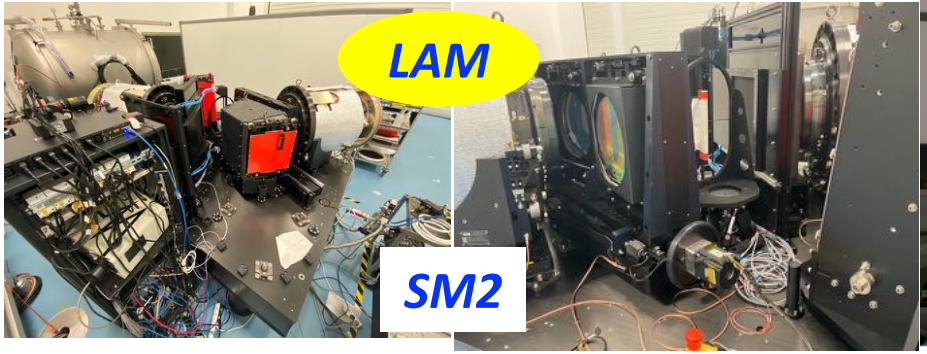
Risk assessment

- Successfully completion of first “module” → Low risk now
  - 42 Cobra modules (+2 spares) are all on PFI.
  - SM1 B+R is now at Subaru → SM2-4
  - Cable B#1 has been successfully integrated → Cable B#2-4
- ***First challenge, one-time works → Still risky …***

  NIR camera: Still the 1st one is under integration and test.
  - PFI validation as one integrated system.
  - System integration and engineering observation at Subaru
  - Optimization of calibration, modeling, and data processing procedure
- COVID-19 → Extra risks to hardware works, shipping, etc
  - Impacts are mitigated to be relatively moderate by optimizing work plan and resource management.
  - Commissioning is labor intensive on site, so any restriction is a concern, although the stable situation in Hawaii is reassuring.

SpS AIT

- LAM
  - SM2 & SM3 under integration
  - SM4 AIT will start after SM2 is shipped out to Subaru.
- JHU
  - VIS cryostats & focal planes: Those for SM4 are remaining.
  - NIR cameras: Integration of #1 is underway with H4RG tests. Those for #2 started.
- LNA
  - Fiber slit assembly (FSA) for SM3 has been shipped.
  - FSA for SM4 is now at LAM but will be shipped back to LNA for repair. Will be returned to LAM in ~Apr.

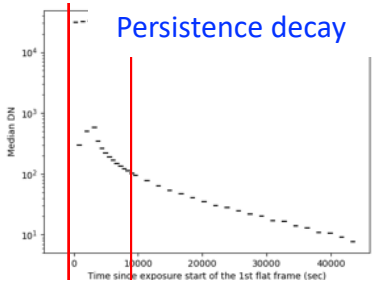


NIR Cam. #1

Red cryo. #4 & NIR cryo. #2

JHU w/ PU & NAOJ

H4RG tests



Top-level schedule

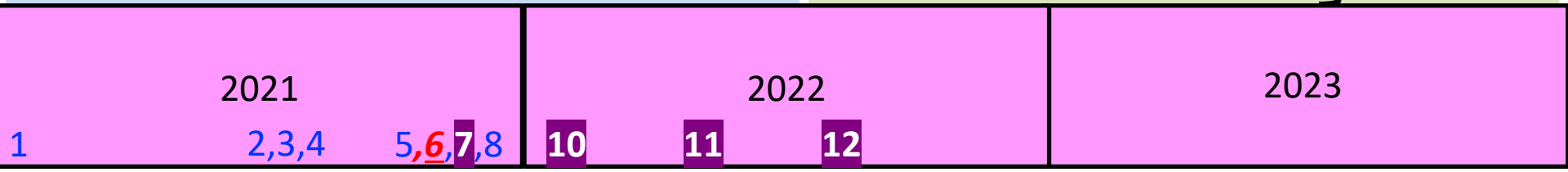
Past major milestones :

- Mar 2012: CoDR
- Feb 2013: PDR
- Mar 2014: SpS CDR
- Mar 2015: PFI CDR
- Feb 2018-Aug 2019: MCS preship review, followed by arrival at Subaru, and test completion in Aug 2019.
- Sep-Dec 2019: SM1 B+R preship review, followed by arrival at Subaru in Nov 2019, reintegration in Dec 2019, and validation in Spring 2020.
- Oct-Dec 2020: Cable B#1 preship review, followed by arrival at Subaru in Dec.

Future major milestones :

1. Cable B#1 installation on the telescope
2. SM2 B+R arrival at Subaru
3. Cable B#2 arrival at Subaru
4. PFI arrival at Subaru
5. Cable B#3 arrival at Subaru
6. ***Start of engineering observations***
7. **SM3 B+R+N arrival at Subaru**
8. SM4 B+R arrival at Subaru
9. Cable B#4 arrival at Subaru
10. **N2 arrival at Subaru (→ SM1)**
11. **N3 arrival at Subaru (→ SM2)**
12. **N4 arrival at Subaru (→ SM4)**

NIR



Subsystem integration and test

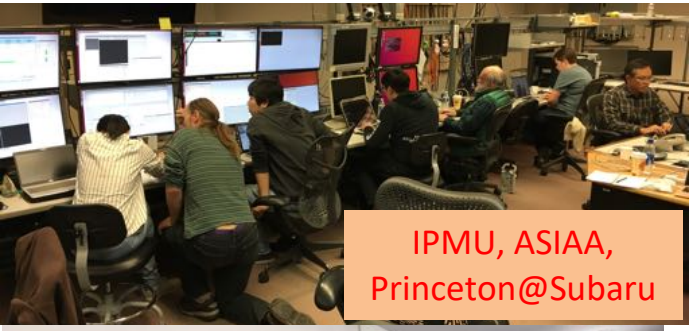
System integration at Subaru

Commissioning + stabilization

Science operation (S23A--)

MANY thanks to ***ALL hard works***

(Apologies many people are missed on these photos ...)

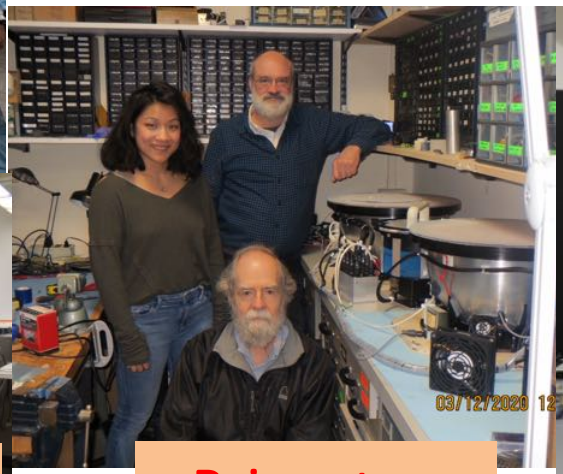


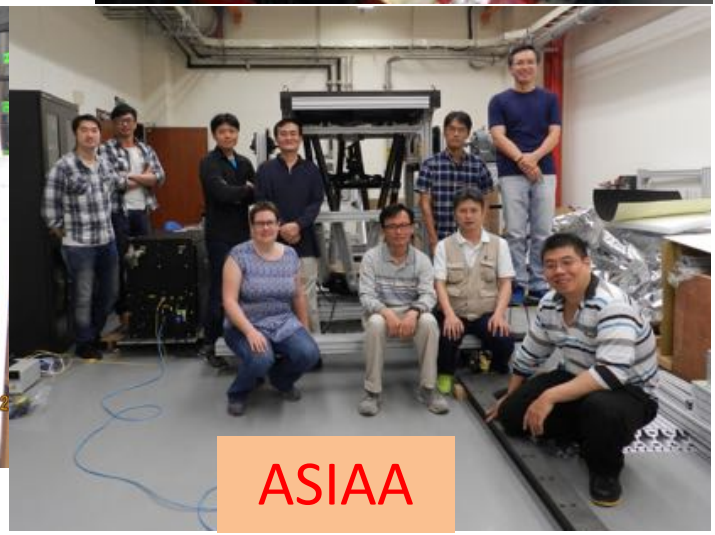
IPMU, ASIAA, Princeton@Subaru

JHU

LAM

LNA





Caltech, JPL

Princeton

ASIAA

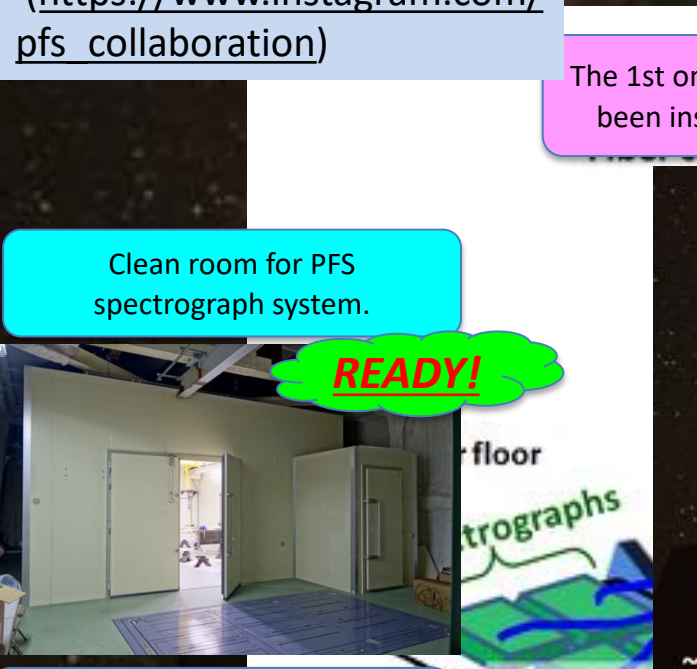
PFS blog
(https://pfs.ipmu.jp/blog/)

PFS Instagram
(https://www.instagram.com/pfs_collaboration)

SUBARU PRIME FOCUS SPECTROGRAPH

The integration & test are ongoing to start scientific use from 2023 despite various outstanding challenges and risks on the way!

The 1st on-telescope fiber cable has been installed on the telescope.



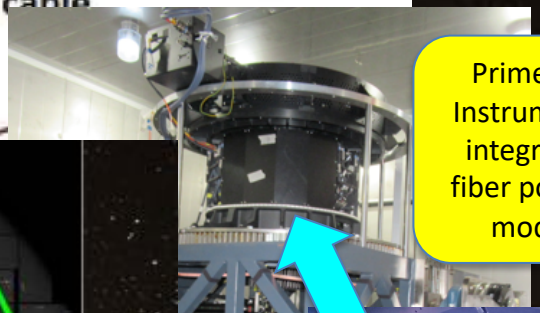
Clean room for PFS spectrograph system.

READY!

The first spectrograph module fully assembled.

1st one is …
READY!

1st one is …
READY!



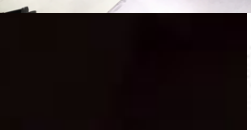
Prime Focus Instrument has integrated all fiber positioner modules.

ALL COBRAS!

All fiber positioner modules have been installed onto PFI.

READY!

The metrology camera that has been fully integrated and tested on the telescope.



Subaru Telescope

Metrology came as a Cassegrain instrument