SUBARU PRIME FOCUS SPECTROGRAPH

PFS – A Subaru's next-generation facility instrument

heading to the end of developments

SuMIRe Prime Focus Spectrograph

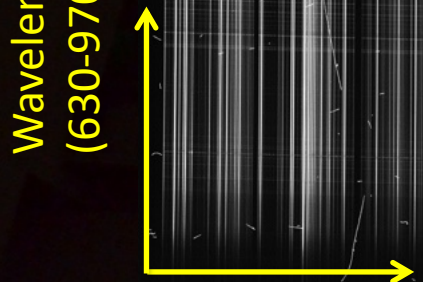
Prime Focus Spectrograph

A report on behalf of
PFS Project Office, PFS collaboration & PFS A project

Naoyuki Tamura (Subaru Telescope, NAOJ)
Subaru Users Meeting FY2023, Jan 23 2024 (JST)

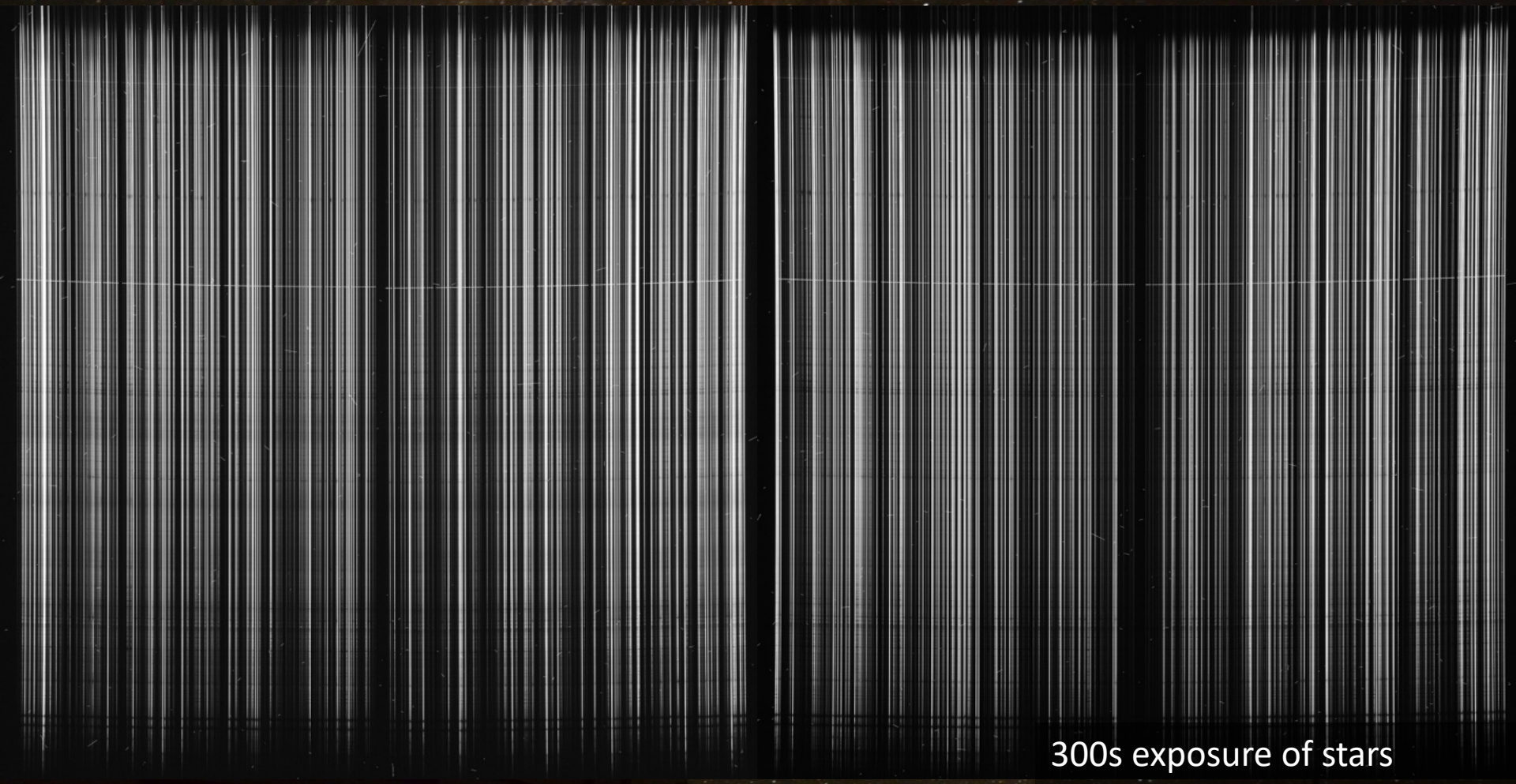
Engineering First Light in Sep 2022

Successfully observed many stars simultaneously by intentionally positioning the fibers on the targets.



300s exposure of stars in an NGC 1980 field w/ SM1 red camera

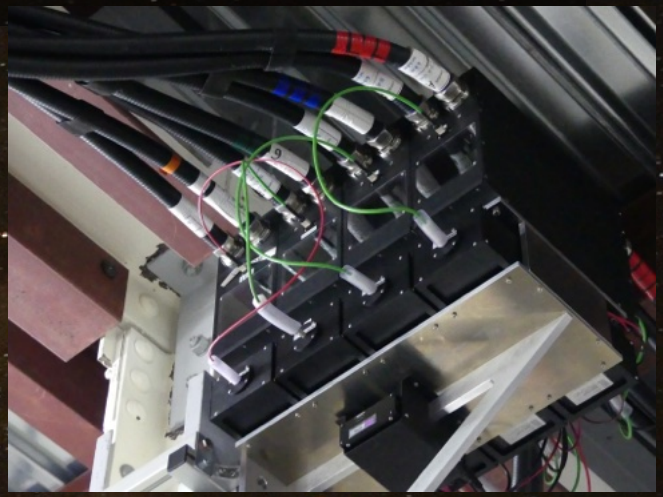
The observation in Nov 2022 with doubled multiplicity: ~600 → ~1200

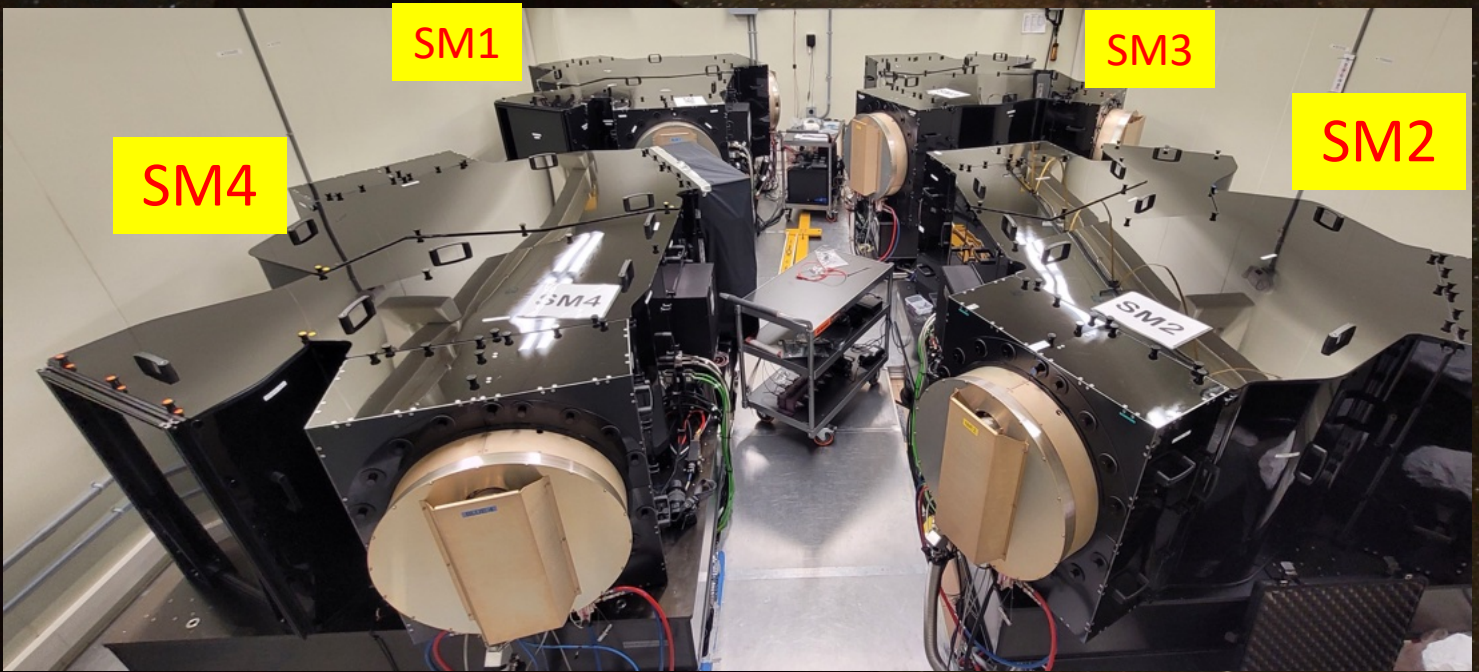


300s exposure of stars
in an NGC 1980 field
w/ SM1 & SM3 blue cameras

Feb, May & Nov 2023: Remaining fiber cables & spectrograph modules were implemented.

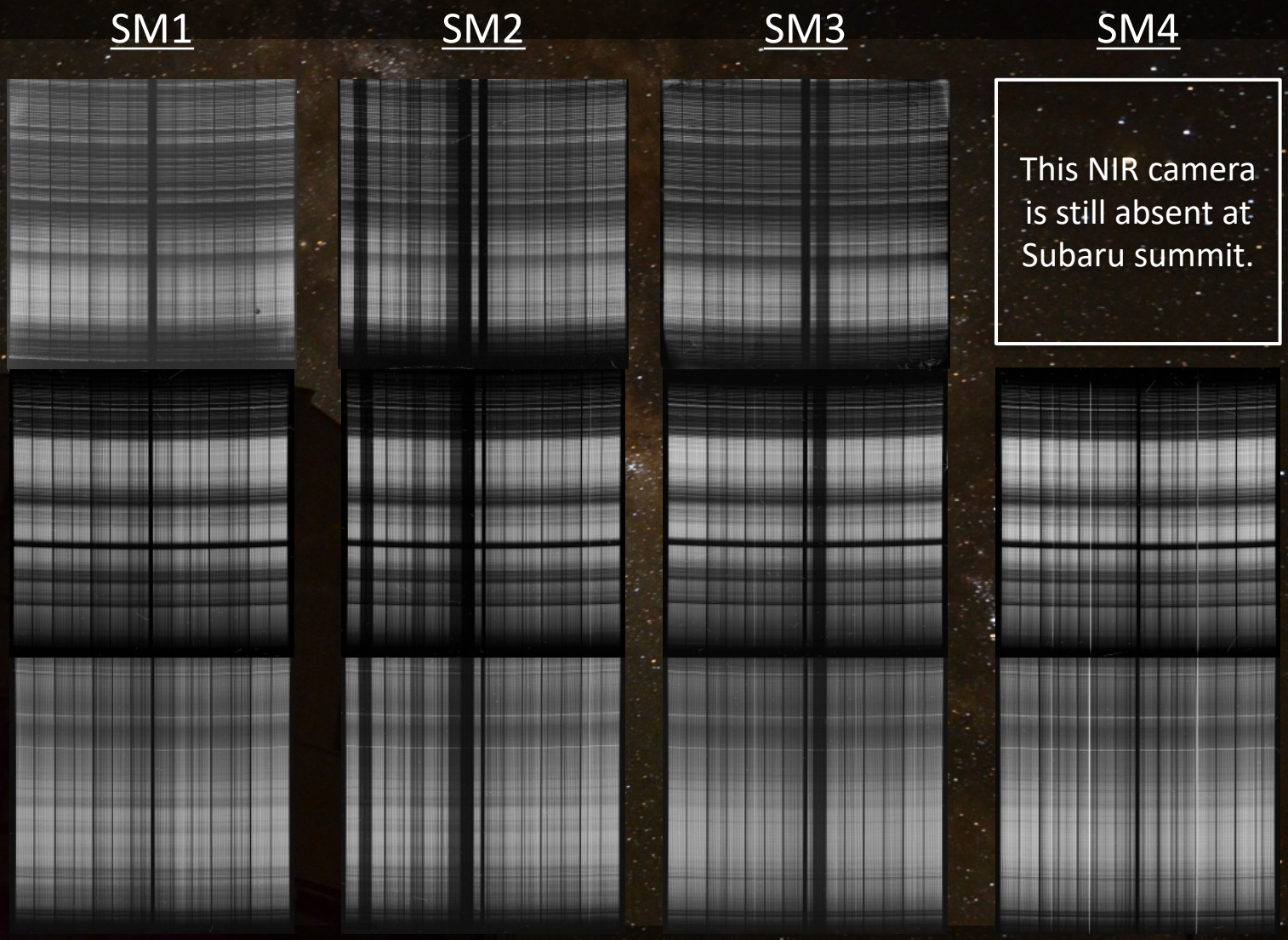
All Cable four Bs on the telescope spider (left) and on the IR3 floor (right)





All four modules @Spectrograph Clean Room (SCR)

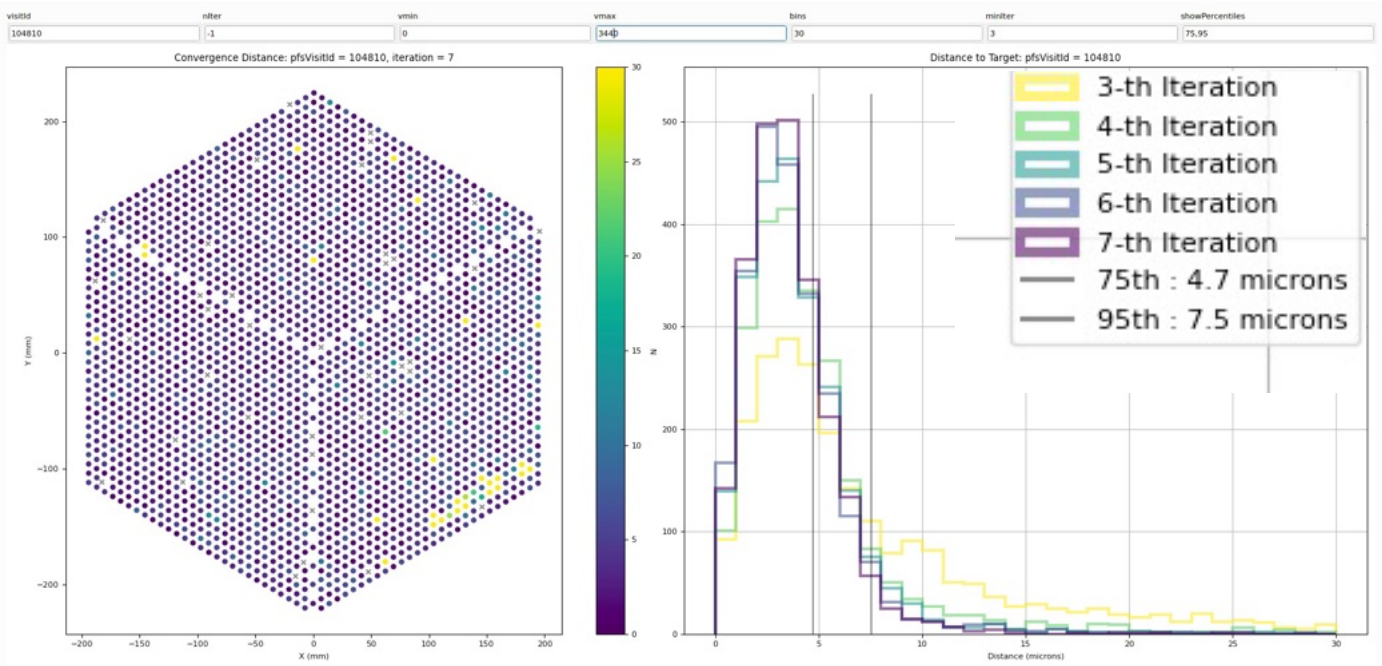
Dec in 2023: On-telescope data acquisition run (with Telescope kept pointing to Zenith)



All spectra from a ***SINGLE*** exposure (twilight sky on Dec 22, 2023)

Fiber configuration

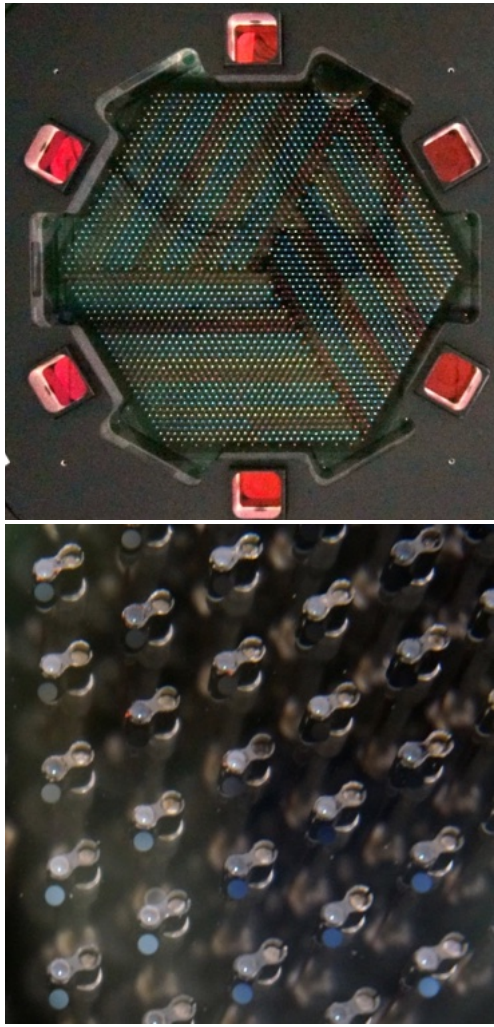
Moving fibers to targeted (x, y) positions:



10um (~0”.1)

PFI focal plane

~40cm



- Fiber core subtends ~1”.1 on the sky = ~100um on the focal plane.
- 8mm between adjacent Cobras.

Fiber configuration time

(1) 12 iterations → 8 iterations

(2) No “go home” at the beginning

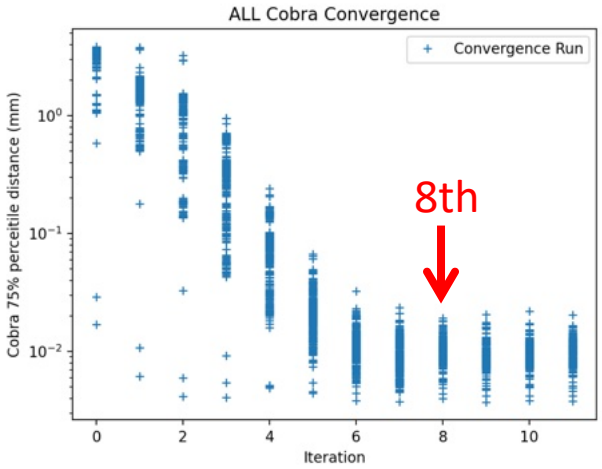
(3) 0.8s (instead of 4.8s) MCS exp. time for the first 2 iterations

(4) No data generation to check fiber trajectories

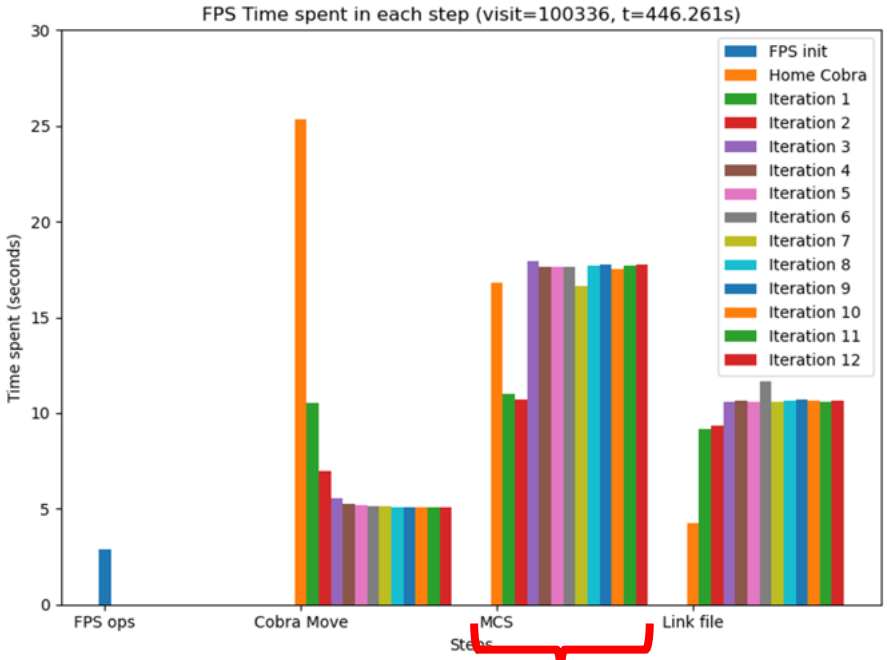
(5) Faster background estimation on MCS images

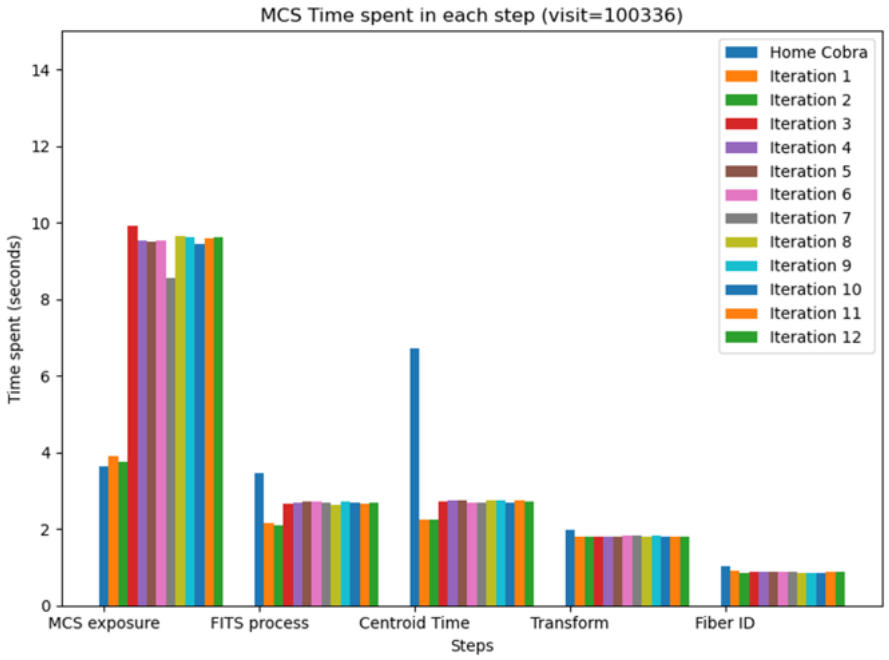
(6) Multi-task parallel processing

Yan (ASIAA)+



~470 sec → ~120 sec as of now



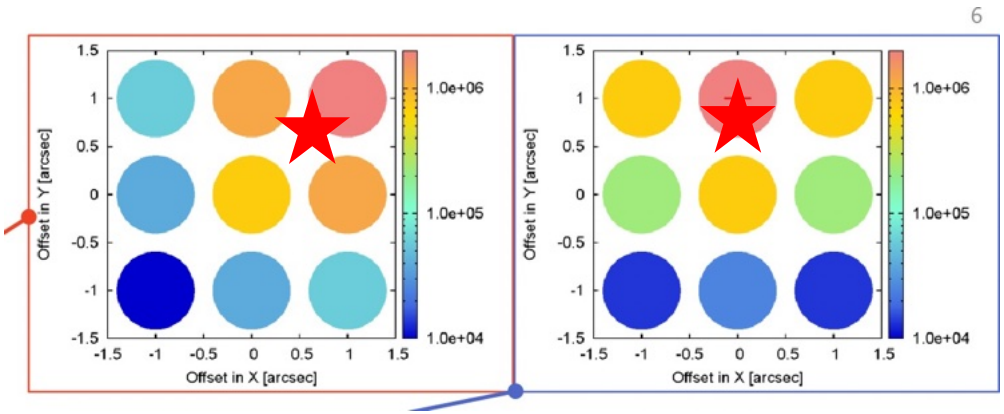


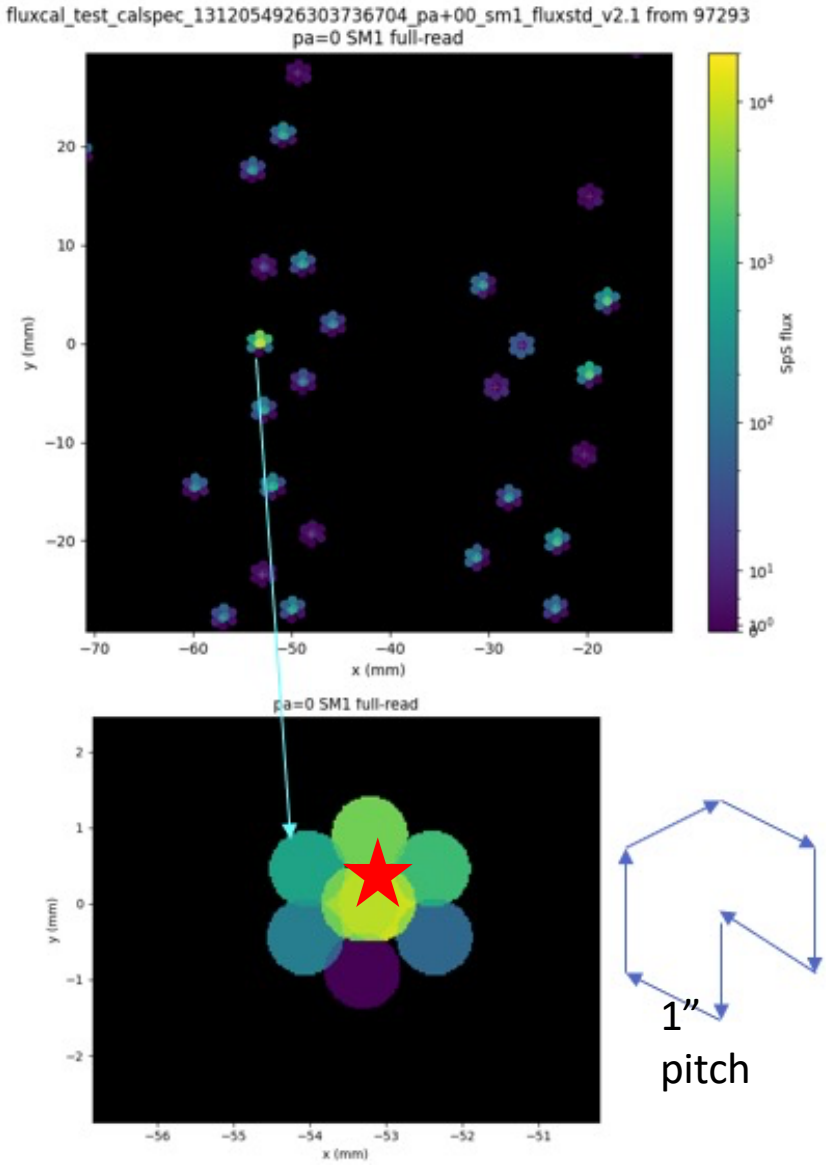
Better deal of bad-behaving Cobras may save more time.

Fiber configuration

Raster scan

- To generate a 2D map of flux coming into the instrument around each fiber.
- The offset of flux peak from the middle is a fiber positioning error.



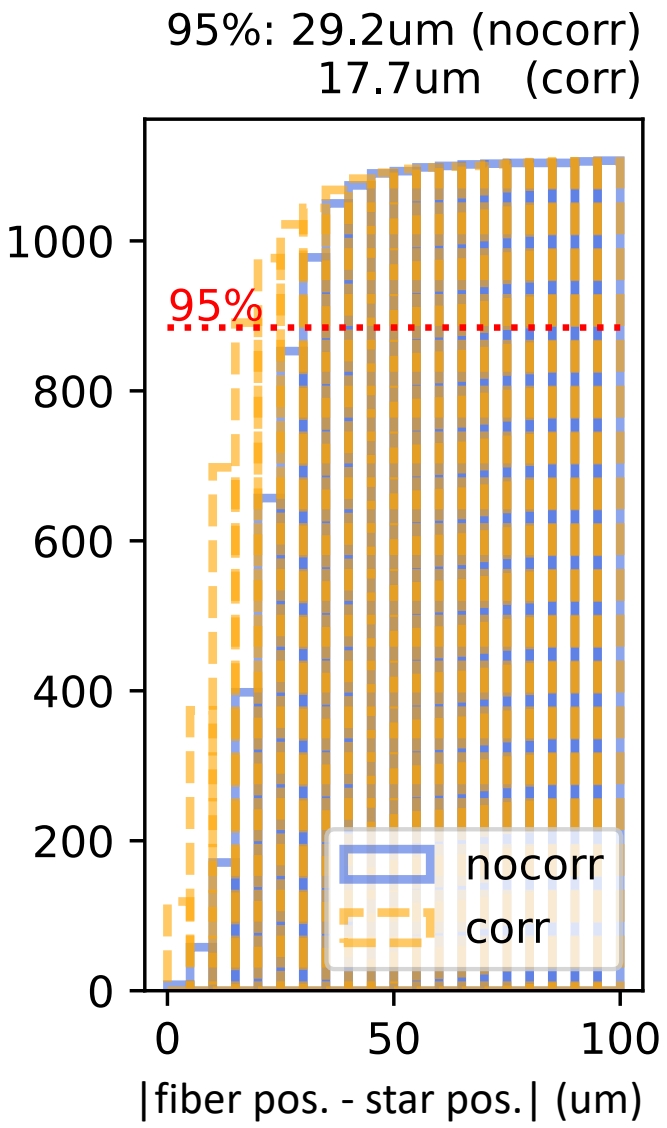


A spectrograph exposure is taken at each dither position keeping fiber positions the same,

”nocorr”: Result directly from data
“corr”: Result after the systematics are moved by hand

Fiber configuration

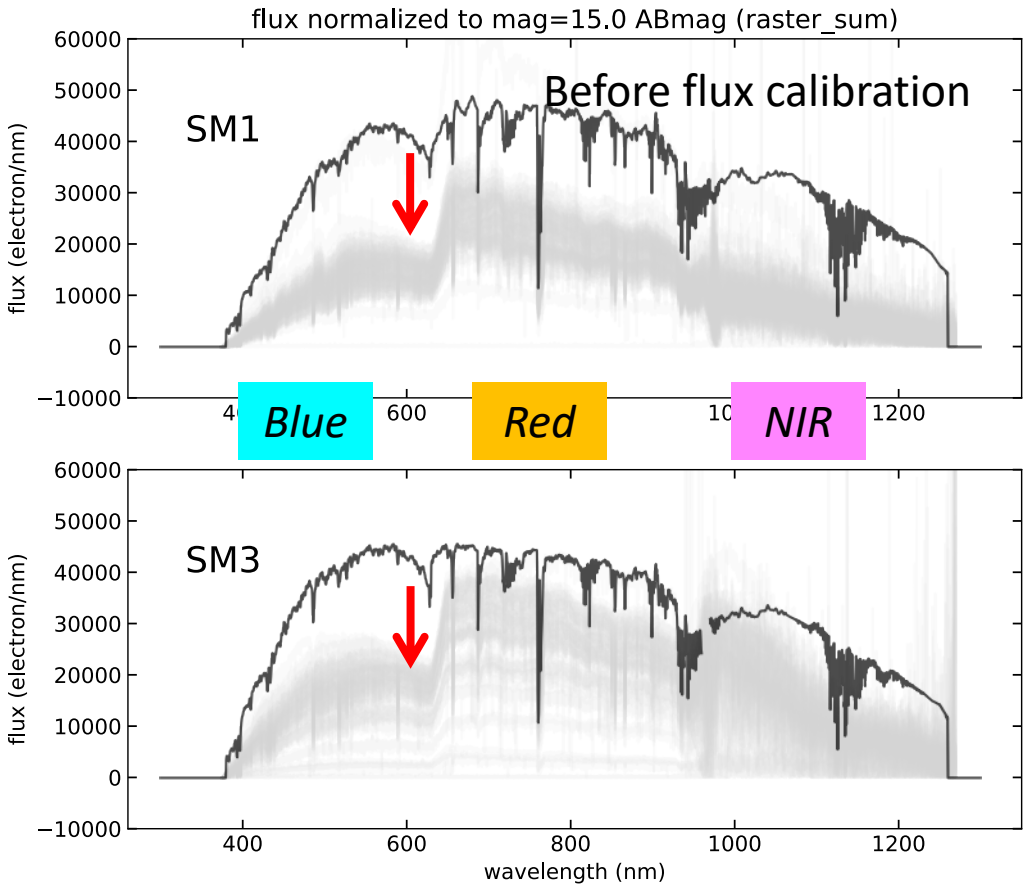
- The on-sky difference between fiber pos. and star pos. is measured by the so-called raster scan operation.
- Still systematic errors remain in translation, rotation, and scale.
  - But the rotational offset has been greatly improved this time (i.e. in the July run) down to ~0.001deg i.e. ~4um at the field edge.
  - A scale error seems to persistently exist, so its removal should be possible by updating the parameter in the model. Will be confirmed next time.
  - Lateral offset exists at a 10um level. More data are needed to characterize it for removal. Perhaps the removal of scale error will ease visualizing how the lateral offset looks.
- 20um error in total is quite reasonable: Most of the fibers within ~10um to target (x,y)@PFI, plus a few to several microns from each of sky->PFI projection, astrometry, and field acquisition & auto guiding.



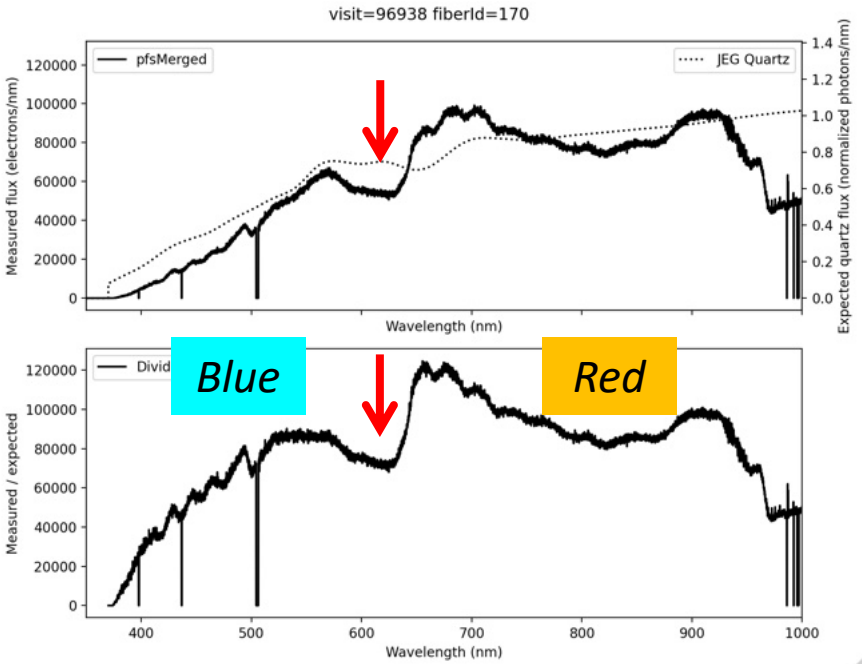
Contributions from many people from NAOJ (Subaru & Mitaka), Princeton, ASIAA, Max Planck …

Throughput measurement

Flux standard (spectral-type-known) stars



Quartz lamp

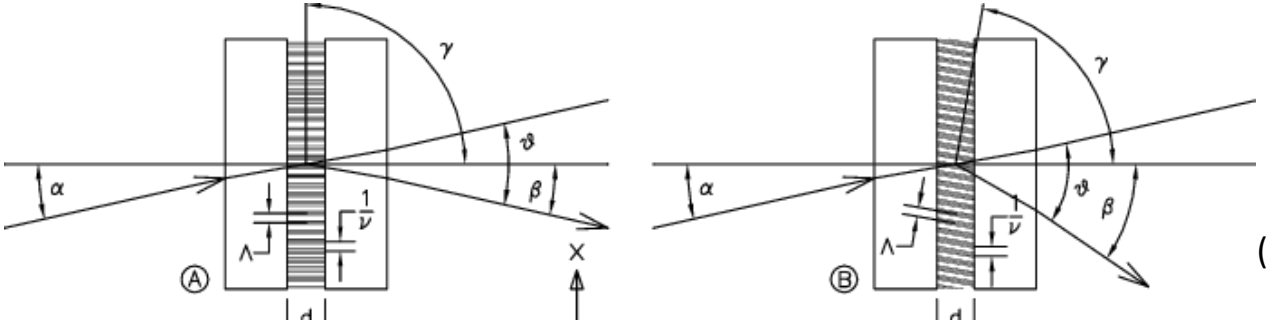


Confirmed this is not due to a pipeline error.

Something fundamental is amiss on the instrument …??

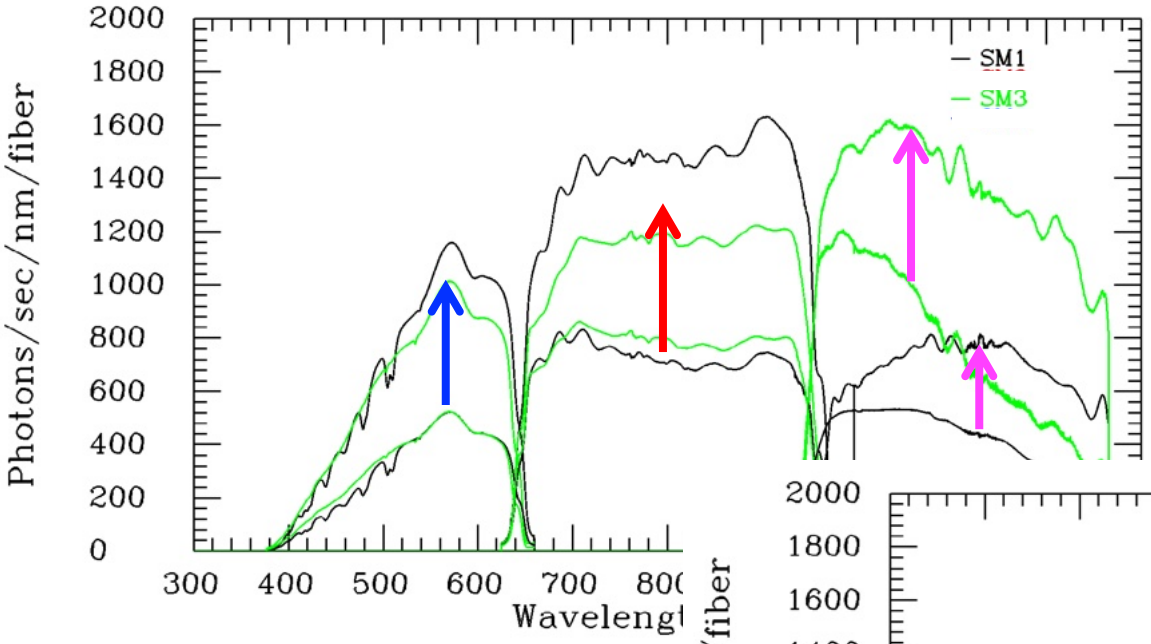
Taskforce ("tiger team") was formed …

- ~15 items were immediately listed as what might be wrong and what could be done to isolate problem(s).
- Visual inspections of the real hardware at LAM and at Subaru summit, document checks, data analyses, and discussions.
- VPHG has been found wrongly mounted:
  - The orientation is rotated by 180 degree around the optical axis
    - The efficiency curve becomes different due to the slant.
    - The red end of the blue is especially impacted in the way we are seeing on the data.



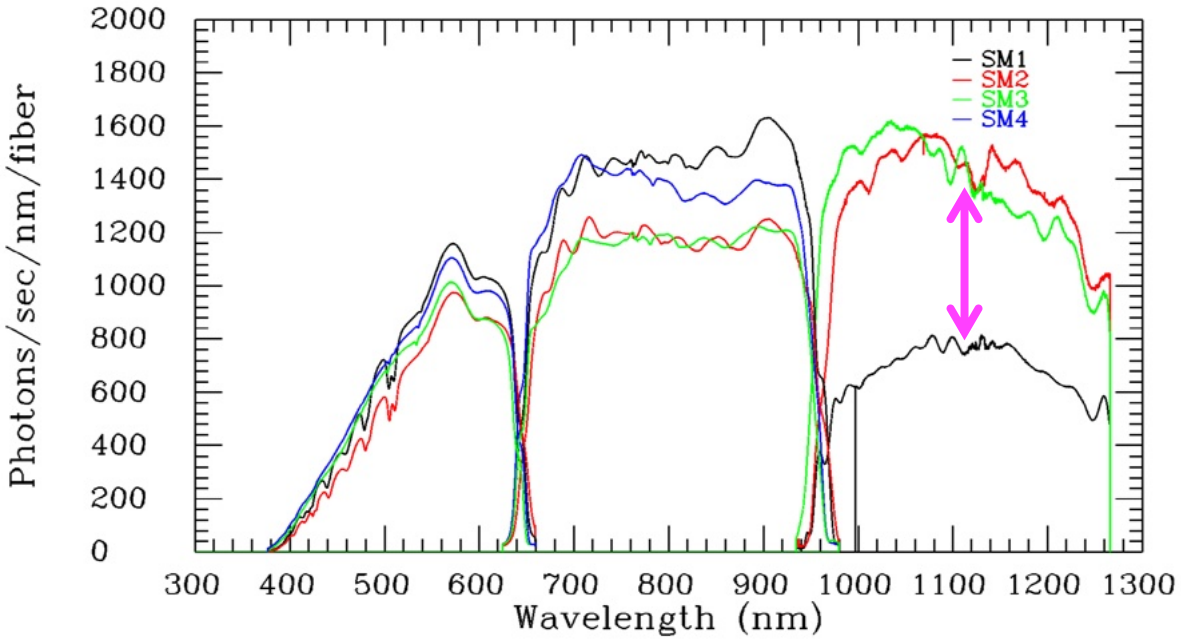
(Barden 1999)

Preliminary results from the latest quartz spectra after grating orientation error was fixed.



- The Low-Resolution grating orientations were all fixed in Nov.
- Quartz spectra before Nov (only SM1 and SM3 were at Subaru at that time) were compared → The throughput has been recovered by a factor of ~1.5-2 in all the bands.
- The Medium-Resolution grating orientation corrections are being planned in Feb.

- Now what's visible are mainly the personalities of individual modules.
  - The detector QE should be the key player in the NIR band.



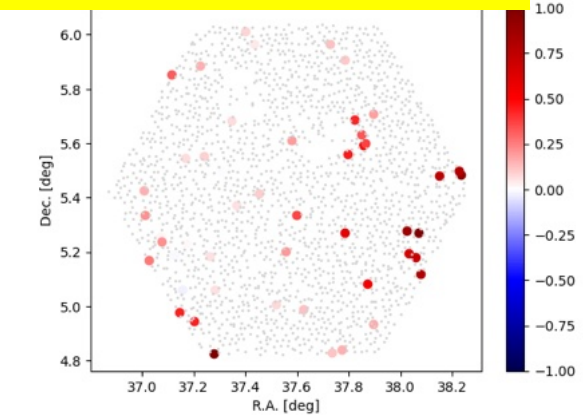
The NIR cameras: Detector issues

- The NIR camera for SM4 is still at JHU because there is no good detector for that …
  - We have a science-grade device that was for this camera but the measurement at JHU indicates a factor of 5-10 lower QE than having been reported at its delivery.
  - We sent this back to Teledyne. Their measurement also indicates a lower QE but only a factor of 2 … No clear explanation yet.
  - Investigations and discussions are continuing.
- The NIR camera on SM1 has a factor-of-2 lower response than those on SM2 and SM4.
  - This seems also due to the lower detector QE: The measurements at JHU indeed indicates a factor of ~2 lower QE on that detector compared to those in the cameras on SM2 and SM3.
  - We will discuss this with Teledyne too.

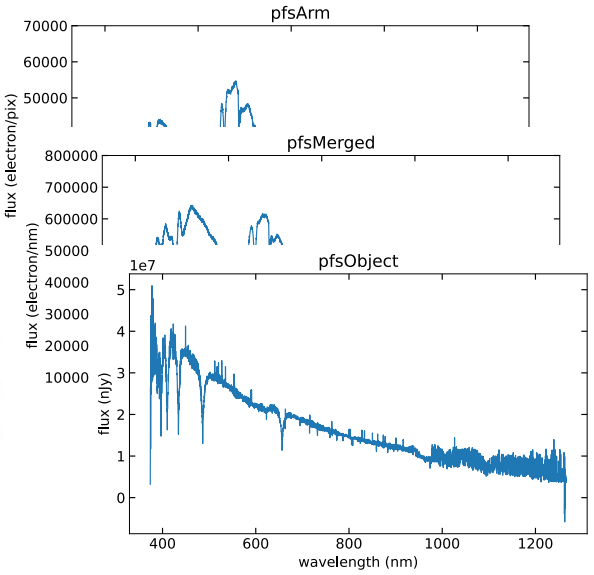
2D Data Reduction Pipeline (2D DRP)

Flux calibration vector@FoV

- It is able to process data from (all the way to flux calibration.
  - Generation of calibration pro
    - Requires experts for optimiz
  - A few main .py commands fo
    - reduceExposure → pfsArm
    - mergeArms → pfsMerged
    - fitFluxCal → pfsSingle
    - coaddSpectra → pfsObject
  - Quality assessments



i-band magnitude difference between synthetic mags from pfsSingle (i.e., flux-calibrated spectra) and the PS1 photometry. The gray points are all objects in pfsConfig and the colored symbols are FLUXSTD. The magnitude difference is synthetic mag - PS1 mag.

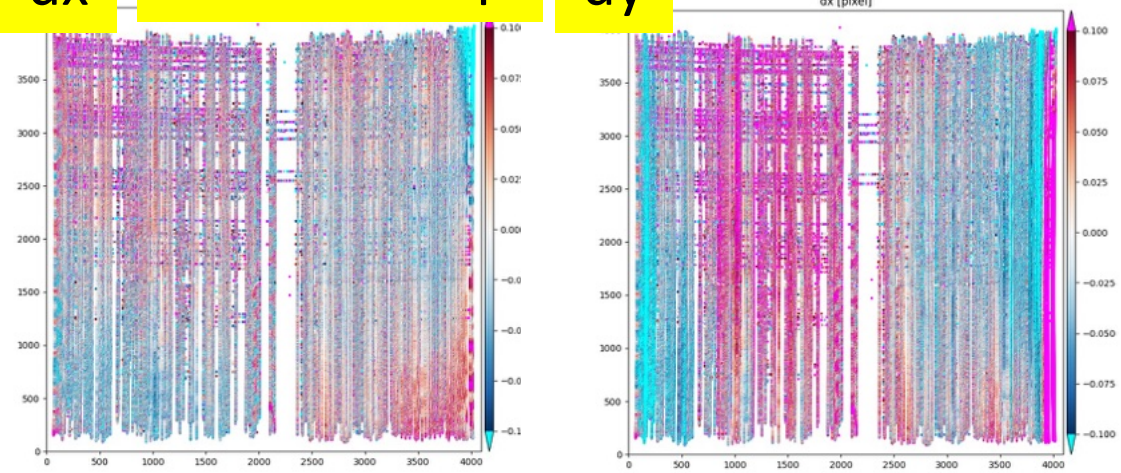


Gee, Yabe (Subaru), Hamano, Mineo, Tanaka (NAOJ)

dx

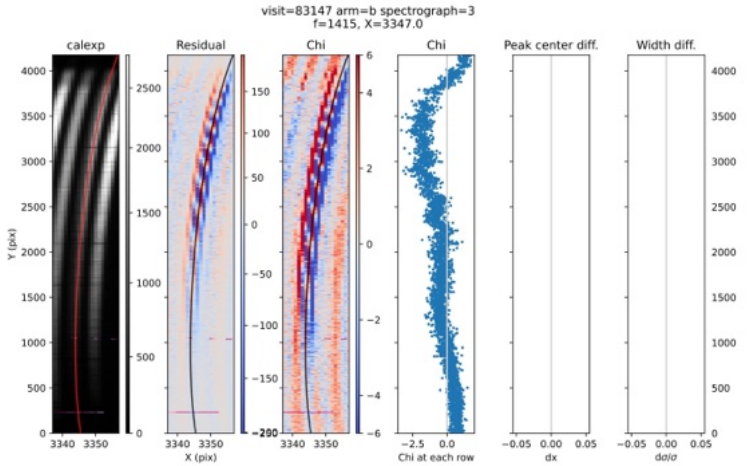
detectorMap

dy



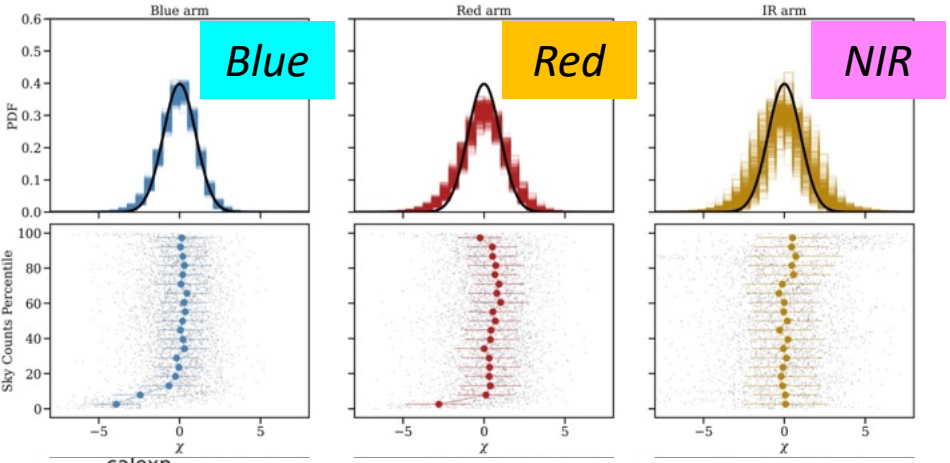
Extraction

FiberID=1415

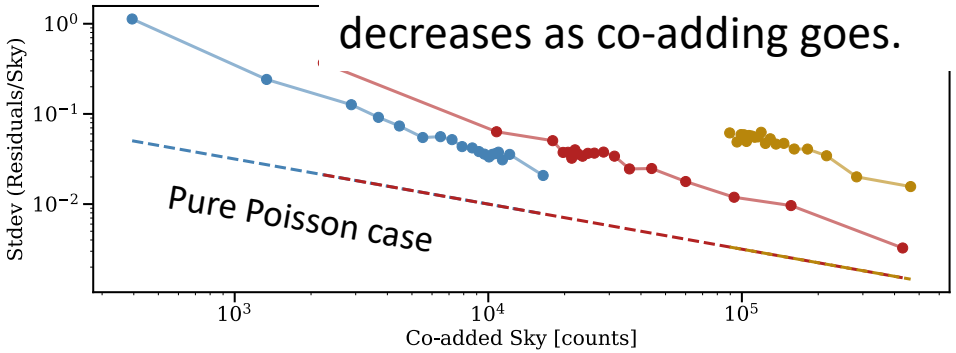


Sky subtraction test with “all-sky” exposures

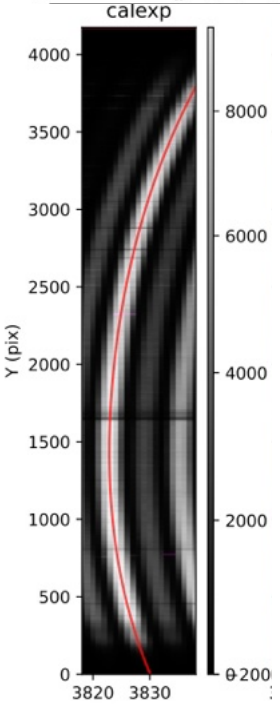
Distribution of sky-sky residuals



Scatter of sky-sky residuals



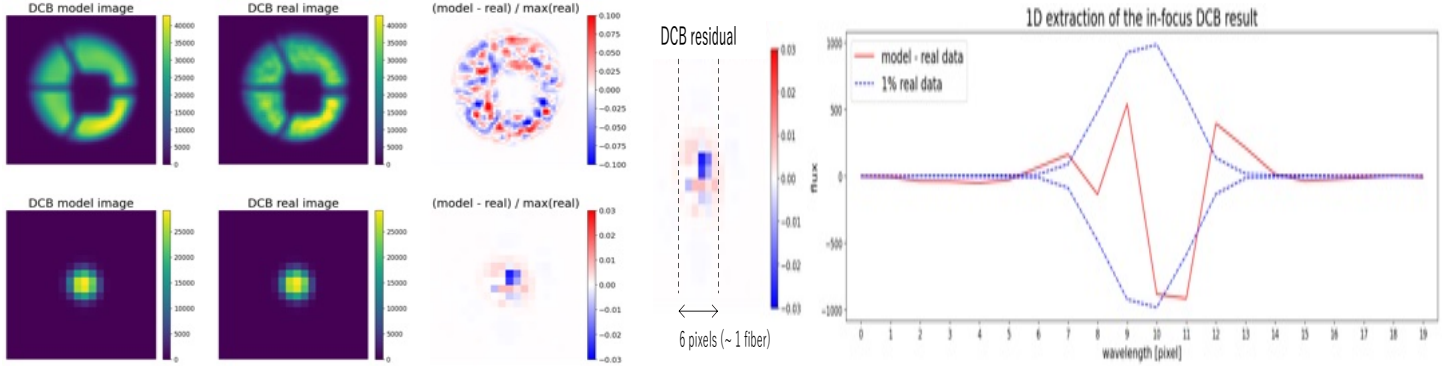
Siegel (Princeton)+



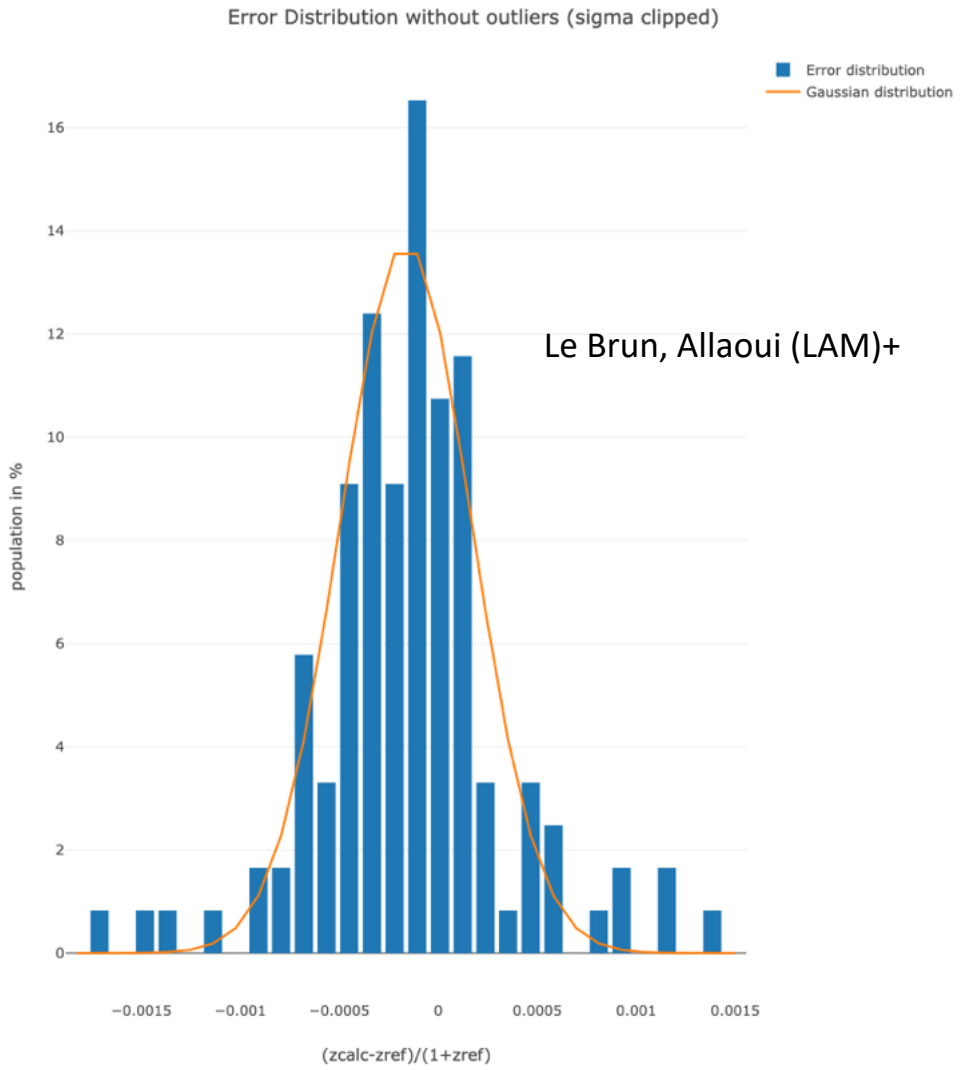
The difficulty is in modeling and subtracting the sky on the fiber observing object + sky based on the sky spectra on different fibers.

← Full characterization of fiber spectrum as a continuous integration of 2D Point Spread Function (PSF) at each wavelength

Hayashi (IPMU), Yabe (Subaru), Capler (UW)+



1D Data Reduction Pipeline (1D DRP)



Le Brun, Allaoui (LAM)+

- It processes the 1D spectra 2D DRP produce from engineering observation data.
- E.g. galaxies in the COSMOS fields with known redshifts.
- When the redshifts are measured successfully, the accuracy is quite good.
- Investigations are underway to understand the failure mode:
  - Too low S/N
  - Insufficient treatments on the 2D DRP sides such as:
    - Bad sky subtraction
    - Non-flagged spurious spikes
    - Irrelevant covariance information

PFS Science Platform

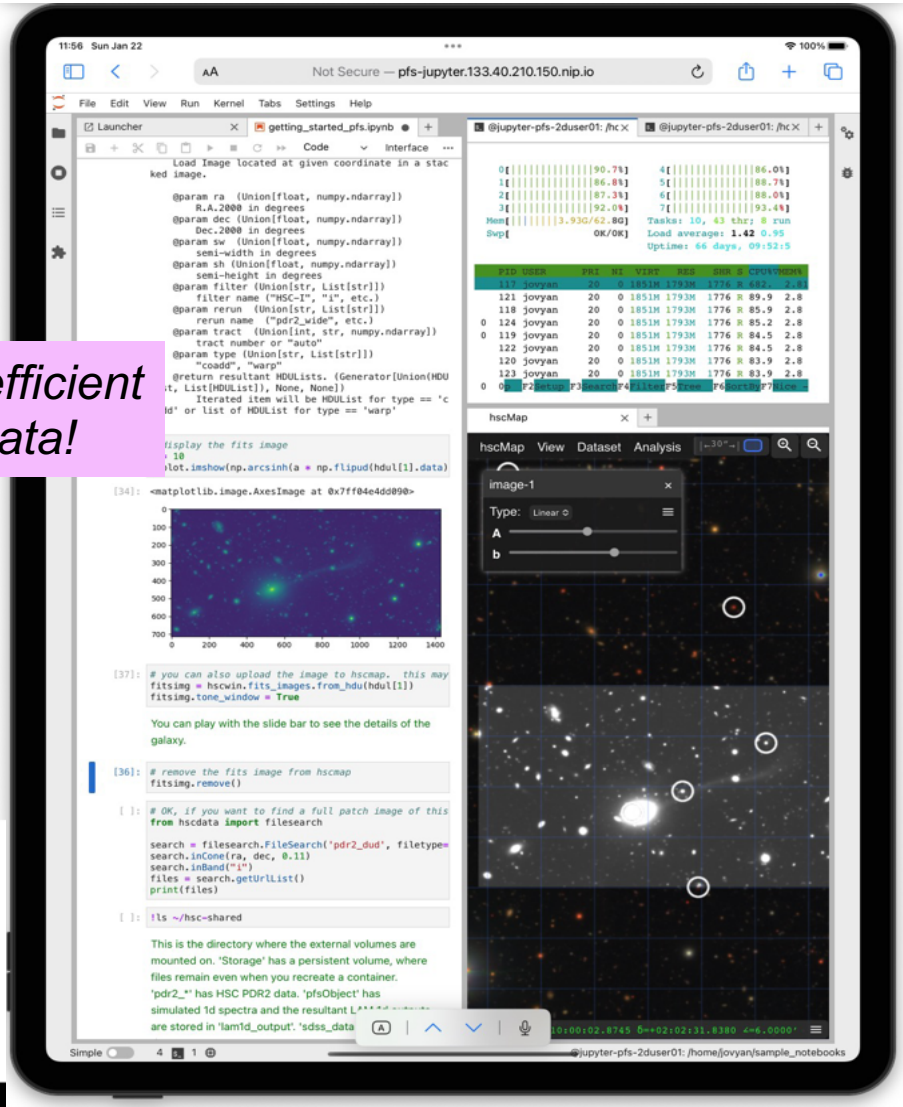
The combination of HSC and PFS yields an extremely massive dataset. NAOJ provides a science analysis environment right next to the data.

The PFS science platform allows you to

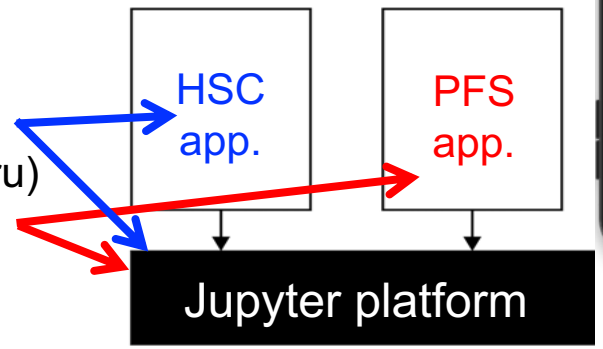
- access HSC and PFS files
- query HSC and PFS databases
- use intuitive image/spec analysis tools

Enables very efficient works on big data!

through Jupyter interface. The engineering data release 2 (EDR2) will occur soon on the PFS science platform. If you are interested, please contact us!

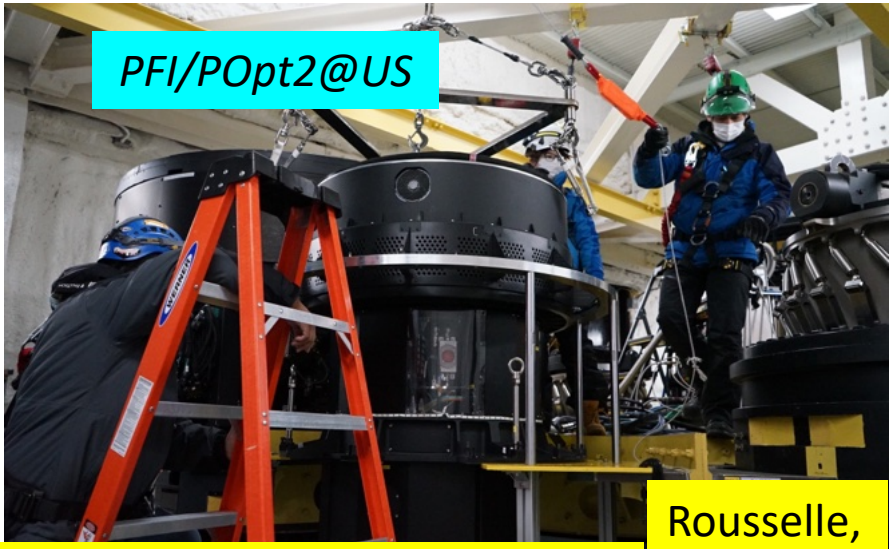


Koike
(NAOJ/ADC-Subaru)
Morishima
(NAOJ/Subaru)



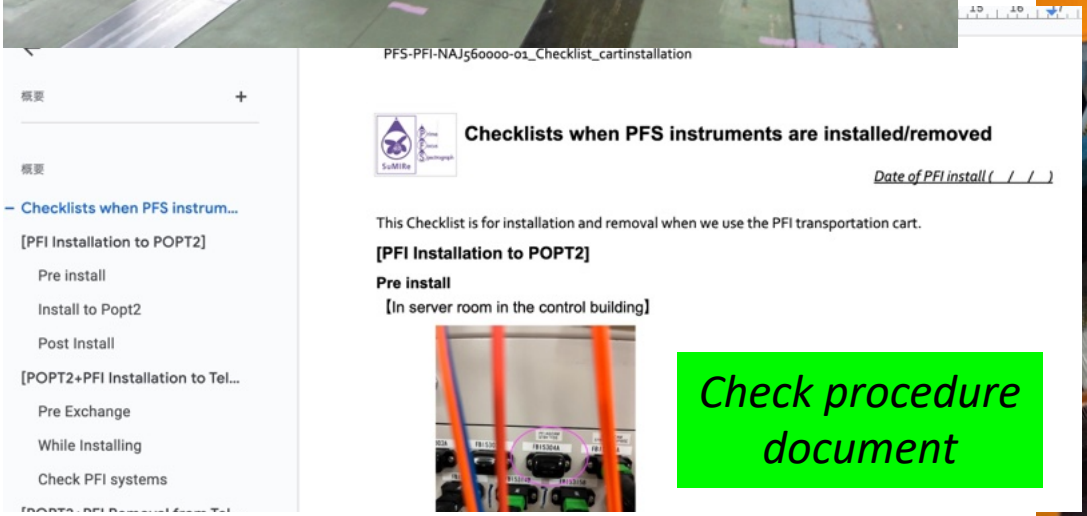
PFI/POpt2 & MCS installations

Routinization/standardization is underway for less time and less supports from the PFS team.



Thanks to great performances of Day Crews and PFS staffs

Rousselle, Wung, Morihana, …



Check procedure document

Pre-check & night operation

- Both engineering and science-operation-like processes are well written as Gen2 commands.
- Actual executions at engineering runs.
- Pre-check only takes a few minutes before each night in a run.

OPE file example

```
#==========================#
# Preparations & Pre-checks
#==========================#

# 0. Only at the first night of a run

# 0-1 Mid-resolution stage movement check
## Only on the first night of a run? Or each night observation requires medium resolusion exposures?

#change to low to med resolution
exec pfs pfscmd actor="iic" cmd="sps rdaMove med"  TIMELIM=180

### !!! Check status on PFS GUI !!! ###

#change from med to low resolution
exec pfs pfscmd actor="iic" cmd="sps rdaMove low"  TIMELIM=180

### !!! Check status on PFS GUI !!! ###

# 0-2 Cobra movement check
## Move Cobras from Home position to the Safe position, then move them back to Home position
### designId for safe position

# Turn on the fiber illuminators
#Exec pfs pfscmd actor="dcb" cmd='power on cableB'
```

Koshida

Takagi

Arai

Passegger

(Much more lines continue …)

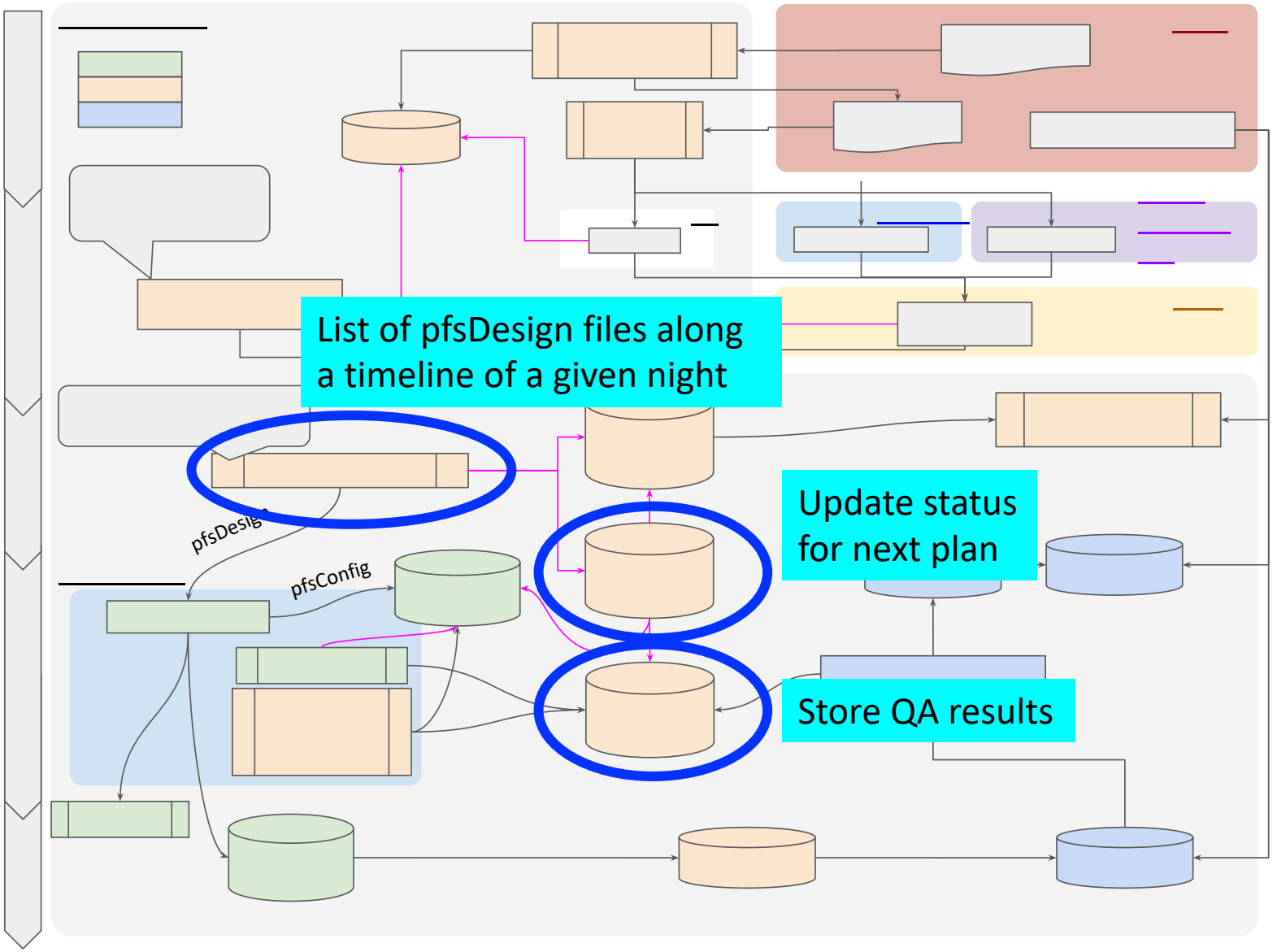
Development of open-use operation framework

Observation processing ("obsproc") WG

Commissioning team	Support Astronomer
Software developer	Data release manager
Observatory operation	HSC queue coordinator
Open use	Ex./current TAC

Arai	He	Ishigaki	Jeschke	Koshida	Koyama	Moritani
Okamoto	Onodera	Pyo	Takagi	Tamura	Tanaka	Yabe

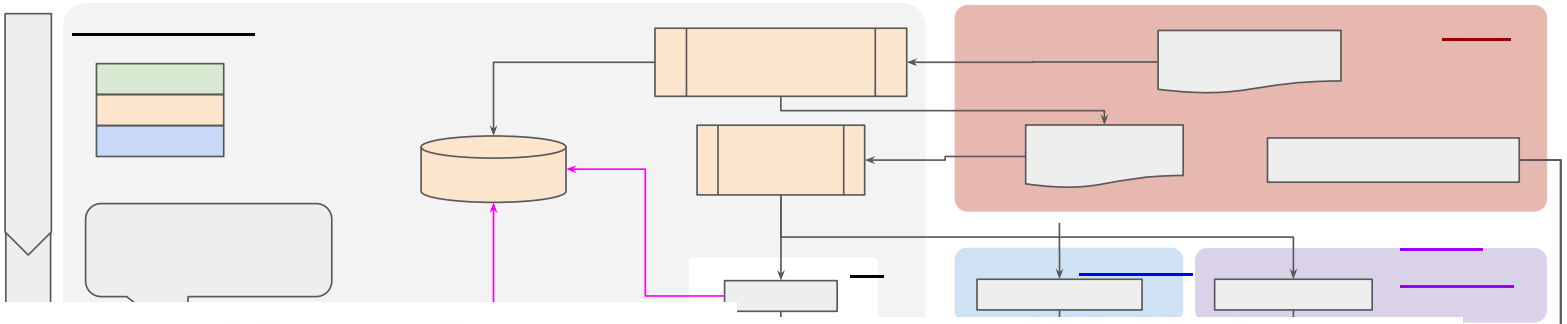
End-to-end operation process: Simulation, implementation & validation

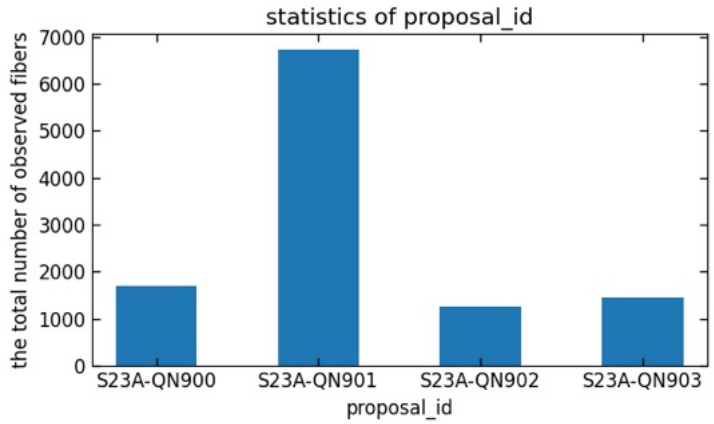


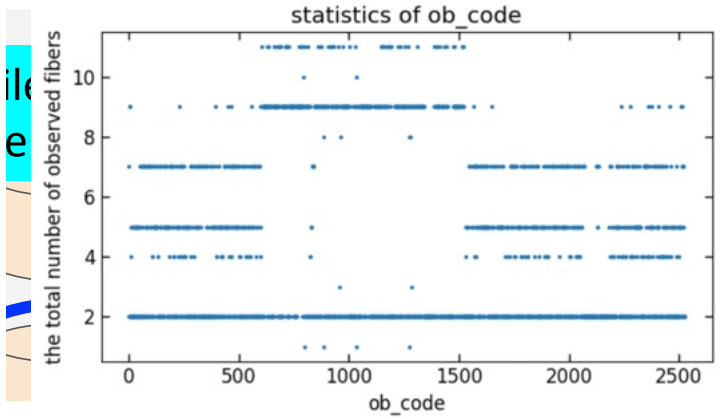
End-to-end operation process: Simulation, implementation & validation

Prop_id
+
ob_code

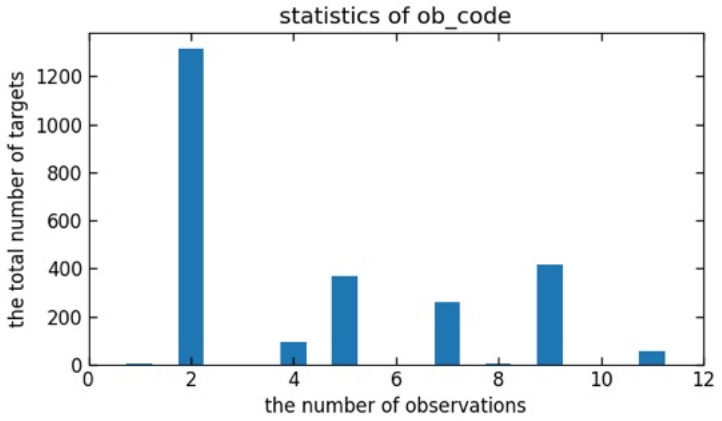
Persistently maintained







The mechanism is being validated with real engineering data.



More thorough checks out to data delivery will be done at upcoming eng. obs. and internal data release.

The original plan to ~2024 (as of Sep 2023)

Schedule	Events at Subaru
10/3-9	Engineering observation run #13 → ***Cancelled***
10/30-11/22	Installation of Spectrograph module #3 and #4 (SM3 & SM4)
11/23-12/13	SM3 and SM4 commissioning and other preparations for upcoming engineering observations
12/14-20	Engineering observation run #14 → ***Cancelled***
Jan 2024	Open use readiness review ← ***Impossible***
Feb 2024	Call for proposal to the community (including PFS)
Feb-Jul 2024	A few engineering observations for optimization and stabilization
Aug 1 2024	***Start of PFS science operation (from S24B)*** ← ***Impossible***

Expected to complete understanding the instrument reasonably well during the October run, and then confirming similarities of the last two spectrograph modules to the others during the December run.

Updated plan as of now after telescope trouble

Schedule	Events at Subaru
10/30-11/22 Done!	Installation of Spectrograph module #3 and #4 (SM3 & SM4)
11/23-12/13 Done!	SM3 and SM4 commissioning for engineering observations
12/20-22, 12/27-29 Done!	On-telescope engineering data acquisition (the telescope was kept pointing to Zenith) instead of engineering observation
1/15-17 2024 Done!	Metrology Camera System (MCS) refocusing
Feb 2024	Engineering works for medium resolution grating orientation correction on the spectrograph system
Apr 2024 Uncertain …	Implementation of the last NIR camera onto SM4
Mar-Jun 2024	***3 engineering observations (3/8-17, 5/2-8, 5/28-6/3)***
July 2024 (or earlier)	***Open use readiness review***
Aug 2024	Call for proposal to the community (including PFS)
Aug 2024-Jan 2025	***~2-3 engineering rus for optimization and stabilization***
Feb 1 2025	***Start of PFS science operation (from S25A)***

Schedules in brown color are still preliminary/TBC.

A few advertisements

- Discussion session about PFS open-use policy
  - 10:45-12:00 on Day 3 (1/25 [Thu] JST) moderated by Tanaka

- PFS posters
  - P05 by Roussllе: Completion of instrument integration at Subaru
  - P06 by Yabe: Current status of DRP development and processing of engineering data
  - P07 by Onodera: Web applications for Subaru/PFS observation planning: Spectral simulator and target uploader
  - P08 by He: Tiling tool for Subaru/PFS open-use programs: PFS Pointing Planner (PPP)

PFS is taking final steps to science operation.

- Hardware integration is complete except for the NIR camera for SM4.
- The correction for the grating orientation indeed recovered the throughput of the spectrograph by a factor of 1.5-2 in the low-res mode.
  - The work for the medium resolution gratings is being prepared for Feb.
- Implementations and validations for open-use operation processes are underway.
- Timeline
  - 3 engineering observation runs have been scheduled in S24A: 3/8-17, 5/2-8, and 5/28-6/3
  - Aiming at open-use readiness review by July 2024 for science operation from S25A.





- ✓ Official web site - https://pfs.ipmu.jp/
- ✓ Blog - https://pfs.ipmu.jp/blog/
- ✓ Instagram - https://www.instagram.com/pfs_collaboration/