SUBARUPRIMEFOCUSSPECTROGRAPH

Updates of the next-gen facility instrument development Started its last phase









Naoyuki Tamura [PFS Project Office] On behalf of PFS collaboration

Jan 11 JST 2022 Subaru Users Meeting FY2021 Prime Focus Spectrograph





PFS subsystems distribution



PFS subsystems distribution



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

1st one is ...

READY!

The first spectrograph module has been fully assembled and tested, and in operation in the dedicated clearn room.

1st one is ...

READY!

or

graf

iber .

Subaru Telescope

Prime Focus Instrument has integrated all fiber positioner modules.

AIT in Taiwan

All fiber positioner modules have been installed onto PFI.

Metrology came as a Cassegrain instrument

The metrology camera that has been fully integrated and tested

on the telescope.

READY!



5/14: Preship review5/25: Approval to shipment6/23: Arrival at Subaru summit



PFI@Subaru summit

4 groups of fibers connected to 4 different spectrograph modules are backlit with 4 different colors.

PFI focal plane

PFI on the test stand in the clean booth on the observation floor.

Focal plane

Camera

Engineering observations

Various others

- Hardware configuration
 - PFI, Cable B1 and SM1 w/ blue & red cameras
 Hybrid style →

National Astronomice

- Dates
 - (1) 9/13-26
 - Kept the dome closed most of the time.
 - (2) 11/19-21

Progresses in various aspects:

 Auto Guiding test, PFI alignment, Cobra convergence, spectral image acquisition & processing, reconfirmation of MCS image quality & dome seeing effect, etc etc ...



AG camera FIRST LIGHT !!





<u>On-telescope</u> Cobra target convergence

The fiber positioners "Cobra "are working well:

- The number of non-converged Cobras is typically several tens out of ~2350 (<5%).
 - Excluding the Cobras that are disabled due to known issues (broken, badly behaving, etc).
- The residual distance between target positions and Cobra final positions is ⁻¹⁰
 ~10um on PFI focal plane.

Improvements are in pursuit:

- ~100% convergence
- Stability & robustness

How these target positions can be set correctly need to be checked by on-sky observations.



↑Color-coded residual distances of the fibers from the targets **set in XY** over the PFI focal plane.



- <u>Commands & mechanisms for</u> <u>cordinated operation have</u> <u>been in place to routinely carry</u> <u>out the convergence process:</u>
- Loading and ingesting pfsDesign
- Iterative moves of Cobras to the targets
 - Turn on fiber back illumination (PFI & SpS)
 - Centroiding backlit fiber spots on MCS images
 - Coordinate transformation to PFI coordinate
 - Moving Cobras towards the targets on PFI
 - Processing MCS images again and Judging the Cobra convergences

More works are needed for:

- Processing optimization
- Quality assurance
- Visualization

7

<u>"AppDot-roach"</u>

- Anther type of Cobra convergence in order to:
 - Let some Cobras app"roach" to the black "dot"s on Field Element
 - Hide the fibers from illumination at the prime focus
 - Sparsely illuminate the spectrograph detectors
 - Characterize the wings of PSFs in detail.
- A few set of small-step data in phi-axis were taken
 - 25 step x 40 strokes
 - Under analysis?
- SpS fast-read mode was developed.
 - Partially readout
 - Readout time decreased to 20 sec.
- At the end of the run, one trial of "dot-roach" was done.
 - Try to move all the Cobras, then reveal some of them from the cobra.
 - In the run, after "dot-roach", 6 fibers were found to be isolated well, so the relevant cobras were moved for PSF modeling study.





ISR-ed spectra at the initial (top, visit=71167) and the last (bottom, visit=71187) position. Not that the scale and the limits of the colorbar are different between the two images.

Spectral images on SM1

1000 sec exposure of sky during the night of 9/26, namely:



- SM1 has been "in operation" inside SCR (Spectrograph Clean Room for PFS spectrograph modules) on the TUE-IR (IR4) floor.
- There was no issue during the September & November runs.
- There have been no engineering works (i.e. no disturbance) in SCR during these periods except for minor works outside SCR.

Unfortunately, we couldn't take sky data in tracking/guiding with fibers intentionally placed on stars etc due to various constraints, Expected in the upcoming runs (so we think PFS not yet formally Engineering First Light(EFL)'ed yet strictly speaking ...).

Stability of Point Spread Function

- The goal is to model and subtract the sky on the spectrum from any fiber across the entire wavelength range.
- The stability of Point Spread Function (PSF) is therefore one key for the accurate sky subtraction.
- One possible cause of disturbing PSF is a chage of Focal Ratio Degradation (FRD) on each fiber due e.g. to Cobra moves.
 - FRD changes
 - \rightarrow Illumination of the spectrograph changes \rightarrow PSF of in-focus image changes
- Images on the right show off-focus & infocus images before and after Cobra moves of 6000 steps (quite large), and their differences.
- The residual in the images and 1D residual seems to be quite small: One source of headache may have been mitigated.



Stability of Point Spread Function

- large Cobra move The goal is to model and subtract the sky on lata, exposure = 71200, `phi` moved by 6000 data exposure = 7119 7000 the spectrum from any fiber across the 6000 5000 entire wavelength range. 4000 1% data $Q_{6735} = 1.13$ 1% data 104 2000 data Linear in Y data Ŧ Logarithmic in Y $\chi^2_{6735} = 3.34$ residual residual $Q_{40000} = 2.17$ 10^{3} $\chi^2_{40000} = 9.11$ 10² 1000 101 flux flux 100 -10^{0} -1000 -10^{1} Ŧ Ŧ -10^{2} 6-0.5) -2000 12 13 14 6 ż 8 9 10 11 15 16 17 18 19 pixel 17 12 S pixel 15.0 \rightarrow PSF of in-focus image changes 10.0 Images on the right show off-focus & in-7.5 focus images before and after Cobra moves of 6000 steps (quite large), and their difference imac differences.
 - The residual in the images and 1D residual seems to be quite small: One source of headache may have been mitigated.



After

Before

"Guiding (PFSAG)" on Gen2 \rightarrow

Only partial success due to rotator trouble etc Continued to the next engineering run.





Guide loop test around east, where InR rotation is small.

- Guiding error in Az-Alt is ~0.01" on average.
- Sometimes guiding error got large, when a group of the used stars changed. (Stars in all AG were used.)
- InR didn't converge, because of rotator was disabled.



Guide loop test around west, where InR rotation is small.

- Guiding error in Az and Alt is ~1" and 0.1" on average, respectively. (Error in Az was larger.). Only stars in AG2 and AG5 were detected.
- InR didn't converge, because of rotator was disabled.

PFS has no Shack Hartmann sensor.

→ Finding offsets of Hexapod positions from where they should be by fitting off-axis defocused images on the AG cameras with composite model images of aberrations.



Re-Analysis using actual Hexapod position.

<u>PFI Alignment result</u>

Analysis by Kawanomoto (NAOJ) [Focus offset=0.8 for Day1, and 0.5 for Day2]

IMAGE	INR	EL	Focus offset	Offsets at G1R1				Seeing size	Calculated Hexapod offsets				Hexapod position (top: current / <mark>bottom: optimized</mark>)			
			dz	sx	sy	tx	ty	SS	SX	SY	тх	ТҮ	SX	SY	тх	ТҮ
[Day 1]									+0.00	+0.00	+0.00	+0.00				
agcc_20211119_2242554.fits	-13.8	63.1	+0.174	+2.817	+1.648	-1.327	-2.243	0.745	+1.543	+2.402	-1.327	-2.243	0.00 -1.543	0.00 -2.402	0.00 +1.327	0.00 +2.243
[Day 2 #1]									+0.03	-2.72	+0.74	+3.20				
agcc_20211121_0402067.fits	48.7	68.0	-0.023	+1.493	-0.155	-0.478	+0.421	1.106	+1.732	+0.117	-0.478	+0.421	+0.03 -1.702	+2.72 - 2.837	+0.74 +1.218	+3.20 +2.779
agcc_20211121_0417390.fits	53.8	65.0	-0.016	+1.992	+3.766	+0.109	+0.059	0.898	+2.025	+3.704	+0.109	+0.059	+0.07 -1.955	+1.34 - 2.364	+1.18 +1.071	+2.35 +2.291
agcc_20211121_0424470.fits	55.8	63.6	-0.010	+1.520	+1.403	-0.305	-0.036	1.061	+1.499	+1.577	-0.305	-0.036	+0.09 -1.409	-0.65 -2.227	+1.07 +1.375	+2.29 +2.326
[Day 2 #2]									+0.00	+0.00	+0.00	+0.00				
agcc_20211121_0431377.fits	57.5	62.1	-0.015	+3.098	+1.453	-1.216	-2.649	0.904	+1.594	+2.144	-1.216	-2.649	0.00 -1.594	0.00 -2.144	0.00 +1.216	0.00 +2.649
agcc_20211121_0437224.fits	58.7	60.9	-0.017	+1.668	-0.649	-0.130	+0.039	0.871	+1.690	-0.575	-0.130	+0.039	+0.02 - 1.670	-3.10 -2.525	+1.22 +1.350	+2.65 +2.611
agcc_20211121_0445083.fits	59.3	60.2	+0.007	+1.409	-1.317	+0.199	+0.059	0.899	+1.443	-1.430	+0.199	+0.059	+0.03 -1.413	-4.82 -3.390	+1.15 +0.951	+2.48 +2.421
[Day 3]									+0.03	-2.72	+0.74	+3.20				
agcc_20211121_1829135.fits	81.0	59.0	-0.114	+1.259	-0.617	-0.389	+0.422	1.657	+1.499	-0.396	-0.389	+0.422	+0.03 - 1.469	-2.72 -2.324	+0.74 +1.129	+3.20 +2.778

On average, optimal Hexapod position for PFS: SX=-1.6, SY=-2.5, TX=+1.2, TY=+2.5 c.f.) Hexapod position for HSC: SX=-1.8, SY=-2.6, TX=+1.0, TY=+2.5

"Event" log & path forward

During the Sep run (9/13-26)

•

- Insufficient safety features for instrument rotator operation
 → No rotator operation was allowed.
- Part of the electronics assembly "E-box" for power distribution & communication behaved very unstably
 No AC compare operation was possible
 - \rightarrow No AG camera operation was possible.
- The Oct run (10/15-21) was cancelled to focus on engineering works in Oct and early-mid Nov.
- On 11/15, the day of PFI → POpt2 right before the Nov run ...
 - Coolant leak was found (it turned out it happened by a human error).
 The leak was quite localized, but clean-up took a couple of days
 - \rightarrow The run had to be shortened from 5 nights to 3 nights.

"Event" log & path forward

During the Nov run (11/19-21)

- It took much longer to be able to run and test field acquisition & auto guiding processes.
 - \rightarrow Came into the 3rd night without many other tests done.
- When we started seeing successful operation of auto guiding, in the midnight of 11/21, a rotator trouble happened (it turned out by breakage of a limit switch due to mechanical interference during transportation)

 \rightarrow No further rotation operation became impossible. Full validation of field acquisition & auto guiding and other on-sky tests ended up being postponed.

After the Nov run ...

•

- Design studies for modifications to prevent such limit switch trouble are ongoing.
- An upgraded "E-box" is being prepared and tested for a replacement
- Various testing, data analyses, and software development activities are ongoing exploiting the six-month interval before the next runs (5/13-19 & 6/15-21)

Data processing

An schematic overview





2D Data Reduction Pipeline (2D DRP)



← Reduced SuNSS data before and after subtraction of sky continuum (lines are also subtracted on a few fibers)



While major developments are being conducted by Princeton, some key elements are being developed by other institutes:

- Flux calibration routine, automatic reduction mechanism (Yamashita, Mineo [NAOJ])
- End-to-end data processing and data evaluation (Yabe, Mardini [IPMU])
- Characterizing FRD impact [Caltech]
- Analysis of *SuNSS "diffuse" spectrum*: Noise on a sky-subtracted spectrum is consistent with 0.6% systematic error.
- Obviously processing on-sky data from upcoming engineering observations and optimizing the processing performance are next steps.

Caltech



1D Data Reduction Pipeline (1D DRP)

Processing 50,000 simulated galaxy spectra at 0.8<z<2.2, assuming 2-hour integration \rightarrow 97.5% success (<10⁻³ relative error)

Redshift error vs. [OII] flux



• 1D DRP

- Various measurements on fully reduced & calibrated 1D spectra
- Developed by LAM (plus NAOJ & Caltech for stars)
- Current version 0.26. Updates are released a few times per year.
- Star separation & radial velocity measurement are part of targets for next major updates.

Correct redshift determination for a



Data processing



An schematic overview





Data processing



An schematic overview

NAOJ & Science DataBase (SciDB) JHU database team

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.

ine SQL Editor 4000 PFS Proto-type Science Database v2 3500 2D SIM 3000 Image Cutouts 2000 1500 Prototype Ver. 2.5 has been OBS 1000 in operation for trials and 500 subsequent feedback to the SM1 data production version. Princet Ploting object w/ NAOJ, LAM Selectable catalo

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.

Open-use observation operation framework

• The main site of discussion and development is the Observation processing ("Obsproc") WG chaired by M. Tanaka (NAOJ).

He et al. poster p4 at this UM.

Also He et al. 2021 ASJ Fall meeting.



- Framework (Tanaka)
- PFS Pointing Planner (He)
- F star selection (Ishigaki)
- Target database (Onodera)
- ... etc

<u>Discussion session (in Japanese)</u> tomorrow afternoon:

- Observation preparation
- Target completeness
- Ranking programs
- Filler targets
- ... etc

On-telescope fiber cable ("Cable B")

- Second cable ("B2")
 - Already in Hilo
 - Passed post-shipment inspections and tests.
 - Pre-installation optical tests and installation to the telescope are to be scheduled.
- Third & fourth cables ("B3" & "B4")
 - In the final phase of integration and test at LNA in Brazil.
 - Optical test results look good so far.
 - Pre-ship review for both cables in Feb?
 - These are the last works by the PFS team in Brazil.





Spectrograph System (SpS)

- Spectrograph Module (SM) #2 and #3 are being integrated and tested.
- However, a while ago the team found an unexpected tilt offset of focal place against the detector which has been stalling/slowing down the progress.
- The root cause still remains to be understood but the team has been intensively doing various tests and analyses and narrowing down potential error sources.
- The goal is to deliver one SM (perhaps only w/ blue and red) to Subaru in June, and another (w/ blue, red and NIR) in summer.







24

NIR Camera Unit (NCU)

- While NCU#2 & #3 are under integration , #1 has been fully assembled and cold for testing.
- The image quality of #1 looks good as expected (i.e. the optics are well aligned).
- The thermal performance of #1 looks good so far. It will be fully validated in the operation condition at LAM (with the ambient temperature controlled to 5<u>degC).</u>
- In parallel, detector testing is ongoing in a test dewar for persistence characterization (Hamano+ 2021, ASJ Fall mtg,), optimal use of interleave reference pixels, etc.
- The goal is to deliver #1 to LAM in April, #2 to Subaru in summer.



NIR1 Image PSFs – actual vs. optical design

We are seeing good agreement in the through-focus curves between the real image data and the Zemax spot diagrams, in terms of overall shape of the PSFs. This comparison is for 1180 nm, before the mask was installed.



PFS coming out of 4th corner

- PFI arrived at Subaru summit in June 2021. Subsequently, engineering observations started with PFI, Cable B1 & SM1 B+R. Two runs completed in Sep and Nov 2021. While various progresses were made, troubles delayed going beyond. Persistent efforts are ongoing for formal First Light & continued success in the upcoming runs, and remaining hardware deliveries.
- Near-term timelines to pursue starting scientific operation from ~2023:
 - Next E-runs in May & June 2022.
 - Cable B3 & B4 in Spring 2022.
 - SM2 in June, SM3 in summer 2022.
 - ... etc









- Official web site <u>https://pfs.ipmu.jp/</u>
- Membership registration <u>https://pfs.ipmu.jp/research/regist_collab.html</u>
- Blog <u>https://pfs.ipmu.jp/blog/</u>
- Instagram <u>https://www.instagram.com/pfs_collaboration/</u>



When Subaru gets a bit older e.g. 30 years-old ... PFS will have been part of its tripodic backbone.



Jo the widest for





Prime Focus Spectrograph







The Sharpest

MATE-Subaru