Fiber throughput variation discovered during PFS engineering observations

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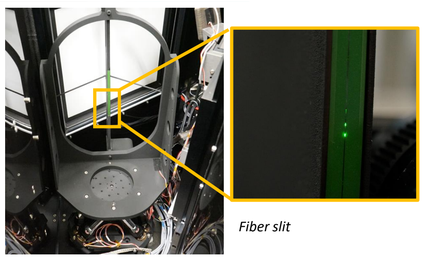
PFS is one of the new and key facility instruments in the Subaru 2 era, developed by the international consortium led by Kavli iPMU, in collaboration with NAOJ. PFS is fiber-fed multi-object (~2400) spectrograph. The fiber cables consist of three sections, with two connectors on the telescope spider arm and in the temperature-controlled clean room. PFS engineering observation using celestial objects started in 2021. Since then, we have been validating the instrument performance, and developing the operation and data processing. Recently, we discovered that the relative throughput among the fibers varies with a few % of amplitude in the timescale of a few hours. This made it impossible to achieve sky subtraction with an accuracy of 0.5 %. The intensive discussions among the team found that the root cause is instability on the fiber connector on the telescope. Change in tiny air gap between the fibers (<1um) changes amplitude and phase of fringe pattern in spectra, which causes throughput variation. Indeed, the fibers to which the index matching gel was applied on the telescope side showed stable throughput for a whole observation period in October 2024. Following the result, we are developing an operation scenario to improve instrument performance considering work load and time. In this poster, we are reporting the discovery of the fiber throughput variation, and the current operation scenario.

1. Introduction -- PFS Fiber system

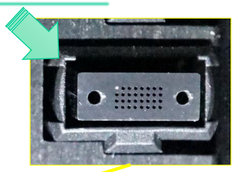
PFS has ~2400 fibers

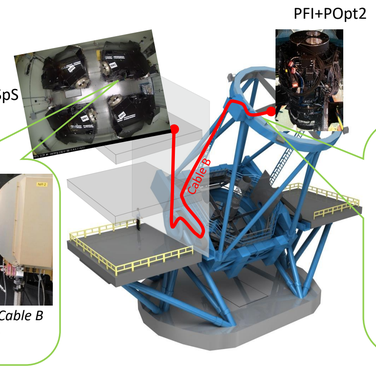
- PFS fiber cables consists of 3 sections (~67m in total)
  1. Cable C : PFI, attached to fiber positioner
  2. Cable B : Routed on the telescope to deliver the light from PFI (at Prime Focus) to SpS (4th floor of the dome building)
  3. Cable A : SpS (fiber slit)
- Therefore, the fiber cables have two connectors.
  - "Tower" connector on the telescope spider arm to connect Cables C and B. -> The connectors are unplugged and re-plugged at every TUE (i.e. every PFS run).
  - "Gang" connector in SCR (Spectrograph Clean Room) to connect Cables A and B, where temperature is controlled to be 4 degC.
- In each connector, USCONEC "MTP" ferrules are accommodated grouping 28 or 29 fibers.
  - Made by plastic.
  - Each SM has 21 MTP ferrules.

Fiber positioner module



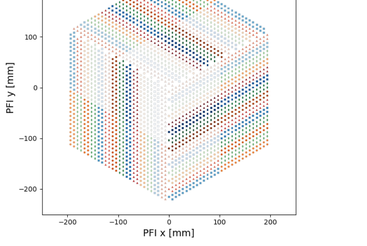
Fiber slit



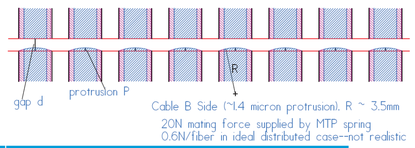


Gang connectors b/w Cable B and SpS in SCR (Stable environment)

Tower connectors b/w Cable B and PFI on the telescope spider (Change in temperature, humidity, gravity)



The science fibers populated on the PFI plane. Colors indicate MTP group. The mark indicate spectrograph



Connector	For	Location	Temperature	Gravity	Cadence of connection
Tower	PFI and Cable B	telescope spider arm	Changing	Changing	every TUE
Gang	SpS and Cable B	SCR (4th floor)	4C +/- 0.25C	Stable	Permanent connection once integration is completed

2. Fiber Throughput Variation

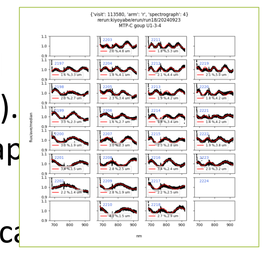
Recently, it was found that relative throughput among the fibers were changing, which makes accurate sky subtraction impossible because normalization doesn't work.

- Time scale: < night
- Amplitude: a few %
- No change by moving the telescope (El, Az, InR) and/or fiber positioners.
- A significant change was observed when the dome was opened and closed in ~50min.
- Variation looks grouped by MTP ferrules.

Comparison of the quartz spectra at different time on a single night (8/28) Right: contour of flux ratio for all the fibers. There are some bands showing fringe with a few % amplitude. (Note: persistence is also seen in nir cameras) Left: averaged flux ratio in wavelength from 557.7nm to 558.5 nm

From the above features, the variation is thought to be caused by change in air-gap between fiber terminations (MTP ferrules).

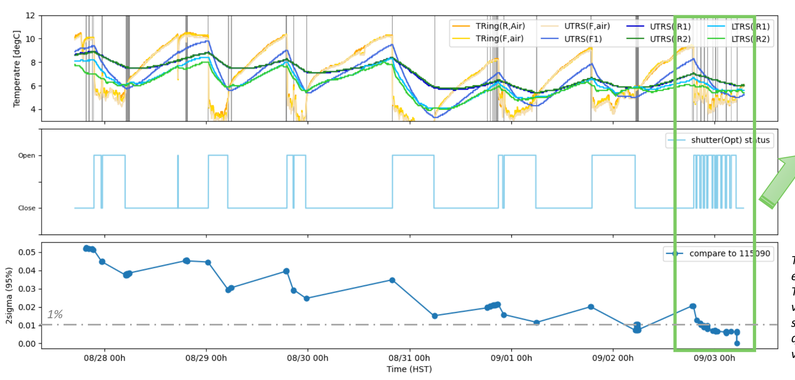
- Fringe in quartz spectra suggests existence of the air gap fiber surfaces at the connectors.
- The fiber of Cable B is polished with protrusion, which ca contact when the fibers were connected.
- Tiny change in gap (<1um) can cause amplitude and/or phase change
  - Tiny change can occur by thermal change as MTP (in size of O(10mm)) is made from plastic. (CTE of plastic: ~1e-5 /degC)



Quartz spectra in r arm for the fibers in the one of the MTPs. Black is data and red line is fitted model.

To normalize the fiber throughput, it is required to take quartz spectra in short interval.

- Large overhead, and load on telescope&dome and its operation.
- Impact on persistence of H4RG detector in NIR cameras



Monitoring the variation on one night suggests that a few quartz spectra should be taken intermittently in the 1st half night, and a couple in the 2nd half night.

Time variation of quartz spectra along with telescope status in the engineering observation in August 2024 (7 days). Top panel shows temperature of telescope truss and surrounding air. The vertical grey lines shows when quartz data were taken. Middle panel shows dome shutter status. Bottom panel shows 2 x standard deviation of quartz spectra divided by reference spectrum as an indicator of amplitude of variation. Here the reference is the last spectrum in the sequence.

3. Solution to reduce the variation

Operational solution (frequent acquisition of quartz spectra) was raised. However, this requires much time and load, so another solution was discussed.
Index matching gel (Nye OC-431A sold as Thorlab G608N3) was suggested to fill the air gap on the connector and suppress the throughput variation.

- Silicon type and commonly used
- Lifetime ~200year (at room temperature)

Effect of the gel was tested in the engineering observation in October 2024.

- The gel was applied to several MTP groups: 6 on Gang connector (SpS, SCR) and 5 on Tower connector (PFI, telescope). 2 MTP groups had a gel on both sides.

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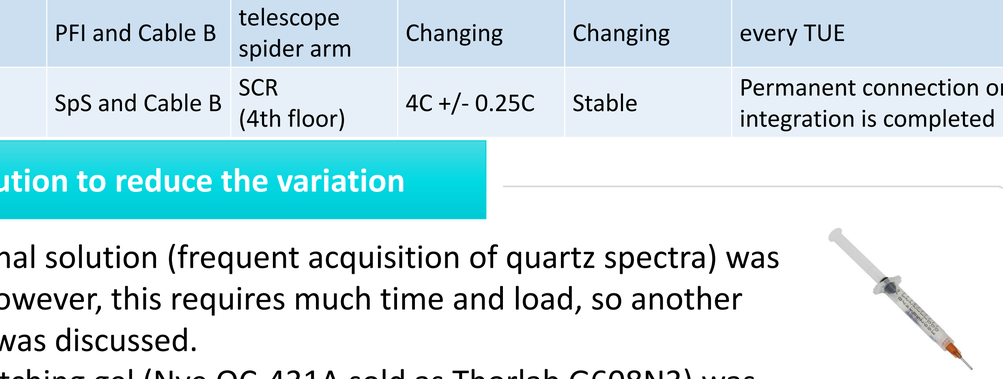
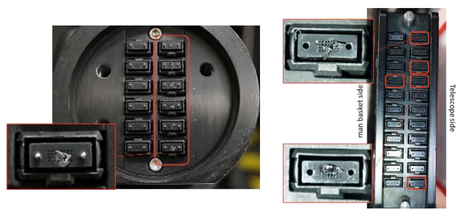
- The fibers to which gel was applied on Tower connector (on the telescope spider) show much smaller variation.
- Also, fibers with gel showed a few% higher throughput, compared to the previous runs.



Time variation of quartz spectra along with telescope status in the engineering observation in October 2024 (6 days).. In bottom panel, in addition to the result for all fibers, result by grouping the fibers in terms of gel application is also shown.

Thorlab G608N3
https://www.thorlabs.com/thorproduct.cfm?partnumber=G608N3



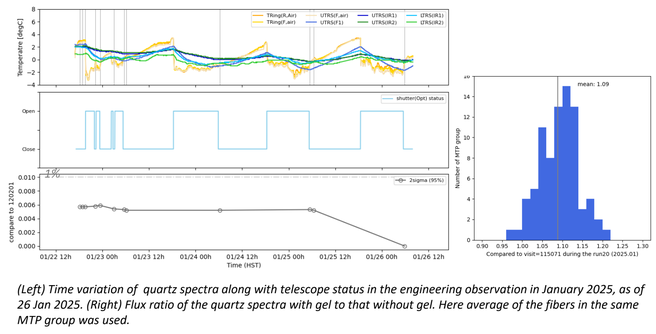
Applied gel on Gang connector (left) and Tower connector (right)

Following the result in October 2024, the throughput stability was being tested in the engineering observation in January 2025. The gel was applied by manually with three persons.

- The effect of gel.
- Time to apply the gel.
  - Tower side: 1 hour by 2 persons.
- Time/load to clean the gel will be estimated after the observation.

Preliminary Results

Preliminary result shows that throughput variation seems small enough at least for a few nights. Also, throughput seems higher by ~8% on average, although there is a few % variation by just unplugging and re-plugging the connectors.
Stability over the run needs to be tested



(Left) Time variation of quartz spectra along with telescope status in the engineering observation in January 2025, as of 26 Jan 2025. (Right) Flux ratio of the quartz spectra with gel to that without gel. Here average of the fibers in the same MTP group was used.

4. Operation Scenario and Future Work

From the test in the last engineering runs the current operation scenario is to use the index matching gel.
Operation for long-term operation needs to be established.

- Time and load to apply and clean the gel. The gel on tower connector needs to be cleaned every run (i.e. monthly or bimonthly).
- How to control the amount of gel.
- Impact on leaving the gel on the fiber surface. Dust may be caught more easily with gel on the surface.

- Tools and part modification are being discussed for more efficient work.
  - Dedicated cleaning machine

Tools to assess to stability of fiber throughput is being developed by DRP team (See Takahashi's poster).