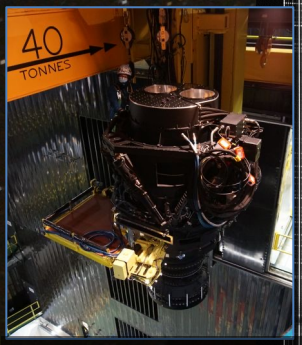
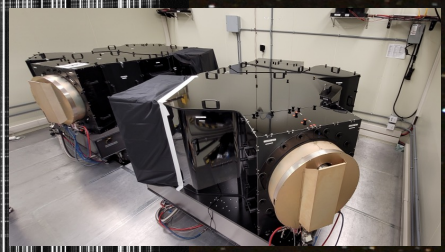
SUBARU PRIME FOCUS SPECTROGRAPH

Updates of the next-generation Subaru facility instrument
under commissioning







Naoyuki Tamura
[Kavli IPMU by 3/31 → Subaru, NAOJ from 4/1]
On behalf of PFS collaboration

SuMIRe
Prime Focus Spectrograph

Mar 8 2023 JST @Kavli IPMU
学術変革領域 FY2022 シンポジウム

Prime Focus Spectrograph

M31 on a single shot by HSC

PFS will configure

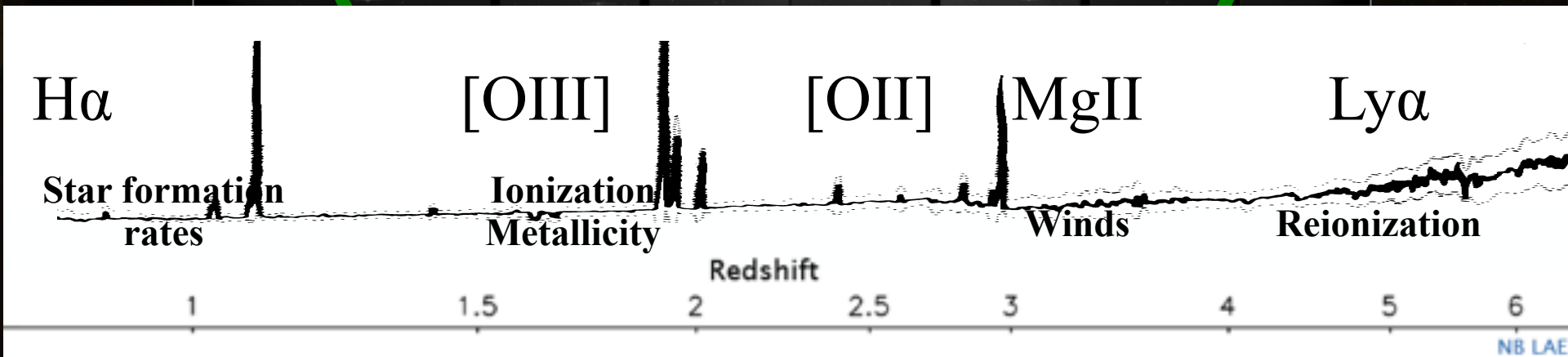
2394 individual fibers

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

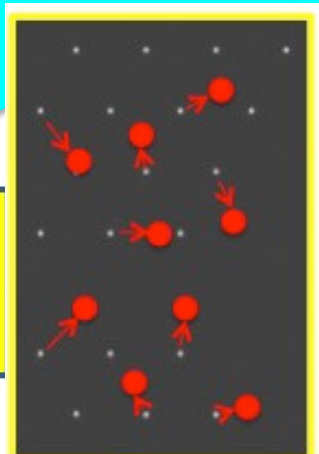
Wide-field corrector

… 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.*

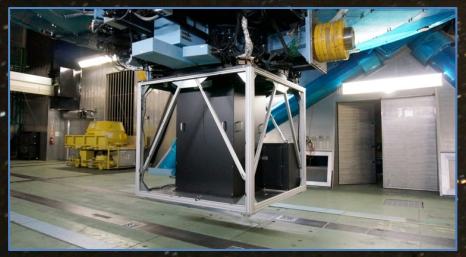
Metrology camera as a Cassegrain instrument



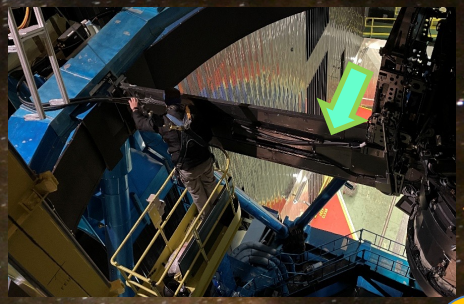
Subaru Telescope

PFS commissioning *has been* underway.

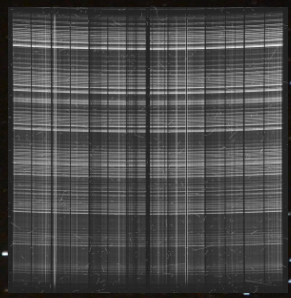
Metrology Camera System installed 1st time on the Cs focus (Jun 2018).



1st Fiber Cable (Cable B1) was installed (Feb 2021).



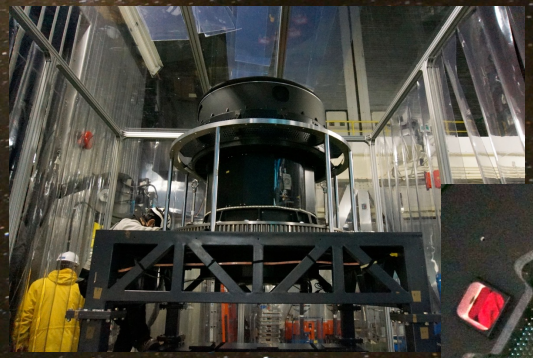
1st system test on the telescope (Sep 2021).



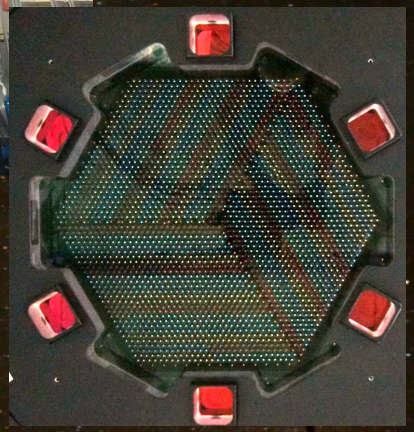
2018 | 2019 | 2020 | 2021 | 2022

Engineering observations

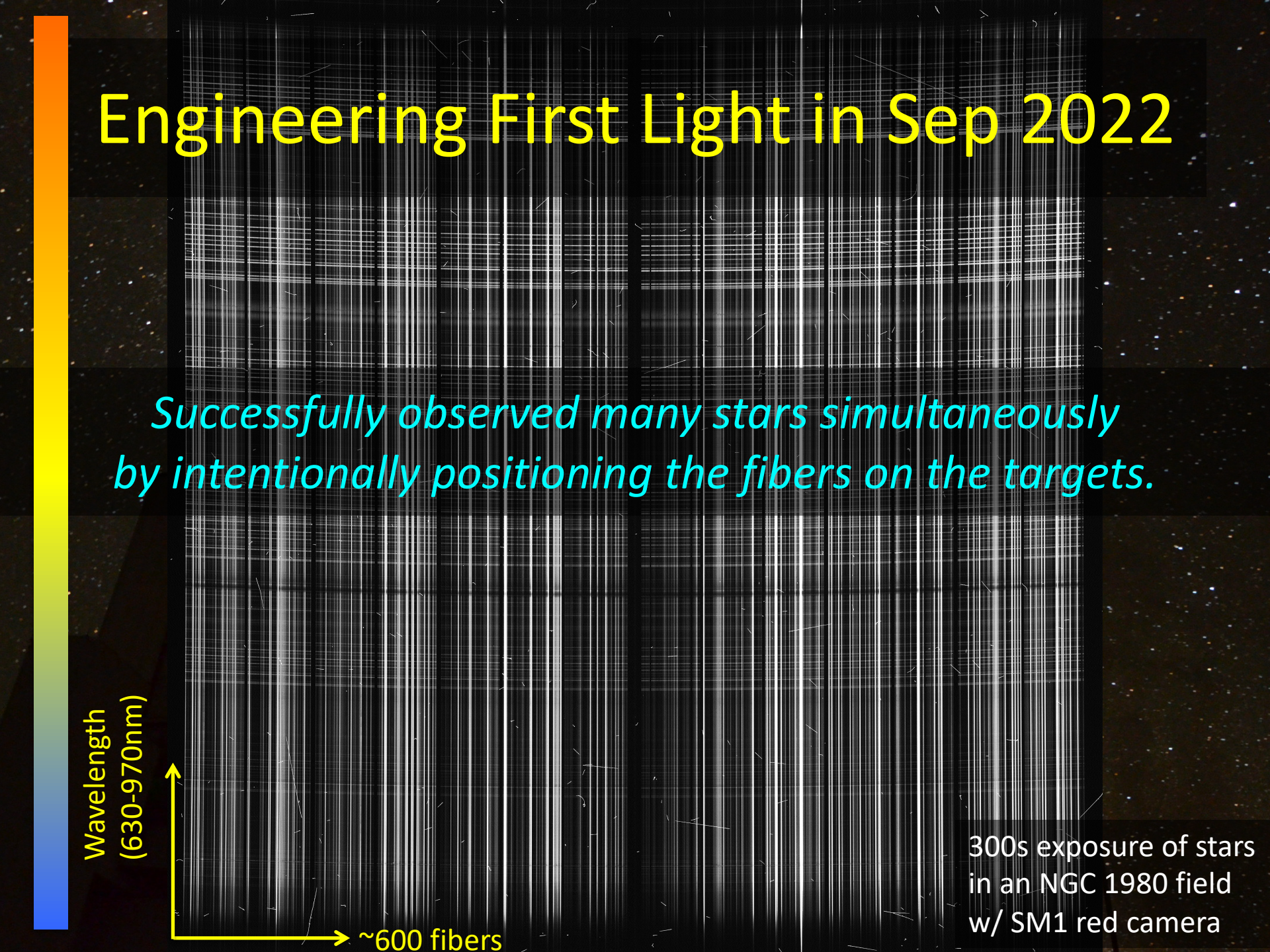
1st Spectrograph Module (SM1) was installed (Dec 2019).



Prime Focus Instrument (PFI) was delivered & re-validated (Jun-Sep 2021).



Engineering First Light in Sep 2022

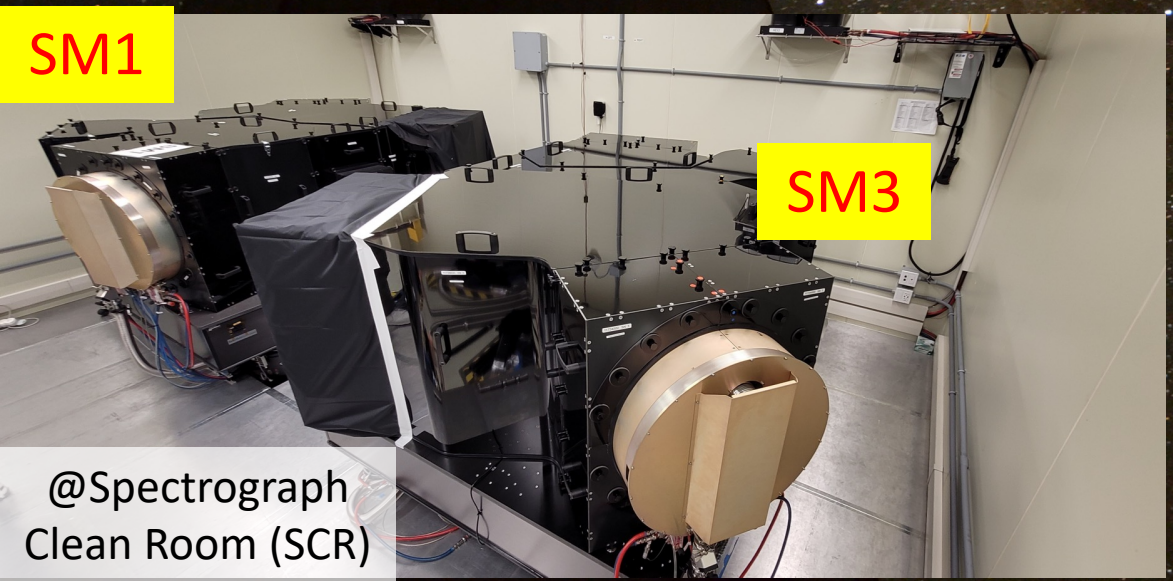


Successfully observed many stars simultaneously by intentionally positioning the fibers on the targets.

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

Now two fiber cables & two spectrograph modules in place

Successful installation of 2nd Fiber Cable (Cable B2) in April 2022.

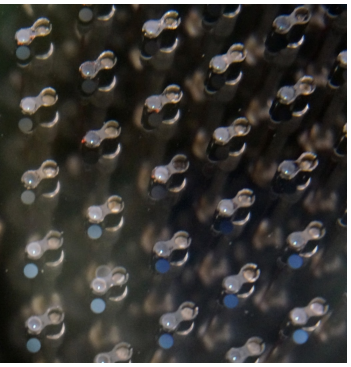


- *Completed installing SM3 in early Nov 2022.*
- *Started its operation right away according to the good results of post-installation tests.*

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

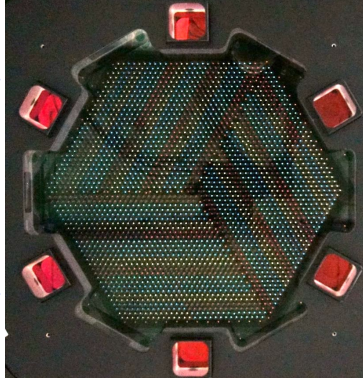
Two more modules to come for the full multiplicity of ~2400

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



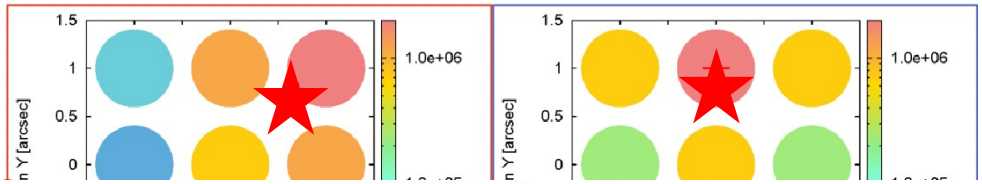
8mm between
adjacent Cobras

40cm



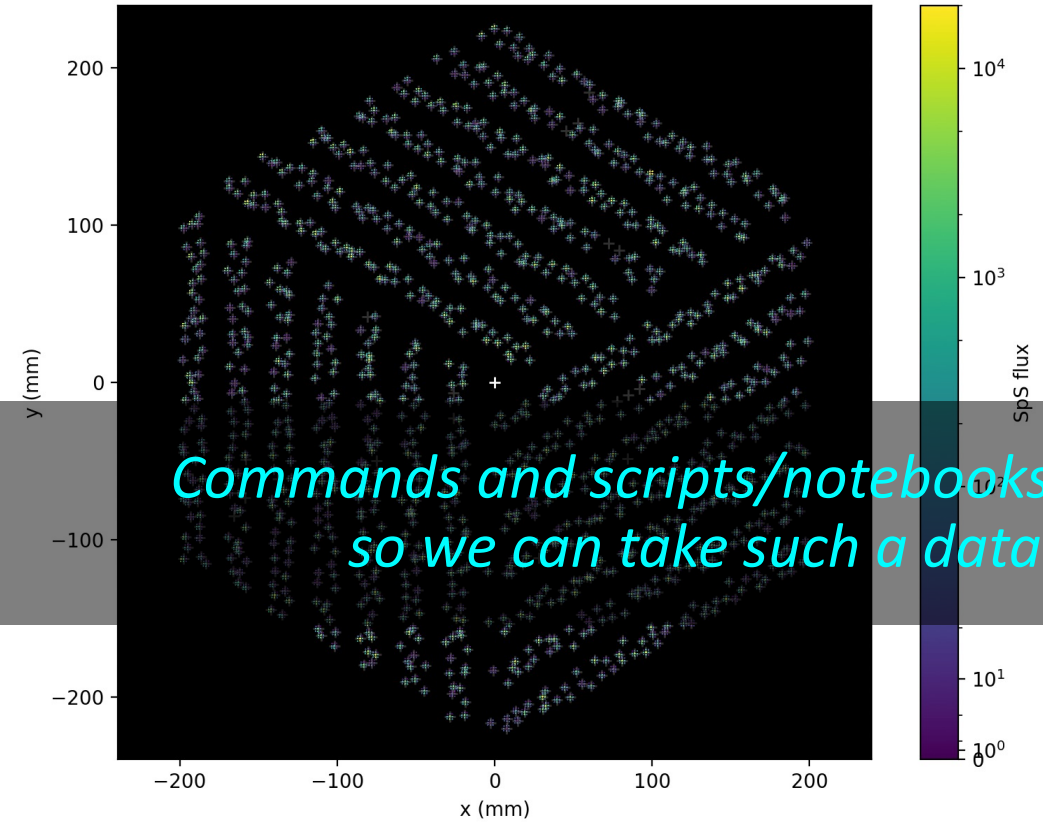
Fiber positioning accuracy

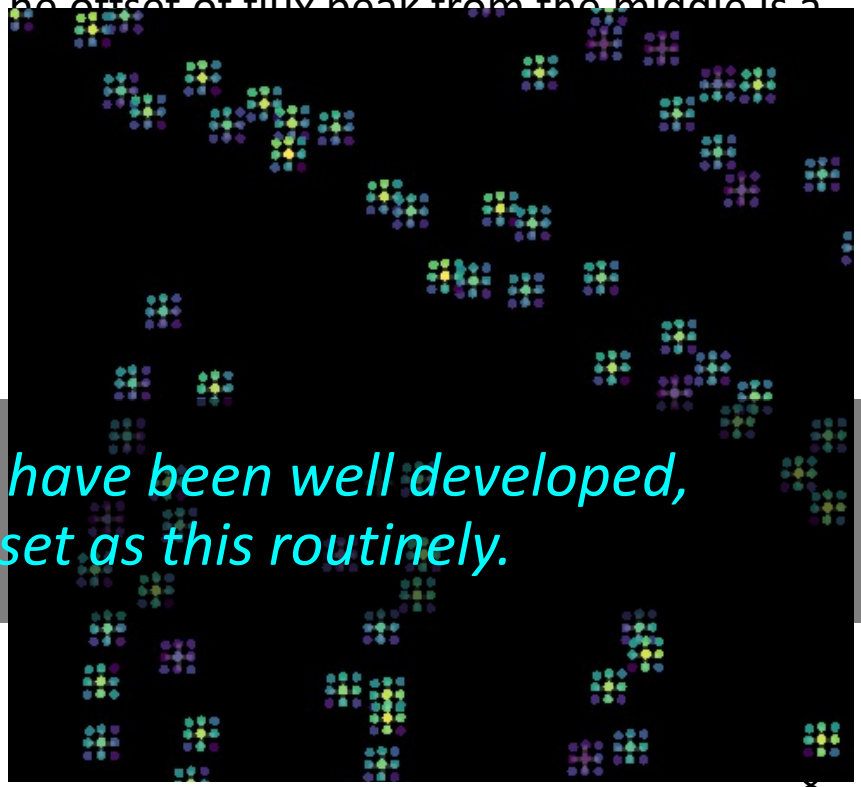
1. Accurately predict (x,y) from (α, δ).
2. Accurately move the fiber to requested (x.y).



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



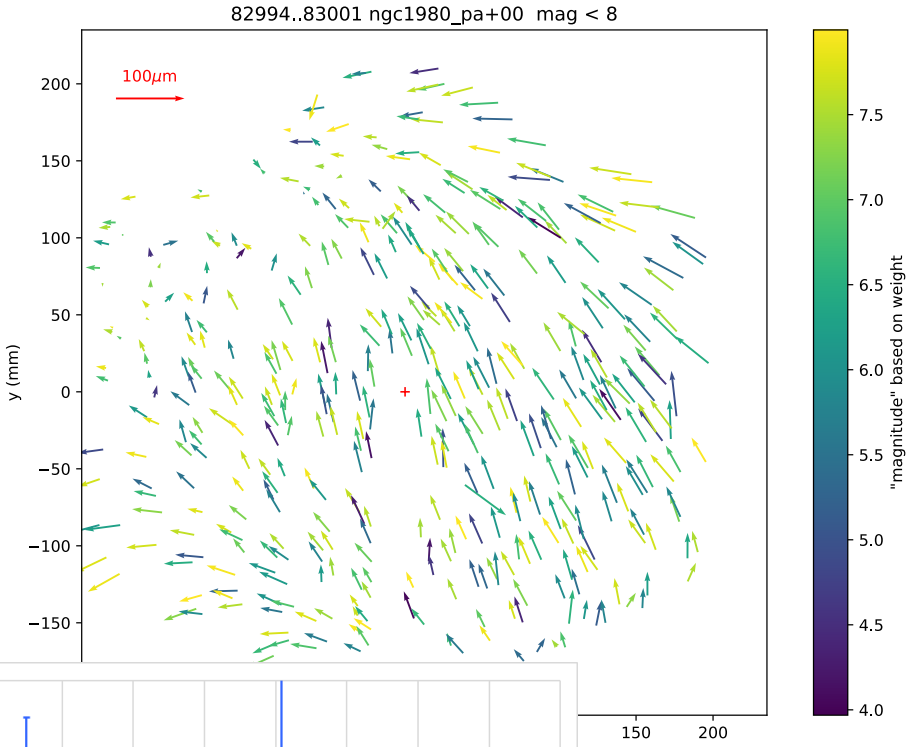


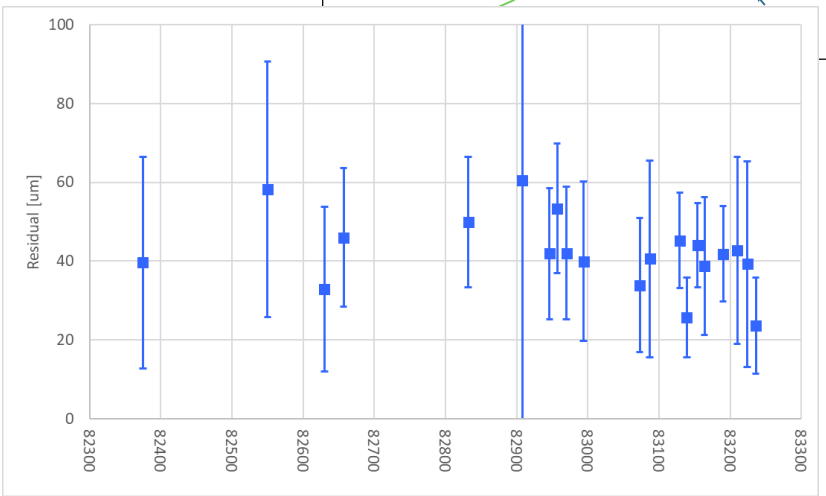
Commands and scripts/notebooks have been well developed, so we can take such a data set as this routinely.

The fiber diameter is equivalent to 100um

- 1”.13@Field center
- 1”.03@Field edge

Fiber positioning accuracy





Systematic errors are dominant.

- Translational/rotational offset
  ← Some issues in the field acquisition and/or guiding?
- Scale error
  ← Inaccurately modeled?

After numerically subtracting these offsets and scale error.

Furthermore, averaging the errors from 10 sets of raster scan data.

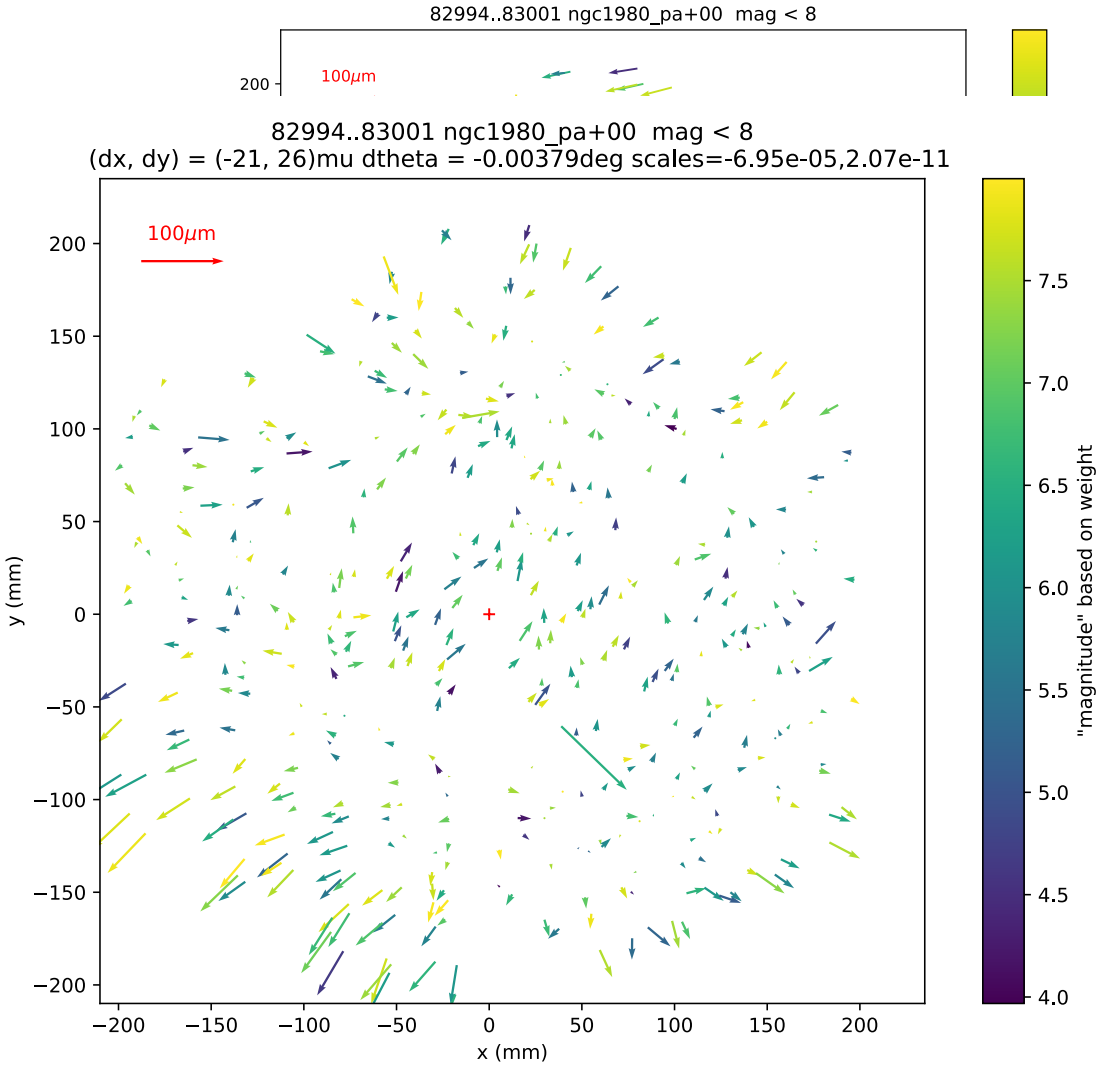
Takeaways:

- The error seems dominated by the large-scale & small-scale systematics. Minimizing these is the priority.
- The contribution from the positioner’s stochasticity seems very little.

The fiber diameter is equivalent to 100um

- 1”.13@Field center
- 1”.03@Field edge

Fiber positioning accuracy



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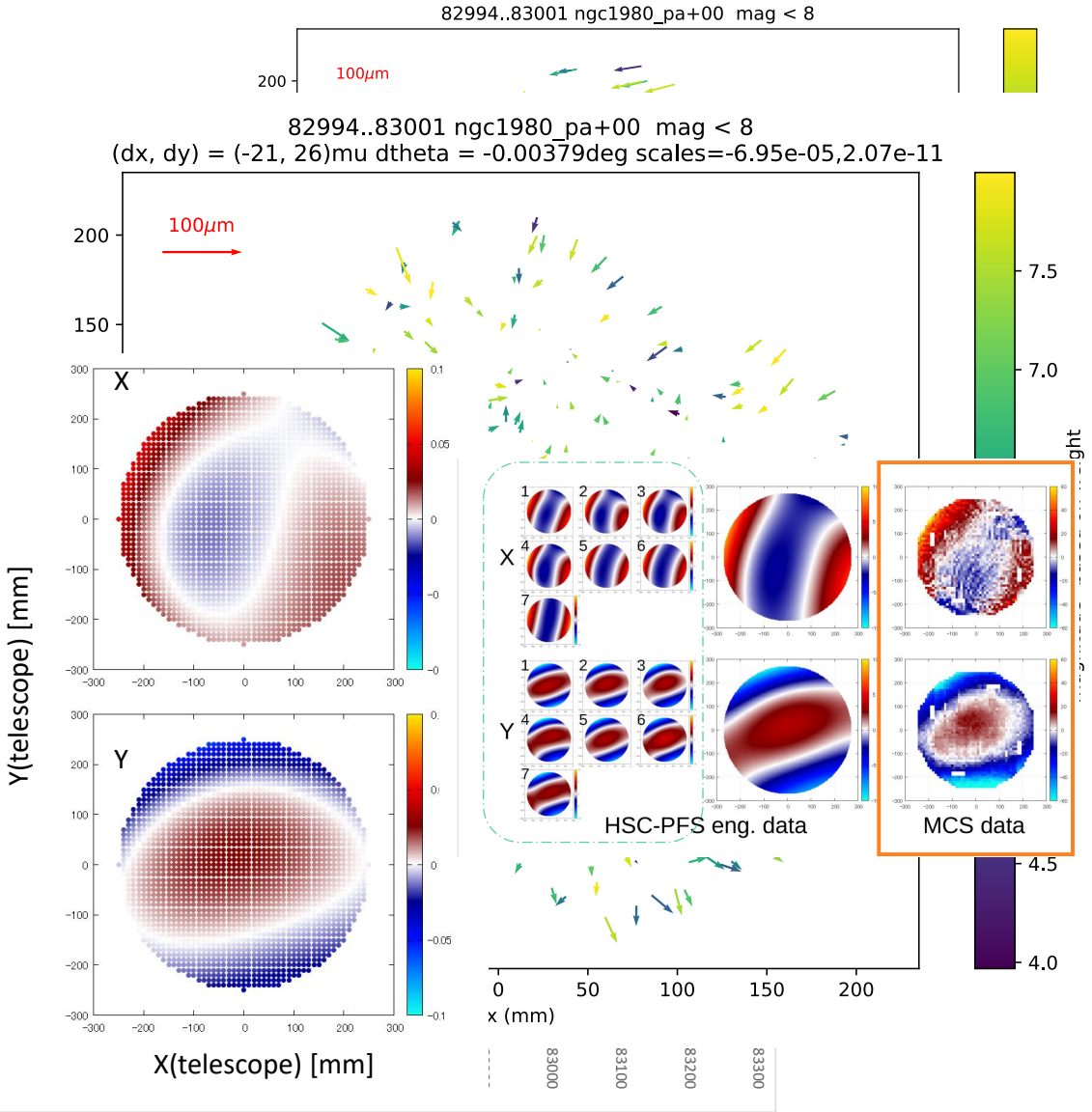

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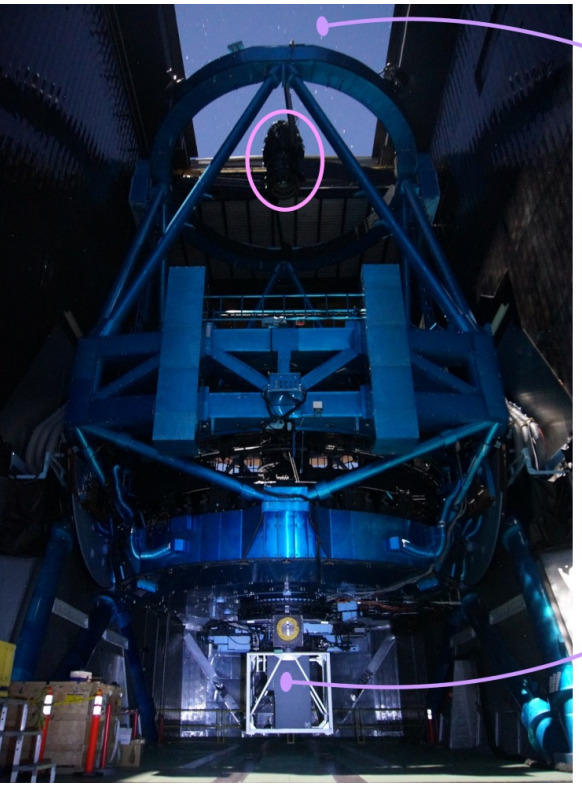
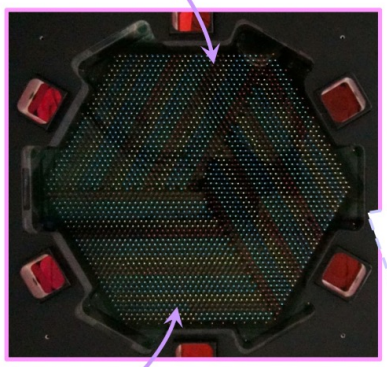
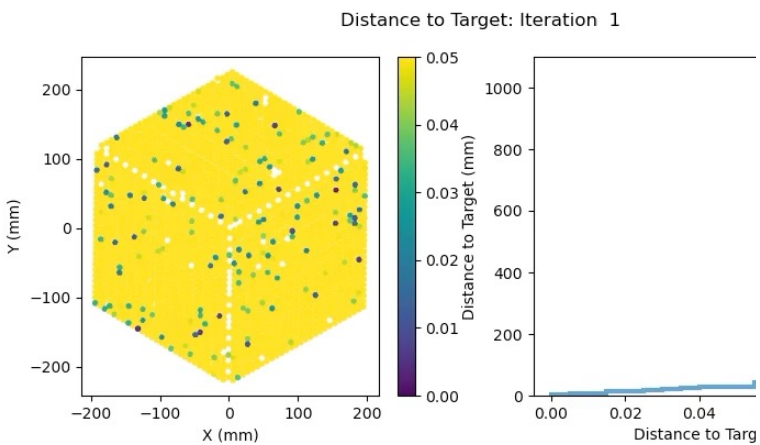
Fiber positioning sequence

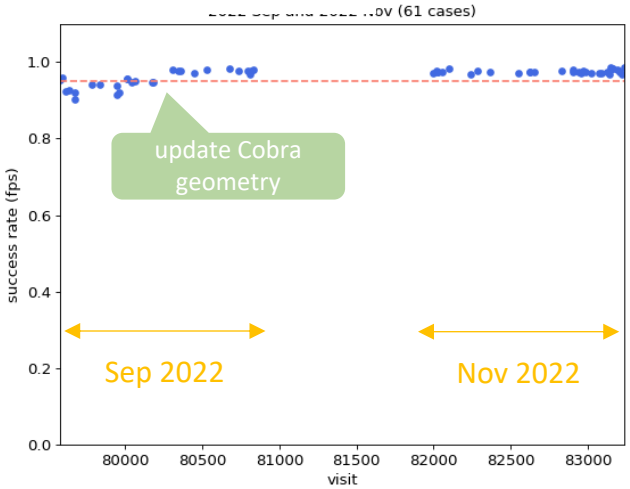
1. Accurately predict (x,y) from (α, δ).
2. Accurately move the fiber to requested (x.y).

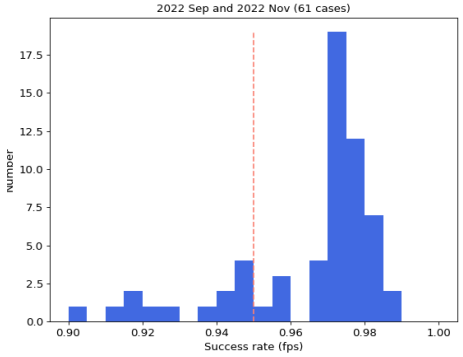




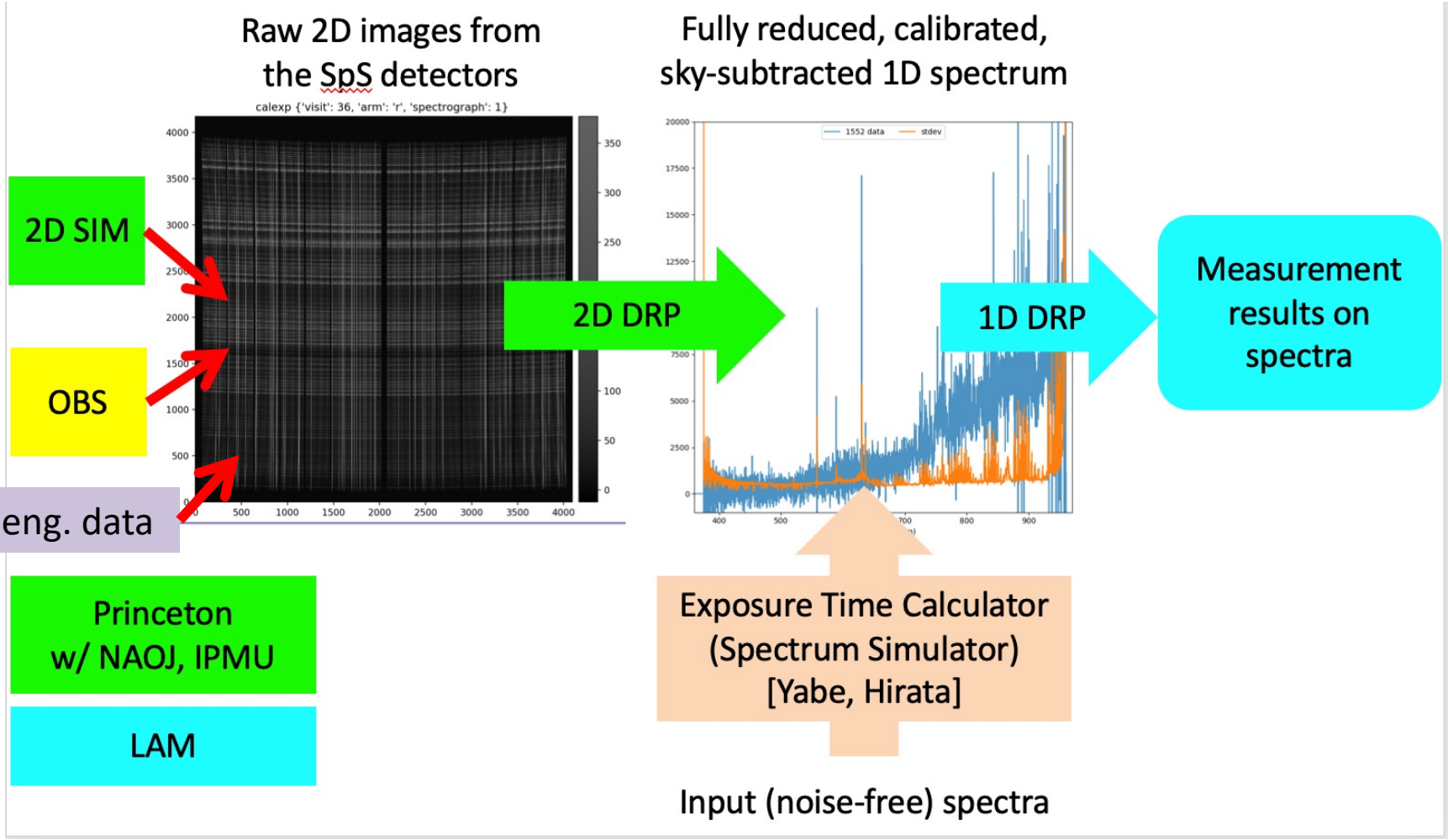
- Iterative process between PFI and MCS: Measure the current positions, calculate deltas, and move the fibers.
- 12 iterations are applied but improvement seems little after ~7th iteration.
- ***>95% success rate*** is now stably achieved with 4.8s MCS exposure.
- The processing time of each iteration is one vital engineering item:
  - ~400s/~270s by 12/7 iterations, respectively.
  - Detailed profiling & optimization are needed, while MCS data I/O seems major contribution







Data processing



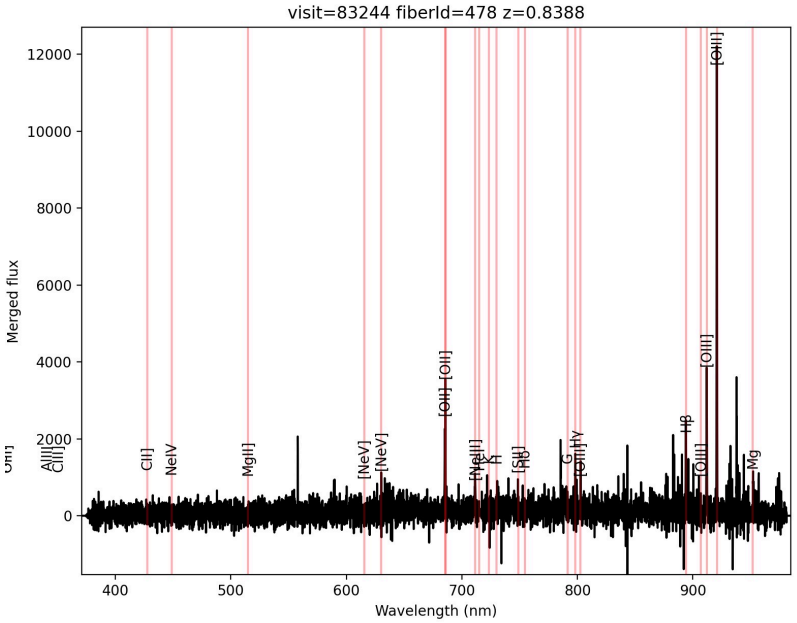
Updates are applied to the pipelines continuously.

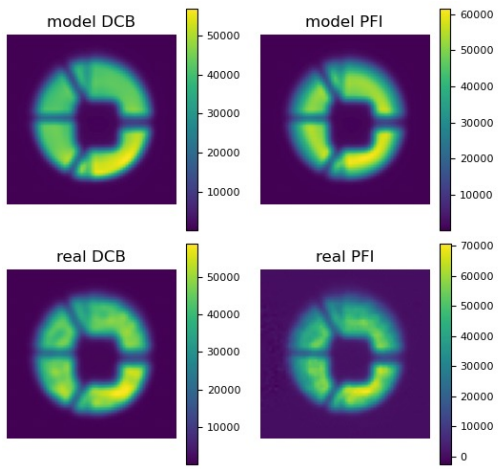
→ ***Weekly*** integration test: 2D (Princeton), 1D (LAM) & ***End-to-end (IPMU)***

2D Data Reduction Pipeline (2D DRP)

Current status:

- The pipeline (Lupton, Price+) is getting to be able to process data from engineering observations all the way down to flux calibration that is being developed at NAOJ (Yamashita, Mineo+).
- 2D PSF modeling as a key to very good sky subtraction still needs substantial development, while the spectrograph part seems quite well modeled already (Caplar, Hayashi, Yabe, Kawanomoto+).
- Useful QA plots are being identified (e.g. those for accuracies of wavelength calibration and sky subtraction) and appropriate tools need to be developed (Hamano, Tanaka, Yabe, Siddiqui, Price+).

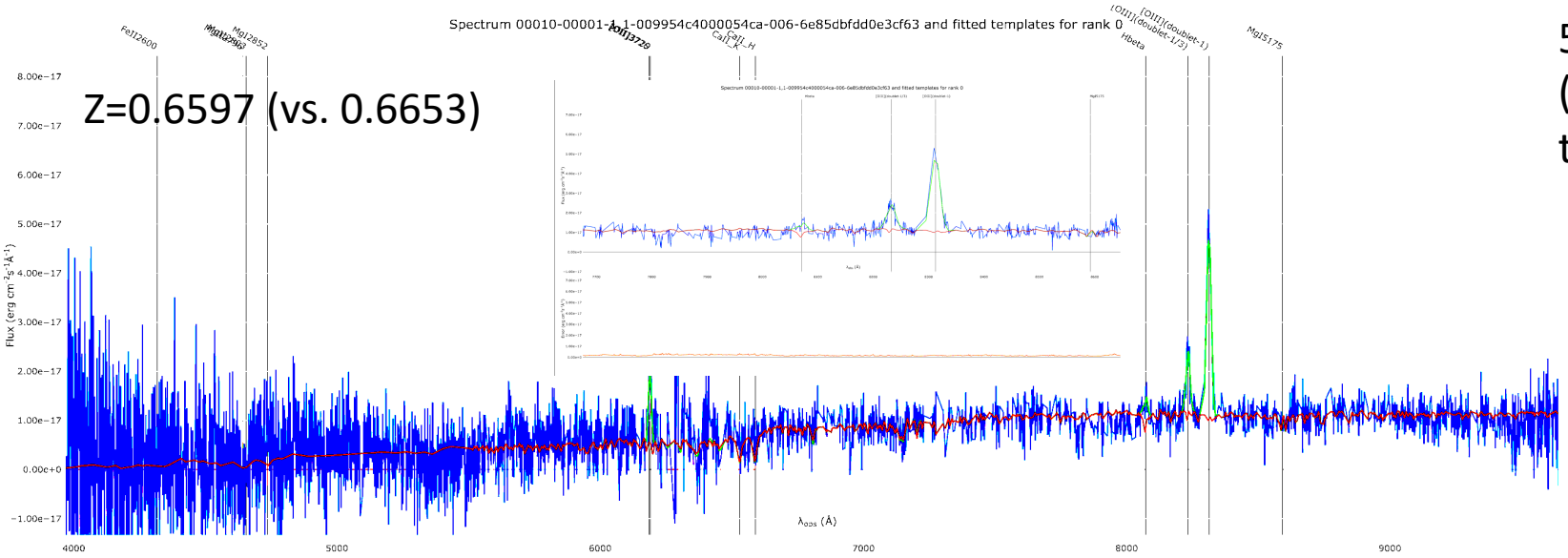




"DCB" ~= Spectrograph
"PFI" ~= Everything

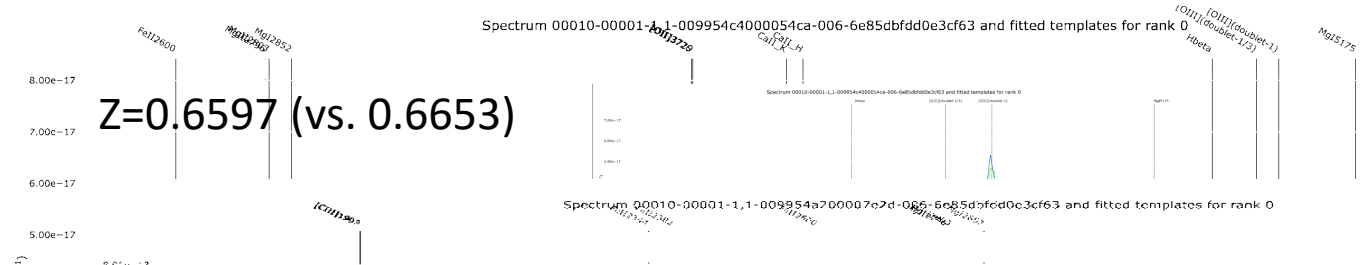
(Hayashi, Yabe [Kavli IPMU] with others)

1D Data Reduction Pipeline (1D DRP)

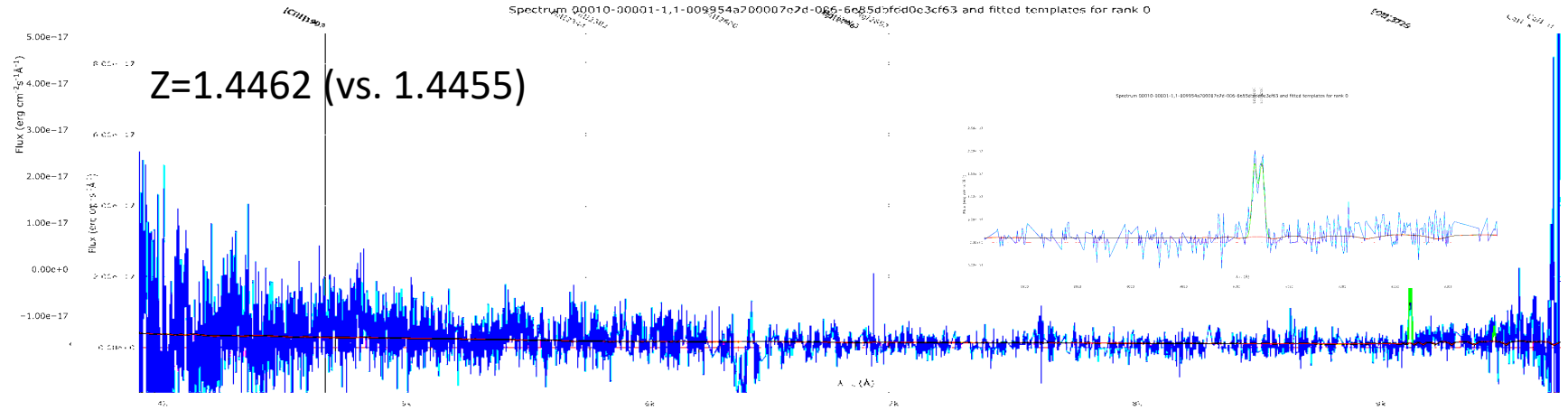


5400sec (900x6) in the Nov run

1D Data Reduction Pipeline (1D DRP)



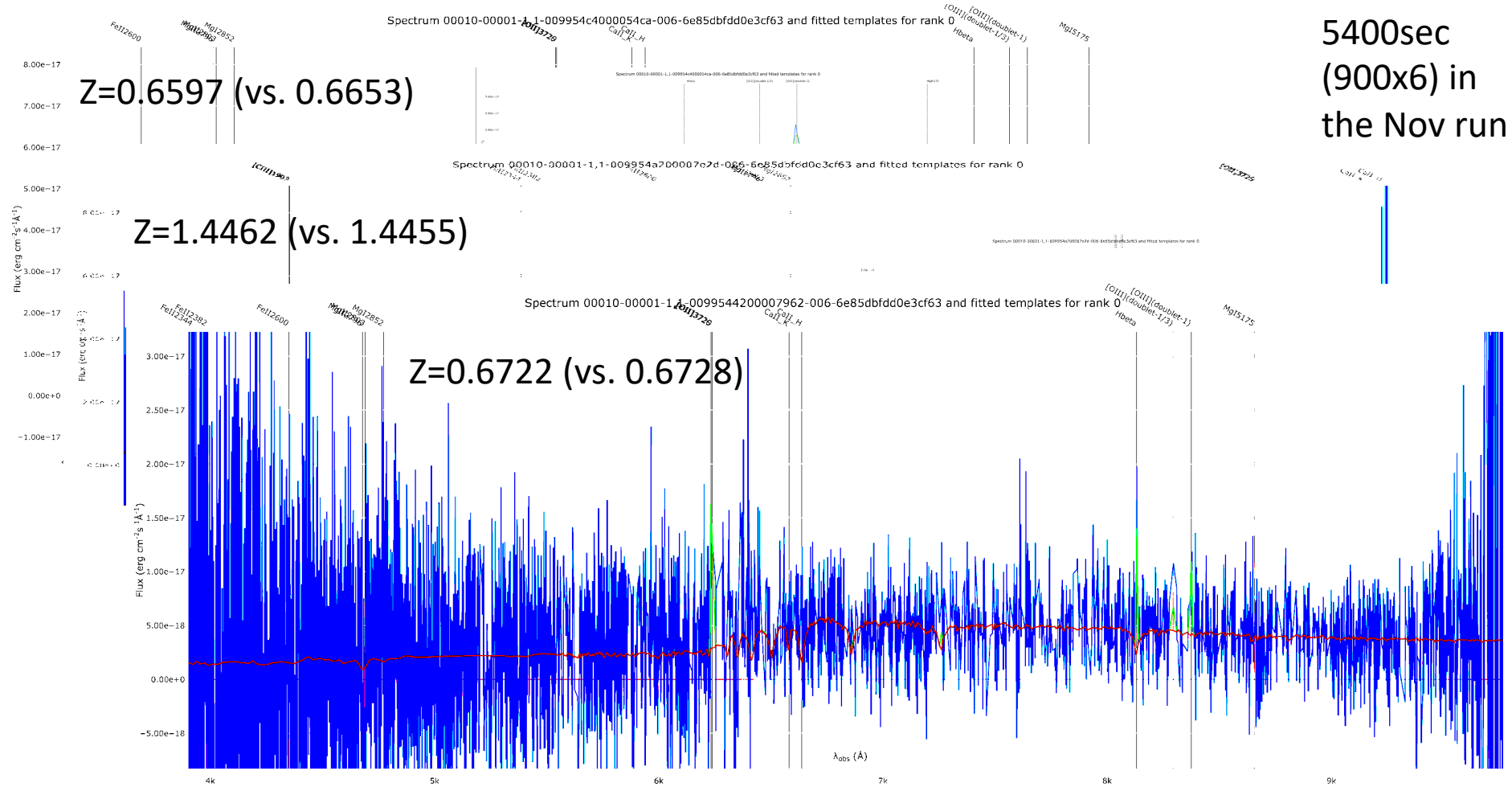
Z=0.6597 (vs. 0.6653)



Z=1.4462 (vs. 1.4455)

5400sec (900x6) in the Nov run

1D Data Reduction Pipeline (1D DRP)



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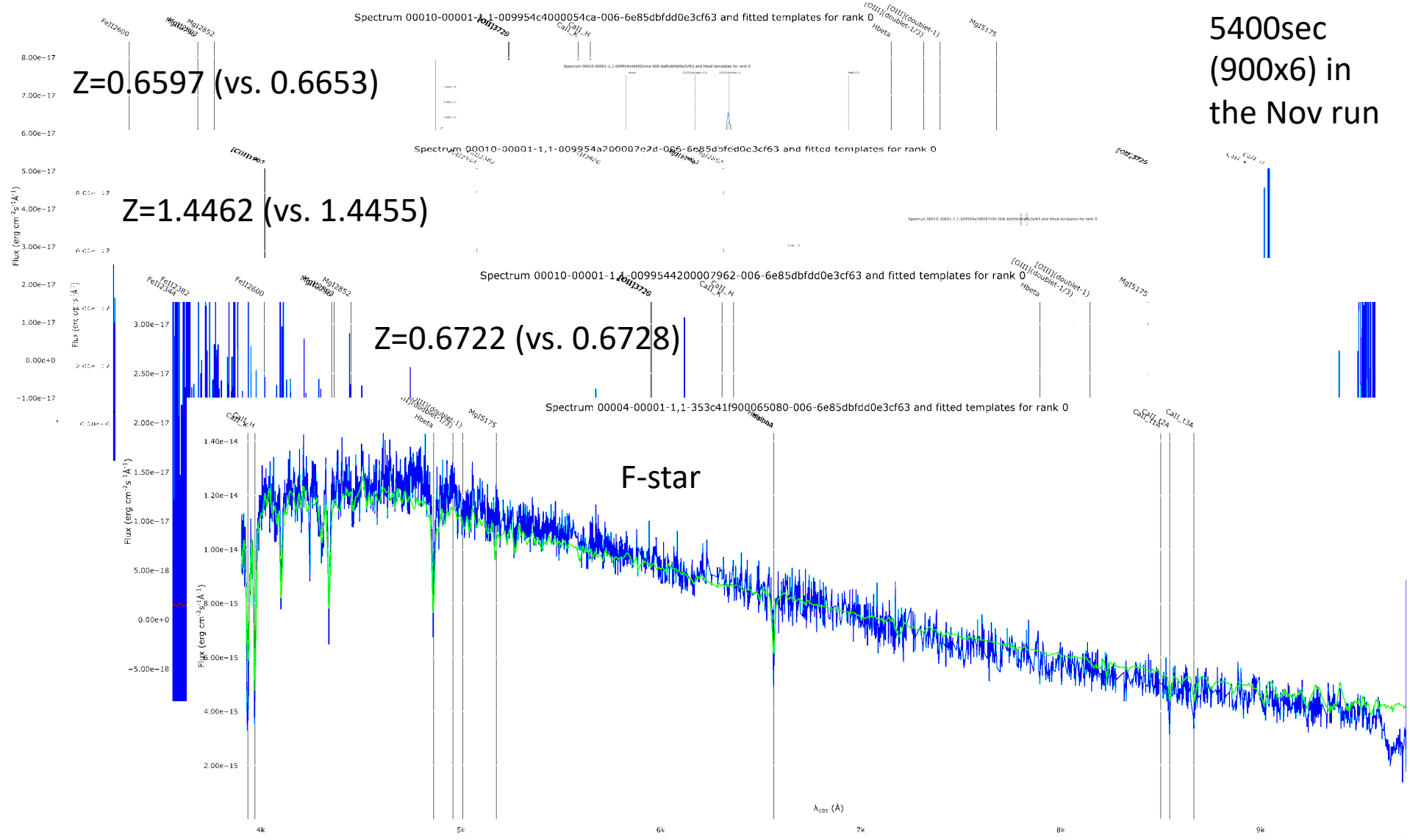
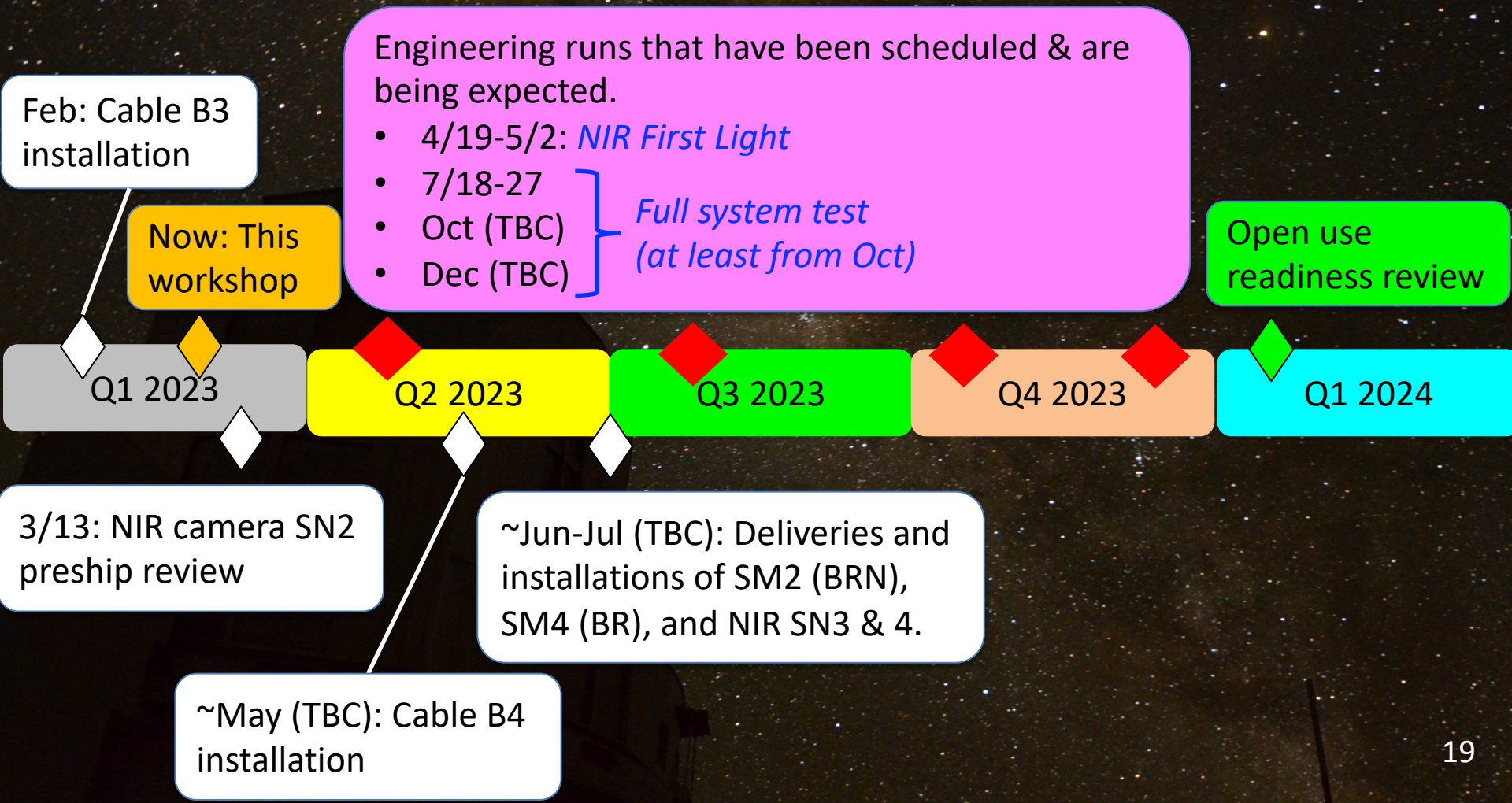


5400sec (900x6) in the Nov run

Updated timeline from now onward



Successful Cable B3 installation on Feb 7-8

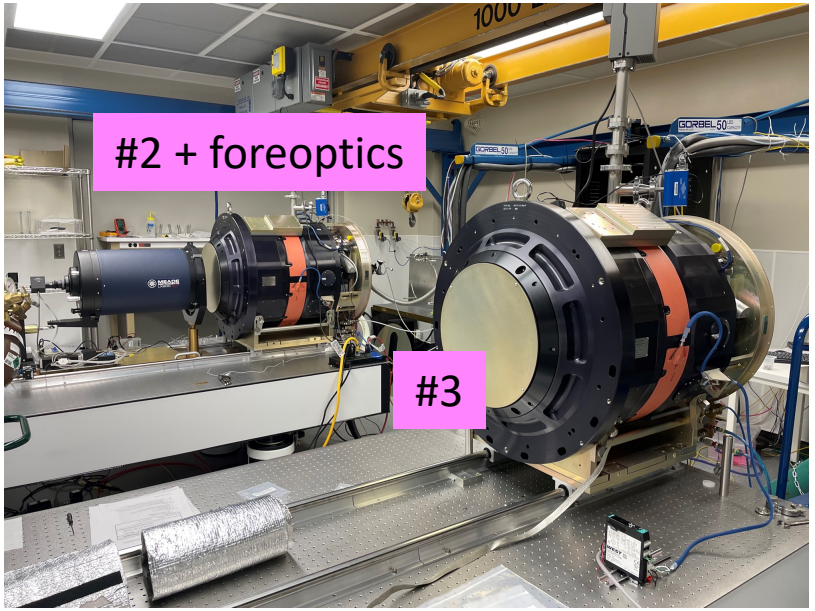
Installing ~60m-long cable over 2 days by ~10 people

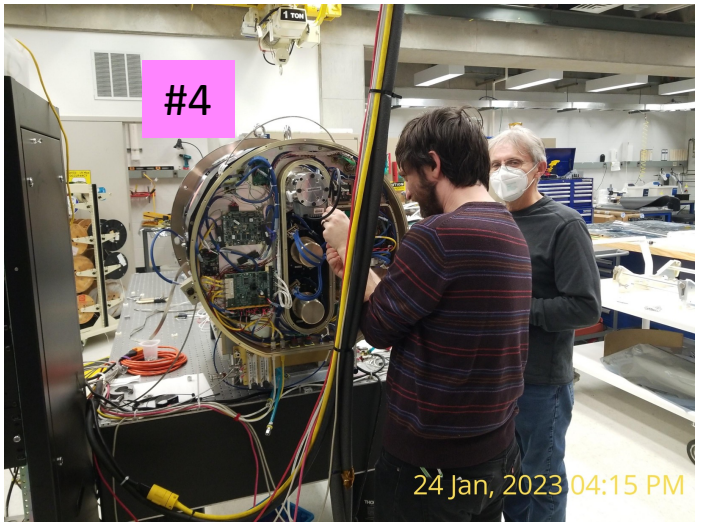
One more cable is remaining. It will be a big job again but should now be a low-risk process:

- The cable is already at the Subaru summit.
- The earlier 3 cables were successfully installed.
- Most of the Daycrews and PFS members are familiar with the installation process.

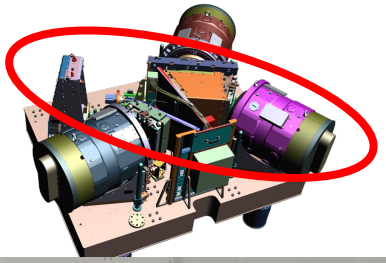
NIR Cameras #2,#3, #4 (N2-4) at JHU

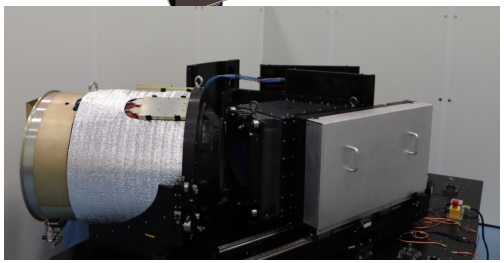
- N2:
  - All tests were done well, except for a sanity check of image quality after focus offset correction work.
  - Documentation for the preship review on 3/13.
- N3:
  - All tests were done well, except for the focus offset correction work and subsequent sanity check of image quality.
  - Hope it will be “ready” soon.
- N4:
  - The cryostat assembly is done. Next is baking, with pumping and then cooling for tests.
  - The detector characterization is ongoing in the test dewar.
- **Near-term goal is to deliver N2 to Subaru in March (and let N3 follow that soon).**



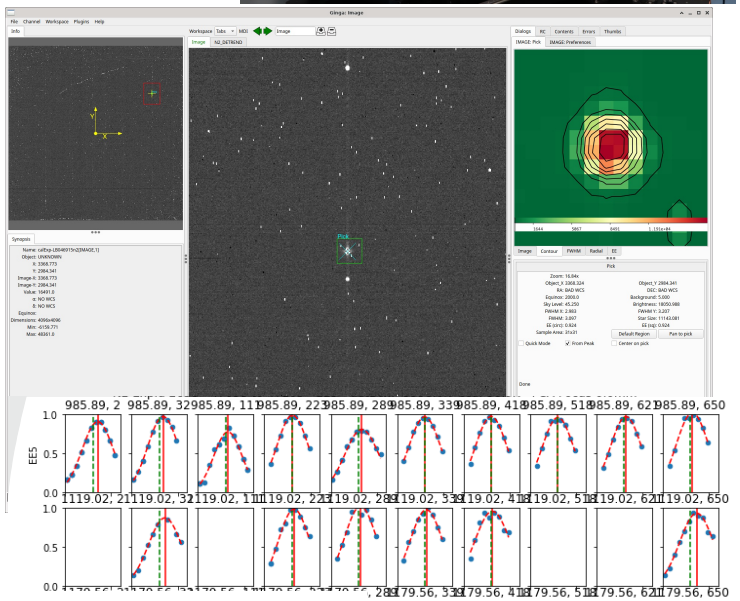


Spectrograph System (SpS) at LAM

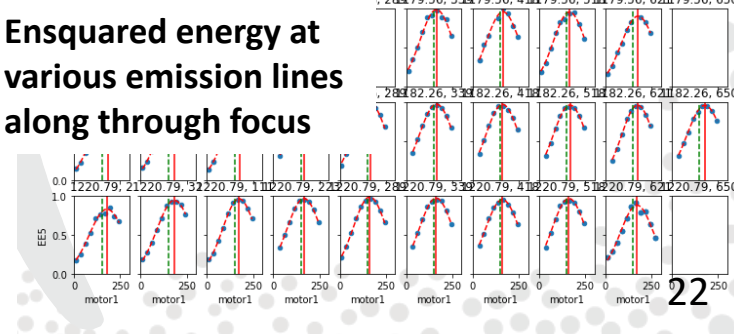


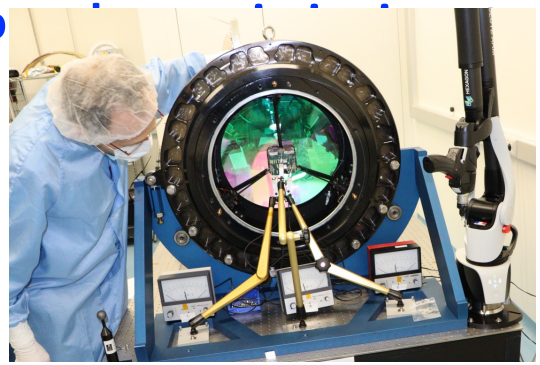


- Tests of the 1st NIR camera (N1) as part of Spectrograph Module #2 (SM2) are ongoing.
  - N1 itself was fully assembled and tested at JHU, passed the preship review and was shipped to LAM.
  - The image quality at LAM looks as good as at JHU even with the system at 5℃ in the chamber to simulate the operating condition at Subaru.
  - There were issues on the ion pumps … but the pumps were replaced and the operation has been recovered.
- The assembly & test of the remaining visible cameras are also ongoing.
- **Aiming at the delivery to Subaru of SM2 (BRN) & SM4 (BR) by mid July (although getting tight)**



Ensquared energy at various emission lines along through focus

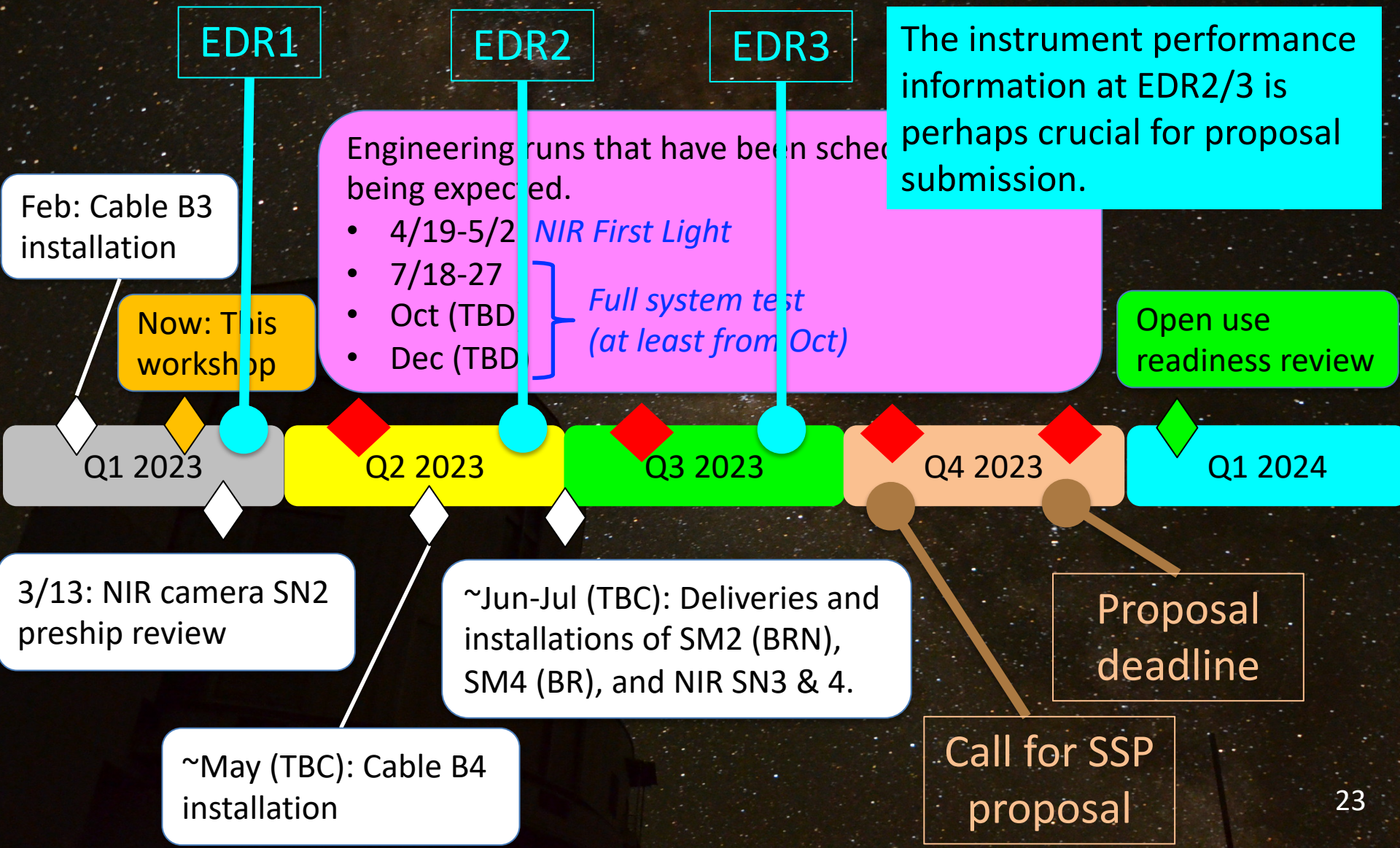




Visible camera under metrology

EDR: Engineering Data Release

Updated timeline from now onward



Science with PFS in the dark sector of the universe

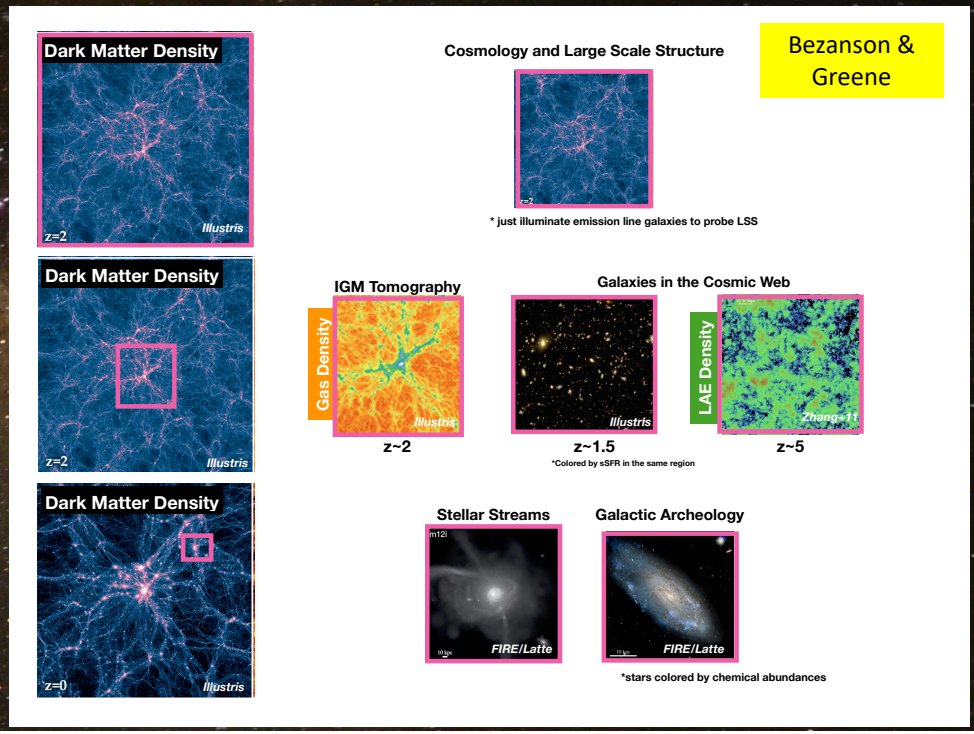
Comprehensive challenges to the major questions of modern astronomy & cosmology by three pillar survey components:

PFS large-sky survey in the framework of Subaru Strategic Program (SSP).

- ~360 nights for ~5 years
- Three pillars
  - Cosmology
  - Galaxy & AGN evolution
  - Galactic Archaeology

Timeline:

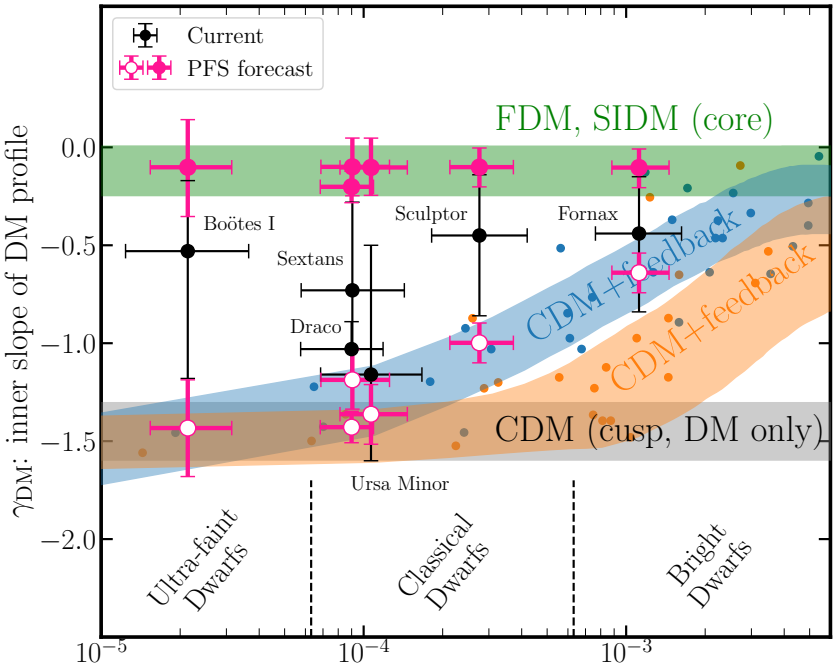
- System integration & survey planning are ongoing.
- On-sky commissioning from late 2021 to 2023 end.
- Science operation from 2024.
- $100M project, $1M shortage



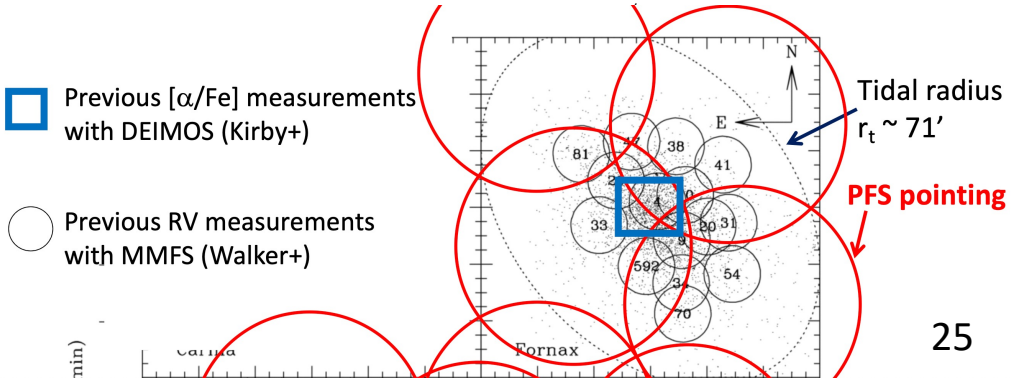
	Testing ΛCDM	Assembly history of galaxies	Importance of IGM
CO	• Nature & role of neutrinos • Expansion rate via BAO up to z=2.4 • PFS+HSC tests of GR • Curvature of space: Ω_K • Primordial power spectrum	• PFS+HSC galaxy association • Absorption probes with PFS QSOs and HSC host galaxies	• Search for emission from stacked spectra
GA	• Nature of DM (dSphs) • Search of MW dark halo	• Stellar kinematics and chemical abundances – MW & M31 assembly history	• dSph as relic probe of reionization feedback • Past massive star IMF from element abundances
GE	• Small-scale tests of structure growth	• Halo-galaxy connection: $M_*/M_{\rm halo}$ • Outflows & inflows of gas • Environment-dependent evolution	• Physics of cosmic reionization via LAEs & 21cm studies • Tomography of gas & DM

PFS science meeting @Kashiwa campus, Mar 2-3

Active & productive in-person+Zoom discussions to brush up the survey plan and proposal of PFS SSP.

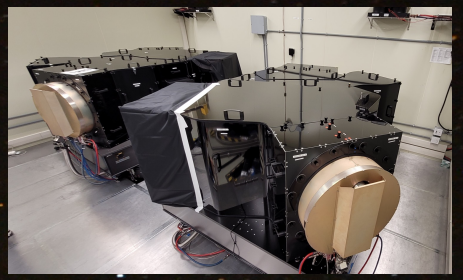


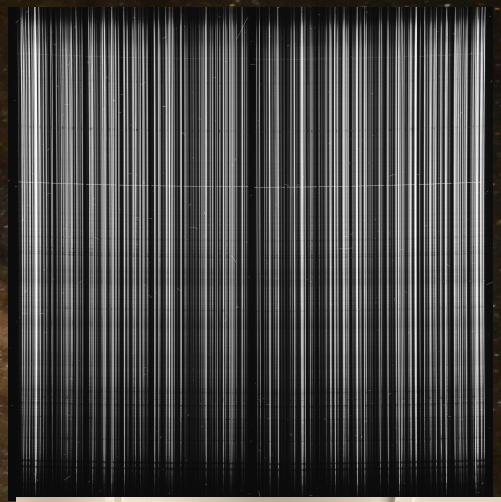
PFS will be a very powerful tool to find crucial evidence for the dark matter profile around dwarf galaxies (see e.g. Hayashi's talk).

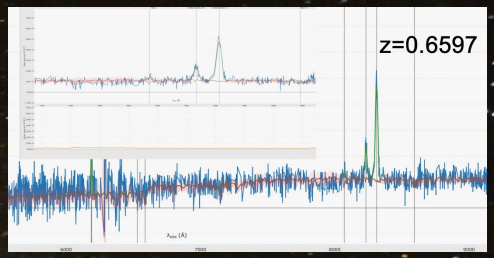


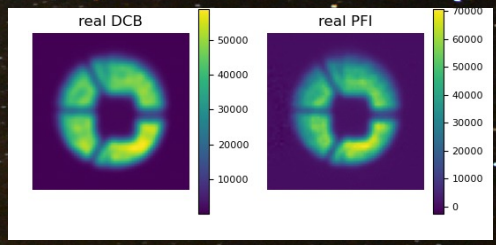
PFS instrumentation is now back on the home stretch.

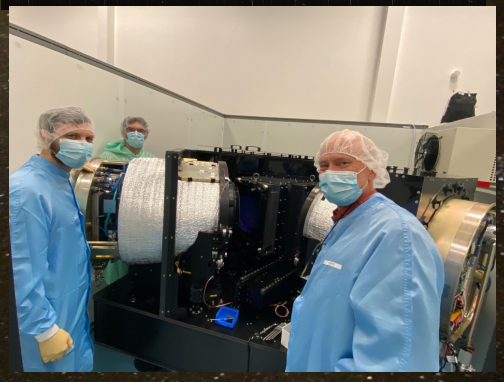
- Engineering observations
  - Engineering First Light in Sep 2022
  - Fiber positioning accuracy is getting better. Minimizing the systematic errors that dominate the accuracy is next priority.
- Ongoing hardware development
  - SM2 is being tested at LAM with the NIR camera. 3 other NIR cameras are being tested at JHU,
- Timeline
  - Install Cable B4 on the telescope in May.
  - Install 1 NIR cameras by mid April, and the rest of SpS in June-July.
    - NIR first light in the April run.
    - 1st run with the full hardware in July.
  - Open-use readiness review in Jan 2024 for science operation from S24B.

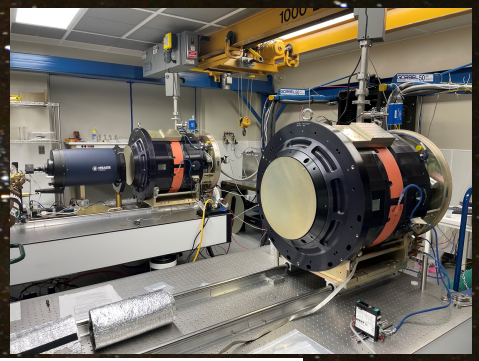












- ✓ Official web site - https://pfs.ipmu.jp/
- ✓ Membership registration - https://pfs.ipmu.jp/research/regist_collab.html
- ✓ Blog - https://pfs.ipmu.jp/blog/
- ✓ Instagram - https://www.instagram.com/pfs_collaboration/