B02: Dark matter search with Subaru Prime Focus Spectrograph (PFS)

fuzzy DM, self-interacting DM, PBH, … neutrino mass

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Our team

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- Tomomi Sunayama (Nagoya)
- Miho Ishigaki (NAOJ)
- Sakurako Okamoto (NAOJ)
- Ryuichi Takahashi (Hirosaki)
- Collaborators: PFS Cosmology and GA WG members including M. Chiba (Tohoku), R. Wise (JHU), J. Cohen (Caltech), E. Kirby (Caltech) ….





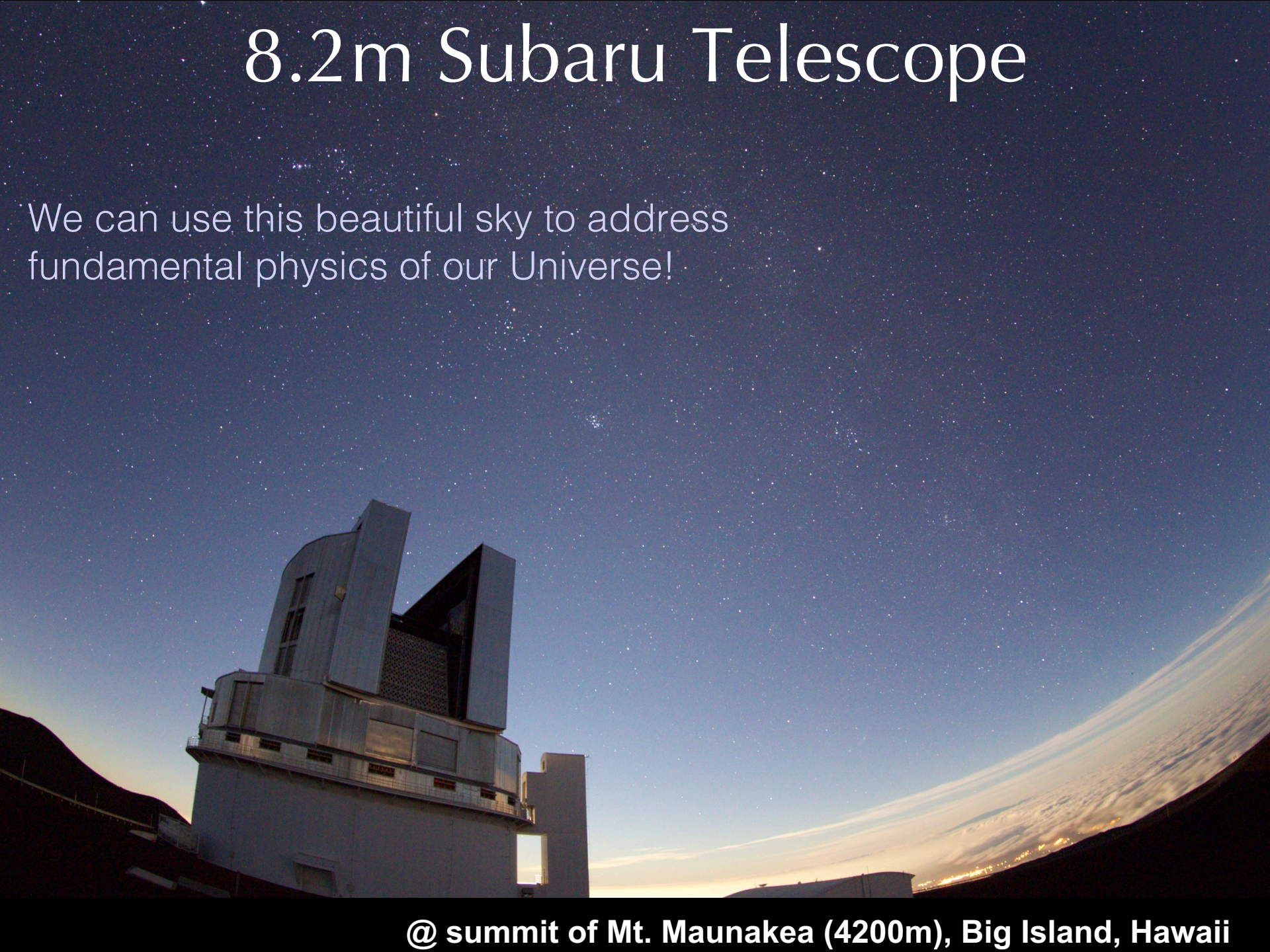







8.2m Subaru Telescope

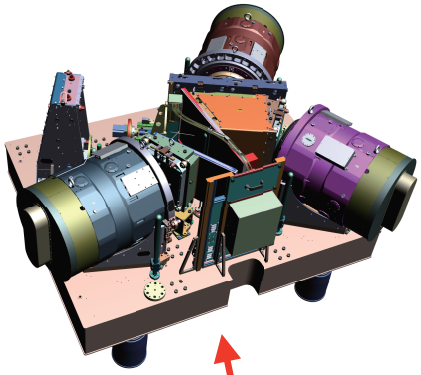
We can use this beautiful sky to address fundamental physics of our Universe!



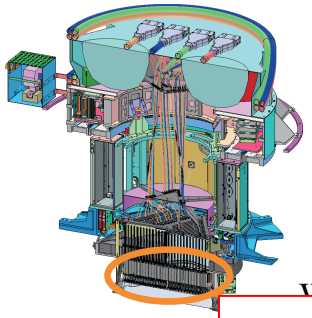
@ summit of Mt. Maunakea (4200m), Big Island, Hawaii

Prime Focus Spectrograph (under construction)

Spectrograph System (SpS)



Prime Focus Instrument (PFI)

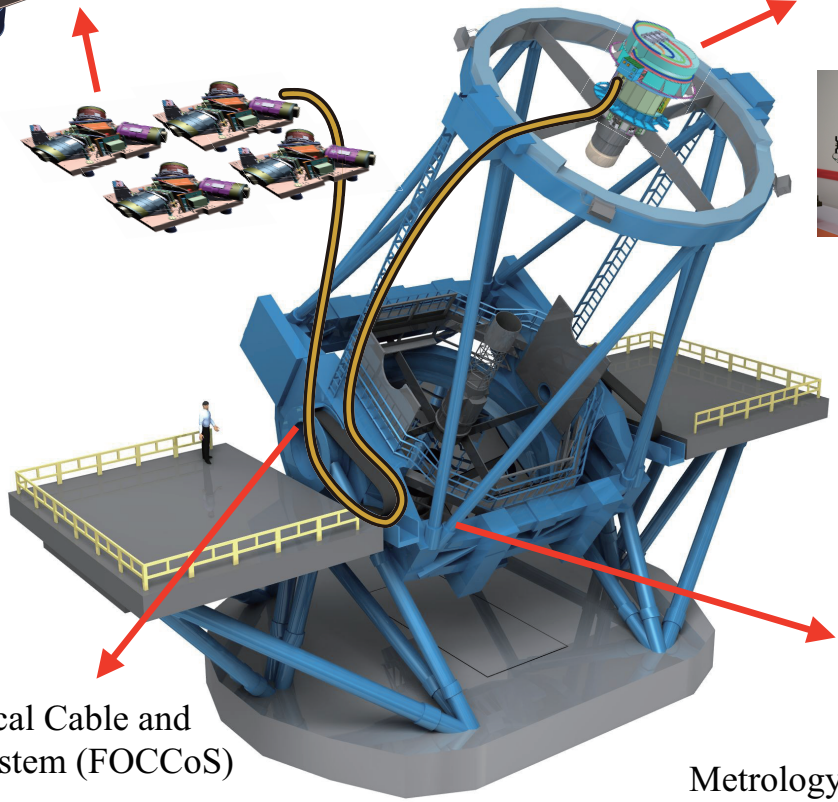


+

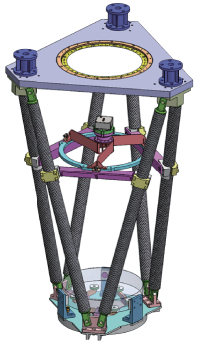
Wide Field Corrector (WFC)

wide field-of-view
large aperture
2400 fibers (high multiplex)

Fiber positioner "Cobra"



Fiber Optical Cable and Connector System (FOCCoS)

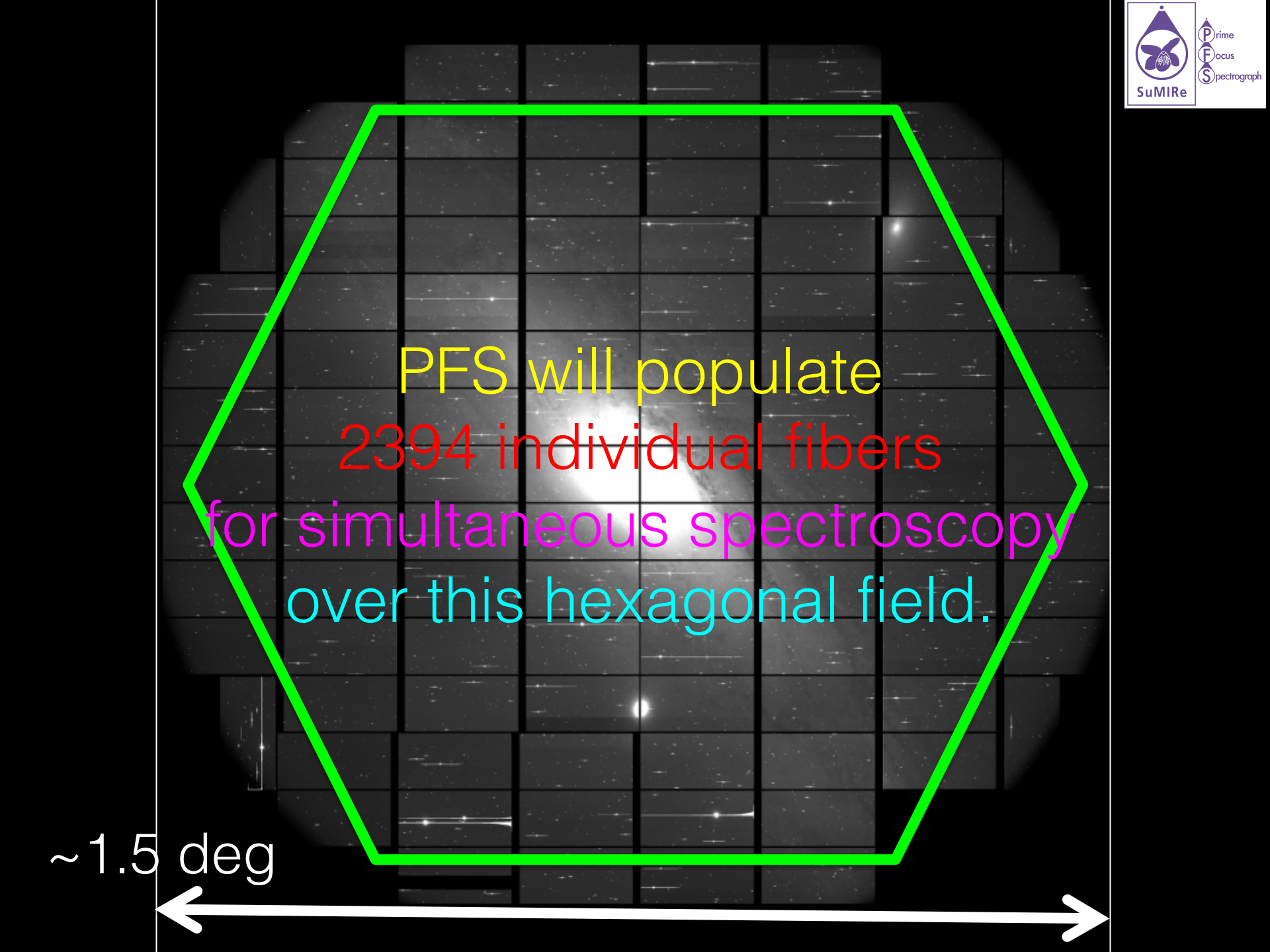


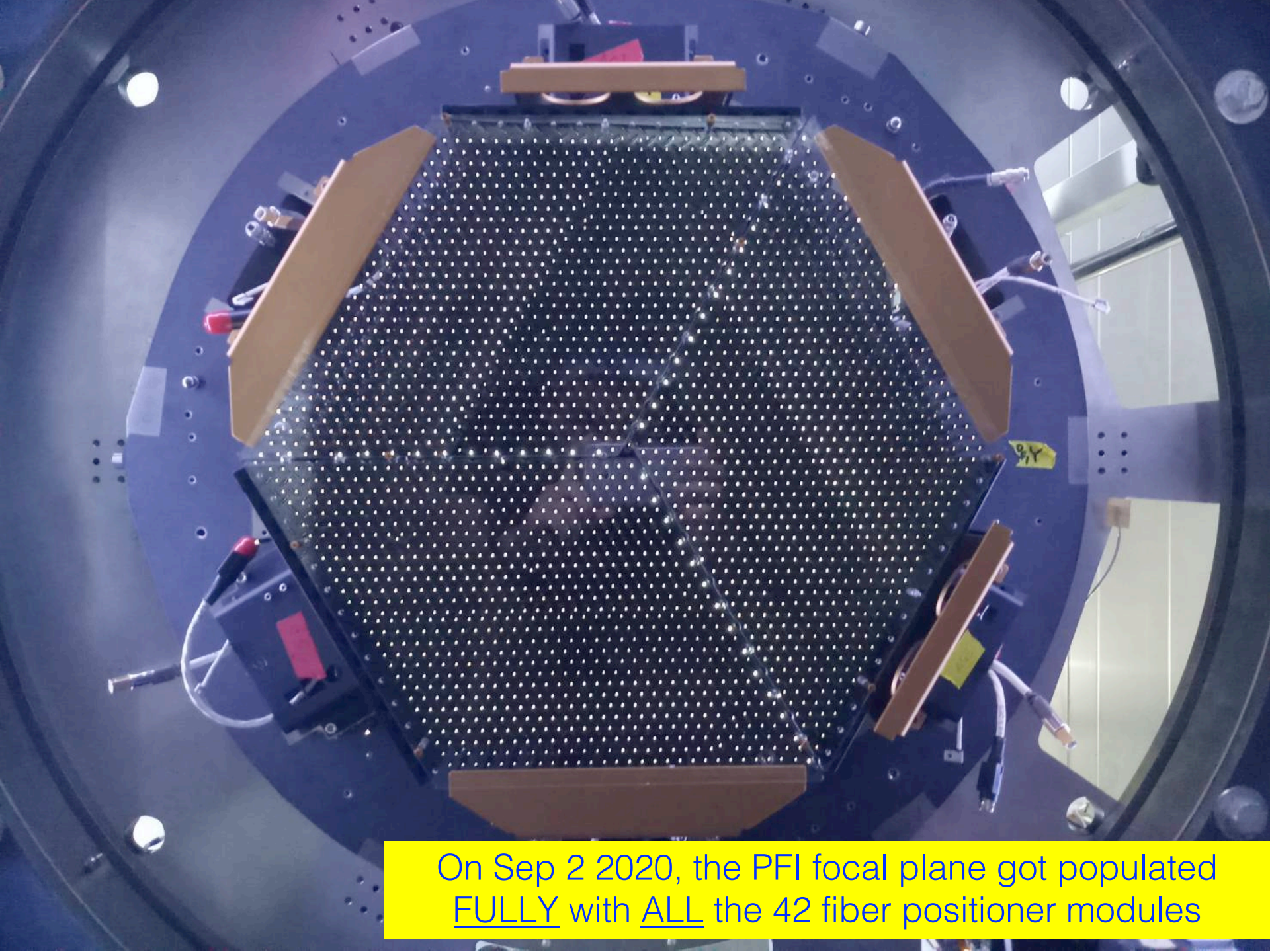
Metrology Camera System (MCS)

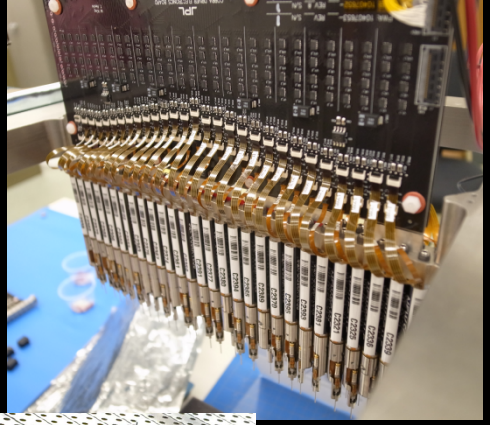
PFS blog: https://pfs.ipmu.jp/blog/ja/

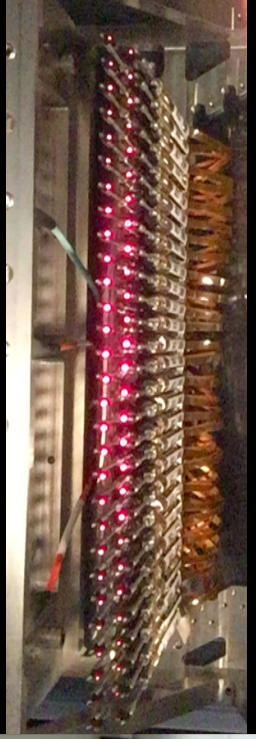
PFS project based on international collaboration (7 countries)
>200 members

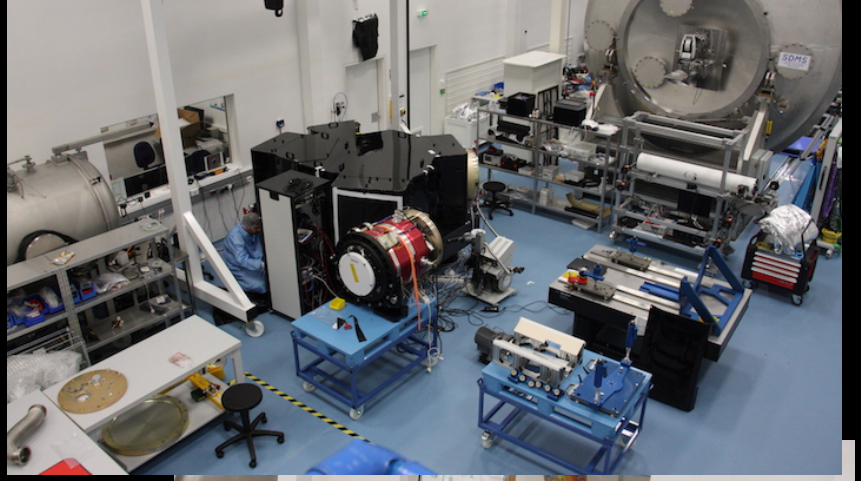
the collaboration meeting at Caltech for Dec 9-13, 2019

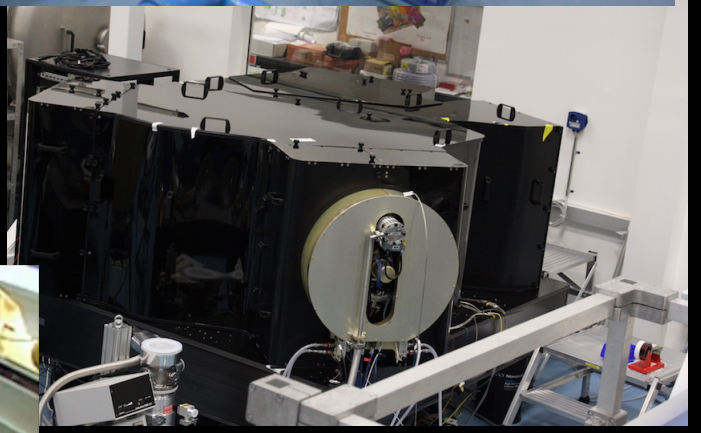

PFS will populate
2394 individual fibers
for simultaneous spectroscopy
over this hexagonal field.
~1.5 deg
SuMIRe
Prime
Focus
Spectrograph

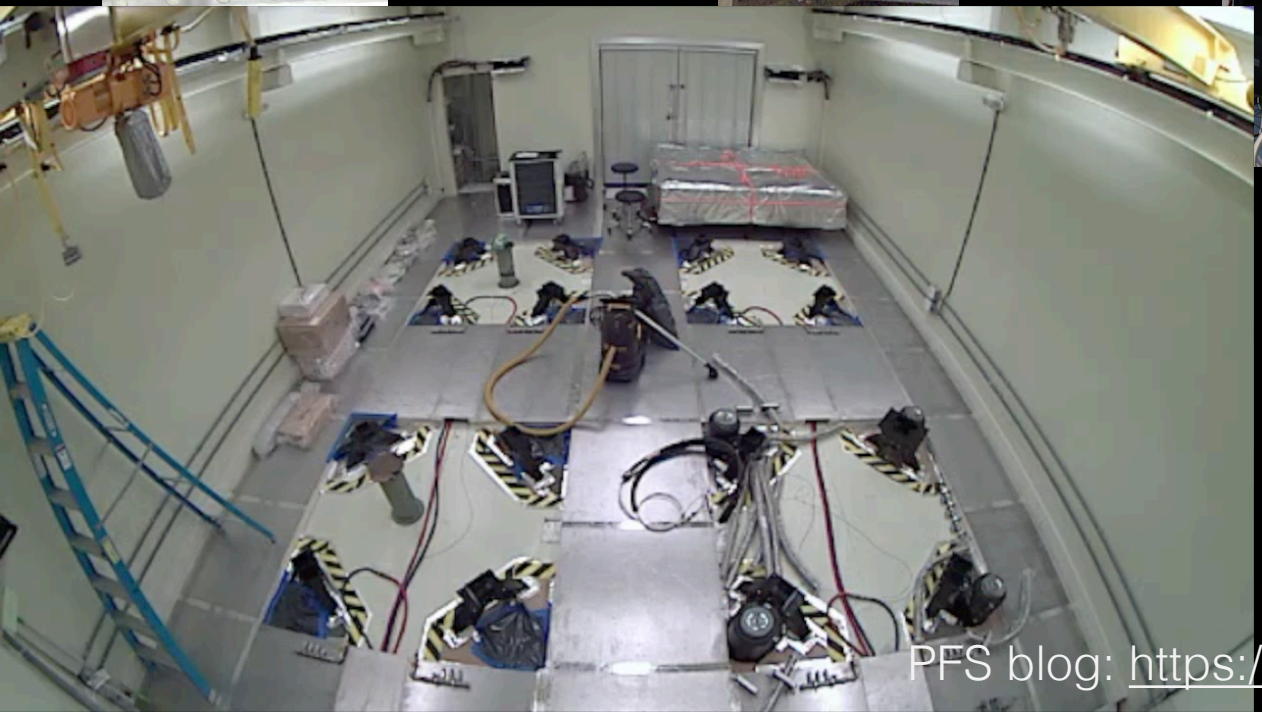

On Sep 2 2020, the PFI focal plane got populated
FULLY with ALL the 42 fiber positioner modules

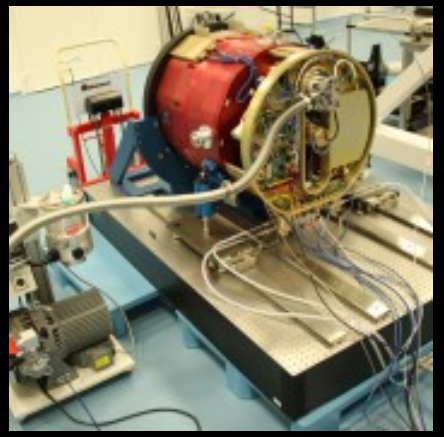












PFS blog: https://pfs.ipmu.jp/blog/ja/

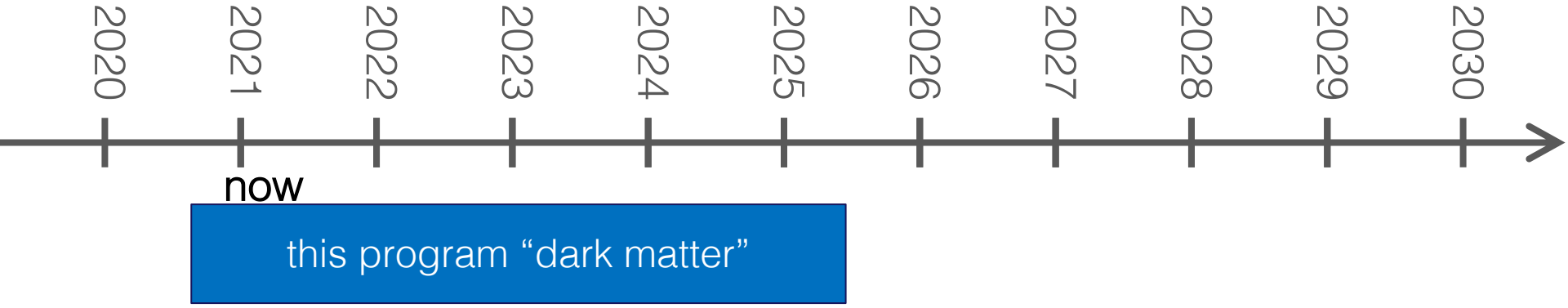
PFS in a global context

mirror size

	Instrument/Telescope	Collecting Area m^2	Field of view deg^2	Multiplex
4m class funded	4MOST	10.7	4.00	1400
	Mayall 4m / DESI	11.4	7.08	5000
	WHT / Weave	13.0	3.14	1000
	Subaru / PFS	**52.8**	**1.25**	**2400**
8-10m class funded/operational	VLT / MOONS	52.8	0.14	500
	Keck / DEIMOS	76.0	0.015	150
Proposed and unfunded	Megamapper	28.0	7.06	20,000
	Keck / FOBOS	76.0	0.087	1800
	MSE @ CFHT	78.5	1.52	4000
	ESO Spectel	113.1	4.90	5000

Via its wide field prime focus, PFS has the great survey capability

Timeline



Subaru HSC (B03)

Subaru PFS (8m)

commissioning | science operation (SSP) | under discussion

DESI (US, 4m, spectroscopy)

4MOST (EU, 4m, spectroscopy)

MOONS (EU, 8m, spectroscopy)

Euclid (EU, imaging/spec.)

Vera Rubin LSST (US, imaging)

Roman space tel. (NASA, imaging/spec.)

PFS dark matter science: **dwarf galaxies**

Note: this is just one “example” we can think of. Any new idea welcome!

DM dominated system

$$M \sim 10^{7-8} M_{\odot}$$

$$M \sim 10^{3-4} M_{\rm star}$$

Size: ~1kpc

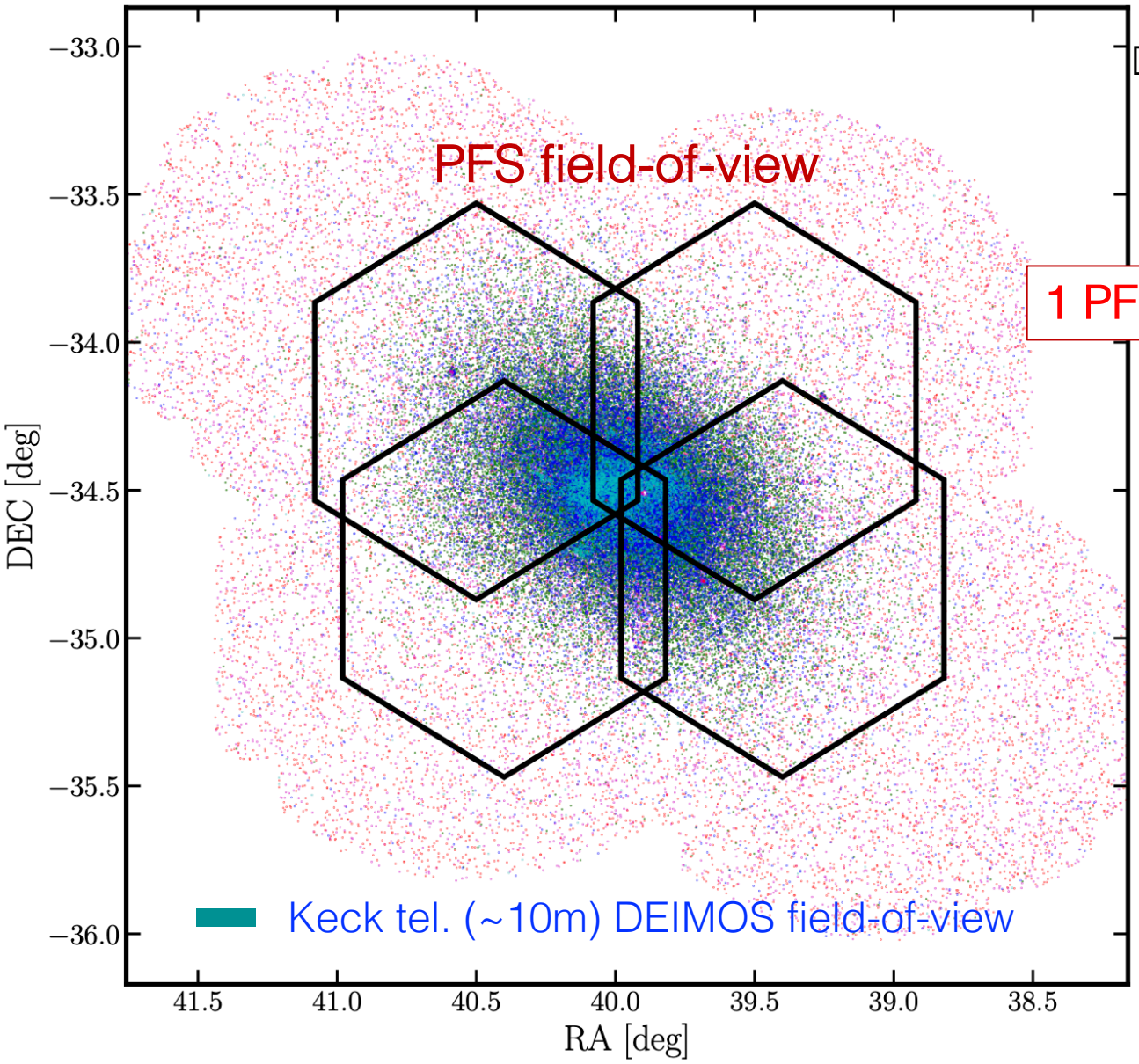
Velocity dispersion-supported system

$$\sigma_v^2 \sim \frac{GM(<r)}{r}$$

Motion of member stars allow us to infer dynamical mass (note back/fore-ground stars; Horigome+20)

PFS can measure line-of-sight velocities of stars from Doppler shifts tin he measured spectra ⇒ give an estimate of dynamical (DM) mass

A power of PFS



Dots (actual data):
member stars (blue/green
fore/back-ground stars (red)

1 PFS night ~50 Keck nights

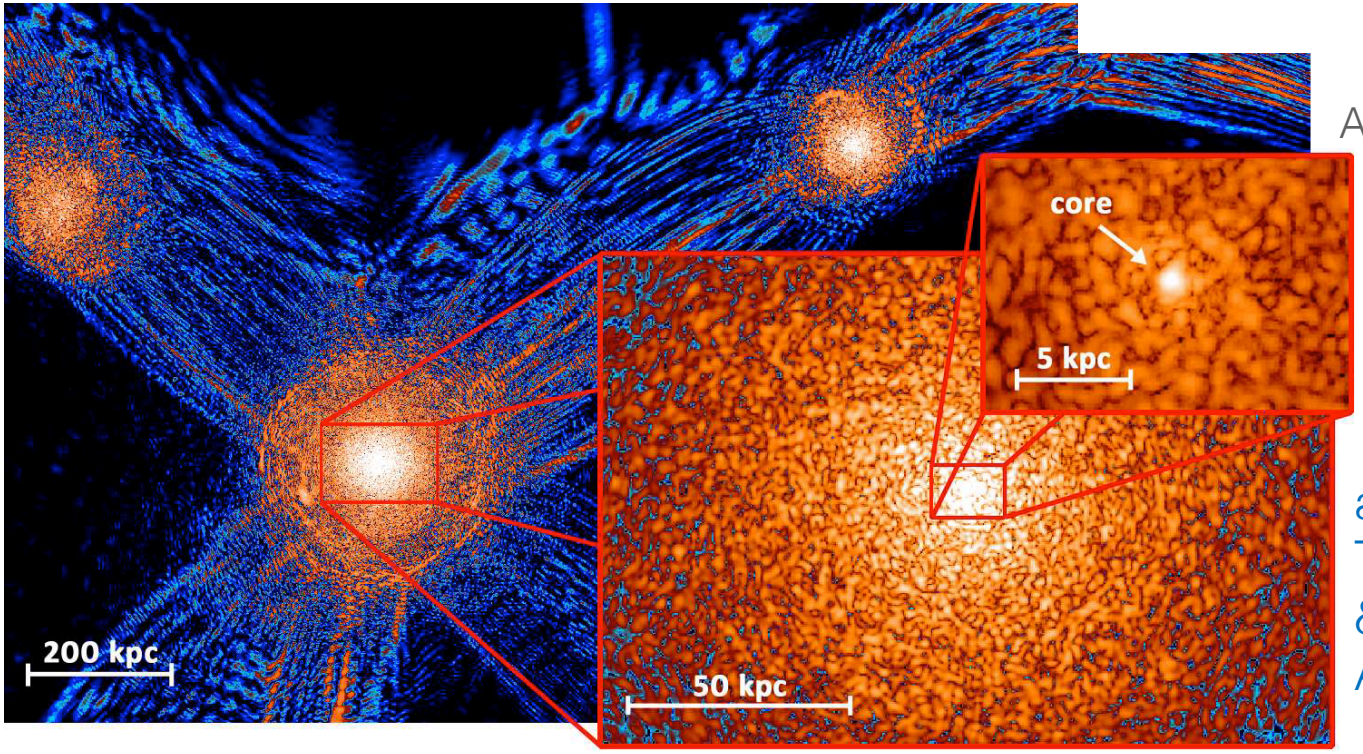
PFS promises an improved measurement of dark matter content in each dwarf galaxy

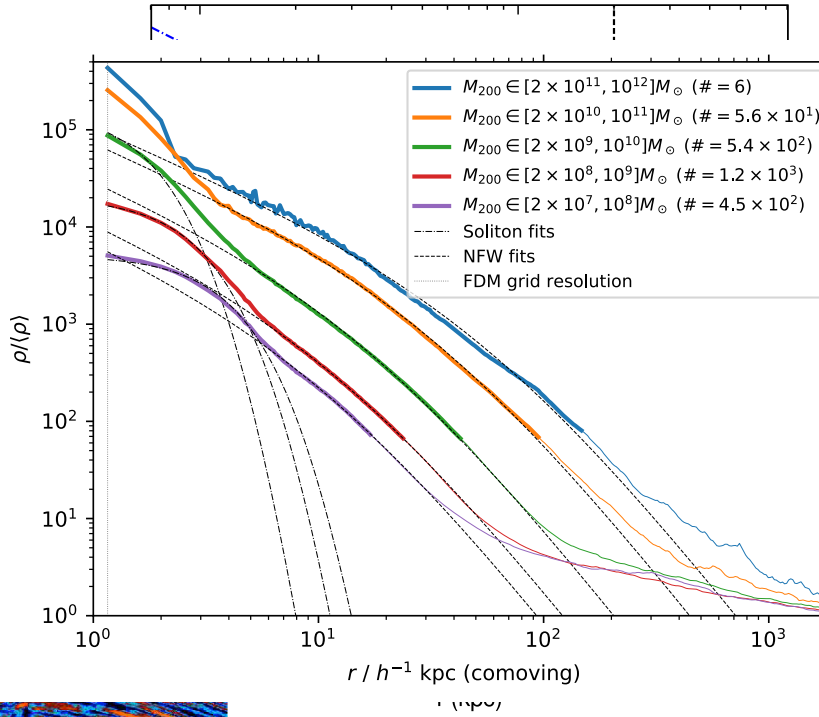
Fuzzy DM (~10^{-23}eV)

appearance of cored profile

$$\lambda_{\rm dB} = \frac{\hbar}{m_a v} \sim 1\ {\rm kpc} \left(\frac{m_a}{10^{-23}{\rm eV}}\right)^{-1}$$

Schive et al. 14

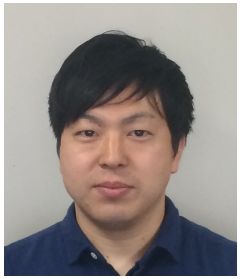




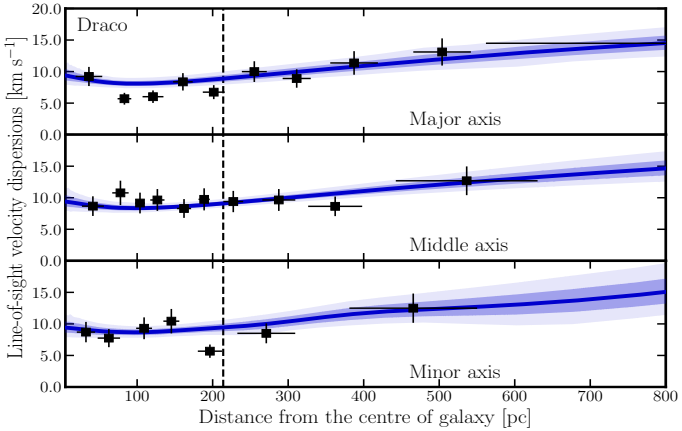
Also see May & Springel 21

also see
Takahashi-san's (A01)
&
Ando-san's groups (C02)

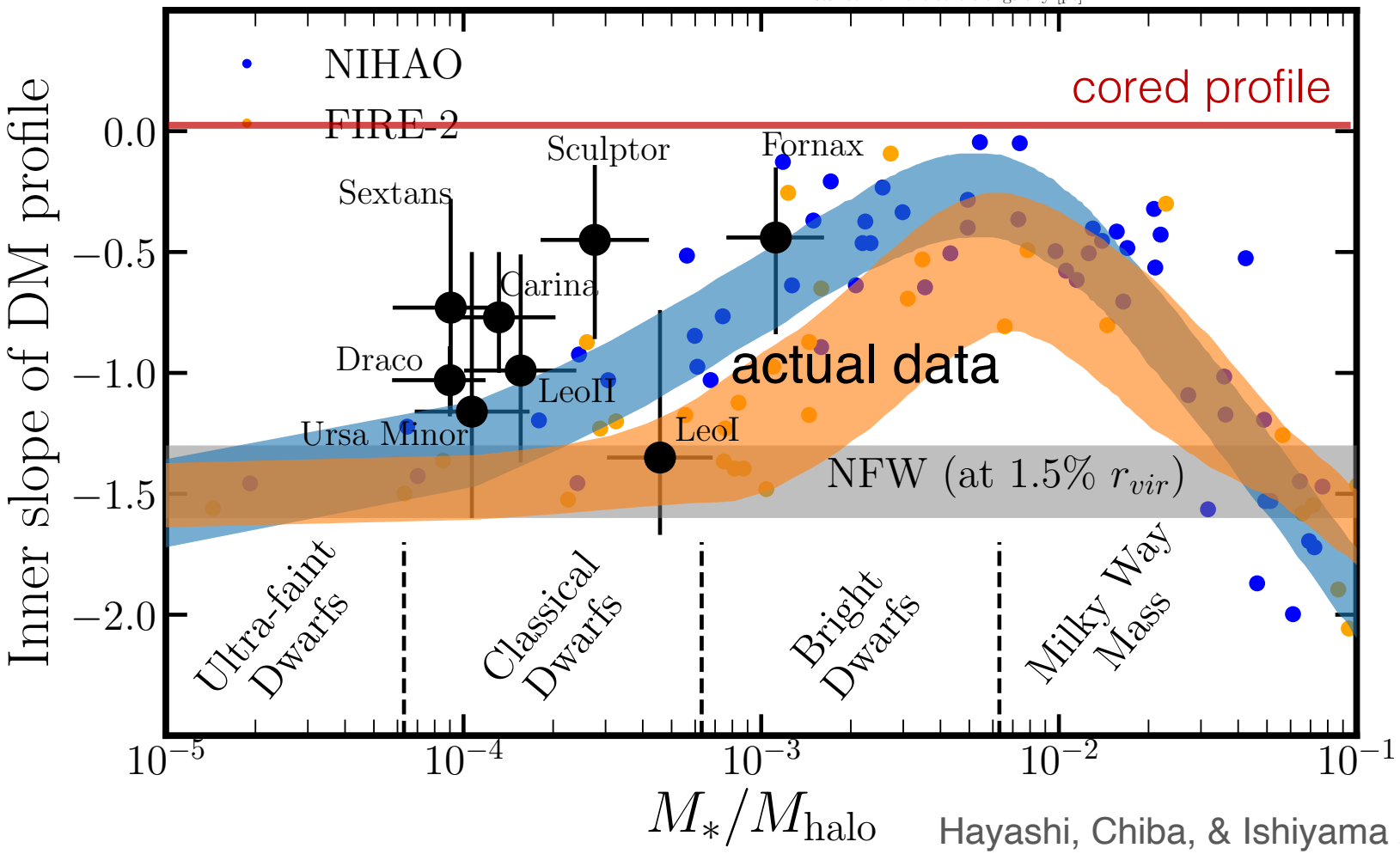
Data vs. Model



Kohei Hayashi
(Tohoku U.)



Velocity dispersion profile (actual data vs. model); note the current data is still noisy

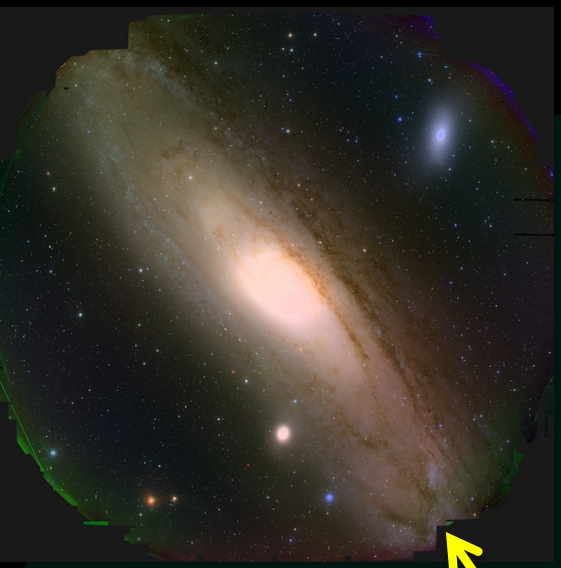


Hayashi, Chiba, & Ishiyama 20

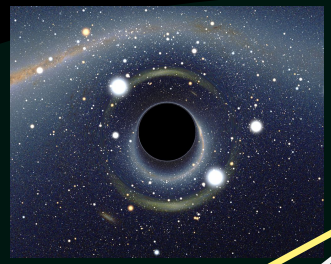
What can we do with PFS?

- PFS promises high-precision measurements of matter (dark matter) distribution, for each of dwarf galaxies
  - Relatively cheap observations: only ~30 Subaru nights
- The improved measurement can be used for
  - Improve the estimation of J-factor and therefore the DM annihilation search from Fermi data (C02)
  - A definitive answer to the core-cusp problem (A01/C02)
  - If the cored profile is found, irrespectively of the star formation history (astrophysics) of each dwarf galaxy, it would be a strong evidence of non-CDM dark matter
  - Axion-like particle dark matter (FDM), and self-interacting dark matter (SIDM) , etc. (A01/C02)
- Other targets for PFS observations: stellar stream, proper motions of halo stars, .. (not discussed today)

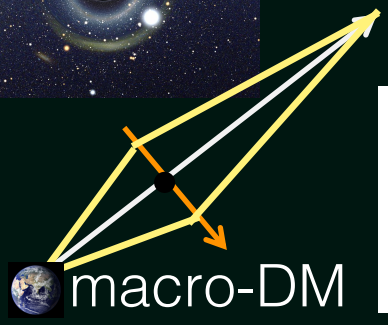
Microlensing search of macroscopic DM

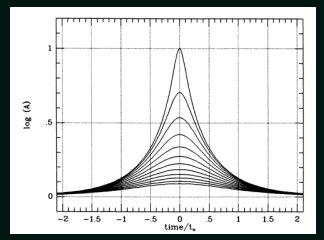


HSC M31 PBH microlensing search

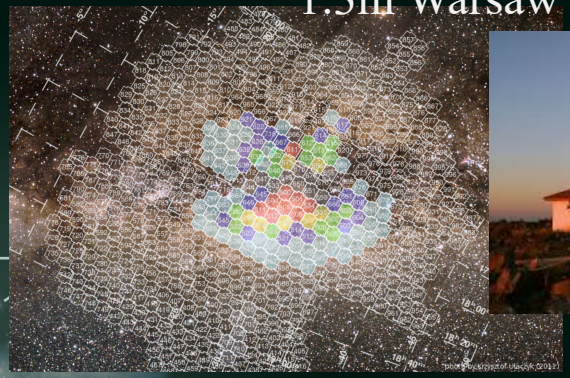


$$t_{\rm E} \simeq \frac{R_{\rm E}}{v_{\rm rel}} \propto \frac{M_{\rm lens}^{1/2}}{200\,{\rm km\ s^{-1}}}$$

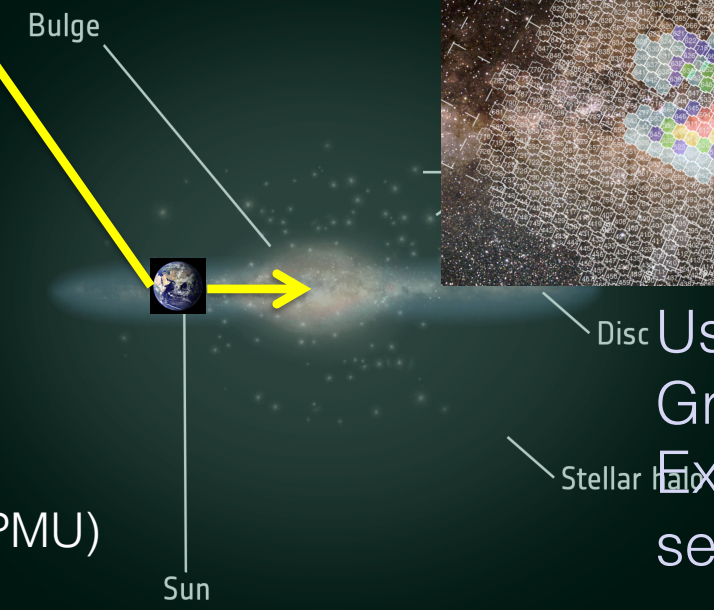




1.3m Warsaw telescope (1992-)



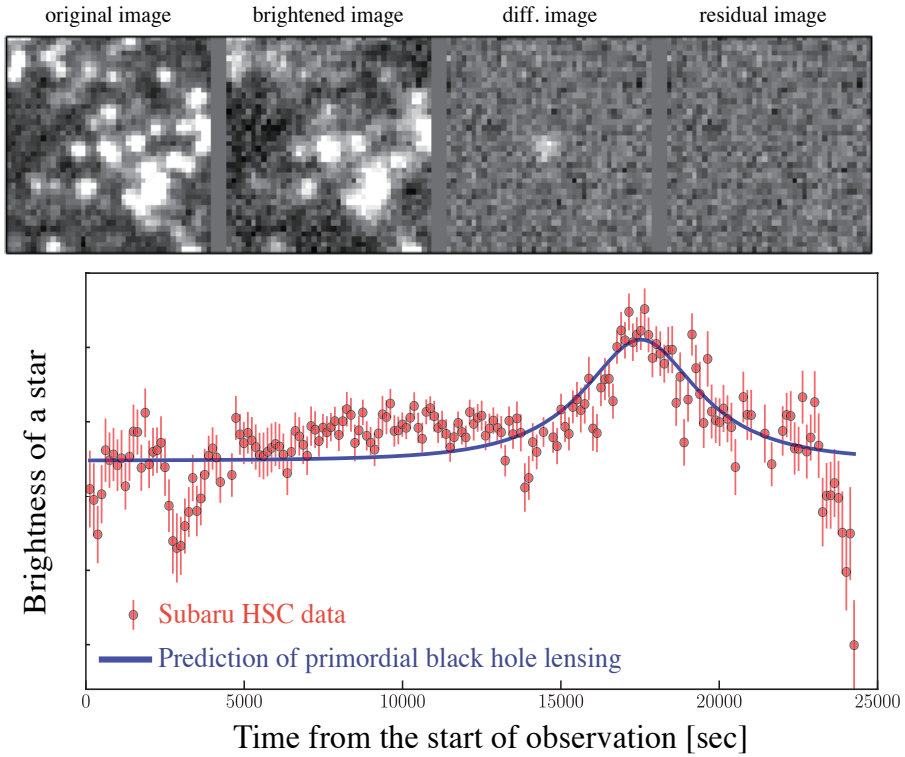
Sunao Sugiyama (D1, IPMU)

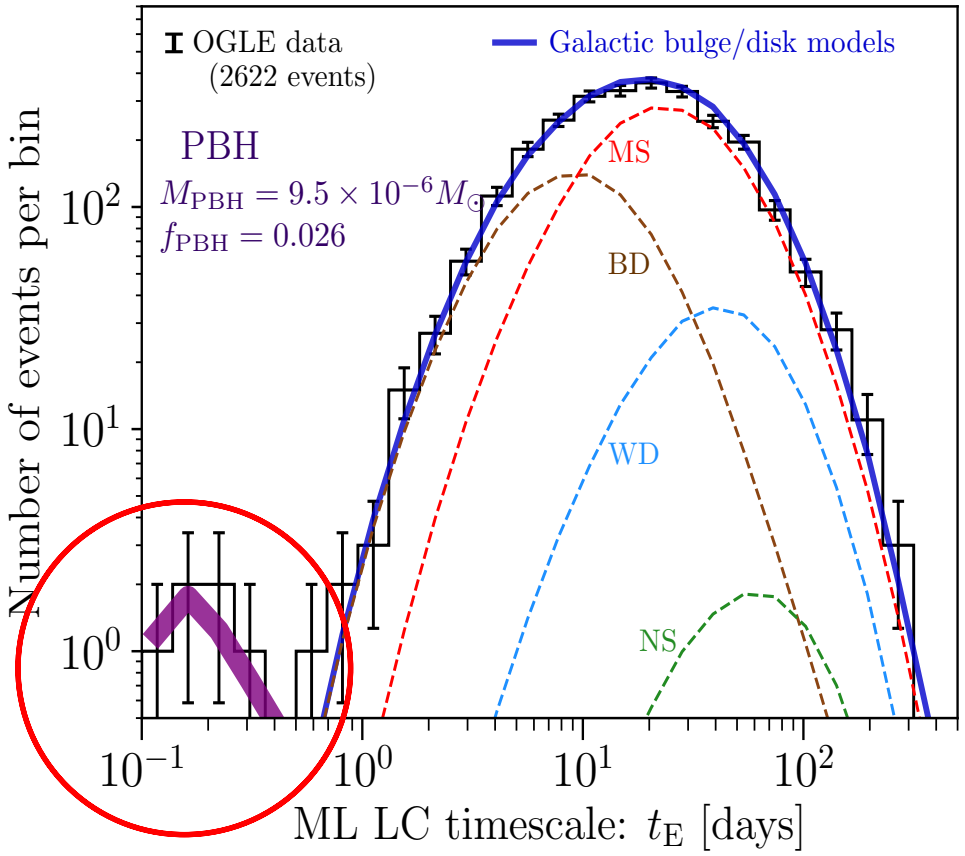


Use OGLE (Optical Gravitational Lensing Experiment) for PBH search

Short time-scale ML events

One possible microlensing event from HSC data of M31 (t_E~1hr) (Niikura et al. Nature Astron. 19)





6 short-timescale events from OGLE data of Galactic bulge (t_E~[0.1,0.3] days) (Niikura et al. PRD 19)

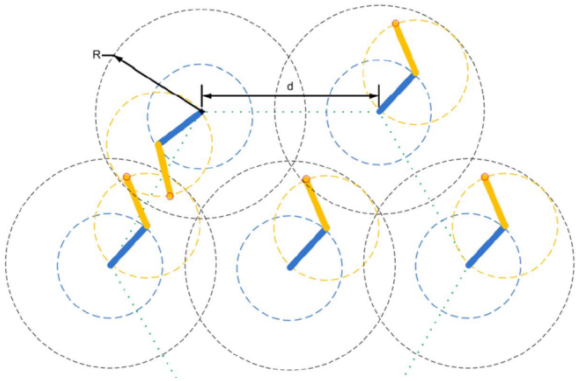
Also see Sugiyama, Takhistov, Vitagliano, Kusenko, Sasaki & MT PRL 20

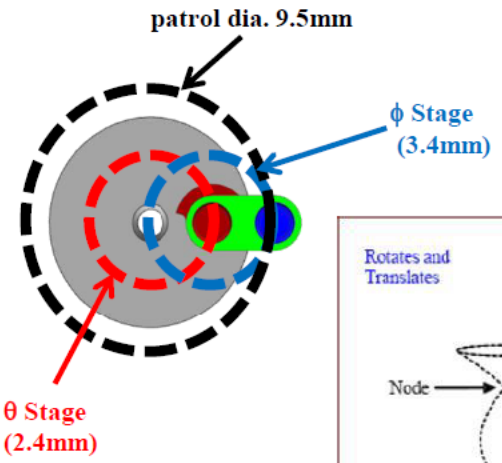
take-home message

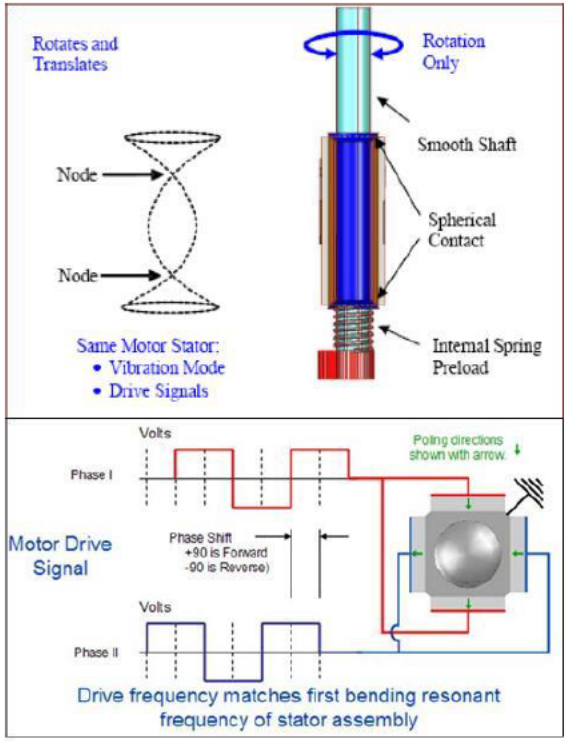
- DM search in optical wavelengths, with Subaru or other telescopes, hasn't been fully explored
- Subaru Prime Focus Spectrograph (PFS) is a very powerful instrument in a coming decade that will be in operation from 2023
  - Properties of dark matter distribution in dwarf galaxies (DM-dominated system): PFS flagship science that can be done with ~30 PFS nights
  - Stellar stream, kinematical structure of stars in the MW halo, … (not discussed today)
  - Any new idea? (PFS will open up new opportunities! New idea welcome!)
- Microlensing search of DM (Subaru HSC now, and eventually LSST)
  - HSC M31 ~1hr-timescale microlensing + OGLE ~0.1days events imply axion stars formed from QCD axions? (Sugiyama & MT in prep.)
  - Primordial Black Holes (Sugiyama et al., in working progress, with new data)

Focal plane: Fiber positioner "Cobra"

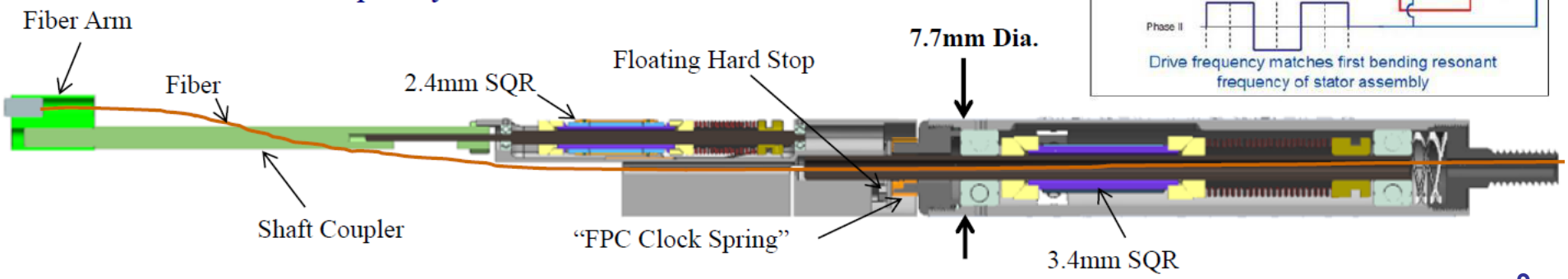
8mm pitch vs.
9.5mm diameter
patrol area
→ Patrol areas
are overlapped.



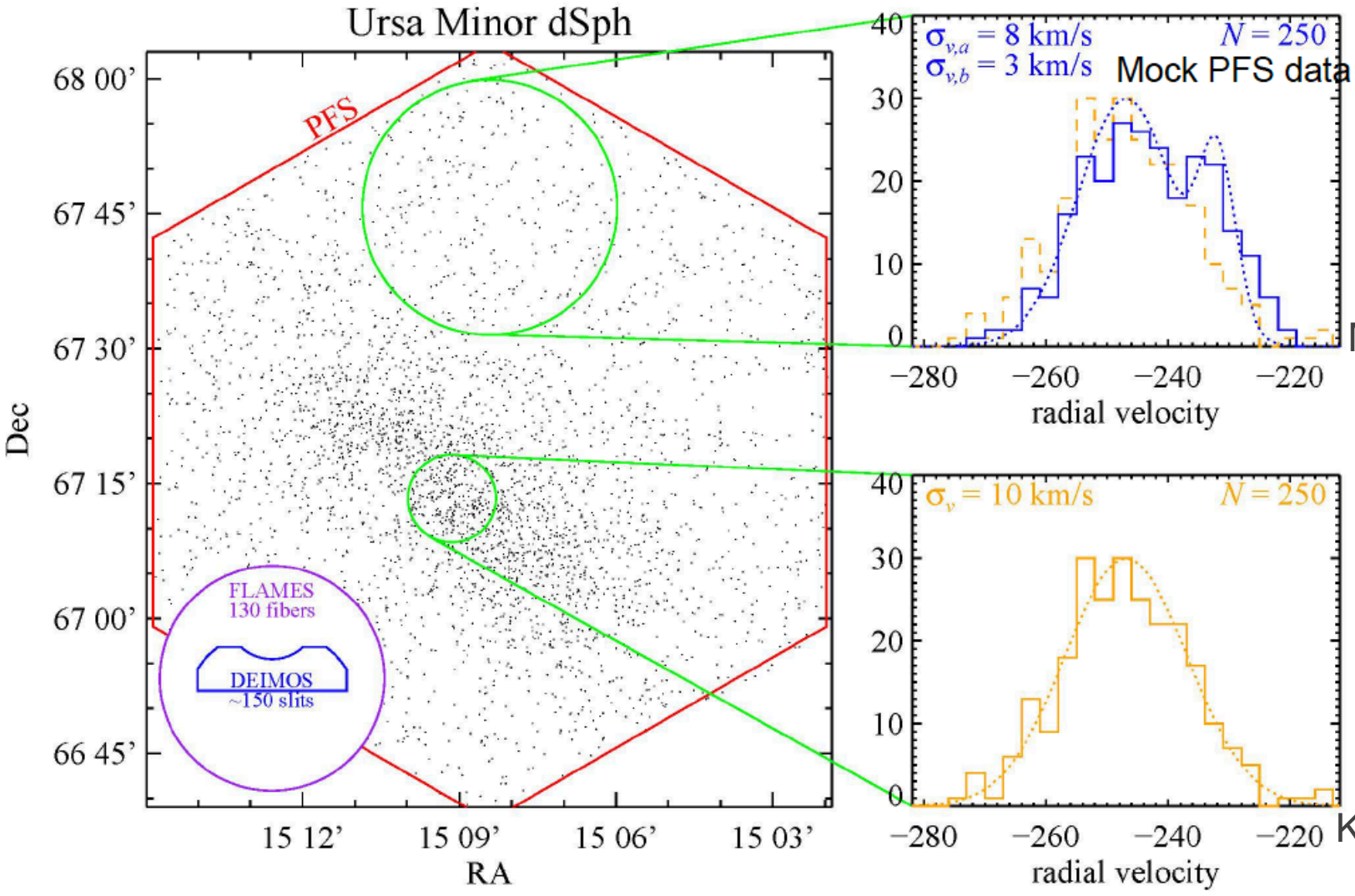




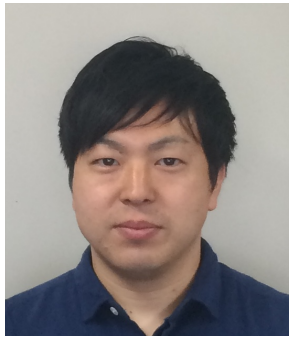
- Fiber is routed from the arm on the phi-stage through the center of the Cobra
  - Stages utilize hard stops to allow for full range of motion, yet prevent over twisting of the optic fiber
  - Protects fiber during handling and operation
- Piezo motors use phase shifted signals to excite the motor body at the first bending resonant frequency



Unveiling dark matter dist. in dwarf gals



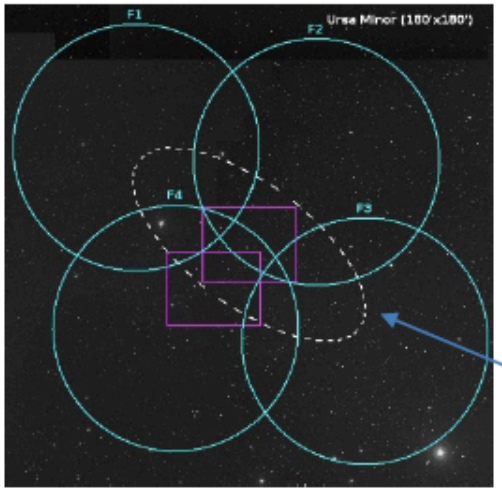
Miho Ishigaki
(Tohoku U.)



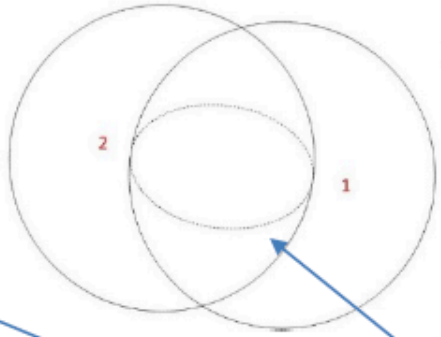
Kohei Hayashi
(U. Tokyo)

Already HSC data of all interesting dwarf gals **in hand**

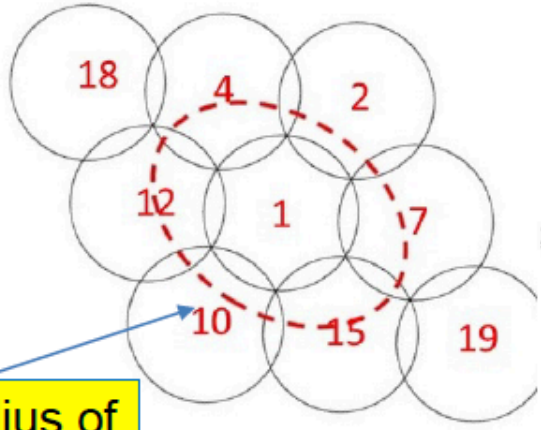
Ursa Minor



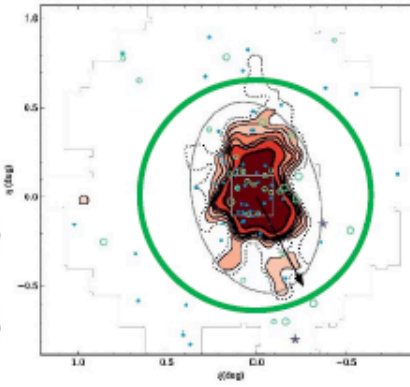
Draco



Sextans

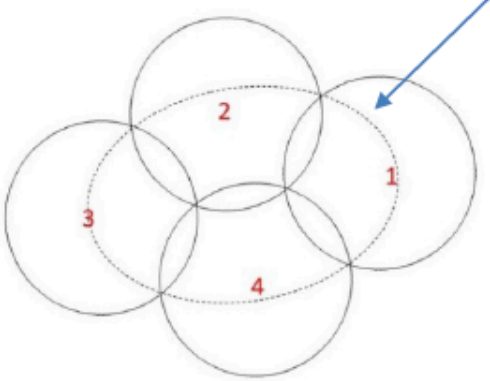


Bootes I

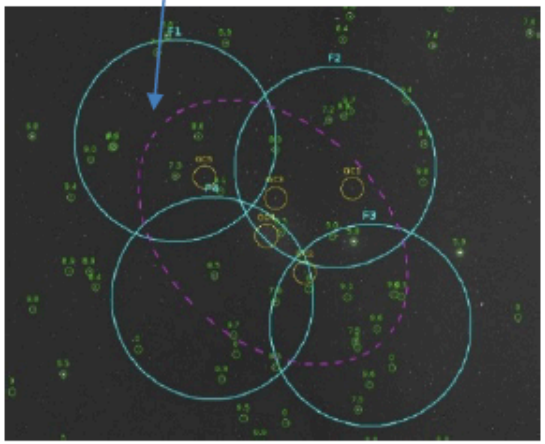


tidal radius of stellar comp.

Sculptor



Fornax



NGC6822