SUBARU PRIME FOCUS SPECTROGRAPH

"PSF" (Point Spread Function) is crucial for "PFS" indeed!

Overview, current status, and future perspectives of upcoming instrument on Subaru Telescope

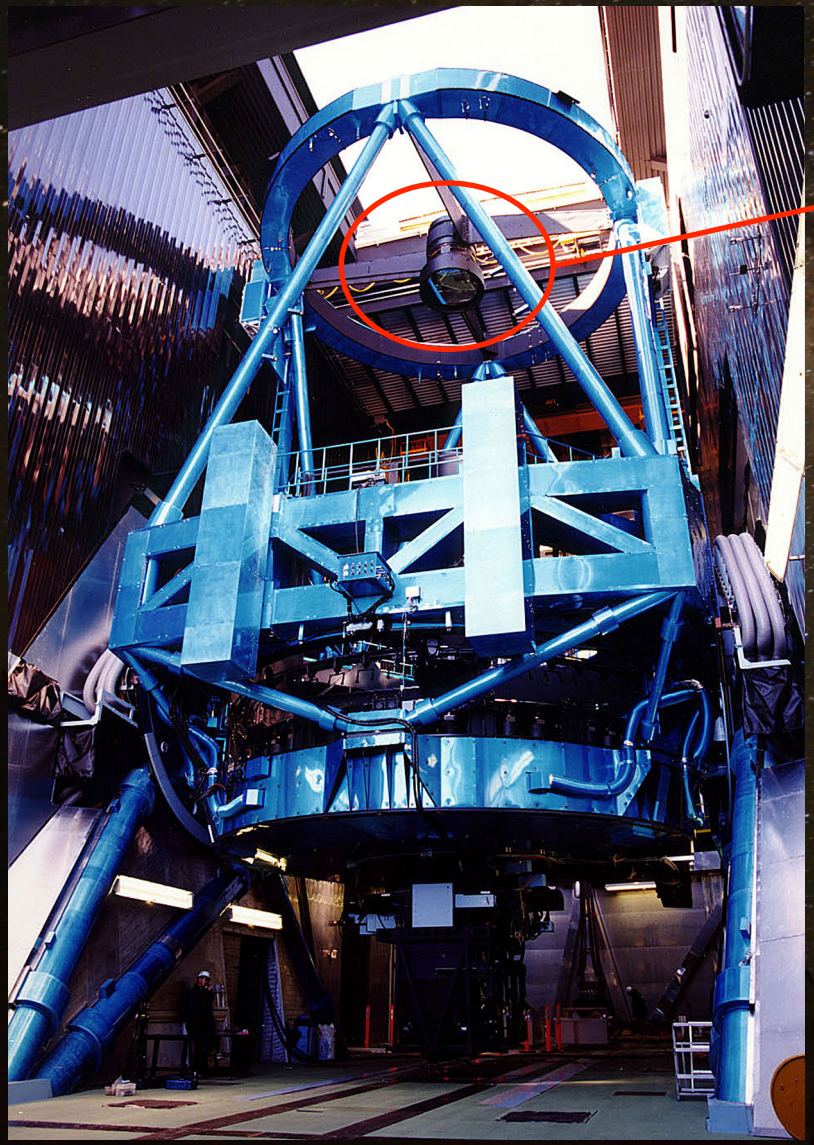
Naoyuki TAMURA

Kavli IPMU, The University of Tokyo
PFS project manager

KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

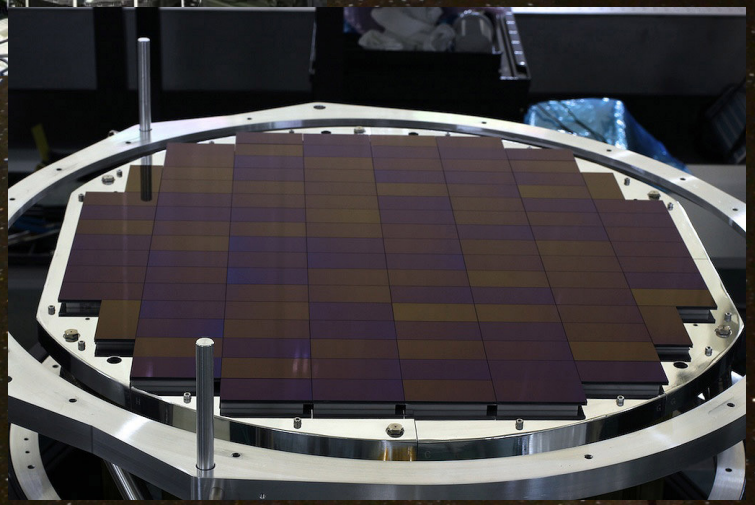
For Subaru Users Meeting FY2016 at NAOJ on Jan 10-12, 2017

Upgraded Subaru Prime Focus with Hyper Suprime Cam (HSC)



Largest camera

- 3m high
- weigh 3 ton
- 104 CCDs (~0.9B pixels)

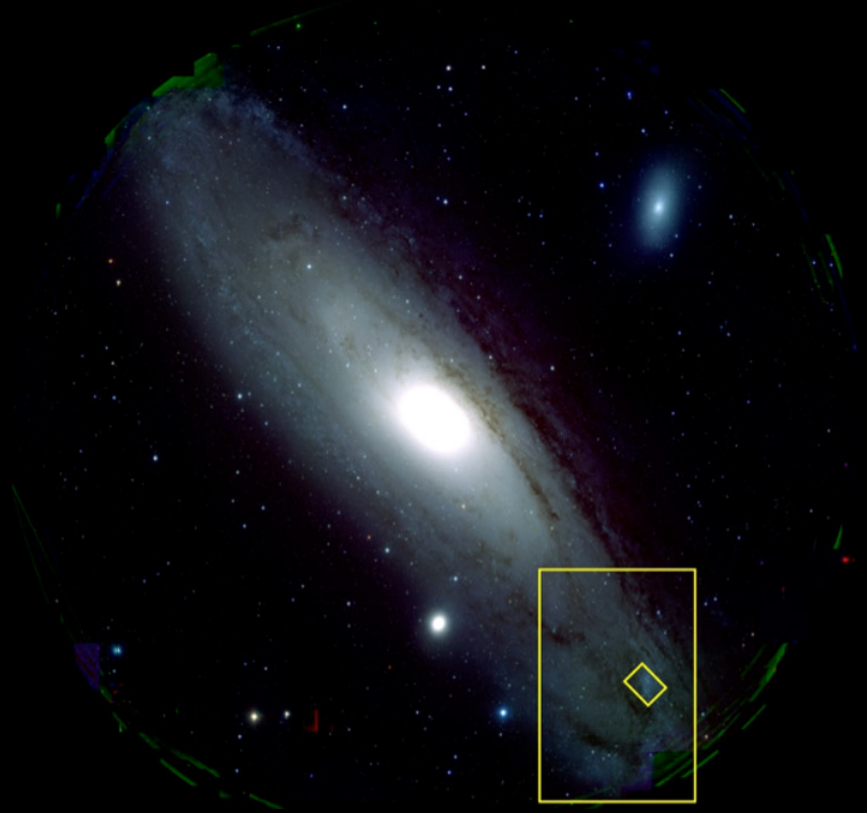


The history of Subaru Prime Focus field of view

The full Moon
~0.5 deg diameter

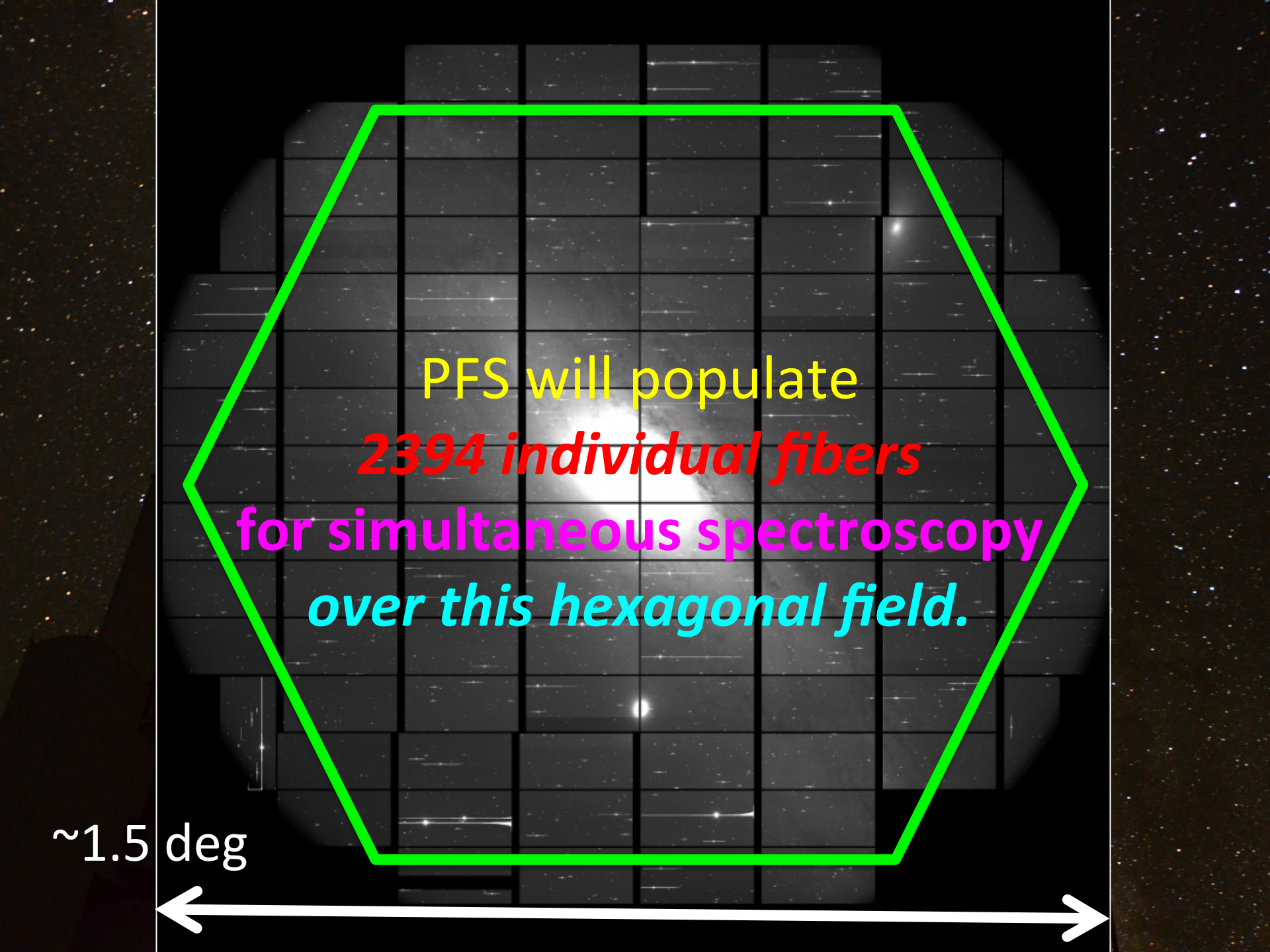
Suprime-Cam
First Light
(Released Jan 1999)

Suprime-Cam
Full operation
(Released Sep 2001)



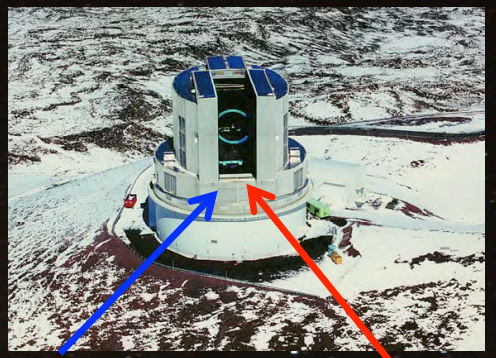
Hyper Suprime Cam
(Released Jul 2013)

Courtesy of M. Takada (IPMU)


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

SuMIRe project

Subaru Measurement of Images and Redshifts



HSC PFS

Exploiting the large light-collecting power of the Subaru Telescope & wide field at its prime focus:

Same telescope

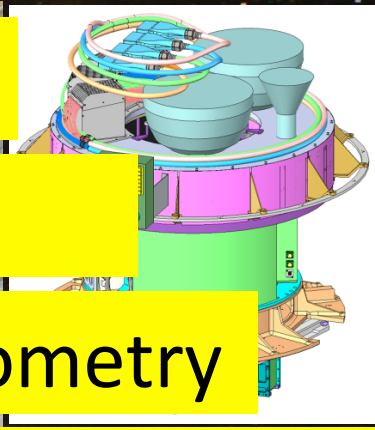
Same patches of sky

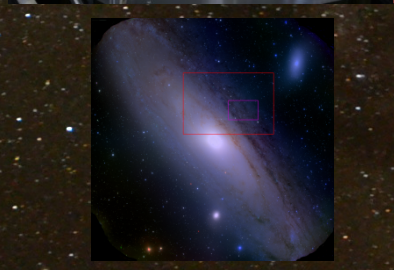
Clean target selection by deep photometry

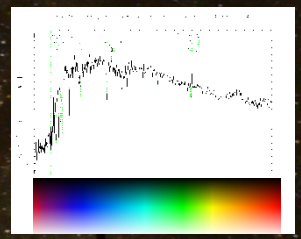
- ✓ 30
- ✓ 1400 sq. degrees. 1 billion galaxies

- *Follow-up*
- *"Prime Fo*
  - ✓ ~2400 optical fibers
  - ✓ ~300 nights from ~2019
  - ✓ ~4M galaxy redshifts
  - ✓ ~1M stars in MW halo/disks/satellites & M31.

Spectroscopic information on top of detailed studies by deep & sharp images

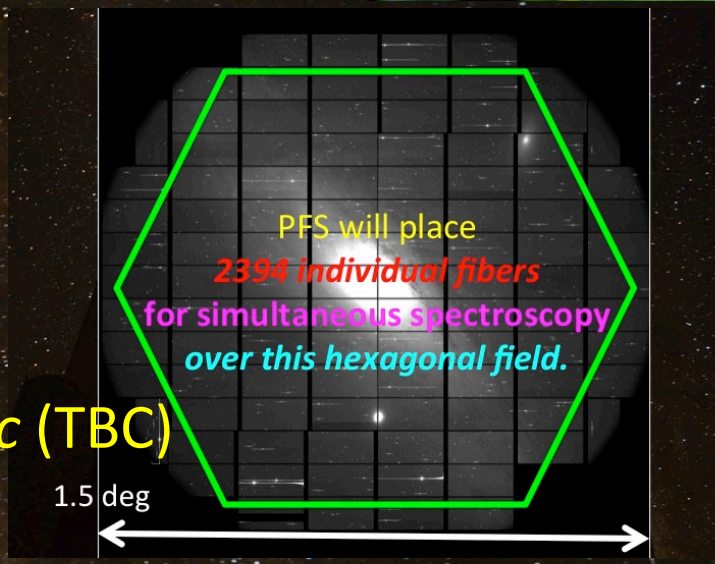






PFS - Fast facts

- Subaru *Prime Focus Spectrograph*:
  The spectroscopy part of the "SuMIRe" project.
  - Wide field: *~1.4 deg* diameter
  - High multiplicity: *2394 fibers*
    - Fiber diameter: ~1.05 arcsec
    - Fiber positioner pitch: ~85 arcsec
    - Minimum fiber separation: ~30 arcsec
  - Quick fiber reconfiguration: *~60-120 sec* (TBC)
    - *Dynamic* survey strategy is allowed.
  - VIS-NIR coverage: *380-1260nm simultaneously*
    - Low resolution mode: ~2.5 A resolution
    - Medium resolution mode (around 800nm): ~1.6 A resolution



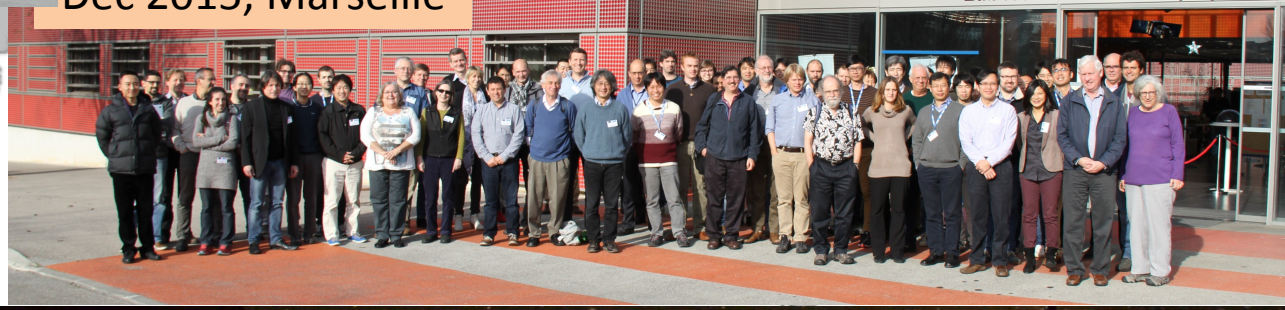
- Aiming at start of science operation & survey program in *2020, as a facility instrument on Subaru Telescope.*

The *updated* PFS collaboration

Scientists & (untries are co-working for rvey planning.

Dec 2016, Baltimore

Dec 2014



Dec 2015, Marseille

Dec 2016, Baltimore (JHU)

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

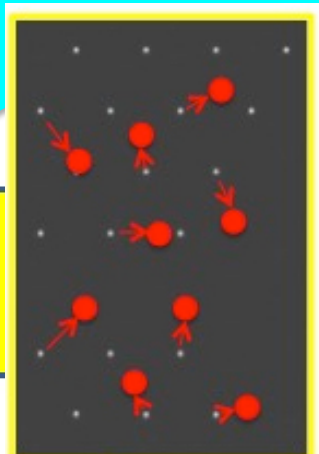
Wide-field corrector

… 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

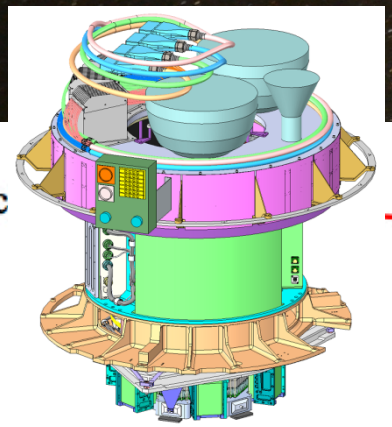
Prime Focus Instrument (PFI)

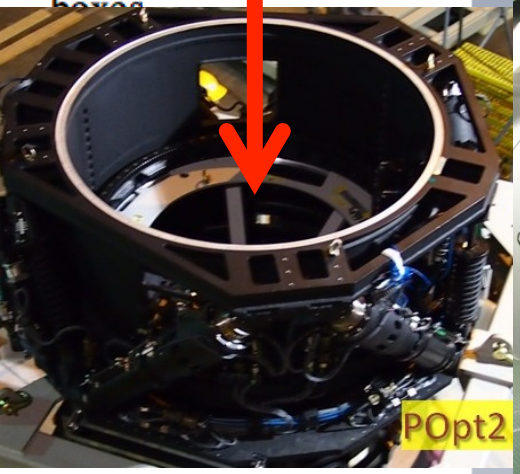
Sits in the prime focus unit “POpt2” and installed to the telescope

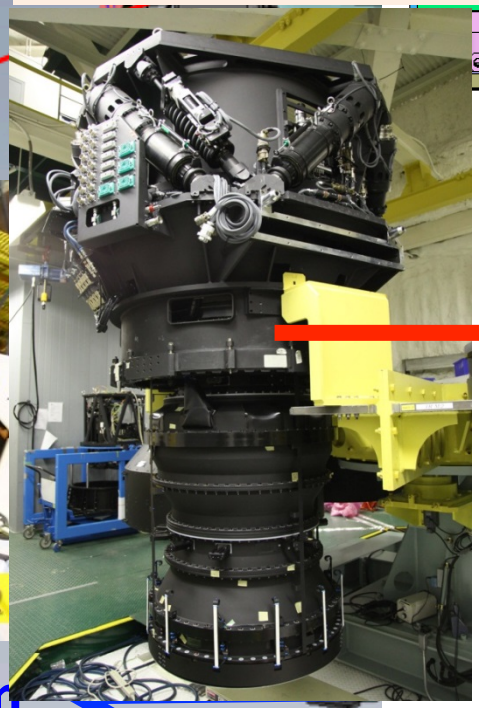
- Fiber positioner system
- Acquisition & Guide (AG) camera
- Fiber cable: “Cable C” & fixed fiducial fibers
- Fiducial fiber illuminator
- Field element (cf. Filter+dewar window@HSC)
- Cable wrapper
- Calibration lamp system

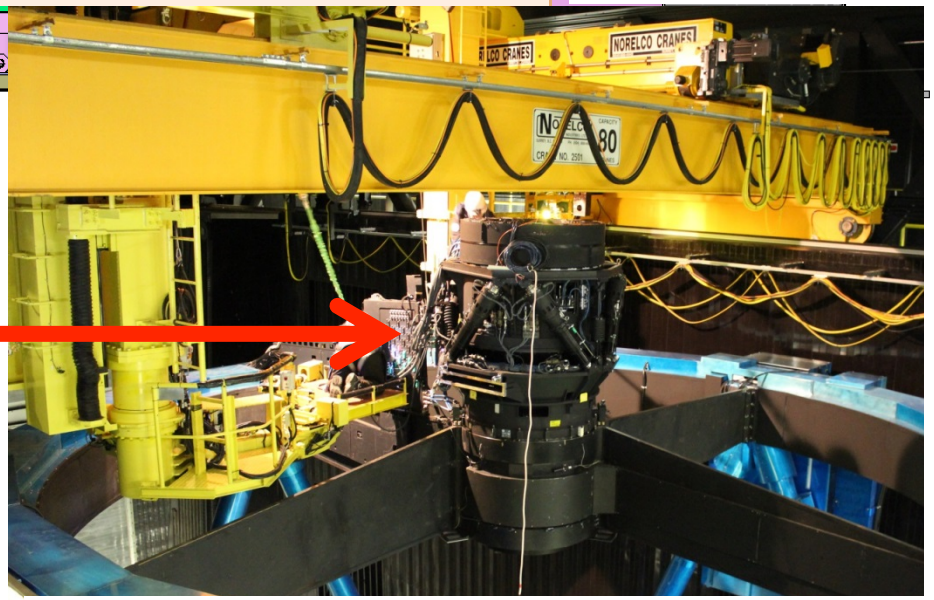
Wang (ASIAA)+ [SPIE 2016]

Caltech-JPL
LNA
ASIAA
IPMU/Princeton



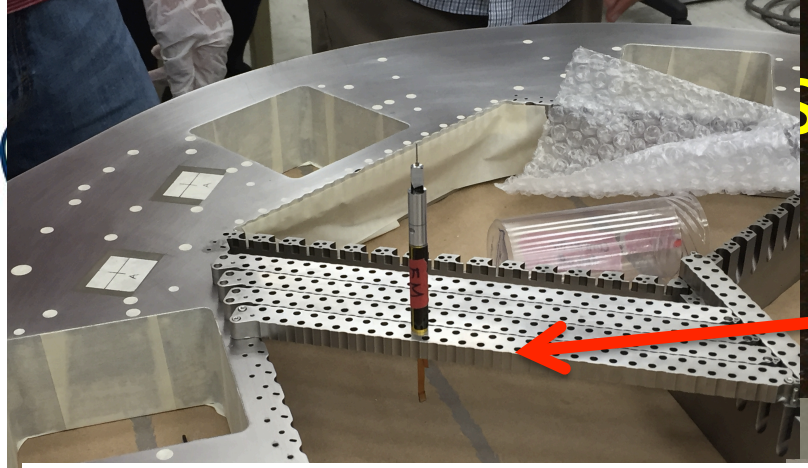






~1.1m

HSC builder’s blog
http://anela.mtk.nao.ac.jp/hscblog/builder/



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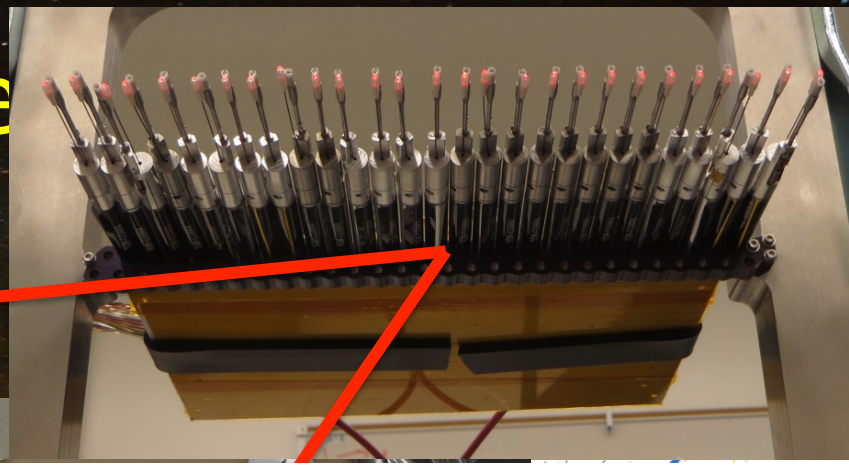
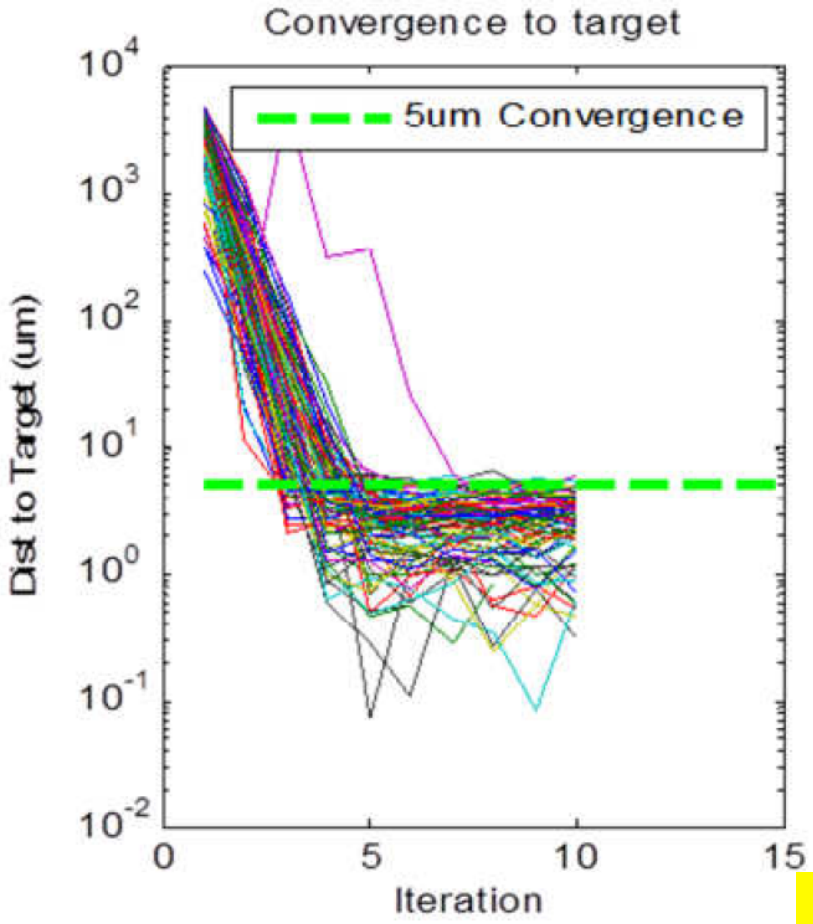
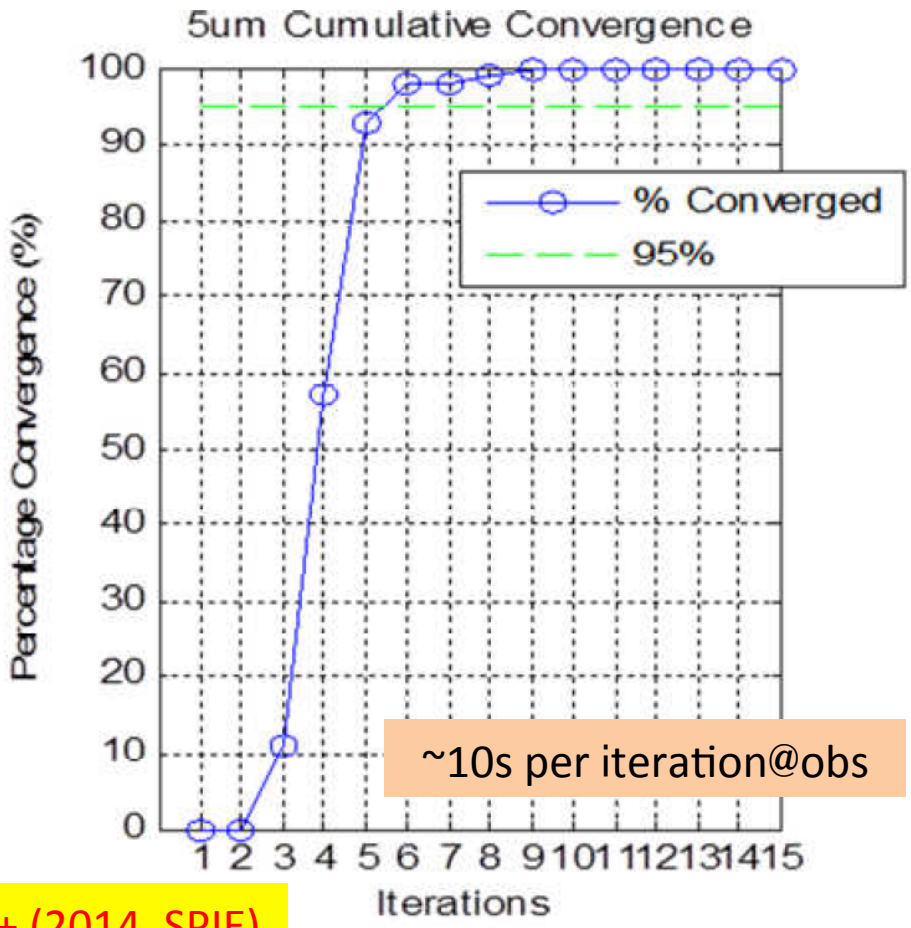






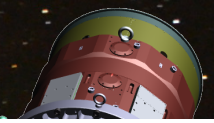
~10s per iteration@obs

Fisher+ (2014, SPIE)

Spectrograph System (SpS)

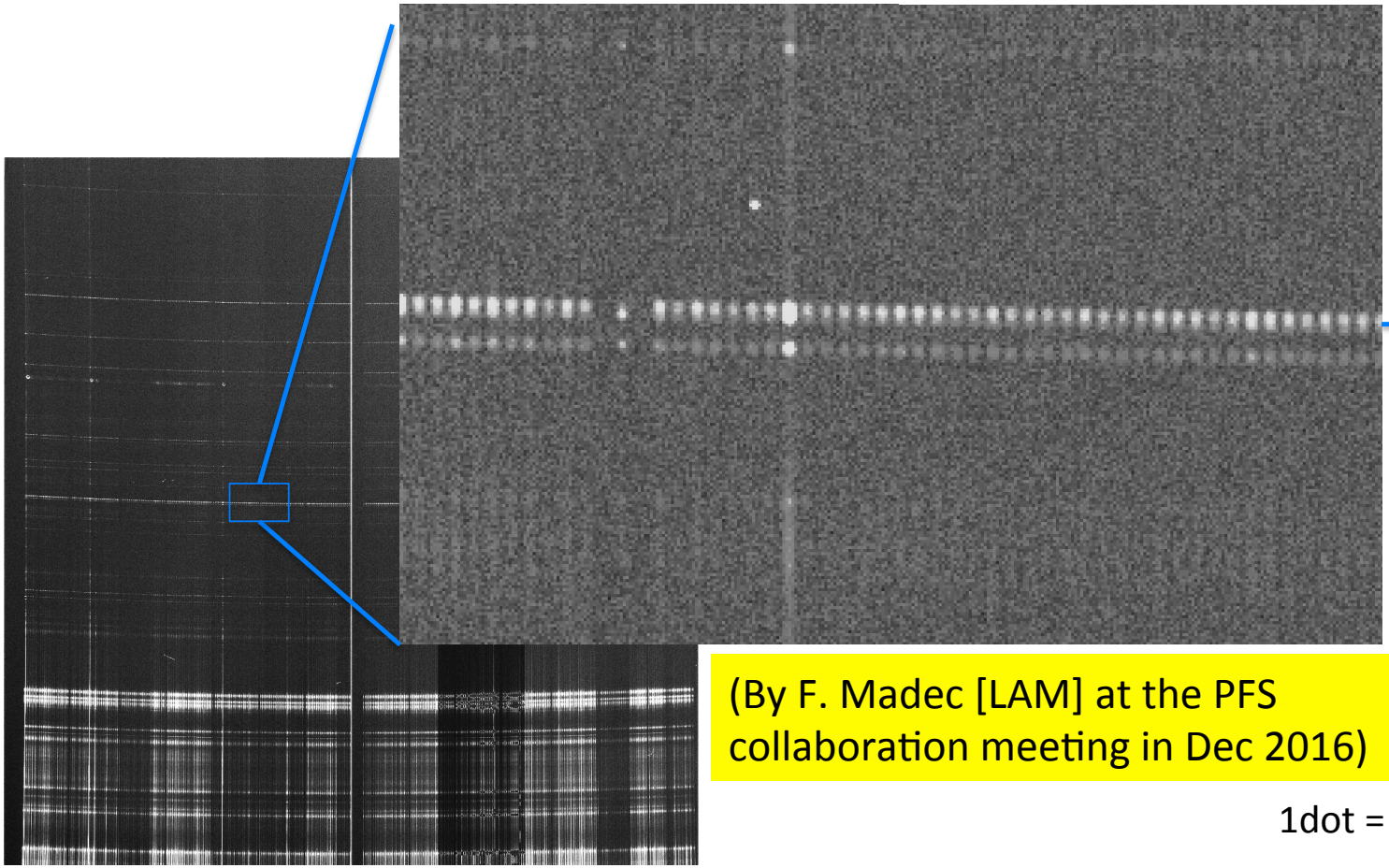
1 module → ~600 fibers
4 modules → ~2400 fibers

"Red"



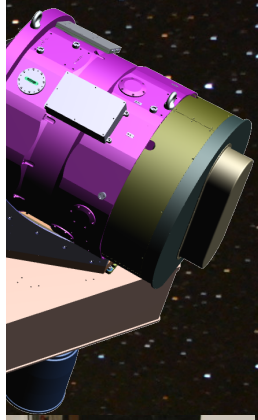
Ambient First Light;-)

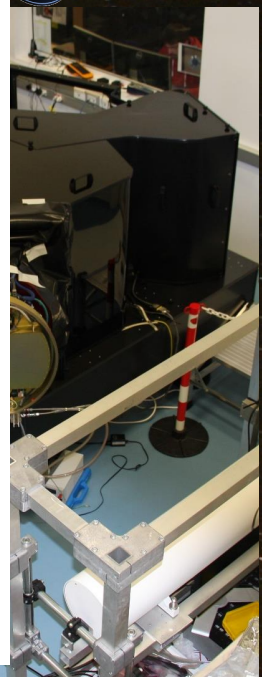
@LAM (with red camera only)

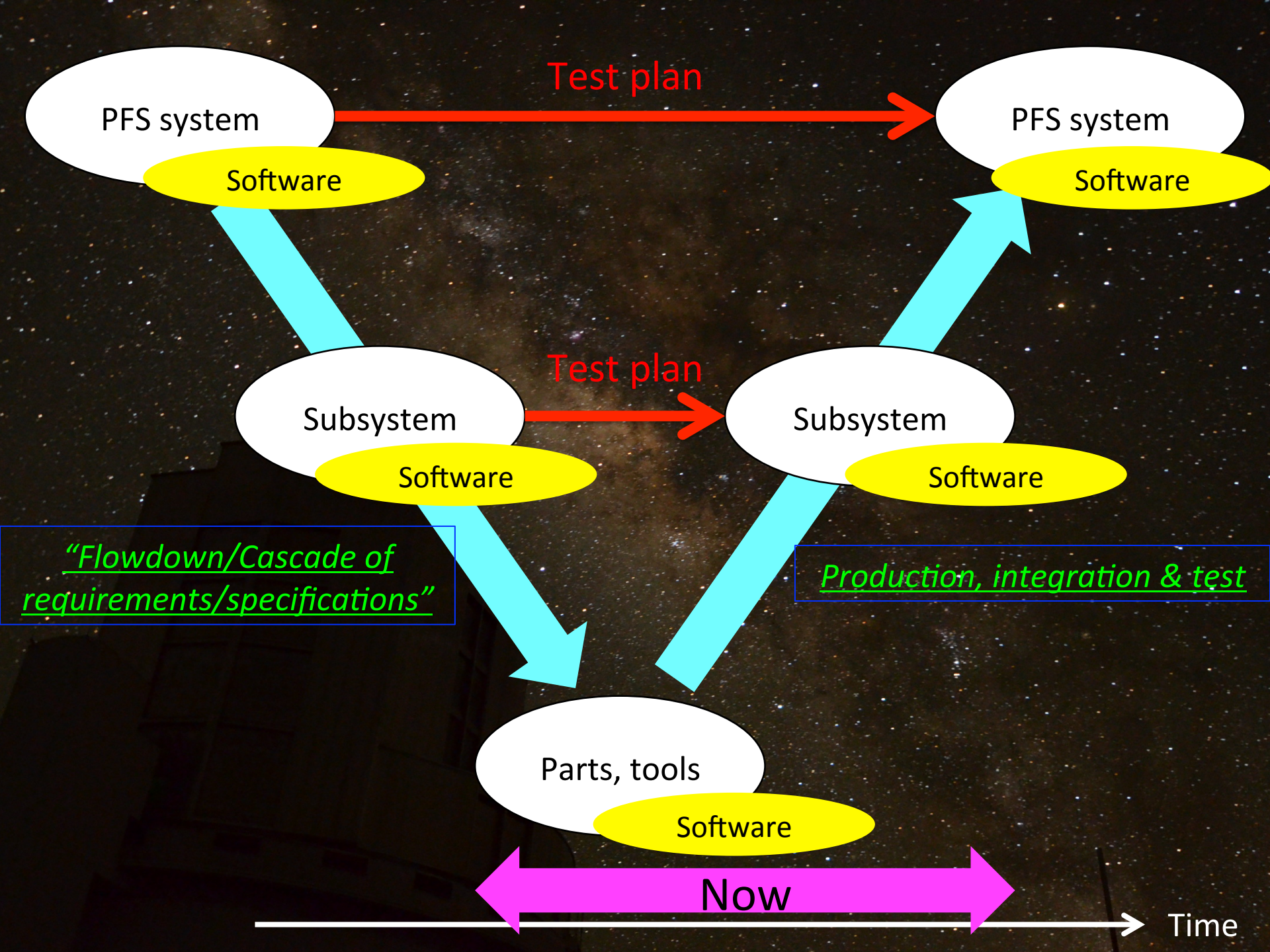


(By F. Madec [LAM] at the PFS collaboration meeting in Dec 2016)

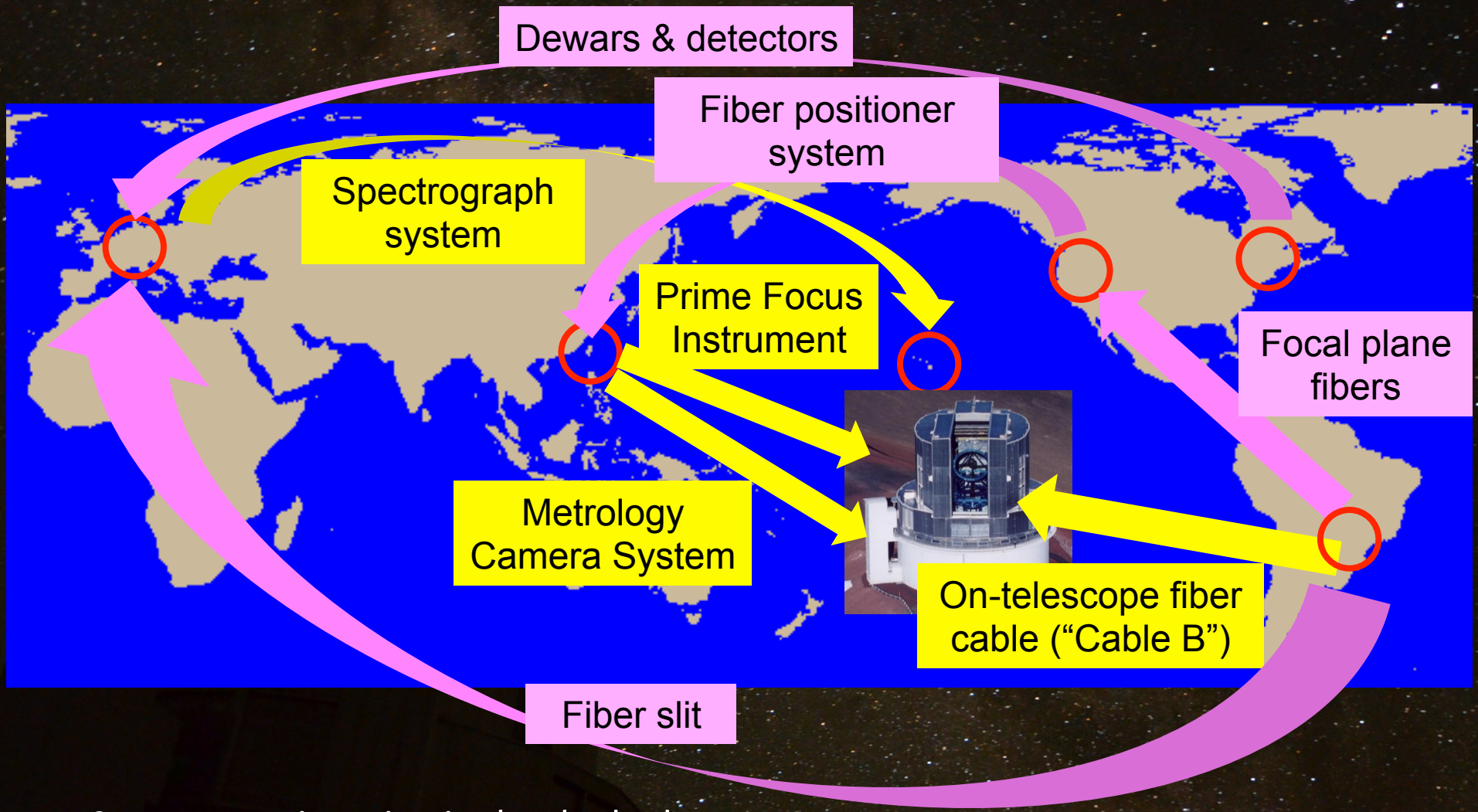
1dot = 1 fiber






PFS system
Software
Test plan
PFS system
Software
Subsystem
Software
Test plan
Subsystem
Software
"Flowdown/Cascade of requirements/specifications"
Production, integration & test
Parts, tools
Software
Now
Time

Logistics for PFS system integration



- Systems engineering is clearly the key.
- Parts/components/subsystem will be validated at each site before their delivery to other places for higher-level integration & finally to Subaru.

Now at subsystem integration

Test uncovers many things …

How should we fight??

By collaboration!

VS

- Additional FRD in the fiber connectors

  → ***In the final validation of updated mating strategy***

- Thermal issues of the camera cryostat (~outgassing e.g. due to less optimal surface finishes)

  → ***Tests under way to confirm the improvements***

Planning of PFS survey program

- Subaru Strategic Program (SSP)
  - HSC SSP has been progressing since 2014.
    - ~300 nights out to ~2019.
  - PFS SSP: A proposal (~300-360 nights) is in preparation.
    - Timely start taking over the HSC SSP
    - A survey program with the three "pillars":

Cosmic evolution and the Dark Sector

Cosmology

Galaxy & AGN evolution

Galactic Archaeology

PFS cosmology component

~1,400 deg^2 of the HSC "wide" survey fields

- Cosmic acceleration
  - Dark matter
  - Dark energy
  - Neutrino mass

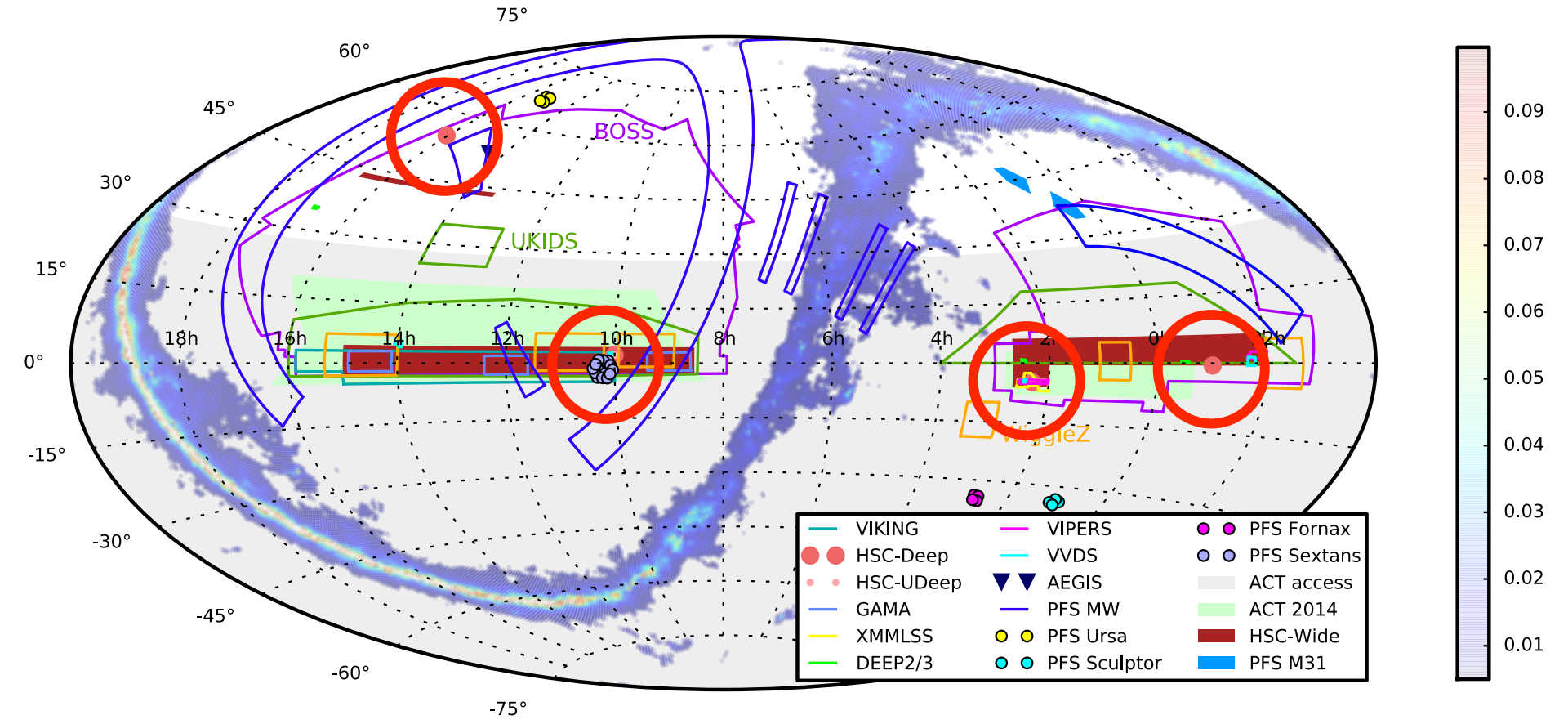
- HSC "+" PFS
  - Clean target selection
  - Joint analysis (e.g. lensing vs. clustering)

Targeting [OII] emission

Prof. Takaaki Kajita (ICRR/IPMU)

PFS galaxy & AGN evolution component

- *HSC "deep" (~25 deg^2) & "ultra-deep" (~3 deg^2)*
- *Prioritizing ~15 deg^2 where NIR data exist already in parallel to efforts for full coverage*



SFR

DUSK

NOON

DAWN

z=0.8

z=2

z=7

PFS GALAXY EVOLUTION

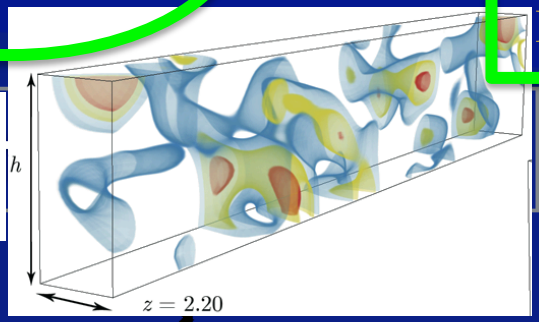
within cosmic web

400,000
Continuum-Selected
Galaxies

200,000
Dropouts

200,000
LAEs

IGM tomography
(e.g. Lee+ 14)



Hα

Star formation
rates

[OIII]

Ionization
Metallicity

[OII]

MgII

Winds

Lyα

Reionization

Courtesy of Jenny Greene (Princeton)

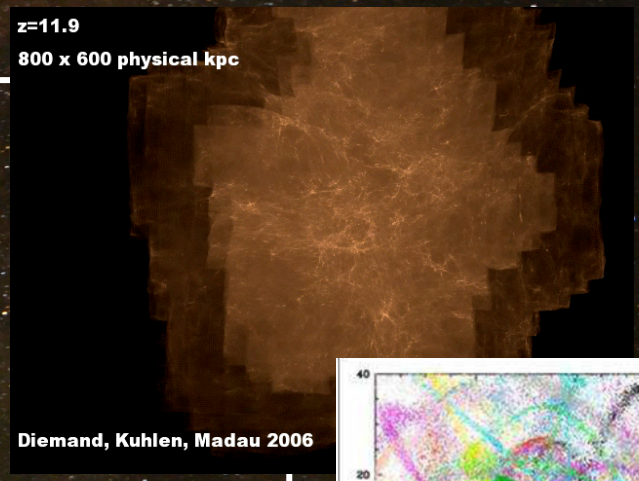
PFS Galactic Archaeology (GA) component

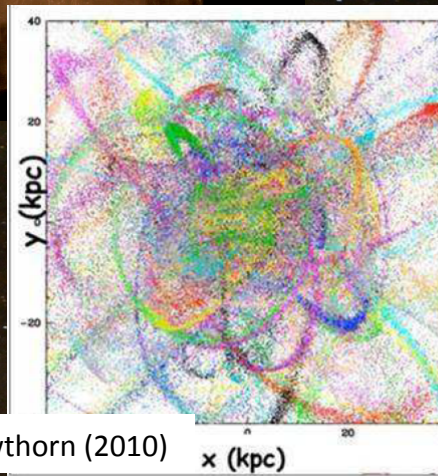
M. Chiba
(Tohoku U.)

Science objectives

We measure radial velocities & chemical abundances for a large number of stars in the Milky Way and Andromeda to constrain the nature of dark matter and its role in the formation of these galaxies

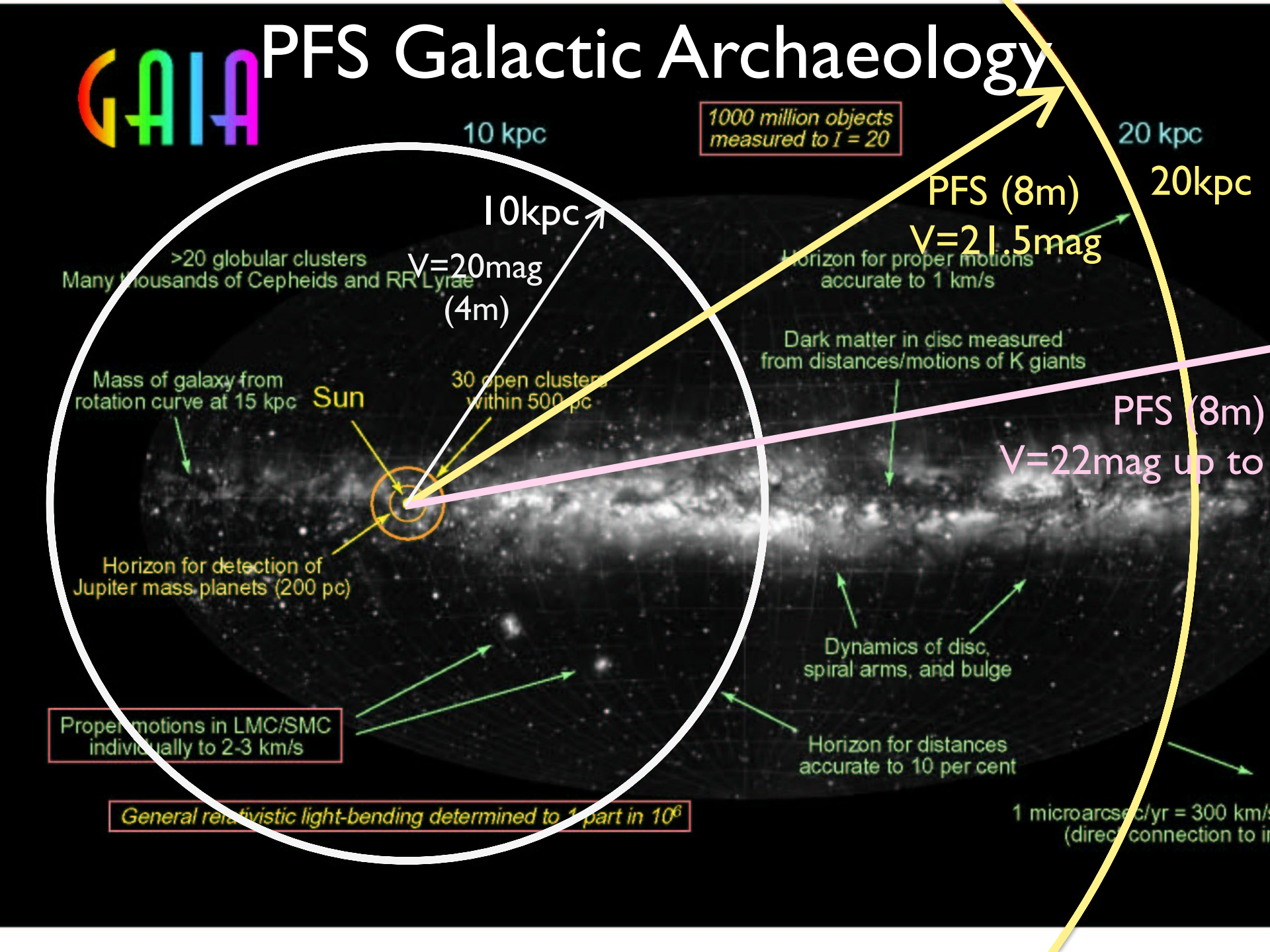
- MW dwarf satellites (Feb, May, Jun, Oct)
  - DM distribution, chemo-dynamics with [α/Fe]
- The M31 halo (Oct)
  - DM/stellar halo structure, chemo-dynamics with spectroscopic [Fe/H]
- MW halo/stream (Feb, Mar, May, Jun, Oct)
  - DM/stellar halo structure, chemo-dynamics
- MW disks (Dec for outer disk, any month for thick disk)
  - Chemo-dynamics with radial migration, disk structure





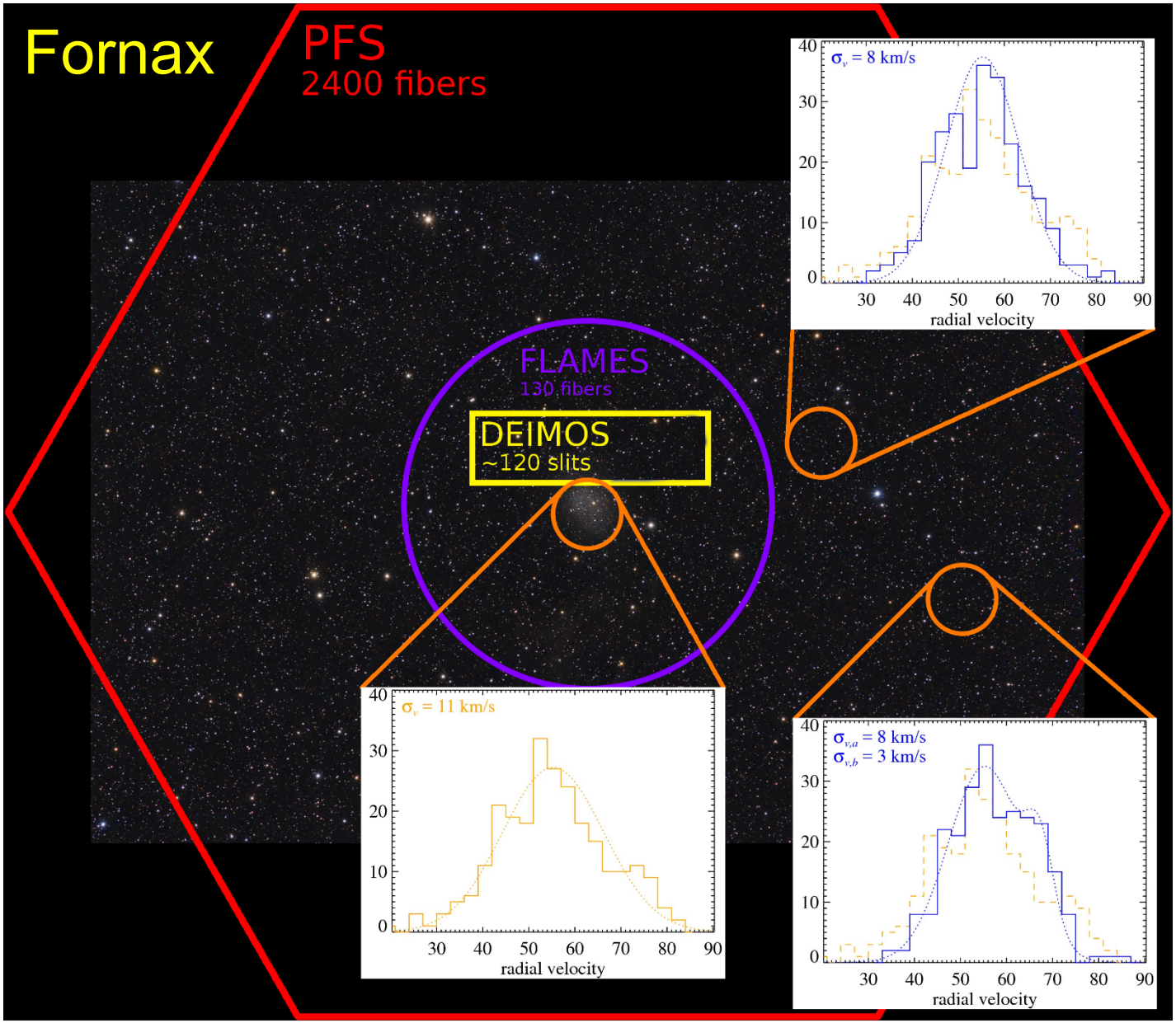
Freeman & Bland-Howthorn (2010)

PFS Galactic Archaeology



Uniqueness of PFS

By E. Kirby
(Caltech)



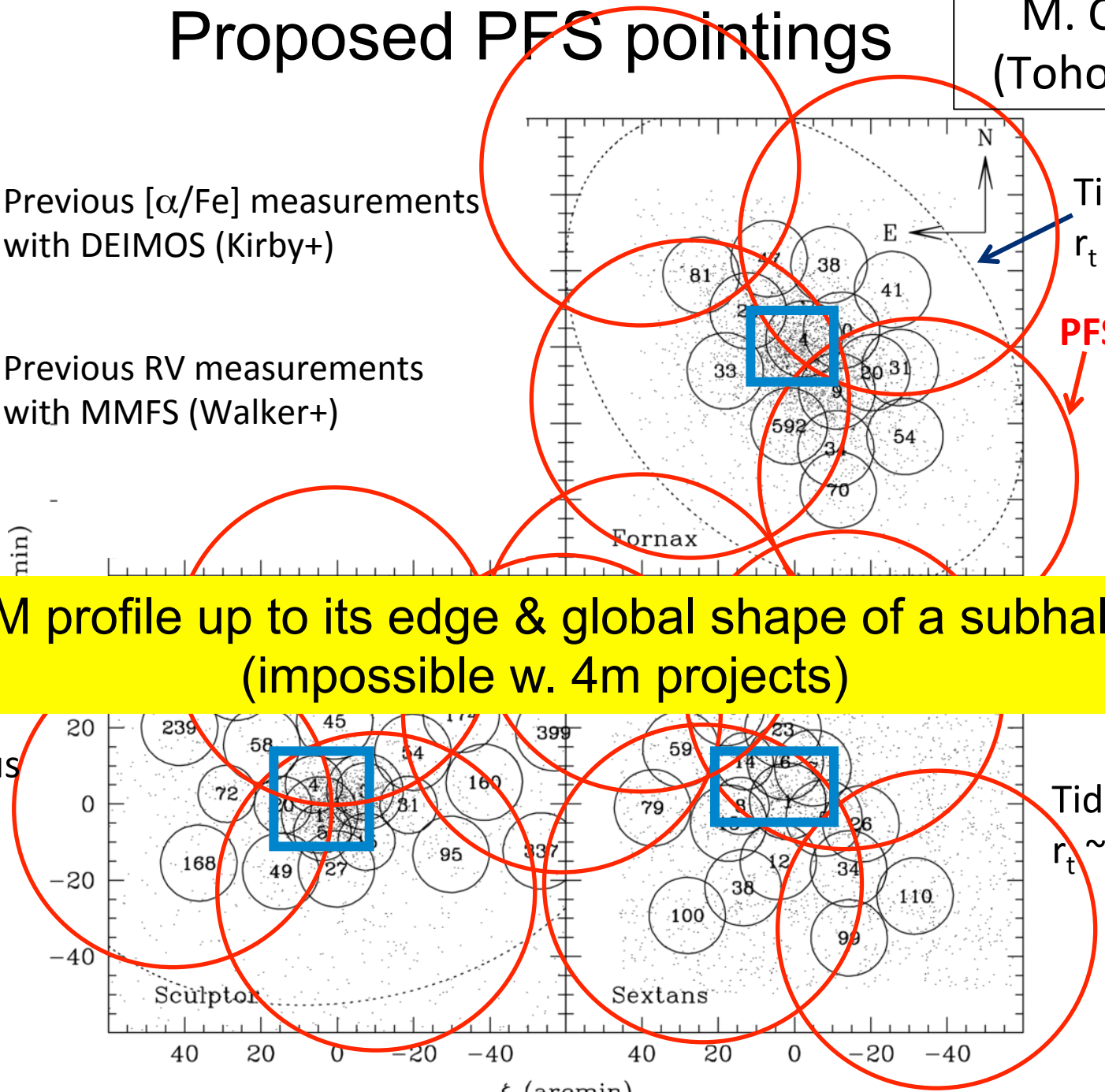
Velocity distribution

Proposed PFS pointings

M. Chiba
(Tohoku U.)

Previous [α/Fe] measurements with DEIMOS (Kirby+)

Previous RV measurements with MMFS (Walker+)



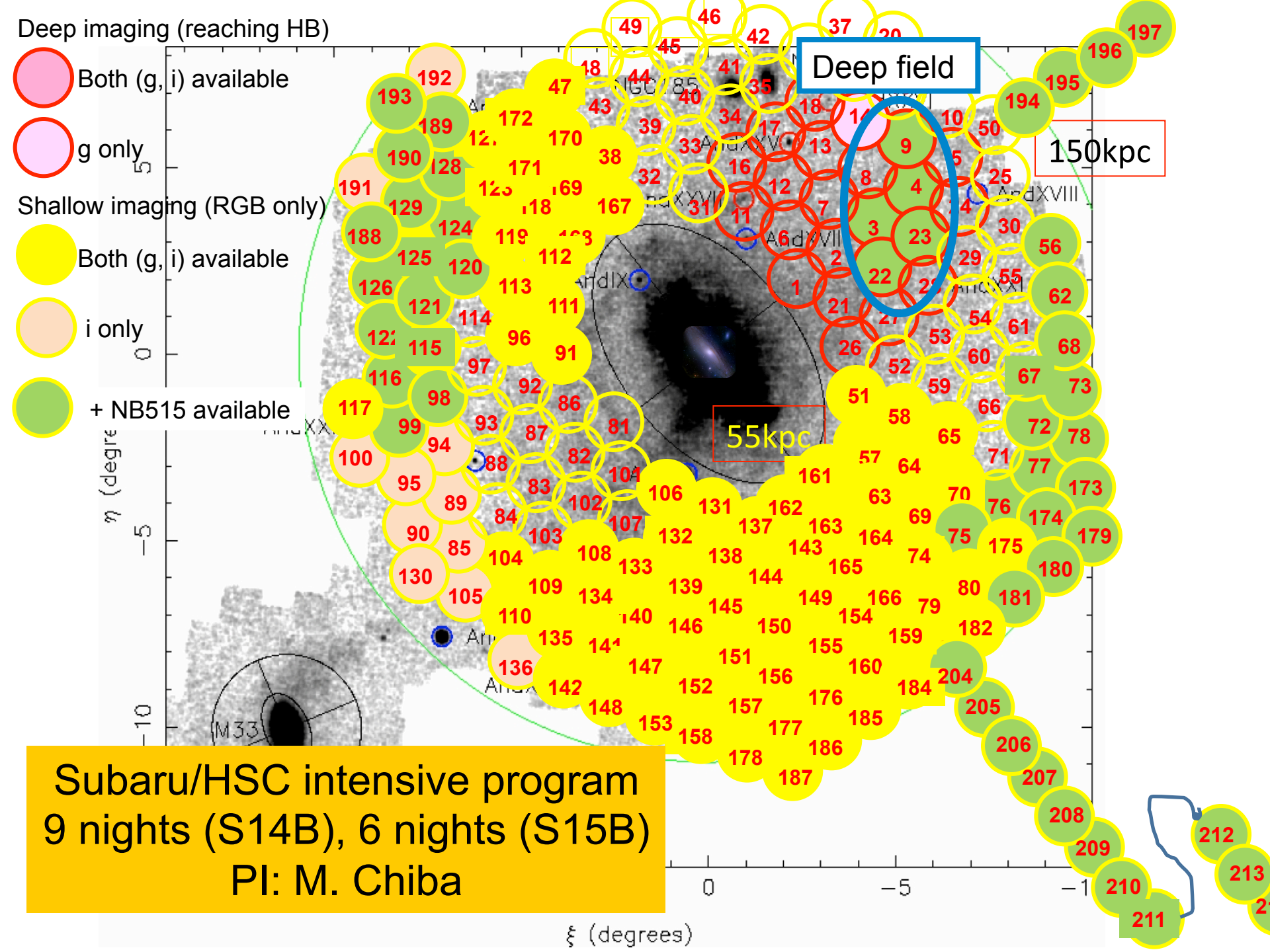
Tidal radius
r_t ~ 71’

PFS pointing

DM profile up to its edge & global shape of a subhalo (impossible w. 4m projects)

Tidal radius
r_t ~ 76’

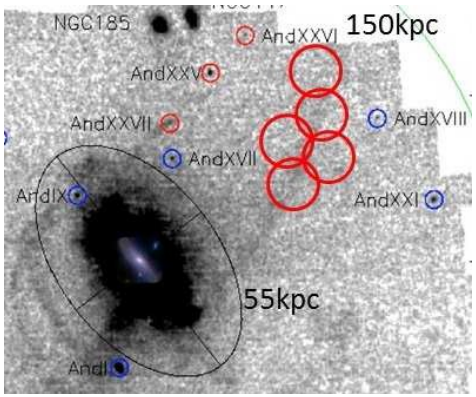
Tidal radius
r_t ~ 160’

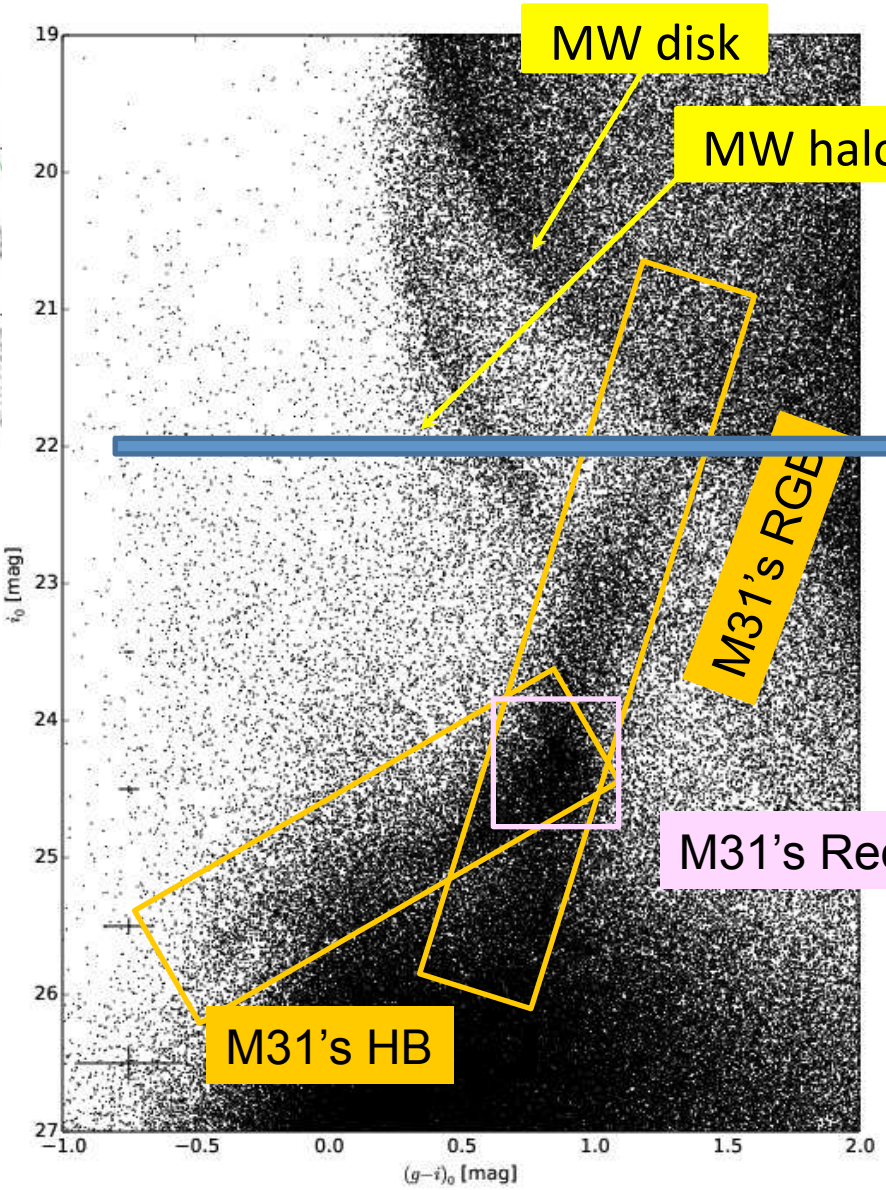

Deep imaging (reaching HB)
Both (g, i) available
g only
Shallow imaging (RGB only)
Both (g, i) available
i only
+ NB515 available
Deep field
150kpc
55kpc
Subaru/HSC intensive program
9 nights (S14B), 6 nights (S15B)
PI: M. Chiba
ξ (degrees)
η (degrees)

Color magnitude diagram

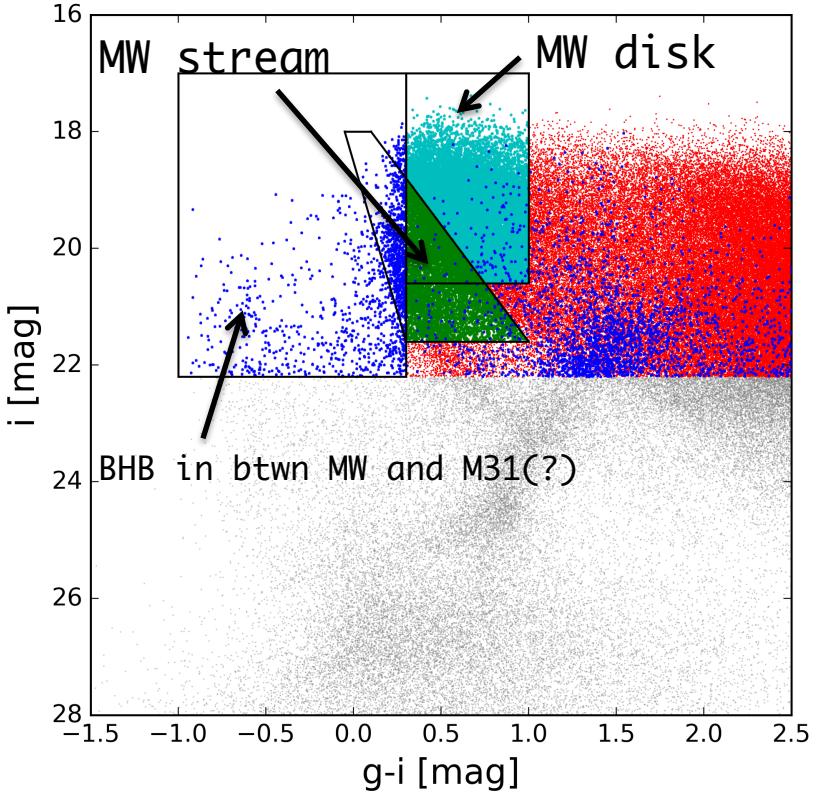
Komiyama
(NAOJ)

North-western stream

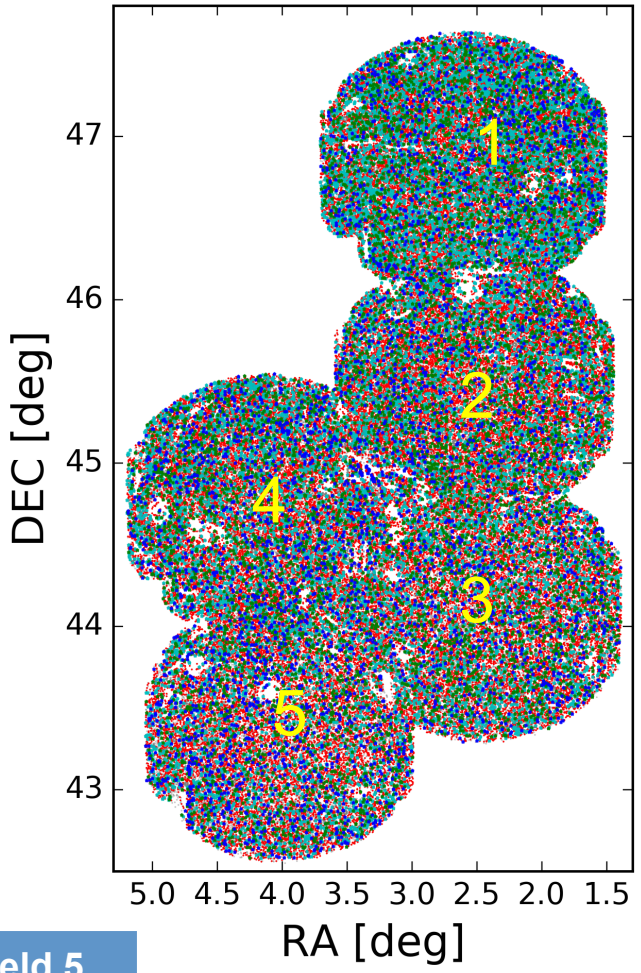




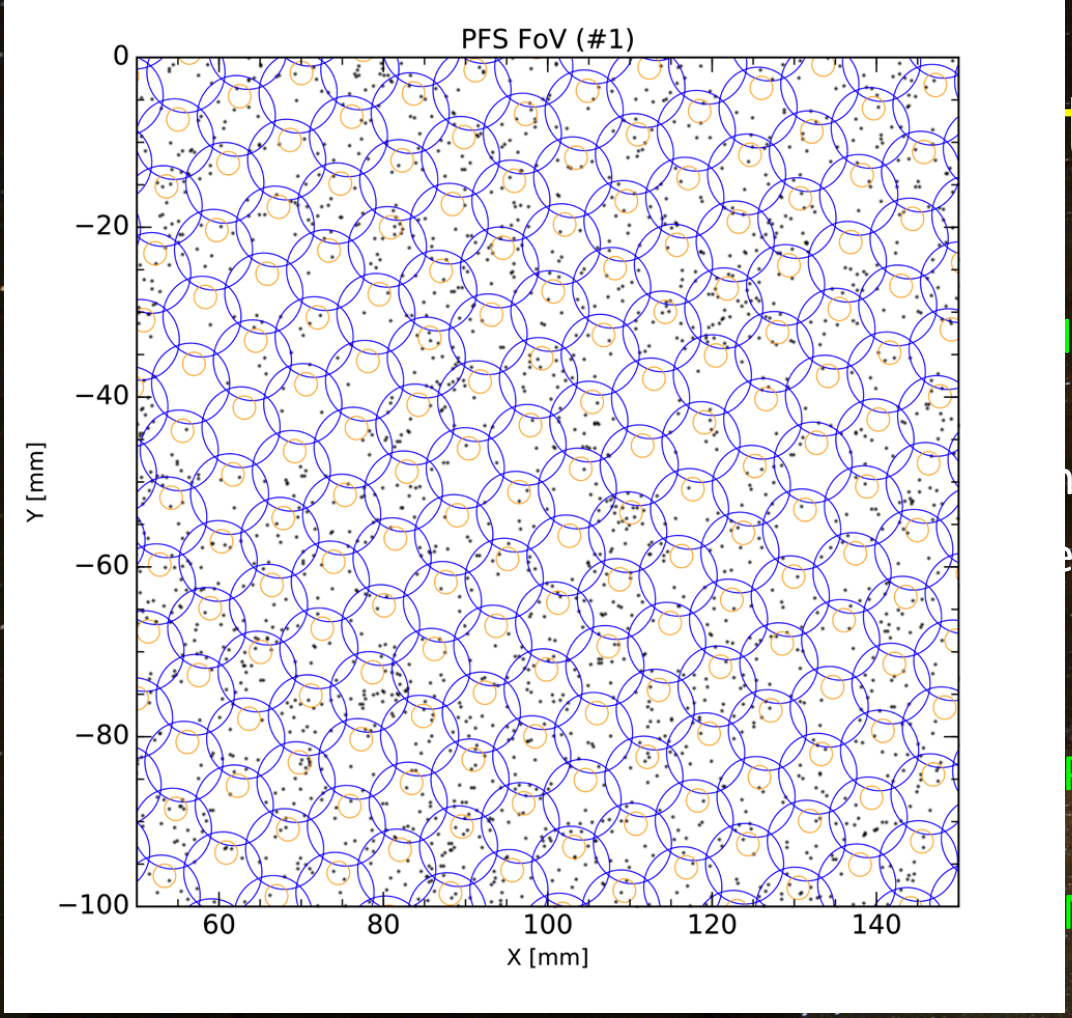
Field tiling and fiber allocation



Hayashi (IPMU → PKU)



	Field 1	Field 2	Field 3	Field 4	Field 5
Blank fiber	329	647	739	628	878
Selected stars	4991	3291	2806	3378	2572
Observable selected stars within 12hr	4957	3282	2799	3350	2556



t (only highlights)

IPMU],

team)

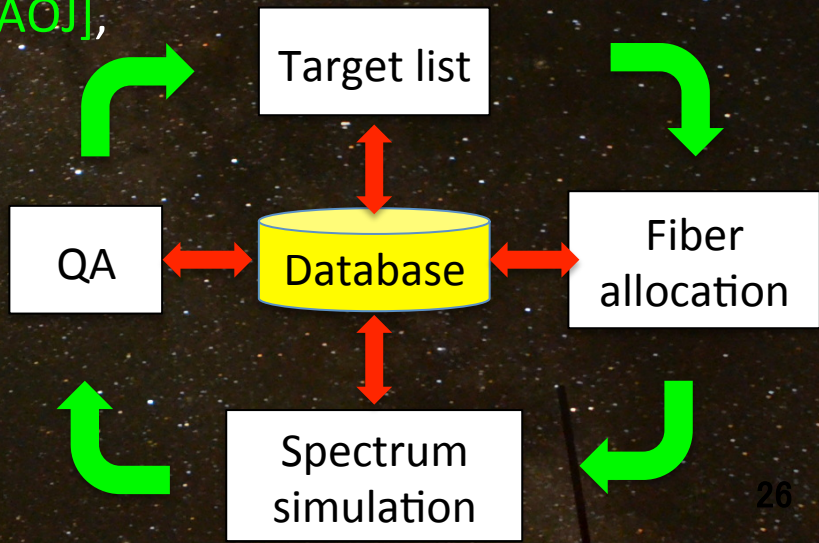
eam)

PMU],

NAOJ],

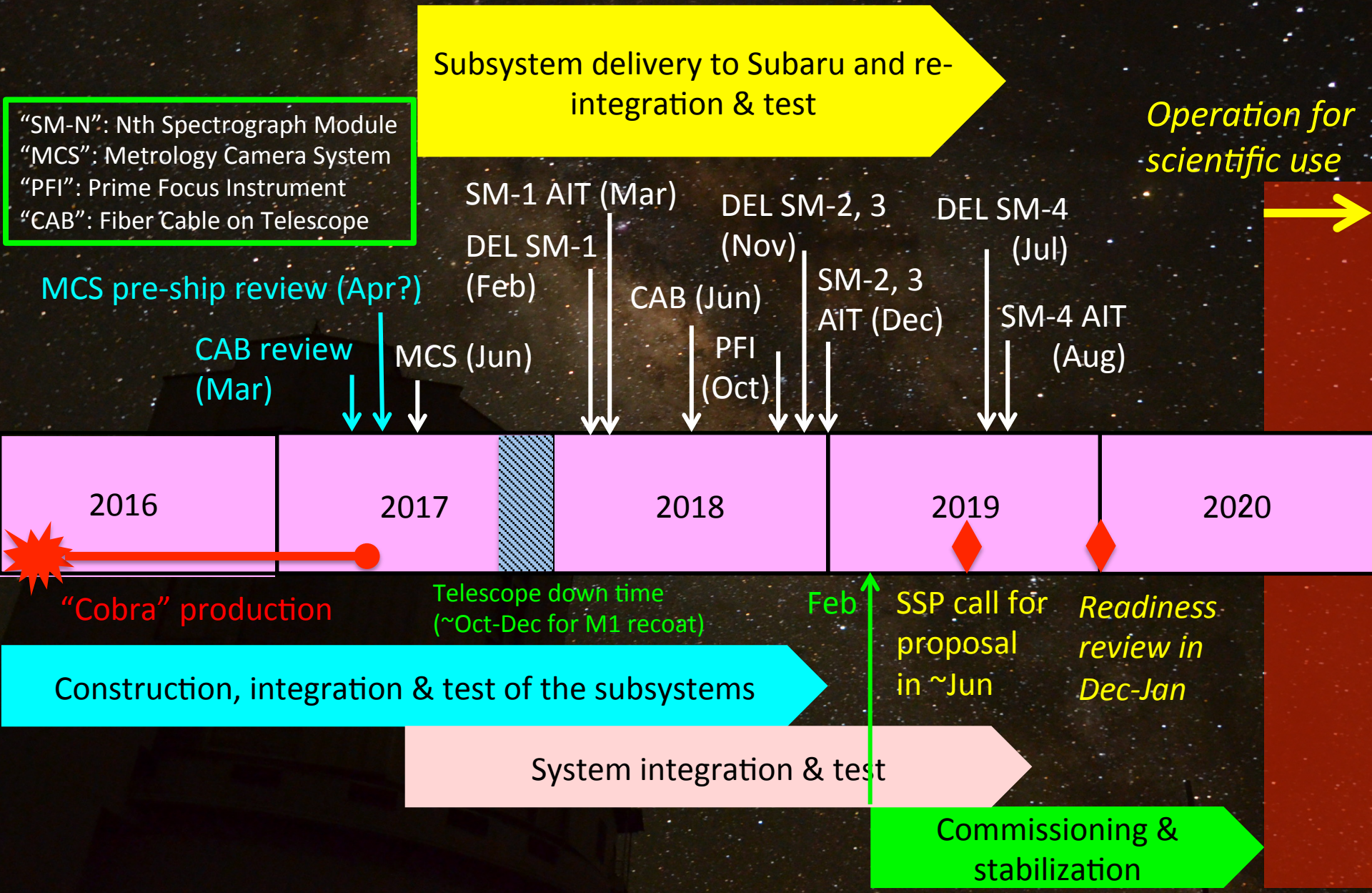
Tools for scientists to:
- Proceed with detailed survey design studies
- Commit to software development

- Survey simulations (Yabe) with:
  - PFS data model & other format control (Lupton)
  - Data quality assurance (Lupton, Yasuda)



Updated top-level schedule

Subject to changes until the end …

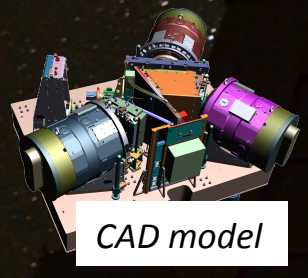


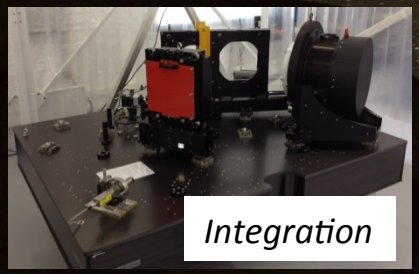
Funding situation

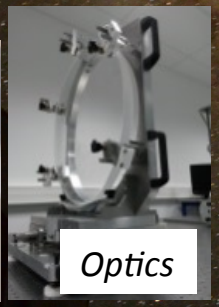
- *Not yet fully funded, but making great improvements:*
  - In the total cost of $~80M, the shortfall is now $~3M including contingency (c.f. $~20M at PDR in 2013).
- *Recent inputs:*
  - The Murayama, Takada, Komatsu et al.'s Grant-in-Aid for Scientific Research (科研費新学術)
    .→ $~1.8M for the PFS NIR cameras over 5 years from 2015.
  - The Chinese consortium joined in Dec 2015 → +US$5M.
  - The PFS US team had NSF MSIP approved in Aug 2016.
  - The Max Planck consortium evolved with MPE in Nov 2016 → +US$1.5M.
- *"Meaningful" cost increase*
- Continuing fundraising efforts.

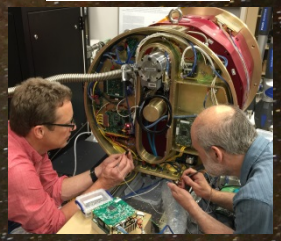
A summary about PFS

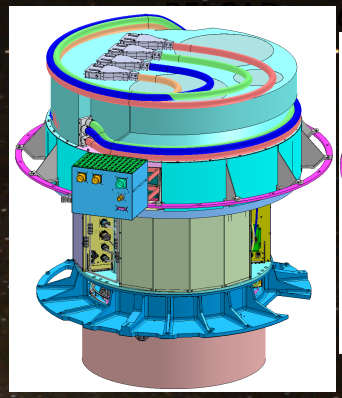
- The project CoDR in 2012, PDR in 2013, and subsystem CDRs in 2014-2015.
- Now construction, integration and test are under way at the subsystem level.
- Aiming at engineering observation from ~early 2019 & science operation from 2020.
- The funding situation has greatly improved.

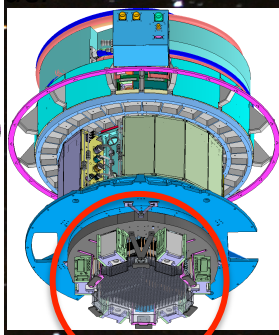

CAD model


Integration


Optics

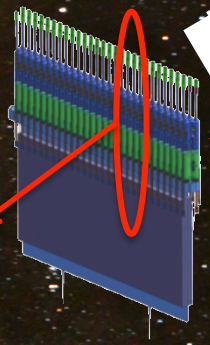
Cryostat


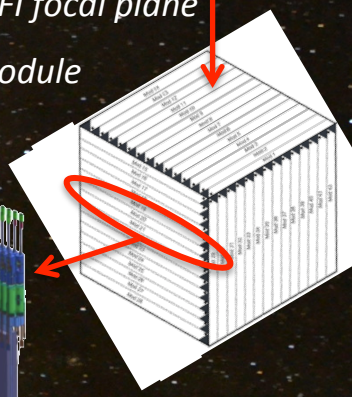




PFI focal plane

"Cobra" positioner module





"Cobra" engineering model module

- Survey planning is underway to be proposed as a ***Subaru Strategic Program*** for cosmology, galaxy/ AGN evolution & Galactic archaeology.
- Enables Subaru to be a world-leading facility out to the next decades through effective synergy with *TMT, LSST, JWST, Euclid, WFIRST,* etc.

Individual "Cobra" positioners