

SUBARUPRIMEFOCUSPECTROGRAPH

*Overview, current status, updates, and future plans
of upcoming instrument on Subaru Telescope*

Naoyuki TAMURA

Kavli IPMU, The University of Tokyo
PFS project manager

K A V L I
IPMU

INSTITUTE FOR THE PHYSICS AND
MATHEMATICS OF THE UNIVERSE

“Why does the Universe accelerate?”, at KEK on Mar 8-10, 2017

Summary

- **Technically:**

- Making good progress! Not only production of individual parts but also integration & test (I&T) are ongoing at subsystem level.
 - Working on problems and issues that have been uncovered at I&T.
 - Subsystem delivery to Subaru will start soon: Metrology camera system in Dec 2017, First spectrograph module in early 2018.

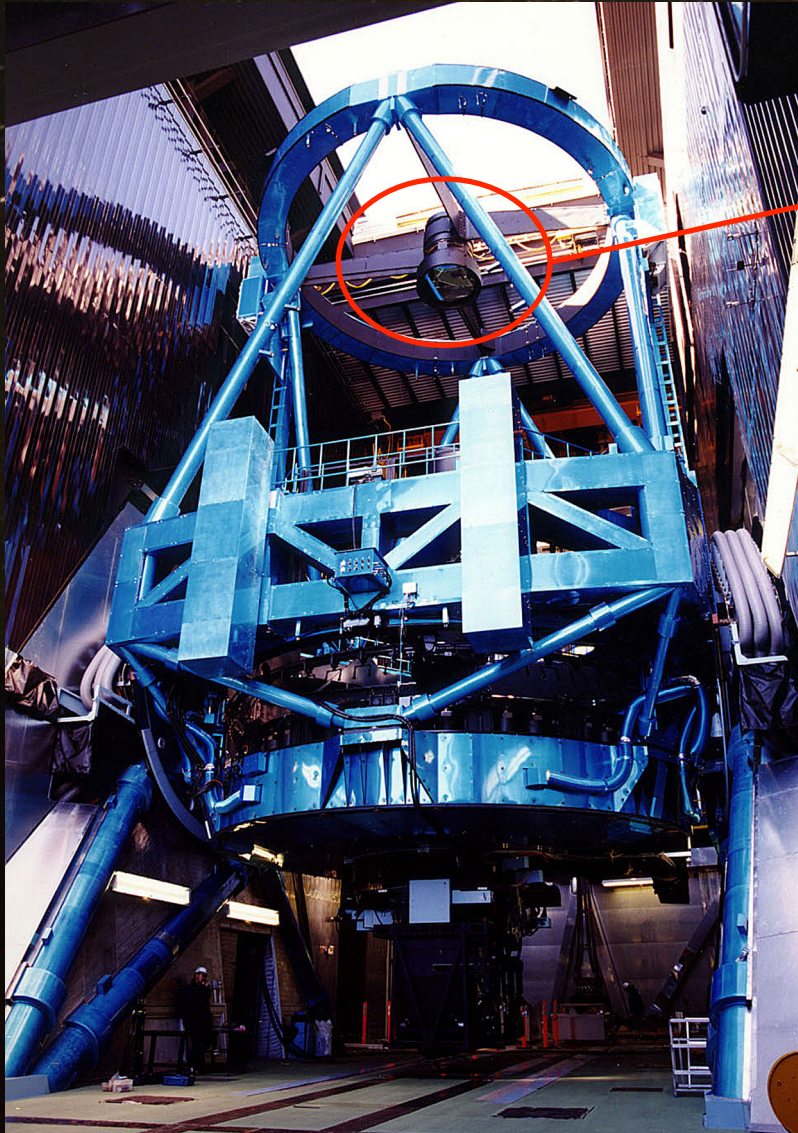
- **Scientifically:**

- Ramping up the ~5-year survey design development:
 - The updated proposal from each working group will be reviewed critically in the team and also by some external members.

- **Mutually:**

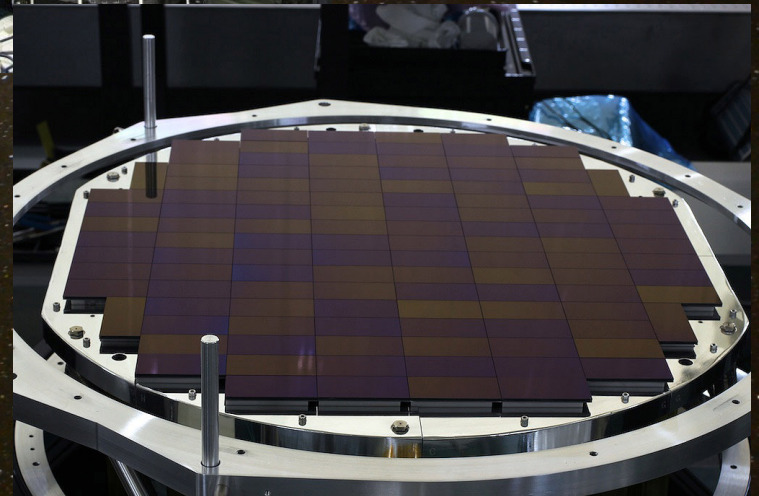
- Detailed planning to build up one coherent survey
- (Re-)Optimization at the beginning & as the survey progresses
 - Data quality assurance, fiber allocation, etc
- Database development for archival legacy-data science

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



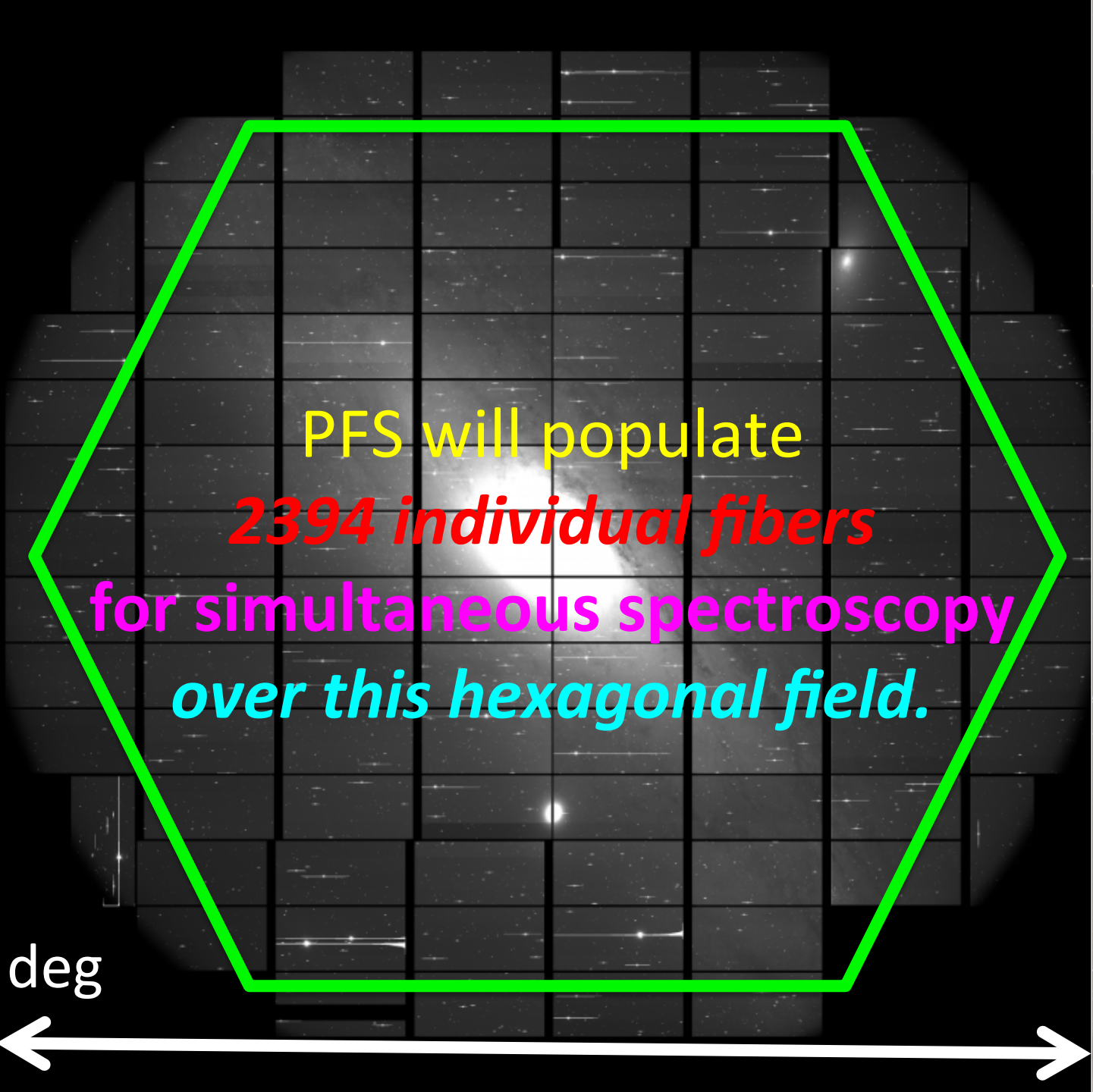
The full Moon
~0.5 deg diameter



Suprime-Cam
First Light
(Released Jan 1999)



Suprime-Cam
Full operation
(Released Sep 2001)



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

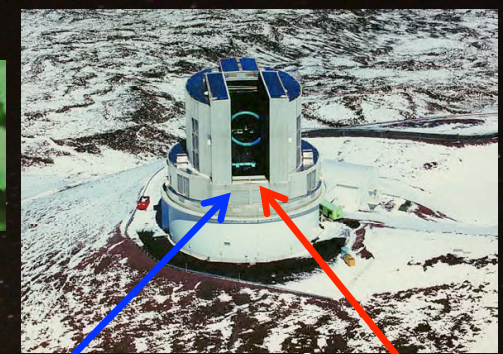
~1.5 deg



SuMIRe project

Subaru Measurement of Images and Redshifts

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



HSC

PFS

Same telescope

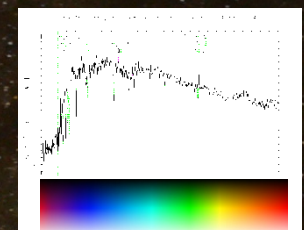
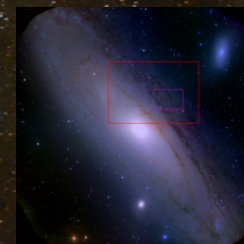
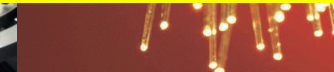
Same patches of sky

Clean target selection by deep photometry

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

Follow-up "Prime Focus"

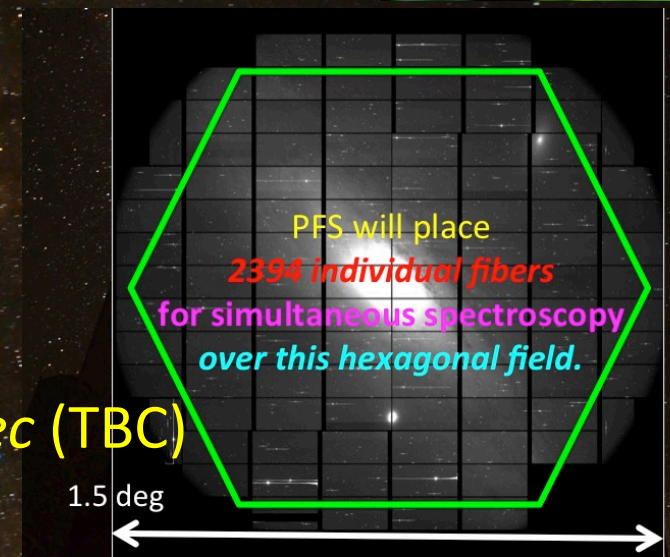
- ✓ ~2400 optical fibers
- ✓ ~300 nights from ~2019
- ✓ ~4M galaxy redshifts
- ✓ ~1M stars in MW halo/disks/satellites & M31.



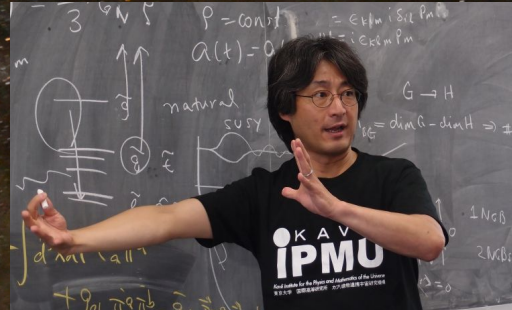
PFS - Fast facts



- 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 Å* resolution
 - Medium resolution mode (around 800nm): *~1.6 Å* resolution
- Aiming at start of science operation & survey program in *2020, as a facility instrument on Subaru Telescope.*



PFS is a perfect suite for *Panoramas of the Evolving Cosmos*



Hitoshi Murayama
[Kavli IPMU director,
PFS project PI]

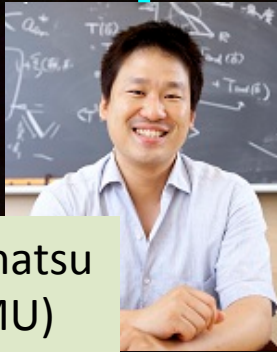
Masahiro Takada
[Kavli IPMU]



Richard Ellis
[UCL/ESO]

Science working group co-chairs

Cosmology



Eiichiro Komatsu
(MPA/IPMU)

Galaxy/AGN
evolution



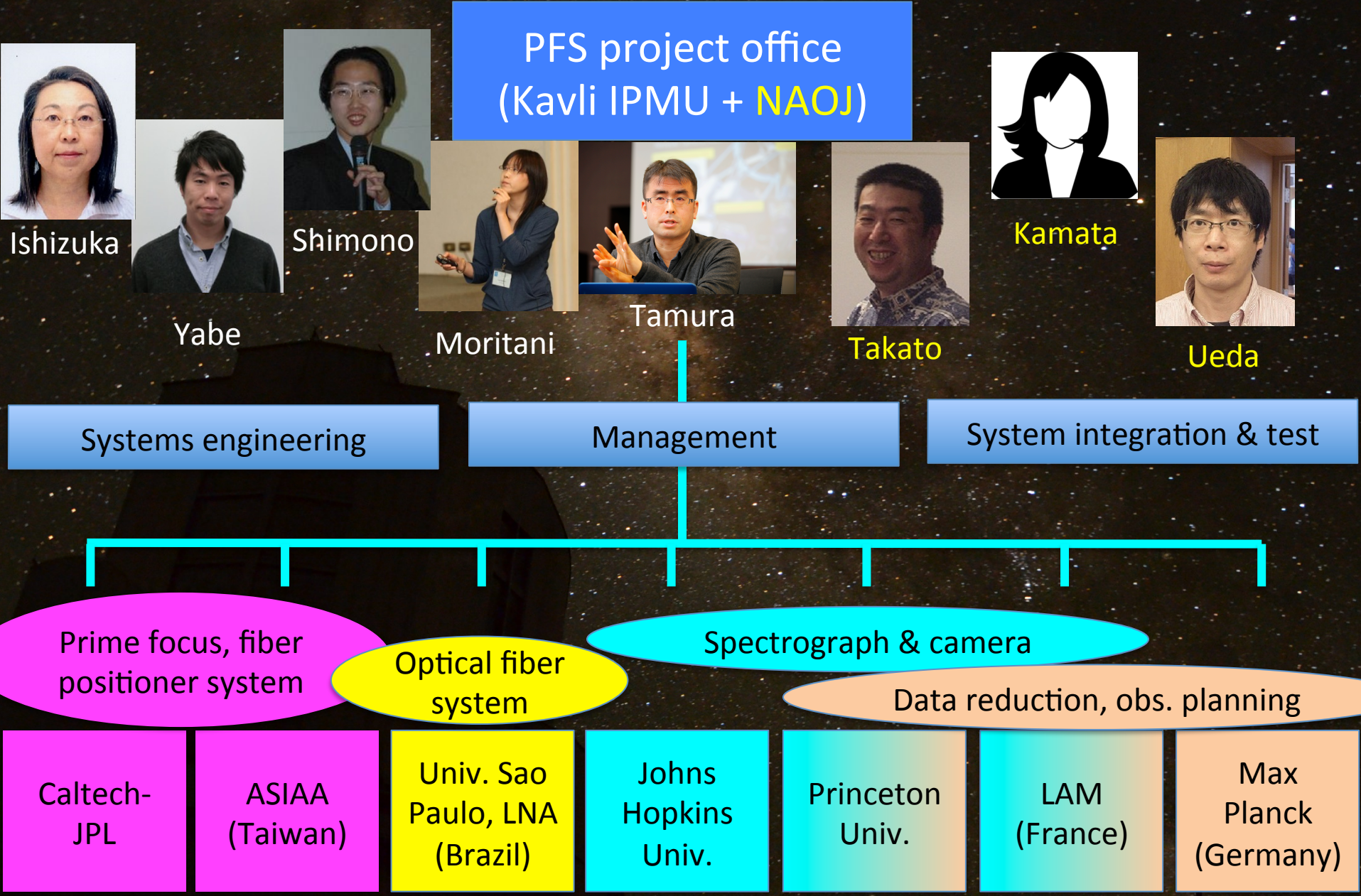
Jenny Greene (Princeton)

Galactic
Archaeology



Masashi Chiba
(Tohoku U.)

Structure for instrument development



The *updated* PFS collaboration

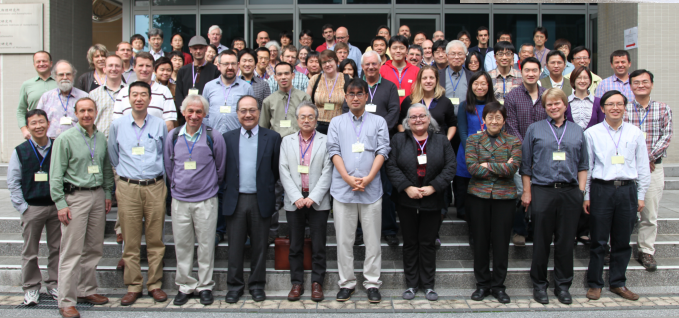
Scientists & countries are co-working for

countries are co-working planning.

Dec 2016, Baltimore



Dec 2014



National Astronomical
Observatory of Japan



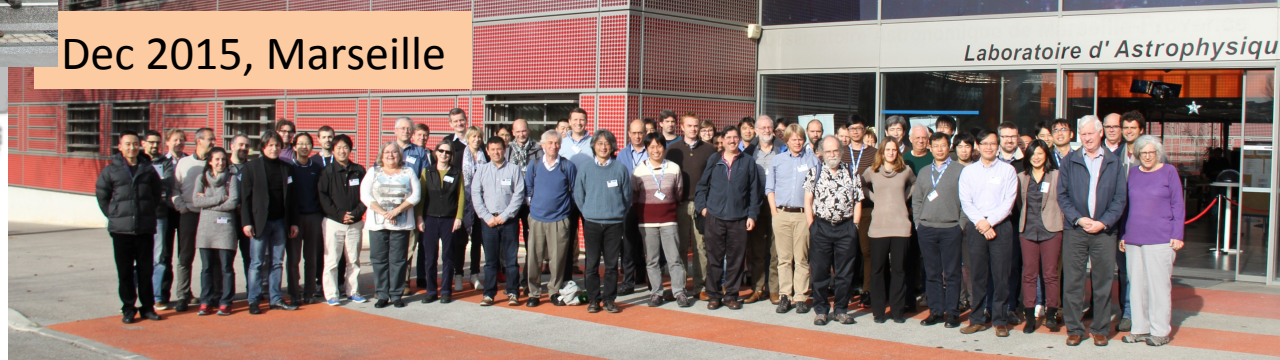
Caltech

JOHNS HOPKINS
UNIVERSITY

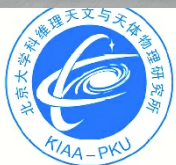
LAM
LABORATOIRE D'ASTROPHYSIQUE
DE MARSEILLE

LNA LABORATÓRIO

Dec 2015, Marseille



Nov 2017, Kashiwa (IPMU)



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

Fiber cable

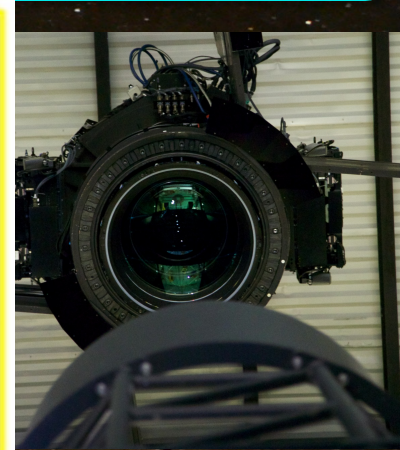
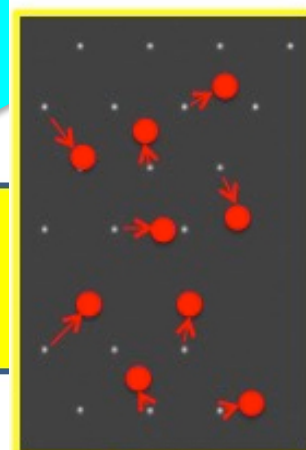
... in Prime focus unit
"POpt2" with Wide Field
Corrector "WFC".

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.*

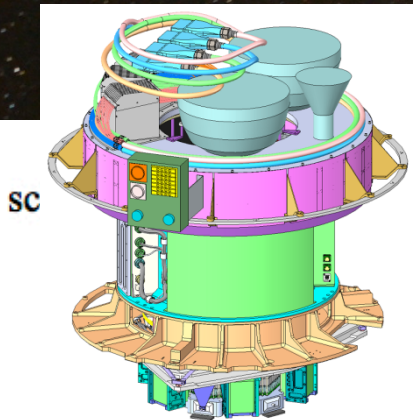
Metrology camera
as a Cassegrain
instrument

Subaru Telescope



Prime Focus Instrument (PFI)

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

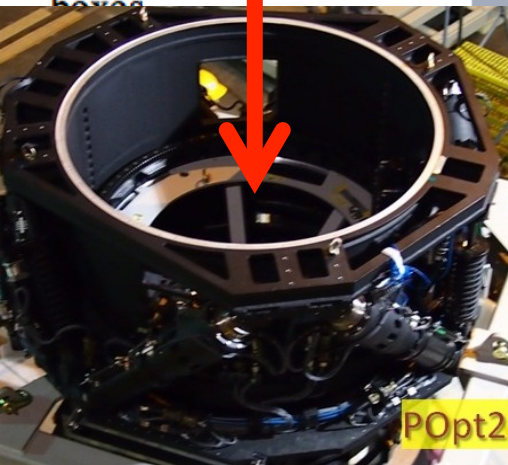


- Fiber positioner system
- Acquisition & Guide (AG) camera
- Fiber cable: “Cable C” & fixed fiducial fibers
- Fiducial fiber illuminator
- Field element (cf. Filter+dewar window@HSC)
- Cable wrapper
- Calibration lamp system

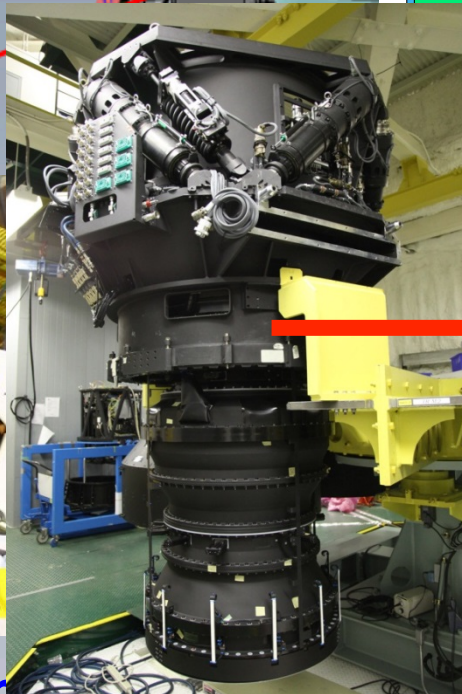
Wang (ASIAA)+
[SPIE 2016]

Caltech-JPL
LNA
ASIAA
IPMU/Princeton

fiber strain relief
boxes

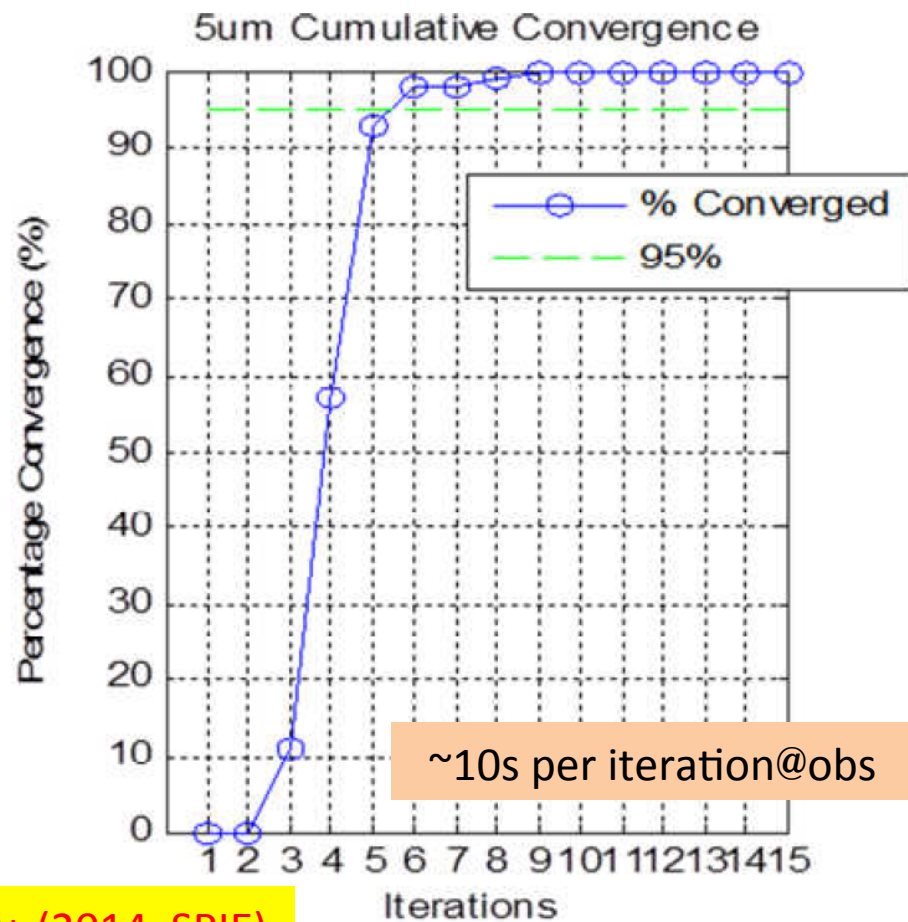
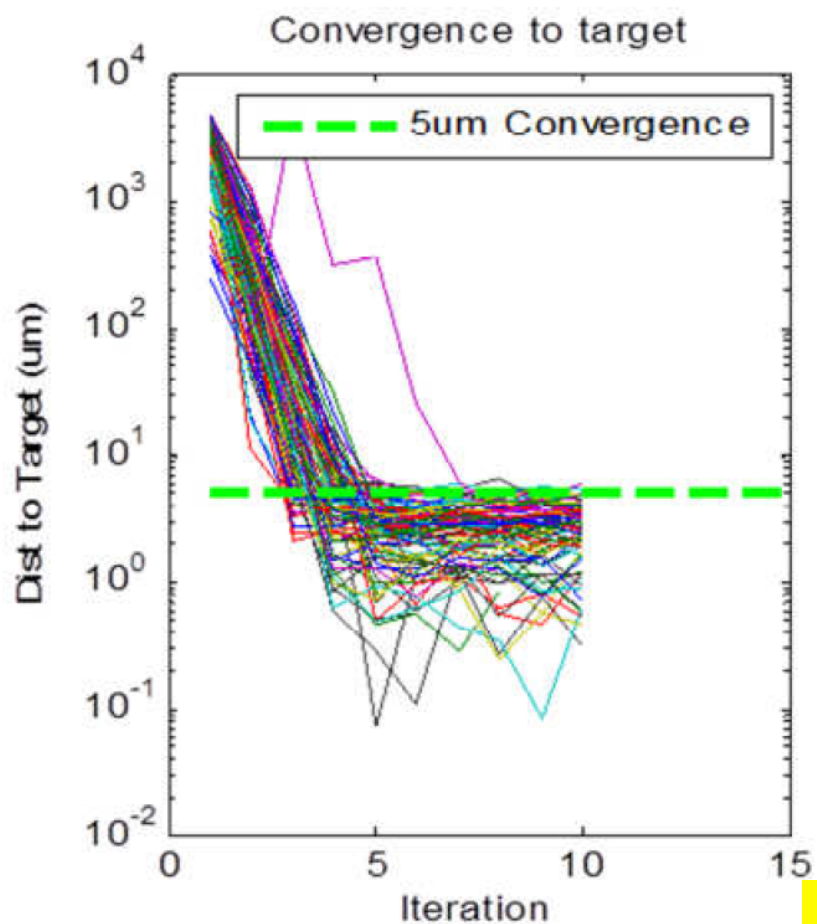
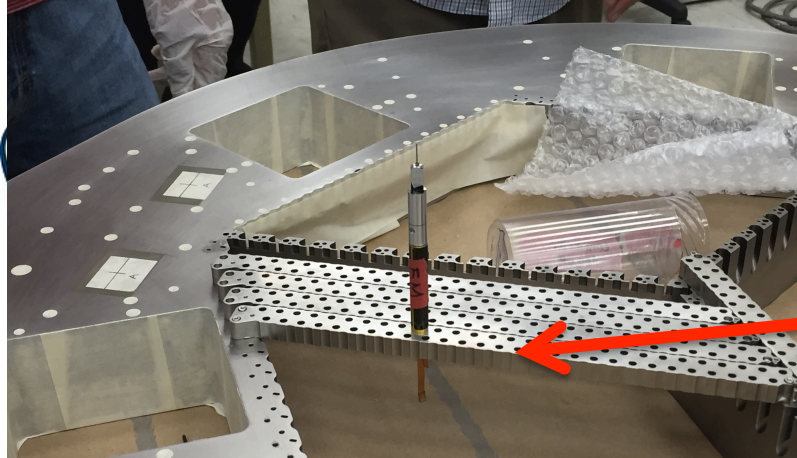


~1.1m



HSC builder's blog
<http://anela.mtk.nao.ac.jp/hscblog/builder/>

sitione



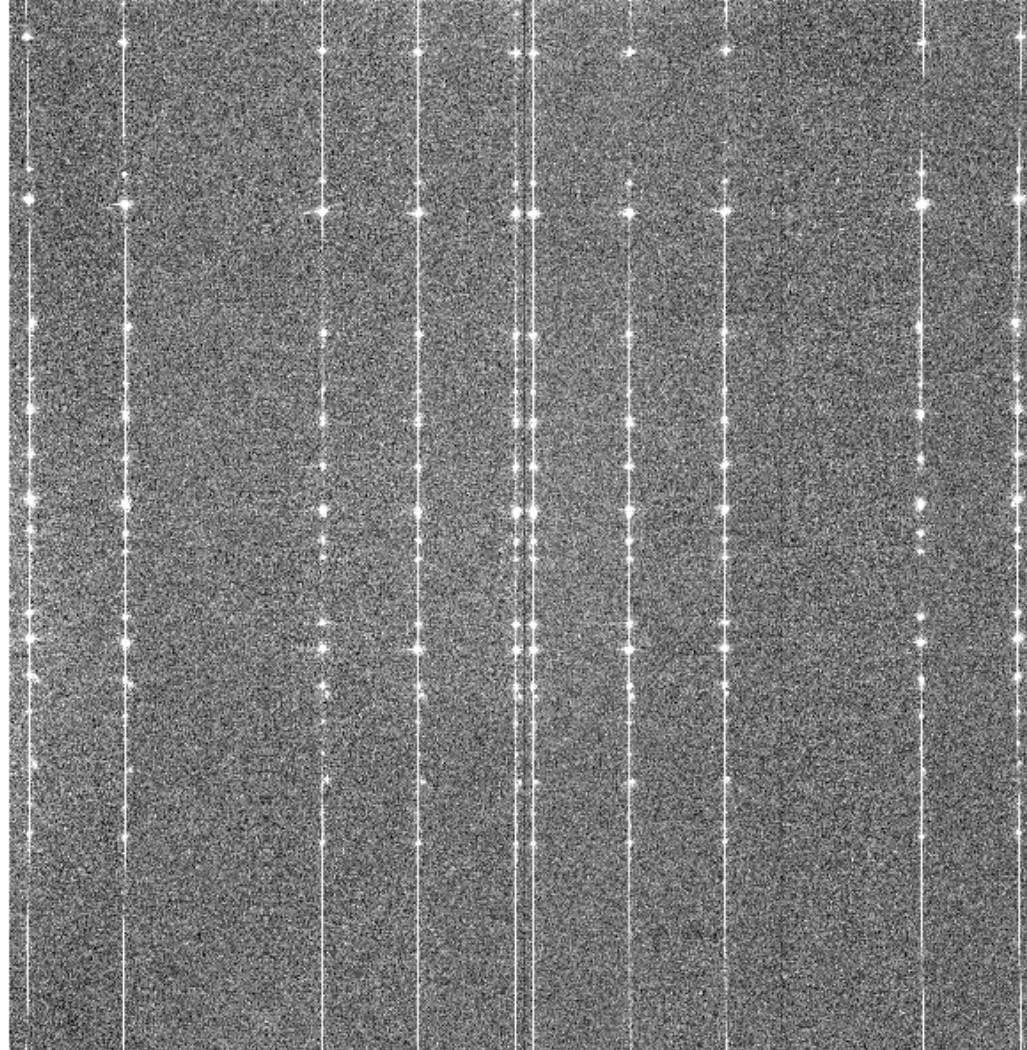
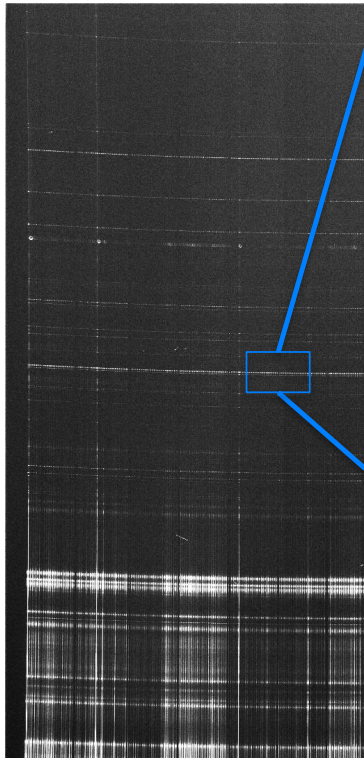
Fisher+ (2014, SPIE)

Spectrograph System (SpS)

1 module $\rightarrow$ ~600
4 modules $\rightarrow$ ~2400

Hg-Ar lines are in-focus over the entire detector plane.

AMBIENT

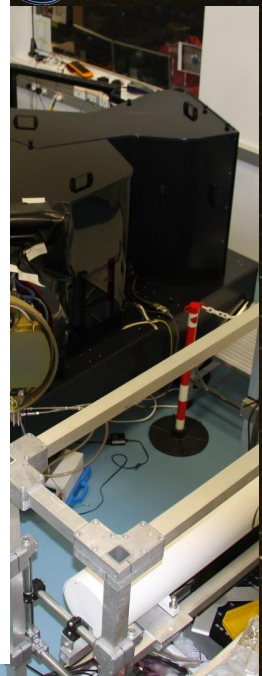
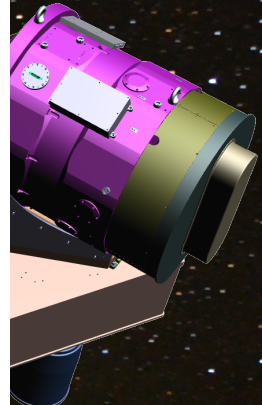
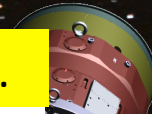


-11 -6.2 -1.6 2.9 7.5 12 17 21 26

ed
)

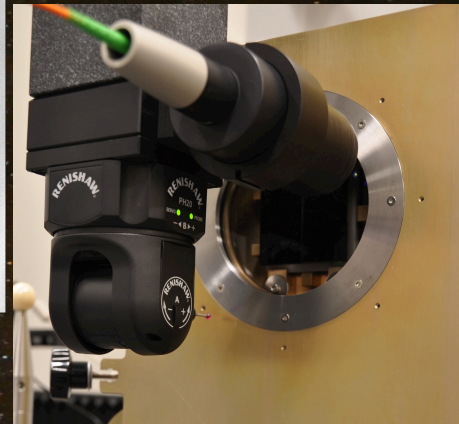
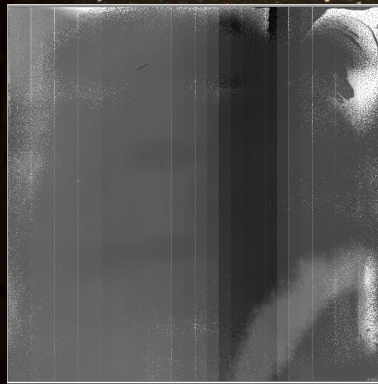
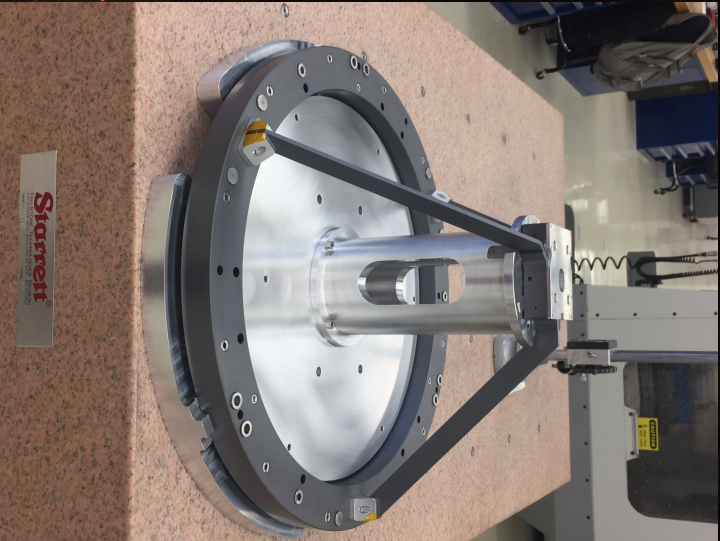
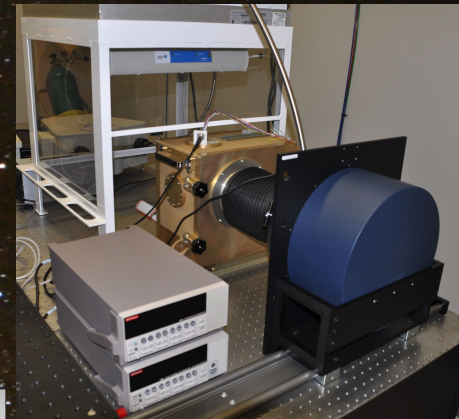


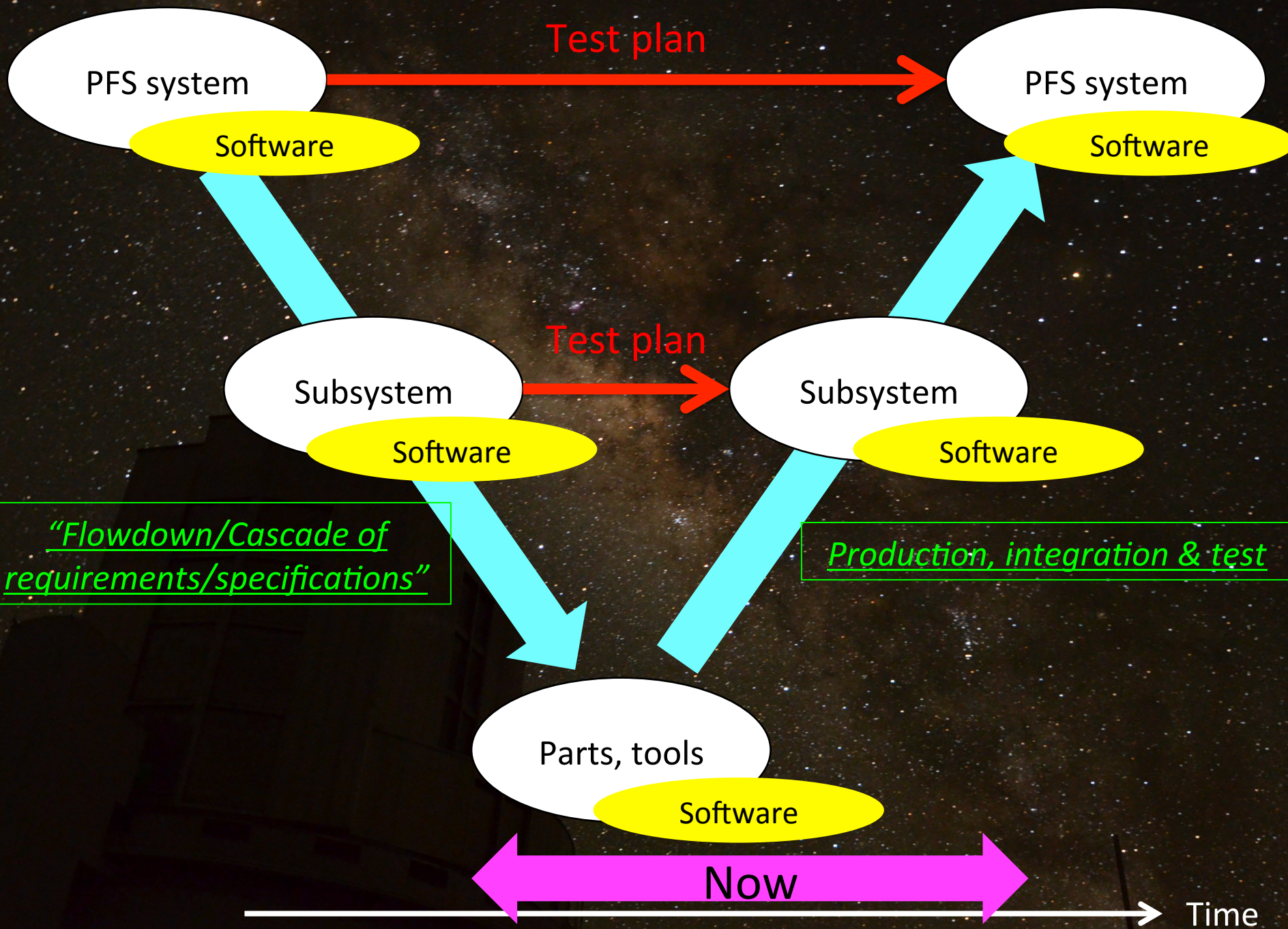
1 fiber



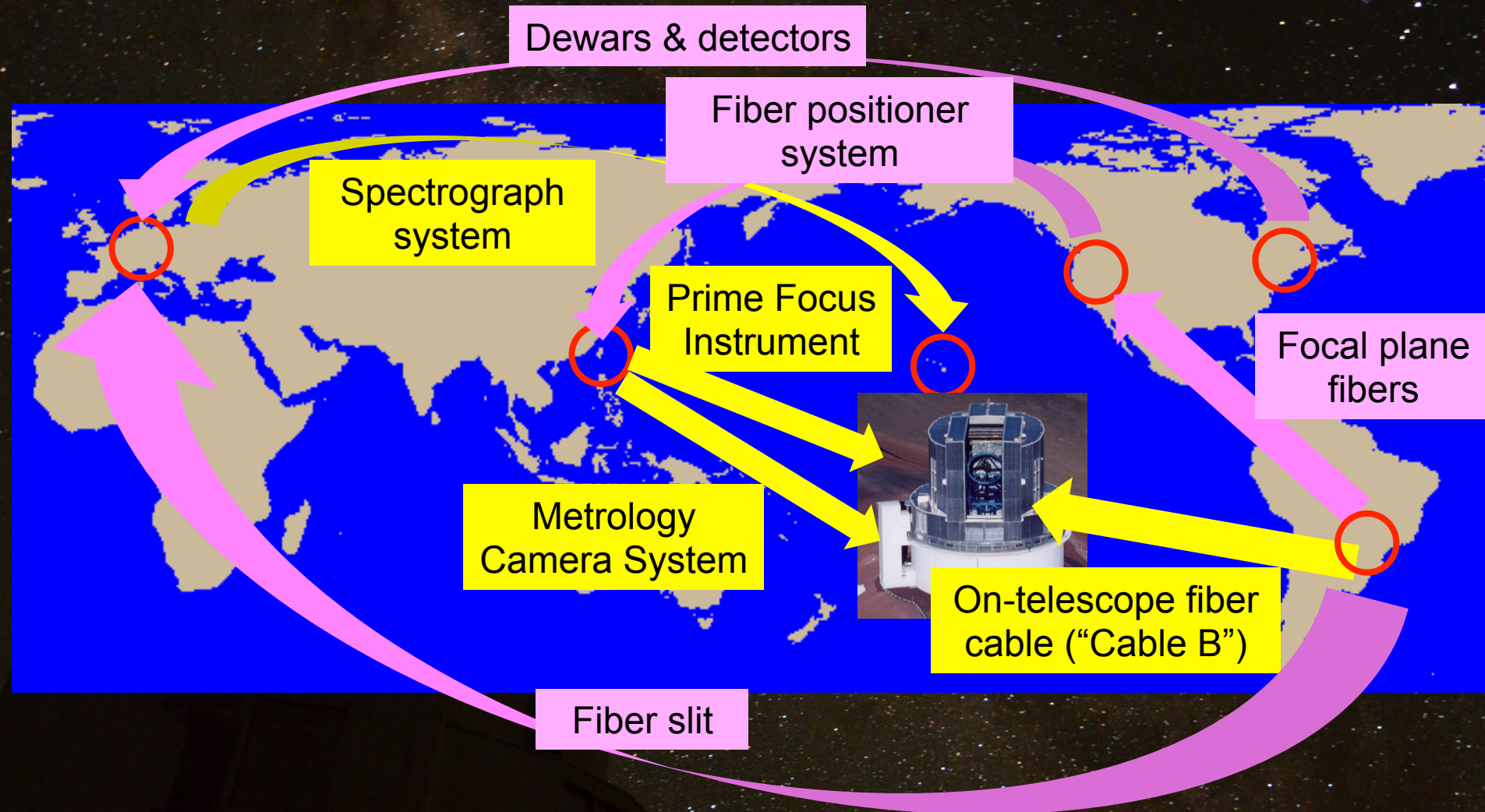
NIR camera development

- Mechanical assembly is ongoing
- 4x science-grade H4RG devices have been delivered.
- Detector characterization is ongoing.





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

Test uncovers many things ...



- 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 by 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

$\sim 1,400 \text{ deg}^2$ 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

10^0 PFS-red (8.2m)

PFS-NIR (8.2m)

1m)

(, 1.3m, 2022-)

1.6 1.8 2.0 2.2 2.4

Ishift z

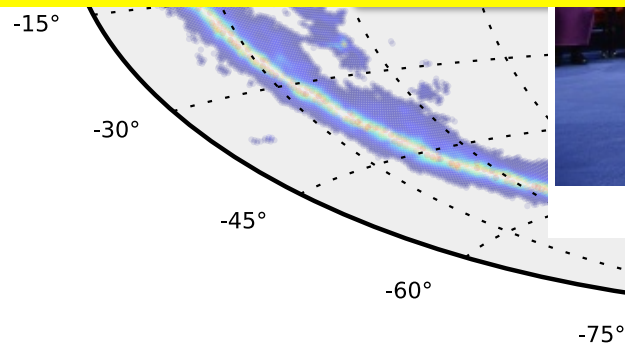
0.01

Prof. Takaaki Kajita (ICRR/IPMU)

DEEP2/3

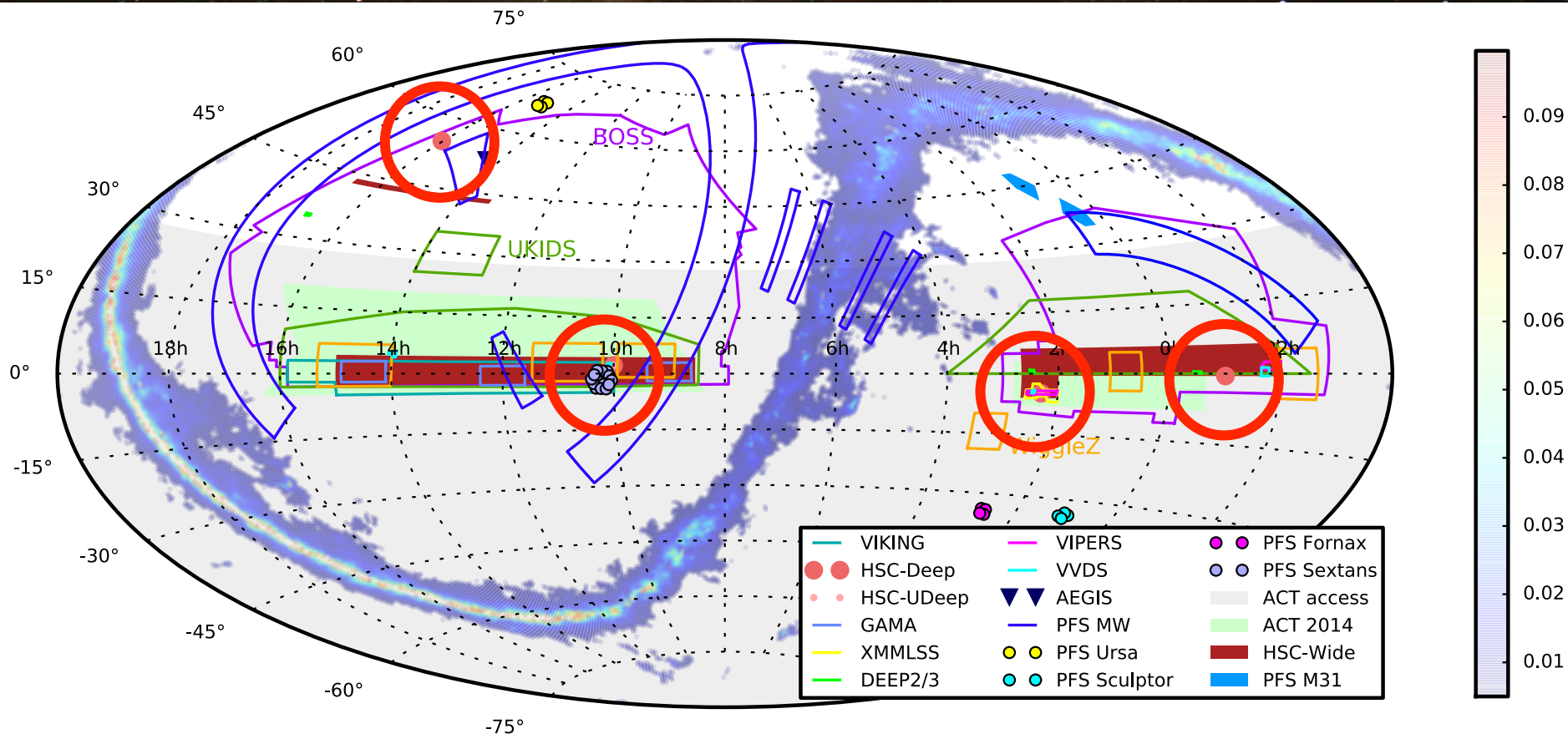
PFS Sculptor

PFS M31



PFS galaxy & AGN evolution component

- HSC “deep” ($\sim 25 \text{ deg}^2$) & “ultra-deep” ($\sim 3 \text{ deg}^2$)
- Prioritizing $\sim 15 \text{ deg}^2$ 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

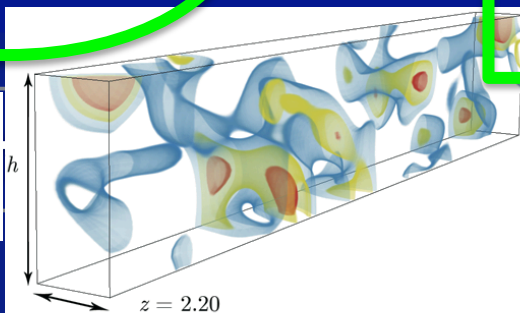
within cosmic web

400,000
Continuum-Selected
Galaxies

200,000
Dropouts

200,000
LAEs

IGM tomography
(e.g. Lee+ 14)



$H\alpha$

Star formation
rates

[OIII]

Ionization
Metallicity

[OII]

MgII

Winds

$Ly\alpha$

Reionization

Courtesy of Jenny Greene (Princeton)

PFS Galactic Archaeology (GA) component

M. Chiba
(Tohoku U.)

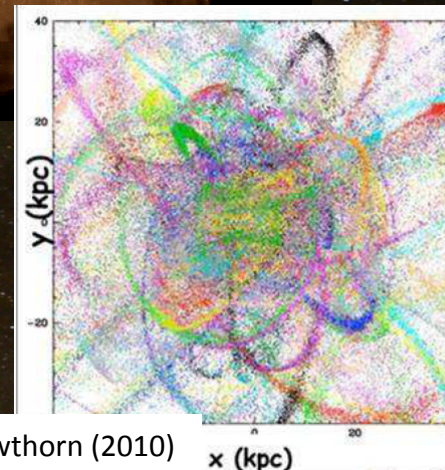
Science objectives

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 $[\alpha/\text{Fe}]$
- **The M31 halo (Oct)**
 - DM/stellar halo structure, chemo-dynamics with spectroscopic $[\text{Fe}/\text{H}]$
- **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

$z=11.9$
800 x 600 physical kpc

Diemand, Kuhlen, Madau 2006

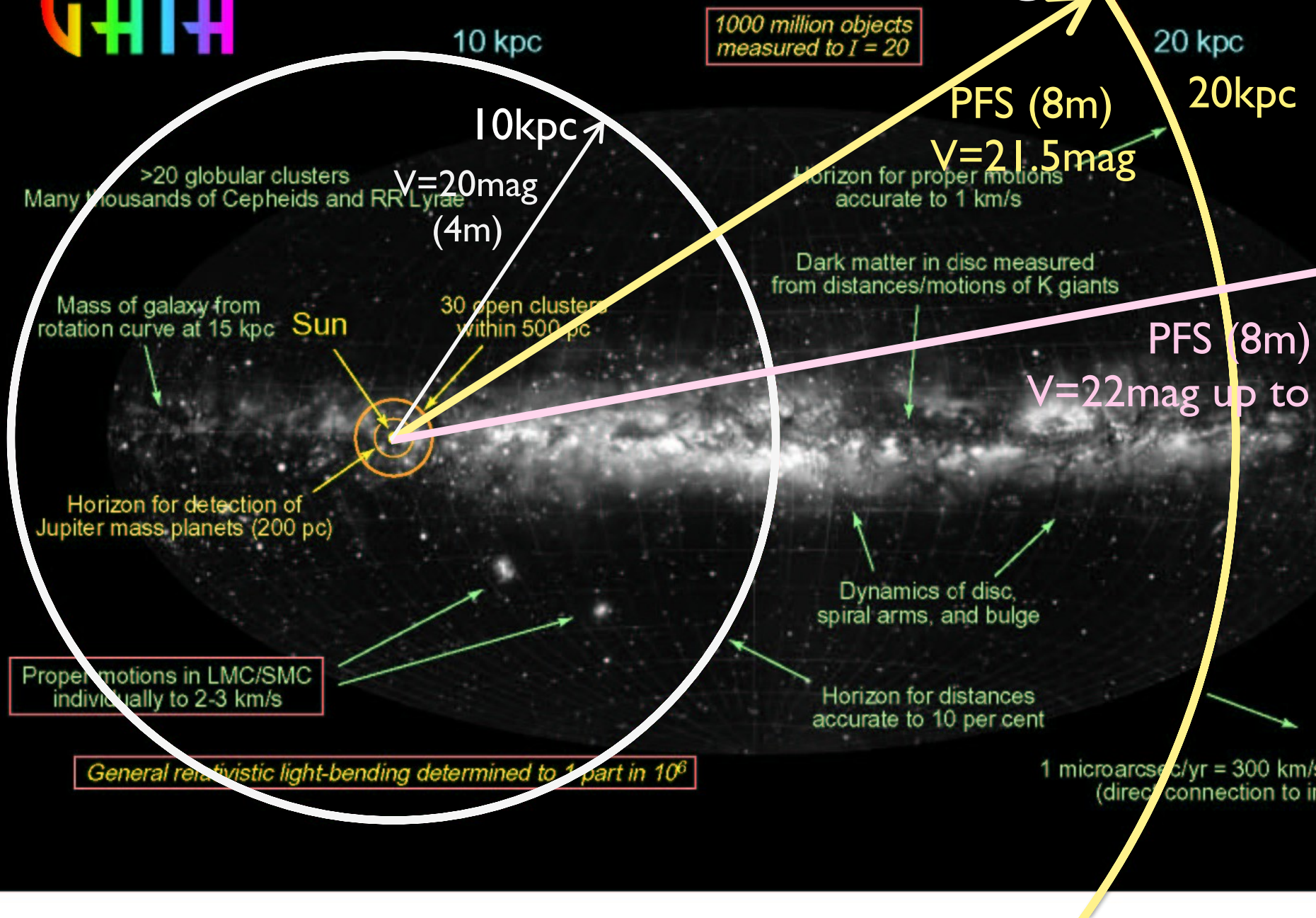


Freeman & Bland-Howthorn (2010)

x (kpc)



PFS Galactic Archaeology



Uniqueness of PFS

By E. Kirby
(Caltech)

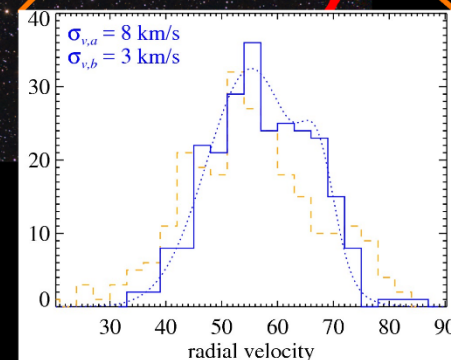
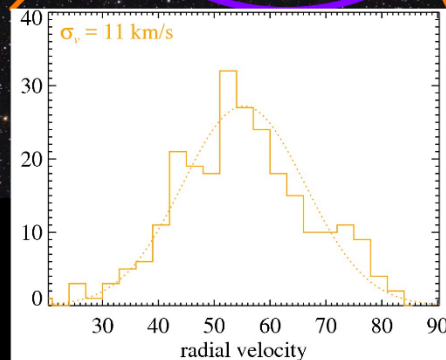
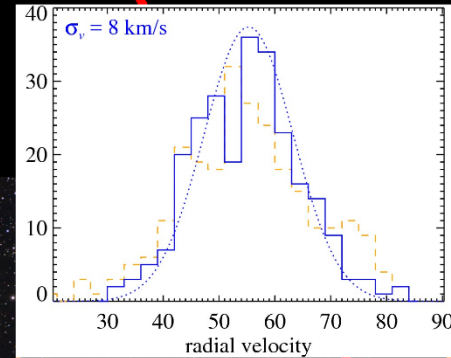
Fornax

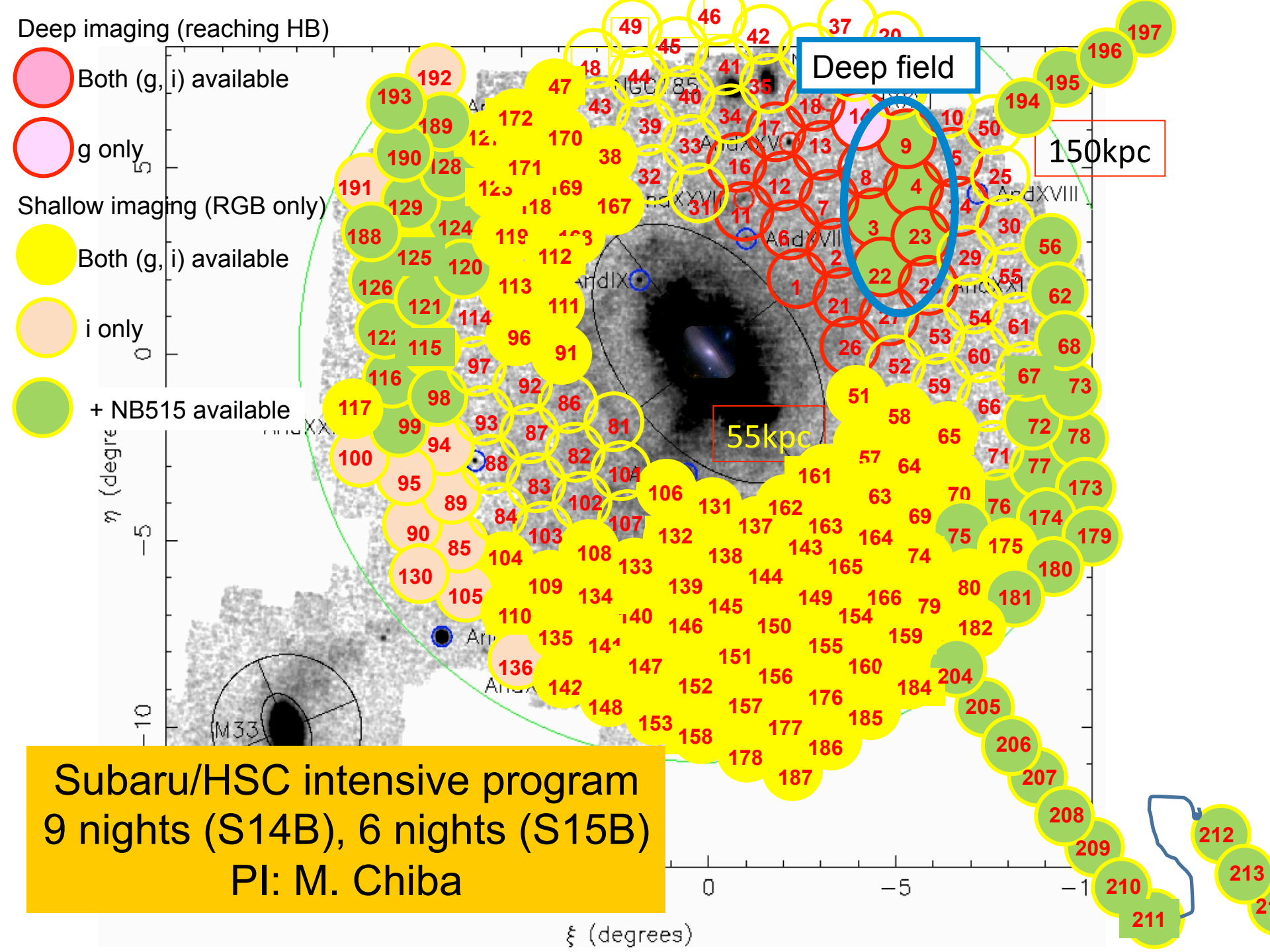
PFS
2400 fibers

FLAMES
130 fibers

DEIMOS
~120 slits

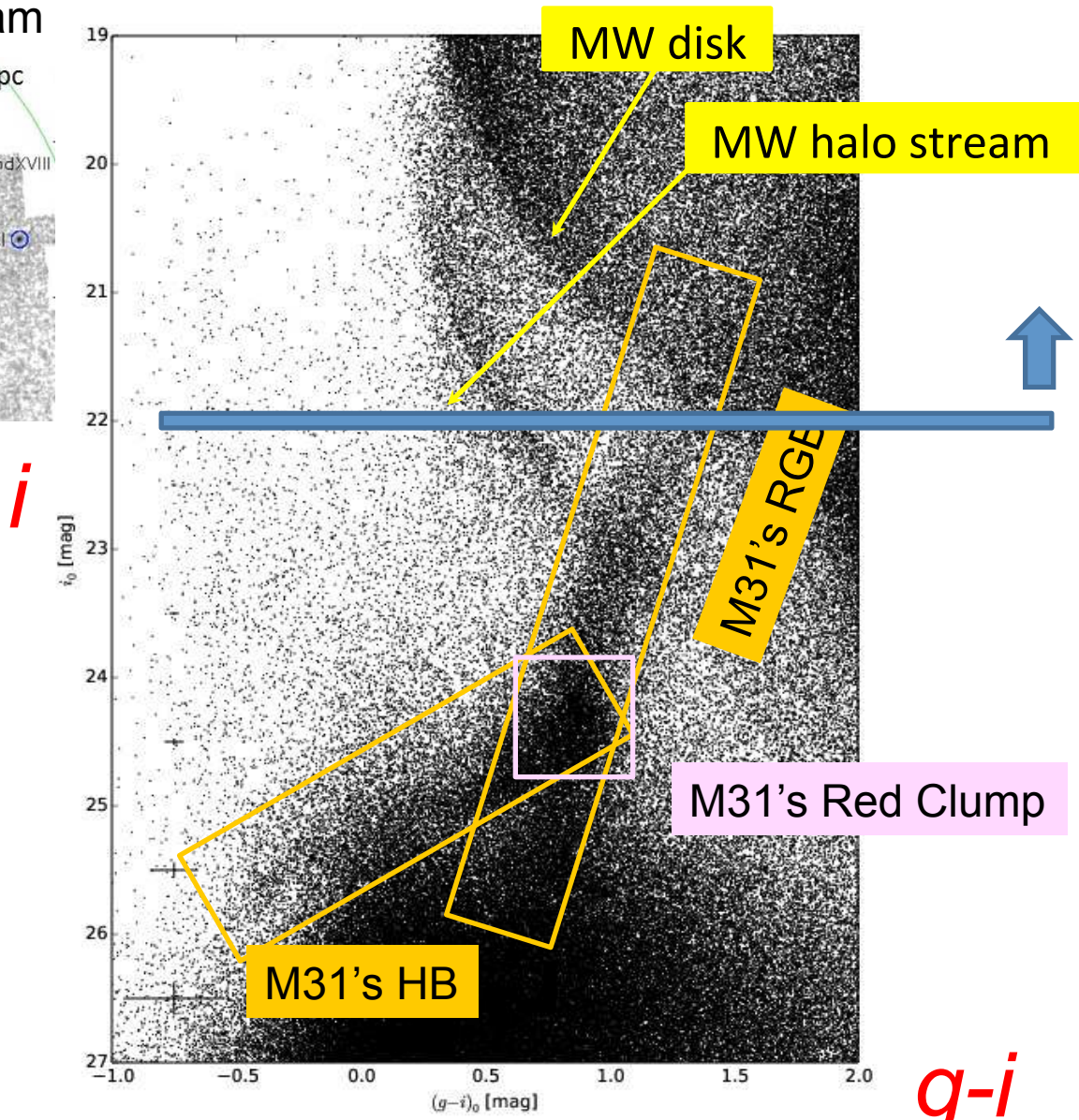
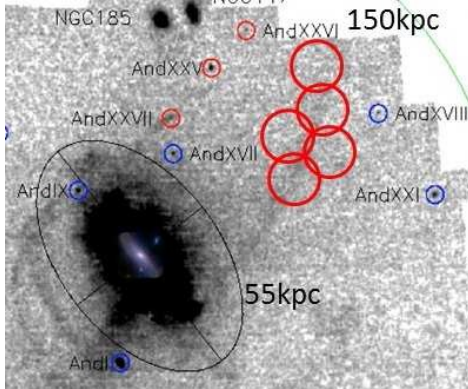
Velocity
distribution





Color magnitude diagram

North-western stream



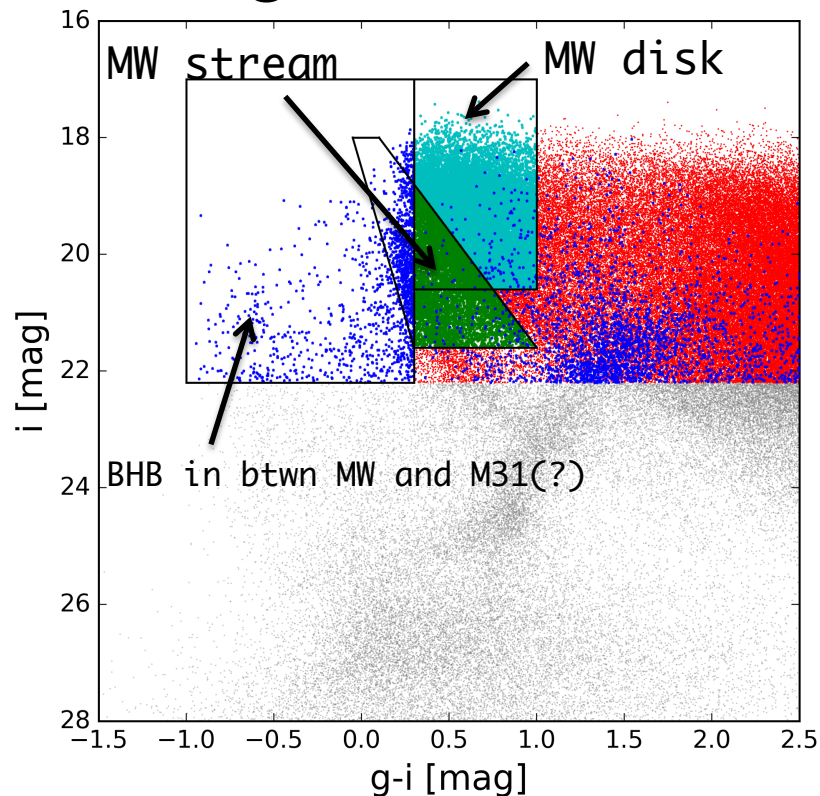
Komiyama (NAOJ)



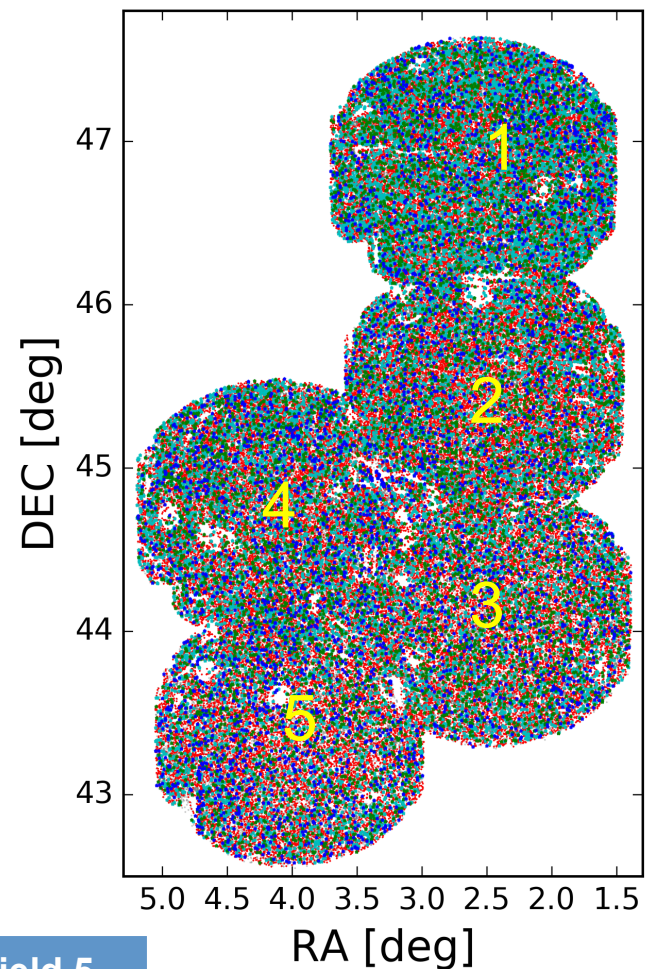
PFS targets

$g-i$

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)

[PMU],

n team)

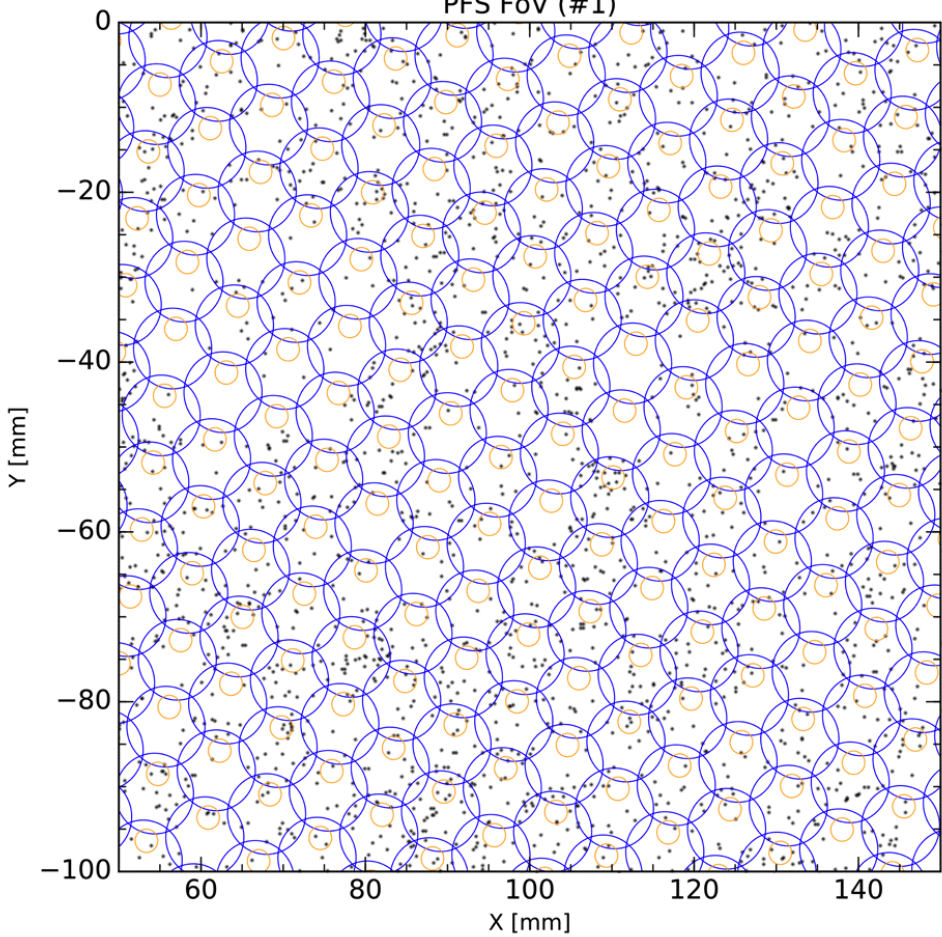
eam)

[PMU],

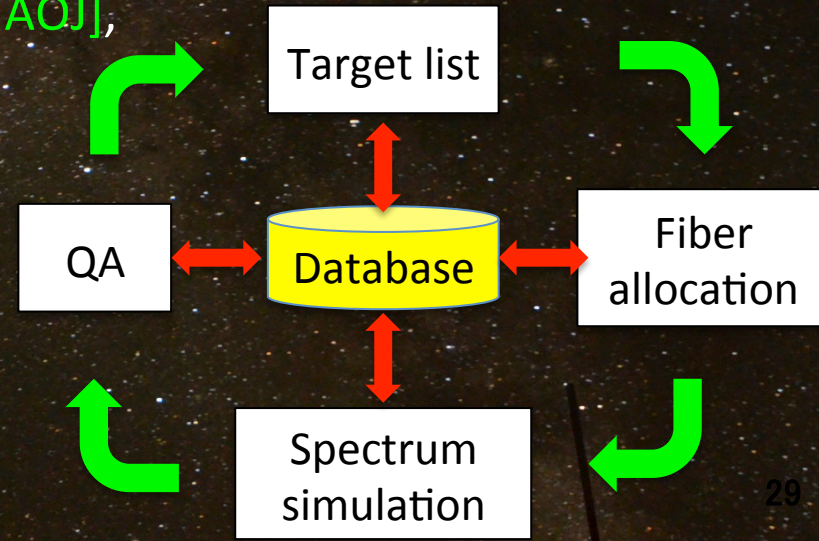
[NAOJ],

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)

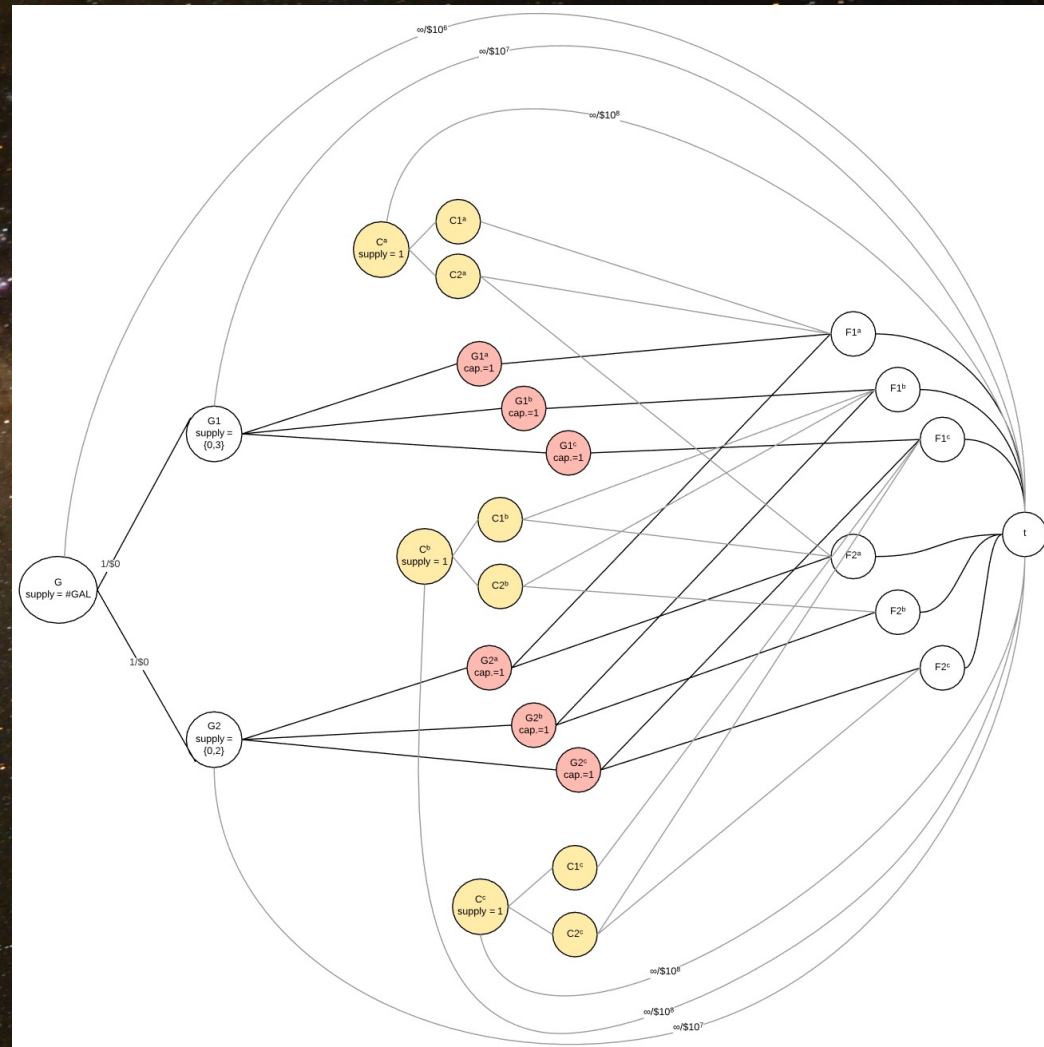
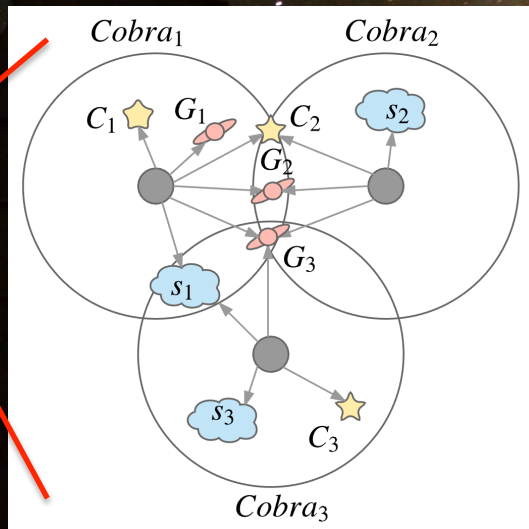


Survey optimization

- Fiber allocation and coordination of visiting fields* need to be done in an *optimal fashion* with various (both scientific and technical) demands flexibly accommodated.

Tiled survey fields

Fiber allocation fields

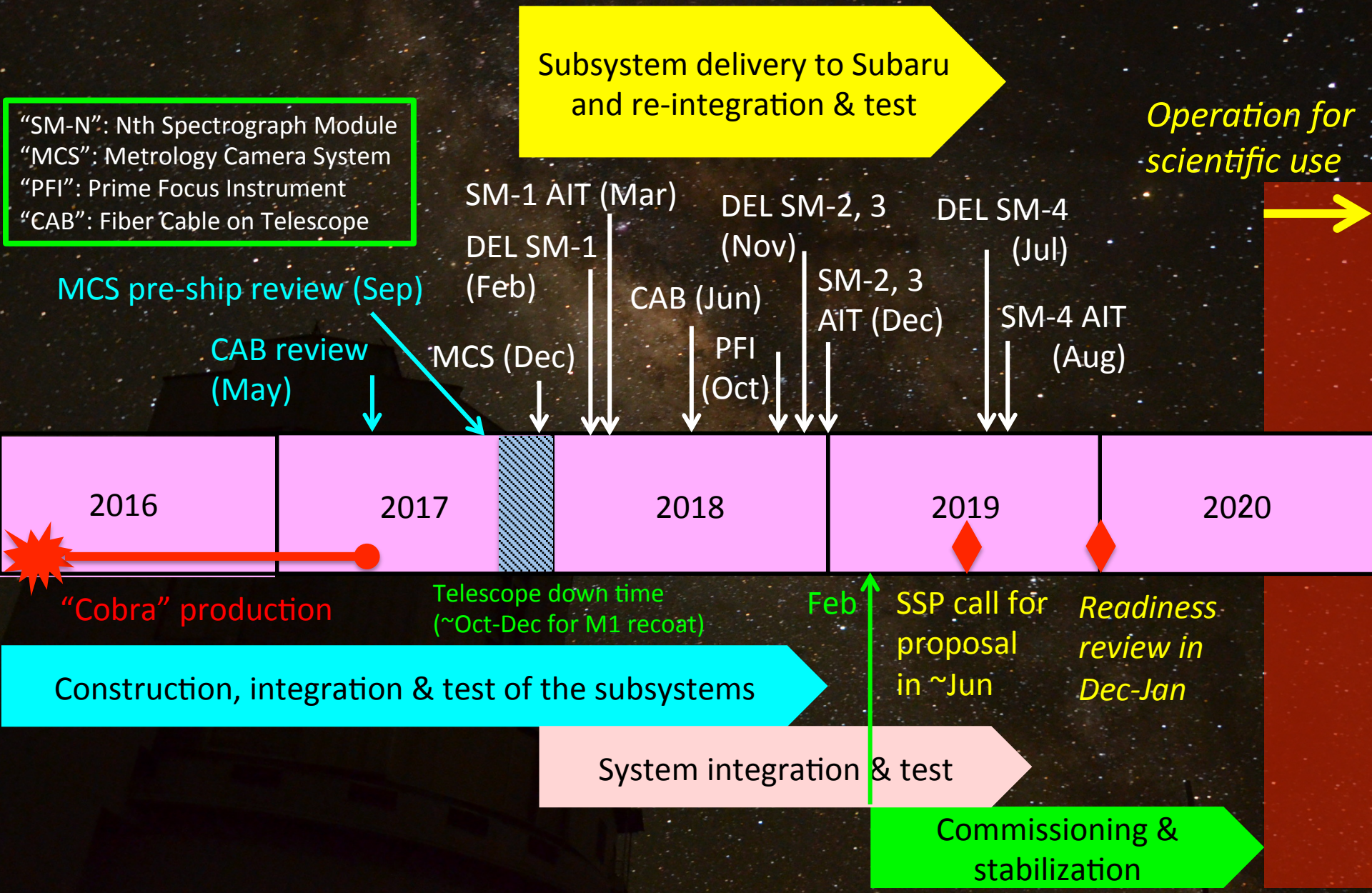


- Application of max. flow/min. cost approach is now under discussion.

Fabricius (MPE) & Reinecke (MPA): Developing the technique by Blanton+ (2003) for SDSS.

Updated top-level schedule

*Subject to changes
until the end ...*



Summary

- Technically:

- Making good progress! Not only production of individual parts but also integration & test (I&T) are ongoing at subsystem level.
 - Working on problems and issues that have been uncovered at I&T.
 - Subsystem delivery to Subaru will start soon: Metrology camera system in Dec 2017, First spectrograph module in early 2018.

- Scientifically:

- Ramping up the ~5-year survey design development:
 - The updated proposal from each working group will be reviewed critically in the team and also by some external members.

- Mutually:

- Detailed planning to build up one coherent survey
- (Re-)Optimization as the survey progresses
 - Data quality assurance, fiber allocation, etc
- Database development for archival legacy-data science