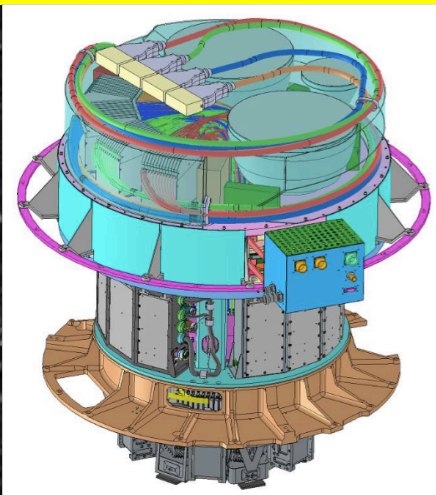# SUBARU PRIME FOCUS SPECTROGRAPH

Synergy with ULTIMATE-Subaru   (Kavli IPMU, PFS Project Office)

- Programmatic & technical aspects   ------------ N. Tamura (~8min)
- Scientific aspects -------------------------------------- K. Yabe   (~10min)

Prime Focus Instrument "PFI"

"Cobra" engineering model module

Production "Cobra"s

Camera cryostat

Spectrograph system

Fiber connectors
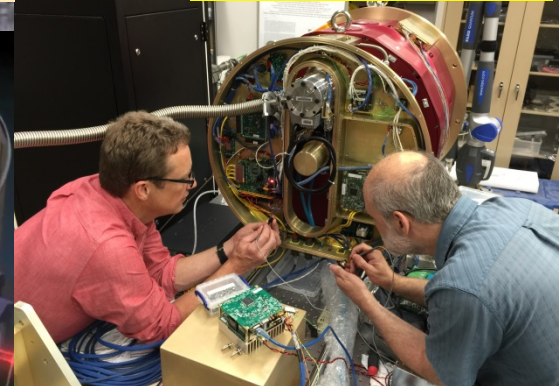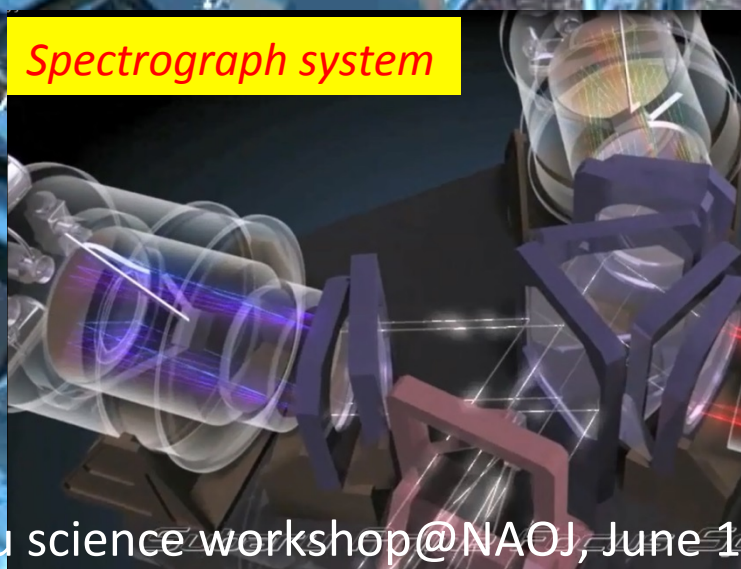
<u>My apology</u> … Confusion with "PSF"

"PFS": **P**rime **F**ocus **S**pectrograph

Candidates under consideration:

- *"SUNS"*: **SU**baru **N**ight-sky **S**pectrograph
- *"SUMO"*: **SU**baru **M**ulti-**O**bject spectrograph
- *"PEACE"*: **P**rime-focus **E**xploring **A**ssembly for **C**osmic **E**volution
- *"SPECIAL"*: **S**ubaru **P**rimefocus **E**quipment for **C**osmic **I**nvestig**A**tion **L**egacy
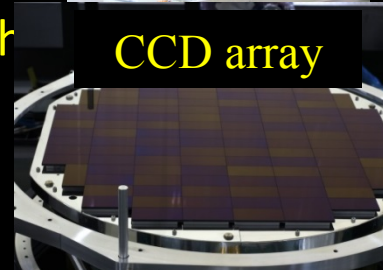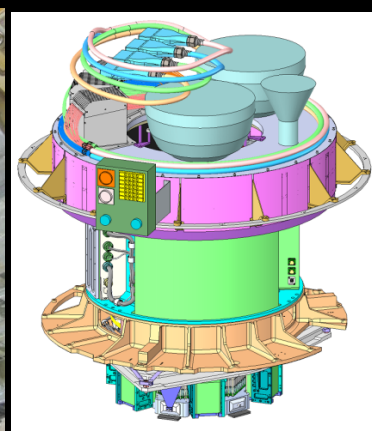- *"FABULOUS"*: …
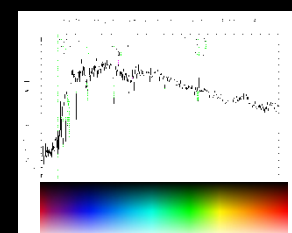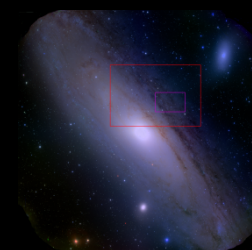
"PFS fast facts
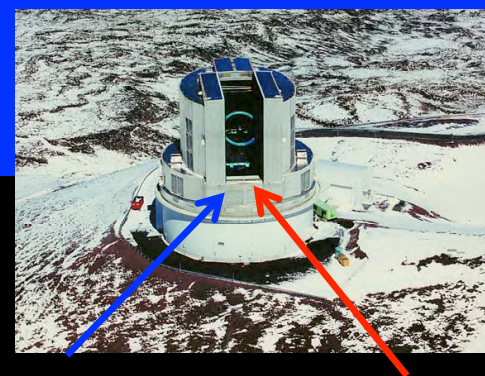
HSC   PFS

- Subaru *Prime Focus Spectrograph*

  - "SuMIRe" (Subaru Measurement of Images & Redshifts)
    = Large sky survey of imaging (HSC) AND spectroscopy (PFS)

  - Wide field: *~1.3 deg* diameter

  - Highly multiplexed: *2394 fibers*

  - Quick fiber reconfiguration: *~60-100 sec* (TBC)

  - VIS-NIR coverage: *380-1260nm simultaneously*

- Developed by *international* collaboration, under the initiative of *Kavli IPMU*

- *Cosmology, Galaxy/AGN evolution, Galactic Archaeology* as the key science areas in the PFS collaboration

- Aiming to start science operation from *2019*, as a *facility instrument* on Subaru.

CCD array   Fiber array

PFS subsystems distribution

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

Fiber cable

Fiber connectors

Prime Focus Instrument

Spectrograph system (SpS)

On the TUE floor (IR side)

4 spectrographs

Fiber cable

Fiber cable

Wide-field corrector

Calibration system

2400 fibers steered by positioners

POpt2 & WFC will be shared with Hyper Suprime Cam (HSC).

Metrology camera as a Cassegrain instrument

Software system

Subaru Telescope

4

Prime Focus Instrument (PFI)

"Cobra" actuators
(production batch)

The hexagonal focal plane:
2394 fiber positioners are
assembled in the 42 modules.
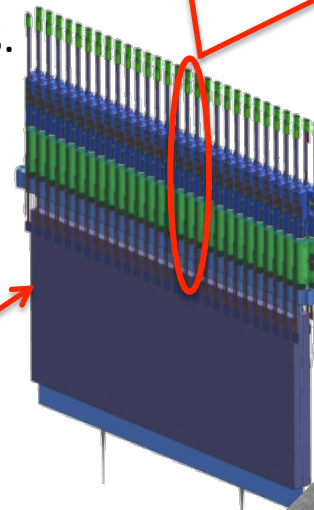
"Top" view
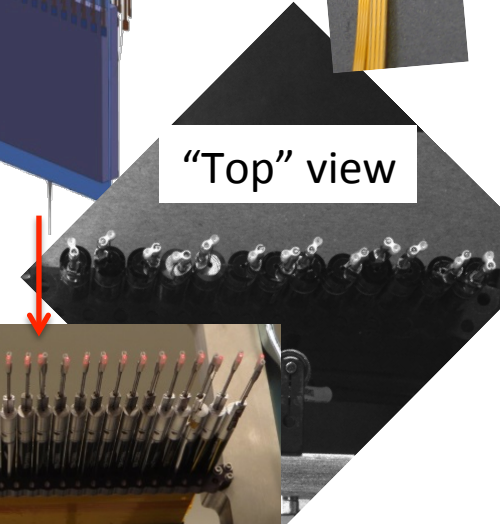
"Cobra" optical bench

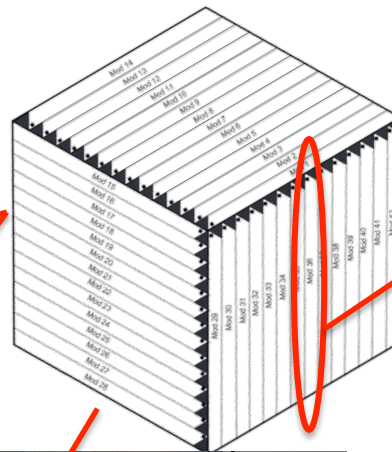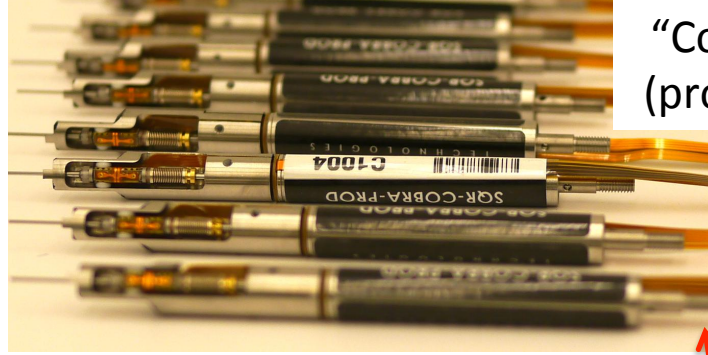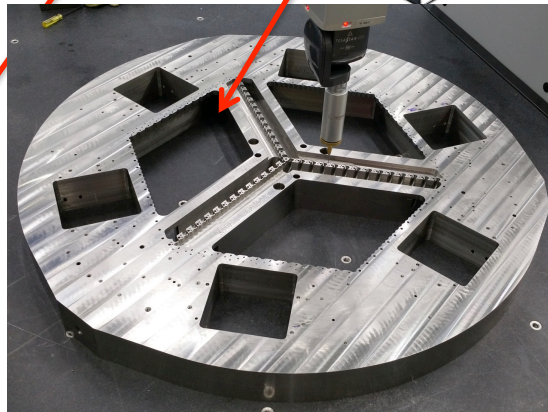"Cobra" eng. model module
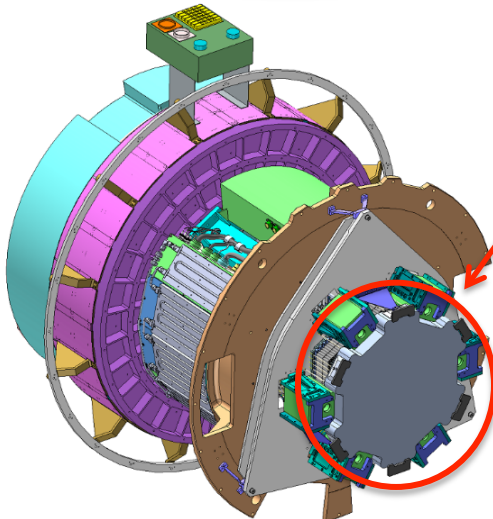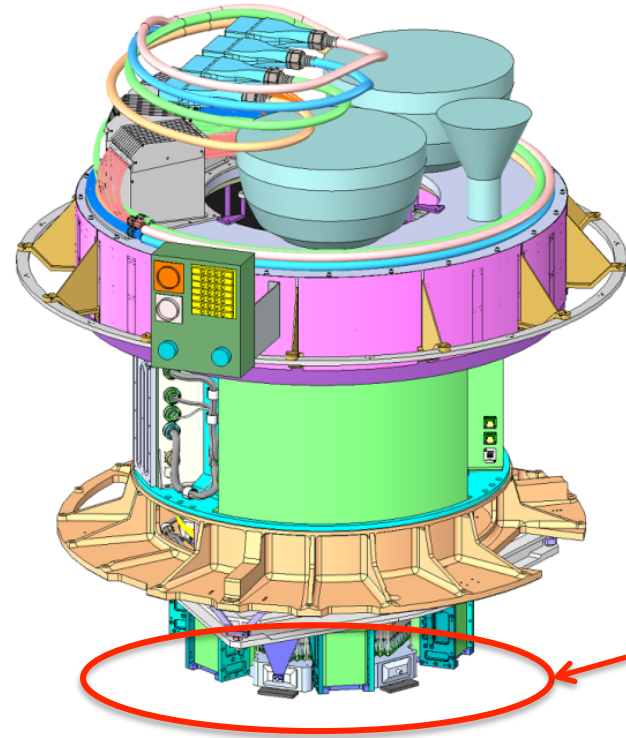
Spectrograph System (SpS)

Dark image of CCD

"Red"

Mangin mirror

Field Flattener & Detector

Corrector 2

Corrector 1

VPHG

Collimator

Schmidt Corrector

Entrance Slit

VPHG

Corrector 1

Corrector 2

Field Flattener & Detector

Dichroics

Schmidt corrector

Schmidt corrector (collimator)

Corrector 1

Corrector 2

Field Flattener & Detector

VPHG

Mangin mirror

"Blue"

Mangin mirror
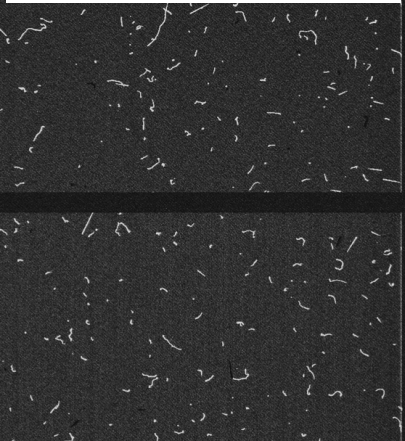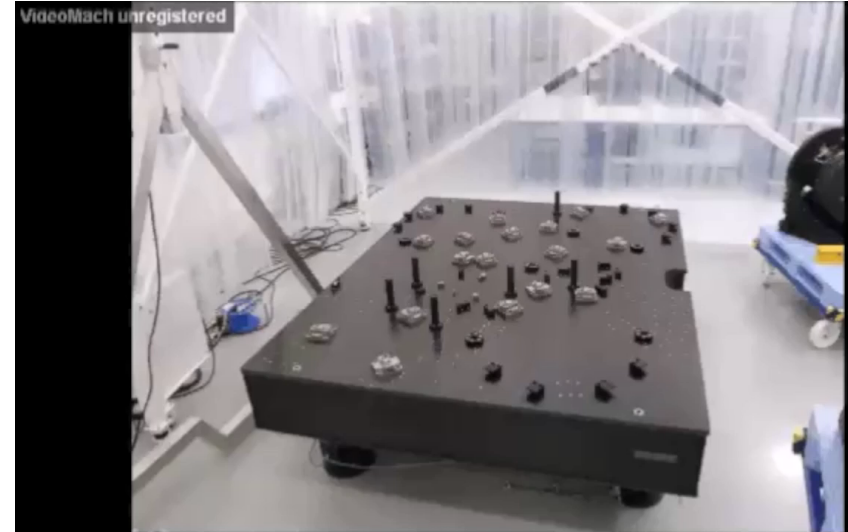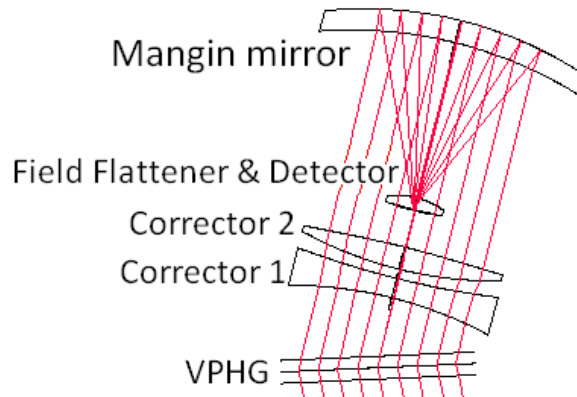
Bench size: 1.9m x 2.4m
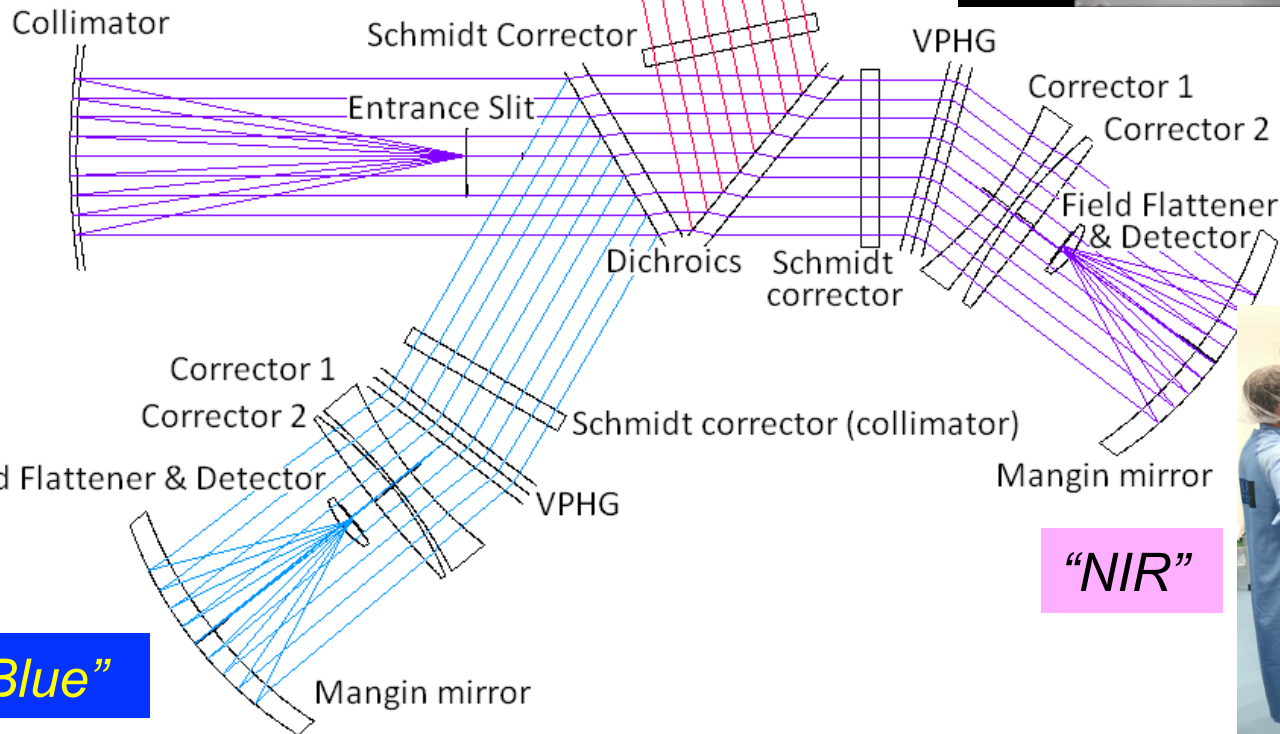
Red camera integration

"NIR"
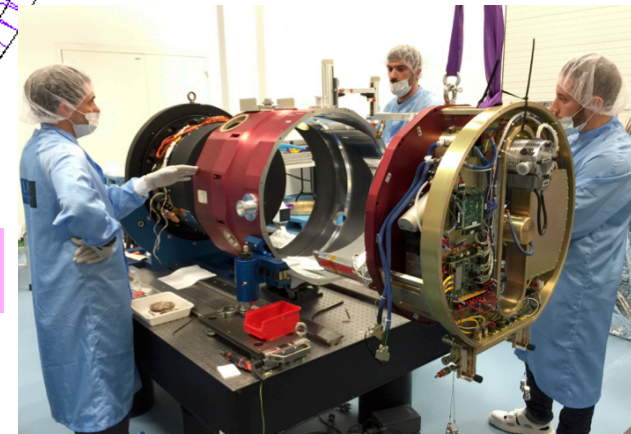
Top-level schedule (subject to updates …)

"SM-N": Nth Spectrograph Module
"MCS": Metrology Camera System
"PFI": Prime Focus Instrument
"CAB": Fiber Cable on Telescope

Subsystem DEL & AIT at Subaru

Start of sci. ope. & SSP

PFI CDR

MCS CDR (Sep) & dCDR (Dec)

SM-1, 2 AIT

DEL SM-1, 2

CAB

DEL SM-3, 4

CAB review   MCS

PFI

SM-3, 4 AIT

| 2015 | 2016 | 2017 | 2018 | 2019 |

"Cobra" production started.

Mar?

SSP call for proposal??

Readiness review in Feb?

Construction, subsystem integration & test

System integration

On-sky commissioning

7
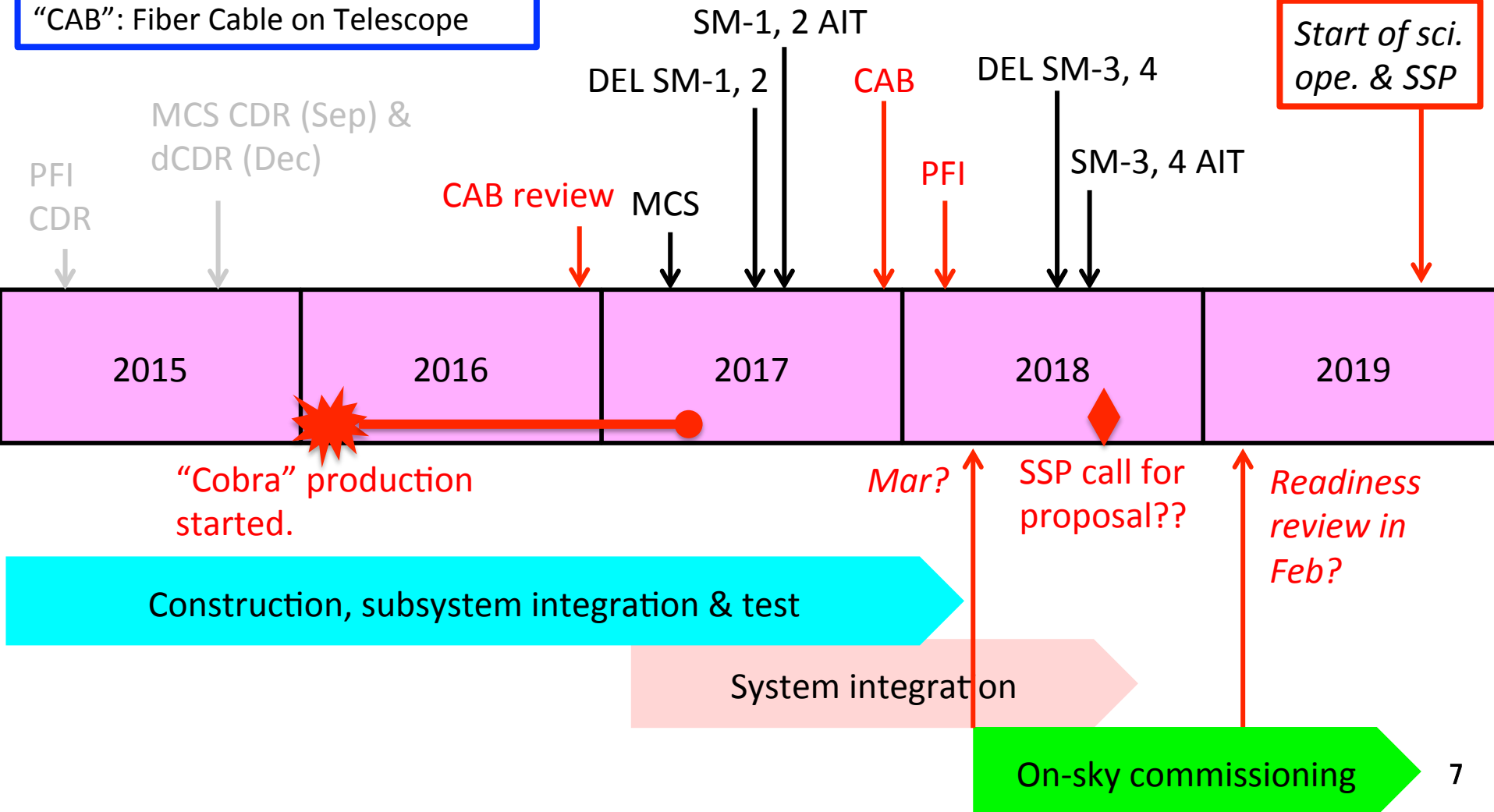
The *SYNERGY* Schedules

Note: The schedules of the competitors are based partly on the information in the official websites etc but partly on informal information, so may be inaccurate.

MOONS: GA and galaxy surveys (FL 2019, Op 2020?-)

(Initially by Ellis at 6th collab. mtg and updated by Tamura)

DESI: Cosmology (FL 2018, Op 2019-)

WEAVE: GA (FL 2017, Op 2018-)

4MOST: GA & galaxy surveys (FL 2020, Op 2021?-)

eBOSS/HETDEX: cosmology

EUCLID: cosmology

HSC SSP

ULTIMATE

PFS CONSTRUCTION

PFS COMMISSIONING

PFS SCIENCE OPS (both PI-type & SSP)

2017 2018 2019 2020 2021 2022 2023 2024
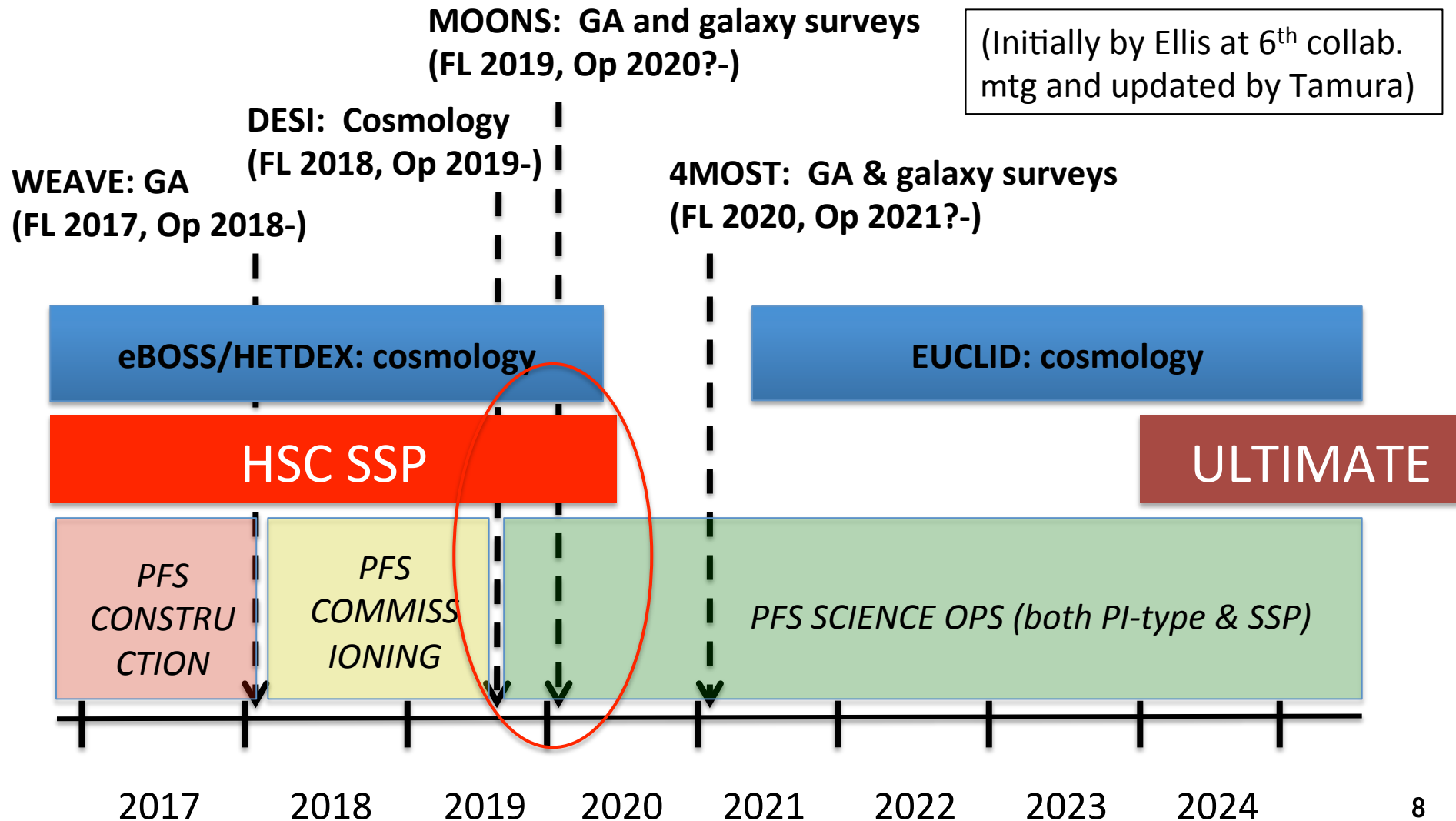
PFS → ULTIMATE

- (Quite a few) PFS spectra will be available (by Yabe-san later).

- The PFS spectrograph system will be available:
  - Early verification of focal plane
  - Bright-night science

Two sets of
fiber connectors

cable C

PFI

cable B

4 spectrographs

TUE-IR
("IR4")
floor

cable A

Fiber slit assembly at the
spectrograph side of Cable A

The connectors at the spectrograph
side have been a part of the design for:
- Easier integration.
- Easier maintenance and test activity.
- Future extension with fiber switcher,
  different focal plane, etc:
  - High res. mode (R~50,000: cf.
    R~5000 in MR mode)
  - IFS (Hyper SuMIRe, ULTIMATE …)

~600 x 4 fibers can be accepted …

- As long as the interface conditions are met.
  - 4x fiber connectors
  - Collimator F/2.5 (& Camera F/1.07)
  - R~4300 in 940-1260nm.
    - Note: Blue & Red data come as bonus(!?)
  - SpS operates at +5 degC
- 0".15 per element on the ULTIMATE focal plane, so e.g.:
  - One big IFU of 48 x 48 = 2304 elements for ~7"x7".
  - One small IFU of 7x7 elements for ~1"x1": 48 IFUs → 2352 elements
  - ~2400 multi-object spectroscopy?

Synergy between ULTIMATE-Subaru and PFS:

Kiyoto Yabe (Kavli IPMU)

- Example cases of ULTIMATE-PFS synergy
  1. Followups of PFS sample with ULTIMATE/IFU
  2. Followups of PFS sample with ULTIMATE/MOS
  3. Followups of ULTIMATE sample with PFS
- In any case, an unprecedentedly large sample can cast a new light on the galaxy formation and evolution
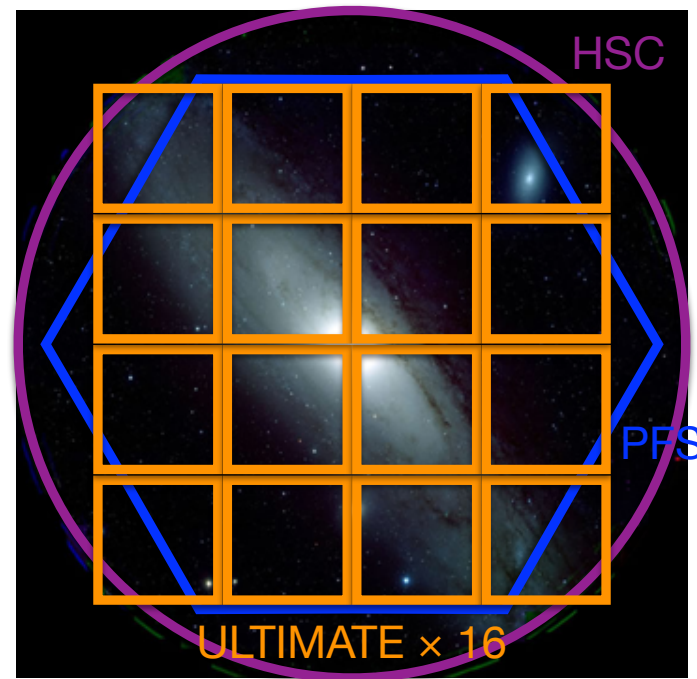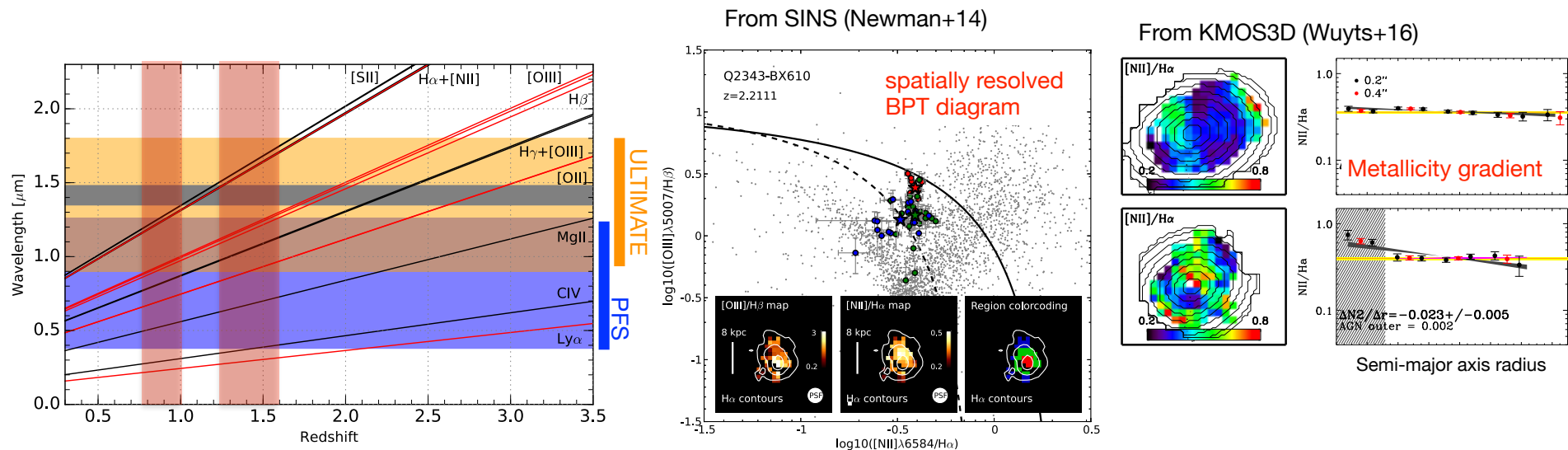
Synergy between ULTIMATE-Subaru and PFS:

- PFS SSP "galaxy evolution" survey constructs a very large spectroscopic sample of galaxies at 0.8<z<7 (main component:1<z<2) over HSC-Deep of ~25 deg^2 including HSC-UD of ~3 deg^2

Redshift	Magnitude [AB mag]	t_{exp} [hr]	Total Number	Main Science Topics
0.8<z<1	Y<22.3	1.5	~40,000	BPT, Hα SFR, Balmer decrement, metallicity, MgII outflows, etc.
1<z<2	J<23.3	3	~340,000	Hβ/[OII] SFR, metallicity, blue BPT, Dn4000, outflows, AGN, etc.
2<z<4	i<24	6	~63,000	UV slope SFR, outflows, Lyα EW & profile, AGN, escape fraction, etc.
z>4 LBGs	y<24-26	5-16	2,000-6,000	UV slope SFR, outflows, Lyα EW & profile, AGN, escape fraction, etc.
z~2 LAEs	NB386 limit	2	~10,000	systemic redshift, Lyα EW & profile, etc.
z=6.6 LAEs	NB921 limit	5	~13,000	Lyα ionization bubbles, reionization, etc.

In addition, AGNs (such as X-ray source) and low-z emitter (Hα, OIII, OII) sample should be included

Synergy between ULTIMATE-Subaru and PFS:

1. Followups of PFS sample with ULTIMATE/IFU
   - PFS galaxies at 0.8<z<2 can be candidate targets for ULTIMATE IFU observations
   - 0.8<z<1.0 (z~0.9) and 1.2<z<1.6 (z~1.4) to avoid atmospheric attenuation
   - Dynamical properties, spatial resolved physical properties such as metallicity, ISM condition, AGN diagnostics, etc.

From SINS (Newman+14)

From KMOS3D (Wuyts+16)

Metallicity gradient

Semi-major axis radius

Synergy between ULTIMATE-Subaru and PFS:

- Really competitive in 2020s compared to other IFU instruments and surveys?
- At least, we need to go to different parameter spaces from other surveys (e.g., environment?)
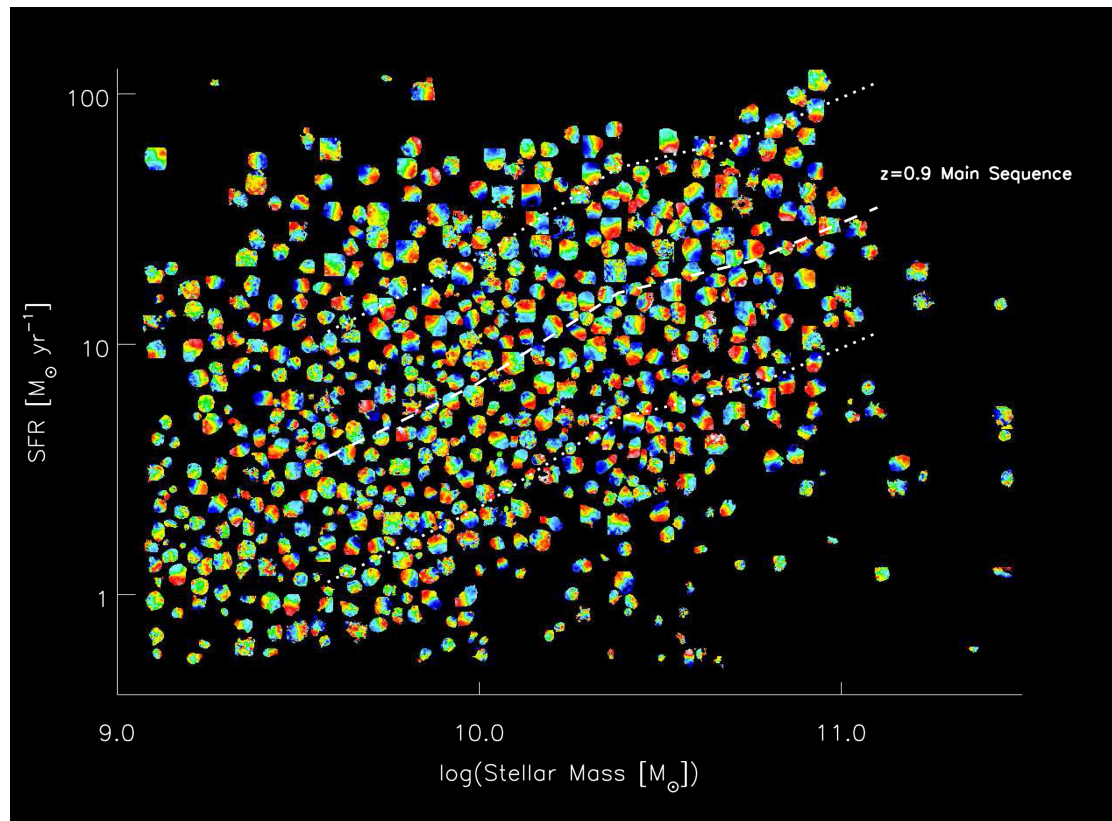
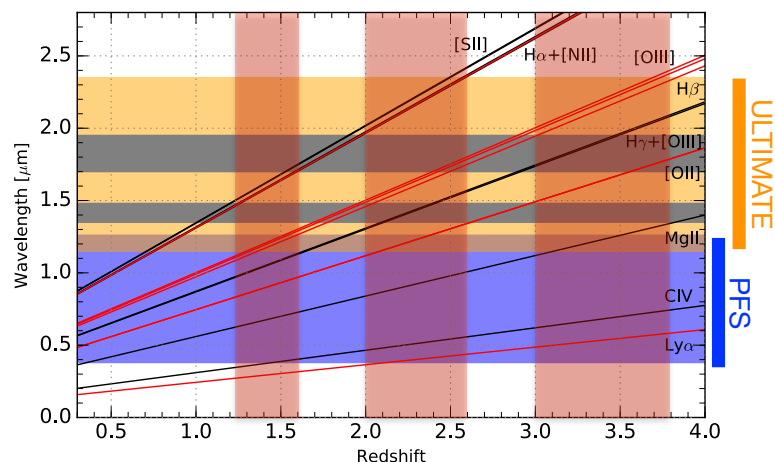~600 KMOS sample at z~1 from KROSS survey (Stott+16)

Synergy between ULTIMATE-Subaru and PFS:

2. Followups of PFS sample with ULTIMATE/MOS
  - PFS galaxies at 1.2<z<1.6, 2.0<z<2.6, 3.0<z<3.8 can be candidate targets for ULTIMATE MOS observations
  - Most of the major emission lines (from rest-UV to opt) can be traced by combining ULTIMATE and PFS

- Chemical properties / ISM conditions / outflows by using optical and UV lines

- It may be a great extension of KBSS-MOSFIRE survey if the sensitivity of the ULTIMATE is well higher than MOSFIRE ?

Redshift	Lyα	CIV, MgII	[OII]	[OIII]+Hβ	Hα+[NII]
1.2<z<1.6	—	PFS	PFS	PFS ULTIMATE	ULTIMATE
2.0<z<2.6	PFS	PFS	PFS ULTIMATE	ULTIMATE	ULTIMATE
3.0<z<3.8	PFS	PFS ULTIMATE	ULTIMATE	ULTIMATE	—

Synergy between ULTIMATE-Subaru and PFS:

3. Followups of ULTIMATE/Imaging sample with PFS

- Low-mass galaxies selected with ULTIMATE deep NIR data and Narrow-band data may be an unique sample
- The current PFS SSP survey is mainly oriented to relatively massive galaxies ($>10^9$ Msun)
- Follow-ups with PFS of ULTIMATE deep K-selected galaxies and NB-selected Hα (and other) emitters over wide area (>10 deg^2?) may be relatively competitive

COSMOS2015 (0.8<z<2.0)

Star Formation Rate [$M_\odot$ yr^{-1}]

Stellar Mass [$M_\odot$]

PFS 4-hr Hα sensitivity @z=0.9

ULTIMATE   PFS-SSP

HAE in NB$_J$ HAE in NB$_H$ HAE in NB$_K$

[SII]   Hα+[NII]   [OIII]

Hβ

Hγ+[OIII]

[OII]

MgII

CIV

Lyα

Wavelength [μm]

Redshift

ULTIMATE

PFS

NB$_J$:1.3μm, NB$_H$:1.65μm, NB$_K$:2.15μm are assumed
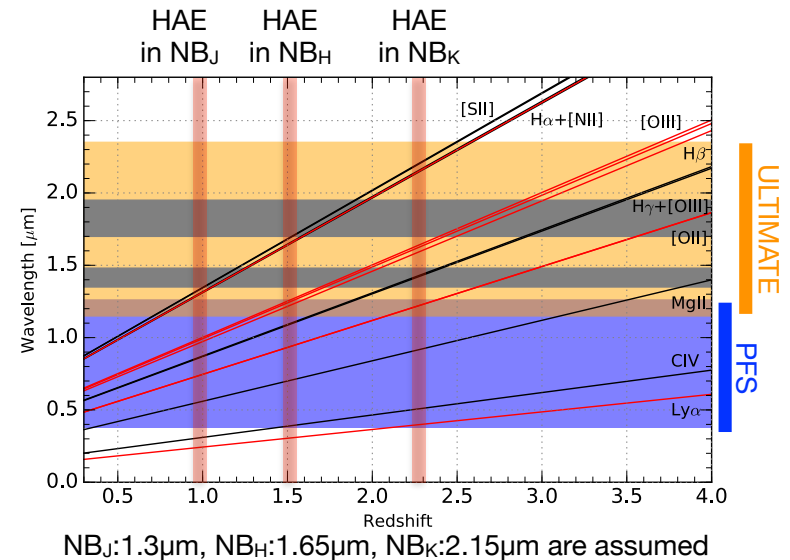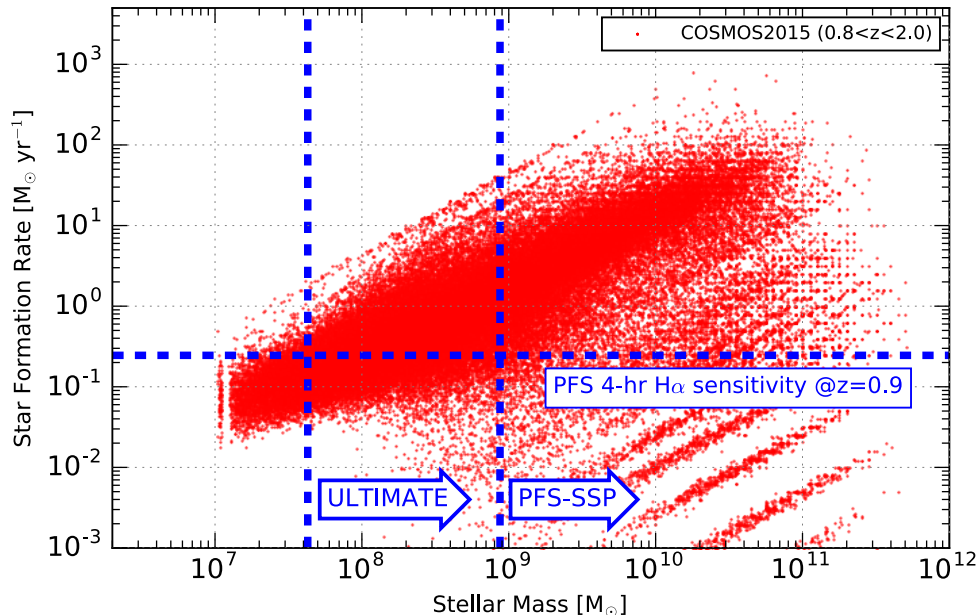
Synergy between ULTIMATE-Subaru and PFS:

Conclusion:
  • Follow-up with ULTIMATE/IFU for PFS sample at z~0.8-1.6 may not be competitive
  • Follow-up with ULTIMATE/MOS for PFS sample at 1.2<z<3.8 may be competitive if the sensitivity is high
  • Follow-up with PFS for ULTIMATE K-band / NB selected galaxies may be unique in 2020s
  • In any case, PFS must have a great synergy with ULTIMATE-SUBARU

The answer to the Questions from WG:
  • A1: The physical properties of galaxies at z≳1
  • A2: WFC / MOS > IFU
  • A3: Pilot surveys can be started with GLAO + MOIRCS
  • A4: (C)+(B)' or (D) would be better