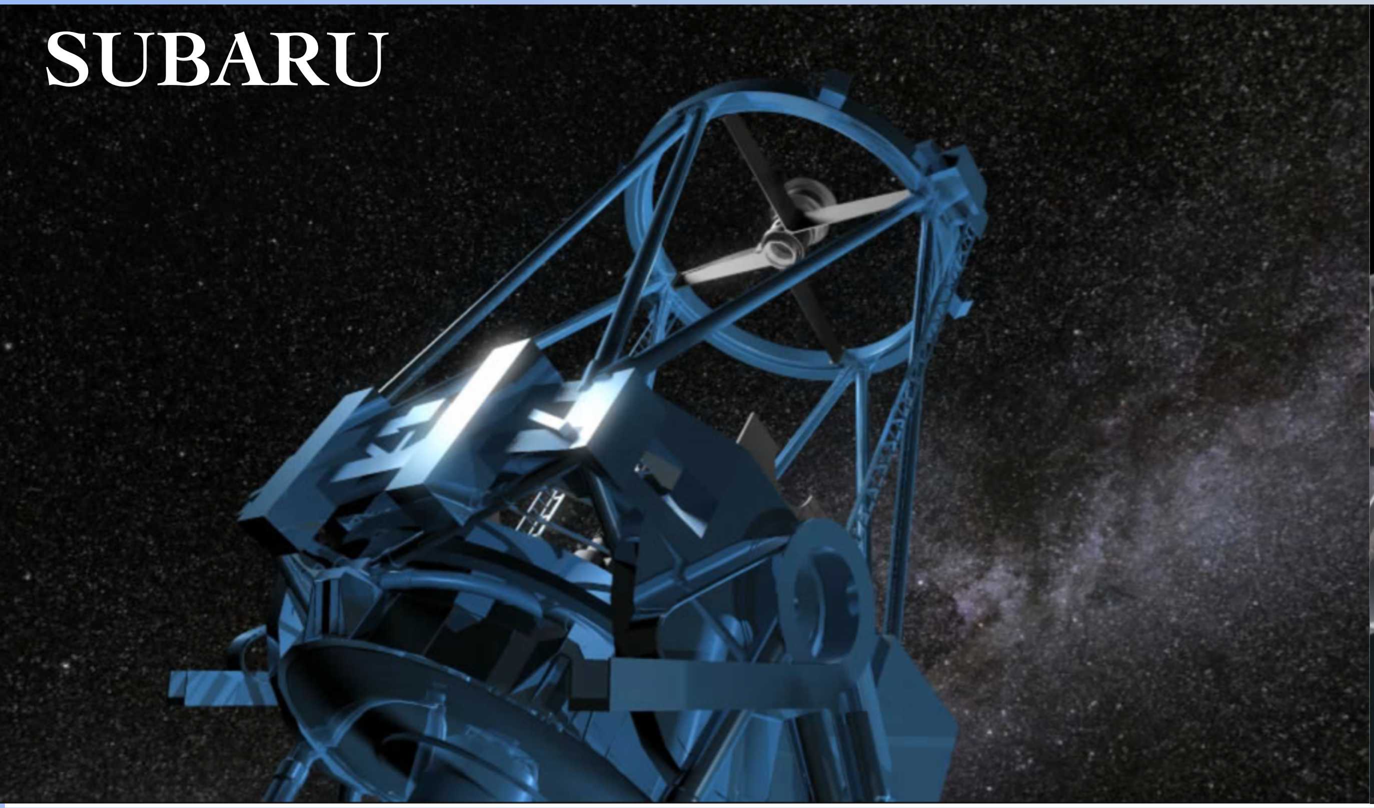
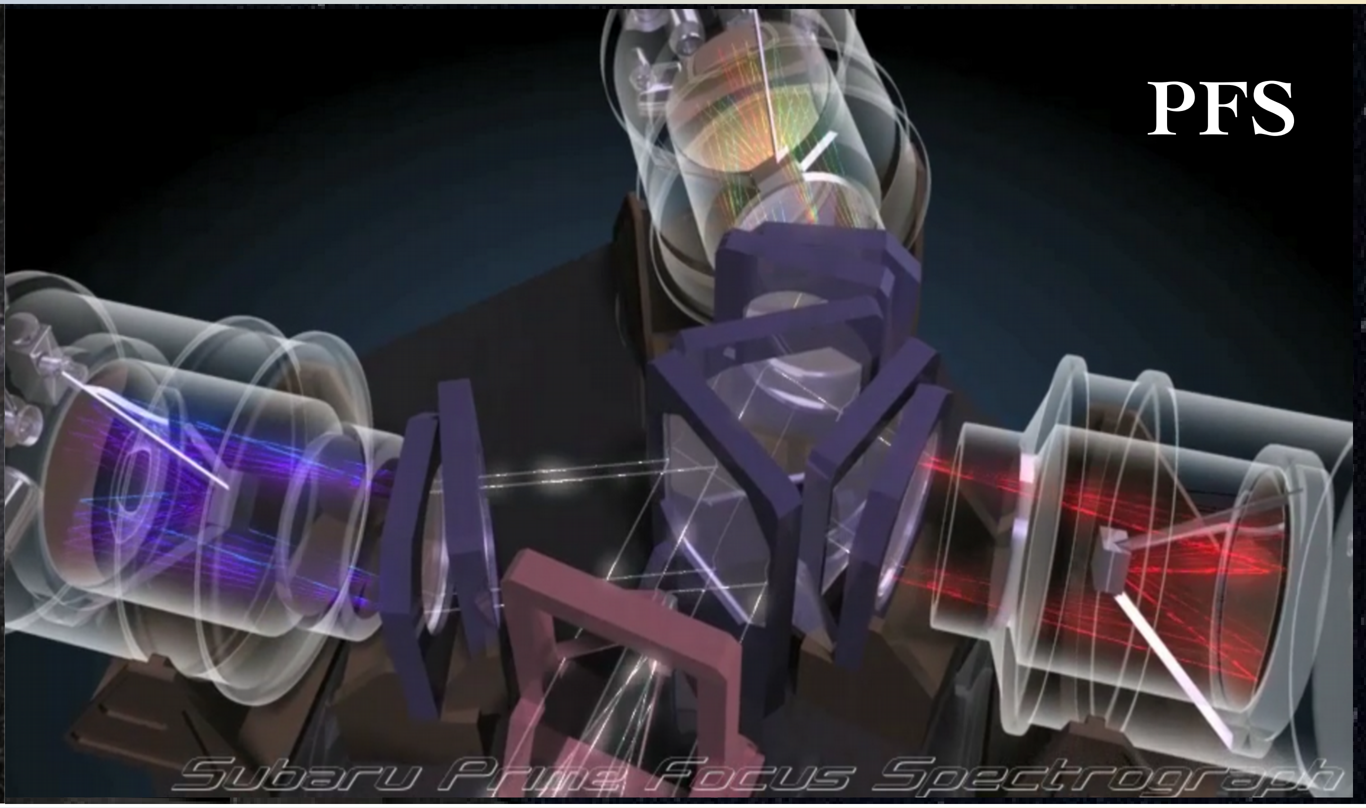
PFS

a Prime Focus Spectrograph on Subaru

PI: Hitoshi Murayama (IPMU & Berkeley)

S. Arnouts (LAM)



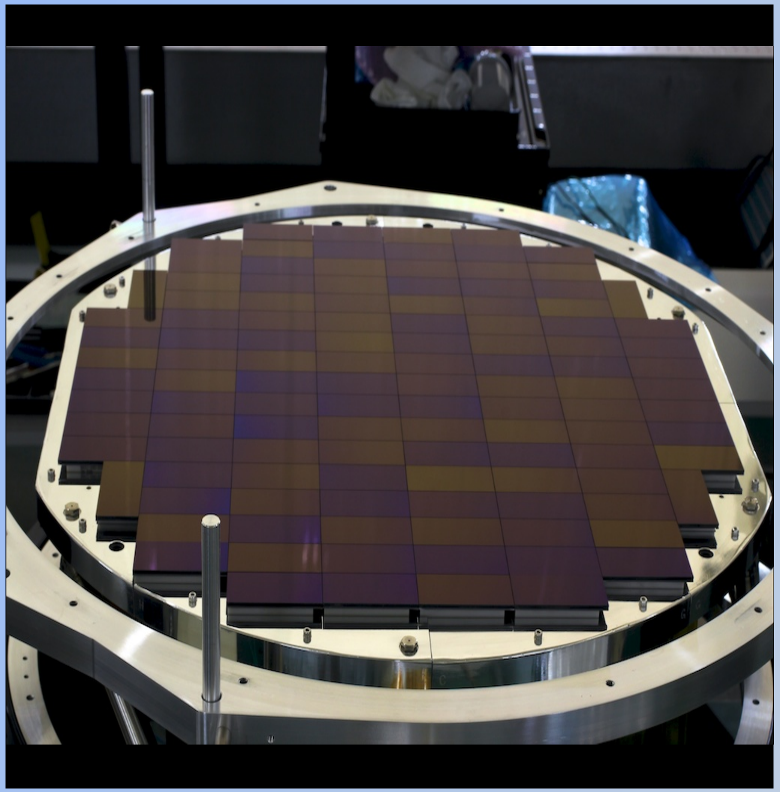


SUMIRe : HSC + PFS

Subaru Measurements of Images and Redshifts

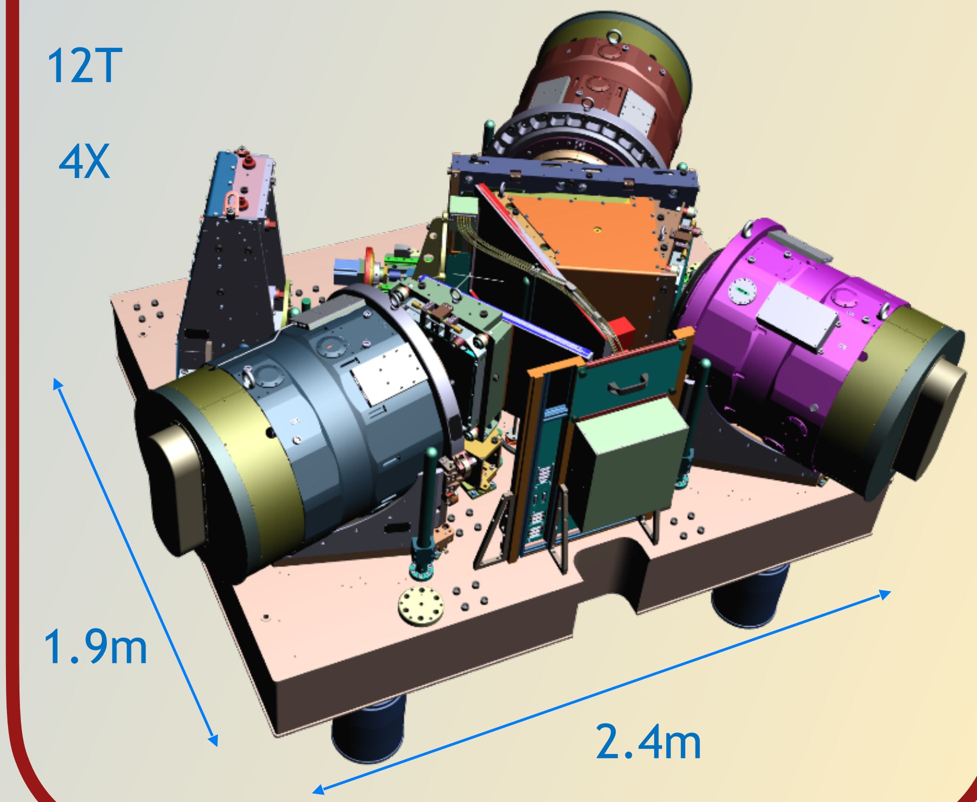
PI: Hitoshi Murayama (IPMU & Berkeley)

HSC : Imaging



Wide Field Corrector

PFS : Spectroscopy



SUMIRe : HSC + PFS

Subaru Measurements of Images and Redshifts

PI: Hitoshi Murayama (IPMU & Berkeley)

HSC : Imaging

FOV : 1.8 deg^2
HSC : 870M pixels
SSP : 330n
Cosmology
Clustering, WL
Galaxy evolution

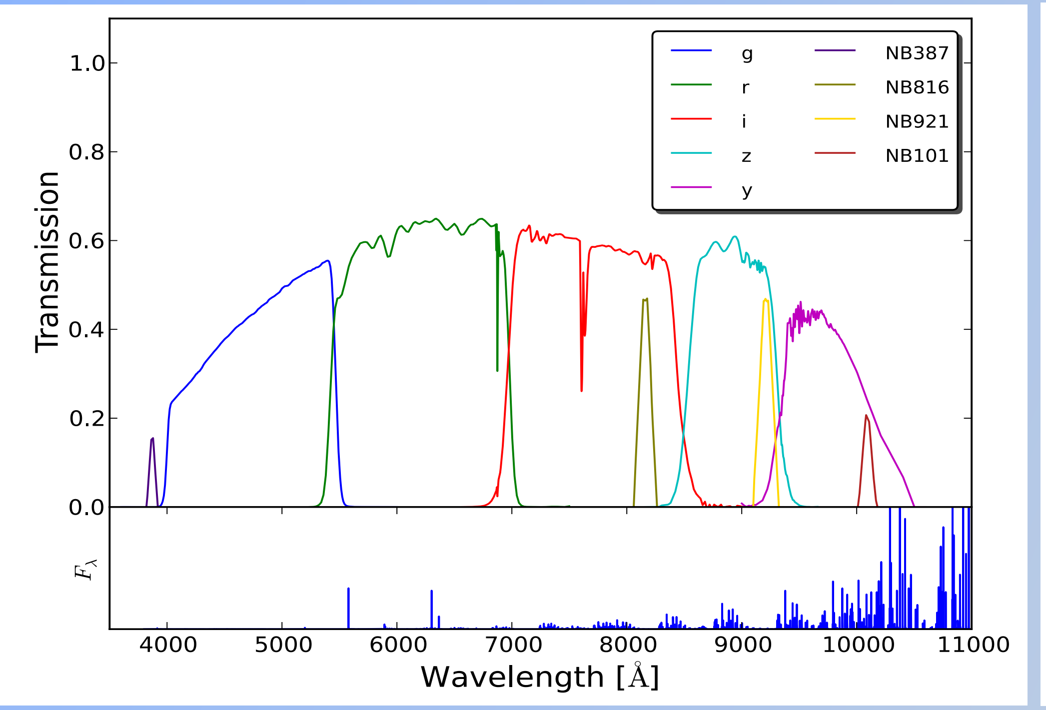
Wide Field Corrector

PFS : Spectroscopy

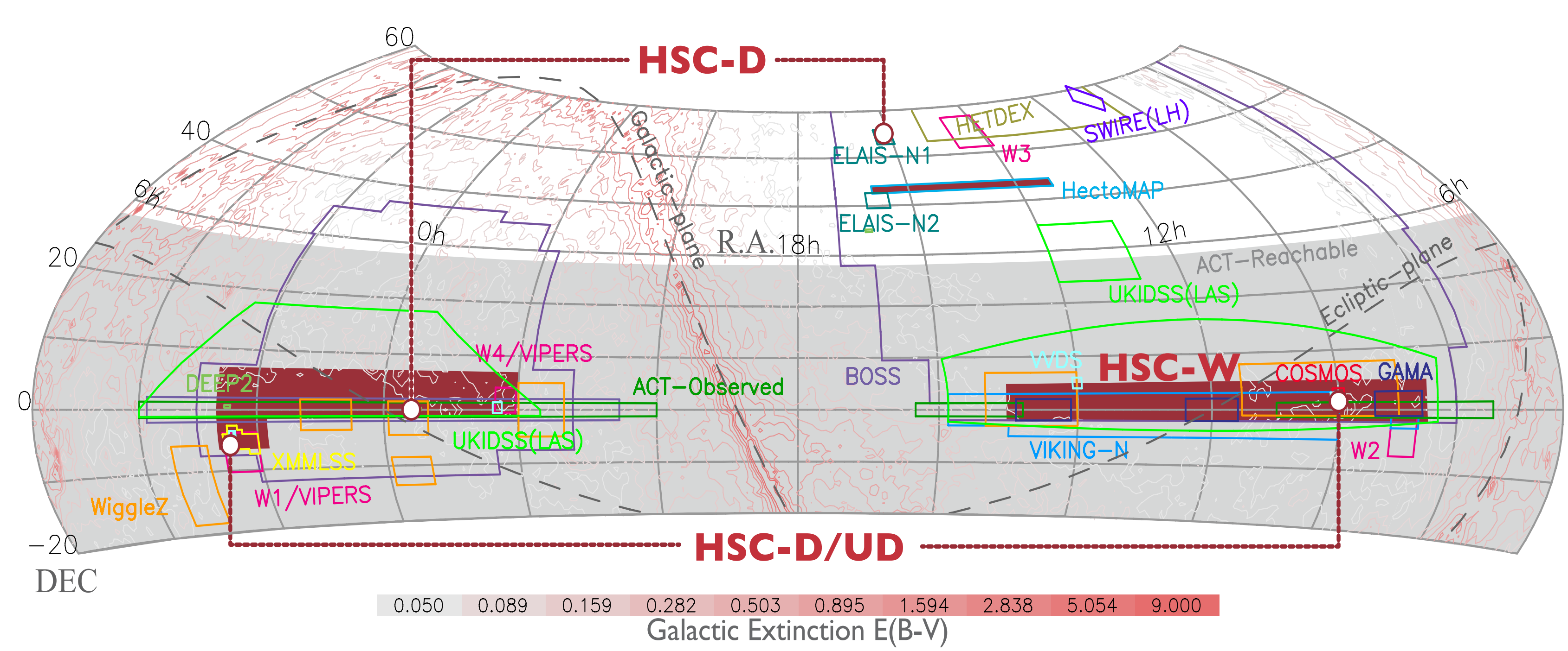
FOV : 1.3 deg^2
PFS : 2400 fib. / 0.38-1.3μm
SSP : 360n
Cosmology
Galactic archeology
Galaxy evolution

HSC survey

Filters



Sky Coverage



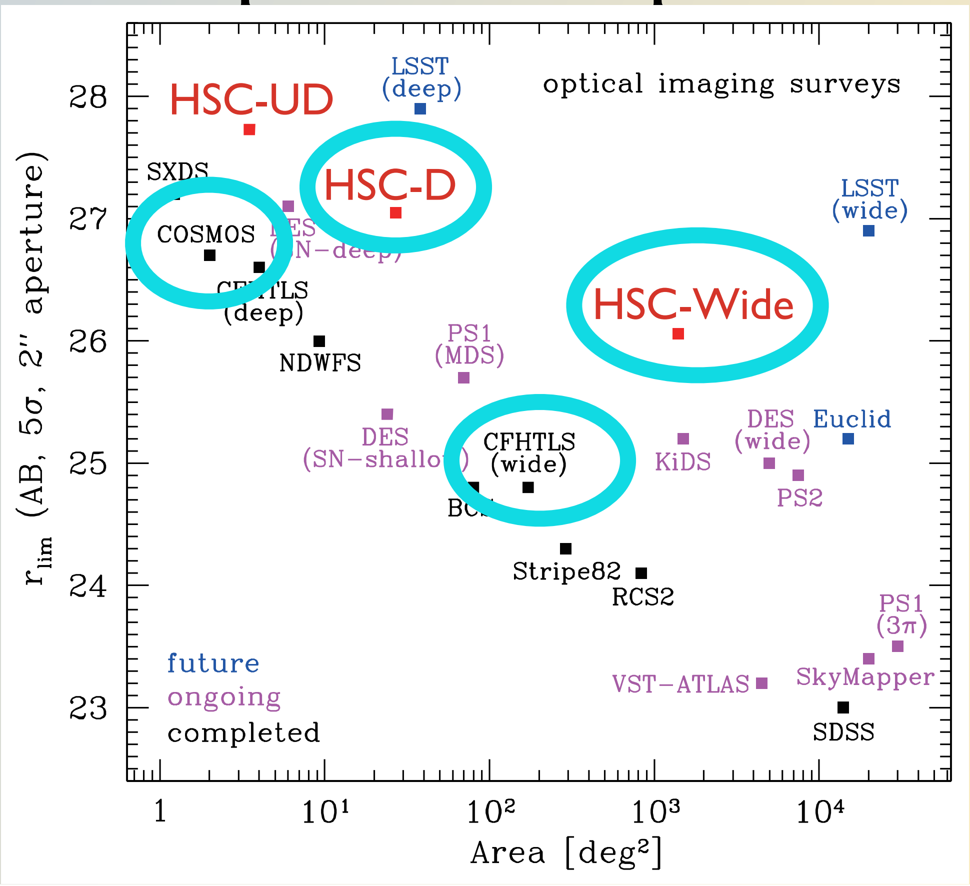
SSP summary

Layer	Area [deg^2]	# of HSC fields	Filters & Depth	Comoving volume [h^{-3}Gpc^3]
Wide	1400	916	*grizy* ($r \simeq 26$)	$\sim 4.4\,(z < 2)$
Deep	27	15	*grizy*+3NBs ($r \simeq 27$)	$\sim 0.5\,(1 < z < 5)$
Ultradeep	3.5	2	*grizy*+3NBs ($r \simeq 28$)	$\sim 0.07\,(2 < z < 7)$

→ with good IQ (<0.8arcsec) for WL

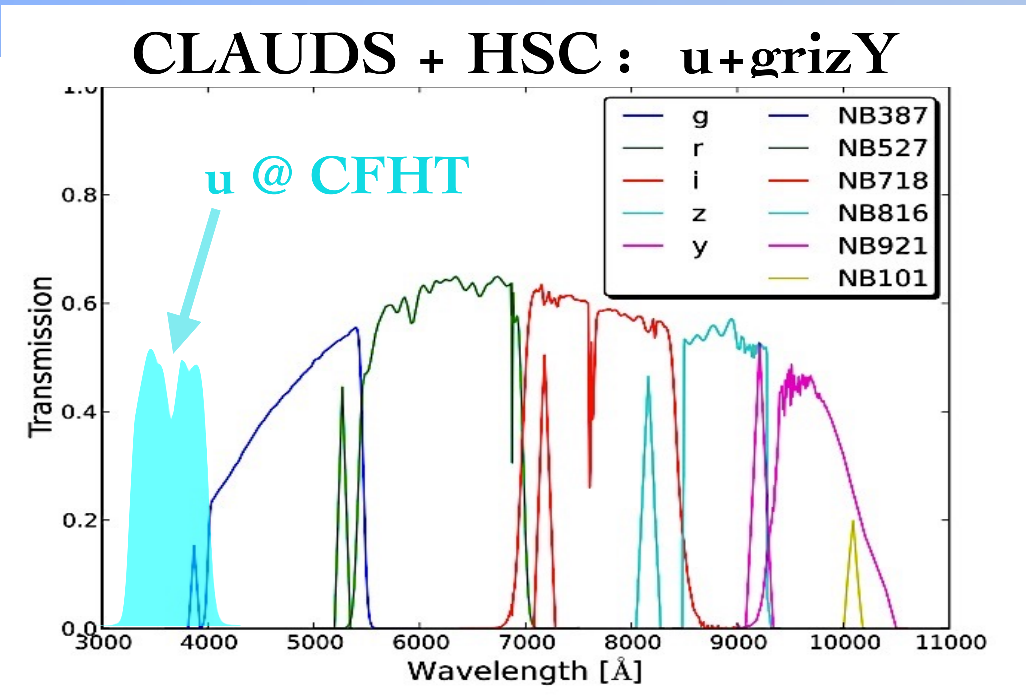
used for the PFS target selection

Depth-Area Comparison



HSC survey

Filters



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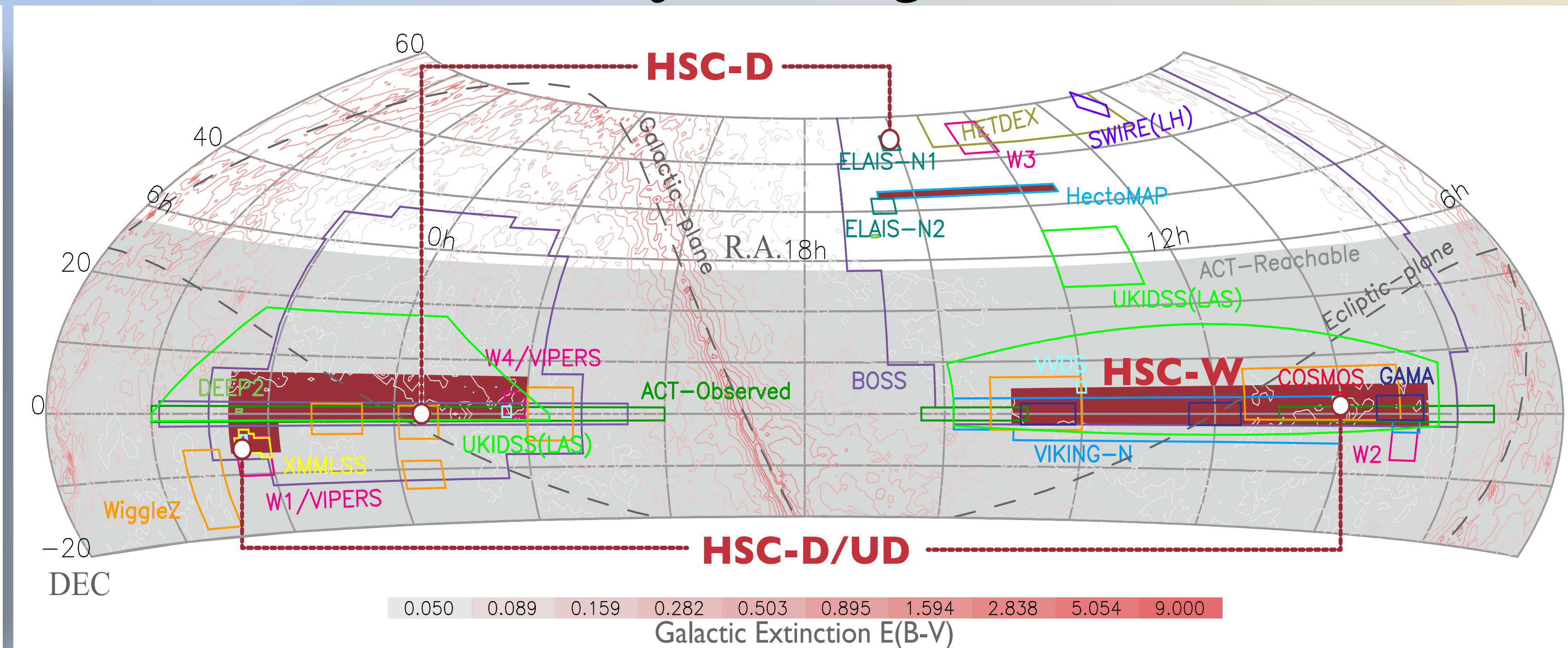
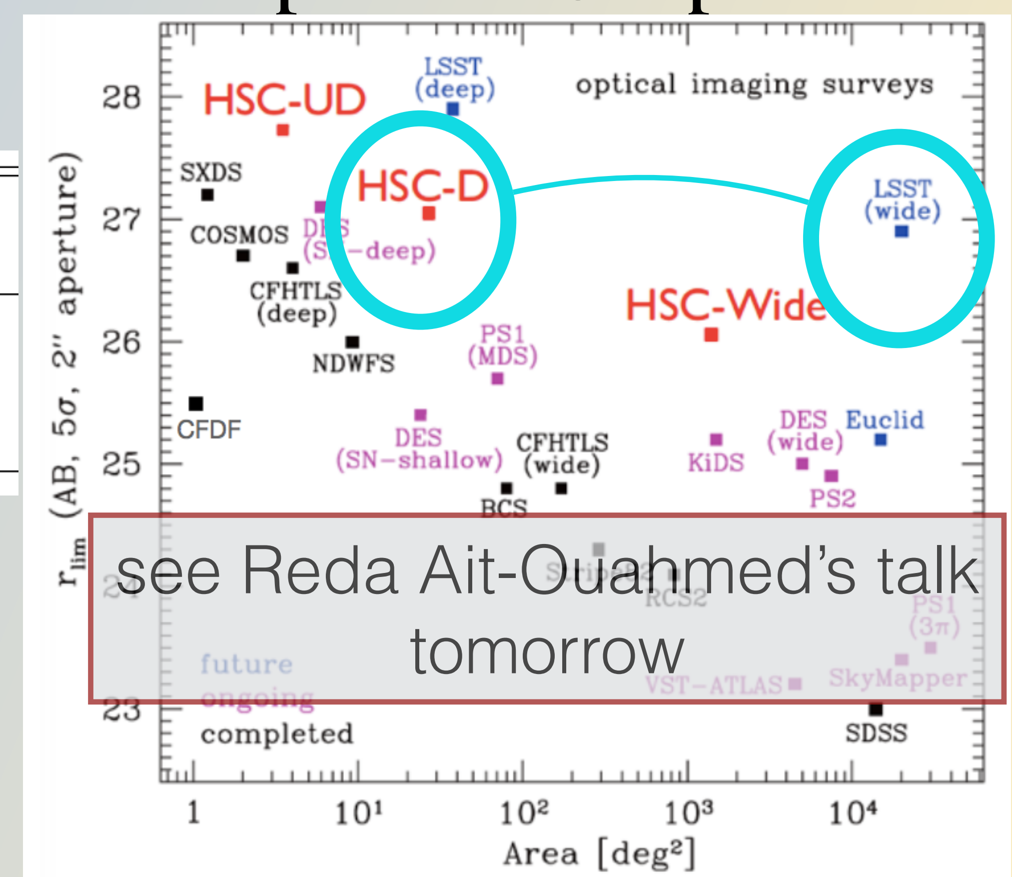


Depth-Area Comparison



see Reda Ait-Ouahmed's talk tomorrow

SSP summary

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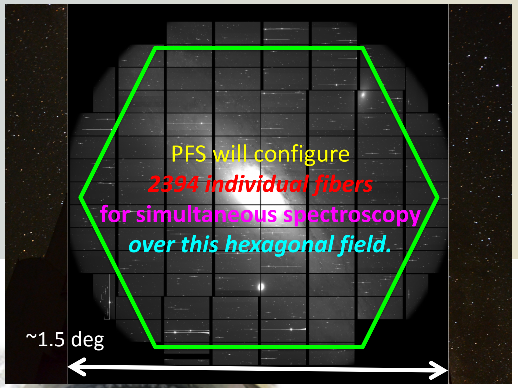
→

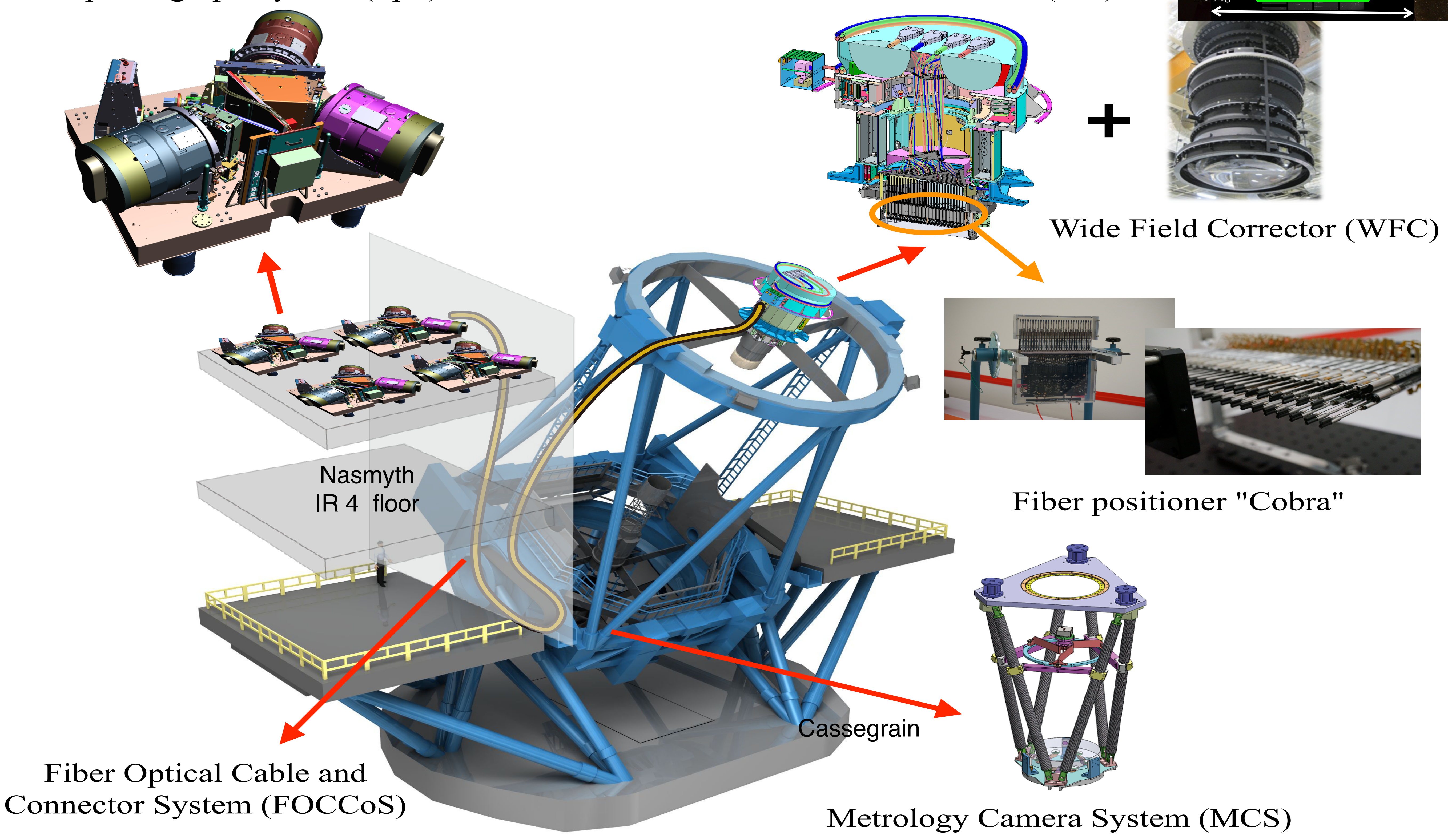
HSC Deep : 28 deg^2 at r~27 +NB+

+ CLAUDS : 25 deg^2 at u~27 (in HSC D/UD)

CLAUDS+HSC deep a unique dataset until LSST

Prime Focus Spectrograph (PFS)

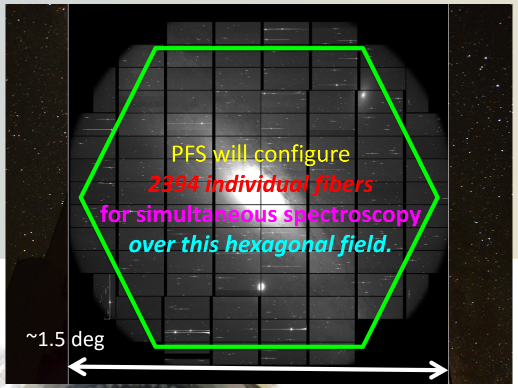




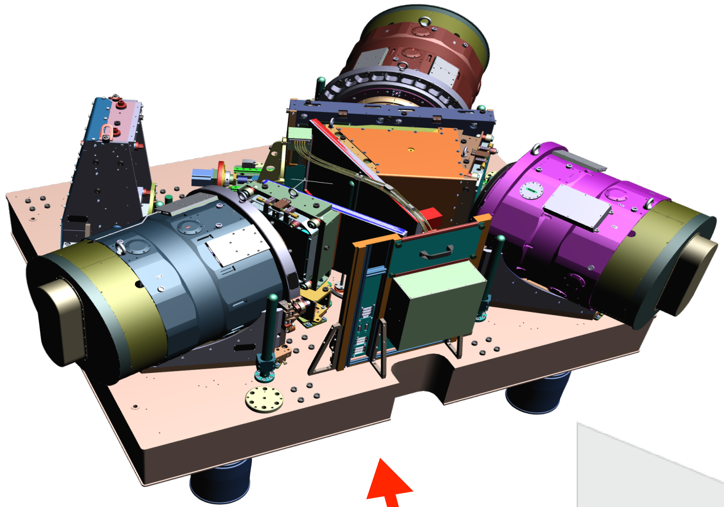
Prime Focus Spectrograph (PFS)

Prime Focus Spectrograph

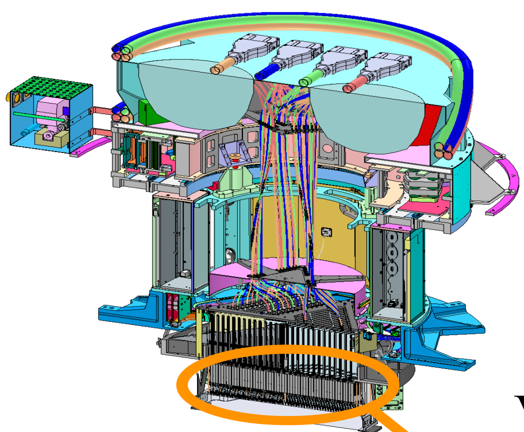
SuMIRe



Spectrograph System (SpS)

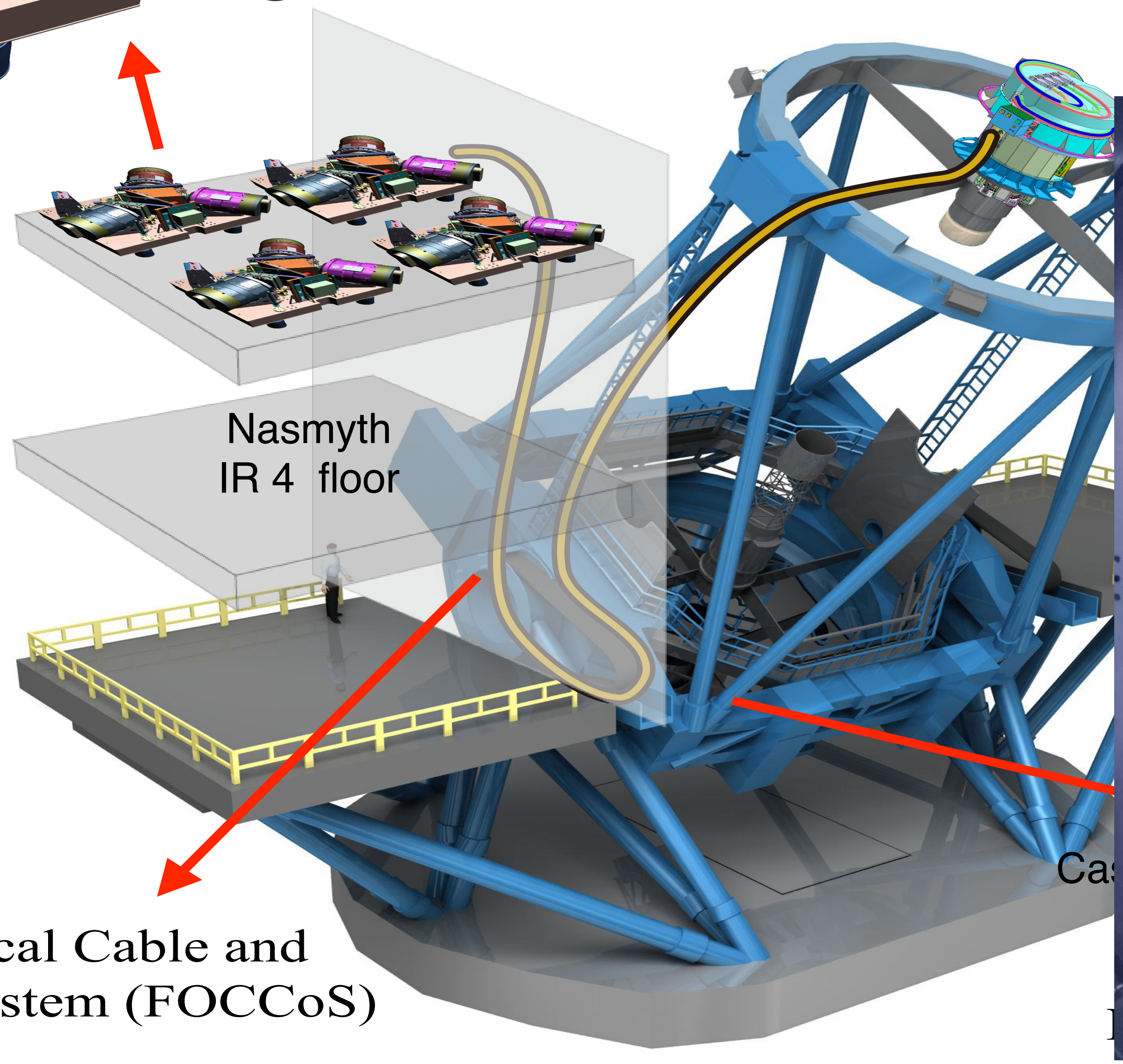


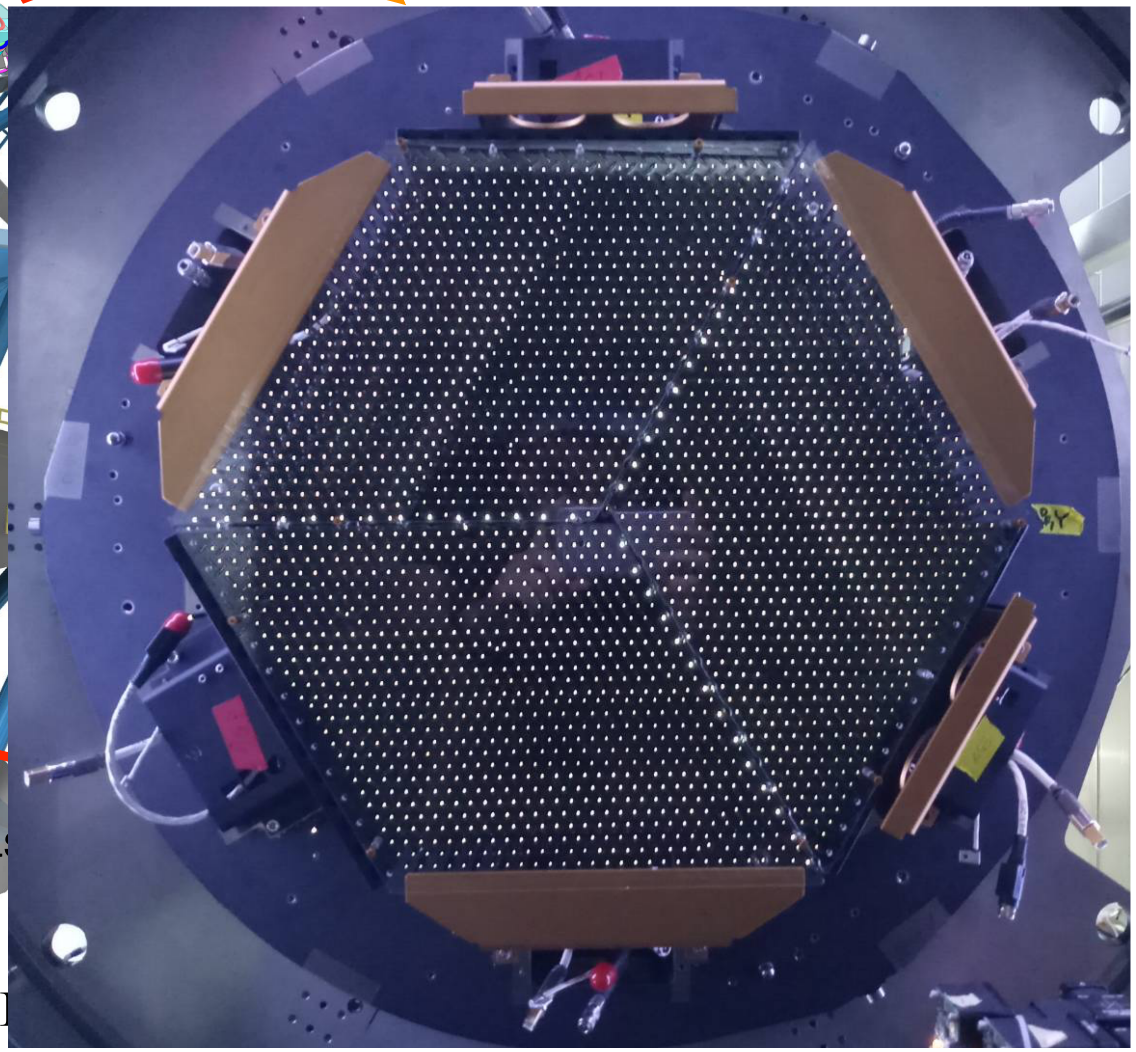
Prime Focus Instrument (PFI)



+

Wide Field Corrector (WFC)

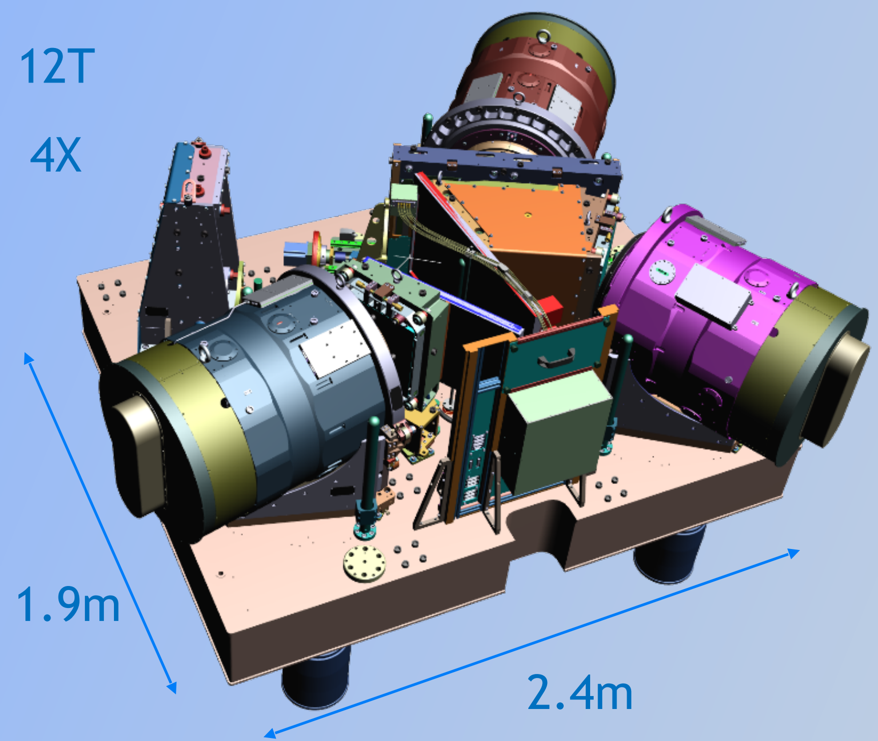


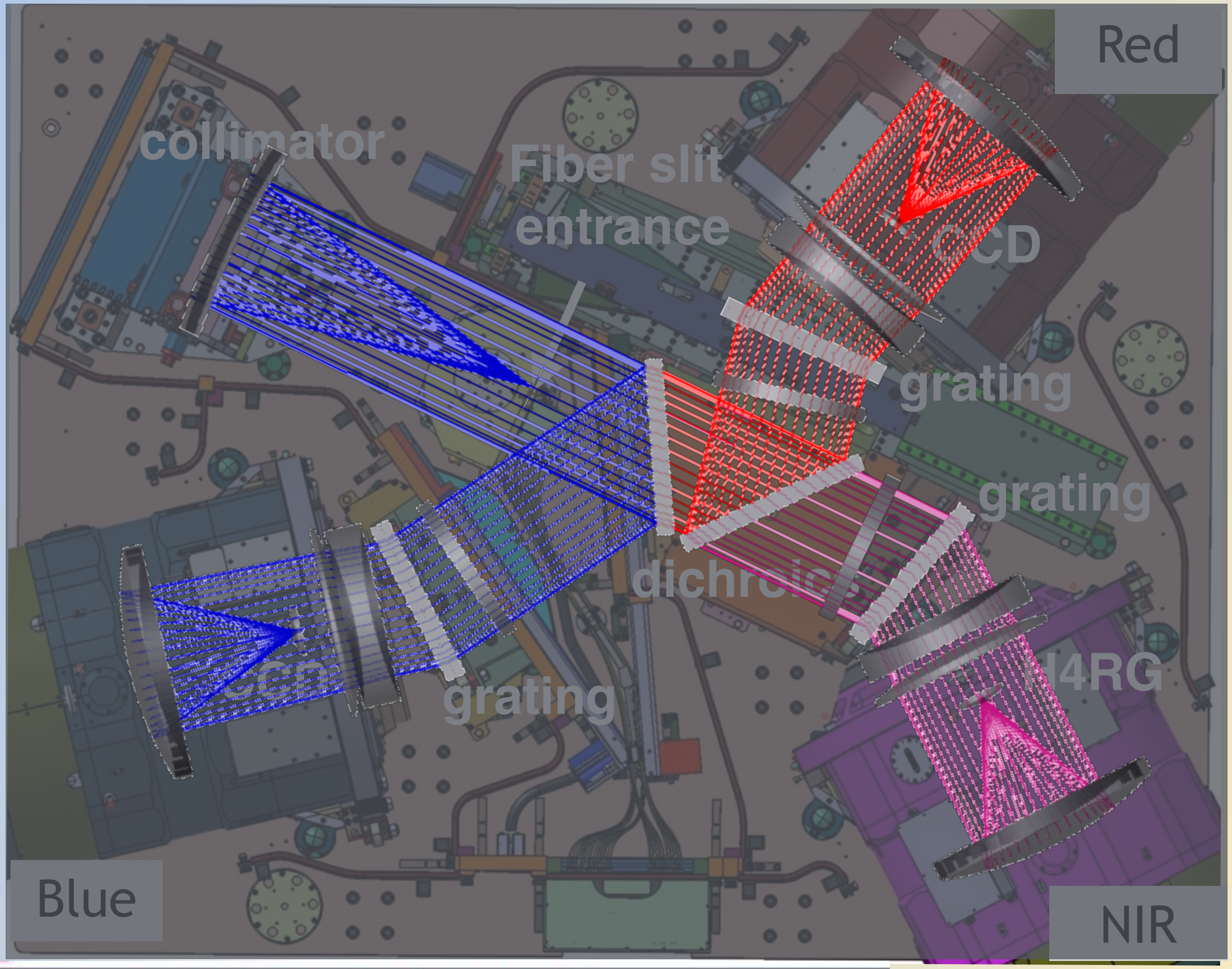


Fiber Optical Cable and Connector System (FOCCoS)

Prime Focus Spectrograph (PFS)

4 Spectrograph Modules with 600 fibers and 3 cameras / SM

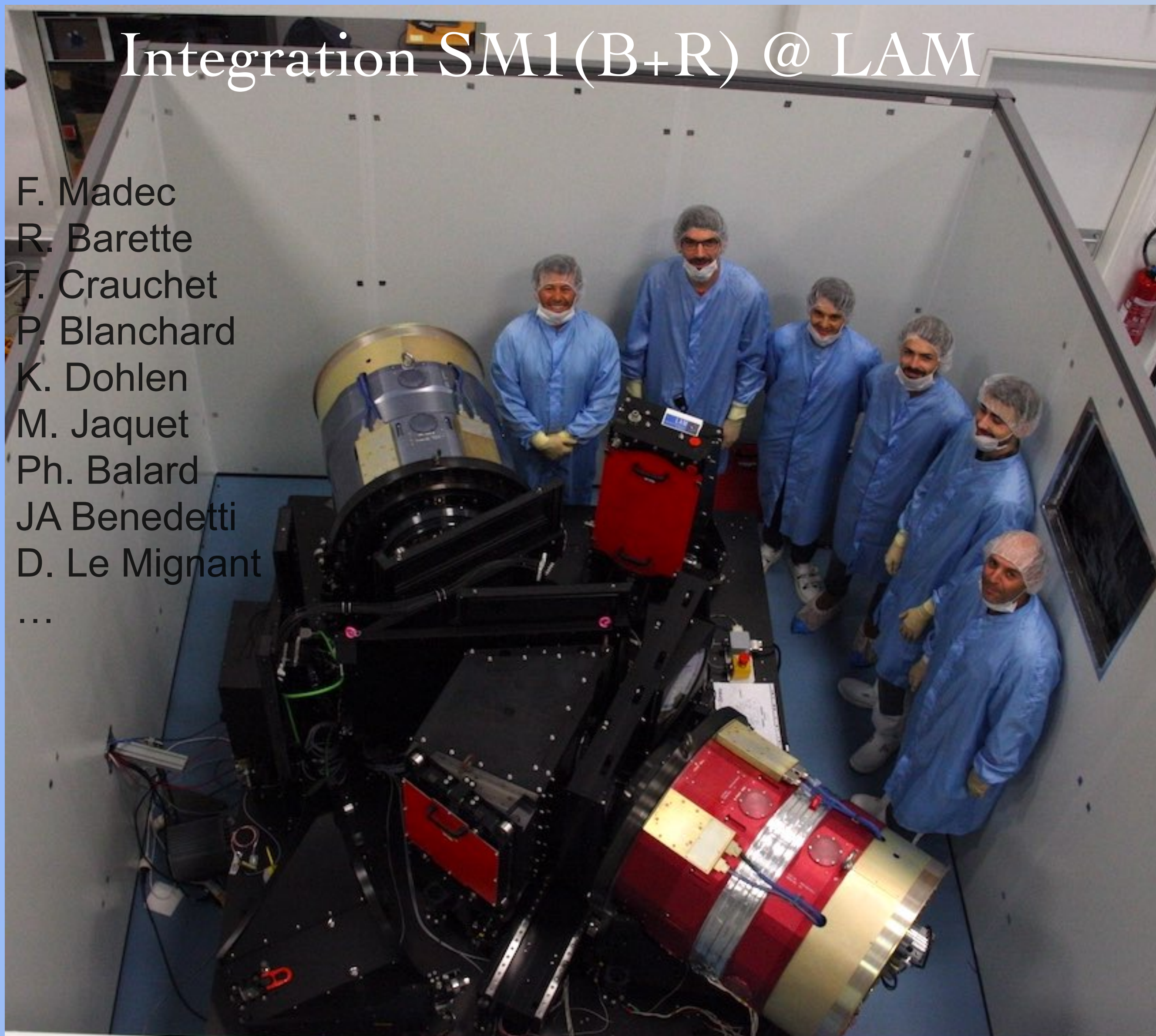




Number of fibers	2400		
Field of view	1.3 deg (hexagonal-diameter of circumscribed circle)		
Fiber diameter	1.13" diameter at center		1.03" at the edge
	Blue	Red	NIR
Wavelength range [nm]	380-650	630-970 (706-890)	940-1260
Central resolving power	~2350	~2900 (~5000)	~4200

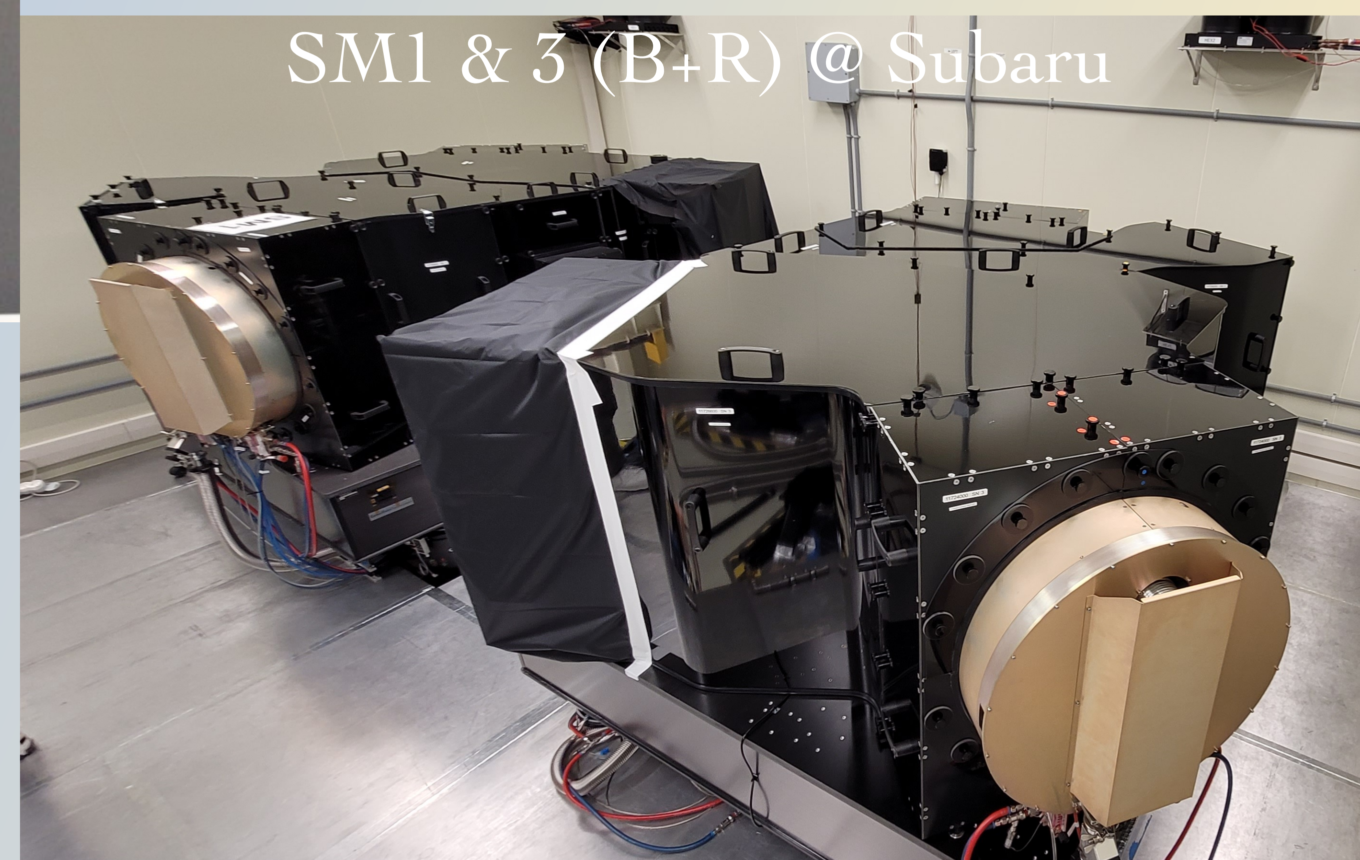
Prime Focus Spectrograph (PFS)

Prime Focus Spectrograph
SuMIRe



Current status

* 2 SMs (B+R) at Subaru
* Start of engineering runs
* First NIR camera @ LAM



Prime Focus Spectrograph (PFS)

International collaboration

LAM technical contributions

* Spectrographs integration (D. Le Mignant / F. Madec)

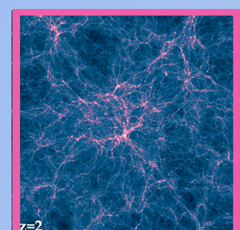
* 1D Data Reduction Pipeline (V. LeBrun)

PFS: Subaru Strategic Program (360n)

three science Pillars

Cosmology

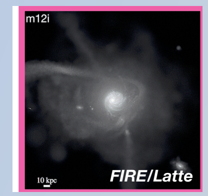
cosmo.
parameters
neutrino mass



4 millions of Emission lines
0.6<z<2.4

Galactic Archeology

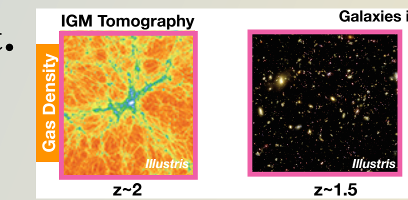
Assembly history
DM profiles



Milky way
Andromeda streams & halos
local Dwarfs

Galaxy Evolution

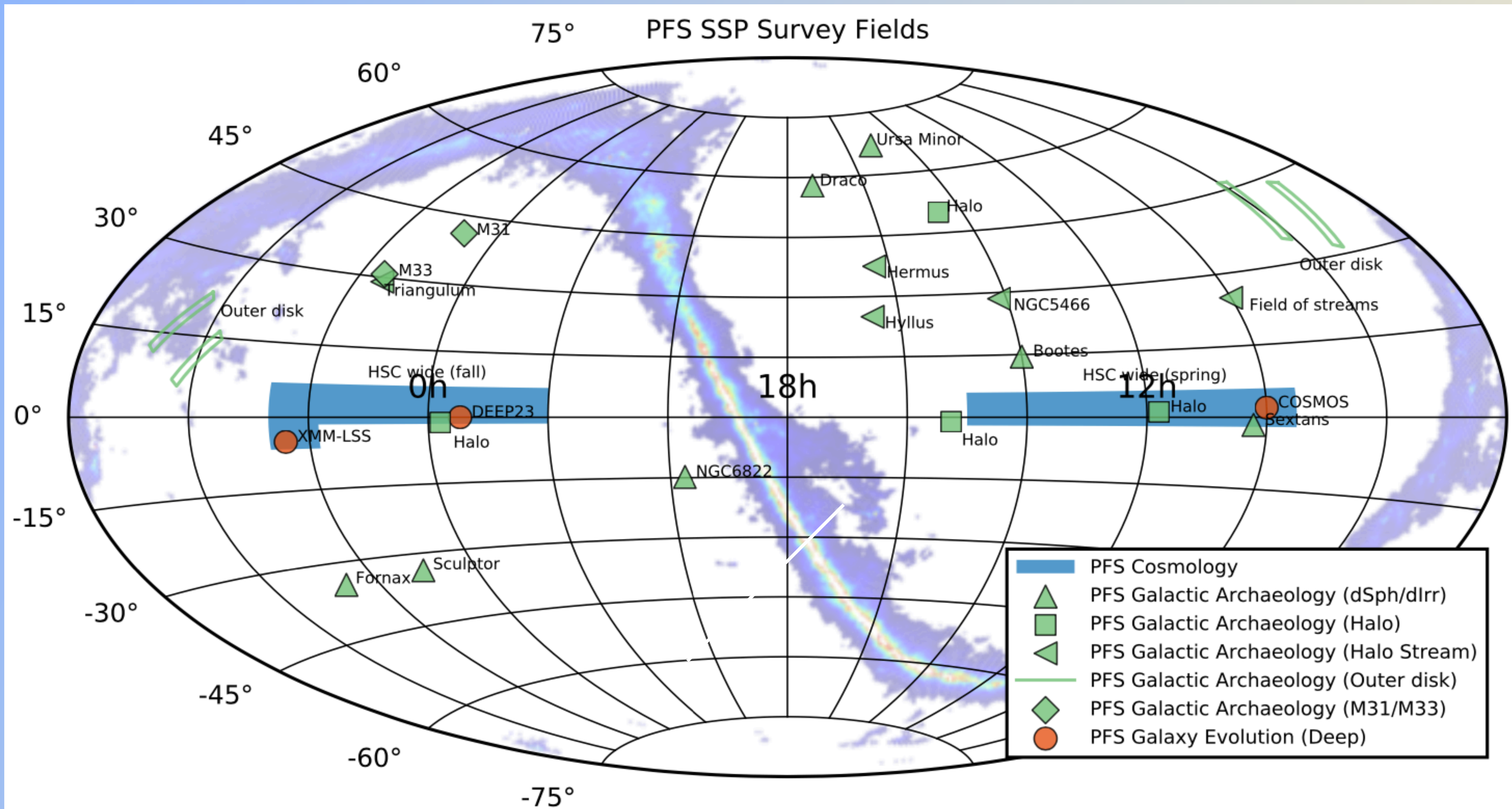
Galaxies & their envt.
IGM tomography
End of Reionization



350,000 spectra over 15 deg2

	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 synergy • Absorption probes with PFS/SDSS QSOs around PFS/HSC host galaxies	• Search for emission from stacked spectra
GA	• Nature of DM (dSphs) • Structure 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

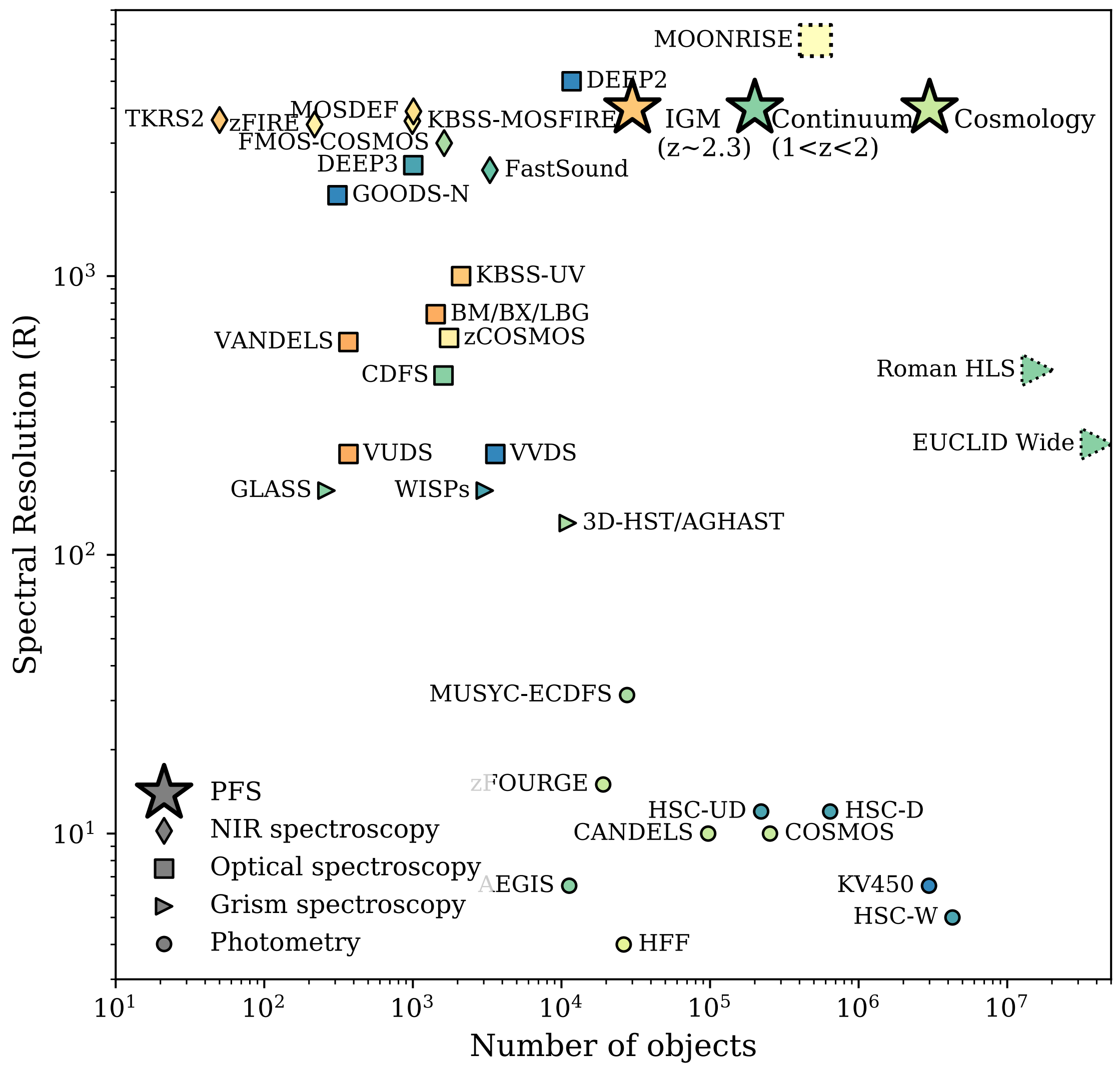
PFS: Subaru Strategic Program (360n)

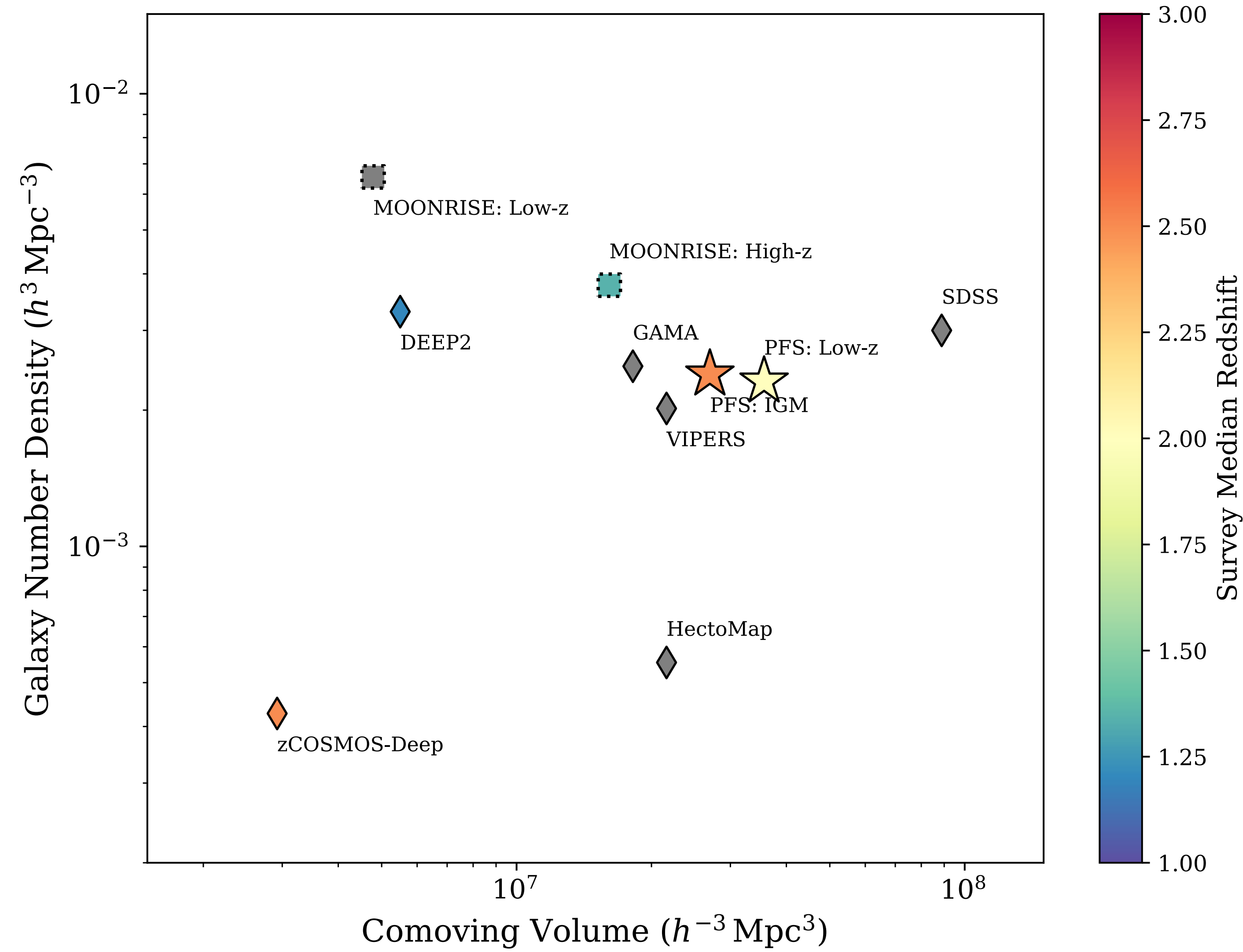


- PFS Cosmology: HSC-Wide (~1200 sq. deg.) region. Shallow (15-30min each field)
- PFS Galaxy Evolution: HSC-Deep (~15 sq. deg.) regions. Deep (>2hrs)
- PFS Galactic Archaeology: based on private HSC data. dwarf gal. sample, M31, streams/outer disk

PFS: Subaru Strategic Program (360n)

—> Next generation of High-z spectroscopic surveys



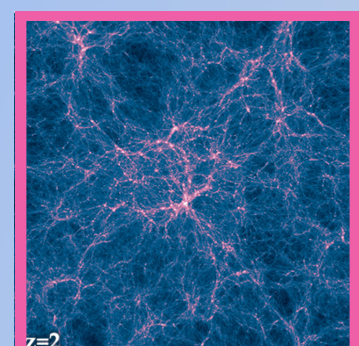


PFS: Subaru Strategic Program (360n)

three science Pillars

Cosmology

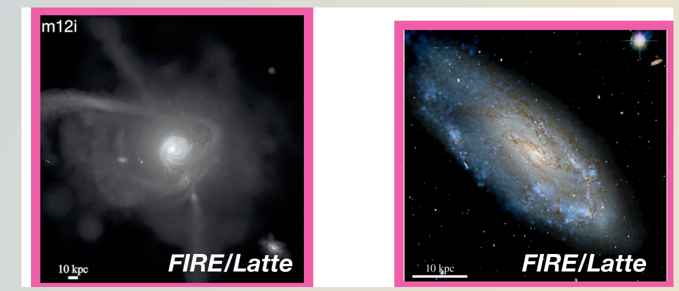
cosmo. parameters
neutrino mass
BAO, RSD, PS



4 millions of Emission lines
over 1400 deg2 in
$0.6<z<2.4$

Galactic Archeology

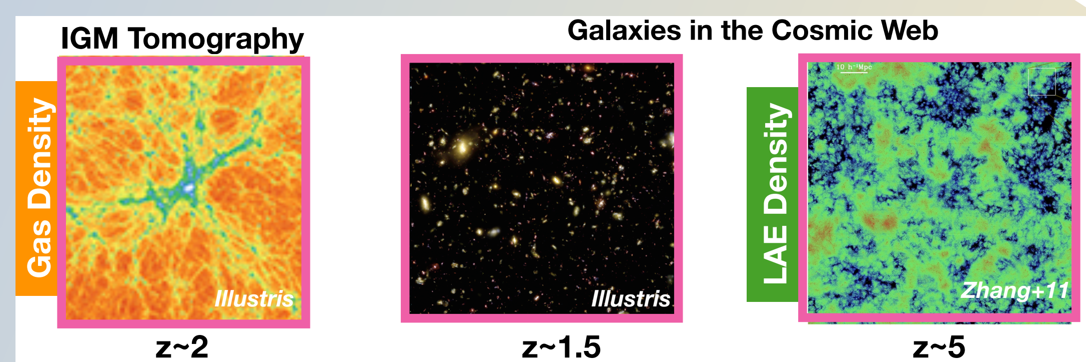
DM profiles
Assembly history



Milky way
Andromeda streams & halos
local Dwarfs

Galaxy Evolution

Galaxies & their environments
($0.7<z<7$)
IGM tomography (Ly-a forest at z>2)
End of Reionization (LAE z>5.5)

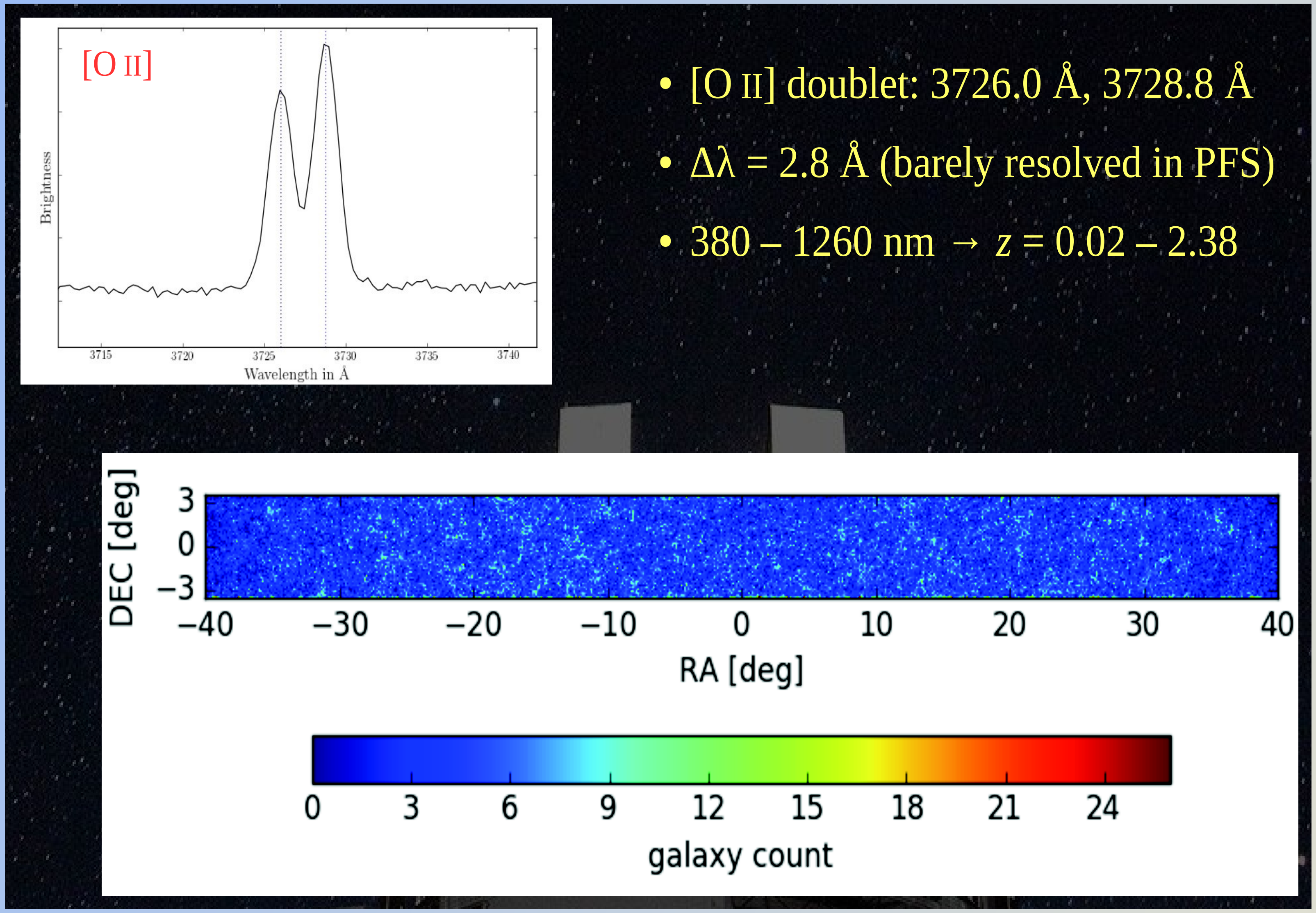


350,000 spectra over 15 deg2

PFS - SSP : Cosmology

Cosmology survey : to measure cosmic length scales at high z

- 1200 deg^2 with 4 millions **ELGs** measured with OII doublet in 0.6<z<2.4 with over a comoving Vol ~ *7* Gpc^3

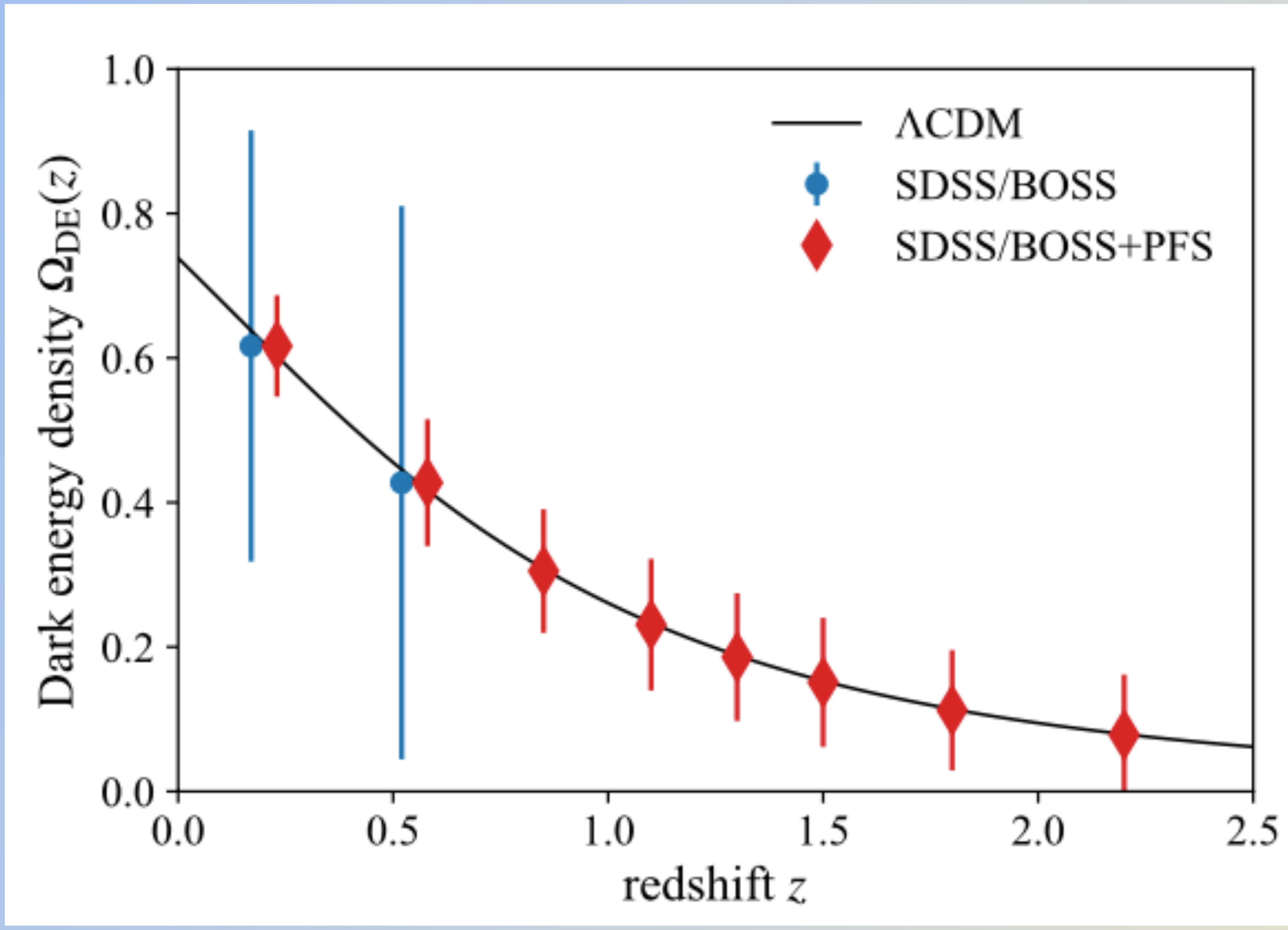


ELGs selected with mag/color criteria

PFS - SSP : Cosmology

Testing Cosmic acceleration with distance scale lengths

- BAO and Alcock-Paczynski measurements : $DA(z)$ and $H(z)$ at 3% at all z
- Expected accuracy with which the PFS BAO-measured $DA(z)$ and $H(z)$ will determine the dark energy density parameter $\Omega_{DE}(z)$



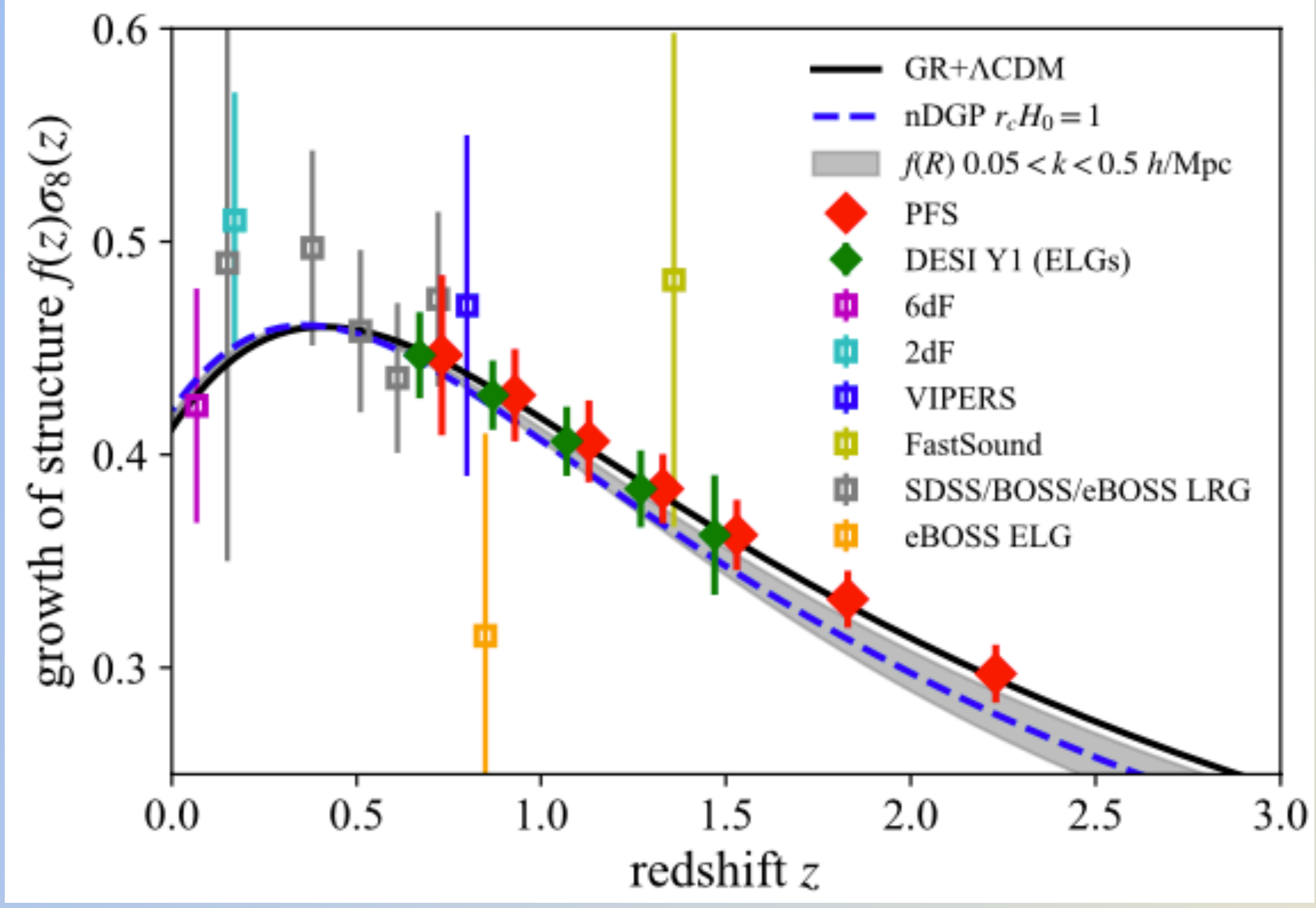
PFS - SSP : Cosmology

Testing Linear growth rate of DM fluctuations

- RSD : $f.\sigma_8(z)$ at 6% up to z=2.4

—> PFS extended to high z w.r.t. DESI (Y1)

—> does cosmic acceleration arise from a modification of GR on large scales ?



—> High density sampling of PFS will allow to use voids for additional constraints on cosmological parameters

PFS - SSP : Cosmology

Constraints on Cosmological Parameters

- PFS uses a single tracer at low and high z

  —> Tension in BAO measurements from SDSS at low (galaxies) and high (Lya forest)

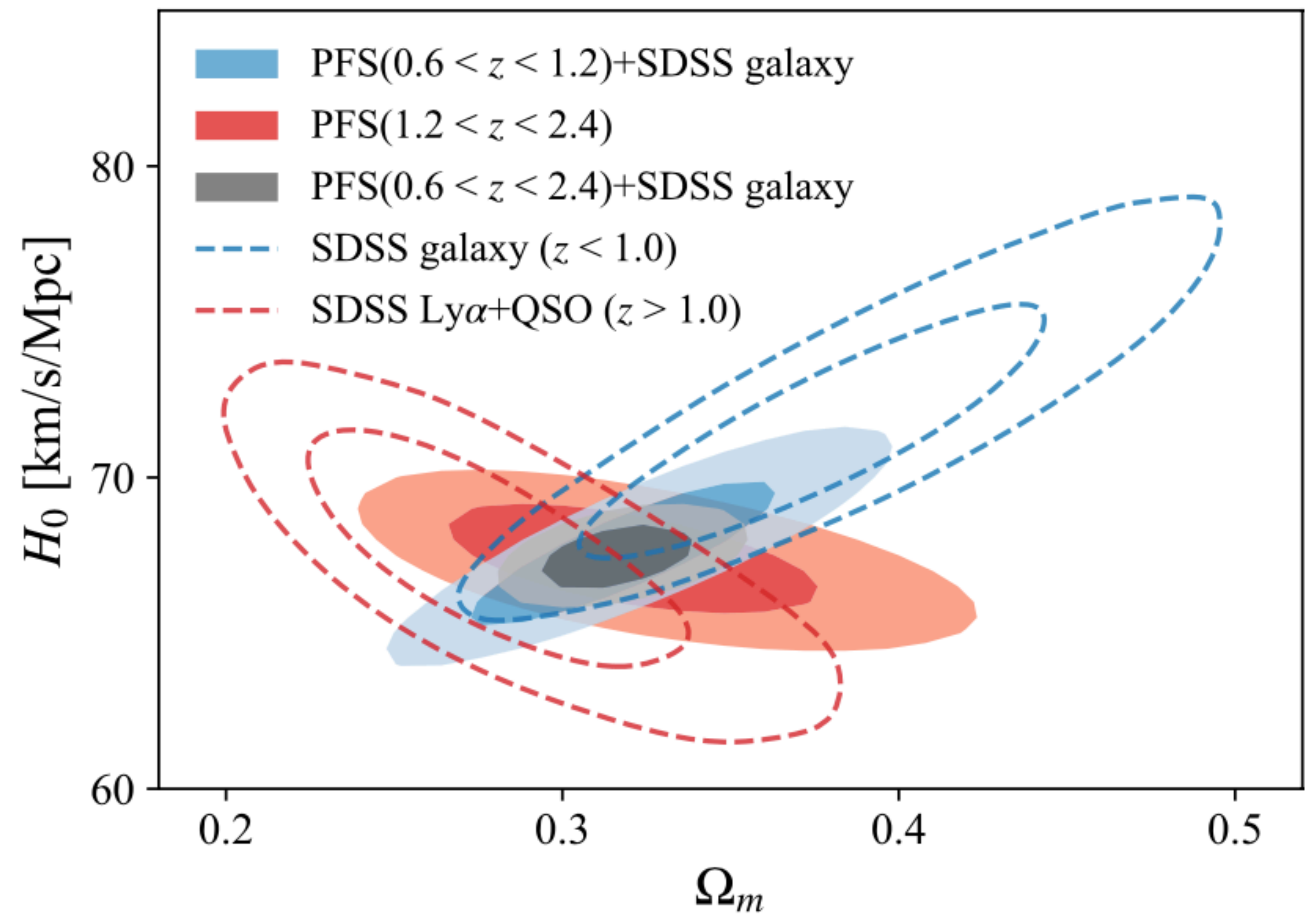


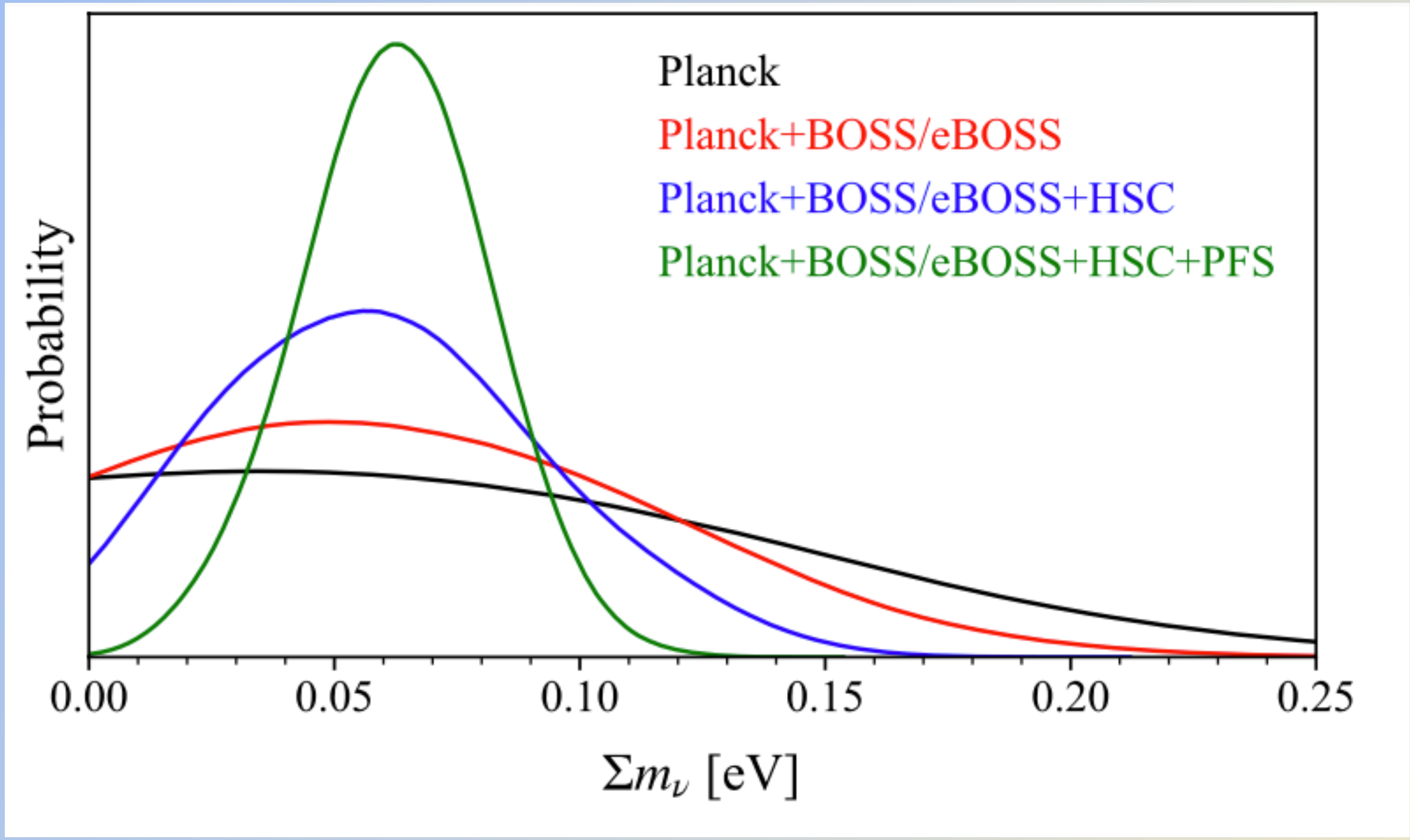
Figure 5. Two-dimensional marginalised joint posterior distributions (68% and 95% CL) in the $\Omega_m - H_0$ plane from the BAO information. All constraints adopt a Big Bang nucleosynthesis (BBN) prior $\sigma(\Omega_b h^2) = 0.02$. Dashed

PFS - SSP : Cosmology

Constraints on total neutrino mass with shape of Power Spectrum

- Growth of density fluctuations suppressed on scales < "neutrino-free streaming length" with z and scale dependence (Takada+2006) : ($\sigma(\Sigma m_\nu) = 0.02$eV)

- Constraints by combining with CMB , Gal. Clust and WL xPS (HSC-PFS)

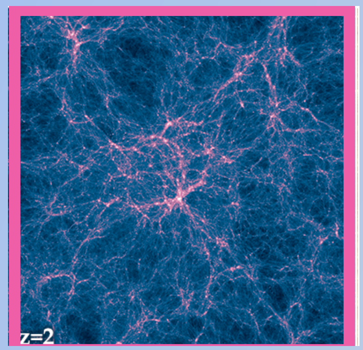


PFS: Subaru Strategic Program (360n)

three science Pillars

Cosmology

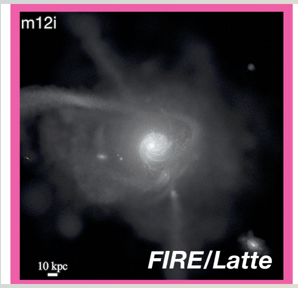
cosmo. parameters
neutrino mass
BAO, RSD, PS



4 millions of Emission lines
over 1400 deg2 in
$0.6<z<2.4$

Galactic Archeology

DM profiles
Assembly history



Milky way
Andromeda streams & halos
local Dwarfs

Galaxy Evolution

Galaxies & their environments
($0.7<z<7$)
IGM tomography (Ly-a forest at z>2)
End of Reionization (LAE z>5.5)

350,000 spectra over 15 deg2

PFS - SSP : Galactic Archaeology

- Assembly history of the Milky Way & M31

- Nature of Dark Matter and DM Structures in nearby galaxies

—> by measuring ~100,000 of stellar spectra
(radial velocity and chemical abundances)

- MW dwarf satellites
  - DM halo profile and [Fe/H] & [α/Fe] over largest areas
- M31 halo
  - DM subhalos, chemo-dynamics with spectroscopic [Fe/H] and [α/Fe]
- MW halo/streams/disks
  - Chemo-dynamics of the MW outer disks, halo dynamics, constraints on the Galactic potential

different chemical abundances
produced on different time scale

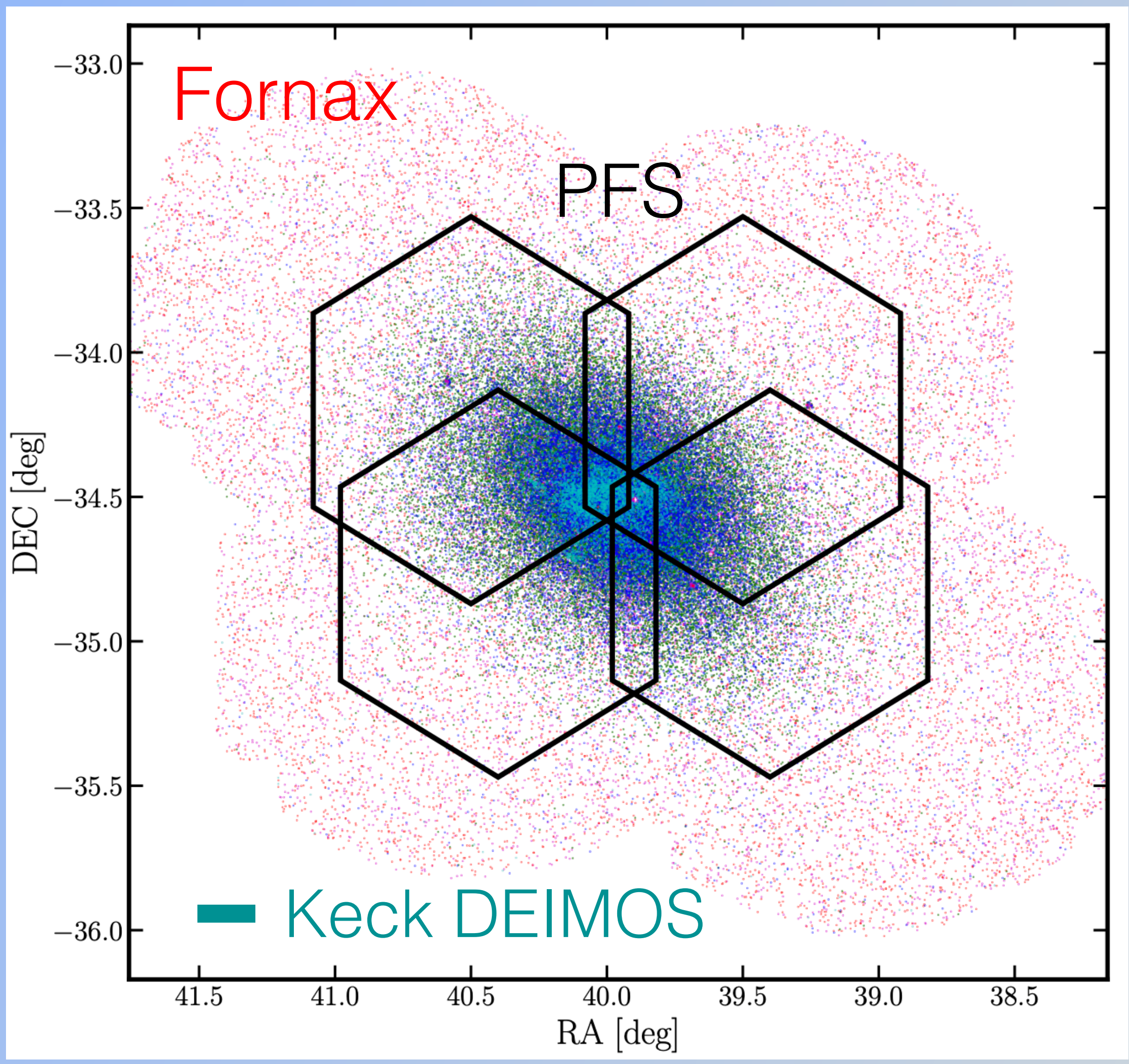
PFS - SSP : Galactic Archaeology

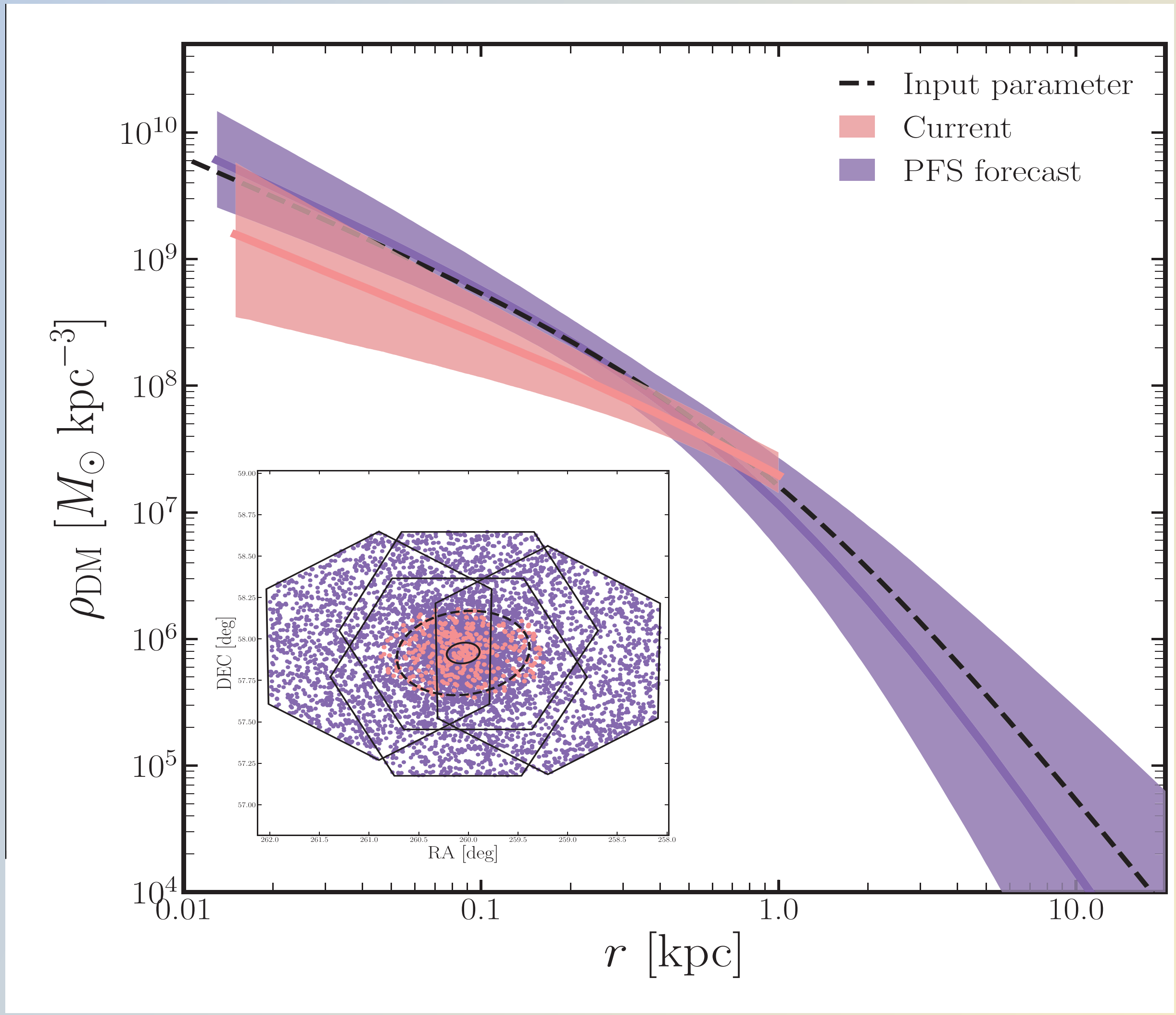
Test Dark Matter model with dwarf galaxy profiles

—> PFS uniquely designed to map dSphs up to tidal Radii

—> Fornax in 4 PFS pointings

—> robust DM profile: inner-outer regions

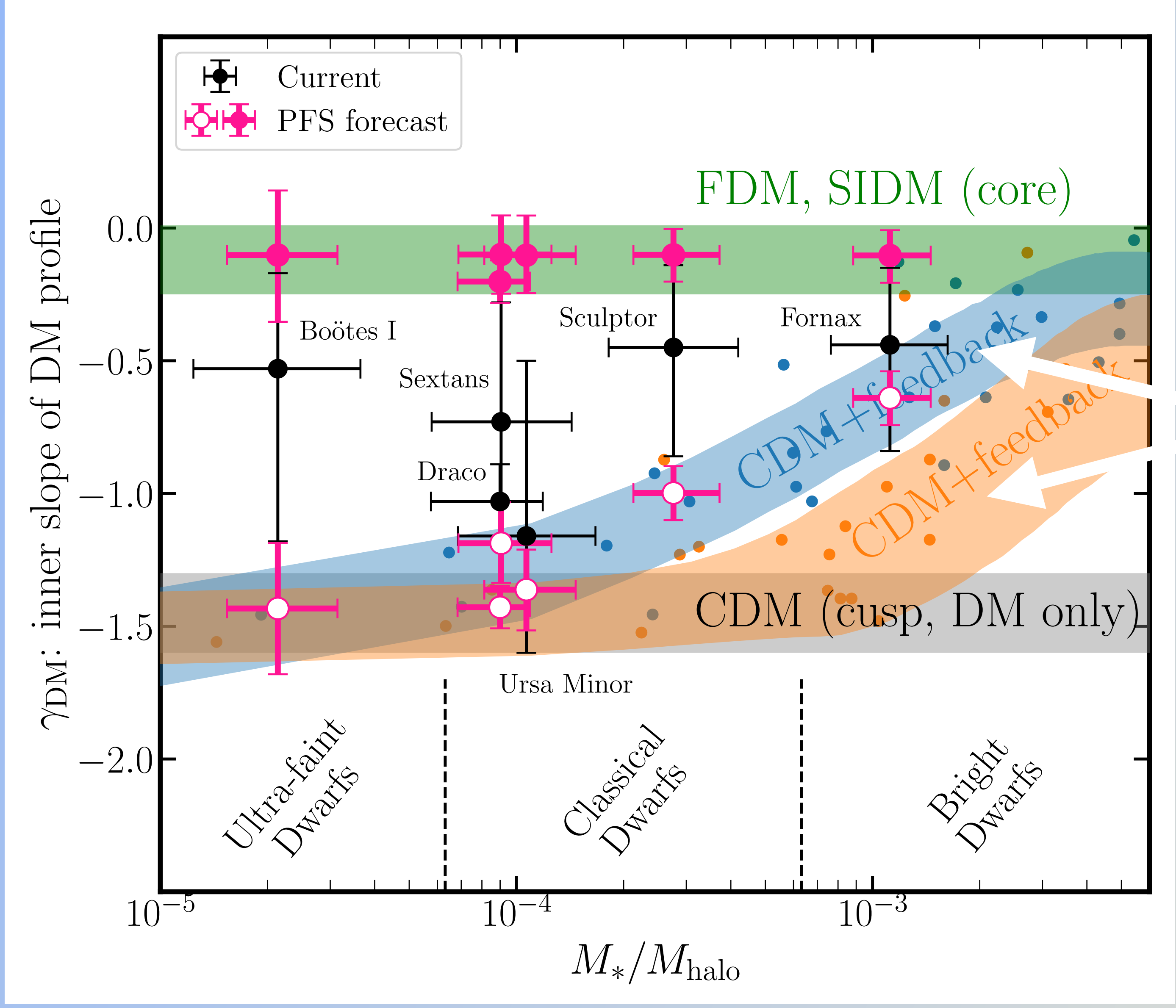




—> 1 PFS night = 60 Keck nights

Test Dark Matter model with dwarf galaxy profiles

—> impact of Baryonic feedback effects on CDM cusp or other DM ?



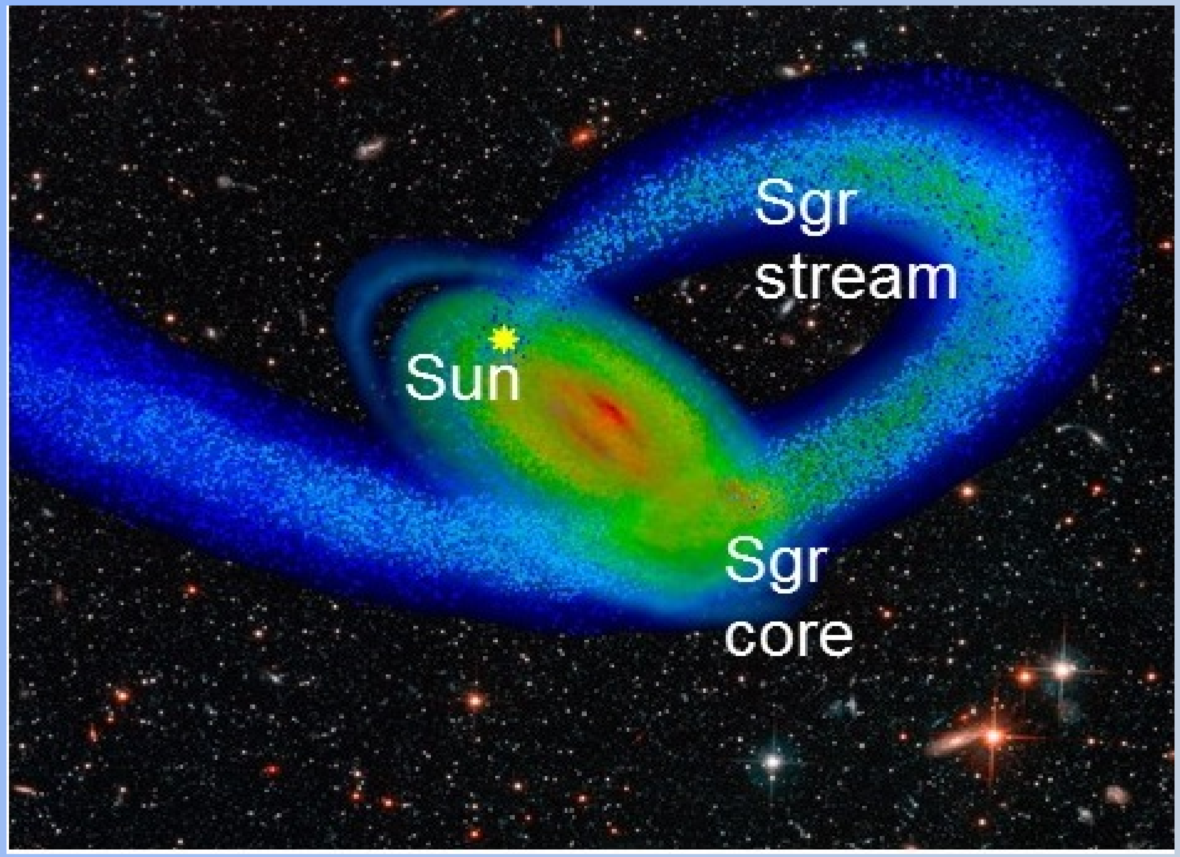
— Current measurements with large uncertainties

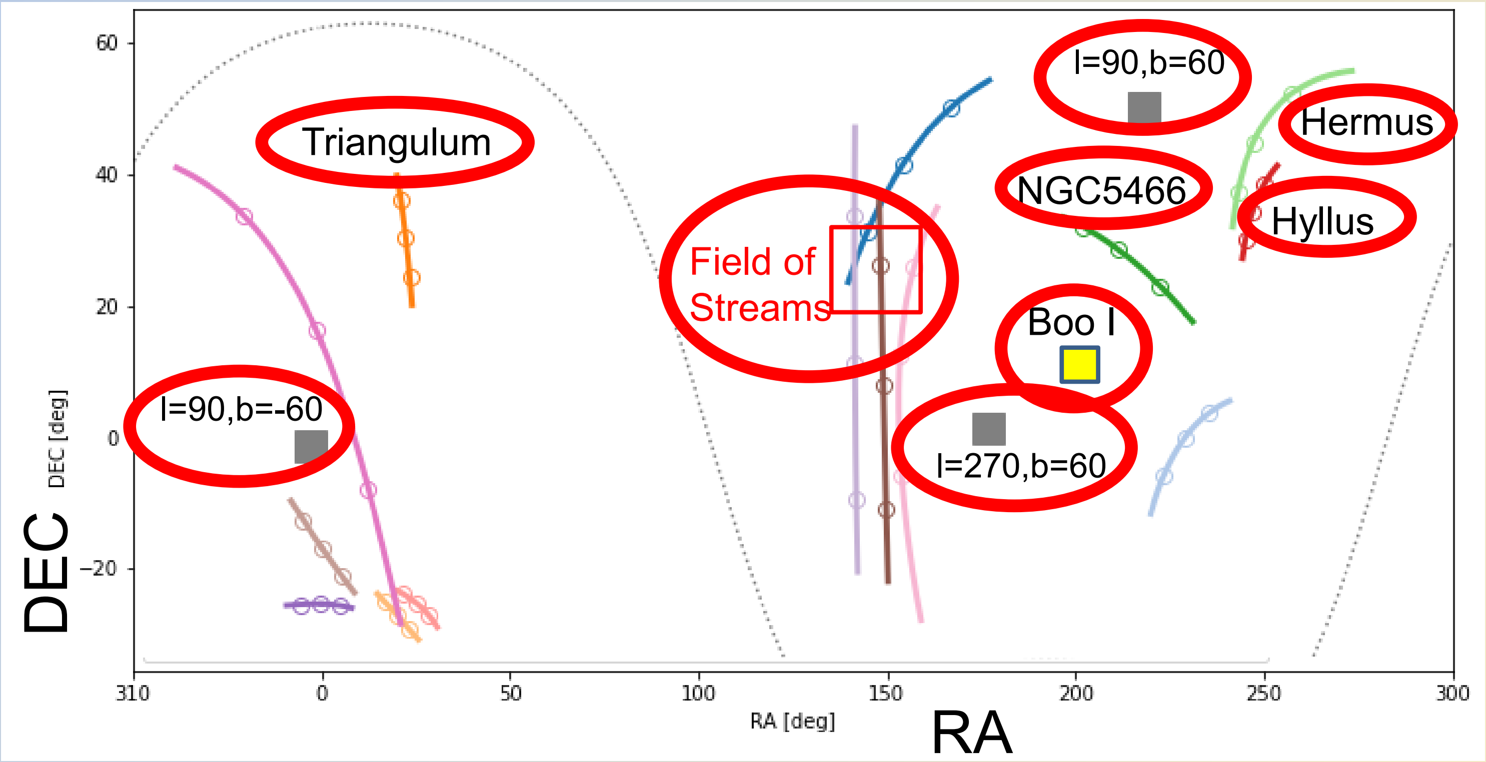
— Baryonic feedbacks from 2 hydro-dynamical simulations (NIHAO, FIRE-2)

— stellar metallicities + [α/Fe] ratios sensitive to high-mass IMF (SNe)

PFS - SSP : Galactic Archaeology

To infer the merging history of the Milky Way





—> response of the MW outer disk to the Sagittarius dwarf (Sag. plunged ~ 500 Myr ago)

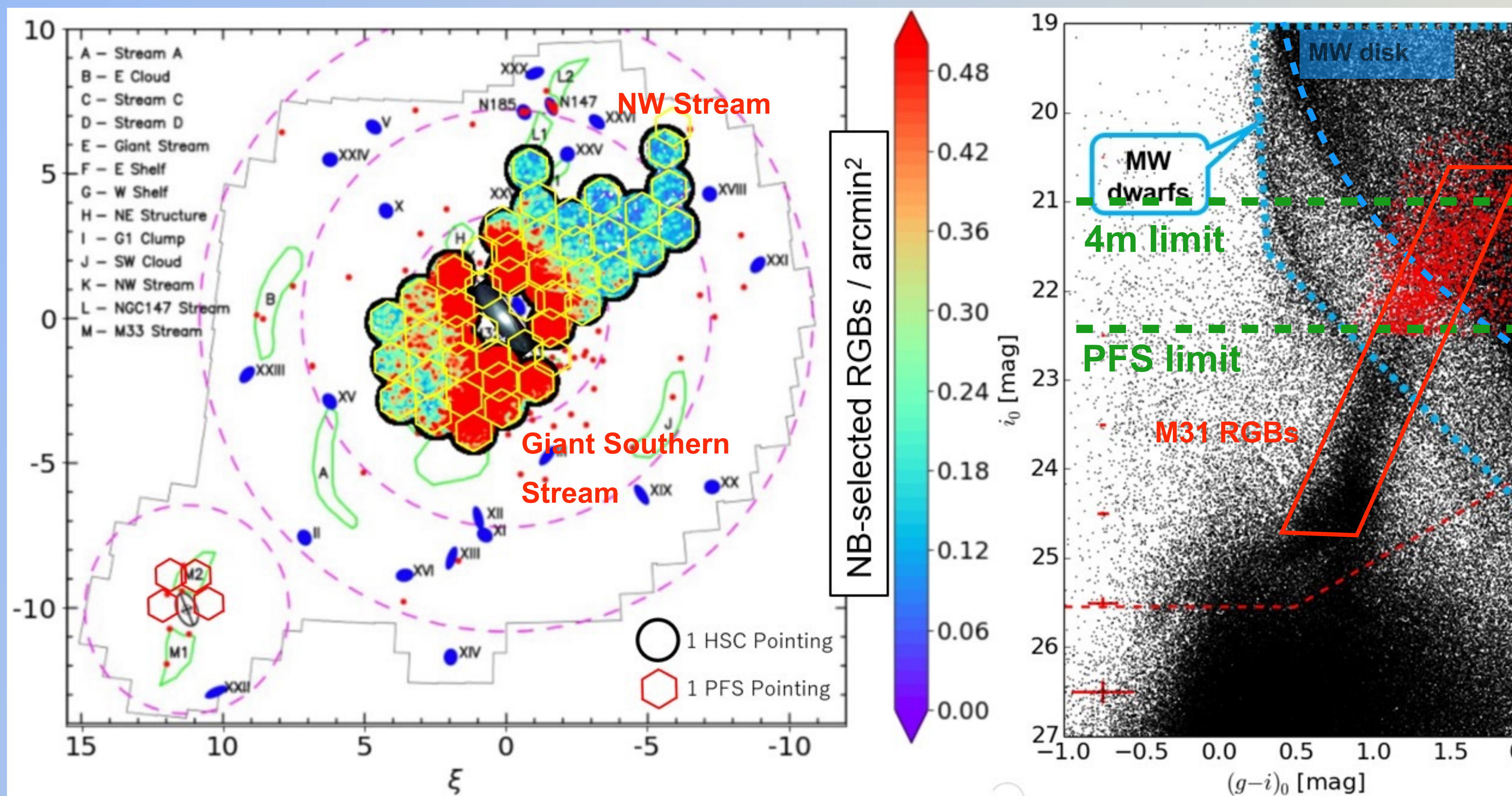
—> accretion events from halo streams

—> Halo streams to constraint the shape of galactic potential

PFS - SSP : Galactic Archaeology

To infer the merging history of the Andromeda

—> stochasticity is expected in the assembly histories of large galaxies (reflected in chemo-dynamics of stellar halos and disks): Different histories for M31 vs MW.



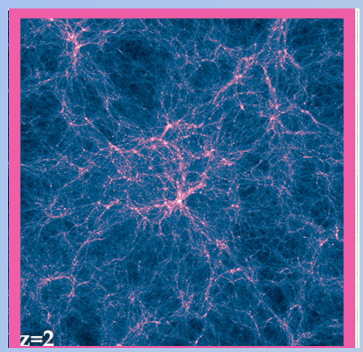
—> PFS will explore disk, halo (15000/22000) stars to detect bimodal chemical distrib. (sign of mergers) and North and South streams to characterize progenitors of the merging galaxies.

PFS: Subaru Strategic Program (360n)

three science Pillars

Cosmology

cosmo. parameters
neutrino mass
BAO, RSD, PS



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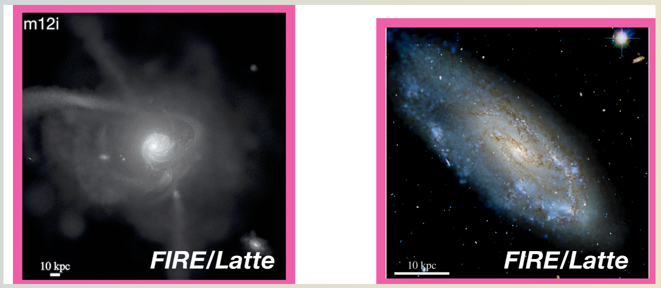
Galactic Archeology

DM profiles
Assembly history



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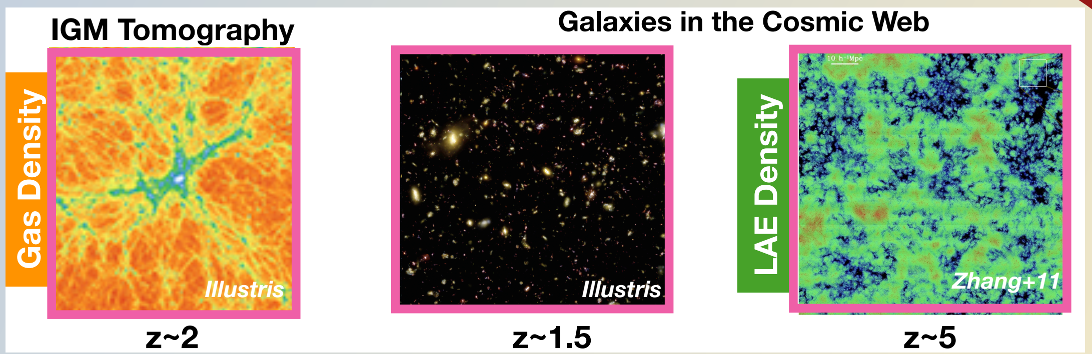
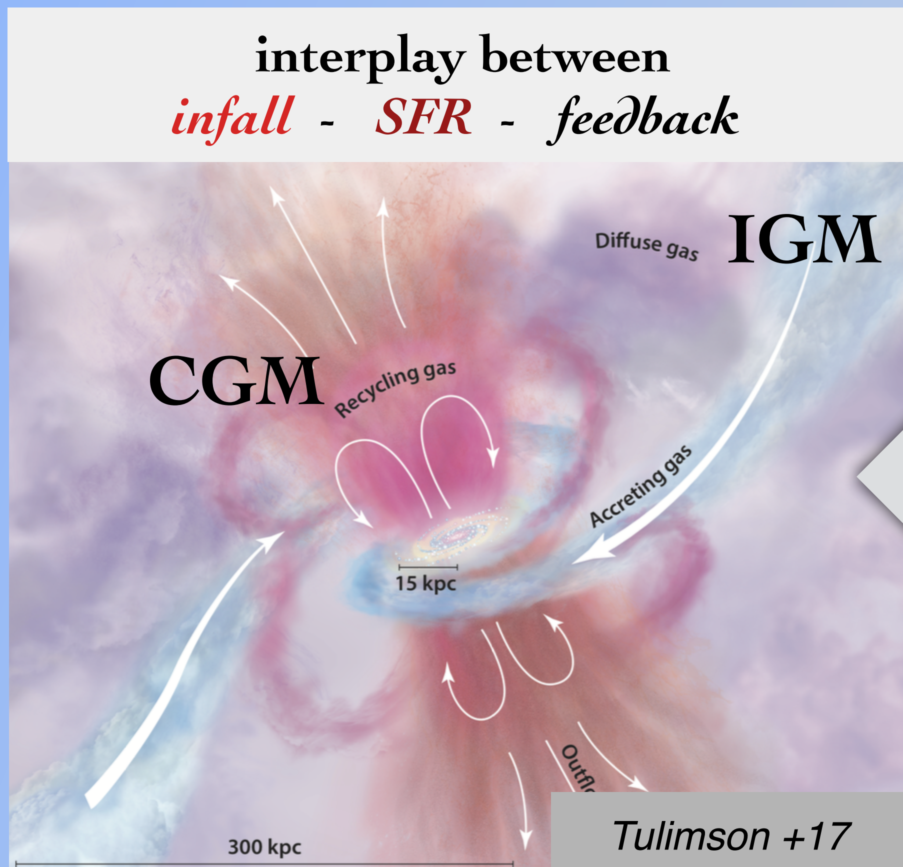


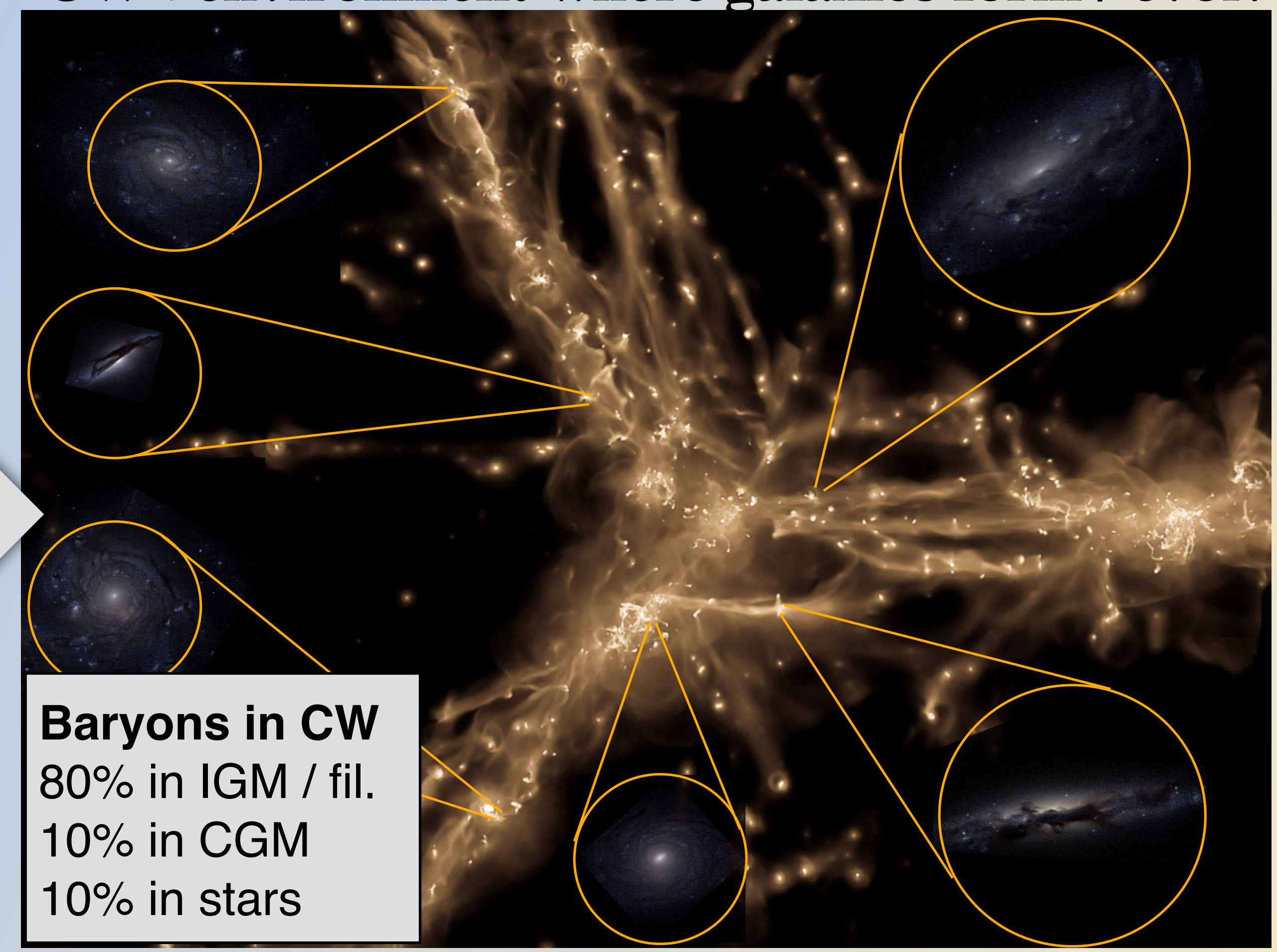
350,000 spectra over 15 deg2

PFS - SSP : Galaxy Evolution

Galaxies : complex systems



CW : environment where galaxies form / evolve



How does the interplay between dark and baryonic matter shape the evolution of galaxies?

How do gas and metals flow into and out of galaxies?

How do relations between galaxy properties arise and evolve?

PFS - SSP : Galaxy Evolution

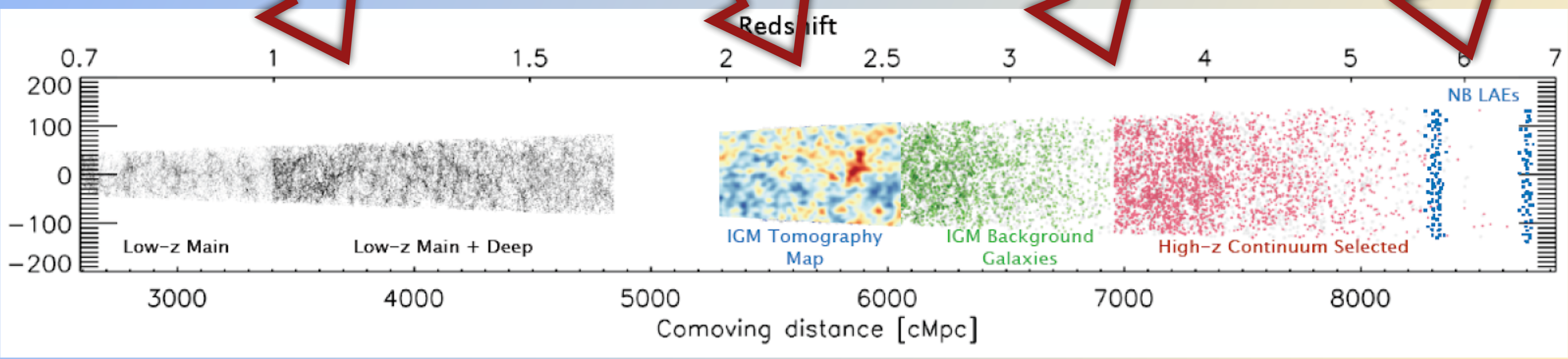
A comprehensive study of galaxy and IGM evolution over a wide range of z & environment

Main Gal Sample
J<22.8 + Photo-z
~275,000 z
Cosmic Web 0.7<z<2

IGM tomography
g<24.7 + Zph
~45,000 z
HI cosmic web 2<z<2.5

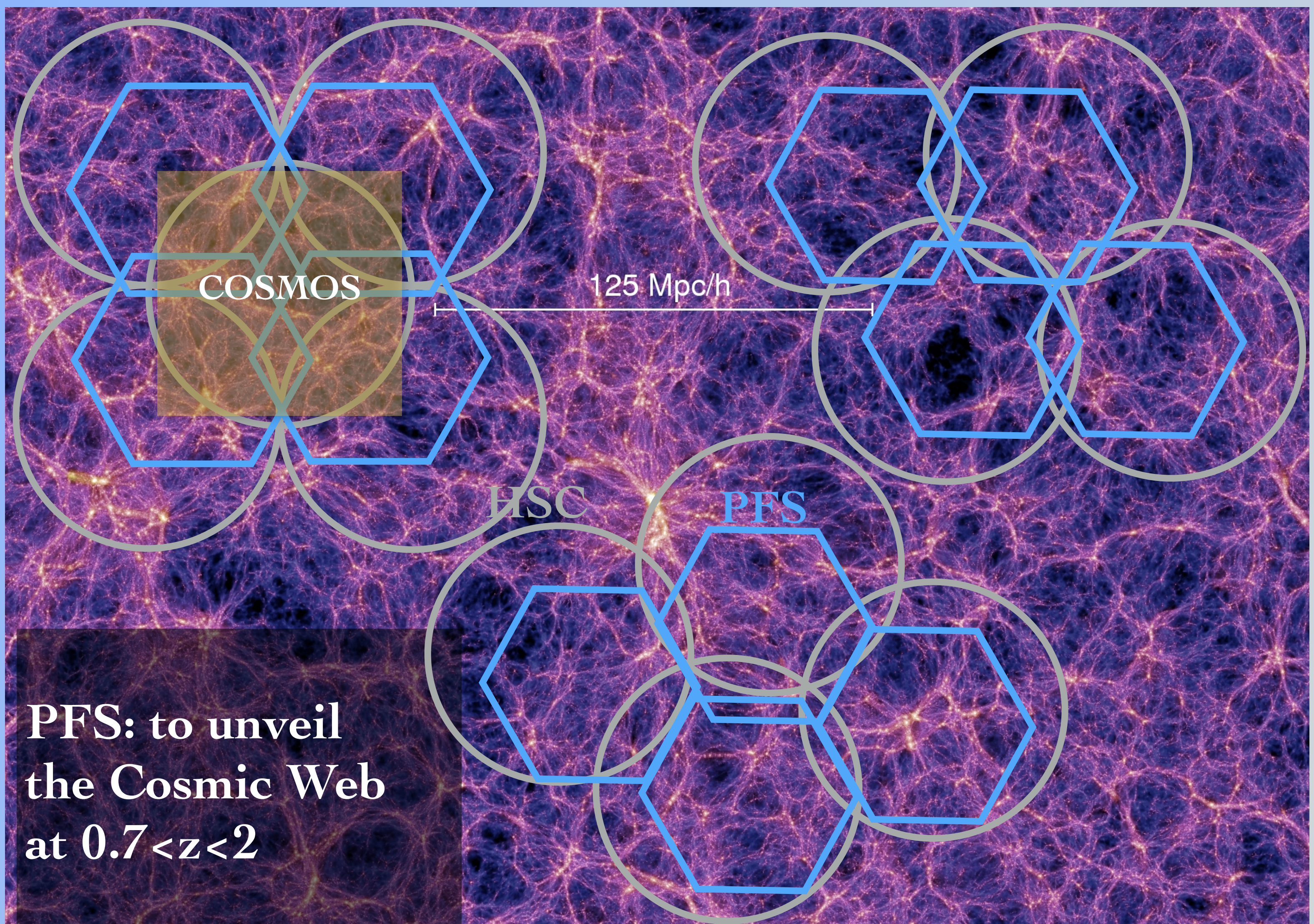
High-z cont. selected
Y<24.5 + Zph
~25,000 z
Proto clusters 2.5<z<5.5

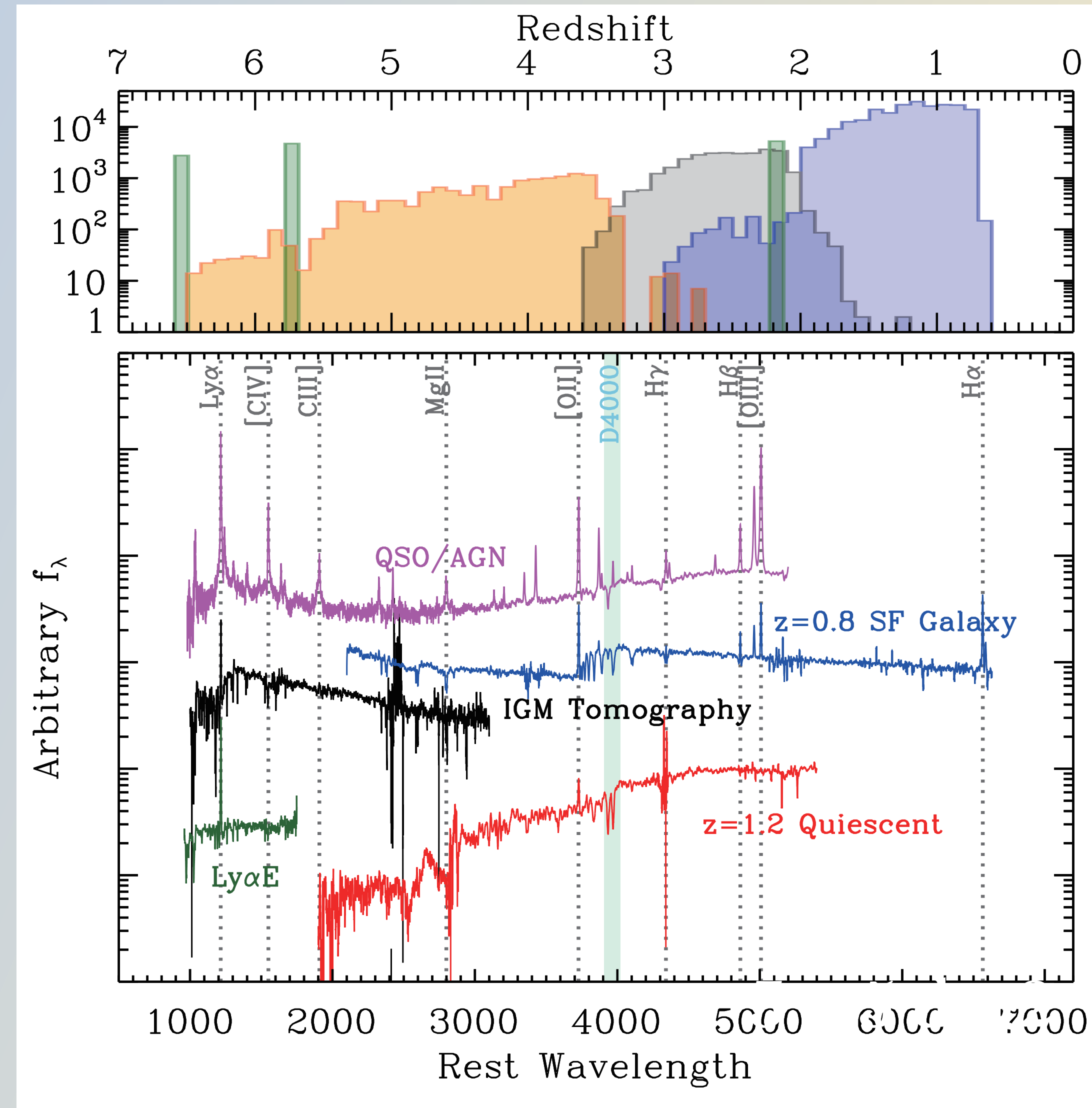
Lya Emitters
HSC NBs select.
~8,000 z
post reio. z>5.5



- **Multi-purposes targets ==> Complex selections**

PFS - SSP : Galaxy Evolution



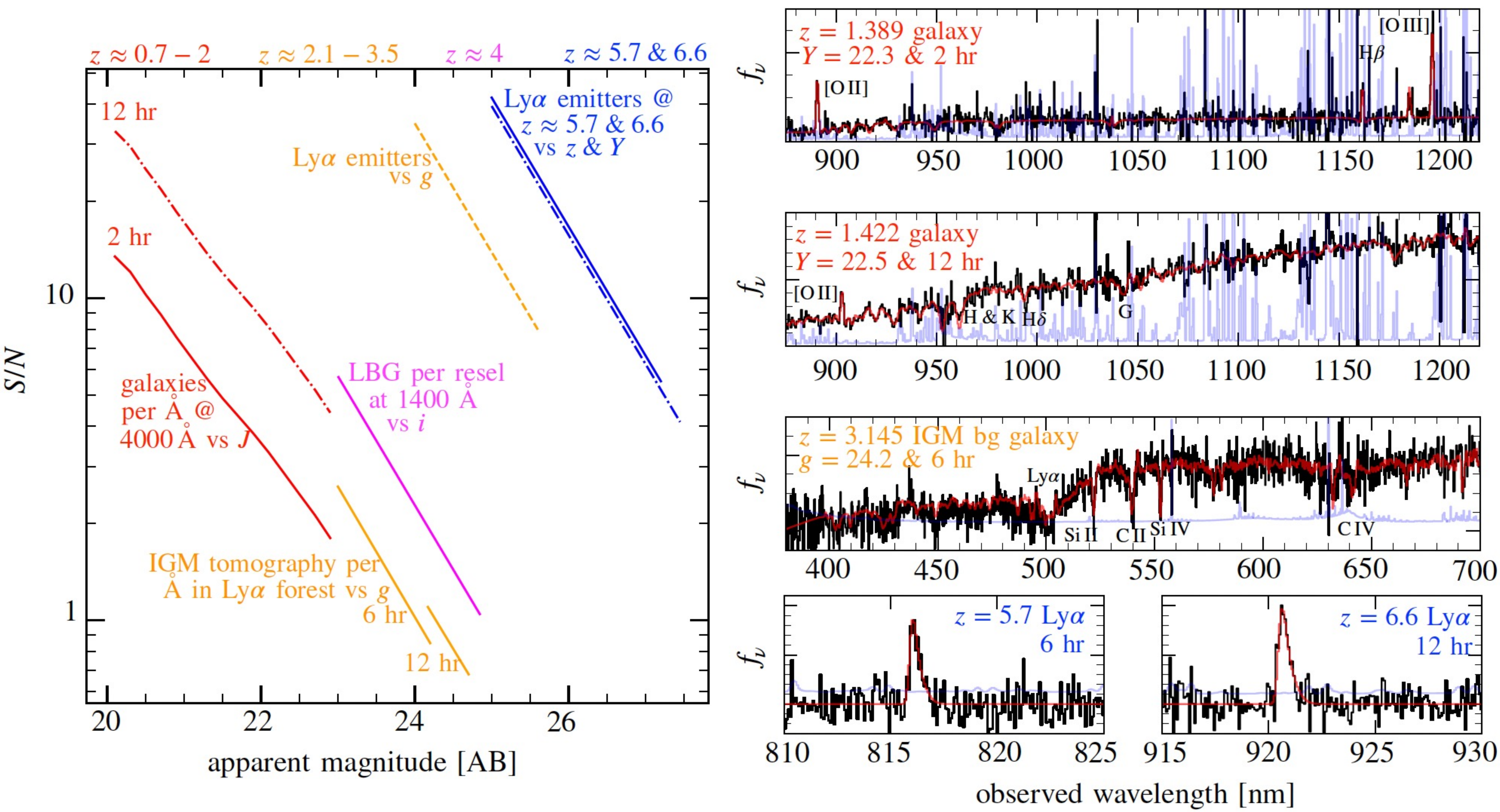


3 HSC-Deep regions covering 15 deg2

—> A large volume to trace the Cosmic Web

350,000 spectra of a wide variety of galaxy population

PFS - SSP : Galaxy Evolution



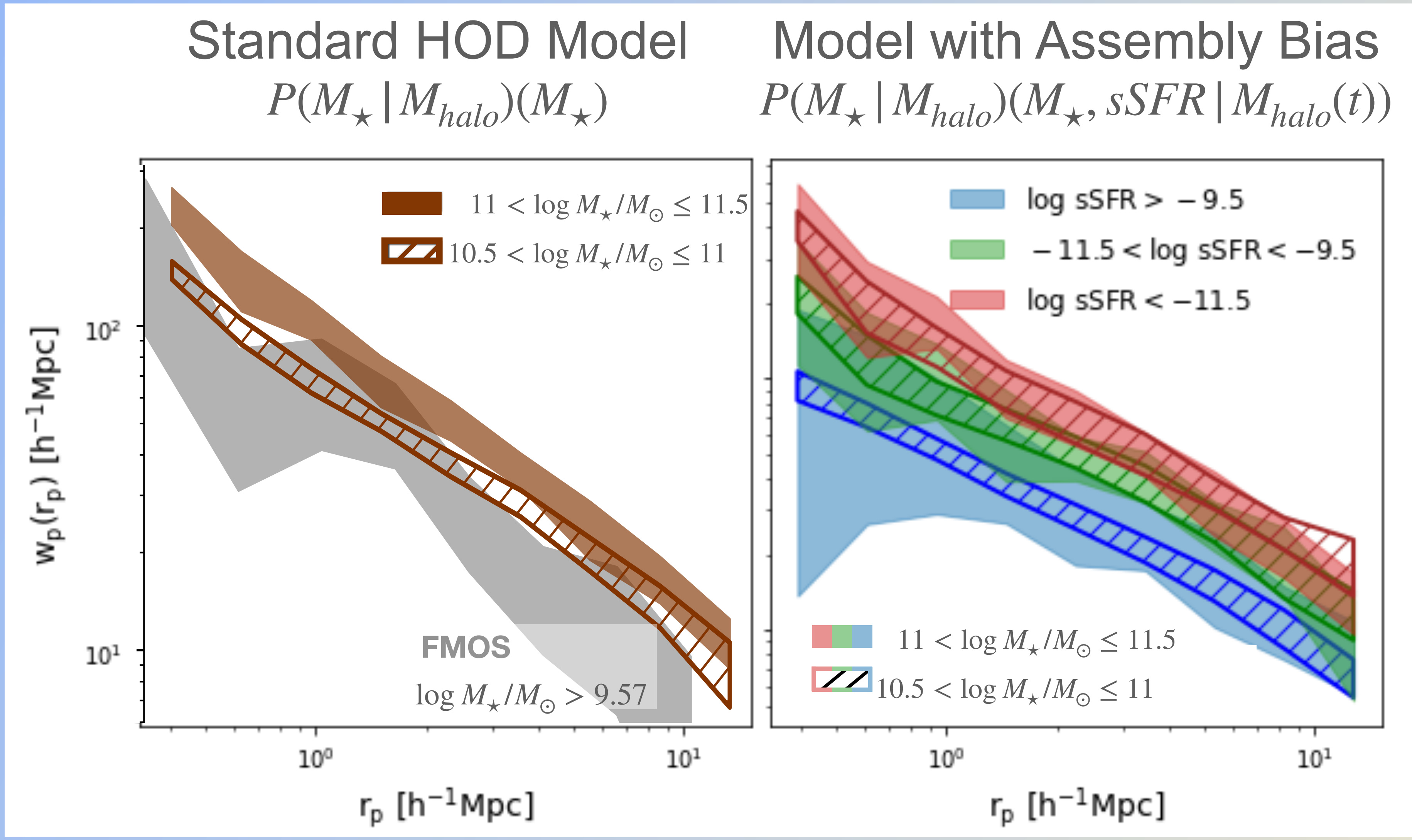
Different exposure time & SNR (Texp=2-12h) —> **detailed studies of massive gal:**

SFR, SFH, M*,met., quenching, feedback/infall

PFS - SSP : Galaxy Evolution

To constrain relationship between Galaxies and their DM Halos envt.

—> via galaxy clustering 0.7<z<5

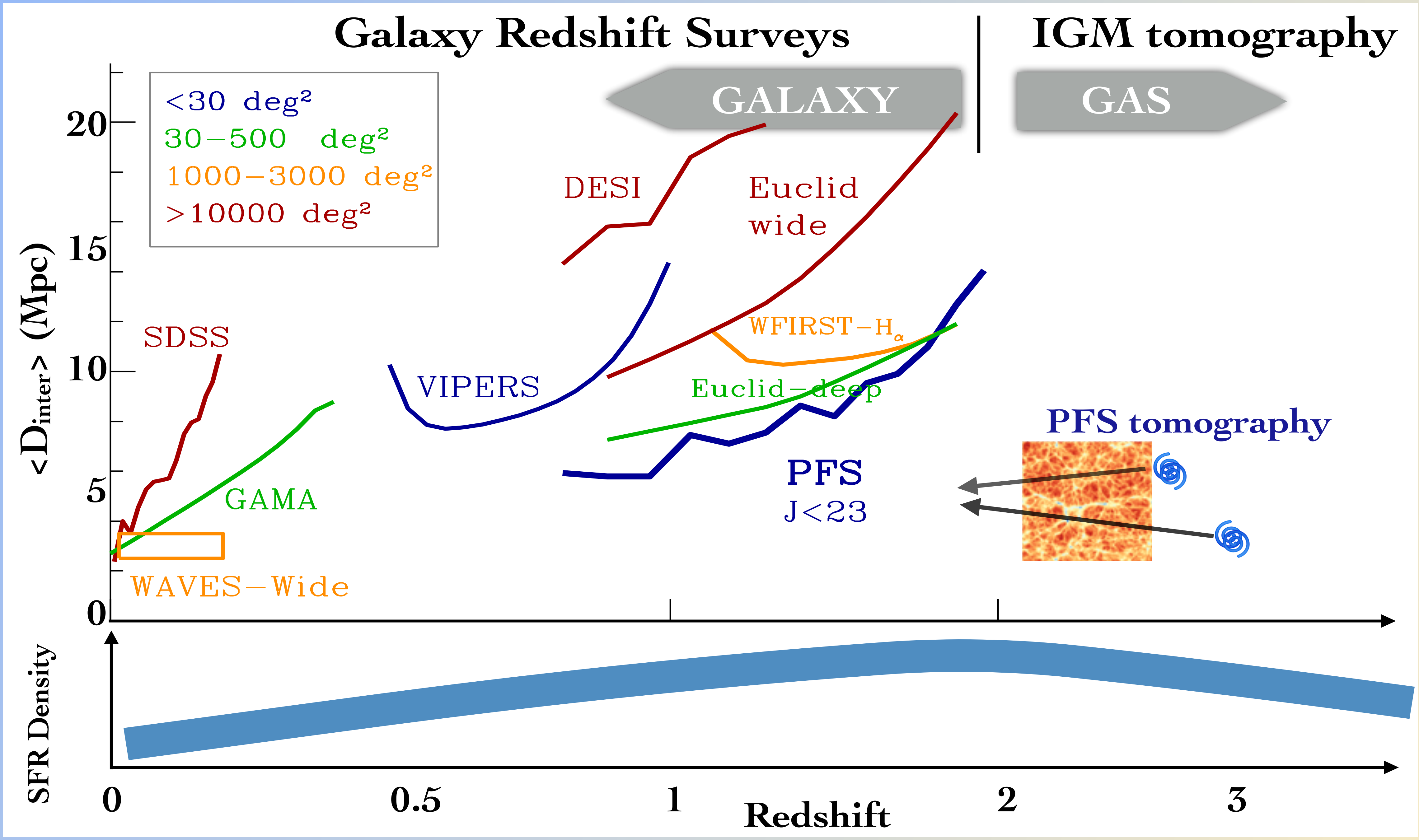


—> SHMR with additional galaxy properties

PFS - SSP : Galaxy Evolution

To constrain relationship between Galaxies and their Large Scale envt.

New generation of spectroscopic surveys to map the cosmic web



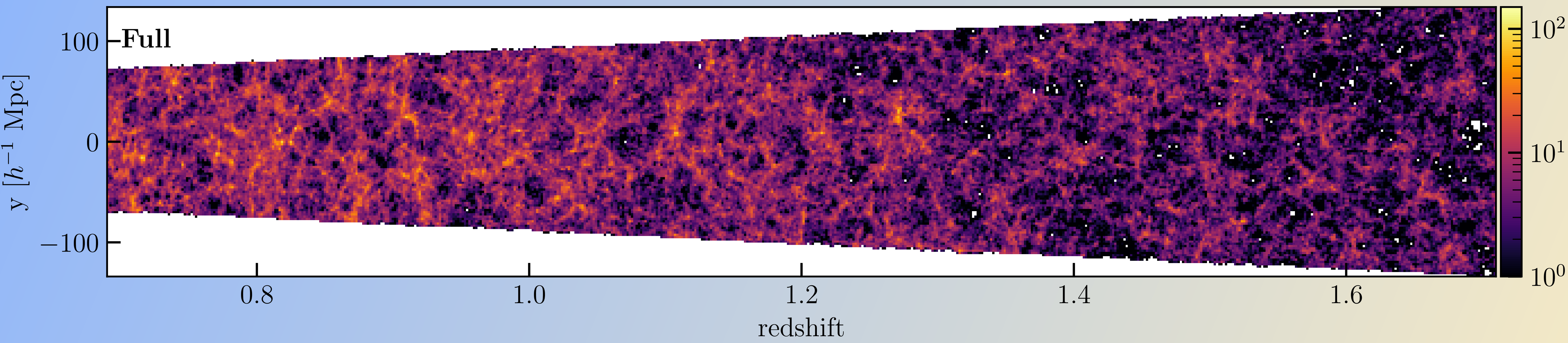
—> exploring the influence of CW on galaxy properties near the peak of SFRD

PFS - SSP : Galaxy Evolution

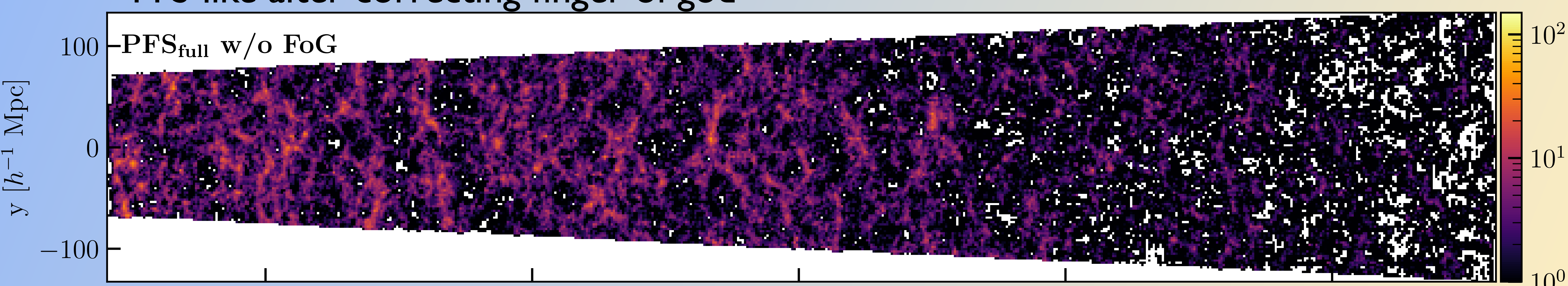
The Cosmic Web reconstruction

Kraljic, in prep

Full simulation



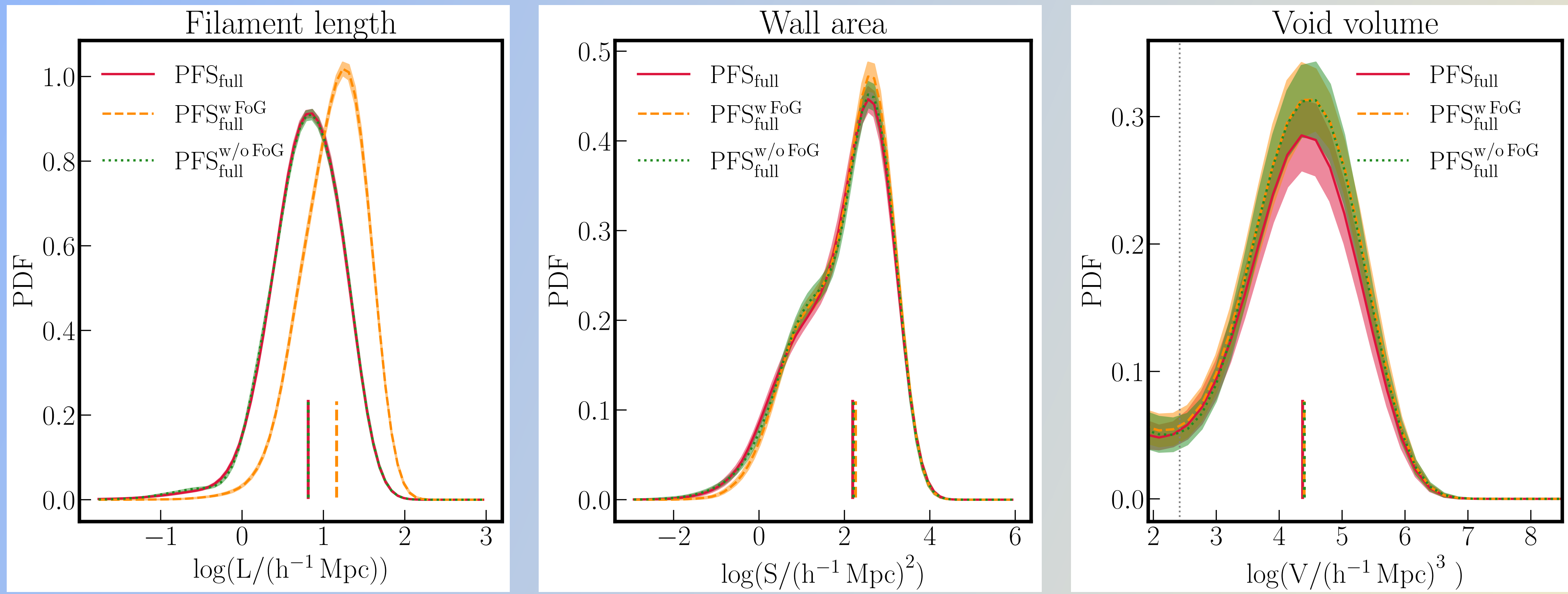
PFS-like after correcting finger of god



PFS - SSP : Galaxy Evolution

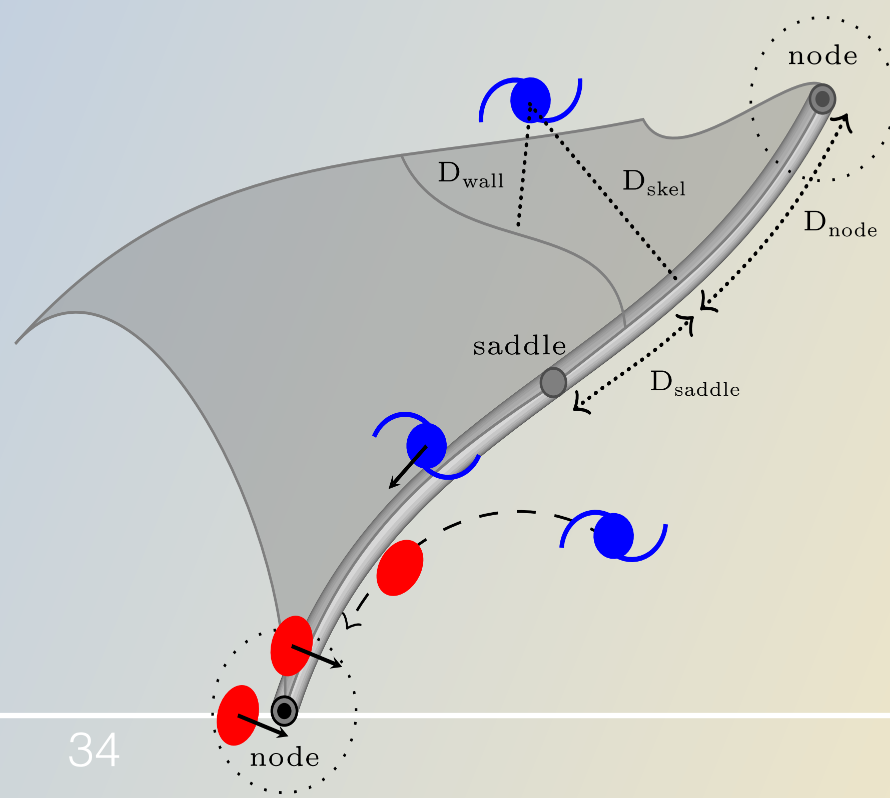
The Cosmic Web reconstruction

Kraljic, in prep

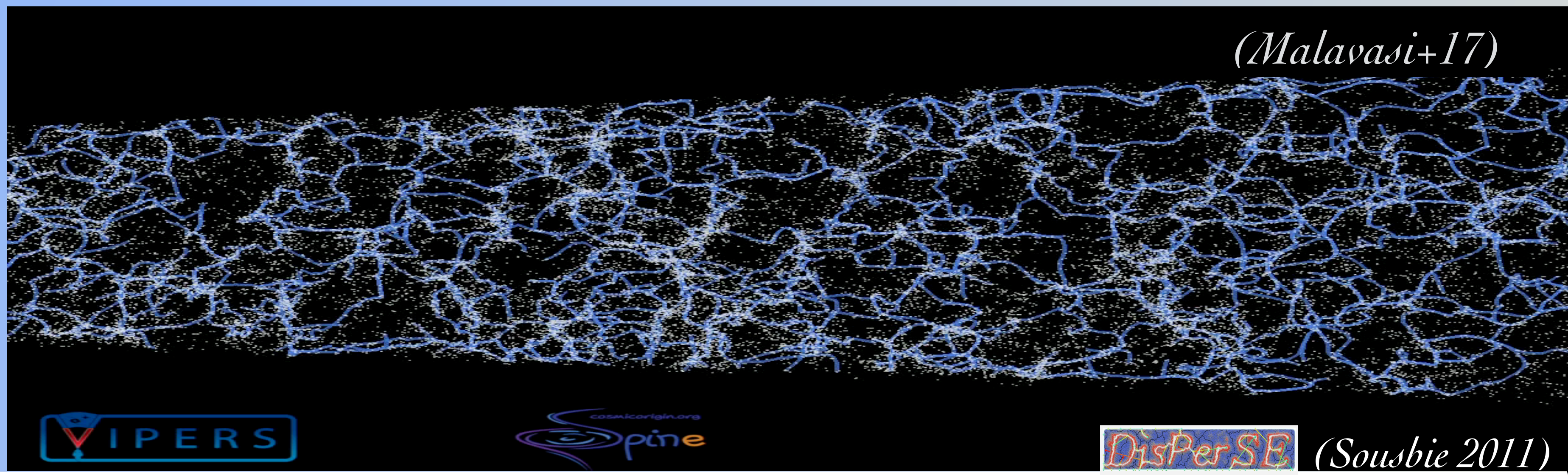


—> Importance to correct for FoG

—> a natural framework
to revisit galaxy evolution

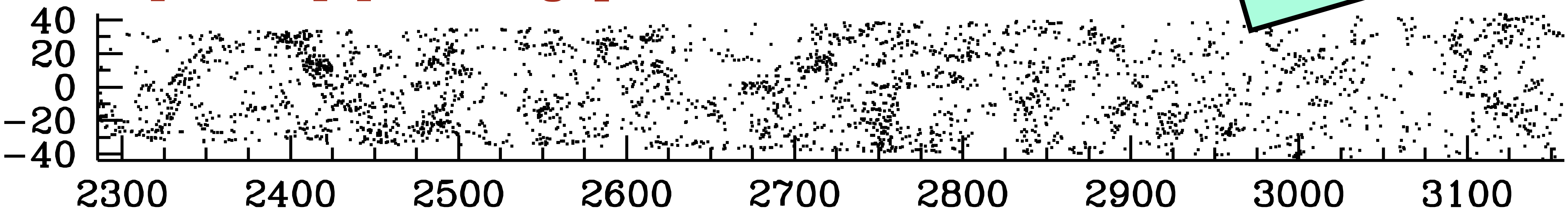


PFS - SSP : Galaxy Evolution

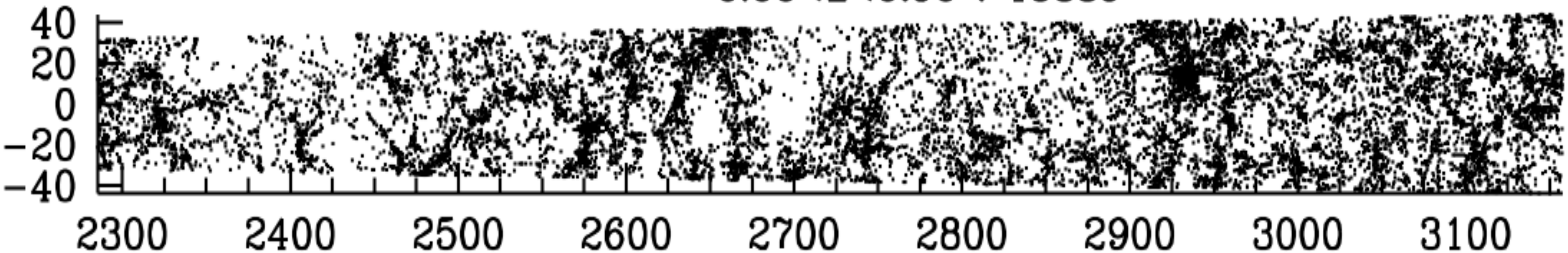


VIPERS best LSS at high z so far

VIPERS [I<22.5] [1.6x1deg^2]



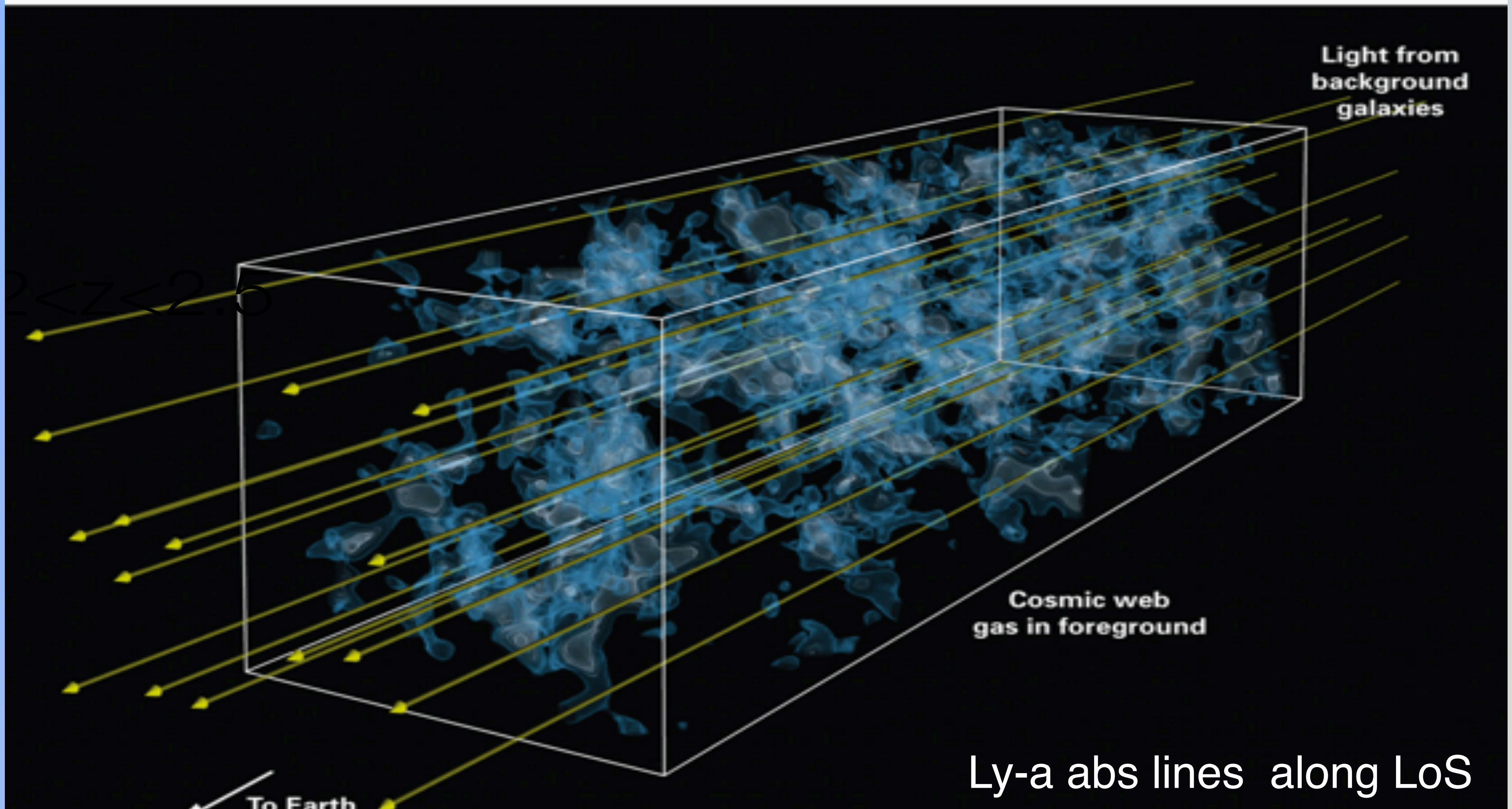
MOCK PFS

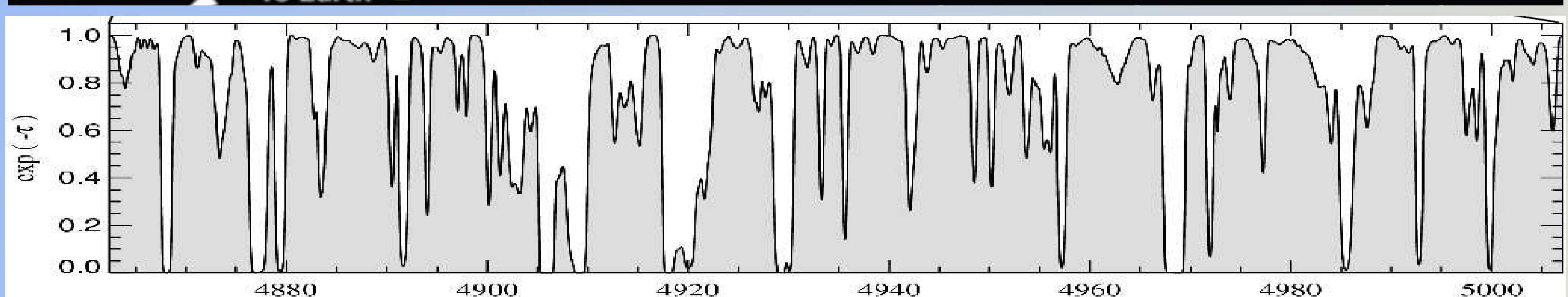


higher sampling and also spectral resolution

PFS - SSP : Galaxy Evolution

To reveal the HI gas Cosmic Web with IGM tomography





Residual neutral hydrogen in the filamentary IGM causes absorption lines in the spectra of Background sources

Transmitted flux,

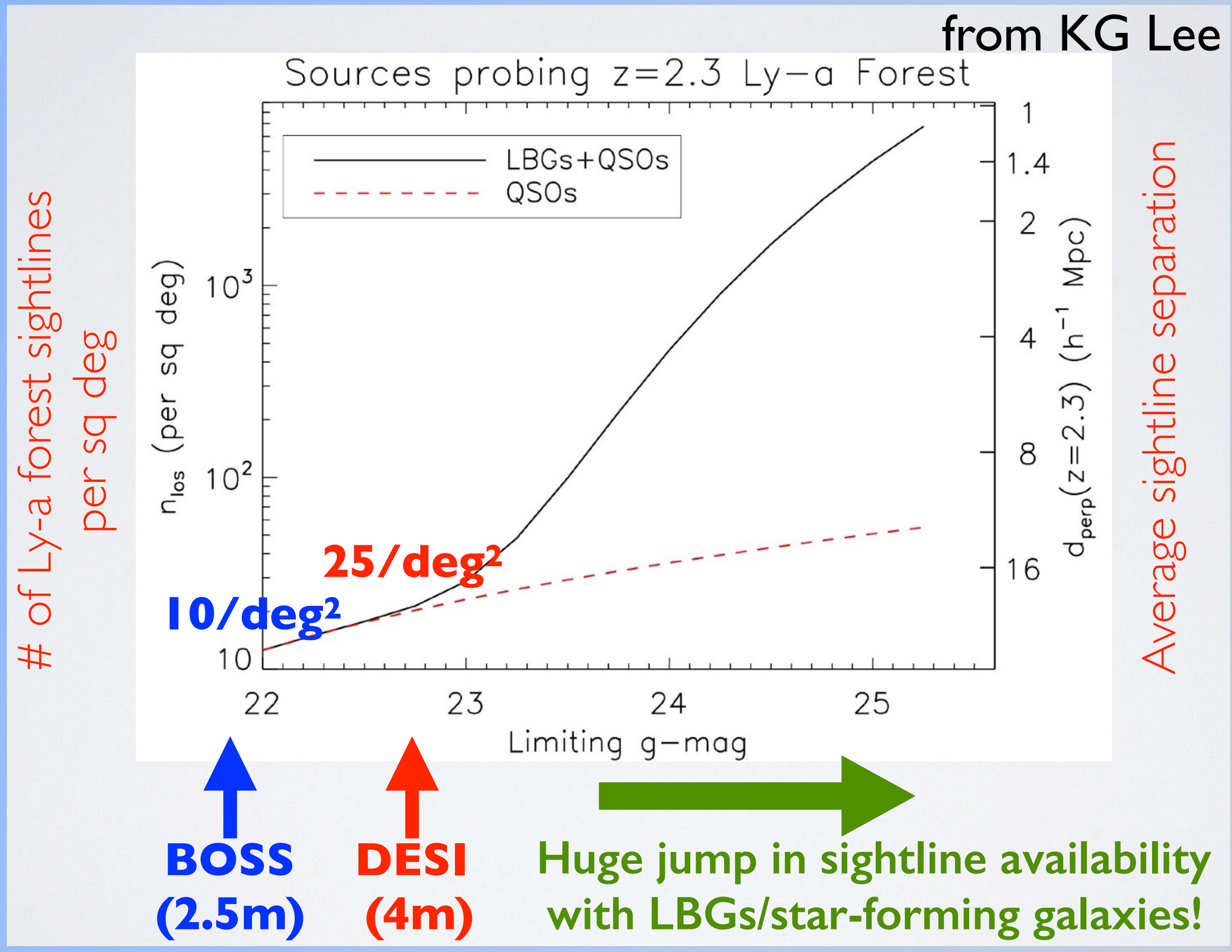
$F = F_0 \exp(-\tau)$ with

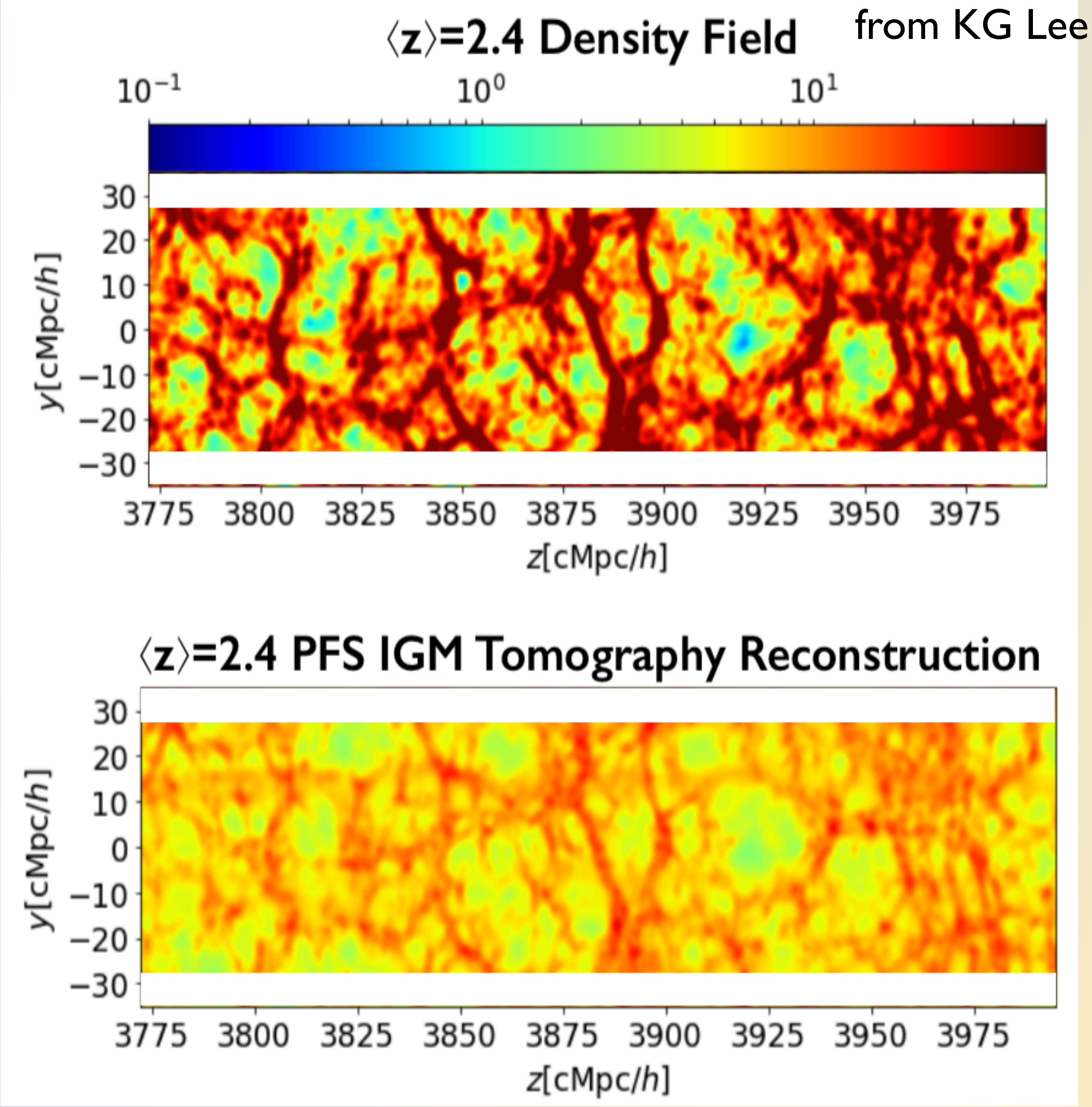
$$\tau_\alpha(x) \propto n_{HI}(x)$$

— > absorptions trace Large Scale Structure

PFS - SSP : Galaxy Evolution

HI CW reconstruction depends on number of background sources





PFS will use QSO/Gal at 2.1<z<3.5 : **3000 spectra/deg2**

—> Reveal the HI CW at 2<z<2.5 with res. ~4cMpc

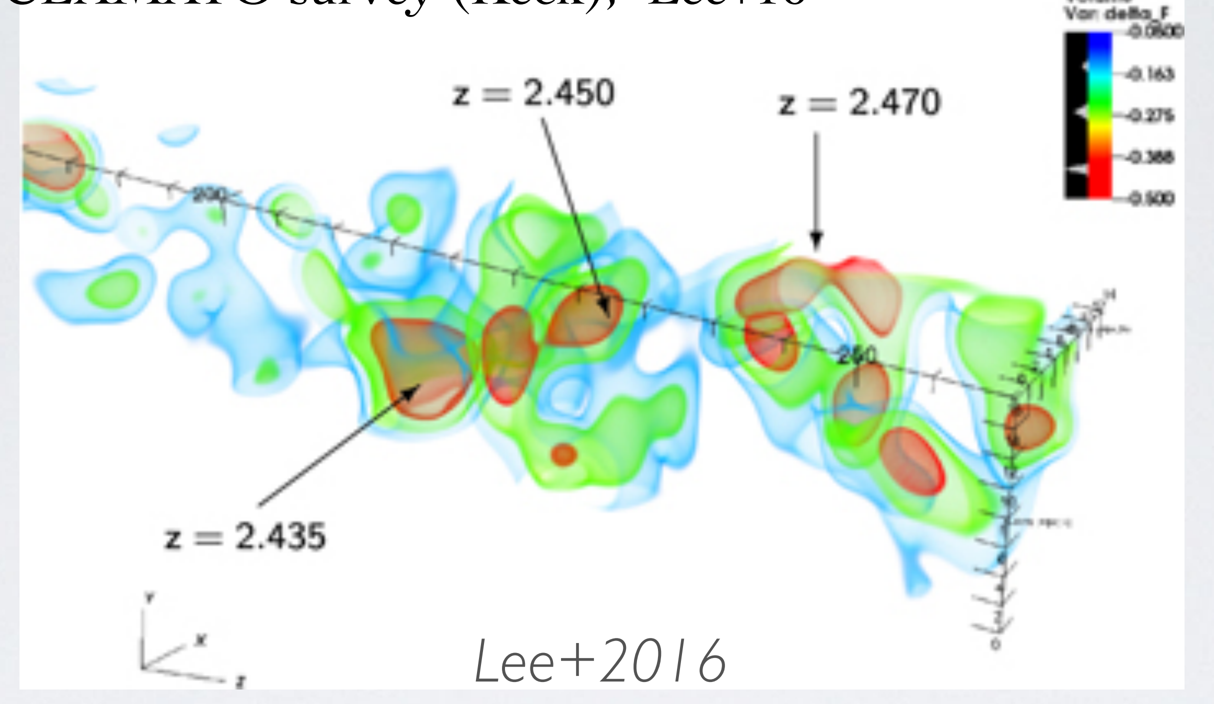
—> First connection between Galaxies and IGM (galaxy gas reservoir)

PFS - SSP : Galaxy Evolution

To reveal the HI gas Cosmic Web with IGM tomography

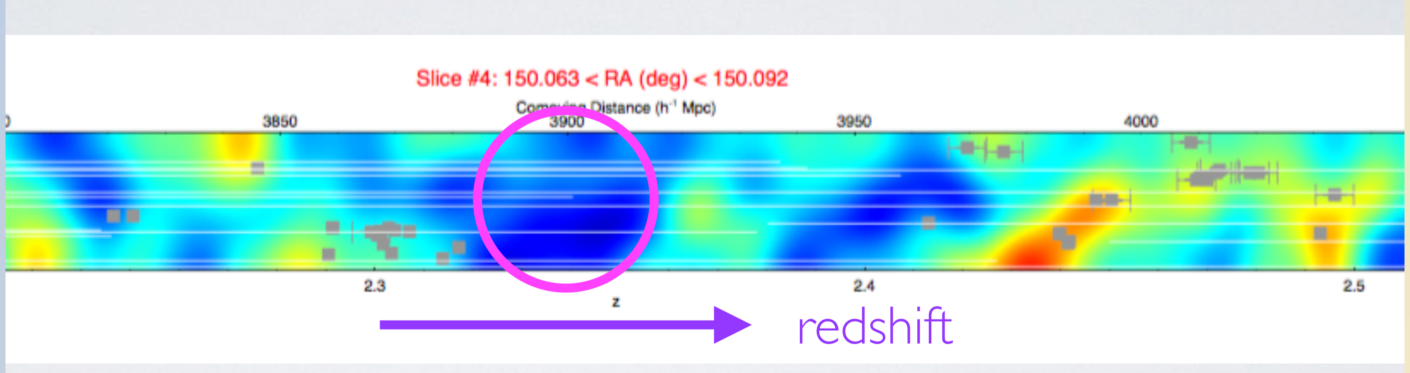
—> Protoclusters with HI over-densities

CLAMATO survey (Keck), Lee+16



—> Cosmic voids with HI under-densities

CLAMATO, Krolewski+18



—> IGM tomography : a new window for high redshift CW

—> First connection between Galaxies and IGM (galaxy gas reservoir)

—> CGM analyses (infall/feedback)

PFS : High Multiplex Spectrograph Landscape

	PFS	MOONS	DESI	WEAVE	4MOST
Telescope	Subaru (8.2m)	VLT (8.2m)	Mayall (4m)	WHT(4.2m)	VISTA(4m)
FoV	1.2 sq. deg.	0.14 sq. deg.	7 sq. deg.	2 sq. deg.	4 sq. deg.
Wavelength	0.38-1.26	0.64-1.8	0.36-0.98	0.4-1.0	0.4-0.885
Multiplex	2394 1800/deg^2	1000/2 5100/deg^2	5000 700/deg^2	800 400/deg^2	800 (low-R) 800 (high-R)
Resolution	R~2,000 (blue) R~3,000 (red) R~4,000 (NIR)	R~4,000-6,600 R~9,000 R~20,000	R~3,000-4,800	R~5,000 R~20,000	R~5,000 R~20,000
Fiber diameter	1.1”	1.05”	1.45”	1.3”	1.4”
Sci. op. start	**2024**	**2024**	**2020**	**2023**	**2024?**
Survey GEv	**130 nights**	**190nights**	500 nights	5yrs+5yrs	???
Science	**Cosmology** **GA** **Galaxy Evol.**	**Galaxy Evol.** GA	**Cosmology** GA Bright galaxies	**GA** Galaxy Evol.	Cosmology GA Galaxy Evol.

PFS and its SSP will revolutionize our view of the high redshift universe as SDSS did 20 yrs ago

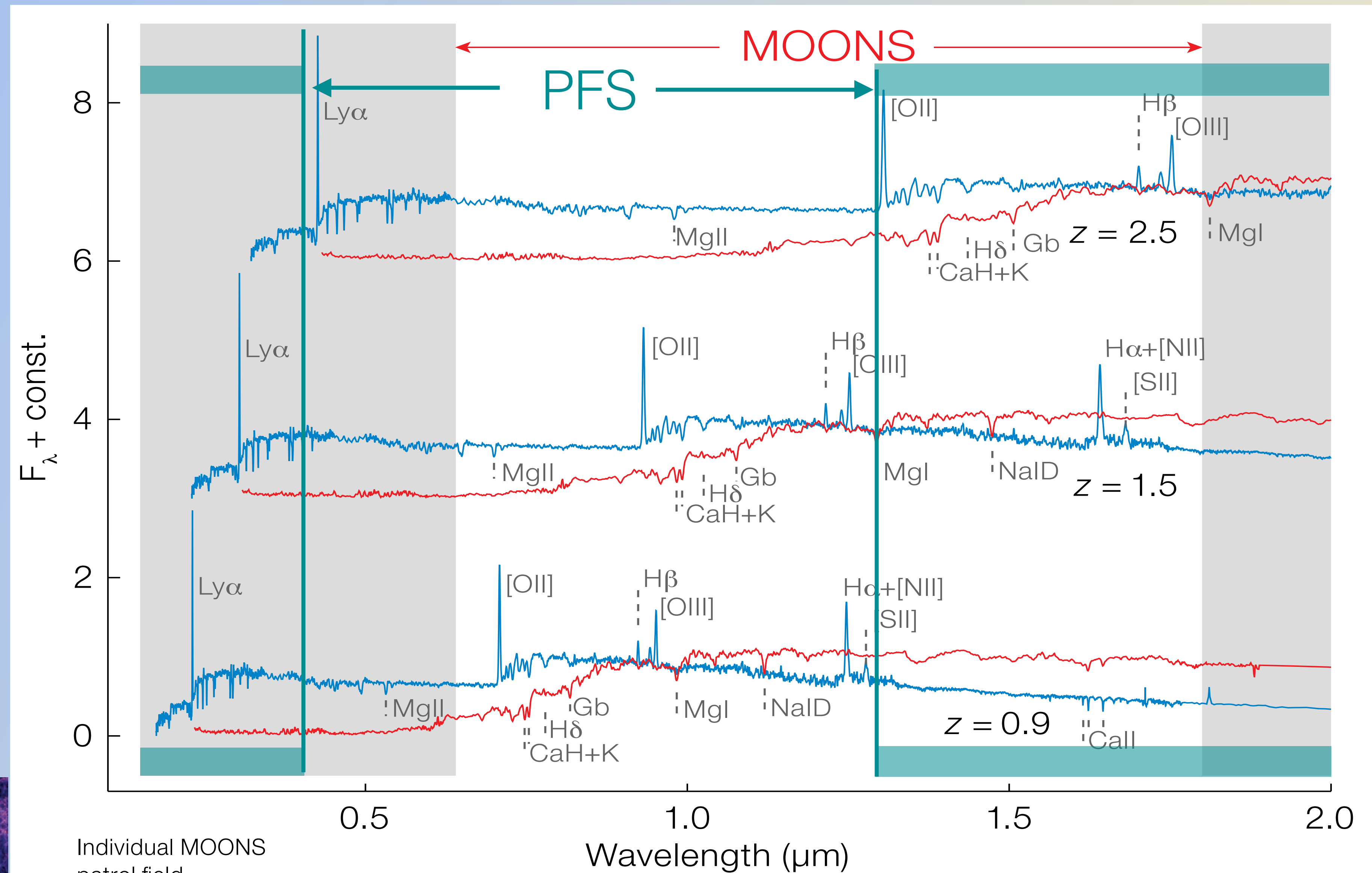
Mahalo !

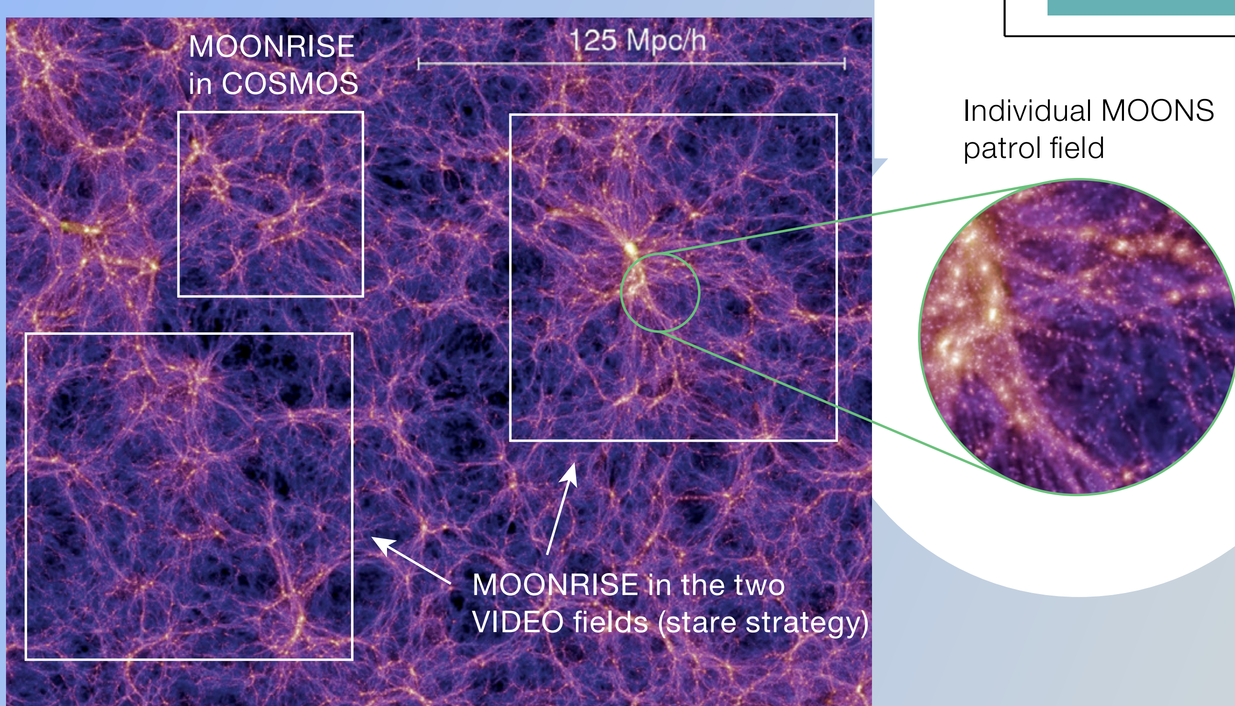
PFS : High Multiplex Spectrograph Landscape

PFS vs MOONS

MOONRISE

- 500,000 gal 0.9<z<2.6
- MOONS unique at high-z with line diagnostics
- BUT small fov for CW





—> 2 fields in common
MOONS/PFS can be complementary