Dark energy interests in Japan: Subaru SuMIRe HSC/PFS project

(soo-mee-ray)

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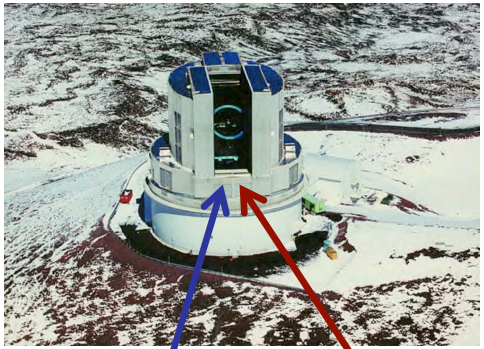
東京大学 THE UNIVERSITY OF TOKYO
wpi

@WFIRS meeting, Pasadena, Nov 2014

Subaru Telescope

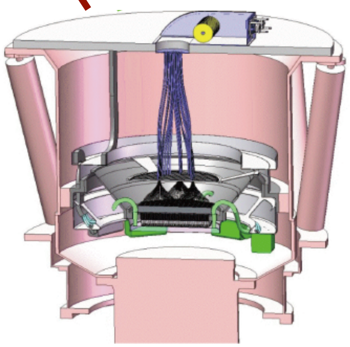
SuMIRe = Subaru Measurement of Images and Redshifts

H. Murayama



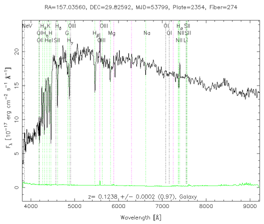
- IPMU director Hitoshi Murayama (PI) funded by the Cabinet in Mar 2009, as one of the stimulus package programs
- Build *wide-field* camera (Hyper SuprimeCam) and *wide-field* multi-object spectrograph (Prime Focus Spectrograph) for the Subaru Telescope (8.2m)
- Explore the fate of our Universe: dark matter, dark energy
- Keep the Subaru Telescope a world-leading telescope in the TMT era
- Precise images of ~1B galaxies
- Measure distances of ~4M galaxies

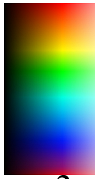
Subaru (NAOJ)



PFS

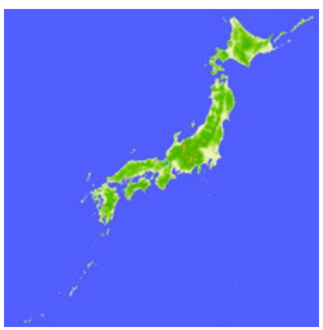
HSC



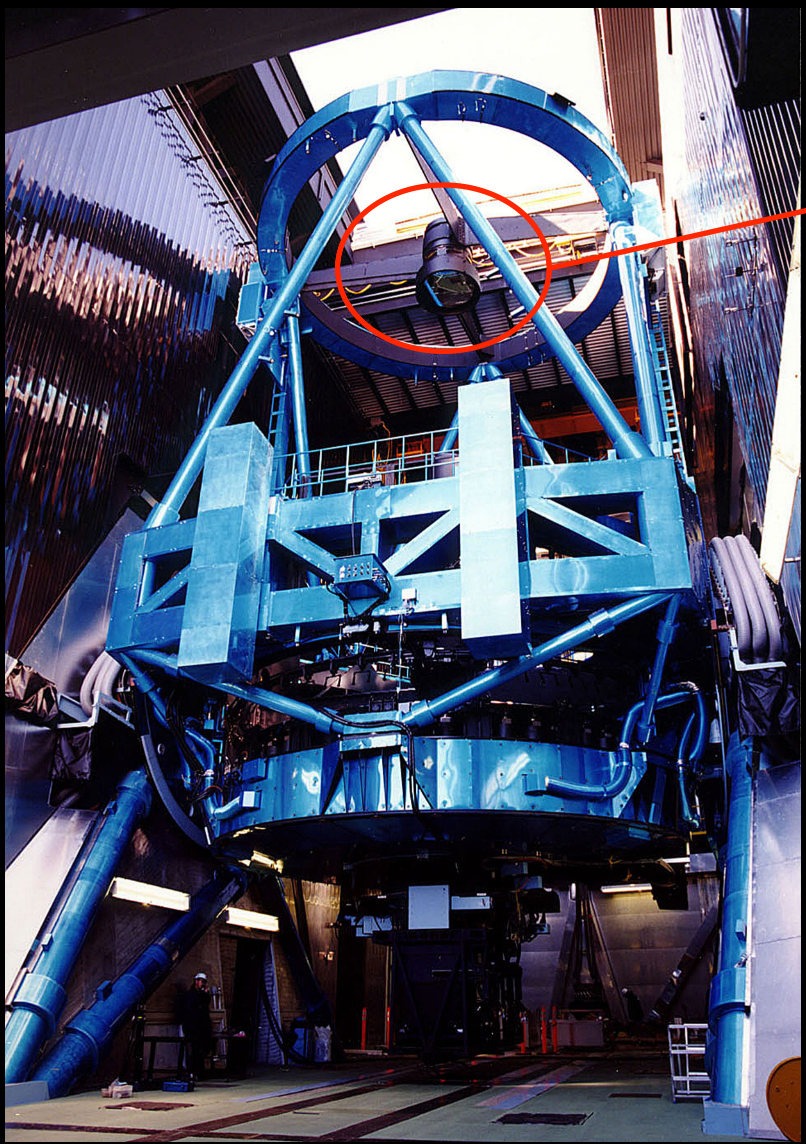


HSC Collaboration

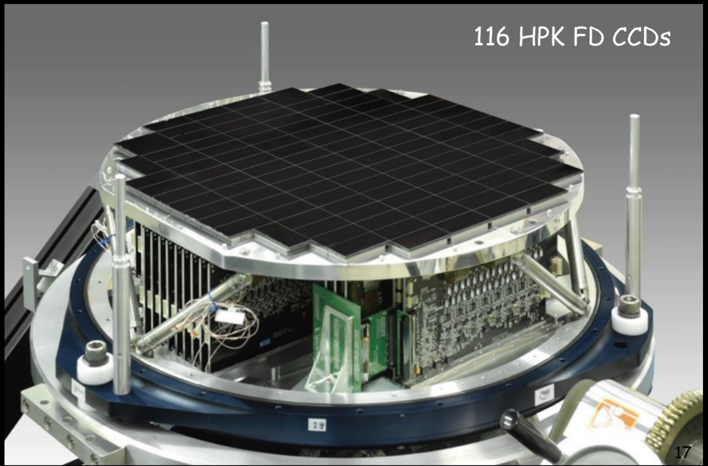
International collaboration: Japan, Princeton, Taiwan



Hyper Suprime-Cam



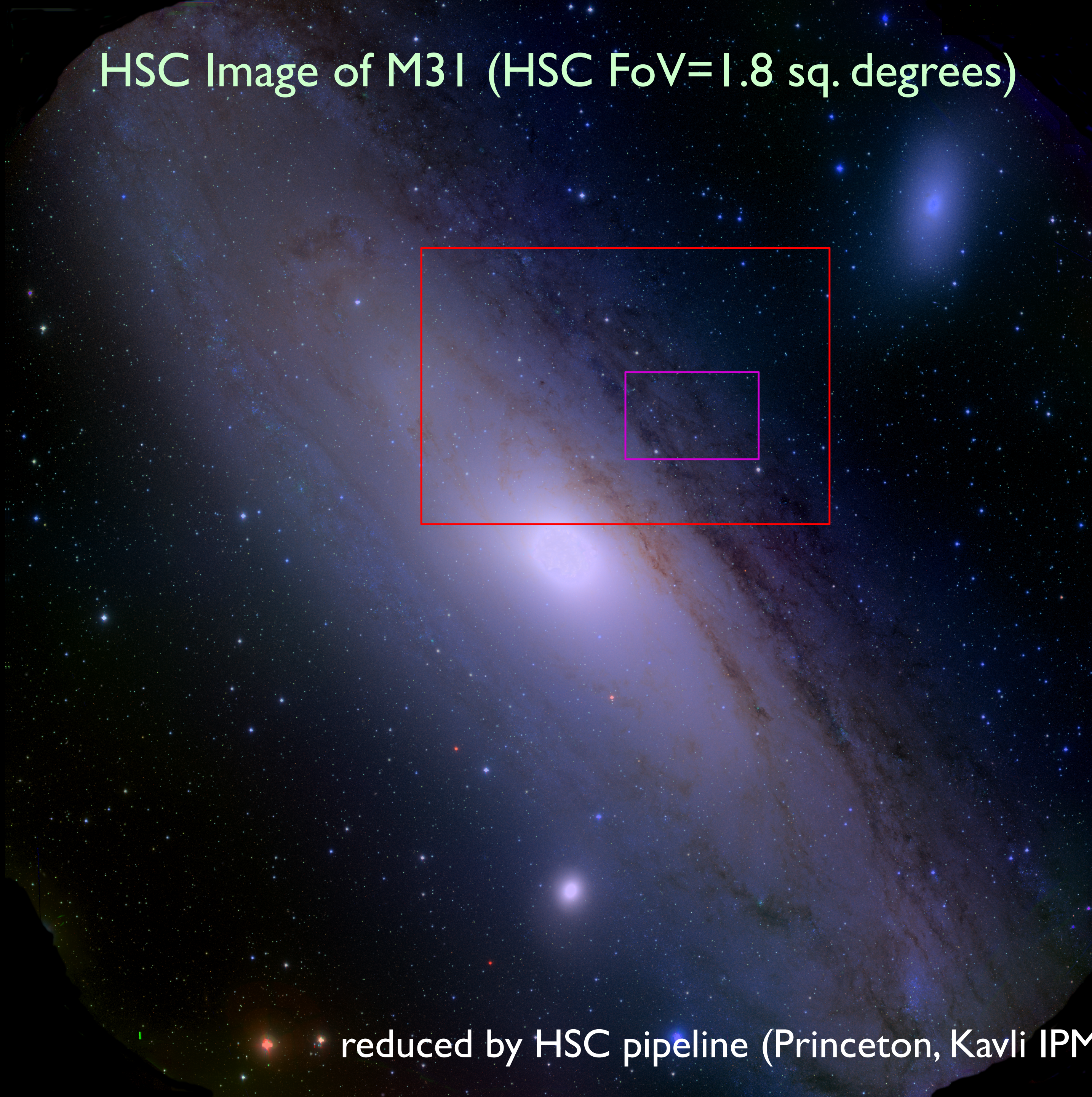
- largest camera
- 3m high
- weigh 3 ton
- 104 CCDs (~0.9B pixels)

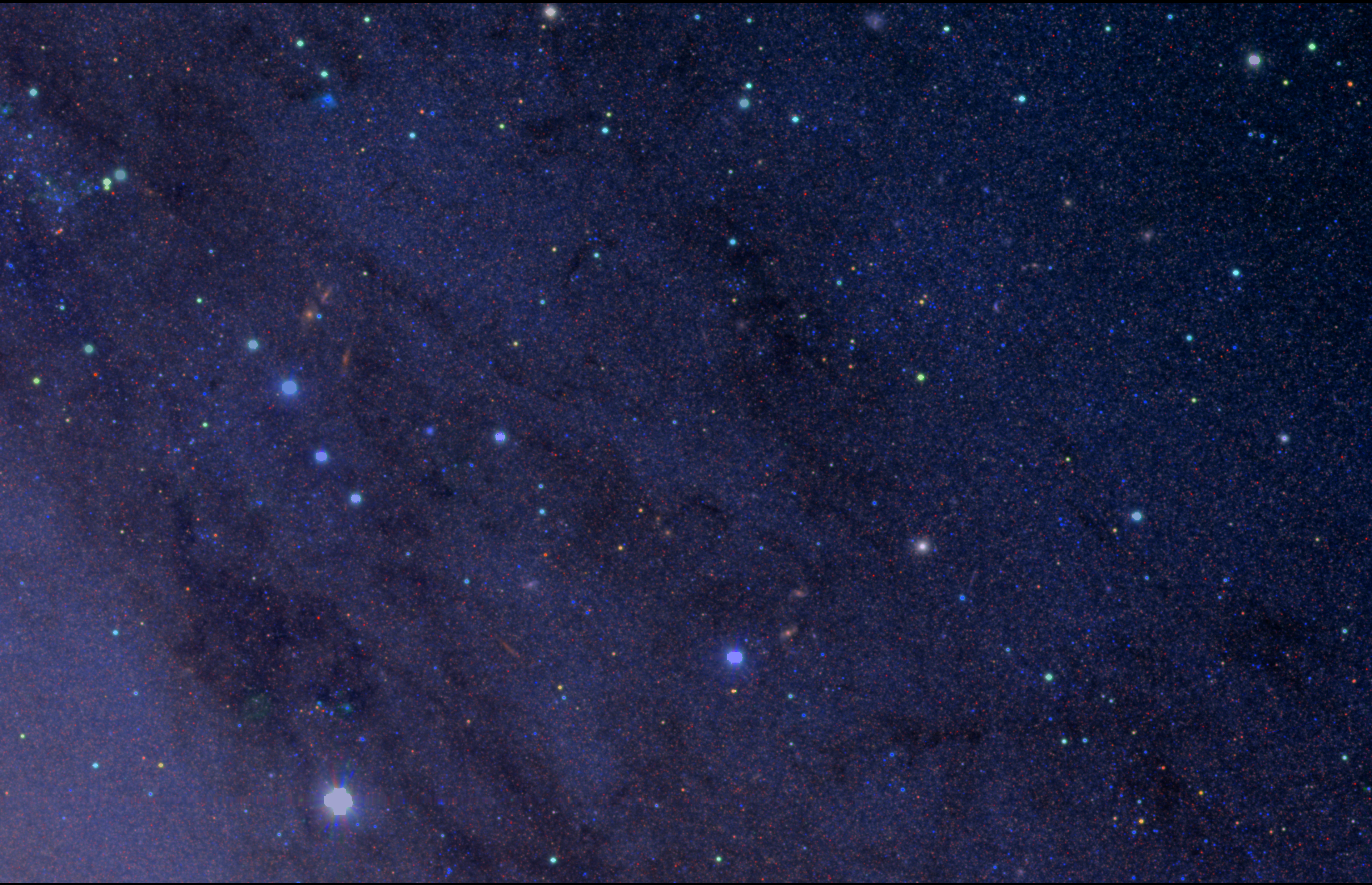


wi

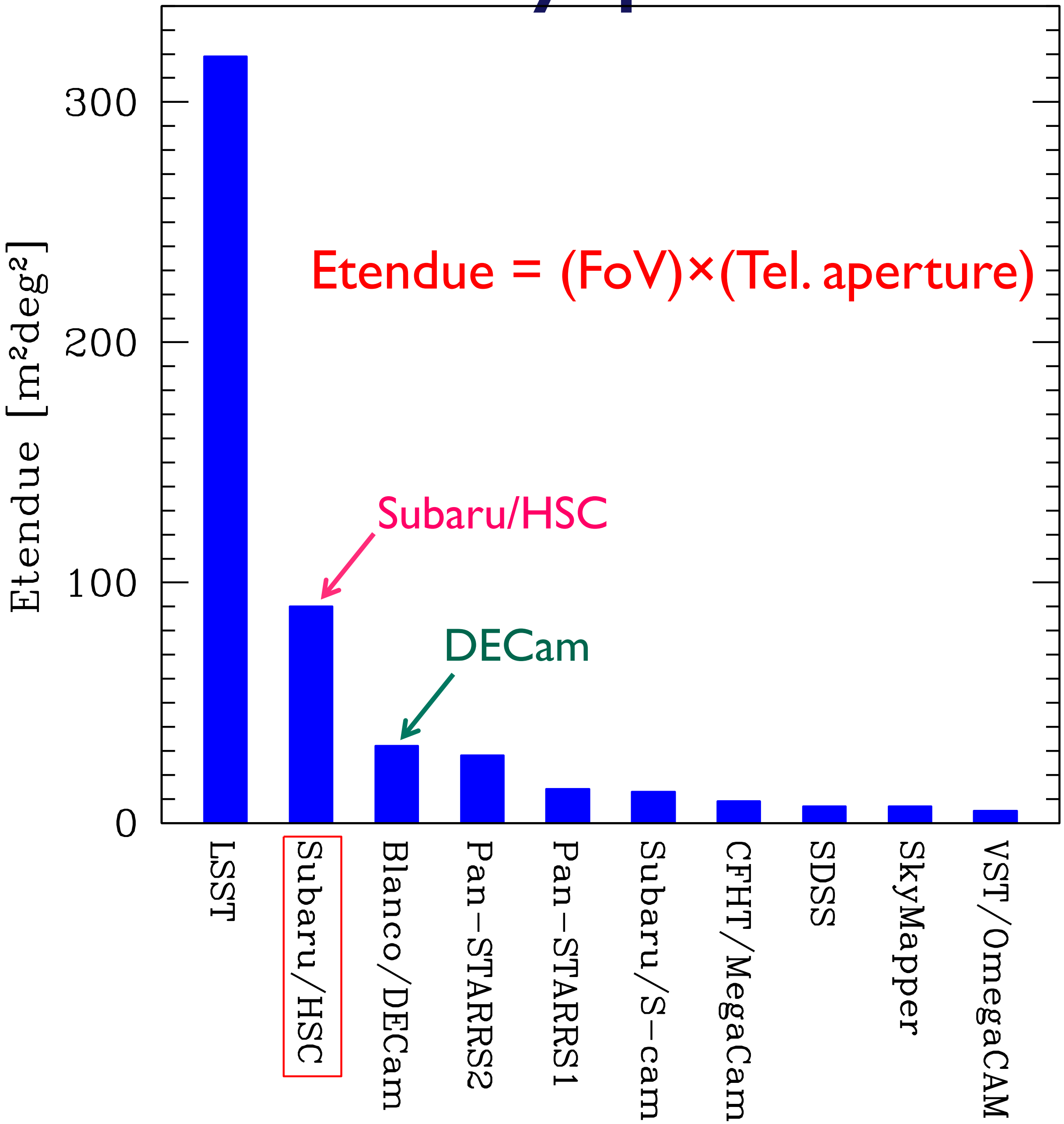
Hyper Suprime-Cam FoV

- **Fast**
- a cos


HSC Image of M31 (HSC FoV=1.8 sq. degrees)
reduced by HSC pipeline (Princeton, Kavli IPMU, NAOJ)



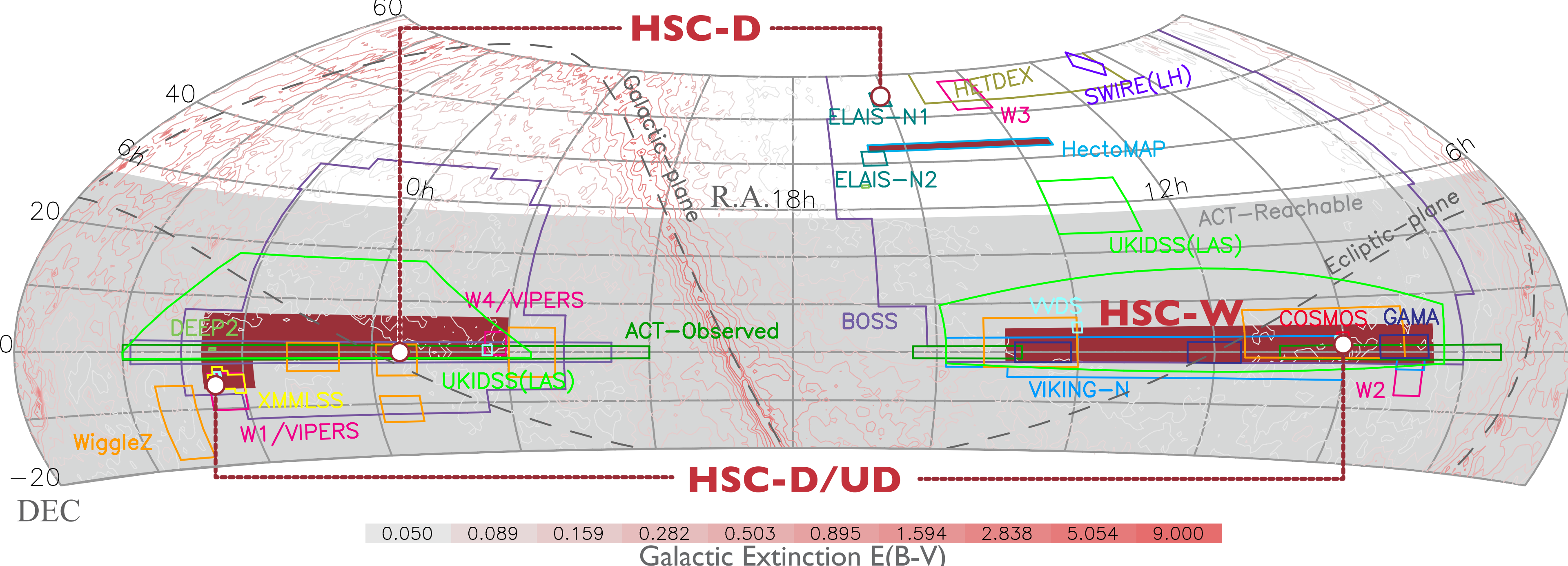
Survey power of HSC



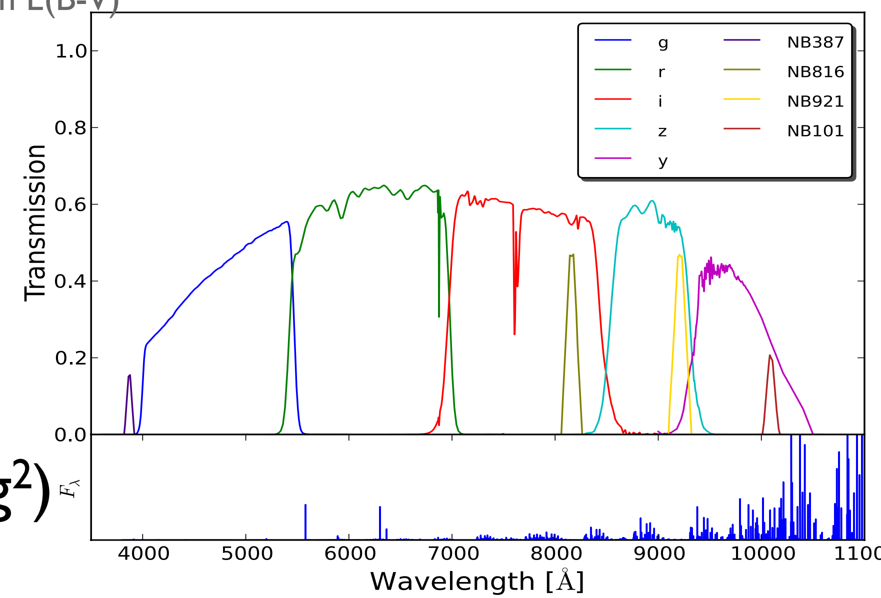
- Photon collecting power of 8.2m Subaru Tel.
- FoV
- Excellent image quality

→ *These make HSC the most powerful survey camera/telescope before LSST*

HSC Survey: 300nights approved



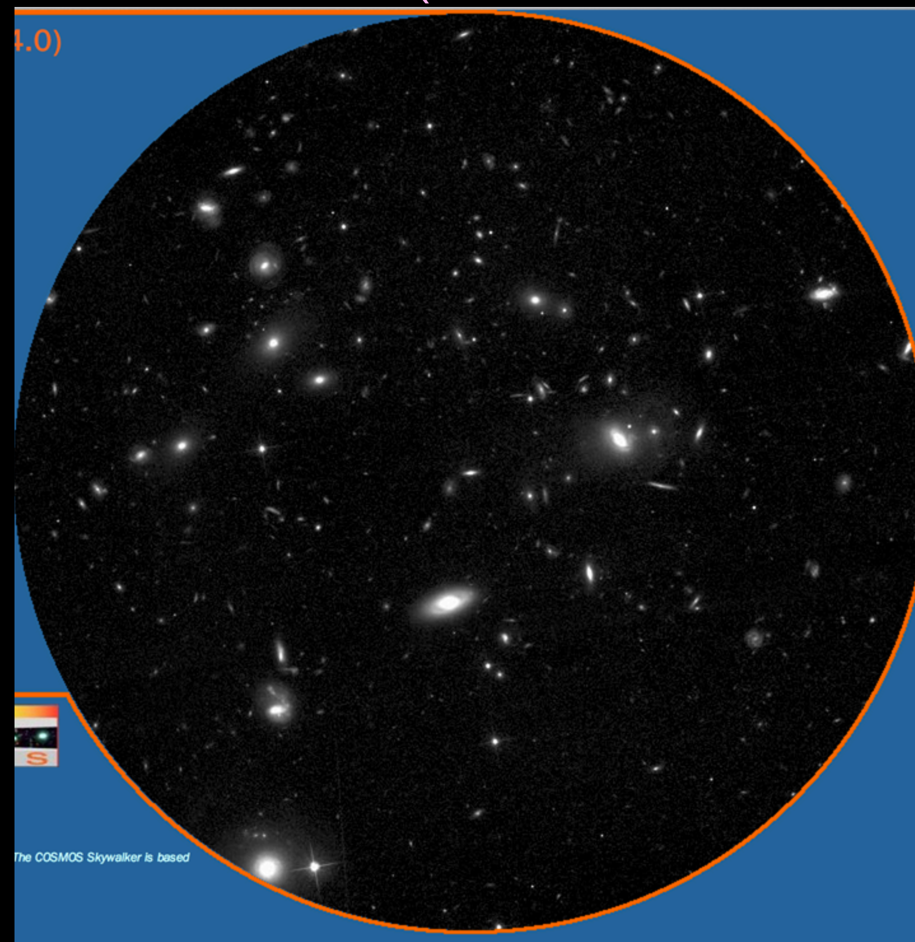
- 2014 – 2018(or 19)
- Three survey layers
  - Wide (i~26, grizy, 1400 deg^2)
  - Deep (i~27, grizy+NBs, 28 deg^2)
  - Ultra-D (i~28, grizy+NBs, 3.5 deg^2)



HSC Survey finally started (March 2014)!
(5 years until 2019, 300 Subaru nights)

Subaru HSC image (riz: ~2.5hrs)

COSMOS HST (640 orbits: ~500hrs)



best seeing ~0.5”
typically ~0.7” for good weather

PFS Collaboration

Caltech

国立天文台 NAOJ

中央研究院 ACADEMIA SINICA 1928

PRINCETON UNIVERSITY

NASA JPL

JOHNS HOPKINS UNIVERSITY

Max-Planck-Institut für Astrophysik

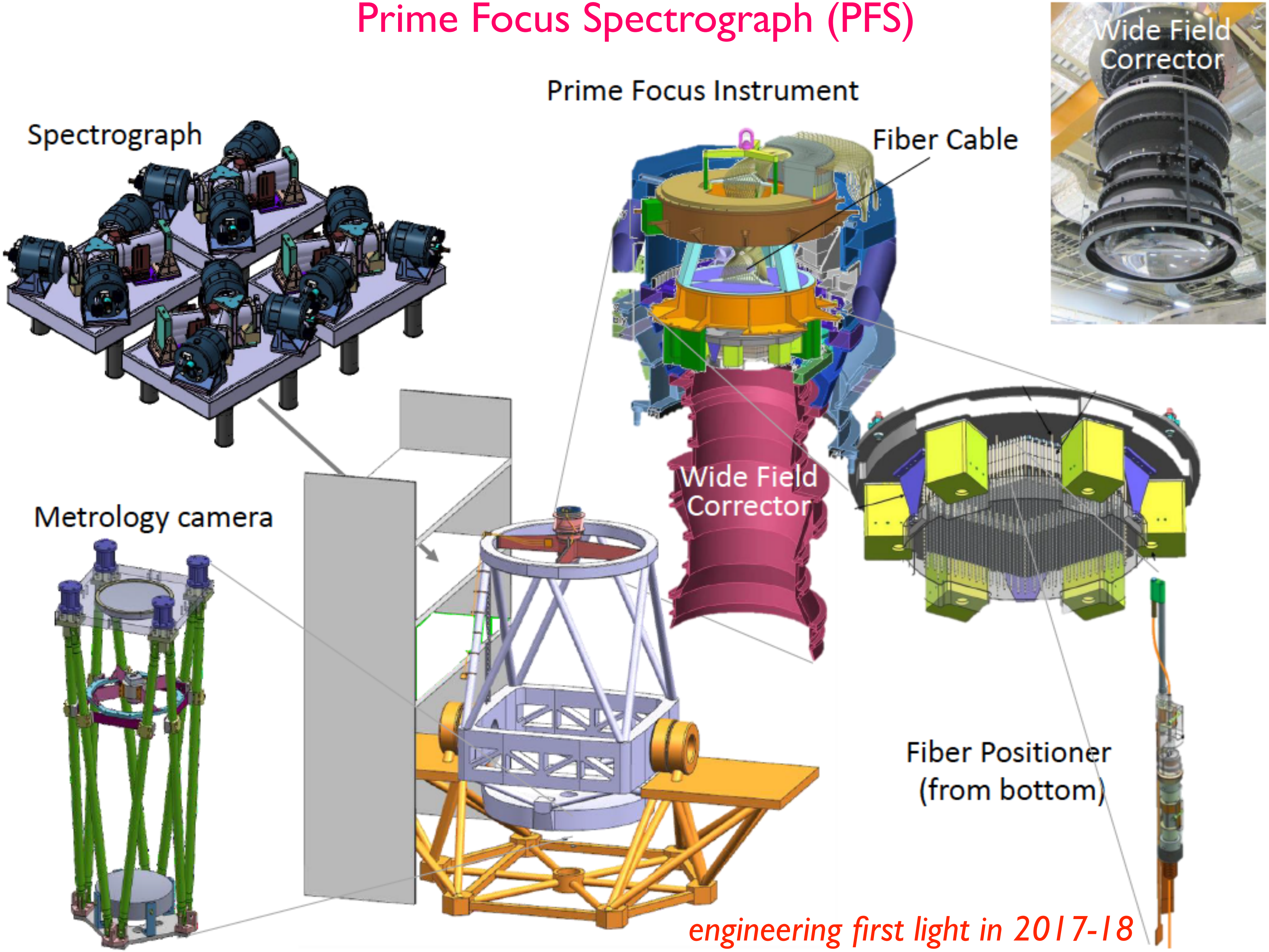
OBSERVATÓRIO DE SÃO PAULO
SANCTI PAVLI CÆLVM AGER MEVS

KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

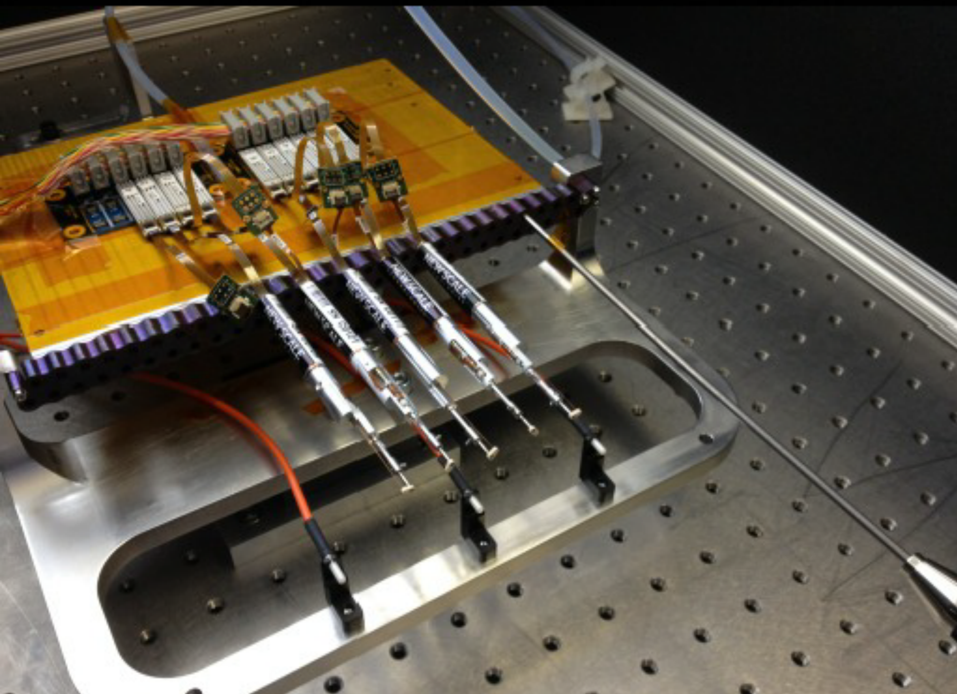
LNA LABORATÓRIO NACIONAL DE ASTROFÍSICA

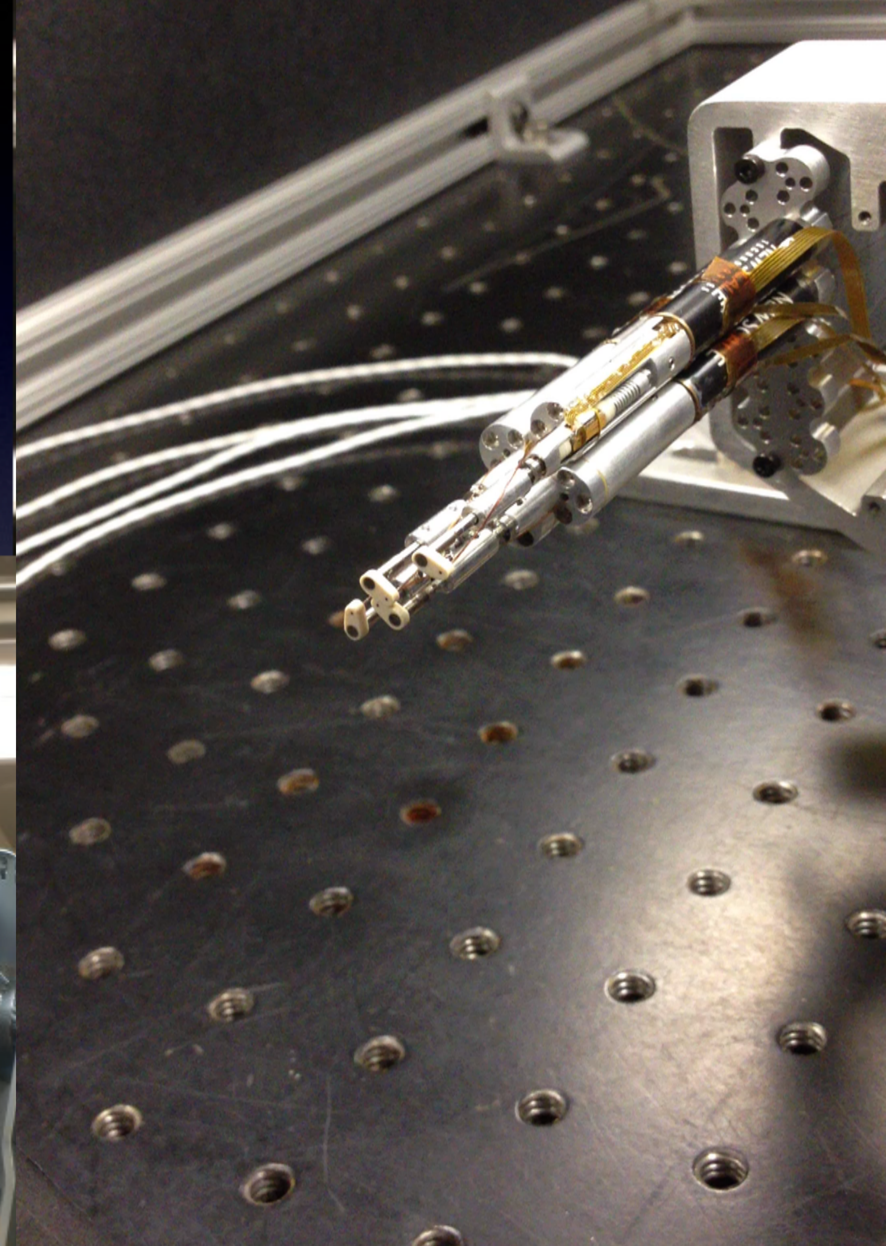
LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

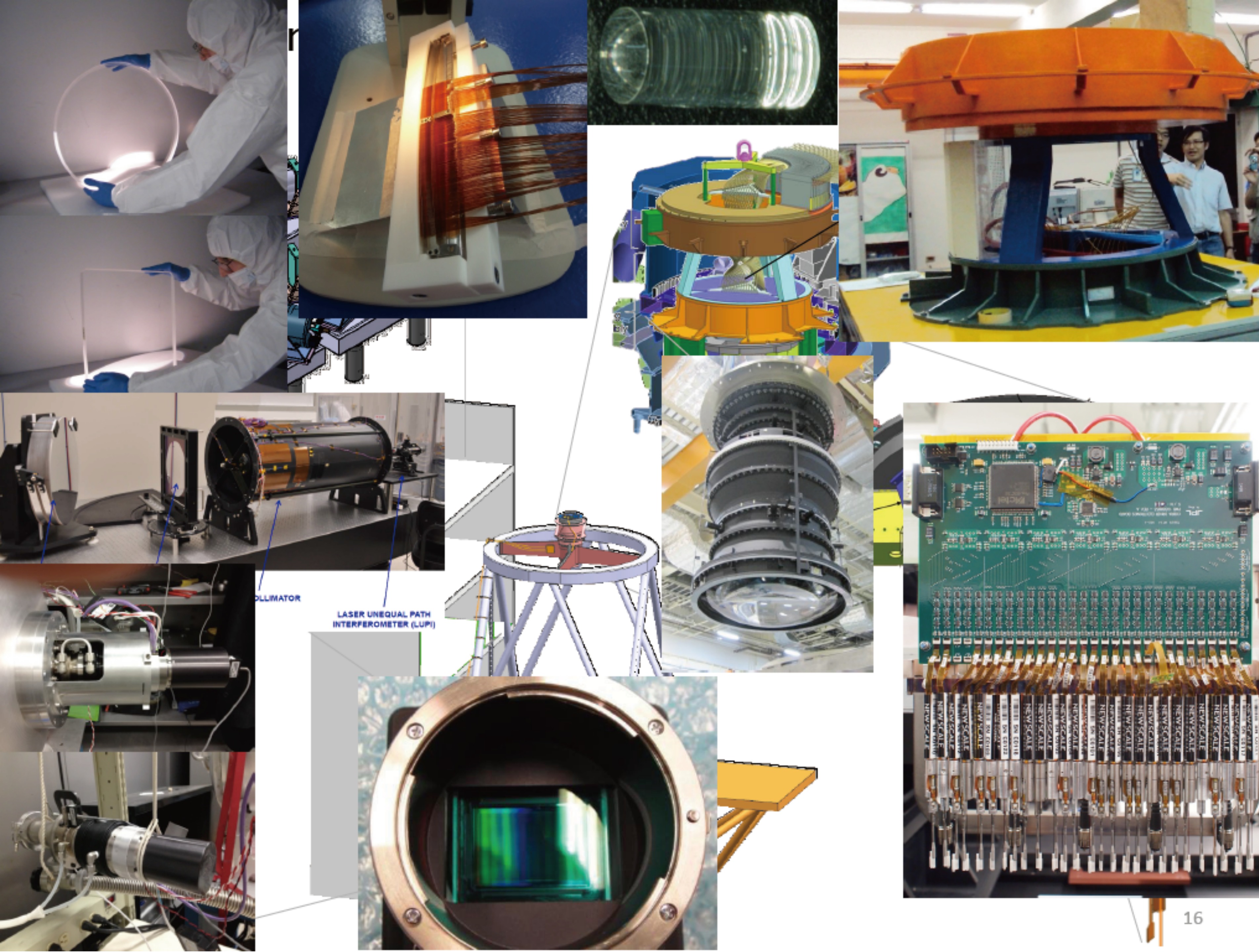
Prime Focus Spectrograph (PFS)



5 μ accuracy in 7 iterations
9.5mm patrol area





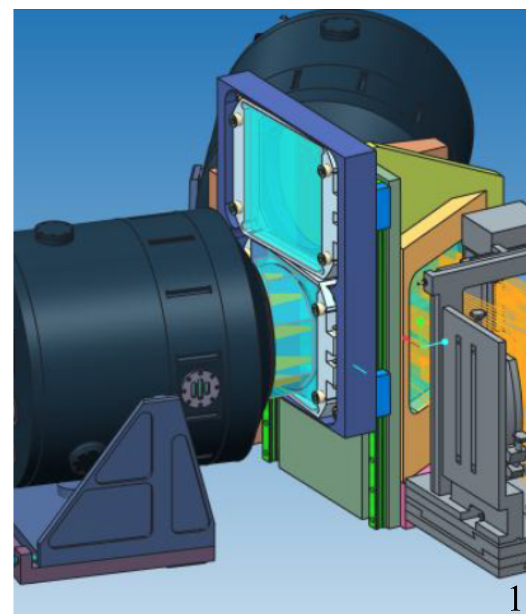

OLLIMATOR
LASER UNEQUAL PATH
INTERFEROMETER (LUPI)

PFS Parameters

Approved by Preliminary Design Review (March, 2013)

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	
Spectrograph	Blue	Red	NIR
Wavelength range [nm]	380-650	630-970 (706-890)	940-1260
Central resolving power	~2350	~2900 (~5000)	~4200
Detector type	CCD	CCD	HgCdTe

- Share WFC with HSC
- 4 spectrographs for 600 fibers each
- λ =380-1260nm with 3 arms (⇔ 360-980nm for DESI)
- Fiber density: 2200/sq. degs (⇔ ~140 for 2.5m BOSS; ~600 for 4m DESI)
- The medium resolution mode (R~5000) for the red arm is *our baseline design*



R1-1

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Review

Takada et al. arXiv:1206.0737

Review

Extragalactic science, cosmology, and Galactic archaeology with the Subaru Prime Focus Spectrograph

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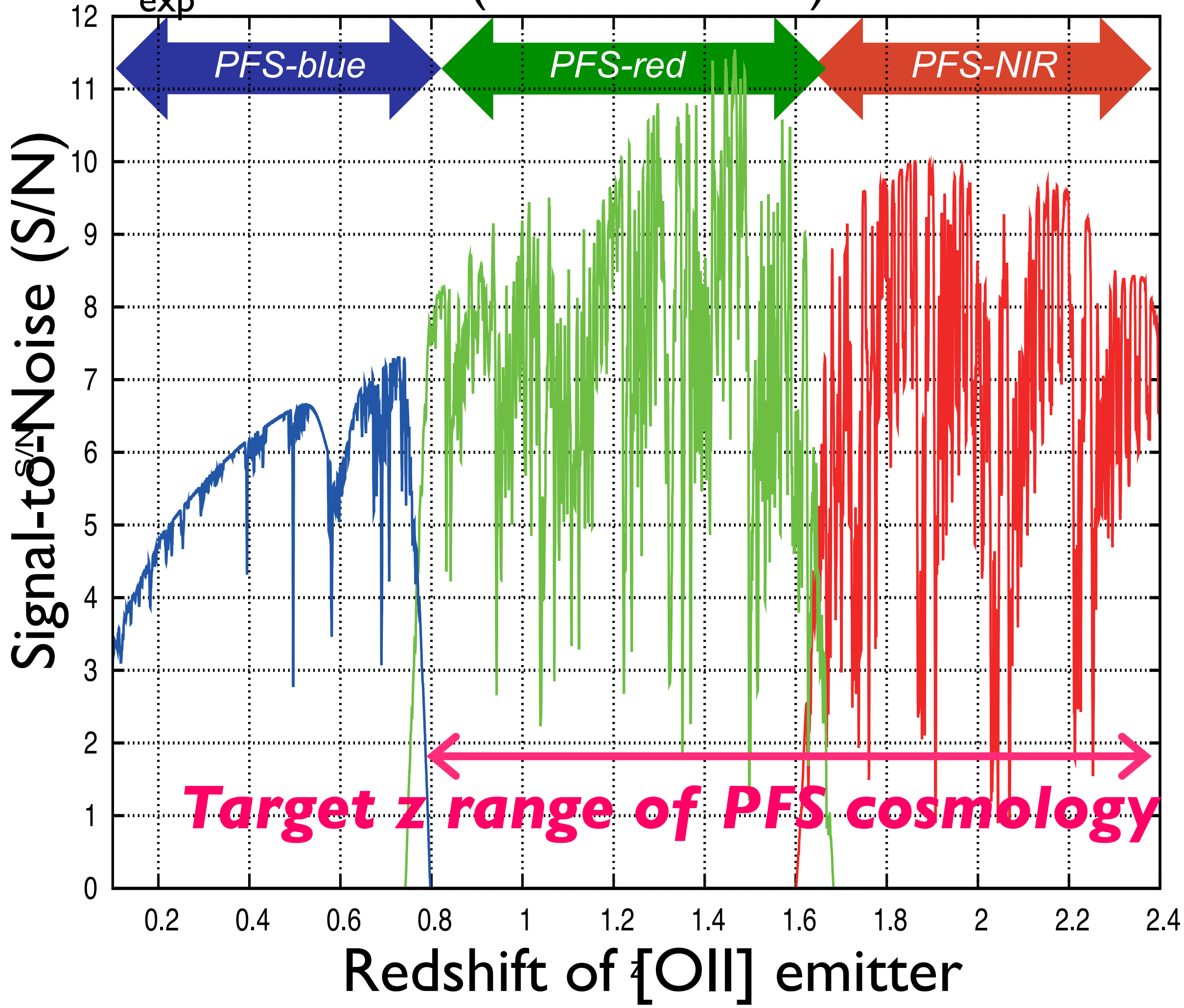
Science Objectives: Three Pillars

All science cases are based on a spectroscopic follow-up of objects taken from the HSC imaging data

- Cosmology (~100 nights): 1400 sq. degrees
  - ~4M redshifts of emission-line galaxies
  - BAO at each of 6 redshift bins over $0.8<z<2.4$
  - Cosmology with the joint experiment of WL and galaxy clustering (HSC/PFS)
- Galaxy Evolution (~100 nights): ~20 deg^2, *see J. Greene's talk!*
  - A unique sample of galaxies (~1M) up to z~2, with the aid of the NIR arm
  - Dense sampling of faint galaxies (also many pairs of foreground/background gals)
  - Studying cosmic reionization with a sample of LAEs, LBGs and QSOs
- Galactic Archaeology (~100 nights): Milky Way/M31/dSphs
  - ~1M star spectra for measuring their radial velocities
  - Use the 6D phase-space structure, in combination with GAIA in order to study the origin of Milky Way (also use the M31 survey)
  - Use a medium-resolution-mode survey of ~0.1M stars to study the chemo-dynamical evolution of stars in Milky Way

Unique capability of PFS: high performance

A working example:
$f_{[OII]}=5\times10^{-17}$erg/cm^2/s, $\sigma_v=70$ km/s, $r_{eff}=0.3''$
$t_{exp}=2\times450$sec (15min in total)



- [OII] line (3727Å) feature used for cosmology survey
- Assuming baseline instrument parameters (fiber size, throughput, readout noise, etc.)
- *Conservative assumption*: 0.8'' seeing, at FoV edge, 26 deg. zenith angle
- *Included sky continuum & OH lines*
- The PFS design allows a matched S/N in Red and NIR arms → a wide redshift coverage, **0.8<z<2.4**
- LSS more linear at higher z

Target selection of [OII] emitters

- Mock Catalog, based on the COSMOS 30 bands, zCOSMOS and DEEP2 (Jouvel et al. 2009, + further updates)
- The wide z-range allows an efficient target selection based on the color cut:

```
22.8<g<24.2 & -0.1<g-r<0.3
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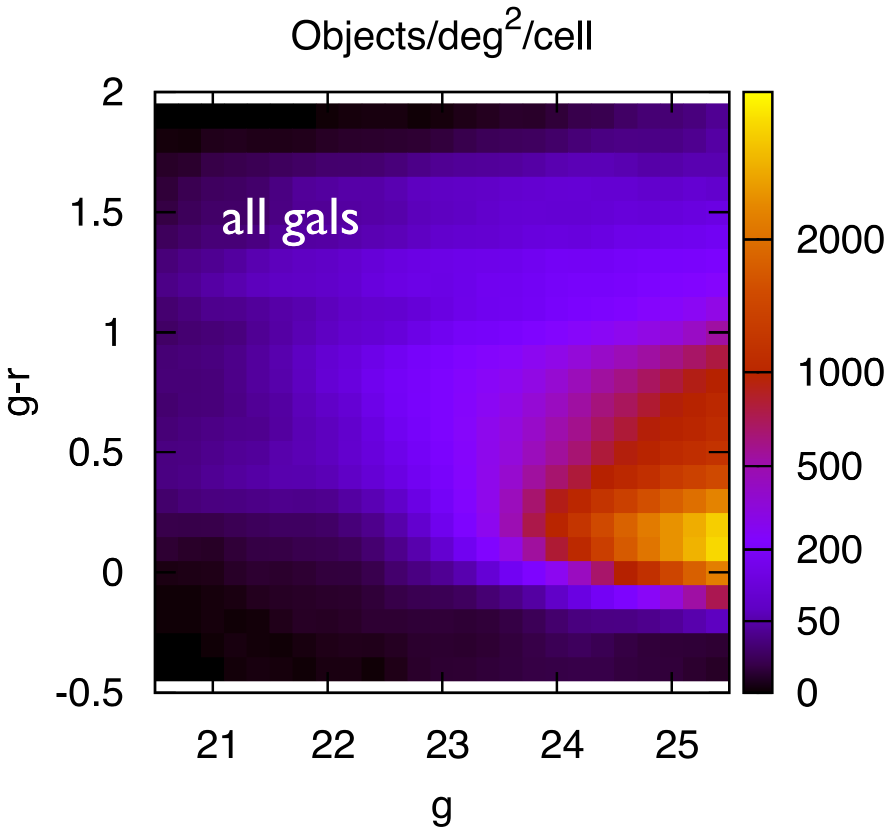
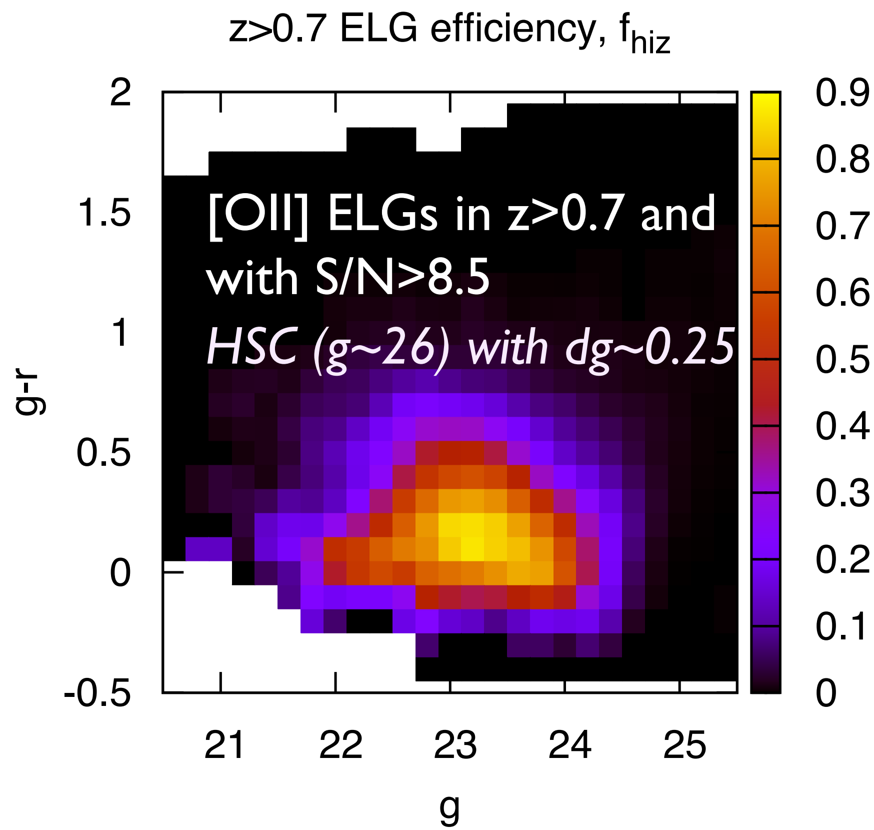
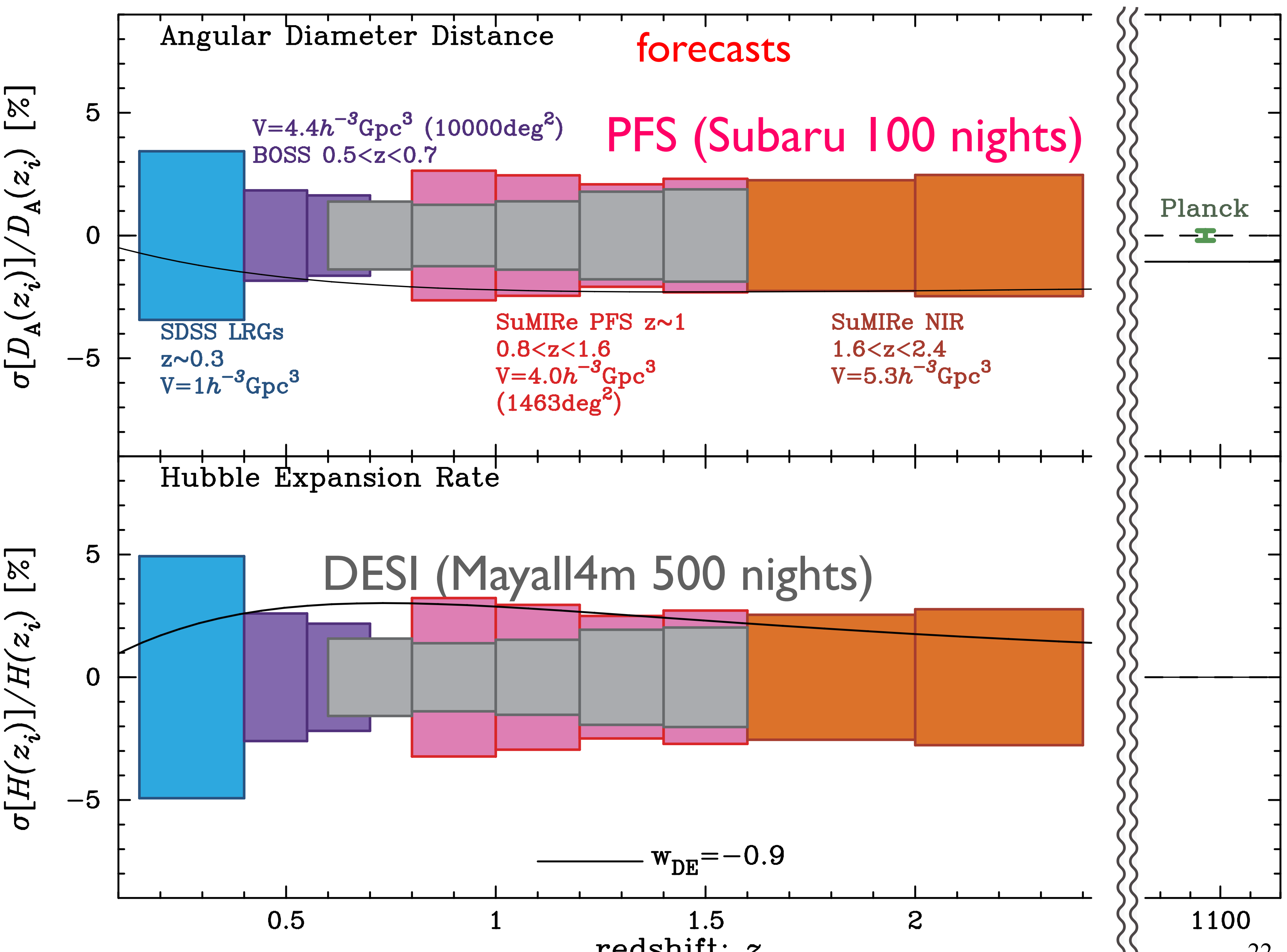
- 7847 targets per the PFS FoV (1.3 deg. diameter)~ 3×(# of PFS fibers)
- **~75%** success rate for 2 visits of each field

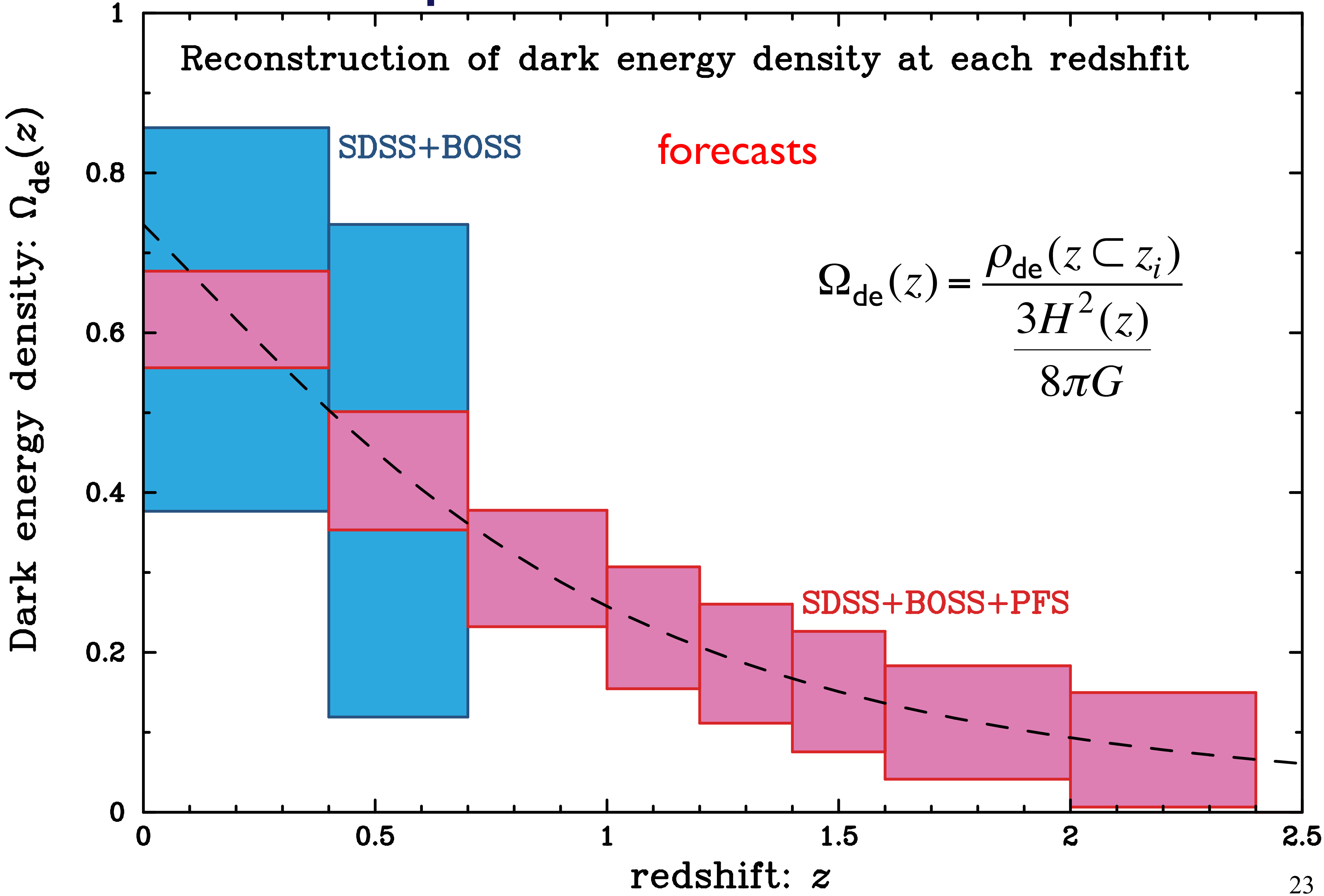




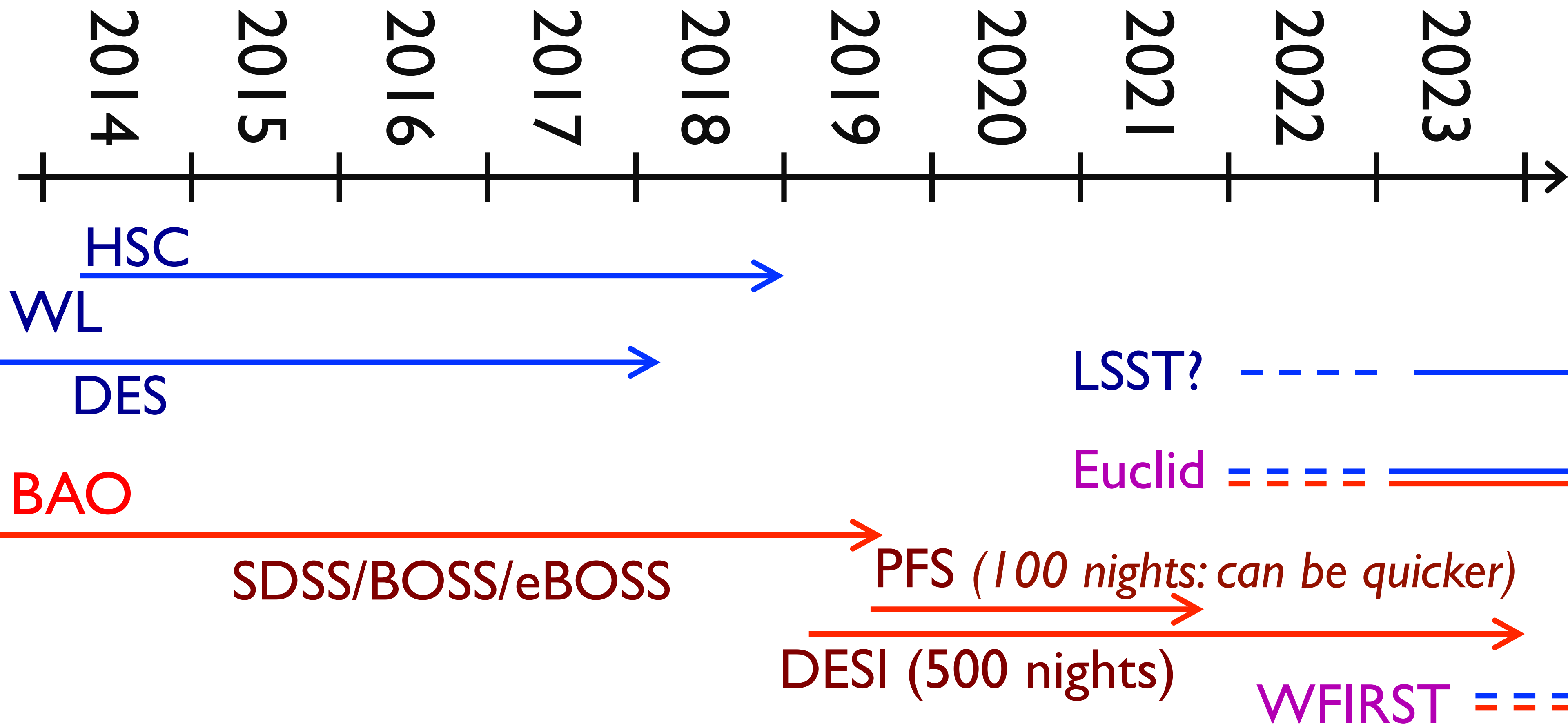


Angular Diameter Distance
forecasts
PFS (Subaru 100 nights)
V=4.4h^{-3}Gpc^3 (10000deg^2)
BOSS 0.5<z<0.7
SDSS LRGs
z~0.3
V=1h^{-3}Gpc^3
SuMIRe PFS z~1
0.8<z<1.6
V=4.0h^{-3}Gpc^3
(1463deg^2)
SuMIRe NIR
1.6<z<2.4
V=5.3h^{-3}Gpc^3
Planck
$\sigma[D_A(z_i)]/D_A(z_i)$ [%]
Hubble Expansion Rate
DESI (Mayall4m 500 nights)
$w_{DE}=-0.9$
$\sigma[H(z_i)]/H(z_i)$ [%]
redshift: z
5
0
−5
0.5
1
1.5
2
1100

Model-independent DE reconstruction



Time line (DE experiments)

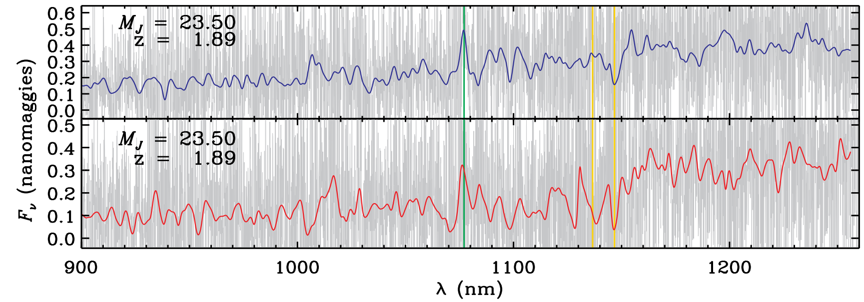


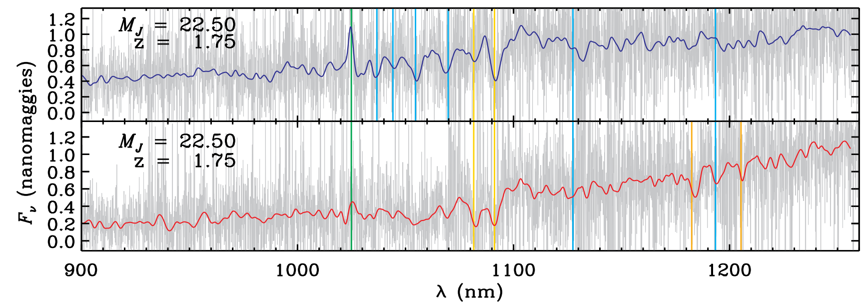
HSC/PFS has an opportunity to make a DE breakthrough before the ultimate surveys, Euclid, LSST and WFIRST

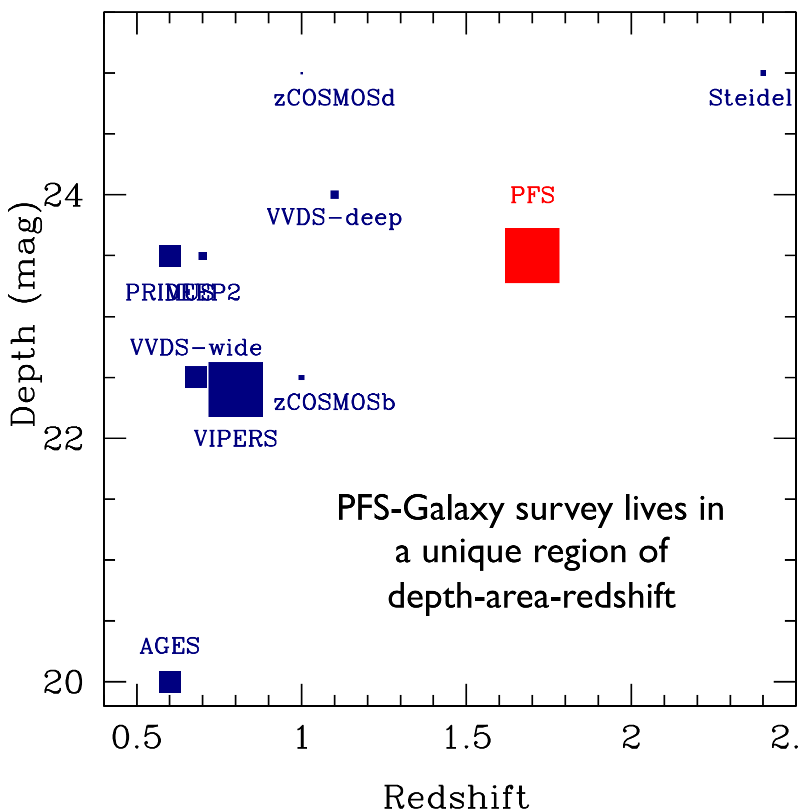
PFS Galaxy Evolution

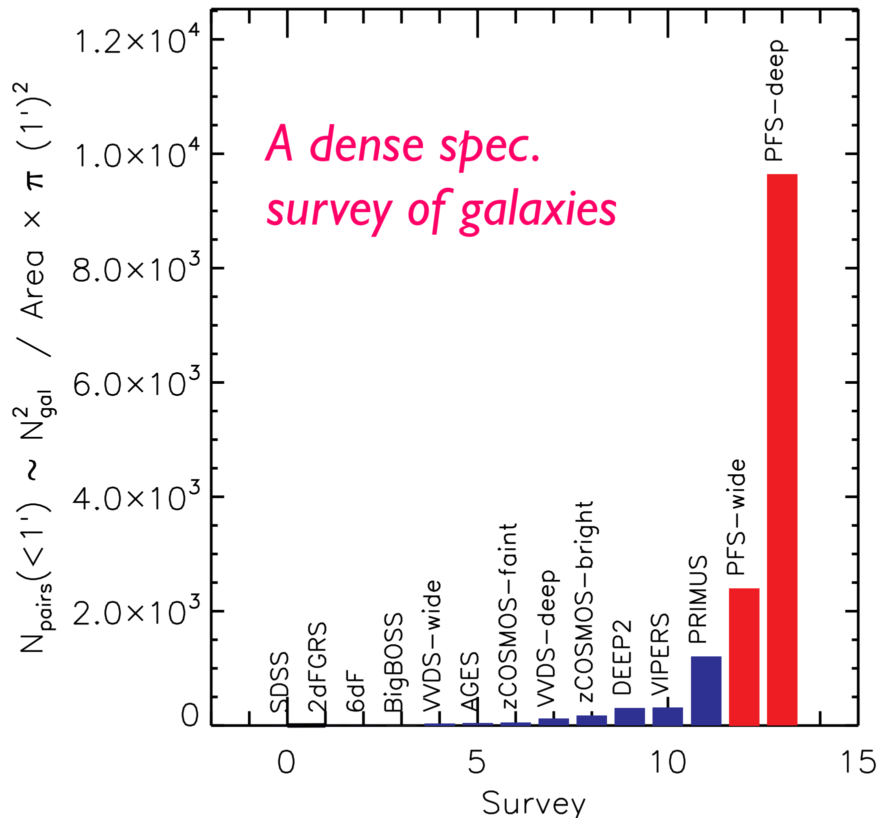
See Jenny Greene's talk

- PFS also enables a spectroscopic survey of "general" galaxies at z~1-2 (a detection of continuum in each spectrum)



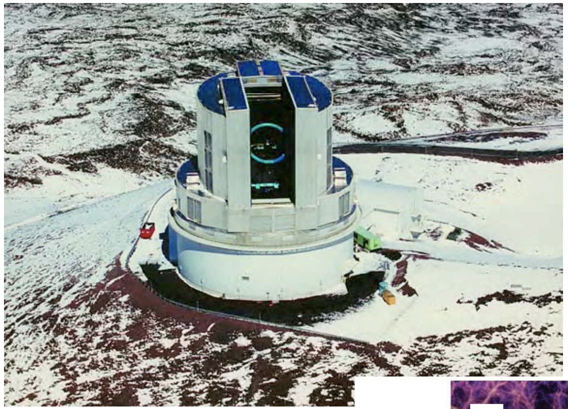


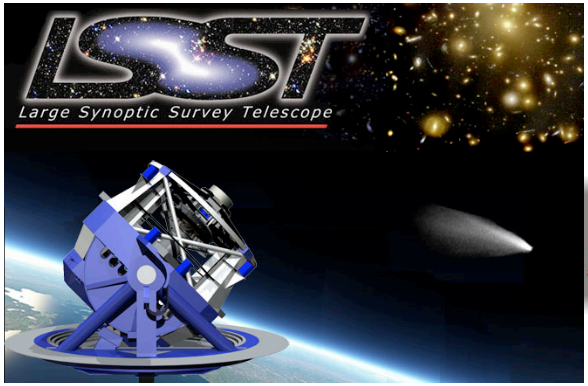


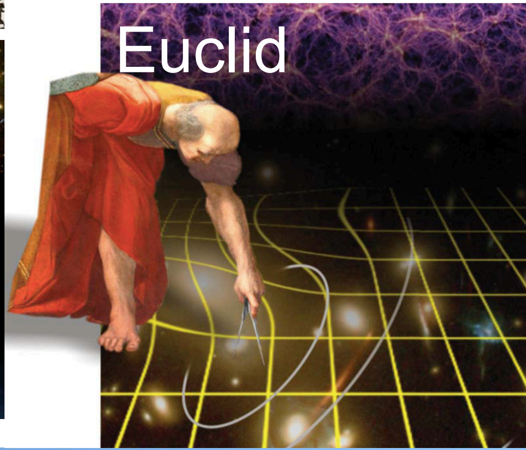


Long Range Strategy of Subaru

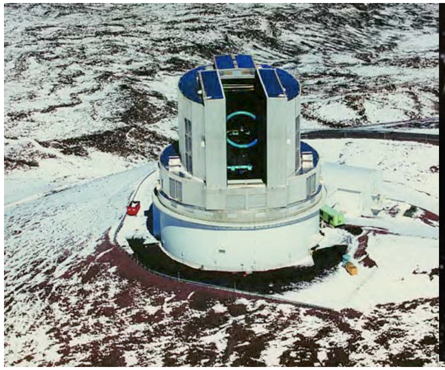
- HSC & PFS allow for making Subaru Tel. a unique facility in 2020era: target obs ⇒ survey telescope
- HSC, PFS, GLAO major instruments in 2020era
- Various synergies with
  - GAIA (2013)
  - Euclid (2019)
  - LSST (2018 or 19? -)
  - WFIRST (???)
  - TMT& E-ELT (???)







Synergies btw PFS and WFIRST



- Japanese community has *a strong interest* in WFIRST
- PFS can play a *unique role* for providing a massive, deep spectroscopic survey of galaxies
  - A training sample of WFIRST photo-z, also via cross-correlations (10-30 nights according to Jeff Newman; also see Menard et al. 14)
  - A more detailed SED measurement
- Other science cases need to be further explored (HSC narrow-band filters, HSC microlensing, PFS Ly-alpha, …)
- *A possible new high-latitude survey with PFS for WFIRST* (the planned PFS survey, 2019-2023, so a plenty of time for the arrangement)

Summary

- SuMIRe (Subaru Measurements of Images and Redshifts)
  - Hyper Suprime-Cam (HSC): 2014-19, ~1B gals, 1400 deg^2
  - Prime Focus Spectrograph (PFS): 2019-22, ~4M spec-z, 1400 deg^2
  - Imaging and spectroscopic surveys for the same region of the sky at the same telescope
- *Strong interest* in DE and survey astronomy in Japan
- Synergies/Complementarities of PFS with future
  - *Unique capability*: no any other (funded) massively-multiplexed spectrograph at 8-10m telescopes
  - *Complementary to WFIRST*: a training sample of photo-z's, a wider coverage of galaxy SED, dens pairs of gals, QSOs, ISMs ...
  - To have the synergies, some WFIRST regions need to be in northern hemisphere: *a new high-latitude PFS survey for WFIRST?*

PFS Cosmology Survey

Redshift	Volume/FoV ($10^{-4}h^{-3}$ Gpc^3)	# of galaxies (per FoV)	Number density (10^{-4} h^3 Mpc^{-3})	bias	nP @k=0.1hMpc^{-1}
0.8<z<1.0	6.4	286	4.4	1.26	1.0
1.0<z<1.2	7.8	438	5.6	1.34	1.25
1.2<z<1.4	8.8	762	8.6	1.42	1.82
1.4<z<1.6	9.7	534	5.5	1.5	1.13
1.6<z<2.0	21	721	3.5	1.62	0.82
2.0<z<2.4	22	620	2.8	1.78	0.81

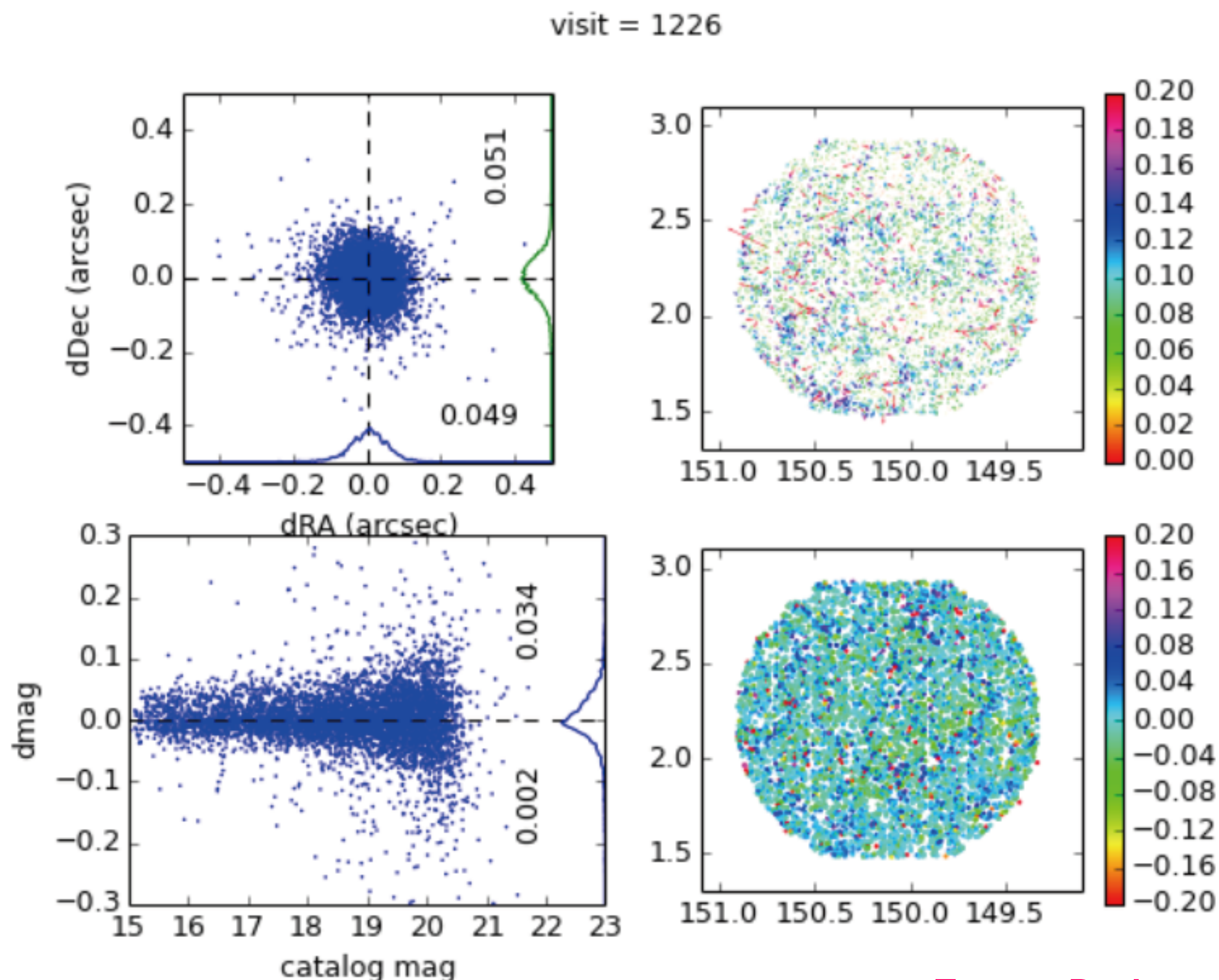
Total # of galaxies : 3361 (0.8<z<2.4)
Area (100 clear nights): 1420 sq. degs. → 9 (Gpc/h)^3 = a factor 2×BOSS

- Need 2 visits to have high number densities of ELGs in each z-slice
- Assumed galaxy bias (poorly known): b=0.9+0.4z
- Assumed 2400 fibers; FoV of 1.35 degree diameter; S/N>9
  - Success rate (0.8<z<2.4; including the fiber allocation efficiency): 71%
  - Assumed 15min exp. of each visit; 5min (conservative) overhead of each visit

Backup slides

@ PFS collaboration meeting

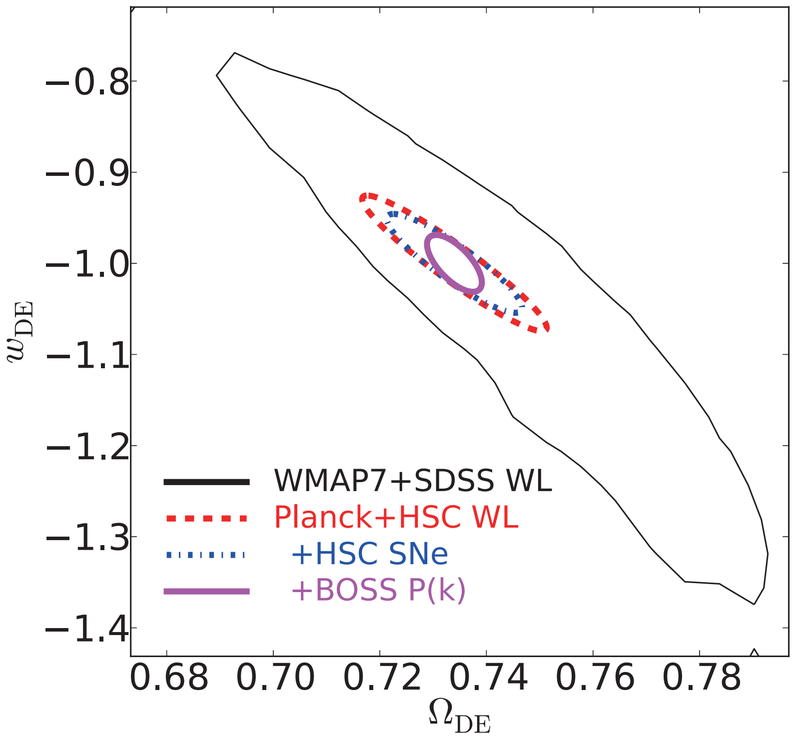
Fluxes relative to PanSTARRSOur Coadd 30s300s



From Robert Lupton

HSC-expected cosmological constraints

Data	$w_{\rm pivot}$	w_a	FoM	γ_g	$m_{\nu,\rm tot}$	$f_{\rm NL}$	n_s	α_s
BOSS-*BAO*	0.064	1.04	15	–	–	–	0.018	0.0057
HSC(WL)-*B* (baseline)	0.080	0.86	15	0.15	0.16	30	0.014	0.0041
HSC(WL)-*O* (optimistic)	0.068	0.66	22	0.083	0.082	18	0.013	0.0040
HSC(WL+SN)-*B*	0.043	0.60	39	0.15	0.16	30	0.014	0.0041
HSC(WL+SN)-*O*	0.041	0.45	54	0.081	0.081	18	0.013	0.0040
HSC-*O*+[BOSS-$P(k)$]	0.028	0.26	136	0.059	0.044	17	0.009	0.0023
HSC-*O*+[BOSS+PFS]	0.023	0.22	194	0.057	0.031	17	0.009	0.0021

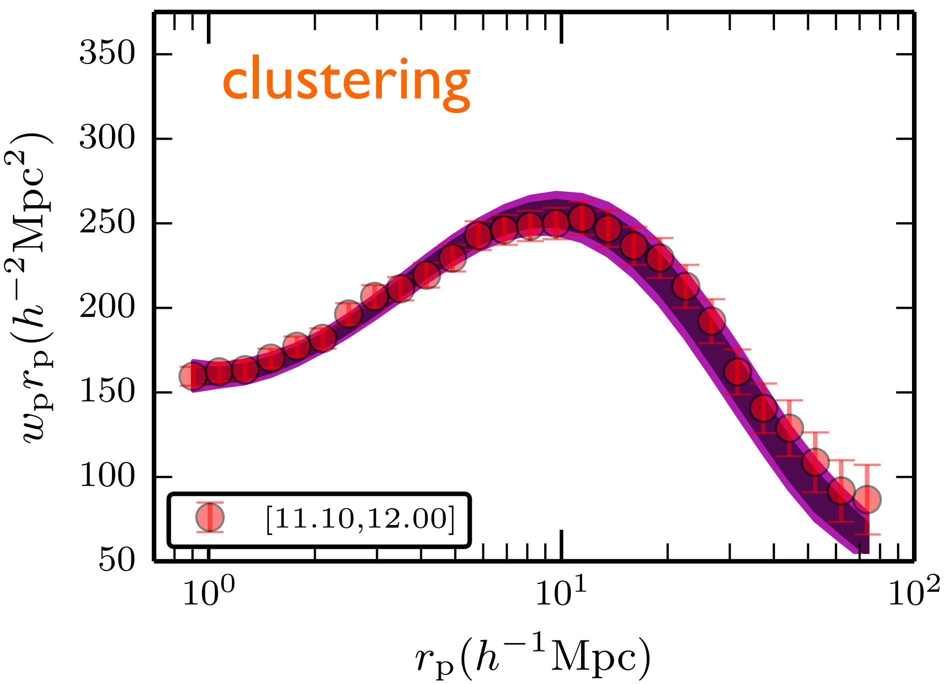


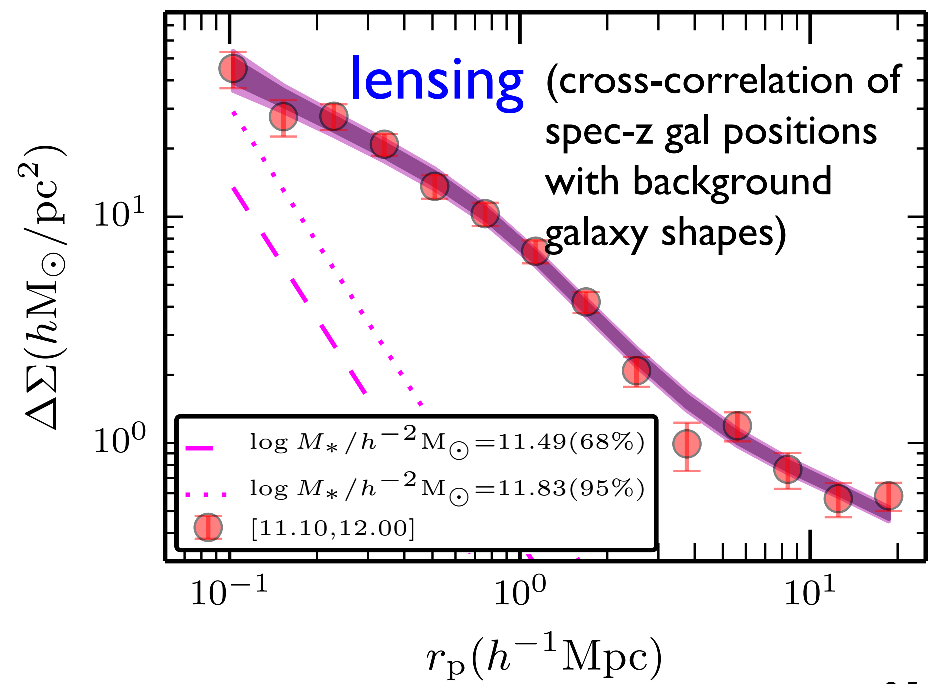
- The HSC promises a significant improvement in the dark energy constraints and our understanding of the universe

Combined probes: Lensing (imaging) + Clustering (spec-z)

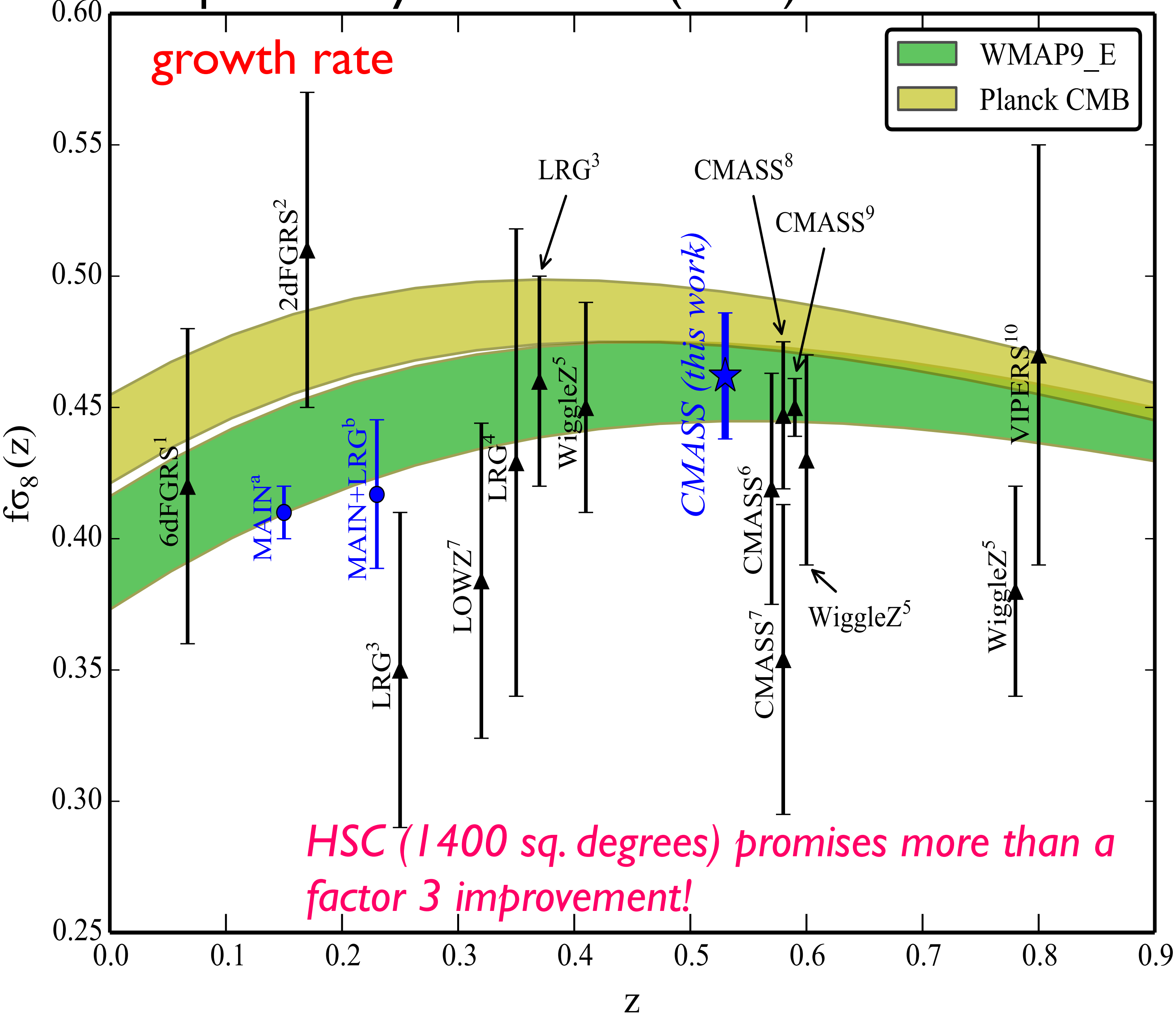
S. More

- Lensing: directly measure the DM distribution, but projected
- Clustering: 3D mapping of galaxy distribution; a much higher S/N, but galaxy bias uncertainty
- More, Miyatake, Mandelbaum, MT, Spergel, et al. (2014): CFHTLenS (3.6m imaging, *only ~120 sq. deg*) + BOSS (2.5m spec-z, 10000 sq. deg)



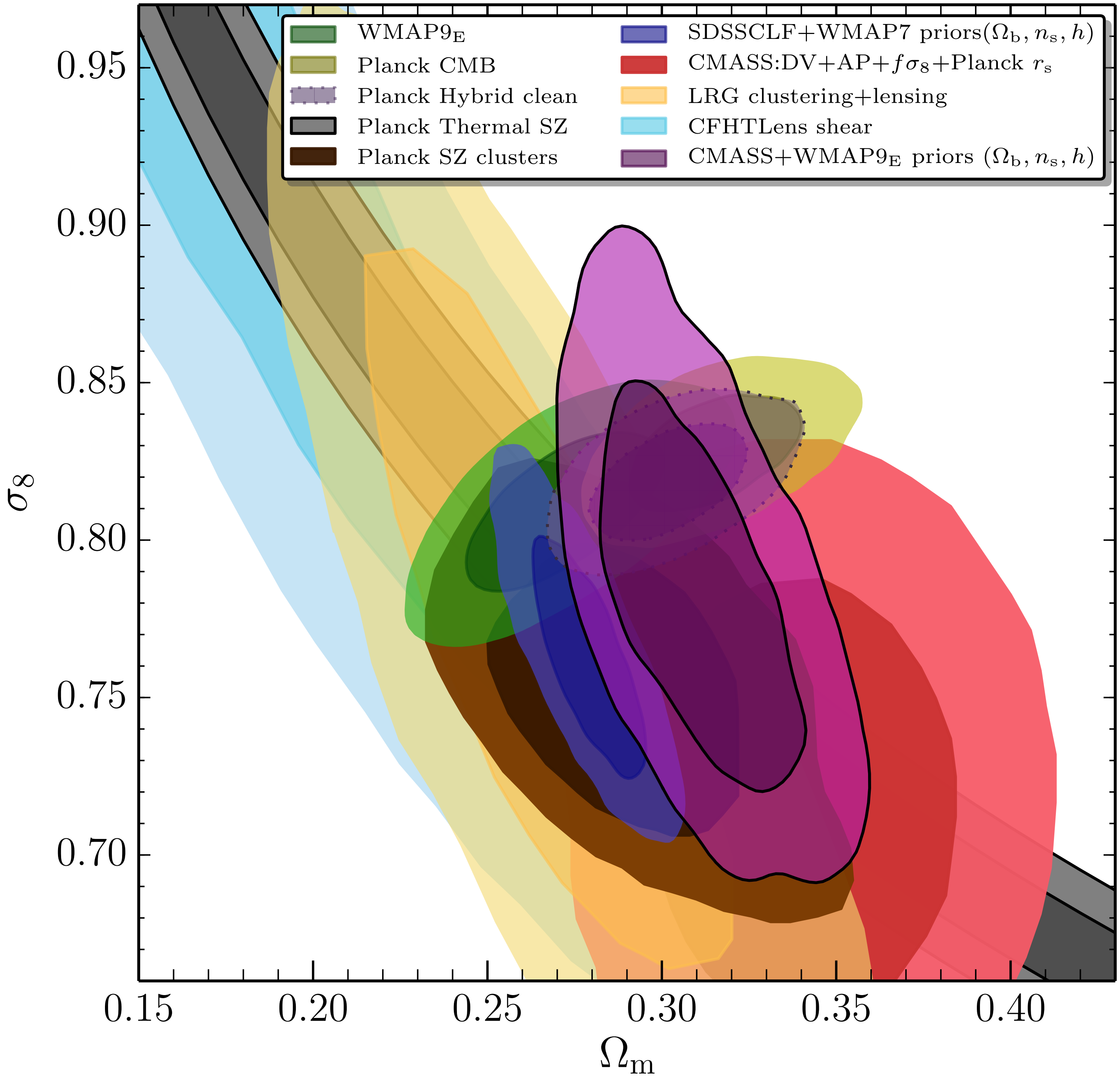


A pilot study: More et al. (2014)



RSD
[1] Beutler et al. (2012)
[2] Percival et al. (2004)
[3] Samushia et al. (2012)
[4] Chuang & Wang (2013)
[5] Blake et al. (2011)
[6] Beutler et al. (2013)
[7] Chuang et al. (2013)
[8] Samushia et al. (2014)
[9] Reid et al. (2014)
[10] de la Torre et al. (2013)

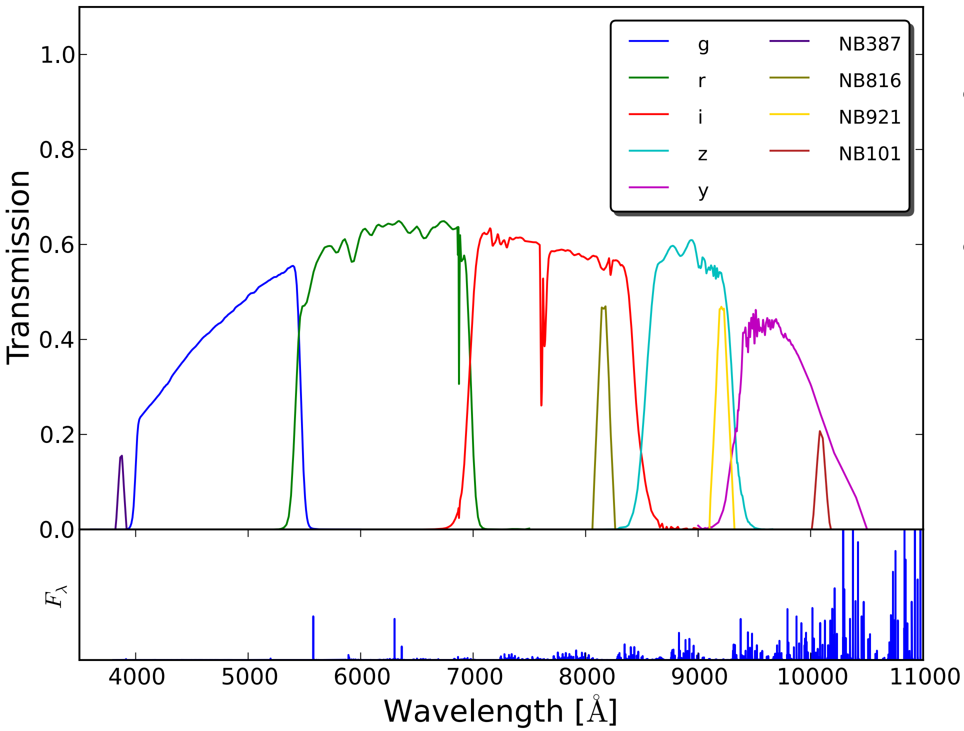
Clustering+Lensing
[a] Cacciato et al. (2013)
[b] Mandelbaum et al. (2013)



WMAP9$_E$
Planck CMB
Planck Hybrid clean
Planck Thermal SZ
Planck SZ clusters
SDSSCLF+WMAP7 priors(Ω_b, n_s, h)
CMASS:DV+AP+$f\sigma_8$+Planck r_s
LRG clustering+lensing
CFHTLens shear
CMASS+WMAP9$_E$ priors (Ω_b, n_s, h)
0.95
0.90
0.85
0.80
0.75
0.70
σ_8
0.15
0.20
0.25
0.30
0.35
0.40
Ω_m

Filters & Depth

	g	r	i	z	y	N3	N8	N9	N10
W	10	10	20	20	20	-	-	-	-
D	84	84	126	210	126	84	168	252	-
UD	420	420	840	1134	1134	-	630	840	1050



- Depth of each filter is carefully designed
- For HSC-Deep and Ultra-Deep, a combination of broad- and narrow-band filters allows to detect Lyman-alpha Emitters at z=2.2, 5.7, 6.6 and 7.3