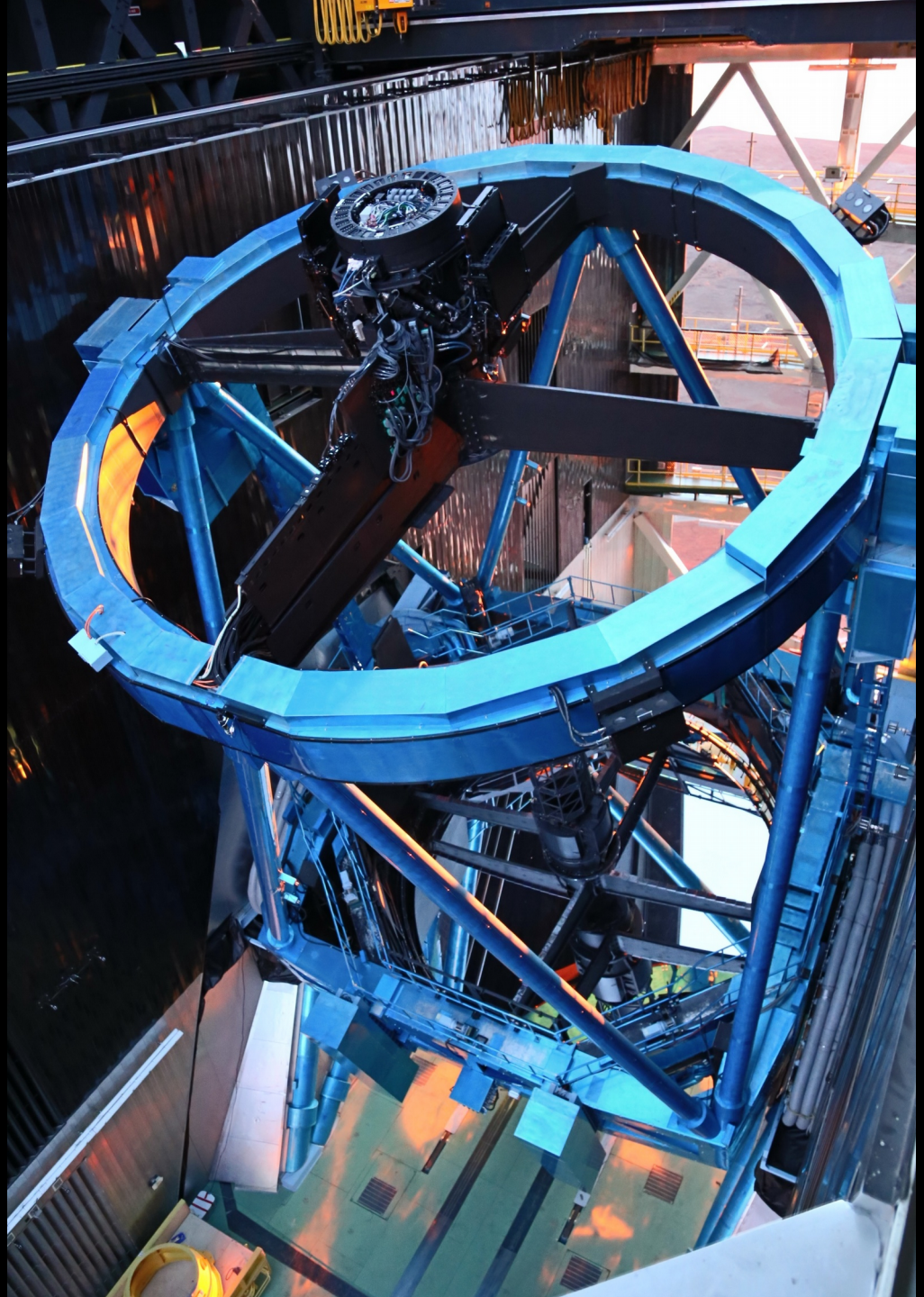
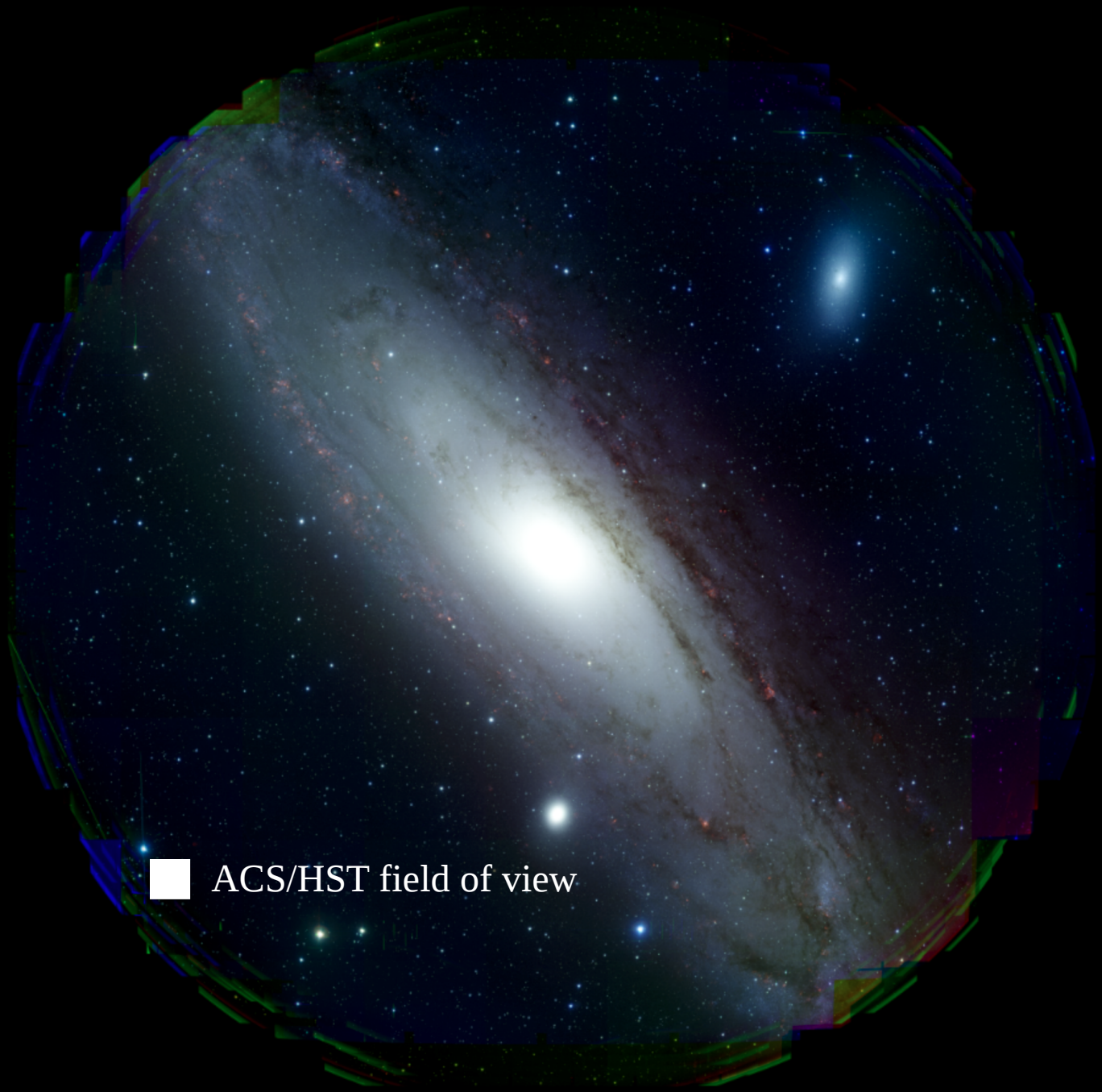
Subaru Strategic Programs with Hyper Suprime-Cam and Prime Focus Spectrograph

Masayuki Tanaka
(National Astronomical Observatory of Japan)

Hyper Suprime-Cam

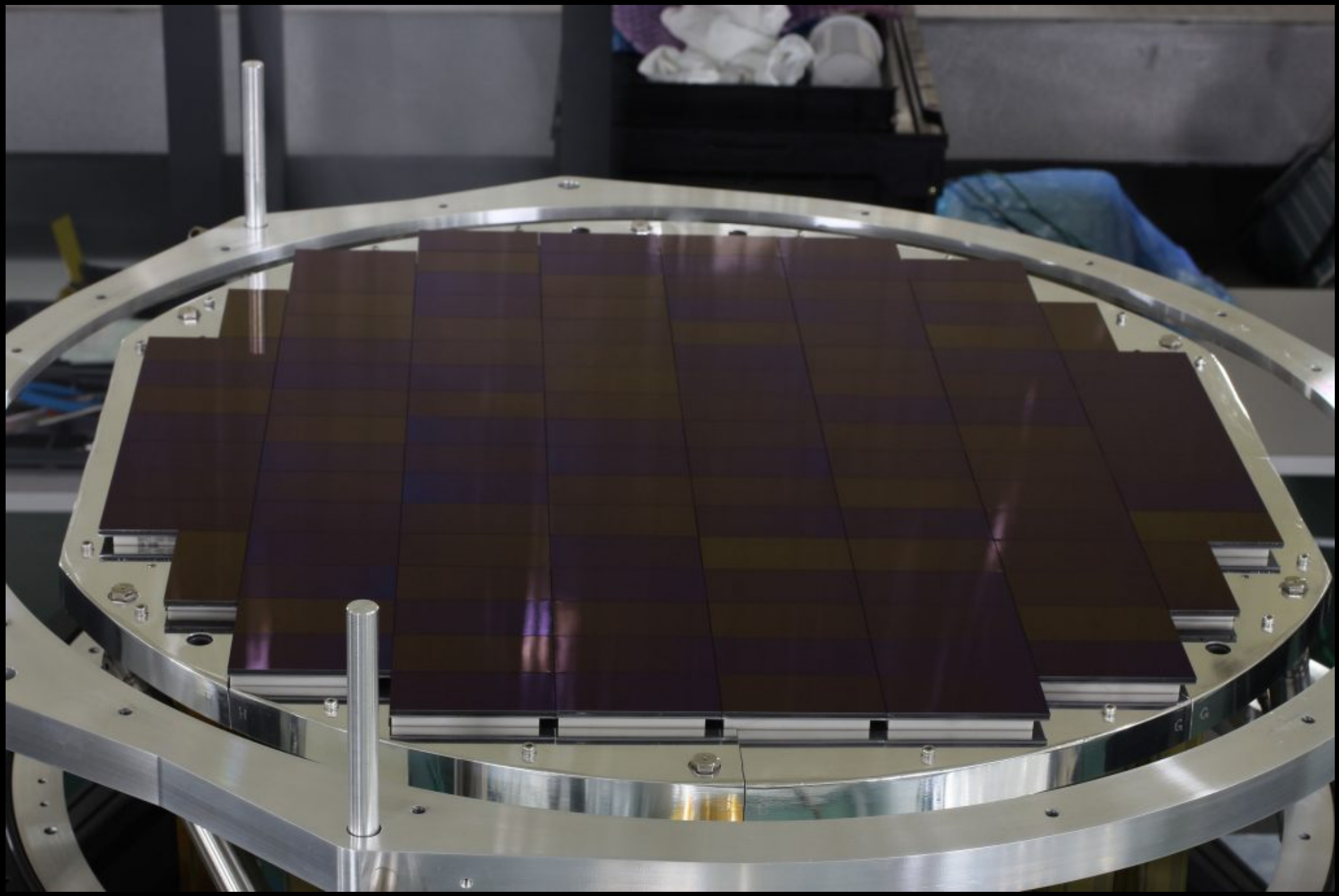



ACS/HST field of view

Camera body

Wide-field corrector

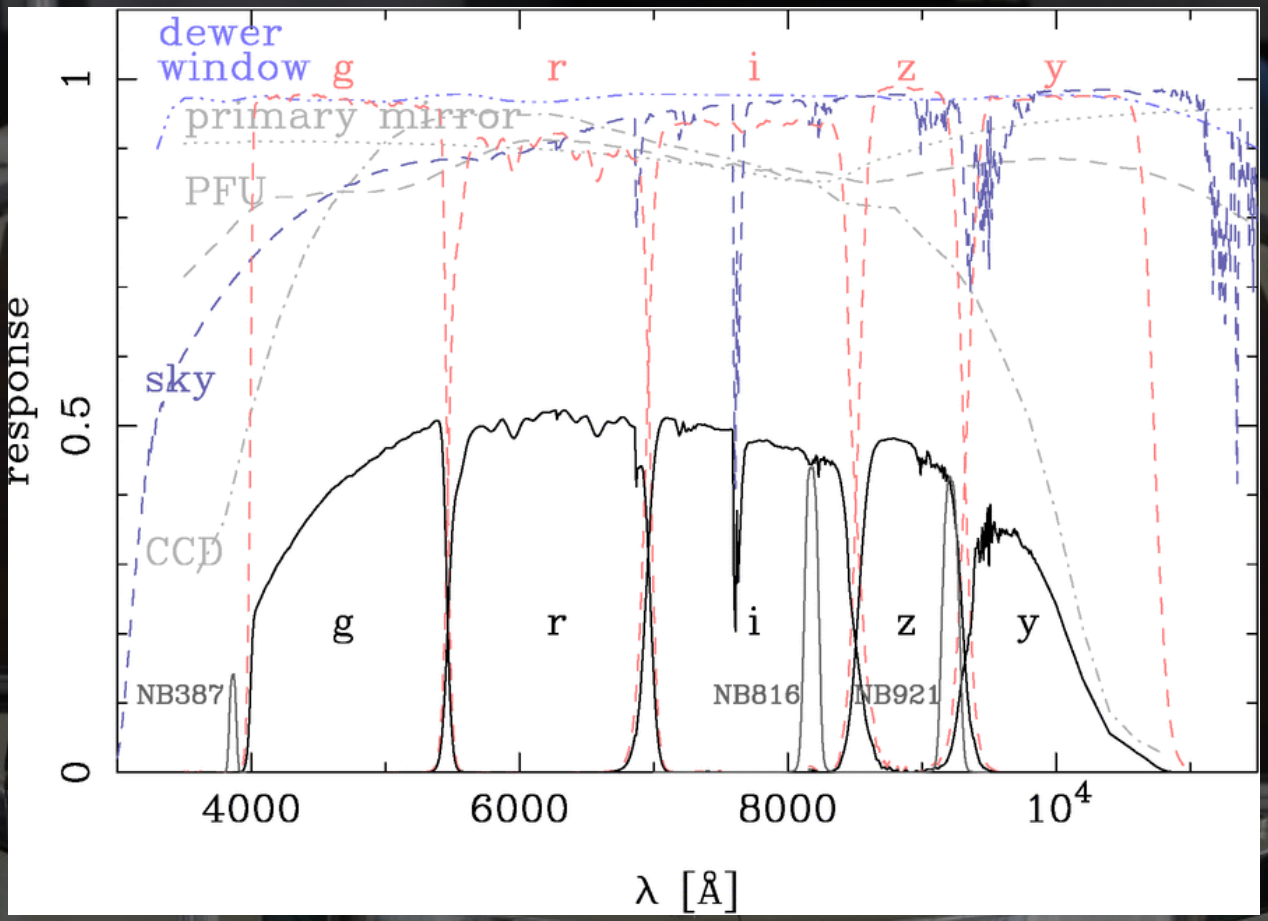
104 full depletion science CCDs. 12 CCDs for guiding and focusing.

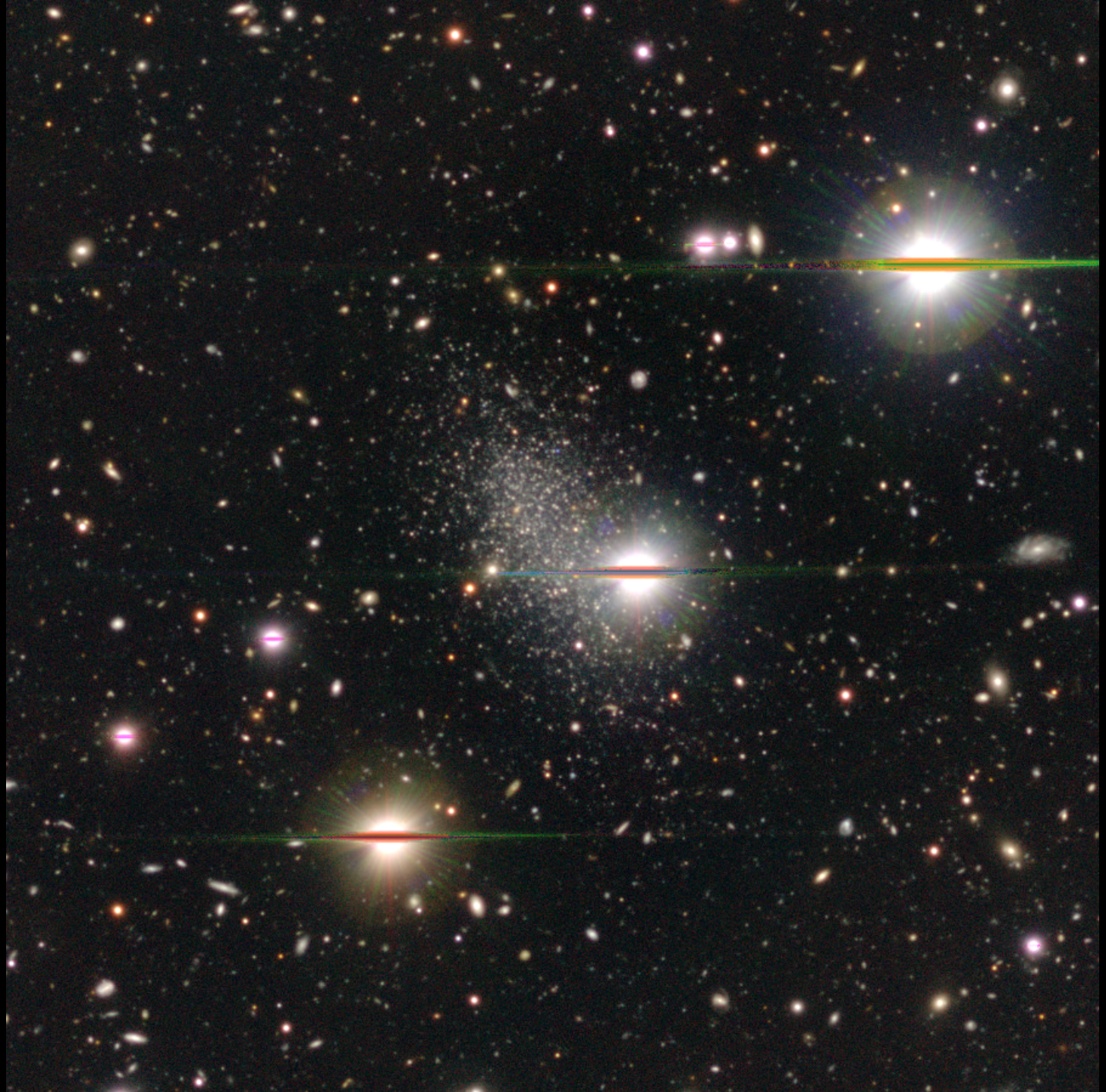


104 full depletion science CCDs. 12 CCDs for guiding and focusing.

HSC filter system

5 broad-band filters (grizy) and several narrow-band filters.





HSC Strategic Survey

Check out our website: http://hsc.mtk.nao.ac.jp/

Group photo from the HSC collaboration meeting at IPMU in August

Subaru Strategic Program

International collaboration of **all Japan**, Princeton, and Taiwan.

Over 170 scientists are putting efforts in a huge observing program of 300 nights over 5-6 years. The survey started in March 2014 and it is about 30% done.

SSP proposal

Wide-field imaging with Hyper Suprime-Cam: Cosmology and Galaxy Evolution

A Strategic Survey Proposal for the Subaru Telescope

PI: Satoshi Miyazaki (NAOJ)
Co-PI: Ikuru Iwata (NAOJ)

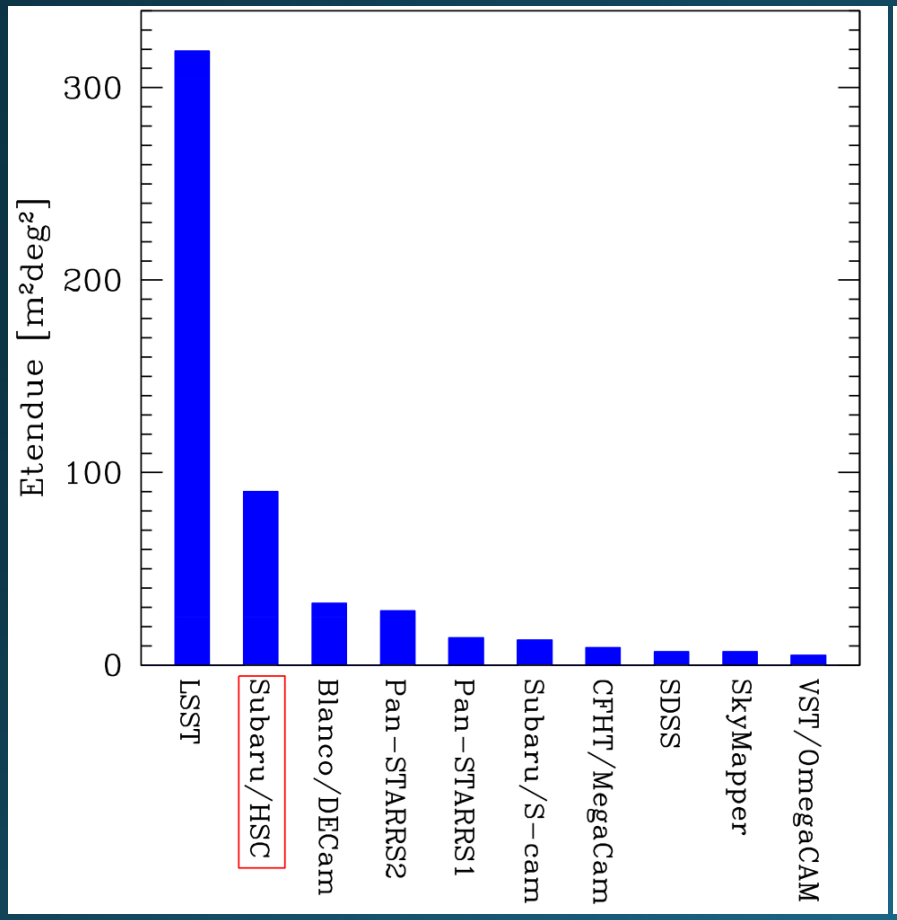
The HSC collaboration team[1]: S. Abe[(1)], H. Aihara[⋆(2),(3)], M. Akiyama[(4)], K. Aoki[(5)], N. Arimoto[⋆(5)], N. A. Bahcall[(6)], S. J. Bickerton[(3)], J. Bosch[(6)], K. Bundy[†(3)], C. W. Chen[(7)], M. Chiba[†(4)], T. Chiba[(8)], N. E. Chisari[(6)], J. Coupon[(7)], M. Doi[(2)], M. Enoki[(9)] S. Foucaud[(10)], M. Fukugita[(3)], H. Furusawa[†(5)], T. Futamase[(4)], R. Goto[(2)], T. Goto[(11)], J. E. Greene[(6)], J. E. Gunn[†(6)], T. Hamana[†(5)], T. Hashimoto[(2)], M. Hayashi[(5)], Y. Higuchi[(2),(5)], C. Hikage[(12)], J. C. Hill[(6)], P. T. P. Ho[⋆(7)], B. C. Hsieh[(7)], K. Y. Huang[†(7)], H. Ikeda[(13)], M. Imanishi[(5)], N. Inada[(14)], A. K. Inoue[(15)], W.-H. Ip[(1)], T. Ito[(5)], K. Iwasawa[(16)], M. Iye[(5)], H. Y. Jian[(17)], Y. Kakazu[(18)], H. Karoji[(3)], N. Kashikawa[(5)], N. Katayama[(3)], T. Kawaguchi[(19)], S. Kawanomoto[(5)], I. Kayo[(20)], T. Kitayama[(20)], G. R. Knapp[(6)], T. Kodama[(5)], K. Kohno[(2)], M. Koike[(5)], E. Kokubo[(5)], M. Kokubo[(2)], Y. Komiyama[(5)], A. Konno[(2)], Y. Koyama[(5)], C. N. Lackner[(3)], D. Lang[(6)], A. Leauthaud[†(3)], M. J. Lehner[(7)], K.-Y. Lin[(7)], L. Lin[(7)], Y.-T. Lin[†(7)], C. P. Loomis[(6)], R. H. Lupton[†(6)], P. S. Lykawka[(21)], K. Maeda[(3)], R. Mandelbaum[†(22)], Y. Matsuda[(5)], K. Matsuoka[(13),(23)], Y. Matsuoka[(12)], S. Mineo[(2)], T. Minezaki[(2)], H. Miyatake[(6)], R. Momose[(2)], A. More[(3)], S. More[(3)], T. J. Moriya[(3)], T. Morokuma[†(2)], H. Murayama[⋆(3)], K. Nagamine[(24)], T. Nagao[†(23)], S. Nagataki[(23)], Y. Naito[(2)], K. Nakajima[(2)], F. Nakata[(5)], H. Nakaya[(5)], T. Namikawa[(2)], C.-C. Ngeow[(1)], T. Nishimichi[(3)], H. Nishioka[(7)], A. J. Nishizawa[†(3)], K. Nomoto[(3)], M. Oguri[†(3)], A. Oka[(2)], N. Okabe[(7)], S. Okamoto[(25)], S. Okamura[(26)], J. Okumura[(23)], S. Okumura[(27)], Y. Okura[(5)], Y. Ono[(2)] M. Onodera[(28)], K. Ota[(23)], M. Ouchi[†(2)], S. Oyabu[(12)], P. A. Price[(6)], R. Quimby[(3)], C. E. Rusu[(2),(5)], S. Saito[(29)], T. Saito[(3)], Y. Saitou[(30)], M. Sato[(12)], T. Shibuya[(5)], K. Shimasaku[†(2)], A. Shimono[(3)], S. Shinogi[(2)], M. Shirasaki[(2)], J. D. Silverman[(3)], D. N. Spergel[⋆(6),(3)], M. A. Strauss[†(6)], H. Sugai[(3)], N. Sugiyama[(12),(3)], D. Suto[(2)], Y. Suto[⋆(2)], K. Tadaki[(2)], M. Takada[†(3)], R. Takahashi[(31)], S. Takahashi[(5)], T. Takata[(5)], T. T. Takeuchi[(12)], N. Tamura[(3)], M. Tanaka[(5)], M. Tanaka[†(3)], M. Tanaka[(4)], Y. Taniguchi[(13)], A. Taruya[(2)], T. Terai[(5)], Y. Terashima[(13)], N. Tominaga[(32)], J. Toshikawa[(30)], T. Totani[(23)], M. Tsai[(1)], E. L. Turner[⋆(6)], Y. Ueda[(23)], K. Umetsu[(7)], Y. Urata[†(1)], Y. Utsumi[(5)], B. Vulcani[(3)], K. Wada[(33)], S.-Y. Wang[(7)], W.-H. Wang[(7)], T. Yamada[(4)], Y. Yamada[(5)], K. Yamamoto[(34)], H. Yamanoi[(5)], C.-H. Yan[(7)], N. Yasuda[†(3)], A. Yonehara[(35)], F. Yoshida[†(5)], N. Yoshida[(2)], M. Yoshikawa[(36)], S. Yuma[(2)] (1) NCU, Taiwan (2) Tokyo (3) Kavli IPMU (4) Tohoku (5) NAOJ (6) Princeton (7) ASIAA (8) Nihon (9) Tokyo Keizai (10) NTNU, Taiwan (11) DARK, Copenhagen (12) Nagoya (13) Ehime (14) NNCT (15) Osaka Sangyo (16) Barcelona (17) NTU, Taiwan (18) Chicago (19) Tsukuba (20) Toho (21) Kinki (22) CMU (23) Kyoto (24) Las Vegas (25) KIAA, China (26) Hosei (27) ISCA (28) ETH (29) Berkeley (30) CUAS (31) Hirosaki (32)

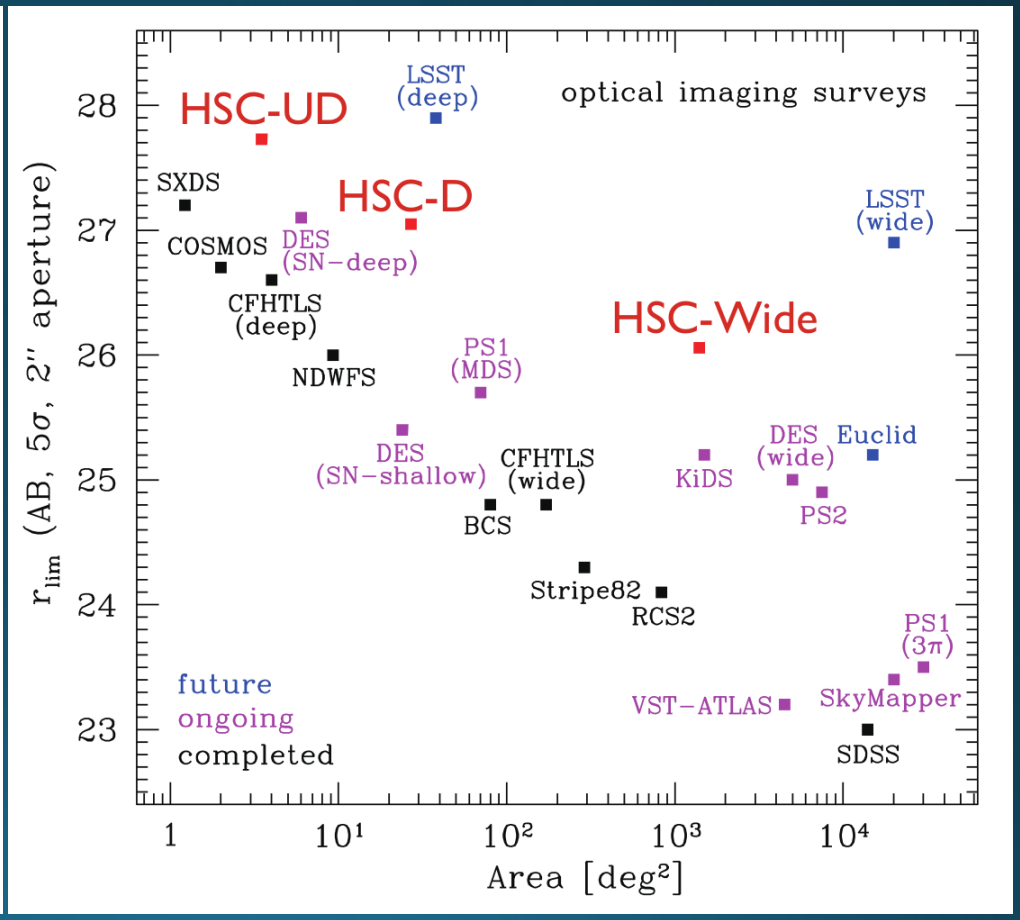
PRINCETON UNIVERSITY

ACADEMIA SINICA 1928

boration meeting at IPMU in August

Survey power

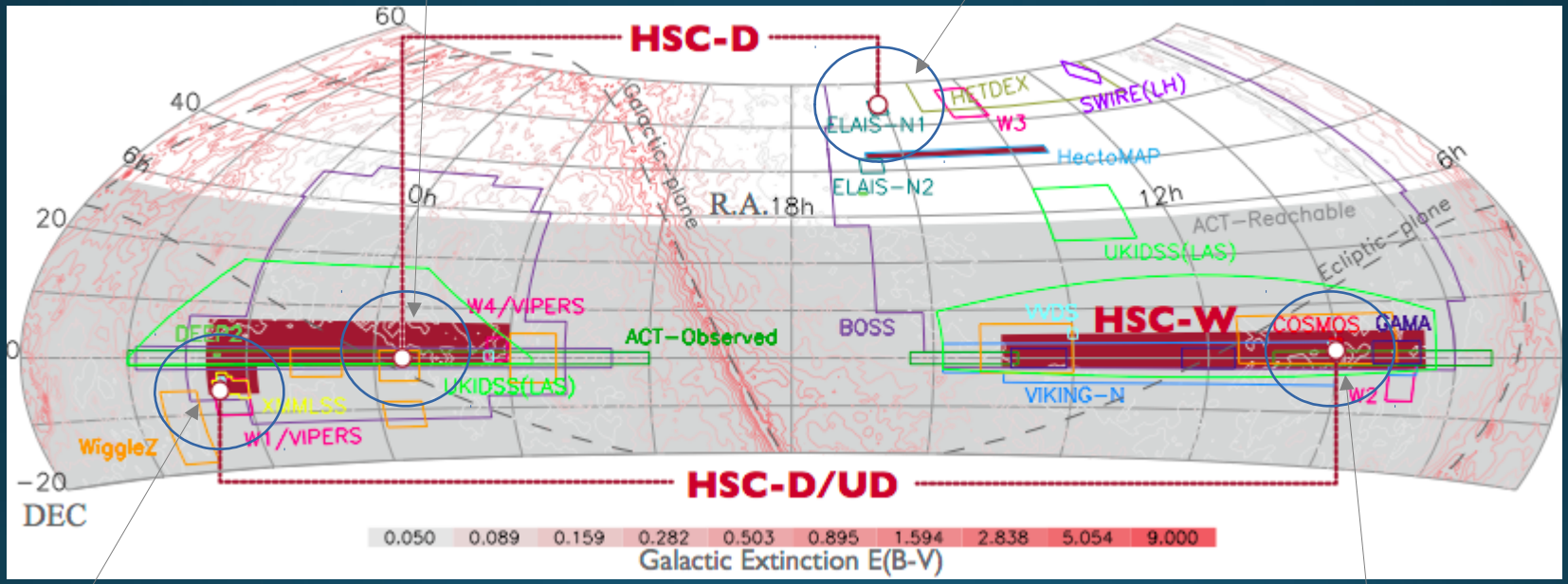




Survey fields

DEEP2-F3 (D)

ELIAS-N1 (D)



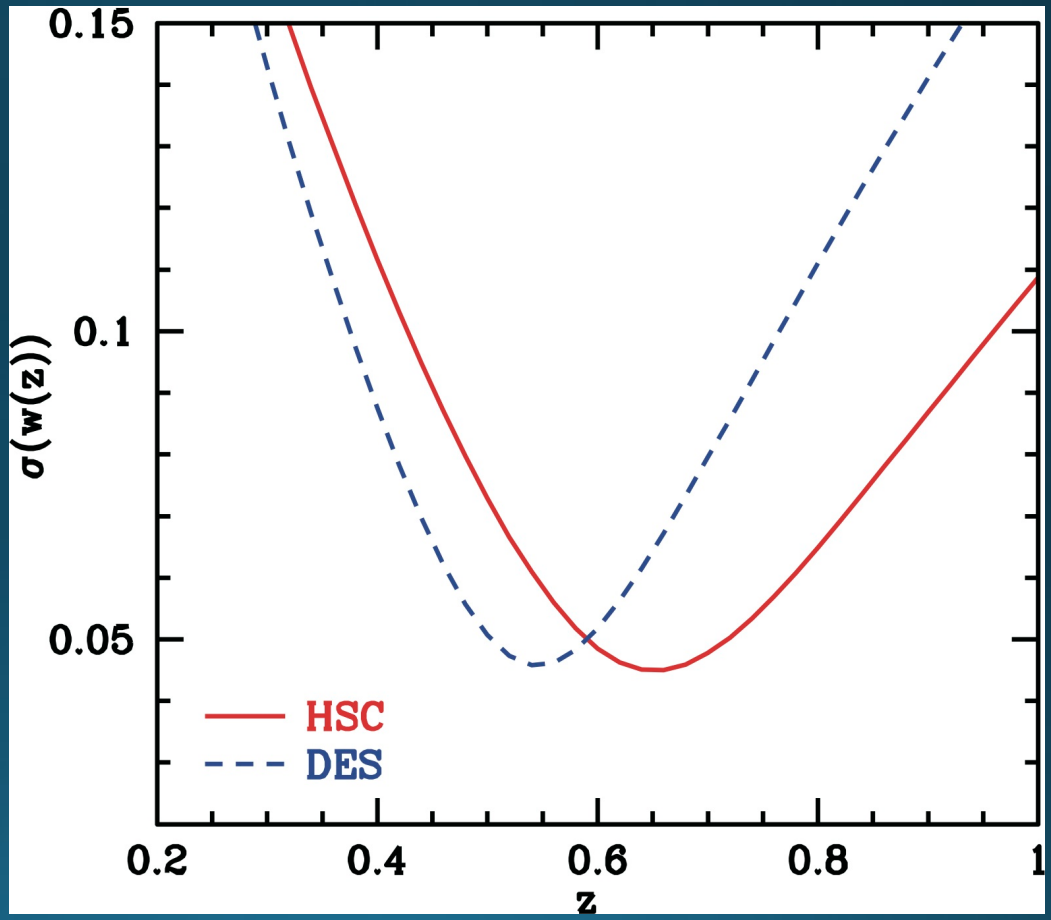
SXDS (UD)
XMMLSS (D)

- Full overlap with SDSS
- Low dust extinction
- Wide R.A. range
- Overlap with other NIR, spec, etc surveys.

COSMOS (UD)
E-COSMOS (D)

Science goals

- **Weak-lensing cosmology**
- High-redshift galaxies
- Galaxy evolution
- Clusters of galaxies
- Transient objects
- Solar system bodies
- AGN/QSO
- Milky Way
- Strong lensing
- ...



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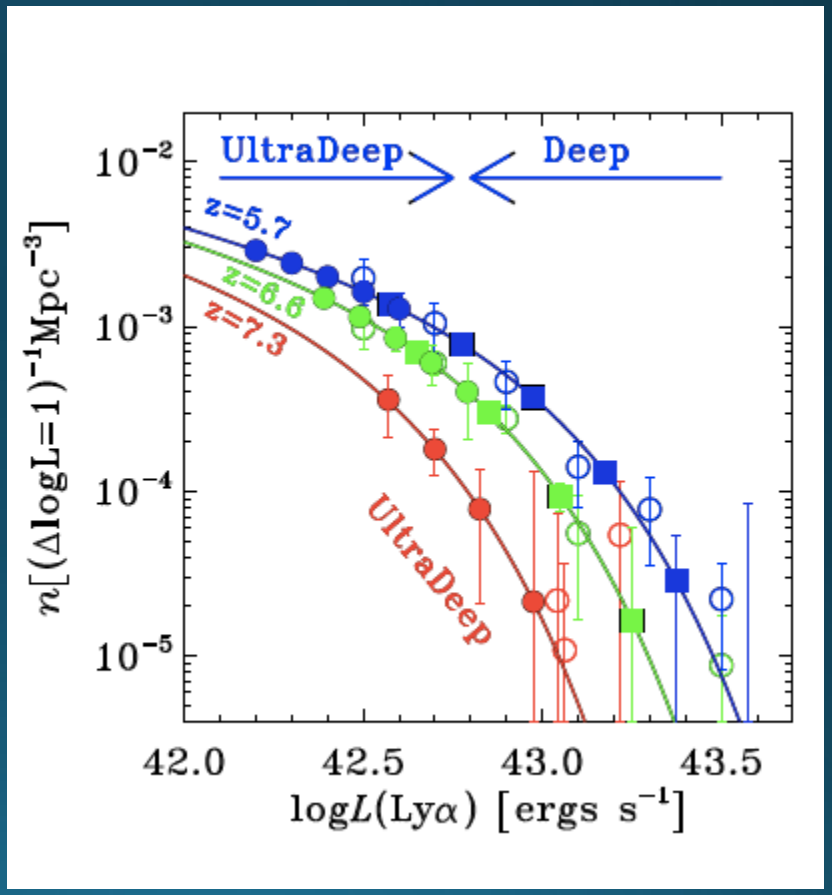

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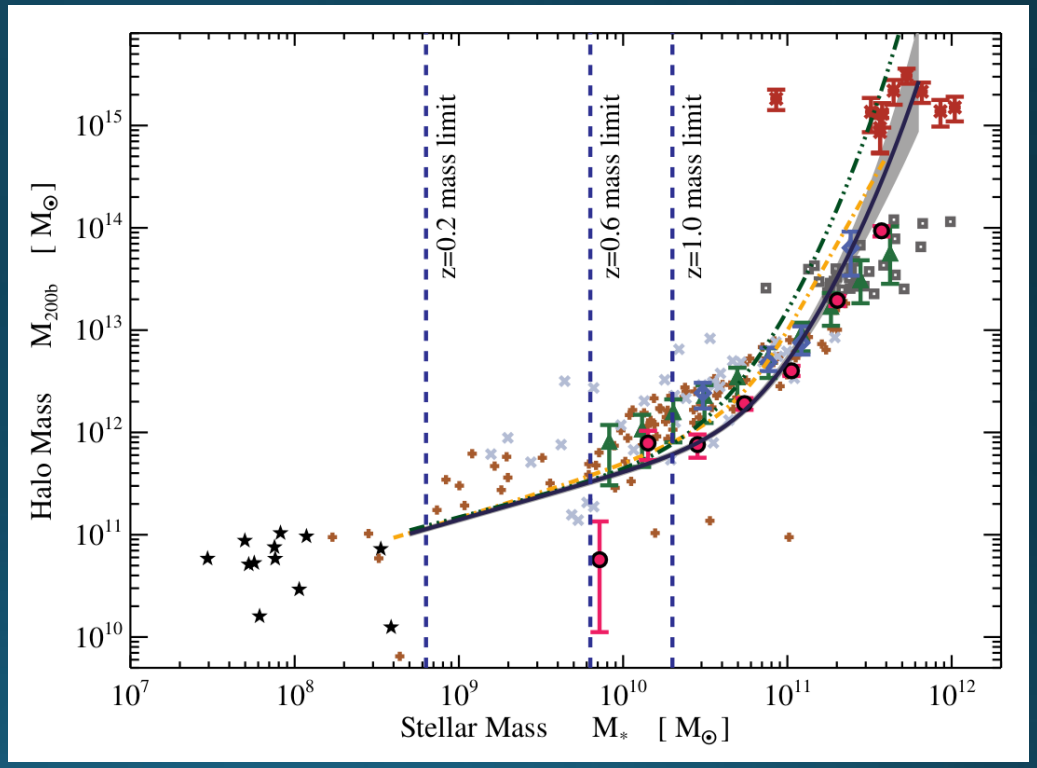
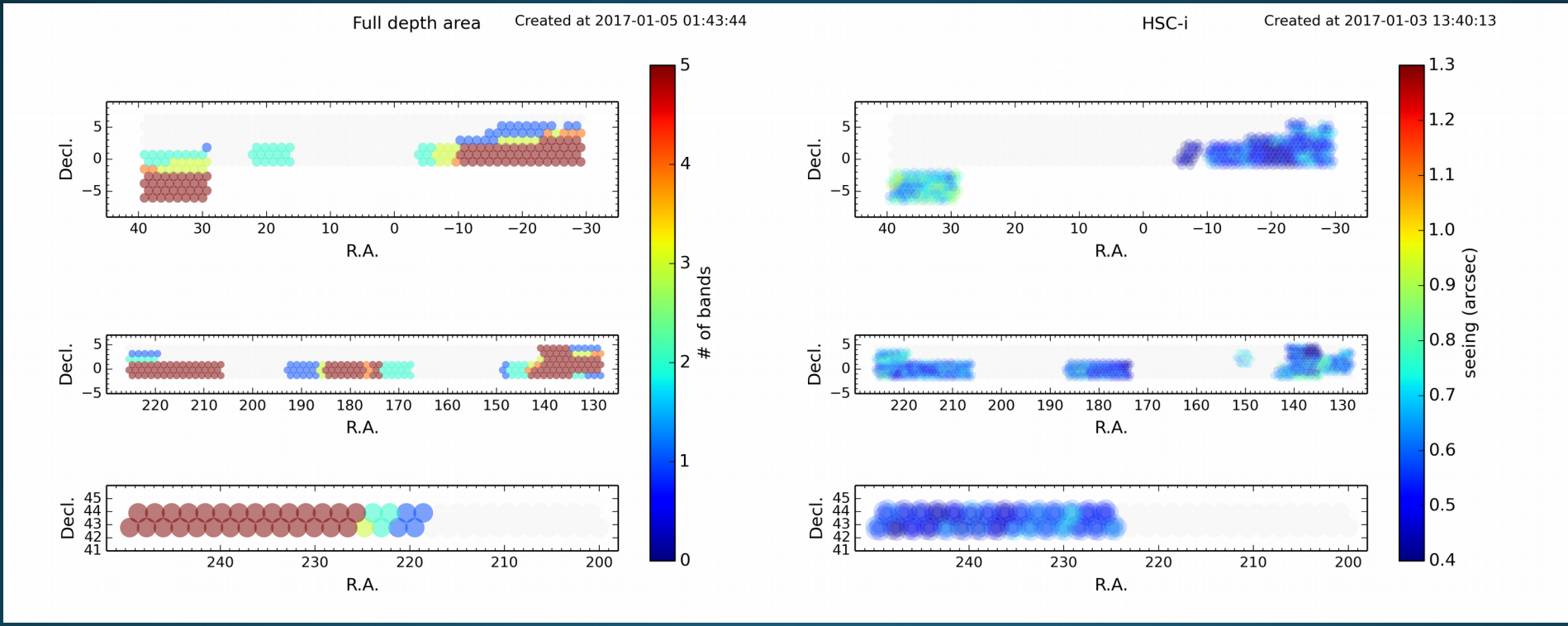
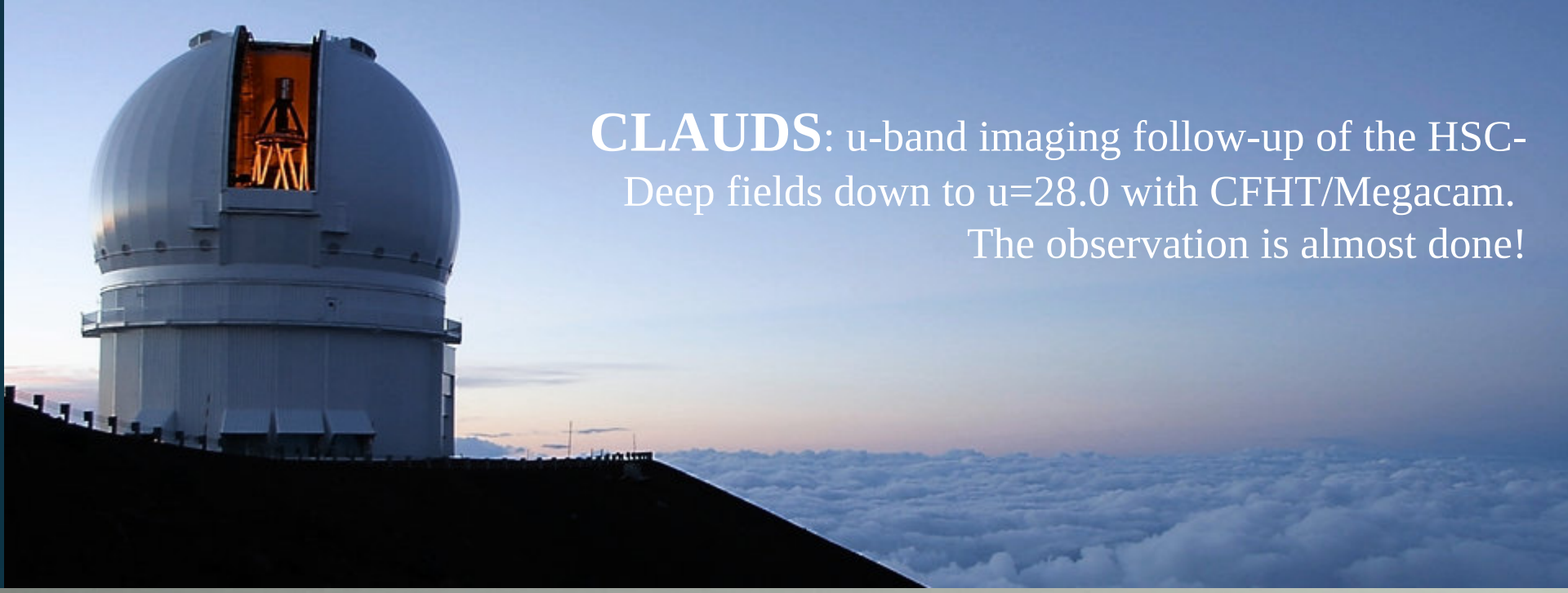


Survey progress



~250 square degrees surveyed so far. Note the excellent seeing!

Figure courtesy: Yasuda-san.



CLAUDS: u-band imaging follow-up of the HSC-Deep fields down to u=28.0 with CFHT/Megacam.
The observation is almost done!

JHK follow-up of the HSC-Deep fields with UKIRT/WFCAM.
2 hours in each band. We are making good progress!

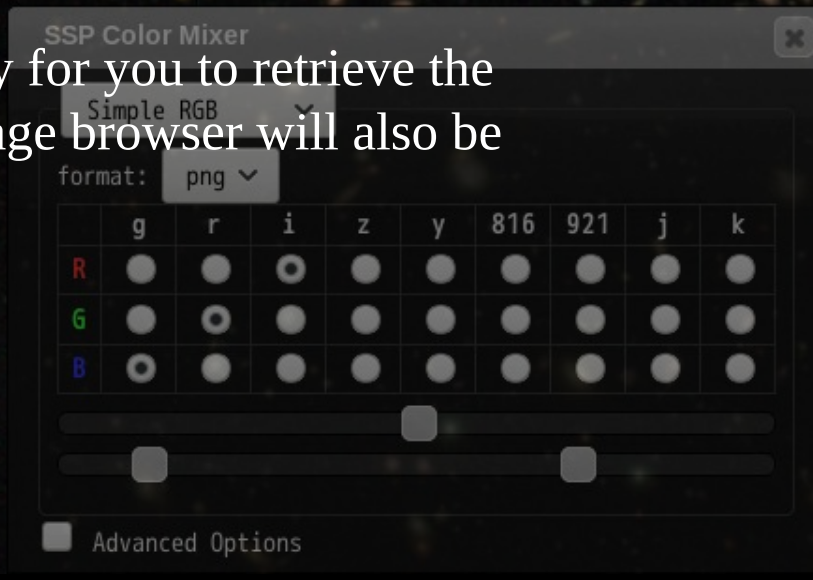
First public data release from HSC

We are going to make the first public data release in February 2017!

The release will include data taken up to Nov 2015 and the processed images and catalogs as well as raw data will be made available to the community. We will release ~100 square degrees of full-color full-depth data.

User-friendly web interfaces make it easy for you to retrieve the data. A super useful googleMap-like image browser will also be extremely useful.

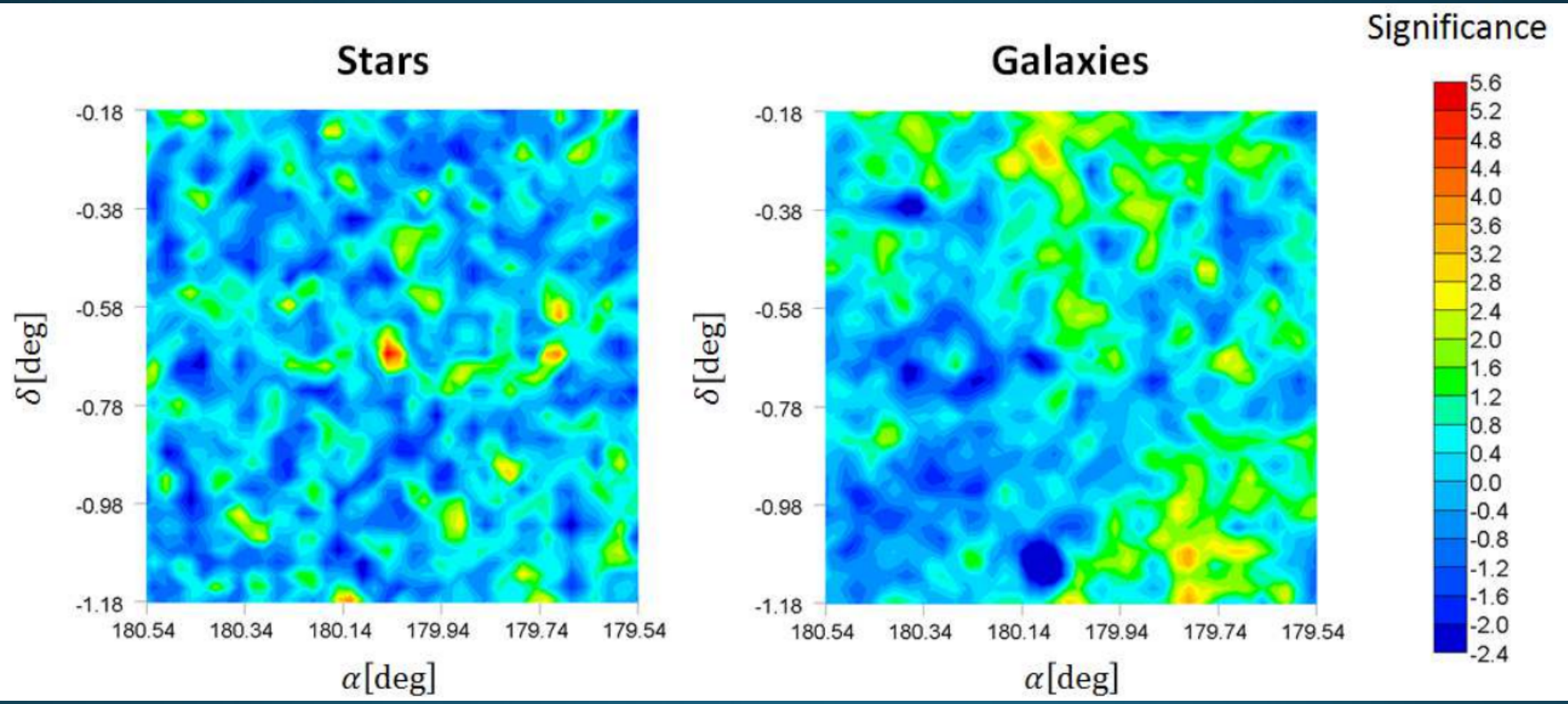
Stay tuned!



Early Science Results

A special PASJ issue is being planned for the first year science papers.

Virgo I – a new dwarf satellite of the Milky Way



Homma et al. ApJ in press (arXiv:1609.04346)

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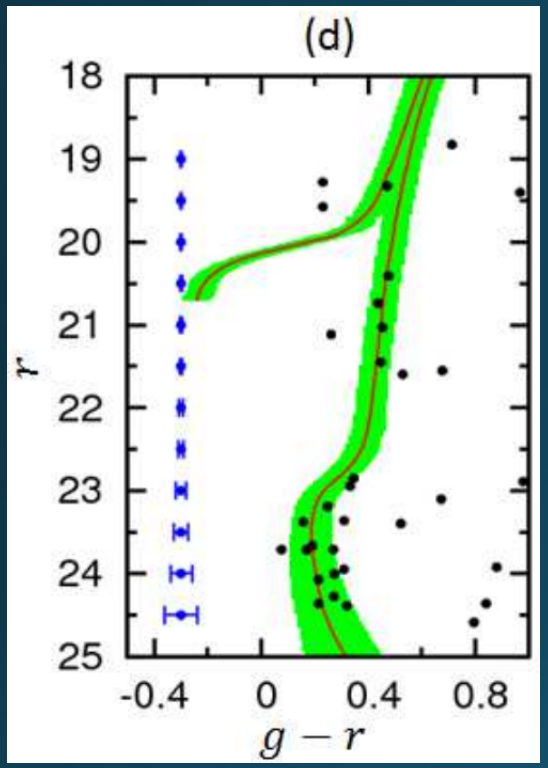
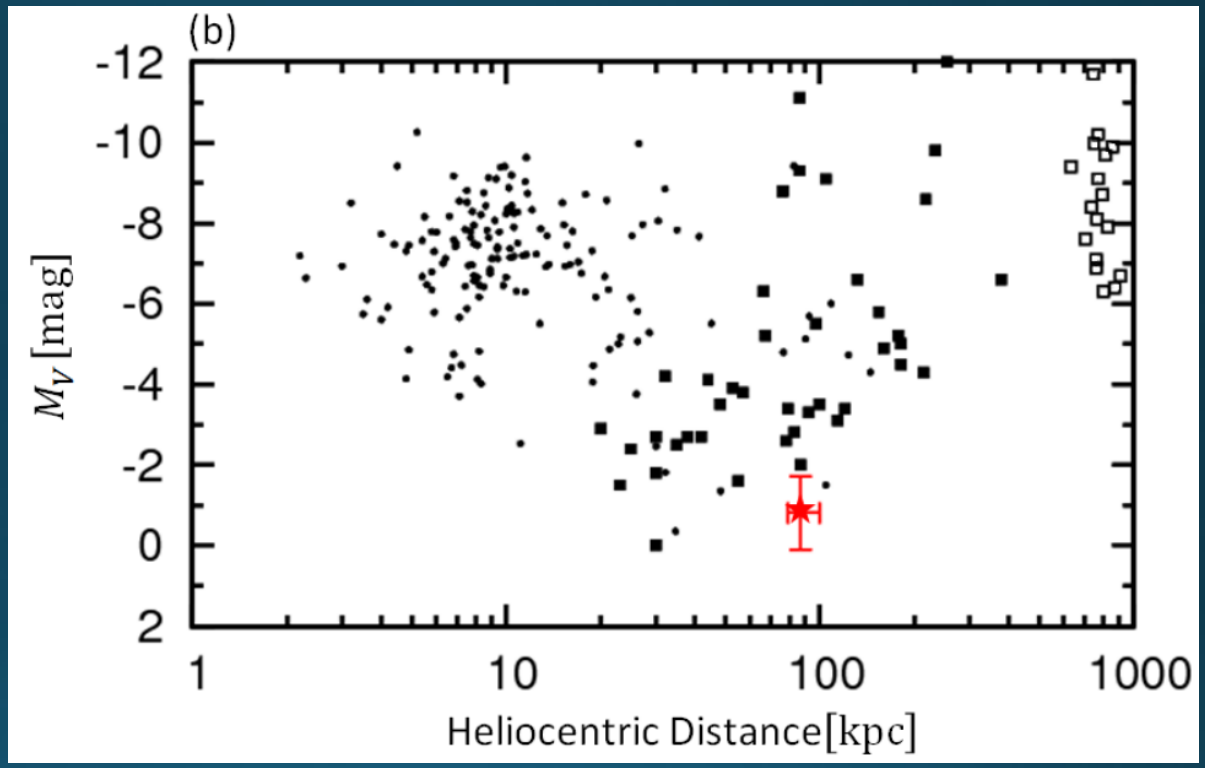


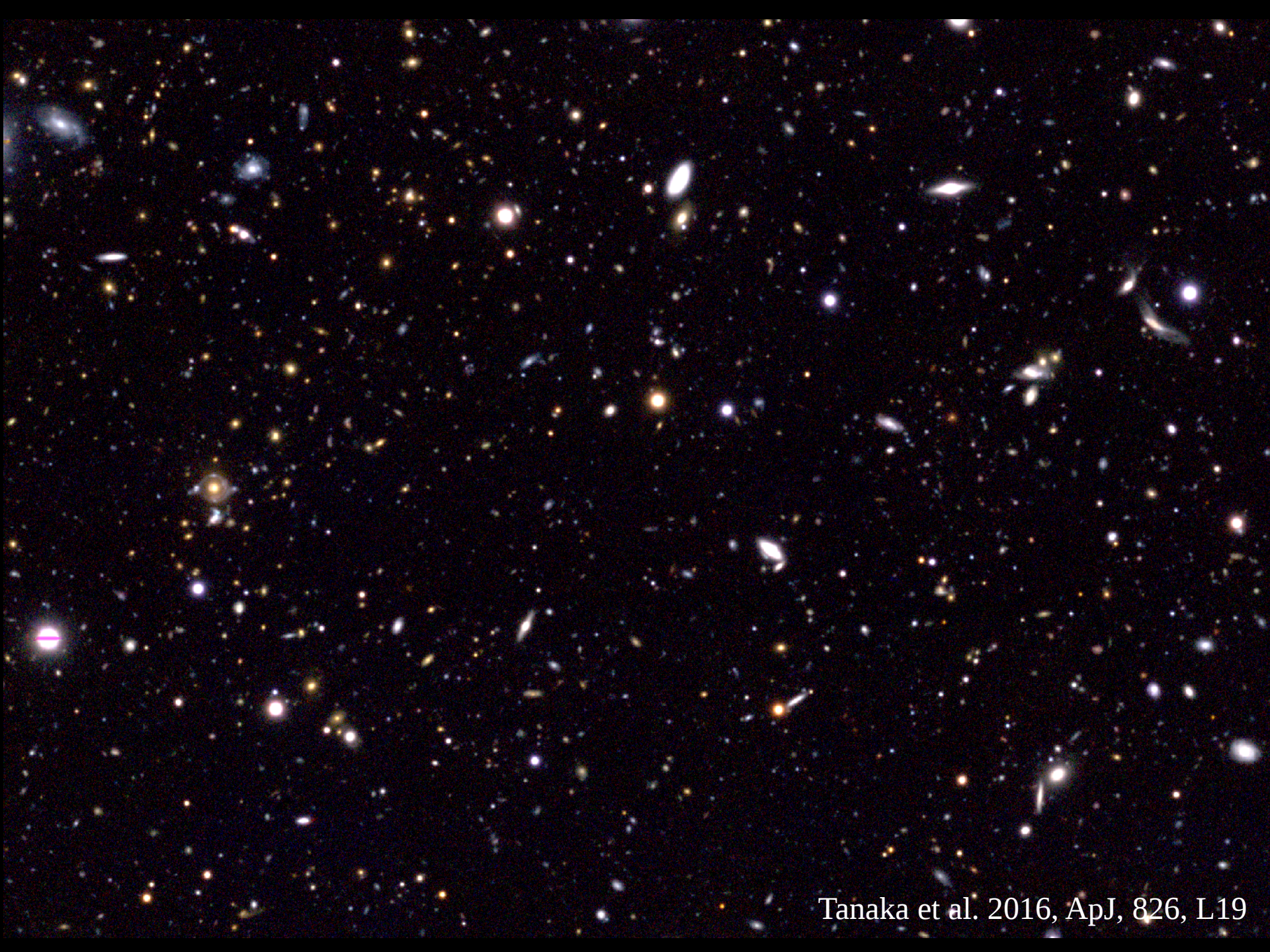


Virgo I is one of the faintest dwarf galaxy located at ~90kpc, demonstrating the power of the HSC survey.

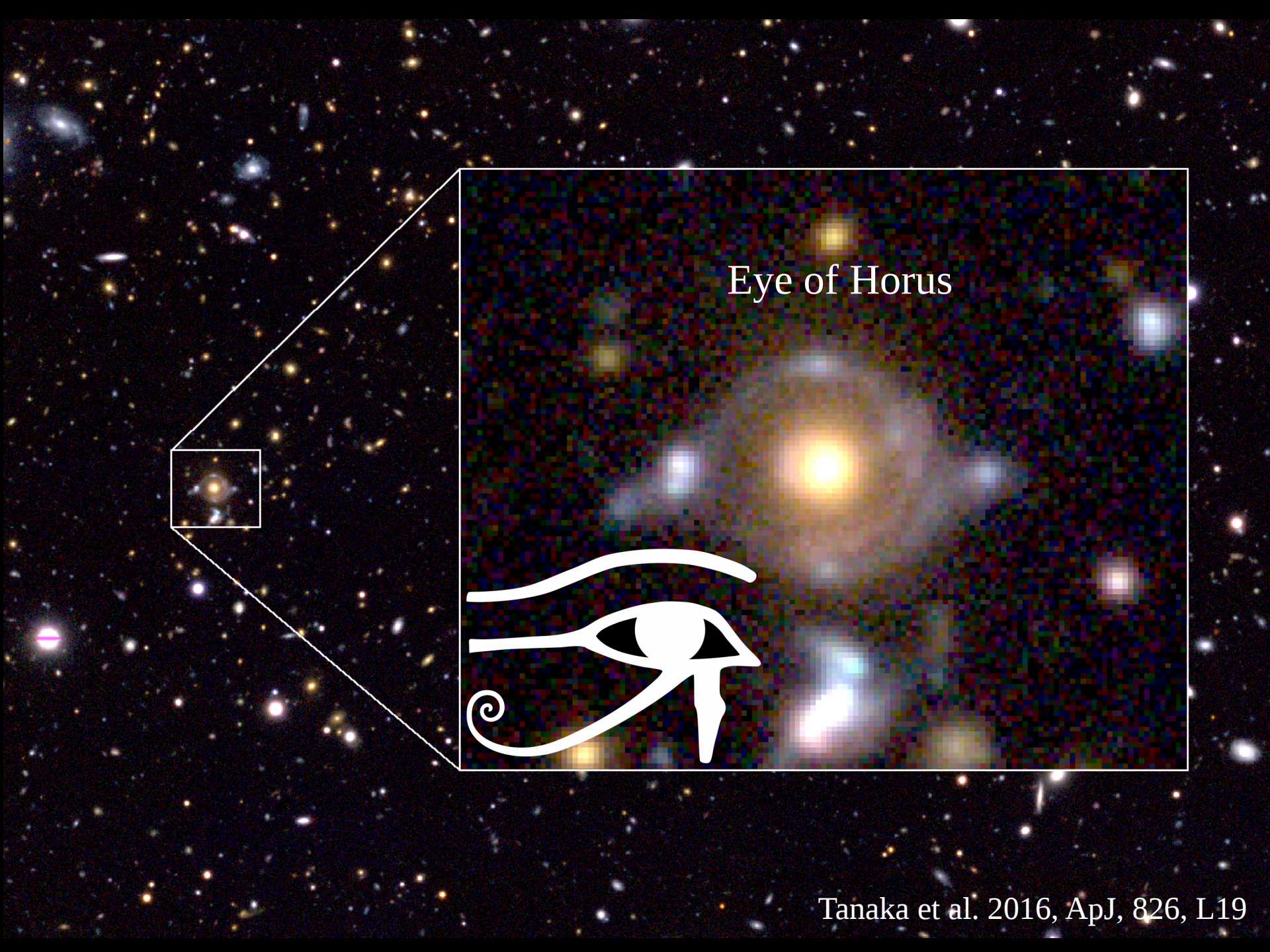
Homma et al. ApJ in press (arXiv:1609.04346)

Ultra Diffuse Galaxies

Tanaka et al. in prep.



Tanaka et al. 2016, ApJ, 826, L19



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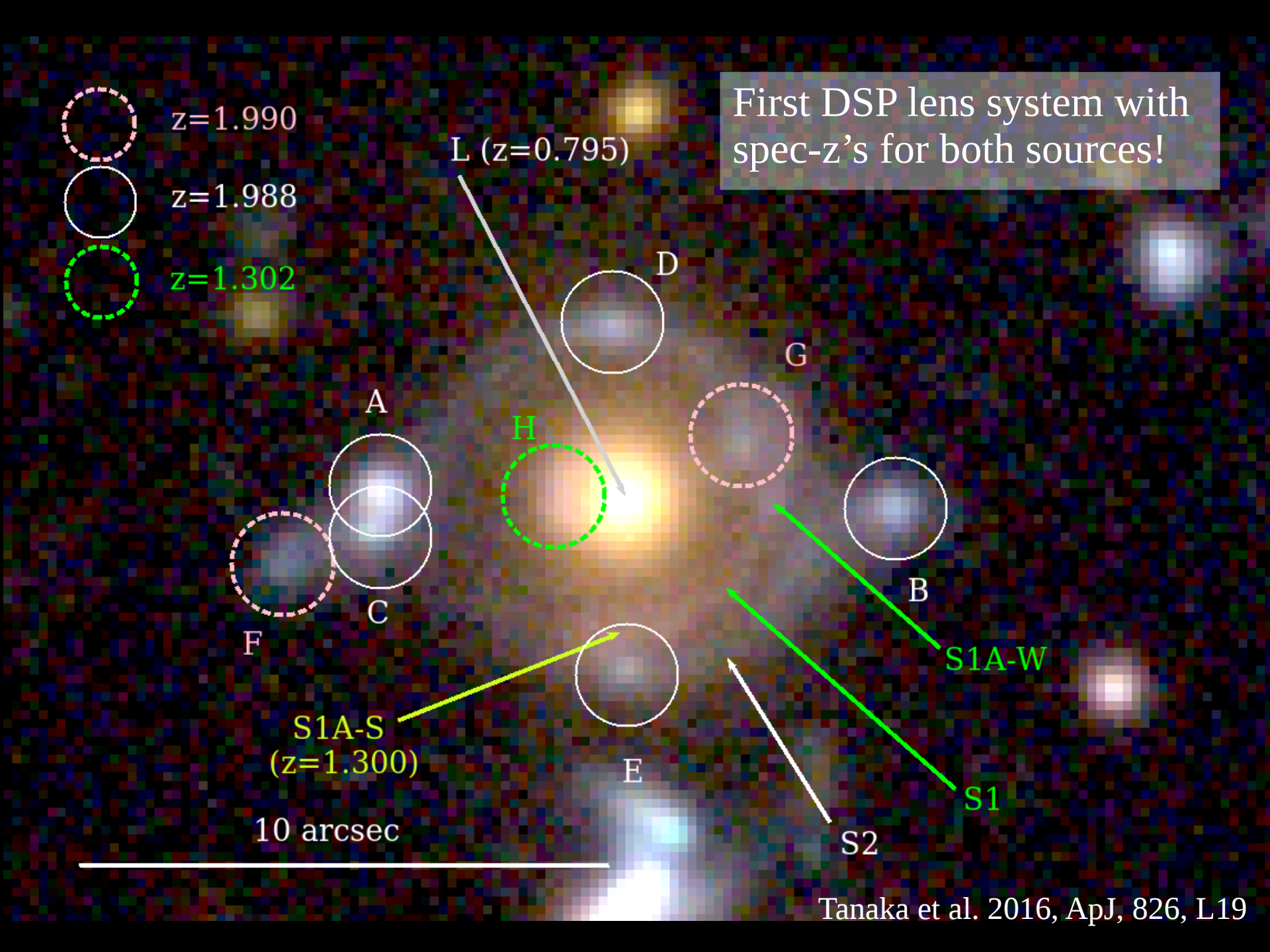
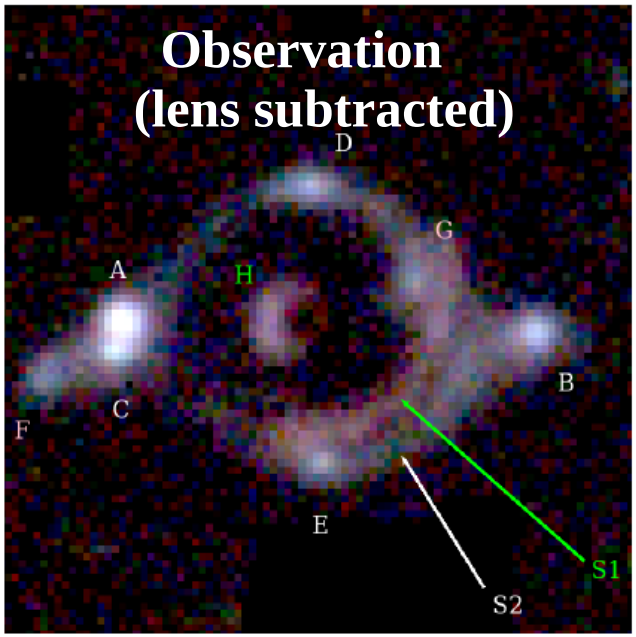
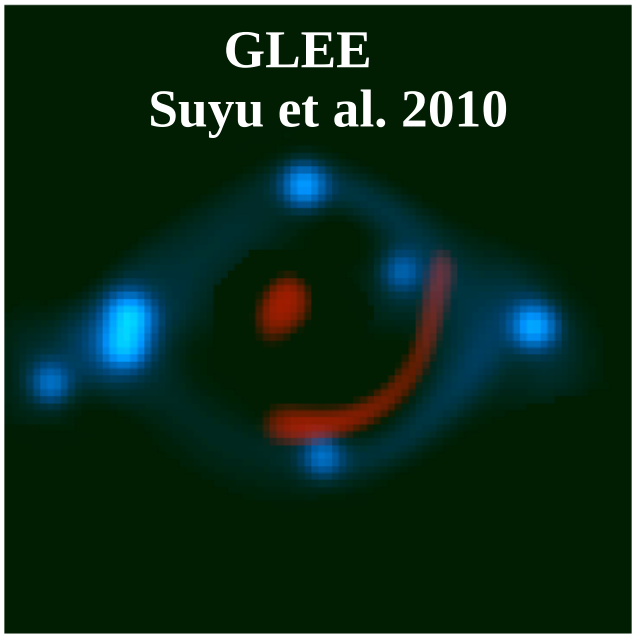
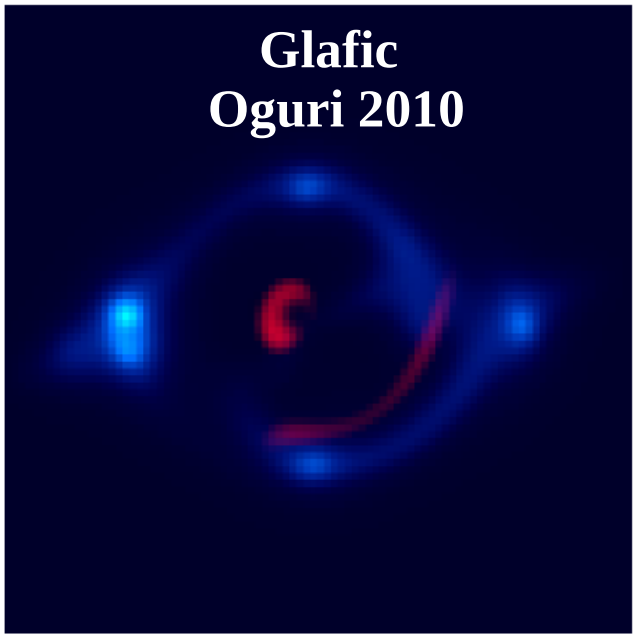


Tanaka et al. 2016, ApJ, 826, L19

Lens models







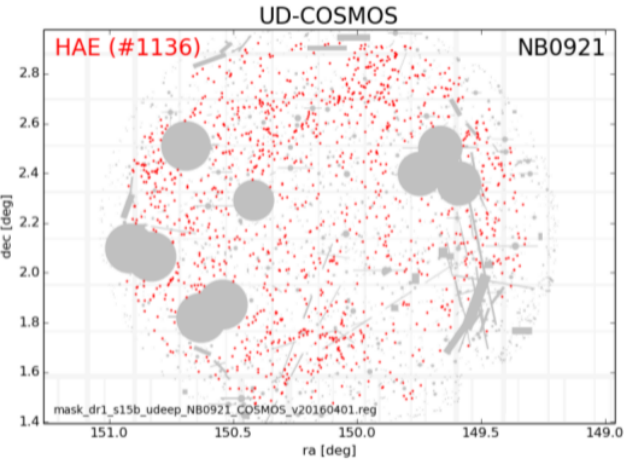
We broadly reproduce the main features of the system using two independent codes.
But, we need a subhalo to reproduce the A+C splitting.

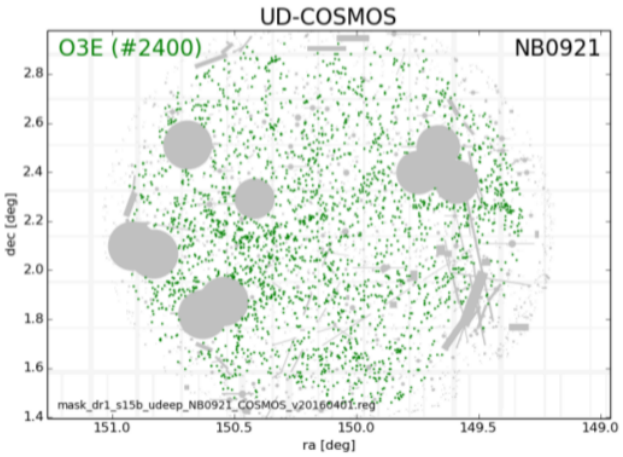
The lens is likely a cluster BCG. Need to incorporate environment effects.

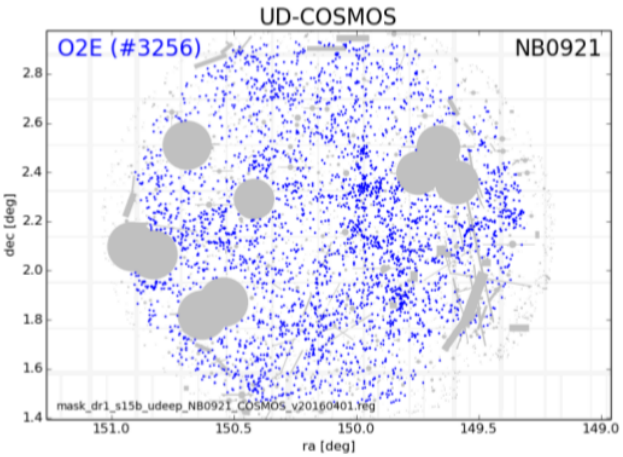
Tanaka et al. 2016, ApJ, 826, L19

Emission line objects

z~0.4 z~0.8 z~1.5



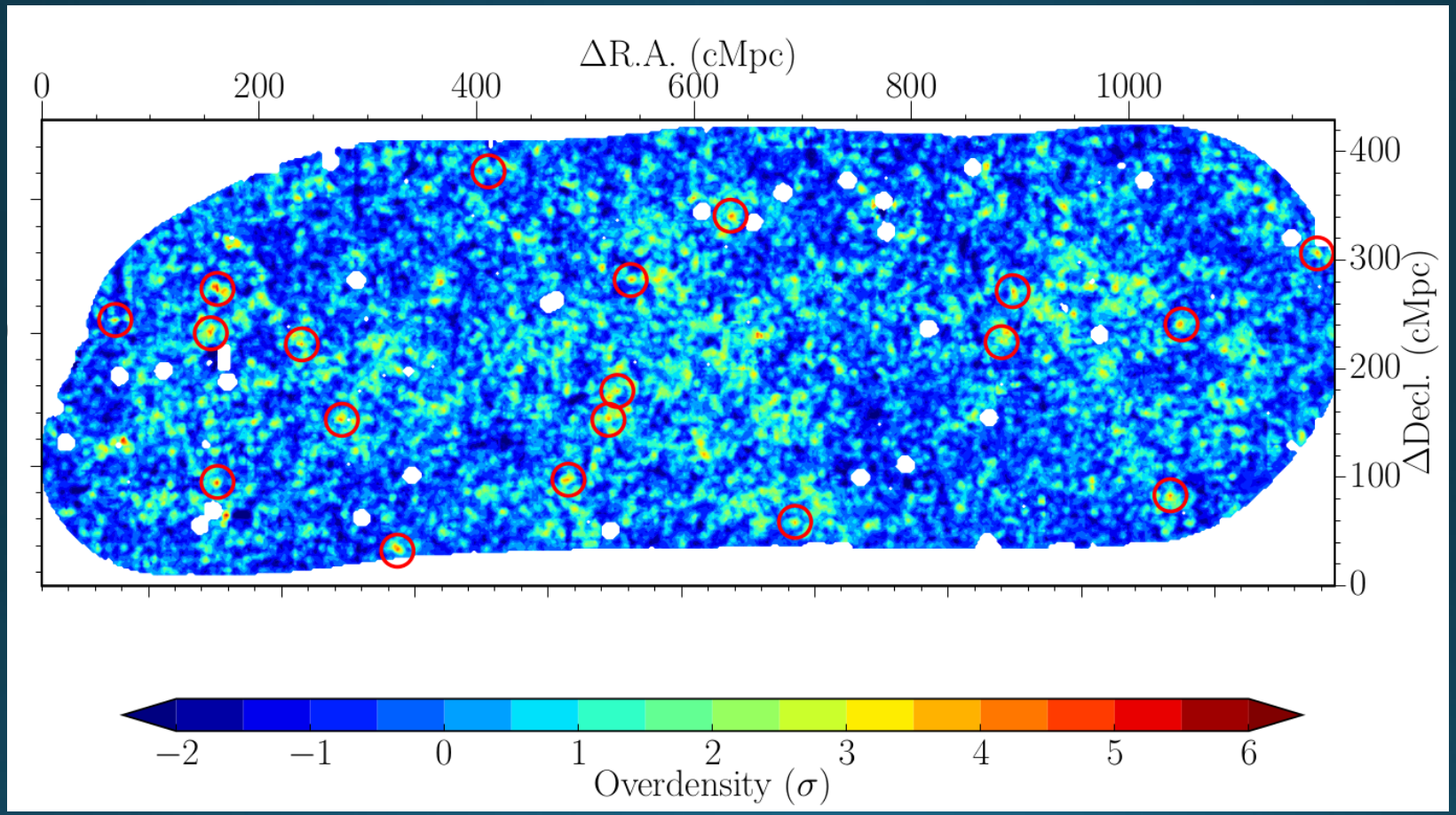




With the narrow-bands, we can detect emission line objects in narrow redshift slices to trace LSS as well as to study effects of LSS on galaxy evolution.

Hayashi et al. in prep.

Proto-clusters traced by LBGs



Over 100 proto-cluster candidates so far. Number density ~ 10^-7 Mpc^-3.
A preliminary clustering analysis suggests r_0~30 Mpc.

Toshikawa/Uchiyama et al. in prep.

...and many more!

Work in progress on

- Very massive galaxies
- Ultra Diffuse Galaxies (UDGs)
- Green peas
- Very bright Lyman alpha emitters
- Very bright Lyman break galaxies
- Solar system bodies
- Dust Obscured Galaxies (DOGs)
- QSO-galaxy cross correlation
- Hosts of radio galaxies
- Galaxy-scale strong lensing
- Cluster-scale strong lensing
- Stellar tidal streams around nearby galaxies
- Blue Horizontal Branch stars to probe the MW halo
- etc, etc, etc...

PFS-Galaxy Survey

Annual collaboration meeting around Dec
WG chair + software meeting every half a year

Extended collaboration

From Tamura-san's slide, a very old version

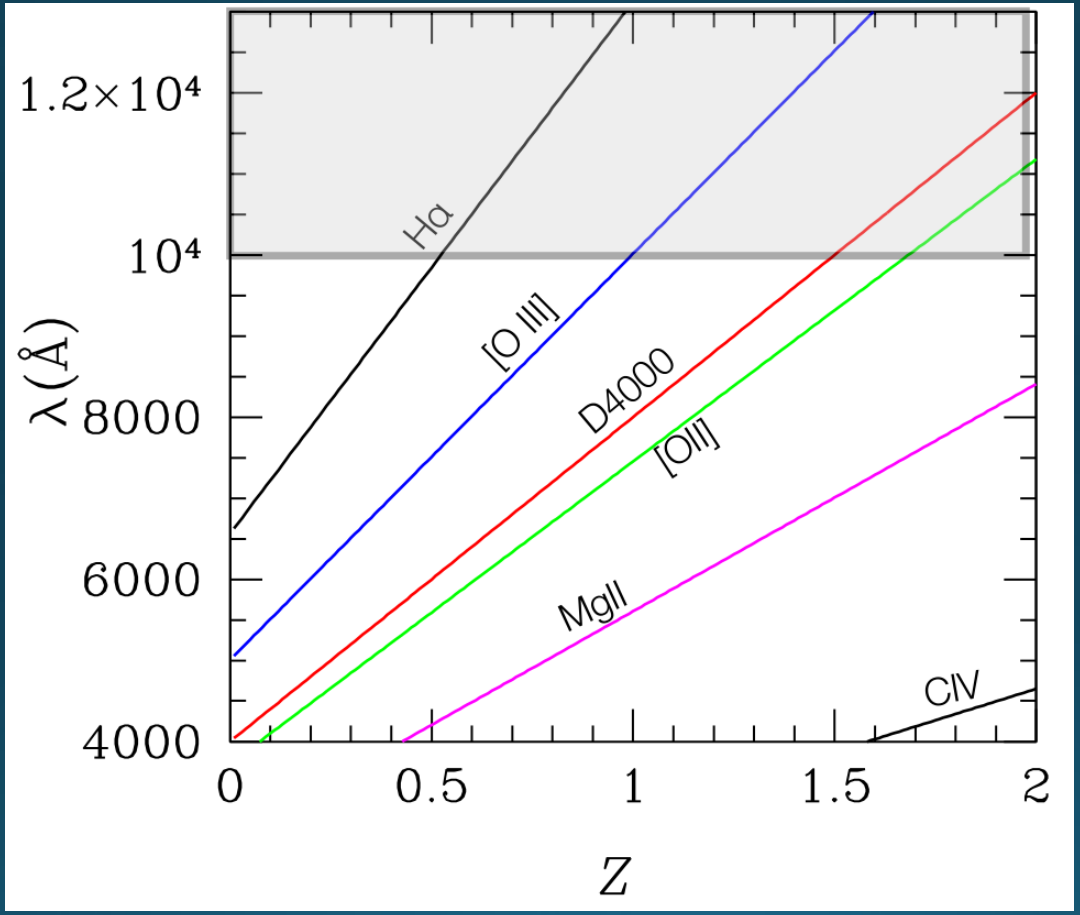
New members:

- Chinese PFS Participation Consortium
- MPE
- Northeastern Consortium?
  - Columbia
  - Connecticut
  - Dartmouth
  - Illinois
  - UMass
  - Pittsburgh
  - Tufts

PFS Instrument Parameters

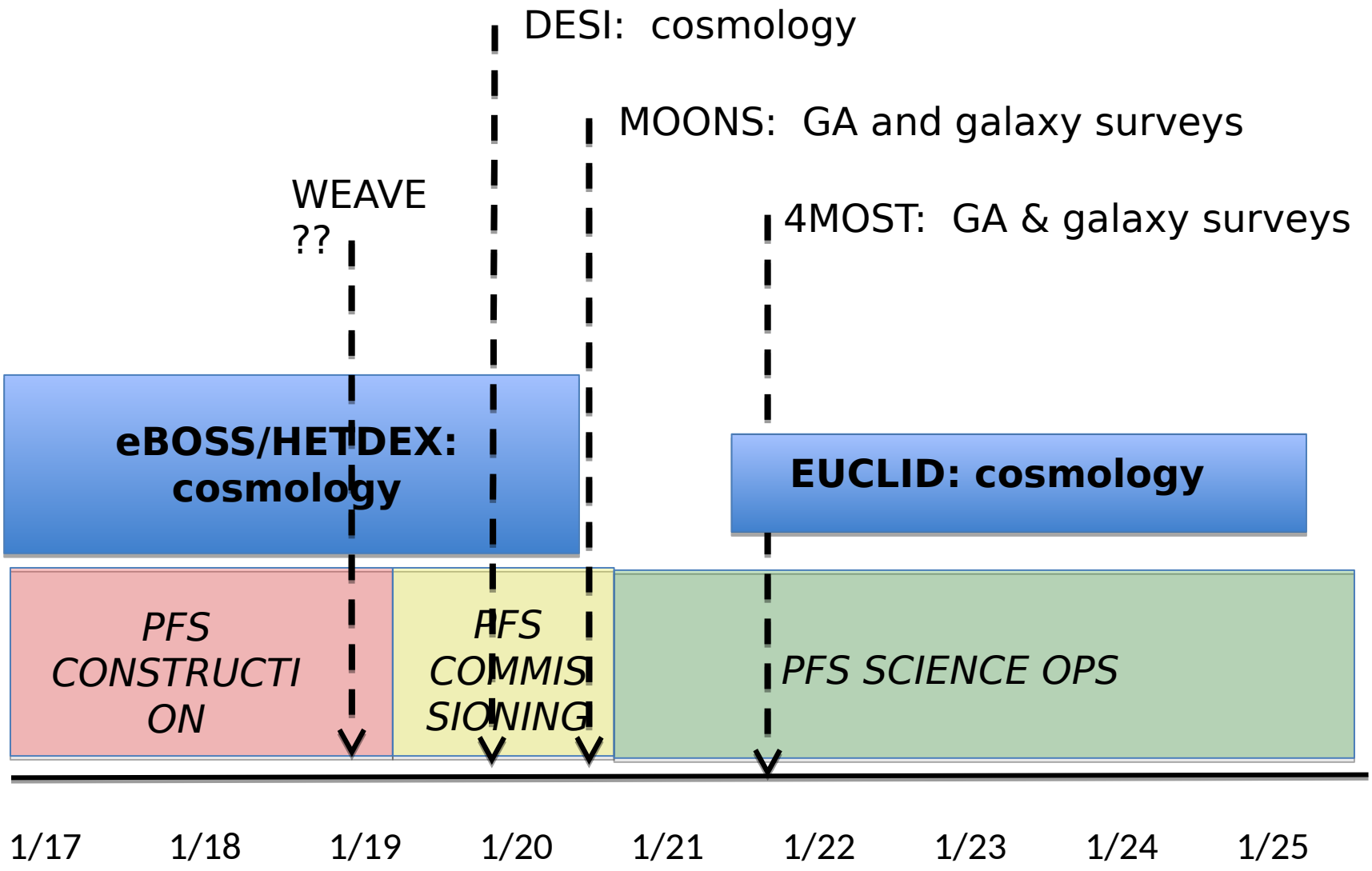
Prime Focus Instrument				
Field of view	~1.4 deg (hexagonal - diameter of circumscribed circle)			
Field of view area	~1.2 deg^2			
Input F number to fiber	2.8			
Fiber core diameter	127 μm (1.12 arcsec at the FoV center, 1.02 arcsec at the edge)			
Positioner pitch	8 mm (90.4 arcsec at the FoV center, 82.4 arcsec at the edge)			
Positioner patrol field	9.5 mm diameter (107.4 arcsec at the FoV center, 97.9 arcsec at the edge)			
Fiber minimum separation (1)	~30 arcsec			
Fiber configuration time	~60-70 sec. [TBC]			
Number of fibers	Science fibers	Fixed fiducial fiber		
	2394	96		
Fiber density	~2000 deg^{-2} / ~0.6 $arcmin^{-2}$			
Number of A&G camera (2)	6			
Field of view of A&G camera	~5.1 $arcmin^2$ per one camera			
Sensitivity of A&G camera	r'~20.0 AB mag for S/N~30 (100) in 1 (10) sec. exposure			
Spectrograph				
Spectral arms	Blue	Red		NIR
		Low Res.	Mid. Res.	
Spectral coverage	380 - 650 nm	630 - 970 nm	710 - 885 nm	940 - 1260 nm
Dispersion	~0.7 Å/pix	~0.9 Å/pix	~0.4 Å/pix	~0.8 Å/pix
Spectral resolution	~2.1 Å	~2.7 Å	~1.6 Å	~2.4 Å
Resolving power	~2300	~3000	~5000	~4300
Spectrograph throughput (3)	~58% (@500nm)	~55% (@800nm)	~52% (@800nm)	~52% (@1100nm)

Unique instrument for z~1 galaxy science



PFS covers all the important emission/absorption features of galaxies around z<~1.
An ideal instrument to follow-up ALPACA sources.

The Competition (updated)



From R. Ellis at PFS collab. Meeting

Proposal writing

Each WG submits a science document summarizing
(1) science objectives
(2) survey design and sample selection
(3) physical parameters to be measured
(4) feasibility
by June 1st, 2017.

The galaxy WG has to submit 4 smaller ones:
(a) LAEs
(b) LBGs
(c) IGM
(d) rest-frame optical at z=0.8-2

All the documents will be abstracted into the first complete SSP proposal by Dec. 2017.

Subaru Telescope
National Astronomical Observatory of Japan
650 North A'ohoku Place, Hilo, Hawaii 96720, U.S.A.

Dear PFS Collaborators,

It was a great pleasure to meet you at the PFS collaborators meeting in Taipei in December 2014. At the meeting, I enjoyed learning how evey one of you has been contributing to the PFS project.

As you remember, I repeatedly emphasized that the three pillars of the future of the Subaru telescope are:

Hyper Suprime-Cam (HSC)
Prime Focus Spectrograph (PFS)
ULTIMATE-Subaru (Ground Layer Adaptive Optics + Wide-field IR instruments)

Among them, HSC is already being used as a facility instrument, while ULTIMATE is still in the planning stage. PFS is the next instrument to be completed and I am very excited to see the progress in its development. The combination of HSC and PFS exploits the very unique features of the Subaru telescope, namely its large aperture of 8.2m with the very large field of view of 1.5 degrees. I envision a long-term future for the Subaru telescope with these instruments, especially so in the era of TMT and LSST.

I truly appreciate your effort in designing and constructing the PFS instrument, as well as raising funds for it. You have made substantial contributions already to the project and all of us at the Subaru Telescope are delighted to start working with you to make it available to the community.

Given the substantial contributions you have already made, and the uniqueness and anticipated power of the instrument, it is obvious that we should use PFS for a large-scale survey project. Using targets selected from the currently running HSC Subaru Strategic Program (SSP), PFS will follow up with spectroscopy for three major science programs, cosmology, galaxy evolution, and galactic archaeology. All of you should be partners in the survey.

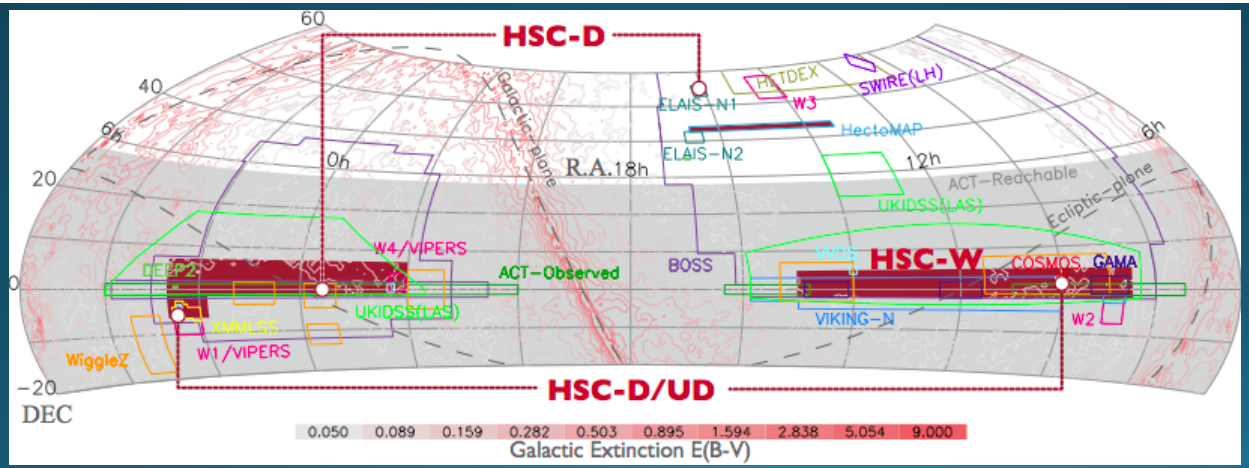
I cannot imagine that the survey using PFS should be less than 300 nights, and we have recently initiated discussions with the Subaru users community as well as the Subaru Advisory Committee (SAC) whether we could increase the number of nights for such a survey. Even though the final approval of a PFS SSP depends on the outcome of an external review of the proposal, I believe it is safe to say that a 300-night survey is a near certainty, and an expanded survey of up to 360 nights will be considered seriously if there is a clear science case.

Administration Office Tel (808) 934-7788 Fax (808) 934-5099 Director's Office Tel (808) 934-5900 Fax (808) 934-5984

Survey design is still under debate...

Resulting Survey Design (somewhat old version)

25 deg^2	~9 deg^2
~200k color- selected galaxies with 0.5 < z < 1.5 (2hr exp)	~170k color- selected galaxies with 1 < z < 2 (3 hr exp)
~82k drop-out selected galaxies with 2 < z < 6 (3 hr exp)	
~20k LAEs with z=2, 6 (5hr exp)	



Summary

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- The HSC survey is a 300-night survey at the Subaru Telescope started about 2.5 years ago.
- The survey is 35% done as of today. We are making good progress!
- Check out our website for the details of the survey, http://hsc.mtk.nao.ac.jp/
- A number of early science papers have been published already; from the discovery of a new MW dwarf galaxy to the discovery of high-z QSOs.
- PFS science operations are likely to start around ~S20B.
- The galaxy survey is still under discussion...