Science with the Hyper Suprime-Cam (HSC) Survey

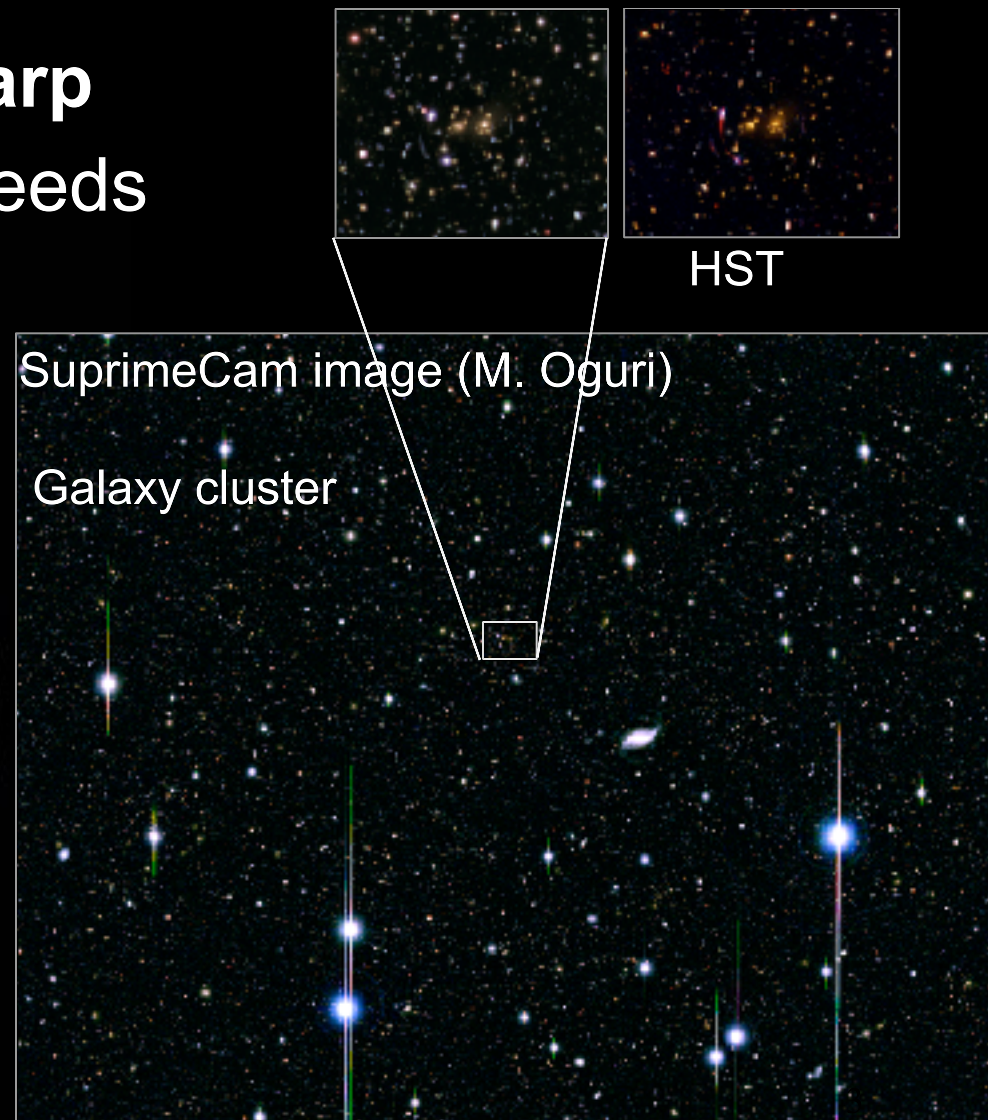
Rachel Mandelbaum

Survey webpage: http://hsc.mtk.nao.ac.jp/ssp/
Data release 1:
https://hsc-release.mtk.nao.ac.jp/doc/

Subaru Telescope

Subaru Telescope: wide FoV & excellent image quality

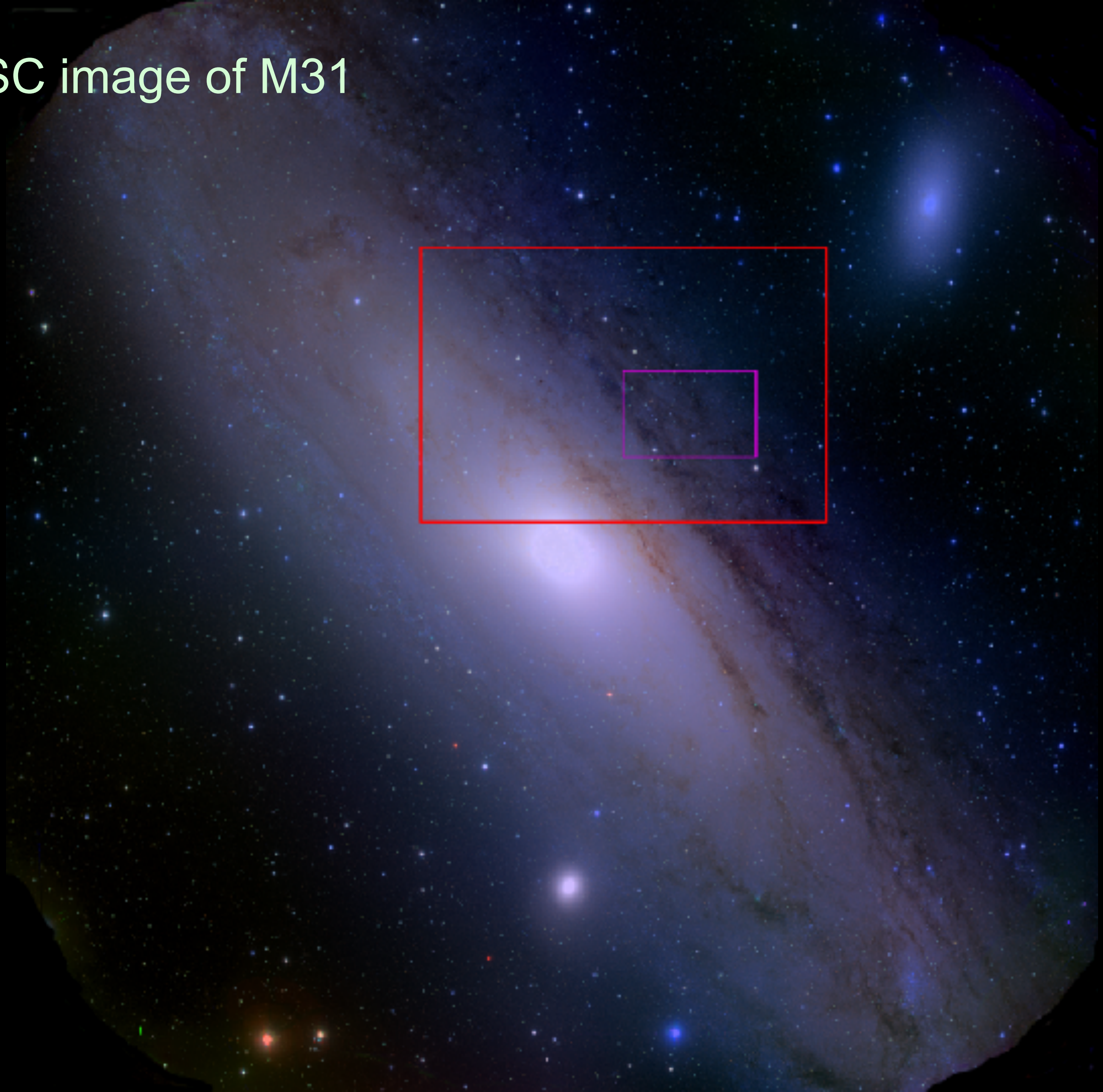
- **Fast, Wide, Deep & Sharp**
- a cosmological survey needs these

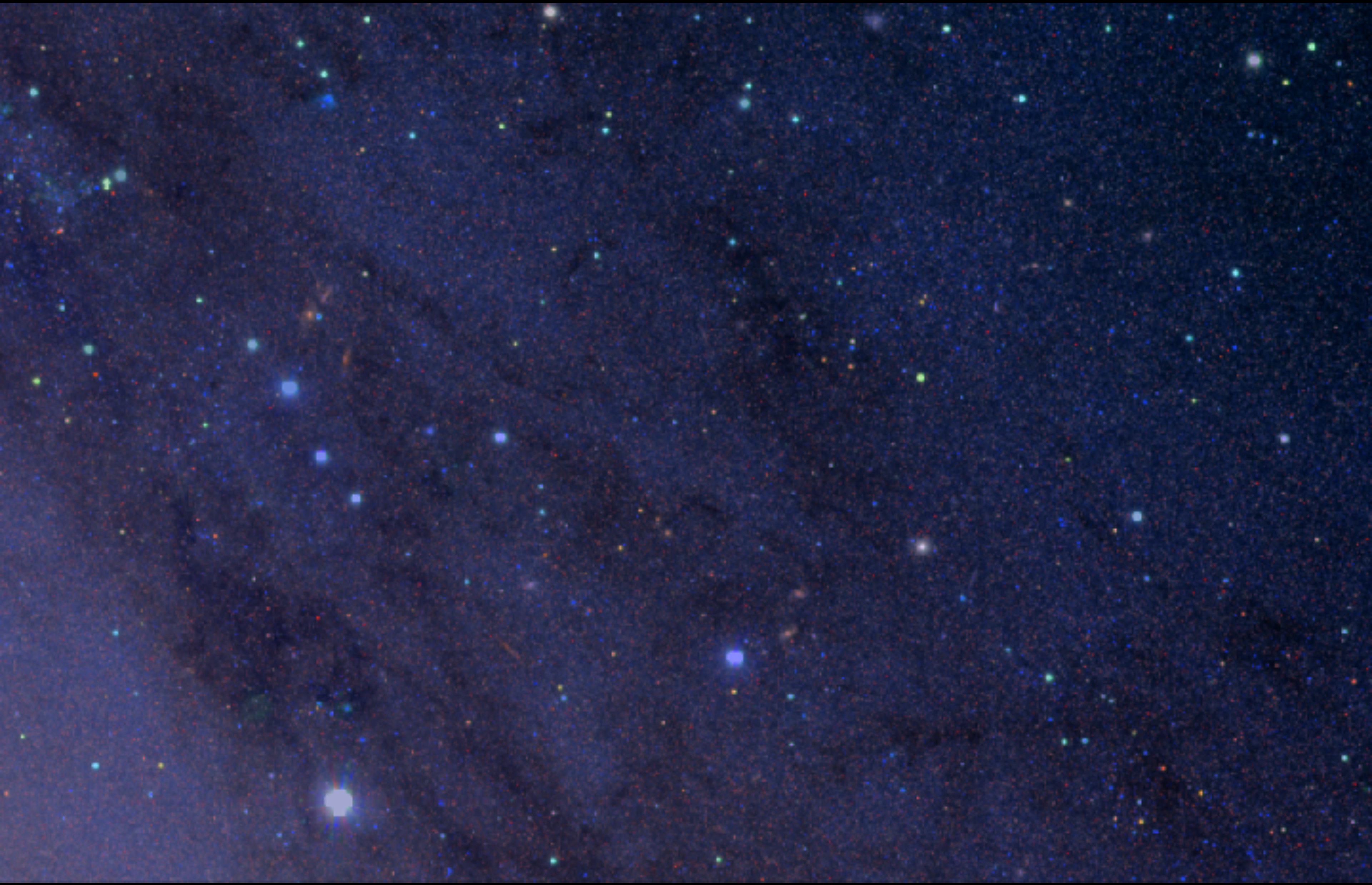


W

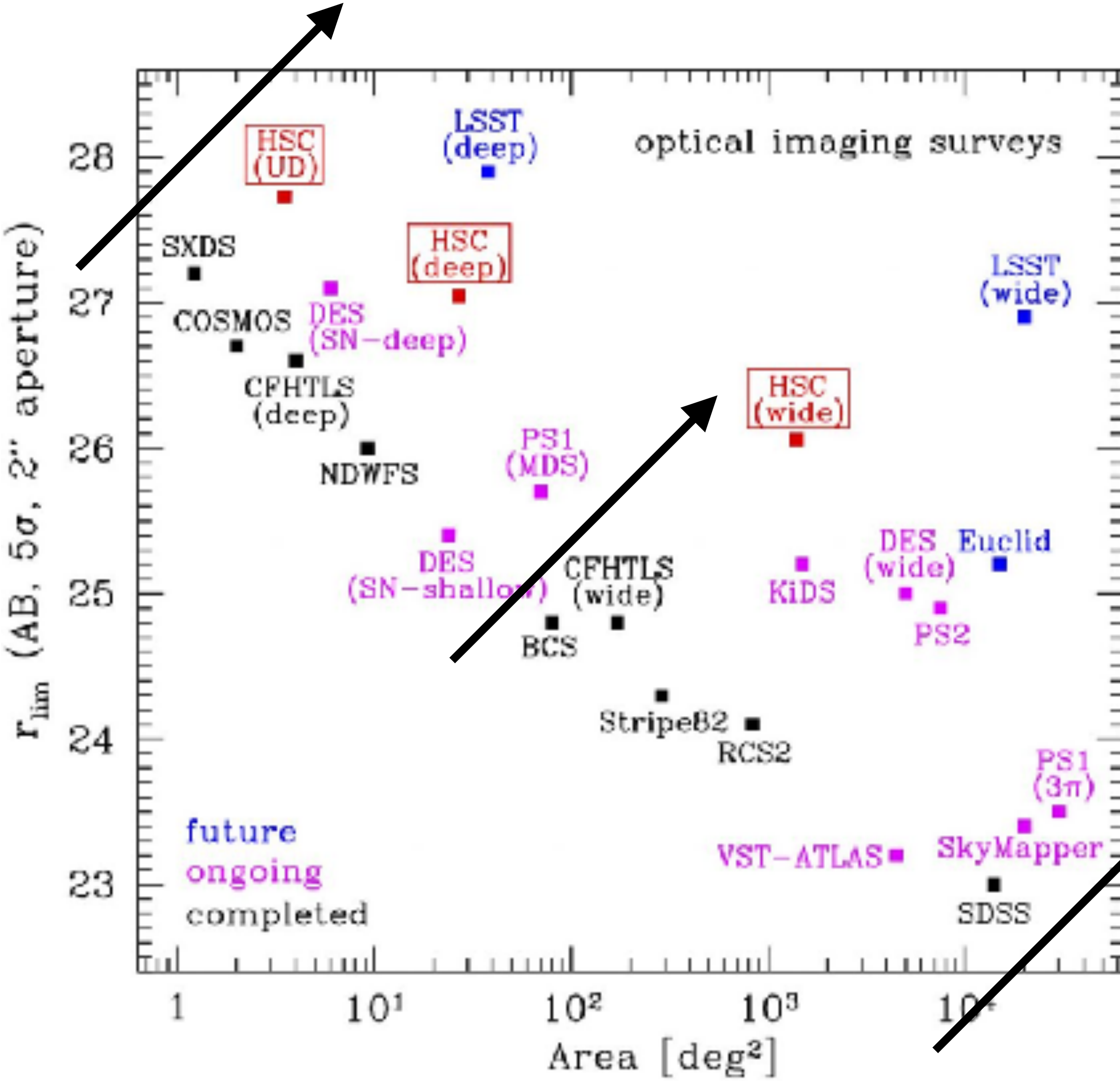
Hyper Suprime-Cam FoV
1.5 degree diameter

- **Fas**
- a co
these


HSC image of M31



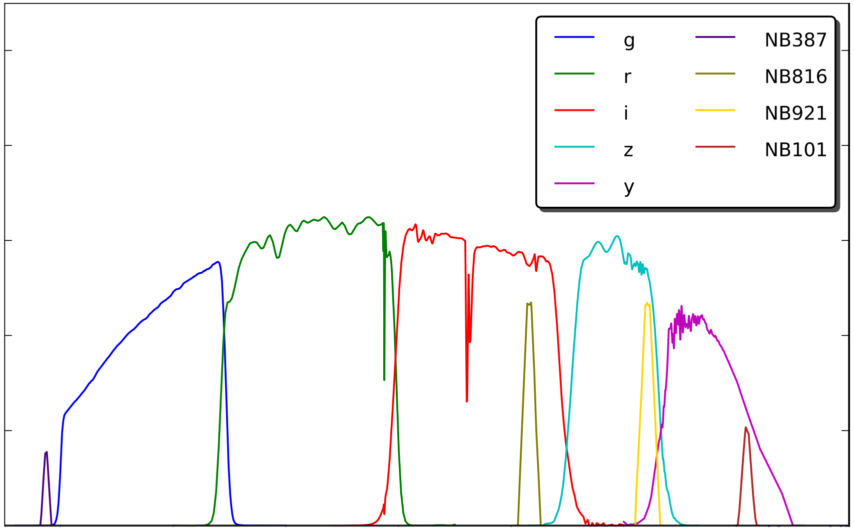
Parameters of HSC SSP Survey



- Wedding-cake-type survey
  - Wide (1400 deg², i~26)
  - Deep (28 deg², i~27)
  - Ultradeep (3 deg², i=27.7)

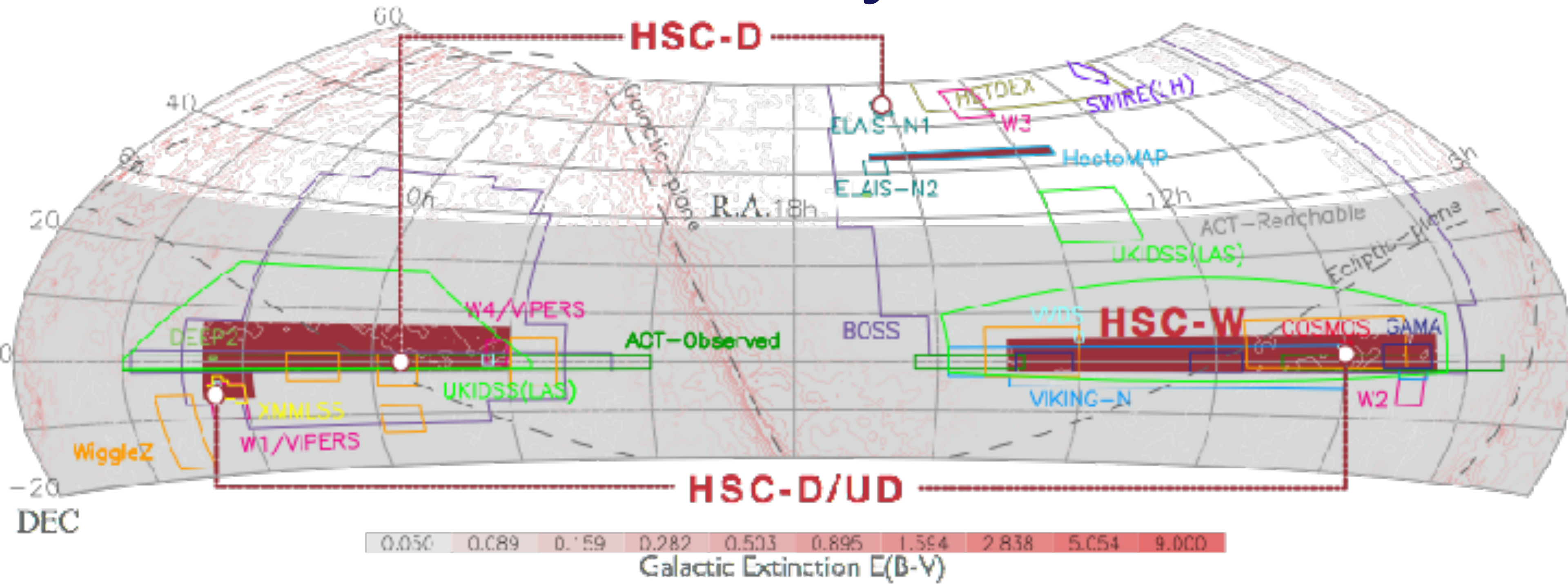
Filters & Depth

	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***



For HSC-Deep and Ultra-Deep, a combination of broad- and narrow-band filters enables detection of Lyman-alpha emitters at z=2.2, 5.7, 6.6 and 7.3

HSC Survey Fields



- HSC Survey Fields selected based on
  - Overlap with SDSS regions, and other interesting datasets (ACT CMB, NIR, spectroscopic surveys, …)
  - Low dust extinction
  - Spread in RA

PI: Satoshi Miyazaki (NAOJ)
Science WG co-chairs: M. Takada, M. Strauss

S. Miyazaki (NAOJ) M. Strauss (Princeton) M. Takada (IPMU)

HSC SSP proposal:
~170 Co-Is (Japan, Taiwan, Princeton)
largest ever galaxy survey at Subaru

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*[3],[2], M. Akiyama[4], K. Aoki[5], N. Arimoto*[5], N. A. Bahcall[6], S. J. Bickerton[3], J. Bosch[6], K. Bundy†[4], C. W. Chen[7], M. Chiba†[4], T. Chiba[8], N. E. Chisari[6], J. Coupon[7], M. Doi[9], M. Enoki[6] S. Foucaud[10], M. Fukugita[3], H. Furusawa†[5], T. Futamase[4], R. Goto[9], 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.

300 Subaru nights approved by Subaru community in 2013

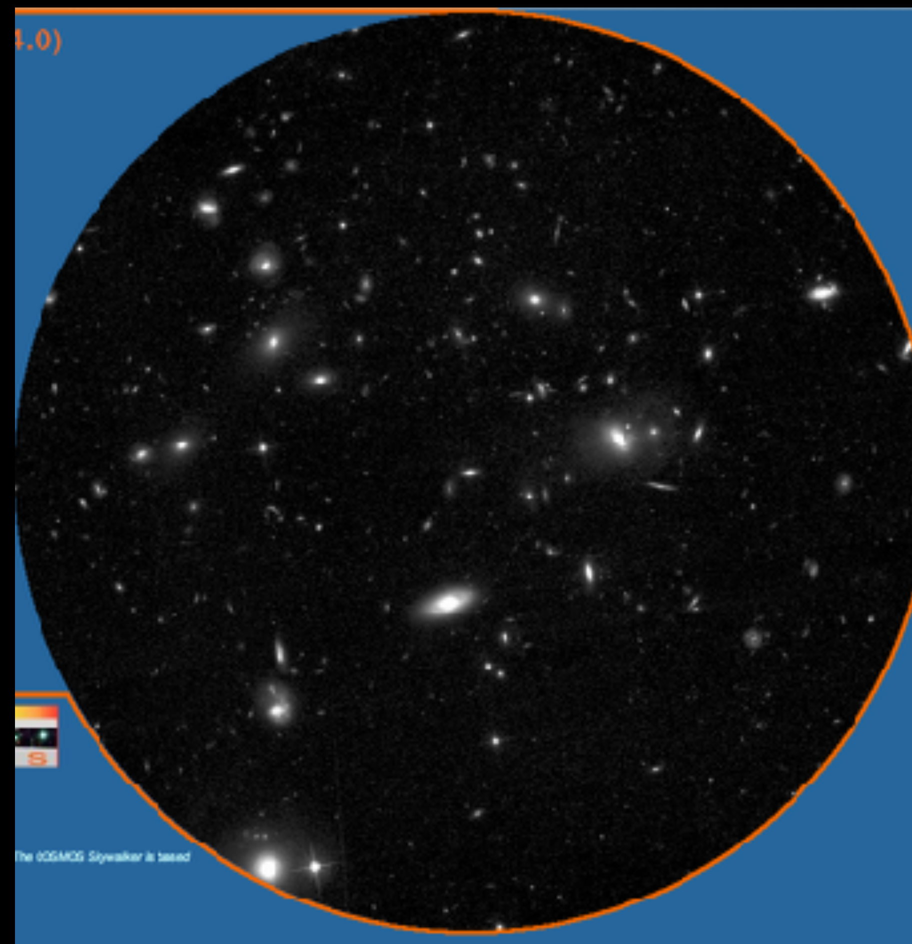
K. Nomoto[3], M. Oguri†[3], A. Oka[2], N. Okabe[7], S. Okamoto[25], S. Okamura[26], J. Okumura[23], S. Okumura[27], Y. Okura[5], Y. Ono[2] M. Onodera[28], K. Ota[23], M. Ouchi†[2], S. Oyabu[12], P. A. Price[6], R. Quimby[3], C. E. Rusu[2],[5], S. Saito[29], T. Saito[3], Y. Saitou[30], M. Sato[12], T. 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†[4], 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[9], T. Terai[5], Y. Terashima[13], N. Tominaga[39], J. Toshikawa[30], T. Totani[32], 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

HSC Survey started in March 2014

~1.5 nights (S14A), ~12 nights (S14B), ~15 nights in S15A
Now (mid-2017) ~50% of the survey's time has been allocated.

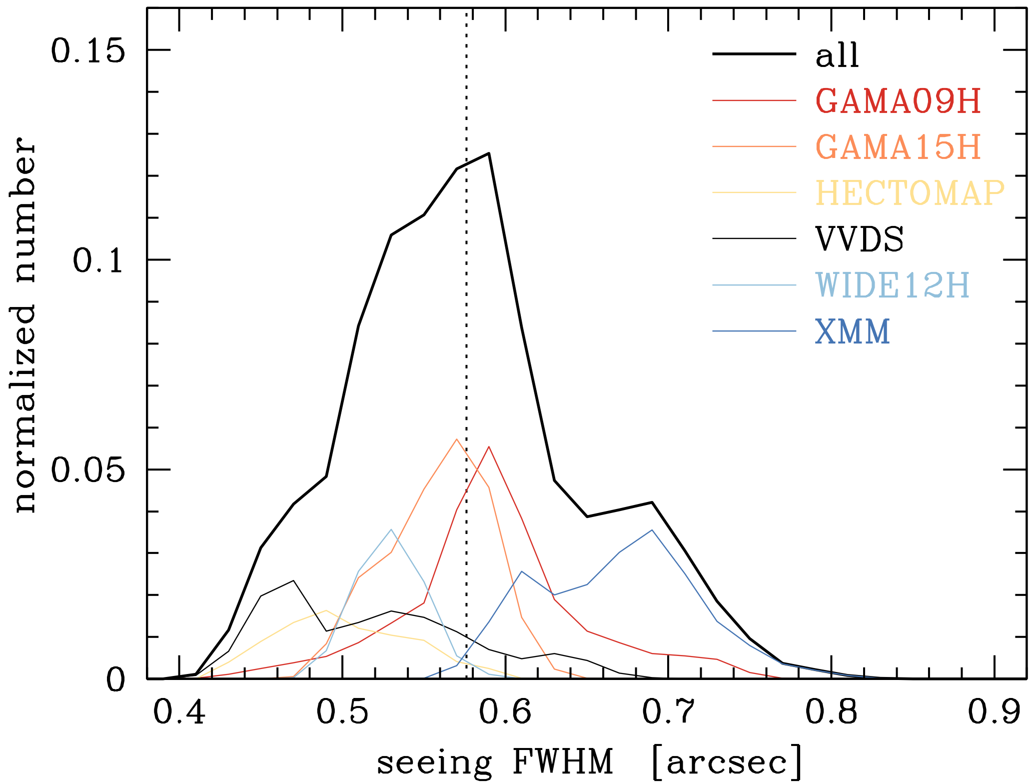
Subaru HSC image (riz: ~2.5hrs) COSMOS HST (640 orbits: ~500hrs)

Reduced by HSC pipeline
(Princeton, Kavli IPMU, NAOJ)



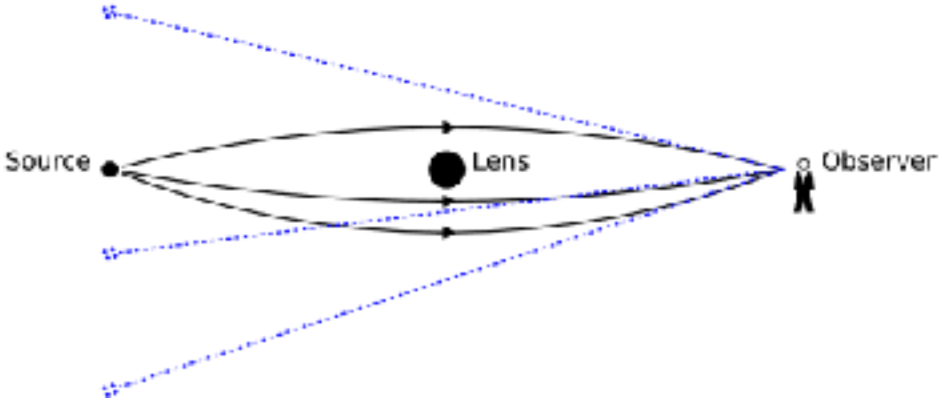
Exquisite image quality

Camera will be presented in Miyazaki+17 in prep



(from RM+17)

Gravitational lensing



Sensitive to all matter along line of sight, including dark matter!

More generally…

Lensing predicted by Newton, with modified predictions by Einstein:

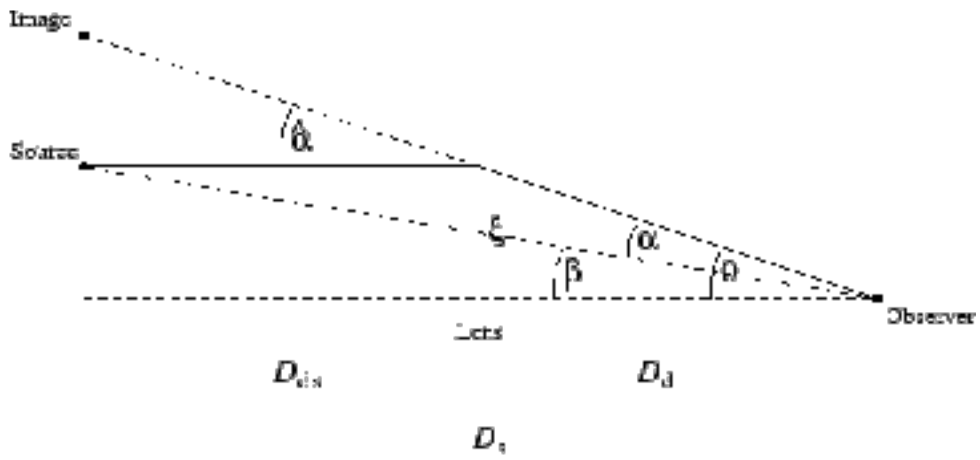
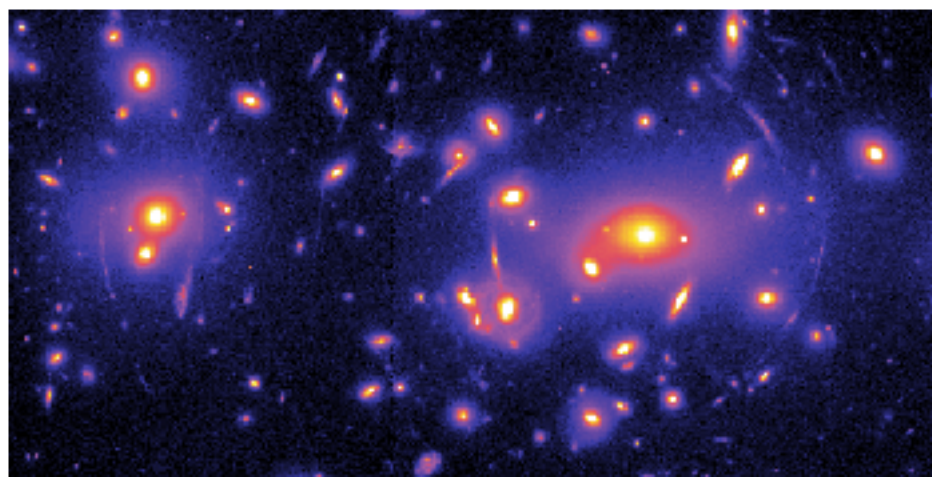


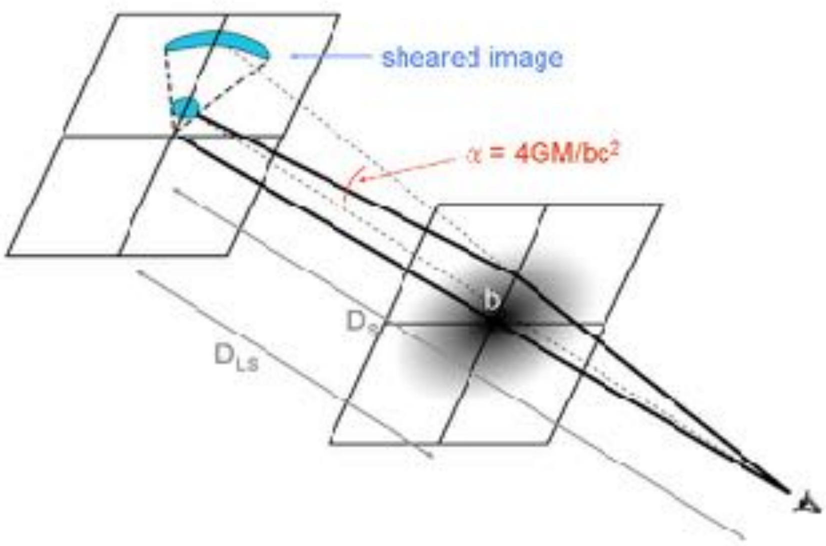
Diagram from Narayan & Bartelmann (1997)

$$\hat{\alpha} = \frac{4G}{c^2}\frac{M(<\xi)}{\xi}$$



Weak lensing

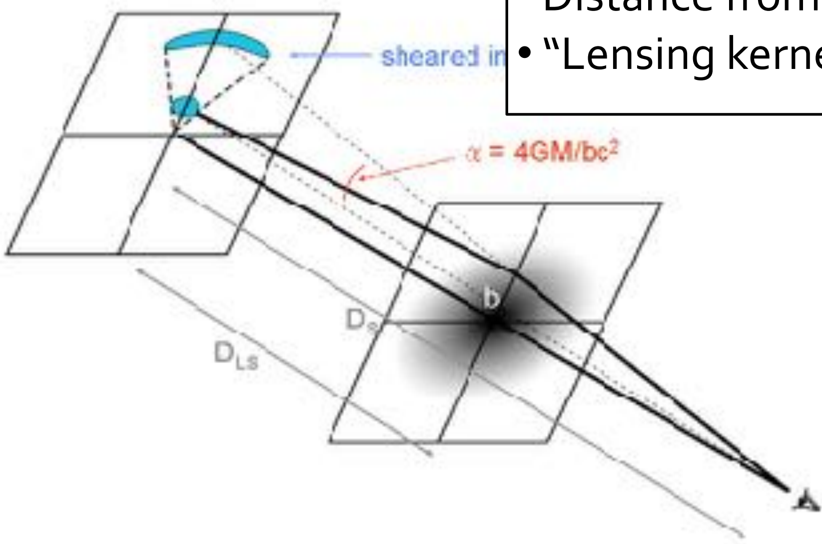
- Very small deflection angles
- Coherent
- Does not require chance superposition like strong lensing



Weak lensing

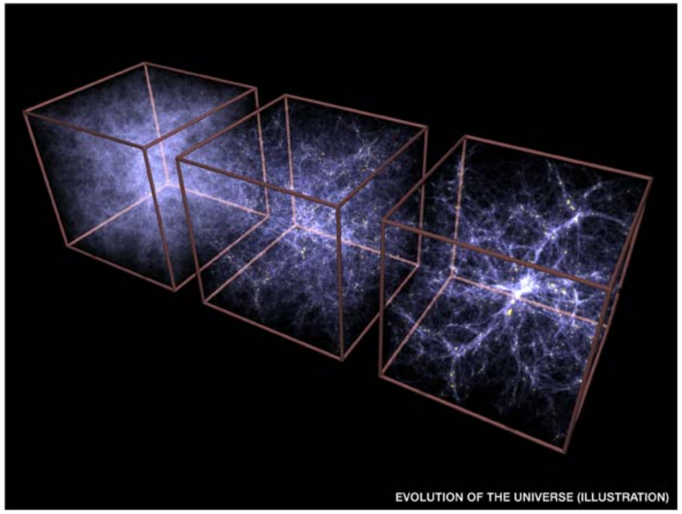
- Very small deflection angles
- Coherent
- Does not require chance superposition like strong lensing

Lensing depends on:
- Enclosed mass
- Distance from that mass
- “Lensing kernel”: distances to lens and sou

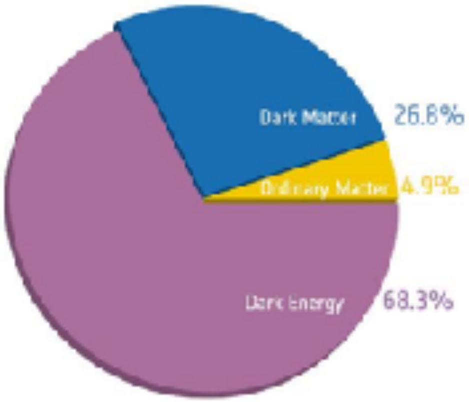


Why should you care about weak lensing?

Structure growth!



Dark matter and dark energy!



ESA/Planck

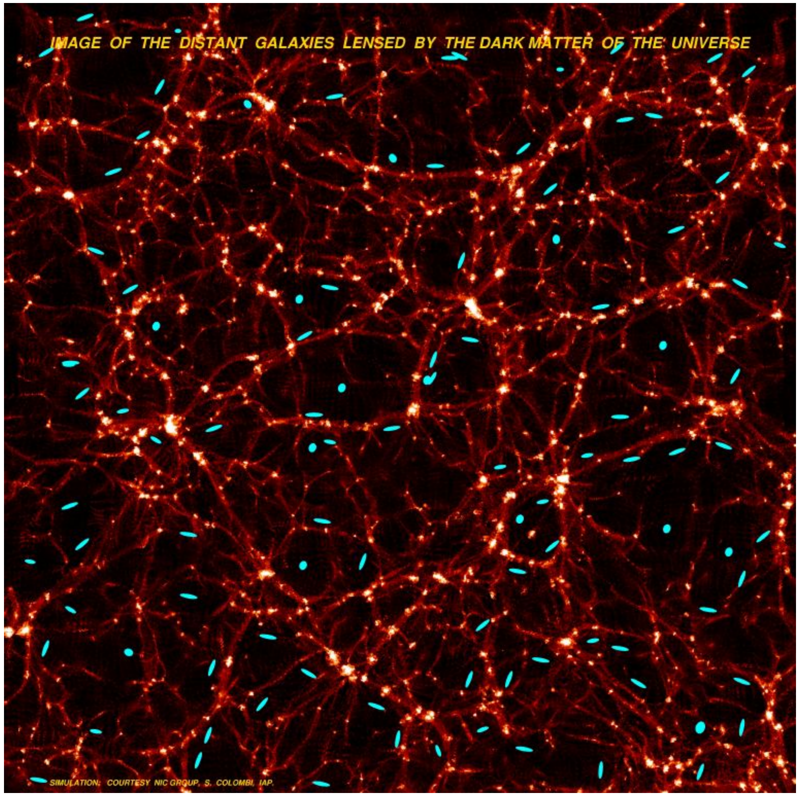
Theory of gravity!

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = 8\pi GT_{\mu\nu}$$

Galaxy-dark matter connection!

So how does this work?

Cosmic shear:
weak lensing by large-scale structure



Requires catalogs with:

1. Galaxy positions
2. Galaxy shear estimates

And an estimate of dN/dz.

So how does this work?

Cosmic shear: weak lensing by large-scale structure

Indices of z bins

Separation on the sky

$$\hat{\xi}^{ij}_{\pm}(\theta) = \frac{\sum \mathrm{w}_a \mathrm{w}_b \left[\epsilon^i_t(\boldsymbol{x_a})\epsilon^j_t(\boldsymbol{x_b}) \pm \epsilon^i_\times(\boldsymbol{x_a})\epsilon^j_\times(\boldsymbol{x_b})\right]}{\sum \mathrm{w}_a \mathrm{w}_b}$$

Shear correlation functions

Tomography requires catalogs with:

1. Galaxy positions
2. Galaxy shear estimates
3. Galaxy redshift estimates (photo-z or p(z))

So how does this work?

Cosmic shear:
weak lensing by large-scale structure

shears in coordinate system
aligned with vector connecting galaxy pair

$$\hat{\xi}_{\pm}^{ij}(\theta) = \frac{\sum \mathrm{w}_a \mathrm{w}_b \left[\epsilon_t^i(\boldsymbol{x_a})\epsilon_t^j(\boldsymbol{x_b}) \pm \epsilon_\times^i(\boldsymbol{x_a})\epsilon_\times^j(\boldsymbol{x_b})\right]}{\sum \mathrm{w}_a \mathrm{w}_b}$$

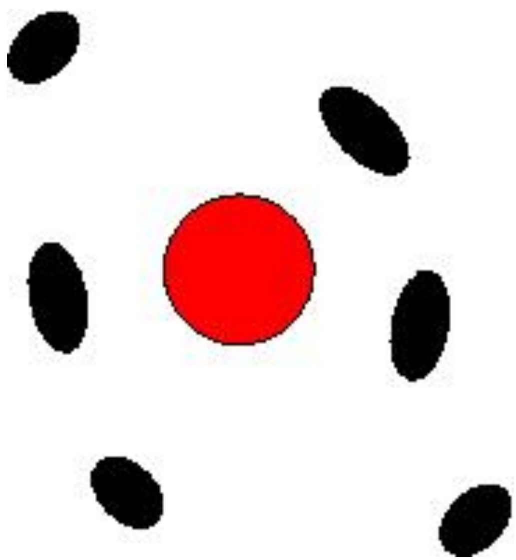
galaxy positions

weight factors

Tomography requires catalogs with:

1. Galaxy positions
2. Galaxy shear estimates
3. Galaxy redshift estimates (photo-z or p(z))

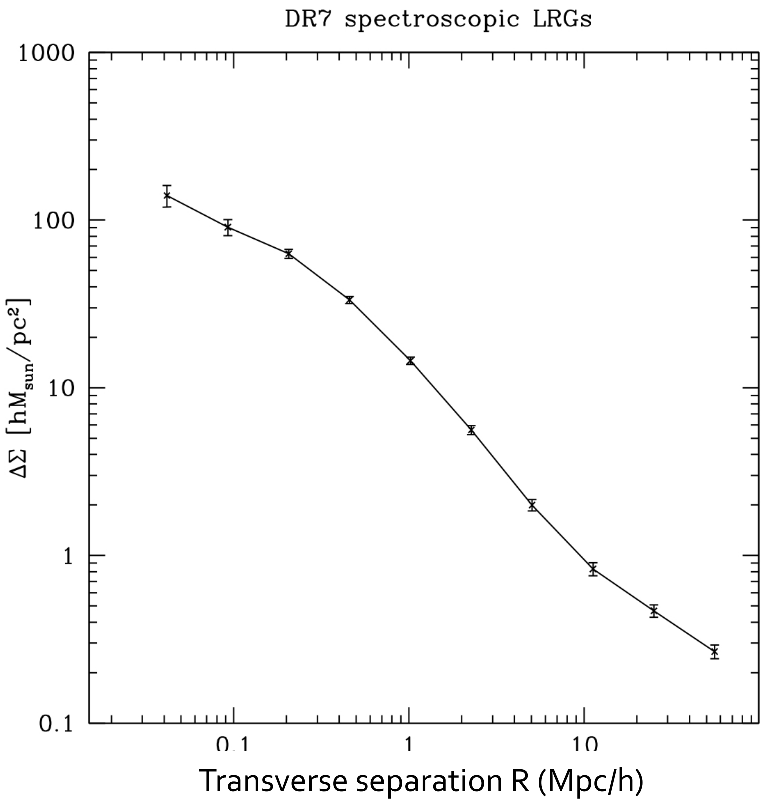
Another option:
galaxy-galaxy or cluster-galaxy lensing



Requires catalogs with:

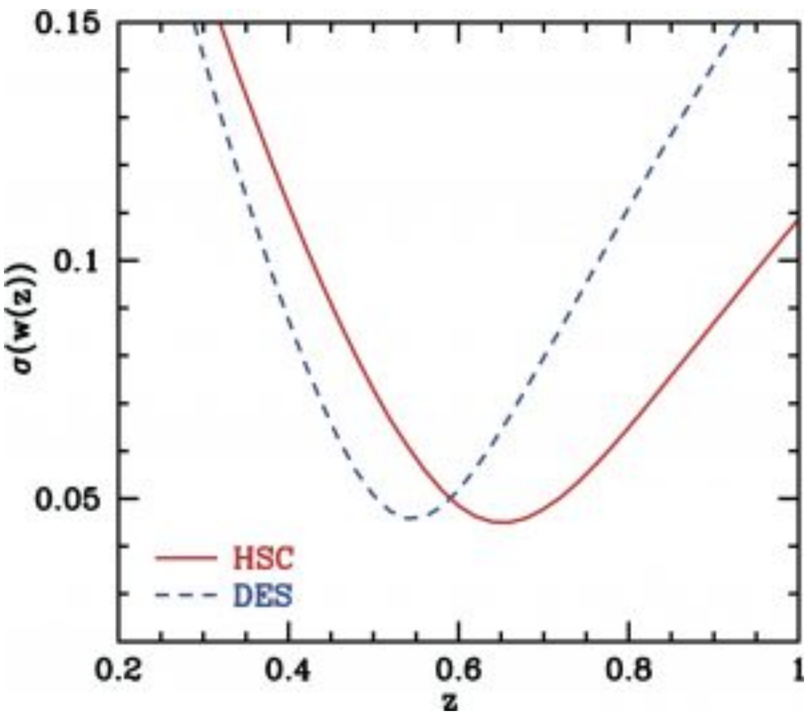
1. Background galaxy positions, shear estimates, redshift estimates
2. A sample of foreground masses

Another option:
galaxy-galaxy or cluster-galaxy lensing

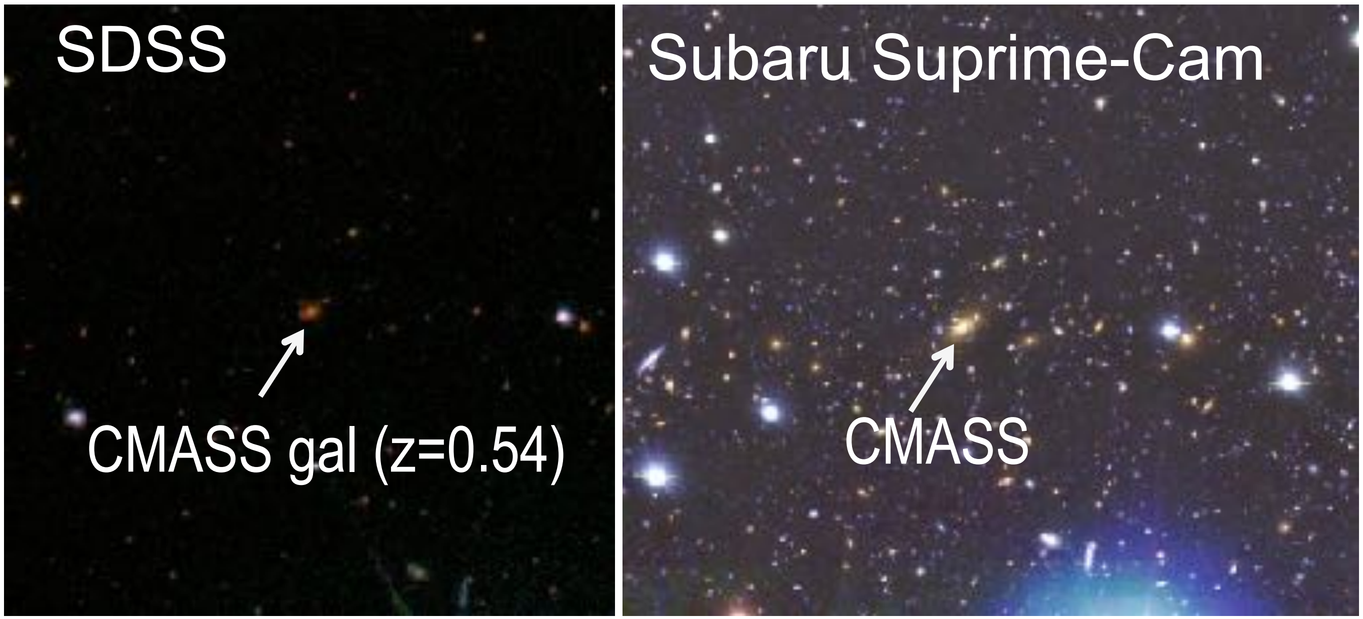


Mass profiles of massive galaxies, including large-scale structure

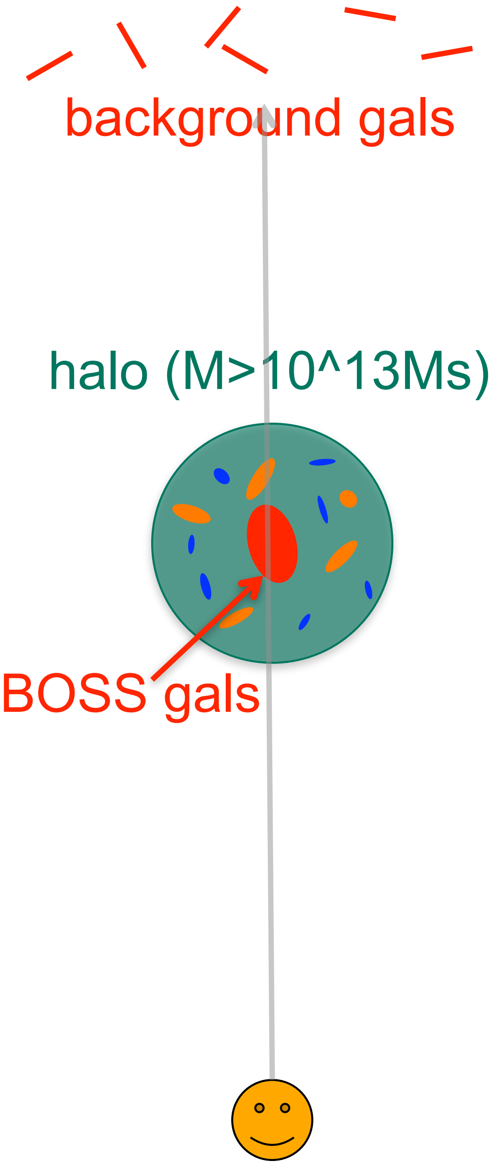
Weak lensing cosmological constraints: dark energy to z=1



Synergy between HSC and BOSS

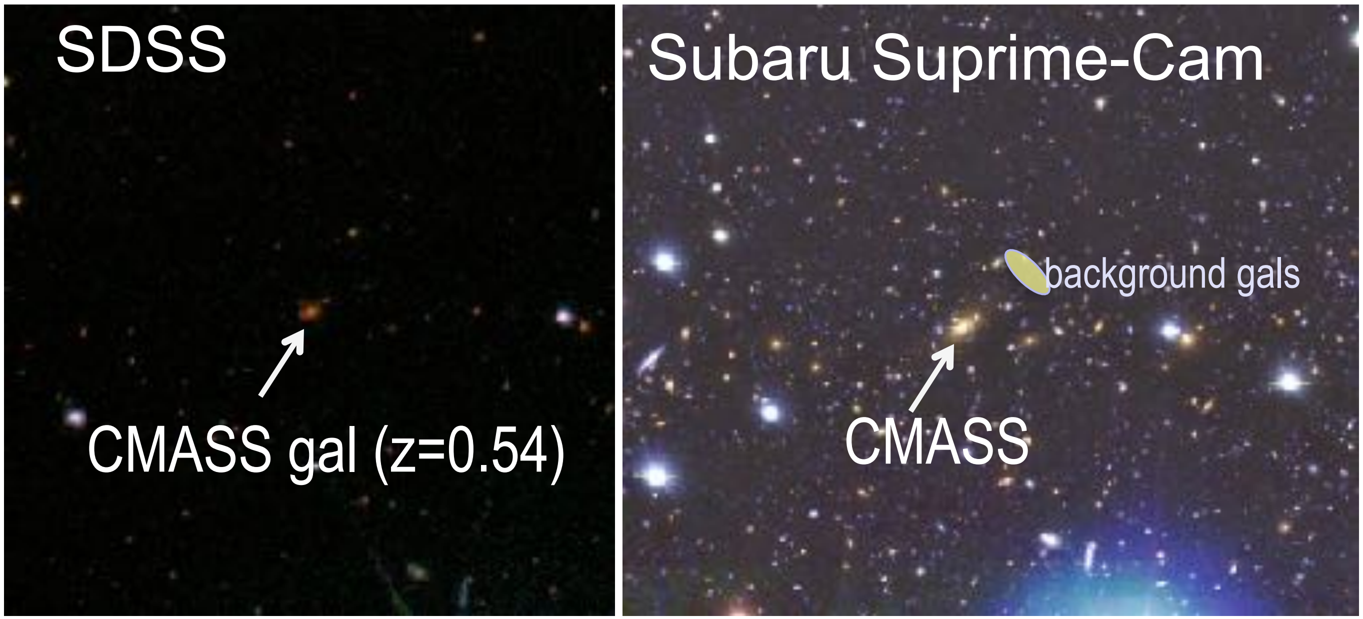


Credit: Masayuki Tanaka (IPMU)

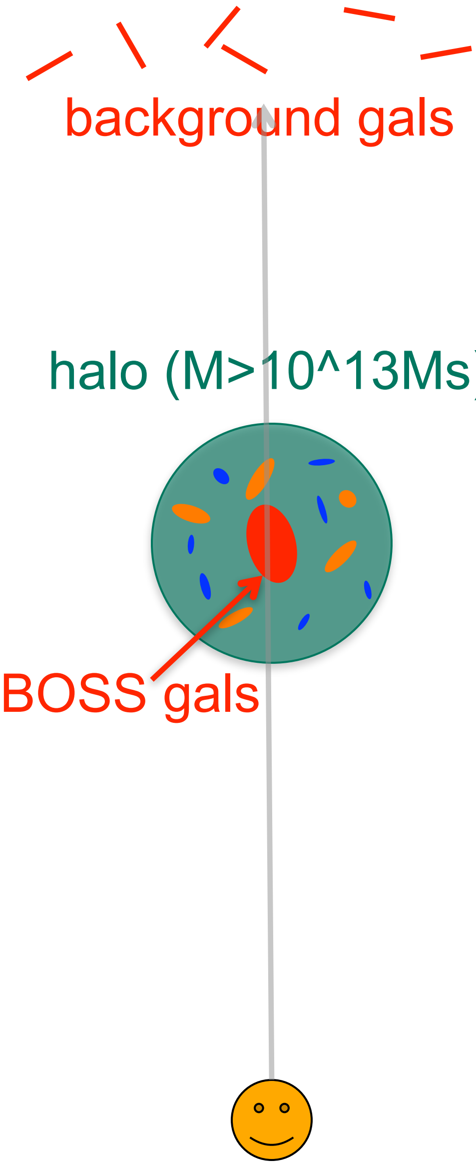


- HSC data will add background galaxies as well as member galaxies around each BOSS galaxy
- Cross-correlation of BOSS with HSC galaxies (shapes and positions) over 1400 sq. degrees

Synergy between HSC and BOSS



Credit: Masayuki Tanaka (IPMU)



- HSC data will add background galaxies as well as member galaxies around each BOSS galaxy
- Cross-correlation of BOSS with HSC galaxies (shapes and positions) over 1400 sq. degrees

DR1 was in Feb 2017

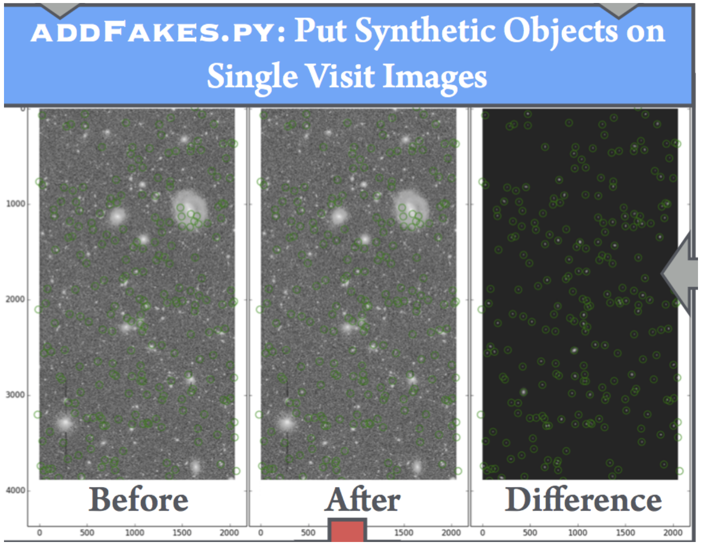
- Includes a wide range of image and catalog-level products, sky map, ...
- ~100 deg^2 of data in all 5 bands to full depth
- Some deep-layer data released as well
- Some more data products in incremental releases as time goes on (e.g., early June, …)

Quick snapshots of some results so far

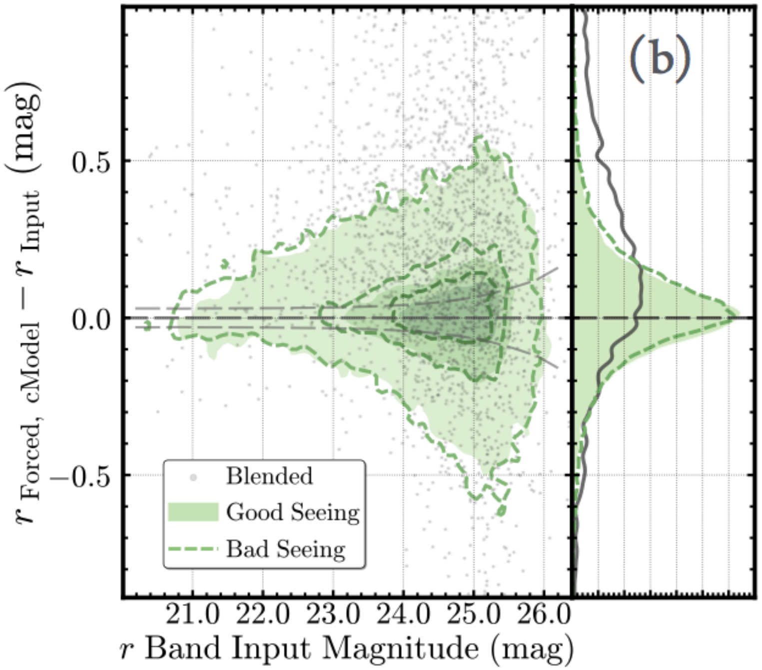
Characterization and Photometric Performance of the Hyper Suprime-Cam Software Pipeline

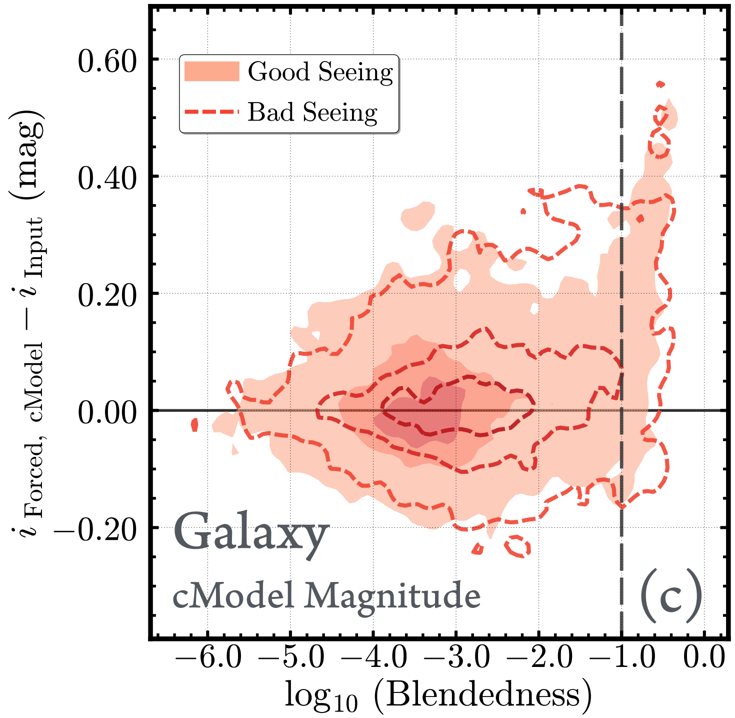
Song Huang [1,2] Alexie Leauthaud [1,2], Ryoma Murata [2,4], James Bosch [3], Paul Price [3], Robert Lupton [3], Rachel Mandelbaum [5], Claire Lackner [2], Steven Bickerton [2], Satoshi Miyazaki [6,7], Jean Coupon [8], Masayuki Tanaka [6]

arxiv:1705.01599



Note software pipeline is described in Bosch et al (2017, arxiv:1705.06766)



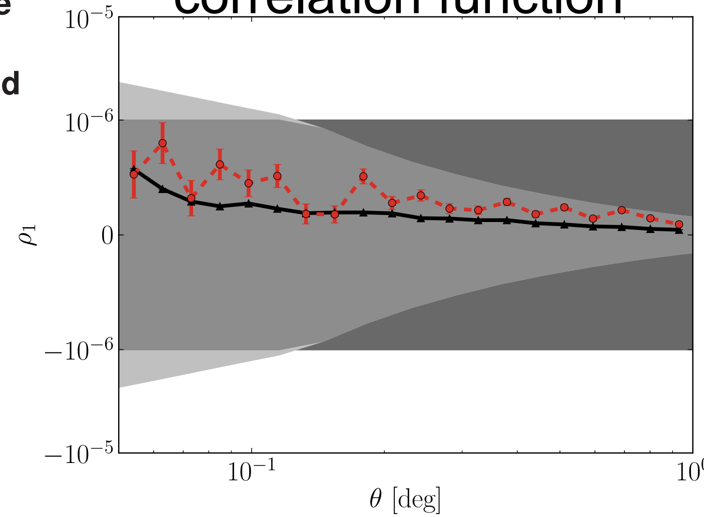


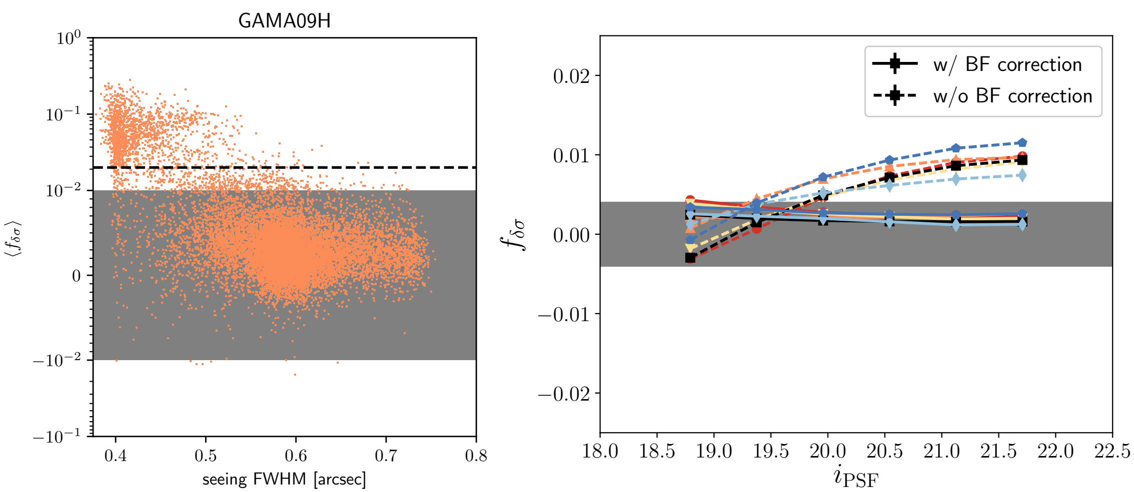
The first-year shear catalog of the Subaru Hyper Suprime-Cam SSP Survey

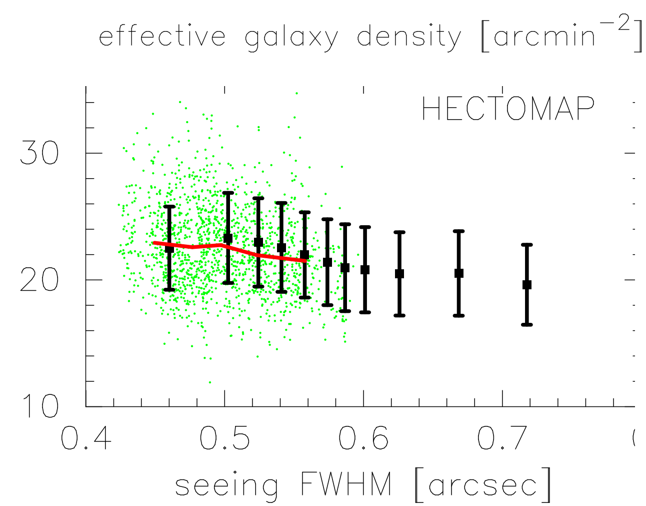
Rachel Mandelbaum[1], Hironao Miyatake[2,3], Takashi Hamana[4], Masamune Oguri[5,6,3], Melanie Simet[7,2], Robert Armstrong[8], James Bosch[8], Ryoma Murata[3,6], François Lanusse[1], Alexie Leauthaud[9], Jean Coupon[10], Surhud More[3], Masahiro Takada[3], Satoshi Miyazaki[4], Joshua S. Speagle[11], Masato Shirasaki[4], Cristóbal Sifón[8], Song Huang[3,9], Atsushi J. Nishizawa[12], Elinor Medezinski[8], Yuki Okura[13,14], Nobuhiro Okabe[15,16], Nicole Czakon[17], Ryuichi Takahashi[18], Will Coulton[19], Chiaki Hikage[3], Yutaka Komiyama[4,20], Robert H. Lupton[8], Michael A. Strauss[8], Masayuki Tanaka[4] and Yousuke Utsumi[16]

arxiv:1705.06745

PSF shape residual correlation function





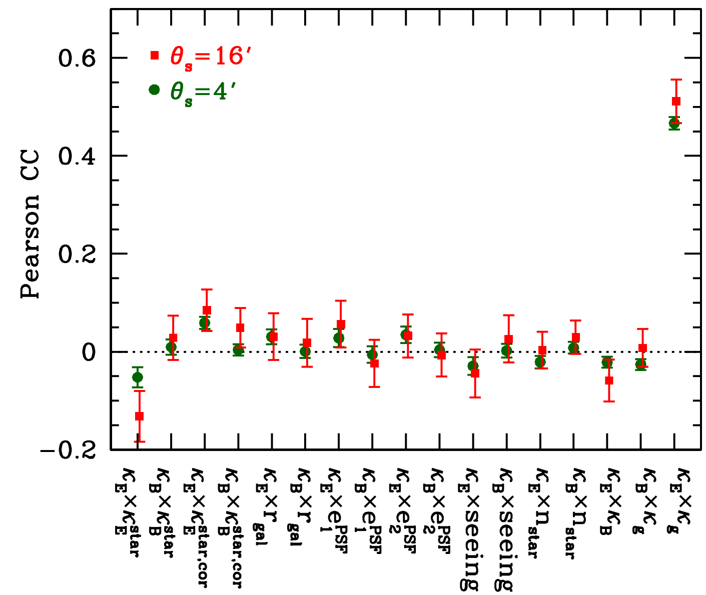


Empirical constraints on PSF modeling errors and the importance of brighter/fatter corrections.

Two- and three-dimensional wide-field weak lensing mass maps from the Hyper Suprime-Cam Subaru Strategic Program S16A data

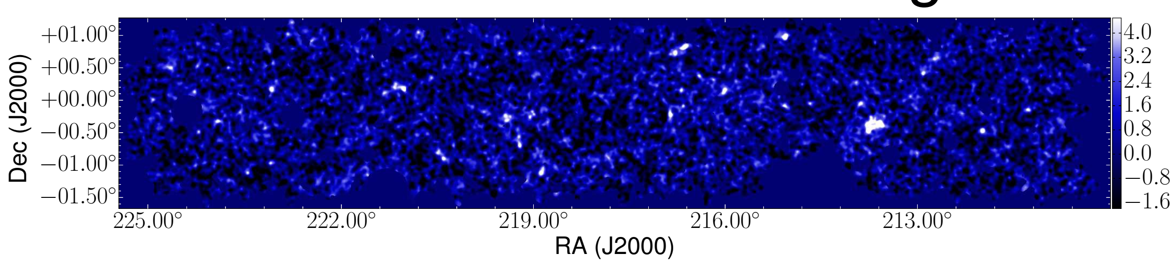
Masamune OGURI[1,2,3], Satoshi MIYAZAKI[4,5], Chiaki HIKAGE[3], Rachel MANDELBAUM[6], Yousuke UTSUMI[7], Hironao MIYATAKE[8,3], Masahiro TAKADA[3], Robert ARMSTRONG[9], James BOSCH[9], Yutaka KOMIYAMA[4,5], Alexie LEAUTHAUD[10], Surhud MORE[3], Atsushi J. NISHIZAWA[11] and Nobuhiro OKABE[7,12,13]

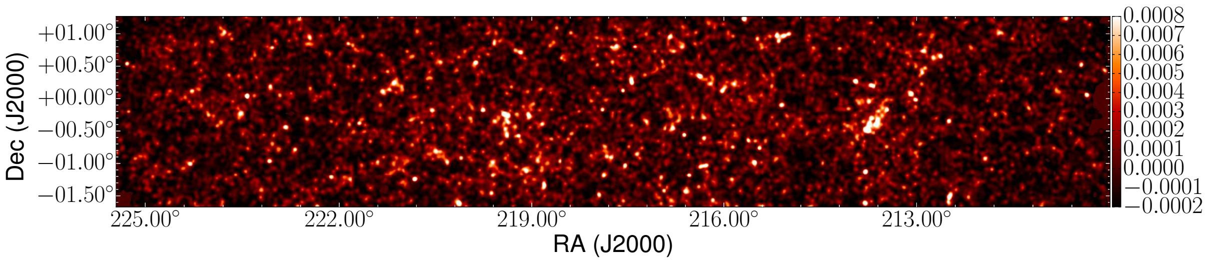
arxiv:1705.06792



Mass map systematics tests

Total mass from lensing

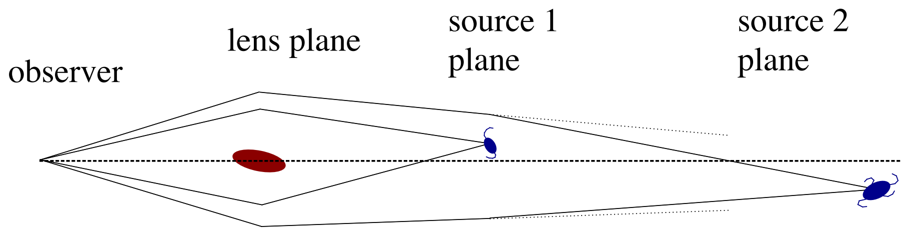


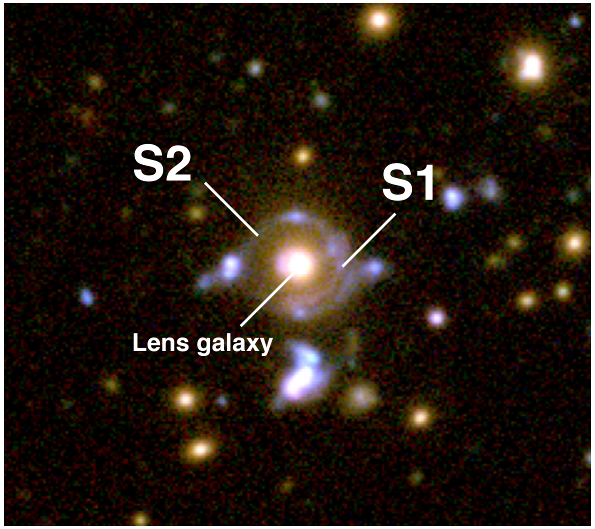


Stellar mass of LRGs

Strong lensing

Very rare double source plane systems



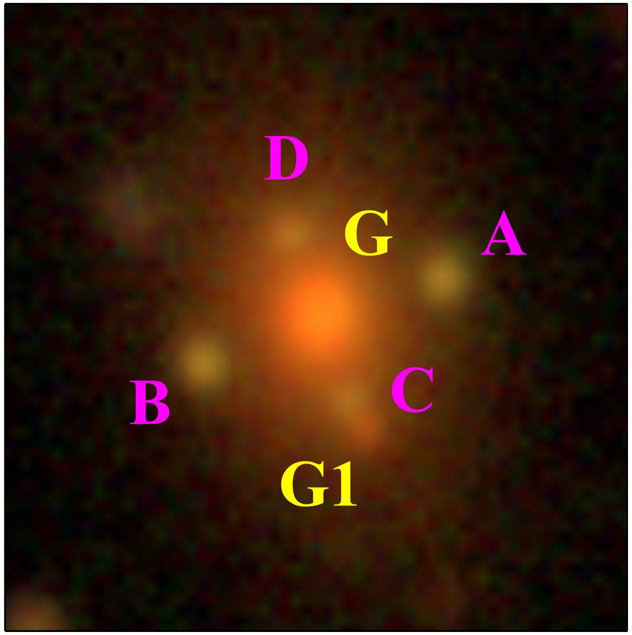


$z_{LENS} = 0.795$

$z_{S1} = 1.30$

$z_{S2} = 1.99$

“The Eye of Horus” (Tanaka, Wong, A. More et al 2016)

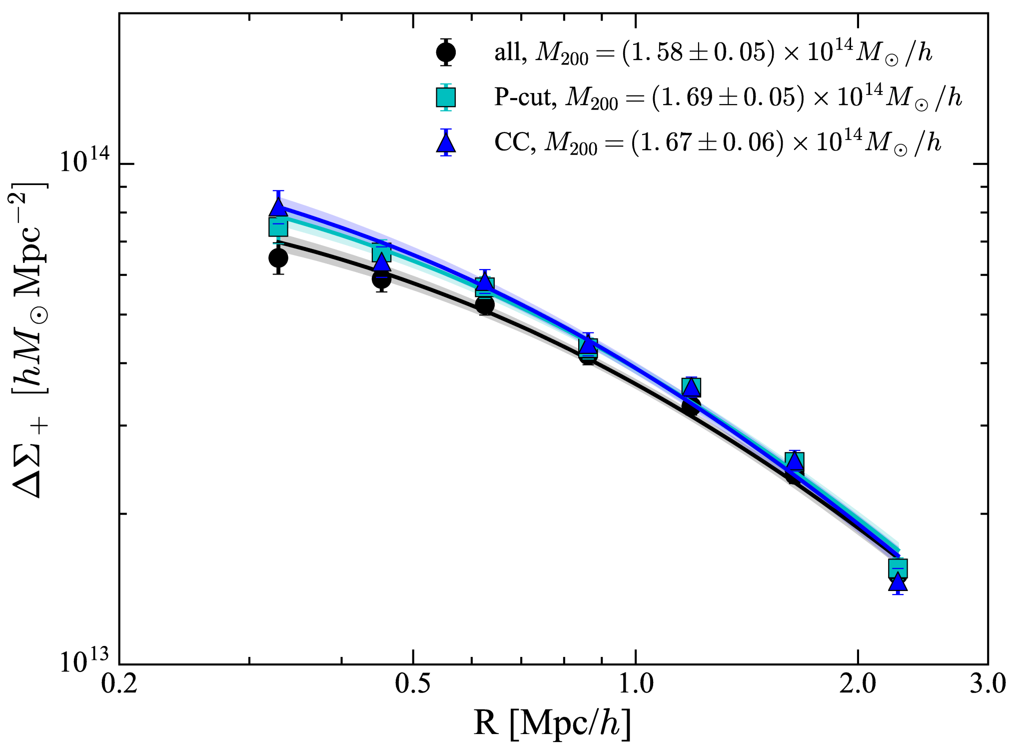


Quadruply lensed AGN! (More et al 2016) z_{QSO}=3.8

Source Selection for Cluster Weak Lensing Measurements in the Hyper Suprime-Cam Survey

Elinor Medezinski[1], Masamune Oguri[2,3,4], Atsushi J. Nishizawa[5], Joshua S. Speagle[6], Hironao Miyatake[2,7], Keiichi Umetsu[8], Alexie Leauthaud[9], Ryoma Murata[2,4], Rachel Mandelbaum[10], Cristóbal Sifón[1], Michael A. Strauss[1], Song Huang[2,9], Melanie Simet[7,11], Nobuhiro Okabe[12,13], Masayuki Tanaka[14] and Yutaka Komiyama[14,15]

arxiv:1706.00427



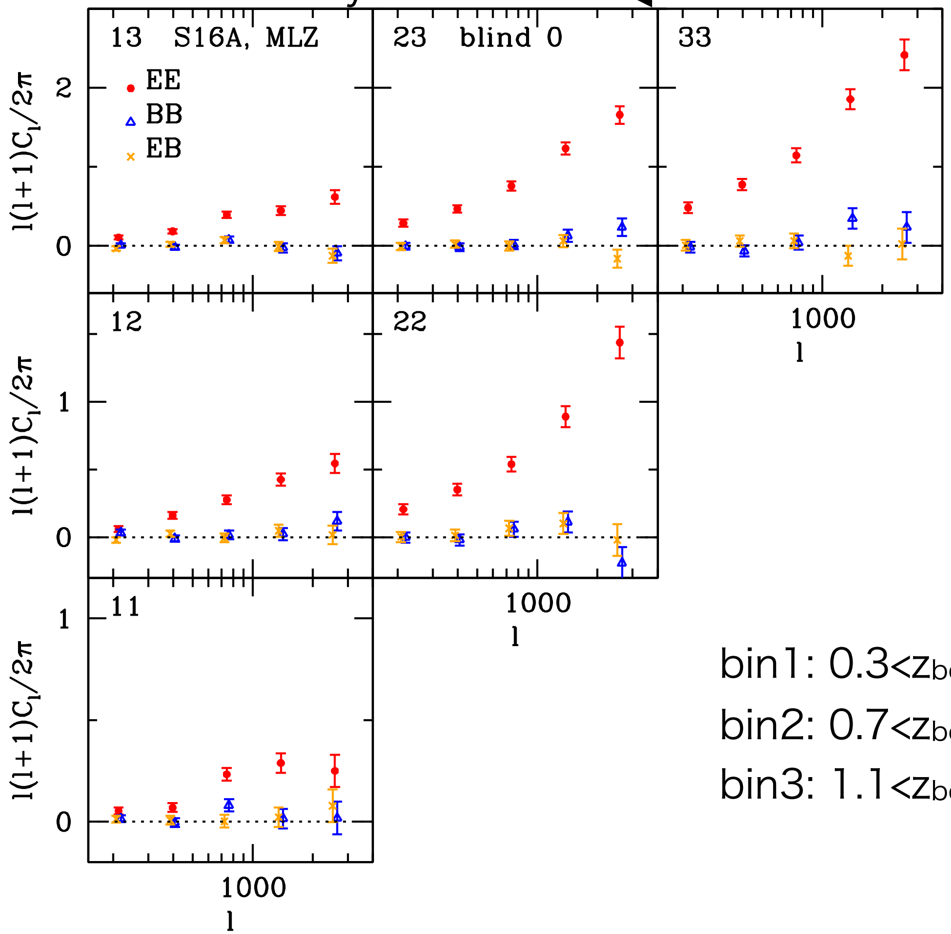
Robust source selection for lensing measurements by optically-selected cluster samples (very high S/N)

Advertisement of ongoing work

Cosmic shear tomography

(cross-correlations of shear in redshift slices)

amplitudes are arbitrary normalized



Part of our blinding scheme for cosmology analysis

To appear in Hikage et al (in prep)

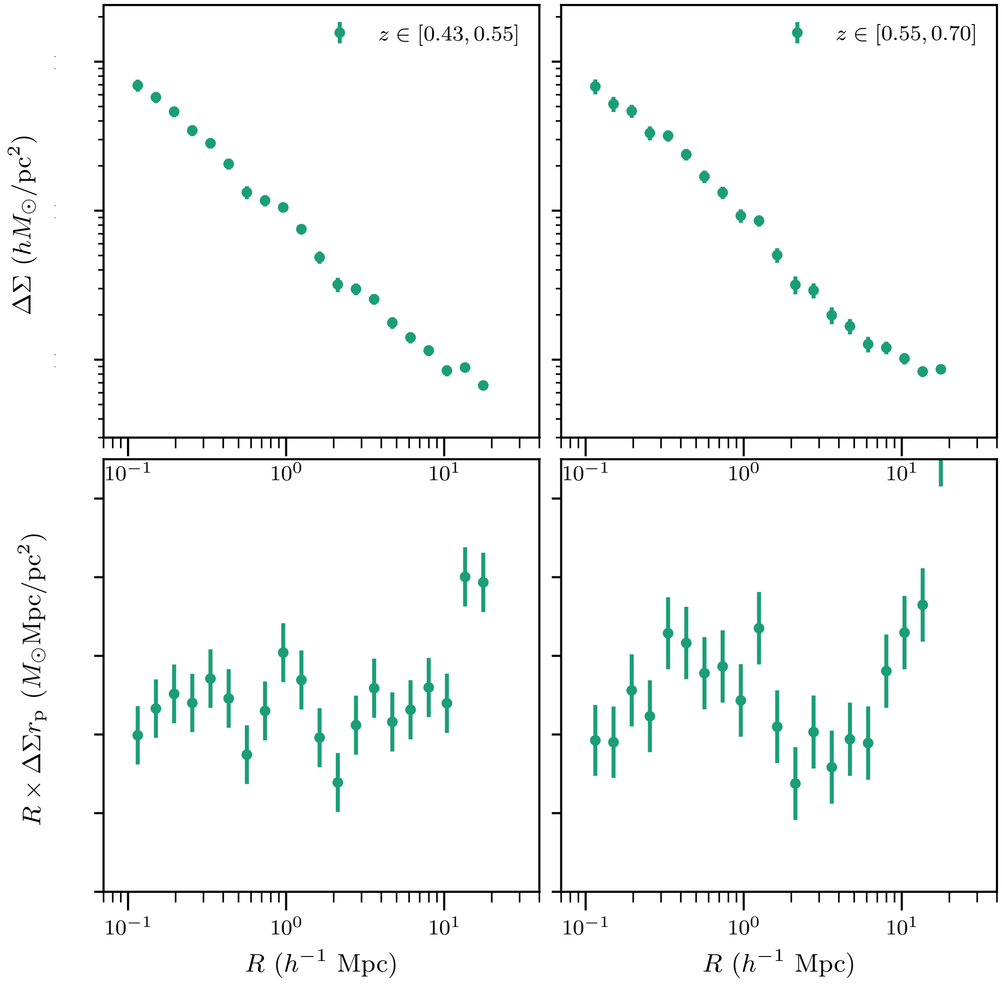
Total S/N exceeds 20

bin1: 0.3<z_{best}<0.7

bin2: 0.7<z_{best}<1.1

bin3: 1.1<z_{best}<1.5

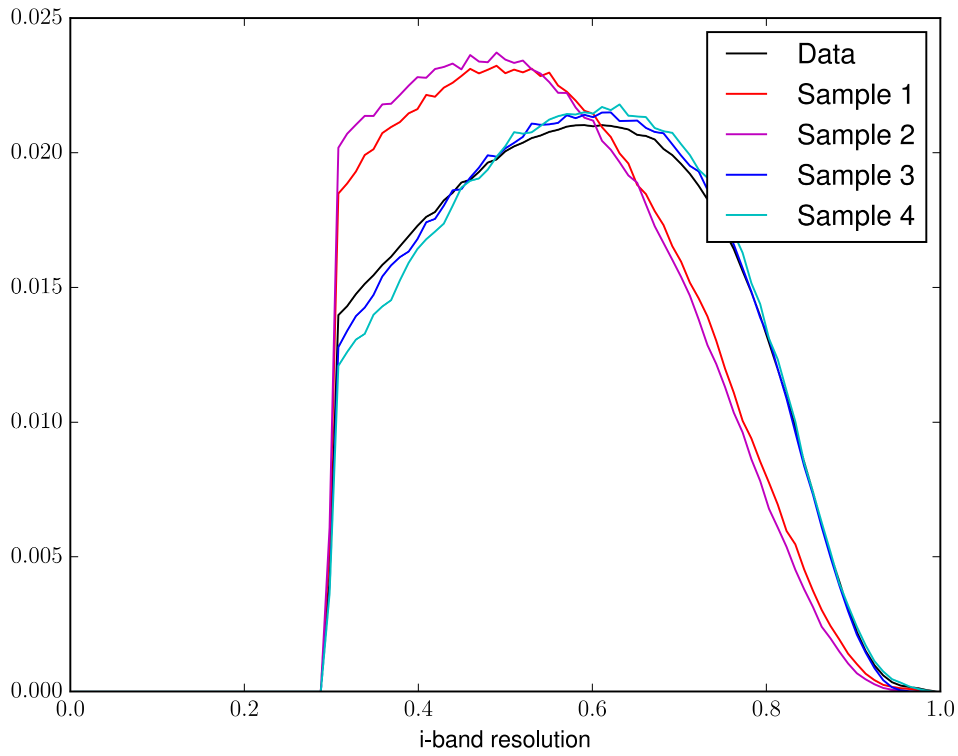
Lensing of SDSS-III BOSS CMASS galaxies



Measurement courtesy of Surhud More

(No amplitudes shown due to use of blinded analysis method)

Validating weak lensing analysis with simulations



Apparent size compared to PSF

How you define your input galaxy sample matters!

Simulations can reproduce observed galaxy properties if we include contributions from neighboring objects (instead of just isolated galaxies)

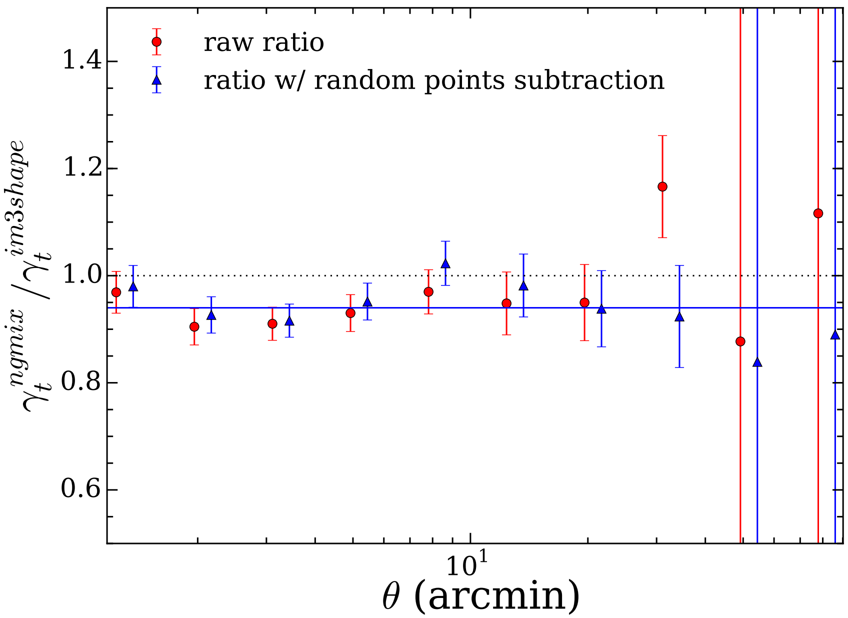
Mandelbaum et al (in prep)

Why should you care?

(aside from the fact that it’s cool stuff)

Lesson 1

- For weak lensing, having two shear estimation methods (RM+17, Armstrong+17 in prep) is tremendously valuable
- Reveals limitations in both methods, selection biases, …



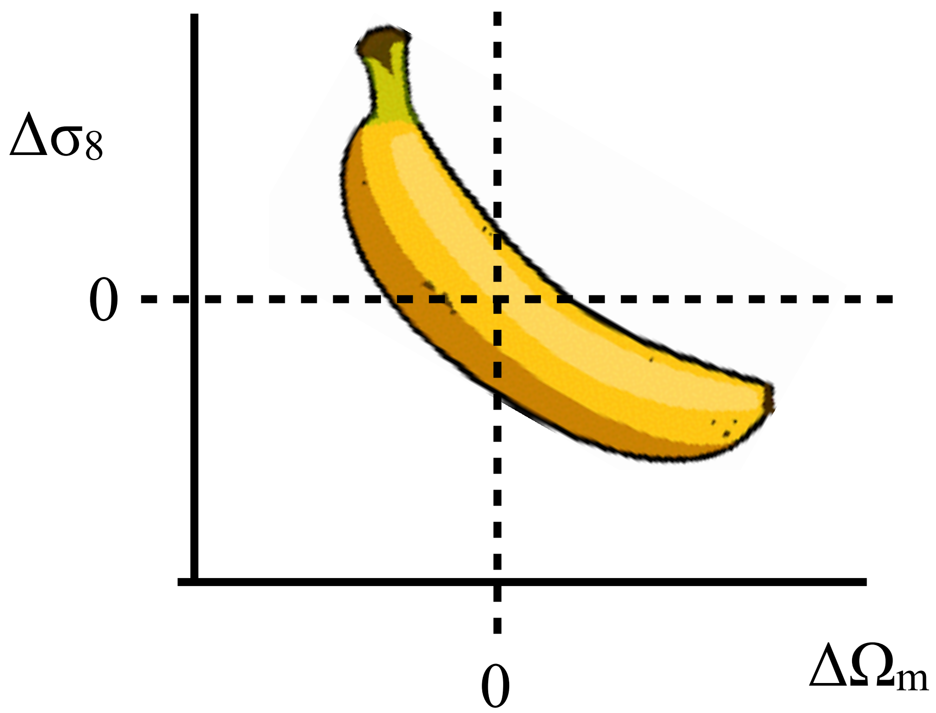
Plot from Dark Energy Survey (Jarvis+16)

Lesson 2

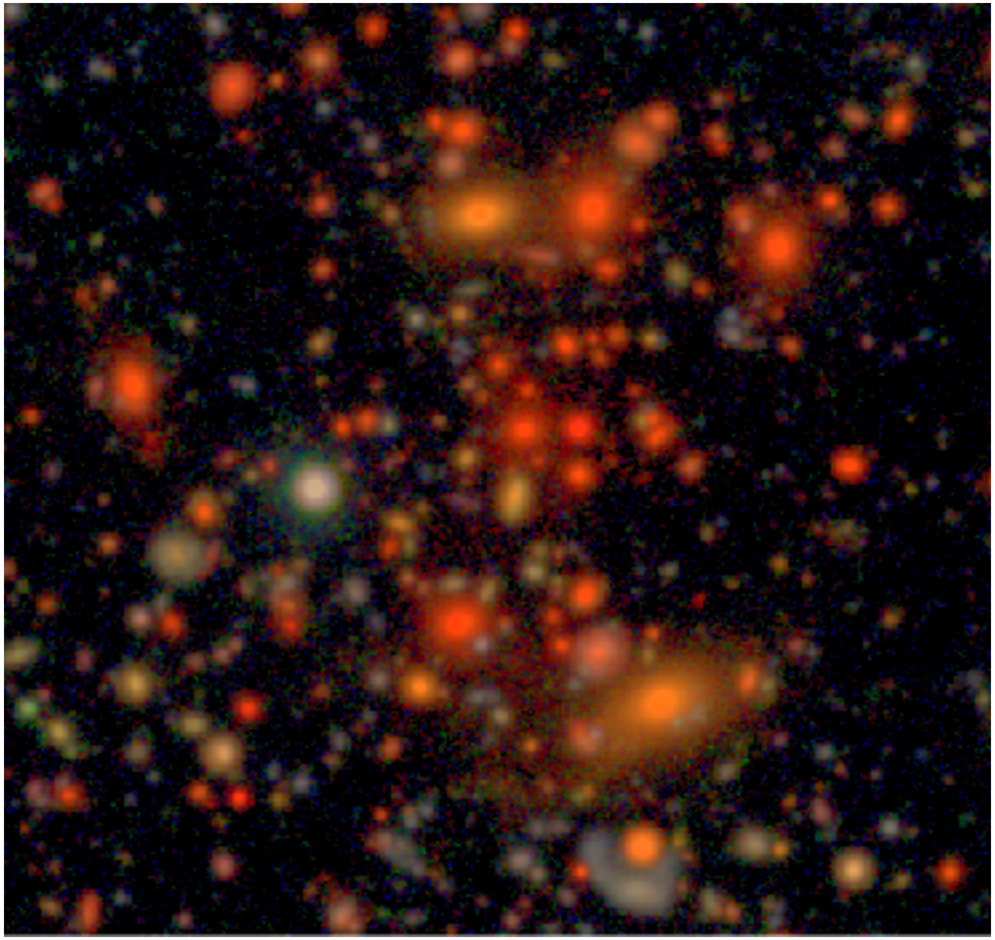
- Carrying out blind analysis is increasingly important for avoiding confirmation bias.
- Common blinding schemes:
  - Multiple catalogs with offsets
  - Blinding after computing two-point statistics.
  - Blinding at the analysis level.
- Most common blinding schemes can be foiled by human error or can make it hard to do a joint analysis across science cases.

Lesson 2

Adopting both catalog-level and analysis-level blinding can better guard against human error.

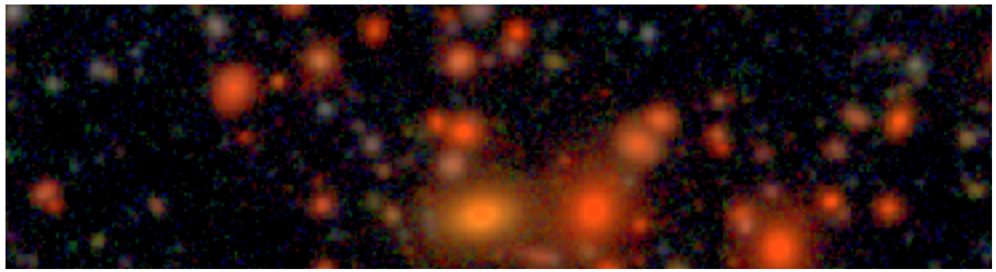


Lesson 3

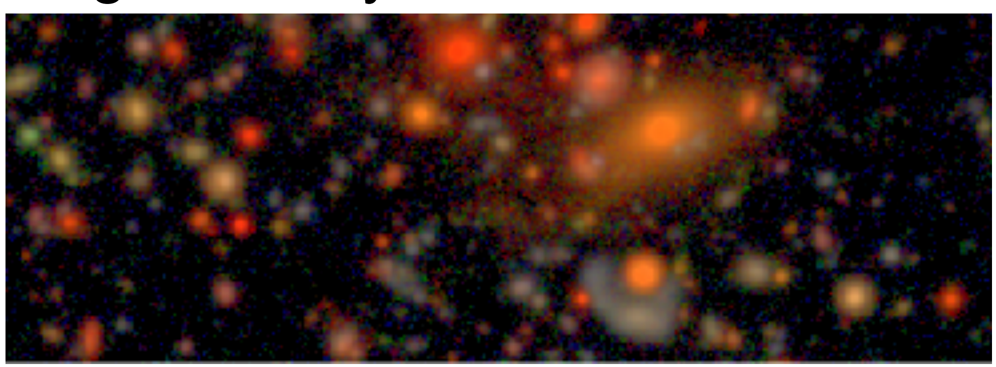


it's ~~turtles~~ galaxies all the way down

Lesson 3



Blending is a major challenge for deep future surveys like HSC, and is likely to affect all aspects of the analysis (photometric redshifts, shear, …). We need to confront this problem and its impact on cosmological analysis.



Summary

- The HSC survey had its first data release
  - You should download and play with our beautiful data! Check out hscMap
- Lots of science is being done!
  - Keep an eye on arxiv
- We are learning valuable lessons for the era of precision cosmology.
- Feel free to e-mail me any questions: rmandelb@andrew.cmu.edu