Subaru Hyper Suprime-Cam (HSC) Survey

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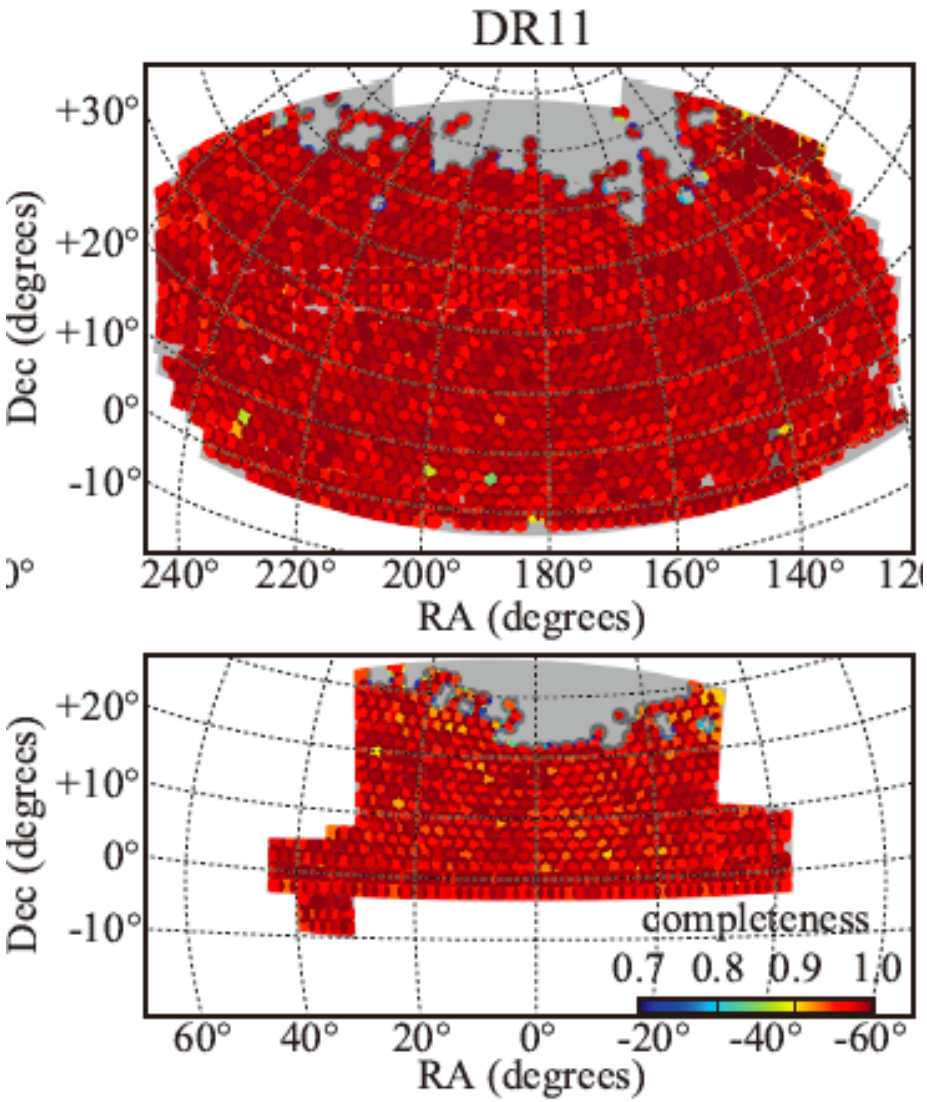
KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

東京大学 THE UNIVERSITY OF TOKYO

wpi

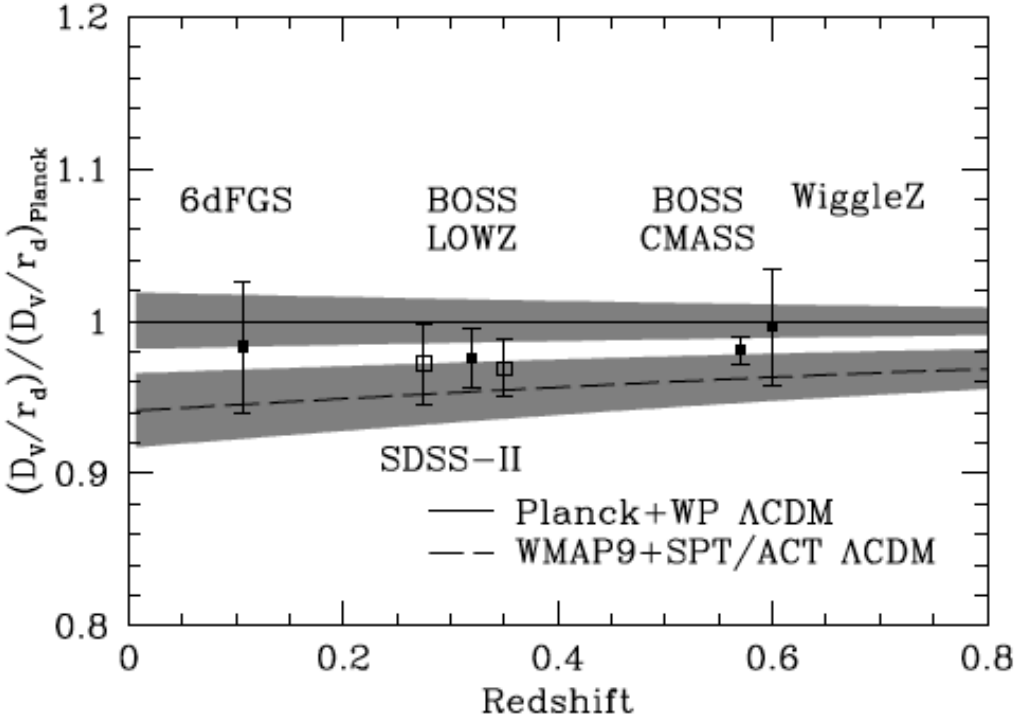
@ Astro-H Workshop, Tokyo U. of Science, Dec 28

BOSS DR11 Results (Dec 18th)



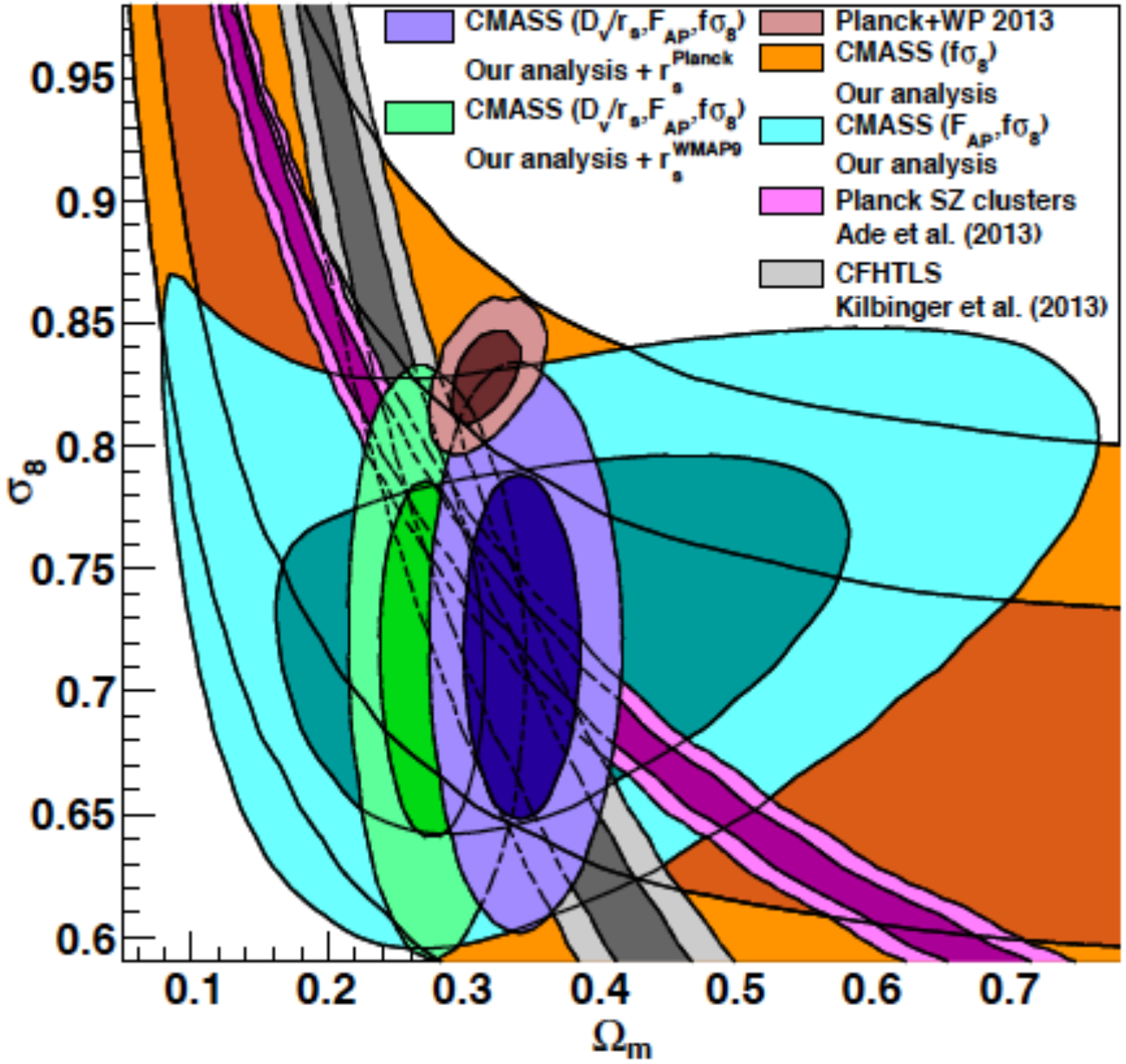
~8400 deg^2

- Anyone at U. Tokyo has the right of full access to the SDSS/BOSS data



~2 σ tension
Should wait for the 2nd Planck result (Sep 2014?)

LSS and Planck tension

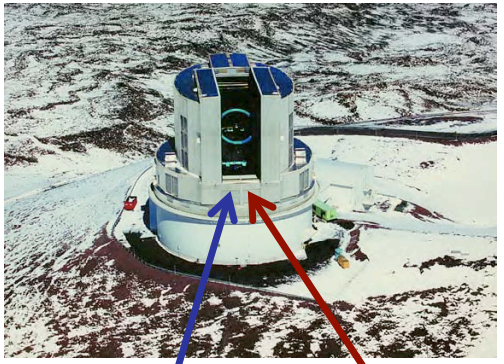


Beutler, Saito + 13

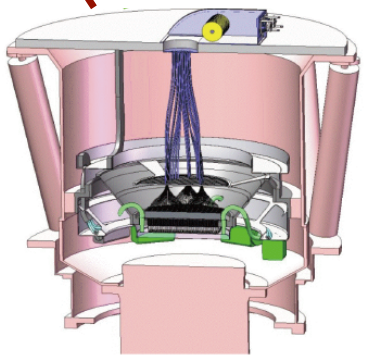
- Planck favors slightly higher matter density (Ω _m) and sigma_8 than the large-scale structure probes (weak lensing, galaxy clustering, CMB lensing, cluster abundance…)

SuMIRe = Subaru Measurement of Images and Redshifts

- IPMU director Hitoshi Murayama funded (~ $32M) 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 1M galaxies

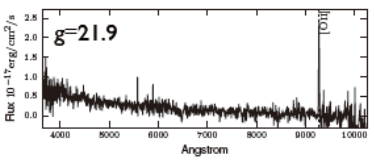


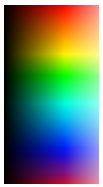
Subaru (NAOJ)



PFS

HSC





Cosmology/Cluster physics with Survey data

- Obtain a universal picture of the features or evolution of large-scale structure/clusters (use ~1B galaxies for HSC)
- Easy to compare & test the cosmological model
- Can also identify a rare object(s) compared to the other majority
  - I was quite often said in the US "You are totally different from Masataka (Fukugita-san). Which one is a typical Japanese?"
  - Unless we have an enough sample of Japanese people, we can't notice that Fukugita-san is special; can't also study a universal trend for other majority Japanese
  - Hence, in order to find >5sigma rare cluster(s), we need a homogenous survey data anyway; discovery vs. understanding

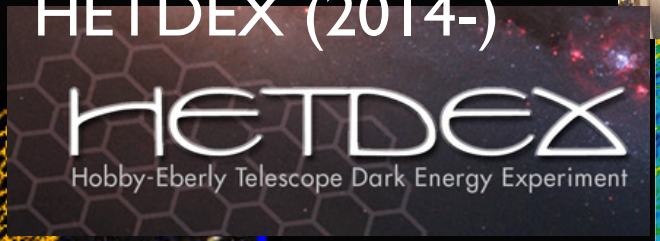
Survey Astronomy/ Cosmology

BOSS (2009-)

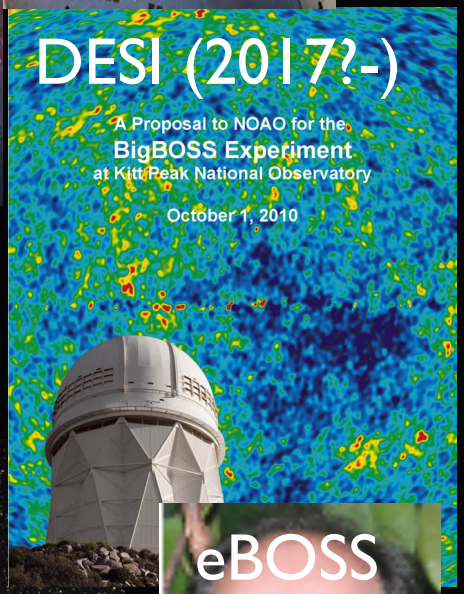
KIDS (2012-)

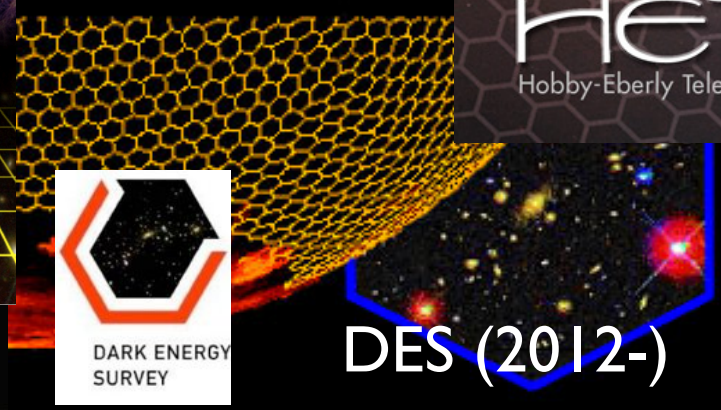
Euclid (2021)

HETDEX (2014-)



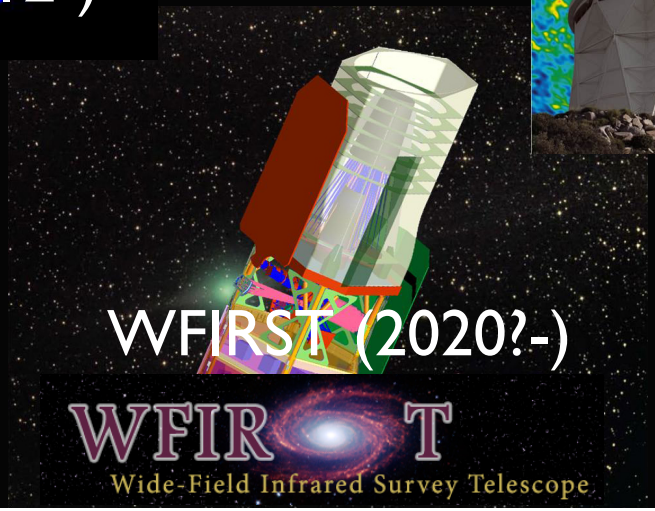
DESI (2017?-)





DES (2012-)

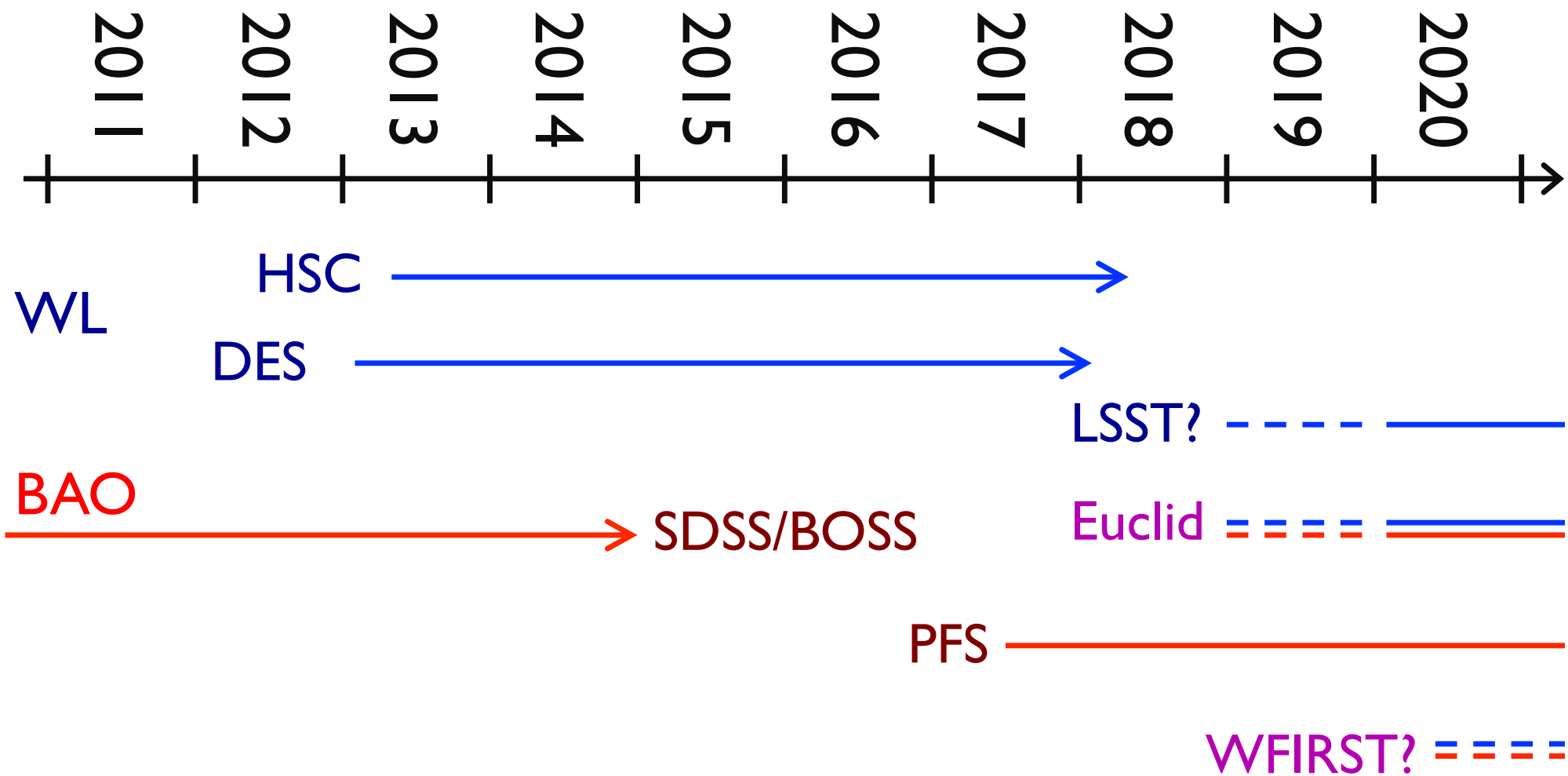
LSST (2020?-)



WFIRST (2020?-)

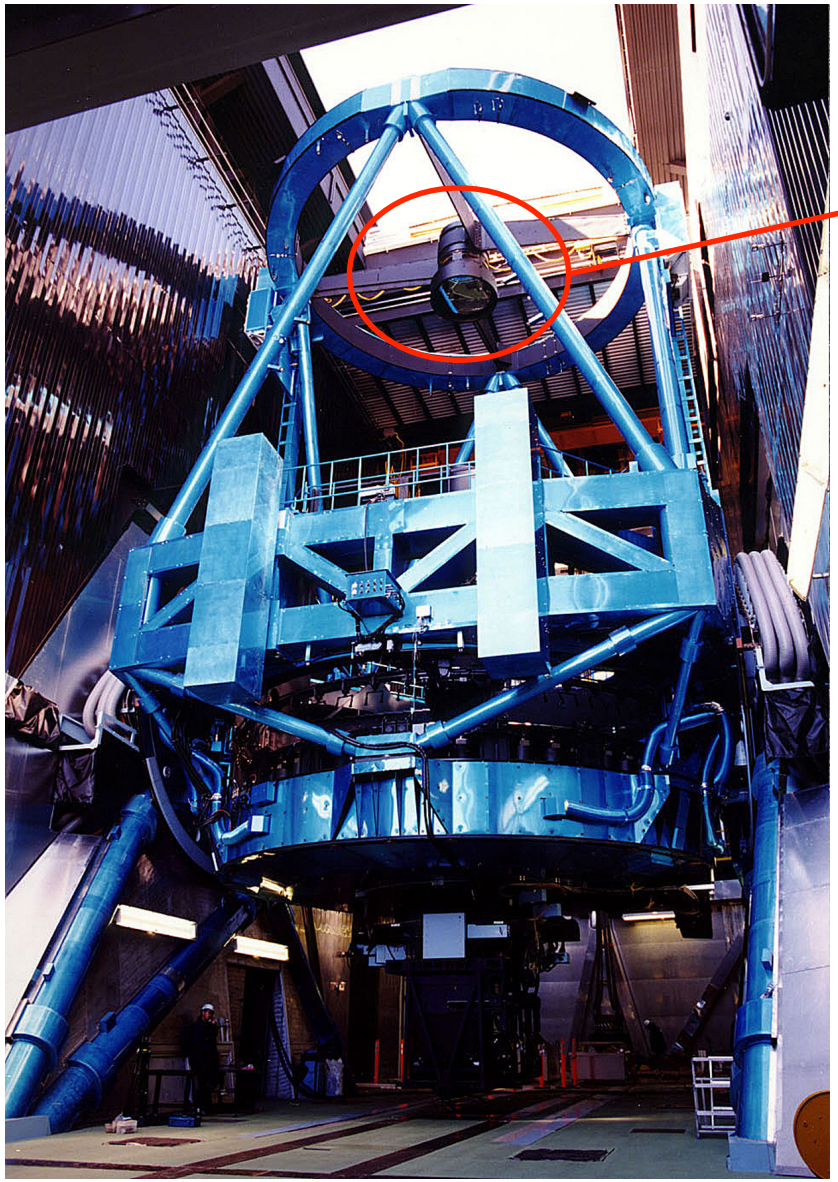
eBOSS

Time line (DE experiments)

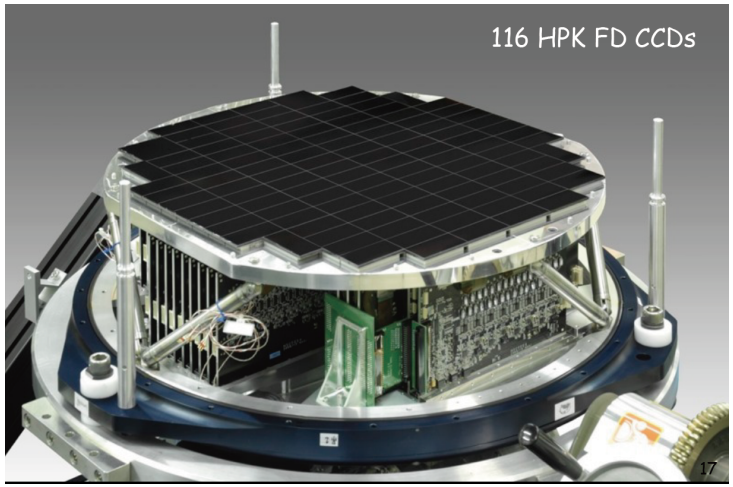


We are in a good position!

Hyper Suprime-Cam Project



- All instruments at Mauna Kea
- The *largest* camera in the world
- 3m high
- 3 tons weighed
- 116 CCD chips (870 millions pixels)



HSC First Light Image of M31

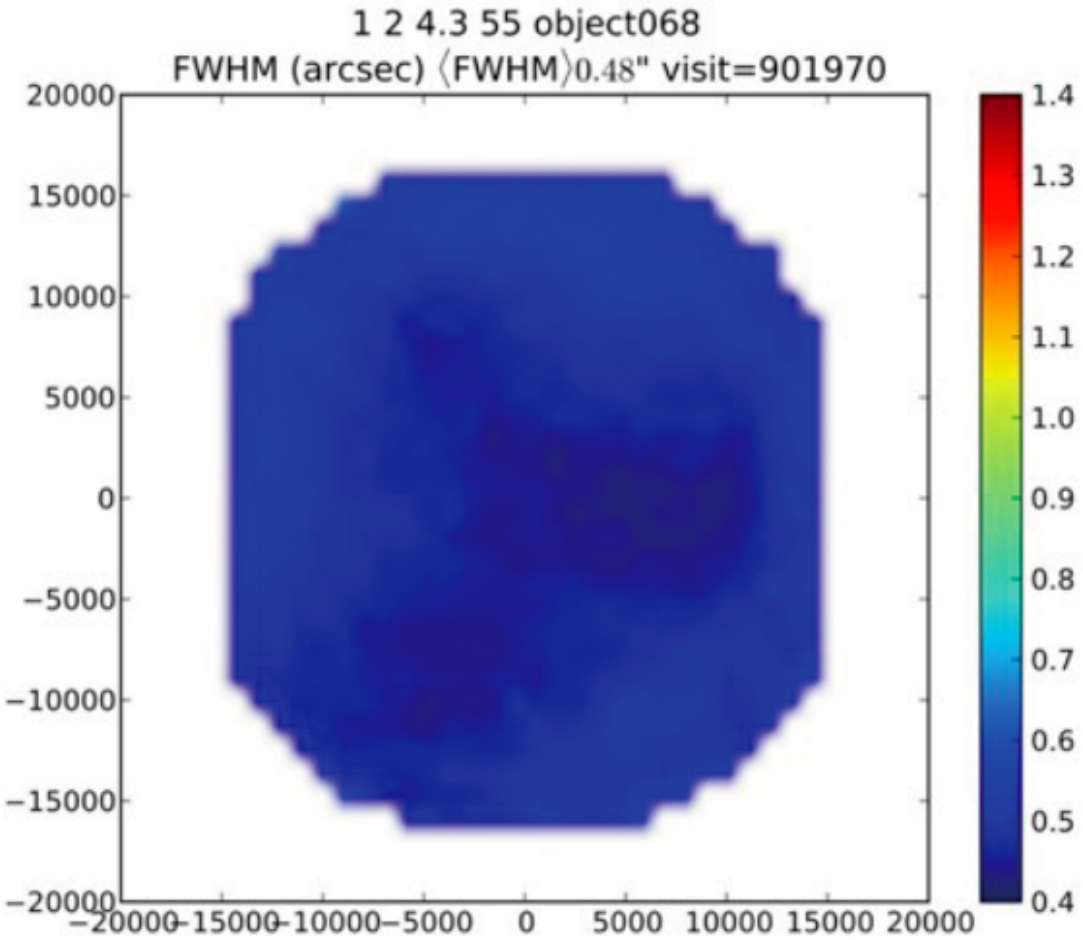
S. Miyazaki
(NAOJ)

N. Yasuda

S. Bickerton

Performance Test 4: Image Quality Uniformity

Feb2, 2013 Seeing 0''.4 ~ 0''.6 FWHM



← DES

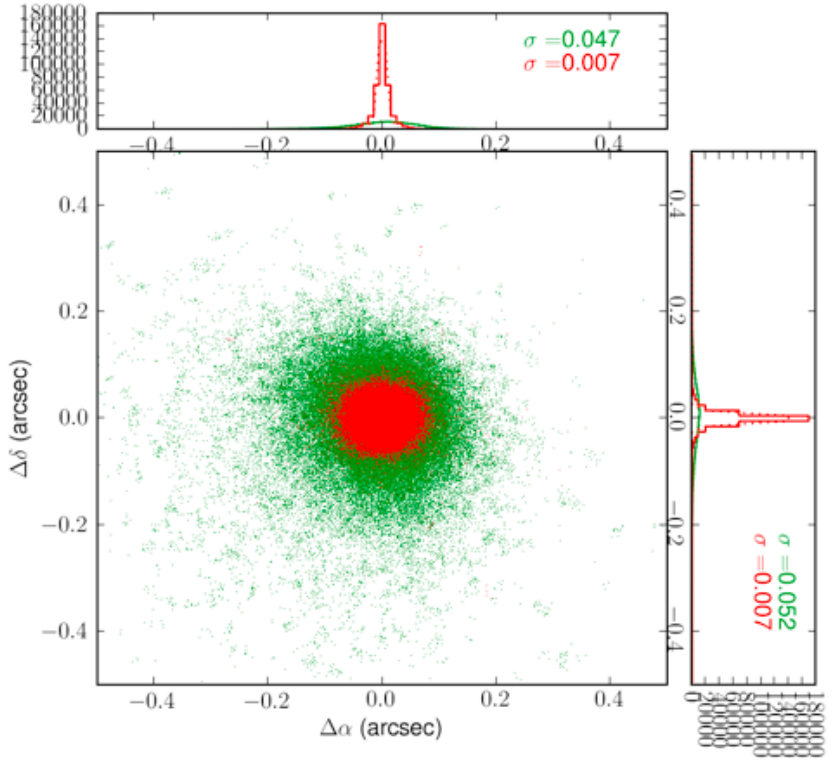
← HSC

10 sec exp
i'-band
EL: 55

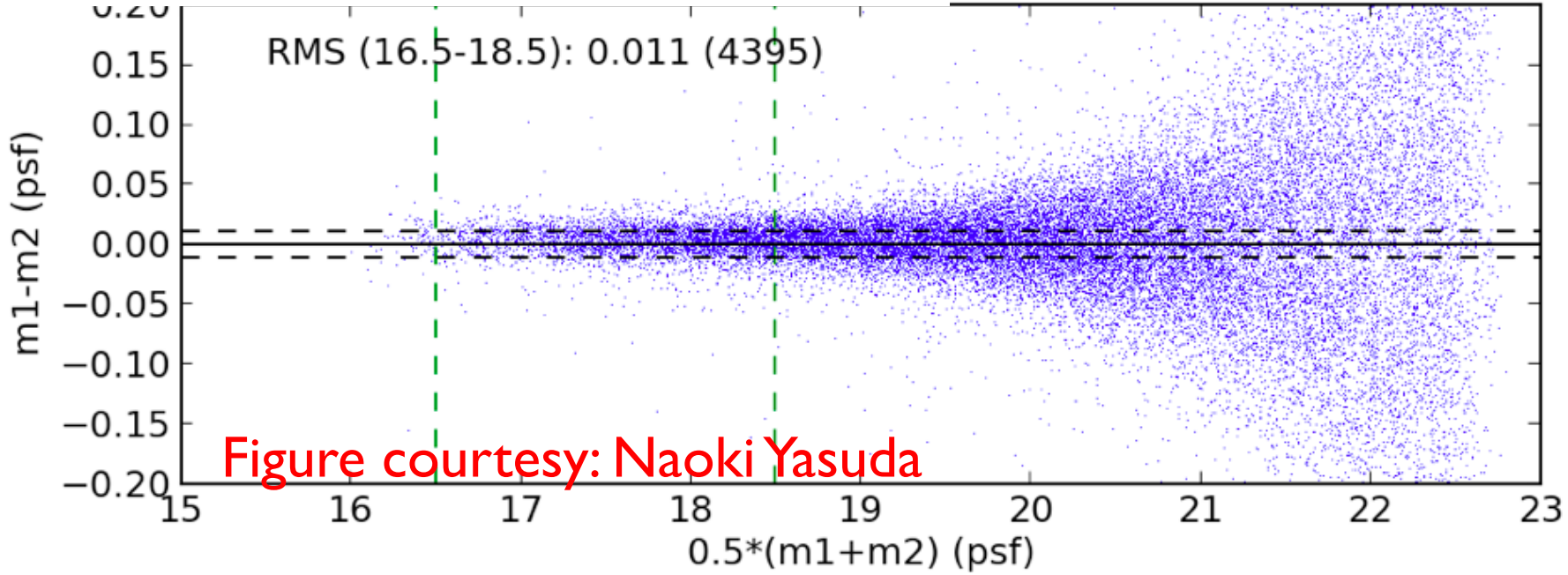
The 1st year science verification data of **DES** (~200 sq. degs) shows ~1.1" FWHM for the median seeing

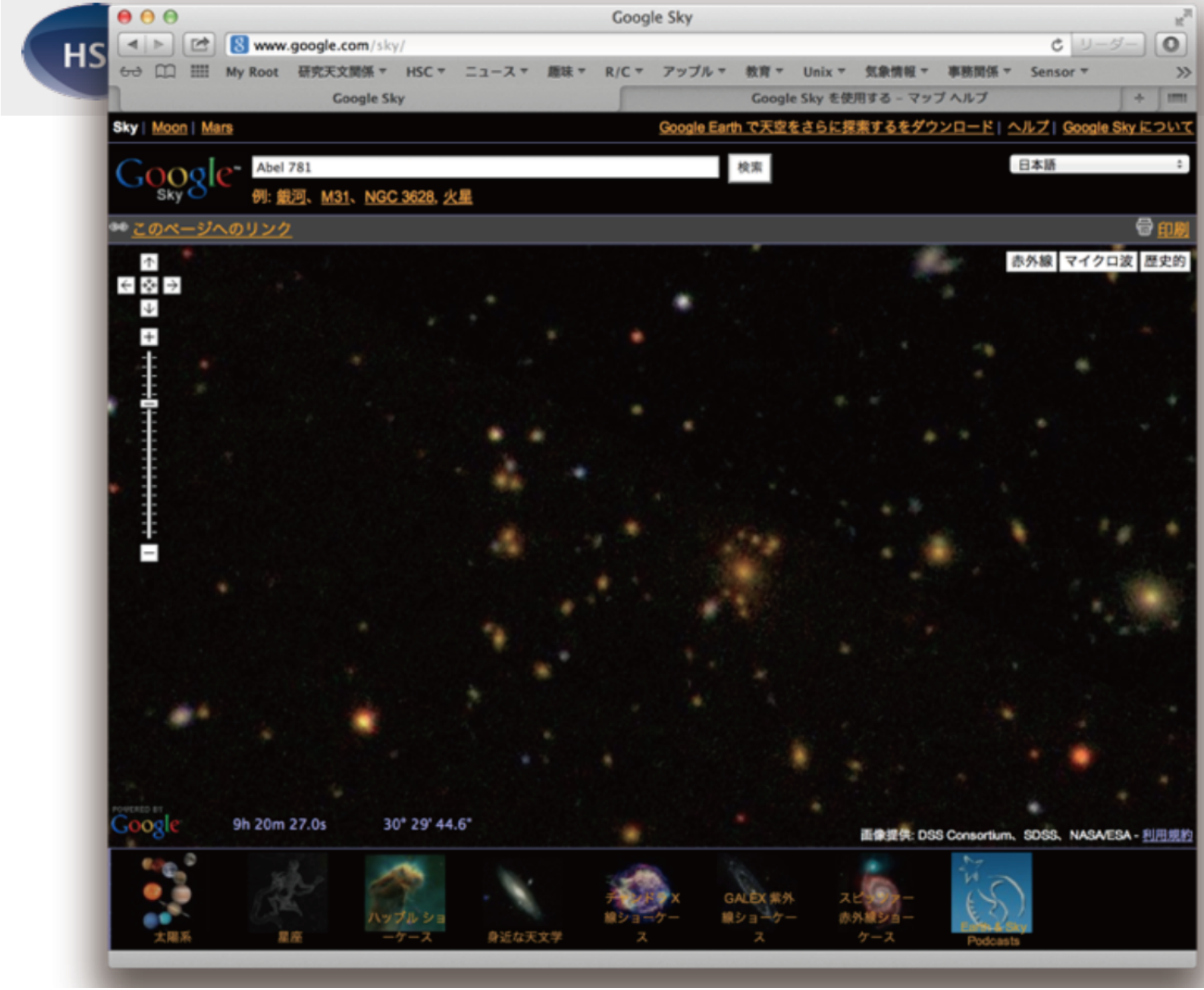
HSC/NAOJ

From S. Miyazaki (HSC PI, NAOJ)



- From the commissioning data (June run)
- Based on the HSC pipeline (based on the LSST pipeline)
- Overlapped with SDSS field
- ~1% photometry accuracy
- ~50mas for astrometry




Google Sky
www.google.com/sky/
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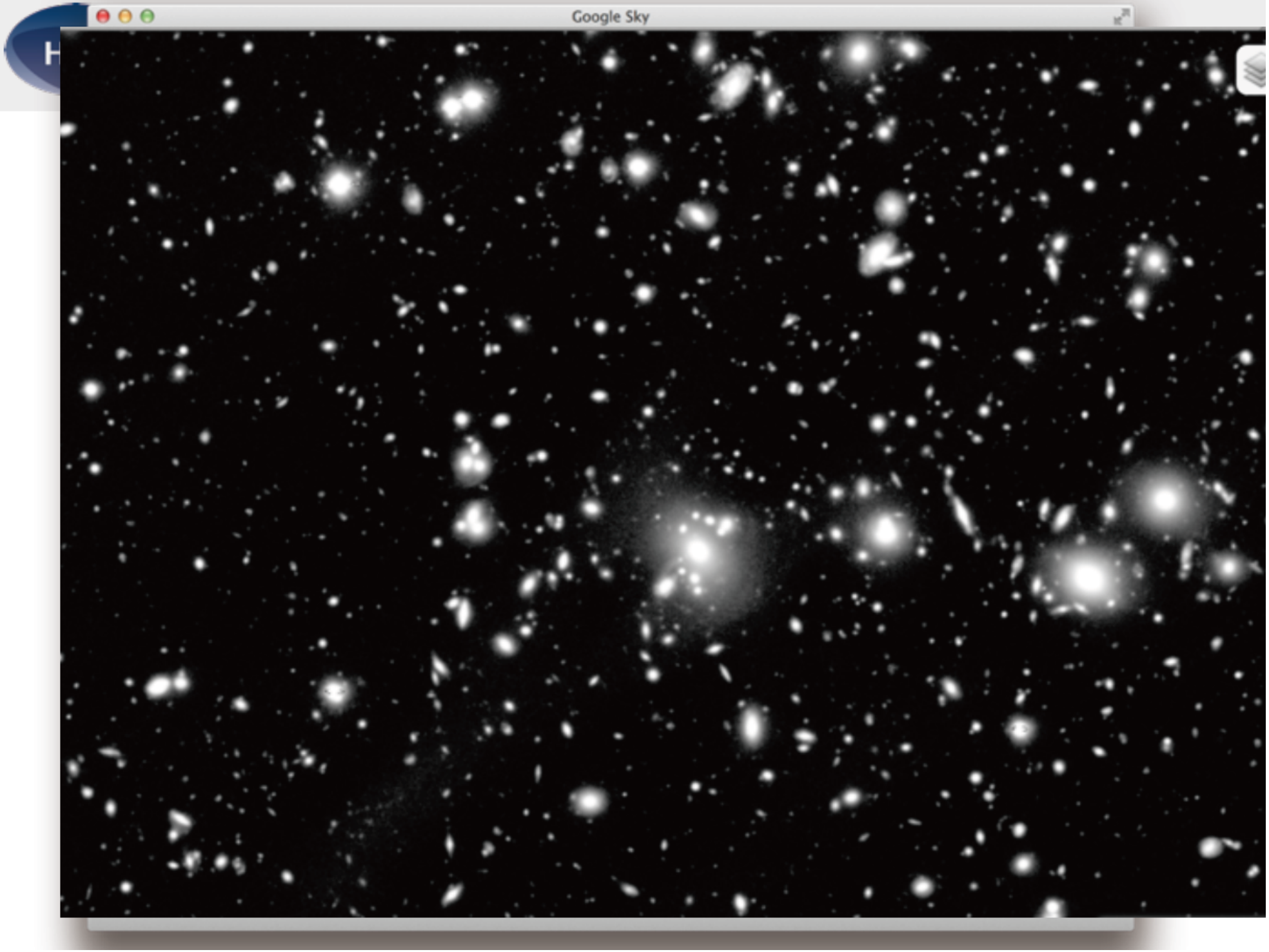
Google Sky
Abel 781
検索
日本語
例: 銀河、M31、NGC 3628, 火星
このページへのリンク
印刷
赤外線
マイクロ波
歴史的
9h 20m 27.0s
30° 29' 44.6"
画像提供: DSS Consortium、SDSS、NASA/ESA - 利用規約
太陽系
星座
ハッブル ショーケース
身近な天文学
GALEX 紫外線ショーケース
スピッツァー 赤外線ショーケース
Earth & Sky
Podcasts


Google Sky

Brief History of HSC

- 2006 HSC grant (~$20M: PI H. Karoji) started
- 2008 Princeton and Taiwan joined
- 2009 FIRST made up for the shortfall (added ~$20M)
- Oct 2012 The survey proposal for the HSC Subaru Strategic Program (HSC SSP) submitted (the reviewing process by the Subaru Community)
- Feb 2013 *HSC first light using all the 104 CCD chips*
- Feb 2013 Troubles of Subaru (in total 3+4 months delay, although we originally wanted to start our survey from this year)
- April 2013 *300 nights approved for HSC SSP*
  - Previous SSP surveys: SEEDS 120nights (08-13), FMOS 120 requested, but only 40 nights approved (12-13 or 14)
- Late June 2013 the second commissioning run
- Oct 2013 – Jan 2014 Commissioning runs (data quality verification)
- Feb 2014 HSC SSP Survey starts till 2019

PI: Satoshi Miyazaki (NAOJ)
M. Takada: Science WG co-chair (with M. Strauss),
Survey Design Committee chair

M. Strauss
(Princeton)

HSC SSP proposal
About 170 Col's, ever largest galaxy survey

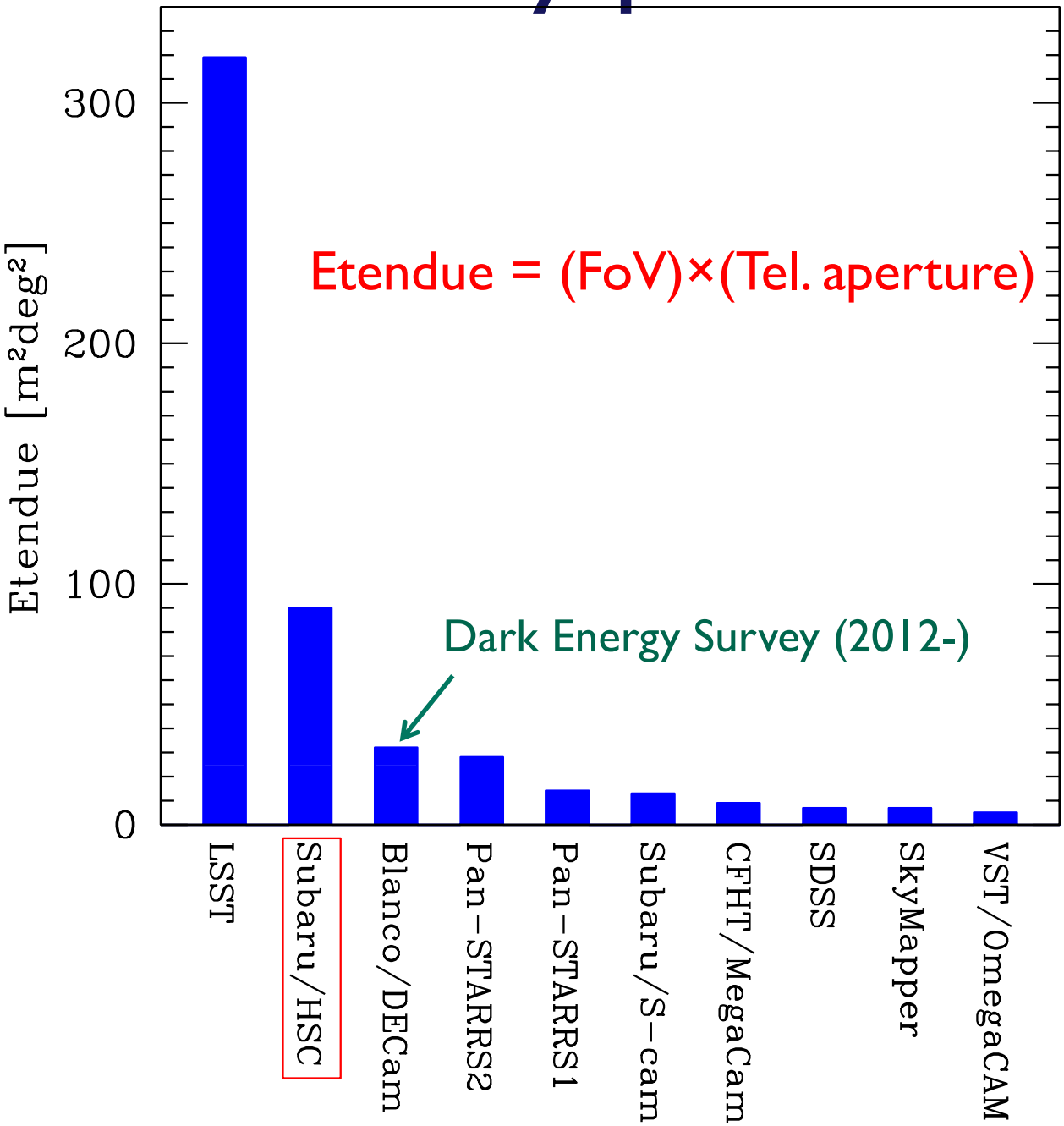
Wide-field imaging with Hyper Suprime-Cam: Cosmology and Galaxy Evolution

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

Survey power of HSC

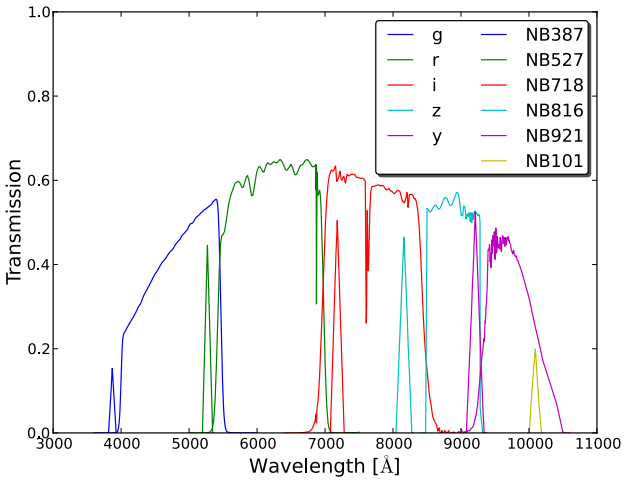


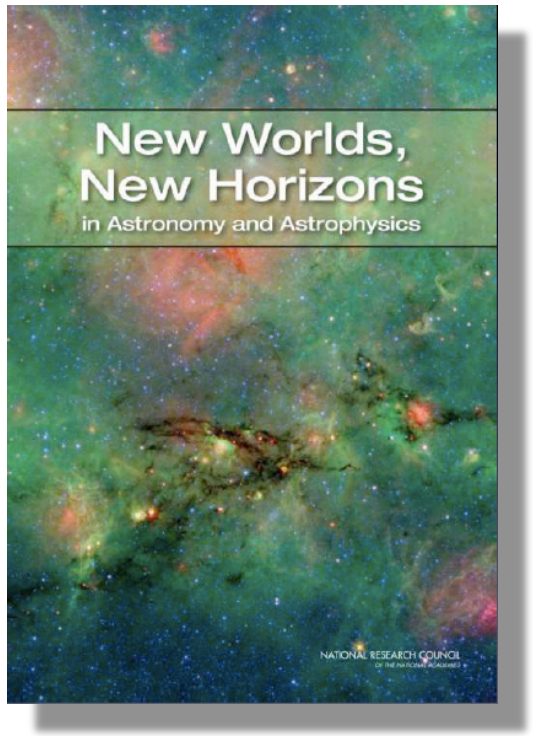
- Photon collecting power of 8.2m Subaru Tel.
- FoV
- In addition, excellent image quality

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

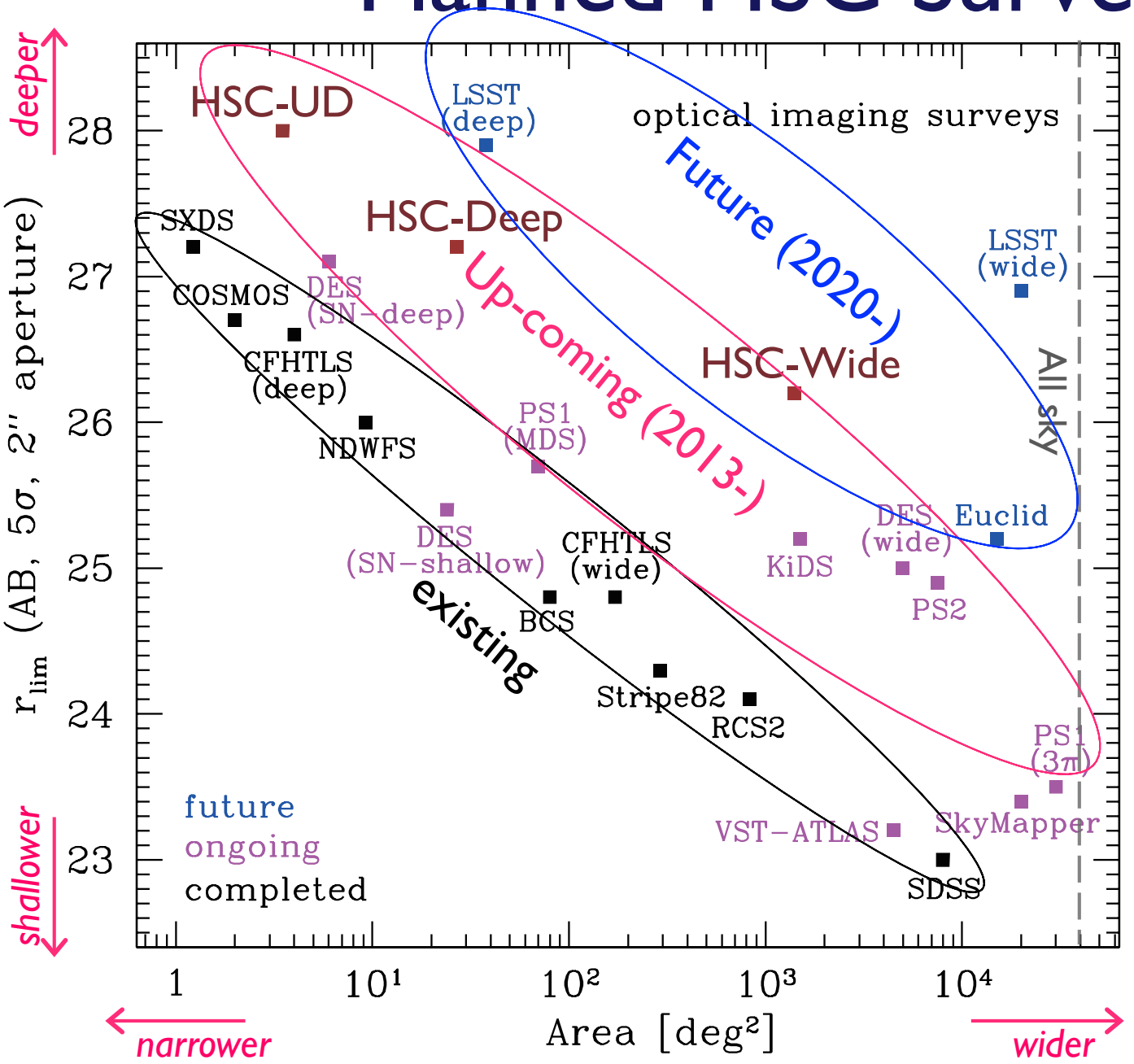
Planned HSC Survey

- Wide Layer: 1400 sq. degs., *grizy* (i_{AB}=26, 5σ)
  - Weak gravitational lensing
  - Galaxy clustering, properties of z~1 L_* galaxy
  - *Dark Energy*, *Dark Matter*, neutrino mass, the early universe physics (primordial non-Gaussianity, spectral index)
- Deep Layer: 28 sq. degs, *grizy*+NBs (*i*=27)
  - For calibration of galaxy shapes for HSC-Wide WL
  - Lyman-alpha emitters, Lyman break galaxies, QSO
  - Galaxy evolution up to z~7
  - *The physics of cosmic reionization*
- Ultra-deep Layer: 2FoV, *grizy*+NBs (i~28)
  - Type-Ia SNe up to z~1.4
  - LAEs, LBGs
  - Galaxy evolution
  - *Dark Energy, the cosmic reionization*





Planned HSC Survey



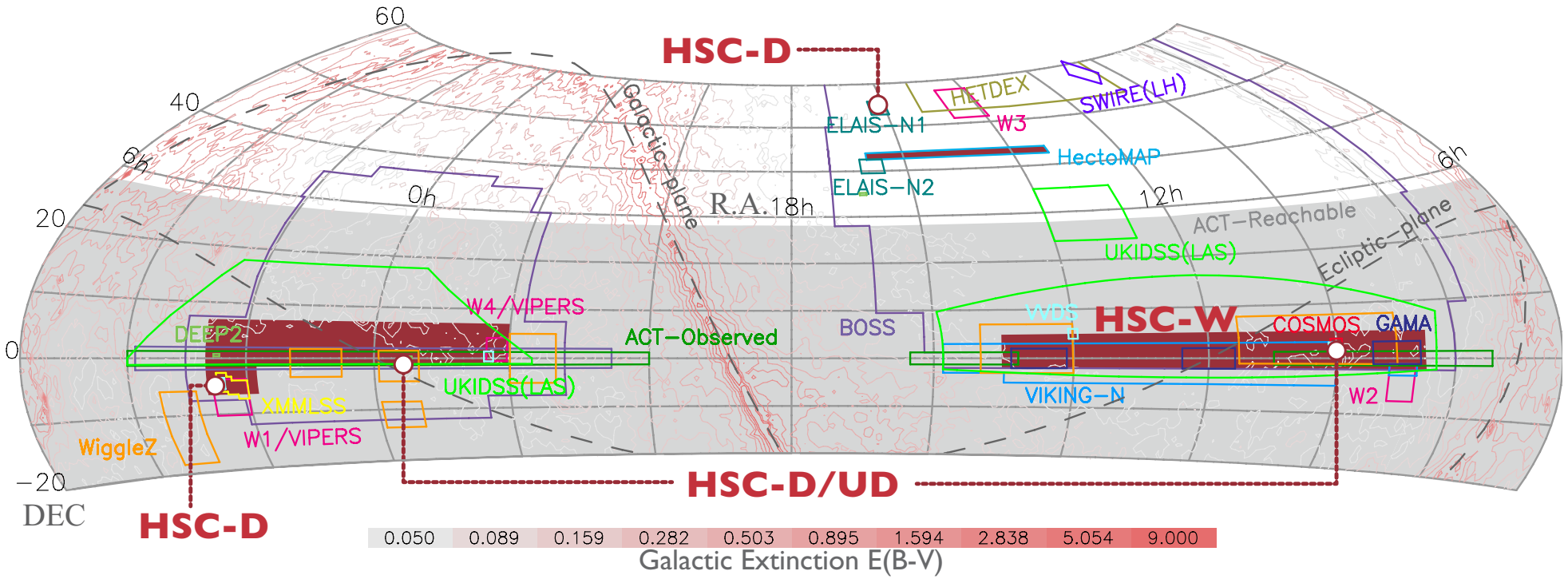
Black: existing

Magenta: upcoming

Blue: future

HSC Layers will explore new regions in survey parameter space

HSC Survey Fields

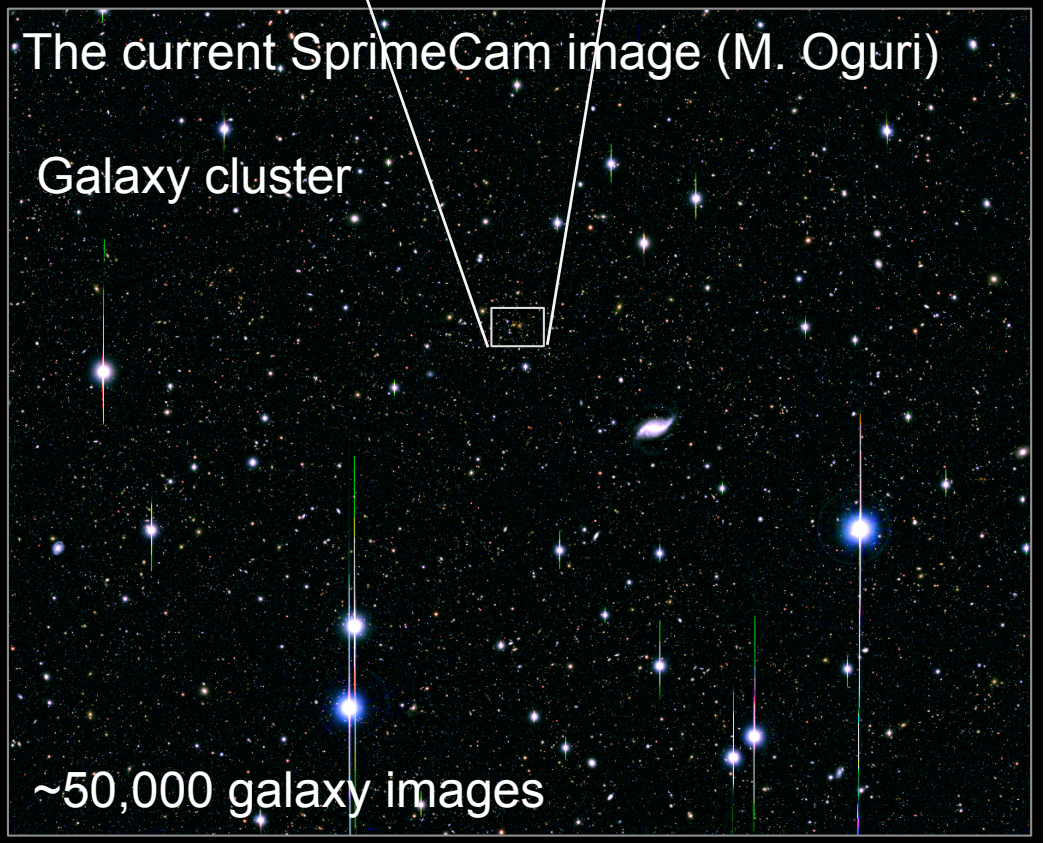


- The HSC fields are selected based on …
  - Synergy with other data sets: SDSS/BOSS, The Atacama Cosmology Telescope CMB survey (from Chile), X-ray (XMM-LSS), spectroscopic data sets
  - Spread in RA
  - Low dust extinction

Subaru Telescope: wide FoV & excellent image quality

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

HST

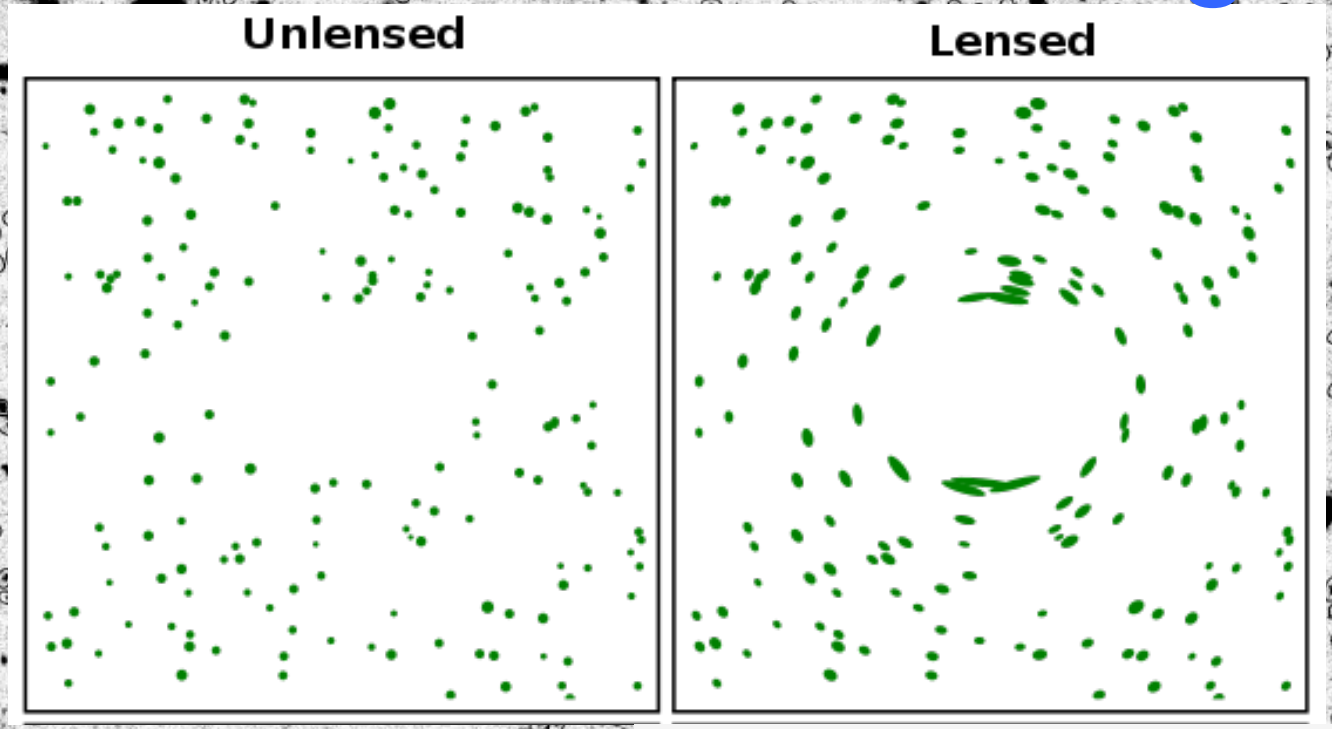


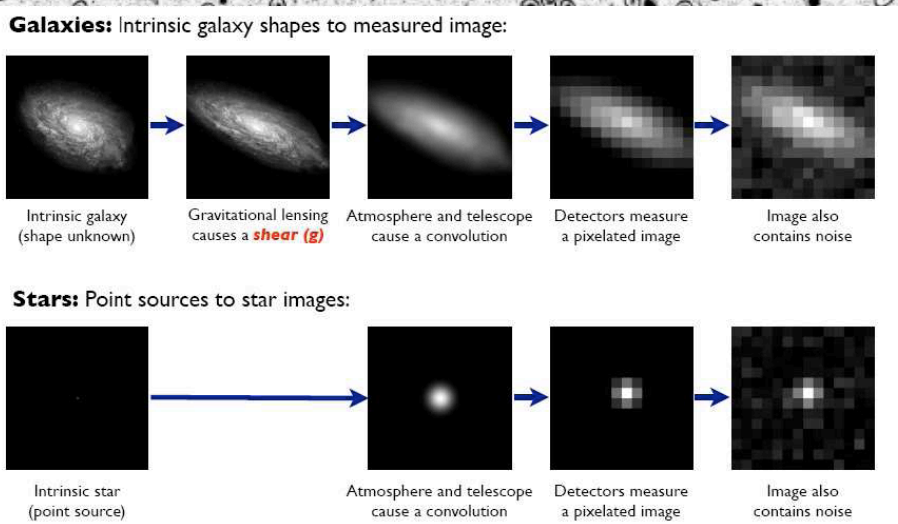
Hyper Suprime-Cam FoV

- **Fast**
- a cos

~50,000

Statistical weak lensing





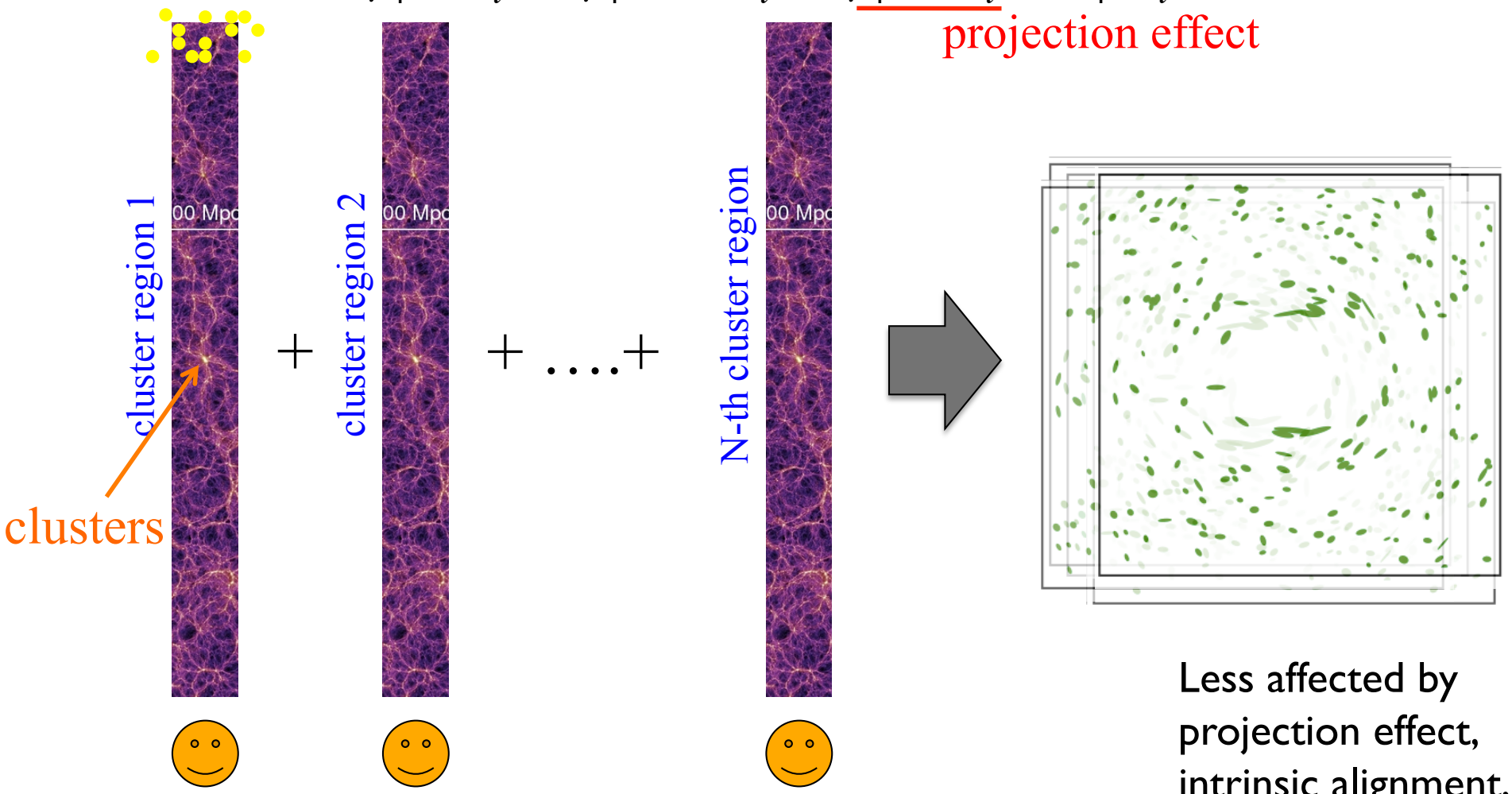
- Need statistics to reduce the intrinsic shape contamination
- Excellent image quality and deep image needed for an accurate WL measurement
- Issues; accurate shape measurements, PSF correction, pixelization effect

Stacked lensing: halo-shear correlation

$$\gamma_+^{\rm obs}(\theta_i) = \gamma_+^{\rm cluster}(\theta_i) + \gamma_+^{\rm LSS}(\theta_i) + \varepsilon_+(\theta_i)$$

Oguri & MT 11

projection effect



$$\langle\gamma_+\rangle(\theta) = \frac{1}{N_{cl}} \sum_{a=1}^{N_{cl}} \sum_{|\vec{\theta}'|\subset\theta} \gamma_{+(a\text{-th cluster})}(\vec{\theta}') \approx \left\langle \gamma_+^{\rm cluster} \right\rangle(\theta)$$

Less affected by projection effect, intrinsic alignment, sys. errors ….

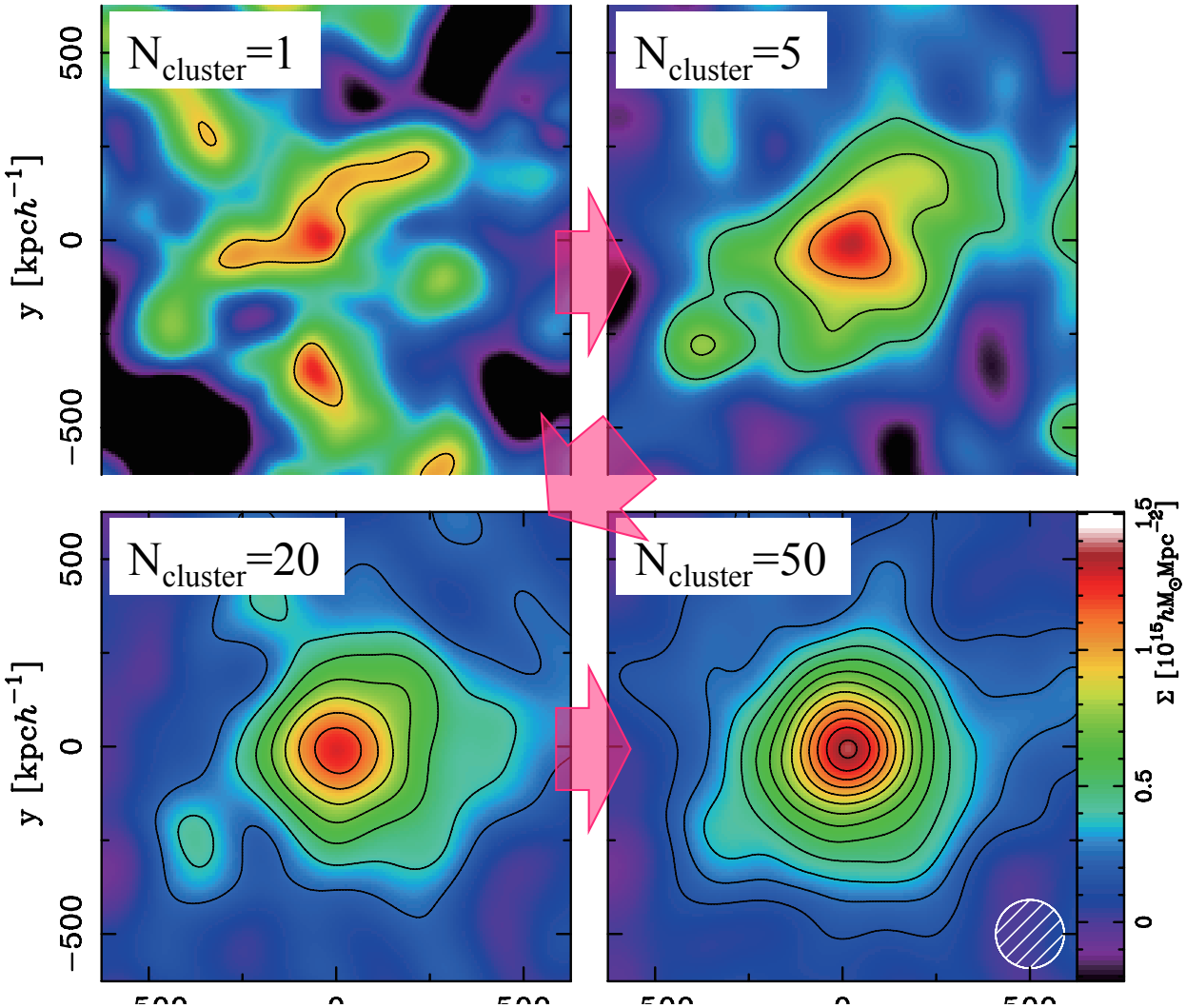
Note: halo center

A preparation study of HSC survey

DM distribution of galaxy clusters

N. Okabe

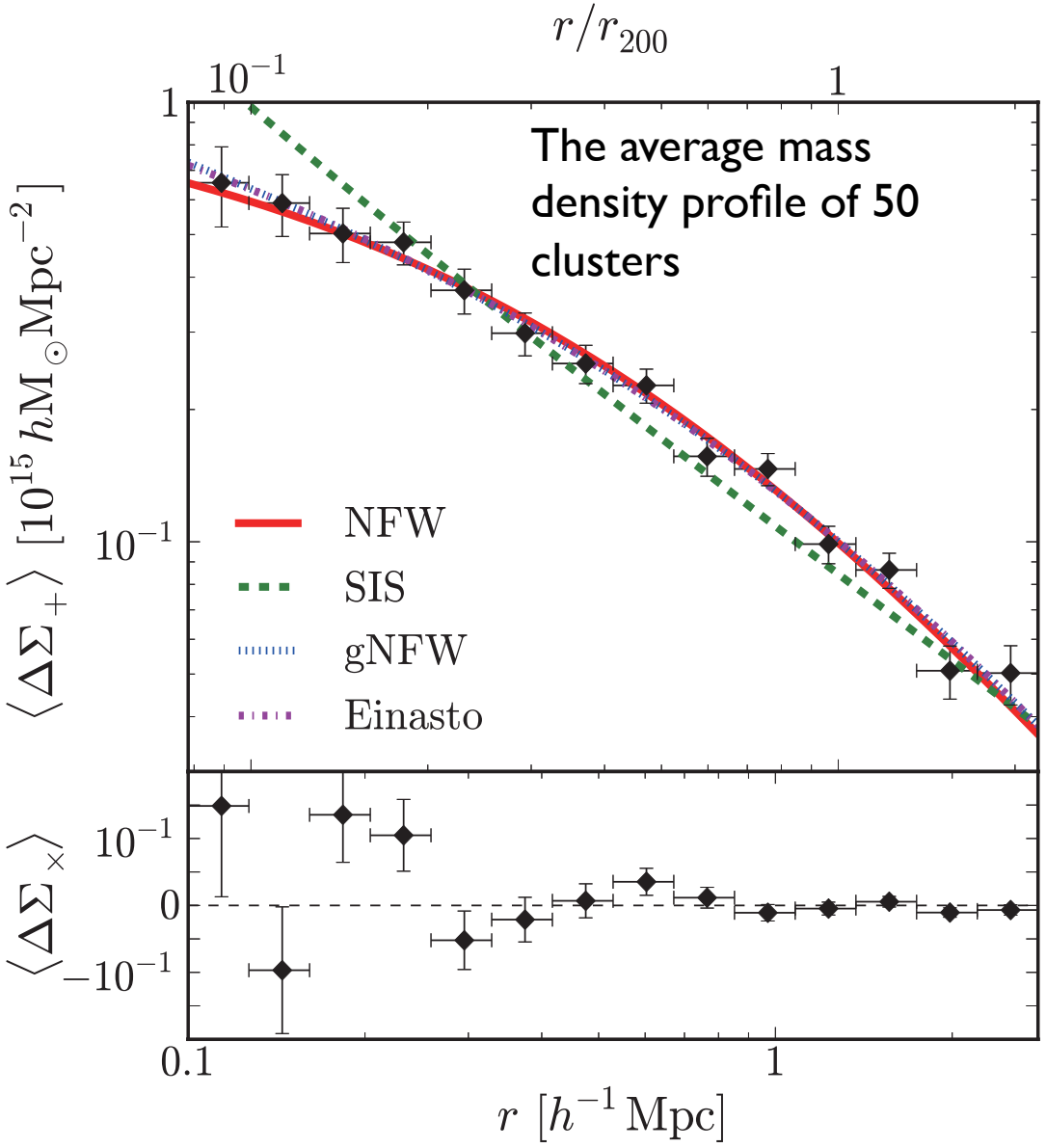
- Collected Subaru data of 50 clusters, *all* the most X-ray luminous clusters accessible from Subaru (about 15 Subaru nights; 5 yrs)
- The averaged DM distribution from the combined WL data

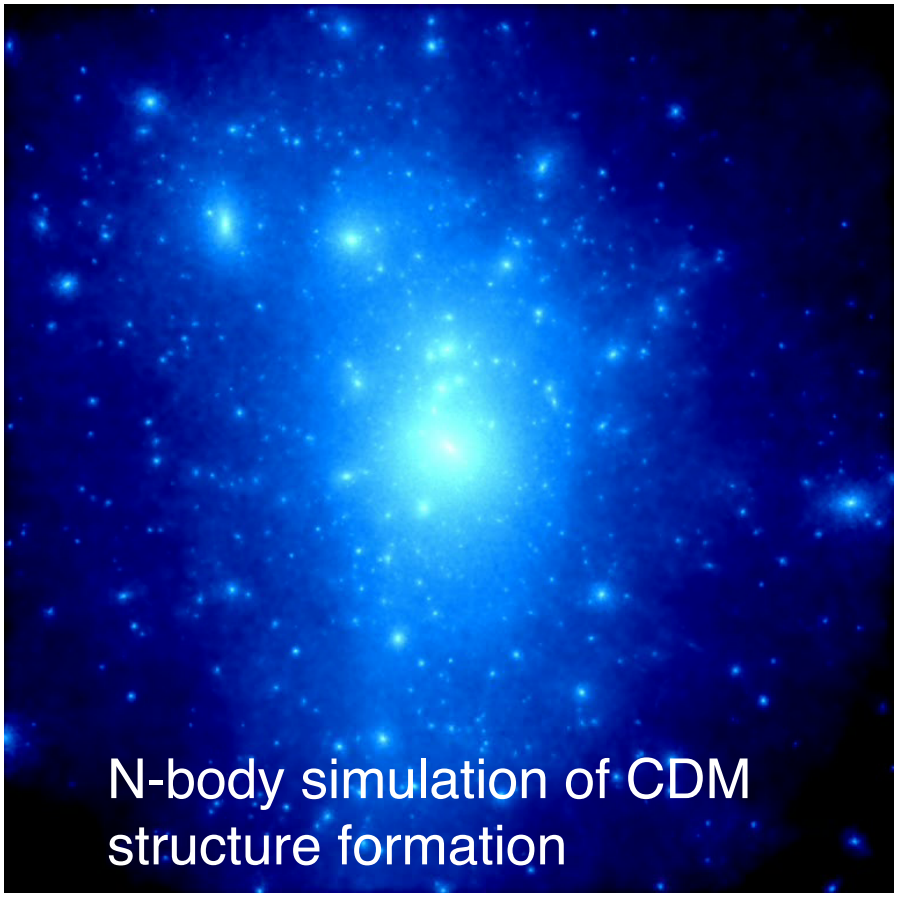


Signal-to-Noise ratio *(S/N)*~5 for one cluster ⇒ *S/N*~30 when 50 clusters combined

Okabe et al. 13, ApJ Letters
Okabe, MT+ 10

DM distribution of galaxy clusters (cont'd)



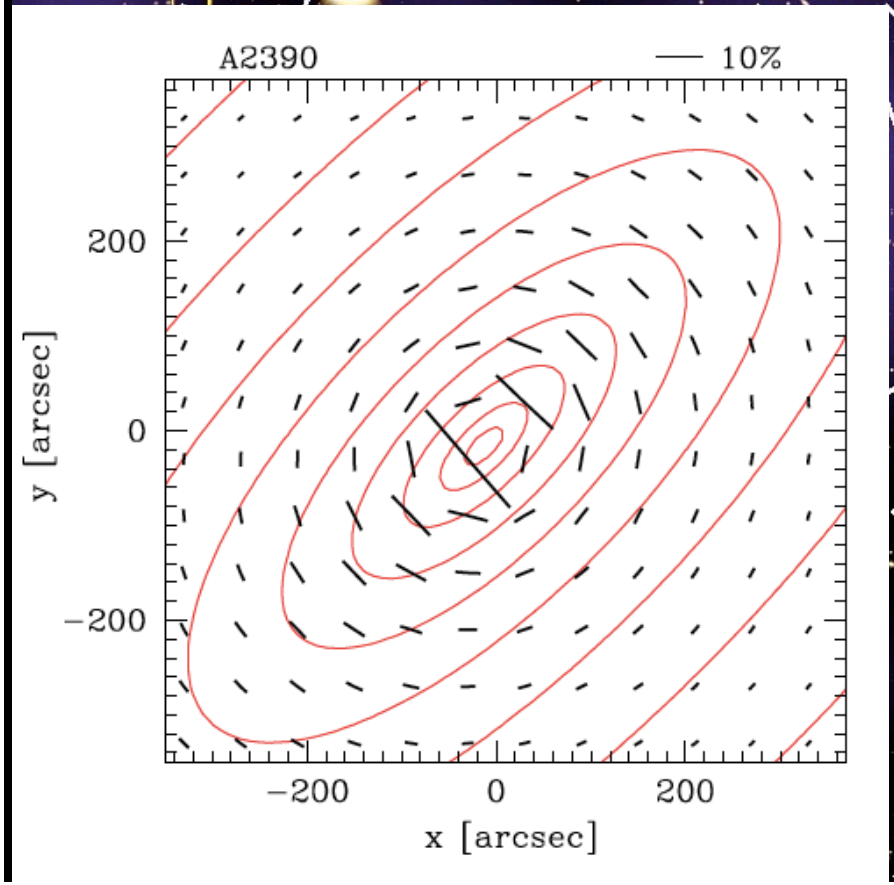


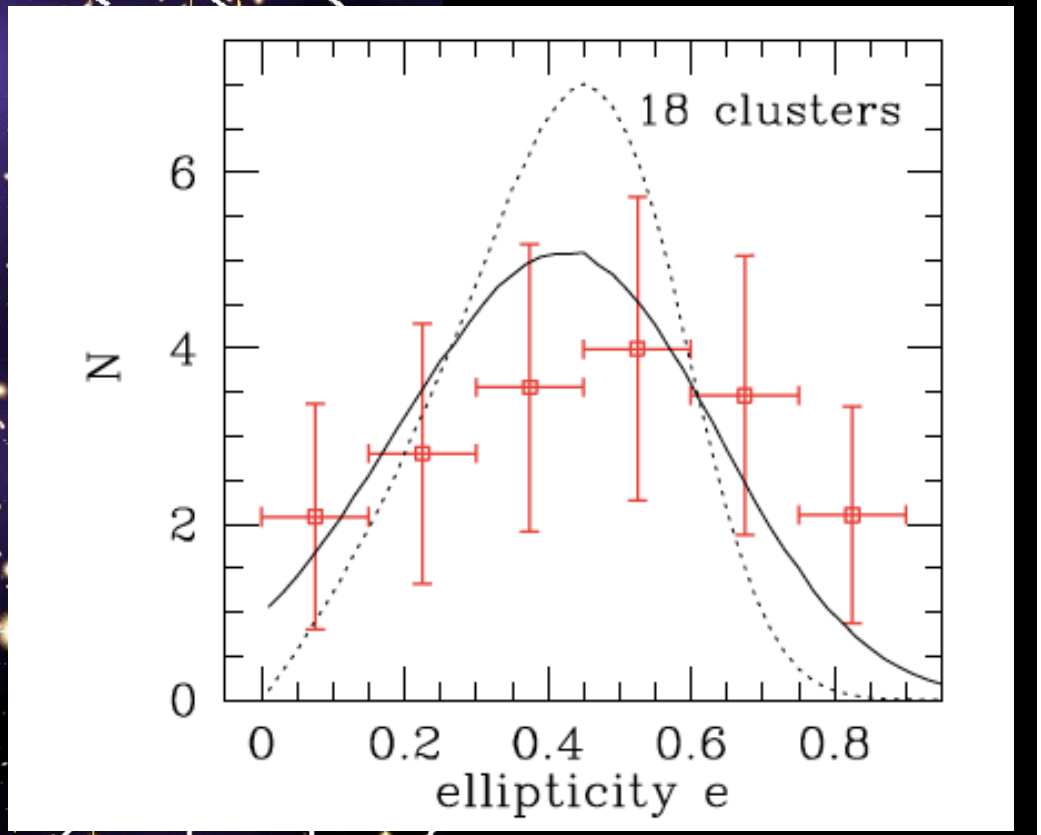
- Subaru WL result shows a perfect agreement with the CDM model prediction

Revealing shape of dark matter halo

Oguri, MT+ 10

X-ray luminous cluster A2390

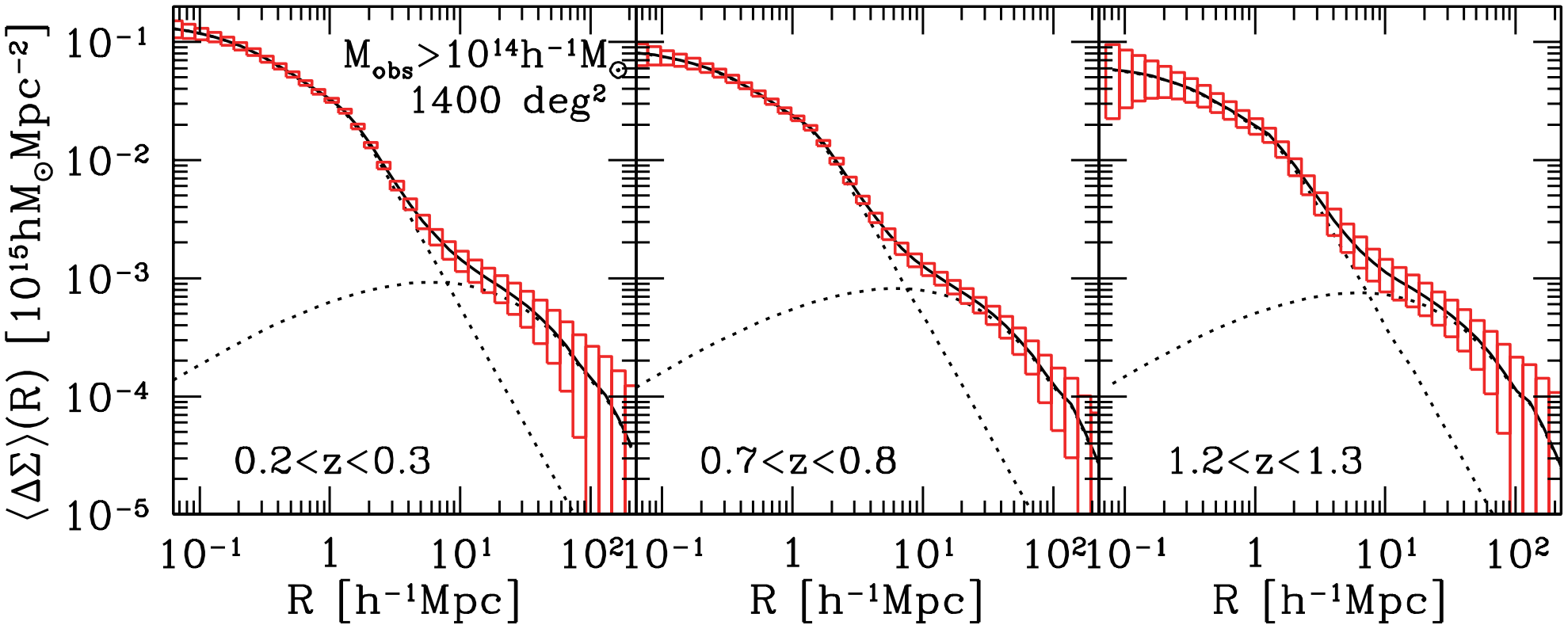




Discovered a flattened shape of DM halo reflecting collision-less nature of DM (gas dist. more spherical)

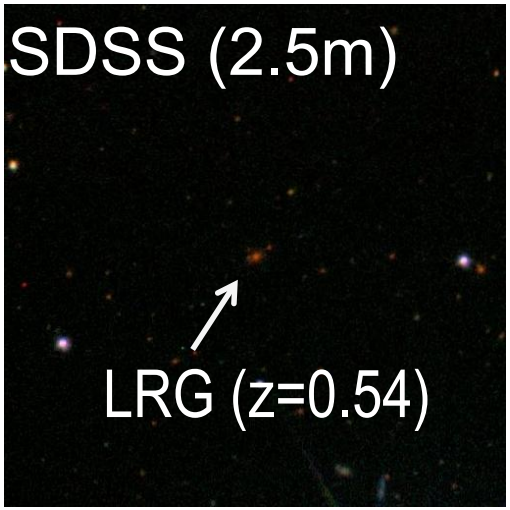
Forecast for stacked lensing with HSC

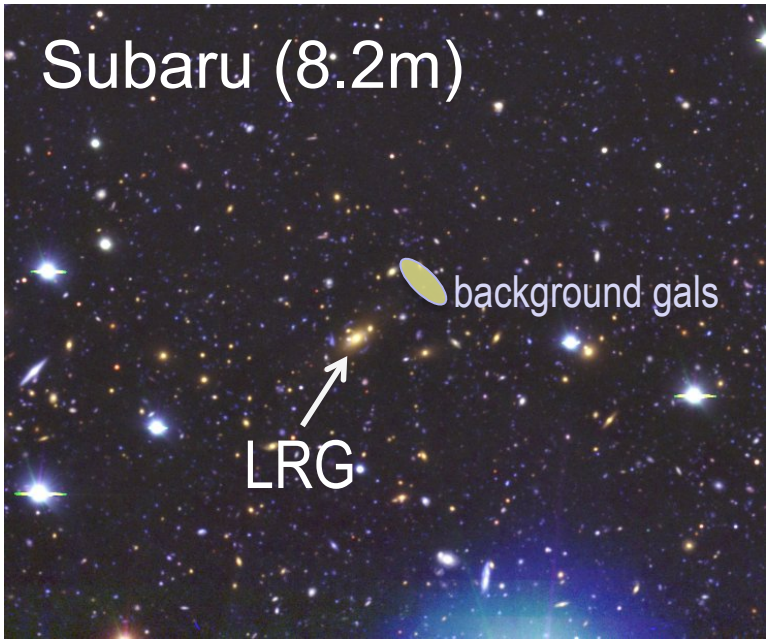
Oguri & MT 10



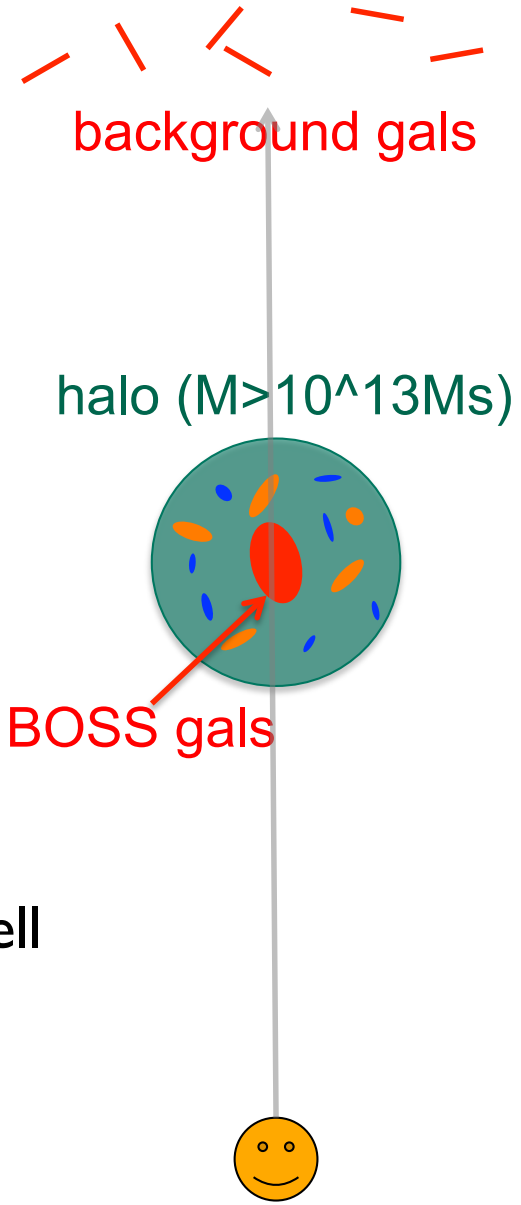
- >10000 clusters with >10^14Msun, up to z~1.4
- HSC can achieve a high S/N detection of stacked WL signals out to z~1.3
- Small-angle signals are from one halo (the mean halo mass and the average shape of mass profile)
- Large-angle signals are from the mass distribution in large-scale structure

Synergy btw HSC and BOSS





Credit: Masayuki Tanaka (IPMU)



- The deep HSC data will add background galaxies as well as member galaxies around each BOSS gal
- Cross-correlation of BOSS gals with HSC galaxies (shapes and positions)
- WL, galaxy clustering, CMB lensing, SZ, X-ray….

Complementarity of different data

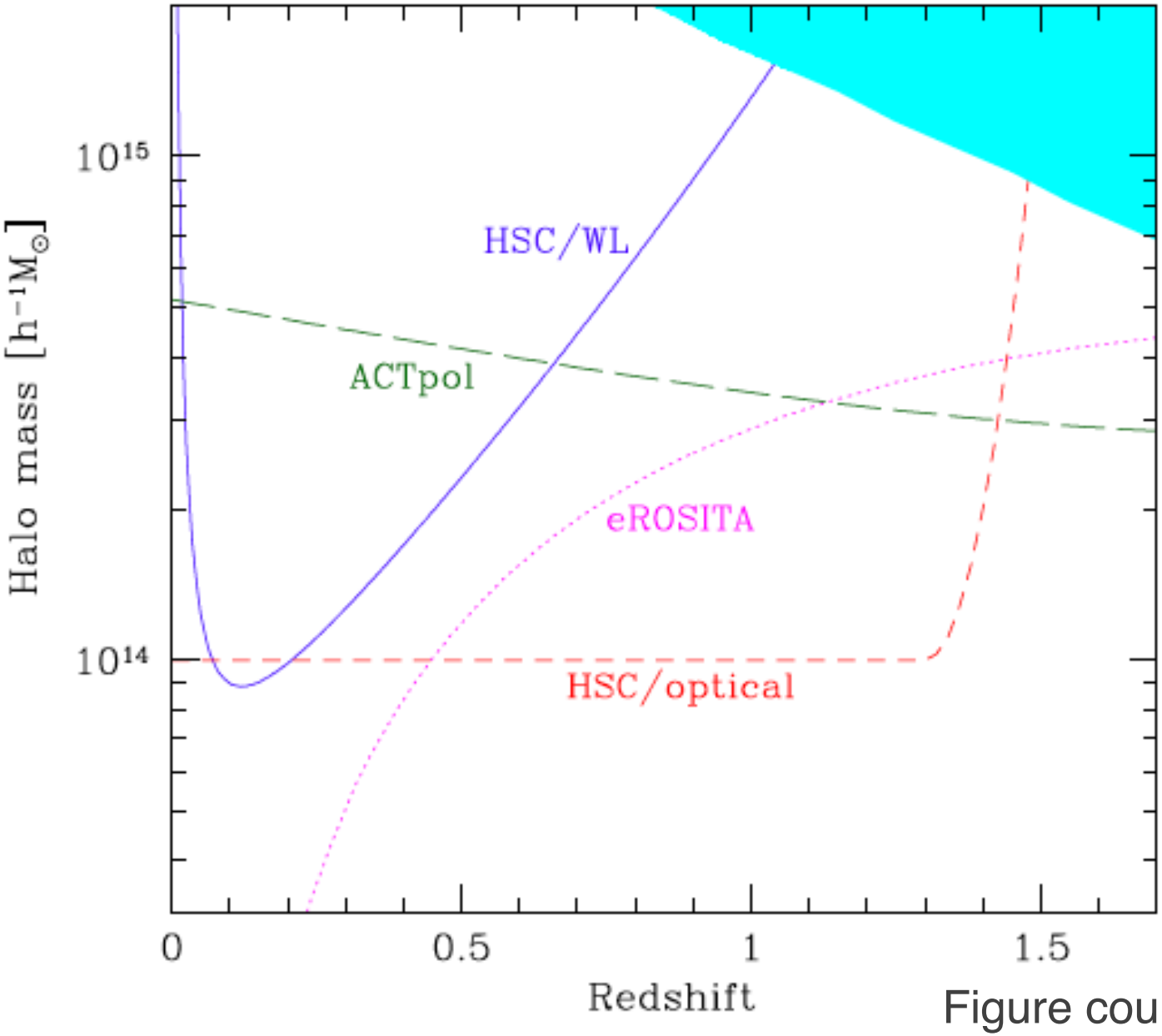
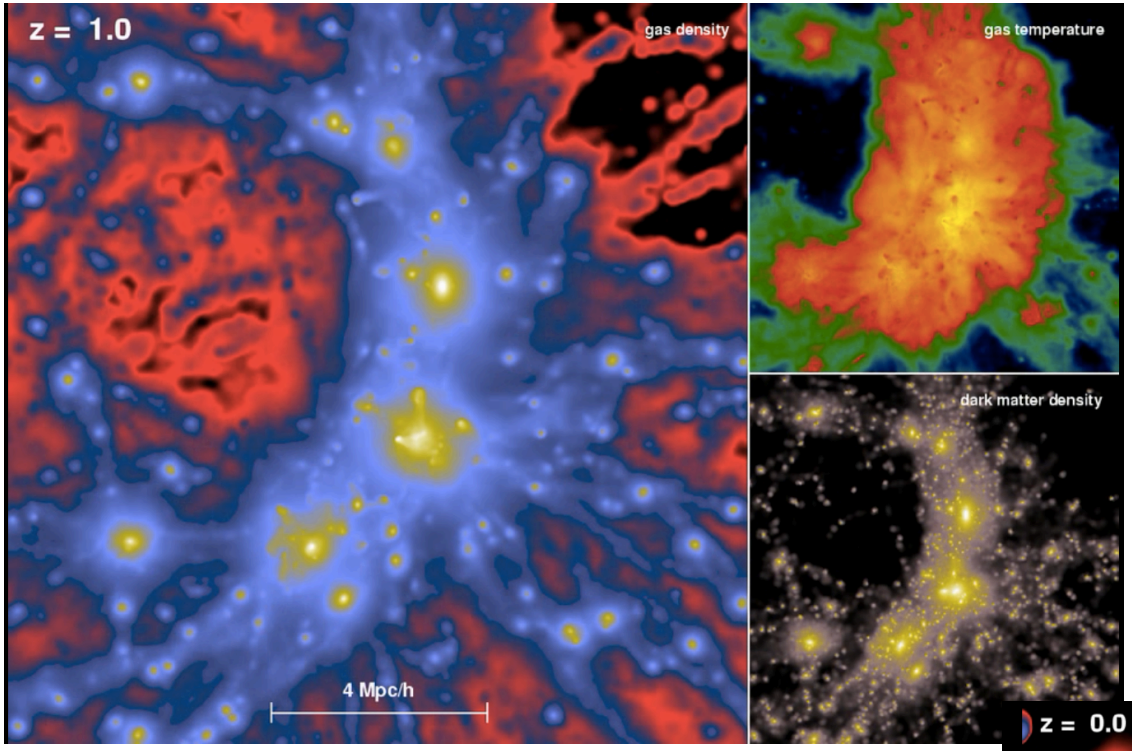


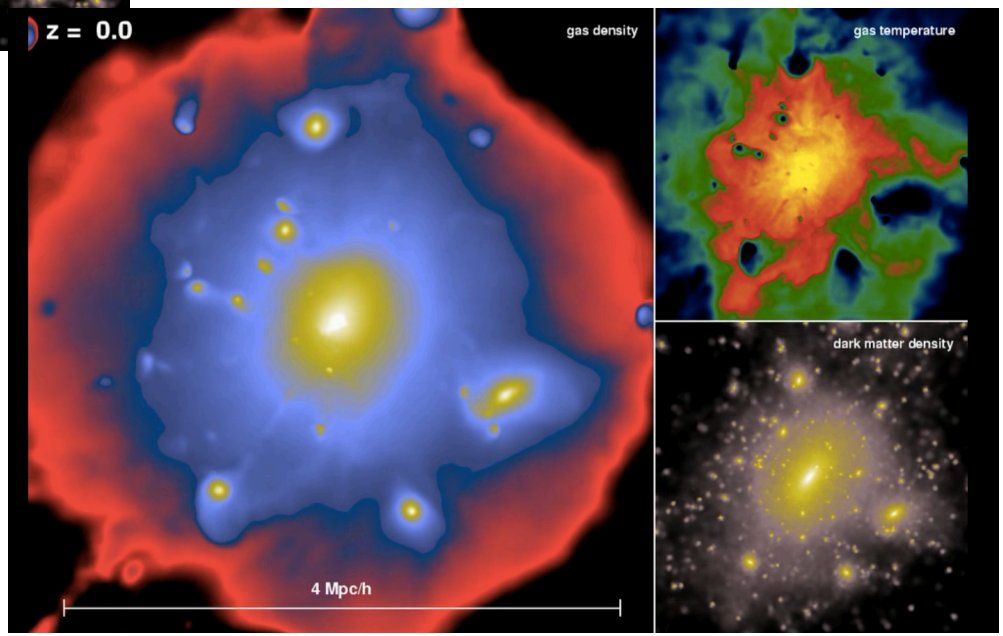
Figure courtesy: M. Oguri

Springel 05

Thermalization



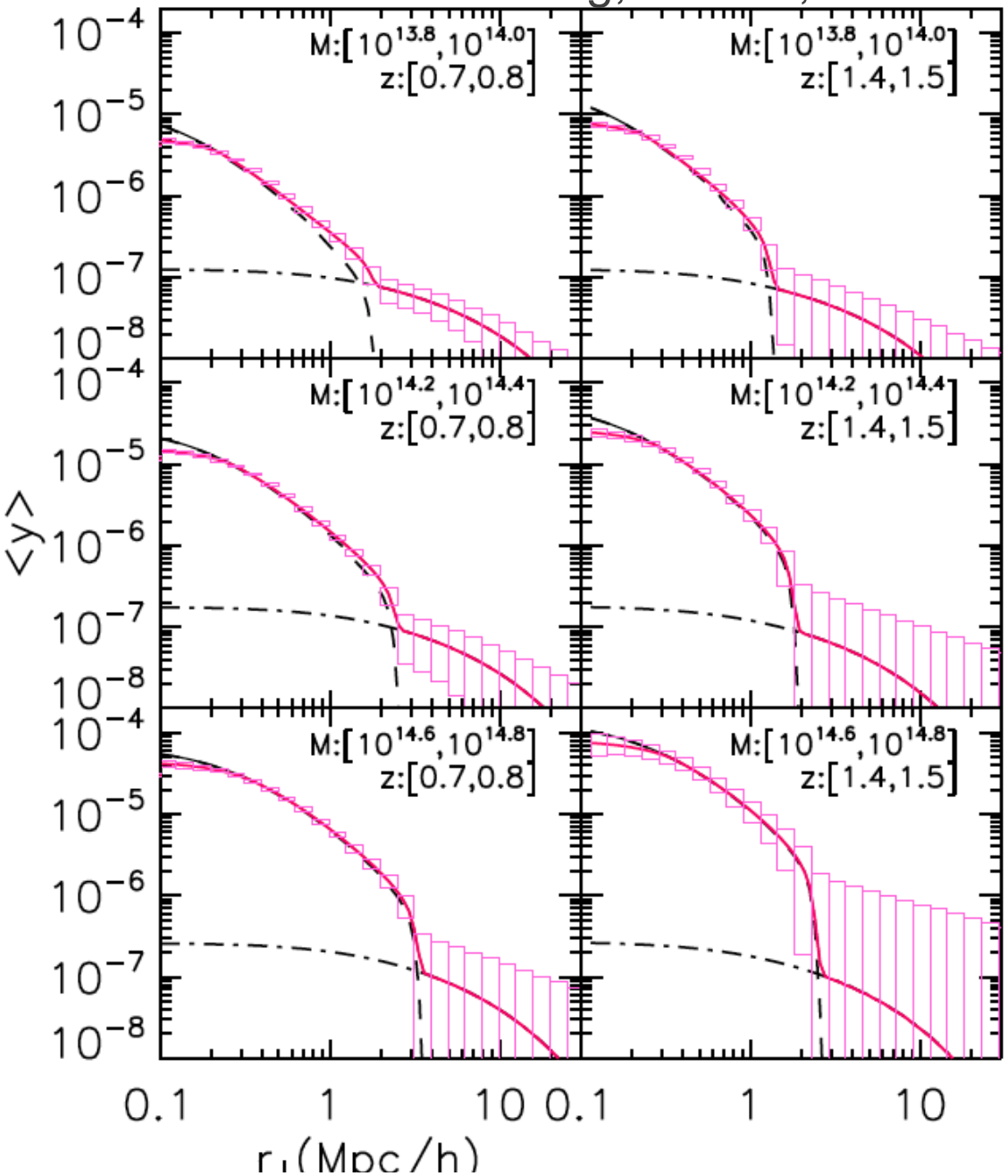
A pop-up of thermal gas to outside the virial radius, due to heating



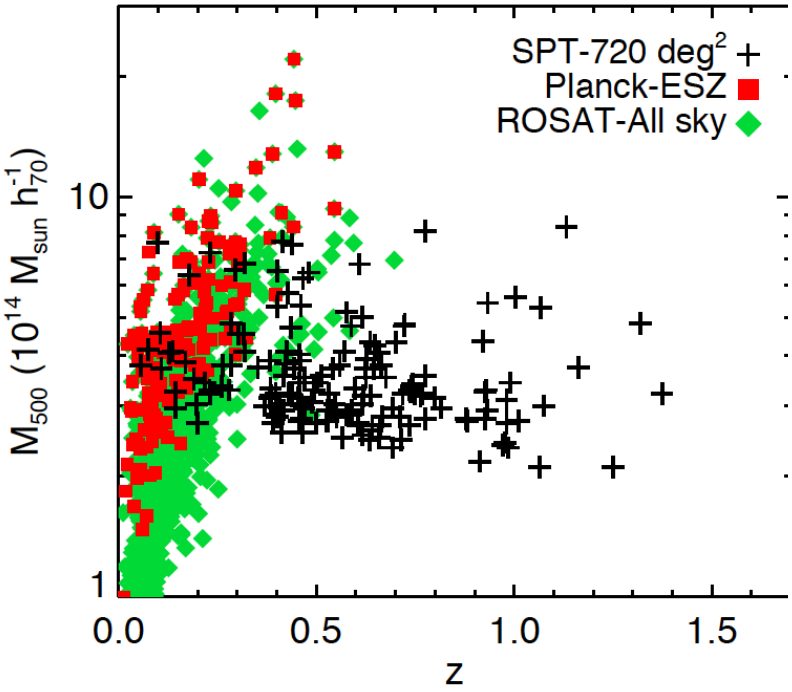
Baryon collisional:
gravitational kinetic energy
⇒ thermal energy via shock

Stacked SZ profile

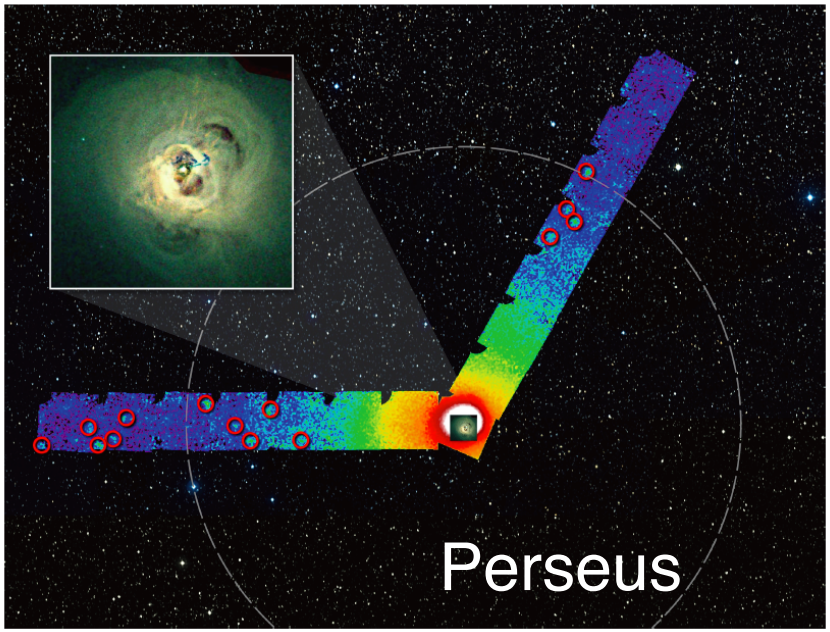
Fang, Kadota, MT 12



- SZ survey: a mass-selected cluster survey, free of redshift surface dimming effect
- Assumed ~17 μ K/pixel for the sensitivity (ACT-like); a factor 3 better for ACTPol, eventually up to 5
- Assumed Komatsu & Seljak for the gas profile, truncated at r_vir

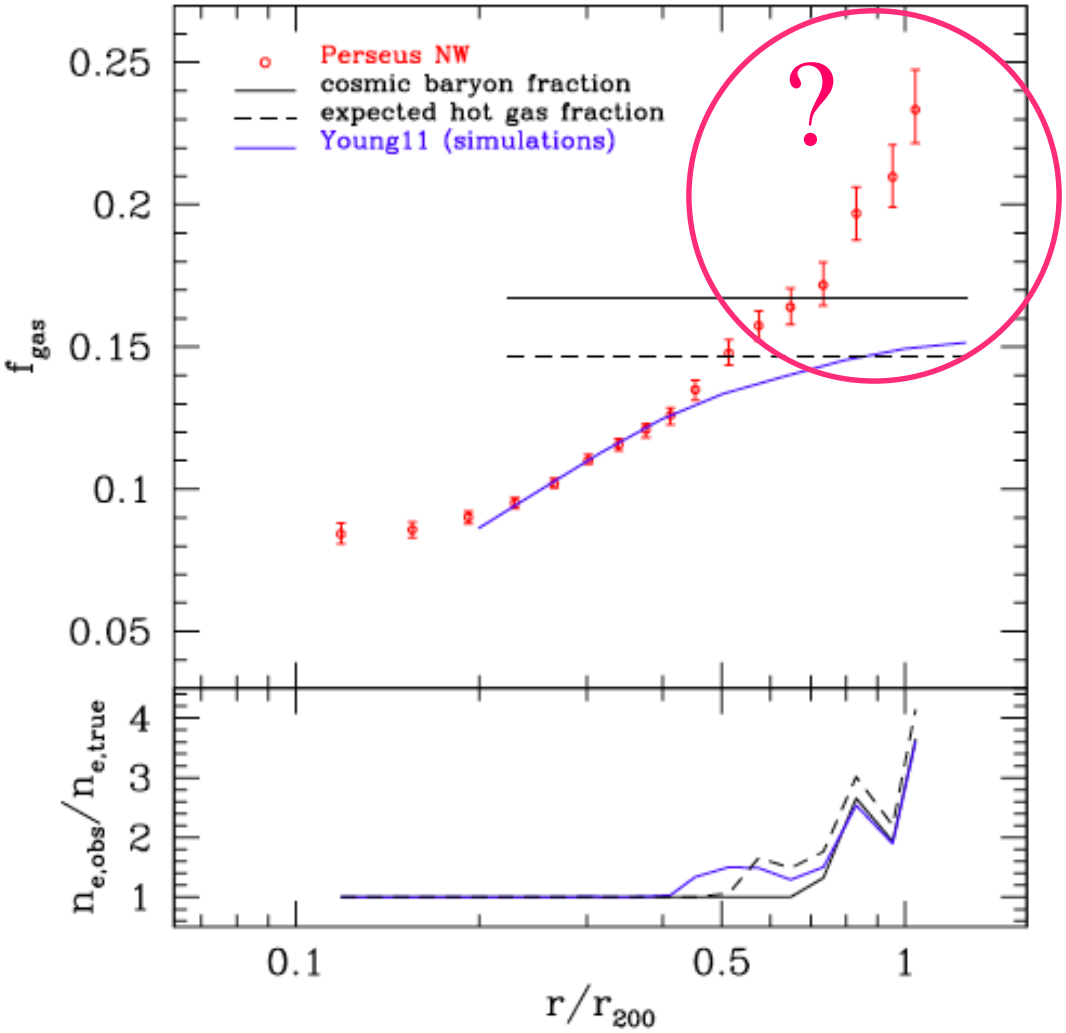


Thermal gas (fraction) radial profile



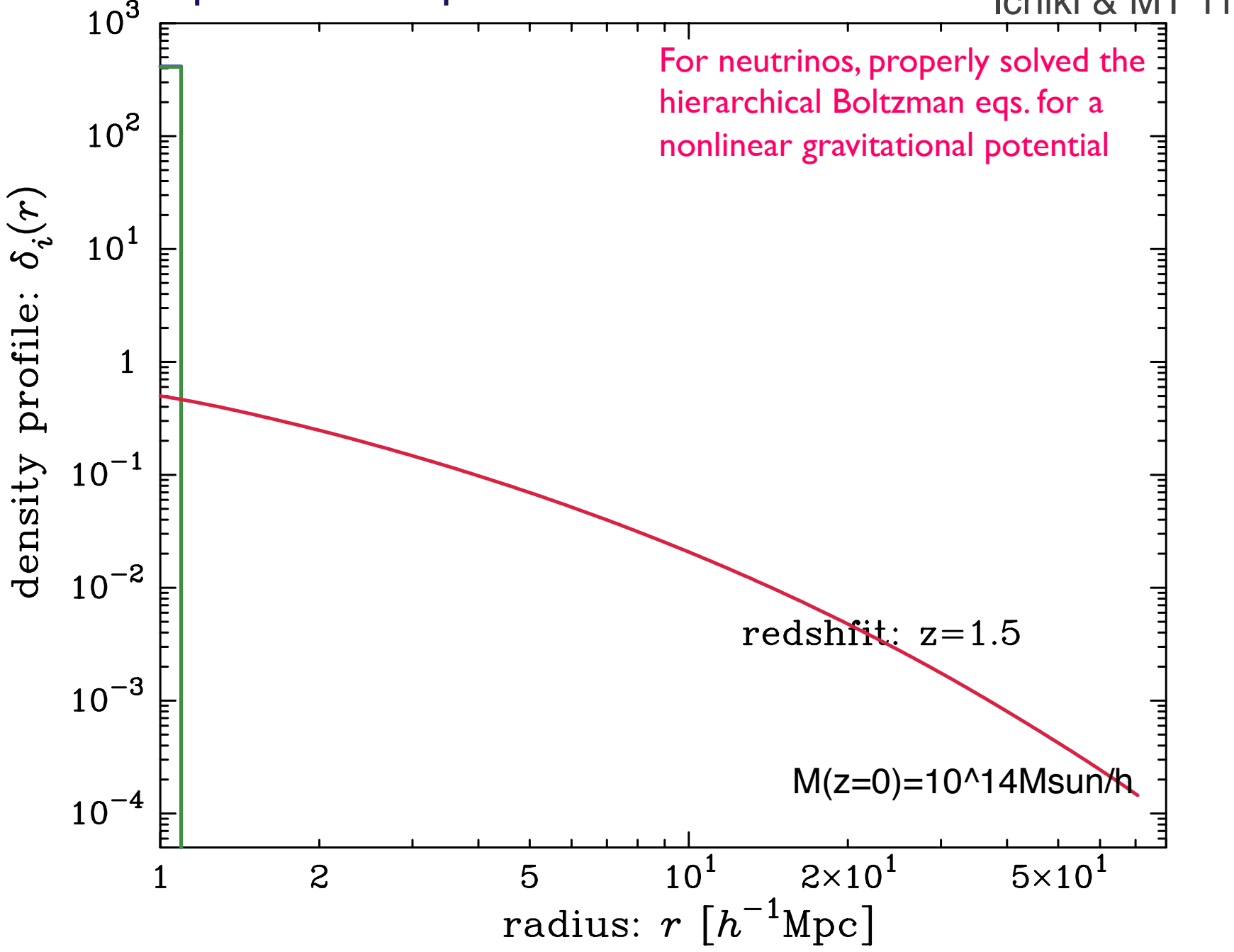
- HSC+ACTPol enables to study the average gas/DM profiles for clusters up to z~1.4
- A direct witness of the kinetic and thermal energy transfer at r~r_vir
- An indirect constraint on the turbulence pressure
- Astro-H → A detailed study of the physics

Siminonescu+ 11

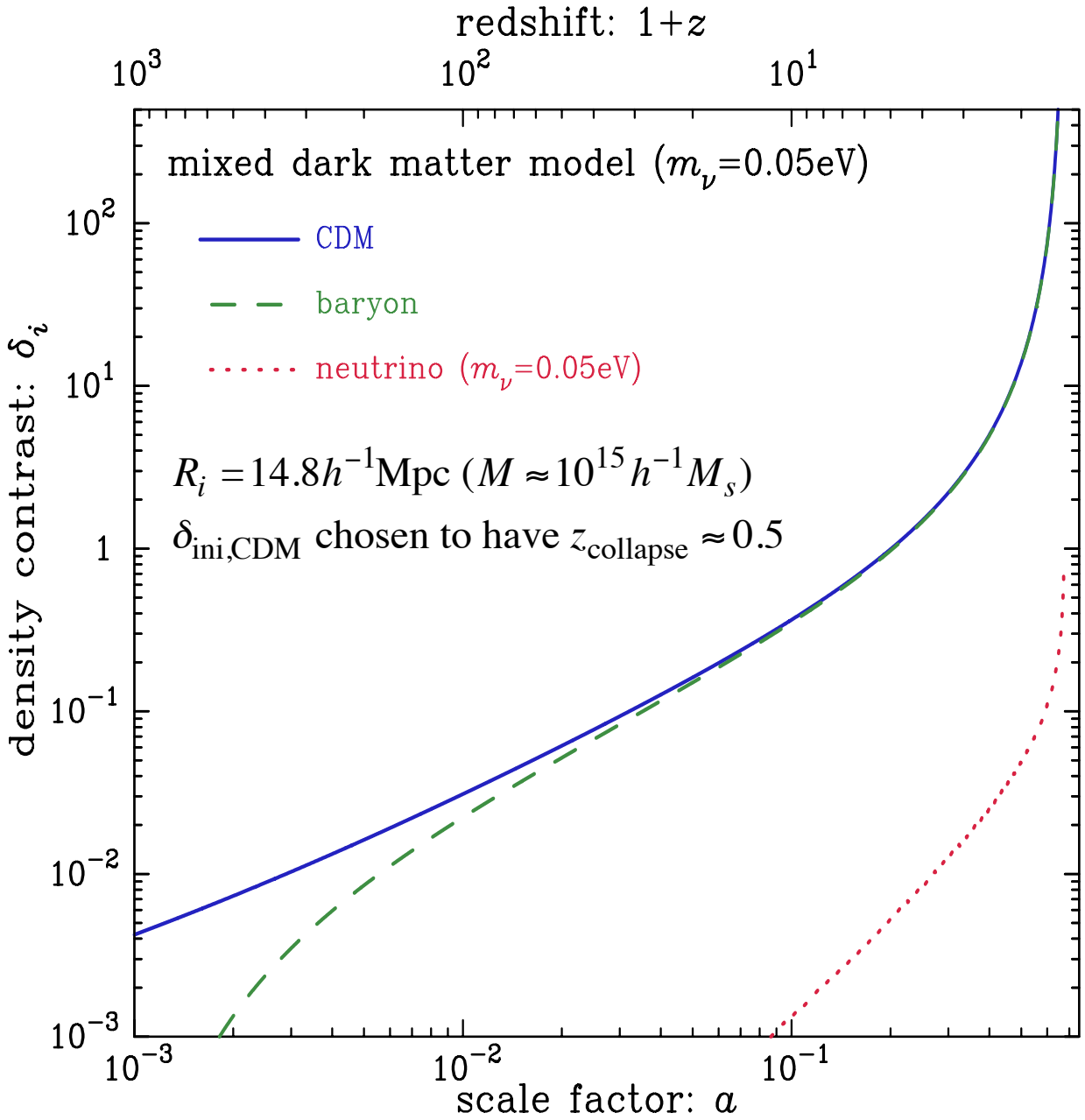


Spherical collapse model for $\nu + \Lambda$CDM

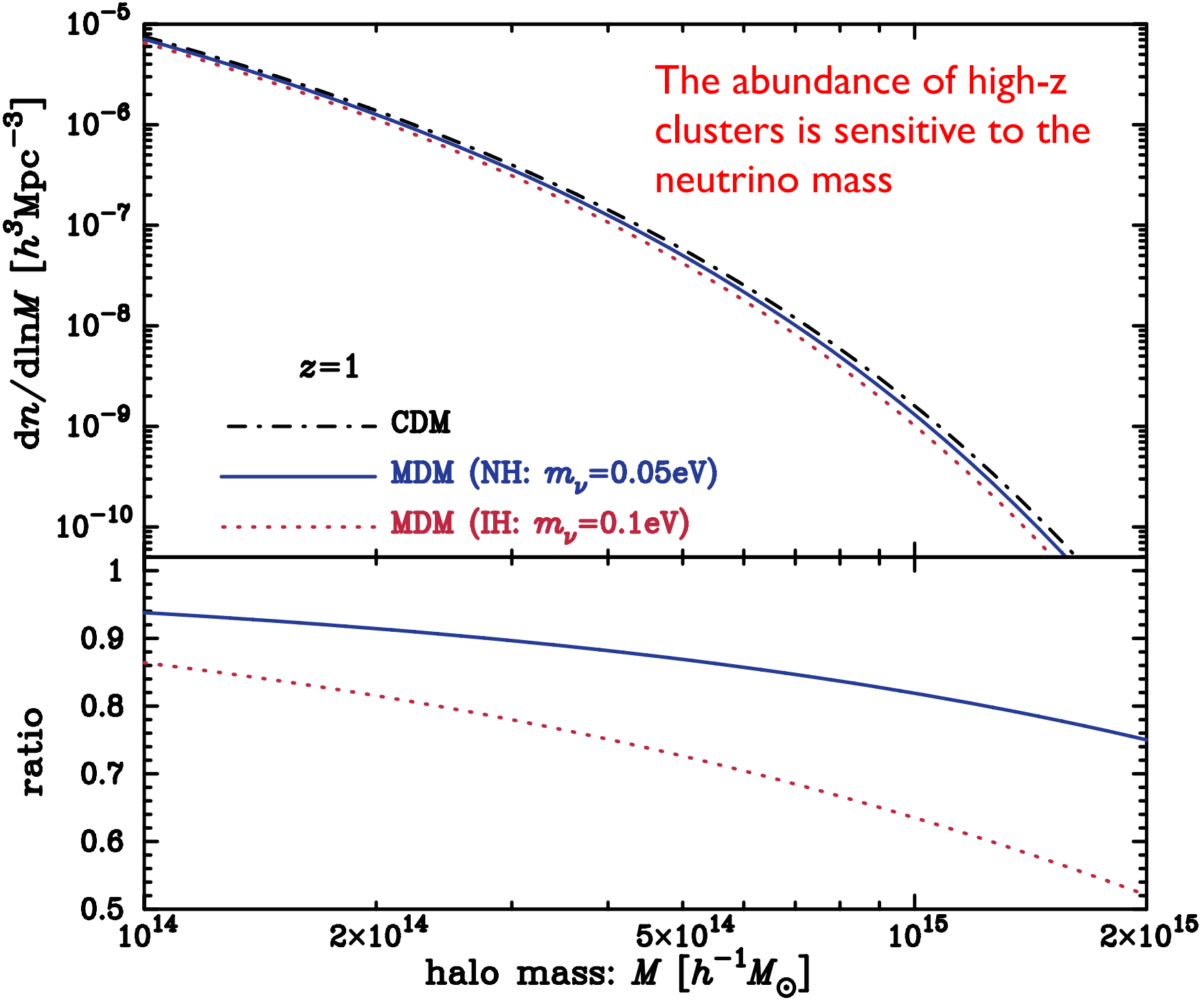
Ichiki & MT 11



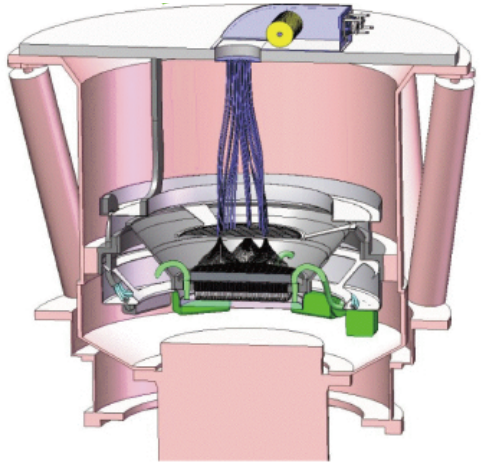
Spherical collapse model for $\nu + \Lambda$CDM



- Baryon can catch up with the CDM overdensity at low redshifts
  - Note that, for halos at much earlier collapse time (e.g. first stars), baryon can't catch up (Naoz & Barkana 05)
- Hence the CDM and baryon can collapse
- Neutrinos can't catch up
  - The neutrino overdensity is still in the regime, $\delta_\nu < 1$ even at the collapse redshift
  - This is also true for M_nu~0.1eV, the lower limit of IMH


The abundance of high-z clusters is sensitive to the neutrino mass
z=1
CDM
MDM (NH: m_ν=0.05eV)
MDM (IH: m_ν=0.1eV)
$dn/d\ln M$ [h^3Mpc^{-3}]
ratio
halo mass: M [$h^{-1}M_\odot$]
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
1
0.9
0.8
0.7
0.6
0.5
10^{14}
2×10^{14}
5×10^{14}
10^{15}
2×10^{15}

Prime Focus Spectrograph (PFS)



- Multi object fiber spectrograph for 8.2m Subaru
- International collaboration; Japan (IPMU+), Princeton, JHU, Caltech/JPL, LAM, Brazil, ASIAA
- Initiated by the stimulus funding (~$30M secure); $50M needed for the instrumentation
- The current baseline design
  - The same optics to HSC
  - 2400 fibers
  - 380-1300nm wavelength coverage
  - R~2000, 3000, 5000 (blue, red, NIR)
- The target first light; around 2017
- Capable of various science cases: cosmology, galaxy, galactic archeology

PFS collaboration

Caltech

NASA Jet Propulsion Laboratory
California Institute of Technology

国立天文台 NAOJ

中央研究院 ACADEMIA SINICA 1928

PRINCETON UNIVERSITY

KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

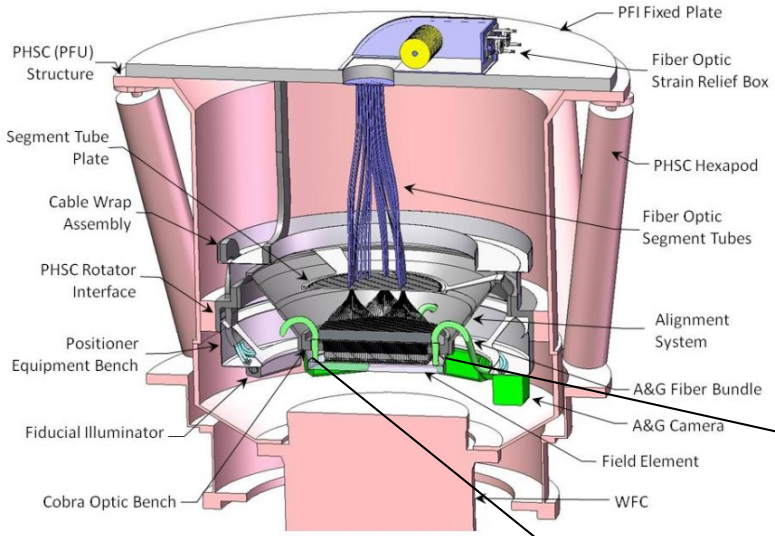
OBSERVATÓRIO DE SÃO PAULO

LNA LABORATÓRIO NACIONAL DE ASTROFÍSICA

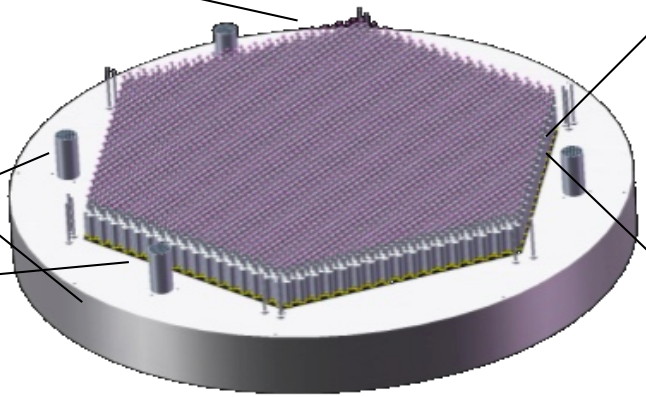
LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

JOHNS HOPKINS UNIVERSITY

PFS Positioner



Positioner Unit - *Cobra*



A&G Fiber Guides

Optical Bench with Positioner Units

Cobra system is the most essential part of PFS, and will be built at JPL

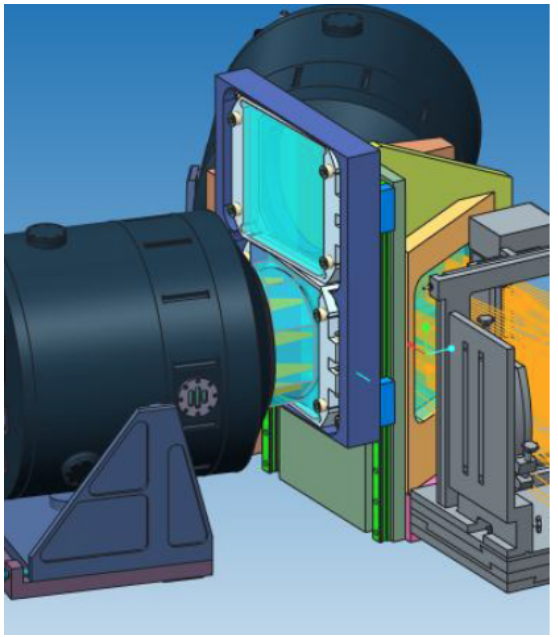
Designed to achieve 5 μ m accuracy in < 8 iterations (40 sec)

PFS Specifications

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	
	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 =0.38-1.26 μ m with 3 arms
- Fiber density: 2200/sq. degs ($\Leftrightarrow$ ~140 for BOSS; ~570 for DESI)
- Now, a medium resolution mode (R~5000) for the red arm is *our baseline design*



Summary

- HSC/ACT/SDSS (eventually eROSITA) allow an unprecedented statistical study of galaxy clusters
  - Weak lensing, SZ and galaxy distribution, up to z~1.4
  - A stringent test of structure formation scenarios with a unique sample of clusters (dark energy, neutrino mass, …)
- Cosmology/Cluster physics: a BIG discovery/excitement with improved data (our own data) will come
  - COBE ← 20 yrs after CMB discovery
  - SDSS: BAO, galaxy clustering ← 20 yrs after the CfA survey
  - Kamiokande: neutrino experiments ← proton decay for GUT
  - LHC: Higgs discovery ← 18 years after the top-quark discovery
- *So now we should work together for the big excitement!*