NeCSuS: Subaru/HSC Weak-Lensing Analysis of Very Nearby Galaxy Clusters

未来を拓く地方協奏プラットフォーム
HIRAKU
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広島大学 極限宇宙研究拠点
CORE-U
Core of Research for the Energetic Universe
HIROSHIMA UNIVERSITY

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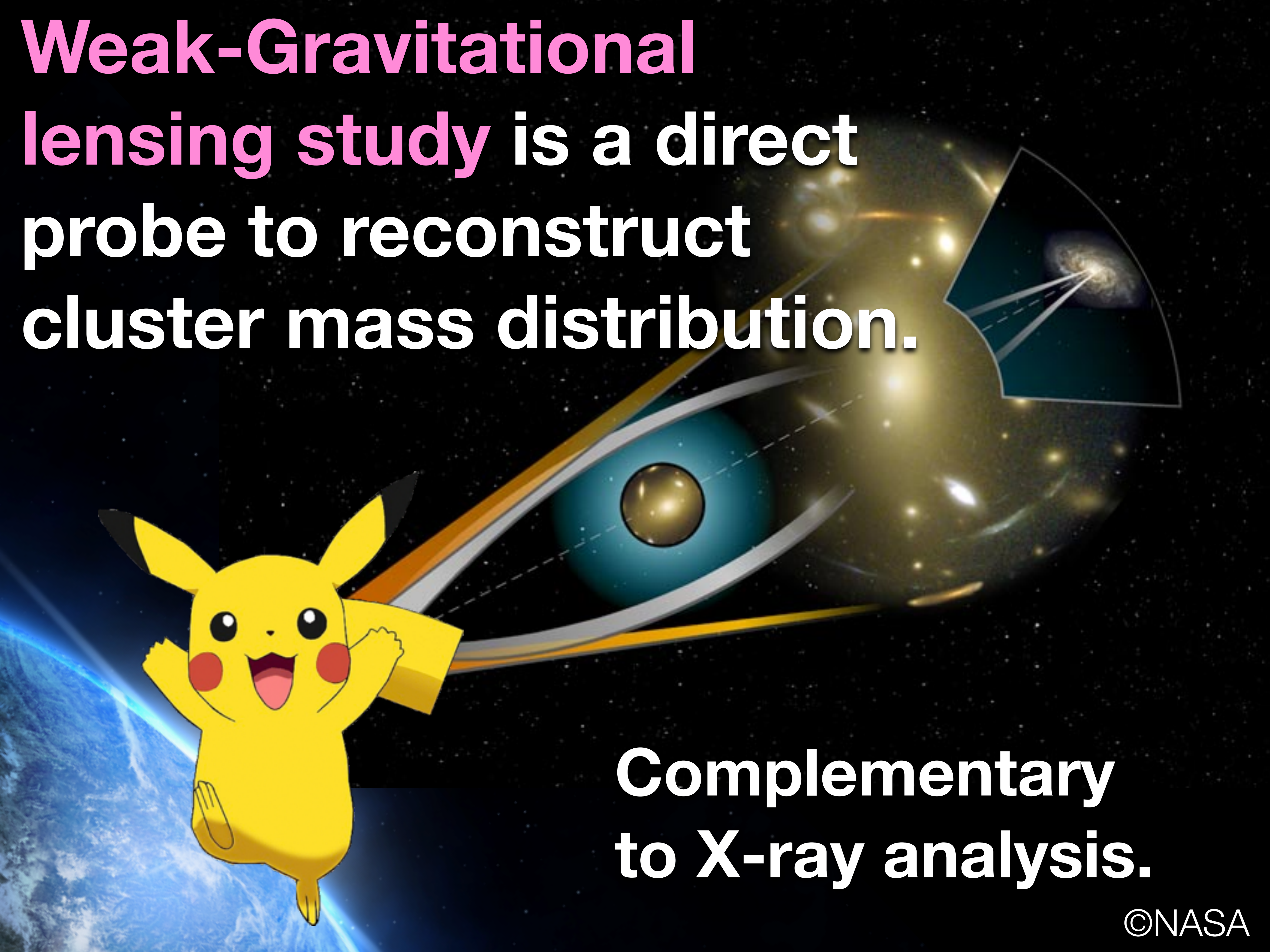
Weak-Gravitational lensing study is a direct probe to reconstruct cluster mass distribution.
Complementary to X-ray analysis.
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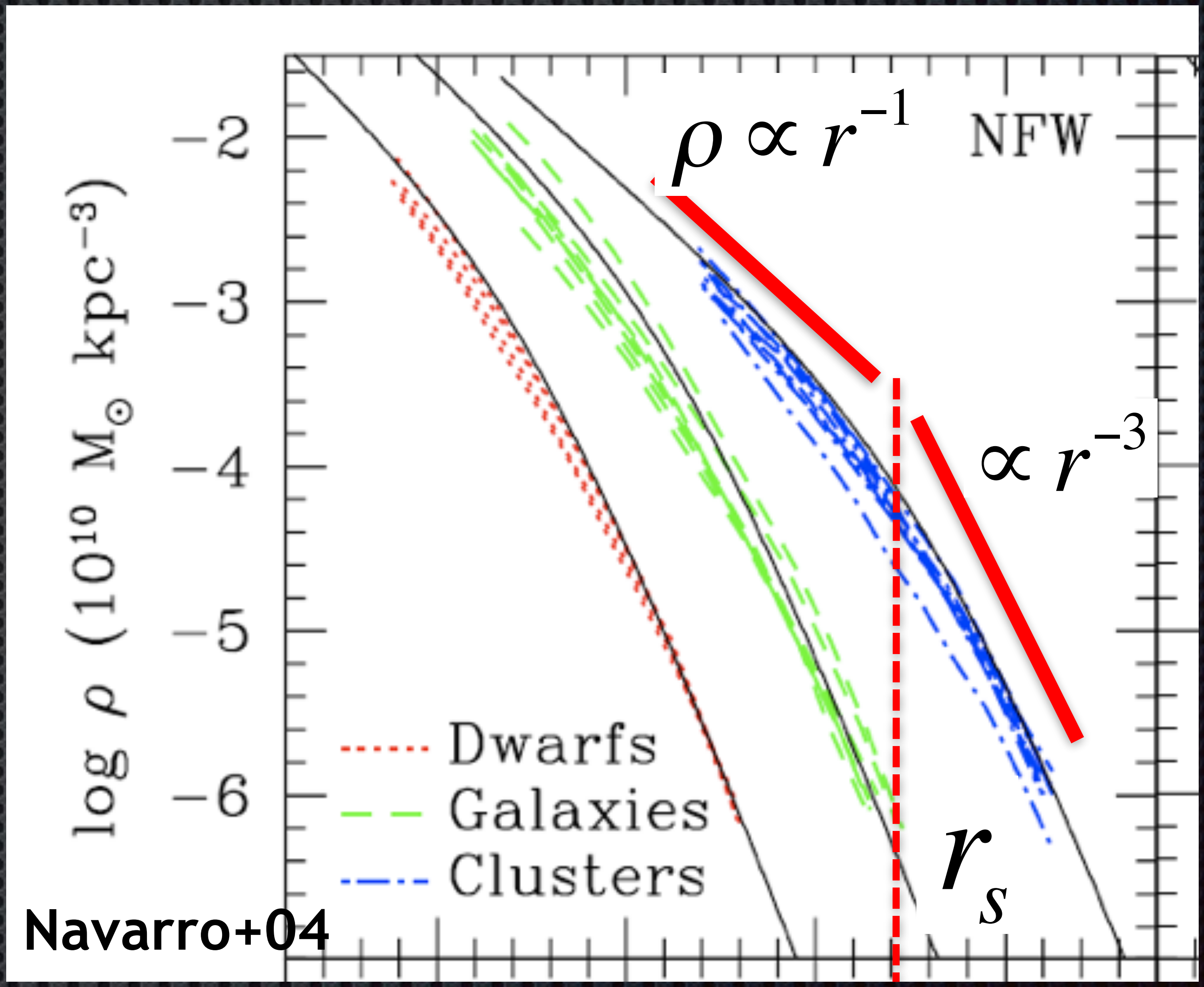
Universal Mass Profile

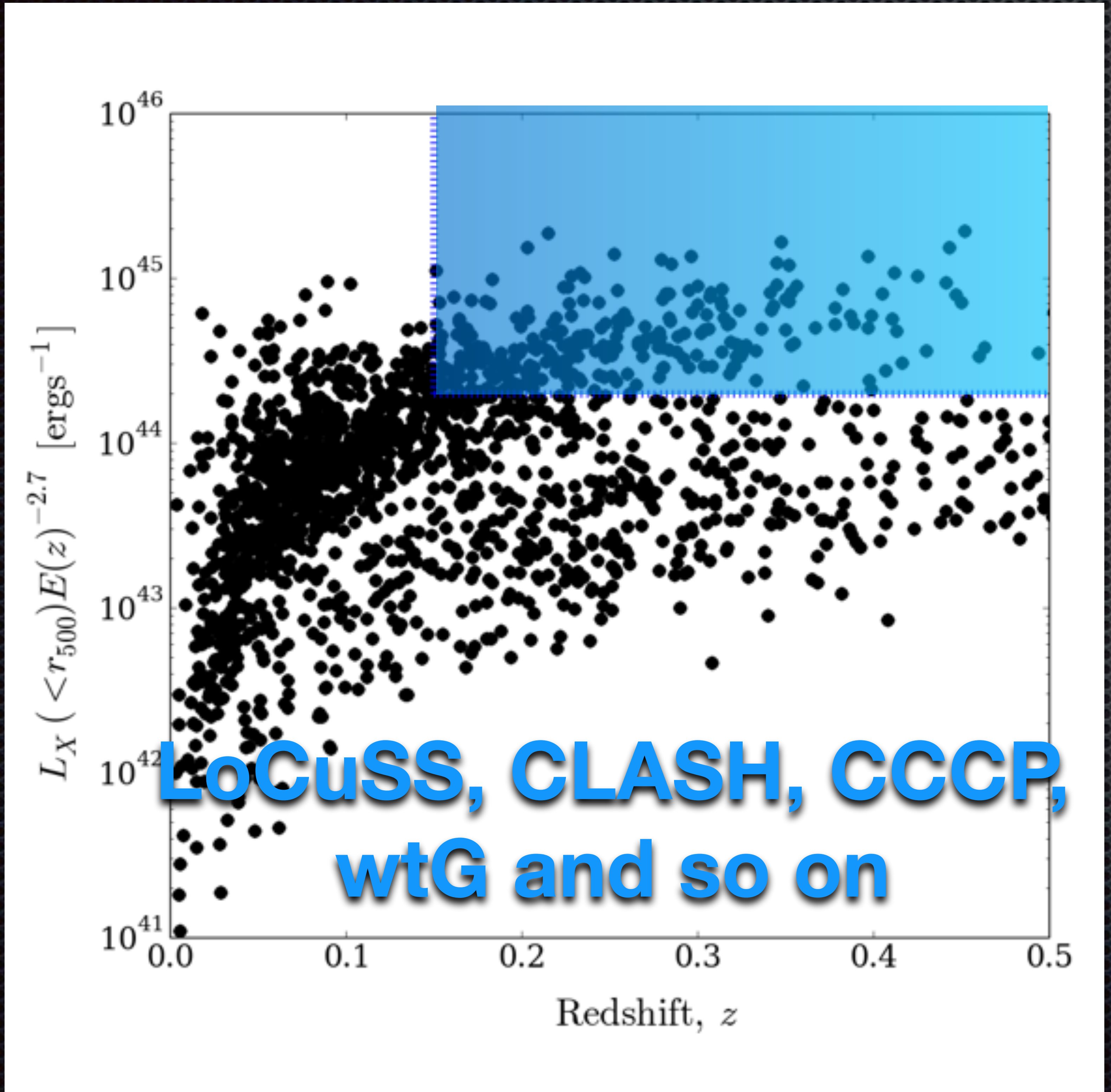
Simulation-based predictions: the appearance of a characteristic, universal density profile (Navarro, Frenk & White 96, 97; NFW profile)



$$\rho_{\mathrm{NFW}}(r) = \frac{\rho_s}{(r/r_s)(1+r/r_s)^2}$$

M_{vir} Cluster Mass $c_{\mathrm{vir}} = r_{\mathrm{vir}}/r_s$ Concentration parameter

Weak-lensing studies of "massive" clusters in recent 10 years



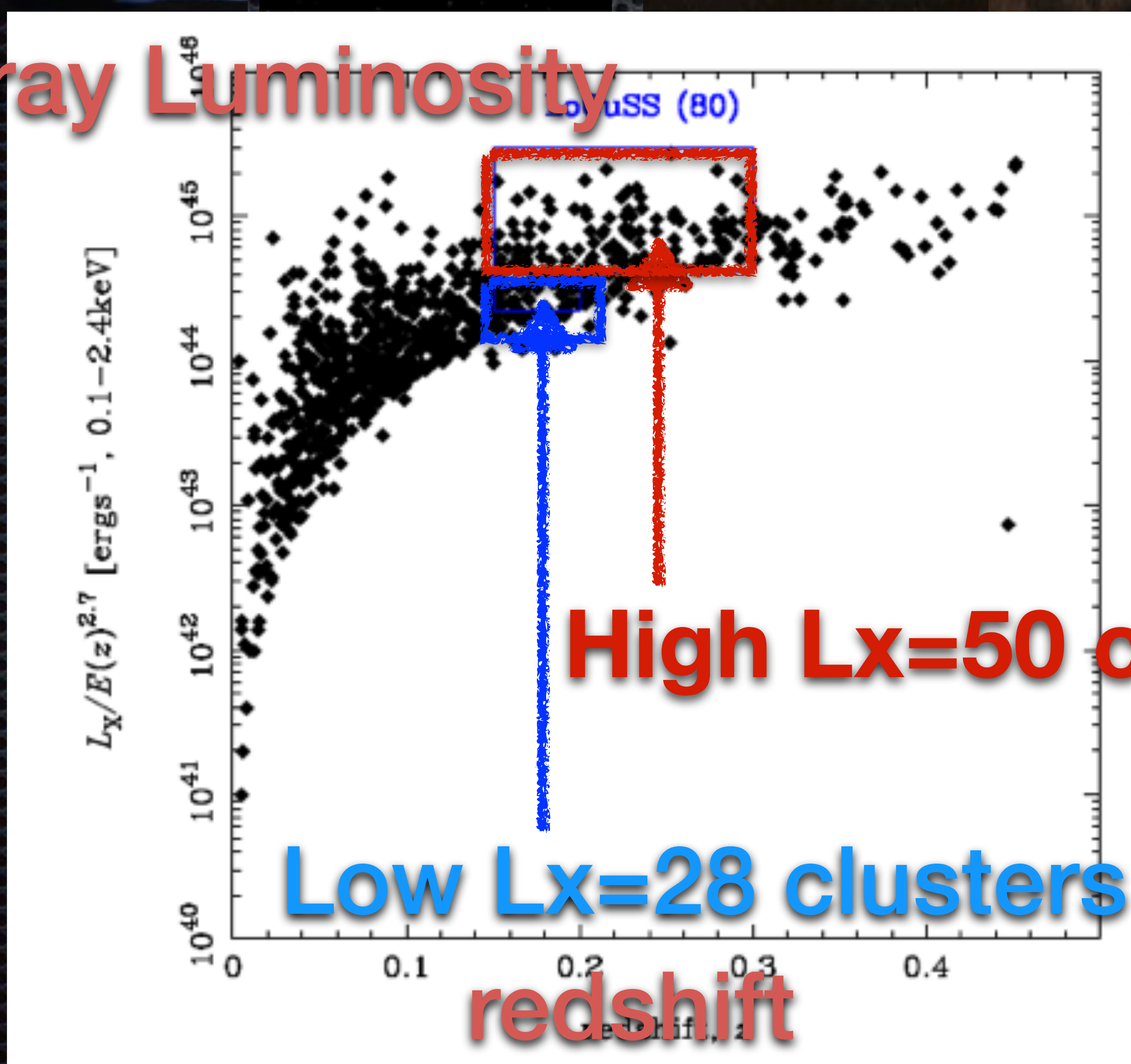
Massive clusters beyond redshift ~ 0.15

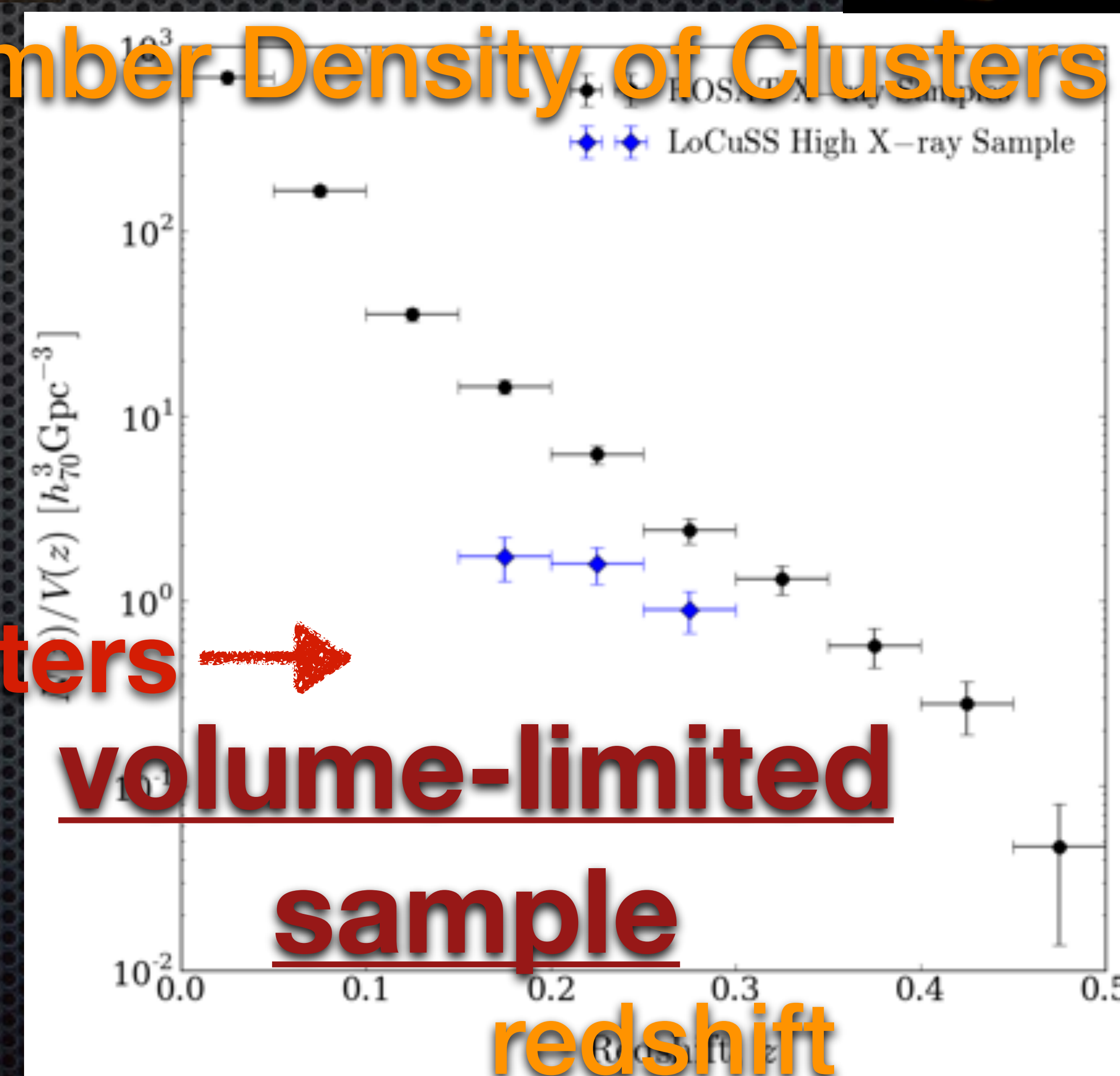
Redshift range are selected by the FoV (~full moon size) of **Subaru/ Suprime-cam**

- exquisite imaging quality
- 8.2 diameter mirror
- one pointing covers viral radii

LoCuSS (Local Cluster Substructure Survey)

multi-wavelength survey for ~ 80 clusters at z = 0.15-3.0, unbiasedly selected from X-ray luminosity





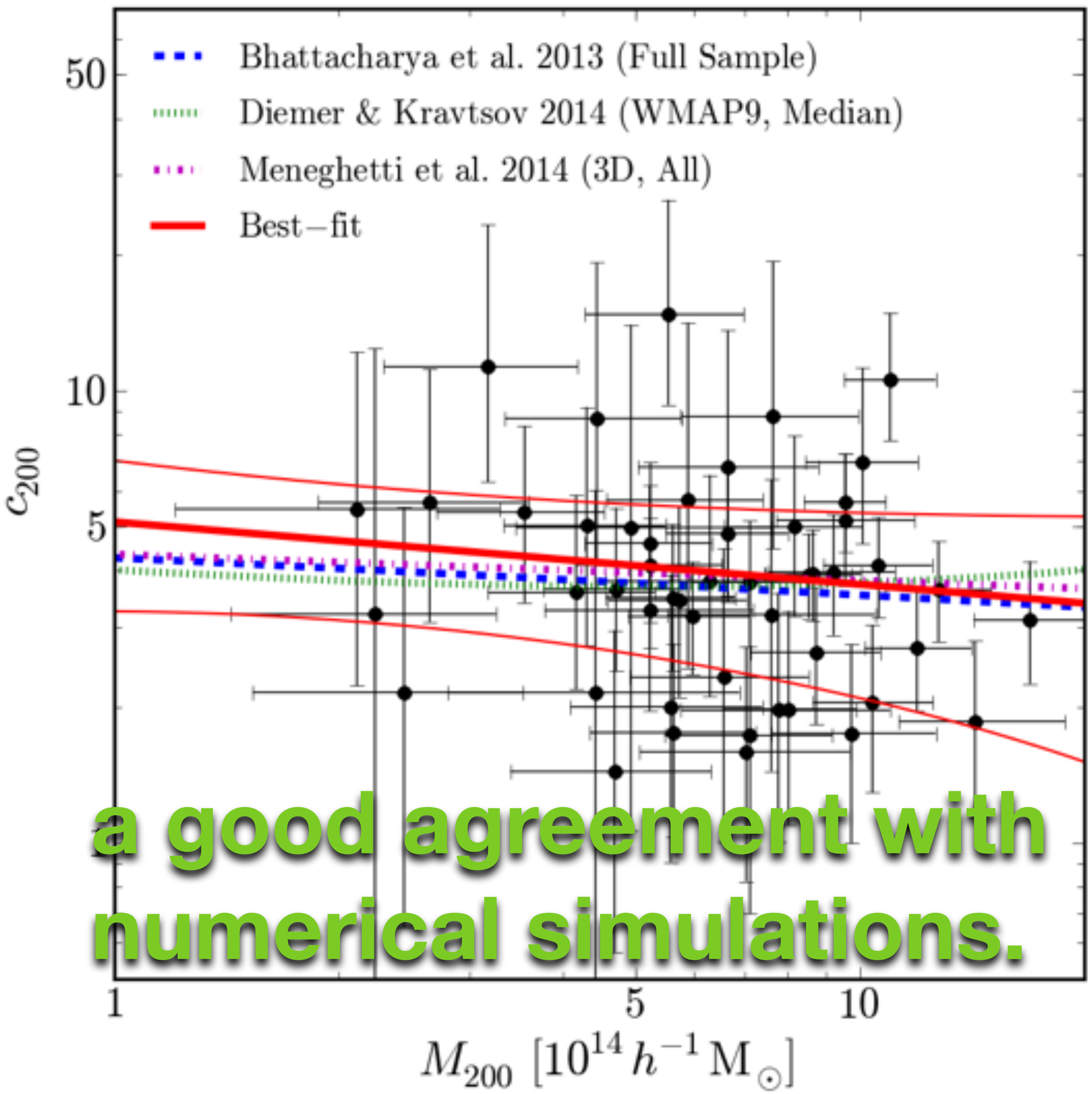
LoCuSS (0.15<z<0.3; 50 clusters)

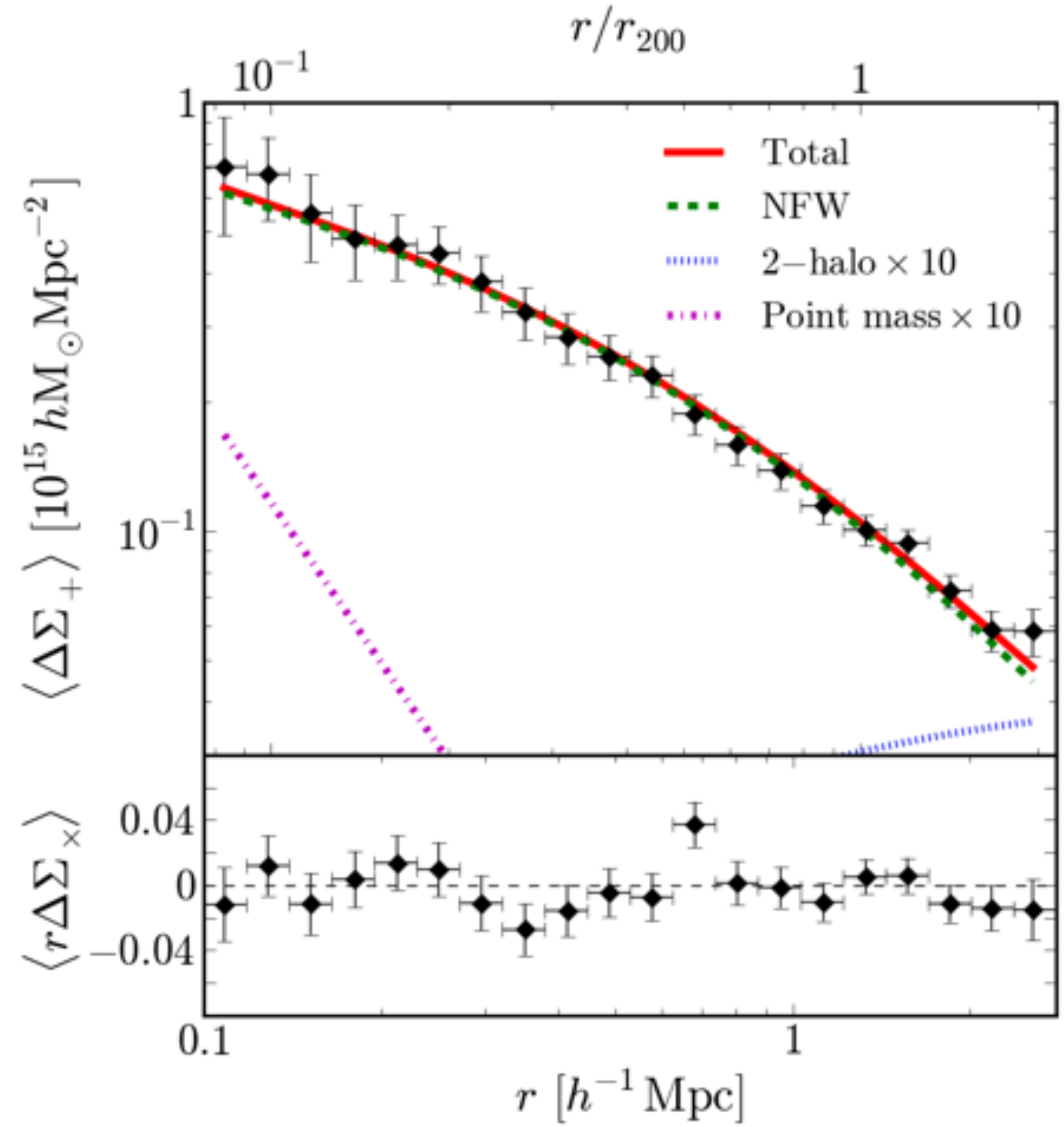
Lensing signal agrees well with NFW/Einasto profiles.

Okabe+Smith16

mass-concentration relation

stacked lensing profile





a good agreement with numerical simulations.

Next Decade :
Hyper Suprime-Cam (HSC)

FoV : 7 times larger

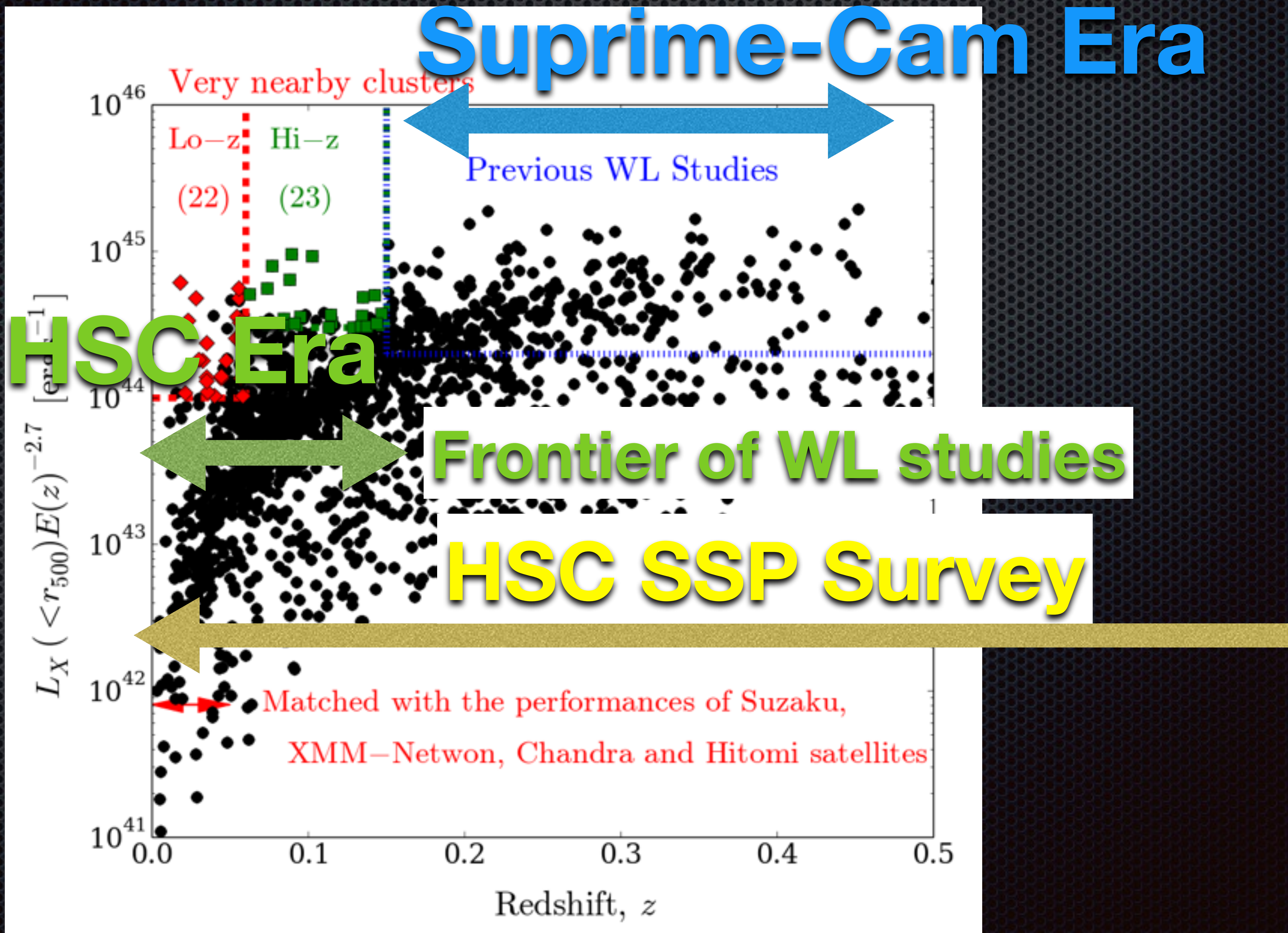
Full moon

Suprime-Cam
Image Release
September 2001

Hyper Suprime-Cam
Image Release
July 2013

(Credit: HSC Project / NAOJ)

HSC is the best interment for clusters at z < ~ 0.1



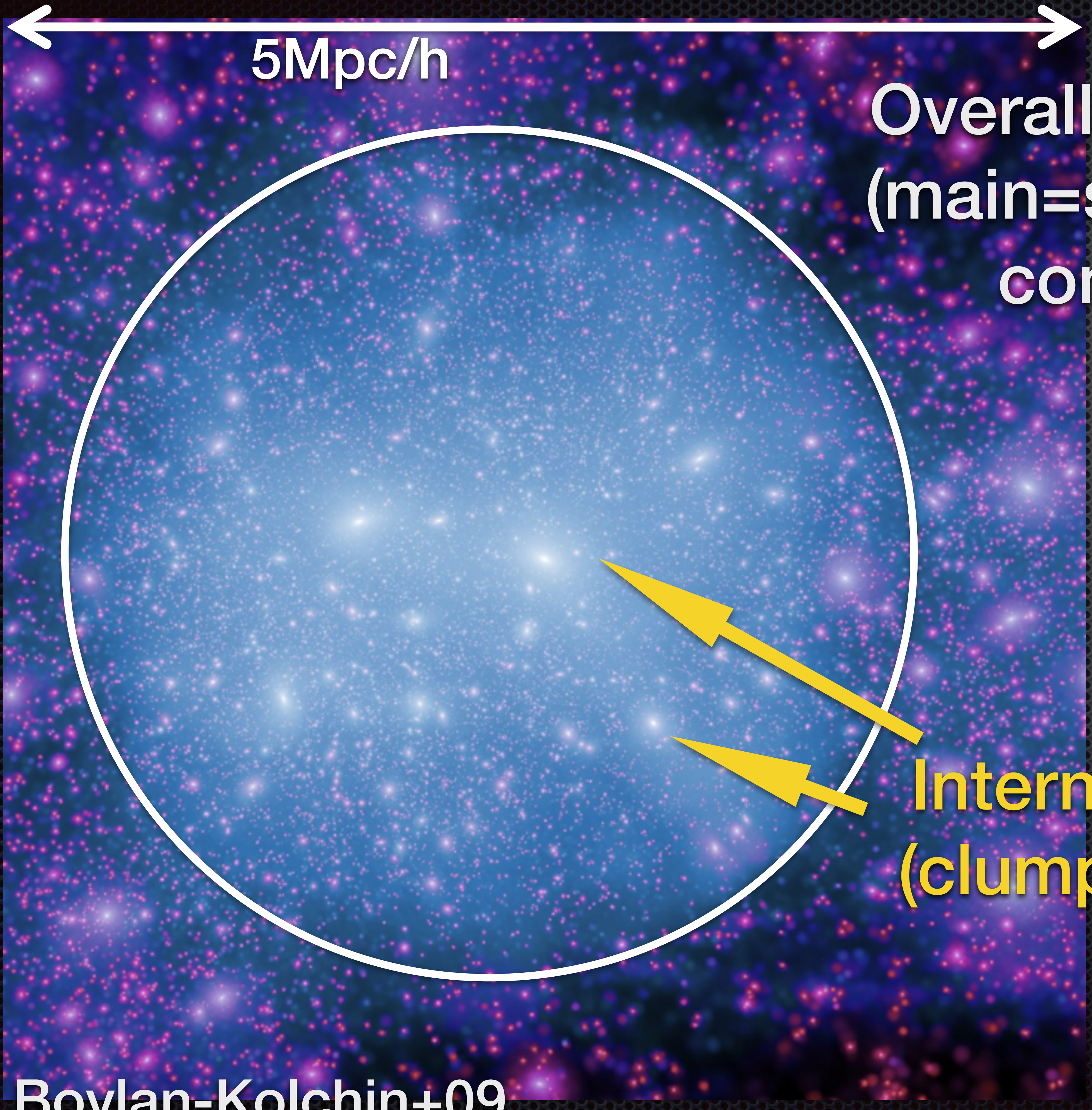
NECSUS

low-z sample :
22 clusters at z < 0.06

NEarby Cluster SUrvey with Subaru

Advantages of WL analysis for very nearby clusters

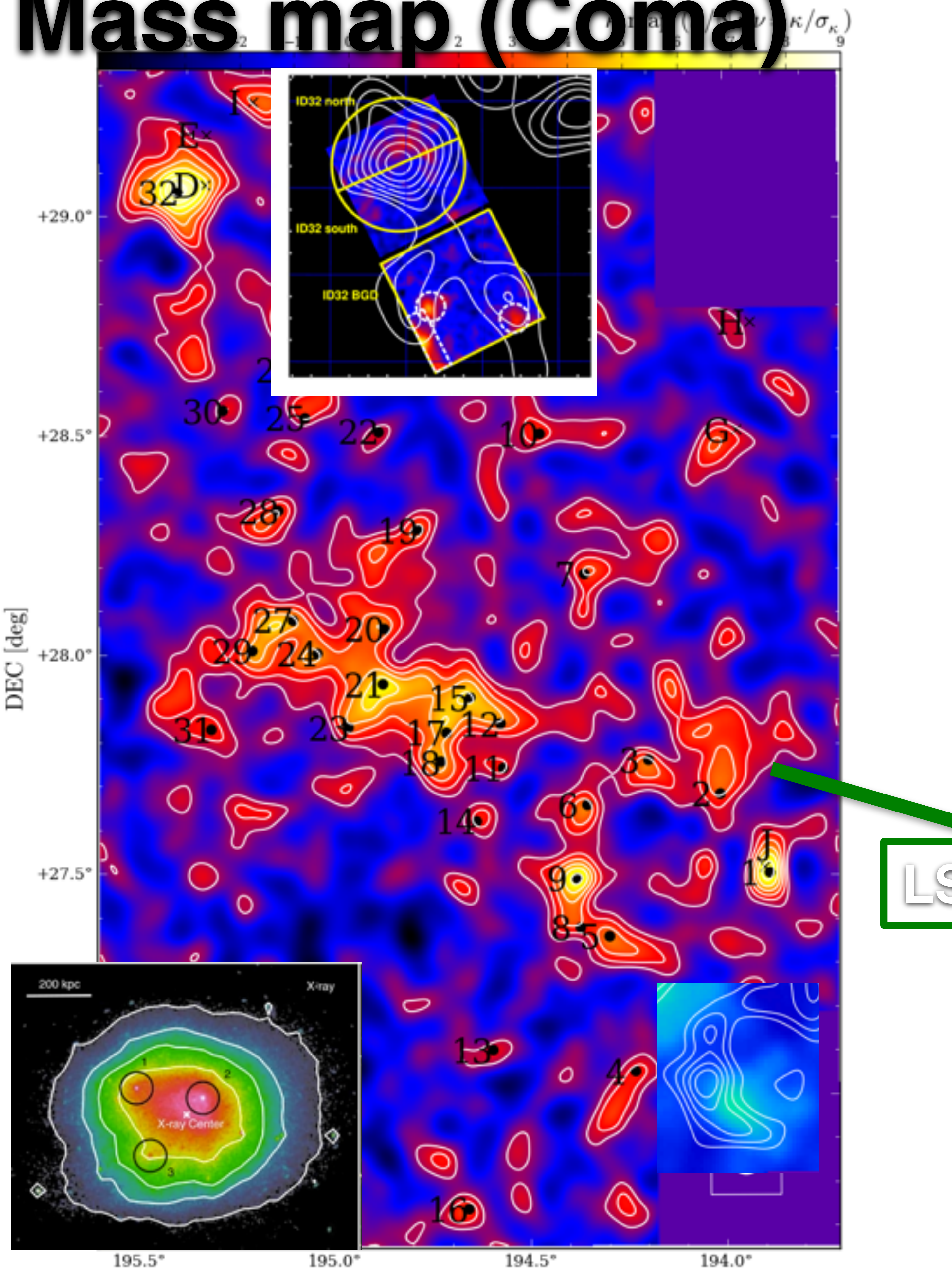
- no (less) contamination of member galaxies
  (contamination is a critical issue at z~0.2)
- the enormous number of background galaxies reduce the statistical shape noise and thus compensates for the low lensing efficiency of the nearby cluster.
  (N_g is 20-60 times higher than that at z~0.2)
- large apparent size resolve less massive subhalos.
  (down to ~ 5×10^{12}-10^{13} Msun)
  (massive subhalos in meting clusters at z~0.2)



Overall Mass Profile (main=smooth mass component)

Internal Structure (clumpy subhalos)

Mass map (Coma)



FWHM = 4arcmin

Pilot Study with Suprime-Cam

32 cluster subhalos detected by WL signals

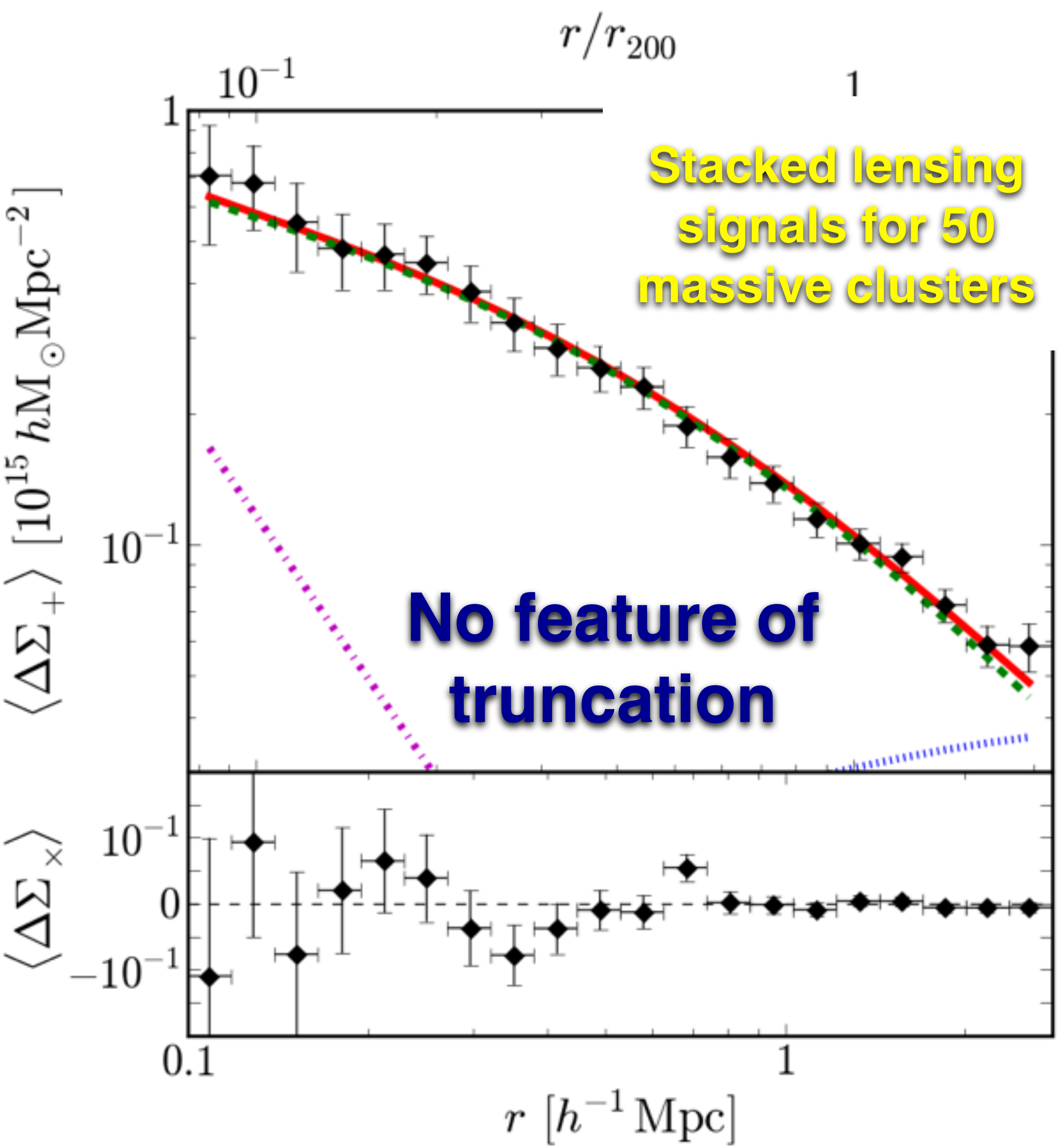
Associated with known optical groups/galaxies

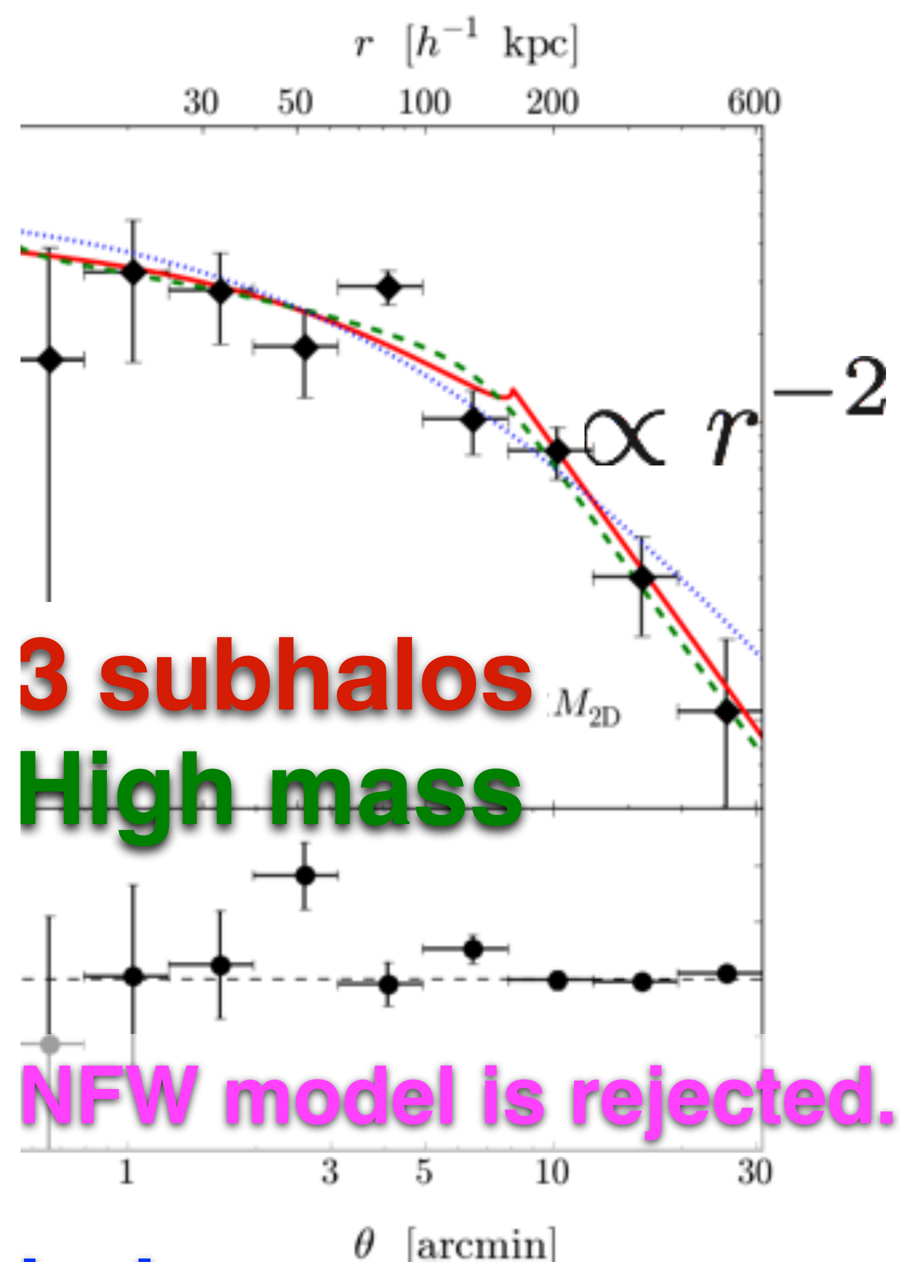
LSS direction

X-ray emission detected from some massive subhalos

Okabe+14a

Stacked Lensing Analysis :



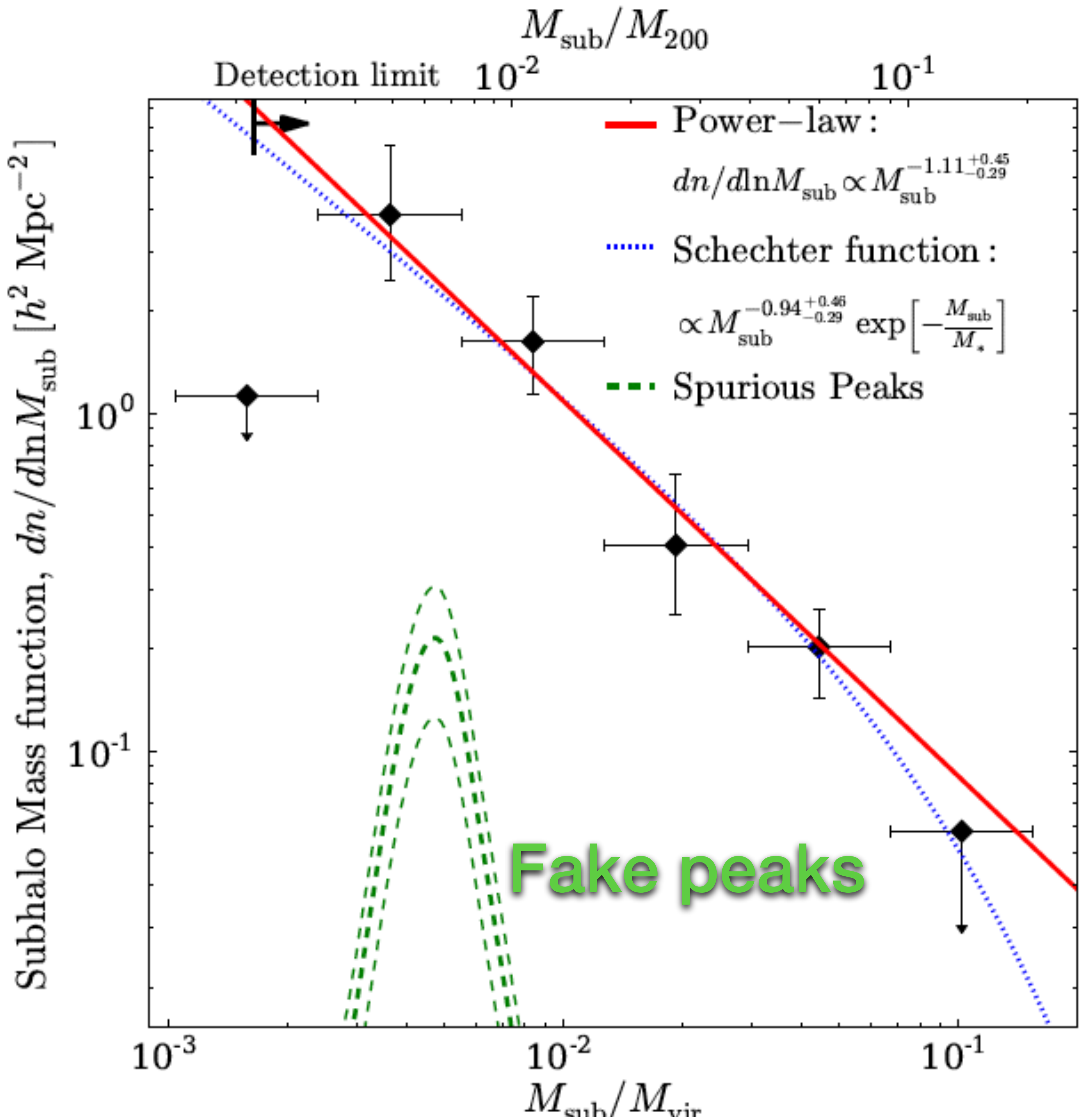


halo center

ature.

$$\rho_{\mathrm{TNFW}} = \begin{cases} \rho_{\mathrm{NFW}} \ (r < r_t) \\ 0 \ \ (r > r_t) \end{cases}$$

Subhalo mass function



$$\frac{dN}{d\ln M_{sub}} \propto \left(\frac{M_{sub}}{M_{vir}}\right)^{-1.11^{+0.45}_{-0.29}}$$

$$\frac{dN}{d\ln M_{sub}} \propto \left(\frac{M_{sub}}{M_{vir}}\right)^{-0.94^{+0.46}_{-0.29}} \mathrm{Exp}\left[-\frac{M_{sub}}{M_*}\right]$$

Consistent with CDM predictions : slope ~0.9-1

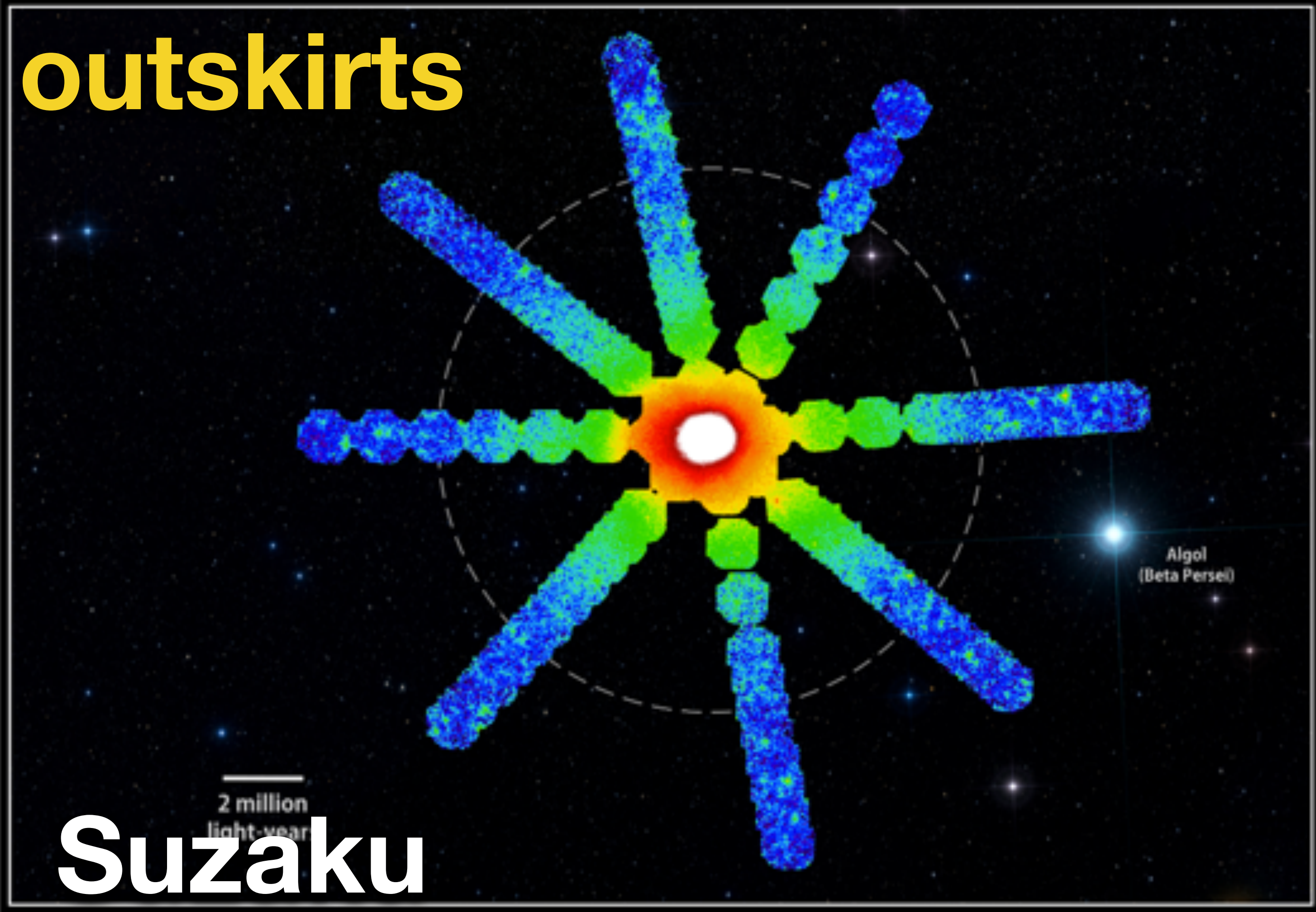
Two orders of the magnitude in mass

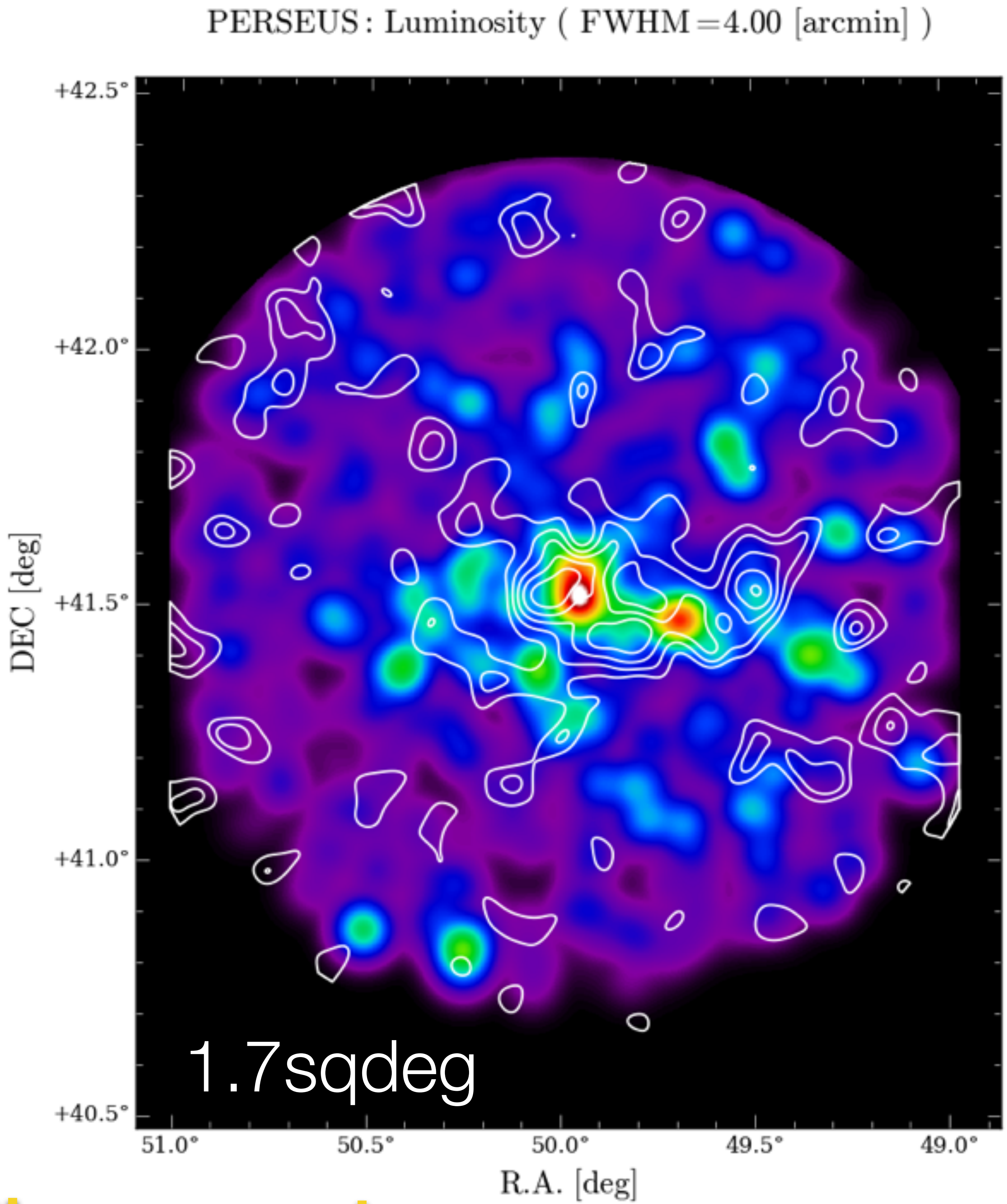
the Perseus Cluster with HSC

z=0.0178

One of primary targets of cluster sciences.

GT target of Hitomi X-ray satellite to directly measure gas motions.

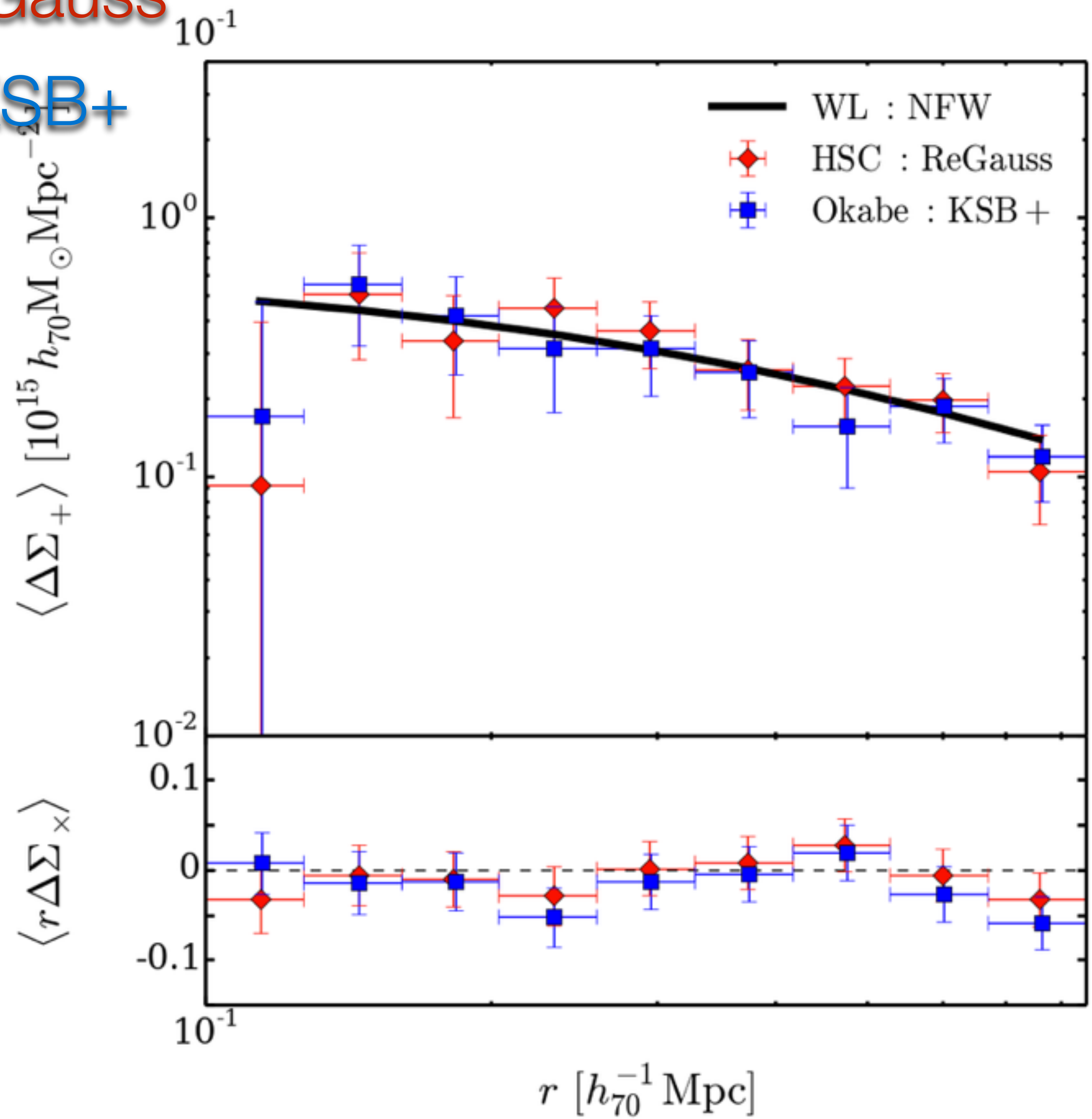




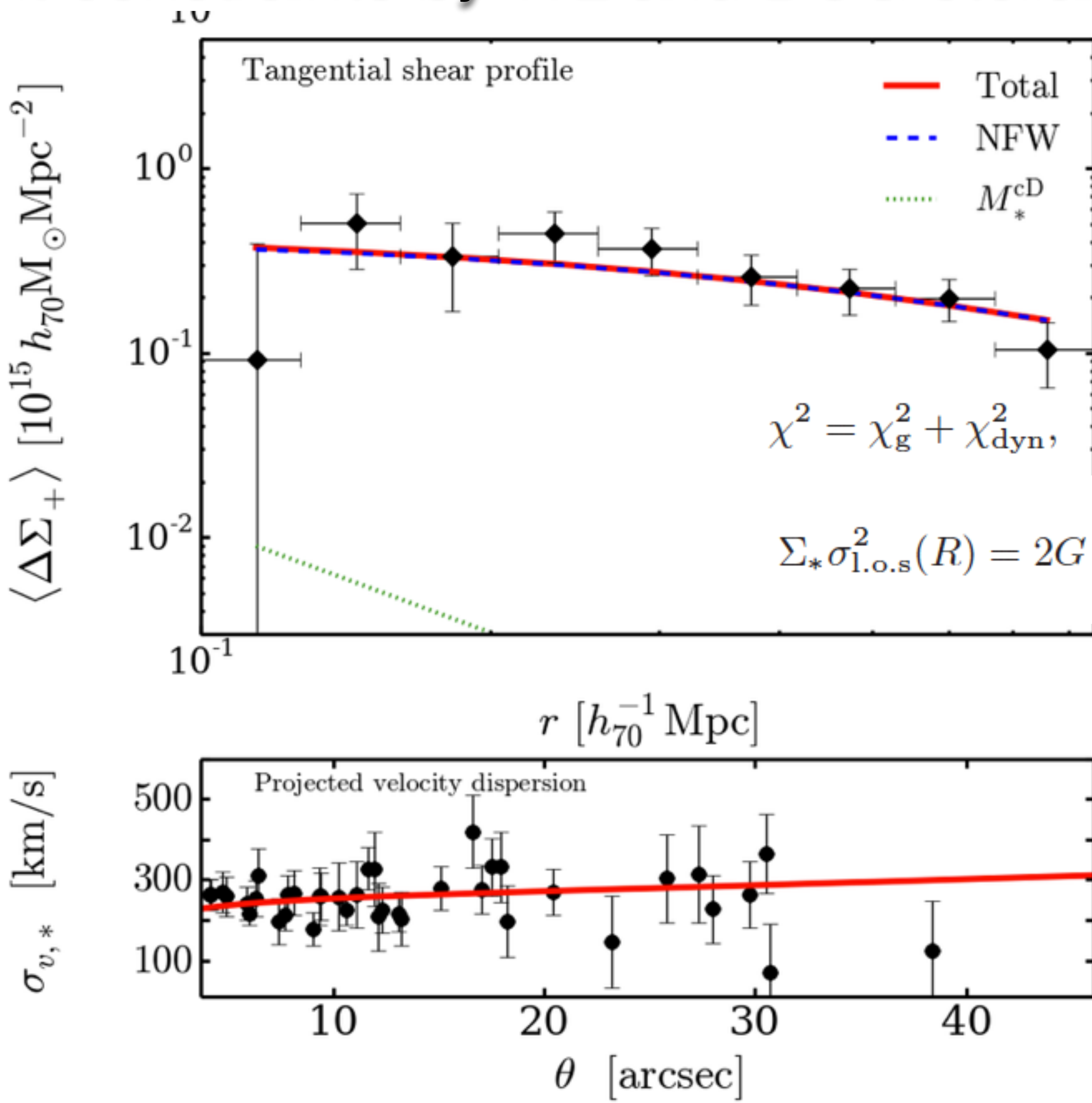
Overlaid with mass contours

HSC : ReGauss

Okabe : KSB+



Joint constraints by WL and BCG stellar kinematics



$$\chi^2 = \chi_{\rm g}^2 + \chi_{\rm dyn}^2,$$

$$\Sigma_* \sigma_{\rm l.o.s}^2(R) = 2G \int_R^\infty \frac{\nu_*(r) M(r) F(r)}{r^{2-2\beta}} dr$$

Joint X-ray and HSC-WL analysis

1: Indirect Constraint of Non-thermal Pressure vs Hitomi/SXS measurement of gas motion

⟷ Importance for cluster cosmology

2: Suzaku Cluster Outskirts Problem

Total Pressure v.s. Thermal Pressure v.s. Non-thermal Pressure

XMM/Chandra/Suzaku

X-ray

Subaru

WL

"indirect"

Thermal pressure

$$P_{\mathrm{th}}$$

total pressure

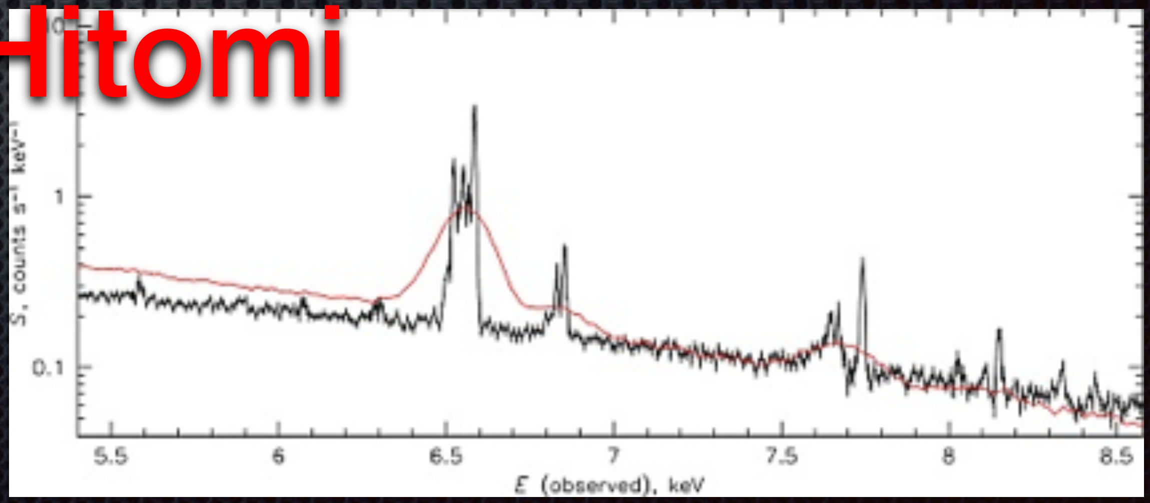
$$P_{\mathrm{g}} = \int_{\infty}^{r} \frac{GM\rho_g}{r^2} dr$$

X-ray

WL

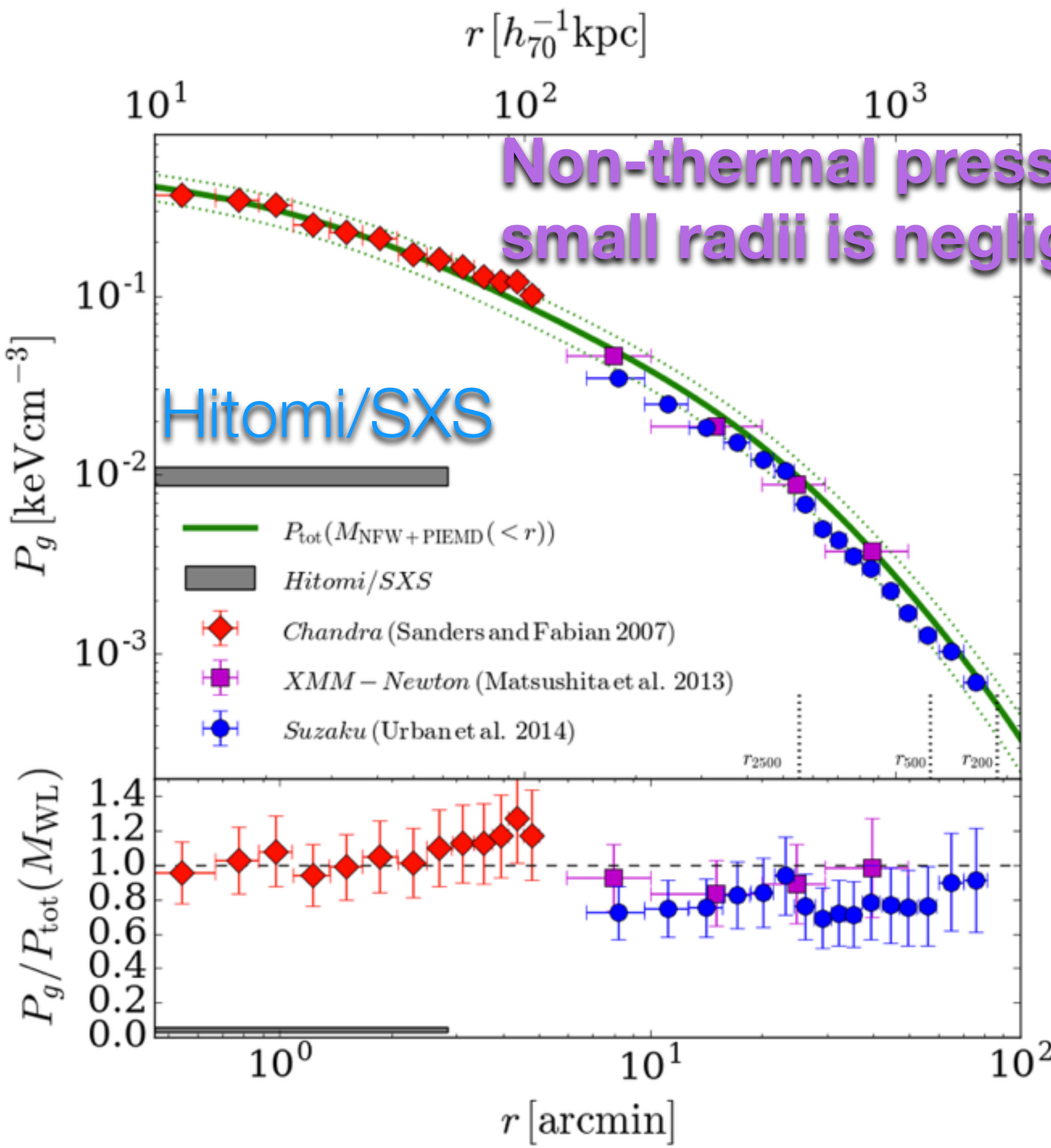
Non-thermal pressure

Hitomi



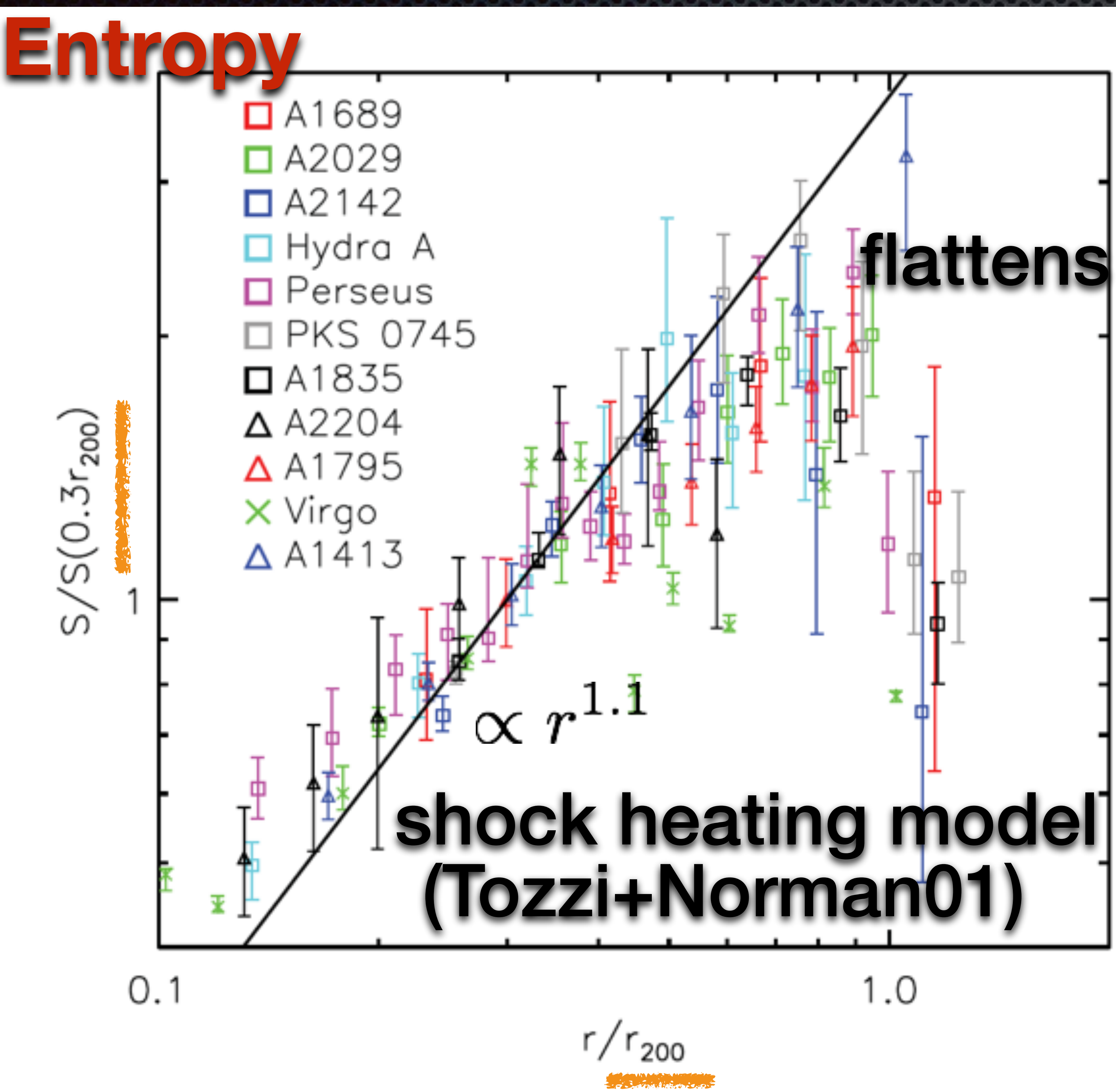
"**direct**" observation of non-thermal pressure.

Non-thermal pressure at small radii is negligible.



Consistent with Hitomi result

Outskirts Entropy Problem



Walker+2012

$$K = \frac{k_B T}{n_e^{2/3}}$$

Possible interpretations

- Temperature drops

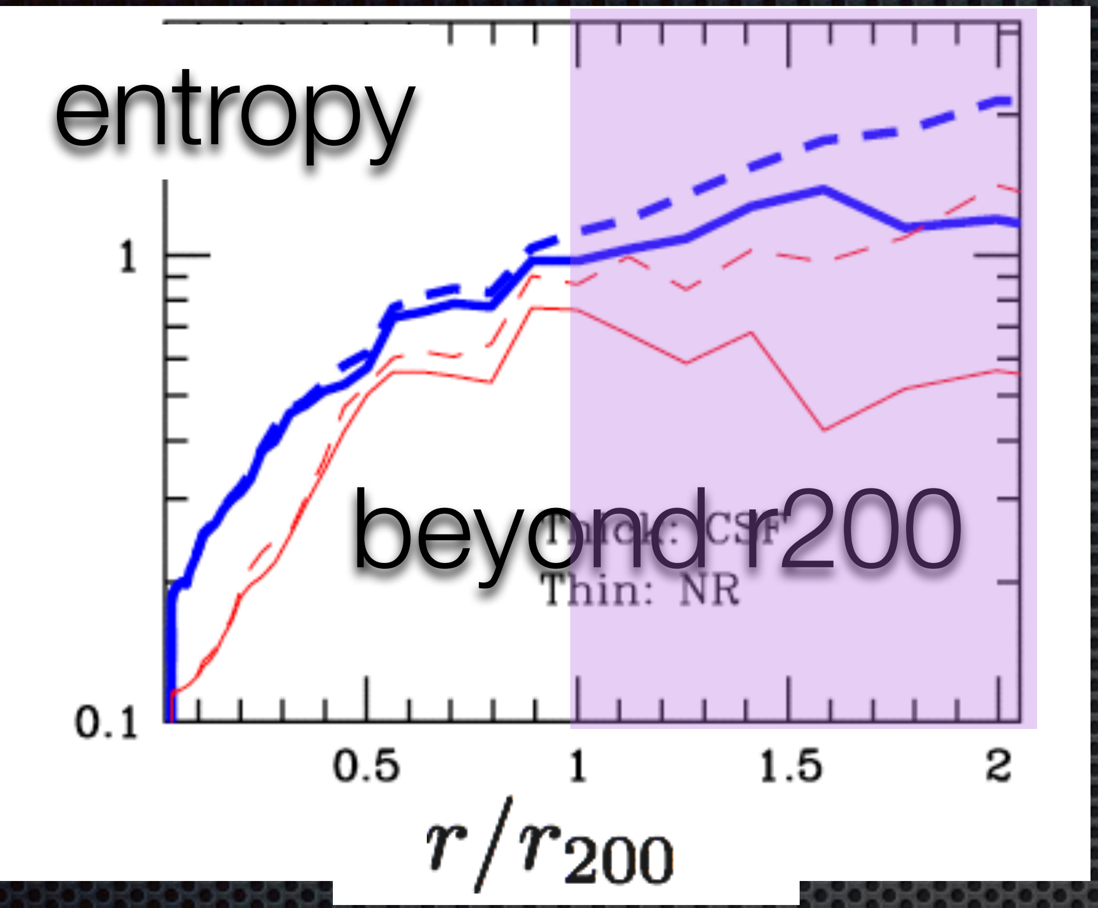
  Non-thermal pressure (Kawaharada+10, Sato+12, Ichikawa+13, Okabe+14c)

- Number density excess

  Overestimated by gas clumpiness (Nagai+Lau11, Simionescu+11, Urban+14)

Clumpiness interpretation

Nagai+Lau 11



[sim]

- Entropy flatting is found beyond r200.

Observations are within r200.

[sim]

- Clumpiness within r200 are negligible.

consistent with gas physics.

Lifetime of gas clumpy structures is very short due to ram-pressure/hydro-instability

Suzaku Observation

Density excess is reported only in the Perseus cluster.

we now have WL and X-ray data for the cluster.

Simultaneous fit of X-ray and WL data

- Do NOT assume existing scaling relations/base-lines to understand the data.

Since we don't know whether the assumption is true or not, we may misunderstand causes.

Self-Consistent Analysis

Okabe+14c

X-ray WL

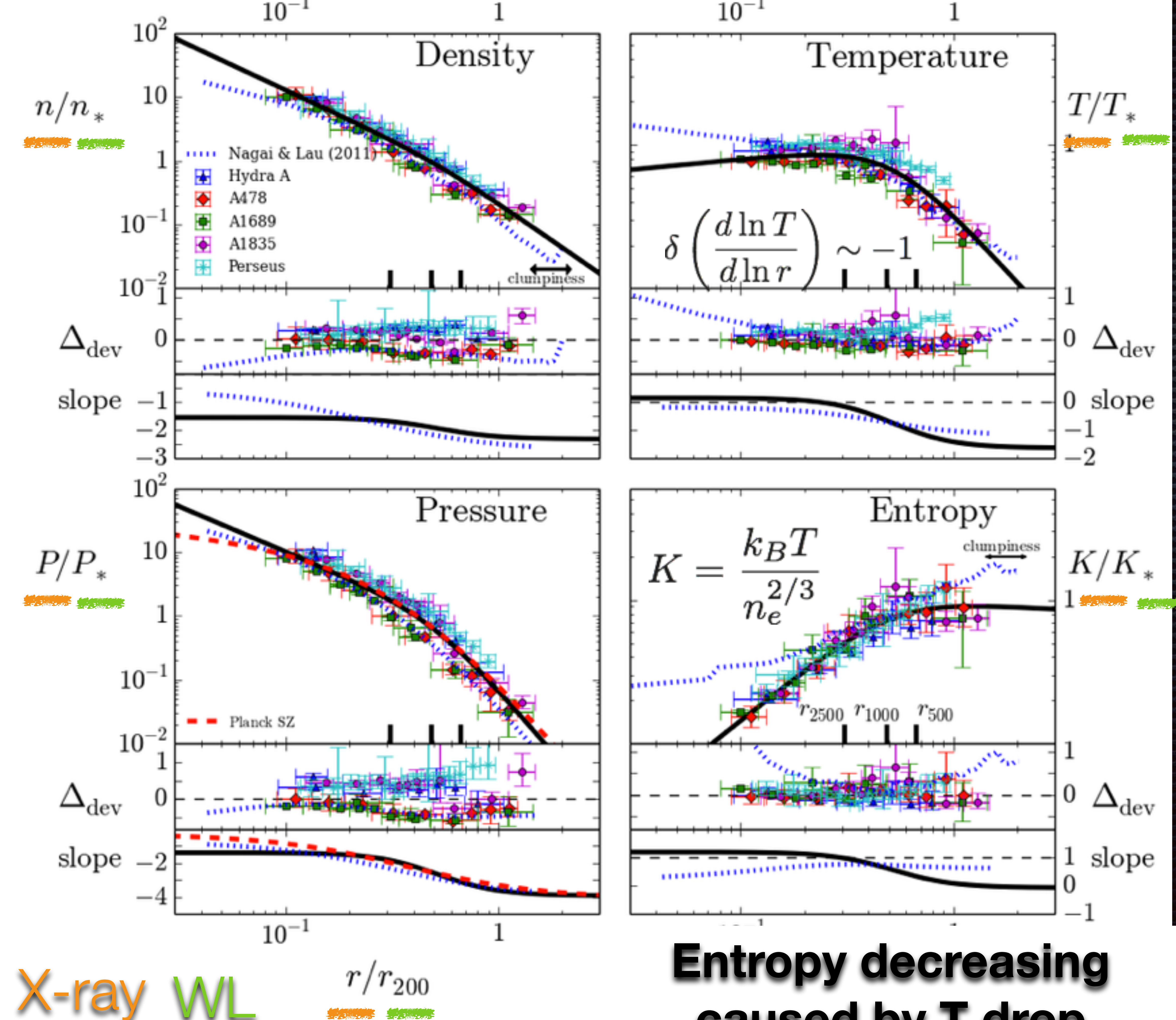
$$f_n(\tilde{r} = r/r_\Delta) = n_0 E(z)^2 \left(\frac{M_\Delta E(z)}{10^{14}\ h_{70}^{-1} M_\odot}\right)^a \left(\frac{\tilde{r}}{\tilde{r_0}}\right)^{-\alpha} \left(1 + \left(\frac{\tilde{r}}{\tilde{r_0}}\right)^\beta\right)^{-\gamma/\beta} \tag{10}$$

$$f_T(\tilde{r} = r/r_\Delta) = T_0 \left(\frac{M_\Delta E(z)}{10^{14}\ h_{70}^{-1} M_\odot}\right)^b \left(\frac{\tilde{r}}{\tilde{r_0}}\right)^{-\delta} \left(1 + \left(\frac{\tilde{r}}{\tilde{r_0}}\right)^\beta\right)^{-\eta/\beta} \tag{11}$$

$$-2\ln\mathcal{L} = \sum_{i,j} \ln(\det(\boldsymbol{C}_{ij})) + \boldsymbol{v}_{ij}^T \boldsymbol{C}_{ij}^{-1} \boldsymbol{v}_{ij},$$

$$\boldsymbol{v} = \begin{pmatrix} \ln(n(\tilde{r})) - \ln(f_n(M_\Delta, \tilde{r})) \\ \ln(T(\tilde{r})) - \ln(f_T(M_\Delta, \tilde{r})) \end{pmatrix},$$

$$\boldsymbol{C} = \boldsymbol{C}_{\rm stat} + \boldsymbol{C}_{\rm int}$$



Entropy decreasing caused by T drop

Summary

NECSUS

- New project for very nearby clusters using Subaru/HSC is launched.
- Indirect constraint of non-thermal pressure agrees well with the quiescent gas by Hitomi's direct observation.
- X-ray gas profiles (n, T, P, and K) scaled by weak-lensing mass and over-density radius have universal forms out to ~ virial radius.
- Low entropy in cluster outskirts is caused by temperature drops rather than gas clumpiness.