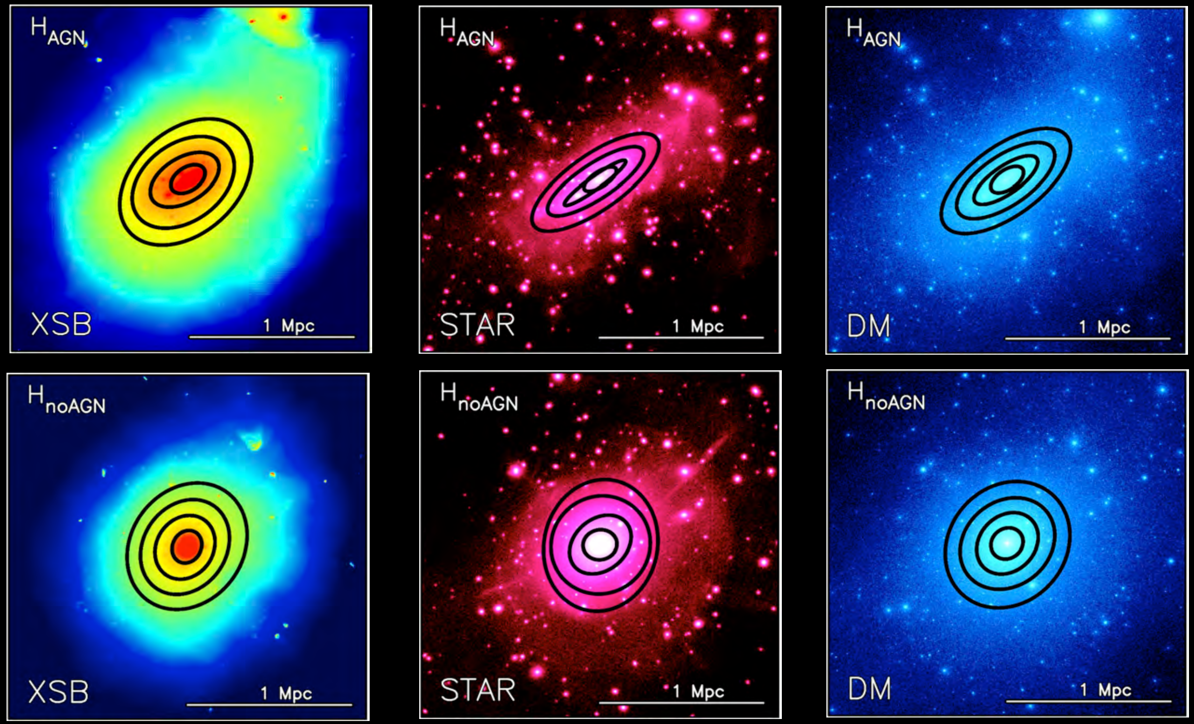
Impact of baryon physics on non-sphericity of galaxy clusters

Hydro-simulation with AGN feedback

Hydro-simulation without AGN feedback



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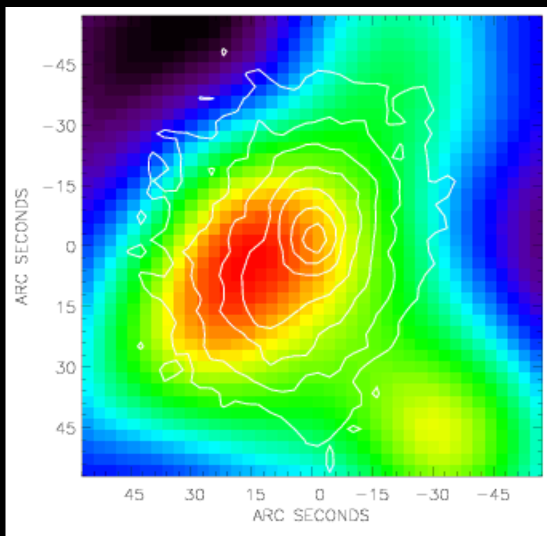
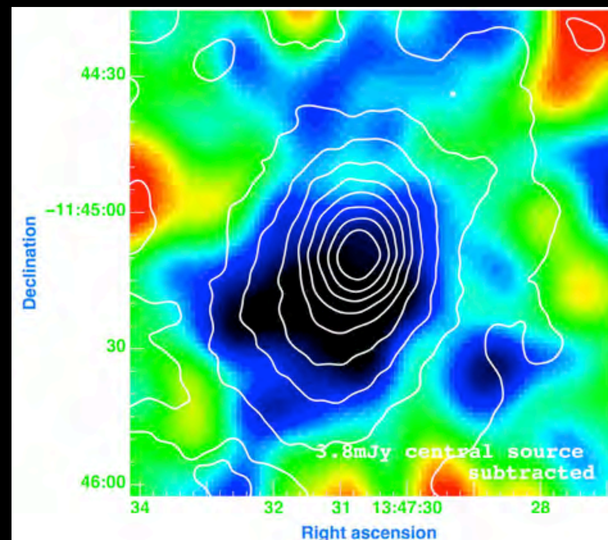
15:45-16:10 on Nov. 1, 2016 @ 7th KIAS cosmology workshop

Progress of SZ mapping of clusters: case of RX J1347.5-1145



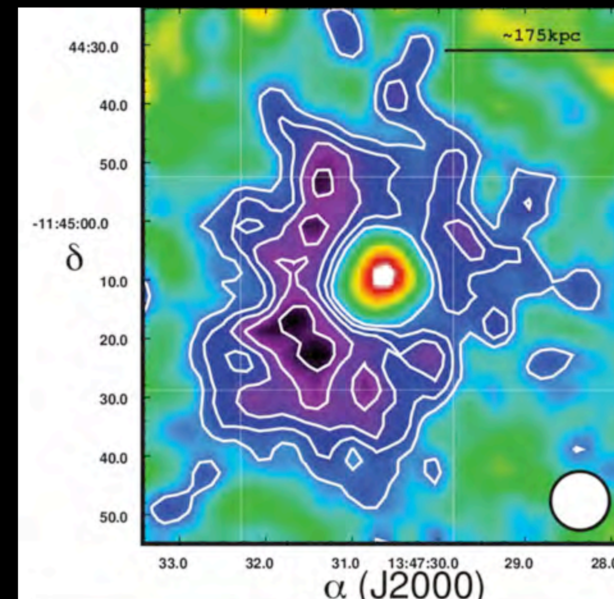
The first SZ map at 350GHz (FWHM=15”)
color: SCUBA@JCMT
contour: Chandra

Komatsu et al. (1999)



150GHz (FWHM=13”)
color: NOBA@Nobeyama
contour: Chandra

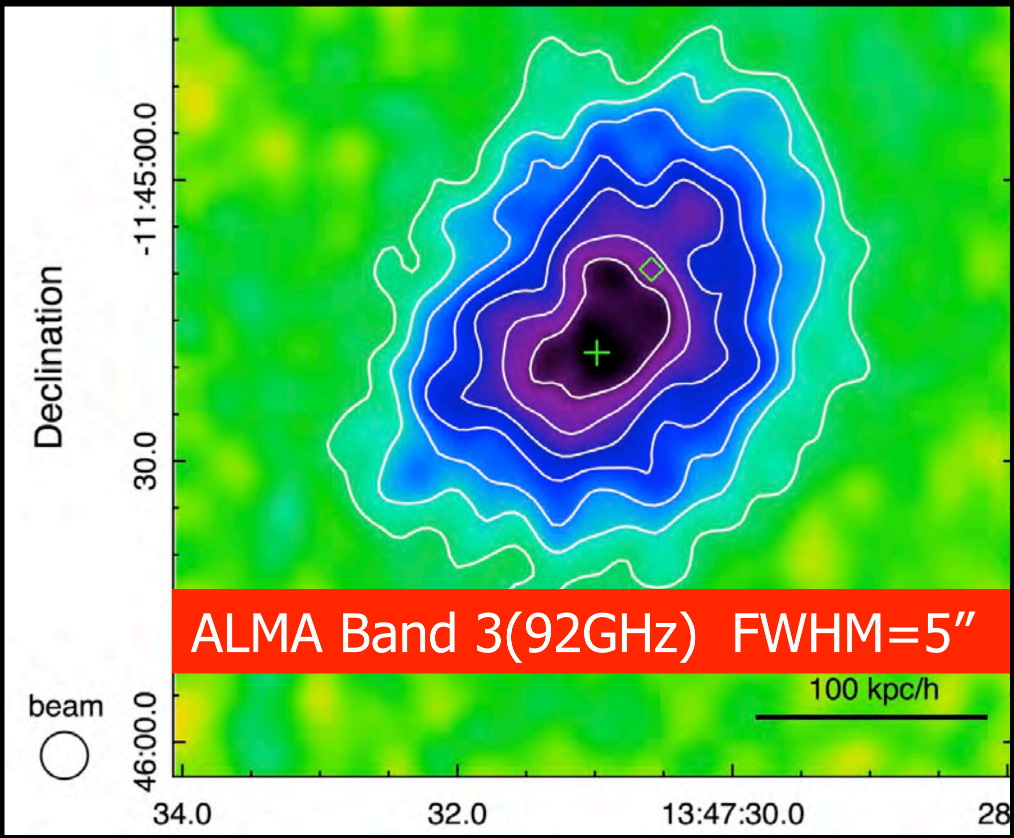
Komatsu et al. (2001)
Kitayama et al. (2004)

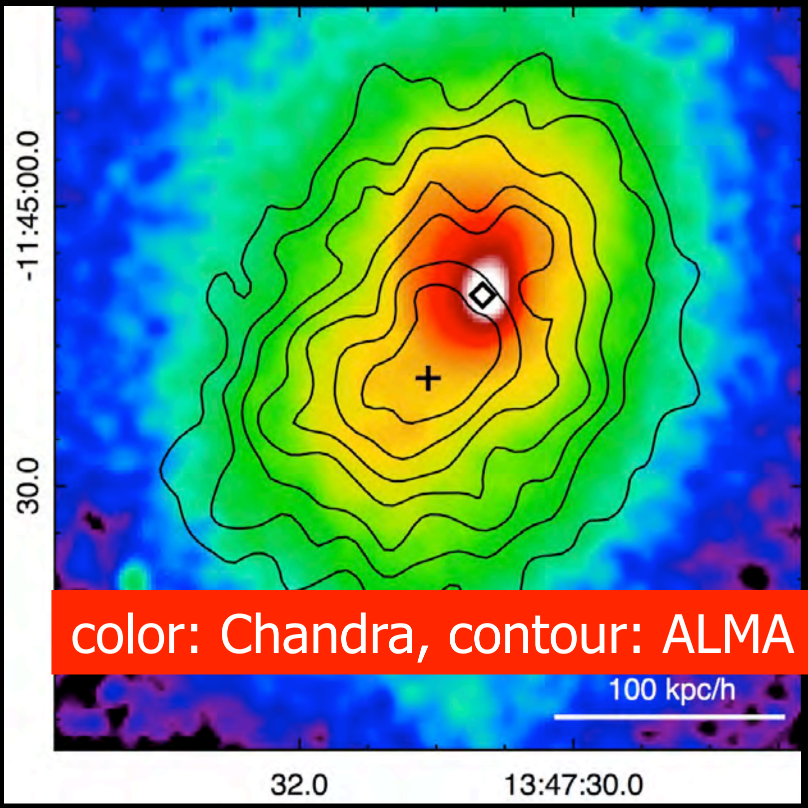


90GHz (FWHM=10”)
MUSTANG @Green bank

Mason et al. (2010)

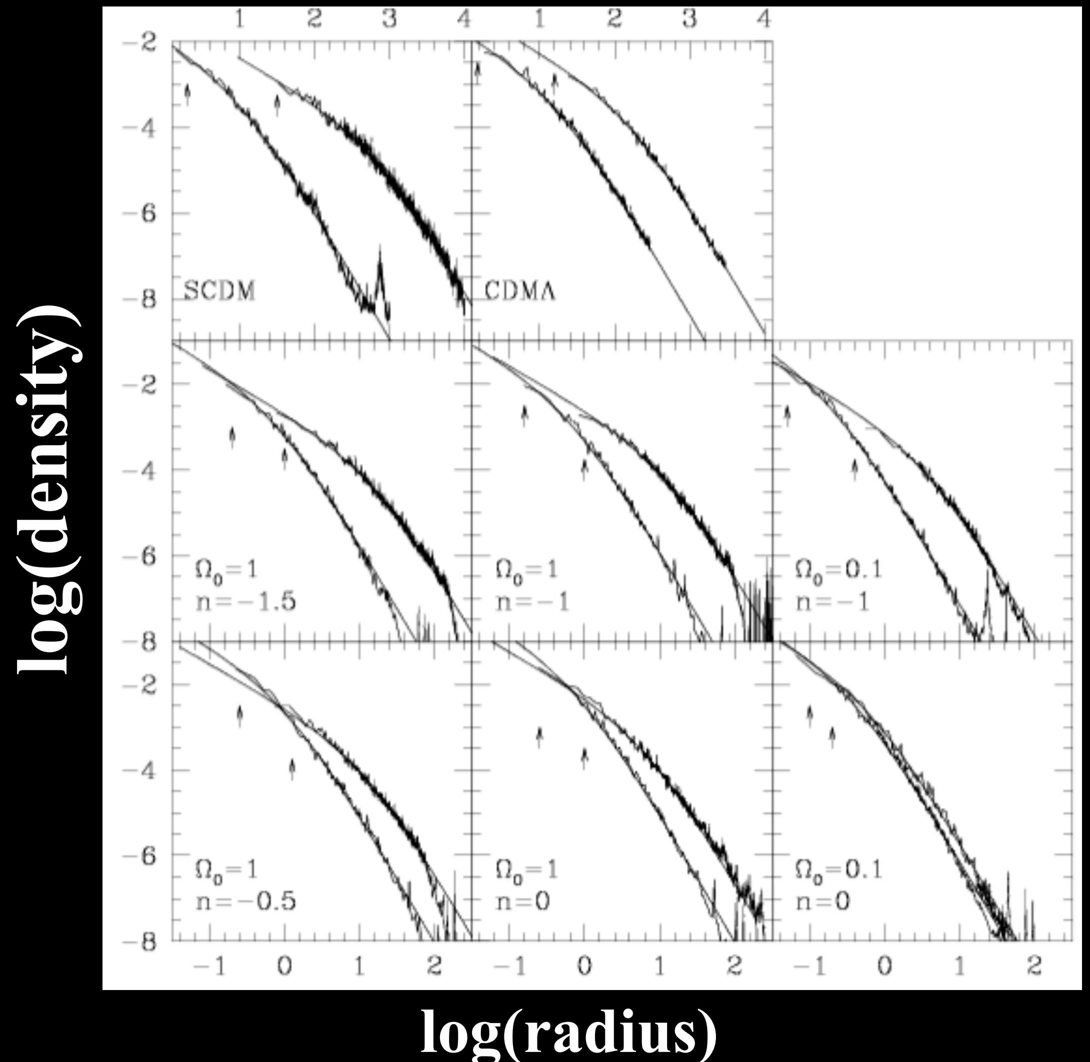
The Sunyaev-Zel'dovich effect at 5″: RX J1347.5-1145 imaged by ALMA





Kitayama et al. PASJ 2016, 68, 88(1-19)
arXiv:1607.08833

Amazing universality of *spherically-averaged* density profiles of halos



- **NFW profile**
  - Spherically-averaged density profiles of collisionless CDM halos

$$\rho(r) = \frac{\delta_c \rho_{crit}}{(r/r_s)(1+r/r_s)^2}$$

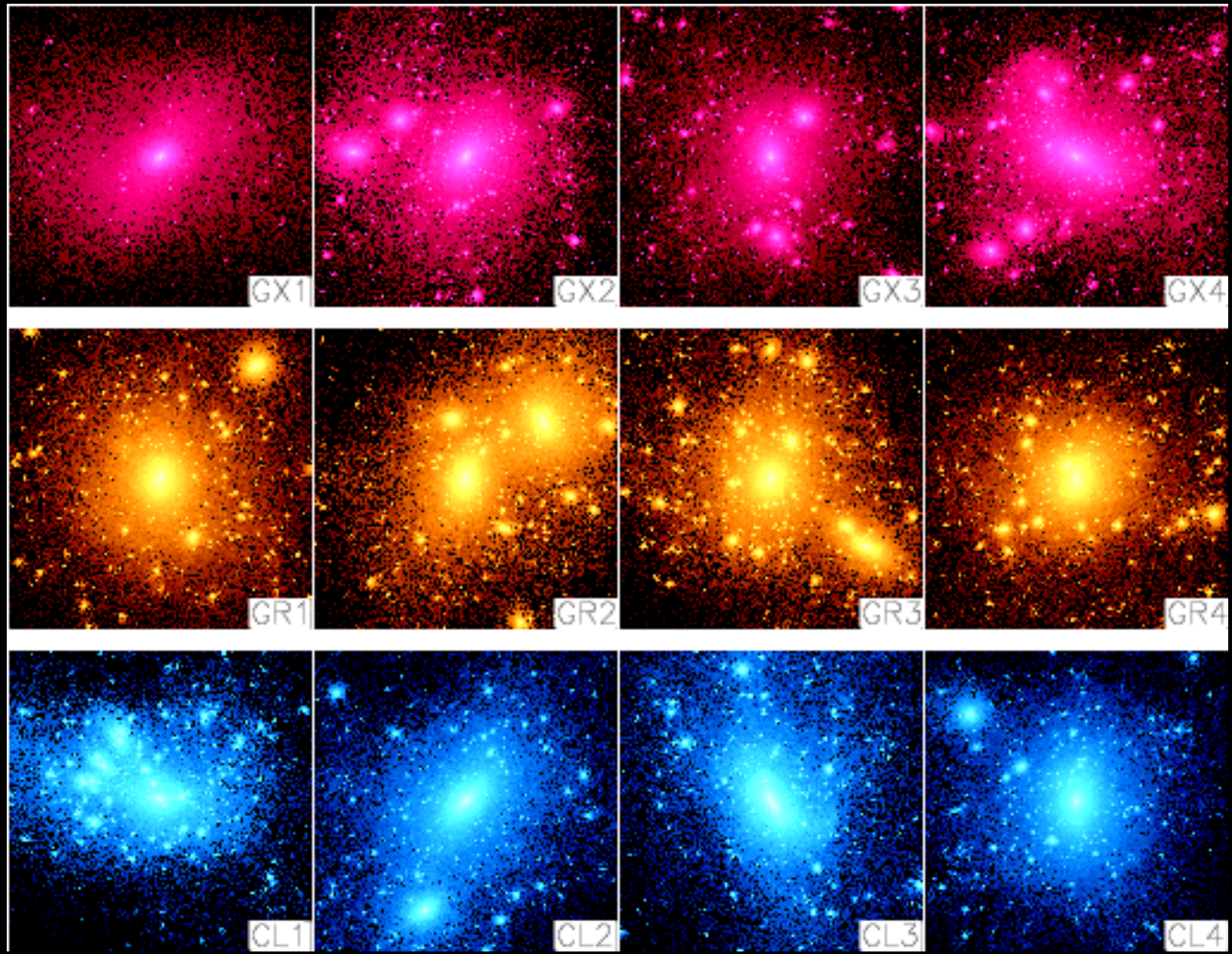
Navarro, Frenk & White (1997)

Shapes of dark matter halos: highly non-spherical

galaxies
$\sim 5\text{x}10^{12}M_{sun}$

groups
$\sim 5\text{x}10^{13}M_{sun}$

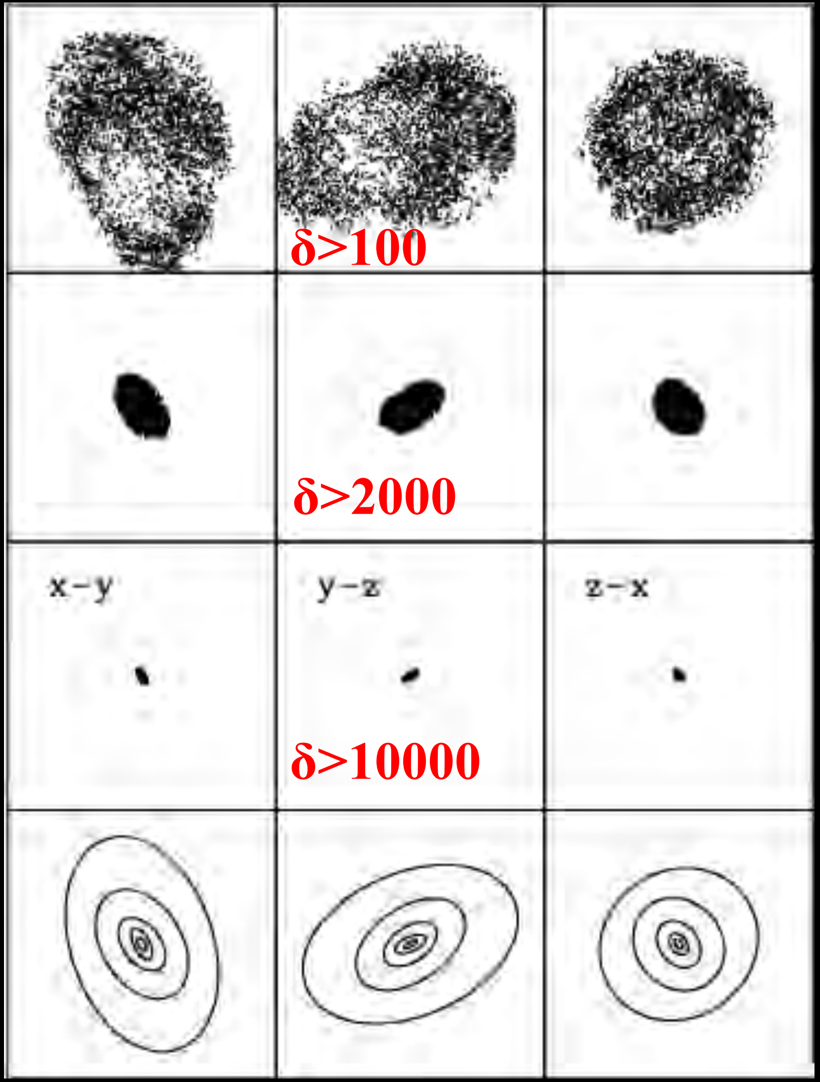
clusters
$\sim 3\text{x}10^{14}M_{sun}$



N-body simulation by Jing & Suto (2000)

Triaxial model of dark matter halos

Isodensity of a halo



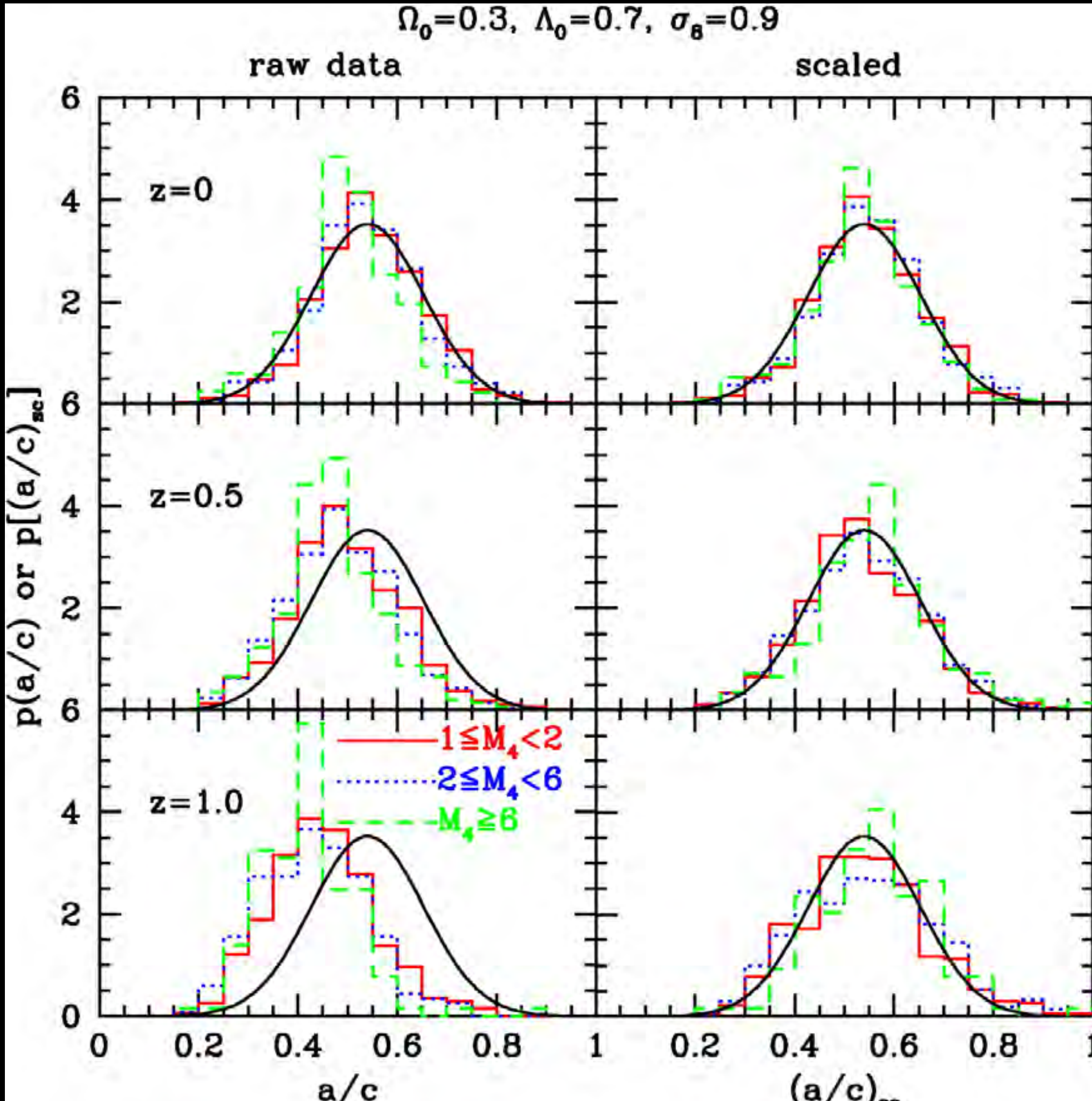
$$\rho(R) = \frac{\delta_c \rho_{crit}}{(R/R_s)^{\alpha}(1+R/R_s)^{3-\alpha}}$$

$$R^2(\rho) \equiv \frac{X^2}{a^2(\rho)} + \frac{Y^2}{b^2(\rho)} + \frac{Z^2}{c^2(\rho)}$$

Jing & Suto ApJ 574 (2002) 538

- widely applied for a variety of cosmological problems, but is fairly simplified
  - concentric, self-similar (axis ratio is independent of radius)

PDF of axis ratio



Jing & Suto (2002)

Scaled axis ratio

$$\tilde{r}_{ac} = \left(\frac{a}{c}\right)_{scaled} = \left(\frac{a}{c}\right)\left(\frac{M_{vir}}{M_{nonlinear}(z)}\right)^{0.07\Omega(z)^{0.7}}$$

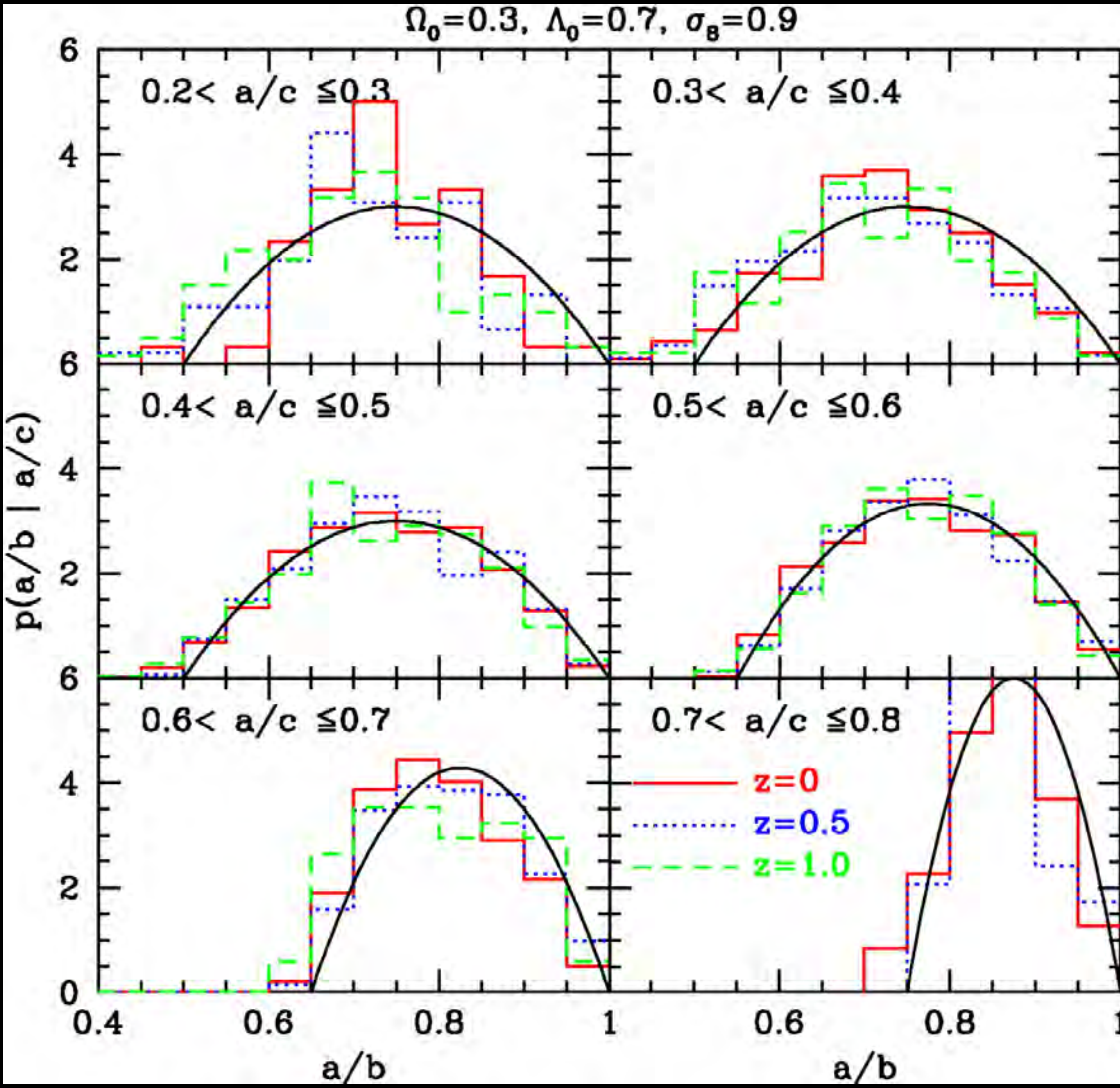
PDF of the scaled axis ratio

$$p(\tilde{r}_{ac}) = \frac{1}{\sqrt{2\pi\sigma^2}}\exp\left(-\frac{(\tilde{r}_{ac}-0.54)^2}{2\sigma^2}\right)$$

$$\sigma = 0.113$$

- Higher z for a given mass, less spherical
- More massive at a given z, very slightly less spherical

Conditional PDF of axis ratio



Jing & Suto (2002)

Joint PDF

$$p\left(\frac{a}{c},\frac{b}{c}\right)d\left(\frac{a}{c}\right)d\left(\frac{b}{c}\right)$$

$$= p\left(\frac{a}{c}\right)d\left(\frac{a}{c}\right)p\left(\frac{b}{c}\middle|\frac{a}{c}\right)d\left(\frac{b}{c}\right)$$

$$= p\left(\frac{a}{c}\right)d\left(\frac{a}{c}\right)p\left(\frac{a}{b}\middle|\frac{a}{c}\right)d\left(\frac{a}{b}\right)$$

conditional PDF

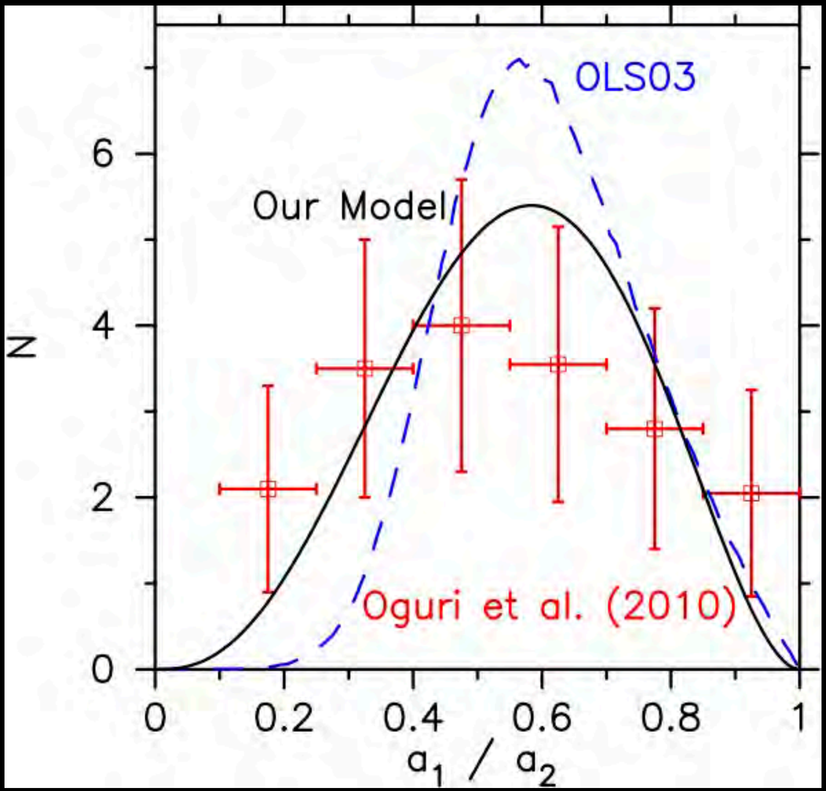
$$p\left(\frac{a}{b}\middle|\frac{a}{c}\right)=\frac{3}{2(1-r_{\min})}\left[1-\left(\frac{2a/b-1-r_{\min}}{1-r_{\min}}\right)^2\right]$$

for $a/b > r_{\min}$, otherwise 0

where $r_{\min} = a/c$ for $a/c > 0.5$

$= 0.5$ for $a/c < 0.5$

Tentative comparison with observed axis ratio from weak lensing



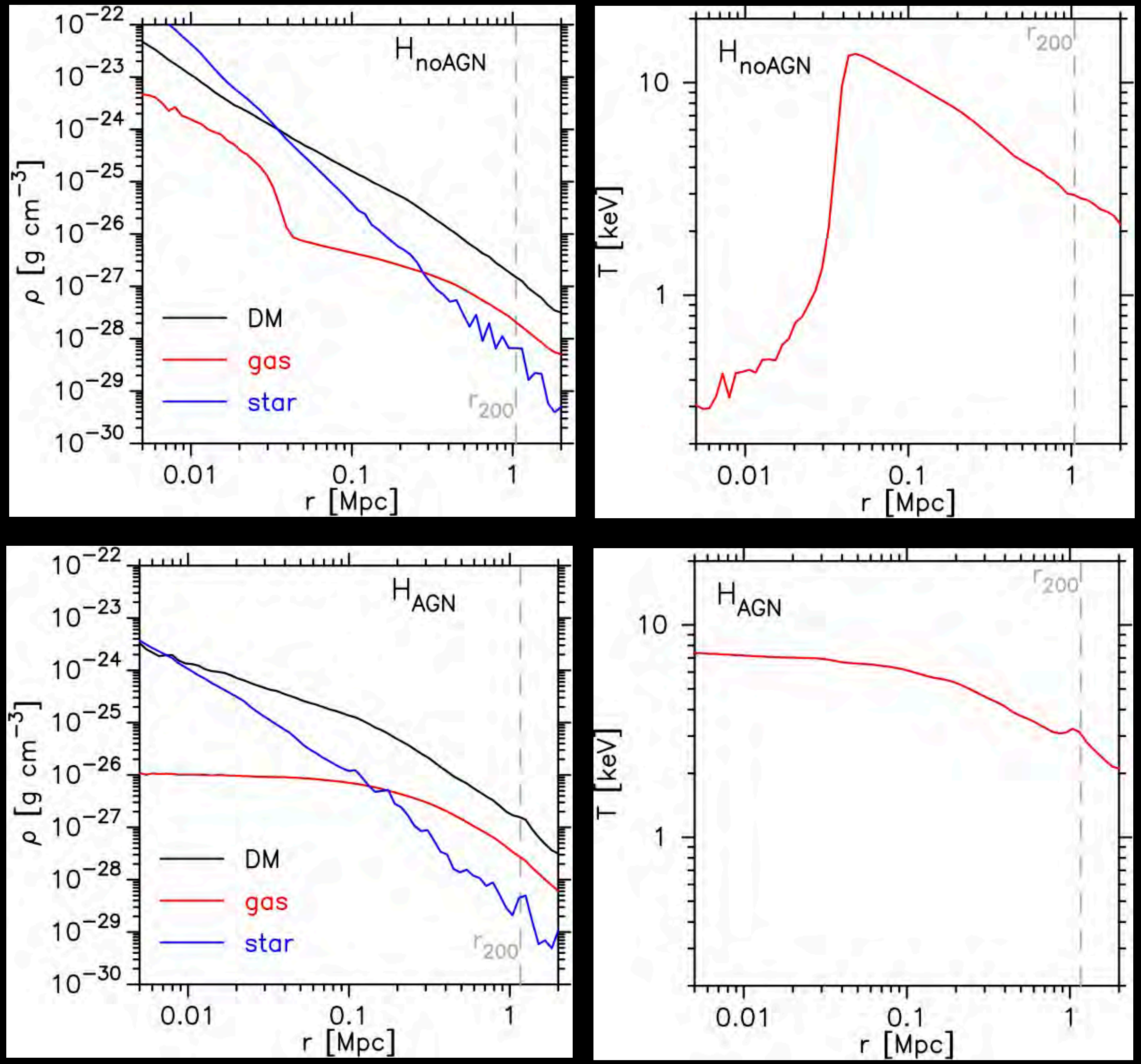
Suto et al. (2016)

- Subaru Suprime-Cam weak-lensing map for 18 massive clusters (Oguri et al. 2010, MNRAS 405, 2215)
- Our result fits the observed data better than the OLS03 prediction
- Promising for future comparison with Subaru Hyper Supreme-Cam data

Horizon simulations

- Cosmological hydro-simulation (Dubois et al. 2014)
  - $N=1024^3$ dark matter particles in a cube of $(100h^{-1}Mpc)^3$; $m = 8.27\times10^7\ M_\odot$
  - Adaptive mesh refinement for gas with initial cell size of 136kpc (refined down to 1.06kpc)
    - Gas cooling, heating due to UV background, star formation, and feedback from stellar winds and type I and II SNe are included
  - H_{AGN} includes feedback from AGN as well by implementing the growth of central BHs

Baryonic effect inside galaxy clusters

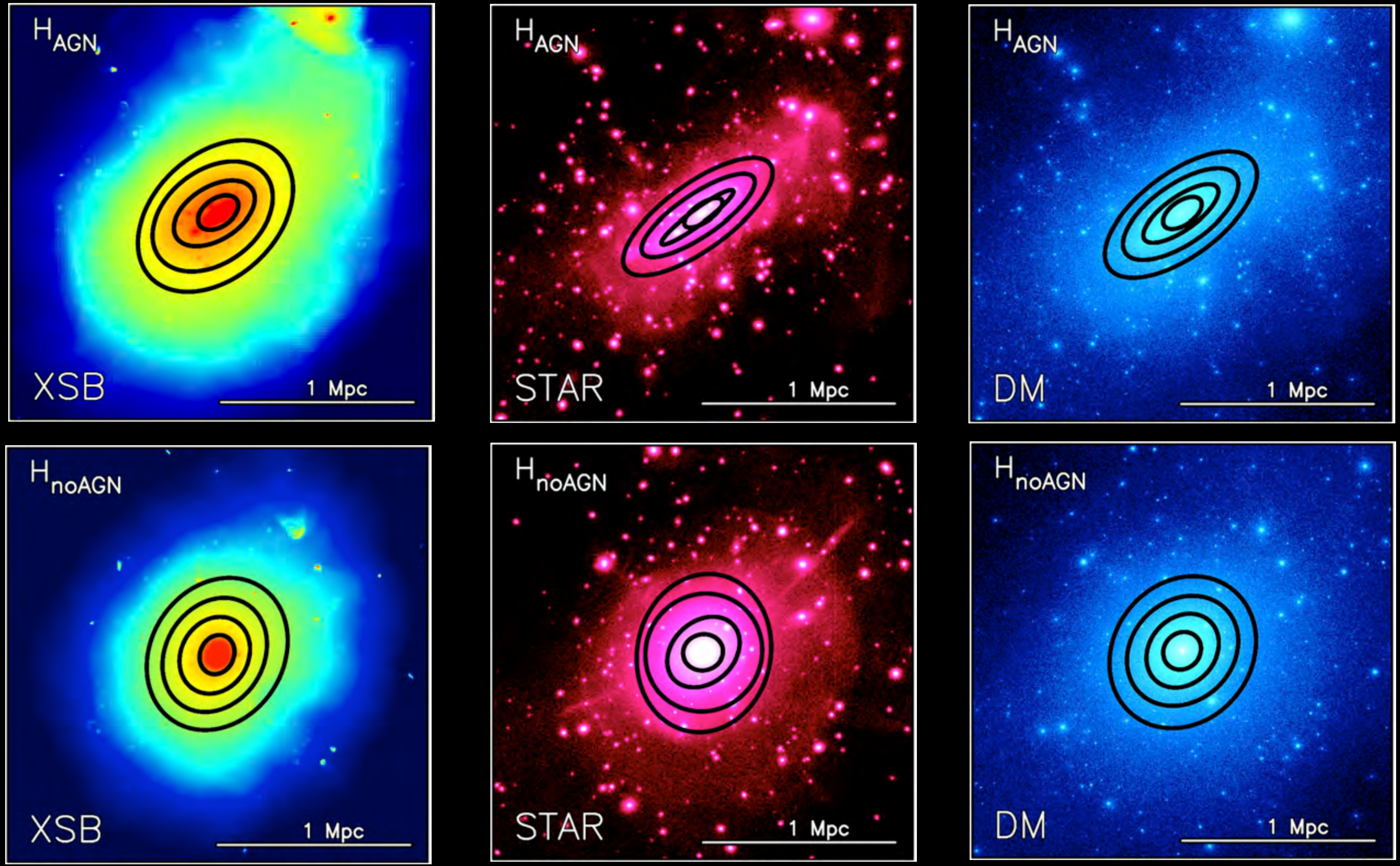


- Both gas cooling and star+AGN feedback need to be properly included in simulations so as to reproduce the (spherically-averaged) observed properties of galaxy clusters

Daichi Suto, Dubois, Peirani, Nishimichi, Kitayama, Sasaki, & Yasushi Suto (2016) submitted to PASJ

Shape of clusters probed by gas, stars, and dark matter

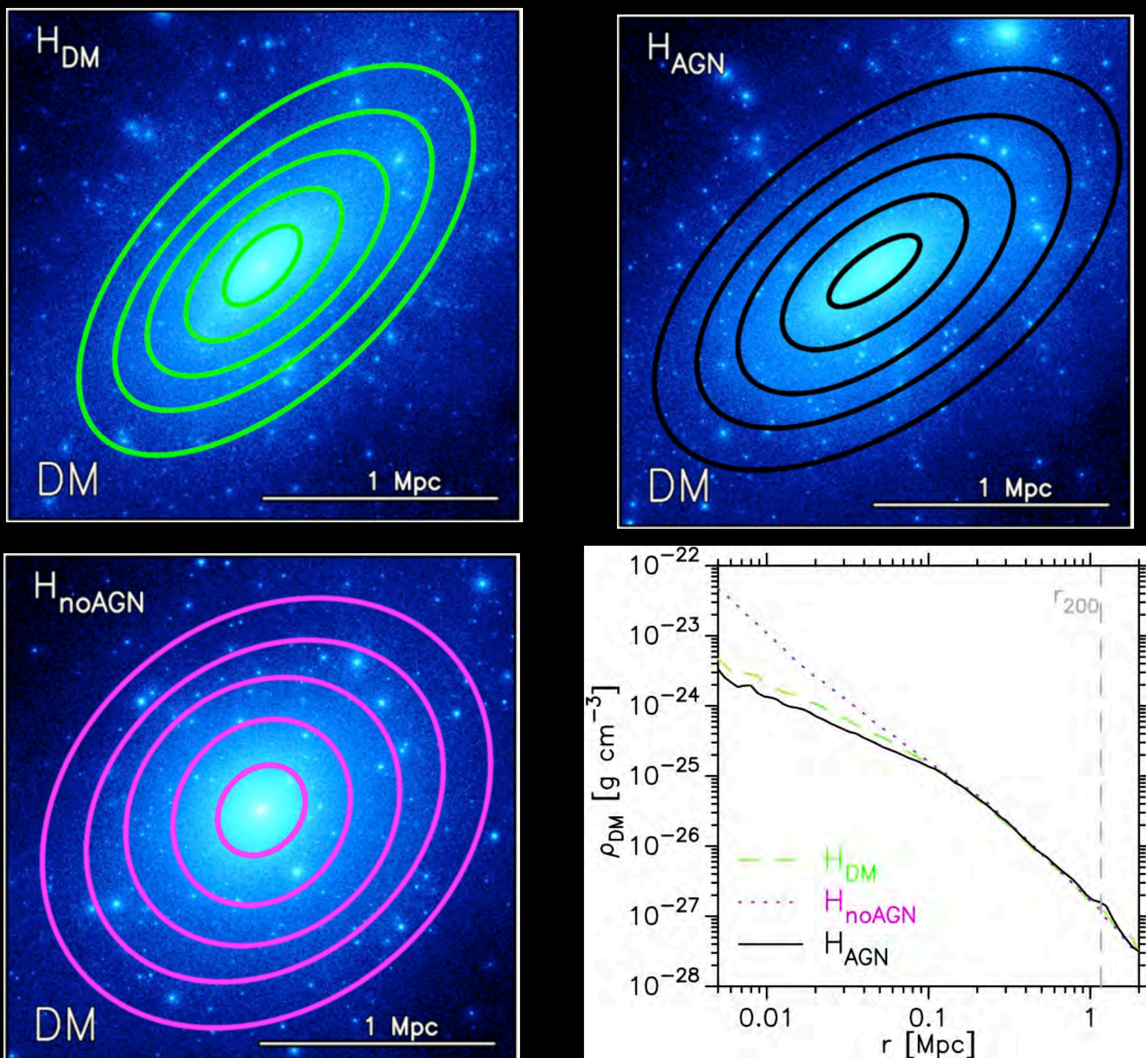
with AGN feedback



without AGN feedback

Suto et al. (2016)

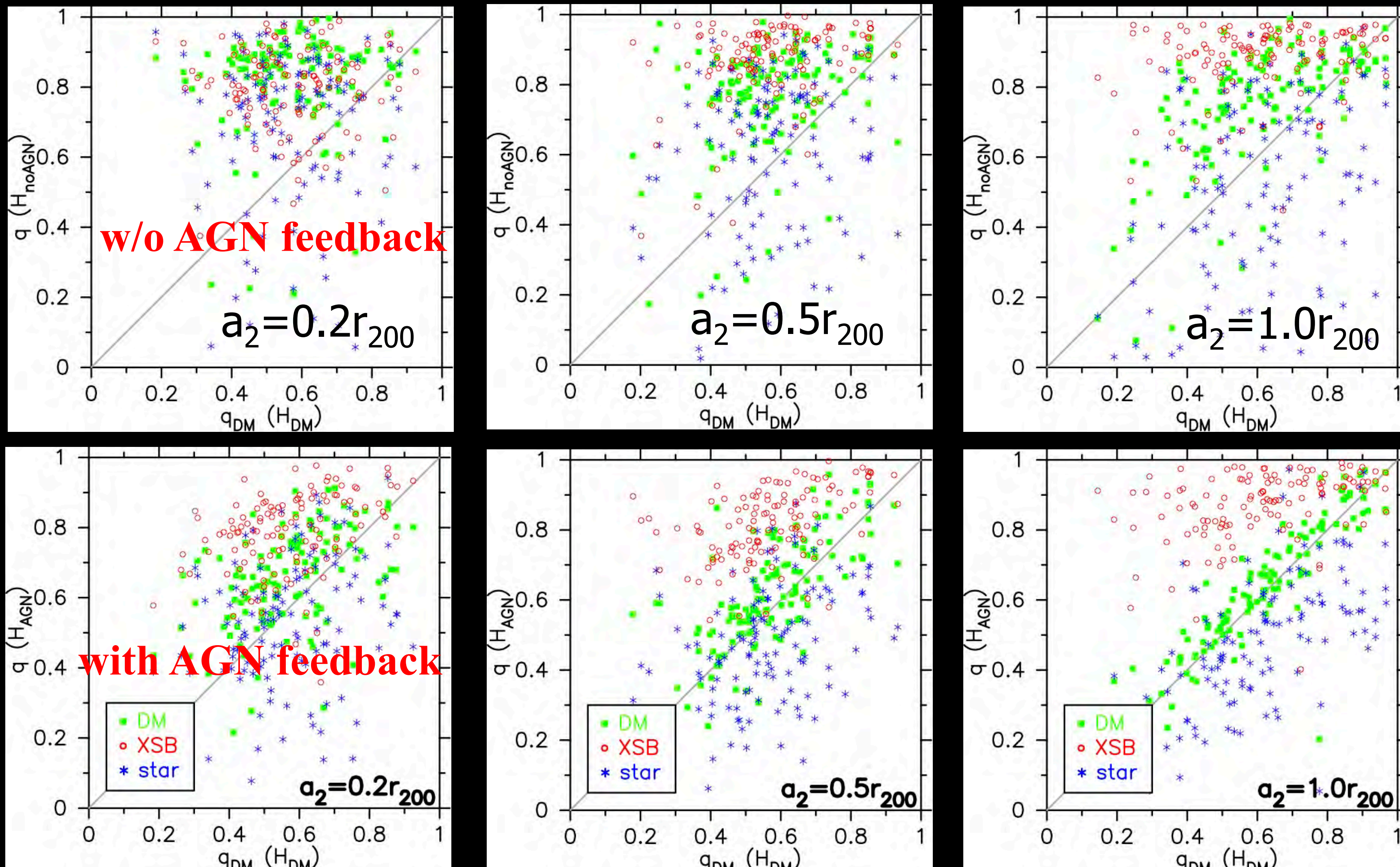
Baryonic effect on the shape of ***dark matter*** distribution



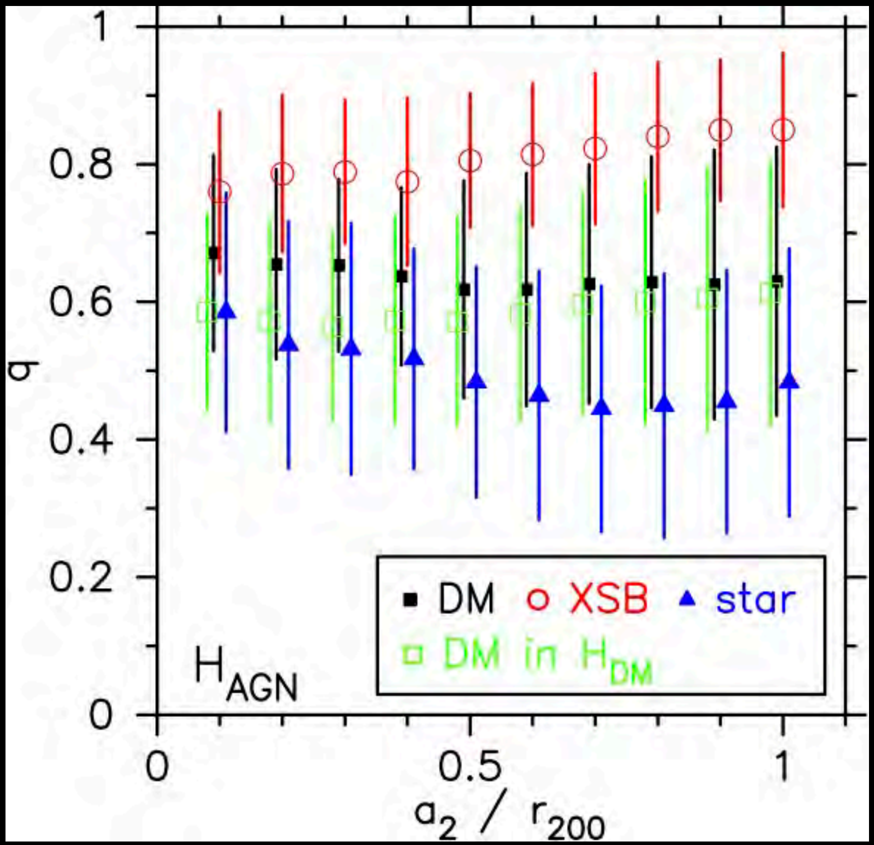
- spherical profiles unchanged for $r>0.1r_{vir}$
- significant impact on shapes even up to $0.5r_{vir}$!

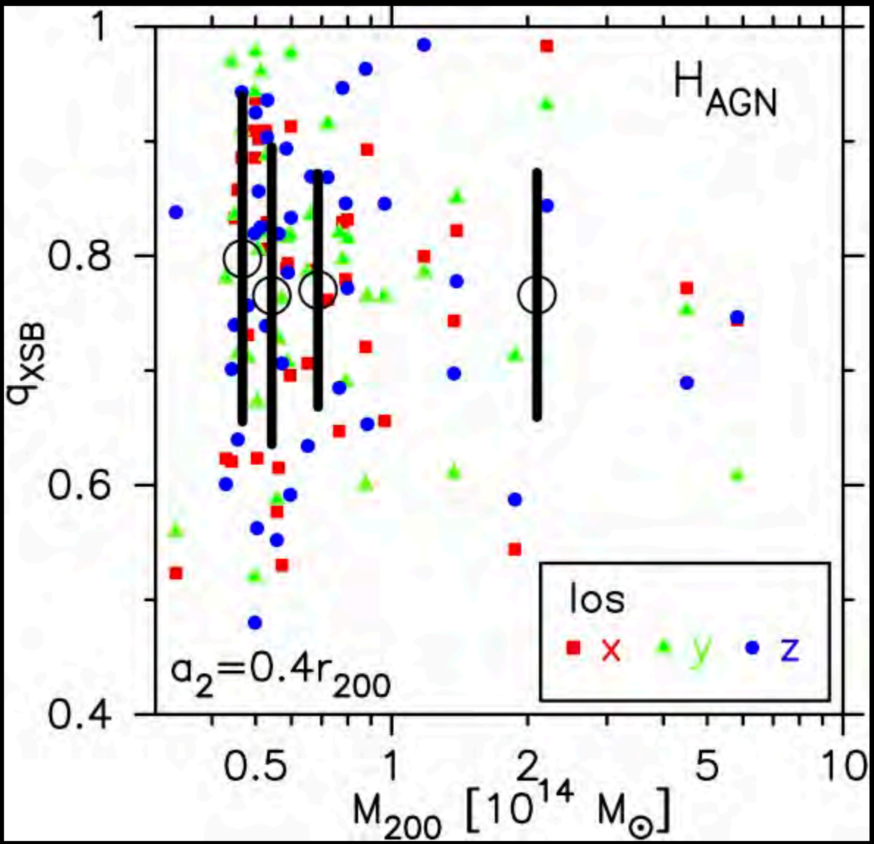
Suto et al. (2016)

Axis ratios of 40 simulated clusters with/without baryon physics



Radial and mass dependence of axis ratio

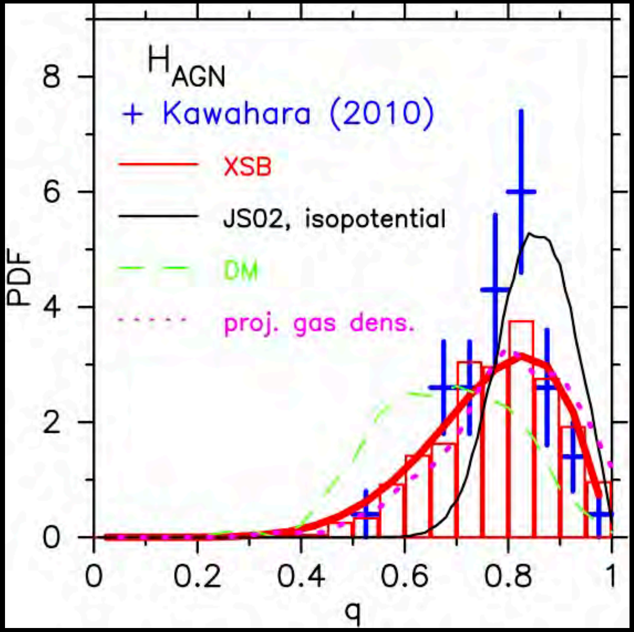




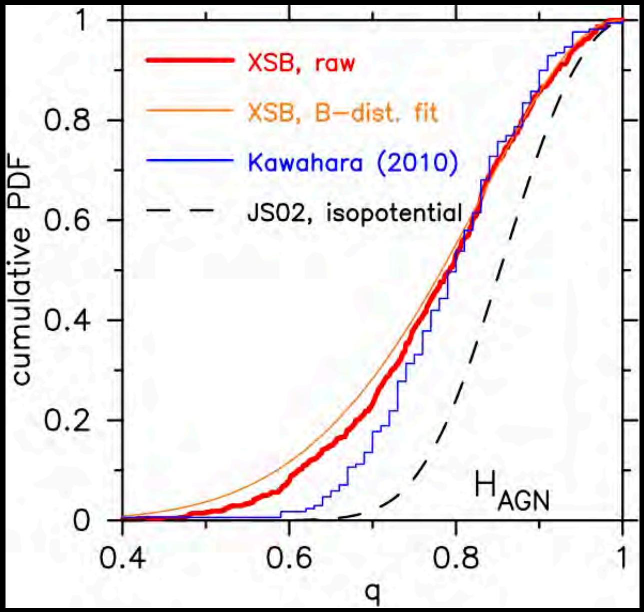
- $q_{XSB} > q_{DM} > q_{star}$
- no significant mass dependence of axis ratio

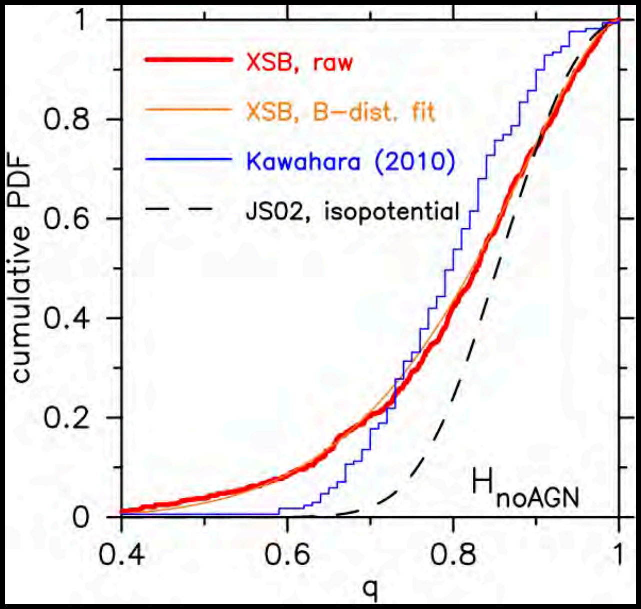
Suto et al. (2016)

Comparison with X-ray observation



- axis ratios of 70 X-ray clusters fitted by Kawahara (2010)
- simulated clusters with AGN feedback reasonably agree with the observed data





Suto et al. (2016)

Summary

- Galaxies and galaxy clusters are highly non-spherical, but their non-sphericity is not easy to model/interpret theoretically
- Reliable simulations with proper baryon physics are required for observational confrontation
- Current simulations reasonably reproduce the observed axis ratios from weak lensing and X-ray data
- Important and complementary probes of cosmology with future data