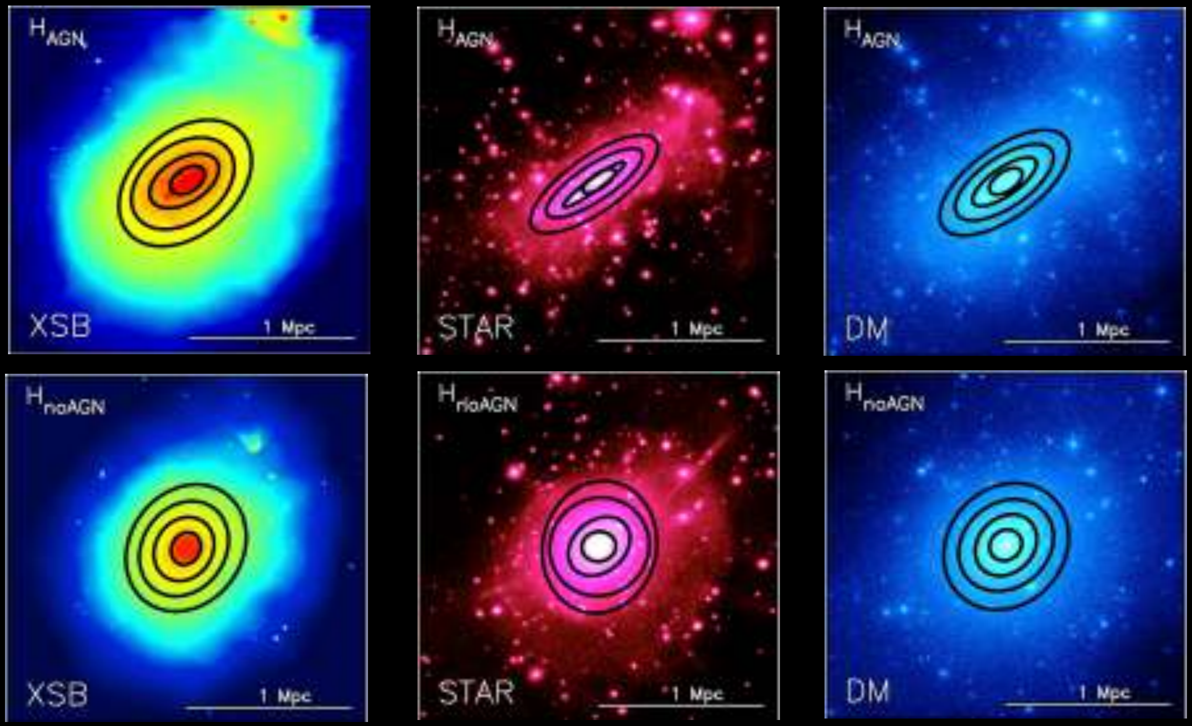
# Impact of baryon physics on non-sphericity of galaxy clusters

Hydro-simulation with AGN feedback

Hydro-simulation without AGN feedback



**Yasushi Suto**

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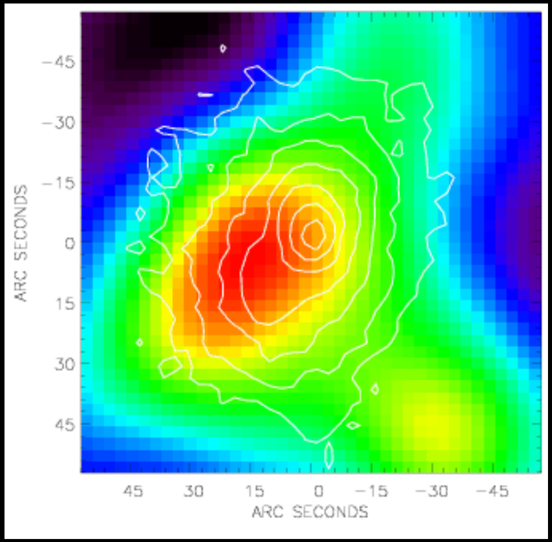
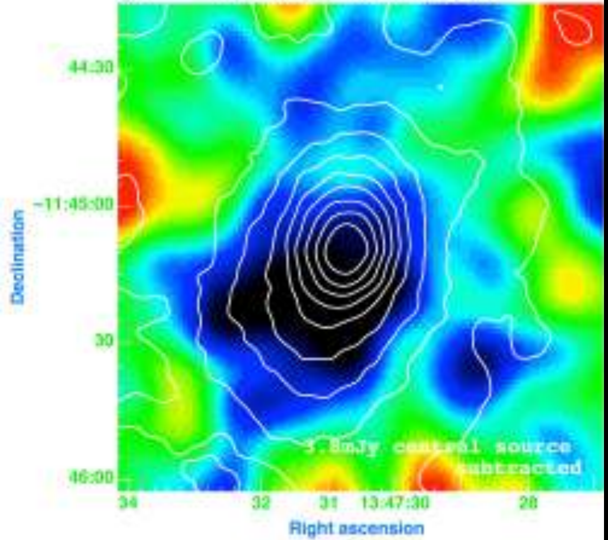
15:45-16:10 on Nov. 1, 2016 @ 7th KIAS cosmology workshop

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



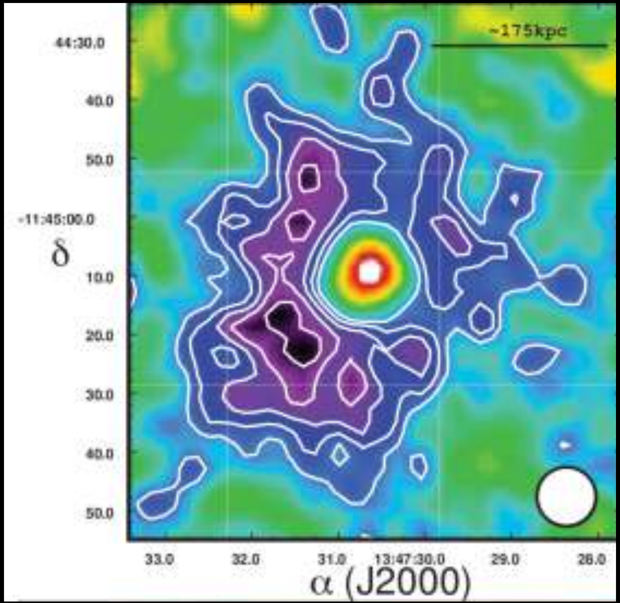
The first SZ map at
350GHz (FWHM=15" )
color: SCUBA@JCMT
contour: Chandra

Komatsu et al. (1999)



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

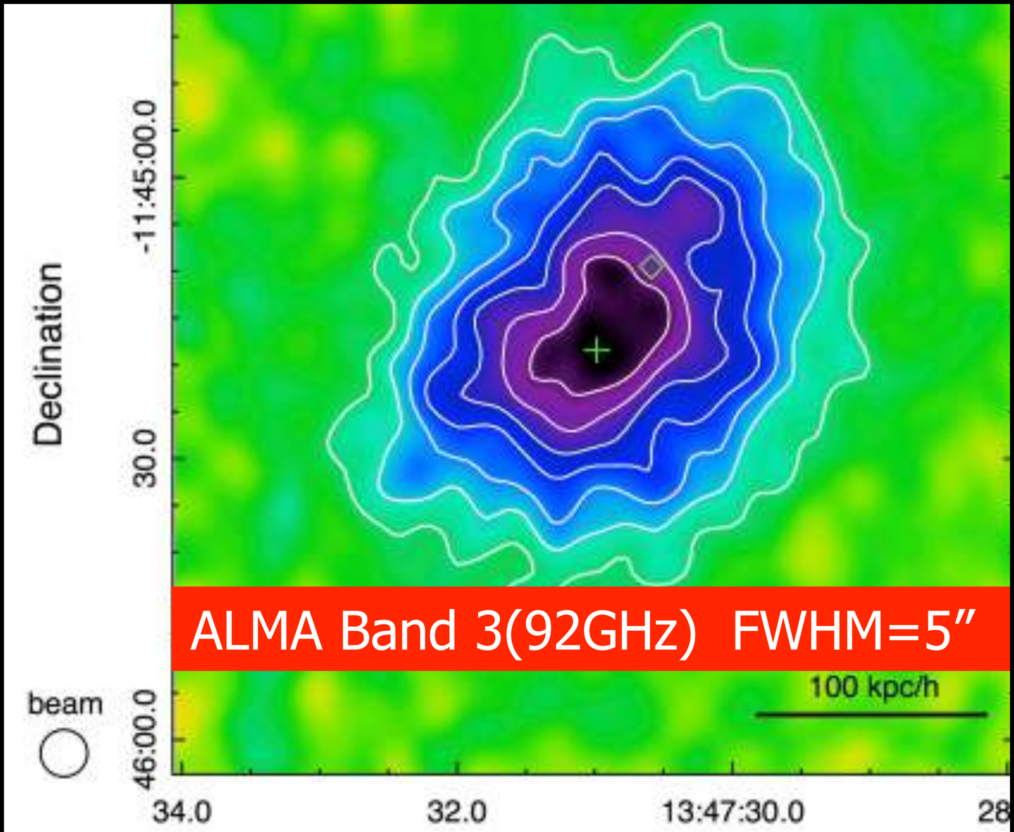
Komatsu et al. (2001)
Kitayama et al. (2004)

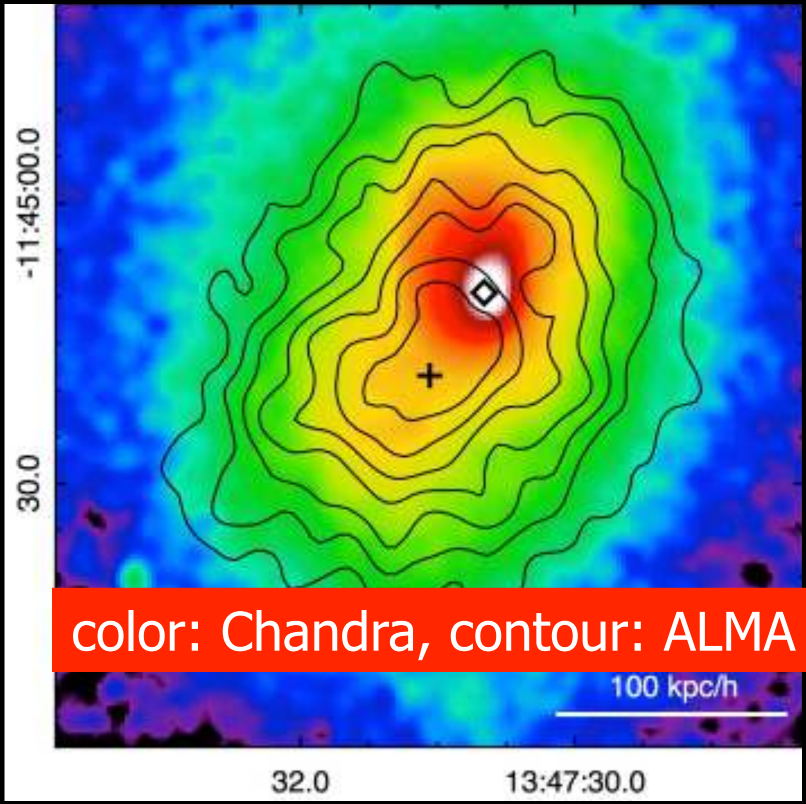


90GHz
(FWHM=10" )
MUSTANG
@Green bank

Mason et al. (2010)

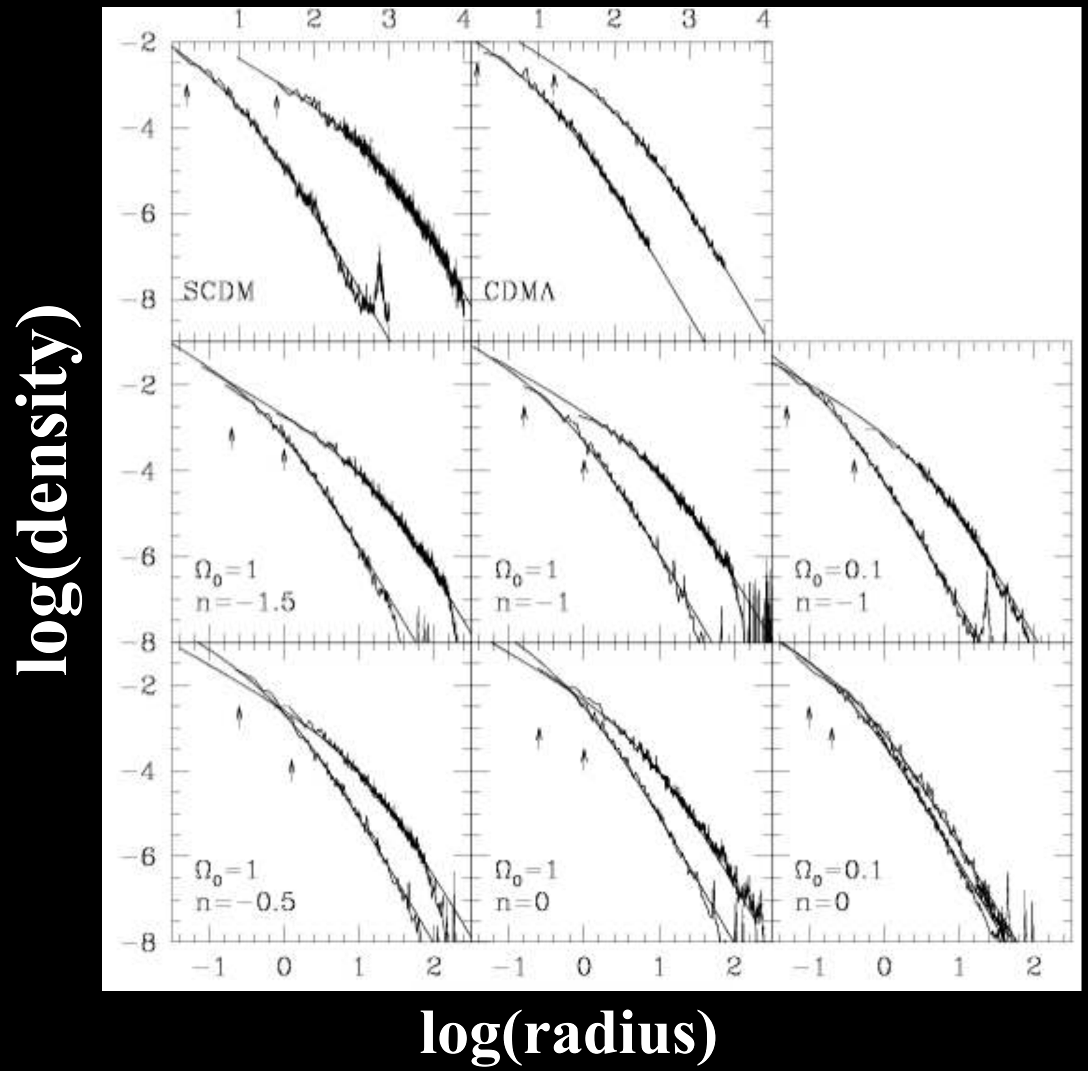
# The Sunyaev-Zel'dovich effect at 5″: RX J1347.5-1145 imaged by ALMA


ALMA Band 3(92GHz)  FWHM=5″


color: Chandra, contour: 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

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

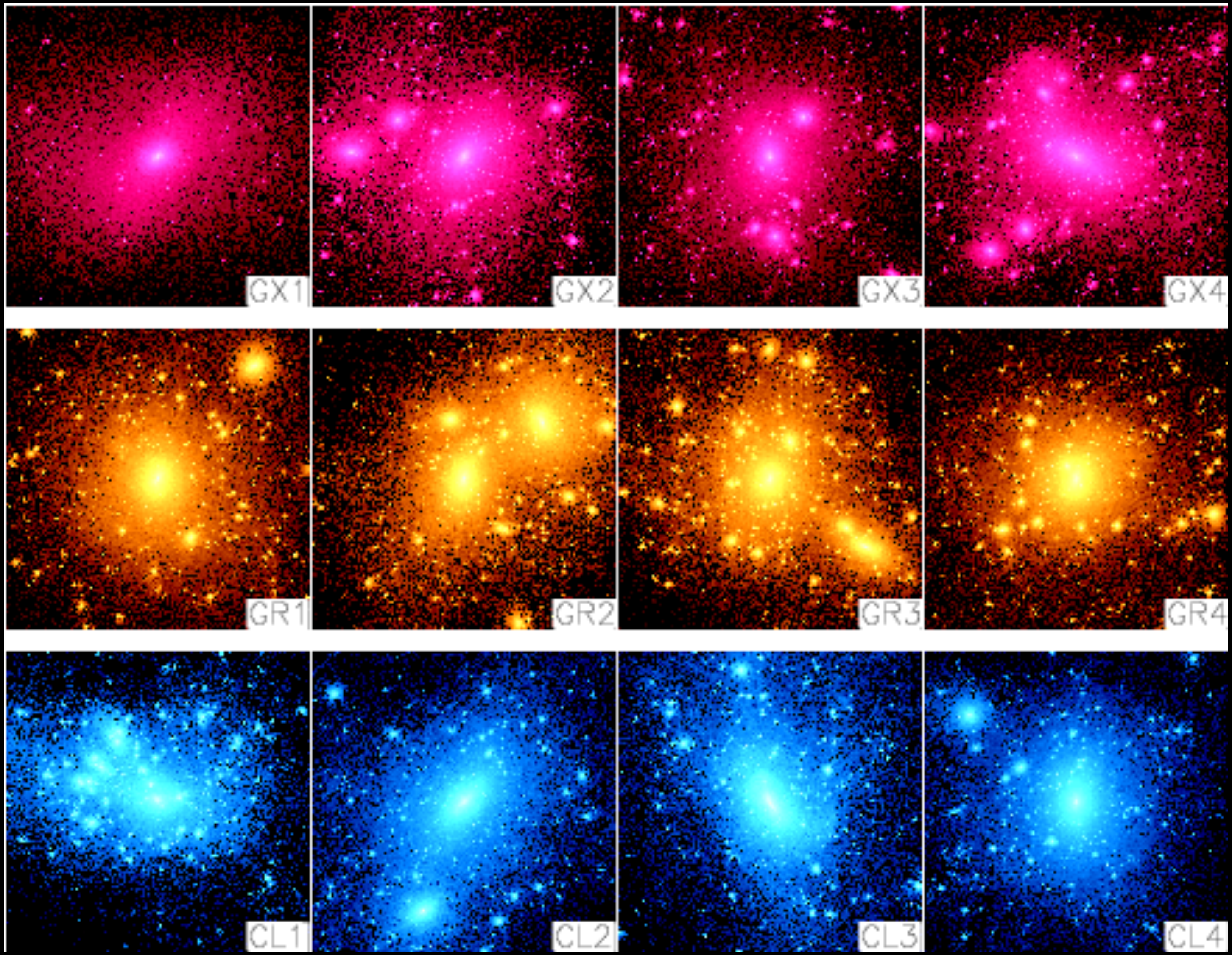
Navarro, Frenk & White (1997)

# Shapes of dark matter halos: highly non-spherical

**galaxies**
~ $5\times10^{12}M_{sun}$

**groups**
~ $5\times10^{13}M_{sun}$

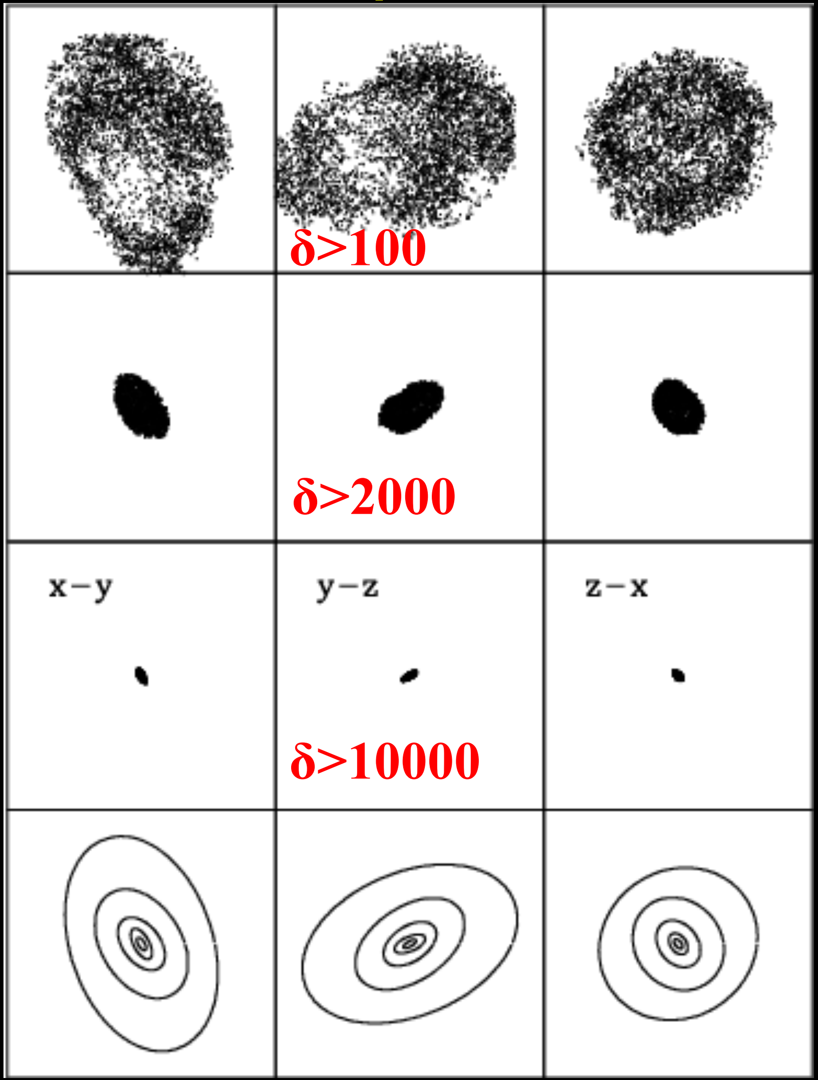
**clusters**
~ $3\times10^{14}M_{sun}$



N-body simulation by Jing & Suto (2000)

# Triaxial model of dark matter halos

Isodensity of a halo



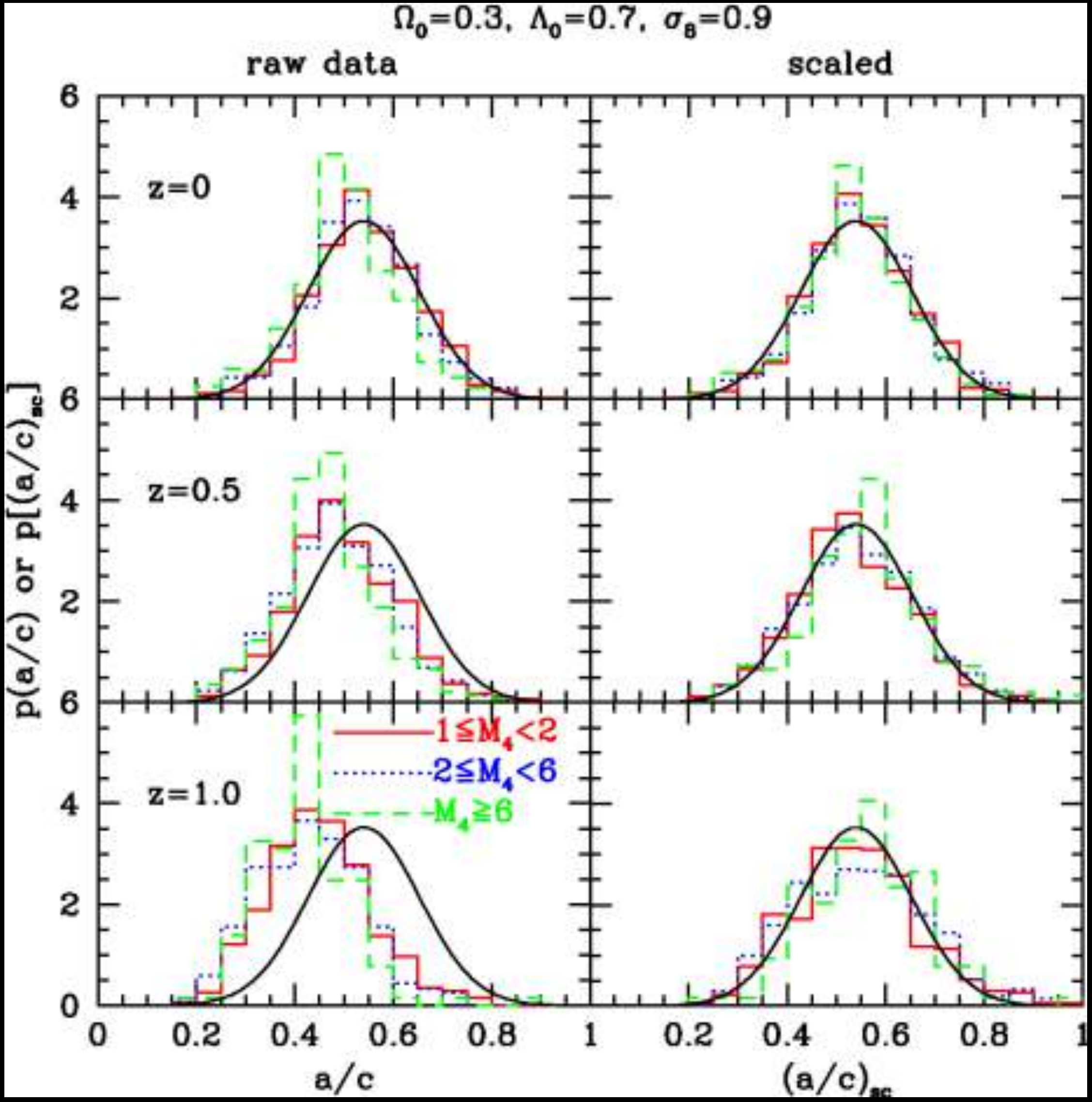
$$\rho(R) = \frac{\delta_c \rho_{crit}}{(R/R_s)^{\alpha}(1+R/R_s)^{3-\alpha}}$$

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

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**

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

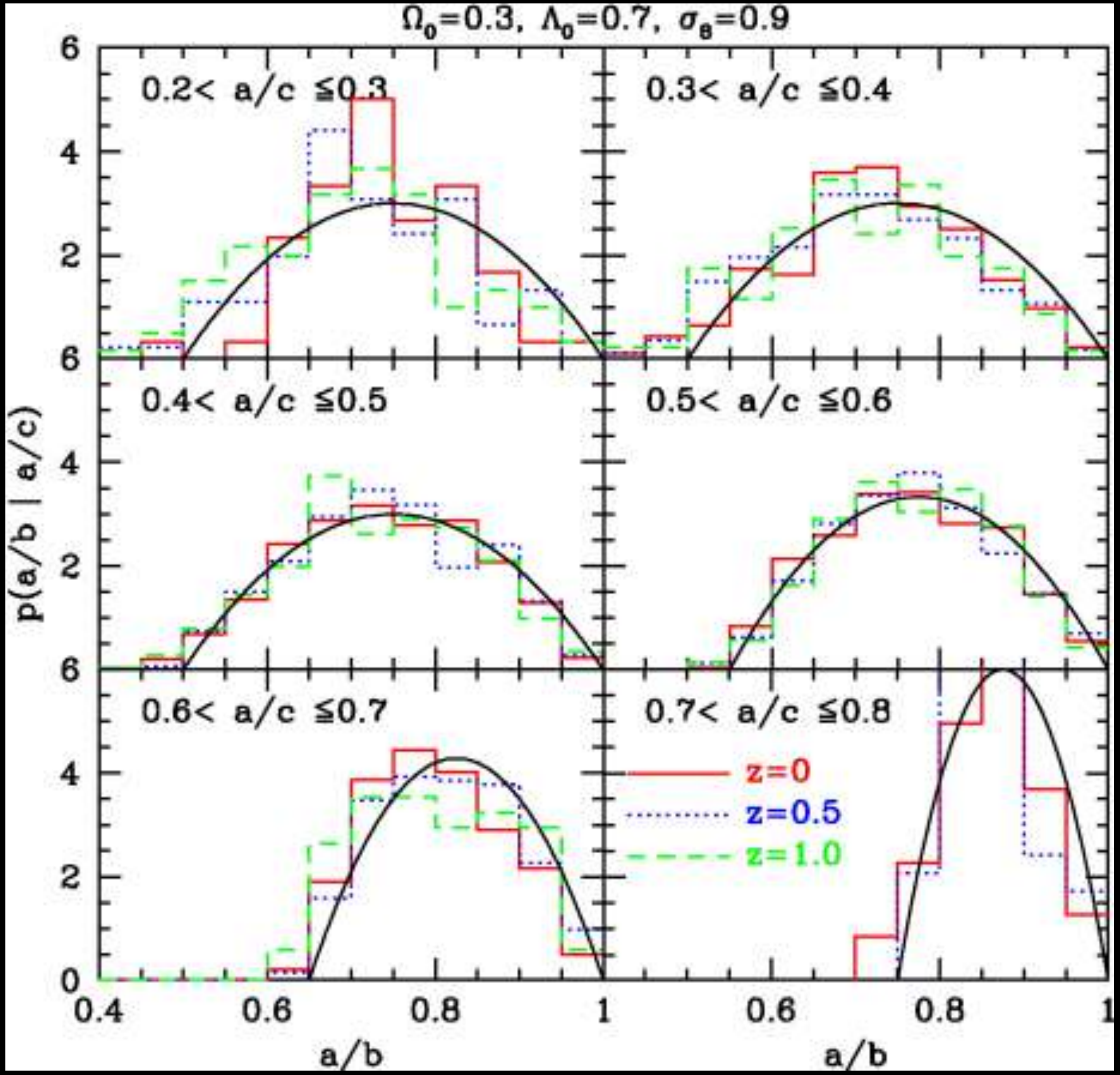
**PDF of the scaled axis ratio**

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

$$\sigma = 0.113$$

- 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**

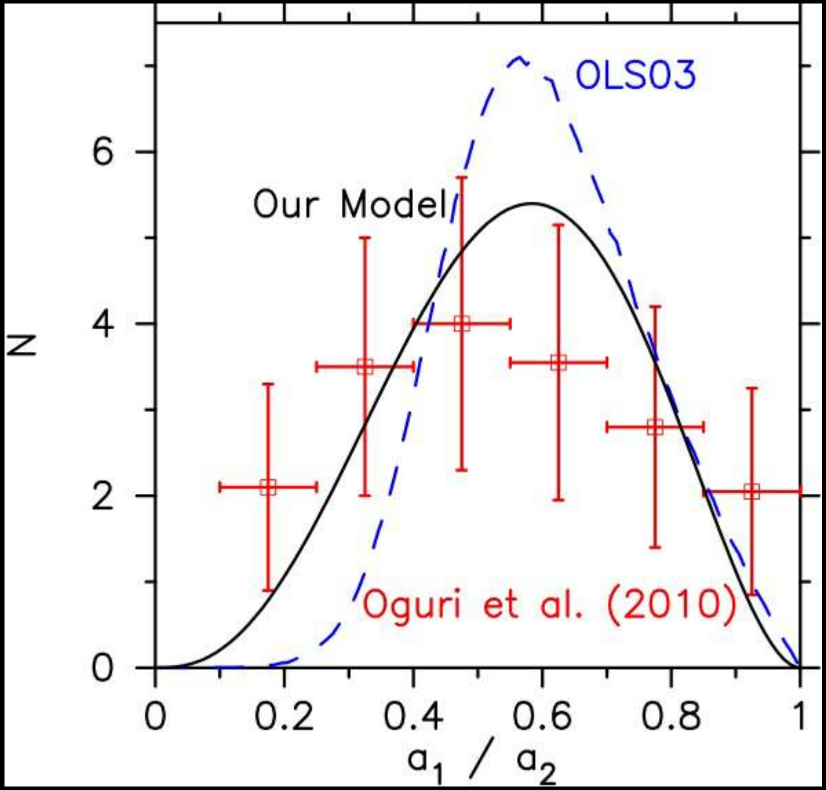
$$p\left(\frac{a}{b}\middle|\frac{a}{c}\right)=\frac{3}{2(1-r_{\min})}\left[1-\left(\frac{2a/b-1-r_{\min}}{1-r_{\min}}\right)^2\right]$$

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



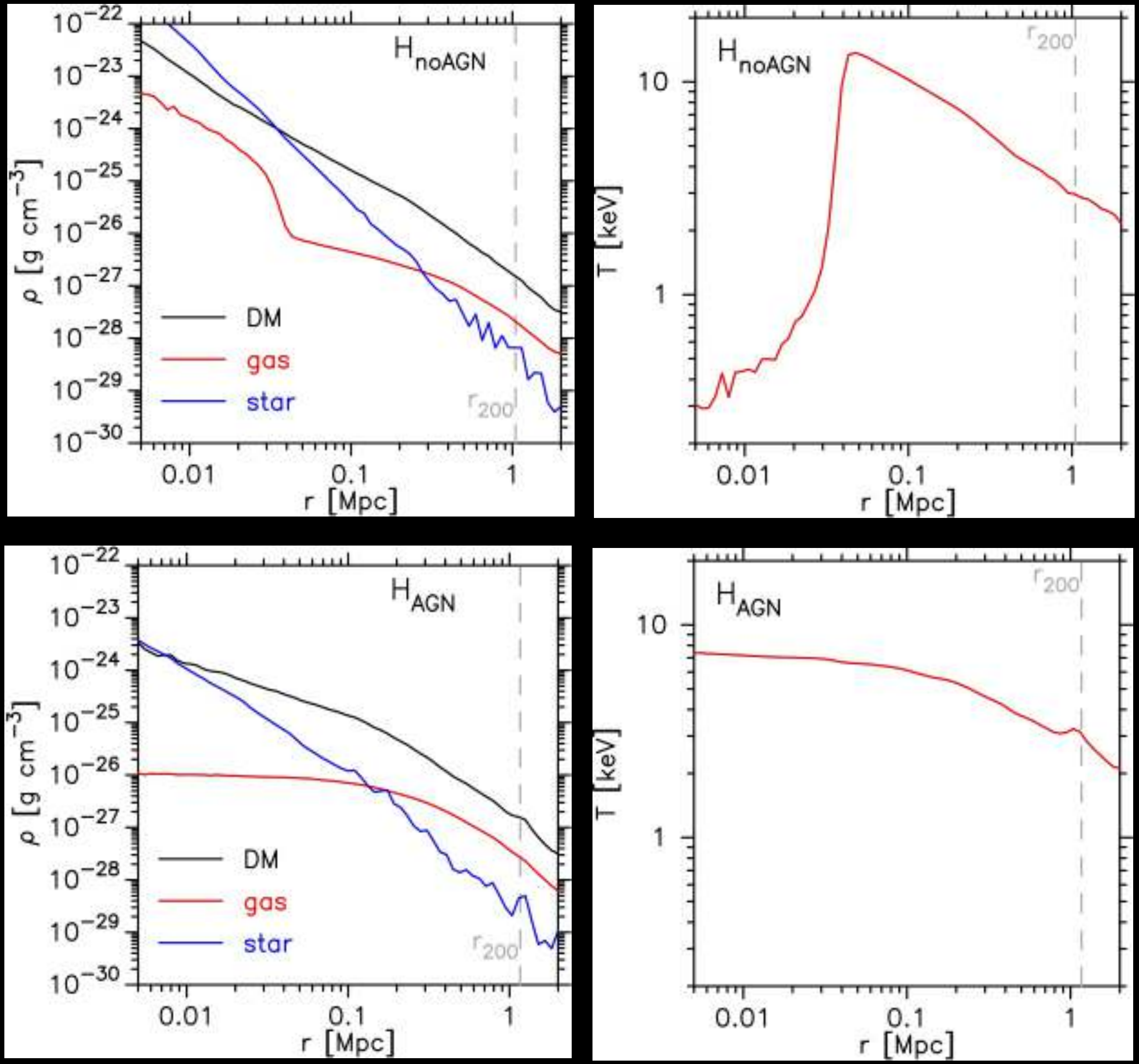
Suto et al. (2016)

- 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 $(100h^{-1}\mathrm{Mpc})^3$ ; 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

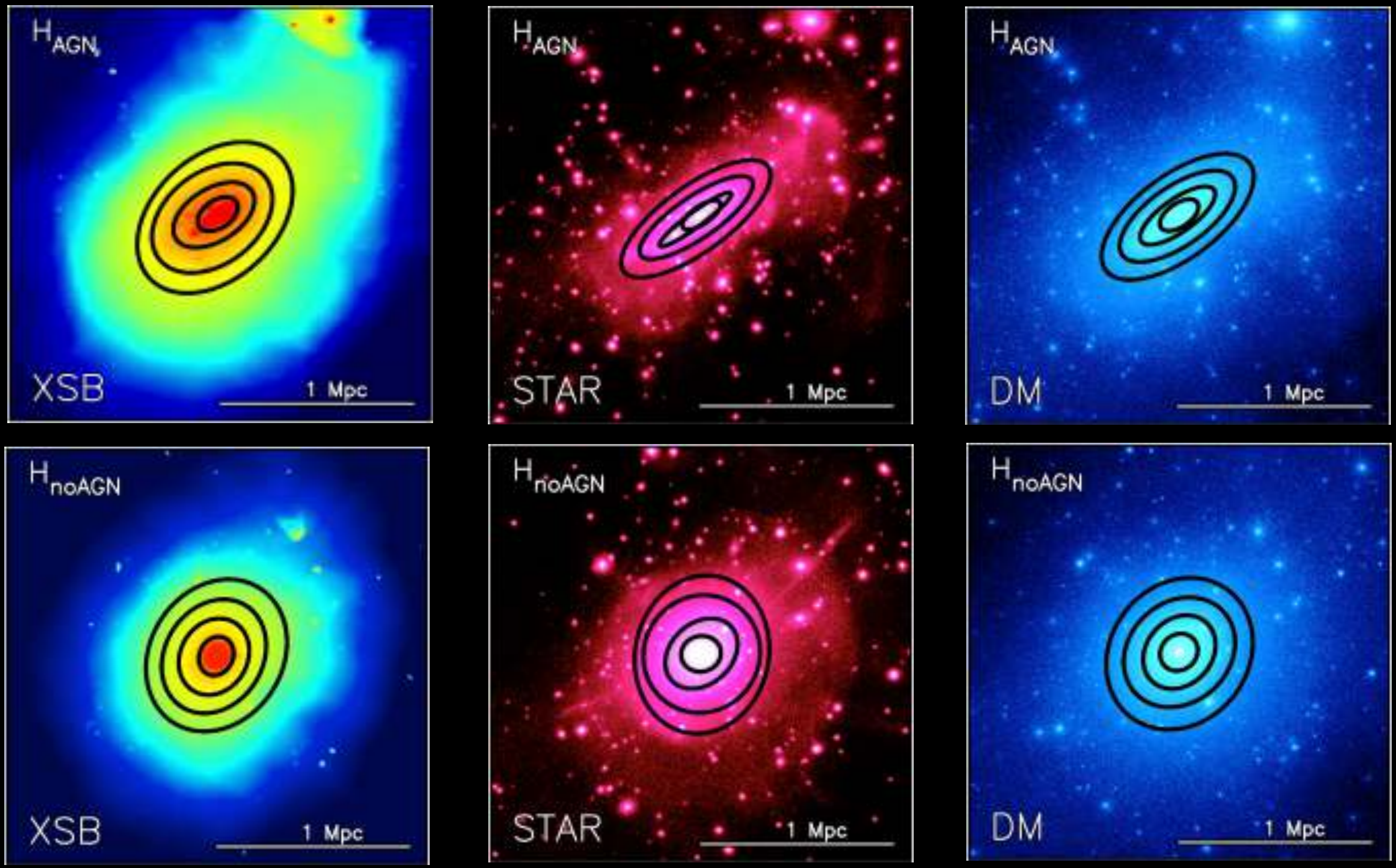


- Both gas cooling and star+AGN feedback need to be properly included in simulations so as to reproduce the (spherically-averaged) observed properties of galaxy clusters

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

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

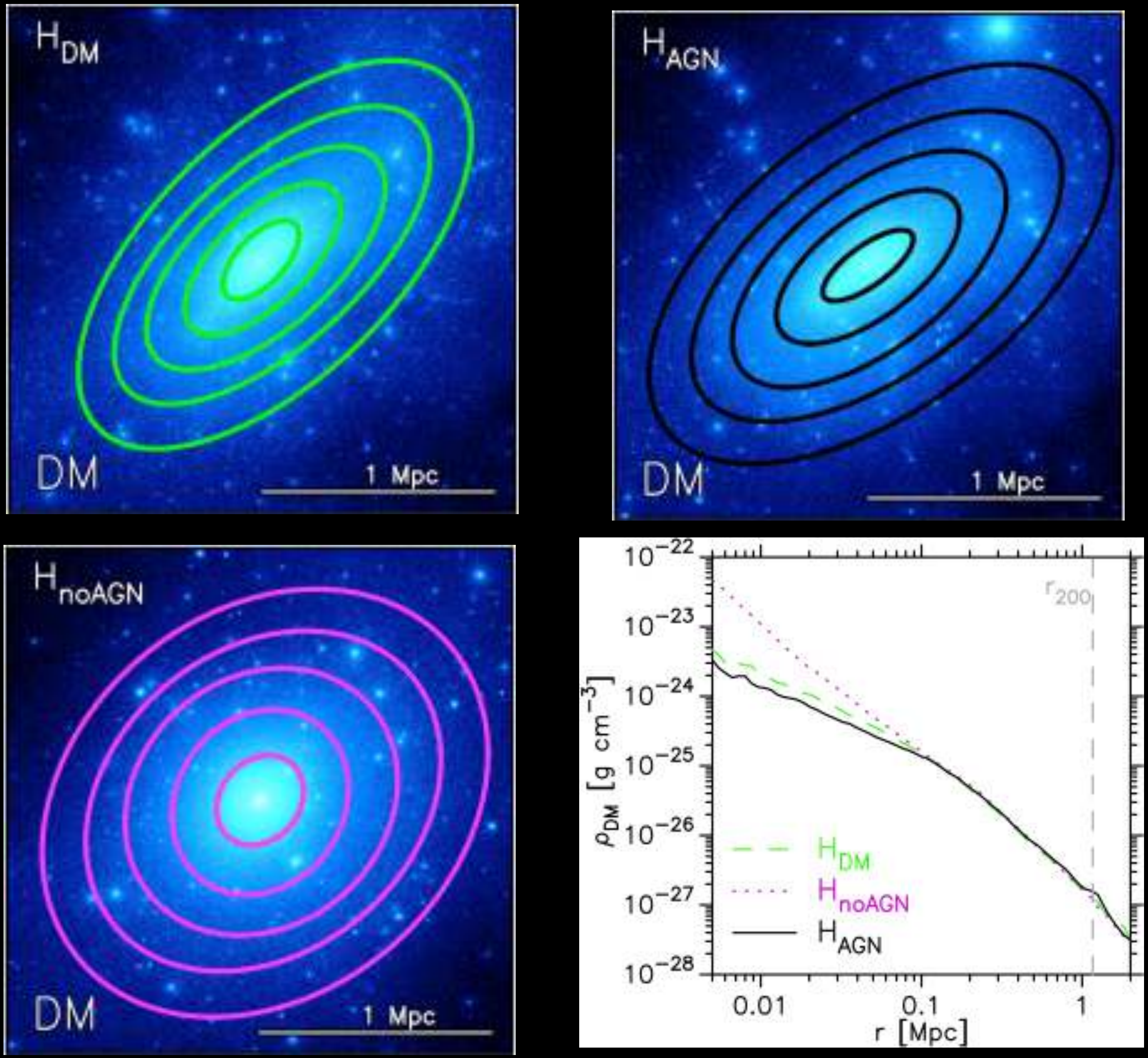
**with AGN feedback**



**without AGN feedback**

Suto et al. (2016)

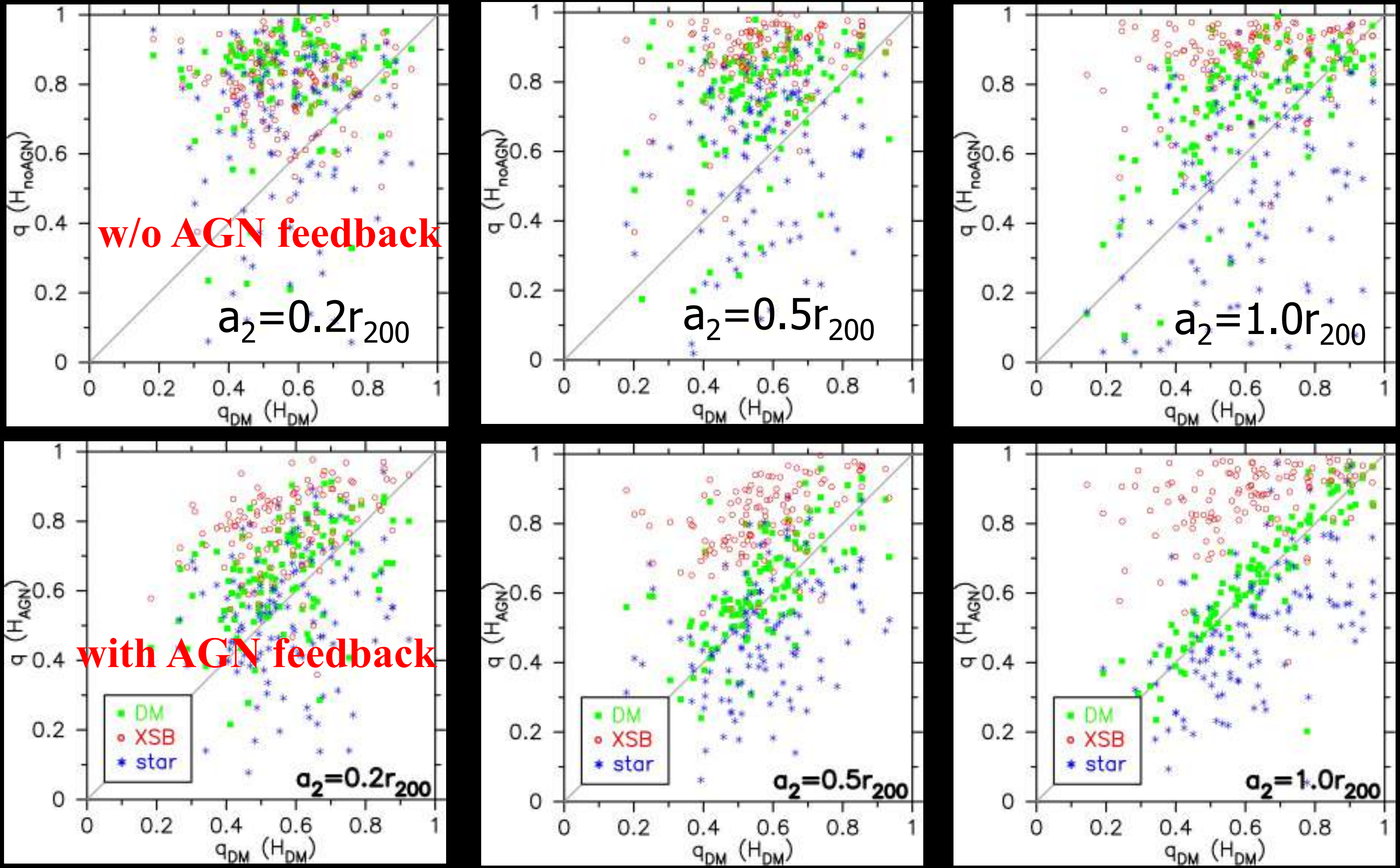
# Baryonic effect on the shape of ***dark matter*** distribution



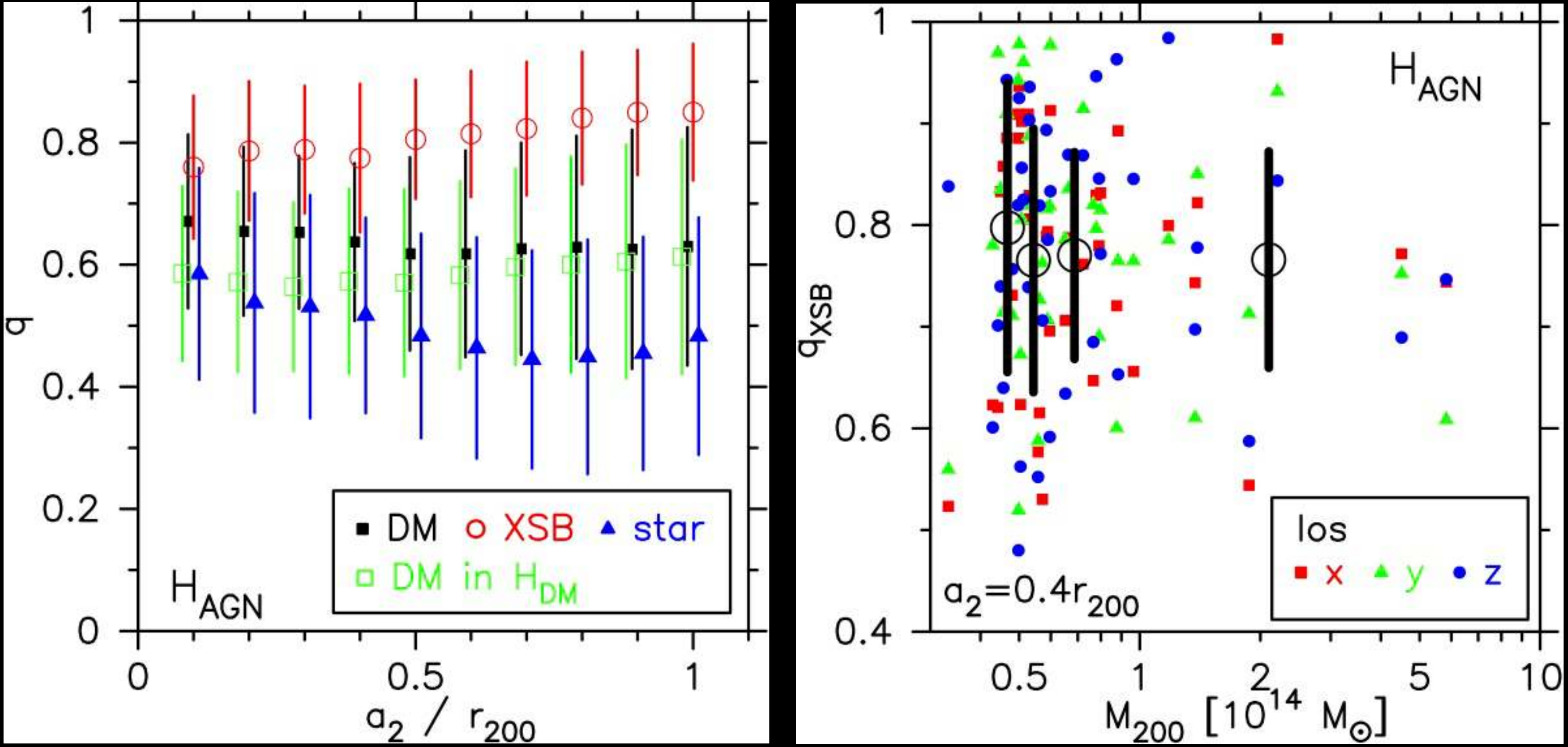
- spherical profiles unchanged for $r>0.1r_{vir}$
- significant impact on shapes even up to $0.5r_{vir}$ !

Suto et al. (2016)

# Axis ratios of 40 simulated clusters with/without baryon physics



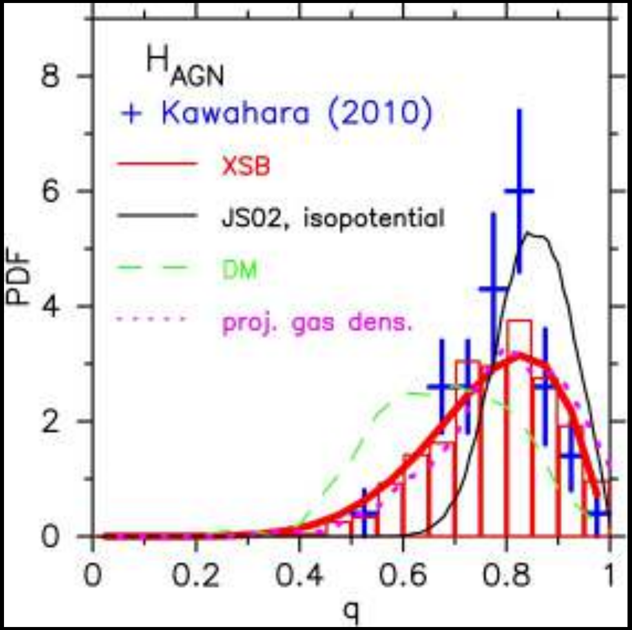
# Radial and mass dependence of axis ratio



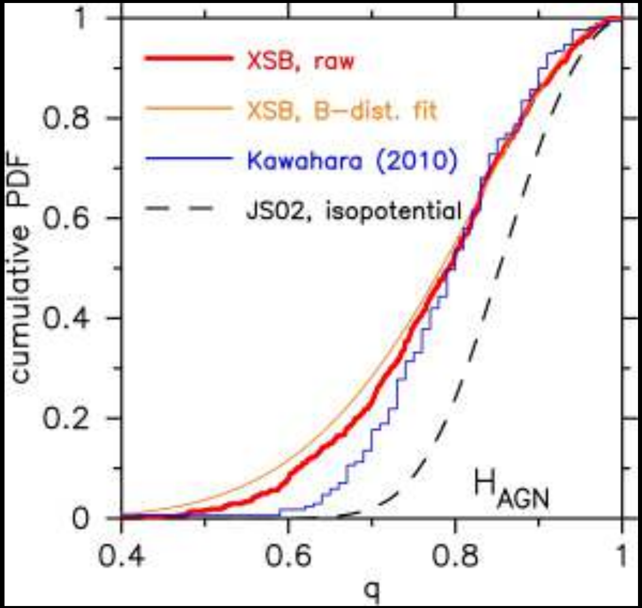
Suto et al. (2016)

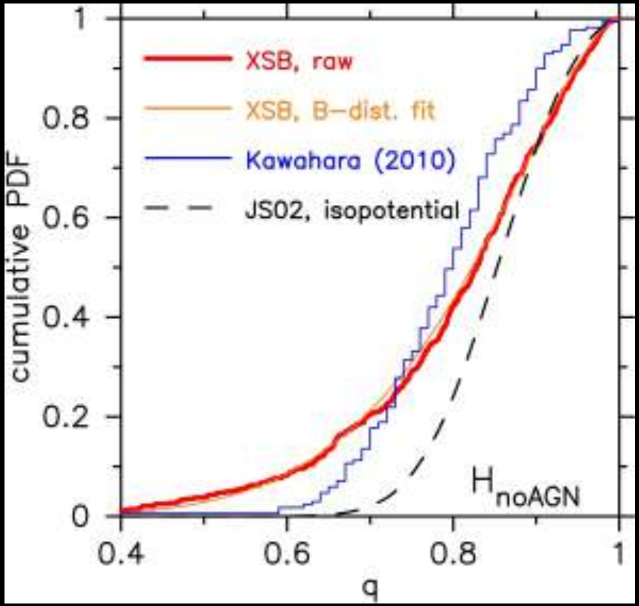
- $q_{XSB} > q_{DM} > q_{star}$
- no significant mass dependence of axis ratio

# 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