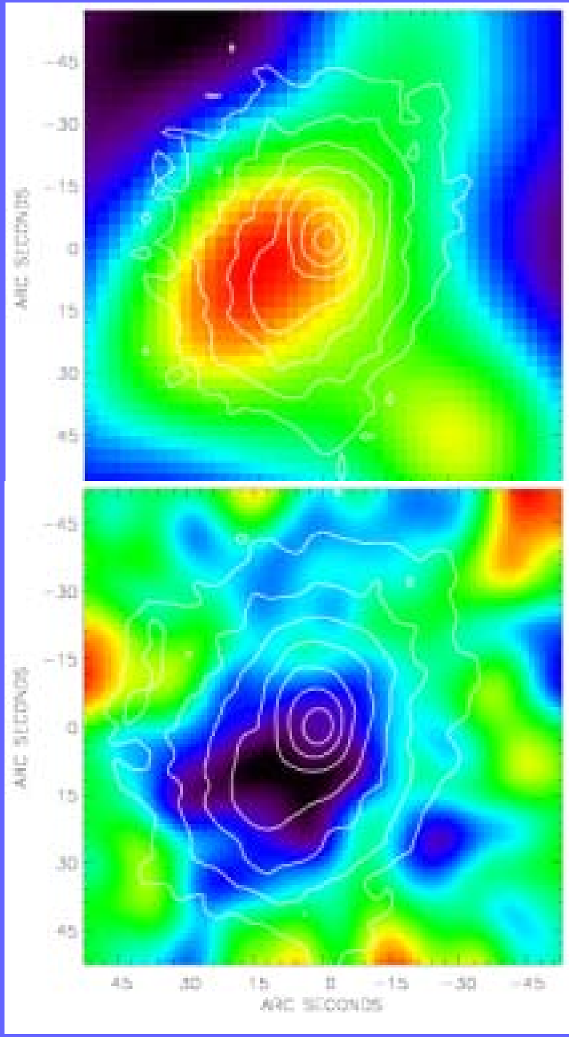
Reliability of galaxy clusters as cosmological probes

Department of Physics
University of Tokyo
Yasushi Suto

Japan-Germany workshop on galaxies and clusters of galaxies

October 31, 2002@ Laforet Shuzenji, Japan



SZ map of RX J1347-1145

Upper: submm (350GHz) with SCUBA at JCMT
Lower: mm (150GHz)with NOBA at Nobeyama
(Komatsu et al. 1999, 2001)

Precision cosmology with clusters

- Power spectrum from cluster distribution (c.f., talk by Schuecker)
- $\sigma_8 - \Omega_0$ relation from cluster abundance
- consistent with CMB, SN and galaxy surveys (c.f., talk by Boehringer).
- Certainly useful and complementary, but can it be precise enough to be competitive with the other probes, especially in the next generation ?
- Or, have we understood what are the clusters ?

What is ***the*** definition of galaxy clusters ?

Abell (optical) clusters

the Abell radius

$m_3 < m < m_3 + 2$

richness class

Press-Schechter halos

spherical collapse

$\Delta_{vir} = 18\pi^2$

SZ clusters

ΔI_{SZ}

$\propto n_e T_e$

Halos in N-body simulations

friend-of-friend

linking length = 0.2

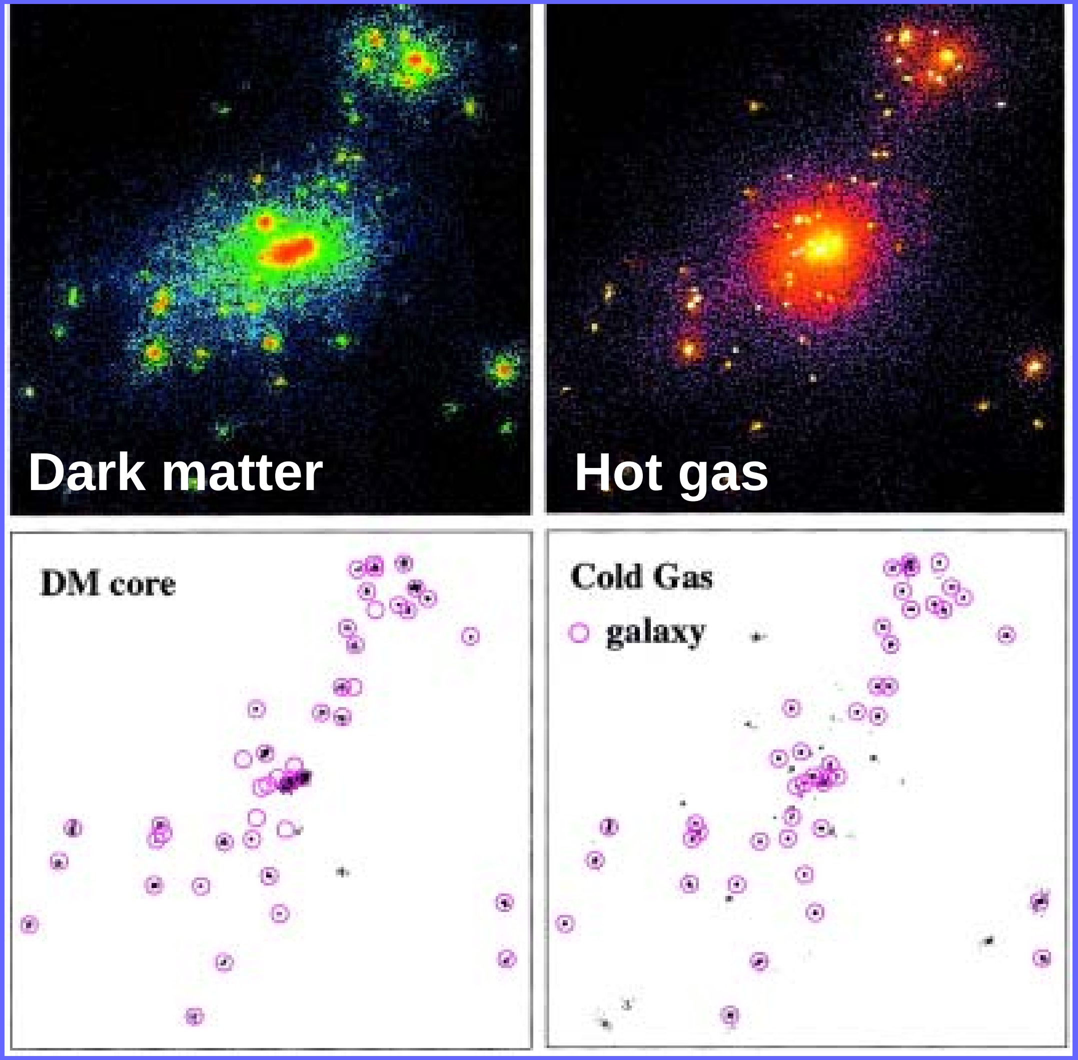
X-ray clusters

$S_x \propto n_e^2 T_e^{1/2}$

- Definitely they are closely related, but the exact one-to-one correspondence is unlikely....

Relation between dark halos and clusters

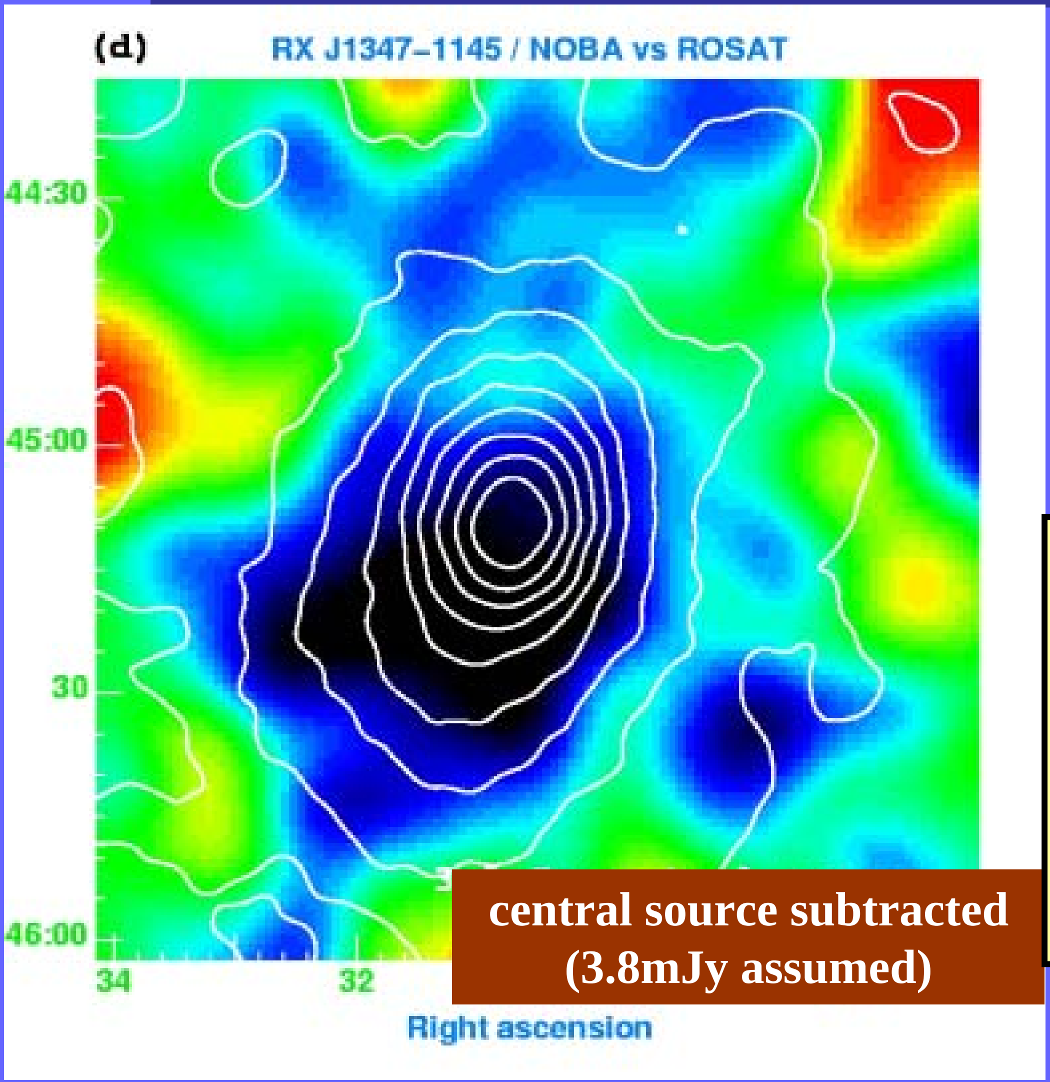
A cluster-size halo ($8x10^{14}M_{sun}$ at z=0)



- Globally similar distribution, but their precise relation is unclear because definitions of clusters (especially at high z) are very ambiguous.

SPH simulations in LCDM: $N=128^3$ boxsize: 75 h^{-1}Mpc (Yoshikawa, Taruya, Jing & Suto 2001)

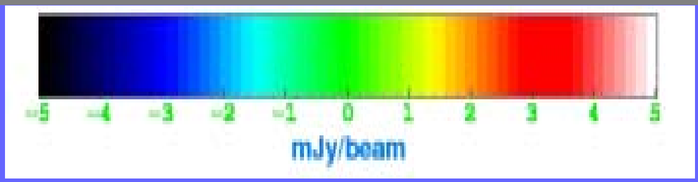
An example; substructure of RXJ1347-1145 (z=0.45) detected via SZ map at 150 GHz



central source subtracted (3.8mJy assumed)

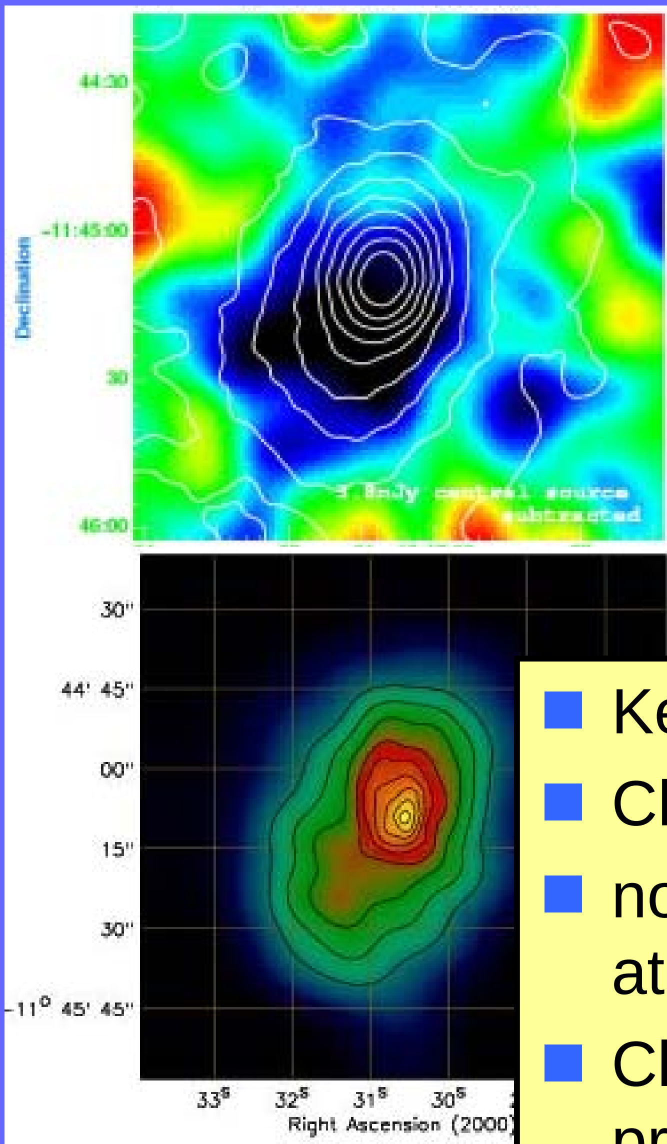
150GHz with NOBA (Nobeyama Bolometer Array) at Nobeyama 45m telescope in March, April, 1999 and February 2000 σ_{FWHM}=13”

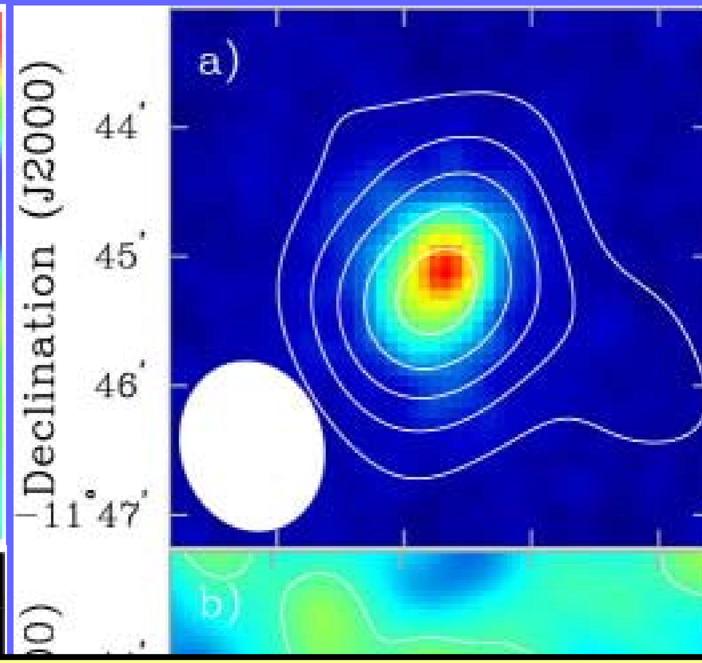
- Globally similar morphology to the X-ray image
- Substructure in the South-East direction



Komatsu et al. PASJ 53(2001)57

Confirmed by Chandra and BIMA observations





RXJ1347-1145

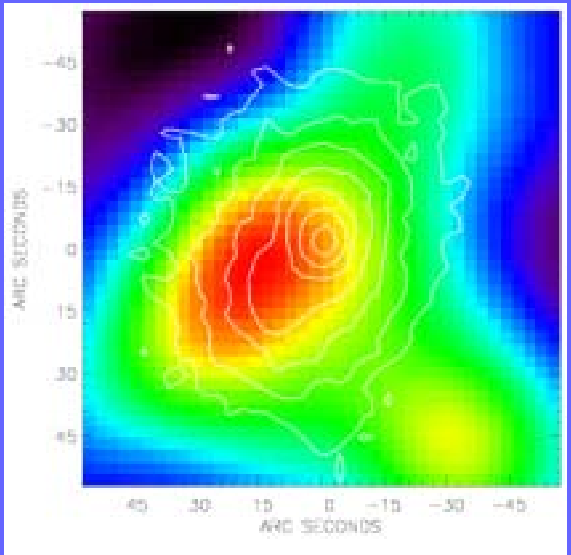
BIMA@30GHz
63"x80" beam
(10.3mJy point source removed)

Carlstrom et al. (2001)

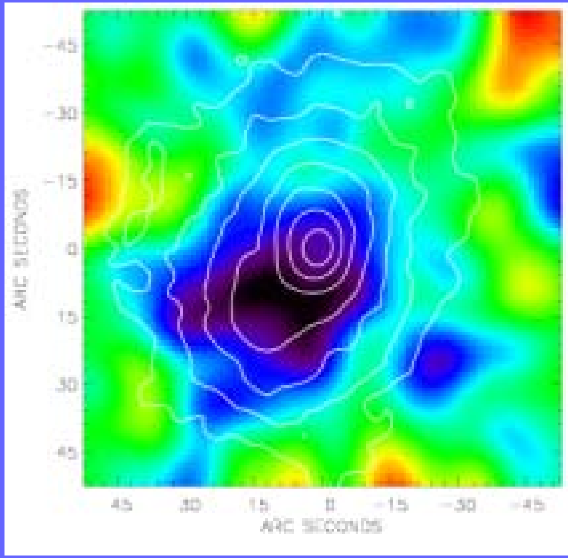
- Keck spectroscopy: Cohen & Kneib (2002)
- Chandra: Allen, Schmidt & Fabian (2002)
- non-spherical modeling is crucial, perhaps at high z in particular.
- Clusters are not so simple as we have pretended to believe (c.f., talk by Briel)

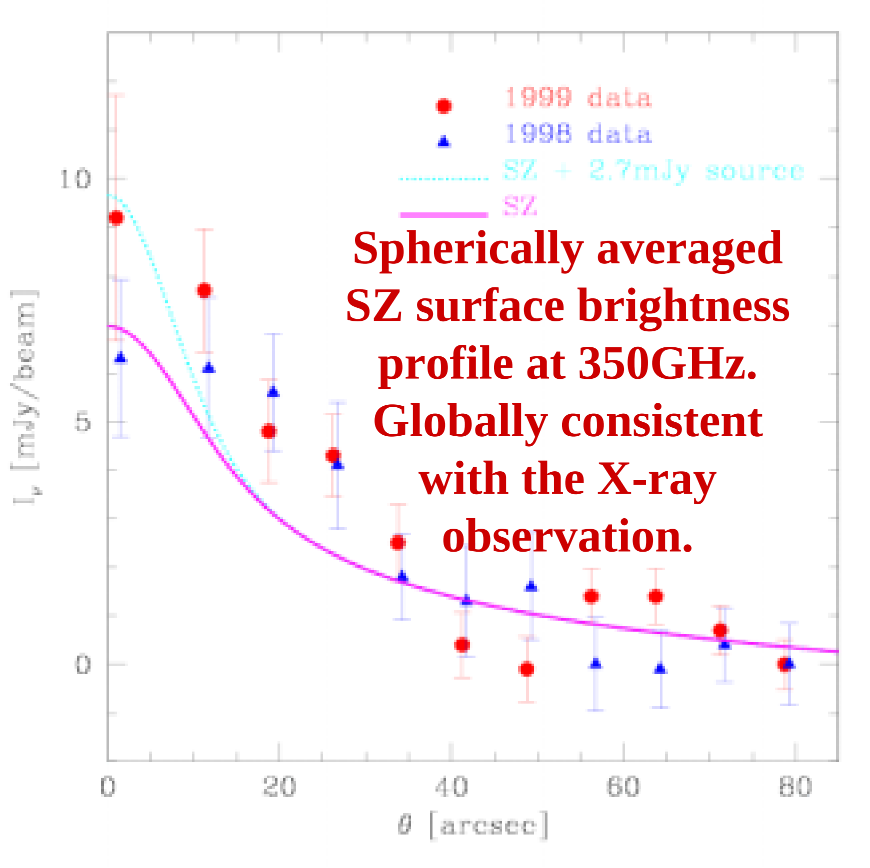
Submm map (350GHz) of RX J1347-1145

The first SZ map of a cluster in the submm band with SCUBA, JCMT. （contours: Chandra X-ray map)



The highest angular resolution SZ map of a cluster in the mm band with NOBA, Nobeyama

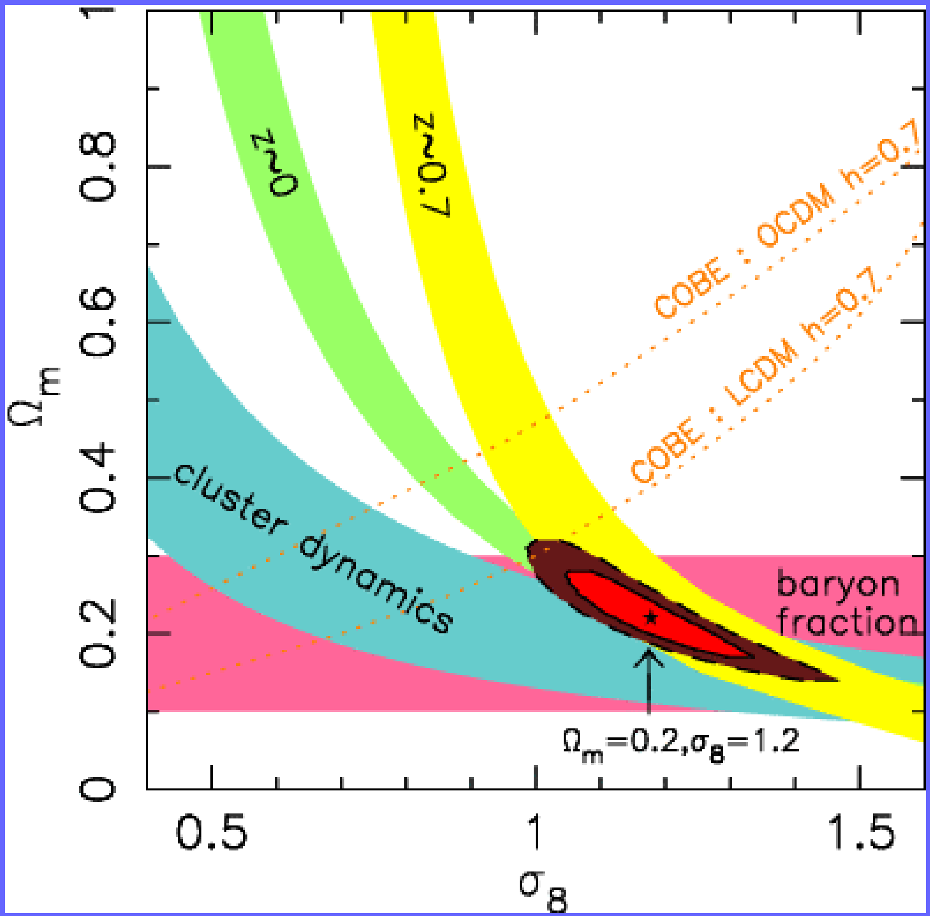


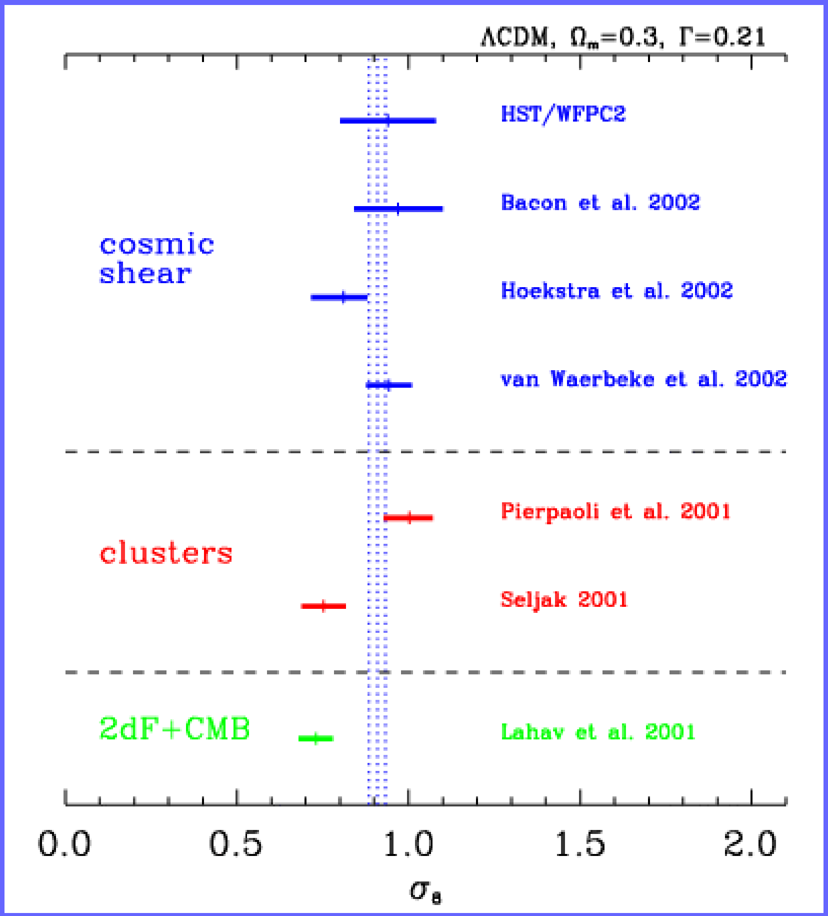


Spherically averaged SZ surface brightness profile at 350GHz. Globally consistent with the X-ray observation.

Komatsu et al.
ApJ 516(1998)L1
PASJ 53(2001)57

σ_8 from cluster abundances and lensing

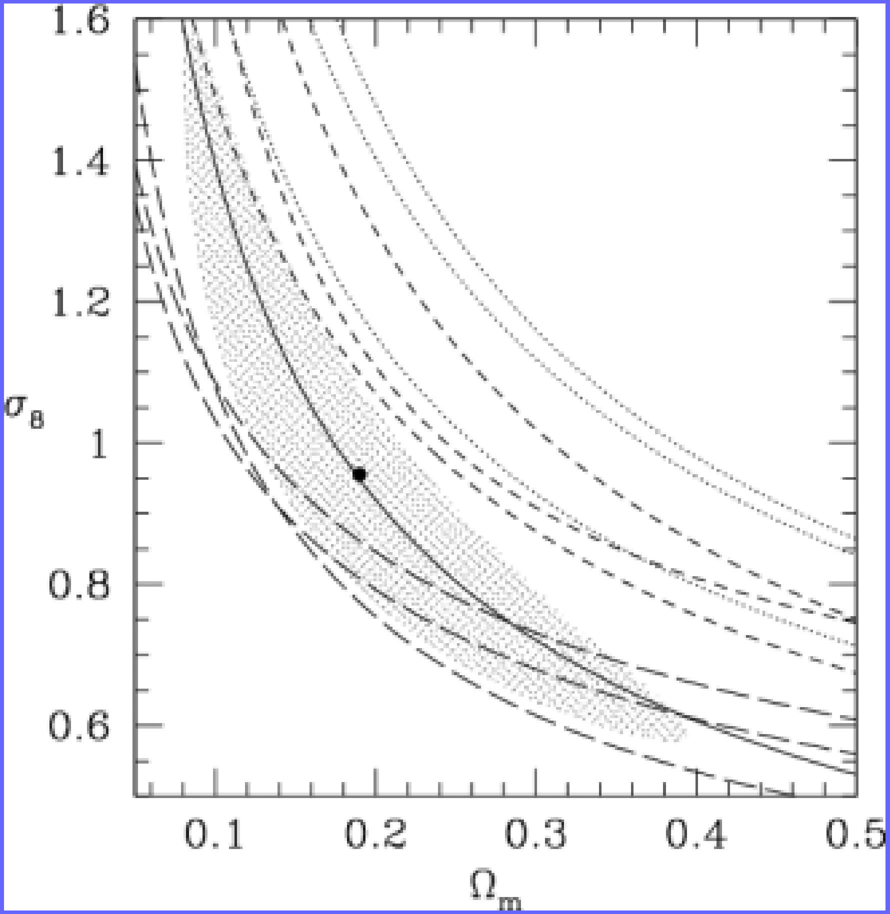




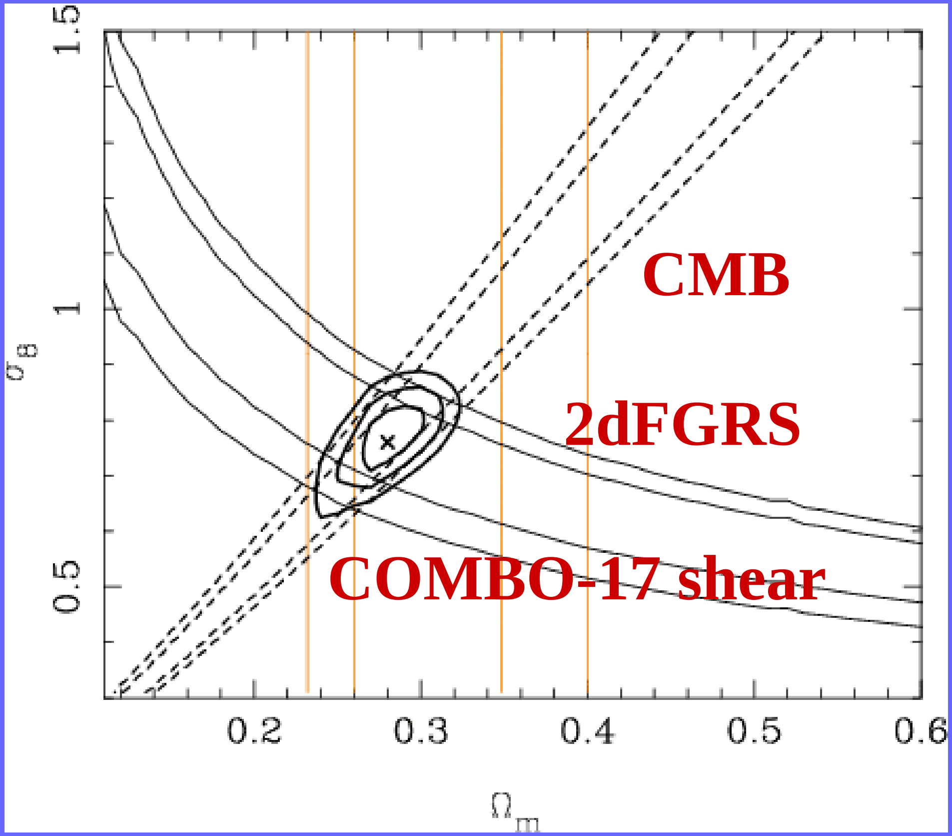
N.Bahcall:
Physica Scripta T85(2000)32

Refregier et al.
ApJ 572(2002)131

More recent estimate of σ_8

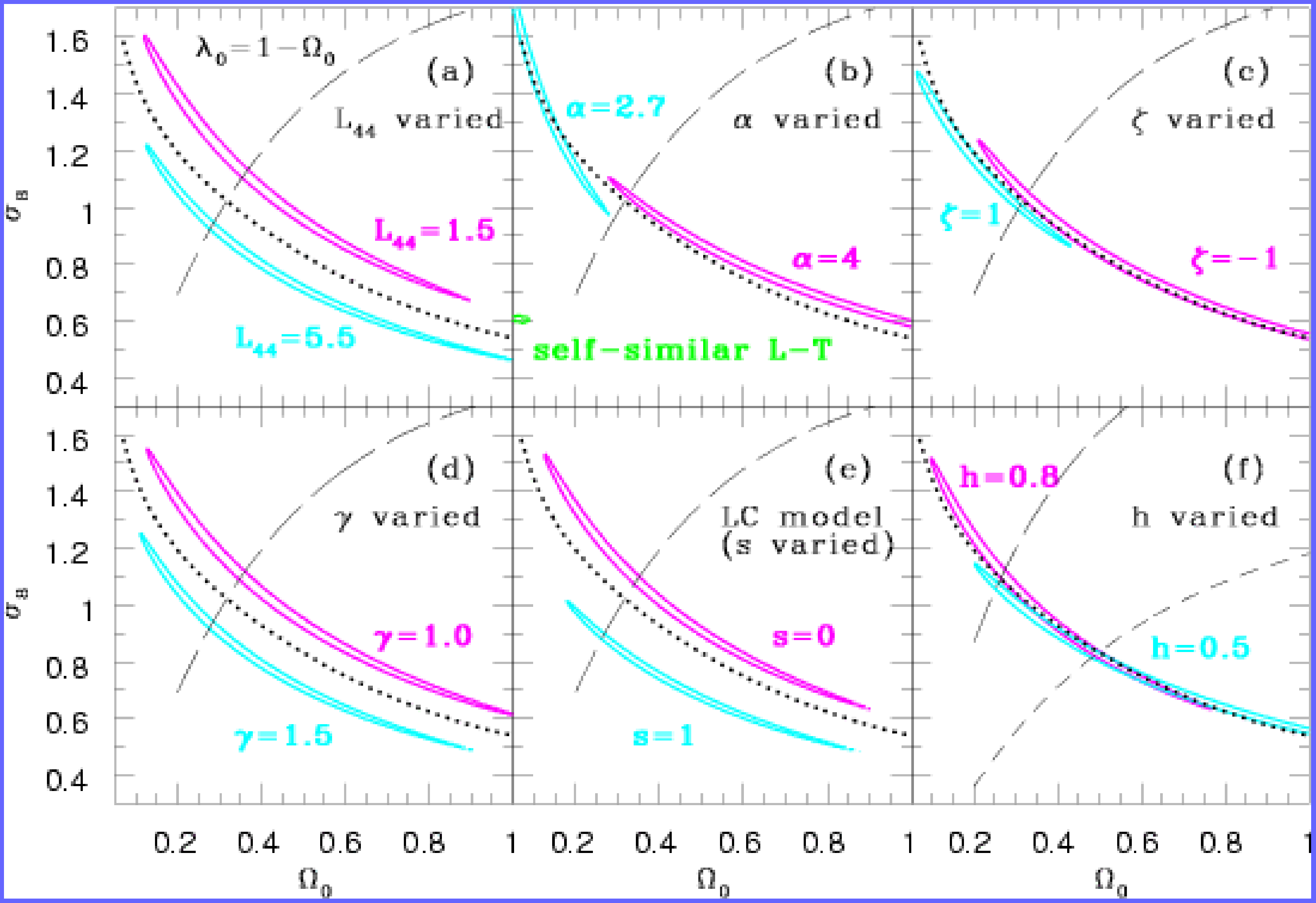


Bahcall et al.(SDSS)
astro-ph/0205490



Brown et al.
astro-ph/0210213
COMBO-17 survey

Systematic uncertainties



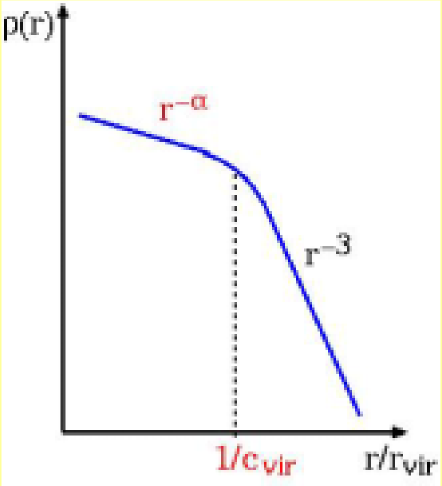
Kitayama & Suto ApJ 490(1997)557

Theoretical modeling of X-ray clusters

- ***Halo density profile***

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

$$c_{vir}(M) \equiv \frac{r_{vir}(M)}{r_s(M)} = \frac{9}{1+z}\left(\frac{M}{2\times10^{13} h_{70}^{-1} M_{Sun}}\right)^{-0.13}$$



- ***Hydrostatic equilibrium gas distribution***

$$\rho_{gas}(r) = \rho_{gas,0} \exp\left[\frac{2c_{vir}}{m(c_{vir})}\frac{T_{vir}}{T_{gas}} f(x)\right]$$

$$f(x) = 1 - \frac{\ln(1+x)}{x} \quad (\alpha = 1)$$

$$= 2\sqrt{\frac{1+x}{x}} - \frac{2}{x}\ln(\sqrt{x}+\sqrt{1+x}) \quad (\alpha = 3/2) \quad \Rightarrow \quad \text{analytic!}$$

Shimizu, Kitayama, Sasaki & Suto (2003)

Mass – temperature relation to X-ray luminosity

- Convert the observed MT relation (M_{500} and M_{2500} to M_{vir} in our adopted dark matter halo profile) :

  • **Finoguenov et al. (2001)**

$$T_{gas} = (1.92 \pm 0.06)\mathrm{keV}\left(\frac{\mathrm{M_{vir}}}{10^{14} h_{70}^{-1} M_{Sun}}\right)^{0.54\pm0.02} \qquad (\alpha = 1)$$

  • **Allen et al. (2001)**

$$T_{gas} = (1.53 \pm 0.56)\mathrm{keV}\left(\frac{\mathrm{M_{vir}}}{10^{14} h_{70}^{-1} M_{Sun}}\right)^{0.57\pm0.12} \qquad (\alpha = 1)$$

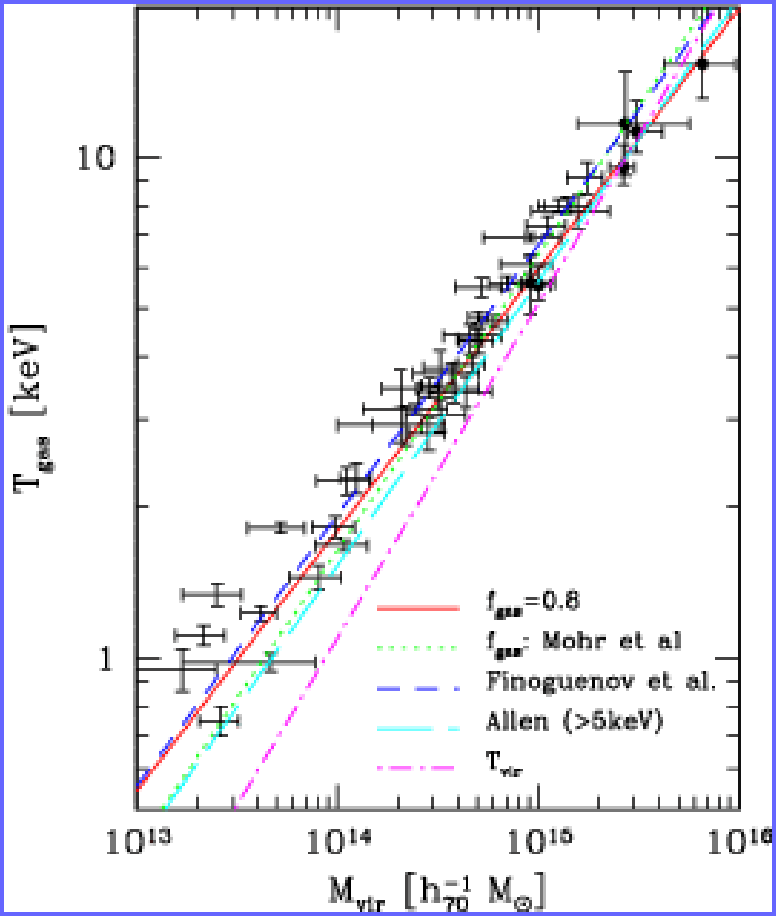
- Gas mass fraction (Mohr et al. 1999)

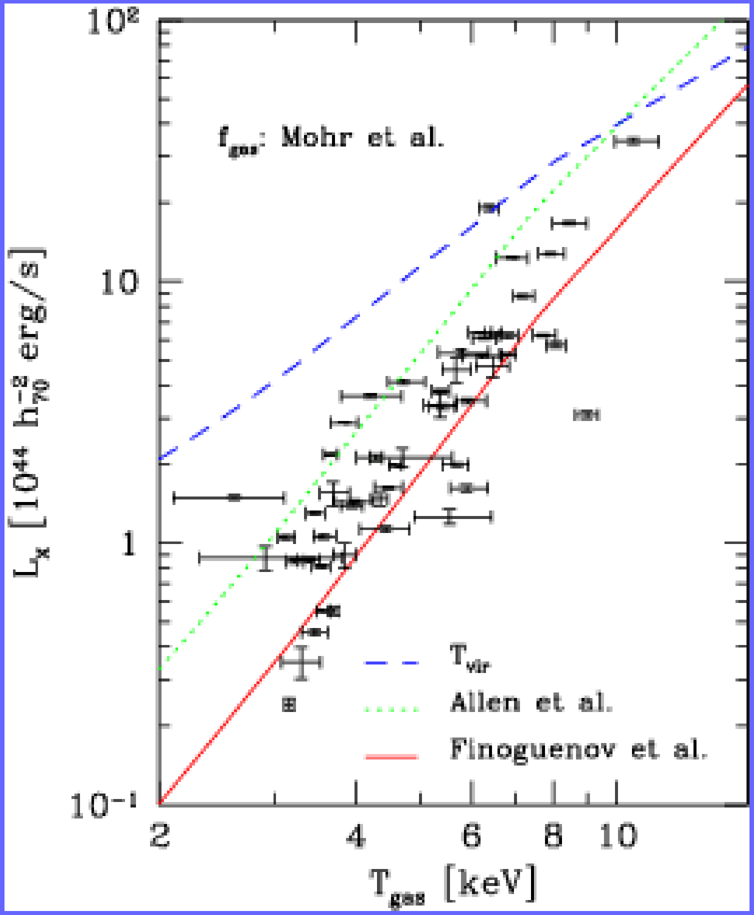
$$f_{gas} = \min\left[0.92 h_{70}^{-3/2}\left(\frac{T_{gas}}{6\mathrm{keV}}\right)^{0.34}, 1\right]$$

- Compute the X-ray luminosity

$$L_X = 4\pi \int_0^{r_{vir}} \Lambda(T_{gas}, Z)\left(\frac{\rho_{gas}(r)}{\mu\, m_{proton}}\right)^2 r^2 dr$$

From the observed mass-temperature relation to the luminosity-temperature relation

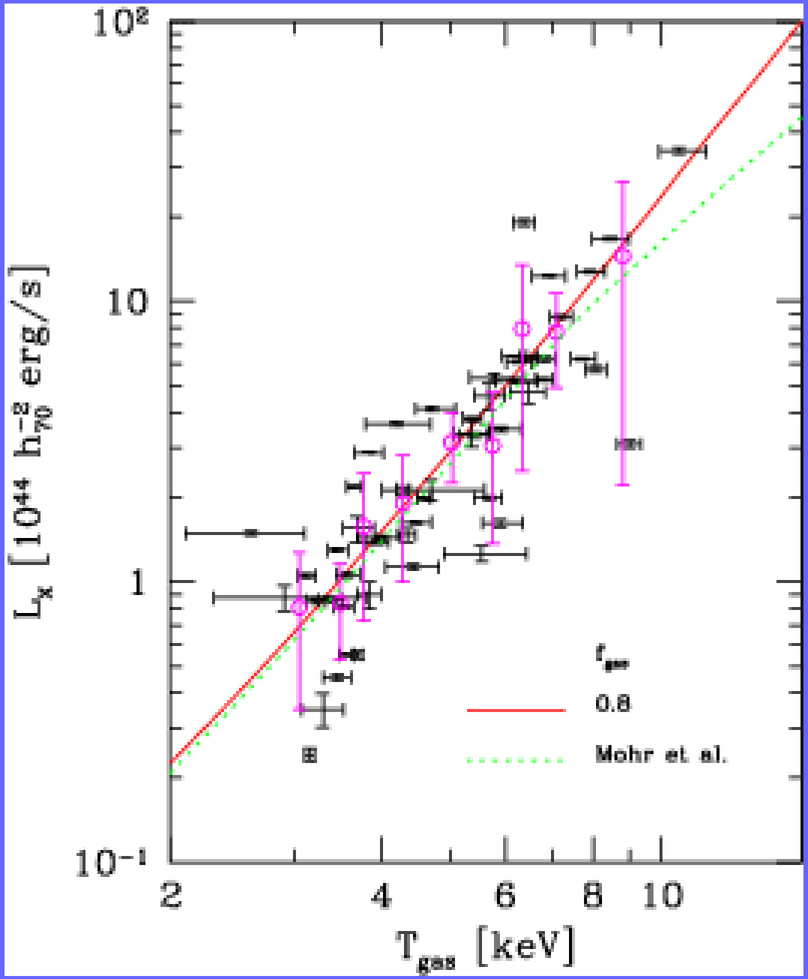


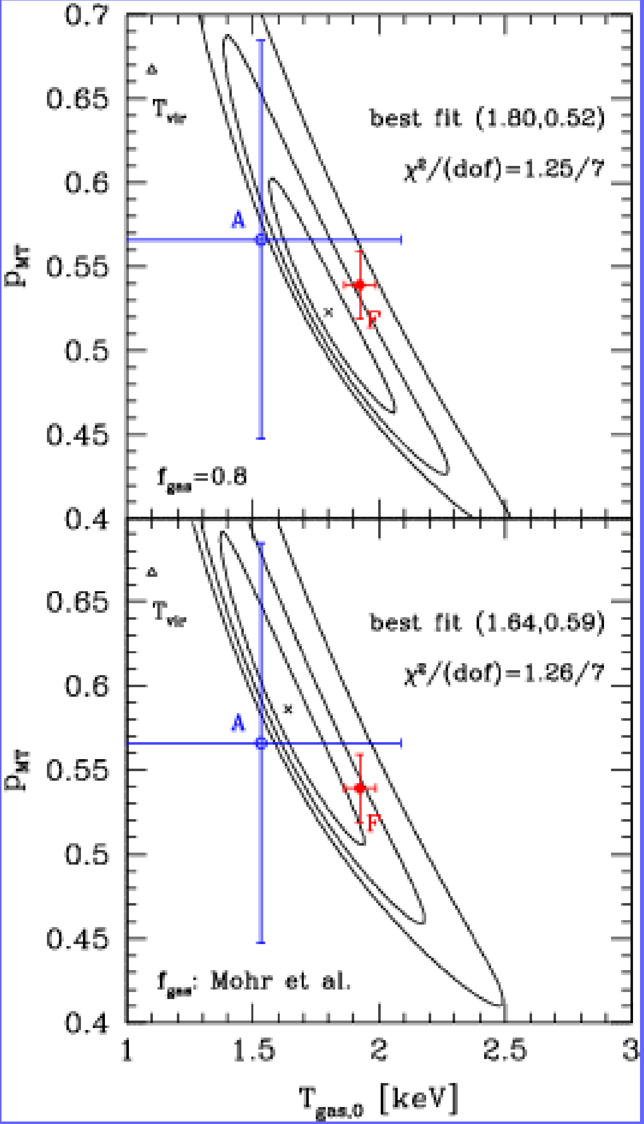


- L-T relation is sensitive to M-T relation

Limits on a parameterized M-T relation from the observed L-T relation

$$T_{gas} = T_{gas,0}\left(\frac{M_{vir}}{10^{14}h_{70}^{-1}M_{Sun}}\right)^{p_{MT}}$$





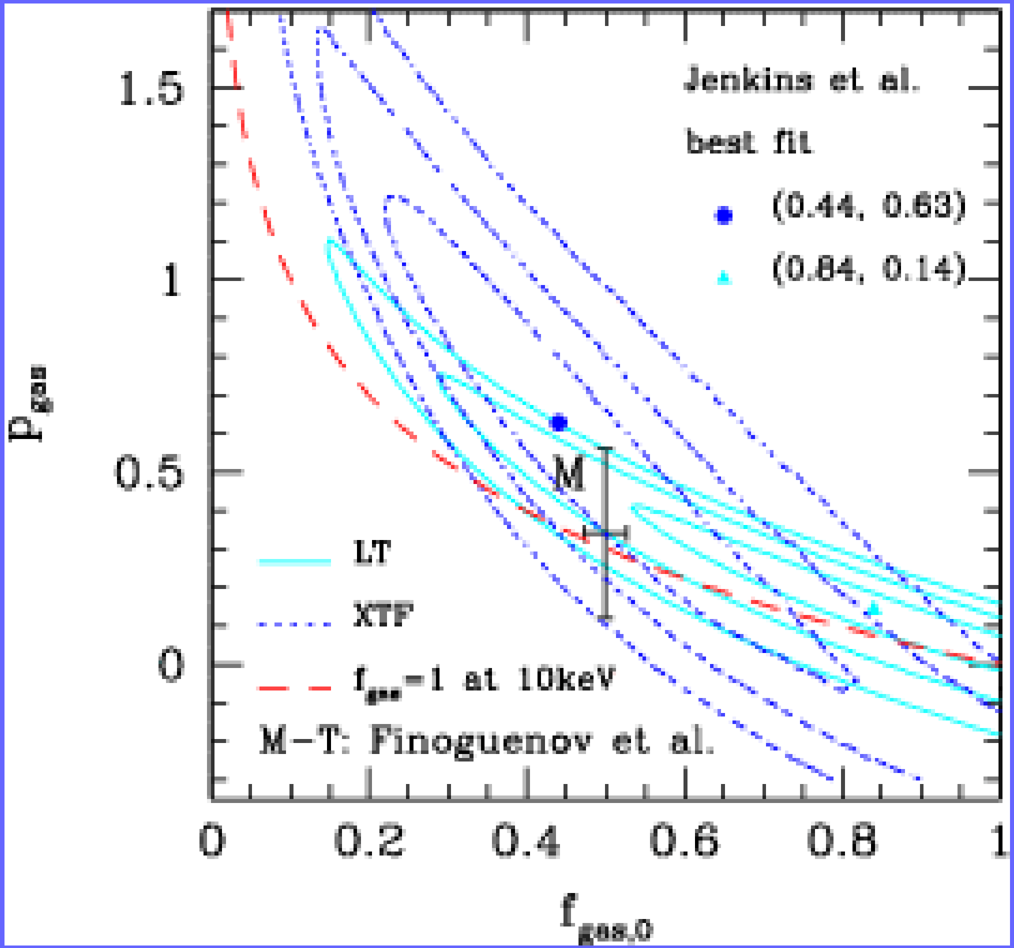
Limit on gas mass fraction from the observed L-T relation

$$f_{gas}(T_{gas}) = f_{gas,0}\left(\frac{T_{gas}}{1\,\mathrm{keV}}\right)^{p_{gas}}$$

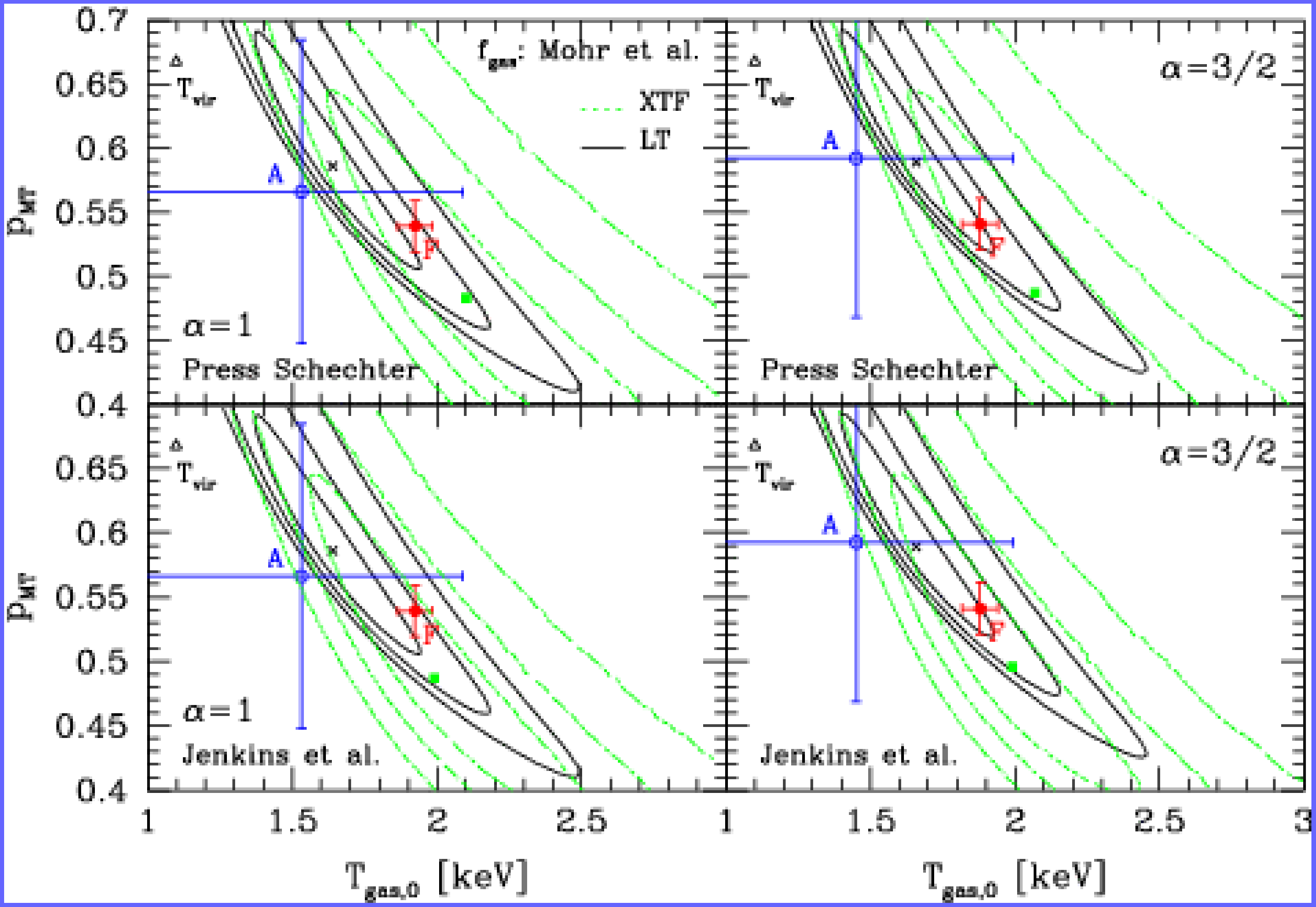
c.f., Mohr et al. (1999)

$$f_{gas} = 0.92 h_{70}^{-3/2}\left(\frac{T_{gas}}{6\,\mathrm{keV}}\right)^{0.34}$$

Shimizu, Kitayama, Sasaki & Suto (2003)

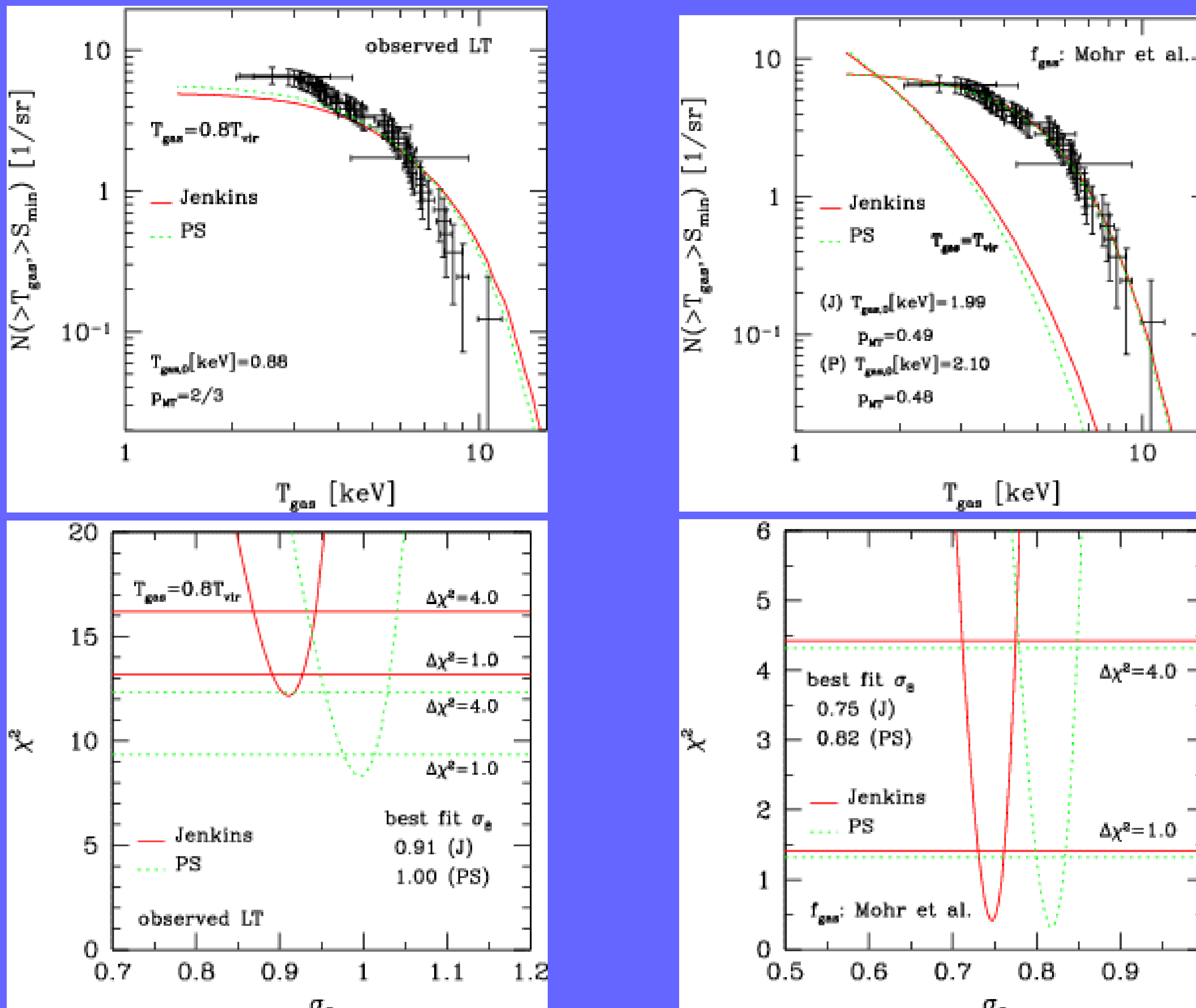


Limits on a parameterized M-T relation from the observed L-T relation and XTF



Shimizu, Kitayama, Sasaki & Suto (2003)

σ_8 from the observed Xray temperature function



Conclusions

- One can perform statistical analysis of X-ray clusters, ***provided a good physical model for halo-cluster connection*** ***beyond the unrealistic one-to-one correspondence .***
- ***From dark halos to visible objects:***
  - halo mass -- cluster gas temperature relation
  - non-gravitational effects inside dark halos (cooling, star/galaxy formation, preheating, supernova feedback, etc.)
- ***The goal of the next generation cluster surveys is not precision cosmology***, ***but is to understand ``what are the clusters of galaxies''***.