Systematic Errors in the Hubble Constant Measurement from the Sunyaev-Zel'dovich effect

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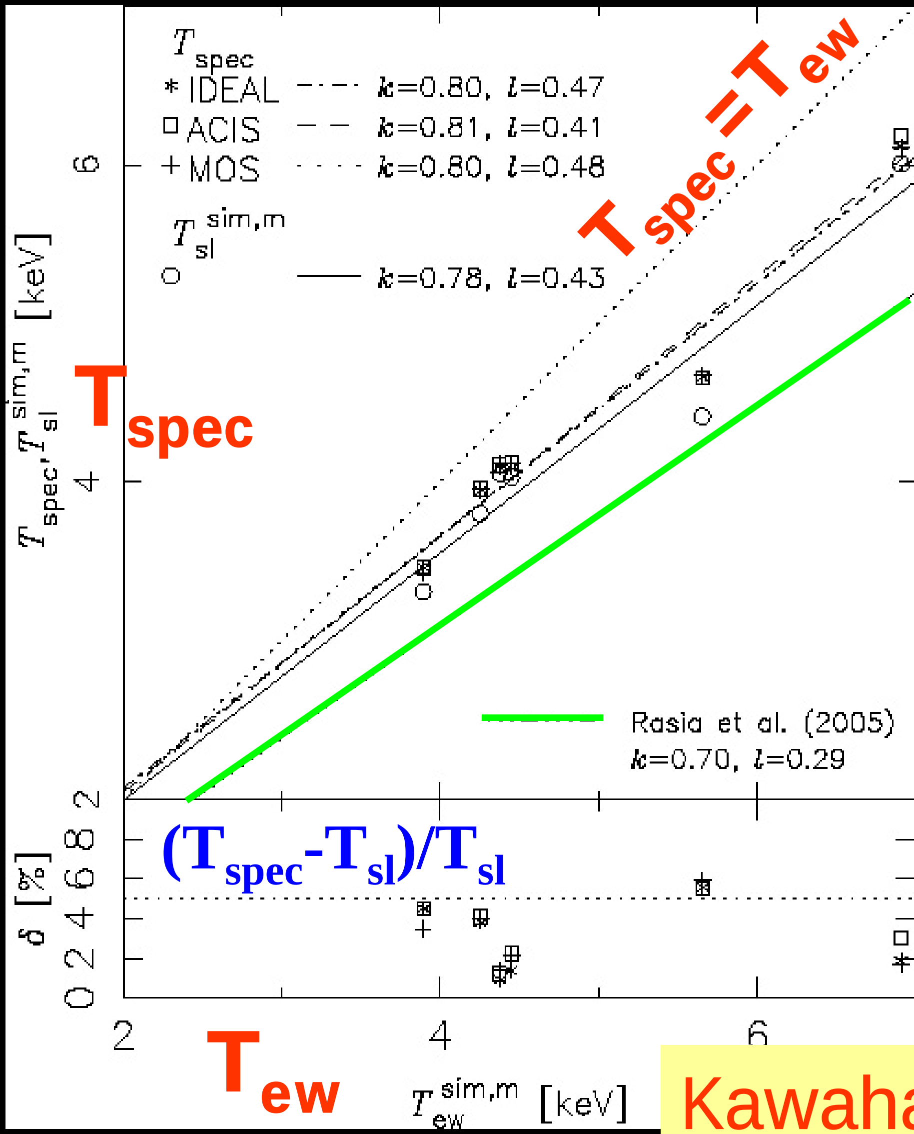
Tracing Cosmic Evolution with Clusters of Galaxies:
Six Years Later
Sesto (BZ) Alto Adige, Italy June 25-29, 2007

Collaborators and references

- **Hajime Kawahara (Univ. of Tokyo), Tetsu Kitayama (Toho Univ.), Shin Sasaki (Tokyo Metropolitan Univ.), Mamoru Shimizu (Univ. of Tokyo), Elena Rasia (Univ. of Michigan), Klaus Dolag (MPA)**
- **Kawahara, YS, Kitayama, Sasaki, Shimizu, Rasia + Dolag (2007)**
  - *Radial Profile and Lognormal Fluctuations of the Intracluster Medium as the Origin of Systematic Bias in Spectroscopic Temperature* ApJ 659(2007)257
- **Kawahara, Kitayama, Sasaki + YS (2007)**
  - *Systematic Errors in the Hubble Constant Measurement from the Sunyaev-Zel'dovich effect* **astro-ph/0705.3288**

It started with Italian insights

T_{spec} is systematically smaller than T_{ew}



- Mazzotta et al. (2004) & Rasia et al. (2005) found $T_{spec} \sim 0.7\ T_{ew}$ from simulations
- We basically confirm their results using simulated clusters of Dolag et al. (2005)

  $T_{spec} \sim 0.8\ T_{ew}$

  (see also Mathiesen & Evrard 2001)

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mass-weighted, emission-weighted, and spectroscopic temperatures of clusters

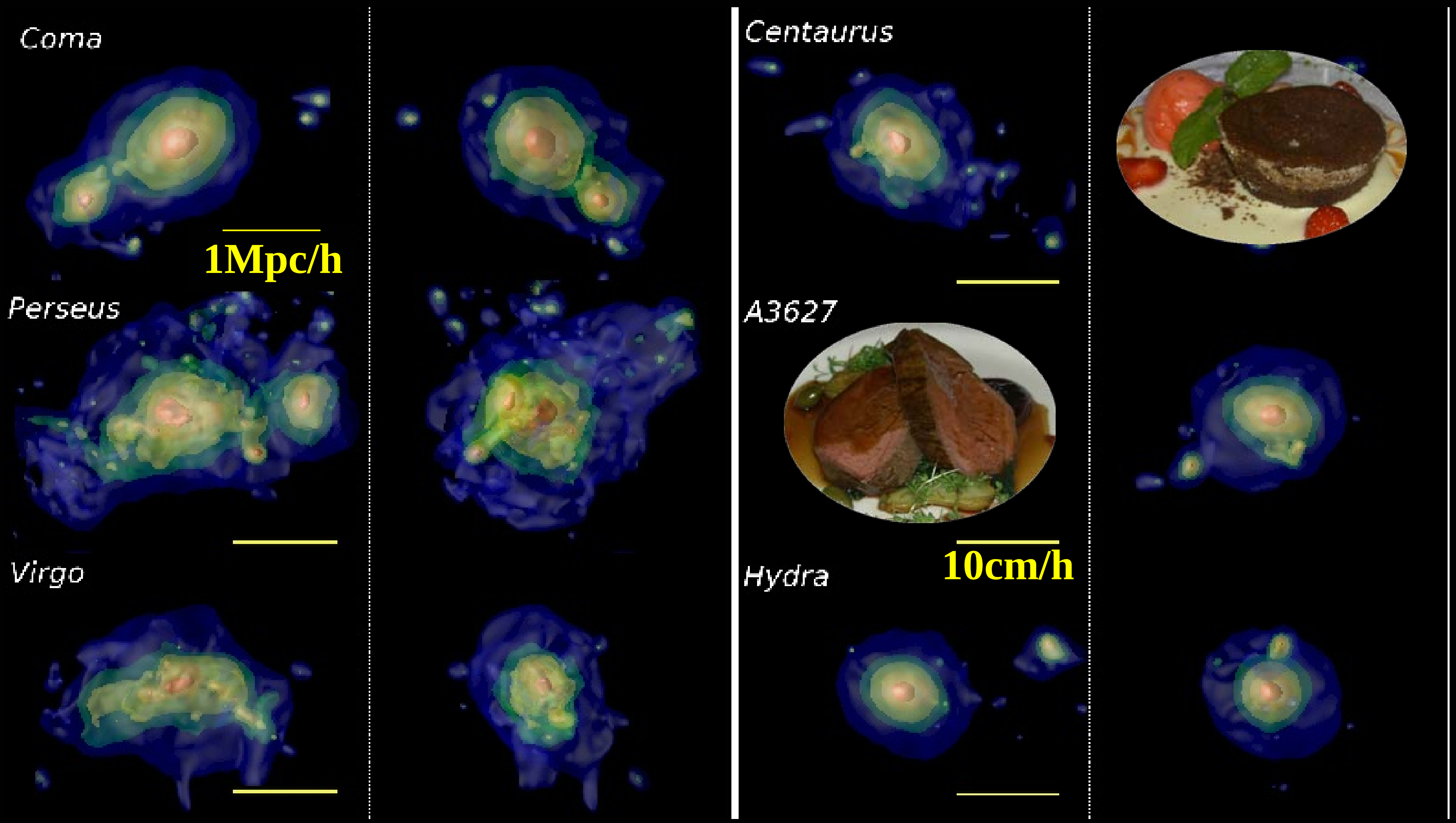
$$\langle T \rangle_W = \frac{\int T W dV}{\int W dV}$$

	name	W	
T_m	mass-weighted	n	
T_{ew}	emission-weighted	$n^2\Lambda(T)$	
T_{spec}	spectroscopic	spectral fit	
T_{sl}	spectroscopic-like	$n^2T^{-0.75}$	Mazzotta et al. (2004)

Simulated clusters in the local universe

- SPH simulations by Dolag et al. (2005)
- Local universe distribution in a sphere of r=110Mpc
- Initial condition: smoothing the observed galaxy density field of IRAS 1.2 Jy survey (over $5h^{-1}$Mpc), linearly evolving back to z=50
- with cooling, star formation, SN feedback, and metalicity evolution in ΛCDM

Projected views of ***simulated clusters***



An analytic model for T_{spec}/T_{ew}

- Spherical polytropic β-model as global mean radial profiles
- Log-normal density and temperature fluctuations
  - Density and temperature correlations ignored
  - Radius independent dispersion adopted
- ⇒ Analytic expressions for the temperature underestimate, T_{sl}/T_{ew}
  - Explain numerical simulations well

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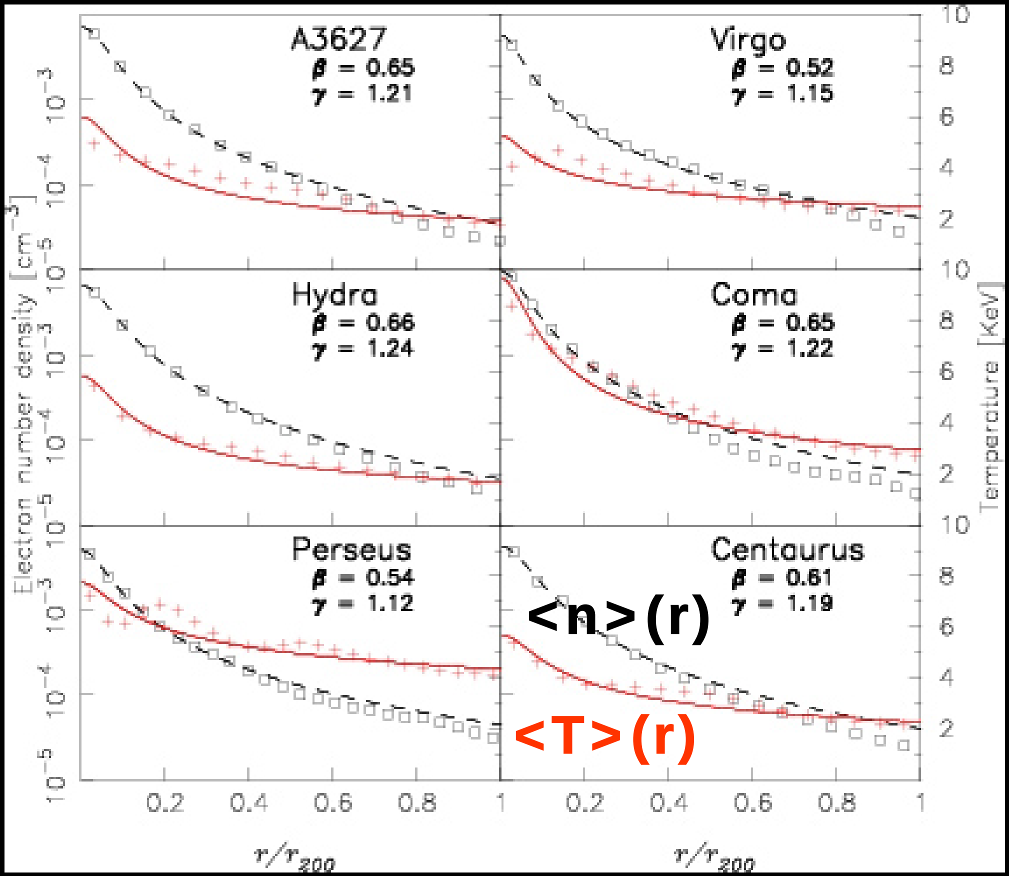
Origin of $T_{spec} < T_{ew}$ (1) mean radial profile



- Density and temperature radial profiles of simulated clusters
- **Polytropic β model**

$$<n>(r) = n_0 \left[\frac{1}{1+(r/r_c)^2} \right]^{3\beta/2}$$

$$<T>(r) = T_0 [<n>(r)/n_0]^{\gamma-1}$$

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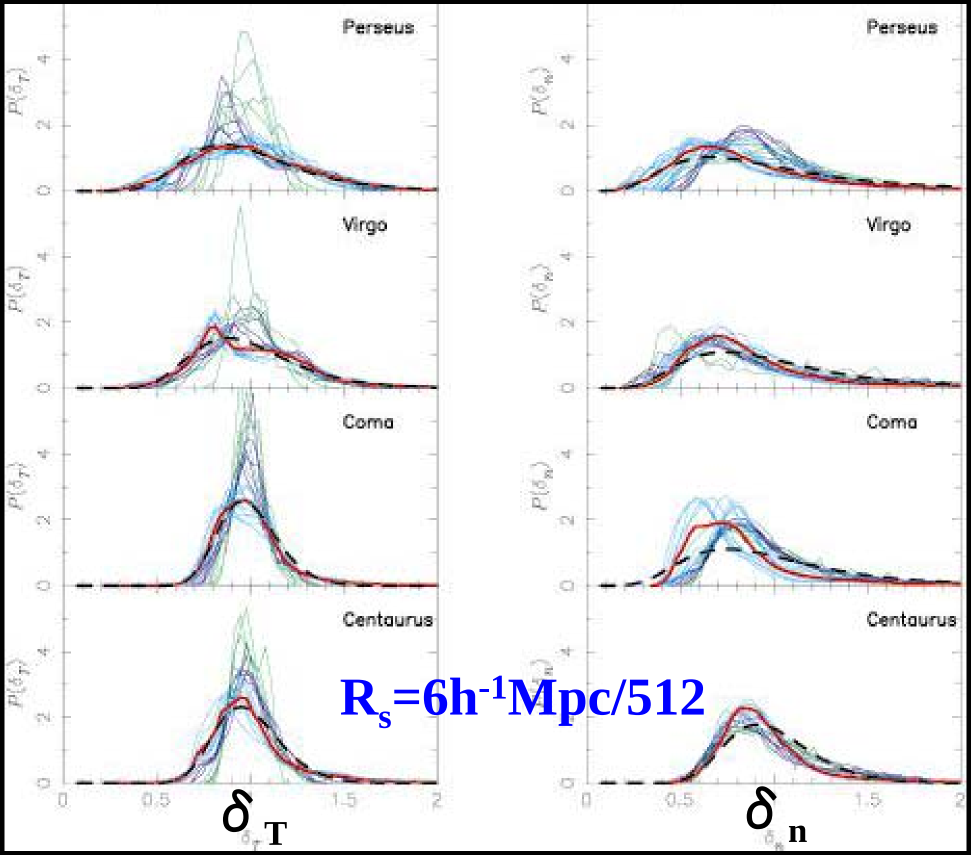
Origin of $T_{spec} < T_{ew}$ (2) Local inhomogeneity



- **Local inhomogeneities of density and temperature of simulated clusters**
  - $\delta_n = n(r, \theta, \phi) / \langle n \rangle (r)$
  - $\delta_T = T(r, \theta, \phi) / \langle T \rangle (r)$
- **Log-normal PDF provides reasonable approximations**

$$P_{LN}(\delta)d\delta = \frac{1}{\sqrt{2\pi\sigma}}\exp\left[-\frac{(\log\delta + \sigma^2/2)^2}{2\sigma^2}\right]\frac{d\delta}{\delta}$$

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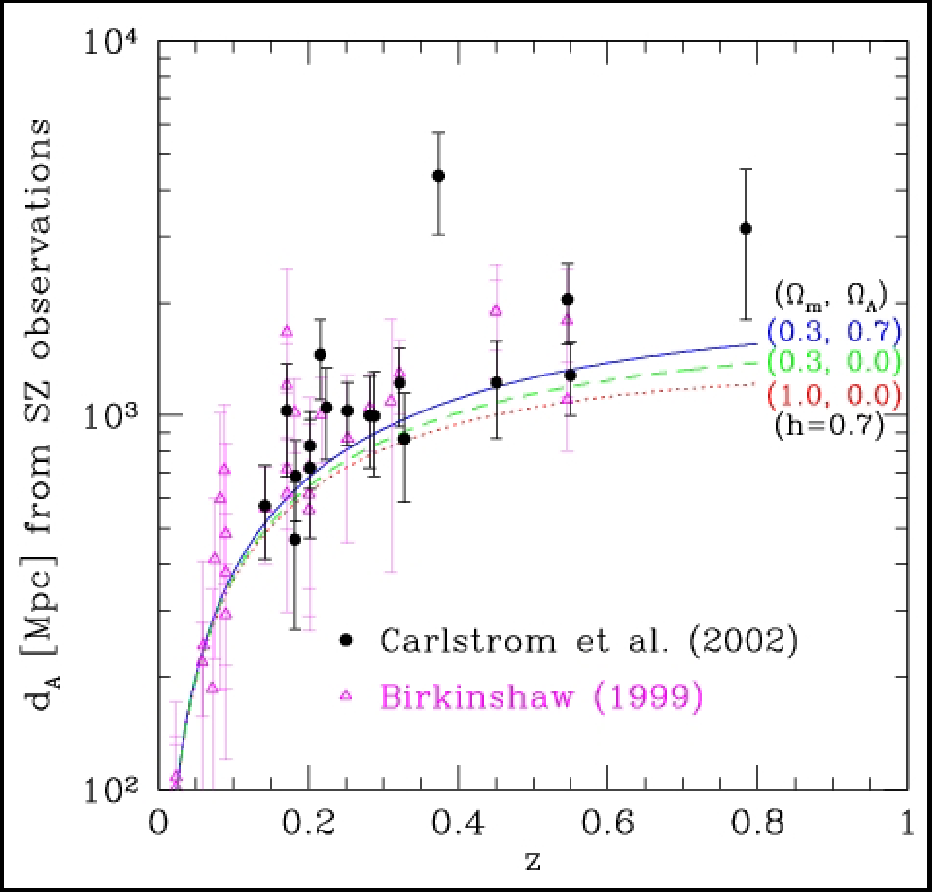
H_0 from the SZ effect



- ROSAT+SZ:
  - 60±3 km/s/Mpc (Reese et al. 02)
- WMAP:
  - 73±3 km/s/Mpc (Spergel et al. 07)
- *Systematically lower ?*
  - Chandra+SZ
  - $76.9^{+3.9}_{-3.4}{}^{+10.0}_{-8.0}$ km/s/Mpc (Bonamente et al. 06)

Isothermal β-model fit

- Polytropic density and temperature profiles

$$< n > (r) = n_0 \left[\frac{1}{1 + (r / r_c)^2} \right]^{3\beta / 2}$$

$$< T > (r) = T_0 [< n > (r) / n_0]^{\gamma - 1}$$

- core radius estimated from X-ray + SZ

$$r_{c,iso\beta}(T_{spec}) = \frac{y(0)^2}{S_X(0)} \frac{m_e^2 c^4 \Lambda(T_{spec})}{4\pi(\sigma_T k T_{spec})^2 (1+z)^4} \frac{G(\beta_{fit})}{G(\beta_{fit}/2)^2}$$

$$\beta_{fit} = \beta \frac{\gamma + 3}{4}$$

Today's main course

Analytic modeling of H_0 measurement

- Spherical polytropic β-model as mean radial profiles
- Log-normal density and temperature fluctuations
- **Still fit to the isothermal β-model,** and the estimated H_0 is biased as

$$f_{H,polyLN|iso\beta} \equiv \frac{H_{0,est}}{H_{0,true}} = \chi_\sigma \ \chi_T(T_{ew}) \frac{\chi_T(T_{spec})}{\chi_T(T_{ew})}$$

inhomogeneity
$$\chi_\sigma = \exp(\sigma_{LN,n}^2 - \sigma_{LN,T}^2/8) \approx (1.1-1.3)$$

non-isothermality
$$\chi_T(T_{ew}) = J(\beta,\gamma,r_c/r_{vir})^{1.5}\left[\frac{G(\beta(\gamma+3)/8)}{G(\beta\gamma/2)}\right]^2 \approx (0.8-1)$$

temperature bias
$$\frac{\chi_T(T_{spec})}{\chi_T(T_{ew})} \approx \left(\frac{T_{spec}}{T_{ew}}\right)^{1.5} \approx (0.8-0.9)$$

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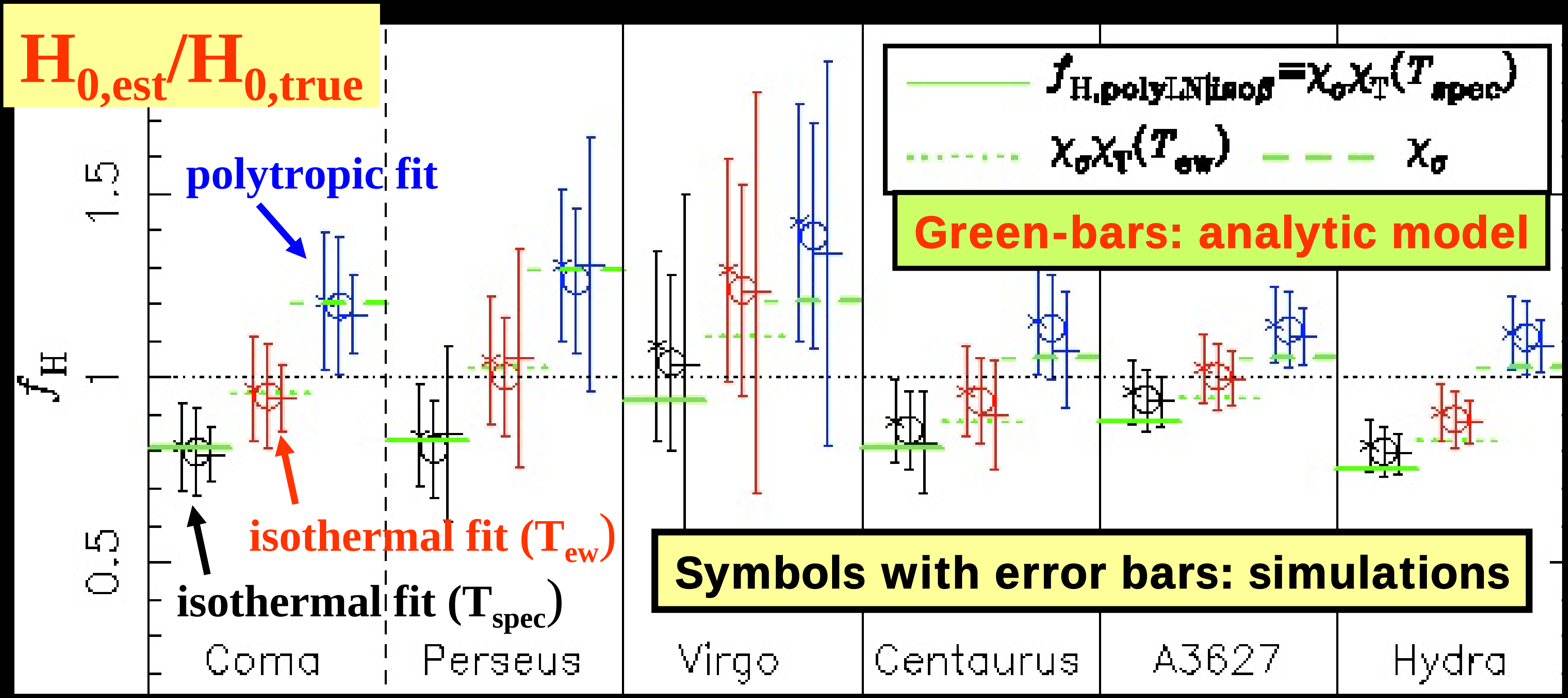
Analytic model vs simulated clusters



- Mean values are in good agreement with the analytic model
- Additional small bias expected due to non-sphericity of clusters even after averaging over l.o.s. angles

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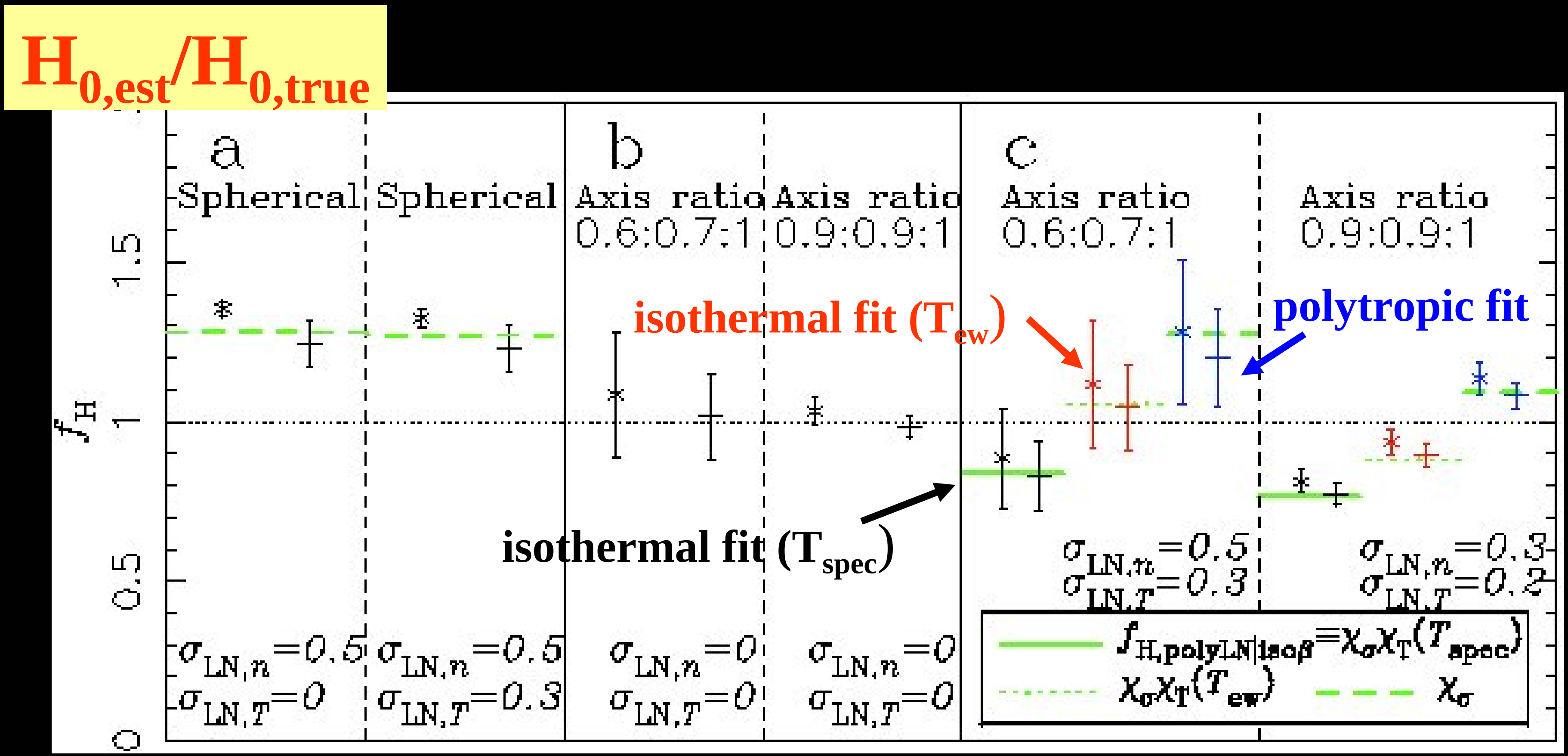
Non-spherical effect : triaxial clusters



- Synthetic triaxial clusters (Jing & YS 2002) + polytropic β + log-normal fluctuations

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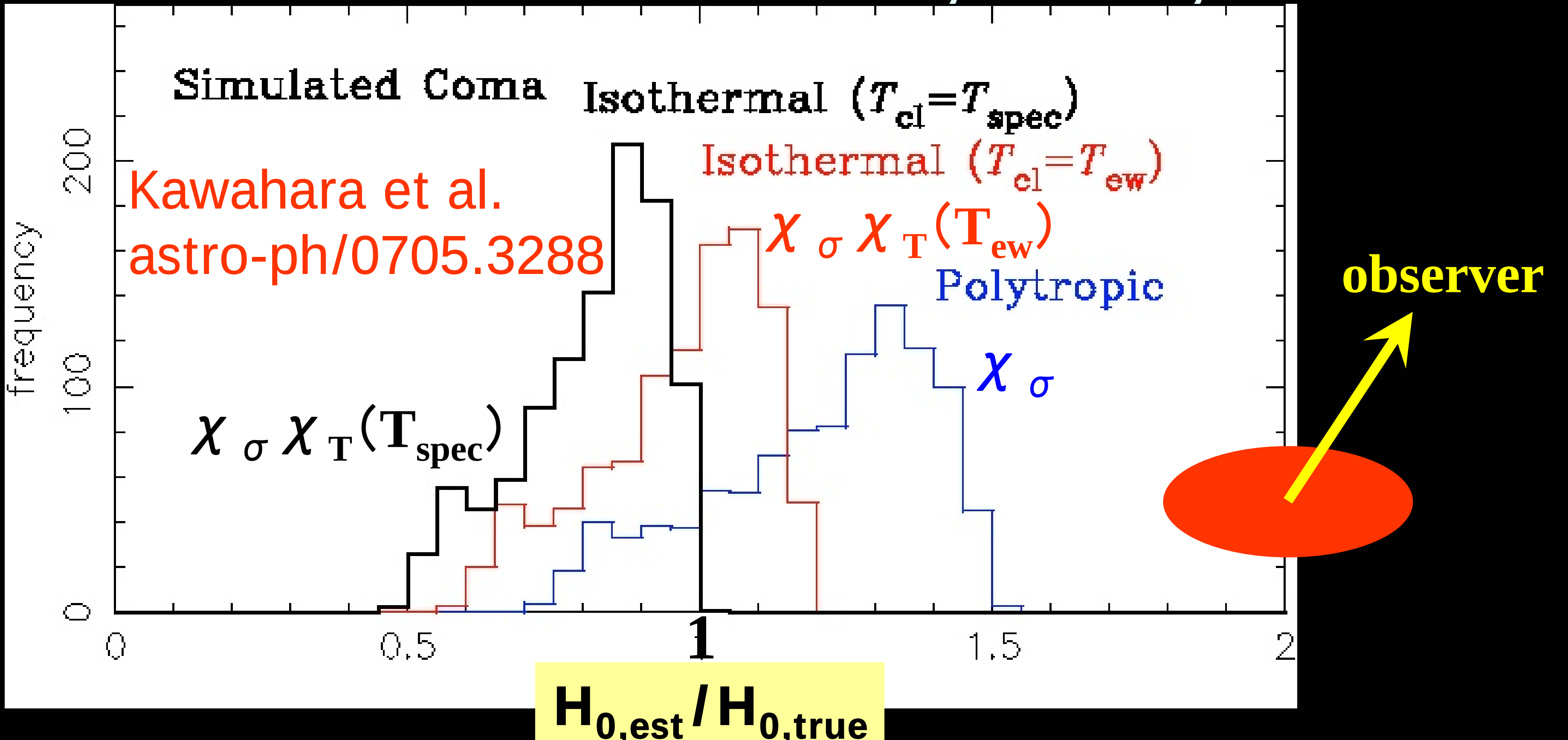
Cool and sweet conclusions: they are not spherical

Distribution of $H_{0,est}$ / $H_{0,true}$



- Skewed distribution due to the prolateness
- Previous studies did not find the large bias because we set T_{cl}=T_{ew} instead of T_{spec} (Inagaki, Suginohara & YS 1995, Yoshikawa, Itoh & YS 1998), consistent with our results of the isothermal fit with T_{ew}

Summary

- Analytic modeling of H_0 from the SZ effect
- **$H_{0,est}/H_{0,true}$ = 0.8-0.9 from simulated clusters is well explained by the combination of inhomogeneity and non-isothermality of ICM**
  - Consistent with Reese et al. (2002), but not with Bonamente et al. (2006) ???
  - Direct comparison between ROSAT and Chandra analyses is now in progress (Reese et al. 2007)

Thanks for the wonderful conference !
(on behalf of the Japanese participants)

Grazie per questa meravigliosa conferenza!
(a nome dei partecipanti giapponesi)