Cluster Temperatures and SZ observations

why we need good angular resolution

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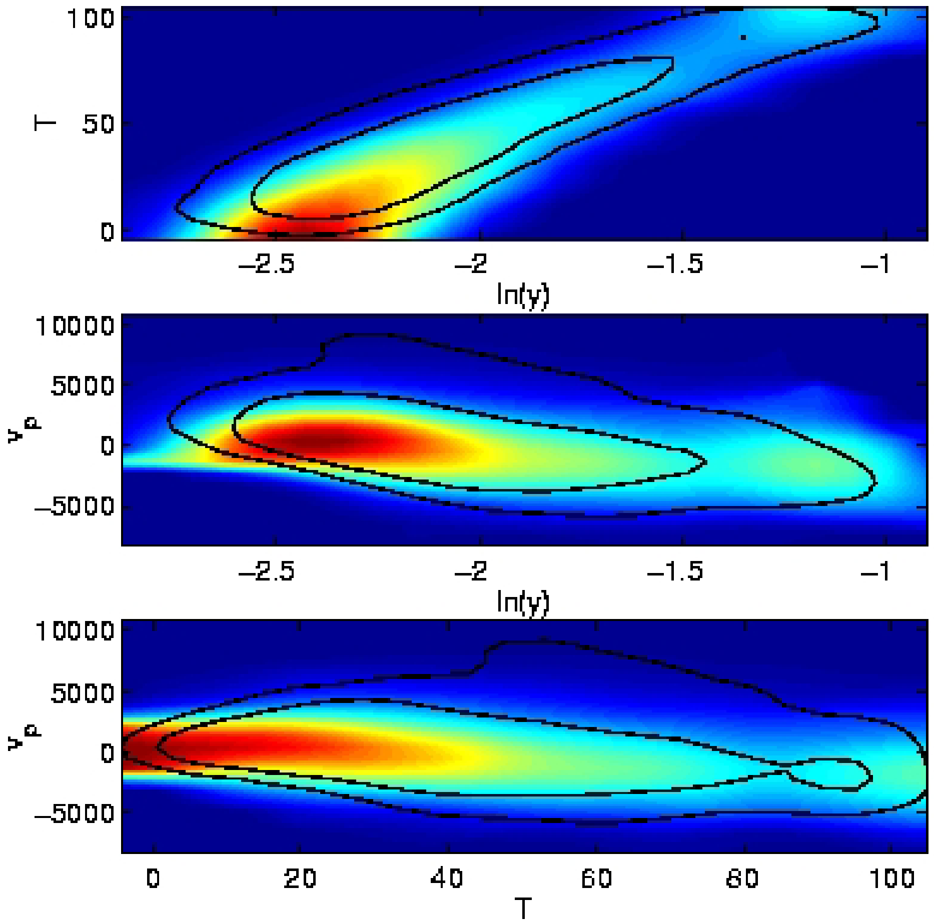
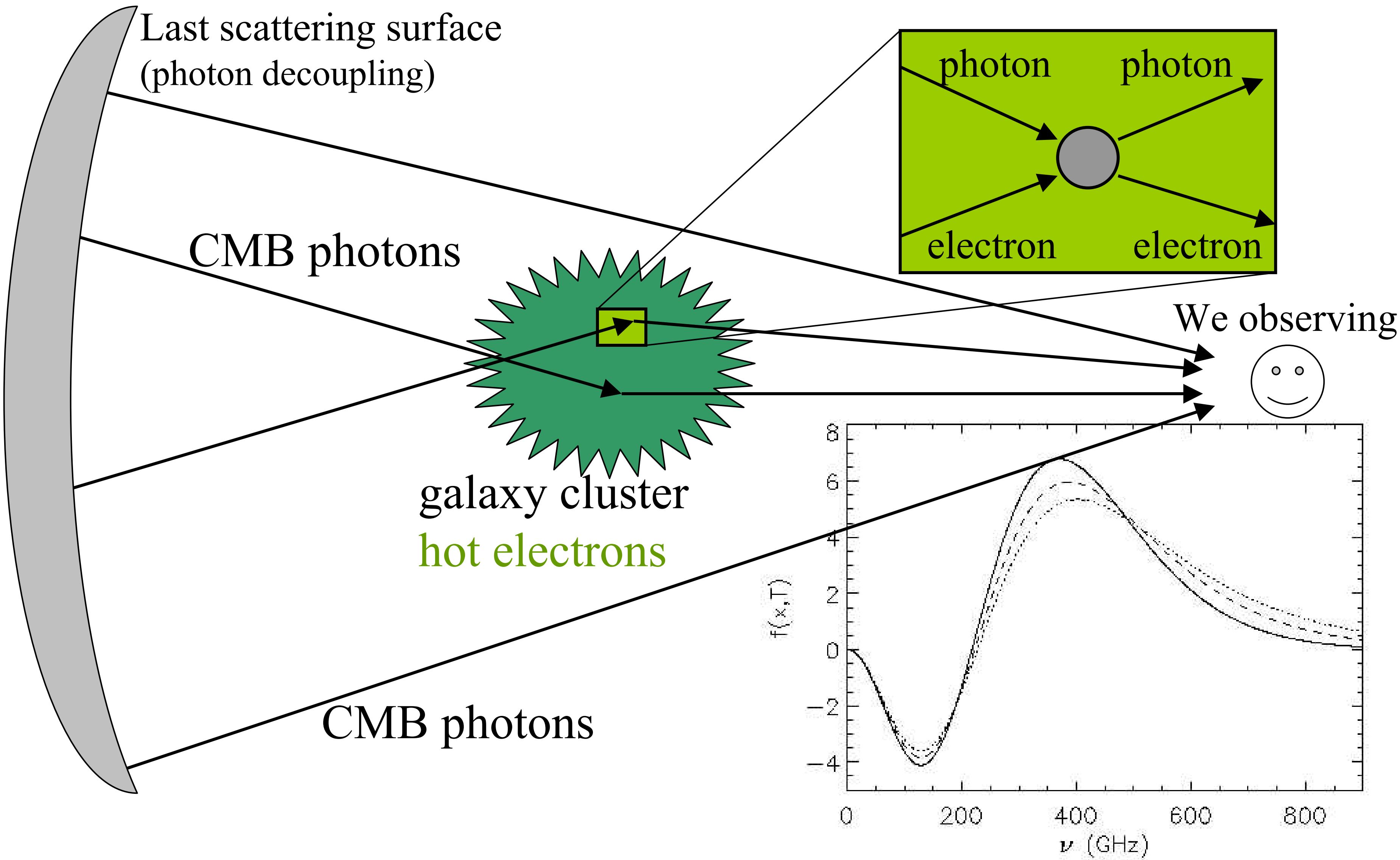
Steen H. Hansen, Zurich

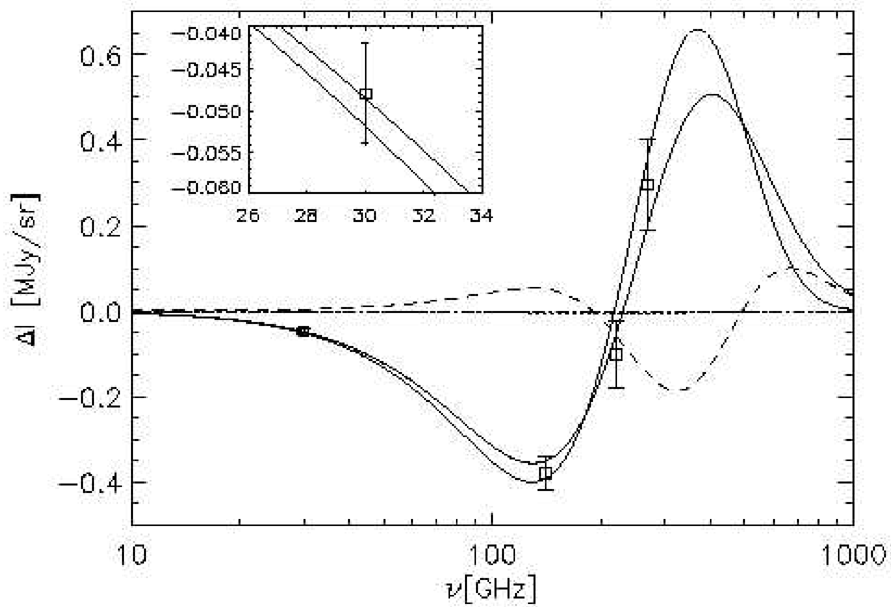


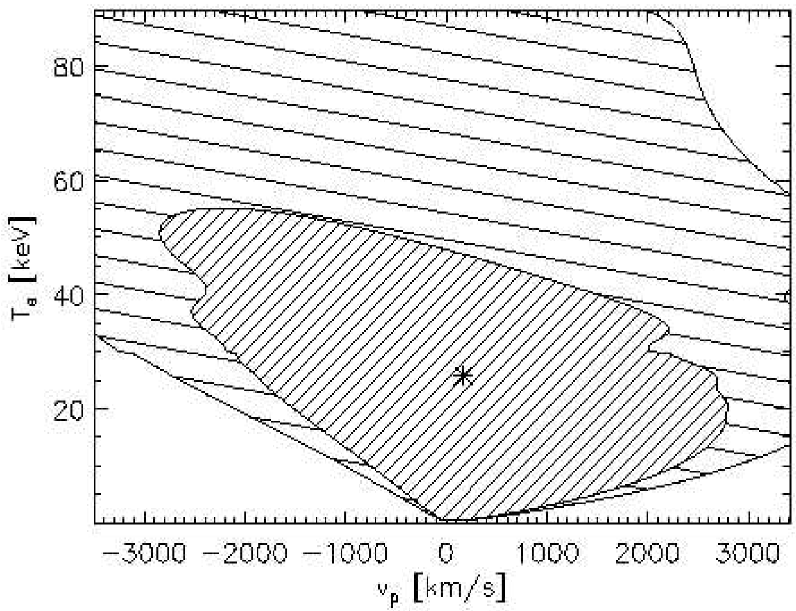
The SZ effect depends on temperature



Measure cluster temperature with SZ

A2163, result is T < 60 keV at 1σ

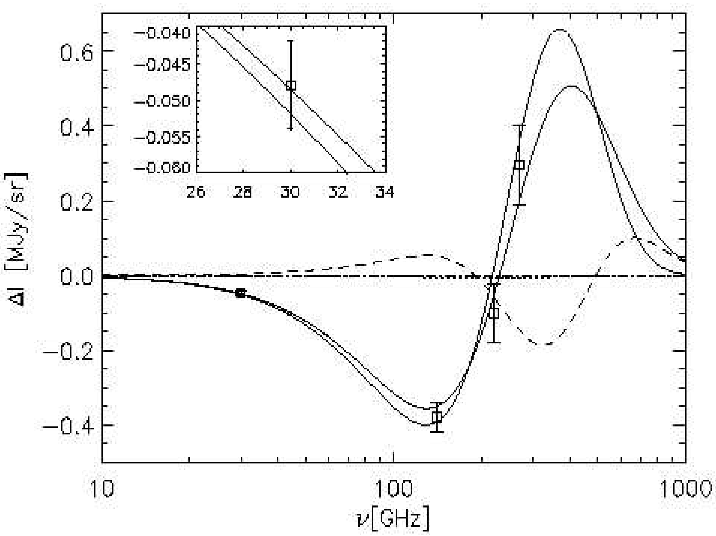


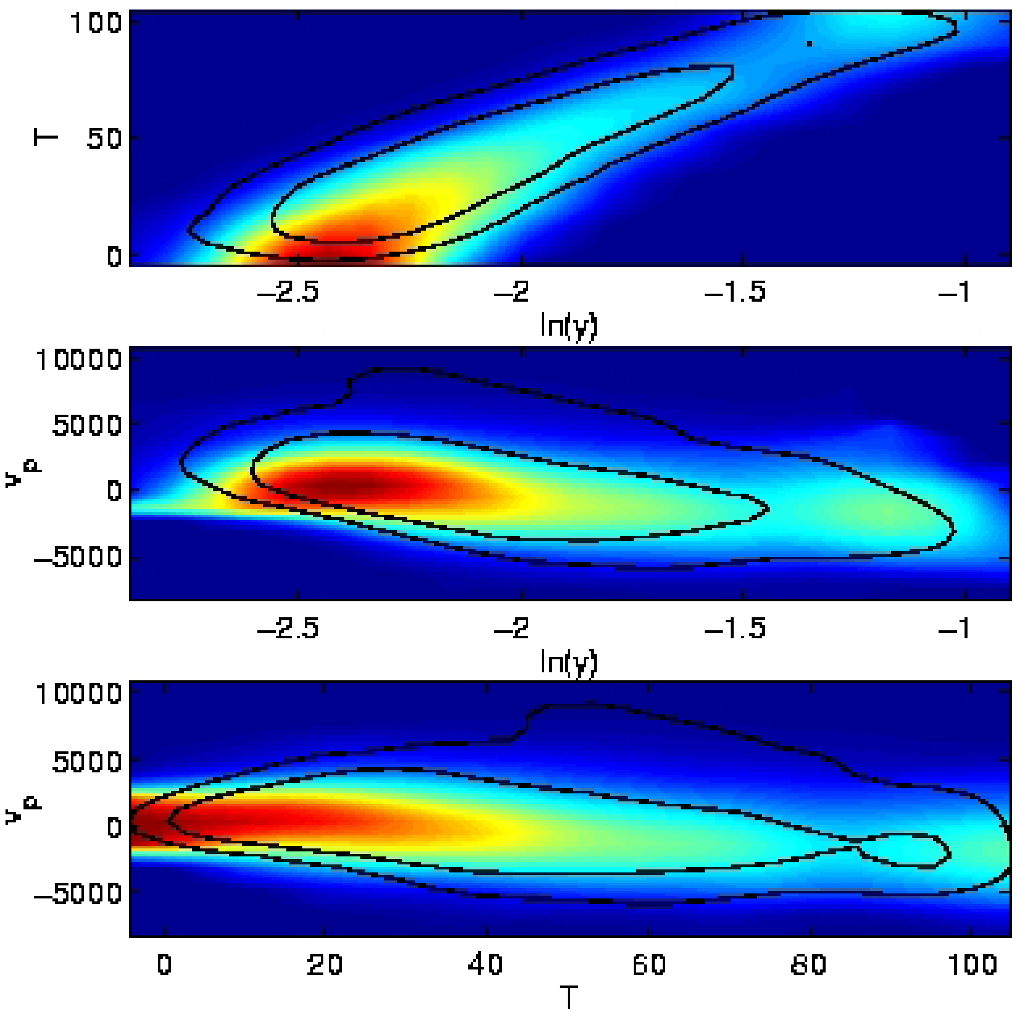


Data:
LaRoque et al, astro-ph/0204134

Temperature analysis:
Hansen et al, ApJ 537 (2002) L69

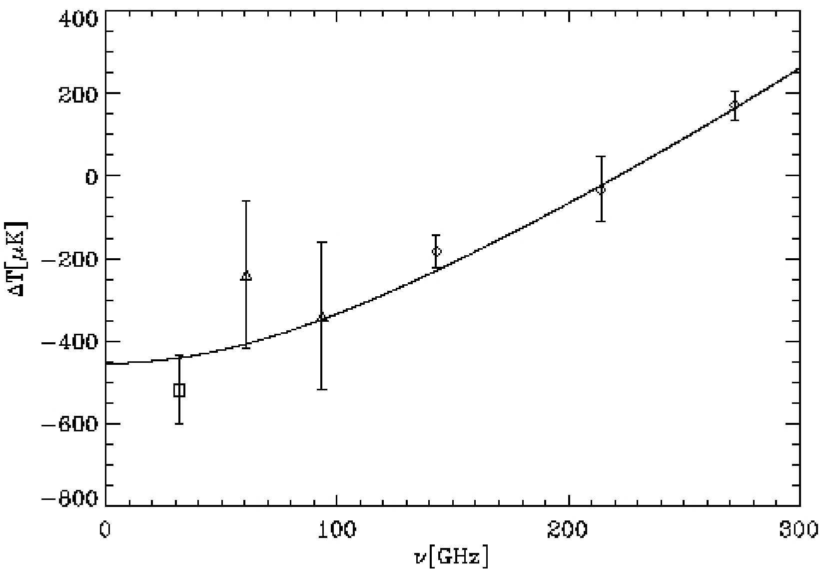
A2163 temperature through SZ, now in colour ☺

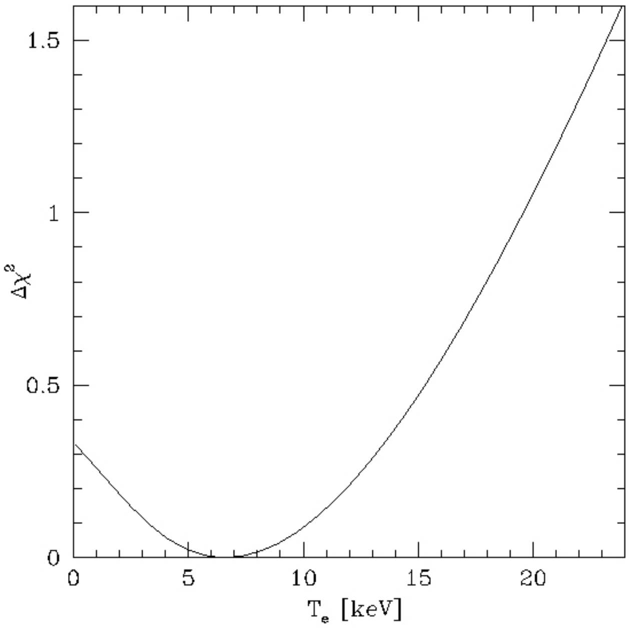




Also Coma temperature determined

Result is T < 20 keV at 1σ





Data:

Battistelli et al, ApJ, 598 (2003) L75

Temperature analysis:

Hansen, New Astron 9 (2004) 279

What does the SZ formula look like

Non-relativistic:

$$\Delta I = y * [g(x)] - \beta * \tau * a(x)$$

Including relativistic effects:

$$\Delta I = y * [g(x) + T * \delta(x,T)] - \beta * \tau * a(x)$$

Everything is integrated along the line of sight.

$\delta(x,T)$ is almost independent of T (Diego et al, MNRAS 338 (2003) 796)

The Compton parameter, y, is dominant

$$\Delta I = y * \{ [g(x) + T * \delta(x)] - \beta * \tau/y * a(x) \}$$

So **if** the cluster is isothermal, then this is simple, since

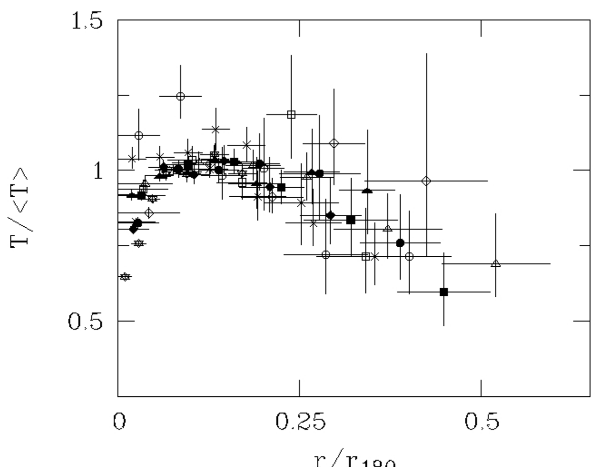
$\tau/y \sim 1/T$

$$\Delta I = y * \{ [g(x) + T * \delta(x)] - \beta / T * a(x) \}$$

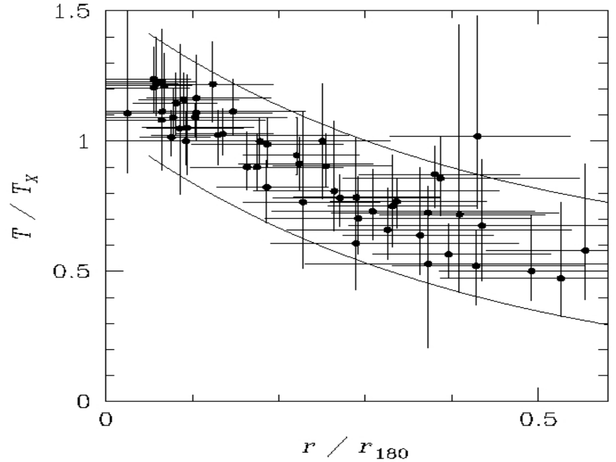
Where the **same** T appears twice

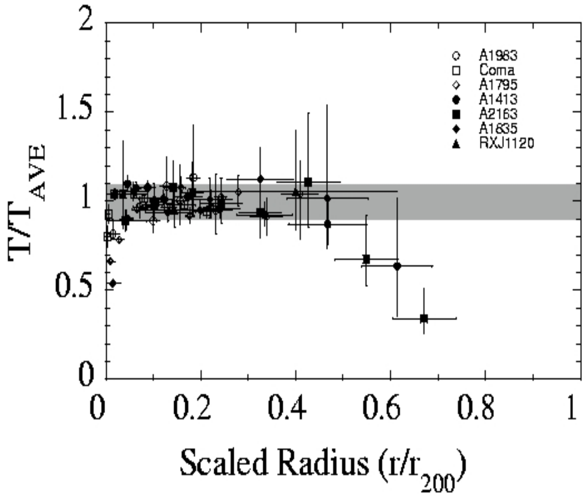
However, the clusters are not isothermal

De Grandi & Molendi, ApJ 567 (2002) 1

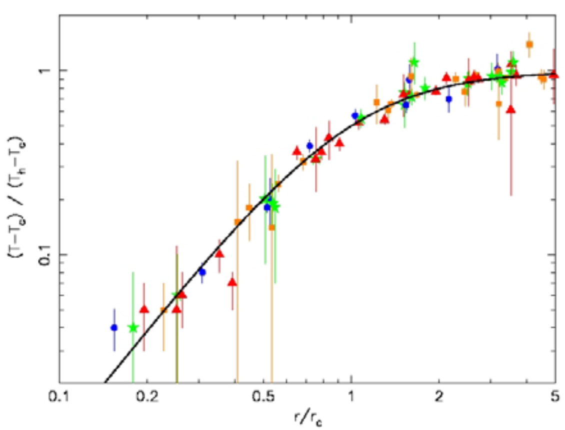


Markevitch et al, ApJ 503 (1998) 77





Arnaud et al, astro-ph/0312398



Kaastra et al, A&A 413 (2003) 415

X-ray is measuring emission weighted quantities

Typically one uses emissivity
ε ~ n^2 * T, and one has

$$\langle \mathcal{O} \rangle_X = \frac{\int \mathcal{O} \epsilon \, dl}{\int \epsilon \, dl}$$

SZ is measuring Compton weighted quantities

$$\langle \mathcal{O} \rangle_y = \frac{\int \mathcal{O} f_y \, dl}{\int f_y \, dl}$$

where f_y is somehow related to the local y~n*T

The formulae look simple after a few definitions

$$n_e(r) = n_e^0\, f_{n_e}(r)$$

$$T_e(r) = T_e^0\, f_{T_e}(r)$$

$$f_y = f_{n_e} f_{T_e}$$

$$y = \kappa_y \int f_y\, dl$$

$$\kappa_y = \frac{\sigma_T n_e^0 k T_e^0}{m_e c^2}$$

$$\langle T_e \rangle_y = \frac{\int T_e f_y\, dl}{\int f_y\, dl} = \frac{\kappa_y \int T_e f_y\, dl}{y}$$

SZ temperature is Compton weighted

(Hansen, MNRAS 351 (2004) L5)

A working example (1)

Consider a beta-model cluster, β = 0.61

$$n_e(r) = n_e^0 \left(1 + \left(\frac{r}{r_c}\right)^2\right)^{-\beta 3/2}$$

and with a non-trivial temperature profile, α = 0.56

$$T_e(r) = T_e^0 \left(1 + \frac{r}{r_c}\right)^{-\alpha}$$

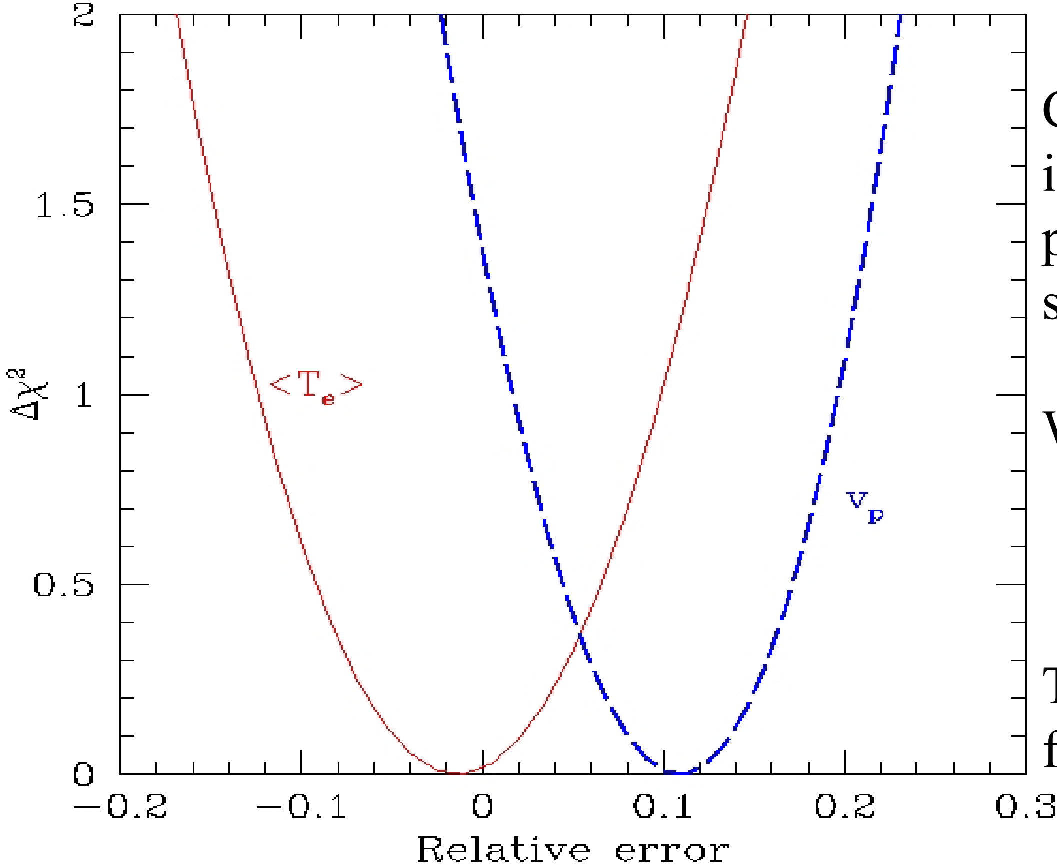
If central temperature is 10 keV, then the Compton averaged temperature is only 7.1 keV, and $\langle 1/T_e \rangle \langle T_e \rangle = 1.12$

$$\Delta I = y * \{ [g(x) + \langle T \rangle * \delta(x)] - \beta * \langle 1/T \rangle * a(x) \}$$

Now it is **not** the same T that appears, since ⟨T⟩ and 1/⟨1/T⟩ differ

A working example (2)

We consider 4 observing frequencies at 90, 150, 220 and 270 GHz, and assume sensitivity of 1μK for each channel



Compton weighted temperature is found correctly, however, the peculiar velocity is **systematically** shifted by 10-12%.

We had predicted it to be

$$\langle 1/T_e \rangle \langle T_e \rangle = 1.12$$

This is independent of observing frequencies and sensitivity.

Hansen, MNRAS 351 (2004) L5

A working example (3)

The emission weighted temperature (from X-ray) for this cluster is about 8 keV. Using that would imply a systematic error on the peculiar velocity of about 20%.

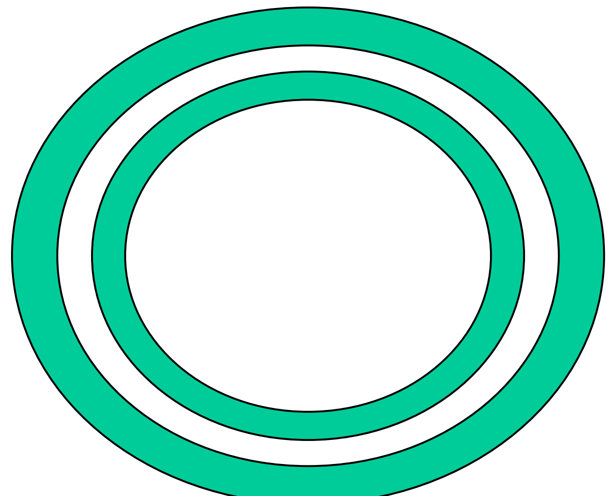
Different (equally realistic) beta-models, or different radial temperature dependence lead to 10-20% systematic error on the peculiar velocity.

Peculiar velocities are most interesting for a large sample of clusters, for which we cannot expect to have accurate x-ray determinations of both density and temperature profiles.

Solution: SZ onion peeling

SZ onion peeling

- First you observe and analyse outer ring
- Observe next ring, and subtract signal from outer rings
- Repeat



This works only if error-bars from outer rings don’t induce too larger errors on inner rings

We can write $n*T \sim r^{\zeta_y}$ Where $\zeta_y \approx \mathbf{-2.5}$

Compare to X-ray, where $\varepsilon \sim r^{\zeta_x}$ and $\zeta_x \approx \mathbf{-4}$

Therefore, if we have resolution (and sufficient sensitivity) then the error-bars should remain under control

Conclusions

- Clusters have a non-trivial temperature profile

- The SZ temperature is **Compton weighted**
  - Be extremely careful when using X-ray observed quantities in the SZ analysis

- The derived peculiar velocity is **systematically** shifted by 10-20%

- A nice solution is to achieve simultaneous good angular resolution and high sensitivity in order to deproject (onion peel) the SZ signal

The End