Galaxy Clusters at Microwave frequencies: awaiting Planck

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5^{th} Iberian Cosmology meeting, Porto, 31 March 2010

I - Galaxy Clusters

➢ Largest collapsed structures

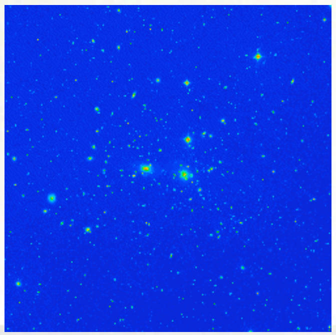
- containing from hundreds of galaxies
- typically 1-2 Mpc / 1e14 - 1e15 Msun
- grav. potential filled with hot gas (~1-15 keV)

➢ Galaxy clusters are probes sensitive

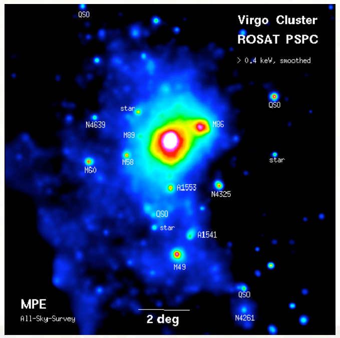
- Cosmology (abundance, redshift evolution, distances...)
- Structure Formation mechanisms (intrinsic cluster properties, cluster scaling relations, statistics and growth rate of perturbations,...)

➢ Observations in a wide range of frequencies

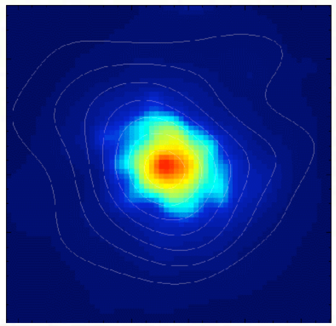
optical



X-rays



millimeter



The Sunyaev-Zel'dovish (SZ) effect:

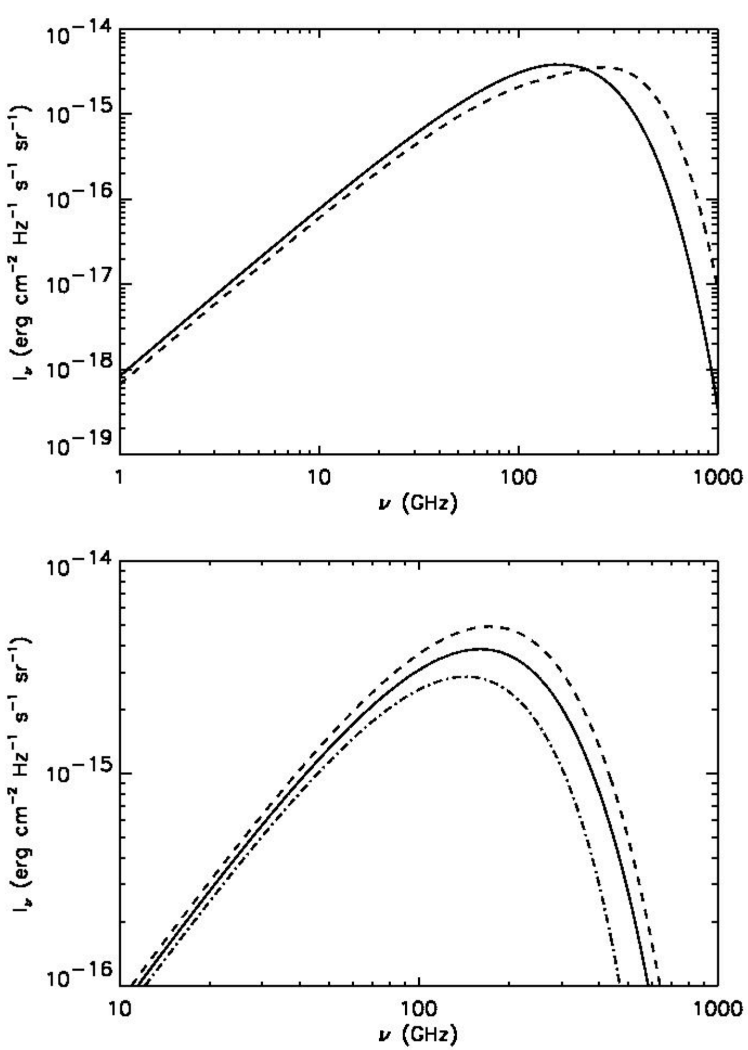
Thermal SZ effect: (electron thermal motions)

$$\Delta I_{\rm th} = I_0\, g(x)\, y$$

$$\frac{\Delta T_{\rm th}}{T} = \left[\frac{x\,(e^x+1)}{e^x-1} - 4\right] y$$

$$y = \int \frac{k_{\rm B}\sigma_{\rm T}}{m_{\rm e}c^2} T_{\rm e}(l) n_{\rm e}(l)\, dl$$

$$g(x) = \frac{x^4 e^x}{(e^x-1)^2}\left[\frac{x\,(e^x+1)}{e^x-1} - 4\right]$$



Kinetic SZ effect: (bulk motion of the gas)

$$\Delta I_{\rm k} = -I_0 h(x) \frac{v_{\rm r}}{c}\tau$$

$$\frac{\Delta T_{\rm k}}{T} = -\frac{v_{\rm r}}{c}\tau$$

$$\tau = \int \sigma_T\, n_{\rm e}(l)\, dl$$

$$h(x) = \frac{x^4 e^x}{(e^x-1)^2}$$

$$I_0 = 2\frac{(k_{\rm B}T)^3}{(hc)^2}$$

Galaxy Clusters at microwave frequencies

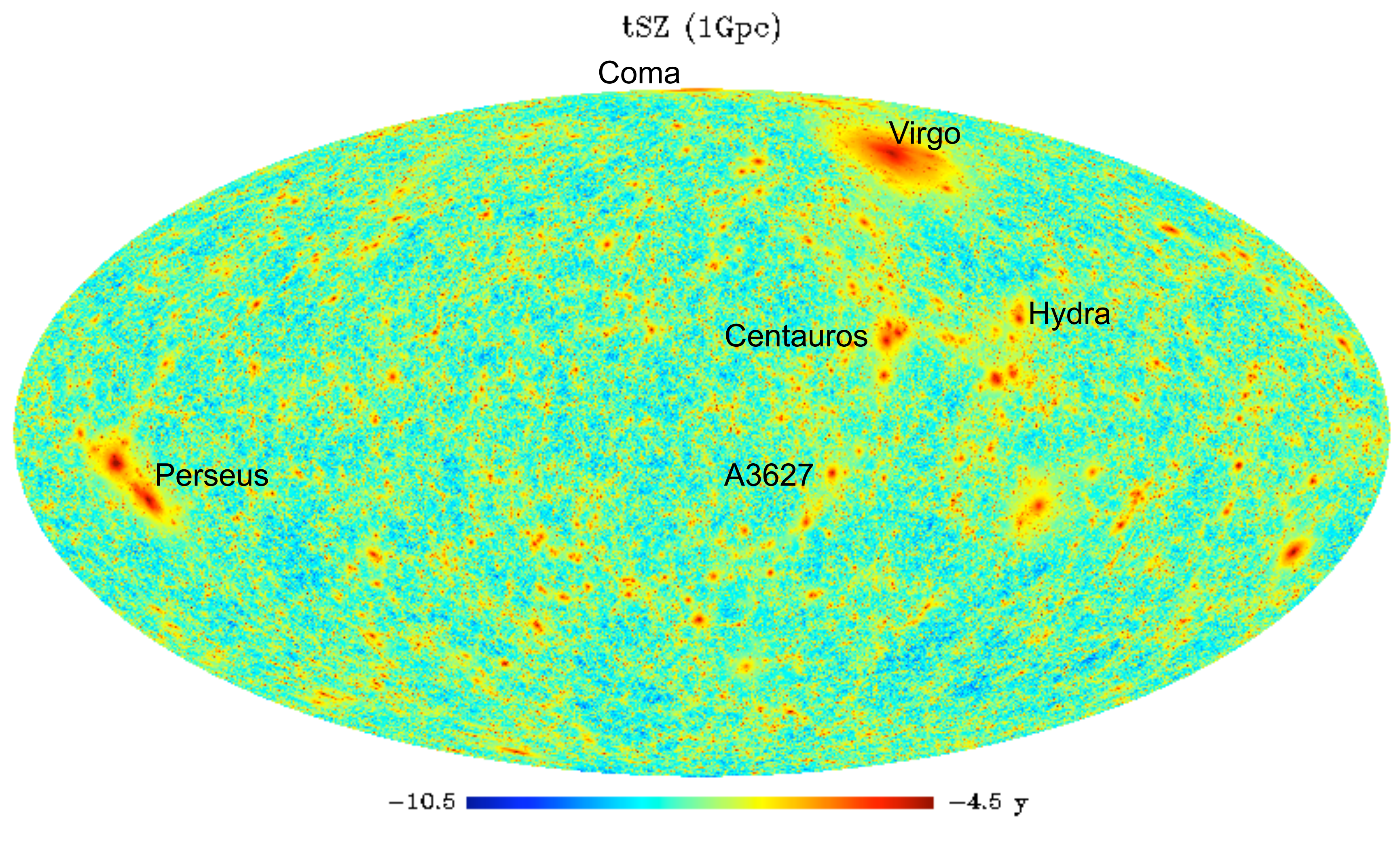
- New generation of CMB experiments

Reprinted from Bartlett 2006

Name	Frequencies [GHz]	Res. *fwhm* [arcmin]	Start date	Inst. noise [μK/beam]	Surf. dens. (5σ) [deg^{-2}]	Survey Area [deg^2]
Interferometers						
AMI	15	1–2	2006	8	16	10
AMiBA	95	~ 2	2006			
SZA	30 (+90)	~ 1	2006			
Bolometers						
ACT	145 225 265	1.7 1.1 0.93	2006	1.7 4.8 7.8	40	200
APEX	150 217	0.8 0.8	2006			
SPT	150 220 275	1 0.7 0.6	2007	10 60 100	11	4000
Planck	143 217 353	7.1 5 5	2008	6 13 40	0.35	40000

Galaxy Clusters at microwave frequencies: Planck Surveyor

WGs LSS Science Project: da Silva, Dolag, Rubiño-Martin 2009

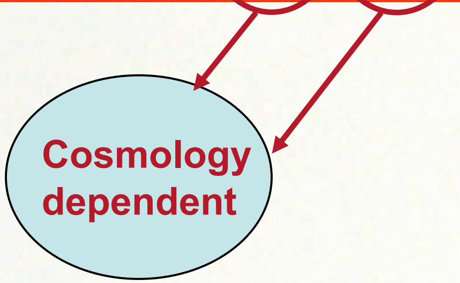


See also: Ana Valente, Master thesis, University of Porto, 2008

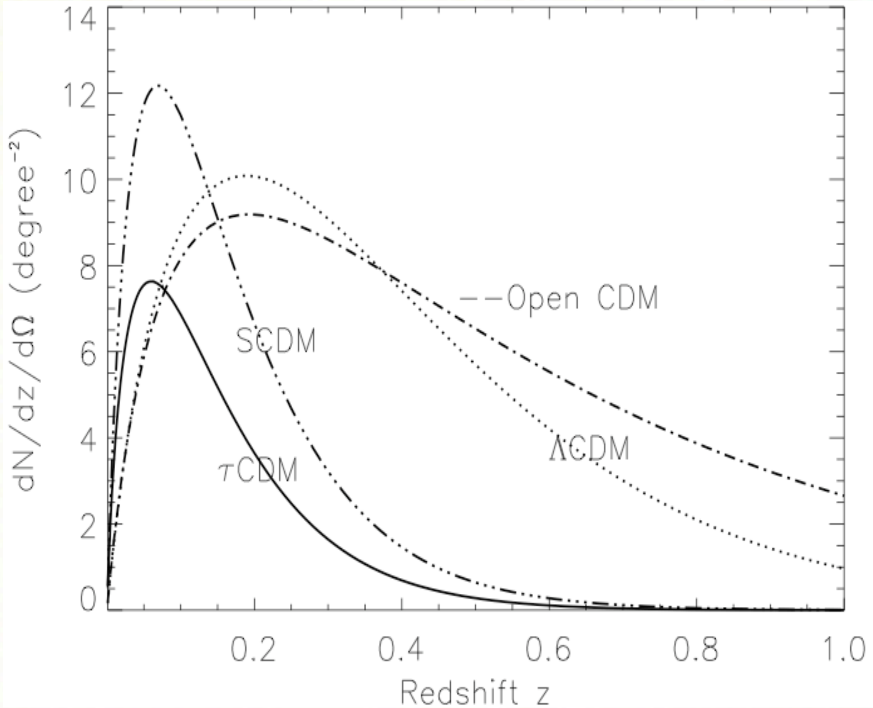
Number counts as probes of Dark Energy

- Redshift distribution of cluster halos

$$\mathcal{N}^{\text{bin}} \equiv \frac{dN}{dz} = \int_{4\pi} d\Omega \int_{M_{\text{inf}}}^{M_{\text{sup}}} \frac{dn}{dM} \frac{dV}{dz\,d\Omega} dM$$



Reprinted from Planck Red Book



- How sensitive are number counts to Dark Energy?

Number counts as probes of Dark Energy

- Redshift distribution of cluster halos

Nunes, da Silva, Aghanim, 2006, A&A, 450, 899

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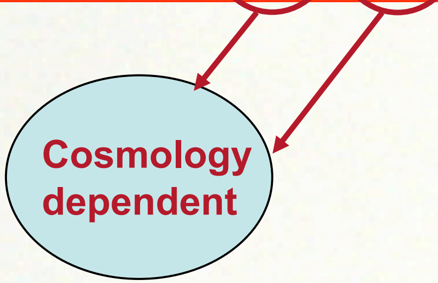
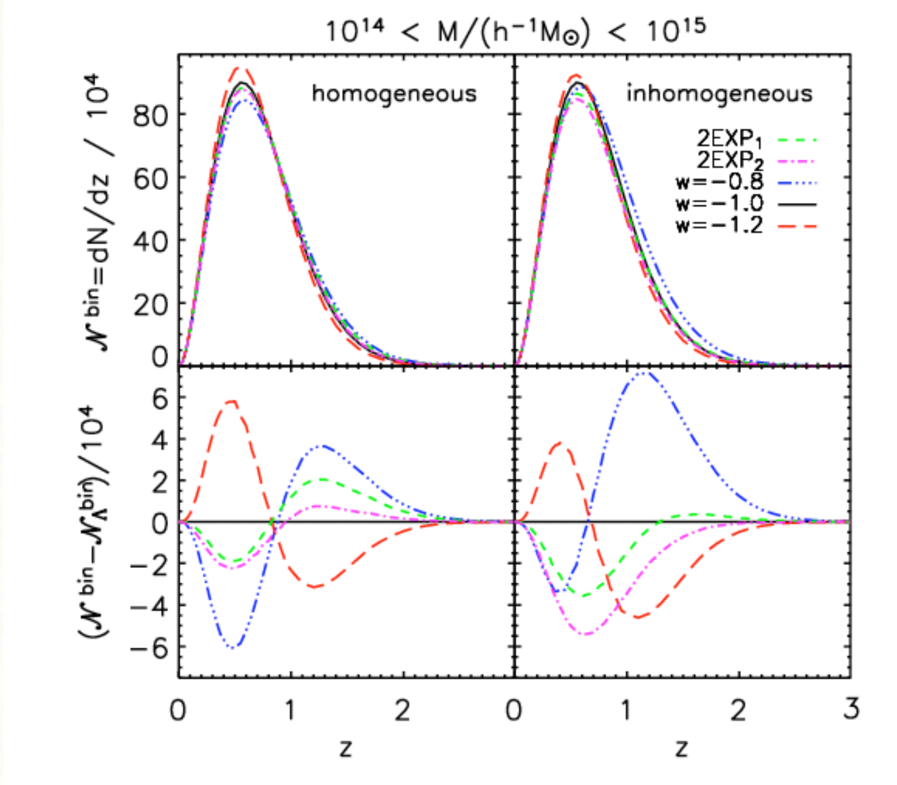




- How sensitive are number counts to Dark Energy?

✓ minimally coupled Quintessence Models

Number counts as probes of Dark Energy

- minimally coupled Dark Energy Models

Equations of state:

- 3 models with w= const.
- 2 models with w=w(z)

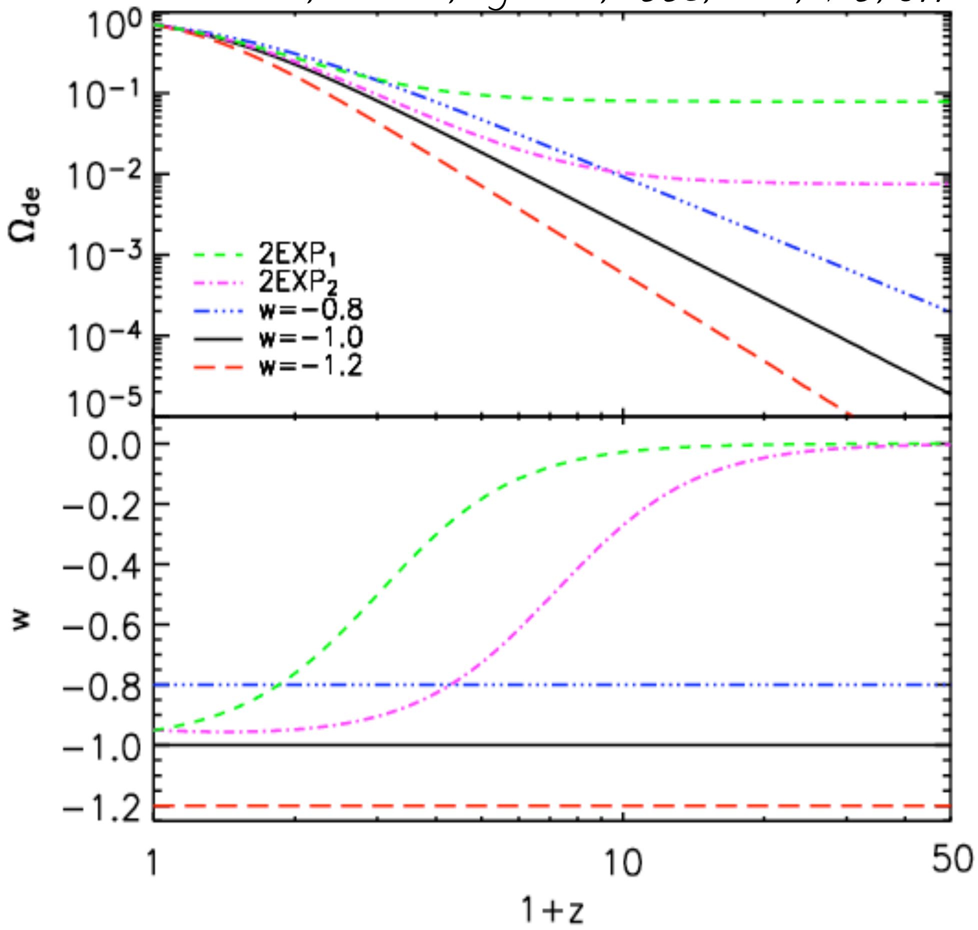
$$V(\phi) = V_0 \left(e^{\alpha\kappa\phi} + e^{\beta\kappa\phi}\right)$$

- 2EXP1 (α=6.2, β=0.1)
- 2EXP2 (α=20.1, β=0.5)

Dark Energy hypothesis:

- homogeneous ($\rho_{DE,halo}=\rho_{DE,back}$)
- inhomogeneous($\rho_{DE,halo}\neq\rho_{DE,back}$)

Nunes, da Silva, Aghanim, 2006, A&A, 450, 899



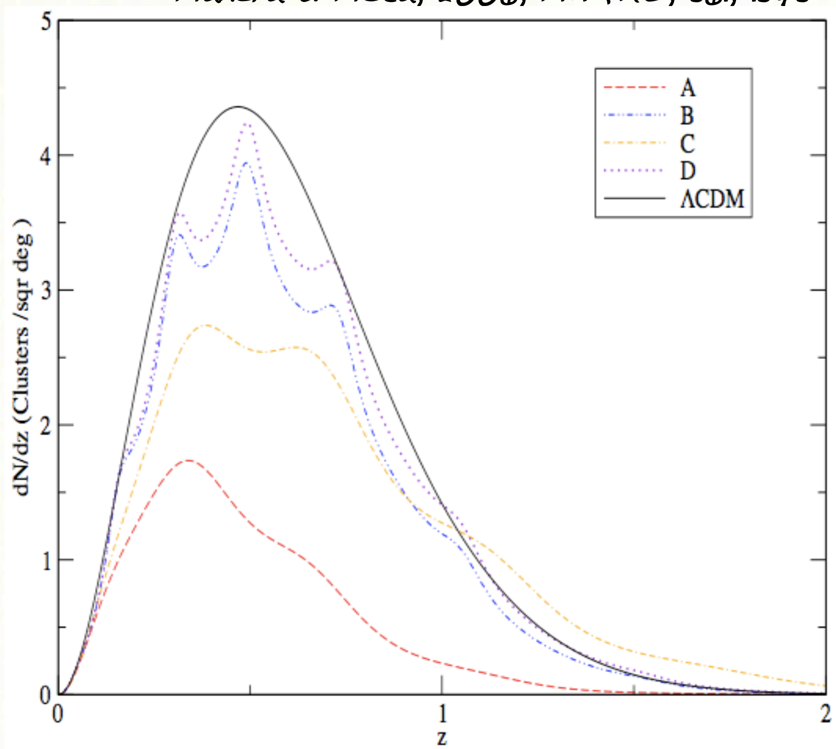
Number counts as probes of Dark Energy

- Redshift distribution of cluster halos

$$\mathcal{N}^{\text{bin}} \equiv \frac{dN}{dz} = \int_{4\pi} d\Omega \int_{M_{\text{inf}}}^{M_{\text{sup}}} \frac{dn}{dM} \frac{dV}{dz\,d\Omega} dM$$

Cosmology dependent

Manera & Mota, 2006, MNRAS, 361, 1373



- How sensitive are number counts to Dark Energy?

✓ minimally coupled Quintessence models

✓ Quintessence models coupled to Dark Mater

Number counts as probes of Dark Energy

Number counts differences are small (1-2 clusters/deg^2)

✓ Large Sky Surveys probing as deep as z~1.5-2 would be necessary

✓ Simultaneous constraints on different categories of objects maximize discrimination between DE models

✓ High sensitivity (Low detections threshold) would improve model discrimination

SZ/X-rays cluster surveys

✓ Mass is not a direct observable: gas Temperatures, Luminosities and SZ integrated Fluxes are.

✓ How gas properties relate with Mass?

✓ Dark Energy differences may be masked by gas physical processes

The Role of the Baryonic Gas Physics:

SZ/Xray cluster surveys: Mass is not a direct observable

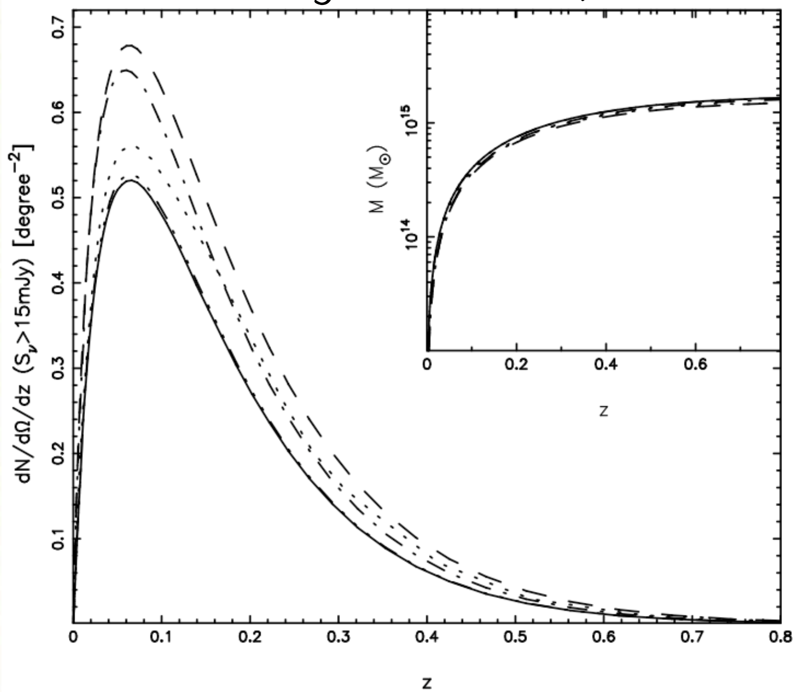
$$\frac{dN(>S_\nu)}{dz\,d\Omega} = \frac{dV}{dz\,d\Omega}\int_{M_{\min}(z,S_\nu)}^{\infty}\frac{dn}{dM}dM$$

$$S_\nu = \frac{g_\nu(x)}{D_a^2(z)}\left(\frac{k_B T}{m_e c^2}\right)\left(\frac{f_b \sigma_T}{\mu_e m_p}\right) M$$

Mass-Temperature scaling

$$T_X = A_{TM}\,(M/M_0)^{\alpha_{TM}}\,(1+z)^{\beta_{TM}}\,E(z)^{2/3}$$

Zhang & Wu, 2003, ApJ 583, 529



Cluster Scaling relations:

- ✓ Need to know dependence on gas physics
- ✓ What's their evolution with redshift?
- ✓ Do they depend on DE?

The Role of the Baryonic Gas Physics:

Local Cluster scalings in minimally coupled homogeneous DE hydrodynamic simulations

Aghanim, da Silva, Nunes, 2009, A&A, 496, 637

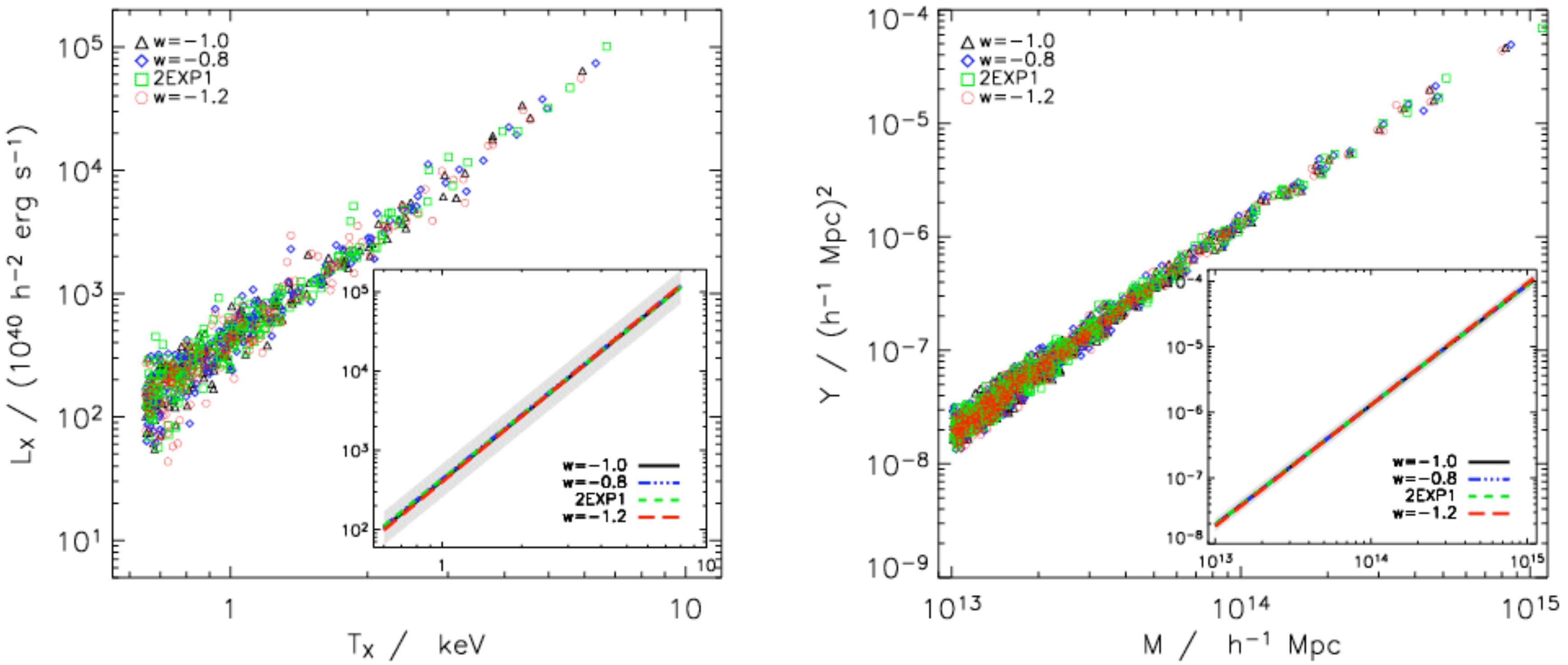


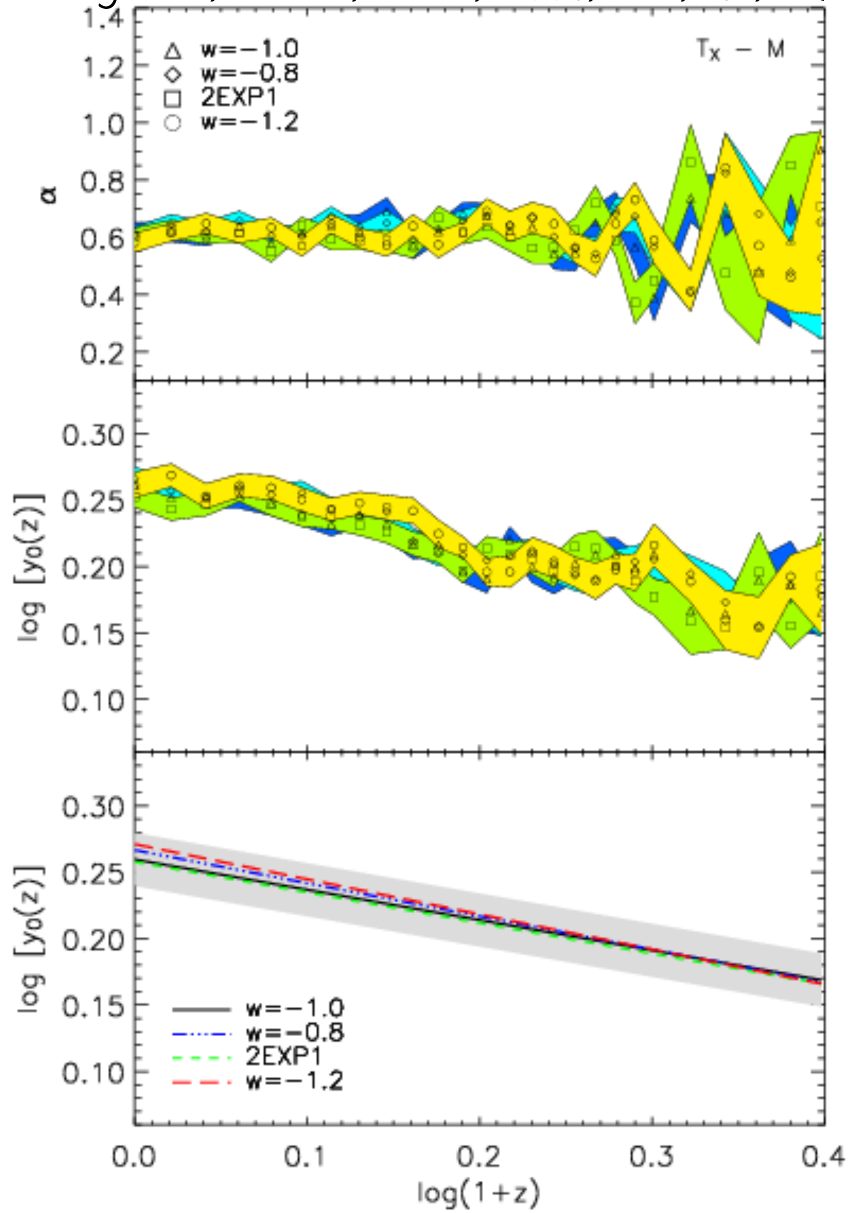
Fig. 1. Cluster scaling relations $L_{X,200} - T_{X,200}$ (left panel) and $Y_{200} - M_{200}$ (right panel) at redshift zero. Displayed quantities are computed within R_{200}, the radius where the mean cluster density is 200 times larger than the critical density. The embedded plots show the best fits with a power law to clusters represented in the main plots for the $w = -1$ (triangles), $w = -0.8$ (diamonds), 2EXP1 (squares) and $w = -1.2$ (circles) models. The shaded regions in the embedded plots give the typical scatter of the fits, i.e. the r.m.s dispersion around the best fit lines.

The Role of the Baryonic Gas Physics:

Evolution of Cluster Scalings in homogeneous quintessence models

$$T_X = A_{TM}\,(M/M_0)^{\alpha_{TM}}\,(1+z)^{\beta_{TM}}\,E(z)^{2/3}\,,$$
$$Y = A_{YM}\,(M/M_0)^{\alpha_{YM}}\,(1+z)^{\beta_{YM}}\,E(z)^{2/3}\,,$$
$$Y = A_{YT}\,(T_{mw}/T_{mw,0})^{\alpha_{YT}}\,(1+z)^{\beta_{YT}}\,E(z)^{-1}\,,$$
$$L_X = A_{LT}\,(T_X/T_{X,0})^{\alpha_{LT}}\,(1+z)^{\beta_{LT}}\,E(z)\,,$$
$$Y = A_{YL}\,(L_X/L_{X,0})^{\alpha_{YL}}\,(1+z)^{\beta_{YL}}\,E(z)^{-9/4}\,,$$

Aghanim, da Silva, Nunes, 2009, A&A, 496, 637



Temperature-Mass:

- model differences within error uncertainties

The Role of the Baryonic Gas Physics:

Evolution of Cluster Scalings in homogeneous quintessence models

$$T_X = A_{TM}\,(M/M_0)^{\alpha_{TM}}\,(1+z)^{\beta_{TM}}\,E(z)^{2/3}\,,$$

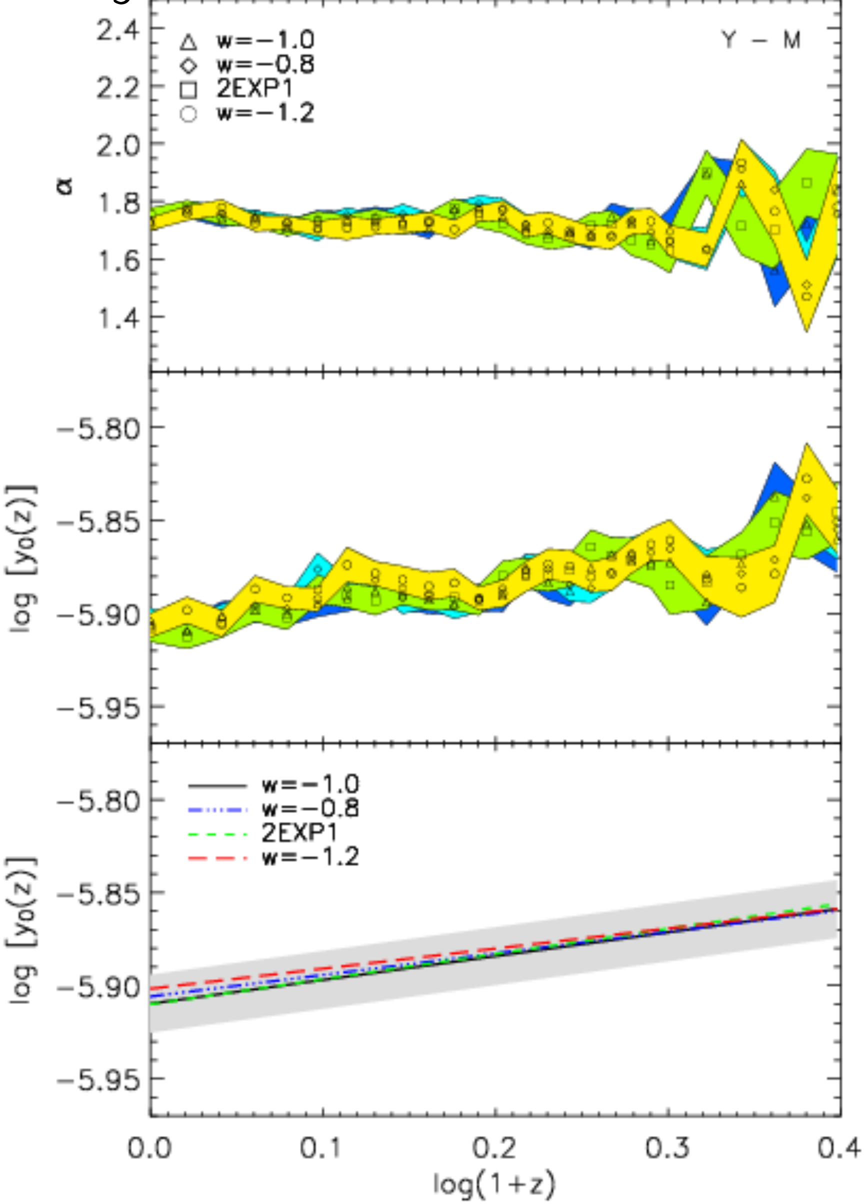
$$Y = A_{YM}\,(M/M_0)^{\alpha_{YM}}\,(1+z)^{\beta_{YM}}\,E(z)^{2/3}\,,$$

$$Y = A_{YT}\,(T_{mw}/T_{mw,0})^{\alpha_{YT}}\,(1+z)^{\beta_{YT}}\,E(z)^{-1}\,,$$

$$L_X = A_{LT}\,(T_X/T_{X,0})^{\alpha_{LT}}\,(1+z)^{\beta_{LT}}\,E(z)\,,$$

$$Y = A_{YL}\,(L_X/L_{X,0})^{\alpha_{YL}}\,(1+z)^{\beta_{YL}}\,E(z)^{-9/4}\,,$$

Aghanim, da Silva, Nunes, 2009, A&A, 496, 637

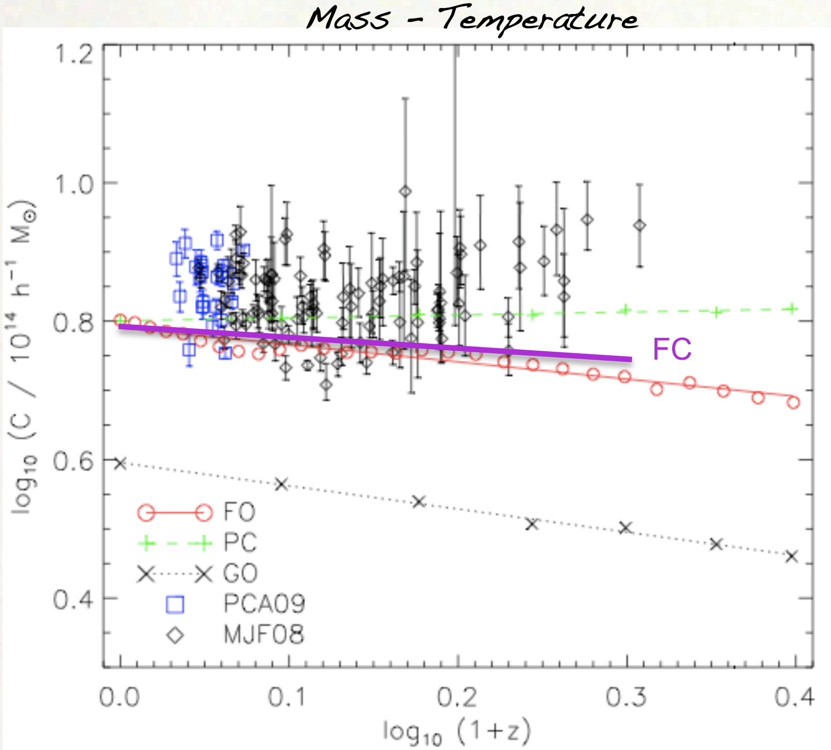


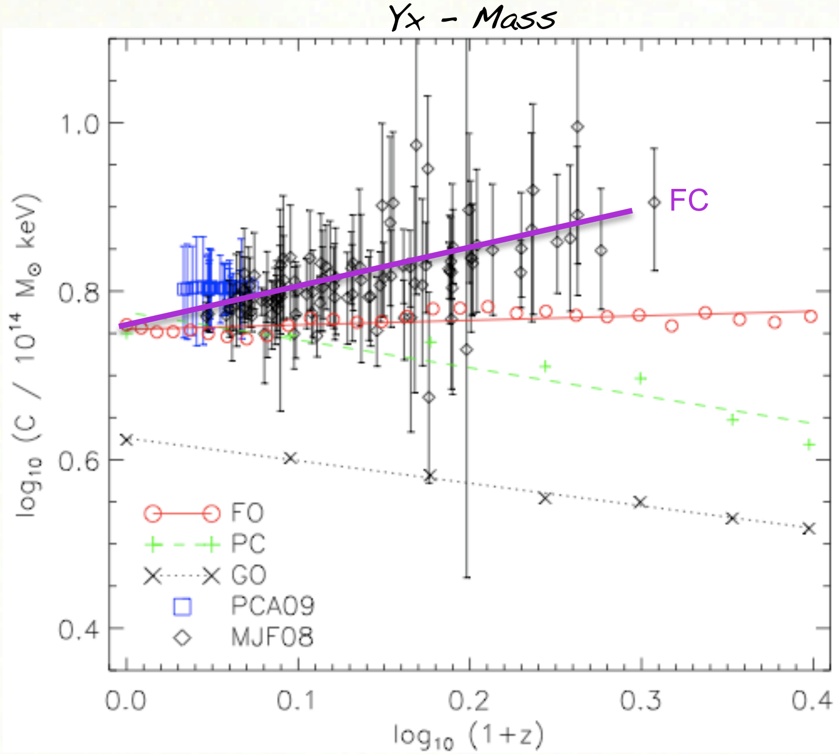
Integrated SZ Luminosity

- model differences within error uncertainties

The Role of the Baryonic Gas Physics

Evolution of Cluster Scalings: dependence with gas physics





Simulation data: GO: Adiabatic ; PC: Pre-heating+cooling; FO: hybrid implementation of feedback by galaxy population from Short, Thomas et al. (members of Millenium gas Project), astro-ph/1002.4539. CF: cooling+feedback from kay, da Silva et al. (clef-ssh collab.) MNRAS, 2007, 348, 1401

Observations: PCA09 from Pratt, Croston, Arnaud, Bohringer, 2009,A&ASup, 498, 361; MJF08: Maughan, Jones, Forman, Speybroeck, 2008, ApJ Supp, 174, 117

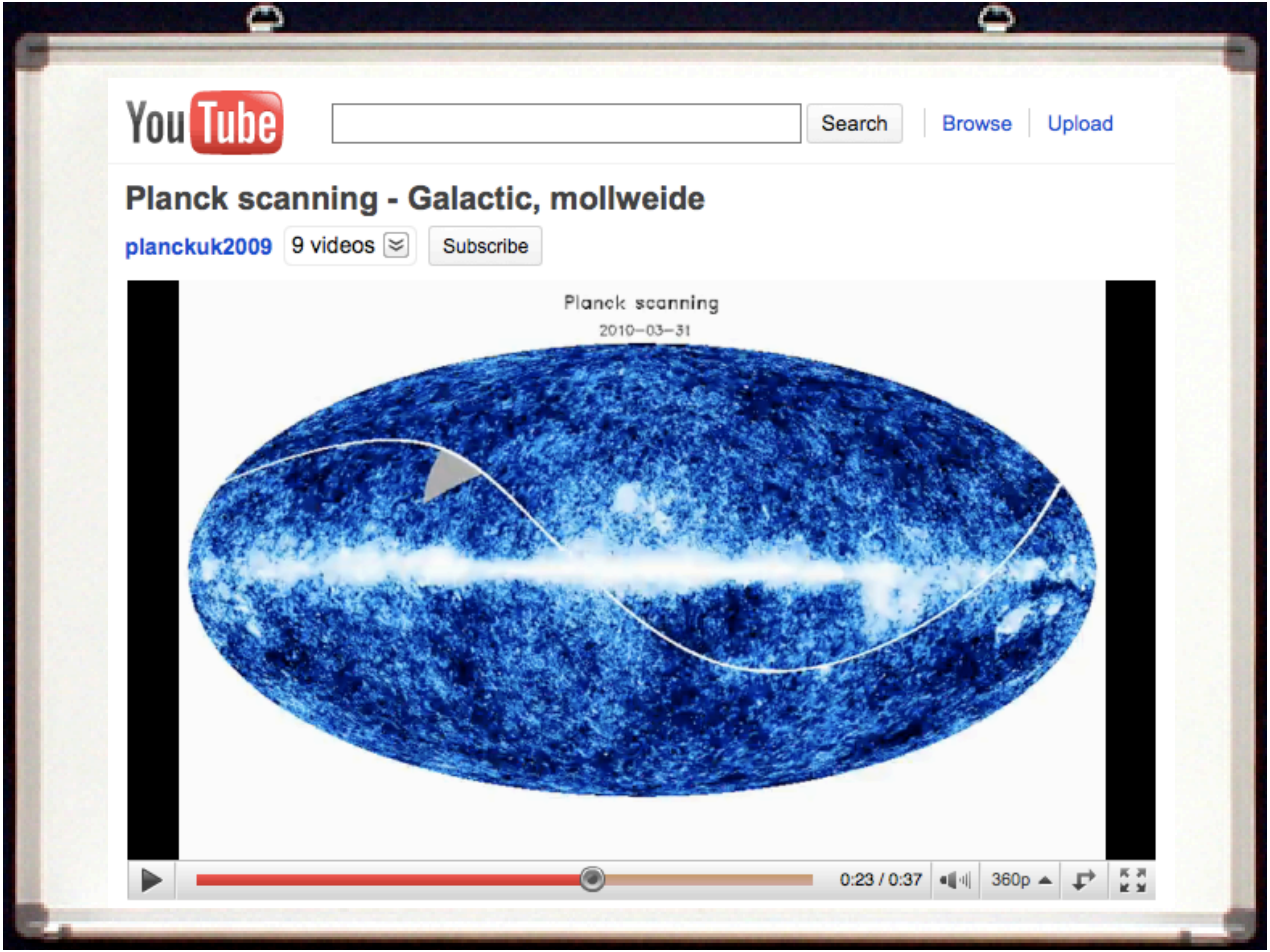
Concluding remarks:

Dark energy simulations of Clusters:

- Gas physics may mask/jeopardise DE parameter constraints
- Good knowledge of the main gas physical processes is necessary
- Cluster scalings in minimally coupled simulations appear fairly insensitive to DE
- If so, Lambda CDM scalings can be used for different DE models

The role of gas physics:

- No general consensus on scaling evolution has yet emerged from simulations or observations. Comparisons require care.
- High-quality, high-reshift observations play a crucial role in validating clusters as cosmological probes
- Large cluster surveys with good knowledge of selection effects will be most welcome!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planckuk2009
9 videos
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Planck scanning
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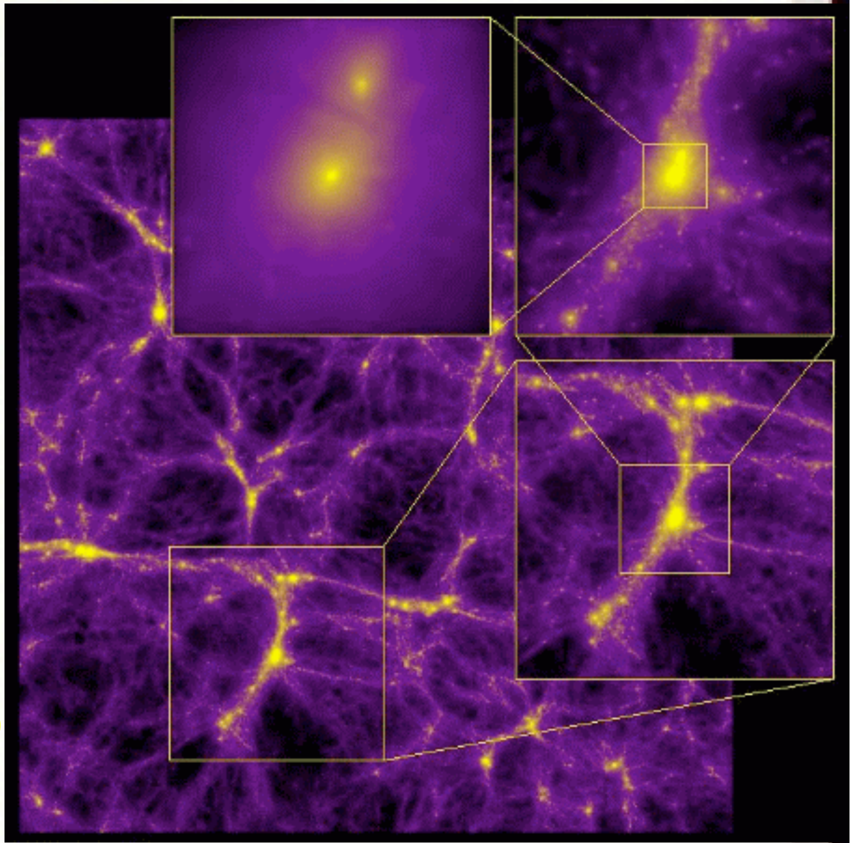
0:23 / 0:37
360p

LSS simulations:

CLEF simulations:

- concordance cosmology: L=200 Mpc/h ; N=2(428)^3
- hydrodynamics. with energy feedback and cooling
- clef-ssh collaboration: http://www.astro.up.pt/~asilva/CLEF_SSH/public/sim_runs_pub.html



Simulations for polarization studies:

- concordance model: L=80 Mpc/h ; N=2(256)^3
- hydrodynamics: Adiabatic
- Collaboration: G. C Liu (U. Taiwan); N. Aghanim (IAS)

Dark-Energy simulations:

- several dark-energy models: L=100 Mpc/h ; N=2(160)^3
- hydrodynamics: Adiabatic and cooling
- Collaboration: N. Nunes (Cambridge); N. Aghanim (IAS)

Simulations with Dust:

- concordance cosmology: L=100 Mpc/h ; N=2(160)^3
- hydrodynamics: several cooling dust models
- Collaboration with CESR, Ob-PM, IAS

CLEF simulation:

Large cluster catalogues:

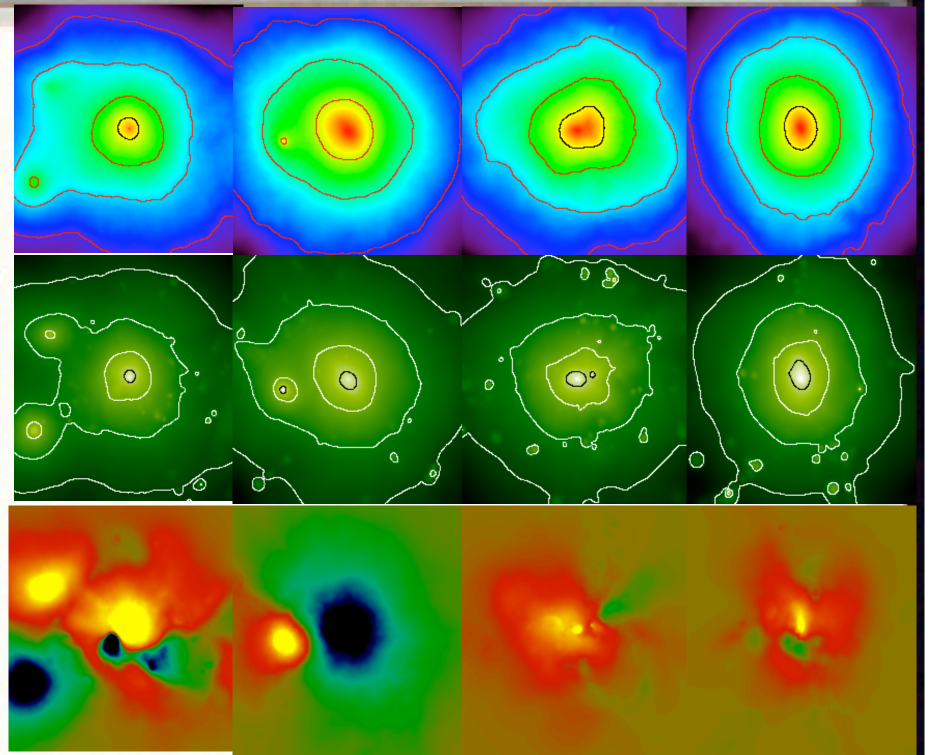
- wide range of mass: 2.5e13-2.5e15Msun/h
- 36 catalogues 0<z<1.5

~10 000 clusters 0<z<1.5

641 / 191 clusters at z=0 / z=1

-95 clusters at z=0 with Tsl>2keV

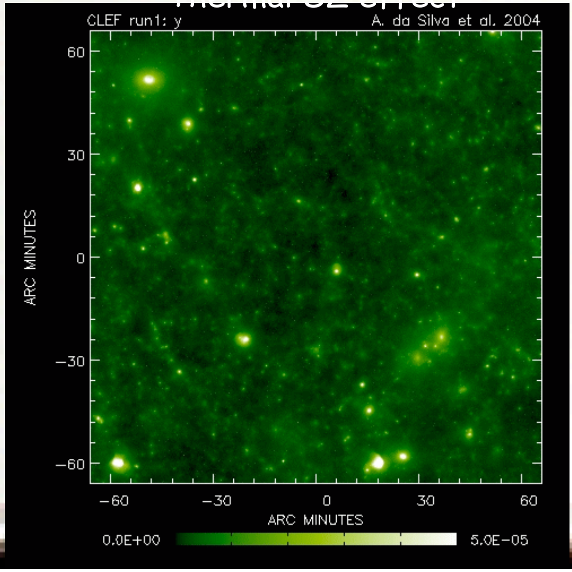
-57 clusters at z=1 with Tsl>2keV



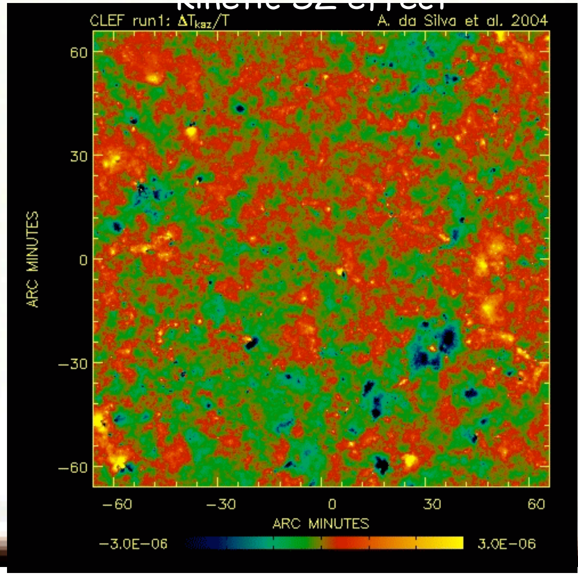
Sky patches (light cone integration):

- high-z convergence hydro quality maps
- characterization of the signal and selection function

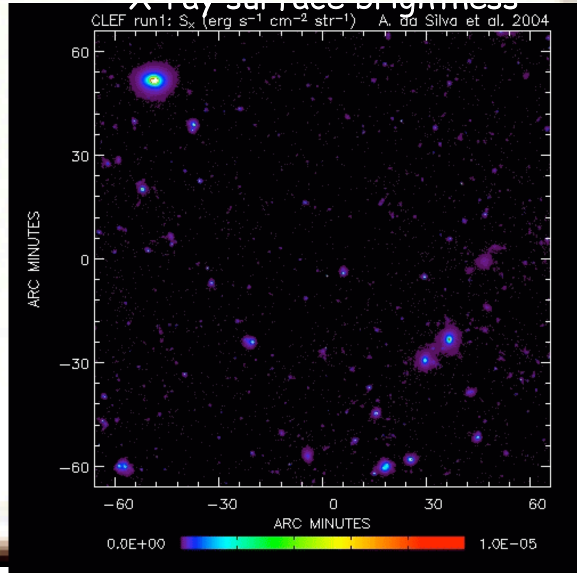
Thermal SZ effect



Kinetic SZ effect

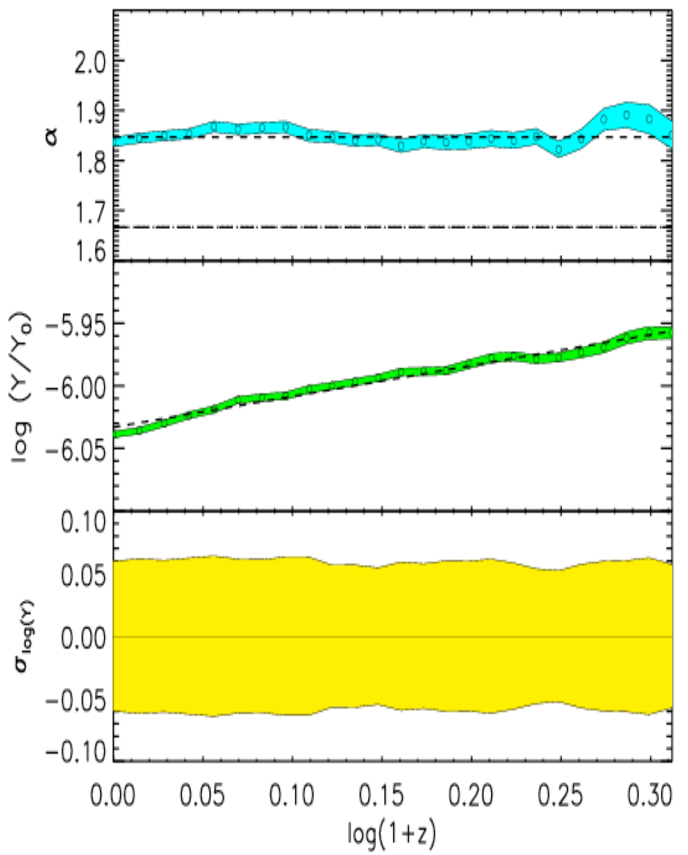


X-ray surface brightness



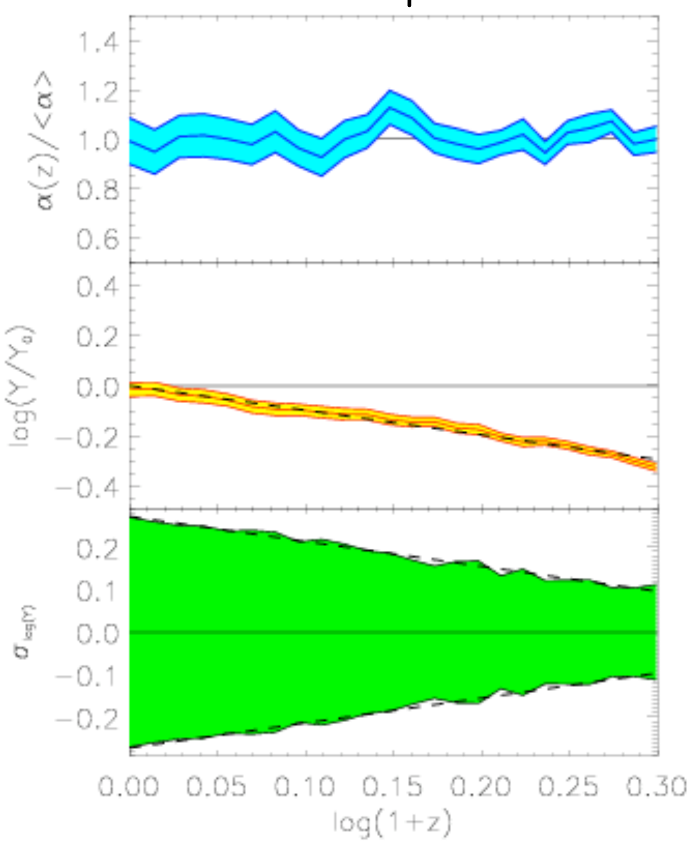
Evolution of scaling laws: $Y = C_0(z)\, X^{\alpha} = Y_0\, X^{\alpha}\, (1+z)^A$

YSZ-Mass



da Silva et al (clef-ssh collab.) in preparation

Lxbol-Temperature



Kay et al (clef-ssh collab.) MNRAS, 2007, 348, 1401

Ysz_Mass

-evolves positively relative to Self-Similar evolution: Y(M) ~ E(z)^5/3 (1+z)^0.3

Lxbol-Tsl

-evolves negatively relative to Self-Similar evolution: L(T) ~ E(z) (1+z)^-0.6

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