PROCEEDINGS OF SCIENCE

Galaxy Catalogs and the Diffuse Warm Gas Phase

Carlos Hernández-Monteagudo[*]
University of Pennsylvania
E-mail: `carloshm@astro.upenn.edu`

H.Trac,
Princeton University
E-mail: `htrac@astro.princeton.edu`

Raul Jimenez, Licia Verde
University of Pennsylvania
E-mail: `raulj,lverde@physics.upenn.edu`

We study the Compton scattering of Cosmic Microwave Background (CMB) photons off free electrons in the Universe (the so called thermal Sunyaev-Zel'dovich effect, [tSZ]). The spectral distortions introduced by this effect on the CMB can be used to search for the *missing baryons*. We analyse a state-of-the-art hydrodynamical cosmological simulation to study the different sources of tSZ: it shows that most missing baryons give rise to a negligible ($<1\%$) fraction of the total tSZ luminosity. However, we find a tight correlation between the galaxy number density and gas pressure, and this allows us to predict the tSZ from existing galaxy catalogs and propose methods to unveil diffuse gas in future CMB maps.

CMB and Physics of the Early Universe
International Conference
Ischia, Italy
20-22 April 2006

---

[*] Speaker.

PoS(CMB2006)038

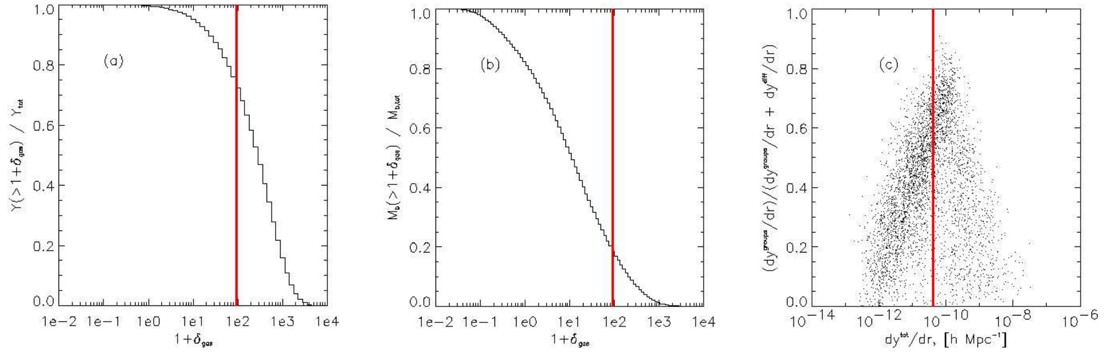

Figure 1: *(a)* Relative contribution to the total tSZ luminosity of regions with gas density contrast bigger than δ_{gas}. The vertical solid line indicates the average gas overdensity in haloes. *(b)* Relative contribution to the total baryon mass of regions with gas density contrast bigger than δ_{gas}. The vertical solid line indicates the average gas overdensity in haloes. Note the asymmetry with respect to the previous (left hand side) panel. *(c)* Ratio of the pressure generated in galaxy groups over the pressure generated in (diffuse gas + galaxy groups), versus the total pressure, in scales of ~ 12.5 h^{-1} Mpc. The vertical solid line denotes this time regions with the background matter density. We see that in slight overdense regions, the tSZ generated by the diffuse gas is most of the times negligible compared to that produced by small (and likely unresolved) haloes: only in very overdense environments, where all haloes are clusters, the diffuse gas component takes over.

Using a 200 h^{-1}Mpc side box hydrodynamical simulation with 1024^3 gas resolution elements and 512^3 Dark Matter particles we aim to study the main sources of the thermal Sunyaev-Zel'dovich (tSZ) effect in the local universe. The finite mass of the Dark Matter particle, close to 9.8×10^9 M$_\odot$ enables the identification of haloes of masses above $M > 10^{12}$ M$_\odot$, and this includes large galaxies, galaxy groups, galaxy clusters and superclusters of galaxies. The tSZ is a measure of the electron pressure, and for this reason we concentrate in those regions of the universe hosting larger combinations of gas density and temperature. In Figure (1a) the histogram already shows that most (>50%) of the pressure (here denoted by Y) is located in regions with gas overdensities above $\sim 50-200$, which correspond to collapsed structures (conservatively confined to the right of the red vertical line). The electron pressure is proportional to the radial derivative of the so-called Comptonization parameter y, i.e., $p_e \propto dy/dr \equiv y'$, and this is the proxy for pressure that we use henceforth. We consider three different environments where pressure is generated: clusters of galaxies (defined as haloes more massive than 5×10^{13} h^{-1}M$_\odot$, and giving rise to y'_{gc}), groups of galaxies (in the mass range M $\in$ [10^{12}h^{-1}M$_\odot$, 5×10^{13} h^{-1}M$_\odot$], and generating y'_{gg}), and diffuse gas, producing y'_{dg}. In our box, 70% of the total tSZ was generated in clusters of galaxies, where, out of the remaining 30%, almost 20% was generated in the diffuse gaseous phase, and around 11% in groups of galaxies. Note that, as displayed by Figure (1b), the histogram of the baryonic mass enclosed in the same gas overdensity regimes is very different: a significant amount of baryonic mass is already contained in regions of low overdensity ($\sim$ 80% in non-collapsed regions). The dependence of the y-ratios on the environment is given in Figure (1b), where the ratio $y'_{gg}/(y'_{dg}+y'_{gg})$ versus $y'_{gg}+y'_{dg}+y'_{gc}$ is shown: the relative weight of galaxy groups over the diffuse gas is important in slightly overdense regions (the red vertical line displays this time *average* environments

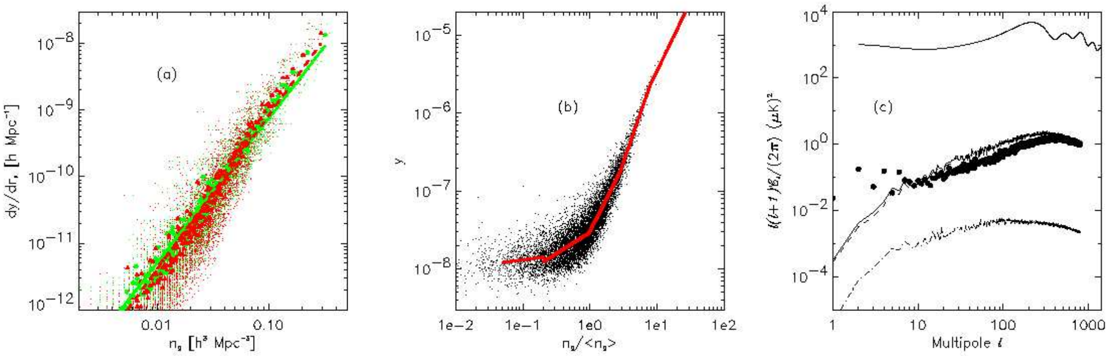

Figure 2: *(a)* Power-law correlation between the gas pressure and the the galaxy number density in scales of 12.5 h^{-1} Mpc: green dots correspond to the galaxy populating scheme given by [2], whereas red dots correspond to that of [3]. *(b)* Comptonization parameter y - projected galaxy overdensity correlation once a volumen inside a sphere of 300 h^{-1} Mpc radius has been projected onto a 2D sky map, as seen by an observed placed in the center of the sphere. Noisy at average galaxy densities, it becomes remarkably tigher as the projected number of galaxies increase. *(c)* After inverting the y-galaxy number relation on a galaxy catalog provided by the 2MASS survey, we obtain an estimation of the tSZ power spectrum (at Rayleigh-Jeans frequencies) for our universe (solid circles). The obtained shape and amplitude is not too different from the tSZ power spectrum obtained after projecting our box (solid line). The contribution of haloes to the tSZ is given by the dashed line (very close to the solid line), which renders the diffuse gas signature almost negligible (dot-dashed line, bottom of the plot).

without over/underdensities), but in environments close to superclusters, practically all haloes are clusters and diffuse gas takes over. (The sizes of the regions where pressure estimates have been averated are $\sim$ 12.5 h^{-1} Mpc). We conclude that, if detectable at all, this diffuse phase should be searched for in the outskirts of the most overdense regions in the universe.

Since galaxy groups and clusters are dominant sources of tSZ, it is obvious that there must be a correlation between the galaxy number density and the gas pressure of their environment: Figure (2a) shows this correlation after populating our haloes with galaxies following the procedures of [2] (green dots) and [3] (red dots): in both cases the slope is close to 2, which in the case of a polytropic gas ($p \propto \rho^{\gamma}$) would correspond to a self-gravitating system. The correlation permits characterising the pressure of the gas in a given environment once the galaxy population has been characterised, i.e., *it enables the prediction of the tSZ effect from optical or IR data.*

After placing an observer in the middle of our simulated box, and assuming that the universe was a periodic repetition of such box, we projected on a 2D sky map the galaxies and the pressure within a sphere of 300 h^{-1} Mpc radius. This permitted computing the correlation between the y Comptonization parameter and the projected galaxy overdensity, as shown in Figure (2b). Although the scatter is considerable where the galaxy density is close to the average, it becomes remarkably tight as the galaxy overdensity increases. Using the galaxy catalog provided by the Two Micron All Sky Survey, (2MASS, [1]), we conducted the reverse process and converted a 2D galaxy map into an estimation of the actual Comptonization parameter y map surrounding us. The power spectrum of such map is given by the filled circles in Figure (2c): its amplitude and shape

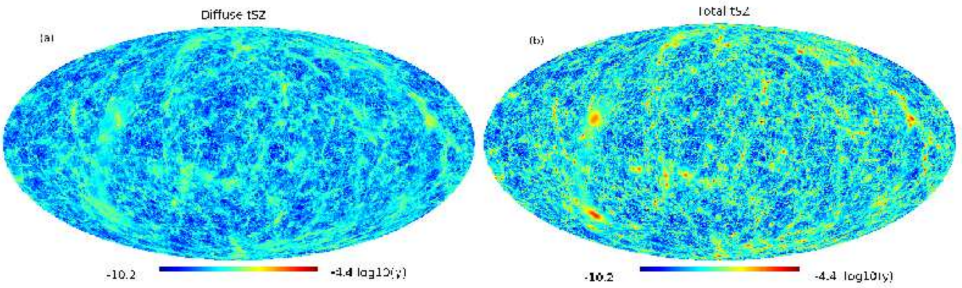

Figure 3: .*(a)* Map of the Comptonization parameter y produced by diffuse gas in our simulation. The depth of the projection is 300 h^{-1} Mpc. Note how it traces the filaments and superclusters defined by clusters of galaxies in the total tSZ map, *(b)* panel.

are very close to the power spectrum obtained from the tSZ map obtained from the simulation (solid line in Figure (2c)). This map can be seen in Figure (3b). The contribution from haloes can be separated from the total, and so the contribution from the diffuse gas. We find that the latter shows amplitudes typically 10 times smaller than the haloes, (100 times in the power spectrum, as dot-dashed line shows in Figure (2c)). The actual diffuse gas tSZ map is displayed in Figure (3a): the emission pattern is associated to those regions hosting the most massive galaxy clusters, and it is likely to be confused by foreground/background galaxy clusters, or even with smaller haloes present in the same environments. Only for those most nearby superclusters for which clusters have been accurately characterised, the poisson-like noise induced by random alignments with other tSZ sources may be controlled, possibly allowing for a direct detection of this diffuse gaseous phase. We end remarking, however, that most of the baryons are present in a diffuse warm medium filling the voids, and giving negligible ($\sim$ 0.3%) contribution to the total tSZ luminosity. Therefore we conclude that the tSZ will still miss most of the missing baryons.

References

[1] Jarrett, T. H., Chester, T., Cutri, R., Schneider, S. E., & Huchra, J. P. *The 2MASS Galaxy Atlas, AJ,* 125, 525, (2003).

[2] Scoccimarro, R., Sheth, R. K., Hui, L., & Jain, B.*How Many Galaxies Fit in a Halo? Constraints on Galaxy Formation Efficiency from Spatial Clustering*, *ApJ*, 546, 20, (2003), [`astro-ph/0006319`]

[3] Kravtsov, A. V., Berlind, A. A., Wechsler, R. H., Klypin, A. A., Gottlöber, S., Allgood, B., & Primack, J. R.*The Dark Side of the Halo Occupation Distribution*, *ApJ*, 609, 35, (2004), [`astro-ph/0308519`]