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THE SUNYAEV-ZELDOVICH EFFECT IN CLUSTERS OF GALAXIES AND THE HUBBLE CONSTANT

N. Falcón[1] and R. Génova-Santos[2]

RESUMEN

La tasa de expansión a gran escala del Universo está determinada por el valor de la constante de Hubble. Diversos métodos se han empleado en su determinación: anisotropías de la Radiación Cósmica de Fondo, observación de supernovas y galaxias activas a alto corrimiento al rojo. En este trabajo se emplea el método de Grainge, para estimar el valor de la constante de Hubble, H, usando el efecto Sunyaev-Zeldovich. Para ello se emplean resultados del interferómetro VSA (Observatorio del Teide) y los del satélite ROSAT de rayos X. El resultado obtenido, $h = 0.78$, es consistente con el reportado para otros cúmulos de galaxias y ligeramente diferente al valor de $h = 0.71$ obtenido por otros métodos. Se discuten las posibles discrepancias en términos de las hipótesis de isotermalidad y esfericidad de los cúmulos, y del efecto cinético Sunyaev-Zeldovich.

ABSTRACT

The large scale expansion rate of the Universe is given by the value of the Hubble constant. Several methods have been used to determine the Hubble constant: CMB anisotropies, supernovae observations, and AGN at high redshift. In this work we use the Grainge method to estimate the Hubble constant by using the Sunyaev-Zeldovich effect with data from the VSA interferometer (Observatorio El Teide) and the X-Ray data from ROSAT. The derived $h = 0.78$ is consistent with the reported value obtained with a different set of clusters of galaxies, and it is slightly higher than the $h = 0.71$ derived with other methods. We discuss the possible discrepancies in terms of the isothermal and spherical cluster hypothesis, and the the Sunyaev-Zeldovich kinetic effect.

Key Words: galaxies: clusters — cosmology — large scale structure of the universe

1. INTRODUCTION

The scattering of cosmic microwave background radiation by the electronic plasma in the hot gas (inverse Compton scattering), is the very well known Sunyaev-Zeldovich effect (SZ). Clusters of galaxies contain extended atmospheres of hot gas and may be sources of detectable SZ effect. The SZ measured in galaxy clusters can be used to determine the Hubble Constant (H_0). The Hubble constant can be reasonably estimated by observing distant type Ia supernovae, however its estimates through SZ and measured X-ray in galaxy clusters does not require empirical calibrating distance and can be used for all redshift.

This method has been used in several clusters of galaxies, but the results are inconclusive because until now, detection of SZ has only been possible in few clusters of galaxies or with high inceteza in the determination truthful in the magnitude of the SZ effect (Grainge et al. 2002). We will use this method to estimate the Hubble Constant using the VSA interferometric telescope for various clusters of Galaxies (Lancaster et al. 2005). As usual we use $H_0 = 100$ h km s^{-1} Mpc^{-1}, with h in the range $(0, 1)$. The SZ effect is manifested, depending on the frequency of observation, as a variation of the intensity of the cosmic microwave background (see Lancaster et al. (2005) for detail) and their magnitude is given by

$$\frac{\Delta T(\kappa)}{T_{\mathrm{CMB}}} = y_c \left[\kappa\ \coth(\kappa/2) - 4\right] \equiv y_c g\,, \tag{1}$$

where κ is the factor frequency, and (y_c) is the Comptonization parameter, it only depends on temperature plasma (T_e) and electronic density. Both contributions are integrated along the line of sight so the SZ effect is independent of distance. It is necessary to specify the distribution of gas in galaxy clusters. In this paper we use the beta model (Cavaliere & Fusco 1976) where the density is written in terms of the number density of electrons (n), the index β, and R_c the radius of the nucleus. Thus the

[1]Depto. de Física, FACYT, Universidad de Carabobo, Apdo. Postal 129, Avda. Bolívar Norte, Valencia, Edo. Carabobo, Venezuela (nfalcon@uc.edu.ve).

[2]Instituto de Astrofísica de Canarias, Spain (rgs@ll.iac.es).

TABLE 1

NORMALIZED HUBBLE CONSTANT (H) FOR STANDARD COSMOLOGICAL MODELS

Cluster	SCDM	CDM	ΛCDM
A401	$1.25^{+1.06}_{-1.21}$	$1.29^{+1.09}_{-1.24}$	$1.35^{+1.14}_{-1.30}$
A478	$0.89^{+1.51}_{-0.87}$	$0.92^{+1.86}_{-0.90}$	$0.97^{+1.65}_{-1.30}$
A1795	$0.42^{+0.29}_{-0.39}$	$0.43^{+0.30}_{-0.39}$	$0.45^{+0.31}_{-0.41}$
A2142	$1.83^{+1.28}_{-1.23}$	$1.89^{+1.33}_{-1.27}$	$2.00^{+1.40}_{-1.34}$
Coma	$0.93^{+0.27}_{-0.28}$	$0.93^{+0.28}_{-0.28}$	$0.95^{+0.28}_{-0.28}$
Mean	$0.78^{+0.27}_{-0.21}$	$0.79^{+0.20}_{-0.21}$	$0.81^{+0.20}_{-0.22}$

Comptonization parameter is now

$$y_c = \frac{2k_B\sigma_T}{m_e c^2} T_e n_0 R_c \int_0^\infty \left[1+\rho^2\right]^{-3\beta x/2} d\rho\,. \quad (2)$$

For frequencies bellow 218 GHz, $g = -2$ (Rayleigh-Jeans regimen), the SZ effect is shown as a decrement in the interferometer images of the galaxies clusters, with temperature decrement given by

$$\Delta T_{\rm SZ} \propto -42.6\langle\mu K\rangle \left[\frac{K_B T_e}{\rm keV}\right]\left[\frac{n_0}{10^{-3}{\rm cm}^{-3}}\right]\left[\frac{R_c}{\rm Mpc}\right]. \quad (3)$$

This distortion in the CMB map is function of the Comptonization parameter and therefore, depends on the geometric distribution of hot gas in the super structure. If we assumed, as a first approximation, that the gas is isothermal we can express the X-ray luminosity (LX) in terms of observables as (Peebles 1993):

$$L_X \cong 1,4\,10^{35}\langle W\rangle \left[\frac{T_X}{\rm keV}\right]^{1/2}\left[\frac{n_0}{{\rm cm}^{-3}}\right]^2\left[\frac{R_c}{\rm kpc}\right]^2. \quad (4)$$

It is clear that this relationship can be used to derive the number density of particles n_0 whenever the X-ray luminosity is known. Furthermore, the profiles of X-ray brightness in the clusters of galaxies fits curves to obtain the parameters n_0, R_0 and β, and measured the effective electronic temperature.

2. RESULTS AND DISCUSSION

Obviously, if $R_c \propto h^{-1}$ and $n_0 \propto h^{1/2}$ as the usual X-ray data, then we can use the equation (3) to determine the coefficient of the Hubble Constant (h)

$$h = \left[\frac{\Delta T^X_{SZ}}{\Delta T_0^{\rm (Obs)}}\right]^2, \quad (5)$$

where the superscript "X" denotes that the central density is calculated using the data of X-rays and the banner "Obs" refers to the SZ temperature decrease. We conducted our estimate for three different cosmological models: SCDM ($\Omega_M = 1.0\,\Omega_\Lambda = 0.0$), CDM ($\Omega_M = 0.3\,\Omega_\Lambda = 0.00$) and ΛCDM ($\Omega_M = 0.3\,\Omega_\Lambda = 0.7$). The values obtained for each cosmology are shown in Table 1, for those clusters where detection of SZ effect is reliable, namely the signal is greater than three times the rms value of the map or region detected. For details of the interferometer observations with VSA see Lancaster et al. (2005).

3. CONCLUSION

The greatest potential source of systematic error is the isothermal assumption for the clusters atmosphere, therefore the overall profile of temperature can decrease the radius and the fraction of baryonic mass can grow with the radio. For example in a non isothermal gas model the X-ray emission (Falcon 2007), which includes A478, A1795, A2142, the baryonic mass fraction can be greater than 20%. The assumption of a spherical profile density could be another source of error, in particular for A478 and A1795. A more realistic estimate for the Hubble Constant: $H_0 = 75 \pm 18\ {\rm kms}^{-1}\ Mpc^{-1}$ (ΛCDM), has been obtained for the cluster A2142 in good agreement with other recent determinations (Falcon 2007).

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