THE SUNYAEV-ZEL'DOVICH EFFECT AND H_0

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ABSTRACT. Observational data on the Sunyaev-Zel'dovich effect for three clusters are used to obtain limits to the value of the Hubble constant. Only a wide bound on the value of H_0, $10\ \mathrm{km\,s^{-1}\,Mpc^{-1}} < H_0 < 160\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$, can be derived, mostly because of the large uncertainty in the measured temperature of the intracluster medium in each cluster. Better information on this temperature and on the distribution of the intracluster medium are needed for this method to yield a good measurement of H_0.

1. THE USE OF THE SUNYAEV-ZEL'DOVICH EFFECT TO MEASURE H_0

The Sunyaev-Zel'dovich effect is a change of brightness of the microwave background radiation produced by its inverse-Compton scattering by electrons in a hot intracluster medium (Sunyaev & Zel'dovich 1972). The X-ray surface brightness of the intracluster medium is usually approximated by

$$l_X \approx l_0 \left(1 + \frac{\theta^2}{\theta_c^2}\right)^{\frac{1}{2} - 3\beta}$$

with $\beta \approx 0.5$. If the intracluster medium is isothermal, the predicted microwave background decrement is

$$\Delta T_{RJ} = \Delta T_0 \left(1 + \frac{\theta^2}{\theta_c^2}\right)^{\frac{1}{2} - \frac{3}{2}\beta}$$

where ΔT_0, the central decrement, and l_0, the central X-ray surface brightness, are related by

$$\frac{\Delta T_0{}^2}{l_0} = 55\, \frac{T_r^2}{\Lambda(T_g)} \left(\frac{k\, T_g}{m_e\, c^2}\right)^2 \sigma_T^2\, D_A\, \theta_c$$

for $\beta = 0.5$. ΔT_0, l_0, θ_c and β can be fitted from the observed Sunyaev-Zel'dovich data and X-ray images, the gas temperature T_g can be derived from X-ray spectra, the X-ray emissivity $\Lambda(T_g)$ is a known function of T_g, and T_r (the radiation temperature of the microwave background radiation), k, m_e, c, and σ_T are known constants. This relation can, therefore, be used to determine the angular diameter distance D_A of a cluster of galaxies, and hence the Hubble constant. This method has been described by a number of authors (Gunn 1978; Silk & White 1978; Cavaliere *et al.* 1979; Birkinshaw 1979).

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2. THE DATA

The Sunyaev-Zel'dovich data are taken from the results of OVRO observations made over the period 1982-6, which add the data taken during the 1985-6 season to those summarized in Birkinshaw & Moffet (1986). These data have been corrected for the presence of weak non-thermal radio sources lying near the clusters, and they have been adjusted to make an allowance for the maximum likely residual systematic errors. The central microwave background decrements, ΔT_0, (deconvolved for the telescope beam) are given in Table 1.

Table 1. Central Sunyaev-Zel'dovich effects ($\beta = \frac{1}{2}$)

cluster	ΔT_0/mK
0016+16	-0.92 ± 0.19
A 665	-1.01 ± 0.16
A 2218	-0.63 ± 0.13

The values of θ_c needed in the deconvolution were taken from the X-ray data of White *et al.* (1981), Forman & Jones (private communication) and Boynton *et al.* (1981). The central X-ray surface brightnesses, l_0, were derived from the fluxes given in these papers, and approximate gas temperatures were derived from the *Einstein* X-ray data for 0016+16 ($T_g > 6$ keV; White *et al.* 1981) and A 2218 ($T_g = 11^{+\infty}_{-4}$ keV; Perrenod & Henry 1981). For A 665 and A 2218, estimates of T_g may also be derived from the cluster velocity dispersions, σ_v (subject to the assumed value of β), since $\beta = \mu m_p \sigma_v^2 / kT_g$ (Cavaliere & Fusco-Femiano 1976). The results for an assumed $\beta = \frac{1}{2}$ are 29 ± 16 keV and 24 ± 7 keV, respectively, and are probably overestimates (Mushotzsky 1984). The uncertainties in the temperatures derived from the velocity dispersions are too large for these estimates to be useful at present, but T_g may be derived in this way in the future if more accurate values of σ_v can be measured and if β can be determined independently.

3. RESULTS

The gas temperature, the central Sunyaev-Zel'dovich decrement, the central X-ray surface brightness, and the structural data can now be combined to produce an independent estimate of the distance (and hence the Hubble constant) for each cluster. The values obtained for H_0 are $> 11\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$ from the data for 0016+16 and $70 \pm 90\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$ from the data for A 2218 (using the X-ray inferred gas temperatures). The large errors in these estimates reflect mostly the uncertainties in the values of T_g, and indicate that accurate estimates of the Hubble constant can be derived from this method only with better (error less than 1 keV) measurements of T_g. At present it is more useful to invert the argument and predict the gas temperatures that would be inferred from good X-ray spectra for these clusters for different assumed values of the Hubble constant. These temperatures are given in Table 2.

Table 2. Predicted T_g for two values of H_0

cluster	$H_0 = 50\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$	$H_0 = 100\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$
	T_g/keV	T_g/keV
0016+16	8 ± 3	12 ± 4
A 665	10 ± 2	14 ± 2
A 2218	10 ± 2	13 ± 3

It can be seen that *overall* the predicted gas temperatures are significantly higher for $H_0 = 100\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$. The difference between the gas temperatures for the two cases suggests that a test for the value of H_0 between the bounds of 50 and 100 $\mathrm{km\,s^{-1}\,Mpc^{-1}}$ may be possible with X-ray spectra with high signal/noise near 10 keV. The values of T_g predicted in Table 2 were derived for an isothermal model with $\beta = \frac{1}{2}$, but are found to depend only weakly on β.

4. THE FUTURE

This method of limiting the value of the Hubble constant may become important if good X-ray data on these clusters of galaxies, or good Sunyaev-Zel'dovich data on nearer clusters of galaxies (for which extensive X-ray data are already available) can be obtained. High quality data should allow the systematic uncertainties in the H_0 estimate caused by the unknown equation of state of the gas (assumed here to be isothermal) and the uncertain value of β (taken to be $\frac{1}{2}$) to be resolved.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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DISCUSSION

ELLIS: Why in the case of 0016+16 were you only able to determine an upper limit to the angular diameter distance? Is the X-ray data inadequate? I thought it was one of the strongest distant X-ray clusters.

BIRKINSHAW: The limit to D_A arises from the lower limit to the gas temperature (T_g > 6 keV) for this cluster. Although 0016+16 is very X-ray luminous, its flux is small, and it is difficult to extract any temperature information from the Einstein data.

CANIZARES: How sensitive is your determination of H_o to the assumption that the X-ray gas is isothermal?

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BIRKINSHAW: Quite sensitive - but in principle this assumption, like the β-parameter assumption, can be tested by comparing X-ray and Sunyaev-Zel'dovich effect maps of the clusters, by using a spatially-resolved X-ray spectrum, or by doing a better job of modelling the X-ray emitting gas.

MANDOLESI: Have you taken into account the emission from weak, unresolved radio sources?

BIRKINSHAW: Yes. The emission from these sources was measured in a multi-frequency VLA survey of the fields of each of these three clusters.

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