Constructing the Universe with Clusters of Galaxies, IAP 2000 meeting, Paris (France) July 2000
Florence Durret & Daniel Gerbal eds.

SPECIFIC ENTROPY IN X-RAY CLUSTERS OF GALAXIES

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It has been shown that self-gravitating systems such as elliptical galaxies have a constant specific entropy and obey a scaling law relating their potential energy to their mass (see Márquez's talk in this workshop), properties which might be due to the physical processes involved in the formation of these structures. Since the X-ray gas in clusters is weakly dissipative, we have checked the hypothesis that it might verify similar properties.
We have analyzed ROSAT-PSPC images of 15 clusters, fitting the density profile of the intracluster gas by a Sersic law. We also found that: 1) all these clusters roughly have the same specific entropy and 2) a scaling law linking the potential energy to the mass of the X-ray gas is observed, with the same slope as that found in elliptical galaxies.
We also found that the Sersic law parameters (intensity, shape and scale) are correlated two by two.

1 Introduction

Clusters of galaxies are self-gravitating and in majority relaxed systems. One interesting subject is to study the physical processes involved in the formation and evolution of these structures.

The analysis of the properties of elliptical galaxies, which are also self-gravitating and relaxed systems, has shown that they all have the same specific entropy (entropy per unit mass) (Gerbal et al. 1997, Lima Neto et al. 1999, Márquez et al. 2000a). It has also been shown that a scaling law exists between the potential energy and the mass in this type of galaxies (Márquez et al. 2000b). Such relations are a consequence of the formation and evolution processes undergone by these objects.

We have searched if the X-ray gas in clusters of galaxies showed similar properties, since this could give us information on the physics of the formation and evolution of these larger structures.

2 The sample

The data used in the present work are observations taken with the ROSAT-PSPC camera in the 0.44 - 2 keV range, retrieved from the archive. This first selection includes 15 nearby clusters of galaxies ($0.02 < z < 0.3$). The selection was made taking into account: *i)* a long exposure time, *ii)* a regular and near-spherical shape, *iii)* the light curve for each band considered (clusters with strong contamination were excluded), and *iv) the absence of substructures.*

The data reduction was done using the sofware developed by Snowden (Snowden et al., 1994).

The ROSAT PSPC image of the cluster Abell 2029 is shown in Fig. 1 as an example.

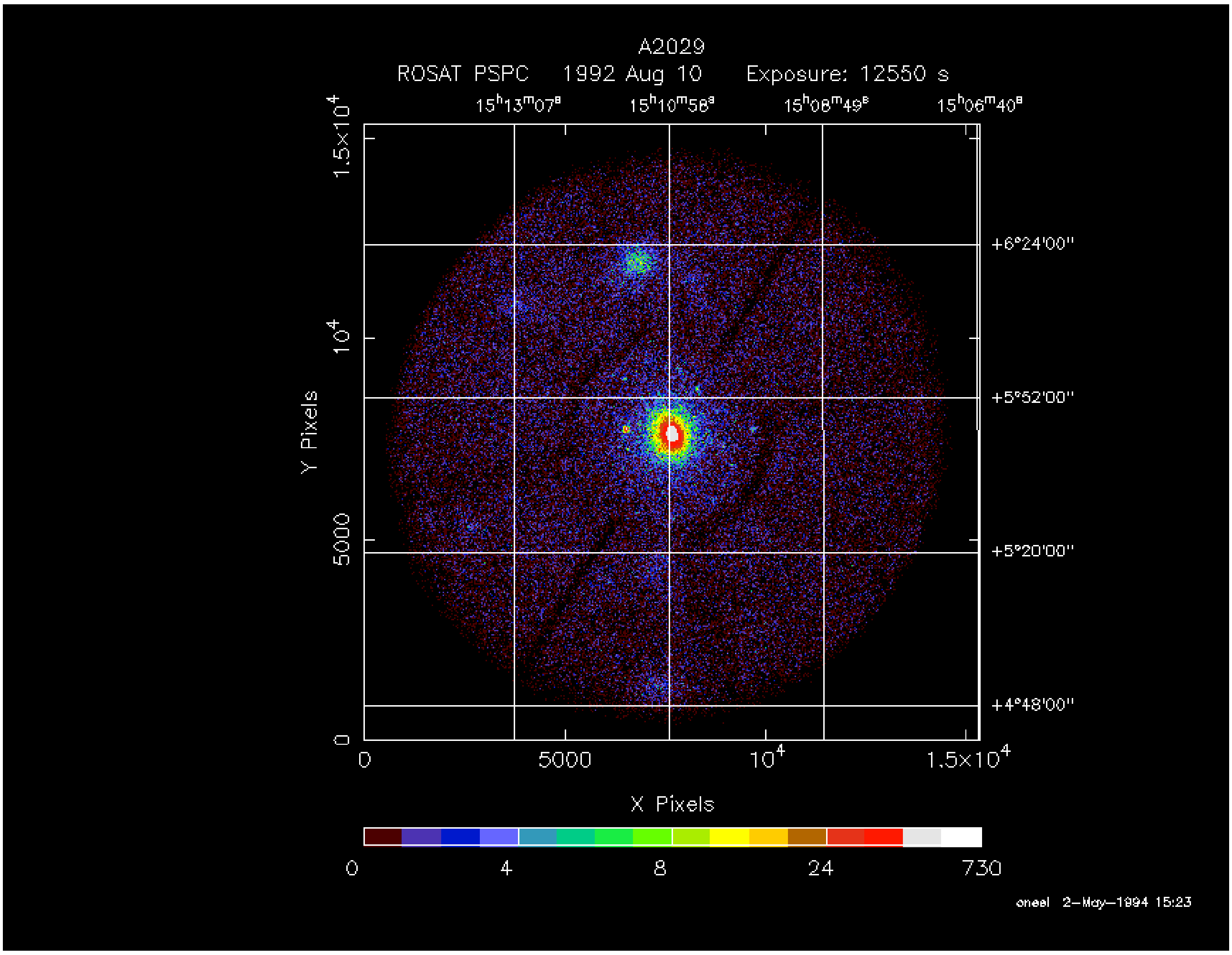

Figure 1: A2029 X-ray image from ROSAT (PSPC-B).

3 How to compute the specific entropy, the mass and the potential energy in a cluster of galaxies

The specific entropy for a system of particles can be obtained from their distribution function in the phase space $f(\overrightarrow{x}, \overrightarrow{v})$ by using the microscopic Boltzmann-Gibbs definition:

$$s \equiv \frac{S}{M} = -\frac{1}{M} \int f \; ln(f) \; d^3x \; d^3v \tag{1}$$

f is obtained by Abel inversion from the density profile. In order to do this, we have used the following hypothesis: 1) spherical symmetry, 2) isotropy of velocity dispersion and 3) $\rho_{DM} \propto \rho_{gas}$.

In order to find the 3D gas density profile for each cluster, we deproject a Sersic law:

$$\Sigma(s) = \Sigma_0 \; exp\left[-\left(\frac{s}{a}\right)^{\nu}\right] \tag{2}$$

where ν is ta shape parameter, Σ_0 is a normalisation factor and a is a scale parameter which is also distance-dependent.

The specific entropy is given by (Lima Neto et al., 1999; Márquez et al., 2000a and b):

$$s = \frac{1}{2}\, ln\, \Sigma_0 \; + \frac{5}{2}\, ln\, a \; + F(\nu) \tag{3}$$

where F is a function of the ν parameter which can be approximated by:
$F(\nu) \simeq 0.205\, ln(\nu) - \frac{1.34}{\nu} \; + \; 3.85 \left(\frac{1}{\nu}\right)^{1.29} \; - \; 2.66$

The total mass and potential energy from Sersic profile are:

$$M_{tot} = 2\,\pi\, a^2\, \Sigma_0\, \frac{1}{\nu}\, \Gamma(\frac{2}{\nu}) \tag{4}$$

$$U_{pot} \equiv \frac{M_{tot}^2}{R_g} = 4\,\pi^2\, a^3\, \Sigma_0^2\, \frac{(\frac{1}{\nu} \; : \Gamma(\frac{2}{\nu}))^2}{R_g^*} \tag{5}$$

where $G = 1$ and R_g is the gravitational radius defined by $R_g \; = \; a\, R_g^*$. Here a is the scale parameter and R_g^* is a dimensionless radius given by the numerical approximation (Márquez et al., 2000):
$ln(R_g^*) \; \simeq \; \frac{0.82032 - 0.92446\, ln(\nu)}{\nu} \; + \; 0.84543.$

The specific entropy, mass and potential energy are then available.

4 How to calculate the density profile from ROSAT images?

We fit the images by a pixel-to-pixel method (code developed by V. Pislar, then F. Magnard) which: i) creates a 3D model of the X-ray emission and ii) projects this model by integration on the line of sight (taking into account the energy response and the point spread function). The result is a synthetical image which can be compared with the ROSAT observation.

The fitting process is carried out with the MINUIT library (James 1994) and allows us to get the 3D density profile. The projection of this profile in 3D is the best approximation to the analytical 2D Sersic profile. Fig. 2 shows the superposition of the X-ray isophotes of the model (in red) and the observation (in green) for the cluster A2029, illustrating the good quality of our fit. In Fig. 3 the 2D and 3D density profiles are shown for the same cluster.

5 Results and conclusions

1) A linear relation exists between the entropy S and the mass M of the X-ray gas (see Fig. 4):

$$s_0 = \frac{S}{M} = 17.1 \pm 0.6$$

$\Longrightarrow$ The specific entropy is constant.

2) A scaling law is observed between the potential energy U and the mass M of the X-ray gas (see Fig. 5):

$$ln(U) \; - \; I\, ln(M) = e_0$$

with $I \simeq 1.67$

These two results are comparable to those found for elliptical galaxies.

6 What are the differences between elliptical galaxies and the X-ray gas in clusters?

A second order effect exists (see Fig. 6): the specific entropy depends on the mass (luminosity) as $s = s_0 + \beta \, log(M)$, where $\beta \simeq 2.6$ for clusters and $\beta \simeq 1$ for ellipticals.

For galaxies, this dependence is due to merging processes (Lima Neto et al., 1999).

The stronger dependence of s with mass for clusters suggests that dissipation processes such Bremsstrahlung ($L \propto M^2$) or cooling flows play a role.

7 Perspectives

- Increase the number of clusters in our sample in order to improve the statistics.
- Extend this study to clusters of galaxies at high redshift, using the new generation satellites such as Chandra and XMM-Newton
- Compare results for low and high redshift clusters in order to obtain informations on the evolution of the specific entropy with time
- Study the correlations between the Sersic parameters taken two by two for high z clusters of galaxies

References

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6. S. L. Snowden and K. D. Kuntz. *Cookbook for analysis procedures for Rosat XRT observations of extended ob jects and the diffuse background, part I: individual observations.* US ROSAT Science Data Center, NASA/GSFC, 1994.

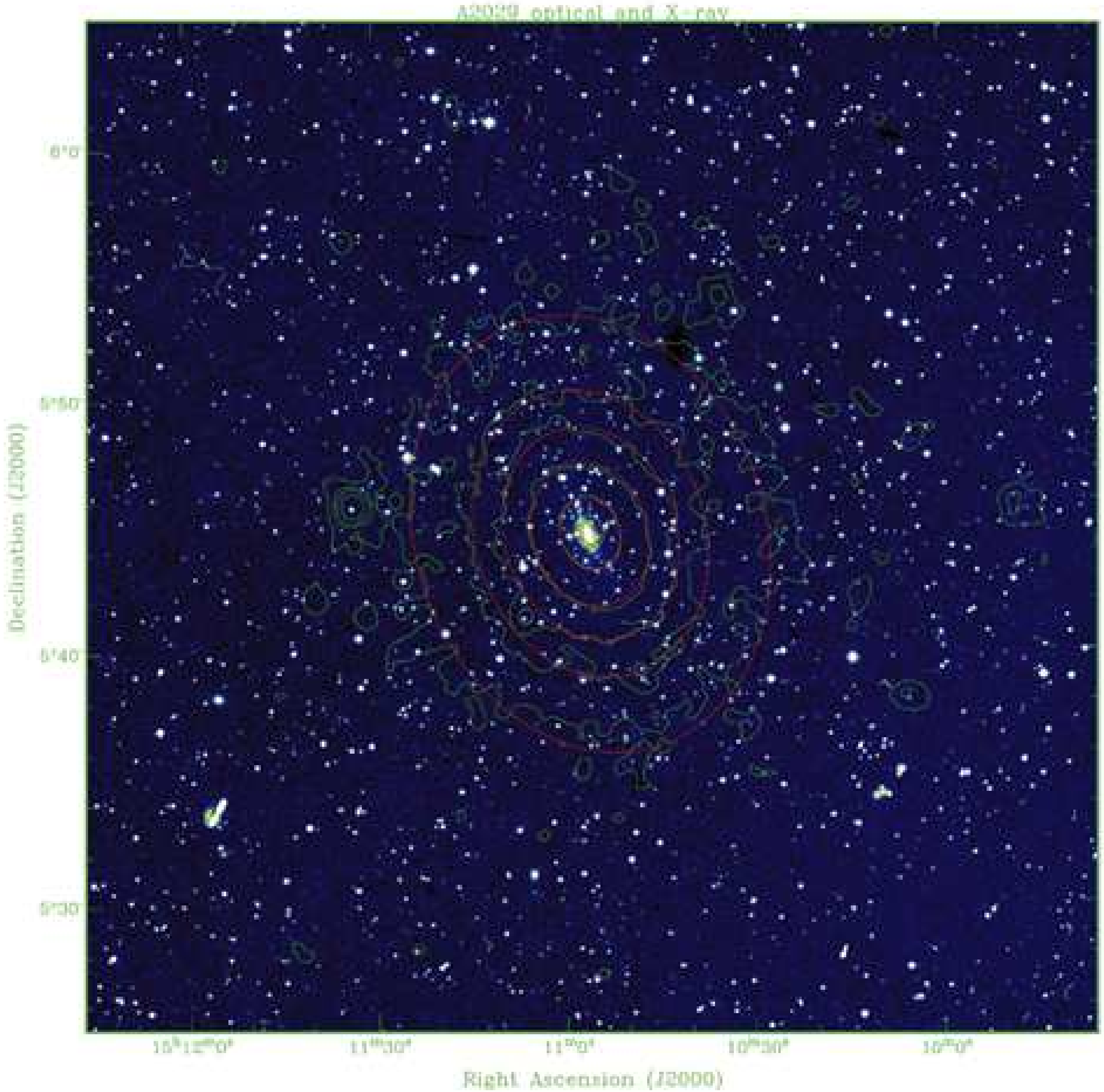

Figure 2: A2029: superposition of the X-ray isophotes for the model (in red) and the observation (in green). This image illustrates the good quality of our fit. The background corresponds to the optical image.

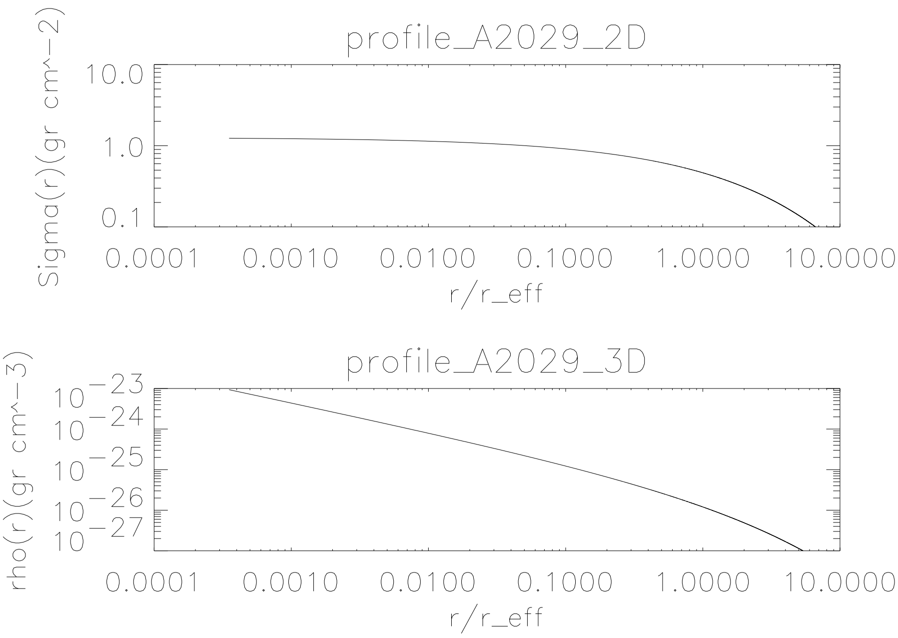

Figure 3: A2029: Sersic density profile (upper plot) and 3D density profile (lower plot). Here $r_{eff} \sim 2800\ kpc$ is an effective radius which contains half of the gas mass.

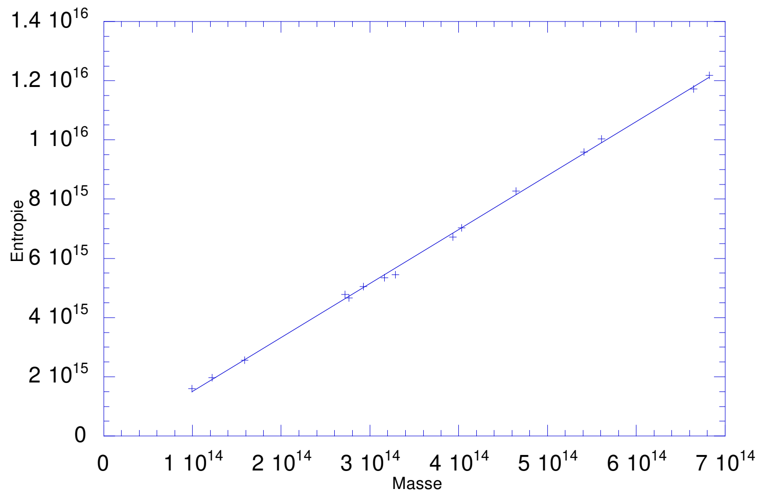

Figure 4: Entropy - mass relation. The linearity shows that the specific entropy in clusters of galaxies is constant.

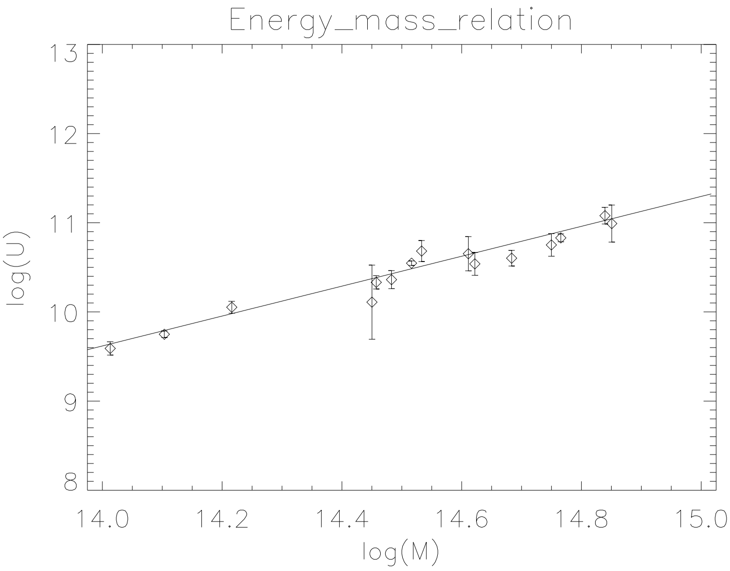

Figure 5: Scaling law between potential energy and gas mass in clusters of galaxies.

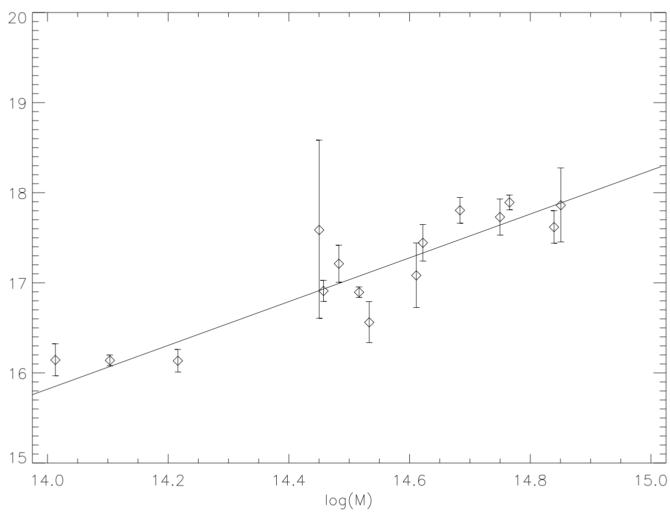

Figure 6: Second order relation between the specific entropy and mass. The stronger dependence of s with mass compared to that for ellipticals, suggests that dissipation processes are more important in clusters.