Astronomisches Rechen-Institut
Zentrum für Astronomie der Universität Heidelberg

Galaxies / Extragalactic Astronomy WS 2007/08

Exercise Sheet 10

To be handed in on Thursday Jan 31 in the exercise class

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12 – The bullet cluster

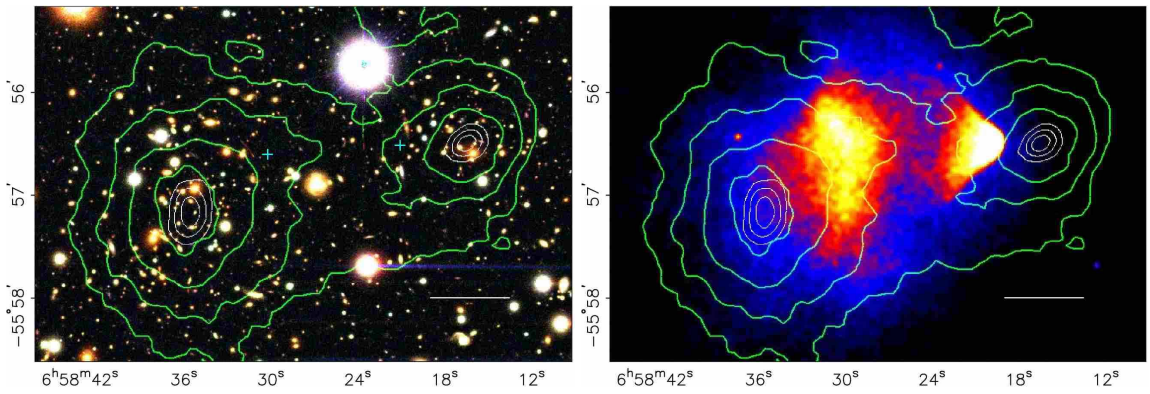

Figure 1: *Left:* Optical image of the "bullet cluster", 1E 0657-558. *Right:* X-ray image showing the hot intracluster gas. In both panels, the density contours obtained from a gravitational lensing analysis are shown. From Clowe et al. (2006).

The bullet cluster is an intriguing object due to the distribution of its galaxies and hot intracluster gas. Both gas and galaxies show two primary concentrations, which, however, are not aligned with each other. It is likely that these are actually two clusters that have just passed through each other and are now moving apart. Due to the friction that the gas experienced in the passage, it now lags behind the galaxies.

a) The X-ray temperature T of the gas is roughly 10 keV. Determine the total X-ray luminosity L_X of the cluster using Fig. 2. Note that you need to divide your value by h^2, with $h = H_0/(100\,\mathrm{km\,s^{-1}\,Mpc^{-1}})$. Use $h = 0.7$.

b) The *luminosity density* L_{vol}, i.e. the total amount of energy emitted per second per unit volume by the hot intracluster gas, depends on the gas temperature T and on the number density n_e of free electrons:

$$L_{\mathrm{vol}} = 1.42 \cdot 10^{-40} \left(\frac{n_e}{\mathrm{m^{-3}}}\right)^2 \left(\frac{T}{\mathrm{K}}\right)^{0.5} \mathrm{W\,m^{-3}} \qquad (1)$$

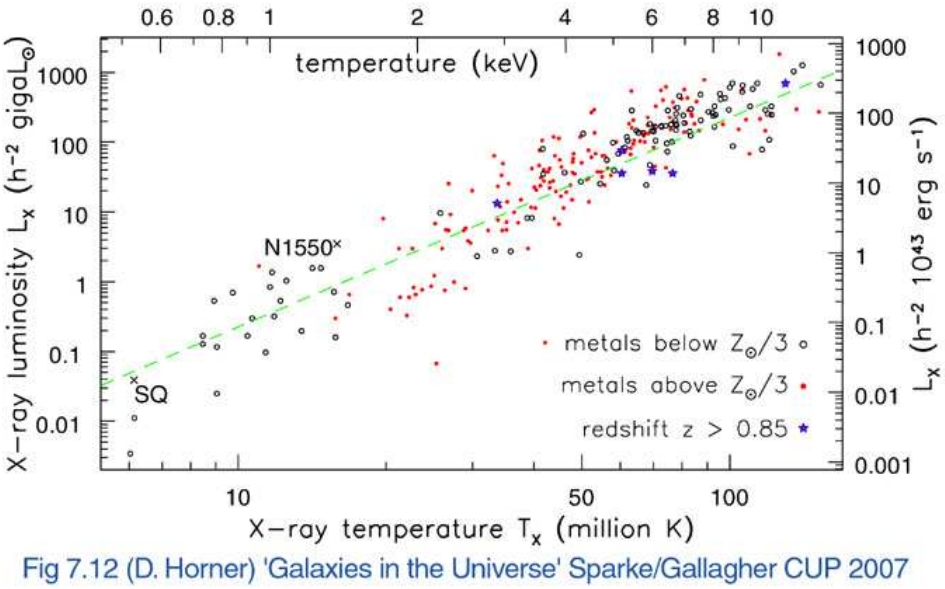

Fig 7.12 (D. Horner) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Figure 2: X-ray temperature vs. X-ray luminosity. From Sparke & Gallagher.

The diameter of the X-ray bright region is about 0.7 Mpc. For simplicity, assume that the gas is spherically distributed. Using the value of L_X from a), determine n_e. (1 erg = 10^{-7} J.)

c) Assume that the gas is purely composed of fully ionized hydrogen, i.e. there is one proton for every free electron. What is the total mass of the gas?

d) The galaxies of the cluster have a total B luminosity of $L_B \approx 1.7 \cdot 10^{12}\, L_\odot$. With a mass-to-light ratio M/L_B of ~ 1 (of the stars only!), this translates into a total mass of $M \approx 1.7 \cdot 10^{12}\, M_\odot$. Figure 1 shows you the galaxies and the location of the hot gas. It also shows density contours that represent the strength of the gravitational lensing effect of the cluster (for contours that lie further inwards, the gravitational lensing is stronger). Given the masses of gas and galaxies, what do you conclude from these density contours?