Highlights of Astronomy, Volume 15
XXVIIth IAU General Assembly, August 2009
Ian F. Corbett, ed.

doi:10.1017/S1743921310009166

The hot ISM of early-type galaxies

G. Fabbiano

Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge MA 02138, USA
email: gfabbiano@cfa.harvard.edu

Abstract. This talks reviews the history of the discovery of the hot ISM in elliptical galaxies, and the ensuing debate on the suitability of X-ray observations of these galaxies for mass measurements. How much of the X-ray emission is truly from a hot ISM, and is this ISM in hydrostatic equilibrium? While the debate went on, a deeper understanding on the evolution of the halos was generated. High resolution *Chandra* observations are providing an answer.

Hot extended halos trapped in cluster potentials were discovered early in the history of X-ray astronomy (Kellogg & Murray 1974). It was soon realized that these halos provided a means for measuring the mass of the associated self-gravitating body, leading to huge amounts of dark matter (e.g. in the central Virgo Cluster galaxy M87, Mathews 1978; later confirmed with the first X-ray imaging telescope, the *Einstein X-ray Observatory*, Fabricant, Lecar & Gorenstein 1980). With *Einstein*, hot halos were also discovered in several early-type galaxies (Forman *et al.* 1979), leading to the realization that if the X-ray emission of E and S0 galaxies were dominated by hot halos in hydrostatic equilibrium, these observations could provide a ready means for measuring their masses (Forman, Jones & Tucker 1985). However, this assumption took a considerable leap of faith, because with the quality of these first X-ray images one could not disentangle a truly diffuse gaseous emission from the unresolved contribution of populations of low-mass X-ray binaries (LMXBs). Moreover, even if the emission was largely thermal, it could not be proved from the data that the hot halo was indeed in equilibrium (e.g., Trinchieri & Fabbiano 1985, hereafter TF85; see review Fabbiano 1989, hereafter F89). This debate is in part still ongoing and has contributed to a deeper understanding of the evolution of early-type galaxies, and their stellar and gaseous components.

The X-ray (L_X) and B-band luminosity (L_B) are correlated, with a large scatter (the $L_X - L_B$ diagram; TF85; Forman *et al.* 1985). The interpretation of this diagram has been central to the 'halo' debate (see other talks in this meeting). Is the $L_X - L_B$ diagram the expression of halo evolution and physics, or is it 'biased' by the contribution of unresolved LMXB populations? TF85 first raised the LMXB problem, based on a comparison with the bulge of M31 and the integrated emission properties of bulge-dominated galaxies, which have L_X/L_B ratios consistent with those of 'X-ray faint' ellipticals. This hypothesis was confirmed by the spectral characteristics of the X-ray emission: harder X-ray emission was found in X-ray faint galaxies with *Einstein* and *ROSAT* (e.g., Kim, Fabbiano & Trinchieri 1992), and the CCD spectra of ASCA found the signature of a hard LMXB emission also in halo-dominated galaxies (Matsushita *et al.* 1994). With the sub-arcsecond telescope of the *Chandra X-ray Observatory*, populations of LMXBs are now obvious in the images of elliptical galaxies, and in some cases account for the bulk of the X-ray emission (e.g. NGC 3379; Brassington *et al.* 2008).

There is sufficient material from stellar outgassing to account for the hot halos. These halos may be further heated by SNIa and by gravity (if they slowly accrete to the center via cooling flows; see F89). AGN feedback may also be an important energy source (e.g. Tabor & Binney 1993). Given all this ready energy input, can we be sure that the halos are in hydrostatic equilibrium? Or are they in an outflow or wind state? Indeed, hydrodynamical modeling of the $L_X - L_B$ diagram suggested that winds, partial outflows and cooling flows could naturally explain the placement of galaxies in this diagram (Ciotti *et al.* 1991). Now, with *Chandra* we have set stringent limits on the amount of diffuse emission in some X-ray faint galaxies, demonstrating the presence of winds. In NGC 3379, for example, we find residual evidence of non-stellar diffuse emission in the 0.7-1.5 keV band, which is well reproduced by independent hydrodynamical modeling of the hot halo (Trinchieri, Pellegrini *et al.* 2008).

Optical indicators of large galaxy potentials and primordial merging are correlated with the presence of large X-ray halos (e.g., Eskridge, Fabbiano & Kim 1995; see Kormendy *et al.* 2009), suggesting that these halos are gravity-held. These hot halos are likely to be experiencing cooling flows, because the denser central regions would cool faster than the outer shells. There is an entire literature on cooling flows (see F89), which I will not explore here, except to say that there are two key observational diagnostics: (1) central colder gas; (2) central star formation. Neither have been detected to the amount expected. What stops the cooling flows? Radio-emitting AGN are frequently found in elliptical galaxies, and a first inkling of the interplay between these nuclear sources and the hot halos was suggested by the *Einstein* results (Fabbiano, Gioia & Trinchieri 1989). *Chandra* observations convincingly prove that AGN feedback is at play (e.g., Finoguenov *et al.* 2008). The evolution of the hot halos is the result of a tug of war between the pull of gravity and the push of feedback from stellar evolution (SNIa) and AGNs.

The above discussion demonstrates that caution must be used when approaching X-ray based mass measurements. In the case of 'dominant' extended hot halos hydrostatic equilibrium is probably a good approximation. However, for less X-ray luminous galaxies the halo may be far from equilibrium, and careful analysis of high resolution X-ray data (*Chandra*) and hydrodynamical modeling is required to understand the physical state of the halo.

GF would like to acknowledge support by NASA Contract NAS8-39073 (CXC).

References

Brassington, N. *et al.* 2008, *ApJS* 179, 142
Ciotti, L. *et al.* 1991, *ApJ* 376, 380
Eskridge, P. B., Fabbiano, G., & Kim, D.-W. 1995, *ApJ* 442, 523
Fabbiano, G. 1989, *ARAA* 27, 87 (F89)
Fabbiano, G., Gioia, I. M., & Trinchieri, G. 1989, *ApJ* 347, 127
Fabricant, D., Lecar, M., & Gorenstein, P. 1980, *ApJ* 241, 552
Finoguenov, A. *et al.* 2008, *ApJ* 686, 911
Forman, W. *et al.* 1979, *ApJ* 234, L27
Forman, W., Jones, C., & Tucker, W. 1985, *ApJ* 293, 102
Kellogg, E. & Murray, S. 1974, *ApJ* 193, L57
Kim, D.-W., Fabbiano, G., & Trinchieri, G. 1992, *ApJ* 393, 134
Kormendy, J. *et al.* 2009, *ApJS* 182, 216
Mathews, W. G. 1978, *ApJ* 219, 413
Matsushita, K. *et al.* 1994, *ApJ* 436, L41
Tabor, G. & Binney, J. 1993, *MNRAS* 263, 323
Trinchieri, G. & Fabbiano, G. 1985, *ApJ* 296, 447 (TF85)
Trinchieri, G., Pellegrini, S. *et al.* 2008, *ApJ* 688, 1000

https://doi.org/10.1017/S1743921310009166 Published online by Cambridge University Press