COSMIC X-RAY SOURCES - II

The X-ray background

During the first discovery flight of ScoX-1 in 1962 an isotropic X-ray background was observed (Giacconi et al. 1962). This had immediate consequences for cosmology. Hoyle's Hot Universe continuous creation theory could not account for this emission, and this created a major difficulty for the theory as a whole. Burbidge suggested that the emission could be due to the sum of unresolved galaxies. With the launch of UHURU in 1970 the existence of the background was confirmed. An upper limit on its granularity was derived which implied either a diffused emission or a very large number of individual sources (10^8 over the entire sky or one every square arc minute). Woltjer and Setti [9] suggested that the background could be made up of quasars if they had the same emission flux as the brightest known nearby quasar 3C273. Giacconi and his coworkers at Harvard were able to demonstrate in 1979 with data obtained with the EINSTEIN Observatory that at least 25% of the background in the 0.5 to 3 keV range was due to single sources, probably quasars [10].

Some astronomers were not convinced and they pointed out the resemblance of the spectrum of the background obtained with the HEAO-A proportional counter in the 3 to 35 kev range to a bremsstrahlung spectrum, concluding that the XRB was due to a hot gas pervading the entire universe. This conclusion seemed to be in conflict with the very large energy requirements to heat this gas for which no source could be suggested, but it appeared to receive support from the fact that the spectrum of individual quasars measured with the same instrument seemed much softer than the background.

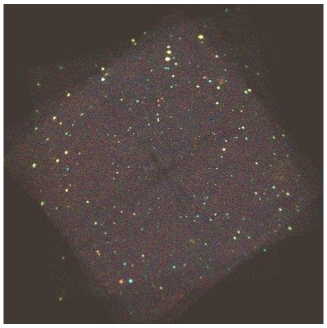

Figure 9: The one-million-second exposure of the Chandra Deep Field South. Red, green and blue colors denote X-rays of increasing energy, from 0.5 to 7 keV [4] [5].

The study of active galaxies with ROSAT showed strong evidence that the in the 0.5 to 3.0 keV range some 80% of the background could be due to quasars, provided only that the background and quasars spectral discrepancy could be explained. We believe the work of the University of Pennsylvania group, led by Niel Brandt, on the CHANDRA deep field north (CDFN[11]), and that of Giacconi's group at Johns Hopkins University on the CHANDRA deep field south (CDFS[12]) have definitively settled the issue (see [13] for a review).

In our Deep Field South we find a source density of 1 per square arc minute or 346 sources in 0.1 square degrees (Figure 9). The sum of the spectra from the 346 sources equals that of the background up to ~8 keV. The total flux in point sources in the 0.5 to 5 keV region corresponds to approximately 95 % of the background, the main uncertainty being our knowledge of the total background flux. At higher energies, a population of "Compton thick" AGN, which are obscured by column densities well in excess of 10^{24} cm^{-3} and comprise a significant fraction of AGN in the local Universe, remains to be unveiled. Faint sources have spectra harder than that of brighter ones. The superb angular resolution of *Chandra*, allowing X-ray source positional accuracies of better than 1 arcsec, has been critical for an efficient source identification program with the largest ground-based telescopes (mainly VLT and Keck), as well as the Hubble and Spitzer Space telescopes. The sources are all identified in the optical or near infrared. They consist mainly of Type –I or Type II AGN+QSO. Study of the variability of these sources yields characteristic times less than 1 year. We conclude that we observe the central massive black hole at the nucleus of the AGNs. Thus the CDFS and CDFN are fields of black-holes and the X-ray background radiation is largely the result of accretion onto super-massive black holes, integrated over cosmic time. The optical/near-IR identification and redshift measurement of large samples of AGN in deep pencil-beam surveys, as well as shallower wide area surveys, has provided a solid determination of the cosmic evolution of their space density at different luminosities, an essential ingredient for our understanding of the co-evolution of super-massive black holes and galaxies (see e.g. [14]).

X-ray emission from clusters of galaxies

The discovery of high temperature plasma pervading the space between galaxies in galaxy clusters has been one of the most important discoveries of X-ray astronomy (Gursky et al. 1972). Starting from the UHURU observations of large angular extent, there followed the determination of the thermal bremsstrahlung nature of the emitted spectrum with the first detection of plasma iron lines (Mitchell et al. 1976), the discovery of structures in the clusters emission and of binary clusters with EINSTEIN and more and more distant clusters with the ROSAT, CHANDRA and XMM-Newton Observatories (Figure 10).

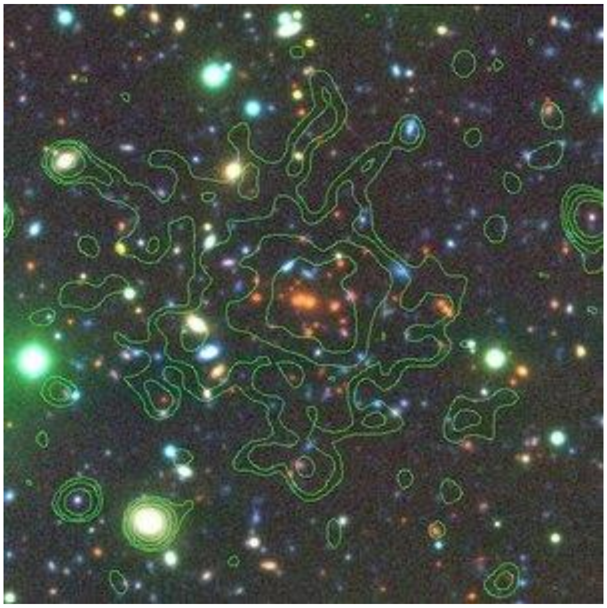

Figure 10: Color composite VLT image of one of the most distant massive cluster known, RDCS1252.9–2927 at z = 1.24, with overlaid *Chandra* X-ray contours (Rosati et al. 2004).

One of the earliest findings was that the X-ray emission from the clusters was due not only to the sum of the X-ray emission from each galaxy but also (and prevalently) by the emission of the diffused gas contained by the gravitational potential of the cluster as a whole. Since this potential is much greater than that of single galaxies, the gas could be at much higher temperature (more than 10 keV rather than 1 keV). As the cluster collapses in time due to gravitational attraction, each particle in the cluster experiences a gain in energy which results in the heating to these very high temperatures. The total mass of the intergalactic gas was found to exceed by factors of 2 to 10 that of all the galaxies contained in the cluster, thus it played an important role in providing the virial mass for the cluster, although dark mass was still required for closure. Because of the large mass (up to 10^{15} solar masses) and high temperature, the X-ray emission from the intergalactic gas can exceed by large factors (10-100) the emission from all stars and galaxies in the cluster.

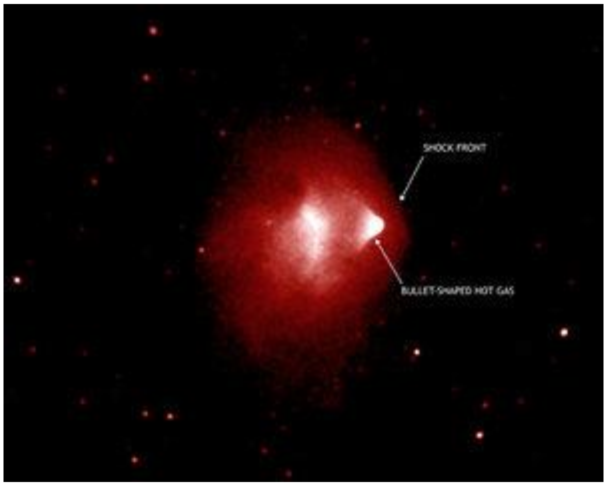

Figure 11: *Chandra* image of merging cluster 1E 0657-56, also known as the bullet cluster (Credit: X-ray: NASA/CXC/CfA/M.Markevitch et al.).

While the optical luminosity can be written as $L_{opt}=\sum L_{gal}$, the X-ray luminosity is given by $L_X=\sum L_{X,gal}+\rho^2_{gas}V_{gas}T^{1/2}_{gas}$. Thus a gravitationally bound system of galaxies announces its presence in X-rays by an extended high luminosity source and a bremsstrahlung spectrum. The presence of emission lines of heavy elements in the cluster gas, which have been observed out to z=1.3 today, tells us that the gas had to be recycled through the first generation of stars to be so enriched.

The most recent results from the *Chandra* observatory have revealed a complex morphology of the cluster plasma due to cluster-cluster interactions. A very interesting example is shown in a deep image of the so-called Bullet cluster obtained by the group at the SAO-Harvard Center for Astrophysics (Figure 11). Comparison between the distribution of dark matter obtained from optical gravitational lensing and that of the hot plasma from direct X-ray imaging, show that contrary to what happens to the plasmas of the colliding clusters, neither the galaxies nor the dark matter interact strongly in the encounter, an important clue to the properties of dark matter.

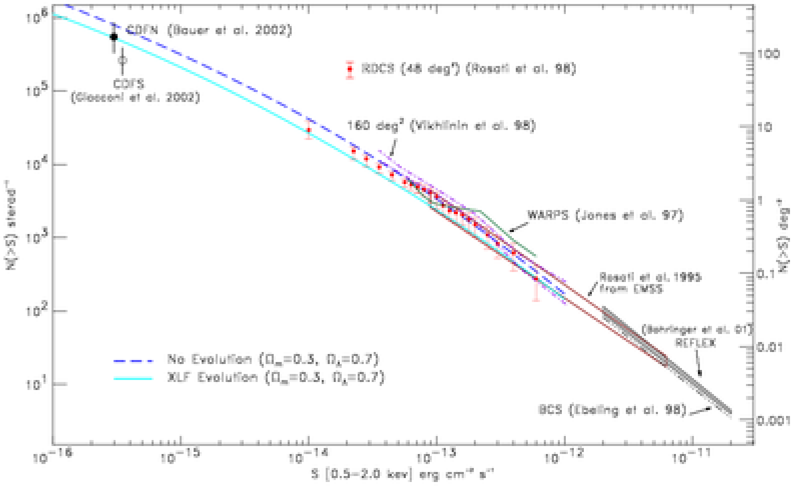

Figure 12: Cumulative number counts of X-ray clusters as a function of the flux, S (from [6]).

Serendipitous cluster surveys, conducted initially with *EINSTEIN* and more extensively with *ROSAT* in the ninenties, have determined that the space density of the bulk of the cluster population remains approximately constant out to redshift unity, while only the abundance of the most massive clusters decreases with redshifts. The Log N-Log S plot of cluster populations (Figure 12) shows a continued increase in the numbers at fainter fluxes (see Rosati et al. 2002 for a review). Recent observations with XMM-Newton have revealed the existence clusters at redshifts as large as z=1.4, with masses well in excess of 10^{14} solar masses, something that was considered extremely unlikely in the mid-nineties. The study of these very distant clusters and the evolution of the cluster abundance over a large redshift range can yield important information on the formation of these systems at early epochs, and tight constraints on cosmological parameters, including the presence ofdark energy which affects the growth of structure in the Universe.

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