X-ray Emission from Galaxies and the Universe

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INTRODUCTION

The study of X-ray emission from normal galaxies began with the launch of the Einstein Observatory in 1978. Before that time only our own Galaxy and the Magellanic Clouds had been studied in any detail (see e.g. Markert et al. 1977). Now many galaxies of all Hubble types have been detected and $\sim$200 point sources have been resolved in the nearest ones. More sources are now known in other galaxies than were known in our own before 1978. It seems clear that statistical studies of bright Galactic sources, which relate to their evolution, are reliant upon the discovery of sources in many other galaxies. A substantial future increase (the Virgo cluster galaxies) requires a telescope system with better than arcminute resolution and a sensitivity better than 10 x that of Einstin.

Little is known of the diffuse X-ray emission from galaxies. The soft X-ray background in our Galaxy (Tanaka & Bleeker 1977, Fried et al. 1981) and evidence for a gaseous halo (Savage & de Boer 1980) suggest that a significant fraction of the gaseous matter in galaxies is at X-ray emitting temperatures. Unfortunately the potential wells of most galaxies are so shallow that the gas densities are then so low as to make detection difficult. Searches for diffuse sources of line emission are likely to be the most rewarding. We can study diffuse gas much better in the deeper wells provided by groups and clusters of galaxies. Here the evolution and cycling of gas is to be observed on a grand scale.

Finally, I would stress that the lumpiness of the Universe on large scales ($\gtrsim$ 10 Mpc) can best be determined from X-ray measurements. The investigation of the detailed patchiness of the X-ray background should be an important priority for the future.

NORMAL GALAXIES

The various components of X-ray emission in our own Galaxy are listed in Table 1. The emission is dominated by the bright Galactic "Bulge" sources and, below 0.25 keV, by the soft X-ray background. The most uncertain contribution is that due to stars (see e.g. Rosner et al. 1981), especially late-type low mass Population II stars that may constitute a large fraction of the stellar population. Unfortunately little has been reported on this issue, but if the indication of an inverse correlation between X-ray emission and age proves to be correct then they are likely to be only weak X-ray sources.

The point source population of a few nearby galaxies is given in Table 2 from the work of Long et al. 1980, 1981, Seward & Mitchell 1981, Van Speybroek et al. 1970, 1980 and Palumbo et al. 1981. The X-ray luminosity functions of M31 and our Galaxy are in marked contrast. Future work must decide why 20 globular cluster sources in M31 have an X-ray luminosity greater than any in our Galaxy and why M31 has so many more 'bulge' sources.

Long (1980) has pointed out that the X-ray emission of ~40 galaxies of all Hubble type appears to be correlated with the optical brightness of the galaxy. $L_x \approx 10^{-3} - 10^{-4} L_{vis}$. Although the sample is small, this does suggest the presence of a common factor. Two possibilities are apparent. The first possibility is the prevalence of Population II ('bulge'-type) sources. One indication that this may be correct is to be found by noting that globular clusters with X-ray sources fall approximately on this correlation. Since the ration of L_x to the stellar X-ray emission in Population II sources is $\sim 10^3$-10^4, only 1 'star' in $\sim 10^6$-10^8 is needed to be a 'bulge' type X-ray source, independent of Hubble type, in order to explain the correlation.

I cannot, however, see how the extended emission from M84 (Forman 1980) or from Cen A (Feigelson et al. 1981) can be easily explained by 'bulge' type sources, which should collect at the centres of galaxies. The second possibility is hot gas, from stellar mass loss heated by Supernova explosions. This cannot explain why globular clusters or the Magellanic Clounds fit the correlation, but could be a significant, or dominant, fraction of the emission from unresolved galaxies. Certainly the diffuse emission from our own galaxy rivals that of the point sources below $\sim$ 1 keV, and a contribution of this magnitude seems possible in M31 as well (Von Speybroeck et al. 1979).

Galactic coranae will be difficult to detect (see e.g. Bregman 1980). The gas temperature should be $\simeq \mu m_H \sigma^2/k$ where σ is the internal velocity dispersion. Thus a temperature of $\sim 10^6$-10^7K is to be expected. Hotter gas would be lost; cooler gas would cool further and collapse. If the IUE Galactic halo observations indicate that a 'galactic-fountain' is operating (Shapiro & Field 1976, Bregman 1980, Songaila 1981) then up to $\sim 1M_\odot\ yr^{-1}$ of cooling must take place. This represents $\sim 10^{40}$erg s^{-1} in soft X-rays, much of which will emerge as lines below $\sim \frac{1}{2}$ keV. The routine detection of diffuse emission from galaxies will probably start when substantial high-galactic latitude exposures are made with detectors and spectrometers sensitive at 0.1 - 0.2 keV. This will have implications/or gas flows in galaxies, the stellar death and birth rates and for chemical enrichment.

Much of the gas lost in winds and by stripping in isolated galaxies must be trapped in the potential wells of clusters. The evolution of clusters, which appears to be continuing at the present time, and of the galaxies within them relies heavily on X-ray observations. A vigorous approach in the future should enable us to understand the evolution of these largest known entities.

The mass distribution in clusters can be determined from detailed observations of the surface brightness profile at two separate energies. Since we know that any gas motions are highly subsonic, that the gas is likely to be closely Maxwellian and that the emission is predominantly bremsstrahlung and line radiation then accurate solutions are possible. Later comparisons with the galaxy motions can unravel the expected anisotropies in their velocity distribution.

The formation of galaxies may be observed through their X-ray emission. Of interest now is the growth of central galaxies in clusters via a cooling flow of intracluster gas (Fabian & Nulsen 1977, Cowie & Binney 1977). Here the gas from other cluster galaxies settles and presumably forms stars around a central stationary galaxy. This process occurs around NGC 1275 in the Perseus cluster (Fabian et al. 1981) and is being observed in an increasing number of other clusters. Young (primeval) galaxies may be rich in X-ray phenomena if a large fraction of the energy produced with the metals is released as X-rays (Bookbinder et al. 1980; Sunyaev, Tinsley & Meier 1979). Perhaps also the non-thermal activity of galaxies is also inversely correlated with age, as for stars. The dissipation of chaotic motions may indirectly produce X-rays. Isolated extragalactic HII regions observed locally, in which bursts of star formation are taking place, may give a good picture of the emission from a primeval galaxy. We (Stewart et al. 1981) have detected one at $L_x \simeq 0.1 L_{vis}$ with the Einstein Observatory.

The activity of galactic nuclei is discussed elsewhere, but does allow galaxies to be identified at large redshifts. E. Boldt has pointed out to me the possibility that X-ray spectral observations can test whether Seyferts and quasars are two separate classes or not. Basically, the energy spectral index of Seyferts is close to 0.7, at least from $\sim$ 3 - 100 keV, and an extrapolation of non-evolving Seyferts out to $Z \sim 1$ gives the MeV bump in the hard

X-ray background (see e.g. Boldt 1980). This suggests that the class of Seyferts does not evolve and predicts that many active galaxies with $L \lesssim 10^{44}$ erg s^{-1} should be observable with spectral indices of ~ 0.7 out to $Z \sim 1$. Quasars must have a much flatter spectrum if they compose the background, otherwise they must be relatively steep.

THE LUMPINESS OF THE X-RAY BACKGROUND

The usefulness of X-ray observations in constraining matter fluctuations on the scale of 100 - 1000 Mpc is discussed in Fabian, Warwick & Pye 1978, Rees 1979 and Fabian 1981. Limits on $\delta\rho/\rho$ of a few percent are obtained from the current limit of 1 percent on excess fluctuations on the scale of $\sim$ 5 degrees (Fabian & Rees 1978, Schwartz 1979). Hopefully these will be improved when the HEAO-1 A2 analysis is complete (Shafer 1981). The observed P(D) fluctuations due to unresolved sources that are not clumped provide a basic limitation. An imaging detector (2 - 6 keV) that enables sources to be eliminated down to $\sim$ 0.01 UFU and scale of $0^{\circ}.5$ would allow a residual fluctuation of $\frac{\delta I}{I} \gtrsim 30\, n^{-\frac{1}{2}}$ percent to be measurable where n is the number of regions surveyed. For $\sim$ 100 fields, the clumping of galaxies (and of quasars) at the 20 Mpc end of the galaxy covariance function (Peebles 1974) should begin to be attainable if the source density is high enough.

Large-scale anisotropies in the X-ray background are expected due to the galactic background, our motion relative to and to shear and other effects on the X-ray background. The situation may be optimum at high energies (> 30 keV) where the galactic effects are hopefully small, and where the steepening of the background spectrum enhances $\frac{\delta I}{I}$ via the Compton Getting effect.

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TABLE 1.

X-RAY EMITTING CONSTITUENTS OF OUR GALAXY

Source type	Number	$\langle L_x \rangle$ erg s^{-1}	η_x (local) erg $pc^{-3}s^{-1}$	L_{Tor}
Early type binaries $L_x > 5 \times 10^{36}$	~ 10	3×10^{37}		3×10^{38}
Pop II binaries(?)	~ 20	6×10^{37}		1.5×10^{39}
Low luminosity binaries	$\gtrsim 100$	$< 10^{36}$		$< 10^{38}$?
Galactic nucleus		5×10^{35}		5×10^{35}
Cataclysmic variables	$\sim 10^5$?	$\lesssim 10^{32}$	$< 10^{26}$	$< 10^{37}$
O-stars	$\sim 5 \times 10^3$	10^{33}		5×10^{36}
Main sequence stars	$\sim 10^{10}$	2×10^{38}	$\sim 10^{27}$	2×10^{38}
Halo M-dwarfs	$< 10^{11}$??	$< 3 \times 10^{27}$?	$< 3 \times 10^{24}$	$< 3 \times 10^{38}$
Supernova remnants	$\sim 10^3$	10^{35}		10^{38}
Galactic (diffuse) background $E < 0.25$ keV			$\sim 2 \times 10^{28}$	10^{39}
$E > 2$ keV			10^{26}	10^{38}

TABLE 2.

Galaxy	D	M	Binaries		SNR	?
			Pop I	Pop II		
LMC	55 kpc	10^{10} $M_\odot$	∿ 8		∿ 40	∿ 20
SMC	65 kpc	$1.5.10^{9}$ $M_\odot$	1 + 2		∿ 5	∿ 15
M31	750 kpc	3.10^{11} $M_\odot$		20 Glob 19 Bulge	1	∿ 47
M33	750 kpc	4.10^{10} $M_\odot$				∿ 9
M101	6 Mpc	∿ 10^{11} $M_\odot$				∿ 5
M100	15 Mpc	∿ 10^{11} $M_\odot$				∿ 2