X-ray, Lyα and Hα Emission from Simulated Disk Galaxies

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Abstract. The X-ray properties of the haloes of disk galaxies formed in fully cosmological, hydro/gravity simulations are discussed. The results are found to be consistent with observational X-ray detections and upper limits. Disk galaxy haloes are predicted to be about an order of magnitude brighter in soft X-rays at $z \sim 1$ than at $z=0$.

The Lyα and Hα surface brightness of an edge-on, Milky Way like model galaxy has been determined. The emission is found to be quite extended, with a scale height of about 600 pc, neglecting extinction corrections.

1. Introduction

Gradual infall of halo gas onto the disk due to radiative cooling is a generic feature of disk galaxy formation models. Such continuing gas infall seems essential to explain the extended star formation histories of isolated spiral galaxies like the Milky-Way and is the most likely explanation of the “G-dwarf problem” — see, e.g., Rocha-Pinto & Maciel (1996) and Pagel (1997).

At the virial temperatures of disk galaxy haloes the dominant cooling mechanism is thermal bremsstrahlung plus atomic line emission. The emissivity, increasing strongly with halo gas density, is expected to peak fairly close to the disk and decrease outwards, and if the cooling rate is significant the X-ray flux may be visible well beyond the optical radius of a galaxy.

Recently, Benson et al. (2000) compared ROSAT observations of three massive, nearby and highly inclined disk galaxies with predictions of simple cooling flow models of galaxy formation and evolution. They showed that these models predict about an order of magnitude more X-ray emission from the galaxy haloes than observational detections and upper limits.

We have determined global X-ray properties of the haloes of a novel sample of 44 model disk galaxies at redshift $z=0$. The galaxies result from physically realistic, fully cosmological gravity/hydro simulations of galaxy formation and evolution. The galaxies span a range in characteristic circular speeds of $V_c = 130–325$ km s$^{-1}$ and have been obtained
Figure 1. Bolometric luminosity at $z=0$ as a function of characteristic circular speed.

**Small symbols:** Flat $\Omega_M = 1.0$ cosmology: Open symbols: baryon fraction $f_b=0.05$, filled circles $f_b=0.1$. Triangles: without UV field, non-triangles: with a UV field of the Efstathiou (1992) type. Connected symbols are the same galaxies run with medium (open circles) and high (open circles with crosses) resolution. All simulations represented by small symbols have primordial abundance. **Large symbols:** Flat $(\Omega_\Lambda,\Omega_M) = (0.7, 0.3)$ cosmology: Open symbols: $f_b=0.05$, filled symbols $f_b=0.1$. Circles correspond to primordial abundance and with a Haardt & Madau (1996) UV field, squares correspond to $Z = 1/3 Z_\odot$ (using the cooling function of Sutherland & Dopita 1993, which does not include effects of a UV field). The curves are the $L_{X,\text{bol}}-V_e$ relationship for the simple cooling flow models for $\Lambda$CDM NFW haloes — see Toft et al. (2002). The curves represent different baryonic fractions (solid curves have $f_b = 0.1$, dotted curves have $f_b = 0.05$) and abundances (thick curves: primordial abundances, thin curves: $Z = 1/3 Z_\odot$).

with a considerable range of physical parameters, varying the baryonic fraction, the gas metallicity, the meta-galactic UV field, the cosmology, the dark matter type, and also the numerical resolution. Details of the simulations and halo X-ray emission calculations are given in Toft et al. (2002), Sommer-Larsen & Dolgov (2001) and Sommer-Larsen et al. (2002).
2. X-ray emission

In Fig. 1 the total bolometric X-ray luminosities $L_{X,bol}$ of the 44 simulated disk galaxies in our sample are plotted versus their characteristic circular speed $V_c$. Also shown are predictions by simple cooling flow models. The X-ray luminosities derived from the simulations are up to two orders of magnitude below values derived from simple models. Toft et al. (2002) show that our model predictions of X-ray properties of disk galaxy haloes are consistent with observational detections and upper limits. As can be seen from the figure $L_{X,bol} \sim 10^{40}$ erg s$^{-1}$ for a Milky Way sized galaxy. This in turn implies that hot halo gas is cooling out and being deposited onto the galactic disk at a rate of $\sim 0.5–1$ $M_\odot$ yr$^{-1}$, consistent with observational upper limits, as discussed by Sommer-Larsen et al. (2002). They also show that the present amount and distribution of hot gas in the haloes of Milky Way like disk galaxies is consistent with observed dispersion measures towards pulsars in the globular cluster M53 and the LMC.
In contrast to what is predicted by simple cooling flow models, it is found that increasing cooling efficiency of the halo gas results in decreasing present day $L_X$. The reason for this is that increasing the cooling efficiency over the course of a simulation results in less hot gas in the halo at $z=0$ to cool (because the total amount of gas available at any given time is always limited to the gas inside of the virial radius). This in turn leads to lower present day accretion rates and lower $L_{X,bol}$.

Finally, it is found for realistic choices of the physical parameters that disk galaxy haloes were up to one order of magnitude brighter in soft X-ray emission at $z\sim1$, than at present.

3. Ly$\alpha$ and H$\alpha$ emission

In the simulations, the local ionization balance of Hydrogen is assumed to be set by collisional ionization, photo-ionization by the redshift dependent, meta-galactic UV field and recombination. Radiative transfer of the ionizing UV photons is included in a simplified way. Given this, the local rate of Ly$\alpha$ and H$\alpha$ emission can be calculated. Fig. 2 shows the appearance of an edge-on, Milky Way like disk galaxy in H$\alpha$ (Ly $\alpha$ is very similar). No extinction correction has been applied; such a correction will clearly be very important within 100-200 pc from the midplane of the disk. The distribution of H$\alpha$ emission is considerably more extended than that of the cold gas and (since the H$\alpha$ emission scale height is about 600 pc) also of the stars. This is in broad agreement with observations (e.g., Hoopes et al. 1999, Wang et al. 2001, Olsen et al. 2002).

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