GAS FLOWS IN ELLIPTICAL GALAXIES

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A great deal of information about the interstellar medium in elliptical galaxies has been acquired over the last decade through analysis of Einstein X-ray data. The X-ray emission from luminous elliptical galaxies arises through thermal emission from extended hot coronae in nearly hydrostatic equilibrium (Forman, Jones, and Tucker 1985; Canizares, Fabbiano, and Trinchieri 1987). Since the radiative cooling time of the hot gas in luminous elliptical galaxies is typically less than a Hubble time, the gas must be slowly cooling and accreting into the center of the galaxy through a cooling flow (Nulsen, Stewart, and Fabian 1984). For a given supernova rate, however, there must exist a critical galaxy luminosity below which ellipticals cannot retain the gas liberated by the stellar systems.

In preparation for the next generation of X-ray telescopes, we have begun a program investigating the evolving X-ray properties of elliptical galaxies (David, Forman, and Jones 1989a and b). Our galaxy models consist of a modified King profile for the luminous portion of the galaxy and can include an isothermal dark halo comprising 90% of the total mass. The stellar population is assumed to form at a rate which decreases exponentially on a dynamical time scale with a Salpeter initial mass function. Stellar mass loss occurs instantaneously as stars evolve off the main sequence. All stars more massive than $8M_\odot$ produce type II supernovae, while less massive stars loss mass through a planetary nebulae. The evolving rate of type I supernovae is normalized to a fraction, r_{snI}, of Tammann's (1974) value. All of this information is then incorporated into a one-dimensional hydrodynamics code to determine the evolving dynamical state of the interstellar medium.

The various evolutionary stages encountered in these models have been discussed elsewhere (David, Forman, and Jones 1989a and b). In this brief contribution, we discuss how the present state of the ISM depends on the galaxy luminosity L_B, the present epoch type I supernova rate, and the presence of a massive halo. The results of a large variety of models with massive dark halos are summarized in Figure 1. As can be seen from this figure, the ISM varies from pure accretion flows, to partial winds, to total subsonic winds, to total transonic winds as either L_B decreases or r_{snI} increases. Using the best estimate on the present type I supernova rate ($r_{snI} =$ 1/4; van den Bergh, McClure, and Evans 1987), the critical optical luminosities separating these dynamic states are $L_B \approx 1.7 \times 10^{10}$, 5.5×10^9, and $1.7 \times 10^9 L_\odot$, or equivalently $M_B \approx -20.2$, -18.9, and -17.7. These critical luminosities depend

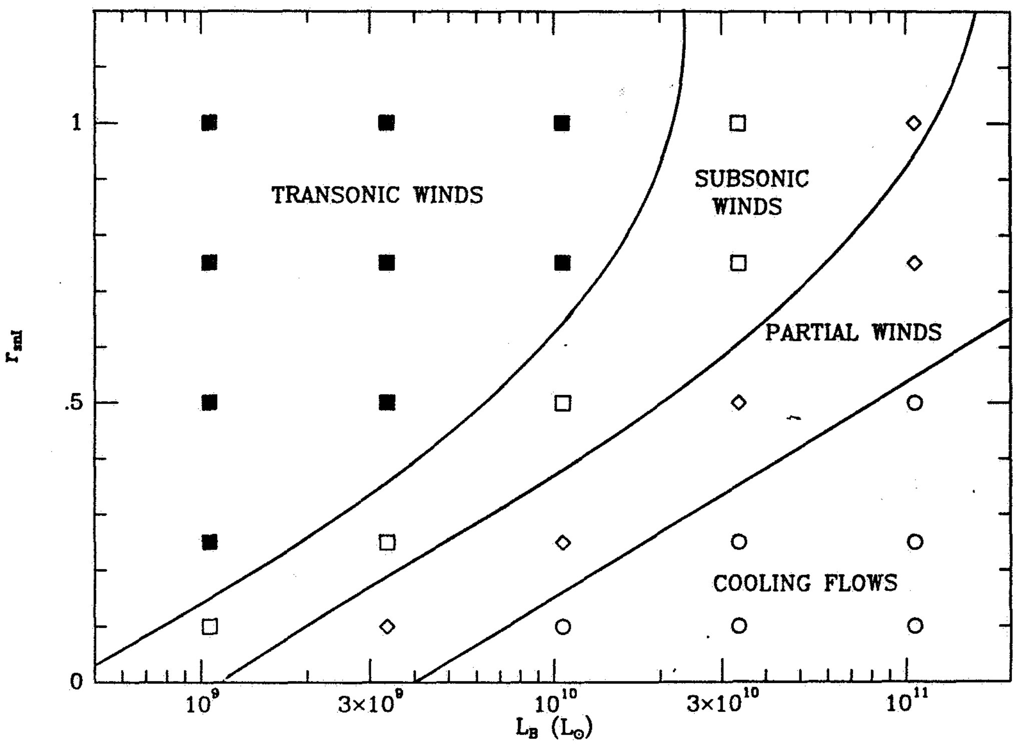

Figure 1. The present dynamic state of the hot ISM in a variety of galaxy models with massive halos. The supernova rate, r_{snI}, is normalized to Tammann's (1974) value. Partial winds have an inner accretion flow and an outer wind.

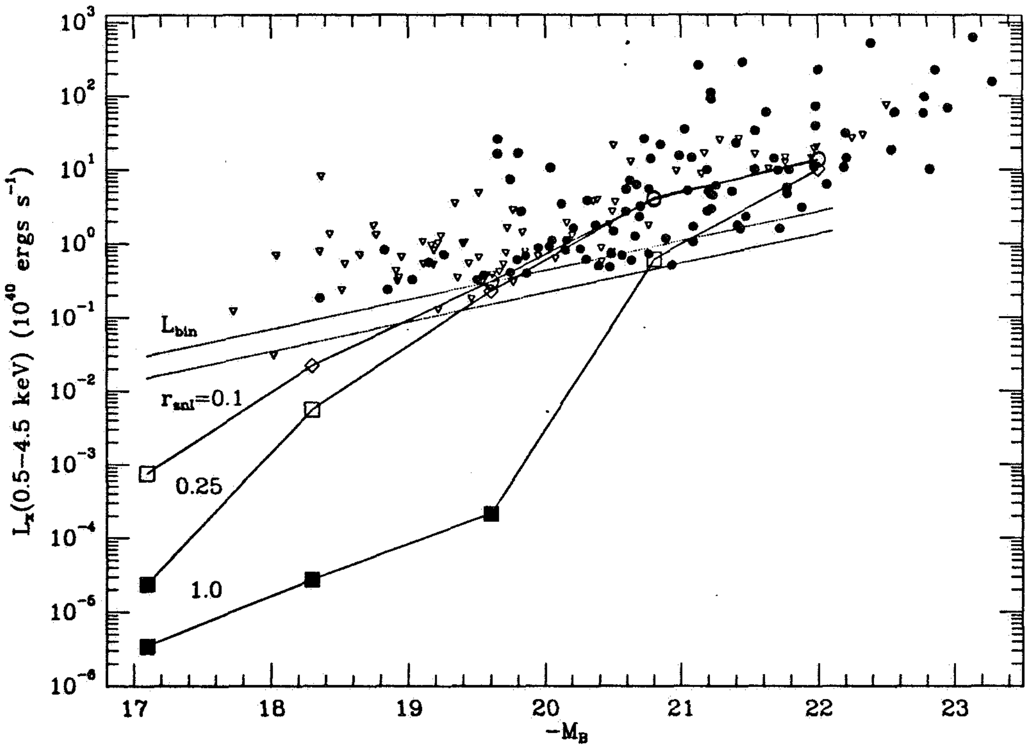

Figure 2. X-ray luminosity of the galaxy models with massive halos for three different supernova rates. For comparison, the Einstein X-ray data on early type galaxies and estimates on the X-ray luminosity from binaries, L_{bin}, are also given. The symbols indicate the dynamic state of the ISM in the models (see Figure 1).

on the ratio of dark to luminous mass and only strictly apply when the dark halo comprises 90% of the total mass of the galaxy. We also have simulated galaxy models without massive halos and find that galaxies with $M_B \gtrsim -20.5$ have total transonic winds at the present time for $r_{snI} = 1/4$.

The present 0.5-4.5 keV luminosity of the galaxy models is shown in Figure 2 along with the Einstein data for early type galaxies (Jones, Forman, and Tucker 1989). For comparison, estimates on the 0.5-4.5 keV luminosity from compact binaries in these galaxies also are shown (Forman, Jones, and Tucker 1985; Canizares, Fabbiano, and Trinchieri 1987). The present X-ray luminosity in our models is very sensitive to the assumed type I supernova rate. In general, the 0.5-4.5 keV luminosity in a given galaxy model increases slightly with increasing supernova rate until heating by supernovae dominates the energetics of the gas and winds develop. When this occurs, most of the supernova energy is converted into the mechanical energy of the wind and the X-ray luminosity decreases rapidly with any further increase in the supernova rate. As the present epoch type I supernova rate is increased, winds and lower X-ray luminosities are generated in increasingly more optically luminous galaxies (see Figure 2). The amount of scatter in the present data is too large to strongly constrain the present type I supernova rate, however, it is clear that Tammann's (1974) value is too high by a factor of at least four to account for the observed X-ray luminosity of galaxies with M_B between -20 and -21. If elliptical galaxies have massive halos and $r_{snI} = 1/4$, our models indicate that the X-ray emission from hot gas should dominate over emission from binaries in galaxies with $M_B \lesssim -19.6$. Galaxies with this absolute blue magnitude have partial winds.

The present 0.5-4.5 keV luminosity of elliptical galaxies also is very sensitive to the presence of a massive dark halo. Our models without halos have predominantly low X-ray luminosity, transonic winds. In models without halos and $r_{snI} = 1/4$, the X-ray emission from the hot ISM only dominates over the X-ray emission from binaries in galaxies more luminous than $M_B \approx -21.1$. Our models indicate that ellipticals with M_B between -20 and -21.5 must have massive dark halos in order to retain the large amounts of hot gas necessary to produce their observed 0.5-4.5 keV luminosities.

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