N91-14101

The Extragalactic Radiation Field and Sharp Edges to HI Disks in Galaxies

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Observations of neutral hydrogen are widely used as a probe of the interstellar medium in galaxies and of galactic kinematics and dynamics. The 21-cm line can be used to determine galactic rotation curves far beyond the optical disk, and is one of the prime sources of evidence for the existence of dark haloes in spiral galaxies. However, a recent attempt to measure the 21-cm emission from NGC 3198 to very low column densities ($N_H \approx 5 \times 10^{18}$) found that the HI disk is very sharply truncated at a column density of a few times 10^{19} (Sancisi 1989, private communication). This discovery reinforces the earlier suggestion (Briggs *et al.* 1980) that extended, low-column density envelopes of neutral hydrogen are not common around galaxies. Here I suggest that the sharp edge seen to the HI disk in NGC 3198 is consistent with a model in which a self-gravitating neutral HI disk is photoionized by the extragalactic radiation field. The possibility that the extragalactic background would produce sharp edges to HI disks was first suggested by Silk and Sunyaev (1976).

The Model: The outer HI disk of a galaxy is modeled in plane parallel geometry. The extragalactic radiation field is assumed to be isotropic and is incident on the HI gas layer. The soft x-ray background shows a power-law distribution of photons with energy; because of absorption by Galactic HI, the far-UV flux is unobservable. In the presence of such a power-law spectrum the usual Strömgren approximation won't hold: since the soft x-ray photons penetrate to much greater optical depths than photons not far above the Lyman limit, the transition from highly ionized to neutral hydrogen will not be sharp. The presence of helium also becomes very important, because He and He^+ can be ionized by photons with energies $E > 24.6$ eV and $E > 54.4$ eV, respectively, where the hydrogen cross-section for photoionization is negligible, while He and He^+ recombination radiation can ionize H. Thus helium acts to degrade soft x-ray, He-ionizing photons into UV, H-ionizing photons.

The extragalactic radiation field is assumed to have a power-law spectrum between 1.5 KeV and 13.6 eV, with the actual intensity at the Lyman limit a free parameter, normalized to the $Z = 0$ value estimated by Sargent *et al.* (1979). The spectral index is then given by $\alpha = 1.45 + 0.490 \log(I_{Ly})$, where I_{Ly} is the intensity at the Lyman limit normalized to 4.0×10^{-23} ergs cm^{-2} s^{-1} Hz^{-1} sr^{-1}.

The gas is taken to have an isothermal ($\rho(z) = \rho_0 \operatorname{sech}^2(z/z_0)$) z-distribution, where the scale-height z_0 is either specified or calculated for a self-gravitating layer with a given velocity dispersion. The gas disk is divided into a series of zones, each of which is assumed to be uniform. The calculation begins at the exterior (z-boundary) of the disk and proceeds inwards, the ionization structure in each zone being used to calculate the incremental optical depth to ionizing radiation. An iterative scheme is used to calculate the ionization, including the effects of the diffuse ionizing recombination radiation (Williams 1967).

Results: Figure 1 shows the results for 3 models with fixed z_0 and $I_{Ly} = 1$. The total and neutral hydrogen column densities are plotted against radius for an assumed exponential decrease in total HI surface density. There is a pronounced break in the slope of N_{H^0} vs. R at a column density of $\approx 3 \times 10^{19}$. The neutral column density drops by a factor of ≈ 10 in a distance of 1 scale-length. Although the column density at which the slope change occurs is in agreement with the the NGC 3198 data, the constant scale-height models cannot explain the sharpness of the edge of the HI disk in NGC 3198: the scale-length for the H I distribution in the outer disk of NGC 3198 is about 9 kpc, whereas the VLA observations of this galaxy show that the column density drops from 5×10^{19} to 5×10^{18} on a scale of about 3 kpc. This suggests that flaring of the H I disk at large R plays an important role.

At the large galactocentric distances to which H I is observed in NGC 3198, the surface density of gas exceeds that of the stars by $\approx$ two orders of magnitude (assuming a constant mass-to-light ratio stellar disk), so that the H I can be accurately treated as a self-gravitating thin disk; a halo component will not affect the z-structure within a few kpc of the disk midplane. For a self-gravitating thin disk, the scale-height z_0 is

$$z_0 = \frac{\sigma_z^2}{\pi G \Sigma(R)} = 8.12 \times 10^{-2} \frac{\sigma_z^2}{N_{HTOT}} \text{ kpc} \qquad (1)$$

where σ_z is the z-velocity dispersion of the disk and $\Sigma(R)$ is the mass surface density, and the right-hand side is for σ_z in km s^{-1} and the total hydrogen column density in units of 10^{20} cm^{-2}.

The scale-height of a self-gravitating H I disk is thus inversely proportional to column density. This flaring of the disk increases the ionization fraction of the H I by lowering the recombination rate.

Figure 2 shows the results for a series of self-gravitating models, for $I_{Ly} = 1$ and several values of σ_z. Comparison with Figure 1 shows that the decline in neutral column density occurs much more rapidly beyond the threshold column density than in the constant scale-height models, with the column density dropping by an order of magnitude in 1/3 of a scale-length.

The main conclusions can be summarized as follows:

1) Photoionization of neutral gas by the extragalactic radiation field can explain the sharp truncation of the H I disk seen in NGC 3198.

2) The H I layer must be self-gravitating, so that the z-thickness increases as the total gas column density declines.

3) H I in the outer disk of NGC 3198 is not in the form of clouds, but is smoothly distributed.

4) If the outer disk of NGC 3198 is typical, the temperature of the neutral gas cannot be greatly in excess of $\approx$ 3000 K, or else H I disks would have much greater z-thicknesses than are observed.

5) More detailed observations and careful modelling of the edges of H I disks in galaxies will allow an accurate determination of the intensity of the extragalactic radiation field near the Lyman limit; there may be interesting implications for the cosmological evolution of neutral disks and absorption-line systems.

References

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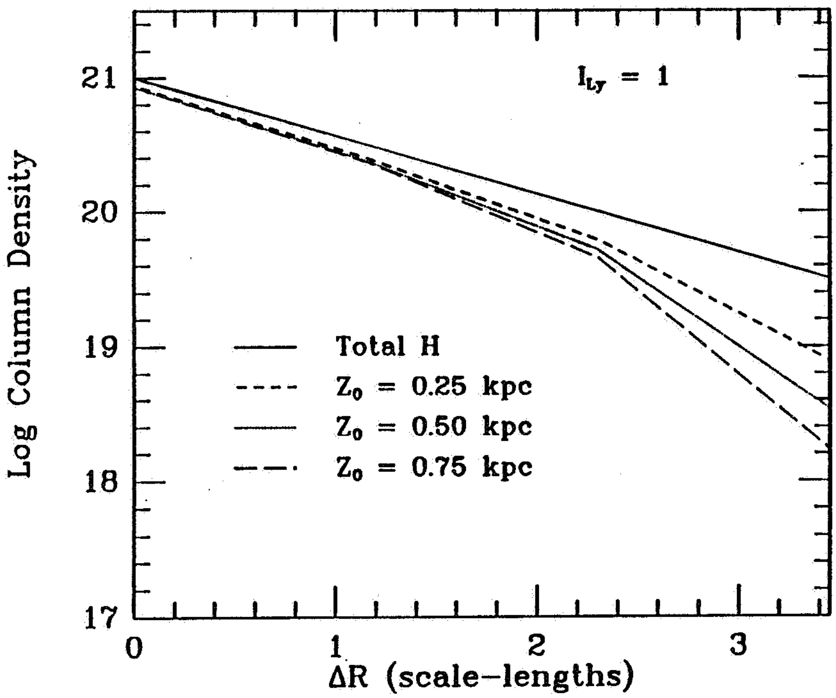

Figure 1. Total and neutral hydrogen column densities for fixed scale-height isothermal models. I_{Ly} is 1 for all models. Each model is labelled with the value of z_0.

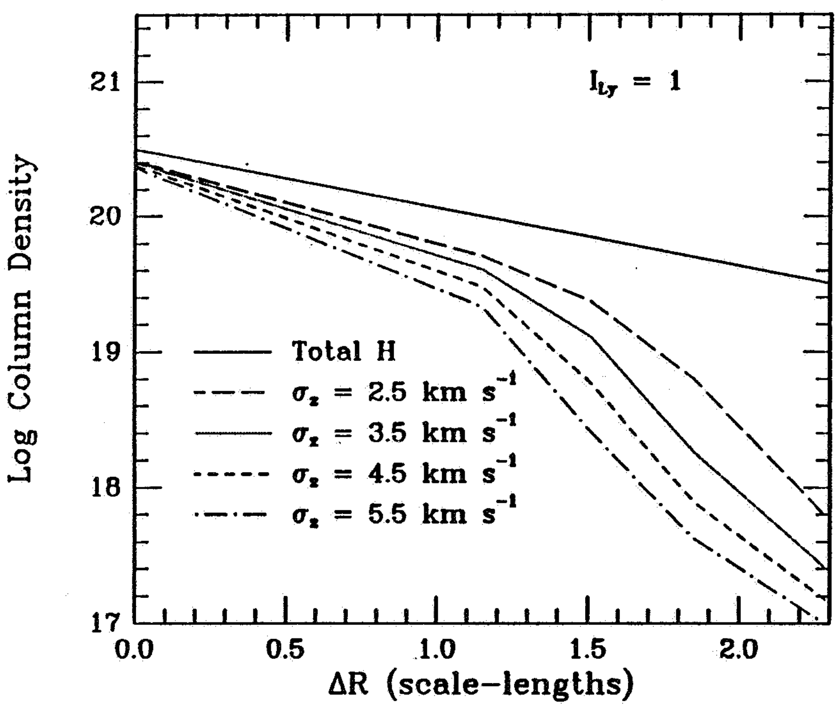

Figure 2. Total and neutral hydrogen column densities for self-gravitating isothermal models. I_{Ly} is 1 for all models. Each model is labelled with the value of σ_z.