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N91-14106

A SCALING LAW OF RADIAL GAS DISTRIBUTION IN DISK GALAXIES

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Based on the idea that local conditions within a galactic disk largely determine the region's evolution time scale, we built a theoretical model to take into account molecular cloud and star formations in the disk evolution process. Despite some variations that may be caused by spiral arms and central bulge masses, we find that many late-type galaxies show consistency with the model in their radial atomic and molecular gas profiles. In particular, we propose that a scaling law be used to generalize the gas distribution characteristics. This scaling law may be useful in helping to understand the observed gas contents in many galaxies.

Our model assumes an exponential mass distribution with disk radius. Most of the mass are in atomic gas state at the beginning of the evolution. Molecular clouds form through a modified Schmidt Law which takes into account gravitational instabilities in a possible three-phase structure of diffuse interstellar medium (McKee and Ostriker, 1977; Balbus and Cowie, 1985); whereas star formation proceeds presumably unaffected by the environmental conditions outside of molecular clouds (Young, 1987). In such a model both atomic and molecular gas profiles in a typical galactic disk (as a result of the evolution) can be fitted simultaneously by adjusting the efficiency constants. Galaxies of different sizes and masses, on the other hand, can be compared with the model by simply scaling their characteristic length scales and shifting their radial ranges to match the assumed disk total mass profile $\sigma_{tot}(r)$. Sigma tot (r).

The idea and an example of applying the scaling law are as follows. Suppose the disk's radial mass distribution is approximately exponential, then our evolution model generally results in atomic and molecular gas profiles shown as shadowed regions in Figure 1 and 2, respectively. For a galaxy with measured disk mass profile $\sigma_{tot}(r)$, these model results can be applied by first figuring out the position of the galactic center on radius axis, and then scaling the axis to determine its actual unit depending on the scale length of $\sigma_{tot}(r)$. For example, the Milky Way Galaxy would fit in if we put the Galactic Center at position GC (of the vertical dot-dashed line), and just ignore part of the figure to the left of that line. A galaxy of smaller mass would correspond to a shift further to the right, while a more massive one to the left. If the disk scale length of our Galaxy is about 2.9 kpc (as in the model of Caldwell and Ostriker, 1981) then the interval between small tickmarks of the horizontal axes in Figure 1 and 2 correspond to 1 kpc in radius. For comparison, we plot the observationally determined surface mass densities $\sigma_{HI}(r)$ and $\sigma_{H_2}(r)$ of our Galaxy as histograms in the two figures. The galactocentric distance of the Sun is corrected to be 9.1 kpc in both cases.

Given the fact that some variations in a number of model parameters (such as the spiral arm pattern and arm-to-interarm density contrast) do not seriously change the general outcome of our calculation, the shadowed regions of the two figures then approximate the

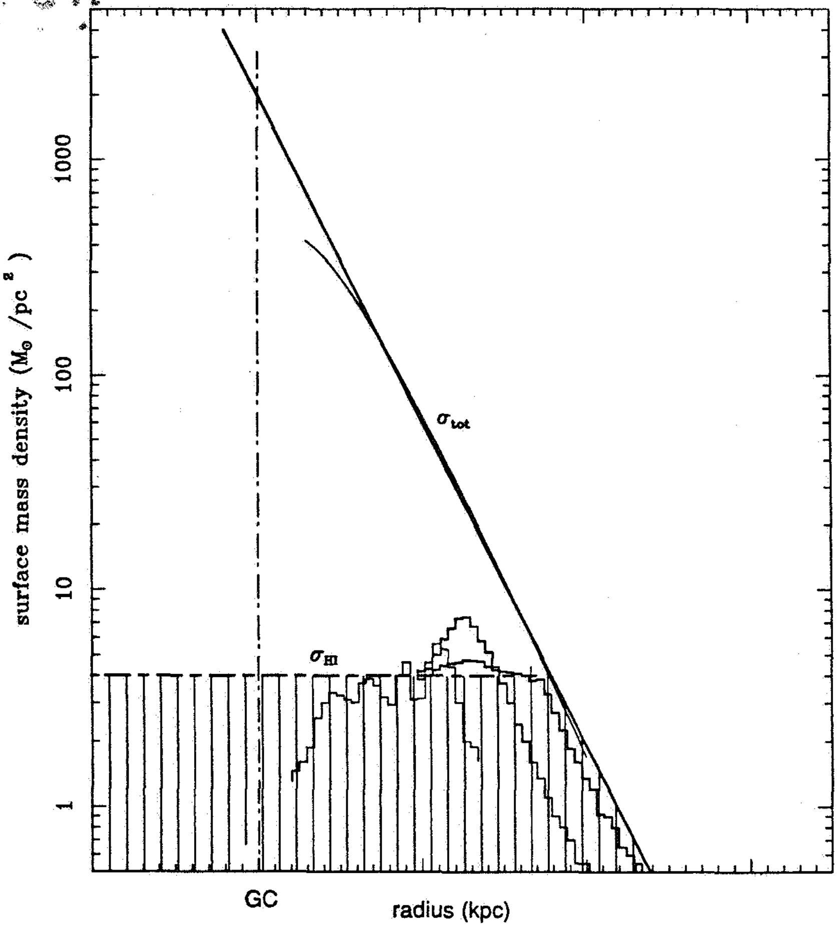

Figure 1. A schematic illustration of the scaling law for HI gas. The three histograms represent measured HI profiles of the Milky Way Galaxy by Burton and Gordon (1978), Kulkarni, Blitz, and Heiles (1982), and Henderson, Jackson, and Kerr (1982). The thin σ_{tot} curve is the Galaxy's disk mass model of Caldwell and Ostriker (1981). See text for details.

HI and H_2 profiles of a typical galaxy, or a galaxy "templet". Tests show that many nearby late-type galaxies with well-sampled HI and CO maps roughly agree with such a model prediction (assuming that CO gas is a proportionality tracer of H_2). Furthermore, the scaling law provides explanation for some observational facts that have received attention only fairly recently. For example, the tendency of dwarf galaxies to have little or no molecular gas in their disks is easily understood from Figure 2, in view of the rapid decrease of $\sigma_{H_2}(r)$ with radius in the templet galaxy.

Some observational data show significant deviations from the general model results of both atomic and molecular gas. The Milky Way Galaxy, for instance, shows pronounced central depression in H_2, and perhaps in HI profile as well. These features can not, as our model work indicates, be simply accounted for without adopting new mechanisms in addition to the azimuthally averaged "one-zone" calculation. Possible causes of these features, which are found to be common among Sa and some Sb type galaxies, include radial gas flows due

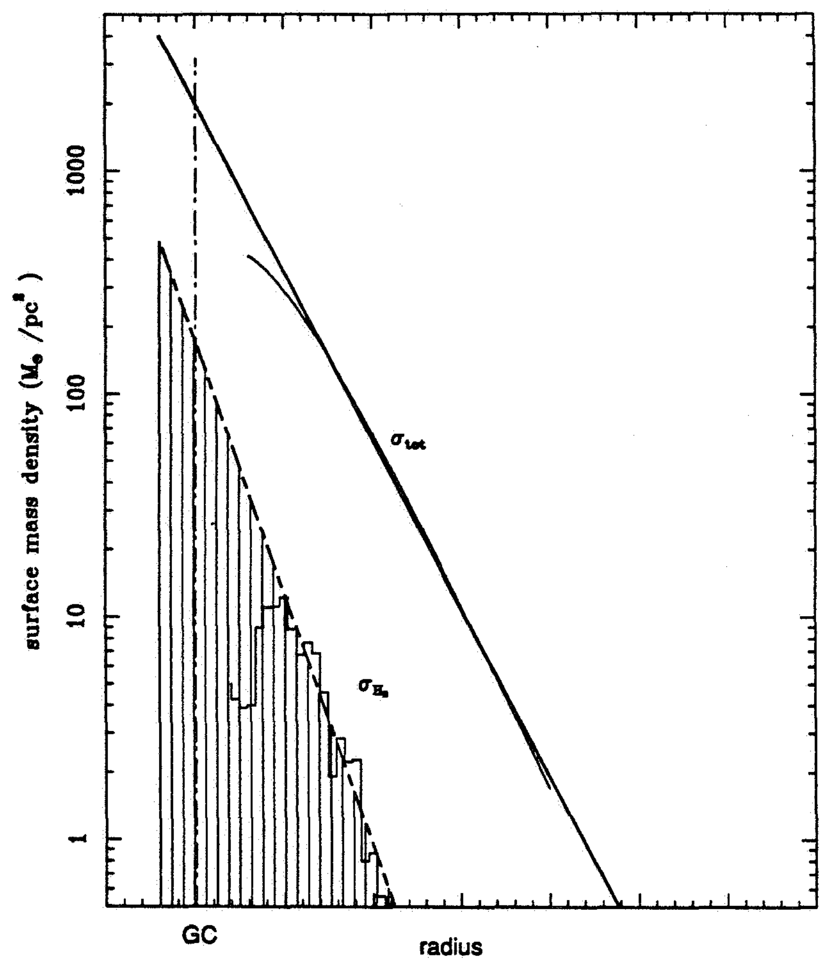

Figure 2. Same as Figure 1, but for H_2 gas. The histogram is from observations of Burton and Gordon (1978) and Clemens, Sanders, and Scoville (1988).

to the effect of the massive central bulge component in these galaxies (Wyse and Silk, 1989; Wang, 1989).

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