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NGC 1058: Gas Motions in an Extended, Quiescent Spiral Disk

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We investigate in detail the motion of gas in the galaxy NGC 1058 using the VLA to map the emission in the 21-cm line. This galaxy is so nearly face-on that the contribution to the line width due to the variation of the rotational velocity across the D-array beam is small compared with the random z-motion of the gas. We confirm results of earlier studies (Lewis 1987, A. & A. Suppl., 63, 515; van der Kruit and Shostak 1984, A. & A., 134, 258) of the galaxy's total HI and kinematics, including the fact that the rotation curve drops faster than Keplerian at the outer edge of the disk, which is interpreted as a fortuitous twist of the plane of rotation in the outer disk. However, our very high velocity resolution (2.58 km s^{-1} after Hanning smoothing) coupled with good spatial resolution, allows us to measure more accurately the line width, and even to some extent its shape, throughout the disk.

One of the most interesting results of this study is the remarkable constancy of the line width in the outer disk. From radius 90" to 210" the Gaussian velocity dispersion (σ_v) of the 21-cm line has a mean value of 5.7 km s^{-1} (after correcting for the spectral resolution) with a dispersion of less than 0.9 km s^{-1} (see Figure 1). Translating this directly into a kinetic temperature ("Doppler temperature"):

$$T_{Dopp} = 121\ K(\sigma_v^2/[km\ s^{-1}]^2)$$

gives 4000 K, with a dispersion of less than 1500 K over the outer disk. This constancy is observed even when comparing the spiral arms versus inter-arm regions (see Figure 2), which in the radius range from 100" to 150" the surface density modulates (defined as the ratio $N_{peak}-N_{trough}/N_{peak}+N_{trough}$) from 0.5 to 0.25 in the range 150" to 200".

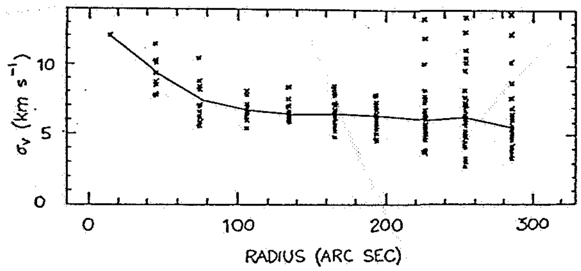
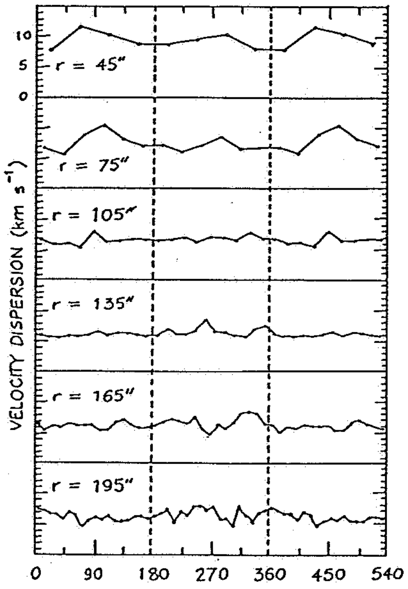


Figure 1. Radial Dependence of Line Width. Beyond 200" the low column densities lead to poorly determined Gaussian parameters.

One simple model to explain the constancy is that the pressure is low enough that all the neutral atomic hydrogen is in the warm phase, with little in cool, diffuse clouds. The constancy of σ_v would then be a natural consequence of the universality of the cooling function, which determines the equilibrium temperature of the warm phase, and hence the line width. However, for solar neighborhood conditions a Doppler temperature of 4000 K would be uncomfortably low, since at least some of the line width must be contributed by macroscopic gas motions. The true kinetic temperature of the gas must then be even lower than 4000 K, a value which is already lower than most estimates for the warm phase temperature.

Another simple model would be to assume some or all of the gas is in cool clouds, whose kinetic temperature is much less than T_{Dopp}. At least some cool clouds must be present in the outer disk, as two supernovae (1961v and 1969ℓ) have been observed there. In this case the line widths would be determined by the velocity distribution function of the clouds themselves. For instance, in the solar neighborhood, the (one dimensional) random velocity distribution for clouds has a half width of about 6 km s^{-1}. With our beam size, which corresponds to between 1 and 3 kpc depending on distance, it is reasonable to expect that many clouds contribute to each observed spectrum. This could possibly explain the smoothness of the Gaussian profiles. If we assume the individual clouds to have thermal line widths of order 1 km s^{-1}, then to find a smooth dispersion of 5.7 km s^{-1}, at least 25 clouds should contribute to each spectrum. In light of this model, the constancy of σ_v is still curious since it implies a remarkably uniform random velocity distribution for the clouds.

A second interesting result of this study is the shape of the residuals after subtracting the best fitting Gaussian from the spectrum. Higher sensitivity is needed to detect deviations from individual pixel spectra, but we can study averages of the residuals to look for widespread deviations from Gaussian-shaped line profiles. We have found that in the inner region corresponding to the optical disk (r < 90") the mean residuals show a characteristic shape suggestive of two superimposed components: a broad, low level feature ($\sigma_v > 10$ km s^{-1}) and a narrow feature ($\sigma_v < 8$ km s^{-1}). The best-fit Gaussian will overestimate the width of the strong, narrow central line in order to reduce the residuals (data minus fit) in the wings and then underestimate the fitted line peak (see Figure 3). The source of the broad feature could be due to observing intermediate velocity clouds, like those seen in the Galaxy. It is difficult to understand the feature being due to thermal motions since it corresponds to a temperature greater than 10,000 K, where neutral hydrogen becomes collisionally ionized. Our detection is very provisional. Better measurement of this low level broad component, and confirmation of its very existence, would be best obtained from a more sensitive observation with more spectral channels. (The present VLA system could provide that with roughly the same integration time as that used here.)



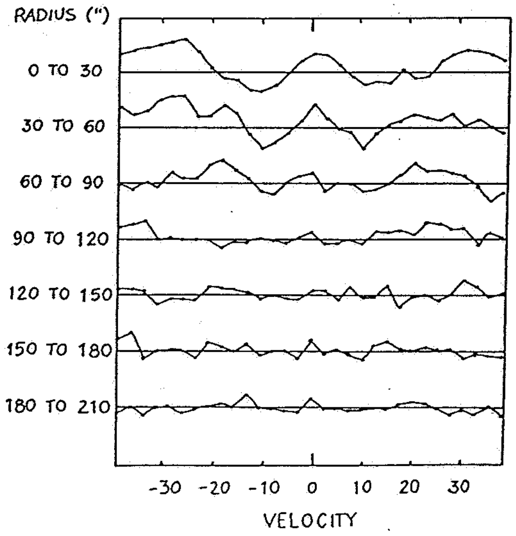


Figure 2. Azimuthal Dependence of Line Width. The spiral arms occur at 180° and 360°.
Figure 3. Data minus Gaussian fit line widths (residuals) as a function of radius.