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DISTRIBUTION AND MOTIONS OF HI IN M31

E. Brinks and W.B. Burton
Sterrewacht, Leiden, The Netherlands

1. INTRODUCTION

It has become clear in the past few years that the distribution and kinematics of HI in M31 is far from simple. The new high-resolution survey made with the Westerbork SRT in the 21-cm line of atomic hydrogen by Brinks and Shane (1983) shows this dramatically. Along almost any line of sight through M31 two separate velocity systems are sampled. Based on a previous survey Shane (1978) and later Bajaja and Shane (1982) proposed that the extra component is due to warping of the plane of the galaxy into the direction of and crossing the line-of-sight. Roberts *et al.*(1978) and Whitehurst *et al.* (1978) emphasized that the observed profile structure ruled out confinement of the gas to a thin plane. Unwin (1983) reached a similar conclusion on the basis of his survey. The most complete model produced up until now which accounts for the two velocity systems is the one by Henderson (1979), based on the 100-m Effelsberg survey of M31 by Cram *et al.* (1980)

The new WSRT survey which was made at a resolution of $\Delta\alpha \times \Delta\delta \times \Delta V = 24'' \times 36'' \times 8.2$ km s^{-1} enables one to see both velocity systems well separated over large portions of the observed area. This separation is most prominent in position-velocity maps made parallel to the major axis of M31. This can be seen in Figure 3a, which shows a map made parallel to the major axis $4\overset{'}{.}8$ to the West. This map was produced after smoothing the original data to a resolution of $\Delta\alpha \times \Delta\delta = 48'' \times 72''$. A complete set of such position-velocity maps is given by Brinks and Shane (1983).

2. THE MODEL

Based on the high-resolution HI data a new model was constructed (Brinks and Burton, in preparation). This model is an extension of the model derived for the inner part of our Galaxy by Burton and Liszt (1978). Only the main characteristics of the model will be discussed here. Figure 1 shows the geometry of the model in a plane which is perpendicular to

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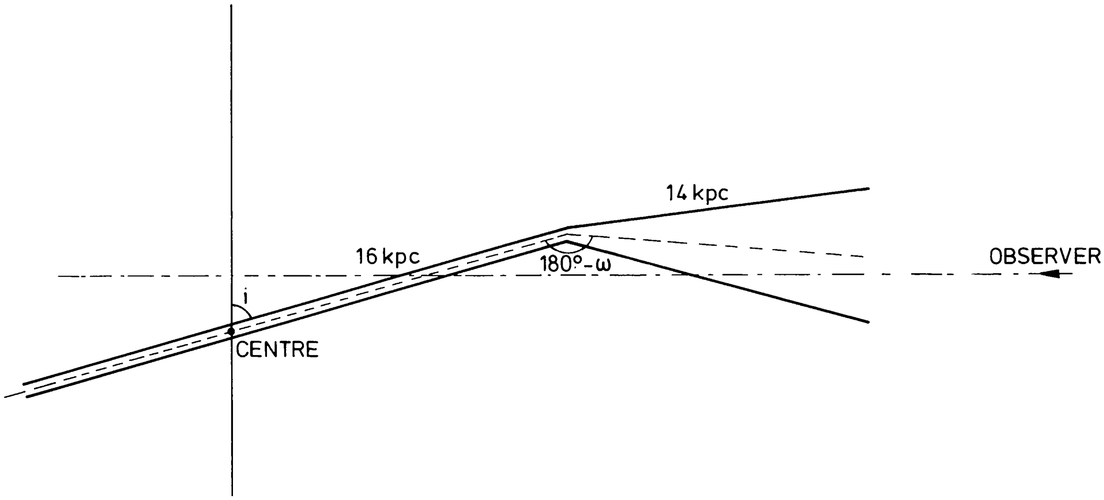

Figure 1: Schematic drawing on scale of the geometry of the model described in the text. The drawing shows the model in the plane which contains the observer and which is perpendicular to the major axis of M31.

the major axis of M31 and which contains the observer. The model starts out with a disk which is inclined at an angle of i = 74° (0° is face-on).

Because many features in the spectra are caused by kinematic rather than by gas-density or temperature effects, we produced synthetic spectra for each line of sight and sorted them to simulate the observed position-velocity diagrams. No convolution with the beam of the observing instrument was applied. The parameters which are needed to specify the geometry and the characteristics of the gas are summarized in Table 1. The model parameters for the gas temperature and density are those employed by Burton and Liszt (1978). The value for the velocity dispersion was deliberately chosen to be lower than the standard 10 km s^{-1} to reduce smearing effects in the synthetic spectra. The HI volume density is kept constant, except for the inner 5 kpc where the lack of gas is simulated by reducing the volume density to 5% of the value used for the rest of the disk.

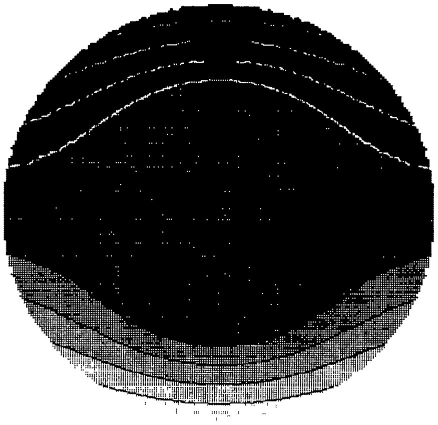

Figure 2: Map showing the deviation of the warp from the mean plane in a face-on view of the model. Contour levels are at -4(1)4 kpc; the dark gray levels correspond to the near side. The diameter of the picture is 60 kpc.

Table 1: Model parameters

Maximum rotational velocity	V_{rot}	$= 260$ km s^{-1}
Region of flat rotation	R	≥ 5.2 kpc
Temperature of the gas	T	$= 120$ K
Velocity dispersion	σ	$= 4$ km s^{-1}

Disk:			Warp:		
Inclination	i	$= 74^{o}$	Angle	ω	$= 20^{o}$
Scale height	h_d	$= 0.33$ kpc	Scale height	h_w	$= 0.3$–3.0 kpc
Density	n_d	$= 0.33$ at cm^{-3}	Density	n_w	$= 0.33$–0.0 at cm^{-3}
Radius	R_d	$= 16$ kpc	Extent	R_w	$= 16$ kpc to 30 kpc

To keep the model simple and to keep the number of free parameters to a minimum, we assume that the warp has a linear dependence of height from the plane of the (extended) unwarped disk along any radius in the galaxy, and that it makes an angle $\omega = 20^{o}$ with the disk at the azimuth, measured in the disk, where the warp reaches its maximum deviation from the plane. The degree of warping, ω, varies as the sine of azimuth. In the model discussed here the line of nodes of the warp runs parallel to the major axis of M31 in such a manner that it bends towards the observer on the near side of the galaxy and away from the observer on the far side, i.e. getting more edge-on. Figure 2 is a face-on view of the model, showing the deviation of the mean plane of the warp with respect to the plane of the disk. We assume cylindrical rotation throughout the disk and the warp. The rotation curve is flat at a circular velocity of 260 km s^{-1} beyond 5.2 kpc, rising linearly from 0 km s^{-1} at the center to the maximum velocity.

3. RESULTS

The most obvious attribute of the warped-galaxy model is its ability - recognized already in the earlier work referenced above - to reproduce the multiply-peaked structures characterizing the observed profiles. Most lines of sight through M31 evidently systematically transverse at least two separate regions of the galaxy. Figure 3 and 4 show both the observed and modelled situation for cuts respectively parallel and perpendicular to the major axis. In Figure 3 the rather linear feature running diagonally across the map corresponds to the warped gas; the other feature is the inner disk. We note that all intensity enhancements in the model are caused by the details of the projections involved; no density structure was put into the model. The model intensity enhancements resemble in a general way the intensity enhancements observed.

In Figure 4 the pedestal features on either side of the major-axis crossing correspond to the warped gas; the inverted-vee shaped feature corresponds to the inner-galaxy disk. During the first stages of the modelling, we constrained the HI scale to be the same, 300 pc, for both the inner disk and the warped part. We found in that case that the broad, diffuse nature of the pedestal corresponding to low-intensity emission in Figure 4a more than 20' from the major axis could not be reproduced.

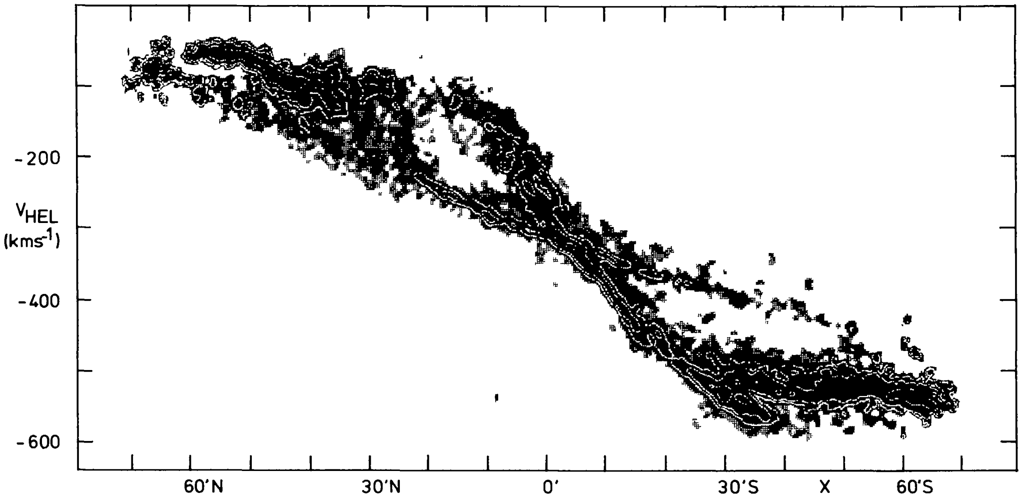

Figure 3a: Position-velocity map made along a line 4'.8 West and parallel to the major axis. Contour levels are at 2.5 , 5 , 10 , and 25 K.

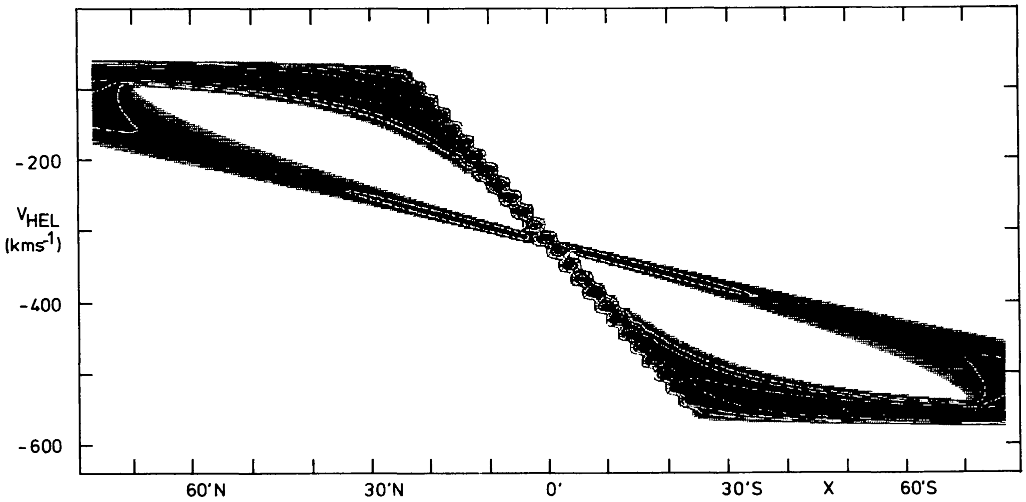

Figure 3b: Model position-velocity map. Same specifications as for Figure 3a.

On the other hand, a flaring warp, in which the scale height of the warped gas increases linearly with radius by about a factor of 10 between the initiation of the warp and the edge of the galaxy does result in synthetic spectra similar in this respect to the ones observed. Also, the low-density HI envelope around M31 seen in a map of the integrated HI brightness (Brinks and Shane, 1983) can be understood in this way. In the model the surface density of the HI in the flaring warp decreases linearly from the value it has in the conventional disk at its initiation to zero at its outer edge.

The principal refinement which we expect to make to the preliminary model shown here involves allowing the line of nodes of the warp to be

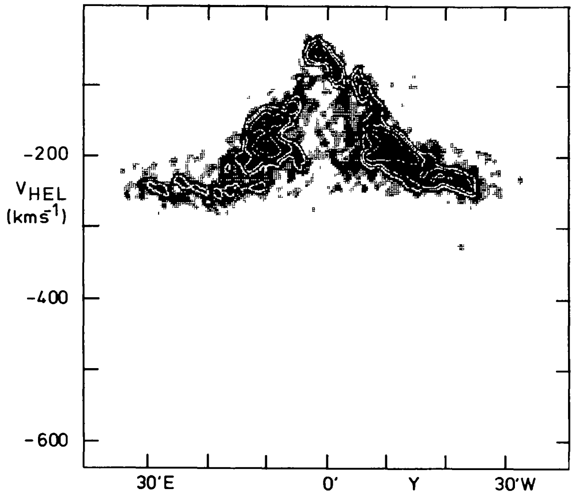

Figure 4a: Position-velocity map made along a line 28'.8 North and parallel to the minor axis. Contour levels are at 2.5, 5, 10, and 25 K.

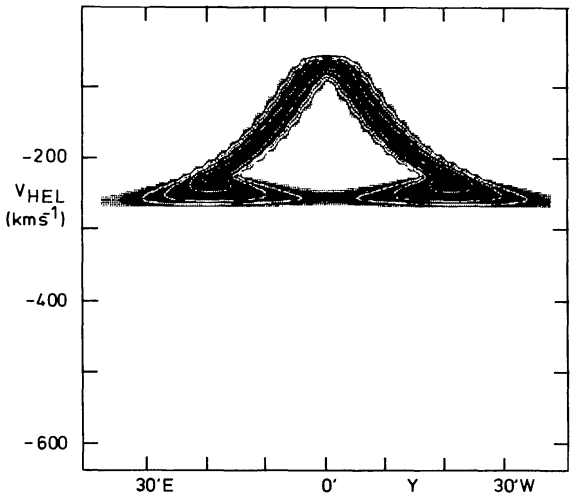

Figure 4b: Model position-velocity map. Same specifications as for Figure 4a.

oriented other than perpendicular to the line of sight. We are investigating if a twist of this orientation may account for the asymmetries in the position-velocity maps with respect to the major and minor axes shown by the observations. Evidence shown by Emerson and Newton (1978) suggests that the warp *is* twisted with respect to the line of sight. The manner in which our model reproduces the observed spectra leads us to favor the warped-galaxy interpretation of the double-peaked position-velocity maps over the interpretation suggested by Byrd (1977) based on the possible gravitational influence of M32 on the disk of M31. Although Byrd showed by computer simulation of such an interaction that multiply-peaked maps could result, only a limited portion of the disk is distorted. Consequently the predicted effects differ much more dramatically on opposite sides of the axes than is observed. In general, the model poorly represents the observed velocity field.

We note that although the model is an *ad hoc* one in the sense that it lacks dynamical justification, some confidence in the plausibility of the model may be found in its similarity to the well-established situation in our own Galaxy. The aspects of the M31 model which are most important to getting a reasonable fit to the data include the sinusoidal variation with azimuth of the warp, the flaring nature of the gas layer in the warp, the large extent of the warp, the general run of HI surface density, and the flat (or at least not rapidly falling) rotation curve. These are all aspects of the morphology of the outer gas layer in our Galaxy (see e.g. Henderson *et al.*, 1982, and Kulkarni *et al.*, 1982) and of other galaxies (Sancisi, 1983). We will make a detailed comparison of the characteristics of the M31 and the Milky Way warps in our paper currently being prepared; we will also address the relative orientation of the two warps.

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DISCUSSION

J.P. Ostriker: Can you comment on the character of the rotation curve?

Brinks: As far as I can tell, it is flat at 260 km/s out to R ~25 kpc.

D. Lynden-Bell: That is quite different from Emerson's result.

Brinks: Yes, but Emerson did not take the warp of the disk into account; the warp explains most of the difference.

I.F. Mirabel: Is there any correlation in position between "holes" in the HI disk and shells going out of the disk? And what is the range of kinetic energies of the HI shells in M31?

Brinks: The average diameter of the holes is about 300 pc; this is smaller than the average of Heiles' supershells. The kinetic energies of the shells are 10^{50} -10^{51} erg, again smaller than Heiles' ~10^{53} erg.

We have not yet been able to discriminate between holes in the HI disk at z = 0 and holes which are offset from the mean HI layer.

J.M. Dickey: Can you estimate the filling factor of neutral hydrogen?

Brinks: On the basis of an analysis of the holes, I estimate the filling factor to be somewhere between 1 and 5%.