A WARP IN THE HI DISTRIBUTION AT THE EXTREME NE AND SW OF M31

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Aperture synthesis observations of the neutral hydrogen in the extreme NE and SW regions of M31 have been made using the Cambridge Half-Mile Telescope, with an angular resolution of 3!6 x 5!5 and a resolution in radial velocity of 16 km/s (Newton and Emerson, 1977). These observations show that a warp in the HI distribution exists in opposite directions at each end of the galaxy.

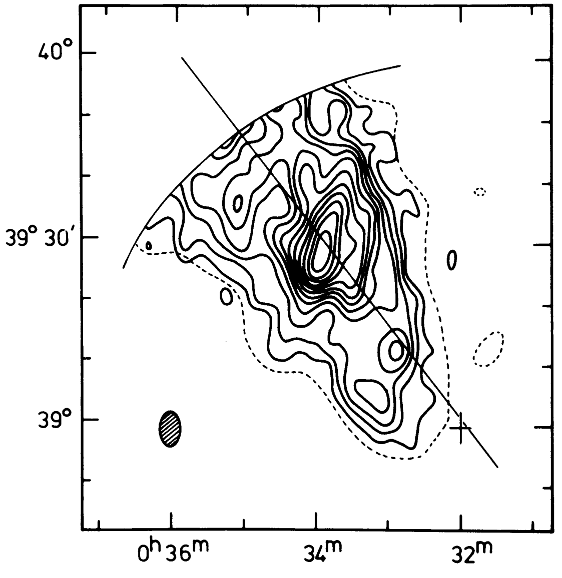

Fig. 1. The integrated hydrogen map at 3!6 resolution of the SW of M31; the contour interval at the map centre is 42 K km/s. The outer (broken) contour is taken from 7' resolution data and shows the extent of HI detected. The major axis (P.A. 38^{o}) is marked by a solid line.

Fig. 1 shows the HI distribution in the SW of M31. No correction has been made for the primary beam pattern of the telescope, which approxi-

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mates a gaussian of 92' FWHP, centred at the point marked with a cross in Fig. 1. Note that there is a sharp edge to the observed HI emission, which is bent to the east of the major axis.

In the extreme NE (R > 24 kpc from the nucleus) of M31 previous observations have been unable to distinguish between HI in M31 and local galactic hydrogen. In the present survey the distinction is possible because of the improved angular resolution, insensitivity to structure with a scale size >2^o, and the higher velocity dispersion of HI emission originating in M31. Fig. 2 shows emission which is believed to originate in M31; note that the angular extent of the emission is extremely narrow in a direction perpendicular to the major axis, certainly narrower than at corresponding positions in the SW. At large distances from the nucleus the HI deviates from the normal major axis by up to 4 kpc in the plane of the sky, an effect similar to that already found in the SW.

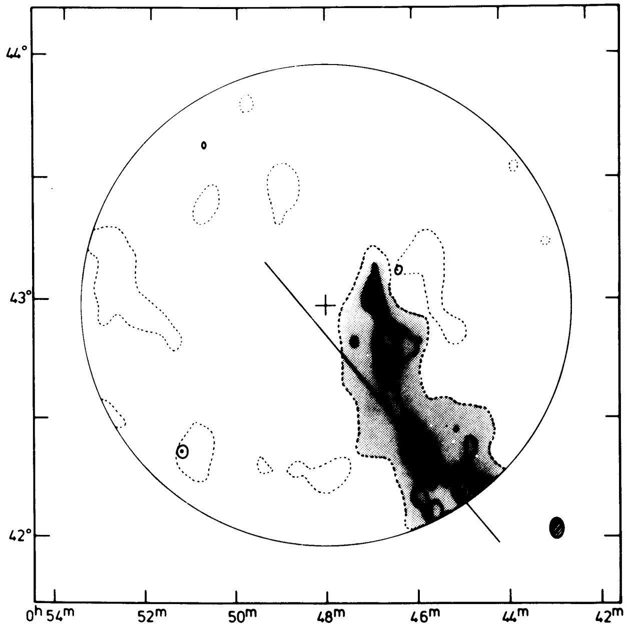

Fig. 2. The integrated HI emission for the NE of M31, as in Fig. 1. The HI emission has been integrated over the velocity range of -121 to -55 km/s, and the contour interval is 22 K km/s at the map centre. The radius (60') at which the power response of the primary beam has fallen to 0.33 is shown as a circle.

OUTER ROTATION CURVE

Fig. 3 shows the rotational velocities derived from the North and South halves of M31 along the dynamical major axis, assuming a heliocentric systemic velocity of -300 km/s. A constant inclination of 78^o has been assumed, but the derived rotational velocities are insensitive to this.

Plate I

A 48 inch Schmidt photograph of M31 (Hale Observatories) with a contour showing the extent of HI in M31 observed by the Half-Mile Telescope. The parts of the contour near the centre are taken from Emerson (1974).

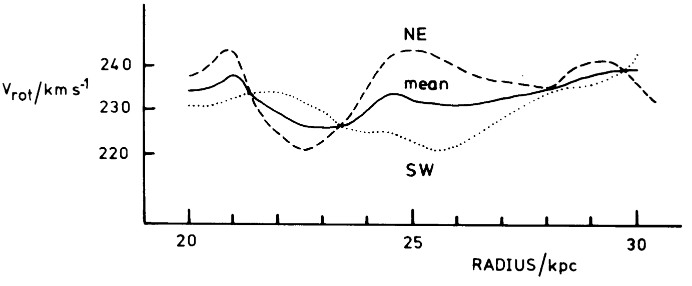

Fig. 3. Rotation velocities for R > 20 kpc, showing the NE, SW and mean curves.

The difference between the NE and SW curves at any radius is less than ∿ 20 km/s, which is typical of local velocity deviations seen at R < 80' by Emerson (1976). The agreement between the curves for the NE and SW suggests strongly that, to within ± 10 km/s, the observed velocities result from the true rotation law of M31, rather than reflecting local non-circular motions. At R > 20 kpc the peak deviation of the mean of the NE and SW curves from a constant VROT of 233 km/s is only ± 7 km/s; from lower resolution observations of the SW alone, Roberts and Whitehurst (1975) suggested a value of 228 km/s.

MODEL HI DISTRIBUTION

The following simple model of the distribution of HI was found to reproduce the observed velocity features well: out to 25 kpc, a flat thin disc of P.A. 38° and inclination 78°, but between 25 and 30 kpc a system of low-density rings, each in circular motion around the nucleus, with P.A. and inclination varying linearly at 1° per kpc, from 38° and 78° at 25 kpc to 33° and 83° at 30 kpc. The simple model was found to match the observed velocities better after including the effects of parallax (the nearer edge of M31, assumed to be the NW, is $\approx$ 9 per cent closer to us than the SE edge).

Fig. 4 gives a 3-dimensional impression of the sense and degree of bending of the plane of M31 suggested by the present observations. Shown in Plate I, is the boundary of HI in M31 detected by the Half-Mile Telescope. Although the model was derived from the observed *velocity* field of M31, the observed HI *densities* and the limit of HI emission indicated in Plate I are also well reproduced by the model.

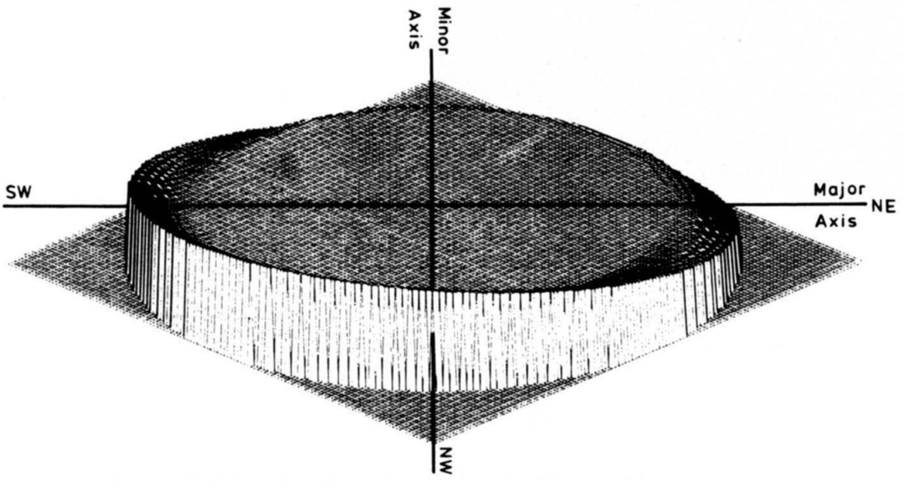

Fig. 4. A 3-dimensional representation of the warp of the plane of M31, based on the model described in the text. The figure shows the distance of the HI distribution from an arbitrary flat plane parallel to and 6 kpc below the main disc of M31, viewed at an angle of 25 degrees to the plane.

REFERENCES

Emerson, D.T.: 1974, *Monthly Notices Roy. Astron. Soc. 169*, 607

Emerson, D.T.: 1976, *Monthly Notices Roy. Astron. Soc. 176*, 321

Newton, K., Emerson, D.T.: 1977, *Monthly Notices Roy. Astron. Soc. 181*, 573.

Roberts, M.S., Whitehurst, R.N.: 1975, *Astrophys. J. 201*, 327

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DISCUSSION FOLLOWING PAPER III.6 GIVEN BY D.T. EMERSON

WELIACHEW: As you have shown, the outer parts of M31 are strongly warped. Then, in order to derive a "rotation curve" in those outer parts you need to make simplifying geometrical assumptions regarding space and velocity coordinates. What assumptions have you made?

EMERSON: It is assumed that the gas is always in circular motion around the nucleus of M31, but in orbits defined by a position angle and inclination which are a function of radius. The derived rotation curve is insensitive to the inclination (an error of ±5 km/s is implied for true inclination varying between 73 and 85 degrees). The position angles of the circular orbits are defined by the locus of maximum deviation of observed velocities from the systemic velocity.

GIOVANELLI: Is your estimate of the warp consistent with the one reported by Dr. Whitehurst? From your last figure I had the impression that yours was farther out.

EMERSON: A substantially flat disk is a good fit to the data as far out as ∿ 20 kpc in the plane of the galaxy. The warp becomes visible beyond 25 kpc.

SHOSTAK: If you look along the major axis in the southern half of M31, at a radius at which the rotation curve has become flat, what is your observed line width?

EMERSON: The observed line width is about 25 km/s, corresponding to a true width of 20 km/s; after allowing for velocity smearing in some parts of the galaxy there is no evidence for any significant deviation from this value.

VAN DER KRUIT: Could you comment on the effects of the warp on the determination of the rotation curve and mass models? Also, are your data on the rotation curve inconsistent with a constant mass-to-light ratio with radius?

EMERSON: The uncertainties in the true rotation curve due to non-circular motions - e.g. the difference between the NE and SW rotation curves at a given radius - are probably more important than the effects of the warp itself. The main uncertainty in derived M/L ratios results from the lack of knowledge of the rotation law beyond 30 kpc. The derived M/L ratio increases by a factor of order 3 from R = 5 to R = 25 kpc. Beyond 25 kpc the M/L ratio is essentially unknown, since the derived mass density is so sensitive to assumptions about the rotation law beyond 30 kpc.

M.S. ROBERTS: Am I correct in concluding that you are only able to obtain a constant M/L ratio with radius when you assume that the mass in M31 extends only to your last measured point?

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EMERSON: The data imply a M/L ratio (uncorrected for absorption) of ∿ 16 at R = 5 and 15 kpc, increasing to ∿ 44 at 25 kpc. Beyond 25 kpc it is only possible to derive a lower limit; the possible values of the M/L ratio range from ∿ 20 (assuming no mass beyond 30 kpc) to ∿ 200 (assuming a flat rotation curve out to 50 kpc).

DAVIES: NEW OUTER HI ARMS IN M31

A high sensitivity neutral hydrogen survey of the southern region of M31 has been made (together with G.P. Davidson) with the MK IA (beamwidth = 13') and the MK II (beamwidth = 33') radio telescope at Jodrell Bank. The area further south than 90' from the center was mapped with a sensitivity better than 0.02 K. The following are the main conclusions of the study:

(a) There is no large bend in the HI distribution beyond 120' south of the center.

(b) Weak emission with a line integral of a few times 10^{18} atoms cm^{-2} is seen out to 162' from the center where it lies approximately 30' either side of the major axis.

(c) The shape and velocity of these weak outer arms suggest that they may have an inclination (i) of ∿ 70^o whereas the main arms have $i = 76^o$ to 78^o.

(d) The emission profiles at more than 120' from the center are narrow. They have full half-power widths of 20 - 25 km/s. Similar narrow emission profiles are seen along the minor axis of M31.

(e) The rotation curve does not fall beyond 80' south of the center. The total mass out to 200' (the distance corresponding to the outermost HI emission) is 5.5×10^{11} $M_\odot$.

ALLEN: I am trying to understand the interpretation of the velocity measurements furthest from the center. I think I understand your geometrical model; if we assume it is correct, what is your physical interpretation of the rising rotation curve at these very great distances?

DAVIES: If the rotation velocity goes up, then we must have more mass in those outer parts.

WRIGHT: What is the velocity dispersion for the outer HI distribution?

DAVIES: About 9 - 11 km/s.

VISSER: What about the possibility that you are looking at high velocity clouds of M31?

DAVIES: You then would expect velocity differences of 50 to 100 km/s, which we don't see.

BURKE: It is not clear that having clouds moving toward the plane on one side and away on the other is more ad hoc than symmetric infall or outflow. An intergalactic wind, condensing into flat sheets of low velocity dispersion in the vicinity of the plane might be just as physically reasonable, and you could still have a flat average rotation curve.

DAVIES: Let me give a partial answer: On the minor axis the velocity differs about 20 km/s from the systemic velocity on one side and less than 5 km/s on the other side.

BURKE: An intergalactic wind need not be uniform over a scale of tens of kiloparsecs.

M.S. ROBERTS: Three points: (1) The high values of rotational velocity you derive can be avoided by adopting relatively minor changes in the position angle of this outermost hydrogen. (2) Rotation curves can go down or up. The requirement that they always decrease after the peak value only reflects a preconceived model of the mass distribution. (3) The shape of a rotation curve tells us nothing of the three-dimensional mass distribution; there is not enough information in $V_{ROT}(R)$ for this. Thus a flat or even an increasing rotation curve does not require a halo for its explanation.

VAN DER KRUIT: A difficulty in studying M31 is its rather closely edge-on view. Astronomers in M31 would have the same problem when studying our Galaxy. This inclination makes it difficult to locate your features and to deproject the velocities. I wonder how big the error bars would be on your rotation curve for the outermost points.

DAVIES: The error on the actually measured velocities is about 5 km/s. The error on the rotation velocities is about 10 km/s.

VAN DER LAAN: In the discussion concerned with the origin of quasar absorption lines, the effective size of galaxies in the gas is a key parameter. We may conclude from your results that M31 has a diameter of at least 100 kpc at column densities $N_H \simeq 10^{18}$ cm^{-2}, as smoothed with a 10' arc beam. For the discussion alluded to, it is very important to determine how smooth or clumpy the HI surface density is in fact. So even this far out, observations with a beamwidth of $\sim$ 1' should be attempted.