Astron. Astrophys. 322, 86–88 (1997)

ASTRONOMY AND ASTROPHYSICS

Research Note

The orientation of warps in the Local Group

A. Zurita[1,2] **and E. Battaner**[1]

[1] Departamento de Física Teórica y del Cosmos, Facultad de Ciencias, Universidad de Granada, E-18002 Granada, Spain
[2] Instituto de Astrofísica de Canarias, E-38200 La Laguna, Tenerife, Spain

Received 25 September 1996 / Accepted 20 November 1996

Abstract. The three major spiral galaxies in the Local Group are known to be warped. The question is investigated of whether or not these three warps are aligned. Using available HI observations we find that they are noticeably aligned. Vectors defining the warp orientation form the following angles: [M 31, M 33]=33º; [M 31, Milky Way]=35º; [M 33, Milky Way]=4º. The alignment of the directions of the warp lines of nodes is lower even though also noticeable.

Key words: Galaxy: structure – galaxies: M 31; M 33 – galaxies: structure

1. Introduction

Whether warps of different spiral galaxies are coherently aligned is an open and interesting question. Battaner *et al.* (1991) used the catalogue of warped edge-on northen spiral by Sánchez-Saavedra *et al.* (1990) to study the orientations of warps in the $\simeq$100 Mpc Milky Way neighbourhood . They found typical cells of about 25 Mpc of coherent alignment. In particular, they identified a Virgo group, containing the Virgo cluster [$6^{\rm h} < \alpha < 18^{\rm h}$; v $<$ 2000 km/s; 12 galaxies] and an adjacent group [$6^{\rm h} < \alpha < 18^{\rm h}$; v $>$ 3000 km/s; 14 galaxies] with a relatively small standard deviation in the distribution of orientations. The mean orientations of the Virgo group and that of the adjacent one were nearly perpendicular. The orientation vector is precisely defined below.

Together with a statistical study of as large a sample as possible, an inspection of the closer and better studied warps would be an interesting complement. Even if we reduce the sample to three galaxies, the Milky Way, M 31 and M 33, it is convenient to study the topic of coherently orientated warps ”at home” in the Local Group.

We will only use 21 cm data. The M 33 warp has been studied by Wright (1979), Deul and van der Hulst (1987), Corbelli, Schneider and Salpeter (1989) and others. For our purposes, we adopted the geometrical description in the early work by Rogstad, Wright and Lockhart (1976). The M 31 warp has been described by Newton and Emerson (1977), Emerson and Newton (1978), Henderson (1979), Bajaja and Shane (1982), Brinks and Shane (1984), Brinks and Burton (1985), Braun (1991) and others. Here we have adopted the detailed analysis by Brinks and Burton (1984) in which it is shown that the M 31 warp is orientated almost directly towards us, near the line-of-sight, in contrast with early works.

The Milky Way warp has been studied in 21 cm by Burke (1957), Kerr (1957), Burton (1978), Henderson *et al.* (1982), Kerr (1983), Burton and te Lintel Hekkert (1986), Burton and Deul (1987), Diplas and Savage (1991) and others. The discussion by Burton (1992) contains the most up-to-date summary of the warp situation in the Milky Way, summarizing also the M 31 and M 33 warps. The interpetration of the 21 cm Milky Way data is somewhat ambiguous and subject to a possible reinterpetration. In some galaxies the warp rises first from the mean plane and then turns back to the plane and moves in the opposite direction. One example is NGC 4012 as observed by combining the data in the optical (Florido *et al.*, 1991) and in 21 cm (Bottema, 1995). The Milky Way warp probably belongs to this kind with an ”elbow” or initial counterwarp. It was already known that the south warp changes its direction in this way. New measurements carried out by Burton (1996) which extend to much larger galactocentric distances, reveal the same behaviour for the north warp. This trend was already appreciable in the early measurements which are now confirmed. We therefore conclude that our own galaxy is warped in this way.

Send offprint requests to: E. Battaner

2. The orientation of the warps of the Milky Way, M 31 and M 33

To characterize the position of a warp in space, we have two possibilities. One of them is the direction of the line of nodes itself. The other one is the ”orientation” vector. Let us precisely define the ”orientation” vector of a warp. Suppose an untwisted line of nodes. Let $\boldsymbol{n}$ be a unitary vector contained in the line

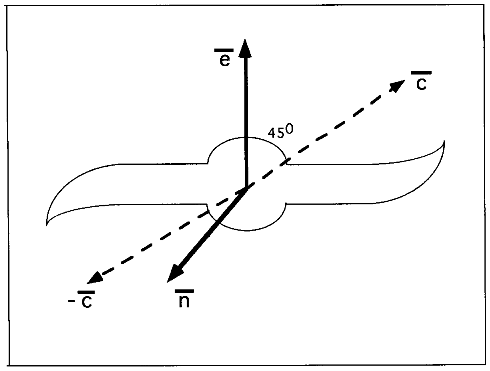

Fig. 1. Definition of the orientation vectors

of nodes. Its direction is conventionally assigned as pointing to a region from which the warps are seen as N-shaped (not S-shaped), i.e. from which, due to the observed bending, the galaxy appears to have a clockwise gyration. Let $\boldsymbol{e}$ be a unitary vector with the direction of a rotation axis. We define the orientation direction as that containing either $\boldsymbol{c}$ defined as

$$\boldsymbol{c} = \boldsymbol{e} + \boldsymbol{e} \times \boldsymbol{n} \quad \text{or} \quad -\boldsymbol{c}.$$

From an observational point of view $\boldsymbol{c}$ and $-\boldsymbol{c}$ are undistinguishable. From a theoretical point of view, whatever the interpretation is assumed, the distinction between $\boldsymbol{c}$ and $-\boldsymbol{c}$ is probably meaningless.

In the figure, we show the direction $[\boldsymbol{c}, -\boldsymbol{c}]$ in a galaxy observed as edge-on. We define $[\boldsymbol{c}, -\boldsymbol{c}]$, in this way, because under the interpretation of warps made in the magnetic model by Battaner *et al.* (1990), $[\boldsymbol{c}, -\boldsymbol{c}]$ would coincide with the direction of the intergalactic field. But it is emphasized that we present this work as completely free from any theoretical interpretation. By defining the orientation in this way we can easily compare it with our previous determinations of other galaxies, too.

The information given by both, the direction of the line of nodes and the orientation vector, are not equivalent. For instance, if the galaxy is gyrated about the line of nodes, its direction would not be modified, but the orientation vector could change. Therefore we have made the calculation about the coherence for both vectors.

Let us calculate $\boldsymbol{c}$ for M 31, M 33 and the Milky Way, using the same coordinate system. The orientation vector defined in the system centred in the plane of the considered galaxy must be subject to the following transformations:

a) From $\boldsymbol{c}$ referred to the plane of the galaxy, we obtain $\boldsymbol{c}$ referred to the plane of the sky, defined by the vectors $\boldsymbol{v}, \boldsymbol{t}, \boldsymbol{s}$ ($\boldsymbol{v}$ in the line of the sight direction; $\boldsymbol{t}$ and $\boldsymbol{s}$ in the tangent plane, $\boldsymbol{s}$ northwards and $\boldsymbol{t}$ eastwards)

$$\boldsymbol{c}_{(v,t,s)} = \begin{pmatrix} -\sin i & 0 & \cos i \\ -\cos p \cos i & -\sin p & -\cos p \sin i \\ \sin p \cos i & -\cos p & \sin p \sin i \end{pmatrix} \boldsymbol{c}_{\text{(plane galaxy)}}$$

b) From $\boldsymbol{c}$ referred to the plane of the sky, we obtain $\boldsymbol{c}$ referred to the plane of the equator

$$\boldsymbol{c} = \begin{pmatrix} \cos\delta_o \cos\alpha_o & \cos\delta_o \sin\alpha_o & \sin\delta_o \\ -\sin\alpha_o & -\cos\alpha_o & 0 \\ -\sin\delta_o \cos\alpha_o & -\sin\delta_o \sin\alpha_o & \cos\delta_o \end{pmatrix} \boldsymbol{c}_{(v,t,s)}$$

where i, p and (α_o, δ_o) are the inclination, position angle and equatorial coordinates, respectively.

The same transformations must be taken into account to obtain the direction of the line of nodes.

3. Conclusions

For M 31, from Brinks and Burton (1984) we know that the warp forms an angle of about 20° with the line of sight, when measured clockwise in the main plane of M 31. On the other hand, the warp points towards the observer in the NW part, so for $\alpha_o = 40^m$, $\delta_o = 41°$, $p = 35°$, $i = 77°$, we obtain

$$\boldsymbol{c}_{\text{M 31}} = (0.628,\ -0.479,\ 0.613)$$

For M 33, following the study by Rogstad, Wright and Lockhart (1976), the warp points in a direction contained in the plane of M 33 which forms 45° (clockwise) with the major axis. Furthermore, the warp points towards the observer at its closest part. Then for $\alpha_o = 1^h 31^m 1.7^s$, $\delta_o = 30.40°$, $p = 23°$, $i = 55°$, we obtain

$$\boldsymbol{c}_{\text{M 33}} = (0.914,\ -0.383,\ 0.130)$$

For the Milky Way, taking the above-mentioned measurements by Burton (1996) and the figure in Battaner, Florido and Sánchez-Saavedra (1990) we obtain

$$\boldsymbol{c}_{\text{Milky Way}} = (0.935,\ -0.346,\ 0.086)$$

We have also calculated the direction of the line of nodes and the angles between them. This is important because in the early paper by Kahn and Woltjer (1959), a relation between the line of nodes and the motion of the galaxy is predicted. Unfortunately, little was known about the motion of galaxies in the Local Group, with the exception of the Magellanic Clouds (Lin, Jones and Klemola, 1995). However, this motion cannot be irregular and a common direction of the line of nodes, specially of those of M 31 and M 33 is to be expected.

For the direction of the line of nodes, $\boldsymbol{n}$, we obtain the following table

	x	y	z	α	δ
$\boldsymbol{n}_{\text{M 31}}$	0.326	-0.554	-0.766	-59.5°	-50.0°
$\boldsymbol{n}_{\text{M 33}}$	0.083	-0.134	-0.988	-58.9°	-81.1°
$\boldsymbol{n}_{\text{Milky Way}}$	0.202	0.714	0.670	74.2°	42.1°

and the angles between them are

[M 31, M 33]=31°

[M 31, Milky Way]=33°

[M 33, Milky Way]=42°

showing a noticeable degree of alignment.

However, the degree of alignment is much higher when we use the vector $\boldsymbol{c}$ to characterize the orientation of the warp. The results obtained are summarized in the following table

	x	**y**	**z**	α	δ
$\boldsymbol{c}_{\mathrm{M\ 31}}$	0.628	-0.479	0.613	-37.3^{o}	37.8^{o}
$\boldsymbol{c}_{\mathrm{M\ 33}}$	0.914	-0.383	0.130	-22.7^{o}	7.5^{o}
$\boldsymbol{c}_{\mathrm{Milky\ Way}}$	0.935	-0.343	0.086	-20.1^{o}	5.0^{o}

The angles between these warp orientations are

[M 31, M 33]=33^{o}

[M 31, Milky Way]=35^{o}

[M 33, Milky Way]=4^{o}

Consider any two random warp orientations. It is easily calculated, taking into account that $\boldsymbol{c}_i$ is the same orientation as -$\boldsymbol{c}_i$, that the probability of obtaining an angle between them, less than α, is

$$P(<\alpha) = 1 - \cos\alpha$$

Therefore the probabilities of having obtained angles as small as the above ones are 0.14, 0.18 and 0.0025, respectively: the highest degree of alignment corresponds to the pair formed by the Milky Way and M 33.

There is therefore a noticeable coincidence. The three largest galaxies in the Local Group seem to be warped in a coherent form.

This fact gives some additional support to the magnetic hypothesis and to the theory by Kahn and Woltjer (1959) (see for current theories about warps the reviews by Binney (1992), Combes (1994), Battaner (1995) and others). It is however difficult to obtain firm conclusions, due to the very small size of the sample and the difficulties in interpreting the warp of our disc. Even so, the calculation carried out is a necessary one to have all data at hand, to physically interpret the phenomenon of warps.

References

Bajaja, E. & Shane, W.W., 1982, A&AS 49, 745
Battaner, E., 1995, in: The formation of the Milky Way., eds. E.F. Alfaro & A.J. Delgado, Cambridge University Press, Cambridge
Battaner, E., Florido, E. & Sánchez-Saavedra, M.L., 1990, A&A 236, 1
Battaner, E., Garrido, J.L., Sánchez-Saavedra, M.L. & Florido, E., 1991, A&A 251, 402
Binney, J., 1992, ARA&A 30, 51
Bottema, R., 1995, A&A 295, 605
Braun, R., 1991, ApJ 372, 54
Brinks, E. & Burton, W.B., 1984, A&A 141, 195
Brinks, E. & Burton, W.B., 1985, The Milky Way Galaxy., D. Reidel Publishing Co., Dordrecht, p. 437
Brinks, E. & Shane, W.W., 1984, A&AS 55, 179
Burke, B.F., 1957, AJ 62, 90
Burton, W.B., 1979, The large-scale characteristics of the Galaxy., College Park, D.Reidel Publishing Co., Dordrecht
Burton, W.B., 1992, Distribution and Observational Properties of the ISM., in: The Galactic Interestelar Medium., eds. Pfenniger, D. & Bartholdi, P., Springer-Verlag, p. 126
Burton, W.B., 1996 Personal communication.
Burton, W.B. & Deul, E.R., 1987, The Galaxy, Cambridge, D. Reidel Publishing Co., Dordrecht, p. 141
Burton, W.B. & te Lintel Hekkert, P.,1986, A&AS 65, 427
Combes, F., 1994 in: The formation of galaxies., eds. C. Muñoz-Tuñón & F. Sánchez, Cambridge University Press
Corbelli, E., Schneider,S.E. & Salpeter, E.E., 1989, AJ 97,390
Deul, E.R. & Van der Hulst, J.M., 1987, A&AS 103, 475
Diplas, A., 1992, A study of neutral hydrogen distribution of the Milky Way through 21 cm emision and Lyman alpha absortion., Ph.D. thesis, Wisconsin Univ.
Diplas, A. & Savage, B.D., 1991, ApJ 377, 126
Emerson, D.T. & Newton, K., 1978, Structure and properties of nearby galaxies., D.Reidel Publishing Co., Dordrecht, p. 183
Florido, E., Prieto, M., Battaner, E., Mediavilla, E. & Sánchez-Saavedra, M.L., 1991, A&A 242, 301
Henderson, A.P., 1979, A&A 75, 311
Henderson, A.P., Jackson, P.D. & Kerr, F.J., 1982, ApJ 263, 116
Kahn, F.D. & Woltjer, L., 1959, ApJ 130, 705
Kerr,F.J., 1957, AJ 62, 93
Kerr,F.J., 1983 Kinematics, Dynamics and Structure of the Milky Way., D.Reidel Publishing Co., Dordrecht, p. 91
Lin, D.N.C., Jones, B.F. & Klemola, A.R., 1995, ApJ 439, 652
Newton, K. & Emerson, D.T., 1977, MNRAS 181, 573
Rogstad, D.H., Wright, M.C.H. & Lockhart, I.A., 1976, ApJ 204, 703
Sánchez-Saavedra, M.L., Battaner, E. & Florido, E., 1990, MNRAS 246, 458
Wright, M.C.H., 1979, ApJ 233, 35

This article was processed by the author using Springer-Verlag LaTeX A&A style file *L-AA* version 3.