ON THE CIRCULAR VELOCITY IN THE ANDROMEDA GALAXY

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Abstract. By analysing a sample of 158 globular clusters belonging to the galaxy M 31 or Andromeda Nebula (AN) in the framework of a spherically symmetric model with constant circular velocity a value of 260 ± 40 km s⁻¹ for this quantity is obtained. It is also found that the number density of AN globulars roughly decreases as the cube of the distance to the centre with a cutoff radius of about 40 kpc. The implied AN mass within this cutoff is about 0.6 Tₘₒ (1 Tₘₒ = 10¹² Mₒ). Bearing in mind the model limitations this mass is rather an upper limit. The present results suggest 1.5 as a probable value for the mass ratio of AN to the Milky Way unless their massive dark coronae are significantly different in size.

The velocity distribution of AN globulars seems to be close to isotropic.

1. Introduction

The aim of the present paper is to estimate the circular velocity in the famous galaxy M 31 (NGC 224), or simply Andromeda Nebula (AN). This means practically to estimate its total mass. Since the observational material is a sample of globular clusters, the questions concerning their distributions in the ordinary space and in that of velocities are unavoidably involved.

The mass of AN has been estimated by use of various approaches: by studying the rotation curve (e.g. Ubriaco and Tharrats, 1984), by studying the motion of the satellites (e.g. Bahcall and Tremaine, 1981) or by imposing a lower limit through the velocity of one satellite (e.g. Saha et al., 1990).

The AN globular clusters have been often used as probes (e.g. Federici et al., 1990 and the references therein). Usually there are two possibilities in such studies to apply the virial theorem (e.g. Kent et al., 1989) and to apply the projected-mass method (e.g. Federici et al., 1990).

Though, at first glance, discordant, the results of the mass determination, nevertheless, show a relatively good agreement. One should not forget that a rotation-curve analysis yields a lower limit only because one can reach distances to the AN centre not more than some 30–40 kpc, whereas on the other hand studies of the satellite motion and of the Local Group as a whole (e.g. Ninkovich et al., 1991) suggest that the total mass of AN is distributed within significantly larger volumes. Thus it seems that a mass value of at least about 0.5–0.6 Tₘₒ, with a possibility to be as high as 1.5–2 Tₘₒ, is acceptable. Certainly, the AN-mass question includes the problem of the dark matter (presumably constituting the dark halo or corona).

The question of the kinematics of the globular-cluster system in AN is also important. It is not clear whether its rotation is essential or negligible. There may be some evidence in favour of the rotation (e.g. Kent et al., 1989), but controversies cannot be avoided (Federici et al., 1990 and the references therein).
As for the distribution of residual velocities, one may assume a priori its global isotropy (equality only of the mean values taken over whole sample), as was done by Kent et al. (1989), but this question, certainly, needs a thorough analysis in the framework of the assumed model. The present paper will try to answer these questions using a simple, spherically symmetric, model for AN.

2. Approach

Bearing in mind the importance of the dark-matter problem it is assumed here that the motion of each sample cluster with respect to the AN centre is governed by the dark corona only. For the latter one a very simple model is assumed - steady state with spherical symmetry where the density within a given radius follows the law $r^{-2}$ ($r$ distance to AN centre), but beyond that radius it vanishes. As well known, the circular velocity in such a model is constant (e.g. Ninkovich, 1986). The approach used in the present analysis is based on the virial theorem.

The advantage of the present model, in addition to its general simplicity, is that one, irrespectively of the spatial distribution of the test particles (globular clusters in the present case), easily obtains by applying the virial theorem

$$\langle v^2 \rangle = u_c^2,$$

where on the left-hand side is the mean velocity square with respect to AN taken over the whole sample and $u_c$ is the circular velocity. Using (1) it is possible to determine the circular velocity. However, one should emphasize that the mean velocity square appearing in (1) is in fact a weighted mean where the weights are proportional to the cluster masses which are not available. In view of the long relaxation time for the halo of a spiral galaxy (to which globular clusters belong, as well) one may accept that the mass distribution of globular clusters is independent of the velocity one so that the equality contained in (1) is also valid for the unweighted mean.

3. Procedure and Results

The present sample consists of a total of 158 globular clusters. The data comprise the identification of each cluster, its angular separation from AN, the line-of-sight velocity and its error. There are additional data, depending on the source, such as the equatorial coordinates and the angular distance converted into kpc according to the assumed heliocentric distance of AN. The list of Kent et al. (1989) containing 149 globular clusters is taken completely; in the present paper the data of Federici et al. (1990), containing 31 objects, are also used. In the paper by Kent et al. the errors of line-of-sight velocities are given individually, for each cluster, whereas in that by Federici et al. the errors are given generally. Since the two lists have 21 clusters in common, one (vdB in MC column of Federici et al., 1990) is rejected as a probable nonmember or an erroneous object (also not considered in discussion