Towards a kinematic model of the Local Group

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Abstract

Key and still largely missing parameters for measuring the matter content and distribution of the Local Group are the proper motion vectors of its member galaxies. Very Long Baseline Interferometry (VLBI) observations of bright H_2O masers in M33 enabled us to measure the 3-D motion of this galaxy relative to the Milky Way of 190 $\pm$ 59 km s^{-1}. This measurement severely constrains the possible values of M31's proper motion. The condition that M33's stellar disk will not be tidally disrupted by either M31 or the Milky Way over the past 10 billion years, favors a proper motion amplitude of 100 $\pm$ 20 km s^{-1} for M31.

1 The proper motion of M33

Two regions of H_2O maser activity in M33 (IC 133 and M33/19) were observed four times with the Very Long Baseline Array (VLBA) over three years (Brunthaler et al. 2005). The observed proper motion $\vec{v}_{prop}$ of a maser in M33 can be decomposed into three components $\vec{v}_{prop} = \vec{v}_{rot} + \vec{v}_{\odot} + \vec{v}_{M33}$. Here $\vec{v}_{rot}$ is the motion of the maser due to the internal galactic rotation in M33. This can be calculated using the known rotation of the H I gas (e.g. Corbelli & Schneider 1997). $\vec{v}_{\odot}$ is the apparent motion of M33 caused by the rotation of the Sun around the Galactic center (e.g. Reid & Brunthaler 2004. The last contribution, $\vec{v}_{M33}$, is the proper motion of M33 relative to the Milky Way. Combining these velocity vectors, we get the proper motion of M33 in right ascension and declination:

$$\dot{\alpha}_{M33} = \dot{\alpha}_{prop} - \dot{\alpha}_{rot} - \dot{\alpha}_{\odot} = -29.3 \pm 7.6 \frac{\mu as}{year} = -101 \pm 35 \frac{km}{s}$$

and

$$\dot{\delta}_{M33} = \dot{\delta}_{prop} - \dot{\delta}_{rot} - \dot{\delta}_{\odot} = 45.2 \pm 9.1 \frac{\mu as}{year} = 156 \pm 47 \frac{km}{s}.$$

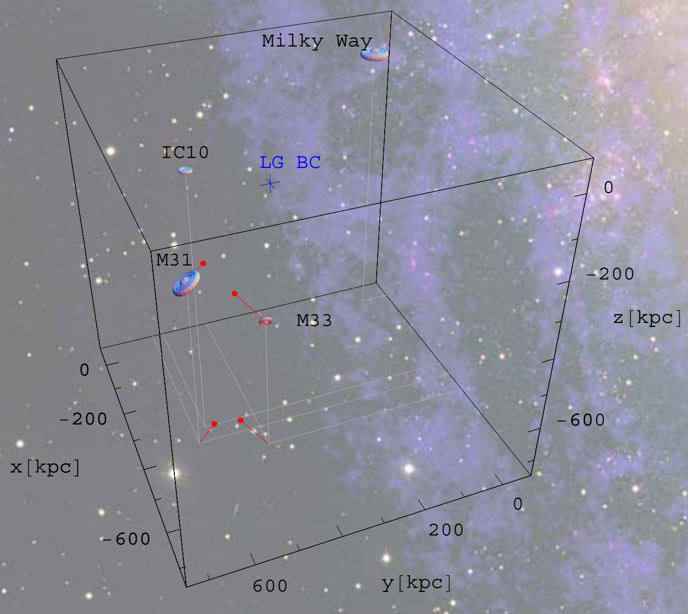

Fig. 1: Schematic view of the Local Group with the space velocity of M33 and the radial velocity of M31. The blue-cross marks the position of the Local Group Barycenter (LG BC).

The radial component of the rotation of the Milky Way towards M33 is -140 ± 9 km s^{-1}. Hence, M33 is moving with -39 ± 9 km s^{-1} towards the Milky Way. This gives now the three dimensional velocity vector of M33 (*Fig.1*). The total velocity of M33 relative to the Milky Way is 190 $\pm$ 59 km s^{-1} and directed towards M31.

2 Constraints on the Proper Motion of M31

Unfortunately, no H_2O maser are known in M31 and its proper motion could not be measured yet. However, the fact that M33's stellar disk was not disrupted by tidal interactions with M31 or the Milky Way over the last 10 billion years puts severe constrains on the possible values of M31's proper motion.

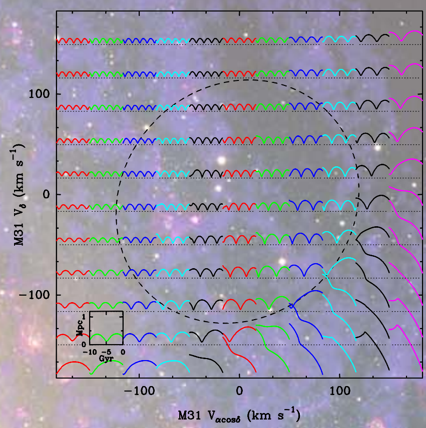

Fig. 2: Separations between M33 and M31 over the last 10 billion years for a grid of trial proper motions of M31.

We simulated the orbits of M33, M31 and the Milky Way over the last 10 billion years using their current positions, M33's measured motion and trial proper motions for M31 (Loeb et al. 2005). The simulations showed close interactions between M33 and M31 for many possible proper motions of M31 (Fig. 2). N-body simulations of M33's stellar disk indicate that a significant fraction of stars are tidally stripped from M33's stellar disk in these close encounters. This is not consistent with the properties of the observed stellar disk in M33.

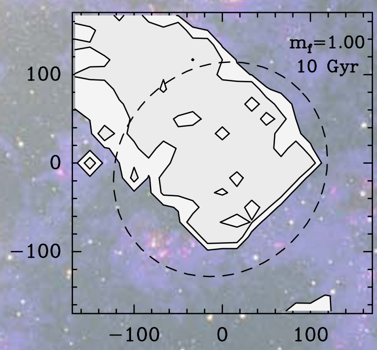

Fig. 3: The fraction of tidally stripped stars as a function of the trial proper motion of M31. Trial proper motions are in Equatorial coordinates (Right Ascension, and Declination). Contours delineate 20% (light grey) and 50% (dark grey) of the total number of stars stripped in the simulation.

Hence, proper motions of M31 that would have lead to a large amount of tidaly stripped stars can be ruled out. This excludes all proper motions with a magnitude of less than 100 km s^{-1} (Fig. 3). Our results imply that the dark halos of Andromeda and the Milky Way will pass through each other within the next 5-10 billion years.

References

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