The role of the Large Magellanic Cloud in the dynamics of streams and satellite galaxies

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1. Context and problem

- The LMC just passed its pericentre at ~ 50 kpc, likely for the first time.
- Its mass is likely $(1-2)\times 10^{11}\,M_\odot$ from various estimates (e.g., perturbations to stellar streams such as Sgr), thus is inflicts a significant force on the Milky Way itself.
- The inner MW (including the Sun) is accelerated and displaced w.r.t. the outer halo and other nearby galaxies, leading to a spatial deformation and a radially varying kinematic offset.
- If ignored, these perturbations bias the inferred MW mass up and significantly affect the orbits of individual objects.

2. Compensating the LMC perturbation

1. For any choice of the MW potential and the LMC mass, reconstruct the past orbits of both galaxies using a simple two-body approach with extended bodies, and obtain the time-dependent non-inertial acceleration in the MW-centered reference frame, plus the force from the moving LMC and the [fixed] MW potential itself.
2. In this time-dependent potential, compute the orbits of test particles – halo stars, globular clusters (GC) and satellite galaxies (dSph) back in time for a couple Gyr until the LMC perturbation is insignificant.
3. Use the standard equilibrium dynamical modelling methods such as distribution function-based models to compute the likelihood of this MW potential against the observational data.

Repeat these steps for many different choices of MW potential to find the best match.

3. Effect of the LMC on dSph orbits

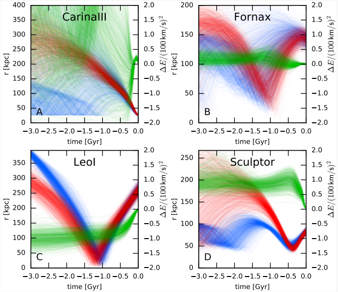

Figure 1: Past orbits of several dSph (evolution of Galactocentric radius with time) neglecting the LMC (blue) or taking it into account (red); green shows the evolution of orbital energy in the latter case. (A) orbits of LMC satellites look very different; (B) no appreciable change in orbit size, only in eccentricity; (C) orbit would have been less bound if we neglect the LMC; (D) or sometimes the opposite.
The distribution of possible past orbits samples over the measurement uncertainties and over the range of acceptable MW potentials simultaneously inferred during the fitting procedure.
The LMC does not substantially affect the non-uniformities in the observed distribution of dSph orbital planes.

References

[1] Vasiliev E., Belokurov V., Erkal D., 2021, MNRAS, 501, 2279
[2–4] Correa Magnus L., Vasiliev E., 2022, MNRAS, 511, 2610
[5] Benisty D., Vasiliev E., Evans N.W., et al., 2022, ApJL, 928, L5

4. Effect of the LMC on the Milky Way mass estimate

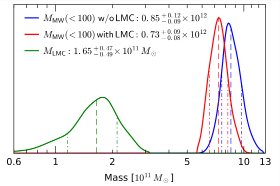

Figure 2: Constraints on the MW mass enclosed within 100 kpc obtained from GC + dSph kinematics ignoring the LMC perturbation (blue) and compensating for it (red); the latter is $\sim 15\%$ lower. The inferred LMC mass (green) lies in the range $(1-2)\times10^{11}\,M_\odot$ and compares well with other independent estimates (e.g. from streams).

5. Revised Timing Argument for the MW–M31 system

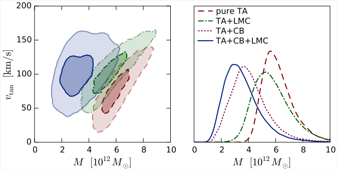

Figure 3: The LMC-induced MW velocity also impacts the estimates of the Local Group mass based on the Timing Argument. We find that the compensating for it increases the M31's tangential velocity, and in turn, decreases the correction factor ("cosmic bias") calibrated against cosmological N-body simulations – in the end, the combined mass of MW and M31 likely lies in the range $(2-4)\times10^{12}\,M_\odot$.