Has the LMC Had Close Encounters With Other Satellite Galaxies?

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Questions:

• How likely is it that the LMC has passed close to Milky Way substructure? To Milky Way satellites?

• We know proper motions, hence approximate orbits, for the LMC, SMC, and six dSphs. Have there been encounters?
A Simple Calculation

- LMC falls in from large radius to $R_p = 47$ kpc (linear path perpendicular to the radial direction at $R_p$)

- Density of satellites/dark halos, $n$, given by a spherical NFW halo with $N_v$ inside the virial radius ($r_{\text{vir}} = 258$ kpc, $c = 12$)

- Calculate collision probability:

$$P_{\text{coll}} = \int n \left( \pi R_{\text{LMC}}^2 \right) ds$$

$$= (7 \times 10^{-4}) \left( N_v \right) \left( R_{\text{LMC}}/4.4 \text{ kpc} \right)^2$$
Some examples:

- $N_v = 250, R_{LMC} = 4.4$ kpc $\rightarrow P_{\text{coll}} = 0.18$
- $N_v = 250, R_{LMC} = 10.5$ kpc $\rightarrow P_{\text{coll}} = 1.0$
- $N_v = 25, R_{LMC} = 4.4$ kpc $\rightarrow P_{\text{coll}} = 0.018$
- $N_v = 25, R_{LMC} = 33$ kpc $\rightarrow P_{\text{coll}} = 1.0$
PM Vectors for All 8 Measured Galaxies
Orbital Poles
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If substructure forms a flattened plane (Kroupa, Theis, & Boily) and the LMC is in the plane: $P_{\text{coll}}$ ↑ by perhaps x4
Have there been encounters?

- Take known positions and space velocities and integrate backwards in a Galactic potential (NFW)
- Monte Carlo by drawing velocities from distributions given by uncertainties
LMC – SMC:

Galaxy-Galaxy Separation for Best Orbits

$S$ (kpc)

Time (Gyr)
LMC - SMC
• Carina, Draco, Fornax, and Ursa Minor never get closer to the LMC than ~60 kpc
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• Sculptor was ~33 kpc away ~0.1 Gyr ago
LMC - Scl

Galaxy-Galaxy Separation for Best Orbits

Relative Velocity at Closest Approach
• Carina, Draco, Fornax, and Ursa Minor never get closer to the LMC than \(~60\) kpc
• Sculptor was \(~33\) kpc away \(~0.1\) Gyr ago
• Sagittarius was \(~40\) kpc away \(~0.1\) Gyr ago
LMC-Sgr

Galaxy-Galaxy Separation for Best Orbits

Relative Velocity at Closest Approach

Histograms of S (kpc) and V (km/s)
• Carina, Draco, Fornax, and Ursa Minor never get closer to the LMC than ~60 kpc
• Sculptor was ~33 kpc away ~0.1 Gyr ago
• Sagittarius was ~40 kpc away ~0.1 Gyr ago

Thus: more close approaches than expected, but no strong interactions.
Cautions:

- Sagittarius and Draco motions are preliminary
- Uncertain location of the LMC center of mass adds uncertainty to the space velocity

A 1.9° change in the location of the center-of-mass on the sky changes the tangential velocity by the uncertainty from the proper motion (~9 km/s)