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_{vir} = 258 kpc, c = 12)
- Calculate collision probability:

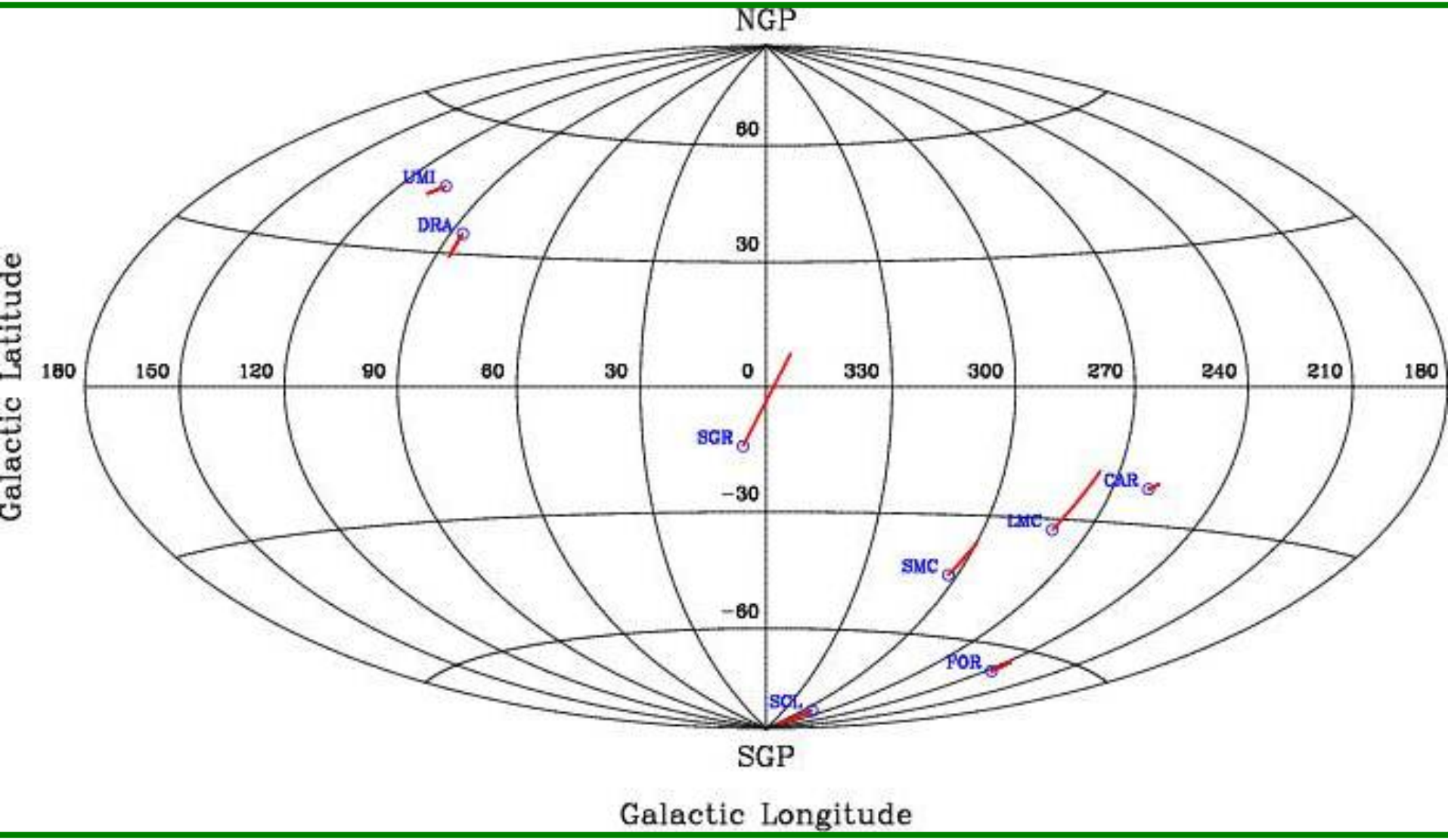
$$P_{coll} = \int n \, (\pi R_{LMC}^2) \, ds$$
$$= (7 \times 10^{-4}) \, (N_v) \, (R_{LMC}/4.4 \text{ kpc})^2$$

Some examples:

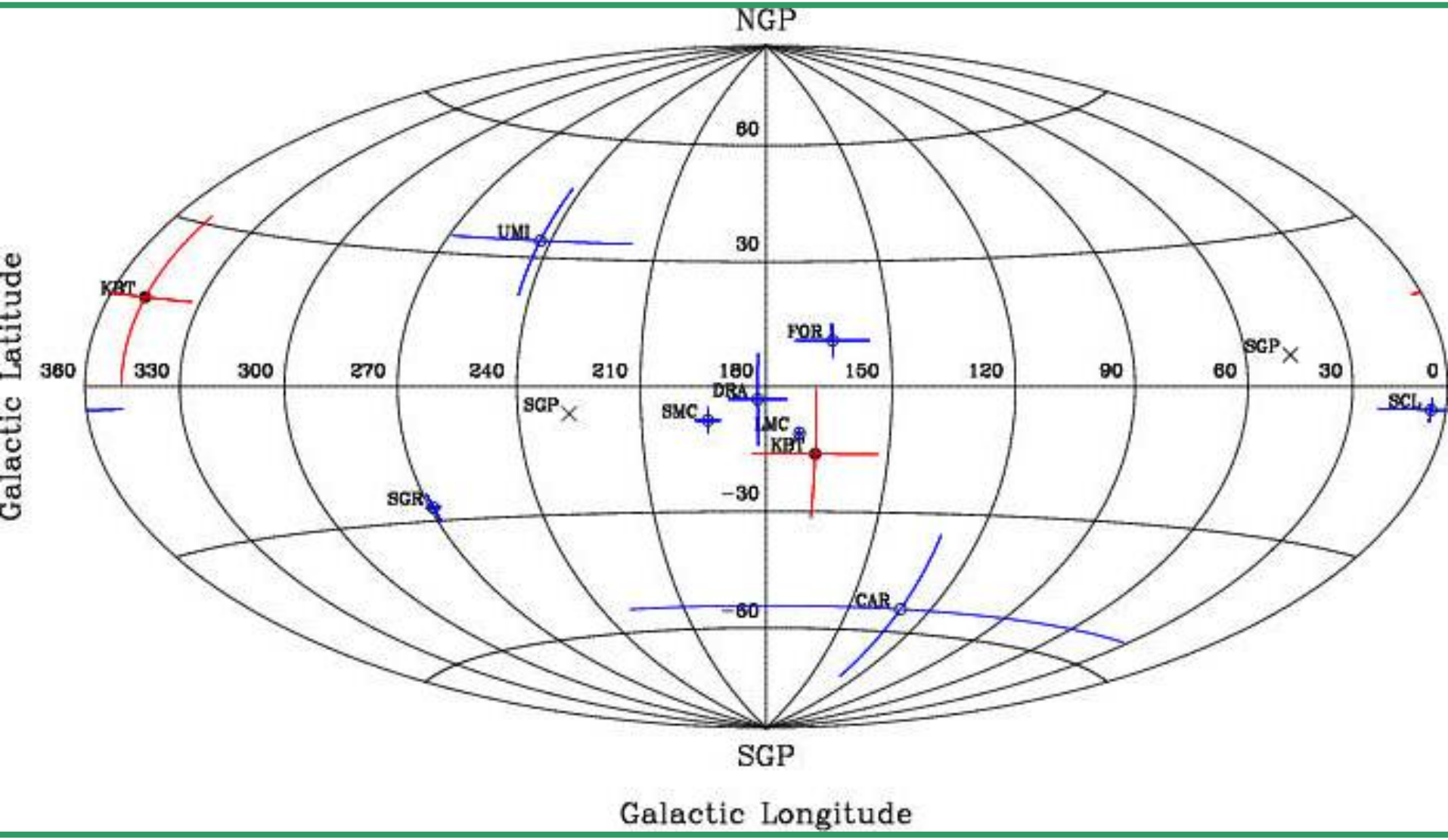
- $N_v = 250$, $R_{LMC} = 4.4$ kpc $\rightarrow P_{coll} = 0.18$
- $N_v = 250$, $R_{LMC} = 10.5$ kpc $\rightarrow P_{coll} = 1.0$

- $N_v = 25$, $R_{LMC} = 4.4$ kpc $\rightarrow P_{coll} = 0.018$
- $N_v = 25$, $R_{LMC} = 33$ kpc $\rightarrow P_{coll} = 1.0$

PM Vectors for All 8 Measured Galaxies



Orbital Poles



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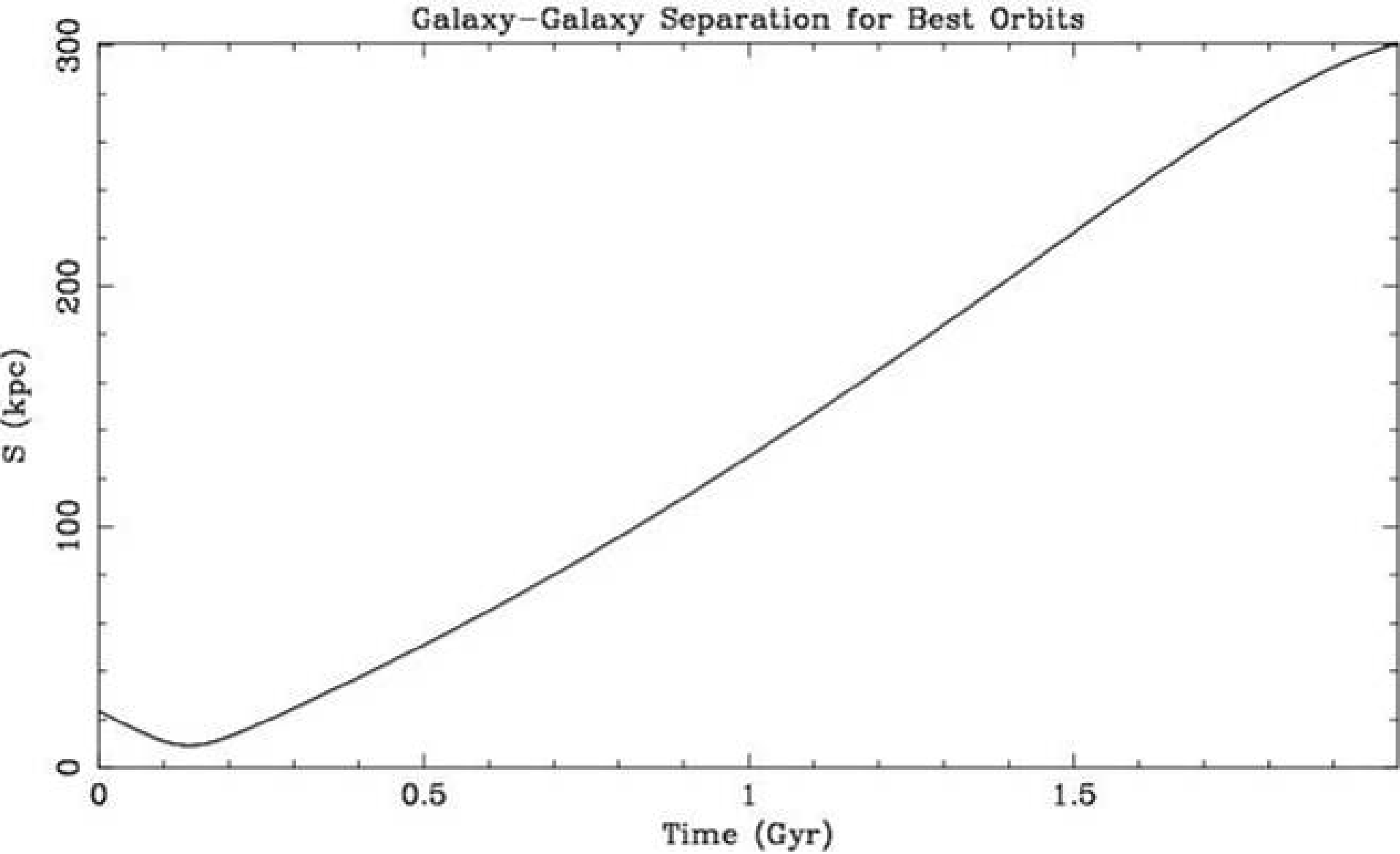
If substructure forms a flattened plane (Kroupa, Theis, & Boily) and the LMC is in the plane: $P_{coll} \uparrow$ by perhaps x4

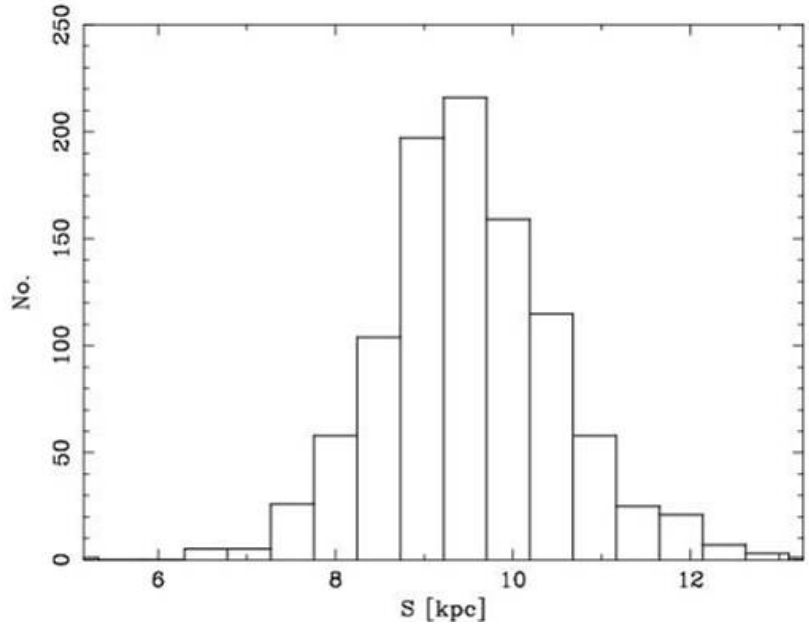
Have there been encounters?

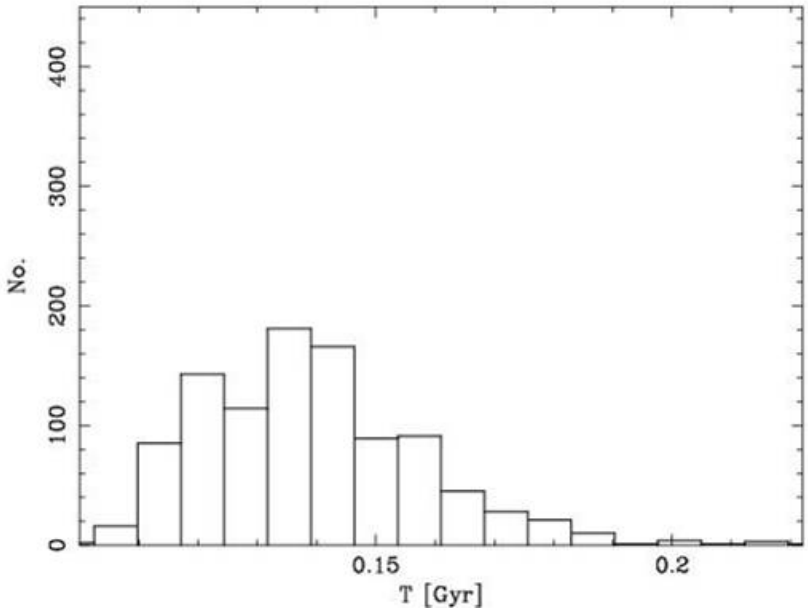
- Take known positions and space velocities and integrate backwards in a Galactic potential (NFW)
- Monte Carlo by drawing velocities from distributions given by uncertainties

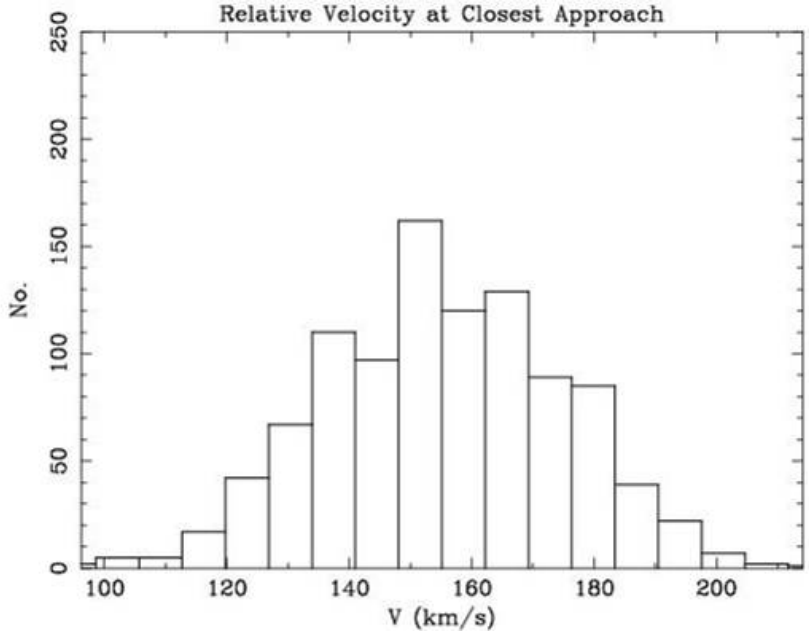
LMC – SMC:


Galaxy–Galaxy Separation for Best Orbits
S (kpc)
0
100
200
300
0
0.5
1
1.5
Time (Gyr)

LMC - SMC


No.
0
50
100
150
200
250
6
8
10
12
S [kpc]


No.
0
100
200
300
400
0.15
0.2
T [Gyr]


Relative Velocity at Closest Approach
No.
0
50
100
150
200
250
100
120
140
160
180
200
V (km/s)

- Carina, Draco, Fornax, and Ursa Minor never get closer to the LMC than ~60 kpc

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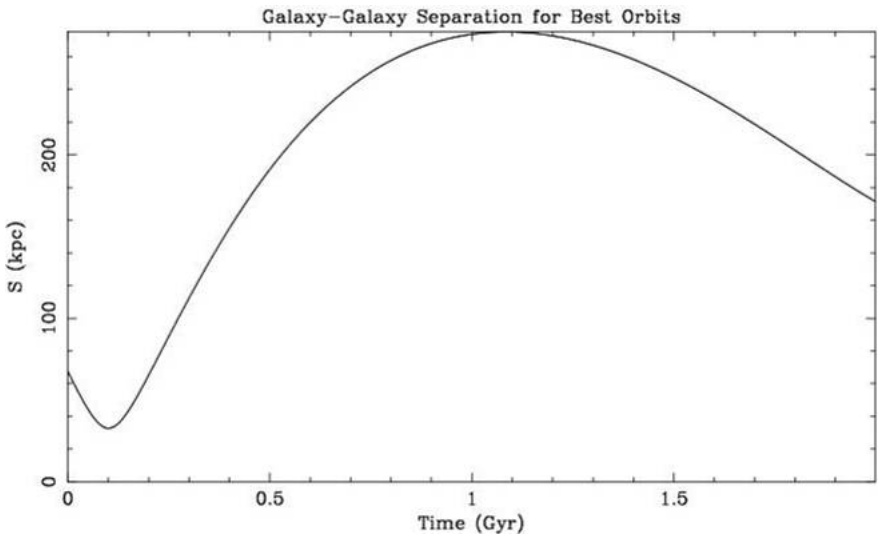
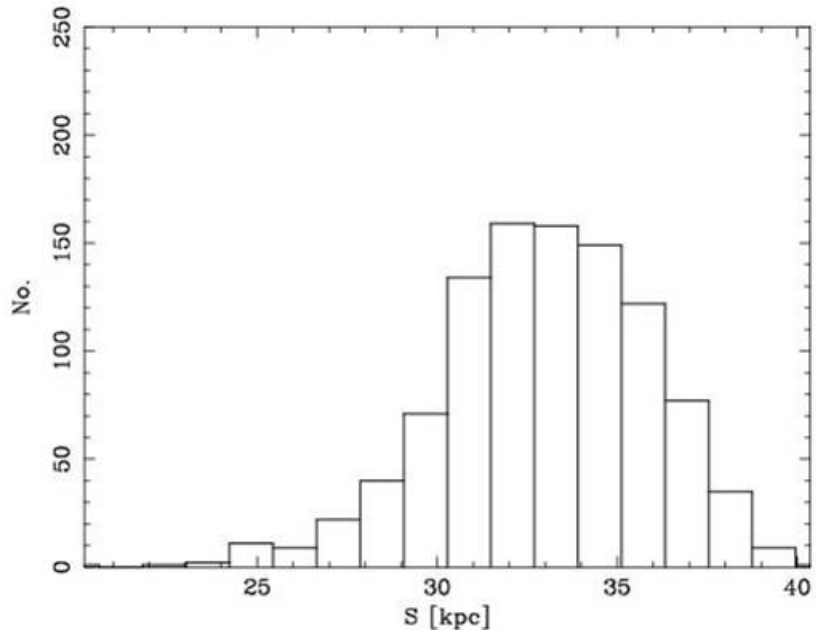
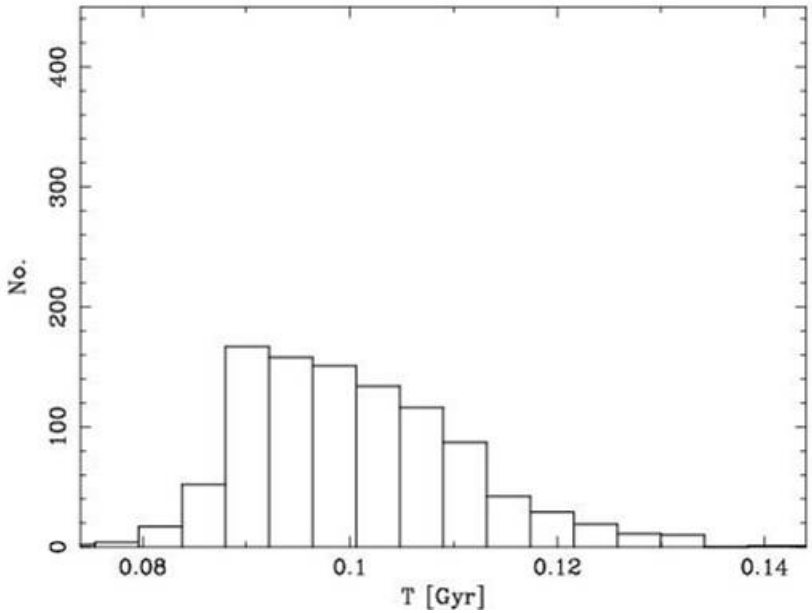
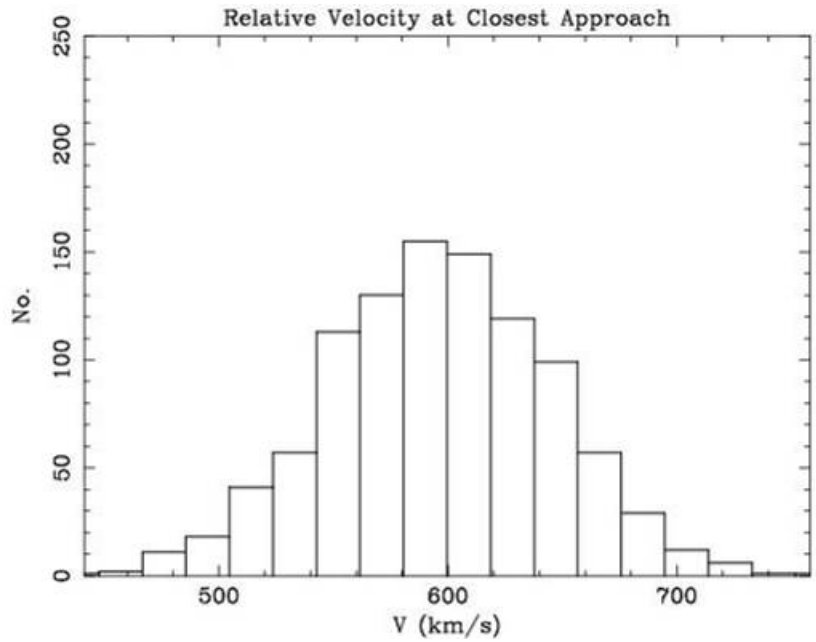
- Sculptor was ~33 kpc away ~0.1 Gyr ago

LMC - Scl


Galaxy–Galaxy Separation for Best Orbits
S (kpc)
Time (Gyr)
0
100
200
0
0.5
1
1.5

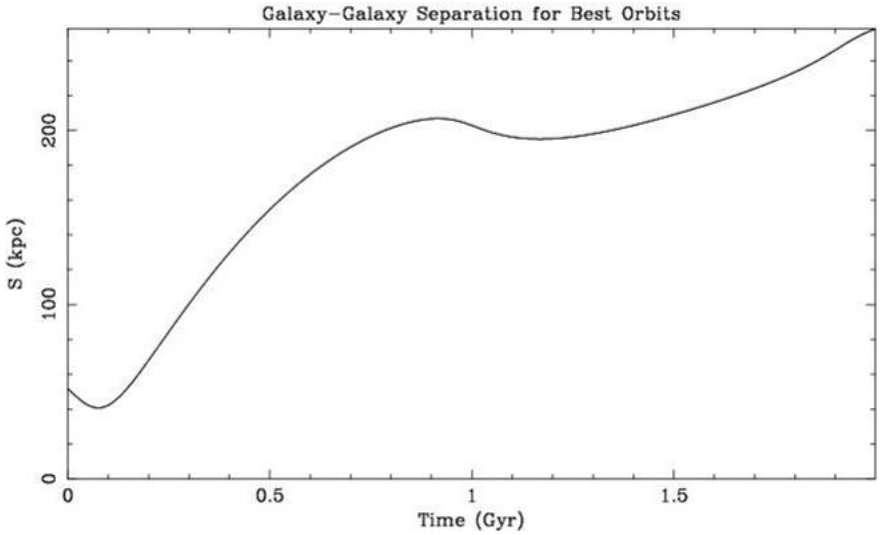

No.
S [kpc]
0
50
100
150
200
250
25
30
35
40

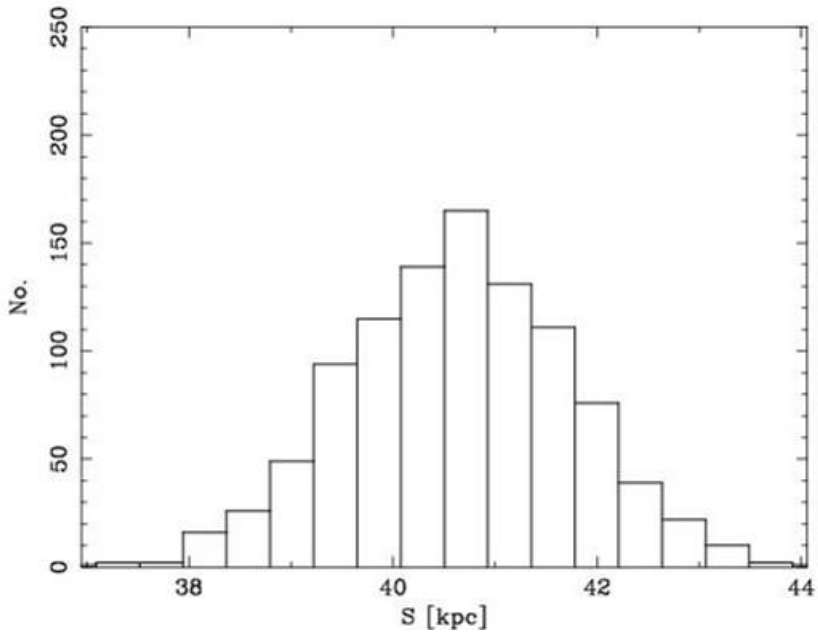

No.
T [Gyr]
0
100
200
300
400
0.08
0.1
0.12
0.14

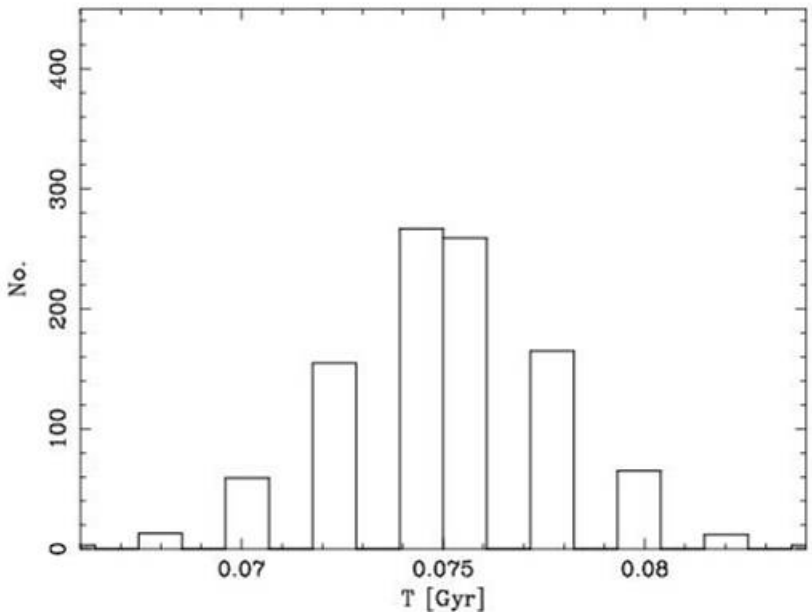

Relative Velocity at Closest Approach
No.
V (km/s)
0
50
100
150
200
250
500
600
700

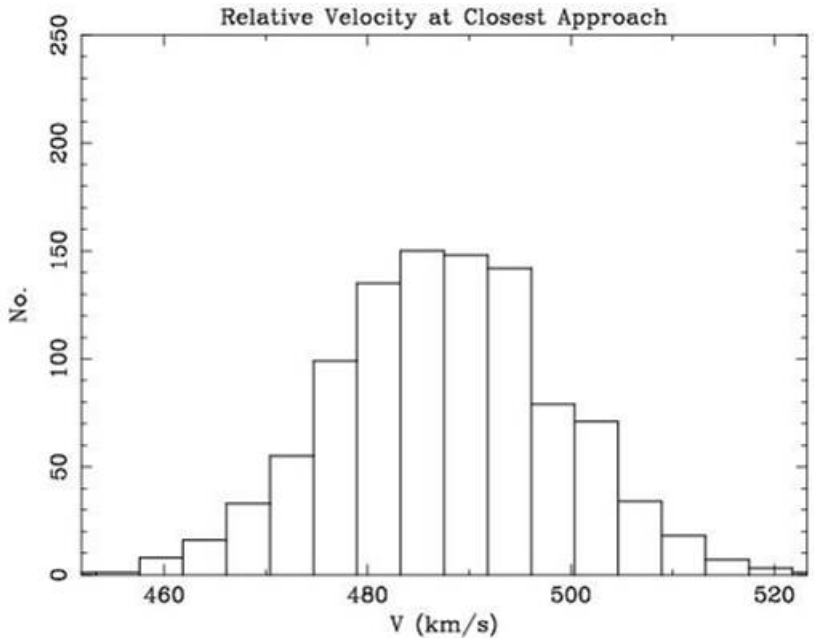
- Carina, Draco, Fornax, and Ursa Minor never get closer to the LMC than ~60 kpc
- Sculptor was ~33 kpc away ~0.1 Gyr ago
- Sagittarius was ~40 kpc away ~0.1 Gyr ago

LMC-Sgr


Galaxy–Galaxy Separation for Best Orbits
S (kpc)
Time (Gyr)
0
100
200
0
0.5
1
1.5


No.
S [kpc]
0
50
100
150
200
250
38
40
42
44


No.
T [Gyr]
0
100
200
300
400
0.07
0.075
0.08


Relative Velocity at Closest Approach
No.
V (km/s)
0
50
100
150
200
250
460
480
500
520

- 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 1.9º 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)