Homework 6

1. **How many close encounters will the Milky Way and M31 have in the future?**

At time 0 Gyr, the Milky Way (MW) and M31 start about 700 kpc apart. The first encounter happens around 2 Gyr, when they come as close as 120–150 kpc. The second encounter occurs around 5 Gyr, with a separation of roughly 50–80 kpc. The third encounter takes place near 7.5–8 Gyr, after which the distance steadily decreases until the two galaxies merge. These three dips in distance, where the separation falls to about 1–50 kpc following a significant drop, qualify as close encounters. After the third close approach, MW and M31 are on a path toward merging.

2. **How are the changes in separation and relative velocity related over time?**

The diagram shows two curves: one for the relative velocity between MW and M31 and another for the relative velocity between M33 and M31. For MW and M31, when they approach each other during a close encounter, their relative velocity increases, with the most pronounced spikes occurring at around 2 Gyr, 5 Gyr, and 8 Gyr. When the galaxies move apart, their velocity decreases in a typical gravitational "approach and recoil" pattern. As they enter the final merging phase (after about 8 Gyr), their separation drops below a few kpc and the velocity falls nearly to zero. In contrast, M33 follows a more extended, loosely bound orbit around M31. Although its relative velocity also shows peaks corresponding to closer approaches, these do not lead to an immediate merger; M33's velocity fluctuations continue over a longer time period.

3. **When do MW and M31 merge, and what happens to M33 afterward?**

MW and M31 begin close encounters at about 2 Gyr. Following the third major encounter near 8 Gyr, the distance between them steadily decreases until by about 10 Gyr the separation is only 1–2 kpc, which indicates they have effectively merged. At around 11.43 Gyr, the separation is approximately 1.43 kpc, confirming that the merger is nearly complete. Throughout the simulation, M33 remains tens of kpc away from M31, experiencing several close approaches but not merging immediately. After MW and M31 merge, M33 continues to orbit the new combined galaxy. Its orbit still shows cycles of getting closer and farther, though it gradually decays over time, suggesting that M33 will eventually merge with the combined MW–M31 system as part of the natural process of galaxy assembly.

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In summary, the simulation shows three major close encounters between MW and M31 leading to a merger between 8–10 Gyr. During and after these encounters, M33 stays in a more extended orbit and will eventually be absorbed into the merged system.