Simulating Collisions Between Satellite and Host Galaxies

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Question

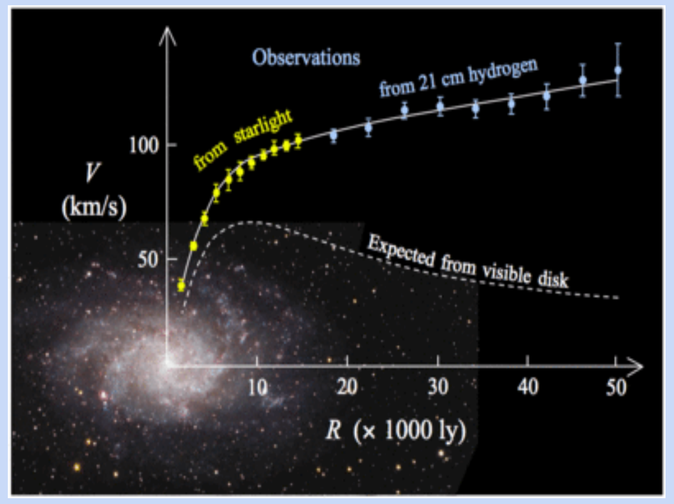
How does mass distribution of a satellite galaxy affect its angular momentum, radius and orbit as it collides with its host galaxy?

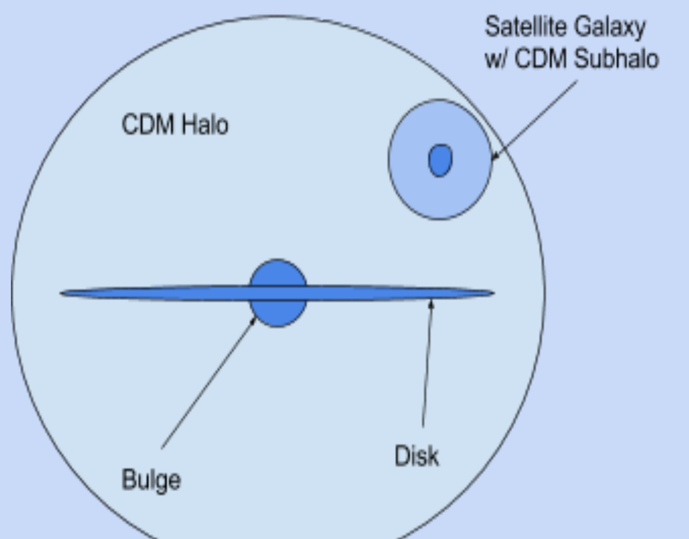
Summary

This study will use an analytical simulation to plot the change in angular momentum, radius, and orbit of satellite galaxies with different mass distributions as they collide with their host galaxies.

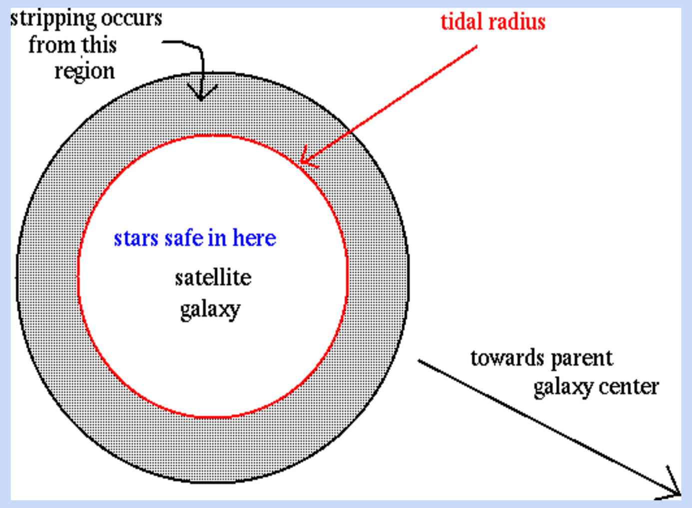
Background

- Cold dark matter (CDM) does not interact with electromagnetic radiation
  - making it impossible to directly observe→"dark"
- CDM *does* interact with ordinary matter via **gravity** due to their mass
  - Properties of CDM indirectly observed by gravitational effect it has on baryonic (ordinary) matter
    - Baryonic Matter = anything that consists of atoms
- **Proof of CDM**: Stars orbiting spiral galaxies do not follow the same Keplerian orbit that planets do
  - Vera Rubin and Kent Ford, 1975 American Astronomical Society Meeting
- Instead, the orbital velocity of stars *increases* the further away they are from the center of their galaxy
  - This is because the **CDM halo** surrounding the galaxy accelerates outer stars with its own gravity
- CDM halo: ↑ gravitational force ➔ ↑ galactic collisions
- The CDM halos of large galaxies attract smaller "satellite" galaxies to orbit around them
  - These orbits are often unstable collision between the two galaxies
- The dynamics of these collisions can be **simulated** in order to gain a better understanding of CDM
- **Dynamic Friction:** when a satellite moves through its host galaxy's CDM halo, it experiences drag, caused by the wake of CDM particles the satellite leaves as it moves through the halo
  - much like a boat traveling through water
- As the CDM particles are pushed together, they amass their own gravity which pushes back on the satellite's movement→ the satellite loses mass
- **Tidal Forces**: Gravity acts more strongly on the side of the satellite that is closer to the host galaxy→ satellite stretches towards its host galaxy
  - Like ocean tides caused by the Moon
- Gravitational force of the host galaxy overcomes the gravitational force holding the satellite together→ strips away the matter on the edge of the satellite
  - The radius of which gravity is able to strip matter away from the satellite is called the **tidal radius**
  - The tidal radius decreases the closer the satellite galaxy is to the host galaxy



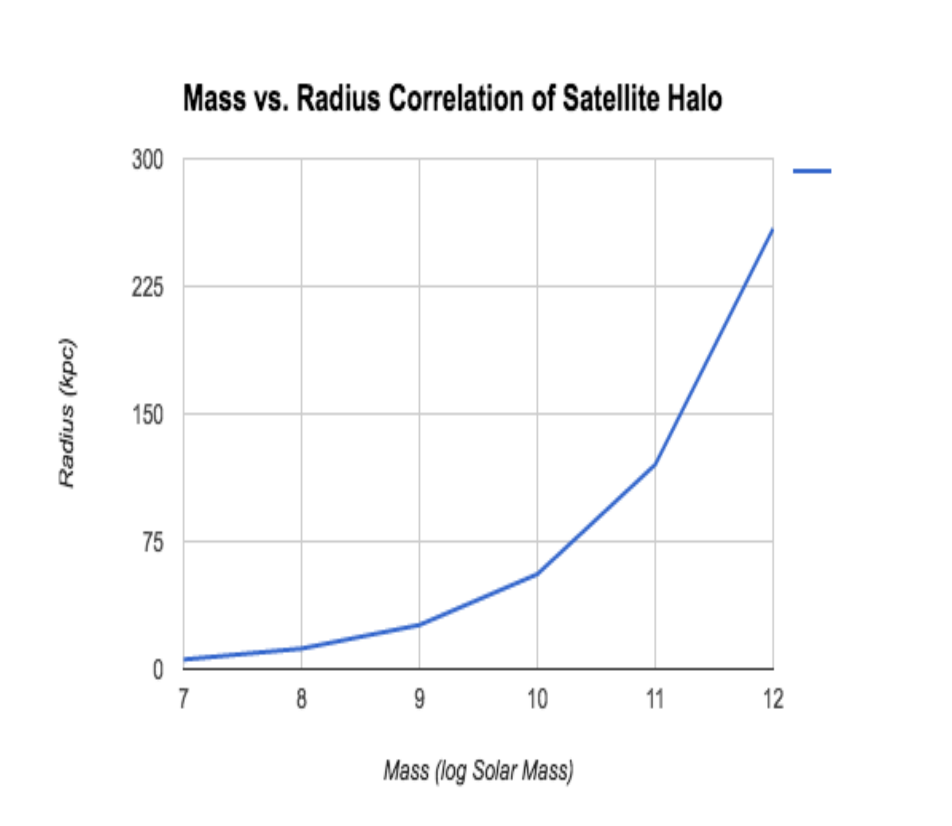


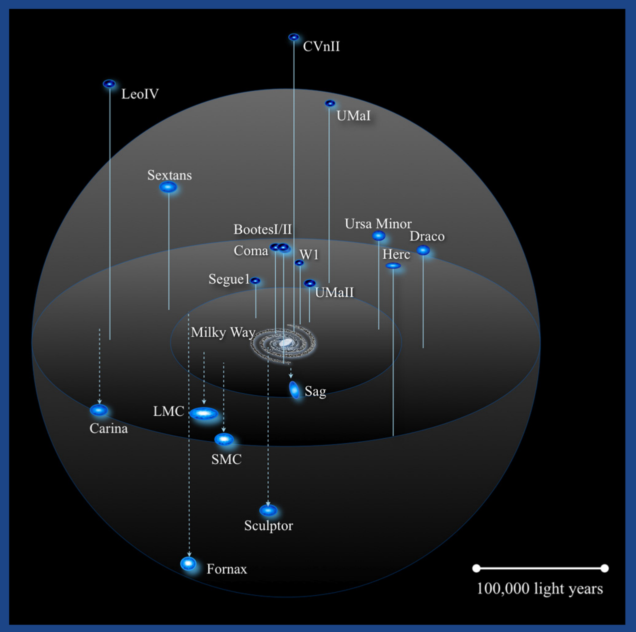
*Size of Satellite Galaxy is exaggerated. It is more accurately a point mass.



Simulation Process

- Mass distribution of the satellite galaxy is dependent on two correlated factors
  - **radius** and **mass** of satellite halo
- Mass is chosen in units of Solar mass
  - 1 Solar Mass = mass of Sun
- From the chosen mass, radius of satellite can be calculated
- Radius is measured in kiloparsecs
  - 1 parsec = 3.26 light years
- The chart depicts Solar Mass on a logarithmic scale
  - 10 = 1x10[7] Solar Masses
- Mass distribution of satellite galaxy affects its angular momentum and subsequently, its orbit and radius to host galaxy





Parameters

Dynamic Friction

Total dynamic friction consists of two parts: the dynamic friction exerted by the disk and the dynamic friction exerted by the halo/bulge. This can be modeled as

$$F_{df} = F_{df,halo} + F_{df,disk}$$

This formula can be equated to Chandrasekhar's equation which describes the dynamic friction caused by a massive particle moving through an isotropic distribution of background particles, much like the subhalo moving through its host galaxy-halo system:

$$F_{df} = -4\pi G^2 M^2_{sat} \sum_{i=h,d} \varrho_i(<V_{rel,i}) \ln\wedge_i \frac{V_{rel,i}}{|V_{rel,i}|^3}$$

where $V_{rel,h} = V_{sat}$, $V_{rel,d} = V_{sat} - V_{rot}$, $\varrho_i(<V_{rel,i}) = \varrho_i(r)[erf(X_i) - X_i erf'(X_i)]$

and $X_i \equiv \frac{|V_{rel,i}|}{\sqrt{2}\sigma_i}$

Tidal Force

The radius of which the gravity of the host is able to strip matter away from the satellite is called the tidal radius. The location of this radius within the tidal field can be found using the equation $Dr_t = \frac{GM_s(r_t)}{r_t^2}$

Where G is the gravitational constant, $M_s(r_t)$ is the mass of the satellite within the tidal radius, and r_t is the tidal radius.

Ram Pressure

Finally, when a satellite galaxy enters a hot region of its host galaxy, it experiences a force called ram pressure. This force is caused by the orbital motion of the satellite's subhalo being disrupted by the hot atmosphere of its host galaxy's halo. The gravity that holds a satellite galaxy together can be quantified using the equation

$$P_{ram} = \varrho_{host} V^2_{orbit}$$

Where ϱ_{host} represents the density of the host galaxy's atmosphere and V_{orbit} represents the orbital velocity of the satellite. When the ram pressure exceeds the force of gravity holding the satellite together, it is able to strip gas away from the satellite.

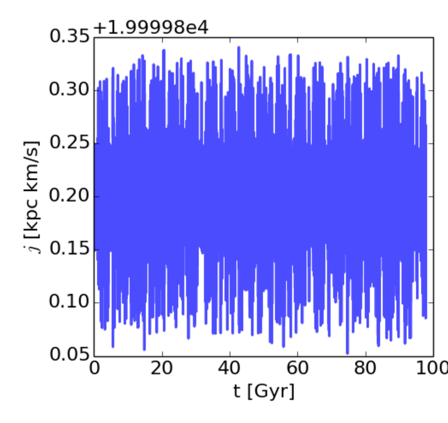
Force of Gravity

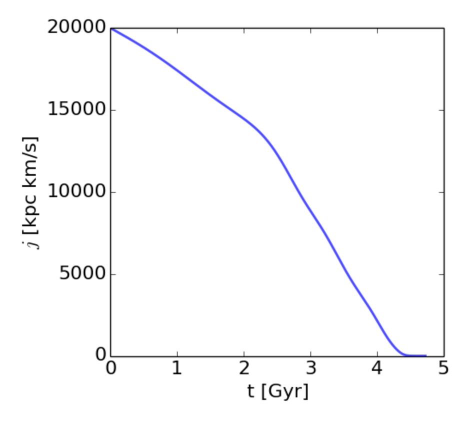
The force of gravity holding together the satellite is found by $F_g = 2\pi G \Sigma_{star} \Sigma_{gas}$

Results

Angular Momentum

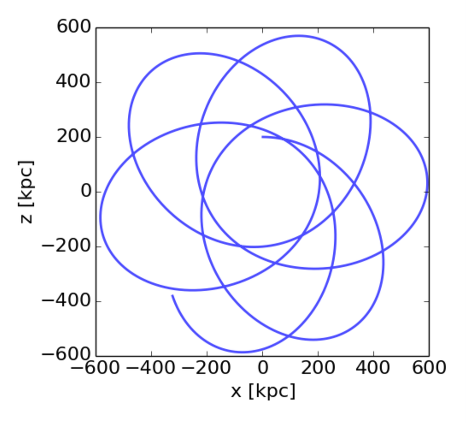
Without dynamic friction, angular momentum remains constant with negligible fluctuations. As the satellite approaches denser regions of its host galaxy, dynamic friction increases which causes reduces the angular momentum of the satellite galaxy.

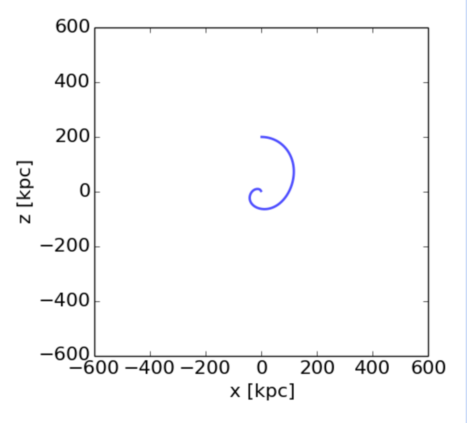




Orbit

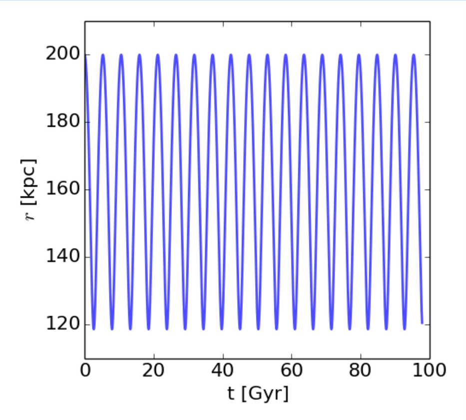
Without dynamic friction, the satellite's orbit is stable around its host galaxy. Since dynamic friction causes the satellite to lose angular momentum, it falls towards its host galaxy.

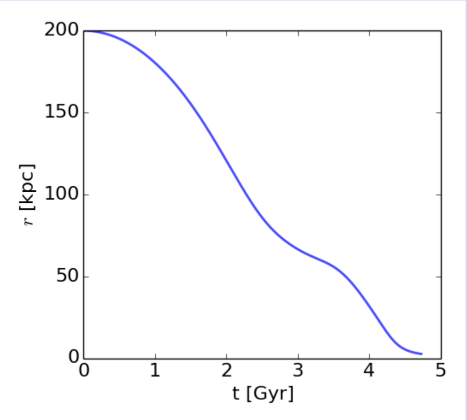




Radius

Without dynamic friction, the radius of the satellite galaxy constantly fluctuates as it orbits its host galaxy. With dynamic friction, the radius decreases as the satellite approaches its host.





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