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Final Project Proposal

Modified Gravitation Models

Explaining Galactic Rotation Curves without Dark Matter

Problem:

In the early 1900's astronomers began noticing that the rotational velocity curves of galaxies appeared to diverge from predictions derived from applying Newtonian gravity to observable matter in the disks. Stars and gas in the outer regions of the disks were orbiting the core at a velocity that would eject them from the galaxy unless there was far more matter inside their orbits than astronomers could see. This problem escalated as time progressed and virtually all galaxy and galaxy clusters were found to require missing matter to maintain their gravitationally bound configuration. The currently most accepted explanation is that there must be vast amounts of a weakly interacting massive particles distributed throughout galaxies and galaxy clusters that provide the needed mass.

In the 1980's an alternative explanation for galaxy rotation curves was developed: Modified Newtonian Dynamics (MOND). MOND is a phenomenological model that modifies Newton's law of gravity in classically low acceleration regimes, providing the force necessary for bound circular orbits.

$$\vec{F}_{Gravity} = m\mu(a_o, a)\vec{a}$$

The interpolating function $\mu(a_o, a)$ is a function of the acceleration and a new physical constant $a_o = 1.2 \times 10^{-10}\ ms^{-2}$ and it is approximately 1 when $a_o \ll a$. Applying the model to galaxy rotation curves replicates the observed results from many galaxies without the need for additional dark matter.

Approach:

A simulated galaxy lattice will be populated with particles according to a density distribution model tuned to the distribution of observable matter in spiral galaxy M33.

$$M(r)M_{\odot} = \begin{cases} 460e^{\left(-\frac{r}{1.56kpc}\right)}, & r \leq 6kpc \\ 9.33e^{\left(-\frac{r}{125kpc}\right)}, & r > 6kpc \end{cases}$$

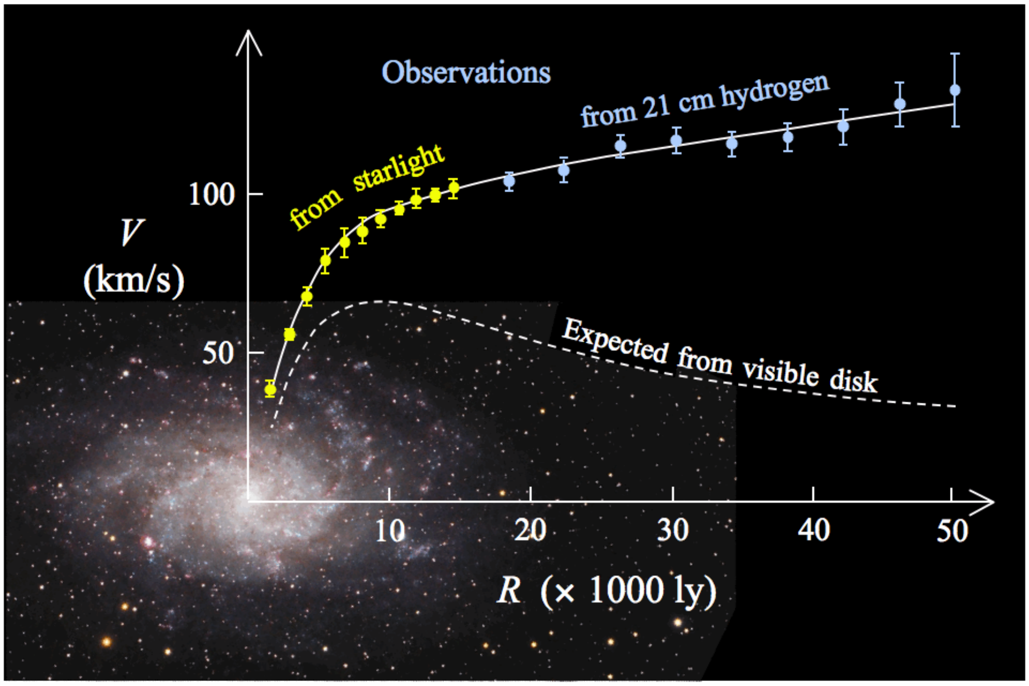
The force on each particle will be calculated with classical gravitation and MOND. A velocity Verlet integrator will be implemented to time evolve the system. The particles radial velocity will be studied over time and plotted as a function of distance from the core. These will be compared to the actual observational rotation curve of M33.

Goals:

1. Implement a 2D lattice of particles that replicates the distribution of baryonic matter throughout galaxy M33.
    i. Calculate the initial velocities needed for the particles to maintain circular orbits in this configuration under: Classical Newtonian gravitation, MOND with $\mu(a_o, a) = \left(1 + \frac{a_o}{a}\right)^{-1}$, MOND with $\mu(a_o, a) = \left(1 + \left(\frac{a_o}{a}\right)^2\right)^{-1/2}$.
2. Implement velocity Verlet loop to simulate the evolution of each system over time.
3. Plot the velocity for a particle at a given radius from the core for each system at different time steps, compare against observational. Is the behavior stable?
4. Measure average kinetic and potential energy for each system over time.

Appendix:

Example of Galactic Rotation Problem:



References:

Introduction to MOND:
http://relativity.livingreviews.org/Articles/lrr-2012-10/fulltext.html
M33 mass distribution:
https://arxiv.org/ftp/arxiv/papers/1208/1208.4889.pdf