Evolution of Rotation Curve Models for NGC 3198

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Introduction:

The orbits of the planets around the sun can be easily modeled using the traditional formulation of Newton's laws and treating the sun as a point mass at the center of the solar system. However, numerous problems arise when this modeling technique is applied to larger systems, as galactic rotation curves do not possess the same properties as planetary systems. Galactic rotation curves bear little resemblance to the expected rotation curve that can be constructed from observations of luminous matter in galaxies. This discrepancy can be resolved in one of two ways: either by introducing a dark matter component to each galaxy in order to account for the mass that has not been observed or by modifying the laws of Newtonian mechanics in such a way that the anomalous rotation curves can be constructed without the introduction of new matter.

Models:

As the simplistic model used within the solar system failed to produce accurate rotation curves on galactic scales (Figure 1), other luminous matter distributions were considered for galactic models. The simplest of these models treated the bulge at the center of the galaxy as a solid spherical body with a constant mass density; this allowed for a sharp increase in rotational velocity within the radius of the bulge while also providing a gradual drop off beyond this point. A more sophisticated model is the exponential disk[2] (Figure 2), which accounts for the initial increase in rotational velocity but fails to explain the relatively constant velocities of points farther from the center of the galaxy. The exponential disk model fails to explain galactic rotation curves unless a dark matter halo is introduced. With the addition of a dark matter halo[4], the model appears to be significantly improved, producing a curve that more closely matches observations (Figure 3). An alternative to dark matter models is MOND[3] (Modified Newtonian Dynamics), which alters Newton's laws to explain the anomalous rotation curves of galaxies (Figure 4). Both MOND and dark matter models seem to experience moderate success in explaining the rotation curve of NGC 3198.

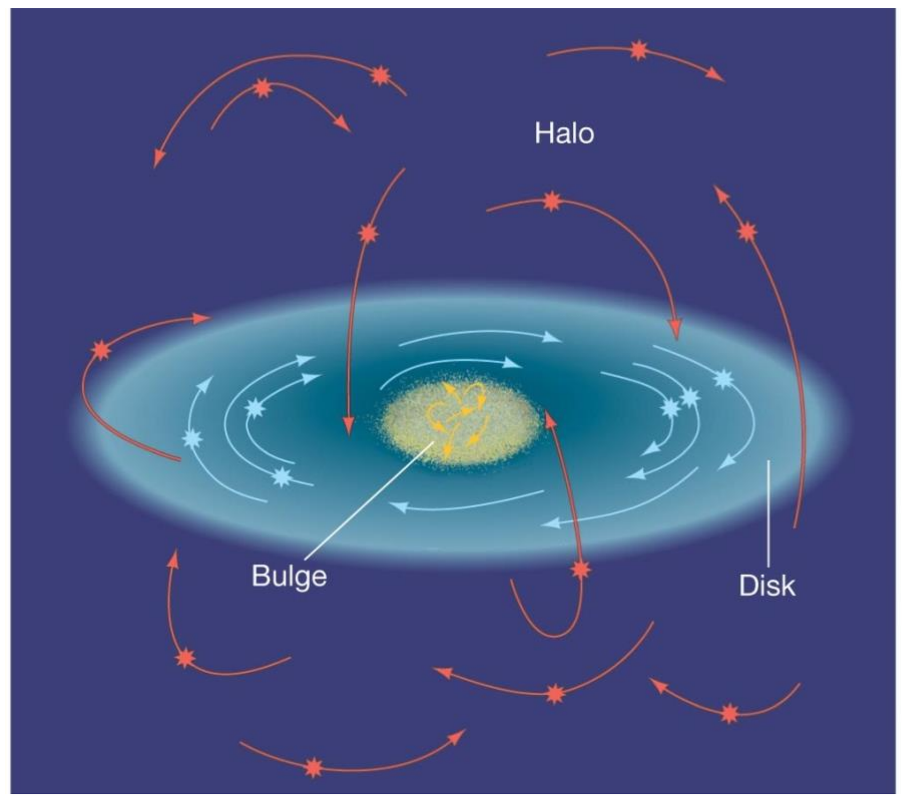

Figure 0: An artist's rendition of a galaxy. Our models show that dark matter is likely to exist is the halo.

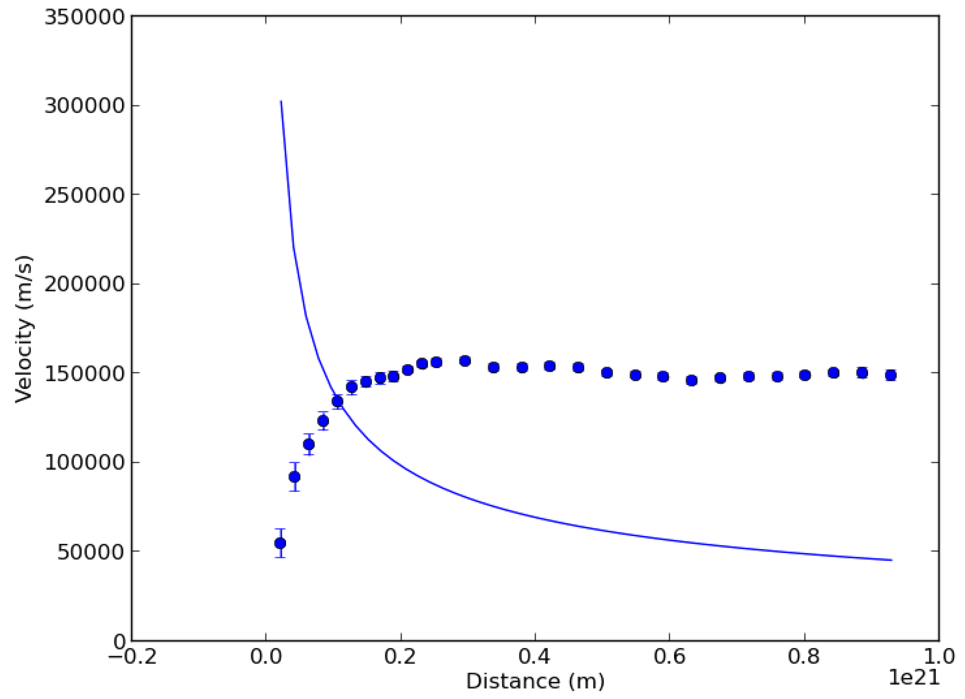

Figure 1: Newtonian mechanics suggests that the velocity curve of galaxies should be given by the solid blue line; however, data taken from galaxies follow the curve created by the blue points.
(Equation 0)

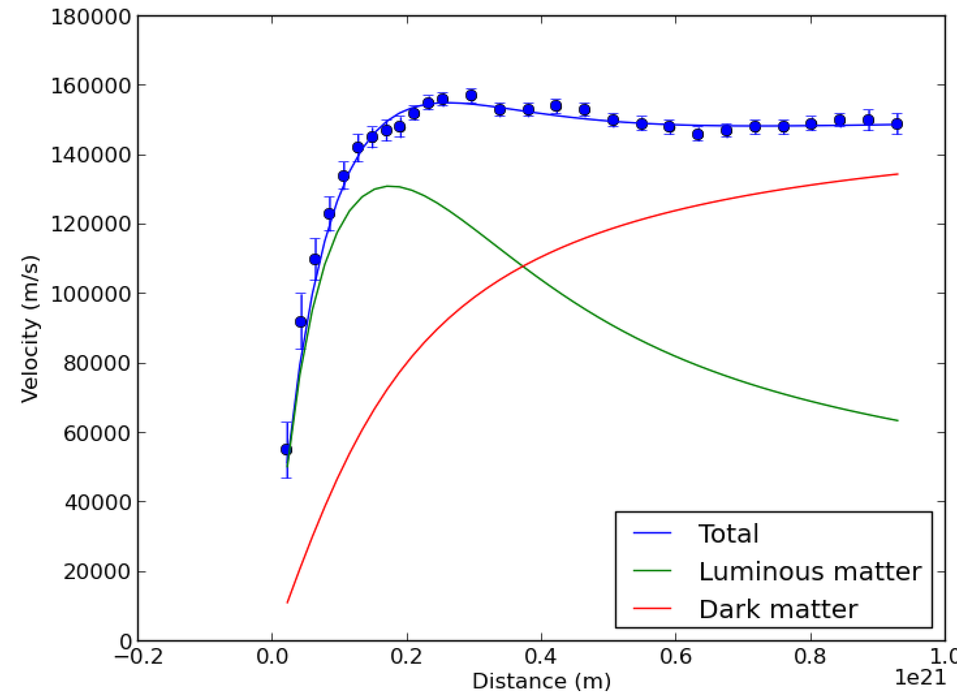

Figure 3: Exponential thin disk model with dark matter halo. Dark matter becomes dominant at large distances from the center, producing a curve that better fits observational data.
(Equations 1, 2, 3, 4)

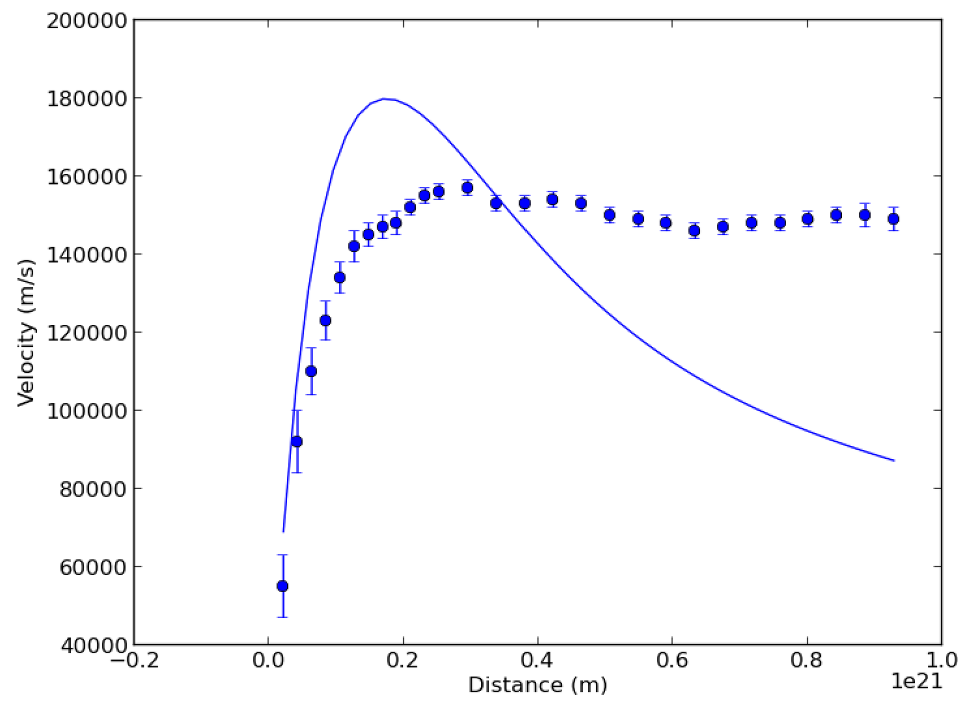

Figure 2: Exponential disk model based solely on luminous matter observations and classical Newtonian dynamics.
(Equations 1, 2)

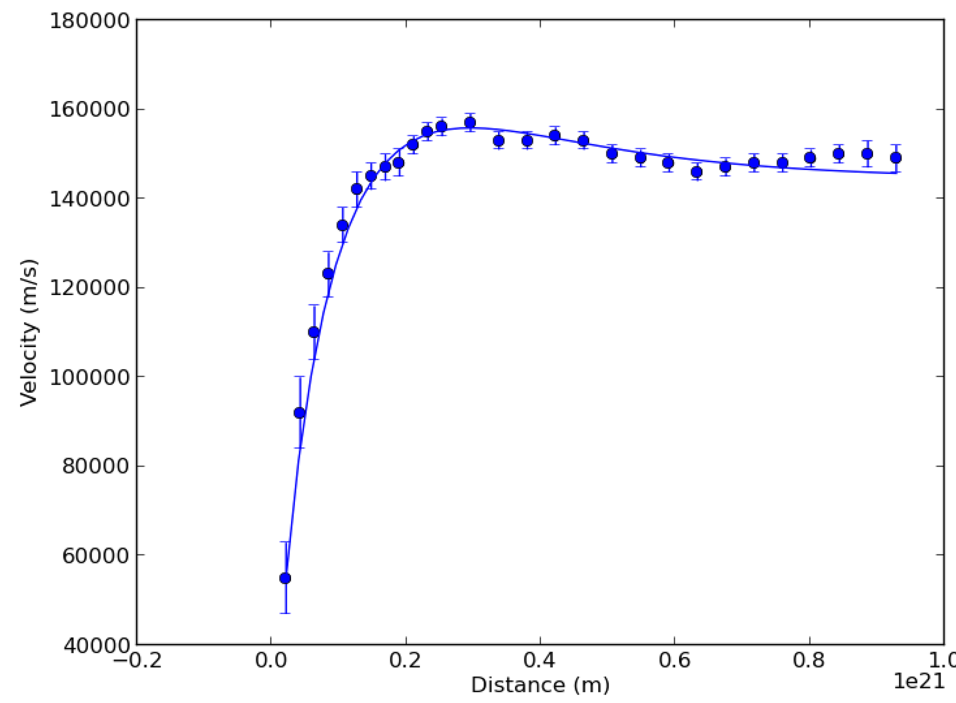

Figure 4: Exponential thin disk model in the context of Modified Newtonian Dynamics.
(Equations 2, 5)

Table 1: Equations	#
$v = \sqrt{\frac{GM}{r}}$	0
$y = \frac{r}{r_d}$	1
$v_{LM}^2 = v_N^2 = 4\pi G \Sigma_0 r_d y^2 \left[I_0(y)K_0(y) - I_1(y)K_1(y) \right]$	2
$v_{DM}^2 = 4\pi G \rho_0 r_c^2 \left[1 - \frac{r_c}{r} \arctan\left(\frac{r}{r_c}\right) \right]$	3
$v_{Total}^2 = v_{LM}^2 + v_{DM}^2$	4
$v^2 = v_N^4 + a_0 r v_N^2$	5

Table 0: NGC 3198 rotation curve data table (R and V reported in arcmin. and km/s, respectively).[1]

R	V	σV	R	V	σV
0.25	55	8	4.5	153	2
0.5	92	8	5	154	2
0.75	110	6	5.5	153	2
1	123	5	6	150	2
1.25	134	4	6.5	149	2
1.5	142	4	7	148	2
1.75	145	3	7.5	146	2
2	147	3	8	147	2
2.25	148	3	8.5	148	2
2.5	152	2	9	148	2
2.75	155	2	9.5	149	2
3	156	2	10	150	2
3.5	157	2	10.5	150	3
4	153	2	11	149	3

Conclusions:

In order to analyze our results, we employed a simplified Bayesian hypothesis test. For each model (exponential thin disk, thin disk with dark matter, MOND), we calculated a Bayes factor corresponding to the probability of the model being in reasonable agreement with prior knowledge and observational data (Table 2). According to this analysis, the exponential thin disk model with dark matter appears to be most successful in explaining the rotation curve of NGC 3198. MOND is more successful than the traditional exponential thin disk model based solely on luminous matter observations.

Table 2: The Bayes factors for the models and their standard deviations.

Exponential Thin Disk
0.00
σ = 0.00
Exponential Thin Disk with Dark Matter
$2.10 * 10^{-6}$
$\sigma = 0.05*10^{-6}$
Mond
$5.3*10^{-8}$
$\sigma = 0.2*10^{-8}$

References:
[1]Begeman, K.G. " H I rotation curves of spiral galaxies. I - NGC 3198." *Astronomy and Astrophysics*. 223. 1-2 (1989): 47-60. Web. <http://adsabs.harvard.edu/abs/1989A&A...223...47B>.
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[3]Milgrom, M. " A modification of the Newtonian dynamics as a possible alternative to the hidden mass hypothesis." *Astrophysical Journal*. 270. (1983): 365-370. Web. 19 Apr. 2013. <http://adsabs.harvard.edu/abs/1983ApJ...270..365M>.
[4]van Albada, T.S., J.N. Bahcall, K. Begeman, and R. Sancisi. " Distribution of dark matter in the spiral galaxy NGC 3198." *Astrophysical Journal*. 295. (1985): n. page. Web. 19 Apr. 2013. <http://adsabs.harvard.edu/abs/1985ApJ...295..305V>.

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