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The Application of ENG (Extended Newtonian Gravitation) to Wide Binary Systems

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Abstract

An Extended Newtonian Gravitation (ENG) model previously developed by the author for galaxies and galaxy clusters was applied to wide binary systems where an apparent missing mass problem was found from the Hipparcos and Gaia catalogue. The ENG model shows results consistent with the experimental values of the asymptotic velocity difference between the stars. MOND (as an inertial paradigm) failed to show its asymptotic behavior when its external field effect was considered. It had an almost Newtonian behavior for accelerations well below MOND's characteristic acceleration. The importance of reducing the uncertainty of the experiments concerning the velocity difference of the wide binary system is remarked because it could provide a solid way to confirm (or falsify) physical hypotheses concerning dark matter and non-Newtonian physics.

Subject Areas

Cosmology

Keywords

Dark Matter, Wide Binary: Kinematics and Dynamics, Cosmology

1. Introduction

Zwicky published a paper at the beginning of the 1930s [1] where an inconsistency between the galaxy circular speeds and the mass of the Coma galaxy cluster was noticed (using the virial theorem). One of his interpretations of the problem was the potential existence of dark matter.

In the 1970s, the need for the so coined dark matter in the outer part of galaxies and well beyond their optical edge was noticed [2]. Later on, missing mass problems were also found in galaxy clusters [3].

Up to this point, the need for dark matter was noticed only in large-scale cosmic structures. However, in 2011, Hernandez *et al.* [4] found a non-Newtonian behavior of the velocity difference between binary stars with large separation distances (greater than about 0.1 pc) in the Hipparcos and Gaia catalogues. This finding implies a missing mass problem that is incompatible with the current dark matter models because the dark matter amount will be very little in such a small distance scale [5] [6].

Since current alternatives to dark matter that modify Newton's gravitation have not solved completely the missing mass problem, reference [7] extended the Newtonian gravitation (ENG) to reproduce the non-Newtonian behavior of rotation curves in galaxies which yields results similar to MOND (Modified Newtonian Dynamics) [8] [9] for galaxies and larger circular speeds than MOND results in a simulated hypothetic compact cluster of galaxies. Note that it is in galaxy clusters where MOND still has a missing mass problem [3].

The application of the ENG model to wide binary systems yielded results compatible with reported experimental results as will be seen later.

MOND (as an inertial modification of Newton's 2nd law) failed to yield its non-Newtonian behavior (where the Newtonian acceleration is much smaller than MOND's characteristic acceleration) when the external field effect was considered. Without the external field effect, the non-Newtonian behavior is restored but with an asymptotic velocity difference significantly smaller than the experimental value.

The main purpose of this manuscript is to determine if the ENG model (developed previously by the author for galaxies and galaxy clusters) could explain the missing mass problem detected in wide binary systems. The results of this research confirm its applicability.

This paper has the following structure: Section 2 describes the equations for the velocity difference of binary stars for the Newtonian, Mondian, and ENG models. Section 3 shows a comparison of the results of the models in question. In Section 4, the summary and concluding remarks are presented.

2. ENG in Wide Binary Systems

Before describing the ENG model the Newtonian and Mondian models are described for a better illustration of the problem and models in question following similar approach as the description presented in [5] [6].

The magnitude of the velocity of a component of a binary star system of equal masses using Newtonian theory (gravitational and inertial force) can be written as

$$v = \sqrt{\frac{GM}{2r}}\,.$$

The magnitude of the velocity difference between the components is then written as

$$\Delta v = \sqrt{\frac{2GM}{r}} \tag{1}$$

where,

G: Newton gravitational constant;

M: Mass of the stars;

r: Separation between the stars.

Note that the velocity direction of one star is the opposite of the other one and therefore $\Delta v = 2v$.

The balance between the gravitational and the Mondian inertial acceleration for a component of the binary system is written as

$$a\frac{a + a_e}{a + a_e + a_0} = \frac{GM}{r^2}$$

where,

a: Newtonian acceleration;

a_0: MOND characteristic acceleration $a_0 \approx \frac{cH_0}{6} \sim 1.2\text{E}{-10}\ \text{m/s}^2$;

a_e: Acceleration to take into account MOND external field effect [5] [6].

Note that the standard interpolation function is used.

That balance can be express as a quadratic equation:

$$a^2 + \left(a_e - \frac{GM}{r^2}\right)a - \frac{GM\left(a_e + a_0\right)}{r^2} = 0$$

Using circular acceleration and equal mass the following Quartic equation is obtained:

$$v^4 + \left(a_e r - \frac{GM}{r}\right)\frac{v^2}{2} - \frac{GM\left(a_e + a_0\right)}{4} = 0$$

Making the substitution $v' = v^2$ that equation is converted to a quadratic one the solution of which is

$$v' = \frac{1}{4}\left(\frac{GM}{r} - a_e r \pm \sqrt{\left(a_e r - \frac{GM}{r}\right)^2 + 4GM\left(a_e + a_0\right)}\right)$$

from which

$$v = \frac{1}{2}\sqrt{\frac{GM}{r} - a_e r \pm \sqrt{\left(a_e r - \frac{GM}{r}\right)^2 + 4GM\left(a_e + a_0\right)}} \tag{2}$$

The velocity difference is $\Delta v = 2v$ where the positive sign is taken in the inner square root of *v*.

In the ENG model [7] the balance between the inertial and gravitational acceleration for a non-relativistic star is written as

$$a = G\frac{M}{r^2} + G_1\frac{M}{r},\quad G_1 = f\left(M\right) \ll G$$

where the following expression was obtained for disk galaxies:

$$G_1 = \frac{\pi G}{2\sqrt{2M}} \Rightarrow v_a^4 = \left(\frac{\pi G}{2}\right)^2 \frac{M}{2}$$

The Baryonic Tully-Fisher relation for the asymptotic speed.

The values of v_a calculated in this way are close to the binned experimental data shown in the next section.

Notice that even though G_1 has a mass dependency it is not a free parameter. It is supposed to be obtained from experimental data and/or experimentally verified correlations.

The value of G_1 for the wide binary systems was obtained from an extrapolation of a power fit to the binned experimental data of galaxies and galaxy clusters as will be seen in the next section. For convenience, the explicit mass dependency of G_1 will not be incorporated into the equation of the velocity difference that follows.

For circular acceleration and equal masses:

$$v = \sqrt{\frac{GM}{2r} + \frac{G_1 M}{2}}$$

The velocity difference is then

$$\Delta v = 2v = \sqrt{2M\left(\frac{G}{r} + G_1\right)} \quad (3)$$

For large r $\Delta v = \sqrt{2MG_1}$ (an asymptotic velocity difference).

3. Computational Results and Analysis

Table 1 shows the binned experimental data of the baryonic mass and the asymptotic circular speeds for galaxies and galaxy clusters reported in [10]. That Table also shows the value of G_1 ($m^2 \cdot s^{-2} \cdot kg^{-1}$) corresponding to the binned data ($G_1 = v_c^2 / M_b$) along with a power law fit to G_1 (see **Figure 1**).The evaluation of G_1 fit for the mass of the sun yields a value of 1.7103×10^{-25}.

Table 2 and **Figure 2** show the asymptotic circular velocity difference for the 3 models described in the previous section.

MOND external field effect was considered taking $a_e = 1 \times 10^{-10}\ \text{m/s}^2$ corresponding to the acceleration of the sun around the center of the Milky Way [5] [6]. Note that the external field effect makes the asymptotic behavior of MOND disappear (it is almost Newtonian). So MOND behavior (using the cited acceleration (a_e) in the solar neighborhood) is incompatible with the experimental trend results for the binary system reported in [4] [11]. This MOND behavior was previously noticed by [5] [6]. Note that without the external field effect MOND yields an asymptotic speed of 0.5 km/s with a monotonous decreasing speed profile. **Figure 3** shows the Newtonian acceleration for comparison with a_0.

The ENG model shows a distinctive asymptotic behavior. Its velocity profile is very different from the Newtonian model even for relatively smaller separations. Notice that ENG yields an asymptotic circular speed of 0.8 km/s, which is about the same value obtained in [11] and shown in [5] [6].

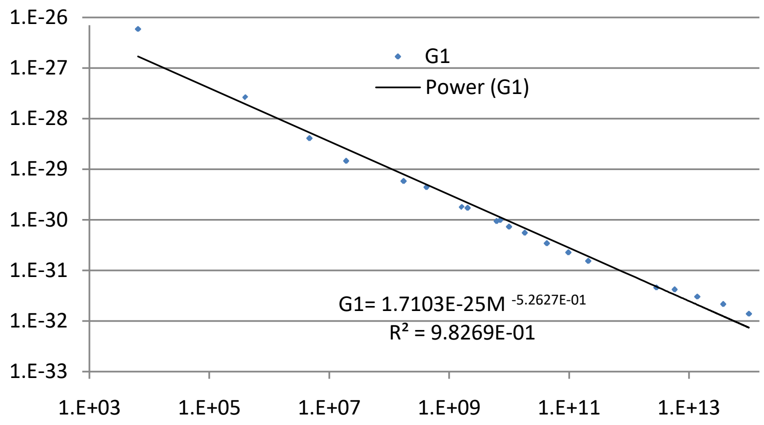

Figure 1. G_1 ($m^2 \cdot s^{-2} \cdot kg^{-1}$) vs. M (solar mass). Power fit to the binned (G_1) data. Both axes are in Log10 scale.

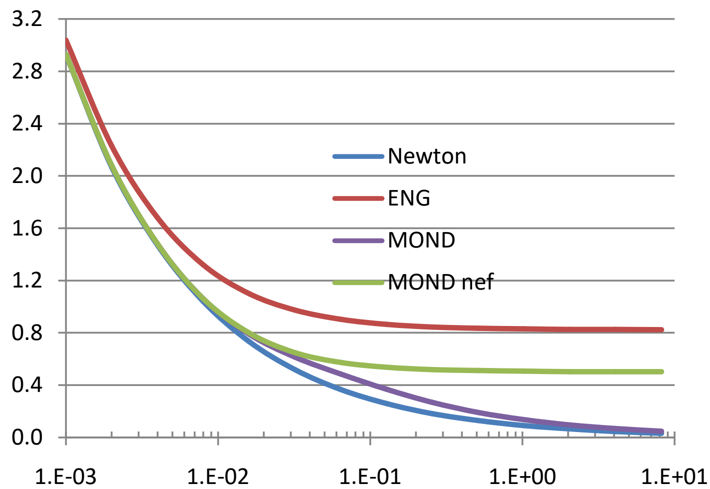

Figure 2. Asymptotic circular velocity difference (km/s) vs. separation between binary stars (pc, Log10 scale). From top to bottom: ENG (red), MOND (no external field, green), MOND (magenta), Newton (blue).

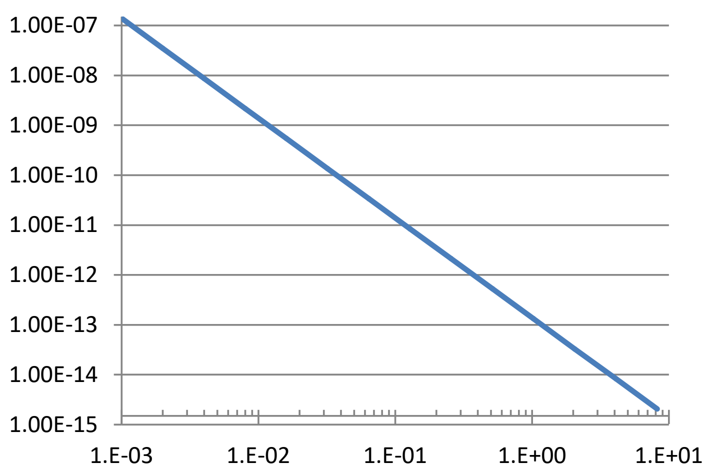

Figure 3. Newtonian acceleration (m/s^2) vs. Separation (pc). Log 10 scale for both axes.

Table 1. Binned experimental data: Baryonic mass and Asymptotic circular speed [10]. G_1 ($m^2 \cdot s^{-2} \cdot kg^{-1}$): Calculated from the binned data along with its fit to a power law.

System	Mb	Vc	G1	
	(Msun)	(km/s)	(Vc^2/Mb)	(Fit)
cluster	1.00E+14	1.66E+03	1.38E−32	7.33E−33
cluster	3.72E+13	1.26E+03	2.14E−32	1.23E−32
Cluster	1.38E+13	9.12E+02	3.03E−32	2.08E−32
Cluster	5.75E+12	6.92E+02	4.18E−32	3.30E−32
Cluster	2.88E+12	5.13E+02	4.59E−32	4.74E−32
Spiral	2.09E+11	2.51E+02	1.52E−31	1.89E−31
Spiral	9.77E+10	2.09E+02	2.25E−31	2.81E−31
Spiral	4.27E+10	1.70E+02	3.40E−31	4.35E−31
Spiral	1.82E+10	1.41E+02	5.51E−31	6.82E−31
Spiral	1.00E+10	1.20E+02	7.27E−31	9.34E−31
Gas Disk	7.08E+09	1.17E+02	9.80E−31	1.12E−30
Spiral	6.17E+09	1.07E+02	9.36E−31	1.20E−30
Spiral	2.04E+09	8.32E+01	1.70E−30	2.16E−30
Gas Disk	1.62E+09	7.59E+01	1.78E−30	2.43E−30
Gas Disk	4.17E+08	6.03E+01	4.38E−30	4.97E−30
Gas Disk	1.74E+08	4.47E+01	5.77E−30	7.88E−30
Gas Disk	1.91E+07	2.34E+01	1.45E−29	2.52E−29
Dwarf	4.68E+06	1.95E+01	4.09E−29	5.28E−29
Dwarf	3.98E+05	1.45E+01	2.64E−28	1.93E−28
Dwarf	6.46E+03	8.71E+00	5.91E−27	1.69E−27

Table 2. Asymptotic circular velocity difference vs. separation between binary stars.

r	v (km/s)			
(pc)	Newton	ENG	MOND	MOND nef
1.00E−03	2.93E+00	3.04E+00	2.93E+00	2.93E+00
2.00E−03	2.07E+00	2.23E+00	2.08E+00	2.08E+00
4.00E−03	1.47E+00	1.68E+00	1.48E+00	1.48E+00
8.00E−03	1.04E+00	1.32E+00	1.06E+00	1.06E+00
1.60E−02	7.33E−01	1.10E+00	7.90E−01	7.98E−01
3.20E−02	5.18E−01	9.74E−01	6.15E−01	6.48E−01
6.40E−02	3.66E−01	9.03E−01	4.85E−01	5.73E−01
1.28E−01	2.59E−01	8.65E−01	3.68E−01	5.37E−01
2.56E−01	1.83E−01	8.45E−01	2.68E−01	5.19E−01
5.12E−01	1.30E−01	8.35E−01	1.91E−01	5.11E−01
1.02E+00	9.16E−02	8.30E−01	1.36E−01	5.07E−01
2.05E+00	6.48E−02	8.27E−01	9.60E−02	5.04E−01
4.10E+00	4.58E−02	8.26E−01	6.79E−02	5.03E−01
8.19E+00	3.24E−02	8.25E−01	4.80E−02	5.03E−01

Asymptotic speed of future precise experiments concerning the wide binary systems could be used to extend the binned data of Table 1 to an even lower mass range from which $G_1\left(v^2/M\right)$ could be obtained. In this case the speed profile (before it levels off) calculated using the ENG model will be the prediction to be tested by precise measurements.

It is noted that the MNG [6] model has an asymptotic behavior yielding also an asymptotic speed about 0.8 km/s however it has a non-monotonous profile in the region between ~0.01 and ~0.1 pc and it has 3 free parameters.

4. Summary and Concluding Remarks

Three models (Newtonian, MOND, ENG) were applied to wide binary systems with an individual star mass of a solar mass to calculate the stars' velocity difference.

The Newtonian and MOND (considering its external field effect) models showed similar results which significantly deviate from the experimental values. The non-Newtonian behavior of MOND for very low acceleration is restored if the external field effect is not considered but its asymptotic velocity difference deviates significantly from the reported asymptotic experimental values.

The ENG model yielded an asymptotic velocity difference close to the reported experimental values.

It is important to reduce the uncertainty of the experiments concerning the velocity difference of the wide binary system because it could provide a solid way to confirm (or falsify) physical hypotheses concerning dark matter and dark physics (non-Newtonian behavior). Note that it has passed about 11 years since the apparent missing mass problem was first noticed in wide binary systems.

Conflicts of Interest

The author declares no conflicts of interest.

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