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Dark Matter in Spiral Galaxies as the Gravitational Redshift of Gravitons

Firmin Oliveira and Michael L. Smith

Abstract

Several recent attempts to observe dark matter with characteristics similar to atomic or subatomic particles as Weakly Interacting Massive Particles (WIMPs) have failed to detect anything real over a wide energy range. Likewise, considerations of large, non-emitting objects as the source of most dark matter fall short of expectations. Here we consider the possibility that massless gravitons suffering slow redshift may be responsible for the properties of spiral galaxies attributed to dark matter. Particles such as gravitons will be extremely difficult to directly detect; the best we can envision is measuring this influence on stellar and galactic motions. Since the motions of stars and galaxies are non-relativistic, we can apply our idea to describe the expected large-scale motions using only Newtonian mechanics. Using our assumption about the importance of the graviton, we here describe the well-known Tully-Fisher relationship of spiral galaxies without resorting to hypothesizing exotic WIMPs or invoking modifications of Newtonian dynamics (MOND).

Keywords: dark matter, spiral galaxies, galaxy dynamics, baryonic Tully-fisher relation, Newtonian mechanics, gravitons, BTFR

1. Introduction

The first hint for the existence of dark matter (DM) between galaxies was the observation over eight decades ago from a study of the luminosities and centrifugal velocities of three galaxies, a galactic “triplet” of the Coma Cluster [1]. Fritz Zwicky noted that the motions of these galaxies about a central point could not be properly described using his presumed values for the galaxy matter densities. He, like all astronomers, estimated matter density assuming that the average density is proportional to the observed luminosity. These three galaxies were behaving as if each contained much more matter than calculated from the luminosities. Zwicky proposed that these three galaxies behaved as if under the influence of a type of plentiful, non-radiating matter, hence DM.

Stellar motions in spiral galaxies The existence of significant DM was later required to explain another interesting problem of astronomy—the intragalactic motions of stars within the Andromeda galaxy [2]. For what seems a general rule,

the rotational motions of stars about the center of the galactic plane, of spiral-type galaxies, do not follow Kepler's laws of planetary motion. Instead, the more distant stars travel at much greater velocities relative to those of the interior [3]. Distant stars circulate at a more frantic pace than those closer to the center contradicting the planetary laws of Kepler; objects more distant from the center should be traveling slower than those closer. Follow-up observations by Rubin and coworkers of the stellar velocities within many other spiral galaxies confirm this observation as a generality [4]. This is strongly supported by another group in a study of over 1000 galaxies [5]. It still seems uncertain if this grand observation by Rubin also holds for globular and other types of galaxies because observation of individual star motions is more difficult for these galaxy types. Investigators also pointed out that presumed DM explains the rotational velocities of stars in low luminosity galaxies better than for luminous galaxies [5]. The reader should understand that the quandaries of both Zwicky and Rubin depend on the belief that the quantity and distribution of "normal" matter can be correctly estimated from the galactic luminosity.

Proper explanation of these anomalies remains without a satisfactory answer after more than five decades. An answer to this conundrum is considered as utmost importance to both physics and astronomy. Many investigators now call for either new physics or for the presence of considerable DM, of some type, to explain the stellar motions in these galaxies [6]. A solution of Rubin's observations was proposed years ago by utilizing Einstein's General Relativity under the condition of cylindrical geometry [7] but was quickly shown deficient for describing other important properties of spiral galaxies [8]. Another and a more credible explanation of the baryonic-Tully-Fisher relation (BTFR) has been made using Carmeli General Relativity (CGR), which does not require new particle physics nor DM [9].

Dark matter identity If DM is the explanation, the exact nature still defies description after all these years. We divide the proposed solutions into three suspects. The first type would be DM as small atomic or subatomic particles, which are often termed **Weakly Interacting Massive Particles** or (WIMPS) [10, 11]. We include exotic particles, as those predicted by weak-scale supersymmetry, in this group [12]. The terms massive, WIMPS refer to particles with energies significantly above the common atomic and subatomic energies. To be effective DM such particles would obviously have to exhibit measurable mass, be non-relativistic and hence *cold* in nature. They would also have to be dark, that is, not interacting with photons. WIMPS must also exhibit elastic collisions with themselves and with baryons (no clumping allowed), and there would have to be a lot of them—about 4–6 times the total mass of ordinary matter. In addition, because WIMPS are non-interactive, cold and nearly frictionless, a novel explanation is required to explain how the velocities were significantly reduced after the Big Bang. This is a long list of special conditions and novel physics.

Many attempts have been made to detect DM, as WIMPS, in terms of particles at near atomic or subatomic energies. We list some of the latest attempts to detect such a particle here. Years of attempting underground detection of entities from intergalactic origin with sensitive probes have been without any success [13]. Attempted detection of particles resulting from WIMP self-annihilation in our sun also ended without positive results [14, 15]. Detection of signals in large Xe-filled detectors over long periods (time) has also not reported positive results [16, 17]. A recent summary of several programs that have failed to detect WIMPS is available [18]. There is one recent event recorded by the Particle and Astrophysical Xenon TPC (PandaX) collaboration, which might be evidence for WIMPS, which obviously needs to be reproduced [19]. In spite of these several failures, there are proposed programs hopeful to deliver positive results. It is questionable if these searches will be funded.

One proposal will use the planned International Linear Collider, which might be built in Japan, to detect heavy WIMPS up to 3 TeV in size [20]. Another suggestion is to rather concentrate on detecting the lightest neutralino of supersymmetry. According to some people, this hypothesized particle remains the best candidate for dark matter with decent detection prospects [21]. On the other hand, faith in small mass WIMPS around the mass of neutrinos as DM candidates has been ruled out from examination of supernovae observations showing the total neutrino and neutralino mass of the Universe is simply too small to be DM [22]. The best chance for detecting massive WIMPS may come from detecting products from cosmic ray collisions, which are high enough energetically to produce particles with energies from 150 and 500 GeV [23]. But the final argument against WIMPS is the need for special pleading around the existence of WIMPS, which supposedly make up about 80% of matter; about 20% of our Universe. It is *special* that WIMPS are everywhere but not in our solar system, an argument contrary to the Cosmological Principle of Einstein [24]. So we can believe in WIMPS and discard the Cosmological Principle or hold this principle true and discard the notion of WIMPS, but not both.

The second explanation is that matter of the common variety is responsible for the effects of DM, and there is much more common matter than we can detect in spiral galaxies. These dark objects are often referred to as **Massive Astrophysical Compact Halo Objects** (MACHOS). This group includes massive objects such as brown dwarfs, Jupiter-sized planets, neutron stars, and “small” black holes [25]. Some investigators also include white and red dwarfs in this group since those inhabiting other galaxies are invisible to our telescopes but would exert gravitational attraction nonetheless [26]. One should also include large clouds of known atomic particles, such as neutral hydrogen and helium. Large clouds of atoms and small molecules may well be undetected in unlit regions of intra- and intergalactic space. Investigations into the MACHO hypothesis have waned the past few years but might revive if data from two planned satellites support the MACHO scenario. There are two programs may uncover data critical to the MACHO hypothesis. The first is the James Webb satellite, rescheduled (again) for launch later this year. This satellite will be able to detect objects emitting light in the near and mid-infrared range, thus allowing a better assay of the population of dark stars and Jupiter-sized planets [27]. Another satellite with a detection range in the visible and near-infrared regions is the Nancy Grace Roman space telescope. This platform will be able to collect data over a much greater volume than any current instrument, be able to detect new Jupiter sized planets and so should also add to our knowledge of MACHOS and hence DM [28]. The planned launch date is sometime in 2025, so it may be collecting data before the James Webb telescope. Finally, it has been pointed out that the methods previously used to calculate the MACHO density have not been optimal, with better observational methods and more satellite data, this explanation of DM may rebound in popularity [29].

One key relationship associated with the presence of luminous matter in galaxies is the Tully-Fisher relation (TFR), which is something like

$$L \propto V_{\theta}^{3.5-4} \quad (1)$$

where L is the apparent luminosity of the stars in the galactic plane, and V_{θ} is the average rotational velocity of these stars. This holds true even when mid-infrared and microwave radiations are assayed [30]. This relationship is sometimes written as

$$M \propto V_{\theta}^{3.5-4} \quad (2)$$

where M is the estimated mass of luminous stars and modeled gas in that galaxy. This empirical finding is thus a broad correlation between the rotational velocities as determined by the Doppler shift and the baryonic matter content of many spiral galaxies [31]. This empirical correlation is sometimes termed the baryonic-Tully-Fisher relation (BTFR).

The third explanation is gravitons. This particle was first proposed by Feynman to modulate the interactions of gravity in analogy to the photon, which modulates interactions between ordinary matter [32]. A graviton is the agent of the gravitational field having zero rest mass traveling at the speed of light in a vacuum. Since a graviton has never been observed, the bulk properties may be like those of axions or even neutralinos [33]. These are all hypothesized “particles” not exhibiting properties of ordinary or DM other than gravitational attraction [34]. The graviton has also been hypothesized as a type of heavy particle outside the standard model (SM) of physics [35]. In general, not much is known about these particle types placing our culture in a situation similar to our understanding of WIMPS. Unlike the frustrating studies of WIMPS, the study of gravitons has been generally overlooked. Here we suggest a simple description of gravitons in action to better explain the BTFR and hopefully stir up more interest in this line of inquiry.

Finally, there are several people who have expressed their concern that the searches for new particles, WIMPS, and other gravity sources have failed and that future investigations are not likely to do any better [36]. In the meantime, WIMPS and MACHOS are suggested solutions over which many investigators lavish time and imagination, some can even directly profit from broadcasting their ideas [37]. Dark matter and dark energy have made their way into YouTube pop-science culture, which helps support some younger investigators [38]. The topic of dark matter has even been unofficially designated as the calendar day: October 31.

To properly model the Zwicky and Rubin observations, people have proposed theories that do not invoke any particle type but rather modify the fundamental equation of gravity. Some look to modified gravity (MoND) as a revolutionary answer to explain problems on scales larger than our solar system—the galactic scale [39]. Some of the problems with MoND have been addressed for public consumption [40]. This topic, however, is outside the interest of this chapter.

2. Theory

We suggest that gravitons, as agents of the gravitational field, may be modeled as a dense soup of massless particles that nonetheless interact with massive particles. When gravitons travel in a gravitational field, modeled by the equivalence principle as an accelerating system [41], over a short time period $\delta t = \delta r/c$, where the acceleration a at a point r in the field is given by $a = -GM/r^2$, they must experience an energy loss of $\delta \Xi$ due to motion in that field. We express this differentially as

$$\delta \Xi = -(mc^2) \frac{\delta v}{c} = (mc) a \delta t = -\frac{GMm}{r^2} \delta r, \quad (3)$$

where m is the total relativistic graviton mass, δv is the change in velocity of the system observed from an inertial reference frame, G is Newton’s gravitational constant, M is the baryonic mass of the field source, r is the distance between the center of the source and the location of the moving gravitons, δt is the short travel time of the gravitons at speed c over distance δr . The energy change is a loss (negative) because δv is in the same direction as the motion of the gravitons, so that for an inertial observer moving with velocity δv , the energy of the graviton is redshifted.

Integrating Eq. (3) between radial positions r_0 and r , where $r_0 \leq r$, we obtain the total graviton energy change $\Delta\Xi$, given by

$$\Delta\Xi = \int_{v_1}^{v_2} - (mc^2) \frac{\delta v}{c} = \int_{r_0}^r - mc \left(\frac{GM}{r^2} \right) \frac{\delta r}{c} = -GMm \left(\frac{1}{r_0} - \frac{1}{r} \right). \quad (4)$$

Eq. (4) describes the gravitational redshift of the graviton energies as these travel from a position r_0 of lower (more negative) to a position r of higher (less negative) potential energy consistent with energy conservation. For simplicity, we assume here that the mass M is a point mass.

Consider the energy equation for a galaxy of baryonic mass M interior to position r_0 with a small baryonic mass m in a circular orbit of radius r . The gravitons traversing the distance from the interior mass to the orbiting mass at speed c have a decrease in energy $\Delta\Xi$ given by Eq. (4). The total orbital energy is given by

$$\frac{1}{2}mv^2 - \frac{GMm}{r} + K_g \Delta\Xi = \frac{1}{2}mv^2 - \frac{GMm}{r} - K_g GMm \left(\frac{1}{r_0} - \frac{1}{r} \right) = E, \quad (5)$$

where $K_g > 0$ for $r \geq r_0$ and $K_g = 0$ for $r < r_0$. K_g is a galaxy dependent dimensionless coefficient, which is necessary to fit the theory with observation, but the actual physical reason for it is not known at this time.

Multiplying Eq. (5) by $2/m$ and moving all terms except v^2 to the right-hand side with the total orbital energy $E = -GMm/2r$, we obtain

$$v^2 = \frac{GM}{r} + 2K_g GM \left(\frac{1}{r_0} - \frac{1}{r} \right). \quad (6)$$

The properties of a typical spiral galaxy are more easily observed than other types and can be described by the final radial distance r_f , at which the final rotational velocity is v_f and the orbiting mass is m . Substituting v_f for v and r_f for r into Eq. (6) and solving for the viral mass M_{vir} , we obtain

$$M_{vir} = \frac{v_f^2 r_f}{G} = M \left(2K_g \left(\frac{r_f}{r_0} - 1 \right) + 1 \right), \quad (7)$$

from which we get the apparent dark matter M_d in the galaxy,

$$M_d = M_{vir} - M = 2MK_g \left(\frac{r_f}{r_0} - 1 \right). \quad (8)$$

Solving Eq. (7) for r_0 , and simplifying yields,

$$r_0 = \frac{2K_g r_f}{\left(\left(v_f^2 r_f \right) / GM \right) + 2K_g - 1}. \quad (9)$$

These results ideally require virtually all the galaxy baryonic mass M to be interior of the radial distance r_0 , with only small test masses beyond r_0 . Additionally, determining the actual mass interior to r_0 and the velocity v_f is not an exact science. Thus, proving the validity of Eq. (9) for determining r_0 can be difficult.

Here we relate r_0 to the baryonic Tully-Fisher relation (BTFR) [10]. At $r = r_0$, by squaring Eq. (6) and putting it into an inverted form of the BTFR, we get

$$v^4 = MA^{-1} = GM \left(\frac{GM}{r_0^2} \right) = GMa_0, \quad (10)$$

where $A \approx 50 M_{\odot} km^{-4} s^4$ and M in solar mass units [42, 43]. For v in ms^{-1} , M in kg and r_0 in m , $a_0 = GM/r_0^2 = (GA)^{-1} \approx 1.507 \times 10^{-10} ms^{-2}$, where we again emphasize that we are assuming that M is the mass interior to r_0 , which is an approximation. However, the BTFR is also an approximation, albeit a very good approximation from a large amount of galaxy rotation data.

For galaxies in general, we model the mass density function $\rho(r)$ as spherically symmetric. The mass $M(r)$ of the galaxy within the radial distance r is given by

$$M(r) = \int_0^r 4\pi\rho(u)u^2 du. \quad (11)$$

With mass density $\rho(r)$, the graviton energy loss Eq. (4) between r_0 and r is expressed by

$$\Delta\Xi(r) = -\int_{r_0}^r m GM(u) \frac{du}{u^2} = -\int_{r_0}^r m G \left(\int_0^u 4\pi\rho(s)s^2 ds \right) \frac{du}{u^2}. \quad (12)$$

Using Eqs. (11) and (12), Eq. (6) becomes

$$v^2 = \frac{GM(r)}{r} - \frac{2K_g \Delta\Xi(r)}{m} = \frac{G}{r} \int_0^r 4\pi\rho(s)s^2 ds + \int_{r_0}^r \frac{2K_g G}{u^2} \left(\int_0^u 4\pi\rho(s)s^2 ds \right) du. \quad (13)$$

To obtain r_0 , solve the following equation iteratively,

$$r_0^2 = \frac{G}{a_0} \left(\int_0^{r_0} 4\pi\rho(s)s^2 ds \right). \quad (14)$$

Solving Eq. (13) for K_g yields the equation,

$$K_g = \frac{v_{flat}^2 - GM/r_f}{\int_{r_0}^{r_f} \left(\frac{2G}{u^2} \right) \left(\int_0^u 4\pi\rho(s)s^2 ds \right) du}, \quad (15)$$

where v_{flat} is the velocity of the flat part of the rotation curve.

3. Results

We performed nonlinear modeling of the graviton model, Eqs. (13)–(15), with the velocity rotation curve data for spiral galaxies NGC 3198 and the Milky Way. The mass density function $\rho(r)$ that we use is defined by,

$$\rho(r) = \left(\frac{M}{(4/3)\pi} \right) \sum_{j=1}^n \left(\left(\frac{b_j}{a_j^3} \right) \exp \left(-\frac{r}{a_j} \right) \right), \quad (16)$$

where the total baryonic mass equals M over the total radial range of the observational data, a_j are scale lengths, and b_j are weights, where the weights sum to unity. Determinations for the mass $M(r, r_1)$ within the positions r_1 and r , where $0 \leq r_1 \leq r$, must be normalized, so the mass is computed from Eq. (16) in the form

$$M(r, r_1) = \left(\frac{M}{\int_0^{r_f} 4\pi\rho(u)u^2 du} \right) \int_{r_1}^r 4\pi\rho(s)s^2 ds, \quad (17)$$

where r_f is the largest radial distance of the data: the galaxy *edge*.

NGC 3198 For the analysis of NGC 3198 rotation data, with stellar mass $2.3 \times 10^{10} M_{\odot}$ and mass of gas $0.63 \times 10^{10} M_{\odot}$, we have a total baryonic mass of $M_{N3198} = 2.93 \times 10^{10} M_{\odot}$ [44]. For the rotation curve data of NGC 3198, we use data from the thesis of Begeman [45]. We set $n = 4$, with the scale lengths $a_1 = 1.1$ kpc, $a_2 = 1.27$ kpc, $a_3 = 1.35$ kpc, $a_4 = 1.5$ kpc, and the weights are $b_1 = 0.4$, $b_2 = 0.3$, $b_3 = 0.2$ and $b_4 = 0.1$. By solving Eq. (14) we obtain $r_0 = 4.254$ kpc, the radial distance where the acceleration equals $a_0 = 1.507 \times 10^{-10} m s^{-2}$. Solving Eq. (15), we obtain a value of $K_g = 0.421$. The result using the NGC 3198 data is presented in **Figure 1**. The fit, not necessarily optimal, has a Mean Absolute Error of $MAE = 4.322 km s^{-1}$, expressed by $MAE = (1/n) \sum_{j=1}^n \|O_j - P_j\|$, where O_j are the observation values and P_j are the model predictor values. The square of the correlation coefficient between the observed v_{obs} and modeled v_{mod} rotational velocities is $r^2 = (corr(v_{obs}, v_{mod}))^2 = 0.986$.

Milky Way Galaxy A fit of the graviton model to the velocity rotation curve data for the Milky Way is shown in **Figure 2**. The mass for our galaxy is approximated by the BTFR given by Eq. (10) with a flat rotational velocity of $v = 202 km s^{-1}$, which yields a mass of $M_{Galaxy} = 8.328 \times 10^{10} M_{\odot}$. The nonlinear curve fit to the rotation curve data [46] is made with $n = 6$, with the scale lengths given by $a_1 = 0.11$ kpc, $a_2 = 0.7$ kpc, $a_3 = 1.71$ kpc, $a_4 = 1.82$ kpc, $a_5 = 1.83$ kpc, and $a_6 = 1.84$ kpc. The weights used are $b_1 = 0.095$, $b_2 = 0.1$, $b_3 = 0.2$, $b_4 = 0.3$, $b_5 = 0.3$, and $b_6 = 0.005$, where the weights sum to unity. Solving Eq. (14), we find the radial distance where the acceleration to be $a_0 = 1.507 \times 10^{-10} m s^{-2}$ is $r_0 = 8.157$ kpc. Then, using this value for r_0 , we solve Eq. (15) to obtain a value of $K_g = 0.418$. The fit of the graviton model, not necessarily optimal, has an error of $MAE = 6.33 km s^{-1}$ for the fit up to r_0 and for the entire range of the data up to 1.28×10^3 kpc, the error is

Figure 1.
The velocity vs. radial distance from the galactic center of NGC 3198. The data points and errors are from [45]. The solid curve is a good fit to the data with the graviton model, Eqs. (13–15).

Figure 2. The velocity vs. radial distance from the galactic center of the milky way galaxy. The data points and errors are from [46]. The solid curve is the fit to the galaxy rotation curve with the graviton model, Eqs. (13–15).

$MAE = 13.25 km s^{-1}$. For the radial distance up to r_0 , the square of the correlation coefficient between the observed and modeled velocities is $r^2 = 0.136$. For the full radial distance up to 1.28 Mpc, the square of the correlation coefficient between observed and modeled velocities is $r^2 = 0.171$.

The results for NGC 3198 and the Milky Way galaxies are summarized in **Table 1**. Our graviton model of the stellar velocity data of these two galaxies exhibits a decreasing rotational velocity for increasing distance from the galactic center, which is a result of the lingering of the Newtonian velocity component in the model, using Eq. (6), expressed proportionally by

$$v(r) \propto \sqrt{\frac{1 - 2K_g}{r} + \frac{2K_g}{r_0}}, \tag{18}$$

for $r_0 \leq r$. This effect may mimic the external field effect observed in spiral galaxies as reported by [47]. Use of the graviton model to analyze more galaxies is necessary to quantify this effect.

For comparison, we also have modeled the stellar rotational velocity vs distance from the galactic centers as a version of this empirical relationship,

$$V_\theta = \frac{V_m D_L}{K_\theta + D_L} \tag{19}$$

where V_θ is the rotational velocity in the galactic plane, V_m is the average maximum velocity, D_L the observed binned distance from the galactic center, K_θ is some constant, which should not be confused with K_g . The general form of this relationship is well known in physical chemistry as the Langmuir equation

Galaxy	r_0 (kpc)	K_g	n	r^2
NGC 3198	4.254	0.421	4	0.986
Milky Way	8.157	0.418	6	0.171

Table 1. Graviton model results from fits of Eq. (13) to the NCG 3198 and milky way full range binned data. Note that r^2 is the correlation coefficient corrected for parameter number and not the value for any radius.

Galaxy	V_m (kpc)	K_θ	r^2
NGC 3198	154 ± 2	0.05 ± 0.1	0.982
Milky Way (113)	211 ± 2	0.20 ± 0.04	0.991
Milky Way (99)	200 ± 2	-0.16 ± 0.05	0.997

Table 2.
Results from nonlinear regression of galaxy binned data with the Langmuir equation. Note that r^2 is the correlation coefficient corrected for parameter number and not the value for any radius.

Figure 3.
The rotational velocity (km s^{-1}) vs. radial distance (kpc) from the galactic center of NGC 3198. The solid curve is a good fit to the data with the Langmuir model, Eq. (32). The errors shown here and used for modeling are the standard deviations from the observations [45].

describing a substrate-saturation curve of a binding site-limited system. Note that we allowed both V_m and K_θ to be the two free parameters. We select this model because the data exhibit an initial quick increase in V_θ followed by a long progression of stars with fairly similar V_θ as evidenced by many barred galaxies [4]. We present the results from nonlinear regression modeling Eq. (19) with the NGC 3198 and the Milky Way data in **Table 2** with all three analyses including the position of the galactic center, velocity, 0,0 without error. Note the results of Milky Way (113) including all data and the results of Milky Way (99) where the 14 data pairs closest to the galactic center are not used because the data are very noisy. This model fairly describes the Milky Way data as the values for r^2 are nearly 1.

Figure 3 presents the best fit to the binned NGC 3198 data using the Langmuir model. It appears that the Langmuir equation is a fair model to the NGC 3198 data for stars at and beyond 4 kpc from the galactic center and might be useful to estimate the average rotational velocity of stars in spiral galaxies, which are not too close to the center. Another thing to note is that the rotational velocity of the Milky Way estimated by both the graviton and Langmuir models is similar at about 200 km s^{-1} .

4. Conclusions

We suggest an alternate explanation to the usual for the Zwicky and Rubin observations without resorting to the special pleading required by the WIMP and

MACHO scenarios. Though there have been several well-intentioned attempts to observe WIMPS through many different energy ranges, we have not read of any experiment or observation that one might call success. The search continues, however, with a portion of the high energy time of the CERN facility dedicated to such experiments [48]. More astronomical observations confirming or denying, indirectly, DM are on the horizon, involving hundreds of people [49]. We wonder if the results of these will make any difference to the opinions of astronomers since observations to data of distant galaxies yielding results that both confirm and deny DM are continually reported to this day; the opinions of astronomers seem to be data-independent [50, 51].

Our results from modeling the rotational data of spiral galaxy NGC 3198 resulting from graviton physics are in close agreement to observations. Examination of **Figure 1** and the results in **Table 1** reveals our graviton model to be an excellent description of this galaxy. The results of using this model with the Milky Way data, **Figure 2**, are not nearly as good. This is probably due to two different sources. First, the Milky Way data is quite noisy, which is to be expected since astronomers are collecting information that necessarily travels through densely packed stars and gas clouds. Second, the large number of parameters needed in the mass density model to properly use our graviton model makes it very difficult to properly select the best values for modeling. A more robust mass density model is needed, rather than the rudimentary density of Eq. (16), to better match the density in the Milky Way and other complex spiral galaxies.

Our results from modeling the data from these two galaxies using the Langmuir equation are good, as seen in **Figure 3** and **Table 2**. We do not claim this model properly describes the rotational velocities of either galaxy. It may be of use to astronomers for selecting the best average velocity of stars a fair distance from the galactic center.

Although the fits to the Milky Way rotation data were weak for the graviton model, due to the poor density model, this does not diminish its potential. The graviton model is based on the physical principle that gravitons are bosons and thus should behave like photons in a gravitational field. Gravitons traveling away from a massive source should lose energy due to gravitational redshift just as observed for photons. This process takes place for gravitons within galaxies, between galaxies, and within galactic clusters and throughout the Universe. Taking proper account for gravitons can go a long way to explain dark matter and even dark energy and orbital decay of binary stars [41]. This effect use of the graviton model has been overlooked for nearly a century.

Cosmological Principle Finally, we draw the readers' attention to the commonly ignored fact that there is no evidence for WIMPS on earth (or in our solar system). The bald fact is that the properties required by DM demand WIMPS should be concentrated at the center of the earth. Few have bothered to investigate this obvious requirement; those who have made some observations have not uncovered evidence for this [52]. Dark matter proponents of WIMPS must resort to special pleading that WIMPS are "out there" but not here. This requirement is simply ignoring the cosmological principle. That is, if WIMPS are common in other galaxies including Andromeda, but not in the Milky Way, then the cosmological principle is not true. If so, astronomy is left without any principles at all.

Conflict of interest

The authors declare no conflict of interest.

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Abbreviations

BTFR	baryonic Tully-Fisher relation
CGR	Carmeli general relativity
DM	dark matter
EE	Einstein equation
MACHO	massive astrophysical compact halo object
SNe Ia	supernovae type Ia
SG	spiral galaxy
SM	standard model of particle physics
TF	Tully-Fisher (relationship)
WIMP	Weakly Interacting Massive Particles

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