

## Relativistic Beaming of Gravity and the Missing Mass Problem

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### ABSTRACT

This paper proposes the idea that gravity emanating from a source moving at relativistic speeds should be beamed in the same manner as light. Further, that an array of compact objects in the galaxy resulting from supernovae, primarily stellar mass black holes undergoing relativistic rotation, could thereby concentrate their gravitational force into the stellar plane of the galactic disk. This would make possible speeds in excess of Keplerian limits for stars and gas clouds, especially in the outer portions of the galaxy. I model the galactic disk as a cylinder, and use Gauss's law to derive a  $1/r$  formula for the resulting gravitational force, which I call "directed gravity." This  $1/r$  force could explain the flat rotation curve of the galaxy. Further, the theory of directed gravity is shown to be compatible with the studies of the Bullet cluster, making it superior to the low-acceleration form of MOND, and a viable alternative to Dark matter halos.

*Keywords:* Milky Way dynamics (1051), Gravitation (661), Dark matter distribution (356), Relativity (1393), Mond (1069)

## 1. INTRODUCTION

The problem of the missing mass is to understand why galaxies such as the Milky Way rotate with flat rotation curves and also why galactic clusters do not fly apart, despite the appearance of insufficient mass to maintain those structures. By flat rotation curves, I mean that high surface brightness spiral galaxies tend to rotate in such a manner that the stars and gas move at similar velocities out to the edge of a given galaxy, rather than moving more slowly near the edge as we would expect from Kepler's laws. The easy solution to these problems is to assume that there exists some new kind of matter, termed dark matter, that exists in halos around the galaxies, and which provides the needed mass. The problem with the easy solution is that no one has been able to find or identify this dark matter, despite considerable theoretical and experimental effort over the last 50 years or so. And I really think that Occam would put away his razor and let his beard grow out when told that dark matter halo theory requires about five times more dark matter than normal baryonic matter to explain the flat rotation curves of spirals and the stability of galactic clusters. (Planck Collaboration et al. 2014)

In this paper I will propose a solution to the missing mass problem that differs starkly from dark matter halos. I call it *Directed Gravity*, by which I mean relativistic beaming of the gravitational force. The key idea is that when compact objects such as neutron stars, stellar mass black holes and supermassive black holes rotate at nearly the speed of light, the gravitation they emit is relativistically beamed in new angles as would be light from such a compact object rotating at the same speed. As I will show in this paper, if a compact object rotates relativistically, we should expect the gravitational flux emitted by the compact object to be concentrated in the equatorial plane of the object, rather than being emitted isotropically. Further, as I will show in the discussion below, this will result in a gravitational field that will decrease in the equatorial directions by approximately  $1/r$ , rather than the usual  $1/r^2$ . As I will show below, a  $1/r$  gravitational field can result in a flat rotation curve.

## 2. RELATIVISTIC BEAMING OF GRAVITY

When a light source is moving relativistically, the emitted light experiences relativistic beaming, which is called *the headlight effect*. The widely used text "An Introduction to Modern Astrophysics" by Carroll and Ostlie explains the headlight

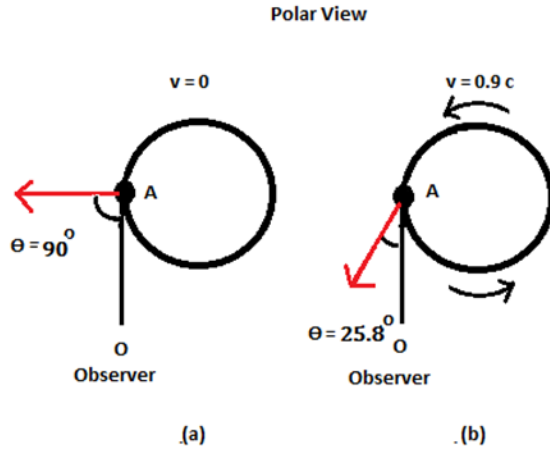
effect using only the facts that light travels at the speed  $c$ , and that light is subject to the formula for the relativistic addition of velocities. No other properties of light are involved. (Carroll & Ostlie 2007, p. 101). But gravity travels at the speed of light,  $c$ , according to Einstein's general relativity, and according to experimental observation as well (Abbott et al. 2017). Further, one should note that the relativistic addition of velocities formula is not a property of light, per se, but is a property of spacetime. Anything that travels through spacetime must be subject to it, including gravity. Thus, we must conclude that gravity must be subject to relativistic beaming, just as light!

It might be argued that gravity does not experience relativistic beaming, because such beaming is a form of aberration, and gravity does not experience aberration. However, gravity does experience aberration! With a little thought, one realizes that the time light effect and aberration both apply to gravity, but we do not readily perceive them because we cannot see the path that gravity takes in the same way that we can see the path of light. Since we know that the gravity originated at the previous (that is, the retarded) position of the source object, we know that the path the gravity took would have been the same path that light would have taken, thus, the time light effect should apply to gravity. And if we were standing on a moving body, such as the earth, looking in the direction of a source of gravity, such as the sun, and if we could see the apparent path of the gravitational force in the same way we can see the apparent path of light, we would undoubtedly perceive gravitational aberration!

The fact that the gravitational force points to the instantaneous position of the object rather than the retarded position does not deny the fact that the gravity travelled from the retarded position. Instead, gravity points to the instantaneous position because gravity has a velocity dependent component. (Carlip 2000)

## 2.1. Relativistically Rotating Compact Objects

Consider a relativistically rotating compact object, that is, a relativistically rotating stellar mass black hole or supermassive black hole, or a neutron star with a core that is relativistically rotating (if such neutron stars exist!). If the compact object were not rotating, we would expect gravitational rays to emit equally in all directions from each point on the compact object. Let us consider a point "A" on the equator of a compact object such that "A" is moving at almost the speed of light,  $c$ , directly toward our observer as in figure 1 below.

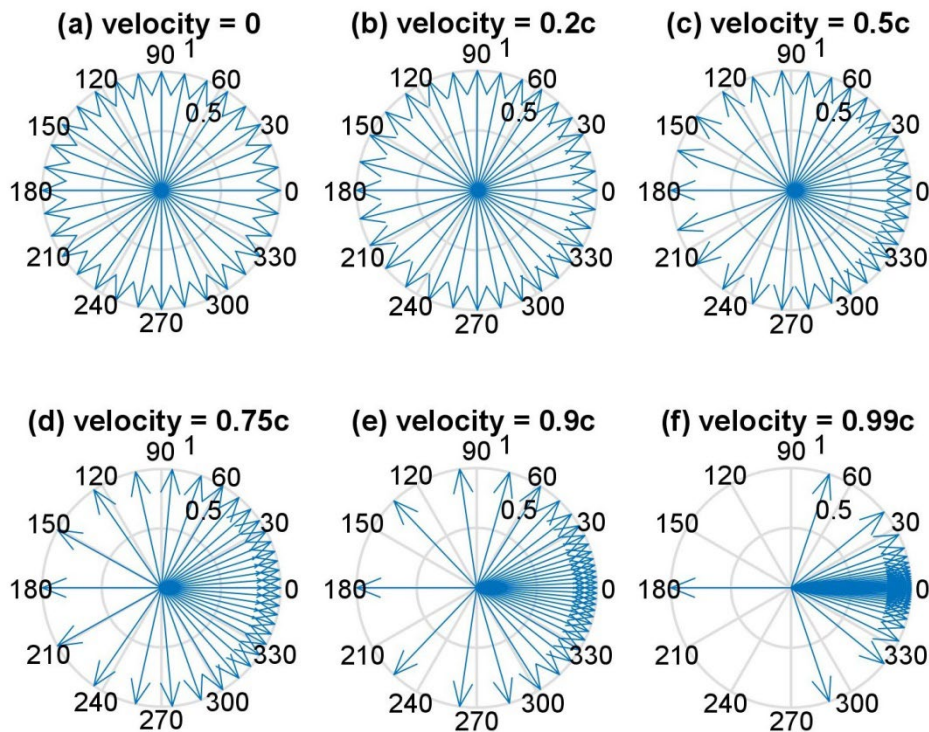


**Figure 1. Consider point “A” on a spherical compact object. In 1(a), the object is not rotating, and emits a ray of gravity at a 90° angle. In 1(b), the object is now rotating at 0.9c. If it emits the same ray of gravity, it will be relativistically beamed to an angle of 25.8°.**

Consider a ray of gravity that would be emitted from point A at the angle  $\theta' = 90^\circ$  if the compact object were not rotating. At what angle  $\theta$  would that ray of gravity be emitted if the object were rotating relativistically at  $0.9 c$ ? To solve this problem, we use Einstein’s relativistic beaming formula. (Einstein 1905). Here, we use the inverse version where  $v$  is replaced by  $-v$  and  $\theta$  by  $\theta'$ .

$$\cos(\theta) = \frac{\cos(\theta') + \frac{v}{c}}{1 + \left(\frac{v}{c}\right) (\cos(\theta'))} \quad (1)$$

If we insert  $\theta' = 90^\circ$  and  $v = 0.9 c$  into the above equation, we obtain the result of  $\theta = 25.8^\circ$ . In other words, a ray of gravity that would have been emitted at  $90^\circ$  will instead be emitted at  $25.8^\circ$ ! Further, rays of gravity emitted from point A in every direction will be relativistically beamed toward the instantaneous direction of  $v$ . Figure 2 illustrates the gravitational beaming from point A for different velocities  $v$ .



**Figure 2.** This figure illustrates the amount of relativistic beaming of gravity for different values of the velocity  $v$ . Figure 2(a) shows that there is no beaming for  $v = 0$ . Figures 2(b) through 2(f) show increasing amounts of beaming for successively higher values of  $v$  as it approaches  $c$ . I created this figure using the compass program from MATLAB® by adjusting the inputted angles using Einstein’s relativistic beaming formula, Eq. 1. The compass program from MATLAB® has copyright 1984-2005 The Mathworks, Inc.

Now, one might argue that the strong gravity in a compact object might change the above result. However, you should note that in general relativity, on the smallest scale, the metric is locally flat and the local manifold will always be Minkowski space. (Hobson et al. 2006, pp. 149, 151). Thus, at the point A where the beaming takes place, the metric will be locally flat, and the beaming will take place according to Einstein’s formula.

### 3. DERIVATION OF THE FORMULA FOR DIRECTED GRAVITY

In this paper we are interested in whether relativistic beaming of gravity could solve the missing mass problem. To that end, we are most interested in compact objects that are rotating at velocities very near  $c$ , and that are additionally rotating such that their angular momentum vectors line up with that of the galaxy. That some such compact objects should exist seems likely, because in recent years researchers have demonstrated stellar alignment in open clusters. (Corsaro et al. 2017, Kovacs 2018). Further, at least one of the two clusters studied by Corsaro showed close alignment with galactic north. (Kamann et al. 2019). Compact objects that are rotating close to  $c$  and are in alignment with galactic north are important in that their directed gravity should mostly stay in the galactic disk, with only very small leakage at the top and bottom of the disk. We will now develop a theory for these particular objects. We will use Gauss's law to develop this theory. By the way, we will need to assume that the mass density of the compact objects is constant for any particular value of the radius  $r$ ,  $r$  being the distance from the central axis of the stellar disk. This will result in the directed gravitational force being a function of  $r$ , such that  $\mathbf{g} = \mathbf{g}(r)$ .

First, we will model the stellar disk of the galaxy as a cylinder. Because the stellar disk is shaped as a cylinder, its outer surface is a closed surface for the purpose of applying Gauss's law of gravity. Thus, by Gauss's law:

$$\oint_S \mathbf{g} \cdot d\mathbf{A} = -4\pi GM \quad (2)$$

The formula is from Simpson (2006), where the left hand side of the equation represents the surface integral of  $\mathbf{g} \cdot d\mathbf{A}$  over the entire surface of the stellar disk's cylinder;  $\mathbf{g}$  being the gravitational acceleration vector while  $d\mathbf{A} = \hat{\mathbf{n}} dA$  is a vector that represents the differential unit of surface area along the outer surface  $S$  of the cylinder, directed outwards.  $M$  is the total mass of the relativistically rotating compact objects described above within radius  $r$  of the central axis of the cylinder and  $G$  is the usual gravitational constant. Note also that  $\hat{\mathbf{n}}$  is the unit normal vector,  $h$  is the height of the stellar disk, and we define  $\bar{G} \equiv 4\pi G$ .

Now, since virtually all of the gravitational flux will exit the sides of the disk, and none at the top or bottom, we have that  $\hat{\mathbf{n}}$  is perpendicular to  $\mathbf{g}$  for the top and bottom of the cylinder. Thus, for the top and bottom, we have:

$$\mathbf{g} \cdot \hat{\mathbf{n}} = 0 \quad (3)$$

So that the top and bottom of the cylinder will not contribute to the integrated surface area, only the outer edge will. Note also that the  $\mathbf{g}$  points in the opposite direction of  $\hat{\mathbf{n}}$  for the outer edge of the cylinder, so that  $\mathbf{g} \cdot \hat{\mathbf{n}}$  will equal  $-g(r)$  around the cylinder's outer edge.

Thus, we have,

$$\begin{aligned} \oint_S \mathbf{g} \cdot d\mathbf{A} &= \oint_S \mathbf{g} \cdot \hat{\mathbf{n}} dA = \oint_S (-g(r))dA \\ &= -g(r) \oint_S dA = -g(r)2\pi rh \end{aligned} \quad (4)$$

And since  $g(r)$  is constant at any particular value of  $r$ , and does not depend on  $A$ , it comes out of the integral. Now, by Eq. 2 and Eq. 4 above, we have:

$$-g(r)\pi 2rh = -4\pi GM \quad (5)$$

Which after simplification gives us our formula for the acceleration  $g(r)$  caused by directed gravity:

$$g(r) = \frac{4\pi GM}{2\pi rh} = \frac{\bar{G}M}{2\pi rh} \quad (6)$$

By multiplying each side of the equation by the test mass  $m$ , we obtain the force equation for directed gravity:

$$F = mg(r) = \frac{\bar{G}Mm}{2\pi rh} \quad (7)$$

$F$  is the force of directed gravity caused by the highly relativistically rotating compact objects that are in alignment with galactic north. The force points toward the center of the stellar disk which is modelled as a cylinder of height  $h$  and radius  $r$ .  $M$  is the mass of the highly relativistically rotating compact objects that are aligned with galactic north and within radius  $r$ , and  $m$  is a test mass. Note that since  $h$  is a constant, the denominator of the force

equation increases by  $r$ , rather than the usual  $r^2$ . Note also that the denominator of the force equation is equal to the area of the outer edge of the cylinder through which the directed gravity passes.

#### 4. COULD DIRECTED GRAVITY FROM THE GALAXY'S SUPERMASSIVE BLACK HOLE EXPLAIN THE MISSING MASS?

We can use our acceleration formula, Eq. 6, derived above to test whether directed gravity from the supermassive black hole at SgrA\* in the center of the galaxy could be the source of the missing mass. That is, could it be responsible for the approximately  $170 \text{ km s}^{-1}$  of rotation speed at the edge of the galaxy that is attributed to missing mass or dark matter. (Kafle et al. 2014, p.10 at figure 8, reading off the circular velocity attributed to the dark halo at approximately 15 kpc.) (de Salas et al. 2019, pp.10 & 11 at figures 3 and 4, reading off the rotation curves at 15 kpc for two different dark halo models.) The mass of the supermassive black hole at SgrA\* has been measured to be  $4.02 \pm 0.16 \times 10^6 M_{\odot}$  (Boehle et al. 2016). I am modelling the stellar disk of the galaxy as a cylinder of radius 50,000 ly and height 1,000 ly. (Coffey 2010; Rix & Bovy 2013). That translates to a radius of  $4.7304 \times 10^{20} \text{ m}$  and a height of  $9.461 \times 10^{18} \text{ m}$ .

First, we will determine the amount of acceleration necessary to create  $170 \text{ km s}^{-1}$  of rotation speed (circular velocity) using the formula for centripetal acceleration,  $a_c$ .

$$a_c = \frac{v^2}{r} = \frac{(170 \times 10^3 \text{ m s}^{-1})^2}{4.73 \times 10^{20} \text{ m}} = 6.11 \times 10^{-11} \text{ m s}^{-2} \quad (8)$$

Now, if all of the measured mass of SgrA\* were rotating at nearly the speed of light, and if it were in alignment with galactic north, then the formula for  $g(r)$  above would apply to SgrA\*. Thus, we will insert the figures for the mass of SgrA\* and the dimensions of the galactic disk into the formula for  $g(r)$ , Eq.6, to determine whether SgrA\* could be the source of the missing mass.

$$g(r) = \frac{4\pi GM}{2\pi r h} = \frac{4\pi(6.67 \times 10^{-11})(7.996 \times 10^{36} \text{ kg})}{2\pi(4.73 \times 10^{20} \text{ m})(9.46 \times 10^{18} \text{ m})} = 2.38 \times 10^{-13} \text{ m s}^{-2} \quad (9)$$

The result of our calculations is that SgrA\* appears to be too small to provide the necessary directed gravity to explain the missing mass. If we divide the calculated acceleration  $g(r)$  by the expected acceleration from missing mass,  $a_c$ , we obtain:



$$\frac{g(r)}{a_c} = \frac{2.38 \times 10^{-13}}{6.11 \times 10^{-11}} = 0.0039 \quad (10)$$

which is clearly inadequate.

So, the conclusion is that the supermassive black hole a SgrA\* probably does not cause the acceleration in the stellar disk attributed to dark matter or missing mass. The supermassive black hole is just too small! However, there are other possible sources of directed gravity in the galaxy: neutron stars and stellar mass black holes that are compact remnants of supernovae. Could the neutron stars or stellar mass black holes be the source of the missing mass?

## 5. COULD DIRECTED GRAVITY FROM NEUTRON STARS OR STELLAR MASS BLACK HOLES EXPLAIN THE MISSING MASS

Our galaxy has probably produced approximately  $10^9$  compact remnants of supernovae consisting of neutron stars and stellar mass black holes. (Branch & Wheeler 2017, p. 597). With neutron stars and stellar mass black holes each more massive than  $1 M_{\odot}$ , this would represent about three orders of magnitude more mass than is present in SgrA\*. Could directed gravity from these compact remnants be the source of gravitational acceleration attributed to dark matter?

### 5.1. Brief Discussion of Neutron Stars and Stellar Mass Black Holes

While neutron stars and stellar mass black holes are the compact remnants of supernovae, neutron stars are believed to result from supernovae of moderate sized stars, while stellar mass black holes would result from supernovae from very large stars. Additionally, the spin of stellar mass black holes is believed to be natal, while neutron star spin is more subject to change from environmental conditions. (Branch & Wheeler 2017, pp. 599, 603) Neutron stars range in mass from about  $1 M_{\odot}$  to  $2 M_{\odot}$ , with the canonical size considered to be  $1.4 M_{\odot}$ . (Branch & Wheeler 2017, p. 598). Stellar mass black holes range from about  $5 M_{\odot}$  to perhaps  $100 M_{\odot}$ , with the canonical size being  $10 M_{\odot}$ . (Branch & Wheeler 2017, p. 602). The outer shells of neutron stars rotate at less than the speed of light, with the fastest discovered so far rotating at 715 Hz (Hessels et al. 2006) which translates to a linear speed at the equator of only  $0.24 c$ . However, the cores of many neutron stars are believed to be composed of neutrons in a superfluid state that rotate at

greater speeds than the stellar surfaces. (Haskell et al. 2018; Haskell & Melatos 2015; Alpar et al. 1984). As for stellar mass black holes, many rotate with spin parameters between 0.7 and 1, which are believed to be relativistic. (Branch & Wheeler 2017, p. 599). For the relative numbers, neutron stars should outnumber stellar mass black holes by about an order of magnitude. (Branch & Wheeler 2017, p. 597)

Clearly, stellar mass black holes are the better candidates for explaining the missing mass problem through directed gravity, because they are known to spin relativistically, while most neutron stars outer shells do not. However, the spin of neutron star cores has not been measured. (Melatos 2012) The cores are believed to be composed primarily of neutrons in a superfluid state, so the question becomes: could those superfluid neutron cores have maintained their natal spin? Especially, could this be true for young neutron stars? (see Melatos 2012) If so, then neutron stars could also contribute to directed gravity.

5.1.2 Could the spin vectors of compact objects be preferentially aligned with the angular momentum vector of the galaxy?

If directed gravity from compact objects is a potential solution to the missing mass problem, the rotation axes of compact objects must exhibit some alignment with the angular momentum vector of the galaxy. Here is an argument that some such alignment should exist.

Most stars and stellar clusters are formed by the gravitational collapse of turbulent molecular clouds. (Corsaro et al. 2017). The precursor stars of most compact objects are most likely created by supernovae in this way. So, the question becomes, if the angular momentum of the galaxy imprints upon the progenitor molecular clouds, does that hold also for the stars, and the resulting compact objects?

Within the last few years, researchers have discovered significant alignment between stars in open clusters. Corsaro et al. (2017) found stellar alignment in two old open clusters NGC 6791 and NGC 6819 using asteroseismology, which is the study of stellar oscillations. And Kamann et al. (2019) found that NGC 6791 rotated in close alignment with its stars, and that the axis was offset by only 14.2 degrees from galactic north. Additionally, Kovacs (2018) found alignment in the

stars of the Praesepe cluster using photometric rotation periods, spectroscopic rotation velocities, and estimated stellar radii. The study of open clusters is important because such clusters can preserve the initial conditions of the progenitor molecular clouds. (Corsaro et al. (2017)). Further, within open clusters there is little interstellar gas and dust to obscure the necessary observations. (Corsaro et al. (2017)). It would be of great interest to perform these studies on giant molecular clouds, of which the 24 most massive host about half of the overall star formation in the Milky Way. (Corsaro et al. 2017) However, these giant molecular clouds are full of gas and dust which prevent direct observations outside of infrared and radio bands. (Corsaro et al. (2017)). So, based on the studies of open clusters, we are left to infer that such alignment also likely exists in giant molecular clouds.

The other issue is whether the angular momentum of the precursor stars imprints upon the compact objects resulting from supernovae. In considering the core collapse of a pre-supernova giant star, Carroll & Ostlie (2007) at p. 584 presented a strong argument that conservation of angular momentum would result in a neutron star with a natal spin period of a few milliseconds. A similar argument could be made for stellar mass black holes resulting from the supernovae of progenitor stars of larger ZAMS mass.

We have argued that there should exist compact objects, primarily stellar mass black holes, that are in alignment with galactic north, and are rotating at speeds close to the speed of light. But exactly how many are in this class, and what is the total mass, is hard to say at this time. But we can speculate!

## 5.2. Missing Mass Calculation with Neutron Stars and Stellar Mass Black Holes

We shall speculate that there is a class of stellar mass black holes and perhaps some neutron stars that rotate at nearly  $c$  and are in close alignment with galactic north, and that their total mass is approximately  $10^9 M_{\odot}$ . The reason for this speculation will become clear as we perform calculations below. Additionally, we will assume that the mass density of this class of neutron stars and stellar black holes is a function of the distance  $r$  to the central axis of the galactic disk, with the

consequence that  $\mathbf{g} = \mathbf{g}(r)$ . Thus, the conditions for our formula for  $g(r)$  are satisfied. Therefore, we can use Eq.6 to figure the acceleration at the edge of the disk due to directed gravity:

$$g(r) = \frac{4\pi GM}{2\pi rh} = \frac{4\pi(6.674 \times 10^{-11})10^9(1.9891 \times 10^{30}kg)}{2\pi(4.73 \times 10^{20}m)(9.46 \times 10^{18}m)} = 5.93 \times 10^{-11}ms^{-2} \quad (11)$$

We can translate that acceleration to circular velocity at the edge of the stellar disk by once again using the formula for centripetal acceleration, Eq. 8, noting that the centripetal acceleration equals the gravitational acceleration.

$$g(r) = a_c = \frac{v^2}{r} \quad (12)$$

That implies:

$$v_c = \sqrt{g(r)r} = \sqrt{(5.93 \times 10^{-11}ms^{-2})(4.73 \times 10^{20}m)} = 167kms^{-1} \quad (13)$$

Of course, 167 km s<sup>-1</sup> is very close to 170 km s<sup>-1</sup> which is the expected value for the circular velocity caused by dark matter at the edge of the stellar disk. So, if our speculation is correct, directed gravity from neutron stars and stellar mass black holes that are rotating at nearly  $c$  and are in close alignment with galactic north could explain the missing mass problem for the galaxy.

### 5.3. Plotting a Circular Velocity Curve for Directed Gravity

We would like to plot the circular velocity for each value of  $r$  within the stellar disk and also beyond the edge of the disk. However, we first need to know whether directed gravity from compact objects outside of the radius  $r$  will affect the gravitational field at  $r$ . It turns out that for a cylindrically shaped stellar disk, with  $\mathbf{g}=\mathbf{g}(r)$ , the directed gravity from the compact objects outside of the radius  $r$  cancels out to zero. As my reviewer pointed out, the proof of this for directed gravity is very similar to the proof for Newtonian gravity, with opposed angles in directed gravity corresponding to opposed solid angles in Newtonian gravity. You can find the proof on my website at [www.directedgravity.com](http://www.directedgravity.com).

Thus, to compute the acceleration at each value of  $r$  within the stellar disk, we simply need to apply the formula for  $g(r)$ , Eq. 6, keeping in mind that the value for  $M = M(r)$  will be a function of  $r$ , in that  $M$  will be the mass of the compact objects

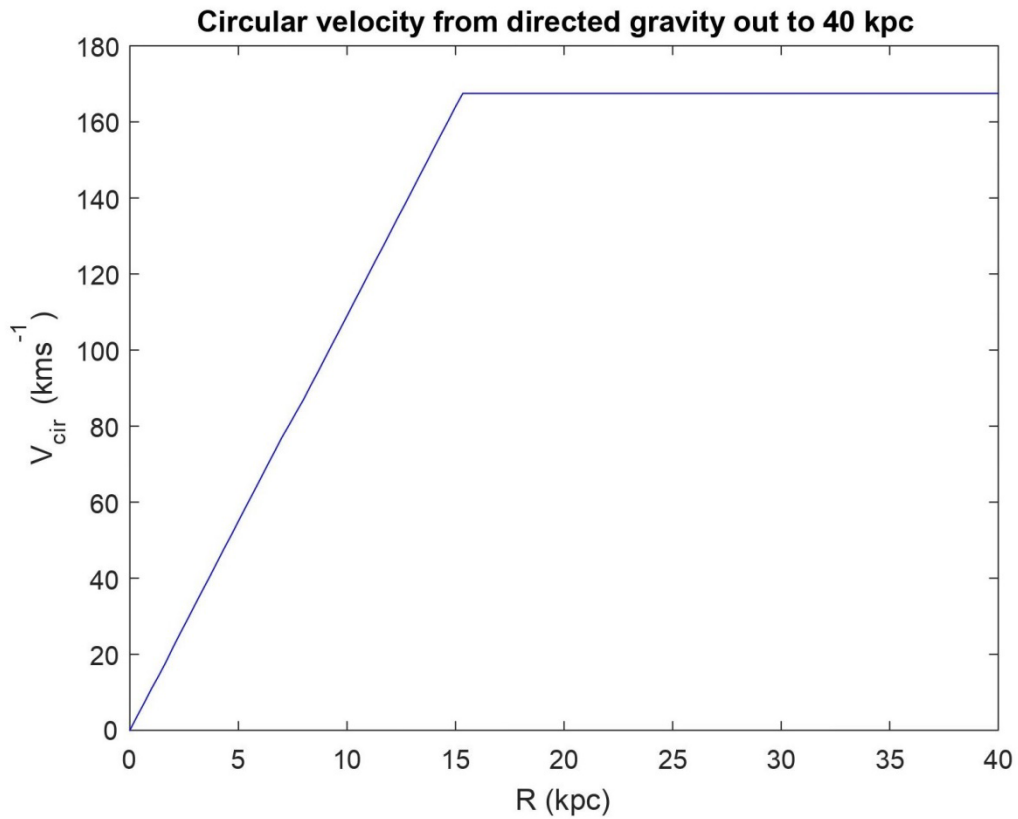
that are within the distance  $r$  of the central axis, and of course are rotating at near  $c$  and in alignment with galactic north. A further complication is that finding  $M(r)$  will be difficult unless we know how the mass density of our class of compact objects varies with  $r$ . To make the calculation possible, we will assume for this particular diagram that the mass density of our class of neutron stars and stellar mass black holes is uniform throughout the stellar disk.

After obtaining  $g$  for each value of  $r$ , we will compute each value for the circular velocity,  $v_c(r)$ . Note that beyond the edge of the stellar disk, that is, beyond about 15 kpc,  $M$  will be a constant. Thus, beyond the disk,

$$v_c = \sqrt{g(r)r} = \sqrt{\frac{4\pi GM}{2\pi h}} \quad (14)$$

$$= \sqrt{\frac{4\pi(6.674 \times 10^{-11})10^9(1.9891 \times 10^{30}kg)}{2\pi(9.46 \times 10^{18}m)}} = 167 \text{kms}^{-1}$$

Thus, we have the following graph for the contribution to circular velocity by directed gravity, where we have made the additional assumption of uniformity of the mass density of our special class of compact objects throughout the stellar disk.



**Figure 3. This figure shows the circular velocity curve of directed gravity in the Milky Way Galaxy from the special class of compact objects, assuming that their mass density is constant throughout the stellar disk, and that their total mass is  $10^9 M_{\odot}$ . Once the edge of the stellar disk is reached at approximately 15 kpc, the curve flattens out to a constant value of  $167 \text{ kms}^{-1}$ .**

You may note that this graph looks very similar to the dark halo contribution to circular velocity from figure 3 of Sofue et al (2009).

## 6. CONCLUDING REMARKS

### 6.1. The Bullet Cluster

In a celebrated paper, Clowe et al. (2006) determined that observations of the Bullet Cluster were inconsistent with modified Newtonian dynamics, (MOND), and claimed that this presented direct empirical evidence of dark matter. During the collision of two clusters, the stellar components and the X-ray emitting plasma were essentially segregated. However, gravitational lensing maps did not trace the plasma, which was the dominant baryonic component, but instead approximately traced the distribution of galaxies. (Clowe et al. 2006). Do these results contradict the theory of directed gravity? The answer is “No.” Directed gravity comes from stellar mass black holes and supermassive black holes that would have stayed with the distribution of galaxies, along with the stars, and would not have been stripped off by ram pressure to join the X-ray emitting plasma. Thus, the observations of the Bullet Cluster, although perhaps indeed disproving MOND, are consistent with directed gravity.

### 6.2. General Conclusion

In this paper we have endeavored to show that gravitation should be subject to relativistic beaming in the same manner as light, and that we can calculate the amount of beaming by applying Einstein’s relativistic beaming formula. As a practical matter, relativistic beaming of gravity will be most easily observed with regards to rotating compact objects such as stellar mass black holes and supermassive black holes. Directed gravity from such compact objects should result in an increased concentration of gravitational flux in the equatorial planes of such objects.

Concentration of gravity in a plane, in particular, in the stellar plane of the galaxy, suggests the possibility of directed gravity providing an efficient solution to the missing mass problem. Thus, we developed a theory for compact objects that are in close alignment with galactic north. We used Gauss’s law of gravity to derive Eq. 6 and 7 for the gravitational force and acceleration due to directed gravity from this class of compact objects.

Using this theory, we considered whether directed gravity from the central supermassive black hole in the galaxy at SgrA\* could be responsible for the additional gravitation attributed to missing mass, but we determined that SgrA\* was just too small.

We next considered the possibility that compact objects from supernovae: stellar mass black holes or neutron stars, could provide the necessary directed gravity. We made a speculation: that the combined mass of stellar mass black holes that were rotating at nearly  $c$ , along with any neutron stars with cores rotating at nearly  $c$ , and which compact objects were also in alignment with galactic north, equaled approximately  $10^9 M_{\odot}$ . With that speculation, we were ready to apply the formula for acceleration of directed gravity at Eq. 6.

The result of that calculation showed that the directed gravity from these compact objects could result in a contribution to the circular velocity at the edge of the galaxy of  $167 \text{ km s}^{-1}$ , which is very close to the expected  $170 \text{ km s}^{-1}$  from missing mass. (Eq.12)

By making a further assumption, that the mass density of this special class of compact objects was uniform throughout the stellar disk, we were able to calculate the circular velocity at each value of  $r$ . Thus we proceeded to plot a circular velocity curve for directed gravity for each value of  $r$  within the stellar disk, and extended the curve to 40 kpc. (Fig. 3) We noted the similarity between the curve we derived for circular velocity from directed gravity and the expected dark halo circular velocity curve from Sofue et al. (2009).

I think in time directed gravity will be recognized as the solution to the missing mass problem. But at present we must speculate as to the total mass of compact objects that are in the special class, so more work needs to be done. Nevertheless, we have suggested a viable theory that could efficiently explain the missing mass problem without increasing the mass of the universe by a factor of five as required for dark matter halos. Further, our theory surpasses the low-acceleration form of MOND as it is compatible with the observations of the Bullet Cluster.

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