Black Holes Leak at the Poles: *Solving the Mass Injection Problem of Astrophysical Jets by using Directed Gravity*

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ABSTRACT

Astrophysical jets emitted at the poles of many black holes are difficult to explain because the gravitational force is presumed too powerful to allow for the escape of massive particles from the hole. However, if Directed Gravity (relativistic beaming of the gravitational force) applies to black holes, then the gravitational force in the polar directions should be reduced, allowing the pressure differential to overcome gravity, such that jets of superfluid neutrons can escape the black hole at the poles.

I first apply the theory to neutron stars, and then apply it to black holes. I will calculate the expected jet speed for a canonical neutron star, as well as for the jets of the stellar mass black hole Cygnus X-1, and the supermassive black hole M-87*. I rely on my paper "Relativistic Beaming of Gravity and the Missing Mass Problem," Thejournalofcosmology.com, Vol.26, No. 27. I also rely on my paper "A Proposed Unification of Neutron Stars and Black Holes," which is available at my website at Directedgravity.com.

Keywords: Black Holes, Neutron Stars, Astrophysical Jets, Directed Gravity, No Hair Theorem.

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1. Introduction

Without doubt, incorrect assumptions have at times held back the progress of science. For example, the assumption that the Earth is the center of the Universe, that everything rotated around the Earth, persisted for millennia. A complex and ultimately useless theory of Epicycles was developed to explain the occasional retrograde motion of Planets. It was not until Copernicus set aside the incorrect assumptions of the Geocentric model, and Galileo followed up with observations of Jupiter's moons, that science was able to progress on that issue.

The current problem of explaining astrophysical jets is extremely difficult to solve. This is especially true for Active Galactic Nuclei, AGNs, which are believed to contain Supermassive Black Holes (SMBHs). The Jets appear to originate at or near the rotational poles of the SMBHs. However, the jets from SMBHs are not believed to originate inside the SMBH, because of certain well-accepted assumptions, one of which is the No-Hair Theorem, and another is the implicit assumption the gravitational force emitted from an object is generally isotropic. These two assumptions will turn out to be of questionable validity, but together, they make it almost impossible to explain astrophysical jets from black holes.

The modern approach is to say that only Poynting flows escape the black hole, which would be possible because they are only electromagnetic and do not contain massive particles, and thus do not violate the No-Hair Theorem. (Romero & Gutierrez, 2020). Then, somehow, outside of the black hole, mass is injected into the Poynting flows, resulting in an astrophysical jet. Here is where the difficulties arise. Many different attempts are made to explain the injected mass, none of which are very convincing, or which can be made quantifiable. (Romero & Gutierrez, 2020). Processes which are poorly understood and not very quantifiable, such as the Blandford-Znajek process, are invoked as attempted explanations. All the while, one of the most powerful engines in the universe, the black hole itself, is not allowed to participate directly in the process, because of the widely held assumptions such as the No-Hair Theorem and the generally isotropic nature of gravity.

In this paper I will set aside these unjustified assumptions. Doing so will result a relatively simple and easily understood theory, which will explain how astrophysical jets originate inside neutron stars and black holes and are emitted from the poles of these compact objects. This theory should lead to quantifiable results and predictions, and should help science progress.

2. The Assumptions

Assumption #1: The No-Hair Theorem

The first assumption which prevents us from finding the solution to astrophysical jets is the No-Hair Theorem, as it is presently understood. Originally, the No-Hair Theorem meant only that the event horizon of a black hole would remain a smooth surface. Thus, any ripples or imperfections in the event horizon would eventually disappear such that the event horizon would remain smooth and even. (i.e., the surface would have no "hair.") (See Thorne, K.S. 1994). It has long been believed that no particles of matter can exit a black hole, because of the extreme gravity. However, this belief has been wrapped into the No-Hair Theorem such that these days the No-Hair Theorem means that no matter particles can escape the black hole, or alternatively, that black holes can be characterized by only three parameters, mass, charge, and angular momentum. (Mavromatos, N. E. 1996) Of course, the gravitational and electromagnetic forces readily escape black holes, as they are not covered by the No-Hair Theorem.

It is generally conceded that the No-Hair Theorem has never been proven for black holes. Thus, it is called by mathematicians the "No Hair Conjecture." (Mavromatos, N. E. 1996). As such, it is basically an assumption. If one believes in the strong version of the No-Hair Theorem, then of course the massive particles of astrophysical jets could not originate inside the black hole. However, there is good reason to believe the strong version of the No-Hair Theorem is false, as you will see in the following discussion of the assumption of isotropic gravity.

Assumption #2: The Gravitational Force is Generally Isotropic

This generally unstated assumption has been believed for so long that many of us are undoubtedly unaware we are making it! It comports with our usual observations, and it is hard to think of any reasons not to believe it is true. Of course, the Kerr solution for a rotating spherical object is not isotropic, but is instead axisymmetric. This fact should make us receptive to the idea that gravity can be other than isotropic. There is a situation where the emission of the gravitational force is very far from isotropy, which I will explain below.

If an object is approaching us at velocity approaching the speed of light, it is well known that light emitted by the object is relativistically beamed in our direction. (Carroll et al., 2006, p.101) Thus, the angles of emission, as measured in the reference frame of the relativistically moving object, become smaller according to us in our reference frame, such that the light is correspondingly of higher intensity (brighter). (Carroll et al., 2006, p.101)

Why should not the same effect of relativistic beaming apply to gravity? If we look at the angles at which gravity is emitted from a relativistically approaching object, should they not also become smaller from our point of view? In general relativity, does not the existence of inertial frames imply that, at least on the smallest scale, the metric must be the Minkowski metric? (see Hobson et al, 2006, p.1) So, if we are looking at the point of emission of gravity, the tiniest scale is relevant, and the emission angle should be well-defined, and that angle should be reduced from our perspective, just as it is with light. Thus, relativistic beaming should apply to gravity as well as light. This effect is more carefully argued in my paper, “Relativistic Beaming of Gravity and the Missing Mass Problem,” (Blake, B.C. 2022)

If relativistic beaming of gravity does exist, then the gravitational force from a relativistically moving object is not emitted isotropically from the point of view of stationary observers such as ourselves. Instead, emission is concentrated in the direction of the observer. Of course, any physical effect is ultimately determined by observation and experiment. But logic, and the need for consistency between the Special and General Theories, indicates that relativistic beaming of gravity probably exists.

Why Relativistic Beaming of Gravity Matters

When would relativistic beaming of gravity be observable, and why would it matter? As a practical matter, relativistic beaming of gravity, which I also call “Directed Gravity,” should become apparent for certain compact objects such as neutron stars and black holes. If such a compact object is rotating such that an appreciable portion of its mass is moving with relativistic speeds as seen by an outside observer, then the gravitational force emanating from that mass should experience relativistic beaming. Simple geometrical arguments show that the gravity will be beamed into the rotational plane of the compact object. (Blake, B.C. 2022). The beaming will strengthen the gravitational force felt by objects in the rotational plane, and weaken that force felt by objects outside the plane. The force will be weakest in the polar directions.

If relativistic beaming of gravity does occur, as I believe it must, then directed gravity becomes the exception to the generally isotropic nature of gravity as is widely assumed. This anisotropy of gravity becomes very important. It may explain the failure of Kepler’s Laws to describe the outer motions in galaxies, i.e., the *missing mass problem.* (Blake, B.C. 2022). Thus, relativistic beaming of gravity will be essential to understanding the structure and stability of galaxies, as well as the stability of galaxy clusters. But for the topic of this paper, directed gravity will be necessary for understanding how beams of massive particles can escape the interiors of neutron stars and black holes in the form of relativistic jets.

3. Directed Gravity as Applied to Neutron Stars

Neutron stars are degenerate objects that result from the collapse of giant stars. They are believed to contain a core which is composed primarily of degenerate neutrons in a superfluid state. (Carroll & Ostlie, 2006, p.583). Superfluids are irrotational, so for the core to rotate, vortices are believed to form in the neutron superfluid, each of which would provide a quantized amount of rotation. (Guenault, 2002, pp. 43-49). In this paper, I adopt this commonly held view of neutron star rotation.

The superfluid theory of neutron star rotation is important to directed gravity. Suppose a neutron star were a solid object that did not contain a superfluid core. Then the maximal rotation would occur only at the outer edges of the equator. Thus, if relativistic rotation were present, it would likely only occur there, so that the mass exhibiting directed gravity would be minimal. However, because the core is believed to be a superfluid, the maximal rotation will occur around each vortex throughout the core, greatly increasing the mass subject to relativistic rotation and directed gravity, especially if the core is a significant portion of the neutron star.

Neutron Star Hydrodynamics

Before presenting the mathematical derivations, I wish to provide a general outline of our approach. We will use a Newtonian derivation for the hydrodynamical situation, because that will best illustrate the interplay of forces at work. Of course, for a calculation with greater precision, one should follow up with a calculation using relativistic hydrodynamics. We will assume the neutron star is hydrodynamically stable, with the force of gravity balancing the pressure at each point of the star, except for any effects of directed gravity. We are interested in the core of the star, which we consider to be composed of superfluid neutrons relativistically rotating around vortices which extend in the polar directions. The relativistic rotation will cause directed gravity, which will increase the gravitational force in the equatorial plane of the star, but will correspondingly decrease the gravitational force in the polar directions. (Blake, B.C. 2022). The decrease in gravity will cause the pressure differential to overcome the gravitation, causing acceleration of a stream of superfluid neutrons in the polar directions. Since a superfluid generally exhibits no friction (as long as it does not exceed a critical Landau velocity) (Guenault, 2002, p.17), we can easily calculate the velocity of the stream of neutrons as it exits the poles of the neutron star.

Of prime importance will be the state of the vortices in the core. Should the vortices be tangled, we can expect the star to have no jet. But if they are parallel, or have merged, then we should expect to see a jet.

Mathematical derivation of Neutron Star Hydrodynamics

Stable stars, including neutron stars, are expected to satisfy the condition of hydrostatic equilibrium. (Carroll & Ostlie, 2006, p.287). Such a neutron star will have a balance between the gravitational force at radius r and the pressure differential at that same radius. The equation which expresses this balance is:

$$\frac{dP}{dr} = -G\frac{M_r \rho}{r^2} = -\rho g \tag{1}$$

(Carroll & Ostlie, 2006, p.287)

Where P is the pressure, r is the radius, G the gravitational constant, M_r , is the enclosed mass at that radius, ρ is the density, and g is the gravitational acceleration at r caused by the enclosed mass M_r.

However, in this paper I propose that directed gravity will cause decreased gravitational force in the polar directions. Assuming that the neutron star is otherwise stable, we can use the precursor equation to the equation of hydrostatic equilibrium to estimate with what velocity the beam of particles will exit the surface of the neutron star. That precursor equation is:

$$\rho \frac{d^2r}{dt^2} = -G\frac{M_r\rho}{r^2} - \frac{dP}{d\rho} \qquad (2)$$

(Carroll & Ostlie, 2006, p.286)

Where d^2r/dt^2 will be the acceleration of the beam of particles. Note that we do not need to insert a term for friction on the right- hand side, because the superfluid neutrons are presumed frictionless.

So, the plan will be to take a neutron star of characteristic size and mass, make assumptions about how fast the superfluid core is rotating, and calculate an estimate for the velocity of the resulting beam of matter. We want to see if the resulting velocity would be relativistic.

We will consider a canonical neutron star of mass, $M_{NS} = 1.4M_\odot$, and radius, R = 10 km. The first thing we must determine is an estimate of the central pressure. To do so, we will make the unrealistic assumption that the density, ρ, is constant. This same procedure is followed in Carroll and Ostlie. This will simplify the math, and it is a conservative assumption that will likely underestimate both the central pressure and the exit velocity of the beam of particles. With the assumption that the density is constant, the equation for estimating the central pressure for a star, here a neutron star, is:

$$P_c \approx \frac{2}{3}\pi G\rho^2 R_{NS}^2 \qquad (3)$$

(Carroll & Ostlie, 2006, pp.492, 559)

For $M_{NS} = 1.4M_\odot$ and R = 10 km, we use the relation ρ= M/V to obtain $\rho = 6.648 \times 10^{17}$kg m^{-3}. Then using equation (3) above, we obtain for the central pressure:

$$P_c \approx 6.1780\ \times 10^{33} Nm^{-2}$$

Next, we need to estimate dP/dr, given the assumptions that ρ is constant, and P=0 at the surface of the neutron star. We do this as follows:

$$\frac{dP}{dr} \approx \frac{\Delta P}{\Delta r} = \frac{P_s - P_c}{r_s - r_c} = \frac{0 - P_c}{r_s - 0} = -\frac{P_c}{R_{NS}} \qquad (4)$$

And we insert the numbers to get:

$$\frac{dP}{dr} \approx -\frac{P_c}{R_{NS}} = \frac{-6.1780 \times 10^{33} Nm^{-2}}{10{,}000\ m} = -6.178 \times 10^{29} Nm^{-3} \qquad (5)$$

Where P_s is pressure at the surface, P_c is pressure at the center, r_s is radius at the surface, and r_c is radius at the center.

Next, we need to determine g, the gravitational acceleration resulting from the enclosed mass. From equation (1) above, we see that:

$$g = G\frac{M_r}{r^2} \qquad (6)$$

Now we need to take equation (2) and divide each term by ρ. The result is as follows:

$$\frac{d^2r}{dt^2} = -G\frac{M_r}{r^2} - \frac{1}{\rho}\frac{dP}{dr} \qquad (7)$$

Now set $d^2r/dt^2 = 0$, which is the condition of equilibrium. In other words, we are assuming that but for directed gravity, the neutron star is stable. This results in the following equation:

$$g = G\frac{M_r}{r^2} = -\frac{1}{\rho}\frac{dP}{dr} \tag{8}$$

But $g = GM_r r^{-2}$. Now, by inserting $\rho = 6.648 \times 10^{17}$ kg m^{-3} and $dP/dr \approx -6.178 \times 10^{29}$ N m^{-3}, each computed above, we obtain:

$$g = G\frac{M_r}{r^2} = -\frac{1}{\rho}\frac{dP}{dr} = 9.293 \times 10^{11} N\ kg^{-1} = 9.293 \times 10^{11} m\ s^{-2} \tag{9}$$

Note that g is the effective gravitational acceleration at radius r. Of course, in this case, due to our assumption of constant density, g is constant for all r such that $R_{NS} \geq r > 0$.

We are nearly ready to apply equation (2), the precursor to the equation of hydrostatic equilibrium, to determine the exit speed of the beam of particles. But first, we must estimate to what extent the gravitation is reduced in the polar directions. This will depend on how fast is the state of rotation in the superfluid core. Let us assume an *ansatz* for the purpose of definiteness that the core rotates at 0.9c.

We will make our estimate by examining Figure (2) from my paper "Directed Gravity and the Missing Mass Problem," (Blake, B.C. 2022). Figure (2) (reprinted below as Figure (1)) illustrates the amount of relativistic beaming of gravity for different velocities of v, and is based upon Einstein's formula for relativistic beaming of light. We can estimate the reduction of gravitational force in the polar direction at 0.9c by comparing Figure 1(a) and 1(e). Simple inspection shows about 6 force arrows between 60° and 120° for Figure 1(a), with no beaming, while one sees about 2 force arrows between the same two degrees for Figure 1(e), for v = 0.9c. Projecting to the surface, we would have 36 force arrows in the first case, and 4 force arrows in the second. Since 36 / 4 = 9, we expect the gravitational force in the polar direction to be about 1/9th as strong for the v = 0.9c case than if the gravitation were isotropic.

Figure 1

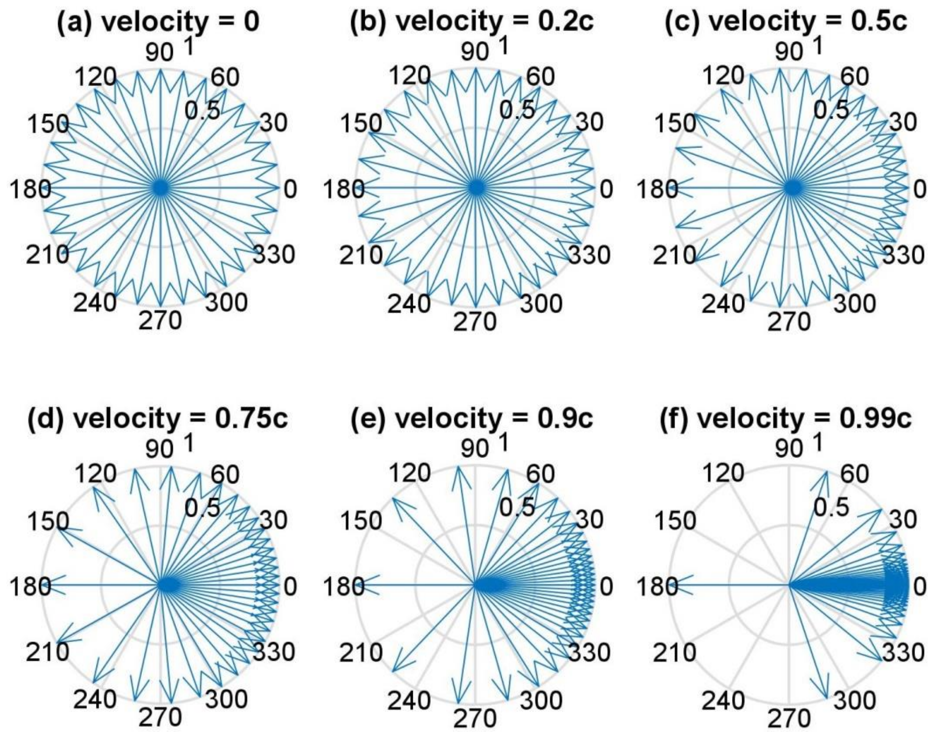

Figure 1. This figure illustrates the amount of relativistic beaming of gravity for different values of the velocity *v.* Figure 1(a) shows that there is no beaming for *v* = 0. Figures 1(b) through 1(f) show increasing amounts of beaming for successively higher values of *v* as it approaches *c.* The figure is taken from Blake, B.C. 2022, and is reprinted with permission of the publisher, The Journal of Cosmology.   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, we look once again at the precursor equation, eq. (2):

$$\frac{d^2r}{dt^2} = -G\frac{M_r}{r^2} - \frac{1}{\rho}\frac{dP}{dr}$$

The left-hand side represents the acceleration of the neutron superfluid in the core. The first term on the right-hand side is the acceleration due to gravity, while the second term is the acceleration due to the pressure differential. But we have concluded that, because of directed gravity, the gravitational term should be reduced, in this case, by a factor of 1/9th. Thus, for this problem, the equation should read:

$$\frac{d^2r}{dt^2} = -(\frac{1}{9})G\frac{M_r}{r^2} - \frac{1}{\rho}\frac{dP}{dr} \tag{10}$$

Then, by eq. (8), we have:

$$\frac{d^2r}{dt^2} = -\left(\frac{1}{9}\right)g + g = \frac{8}{9}g \tag{11}$$

Which simplifies to:

$$\frac{d^2r}{dt^2} = \frac{8}{9}(9.293 \times 10^{11} m\ s^{-2}) = 8.260 \times 10^{11} m\ s^{-2} \tag{12}$$

Thus, we have determined the acceleration toward the poles for a beam of superfluid neutrons in this case to be $8.260 \times 10^{11} m\ s^{-2}$.

Calculation of the Velocity of the Polar Beams

Now, we can calculate the exit velocity of the beams at the surface of the neutron star. We wish to determine whether the beams will be relativistic. We start by integrating the acceleration with respect to time.

$$v(t) = \int \frac{d^2r}{dt^2}dt + v_0 \tag{13}$$

But $v_0 = 0$. So, inserting the value for the acceleration gives:

$$v(t) = \int 8.260 \times 10^{11} m\, s^{-2}\, dt = 8.260 \times 10^{11}\, t \tag{14}$$

Next, we will calculate the distance in terms of t by integrating our expression for v(t).

$$d = \int v(t)dt + d_0 \tag{15}$$

But $d_0 = 0$. Inserting the value of v(t) gives:

$$d = \int 8.260 \times 10^{11} t dt = 4.13 \times 10^{11} t^2 \tag{16}$$

Now, we find t for $d = R_{NS} = 10{,}000\, m$.

$$10{,}000\, m = 4.13 \times 10^{11} t^2 \tag{17}$$

Which yields:

$$t = 1.56 \times 10^{-4} s \qquad (18)$$

Now that we have the time when the beam reaches the surface of the neutron star, we can easily determine the velocity at that time.

$$\begin{gathered} v(t) = 8.260 \times 10^{11} t = 8.260 \times 10^{11} (1.56 \times 10^{-4} s) \\ = 1.29 \times 10^{8} m s^{-1} = 0.43c \end{gathered} \qquad (19)$$

Thus, we found that a canonical neutron star, for which the superfluid neutron core was rotating at 0.9 c, could emit jets of superfluid neutrons from each pole with velocity 0.43 c, based on the theory of directed gravity.

4. Directed Gravity Applied to Black Holes

We can apply the theory of directed gravity to black holes in a similar manner as for neutron stars. I take this approach for several reasons. Firstly, it is possible that black holes in the real world are just neutron stars that are entirely enclosed by their Schwarzschild radius. (Blake,B.C., 2021) Of course, this idea is contrary to the usually accepted picture of a black hole containing a singularity. Both of these ideas rely on Dr. Penrose's work on trapped surfaces, the difference being that singularities depend on the assumption that gravitational collapse continues beyond the neutron star stage, while I surmise that such collapse stops at the neutron star stage.

So, I follow my theory of unification of neutron stars and black holes from Blake, B.C. 2021, because firstly, it may be true, but secondly, it makes possible the use of the same techniques we used above in the calculation of the speed of jets from black holes. Note also that it will predict that black hole jets begin as beams of superfluid neutrons, which will become visible once the neutrons begin to decay into protons and electrons, allowing for the production of synchrotron radiation if magnetic fields are present.

To apply the theory of directed gravity to black holes, we will first calculate the size of the presumed enclosed neutron star. We will presume that all neutron stars have approximately the same average density; so, we will use the density of the canonical neutron star in our calculations. Then we will take the observed mass of the black hole, and make that equal to the mass of the enclosed neutron star, which is consistent with our approach that black holes are just neutron stars inside their Schwarzschild radius. With the given mass and density, we can then calculate the radius of the enclosed neutron star. This gives us all of the information we need to calculate the velocity of the jet in the same manner we did for neutron stars.

4(a) Applying Directed Gravity to Cygnus X-1

Cygnus X-1 is a galactic X-ray source that is believed to be a stellar mass black hole. It's distance from Earth has been recently reexamined with the conclusion that it is further away than previously believed. This causes a reassessment of its mass, with the latest mass determination of 21.2 $M_\odot$. (Miller-Jones et al. 2021)

Applying the analysis described above, we first find the radius of the presumably enclosed neutron star, R_{NS}. Once again presuming that all neutron stars have approximately the same density, $\rho = 6.648 \times 10^{17} kg\ m^{-3}$, we can divide the mass, 21.2 $M_\odot$, by the density ρ, above, to get the volume, $V = 6.343 \times 10^{13}\ m^3$, which by using the usual formula for the volume of a sphere, implies that $R_{NS} = 24.74\ km$.
We then use (3) to determine the estimate of the central pressure, $P_c \approx 3.77 \times 10^{34} Pa$, and (4) to obtain dP/dr ≈ $-1.53 \times 10^{30} N\ m^{-3}$. We further determine using (8), that $g = 2.30 \times 10^{12} m\ s^{-2}$. Finally, by using (11), we determine that the acceleration of the neutron jet is $\frac{d^2r}{dt^2} = 2.04 \times 10^{12} m\ s^{-2}$.

With the acceleration of the jet, we can use simple calculus to find that the velocity of the jet equals 1.06 c. This confirms that the velocity is relativistic. Of course, the actual velocity must be less than c, but we can use this result to estimate the gamma factor. We do this by imagining a Universe that has a speed limit either much larger than c, or has no speed limit. We will calculate the Newtonian kinetic energy for that Universe. Then, we will set the result equal to the relativistic kinetic energy in our Universe, and solve for γ.

$$KE = \frac{1}{2}mv^2 = 1/2m(1.06c)^2 \tag{20}$$

$$KE_{rel} = (\gamma - 1)mc^2 \tag{21}$$

Setting $KE = KE_{rel}$, and solving for γ, yields γ ≈ 1.56.

4(b) Applying directed gravity to M87

M87 is a giant Elliptical galaxy in the Virgo cluster. It contains a supermassive black hole from which extends a visible blue jet. We will use the theory of directed gravity to obtain an estimate of the speed of the jet, in particular, to determine if it should be relativistic.

For the mass of M87*, the supermassive black hole, we use $7.22 \times 10^9 M_{\odot}$. (Miller-Jones et al. 2021) For density of presumed enclosed neutron star, we once again use by assumption the density of a canonical neutron star, $\rho = 6.648 \times 10^{17} kg\ m^{-3}$. For the volume of the enclosed neutron star, we get $V = \frac{m}{\rho} = 2.16 \times 10^{22}\, m^3$. This results in a radius of the enclosed neutron star, $r_{NS} = 1.73 \times 10^7 m$. Using these figures we then compute the approximate central pressure, P_c:

$$P_c \approx \frac{2}{3}\pi G \rho^2 R_{NS}^2 = 1.85 \times 10^{40} P_a \tag{22}$$

We then obtain,

$$\frac{dP}{dr} \approx -\frac{P_c}{R_{NS}} = -1.07 \times 10^{33} N\, m^{-3} \tag{23}$$

And for gravitational acceleration, g, of the superfluid neutron stream,

$$g = -\frac{1}{\rho}\frac{dP}{dr} = 1.61 \times 10^{15} m\, s^{-2} \tag{24}$$

Once again, we will presume an ansatz for definiteness that the linear rotation speed around the vortexes in the core of the enclosed neutron star is about 0.9 c. This will result in a reduction of the gravitational term in (7) of 1/9, as shown above.

$$\frac{d^2 r}{dt^2} = -(\frac{1}{9})G\frac{M_r}{r^2} - \frac{1}{\rho}\frac{dP}{dr} \tag{25}$$

Then, by (11), we have:

$$\frac{d^2 r}{dt^2} = -\left(\frac{1}{9}\right)g + g = \frac{8}{9}g \tag{26}$$

We then obtain for the net acceleration of the jet:

$$\frac{d^2r}{dt^2} = \frac{8}{9}(1.61 \times 10^{15} m\ s^{-2}) = 1.43 \times 10^{15} m\ s^{-2} \tag{27}$$

Once again, we use simple calculus to obtain the velocity of the jet while within the enclosed neutron star:

$$v(t) = \int \frac{d^2r}{dt^2} dt = 1.43 \times 10^{15} t \tag{28}$$

The distance from the center, while in the enclosed neutron star, is:

$$d = \int v(t) dt = 7.14 \times 10^{14} t^2 \tag{29}$$

The time it takes to reach the surface of the enclosed neutron star is:

$$t = 1.56 \times 10^{-4} s \tag{30}$$

And the resulting velocity at the surface of the enclosed neutron star is:

$$v(t) = 2.22 \times 10^{11} m\ s^{-1} = 742\ c \tag{31}$$

This is of course much faster than the speed of light. We can conclude that the Newtonian calculation of the speed of the jet indicates that it is likely relativistic, although it could not actually exceed the speed of light. We can estimate the γ factor, as we did for Cygnus X-1. The result is: $\gamma \approx 2.8 \times 10^5$, which is also very high. We will discuss how to improve these calculations in the conclusion.

5. Comparison with Observations

5(a) Neutron star

For a canonical neutron star, we calculated a jet speed of 0.43 c, which we pointed out should be an underestimate. We can compare that result with the observed estimates of the jet speed of the pulsar in the Light House Nebula, estimated at 0.8 c, (Pavan et al. 2014) and the jet speed of the Vela Pulsar, estimated at 0.9 c. (Durant et al., 2013 at p. 771). Of course, both of these pulsars are young neutron stars, which resulted from supernova that occurred during human history. It might be appropriate to choose a higher ansatz for the speed of rotation of the core than the 0.9 c that I used in my calculations when modelling young neutron stars such as these.

5(b) Cygnus X-1

For the stellar mass black hole Cygnus X-1, we calculated a jet speed of 1.06 c, which is slightly more that the speed of light, which is a relic of our use of Newtonian hydrodynamics. However, we estimated that the gamma factor should be about 1.56. Because the jets of Cygnus X-1 are dark, I am not aware of observations of the jet speed, except that the jets are believed to be relativistic. We know that there are jets, however, because they impact with the interstellar medium and form an energized ring detectable by radio emission. (Gallo et al. 2005)

5(c) M-87*

For the supermassive black hole M-87*, we calculated a jet speed of 709 c, with a gamma estimate of 2.5×10^5. Chandra x-ray observations indicate that parts of the jet are moving in excess of 0.99 c, which is a high gamma factor. (Mohon, L. 2020)

6. Conclusion

This paper takes the first step in determining whether *directed gravity* can explain the existence of jets emerging from the poles of neutron stars and black holes.

The first step was to perform the calculations with Newtonian hydrodynamics to see whether the result was reasonable, i.e., whether the jets would be relativistic as observed. By this measure the theory was successful for neutron stars, stellar mass black holes, and even supermassive black holes.

The next step should be to revisit these calculations using relativistic hydrodynamics. Of course, one must be sure that the relativistic hydrodynamic theory does not have implicit assumptions that are inconsistent with *directed gravity.* If it does, then a recasting of the hydrodynamic theory may be necessary.

Another issue relates to my decision to include no friction term in the precursor equation (2). The justification was that the jet was composed of a superfluid of neutrons which should be frictionless. However, most superfluids have a Landau critical velocity above which friction results. My problem was that I have no idea what that critical velocity would be for superfluid neutrons, and I have no way to reliably estimate it. The Landau critical velocity could be important, especially for supermassive black holes, which might help explain the very high value for γ that I found for M-87. Also, using relativistic hydrodynamics might improve the result.

Another concern for compact objects is the relative mass of the core as compared to the mass of the entire compact object. If the mass of the core rotating near the speed of light is very small compared to the mass of the compact object, then the $1/r^2$ gravity from the rest of the compact object may prevent the jet from escaping the compact object. Then, of course, there would be no visible jet.

Finally, I would like to point out why the *directed gravity* solution to the mass injection problem is so enticing. Jets from SMBHs can be hundreds of Kilo parsecs long. (Doeleman et al, 2012) For the beams to travel so far, it would seem likely that a major component should be neutrons. Additionally, the jets stay columnated at these extreme distances, requiring special properties of the jet for this to occur. *Directed gravity* indicates that these jets begin as a relativistic flow of superfluid neutrons that are rotating relativistically. Thus, we have a beam of neutrons with extreme angular momentum, allowing for the beam to remain stable while travelling such great distances.

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