Specific Energy Limit and its Influence on the Nature of Black Holes

Javier Viaña [0000-0002-0563-784X]
University of Cincinnati, Cincinnati OH 45219, USA
vianajr@mail.uc.edu

What if the universe has a limit on the amount of energy that a certain mass can have? This article explores this possibility and suggests a theory for the creation and nature of black holes based on an energetic limit.

The Specific Energy Limit

The energy is an extensive property, and we know that as we add more mass to a given system, we can easily increase its energy. The specific energy on the other hand is an intensive property. It is defined as the energy divided by the mass and it is measured in units of J/kg. If the mass is homogenous, the specific energy does not increase as we add more mass to the system. It seems reasonable that if there exists such concept as an energetic limit, it will refer to the specific energy, such that no unitary mass can surpass this hypothetical boundary.

Let us start considering the relativistic kinetic energy, E_k. This is the total energy of a mass minus the rest energy,

$$E_k = \gamma m_0 c^2 - m_0 c^2 \quad , \tag{1}$$

where γ is the Lorentz factor,

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \quad , \tag{2}$$

m_0 the rest mass, c the speed of light, and v the speed of the mass. If we want to get the relativistic specific kinetic energy, identified by ε_k, we need to divide the kinetic energy over the relativistic mass, m_{rel},

$$\varepsilon_k = \frac{E_k}{m_{rel}} = \frac{E_k}{\gamma m_0} = c^2 - \frac{c^2}{\gamma} \quad . \tag{3}$$

For a more rigorous demonstration, refer to Appendix A. The maximum value of ε_k can be obtained if v is the speed of light. In that case, the Lorentz factor becomes infinite,

$$\varepsilon_{k_{max}} = c^2 \tag{4}$$

In order to explore the limits in other types of specific energies (gravitational, electrostatic, internal, etc.), we will resort to the explanation that follows. Let us consider a mass with a specific potential energy greater than c^2. Using the energy conservation law, that potential energy could be transformed into kinetic energy, but the particle would surpass the specific energy limit and we know from equation (4) that this would not be possible. Thus, we can also argue that there exists a limit regardless of the type of specific energy.

There is one caveat; The value of the gravitational potential energy for example, depends on the reference taken. Nevertheless, the specific energy limit should not depend on the reference. For all the references that one could take, this energetic boundary should hold. Otherwise, if we consider the reference that would produce the greatest kinetic energy, we could theoretically surpass the specific energy limit, which cannot happen according to the previous description.

Black holes are undoubtedly one of the most brutal phenomena in the universe, and if there exists an energetic limit they could be somehow related to it. The following section is a theory on the nature and creation of black holes taking into account this energetic limit.

Theory on the Creation of Black Holes

Let us consider a star that is about to collapse into a black hole. The gravitational pull is extremely high, and there could be particles inside the star that are getting close to the hypothesized energetic limit. In the Appendix B we provide a demonstration of why the center of the star is the location with highest internal energy if symmetry and homogeneity holds. If the particle that reached the specific energy limit (likely in the center) increases its energy, then it would be violating the energetic limit condition. At this point we face the following question; What does nature provide in order to prevent the particle from surpassing the energetic boundary?

Fig. 1 (a) shows a simplified two-dimensional idealized representation of the forces acting on a particle located at the center of the star. For this explanation, we assume that the particle is about to surpass the energetic limit. If the particle is compressed due to these forces (Fig. 1 (b)), the magnitude of the forces acting on it would increase (Fig. 1 (c)). This follows from the demonstration of Appendix B for inner layers of a solid sphere. That would imply greater internal energy and a violation of the energetic limit.

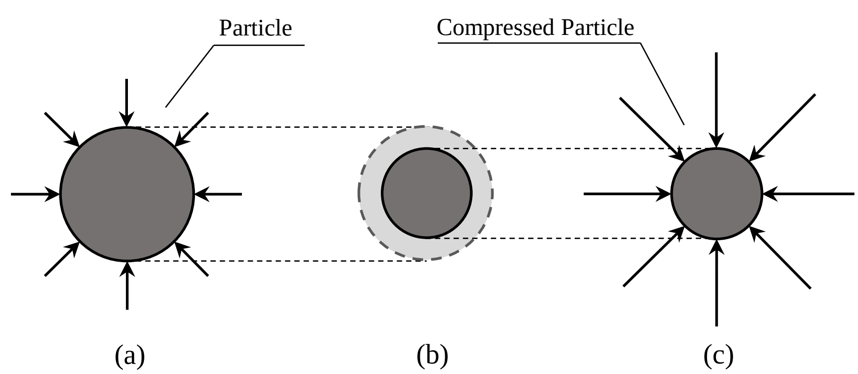

Fig. 1. Two-dimensional idealized representation of the forces acting on a particle located at the center of the star: (a) Initial configuration of the particle. (b) Compression of the particle. (c) Final configuration of the particle with an increase in the magnitude of the forces.

To avoid the previous scenario, we theorized that a new type of force could emerge from the center of gravity of this particle and in opposite direction to those forces already present in the particle (Fig. 2 (b)). The purpose of this force is to prevent the compression of the particle beyond a certain limit, and thus to avoid surpassing the energetic boundary. This force would create a non-existent space-time region inside the particle itself, as seen in Fig. 2. According to the energetic limit, no particle can exist with a specific energy greater than c^2, thus, it may seem reasonable that the inner region of the described system is non-existent. As a result of these two sets of forces (outer and inner), the mass of the particle would be compressed and scattered in a thin shell (Fig. 2 (c)).

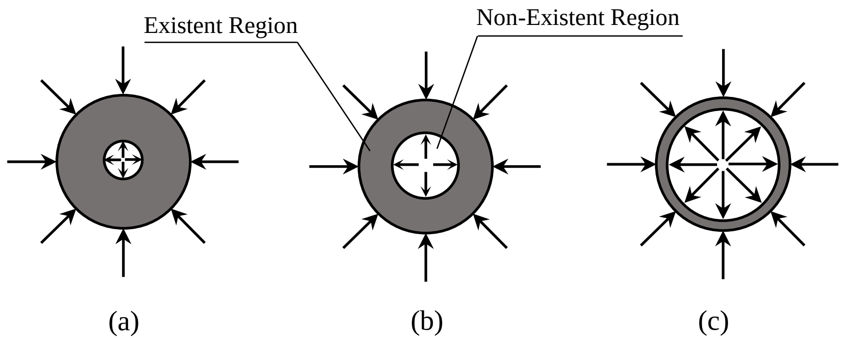

Fig. 2. Creation of the non-existent space-time region inside a particle that is about to surpass the energetic limit. (a) Initial state, creation of the reality boundary. (b) Intermediate state, expansion of the reality boundary. (c) Final state, formation of the thin shell.

This new type of force, that tries to preserve the energetic limit, could be understood as the reaction force that the non-existent region exerts to the existent region when the particle tries to cross to the other side. In a way, it would be no different than the reaction force that we experience when pushing a wall.

Initially, the shell would be formed by the mass of the particle that reached first the energetic limit. The remaining mass of the collapsing star would eventually fall into the shell gradually because of the gravitational pull. Nevertheless, in order to avoid surpassing the energetic limit, the shell would need to grow as more mass its added on it. In other words, every falling mass would spread over the shell and expand the shell to avoid an excess of overlapping mass. The specific energy of a mass on the shell coincides with the specific energy limit, c^2, since every mass is precisely in the boundary between the existent and non-existent region.

If there are other locations of the imploding star that are collapsing as well, they would be eventually colliding and merging into a bigger entity. The shell stops growing once it has the entire mass of the star.

To summarize, we believe this shell is a black hole, and that the energetic limit plays a key role in the creation of it.

Comparison of the Theory

The process described in the previous section, is a theory, presented in this paper, of how a black hole could be created. This empty nature could also be perceived from the fact that the black hole entropy is only dependent on the area of its surface, not on its volume.

We now compare this theory with the specific energy of a hollow Schwarzschild black hole. In the first place, we know that the Schwarzschild radius is directly proportional to the mass of the black hole. In our theory we state that the size of the shell of the black hole should also increase as more mass its added on it to preserve the specific energy. Second, we will calculate the specific energy of a particle of the Schwarzschild black hole. There are two essential results from the development that follows in order to be compatible with the theory proposed in this paper; The specific energy of any particle should be exactly c^2 and this should be the value regardless of the size of the black hole.

In order to be coherent with the theory, we incorporate an inner force that is exerted on the inside the black hole, which balances the outer gravitational force of the black hole to keep it stable. Fig. 3 shows a mass m sufficiently small and concentrated at the surface of the hollow Schwarzschild black hole. It also shows the forces acting on it considering the presence of the inner/reaction force.

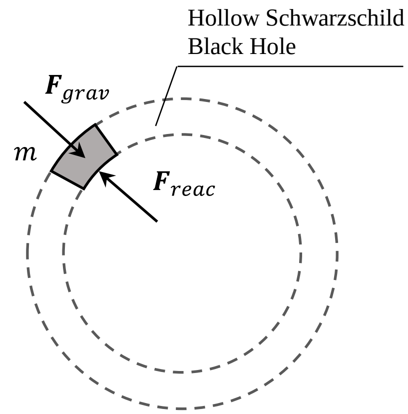

Fig 3. Mass m sufficiently small and concentrated at the surface of the hollow Schwarzschild black hole and the forces acting on it considering the presence of the inner force.

The total energy of the mass shown in Fig. 3, is the sum of the energetic contributions of both forces acting on it, the gravitational force (F_g), and the inner force (F_i). The gravitational force acting on a mass m on the surface of a hollow sphere of mass M and radius R is

$$F_g = \frac{GMm}{R^2} \quad . \tag{5}$$

Recall that there is no difference between (5) and the formula of a gravitational force that a solid sphere would exert on the particle. Let us take as reference the center of the sphere. We do so because this reference is the one that implies the greatest gravitational energy, and according to the theory of this paper, the energetic limit should apply regardless of the reference. Thus, the gravitational potential energy is

$$E_g = \frac{GMm}{R} \quad , \tag{6}$$

and the specific gravitational energy is

$$\varepsilon_g = \frac{GM}{R} \quad . \tag{7}$$

We now replace R in (7) with the value of the Schwarzschild radius, $\frac{2\,G\,M}{c^2}$,

$$\varepsilon_g = \frac{c^2}{2} \quad . \tag{8}$$

We can see that the gravitational specific energy of the Schwarzschild black hole is constant regardless of the size or the mass of the black hole, as predicted.

The inner force has the same value as the gravitational force and thus its energetic contribution is the same.

$$\varepsilon_i = \frac{c^2}{2} \tag{9}$$

Adding both, the resulting specific energy is c^2.

The Value of the Net Force

We can think of the reaction force of the black hole in terms of the pressure exerted on the inner surface of the black hole's shell of mass. To calculate this pressure, p, let us consider the mass m depicted in Fig. 3, subject to the gravitational and the reaction forces, $\boldsymbol{F}_{grav}$ and $\boldsymbol{F}_{reac}$. We will identify a as the portion of area of the inner surface and A as the entire area. We know that since the forces are balanced,

$$F_{reac} = F_{grav} \ , \tag{10}$$

$$pa = \frac{GMm}{R^2} \ . \tag{11}$$

Substituting the Schwarzschild radius,

$$pa = \frac{m}{M}\frac{c^4}{4\,G} \ . \tag{12}$$

We assume that the mass is evenly distributed over the surface. Then, the following proportionality holds

$$\frac{a}{A} = \frac{m}{M} \ . \tag{13}$$

Using (13) in (12) leads to

$$p = \frac{c^4}{4\,GA} \ . \tag{14}$$

Expression (14) defines the pressure exerted on the inner spherical boundary. Should we decided to flatten this surface, such that the forces do not compensate each other, the net force over that area would be

$$F_{net} = pA = \frac{c^4}{4\,G} \ . \tag{15}$$

or expressed as a function of the hypothesized energy limit, ε_{max},

$$F_{net} = \frac{\varepsilon_{max}^2}{4\,G} \ . \tag{16}$$

Equation (15) is shocking, since it tells us that the net force exerted on the black hole, and similarly the net reaction force, are not dependent on the size nor the mass of the black hole, they are both constant. In other words, all the Schwarzschild black holes have a net force of approximately 1.21×10^{44} [N]. Which provides an interesting perspective on what this theorized new type of forcefield could be.

Further Considerations

In the case of spinning black holes, the shape of the event horizon is not a sphere. The contribution of the rotational energy is greater the further we are from the rotation axis. If we follow the theory presented in this paper, the gravitational contribution at the hemisphere should be smaller to avoid surpassing the energetic limit. Thus, the hemispherical ring of a rotating black hole, would be further from the center than the poles to have a smaller gravitational energy. This actually coincides with what we know so far from rotating black holes. In fact, it would be an interesting exercise to derive the radii of the Kerr, Kerr-Newman, or the Reissner-Nordström black holes, using the energetic limit. To do so, we would need to consider the combined effect of the electrostatic, the rotational and the gravitational specific energies. Nevertheless, one can perceive the influence of the energy from the fact that the charge, the rotation, and the mass can produce different shapes of black holes.

Another interesting idea would be related to the Hawking radiation that is ejected from the poles of a rotating black hole. The inner force that we hypothesized in this paper could be related to why these jets have speed when exiting the black hole.

Conclusion

The main contributions of this paper are three theories. First, the concept of specific energy limit. Second, the introduction of a new type of force that prevents any particle from surpassing the energetic limit (i.e., crossing to the non-existent region of space-time). Third, the shell nature and formation of the black hole. Future work should be focused on simulations to benchmark the proposed theory with observations.

Appendix A

We consider the derivative of the energy as a function of the relativistic mass,

$$\varepsilon_k = \frac{dE_k}{dm_{rel}} = \frac{d(\gamma m_0 c^2 - m_0 c^2)}{d(\gamma m_0)} = c^2 \frac{d(\gamma m_0)}{d(\gamma m_0)} - c^2 \frac{dm_0}{d(\gamma m_0)} = c^2 - c^2 \frac{1}{\frac{d(\gamma m_0)}{dm_0}} \ . \tag{17}$$

We also know that γ does not depend on m_0, so

$$\frac{d(\gamma m_0)}{dm_0} = m_0 \frac{d\gamma}{dm_0} + \gamma \frac{dm_0}{dm_0} = \gamma \ , \tag{18}$$

which finally leads to

$$\varepsilon_k = c^2 - \frac{c^2}{\gamma} \ . \tag{19}$$

Appendix B

We assume a symmetric and homogeneous solid sphere subject only to its own gravitational pull. For this development, we will consider a sector of the sphere and we will make radial partitions or sections to visualize the internal forces acting on each section. Fig. 4 shows the sector of the sphere and the radial partitions chosen. Additionally, we know that the gravitational force exerted on a mass inside a solid sphere is proportional to the distance to the center of the sphere. Fig. 4 also shows the gravitational forces that would act on each of the centers of gravity of the radial sections.

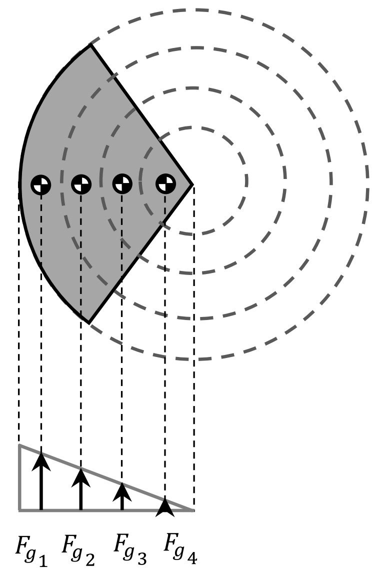

Fig. 4. Sector of the solid sphere and radial sections with the respective centers of gravity and their associated gravitational forces.

Let us do the rigid body analysis of each of the sections to see the forces that are present. Fig. 5 shows the reaction forces (identified by R) and the gravitational forces (identified by F_g) for each section. This figure reads from left to right. We can appreciate how the reaction force of deeper sections incorporates not only the gravitational force of the current section, but also the reaction from the previous section.

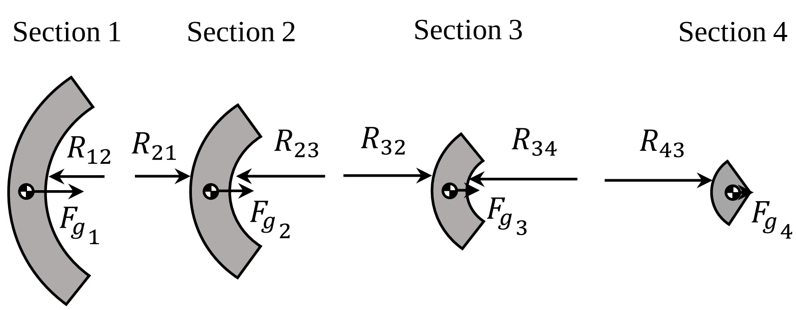

Fig. 5. Rigid body analysis for each of the four sections considered of the sphere's sector. Note that we did not add the reactions of section four because we restricted the study to this particular sector (section four is part of the core of the sphere).

As it can be seen in Fig. 5, the center of the solid sphere is the location subject to the highest forces and thus with the highest internal energy.