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Magnetospheric Eternally Collapsing Objects (MECOs): Likely New Class of Source of Cosmic Particle Acceleration

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It is known that spinning pulsars could be source of VHE-UHE cosmic particle acceleration. It is also conjectured that (fictitious) spinning Black Holes (BH) could be sites of cosmic particle acceleration. However, it has been shown by Mitra[1, 2, 3, 4, 5] and Leiter and Robertson[6] that General Relativity (GR) actually *does not allow the existence or formation of finite mass BHs*! It was predicted that the BH Candiadates (BHCs) have strong intrinsic magnetic fields (like pulsars) instead of Event Horizons. And this prediction has tentatively been verified in a series of papers by Robertson & Leiter and Schild[7, 8, 9, 10]. Thus all observed BH Candidates are actually not BHs, and, they are expected to be MECOs. In fact, "MECO" has been listed as one of the frequently used abbreviations in current A& A literature ($www.phys.uni - sofia.bg/\ astro.html$). Stellar mass MECOs are GR analogs of conventionally known isolated pulsars. While pulsars are/have (i) COLD, i.e., not supported by radiation pressure, MECOs are HOT, i.e., supported primarily by trapped radiation pressure, (ii) upper mass limit of 3-4 $M_\odot$ MECOs, being HOT, have no Upper Mass Limit, (iii) surface gravitational red shift, $z \sim 0.1 - 0.2$, MECOs have $z \gg 1$ so that photons can remain almost permanently trapped inside them. It may be recalled that isolated (non- accreting) uncharged BHs are cold and dead objects without any physical activity. On the other hand, spinning MECOs are like GR pulsars.

1. Introduction

Cosmic Ray Acceleration may take place in several kinds of sites. One kind of sites could be of extended nature, e.g., Supernova Remnants (SNRs), Pulsar Wind Schocks/Nebula (PWNs), or Jets. The other kind could directly involve Compact Objects such as Spinning Neutron Stars, i.e., Pulsars and (fictitious) Spinning Black Holes. The accretion shocks around such compact objects might also be the sites of acceleration even when such compact objects would not spin. In particular, for extragalactic point sources, we invariably invoke massive BHs as the Central Compact Object. But it is time now to have a fundamental revision of this idea in the light of theoretical astrophysics/GR research carried out in past few years. Although it will sound unthinkable, it is a hard fact that, it has been unequivocally shown that the supposed BH candidates cannot be BHs and they must be something else[1, 2, 3, 4, 5, 6]. Within the context of the classical GR, this "something else" has turned out to be Eternally Collapsing Objects (ECOs) and their specific version: Magnetospheric Eternally Collapsing Objects (MECOs). Even though the magnetic moment of MECOs (as measured by distant observers) could be same or even lower than typical young pulsar values, the spinning MECOs could beat the pulsars as sources of acceleration of high energy ions/electrons by virtue of extreming GR Frame Dragging effect[11]. In the present paper, we would like to introduce ECOs/MECOs to cosmic ray astrophysicists in general and also argue why ECOs are (rather than BHs) inevitable products of collapse of massive stars.

2. Reasons for Non-existence of BHs

It is true that the so-called vacuum Schwarzschild solution of GR *apparently* makes a strong case of existence for BHs. This solution involves an *integration constant* α_0 which is interpreted as twice the mass of the BH:

$$\alpha_0 = 2GM_0/c^2 \tag{1}$$

where G is the gravitational constant and c is the speed of light. It has all along been **assumed** that this integration constant can have arbitrary finite value. But by application of basic differential geometry (invariance of 4-volume), it has been shown recently, that, actually, this integration constant is unique: $\alpha_0 \equiv 0$[3]. This shows that, the vacuum Schwarzschild solution is only of notional value in the sense that BHs have a unique mass $M_0 \equiv 0$, and as far as real objects ($M > 0$) are concerned, they cannot be BHs. What are the physical reasons for non-occurrence of finite mass BHs?

1. It turns out that the radius of the BH is none other than α_0 and the fictitious boundary with $r = \alpha_0 = r_g$ is called the "Event Horizon" (EH). In case there would be a finite mass (and radius) BH, then the speed of any material particle would become $v = c$ at the EH. Further one would have $v > c$ for $r < \alpha_0$. This would be in violation of GR and hence there cannot be a region with $r < \alpha_0$. In other words ,one must have $\alpha_0 = 2GM_0/c^2 \equiv 0$, implying $M_0 \equiv 0$.
2. The acceleration of any object as measured by any observer (i.e., acceleration scalar) would be $a = \infty$ at the EH in tune with an infinite Lorentz factor at $r = \alpha_0$ And for $r < \alpha_0$, one would have $a = imaginary$(!!) just like the Lorentz factor would become imaginary if one would misconceive of a situation with $v > c$.
3. It has all along been **assumed** that if a massive star would collapse, somehow a *trapped surface* would be formed - and then, the formation of a BH would be inevitable. But it has been shown, in a highly transparent and exact manner, that GR actually does not allow formation of trapped surfaces[4].
4. The physical reason for non-occurrence of trapped surfaces is again essentially the same: Formation of a trapped surface corresponds to a speed of the collapsing fluid $v \geq c$ in violation of GR.

3. Then What Happens?

To appreciate this, one has to recall the definition of "Gravitational Redshift" z associated with any spherical object of mass M and radius R[12]:

$$1 + z = (1 - 2GM/Rc^2)^{-1/2} \tag{2}$$

For the Neutron Stars, supposed to be highly compact, the value of z lies in the modest range of $0.1 - 0.2$. But for the EH of a Schwarzschild BH, one has $z = \infty$. If one plots the compact objects against z, there would be and *infinite gap* between a NS and a BH! And it believed that during the collapse, once the star crosses the limit of $z = 0.1 - 0.3$ (NS), then it directly jumps to $z = \infty$ (BH). Obviously the star has to pass through the range of say $z = 1$, $z = 10$ and so on before arriving at $z = \infty$. But it is known that, the escape angle ψ of even photons/ neutrinos (not to talk of matter) becomes extremely narrow for $z > 2.0$ even in vacuum[11]:

$$\sin\psi < \frac{3\sqrt{3}GM}{rc^2}(1+z)^{-1} \approx 2.5(1+z)^{-1};\ \ z \gg 1 \tag{3}$$

As a result, once the collapse is strong enough to overcome the NS stage, for sufficiently massive stars, the radiation generated during the collapse *becomes virtually trapped* within the collapsing body as $\psi \to 0$ (almost). It is quite likely that the luminosity of the trapped radiation attains the appropriate Eddington value at extremely high value of z. And it is this *trapped radiation and the associated pressure which virtually halt the collapse* to make a quasi steady ECO.

Why Eternally Collapsing? In a strict sense some radiation always escape at any finite z, and in the same sense, and an ECO is always collapsing and losing mass-energy. It asymptotically tries to achieve the $z = \infty$ BH stage with $M \to M_0 \equiv 0$.

3.1 What is a MECO?

Robertson & Leiter[7, 8, 9] found that the X-ray as well as radio observations from all stellar mass binary NSs and BHCs can be understood in terms of the ECO model where the magnetic energy density is almost as strong as gravitational energy density, $B \sim 10^{16-17}$ G, and ECOs with such super strong B are called MECOs. For self-consistency, they argued that, (observed) MECOs should have $z \sim 10^{7-8}$. If the reader would have difficulty in accepting such high values of z, recall that BHs have $z = \infty$. The MECO model, and, in particular the idea that MECOs must be supported by Eddington limited internal luminosity, is due to Robertson & Leiter[6, 7, 8].

4. Some Expected Questions

1. What about the Exact Oppenheimer-Snyder Collapse Solution?

   The exact solution of gravitational collapse is indeed due to Oppenheimer & Snyder. But they adopted a fluid (dust) whose pressure $p \equiv 0$. Thermodynamics demands that $p \equiv 0$ is possible iff density $\rho \equiv 0$. Therefore, the corresponding mass of the Oppenheimer-Snyder BH is $M = M_0 \equiv 0$ in accordance with[3].

2. What about the Upper Limit of Mass of Neutron Stars?

   Both Chandrasekhar Limit and NS upper mass Limit correspond to **cold** objects, i.e., objects primarily supported by cold degeneracy pressure. Objects which are not primarily supported by such degeneracy pressure may have any mass: e.g., there are individual stars with mass $\sim 100 M_\odot$, our galaxy has a mass $\sim 10^{11} M_\odot$. However such objects are not compact. Nonetheless, *stable* supermassive stars, supported by radiation pressure, can have arbitrary high mass and compactness somewhat smaller than NSs.

   ECOs are GR version of *unstable* radiation/magnetic pressure supported objects and GR very much admits their existence by means of the *Vaidya Metric*[6]. Because of intense internal radiation, the baryonic plasma of ECOs may not be degenerate at all.

3. If BHs really are not there, how is it that almost all GR experts and astrophysicists have been using it and getting nice results too?

   This question is essentially a sociological one and has been partly answered in the small article : Why no "New Einstein" by Lee Smolin[13].

   To be precise, not a single astrophysical research paper, to the knowledge of the present author, has so far used the exact EH boundary conditions, like $z = \infty$, $a = \infty$ in any exact astrophysical computation. Invariably, they avoid the EH and work away from it, e.g., like the "Membrane Paradigm"[14] where one virtually replaces the EH by a physical conducting surface above it! In fact, these authors admit (p.46)[14] that:

   "The mental **deceit** of stretching the horizon is made mathematically viable, indeed very attractive, by the elegant set of membrane-like boundary conditions to which it leads at the stretched horizon...." (The emphasis is by the author)

   If BHs were physical objects, there would not have been any need for a "mental deceit" and they could have been treated exactly without the prop of a "membrane".

5. Conclusions

The so-called BH candidates are most likely to be ECOs. An isolated spinning ECO, by virtue of intense GR frame dragging effect, will generate an induced electric field which could be stronger by a factor of $\sim 10^4$ than that of conventional pulsars[11]. Although, Robertson & Leiter have constructed reasonably self-consistent model of ECOs (MECOs) with a range of $B \sim 10^{16-17}$G and $z \sim 10^{7-8}$ for observed stellar mass BHCs, there could be ECOs with much lower B and z and which might be unidentified at present. For various physical properties of MECOs/ECOs, the reader is referred to[10]. It may be mentioned that as far as detail internal structure of a quasar is concerned, probably, Q0591+561 makes the best case as it has been studied for 40 years. In particular, 25 years of gravitational lensing and microlensing studies have revealed an internal structure which cannot be understood by the BH paradigm. On the other hand, the MECO model has been successful in fixing some of basic structure parameters[10]. More on ECO accelerators will be presented in an adjacent paper[11].

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