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On the Probable Nature of the "Dark Particle Accelerators" Discovered by HESS

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We estimate that the vacuum electric field associated with a spinning Magnetospheric Eternally Collapsing Object MECO[1, 2, 3, 4, 5, 6, 7, 8, 9] could be *higher by a factor of* $\sim 10^4$ than the corresponding pulsar value because of extreme relativistic Frame Dragging Effect. Thus isolated spinning MECOs could be source of UHE cosmic ray acceleration and VHE γ-ray production. However because of the steeply varying gravitational field close to the surface of the MECO, any signal generated there would be both extremely redshifted and distorted. As a result, there may not be any significant pulsed X-ray or Radio emission from close to the surface, and consequently, the γ-ray source may appear as "Unidentified" and the particle accelerator may appear as "Dark"[10, 11].

1. Introduction

The VHE γ-ray telescope, HESS, has unrivalled sensitivity and success. It is in the process of revolutionizing the dormant and sluggish existing VHE γ-ray catalog the same way EGRET revolutionized GeV γ-ray catalog almost 10 years ago. Accordingly it has been discovering "unidentified" sources of VHE γ-ray sources[10, 11]. While some of such unidentified sources already discovered or those which will be discovered routinely, could turn out to be sources about which we already have idea, we predict that, some of the sources, could belong to an entirely new class.

For galactic sources, in the former category, we can have (1) Radio Pulsars, (2) Pulsar Wind Nebulae (PWNe) (3) Supernova Remnants (SNRs), (4) X-ray binaries containing Neutron Stars (NS), (5) Magnetars, (6) X-ray binaries containg supposed Black Holes Candidates (BHCs), with Microquasars being a sub-class, (7) Hot Wolf -Rayet Star Wind Shocks[12] (8) Hot O-B Star Wind Shocks[11].

In the latter category, we may have (9) Magnetospheric Eternally Collapsing Objects (MECOs) as the entirely new class of VHE γ- ray sources. MECOs are end products of collapse of massive stars and held in quasistatic (unstable) equilibrium by internal Eddington limited radiation luminosity and sperstrong (local) magnetic pressure[1, 2, 3, 4, 5, 6, 7, 8, 9]. Eternally Collapsing Objects (ECOs) have also been briefly discussed in ref.[13]. The surface redshift of a spherical object with radius R is

$$z = (1 - 2GM/Rc^2)^{-1/2} - 1 = (1 - r_g/R)^{-1/2} - 1; \qquad r_g = 2GM/c^2 = 30(M/10M_\odot)Km \qquad (1)$$

where G is the gravitational constant and c is the speed of light. During gravitational collapse of massive stars, as z tends to increase indefinitely, the internal radiation and heat get virtually trapped, and, catastrophic collapse is halted. It is then that a MECO is formed. It is only when one overlooks this general relativistic possibility of *virtual trapping of internal radiation* (which has been done for past 90 years), one would have "trapped surfaces" "Event Horizons" and (finite mass) BHs. While degeneracy pressure supported *cold & strictly static* compact objects must have $z < 2$ and $M < (3-4)M_\odot$, ECOs/MECOs being *hot & unstable*, may have arbitrary high but finite z and M. In particular, Robertson & Leiter[2, 3, 4] have shown that for the MECOs lying in the X-ray binaries, one expects, $z \sim 10^{7-8}$ and magnetic moment, *as seen by a distant observer*, $\mu \sim 10^{30}$ Gauss cm^3. While this latter value of μ is comparable with the magnetic moment of the young pulsars, it may be recalled that, a typical NS or a pulsar has $z < 0.25$. Thus MECOs can act as extreme

GR pulsars and hence their role in cosmic particle acceleration and γ-ray production needs to investigated. This paper is a highly preliminary study to this effect.

2. Unipolar Inductor

It is known that an isolated spinning NS having a dipole magnetic moment μ generates induced *vacuum* electric field around it whose components are[14]:

$$E^r = -\frac{\mu \Omega R^2}{c r^4}(3\cos^2\theta - 1); \qquad E^\theta = -\frac{\mu \Omega R^2}{c r^4}(2\sin\theta\cos\theta) \tag{2}$$

Here we have considered an aligned rotator, i.e., one for which the spin vector $\vec{\Omega} \parallel \vec{\mu}$. It is this electric field which overwhelms the gravitational pull on ions/electrons and fling them into acceleration. The parallel electric field at the surface is

$$E_{\|} \sim \frac{\mu\Omega}{cR^2} \sim \frac{R\Omega}{c} B_s \sim 2.10^8 P^{-1} B_{12}\ volts\ cm^{-1} \tag{3}$$

where B_{12} is the value of the surface magnetic field, B_s in units of 10^{12} Gauss. If the accelerating regions would be of the extent of stellar radius, $R \sim 10$ Km, one would have particle acceleration of $> 10^{14}$ eV even for a slow rotator with $P = 1$s. However, despite initial expectations, as of now, there is no direct evidence that pulsars are sources of UHE cosmic rays. On the other hand, the discovery of MeV-GeV γ-ray pulsars have shown that electrons/pairs are accelerted atlest by a Lorentz Factor of $\Gamma \sim 10^{2-3}$ or probably upto $\Gamma \sim 10^{6-7}$[15]. The torn off charges along with pairs produced around the initially vacuum NS eventually form a "magnetosphere" which is some sort of a rigid extension of the conducting and spinning NS. In this non-vacuum of the magnetosphere, the magnitude of the vacuum electric fields as well as the associated potential drops reduce significantly. Further, acceleration of charged particles gets quenched by (a) Curvature Radiation Losses and (b) Inverse Compton Losses. The energy of the emitted photons can be limited by either (a) $\gamma + \gamma \rightarrow e^{\pm}$ or (b) single photon pair production, $\gamma + B \rightarrow e^{\pm} + B$, in the strong magnetic field. The break found in the speectra of the EGRET γ-ray pulsars could be because of the latter process.

As of now no pulsar is known to emit pulsed VHE γ-rays and almost all known γ-pulsars (probably Geminga too) shine in radio band. In the following we shall briefly outline the basic difference of spinning MECOs vis-a-vis pulsars and point out why they might be VHE γ emitters even being *quiet as radio pulsars*.

3. GR Unipolar Inductor

When any massive object rotates, it tries to drag the surrounding spacetime along with it at a rate $\omega(r) = J/r^3$ (for slow rotation), where $J = I\Omega$ is the angular momentum and I is the moment of inertia of the body. The strength of gravitation of the body is measured by z and recall that while the value of $z \sim 0.2$ for a typical NS, the same for a MECO is $z \sim 10^8$. By taking $G = c = 1$, the corresponding induced vacuum electric fields (as seen by a *local* observer) is[15]

$$E^r = \frac{\mu(3\cos^2\theta - 1)}{4M^6 r^3 c}\left\{C[6M^4r^3(2r-3M)\ln N^2 + 4M^5 r(6r^2 - 3Mr + M^2)] + \frac{3\omega M^3 r^4}{2}\ln N^2 + 3M^4\omega r^3\right\} \tag{4}$$

$$E^\theta = \frac{-3\mu\cos\theta\sin\theta}{M^6 r^4 N c}\left\{C[3M^4r^3(r^2 - 3Mr + 2M^2)\ln N^2 + 2M^5r^2(3r^2 - 6Mr + M^2)] + \frac{\omega M^5 r^3}{2}\right\} \tag{5}$$

where $N^2(r) = (1 - r_g/r)$ and $N_R^2 = (1 - r_g/R) = (1 + z)^{-2}$. The constant C involves N_R, Ω, M and R. For extremely high $z \gg 1$, $R \to r_g = 2M$, and, then, we have found that

$$C \sim (2 \ln N_R^2 + 3) \frac{\Omega}{r_g} \sim -4 \ln(1 + z) \frac{\Omega}{r_g} \tag{6}$$

Little away from the MECO surface $r = R$, E^r and E^θ contain components falling off almost as slowly as $\sim \Omega/r$ whereas in a flat spacetime they fall off as $\sim \Omega/r^4$! For a comparison, at $r = 2R \approx 2r_g$, for a MECO with $z = 10^8$, we have

$$E^r \sim 6000 \frac{\mu\Omega}{c r_g^2} (3 \cos^2\theta - 1) \tag{7}$$

Let us compare this with the almost flat NS case with $r = 2R$:

$$E^r = -\frac{\mu\Omega}{16 c R^2} (3 \cos^2\theta - 1) \tag{8}$$

Thus, for a $10 M_\odot$ MECO, we have the outstanding result that for a given Ω and μ, the basic *vaccum accelerating electric field will be higher by a factor of* $\sim 10^4$. The resultant particle acceleration is not appreciably quenched by the curvature radiation reaction because curvature losses $\propto \Gamma^{1/4}$. A naive scaling would indicate that MECOs thus could the source of UHE cosmic rays and γ-rays. However, like the pulsar case, the actual available potential drop could be much lower because of variety of reasons, yet, we feel, it should be sufficient to generate UHE cosmic ray acceleration and VHE γ-ray production.

4. Distinct Features of Spinning MECOs

All γ-ray pulsars are likely to be radio pulsars too because, (i) Radio emission involves much lower energy pairs and (ii) the condition of *coherent curvature radiation*, believed to be the reason behind the radio emission, can easily be satisfied in an almost *flat spacetime* around a NS.

But the spacetime around a MECO is completely different: even if the value of $N(r)^{-1} = (1 - r_g/r)^{-1/2}$ is $\sim 10^8$ at the surface $r = R \approx r_g$, its value drops to $\sim \sqrt{2.0}$ for $r = 2R \approx 2r_g$! Because of this almost step function like behaviour of $N(r)^{-1}$ near $r = R$ and further additional distortion of spacetime by Frame Dragging (rotation), there cannot be any coherent process occurring either near the surface or any "Polar Cap". Thus unless radio signals originate in some far-off "outer gaps" there will not be any pulsed radio emission.

The hot MECO surface however has a highly redsfited quiesent weak luminosity of $\sim 10^{30-31}$ erg/s (as measured, by a distant observer), and this may be UV/Soft X-rays[2, 3, 4, 5]. And since this originates near the surface, it is unpulsed.

However hard X-ray or γ ray emission is *no coherent* process and presumably may originate sufficiently away from the surface to become pulsed with certain distortions.

We have found that because of intense GR effects on the magnetic field structure, B will be sufficiently low at $r > 2R$ to avoid magnetic pair production of VHE γ-rays. Thus it might indeed be possible to have (somewhat distorted) pulsed VHE γ-ray emission from isolated spinning MECOs. But the value of L_γ could be less than corresponding pulsar values because of lower Ω and μ except for exceptional cases. Even if pulsed VHE γ-ray production would be suppressed by some unforseen reasons, a spinning MECO could be generate an outflow of UHE pairs beyond the light cylinder, i.e., there should be a relativistic MECO wind. And this MECO wind may generate unpulsed γ-rays (nebula) extending far beyond the VHE range.

In fact, there are almost 25 PWNe *with no detected pulsar*[16]. Some of these supposed PWNe could actually be MECOWNe. Interestingly, several of such supposed PWNes have been detected in γ-rays by either COMPTEL or EGRET[17]. In other words, some of the unidentified EGRET sources too can be actually associated with MECOs or MECOWNe.

5. Discussion

We have indicated that isolated spinning MECOs could be a new class of source of VHE γ-rays and there may not be any pulsed radio emission associated with them. The (10) Wind Nebulae associated with the spinning MECOs could be yet another class of (unpulsed) VHE γ-rays. MECOs are born by the collapse of massive stars and we are certain that the central compact objects associated with long duration powerful Gamma Ray Bursts harbour MECOs rather than BHs. Irrespective of this association, the remnant associated with GRBs could be indentified as VHE γ-ray emitters. Recall that while Supernova Events release only 10^{48-49} erg/s/sr of electromagnetic energy energetic GRBs emit 10^{51-53} erg/s/sr of electromagnetic energy. Thus GRB remnants should be a class distinct from much more frequent SNRs. It is likely that the ambient magnetic field in the GRBRs is much higher than in SNRs. Consequently, (11) GRBRs could be some of the extended "Dark Accelerators" because the central MECO may not generate any pulsed radio emission.

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