General Relativistic Radiation Pressure Supported Stars as Quasar Central Engines in an Universe Which is Recycling Matter

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Hoyle & Folwler (1963a,b) suggested that quasars may contain Radiation Pressure Supported Stars (RPSS), which are quasi-Newtonian (surface redshitf $z \ll 1$) and supermassive. This proposal however did not work and one of the reasons was that such quasi-Newtonian PRSSs are unstable to gravitational contraction to become extremely general relativistic RPSSs. And since trapped surfaces are not allowed, (Mitra 2009a) these relativistic RPSSs are bound to hover around their instantaneous "Schwarzschild Radius" $R_s = 2GM/c^2$. In view of the fact that they have $z \gg 1$, they appear as "Black Holes" (BH) to distant observers. However since, they are always radiating, in a strict sense, they are always contracting. During such extreme compatification, RPSSs are likely to acquire extremely large magnetic field due to magnetic flux freezing, and hence they have strong magnetosphere around them by which they may arrest the accretion disk surrounding them at "Alfven Radius", $R_a \gg R_s$. In contrast, for an accreting Schwarzschild black hole, one expects the inner edge of the accretion disk to be at $R_i = 3R_s$. Consequently, such ultramagnetized RPSSs have been nick named as Magnetospheric Eternally Collapsing Objects" (MECOs). Microlensing studies of several quasar structures have shown that indeed $R_i \sim 35R_s$ rather that $R_1 = 3R_s$, and which confirms that quasars harbor MECOs rather than true black holes (Schild et al. 2006, 2008, Lovegrove et al. 2011). Further the recent proof that the true BHs have $M = 0$ confirms that the BH candidates are not true BHs (Mitra 2004a,b; 2009b). Here we highlight the facts (i) outflows from quasars and (ii) their ability to recycle cosmic matter for having new stars and galaxies are best understood by realizing that they contain MECOs rather than true BHs.

Keywords: Quasar, Black Hole, Radiation Pressure Supported Star, Magnetospheric Eternally Collapsing Object, Cosmology, Big Bang

I. INTRODUCTION

One of the cornerstones of modern physics and astronomy is the idea of the Black Holes (BH) in which everything can enter but from which nothing can come out, atleast at the classical level. Black holes are supposed to exist as the compact object in many X-ray binaries, in the center of core collapsed star clusters, in the core of the quasars, Active Galactic Nuclei (AGN), as well as in the core of many normal galaxies, like the Milky way. Despite such popular notions, the facts remains that most of the evidences for the detection of BHs are highly circumstantial; and, in reality, what one observes is actually Massive Compact Dark Objects or sometimes even luminous Massive Objects *ejecting matter*. Note, the imaginary boundary of a Schwarzschild BH is given by its Event Horizon (EH) radius:

$$R_{BH} = R_s = \frac{2GM}{c^2} \tag{1}$$

where G is the gravitational constant and c is the speed of light. It is widely believed that the center of our galaxy harbors a BH of mass $M \sim 10^6 M_\odot$ ($M_\odot$ = Solar Mass) having a radius $R_s \sim 3 \times 10^{11}$ cm. But actually the spatial resolution with which we can scan this region is still $\sim$ *many* R_s, and further, by definition a true EH cannot be detected because "nonthing, not even light can come out of it".

In the present time, many astrophysicists may not be aware that Hoyle & Fowler (1963a,b) proposed that the compact objects in quasars could be massive Radiation Pressure Supported Stars (RPSSs) rather than BHs. This idea was remarkable in the sense that it highlighted the fact that *if a compact object would be sufficiently hot*, then the concepts like Chandrasekhar Mass Limit (M_{ch}) and Oppenheimer -Volkoff Mass Limit (M_{ov}) *get completely invalidated*. They however conceived the RPSSs in the framework of Newtonian gravity whose surface gravitational red-shifts

$$z = \left(1 - \frac{2GM}{Rc^2}\right)^{-1/2} - 1 \ll 1, \tag{2}$$

though in the extreme case, some RPSS may have $z \sim 0.1$, the same as that of a typical Neutron Star. But it transpired that Newtonian RPSSs are really not suitable to replace the concept of BHs in the quasars (Shapiro & Teukolsky 1983). Nevertheless, it was later shown that RPSSs can have a general relativistics version with $z \gg 1$ (Mitra 1998, Mitra 2006a,b,c; Mitra & Glendenning 2010). For such Relativistic RPSSs (RRPSSs), not only radiation pressure $p_r \gg p_m$, the gas/baryonic matter pressure; but also the radiation energy density $\rho_r \gg \rho_m$, the baryonic rest mass energy density (Mitra 2006a). Thus such extremely general relativistic RPSSs are indeed balls of pure fire or energy! All RPSSs must be highly ionized and act as highly conducting fluids. For such a fluid, any pre-existing magnetic flux remains conserved. While in the Newtonian regime, the mean threaded magnetic field is expected to increase as $B \sim 1/R^2$, in the GR regime, there should be additional increment of the magnetic field $\sim (1+z)$. Thus, the Relativistic RPSSs are likely to be ultramagnetized too, and the source of their extreme local luminosity may be ascribed to synchrotron emission and relativistic Bremstrahlung of the electrons, pairs or quarks. In case, matter will have further inner degrees of freedom and quarks will have sub-blocks, then RRPSSs may even derive their luminosity by exciting those new degreees of freedom! Now there are good observational evidences that the compact object in some quasars are such ultramagnetized RPSSs rather than true BHs. Since by definition, a RPSS is always radiating, its mass is always decreasing extrememy slowly. And in oder that the radius of a relativistic RPSS remains practically same as the "Schwarzschild Radius", a consequence of $z \gg 1$, it is always shrinking at an infintesimal rate. It has been found that this shrinking must continue indefinitely, and accordingly, such objects are called "Magnetospheric Eternally Collapsing Objects" (MECO). Before we describe them in some detail, we first briefly review the idea of Newtonian RPSSs.

II. RADIATION PRESSURE SUPPORTED STAR

A RPSS is supported almost entirely by its radiation pressure (Weinberg 1972, Shapiro & Teukolsky 1983):

$$p_r = \frac{1}{3} a T^4 \tag{3}$$

where a is the radiation constant. On the other hand, by assuming the plasma to be made of hydrogen only, the matter pressure is given by

$$p_m = nkT \tag{4}$$

where k is the Boltzman constant and n is the proton number density. The structure of a Newtonian RPSS is closely given by a polytrope of index 3, and the ratio of matter pressure to gas pressure works out to be (Weinberg 1972):

$$\beta = \frac{p_m}{p_g} \approx 8.3 \left(\frac{M}{M_\odot}\right)^{-1/2} = 8.3 \times 10^{-4} M_8^{-1/2} \tag{5}$$

where $M = M_8 10^8 M_\odot$ and $M_\odot$ is solar mass. This shows that a RPSS should have a minimum mass $\sim 7200 M_\odot$ (Weinberg 1972) in order to have a value of $\beta < 0.1$. A Newtonian RPSS may be defined as one for which the rest mass energy density of the plasma dominates over the radiation energy density, $\rho_m \gg \rho_r$, even though $p_m \ll p_r$. It then follows that, the "compactness" of a Newtonian RPSS is very small (Weinberg 1972):

$$\frac{2GM}{Rc^2} \ll 0.78 \tag{6}$$

In other words the surface red-shift of a Newtonian RPSS is very small

$$z = \left(1 - \frac{2GM}{Rc^2}\right)^{1/2} - 1 \ll 0.39 \tag{7}$$

In this limit of small z, we can approximate

$$z \approx \frac{GM}{Rc^2} \tag{8}$$

Most of the stable (Newtonian) RPSSs are likely to have $10^{-4} < z < 10^{-2}$ (Shapiro & Teukolsky 1983).

If a RPSS is in *hydrostatic equilibrium*, its luminosity is close to the corresponding Eddington value :

$$L_{ed} = (1-\beta) \frac{4\pi c GM}{\kappa} \approx 1.26 \times 10^{46} M_8 \ erg/s \tag{9}$$

where κ is the Thompson opacity. Assuming that $\beta \ll 1$, we obtain,

$$L = \frac{4\pi c G M}{\kappa} \approx 1.26 \times 10^{46} M_8 \; erg/s \tag{10}$$

Since this range of luminosity is comparable to typical quasar values, one can appreciate the basic reason behind hypothesizing that the quasars could be powered by RPSSs. Note, an assumed strict hydrostatic equilibrium must be effected by the release of energy by nuclear fusion at the center. But the efficiency for energy generation by hydrogen fusion is only $\sim 0.7\%$, and given Eddington limited accretion rate, the fusion process can not deliver the necessary luminosioty for massive RPSSs. Various other arguments were offered to show that such Newtonian RPSSs cannot explain the prolonged quasar activities (Shapiro & Teukolsky 1983). Being radiation pressure dominated they are unstable to gravitational collapse and thus expected to eventually become extreme general relativistic objects.

III. GENERAL RELATIVISTIC RADIATION PRESSURE SUPPORTED STARS

The above picture may change dramatically once GR will be itroduced in the problem in its full glory. While, in GR, the locally measured L_{ed} increases by a factor of $(1+z)$, the distant oberserved perceives it to be lower by a factor of $(1+z)^2$. As a result, in the observer's frame, the GR Eddington luminosity is (Mitra 1998b, Mitra 2006b,c)

$$L_{ed}^{\infty} = \frac{4\pi c G M}{\kappa(1+z)} = \frac{L_{ed}^{New}}{1+z} \tag{11}$$

Now the exterior metric will be the radiative Vaidya metric and distant's observer time is indicated by Vaidya time u. The luminosity seen by the distant observer resulting from infinetisimal slow contraction is

$$\dot{M} c^2 = c^2 \frac{dM}{du} \tag{12}$$

It can be easily seen from Eq.(11) that, since z can be arbitrarily high, there is no inconsistency in assuming that L_{ed} of the RPSS is indeed fed by loss of mass energy resulting from such contraction:

$$L = L_{ed}^{\infty} = \dot{M} c^2 \tag{13}$$

Since the ultimate reservoir of energy is $E = Mc^2$, the time scale for such quasi-static contraction is (Mitra 2006b,c; Mitra & Glendenning 2010)

$$u_{KH} = \frac{Mc^2}{L_{ed}^{\infty}} = (1+z) \frac{c^3}{4\pi G c} \tag{14}$$

Note, this time scale is **independent on the mass of the star** and is getting constantly **stretched to infinity** as $z \to \infty$. Therefore, once the collapsing object enters into deep gravitational potential well, the contraction becomes eternal! Such an observer eternity is not same as the case of idealized Oppenheimer -Snyder (1939) dust collapse. This is so because, for the case of a dust, there is no quasi-static equilibrium, no pressure gradient, no balancing effect and of course no Eddington Luminosity (Mitra 2006c). If this contraction would proceed asymptotically, naturally, the star would lose its entire mass energy to attain a $M = 0$ true BH state (Mitra 2009a,b).

IV. MEAN LOCAL TEMPERATURE OF MECOS

In case, a relativistic object will have a "hard surface", the GTR expression for accretion luminosity will be (Mitra 1998b, 2002)

$$L_{acc} = \frac{z}{1+z} \dot{M} c^2 \approx \dot{M} c^2; \qquad if, \; z \gg 1 \tag{15}$$

However, the RRPSSS have *no hard surface*: The mean mass energy density of a RRPSS is (Mitra 2006b, Mitra & Glendenning 2010):

$$\rho = \frac{M}{(4\pi/3)R^3} \tag{16}$$

And since for $z \gg 1$, $R \approx R_s$, the mean density is

$$\rho \approx \frac{3c^8}{32\pi G^3 M^2} \tag{17}$$

Further, in this limit, the RRPSS is completely dominated by radiation energy (Mitra 2006a):

$$\frac{\rho_r}{\rho_m} \sim z \tag{18}$$

so that

$$\rho_m \sim \frac{\rho}{z} \sim \frac{3c^8}{32\pi z G^3 M^2} \tag{19}$$

For an RPSS of $M \sim 10 M_\odot$, one would obtain $\rho \sim 10^{14}$ g cm^{-3} while ρ_m would be lower by a factor z. The corresponding local mean temperature is (Mitra 2006b,c)

$$T \sim 200\ MeV \left(\frac{M}{10 M_\odot}\right)^{-1/2} \tag{20}$$

At such high temperatures, despite high density, the RRPSS will be a molten plasma. In fact, *it will be a Quark Gluon Plasma* (Mitra & Glendenning 2010). For, $M \sim 10^8 M_\odot$, one will have $\rho \sim 1$ g cm^{-3}. The corresponding mean temperature $T \sim 60$ KeV would be lower too. In this case, the RRPSS will be a completely ionized gaseous plasma at the atomic level.

Seen this this way, one may infer an upper mass limit of RRPSSs: $M \sim 10^{11} M_\odot$ where $T \sim 2$ KeV. For a higher M and a lower T, the condition for complete ionization *may not be satisfied* atleast near the surface regions. And indeed *quasars seem to obey such an upper mass limit.*

In principle however there could be many other models for the BH candidates. For example, it has been suggested that if one would consider a modified electrodynamics, there could be static non-singular compact objects with $z \gg 1$ (Corda & Cuesta 2010).

V. NEW GALAXY FORMATION & SUPPLY OF FRESH GAS

In the ideal Big Bang scenario, the elements are produced in the *first few minutes*, may be at a cosmological redshift of $Z \sim 10^{10}$. Similarly most of the gas must have been prepared too early ($Z >>> 1$). In the ideal Big Bang scenario, events occur in a neat sequential manner, and formation of new galaxies at recent epochs could be a rather anomalous event. But in reality, not only new stars are formed within pre-existing galaxies, new galaxies are getting formed. May be other hierarchial structures too are formed even at present epoch. Can supernovae and star burst activities regenerate all the required gas needed to explain such new star formation, new galaxy formation, and may be new hierarchial structures at all levels?

Recently Hubble's Cosmic Origin Spectograph has found that the circumgalactic medium (CGM) is fed by galaxy outflows and accretion of intergalactic gas (Tripp et al. 2011). While such outflows must be generated by intense starburst and supernovae activities, there is a net accounting problem atleast in some cases (Lehner & Honk 2011):

"Without a source of new gas, our Galaxy would exhaust its supply of gas through the formation of stars. Ionized gas clouds observed at high velocity may be a reservoir of such gas, but their distances are key for placing them in the Galactic halo and unraveling their role."(Lehner & Honk 2011).

If all the galaxies in the universe would contain supermassive BHs at their core, in the long run, *all recycling activities must slow down.* In particular, since the supposed supermassive BHs must be gulping matter, *and nothing can come out of event horizons*, the net amount of material available for recyling must steadily be getting diminished. Then how can one expect additional **source of new gas**? This problem challenges not only the BH paradigm but the Big Bang paradigm too :

For example, a new submillimeter camera has discovered more than a hundred dusty galaxies in the early Universe, each of which is in the throes of an intense burst of star formation. These submillimeter galaxies are associated with the early formation of some of the most massive galaxies in the present-day Universe: giant elliptical galaxies. One of these galaxies is an example of a rare class of starburst, seen just 1 billion years after the Big Bang, and may present a direct challenge to current ideas of how galaxies formed (Coppin et al. 2009, Elbaz et al. 2009).

All such cosmic puzzles can be much better understood in a paradigm where the BHs are MECOs, balls of ultra-magnetized hot plasma:

The MECOs being ball of extremely hot plasma, they are always vulnerable to various radiation & magnetic driven instabilities vis-a-vis BHs which are dead and cold singularities. By virtue of such radiation- magnetic instabilties, a **MECO behaves like the Sun or Eta Carinae on a much grander scale**. Just like the Sun ejects plasma by *Coronal Mass Ejection* and *Solar Flares*, a MECO is likely to inject plasma into its surroundings triggering flaring activities in an unpredictable manner. The worst of such instabilities in fact happen during pre-natal stages of ECO formation when radiation driven ECO plasma is thrown out in the form of Gamma Ray Bursts (Mitra 2008a,b).

"A quiescent ECO would however synthesize light elements in its envelope (for stellar mass cases) or in its body (for supermassive cases). And such light elements would also be thrown by intermittent ECO flares into the ISM. Light elements apart, ECOs toss out pure QGP or hydrogen into the ISM both during GRBs or during perennial mini-flares. While doing so, an ECO may wither away prematurely after an age which is expected to astronomically significant." (Mitra2008a).

A MECO may also steadily eject plasma by *solar wind* like phenomenon. Thus while a MECO can grow by accreting matter from its surroundings; it can also move to a phase in which it *has a net loss of mass*. Thus in principle, a MECO can wither away in the inter galactic medium (IGM).

One proposed scheme of *recycling in the cosmos is the following* (Mitra 2008b):

1. Light stars collapse to become White Dwarfs (WD) and eject material by Planetary Nebulae. CO white dwarfs accrete gas to acquire Chandrasekhar Mass limit, then they explode completely by Type 1a SN , i.e., they eventually wither into the Interstellar Medium (ISM).

2. Massive Stars Collapse to become Neutron Stars (NSs) and eject stellar material as well as heavy elements by Supernova explosion. Eventually NSs accrete to become ECOs.

3. Very Massive Stars or accreting NSs Collapse to become ECOs; and eventually ECOs withers into the IGM.

4. In an infinitely old universe, even low mass White Dwarfs, Brown Dwarfs, Black Dwarfs have enough time to attain Chandrasekhar mass limit by accretion. Then they too eventually undergo gravitational collapse by either WD or ECO route .. i.e., eventually everything may dissolve into ISM or IGM.

But if there would "Event Horizons" around all central mass condensations, this scheme will certainly fail.

Similarly it has been reported that *Dead' galaxies are not so dead after all*, the elliptical M105 may have sprung into life (Ford & Bregman 2011). If true, this may be suggesting that the compact object in M105 is not a BH but a MECO, and which may have erupted to release fresh plasma to trigger fresh star formation.

Recently, a gas cloud having almost no metallicity has been detected at $Z \sim 3.0$. This has been interpretated as an evidence for primordial Big Bang gas. But how can a primordial gas generated at $Z >>> 1$ can remain unsullied almost upto the present epoch $Z \sim 3$ (Umagalli, O'Meara, & Prochaska 2011). On the other hand, it is much more likely that this low metallicity gas has been born recently from the condensation of some pure plasma ejected by a quasar MECO.

VI. BELCHING & BURPING EVENT HORIZONS?

It has been claimed that the quasar Mrk 231 has been *belching* out plasma (Rupke & Veilleux 2011):

Similarly the nebula S26 in the nearby galaxy NGC 7793 is believed to be powered by a black hole with a pair of collimated jets with power 10^{40} erg/s (Pakull, Soria, & Motch 2010). This jet seems to be 10^4 times more energetic than the X-ray emission from the core. Again this has been explained in terms of *belching* by the modestly massive BH .

It is claimed that "Like cosmic bubble makers, some black holes spew out behemoth blobs of hot gas into their home galaxies" (Finoguenov et al. 2008). .

Obviously such evidences for outflows from the BH candidates could be much better explained by realizing that the BH candidates are actually MECOs with no event horizons.

VII. DISCUSSIONS

In view of the radiative instability of Newtonian supermassive stars they should eventually collapse to become extremely general relativistic objects. However, in view of the fact that trapped surfaces and EHs are not allowed for spherical gravitational collapse (Mitra 2004a, Mitra 2009a), RPSSs, after collapse, are bound to hover just above their instantaneous Schwarzschild radii to become Magnetospheric Eternally Collapsing Objects (MECOs). It was found that MECOs can replace BHs as the compact object in quasars. This possibility gets confirmed by the fact that in oder that timelike geodesics of an infalling particle must remain timelike, there cannot be any Schwarzschild or Kerr BH (Kiselev, Logunov, & Mestvirishvili 2010). Further it was independently shown that the integration constants associated with the Kerr BH are zero ($a = m = 0$). This means that, during continued gravitational collapse, the object must radiate out entire angular momentum and mass-energy asymptotically to attain a state of absolute rest with $a = m = 0$, a state which has no *closed time like curves* in its interior unlike the case of a Kerr BH (Mitra 2004a,b). Further it has also been shown that true Schwarzschild BHs too have zero gravitational mass (Mitra 2009a,b).

Thus the observed BH candidates with finite a and m must be non-singular objects. And it has been found that indeed some of the spinning quasars have *strong intrinsic magnetic fields* which Kerr BHs cannot possess (Schild, Leiter & Robertson 2006, 2008; Lovegrove, Schild, & Leiter 2011). Similarly, the detection of a strong magnetic field $B \sim 10^8$ G near the inner edge of the accretion disk of the compact object in Cygnus X-1 too suggests that the relevant compact object has strong intrinsic magnetic moment (Gnedin, Borisov, Natsvlishvili, Piotrovich, & Silant'ev, 2003). Such evidences support the paradigm that the so-called BH candidates are actually "Magnetospheric Eternally Collapsing Objects" (MECOs): quasistatic ultracompact and ultramagnetized balls of plasma.

By using this paradigm, one can easily understand how the so-called BH candidates radiate their rotational kinetic energy; essentially the spinning MECOs act like extremely general relativistic pulsars (Mitra 2005). By using such a paradigm, most of the observations associated with the BH candidate X-ray binaries have already been explained (Robertson & Leiter 2002, 2003, 2004). Similarly, the crucial observations about Sgr A*, the supposed supermassive BH in the Milkyway too can be explained in this paradigm. The Kpc scale bubble around Sgr A*, detected by Fermi, can be easily understood by assuming a massive outburst from this MECO, a la Eta Carinae, in the past.

Further, it has recently been shown that, the Oppenheimer -Snyder exact solution for BH formation was only a mathematical illusion; a strict zero pressure dust has zero density too $\rho = 0$. Hence OS collapse does not represent any GR collapse at all (Mitra 2011).

Thus all theoretical developments and all observations show that the so-called BH candidates cannot be true BHs. Accordingly, the quasars may indeed contain MECOs rather than true BHs. Further, from the recycling of cosmic material needed to account for birth of new galaxies strongly suggest that quasars contain MECOs. And the presence of "EH" in the universe would deplete the amount of material available for cosmic recyling.

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