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Why the Central Monster in M87 Should Be a Massive DEO Rather than a SMBH?

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Abstract

In this paper, we show that massive envelopes made of highly compressed normal matter surrounding dark objects (DEOs) can curve the surrounding spacetime and make the systems observationally indistinguishable from their massive black hole counterparts. DEOs are new astrophysical objects that are made up of entropy-free incompressible supranuclear dense superfluid (SuSu-matter), embedded in flat spacetimes and invisible to outside observers, practically trapped in false vacua. Based on highly accurate numerical modelling of the internal structures of pulsars and massive neutron stars, and in combination with using a large variety of EOSs, we show that the mass range of DEOs is practically unbounded from above: it spans those of massive neutron stars, stellar and even supermassive black holes: thanks to the universal maximum density of normal matter, $\rho_{cr} \approx 3 \times \rho_0$, beyond which normal matter converts into SuSu-matter. We apply the scenario to the Crab and Vela pulsars, the massive magnetar PSR J0740+6620, the presumably massive NS formed in GW170817, and the SMBHs in Sgr A* and M87*. Our numerical results also reveal that DEO-Envelope systems not only mimic massive BHs nicely but also indicate that massive DEOs can hide vast amounts of matter capable of turning our universe into a SuSu-matter-dominated one, essentially trapped in false vacua.

Keywords

General Relativity, Big Bang, Black Holes, QSOs, Neutron Stars, QCD, Condensed Matter, Incompressibility, Superfluidity, Super-Conductivity

1. Introduction

Modern cosmological observations raised many questions that ΛCDM-cosmologies fail to answer reliably [1] [2] [3] [4] [5]. Among others, after decades of intensive research, the nature of the main three invoked pillars of ΛCDM cosmologies, namely inflation, dark matter and dark energy [6] [7] [8], are still persistent problems with no solutions in sight. Also, very recently, several high redshift galaxies, e.g. $z \geq 7.4$, have been detected that were found to be as massive and developed as our late Milky Way Galaxy [9]. This would suggest that these galaxies most likely have settled into their final configurations within the first 500 - 700 years after the Big Bang, which is too short a time scale. Moreover, the cosmic evolution of the recently detected quasar, UHZ1, which hosts roughly $4 \times 10^7 M_\odot$ massive BH, seems to have formed within the first 370 Myr after the big bang [10], which again hints to unreasonably rapid growth of the BH in that epoch [11].

In previous articles [4] [5] [12], it was argued that these discrepancies arise, because we consider the existence of black holes in our universe a settled problem.

Indeed, based on observation, the existence of massive and invisible dark objects at the centre of numerous galaxies, both in the early and late universe, has been proved to be beyond doubt. The high-resolution and the impressive images of the shadows of the BHs in M87 and Sagittarius A* generated by the Event Horizon Telescope collaboration [13], seem to have provided us with the ultimate evidence.

In **Figure 1**, the horizon of the SMBH in M87 superimposed on a brightness image obtained by the EHT collaboration is shown [13]. The shells depicted with the zigzag lines correspond to the uncertainties in distance and mass measurements and amount to roughly 10%. Here, both the event horizon and the photon ring with their associated uncertainties are inside the shadow of the SMBH candidate. In terms of length scales, these uncertainties correspond to shells having widths of order $R_{Sch}/10 \approx 10\ \text{AU}$. If we fill the blue shell with cold nuclear dense matter, the resulting mass would be of order $10^{28} M_\odot$. This implies that we, as remote observers, cannot decide whether the $6 \times 10^9 M_\odot$ of cold nuclear dense matter is inside the envelope (blue zigzag line) or inside the underlying event horizon.

As it will be shown later, increasing the shell's width up to billions of kilometers by decreasing the average density, it would still safely fall inside the shadow of the SBMH in M87.

Based on theory and observations, both Sag A* and M87 are classified as accreting systems with roughly 90% of the accreted hot plasmas are predicated to cross the event horizon. These plasmas should have emitted about 6% of their rest mass energy when crossing the innermost last stable orbit (ILSO), where they become low radiators and their motions turn predominantly radial [14]. Although the enclosed region appears to be roughly identical to the observed shadows of Sag A* and M87* reported in [13], the related bright spots were verified to originate from the surrounding optically thin accretion disk rather than to the photon rings [15]. Indeed, the latter argument is a consequence of the strongly warped spacetime in the vicinity of the event horizon and not of the

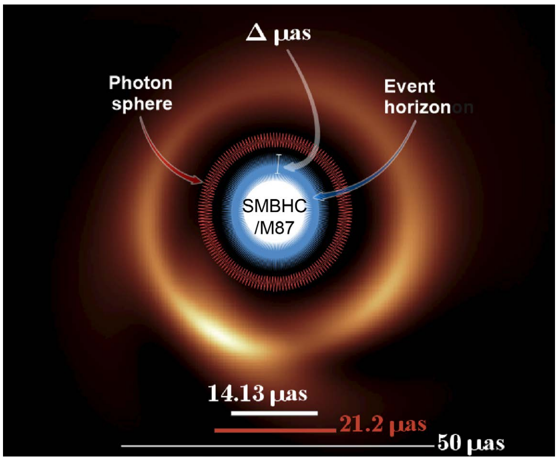

Figure 1. The diameters of the event horizon (blue zigzag line), the corresponding photon sphere (red zigzag line) and of the shadow of the supermassive black hole candidate in M87 superimposed on an image revealed from EHT observations. The widths of the rings with the zigzag lines ($\Delta \mu as$) amount to 10% resulting from uncertainty in distance and mass measurements of the M87-system. Note that both the event horizon and the photon sphere laying deeply inside the shadow-region.

accretion phenomena, and, needless to mention, photon rings are highly unstable and would immediately collapse in the presence of inflowing plasmas [16].

However, there are several fundamental problems related to BHs, in particular:

- The images obtained by the ETH collaboration are not accurate enough to explain whether the bright spots originate from the thin accretion disk or from the photon ring around the BHs in Sag A* and M87*. Also, it is still unclear if the observed jet is powered by the accretion disk or by the boundary layer (BL) between the disk and the event horizon, whose width is roughly 5 × 10^{15} cm. In fact, as the disk is optically thin but geometrically thick, it is practically a hot corona that shields the event horizon. Therefore, the corona should be capable of illuminating 90% of the supposedly infalling particles in the BL and slowing their motions. Thus, the possibility that the BL is a decelerating rather than an acceleration region for the particles should not be excluded [17].
- The nature of the remnant object that should have formed from the merger event in GW170817 [18] [19] is still not resolved. While theoretically agreed that the remnant should end up as a stellar BH, there is still no single conceivable observational evidence that favors this evolutionary track [20] [21].
- The formation of a BH is known to be an energetically irreversible process[1]. However, the incredible amount of mass of normal matter that made up the

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[1] Save Hawking radiation, which can be safely ignored due to its inefficiency.

progenitor of the Big Bang should have collapsed into a giant BH, which contradicts reality. One way to circumvent this paradox was by invoking inflation, though its physical origin remains a mystery.

Noteworthy is the widely accepted argument that the contents of BH's progenitors should crush and disappear in the singularities at their centre, where matter density peaks to infinity. On the other hand, the existence of a maximum universal density, beyond which ultra-cold supranuclear dense matter becomes incompressible is still struggling for acceptance [22], although our current knowledge of the physics of ultra-cold supranuclear dense matter, such as those governing the matter inside the cores of massive NSs, is far from certain [23]. It turns out that the latter possibility gives rise to the formation of new types of objects, DEOs (see **Figure 2**), capable of mimicking stellar and massive black holes nicely. Indeed, this finding was used as the central pillar of the newly proposed model of the universe: UNIMOUN—The Unicentric Model of the Observable Universe [5]. The model may comfortably accommodate recent observations and even provide reasonable answers to several open questions in astrophysics and cosmology. The properties that are relevant for the present study read:

- The progenitor of the Big Bang (BB) was a giant dark energy object (DEO) made of SuSu-matter. The effects of incompressibility here are threefold: 1) The matter is governed by a constant density $\rho = \rho_{cr} \approx 3\rho_0$, 2) Spacetimes embedding SuSu-cores must be flat, which is necessary for preserving causality, 3) The progenitor of the BB was of a measurable macroscopic size. Based thereon, the radius of the progenitor is predicated to be of the order of several AUs (Hujeirat, 2023). Prior to hadronization, the spacetime embedded in both the progenitor of the BB and its surroundings must have been completely flat.
- The compressibility of matter in our universe has a limited range [22]: [$\rho_{vac} \le \rho \le \rho_{SuSu}$]. Among others, it may explain: 1) Why the current average density of the universe, $\langle \rho \rangle_{nm}^{universe}$, is of the same order as the cosmological vacuum density ρ_{vac}^{Λ}: known as the coincidence problem in cosmology. The latter value may be derived from the cosmological constant. Hence, creating virtual particles in the low-density regime ensures that $\rho \ge \rho_{vac}$ must hold, even when the universe continues to expand. Indeed, recently $\langle \rho \rangle_{vac} = \rho_{nm}^{universe}$ was taken to be the average density of the parent universe [22]. On the other hand, the upper-bound is vital for addressing the possibility that massive collapsars should not necessarily end up forming black holes, which applies to the first generation of massive stars as well as to the remnant of the merger event GW170817 [18] [24]. 2) Objects made up of SuSu-matter with $\rho = \rho_{SuSu}$ are invisible to remote observers, as the state of matter here corresponds to zero-point energy and, therefore, must be trapped in a false vacuum. Similar to gluon-quark plasma inside isolated nucleons, SuSu-cores must be confined by powerful tensorial surface tensions that render their communication with the outside world impossible.

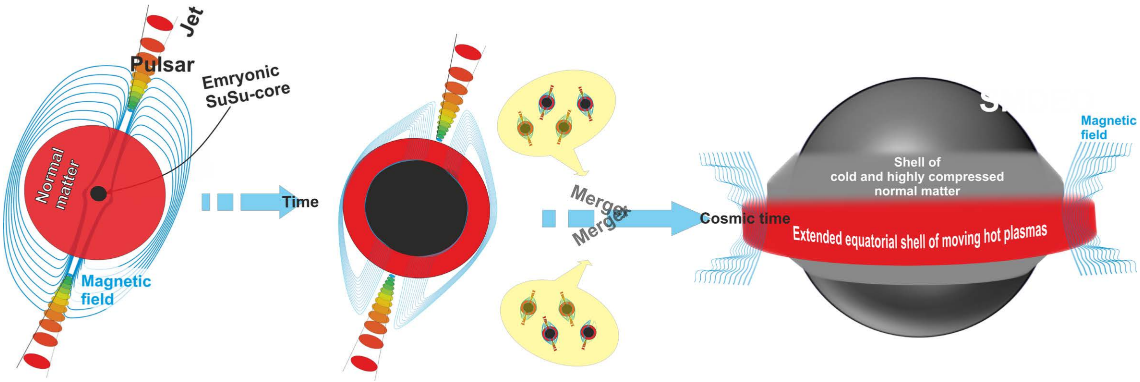

Figure 2. A schematic description of the DEO-RING model: Pulsars are born with embryonic SuSu-cores, whose growth evolves discretely with time and is associated with glitch events. However, massive pulsars should convert entirely into DEOs. On much longer cosmic time scales, DEOs may grow via merger and powerful accretion to end up as supermassive DEOs (SMDEOs). The resulting system consists mainly of three components: 1) A central SMDEO, 2) An envelope of cold and highly compressed normal matter (which resembles BH-candidates, and 3) An extended equatorial ring filled with hot moving plasmas.

- At a particular instance of time, the giant DEO serving as the progenitor of the BB, underwent an abrupt decay, triggering thereby a hadronization front that started propagating from outside-to-inside and converting the SuSu-matter into normal compressible and dissipative matter. The newly created normal matter behind the front started curving the embedding spacetime but ended roughly one hour after the progenitor completed hadronization. Since then, the flattening process has been ongoing and will finally diffuse out into the vast flat-parent universe.
- The progenitor of the BB happened to occur in our neighbourhood, thereby endowing the universe the observed homogeneity and isotropy.

2. Numerical Methods & Results

Our numerical investigation is based on solving the TOV equation from outside to inside, using a large sample of verified EOSs [23]. For a given mass of normal matter $\mathcal{M}_{nm}$, we use the corresponding Schwarzschild radius as the radius of the enclosed DEO[2], *i.e.* $R_{DEO} = R_{Sch} = 2G\mathcal{M}_{nm}/c^2$. However, for $r \le R_{DEO}$. the spacetime is flat, and therefore, the curvature of the external field is uniquely determined by the normal matter outside the enclosed DEO, *i.e.* in $r > R_{DEO}$. Using a sample of EOSs, the TOV equation is then solved iteratively, starting from an initial outer radius, until the given maximum density ρ_{max} at R_{DEO} and $\mathcal{M}_{nm}$ are recovered. In massive NSs, ρ_{max} may easily attain values of order $\rho_{cr} = 3\rho_0$ or even beyond, though in the case of massive BH-candidates, ρ_{max} may be much lower than ρ_{cr}, if reasonable widths of the surrounding normal matter shells, δR_{sh}, are to be obtained.

Indeed, this strategy was found to apply nicely to the well-studied Crab and Vela pulsars, as here R_{DEO} was found to differ only slightly from the corres-

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[2] The reason therefor will be clarified later.

ponding Schwarzschild radius R_{Sch}.

Hence the normal matter outside R_{core} is the agent that dictates the topology of the spacetime outside a DEO. Massive envelopes curve the embedding spacetime strongly, leading to enhanced compression and, therefore to higher ρ_{max} at R_{DEO}. It should be noted that the widths of the envelopes are decidedly important for the validity of field equations, as δR_{sh} around supermassive DEOs may fall to microscopic length scales.

In **Figure 3**, we show the density-radius relation for two well-known pulsars, the magnetar PSR J0740+6620 and the remnant massive NS in GW170817. Each object consists of a SuSu-core surrounded by an envelope of normal matter. The mass content inside the envelope is taken to be the one making up the object's mass revealed from observations.

However, the object inside R_{Sch}, is not a black hole but rather a DEO. Recalling that DEOs are made up of incompressible SuSu-matter, then the mass-radius relation obeys the following relation:

$$M_{DEO} = \left(\frac{4\pi}{3} R_{Core}^3\right)\rho_{cr} = 4.4\times10^{-2}\left(\frac{R_{Core}}{R_{Sch,\odot}}\right)^3 M_\odot, \tag{1}$$

where $R_{Sch,\odot}$ denotes the Schwarzschild radius of the Sun. For clarity, in the

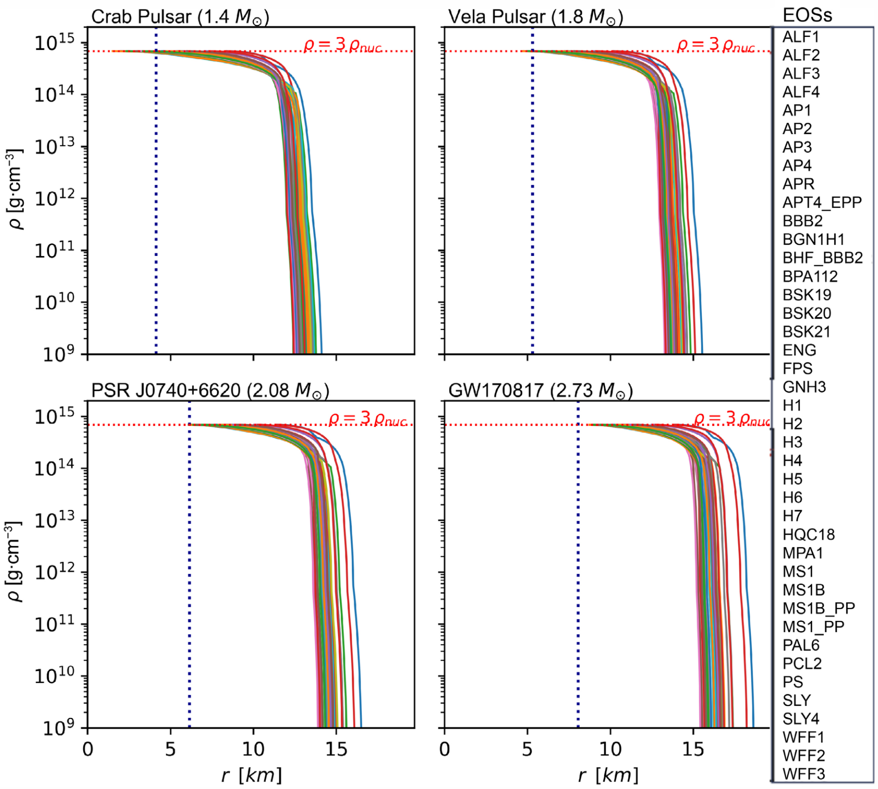

Figure 3. The density-radius relation for the Crab and Vela pulsars as well as of the magnetar PSR J0740+6620 and the presumably remnant NS in GW170817, using a variety of EOSs (right column). The blue vertical dashed lines denote the Schwarzschild radii that are set to coincide with the radii of the enclosed DEOs.

following table, we show several selected masses of BHs as opposed to the masses of their DEO counterparts in units of solar mass:

$\mathcal{M}_{nm}/\mathcal{M}_\odot$	$\mathcal{M}_{DEO}/\mathcal{M}_\odot$
10^2	4.4×10^4
10^4	4.4×10^{10}
3×10^6	1.32×10^{17}
6×10^9	2.64×10^{26}

(2)

The table shows that when replacing BHs with DEOs, the masses hidden behind their event horizon exceed those of BHs by many orders of magnitude.

However, it turns out that in order to obtain the observed mass of the massive BH with the matter density $\rho(r=R_{DEO})=\rho_{cr}$, then δR_{sh} decreases down to microscopic values, where the macroscopic field equations turn invalid.

In **Figure 4**, it is shown that a massive shell made of stratified normal of $100\mathcal{M}_\odot$ with $\rho(r=r_{in})=\rho_{cr}$, has a width $\delta R_{sh}<1$ km, yielding the ratio $\Delta_{schell}/R_{Sch}<10^{-2}$. Although the ratio here is relatively small, it is of order as those corresponding to viscous boundary layers.

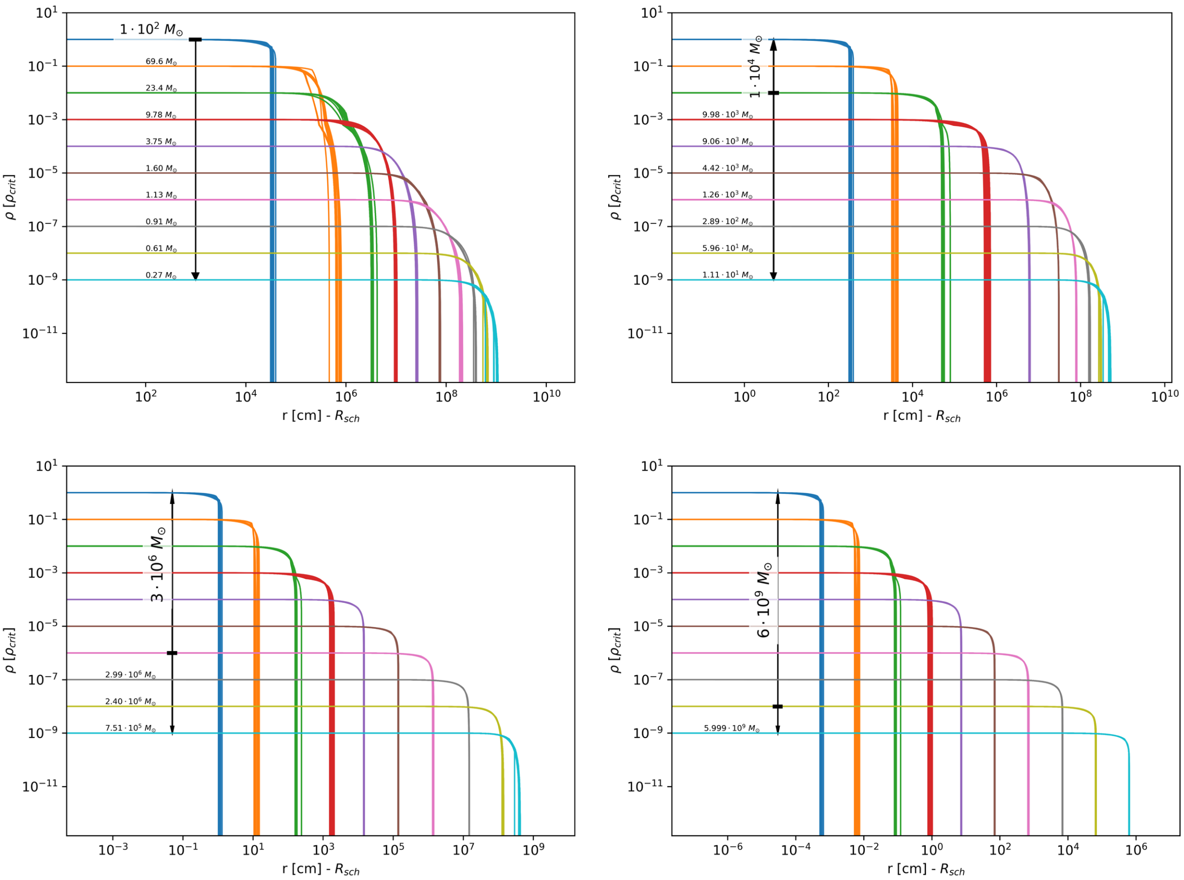

Figure 4. The density-radius relation for 10^2, 10^4, 3×10^6 and 6×10^9 solar masses rings of normal matter that set to surround the central DEOs. The radii of the enclosed DEOs are identical to the Schwarzschild ones and correspond to 10^2, 10^4, 3×10^6 and 6×10^9 solar masses. For a given mass envelope's mass and maximum matter density at R_{DEO}, the widths of the envelopes are obtained by integrating the TOV equation from outside-to-inside using a variety of EOSs.

As shown in the same figure, the width of the shell may be made greater if the maximum density of normal matter is allowed to acquire lower values than ρ_{cr}, though the integrated mass $\mathcal{M}_{nm}$ falls then to reach the observed mass.

Also, Figure 4 shows that the ratios of $\delta R_{sh}/R_{Sch}$ decrease with increasing the mass of the BH-candidate, and, it may even drop down to unreasonably small values, such as 10^{-17} for the BH in M87, provided that $\rho(R_{DEO}) = \rho_{cr}$. However, the $\delta R_{sh}/R_{Sch}$ may be increased, if $\rho(R_{DEO})$ is allowed to attain much lower values than ρ_{cr}. Indeed, the predicted mass of the BH in M87 may be compressed into a shell, with $\delta R_{sh} \approx 10$ km for $\rho(R_{DEO}) \approx 10^{-9}\rho_{cr}$. This yields a huge density gap:

$$\rho = \begin{cases} \rho_{cr}, & \text{for } r \le R_{DEO} \\ \rho_{nm}, & \text{at } r = R_{in}, \end{cases} \tag{3}$$

where R_{in} denotes the inner radius of the shell. Depending on the ratio $\alpha_{cr}^{nm} = \rho_{nm}/\rho_{cr}$ across R_{DEO}, the following consequence may be drawn:

In the absence of powerful sources of normal matter, e.g. rapid mergers with stars and galaxies, the growth rates of most observed SMBH candidates may easily stagnate. This is due to the extraordinarily large area of the spherical surface at $r = R_{Sch}$ of SMBHs. A shell with an unreasonably small thickness, δR_{sh}, may still accommodate an extraordinarily large amount of normal matter. However, the inertia of the shell relative to that of the embedded DEO may be estimated as follows:

$$\frac{I_{shell}}{I_{DEO}} \sim \frac{1}{\rho_{cr}} \frac{\mathcal{M}_{shell}}{R_{DEO}^3} \approx \alpha_{cr}^{nm} \left(\frac{\delta R_{sh}}{R_{DEO}} \right). \tag{4}$$

Recalling that:

$$\left\{ \alpha_{cr}^{nm}, \frac{\delta R_{sh}}{R_{DEO}} \right\} \ll 1$$

we conclude that, in the absence of a powerful supply of normal matter from external sources, the ratio $\frac{I_{shell}}{I_{DEO}}$ remains negligibly small. Also, as DEOs inside pulsars are quantum entities, their mass growths are expected to follow a well-defined sequence of glitch events, whose reoccurrences found to anticorrelate their masses and ages [25]. Recalling that DEOs are embedded in flat spacetime and made of incompressible SuSu-matter, then their growths may evolve according to the time-dependent Onsager-Feynman equation of superfluidity:

$$\frac{\mathrm{d}}{\mathrm{d}t}\left(M_{DEO}^{2/3} \Omega \right) \approx a \frac{\mathrm{d}N}{\mathrm{d}t}, \tag{5}$$

where $\{S, \Omega, N\}$ denote the cross-section of the DEO, the rotational frequency of normal matter that set to merge with the DEO and the enclosed number of vortices. Assuming the newly created vortices at the base of the shell to go into powering the highly energetic jet in M87 during glitching, then a small change of Ω requires a great amount of dense and cold normal matter to convert into

SuSu-matter and merge with the SMDEO, though such large amounts of normal matter are hard to find in our dilute universe. Nonetheless, this behaviour is similar to DEOs inside massive pulsars, where the repetitiveness of glitch events is observed to decrease with their masses and ages [25] [26]. The width of the normal matter shell δR_{nm} may be estimated as follows:

$$\delta R_{Sh} \approx \frac{M_{nm}}{A_{DEO}\left\langle \rho \right\rangle} \approx \left[\frac{M_{\odot}}{4\pi R^2_{Sch,\odot}\rho_{cr}}\right]\frac{1}{\alpha_{DEO}}\frac{\rho_{cr}}{\left\langle \rho \right\rangle} = 2.2\times 10^6\,\frac{1}{\alpha_{DEO}}\frac{\rho_{cr}}{\left\langle \rho \right\rangle}\,\text{cm}, \tag{6}$$

where $A_{DEO}, R^2_{Sch,\odot}, \alpha_{DEO}\left(\doteq M_{nm}/M_{\odot}\right)$ denote the surface area of the DEO, the Schwarzschild radius of the Sun and the mass of the observed object in units of solar mass, respectively. As shown **Figure 5**, δR_{nm} decreases with increasing DEO-masses, *i.e.* with α_{DEO}, but may increase if the matter density at the base of the shell is allowed to be lower than ρ_{cr}. Such a correlation is problematic for massive BH-candidates: for large α_{DEO} and $\left\langle \rho \right\rangle \approx \rho_{cr}$, δR_{Sh} may drop down to microscopic values, where the validity of field equations breaks down. Hence, in most of cases $\left\langle \rho \right\rangle$ is much lower than ρ_{cr}, implying that SMDEOs spend most of their lifetimes without a significant growth.

This may explain the extreme rarity of BB-explosions inside our observed universe, though the probability that next BB takes off is around the corner. Based on the here-presented scenario, the region between the event horizon and the ILSO, *i.e.* [$R_{Sch} \le r \le 3R_{Sch}$], is the one where the matter settles down and liberates its secondary energies in the form of radiation in many frequency bands, as well as powering the energetic jet observed to emanate in these systems.

On these length scales, however, the mass growth of the central SMDEO may easily stagnate due to the absence of extensive matter supply needed to generate the conditions appropriate for converting normal matter into SuSu-matter. This, in turn, requires the embedding spacetime to be sufficiently curved to enable compressing the normal matter up to supranuclear densities.

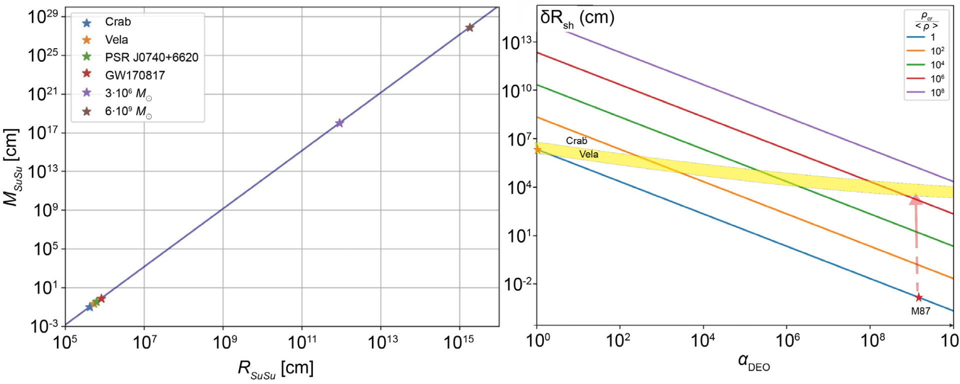

Figure 5. The mass contents of stellar and supermassive DEOs versus radii. These are governed by $\rho = \rho_{cr} = const.$ and therefore their masses increase linearly with their radii on the logarithmic scale (left panel). In the right panel, the widths of the envelopes of normal matter versus mass for different ratios of ρ_{cr} over the mean density $\left\langle \rho \right\rangle$ are shown (see Equation (6)).

Recalling that the gradients of the gravitational potential and pressure vanish at the centre of compact objects, which render the matter incompressible, these conditions may safely apply at the base of the shells, where the spacetime undergoes a topological change from a curved into a flat one, though in a discontinuous manner (see Figure 5 in [27]).

3. DEOs and the Holographic Principle

Originally invented to resolve the problem of the quantum information paradox in BH's evaporation systems, it is tempting here to investigate its validity for systems containing DEOs [28] [29].

Recalling that DEOs are made up of incompressible supranuclear dense entropy-free superfluids (SuSu-matter), and motionless and embedded in flat spacetimes, then, perturbations due to local pressure are doomed to vanish, *i.e.* $\forall\, r \le R_{core} : \nabla P_{local} = 0$, and therefore communications between the constituents can be mediated by one single speed: the speed of light. However, this necessitates that all the constituents be fully coupled, forming a single quantum entity and occupying one quantum state. Due to causality, the constituents making up the macroscopic entity are prohibited from moving in space, though they may vibrate in space collectively, depending on the boundary conditions imposed on the confining 2D surface.

The situation here is strikingly similar to modelling the dynamics of weakly compressible terrestrial fluids, where the non-local pressure imposed on the boundaries, *i.e.* the Lagrangian multiplier, determines the dynamics of the enclosed fluids.

However, the case of the above-mentioned macroscopic entity may become even more straightforward, as:

- The constituents are everywhere the same.
- They share the same quantum energy state.
- The speed of light is the only permitted communication speed.

This implies that only a bunch of quantum information is needed to describe the 3D structure of the macroscopic entity, which may safely be encoded on the corresponding confining 2D surface. As the number of permitted quantum states associated with the entity counts to one, $\Omega = 1$, then its entropy must vanish: $S = k_B \ln(\Omega) = 0$. This is by no means comparable to the Bekenstein-Hawking entropy of BHs: $S_{BH} \approx A/\ell_P^2$, which is approximately twenty orders of magnitude larger than the entropy of the BH's progenitor [22]. Similar to gluon-quark plasmas inside isolated nucleons, the above-mentioned macroscopic entities are incapable of surviving in free space, hence the confining membrane maintains them invisible to outside observers, practically trapping them in false vacua.

4. Summary & Conclusions

This paper shows that massive DEOs are observationally indistinguishable from their massive black hole counterparts. Born as embryonic SuSu-cores inside newly formed pulsars, they should grow as the embedding pulsars cool down. Their growths proceed discretely with time and are associated with glitch events, during which compressible and dissipative normal matter is converted into incompressible supranuclear dense entropy-free superfluids (SuSu-matter). Spacetimes embedding cores of SuSu-matter were verified to be flat and confined by membranes that render them invisible to remote observers, practically trapped in false vacua.

We have shown that the mass range of DEOs is unbounded from above; they safely encompass those of massive pulsars, neutron stars, and stellar and supermassive black holes.

As in the case of massive NSs, the mass of the cold and highly compressed normal matter surrounding the enclosed DEOs determines the topology of the exterior spacetime. However, the effects of normal matter in the shells weaken as cosmic times go on and the masses of the enclosed DEOs increase. Indeed, this has been manifested by the observations of glitching pulsars, revealing that the repetitiveness of glitch events decreases as pulsars age. Similarly, massive DEOs also undergo glitching, though the amount of mass of normal matter needed to facilitate such events must be sufficiently large, which may be supplied through extensive mergers and extremely powerful accretion. As shown in Equation (4), the moments of inertia of normal matter surrounding the DEOs inside the Crab and Vela are significant, and therefore they may easily trigger the glitch events observed. For an SMDEO with roughly $10^{28} M_{\odot}$, such as im M87, the width of the shell relative to the radius, *i.e.* $\delta R_{sh}/R_{Sch}$ is negligibly small, and therefore the field equations may fail to apply. This implies that δR_{sh} should vary slowly with the mass content of normal matter, as depicted in the yellow horizontal strip in (see **Figure 5**). In the present universe, there is too little normal matter to supply such a huge amount of normal matter (e.g. $10^{10} M_{\odot}$), hence why the mass growths of most SMDEOs need super cosmic time to grow significantly.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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