Dynamic Gravastars: A short review

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The main physical ideas about Dynamical Gravastars, are briefly presented in common with the main properties of their field configuration. Also, we estimate the place that these solutions should take within the current astrophysical ideas for describing the super-massive galaxy centers and stars.

The internal structure of the observed compact objects (CO) is actually one of the most debated open problems in astrophysics. In addition, the recent technological milestones, as the gravitational wave experiment like Ligo-Virgo, and the observation by the Event Horizon Telescope of the CO $M87^*$, had began a decade of astrophysics models test. This advances had opened a door to a new word of theoretical models, that try to better explain the observations.

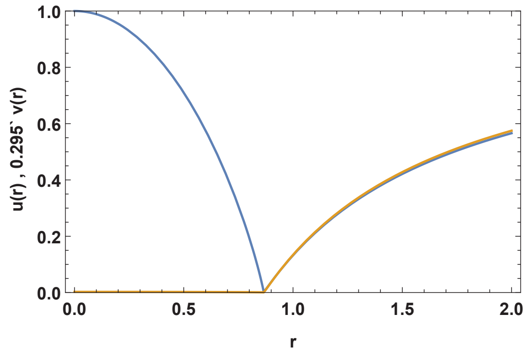
Dynamical Gravastars (DG) are compact objects models that had been recently advanced in reference [1]. These field configurations arise from solving the Einstein-Klein-Gordon (EKG) equations, by also including direct interaction terms between the scalar field and matter. The model is similar to the first gravastar proposed by Mazur and Motola (that we will name as MMG) in 2004, from which it takes part of its name [4]. As in the MMGs, the principal property of the DGs is they singularity free central region. However, unlike the MMG's structure, in the DG a "more" dynamical scalar field plays a role analogous to the De Sitter space in the known MMG. The possibility for such static scalar field solutions of the EKG equations to exist, is essentially allowed by the assumed direct interaction between the scalar field and matter. In other words, in the DG, is the scalar field which plays the role of the cosmological constant that repels matter in the MMG solutions. This property is the one suggesting the *Dynamical* adjective in the name of the DGs.

The structure of the Dynamic Gravastar

The EKG field equations solved in reference [1] for arguing the existence of the DG, can be compactly written as follows:

$$
\begin{aligned}
T_{ij}[\phi, e, J[n_\alpha, e]] - \frac{1}{2} g_{ij} \times & \\
T_{ij}[\phi, e, J[n_\alpha, e]] &= R_{ij} \qquad (1)\\
\nabla_\mu T_{\mu\nu}[\phi, e, J[n_\alpha, e]] &= 0 \qquad (2)\\
\Phi[\phi, e, J[n_\alpha, e]] &= 0 \qquad (3)
\end{aligned}
$$

where the indices i, j take values $\{0, 1\}$ and correspond to the temporal and radial components of the energy momentum tensor. The squared bracket defines the functional dependence of the energy momentum tensor $T_{\mu\nu}$ with the scalar field ϕ, the matter energy density e and the source of the scalar field $J[n_\alpha, e]$. The second equation is the Bianchi identity which physically



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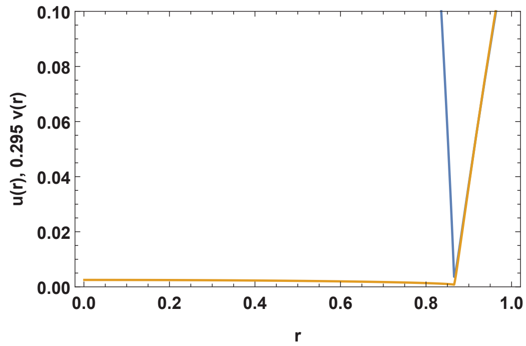

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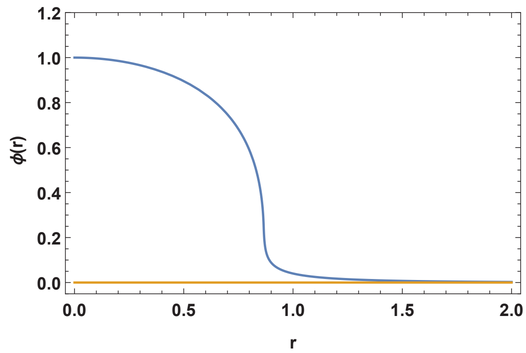


(c)

Figure 1: (a) The DG's covariant temporal metric component $v(r)$ (Y) and the contra-variant radial component $u(r)$ (B). (b) The same quantities, but for an augmented magnification, showing the radial region in which the metric avoids the change in signature. (c) The radial dependence of the scalar field, showing its cosmological constant like behavior at low radii and the Yukawa like decaying at large distances.

determines the mechanical equilibrium of the system. $\Phi = 0$ represents the Klein-Gordon (KG) equation of the massive real scalar field. The solution was searched as having spherical symmetry and a direct interaction of the scalar field with matter. For simplicity in the Einstein field equations, only the ones corresponding to the temporal and radial components of the energy momentum tensor and the Bianchi identity one were included in the equation solved. This was done because the two angular components are equal, and were substituted by the Bianchi equation. The set of equation were completed after adding the constitutive relation between the pressure and energy density of matter. Two types of matter were considered: an elastic body and a polytropic gas, though the relation

$$e = e[k_\alpha, p] \tag{4}$$

where k_α indicates the type of matter. The n_α and k_α represent the set of parameters of the equations that determine a particular solution. It can be remarked that by varying the parameters of Eq. 3 it can to expected to obtain a variety of mixed boson stars [2, 3].

It should be underlined the fact that the main element allowing the DG solutions to exist is the presence of scalar-field-matter interaction. This interaction was introduced by assuming that the source $J(r)$ of the scalar field is proportional to the matter energy density $\epsilon(r)$ (which is at rest in the DG). Such static solutions don't exist for the regular EKG equations.

The radial dependence of the DG field configurations are illustrated in figures 1a, 1b and 1c. Figure 1a shows the temporal component of the covariant metric $v(r) \equiv g_{tt}$ and the radial one (but of the contravariant metric) $u(r) \equiv g^{rr}$ in common. It should be noted that the metric for radial distances larger than r_b rapidly tends to the Schwarschild space-time one. For the internal region of radius $r < r_b$, both $v(r)$ and $u(r)$ tend to constant values at the origin, but with $v(0)$ much smaller than $u(0)$. However, the main property of the DG solution follows from the radial region in the vicinity of r_b. As it can be observed from figure 1a, the metric components although closely approaching to modify their signature, by changing the signs of $u(r)$ and $v(r)$ (as it happens in the Schwarzschild black hole) suddenly start growing after even more reducing the radial position. This behavior is closely similar to the one shown by the standard MMG, and indicates that almost all the mass of looks from faraway distances as being inside a Schwarzschild black hole, but in fact it is within a space-time without a signature change of the metric. That is, in the absence of a central singularity. The figure 1b is simply a magnification of the radial region being close to the radius r_b. It shows, that the $u(r)$ and $v(r)$ for the particular solution obtained, closely approaches to define an horizon, but suddenly change their slope and start growing upon diminishing the radial position.

The radial behavior of the scalar is shown in figure 1c. The picture clearly illustrates that the scalar field in the DG plays a closely similar role to the one implemented by the cosmological constant of the De Sitter solution, in the MMG: contributing in the internal region with smooth varying energy density and crating a negative contribution to the pressure in the same region. That is, qualitatively, it can be imagined as if the cosmological constant of the MMG had been substituted by a dynamical quantity: the scalar field. It should be commented, that the Yukawa like behavior of the scalar field in the large radial direction was obtained after varying the initial conditions of the scaler field at the origin. For deviations of the initial conditions of proper values, the the scalar field at large distances either tend to large positive or negative values in dependence of the sign of the deviation. The DG solution was following after iterating this deviation in order to approach the decaying Yukawa like behavior in the faraway regions.

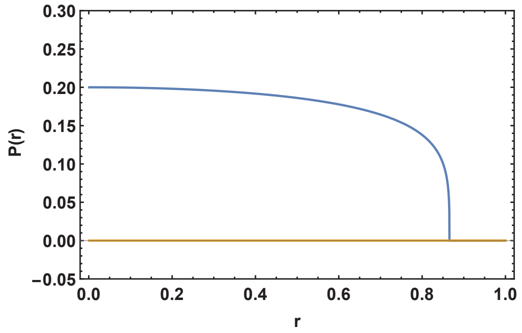
The pressure radial dependence is shown in figure 2a. The pressure vanishes in the outside region $r > r_b$ and smoothly varies in the internal region $r < r_b$ for approaching a finite value at the symmetry center. In referenc [1] a condition was derived which determines the radial point r_b at which the sudden change of the pressure to zero occurs. The condition was expressed by a function $Z(r)$ which zero value determines r_b. Figure 2b depicts the radial dependence of the function $Z(r)$ which zero value defines the radius r_b.

Summarizing, the DG have a structure composed by: a non singular core in which a real massive scalar field in interaction with matter represent a collapsed matter, which shows no singularity. This core is delimited by a spherical symmetric surface, at the boundary of which the metric approximates, but not arriving, to form an event horizon. Outside this central zone a Schwarzschild like space-time surround this configuration. A sketch of the metric component is shown in figures 1a,b. Some relevant aspects of this configuration are the following. The coupling between the scalar field and the matter has a central role in determining the existence of the solution. From the metric functions form in figure 1a,b , it is expected that a kind of " matter wall" appears around this surface at $r = r_b$, in which the accreting matter in the DG will scatter. This last point could be fundamental for observationally distinguish the DG from a black hole, in which a weak accretion matter dispersion is expected.

Phenomenology

As it occurs for other hypothesized compact objects the DGs connection with the phenomenological background information is unclear yet. But, there are some theoretical frames which give hints about where to look for them in Nature.

One important and new research area is related with recently performed black-hole photographs [5]. The current limited resolutions of the photographs are still



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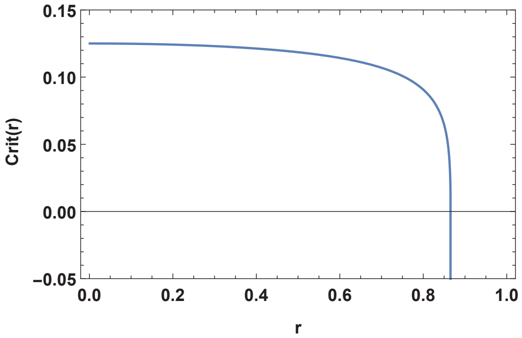

(b)

Figure 2: The figure (a) illustrates how the pressure of the elastic body varies on going away from the symmetry center. It slowly diminishes from the finite value at the origin and suddenly drops to zero at the radius r_b. Figure (b) shows the function $Z(r)$ whose vanishing determines r_b.

not allowing to resolve the details about how accreting matter enters the central compact object. The ongoing search for improving this resolution might solve this difficulty. Then, it becomes of interest to improve the knowledge about what kind of structures these compact objects can have. The first possibility under consideration is a Schwarzschild black hole. However, the MMG constitutes one alternative of a structure not showing a central singularity, which is recognized as an allowed possibility. Therefore, we expect that the DG will furnish a second alternative to the black hole nature of the photographed compact objects [5].

The DG solutions can also be investigated for its consequences for the existence and constitution of a Primigenial Dynamic Gravastar (PDGs) forming in inflationary scenarios. One noteworthy property is its nonrotational configuration. Therefore, a formation mechanism, similar to the investigated formation processes of the Primigenial Black Hole in the early universe, can be investigated for the DG. This can be an alternative to the usually considered mechanism of compact object formation as an ending state of of stars. However the rotational variants of DGs are still not derived, although its existence is possible [6].

Finally, consider by example the scalar field in interaction with matter in the core of the DG. This core constituency directly suggests the possible relevance of the string theory in this region. This idea comes form the fact that the sizes of the compactified dimensions (the moduli) constitute scalar fields in the low energy field theory versions of the string theories. Thus, in the effective Lagrangians of these field theories it can be expected to appear interaction terms of scalar fields with matter of the sort considered in reference [1].

Conclusions

A Dynamic Gravastar is a recently proposed in reference [1] compact object model, which arises as a solution of the Einstein-Klein-Gordon equation including matter which directly interacts with the scalar field. With its internal configuration associated to non exotic physics, it would be an alternative to other objects, such as classic black holes and MMG, for understand the nature of the observed compact objects at the galactic centers. It can be expected that in the next decade, with the planned increase of the Event Horizon Telescopic resolution it may be possible to distinguish the DG's from the black holes or MMGs by observing their different scattering of the accreted matter.

Notes

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