Exotic objects

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This handout provides a short list of conjectured exotic objects[1]

Quark stars and strange stars: A quark star is a hypothesized object that results from the decomposition of neutrons into their constituent up and down quarks under gravitational pressure. It is expected to be smaller and denser than a neutron star, and may survive in this new state indefinitely, if no extra mass is added. Quark stars that contain strange matter are called strange stars.

Electroweak stars: An electroweak star is a theoretical type of exotic star in which the gravitational collapse of the star is prevented by radiation pressure resulting from electroweak burning; that is, the energy released by the conversion of quarks into leptons through the electroweak force. This process occurs in a volume at the star's core approximately the size of an apple and containing about two Earth masses.

Preon star: A preon star is a proposed type of compact star made of preons, a group of hypothetical subatomic particles. Preon stars would be expected to have huge densities, exceeding 10^{23} kg/m^3. They may have greater densities than quark stars, and they would be heavier but smaller than white dwarfs and neutron stars. Preon stars could originate from supernova explosions or the Big Bang. Such objects could be detected in principle through gravitational lensing of gamma rays. Preon stars are a potential candidate for dark matter.

Boson star: A boson star is a hypothetical astronomical object formed out of particles called bosons (conventional stars are formed from mostly protons, which are fermions, but also consist of Helium-4 nuclei, which comprise bosons). For this type of star to exist, there must be a stable type of boson with self-repulsive interaction; one possible candidate particle is the still-hypothetical "axion" (which is also a candidate for the not-yet-detected "non-baryonic dark matter" particles, which appear to compose roughly 25% of the mass of the Universe). It is theorized that unlike normal stars (which emit radiation due to gravitational pressure and

[1] text adapted from `https://en.wikipedia.org/wiki/Exotic_star` and `https://en.wikipedia.org/wiki/Gravastar`.

nuclear fusion), boson stars would be transparent and invisible. The immense gravity of a compact boson star would bend light around the object, creating an empty region resembling the shadow of a black hole's event horizon. Like a black hole, a boson star would absorb ordinary matter from its surroundings, but because of the transparency, matter (which would probably heat up and emit radiation) would be visible at its center. Simulations suggest that rotating boson stars would be torus, or "doughnut-shaped", as centrifugal forces would give the bosonic matter that form. As of 2024, there is no significant evidence that such stars exist. However, it may become possible to detect them by the gravitational radiation emitted by a pair of co-orbiting boson stars. Boson stars may have formed through gravitational collapse during the primordial stages of the Big Bang. At least in theory, a supermassive boson star could exist at the core of a galaxy, which may explain many of the observed properties of active galactic cores. Boson stars have also been proposed as candidate dark matter objects, and it has been hypothesized that the dark matter haloes surrounding most galaxies might be viewed as enormous "boson stars".

Planck star: In loop quantum gravity, a Planck star is a theoretically possible astronomical object that is created when the energy density of a collapsing star reaches the Planck energy density. Under these conditions, assuming gravity and spacetime are quantized, there arises a repulsive "force" derived from Heisenberg's uncertainty principle. In other words, if gravity and spacetime are quantized, the accumulation of mass-energy inside the Planck star cannot collapse beyond this limit to form a gravitational singularity because it would violate the uncertainty principle for spacetime itself. This would be a "quantum way" towards the elimination of singularities like those predicted to exist inside Schwarzschild black holes. These stars would however be really extreme. The Planck length is derived from a combination of fundamental constants that yields a length:

$$G \approx 6.7 \times 10^{-11}\ \mathrm{N\ m^2\ kg^{-2}}; \quad c \approx 3 \times 10^{8} \mathrm{m\ s^{-1}}\ \hbar \approx 1.1 \times 10^{-34} \mathrm{J\ s}$$

$$\Rightarrow \quad \ell_{\mathrm{Planck}} = \sqrt{\frac{G\hbar}{c^3}} \approx 1.6 \times 10^{-35} \mathrm{m} \quad (1)$$

Similarly, it is possible to define a Planck volume and a Planck mass

$$\ell^3_{\mathrm{Planck}} = \sqrt{\frac{G^3\hbar^3}{c^9}} \approx 4.2 \times 10^{-105} \mathrm{m}^3; \quad m_{\mathrm{Planck}} = \sqrt{\frac{\hbar c}{G}} \approx 2.2 \times 10^{-8} \mathrm{kg} \quad (2)$$

Finally, the Planck density of a Planck star would be something like

$$\rho_{\mathrm{Planck}} \approx 5.2 \times 10^{96} \mathrm{kg/m}^3. \quad (3)$$

Gravastar: A gravastar is an object hypothesized as an alternative to the black hole theory. It has usual black hole metric outside of the horizon, but de Sitter metric inside. On the horizon there is a thin shell of matter. The term “gravastar” stands for “gravitational vacuum star”. In a gravastar, the event horizon is not present, and due to the absence of an event horizon the time coordinate of the exterior vacuum geometry is everywhere valid.