Astrophysical aspects of string compactifications

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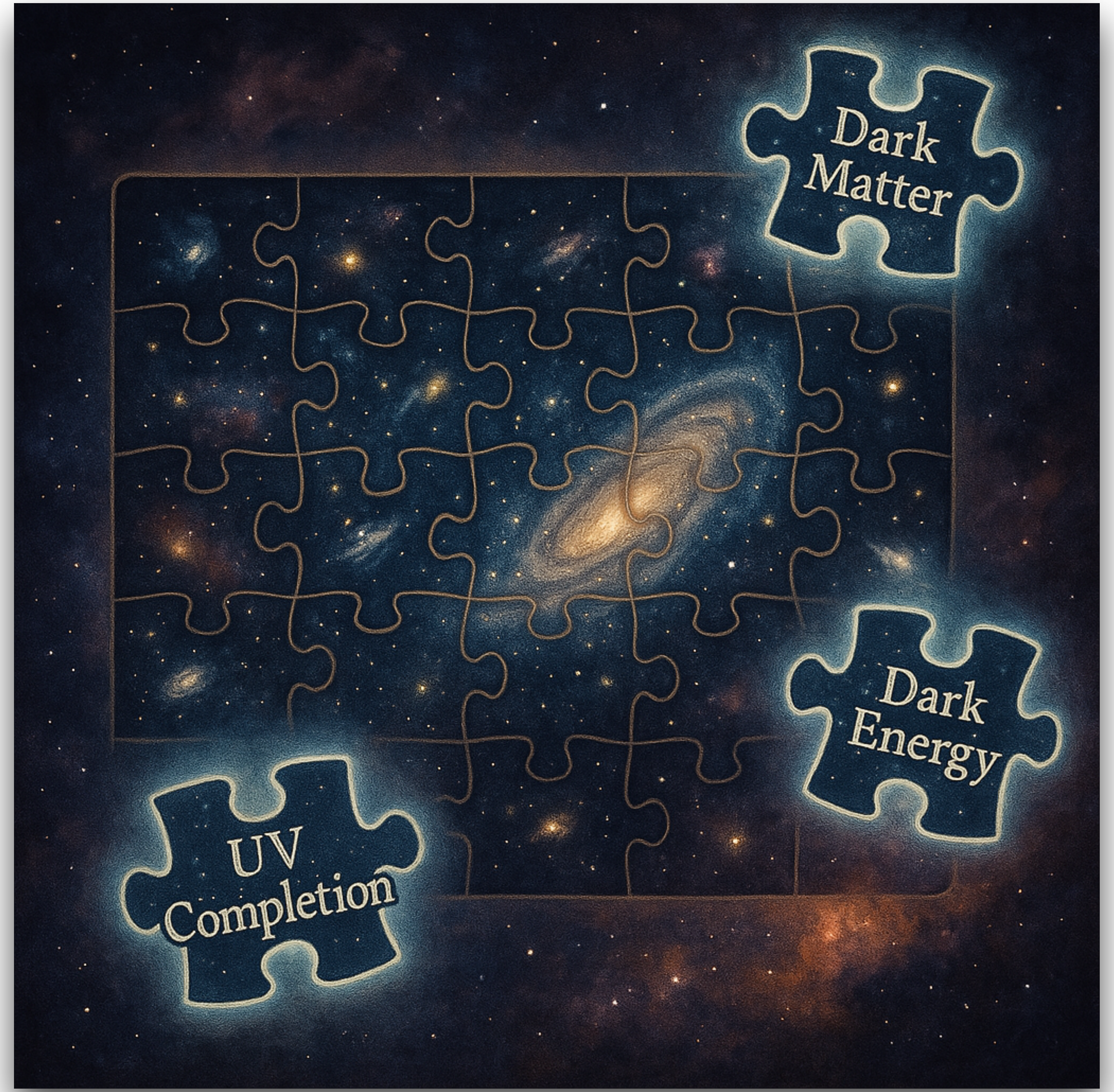

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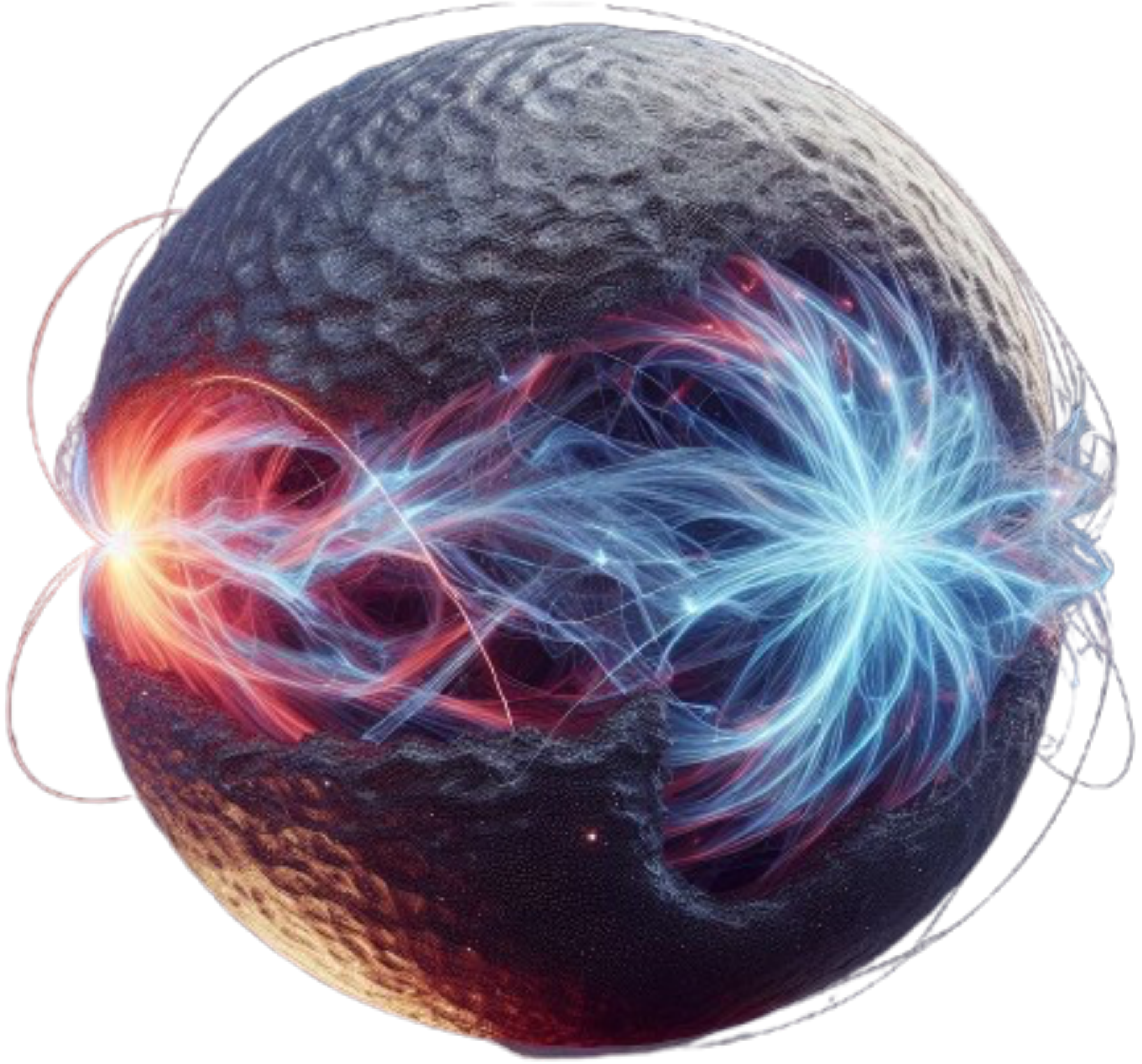

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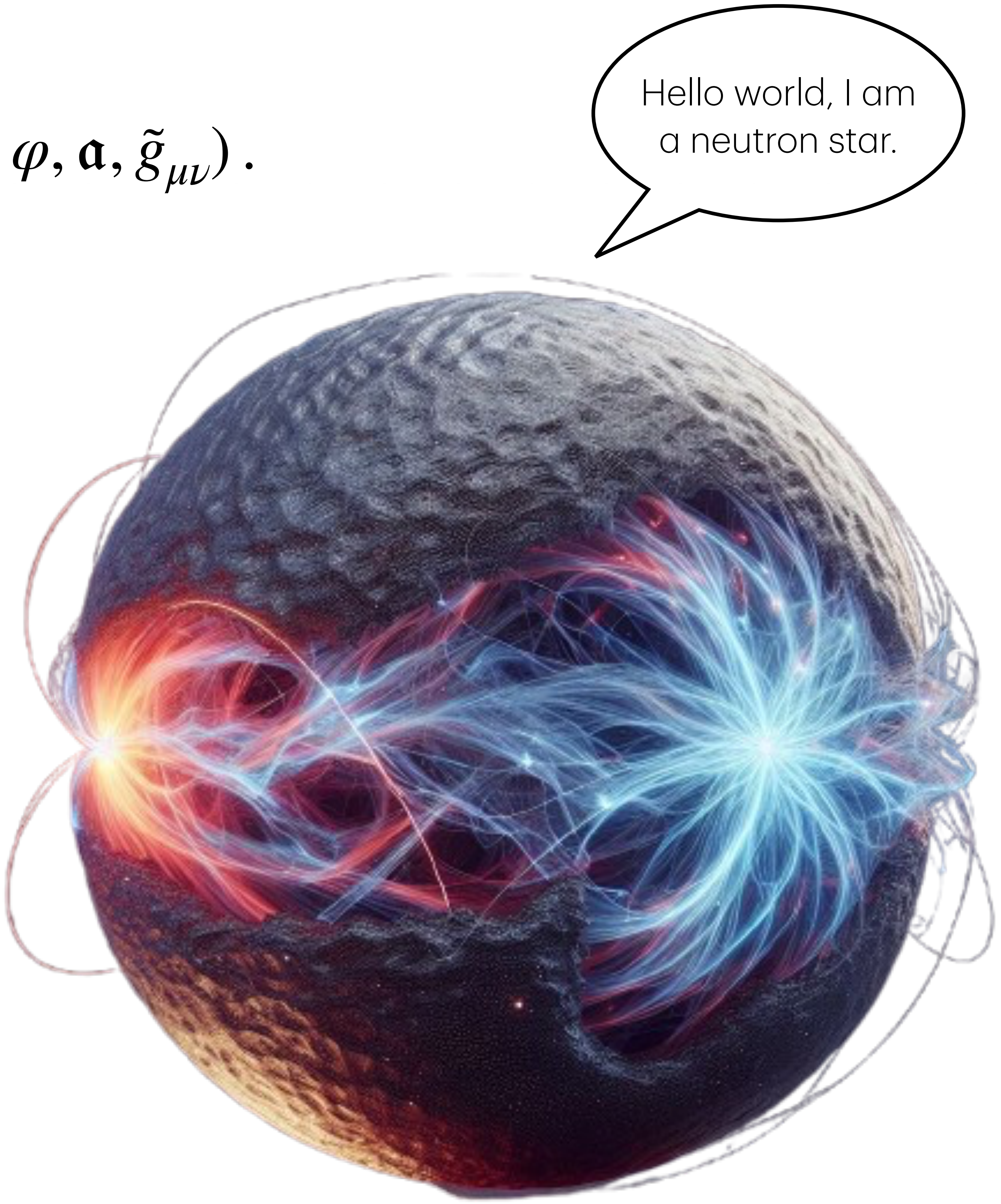

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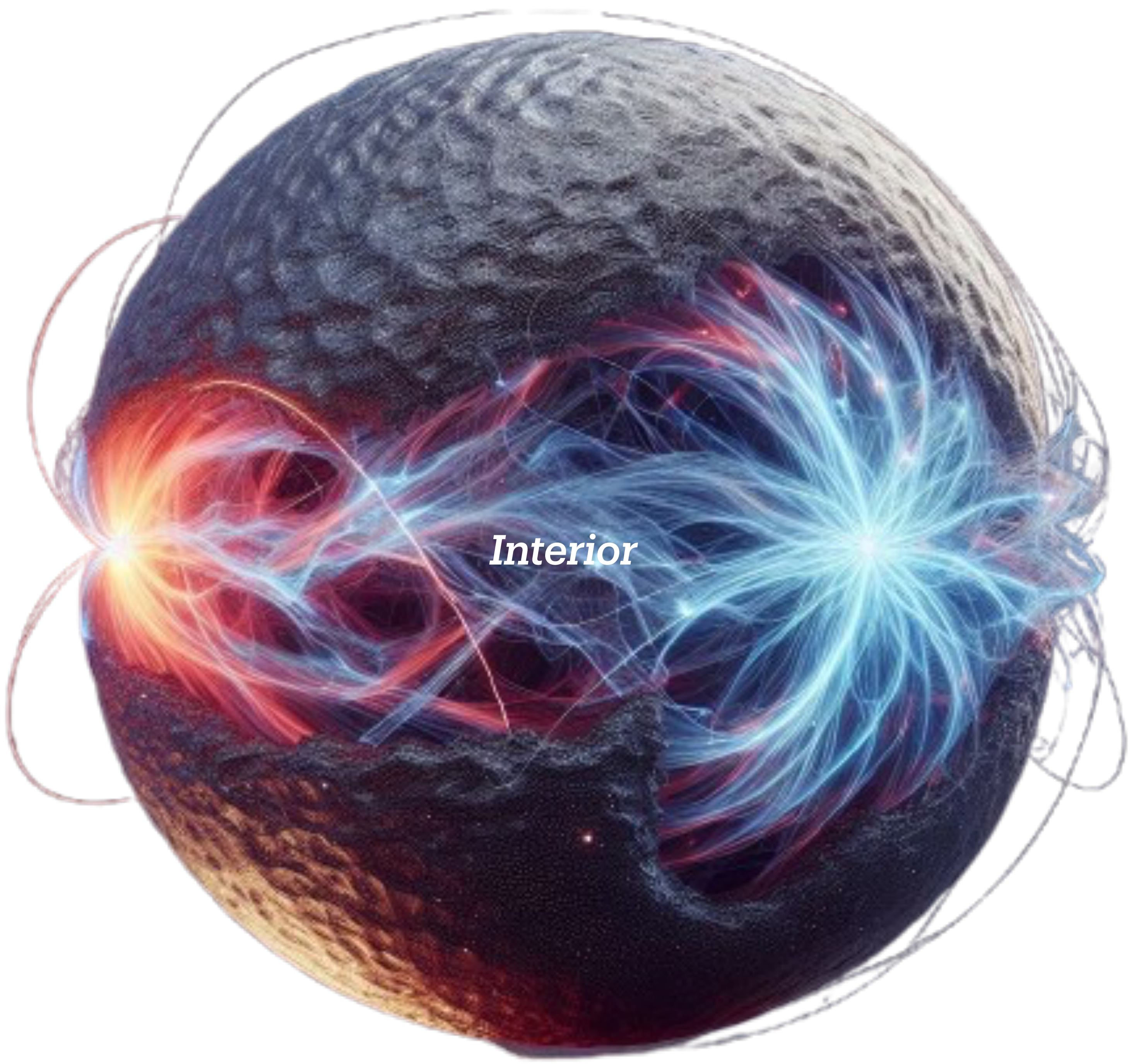

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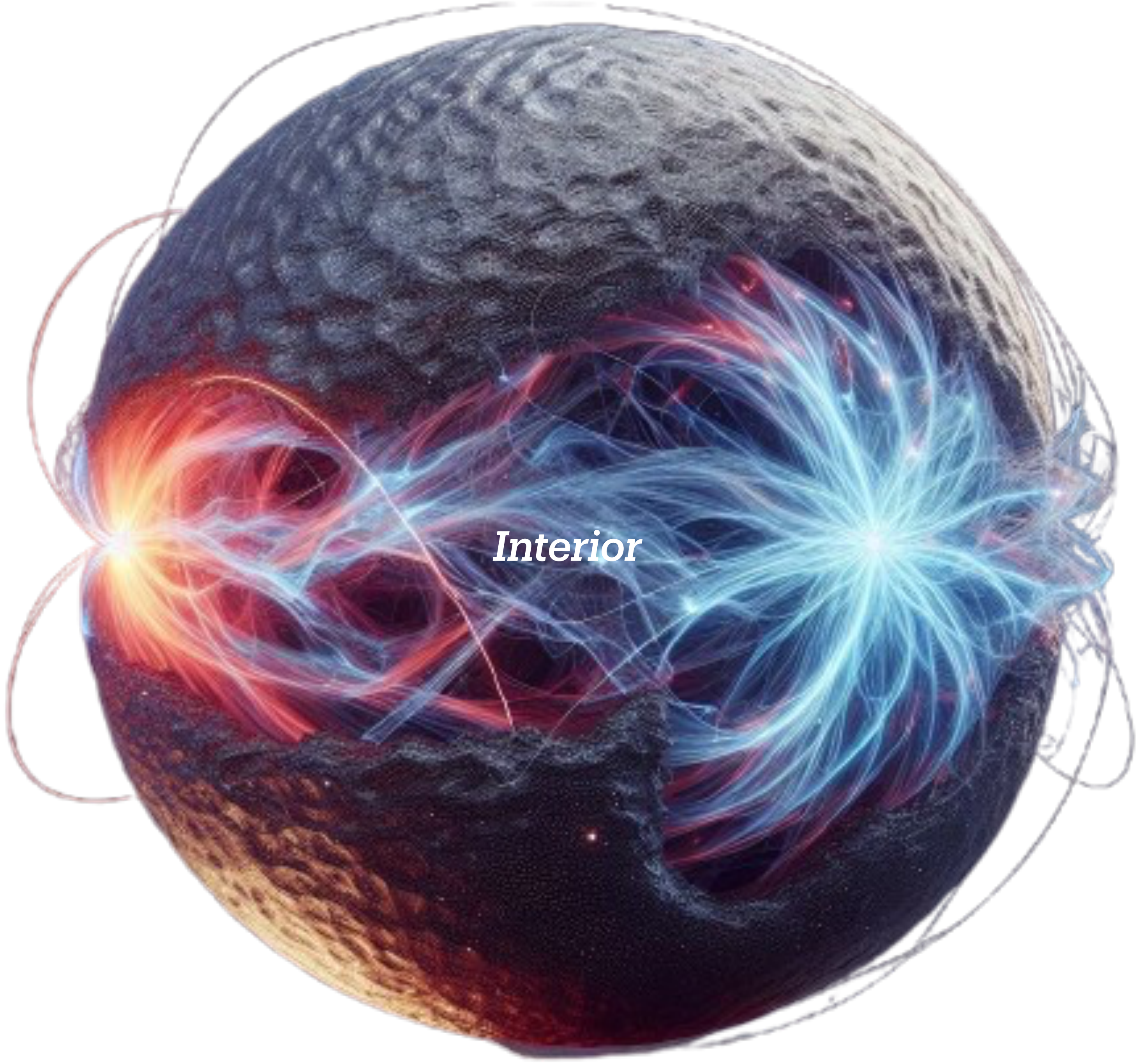

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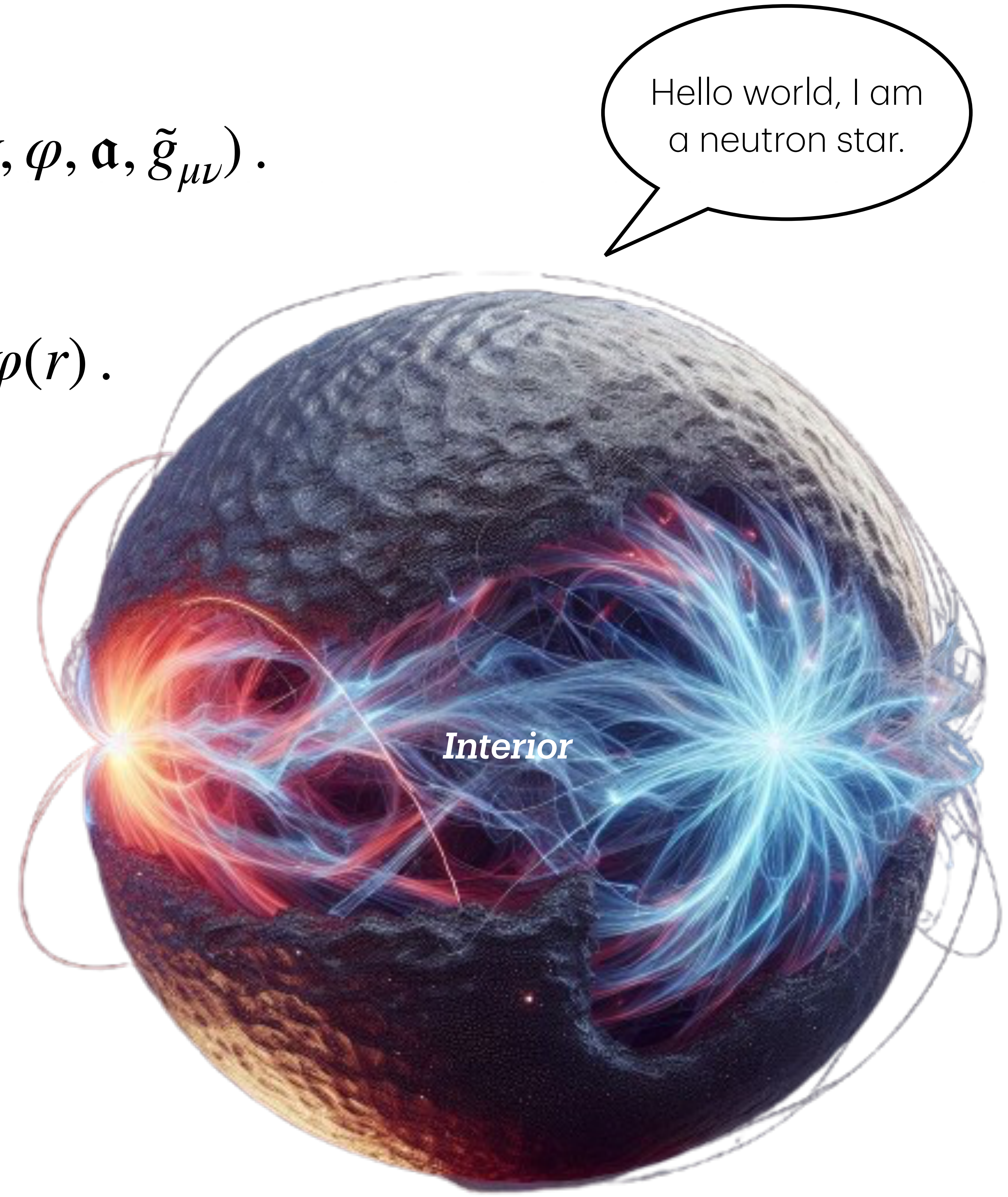

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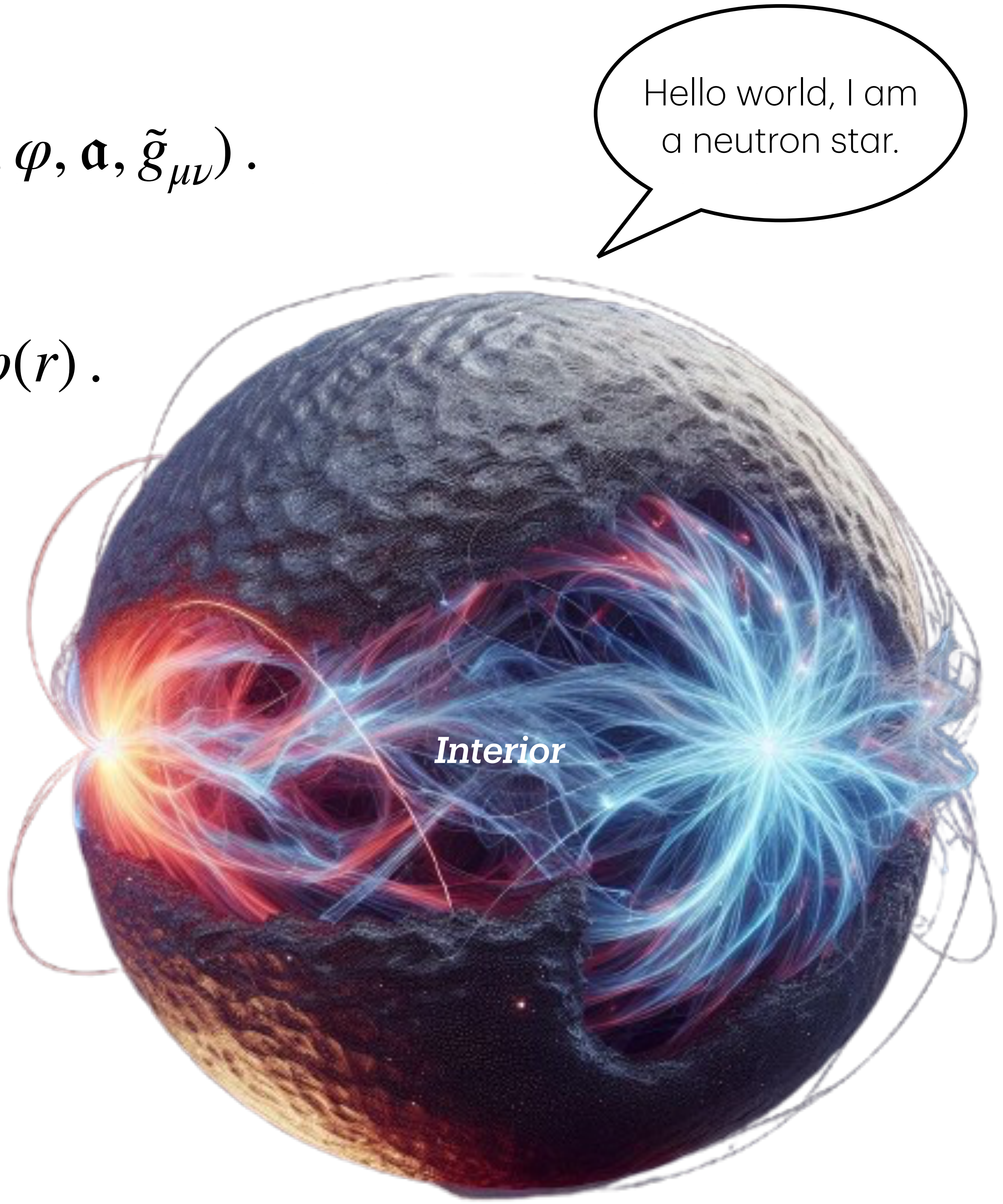
The potential $\mathscr{V}(\mathfrak{a})$ can be considered as the contribution of two regions



Axio-dilaton

$$\mathscr{L} = -\sqrt{-g}\left[\frac{M_p^2}{2}\mathscr{R} + \frac{M_p^2}{2}(\partial\varphi)^2 + \frac{M_p^2}{2}W^2(\varphi)(\partial\mathfrak{a})^2 + \mathscr{V}(\mathfrak{a})\right] + \mathscr{L}_m(\psi, \varphi, \mathfrak{a}, \tilde{g}_{\mu\nu})\,.$$

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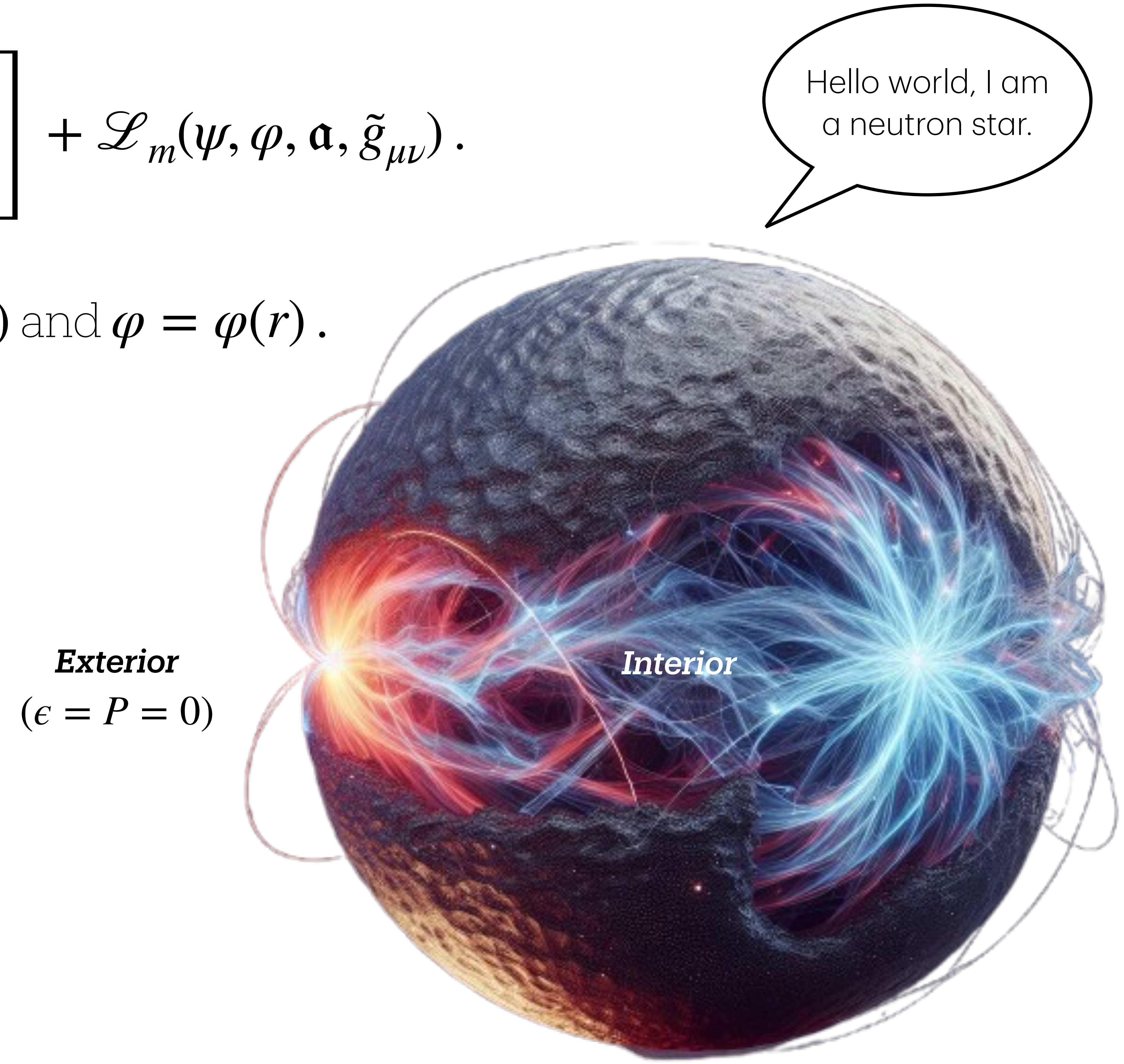

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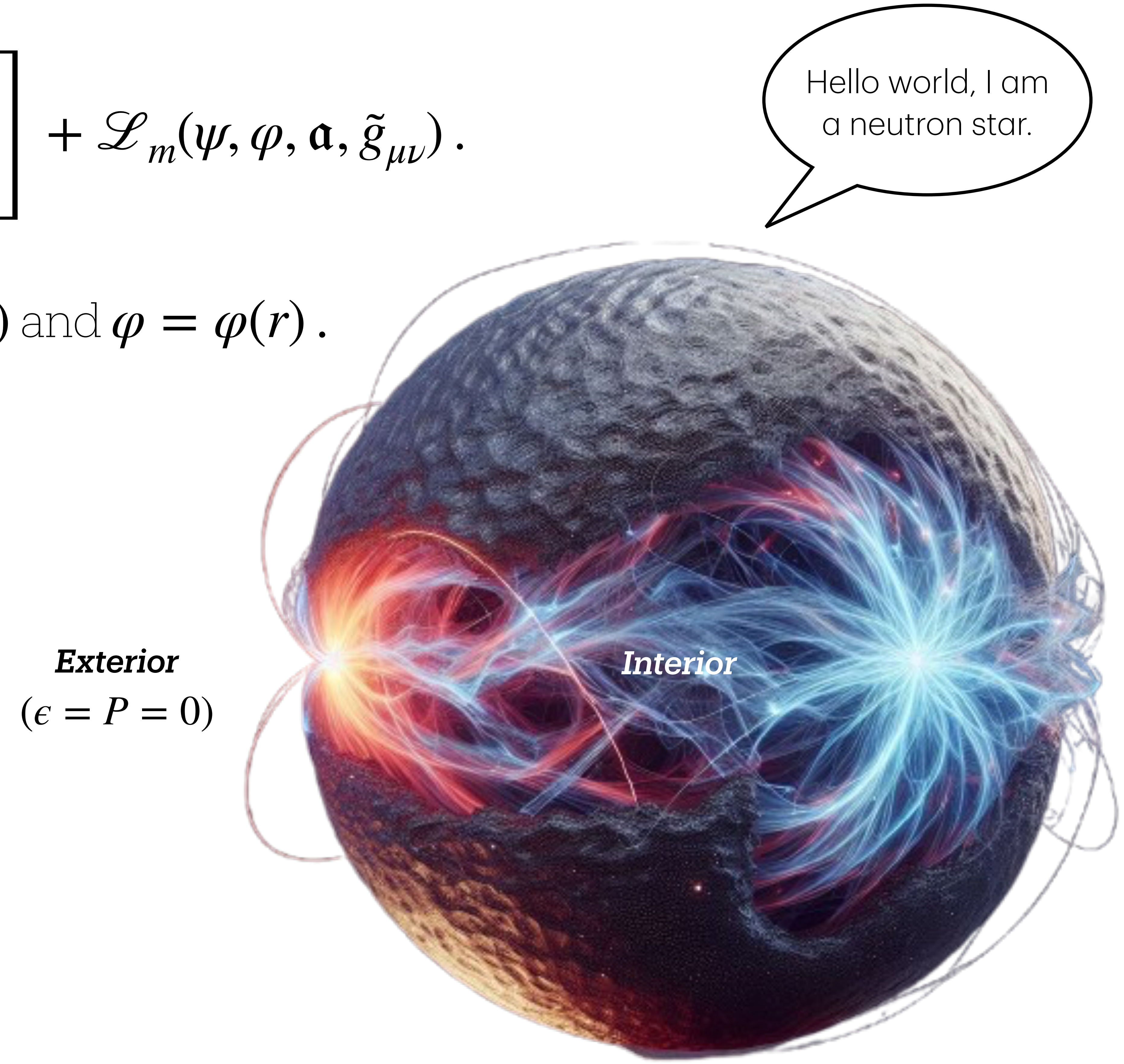

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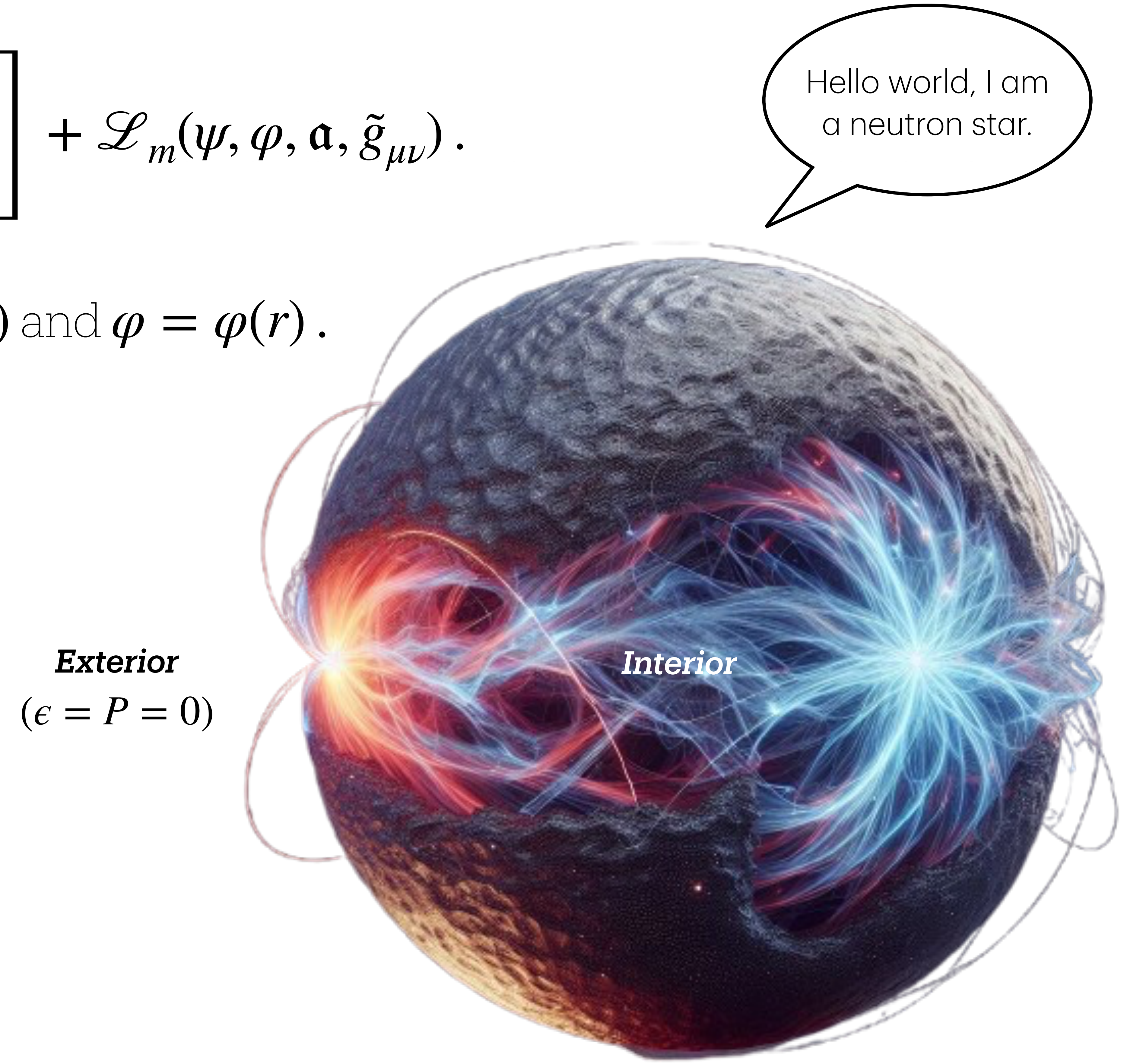

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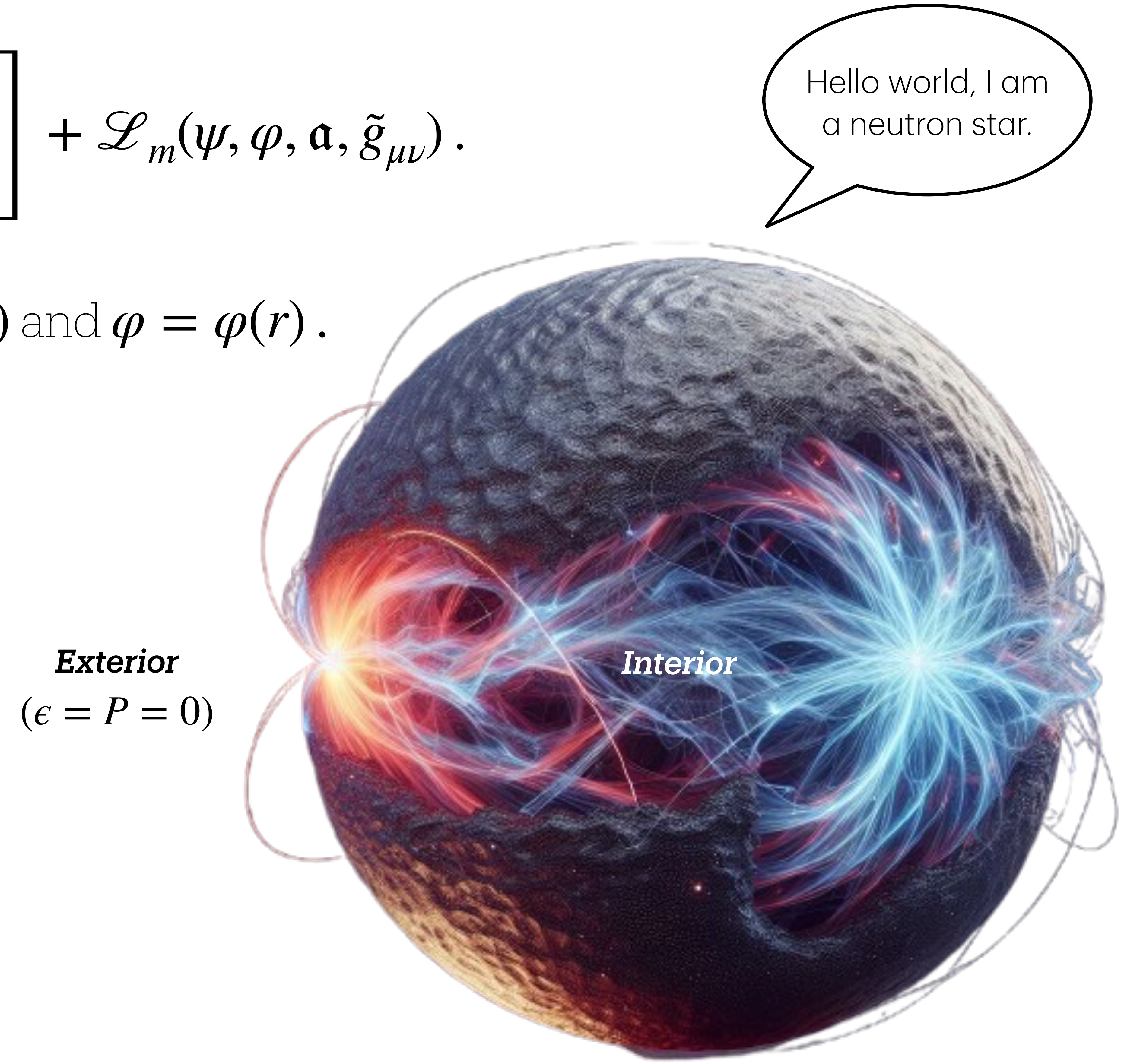

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Hello world, I am a neutron star.

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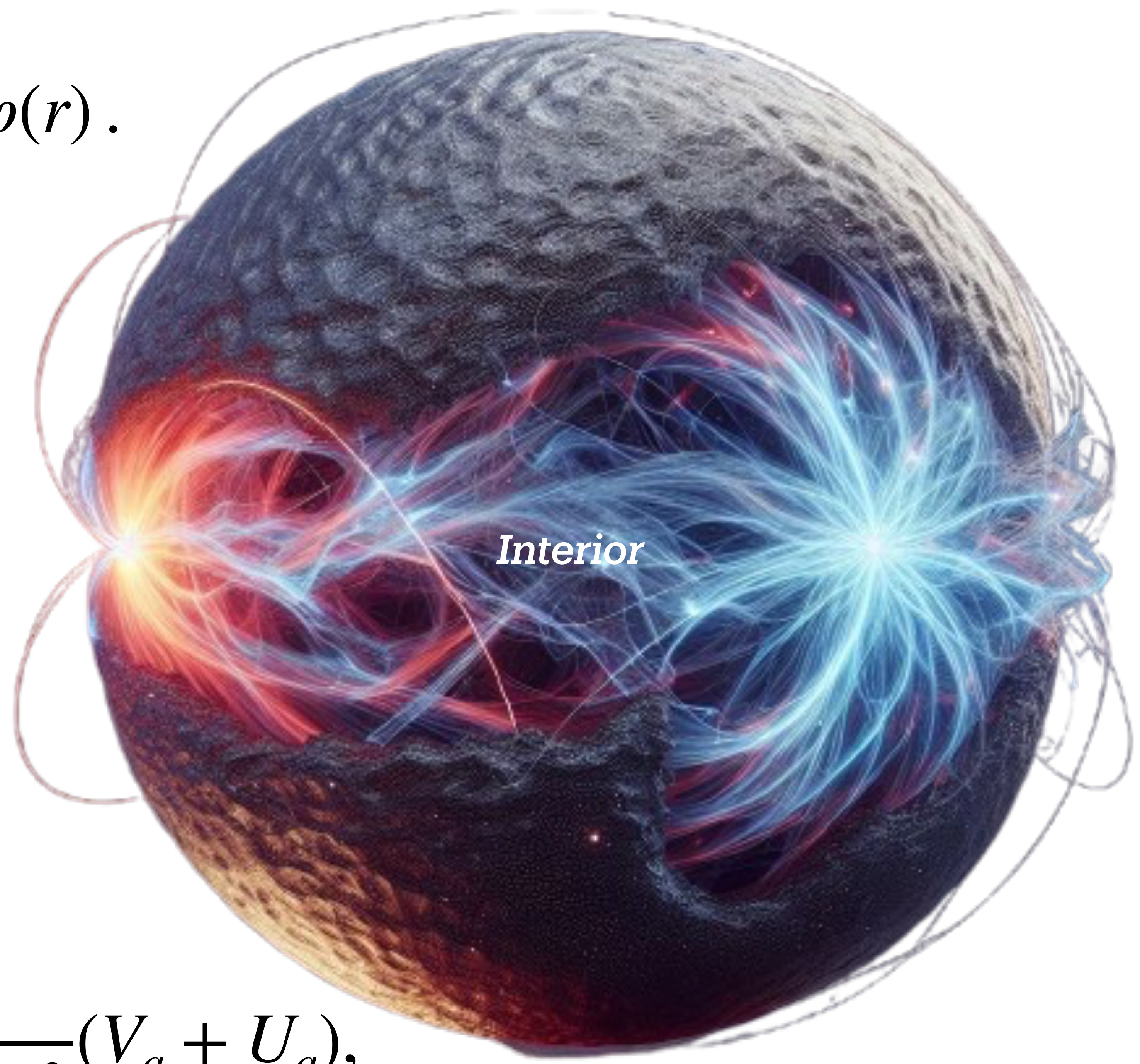

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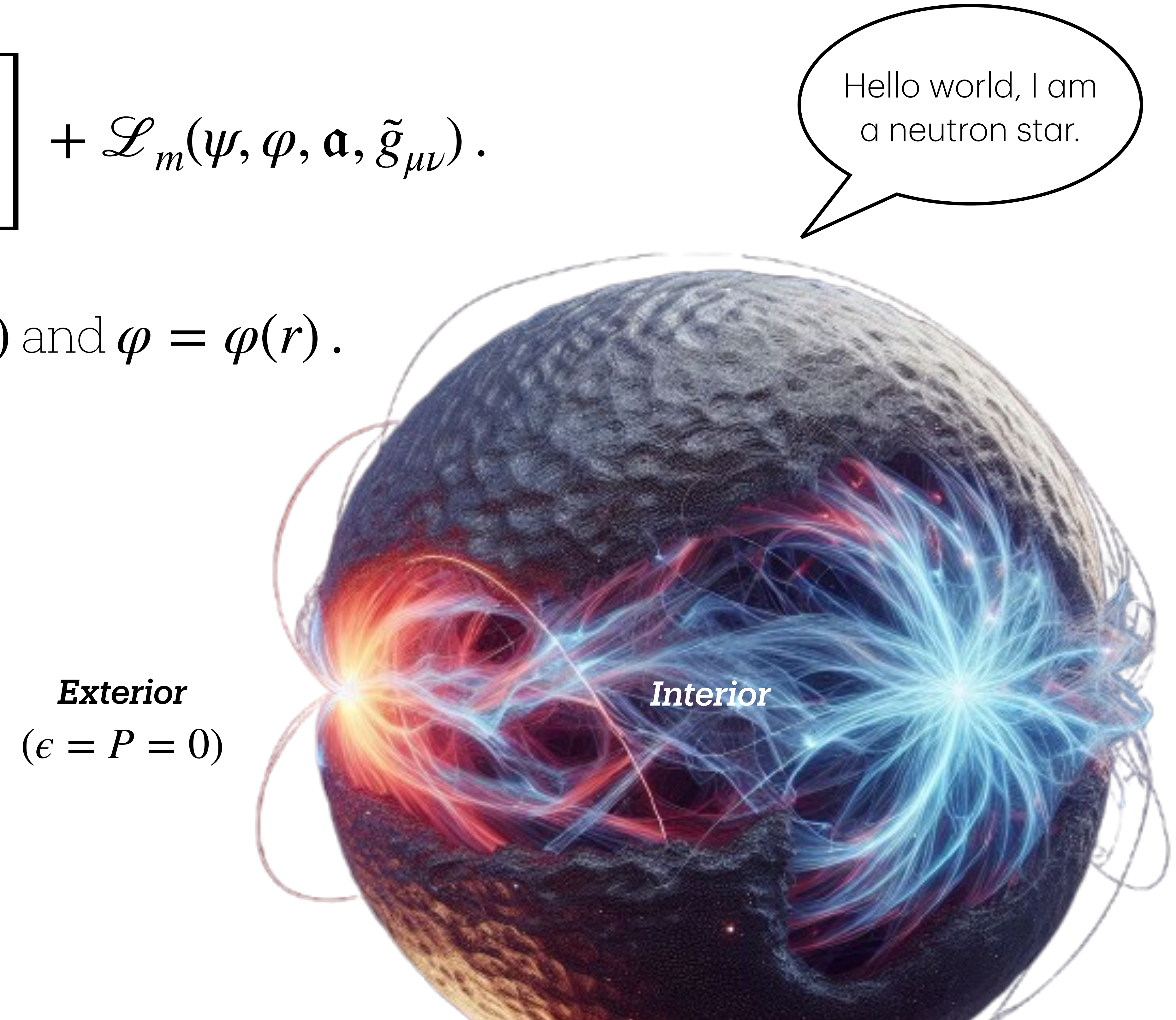

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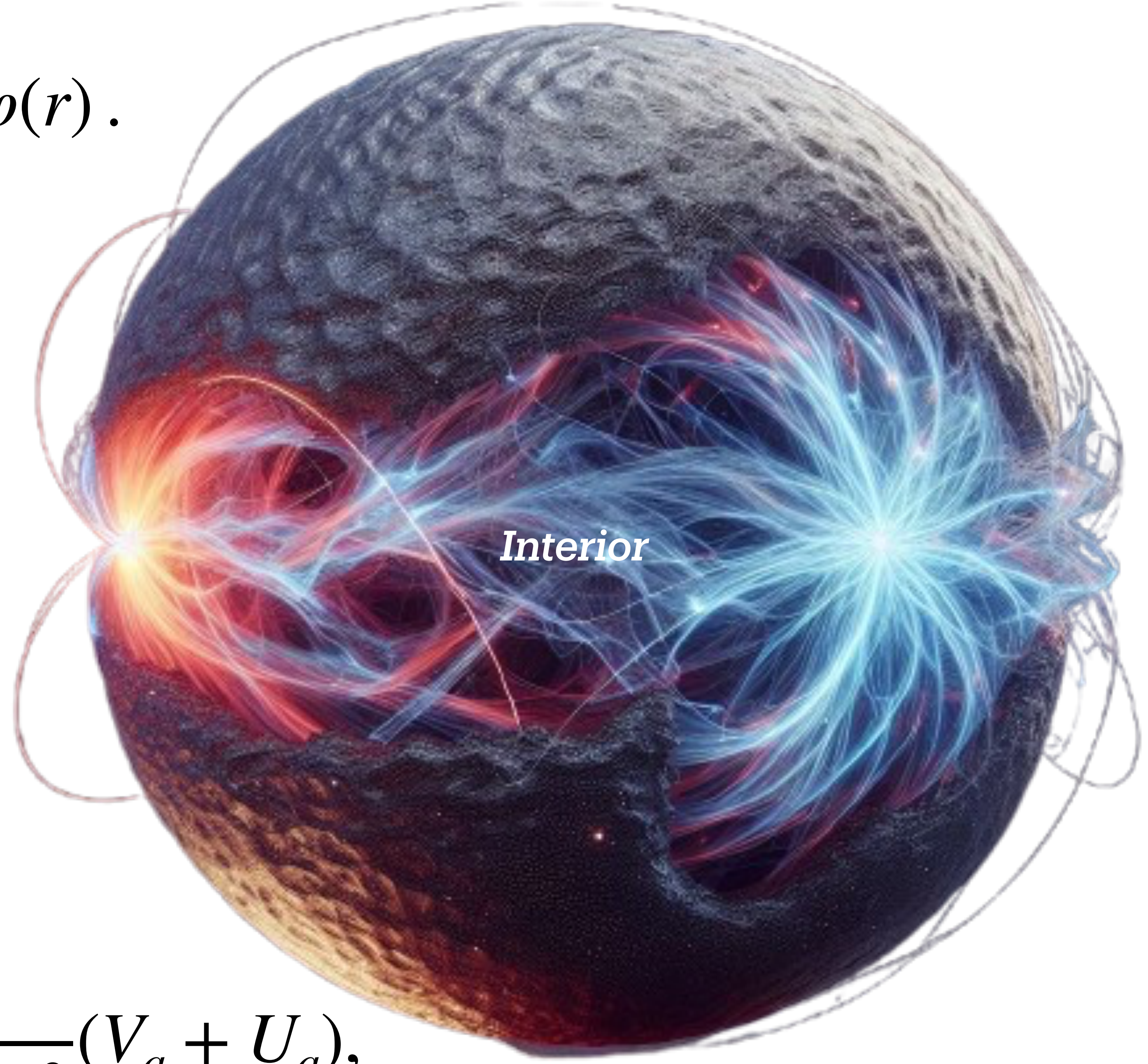

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where $T \simeq T_{\mu\nu}g^{\mu\nu}$ which in the non-relativistic limit can be approximated as $T \simeq -\epsilon$.

Axio-dilaton-TOV system

Axio-dilaton-TOV system

$$\frac{d}{dr}\begin{bmatrix} y_0(r) \\ y_1(r) \\ y_2(r) \\ y_3(r) \\ y_4(r) \\ y_5(r) \\ y_6(r) \end{bmatrix} = \frac{d}{dr}\begin{bmatrix} \tilde{P}(r) \\ m(r) \\ \nu(r) \\ \varphi(r) \\ \psi(r) \\ a(r) \\ \chi(r) \end{bmatrix} = \begin{bmatrix} -(\tilde{\epsilon}+\tilde{P})\left[\frac{4\pi r^3(A^4\tilde{P}+V)+m}{r(r-2m)} - \frac{r}{4}(\psi^2+W^2\chi^2)+\mathfrak{g}\psi\right] \\ 4\pi r^2 A^4(\varphi)\tilde{\epsilon} + \frac{r(r-2m)}{4}\left(\psi^2+W^2\chi^2\right) \\ \frac{8\pi r^3(A^4\tilde{P}+V)+2m}{r(r-2m)} - \frac{r}{2}(\psi^2+W^2\chi^2) \\ \psi(r) \\ -\frac{2}{r}\psi + WW_\varphi\left(1-\frac{2m}{r}\right)\chi^2 - 8\pi\mathfrak{g}A^4\tilde{\epsilon} \\ \chi(r) \\ -\frac{2}{r}\chi - 2\frac{W_\varphi}{W}\left(1-\frac{2m}{r}\right)\chi\psi + \frac{1}{W^2M_p^2}(V_\mathfrak{a}+U_\mathfrak{a}) \end{bmatrix}.$$

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With the boundary conditions,

Axio-dilaton-TOV system

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Additionally, outside of the star, $\tilde{\epsilon} = \tilde{P} = 0$, and therefore only V contributes at the exterior of the star. We chose the central density* as typical of a neutron star (NS), namely, $\rho_c \simeq 1 \times 10^{15}$ gm/c^3.

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Axio-dilaton-TOV system

$$\frac{d}{dr}\begin{bmatrix} y_0(r) \\ y_1(r) \\ y_2(r) \\ y_3(r) \\ y_4(r) \\ y_5(r) \\ y_6(r) \end{bmatrix} = \frac{d}{dr}\begin{bmatrix} \tilde{P}(r) \\ m(r) \\ \nu(r) \\ \varphi(r) \\ \psi(r) \\ \mathfrak{a}(r) \\ \chi(r) \end{bmatrix} = \begin{bmatrix} -(\tilde{\epsilon}+\tilde{P})\left[\frac{4\pi r^3(A^4\tilde{P}+V)+m}{r(r-2m)} - \frac{r}{4}(\psi^2+W^2\chi^2)+\mathfrak{g}\psi\right] \\ 4\pi r^2 A^4(\varphi)\tilde{\epsilon} + \frac{r(r-2m)}{4}\left(\psi^2+W^2\chi^2\right) \\ \frac{8\pi r^3(A^4\tilde{P}+V)+2m}{r(r-2m)} - \frac{r}{2}(\psi^2+W^2\chi^2) \\ \psi(r) \\ -\frac{2}{r}\psi + WW_\varphi\left(1-\frac{2m}{r}\right)\chi^2 - 8\pi\mathfrak{g}A^4\tilde{\epsilon} \\ \chi(r) \\ -\frac{2}{r}\chi - 2\frac{W_\varphi}{W}\left(1-\frac{2m}{r}\right)\chi\psi + \frac{1}{W^2M_p^2}(V_\mathfrak{a}+U_\mathfrak{a}) \end{bmatrix}.$$

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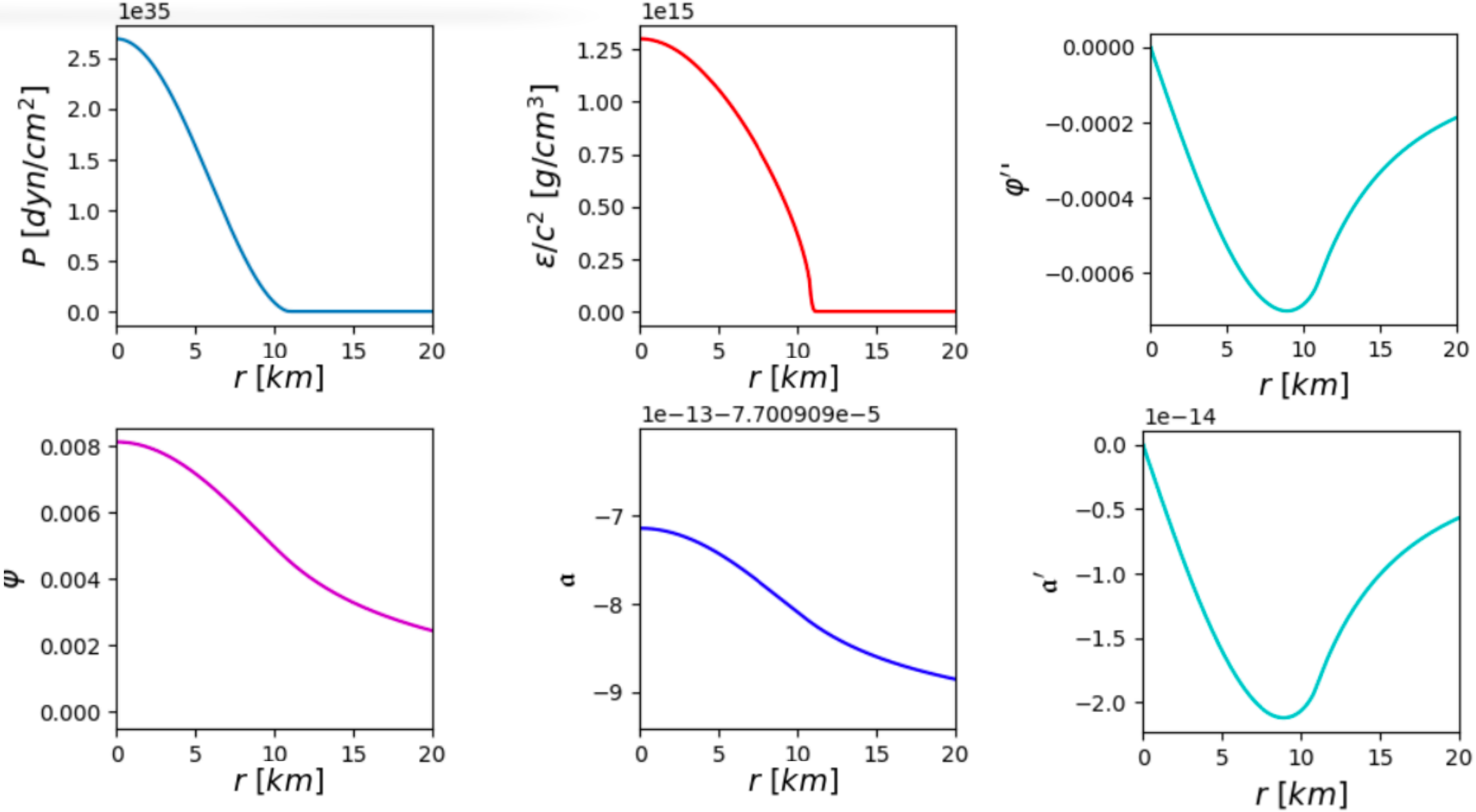

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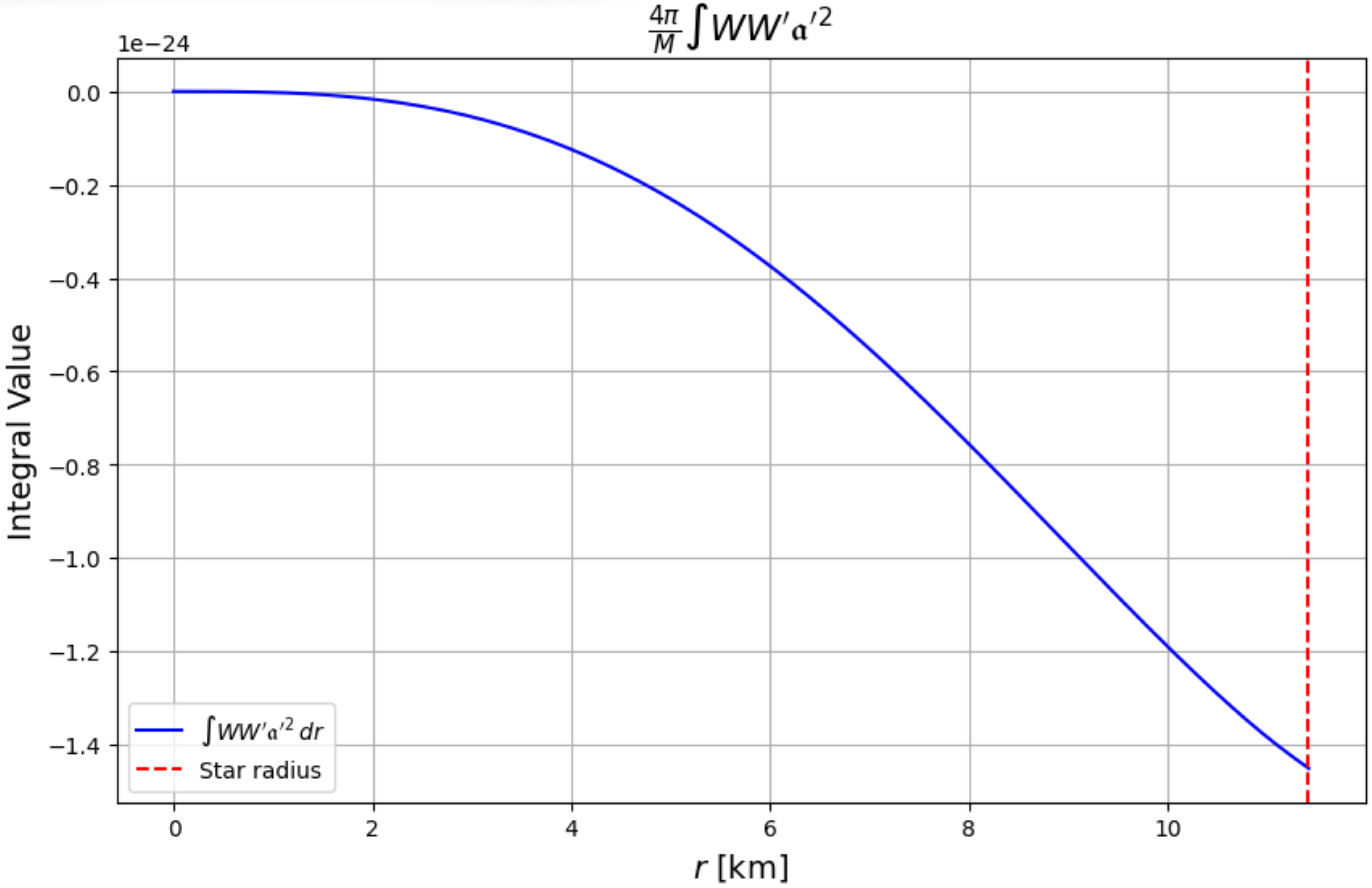

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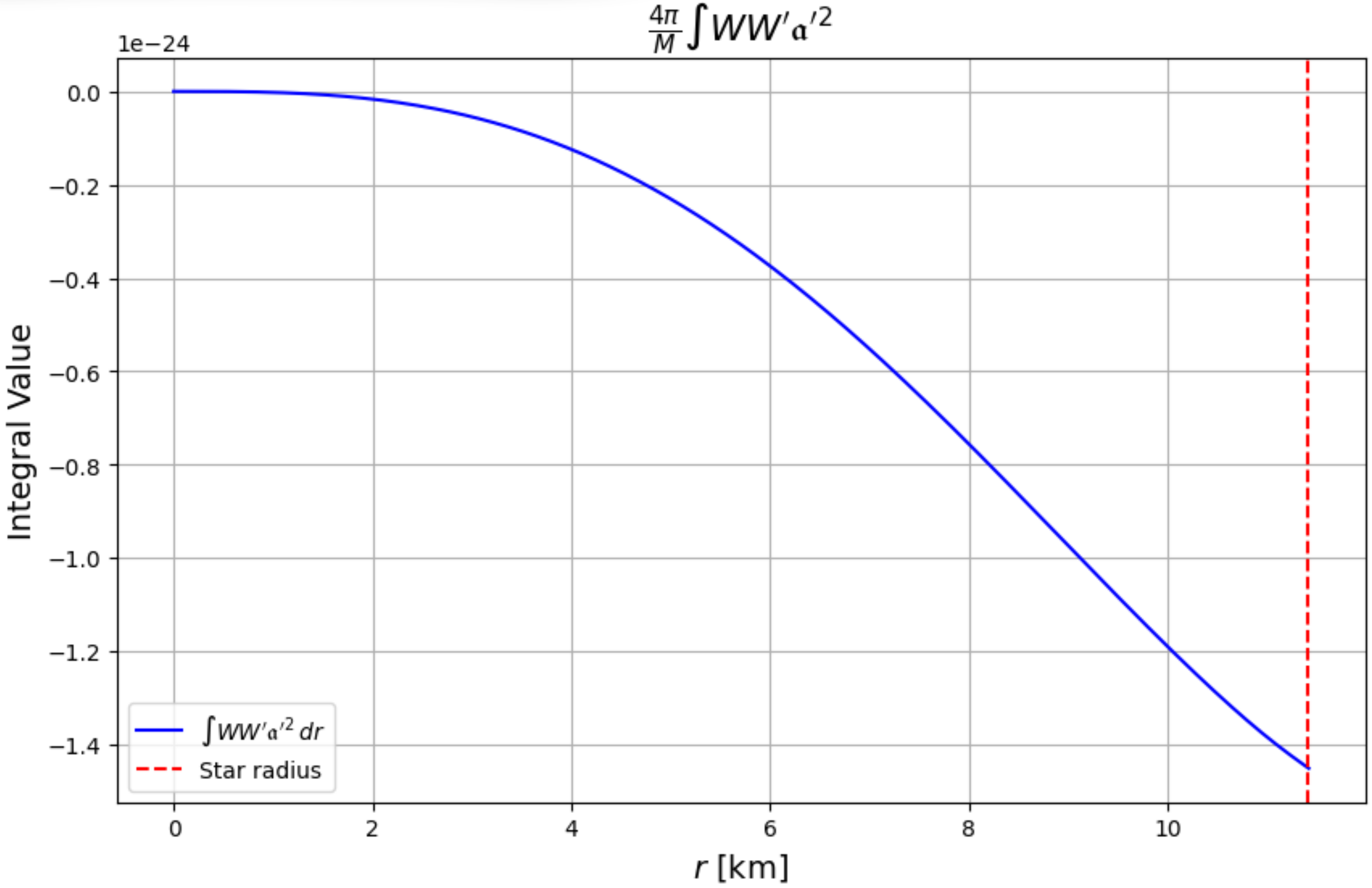

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- Further studies of multiple scalars interacting through two-derivative sigma-model couplings.

Thank you

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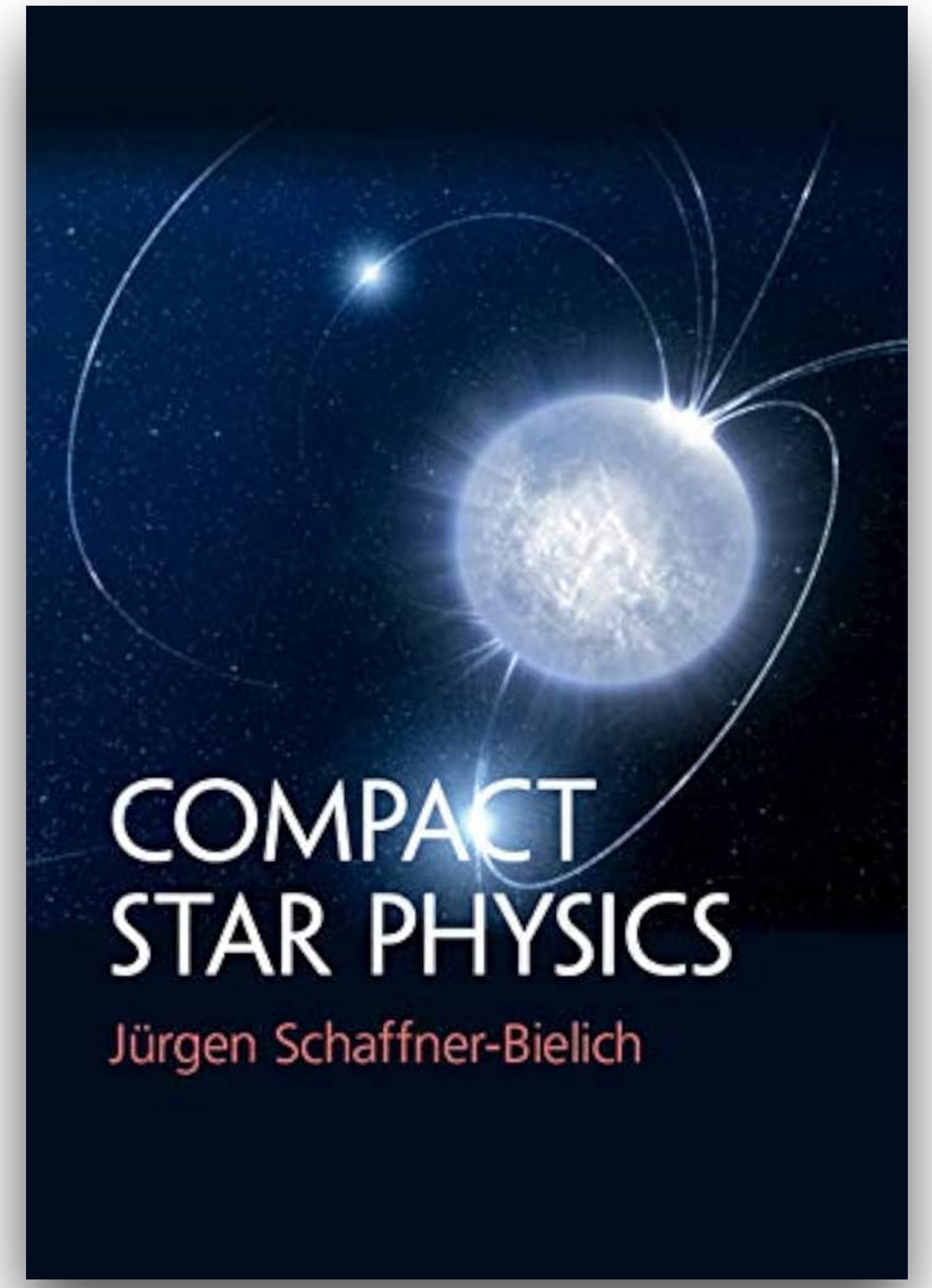
DAMTP | University of Cambridge
(Applying for postdocs this fall)

Compact objects

They are the endpoint of stellar evolution and an astrophysical laboratory. Different mechanisms support them against gravitational collapse:

- White dwarfs: supported by the degeneracy pressure of electrons.
- Neutron stars (NS): interaction between nucleons.
- Black holes: completely collapsed, gravitational singularity.



[J. Schaffner-Bielich , 2020]

More information on radii and masses available for NS:

- Original massive star containing 8-25 $M_{\odot}$ before supernova explosion.
- Theoretically, remnant NS compresses $1.4 M_{\odot}$ into a $10 - 15$ km sphere.
- Experimentally, (Satellite mission NICER) measured PSR J0030 + 0451 radius:

$$12.71 \pm 1.19 \text{ km}$$
$$13.02 \pm 1.24 \text{ km}$$

[Riley, T. E. et al , 2019]
[Miller, M. C. et al , 2019]

Equation of state

We consider a piecewise polytropic equation of state:

$$P(\rho) = K_i \rho^{\Gamma_i},$$

[F. Douchin and P. Haensel,, 2001]

where ρ is the rest-mass density, K_i are some constants and Γ_i adiabatic indices. In addition, $\rho_1 = 10^{14.7}\text{g/cm}^3$ and $\rho_2 = 10^{15.0}\text{g/cm}^3$, such that for each region of the piecewise density

$$\rho_{i-1} \leq \rho \leq \rho_i\,.$$

The energy density ϵ of this adiabatic ideal gas follows the first law of thermodynamics

$$d\left(\frac{\epsilon}{\rho}\right) = -\,P\,d\left(\frac{1}{\rho}\right),$$

which implies by continuity,

$$\epsilon = (1+\alpha_i)\rho + \frac{K_i}{\Gamma_i - 1}\rho^{\Gamma_i}, \quad \text{with} \quad \alpha_i = \frac{\epsilon(\rho_{i-1})}{\rho_{i-1}} - 1 - \frac{\Gamma_i}{\Gamma_i - 1}K_i\rho^{\Gamma_i - 1}\,.$$

Einstein equations

We can write variables in the JF, particularly pressure and density as

$$P = A^4(\tau)\tilde{P} \quad \text{and} \quad \epsilon = A^4(\tau)\tilde{\epsilon}\,.$$

Defining $\mu(r) = m(r)/r$, the independent Einstein equations are given by

$$r\mu' + \mu = 4\pi G r^2 (A^4\tilde{\epsilon} - V) - \frac{r^2}{4}(1-2\mu)(\varphi'^2 + W^2\mathfrak{a}'^2),$$

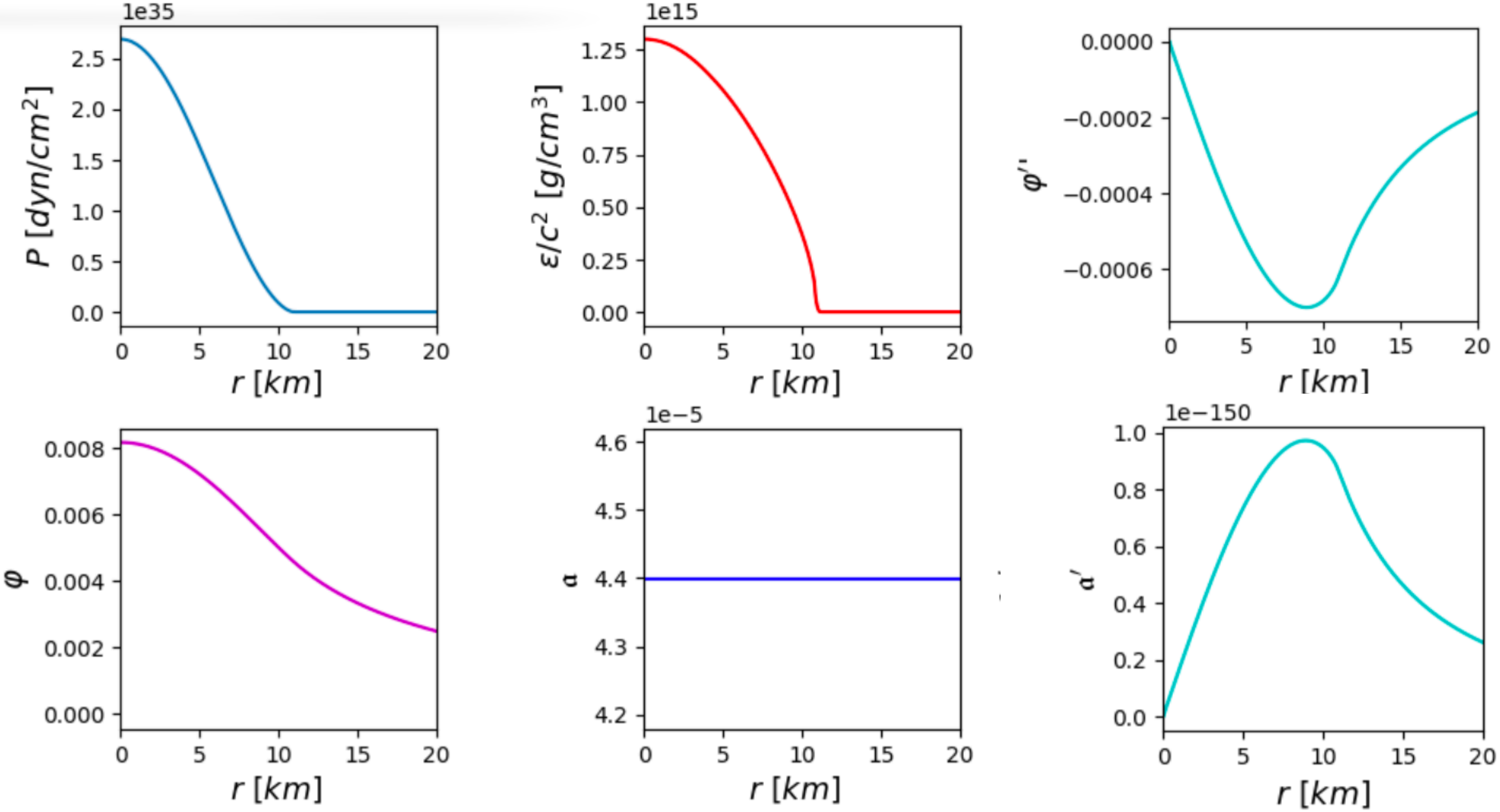
$$\nu' = \frac{8\pi G r^2 (A^4\tilde{P} + V) + 2\mu}{r(1-2\mu)} - \frac{r}{2}(\varphi'^2 + W^2\mathfrak{a}'^2),$$

$$\frac{\nu''}{2} + \frac{(\nu')^2}{4} - \frac{\nu'\mu'}{2(1-2\mu)} + \frac{1}{2r}\left(\nu' - \frac{2\mu'}{1-2\mu}\right) = \frac{8\pi G(A^4\tilde{P} + \mathscr{V})}{(1-2\mu)} + \frac{1}{2}(\varphi'^2 + W^2\mathfrak{a}'^2),$$

And additionally, the Tolman-Oppenheimer-Volkoff (TOV) equation

$$\tilde{P}' = -\,(\tilde{\epsilon} + \tilde{P})\left[\frac{4\pi G r^2(A^4\tilde{P} + \mathscr{V}) + \mu}{r(1-2\mu)} - \frac{r}{4}(\varphi'^2 + W^2\mathfrak{a}'^2) + \mathfrak{g}\varphi'\right].$$

Numerical solutions



In this figure, we use the following values for the parameters:

$$\mathfrak{g} = 0.01, \quad \xi = 1, \quad m_{in} = 10^{-6} eV \quad \text{and} \quad m_{\text{out}} = 10^{-9} eV \quad \longrightarrow \quad R = 11.4 km \,.$$

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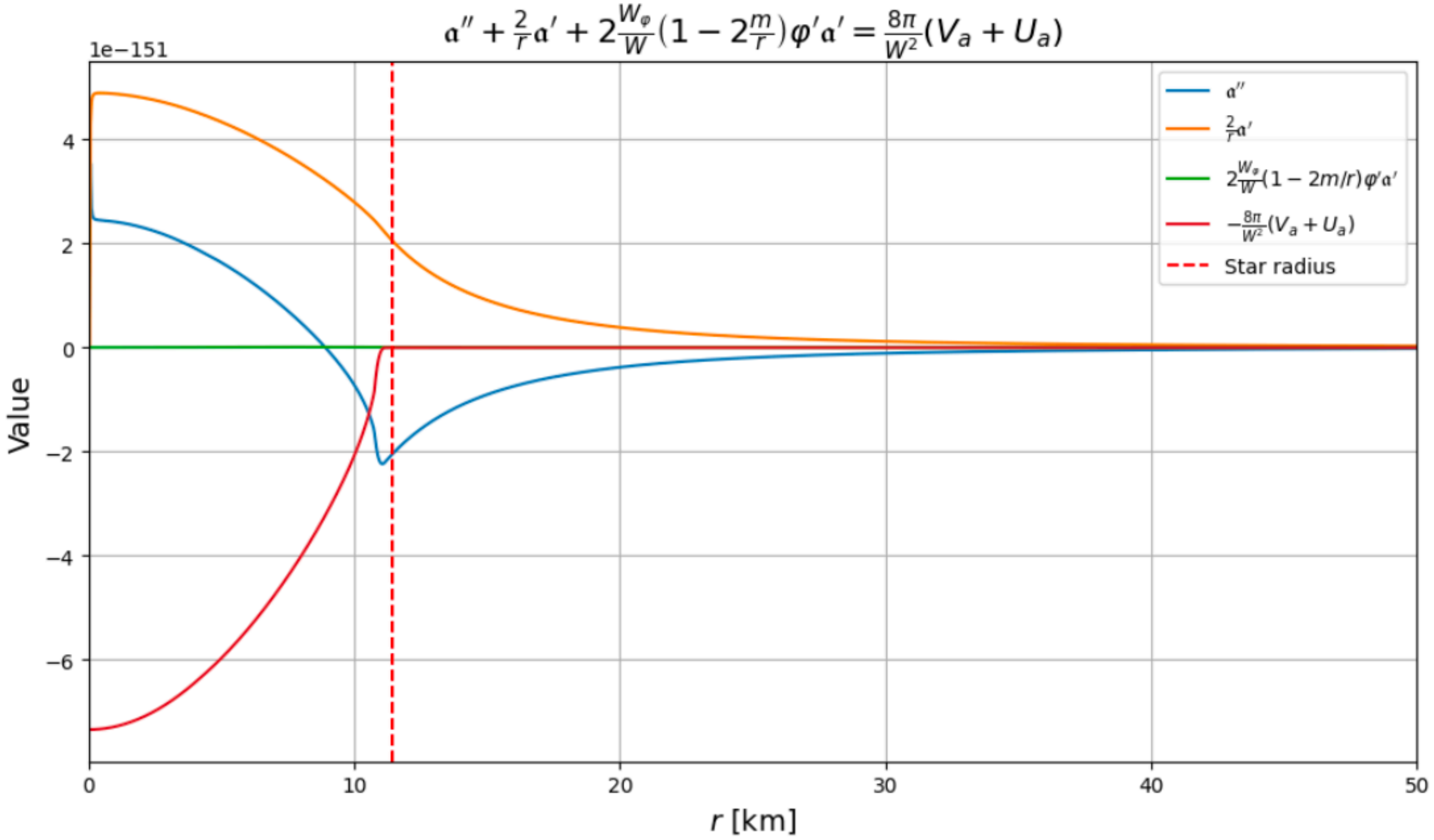
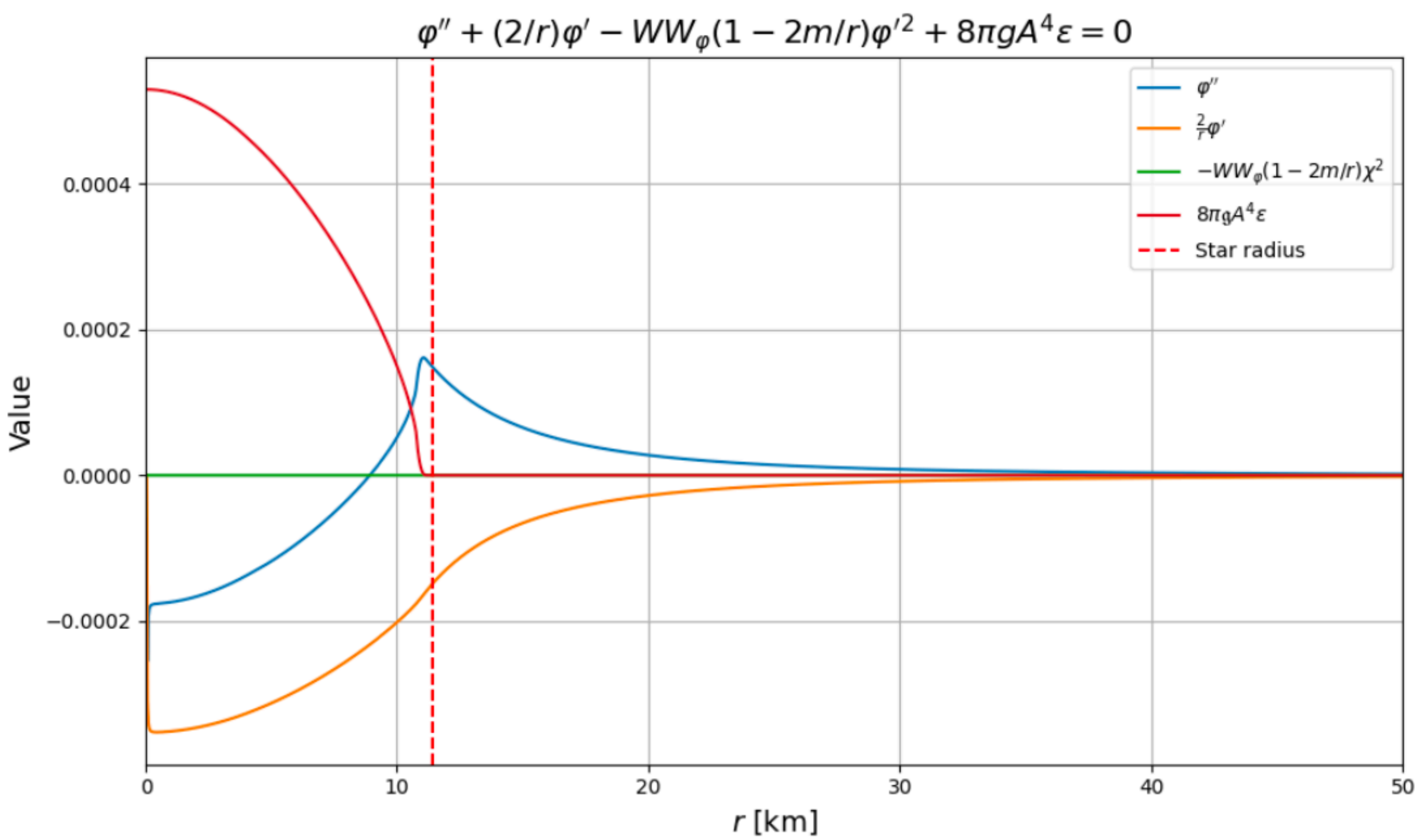


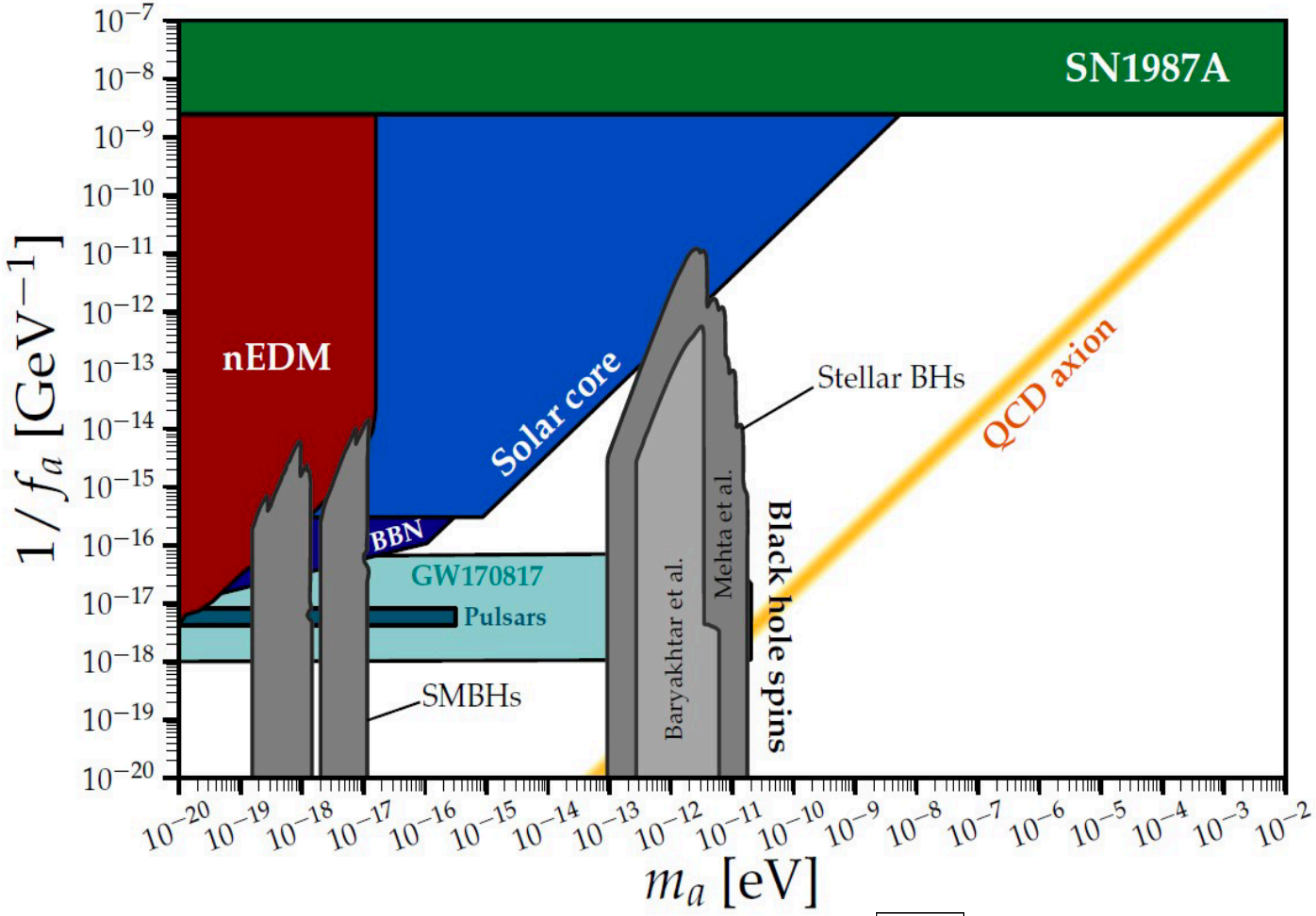


Evolution of the axio-dilaton system. The equations are satisfied along the whole radial coordinate.

Phenomenology

Phenomenological values would require $\xi > 10^9$ which requires $f \leq 10^9$ GeV.

[P. Brax, , C. Burgess and F. Quevedo, 2023]



[P.A. Zyla et al. (Particle Data Group), 2020]

Adiabatic approximation

Consider the following potential for the axion field:

$$V(\mathfrak{a}) = \frac{1}{2}\mu^2_{\rm out}M_p^2(\mathfrak{a} - \mathfrak{a}_+)^2 \quad \text{and} \quad U(a) = \frac{1}{2}\mu^2_{\rm in}M_p^2(\mathfrak{a} - \mathfrak{a}_-)^2\epsilon(r),$$

where $\mu_{in/out}M_p = m_{in/out}f = m_\mathfrak{a}M_P W(\varphi)$. Extremizing the effective potential with respect to the axion field,

$$\frac{d(V(a) + U(a))}{da} = 0,$$

turns out into the axion solution

$$\mathfrak{a}(r) = \frac{\mu^2_{\rm out}\mathfrak{a}_+ + \mu^2_{\rm in}\epsilon(r)\ \mathfrak{a}_-}{\mu^2_{\rm out} + \mu^2_{\rm in}\epsilon(r)}\ .$$

The **adiabatic limit** inside the source implies, in particular, $m_{in}R \gg 1$, that is, the Compton wavelength is way smaller than the star's radius.

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