Fermion-Boson Stars

Neutron Stars Admixed with Ultra-Light Dark Matter

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Based on 2303.04089

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CRC-TR 211 Strong-interaction matter under extreme conditions

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Boson Stars

$$\mathcal{L} = \frac{1}{2}\left(g^{ab}\nabla_a\bar{\Phi}\nabla_b\Phi + V(|\Phi|^2)\right)$$

- **Massive Free Field**

$$V(|\Phi|^2) = m^2|\Phi|^2$$

  - Maximum Mass $M_{max} \sim \frac{M_{Pl}^2}{m}$
  - Solar Masses for $1.34 \times 10^{-10}\,\mathrm{eV}$

- **with self-interactions**

$$V(|\Phi|^2) = m^2|\Phi|^2 + \frac{1}{2}\lambda|\Phi|^4$$

  - Effective Interaction Strength

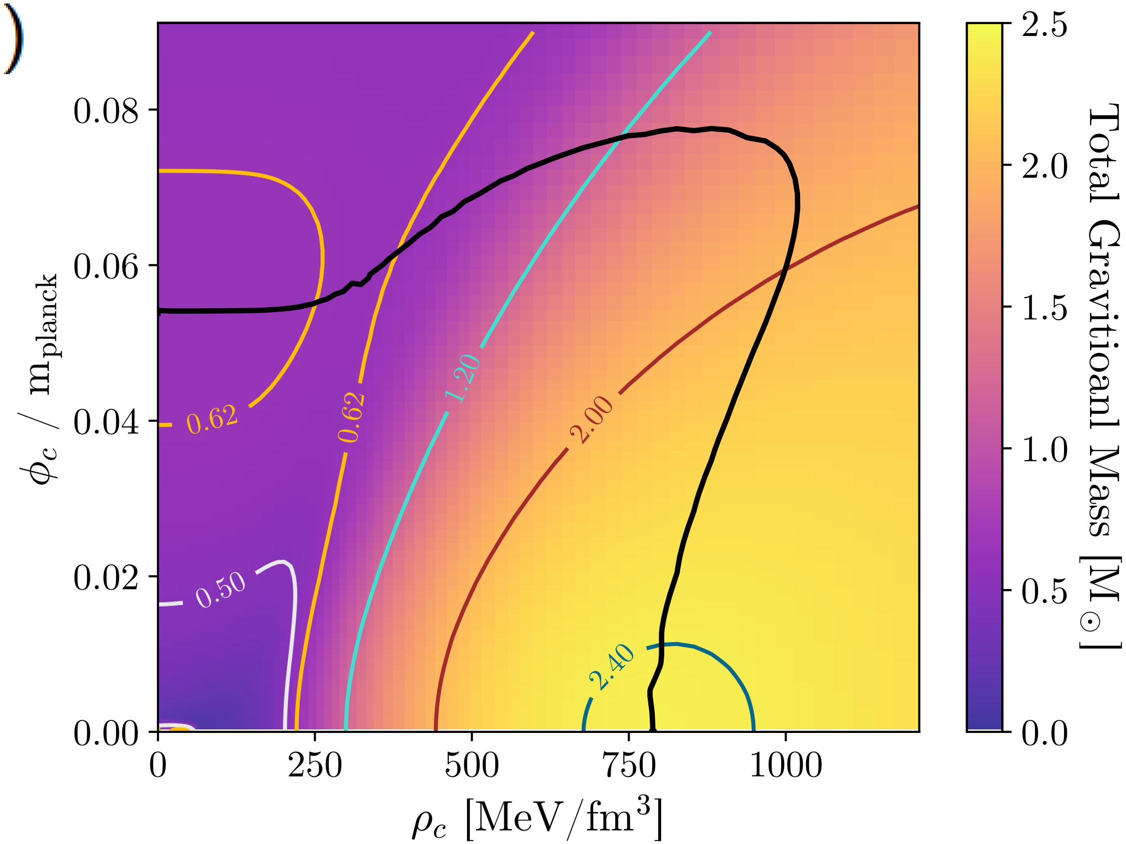
Fermion-Boson Stars

$$T_{\mu\nu} = T^{(NS)}_{\mu\nu} + T^{(\Phi)}_{\mu\nu}$$

- **Modified TOV Equations**
  - Initial Conditions

    $$\rho_c, \Phi_c$$

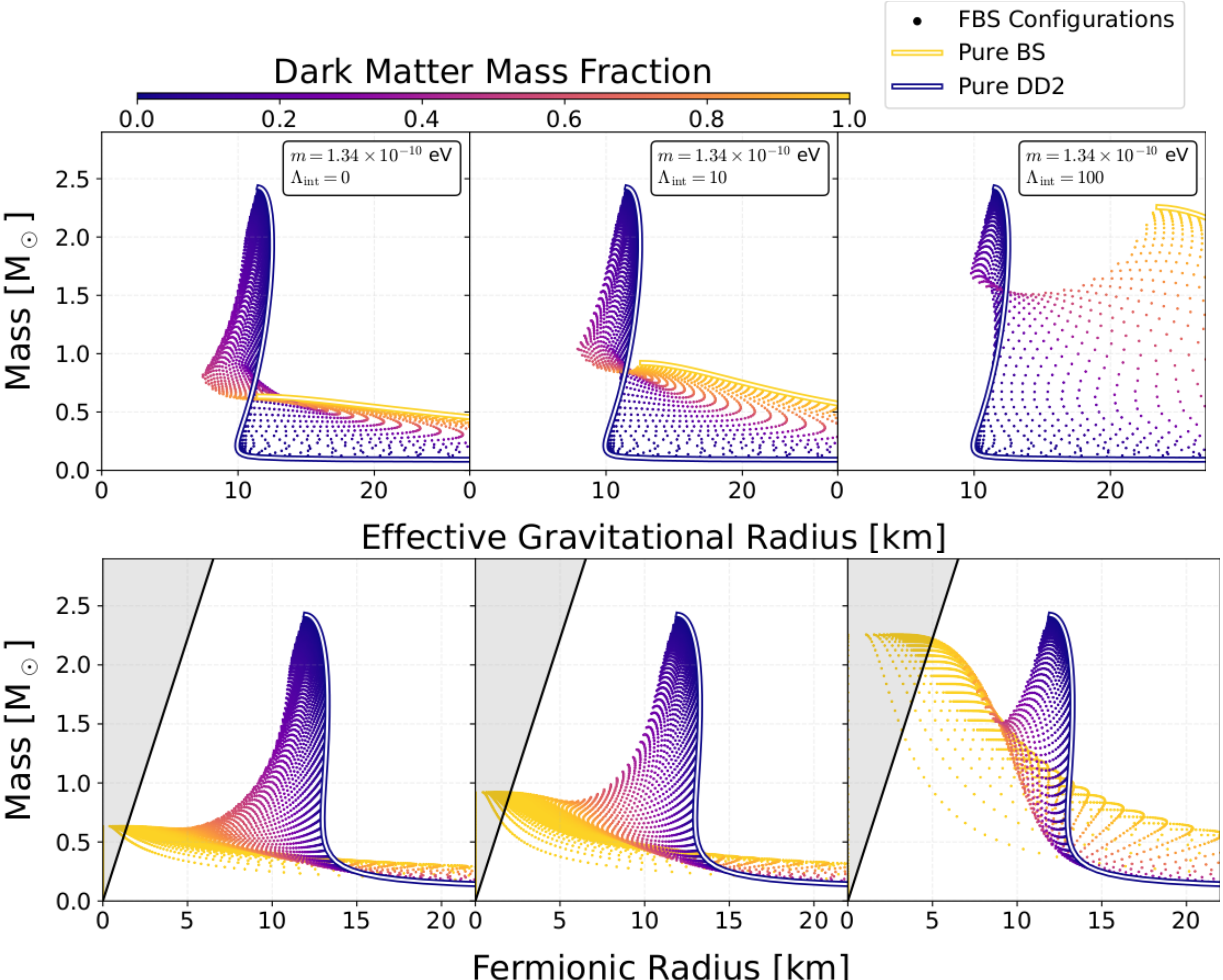
  - Here: DD2 EoS



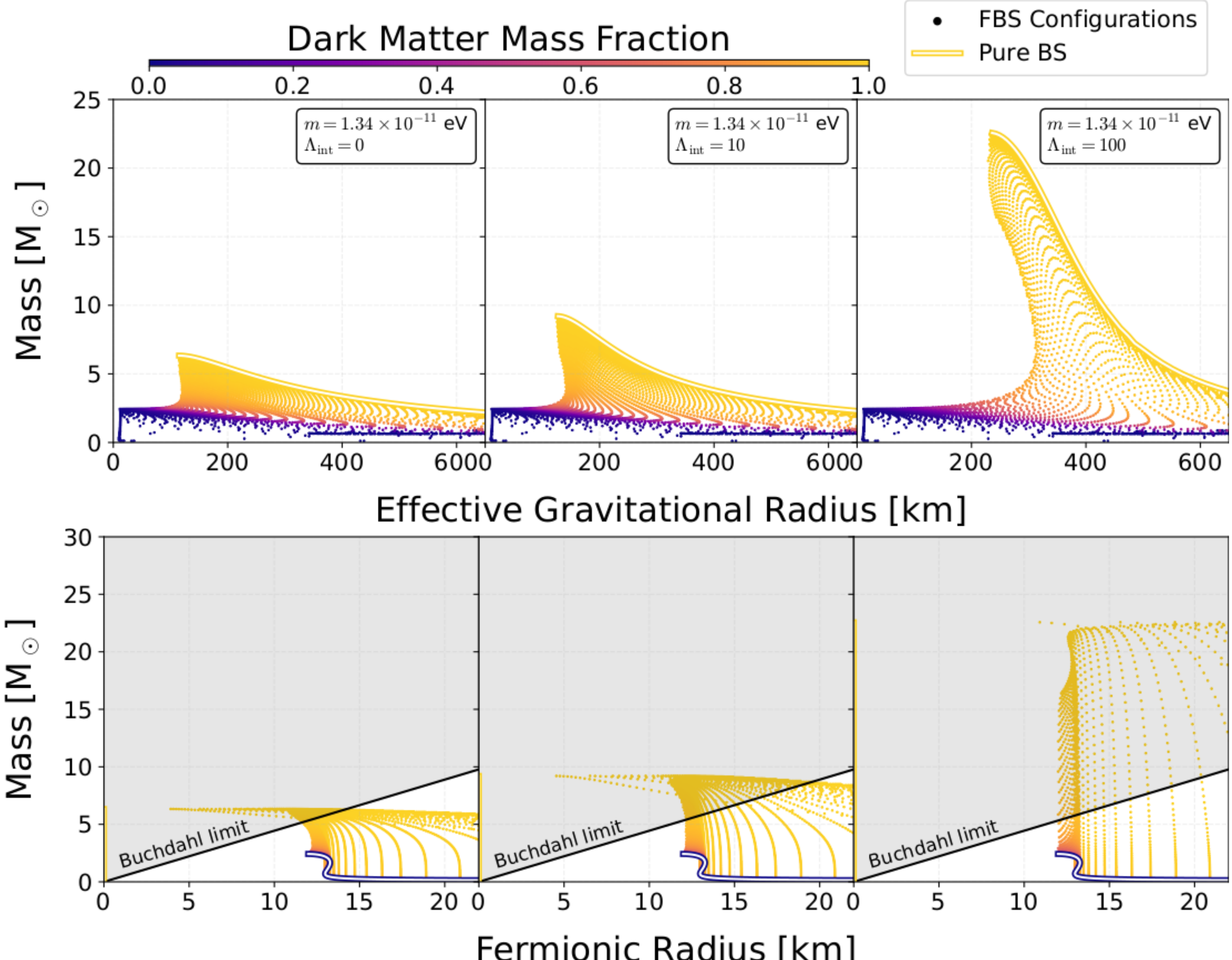
- **Stability Conditions**

$$\frac{dN_{\mathrm{f}}}{d\sigma} = \frac{dN_{\mathrm{b}}}{d\sigma} = 0$$

Mass-Radius Relations



Mass-Radius Relations



Tidal Deformability

- **Quadrupolar tidal field** $\mathcal{E}_{ij}$
- **Induces linear response at large radii**

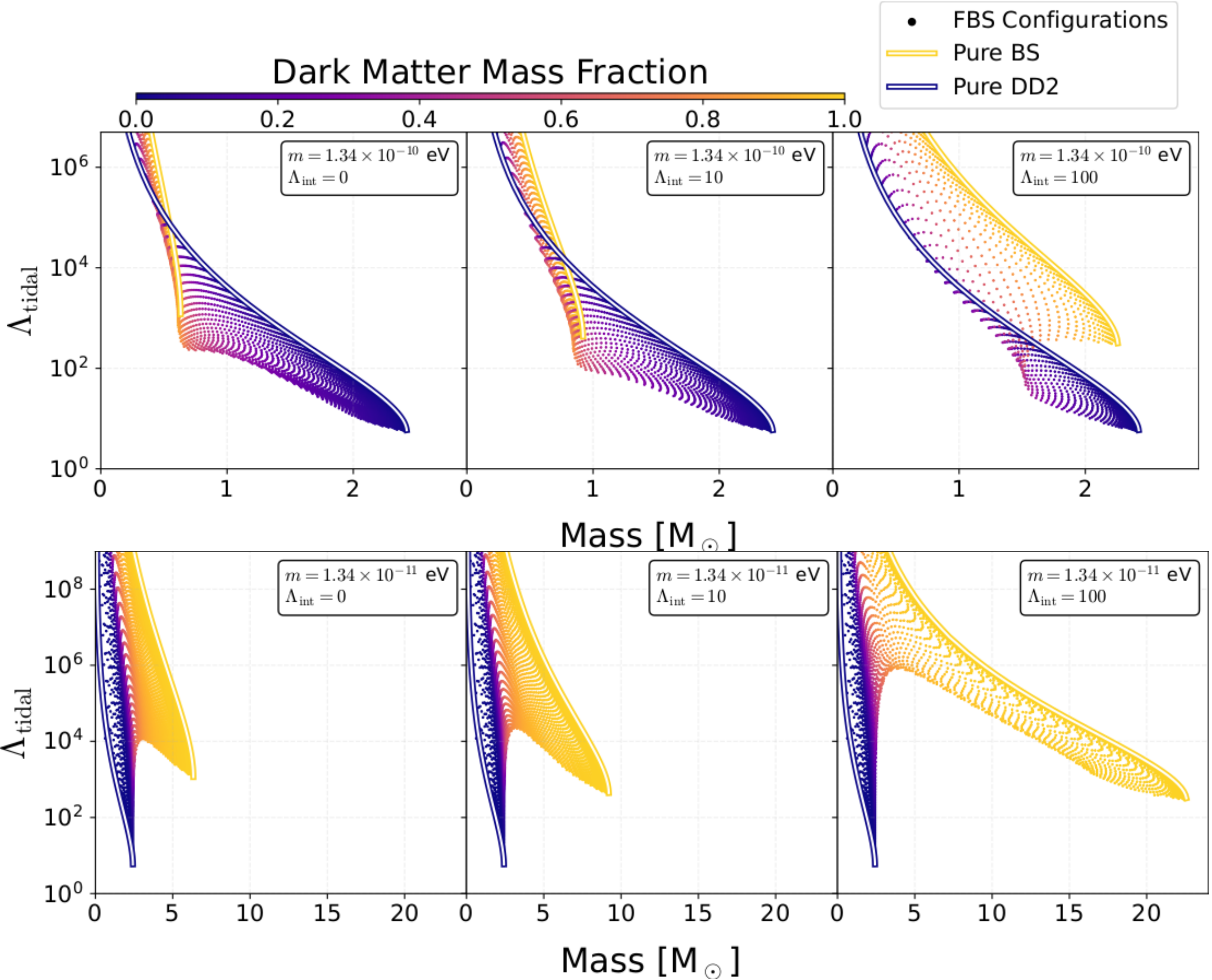
$$g_{tt} = -1 + \frac{2M}{r} + \mathcal{E}_{ij} x^i x^j \left(1 + \frac{3\lambda_{\text{tidal}}}{r^5}\right)$$

- **Dimensionless Tidal Deformability**

$$\Lambda_{\text{tidal}} = \frac{\lambda_{\text{tidal}}}{M^5}$$

- **Calculate via pertubative expansion to fields & metric**

Tidal Deformability



Thanks for your attention

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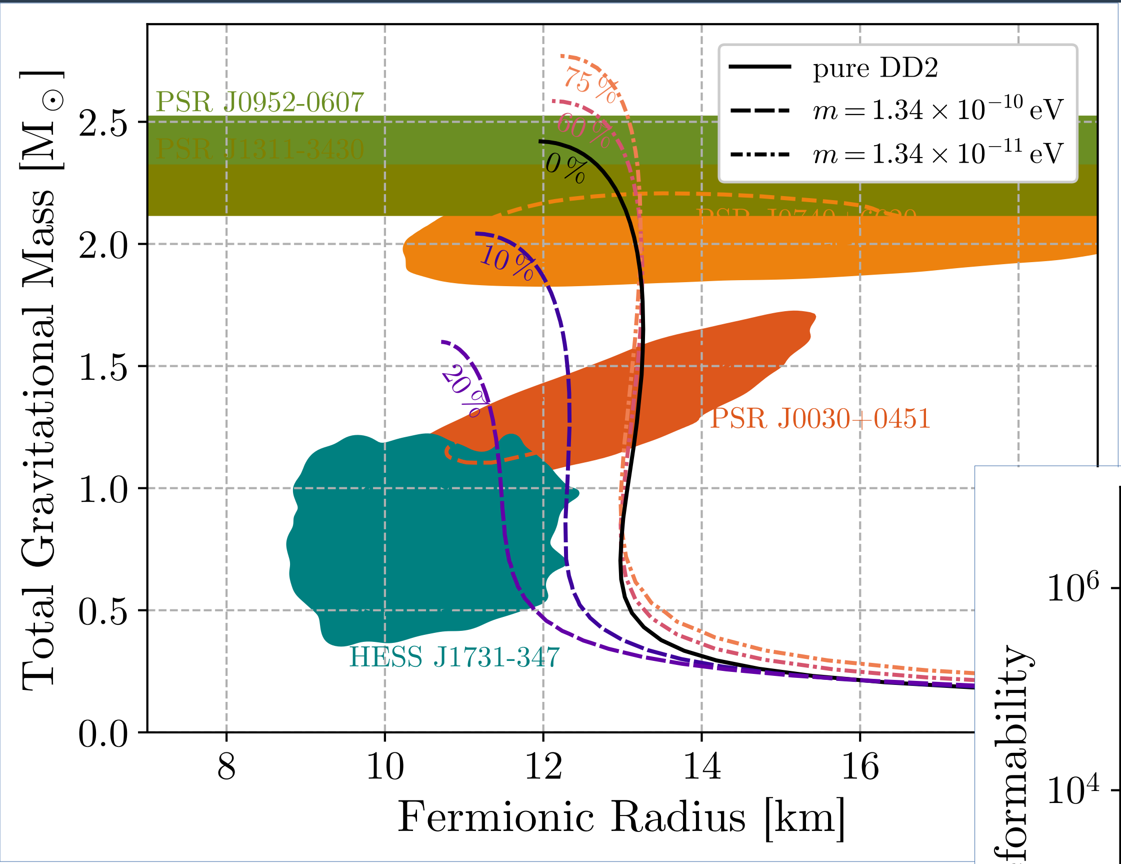
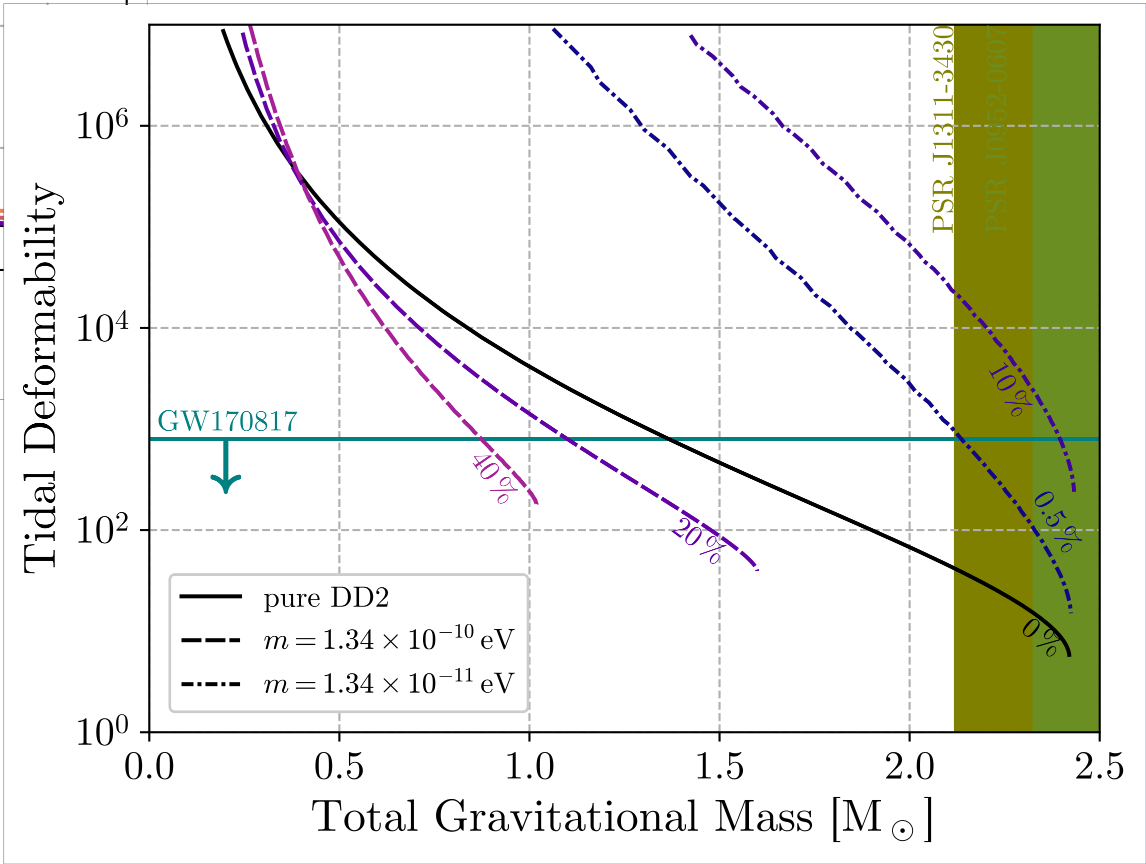
Observational Constraints





Perturbative Expansion

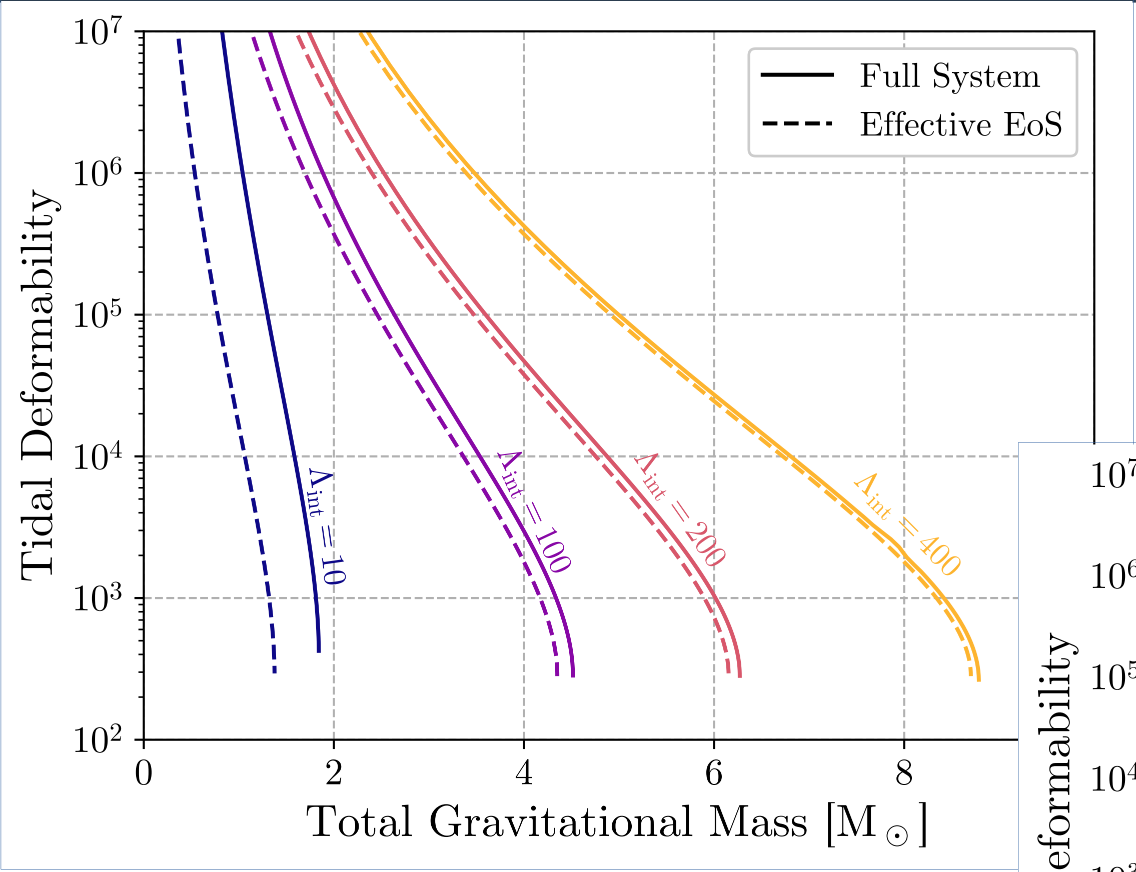
$$h_{\mu\nu} = Y_{20}(\theta,\varphi)\times \operatorname{diag}\left(-e^{v(r)}H_0(r), e^{u(r)}H_2(r), r^2K(r), r^2K(r)\sin^2\theta\right)$$

$$\delta\Phi(t,r,\theta,\varphi) = \phi_1(r)\frac{e^{-i\omega t}}{r}Y_{20}(\theta,\varphi),$$

$$\begin{aligned}
&H_0'' + \left(\frac{v'-u'}{2} + \frac{2}{r}\right)H_0' \\
&+ \left[-4\pi\frac{c_s^2+3}{c_s^2}\phi_0'^2 + 4\pi\omega^2 e^{u-v}\frac{c_s^2-1}{c_s^2}\phi_0^2 - \frac{u'v'+v'^2}{2} + v'' + \frac{3u'+7v'}{2r} + \frac{u'+v'}{2rc_s^2} - \frac{6}{r}e^u\right]H_0 \\
&= \left[-\frac{8\pi}{r}\frac{c_s^2+3}{c_s^2}\phi_0'' + \frac{4\pi}{r}\left(u'+v'+\frac{u'-v'}{c_s^2} - \frac{4}{r}\frac{c_s^2+3}{c_s^2}\right)\phi_0' + \frac{8\pi}{r}e^u\left(\mu^2+\omega^2e^{-v}+\frac{V'(\phi_0^2)-\omega^2e^{-v}}{c_s^2}\right)\phi_0\right]\phi_1.
\end{aligned}$$

$$\begin{aligned}
\phi_1'' &= \frac{u'-v'}{2}\phi_1' + \left[-2\phi_0' - r\phi_0'' + \frac{v'+u'}{2}r\phi_0' + \omega^2 r\phi_0 e^{u-v}\right]H_0 \\
&\quad + \left[\frac{6e^u}{r^2} + \frac{v'-u'}{2r} + 16\pi\phi_0'^2 + e^u\left(V'(\phi_0^2) + 2\phi_0^2V''(\phi_0^2) - \omega^2e^{-v}\right)\right]\phi_1.
\end{aligned}$$

Comparison to Effective EoS



$$P = \frac{4}{9}\rho_0 \left[\left(1 + \frac{3}{4}\frac{e}{\rho_0} \right)^{1/2} - 1 \right]^2$$