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SMOKING GUN SIGNALS OF DARK MATTER IN COMPACT STARS

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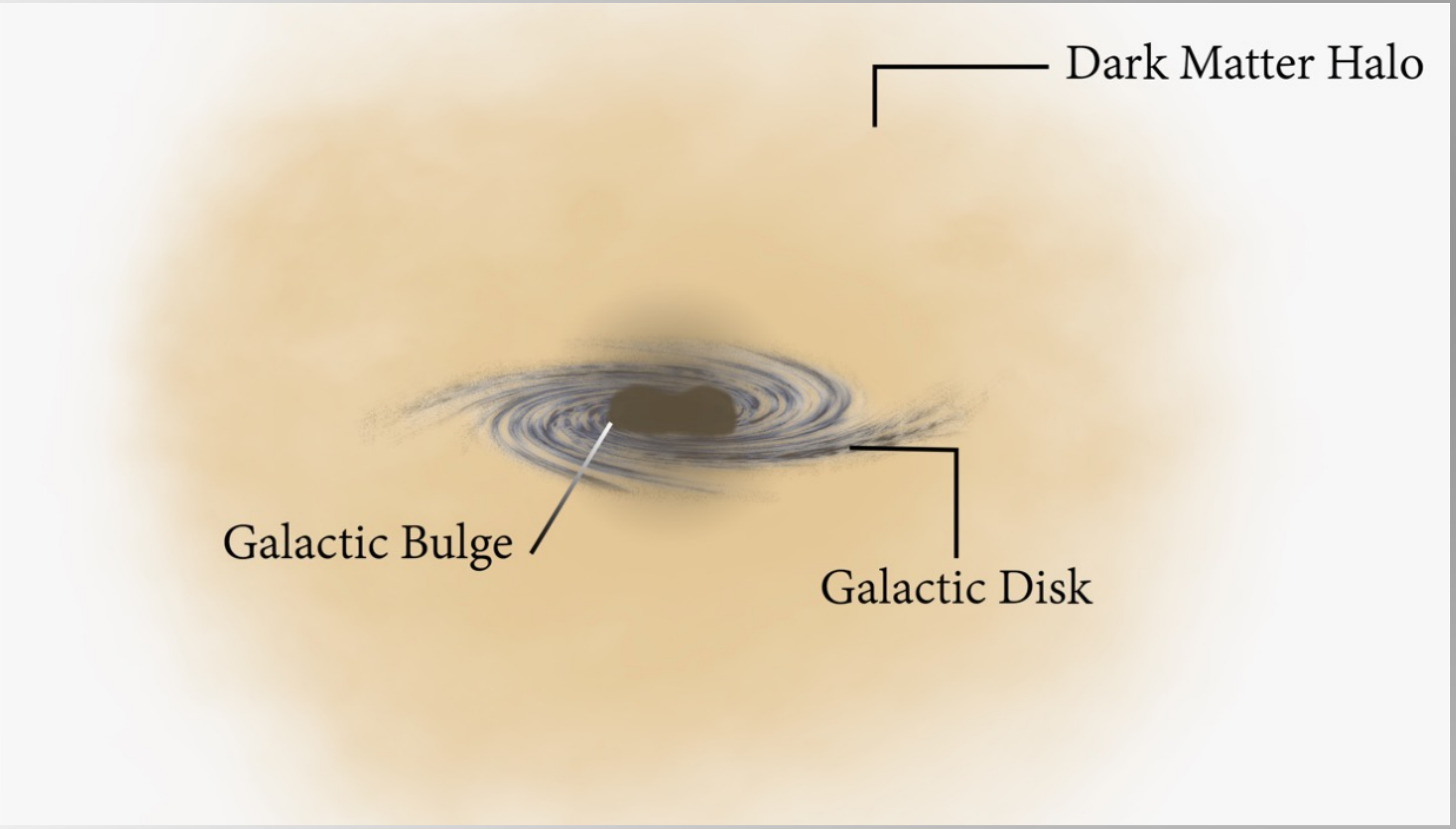
Accretion of Dark Matter

Due to their huge compactness, NS may be able to accumulate a sizeable amount of Dark Matter (DM);



- Proto-cloud - mixture of Baryonic Matter (BM) and Dark Matter (DM);
- Main Sequence star accretion;
- Supernovae - creation of DM;
- DM Clumps;
- Accretion of Self-Interacting DM;

CHECK IVANYTSKYI'S TALK TOMORROW!

Effects on Masses and Radii

The Bullet Cluster provides constraints on the cross section $\sigma_{\chi n}$

$$\begin{cases} \dfrac{dP_B}{dr} = -\dfrac{Gm}{r^2}\left(\rho_B + P_B\right)\left(1 + \dfrac{4\pi r^3 P}{m}\right)\left(1 - \dfrac{2Gm}{r}\right)^{-1} \\ \dfrac{dP_\chi}{dr} = -\dfrac{Gm}{r^2}\left(\rho_\chi + P_\chi\right)\left(1 + \dfrac{4\pi r^3 P}{m}\right)\left(1 - \dfrac{2Gm}{r}\right)^{-1} \end{cases}$$

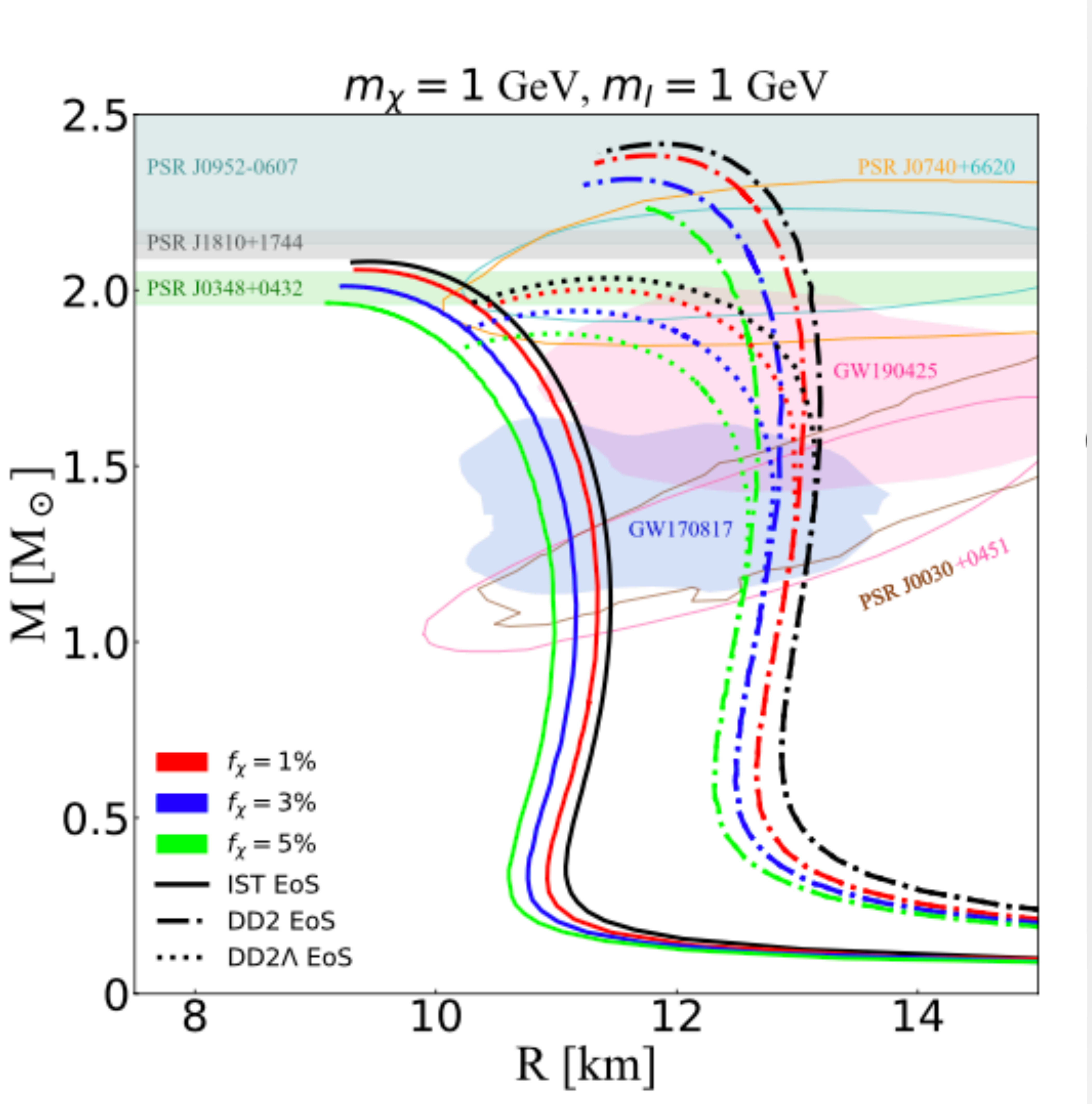
Total pressure $P(r) = P_B(r) + P_\chi(r)$

Gravitational Mass $m(r) = m_B(r) + m_D(r)$

$$m_i(r) = 4\pi \int_0^r \rho_i(r') r'^2 dr'$$

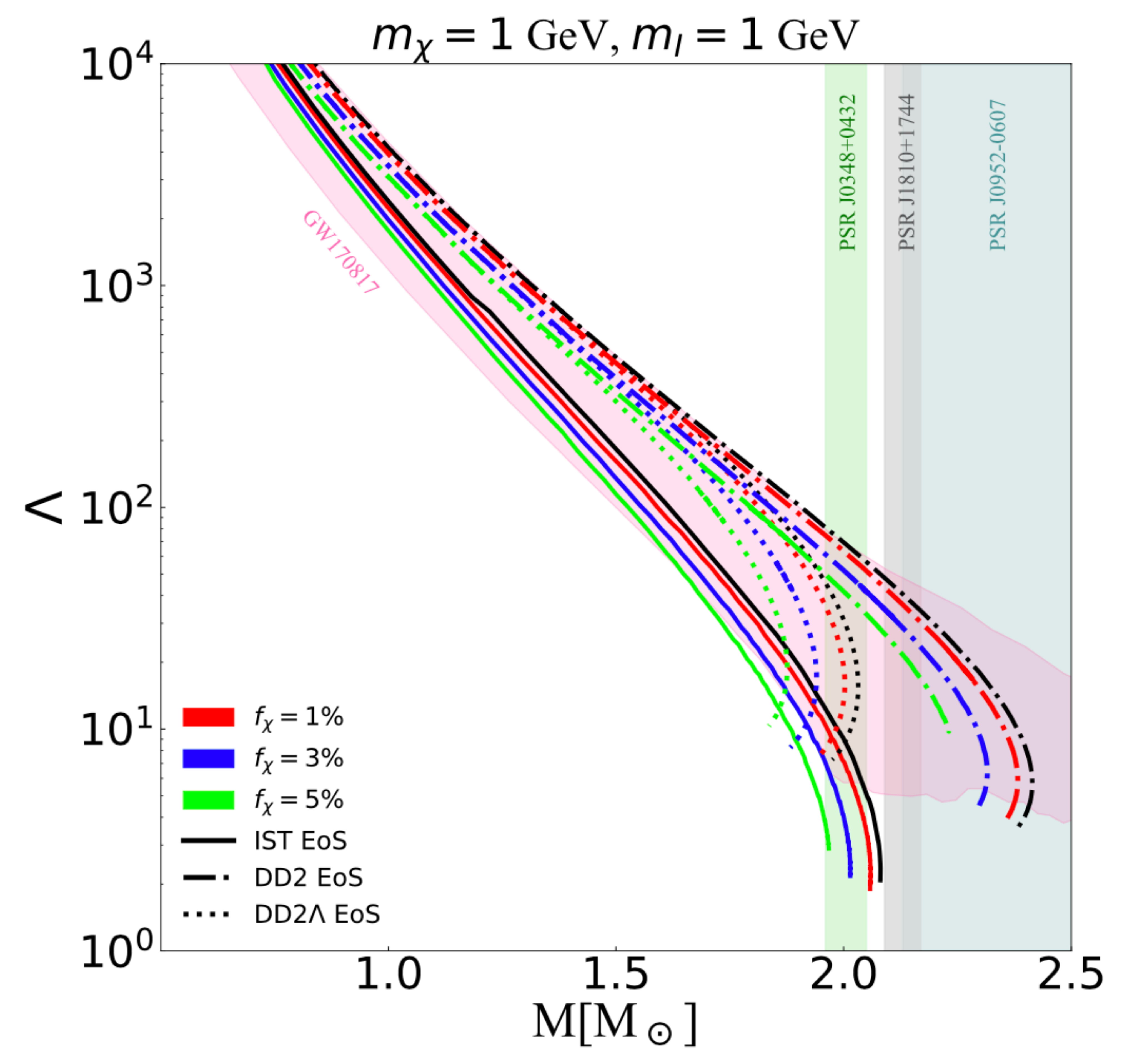
Total gravitational mass $M_{\text{tot}} = M_B(R_B) + M_D(R_D)$

DM fraction $f_\chi = \dfrac{M_D}{M_{\text{tot}}}$



MR curves for self-interacting bosonic DM core scenarios
Giangrandi et al., 2022

Effect on tidal deformability



Lambda-M curves for self-interacting bosonic DM core scenarios
Giangrandi et al., 2022

$$\Lambda = \frac{2}{3}k_2\left(\frac{cR_{\mathrm{out}}}{GM_{\mathrm{tot}}}\right)^5$$

DM Halo $R_{\mathrm{out}} = R_{\mathrm{D}}$

Λ increase

DM core $R_{\mathrm{out}} = R_{\mathrm{B}}$

Λ Decrease

Effective speed of sound approach

Giangrandi et al., 2022
Das et al., 2020

Giangrandi et al., 2022
Ellis et al., 2018
Bezares et al., 2019
Karkevandi et al., 2022
Miao et al., 2022
Leung et al., 2022

Effects on thermal evolution

Time evolution equation of the red-shifted temperature

$$C\frac{dT^{\infty}}{dt} = -L_{\nu}^{\infty} - L_{\gamma}^{\infty} \pm L_{\chi}^{\infty}$$

Heat Capacity

Red-shifted Neutrino Luminosity

Red-shifted Photon Luminosity

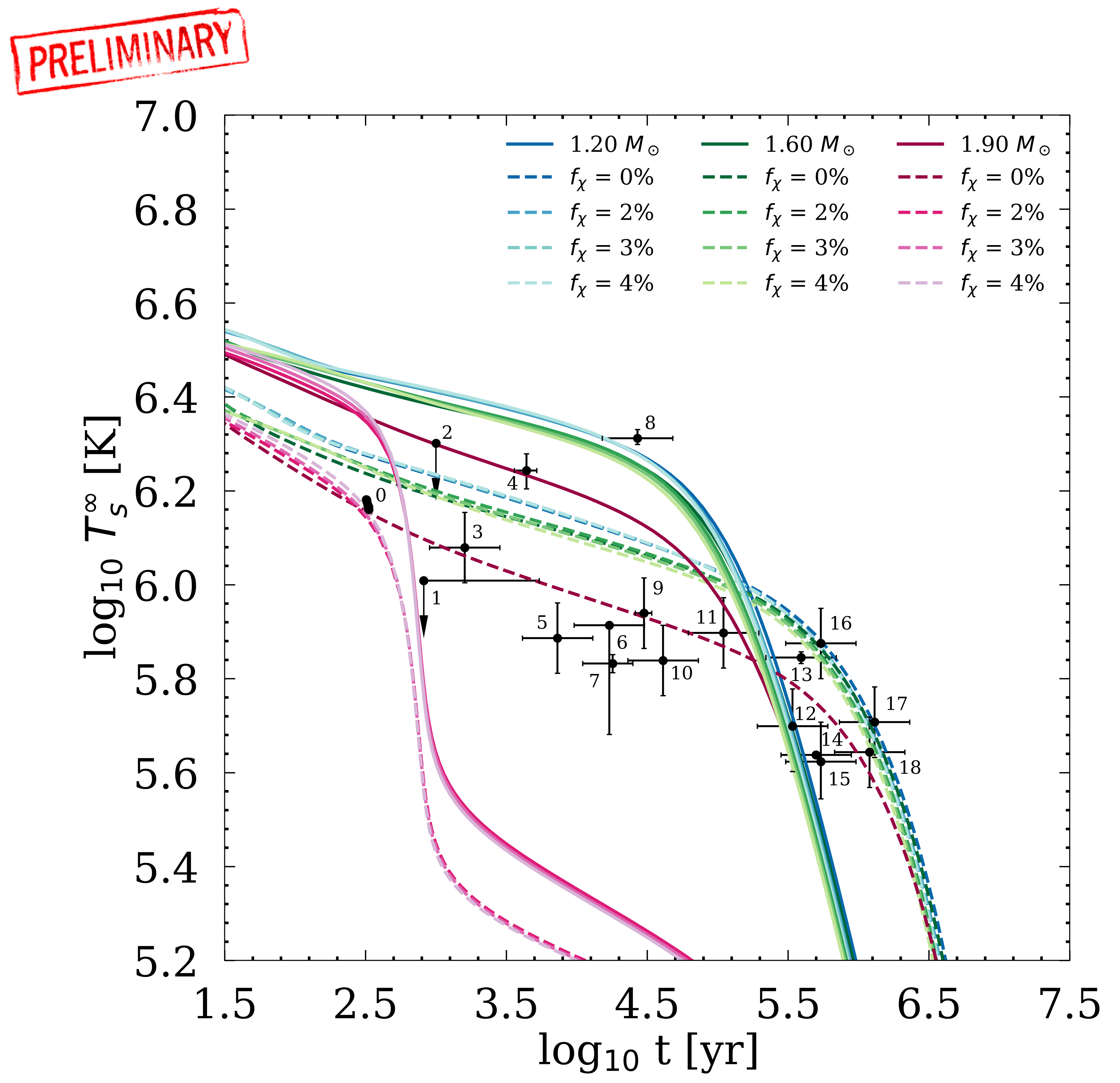
Red-shifted Heating/Cooling due to DM

Light DM particles, such as axions, could contribute as an additional cooling channel in NS and their mergers

Effects on cooling curves

- Even asymmetric DM models may affect NS thermal evolution;
- DM gravitational pull leads to denser baryonic cores

Direct Urca process triggers at lower mass configurations



Logarithm of the red-shifthed effective surface temperature as a function of time.
Avila, **Giangrandi** et al, 2023, *(in prep)*

CHECK A. AVILA'S POSTER AT -2 FLOOR

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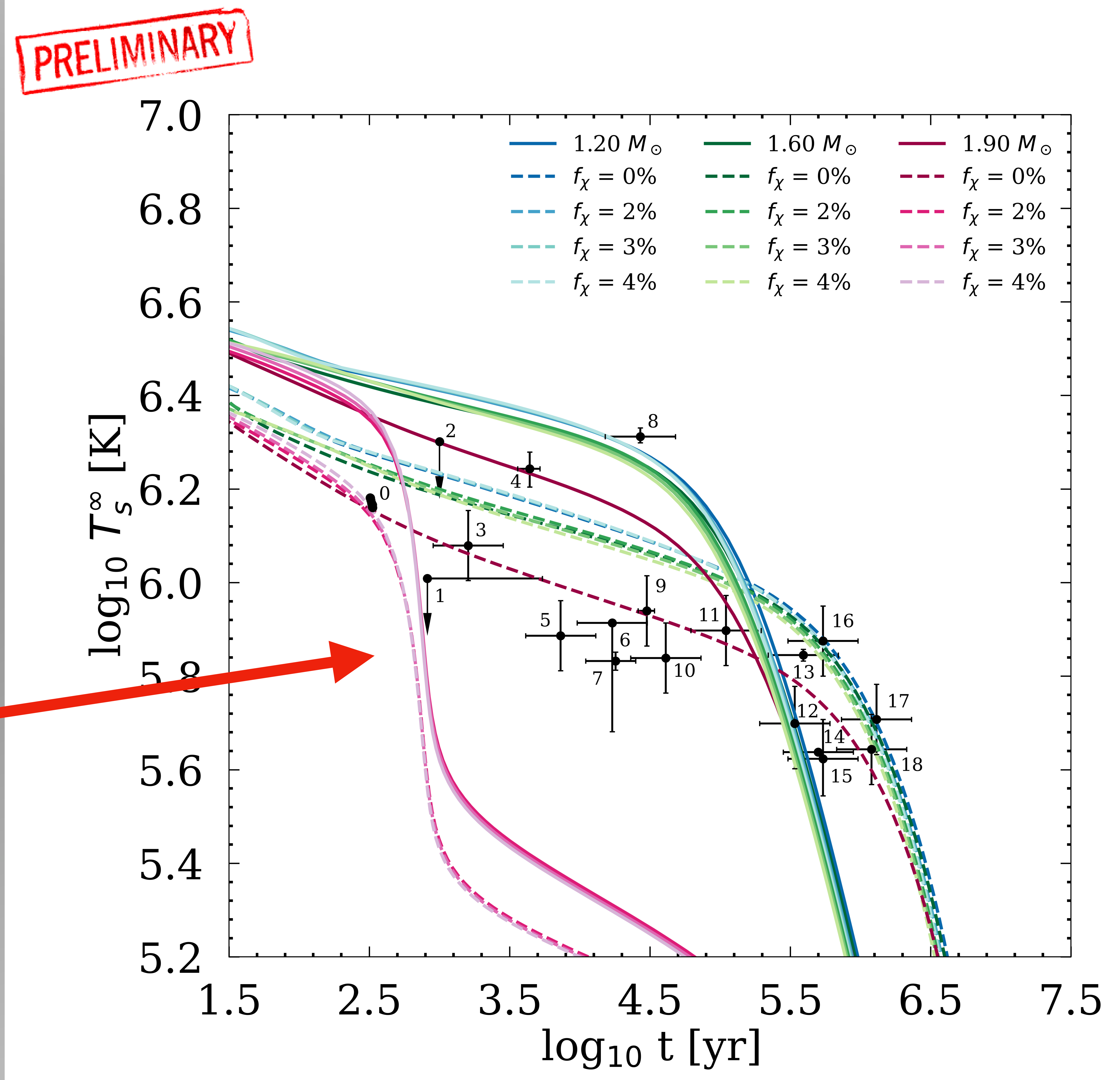

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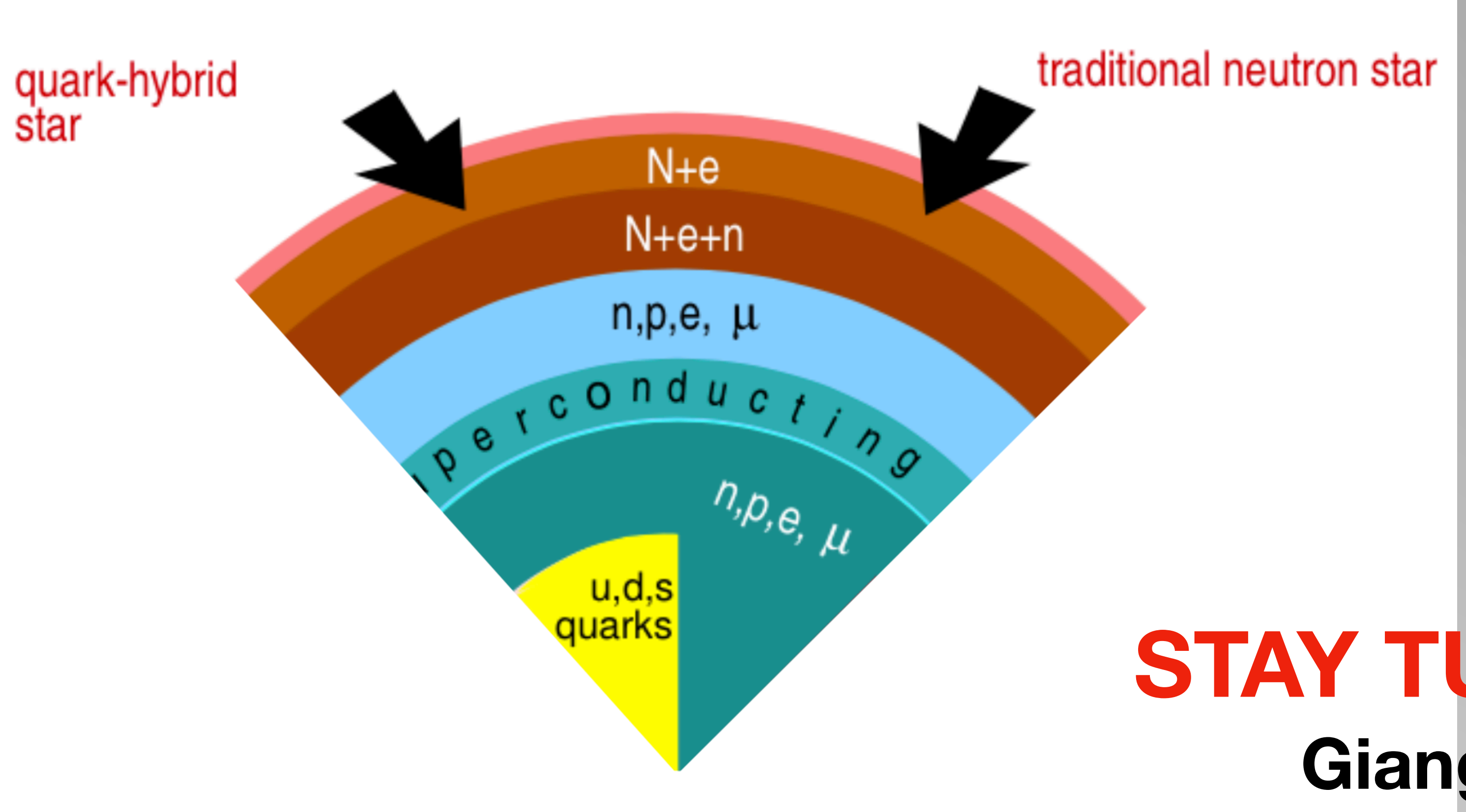
Degeneracy with QGP cores

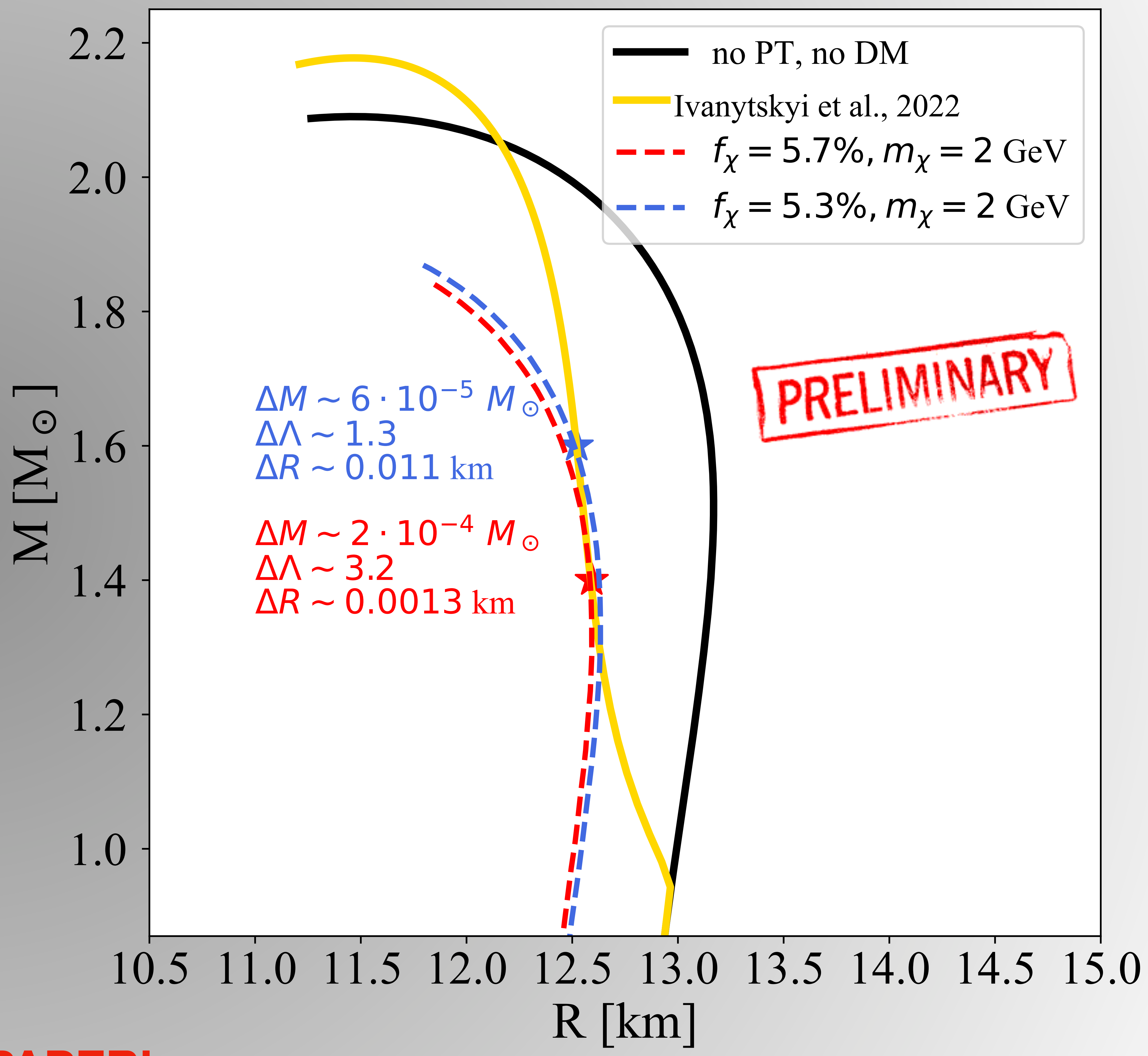
- Deconfinement phase transition to a quark-gluon plasma (QGP) in the inner NS core;
- DM and QGP cores may present undistinguishable mass, radius and tidal deformability;

How to split this degeneracy?

Future measurements of NSs

moment of inertia





MR curves degeneracy between DM-admixed and Hybrid NSs.

STAY TUNED FOR THE PAPER!

Giangrandi et al., 2023, *in prep*.

Summary

1) Measuring mass, radius and moment of inertia of NSs with few-% accuracy

Radio telescopes: MeerKAT, SKA, ngVLA plan to increase pulsar timing and discover Galactic centre pulsars
Space telescopes: NICER, ATHENA, eXTP, STROBE-X are expected to measure mass and radius of NSs with high accuracy

DM core	Mass and radius reduction of NSs towards the Galaxy centre
DM halo	Mass increase of NSs toward the Galaxy centre

2) Performing numerical simulations of binary neutron star mergers and kilonova ejecta for DM-admixed NS for different DM candidates, particle mass, interaction strength and fractions

supplementary peak in the characteristic GW spectrum of NS mergers; exotic waveforms; modification of the kilonova ejecta;
post-merger regimes: the next generation of GW detectors, i.e., the Cosmic Explorer and Einstein Telescope.

Large statistic on NS-NS, NS-BH mergers by LIGO/Virgo/KAGRA and Einstein Telescope would be very helpful

Supplementary peak in the GW spectrum
Exotic waveforms
Modification of the kilonova ejecta

High precision required, thus the Einstein Telescope

3) Detecting objects that go in contradiction with our understanding (Anomalous thermal evolution, MR curves, e.g. HESS J1731-347)

$$\begin{cases} M \sim 0.77^{+0.20}_{-0.17}\ \mathrm{M}_\odot \\ R \sim 10.4^{+0.86}_{-0.78}\ \mathrm{km} \end{cases}$$

Doroshenko et al., 2022

4) High/Low surface temperature of NSs towards the Galaxy Centre due to symmetric DM

5) Modification of the pulsar pulse profile or light bending as a consequence of a DM Halo

6) Degeneracy between QGP and DM cores

Thank you so much!

Effective speed of sound

BM and DM chemical potentials scale proportionally

$$\mu_{\chi,c} = \xi \mu_{b,c}$$

We can rewrite the speed of sound squared as follows

$$c_{s,tot}^2 = \frac{dp_{tot}}{d\varepsilon_{tot}} = \frac{\frac{\partial p_B}{\partial \mu_B} + \frac{\partial p_\chi}{\partial \mu_\chi}\frac{d\mu_\chi}{d\mu_B}}{\frac{\partial \varepsilon_B}{\partial \mu_B} + \frac{\partial \varepsilon_\chi}{\partial \mu_\chi}\frac{d\mu_\chi}{d\mu_B}} = \frac{\frac{\partial \varepsilon_B}{\partial \mu_B} c_{s,B}^2 + \frac{\partial \varepsilon_\chi}{\partial \mu_\chi}\frac{d\mu_\chi}{d\mu_B} c_{s,\chi}^2}{\frac{\partial \varepsilon_B}{\partial \mu_B} + \frac{\partial \varepsilon_\chi}{\partial \mu_\chi}\frac{d\mu_\chi}{d\mu_B}}$$

Let’s define a new parameter

$$\eta \equiv \frac{\partial \varepsilon_B}{\partial \mu_B}\left[\frac{\partial \varepsilon_B}{\partial \mu_B} + \frac{\partial \varepsilon_\chi}{\partial \mu_\chi}\frac{d\mu_\chi}{d\mu_B}\right]^{-1} = \frac{\partial n_B}{\partial \mu_B}\left[\frac{\partial n_B}{\partial \mu_B} + \xi^2 \frac{\partial n_\chi}{\partial \mu_\chi}\right]^{-1}$$

$$c_{s,\text{eff}}^2 = \eta c_{\text{s,B}}^2 + (1-\eta) c_{s,\chi}^2$$

By construction, we have

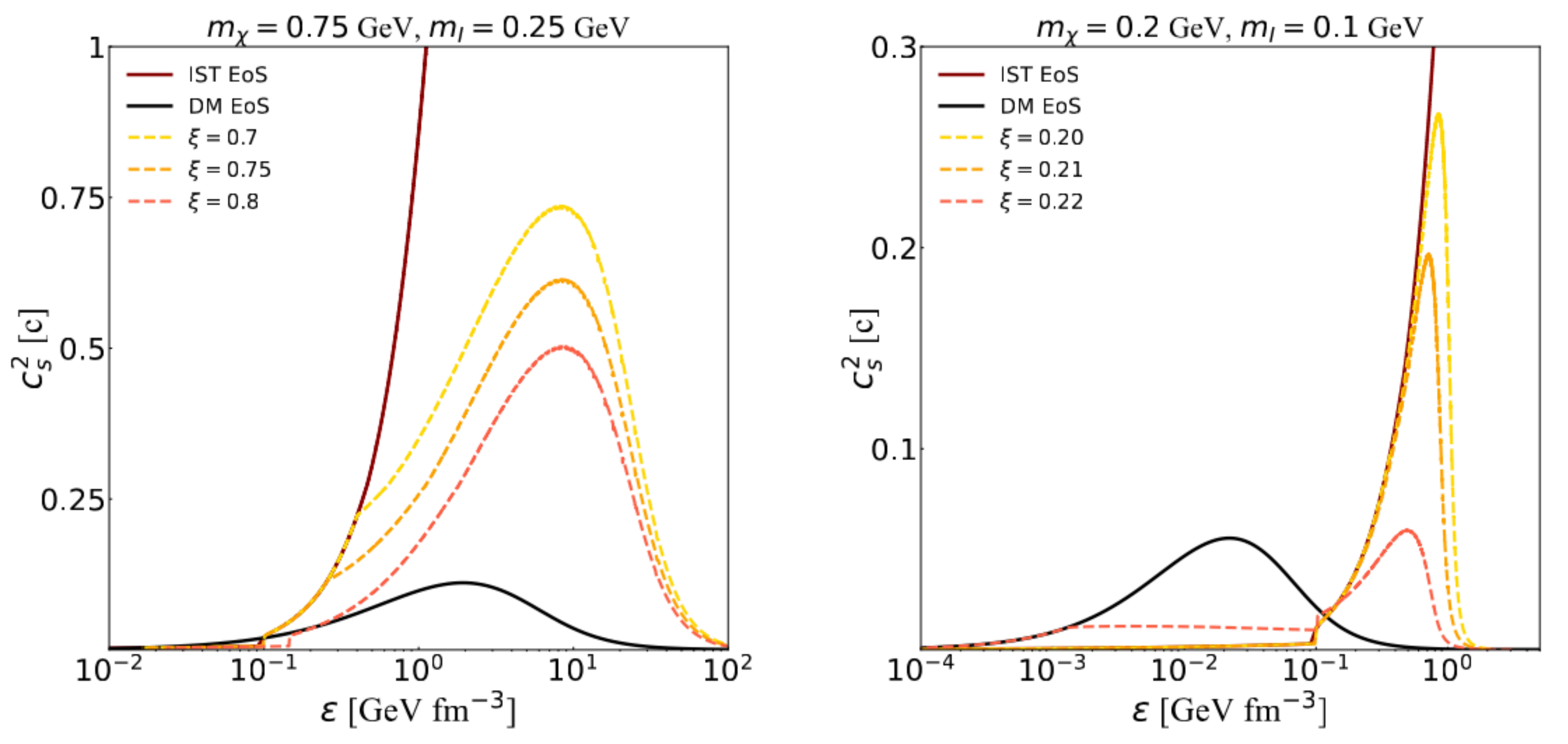
$$\eta \in [0,1]$$

Effective speed of sound

$$\mu_{\chi,c} = \xi \mu_{b,c}$$

$$c^2_{s,\mathrm{eff}} = \eta c^2_{\mathrm{s,B}} + (1-\eta) c^2_{s,\chi}$$

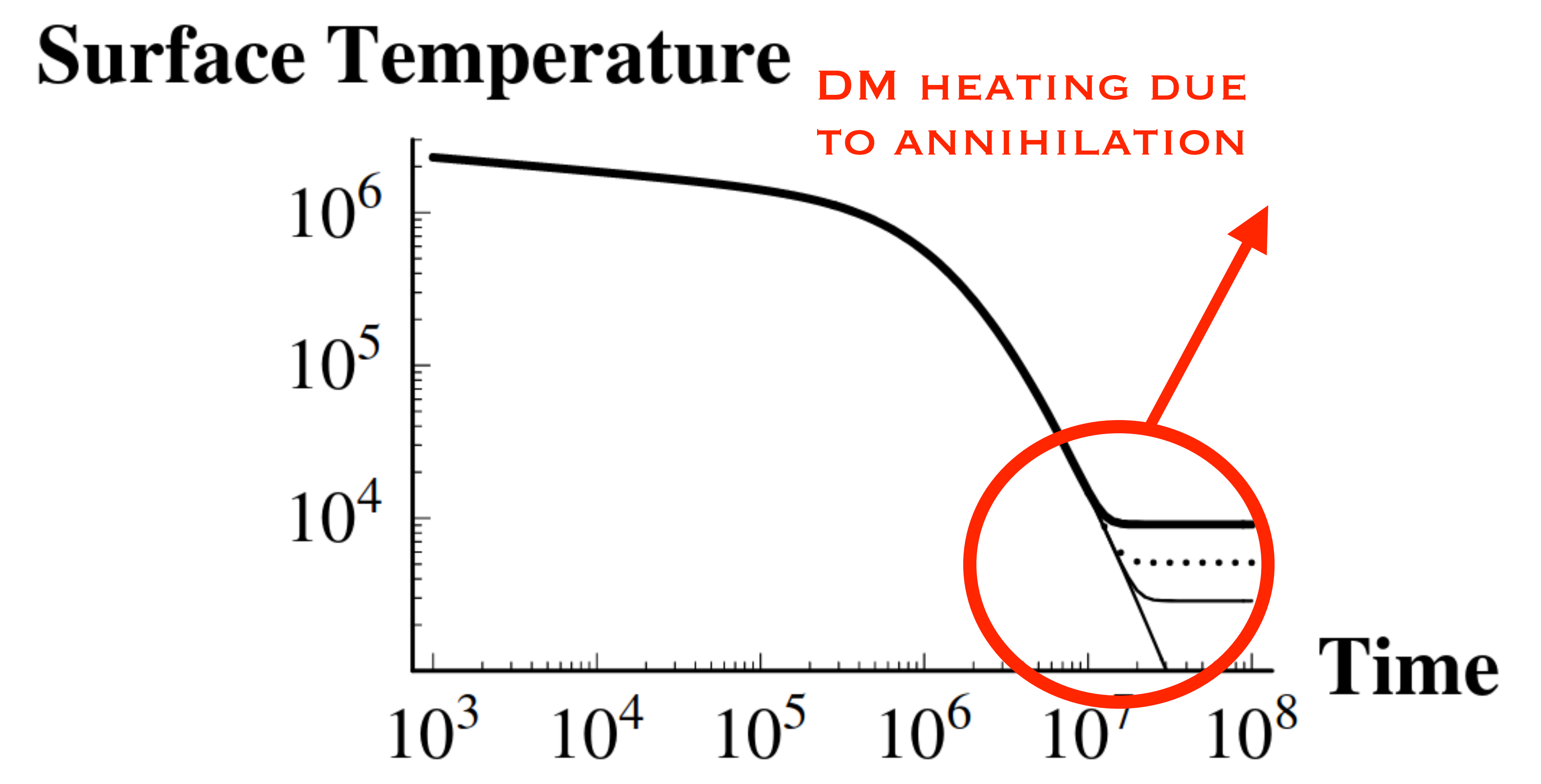
BM and DM chemical potentials scale proportionally



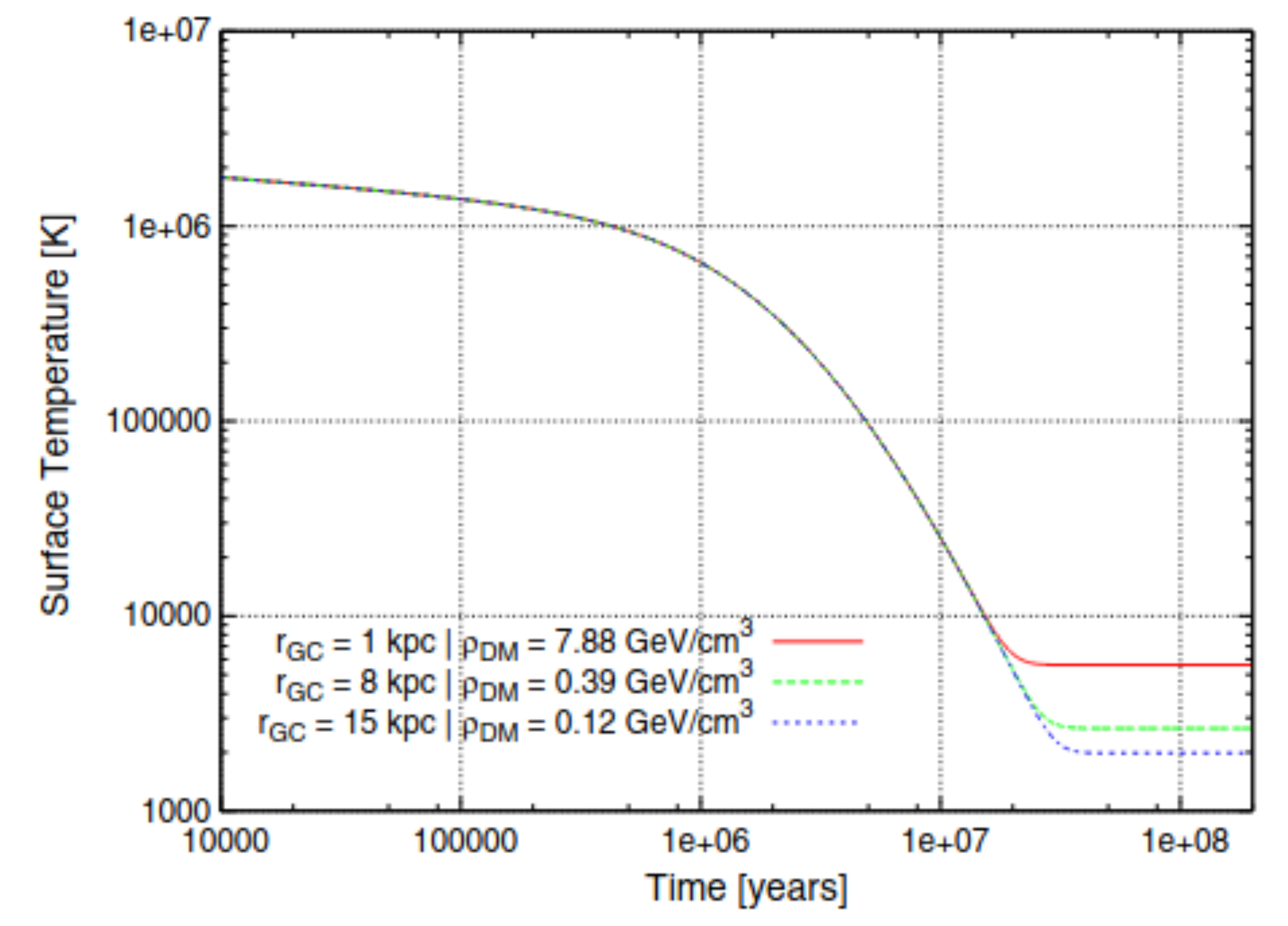
Speed of sound for a DM core (Left Panel) and halo scenarios (Middle Panel).

GIANGRANDI ET AL., 2022

Thermal evolution



Kouvaris 2008
Kouvaris&Tinyakov, 2010
Hamaguchi et al., 2019



Evolution of the surface temperatures of a 1.44 $M_\odot$ neutron star situated at various galactic radii. In the present case, $m_\chi = 10$ GeV, $\sigma_0 = 1.5 \times 10^{-41}$ cm^2 and $(r_{-2}, \alpha) = (16$ kpc$, 0.19)$.

Lavallaz & Fairbairn, 2010

The closer to the Galactic centre, the greater the DM amount, hence the heating