Constraint on dark matter (DM) using Neutron stars

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Abundance of DM and method to constraint

DM constitutes the approximately 25% of the total matter present in the universe.

DM does not interact with ordinary matter except through gravity

Neutron stars and other compact objects can accrete DM.

In a cold neutron star DM must settle inside it.

DM assumption

DM has a particle nature.

DM is self-interacting.

Does DM always sit inside the core?

Depends on the nature of the DM.

If DM is fermionic it can not condense and might spread all over the neutron star?

If DM is bosonic it must condense in the core.

Fermionic DM

Construct a self-interacting fermionic DM Equation of state (EoS) using similar approach to a vector meson exchange in the hadronic matter

$$\epsilon_\chi = m_\chi^4 \chi(x) + \frac{1}{(3\pi^2)^2} \frac{x^6 m_\chi^6}{m_I^2}$$

$$P_\chi = m_\chi^4 \phi(x) + \frac{1}{(3\pi^2)^2} \frac{x^6 m_\chi^6}{m_I^2} \qquad x = \frac{(3\pi n_\chi)^{1/3}}{m_\chi}$$

$$\chi(x) = \frac{1}{8\pi^2}(x\sqrt{1+x^2}(1+2x^2) - \log(x+\sqrt{1+x^2}))$$

$$\phi(x) = \frac{1}{8\pi^2}(x\sqrt{1+x^2}(2x^2/3-1) + \log(x+\sqrt{1+x^2}))$$

Bosonic DM

Below a critical temperature all particle must condensate.

For a dilute gas of bosonic particles at such low temperature, only binary collisions at low energy are relevant, which are characterized by scattering length ($l\chi$) parameter.

Construct an EoS for self-interacting bosonic DM

$$P_\chi = \frac{2\pi\hbar l_a}{m_\chi^3}\epsilon_\chi^2$$

Neutron stars

- Astrophysical laboratories
- Physics at extreme conditions
- Select model for ordinary matter at extreme conditions.
- Have some observational constraint.

Selected models for neutron star for ordinary matter

Neutron star contains nucleons only matter (N-QMC700)

Neutron star contains nucleons and hyperons (F-QMC700)

Neutron star contains nucleons and strange matter (Deconfined quark matter)

Constraints

Neutron star must have a maximum mass of at lease 2 solar masses

Radius should be 9-13 kms for neutron stars.

Tidal deformability must follow gravitational wave observational constraint (Λ = 400-800) for neutron star of 1.4 solar masses.

Two fluid structural equation

Ordinary TOV equation for one fluid will not work.

Construct a TOV equation for two fluids.

$$\frac{dP_{nucl}}{dr} = -\frac{[\epsilon_{nucl}(r) + P_{nucl}(r)][4\pi r^3(P_{nucl}(r) + P_{DM}(r)) + m(r)]}{r^2(1 - \frac{2m(r)}{r})}.$$

$$m_{nucl}(r) = 4\pi \int_0^r dr.r^2 \epsilon_{nucl}(r).$$

$$\frac{dP_{DM}}{dr} = -\frac{[\epsilon_{DM}(r) + P_{DM}(r)][4\pi r^3(P_{nucl}(r) + P_{DM}(r)) + m(r)]}{r^2(1 - \frac{2m(r)}{r})}.$$

$$m_{DM}(r) = 4\pi \int_0^r dr.r^2 \epsilon_{DM}(r).$$

$$m(r) = m_{nucl}(r) + m_{DM}(r).$$

Solve

Fermionic DM EoS + ordinary matter EoS + Structural equation

Bosonic DM EoS + ordinary matter EoS + Structural equation

Constraint on DM

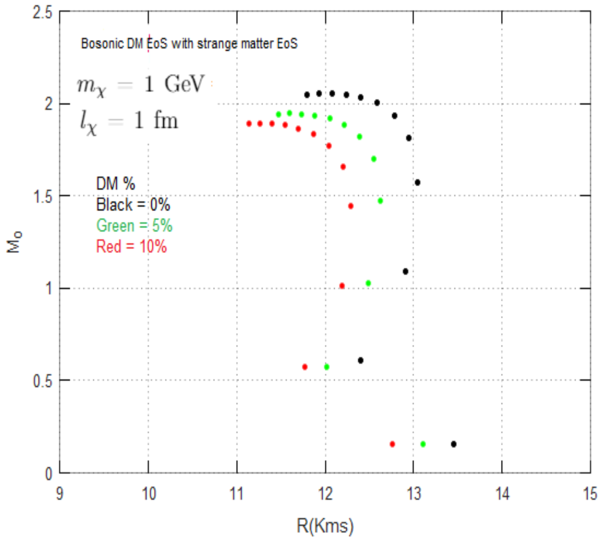
For this mass select properties for DM particles.

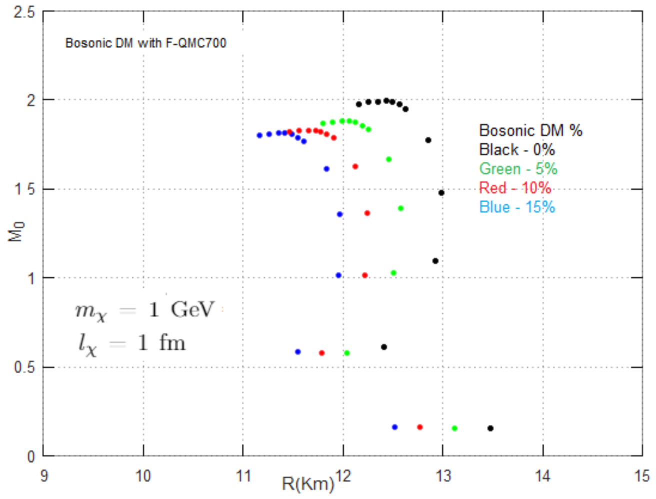
Select how much DM mass a neutron star contains.

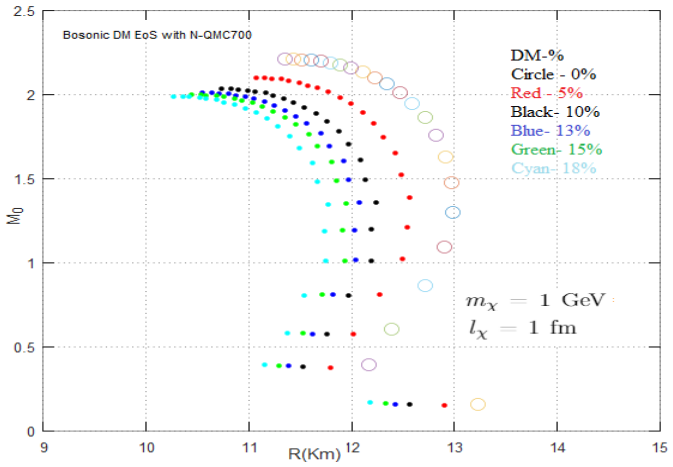
Does the selected properties of the DM particles follow the constraints on the neutron star?

A Few Results

BOSONIC DM WITH DIFFERENT ORDINARY MATTERS – **MASS VS RADIUS**

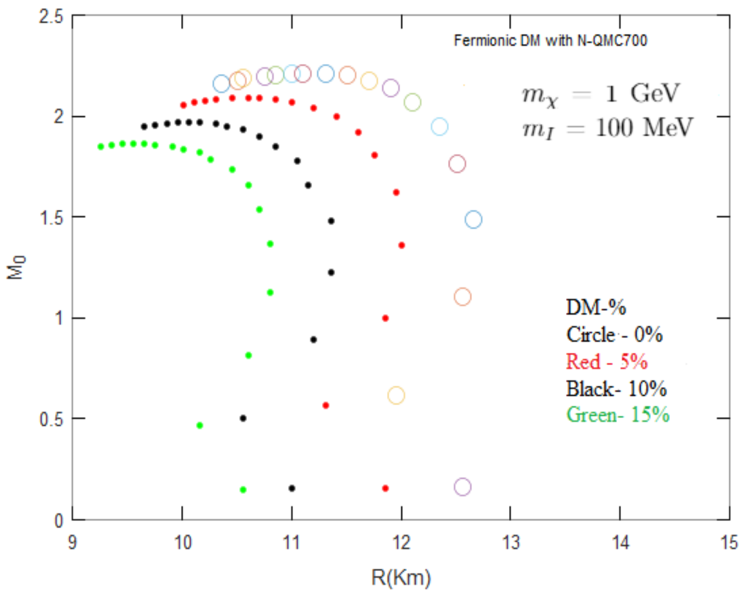


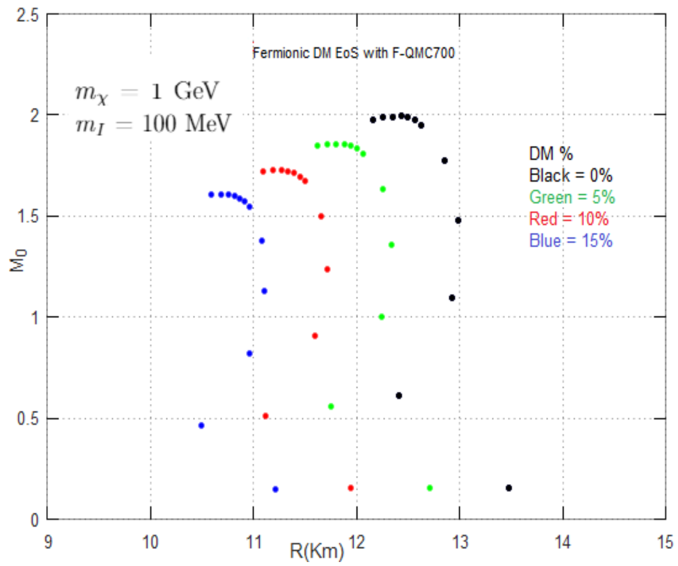


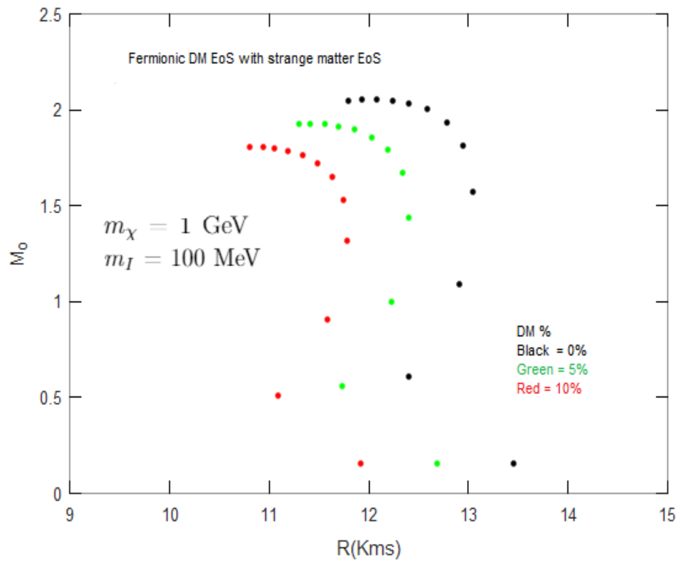


Results

FERMIONIC DM WITH DIFFERENT ORDINARY MATTERS- **MASS VS RADIUS.**

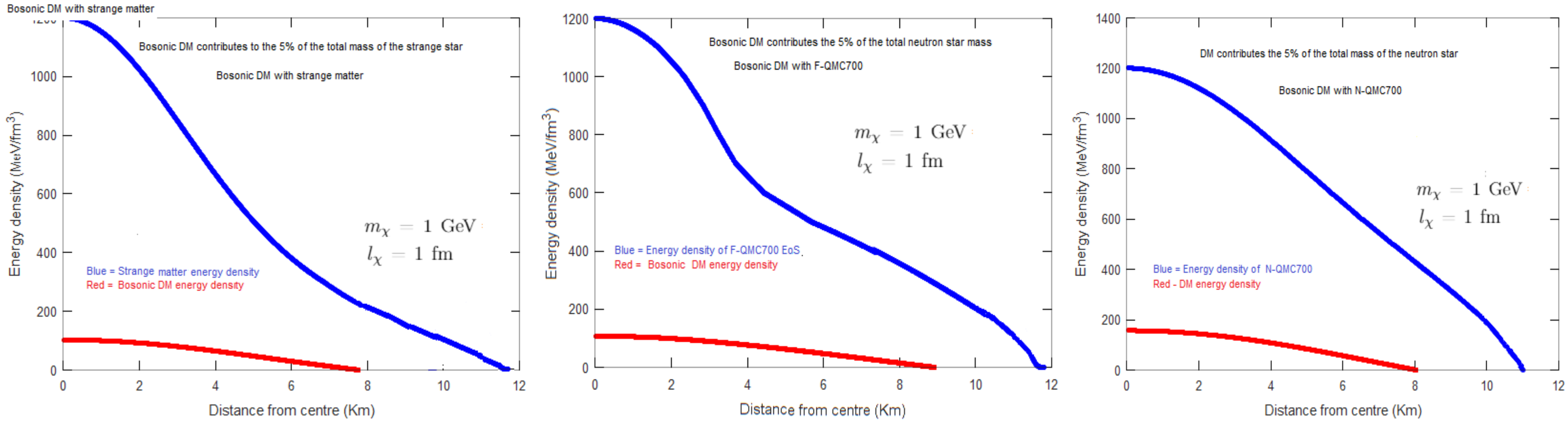






Distribution of DM inside neutron stars

Energy density distribution of bosonic DM when DM contributes to the 5% of the total neutron star mass.



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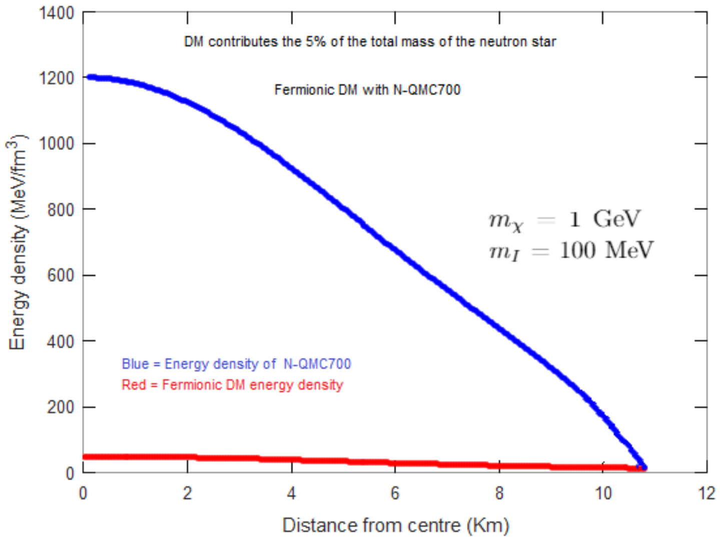

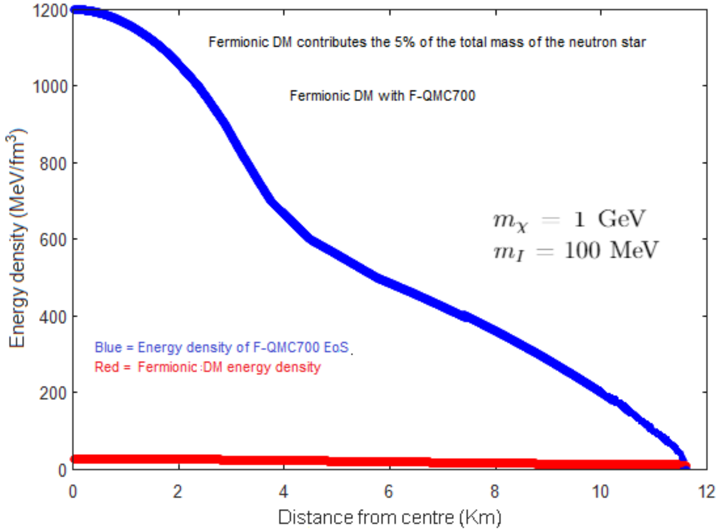

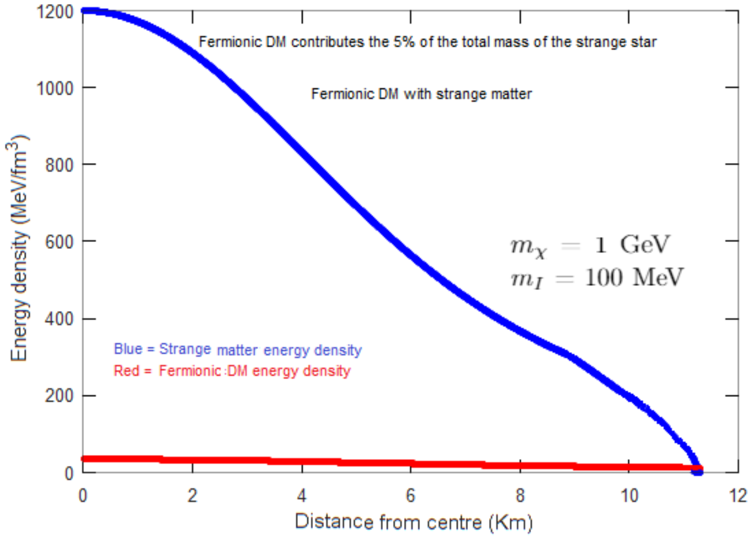

Future work

- Calculate tidal Love numbers and test tidal deformability constraint.

- Make DM mass contribution to neutron star more realistic by constructing a Neutron star DM accretion model, get the age a neutron star and test how much DM it may has accreted.

Thank You

Any Questions?