Mass-Radius Relation of Neutron Stars in a Scalar-Tensor Theory

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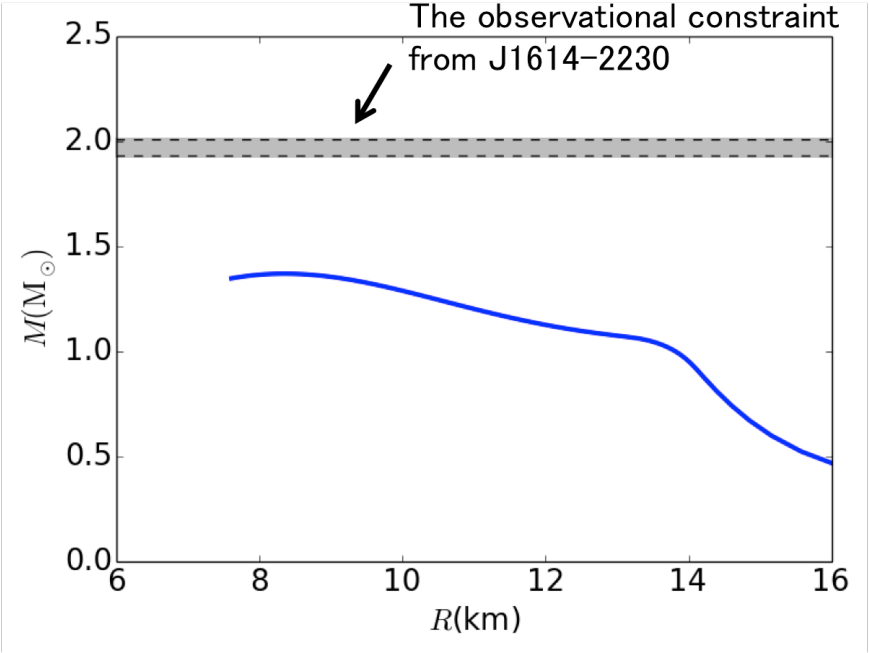
Introduction

- Tests of GR by NS-NS coalescence
- The existence of the $2M_\odot$ NS[1]

The structure of NSs in alternatives to GR?
$2M_\odot$ can be explained?



MR relation with GS1 EOS

[1] P. Demorest *et al.*, Nature **467**, 1081(2010).

Scalar-tensor theory

The scalar-tensor theory proposed in [2]

Include a massive scalar field, ϕ

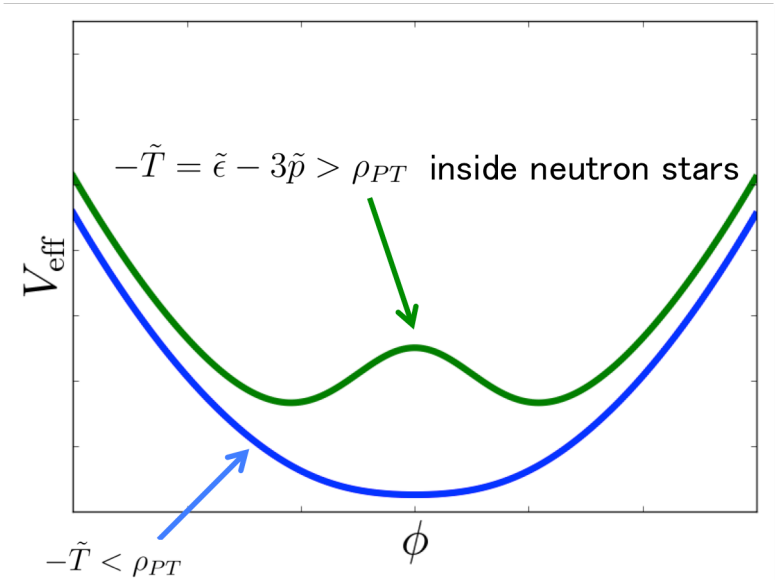
ϕ = Dark matter

(Properties)

- The effective gravitational constant depends on ϕ .
- The effective potential of ϕ depends on the density of the surrounding matter.

[2] P. Chen, T. Suyama and J. Yokoyama, Phys. Rev. D **92**, 124016 (2015).

Symmetry breaking inside NSs



(e.g. in the solar system)

Gravity is weakened inside NSs

→ More massive NSs may be allowed.

η :How much gravity is weakened

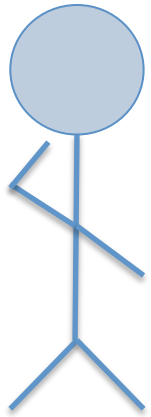
$\rho_{\rm PT}$:Critical density for symmetry breaking

λ_ϕ :Compton wave length

Structure of NS

$$\lambda_\phi \lesssim 10\mathrm{km} \sim R_{\mathrm{NS}}$$

?

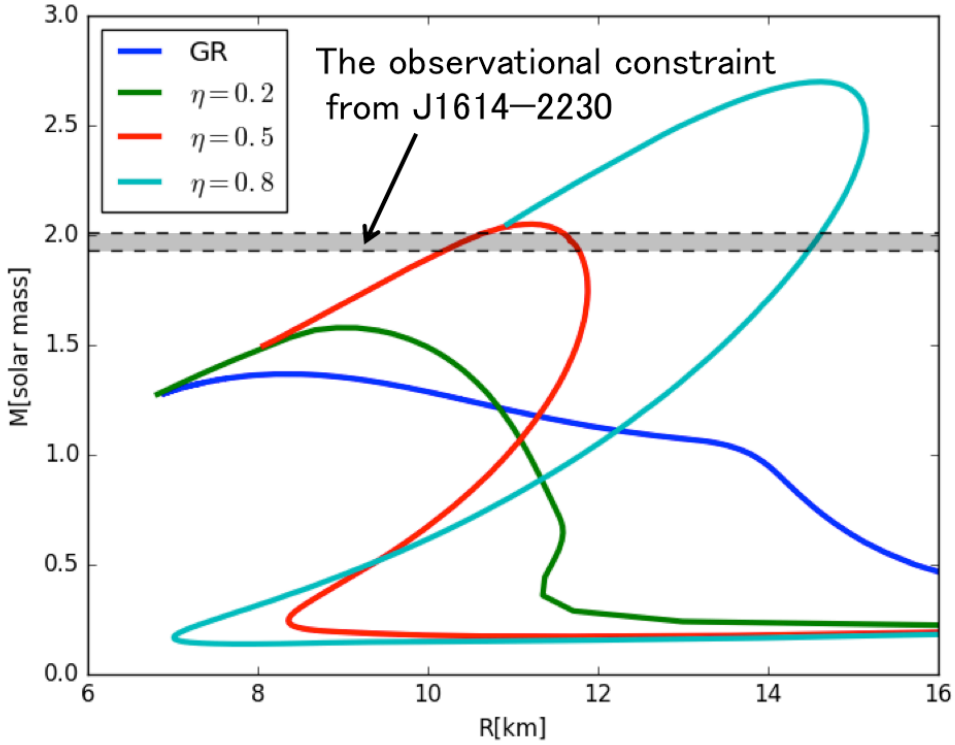


NS

- ✓ Solar system experiments
- ✓ Binary pulsar observations

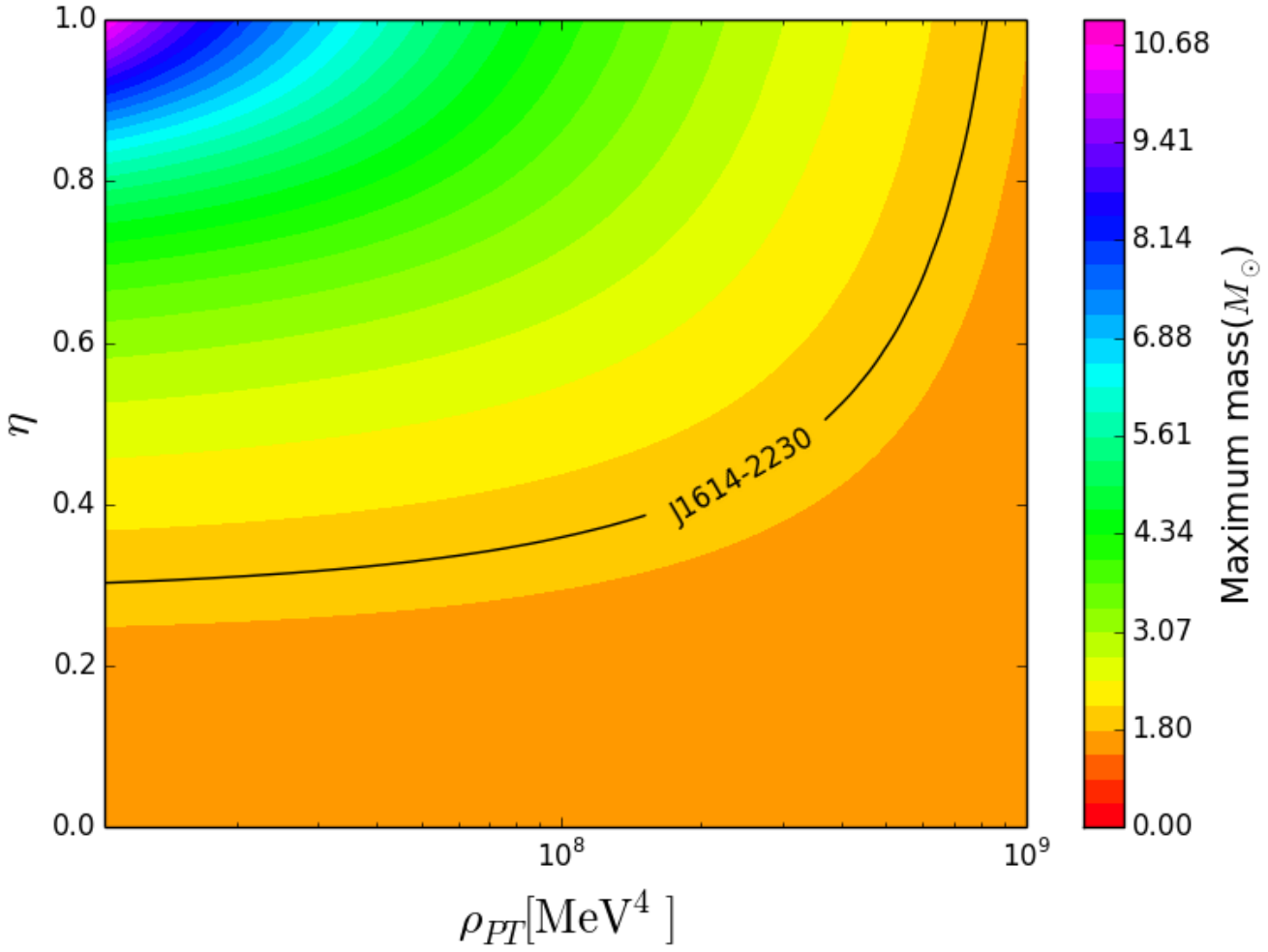
Mass-Radius Relation

$2M_\odot$ is allowed!!



$$\rho_{\rm PT} = 10^8 {\rm MeV}^4, \ \lambda_\phi = 10{\rm km}$$

The maximum mass



$$\lambda_\phi / R_{\mathrm{NS}} \ll 1$$

Summary

- The existence of the $2M_{\odot}$ NS is allowed in our model.

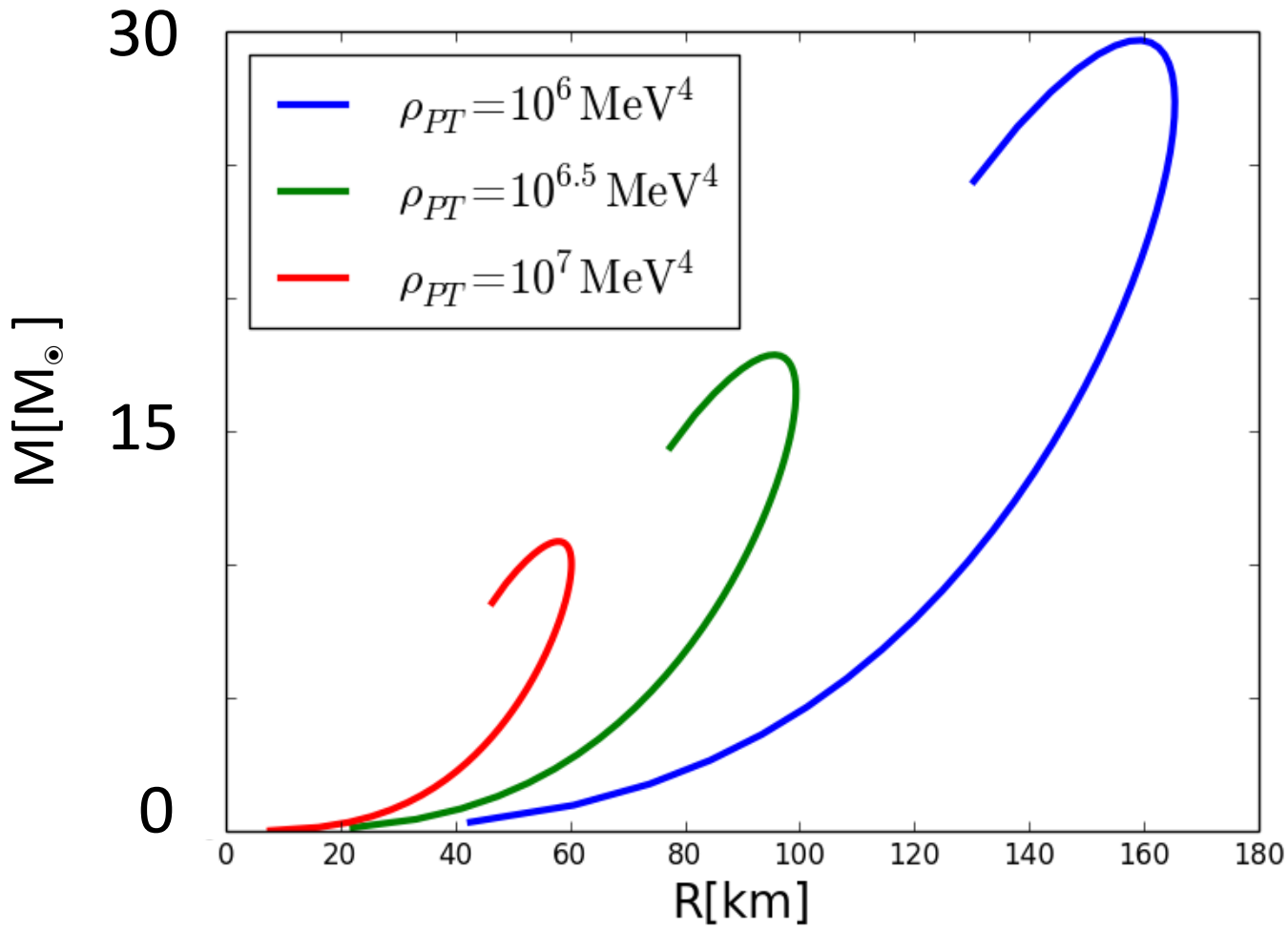
Future work

- How to test our model by GWs.

  Detections of massive NSs?
  Tidal deformability?

Bonus slide

$30M_\odot$ neutron stars



…..but it seems to be inconsistent with the X-ray observations.

Scalar force

The new force, scalar force, appears.

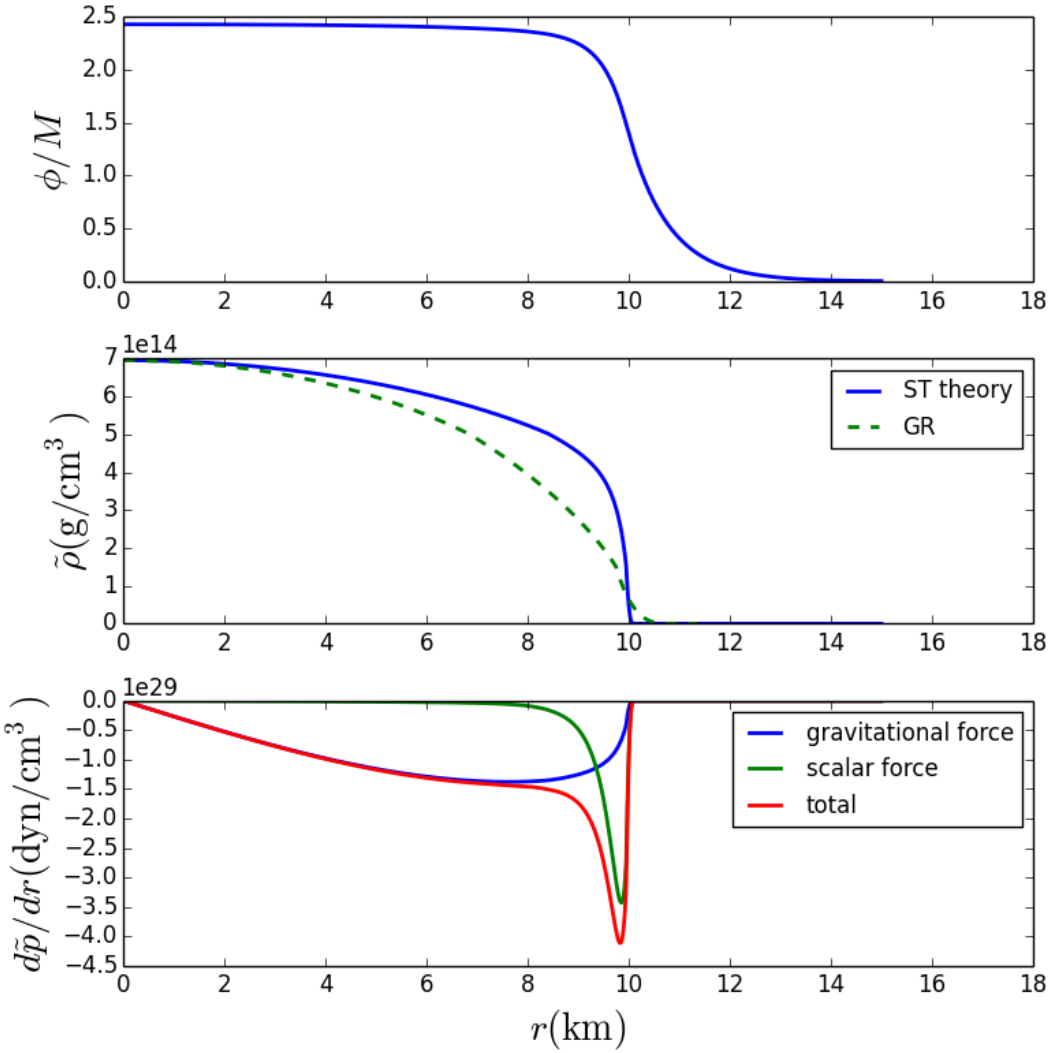
$$\tilde{p}' = -\frac{\tilde{\epsilon}+\tilde{p}}{2}\left(\nu' + 2(\ln A(\phi))'\right).$$

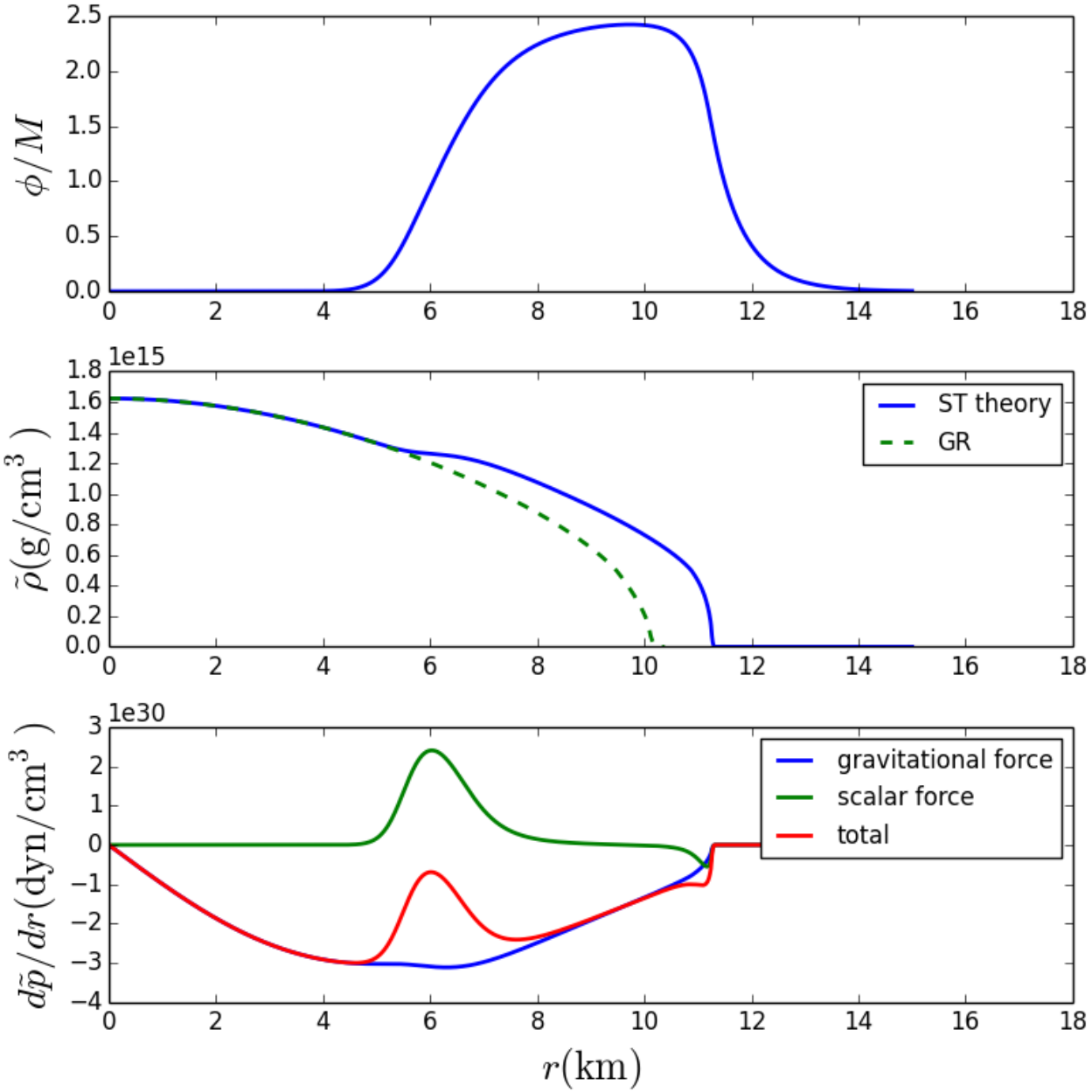
Gravitational force

Scalar force

ϕ decreases → compresses the star

Internal structure




ϕ/M
1e15
$\tilde{\rho}(\mathrm{g/cm^3})$
ST theory
GR
1e30
$d\tilde{p}/dr(\mathrm{dyn/cm^3})$
gravitational force
scalar force
total
$r(\mathrm{km})$

Allowed parameter region for DM