MOGRA2018@Nagoya, Aug. 9, 2018

Scalar-tensor theories after GW170817 and relativistic stars in DHOST

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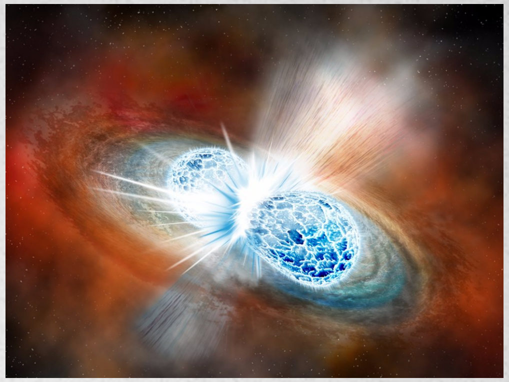
GW170817

Abbott *et al.* (2017)



- Nearly simultaneous detection of GWs and gamma-ray burst from binary neutron star merger

$$\longrightarrow \quad |c_{\rm GW}^2 - 1| < \mathcal{O}(10^{-15})$$

  - Tight constraint on modified gravity (**scalar-tensor**, vector-tensor, Horava gravity, …)

Creminelli & Vernizzi; Sakstein & Jain; Ezquiaga & Zumalacarregui; Baker *et al.*; Gumrukçuoglu *et al.*, Gong *et al.*; Oost *et al.*; Kase & Tsujikawa; … (2017, 2018)

> A. Nishizawa's talk yesterday

- Caveat: *This talk concerns modified gravity in the low-redshift Universe ($z \lesssim 0.01$); modification in the early Universe is free from this constraint*

Talk plan

- Horndeski theory and beyond after GW170817

- Vainshtein mechanism after GW170817

- Relativistic stars in Vainshtein-breaking theories after GW170817

  TK & T. Hiramatsu
  Phys.Rev. D97 (2018) no.10, 104012
  [**1803.10510**]

- Summary

- Horndeski theory and beyond after GW170817
- Vainshtein mechanism after GW170817
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Horndeski theory

Horndeski (1974)
Deffayet *et al.* (2011)
TK, Yamaguchi, Yokoayama (2011)

- The most general scalar-tensor theory with **2nd-order EOMs** (= trivially Ostrogradsky stable)

$$
\begin{aligned}
\mathcal{L} = &\, G_2(\phi, X) - G_3(\phi, X)\Box\phi \\
&+ G_4(\phi, X)R + G_{4X}\left[(\Box\phi)^2 - (\nabla_\mu\nabla_\nu\phi)^2\right] \\
&+ G_5(\phi, X)G^{\mu\nu}\nabla_\mu\nabla_\nu\phi - \frac{1}{6}G_{5X}\left[(\Box\phi)^3 - 3\Box\phi(\nabla_\mu\nabla_\nu\phi)^2 + 2(\nabla_\mu\nabla_\nu\phi)^3\right]
\end{aligned}
$$

- 4 free functions of ϕ and $X := -\frac{1}{2}g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi$

Horndeski after GW170817

> A. Nishizawa's talk yesterday

- Speed of GWs

0

$$c_{\rm GW}^2 = \frac{G_4 - X(\ddot{\phi} G_{5X} + G_{5\phi})}{G_4 - 2XG_{4X} - X(H\dot{\phi} G_{5X} - G_{5\phi})}$$

- $c_{\rm GW}^2 = 1$ scalar-tensor theory within Horndeski

$$\mathcal{L} = G_4(\phi)R + G_2(\phi, X) - G_3(\phi, X)\Box\phi$$

Creminelli & Vernizzi; Sakstein & Jain; Ezquiaga & Zumalacarregui; Baker *et al.* (2017)

[*See however de Rham & Melville (2018)*]

- But, this is not the end of the story;
  Go beyond Horndeski!

Evading Ostrogradsky instability

Degenerate **H**igher-**O**rder **S**calar-**T**ensor theories = **DHOST**

Horndeski (2+1 dofs)

2nd-order EOMs

GR (2 dofs) ⟶ •

Higher-order EOMs, but **degenerate**

⇨ 2+1 dofs, Ostrogradsky stable

Langlois & Noui (2015); Crisostomi *et al.* (2016); Ben Achour *et al.* (2016)

Higher-order EOMs, non-degenerate ⇨ More than 3 dofs, Ostrogradsky unstable

Viable class before GW170817

Horndeski (2+1 dofs)

2nd-order EOMs

GR (2 dofs) ⟶ •

Disformally related to Horndeski

$$\widetilde{g}_{\mu\nu} = \Omega(\phi, X) g_{\mu\nu} + \Gamma(\phi, X) \nabla_\mu \phi \nabla_\nu \phi$$

Ostrogradsky stable, but
no stable FRW solutions
(in all known theories)

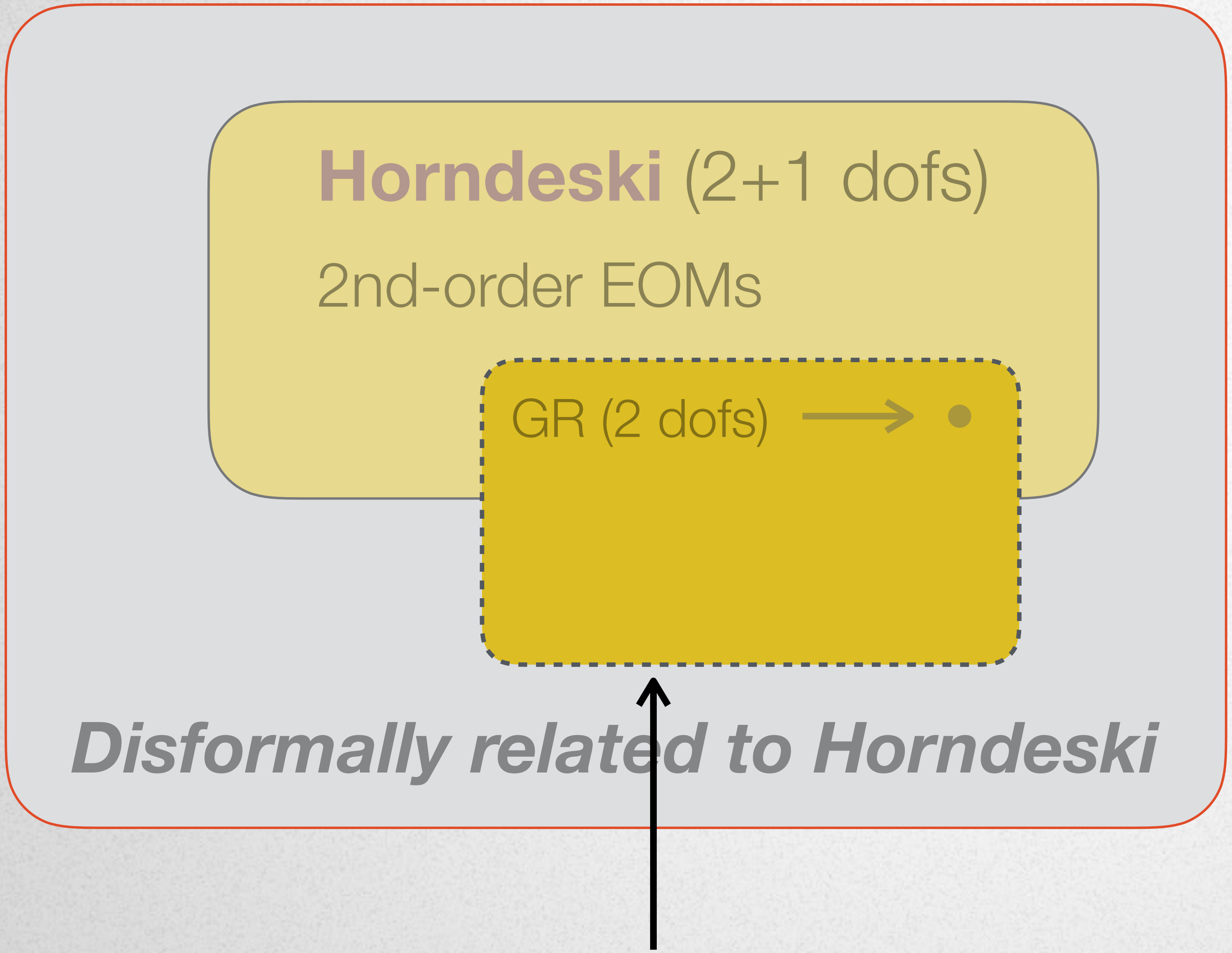
> K. Takahashi's talk yesterday

de Rham & Matas (2016);
Takahashi & TK (2017);
Langlois *et al.* (2018)

$\exists$ Stable FRW solution

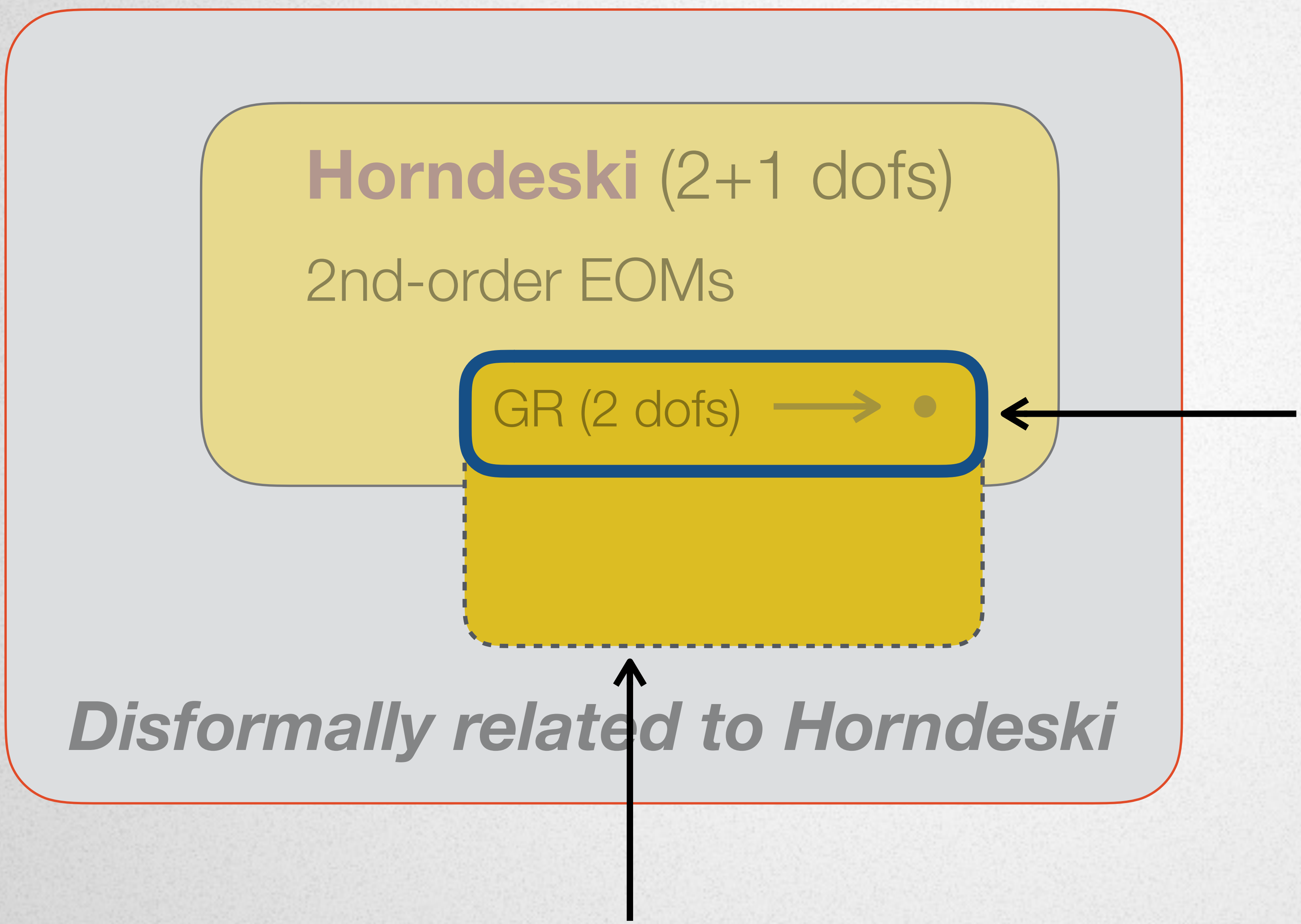
Only Horndeski and its disformal relatives admit stable FRW solutions

Viable class after GW170817



$c_{\mathrm{GW}}^2 = 1$

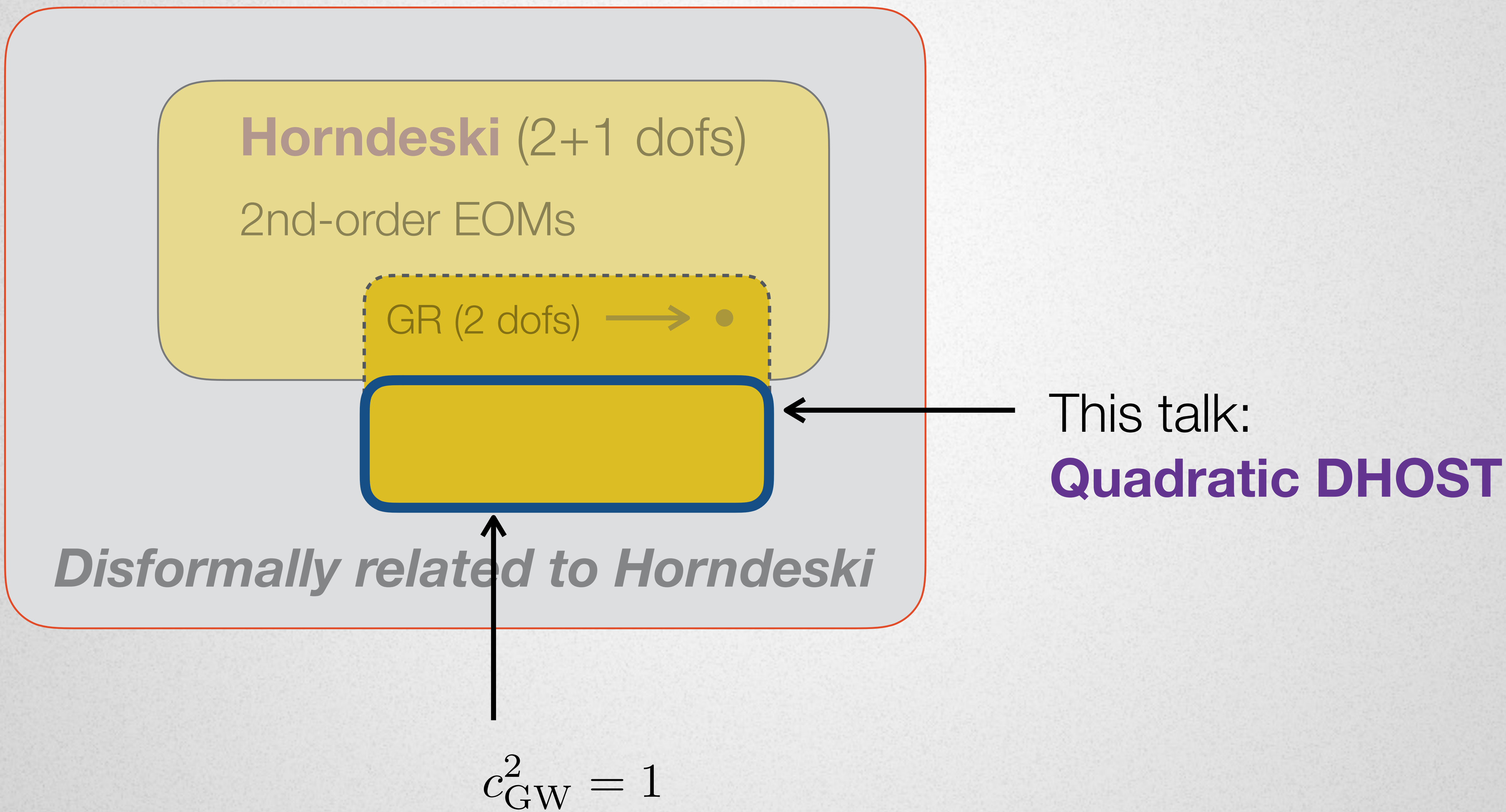
Viable class after GW170817



$$\mathcal{L} = G_4(\phi)R + G_2(\phi, X) - G_3(\phi, X)\Box\phi$$

$$c_{\rm GW}^2 = 1$$

Viable class after GW170817



Quadratic DHOST

Langlois & Noui (2015); Crisostomi *et al.* (2016)

- Generalization of "G4" (G2, G3 + **6** functions)

$$\mathcal{L} = G_2(\phi, X) - G_3(\phi, X)\Box\phi + \mathcal{L}_{\rm qDHOST}$$

$$\mathcal{L}_{\rm qDHOST} = f(\phi, X)R + \sum_{I=1}^{5} \mathcal{L}_I$$

$\sim (\partial\partial\phi)^2$

$$\mathcal{L}_1 := A_1(\phi, X)\phi_{\mu\nu}\phi^{\mu\nu}$$
$$\mathcal{L}_2 := A_2(\phi, X)(\Box\phi)^2$$
$$\mathcal{L}_3 := A_3(\phi, X)\Box\phi\phi^\mu\phi_{\mu\nu}\phi^\nu$$
$$\mathcal{L}_4 := A_4(\phi, X)\phi^\mu\phi_{\mu\rho}\phi^{\rho\nu}\phi_\nu$$
$$\mathcal{L}_5 := A_5(\phi, X)(\phi^\mu\phi_{\mu\nu}\phi^\nu)^2$$

- Degeneracy conditions (complicated…)

  $\longrightarrow$ **3** conditions on f, A_I

- $c_{\rm GW}^2 = 1$ constraint

  $\longrightarrow$ 6 – 3 – 1 = **2** free functions (+ G2, G3)

Creminelli & Vernizzi; Sakstein & Jain; Ezquiaga & Zumalacarregui; Baker *et al.* (2017)

Quadratic DHOST

- Speed of GWs: de Rham & Matas (2016)

$$c_{\mathrm{GW}}^2 = \frac{f}{f - XA_1}$$

($A_1 \to 0$)

(Hereafter $X := g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi$)

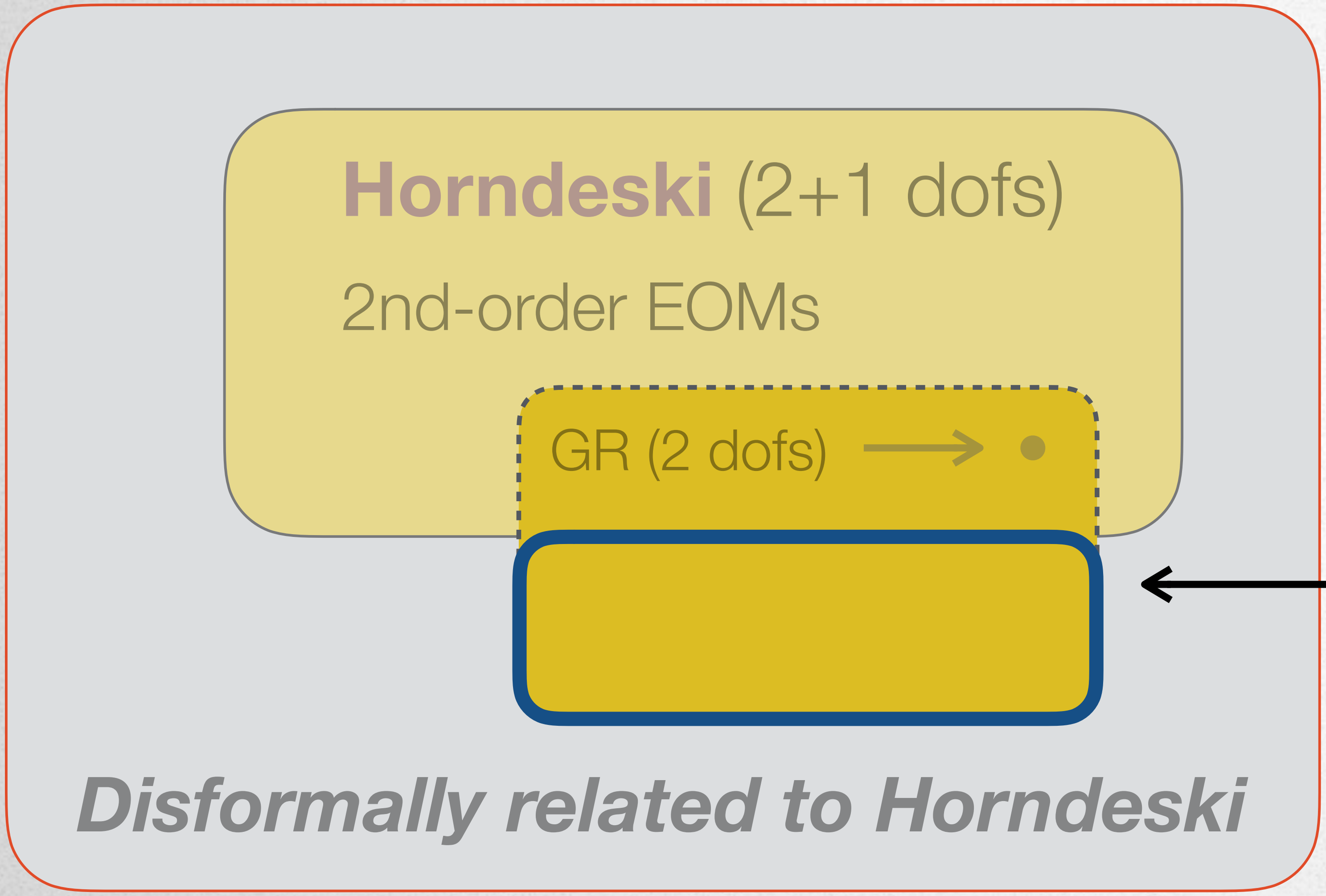
- Degeneracy conditions + $c_{\mathrm{GW}}^2 = 1$ constraint

$$A_2 = -A_1 = 0$$

$$A_4 = -\frac{1}{8f}\left(8A_3 f - 48 f_X^2 - 8A_3 f_X X + A_3^2 X^2\right)$$

$$A_5 = \frac{A_3}{2f}\left(4f_X + A_3 X\right)$$

Quadratic DHOST



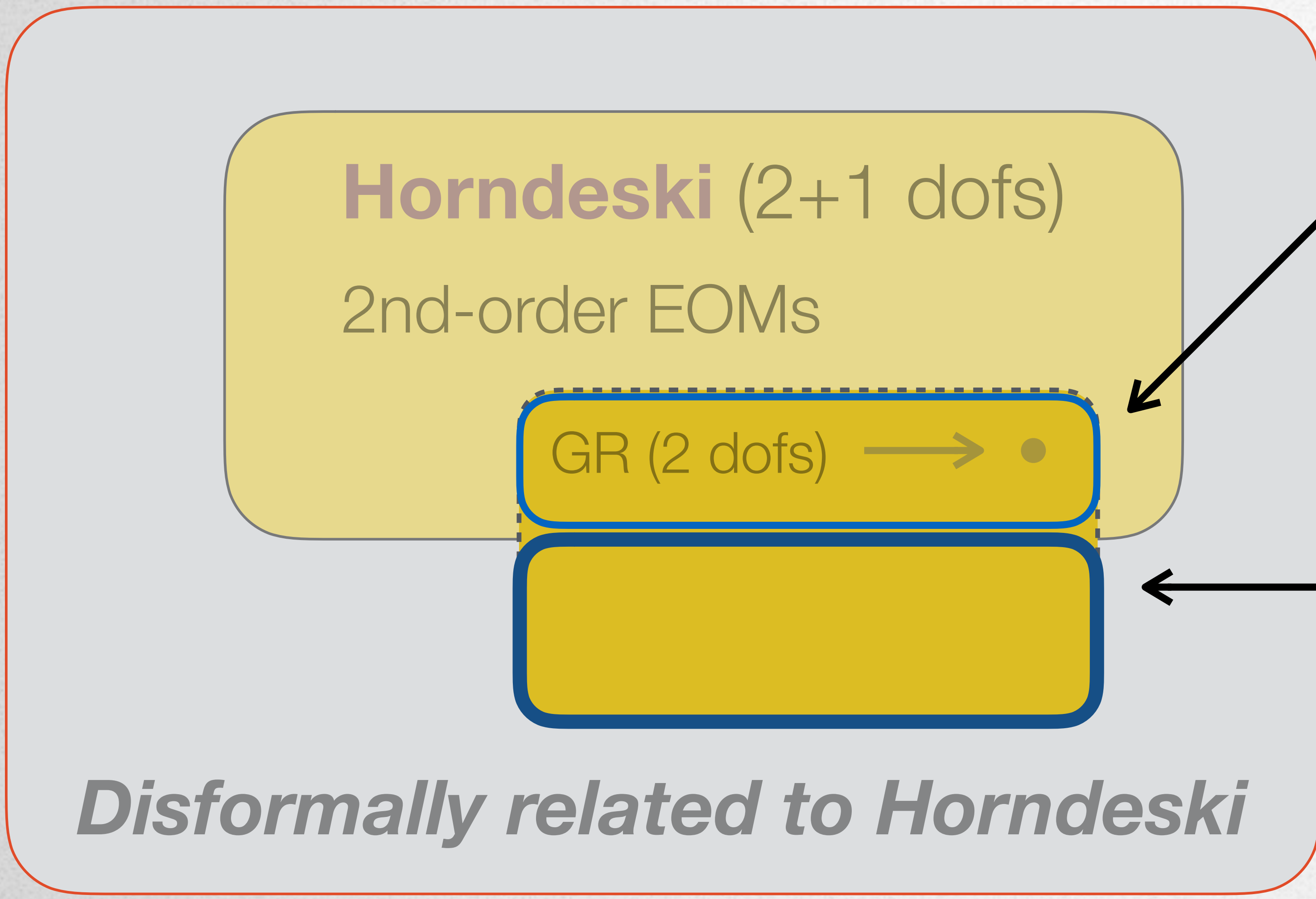
$$\mathcal{L} = G_2 - G_3\Box\phi + \mathcal{L}_{\rm qDHOST}$$

2 free functions

$$f(\phi, X), A_3(\phi, X)$$

Summary so far

Viable scalar-tensor theories after GW170817



$$\mathcal{L} = G_4(\phi)R + G_2(\phi, X) - G_3(\phi, X)\Box\phi$$

$$[f = G_4(\phi),\ \ A_3 = 0]$$

$$\mathcal{L} = G_2 - G_3\Box\phi + \mathcal{L}_{\rm qDHOST}$$

2 free functions

$$f(\phi, X), A_3(\phi, X)$$

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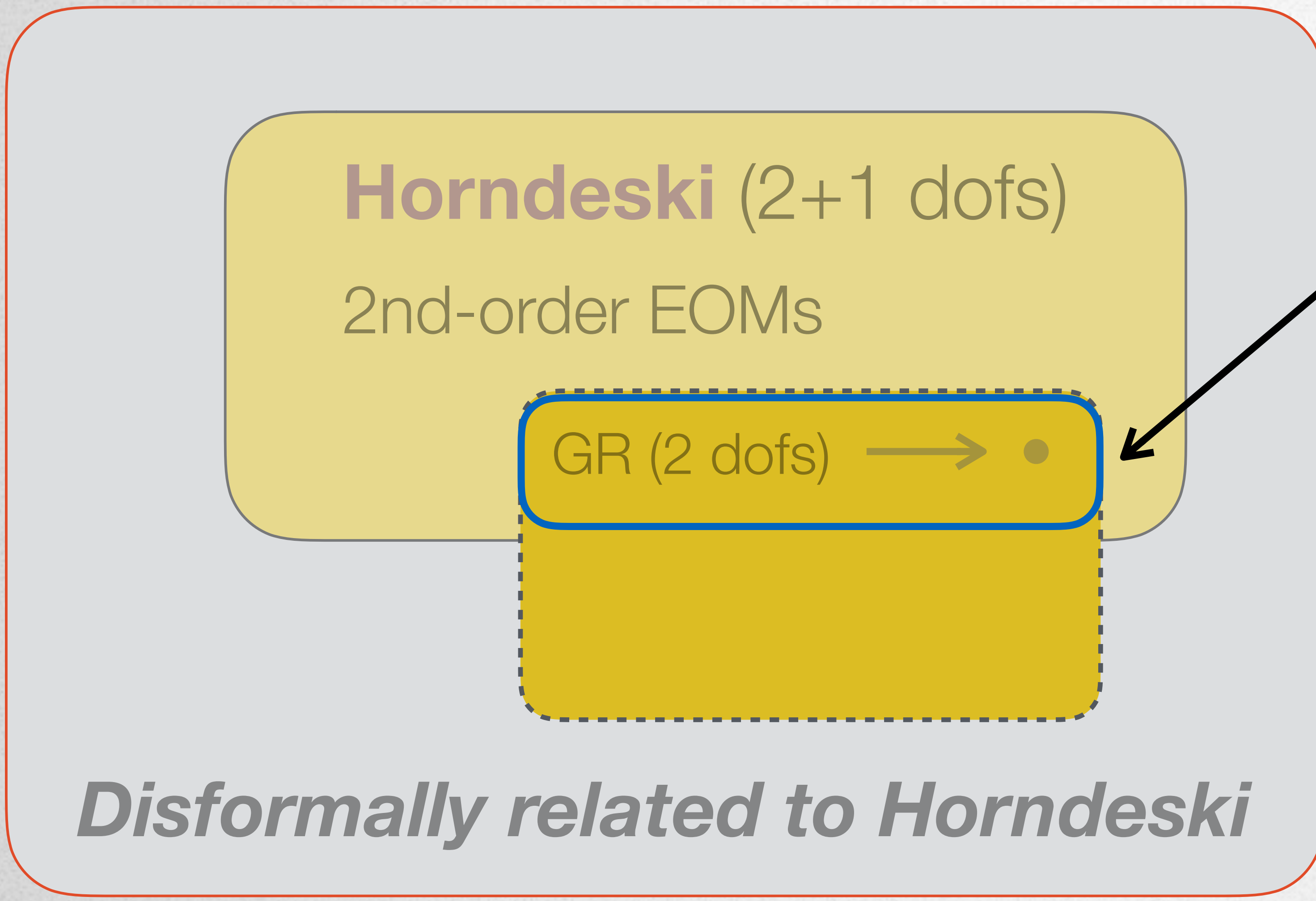
Vainshtein mechanism

Vainshtein (1972)

$$\mathcal{L} = G_4(\phi)R + G_2(\phi, X) - G_3(\phi, X)\Box\phi$$

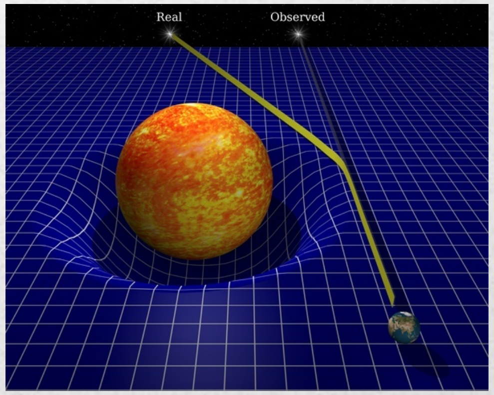
~ cubic Galileon

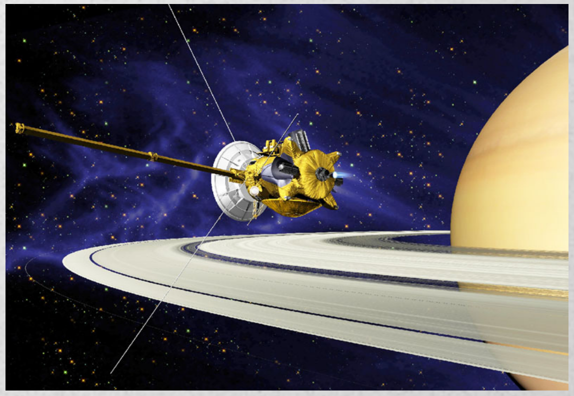
$(\sim (\partial\phi)^2\Box\phi)$



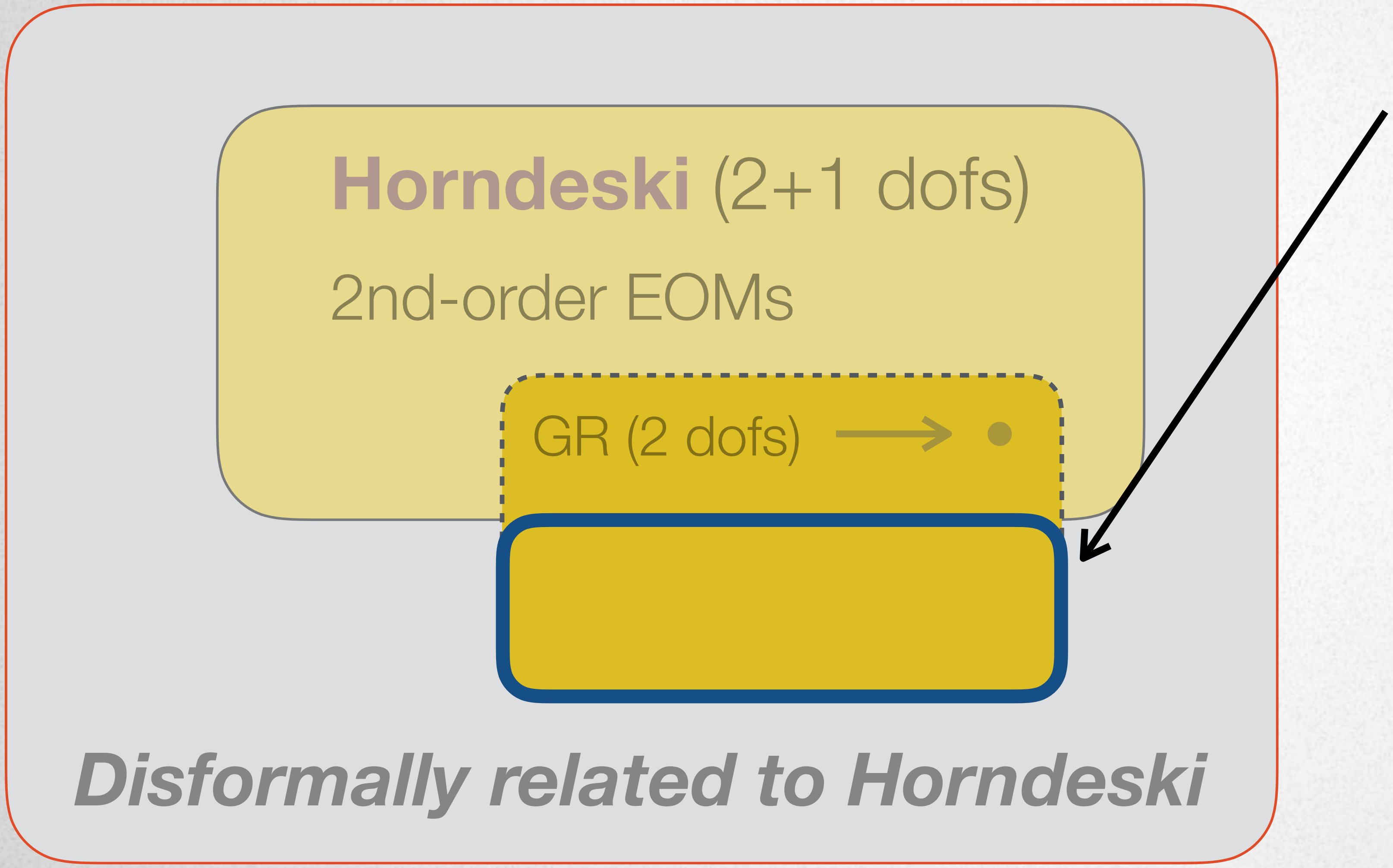
Vainshtein mechanism works, recovering GR near the source

De Felice *et al.* (2012); Narikawa *et al.* (2013)
Koyama *et al.* (2013) …





Breaking of Vainshtein mechanism



qDHOST + matter

~ Horndeski + disformally coupled matter

Partial breaking of Vainshtein mechanism: gravity is modified only **inside matter** (such as astrophysical bodies)

Interesting theories to test!

TK, Watanabe, Yamauchi (2015);
Crisostomi & Koyama (2017);
Langlois *et al.* (2017);
Dima & Vernizzi (2017)

Testing Vainshtein–breaking theories in weak gravity regime

- Partial breaking of Vainshtein screening *beyond* Horndeski

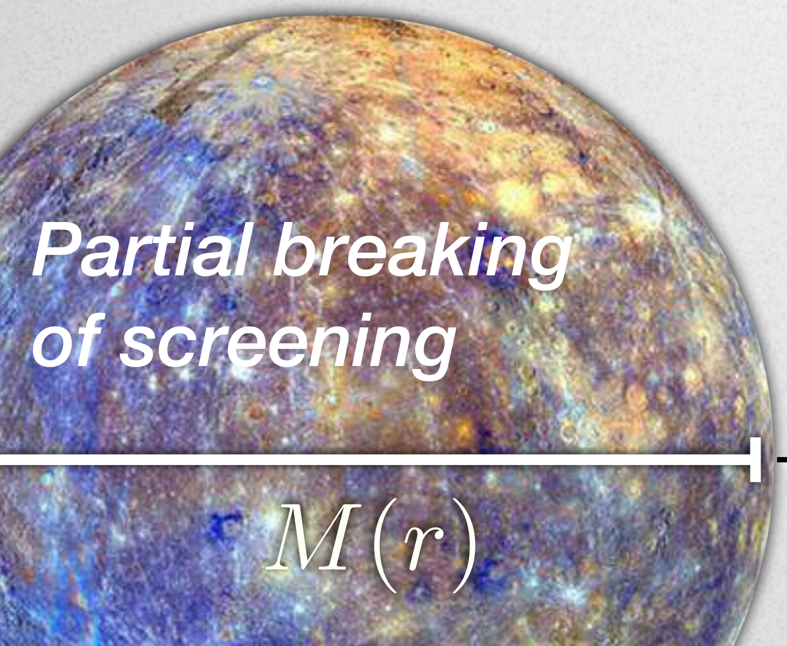
$$\mathrm{d}s^2 = -(1+2\Phi)\mathrm{d}t^2 + (1-2\Psi)(\mathrm{d}r^2 + r^2\mathrm{d}\Omega^2)$$

$$\frac{\mathrm{d}\Phi}{\mathrm{d}r} = \frac{G_N M}{r^2} + \Upsilon_1 \frac{G_N M''}{4} \quad \longleftarrow \text{Newtonian}$$

$$\frac{\mathrm{d}\Psi}{\mathrm{d}r} = \frac{G_N M}{r^2} - \frac{5\Upsilon_2}{4}\frac{G_N M'}{r} + \Upsilon_3 G_N M'' \quad \longleftarrow \text{Post-Newtonian, relativistic}$$

$$(8\pi G_N)^{-1} = 2f - 2Xf_X - \frac{3}{2}X^2 A_3, \ \ \Upsilon_i = \Upsilon_i[f, A_3]$$

$M(r)$: enclosed mass



Successful screening

$$M = \text{const}$$

TK, Watanabe, Yamauchi (2015); Crisostomi & Koyama (2017); Langlois *et al.* (2017); Dima & Vernizzi (2017)

Testing Vainshtein-breaking theories in weak gravity regime

$$\frac{\mathrm{d}\Phi}{\mathrm{d}r} = \frac{G_N M}{r^2} + \Upsilon_1 \frac{G_N M''}{4}$$ ← Newtonian

$$\frac{\mathrm{d}\Psi}{\mathrm{d}r} = \frac{G_N M}{r^2} - \frac{5\Upsilon_2}{4}\frac{G_N M'}{r} + \Upsilon_3 G_N M''$$ ← Post-Newtonian, relativistic

- Constraints on Υ_i: not so strong

Koyama & Sakstein (2015); Jain *et al.* (2015); Sakstein *et al.* (2016, 2017); Salzano *et al.* (2017); Saltas *et al.* (2018)

  - Newtonian stellar structure

Gravity must be attractive near the center

Saito *et al.* (2015)

$$-2/3 < \Upsilon_1 < 1.6$$

Minimum mass for hydrogen burning < Mass of observed red dwarfs

Sakstein (2015)

  - X-ray + lensing profiles of galaxy clusters ($\Upsilon_3 = 0$ theories)

$$\Upsilon_1 = -0.11^{+0.93}_{-0.67}, \ \Upsilon_2 = -0.22^{+1.22}_{-1.19}$$

Sakstein *et al.* (2016)

Strong gravity regime: ***Relativistic stars?***

Babichev *et al.* (2016); Sakstein *et al.* (2016)

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- Summary

TOV system in qDHOST

- Lagrangian:

Cf. Chagoya & Tasinato (2018); De Felice *et al.* (2015); Kase *et al.* (2016) > angular deficit

$$\mathcal{L} = G_2 - G_3 \Box\phi + \mathcal{L}_{\mathrm{qDHOST}} + \mathcal{L}_{\mathrm{matter}}$$

$$\mathcal{L}_{\mathrm{qDHOST}} = f(X) R + A_3(X) \Box\phi \phi^\mu \phi_{\mu\nu} \phi^\nu + \cdots$$

Shift-symmetric qDHOST

- Ansatz:

$$\mathrm{d}s^2 = -e^{\nu(r)} \mathrm{d}t^2 + e^{\lambda(r)} \mathrm{d}r^2 + r^2 \mathrm{d}\Omega^2$$

$$\phi = vt + \psi(r)$$

$$T^\nu_\mu = \mathrm{diag}(-\rho, P, P, P)$$

TOV system in qDHOST

- Field equations: $\mathcal{E}_\mu^\nu = T_\mu^\nu, \quad \mathcal{E}_\phi = 0, \quad \nabla_\nu T_\mu^\nu = 0$

$$\mathcal{E}_t^t = b_1\nu'' + b_2 X'' + \cdots = -\rho$$
$$\mathcal{E}_r^r = c_1\nu'' + c_2 X'' + \cdots = P$$
$$\mathcal{E}_{tr} = d_1\nu'' + d_2 X'' + \cdots = 0$$
($\longrightarrow$ $\mathcal{E}_\phi = 0$ is automatic)
$$P' = -\frac{\nu'}{2}(\rho + P)$$

$$X = -e^{-\nu}v^2 + e^{-\lambda}(\psi')^2$$

- X is more convenient than ψ'
- Higher derivatives can be eliminated in the end by combining the equations (because the system is ***degenerate***)

TOV system in qDHOST

- Final form of the field equations:

$$e^{\lambda} = \mathcal{F}_{\lambda}(\nu, \nu', X, X', P)$$

$$X' = \mathcal{F}_1(\nu, X, \rho, P)\nu' + \frac{\mathcal{F}_2(\nu, X, \rho, P)}{r}$$

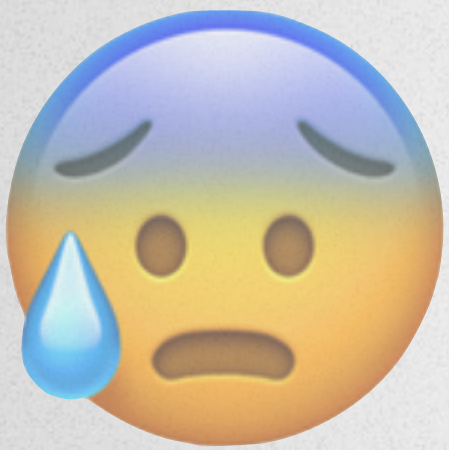
$$\nu' = \mathcal{F}_3(\nu, X, \rho, \rho', P)$$

$$P' = -\frac{\nu'}{2}(\rho + P)$$

+ EOS

- Explicit expressions of the right-hand sides are messy

Appendix A: Explicit form of $\mathcal{F}_1, \mathcal{F}_2$, and $\mathcal{F}_3$



Here we present the explicit expression for $\mathcal{F}_1$, $\mathcal{F}_2$, and $\mathcal{F}_3$ that appear in Eqs. (30) and (31):

$$\mathcal{F}_1 = \frac{U_1}{V}, \quad \mathcal{F}_2 = \frac{U_2}{V}, \quad \mathcal{F}_3 = \frac{U_3}{W}, \tag{A1}$$

where

$$\frac{U_1}{2fe^{\nu}X^2} = 2r^2v^2(P+\rho)\left(B_1 f - X f_X\right) + e^{\nu}X\left\{B_1 f\left[r^2(\rho-5P)-8f\right] + 2Xf_X\left(4f+Pr^2\right)\right\}, \tag{A2}$$

$$\frac{U_2}{2fe^{\nu}X^2} = -2v^2\left(B_1 f - X f_X\right)\left[4f + r^2(P-\rho)\right] + e^{\nu}X\left\{B_1 f\left[r^2(\rho-5P)-8f\right] + 2Xf_X\left(4f+Pr^2\right)\right\}, \tag{A3}$$

$$\begin{aligned} V = &-8r^2v^4(P+\rho)\left(B_1 f - X f_X\right)^2 + 2e^{\nu}v^2X\left(Xf_X - B_1 f\right)\left\{B_1 f\left[r^2(5\rho-9P)-20f\right] + 4Xf_X\left(4f+Pr^2\right)\right\} \\ &+ 3B_1 f e^{2\nu}X^2\left\{B_1 f\left[8f + r^2(5P-\rho)\right] - 2Xf_X\left(4f+Pr^2\right)\right\}, \end{aligned} \tag{A4}$$

$$\begin{aligned} U_3 = &-16e^{3\nu}fr^4f_X^2\left[B_1(Xf_X-2f) + X(fB_{1X}+f_X-Xf_{XX})\right](\rho-3P)^2X^5 \\ &+ 8e^{2\nu}r^2(fB_1-Xf_X)^2\big\{16\left[e^{\nu}f_X + (v^2+e^{\nu}X)f_{XX}\right](3P-\rho)f^2 \\ &+ 2\left[f_{XX}(\rho-3P)((2v^2+e^{\nu}X)\rho - (2v^2+5e^{\nu}X)P)r^2 + e^{\nu}f_X(\rho^2-8P\rho+15P^2)r^2\right. \\ &+ \left.4f_X^2(6(v^2+2e^{\nu}X)\rho - 18(v^2+2e^{\nu}X)P + r(v^2+3e^{\nu}X)\rho')\right]f \\ &+ r^2f_X^2\left[(-408e^{\nu}XP^2 + (8(21v^2+29e^{\nu}X)\rho + r(28v^2+33e^{\nu}X)\rho')P\right. \\ &- \left.\rho(8(7v^2+4e^{\nu}X)\rho + r(16v^2+9e^{\nu}X)\rho')\right]\big\}X^4 \\ &- 2e^{2\nu}r^2f_X(4fB_1-4Xf_X)(3P-\rho)\big\{-e^{\nu}r^2f_X^2(10\rho-30P+3r\rho')X^3 \\ &+ 16f^2(v^2+e^{\nu}X)\left[B_1(Xf_X-2f) + X(fB_{1X}+f_X-Xf_{XX})\right] \\ &+ 2fr^2\left[\rho(e^{\nu}X^3f_{XX} - (2v^2+e^{\nu}X)(B_1(Xf_X-2f) + X(fB_{1X}+f_X-Xf_{XX})))\right. \\ &- \left.(3e^{\nu}X^3f_{XX} - (2v^2+5e^{\nu}X)(B_1(Xf_X-2f) + X(fB_{1X}+f_X-Xf_{XX})))P\right]\big\}X^3 \\ &+ 8e^{\nu}(fB_1-Xf_X)^3\big\{f_X\left[2(68v^4-24e^{\nu}Xv^2-305e^{2\nu}X^2)P^2 + (4(8v^4+122e^{\nu}Xv^2+73e^{2\nu}X^2)\rho\right. \\ &+ \left.r(12v^4+76e^{\nu}Xv^2+39e^{2\nu}X^2)\rho')P - (2v^2+e^{\nu}X)\rho(52\rho v^2+34e^{\nu}X\rho + r(14v^2+9e^{\nu}X)\rho')\right]r^4 \\ &+ 2f\left[e^{\nu}(\rho-5P)((2v^2+e^{\nu}X)\rho - (2v^2+5e^{\nu}X)P)r^2 + 8f_X(3(2v^4+9e^{\nu}Xv^2+5e^{2\nu}X^2)\rho\right. \\ &+ \left.3(2v^4-9e^{\nu}Xv^2-19e^{2\nu}X^2)P + r(v^4+6e^{\nu}Xv^2+3e^{2\nu}X^2)\rho')\right]r^2 + 128e^{\nu}f^3(v^2+e^{\nu}X) \\ &+ 16e^{\nu}f^2\left[-(3v^2+2e^{\nu}X)\rho r^2 + (7v^2+10e^{\nu}X)Pr^2 - 8X(v^2+e^{\nu}X)f_X\right]\big\}X^2 \\ &- 8(fB_1-Xf_X)^4\big\{4(16v^6-60e^{\nu}Xv^4+20e^{2\nu}X^2v^2+75e^{3\nu}X^3)P^2r^4 \\ &+ (2v^2+e^{\nu}X)^2(4v^2+3e^{\nu}X)\rho(4\rho+r\rho')r^4 - 8e^{\nu}fX(2v^2+e^{\nu}X)\left[6(4v^2+3e^{\nu}X)\rho + r(5v^2+3e^{\nu}X)\rho'\right]r^2 \\ &- P\left[-(2v^2+e^{\nu}X)(8(8v^4-12e^{\nu}Xv^2-15e^{2\nu}X^2)\rho + r(8v^4-18e^{\nu}Xv^2-15e^{2\nu}X^2)\rho')r^2\right. \\ &- \left.48e^{\nu}fX(-8v^4+10e^{\nu}Xv^2+15e^{2\nu}X^2)\right]r^2 + 384e^{2\nu}f^2X^2(v^2+e^{\nu}X)\big\}, \end{aligned} \tag{A5}$$

$$\begin{aligned} \frac{W}{r} = &\ 16e^{3\nu}fr^4f_X^2\left[B_1(Xf_X-2f) + X(fB_{1X}+f_X-Xf_{XX})\right](\rho-3P)^2X^5 \\ &- 4e^{2\nu}r^2(fB_1-Xf_X)^2\Big\{\left[3r^2(16v^2-77e^{\nu}X)P^2 + 4\left((3v^2+71e^{\nu}X)\rho r^2 + 6f(v^2-9e^{\nu}X)\right)P\right. \\ &+ \left.\rho(24f(v^2+7e^{\nu}X) - r^2(36v^2+61e^{\nu}X)\rho)\right]f_X^2 - 4e^{\nu}f(\rho-3P)(-\rho r^2+5Pr^2+8f)f_X \\ &- 4ff_{XX}(\rho-3P)\left[-2v^2\rho r^2 - (2v^2-5e^{\nu}X)Pr^2 + e^{\nu}X(8f-r^2\rho)\right]\Big\}X^4 \\ &+ e^{2\nu}r^2f_X(4fB_1-4Xf_X)(3P-\rho)\big\{-e^{\nu}r^2f_X^2(17\rho-15P)X^3 + 32e^{\nu}f^2\left[B_1(Xf_X-2f) + X(fB_{1X}+f_X-Xf_{XX})\right]X \\ &+ 4fr^2\left[\rho\left(e^{\nu}X^3f_{XX} - (2v^2+e^{\nu}X)(B_1(Xf_X-2f) + X(fB_{1X}+f_X-Xf_{XX}))\right)\right. \\ &- \left.\left(3e^{\nu}f_{XX}X^3 + (2v^2-5e^{\nu}X)(B_1(Xf_X-2f) + X(fB_{1X}+f_X-Xf_{XX}))\right)P\right]\big\}X^3 \\ &- 4e^{\nu}(fB_1-Xf_X)^3\big\{4e^{\nu}f(-\rho r^2+5Pr^2+8f)\left[-2v^2\rho r^2 - (2v^2-5e^{\nu}X)Pr^2 + e^{\nu}X(8f-r^2\rho)\right] \\ &- f_X\left[5(20v^4-40e^{\nu}Xv^2+79e^{2\nu}X^2)P^2r^4 + 4v^4\rho(12f-5r^2\rho)r^2 + 36e^{\nu}v^2X\rho(3r^2\rho-4f)r^2\right. \\ &+ \left.2\left((40v^4-46e^{\nu}Xv^2-199e^{2\nu}X^2)\rho r^2 + 24f(v^4-3e^{\nu}Xv^2+18e^{2\nu}X^2)\right)Pr^2 + e^{2\nu}X^2(71\rho^2r^4-480f\rho r^2+256f^2)\right]\big\}X^2 \\ &+ 4(fB_1-Xf_X)^4\big\{-48r^4\rho^2v^6 + 12e^{\nu}r^2X\rho(\rho r^2+20f)v^4 + 8e^{2\nu}r^2X^2\rho(9r^2\rho-47f)v^2 \\ &- r^4(48v^6-180e^{\nu}Xv^4+200e^{2\nu}X^2v^2-225e^{3\nu}X^3)P^2 + 3e^{3\nu}X^3(9\rho^2r^4-104f\rho r^2+256f^2) \\ &- 4r^2\left[24r^2\rho v^6 - 12e^{\nu}X(4\rho r^2+5f)v^4 + 2e^{2\nu}X^2(16\rho r^2+47f)v^2 - 15e^{3\nu}X^3(14f-3r^2\rho)\right]P\big\}. \end{aligned} \tag{A6}$$

Boundary conditions

- Exact exterior solution: Schwarzschild

$$e^{\nu} = e^{-\lambda} = 1 - \frac{2G_N\mu}{r}, \quad \mu = \mathrm{const}$$

$$X(r) = -v^2$$

- Center

$$\nu = \nu_c, \quad X = -e^{-\nu_c} v^2 \ \ (\leftarrow \psi'(0) = 0), \quad \rho = \rho_c$$

↳ shooting parameter

- Matching at the surface $r = R$

$$X(R) = -v^2, \quad e^{\nu(R)} = 1 - \frac{2G_N\mu}{R}$$

↳ integration const determined

Concrete model

- Model: $f = \frac{M_{\rm Pl}^2}{2} + \alpha X^2, \quad A_3 = -8\alpha - \beta$ ($\beta = 0 \rightarrow$ GLPV)
  - Viable self-accelerating cosmology — Crisostomi & Koyama (2017)
  - Dimensionless parameters

$$\bar{\alpha} = \frac{\alpha v^4}{M_{\rm Pl}^2}, \quad \bar{\beta} = \frac{\beta v^4}{M_{\rm Pl}^2}$$

Vainshtein-breaking in weak gravity regime

$$\Upsilon_i \sim \bar{\alpha}, \bar{\beta} \lesssim \mathcal{O}(0.1)$$

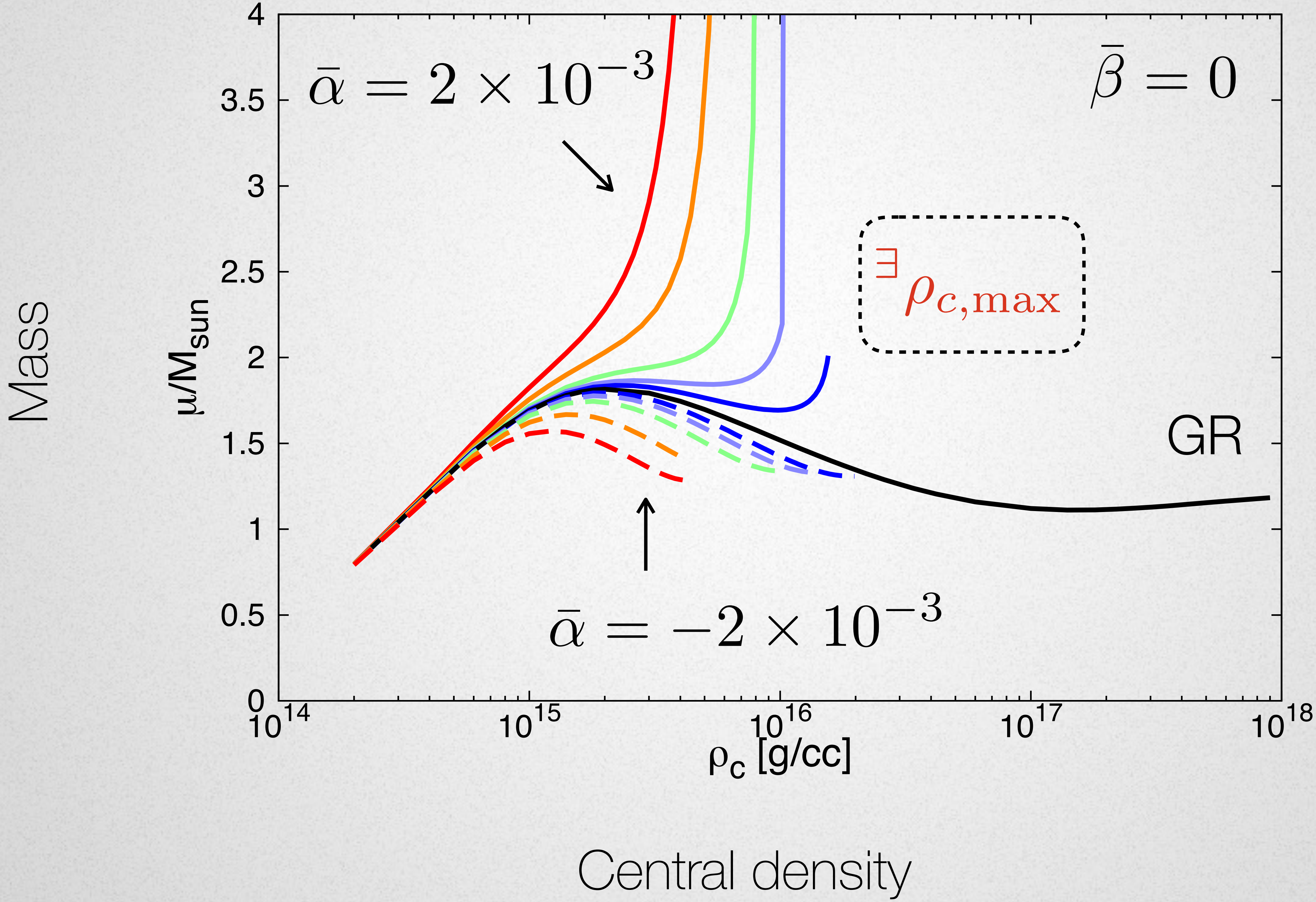
Hulse-Taylor pulsar constraint — Beltran Jimenez *et al.* (2015); Dima & Vernizzi (2017)

$$G_{\rm GW}/G_N - 1 \sim \bar{\alpha}, \bar{\beta} < \mathcal{O}(10^{-3})$$

"*G*" for GWs

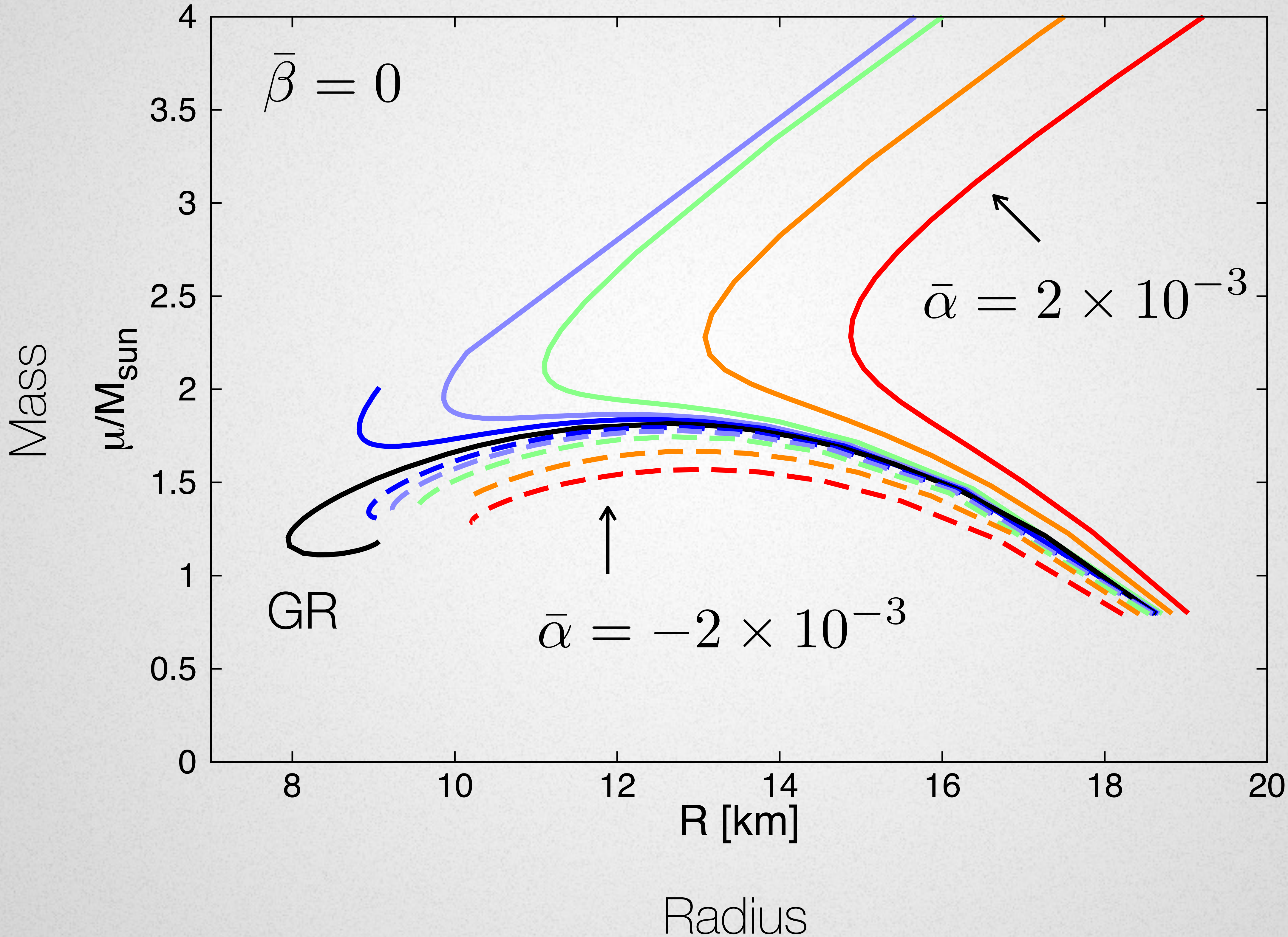
Results

$$\rho = \left(\frac{P}{K}\right)^{1/2} + P, \quad K = 123 M_\odot^2$$



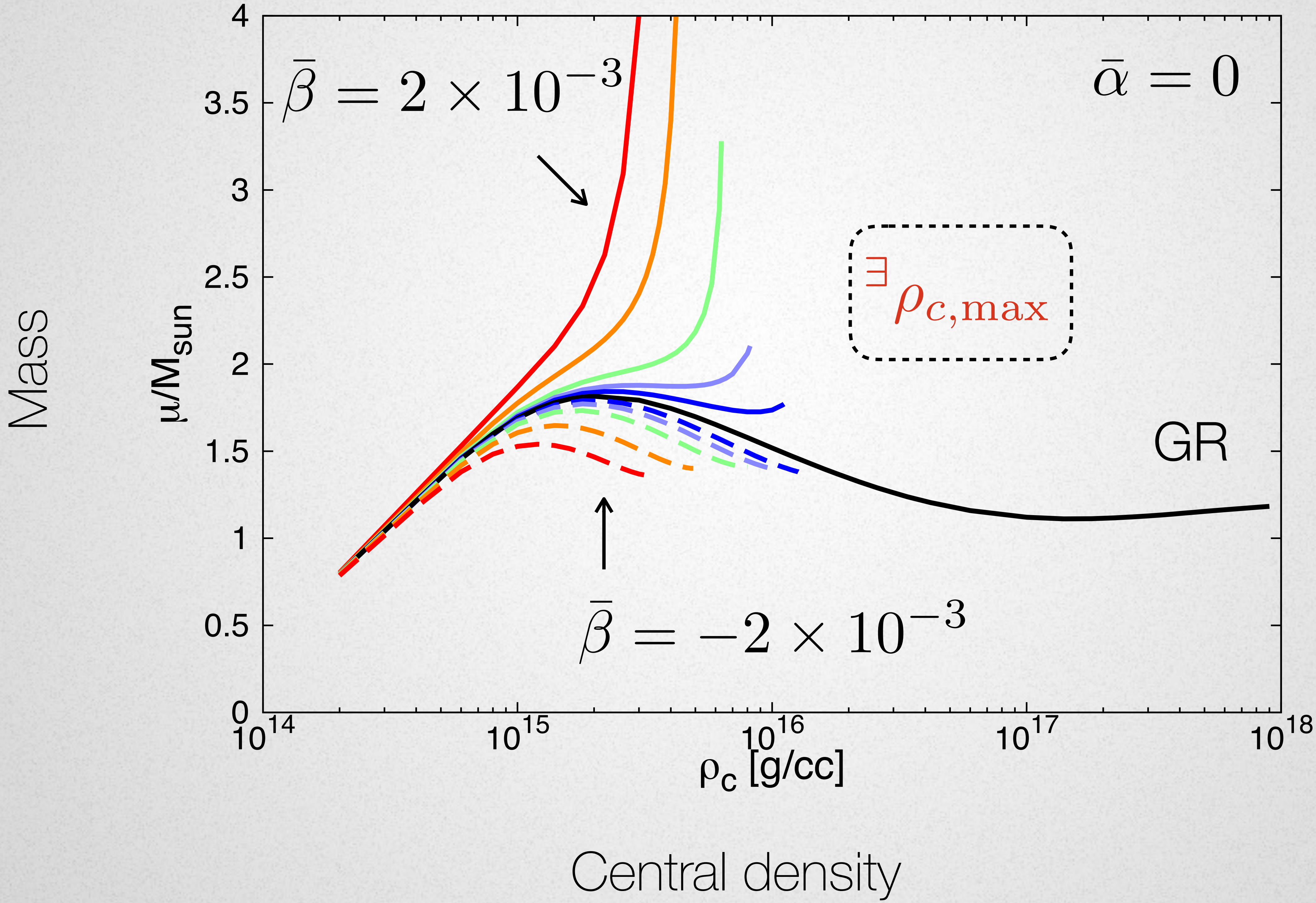
TK & Hiramatsu (2018)

Results



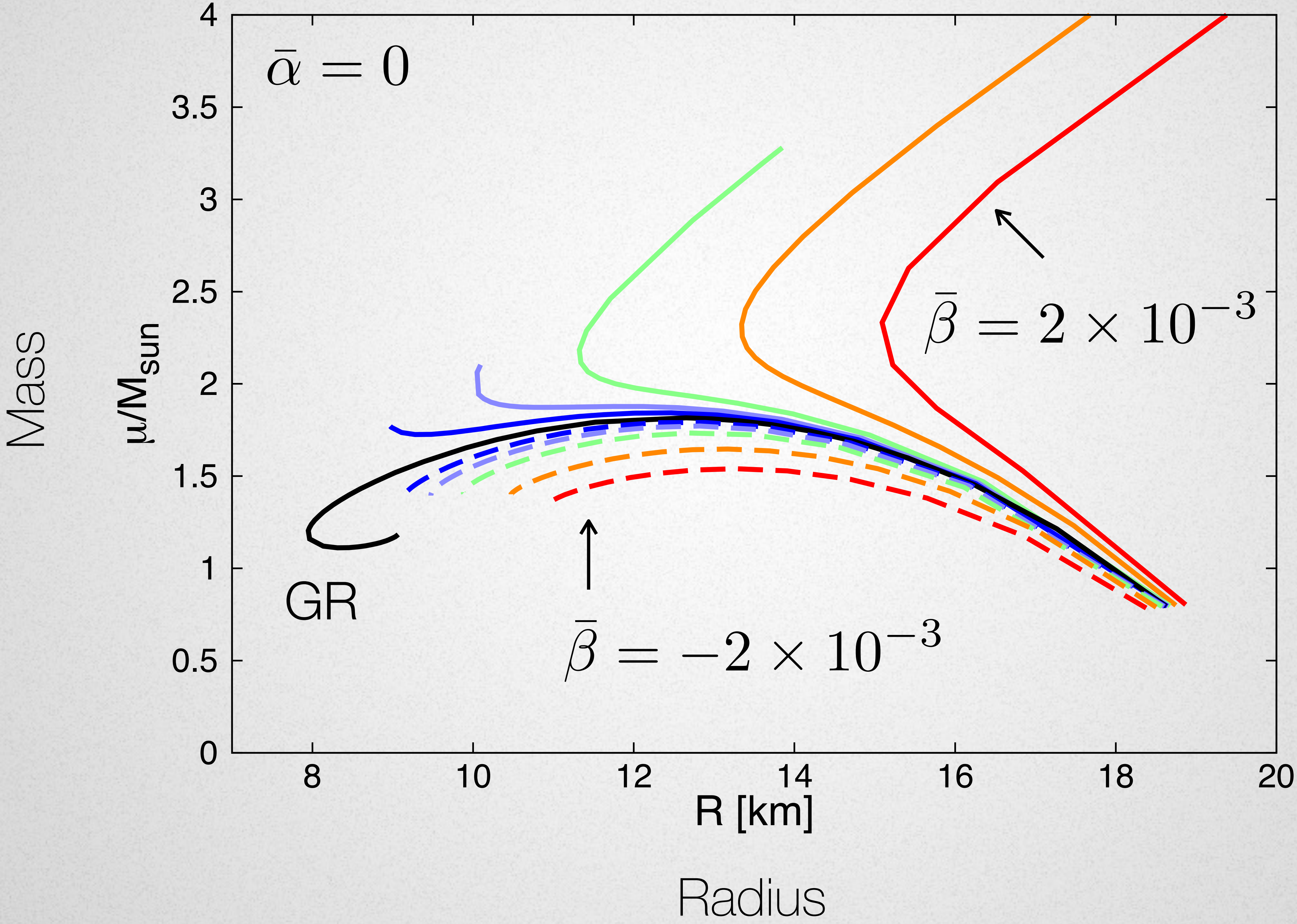
TK & Hiramatsu (2018)

Results



TK & Hiramatsu (2018)

Results



TK & Hiramatsu (2018)

- Horndeski theory and beyond after GW170817
- Vainshtein mechanism after GW170817
- Relativistic stars in Vainshtein-breaking theories after GW170817
- Summary

Summary

- qDHOST survived after GW170817
  - Partial breaking of Vainshtein screening inside matter
  - Constraints in weak gravity regime still not so strong
- Relativistic stars in qDHOST
  - Large modification to M-R relation even if parameters are small and only tiny corrections are expected in weak gravity regime
  - Maximum central density
  - To what extent model-dependent results?

JG
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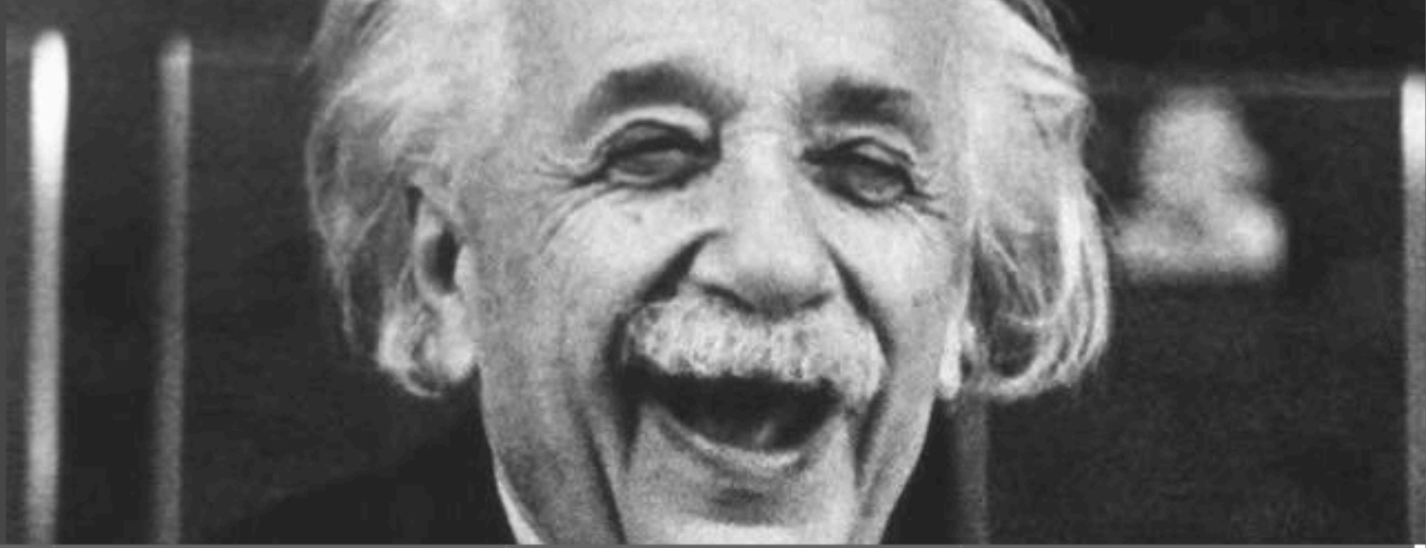
28

The 28th Workshop on General Relativity and Gravitation in Japan - JGRG28
Tachikawa Memorial Hall, Rikkyo University
5-9 November 2018



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