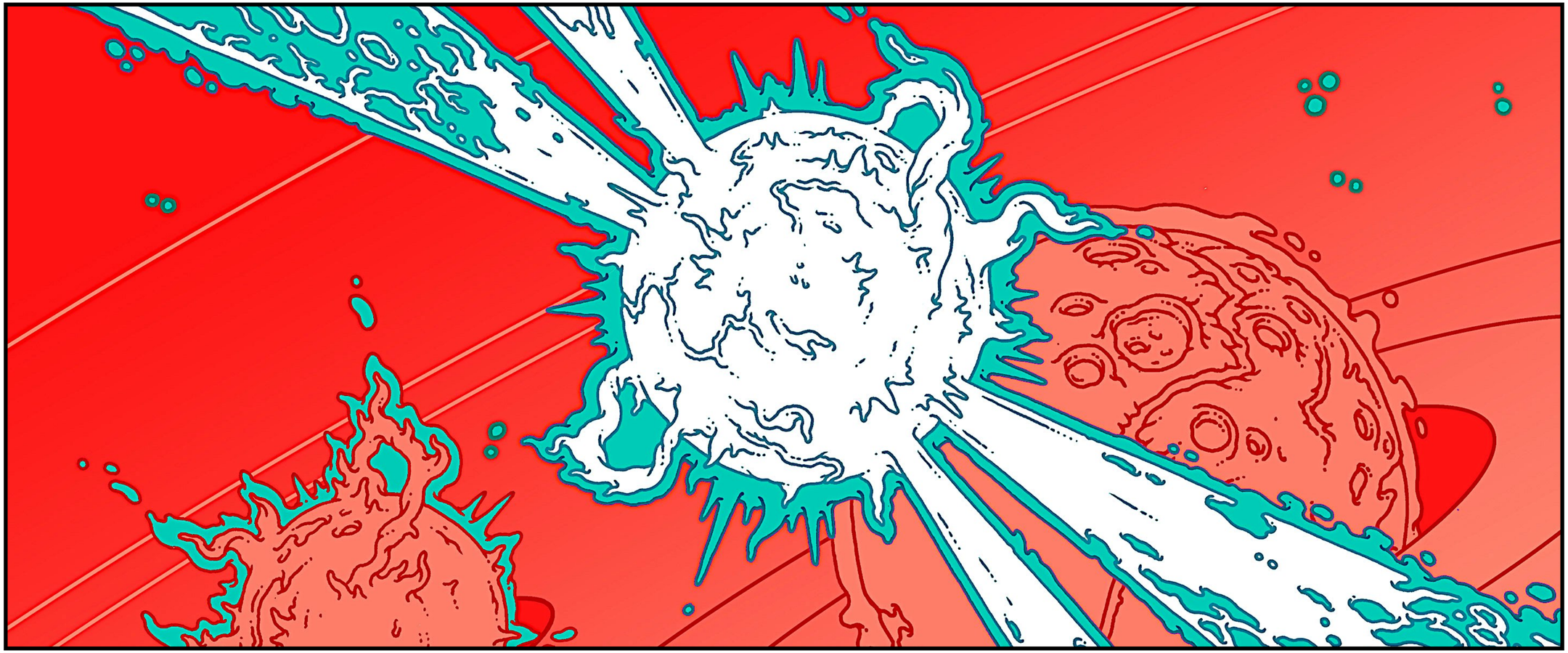
Dynamics of Screening in Modified Gravity



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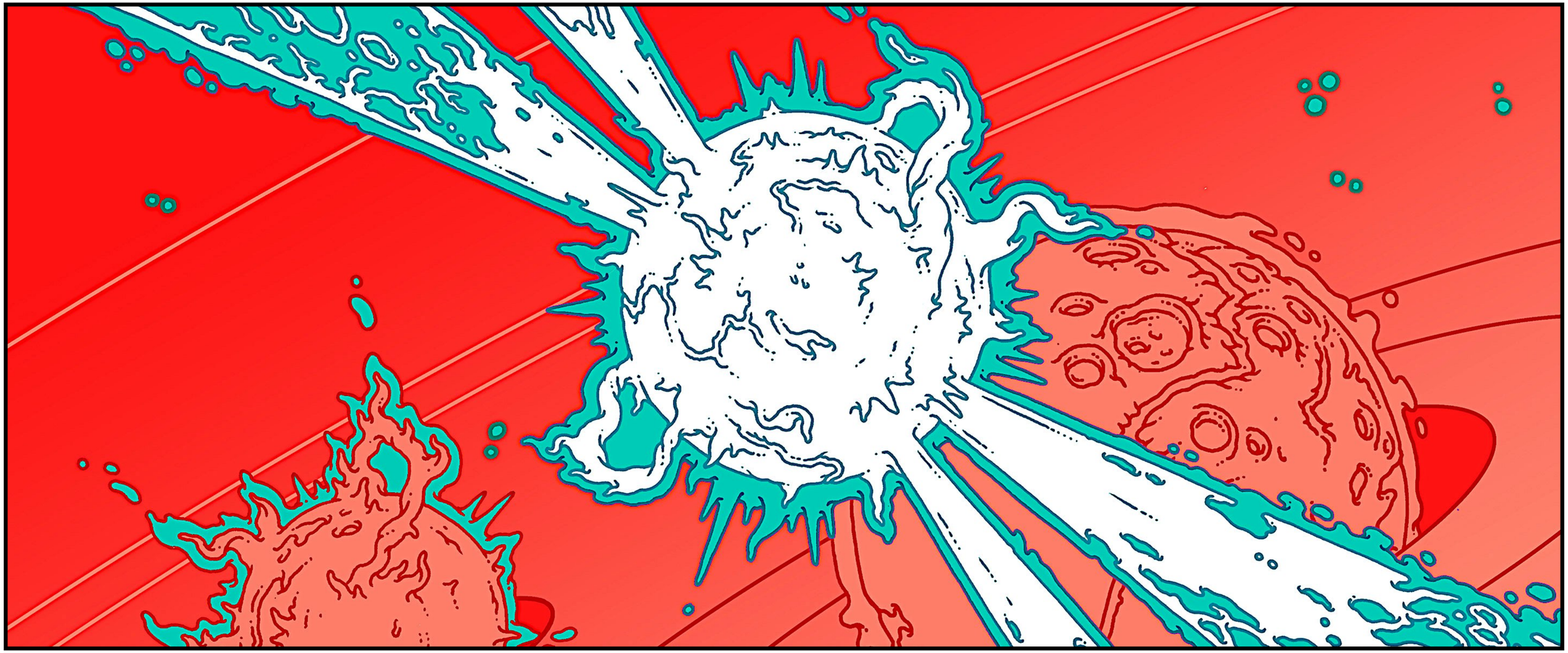
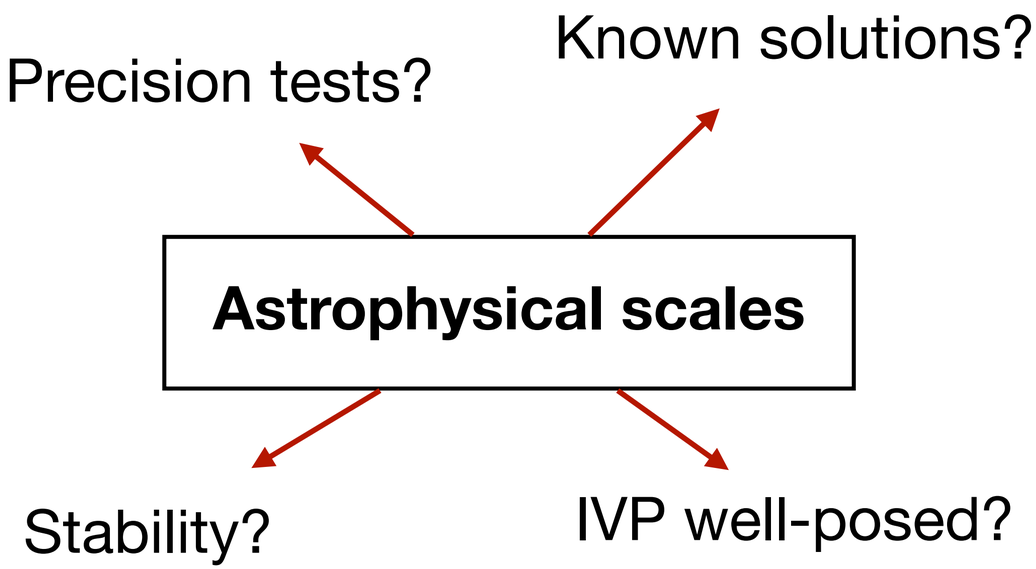


Based on *Phys.Rev.Lett.* 126 (2021) 091102, in collaboration with

Miguel Bezares, Marco Crisostomi, Enrico Barausse, and Carlos Palenzuela

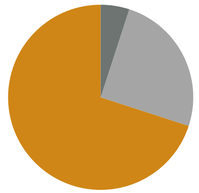
(Picture by Eric Nyquist for Quanta Magazine)

Compact Objects in Modified Gravity



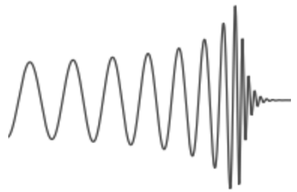
Neutron stars

$g_{\mu\nu}$, ϕ → k-**essence**



Dark Energy[1,2]

No Ostrogradski ghosts



Unconstrained by GW170817[3]

[1] *T. Chiba, T. Okabe, and M. Yamaguchi, astro-ph/9912463*
[2] *C. Armendariz-Picon, V. Mukhanov, and P.J. Steinhardt, PRL 85 (2000), 4438*
[3] *P. Creminelli, G. Tambalo, F. Vernizzi, and V. Yingcharoenrat, 1910.14035*

Neutron Stars in k-essence

$$S = \int \mathrm{d}^4x\sqrt{-\tilde{g}}\left(\frac{M_{\rm Pl}^2}{2}\tilde{R} + K(\tilde{X}) + \mathscr{L}_{\rm m}\left(A(\phi)\tilde{g}_{\mu\nu}, \psi\right)\right)$$

$$\tilde{X} \equiv \nabla_\mu\phi\,\nabla^\mu\phi$$

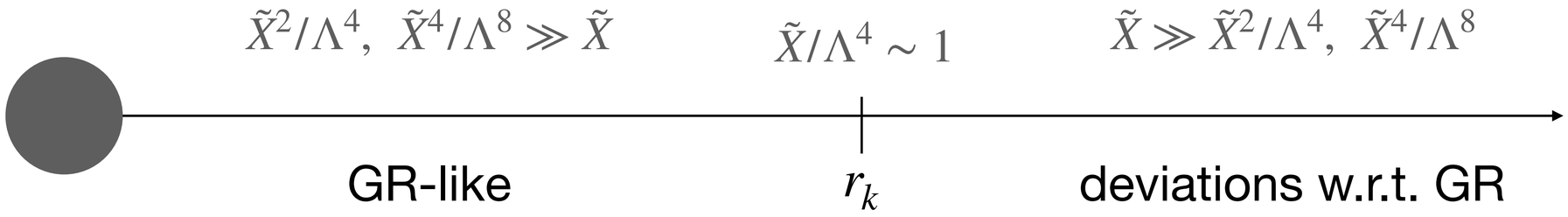
$$K(\tilde{X}) = -\frac{1}{2}\tilde{X} + \frac{\beta}{4\Lambda^4}\tilde{X}^2 - \frac{\gamma}{8\Lambda^8}\tilde{X}^3$$

$$A(\phi) = e^{\alpha\phi/M_{\rm Pl}}$$

$$\alpha, \beta, \gamma \sim \mathcal{O}(1)$$

Screening: Scalar modes are damped by non-linearities within the screening radius.

k-mouflage[1]



[1] *E. Babichev, C. Deffayet, and R. Ziour, 0905.2943*

What **questions** did we have?

Do we still see screening if we solve the **full non-linear system** numerically?

Does k-mouflage survive in the **strong-field regime**?

Are the obtained screened solutions **stable**?

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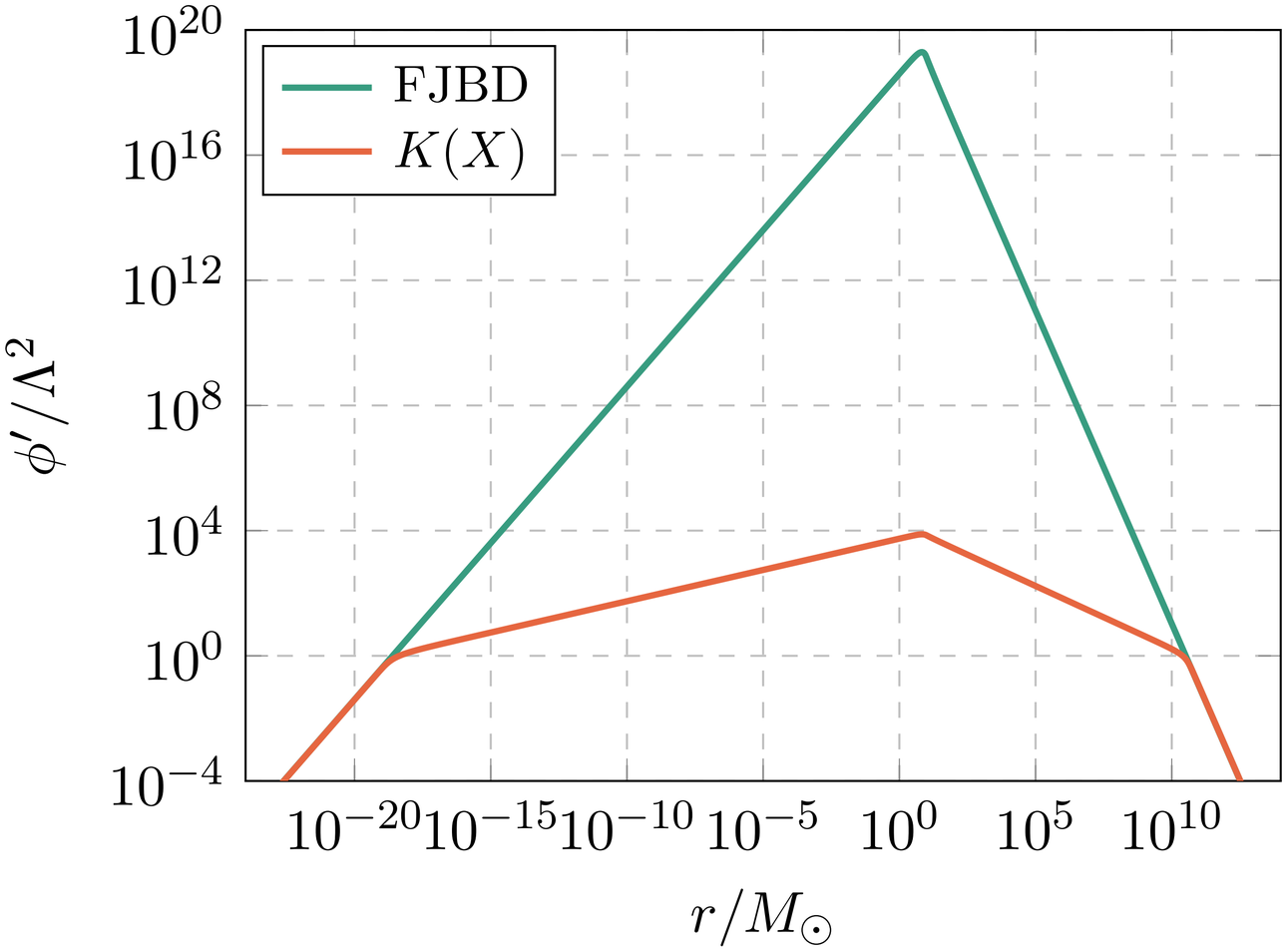
Screening for Neutron Stars



$$\rho(r) = \frac{P(r)}{\Gamma - 1} + \left(\frac{P(r)}{\kappa}\right)^{1/\Gamma}$$

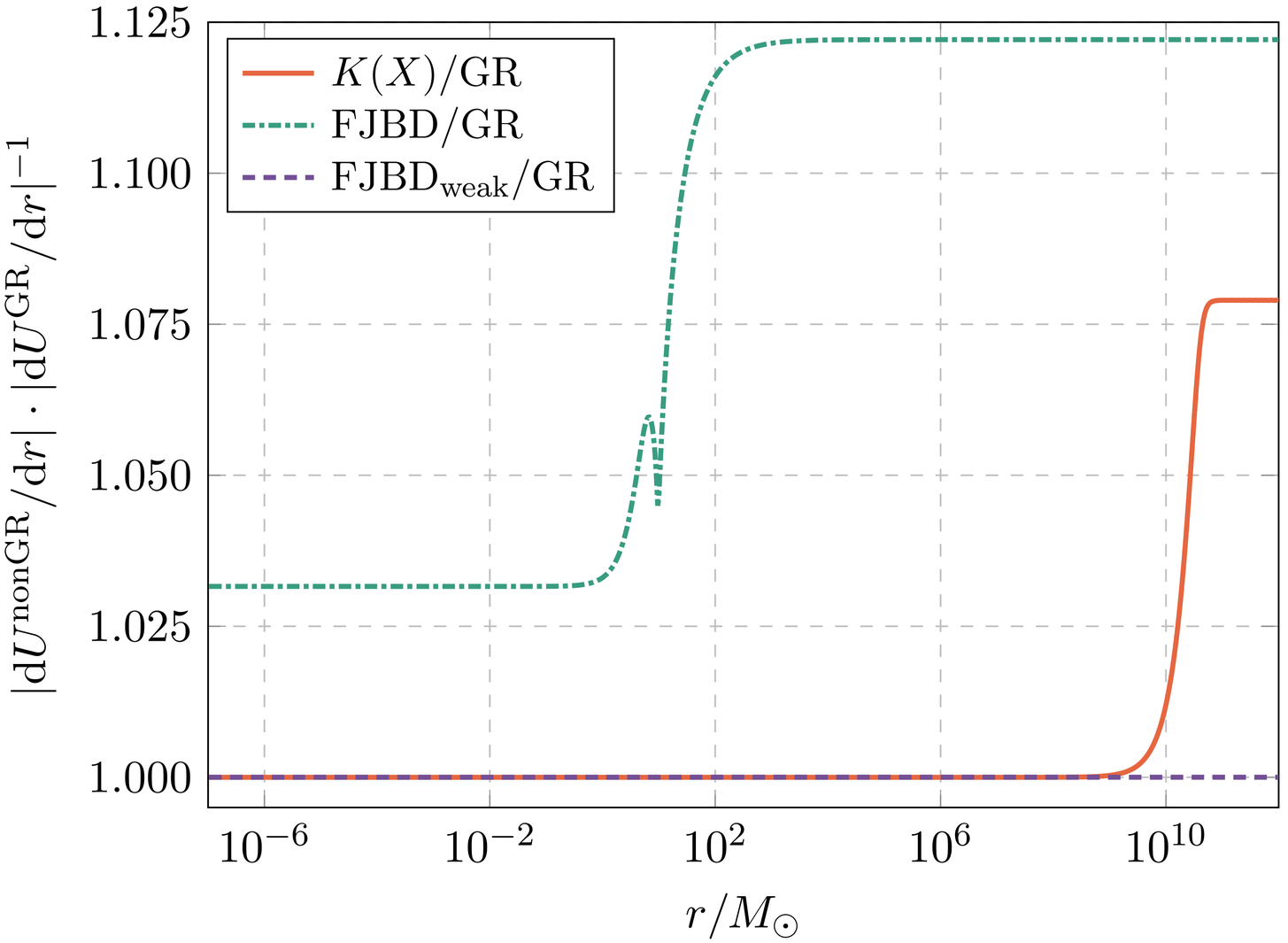
$\Gamma = 2 \qquad \kappa = 123$

$G = c = M_\odot = 1$

results hold for any $\beta < 0$ and $\gamma > 0$

LtH, M. Bezares, M. Crisostomi, E. Barausse, and C. Palenzuela, 2009.03354

Newtonian Fifth Force



$$U = -(g_{tt} + 1)/2$$

FJBD constraint:

$$\alpha \sim 5 \times 10^{-3}$$

LtH, M. Bezares, M. Crisostomi, E. Barausse, and C. Palenzuela, 2009.03354

What **questions** did we have?

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YES

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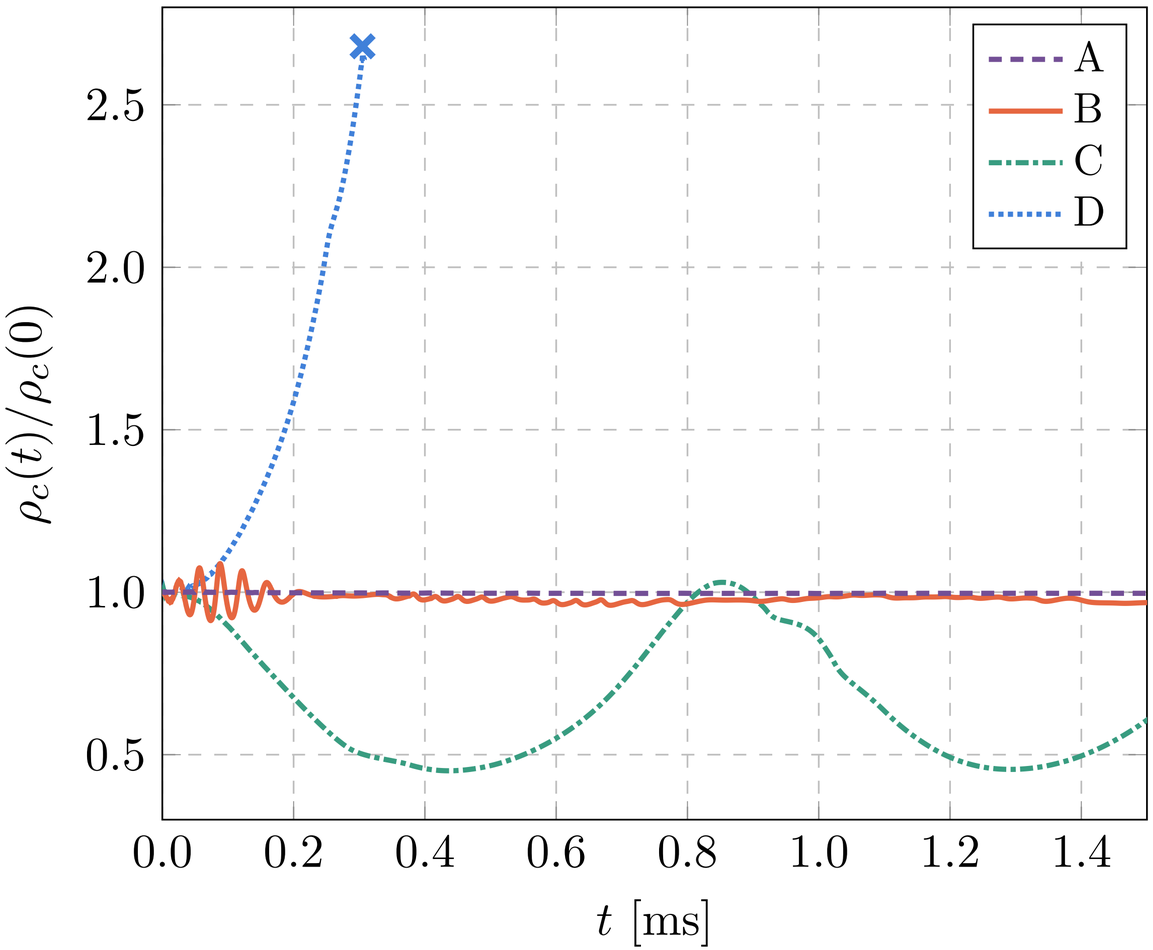
Are the obtained screened solutions **stable**?

Evolution of K-mouflage



A: static
B: small perturbation
C: large perturbation
D: perturbation that triggers gravitational collapse

Evolution of K-mouflage

We define an **effective metric**

$$\gamma^{\mu\nu} \equiv \tilde{g}^{\mu\nu} + \frac{2K''(\tilde{X})}{K'(\tilde{X})} \tilde{\nabla}^{\mu}\phi \, \tilde{\nabla}^{\nu}\phi \quad \rightarrow \quad \gamma^{\mu\nu} \tilde{\nabla}_{\mu} \tilde{\nabla}_{\nu} \phi = \frac{1}{4K'(\tilde{X})} A^{-1}(\phi) A'(\phi) \tilde{T}$$

The characteristic matrix of the principal part is…

$$M = \begin{pmatrix} 0 & \dfrac{\sqrt{-\tilde{g}_{tt}}}{\sqrt{\tilde{g}_{rr}}} \\ -\dfrac{\sqrt{\tilde{g}_{rr}}}{\sqrt{-\tilde{g}_{tt}}} \dfrac{\gamma^{rr}}{\gamma^{tt}} & -\dfrac{2\gamma^{tr}}{\gamma^{tt}} \end{pmatrix}$$

And its eigenvalues read…

characteristic speeds

$$V_{\pm} = -\frac{\gamma^{tr}}{\gamma^{tt}} \pm \sqrt{\frac{-\det\left(\gamma^{\mu\nu}\right)}{(\gamma^{tt})^2}}$$

$$\gamma^{tt} \rightarrow 0 \quad \rightarrow$$

Keldysh problem: The necessary time-step goes to zero when the speeds diverge.

References

Dynamics of Screening in Modified Gravity
LtH, M. Bezares, M. Crisostomi, E. Barausse, and C. Palenzuela, *Phys. Rev. Lett.* 126 (2021) 091102, arXiv:2009.03354 [gr-qc]

k-dynamics: well-posed initial value 1+1 evolutions in k-essence
M. Bezares, M. Crisostomi, C. Palenzuela, E. Barausse, *JCAP* 03 (2021) 072, arXiv:2008.07546 [gr-qc]

Conclusions

We have shown by solving numerically the full field equations that **screened** solutions in k-essence do not only exist for Sun-like stars, but also for **neutron stars**.

These k-mouflage solutions are **stable** to small perturbations, and also to large ones as long as they do not cause gravitational collapse.

However, in some cases we run into a so-called **Keldysh problem**, and we cannot evolve the k-essence field equations starting from a k-mouflage configuration.

Outlook: solve Keldysh problem, evolve in 3+1.

Thank you for your attention!