# Black Holes and Abelian Symmetry Breaking

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# Bekenstein 1972

$$S = \int d^4x \sqrt{-g} \left( M_p^2 R - F^2 - m^2 A^2 \right)$$

No Go Theorem

Phys. Rev. D 5, 1239
Phys. Rev. Lett. 28
Phys. Rev. D 5

- No Black Holes with non-trivial Proca field

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## No Go Theorem

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- No Black Holes with non-trivial Proca field

$$D_\mu F^{\mu\nu} \sim mA^\mu$$

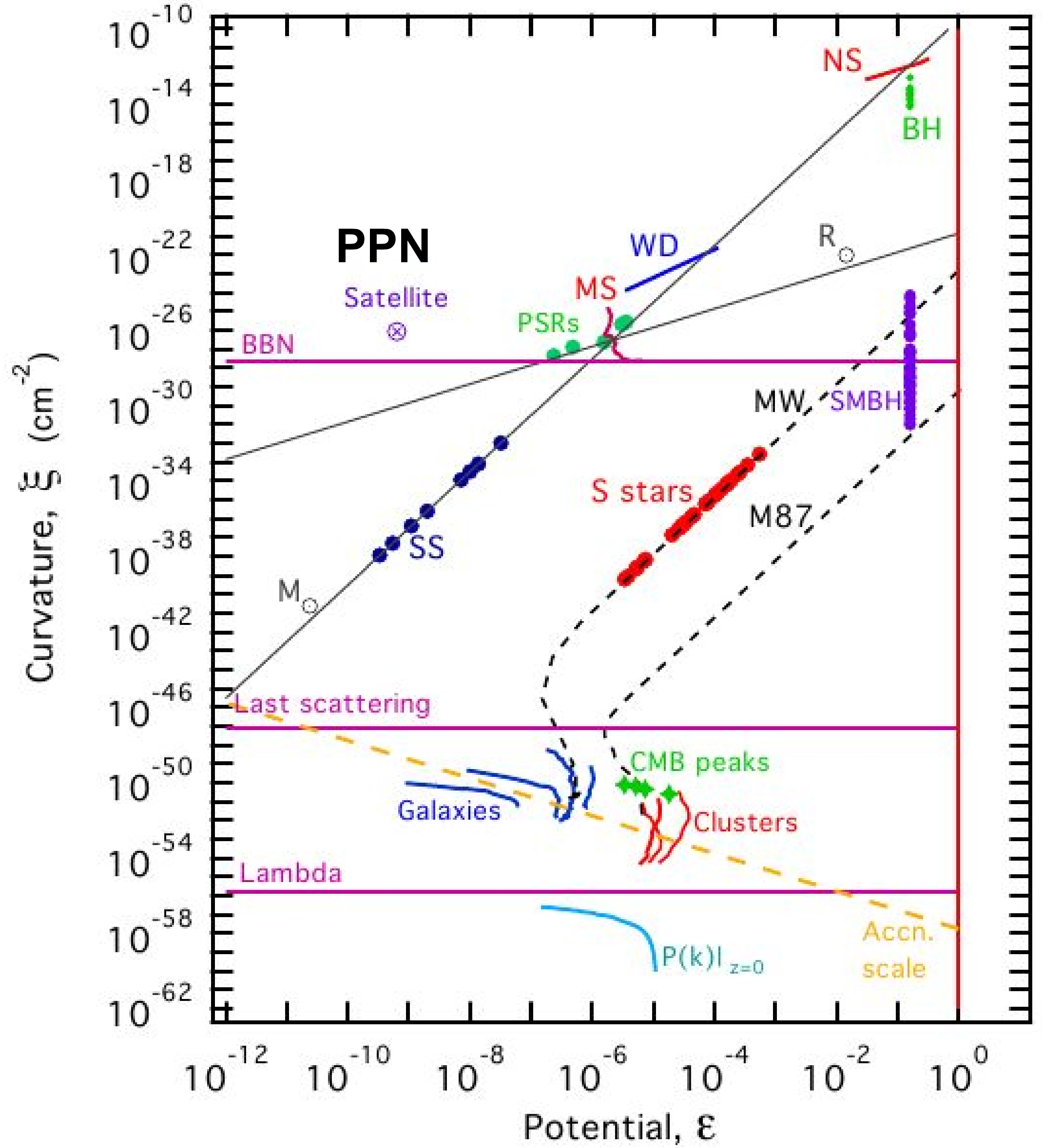
Cannot have non-zero ***Ao*** and ***Ai*** without breaking time reversal

# Can modified gravity avoid this?

O(1) modification in

*Strong field regime

*(maybe) cosmology




Baker et al, 2014

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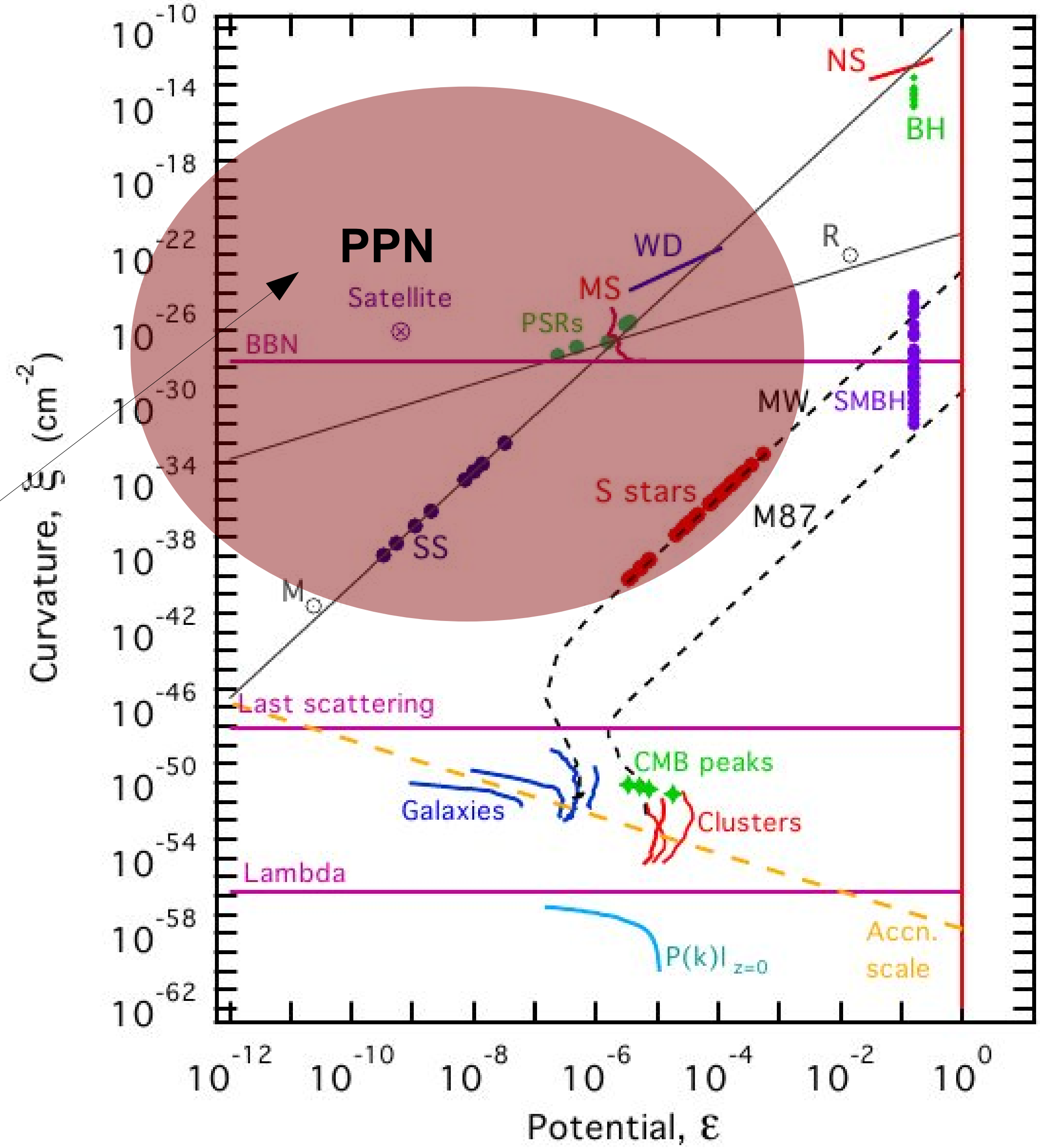
Screening Mechanism

on solar system!




Baker et al, 2014

# Derivative operators

- Screening mechanism via Vainshtein
- Galileon-like interactions for A

$$(D_\mu A^\mu)^2 - D_\mu A_\nu D^\nu A^\mu - \frac{1}{2} A^2 R$$

G. Tasinato,
L. Heisenberg

No ghost combination

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Equivalent to

$$G_{\mu\nu} A^\mu A^\nu$$

Effective mass term depending on the background

# New “mass” term

$$S = \int d^4x\sqrt{-g}\left(\frac{M_p^2}{2}R - \Lambda - \frac{1}{4}F^2 + \beta G_{\mu\nu}A^\mu A^\nu\right)$$

Breaks gauge symmetry ➡ 5 dof

Eqn for A. $$D^\mu F_{\mu\nu} = -2\beta G_{\mu\nu}A^\mu$$

Avoids Bekenstein's argument

Can now turn on the longitudinal mode!

# Spherically Symmetric Solutions

Ansatz

J. Chagoya, GN, G. Tasinato

$$ds^2 = -f(r)dt^2 + h(r)^{-1}dr^2 + r^2 d\theta^2 + r^2 \sin^2\theta d\varphi^2$$

$$A_\mu = (A_0(r), A_L(r), 0, 0)$$

Eoms

$$0 = \beta A_L \left[h - f(f + rf')^{-1}\right] \ldots$$

$$\beta \neq 0, \quad A_L \neq 0$$

Asymptotically

$$f \sim r^n, \quad n \neq -1$$

$$R = \frac{(2f - rf')(2f' + rf'')}{2r(f + rf')^2} \longrightarrow 0$$

# Spherically Symmetric Solutions

## Ansatz

J. Chagoya, GN, G. Tasinato

$ds^2$ … $\sin^2\theta d\varphi^2$

$A_\mu$ …

Screens cosmological constant

(cf. Fab Four of Charmousis et al)

## Eoms

$\beta$ … ptotically

$n \neq -1$

$$R = \frac{(2f - rf')(2f' + rf'')}{2r(f + rf')^2} \longrightarrow 0$$

# Without cosmological constant

If $g_{\mu\nu} \xrightarrow{r\to\infty} \eta_{\mu\nu} \quad \left(f, h \xrightarrow{r\to\infty} 1\right)$ ➡ $\beta = \frac{1}{4}$

Then we found

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$$f = h = 1 - \frac{2M}{r}$$

$$A_0 = \frac{Q}{r} + P$$

$$A_L = \frac{\sqrt{Q^2 + 2\,P\,Q\,r + 2\,M\,P^2\,r}}{r - 2M}$$

c.f. Reissner-Norsdrom

$$f = h = 1 - \frac{2M}{r} + \frac{Q^2}{2M_{pl}^2 r^2}$$

$$A_0 = \frac{Q}{r} + P$$

$$A_L = 0$$

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If $g_{\mu\nu} \xrightarrow{r\to\infty} \eta_{\mu\nu} \quad \left(f, h \xrightarrow{r\to\infty} 1\right)$ ➡ $\beta = \dfrac{1}{4}$

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**STEALTH SOLUTION**

*Schwarzschild background

*Non-trivial ***Ao*** and ***AL***

*Effective $T^A_{\mu\nu} = 0$

*No singularity at ***r=2M***

*Avoids Bekenstein's th.

cf. Babichev and Charmousis

# Other findings

- Stable under spherically symmetric perturbations, for small vector charges

- Higher dimensional extension

- Slowing rotating solutions are the same as Kerr's slowly rotating limit

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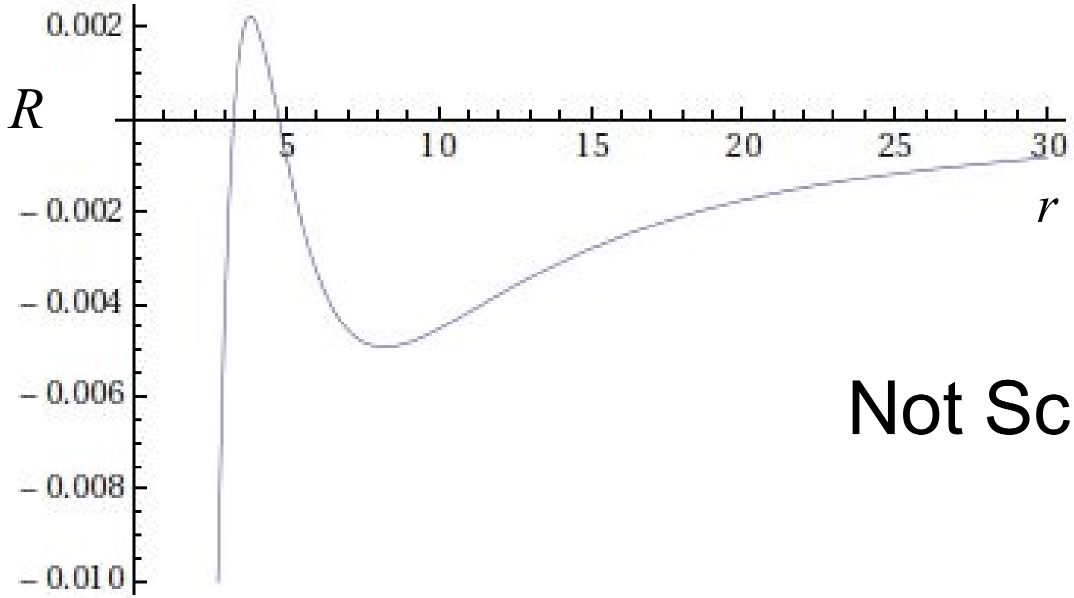
# Other findings

- With a bare cosmological constant, found $(\beta = 1/4)$

$$f = 1 - \frac{2M}{r} + \frac{4r^2\Lambda_P}{3} + \frac{4}{5}r^4\Lambda_P^2 \qquad h = f\ \left(1 + 2r^2\Lambda_P\right)^{-2}$$

$$A_0 = \frac{Q}{r} + P\left(1 + \frac{2}{3}r^2\Lambda_P\right) \qquad A_L = F(\Lambda_p, f, h, Q, P, M_{pl})$$




$$\boxed{\Lambda_P \equiv \frac{\Lambda}{P^2 - 4M_{pl}^2}}$$

Not Schwarzschild-de Sitter

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# Conclusions

$G_{\mu\nu}A^{\mu}A^{\nu}$ term avoids Bekenstein's conclusion

Stealth solutions with two “unseen” vector charges

Cosmological constant screened asymptotically

May describe EM since $G_{\mu\nu}$ < Mass constraints

Need further (strong field) studies to constrain the model