Prospects for testing (two) quantum gravity inspired deviations from GR

Andrew Coates

Wednesday 22nd January, 2020

Based on work carried out at:
Eberhard Karls Univerity of Tübingen
University of Nottingham

Outline

Area quantization (with Sebastian and KK):

- What and wherefore[1] of area quantizationBekenstein 1974; Mukhanov 1986

[1] No Purchase Necessary!

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Using standard quantization of spin the mass spectrum for a Kerr black hole is:

$$M^2 = \frac{c}{16\pi G}\left(\alpha\hbar n + \frac{64\pi^2\hbar j^2}{\alpha n}\right)$$

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The question is: are there disco balls in the sky?

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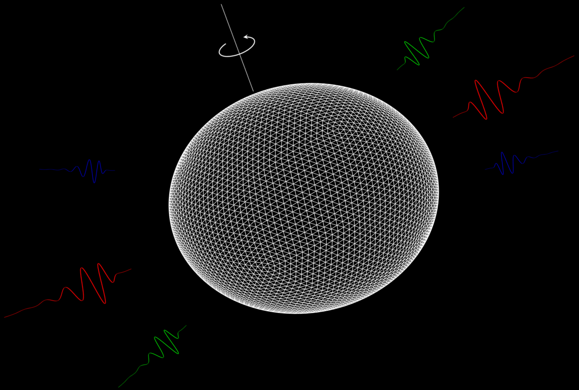
A highly accurate numerical simulation



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To get this: use $\dot{A}$ instead of $\dot{M}$ and parametrize $\langle \delta n \rangle$ in a nice way.

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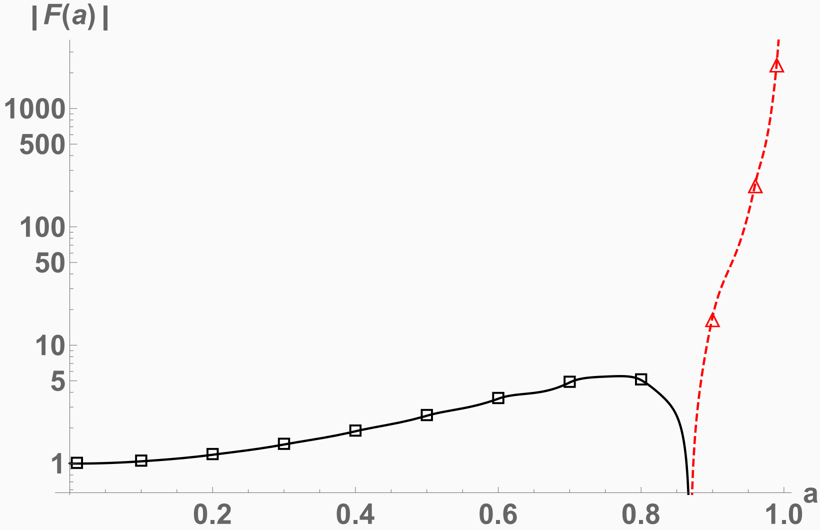
Area quantization IV



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Final words: reflectivity unlikely in astrophysics (spins generally large). Also basically no chance of noticable spectral lines, even in Schwarzschild.

[5] $\alpha \approx 2.7$ corresponds to the $1/5$

End of first part

Questions?

Equivalence Principles

Definitions based on[6]

- Weak Equivalence Principle
  - Test particles have universal free-fall

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GR only known viable theory with SEP[7] and WEP at risk outside of GR.

---

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[7] isolated system when local flatness is not enough?

Brief recap: spontaneous scalarization I

Action of scalar-tensor theory

$$S = \frac{1}{16\pi G} \int \mathrm{d}^4 x \sqrt{-g} \left[R - 2\partial_\mu \phi \partial^\mu \phi - V(\phi) \right] + S_m \left[A^2(\phi) \mathbf{g}, \Psi_m \right].$$

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SEP violation via ϕ_∞

useful to define: $\alpha = \dfrac{\mathrm{d}A}{\mathrm{d}\phi}$

Brief recap: spontaneous scalarization II

Now linearize scalar equation around GR solution with constant scalar ϕ_0[8]

$$\Box\varphi = \left(m^2 - 4\pi G T \beta\right)\varphi$$

where

$$\phi = \phi_0 + \varphi + \cdots , \quad m^2 = \frac{1}{4}V''(\phi_0), \quad \beta = \alpha'(\phi_0).$$

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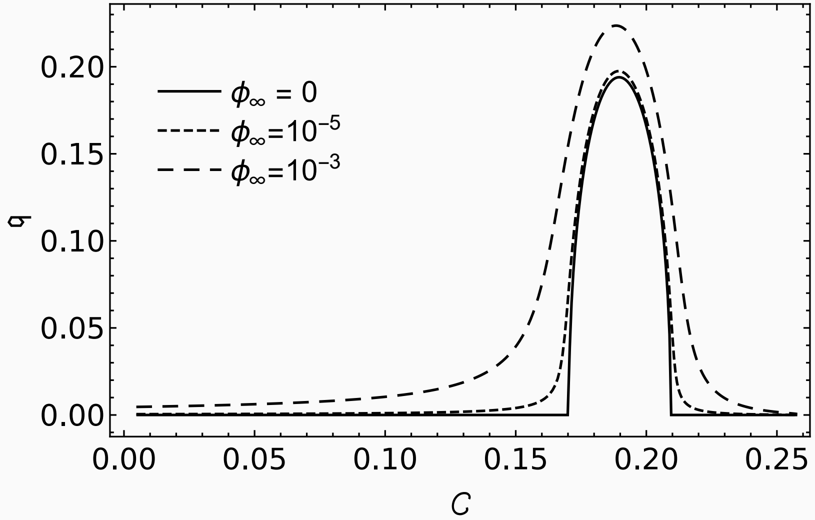
Upshot: screened[9] SEP violations which show up in strong gravity (just one example).

[8] requires $V'(\phi_0) = \alpha(\phi_0) = 0$
[9] Damour et al. 1993.

Brief recap: spontaneous scalarization III



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But: WEP violations very broad, should first study a toy model[10]. Particularly as a pilot for future work.

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Properties:

- A screening mechanism
- Tractablilty
- Some WEP violation

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The gravitational Higgs mechanism: the action

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$$\mathcal{D}_\mu\phi = \partial_\mu\phi - iqA_\mu\phi,$$

A_μ is a $U(1)$ gauge field.[11]

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Ongoing work with Nicola to understand the solutions in this case.

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For spherically symmetric stars, only standard scalar-tensor theory solutions[14].

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Note: $1/r$ falloff so need $\sim 10^{39}$ NS radii $\sim 10^{40}\mathrm{km}$ to satisfy that bound[15]...

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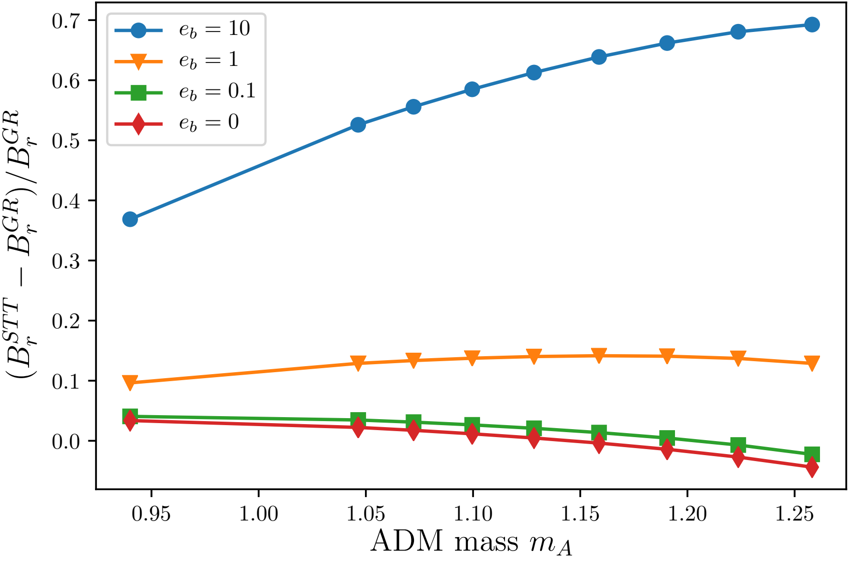

$e_b = 10$
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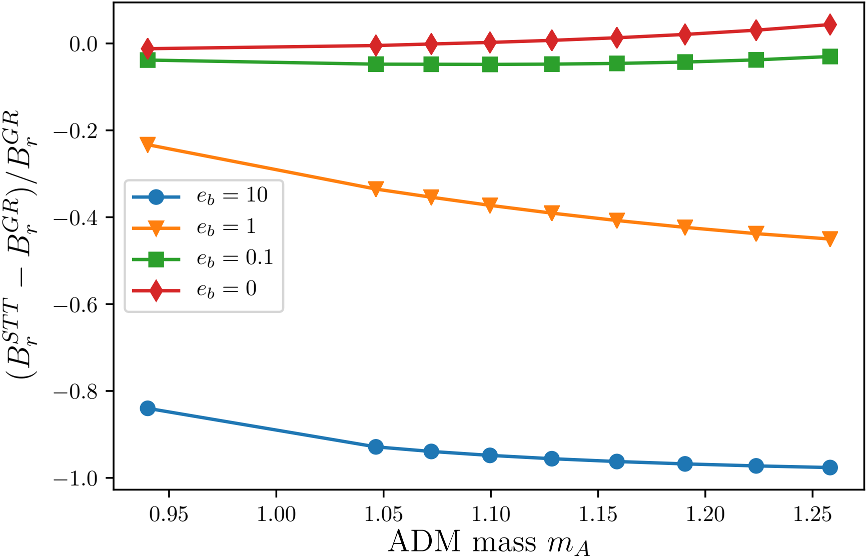
$(B_r^{STT} - B_r^{GR})/B_r^{GR}$
ADM mass m_A
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.95
1.00
1.05
1.10
1.15
1.20
1.25



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- Need to go beyond the toy and seems worthwhile.

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May be useful to take a detour through cosmology.

Thank you!

Questions?

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$$A_\mu = \mathrm{Re}\left[\left(a_\mu + \epsilon b_\mu + \mathcal{O}(\epsilon^2)\right) \exp \frac{i\theta}{\epsilon}\right]$$

important to keep ϕ of order $1/\epsilon$ (else geometric optics is also ultra relativistic).

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$$\ell^\alpha \nabla_\alpha \ell^\beta = -\left(\nabla_\alpha \log\phi\right)\left(g^{\alpha\beta} + \ell^\alpha \ell^\beta\right)$$

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Making a gauge choice, the gauge field's equation of motion are Proca-like:

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In spherical symmetry and staticity the r (areal radius) component of the gauge fields equation reads:

$$m_\gamma^2 A_r = 0,$$

(in the above guage) and so $A_\mu = (A_t, 0, 0, 0)$.

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Sketch: Contract the Proca-like equation with A^ν and integrate over some spacetime volume, $\mathcal{V}$,

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Finally look at the integrand of the left-hand-side, it is sign definite and one gets $A_t = 0$.

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Backup: parametric oscillator analogy

Compare the flatspace Klein-Gordon equation with a field dependent mass[17]:

$$-\partial_t^2 \psi = \left(k^2 + m^2(|\phi|) \right) \psi,$$

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So in dynamical situations can expect some excitation of ψ (*c.f.* reheating).

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