Title: Testing pseudo-complex general relativity with gravitational waves

Date: Nov 08, 2017 02:40 PM

URL: http://pirsa.org/17110072

Abstract: We show how the model of pseudo-complex general relativity can be tested using gravitational wave signals from coalescing compact objects. The Model, which agrees with Einstein gravity in the weak-field limit, diverges dramatically in the near-horizon regime, with certain parameter ranges excluding the existence of black holes. We show that simple limits can be placed on the model in both the inspiral and ringdown phase of coalescing compact objects.
We discuss further how these limits relate to current observational bounds.
In particular, for minimal scenarios previously considered in the literature, gravitational wave observations are able to constrain pseudo-complex general relativity parameters to values that require the existence of black hole horizons."

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“No Horizons”?
Testing
Pseudo-Complex General Relativity
with
Gravitational Waves

Ofek Birnholtz, Alex Nielsen

arxiv: 1708.03334 [gr-qc]

“Quantum Black Holes in the sky?”, Perimeter Institute

8 November 2017

Solutions of pc-GR

- Schwarzschild-like:

$$-g_{tt} = 1 - \frac{2M}{r} + \frac{1}{r}\int \xi \, dr = 1 - \frac{\psi}{\Sigma}$$

$$\psi = 2m(r)r \qquad m(r) = M - \frac{B}{2r^n} = M\,g(r)\;,\quad g(r) = \left[1 - b\left(\frac{M}{r}\right)^n\right]$$

- Kerr-like (Caspar et. al. 2012)

$$g_{tt} = -\left(1 - \frac{\psi}{\Sigma}\right) \quad , \quad g_{rr} = \frac{\Sigma}{\Delta} \quad , \quad g_{\theta\theta} = \Sigma \; ,$$

$$g_{\phi\phi} = \left(\left(r^2 + a^2\right) + \frac{a^2\psi}{\Sigma}\sin^2\theta\right)\sin^2\theta \; ,$$

$$g_{t\phi} = g_{\phi t} = -a\frac{\psi}{\Sigma}\sin^2\theta \; ,$$

- (Also: Reissner-Nordstrom-like)

What is pc-GR?

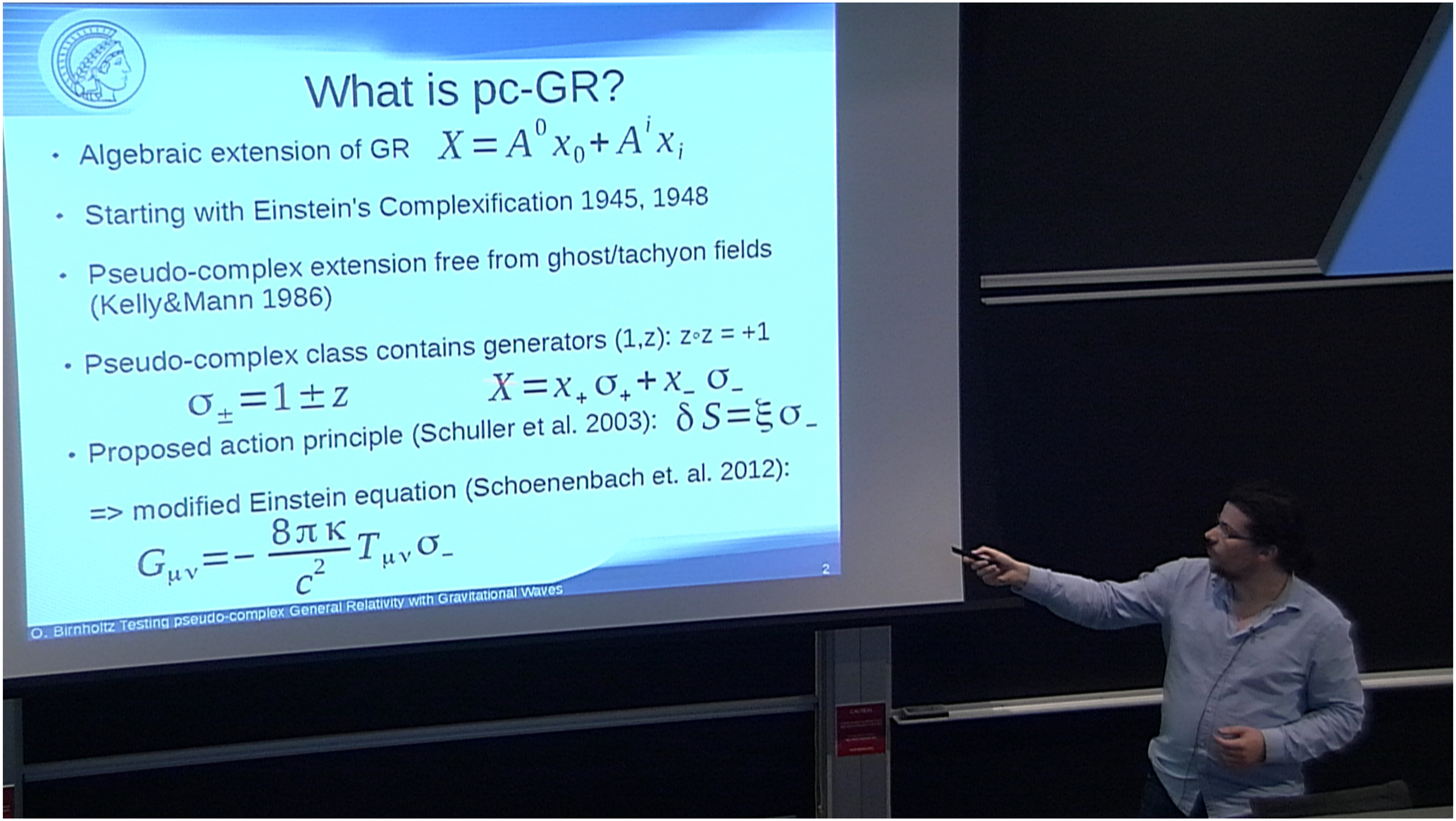
- Algebraic extension of GR $X = A^0 x_0 + A^i x_i$
- Starting with Einstein's Complexification 1945, 1948
- Pseudo-complex extension free from ghost/tachyon fields (Kelly&Mann 1986)
- Pseudo-complex class contains generators (1,z): z∘z = +1

$$\sigma_\pm = 1 \pm z \qquad X = x_+ \sigma_+ + x_- \sigma_-$$

- Proposed action principle (Schuller et al. 2003): $\delta S = \xi \sigma_-$

=> modified Einstein equation (Schoenenbach et. al. 2012):

$$G_{\mu\nu} = -\frac{8\pi\kappa}{c^2} T_{\mu\nu} \sigma_-$$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2
O. Birnholtz Testing pseudo-complex General Relativity with Gravitational Waves

Solutions without horizons

- Define a dimensionless parameter:

$$b = -\left(\frac{r}{M}\right)^{n} \frac{\int \xi}{2\,M}\, dr$$

- Large b => no horizons & “no black holes”

$$b_{\mathrm{max_H}} = \Upsilon^{n}_{\mathrm{max_H}} \left(1 - \frac{\chi^2}{2\Upsilon_{\mathrm{max_H}}} - \frac{\Upsilon_{\mathrm{max_H}}}{2}\right)$$

$$\Upsilon_{\mathrm{max_H}} = (n + \sqrt{n^2 - (n^2-1)\chi^2})/(n+1)$$

For n=2 and no spin, b_{maxH} = 16/27

Why test pc-GR?

- "Good" Mathematical model
- Rich Phenomenology:
  - Dark-energy
  - New length scale
  - Vanishing horizons
  - (n,b) cover many "ECO" regimes
- Complementary Tests:
  - Solar System tests => n>1
  - EM observations of disks

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Electromagnetic Tests

- Disk approximations: EMRI + ISCO
  - Geodesic equation's r-component (Kepler's Law)

$$(\omega a+1)^2(m-m'r)-\omega^2 r^3=0$$

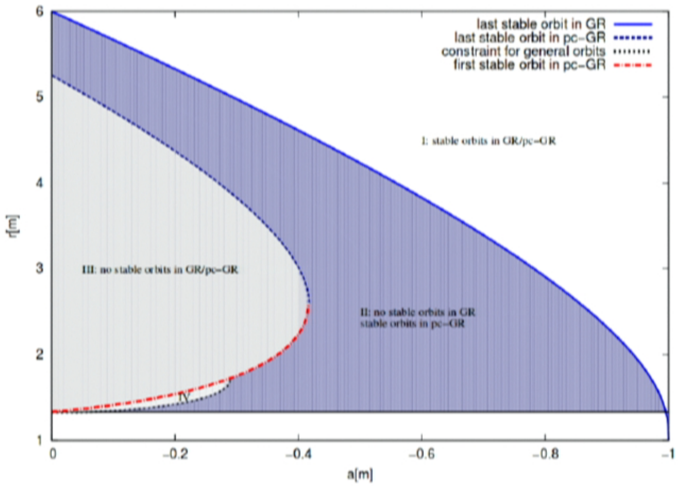


Fig 9 of Schönenbach et al 2012

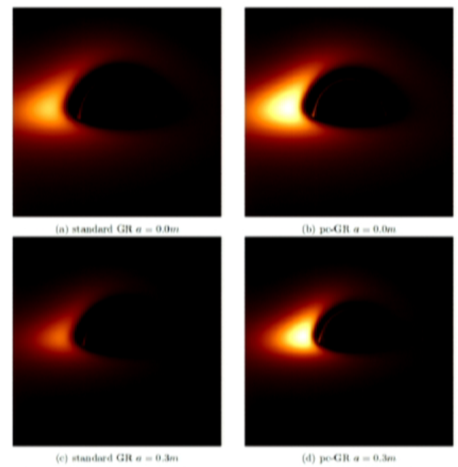
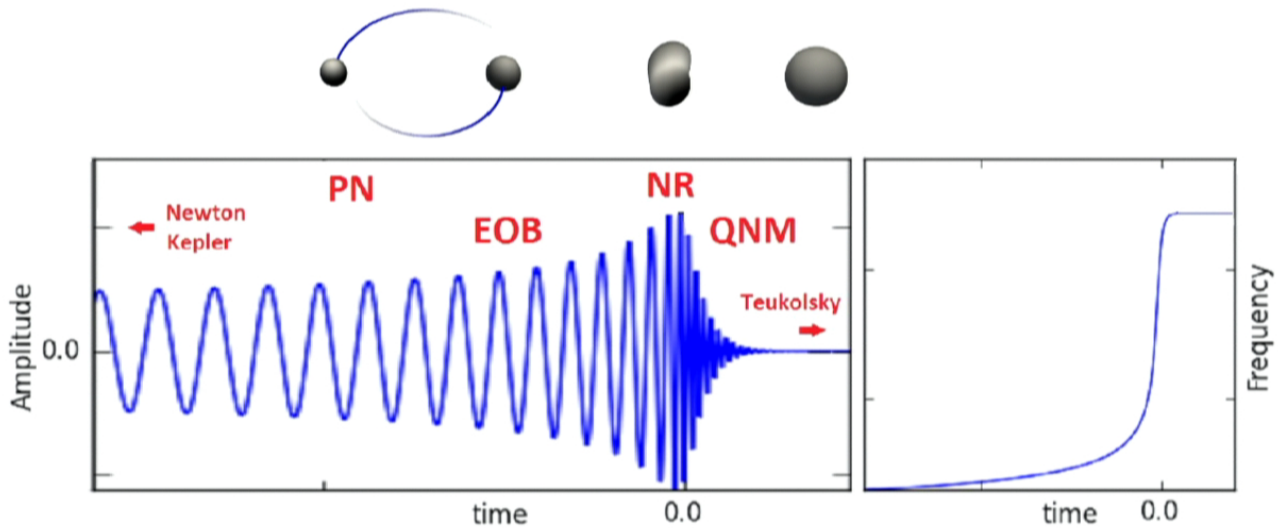


Fig 2 of Schönenbach et al 2014

- EHT Results ~*spring 2018*

What can GWs test?

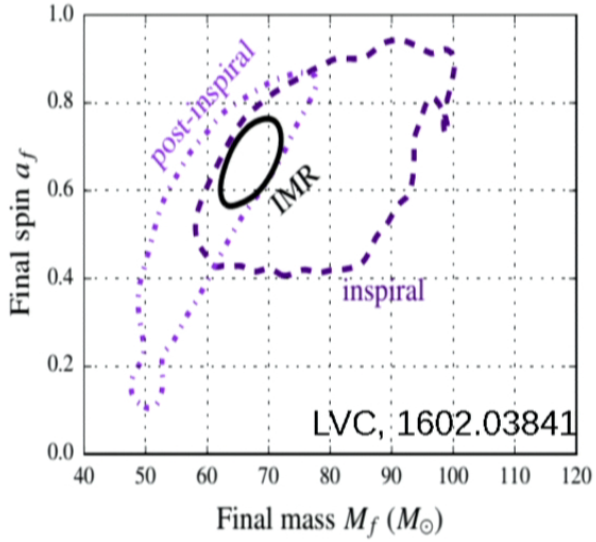


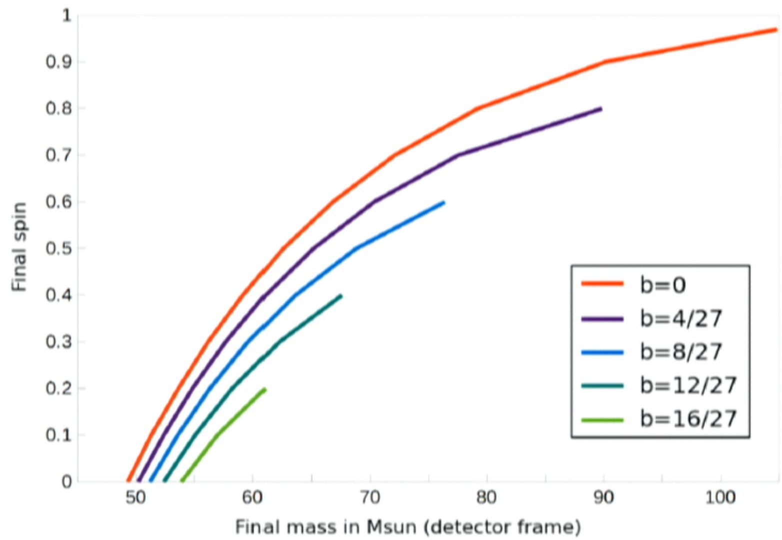
- The post-Newtonian parameter x : $\sqrt{x} = v/c = \omega r/c = \sqrt[3]{\pi G M f_{GW}}/c$
- For $x \sim 0.1$: $\frac{M}{20\,\mathrm{M}_\odot} \sim \frac{100\,\mathrm{Hz}}{f_{GW}}$
- $M = m_1 + m_2$ $\left(\frac{G\mathrm{M}_\odot}{c^3} \sim 5\mu s\right)$

Light Ring & “ringdown”

$$\sqrt{\Delta}(r^3 - a^2 F) + a(2r^2 m + (r^2 + a^2)F) - r\sqrt{rF}g_{\phi\phi} = 0$$

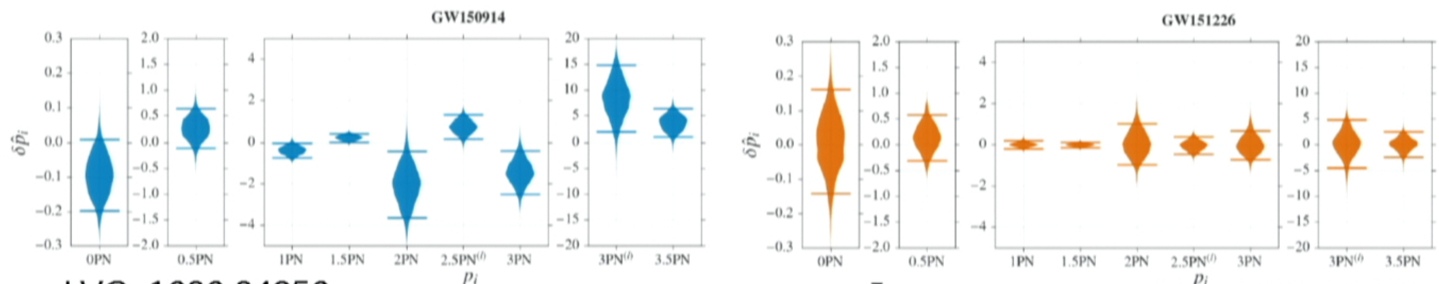
$F = m - m'r$ Hess et. al. (2016)





“...in the postmerger phase of a compact binary coalescence, the initial ringdown signal chiefly depends on the properties of the light ring – and not on the QNMs – of the final object.”
Cardoso et al. 2016, Pani this morning

Post-Newtonian constraints



LVC, 1606.04856

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$$m(r) = M - \frac{b}{2r^n}$$

$$nPN\ term = \frac{20b(n+2)(n+1)(1+q^n)}{3(n-4)(2n-5)(1+q)^n}(\pi M f_{GW})^{2n/3}$$

n	$\Upsilon_{\max_H}$	$b_{\max_H}$	$p_n^{\mathrm{pc-GR}}$	p_n^{GR}	δ_ϕ	$range(\delta_\phi)$
1	1	0.5	20/9	6.44	34%	(−20%, 5%)
2	4/3	16/27	320/27	46.2	26%	(−130%, 15%)
3	1.5	27/32	-225/8	-652	4.3%	(−100%, 600%)

Conclusions

- Horizon-less objects ruled out for n=1, 2
- 1st stage tests: pre- & post-merger

=> 2nd stage: which theories to focus on for N(non-G)R merger simulations?

- Echoes?