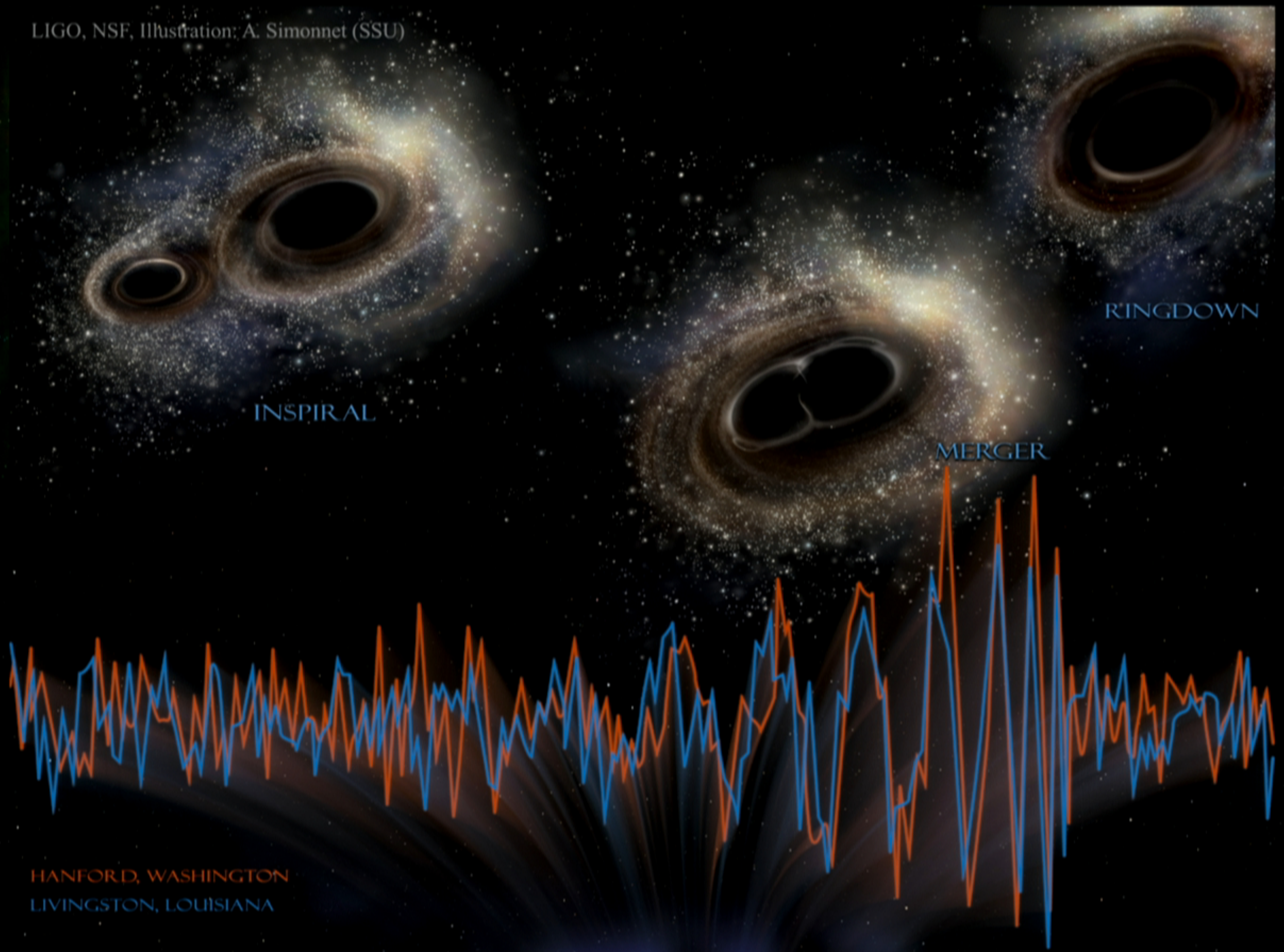
Title: Inspiral Tests of Strong-field Gravity and Ringdown Tests of Quantum Black Holes

Date: Nov 08, 2017 02:00 PM

URL: http://pirsa.org/17110075

Abstract: The binary black hole merger events recently discovered by the LIGO and Virgo Collaboration offer us excellent testbeds for exploring extreme (strong and dynamical-field) gravity that was previously inaccessible. In this talk, I will first explain the current status of probing fundamental pillars of General Relativity using the inspiral part of the gravitational waveform. I will next describe how well one can constrain one type of quantum black holes, collapsed polymers, with the GW150914 ringdown. I will conclude with a list of important open problems.

Outline



Outline Kent Yagi

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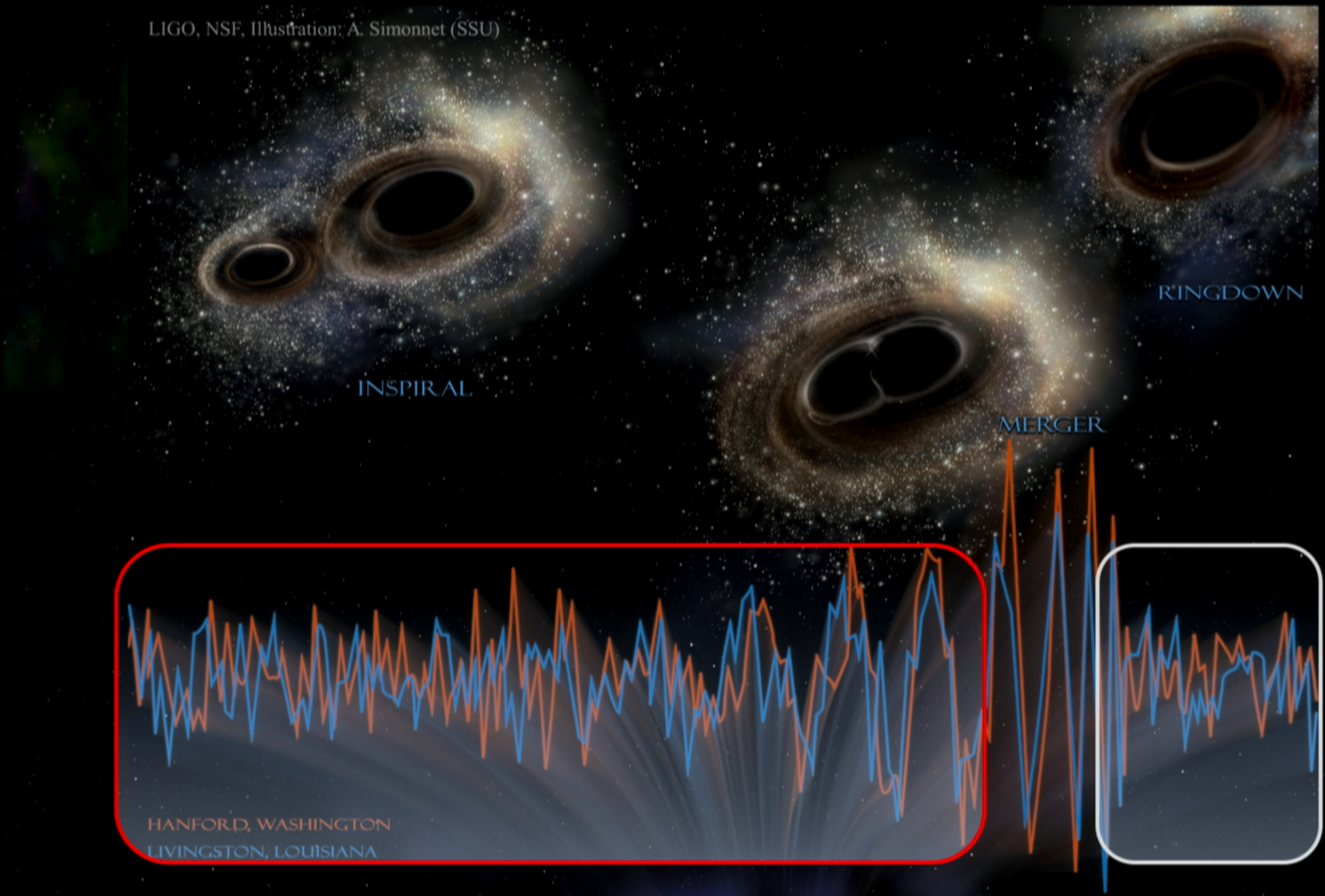

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Fundamental Pillars in General Relativity (GR)

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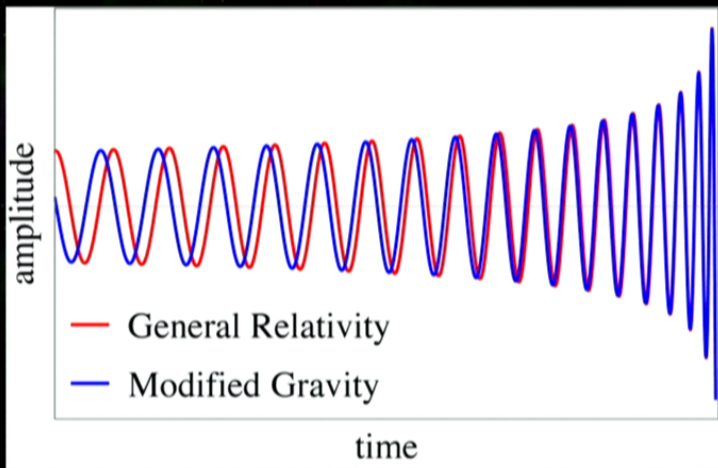
parameterized post-Einsteinian (ppE) Formalism

[Yunes & Pretorius (2009)]



relative velocity

waveform phase: ppE parameter

$$\Psi^{(\mathrm{insp})} = \Psi^{(\mathrm{insp})}_{\mathrm{GR}} + \beta\, (v/c)^{2n-5}$$

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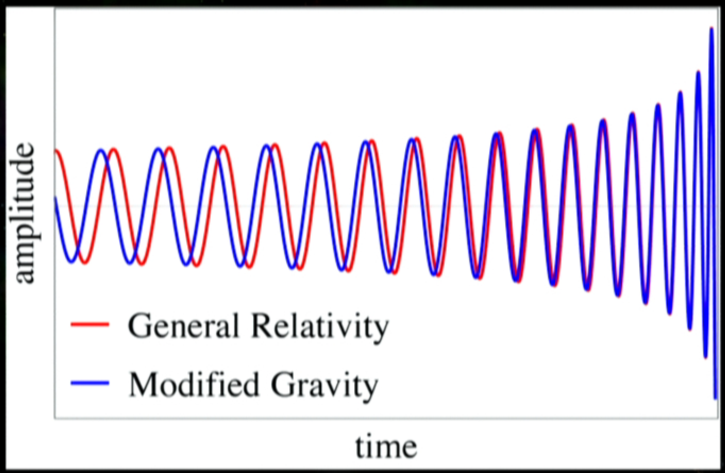
parameterized post-Einsteinian (ppE) Formalism

[Yunes & Pretorius (2009)]



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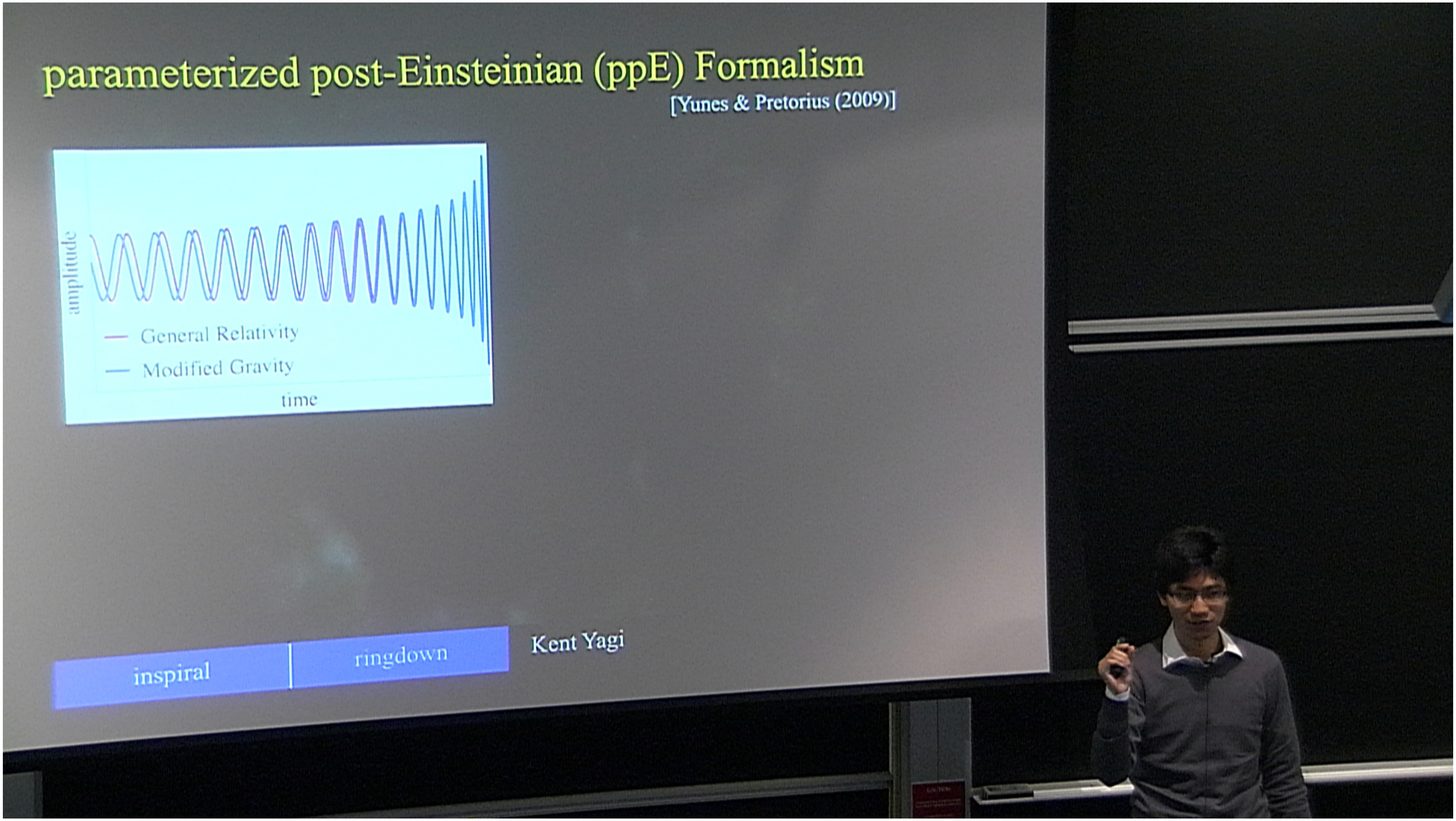
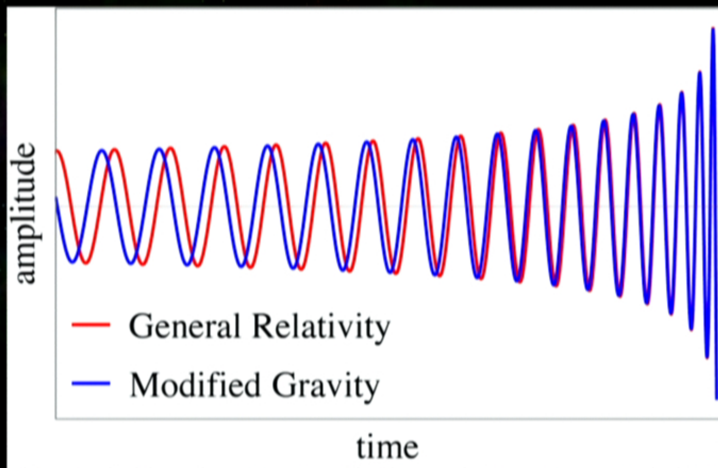

parameterized post-Einsteinian (ppE) Formalism
[Yunes & Pretorius (2009)]
amplitude
General Relativity
Modified Gravity
time
inspiral
ringdown
Kent Yagi

parameterized post-Einsteinian (ppE) Formalism

[Yunes & Pretorius (2009)]



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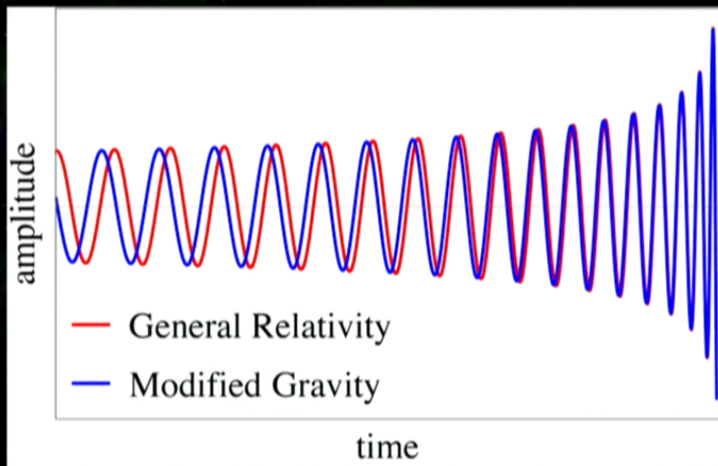

waveform phase:

ppE parameter

relative velocity

*n*th post-Newton (PN) correction

$$\Psi^{(\mathrm{insp})} = \Psi^{(\mathrm{insp})}_{\mathrm{GR}} + \beta \, (v/c)^{2n-5}$$

PN approximation:

$$v/c \ll 1$$

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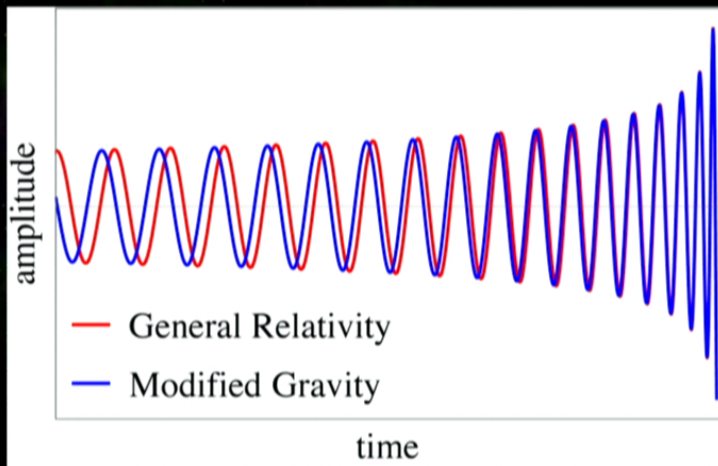

relative velocity

ppE parameter

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waveform phase:

$$\Psi^{(\mathrm{insp})} = \Psi^{(\mathrm{insp})}_{\mathrm{GR}} + \beta\,(v/c)^{2n-5}$$

$$\Psi^{(\mathrm{merg,ring})} = \Psi^{(\mathrm{merg,ring})}_{\mathrm{GR}}$$

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parameterized post-Einsteinian (ppE) Formalism

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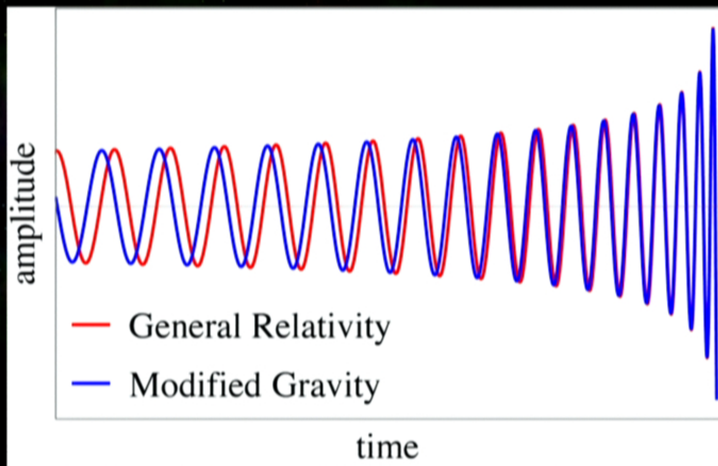

relative velocity

ppE parameter

nth post-Newton (PN) correction

<u>waveform phase:</u>

$$\Psi^{(\mathrm{insp})} = \Psi^{(\mathrm{insp})}_{\mathrm{GR}} + \beta \, (v/c)^{2n-5}$$
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<u>PN approximation:</u>

$$v/c \ll 1$$

(lack of sufficient binary black hole merger simulations in non-GR theories)

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parameterized post-Einsteinian (ppE) Formalism

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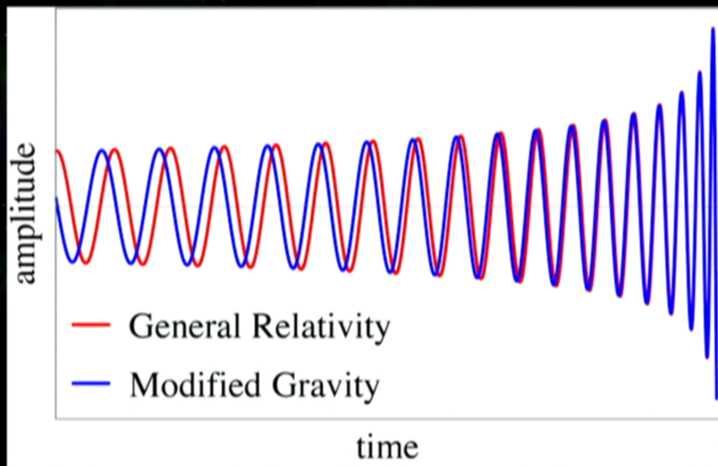

Fisher Analysis

signal: GR waveform consistent with GW150914 & GW151226

template: ppE modified waveform

waveform phase:

ppE parameter

relative velocity

nth post-Newton (PN) correction

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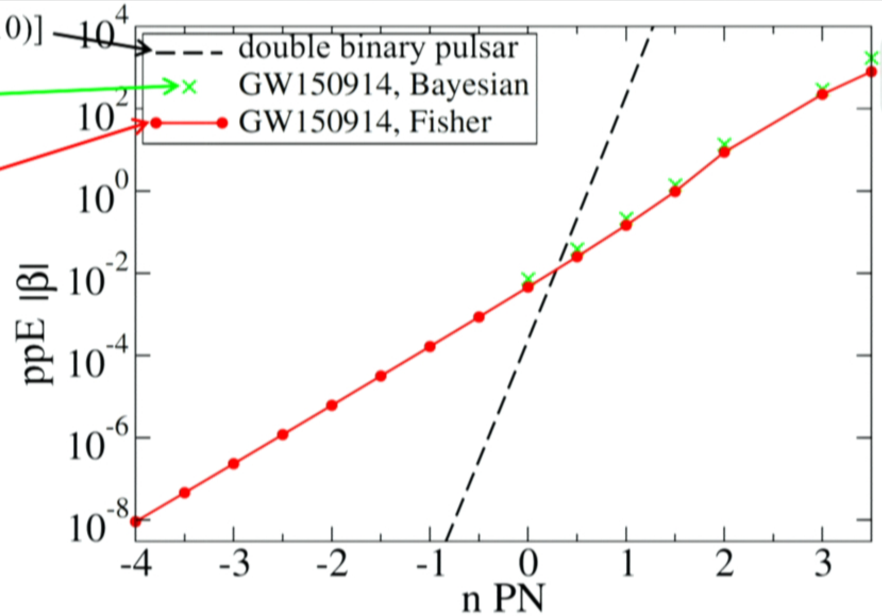
Constraints on GW Generation



$$\delta\Psi = \beta\, v^{2n-5}$$

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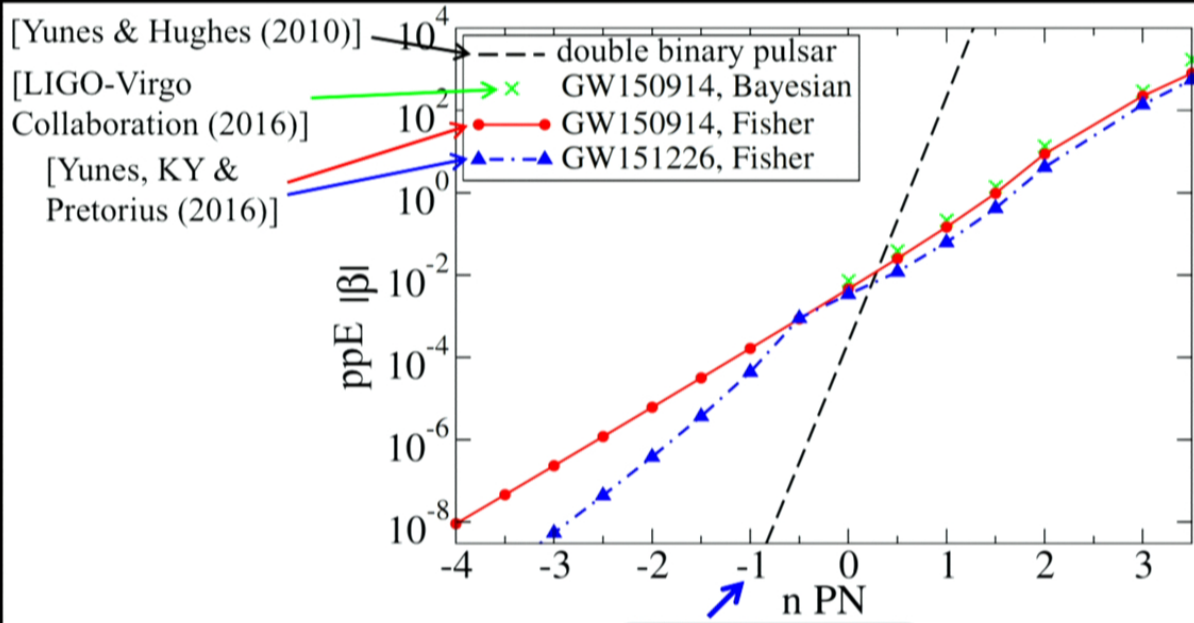
Constraints on GW Generation

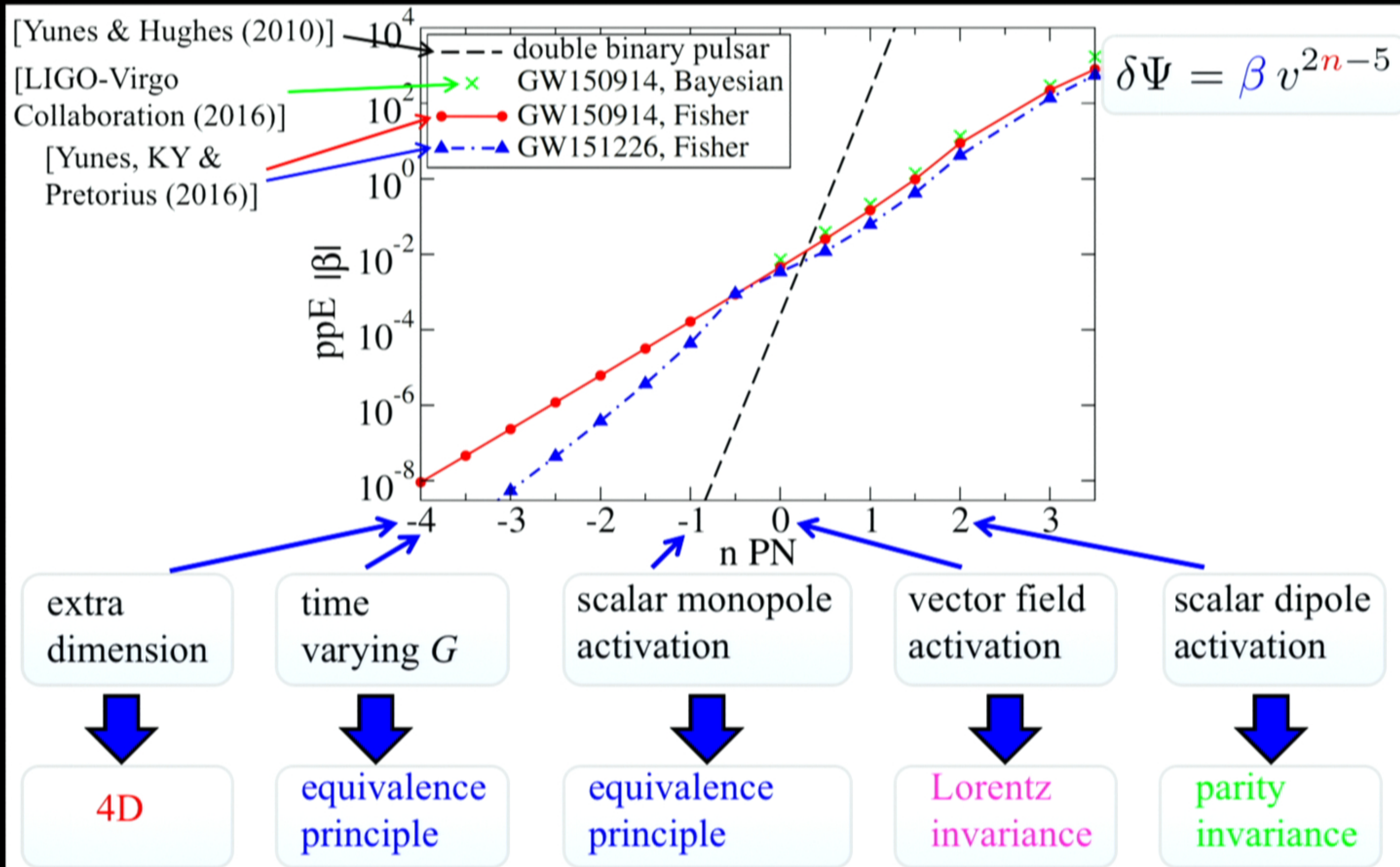


$$\delta\Psi = \beta\, v^{2n-5}$$

scalar monopole activation

equivalence principle

Constraints on GW Generation



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Theoretical Constraints

[Yunes, KY & Pretorius PRD (2016)]

Example Theories (Theoretical Parameters)	GR Pillar	Example Theory Constraints	
		GW150914	Others

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Theoretical Constraints

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Example Theories (Theoretical Parameters)	GR Pillar	Example Theory Constraints	
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Einstein-dilaton Gauss-Bonnet ($\sqrt{\lvert\alpha_{\rm EdGB}\rvert}$ [km])	Equiv. Princ.	—	10^7, 2
scalar-tensor ($\lvert\dot{\phi}\rvert$ [1/sec])	Equiv. Princ.	—	10^{-6}
dynamical Chern-Simons ($\sqrt{\lvert\alpha_{\rm dCS}\rvert}$ [km])	Parity Inv.	—	10^8

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Einstein-Æther (c_+, c_-)	Lorentz Inv.	$(\mathbf{0.9}, \mathbf{2.1})$	$(0.03, 0.003)$
RS-II Braneworld (ℓ [μm])	4D	$\mathbf{5.4 \times 10^{10}}$	10–10^3
time-varying G ($\lvert\dot{G}\rvert/G$ [10^{-12}/yr])	Equiv. Princ.	$\mathbf{5.4 \times 10^{18}}$	0.1–1

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graviton dispersion relation: $E^2 = (p\ c)^2 + A\ (p\ c)^\alpha$

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Theoretical Constraints

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Example Theories (Theoretical Parameters)	GR Pillar	Example Theory Constraints: GW150914	Example Theory Constraints: Others
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time-varying G ($\lvert\dot{G}\rvert/G$ [10^{-12}/yr])	Equiv. Princ.	$\mathbf{5.4 \times 10^{18}}$	0.1–1
Massive Gravity (m_g [eV])	$m_g = 0$	10^{-22}	10^{-29}–10^{-18}
Modified Special Rel. ($\eta_{\rm dsrt}/L_{\rm Pl} > 0$)	Lorentz Inv.	$\mathbf{1.3 \times 10^{22}}$	—
Modified Special Rel. ($\eta_{\rm dsrt}/L_{\rm Pl} < 0$)			2.1×10^{-7}

graviton dispersion relation: $E^2 = (p\ c)^2 + A\ (p\ c)^\alpha$

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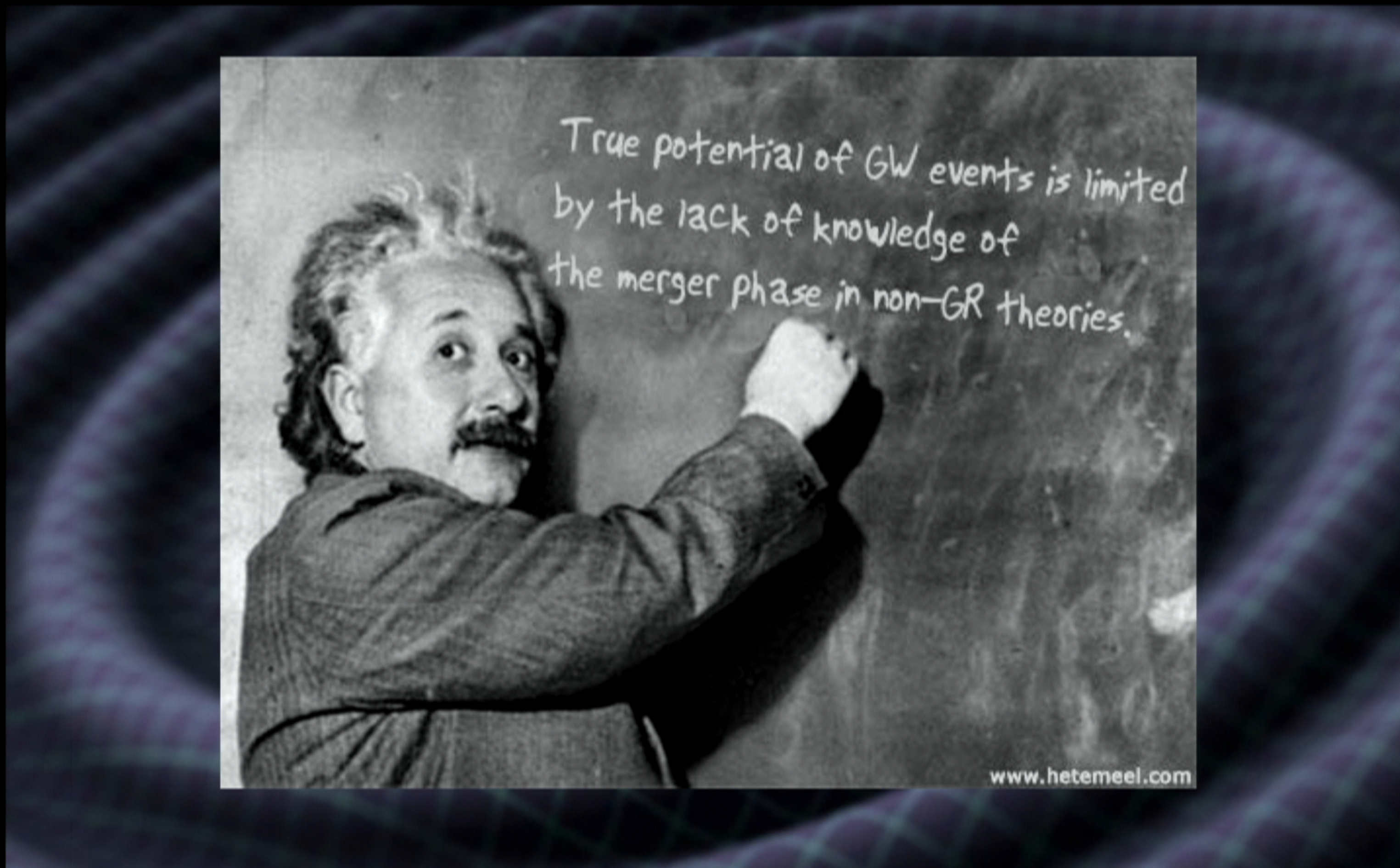
Important Message



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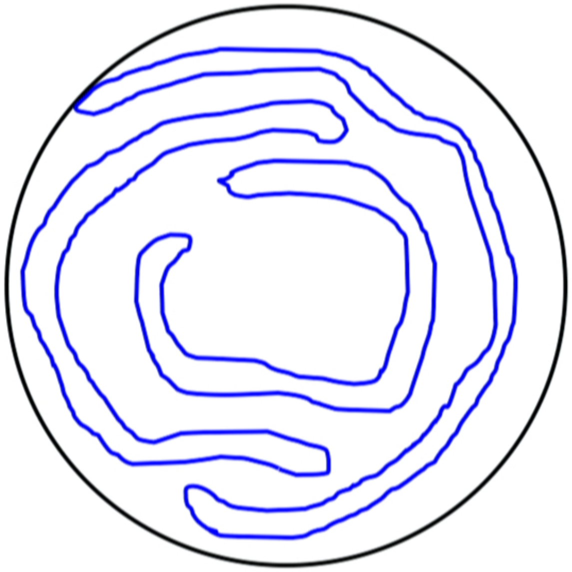
Collapsed Polymers

[Brustein & Medved (2016)]

[see Brustein's Talk on Friday]

BH interior filled with long, closed, excited, interacting strings



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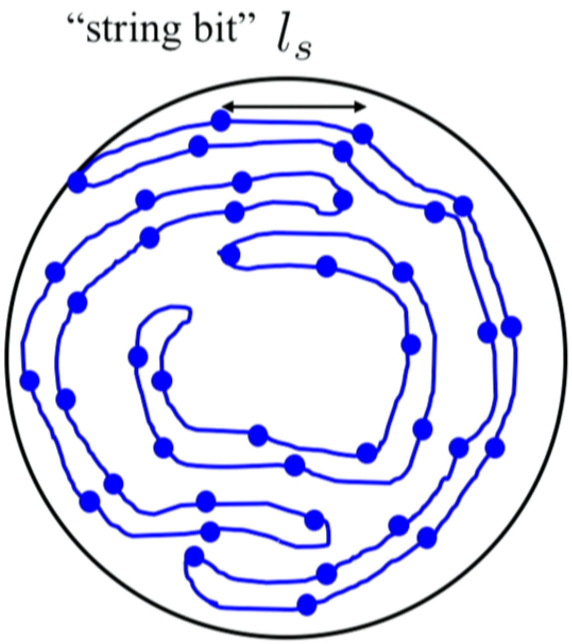

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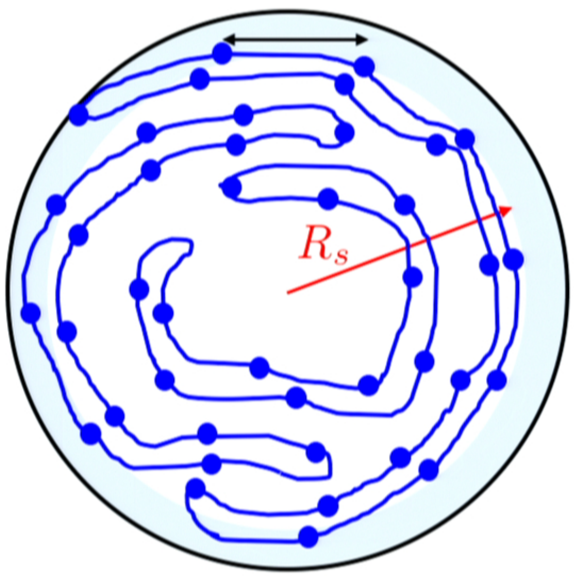

BH interior filled with long, closed, excited, interacting strings

"string bit" ⟷ monomer

long string ⟷ polymer

Planck length

Coupling constant: $g_s = \frac{l_p}{l_s}$

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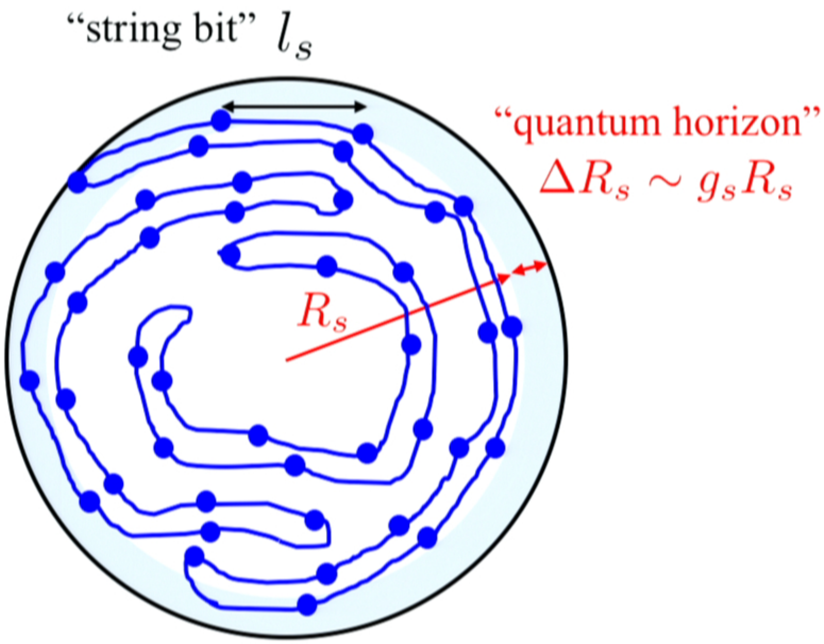

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Planck length

Coupling constant: $g_s = \dfrac{l_p}{l_s}$

e.g. grand unification between gravity and gauge theory:

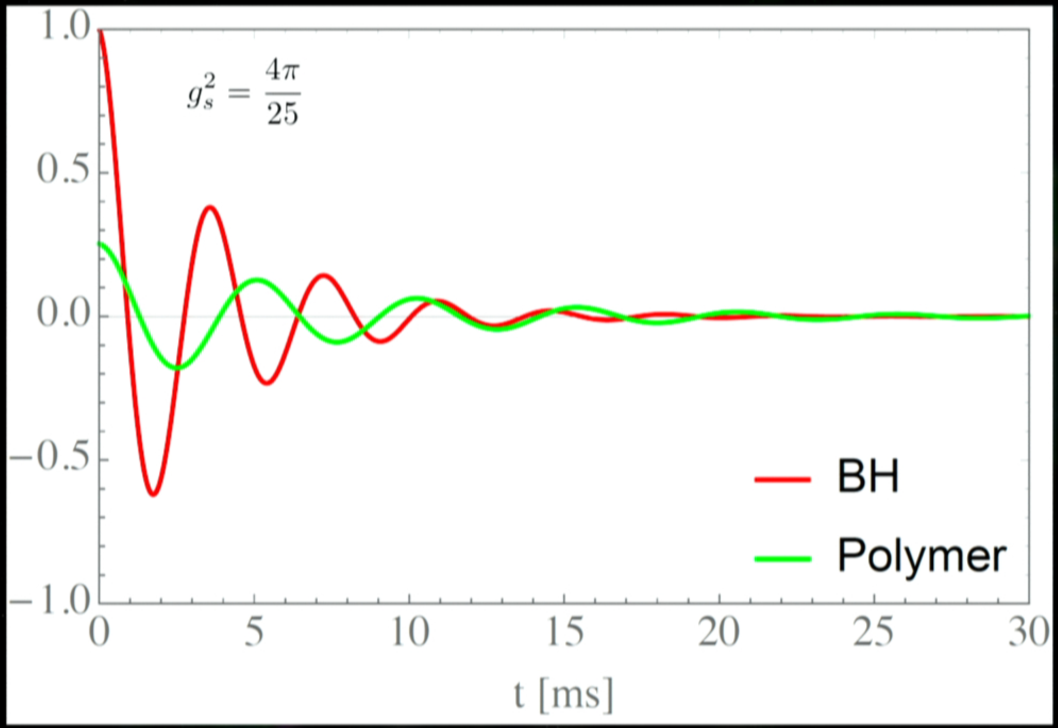
$$g_s^2 = \frac{4\pi}{25} \sim 0.5$$

Polymer Ringdown

[Brustein, Medved & KY (2017)]

$$h(t) = Ae^{-t/\tau}\cos(2\pi f t + \phi)$$

GW150914



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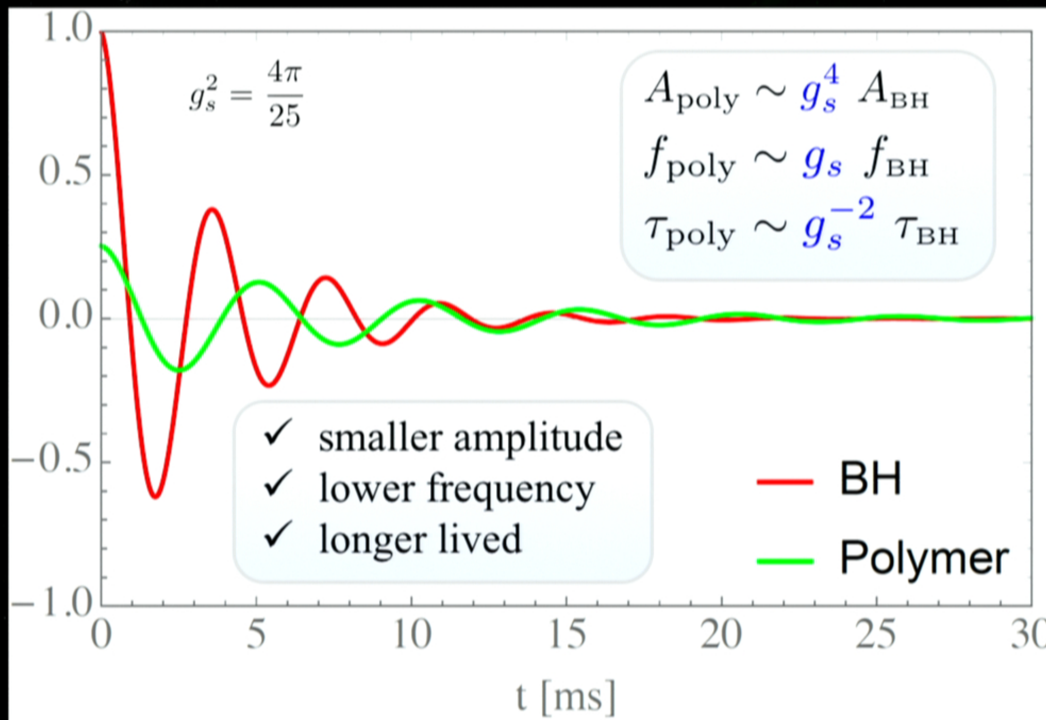

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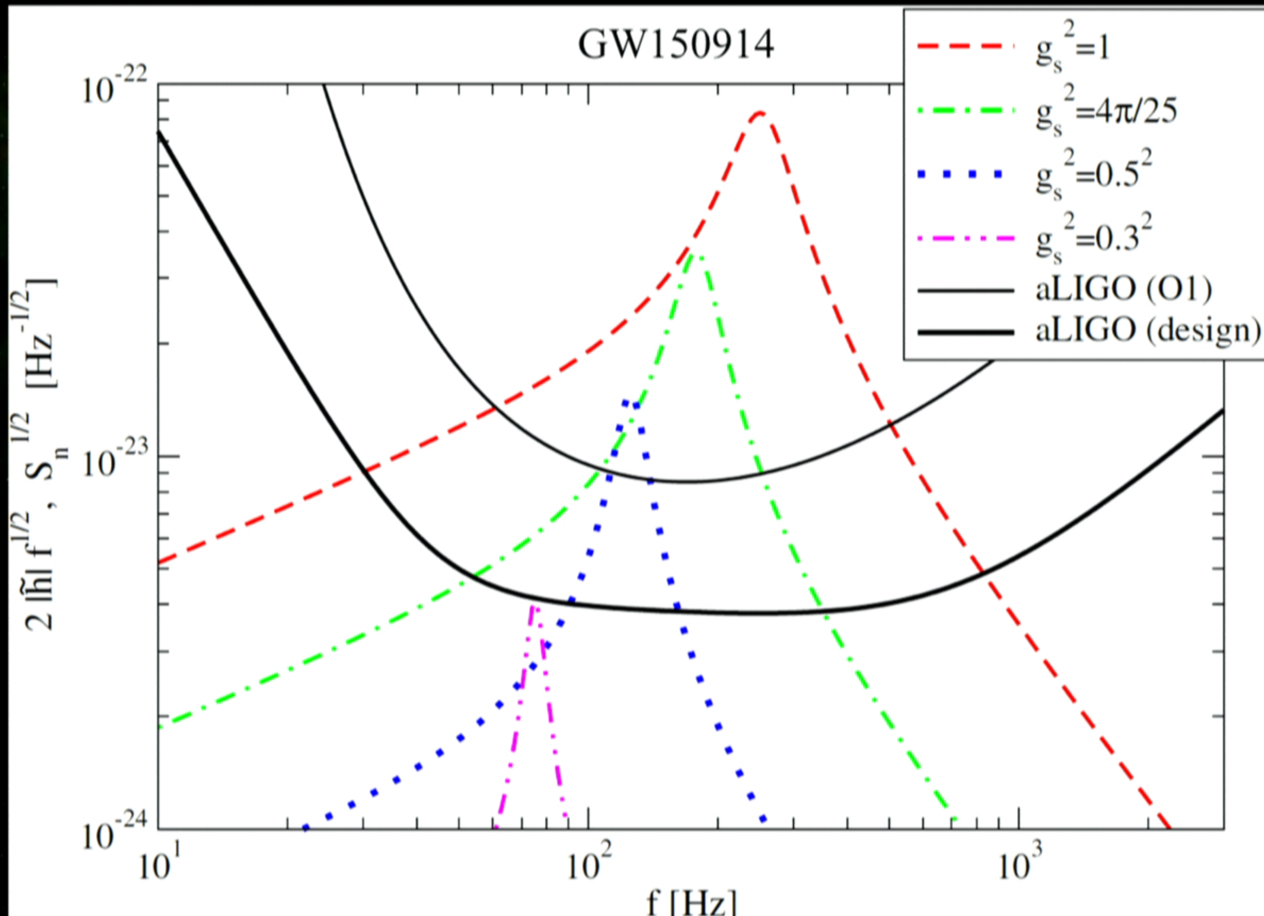
GW Spectrum

[Brustein, Medved & KY (2017)]



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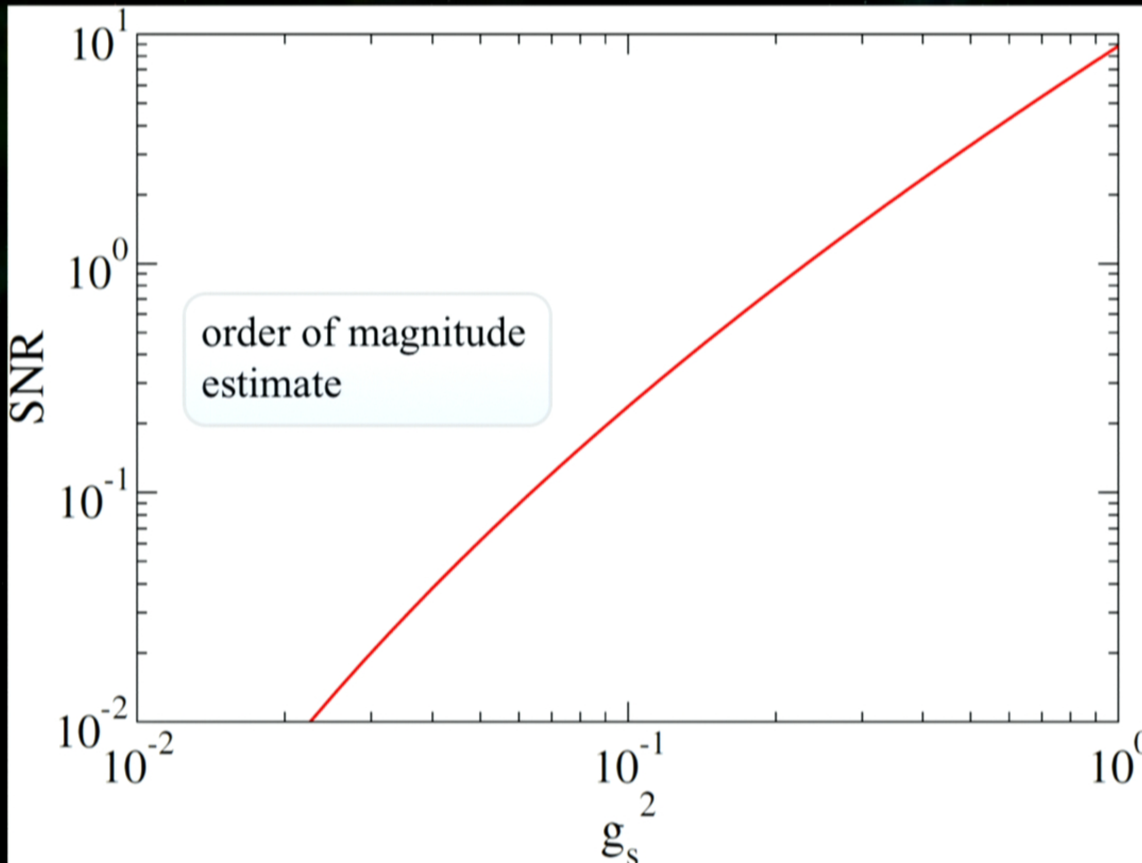
Bounds from GW150914

[Brustein, Medved & KY (2017)]



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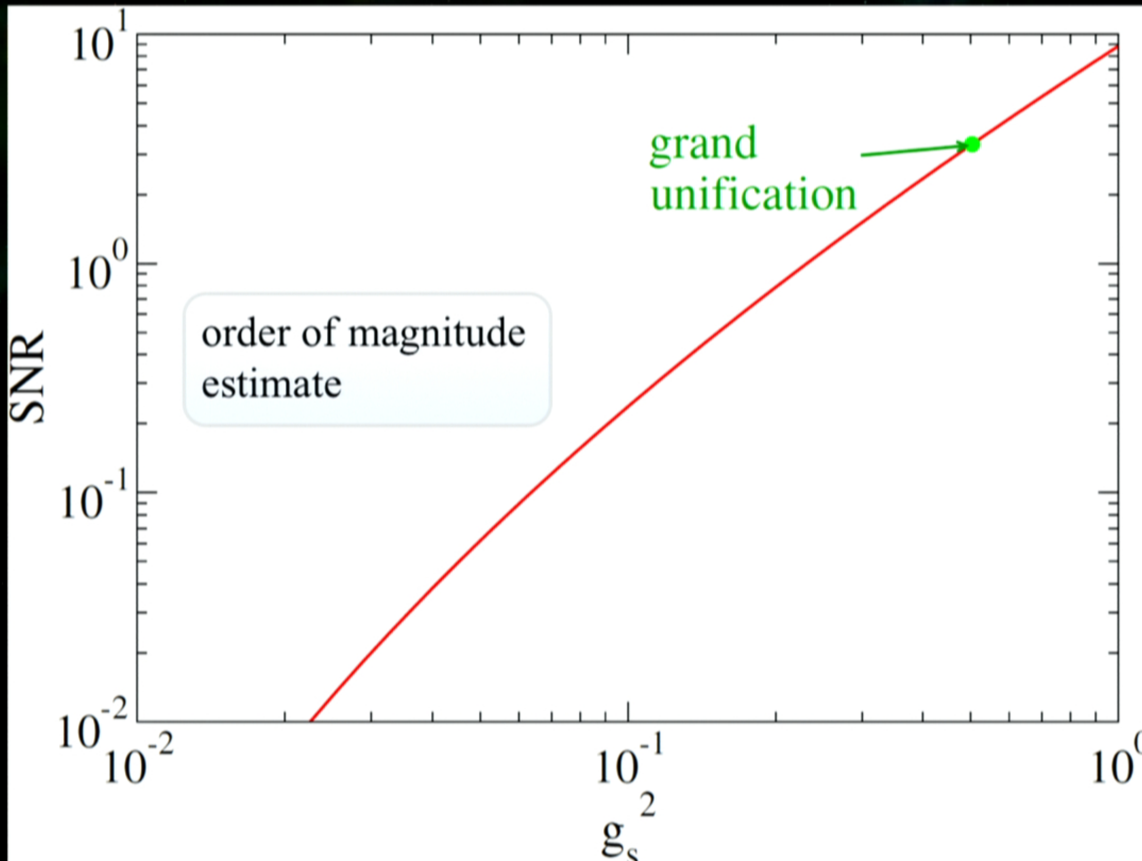

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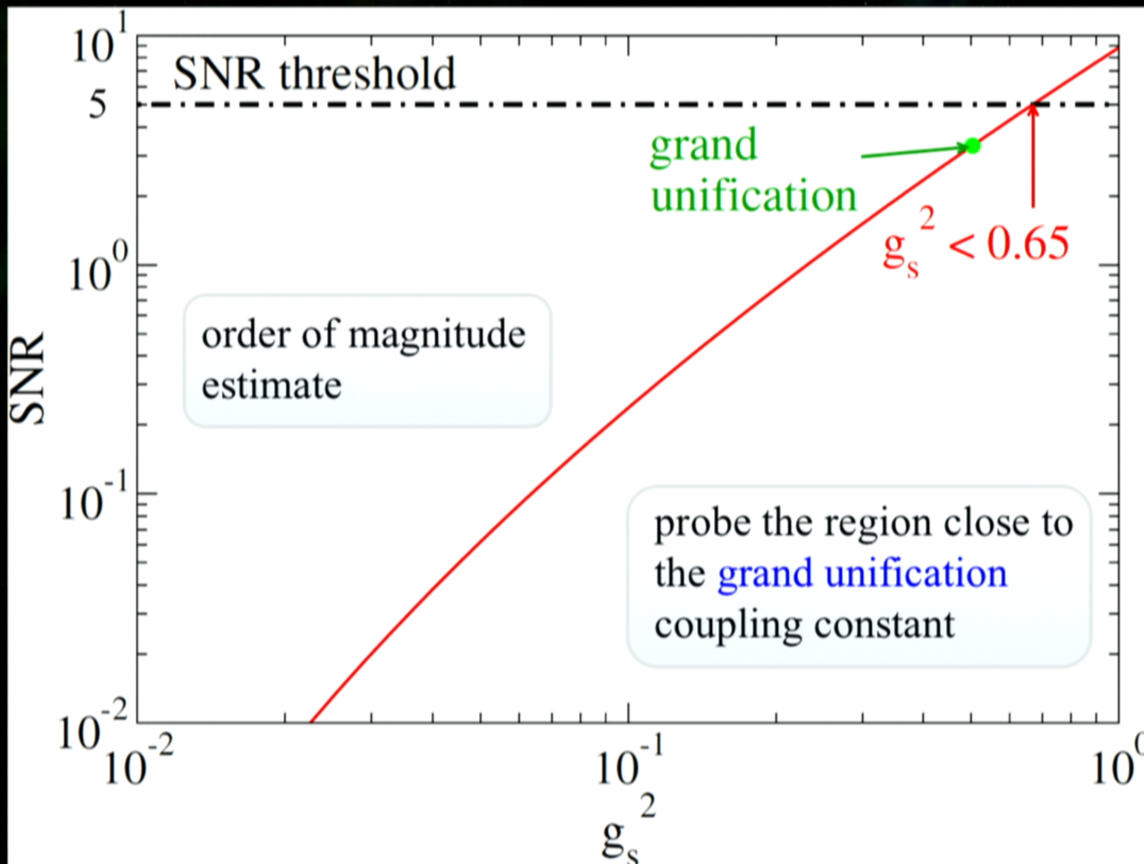

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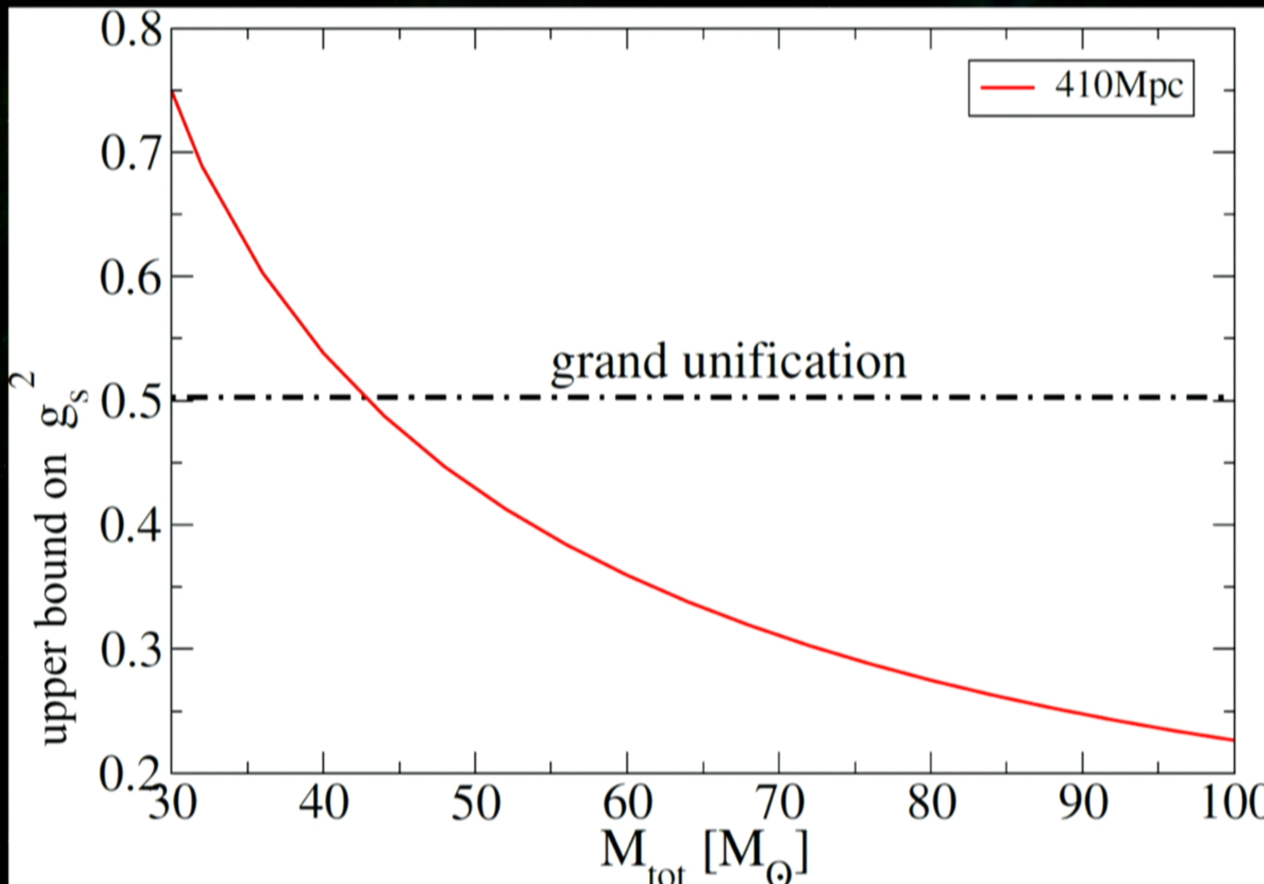
aLIGO Design Sensitivity

[Brustein, Medved & KY (2017)]



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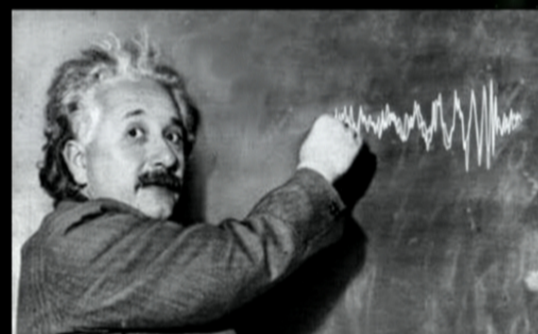
Takeaway

inspiral:
-weak bound
-first strong/dyn. gravity constraint

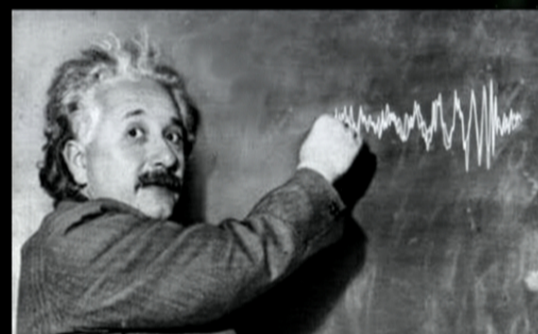


Conclusion Kent Yagi

Takeaway

inspiral:
-weak bound
-first strong/dyn. gravity constraint

ringdown:
-collapsed polymer
-grand unification coupling



- ✓ effect of Higher PN corrections
- ✓ strong-field non-GR parameterization (merger)
- ✓ use real data