# Test of Gravity with NS Mergers

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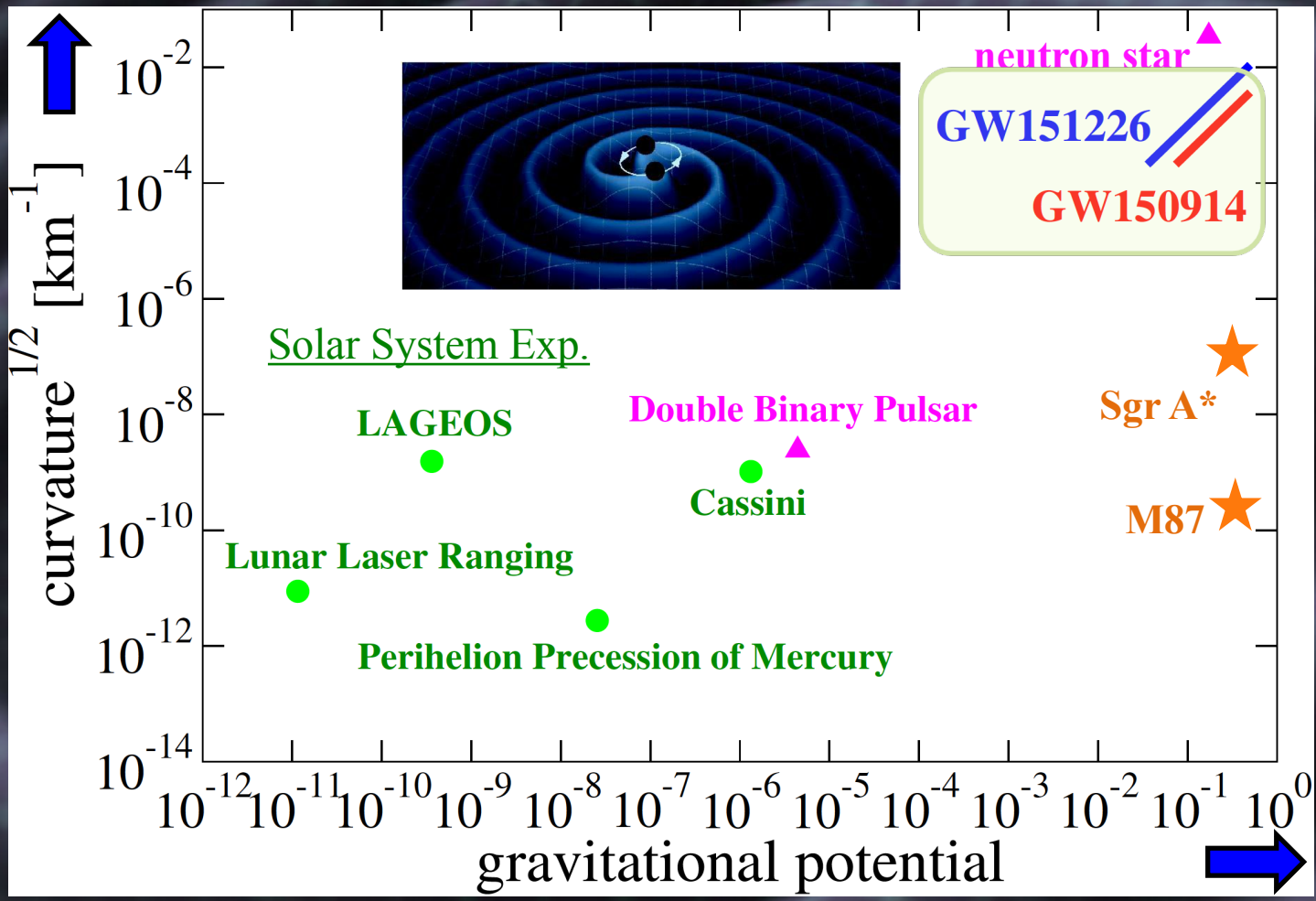
# Sources for Tests of Gravity

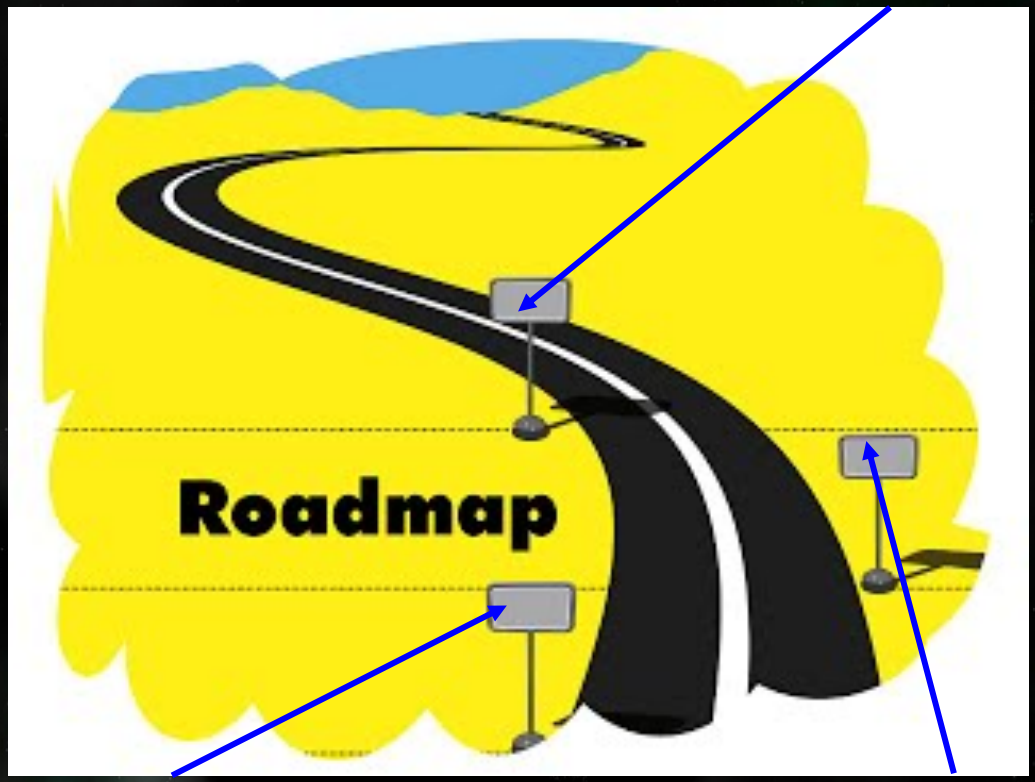
Strong & Dynamical Gravity




[Yunes, KY & Pretorius PRD (2016)]

# Roadmap

Universal Relations

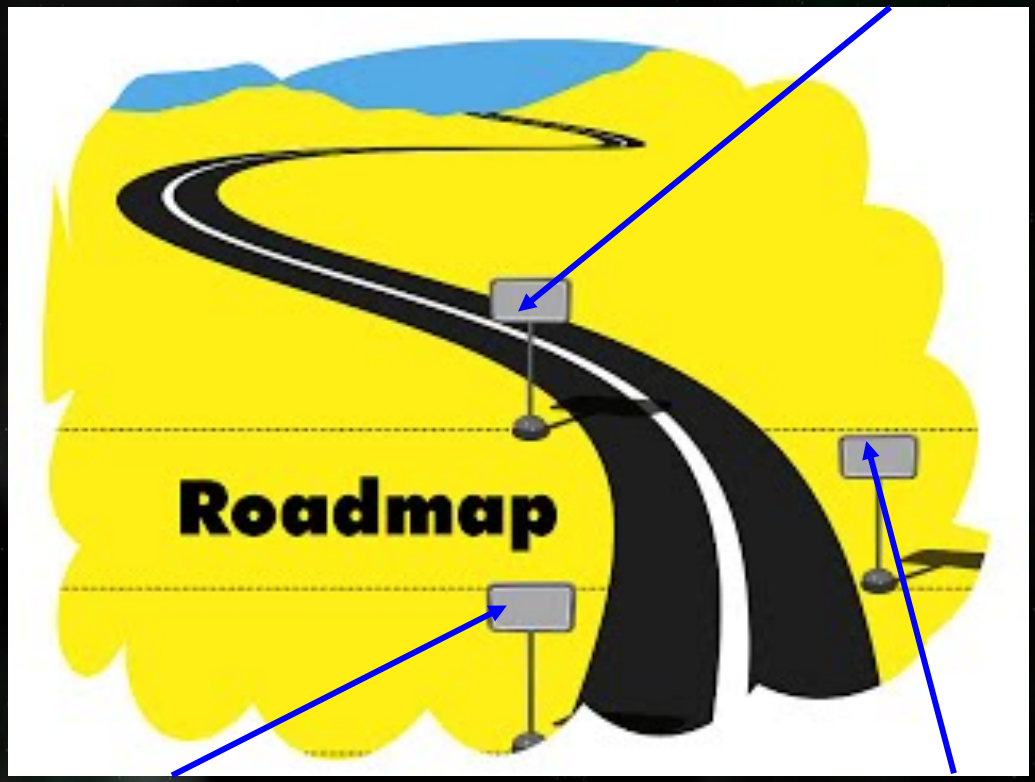



GW170817

Spontaneous/Dynamical Scalarization

# Roadmap

Universal Relations

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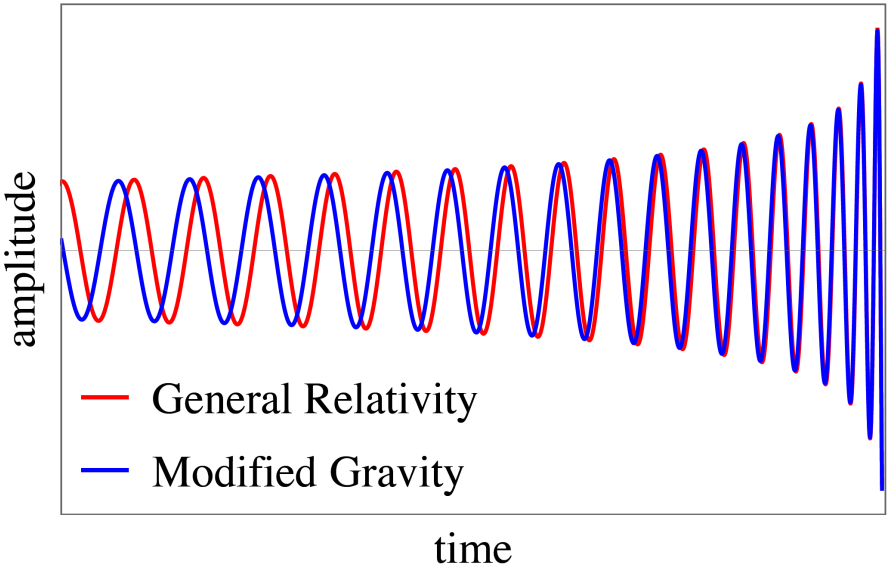
Spontaneous/Dynamical Scalarization

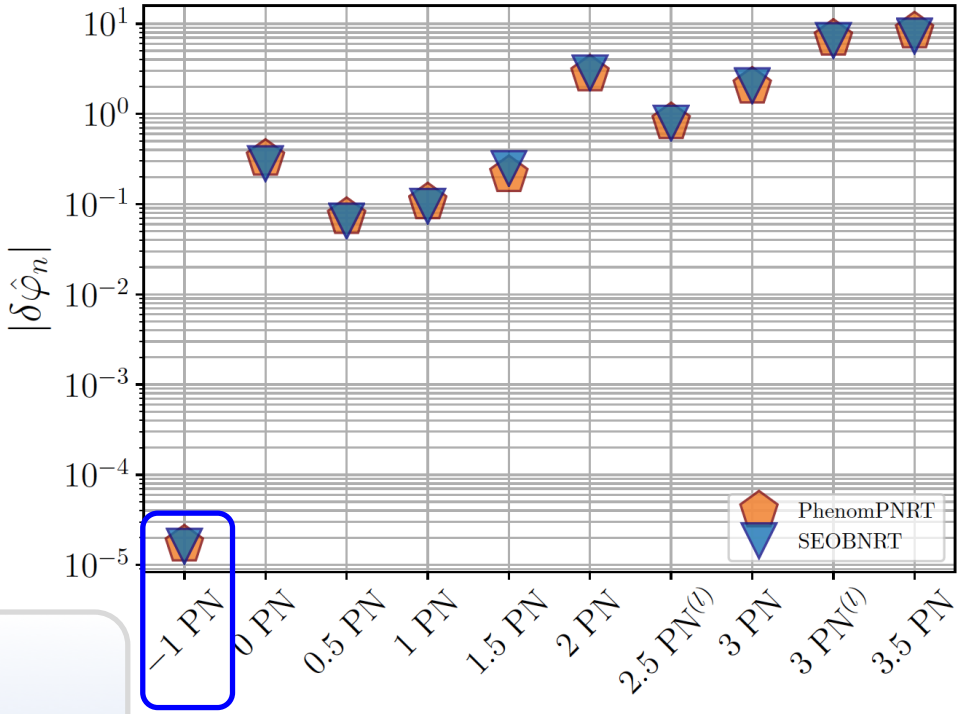
# Parameterized Tests

[Yunes & Pretorius (2009)]
[LVC, PRL 116, 221101 (2016)]

Waveform phase:

$$\Psi(f) = \frac{3}{128\eta}\sum_{k=0}^{7}\phi_k^{(\mathrm{GR})}(1+\delta\phi_k)(\pi m f)^{(k-5)/3}$$



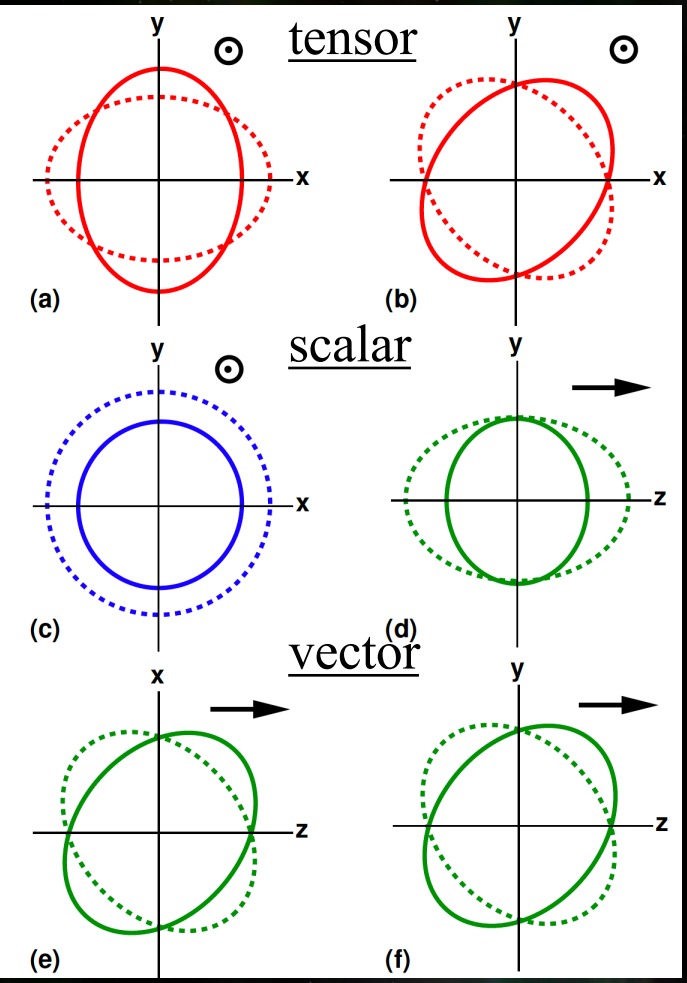

scalar dipole radiation @ -1PN

⇒ violation of strong equiv. principle

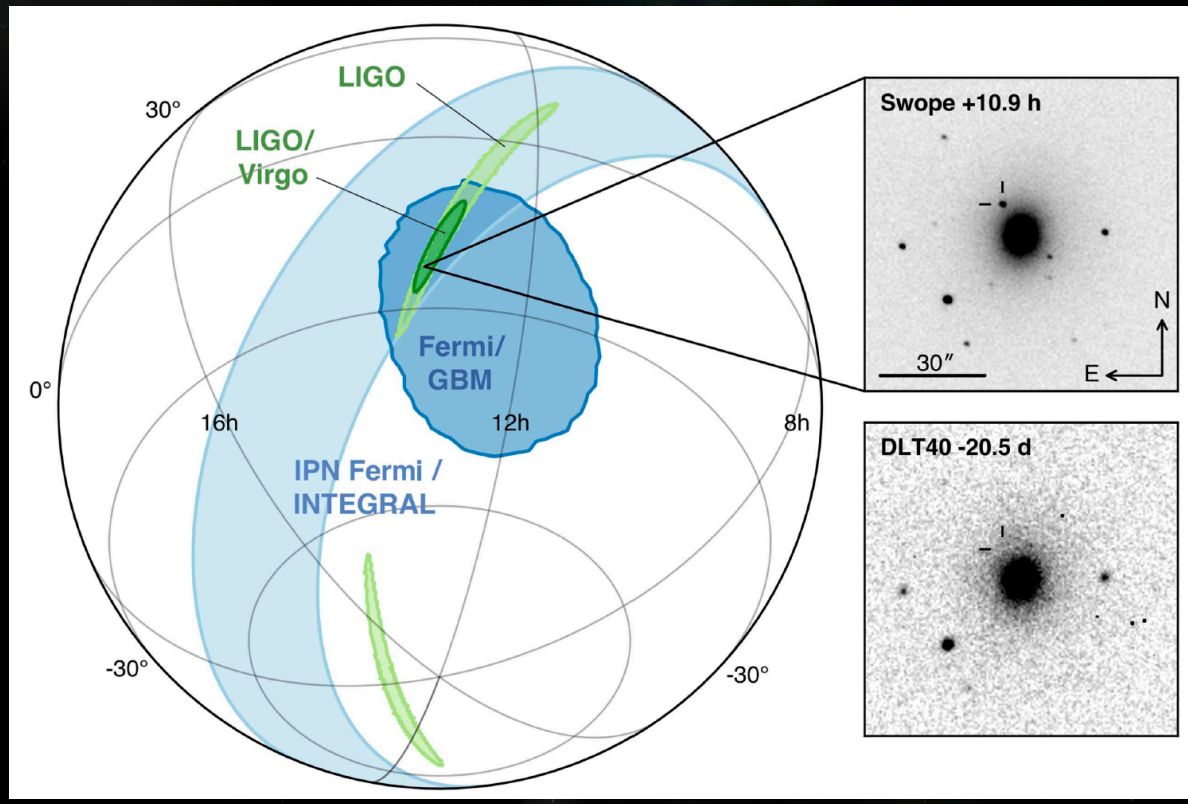
[LVC, arXiv:1811.00364]

# Polarization

[LVC, arXiv:1811.00364]




[Will (2014)]



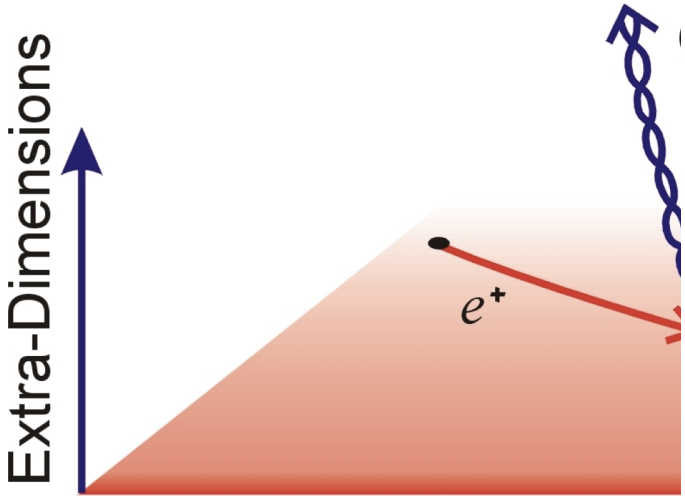

Bayesian Model Selection:

$$(\text{tensor only}) \text{ vs } (\text{scalar only}) = 10^{21} : 1$$

$$(\text{tensor only}) \text{ vs } (\text{vector only}) = 10^{23} : 1$$

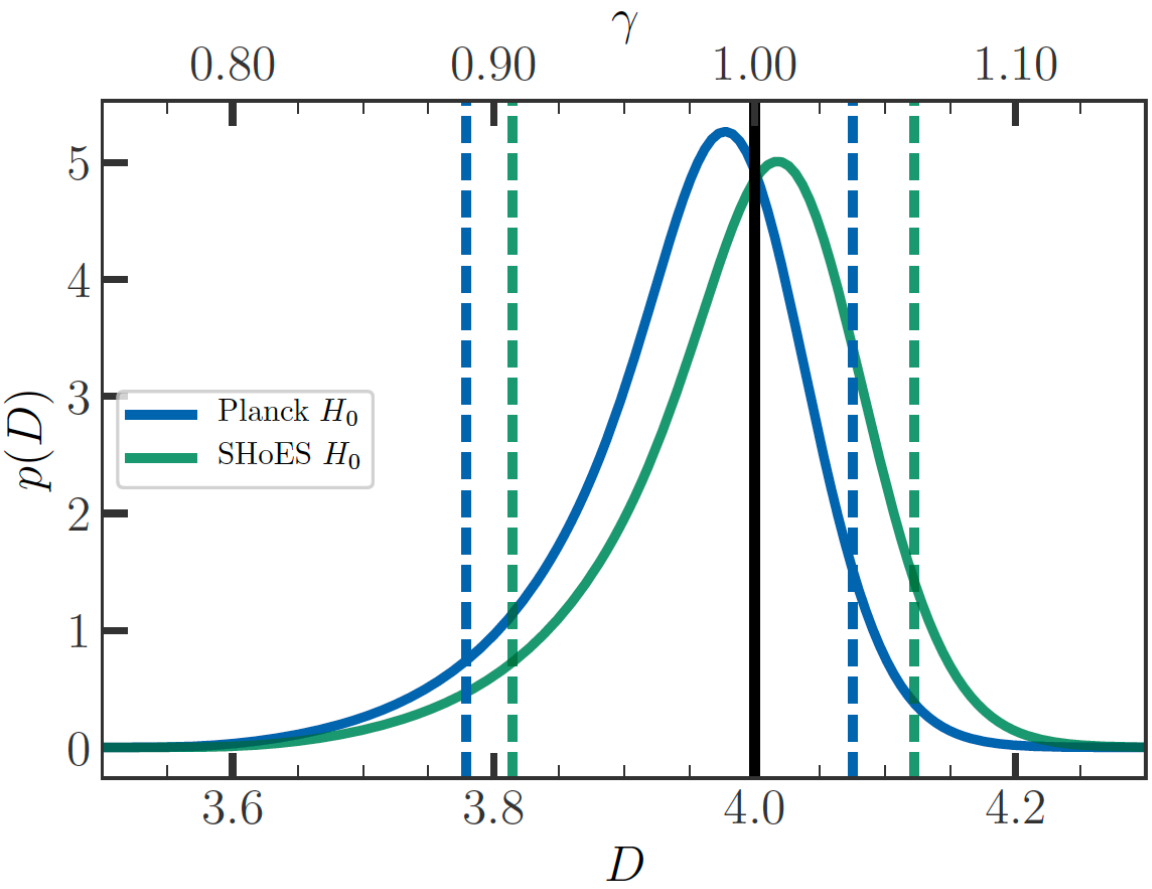
# # of Spacetime Dimension

[Pardo, Fishbach, Holz & Spergel, arXiv:1801.08160]




$$h \propto d_L^{-(D-2)/2}$$

$$\Rightarrow \quad d_L^{(\mathrm{GW})} \neq d_L^{(\mathrm{EM})}$$



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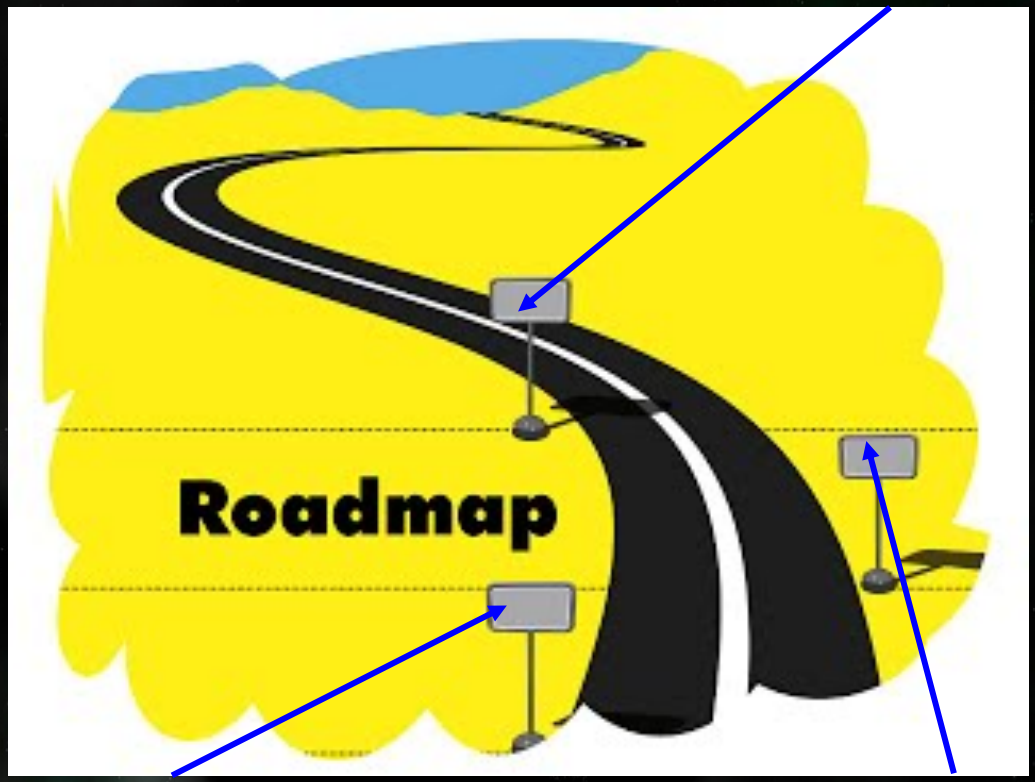



GW170817

Spontaneous/Dynamical Scalarization

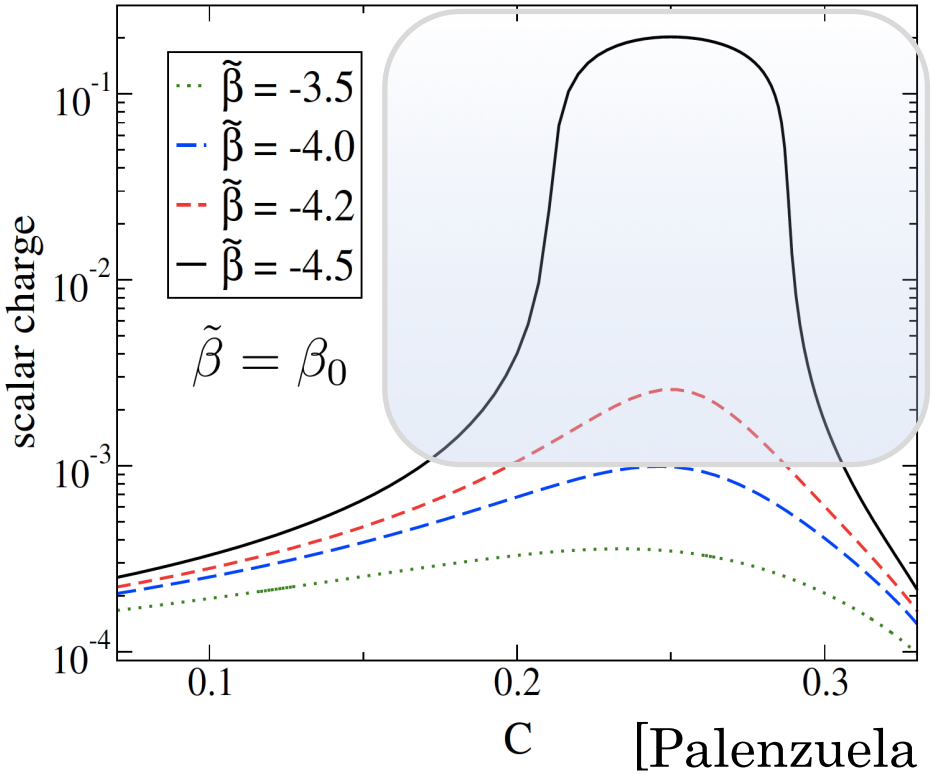
# Spontaneous Scalarization

[Damour & Esposito-Farese (1992, 1993)]

scalar-tensor theories $(g_{\mu\nu}, \phi)$

$(\alpha_0, \beta_0)$ coupling between the scalar field and matter

controls neutron star scalarization




spontaneous scalarization

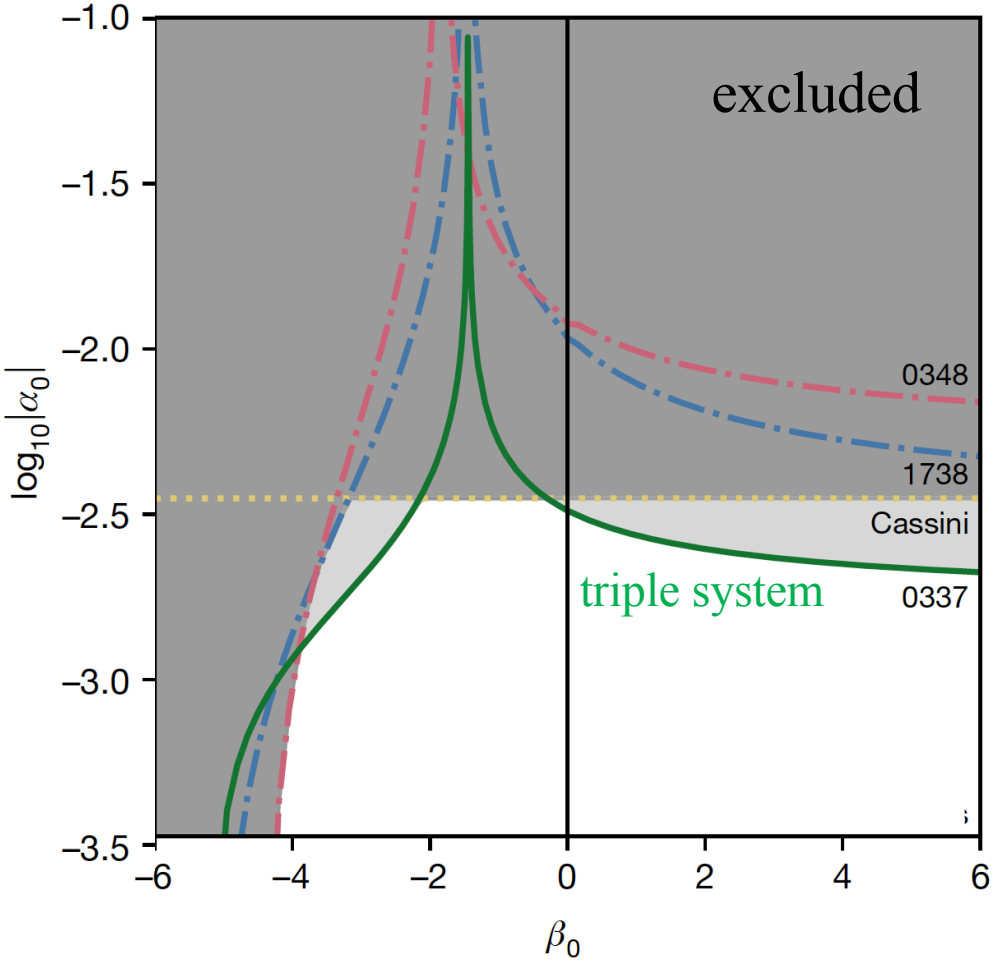
(nonlinear growth of the scalar field)

[Palenzuela et al. arXiv:1310.4481]

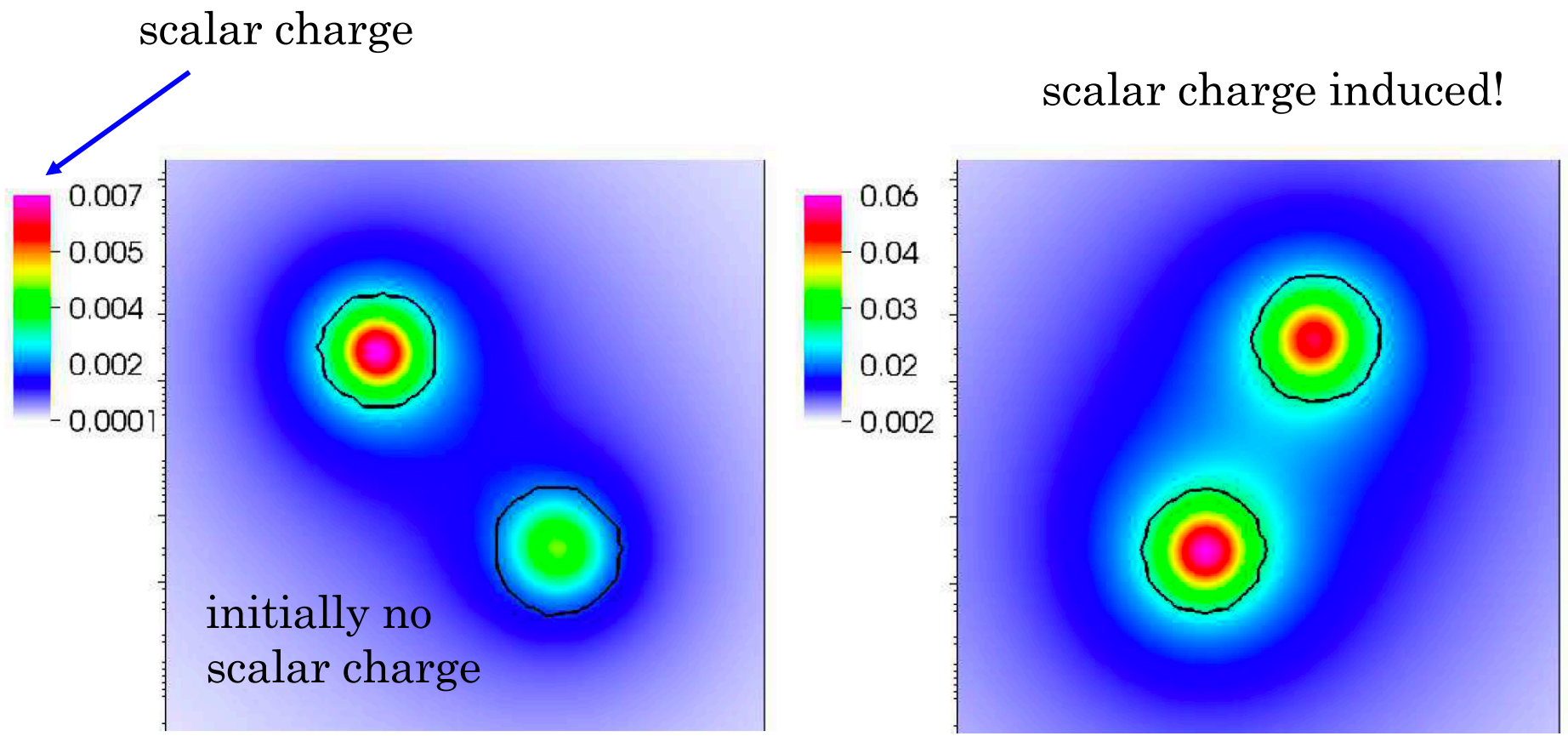
# Existing Bounds

[Archibald et al. (2018)]

scalar charge ⇒ scalar dipole radiation



# Induced / Dynamical Scalarization




[Barausse et al. arXiv:1212.5053]

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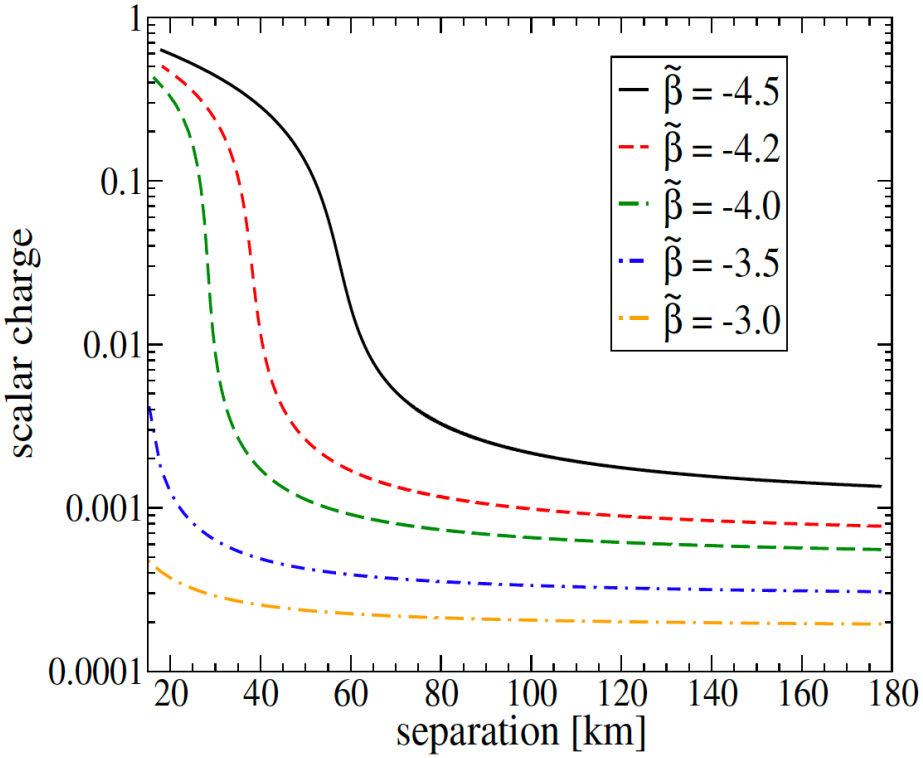


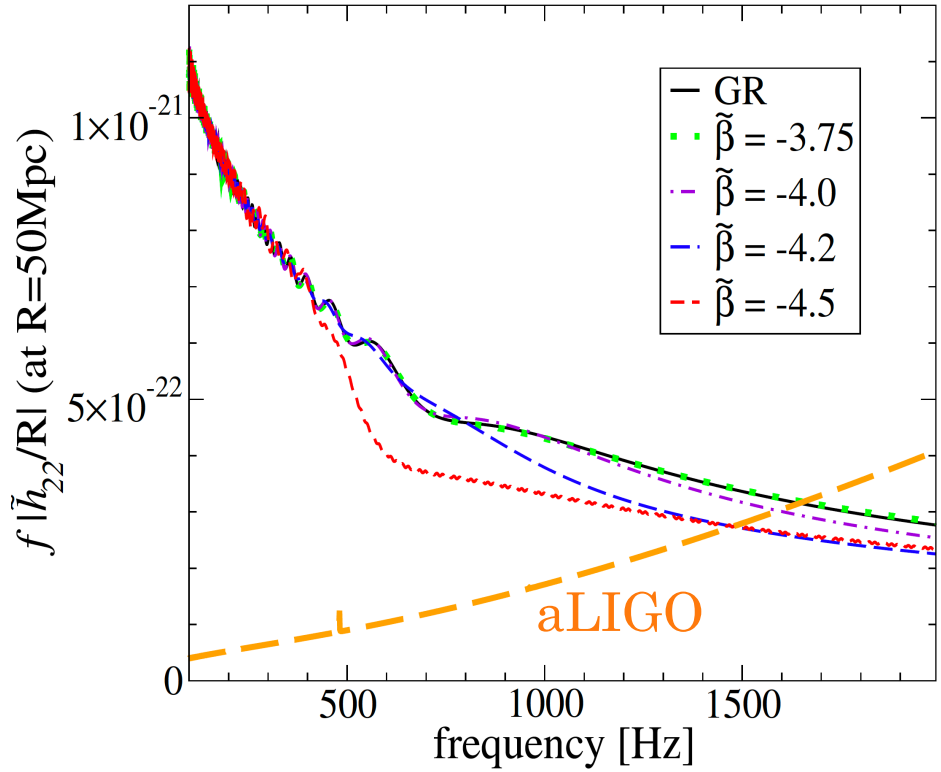


Phenomenon cannot be probed by binary pulsars!

[Palenzuela et al. arXiv:1310.4481]

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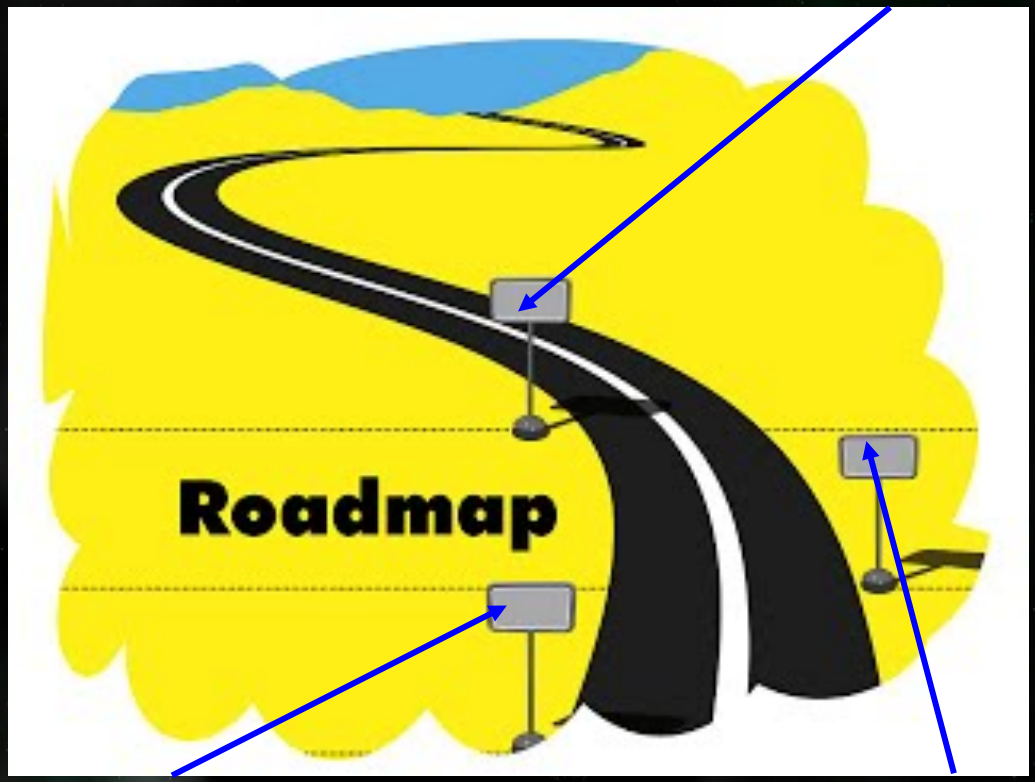



GW170817

Spontaneous/Dynamical Scalarization

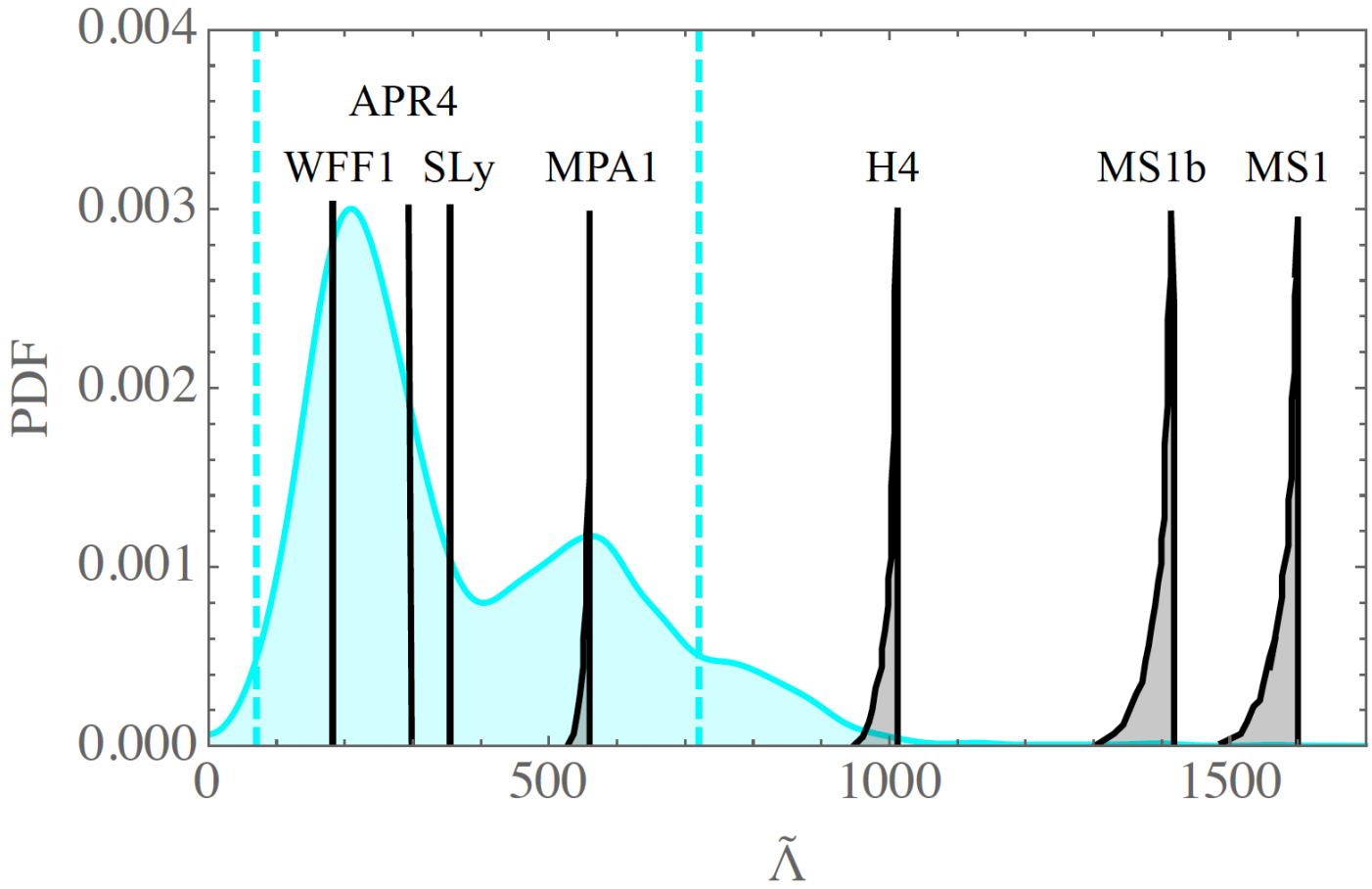
# Tidal Measurement by LVC

Leading tidal parameter in the waveform: [LVC, arXiv:1805.11579]

$$\tilde{\Lambda} = \frac{16}{13}\frac{(1+12q)\Lambda_1 + (12+q)q^4\Lambda_2}{(1+q)^5},$$

tidal measurement can also be used to probe gravity

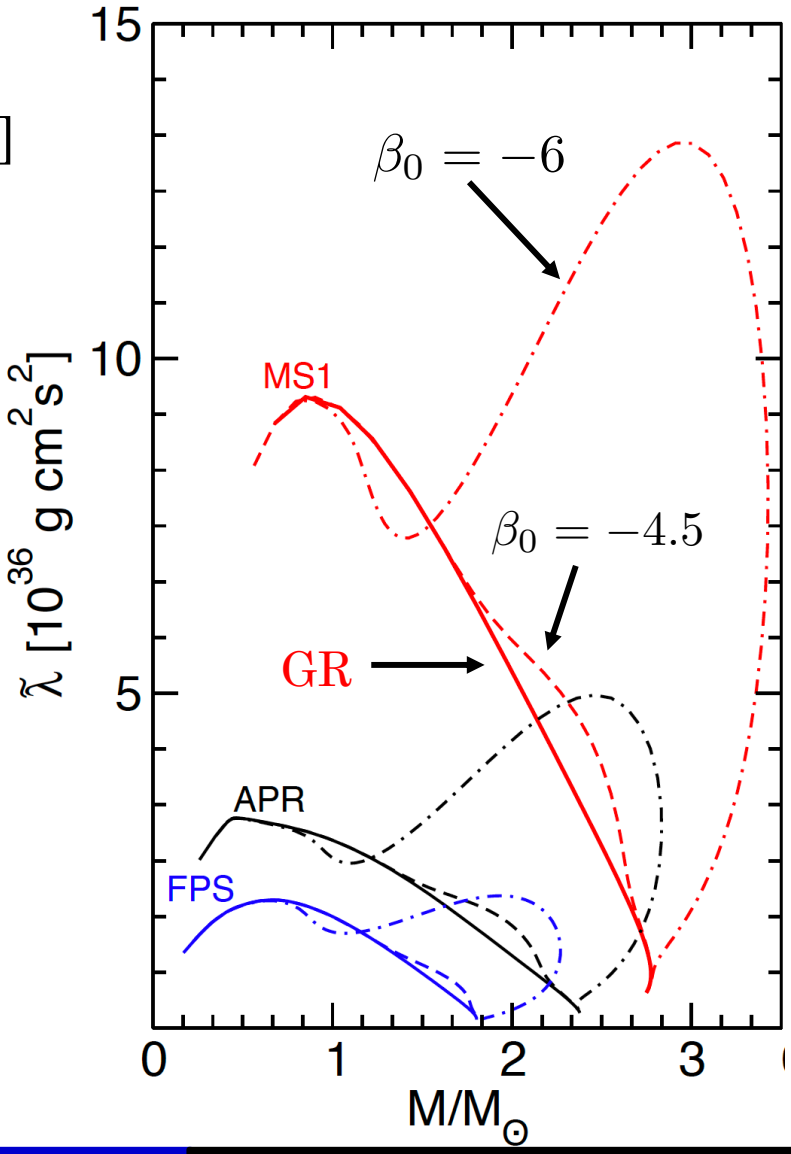
$q = m_1/m_2$



# Love numbers in non-GR Theories

scalar-tensor theories

[Pani & Berti arXiv:1405.4547]

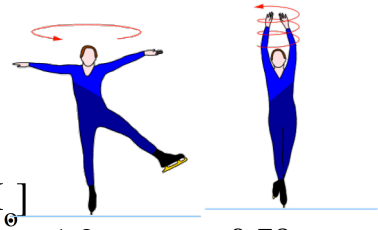



EoS vs non-GR…

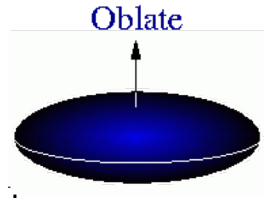
# I-Love-Q Relations!

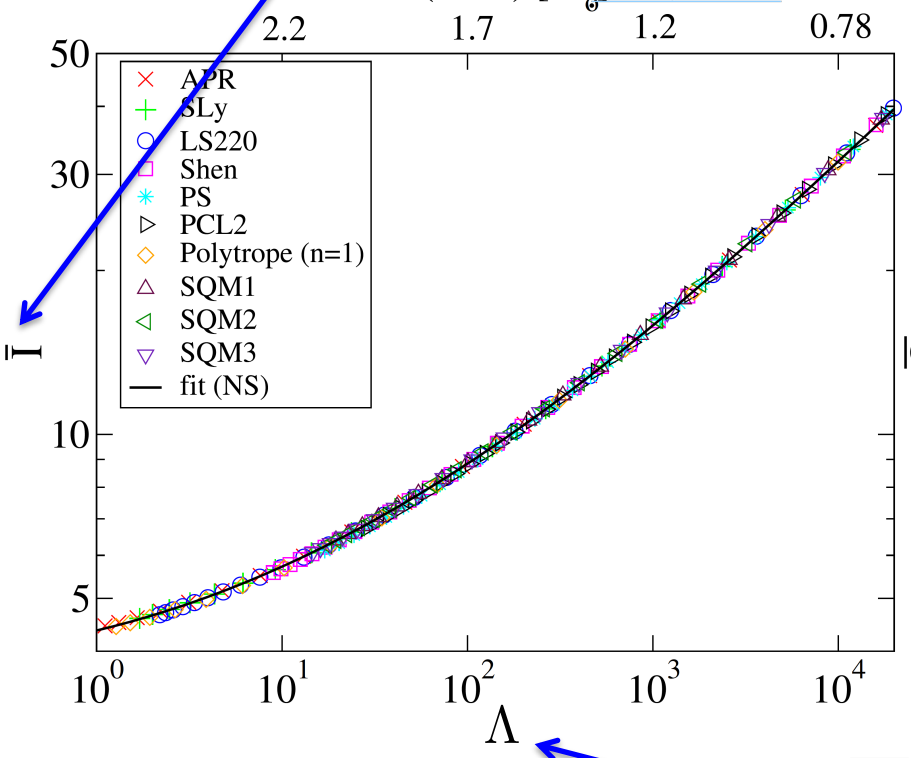
[KY & Yunes arXiv:1302.4499]
[KY & Yunes arXiv:1303.1528]

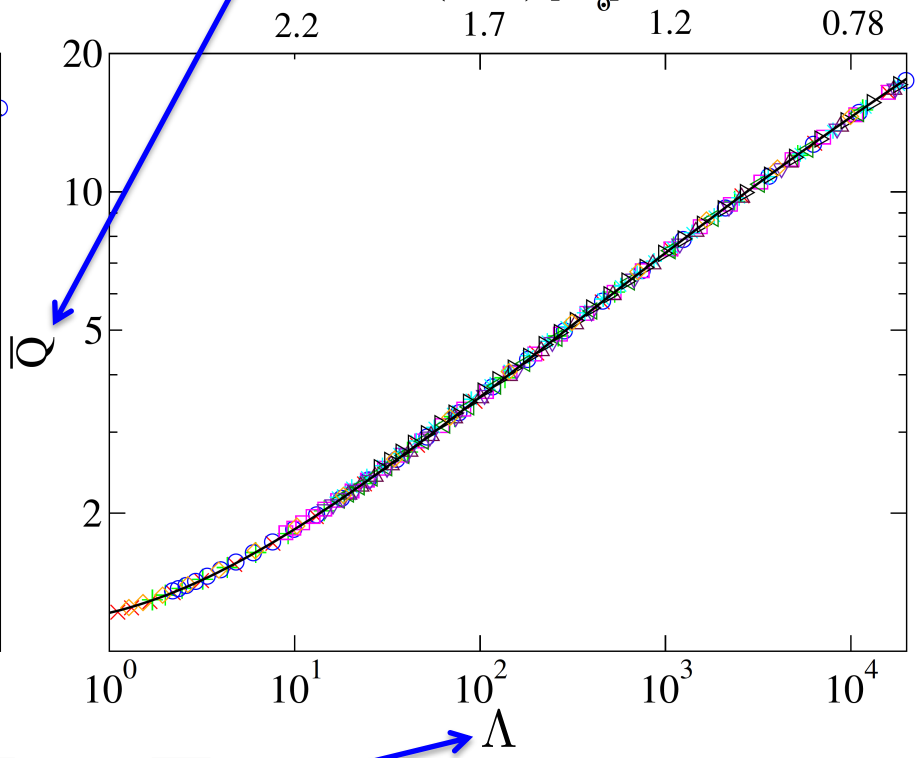
moment of inertia



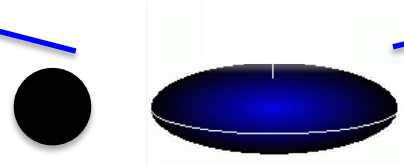
(spin-induced)
quadrupole moment



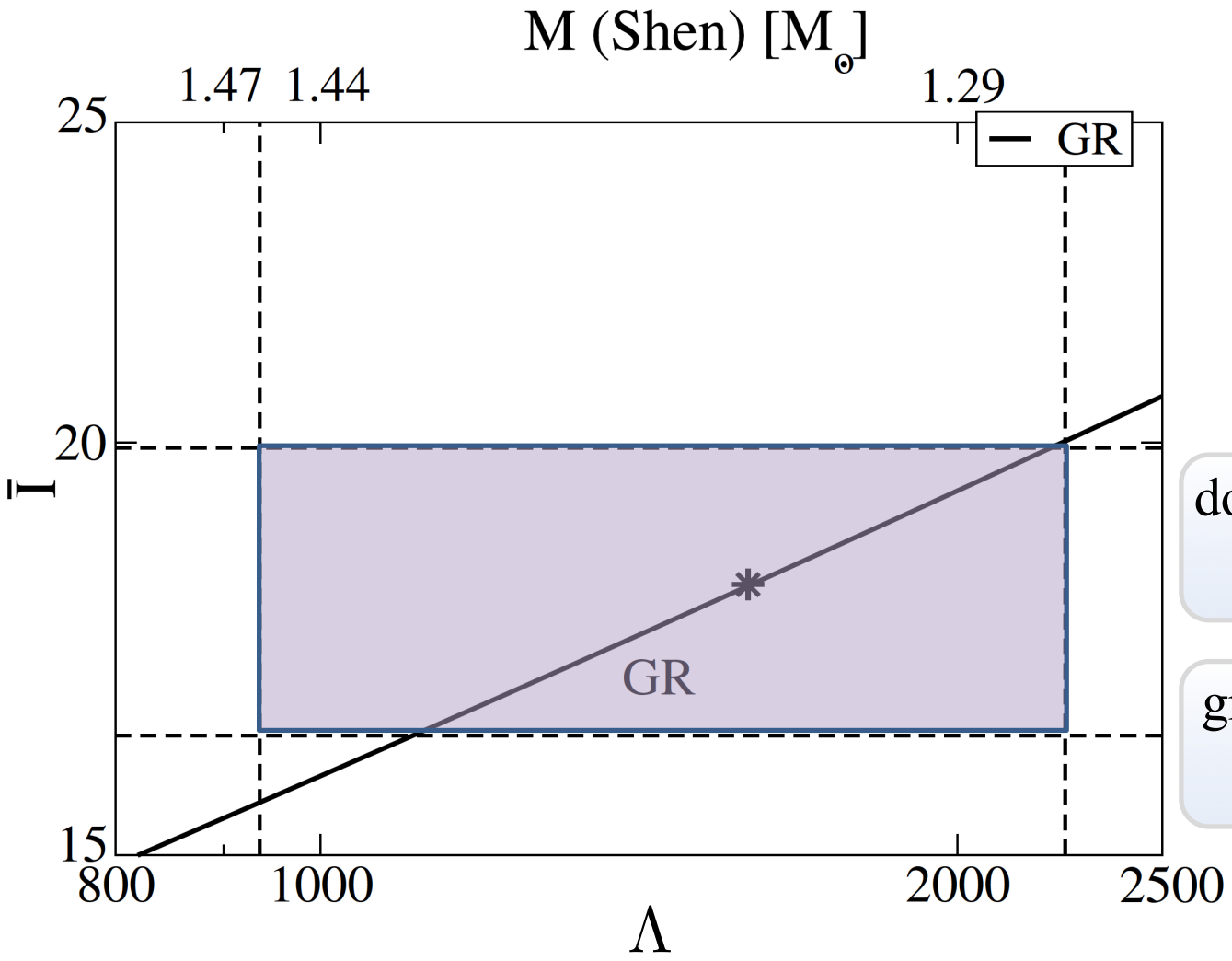



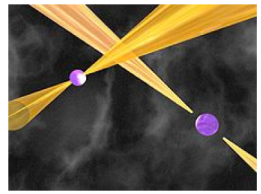

tidal Love number
(tidal deformability)



# Strong Gravity Tests

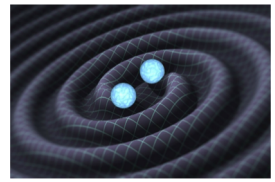
[KY & Yunes arXiv:1302.4499]
[KY & Yunes arXiv:1303.1528]



double pulsar binary
$\Delta\bar{I}/\bar{I} = 10\%$

gravitational waves
$\Delta\Lambda/\Lambda = 40\%$



# Strong Gravity Tests

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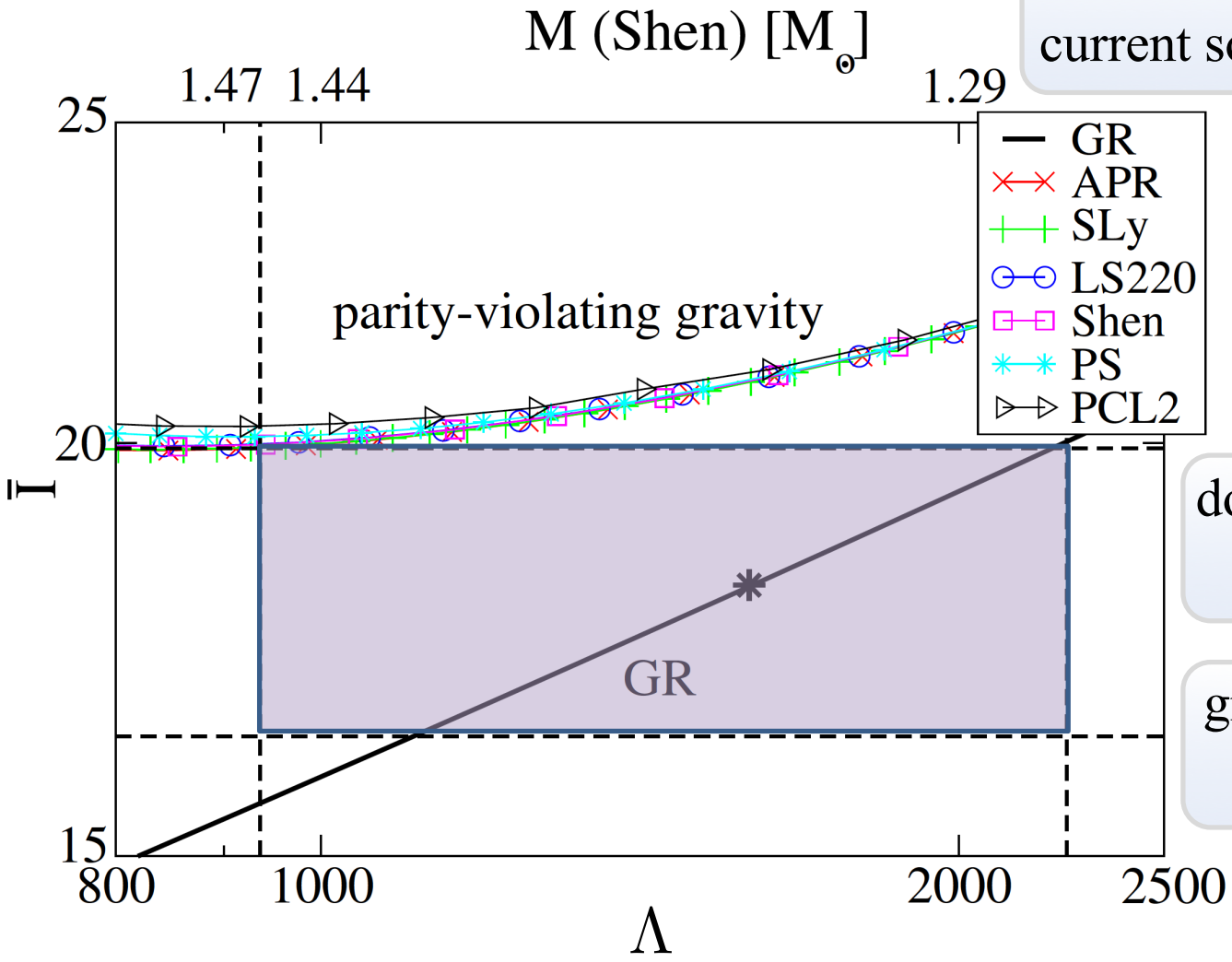
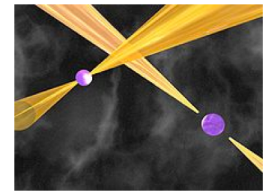
$10^6$ times stronger than the current solar system bound!



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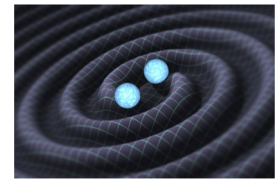
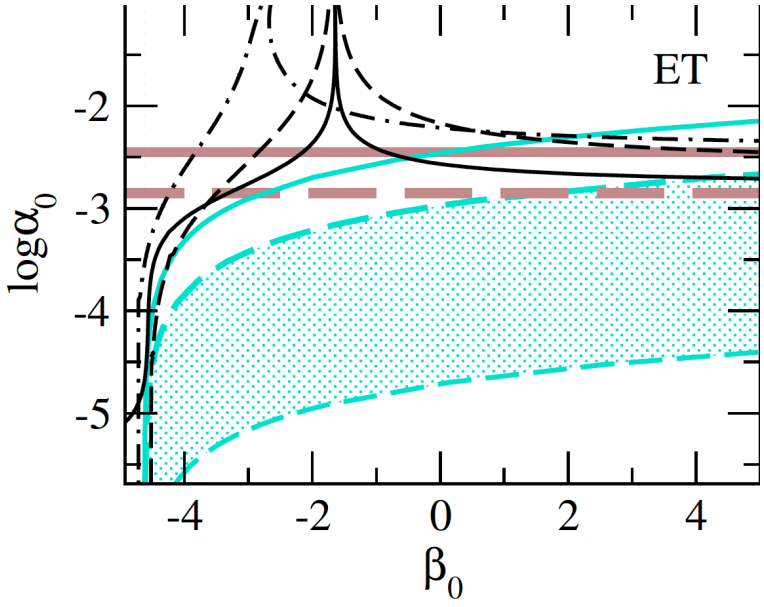
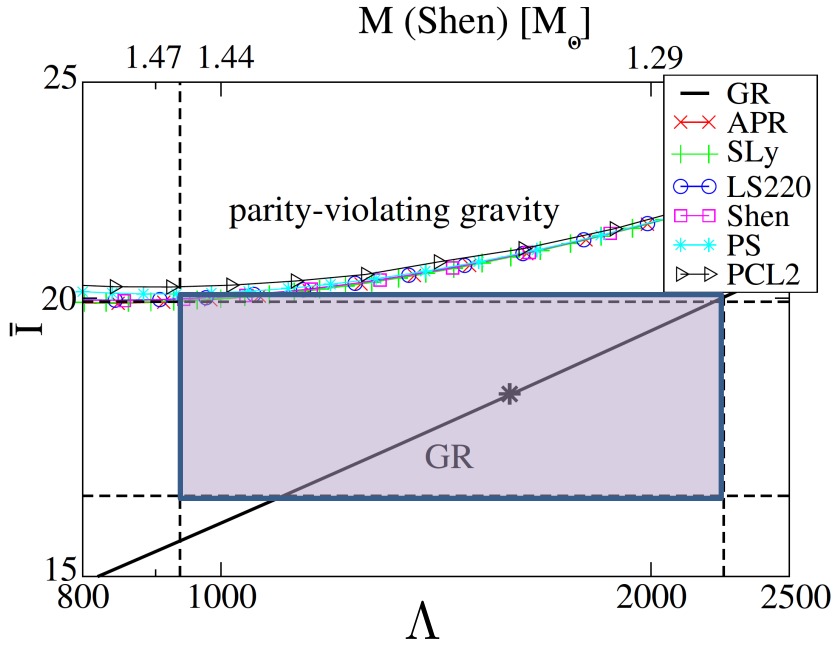


# Conclusions

# Takeaway




- ✓ GW170817 places stringent bounds on
  1. scalar dipole radiation
  2. non-GR polarizations
  3. # of spacetime dimension




- ✓ stringent bounds on scalar-tensor theories expected with future detectors
- ✓ universal relations can break degeneracies between uncertainties in nuclear physics and grav. physics

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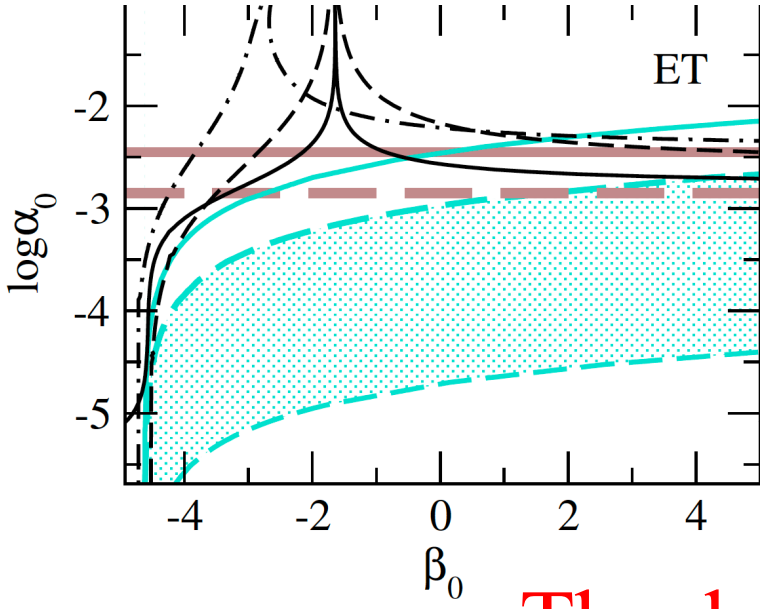


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Thank You!

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