What can we learn about Theoretical Physics with Future Gravitational Wave Detections?

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eXtreme Gravity Institute
Montana State University

GC2018,
Yukawa Institute for Theoretical Physics
March 2nd, 2018

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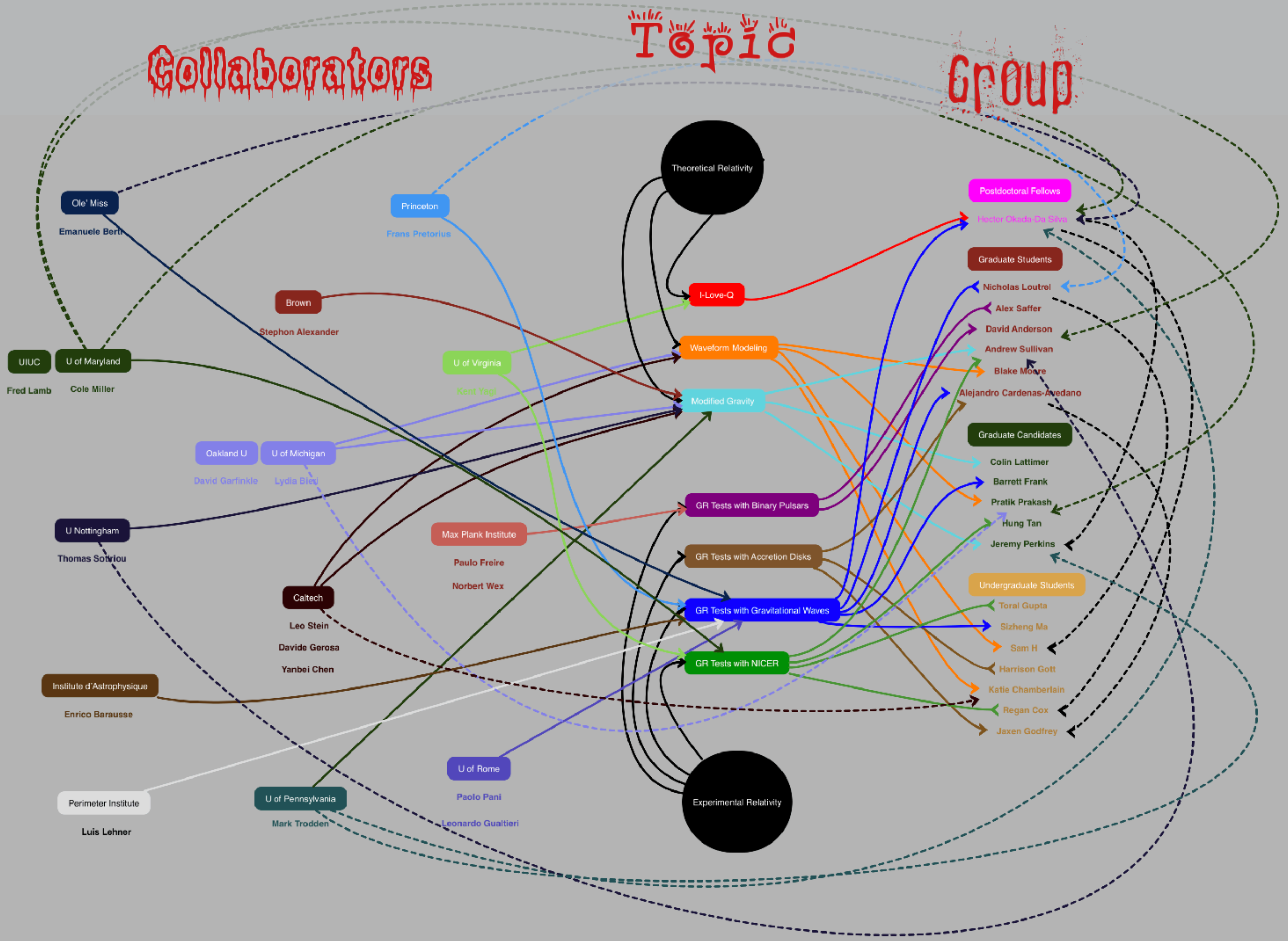
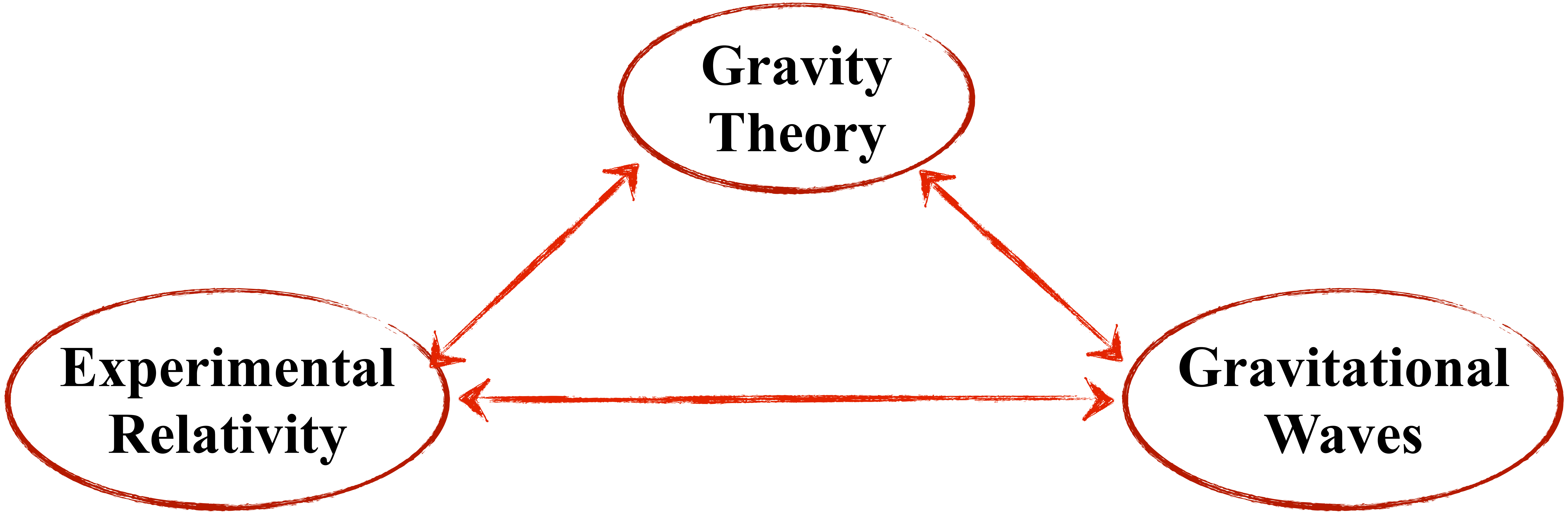
Nico’s Adinkra



Nico’s Adinkra

Cleaning up the Adinkra

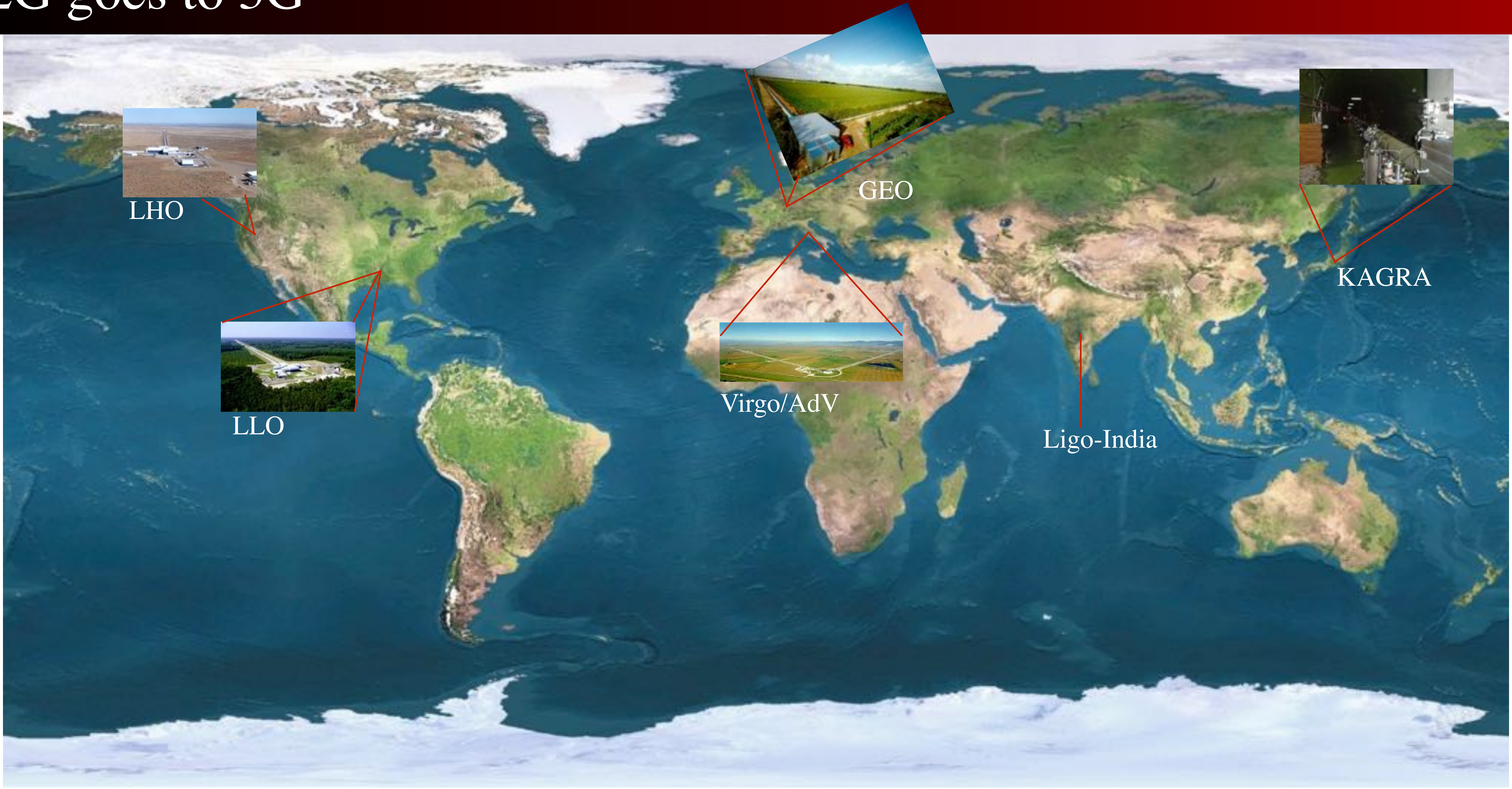


What can we learn about theoretical physics from future GW observations?

Roadmap


3G Physics
Multi-Band
I-Love-Q
Frodo and Sam
ARNOR
ARTHEDAIN
NORTH DOWNS
FORLINDON
RHUDAUR
SOUTH DOWNS
CARDOLAN
ERIADOR
HARLINDON
MINHIRIATH
ENEDWAITH
DUNLAND
MIRKWOOD
IRON HILLS
RHÛN
The SEA of RHÛN
The BROWN LANDS
THE WOLD
ROHAN
ERED NIMRAIS
GONDOR
MORDOR
BELEGAER
(the Great Sea)

2G goes to 3G



3G Detectors

The Parameterized post-Einsteinian Framework

$$\tilde{h}(f) = \tilde{h}_{GR}(f)\,(1+\alpha f^{a})\,e^{i\beta f^{b}}$$

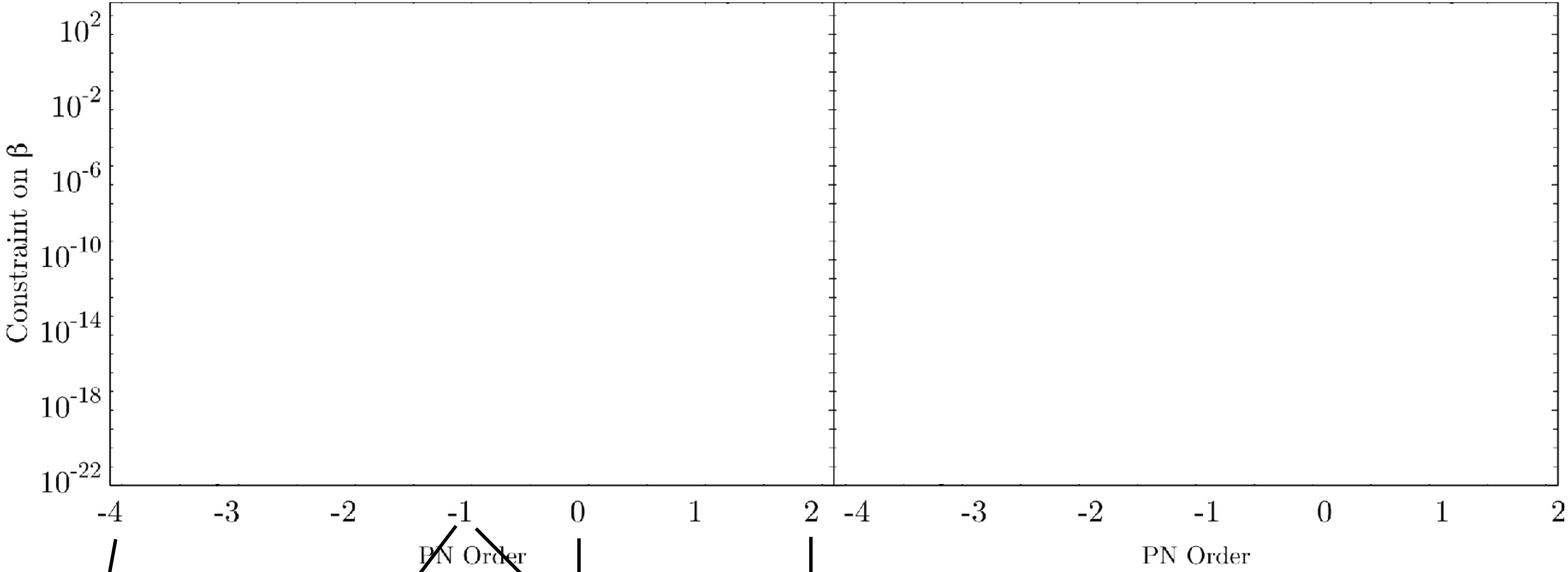
[Yunes & Pretorius, PRD 2009]

Theoretical Effect	Theoretical Mechanism	Theories	ppE b	Order	Mapping
Scalar Dipolar Radiation	Scalar Monopole Field Activation	EdGB [140, 142, 149, 150]	-7	-1PN	$\beta_{\rm EdGB}$ [140]
	BH Hair Growth	Scalar-Tensor Theories [59, 151]	-7	-1PN	$\beta_{\rm ST}$ [59, 151]
Anomalous Acceleration	Extra Dimension Mass Leakage	RS-II Braneworld [152, 153]	-13	-4PN	$\beta_{\rm ED}$ [141]
	Time-Variation of G	Phenomenological [137, 154]	-13	-4PN	$\beta_{\dot{G}}$ [137]
Scalar Quadrupolar Radiation Scalar Dipole Force Quadrupole Moment Deformation	Scalar Dipole Field Activation due to Gravitational Parity Violation	dCS [140, 155]	-1	$+2$PN	$\beta_{\rm dCS}$ [146]
Scalar/Vector Dipolar Radiation Modified Quadrupolar Radiation	Vector Field Activation due to Lorentz Violation	EA [109, 110], Khronometric [111, 112]	-7 -5	-1PN 0PN	$\beta_{\AE}^{(-1)}$ [113] $\beta_{\AE}^{(0)}$ [113]
Modified Dispersion Relation	GW Propagation/Kinematics	Massive Gravity [156–159]	-3	$+1$PN	$\beta_{\rm MDR}$ [145, 156]
		Double Special Relativity [160–163]	$+6$	$+5.5$PN	
		Extra Dim. [164], Horava-Lifshitz [165–167],	$+9$	$+7$PN	
		gravitational SME ($d=4$) [179]	$+3$	$+4$PN	
		gravitational SME ($d=5$) [179]	$+6$	$+5.5$PN	
		gravitational SME ($d=6$) [179]	$+9$	$+7$PN	
		Multifractional Spacetime [168–170]	3–6	4–5.5PN	

[Cornish et al PRD 84 ('11), Sampson et al PRD 87 ('13), Sampson, et al PRD 88 ('13),
Sampson et al PRD 89 ('14), Yunes, Yagi & Pretorius ('16)]

Future ppE Constraints

[Chamberlain & Yunes, PRD '17]



Anomalous Acceleration

Scalar Dipole Radiation

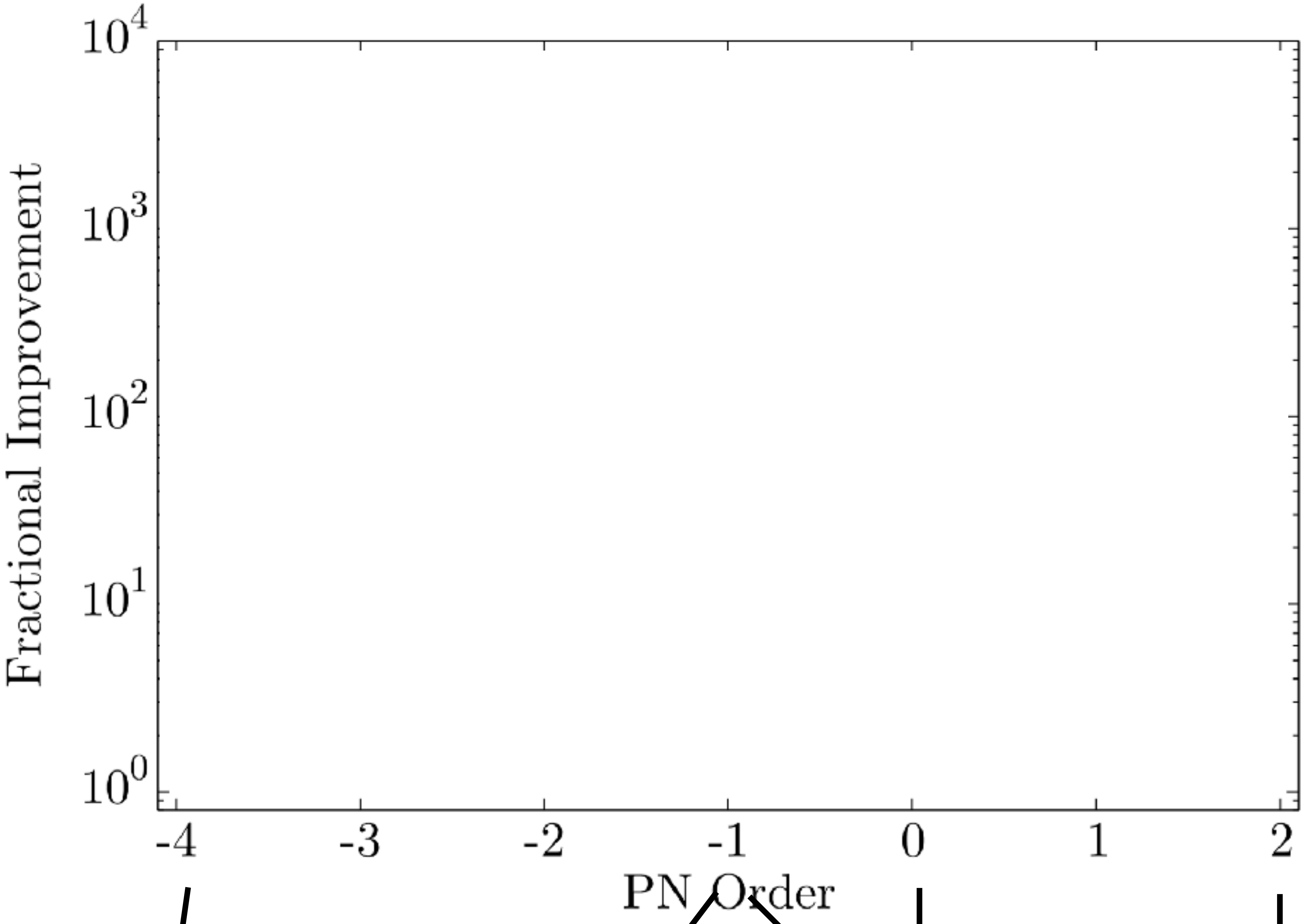
Lorentz Violation

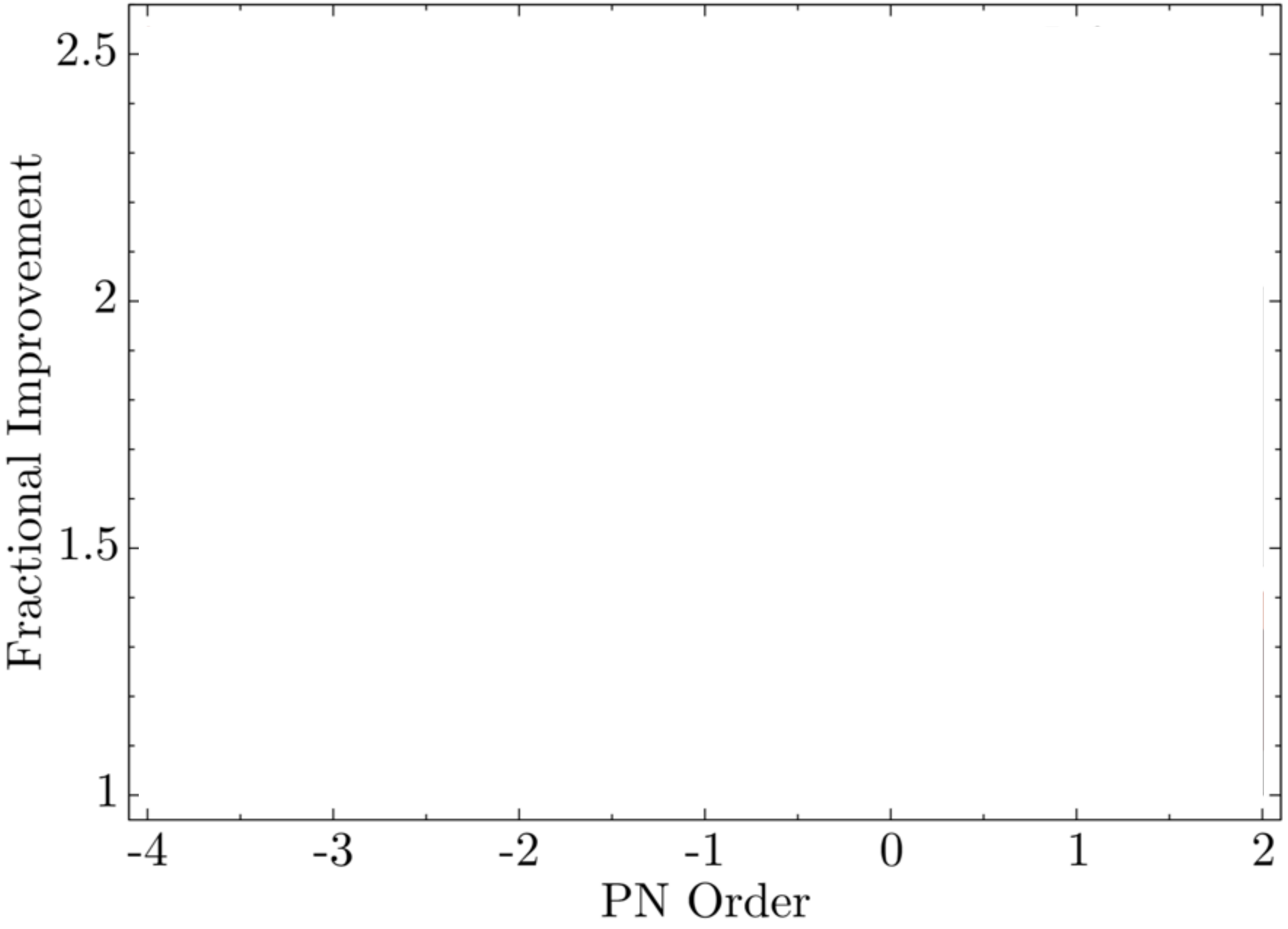
Parity Violation

$$\tilde{h}(f) = \tilde{h}_{GR}(f)\,(1 + \alpha f^{a})\,e^{i\beta f^{b}}$$

Fractional Improvement with Detector Upgrade

[Chamberlain & Yunes, PRD '17]





Anomalous Acceleration

Scalar Dipole Radiation

Lorentz Violation

Parity Violation

$$\tilde{h}(f) = \tilde{h}_{GR}(f)\,(1+\alpha f^a)\,e^{i\beta f^b}$$

Future Constraints on Graviton Mass

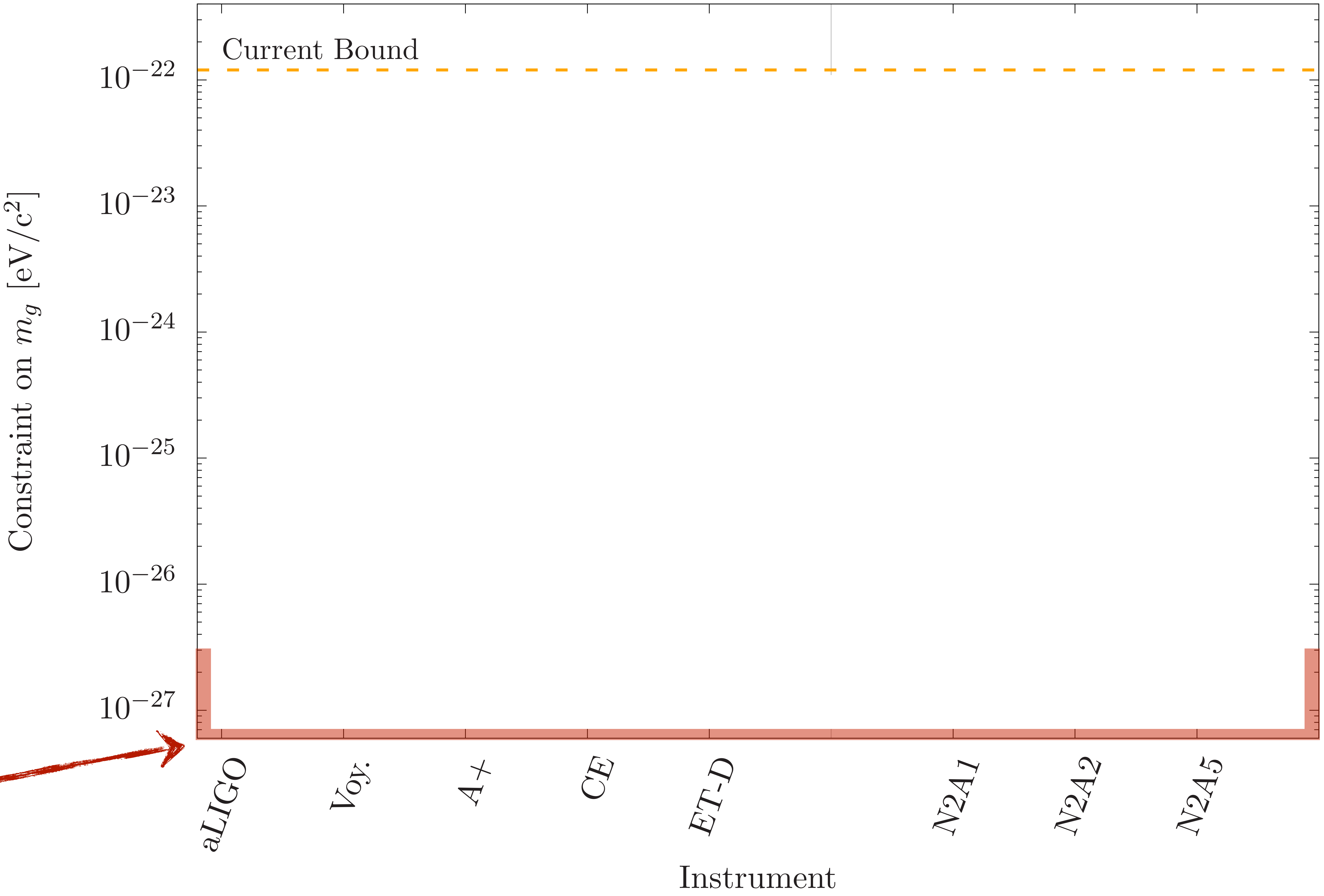
Case Study:
Massive Graviton

$$\frac{v_g^2}{c^2} = 1 - \frac{m_g^2 c^4}{E^2}$$

$$\tilde{h}(f) = \tilde{h}_{GR}(f)\,(1+\alpha f^a)\,e^{i\beta f^b}$$

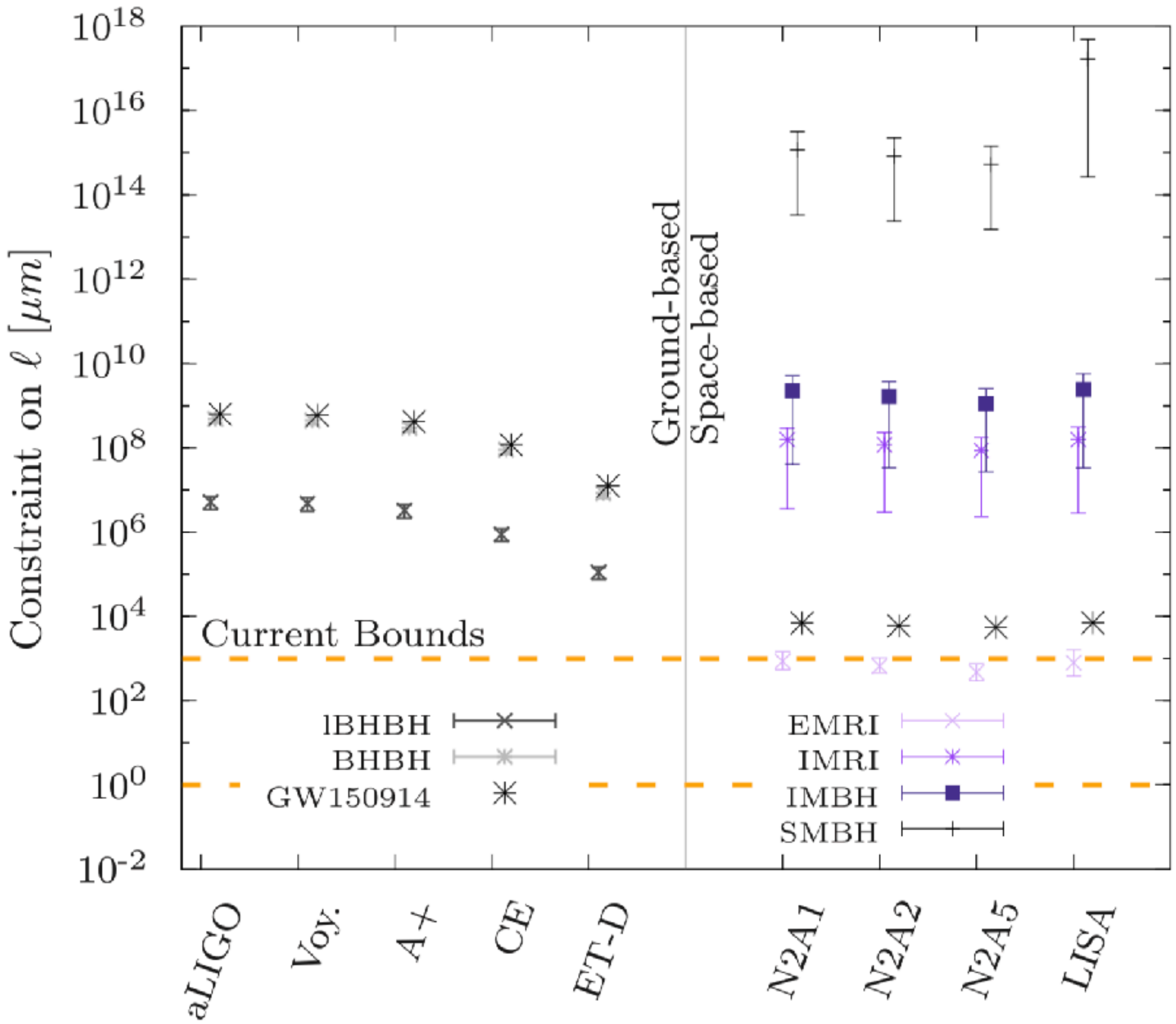
$$\beta = \pi^2 \frac{D\,\mathcal{M}_z}{1+z} m_g^2$$

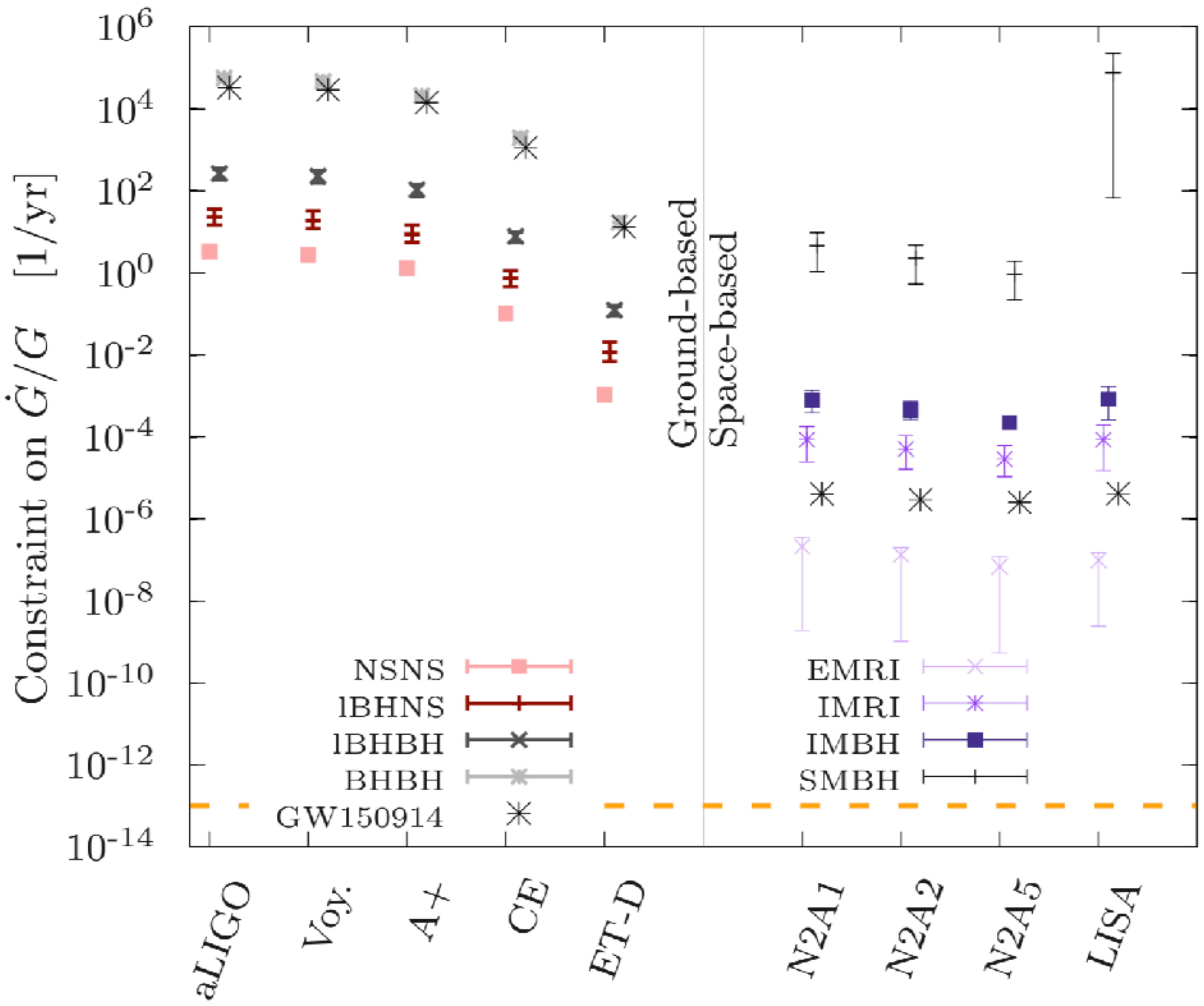
10^5 times better than current bounds!!



[Chamberlain & Yunes, PRD ’17]

Other Future Constraints





[Chamberlain & Yunes, PRD ’17]

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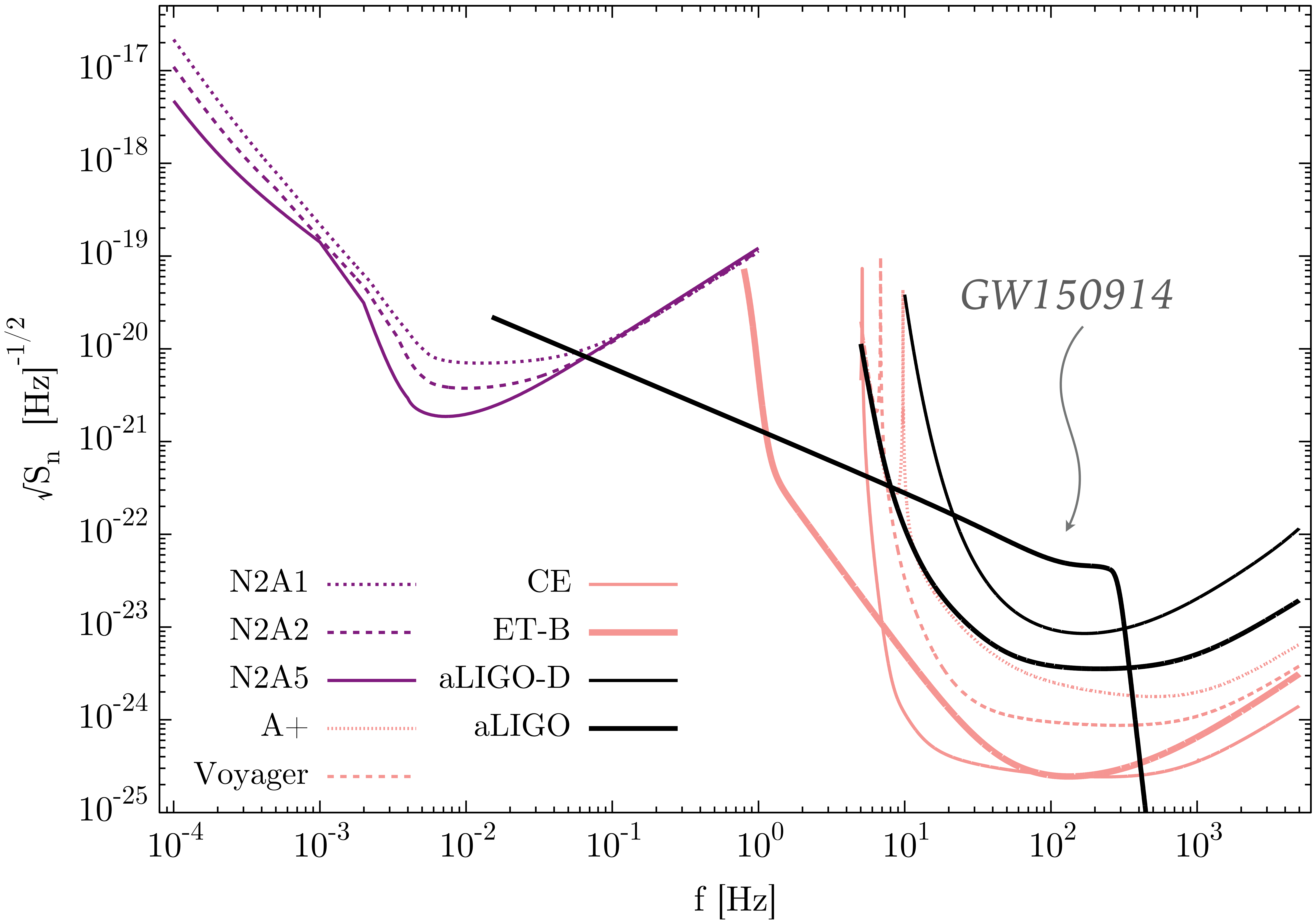
(the Great Sea)

Multi-Band Events



Future Multi-Band Constraints

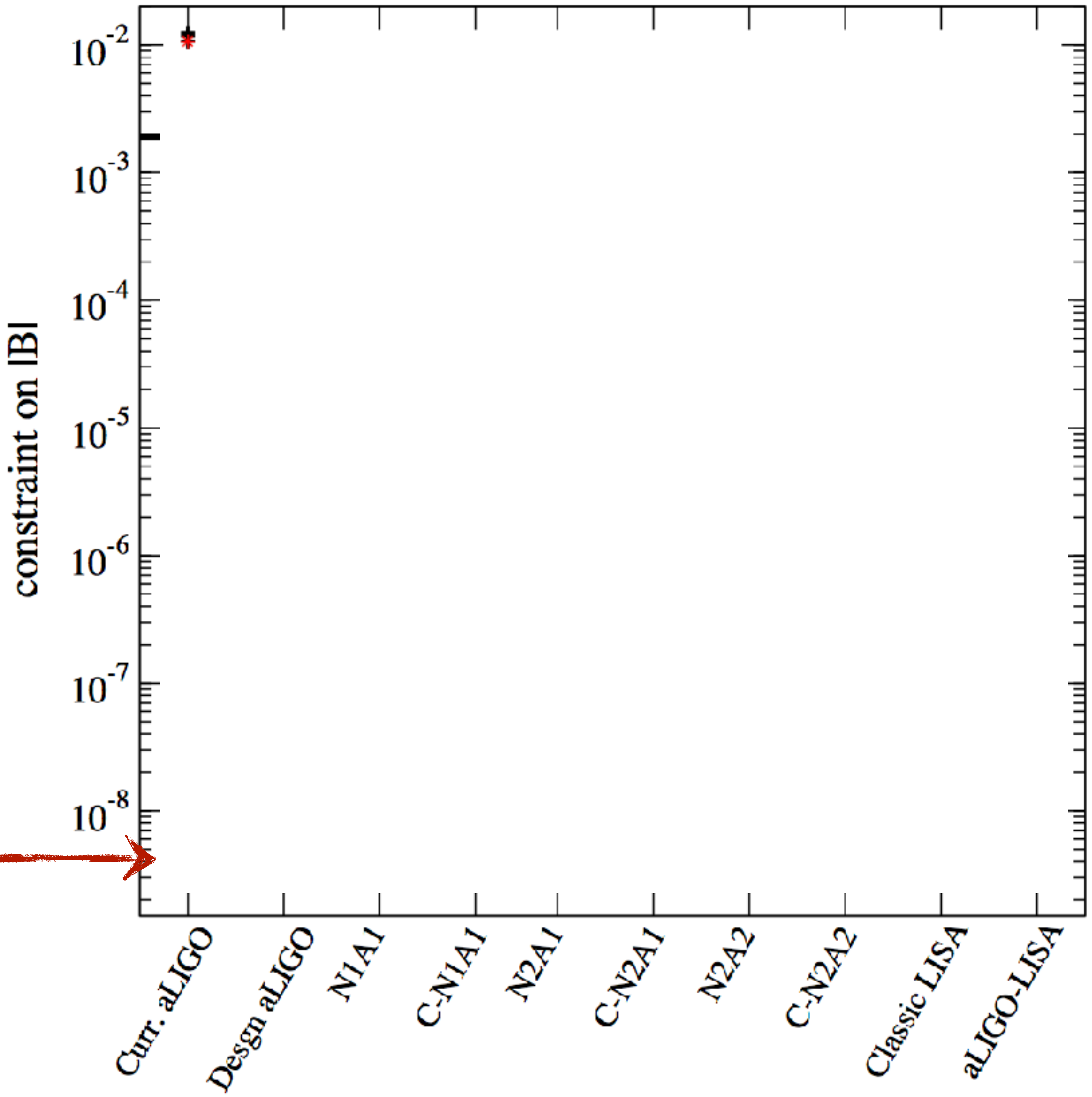
Case Study:
Dipole Radiation

$$\dot{E}_{\rm GW} = \dot{E}_{\rm GR}\left[1 + B\left(\frac{Gm}{r_{12}c^2}\right)^{-1}\right]$$

$$\tilde{h}(f) = \tilde{h}_{GR}(f)\,(1+\alpha f^a)\,e^{i\beta f^b}$$

$$\beta = -\frac{3}{224}\eta^{2/5}B$$

10^6 times better than current bounds!!



[Barausse, Yunes, Chamberlain, PRL '16]

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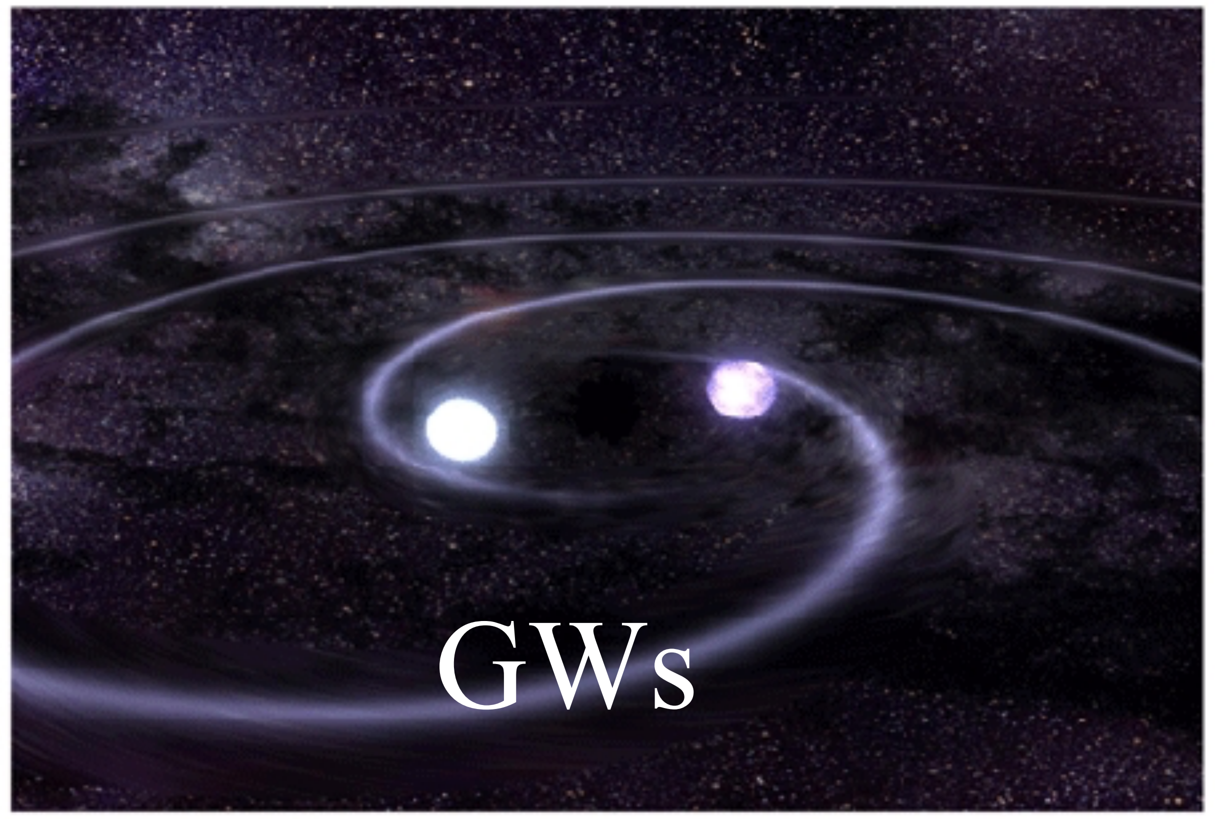
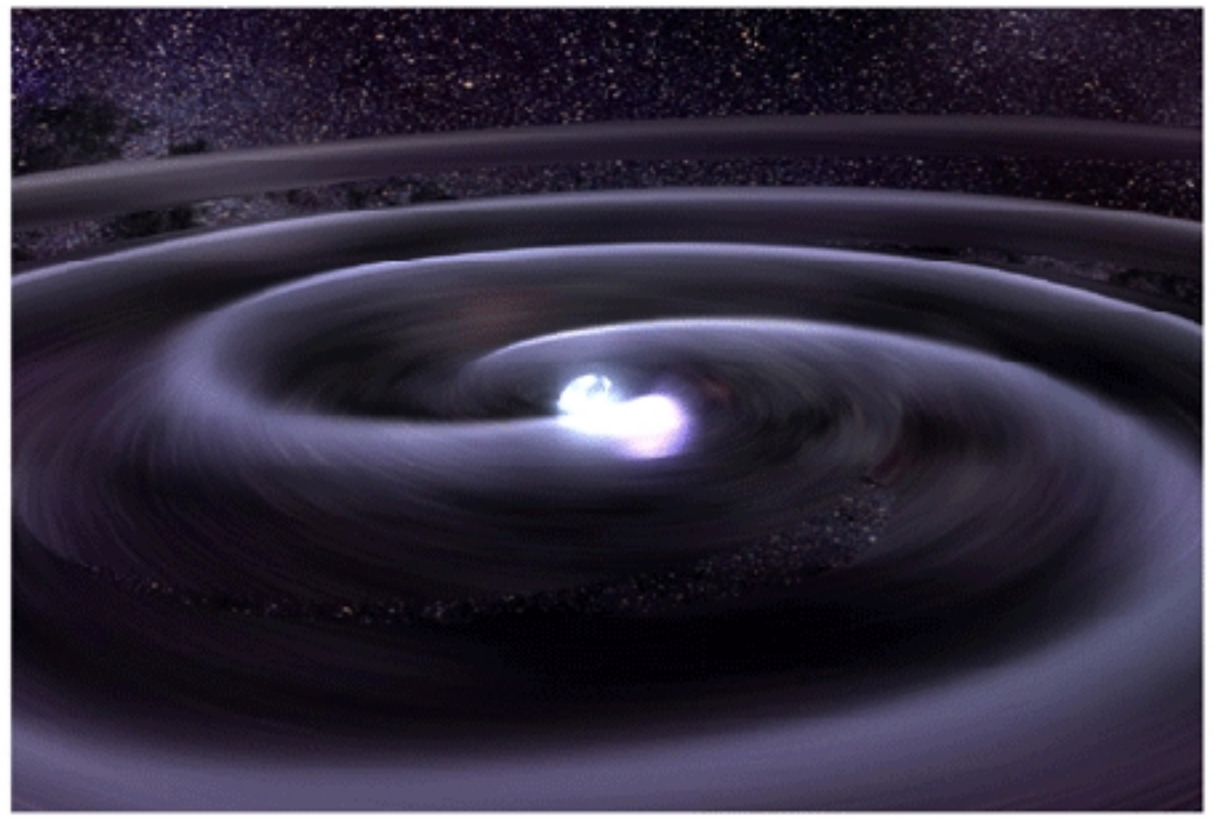
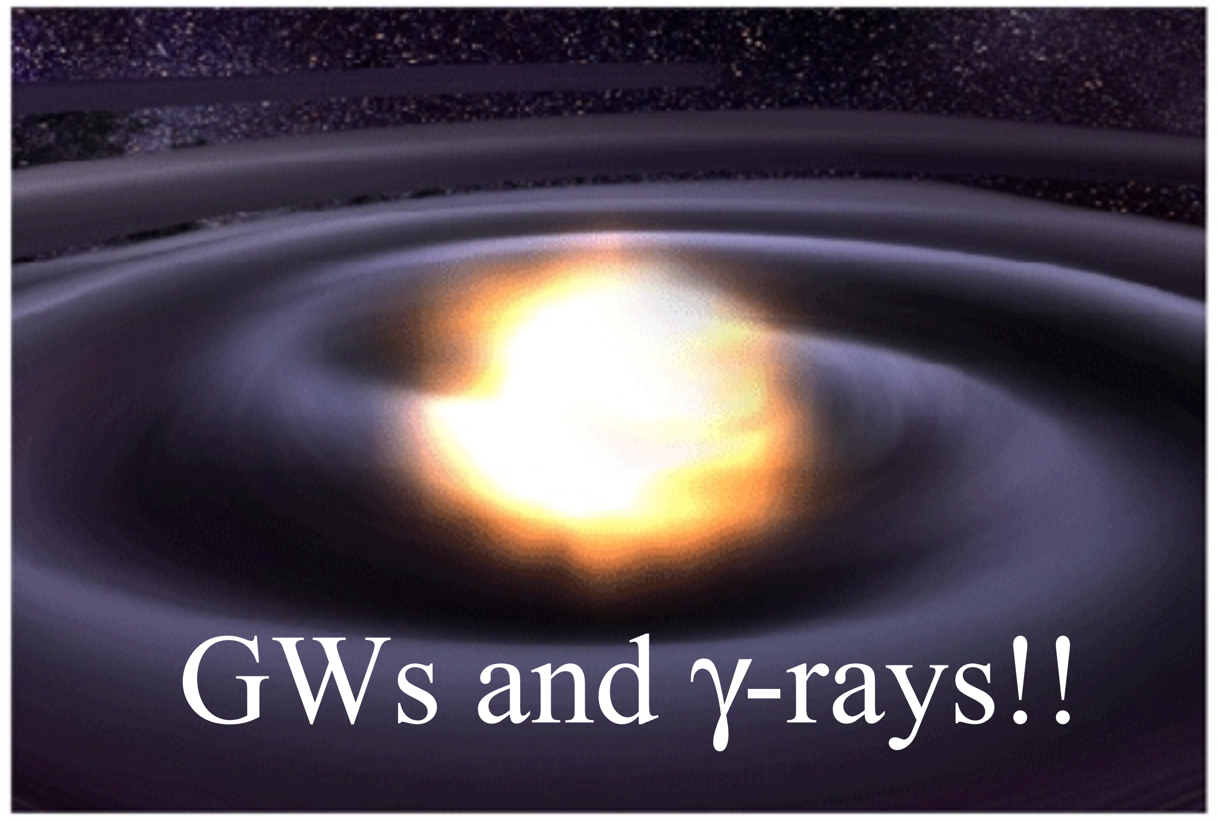
Gravitational Waves Will Find Love



test-particles



tidal deformations

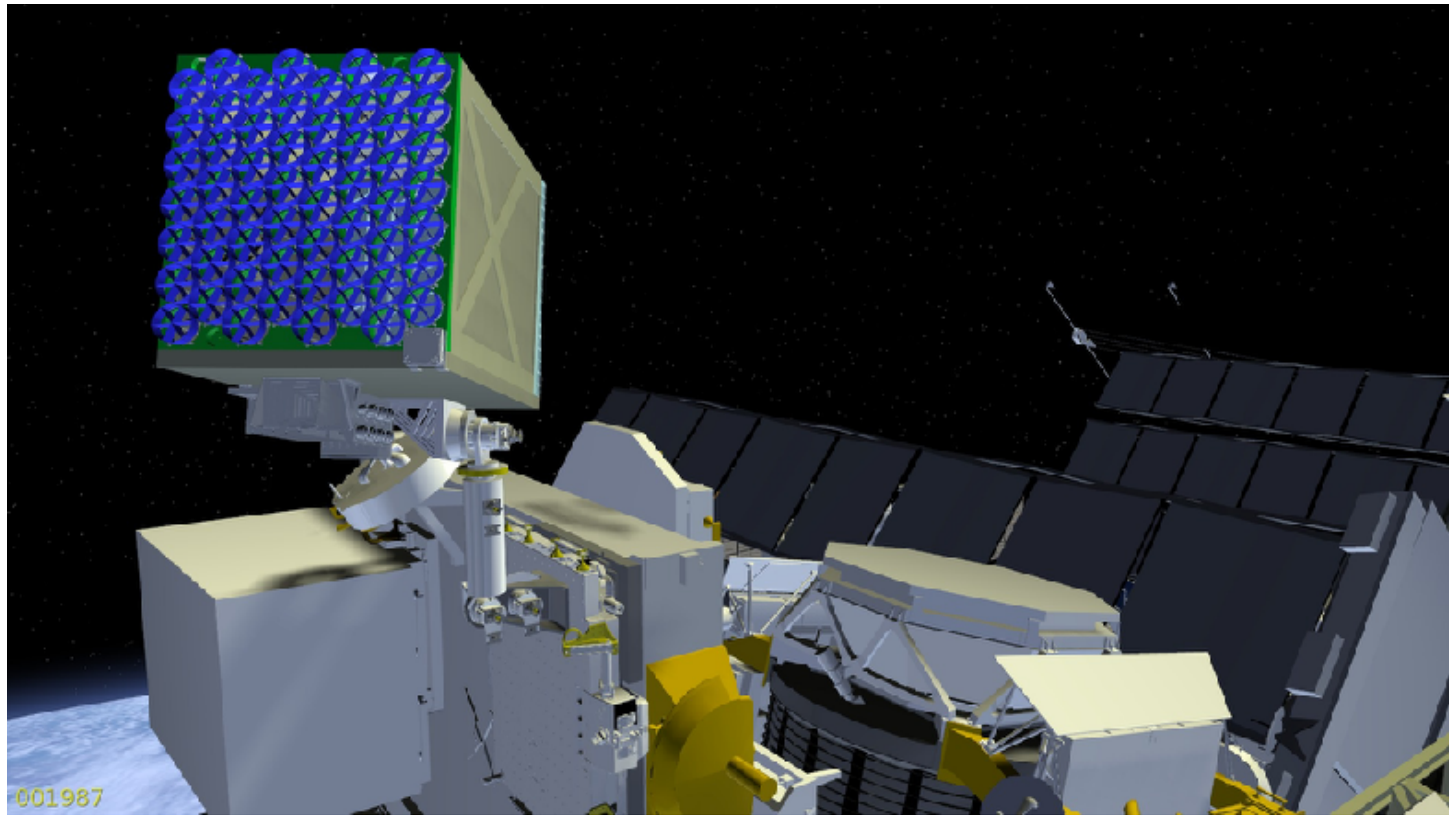


merger

Gravitational Waves from Neutron Star Binaries depend on (λ_1,Q_1,λ_2,Q_2)

Somebody will find I

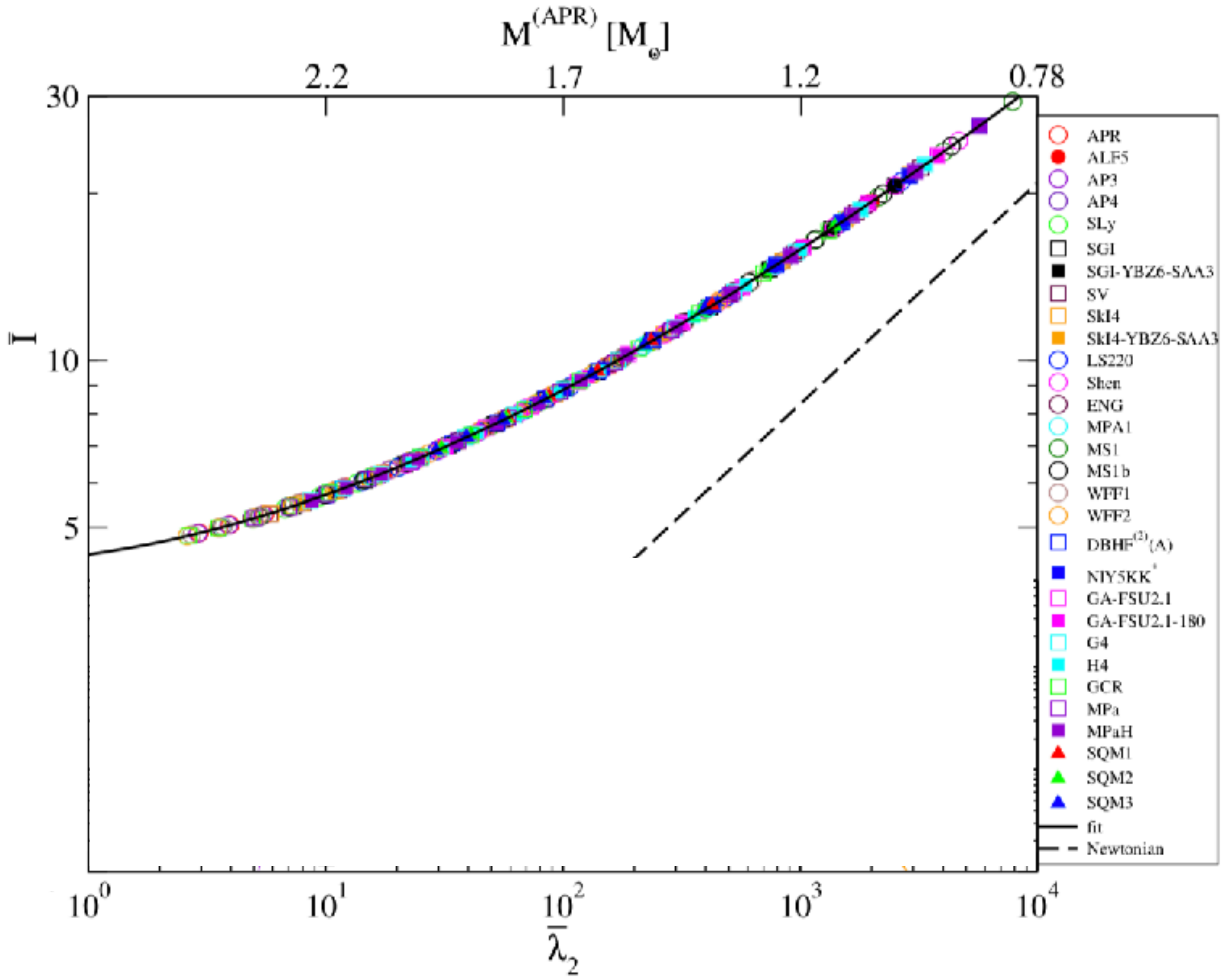
Option 1: Use NICER



Option 2: Use Binary Pulsars

Either NICER or Binary Pulsars will measure the Moment of Inertia

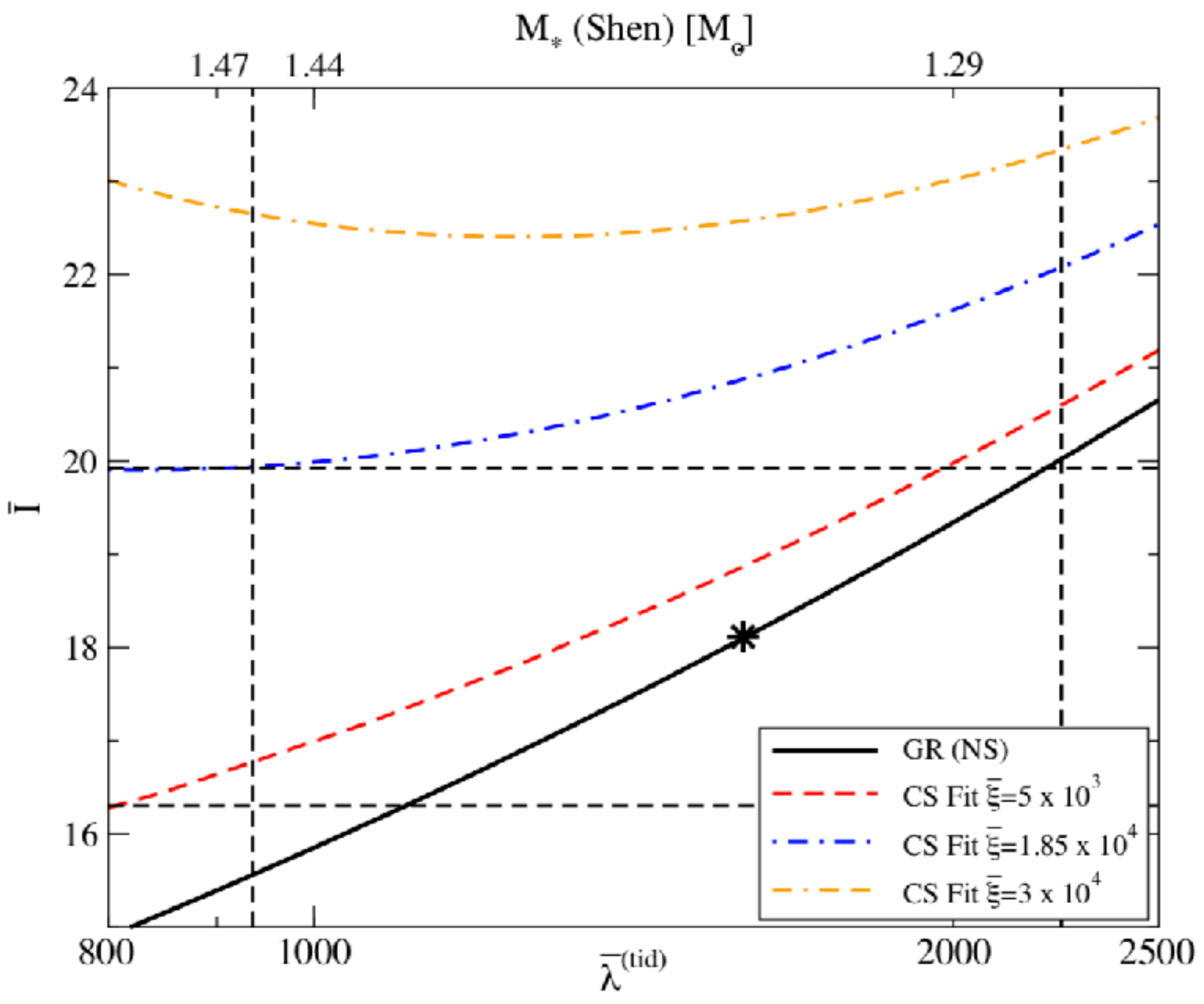
I-Love-Q Relations

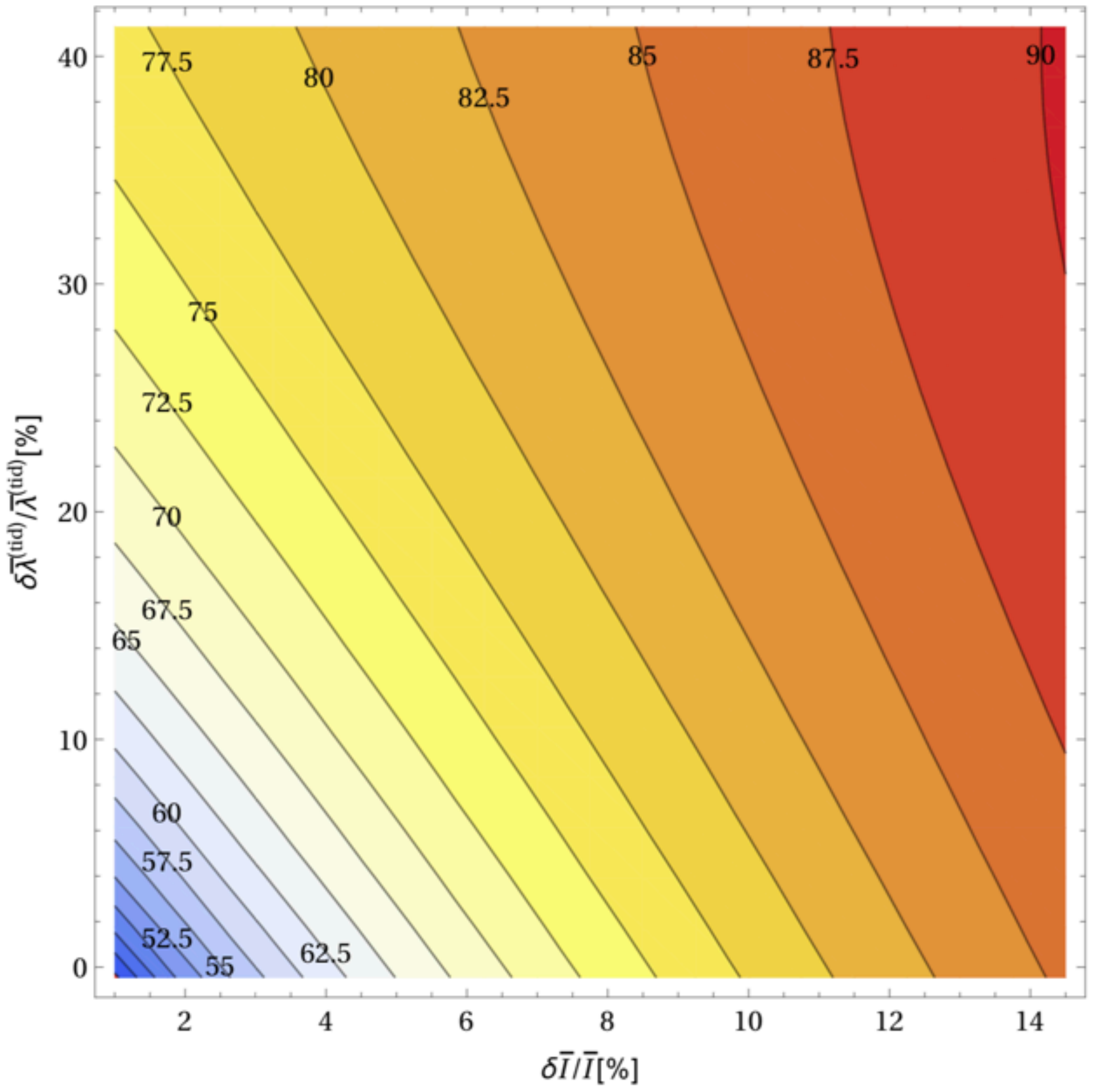


[Yagi & Yunes, Science 341 2013, Yagi & Yunes, PRD 88 2013]

The moment of inertia, quadrupole moment and Love number satisfy Universal, EoS-independent relations!

I-Love-Q Test





I-Love test leads to strong constraints on modified gravity

[Yagi & Yunes, Science 341 2013, Yagi & Yunes, PRD 88 2013, Gupta et al, CQG 2017]

Conclusions

3G Detectors Will Allow for Precision Tests of GR
(extreme gravity, clean, localized, constraint maps)

Multi-Band Observations Will Be Ultimate Test
(requires synchronized LISA-Earth Detector effort)

I-Love-Q Tests Will Allow Different And Stringent Tests
(constraints on parity violation and Lorentz violation)

Important Topics I Had To Leave Out:
Constraints on Parity violation, on Lorentz violation
Quasinormal BH ("hair") tests
Constraints on additional polarizations

Thank You