2105.04559

Detecting new forces in the gravitational wave background

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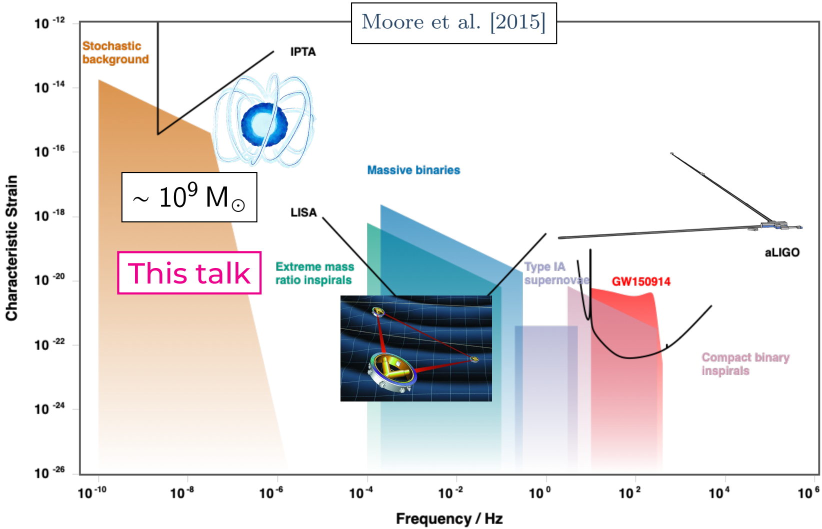
The era of gravitational waves



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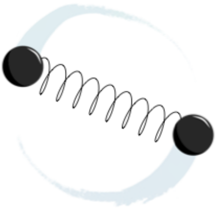
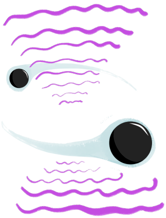
This talk in one slide



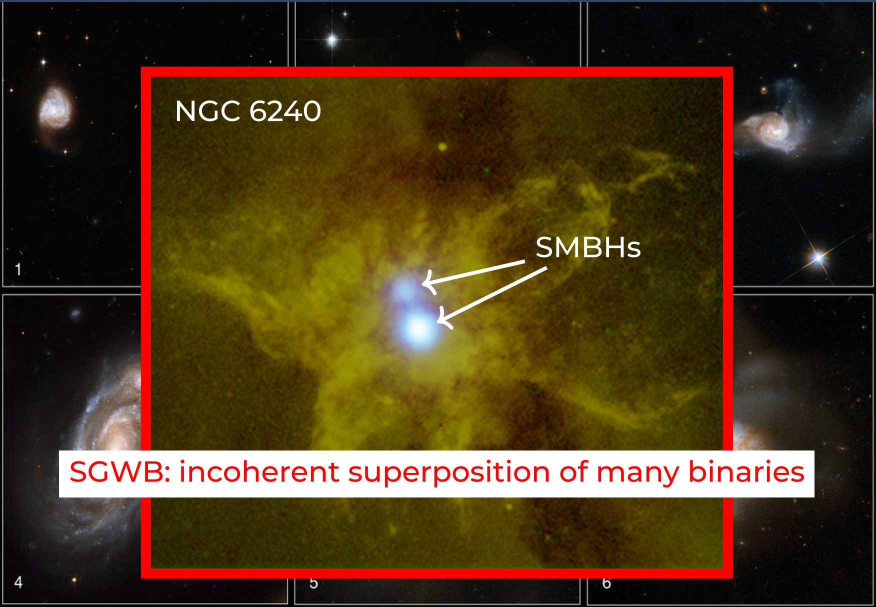


1. SMBH GW background is a guaranteed discovery

2. Long range forces can *detectably* modify spectrum

3. SMBH GWs potentially probe many BSM scenarios

The stochastic GW background



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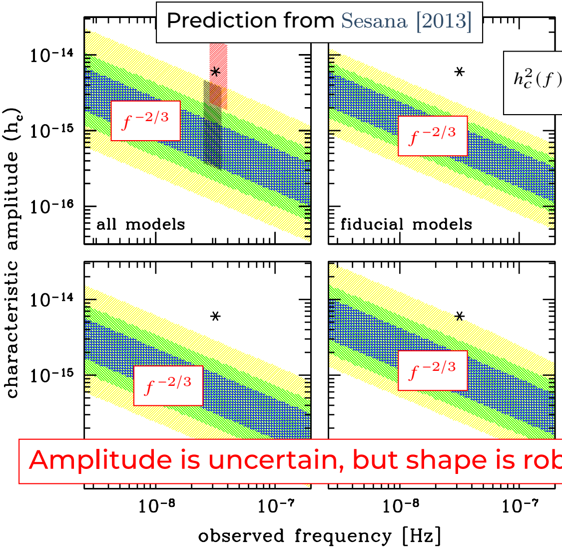
Stochastic background spectrum



$$h_c^2(f) \propto \frac{1}{f} \sum_{\text{sources}} \frac{dE_{GW}}{df}$$

$$h_c \propto f^{-2/3}$$

Amplitude is uncertain, but shape is robust

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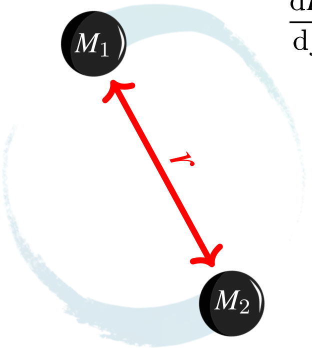
Gravitational waves drive the evolution of the binary



$2 f_{\text{orbit}}$

$$\frac{\mathrm{d}E_{\text{GW}}}{\mathrm{d}f_{\text{GW}}} = -\pi^2 \mu r^2 f_{\text{GW}} \left(\frac{2 f_{\text{GW}}}{r} \frac{\mathrm{d}r}{\mathrm{d}f_{\text{GW}}} + 1 \right)$$

$$f_{\text{orbit}}(r) = \left(\frac{G(M_1 + M_2)}{4\pi^2 r^3} \right)^{1/2}$$

(Kepler's third law)

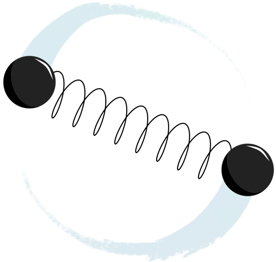
$$\frac{\mathrm{d}E_{\text{GW}}}{\mathrm{d}f_{\text{GW}}} \propto f^{-1/3} \implies \frac{\mathrm{d}h_c}{\mathrm{d}f_{\text{GW}}} \propto f^{-2/3}$$

[Phinney, 2001]

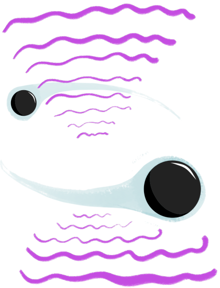
New physics can break this prediction

Assumptions are made to be broken

1. $f \leftrightarrow r$ relation
   Kepler's law



2. All energy loss is
   gravitational



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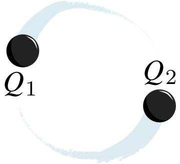
Benchmark model

Click for details

Additional dynamics spoil the $-2/3$

Toy model: charge BHs under dark U(1)

1. New force changes Kepler's law
2. New radiation takes energy



Charge parameters

$$\underbrace{\alpha = \frac{Q_1 Q_2}{G M_1 M_2}}_{\text{Force}}$$

$$\underbrace{\gamma = \frac{1}{G}\left(\frac{Q_1}{M_1} - \frac{Q_2}{M_2}\right)^2}_{\text{Radiation}}$$

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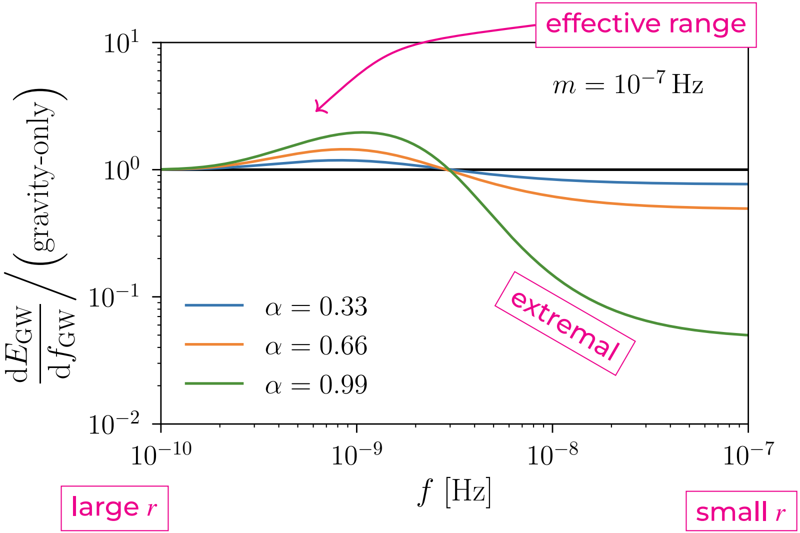
Modifying the force law ($|\alpha| > 0$)



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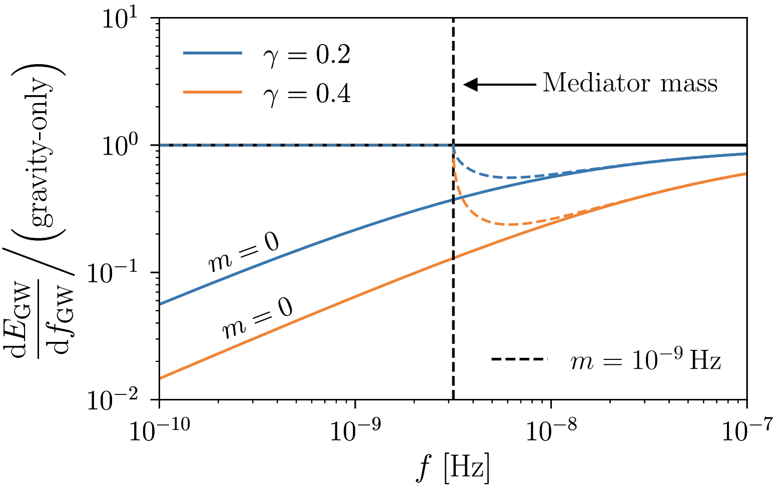
New dipole radiation ($|\gamma| > 0$)



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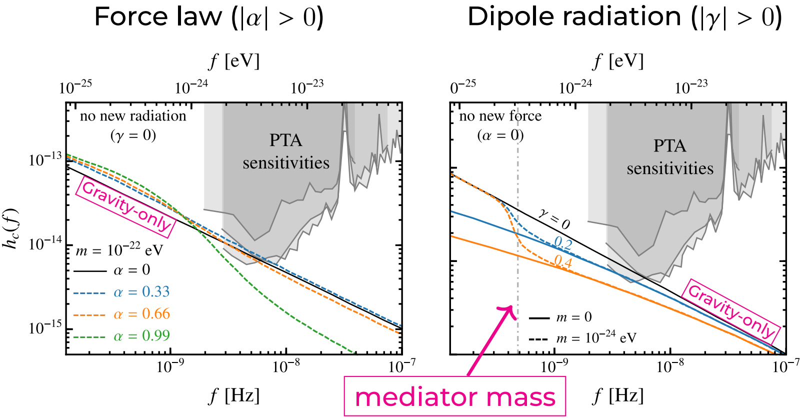
The observable spectrum



1. Single-source features are intact
2. Both modified slope and novel features observable
3. Sensitivity curves: this is happening **NOW**

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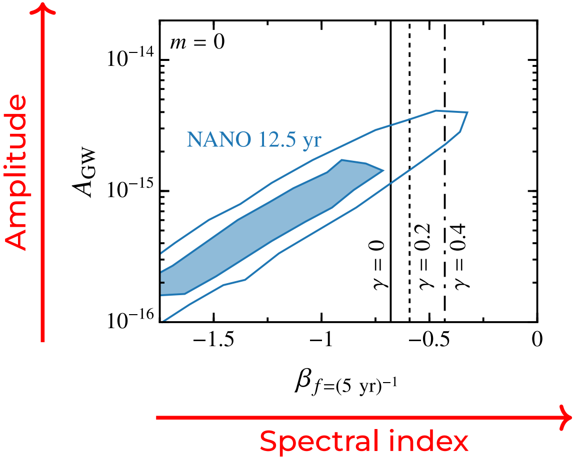
NANOGrav sees evidence for a GW background now!



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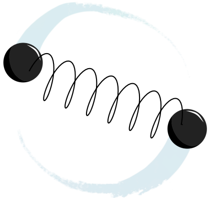
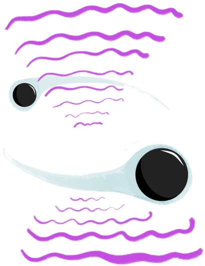
Conclusions

Supermassive black holes are our new laboratories

SGWB discovery
is imminent



Long-range forces
are detectable



SMBHs can probe
many NP scenarios

Data is on the way!

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References I

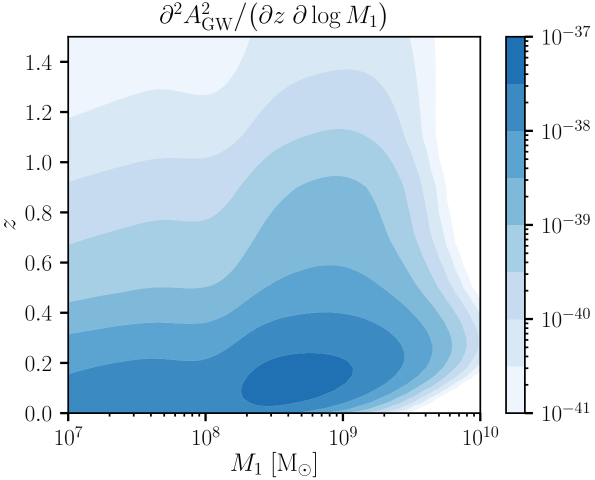
C. J. Moore, R. H. Cole, and C. P. L. Berry. Gravitational-wave sensitivity curves. *Class. Quant. Grav.*, 32(1):015014, 2015. doi: 10.1088/0264-9381/32/1/015014.

E. S. Phinney. A Practical theorem on gravitational wave backgrounds. 7 2001.

A. Sesana. Systematic investigation of the expected gravitational wave signal from supermassive black hole binaries in the pulsar timing band. *Mon. Not. Roy. Astron. Soc.*, 433:1, 2013. doi: 10.1093/mnrasl/slt034.

HIDDEN SECTOR

Distribution of sources



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GW spectrum with a new force

New force and radiation modify the spectrum

$$\frac{\mathrm{d}E_{\mathrm{GW}}}{\mathrm{d}f_{\mathrm{GW}}} = -\pi^2 \mu r^2 f_{\mathrm{GW}} \left(\frac{2 f_{\mathrm{GW}}}{r} \frac{\mathrm{d}r}{\mathrm{d}f_{\mathrm{GW}}} + 1 \right) \underbrace{\frac{P_{\mathrm{GW}}}{P_{\mathrm{GW}} + P_{\mathrm{new}}}}_{\text{radiation}}$$

$$F = \frac{G M_1 M_2}{r^2} \left(1 - \underbrace{\alpha e^{-mr} (1 + mr)}_{\text{new force}} \right)$$

$$P_{\mathrm{new}} = \frac{1}{3} G \gamma^2 \mu^2 r^2 \omega^4 \, \mathrm{Re} \left[\sqrt{1 - \frac{m^2}{\omega^2}} \right] \begin{cases} \left(1 - \frac{m^2}{2\omega^2} \right) & \text{(scalar)} \\ 2 \left(1 + \frac{m^2}{2\omega^2} \right) & \text{(vector)} \end{cases}$$

Back

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