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Detecting new forces in the gravitational wave background

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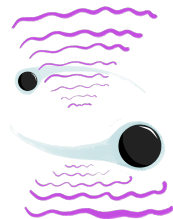
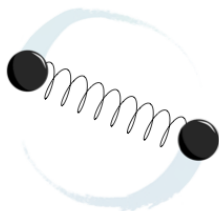
+Jeff A. Dror, Hiren H. Patel, & Stefano Profumo

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This talk in one slide

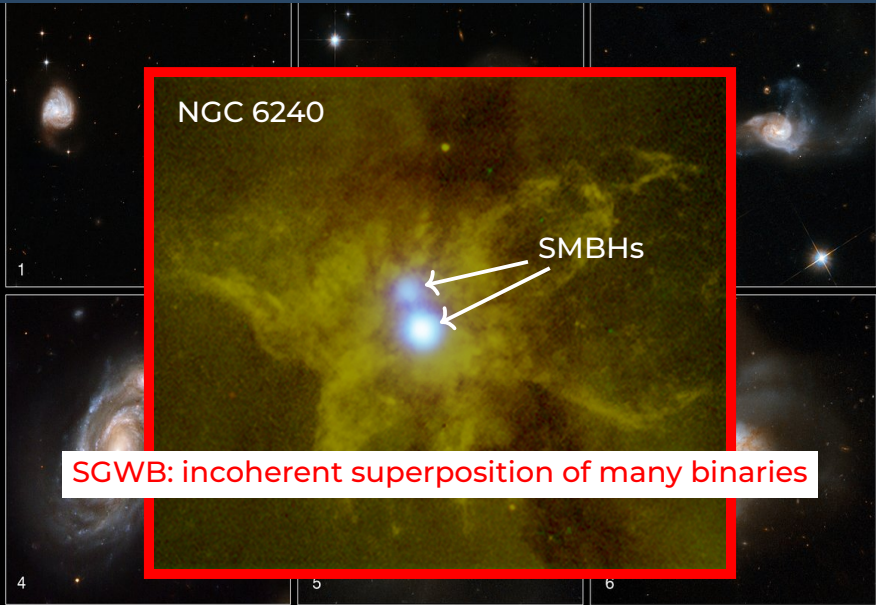


1. SMBH GW background is a guaranteed discovery

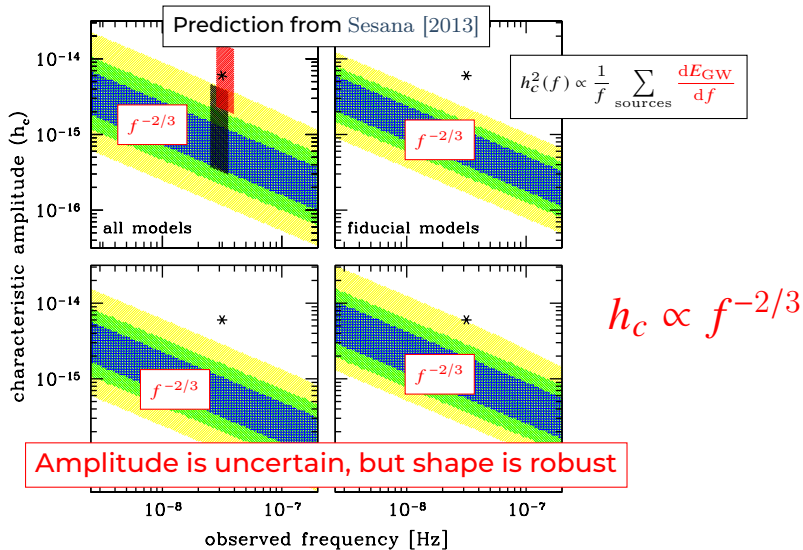
2. Long range forces can *detectably* modify spectrum

3. SMBH GWs potentially probe many BSM scenarios

The stochastic GW background

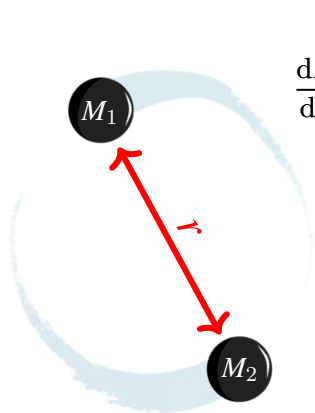


Stochastic background spectrum



Why is the index $-2/3$?

Gravitational waves drive the evolution of the binary



$$\frac{dE_{\text{GW}}}{df_{\text{GW}}} = -\pi^2 \mu r^2 \overset{2f_{\text{orbit}}}{\downarrow} f_{\text{GW}} \left(\frac{2f_{\text{GW}}}{r} \frac{dr}{df_{\text{GW}}} + 1 \right)$$

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

(Kepler's third law)

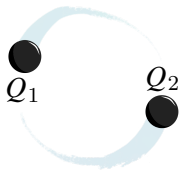
$$\frac{dE_{\text{GW}}}{df_{\text{GW}}} \propto f^{-1/3} \implies \frac{dh_c}{df_{\text{GW}}} \propto f^{-2/3}$$

[Phinney, 2001]

New physics can break this prediction

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

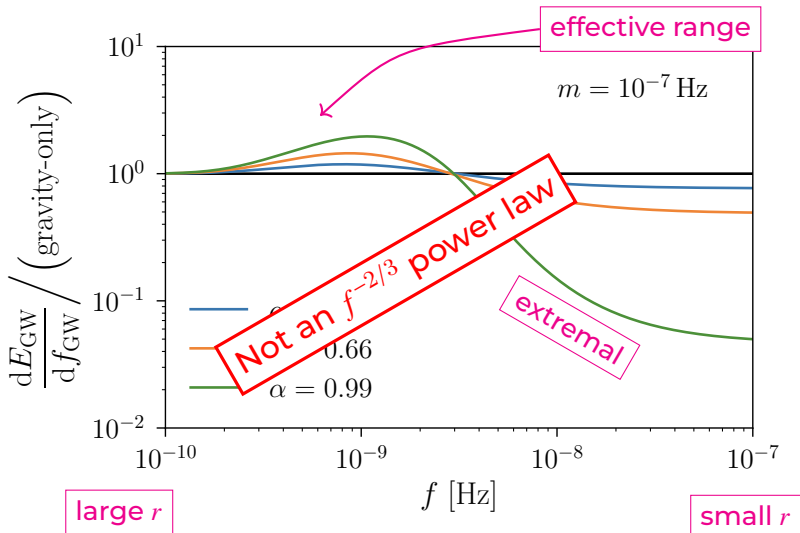
$$\alpha = \frac{Q_1 Q_2}{GM_1 M_2}$$

Force

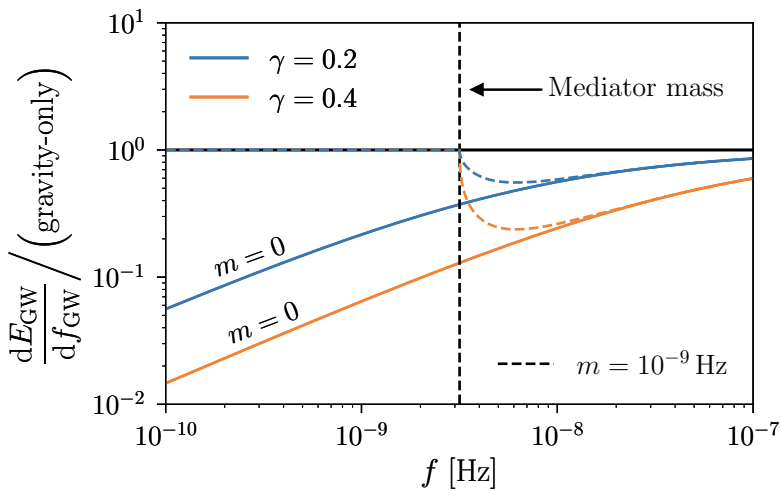
$$\gamma^2 = \frac{1}{G} \left(\frac{Q_1}{M_1} - \frac{Q_2}{M_2} \right)^2$$

Radiation

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

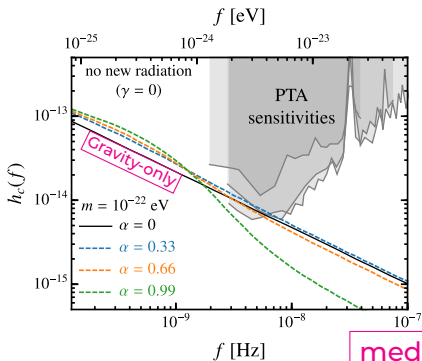


New dipole radiation ($|\gamma| > 0$)

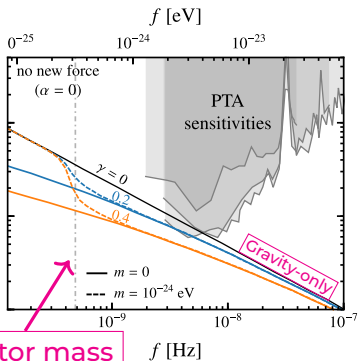


The observable spectrum

Force law ($|\alpha| > 0$)

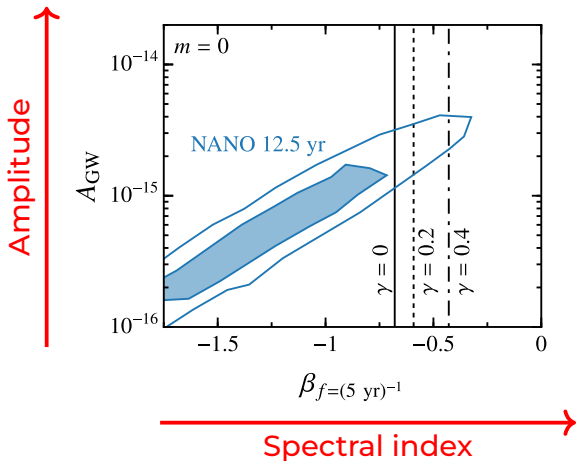


Dipole radiation ($|\gamma| > 0$)



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

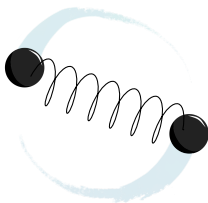
NANOGrav sees evidence for a GW background now!



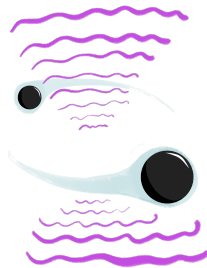
Supermassive black holes are our new laboratories



SGWB discovery
is imminent



Long-range forces
are detectable



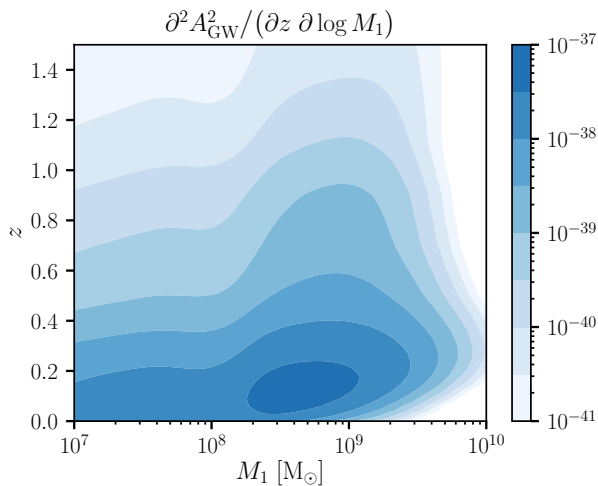
SMBHs can probe
many NP scenarios

Data is on the way!

- 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



GW spectrum with a new force

New force and radiation modify the spectrum

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

$$F = \frac{GM_1 M_2}{r^2} \left(1 - \underbrace{\alpha e^{-mr} (1 + mr)}_{\text{new force}} \right)$$

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