

TESTING THE SPEED OF GRAVITY
WITH
BLACK HOLE RINGDOWN

LISA - SPECIAL TOPIC - NOVEMBER 2023

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TESTING GRAVITY

- SO WHY SHOULD WE TEST GR ?

- DARK ENERGY
- SINGULARITIES
- NOT QUANTIZABLE
- ...
- WHY NOT?

TESTING GRAVITY

$$\left. \begin{array}{l} 4D \\ g_{\mu\nu} \\ \text{LOCAL} \\ \text{2}^{\text{nd}} \text{order EOM} \end{array} \right\} \text{GR} \rightarrow S = \int d^4x \sqrt{-g} R[g_{\mu\nu}]$$

(LOVELOCK'S THEOREM)

$$\left. \begin{array}{l} 4D \\ g_{\mu\nu} + \phi \\ \text{LOCAL} \\ \text{2}^{\text{nd}} \text{order EOM} \end{array} \right\} \text{HORNDESKI} \rightarrow S = \int d^4x \sqrt{-g} H[g_{\mu\nu}, \phi]$$

TESTING GRAVITY

THEORY
↓
OBSERVABLE

$S = \int d^4x \sqrt{-g} R$
↓
 $\alpha = 0$

$S = \int d^4x \sqrt{-g} H$
↓
 $\alpha \neq 0$

"SMOKING
GUN SIGNAL"

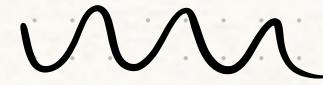
GRAVITATIONAL WAVES

GR

$$S = \int d^4x \sqrt{g} R \longrightarrow G_{\mu\nu} = T_{\mu\nu}$$

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu} \xrightarrow{\text{WEAK FIELD}}$$

$$\square h_{\mu\nu} = T_{\mu\nu}$$

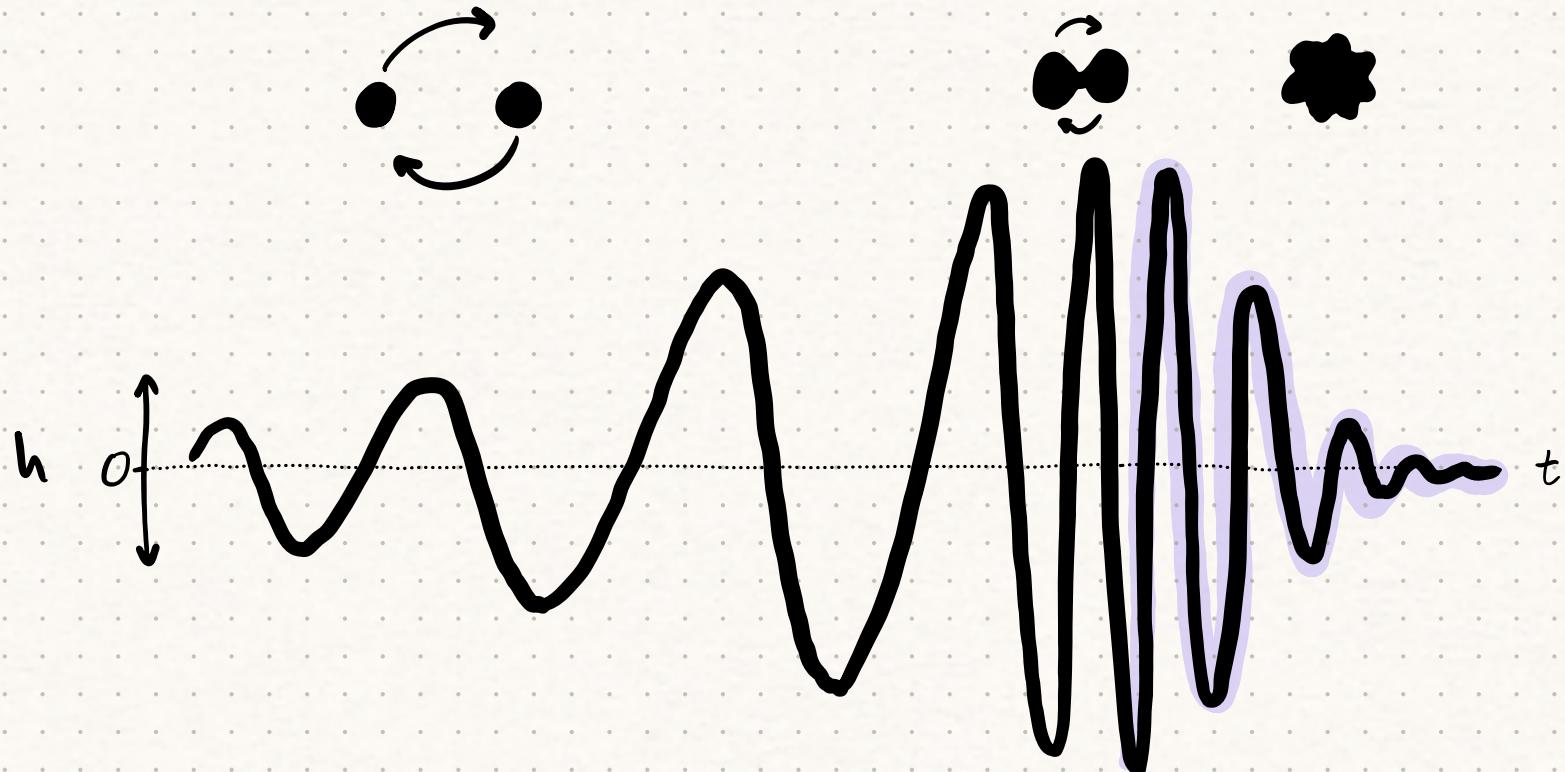


ASTROPHYSICAL SOURCES : MERGERS (BLACK HOLES / NEUTRON STARS)

INSPIRAL

MERGER

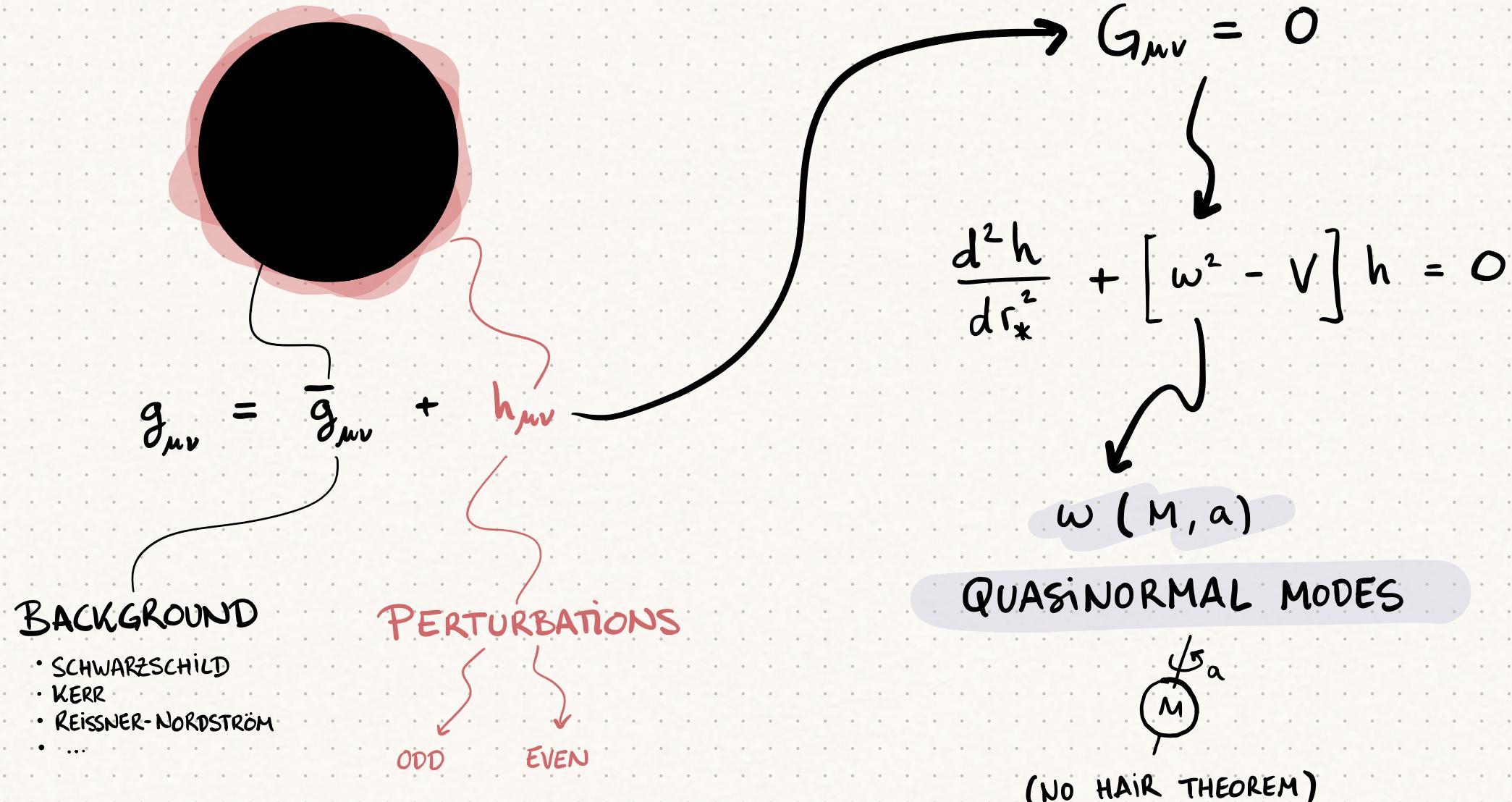
RINGDOWN



GRAVITATIONAL WAVES

GR

RINGDOWN : BLACK HOLE PERTURBATION THEORY

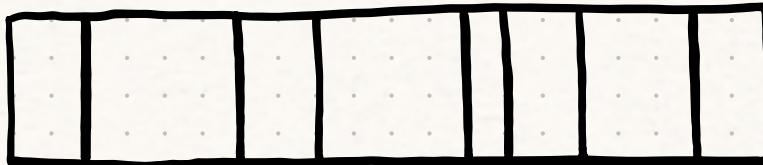


GRAVITATIONAL WAVES

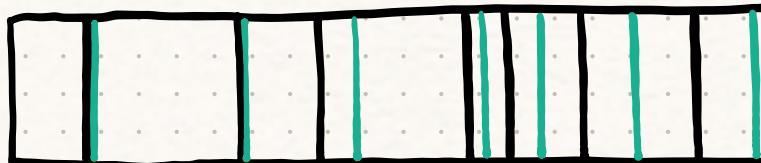
BLACK HOLE SPECTROSCOPY

$\omega(M, a)$

- 1st QNM sets M
- 2nd QNM sets a
- All other QNMs are fixed in GR



MEASURING QNMs PROVIDES CLEAN TESTS OF
BACKGROUND GEOMETRY AND UNDERLYING THEORY



GR $\omega(M, a)$
MG $\omega(M, a, \alpha)$

SPEED OF GRAVITY

HORNDESKI

$$S = \int d^4x \sqrt{-g} H(g_{\mu\nu}, \Phi)$$



$$\frac{d^2 h}{dr_*^2} + [w^2 (1 + \alpha_T) + V + \alpha_T \delta V] h = 0$$



$$w(M, a, \alpha_T)$$

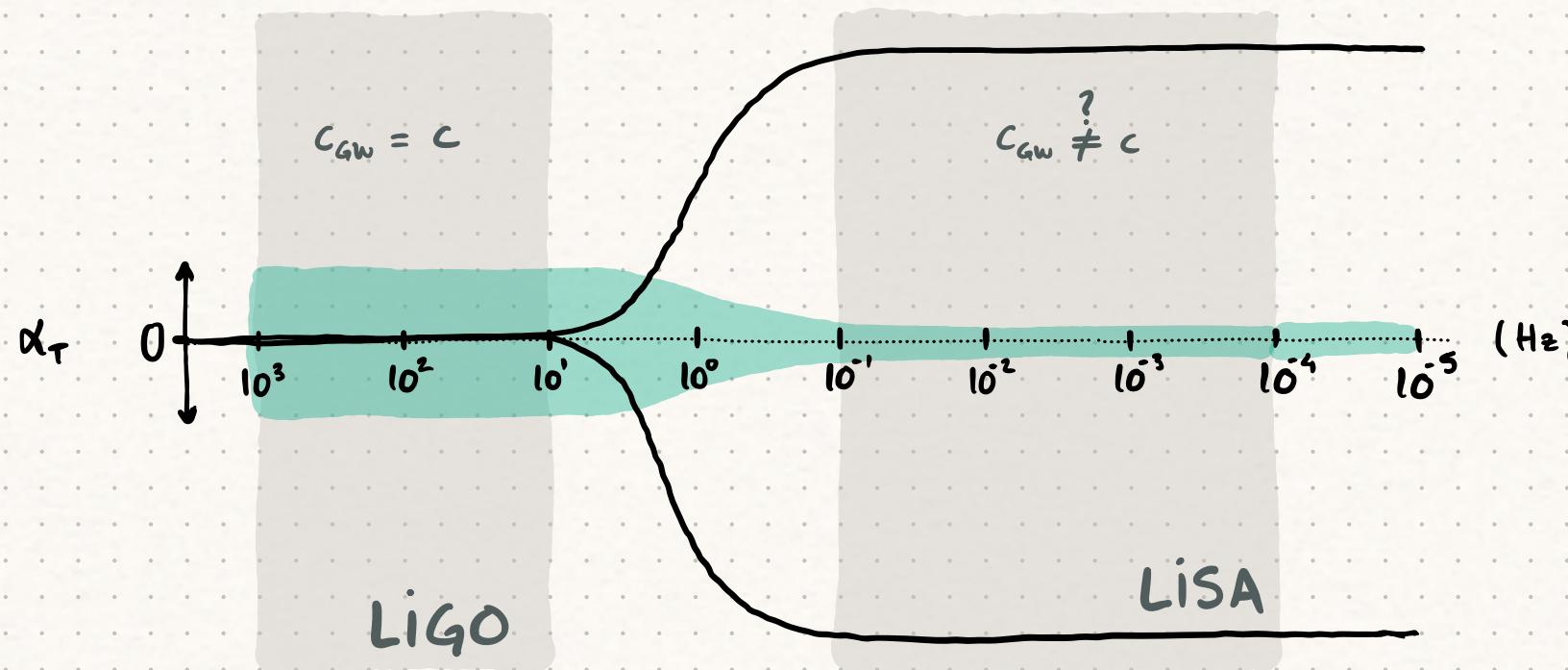
$$\alpha_T = \frac{c_{GW} - c}{c} \neq 0$$

GRAVITATIONAL WAVE SPEED EXCESS

SPEED OF GRAVITY

WHAT DO WE KNOW ABOUT α_T ?

- LIGO : $\alpha_T \lesssim 10^{-15}$ (GW170817)
- BUT! GENERIC FREQUENCY DEPENDENCE



FISCHER FORECASTS:

FOR 1 LOUD MERGER :

- LISA : $\alpha_T \lesssim 10^{-4}$
- LIGO/ET $\alpha_T \lesssim 10^{-1}$

[2301.10272]

↳ SS, JOHANNES NOLLER



[sergilsl/ringdown-calculations](#) Public