The Horizon Modes of Black Holes

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Waves from final plunge

- Mino, Brink (2008)
  GWs from final plunge

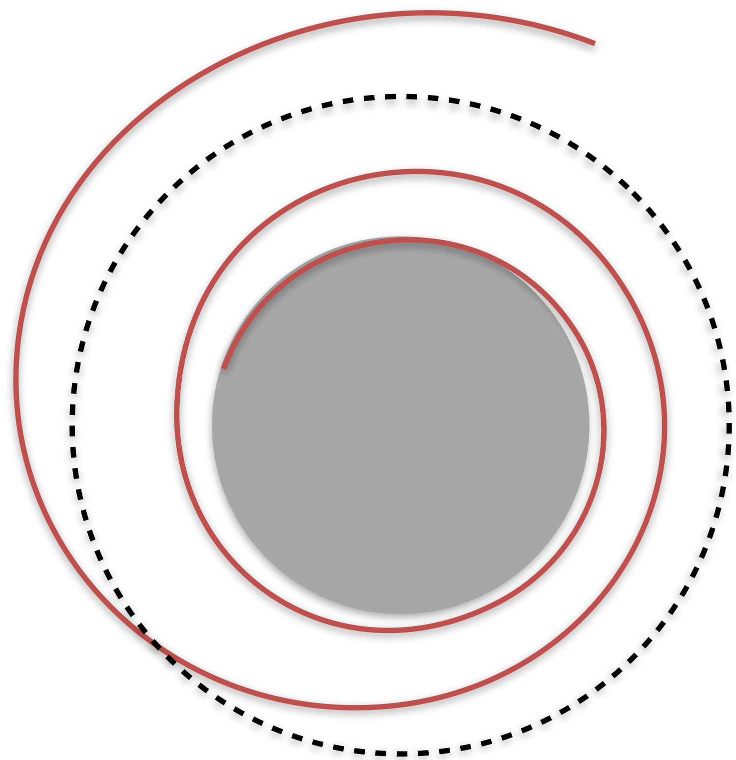
$$x = \frac{r - r_+}{r_+} \ll 1$$

- Universal trajectories

$$t_p = -\frac{1}{2\kappa} \ln x + O(x \ln x)$$

$$\phi_p = -\frac{\Omega_H}{2\kappa} \ln x + O(x \ln x)$$

$$\theta_p = \theta_0 + O(x)$$



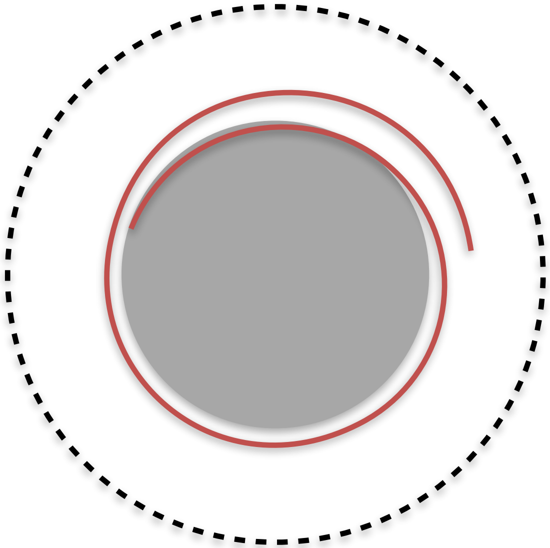
- Source universal radiation: probe of near horizon geometry

Scalar horizon modes

- Sourced wave eq:

$$\Box_g \Phi = -4\pi T$$

$$T = \mu \int d\tau \frac{\delta_4(x^\mu - x_p^\mu)}{\sqrt{-g}}$$



- Green fn in freq domain

$$\Phi \to \frac{1}{r} \int d\omega \sum_{lm} {\color{red} Z_{lm\omega}} e^{-i\omega u + im\phi} S_{lm\omega}(\theta)$$

$$Z_{lm\omega} = \frac{1}{2i\omega B^{\text{in}}} \int_{r_+}^{\infty} dr R^{\text{in}}_{lm\omega} T_{lm\omega}$$

Scalar horizon modes

- Source and integral simplify:

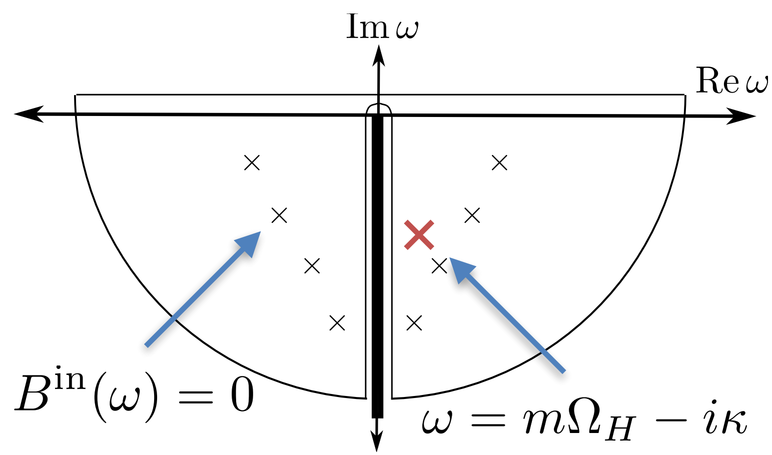
$$T_{lm\omega} \propto e^{i\omega t_p - im\phi_p} \propto x^{-i(\omega - m\Omega_H)/(2\kappa)}$$

$$Z_{lm\omega} \propto \frac{B^{\mathrm{trans}}}{\omega B^{\mathrm{in}}} \int_0^{x_c} dx\, x^{-i(\omega - m\Omega_H)/\kappa} \propto \frac{B^{\mathrm{trans}}}{\omega B^{\mathrm{in}}(\omega)} \frac{x_c^{-i(\omega - m\Omega_H + i\kappa)/\kappa}}{\omega - m\Omega_H + i\kappa}$$

- Poles generate decaying oscillations

$$\Phi_{lm} \sim \frac{1}{r} \int d\omega\, Z_{lm\omega} e^{-i\omega u + im\phi}$$

$$\sim \frac{e^{-i\Omega_H u + im\phi} e^{-\kappa u}}{r} + \Phi_{lm}^{\mathrm{QNM}}$$

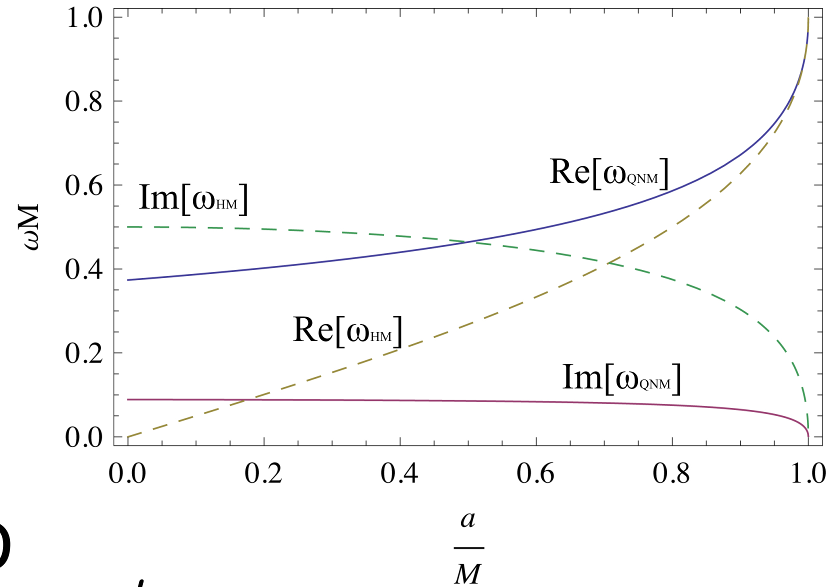


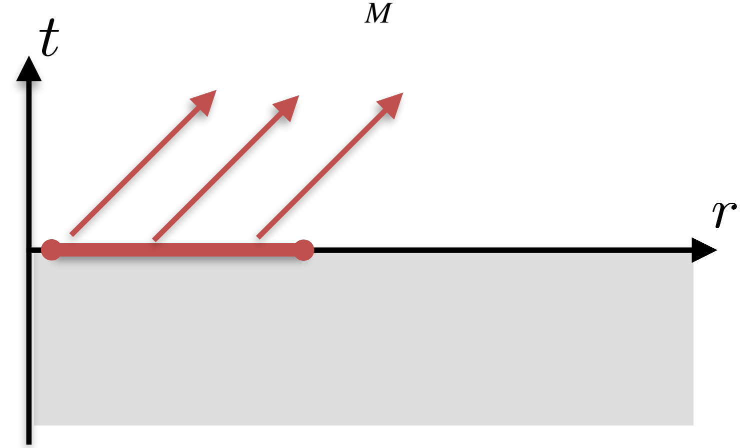
Horizon modes in BBH

- Expect new modes:

$$\omega_{\rm HM} = m\Omega_H - in\kappa$$

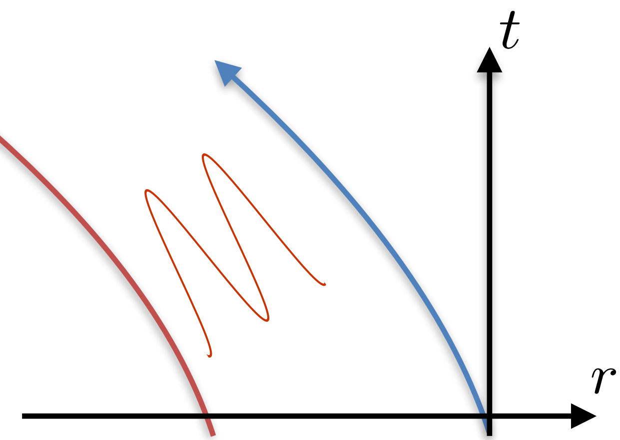
- MB calculated grav case
- AZ, Chen (2011): HMs occur for near horizon ID
- Sign error in MB
- Amplitude and decay rate must be recomputed at higher order





Bounds on decay

- Derive a general bound for spin s fields
- Consider infalling observer outside source $(v, r, \theta, \tilde{\phi})$

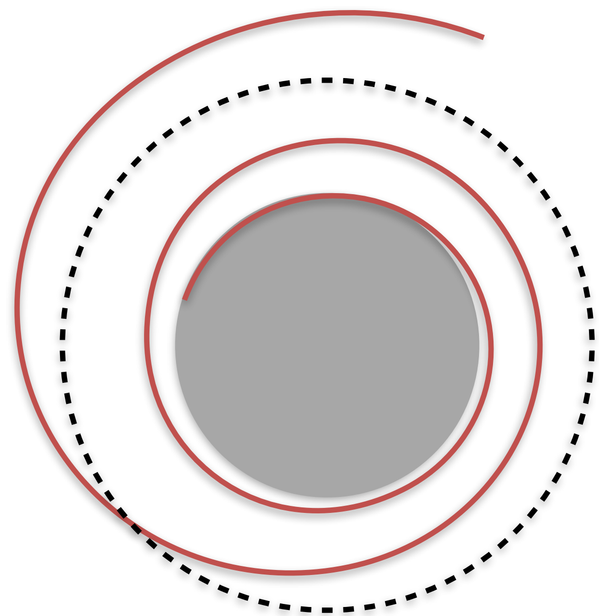


$$\psi_s \sim (r - r_+)^s \exp[-i\omega v + im\tilde{\phi} + 2i(\omega - m\Omega_H)r_*]$$
$$\sim \exp[-i\omega v + im\tilde{\phi} + 2(n+s)\kappa r_*]$$

- For s = -2 (outgoing GWs), n = 2 saturates
- General arguments indicate this is the leading behavior (AZ, Chen 2011), $\omega_{\rm HM} = m\Omega_H - 2i\kappa$

Summary and future work

- Universal near horizon dynamics drives QNM-like modes
- Direct probe of near horizon geometry
- Amplitude for GWs needs high order calc (underway)
- Investigation on detectability underway (Mark, AZ, Chen in prep)



$$\omega_{\rm HM} = m\Omega_H - in\kappa$$