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The imprint of Gas on GWs from LISA IMBH Binaries

Mudit Garg

https://muditgarg96.github.io/

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Toulouse, France

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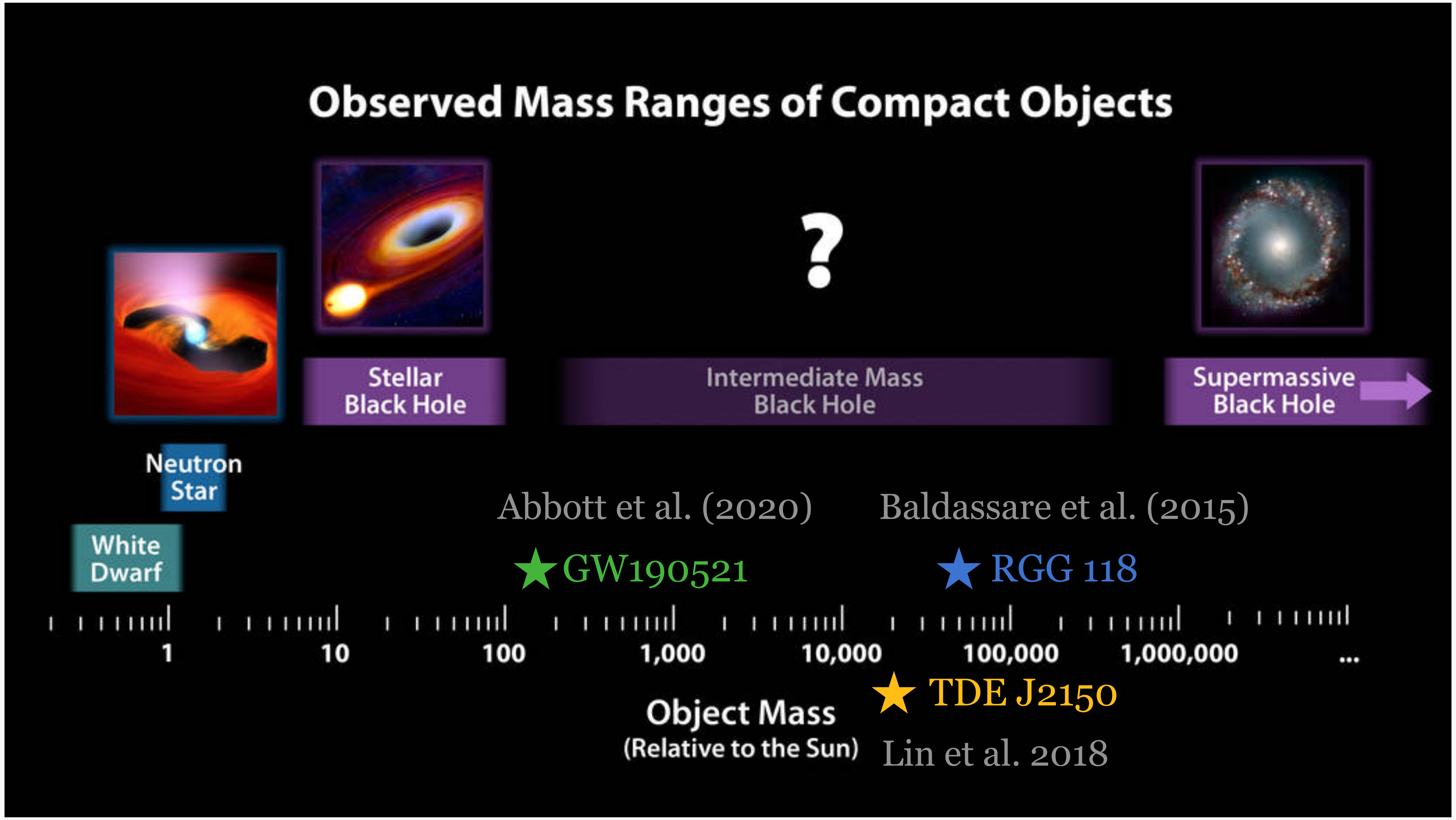
Intermediate Mass Black Hole

Pic Credit: NASA/JPL-Caltech



$$\boxed{M_{\mathrm{IMBH}} \sim 10^2\text{-}10^5 \mathrm{M}_\odot}$$

Intermediate Mass Black Hole

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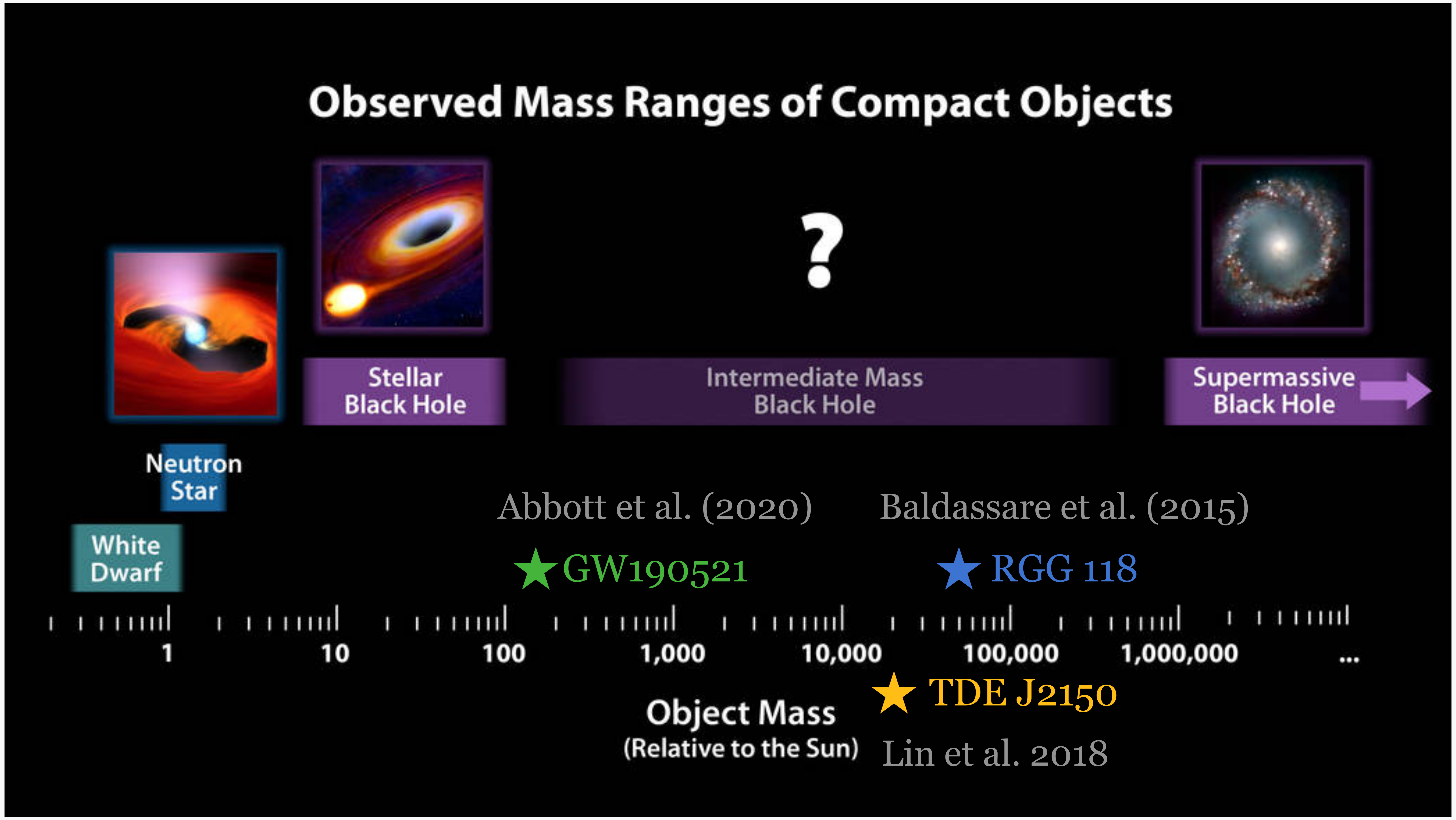


Abbott et al. (2020)

★GW190521

Baldassare et al. (2015)

★ RGG 118

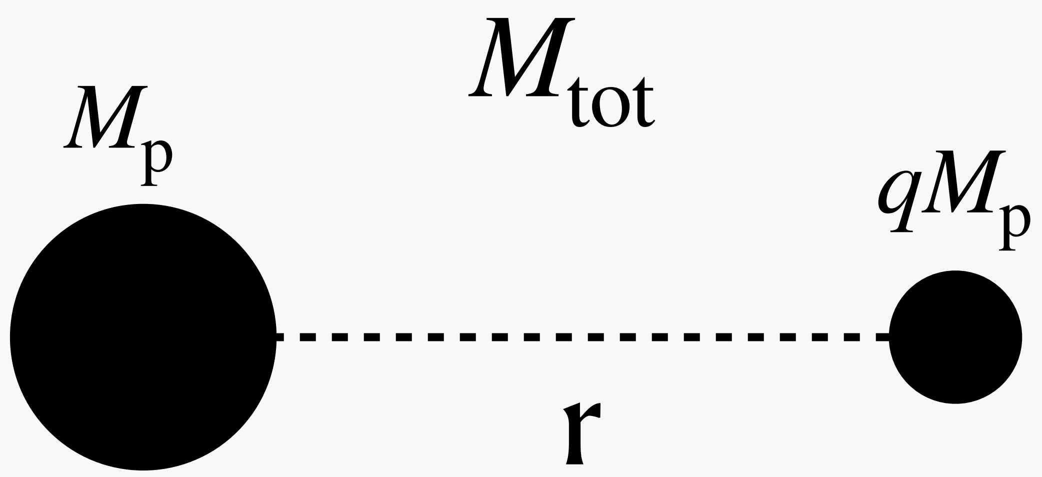
★ TDE J2150

Lin et al. 2018

$$\boxed{M_{\rm IMBH} \sim 10^2\text{-}10^5 M_\odot}$$

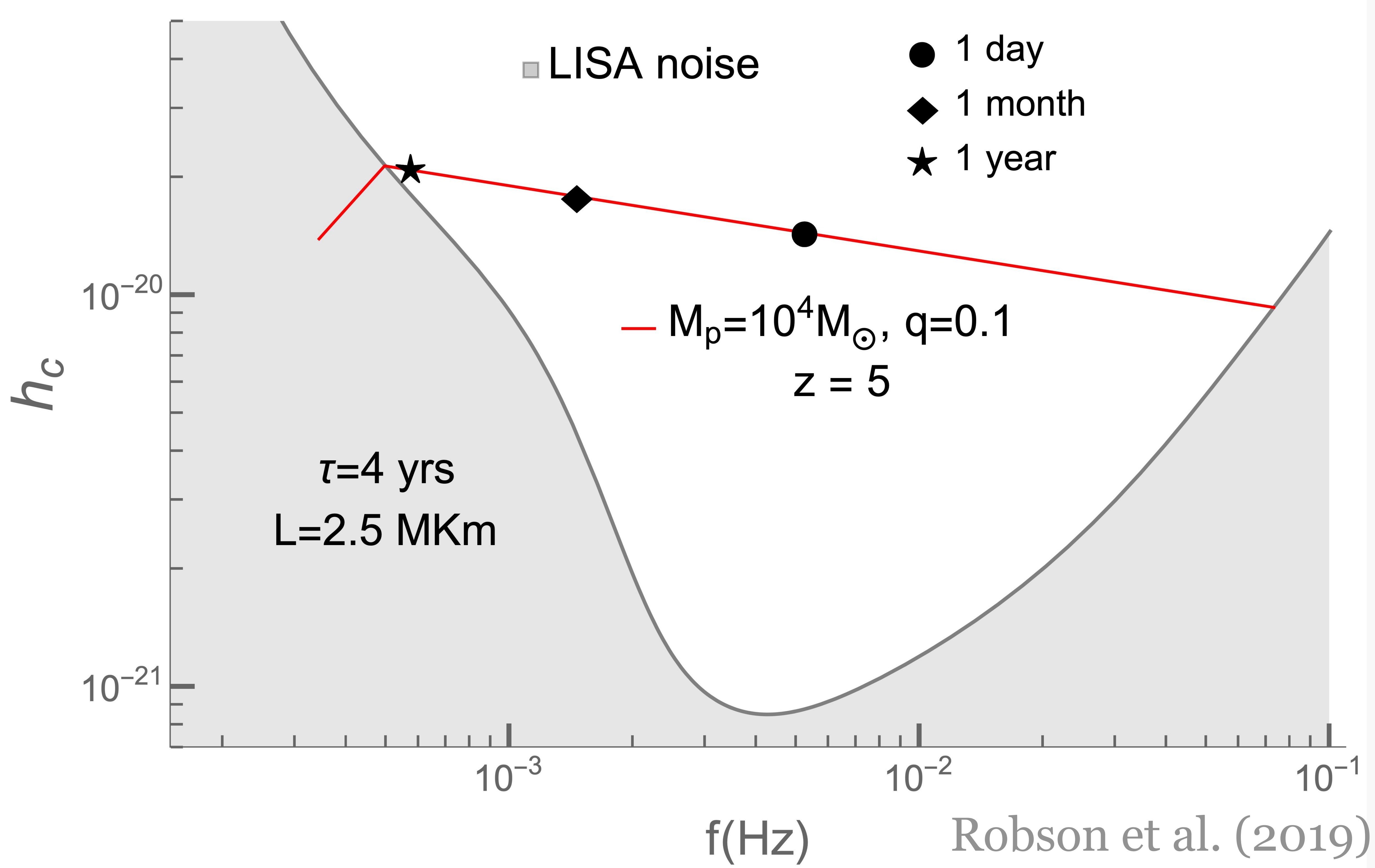
IMBH Binary ≡ both IMBHs

Vacuum IMBHBs in the LISA band



Binary parameters

- Primary mass $M_{\rm p} = 10^3$-10^5 $M_\odot$
- Mass ratios $q = 10^{-3}$-10^{-1}
- Redshifts up to $z = 10$



Robson et al. (2019)

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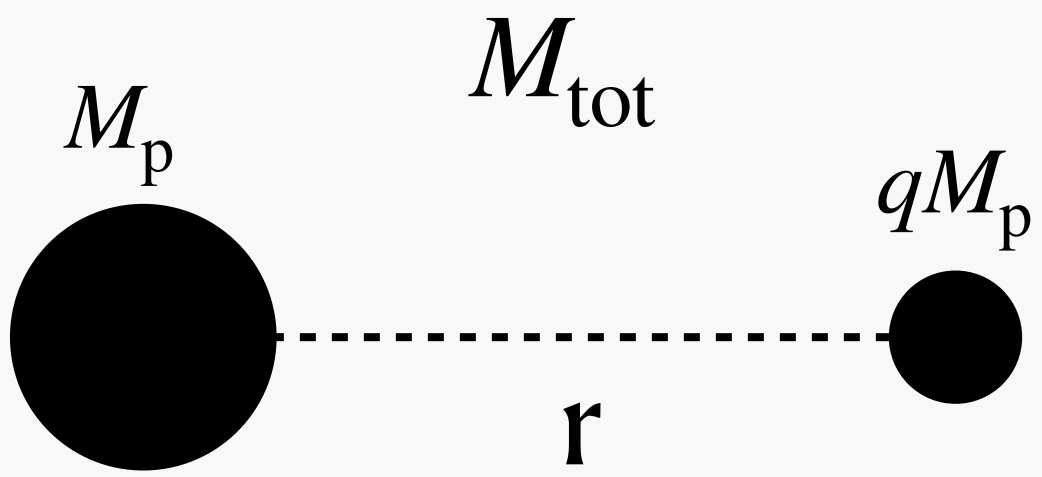

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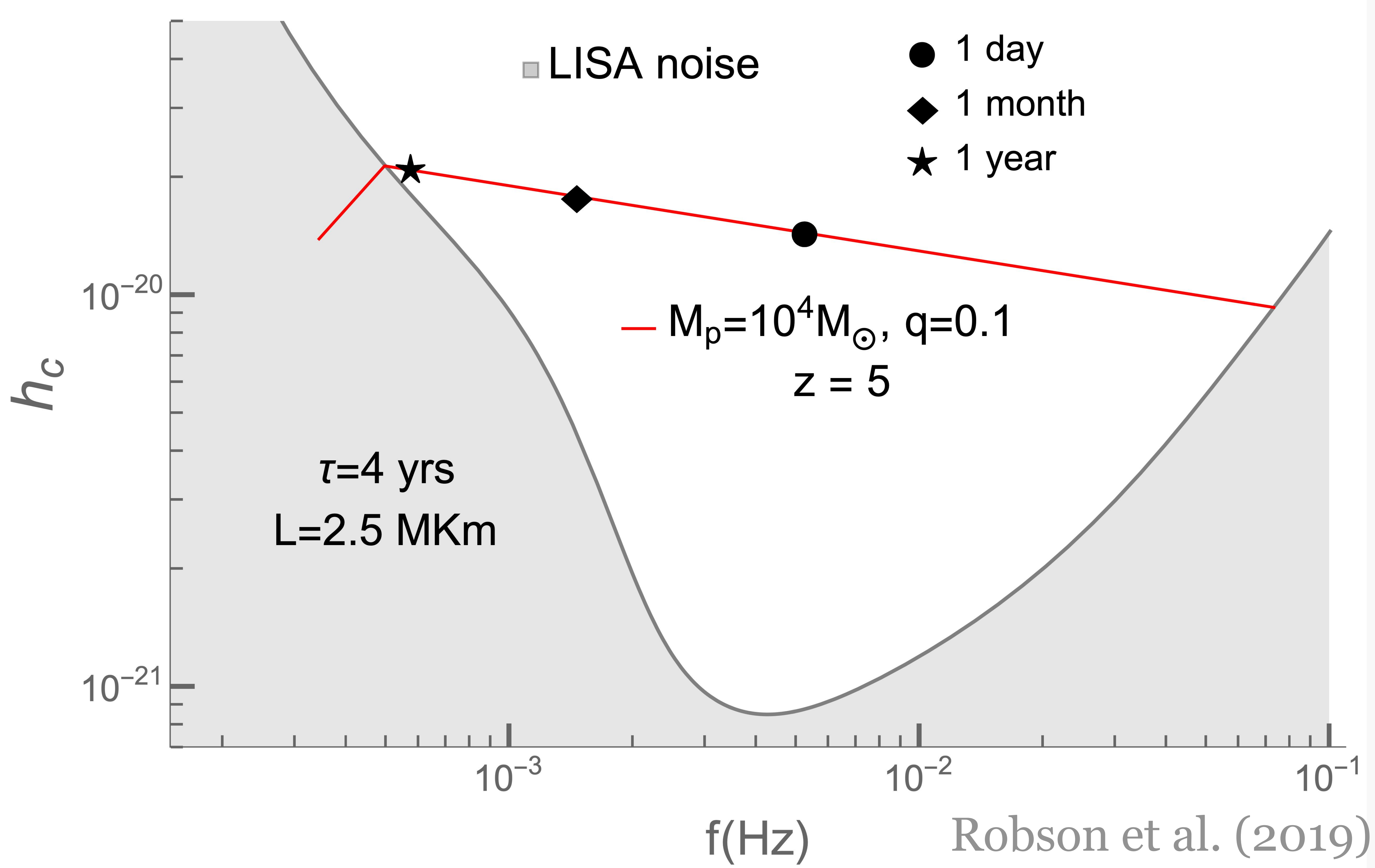
- SNR $\sim 5 - 1000$ (Threshold SNR ≥ 8)

Garg et al. (2022)



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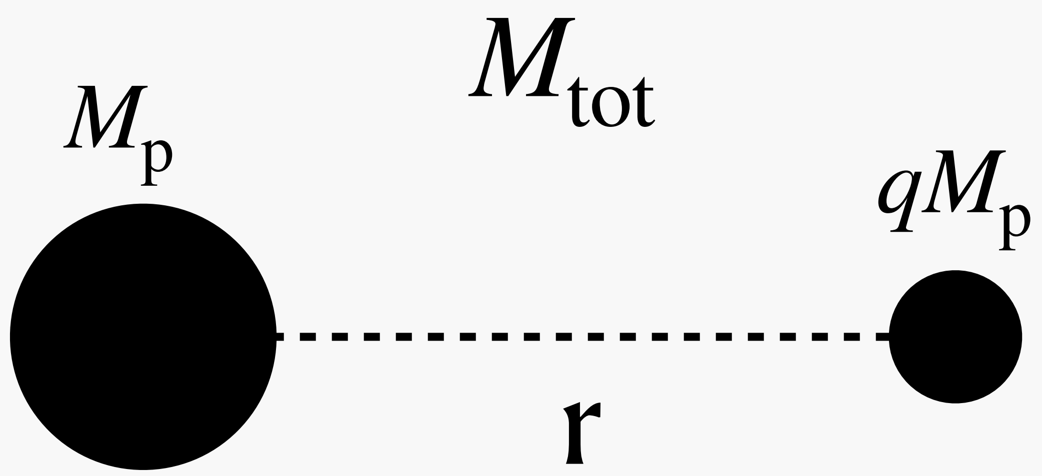

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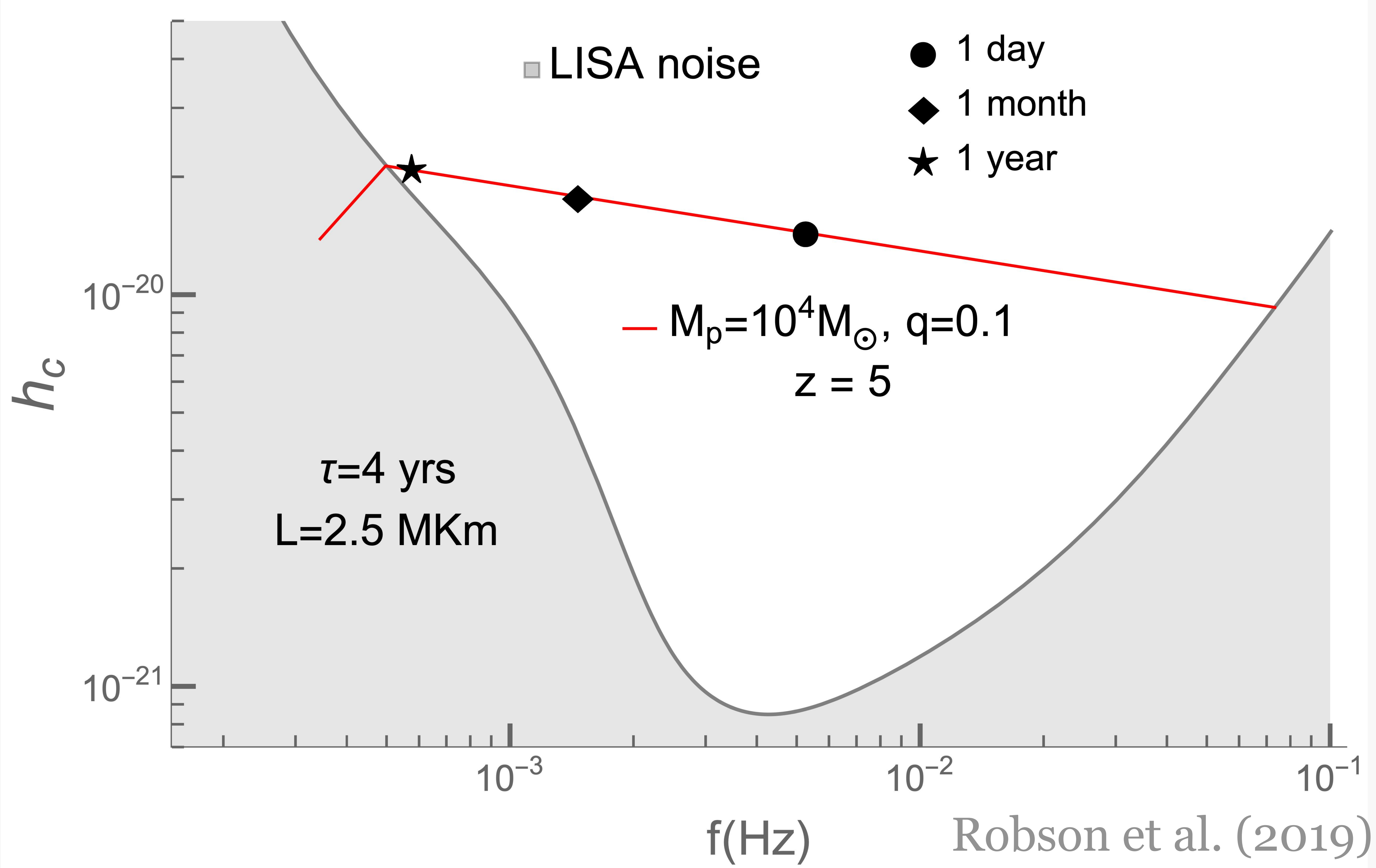

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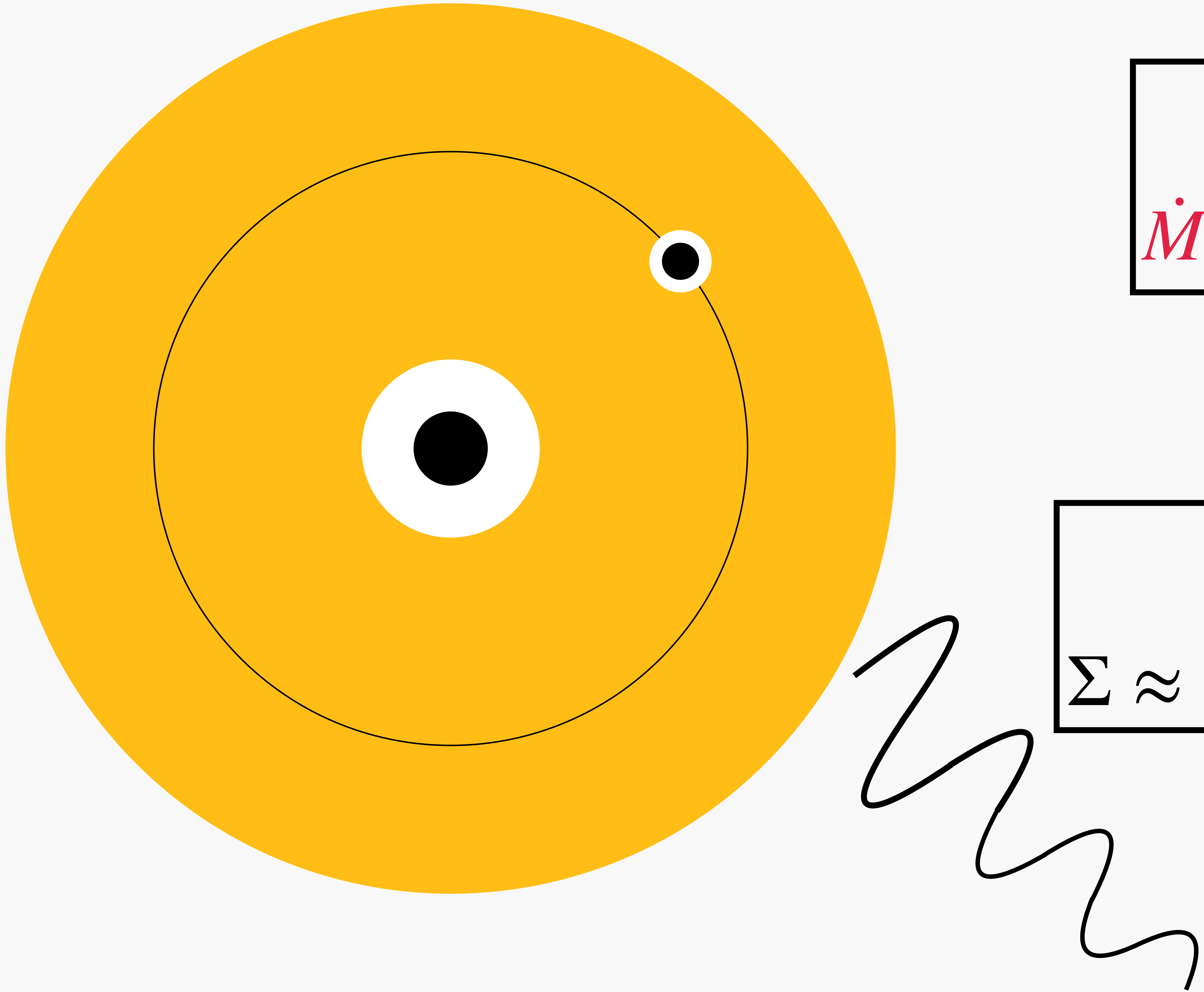
Only circular case!

Only Newtonian order!

Only Quadrupole term!

IMBH binary embedded in a gas disc



Shakura & Sunyaev (1973)

$$\alpha = 0.01$$

$$\dot{M} = 0.1\dot{M}_{\mathrm{Edd}}$$

$$\mathscr{M}_{\mathrm{a}} \approx 80$$

$$\Sigma \approx 2 \times 10^5 \ \mathrm{g\,cm^{-2}}$$

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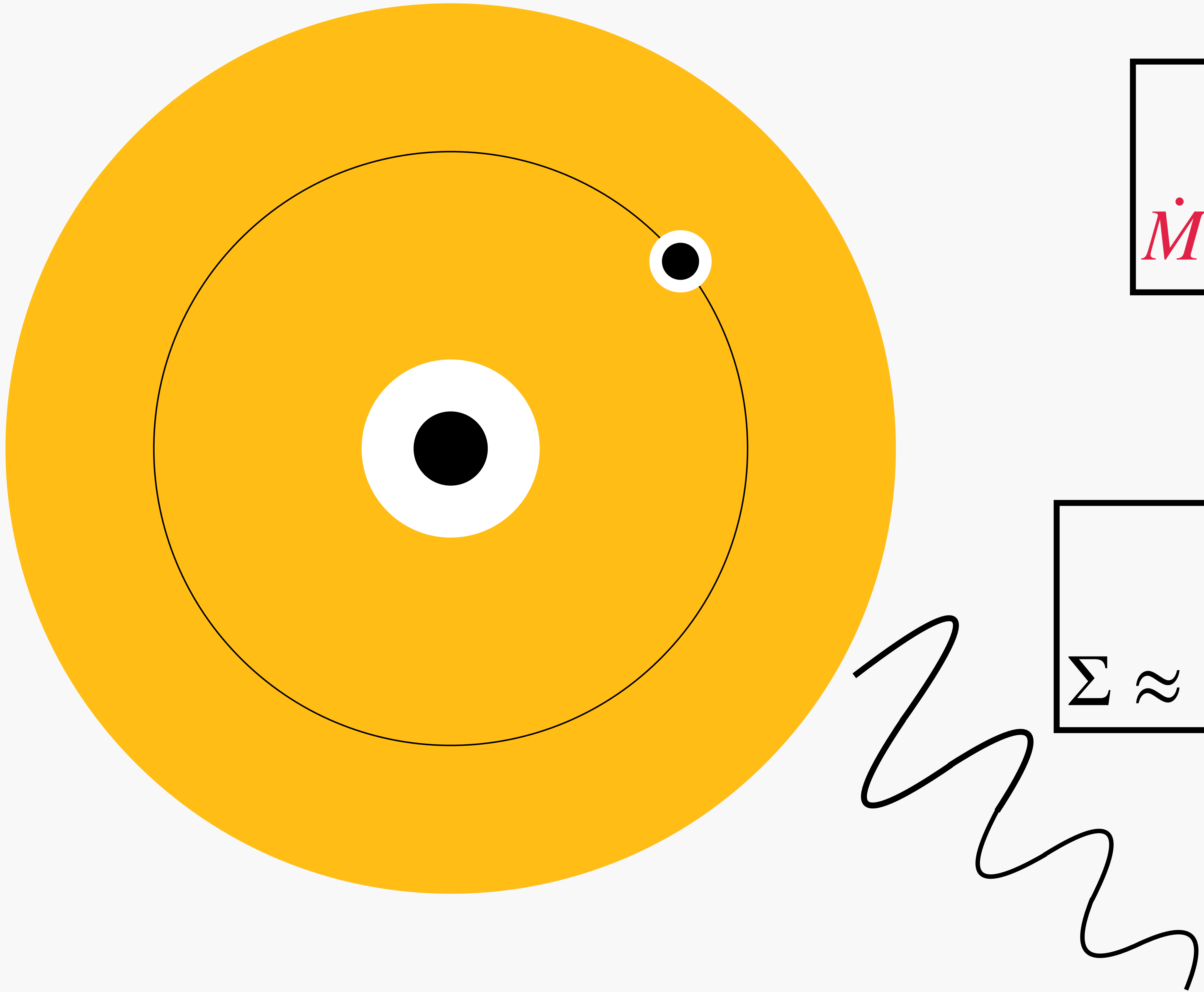

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Gas can follow the binary till the merger

MacFadyen & Milosavljeíc (2008); Haiman et al. (2009); Duffell et al. (2014); Farris et al. (2014); D'Orazio et al. (2016); Kanagawa et al. (2018); Duffell et al. (2020); Muñoz et al. (2020); Tiede et al. (2020); Derdzinski et al. (2019, 2021)

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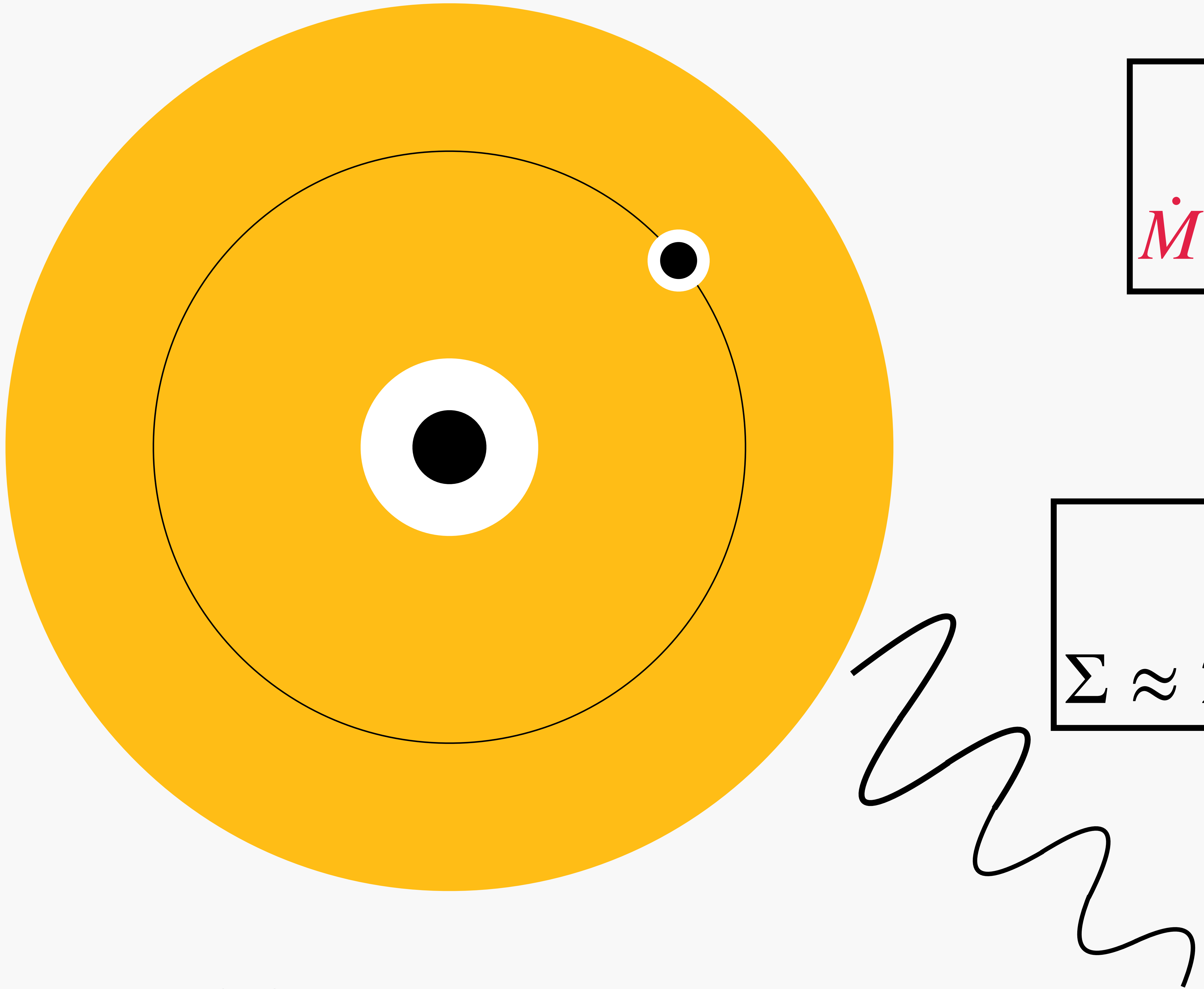

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But IMBHB can open a gap/cavity!

Garg et al. (2022)

IMBHB opens a gap/cavity

Garg et al. (2022)

$q < 0.04 \implies$ **Gap**

D’Orazio et al. (2016)

$q > 0.04 \implies$ **Cavity**

IMBHB opens a gap/cavity

Garg et al. (2022)

$$= \dot{M} r^2 \Omega$$

$$\boxed{\Gamma_{\rm gas} = (0.1, 10)\ \Gamma_{\rm vis}}$$

Fung et al. (2014), Farris et al. (2014), Duffell et al. (2014, 2020), Kanagawa et al. (2018), Dittmann & Ryan (2022)

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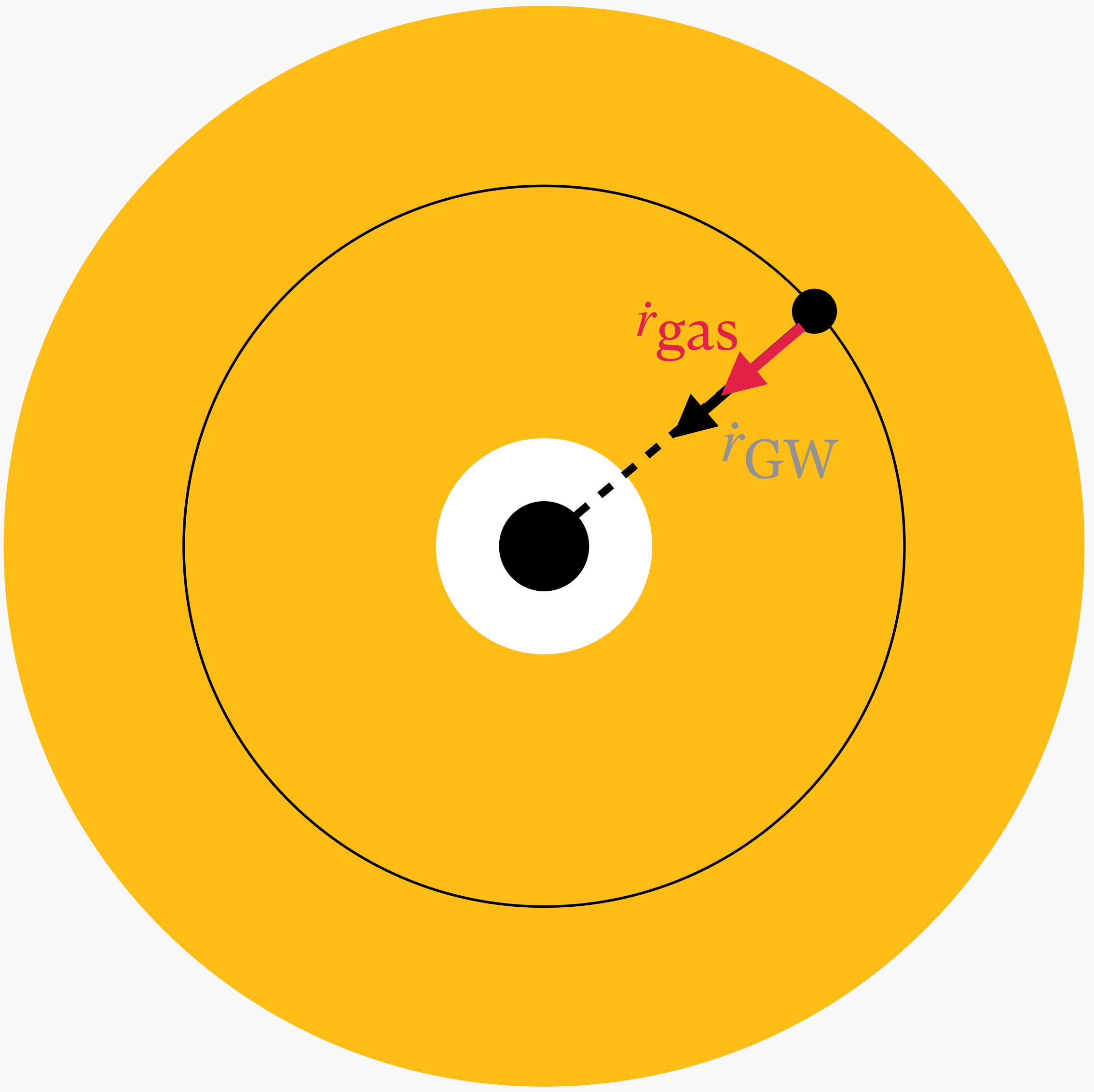
$$\boxed{\dot{r}_{\rm gas} \propto \Gamma_{\rm gas}}$$

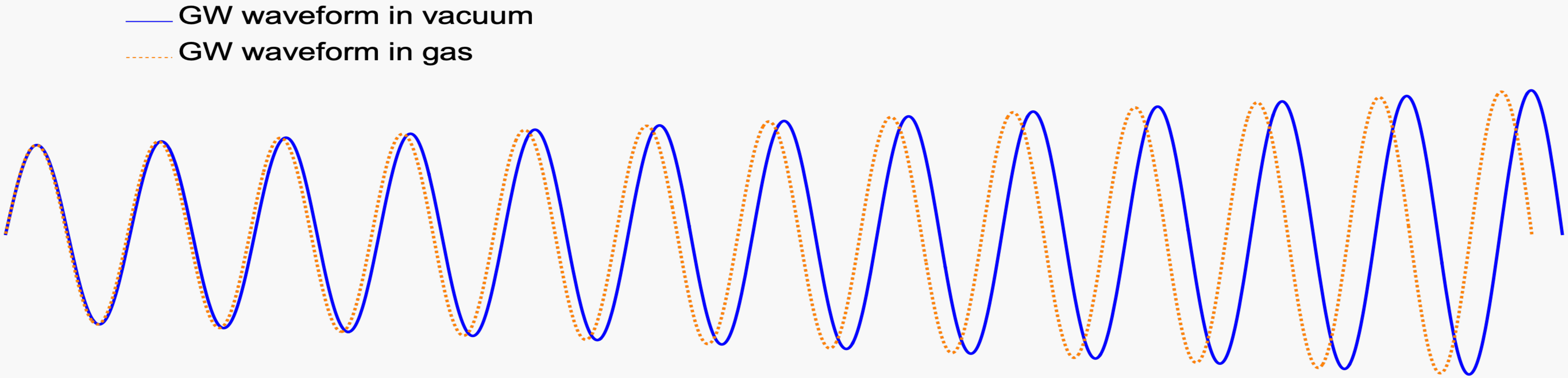


We assume inwards $\dot{r}_{\rm gas}$ only!

$$\boxed{\dot{r} = \dot{r}_{\rm GW} + \dot{r}_{\rm gas} \text{ due to } \dot{r}_{\rm gas} \ll \dot{r}_{\rm GW}}$$

Gas signatures in the GW phase

Stationary phase approximation: gas affect phase not amplitude



Dephasing : $\delta\phi = |\Phi_{\mathrm{GW}} - \Phi_{\mathrm{GW+Gas}}|$

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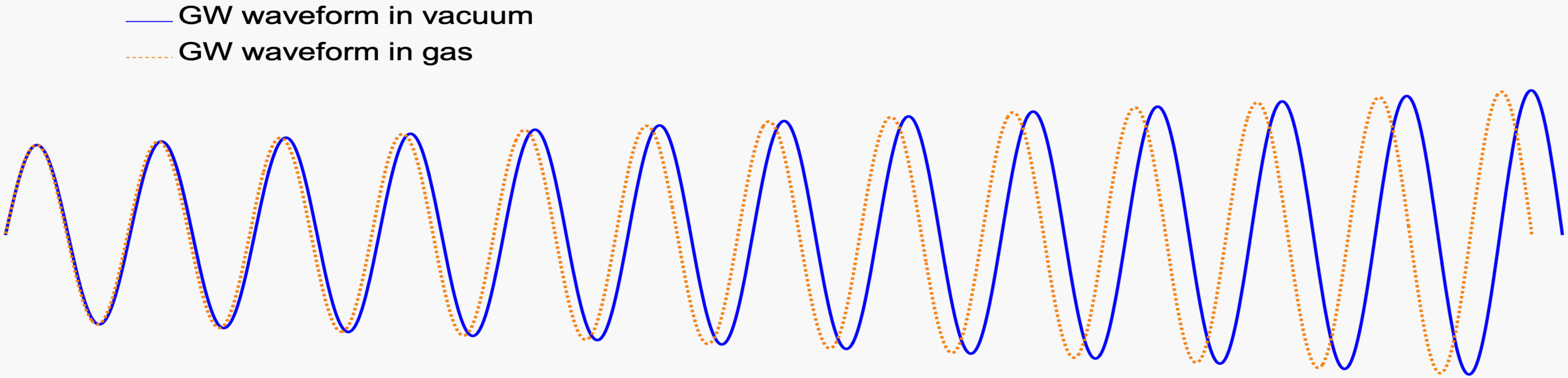


Dephasing : $\delta\phi = |\Phi_{\rm GW} - \Phi_{\rm GW+Gas}|$

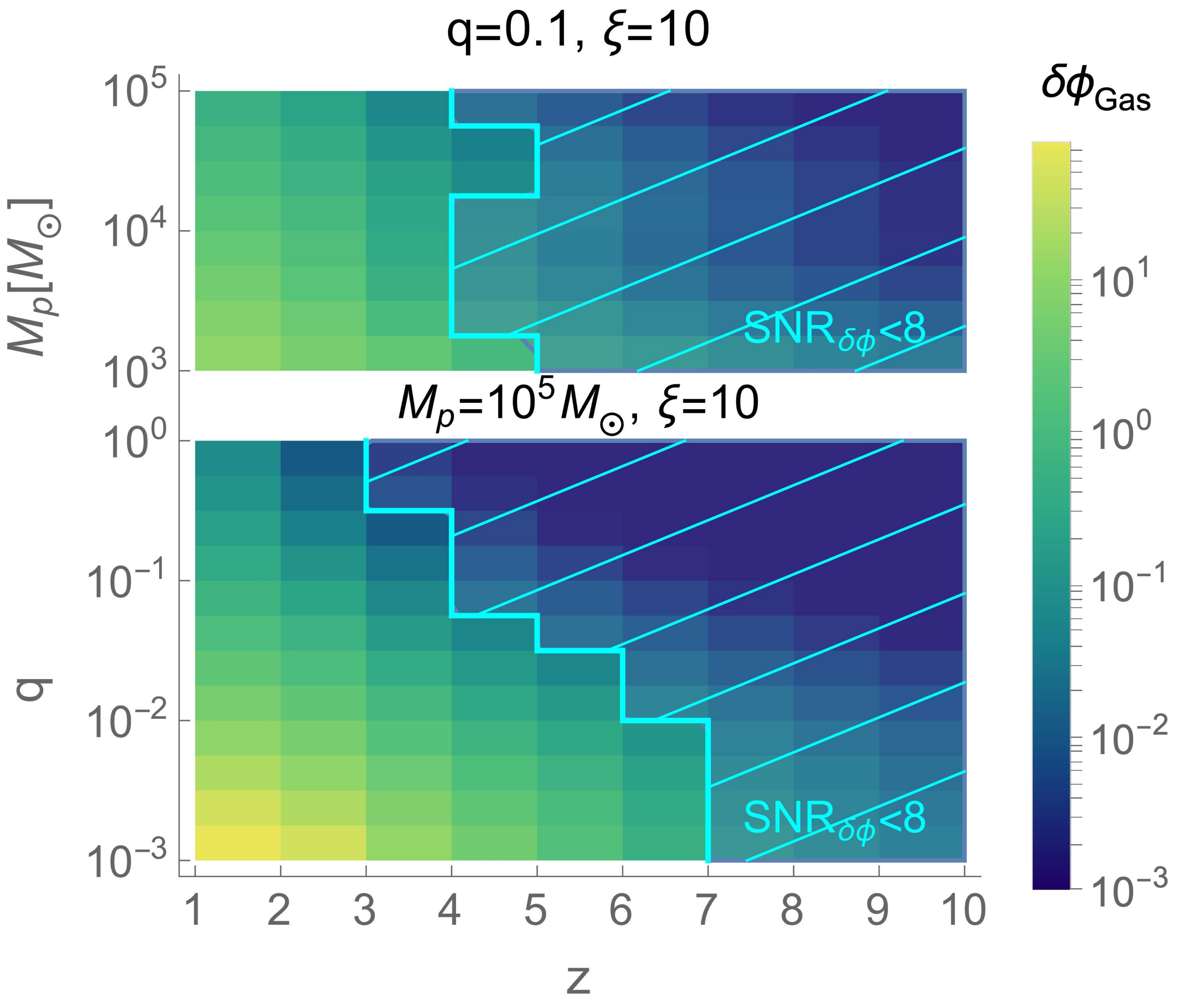
Dephasing for EMRIs

Detectable for a subset of EMRIs at $z \lesssim 1$

Yunes et al. (2011), Kocsis et al. (2011), Barausse et al. (2014), Derdzinski et al. (2019, 2021)

Dephasing in IMBHBs due to gas

Garg et al. (2022)



Two sets of IMBHBs

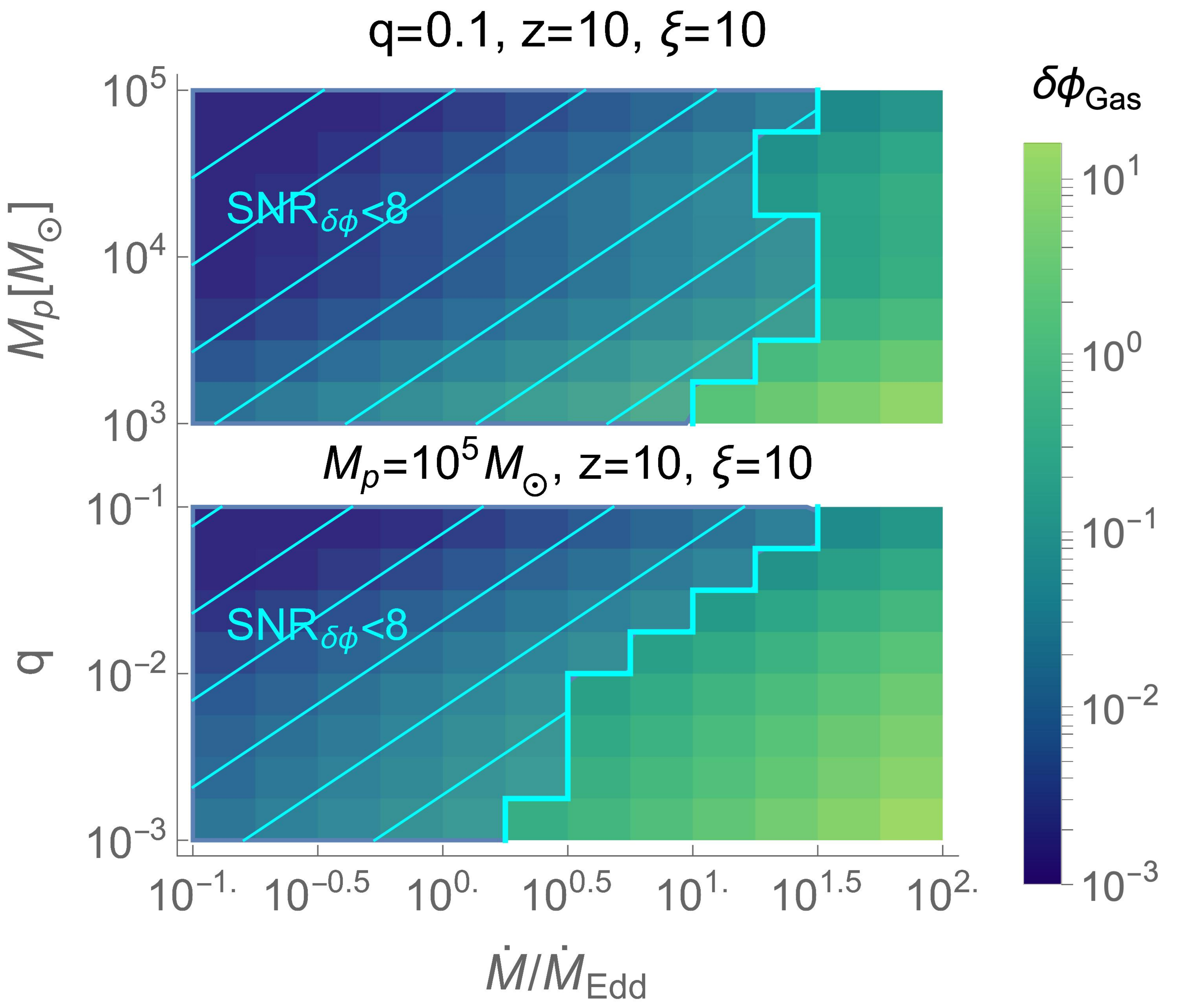
- $M_p = 10^3\text{-}10^5\ M_\odot$ & $q = 0.1$
- $M_p = 10^5\ M_\odot$ & $q = 10^{-3}\text{-}10^0$

Detectable dephasing

Up to ~ 96 radians or ~ 15 GW cycles

What about high z IMBHBs?

Garg et al. (2022)



Simply scaling $\Gamma_{\rm vis} = \dot{M} r^2 \Omega$

Conclusion

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Thank you for your attention

Questions? Comments? Feedback?

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