Constraints on PBH binaries from N-body simulations

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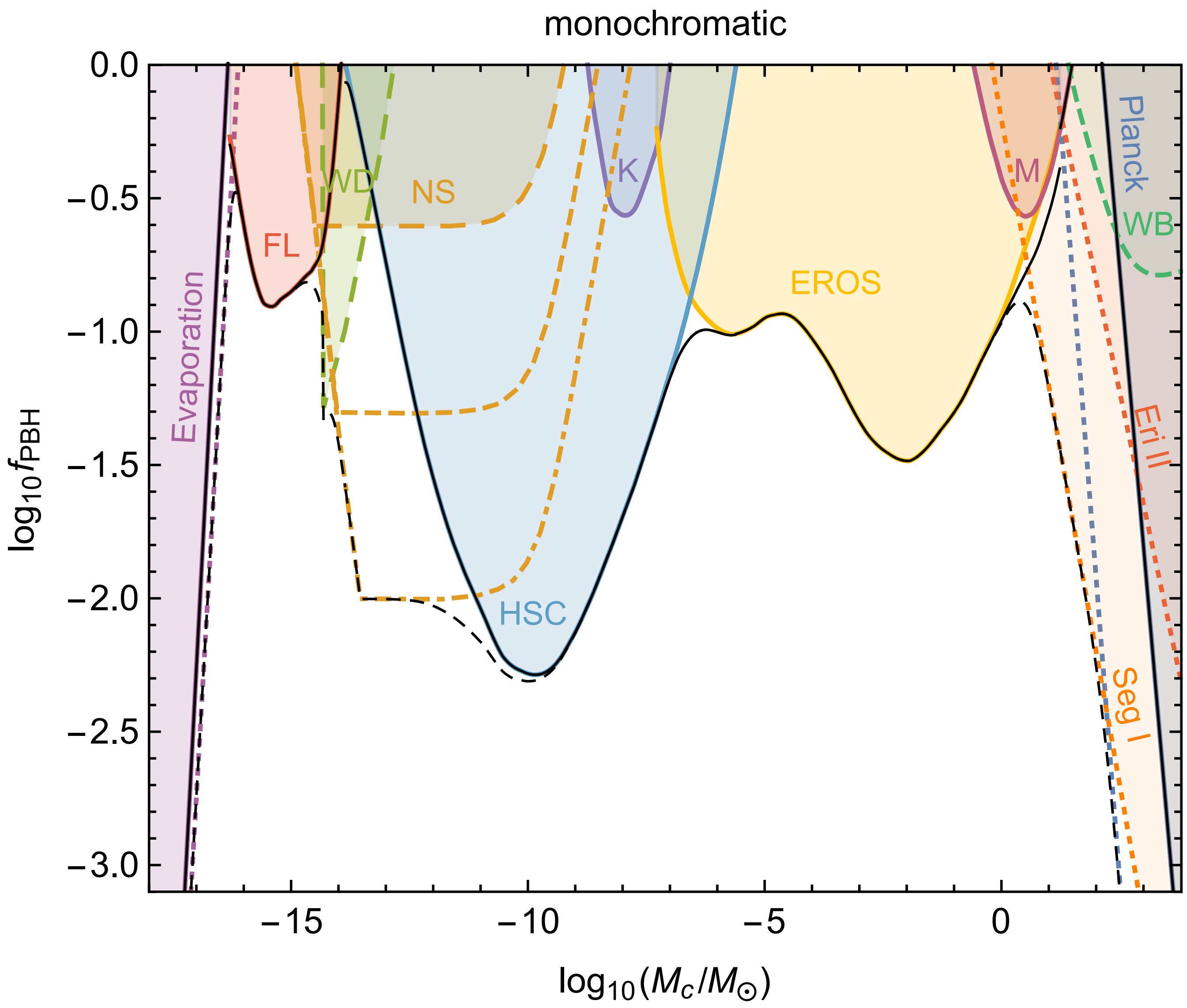
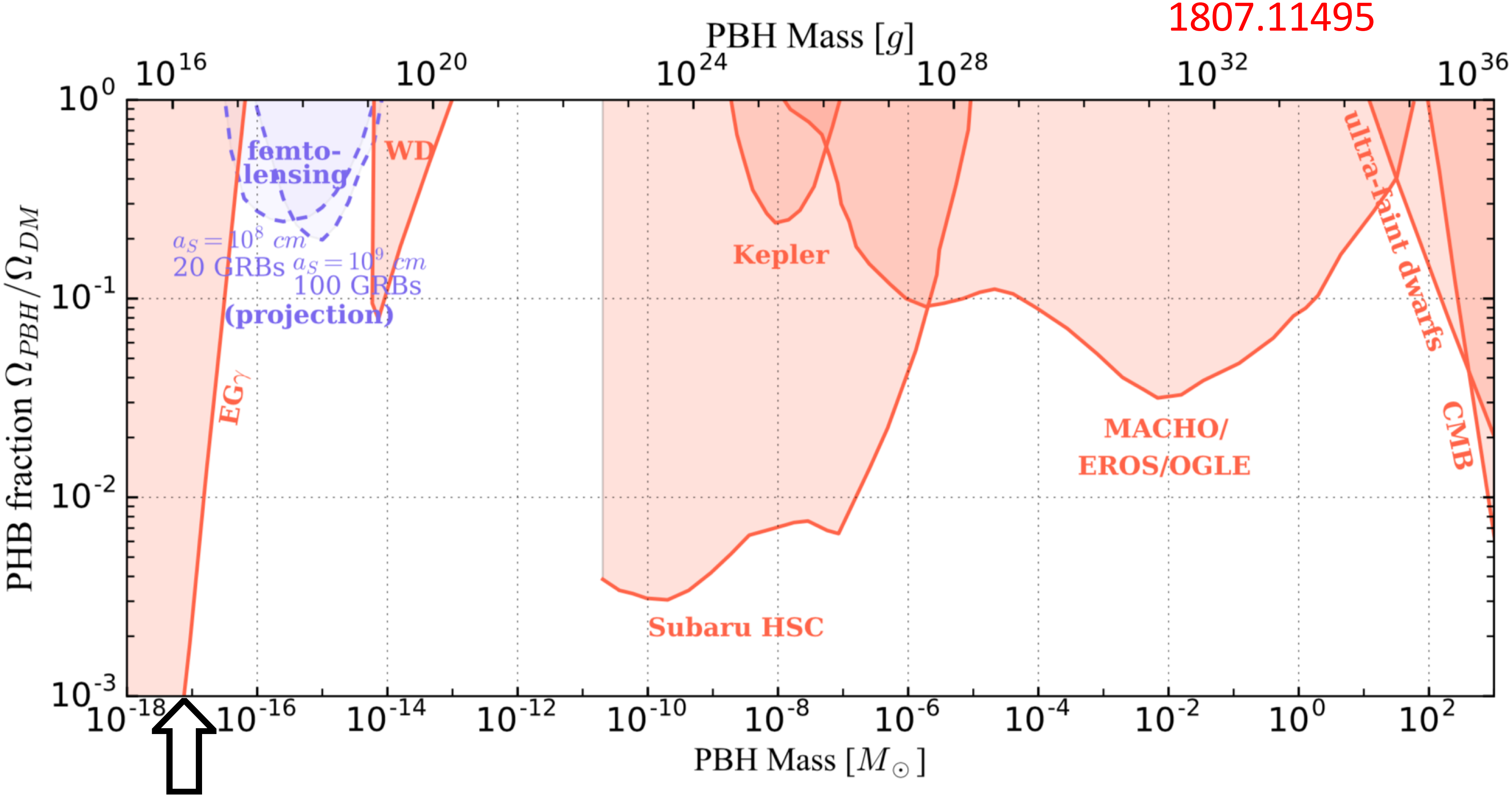
arXiv:1812.01930

Constraints from Carr et al., arXiv:1705.05567



Wave optics and GRB finite size effects

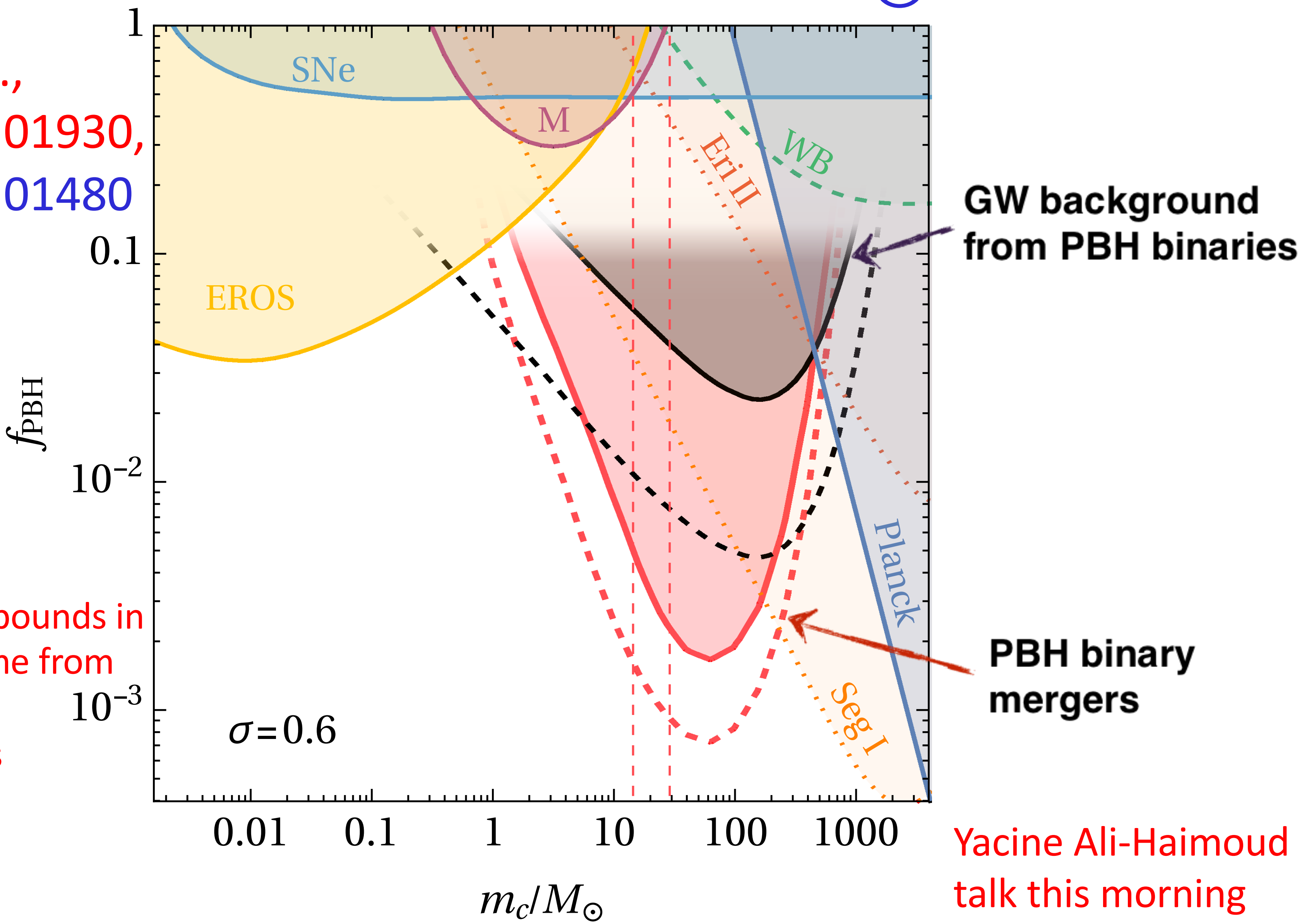
1807.11495



Raidal et al., arXiv:1802.07728 (bound from Hawking radiation can be removed)

The LIGO region of 20 $M_\odot$ PBHs

Raidal et al., arXiv:1812.01930, arXiv:1707.01480



The strongest bounds in this region come from the LIGO GW measurements

Yacine Ali-Haimoud talk this morning

Lognormal mass function

- Assume a mass function of the form

$$\psi(M) = \frac{f_{\mathrm{PBH}}}{\sqrt{2\pi}\sigma M} \exp\left(-\frac{\log^2(M/M_c)}{2\sigma^2}\right)$$

- We converted the bounds for mass functions

$$f_{\mathrm{PBH}} \equiv \frac{\Omega_{\mathrm{PBH}}}{\Omega_{\mathrm{DM}}} = \int \mathrm{d}M\, \psi(M)$$

- The strongest bounds in this region come from the LIGO GW measurements

The merger rate of PBH binaries

Merger rate of PBH binaries at t

=

Density of initial conditions (pairs)

×

P(PBH binary with coalescence time t | initial conditions)

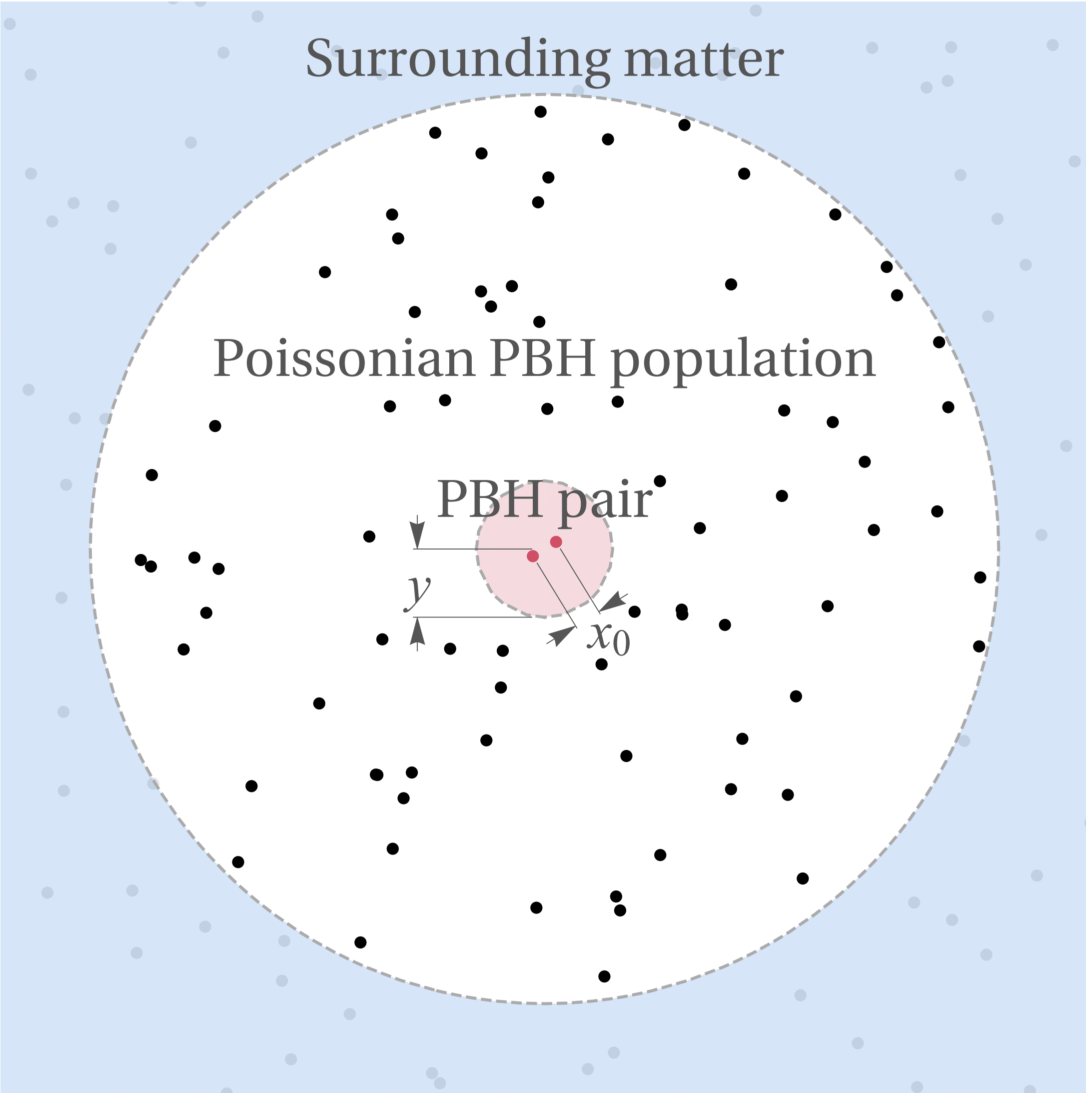
Teruaki Suyama's talk yesterday

astro-ph/9708060
astro-ph/9807018
arXiv:1707.01480
arXiv:1709.06576

$$\mathrm{d}R = \int \mathrm{d}n_{\mathrm{b}} \mathrm{d}j \frac{\mathrm{d}P}{\mathrm{d}j} \delta\left(\tau - \frac{3}{85} \frac{r_a^4}{\eta M^3} j^7\right)$$

$$= \frac{1}{14\tau} \mathrm{d}n(m_1) \mathrm{d}n(m_2) \int \mathrm{d}V(x_0) e^{-\bar{N}(y)} j \frac{\mathrm{d}P(j|x_0, y)}{\mathrm{d}j}\bigg|_{j=j(\tau)}$$

Formation of PBH binaries in early Universe



- Initially close pairs form binaries
- Tidal forces fix the eccentricity
- Coalescence time

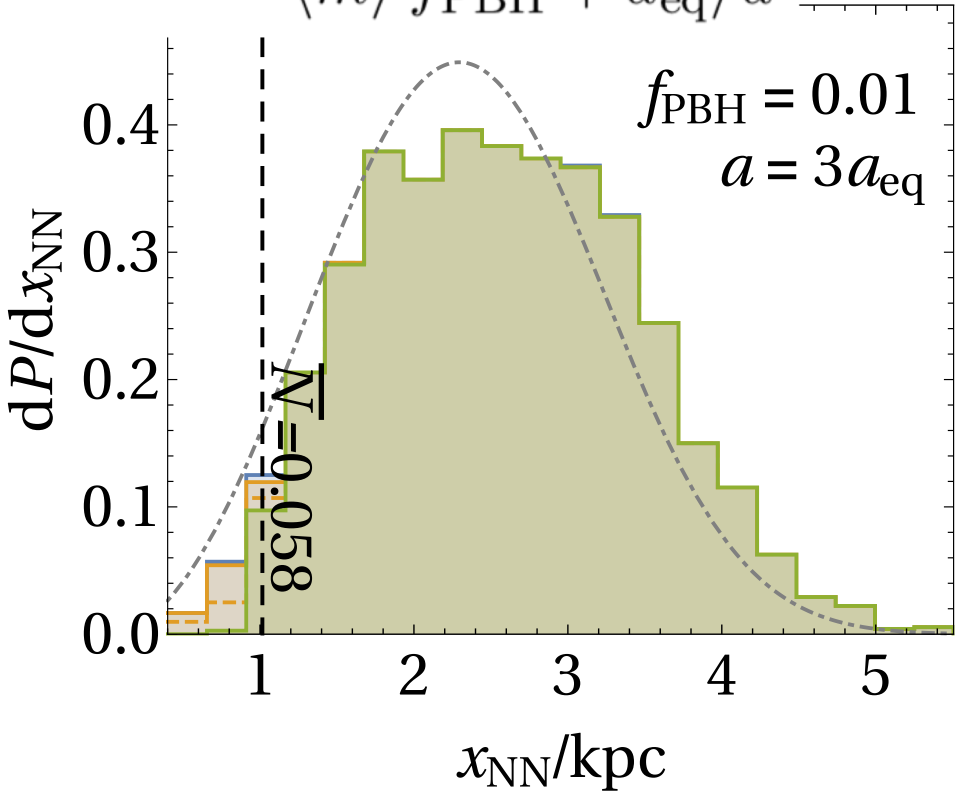
$$\tau = \frac{3}{85}\frac{r_a^4}{\eta M^3} j^7$$

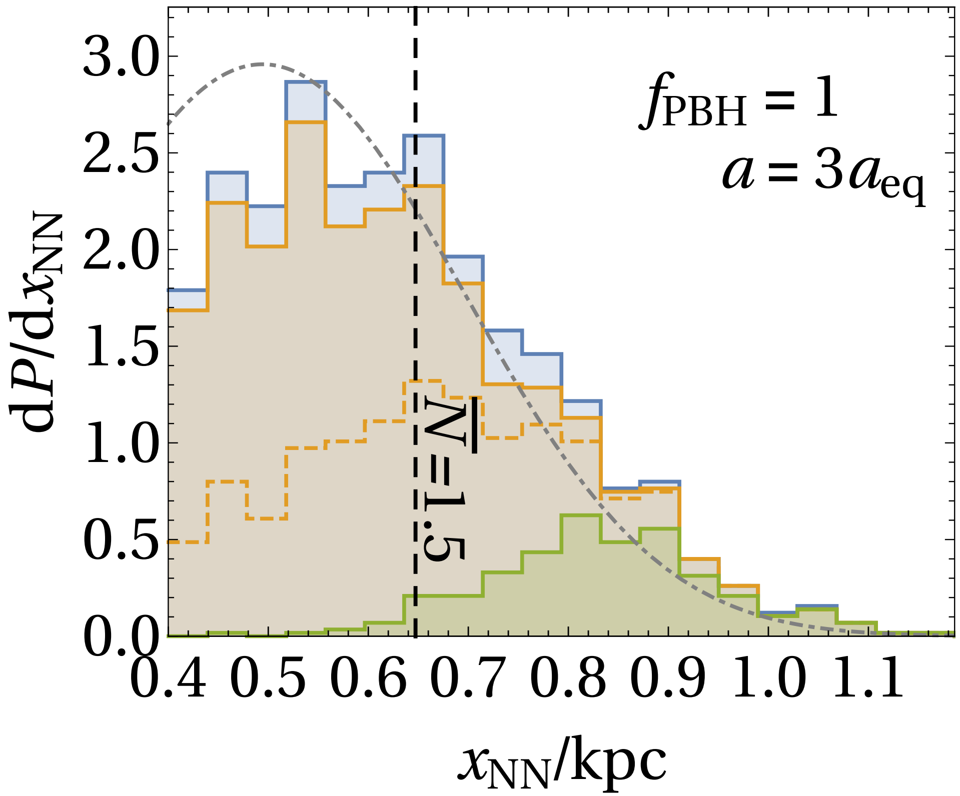
- Approximation: the binary evolution depends on x, y:

$$\bar{N}(y) \equiv nV(y)$$

The fate of initial binaries

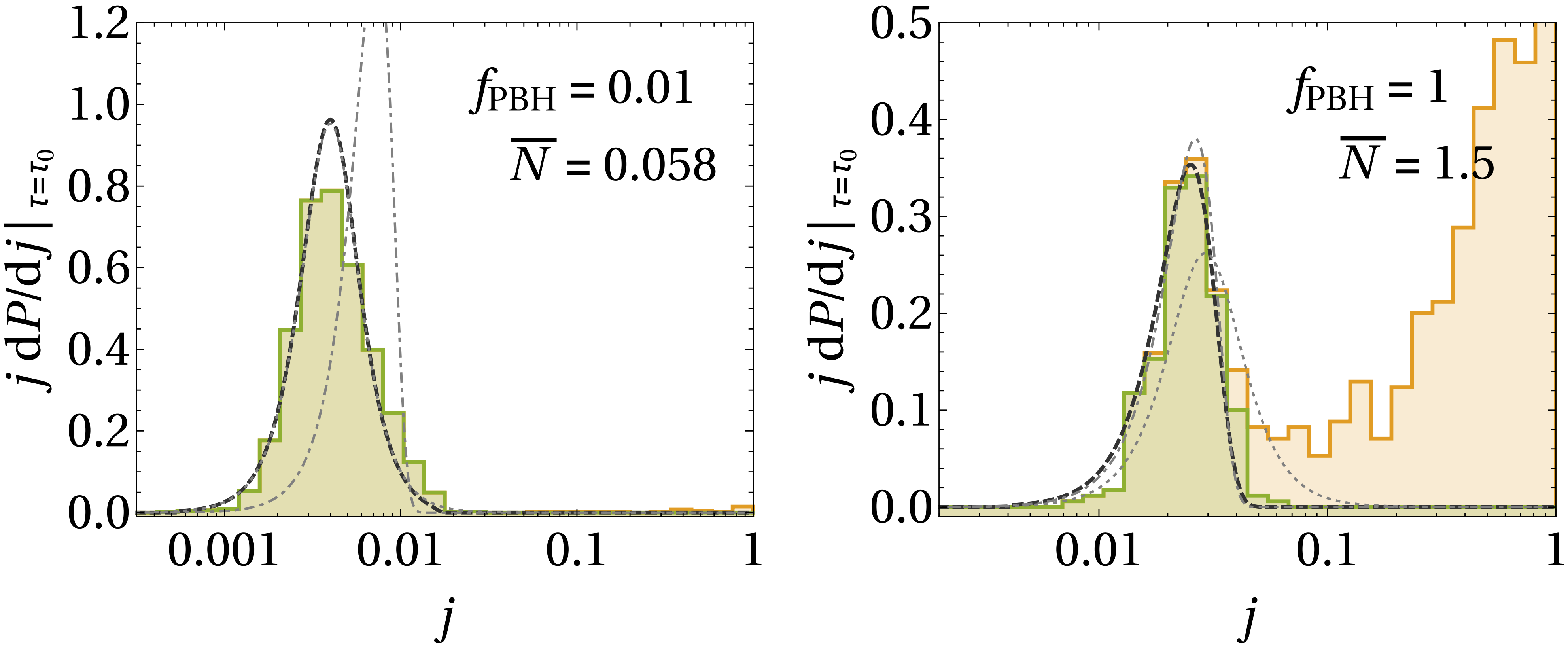
$$\bar{N}(y) \approx \frac{M}{\langle m \rangle} \frac{f_{\rm PBH}}{f_{\rm PBH} + a_{\rm eq}/a}$$





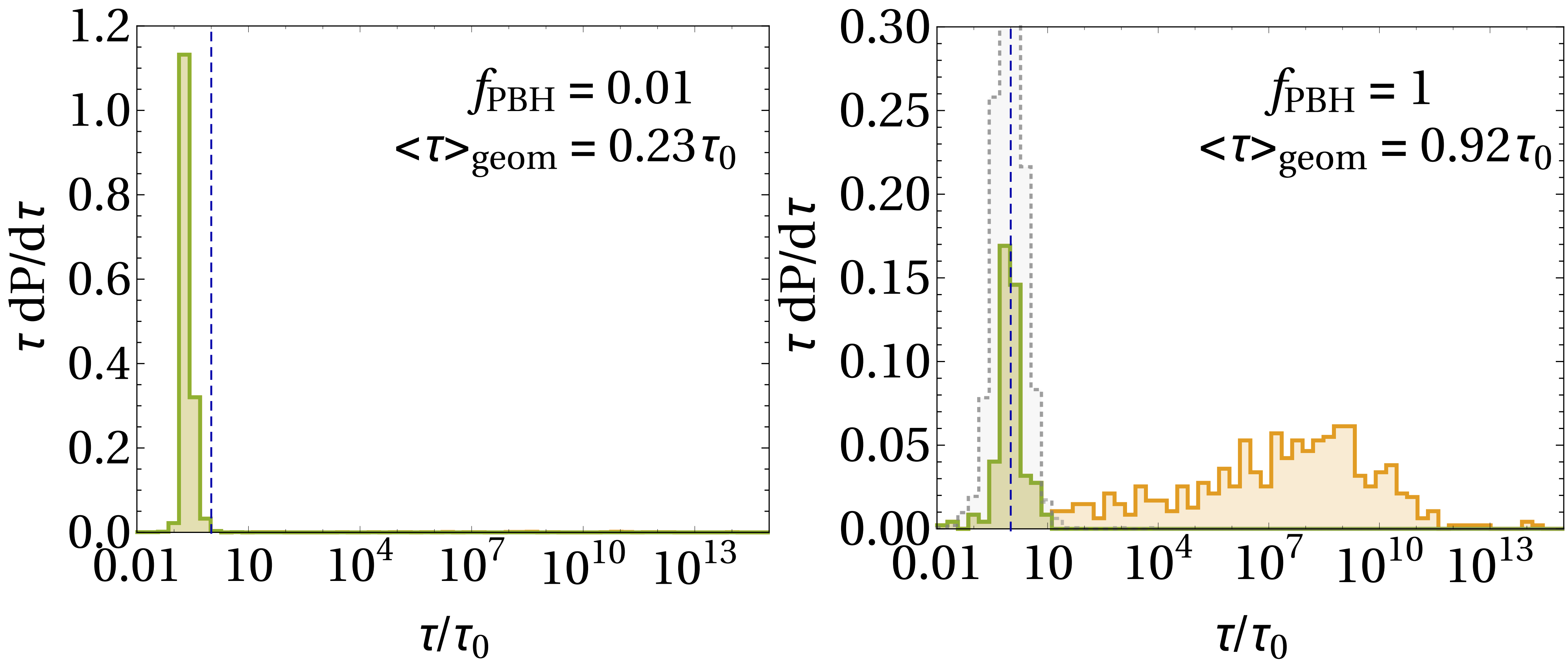
- For small $f_{\rm PBH}$: most of the initial binaries remains un-disturbed
- For $f_{\rm PBH}=1$: most of the initial binaries are destroyed

Initial binaries are highly eccentric

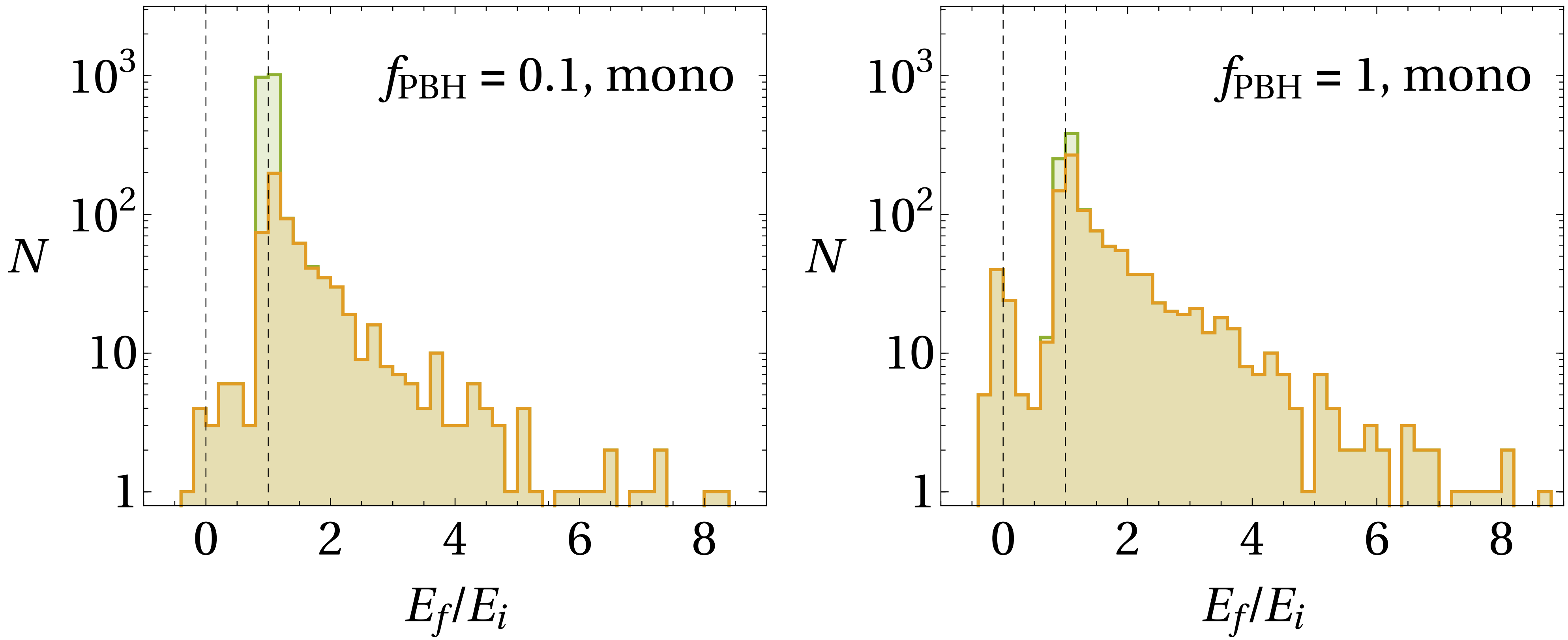


The perturbed binaries tend to have more circular orbits

Coalescence time increased by many orders of magnitude

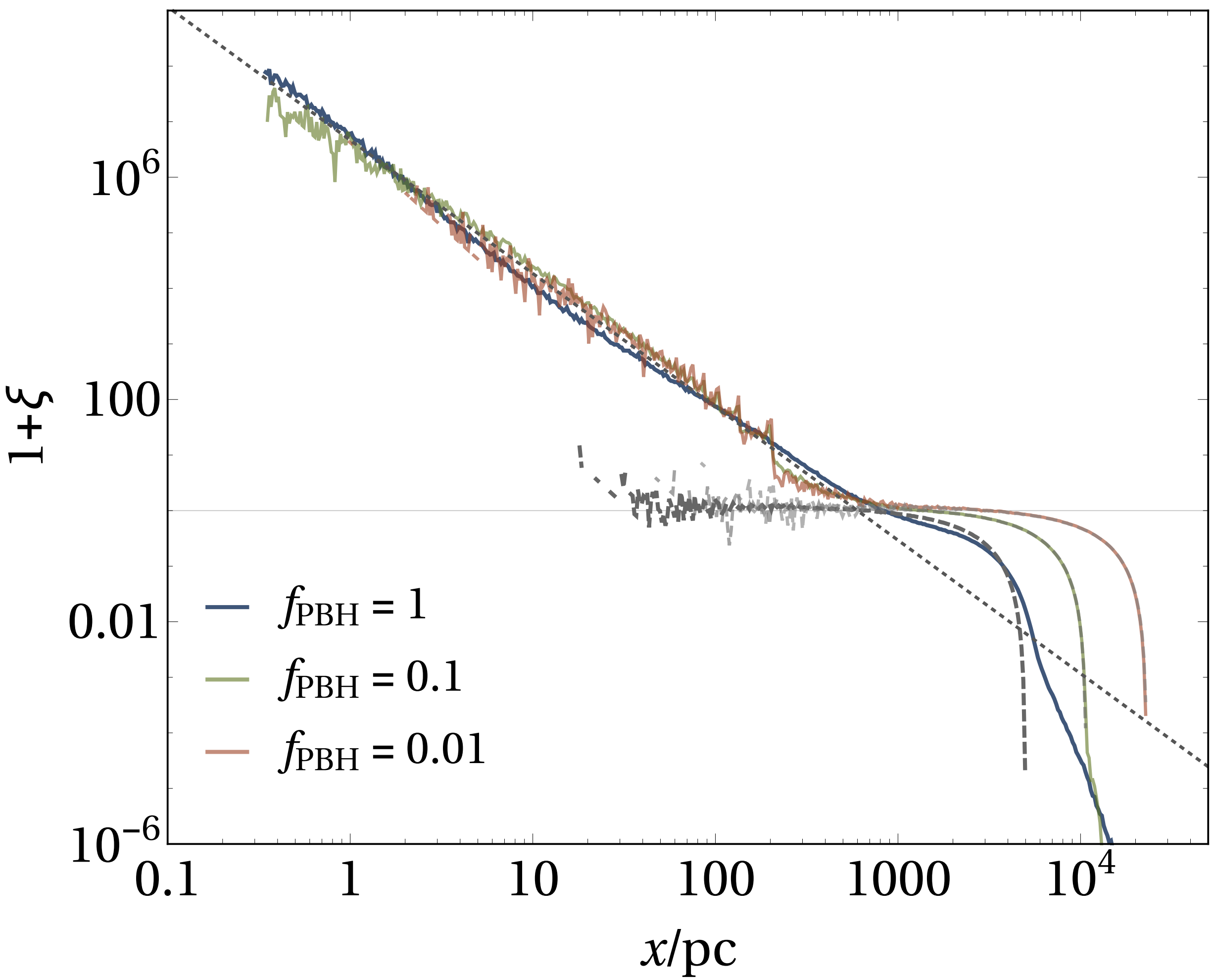


Binding energy is increased



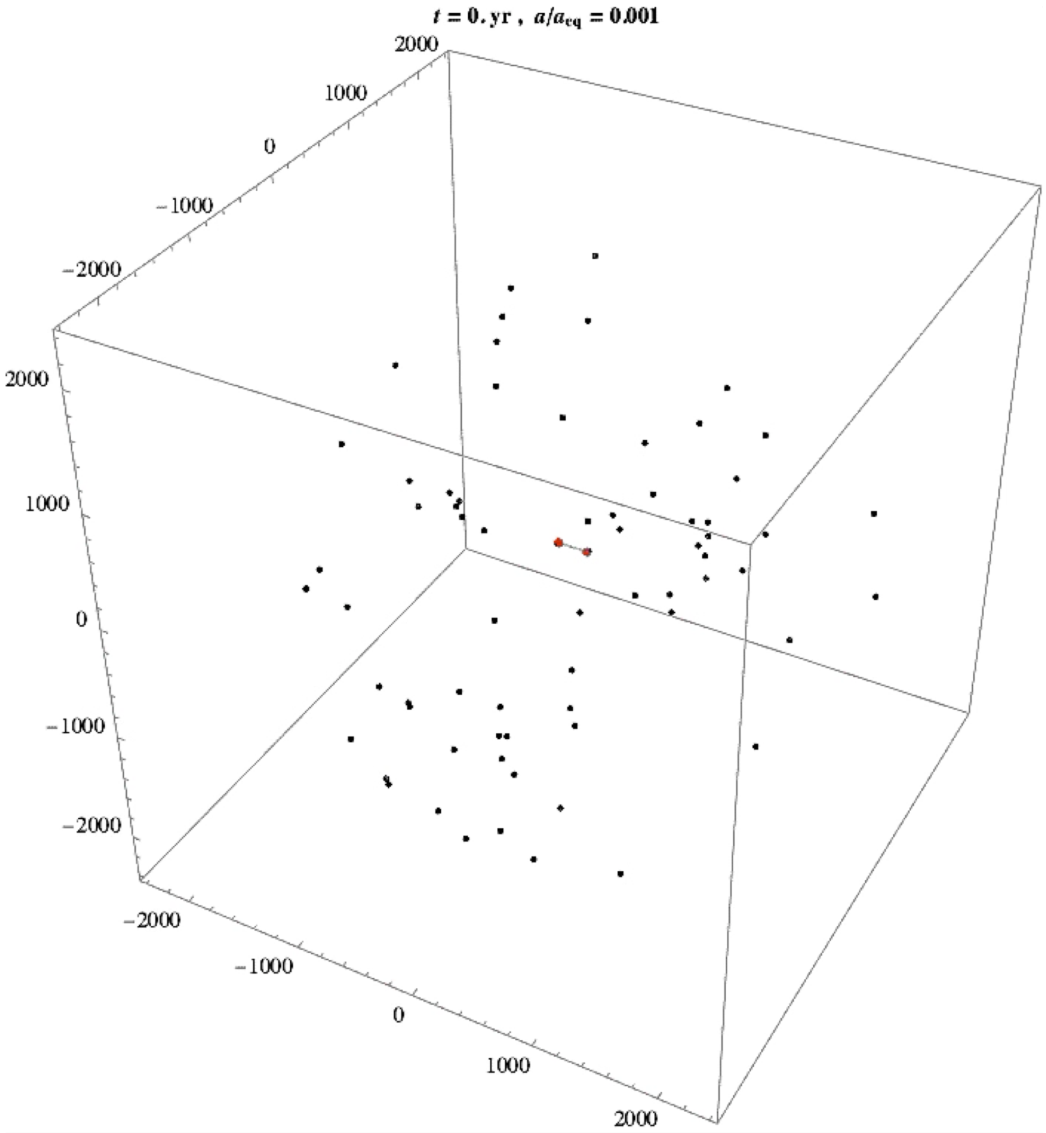
The disturbed binaries become hard

Enhanced small scale structure formation

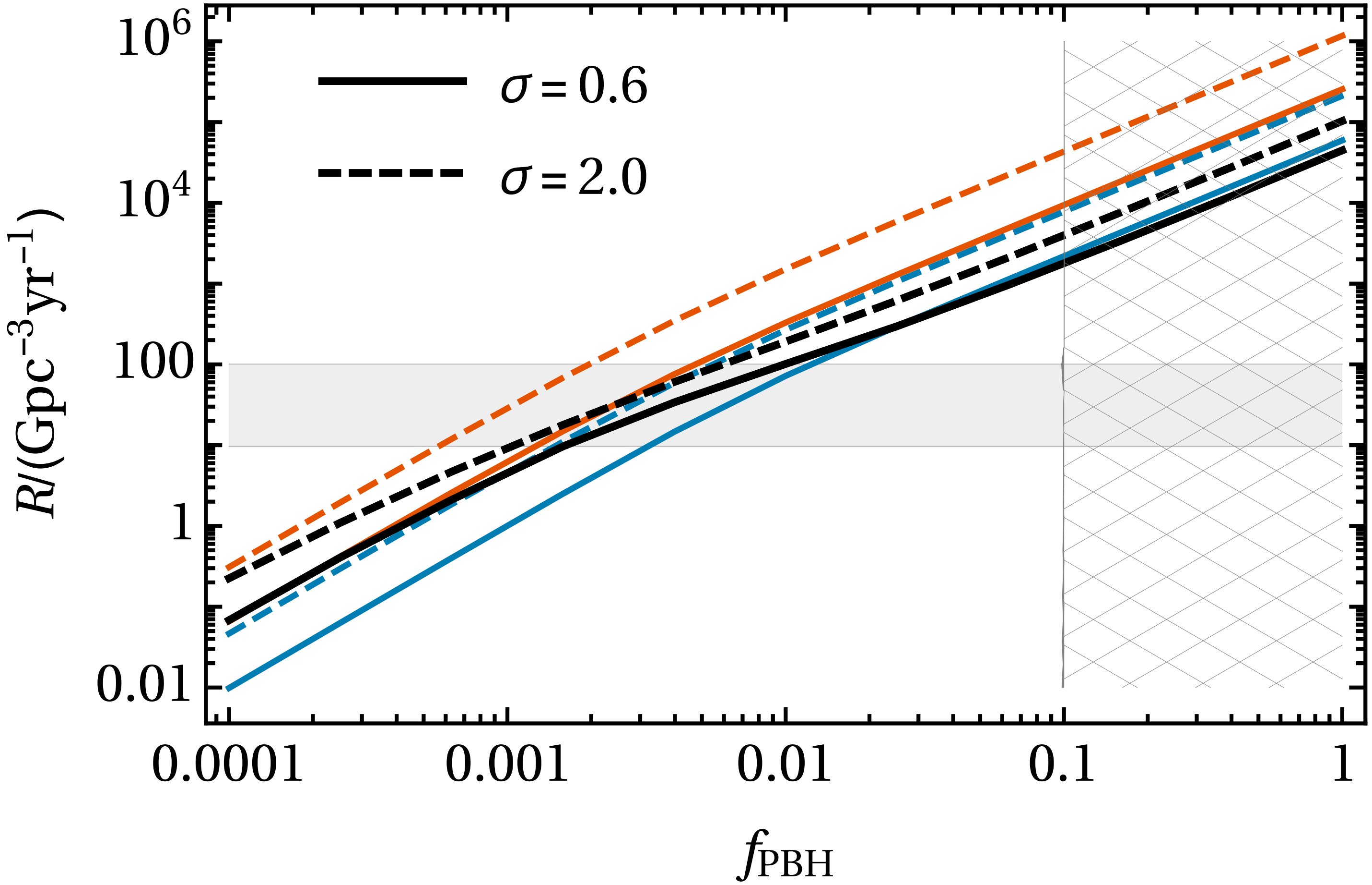


Formation of PBH clusters enhances the binary disruption

Binary destroyed by a mini-cluster

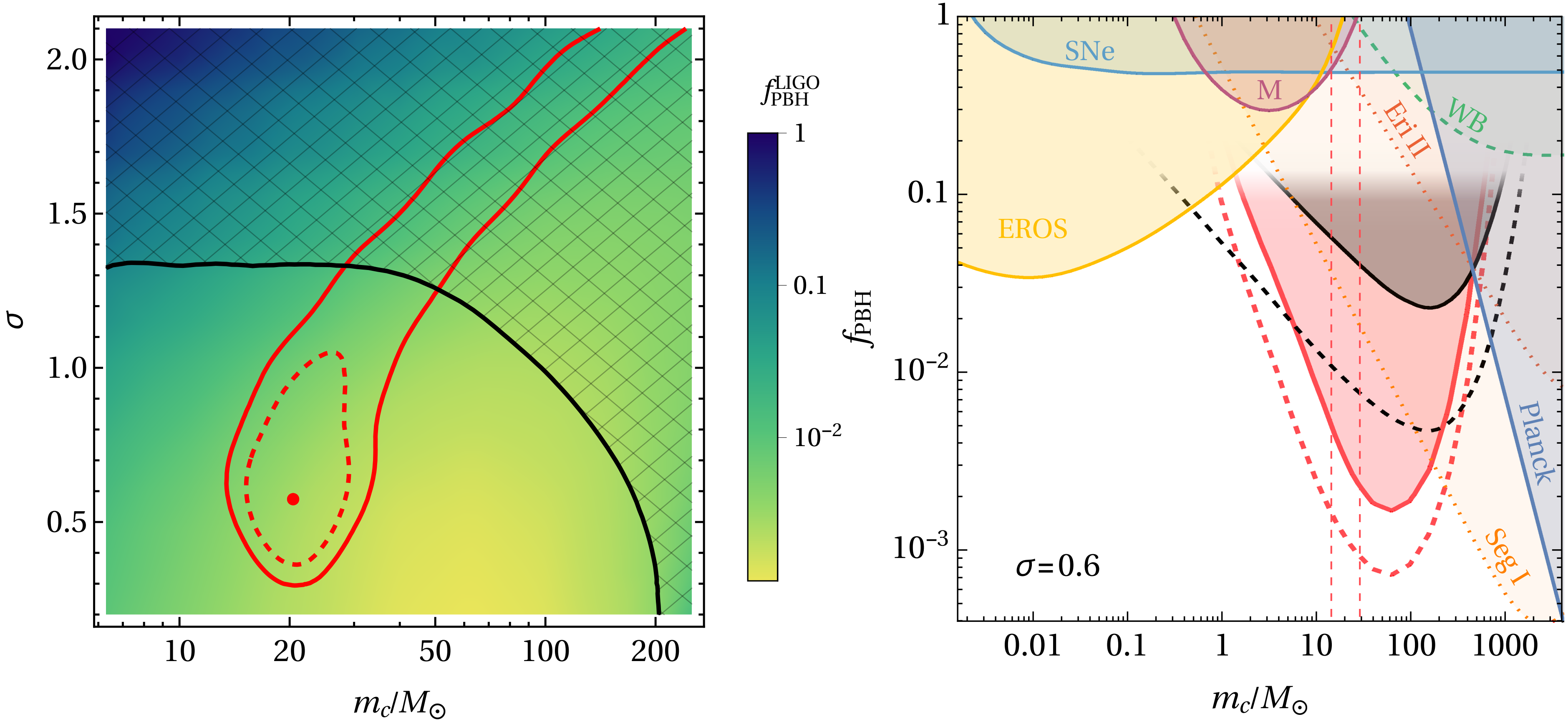


The LIGO/VIRGO rate



We do not know what happens for $f_{PBH}>0.1$

A fit to LIGO/Virgo data



Do the bounds apply for the f_{PBH}=1 case too?

OR

Are all binaries destroyed by clustering for f_{PBH}=1 and no bounds apply?

Clustering: Implications for the CMB

- Photons radiated by accretion of gas by PBHs results in the bound on the PBH abundance

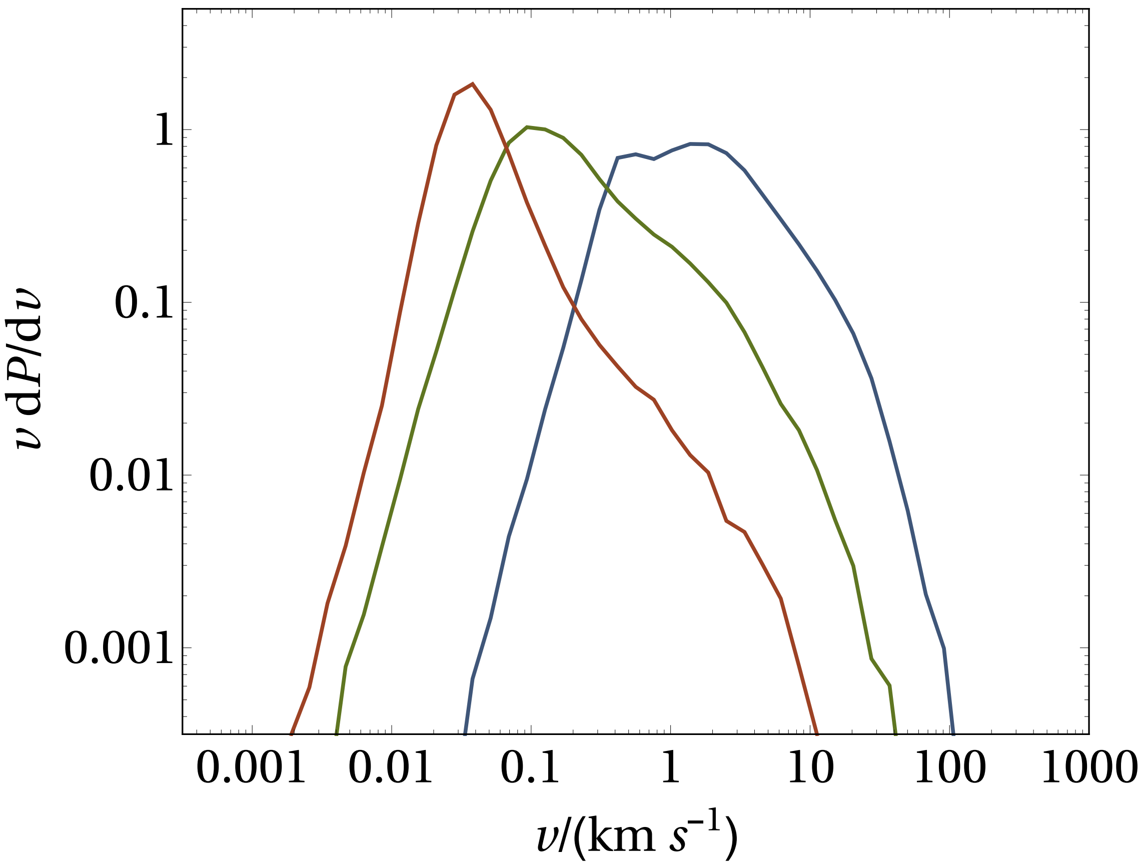
Yacine Ali-Haimoud
Francesca Carone

- Two competing effects due to clustering:
  - **$1/v^6$ reduction** of accretion due to the extra velocity of PBHs inside the early clusters (ADAF accretion model):

$$L \simeq 4\times10^{29}\,\frac{\mathrm{erg}}{\mathrm{s}}\,f\lambda^2\left(\frac{M_{\mathrm{BH}}}{10\,M_\odot}\right)^3\left(\frac{n_{\mathrm{H}}}{1\,\mathrm{cm}^{-3}}\right)^2\left(\frac{v_{\mathrm{eff}}}{10\,\mathrm{km\,s}^{-1}}\right)^{-6},$$

  - Possible **N^2 coherent accretion enhancement** if the accretion radius=the distance between PBHs

The velocity distribution due to clustering



However, DM–baryon streaming velocity at recombination is 30km/s

Just a few % effect for the CMB bound

but the effect might be large later - revise PBH bounds from radio astronomy

Coherent accretion due to clustering

- arXiv:1901.03649 argued that if the accretion radius,

$$R_a = \frac{2GM}{v_\infty^2},$$

  exceeds the distance between PBHs, the accretion is coherent and enhanced by N^2
- Our simulation: this seems to be the case for $f_{PBH}=1$

- The CMB bounds on PBH abundance should be approximately N=10 times more stringent

Conclusions

- **For f_{PBH}<<1** most initial binaries are unperturbed
  - Results in literature are qualitatively valid
  - The strongest bound for 10 $M_{\odot}$ PBHs is given by LIGO
- **For f_{PBH}=1** most binaries are disrupted
  - Late evolution of binaries needed to derive constraints
- **Enhanced small scale structures** already at recomb.
  - PHB clusters enhance the binary merger/disruption rate
  - Coherent accretion of gas makes the CMB bound on f_{PBH} about N=10 times more stringent