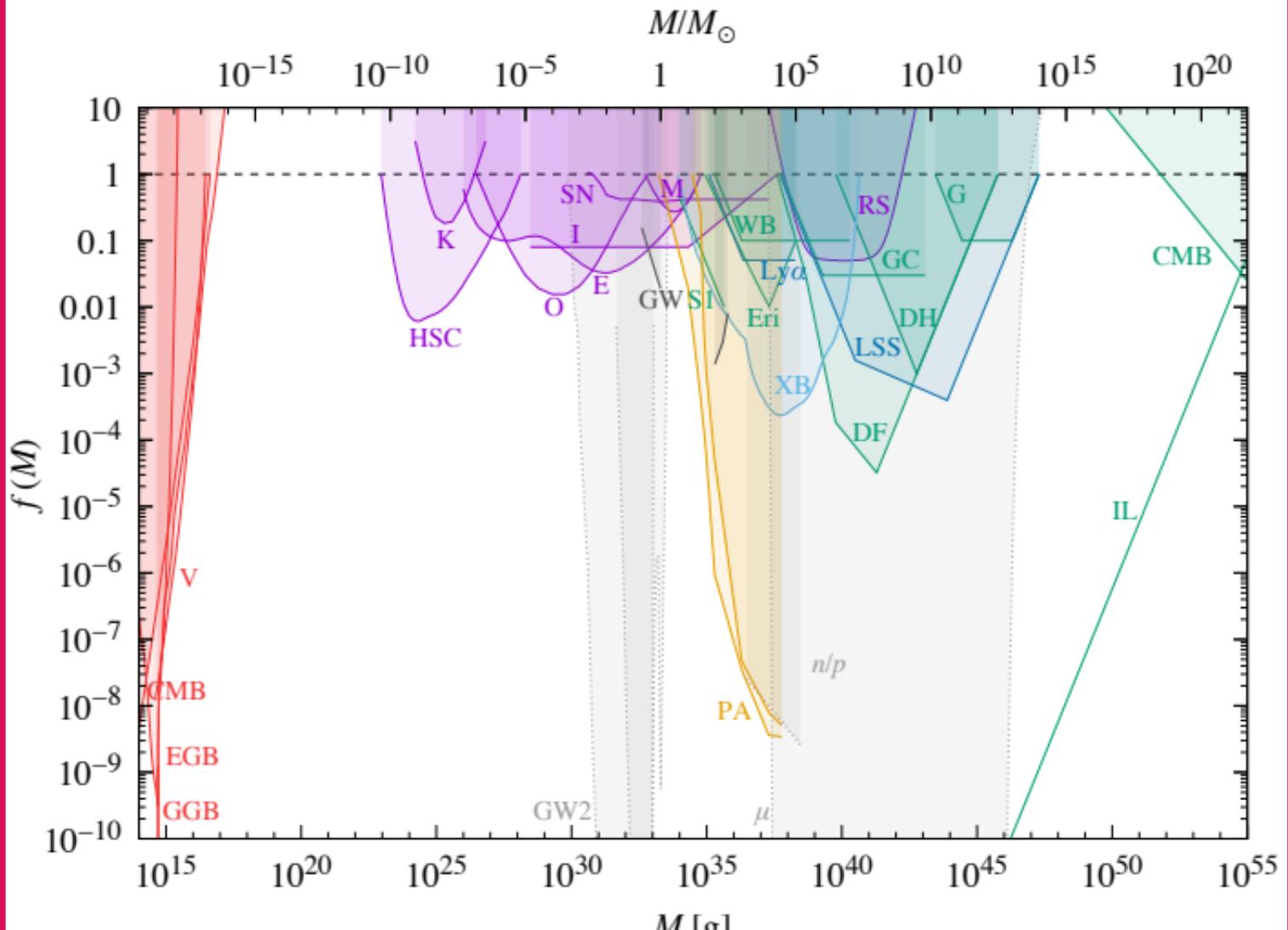


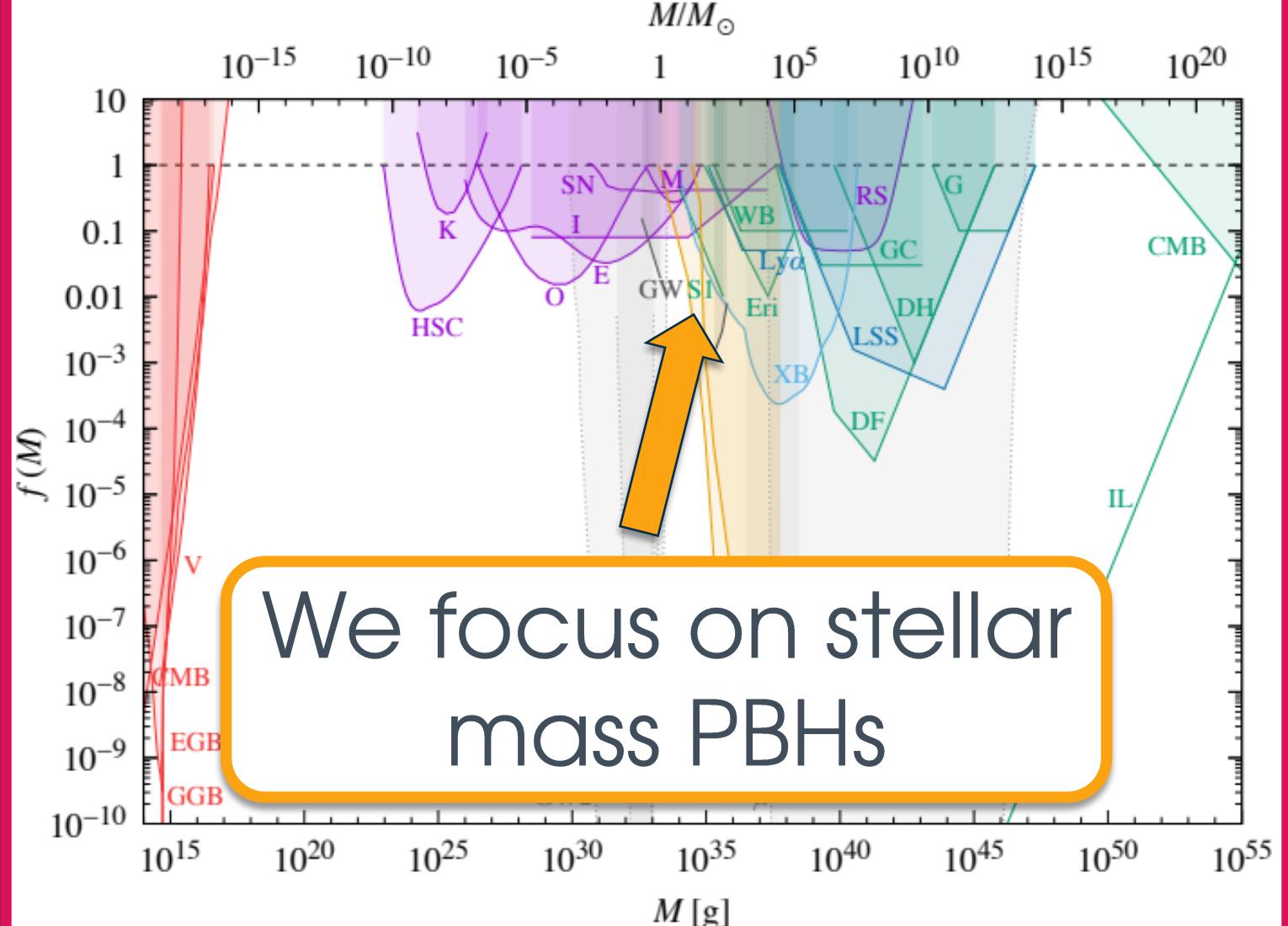
News From the Dark 2025

Nicolas Esser



**Primordial black hole – star
binaries via dynamical friction**

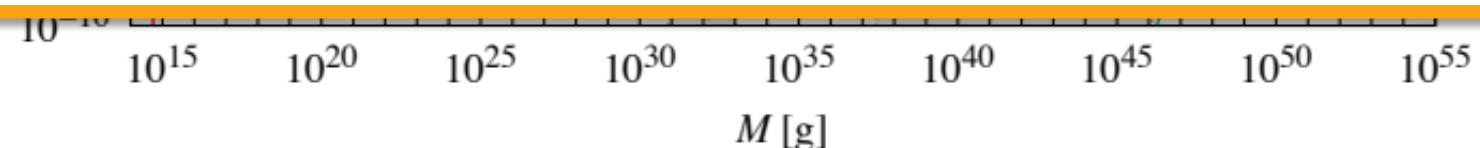




Carr et al. (2021)



Primordial black holes
are constrained more
and more...



Carr et al. (2021)

What if PBHs exist as a
subdominant contribution
of the DM ?

What if PBHs exist as a
subdominant contribution
of the DM ? Will they
interact with the rest of it ?

yes

DM minihalos around PBHs

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DM minihalos around PBHs

- Radiation era: DM particles decouple from Hubble flow and form a compact halo around the PBH
- More accurate calculations / simulations show different regimes (Boudaud et al. 2021, Salati & Lavalle 2025)...
- What about PBHs?

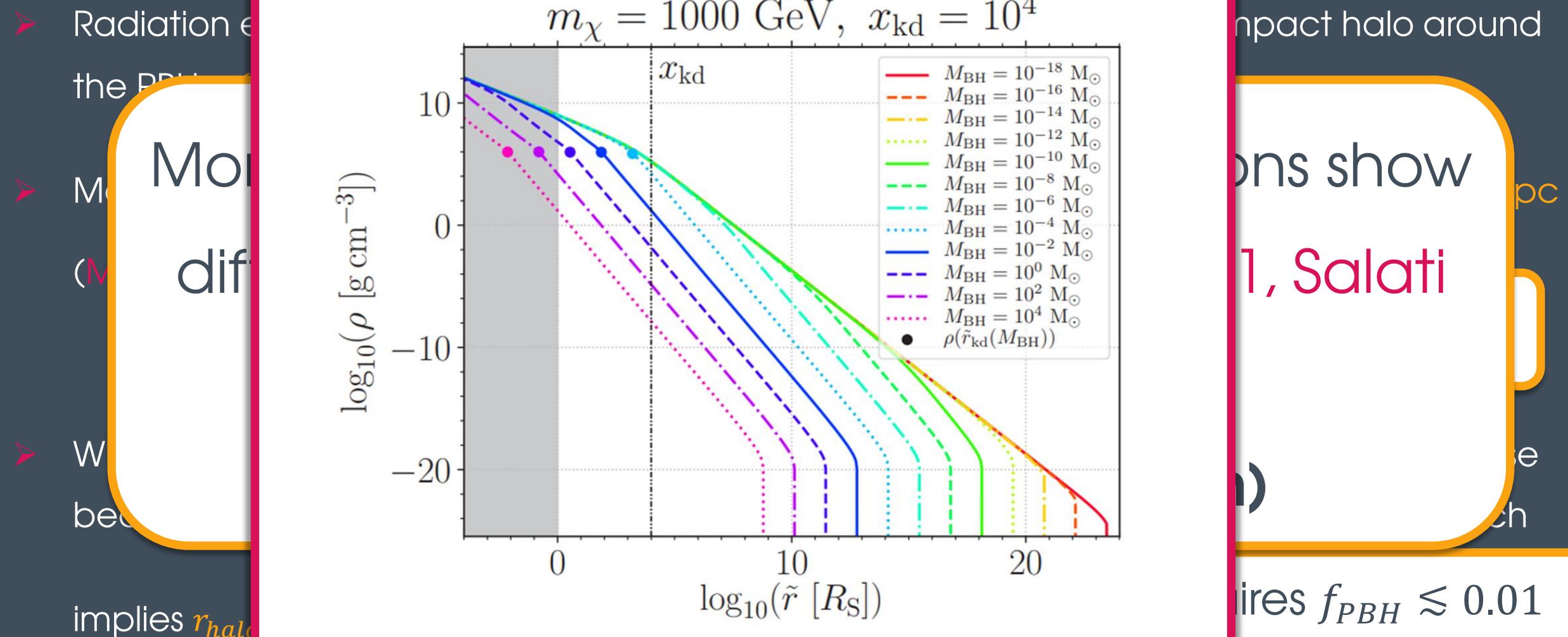
Ask Julien about it! (sorry Julien)

$$\text{implies } r_{\text{halo}} \simeq 1.17 \times \left(\frac{M_{\text{PBH}}}{M_{\odot}} \right)^{1/3} \text{ pc}$$

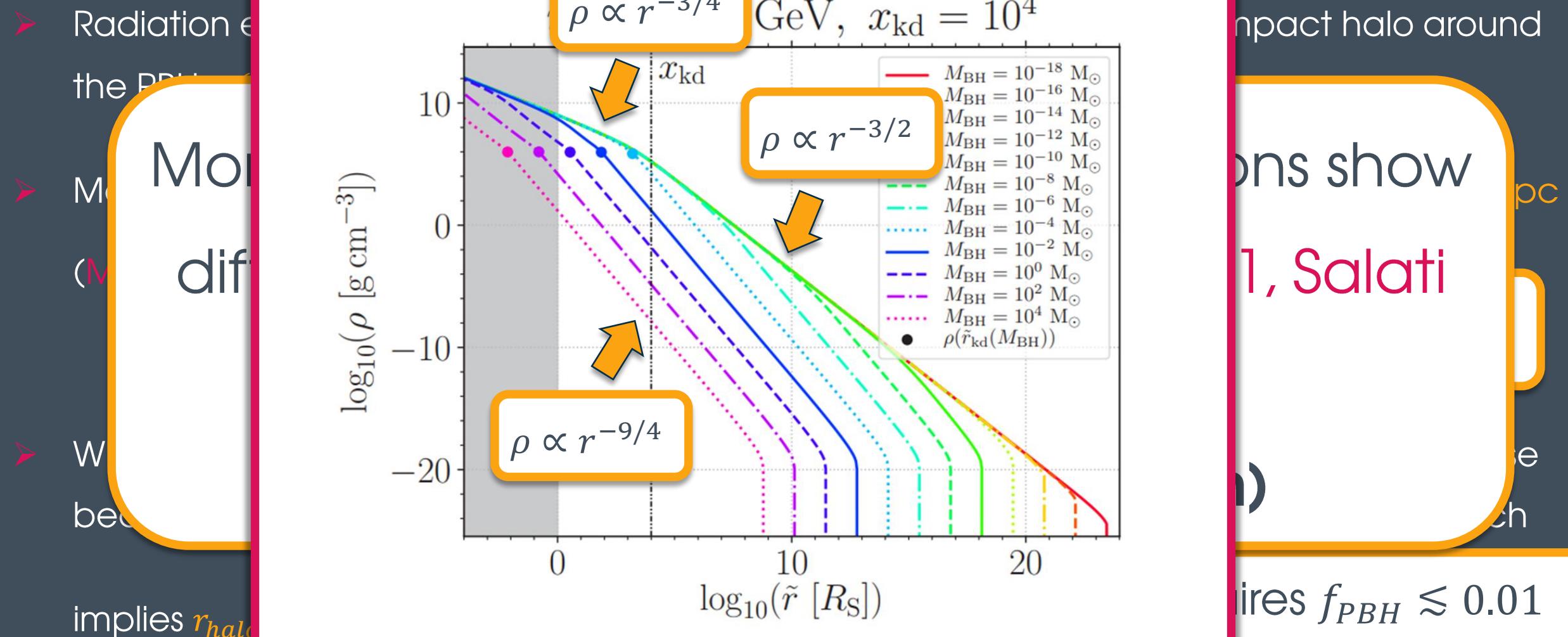


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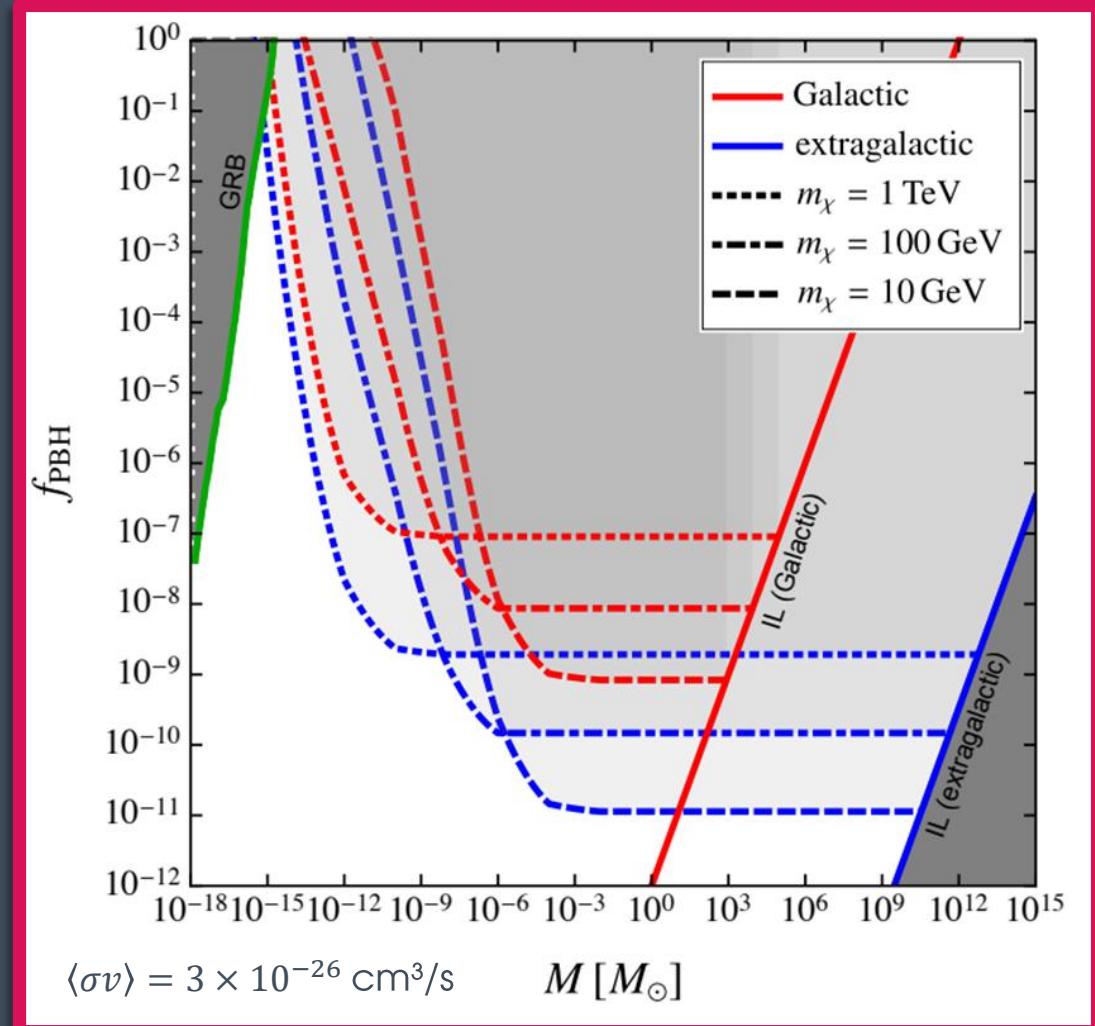
Observable effects ?

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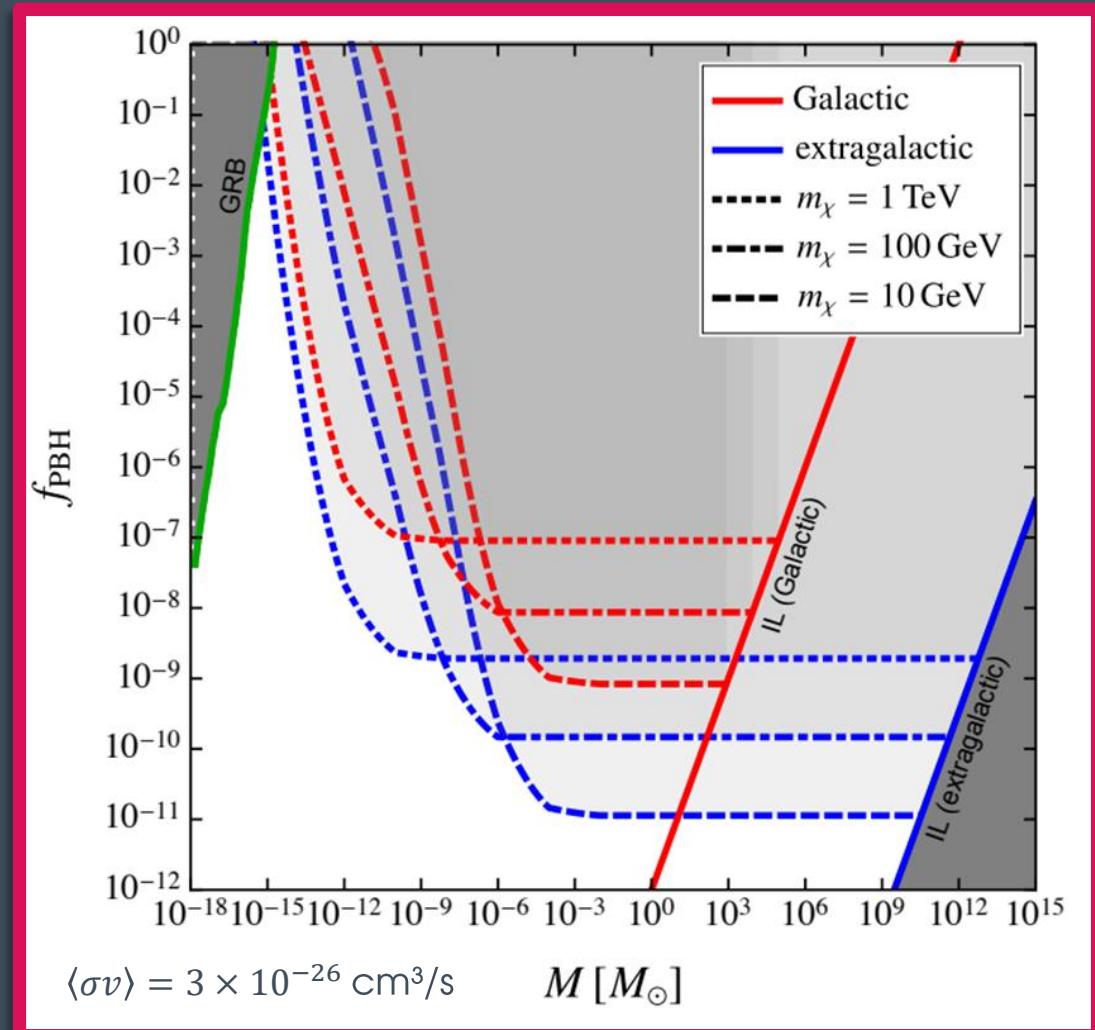
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Observable effects ?

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Constraints on PBHs if we detect the WIMP,
constraints on WIMP if we find PBHs.



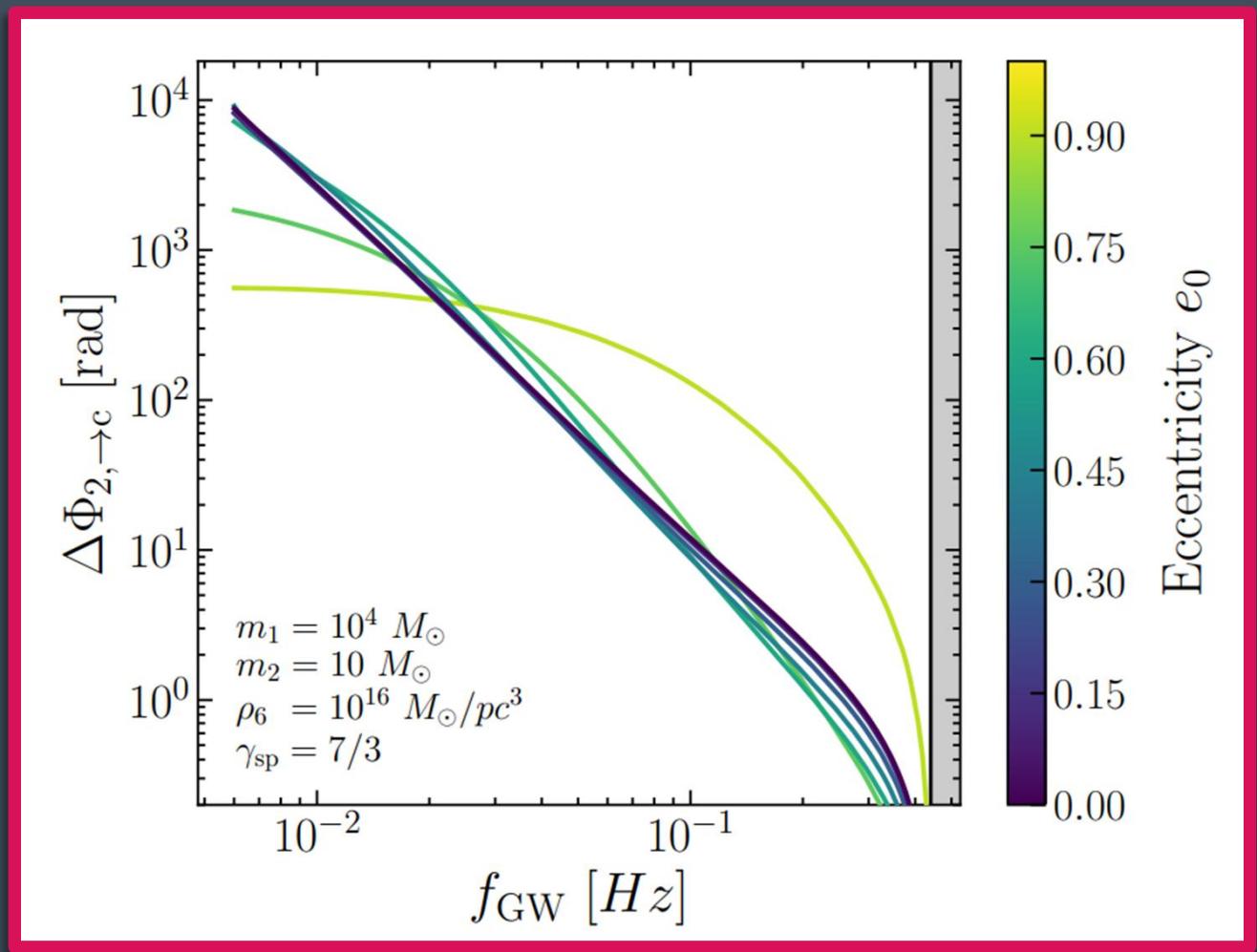
Observable effects ?

- Imprint of minihalos on GW waveforms in mergers (e.g. Bertone et al. 2024) and on merger rates (Kavanagh, Gaggero and Bertone 2018)

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Karydas, Kavanagh & Bertone (2024)

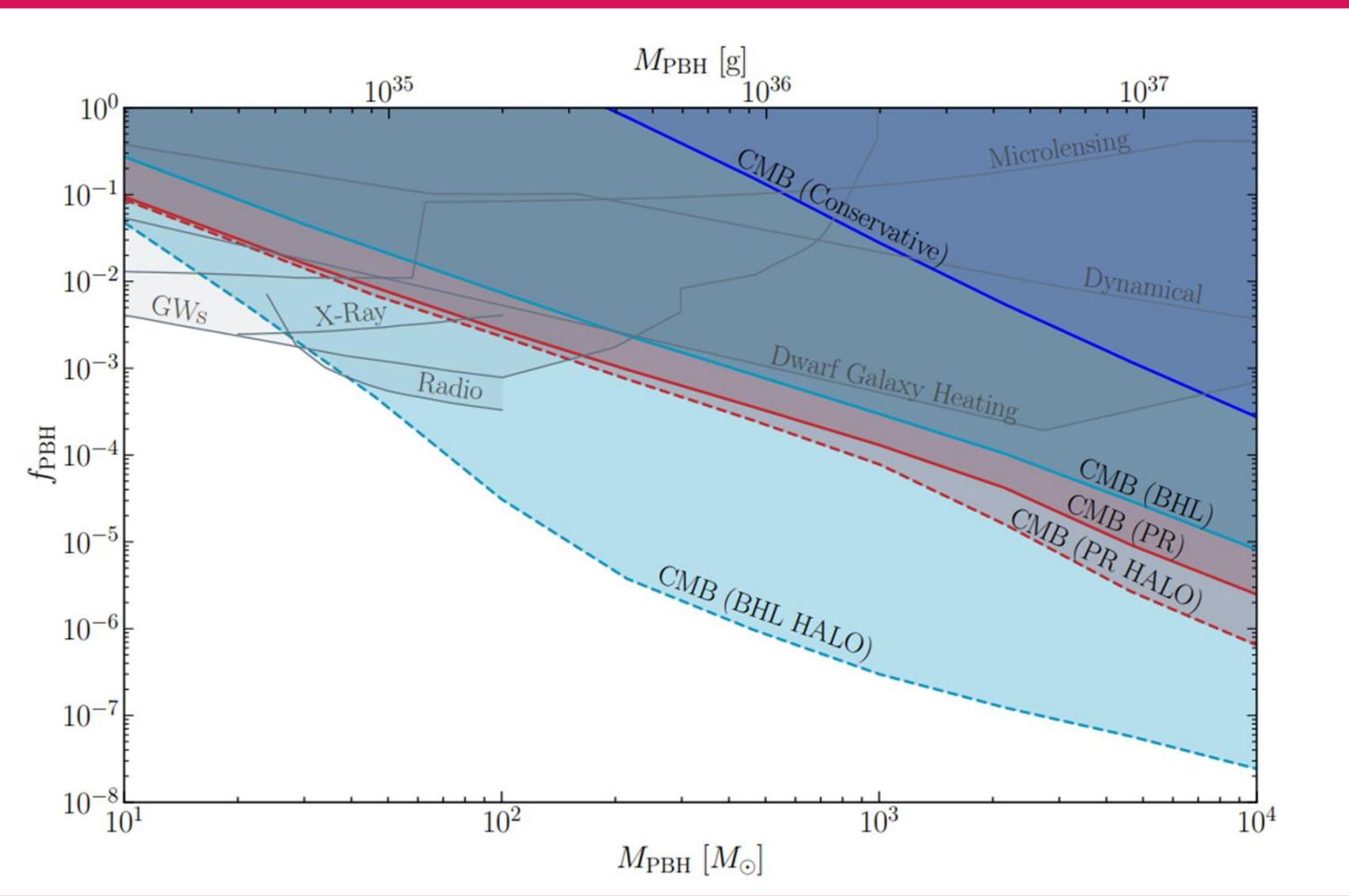


Observable effects ?

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Observable effects ?

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Surely there are other
observables...

Minihalos heavily boost
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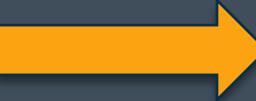
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Many stars cross the PBH minihalos.
Maybe some can be captured?

Capture of stars

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i.e. star gravitationally bound to
the PBH minihalo, $E < 0$.

Capture of stars



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Requires energy loss mechanism

Capture of stars

Dynamical friction:

$$a_{DF} = -4\pi G^2 m_* \rho(r) \xi(r, v) \ln \Lambda \frac{v}{v^3}$$

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(specific) $E_{loss} = \int a_{DF} \cdot dl$



Only applies for PBHs of solar mass and above, since this is only valid for $M_{halo} \gg m_*$.

Capture of stars

- Volumetric encounter rate $\frac{d\Gamma}{dV} = n_{PBH} n_* \times 2\pi b \cdot db \times v_\infty f(v_\infty) \cdot dv_\infty$

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(exponential term neglected) we get $\frac{d\Gamma}{dV} = 3\sqrt{6\pi} \times n_{PBH} n_* \times dL^2 dE$

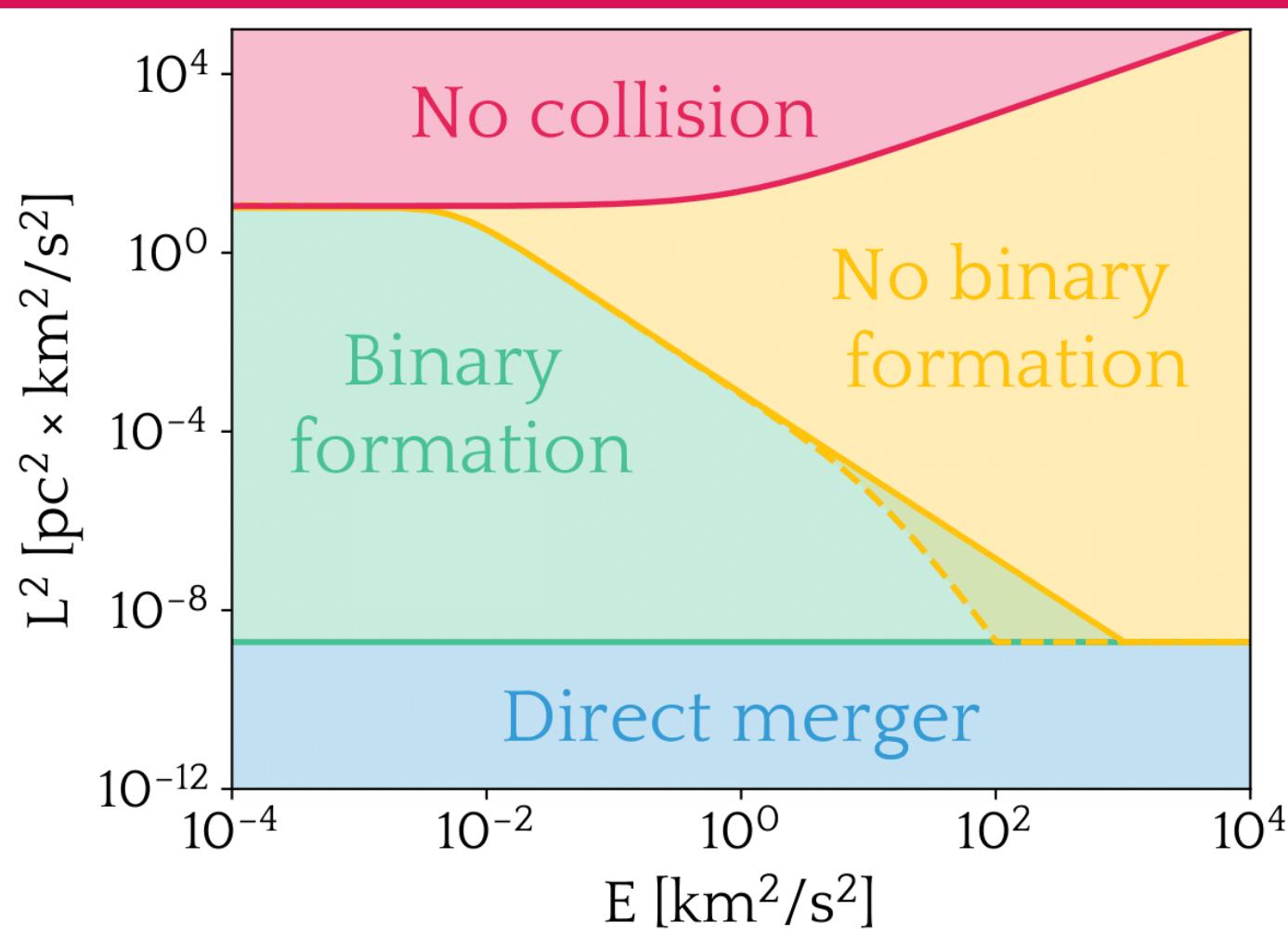
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 - Total volumetric rate: 
- Leading to capture!
(i.e. $E_{loss} > E_{ini}$)

Capture of stars



$$\tau b \cdot db \times v_\infty f(v_\infty) \cdot dv_\infty$$

Slow stars are captured

$$\int_E \int_{L^2} 3\sqrt{6\pi} \times n_{PBH} n_* \times dL^2 dE$$



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Merger rate

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- At each passage through the minihalo the star loses energy via friction.
 r_{min} is unchanged while r_{max} diminishes.
- Energy loss is the same at each passage.
- Finite-time merger: $r_{max} < r_{crit} = E_{loss}^2 T_u^2 / (2\pi^2 G M_{halo})$

Merger rate

This is an idealized scenario!

Merger rate

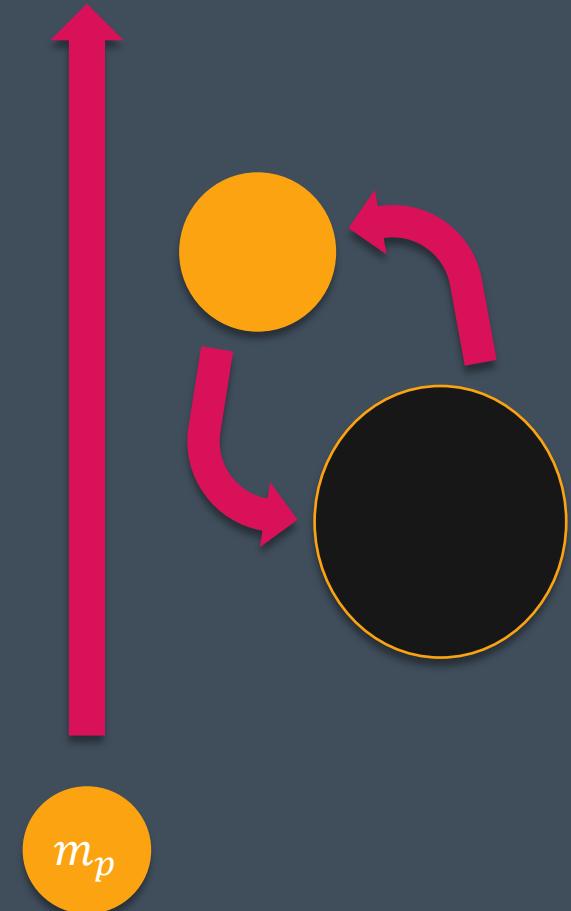
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The PBH-star binary is surrounded by other stars, which may disrupt the system via 3-body interactions.

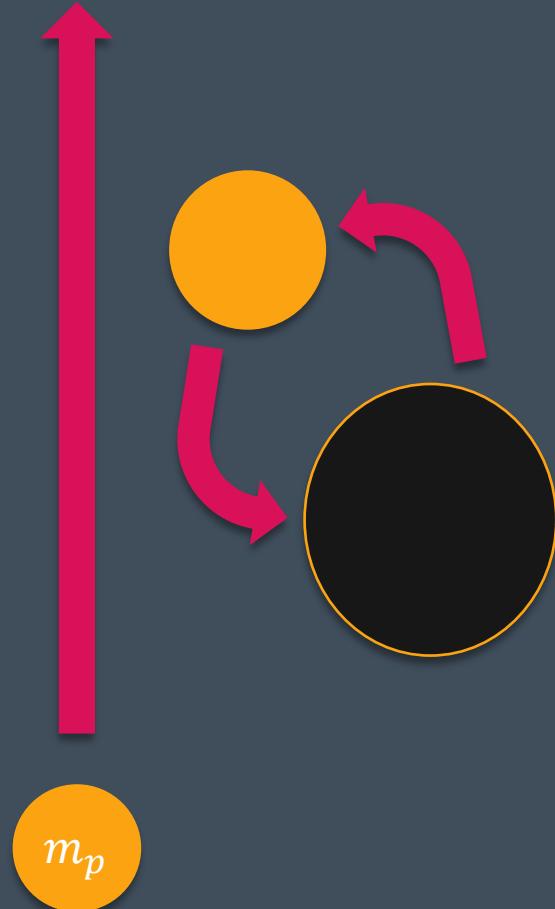
Effect of perturbers

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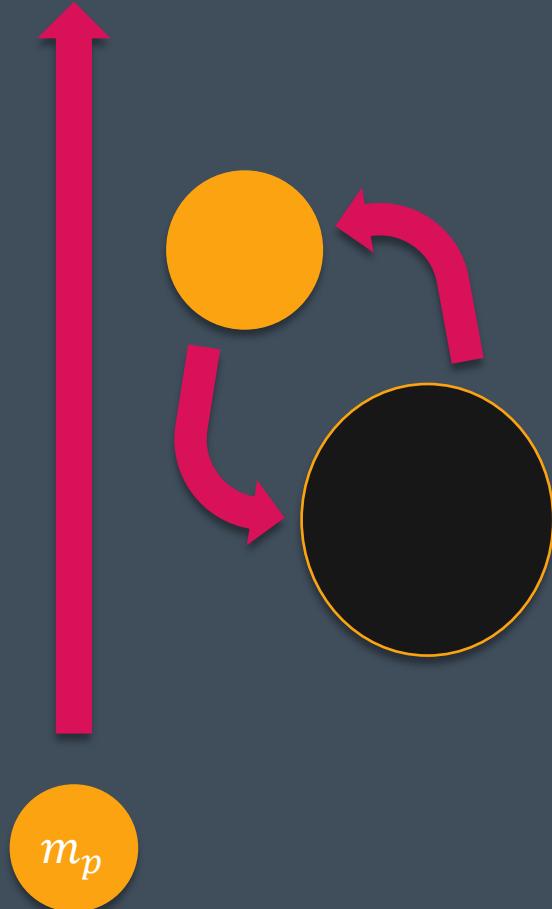
Effect of perturbers

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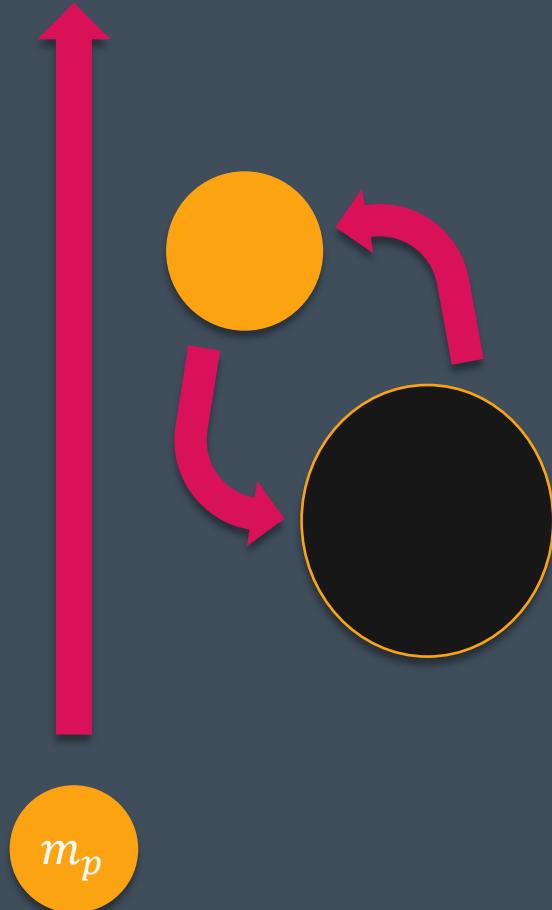
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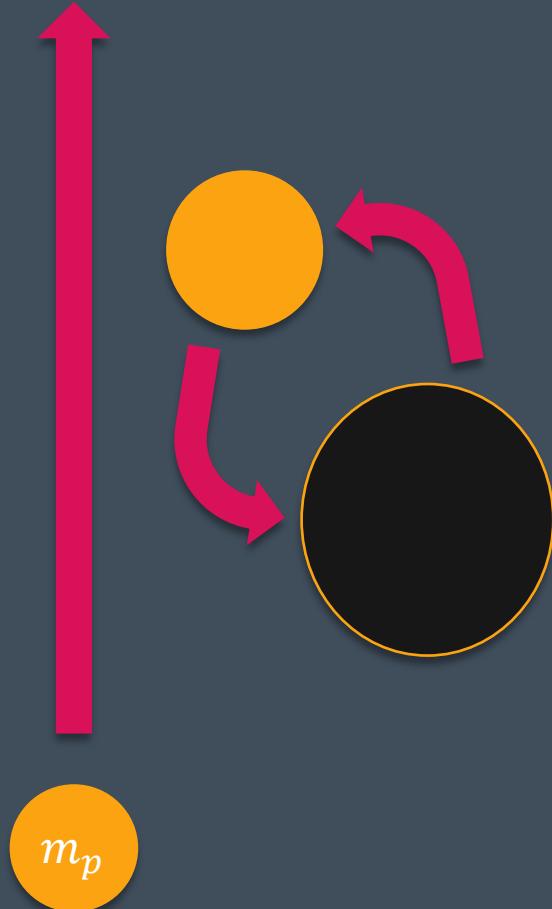
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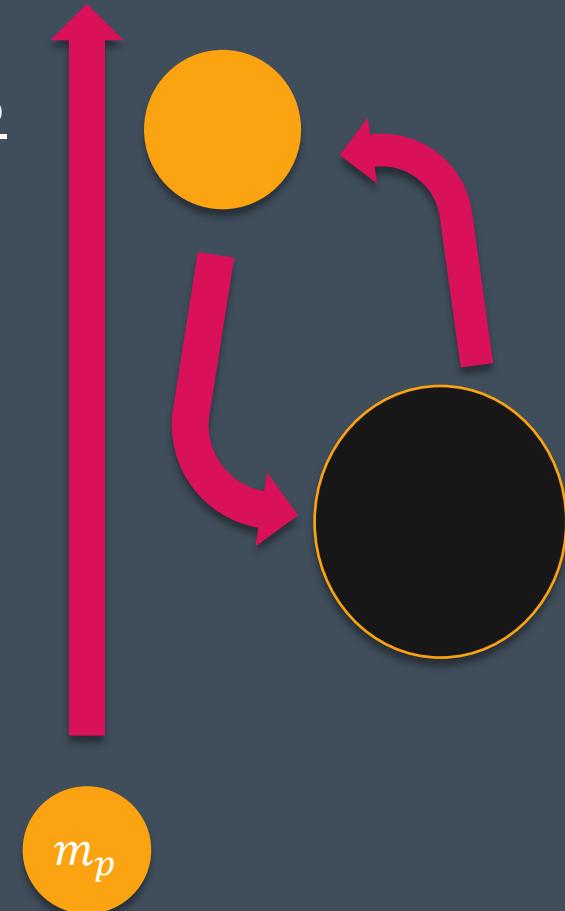
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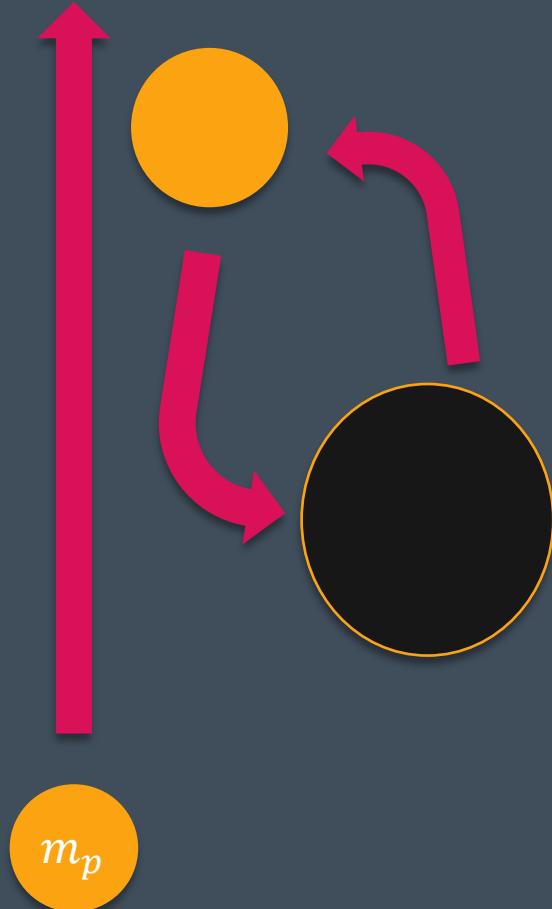
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- $E_{loss}^{with\ pertu} = E_{loss}(r_{min} + \Delta r_{min}) - \Delta E_{pertu}$



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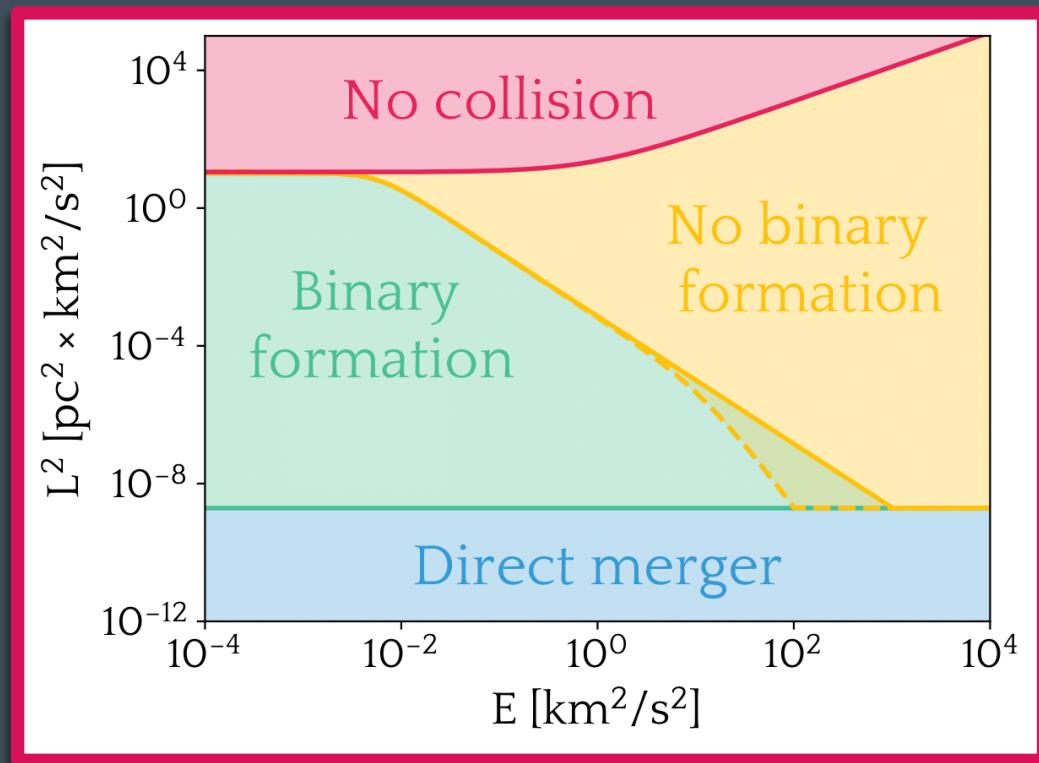
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Leading to capture
AND merger!
(merger time +
perturbers)

Merger rate

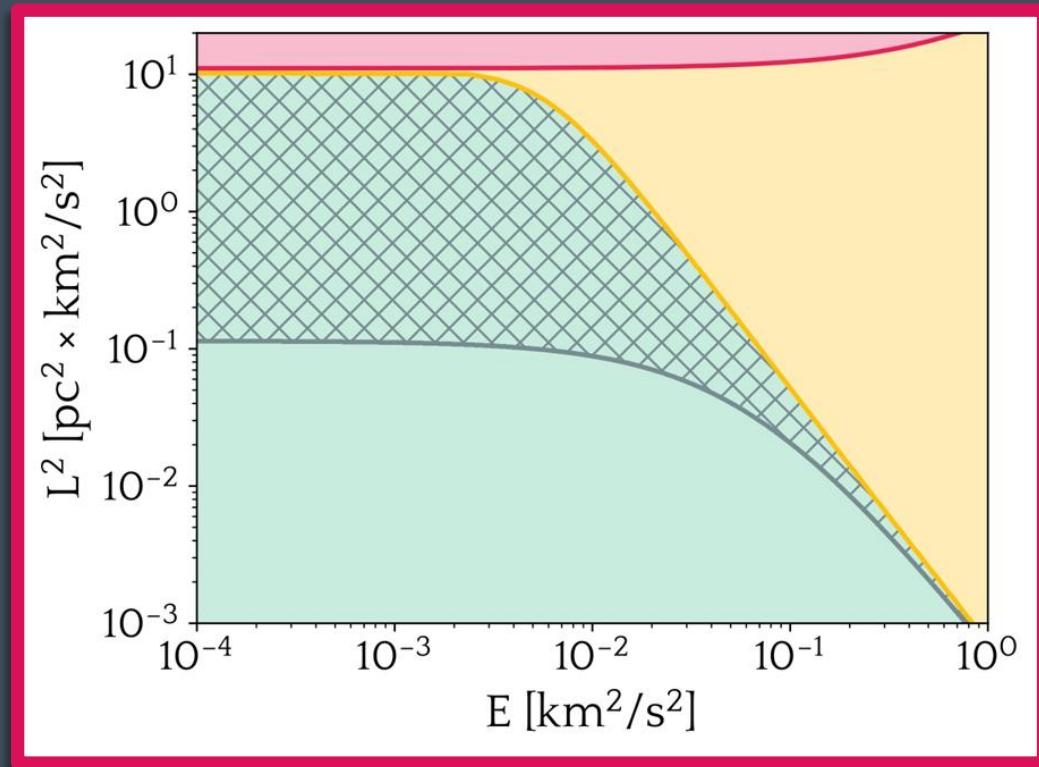
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We have obtained merger rates.
Now we consider specific
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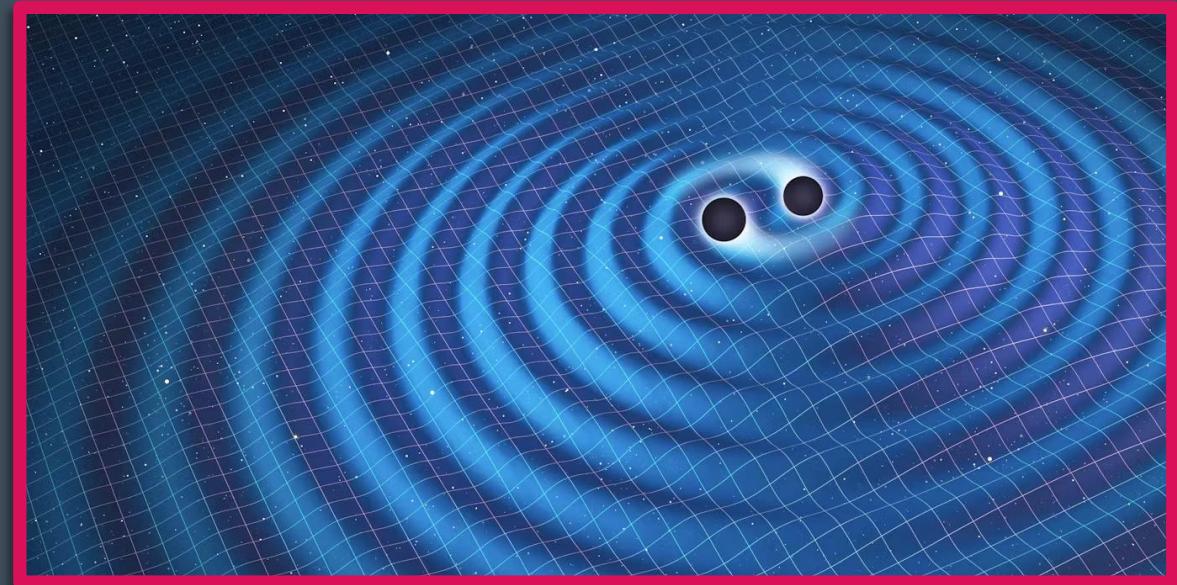
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Merger rate

$$\text{Total merger rate: } \Gamma = \iiint_V E L^2 3\sqrt{6\pi} \times n_{PBH} n_* \times dL^2 dE$$

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Observables ?



X-ray binaries
in the MW

GW events

Observables ?



Minihalos
capture stars



Minihalos capture
neutron stars and
stellar BHs

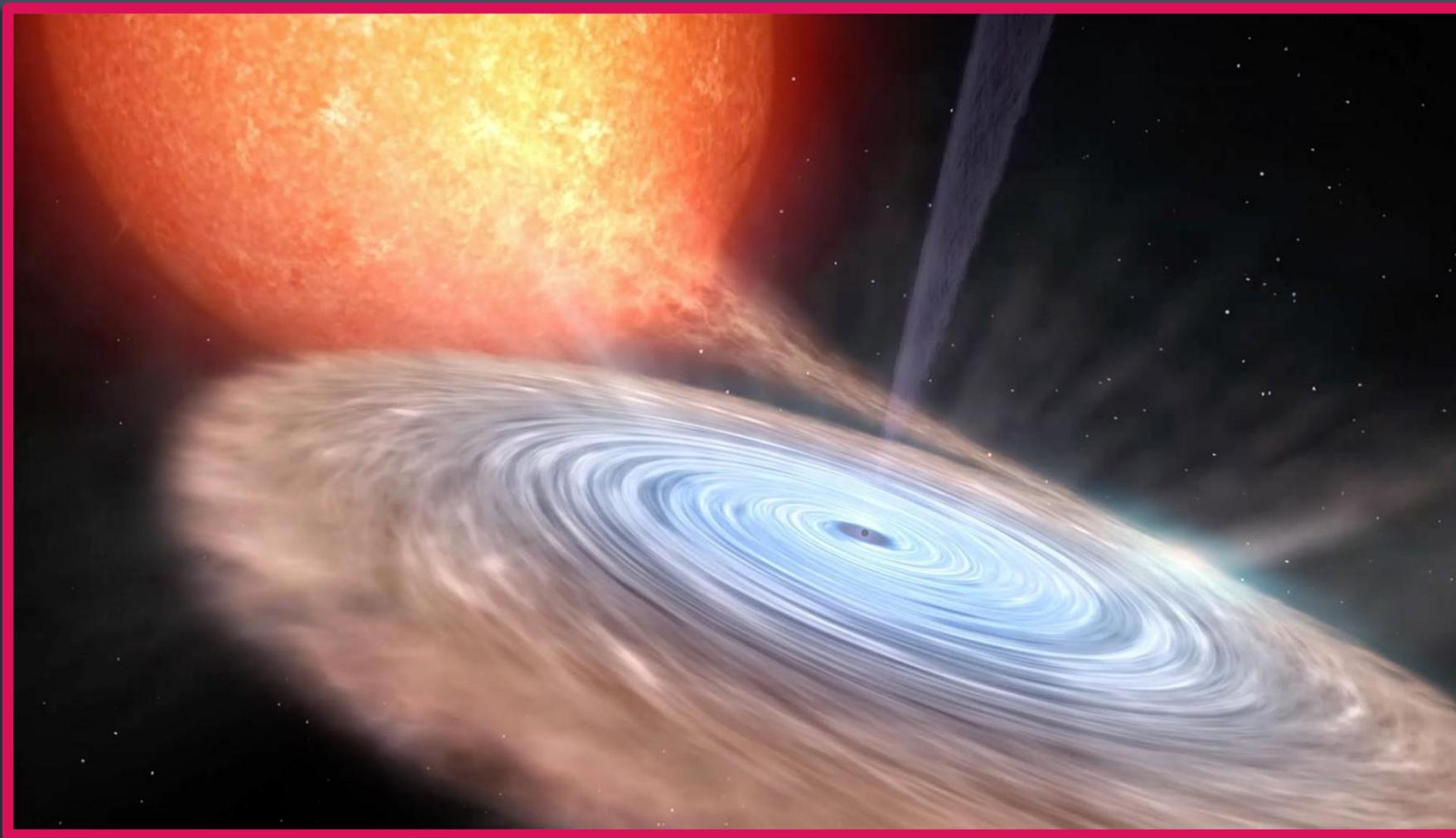


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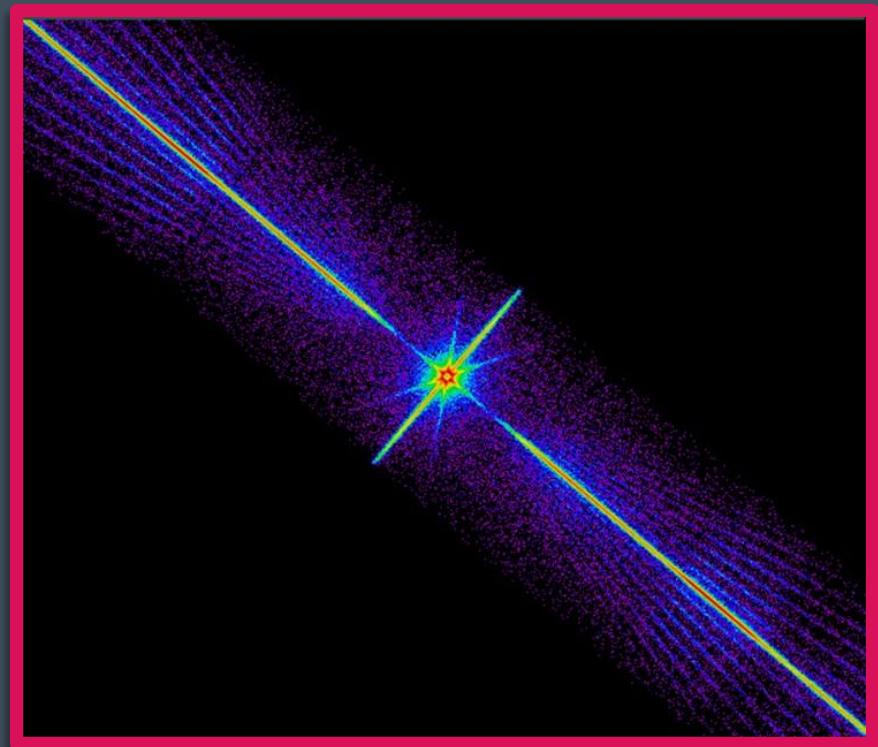
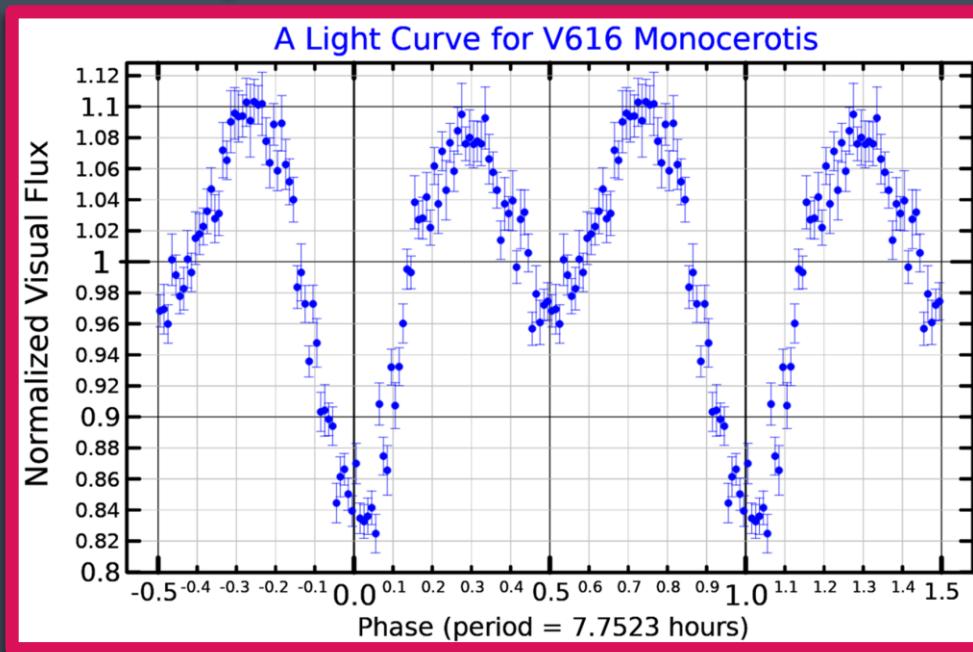


X-ray binaries in the MW

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- 1-2 order of magnitudes below expectation
- Could be explained with DM minihalo

X-ray binaries in the MW

Merger rate: $\Gamma = \int_V \int_E \int_{L^2} 3\sqrt{6\pi} \times n_{PBH} n_* \times dL^2 dE$

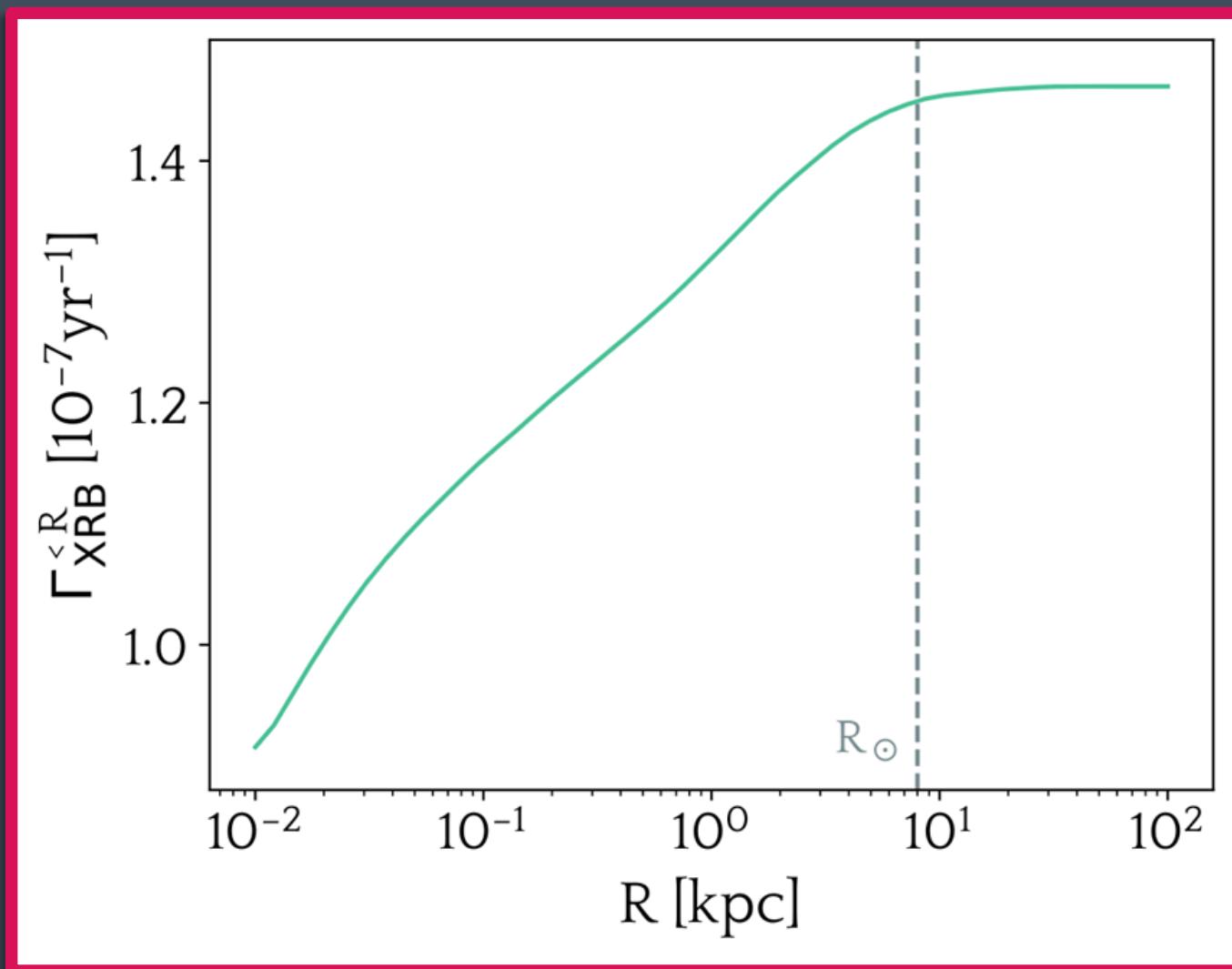
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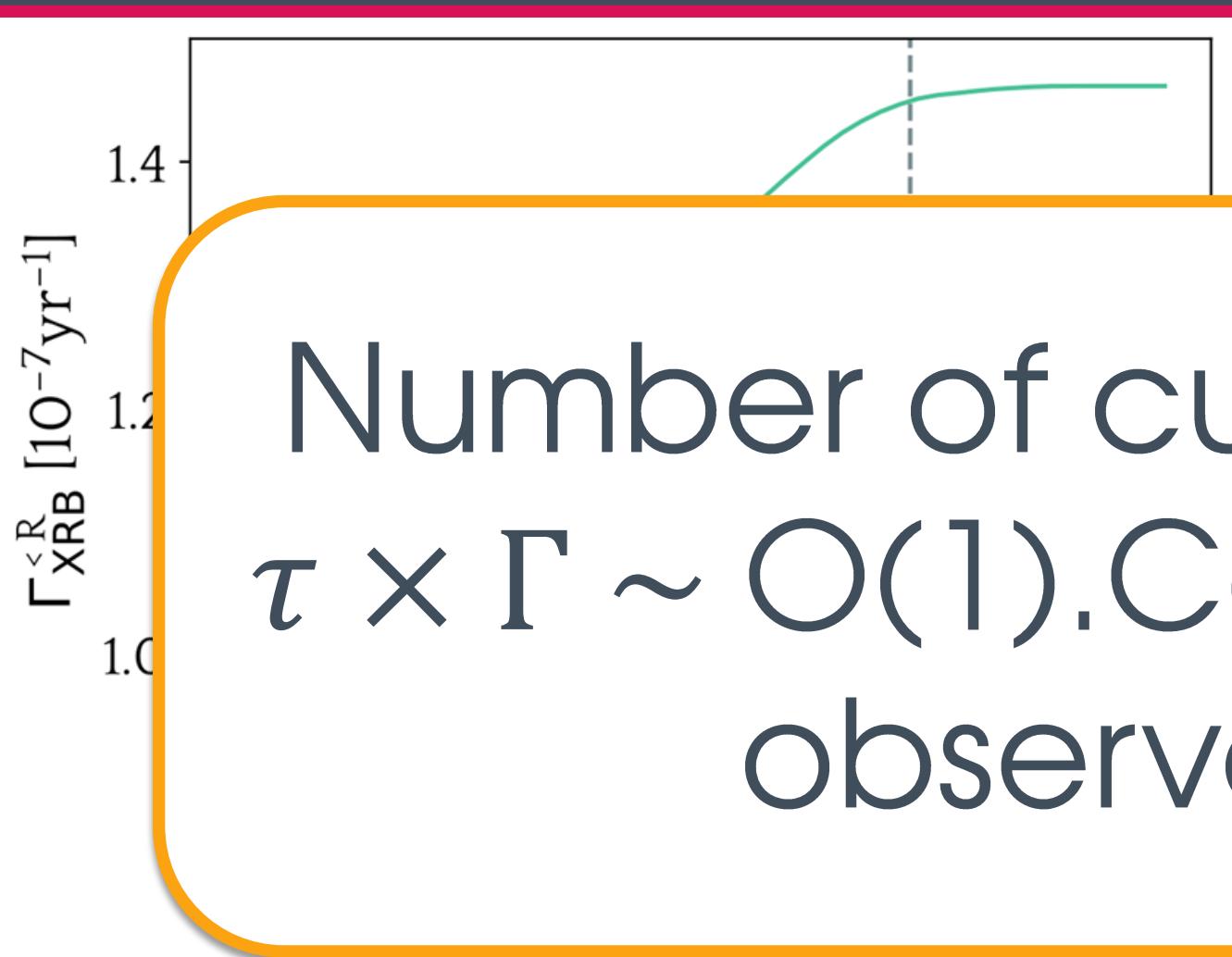


Milky Way model
(McMillan 2017)

X-ray binaries in the MW



X-ray binaries in the MW

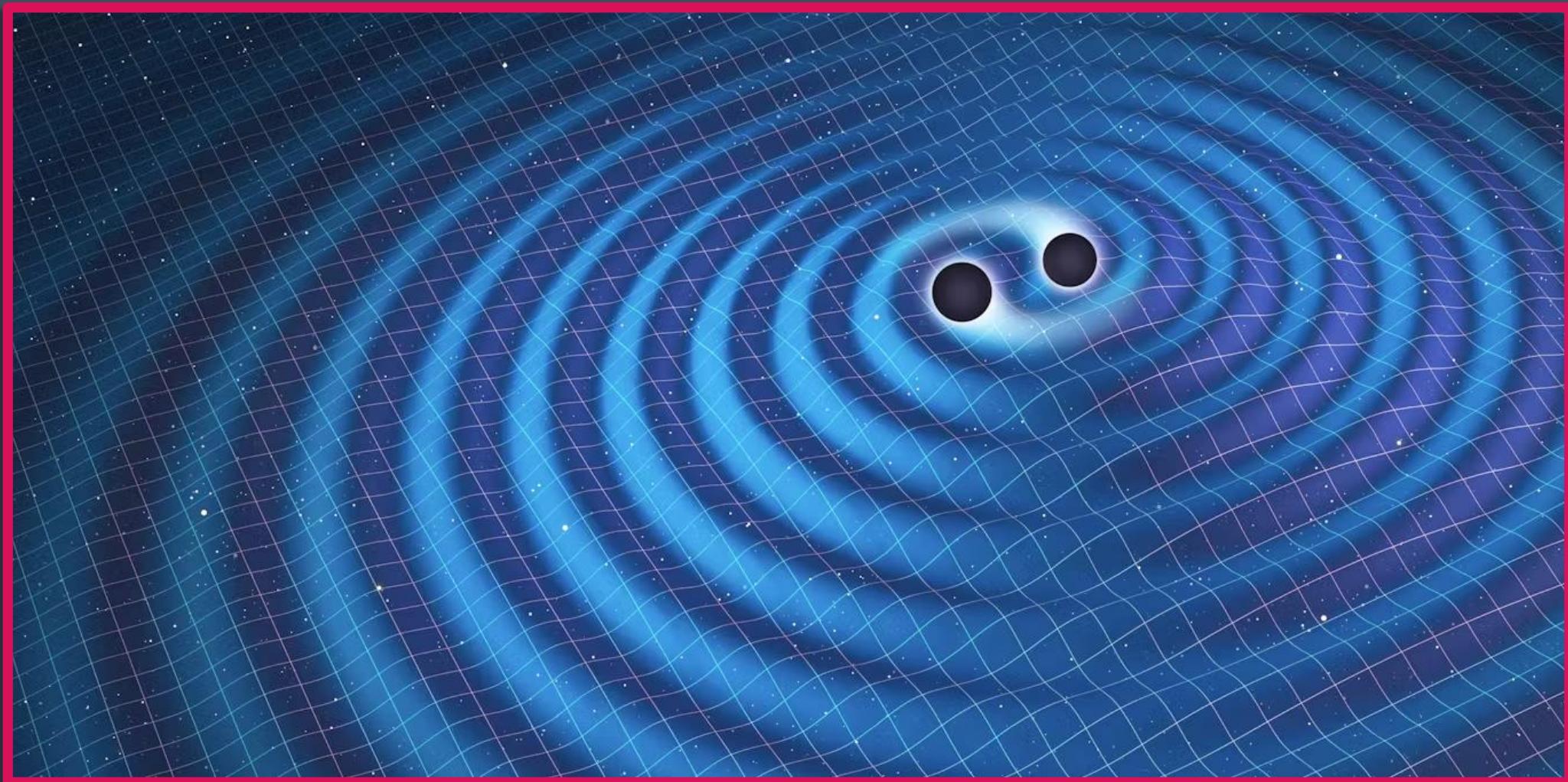


Number of current events:
 $\tau \times \Gamma \sim \mathcal{O}(1)$. Consistent with observations.

X-ray binaries in the MW

PBHs w/ minihalos capturing stars provide a viable explanation to the rapidly decaying X-ray binaries

GW events

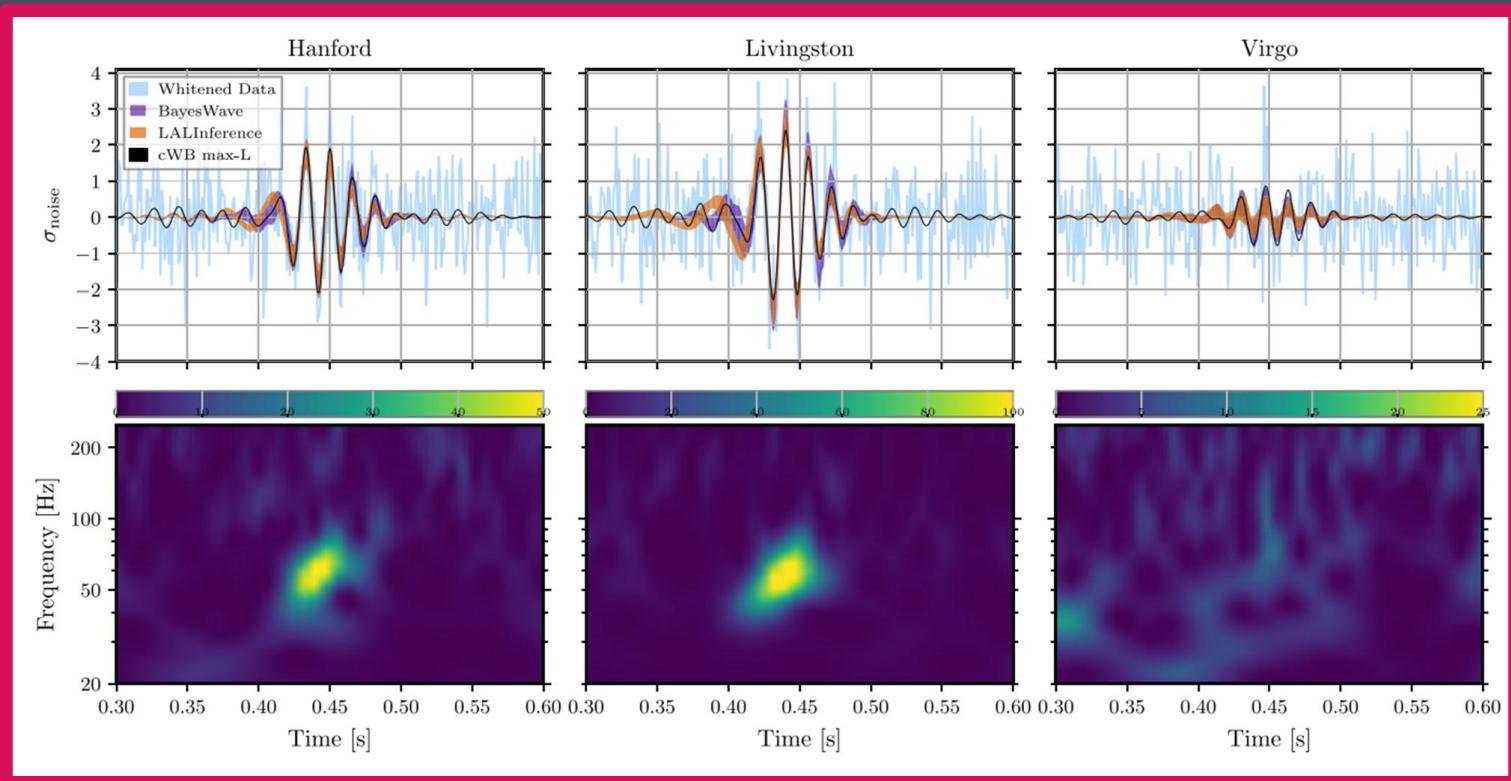


GW events

- Challenging observations and candidates, e.g. GW190521, GW190814, SSM200308

GW events

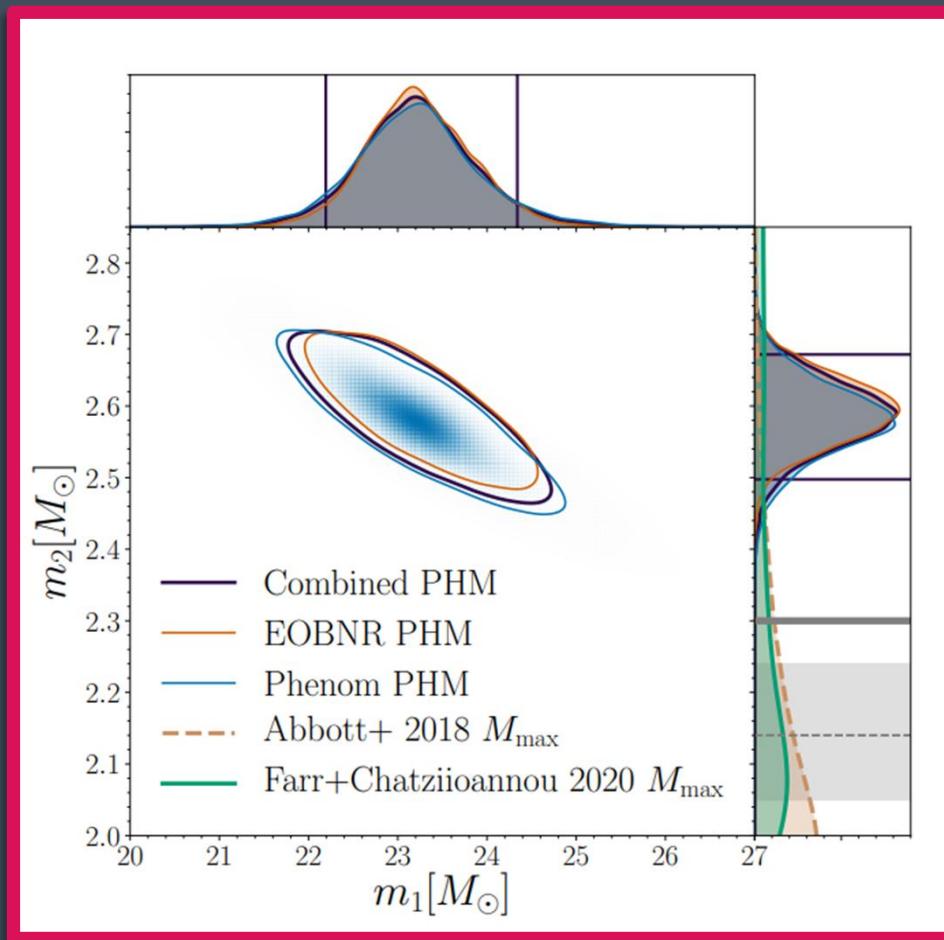
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2009.01075

GW events

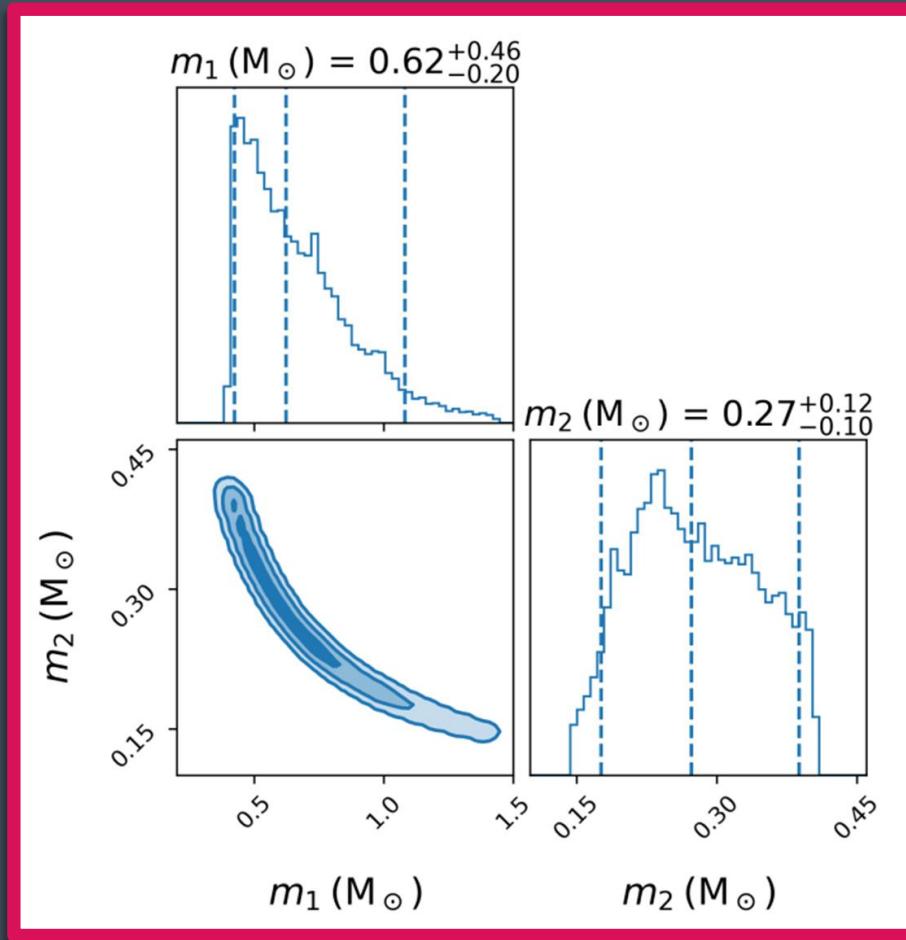
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2006.12611

GW events

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Prunier et al. (2024)

GW events

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GW events

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Galaxy population model

GW events

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Galaxy population model



Assume DM and baryon profile, stellar-to-halo mass ratio, galaxy stellar mass function.

GW events

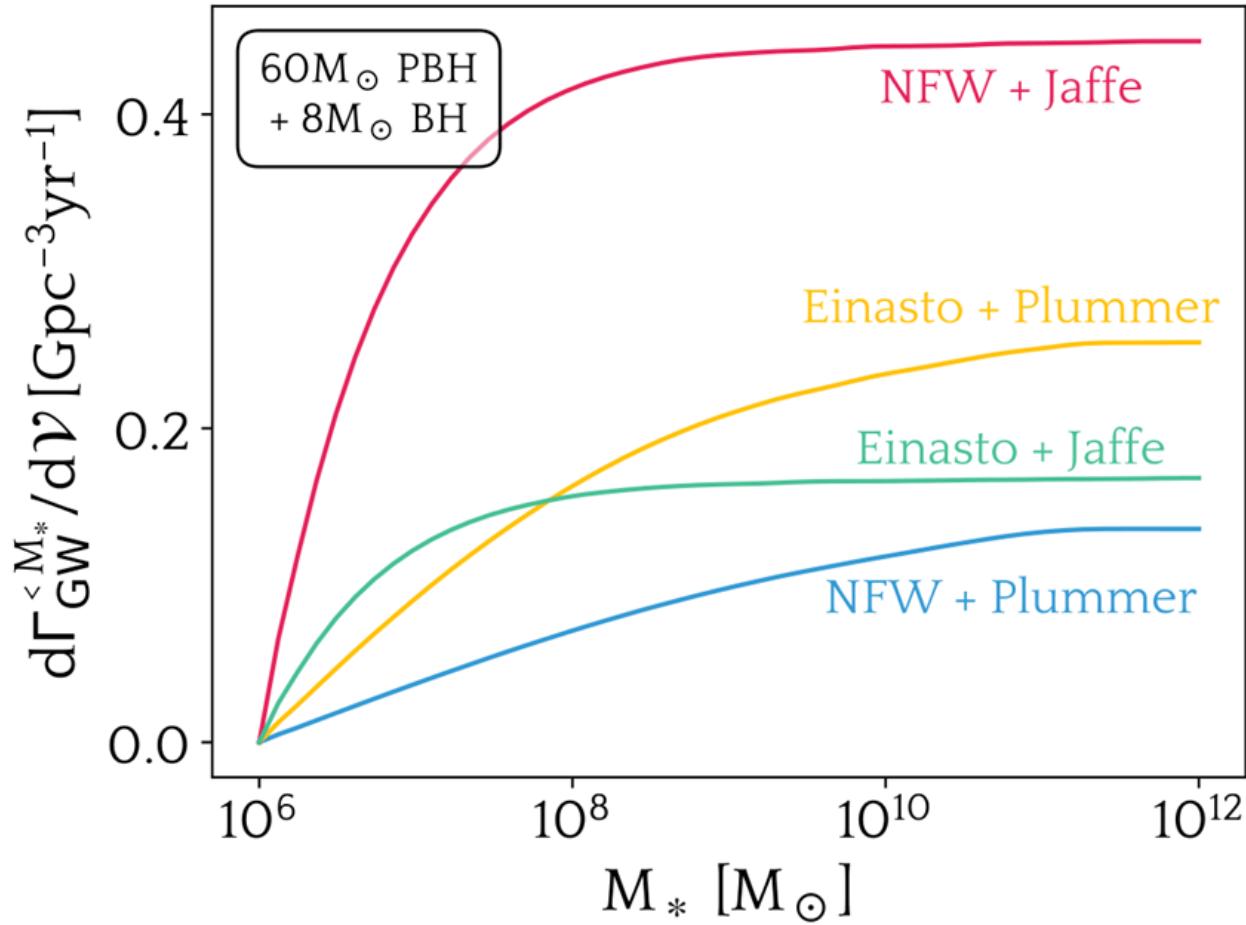
	NFW + Jaffe	Einasto + Plummer	Einasto + Jaffe	NFW + Plummer
$1M_{\odot}$ PBH + $8M_{\odot}$ BH	1.23	0.47	0.35	0.22
$1M_{\odot}$ PBH + $1.4M_{\odot}$ NS	0.61	0.31	0.21	0.16
$60M_{\odot}$ PBH + $8M_{\odot}$ BH	0.45	0.25	0.17	0.14
$60M_{\odot}$ PBH + $1.4M_{\odot}$ NS	0.07	0.04	0.03	0.02

GW events

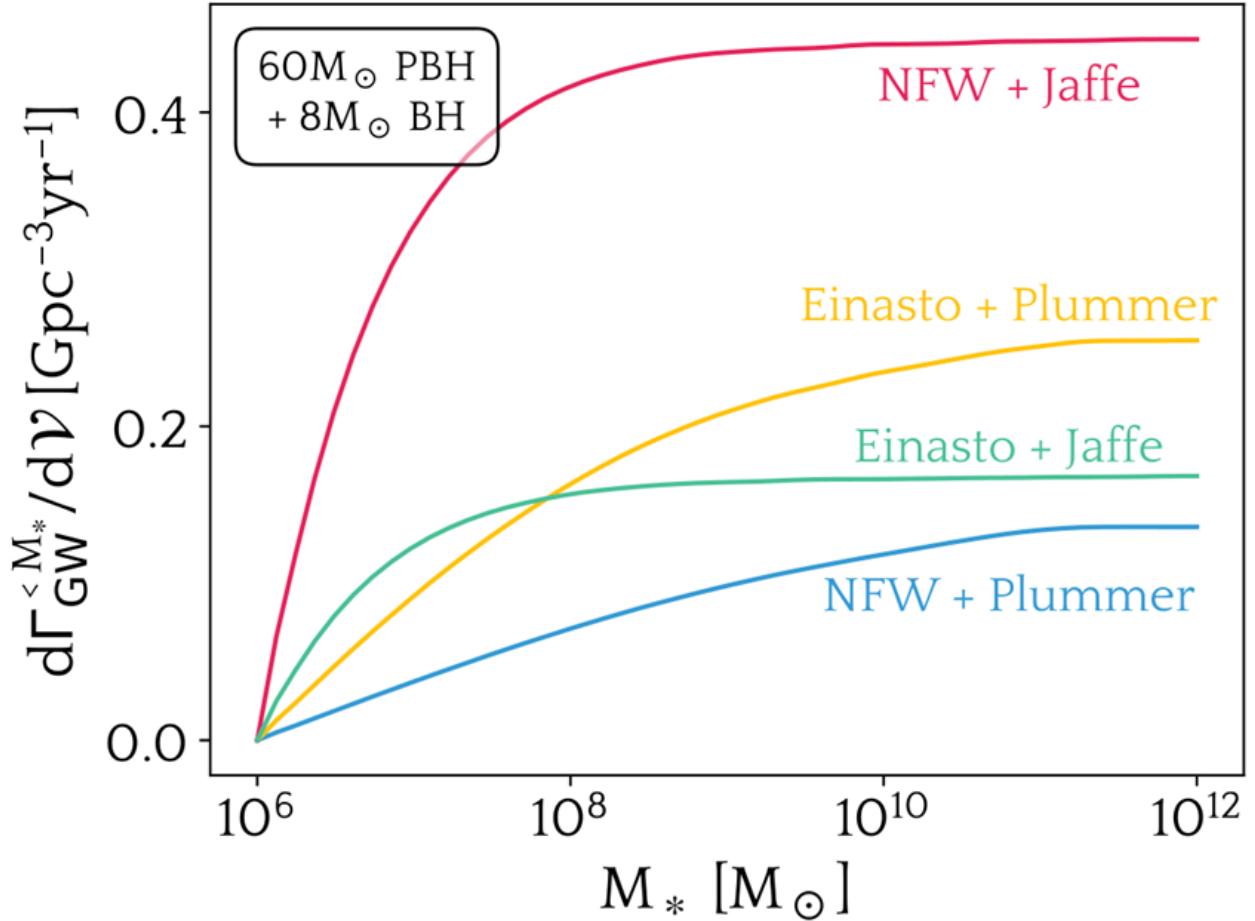
	NFW + Jaffe	Einasto + Plummer	Einasto + Jaffe	NFW + Plummer
$1M_{\odot}$ PBH + $8M_{\odot}$ BH	1.23	0.47	0.35	0.22
$1M_{\odot}$ PBH + $1.4M_{\odot}$ NS	0.61	0.31	0.21	0.16
$60M_{\odot}$ PBH + $8M_{\odot}$ BH	0.45	0.25	0.17	0.14
$60M_{\odot}$ PBH + $1.4M_{\odot}$ NS	0.07	0.04	0.03	0.02

Merger rate of
 $\mathcal{O}(0.3)$ Gpc $^{-3}$ yr $^{-1}$

GW events

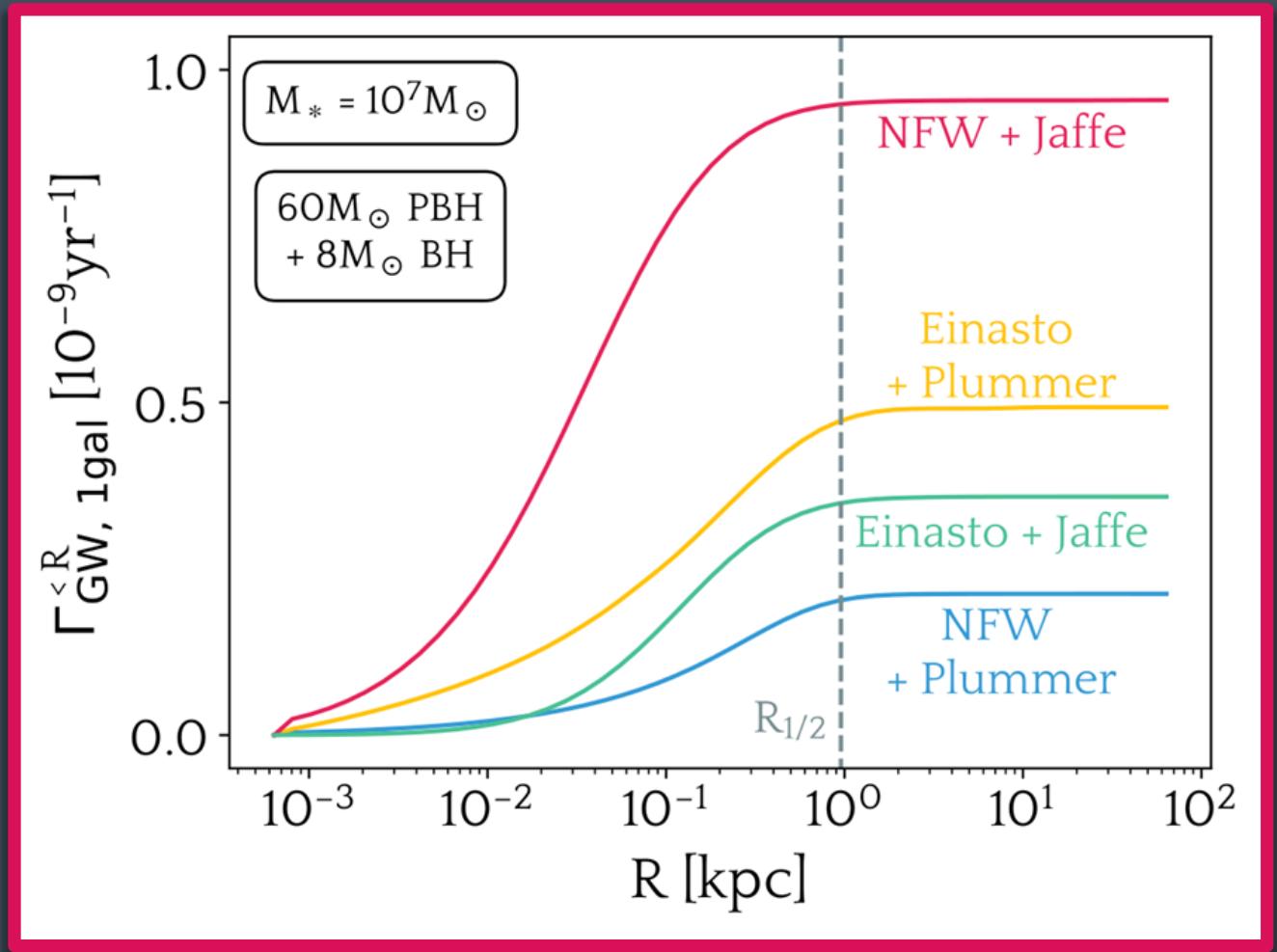


GW events



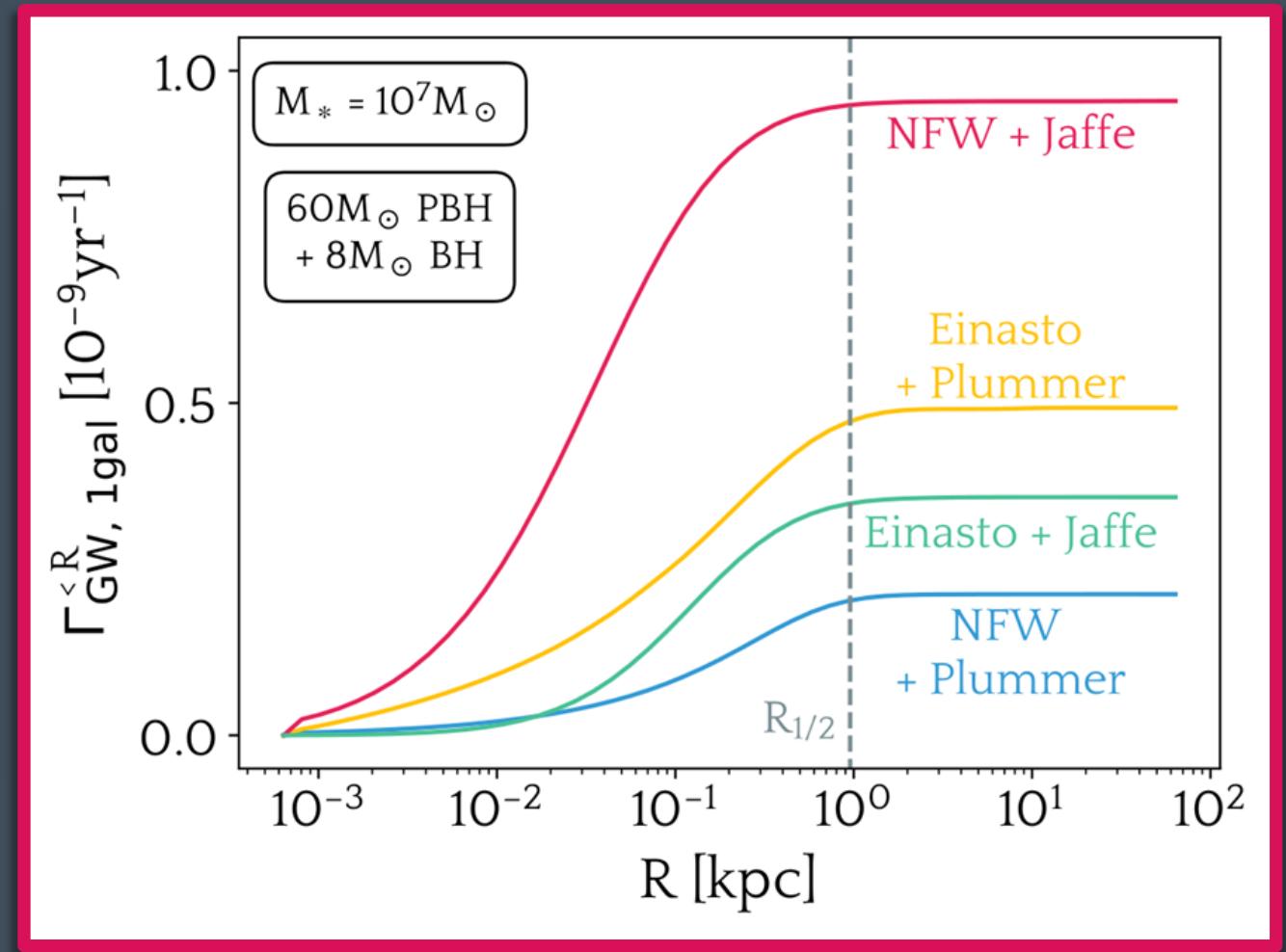
Main
contribution
from dwarf
galaxies

GW events



GW events

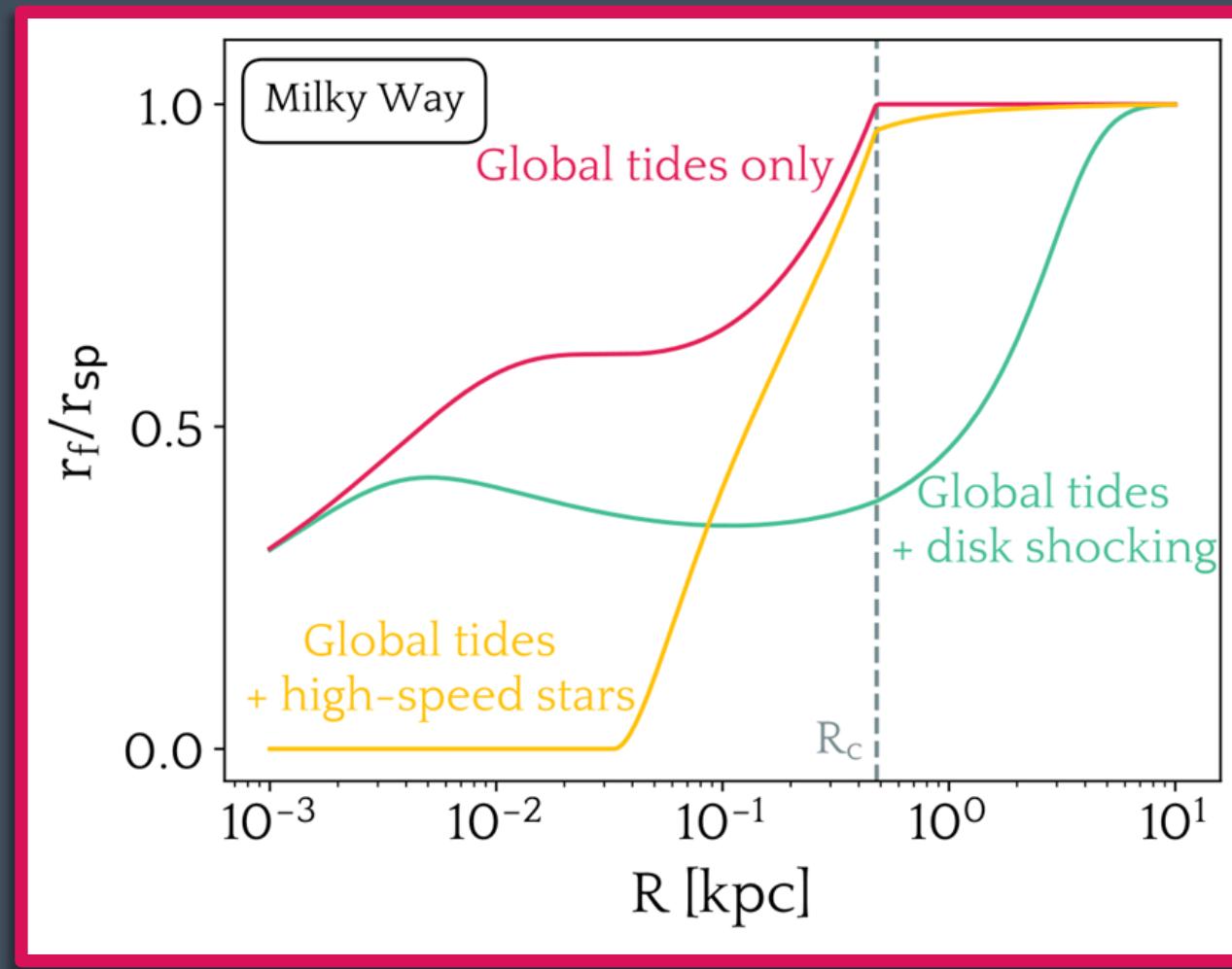
Mergers in
intermediate
region of
galaxies



GW events

PBHs w/ minihalos
capturing stars provide a
viable explanation to
unusual GW events

Note on minihalo survival



Summary

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- Proof of concept: OK. Next: Accuracy.

What next for PBH minihalos?

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- More accurate modelling of the PBH minihalo growth and disruption at late times, combine all effects! (simulations?)

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- More accurate modelling of the PBH minihalo growth and disruption at late times, combine all effects! (simulations?)
- Taking into account the co-evolution of the PBH-star binary with the minihalo ([Kavanagh et al. 2020](#))

Any other ideas
regarding minihalos
around PBHs ? Discussion



Thank you!

2505.05564 (PRD)

Nicolas Esser

Btw: I am now working on observational aspects of stars in the faintest MW satellites & how to probe the DM there...

Thank you!

2505.05564 (PRD)

Nicolas Esser