ULB

Dark Matters 2022

PHYS

Constraints on primordial black holes from observation of stars in dwarf galaxies

Nicolas Esser & Peter Tinyakov

arXiv:2207.07412

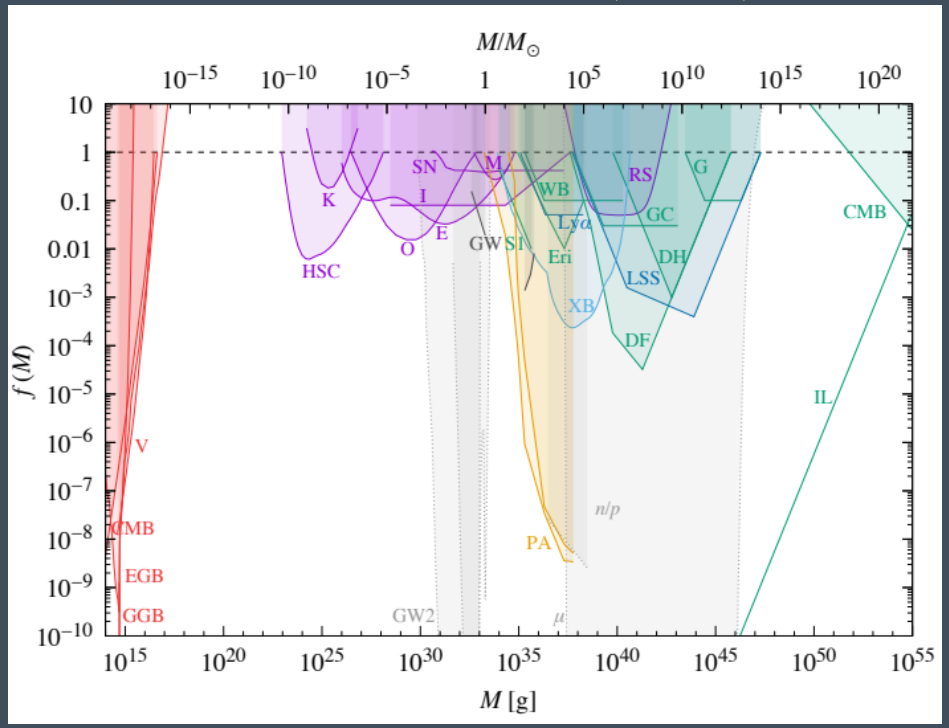
Outline

- Introduction
- Probability of star destruction by a PBH
  1. PBH capture during star formation
  2. Sinking of the PBHs and star destruction
- Ultra-faint dwarf galaxies
- Constraints

Introduction

- PBHs as a DM candidate
- Numerous constraints ∃ for various mass ranges

Figure: B. Carr et al. (2021)



Introduction

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- Numerous constraints ∃ for various mass ranges
- However PBHs of asteroïd-mass $\sim 10^{20}$ g remain unconstrained

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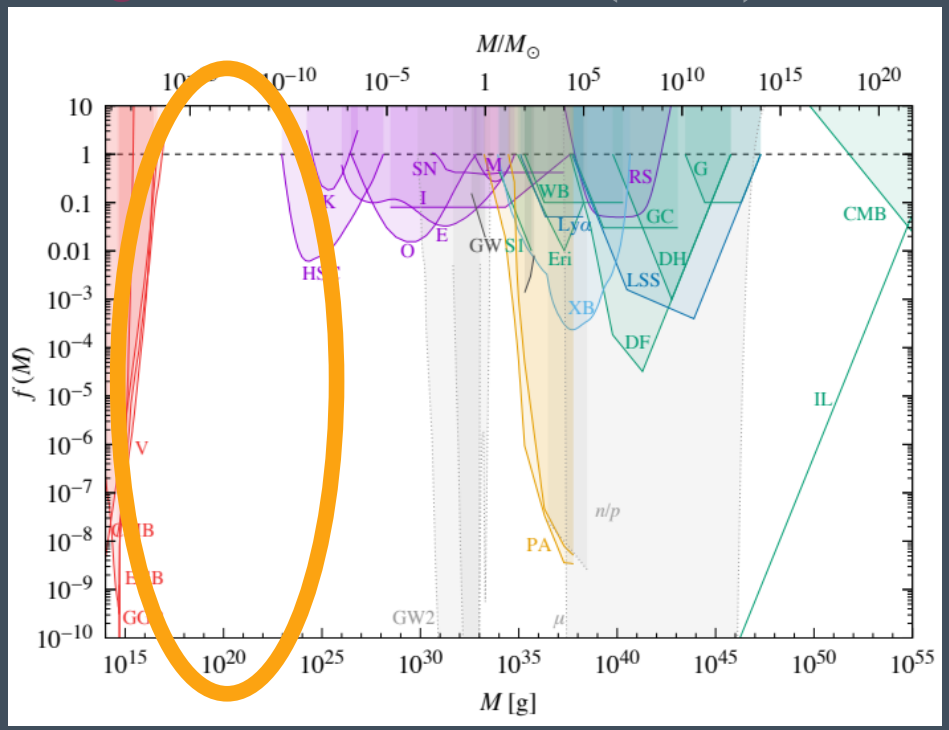

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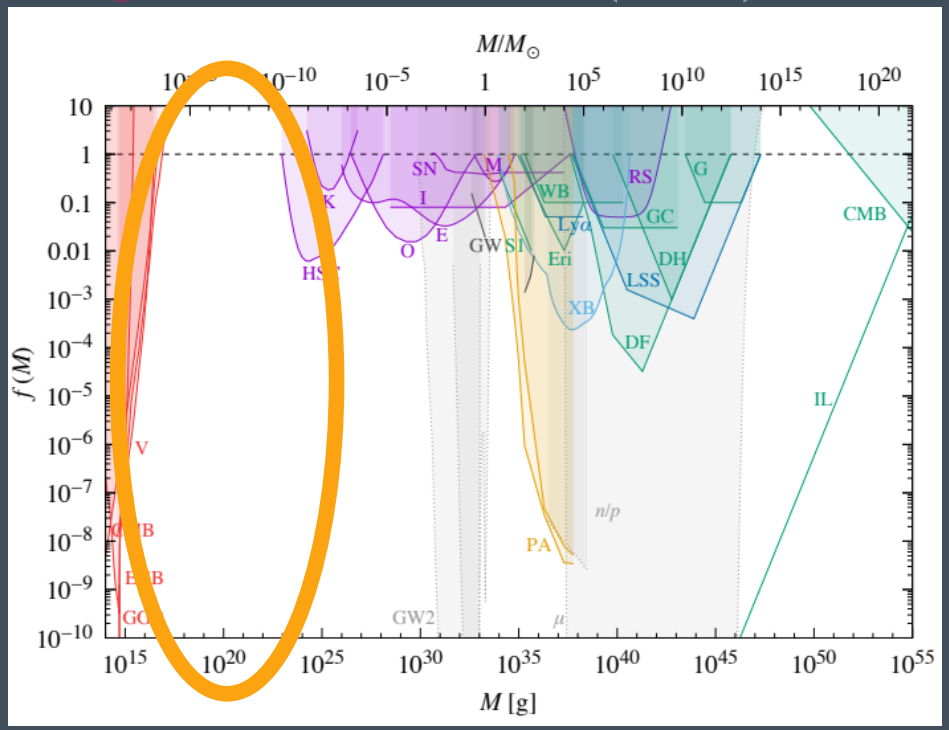

We aim to derive constraints on these atomic-sized PBHs through their capture by main sequence stars

PBH capture during star formation

- 4×10^6 PBHs with Maxwellian distribution around a protostellar cloud, integrated on the bound trajectories with small angular momentum :

$$\overline{\rho}_{\mathrm{DM}} = 4\pi\rho_{\mathrm{DM}} \left(\frac{3}{2\pi\sigma^2}\right)^{3/2} \frac{{v_{\mathrm{esc}}}^3}{3} \quad \propto \quad \frac{\rho_{\mathrm{DM}}}{\sigma^3} \qquad (1)$$

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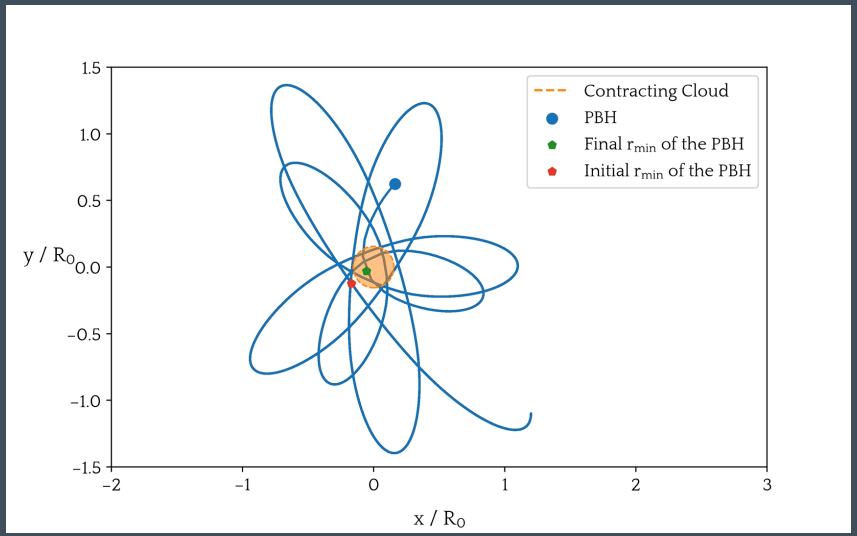

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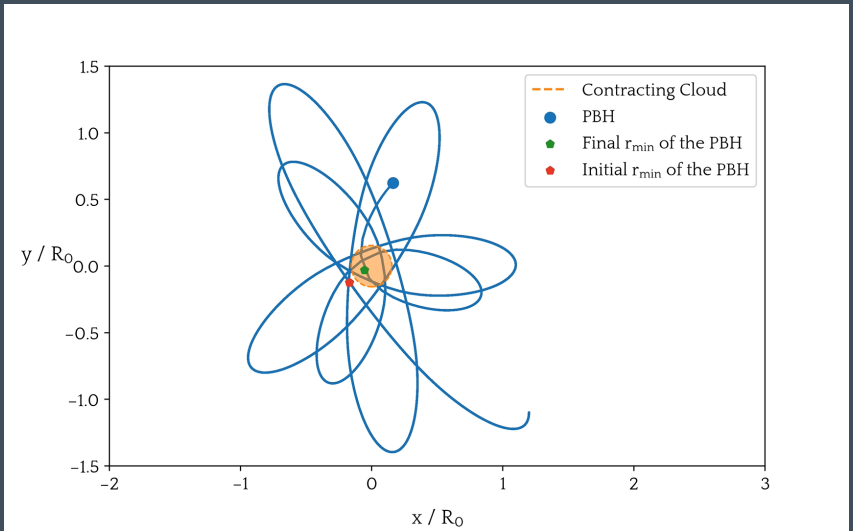

Final r_{min} and r_{max} computed for each PBH

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2. Deviation : increase of r_{min} due to nearby stars located at distance $d <$ main star's radius R_* :

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- Destruction of the star by accretion - no limit for the considered mass range :

$$t_{acc} = \frac{c_s^3}{4\pi\rho_* G^2 m_{BH}} \sim 10^6 \text{ yr for a } 10^{20} \text{ g PBH} \tag{4}$$

Probability of star destruction

$$
\begin{aligned}
&N_{BH,i} \\
&\text{- PBHs with } r_{min} > R_* \\
&\text{- PBHs with } r_{max} > r_{crit} \\
&= N_{BH,f}
\end{aligned}
$$

- $N_{BH,i} = 4 \times 10^6$ PBHs
- $N_{BH,f}$ = # of PBHs that are captured

- $\frac{N_{BH,f}}{N_{BH,i}} \times \overline{\rho}_{DM} \times R_B^3 = \overline{M}_{cap}$, the mean captured PBH mass

- Probability of destruction : $\xi = 1 - \exp\left(-\frac{\Omega_{PBH}}{\Omega_{DM}} \frac{\overline{M}_{cap}}{m_{BH}}\right)$

$$
\longrightarrow \Omega_{PBH}/\Omega_{DM} < \frac{m_{BH}}{\overline{M}_{cap}} \ln\left(\frac{1}{1-\xi}\right)
$$

Ultra faint dwarf galaxies (UFD)

- DM dominated galaxies, with high DM density and low mean velocity dispersion ($\rho_{\rm DM} \sim 200$ GeV/cm^3, $\sigma \sim 7$ km/s)

  $\longrightarrow$ Interesting for us (cf. eq (1)) since $\overline{\mathbf{M}_{\mathbf{cap}}} \propto \frac{\rho_{\mathbf{DM}}}{\sigma^3}$

- Major improvements in their census recently (cf. e.g. J.D. Simon (2019) for a review)

Name	σ [km/s]	$\rho_{\rm DM}$ [GeV/cm^3]	$\left(\frac{\rho_{\mathbf{DM}}}{\mathbf{100}\ \text{GeV/cm}^3}\right)\left(\frac{\mathbf{7}\ \text{km/s}}{\sqrt{\mathbf{2}}\boldsymbol{\sigma}}\right)^{\mathbf{3}}$
Triangulum II	< 5.9	$< 160 \pm 80$	0.95 ± 0.51
Tucana III	< 2.1	$< 3.7 \pm 1.8$	0.51 ± 0.22
Segue 1	$6.4^{+2.4}_{-1.9}$	85^{+100}_{-85}	$0.39^{+0.85}_{-0.72}$
Solar system	~ 220	~ 0.4	$\sim 10^{-8}$

Constraints

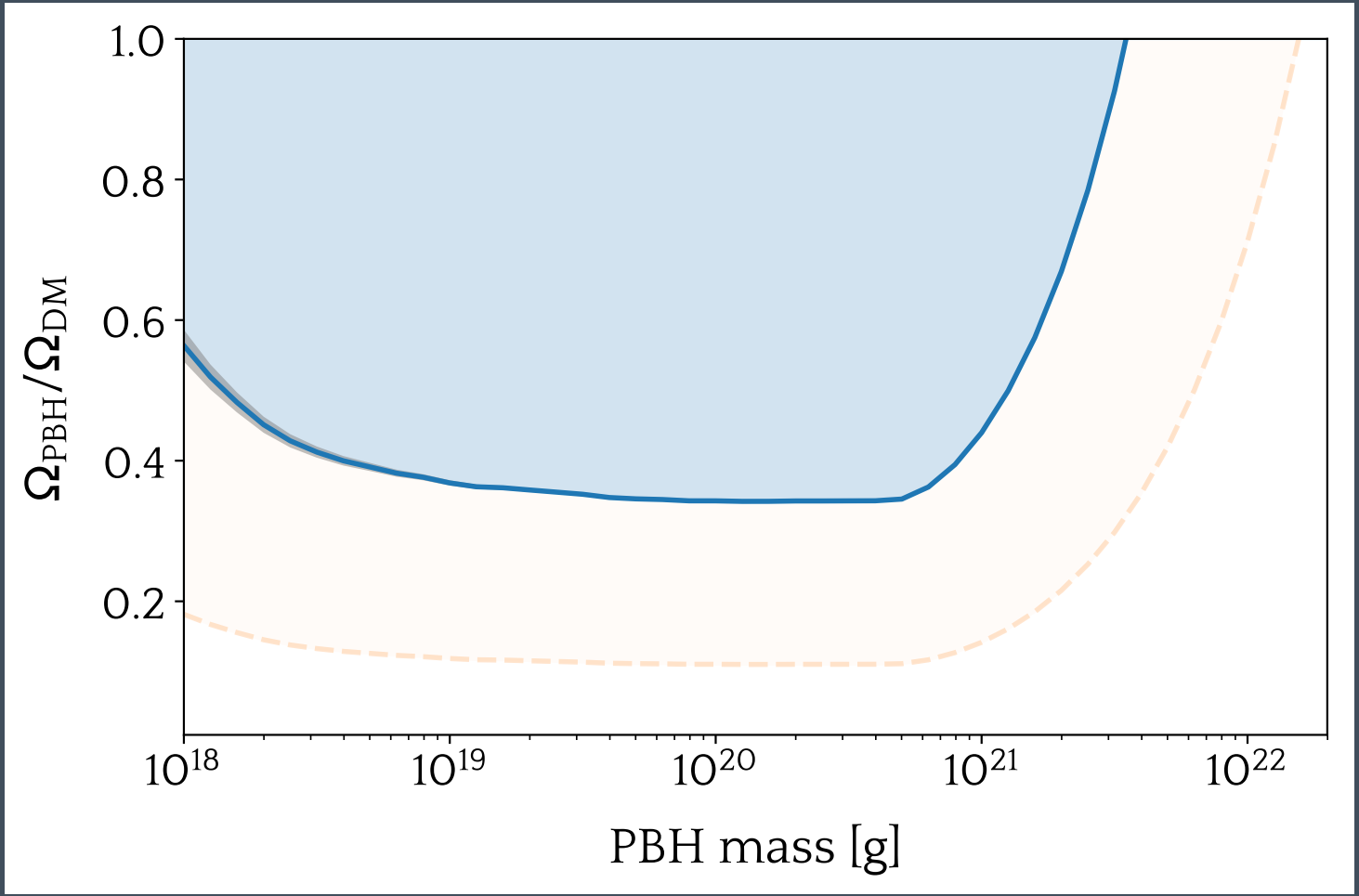

Figure: N. Esser & P. Tinyakov (2022), constraints on the abundance of PBHs in Triangulum II, with $\xi = 0.5$ (blue) and $\xi = 0.2$ (orange).

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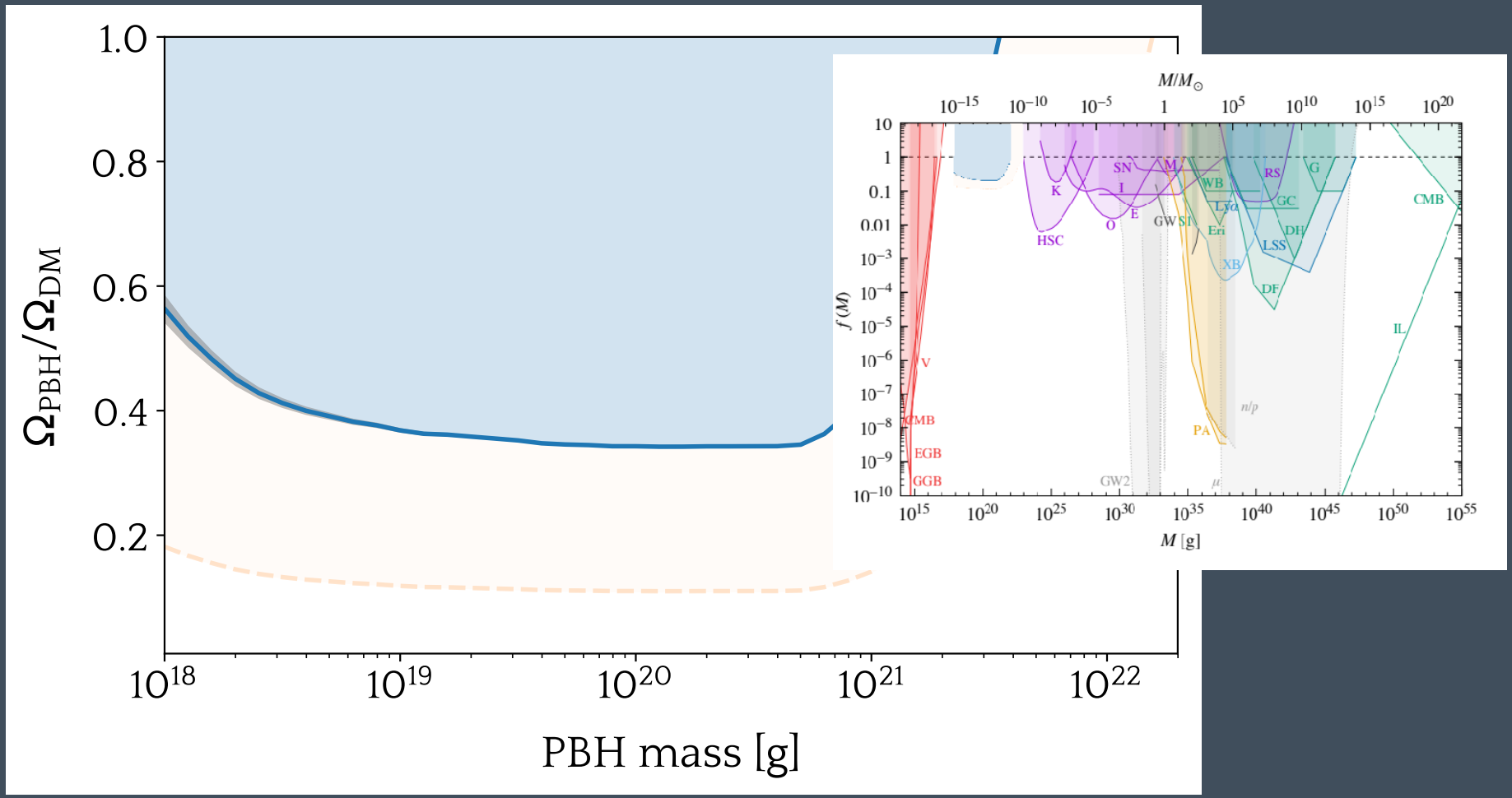

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Future prospects

- We are currently working on a way to determine the maximum fraction ξ of stars destroyed during the lifetime of a given UFD
- We need to refine the accretion process (especially taking into account the rotation of the star) in order to clear out the constraints at low $(< 10^{18}\mathrm{g})$ masses
- New UFD data that would allow us to obtain more precise and more stringent constraints

Thank you for your attention !

Nicolas Esser

Research group in theoretical physics (ULB)

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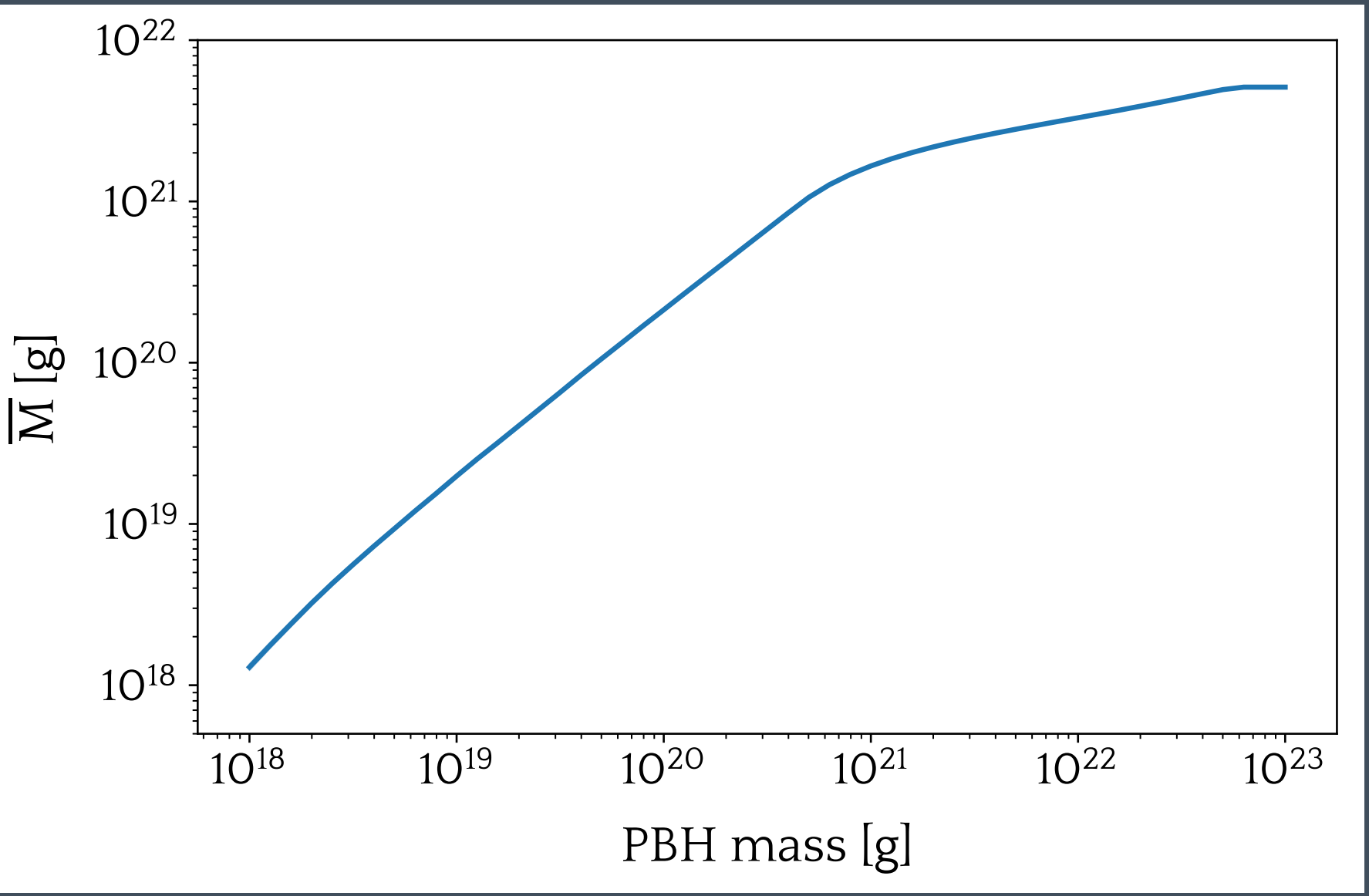

Figure: Captured mass as a function of the PBH mass. Statistical uncertainties are not visible on the plot. From N. Esser & P. Tinyakov (2022).