
BRAUHAUS
JOH.ALBRECHT
Welcome to our Session!

New Constraints on Primordial Black Holes as Dark Matter

Florian Kühnel

Talk at *13. Kosmologietag*
Bielefeld, 4th of May 2018

work in particular with
Bernard Carr
Katherine Freese
Jens Jasche
Pavel Naselsky
Tommy Ohlsson
Glenn Starkman

PBH Generalities

- Black-hole (BH) formation for $R < R_S$.
  - Astrophysical: From $10^9\, M_\odot$ down to $M_\odot$ but not lower.
  - Have a look at the density $$\rho_S = 10^{18} \left(\frac{M}{M_\odot}\right)^{-2} \frac{\mathrm{g}}{\mathrm{cm}^3}$$
    - → To form smaller black holes we need higher density
    - → Compare to cosmological density $$\rho_C = 10^6 \left(\frac{t}{\mathrm{s}}\right)^{-2} \frac{\mathrm{g}}{\mathrm{cm}^3}$$
    - → Formation at early times; primordial black holes (PBHs)
  - Masses of primordial black holes:

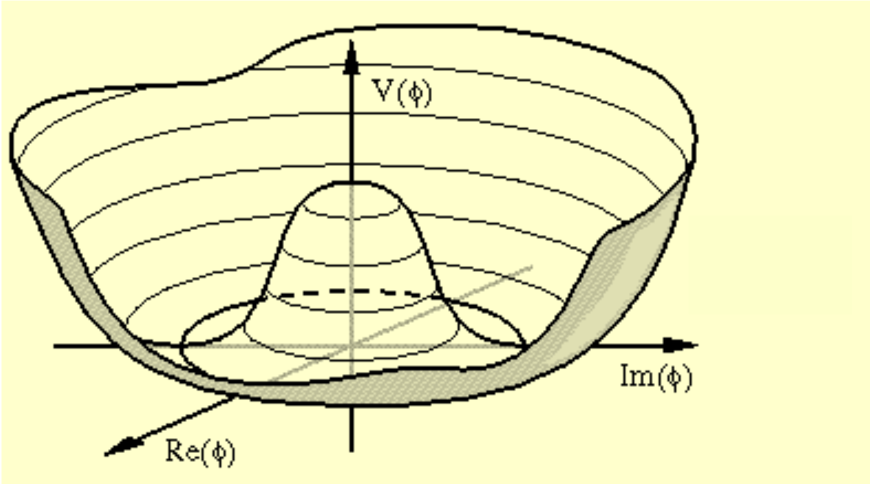
$$M(t = 10^{-23}\,\mathrm{s}) = 10^{15}\,\mathrm{g}, \qquad M(t = 10^{-6}\,\mathrm{s}) = M_\odot$$

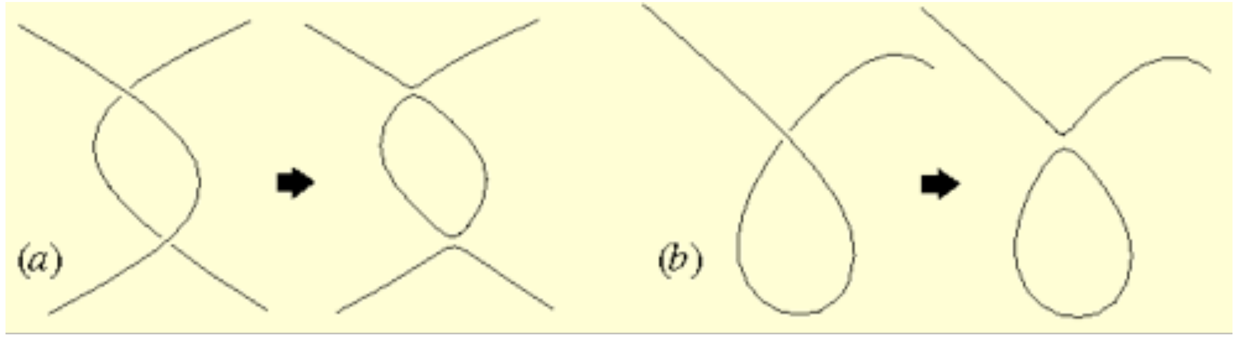
PBH Formation Mechanisms

- Formation of primordial black holes

PBH Formation Mechanisms

- Formation of primordial black holes by
  - Cosmic string loops





http://www.damtp.cam.ac.uk/research/gr/public/cs_top.html

PBH Formation Mechanisms

- Formation of primordial black holes by
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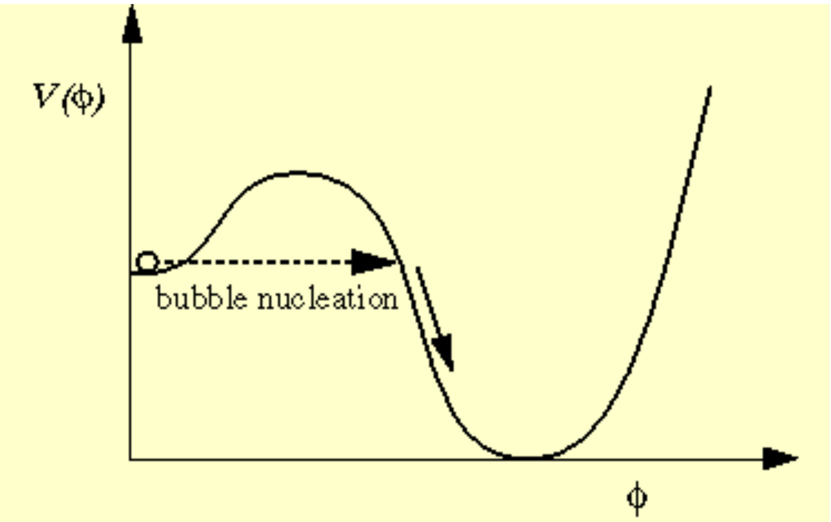

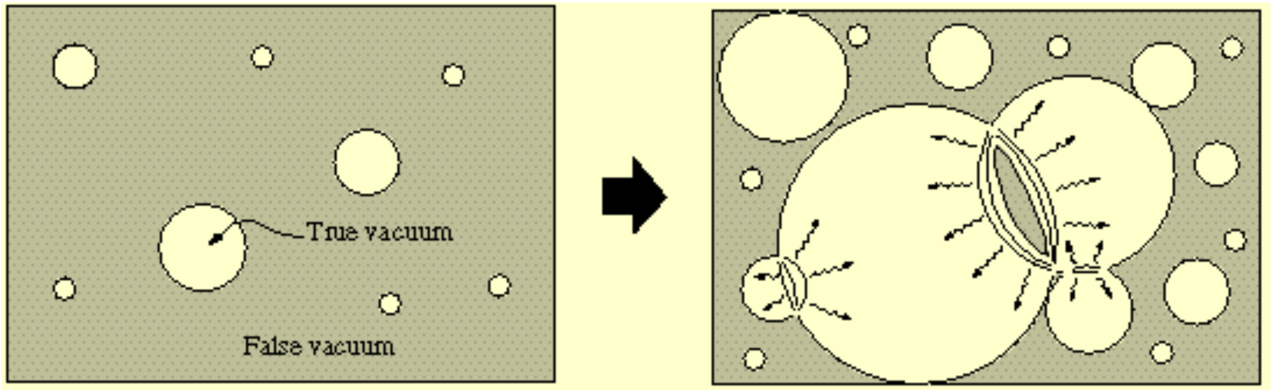

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PBH Formation Mechanisms

- Formation of primordial black holes by
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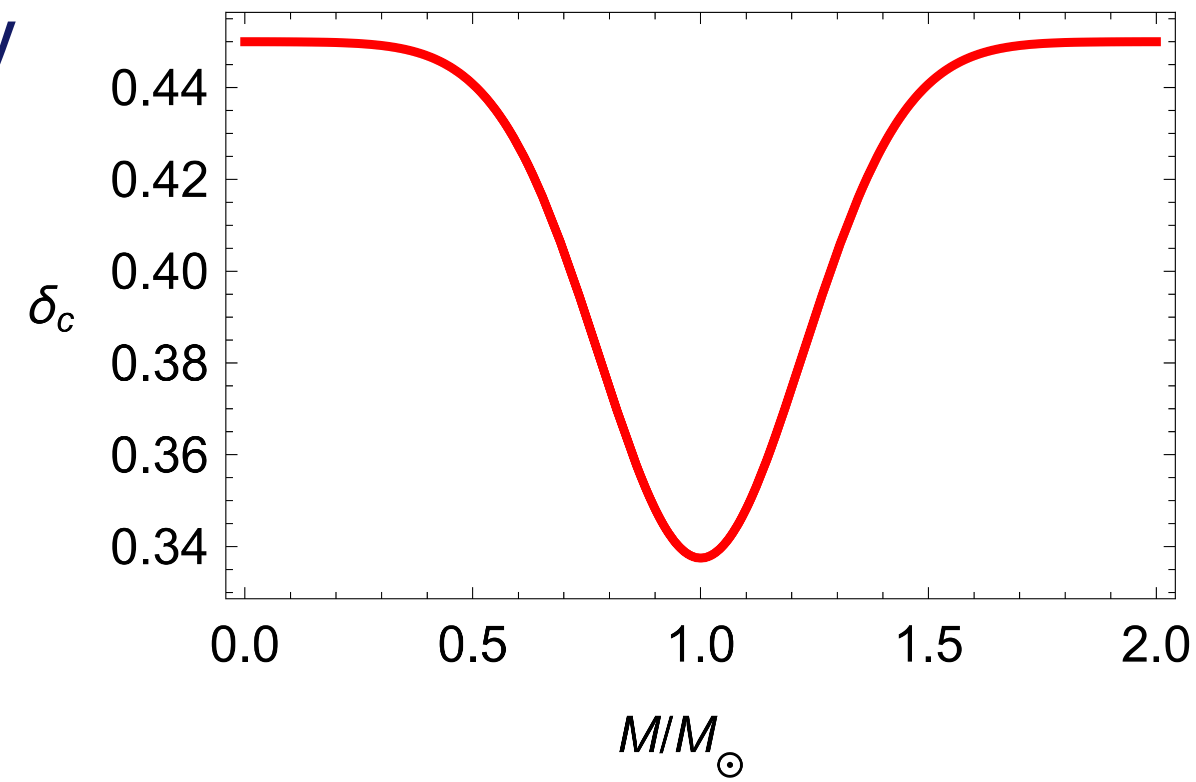

PBH Formation Mechanisms

- ★ Formation of primordial black holes by
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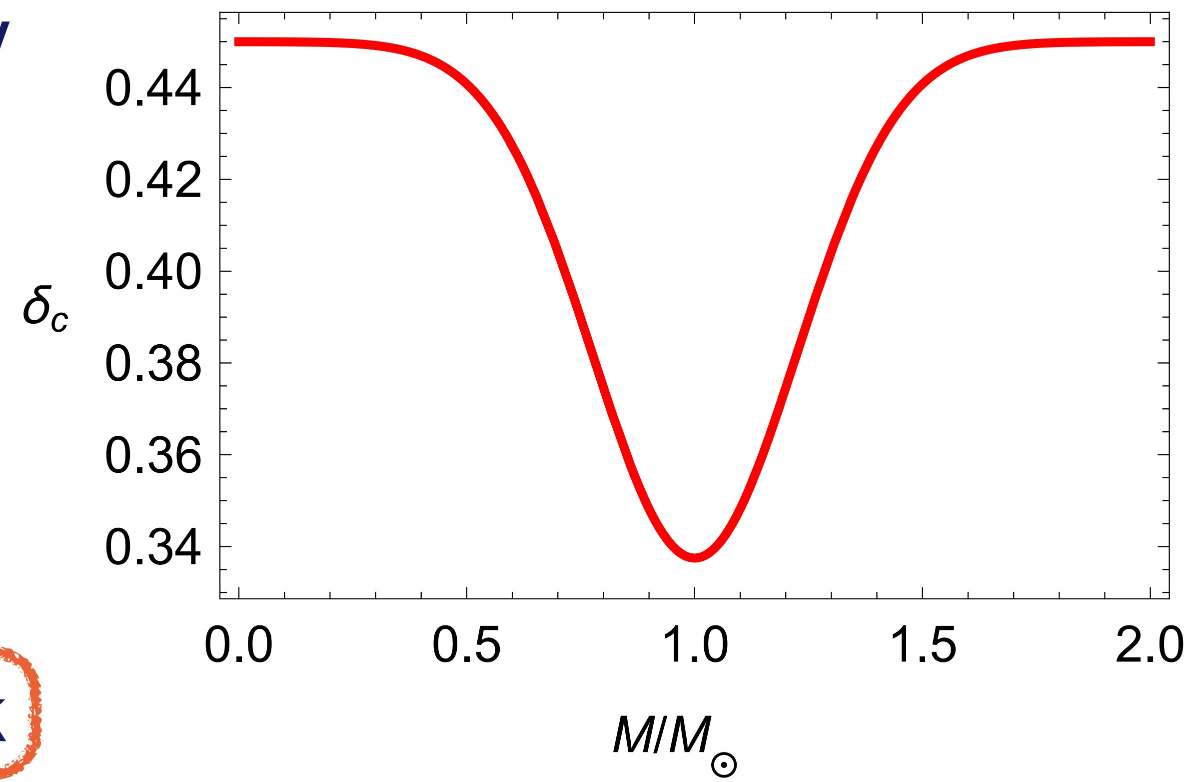
More in Chris' talk



PBH Formation Mechanisms

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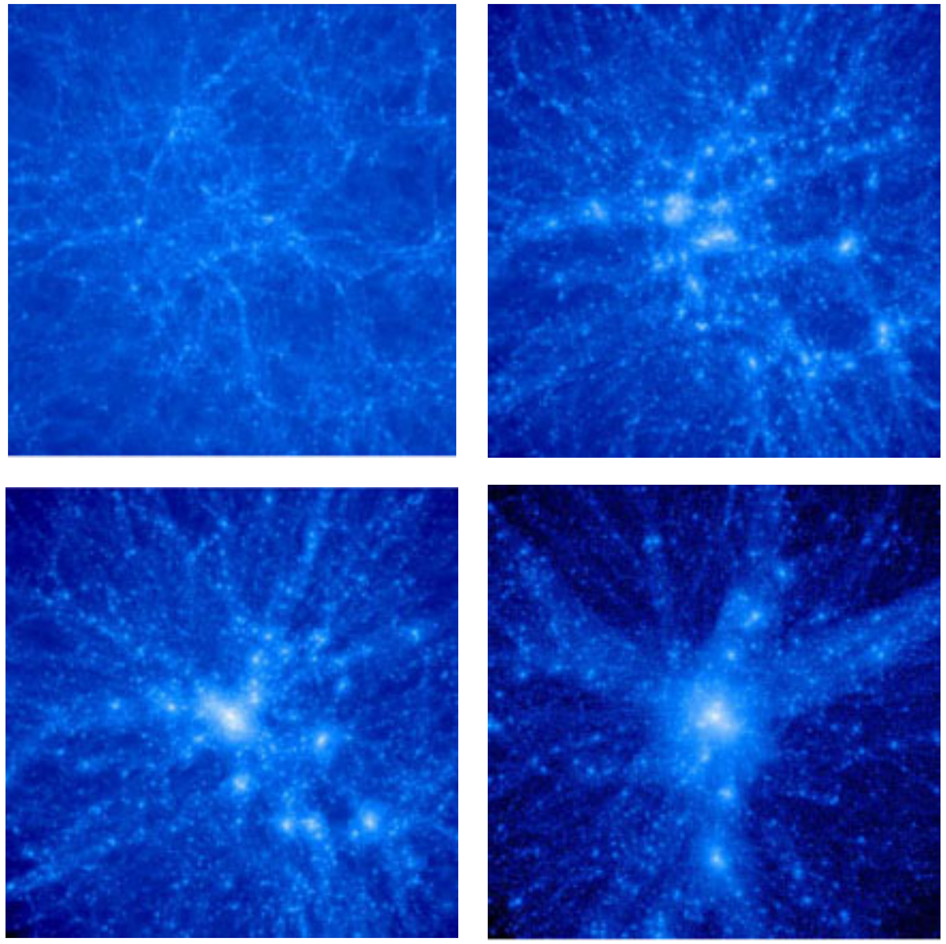
PBH Formation Mechanisms

★ Formation of primordial black holes by

- ★ Cosmic string loops
- ★ Bubble collisions
- ★ Pressure reduction
- ★ Large density perturbations



https://ned.ipac.caltech.edu/level5/Sept12/Kravtsov/Kravtsov3.html

→ Simple estimate:

[Carr 1975]

$$R > R_J \quad \Rightarrow \quad \boxed{\delta_H > w} \quad , \quad \text{for} \quad p = w\,\rho$$

scale of the over density

Jeans length

PBH — Probes of Scales

★ Probe a huge range of scales:

$M \sim 10^{-5}\mathrm{g}$	Quantum Gravity:	Planck relics, Extra dimensions and higher-dimensional black holes, …
$M \lesssim 10^{15}\mathrm{g}$	Early Universe:	Baryogenesis, Nucleosynthesis, Reionisation, …
$M \sim 10^{15}\mathrm{g}$	High-Energy Physics:	Cosmological and galactic gamma-rays, …
$M \gtrsim 10^{15}\mathrm{g}$	Gravity:	Critical phenomena, Cold dark matter, Dynamical effects, Lensing effects, Gravitational waves, Black holes in galactic nuclei, …

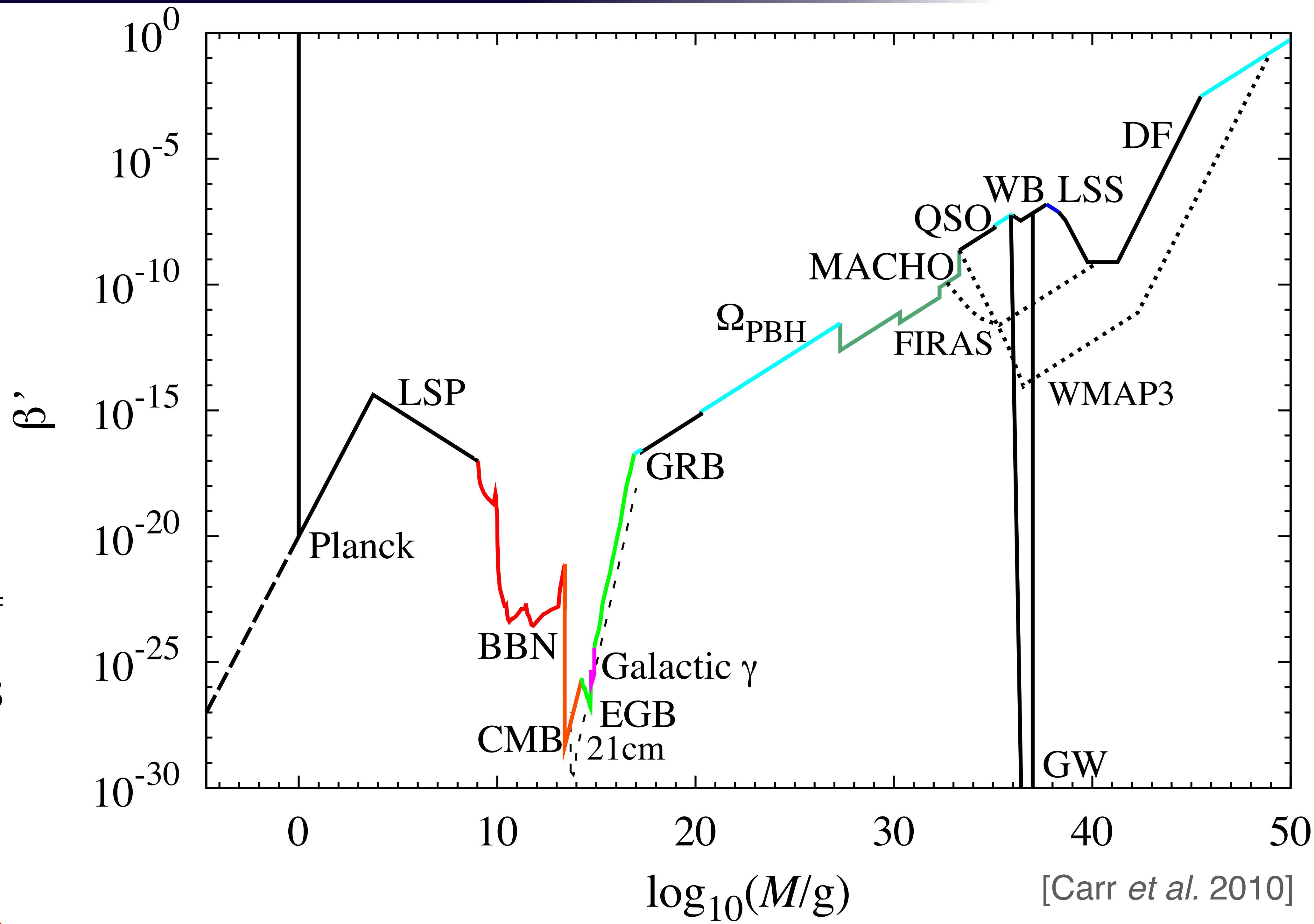
PBH — Some Numbers

- Consider an example of primordial black holes constituting all of the dark matter:

  - Mass range: $10^{20}\,\mathrm{g}$
  - Size: $10^{-8}\,\mathrm{cm}$
  - Number in our Galaxy: 10^{25}
  - Distance: $10\,\mathrm{AU}$

PBH Constraints at Formation

$\propto \Omega_{PBH}\Big|_{form}$



[Carr *et al.* 2010]

★ Note that

$$\rho_{rad} \propto a^{-4}$$

$$\rho_{PBH} \propto a^{-3}$$

and hence

$$\Omega_{PBH} \propto a$$

PBH & Particle Dark Matter

Oskar Klein centre

- If PBHs do not constitute the entirety of the dark matter, the latter must necessarily contain something else.

- One possibility: a combined scenario, e.g. DM = PBHs + Particles

- Let us now study WIMP annihilations in PBH halos:
  - The annihilation rate $\Gamma \propto n^2$.
    - → Halo profile does matter; enhancement of Γ in density spikes.

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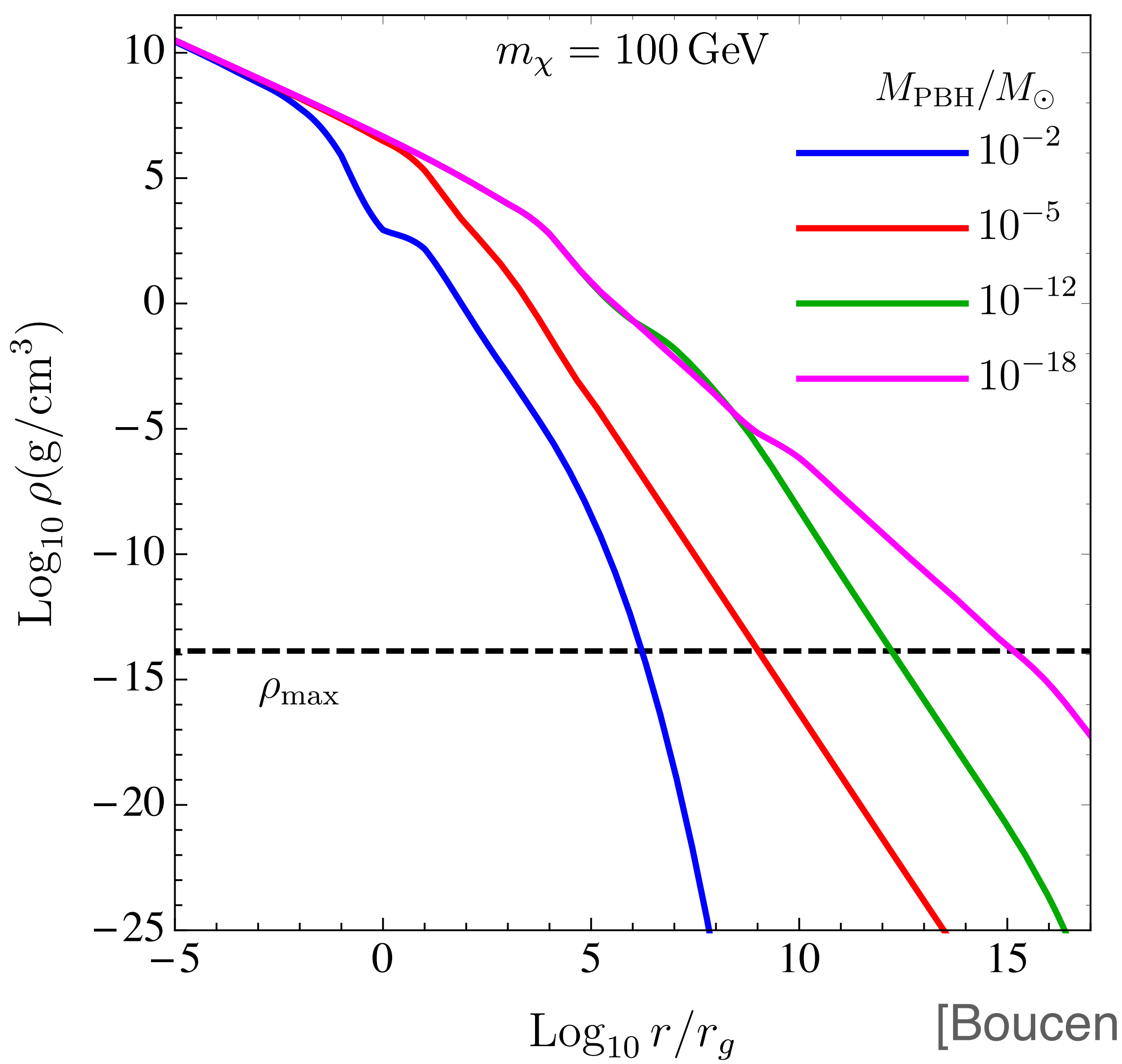

[Boucenna, FK, Ohlsson, Visinelli 2018]

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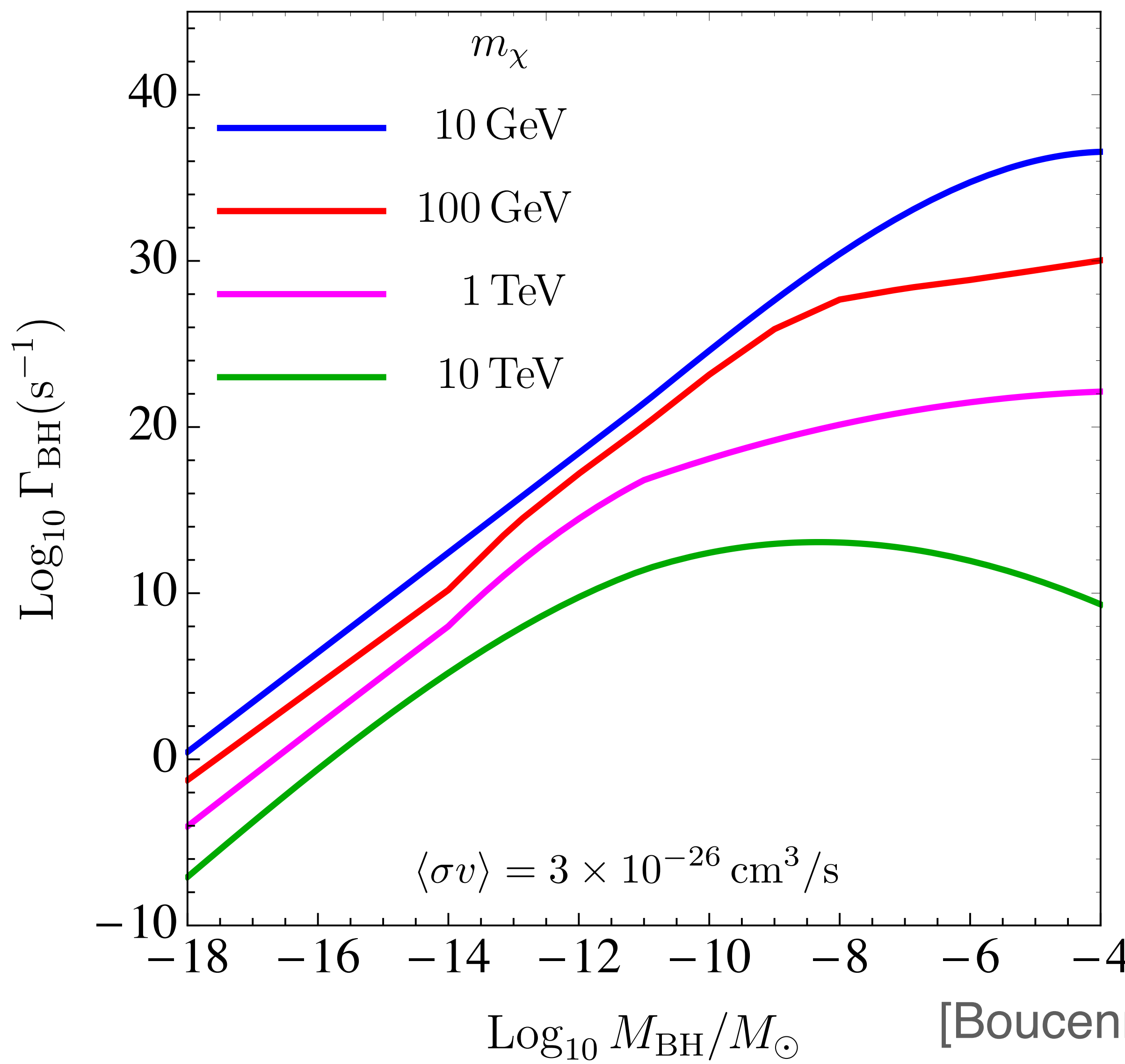

[Boucenna, FK, Ohlsson, Visinelli 2018]

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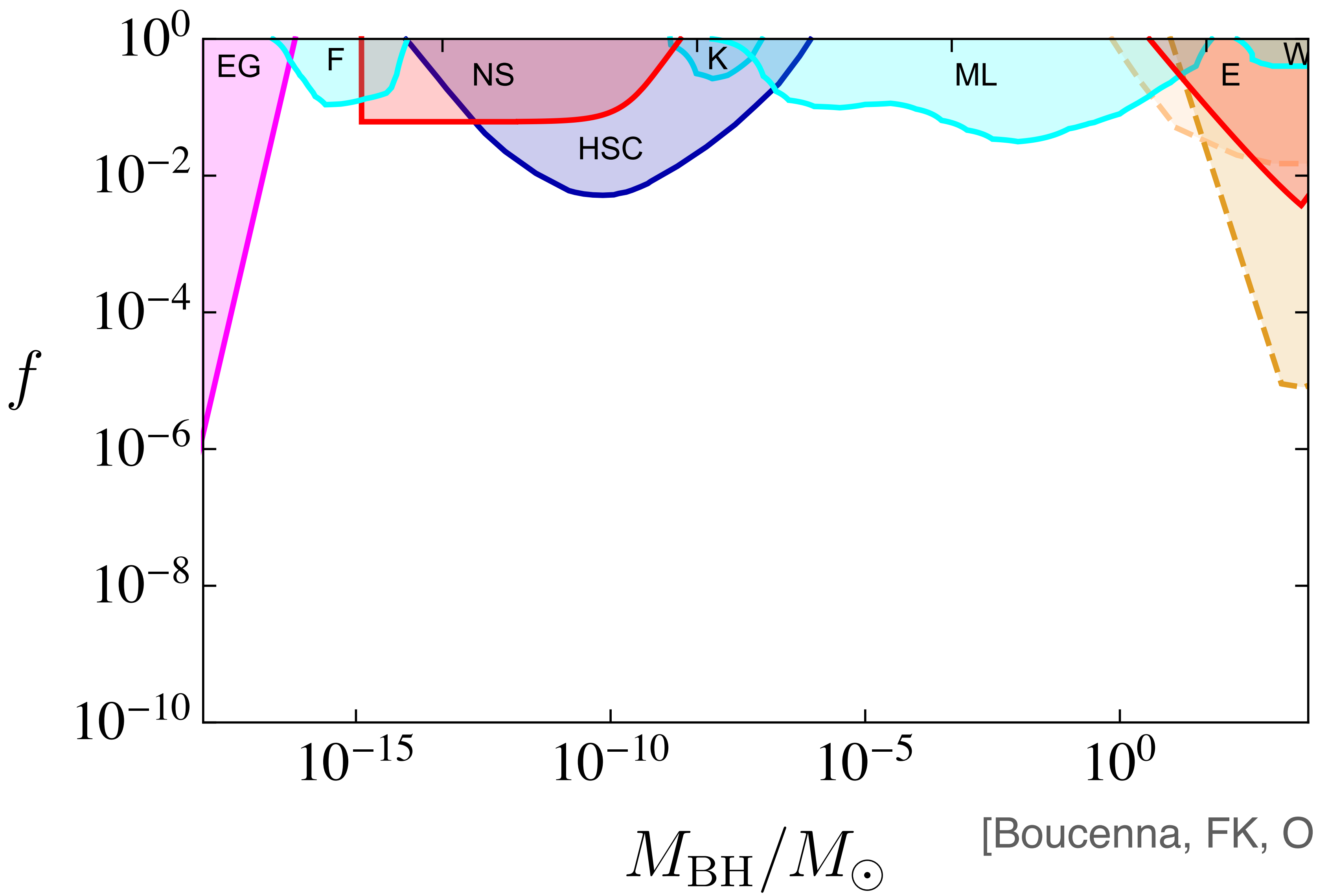

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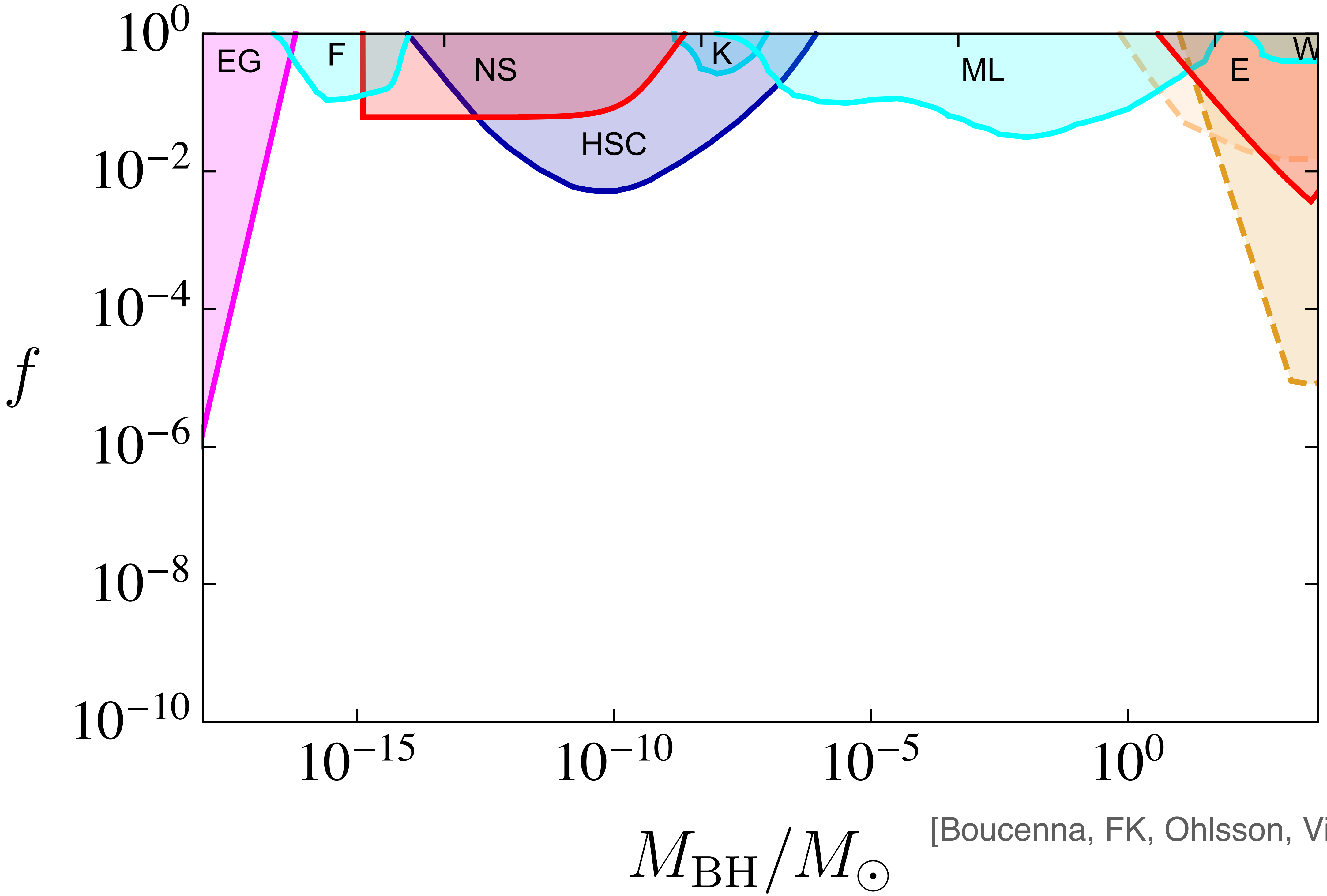

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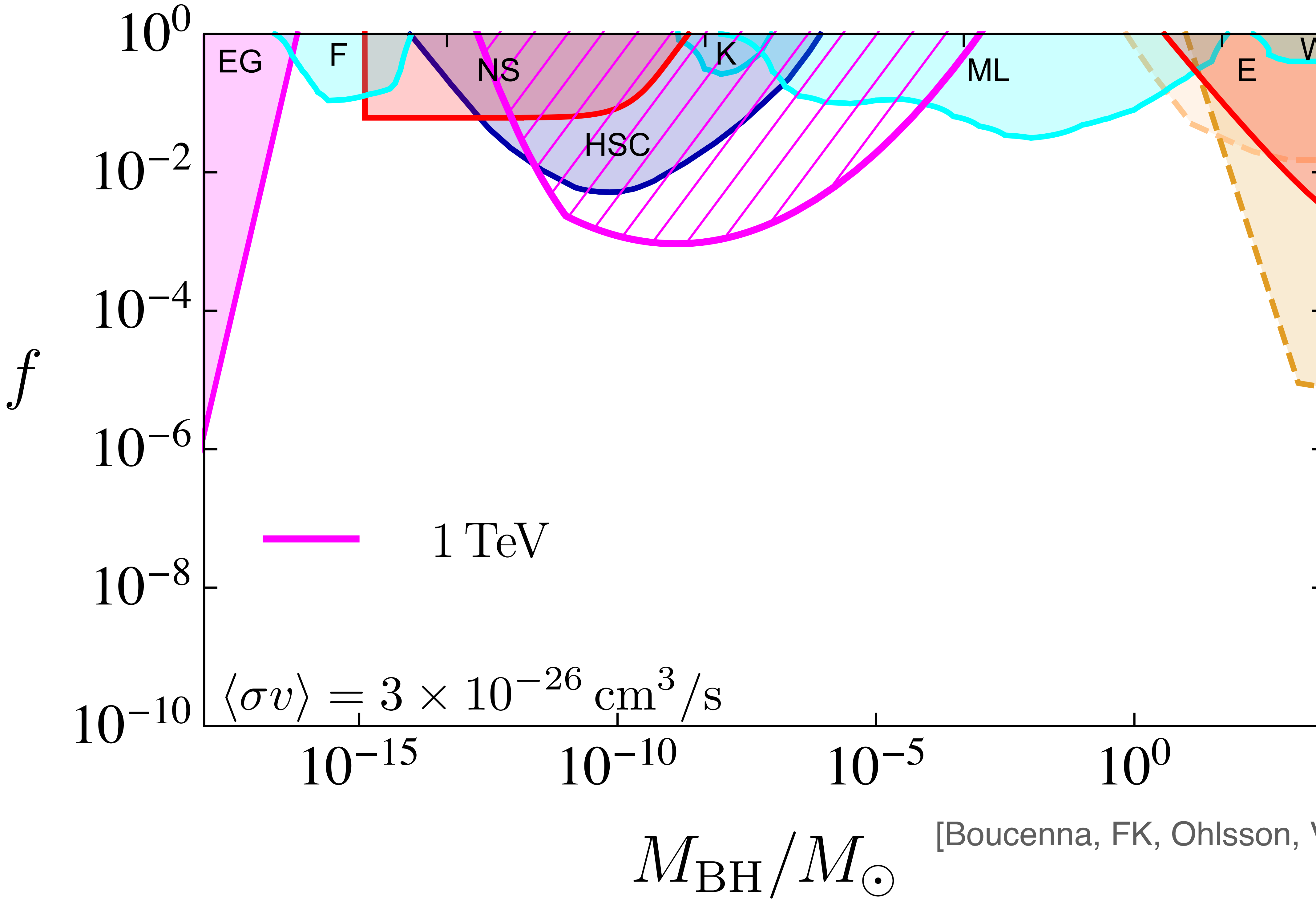

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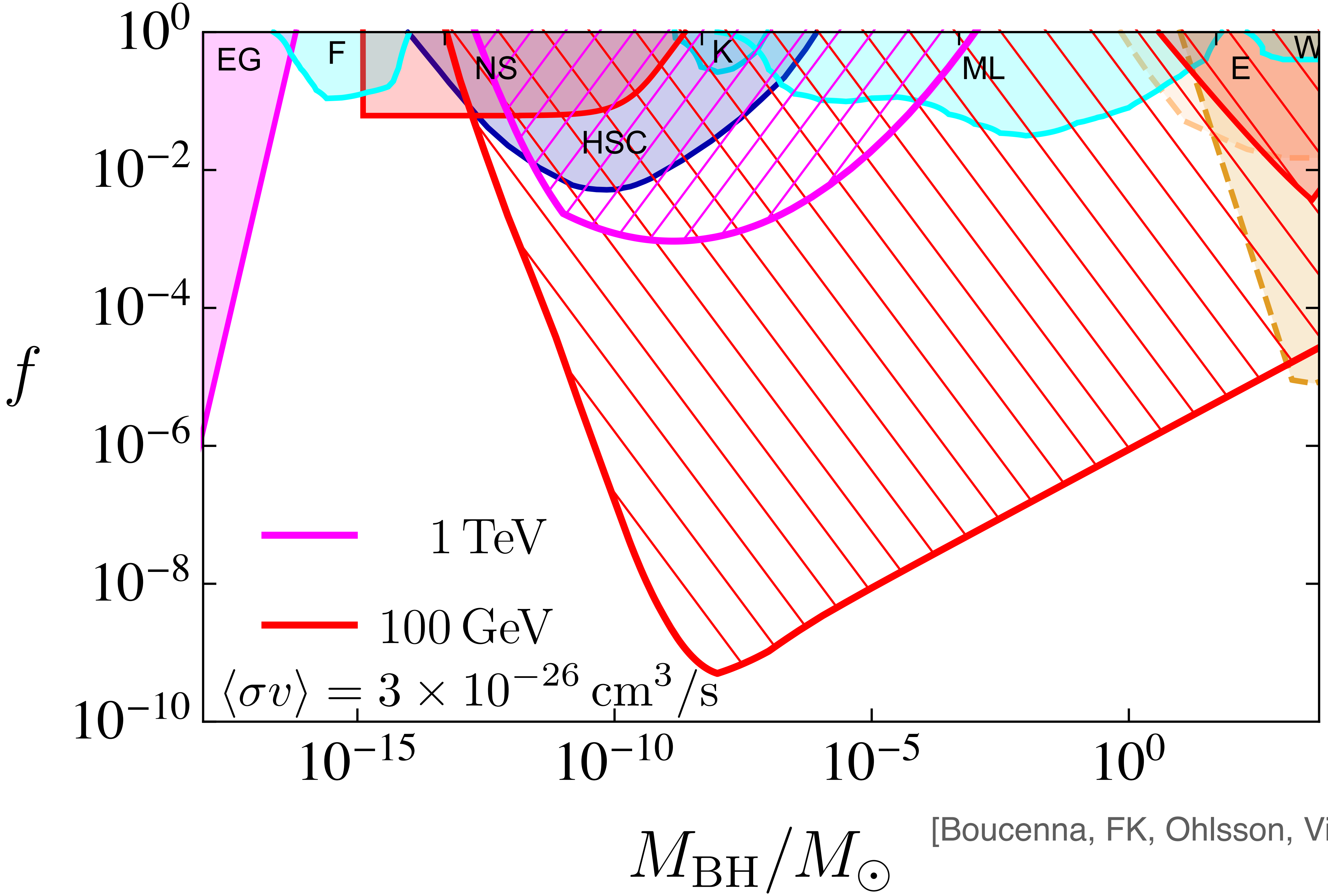

[Boucenna, FK, Ohlsson, Visinelli 2018]

Conclusion

Oskar Klein centre

- Primordial black holes are very interesting!
  - They are unique probes of their formation scenarios.
  - If PBHs do not constitute the entirety of the dark matter, the latter must necessarily contain something else, with combined dark-matter scenarios (PBHs + WIMPs) are amongst the most plausible ones.
  - These scenarios (also those with sterile neutrinos) have distinct signatures and might be falsified or confirmed in the near future.