

# 2<sup>nd</sup> EuCAPT Annual Symposium

Primordial black hole formation in a matter-dominated early universe

2109.04896

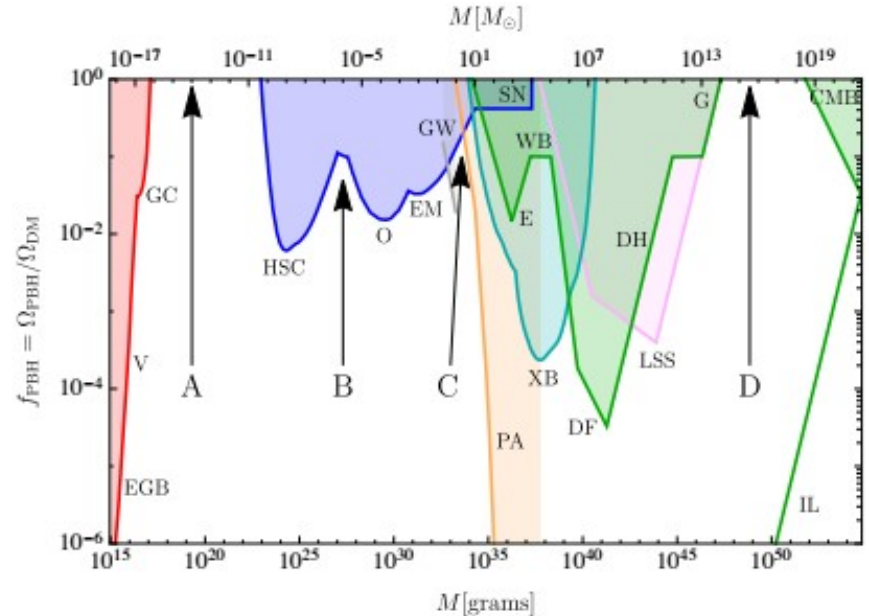
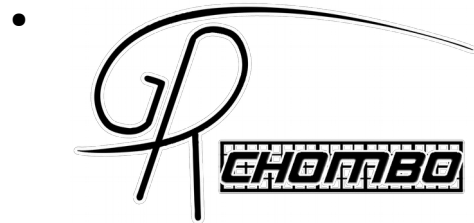
(with Josu Aurrekoetxea, Eugene Lim)

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**25 May 2022**

# Primordial black holes (PBHs)

- Black holes that form in the early universe
- PBHs could make up part of dark matter
- We consider the collapse of overdense regions of the universe

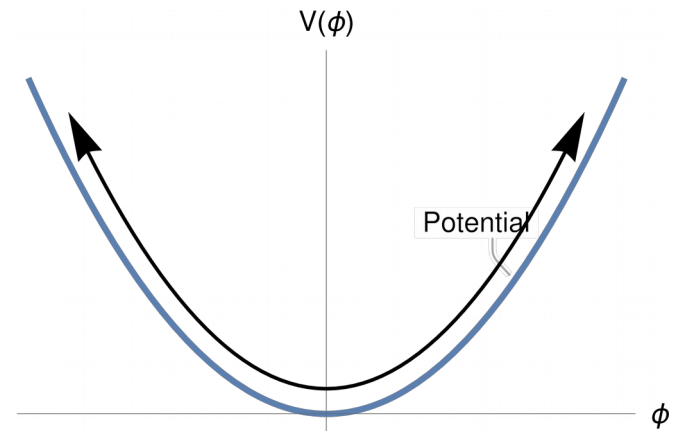


From: Carr & Kuhnel, arXiv:2006.02838

# Matter domination

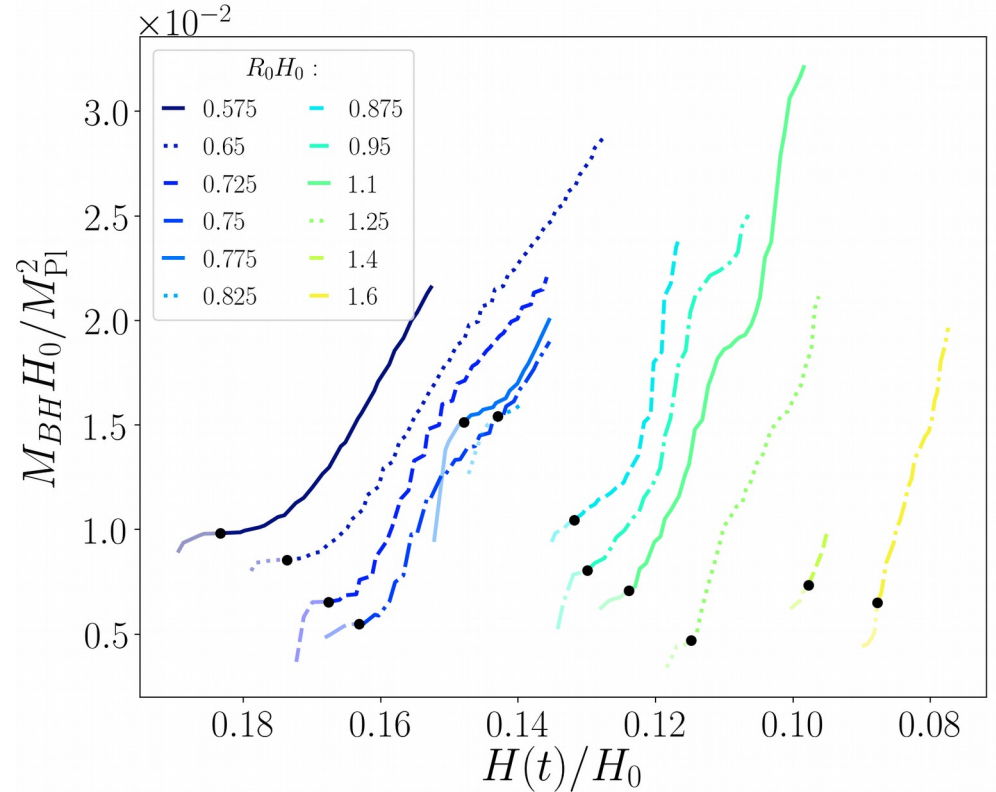
- Matter dominated universe
- Expansion is dominated by an oscillating scalar field
- Collapsing perturbation provided by massless scalar field

$$\mathcal{L}_\phi = \frac{1}{2} \nabla^\mu \phi \nabla_\mu \phi + \frac{1}{2} m^2 \phi^2$$



# Final PBH mass

- Initial PBH masses  $\sim 1\%$  of Hubble mass
- Rapid initial accretion
- PBH mass is bounded by:
  - Hubble mass
  - BBN at  $T = 1\text{MeV}$
- If the PBH grows rapidly until horizon mass and self-similarly after: upper mass limit of  $10^5$  solar masses

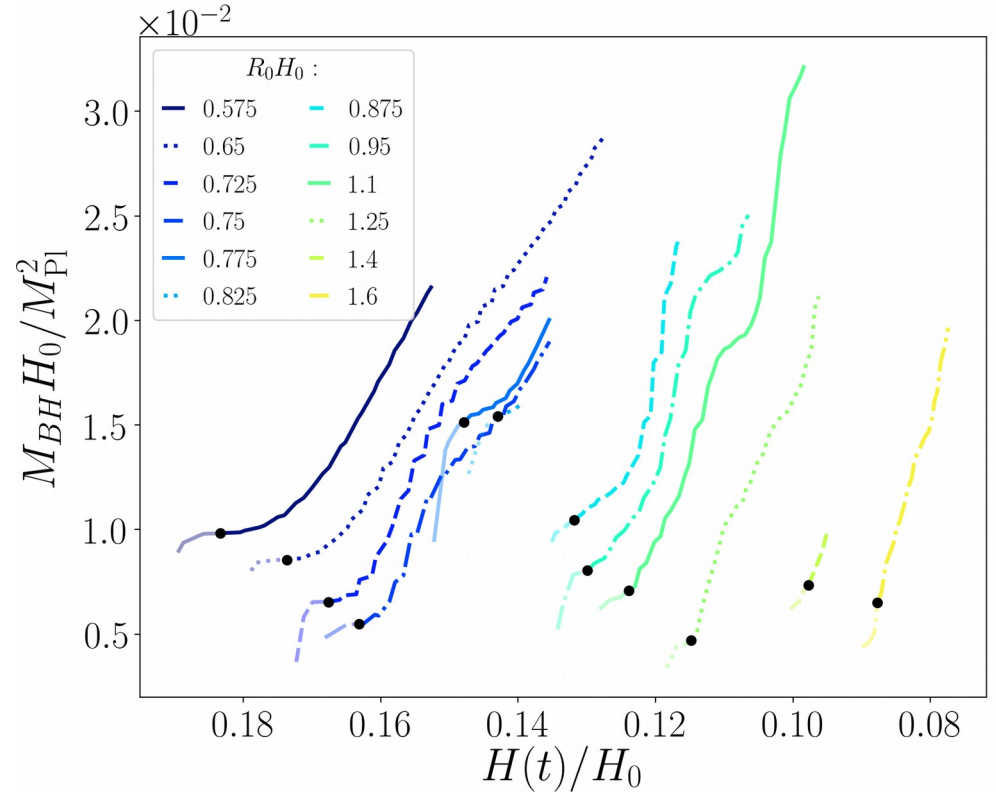


# Final PBH mass

- Initial PBH masses  $\sim 1\%$  of Hubble mass
- Rapid initial accretion
- If accretion slows down earlier, PBH mass is also bounded from below

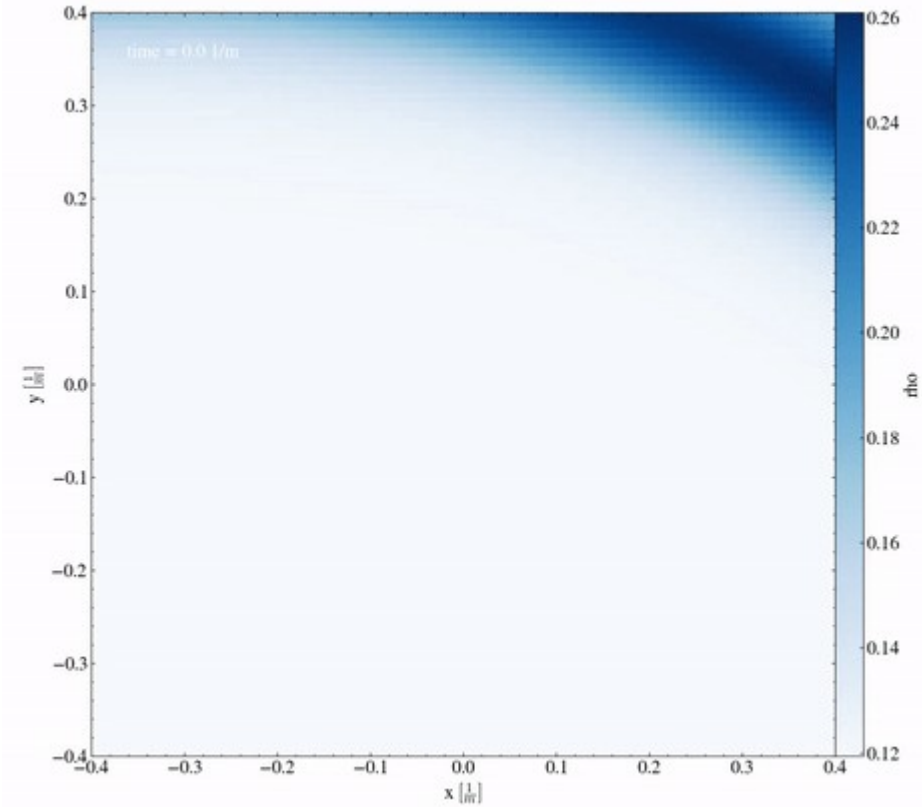
$$M_{BH} \gtrsim 10^{-2} H^{-1}$$

- If PBHs form around  $T = 5\text{MeV}$ , PBHs can be formed that are detected by LIGO/Virgo/KAGRA



# Why 3+1: beyond spherical symmetry

- Spheroidal initial conditions
- Spinning initial conditions



# Summary

- Non-linear initial perturbations, both sub- and superhorizon
- Initial PBH mass  $\sim .01/H_0$
- Two distinct PBH formation mechanisms
- Rapid post-collapse accretion
- If the PBH accretes rapidly until it reaches horizon mass, the final mass is  $\sim 10^5$  solar at BBN
- If accretion slows down earlier, a wide range of masses is possible, including LVK PBHs