

# UK HEP Forum 2021

Primordial black hole formation in a matter-dominated early universe

2109.04896

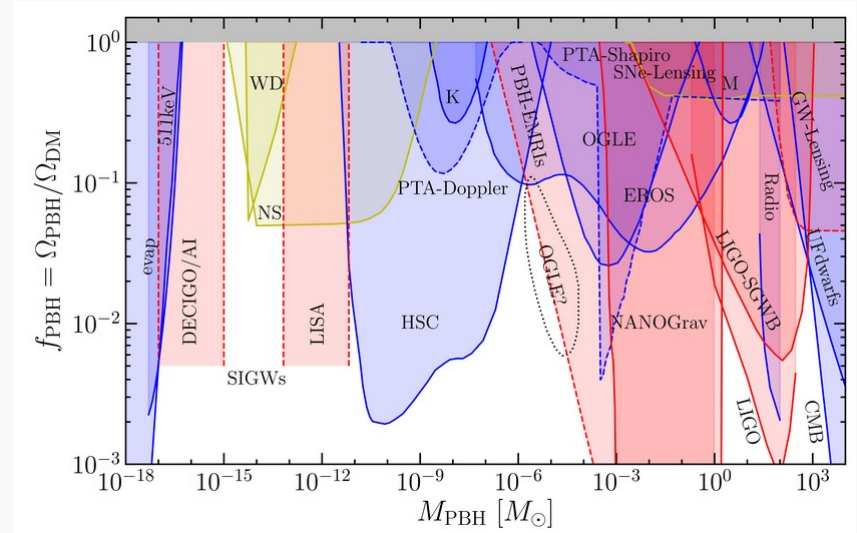
(with Josu Aurrekoetxea, Eugene Lim)

**Eloy de Jong (KCL)**

**23 November 2021**

# Primordial black holes (PBHs)

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

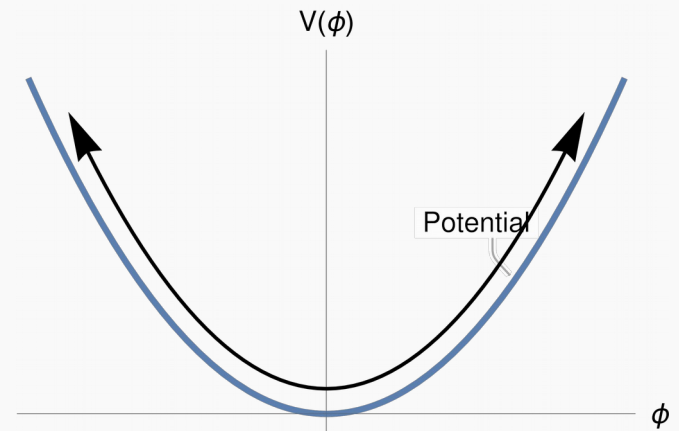


From: <https://github.com/bradkav/PBHbounds>

# Matter domination

- We choose a matter dominated universe: assume early epoch of matter domination
- Universe expansion is dominated by a homogeneous scalar field, oscillating in a quadratic potential

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

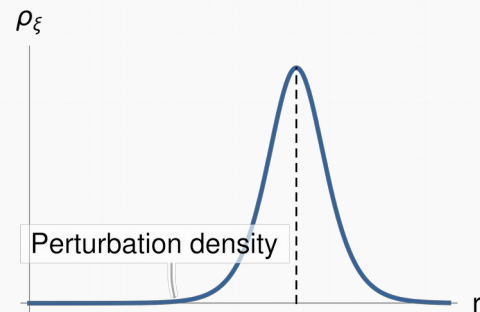
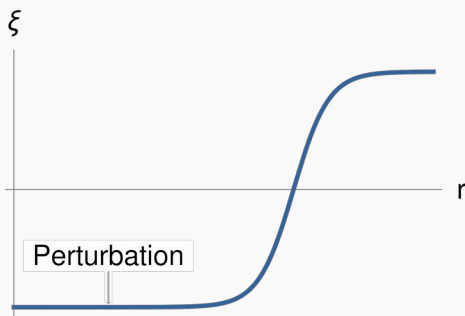


# Energy perturbation

- The energy density perturbation is provided by a 2<sup>nd</sup> massless scalar field

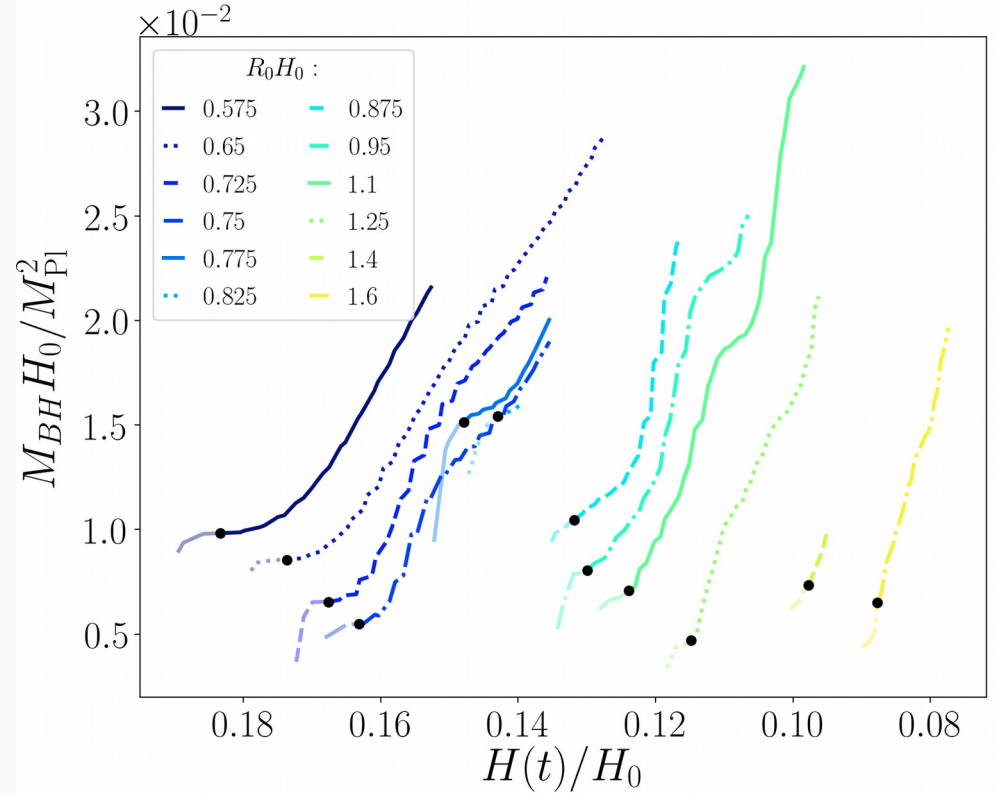
$$\mathcal{L}_\xi = \frac{1}{2} \nabla^\mu \xi \nabla_\mu \xi$$

- This work: spherically symmetric perturbations only
- Total perturbation mass much smaller than total background mass



# Final BH mass

- Initial PBH masses  $\sim 1\%$  of Hubble mass
- We observe 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

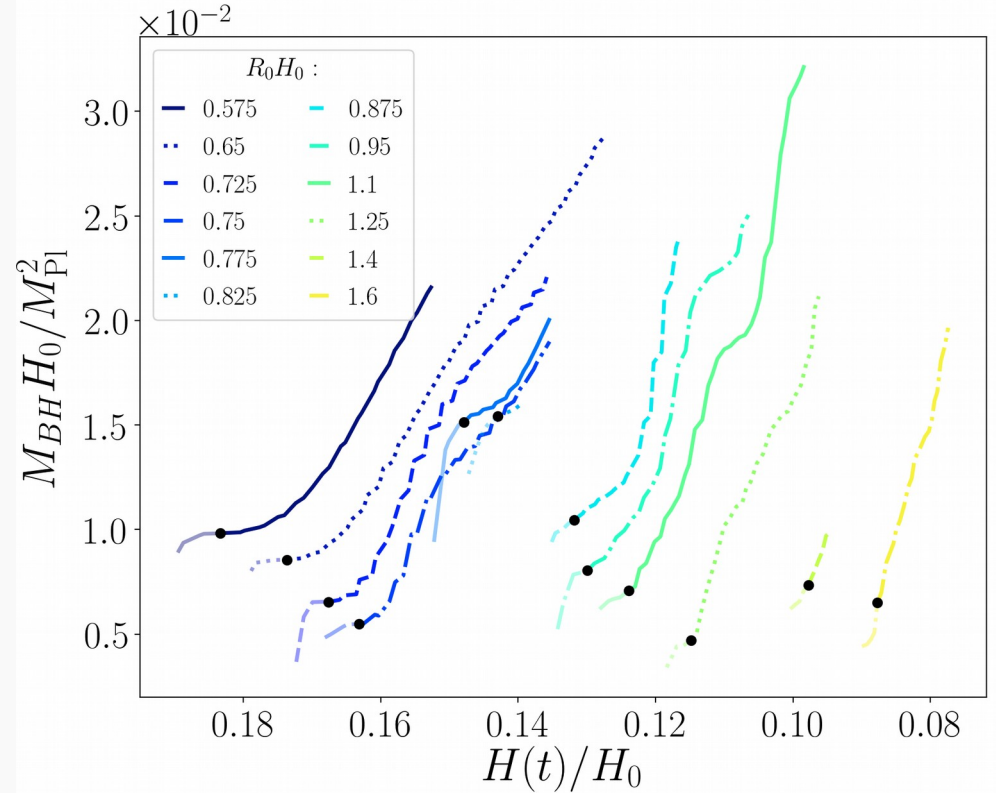


# Final BH mass

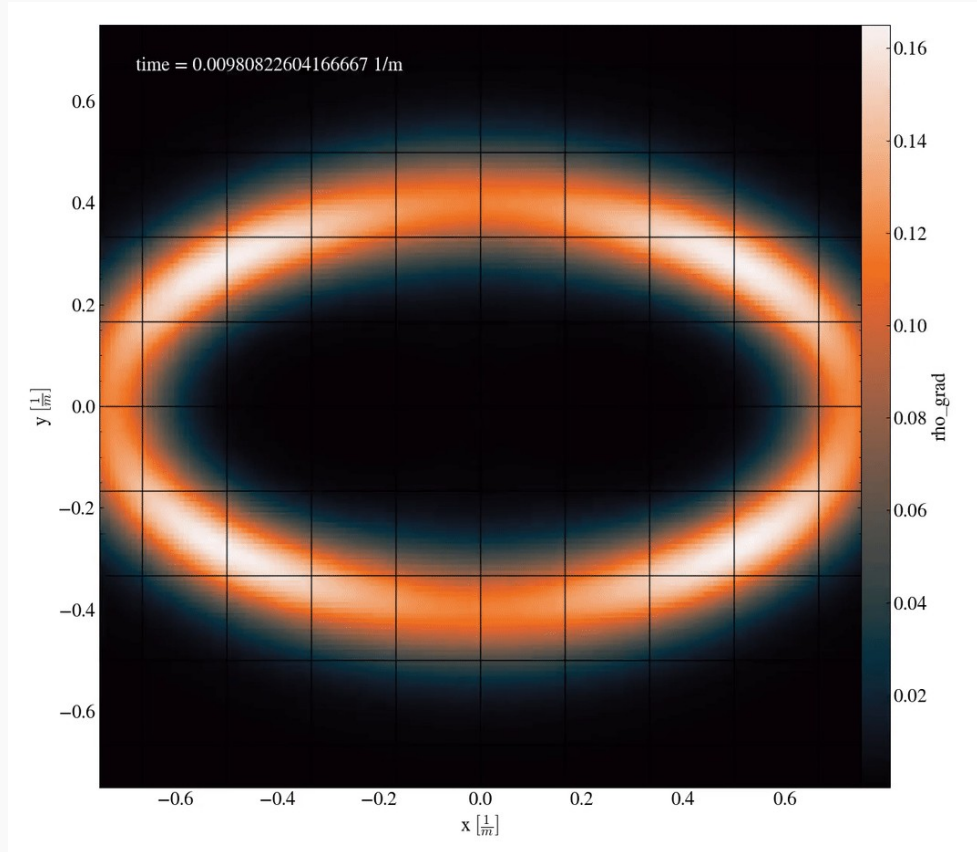
- Initial PBH masses  $\sim 1\%$  of Hubble mass
- We observe rapid initial accretion
- If accretion slows down earlier, PBH mass is also bounded from below

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

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



# Why 3+1: going beyond spherical symmetry



# 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