

# 12<sup>th</sup> Iberian GW Meeting

Primordial black hole formation in a matter-dominated early universe

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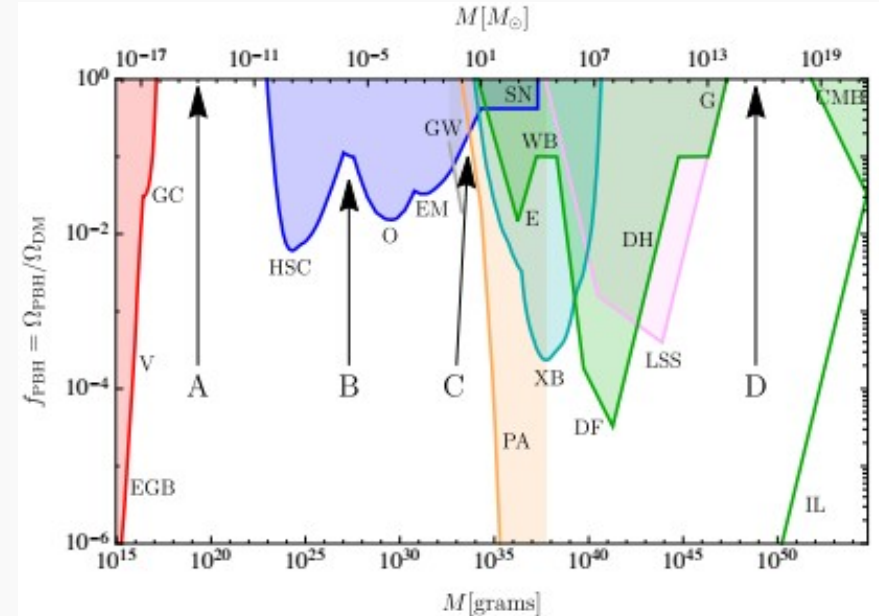
**8 June 2022**

# PBH formation: main results

- Non-linear initial perturbations, both sub- and superhorizon
- At formation  $M_{\text{PBH}}H \sim 10^{-2}$
- Rapid post-collapse accretion
- Maximum final PBH mass with rapid accretion + self-similar growth  $10^5 M_{\odot}$
- With slower accretion, potentially LVK PBHs

# Primordial black holes (PBHs)

- Black holes that form in the early universe
- PBHs were first considered by Zeldovich/Novikov (1967) and Hawking (1971)
- PBHs could make up part of dark matter
- Many PBH formation mechanisms

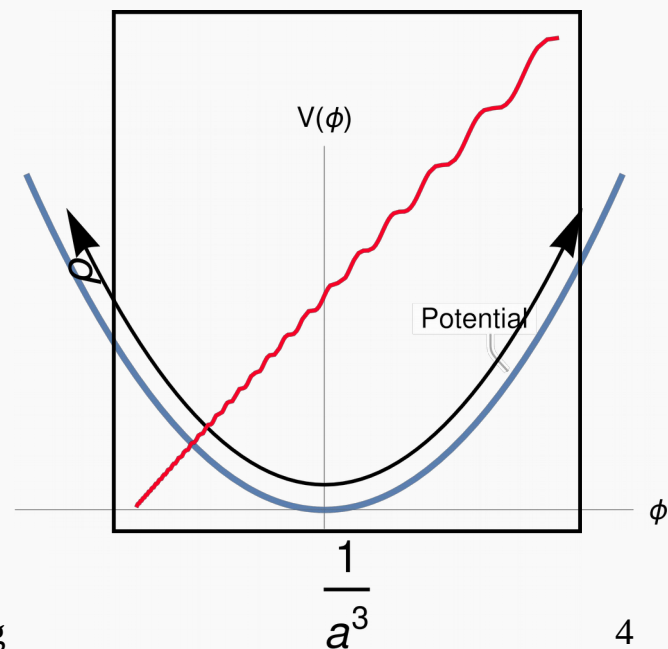


From: Carr & Kuhnel, arXiv:2006.02838

# Matter domination

- Mostly radiation domination in PBH literature
- We choose matter-dominated universe
- Expansion driven by scalar field in quadratic potential
- Need  $m \gg H$

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

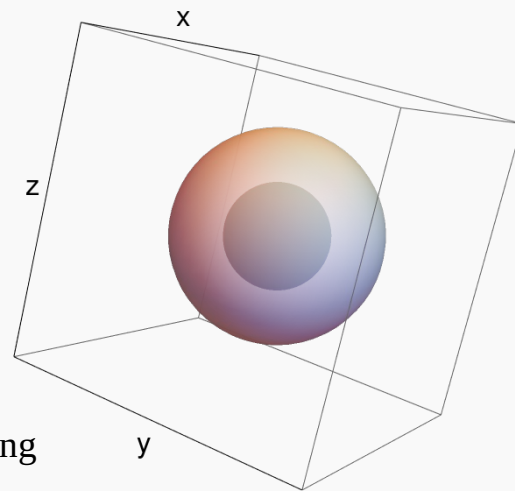
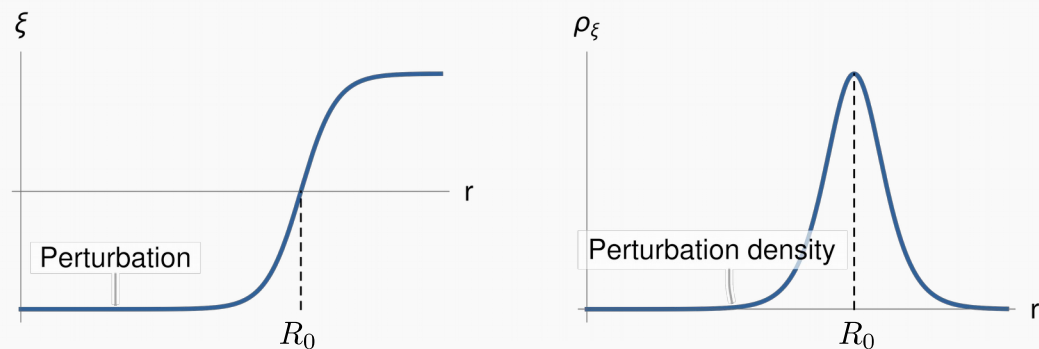


# Energy perturbation

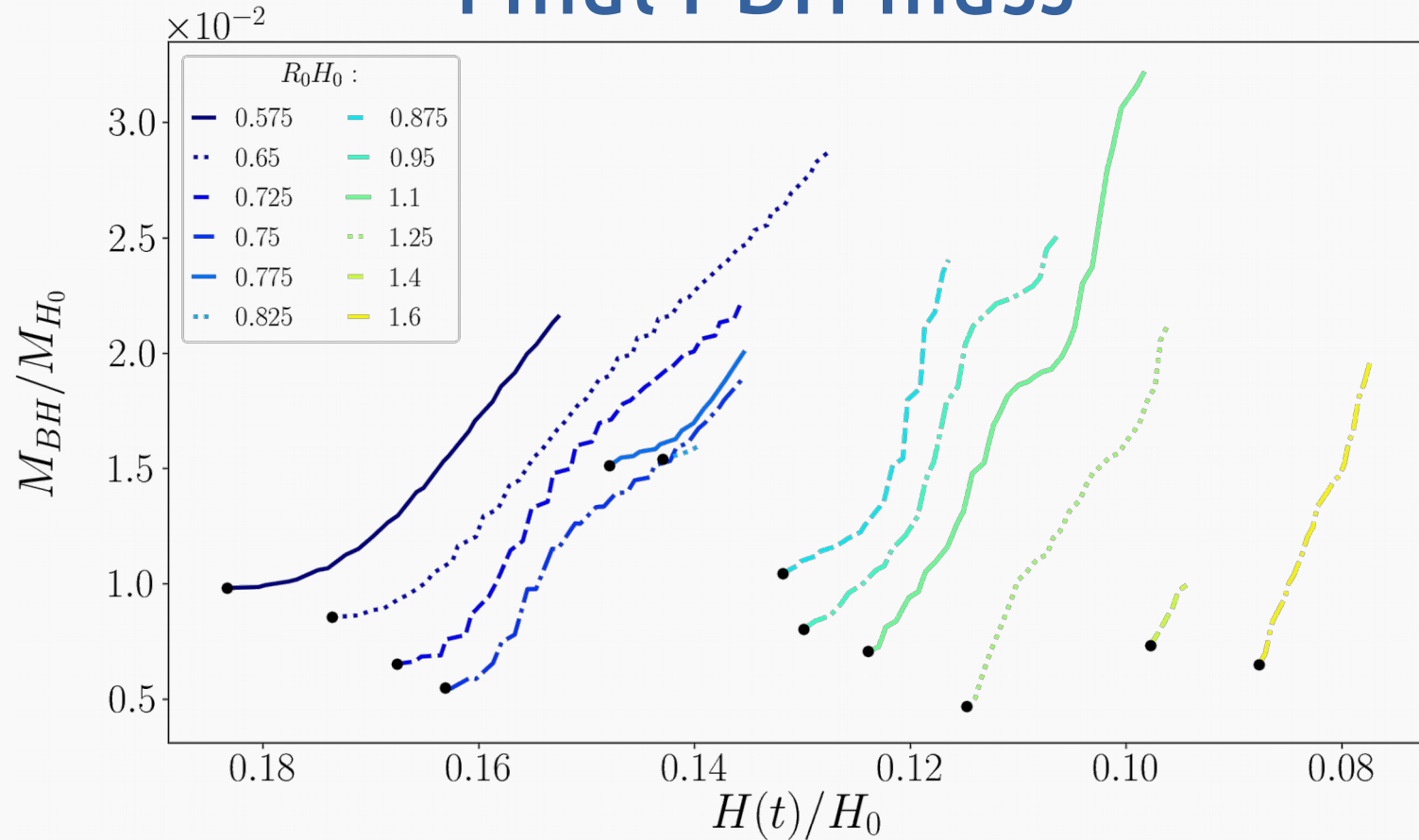
- 2<sup>nd</sup> massless scalar field

$$\rho_\xi(t = 0) = \frac{1}{2} (\partial_i \xi)^2$$

- Fixed amplitude and width, varying radius
- Spherically symmetric perturbation “shells”, sub- and superhorizon
- We have  $M_{\text{shell}} \ll M_{\text{Hubble}}$



# Final PBH mass



# PBH accretion

- Rapid initial accretion

- Naive argument (Z&N 1967):

$$\frac{dM_{\text{PBH}}}{dt} \sim R_{\text{PBH}}^2 \rho_{\text{background}} v_{\text{infall}}$$

$$\frac{dM_{\text{PBH}}}{dt} \sim M_{\text{PBH}}^2 \rho_{\text{background}} v_{\text{infall}}$$

- if  $\rho_{\text{background}} \sim H^2, v \lesssim 1$

$$\frac{dM_{\text{PBH}}}{dt} \sim M_{\text{PBH}}^2 H^2$$

- integrating:

$$M_{\text{PBH}} H \sim C$$

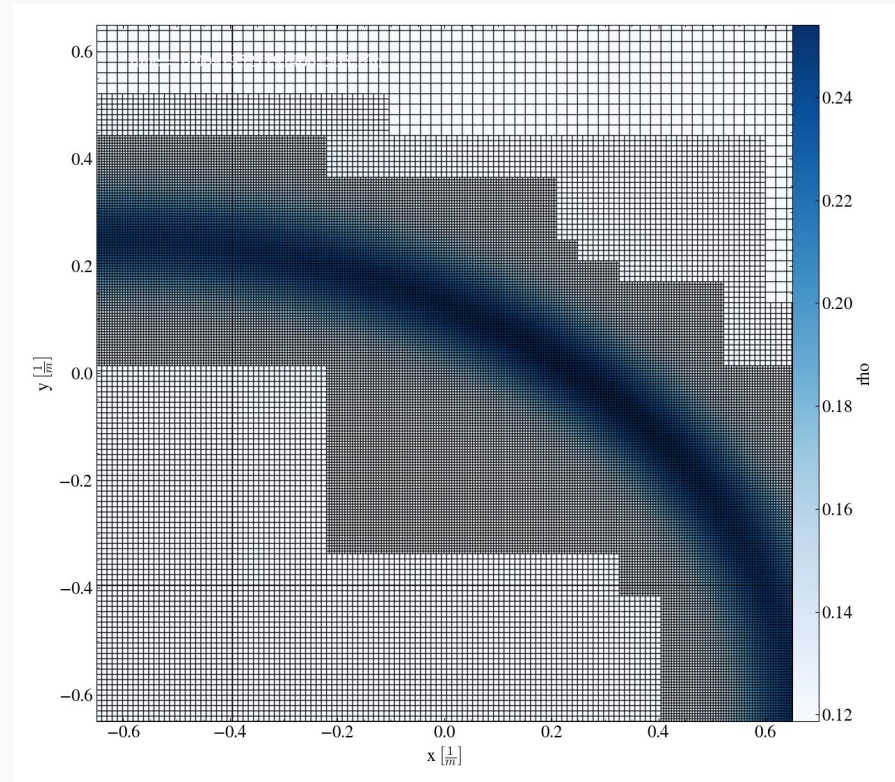
- Upper limit: expansion makes self-similar growth impossible (Carr 1974)

# Final PBH mass

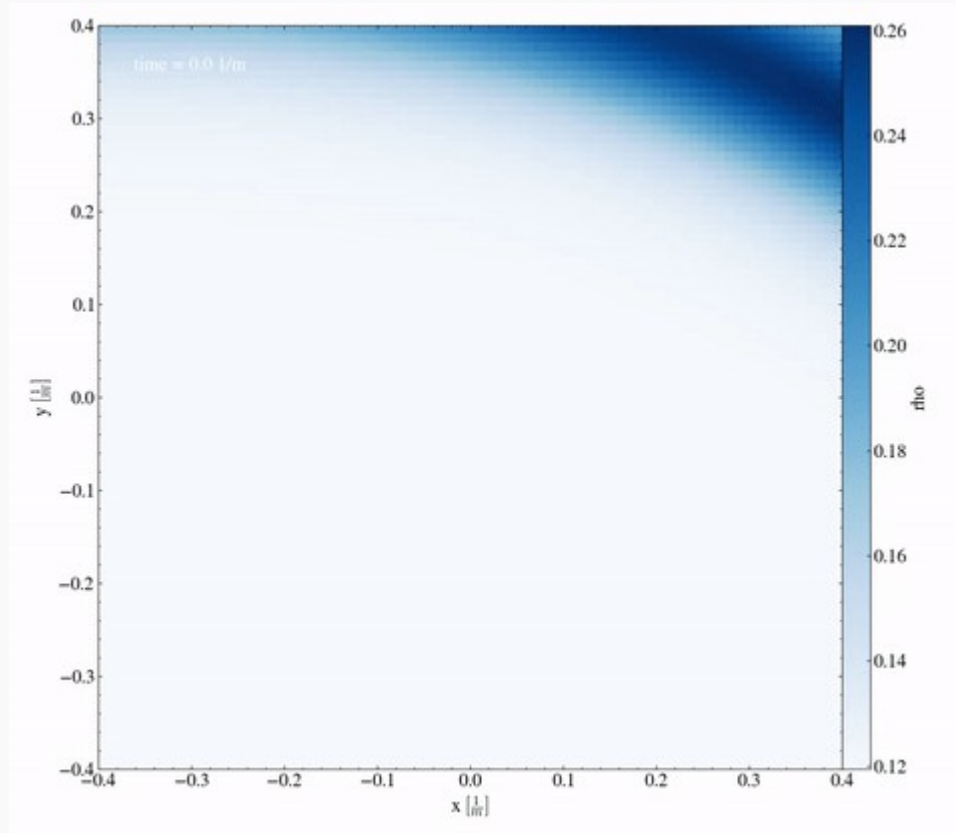
- PBH mass can catch up with horizon mass
- However,  $M_{\text{PBH}}H \lesssim 1$
- BBN at  $T = 1\text{MeV}$   
 $M_{\text{PBH}} \lesssim 10^5 M_{\odot}$
- If PBH accretion slows down earlier,  
 $M_{\text{BH}} \gtrsim 10^{-2} H^{-1}$
- For formation around  $T = 5\text{MeV}$ ,  
LIGO/Virgo/KAGRA PBHs can be formed



# Why 3+1: beyond spherical symmetry



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# Main results

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- Questions?