Title: The Effect of Multiple Cooling Channels on the Formation of Dark Compact Objects

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Collection: Dark Matter, First Light

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Abstract: A dissipative dark sector can result in the formation of compact objects with masses comparable to stars and planets. In this work, we investigate the formation of such compact objects from a subdominant inelastic dark matter model, and study the resulting distributions of these objects. In particular, we consider cooling from dark Bremsstrahlung and a rapid decay process that occurs after inelastic upscattering. Inelastic transitions introduce an additional radiative processes which can impact the formation of compact objects via multiple cooling channels. We find that having multiple cooling processes changes the mass and abundance of compact objects formed, as compared to a scenario with only one cooling channel. The resulting distribution of these astrophysical compact objects and their properties can be used to further constrain and differentiate between dark sectors.

The Effect of Multiple Cooling Channels on the Formation of Dark Compact Objects

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Dark Matter, First Light – Perimeter Institute
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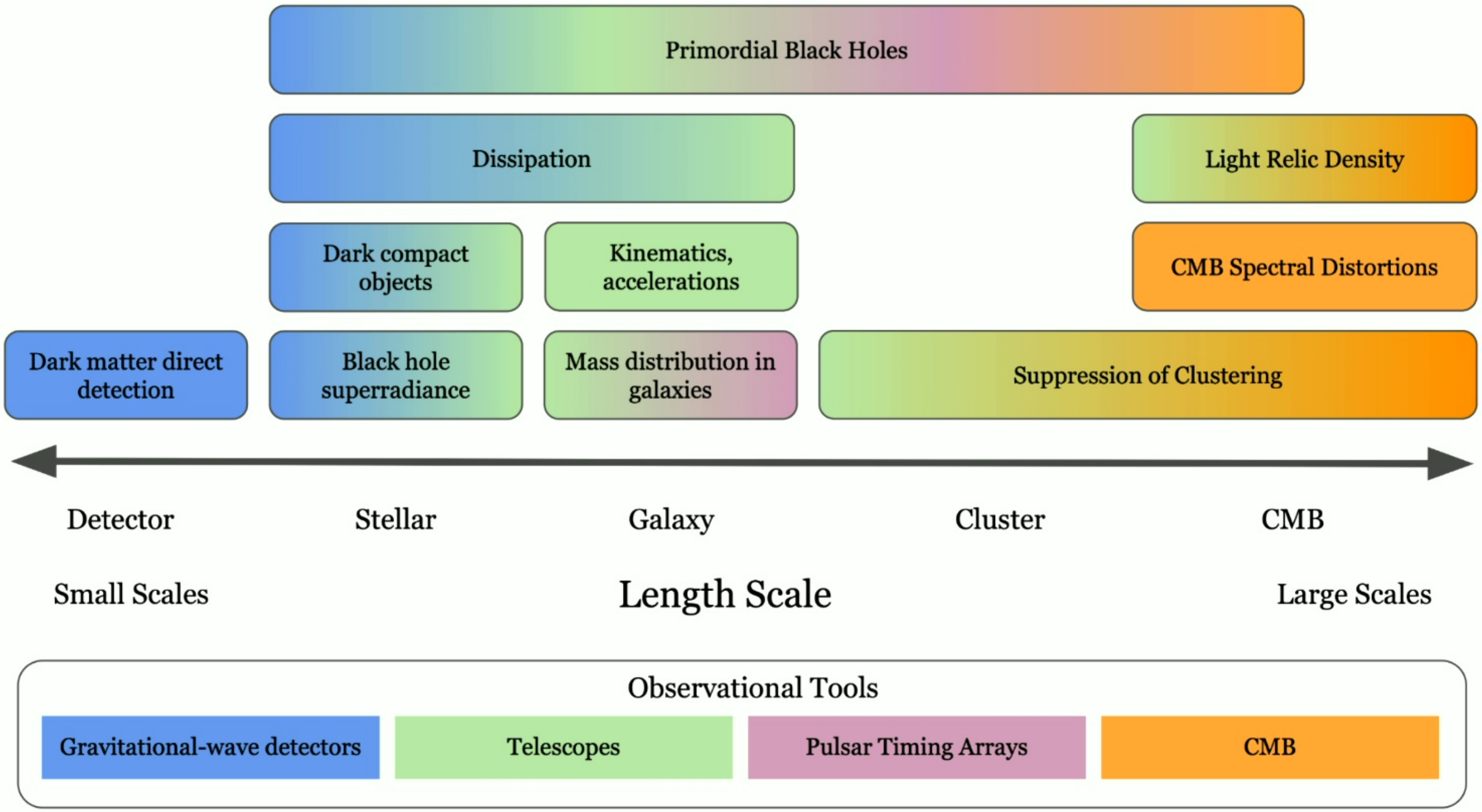
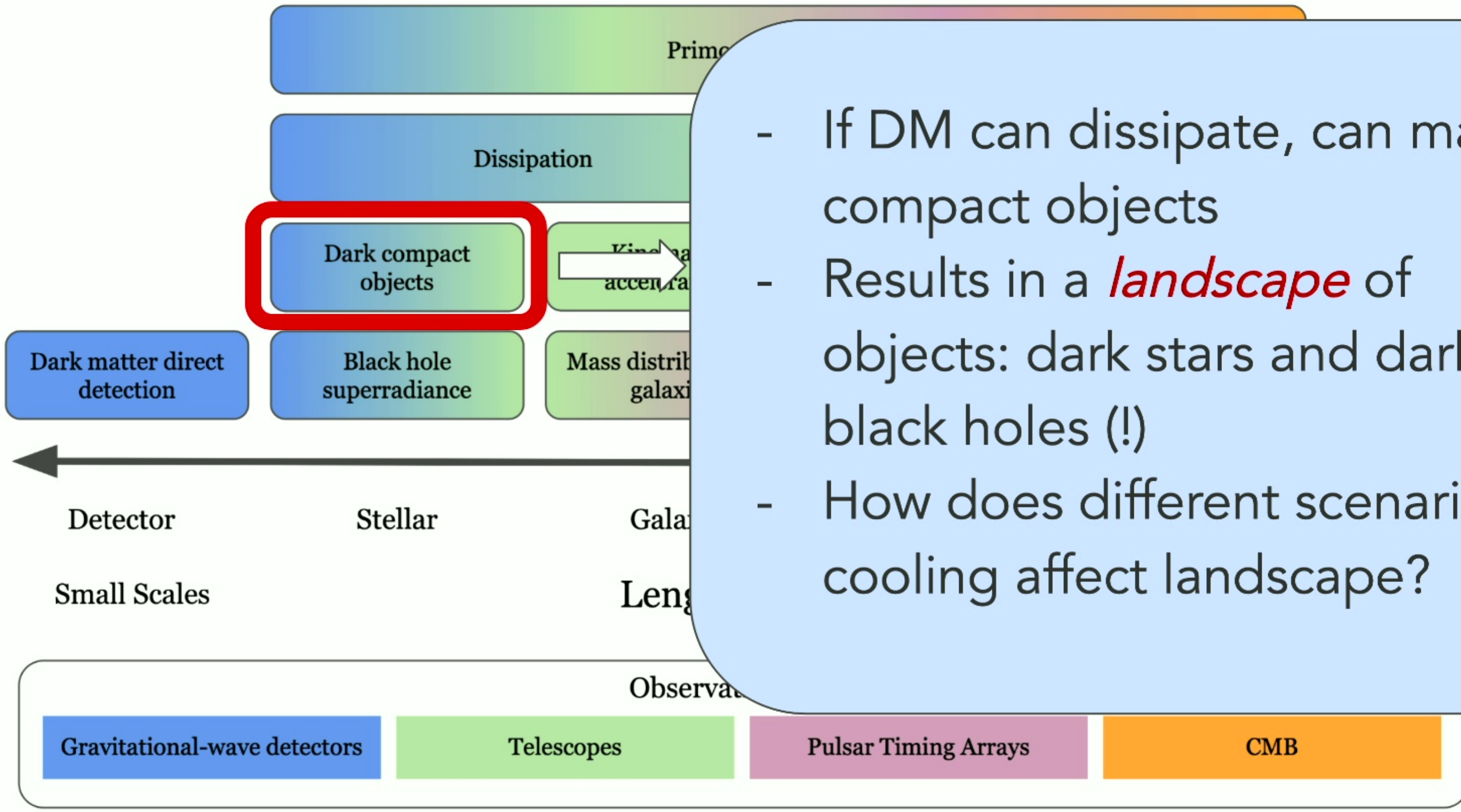


Figure from Snowmass 2021
White Paper (Brito et al., 2021)

How to Make Compact Objects

- SM forms stars due to dissipative processes

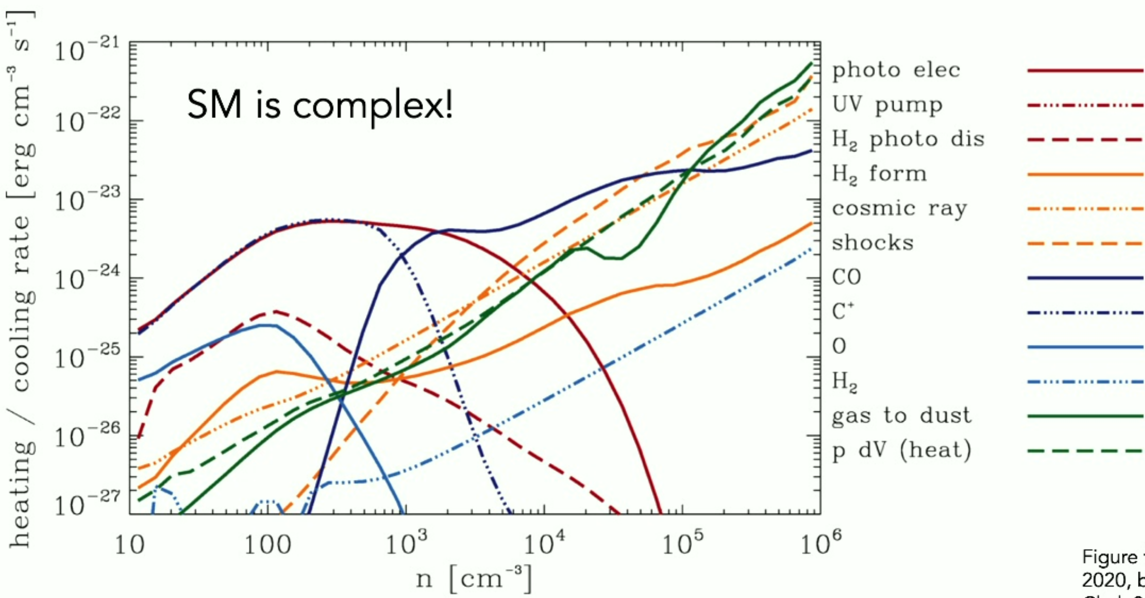


- If DM can dissipate, can make compact objects
- Results in a *landscape* of objects: dark stars and dark black holes (!)
- How does different scenarios of cooling affect landscape?

Figure from Snowmass 2021 White Paper (Brito et al., 2021)

How to Make Compact Objects

- SM forms stars due to dissipative processes
- Gas particles loses kinetic energy-> fall into gravitational potential
- Can further collapse and form compact objects



Let's make DM cool in a simple dark sector!

Figure from Girichidis et al. 2020, based on Glover & Clark 2012

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How to Make Compact Objects

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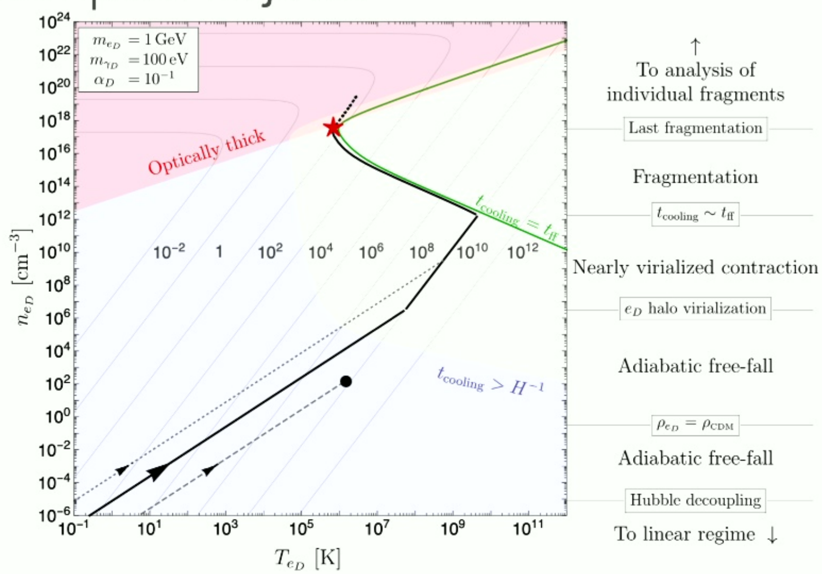
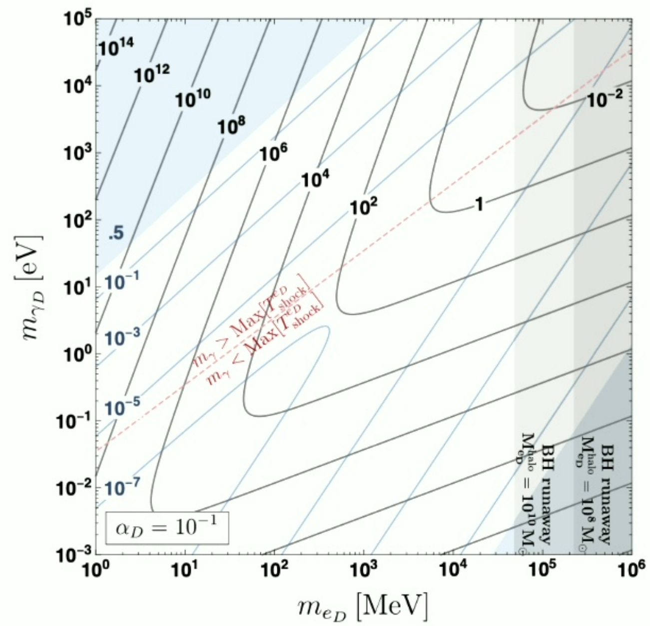
Structure Formation from Dissipative Dark Sectors

- In Chang et al. 2019, a *simple*, *asymmetric*, *subdominant* dark sector composed of the dark electron + dark photon was studied
- They showed that Bremsstrahlung cooling would lead to interesting dark compact objects





Figures from Chang et al. 2019

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Inelastic Dark Matter

- *Asymmetric, subdominant* model: dark Dirac fermion & dark photon
- Mass splitting for fermion results in an excited state and ground state
- New inelastic processes allow for new ways to cool!
- How does this affect compact object formation?
- Only 4 particle physics parameters in our simplified model:

$$m_\chi, m_{\gamma_D}, \alpha_D, \delta$$

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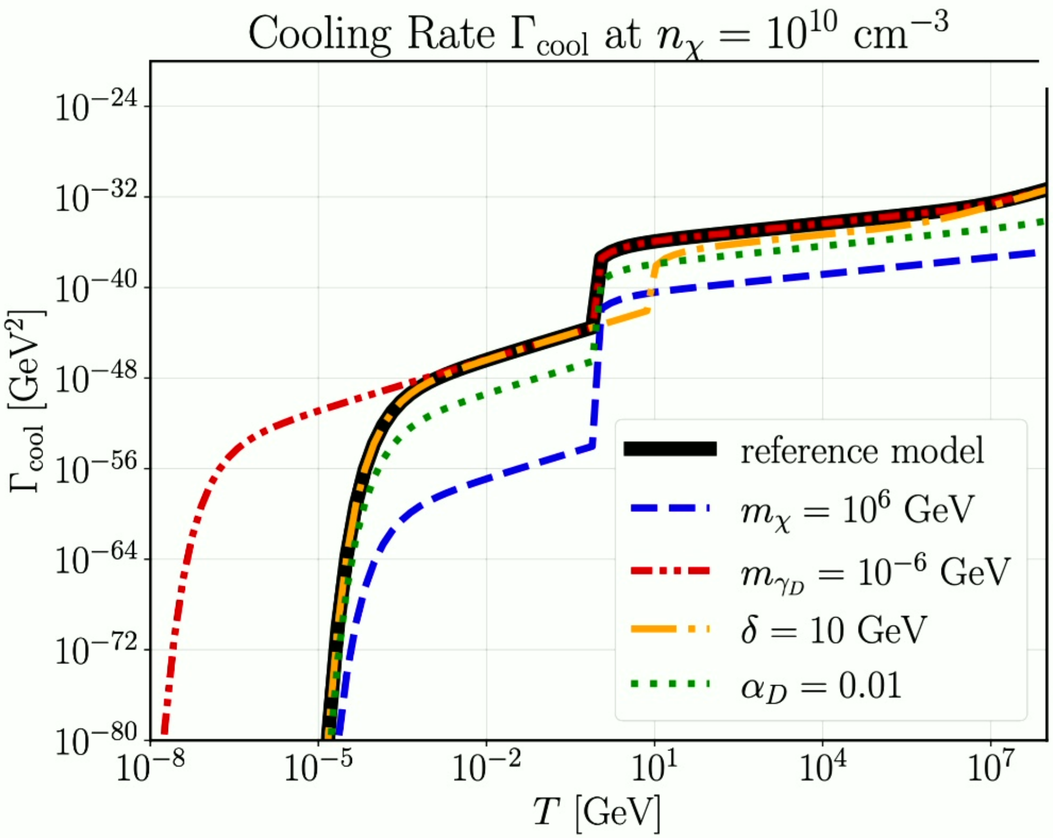
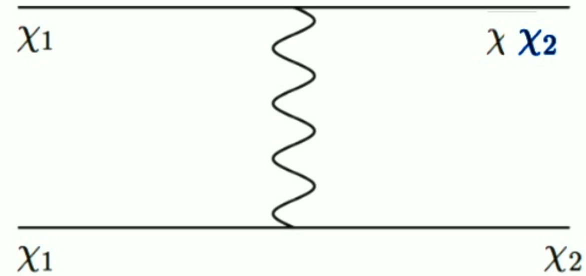
Cooling -> Collapse





Figures & cross section.
from Schutz & Slayter 2015

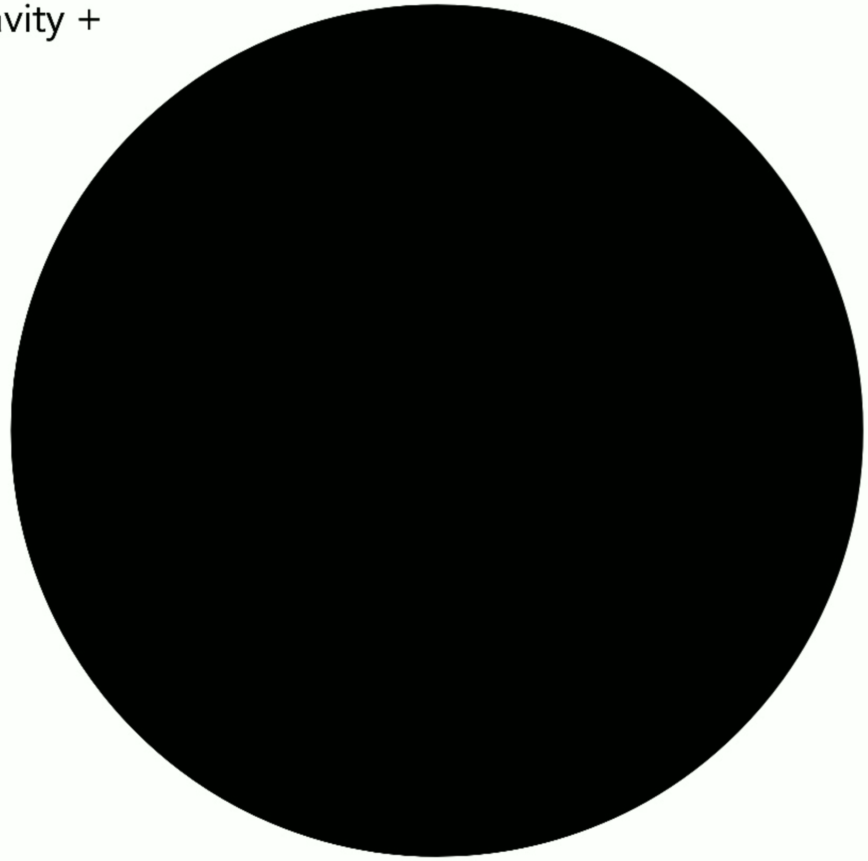
$$m_\chi = 10^3 \text{ GeV}$$
$$m_{\gamma_D} = 10^{-3} \text{ GeV}$$
$$\alpha_D = 0.1$$
$$\delta = 1 \text{ GeV}$$

$$t_{\rm cooling} = \frac{3T_\chi}{m_\chi \Gamma_{\rm cool}}$$

$$\frac{d\log T_\chi}{d\log \rho_\chi} = \frac{2}{3}\frac{m_\chi P_\chi}{\rho_\chi T_\chi} - 2\frac{t_{\rm collapse}}{t_{\rm cooling}}$$

Chang et al. 2019: A Simplified History:

Gravity +



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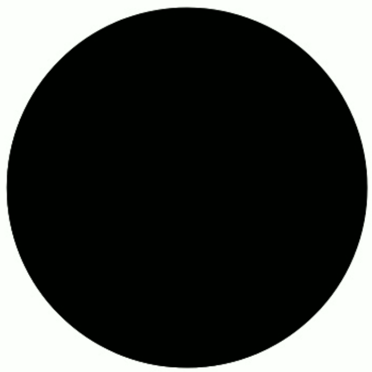
Chang et al. 2019: A Simplified History:

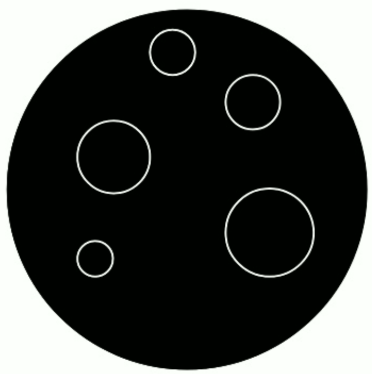
Gravity +
Pressure +



1. **Adiabatic free-fall**: dark halo free-falls

2. **Nearly virialized contraction**: dark halo virializes due to increase in kinetic pressure; halo collapses at const. Jeans mass

Gravity +
Pressure +
Cooling



Chang et al. 2019: A Simplified History:

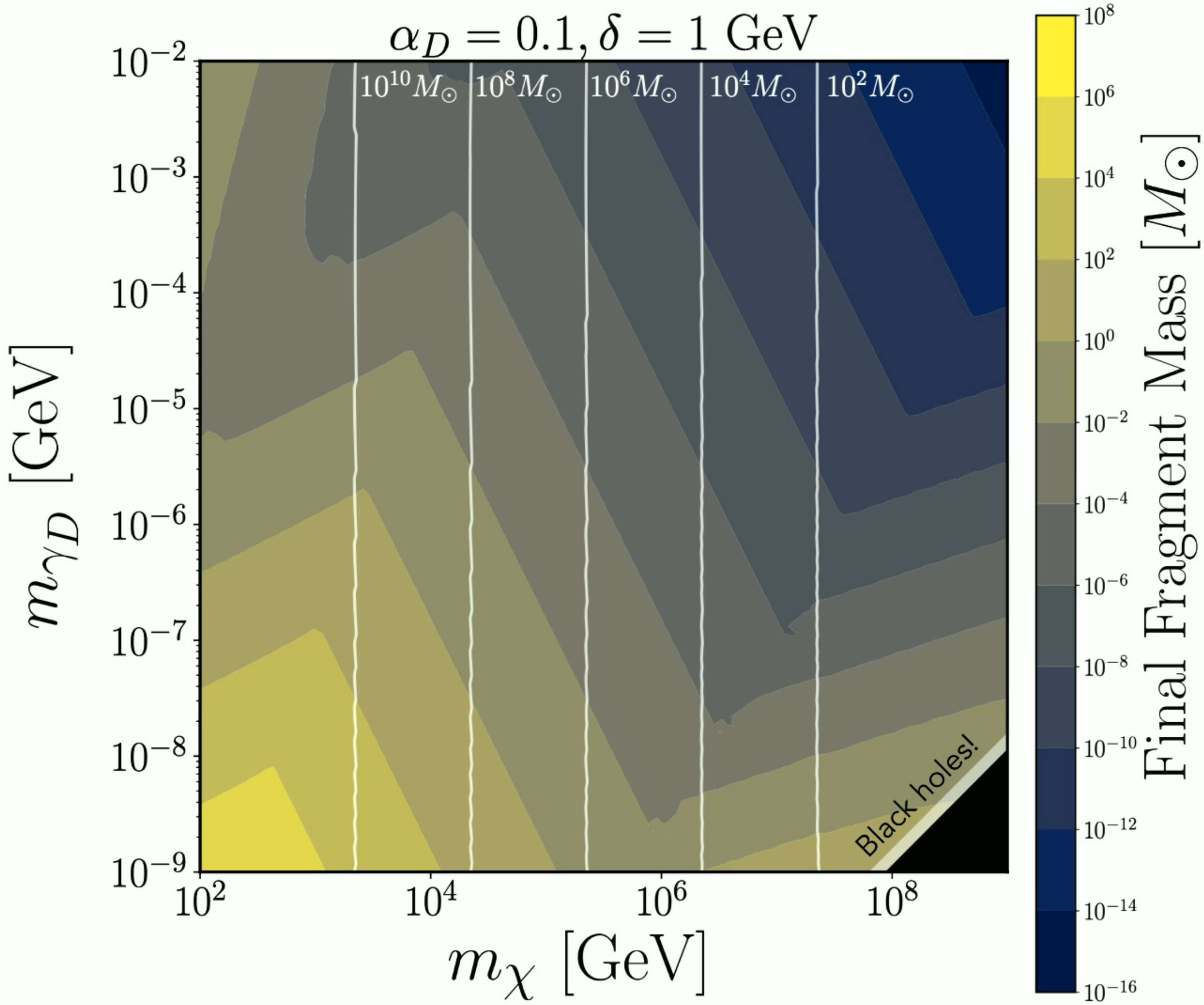
1. **Adiabatic free-fall**: dark halo free-falls

2. **Nearly virialized contraction**: dark halo virializes due to increase in kinetic pressure; halo collapses at const. Jeans mass

3. **Fragmentation**: decrease in Jeans mass results in the halo dividing into smaller clumps

Stops for 2 reasons:

- Cooling becomes inefficient
- Pressure of halo becomes dominated by dark repulsive force -> Jeans mass is independent of temperature, doesn't decrease!



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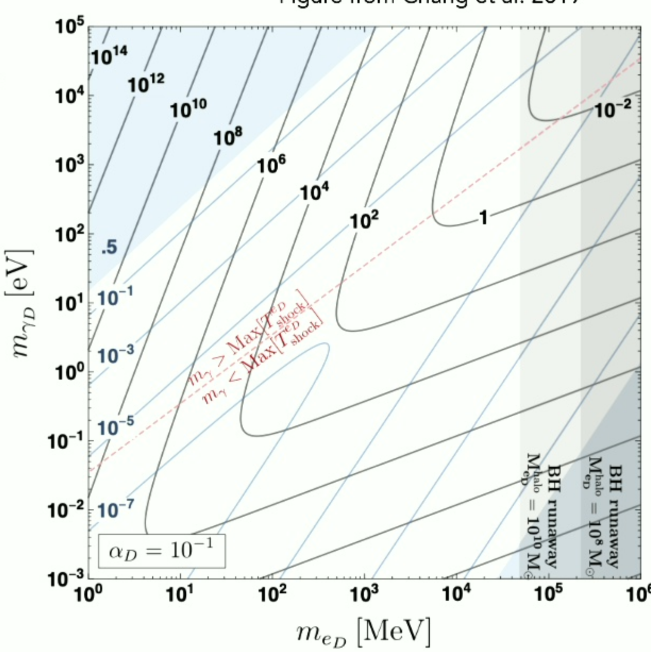

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To summarize…

- Dissipative dark sectors can influence the formation and evolution of astrophysical compact objects
- We considered a dark sector with multiple cooling channels
- Lives of compact objects are significantly different, leading to different landscape!

In the future…

- We only considered masses of the minimal fragments, can also consider simulations to get better picture (see Roy et al. 2023, Gemmell et al. 2023 for Atomic DM simulation)
- Dark BHs from dissipative dark sectors can have subsolar masses! Interesting GW prospects… (see Shandera et al. 2018, Chang et al. 2019, Gurian et al. 2023)

Thank you!