Title: Formation of Dark Compact Objects in an Early Matter Dominated Era

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Collection: Dark Matter, First Light

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Abstract: Self interacting dark matter can form halos and compact objects in an early matter dominated era before Big Bang Nucleosynthesis. This talk explores how an asymmetric dark fermion which self interacts via a heavy vector can undergo halo formation in an early matter dominated era. These halos then cool via bremsstrahlung until they either collapse into black holes or fragment into compact pressure support objects. Radiation domination is restored via a phase transition. This provides a simple new mechanism to produce both primordial black holes and dark compact objects.

Formation of Dark Compact Objects in an Early Matter Dominated Era

Dark Matter First Light Workshop

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We found…

- A new mechanism to produce MACHOs
- A new way to form primordial black holes
- Late time collapse into low mass black holes
- Late time decay of low mass black holes
- Dissipative dark sector can be all of dark matter
- Dark halo size set by features of the dark matter model

Key Ingredients

Heavy dark particle to dominate the energy density of the Universe

χ

"Dark electron"

$m_\chi > 10^4$ GeV

Asymmetric fermion

Dark mediator to dissipate energy and help with structure collapse

γ_D

"Dark photon"

$m_\chi > 10^{-4}$ GeV

Heavy vector

An exit strategy to return the universe to radiation domination

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An exit strategy to return the universe to radiation domination

A scalar field undergoes a phase transition

Rapid expansion dilutes χ

Field decays to standard model

The dark sector model

$$\mathscr{L} \supset \bar{\chi}(i\gamma^{\mu} - m_{\chi})\chi - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{1}{2}m_{\gamma_D}^2 A_{\mu}A^{\mu}$$

$$D_{\mu} = \partial_{\mu} - i4\pi\alpha^{1/2}A_{\mu}$$

Original model in Chang et al 2019

The dark sector model

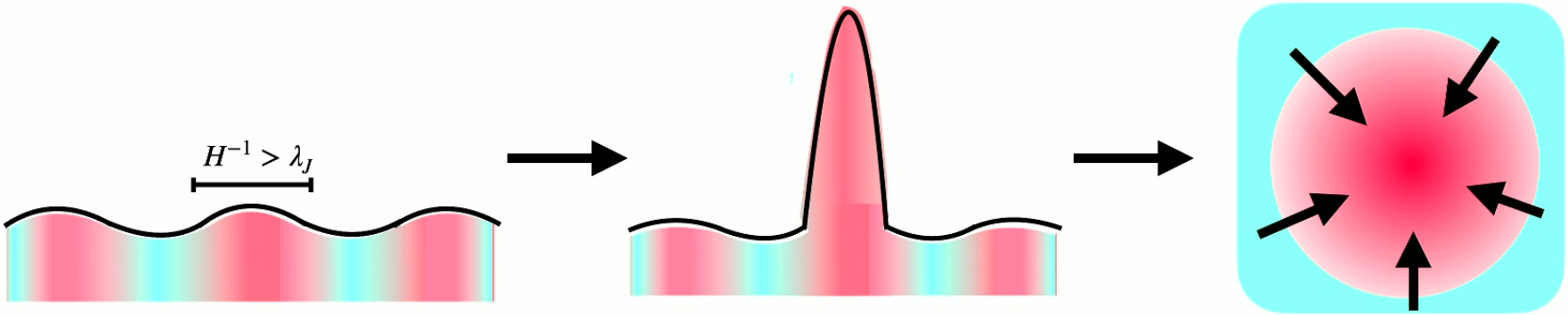
$$\mathscr{L} \supset \bar{\chi}(i\gamma^{\mu} - m_{\chi})\chi - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{1}{2}m_{\gamma_D}^2 A_{\mu}A^{\mu}$$

$$D_{\mu} = \partial_{\mu} - i4\pi\alpha^{1/2}A_{\mu}$$

The scalar field phase transition

$$V(\phi) = V_0 - \frac{1}{2}m^2|\phi|^2 + T^2|\phi|^2 + \ldots$$

Evolution of dark electron halos during early matter domination

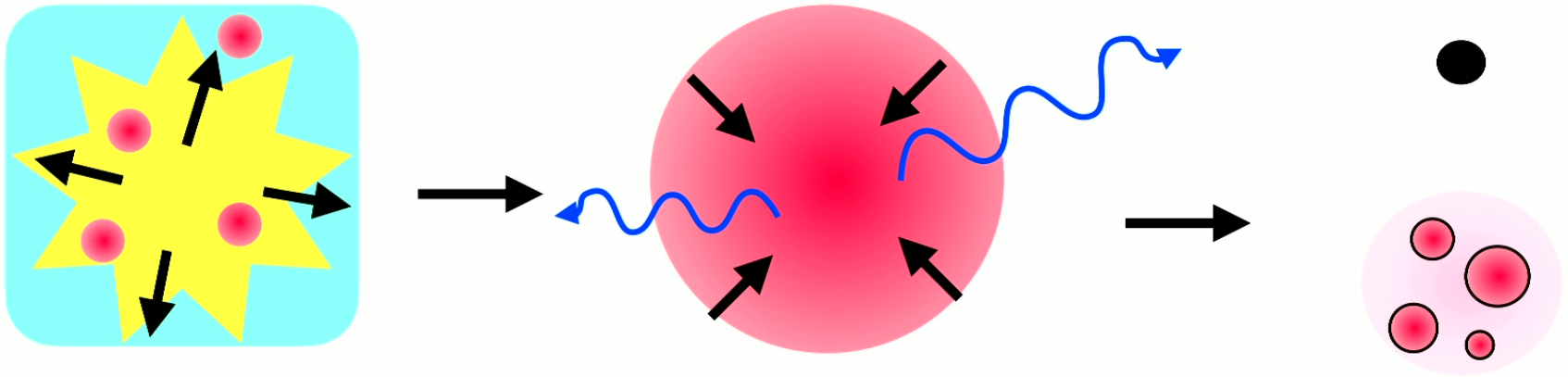


Perturbations enter the horizon and begin growing when Jean's length less than Hubble length

Slight over densities grow linearly with the expansion of the universe

Once density contrast ~ 1 overdense regions begin to collapse and virialize

Returning to Standard Cosmology

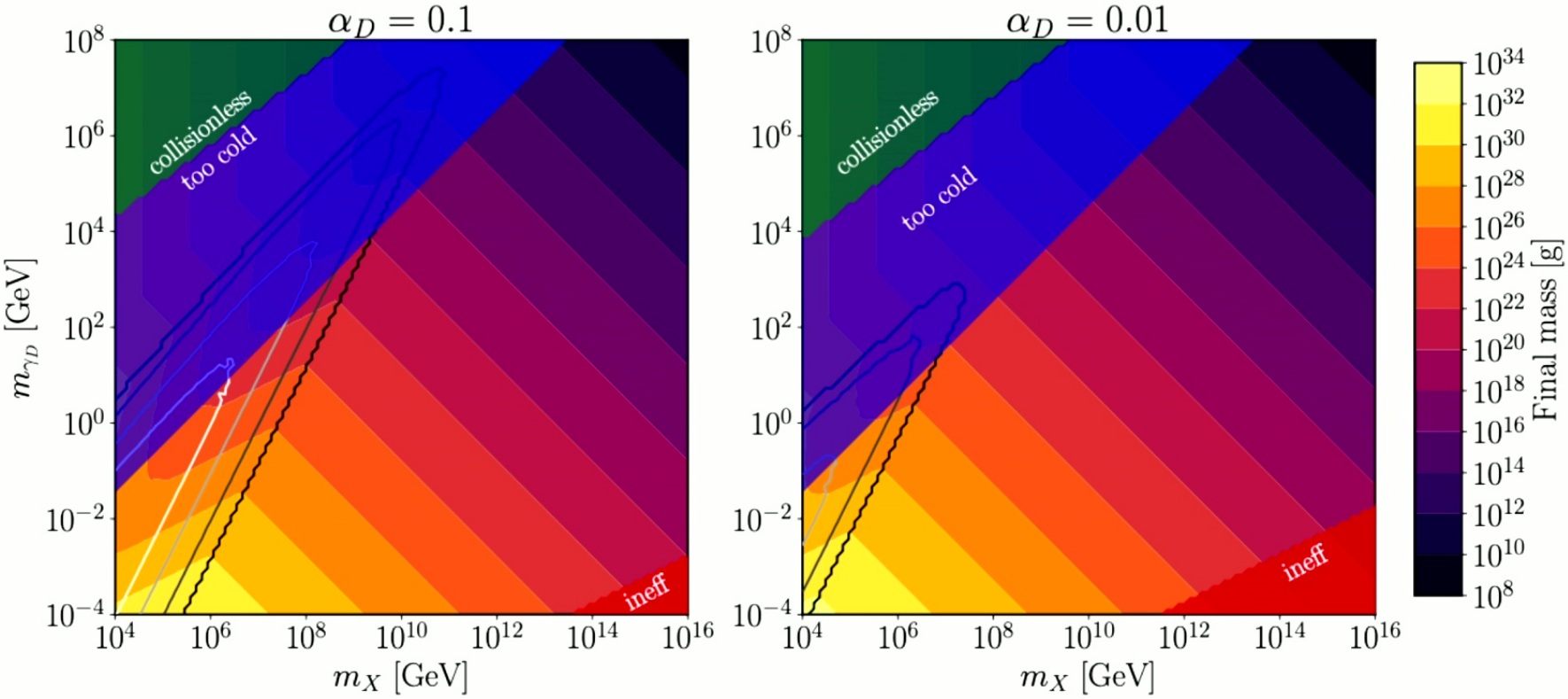


Phase transition dilutes dark matter and returns universe to Standard model radiation domination

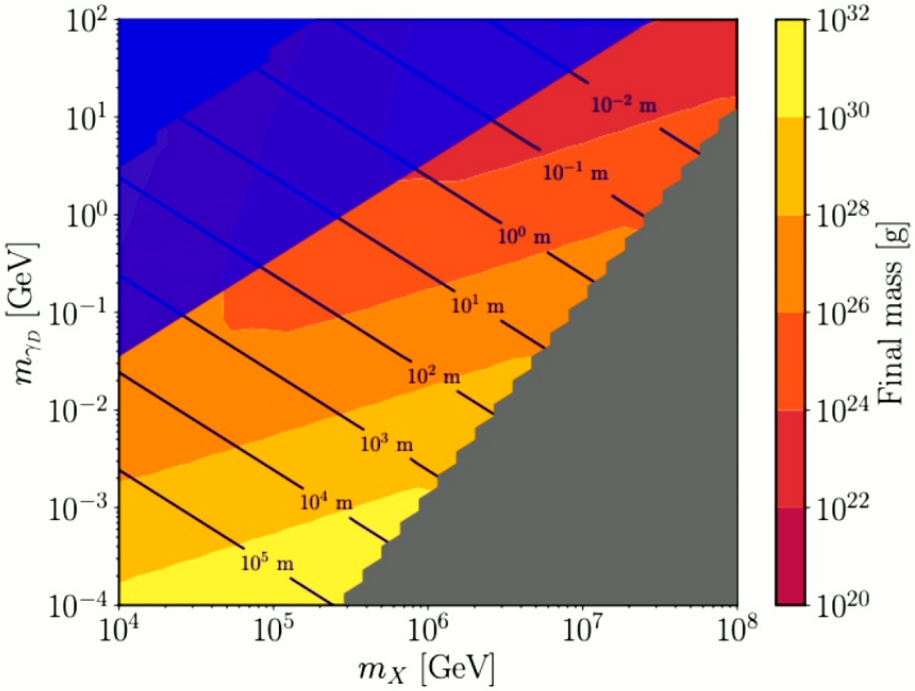
Halo continues to cool and compactly via dark bremsstrahlung

Halo collapses to a black hole or fragments into pressure supported dark compact objects

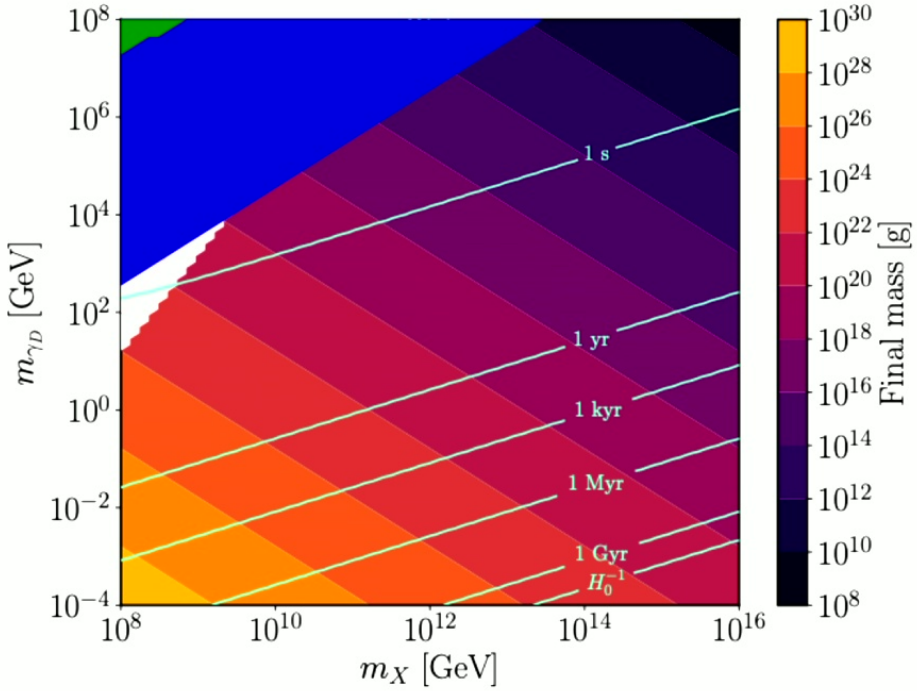
Final evolution of dark electron halos



Final evolution of dark electron halos $\alpha_D = 0.1$ (zoomed in)



Fragments



Black Holes

Conclusions

- Many of the tools used for star and galaxy formation are relevant to the dark sector once we introduce self interactions
- A dissipative dark sector can dominate the universe before BBN and lead to the creation of black holes and dark compact objects
- Predictions for the size and evolution of these objects follows straightforwardly from one's choice of dark matter model

Thank You