EXOTIC COMPACT OBJECTS IN A DISSIPATIVE DARK SECTOR

ArXiv:1812.07000

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2018/05/06 Phenomenology Symposium

Q: Can we learn about the particle nature of DM if it interacts with SM sector only gravitationally?

A: Yes !

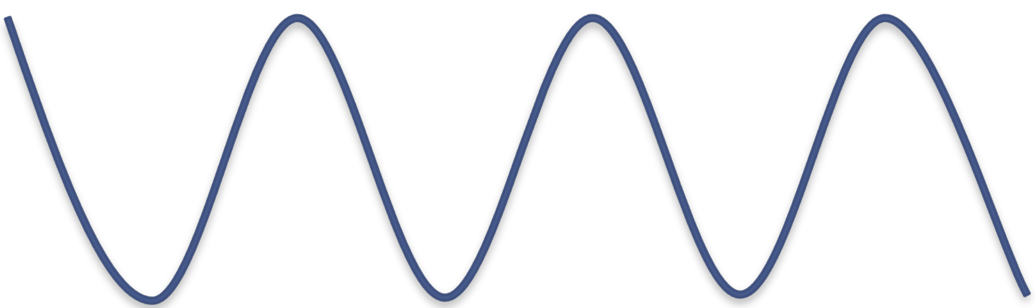
If it forms compact objects

- Called exotic compact objects (ECO)
- Can be found by high-precision observatories (GW or weak lensing)
- Properties of compact objects are determined by particle nature of DM

Goal: Using a simple DS model, find properties of the exotic compact objects according to model parameters

SCHEMATIC OF
COMPACT OBJECT FORMATION

- In early Universe, there are overdensities and underdensities
- Described by primordial power spectrum



- Perturbation grows with time
- Can be analyzed with linear theory
- Enters non-linear regime at some point

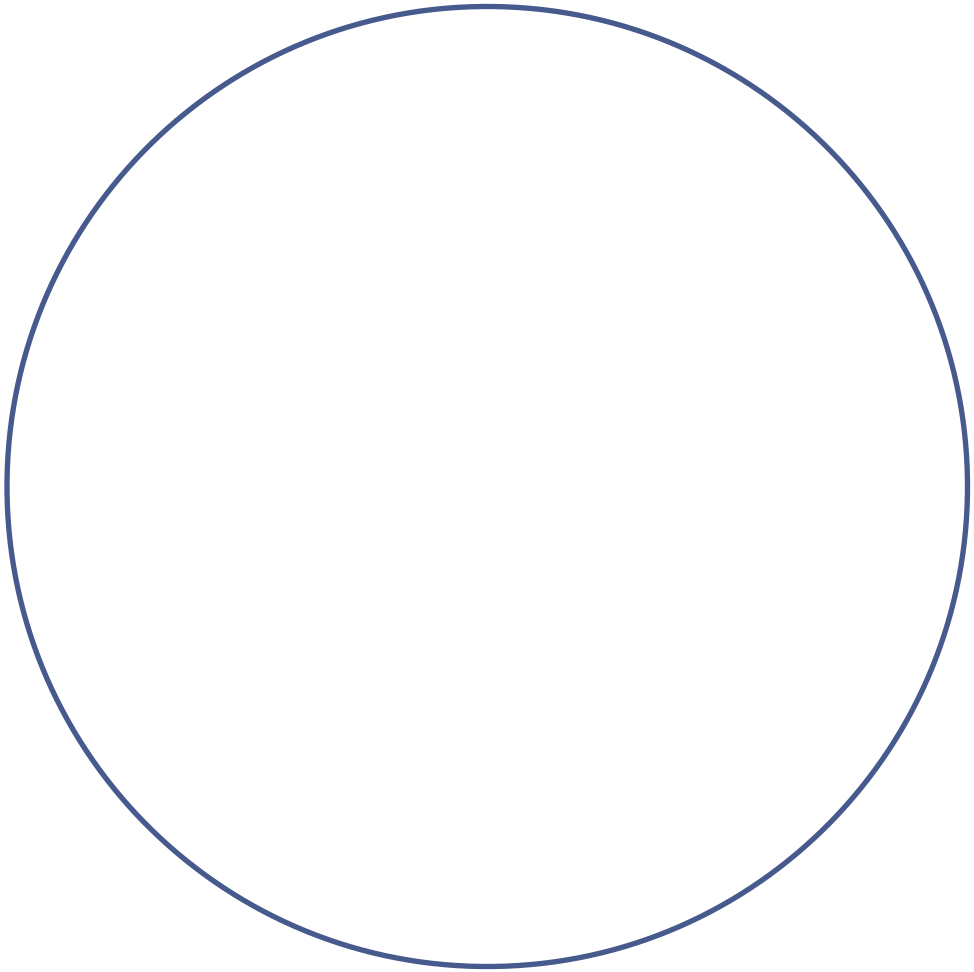
Jeans Mass M_J

- Maximum mass of gas that pressure can support

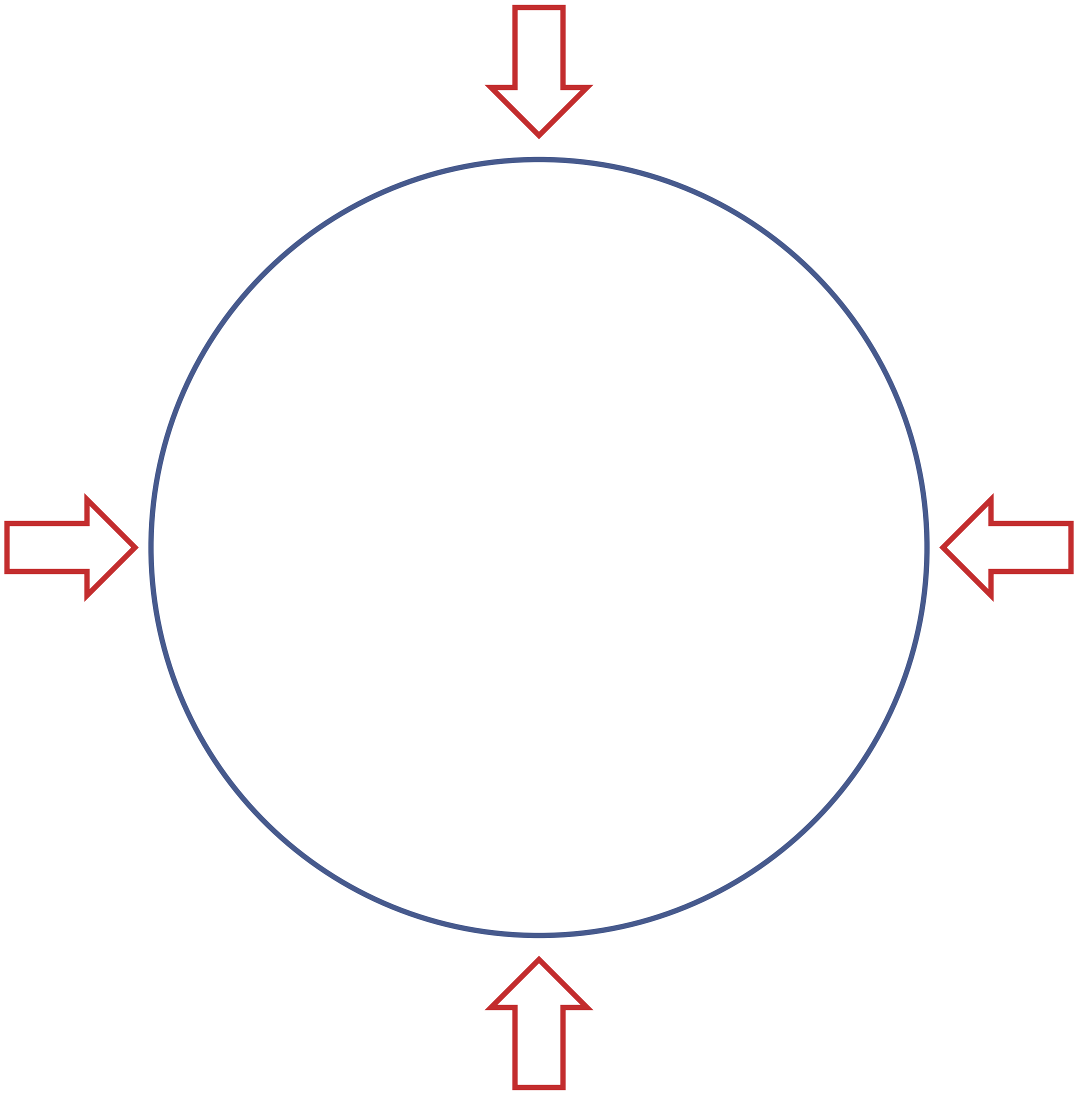
- If $M > M_J$, a mass clump collapses

- $M_J = \frac{\pi}{6} c_s^3 \left(\frac{\pi}{G}\right)^{3/2} \left(\frac{1}{\rho}\right)^{1/2}$

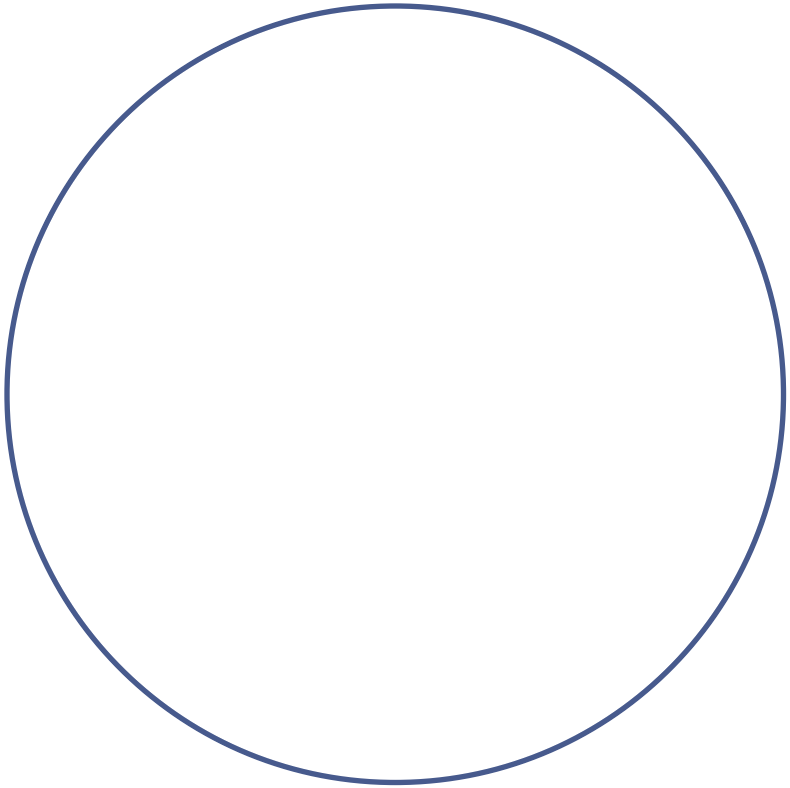
- c_s depends on particle nature



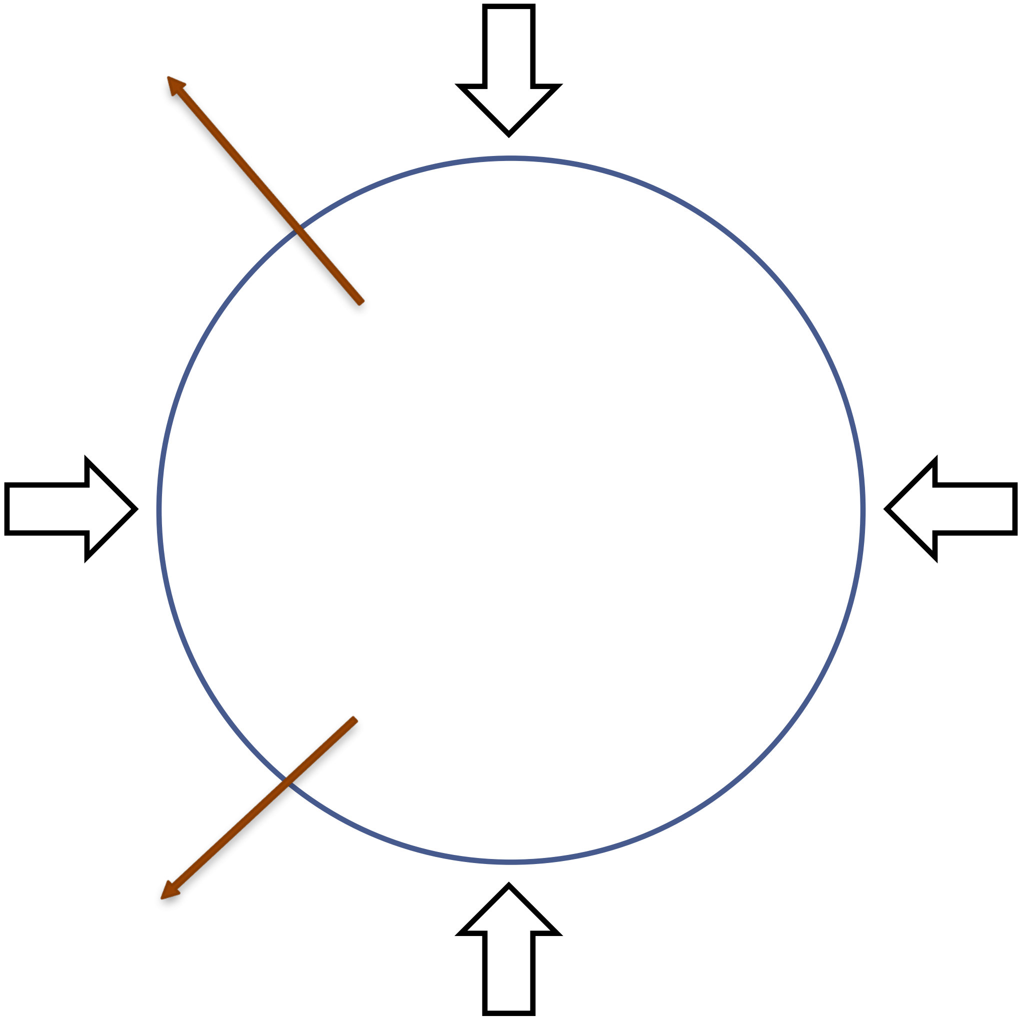
- A big mass perturbation from linear growth
- Suppose $M > M_J$



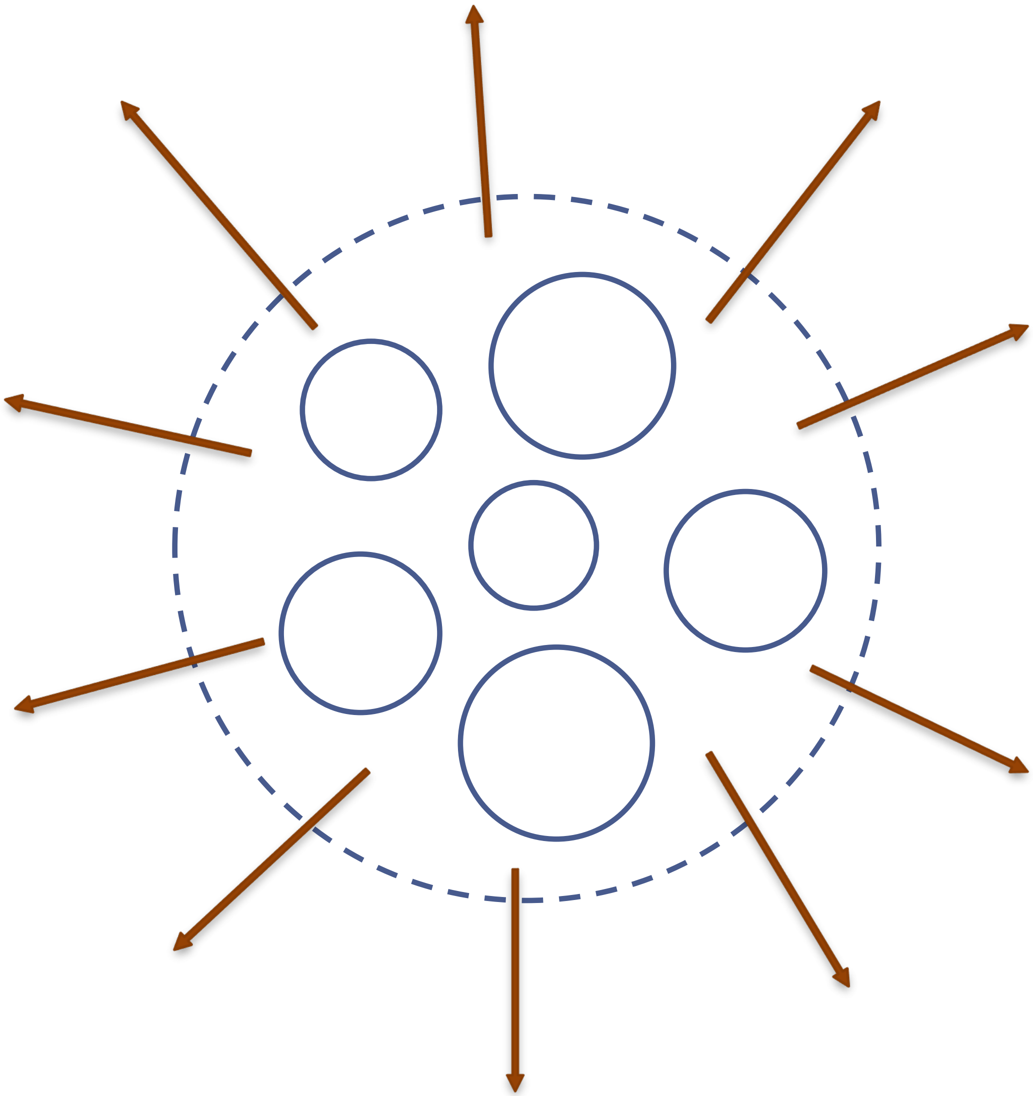
- Adiabatic collapse
- Temperature increases
- M_J increases



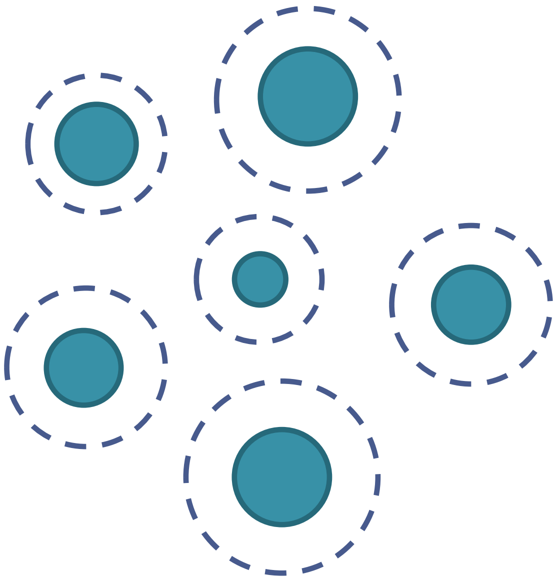
- Reaches $M_J = M$
- The mass perturbation is virialized
- Collapse stops



- If there's cooling, it keeps collapsing
- Cooling is slower than collapse, temperature increases
- Virialized collapse



- Cooling becomes important as number density increases
- Temperature and M_J decrease
- Fragmentation happens



- Cooling stops as optical depth becomes large
- Fragmentation stops
- Collapse to final objects

Baryons are too complicated!

- They form bound states, a lot of cooling processes…

- Hard to handle analytically

- As a starting point, we consider a DS model as simple as possible

A SIMPLE DARK SECTOR MODEL FOR ECO FORMATION

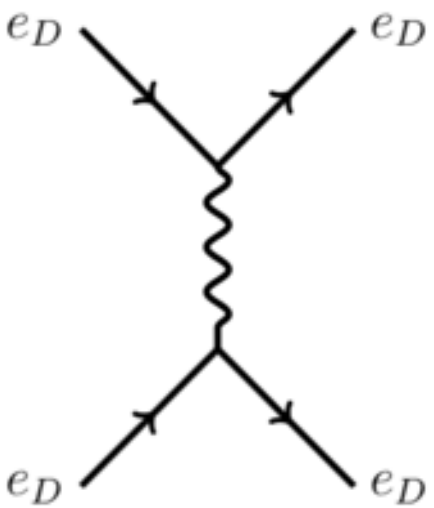
The Model Needs …

- Self-Interaction
  - Otherwise behaves like CDM
  - Sub-dominant (We assume 1% of total DM)
- Asymmetry
  - To forbid annihilations so final objects are stable
- Cooling process
  - Necessary for "fragmentation"

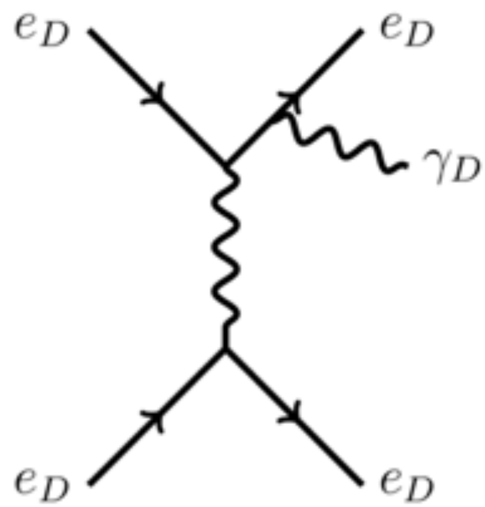
The Simplified Model in this Work

- Contains only two particles
  - Dark electron e_D^- : Compose matter
  - Dark photon γ_D : Mediate interactions
- Has charge asymmetry
  - Negligible dark positron
  - Not simple in terms of model building, but simple to handle astrophysical phenomenon

Interactions in the Model



Self Interaction



Bremsstrahlung cooling

Satisfies all the conditions

Advantages of the Model

- There are no bound-states
- Only one cooling process
- Only three model parameters: $m_{e_D}, m_{\gamma_D}, \alpha_D$

QUANTITATIVE ANALYSIS

Master Equation

$$\frac{dE}{dt} = -P\frac{dV}{dt} - \Lambda$$

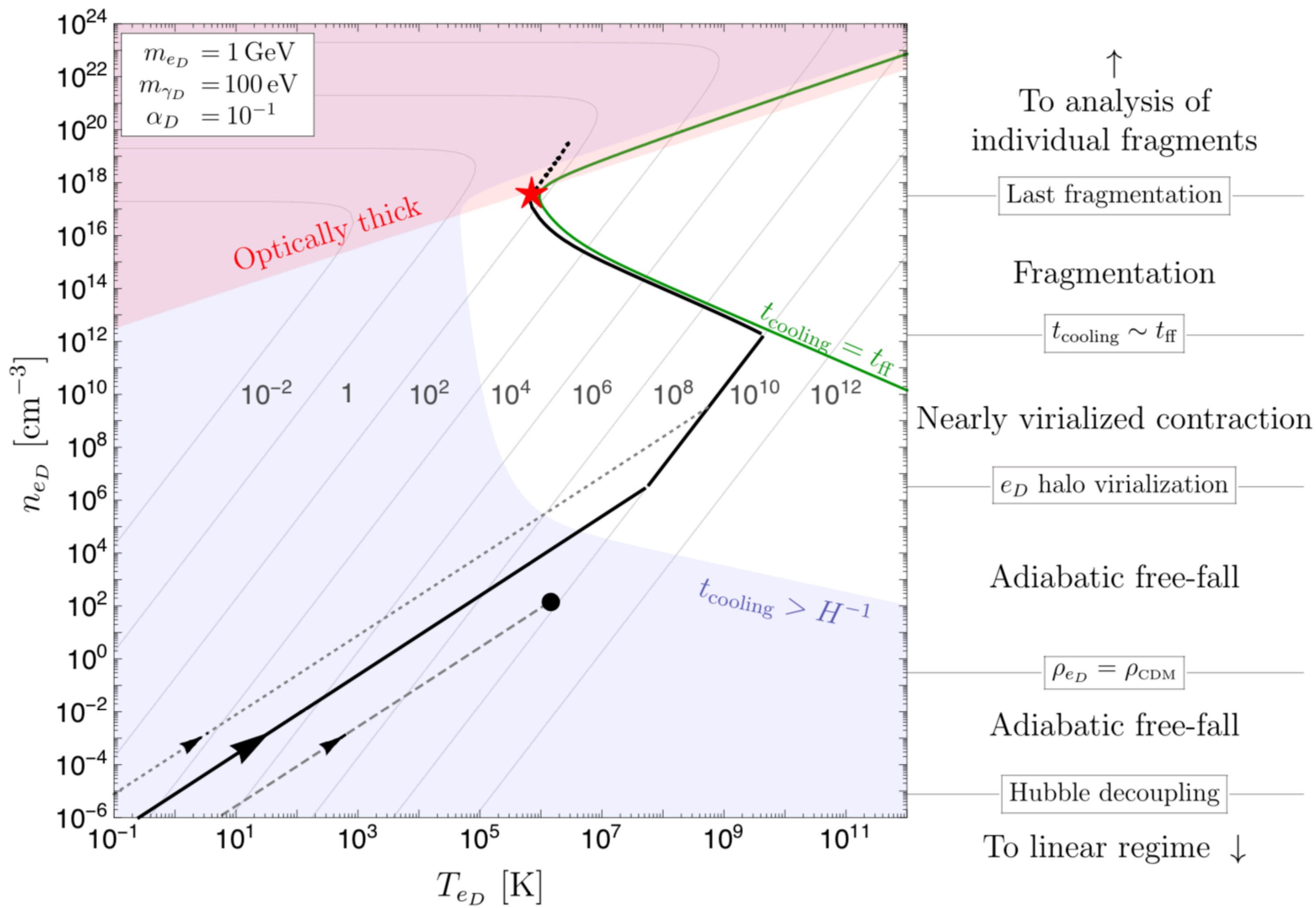
Λ is cooling rate

$$\Downarrow$$

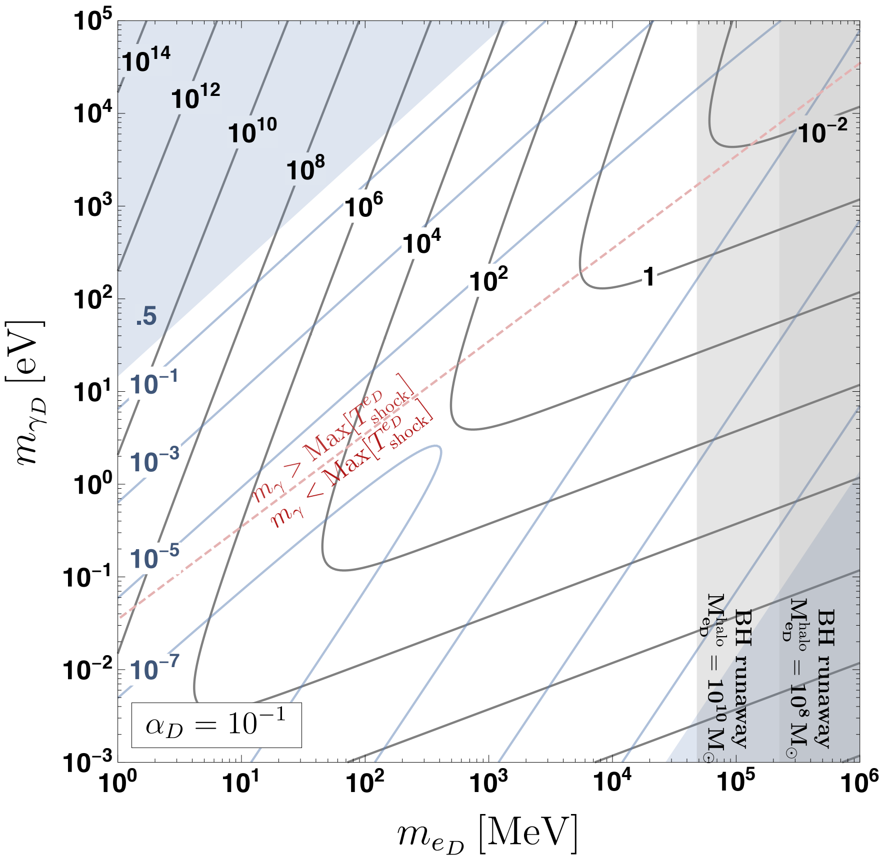
$$\frac{d\log T}{d\log\rho} = \frac{2}{3}\frac{m}{\rho}\frac{P}{T} - 2\frac{t_{\text{collapse}}}{t_{\text{cooling}}}$$

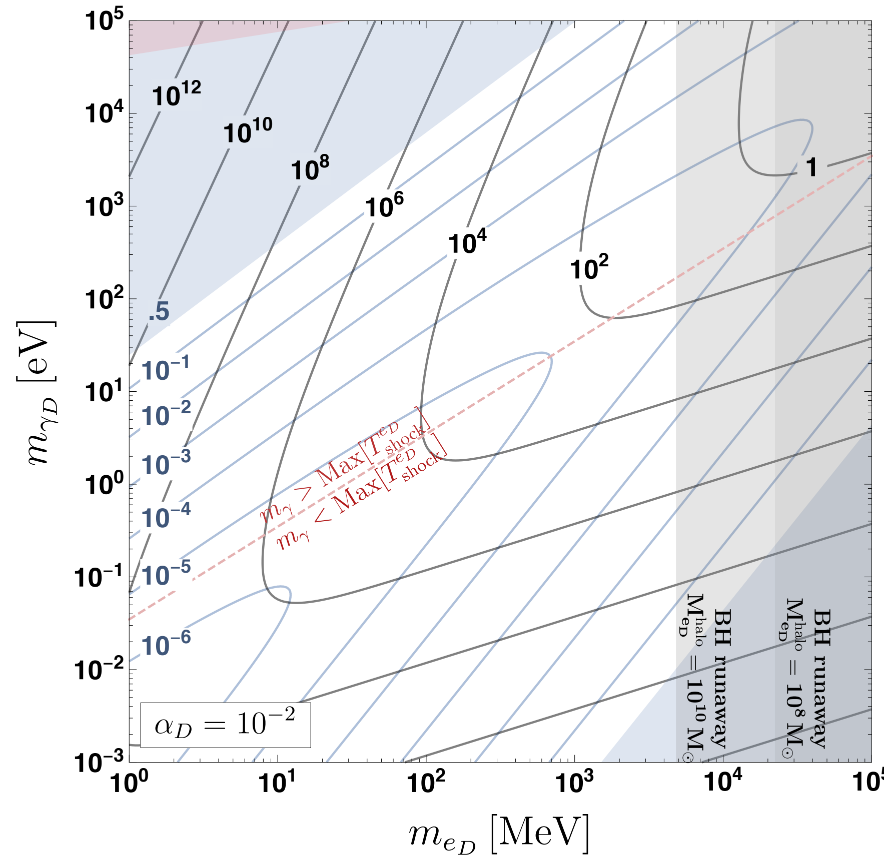
- Mass perturbation is parameterized with ρ and T

Evolution Trajectory ($M = 10^{10} M_\odot$)



Results According to Model Parameters





- Black lines : Minimum M_J in $M_\odot$ after fragmentation
- Blue lines : Corresponding compactness ($C = GM/R$)

Conclusion

- We described the complete history of structure formation of a simple dissipative dark sector model.

- We provided a map between astronomical properties and particle physics parameters.

Conclusion

- A wide range of opportunities lies ahead,
  - What is the behavior of more complicated dark-matter models with cooling?
  - What are the astronomical signatures of such models?
  - Numerical simulations?

- Lots of progress to make from the theory side, even if DM interacts with us only gravitationally

THANK YOU