Title: Illuminating Hidden Sector Dark Matter With Early-Forming Microhalos

Speakers: Himanish Ganjoo

Collection: Dark Matter, First Light

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Abstract: The absence of dark matter signals in direct detection experiments and collider searches has prompted interest in models in which dark matter belongs to a hidden sector minimally coupled to the Standard Model. In these scenarios, a long-lived massive particle might come to dominate the energy density of the early universe temporarily, causing an early matter-dominated era (EMDE) prior to the onset of nucleosynthesis. During an EMDE, matter perturbations grow more rapidly than they would in a period of radiation domination, which leads to the formation of microhalos as early as a redshift of ~5000. These microhalos generate distinct observable signatures, but the constraints on these signatures are highly sensitive to the small-scale cut-off in the matter power spectrum. We discuss the effects of an EMDE on the matter power spectrum, focusing on cases where the particle that dominates the Universe during the EMDE was initially relativistic, and the small-scale cut-off in the power spectrum is set by its pressure support. In addition, we present N-body simulations of the formation and dissipation of microhalos due to an EMDE, which imposes a free-streaming cut-off on the power spectrum after the EMDE. We discuss the implications of this gravitational heating on the (re)formation of microhalos close to the epoch of matter-radiation equality. We constrain these EMDE cosmologies using the observations of the Isotropic Gamma Ray Background and the boosted annihilation rates from the early bound structures resulting from an EMDE. In addition, we discuss prospects for observing these microhalos through pulsar timing arrays and microlensing.

Illuminating Hidden Sectors With Early Matter Domination

Himanish Ganjoo

Dark Matter, First Light

28 Feb 2024 / Perimeter Institute

arXiv: 2209.02735 / JCAP 01, 2023 (with Adrienne Erickcek, Weikang Lin, Katie Mack)
arXiv: 2306.14961 (with Sten Delos)

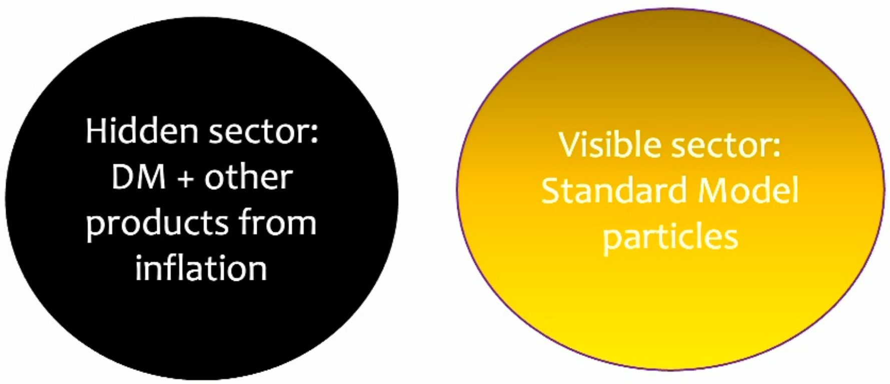
Motivations: Hidden Sector DM

NEWS FLASH!

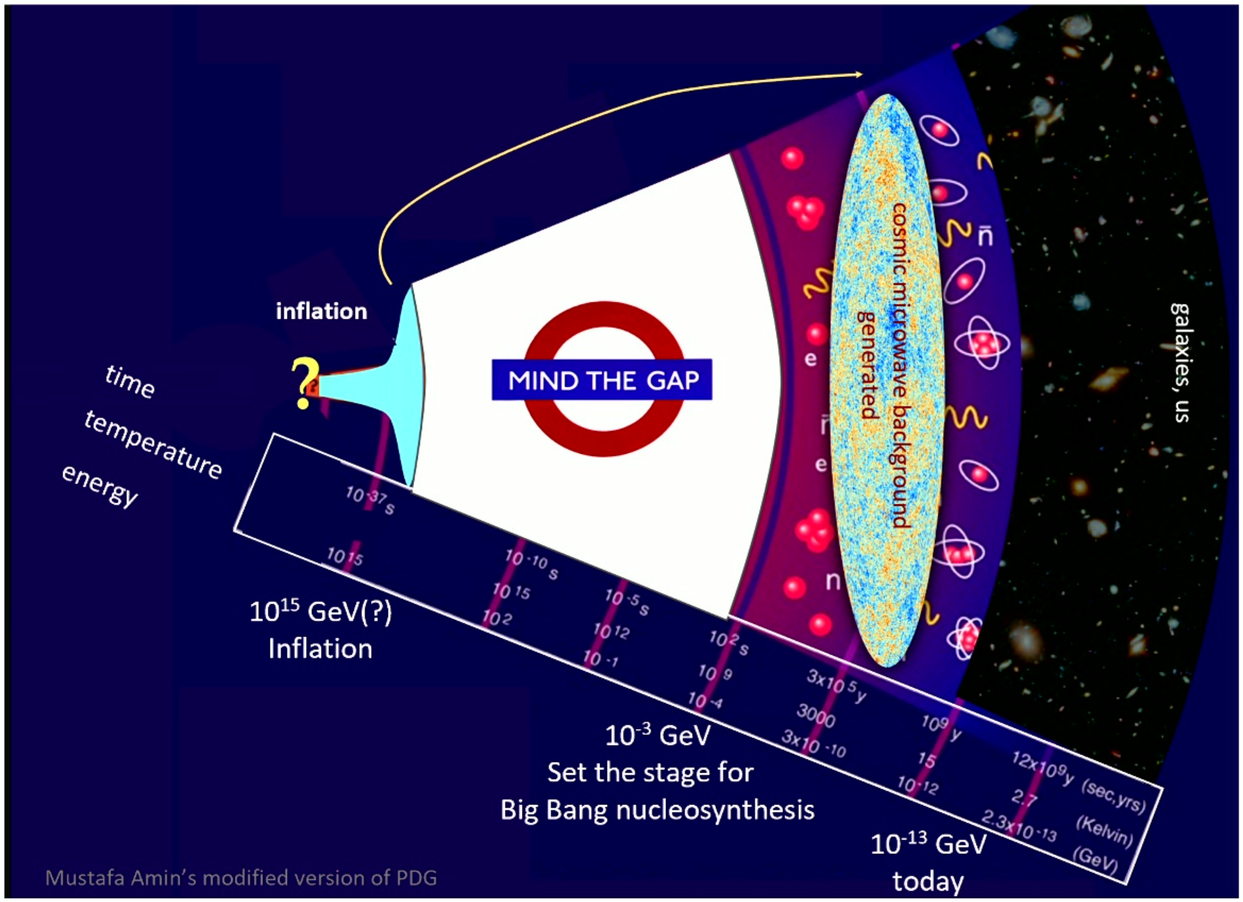
No conclusive signatures of DM in collider and direct detection experiments.

DM might be part of a **hidden sector**, "secluded" from the Standard Model.

[Pospelov+ 2007 (0711.4866), Arkani-Hamed+ 2009 (0810.0713), Hooper+ 2012 (1206.2929), Berlin+ 2014 (1405.5204)]



Alternative Thermal Histories and EMDEs



Alternative Thermal Histories and EMDEs

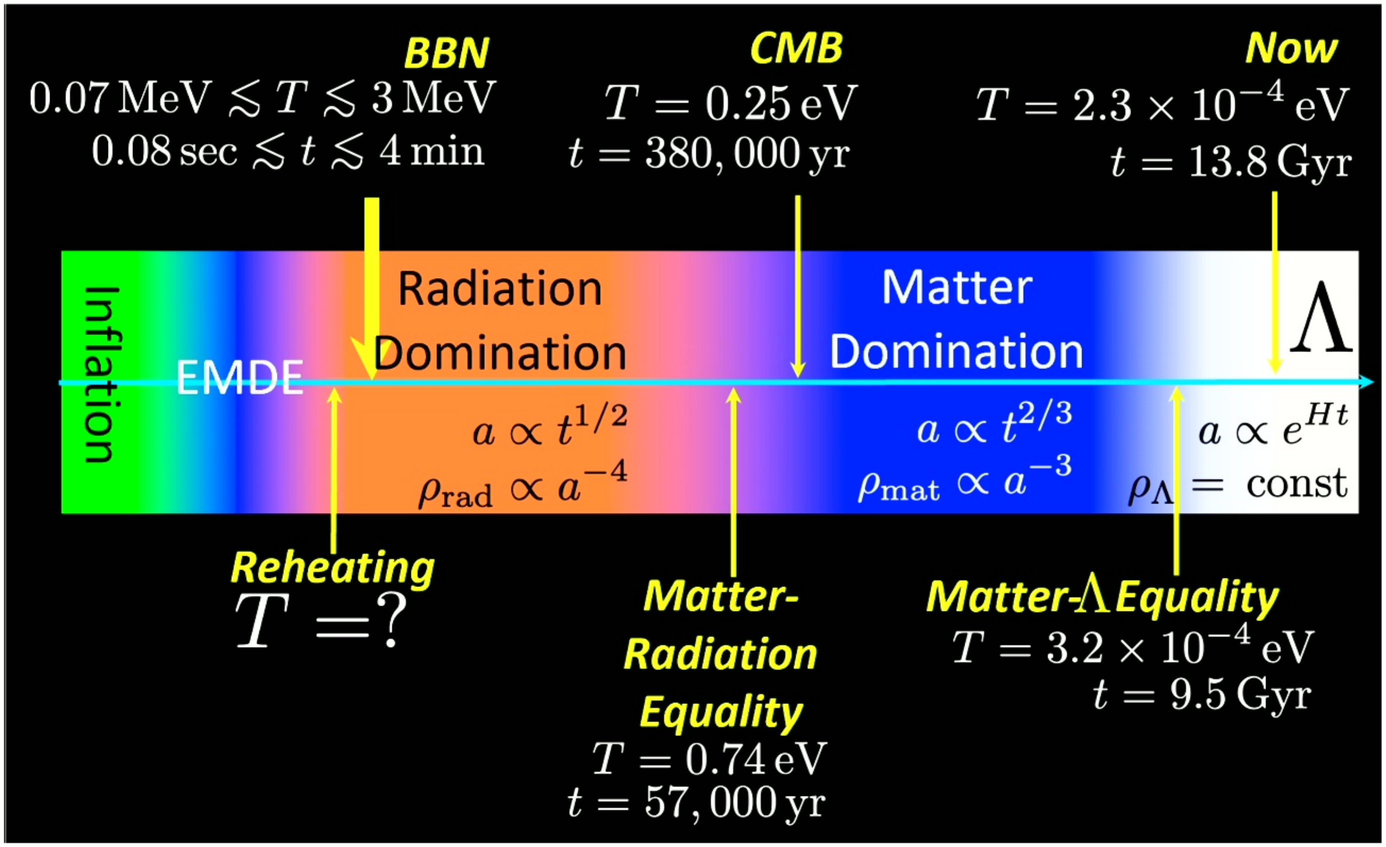


Figure: Adrienne Erickcek

A possible period of matter domination between inflation and BBN, caused by particles in the hidden sector.

Zhang 2015 (1502.06983)

Berlin+ 2016 (1602.08490)

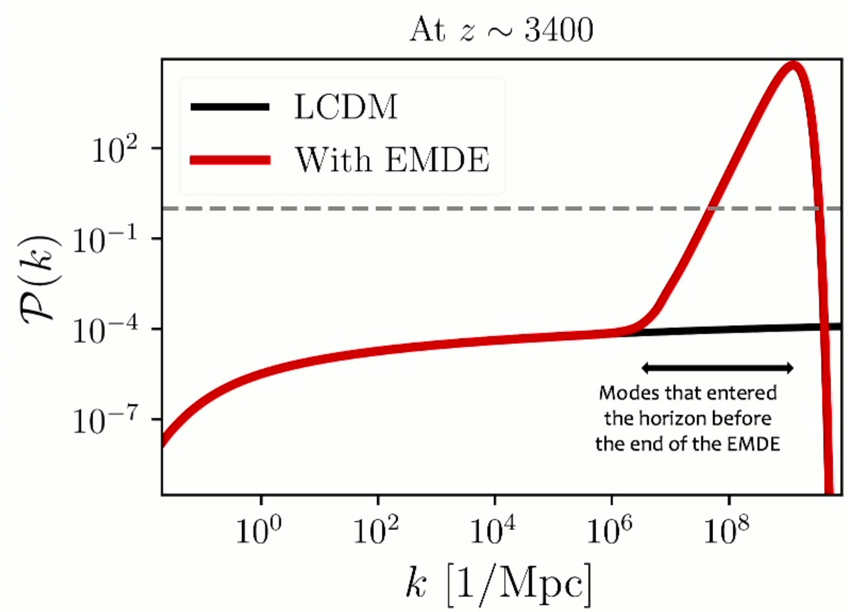
Dror+ 2016 (1607.03110)

See 2006.16182 for a general review

Why do we care?

1. Much lower DM cross-sections r
abundance – opens parameter spa

2. Observable signatures: linear gr
perturbations – formation of dens

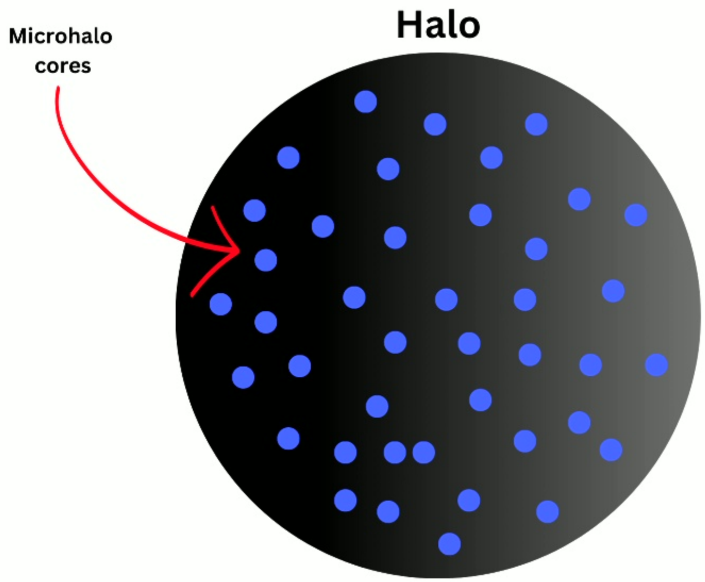


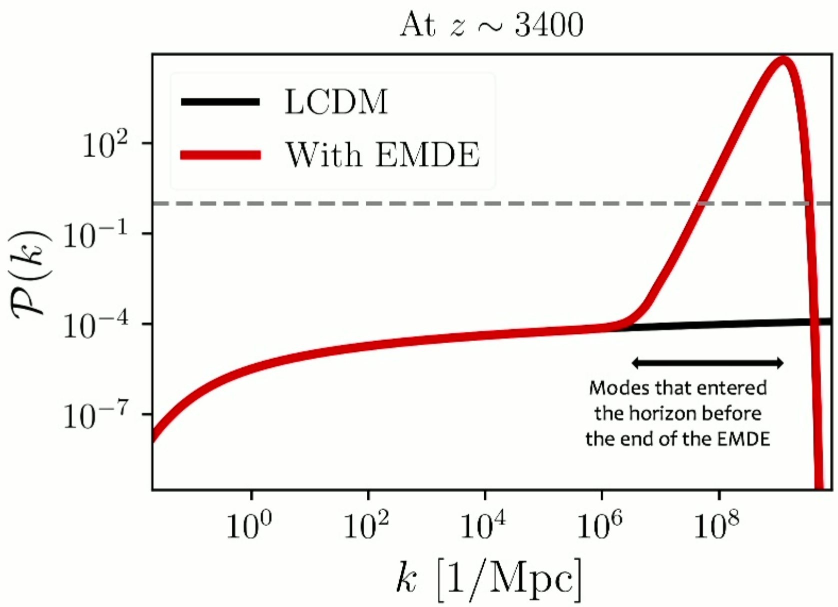
Why do we care?

1. Much lower DM cross-sections needed for relic abundance – opens parameter space

2. Observable signatures: linear growth of matter perturbations – formation of dense substructures

Why do we care?





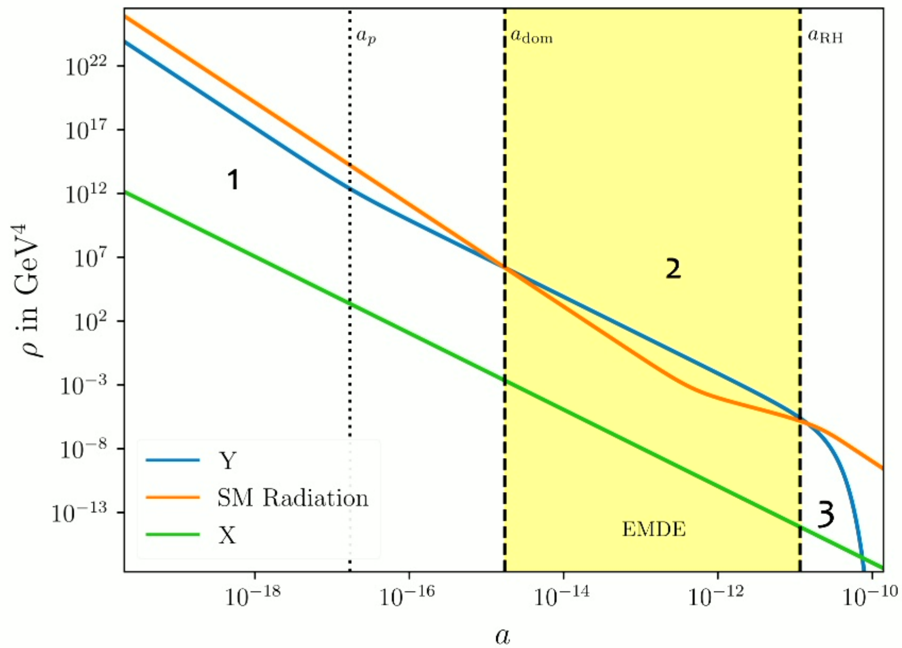
Background Evolution / The Setup

Universe has three components: Y particles, DM, and the bath of relativistic SM particles.

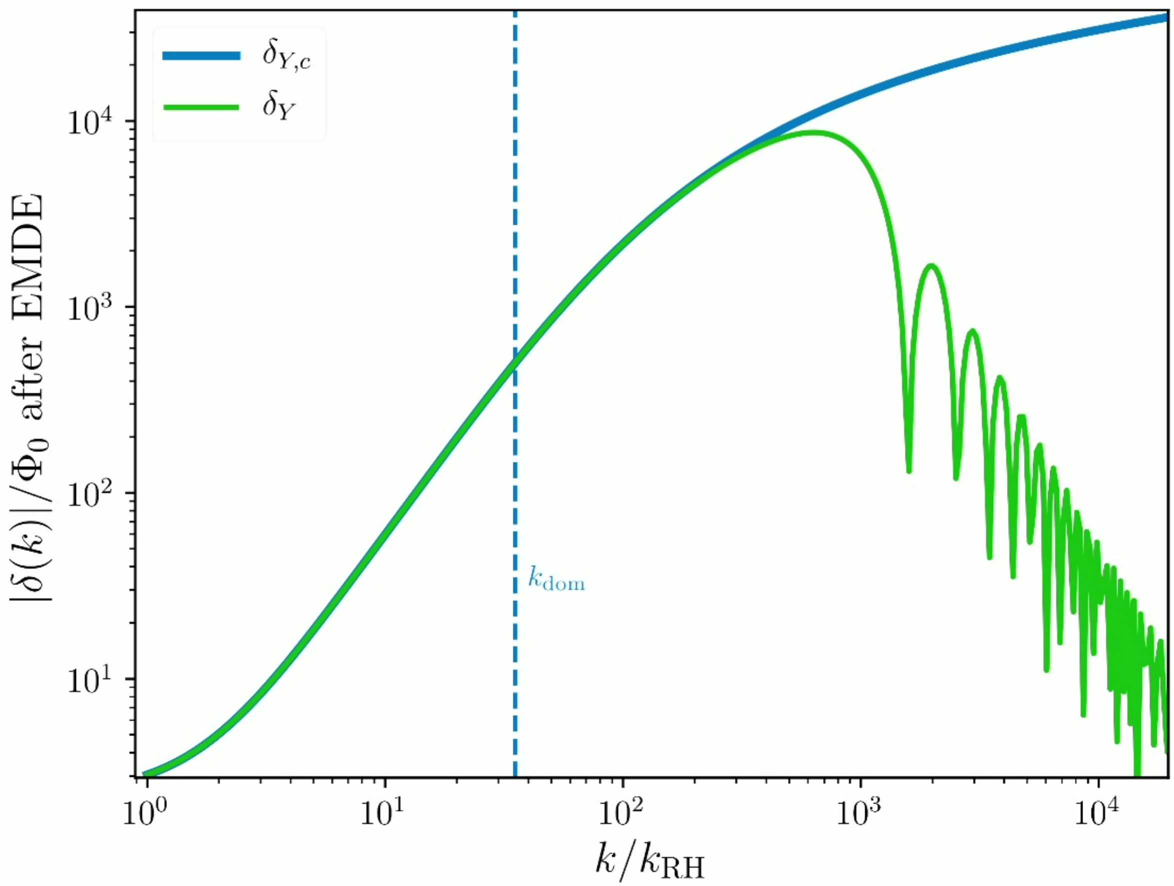
1. Y particles in hidden sector: initially relativistic and transition to nonrelativistic behavior.

2. The energy density of the Y particles dominates the Universe after the particles become nonrelativistic. This is the EMDE.

3. Y particles are minimally coupled to the Standard Model and decay into the SM bath with decay rate Γ. Y particle decay increases rapidly at **reheating** and radiation domination is restored.



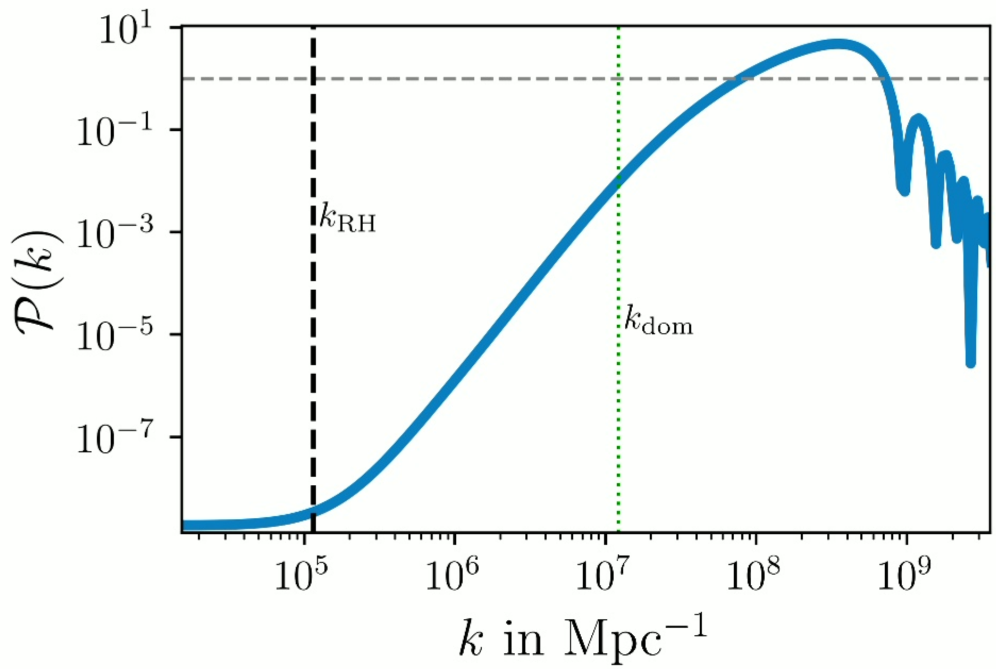
Perturbation Amplitude in k-space



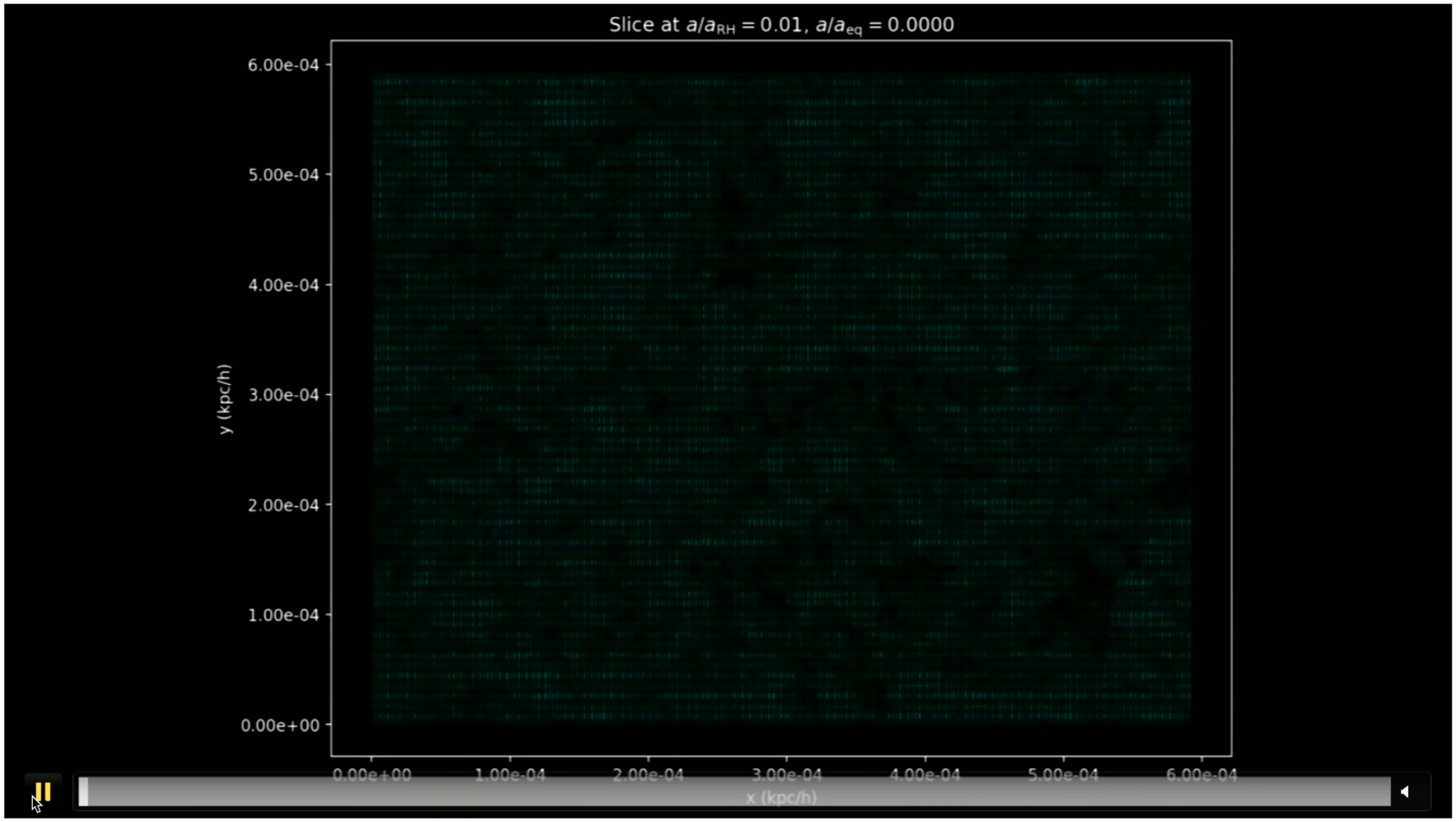
Gravitational Heating

- Halos can form before the EMDE ends.

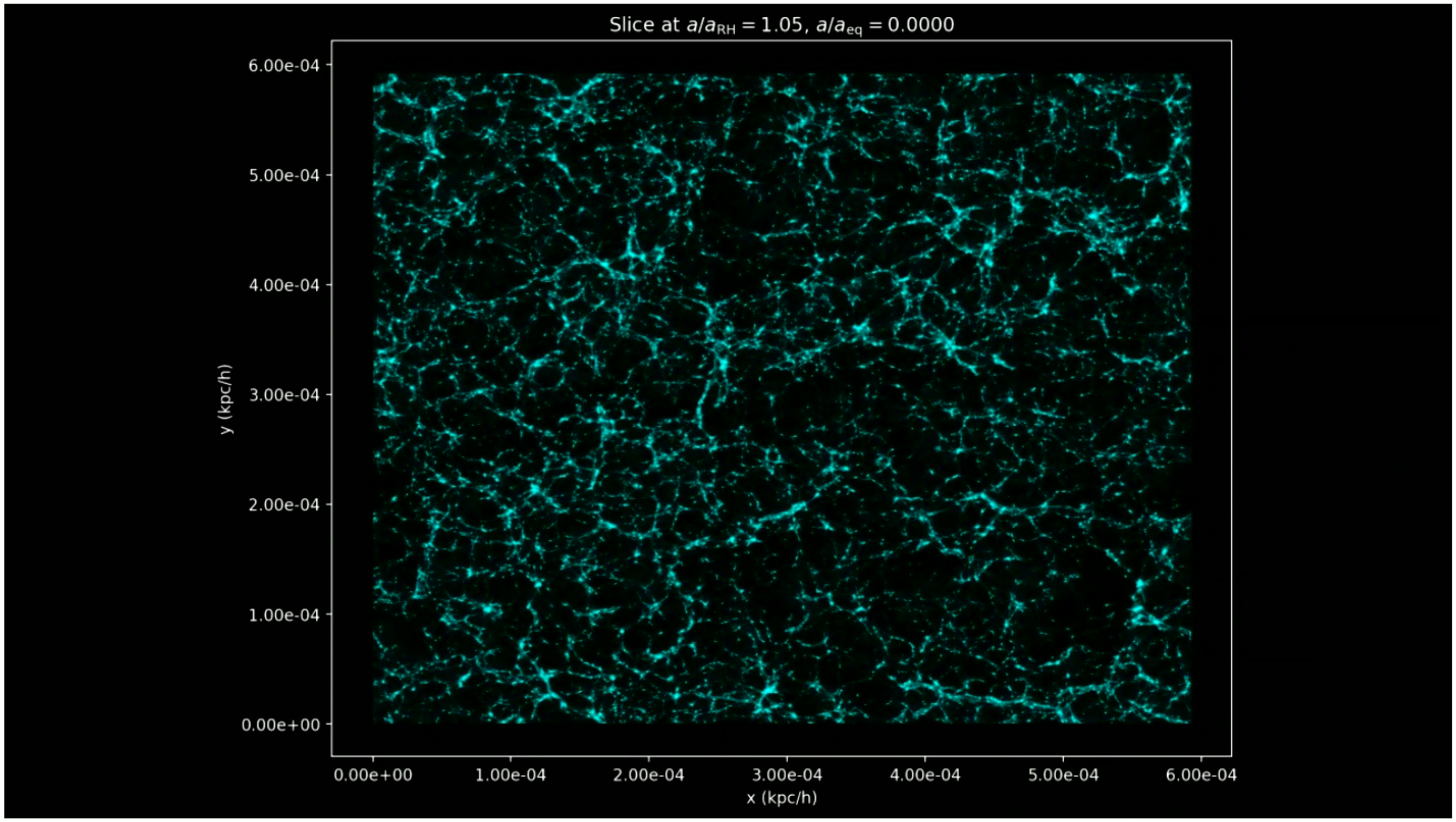
- These halos are mostly Y particles, which decay at the end of the EMDE.



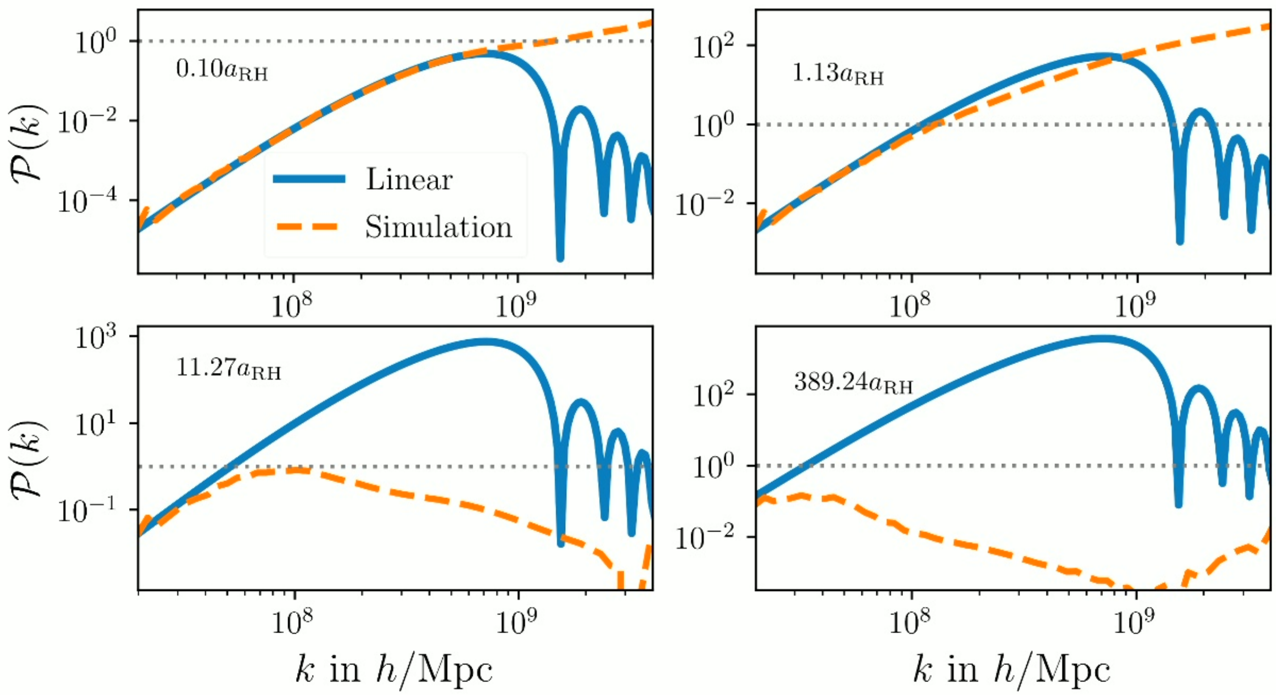
Gravitational Heating: Destroying Structure



Gravitational Heating: Destroying Structure



Free-Streaming Cut-off via Gravitational Heating



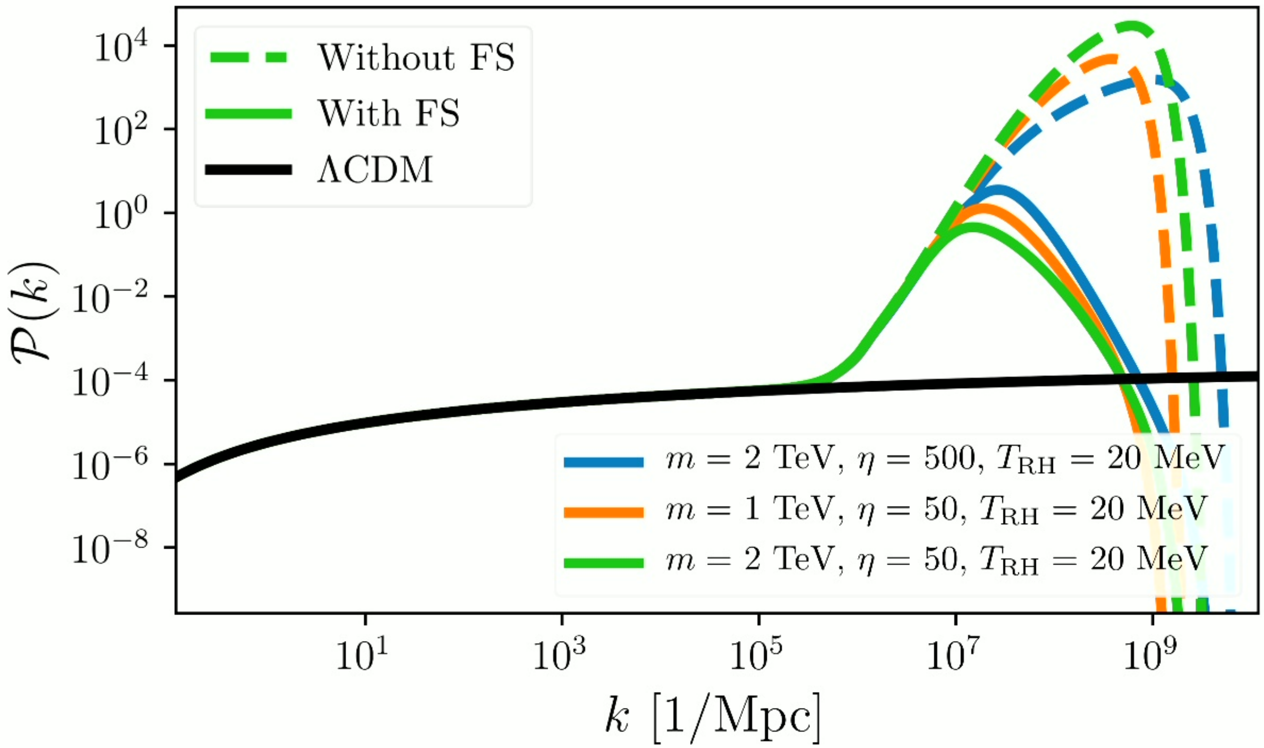
Cut-off function fits simple power law

Cut-off scale related to EMDE power spectrum via linear velocity dispersion

Suppressed Power Spectra at Matter-Radiation Equality

A significant portion of the EMDE based enhancement is retained even after gravitational heating!

Microhalos (re)form much earlier than in LCDM cases.



Observational Avenues

Caustic microlensing

Small-scale compact objects lead to detectable variations in the brightness of stars

N. Blinov, M.J. Dolan, P. Draper and J. Shelton, 2021 (2102.05070)

Pulsar Timing Arrays

Microhalos tug on pulsars, leading to shift in the pulsar signals detectable via PTAs

M.S. Delos and T. Linden, 2022 (2109.03240)

Indirect Detection

Significant boosts to the DM annihilation signal from dense substructures

“Prompt” Cusps

Delos and White (2022), 2209.11237

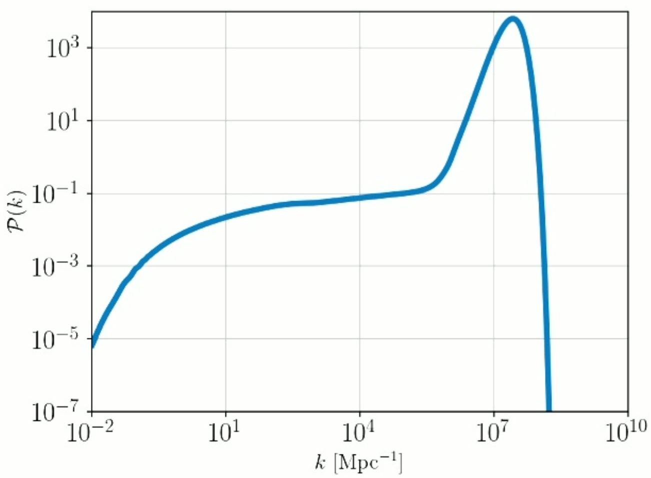
- First structures form from the direct collapse of density peaks
- Have $\rho = Ar^{-3/2}$ profiles that persist even after mergers / accretion
- Persist as substructure in current-day halos
- Contribute heavily to DM annihilation signal as halo substructure despite containing ~1-10% of DM.

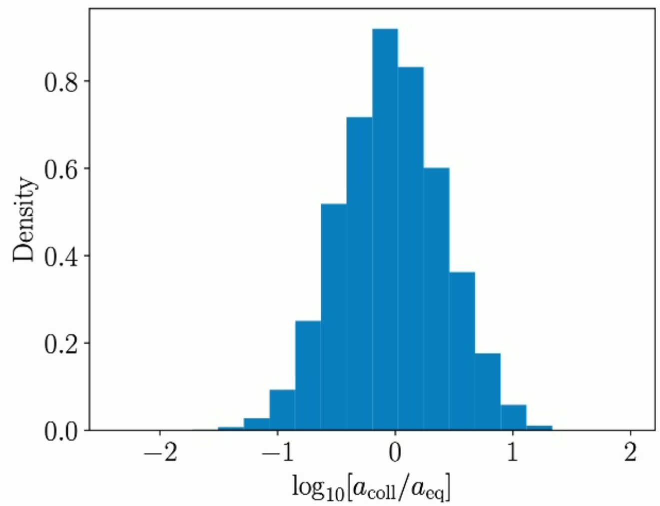
HG, Sten Delos (in prep.)

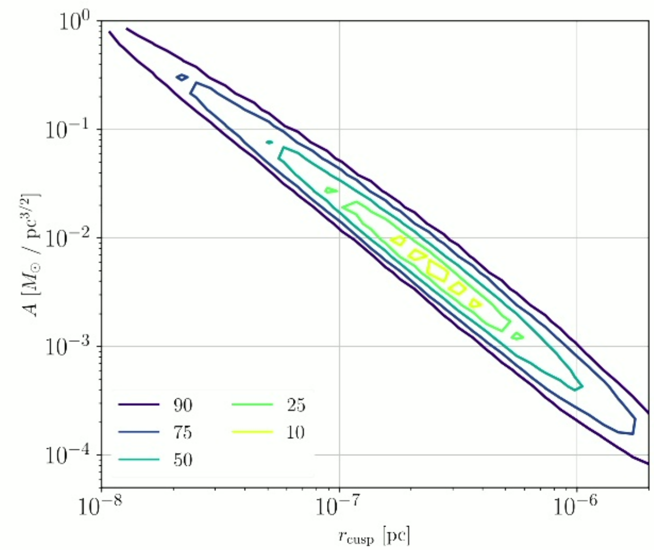
Cusps due to an EMDE with Heating

Modified Cusp-Encounters code [Stucker et al, 2301.04670] to include EMDE power spectra, growth functions, time-dependent collapse for RD, and heating effects.

EMDE-enhanced PS with heating cut-off → Collapse of peaks → Formation of cusps





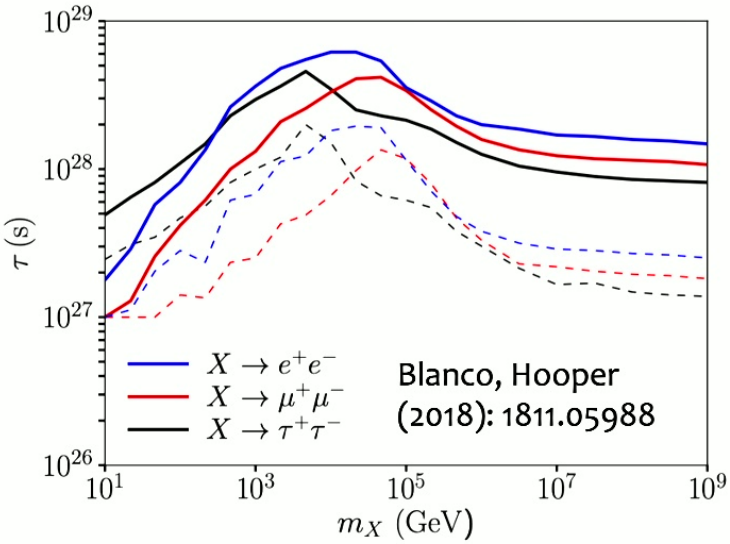


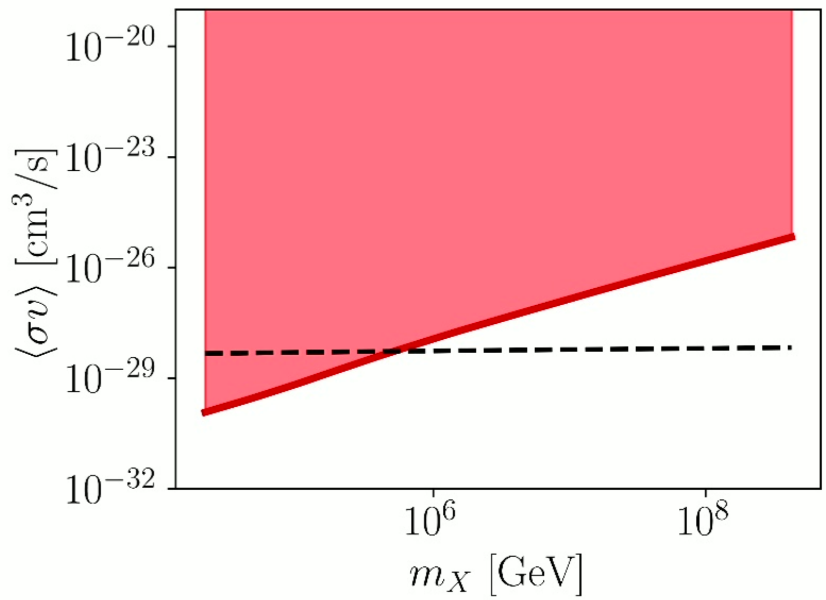
HG, Sten Delos (in prep.)

Using IGRB Limits on Decaying DM

$$\frac{\langle \sigma v \rangle}{2m_{\rm DM}^2} \frac{J}{M_{\rm DM}} \longleftrightarrow \frac{1}{2\tau m_{\rm DM}}$$

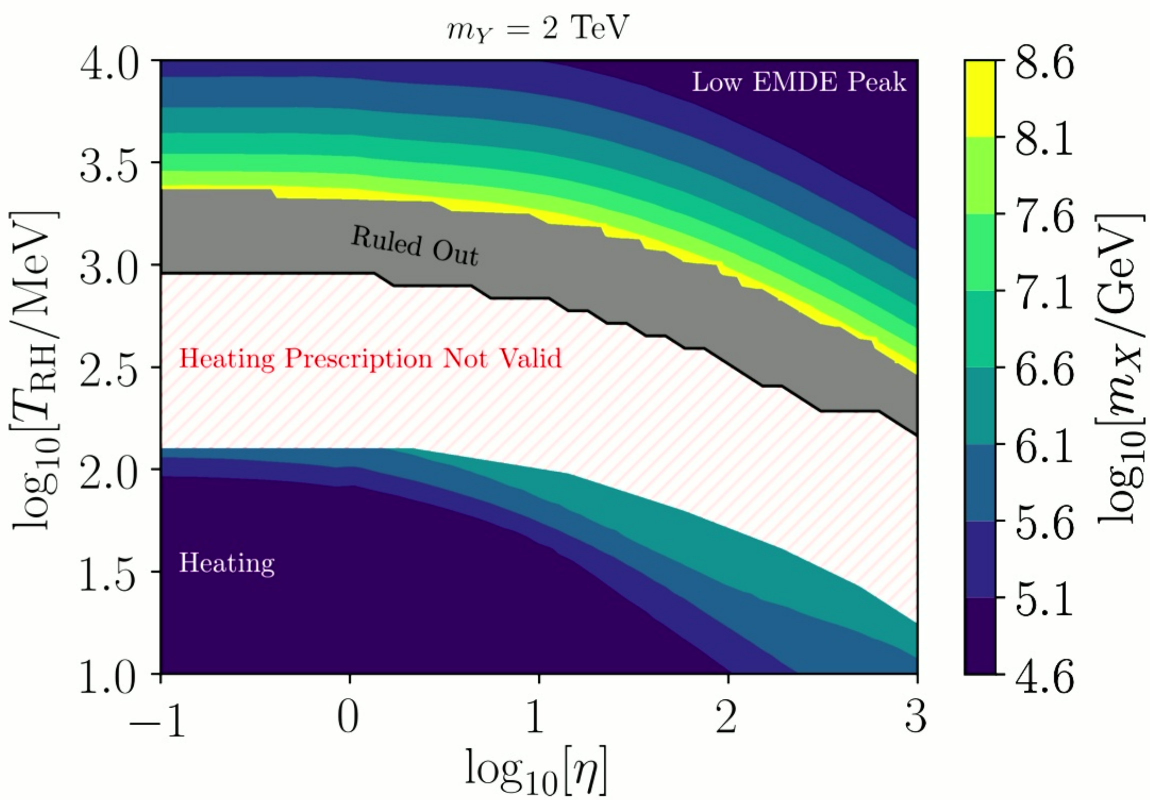
Particle physics — Structure — Decaying DM





Lower Limits on DM Mass

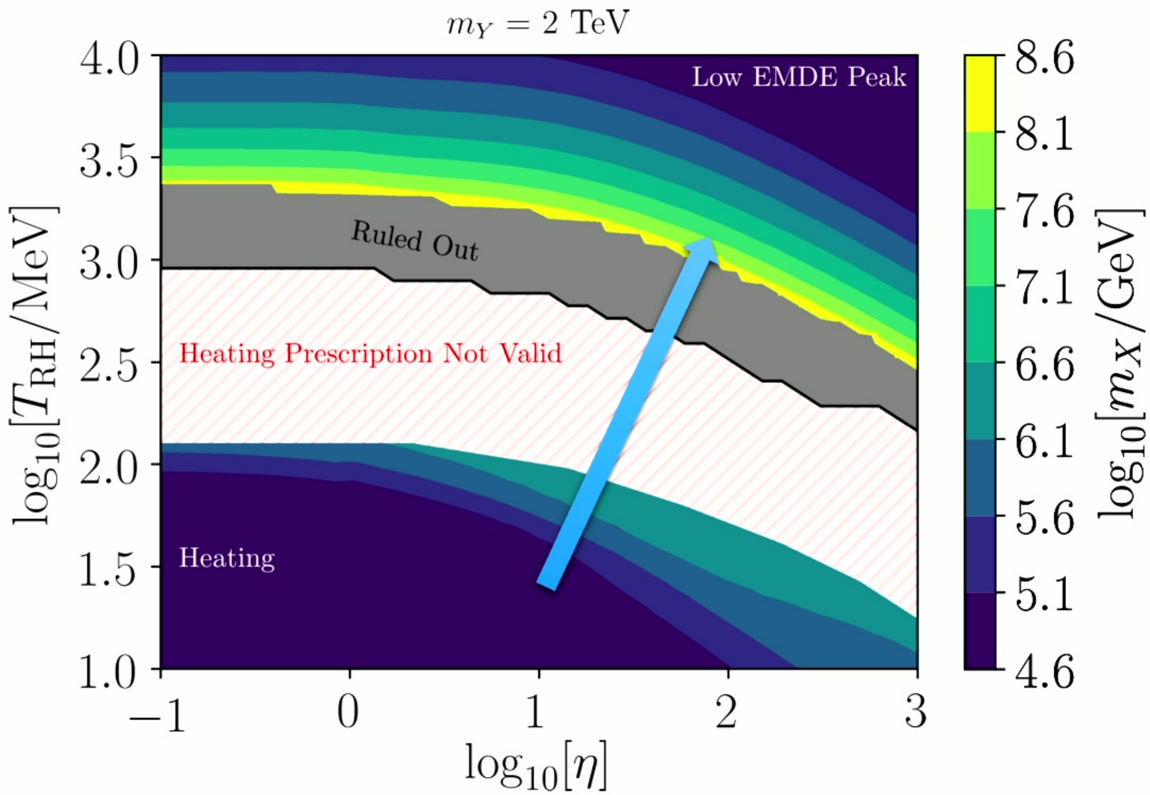
HG, Sten Delos (in prep.)



Lower Limits on DM Mass

HG, Sten Delos (in prep.)

Non-Heating → Shorter EMDE → Smaller PS Peak → Lower J → Lower DM mass lower bound



Summary and What's Next

Dark matter might be hidden, but it's not all darkness: hidden sectors can leave detectable signatures via the creation of extremely small-scale compact objects

Next Steps:

- simulations of halos forming around matter-radiation equality, or in radiation domination
- Modify CHIMERA to include boosted radial profiles and check the impact of annihilation on the gas heating and star formation in EMDE scenarios

Lower Limits on DM Mass

HG, Sten Delos (in prep.)

Heating → Shorter EMDE → Less Structure Formation → Larger peak → Higher J → Higher DM mass lower bound