Self-Interacting Asymmetric Dark Matter Coupled to a Light Massive Dark Photon

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What would a "similar" dark matter model look like?

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- Has a self-interaction which is described by a $\mathrm{U_D}(1)$ gauge group.
- Carries a global quantum number: dark baryon number.

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- We further assume that DM today has a nonzero dark baryon number.
- The production of these asymmetries may be related.
  (Review: Petraki & Volkas, 2013)

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  - Others: baryon effects, warm dark matter...

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- Hence an equal asymmetry is produced in some negatively-charged particle!
- This negatively charged particle can't be the antiparicle; otherwise there's no net asymmetry in dark baryon number.

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Like the Standard Model:

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- Since electromagnetism is a good symmetry, this same process also made an equal number of negatively charged electrons.

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- This means that there is a phase transition above which the $\mathrm{U_D}(1)$ symmetry is restored, and below which it is broken.

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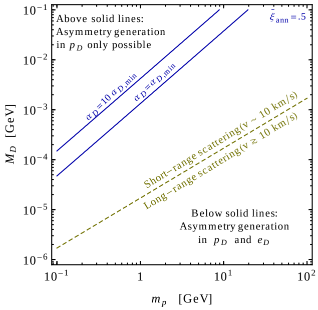
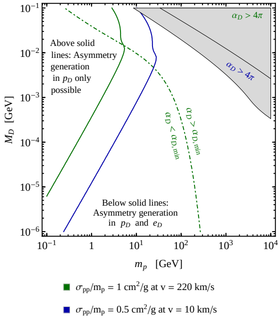
- DM is multi-component in much of parameter space.





$\alpha_{D,\min}$: minimum for sufficient annihilation of the thermal dark protons in the early universe.

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- Halo shapes?

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These events change number of d.o.f. in dark sector.
Ratio of dark to SM d.o.f. ξ is time-dependent and may be > 1 or < 1.

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The $\rm U_D(1)$-breaking phase transition can occur before dark recombination or freeze-out of dark proton and/or dark electron annihilations

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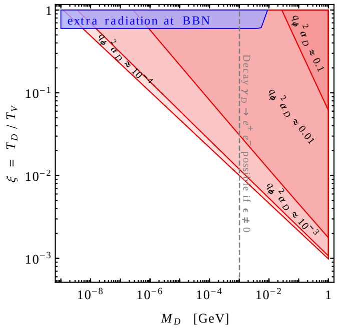

Red: relic abundance of the dark photons may alter the time of matter-radiation equality or dominate the DM density

Blue: Too much radiation at BBN

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- However, if self-interactions are too large, than large halos may not be elliptical.
- Both of these questions must be revisited if dark matter is multi-component, with different intra- and inter-species interactions.

Momentum-Transfer in Halos

Momentum-Transfer Rate

- Define effective momentum transfer rate:

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- Atom-atom interaction: Cline, Liu, Moore, & Xue (2014), Cyr-Racine & Sigurdson (2013)
  Atom-ion interactions: Cyr-Racine & Sigurdson (2013)
  Ion-ion interactions: Khrapak, Ivlev & Morfill (2004)

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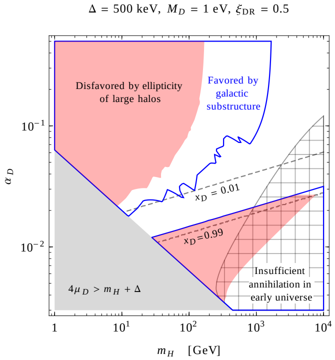
Sample Plots



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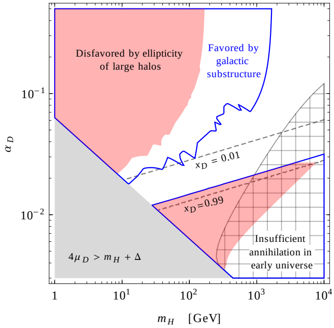
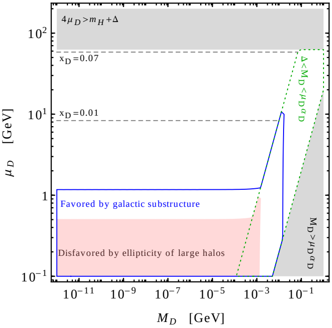
$\Delta = 500$ keV, $M_D = 1$ eV, $\xi_{DR} = 0.5$



$m_H = 250$ GeV, $\alpha_D = 0.05$, $\xi_{DR} = 0.3$



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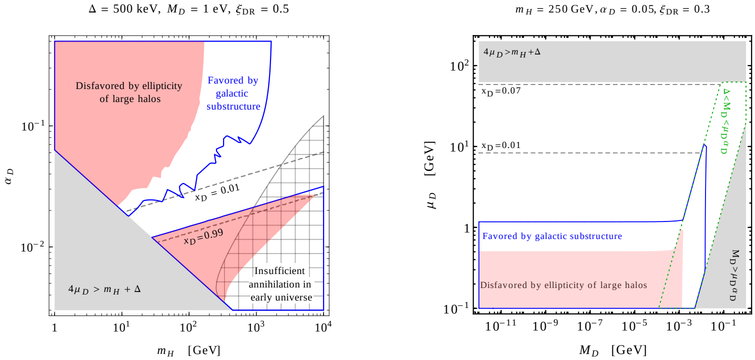
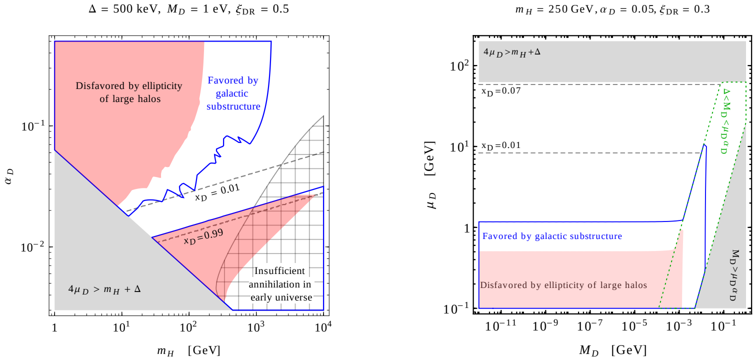


- Regions where self-interaction can modify small halos without destroying the ellipticity of large halos: due to velocity-dependence of cross sections.

Sample Plots



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- Can take mass of dark photon $\rightarrow 0$; screening provided by bound state formation.

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- This is the reason for the "wedge" shape.

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- This remains true for a light but not necessarily massless mediator gauge boson.
- Cosmological constraints may take very different forms depending on the sequence of cosmological events.
- There exist regions of parameter space in which DM self-scattering can affect clustering in small halos without endangering the ellipticity of larger halos.