Self-interacting dark matter from late decays and the H_0 tension

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Anomalies 2021

Based on:

A. Hryczuk, KJ, 2006.16139

ΛCDM problems

small scale

- core-cusp: CDM simulations indicate $\rho_{DM} \sim 1/r$ while observations suggest $\rho_{DM} \sim$ const
- too-big to fail: observed Milky Way satellites are less massive than predicted
- diversity: disk galaxies with the same max circular velocity exhibit large scatter in rotation velocities in the interior
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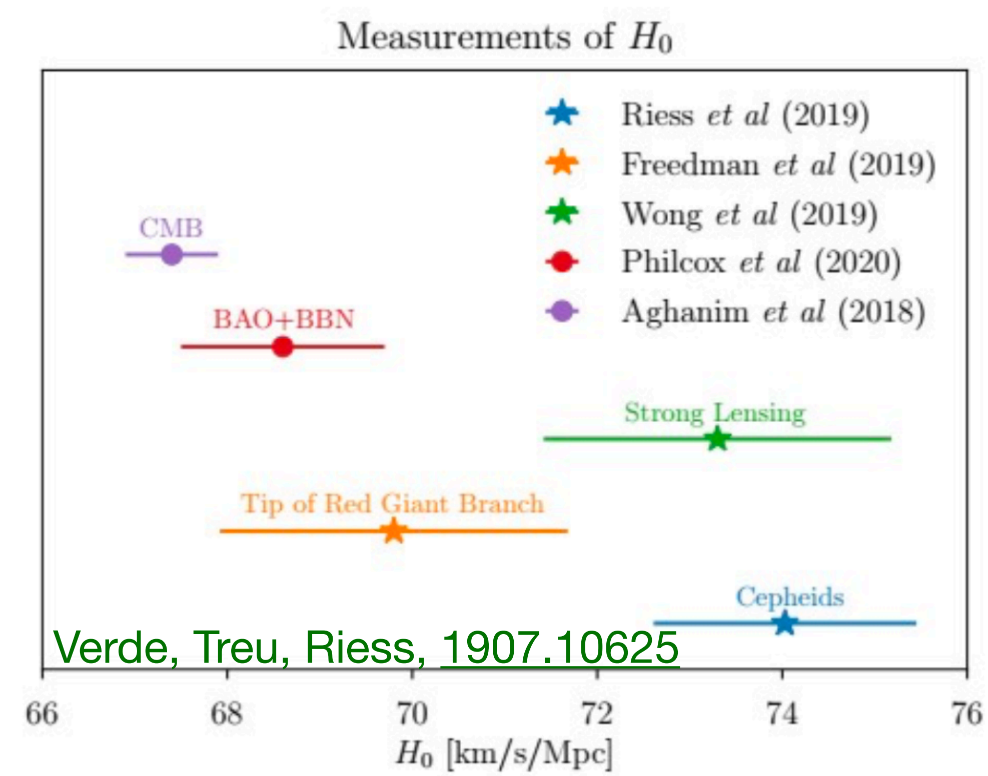
large scale

- Hubble tension: H_0 inferred from early Universe (CMB) smaller by $\sim 4\sigma$ compared to late Universe direct measurements (distance ladder)



Verde, Treu, Riess, 1907.10625

- σ_8 tension: amplitude of density fluctuation inferred from Planck is larger by $\sim 3\sigma$ compared to weak lensing surveys

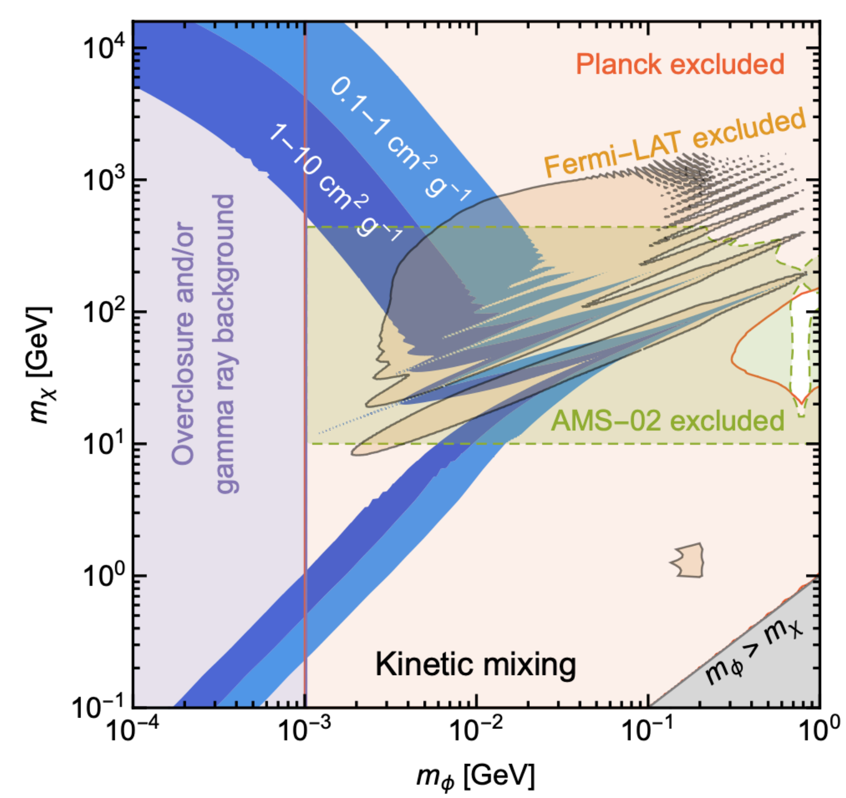
Going beyond CDM

small scale

- warm or self-interacting DM allows one to solve small scale problems

- *velocity-dependent SIDM* is well-motivated and seems to fit the data well   Tulin, Yu 1705.02358

- self-interactions due to exchange of light mediator → strong constraints from e.g. Bullet Cluster
- CMB rules out light mediator that is in thermal equilibrium with SM



Bringmann et al. 1612.00845

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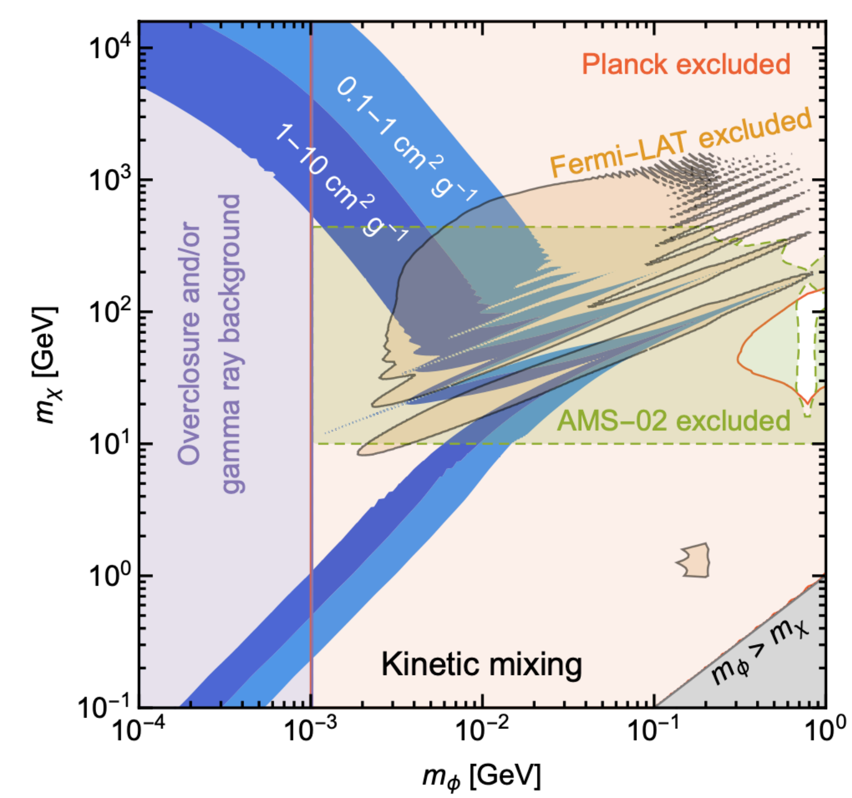
large scale

- It is well-known Chudaykin et al. 1711.06738, Bringmann et al. 1803.03644,… that DM transferring energy to radiation due to *late annihilations or decays increases* H_0 → Hubble tension solution (?)



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Inferring H_0 from CMB

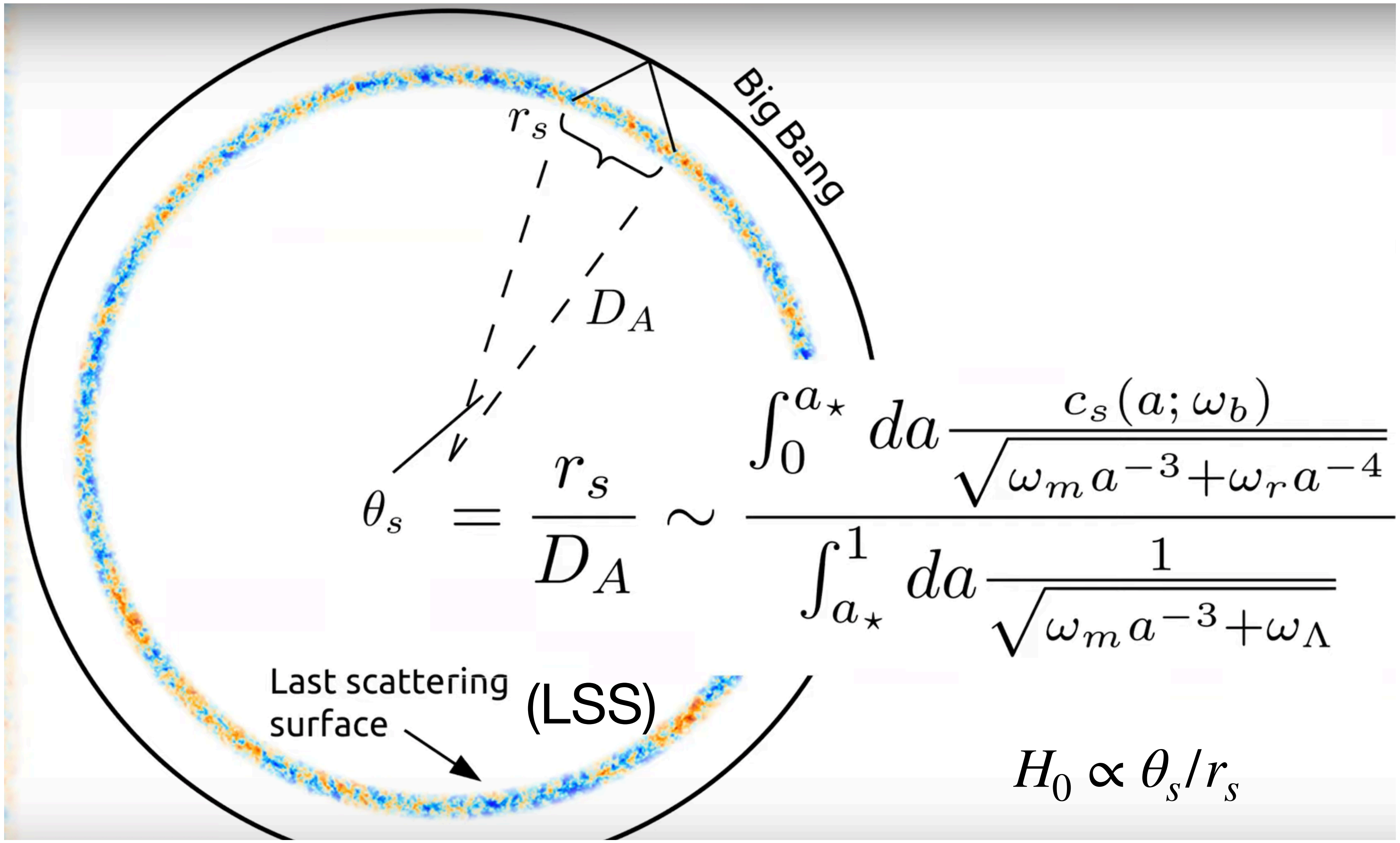


Fig. by M. Millea. See also extensive discussion in Knox, Millea 1908.03663.

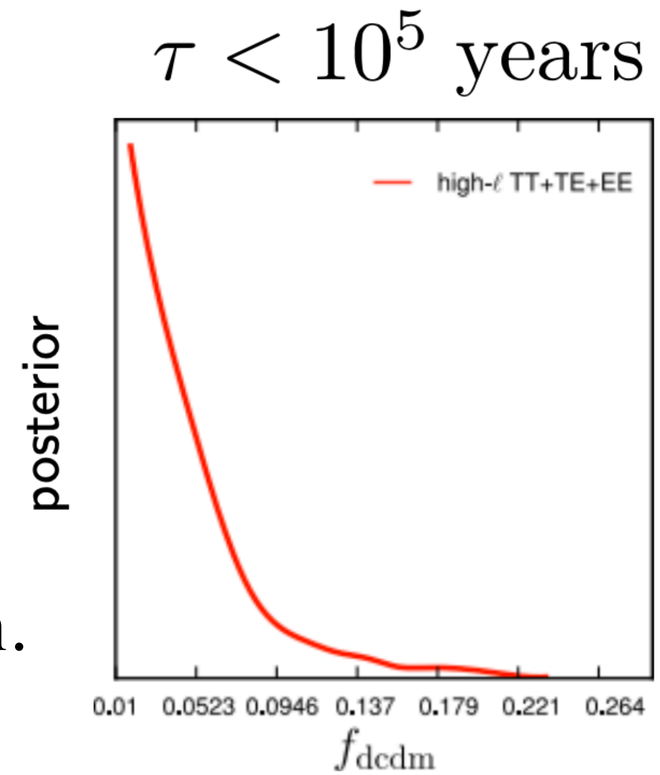
Universe with more matter ω_m will have smaller sound horizon r_s while angular size of LSS θ_s will be fixed → H_0 increases.

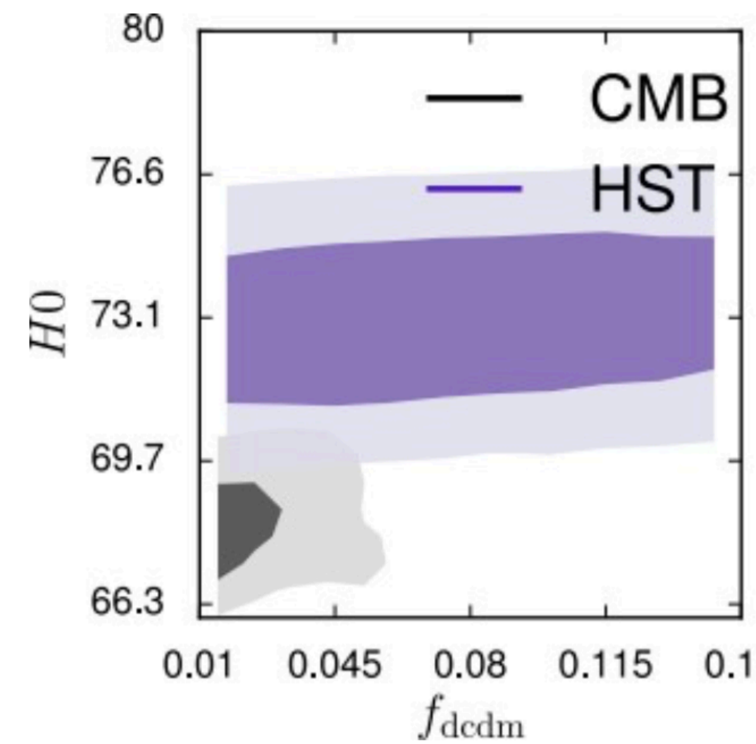
Decaying Cold Dark Matter model (DCDM)

1) Fraction f of CDM decays into dark radiation, 2) with decay rate $1/\tau$.

DCDM and Hubble tension

CMB generically disfavours large DCDM contribution which is necessary to go from $H_0 \sim 67$ km/s/Mpc (ΛCDM) to $H_0 \sim 72$ km/s/Mpc for decays taking place before recombination.





Poulin, Lesgourges, Serpico 1606.02073

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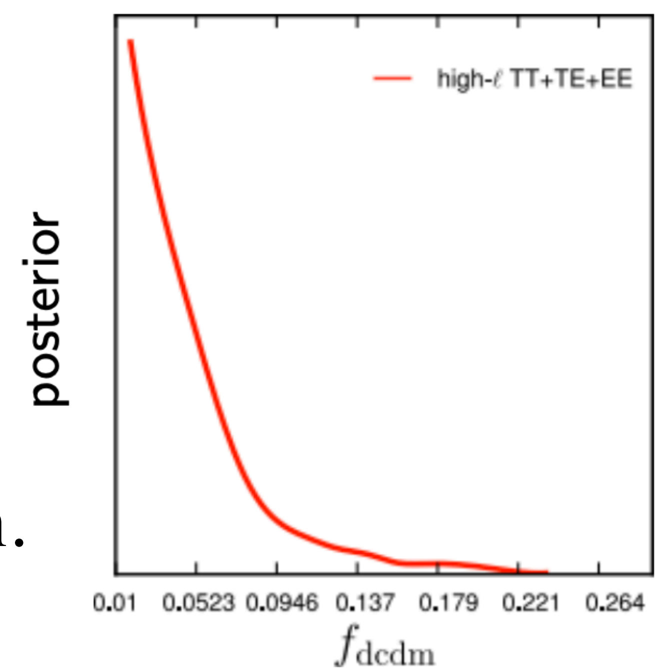
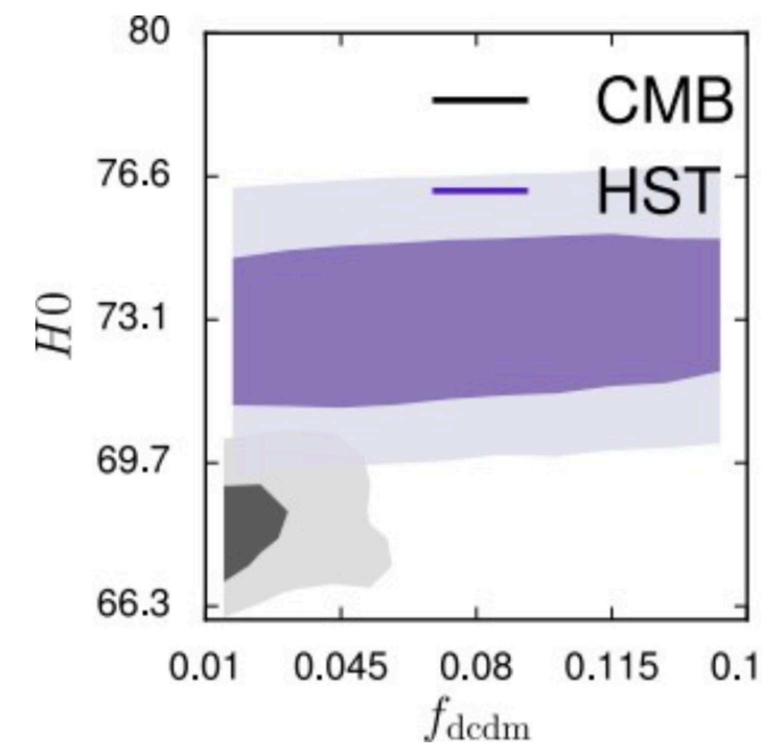
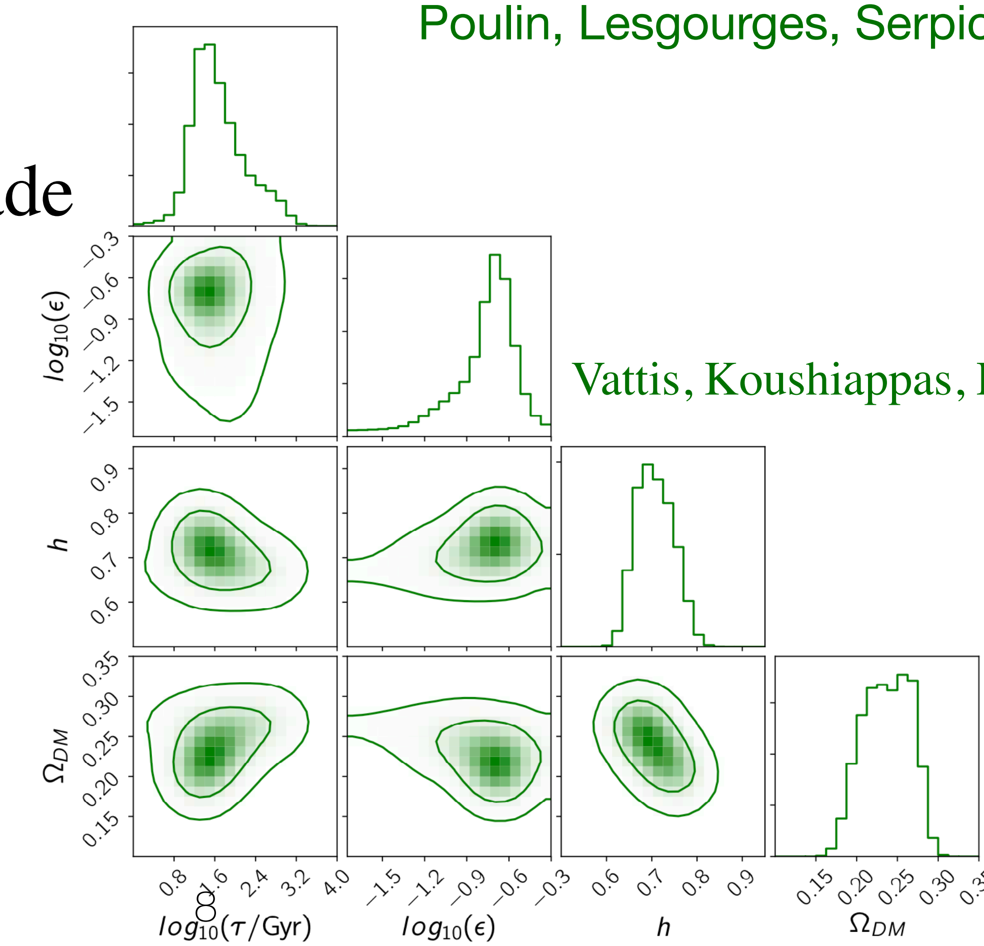
$\tau < 10^5$ years





Poulin, Lesgourges, Serpico 1606.02073

Loeb et al. 1903.06220 - very late decays $\tau \gtrsim 13$ Gyr with $f_{DCDM} \sim 0.15$ evade those constraints while leading to $H_0 \sim 72$ km/s/Mpc.



Vattis, Koushiappas, Loeb 1903.06220

Further works Haridasu, Viel 2004.07709, Clark et al. 2006.03678 showed other observables constrain such scenario further shifting best fit to $f_{DCDM} \sim 0.08$ and $H_0 \sim 69$ km/s/Mpc.

SIDM from DCDM

Thermally produced ~1-100 GeV SIDM χ is strongly constrained by CMB (in case of unstable mediator A) or by requiring that $\Omega_{DM}h^2 \sim 0.1$ which excludes light mediator coupled to SM.

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Consider WIMP-like particle S which obtains correct relic density due to freeze-out. Assume S is also coupled to Dark Sector particles - χ and A.

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$$L_{int} \supset \lambda_{HS} S^2 H^\dagger H + \epsilon S \bar{\chi}\chi + g A^\mu \bar{\chi}\gamma_\mu \chi$$

freeze-out — decay — self-interactions

S decays

- LO: $\Gamma_{S\to\chi\chi} \propto \epsilon^2$,
- NLO:
  - $\Gamma_{S\to\chi\chi A} \propto \epsilon^2 g^2$,
  - $\Gamma_{S\to AA} \propto \epsilon^2 g^4$.

Amount of injected radiation depends on g, as $BR(S\to AA) \propto g^4$ and $BR(S\to \chi\chi A) \propto g^2$. → $g \sim 0.1$

Lifetime τ_S essentially fixed by $\epsilon \lesssim 10^{-12}$.

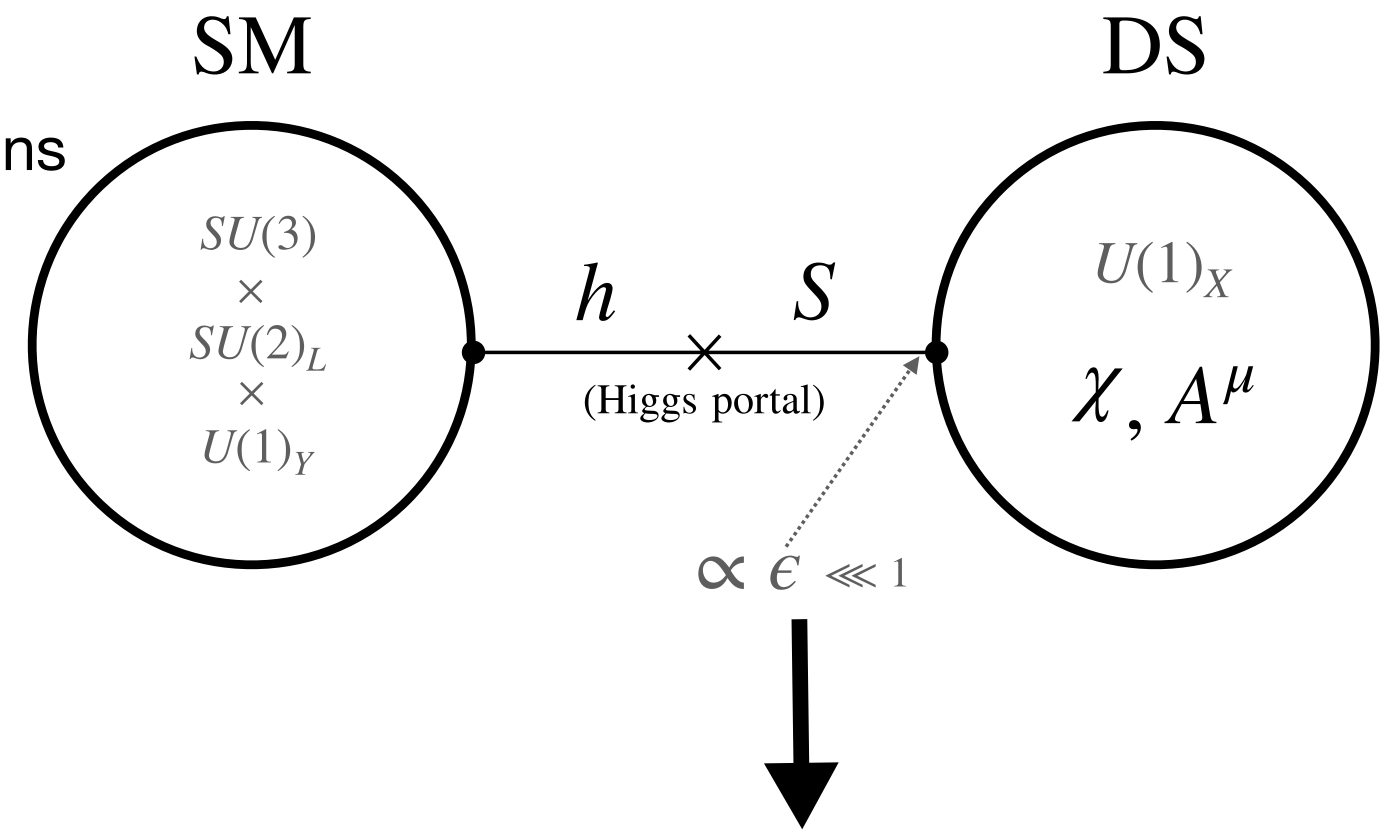
In order not to spoil structure formation: $v_{kick} \approx 1 - \dfrac{2m_\chi}{m_S} \lesssim 10^{-3}$

SIDM from DCDM in Higgs Portal

$L_{int} \supset \lambda_{HS} S^2 H^\dagger H \; + \; \epsilon S \bar{\chi} \chi \; + \; g A^\mu \bar{\chi} \gamma_\mu \chi$

freeze-out — decay — self-interactions

Assume WIMP-like Z_2 symmetry: $S \mapsto -S$, that is broken with breaking parametrized by ϵ.



One can view this model as an extension of the usual Higgs portal to weaker couplings - smaller than in freeze-in.

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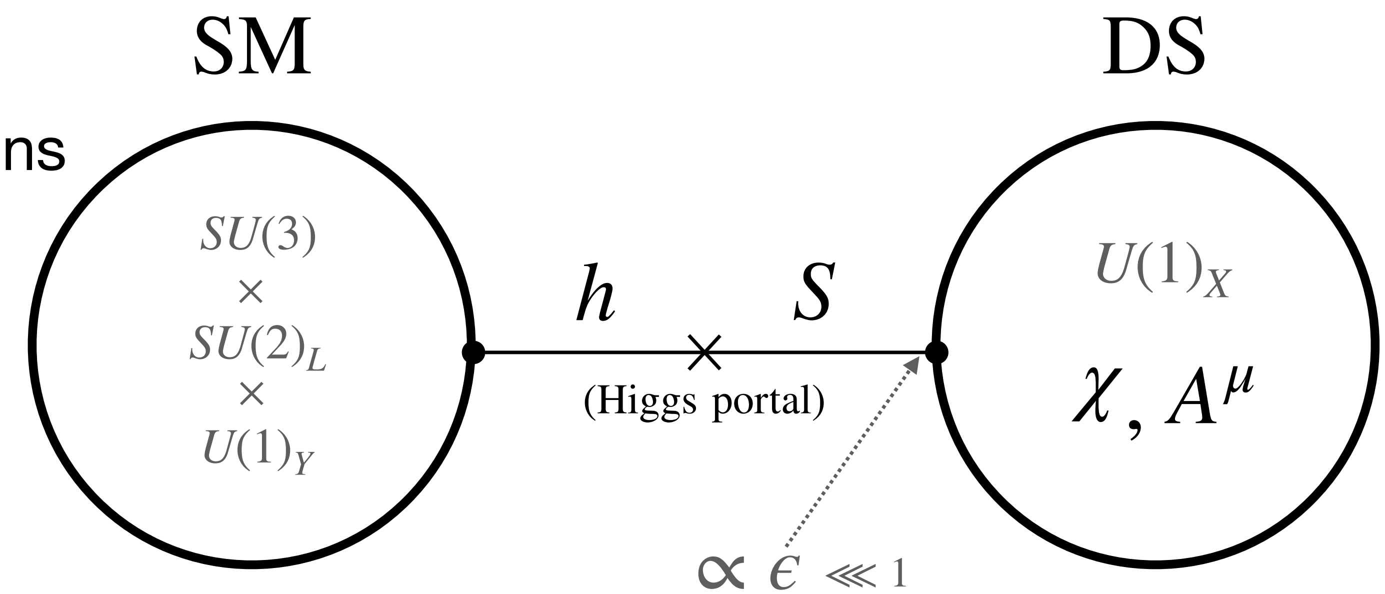
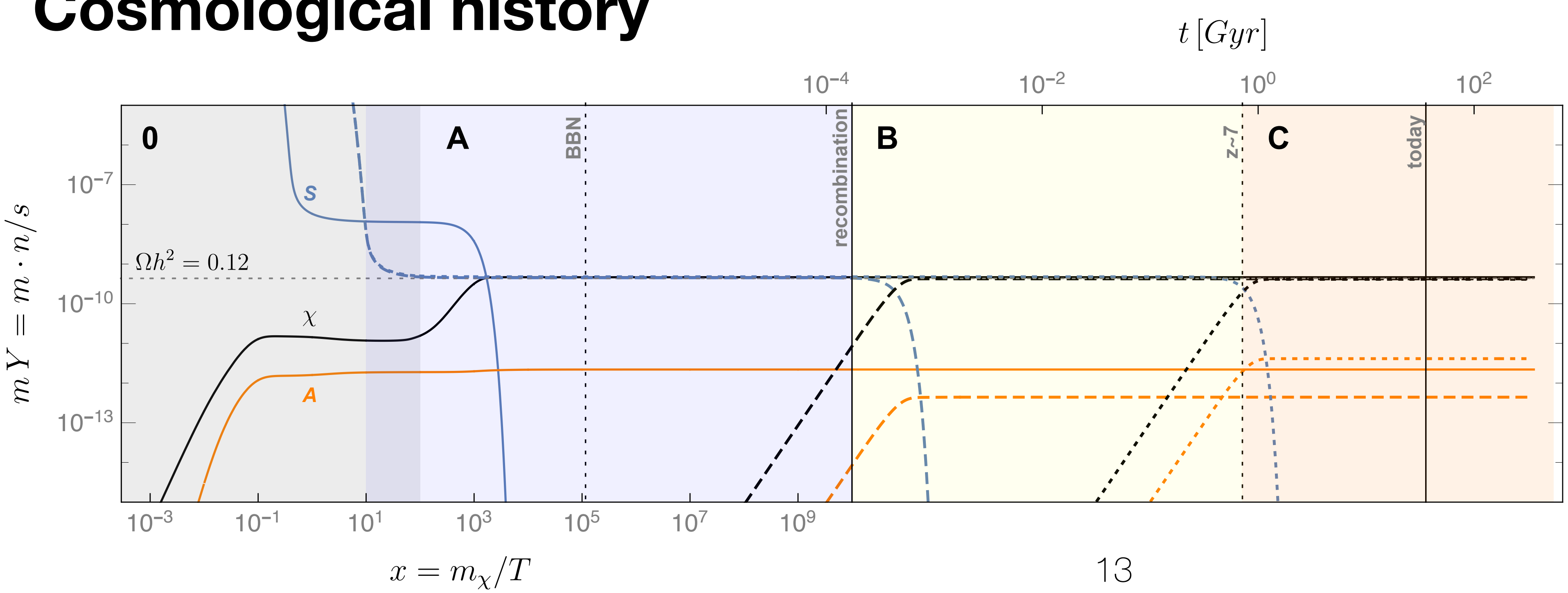


0) weak $\lesssim \epsilon$ — DS thermalizes - standard SIDM

Cosmological history



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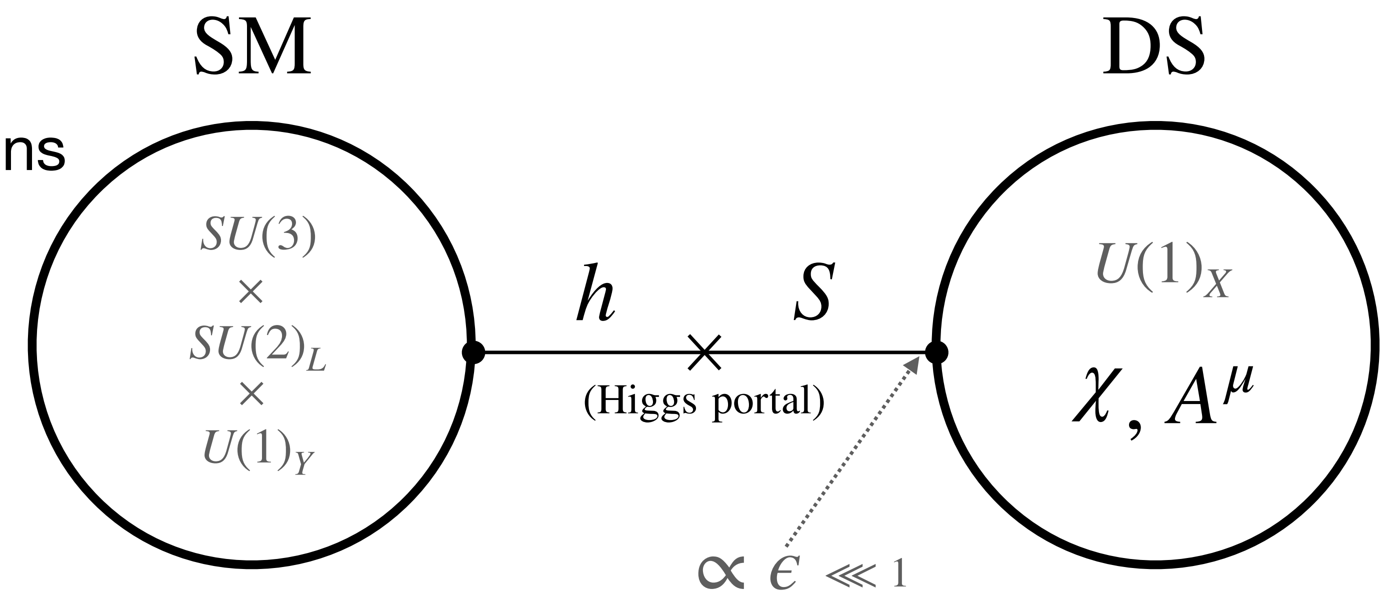

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A) very weak $\lesssim \epsilon \lesssim$ weak — SIDM production with no impact on H_0

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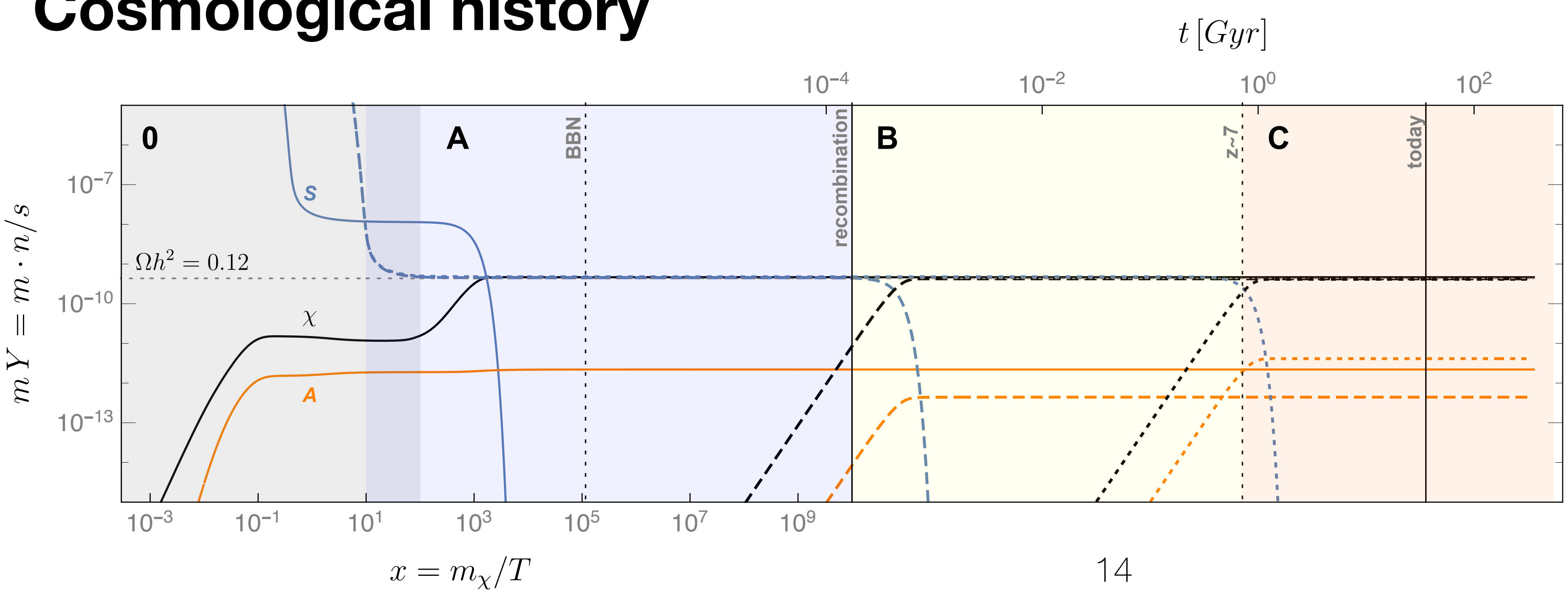

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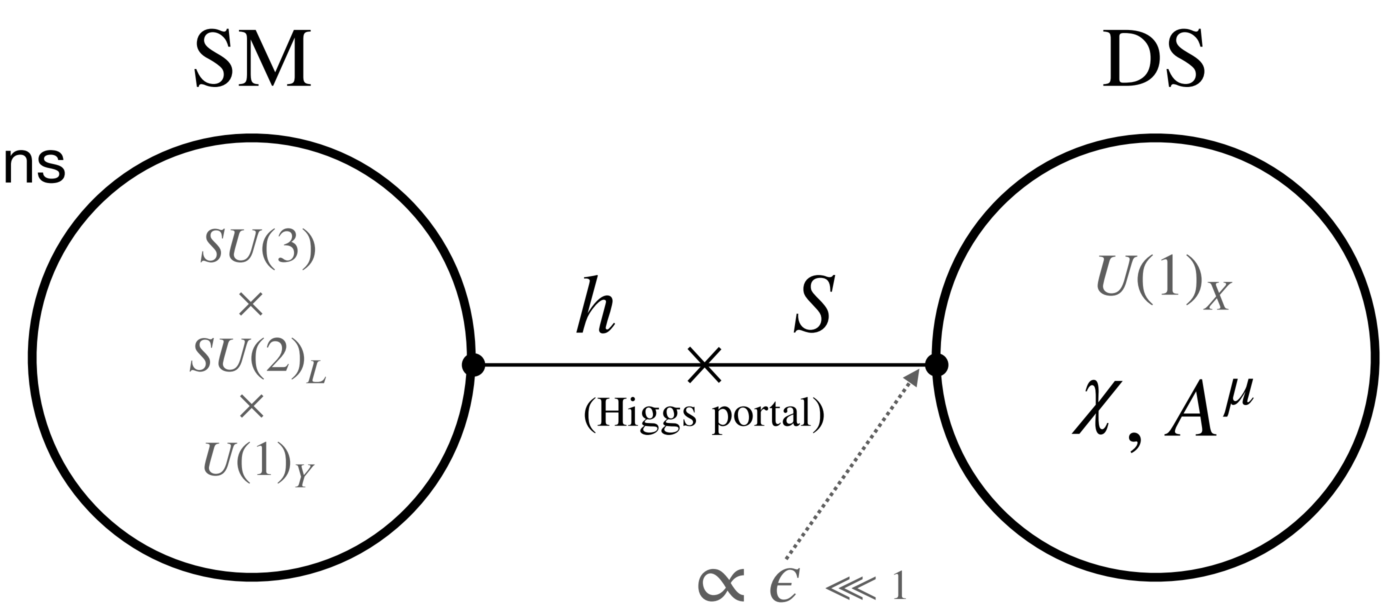

0) weak $\lesssim \epsilon$ DS thermalizes - standard SIDM

A) very weak $\lesssim \epsilon \lesssim$ weak SIDM production with no impact on H_0

B) ultra weak $\lesssim \epsilon \lesssim$ very weak SIDM production with impact on H_0

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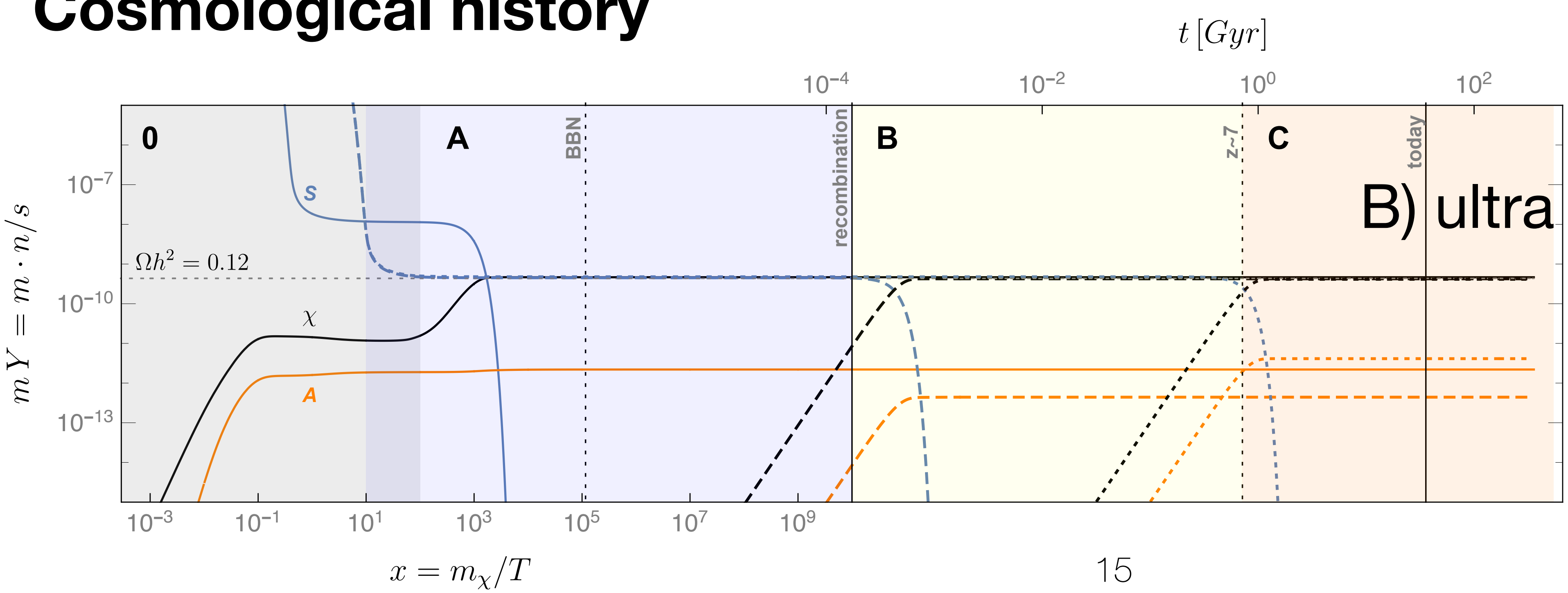

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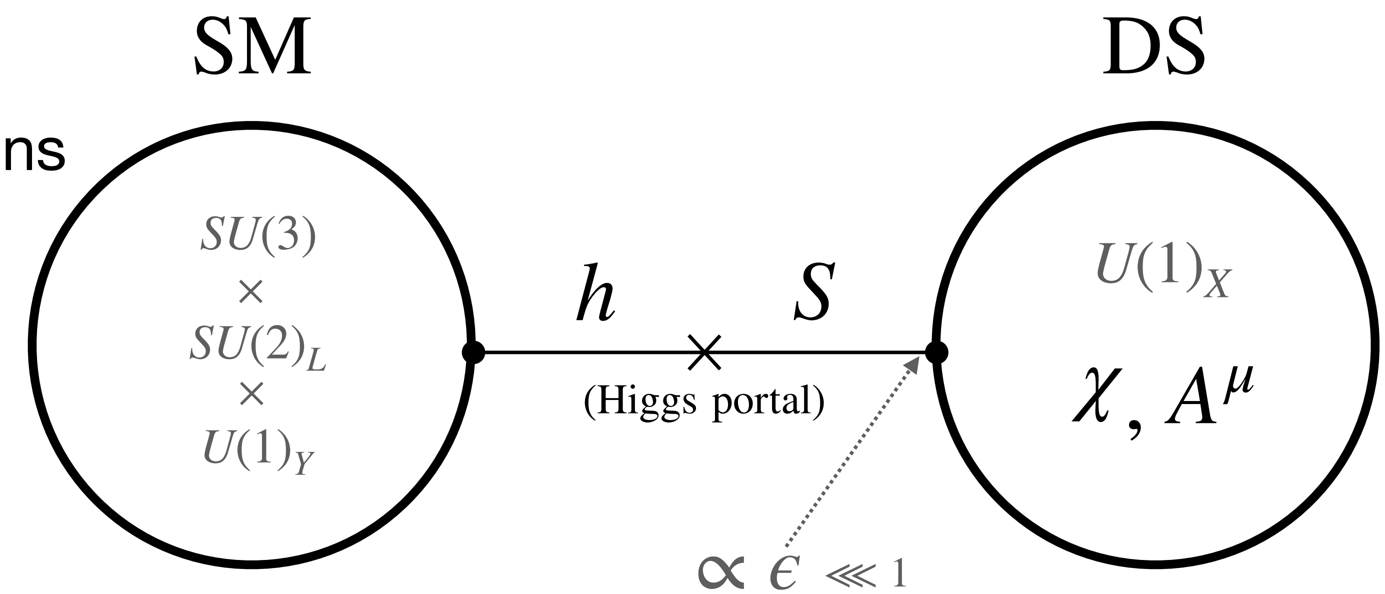
freeze-out | decay | self-interactions



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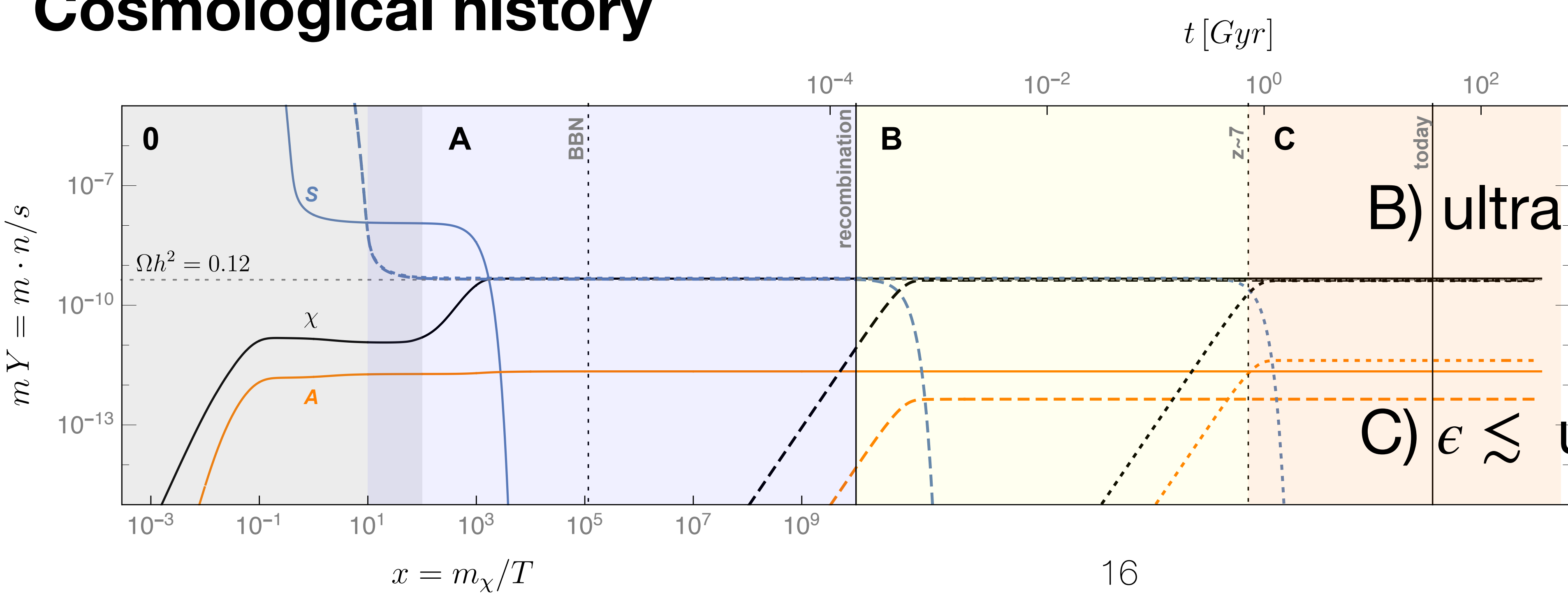
0) weak $\lesssim \epsilon$ — DS thermalizes - standard SIDM

A) very weak $\lesssim \epsilon \lesssim$ weak — SIDM production with no impact on H_0

B) ultra weak $\lesssim \epsilon \lesssim$ very weak — SIDM production with impact on H_0

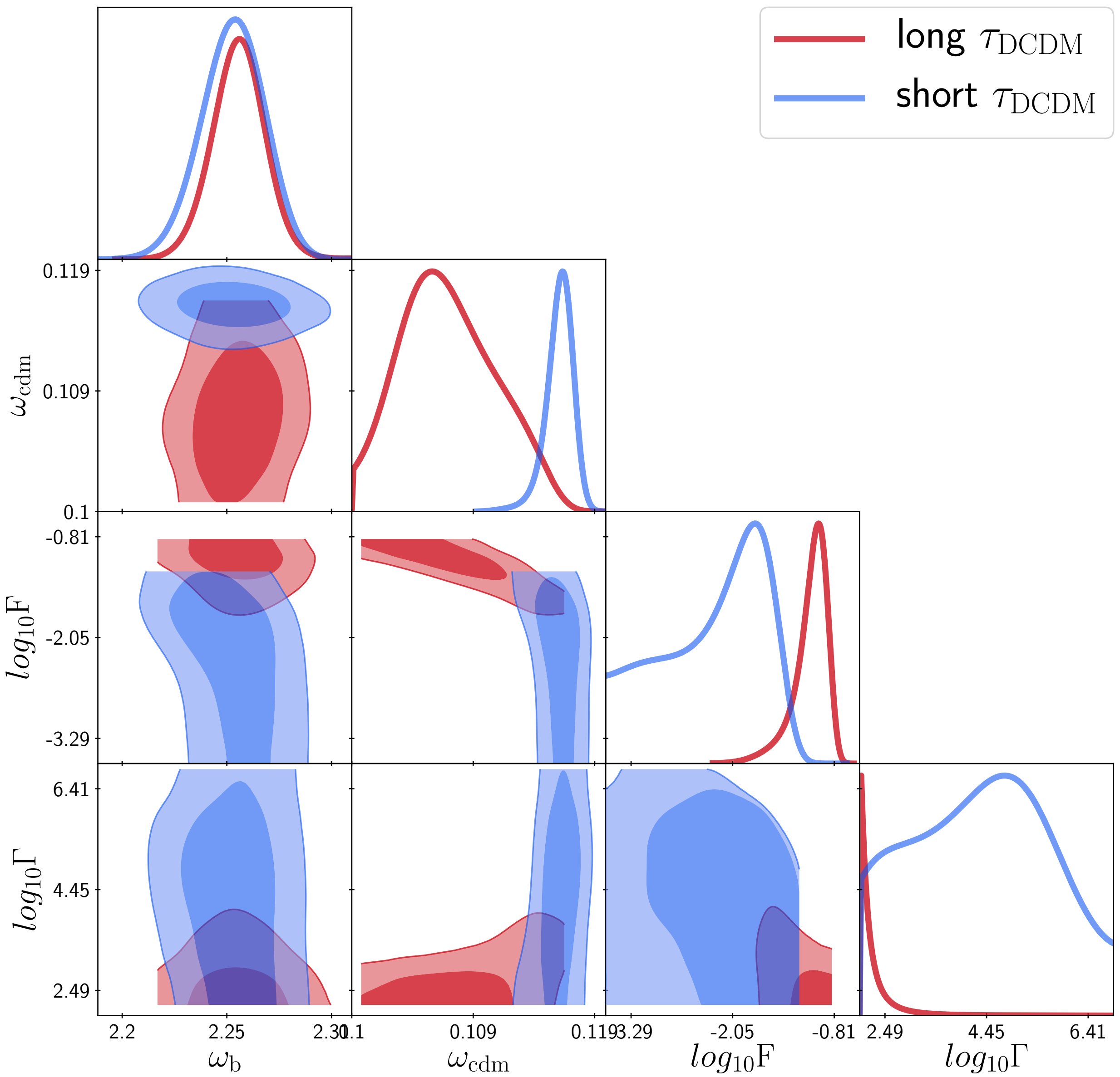
C) $\epsilon \lesssim$ ultra weak — uSIDM production with impact on H_0

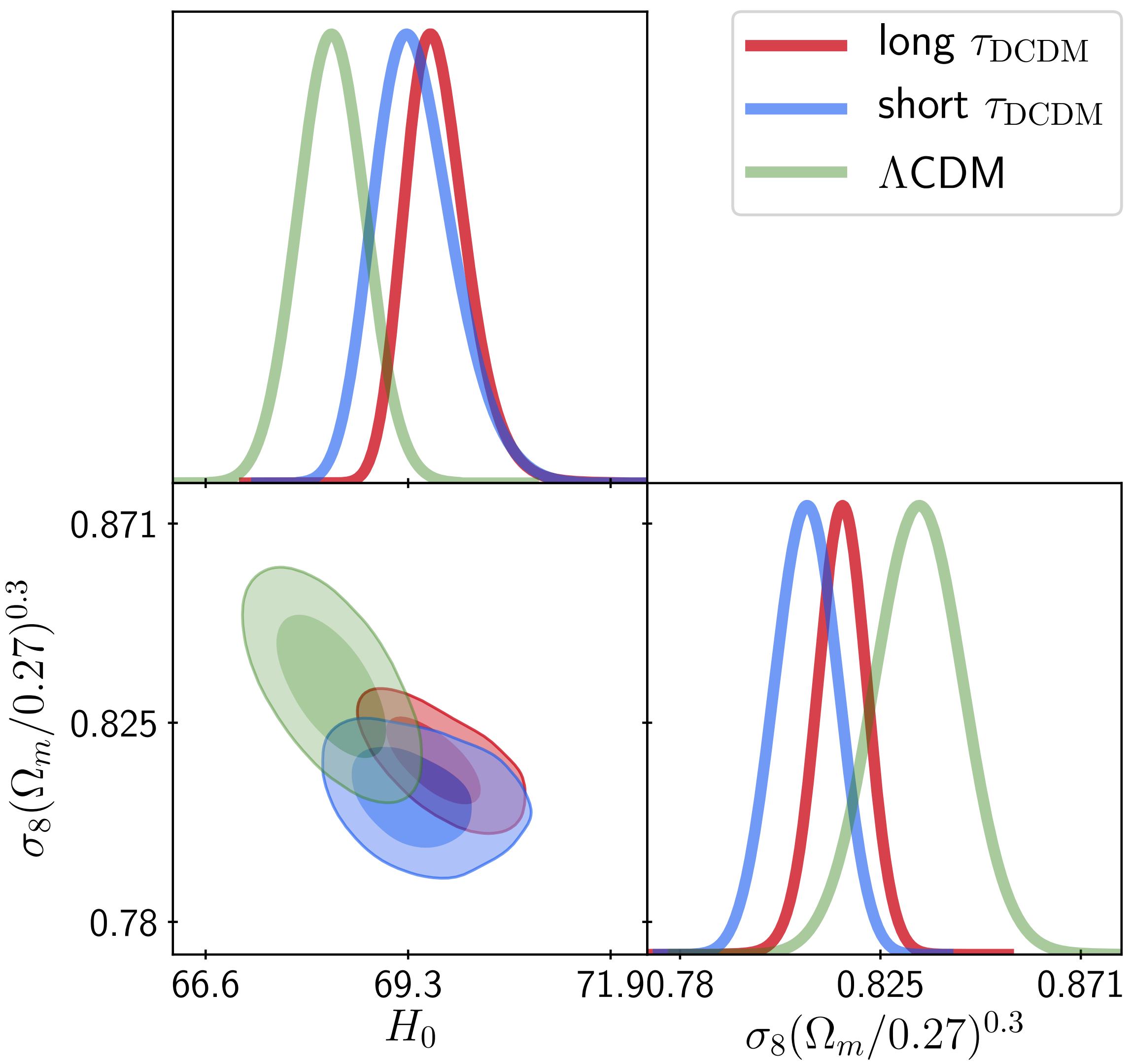
Cosmological history



SIDM from DCDM and Hubble tension

We performed cosmological fit using MontePython in regimes of *long and short* τ_S. We used combined datasets from: i) Planck 2018 CMB, ii) BAO data from BOSS survey, iii) local measurements from Hubble Space Telescope and iv) the galaxy cluster counts from Planck catalogue.





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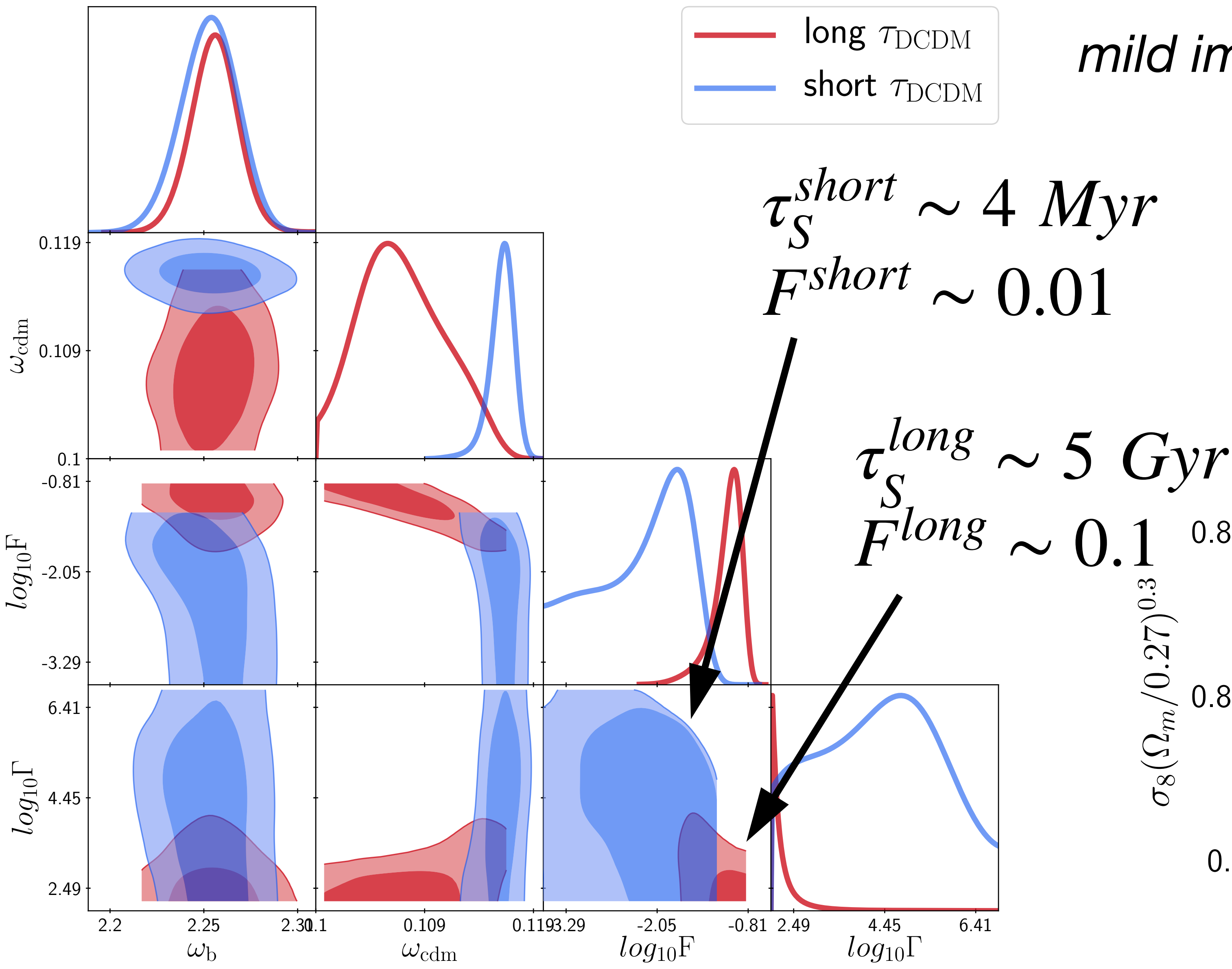
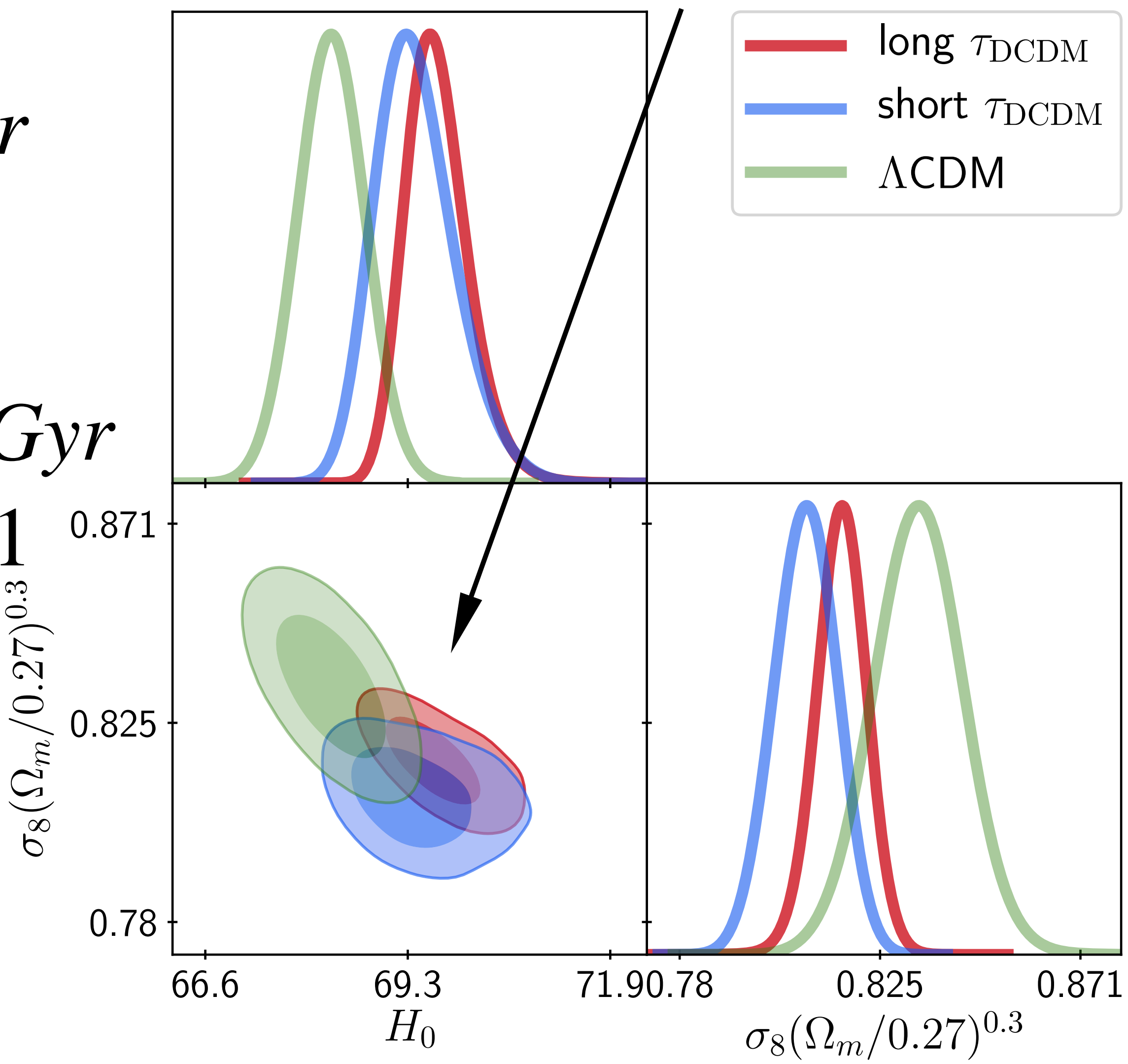


mild improvement over ΛCDM in both regimes



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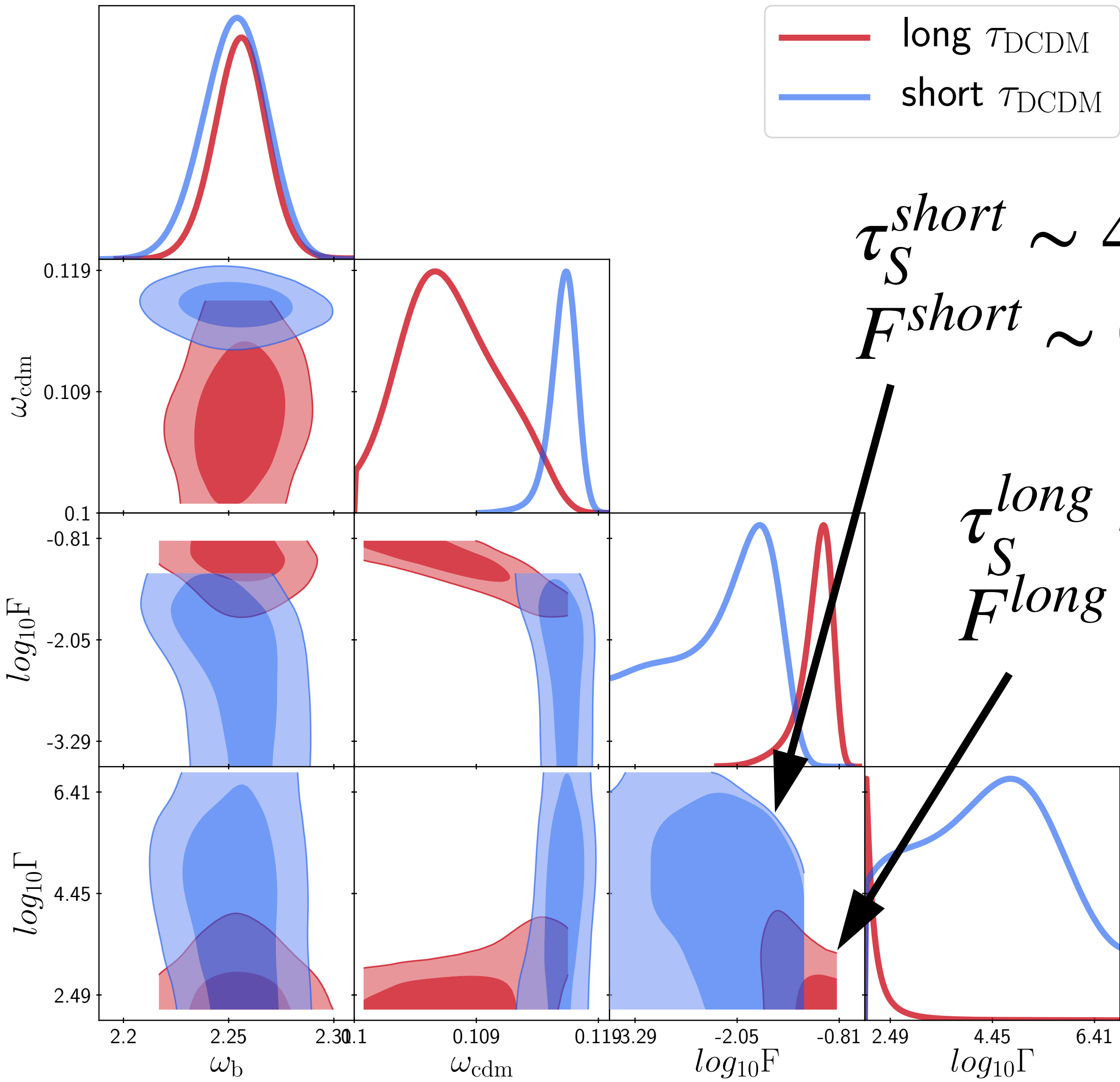
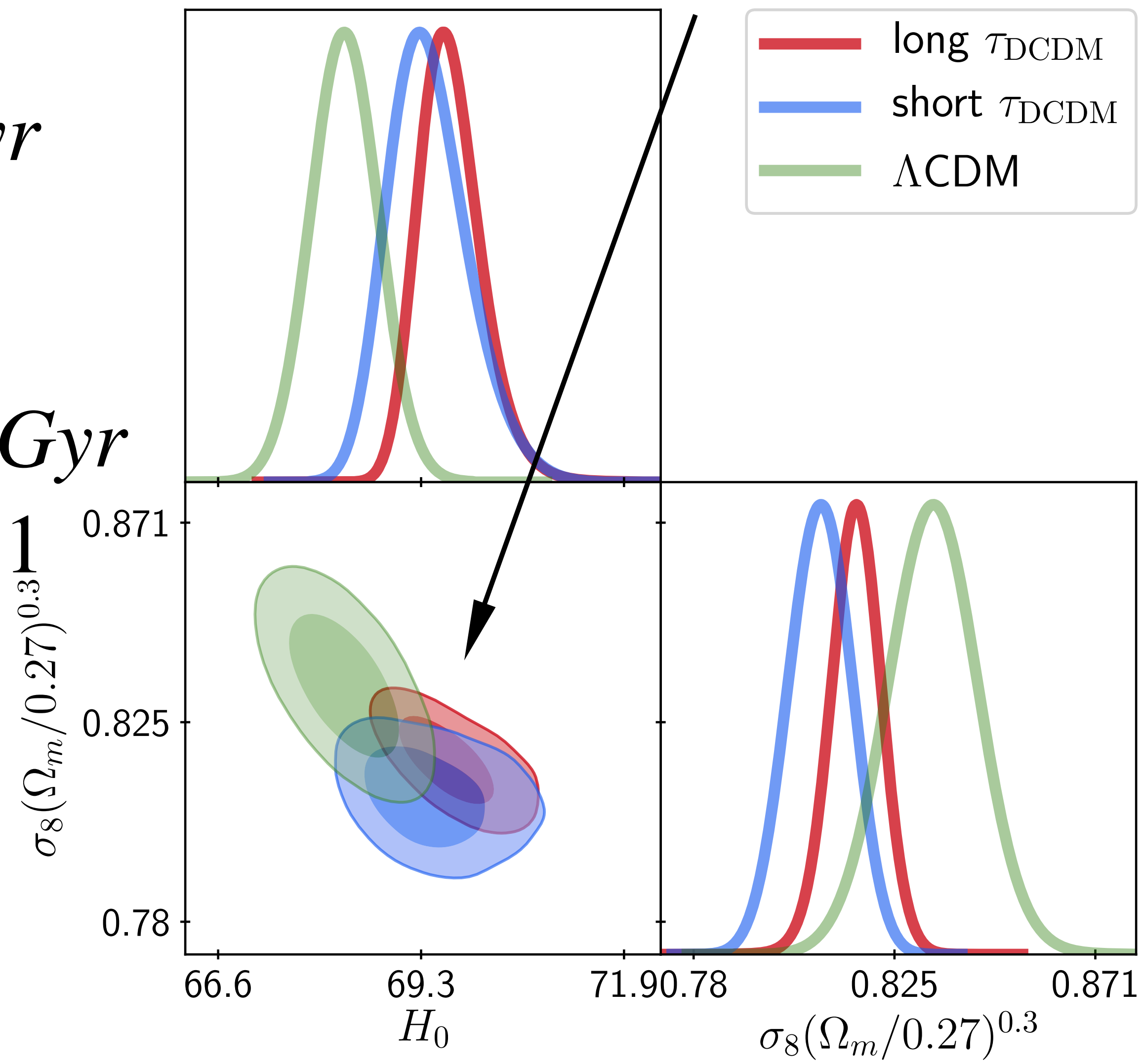


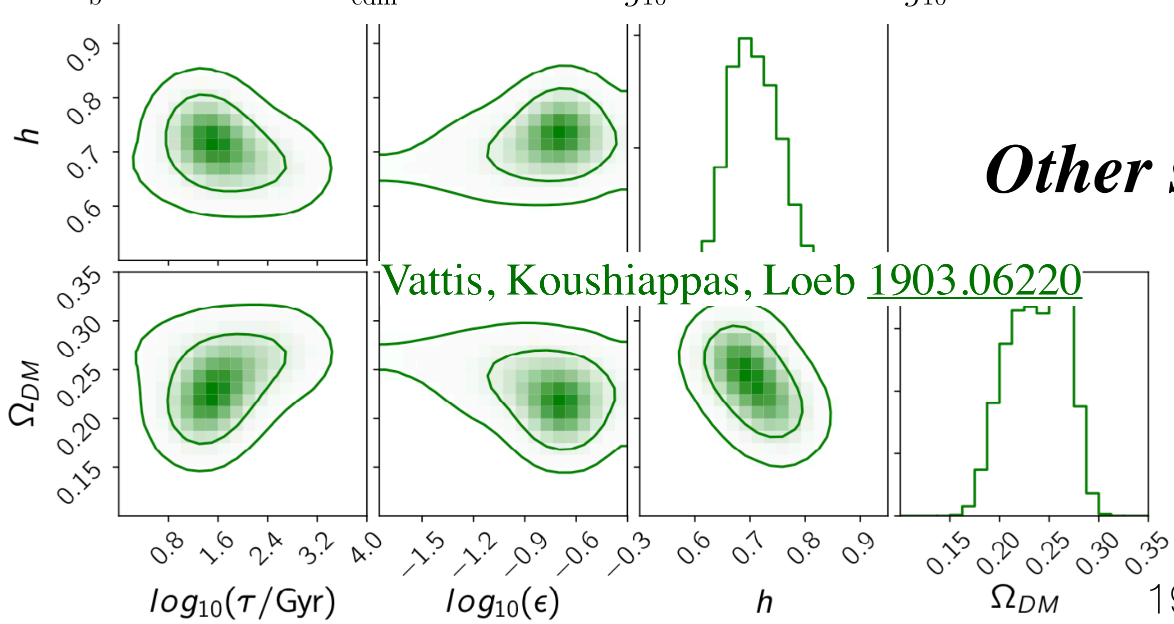
$\tau_S^{short} \sim 4\ Myr$
$F^{short} \sim 0.01$

$\tau_S^{long} \sim 5\ Gyr$
$F^{long} \sim 0.1$

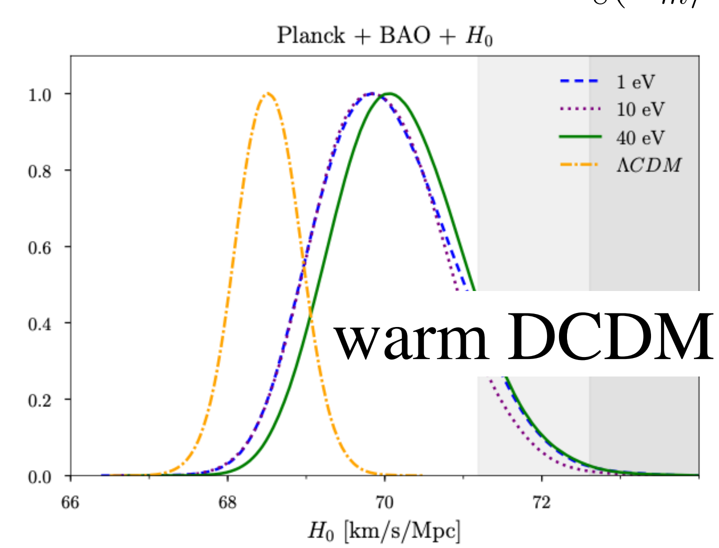
mild improvement over ΛCDM in both regimes



Other studies



Vattis, Koushiappas, Loeb 1903.06220

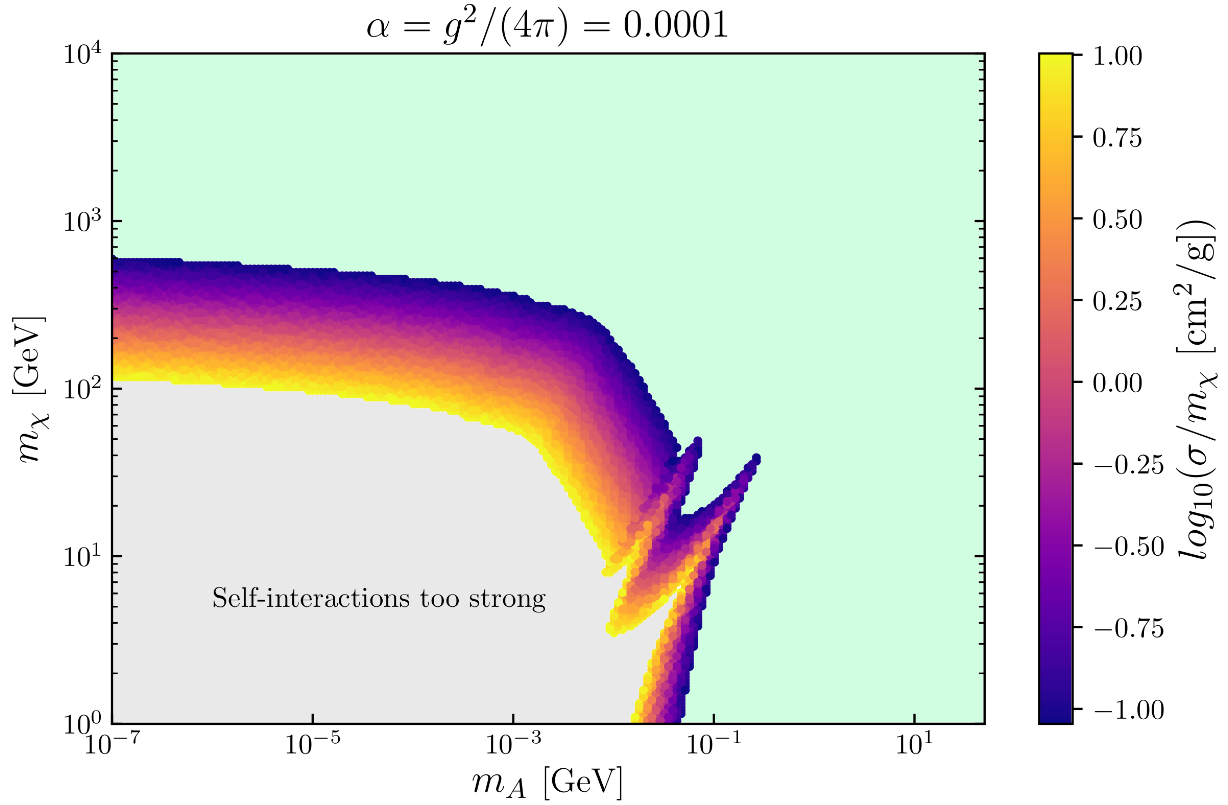


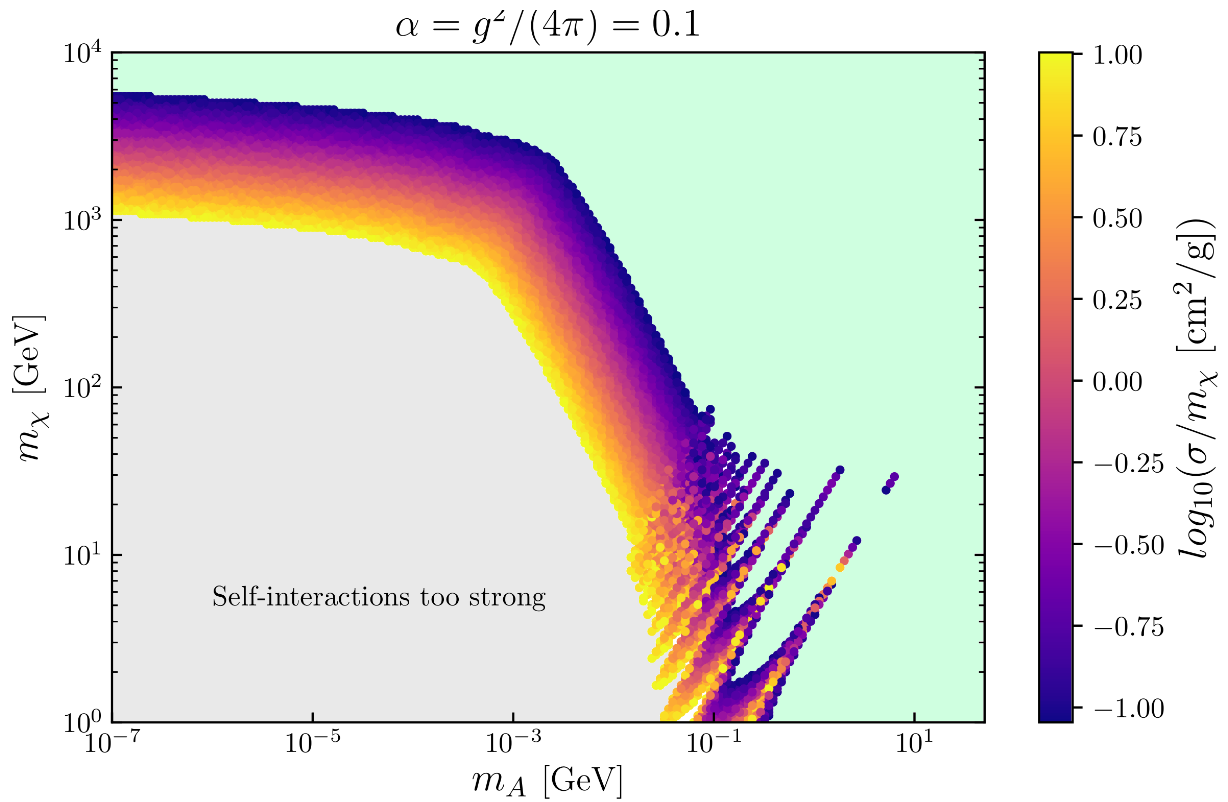
warm DCDM

Blinov, Keith, Hooper 2004.06114

Cosmological impact of SIDM produced from DCDM in different τ_S regimes

Regime A - only SIDM - $\tau_S \lesssim 0.1\ Myr$





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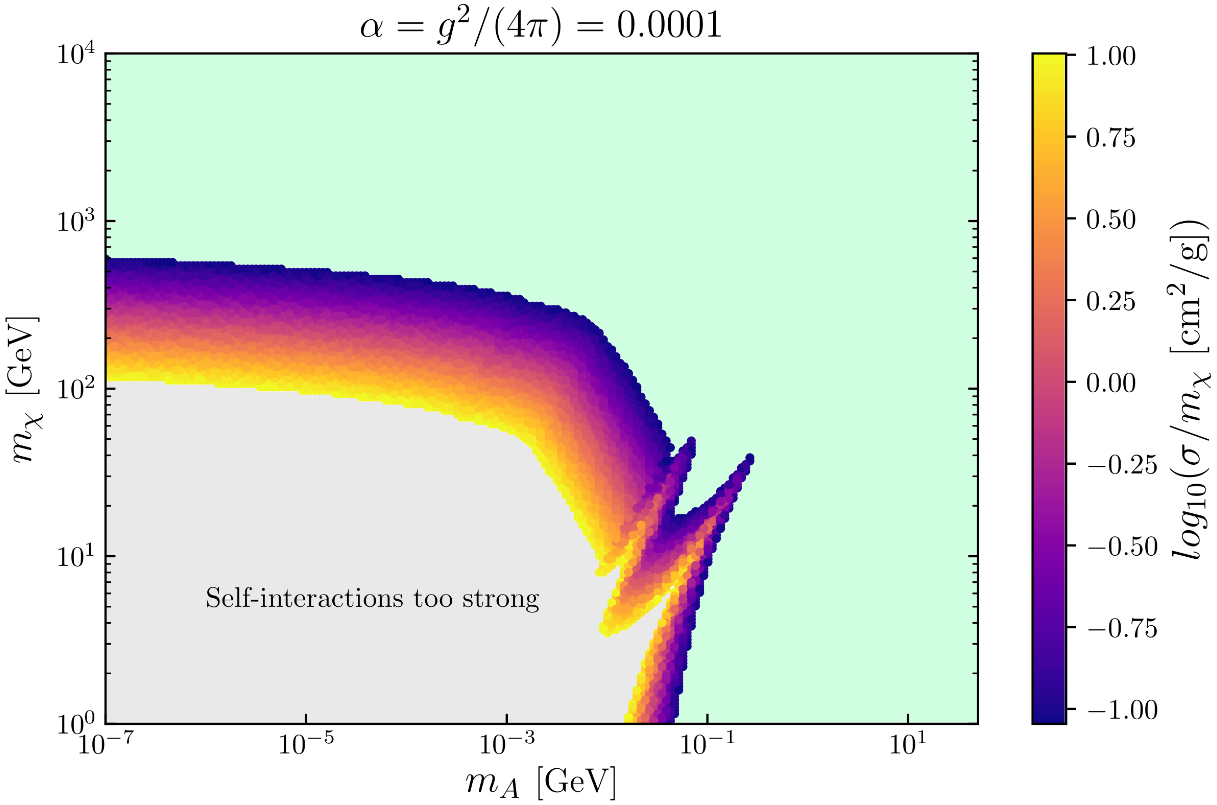
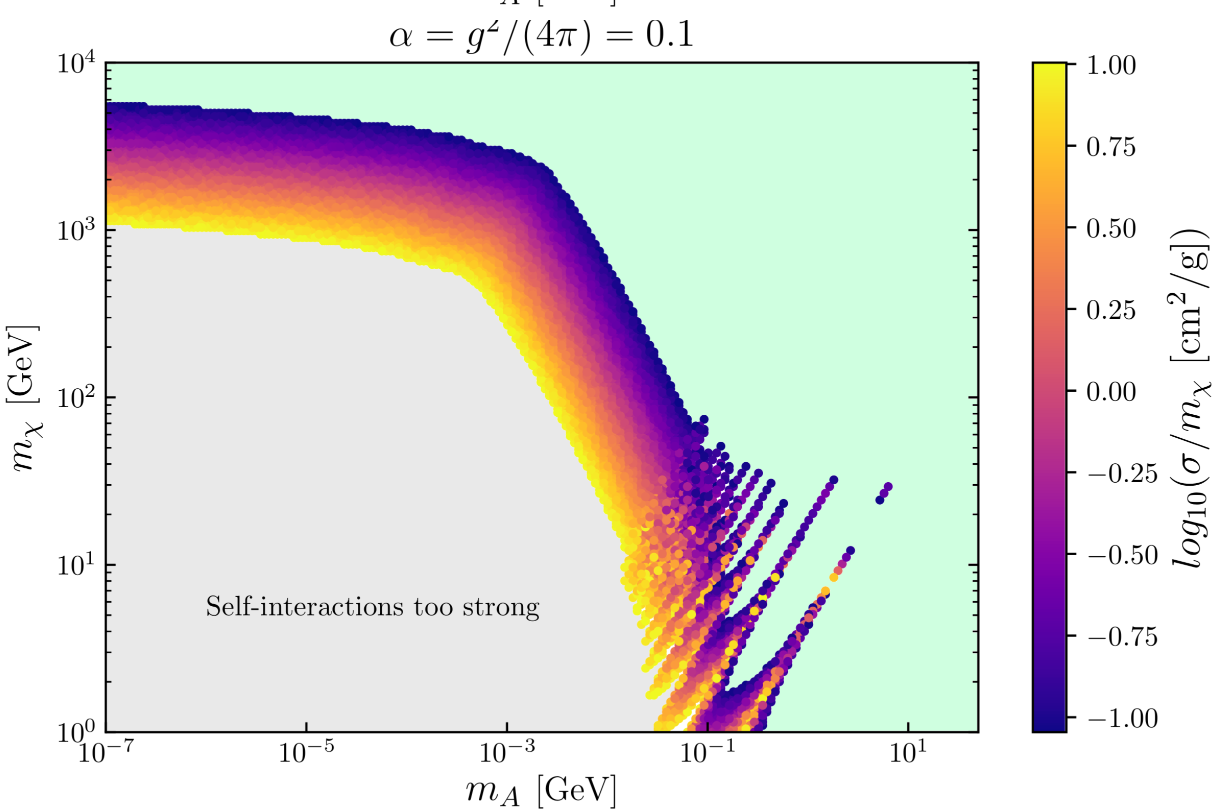
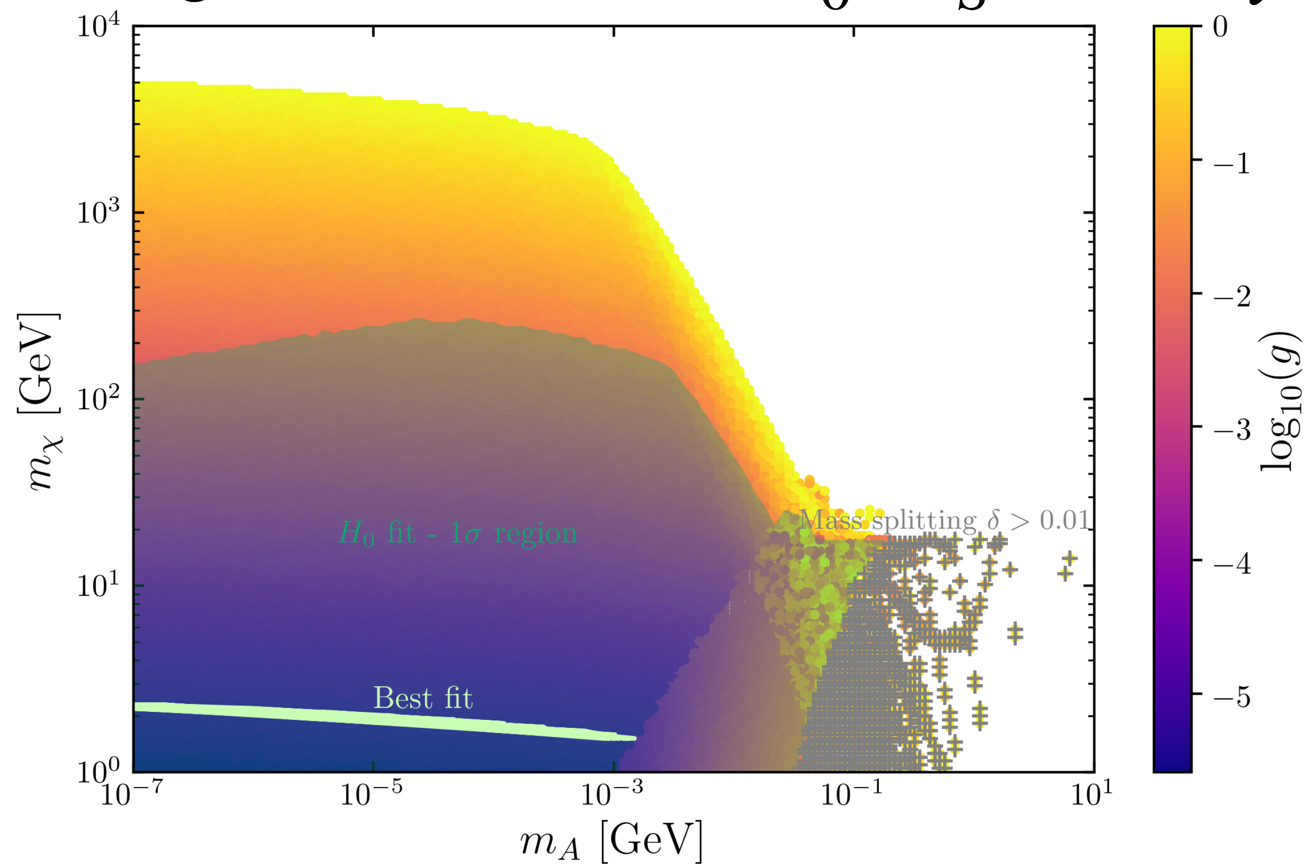




Regime B - SIDM + H_0 *-* $\tau_S \sim 4\ Myr$



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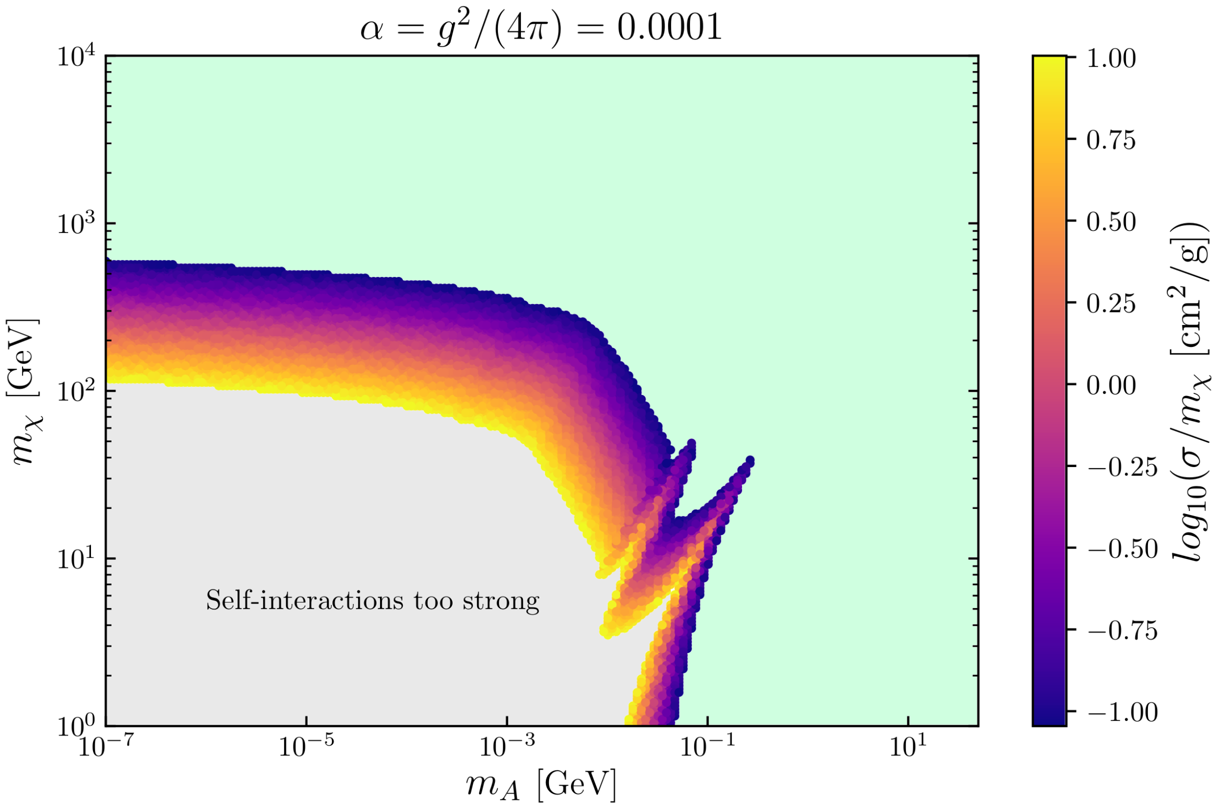

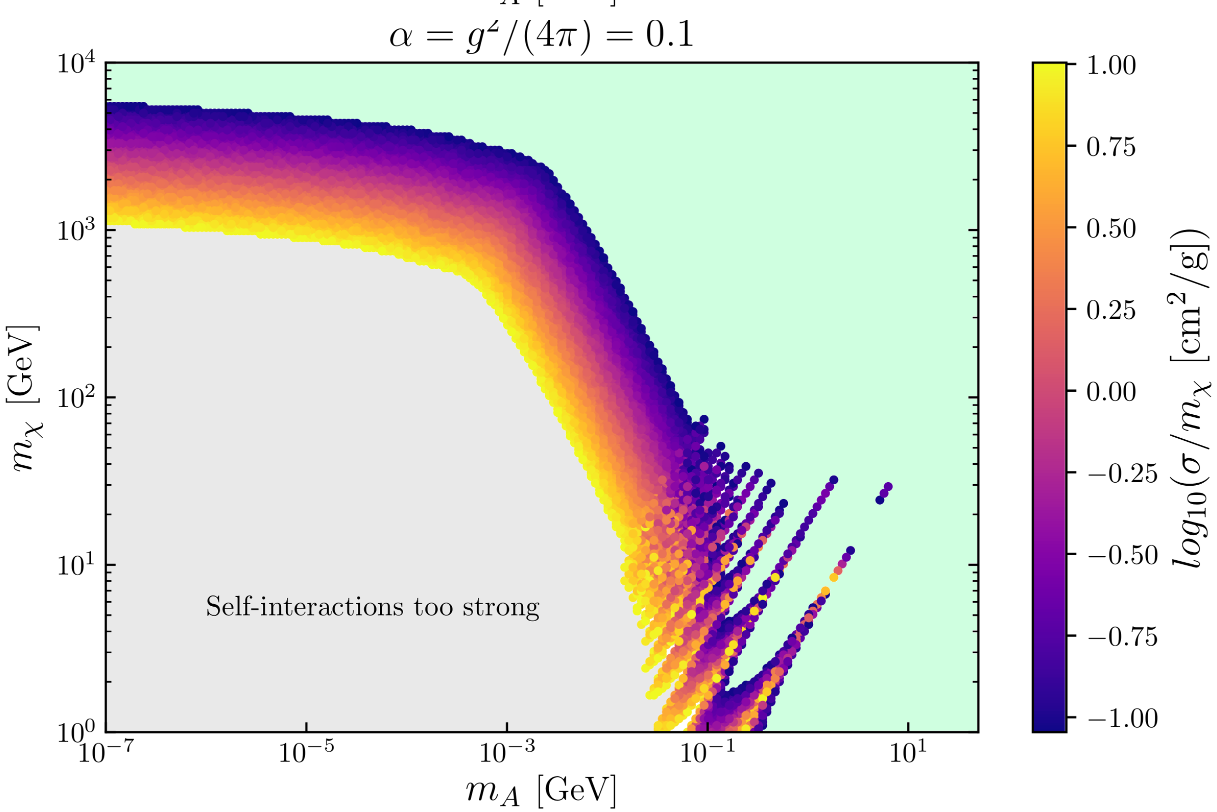

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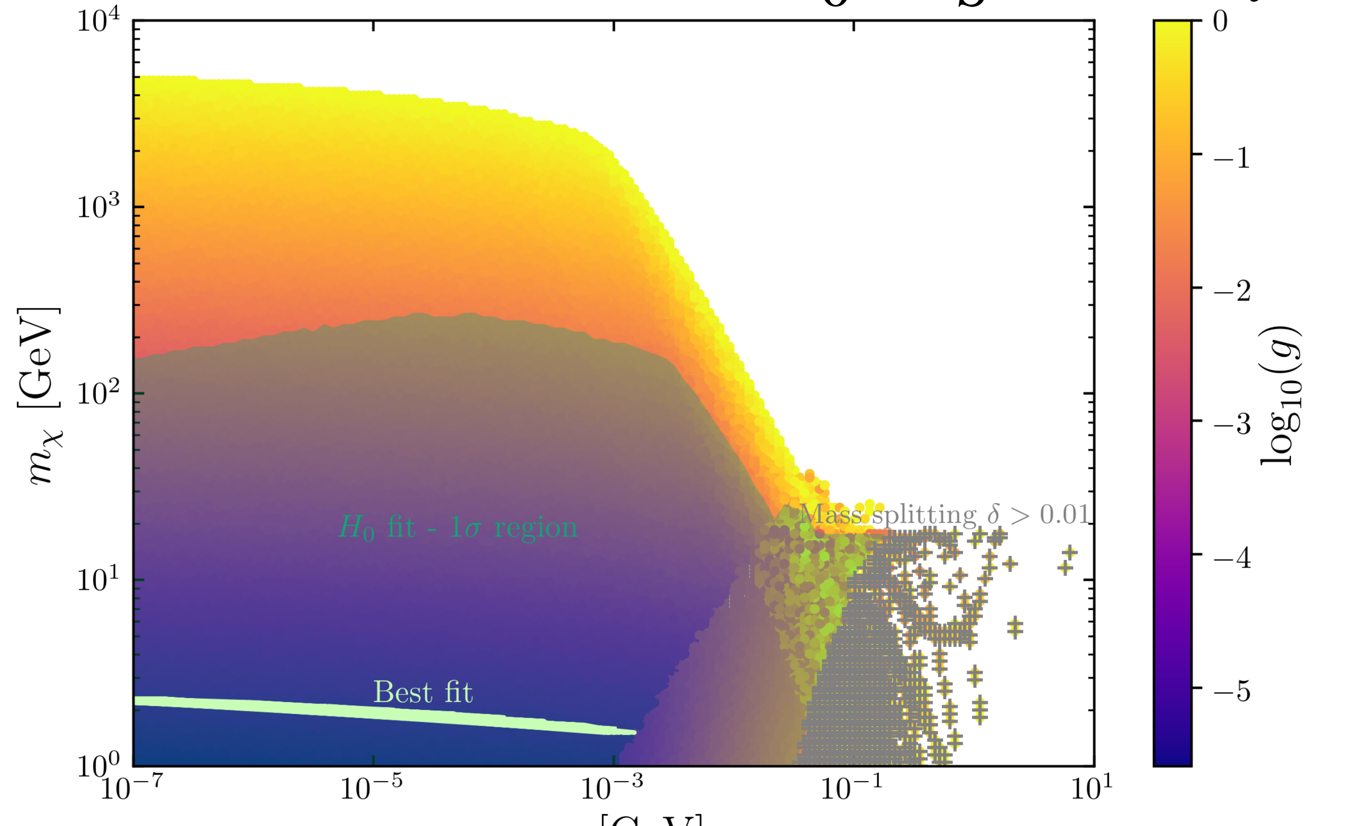
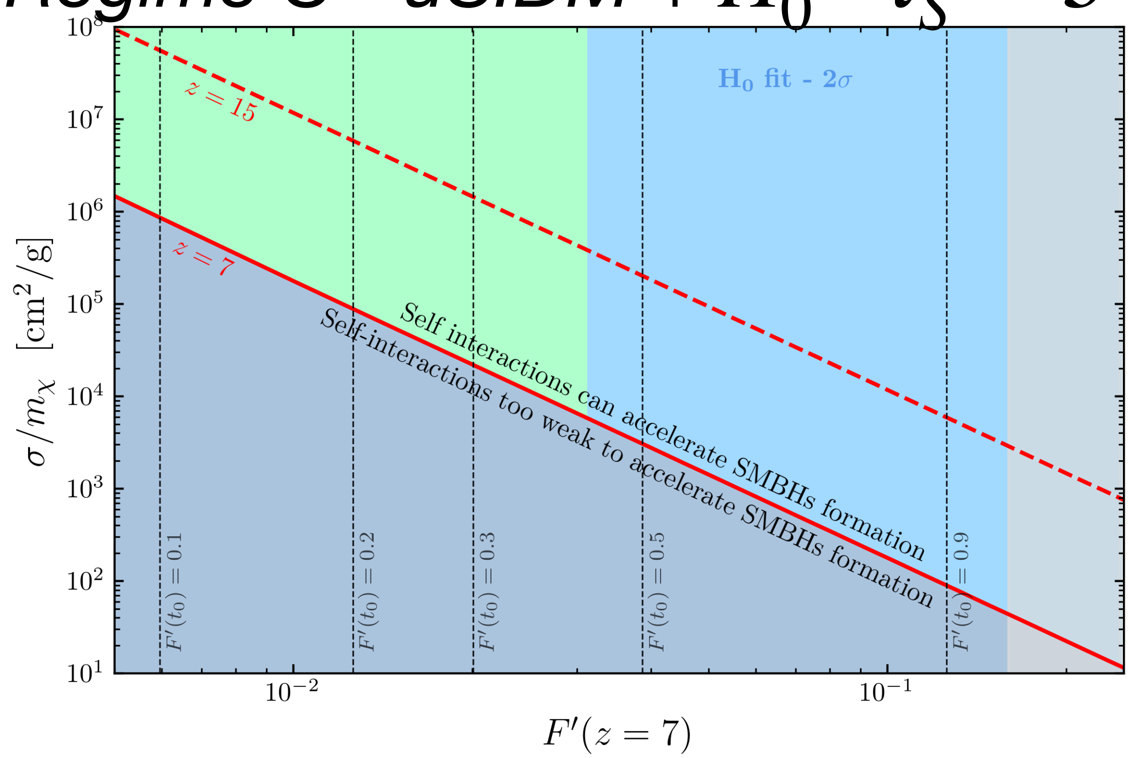


Regime C - uSIDM + H_0 - $\tau_S \sim 5\ Gyr$



Conclusions

- Novel **SIDM production mechanism based on decays of unstable dark sector state** which avoids otherwise stringent constraints.

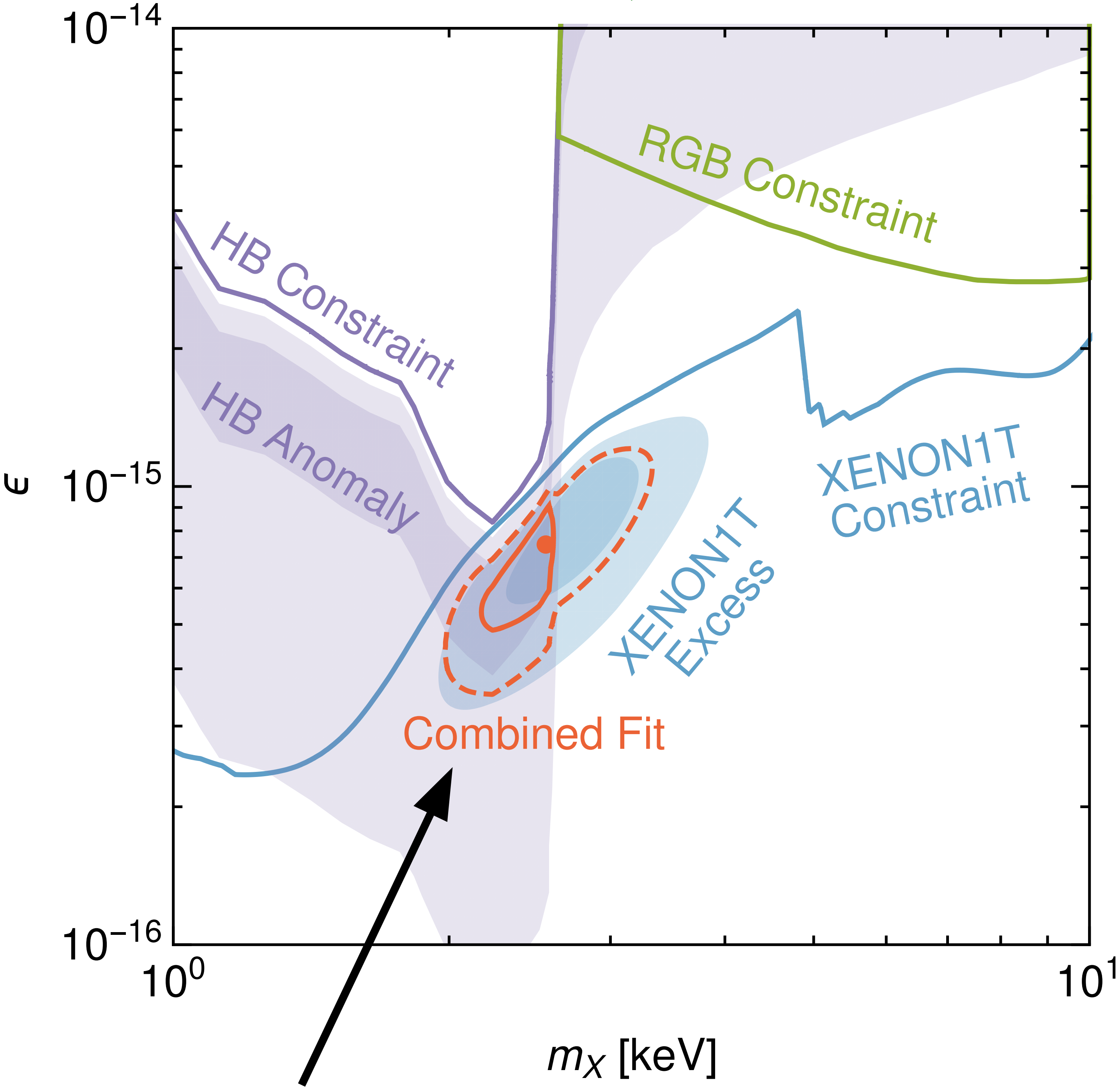
- The mechanism naturally leads to transferring $O(0.05)$ of the dark matter energy density to radiation. *If the decay happens after recombination, it mildly alleviates the H_0 tension*.

- We studied realization of the mechanism within Higgs portal DM model and identified large regions of parameter space that lead to interesting astrophysical and cosmological behaviour.

Backup

XENON1T anomaly

G. Alonso-Ivarez, et al. 2006.11243.



mass range within *best fit* region to self-interaction strength and H_0

We assumed absolutely stable mediator, however *sufficiently long lived mediator will not influence any of the presented results.*

Recent report of unaccounted excess of events in electronic recoils XENON Collaboration 2006.09721 could be due to New Physics, e.g., *absorption of light, very-weakly interacting dark photon* G. Alonso-Ivarez, et al. 2006.11243.

The best fit from this work can easily be included in our model.