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

NATIONAL CENTRE FOR NUCLEAR RESEARCH ŚWIERK

A. Hryczuk, K. Jodłowski

National Centre for Nuclear Research, Poland

We study a dark matter production mechanism based on **decays of a messenger WIMP-like state into a pair of DM particles that are self-interacting** via exchange of a light mediator. Its distinctive thermal history allows the mediator to be stable and therefore avoid strong limits from the cosmic microwave background and indirect detection. A natural by-product of this mechanism is a possibility of a **late time transition to subdominant dark radiation component which can help alleviate the H_0 tension**. We provide a simple realization of the mechanism in a Higgs portal dark matter model. We find a significant region of the parameter space that leads to a mild relaxation of the Hubble tension while simultaneously having the potential of addressing **small-scale structure problems of ΛCDM**. In addition, the light mediator lying in cosmologically preferred region we considered was recently shown to provide one of most promising explanations of XENON1T electronic recoils excess.

Shortcomings of ΛCDM model

- **small-scale problems**
  - too big to fail
  - missing satellites
  - core-cusp, ...
- **early-late Universe tensions**
  - H_0, σ_8 tension
  - T_0 tension (?), ...

$\Longrightarrow$ Introduce self-interacting DM (χ) produced by WIMP (ϕ) decays taking place after recombination.

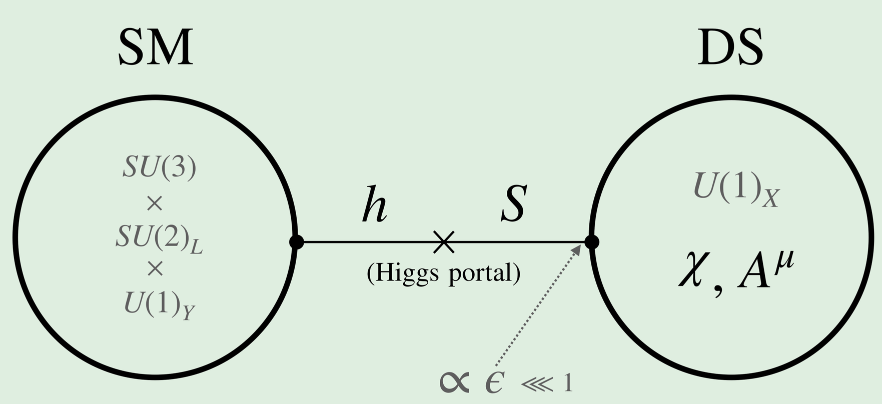
Model

- Consider a dark sector comprised of a Dirac fermion χ charged under new gauged $U(1)_X$ broken spontaneously at some higher scale resulting in massive vector A^μ.
- The dark sector part of the Lagrangian after the $U(1)_X$ breaking reads:

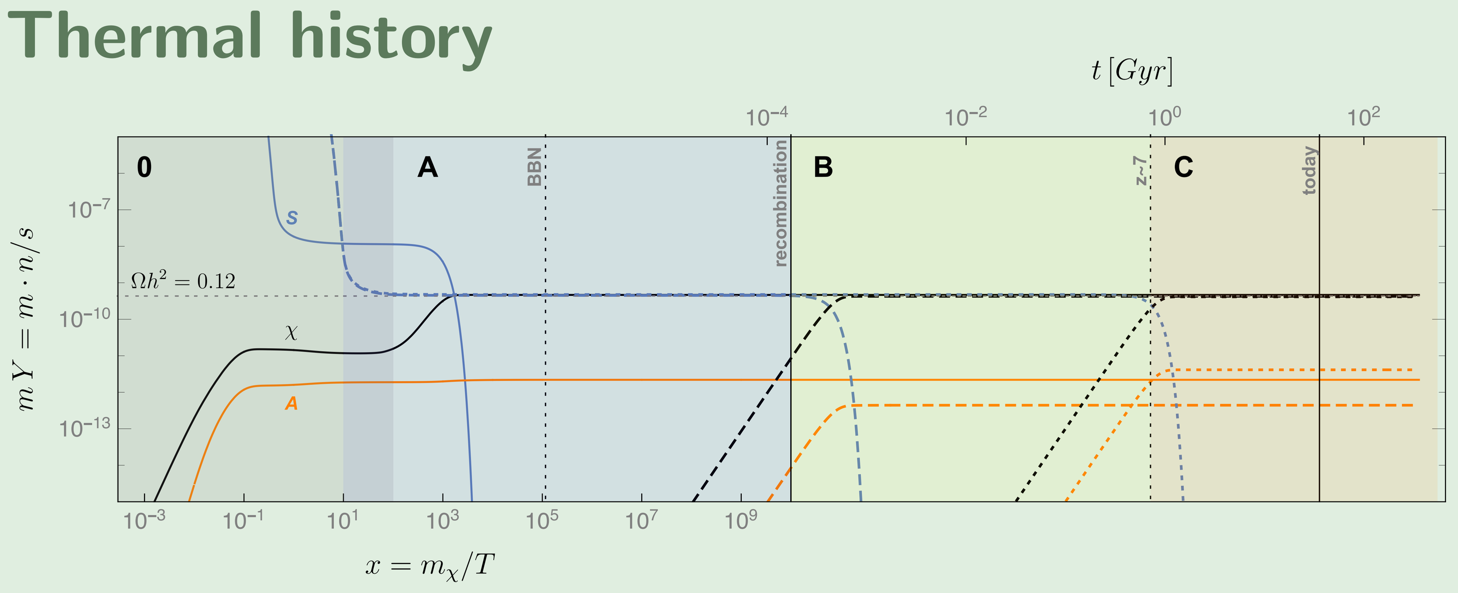
$$\mathcal{L}^{\rm DS} = \bar{\chi}(i\gamma_\mu\partial^\mu - m_\chi)\chi + \frac{1}{2}m_A^2 A_\mu A^\mu + ig A^\mu \bar{\chi}\gamma_\mu\chi + \epsilon\, S\bar{\chi}\chi .$$

- Connection with the visible sector is given by the portal:

$$\mathcal{L}^{\rm portal} = \frac{1}{2}(\partial^\mu S)(\partial_\mu S) + \frac{\mu_S^2}{2}S^2 + \frac{\lambda_3}{3!}S^3 + \frac{\lambda_4}{4!}S^4 + \epsilon\,\mu_{HS} S\, H^\dagger H + \lambda_{HS}\, S^2 H^\dagger H\,.$$



Thermal history



- The illustration of the thermal history of S (blue), χ (black) and A^μ (orange) with example parameter choices leading to early (regime A, solid lines), late (regime B, dashed) and very late (regime C, dotted) decays of S.
- Parametrizing the symmetry breaking by a small parameter ϵ, one can distinguish four regimes:

0) weak $\lesssim \epsilon$: *usual thermal self-interacting model subject to strong limits*

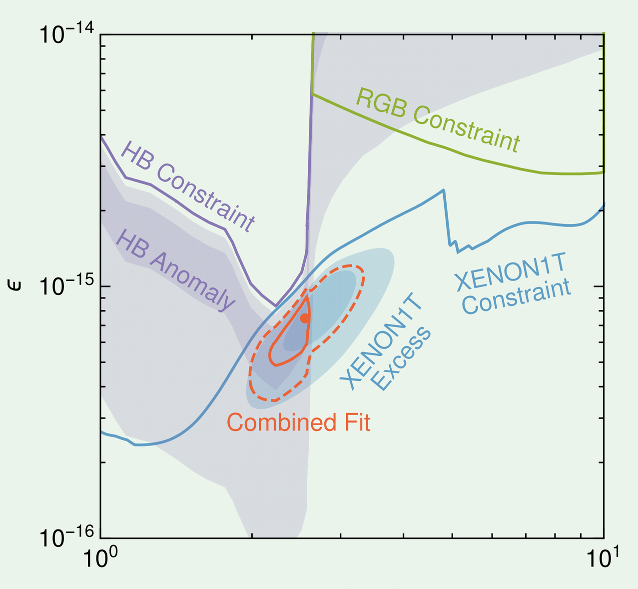
A) very weak $\lesssim \epsilon \lesssim$ weak: *viable regime for self-interacting DM*

B) ultra weak $\lesssim \epsilon \lesssim$ very weak: *regime for self-interacting DM with an impact on the H_0 tension*

C) $\epsilon \lesssim$ ultra weak: *regime potentially addressing the H_0 tension and providing an uSIDM candidate.*

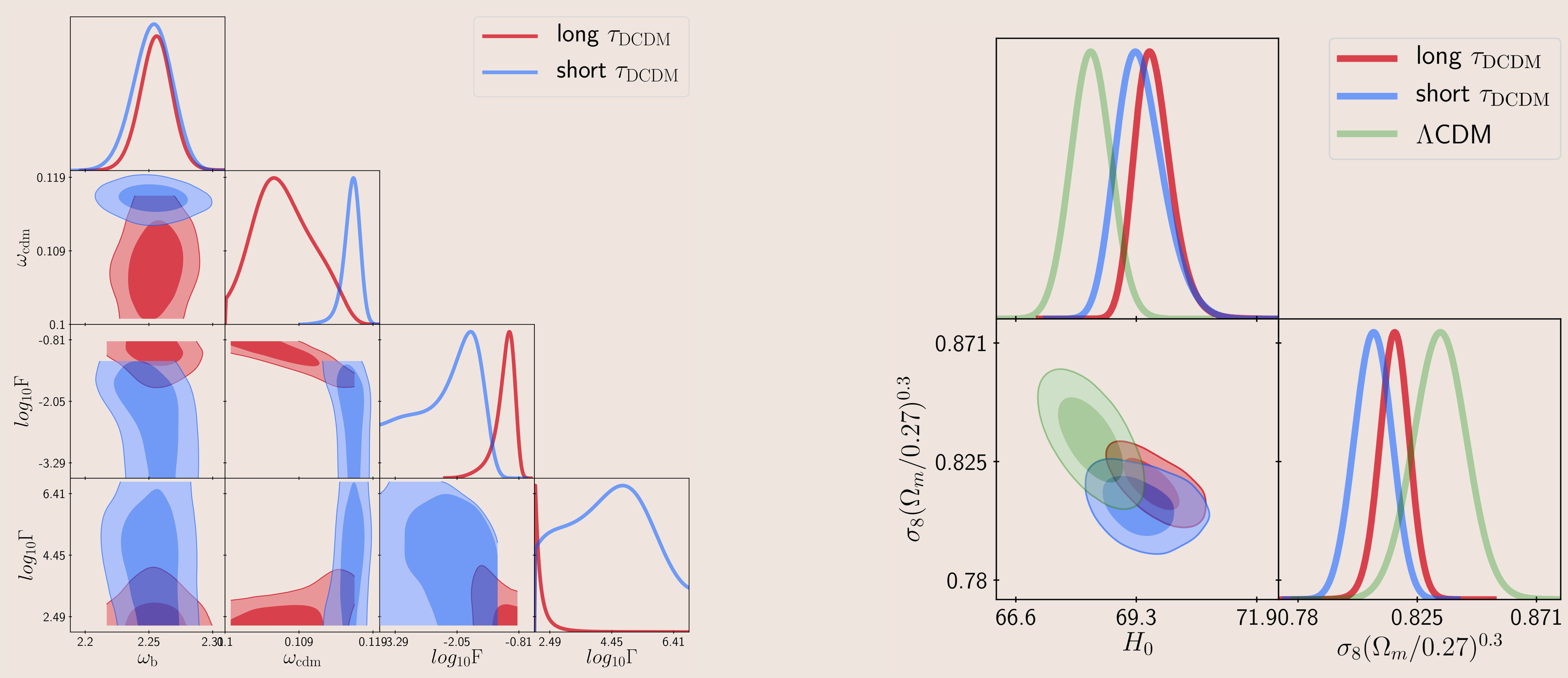
XENON1T electronic recoils excess

- As shown by G. Alonso-Alvarez, F. Ertas, J. Jaeckel, F. Kahlhoefer, L. Thormaehlen, hep-ph/2006.11243, anomalous signal recently detected by XENON1T, hep-ph/2006.09721, could be due to New Physics.
- Light, very weakly interacting dark photon seems well suited to simultaneously explain the excess as well as provide extra cooling of stars, as favored by observations of horizontal branch stars.
- This scenario can be easily accommodated for in our model.



Cosmological scan

- We used public MCMC code `MontePython` with combined datasets from Planck, BAO data from the BOSS survey, the galaxy cluster counts from Planck catalogue and local measurement of the Hubble constant to constrain decaying DM model and compare with standard ΛCDM cosmology.

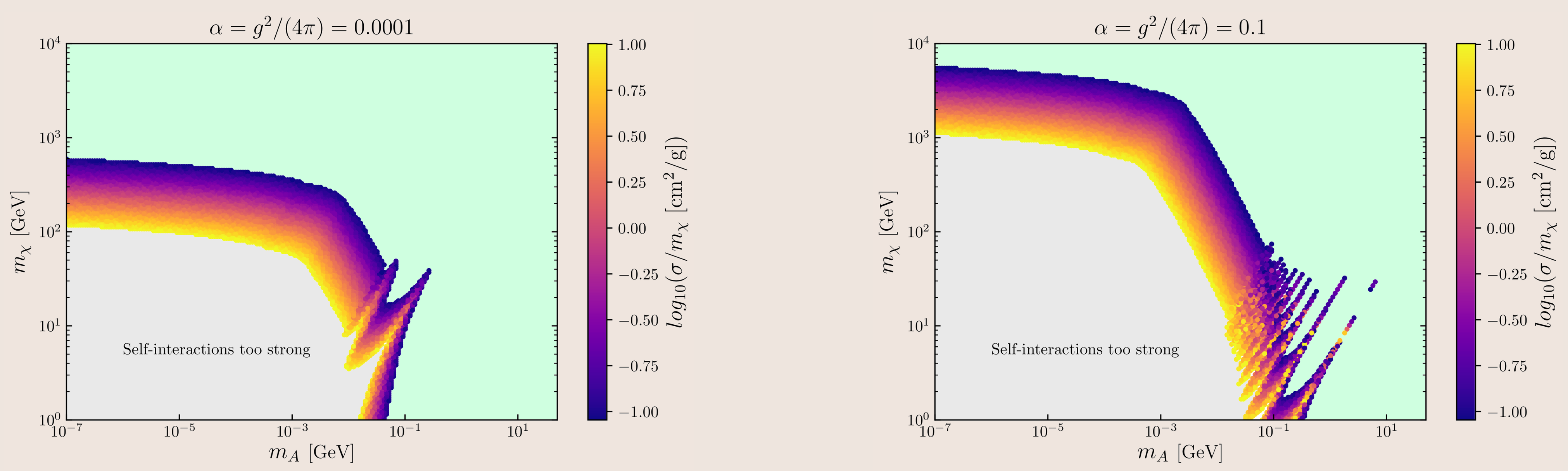


(a) (b)

- We found two preferred lifetime regimes:
  - **short** (regime B): $\tau \sim 4$ Myr while fraction of dark radiation is strongly constrained to by below $\sim 1\%$
  - **long** (regime C): $\tau \sim 5$ Gyr while fraction of dark radiation is allowed to be as big as $\sim 10\%$.

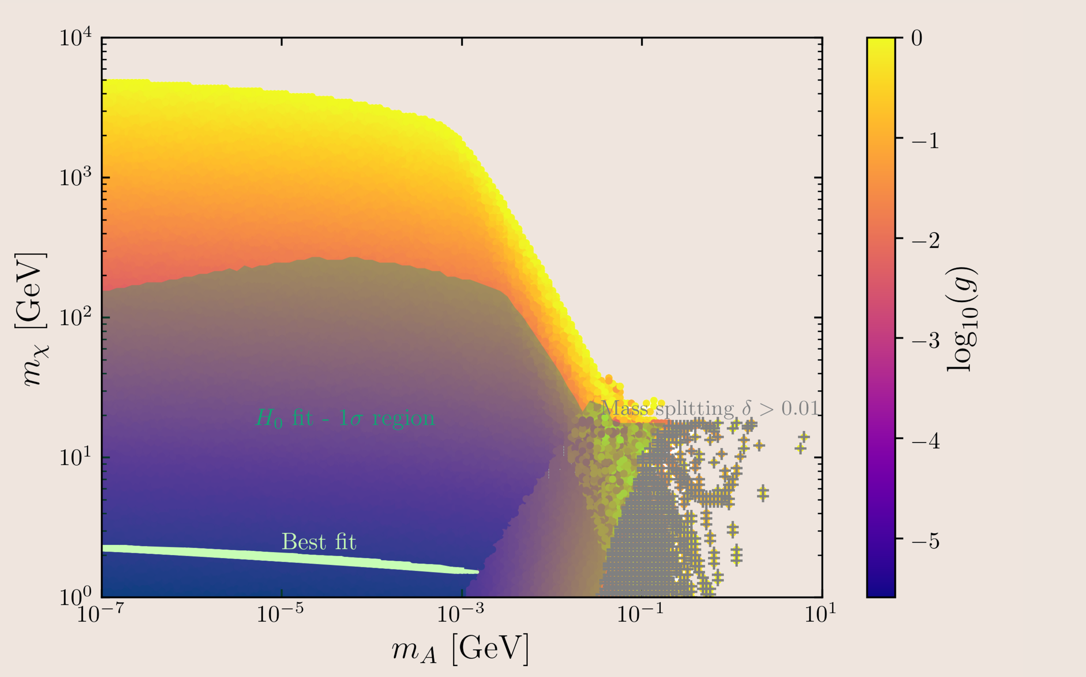
SIDM regime - early decays

- **Regime A**: SIDM solution of the small scale problems require σ/m_χ in the range 0.1–10 cm^2/g. Preferred region in the m_A–m_χ plane for two representative values of coupling constant $\alpha = 0.0001$ (left) and $\alpha = 0.1$ (right).



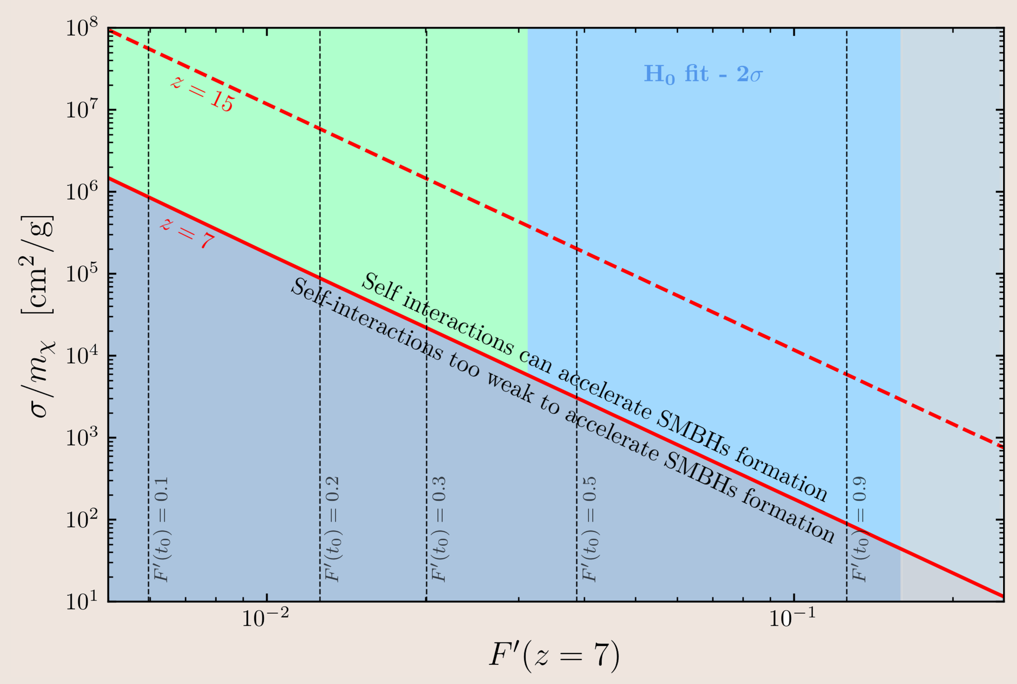
(a) (b)

- **Regime B**: SIDM originating from S decays taking place after recombination. Color coding denotes the value of the coupling g for the points that satisfy the condition $\sigma/m_\chi \sim (1 \pm 10\%)$ cm^2/g. Dark green shade denotes the region at the 1σ level around the mean values of DCDM parameters, which relax Hubble tension in the short lifetime scenario. Gray pluses overlay points that have $\delta > 0.01$ which are in this model in tension with the structure formation.



uSIDM regime - late decays

- **Regime C**: Subdominant component of ultrastrong self-interacting DM may positively affect the supermassive black hole formation rate where standard models of formation seem to be in tension due to observations of very early ($z \sim 7$ which corresponds to lifetime $\tau \sim 0.8$ Gyr) SMBH.
  - uSIDM regime is found to be viable, but...
  - challenging to simultaneously accommodate for Hubble tension and sufficient production of uSIDM, as cosmologically preferred lifetime corresponds to longer lifetimes $\tau > 5$ Gyr.



Takeaway

- SIDM production by late decays of WIMP-like messenger
- Mechanism exemplified in a Higgs portal DM model
- Well-motivated mechanism deserving further model building

Based on: **hep-ph/2006.16139**. See also Andrzej's talk on Friday, 12:40.

Supported by: NCN grant No. 2015-18-A-ST2-00748 and No. 2018/31/D/ST2/00813.

NATIONAL SCIENCE CENTRE POLAND