A Global Analysis of Resonance-enhanced Light Scalar Dark Matter

Tobias Binder, Sreemanti Chakraborti, Shigeki Matsumoto and Yu Watanabe **arXiv:2205.10149**

1.Introduction

- Thermal dark matter($\mathcal{O}(1)\mathrm{MeV} \lesssim \mathrm{m_{DM}} \lesssim \mathcal{O}(100)\mathrm{TeV}$) is an attractive DM candidate.
- Among them, WIMP($\mathcal{O}(1)\mathrm{GeV} \lesssim \mathrm{m_{DM}} \lesssim \mathcal{O}(1)\mathrm{TeV}$) has intensively searched for, however not been founded.
  → **Light thermal DM($m_{\mathrm{DM}} \lesssim \mathcal{O}(1)\mathrm{GeV}$) is getting a more attention.**
- Light thermal DM is known to be severely constrainded by CMB. To overcome it, $\langle \sigma v \rangle$ should be **velocity-dependent** e.g. s-channel resonance. Such candidate may **solve the core-cusp problem**.
- As an example of those models we studied the model including the **scalar singlet DM and mediator**.

2.Model

- The Lagrangian is

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \frac{1}{2}(\partial_\mu \chi)^2 - \frac{\mu_\chi^2}{2}\chi^2 - \frac{\lambda_{H\chi}}{2}|H|^2\chi^2 - \frac{\lambda_\chi}{4!}\chi^4 + \frac{1}{2}(\partial_\mu \Phi)^2 - \frac{\mu_{\Phi\chi}}{2}\Phi\chi^2 - \frac{\lambda_{\Phi\chi}}{4}\Phi^2\chi^2 - V(\Phi, H),$$

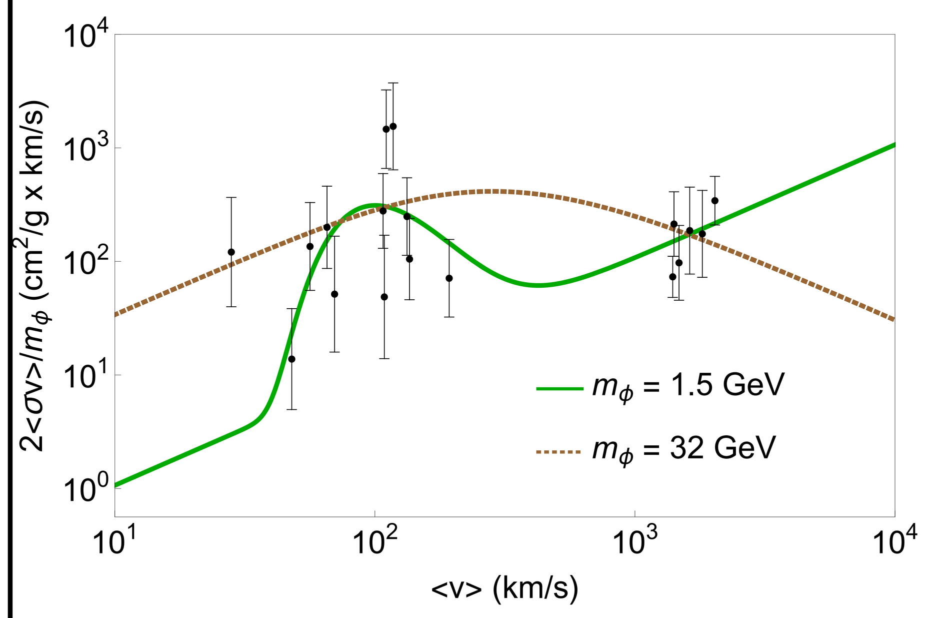
$$V(\Phi,H) = \mu_{\Phi H}\Phi|H|^2 + \frac{\lambda_{\Phi H}}{2}\Phi^2|H|^2 + \mu_1^3\Phi + \frac{\mu_\Phi^2}{2}\Phi^2 + \frac{\mu_3}{3!}\Phi^3 + \frac{\lambda_\Phi}{4!}\Phi^4,$$

- Phenomenologically important parametars are
  - m_ϕ ⋯ mass of mediator
  - v_R ⋯ place of resonance ($\equiv 2(m_\phi/m_\chi - 2)^{1/2}$)
  - $\sin\theta$ ⋯ mixing angle between mediator and higgs boson
  - γ_ϕ ⋯ invisible decay rate of mediator ($\Gamma(\phi \to \chi\chi) = \gamma_\phi m_\phi v_{DM}$)
  - σ_0 ⋯ velocity-independent part of the self-scattering cross section
- We focus on the parameter region in which $v_R \simeq 0$ (**s-channel resonance**).

3.Favored parameter regions

- ### Self-Scattering

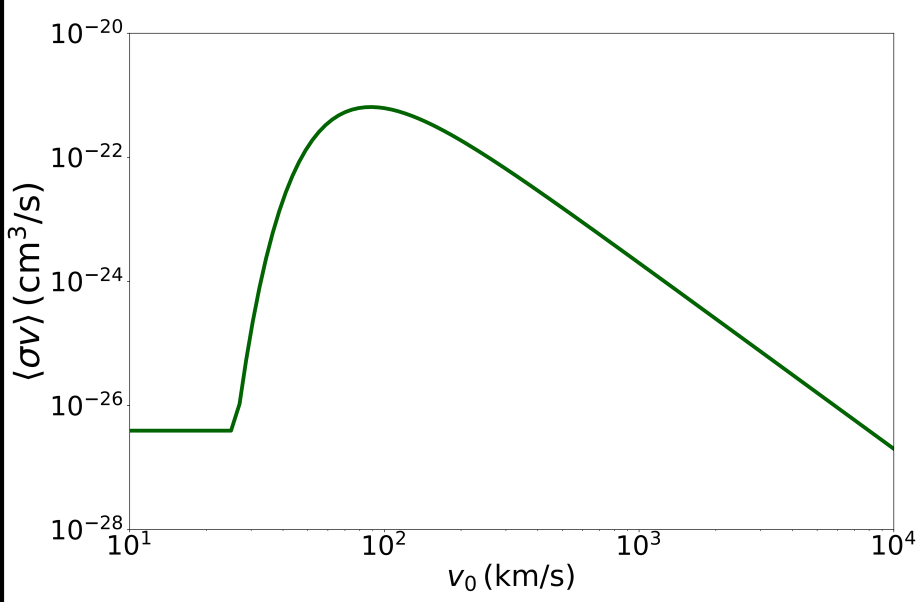
  - N-body simulations(astrophysical observations) prefer DM density profile with a cusp(core) near the galactic center(GC). This mismatch may be **solved by self-scattering of DM**, which thermalize DM near the GC.



  - Self-scattering cross sections needed to solve core-cusp problem.
  - Velocity-dependent self-scattering cross sections seem to fit the data well.

- ### CMB

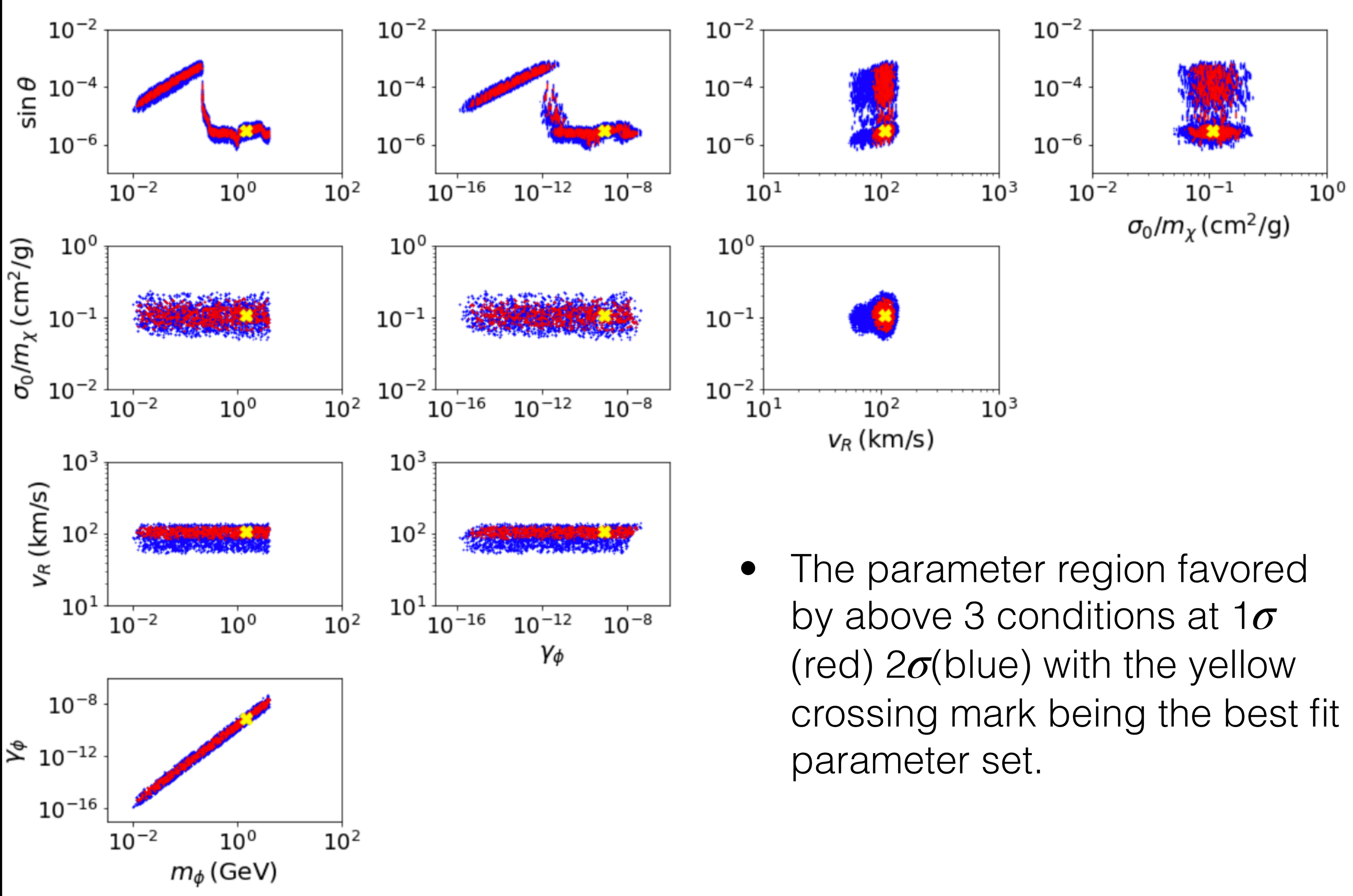
  - Decoupling of thermal BSM particles after that of neutrino is forbidden due to the asymmetrical entropy injection to the primodal prasma.



  - $\langle \sigma v \rangle$ at the reconbination era($v \ll 10\,\mathrm{km/s}$) should be small in order not to modify the anisotropy of CMB.
  - S-channel resonance make $\langle \sigma v \rangle$ **enhanced(suppressed) at freeze-out(recombination).**

- ### Relic abundance

  - We assume DM is produed by freeze-out mechanism.
  - Since DM annihilations are enhanced through s-channel resonance, $\sin\theta$ becomes small. → **Early Kinetic Decoupling** occurs.
  - This **reduces the abundance**, and makes $\sin\theta$ **6 times smaller**.



  - The parameter region favored by above 3 conditions at 1σ (red) 2σ(blue) with the yellow crossing mark being the best fit parameter set.

  - The correration among v_R, γ_ϕ and σ_0, $\sin\theta$ and range of m_ϕ are decided by self-scattering, relic abundance and CMB, respectively.

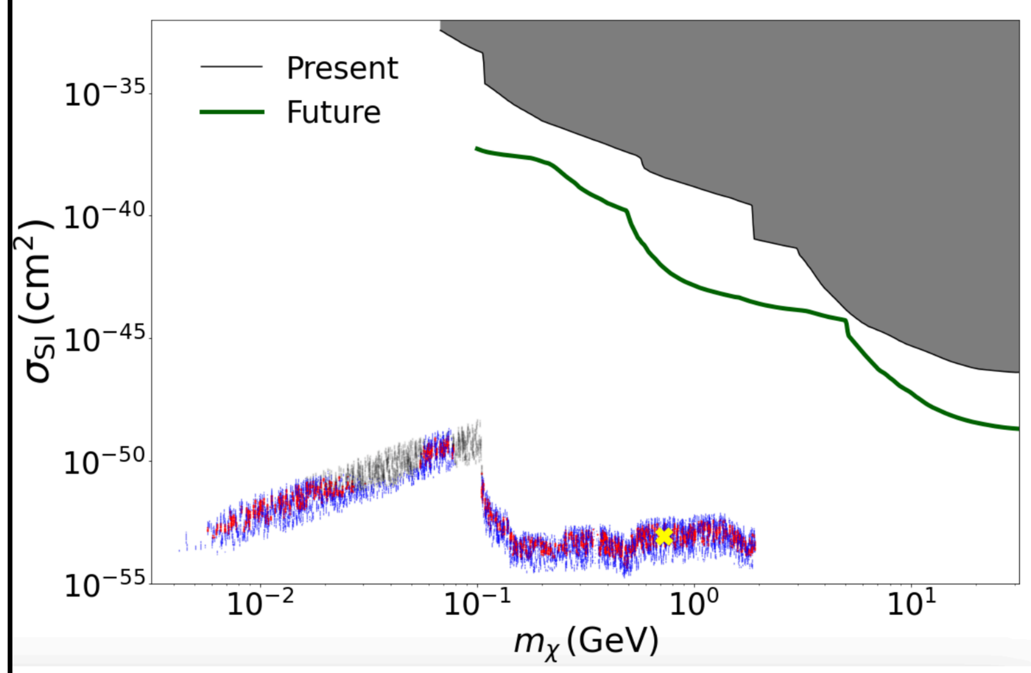
4.Constraints from experiments

- ### Collider

  - Since in the favored parameter space the **mediator decays invisibly**, **invisible decays of SM particles** e.g. Higgs boson, K and B meson gives the severe constraint.

- ### Direct Detection

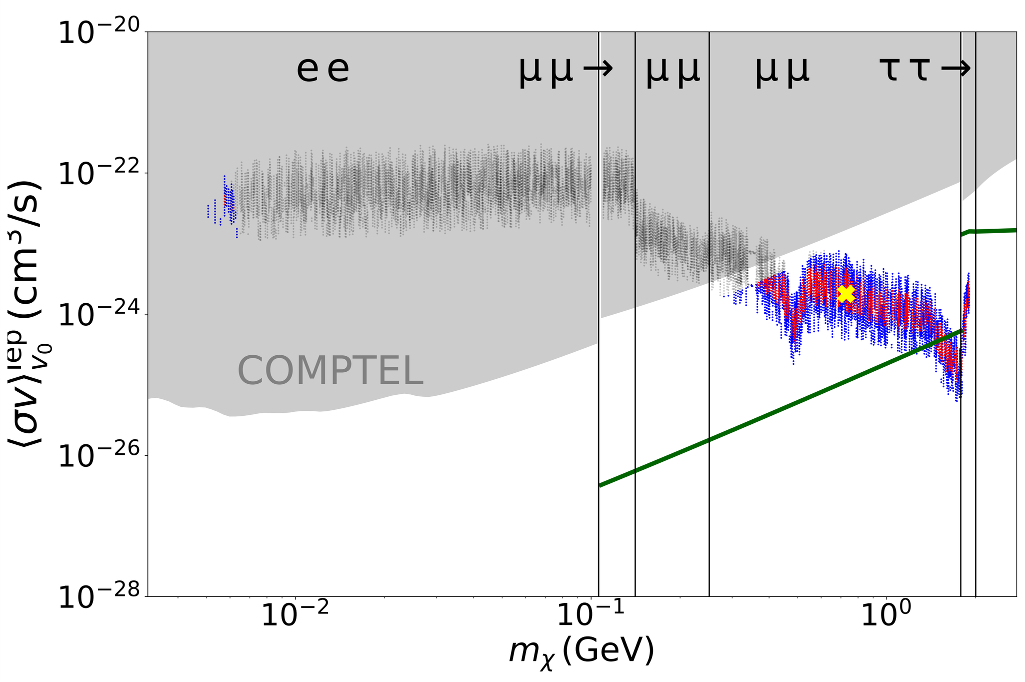
  - The **scattering cross section between DM and a nucleon** is constrained. **Migdal effect** plays an important role.



  - The constraint from collider(gray dots), direct detection at present(gray-shaded region) and that in the nerar future(green line).
  - Since $\sin\theta$ is **suppressed,** the constraint is **weak**.

- ### Indirect Detection

  - Voyager can observe $e^\pm$ produced by annihilation of DM.
  - COMPTEL gives the most straingent constraint to the γ-ray produced by annihilation of DM.
  - There are **large uncertainties** e.g. DM profile, hadronic fragmentation functions of sub-GeV DM.



  - The constraint from Voyager(gray dots), COMPTEL (gray-shaded region) and γ-ray observations in the nerar future(green line).
  - Several parameter sets **survives** at **present** and **almost all** of them will be **constrained**.

5.Summary

- **Light thermal DM with velocity-dependent $\langle \sigma v \rangle$ is** an attractive DM candidate.
- As an example of those models we studied the model including **the scalar singlet DM and mediator**.
- A part of **attractive regions** in which DM can solve core-cusp problem, explain the relic density and overcome the constraint from CMB is still **surviving** from constraints at present concerning the uncertainties.
- Almost all of these will be **constrained** by **near future** MeV γ-ray observations e.g. GECCO and COSI.