Solar constraints on captured electrophilic dark matter

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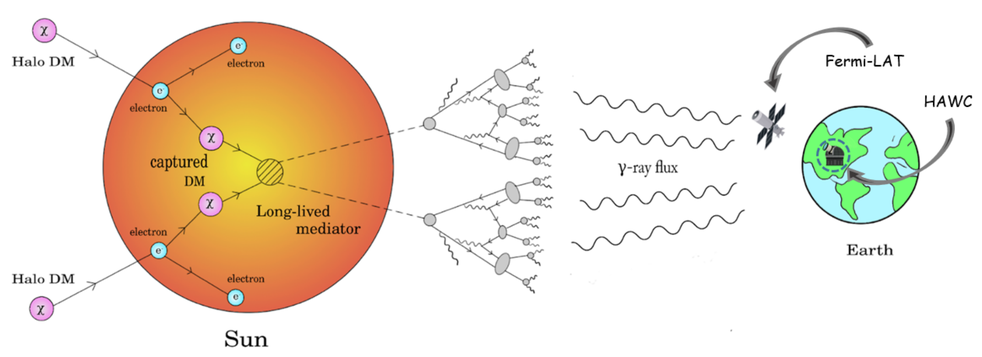
Abstract

Dark matter captured by interaction with electrons inside the Sun may annihilate via long-lived mediator to produce observable gamma ray signals. We utilize solar gamma ray flux measurements from the Fermi Large Area Telescope and High Altitude Water Cherenkov observatory to put bounds on the dark matter electron scattering cross-section. We find that our limits are four to six orders of magnitude stronger than the existing limits for dark matter masses ranging between GeV to PeV scale.

Schematic Diagram



DM capture inside the Sun

The DM capture rate of DM particles after scattering with the solar electrons is given by

$$C_\odot = \left(\frac{\rho_\chi}{m_\chi}\right)\int_0^{R_\odot} dr\, 4\pi r^2 \int_0^{u_{esc}} du_\chi \frac{f(u_\chi)}{u_\chi} w(r) \int_0^{v_{esc}(r)} dv\, \Omega^-(w(r)\to v)$$

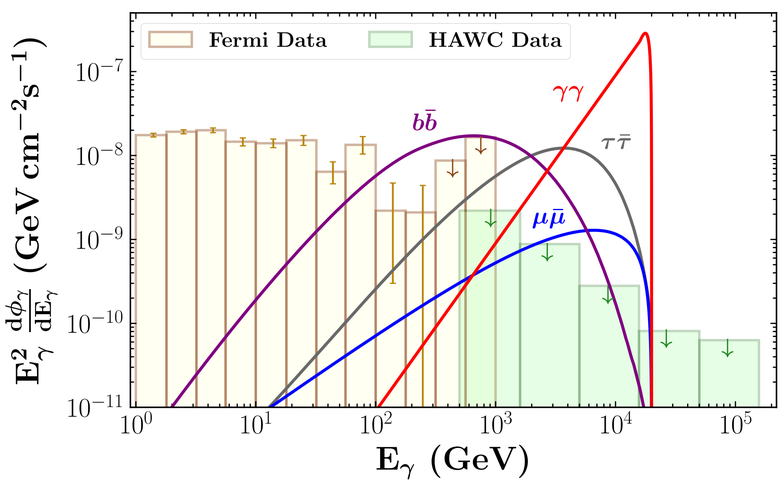
DM number density at solar neighborhood; DM velocity distribution; Integrating over the solar interior; Integrating over the DM velocity; DM velocity at position r; Rate of scattering for w(r) -> v

Gamma ray flux

The differential gamma ray flux produced by annihilation of electrophilic DM particles through long-lived mediators is given by

$$E_\gamma^2 \frac{d\phi_\gamma}{dE_\gamma} = \frac{\Gamma_{ann}}{4\pi D_\odot^2} \times \mathrm{Br}\left(Y \to SM\bar{SM}\right) \times E_\gamma^2 \frac{dN_\gamma}{dE_\gamma} \times \left(e^{-\frac{R_\odot}{\eta c \tau_Y}} - e^{-\frac{D_\odot}{\eta c \tau_Y}}\right)$$

Annihilation rate; Branching ratio; Earth-Sun distance; Photon spectrum; Survival probability



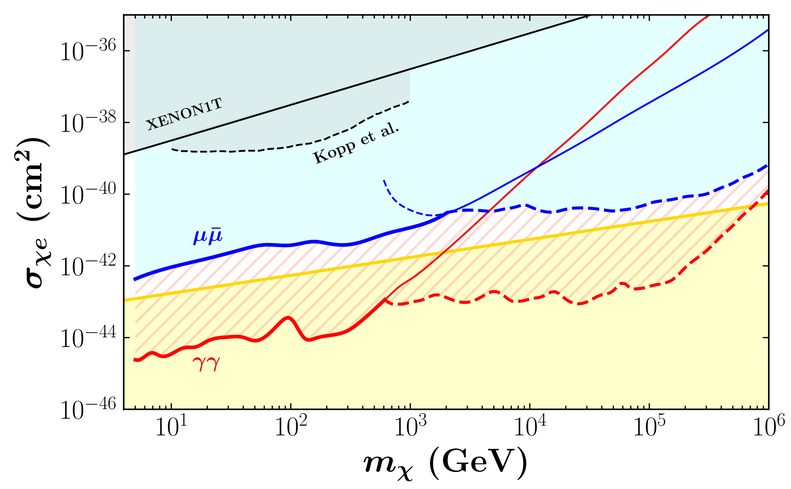
Solar disk measurements

State-of-the-art gamma ray detectors measure solar gamma ray flux in the GeV-TeV energy range:

- Fermi Large Area Telescope (Fermi-LAT) : 0.1-10^3 GeV
- High Altitude Water Cherenkov (HAWC) : 0.5-100 TeV (95 % confidence level upper limits)
- In previous figure, we depicted the Fermi-LAT and HAWC measurements with histograms along with our expected signal.

Results

- The limits on the DM-electron scattering cross-section obtained by assumming the entire solar disk gamma ray flux originates from captured DM.



- The solid and dashed lines are obtained incorporating Fermi-LAT and HAWC measurements respectively for the considered SM final state channels.

Conclusions

- In this analysis, we have probed the gamma ray in the GeV-TeV range from the captured electrophilic DM inside the Sun and annihilating through a long-lived mediator.
- The constraints have been obtained by comparing the signal events with the measured solar gamma ray flux in the Fermi-LAT and HAWC detectors.
- The bounds obtained from this analysis on the DM-electron scattering cross-section are 4 to 6 orders of magnitude stronger than the existing limits for the GeV-TeV mass of the DM.

Reference

D. Bose, T. N. Maity and T. S. Ray, Phys. Rev. D 105 (2022) 123013, [arXiv:2112.08286]

Assumptions :

- 100% branching ratio to each SM final states,
- DM-electron scattering cross-section, $\sigma_{\chi e} = 10^{-40}\,\mathrm{cm}^2$,
- DM mass, $m_\chi = 20\,\mathrm{TeV}$ and mediator mass, $m_Y = 5\,\mathrm{GeV}$