Solar Reflection of Dark Matter with Dark Photon Mediators

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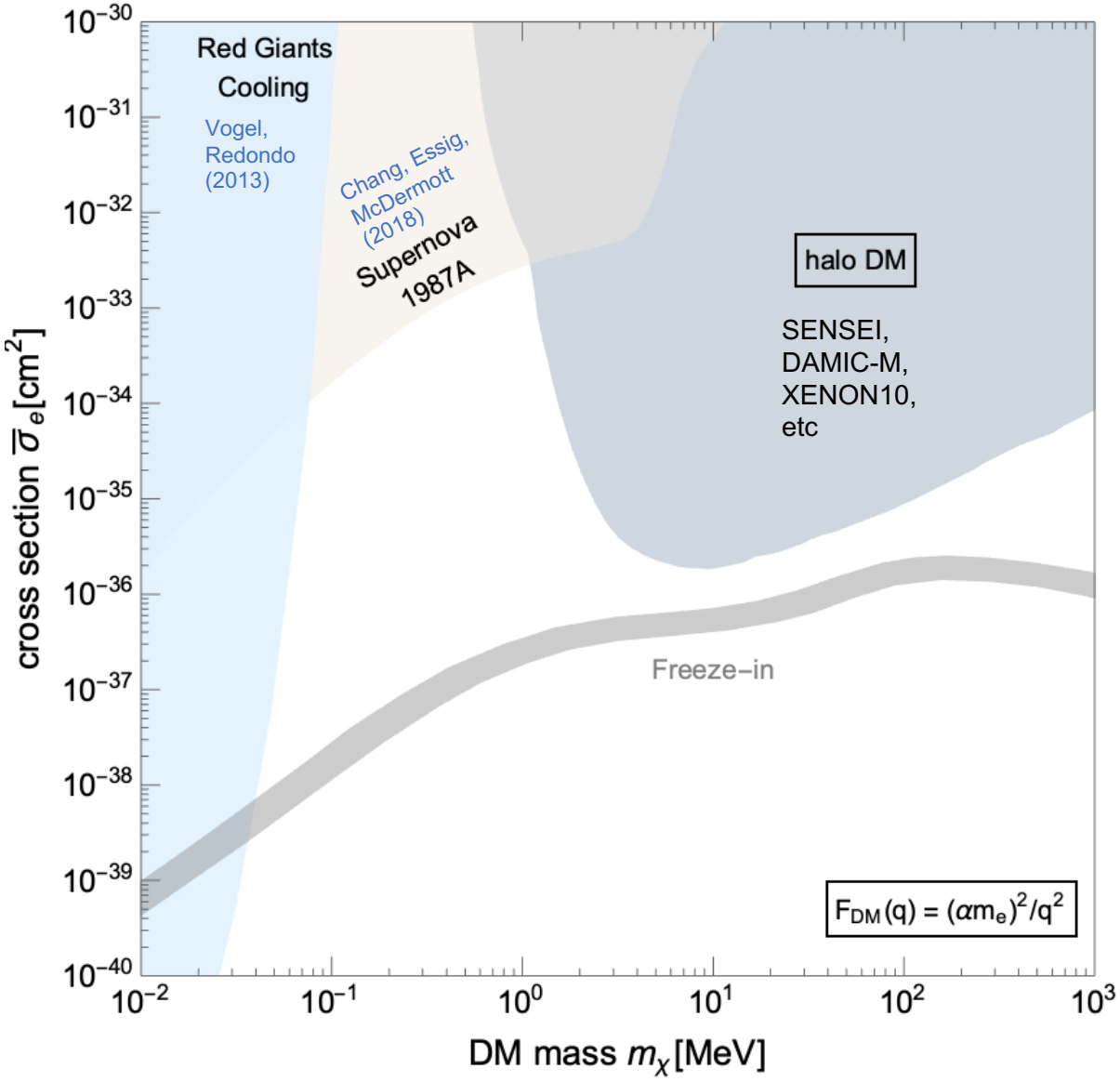
Direct Detection of Halo Dark Matter

- Searching for nuclear or electron recoils caused by halo dark matter particles
- Halo DM: can be as fast as ~ 840 km/s in Earth frame
- No existing direct detection bounds on sub-MeV DM



Solar Reflected Dark Matter (SRDM)

Emken, Kouvaris, Nielsen (2017)
An, Pospelov, Pradler, Ritz (2017)

- Halo DM particles get gravitationally attracted by the Sun, up-scatter in hot solar plasma, acquire energy, and escape
- Results in a highly energetic solar reflected dark matter (SRDM) flux
- Allows current direct-detection experiments to probe sub-MeV DM

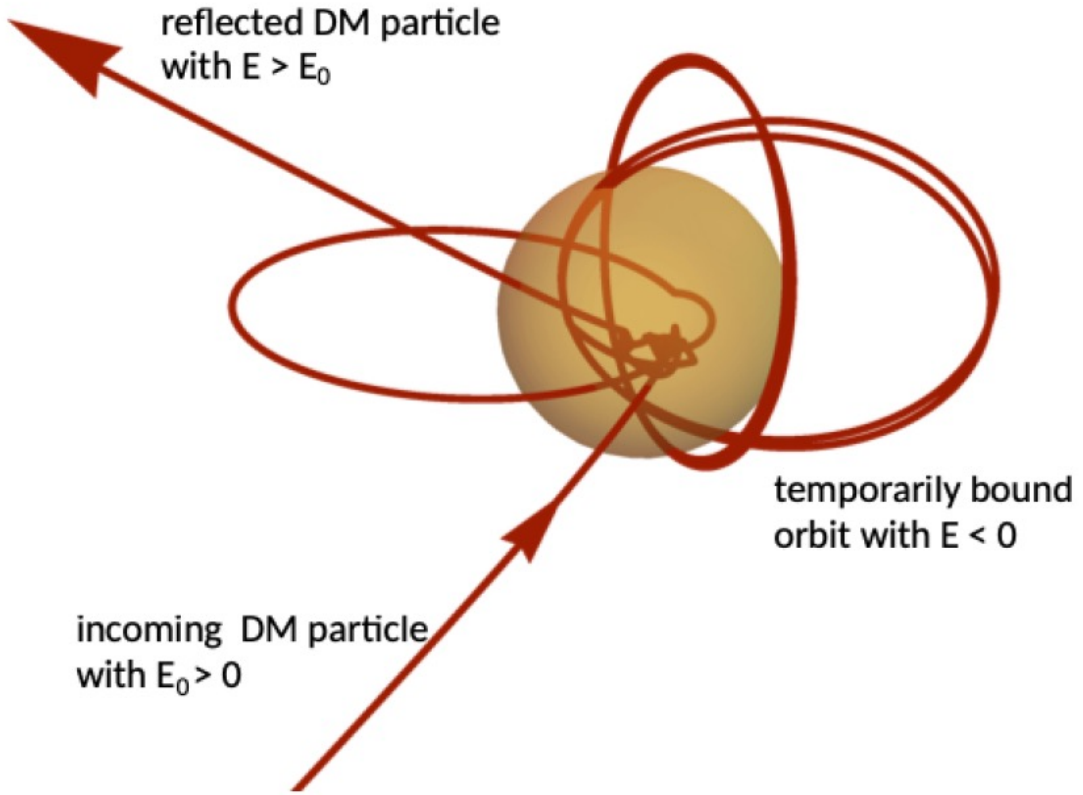
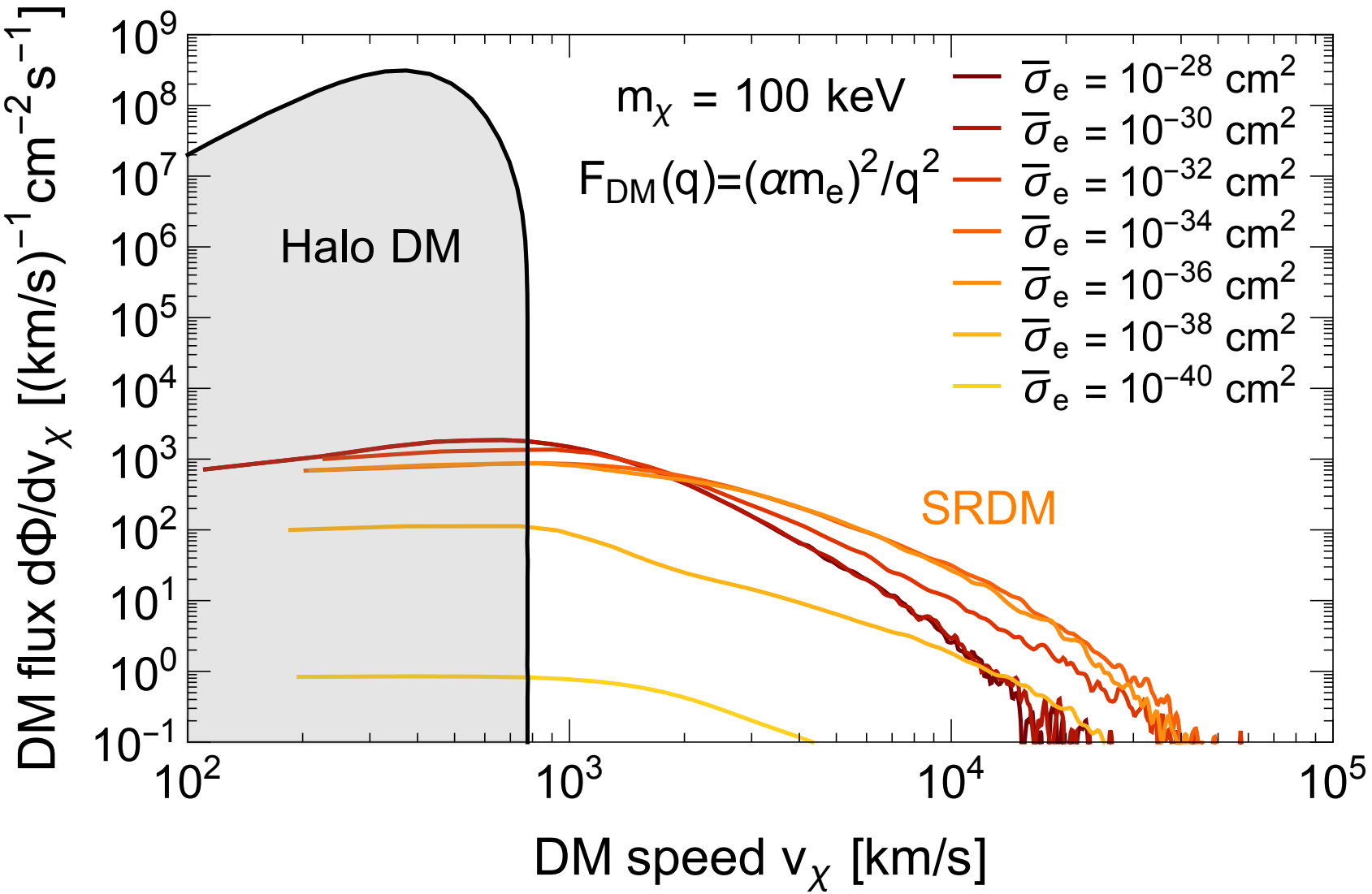


Figure credit: Emken

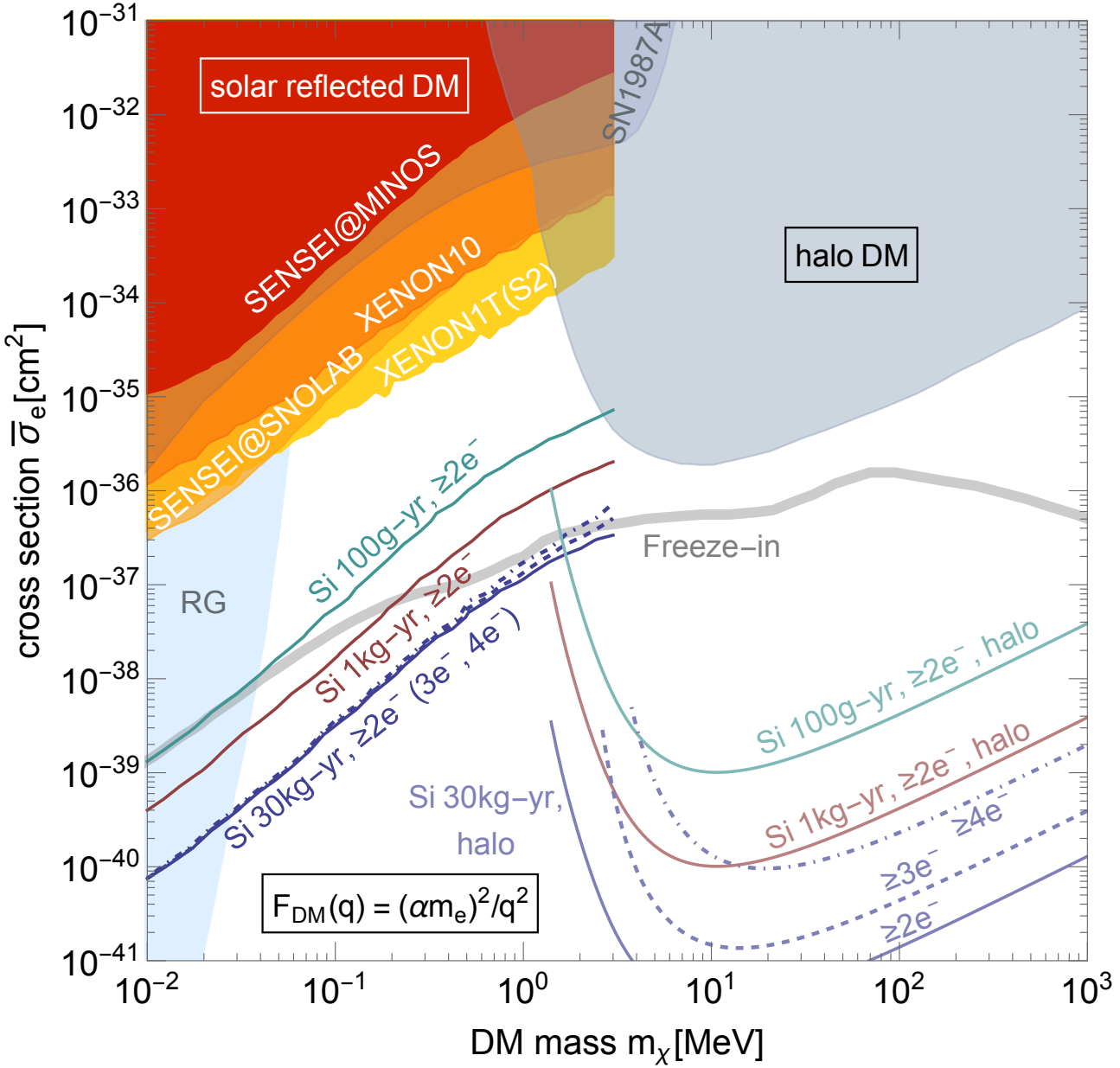
- DaMaSCUS-SUN (Dark Matter Simulating Code for Underground Scatterings – Sun Edition, by Timon Emken, link: https://github.com/temken/DaMaSCUS-SUN)

Reflected Flux



- Larger cross section σ: DM scatters at solar surface – cooler – fewer high-energy particles
- Lower σ: DM can access to hotter bulk – more high-energy particles
- Very low σ: transparent Sun. Flux is attenuated overall

Direct-Detection Constraints & Projections

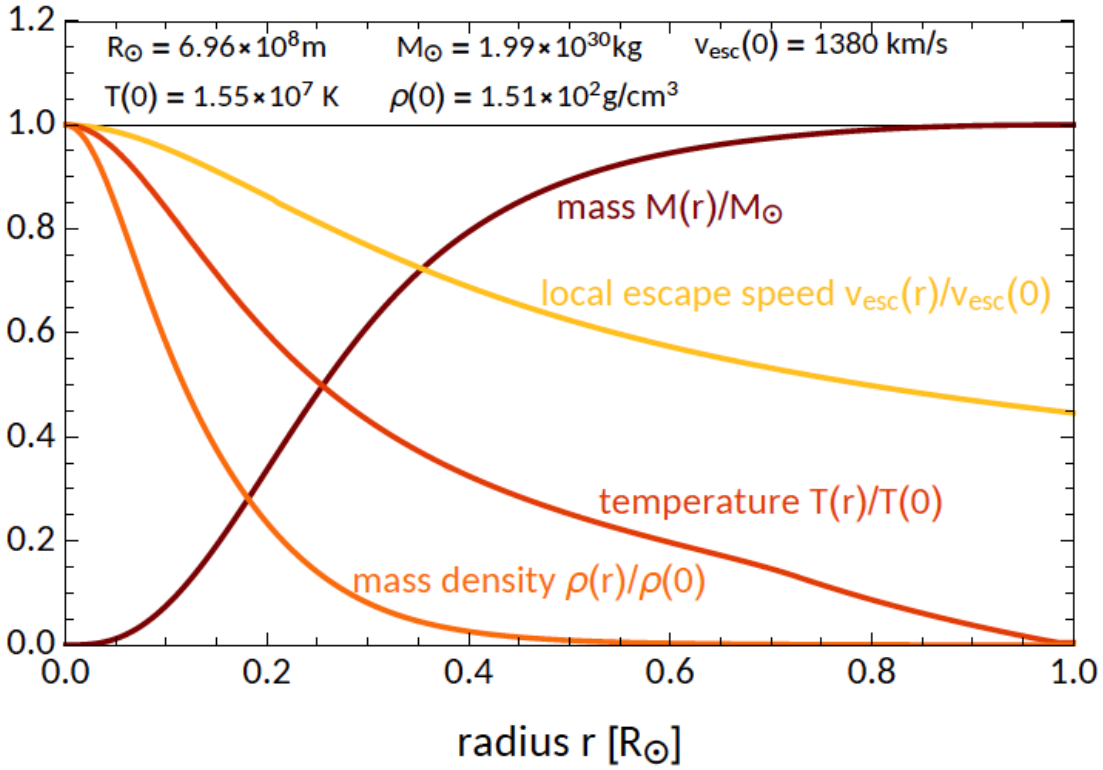


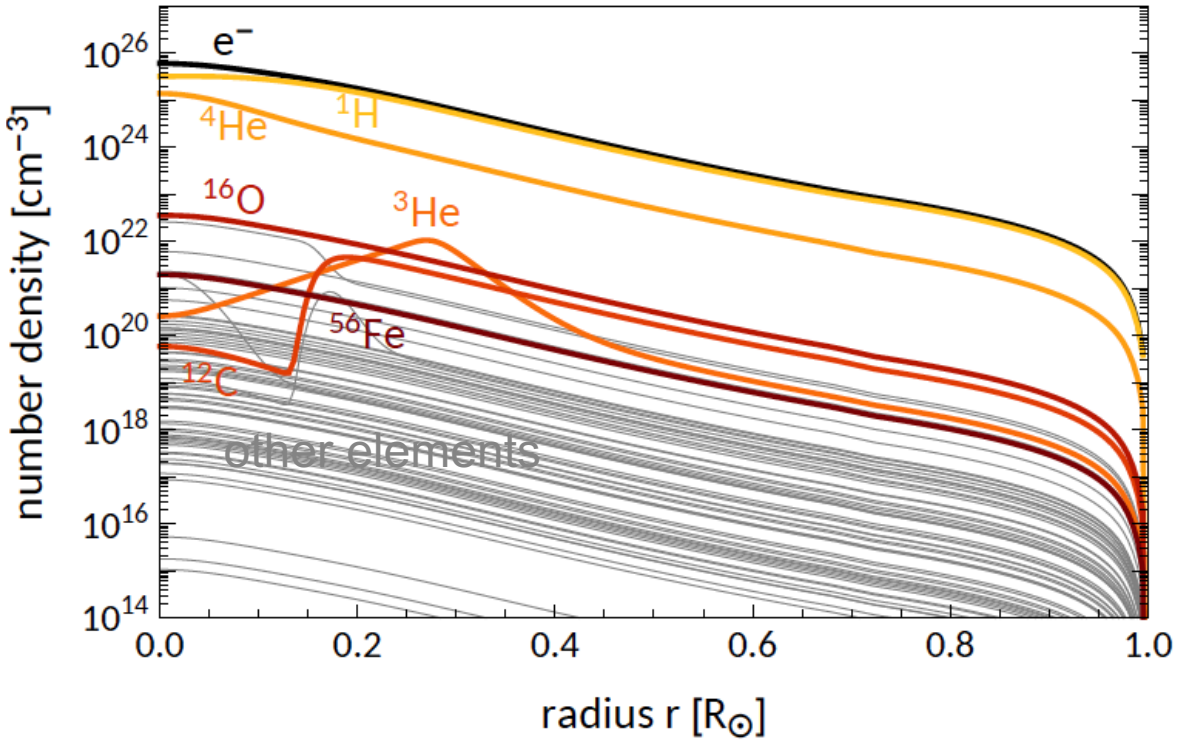
DM with ultralight dark photon

- Exclude vast region of sub-MeV DM.
- Entire ‘freeze-in’ line probed/excluded when combining SRDM and halo limits for future DM detectors (‘Si 30kg-yr’ for Oscura).

Supplementary materials: Standard Solar Model

Serenelli, Basu, Ferguson, Asplund (2009)



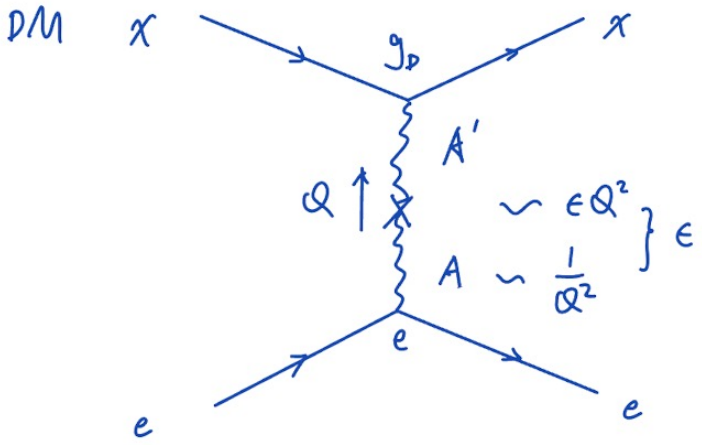


Supplementary materials: Dark Photon Model

- Dark Photon A': vector boson for $U(1)_{\mathrm{D}}$, kinetically mixed with SM hypercharge. At low energies, mixing is between A' and A (ordinary photon).

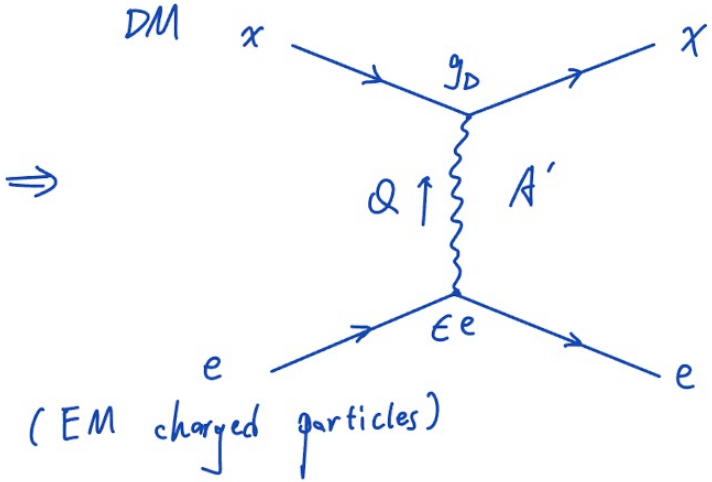
SM photon kinetic term | dark photon kinetic term | kinetic mixing | dark photon mass term | SM photon - current | dark photon - dark current

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} - \frac{\epsilon}{2}F_{\mu\nu}F'^{\mu\nu} + \frac{1}{2}m^2_{A'}A'_\mu A'^\mu + eA_\mu J^\mu_{\mathrm{EM}} + g_D A'_\mu J^\mu_D$$



(In vacuum)

$\Rightarrow$

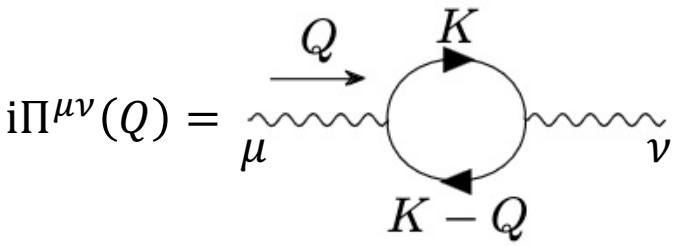


$$\langle |M_e(q)|^2 \rangle = \frac{16\epsilon^2 e^2 g_D^2 m_e^2 m_\chi^2}{(q^2 + m^2_{A'})^2}$$

Scattering is q-dependent for light mediator.

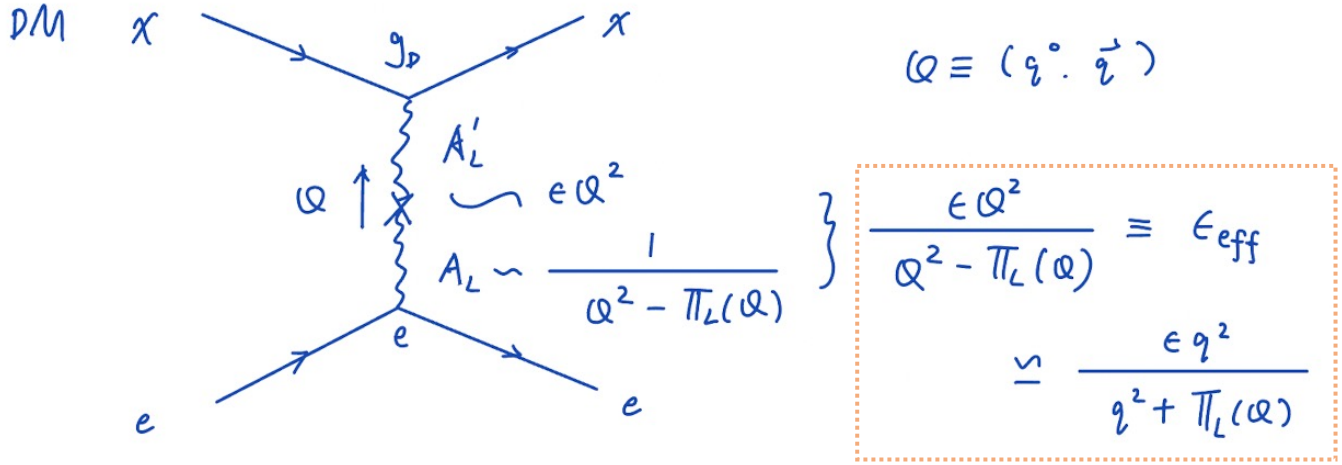
Supplementary materials: In-Medium Effect

- Photon interacts with medium, acquires thermal mass, modifies propagator



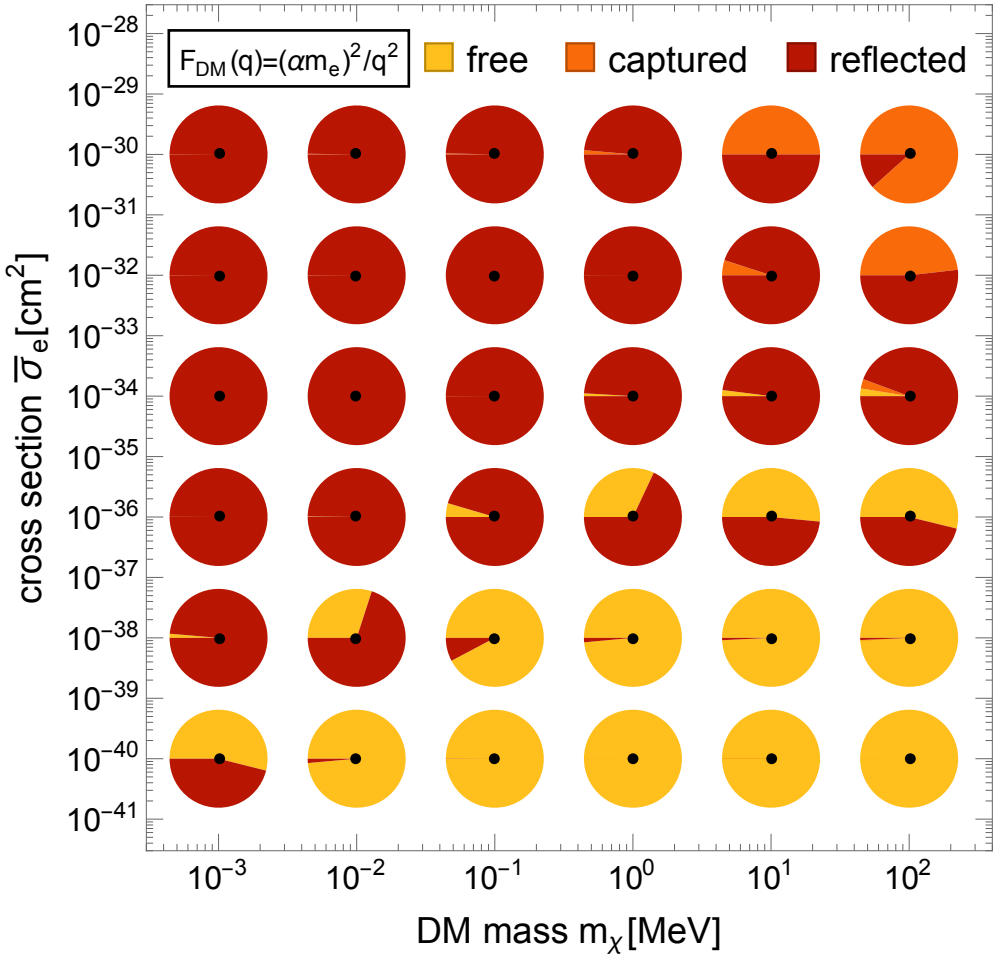
Feynman diagram for photon self-interaction

DeRocco, Galanis, Lasenby (2022)



Dark photon's coupling to EM current: 'effective coupling' ϵ_{eff}

Supplementary materials: Reflected, Captured, and Free Particles



- Captured: still in the Sun after 10^4 scatters or in a bound orbit for too long
- Reflected: gets scattered at least once and escapes
- Free: no scattering, and escapes