University of Southern Denmark

Astrophysical Signatures of Dark Matter

Chris Kouvaris

CP3 - Origins

Particle Physics & Origin of Mass

DSU 2016, Bergen

Dark Stars

Annihilating Dark Matter: Freese, Gondolo Spolyar ‘07

Asymmetric fermionic dark matter with Yukawa self-interactions

$$V_{ij} = \pm\alpha \frac{e^{-\mu r_{ij}}}{r_{ij}}$$

Equation of state

$$P = \frac{g_s}{2} m_\chi^4 \psi(x) \pm \frac{\alpha g_s^2}{18\pi^3} \frac{m_\chi^6}{\mu^2} x^6$$

$$\rho = \frac{g_s}{2} m_\chi^4 \xi(x) \pm \frac{\alpha g_s^2}{18\pi^3} \frac{m_\chi^6}{\mu^2} x^6$$

$$x = p_F / m_\chi$$

it can be approximated by polytropic $P=K\rho^\gamma + \beta\rho^2$

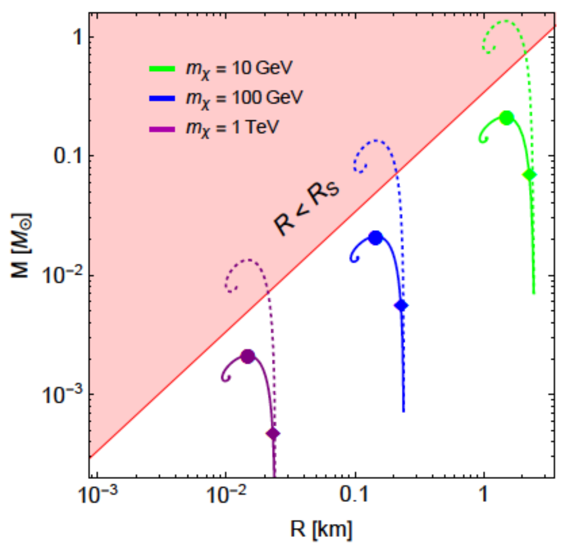
Tolman-Oppenheimer-Volkoff

$$\frac{dP}{dr} = -\frac{GM\rho}{r^2} \frac{\left[1+\frac{P}{\rho}\right]\left[1+\frac{4\pi r^3 P}{M}\right]}{\left[1-\frac{2GM}{r}\right]}$$

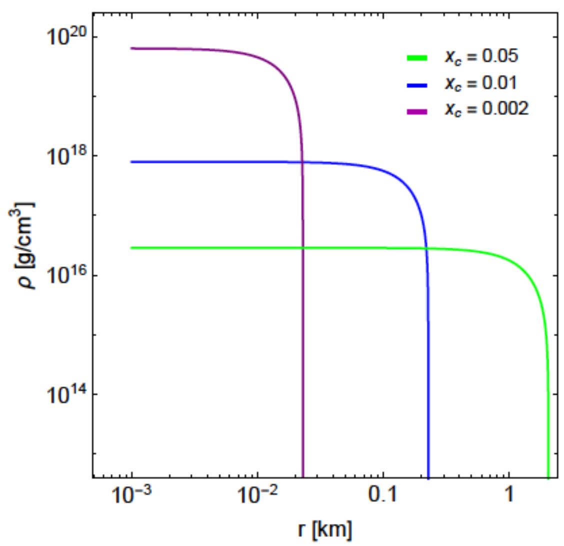
Asymmetric Dark Stars

Dark star profiles

Fermionic



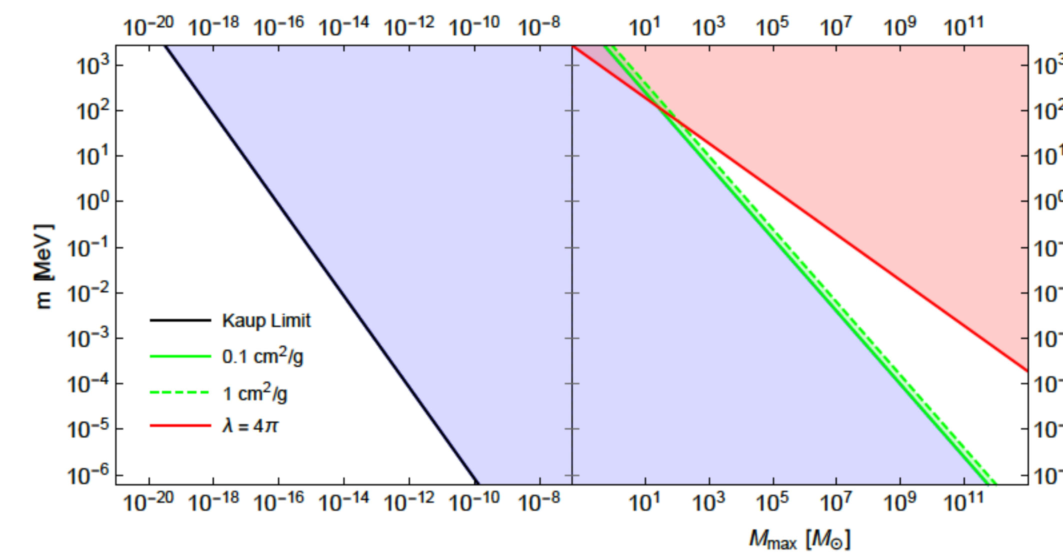
(a) $M(R)$ for repulsive interactions



(b) $\rho(r)$ for repulsive interactions

CK, Nielsen '15

Bosonic



Eby, CK, Nielsen, Wijewardhana '15

Formation

- Cosmological Perturbations
- Gravothermal Collapse

Observation

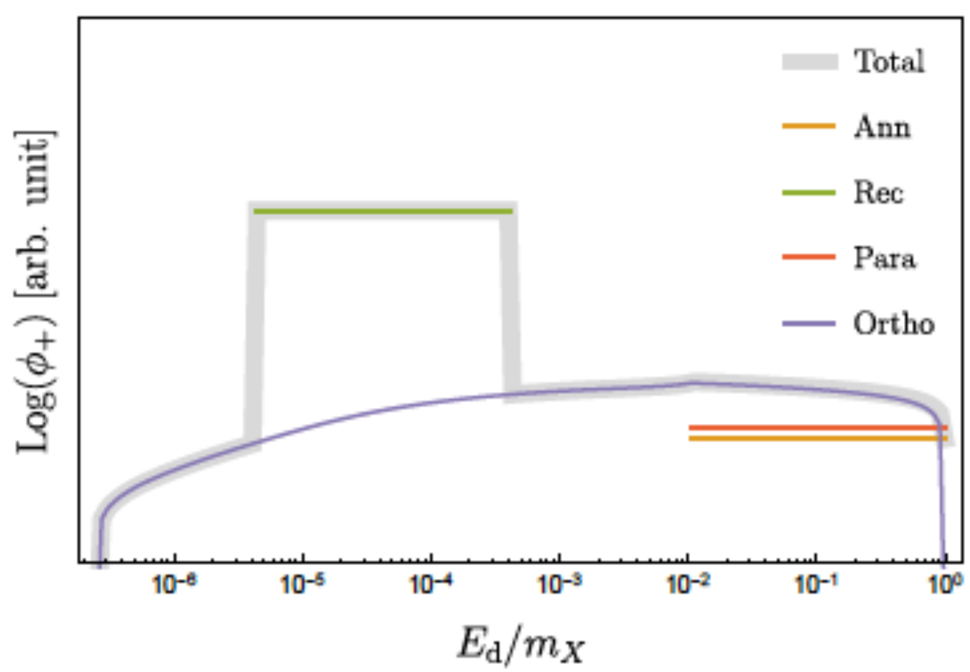
- Gravitational Waves (Giudice McCullough Urbano '16)
- Gravitational Lensing
- Luminosity via kinetic mixing

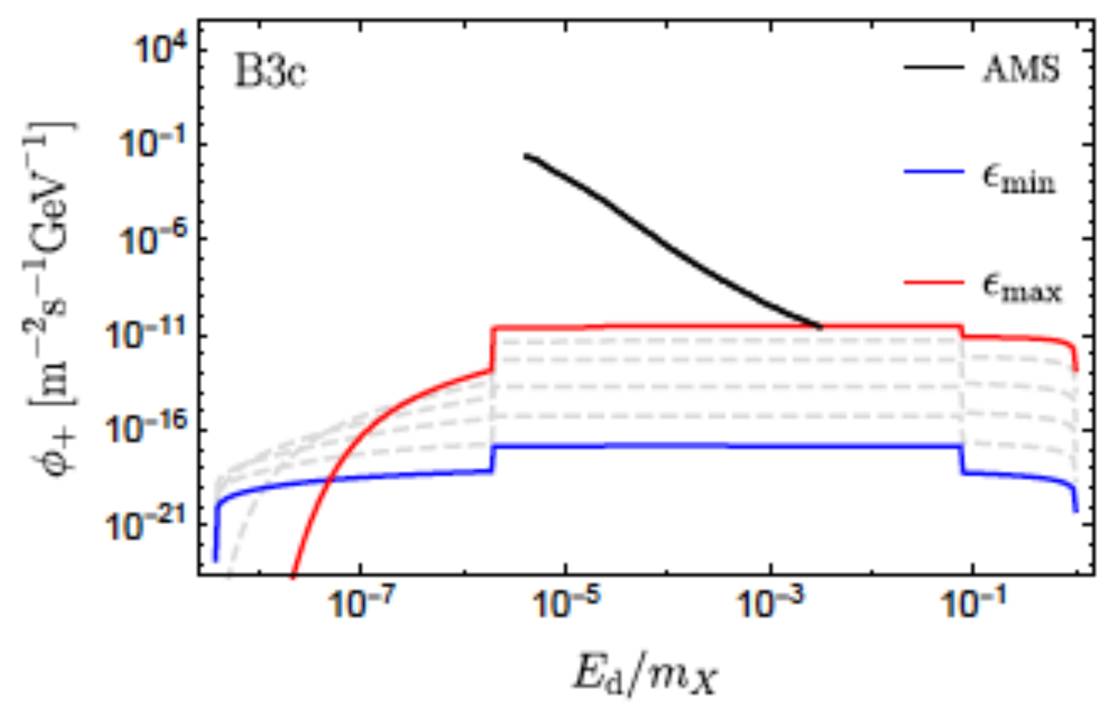
The Spectrum of Darkonium

Symmetric dark matter (that couples to dark photons) captured by the Sun can produce a positron spectrum via

- Annihilate to dark photons   Feng Smolinsky Tanedo, '16
- Form positronium-like states (ortho- or para-) and then decay to dark photons
- Produce recombination dark photons

Positron Spectrum



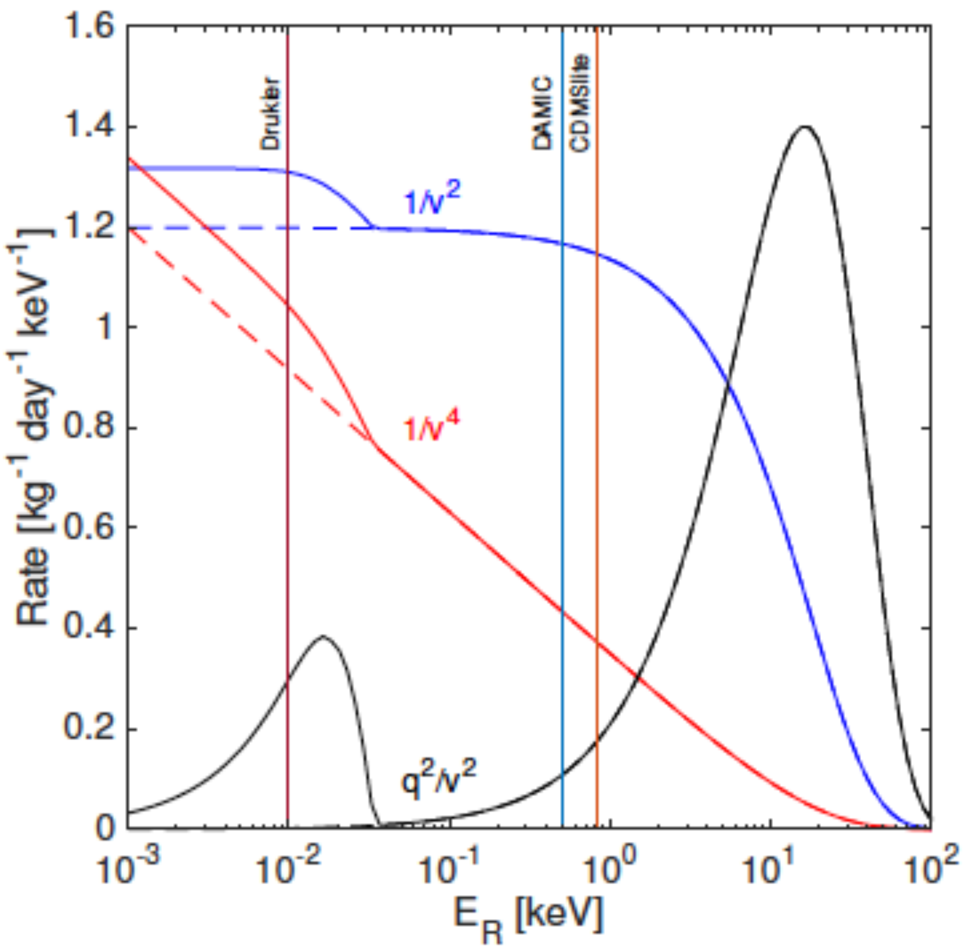


CK, Nielsen, Langaeble '16

New Spectral Features from Bound Dark Matter

DM that get captured by the Earth, can later on recoil in detectors

Gould Frieman Freese ‘89
Damour, Krauss ’98,



CK, Catena ‘16

$O_9\, O_{10}\, O_{11}\, O_{12}$

give hundreds of times higher rate for bound DM compared to halo at low energies

Low experimental energy threshold is essential to this signal

Ratio bound/halo independent of cross section

Go beyond the neutrino floor

Probing sub-GeV Dark Matter I

Dark Matter lighter than ~3.3 GeV will eventually evaporate from the Sun after capture

Equilibrium between capture and evaporation rates $$\frac{dN}{dt} = F - C_e N - C_a N^2$$

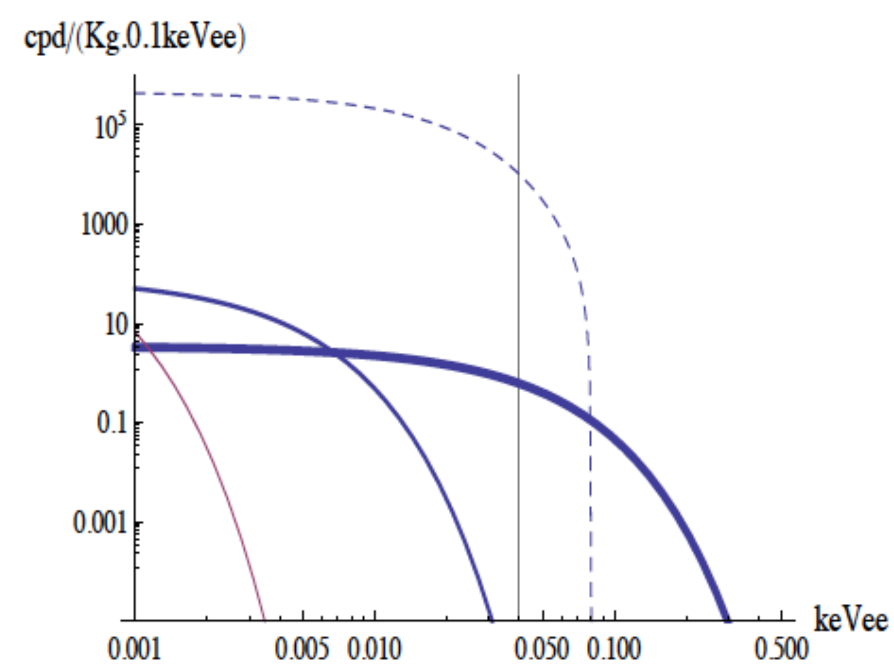
Halo DM velocities are bound by the escape velocity of the Galaxy.
Light DM that cannot trigger the detector is boosted to larger velocities via evaporation arriving in the Earth with velocities that allow detection

$$\frac{dR}{dE_R} = N_T \left[\int_{v_{min}}^{\infty} \frac{d\sigma}{dE_R} \mathcal{F}_l(v) dv + \frac{\rho_\chi}{m_\chi} \int_{v_{min}}^{v_{esc}} \frac{d\sigma}{dE_R} f(v) v d^3 v \right]$$

$$\mathcal{F}_l = C e^{-\frac{m_\chi}{2kT_\chi}(v^2 + v_s^2 - v_e^2)} v^3$$

evaporation

halo DM

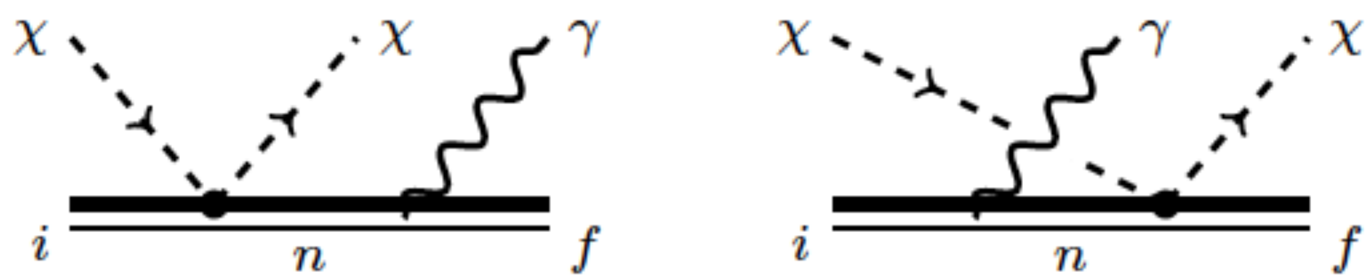


CK, '15

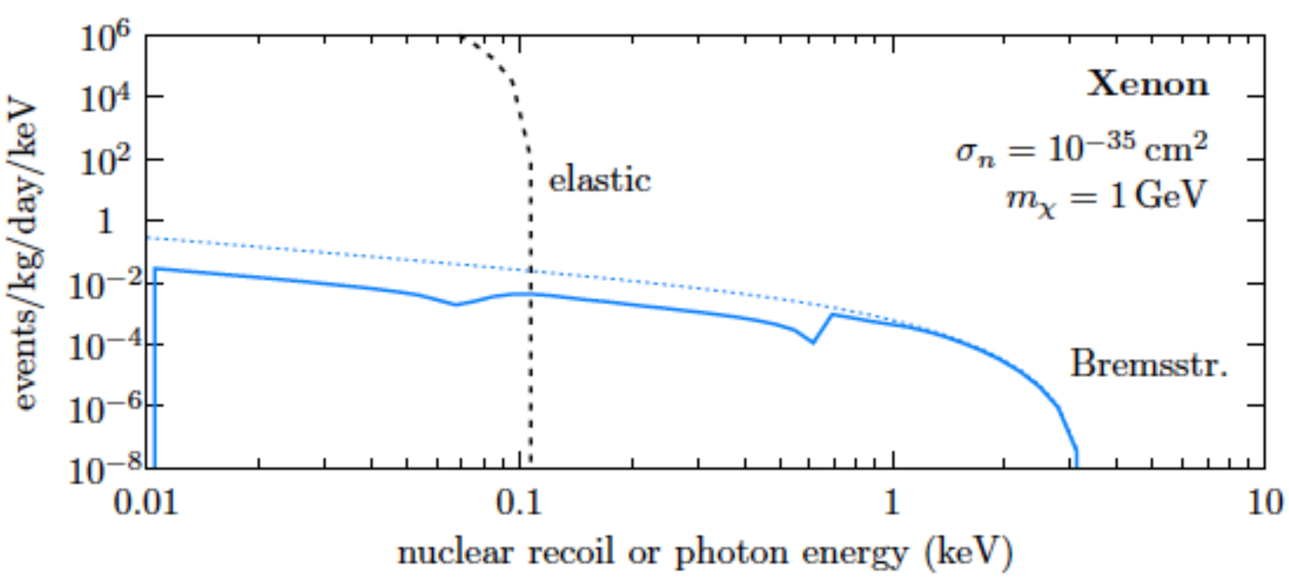
Probing sub-GeV Dark Matter II

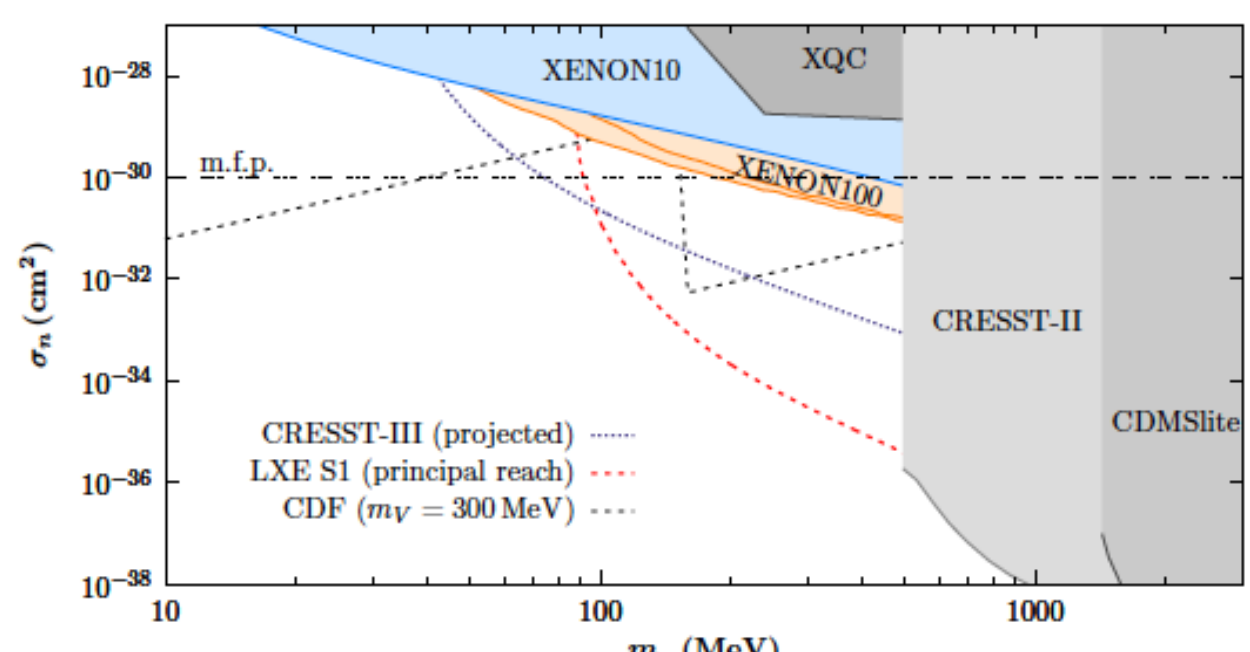
Bremsstrahlung

$$E_R \leq 2\mu_N^2 v^2 / m_N$$
$$\omega \leq \mu_N v^2 / 2$$



$$|V_{fi}|^2 = 2\pi\omega |M_{\rm el}|^2 \left| \sum_{n, n\neq i} \left[\frac{(\mathbf{d}_{fn}\cdot \hat{\mathbf{e}}^*)\,\langle n| e^{-i\frac{m_e}{m_N}\mathbf{q}\cdot\sum_\alpha \mathbf{r}_\alpha}|i\rangle}{\omega_{ni}-\omega} + \frac{(\mathbf{d}_{ni}\cdot \hat{\mathbf{e}}^*)\,\langle f| e^{-i\frac{m_e}{m_N}\mathbf{q}\cdot\sum_\alpha \mathbf{r}_\alpha}|n\rangle}{\omega_{ni}+\omega} \right] \right|^2 . \quad (4)$$





CK, Pradler '16

Conclusions

- Asymmetric Dark Stars
- Positron Spectrum of Darkonium from the Sun
- Direct Detection of Bound Dark Matter
- Probing sub-GeV Dark Matter via Evaporation from the Sun
- Probing sub-GeV Dark Matter with Inelastic Bremsstrahlung