Dark Gamma Ray Bursts

based on :

VB, J. Kopp, J. Liu, Phys. Rev. D 95, 055031(arXiv:1607.04278)

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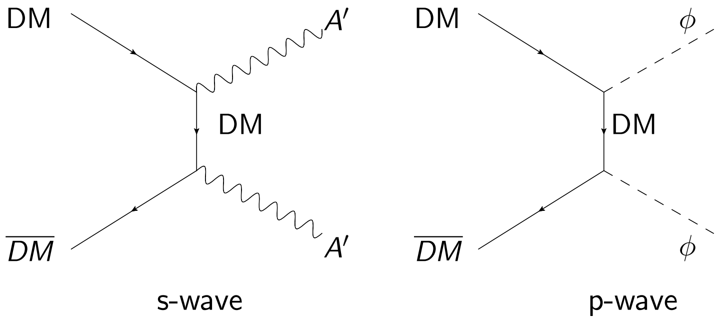
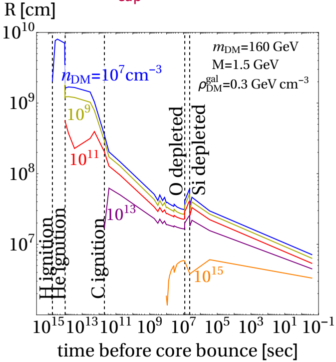
BSM particle content

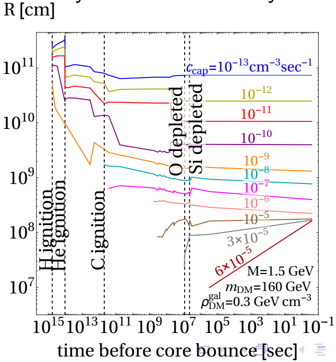
- fermionic (Dirac) DM $\sim$ (1,1,0)
- $\sim \mathcal{O}(1)$ GeV dark photon or scalar coupling to
  - DM
  - SM via kinetic mixing (vector) or higgs portal (scalar)



Capture Rates and DM Distribution in the Star

- $\rho_i(r,t), T(r,t)$ and chemical composition from Heger *et al.*
- $m_{DM} \in [10, 10^3]$ GeV, $\sigma^{SD} = 10^{-40} cm^2$, $\sigma^{SI} = 10^{-46} cm^2$
- DM core contracts along with the baryonic matter
- Quasi-instantaneous thermalization ($n_{\rm DM}(r) = n_0 \exp[-m_{\rm DM}\phi(r)/T_{\rm DM}]$)
- Large $C_{\rm cap}$ at early times due to large σ_{SD} on H
- $C_{\rm cap}$ at later time dominated by H in the outer layers and ^{14}N

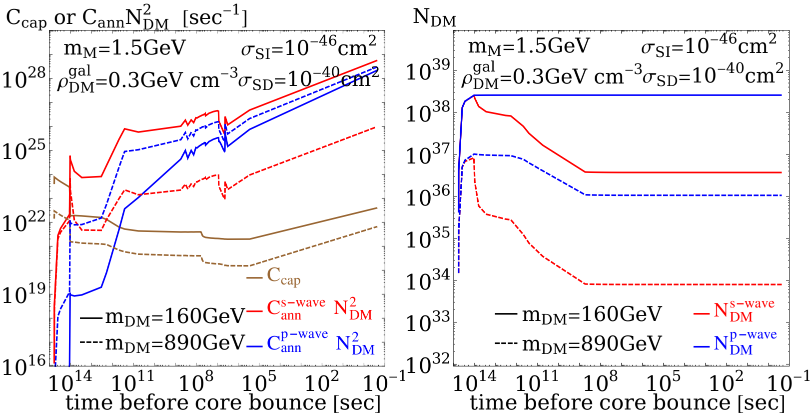




Capture and Annihilation Rates

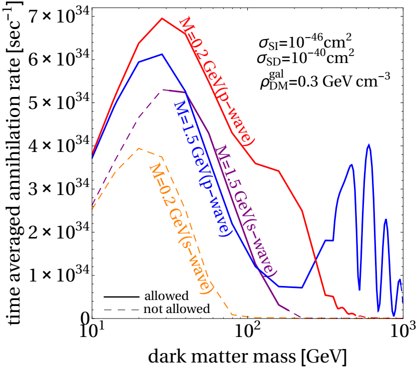
$$\dot{N}_{\rm DM}(t) = C_{\rm cap}(t) - C_{\rm ann}(t) N_{\rm DM}(t)^2 + C_{\rm self}(t) N_{\rm DM}(t)$$

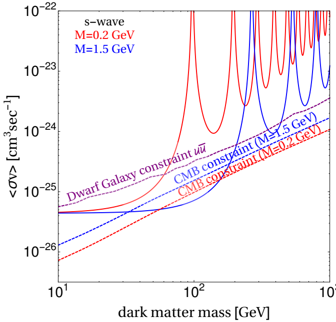
$$C_{\rm cap} = \sum_i \int_0^{R_{\rm star}} dr\, 4\pi r^2 \frac{dC_i(r)}{dV} \qquad C_{\rm ann} N_{\rm DM}^2 \equiv \int d^3 r\, \langle \sigma v_{\rm rel} \rangle\, n_{\rm DM}^2(r)$$



DM Annihilation Burst during Supernova cooling phase

- density and temperature fixed to $10^{14}\ \mathrm{g\,cm}^{-3}$ and 3 MeV
- DM particles within $R_{core} \sim 30km$ (size of proto-neutron star)
- DM gets thermalized within $\sim 10^{-6}$ seconds
- $N_{\rm DM}(t) = \frac{N_0}{1+t\, C^{SN}_{\rm ann} N_0}$ $\quad \Delta t_{dur} \sim \left(C^{SN}_{\rm ann} N_0\right)^{-1}$ $\quad C^{SN}_{\rm ann} = \langle \sigma v_{\rm rel}\rangle \left(\frac{G_N m_{\rm DM} \rho_{\rm SN}}{3 T_{\rm SN}}\right)^{3/2}$

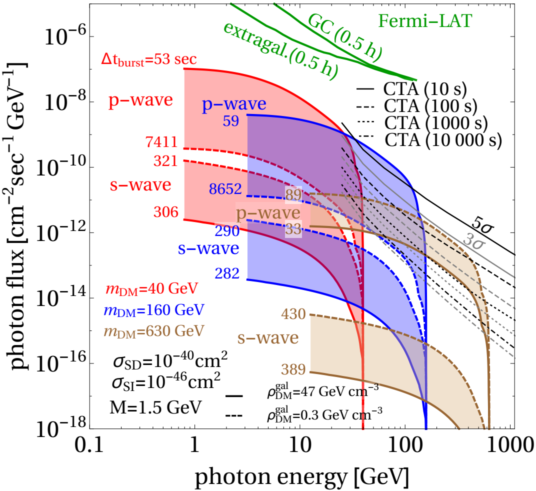




Dark Gamma Ray Burst

Properties

- An observable gamma ray signal after ν arrival
- $\Delta t_{burst} = (C_{ann}^{SN} N_0)^{-1}$ related to sensitivity
- $\Delta t_{burst} \in [\mathcal{O}(10), \mathcal{O}(10^3)]$ sec for p-wave, $\mathcal{O}(10^2)$ sec for s-wave
- Benchmark locations: $0.1 kpc$ and $8 kpc$ from GC



Summary

- We have computed the evolution of the DM core in a massive star until core collapse
- If the DM annihilation products are able to leave the exploding star and decay to SM particles later, this may lead to an observable signal
- Such dark gamma ray burst can be detected by CTA for p-wave DM
- p-wave has larger photon flux than s-wave!

  This is a special feature since p-wave annihilation is generally harder to detect than s-wave ($< \sigma v >= \sigma_0 v^2$, with $v \sim 10^{-3}$ for galactic DM)
- The best signal is around $m_{\rm DM} \sim O(100)$ GeV

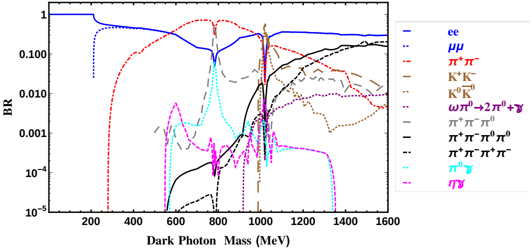
BACKUP SLIDES

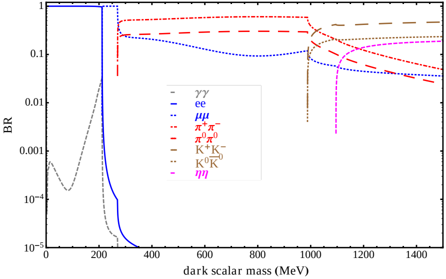
DM annihilation in the Sun

Capture and Annihilation ($dN/dt = C_{cap} - C_{ann} N^2$)

1. Conditions:
   - $C_{ann}^{\rm Sun} \equiv \frac{1}{N^2} \int d^3 r \, \langle \sigma v_{\rm rel} \rangle \, n_{\rm DM}^2(r) \sim 10^{-53} s^{-1}$
   - $C_{cap} = \sum_i \int_0^{R_{\rm star}} dr \, 4\pi r^2 \, \frac{dC_i(r)}{dV} \sim 10^{22} s^{-1}$
   - parameters: $m_{DM} = 100 \, GeV$, $\sigma_{SD}^H = 10^{-40} cm^2$ and $\langle \sigma v_{\rm rel} \rangle = 3 \times 10^{-26} cm^3 s^{-1}$
2. Results:
   - $N(t) = \sqrt{\frac{C_{cap}}{C_{ann}}} \tanh \frac{t}{t_{eq}} \rightarrow \sqrt{\frac{C_{cap}}{C_{ann}}} \sim 10^{37}$
   - $t_{eq} \equiv 1/\sqrt{C_{cap} C_{ann}} \sim 10^{15} s$, $t_{Sun} = 10^{17} s$
   - $C_{ann} N^2 = C_{cap} = 10^{22} s^{-1}$
3. Conclusion: **For the case of the Sun, there is an equilibrium!**

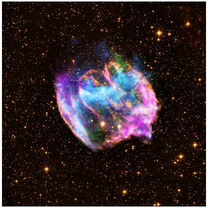
Decay modes of dark mediators





Liu,Weiner, Xue, arXiv:1412.1485

Supernova progenitors versus the Sun

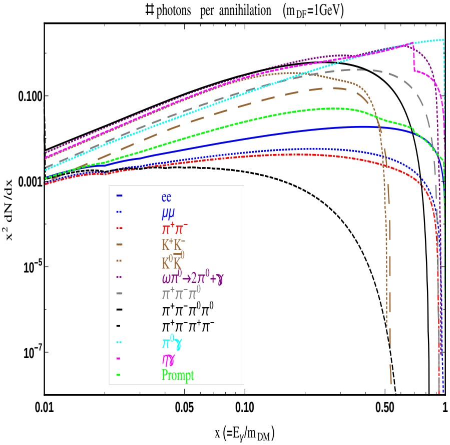


- $\mathcal{O}(10^8)$ further than the Sun, $\sim 1kpc$
- much heavier than the Sun, $\gtrsim 8M_{Sun}$
- $\mathcal{O}(10^{-2})$ shorter lifetime $\sim 10^{15}s$
- density, temperature and chemical composition change in time much faster
- End up with a core collapse Supernova
- Peak annihilation rate (dark gamma ray burst coincident with the supernova) $\mathcal{O}(10^{12})$ larger than the Sun!
- Capture and Annihilation *Not* in Equilibrium!

Photon Spectrum

Liu,Weiner, Xue, arXiv:1412.1485

dN/dx for dark photon



dN/dx for dark scalar