Inelastic Dark Matter Capture in White Dwarf Stars

Planck 2010, CERN

Based on: arXiv:1001.2737 - M. M, M. Fairbairn. Phys.Rev.D81:083520.

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Overview

- Inelastic Dark Matter.
- Indirect Detection from Solar Capture.
- Indirect Detection from Capture in White Dwarf stars.
- Conclusions and Prospects.

Inelastic Dark Matter

A dark matter particle for which the dominant scattering on a nucleus is inelastic. Proposed to explain the DAMA NaI results, [Weiner, Smith 01].

If χ_+ and χ_- split by a small mass δ, then to impart a recoil energy E_R to the nucleus, χ_- must have a minimum relative velocity:

$$v_{min} = \sqrt{\frac{1}{2m_N E_R}}\left(\frac{m_N E_R}{\mu} + \delta\right) \tag{1}$$

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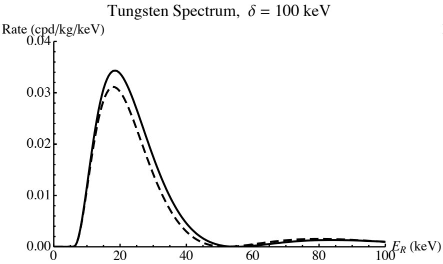
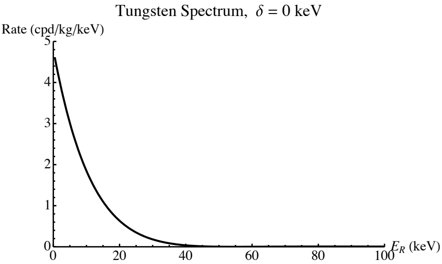
- Sneutrino iDM - [Tucker-Smith, Weiner 01, 05; March-Russell, McCabe, M. M. 09]
- Fourth Generation Neutrino iDM - [Tucker-Smith, Weiner 01, 05]
- Dirac Neutralinos, Warped Fermions/Scalars, Z' Mediation - [Cui, Morrissey, Poland, Randall 09]
- Broken Non-Abelian Dark Sector - [Arkani-Hamed, Finkbeiner, Slatyer, Weiner 08]
- Composite - [Alves, Behbahani, Schuster, Wacker 09]

This greatly changes the phenomenology of direct detection, leading to:

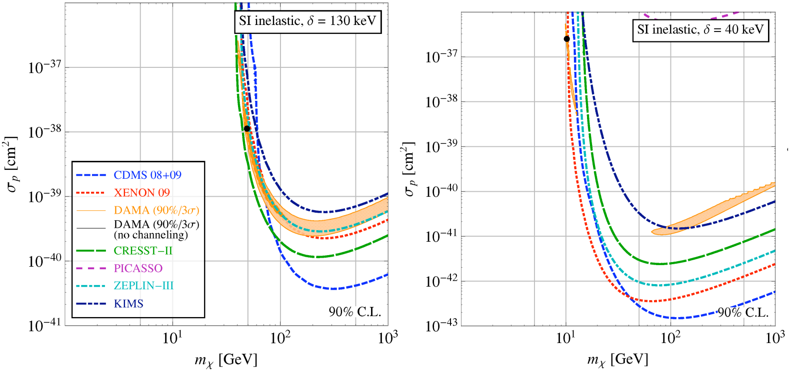
- Elimination of many low-energy events due to the kinematics.
- Enhancement of signal modulation.
- A preference for scattering on heavier nuclei.
- Allowed σ_n factors of > 10 compared to elastic DM scattering.





Direct Detection Results

Recent studies of Direct Detection of inelastic dark matter (arXiv:0912.4264 - J. Kopp, T. Schwetz and J. Zupan) find:



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Answer: Capture in the Sun! Nussinov, Wang, Yavin 2009; Menon, Morris, Pierce, Weiner 2009.

Pros:

- Escape velocity $v_{esc} \sim 1000$ km/s - $KE > \delta$.
- Heavy elements (up to Fe) present.

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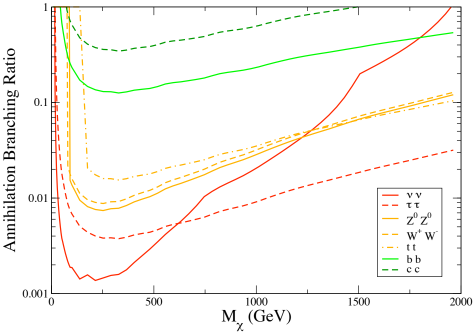
Cons:

- Mostly H and He and for $\delta \sim 100$ keV scattering on these elements is suppressed.
- Heavy elements only make up small fraction, i.e. Fe roughly $\sim 10^{-3}$.
- Search for DM annihilating to $\nu\nu$, so models of DM that annihilate to e^+e^- are unconstrained.
- Neutrinos are hard to detect.

Should we be pessimistic?

iDM Capture in the Sun

No! Neutrino telescopes are now so good that strong limits can be placed on this scenario. Limits from Nussinov et al:



- Icecube should improve these limits by greater than an order of magnitude.
- Get out clause: Annihilation to $e^+e^-, \mu^+\mu^-, \gamma\gamma$, light hadrons or gluons. Or the light iDM scenario mentioned above.

DM Capture in White Dwarf Stars

These two models left with avenues for escape:

- Annihilation to $e^+e^-, \mu^+\mu^-, \gamma\gamma$, light hadrons or gluons.
- $m_\chi \sim 10$ GeV.

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Pros:

- Escape velocity $v_{esc} \sim 10000$ km/s - $KE >> \delta$.
- WD luminosity sensitive to annihilation channels: $e^+e^-, \mu^+\mu^-, \gamma\gamma$, light hadrons or gluons.
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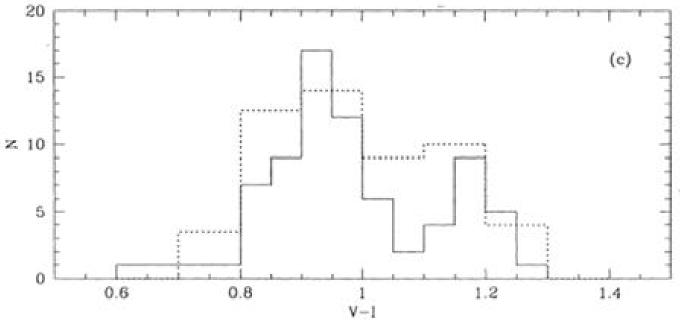
Cons:

- Observed cold WDs reside in the dense cores of globular clusters, and DM density in GC cores not well determined.

GCs in galaxies typically have a 'bimodal' distribution of colour, metallicity and spatial distribution. (Taken from Elson and Santiago 1996)



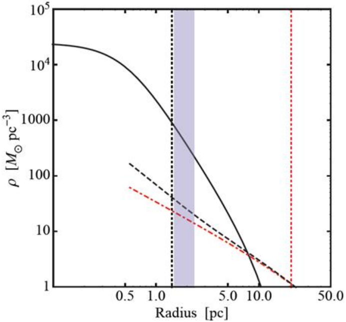
This prompts consideration of two distinct modes of globular cluster formation.

- Younger, higher metallicity, 'red' GCs forming in gas mergers - i.e. no DM.
- Old, metal-poor, 'blue' GC formation... subject to debate.

The GC we're interested in is M4, and fits into the second category.

We model stellar distribution with a King profile, assuming $M_{M4} = 10^5 M_\odot$ and tidal radius $r_t = 21$ pc. Find a velocity dispersion of $\overline{v} \sim 8$ km/s.

King profile goes to zero at the tidal radius, truncate DM profile here too. Assuming primordial formation:



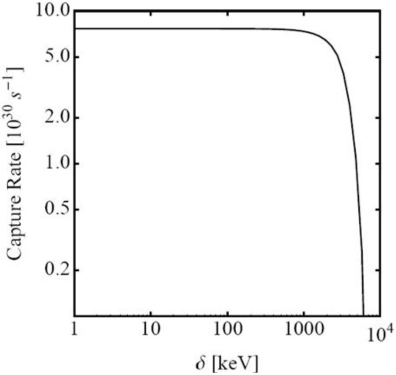
Conversion of densities: 1 $M_\odot$ pc^{-3} = 38 GeV cm^{-3} giving $\rho_{DM} \approx 798 GeV cm^{-3}$.

Formation with no DM: $\rho_{DM} \sim$ few $GeV cm^{-3}$

iDM Capture in WDs.

Calculate the capture rate in a given WD using the formalism from Gould 1987, and for iDM capture in Nussinov et al. 2009.

Assume the WDs are composed of Carbon and use the Salpeter equation of state.



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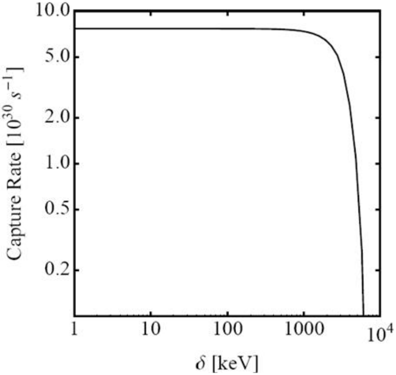

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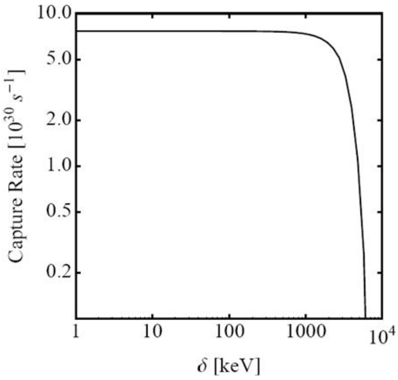

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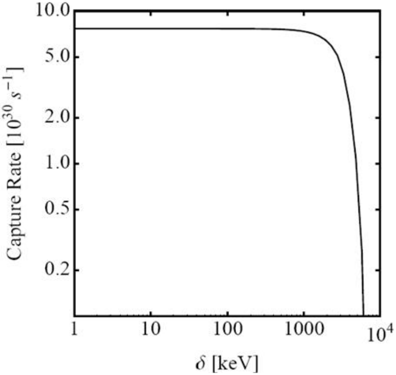

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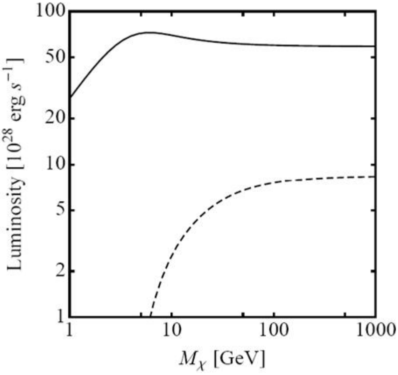
For $\sigma_n > 10^{-41}$ cm^2 capture rate saturates and becomes independent of σ_n.

Capture rate roughly goes as $C_\star \propto M_\chi^{-1}$.

Expect luminosity independent of mass, but complicated behaviour at low masses.



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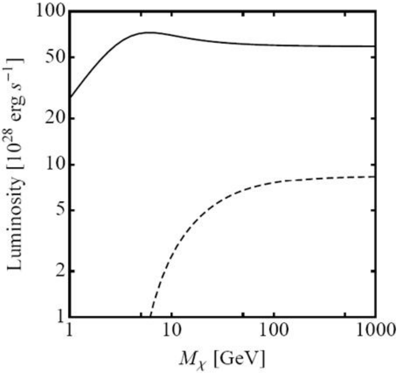

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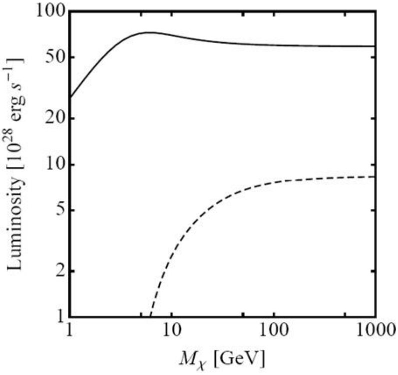

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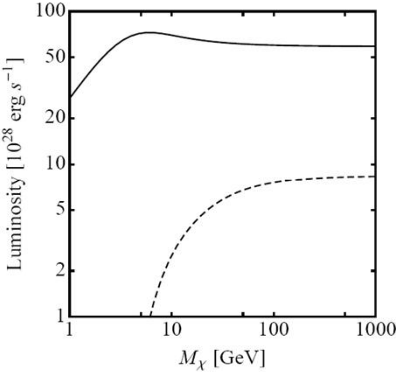

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- For M_χ large $\frac{1}{2}M_\chi v_{esc}^2$ is large and form factor suppression is greater.
- v_{esc} depends on WD mass.

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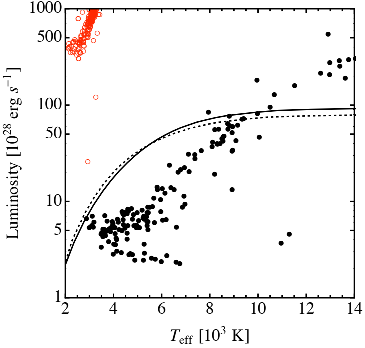
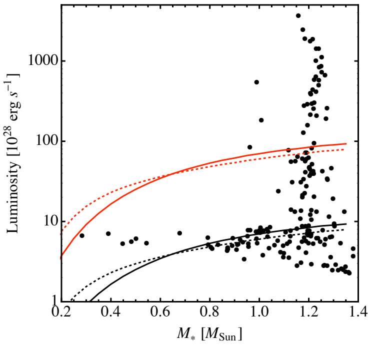
Comparing luminosity due to DM capture (lines) with data:





On the left $\sigma_n = 10^{-41}$ cm^2 and on the right $\sigma_n = 10^{-41}$, 10^{-42} cm^2.

Thick line for $m_\chi = 10$ GeV and dotted for $m_\chi = 100$ GeV.

If M4 formed with no DM in core then luminosity below observed WDs.

Conclusions and Prospects

Does this rule out annihilating iDM or light WIMPs? No. It is possible that M4 formed with no DM in its core.

Hooper, Spolyar, Vallinotto and Gnedin estimate the DM in core for this scenario at $\rho_{DM} \sim$ few GeV cm^{-3}. Puts luminosity from iDM capture just below observed WDs, so formation of M4 will need to have been very baryonic-matter-pure.

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Definite conclusions:

- The capture of iDM and light WIMPs in WDs is interesting.
- This could lead to observable physics.
- Annihilating iDM and light WIMPs appear inconsistent with a model of old, metal-poor GC formation.
- If DM is discovered then cold WDs could be used to place limits on DM density in GCs, thus giving clues as to their formation history.
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See also 'Inelastic Dark Matter as an Efficient Fuel for Compact Stars' Hooper, Spolyar, Vallinotto and Gnedin 2009 for similar work, although assuming no DM in GCs.

Thanks!