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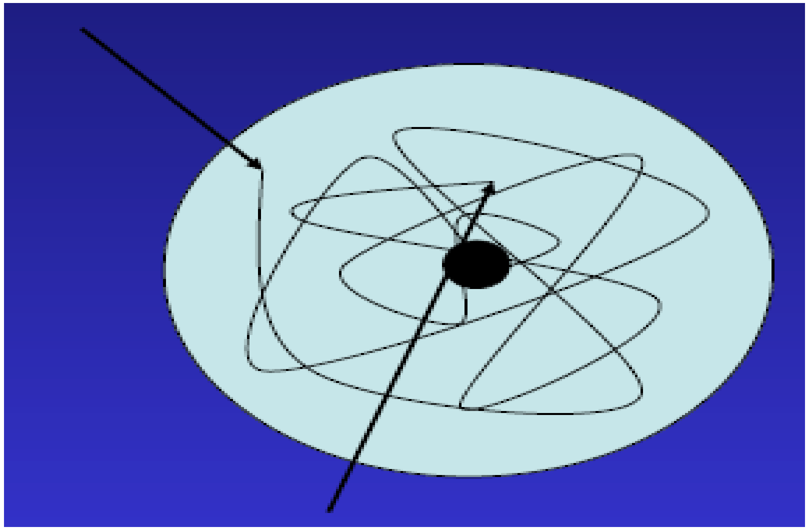
Effects of low mass DM particles on the Sun

with F.Iocco, G.Bertone, G.Meynet, P.Eggenberger

Identification of Dark Matter 2010

Montpellier, 26-30 July 2010

WIMPs capture by a star



Credit: F. Iocco

Halo WIMPs crossing the star can scatter off nuclei to a velocity lower than the escape velocity. These particles are gravitationally CAPTURED by the star.

Once captured, WIMPs orbit inside the star, scatter off nuclei and sink to the center

WIMPs CAPTURE rate $$C \propto \sigma_{\chi N} \frac{\rho_\chi}{m_\chi} \frac{M_*}{M_N} \frac{v_{escp}^2}{\bar{v}}$$

A.Gould (1987)

The number of WIMPs inside the star is given by:

$$\dot{N}_\chi = C - 2AN_\chi^2 - EN_\chi$$

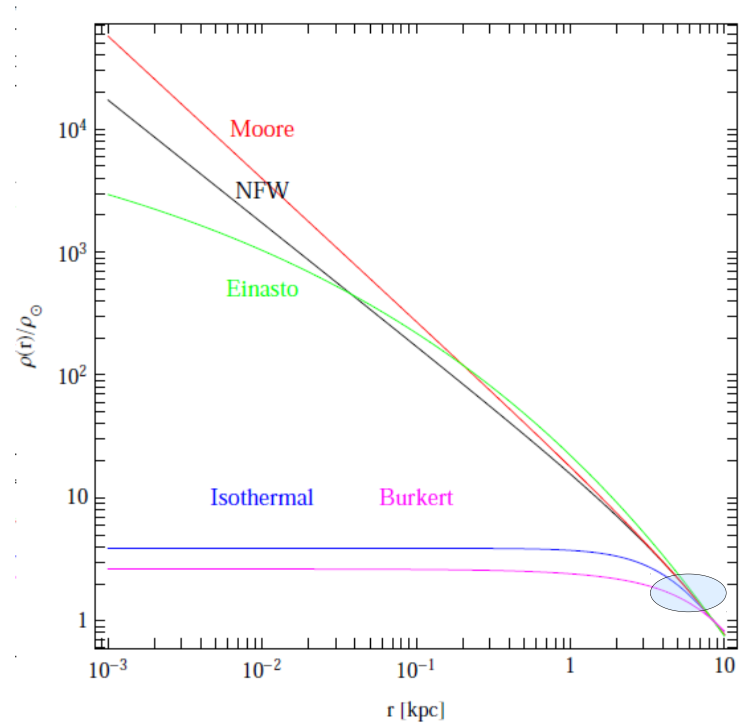
A is the ANNIHILATION rate E is the EVAPORATION rate

Evaporation is relevant only for DM masses ≤ 4 GeV

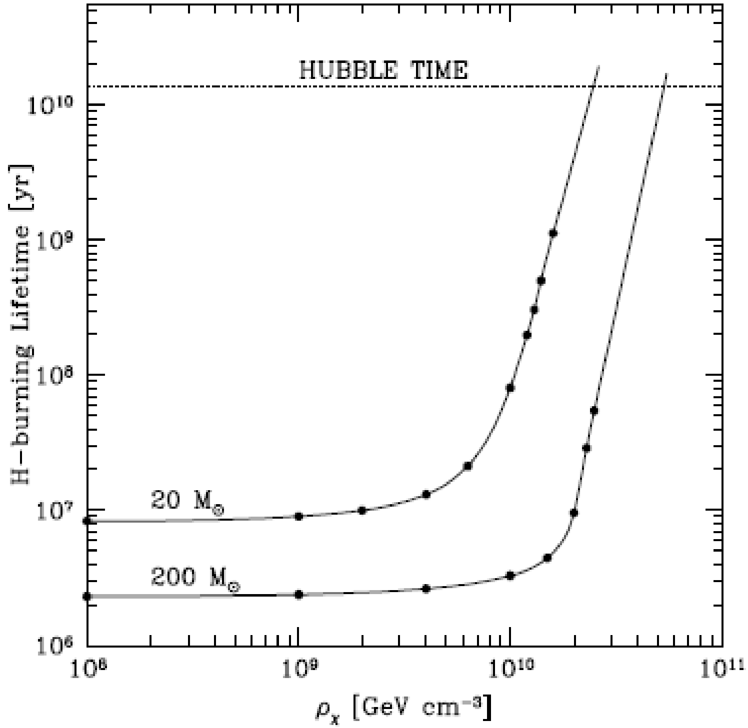
The DM distribution inside the star is $$n_\chi(R) = n_0 e^{-R^2/R_\chi^2}$$

with $R_\chi << R_*$ WIMPs are confined in a region typically of $\mathcal{O}(0.1)$ of the core radius

Large capture rates at the center of DM halos.



Taoso et al. 2008



The evolution of first stars may be dramatically modified by WIMPs annihilations!

Strong effects in stars in high DM density environments,

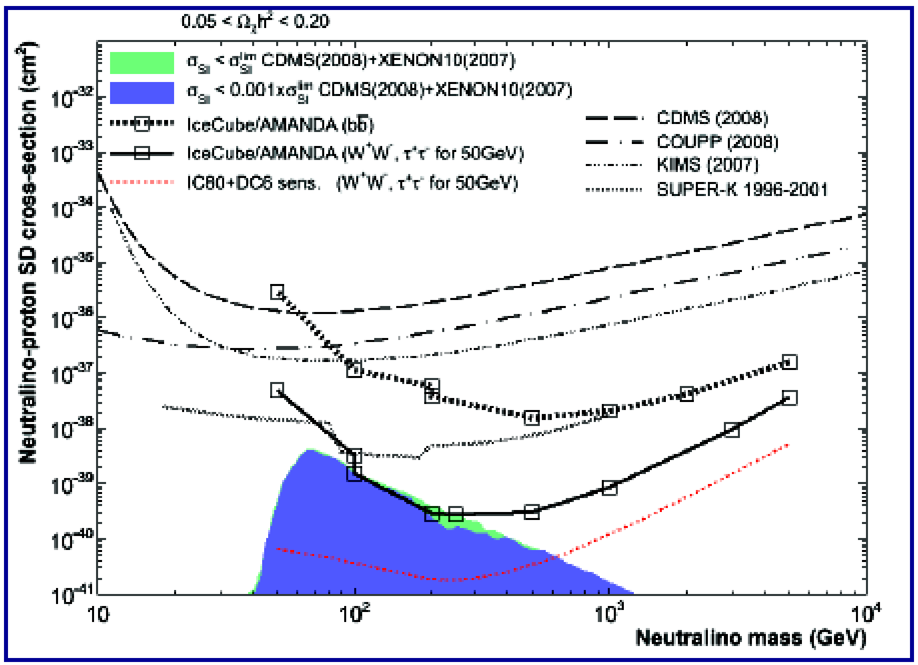
e.g. stars close to the galactic center or first stars. Taoso et al, Iocco et al. Freese et al., Scott et al.

“Standard” WIMP with $\langle \sigma v \rangle \sim 3 \times 10^{-26}\ \mathrm{cm}^3\ \mathrm{s}^{-1}$

After a small temporal transient τ_χ annihilations and capture reach a $N_\chi = C \tau_\chi$

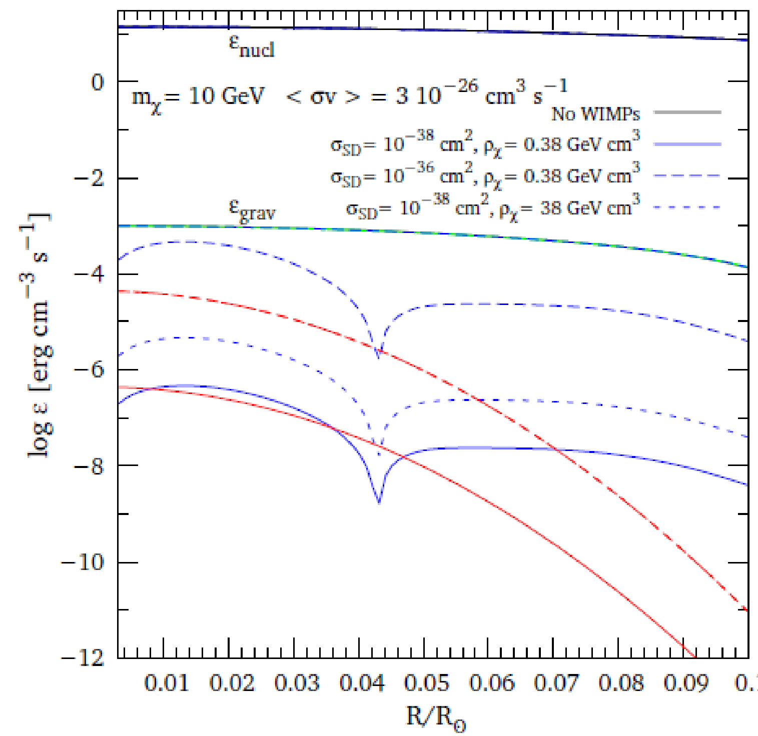
High Energy ν from DM annihilations

Upper bounds on SD DM-p cross section



Negligible energy provided by

WIMPs annihilations inside the Sun



“Standard” WIMPs does not affect sensibly the properties of the Sun

The case of ASYMMETRIC DM

Annihilations are **absent** if the DM particle is not autoconjugate and the DM sector present an asymmetry between particles and anti-particles, in analogy to SM baryon number

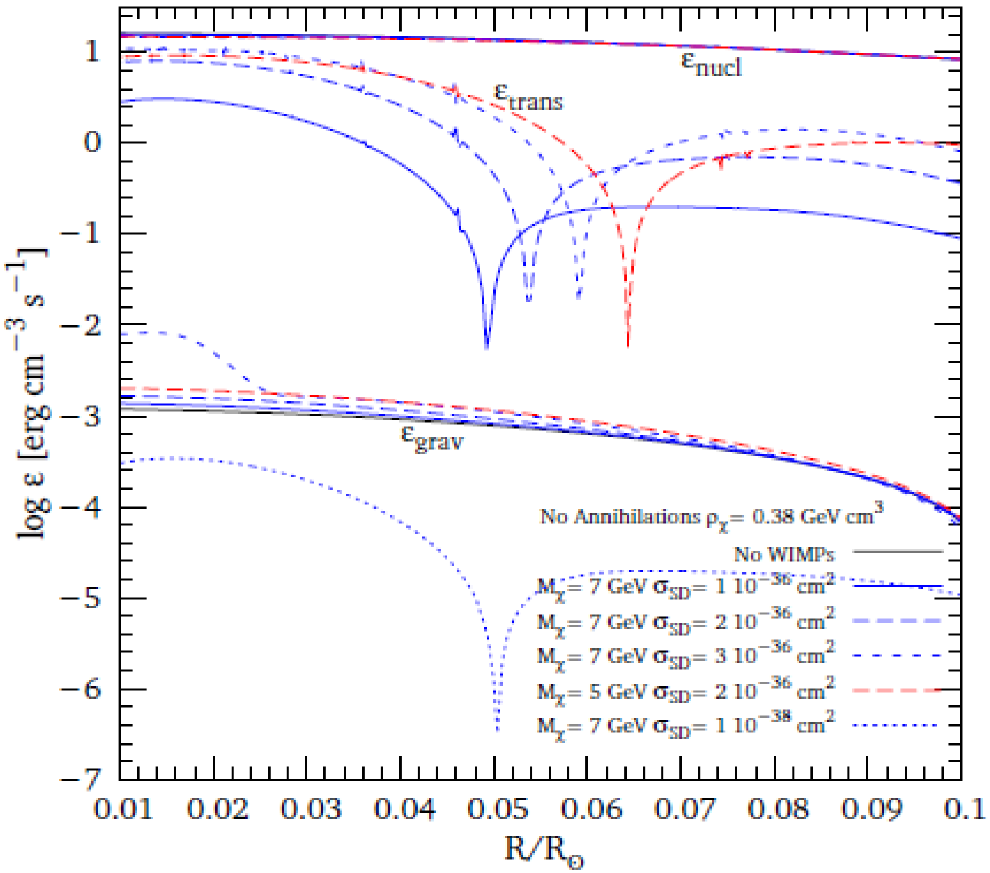
If a global charge is shared between SM and the DM sector Ω_χ and $\Omega_{\mathrm{baryibs}}$ are related

$$\frac{\Omega_\chi}{\Omega_b} \sim \frac{m_\chi}{m_b}$$

The number of WIMPs inside the Sun is boosted with respect to the annihilating case

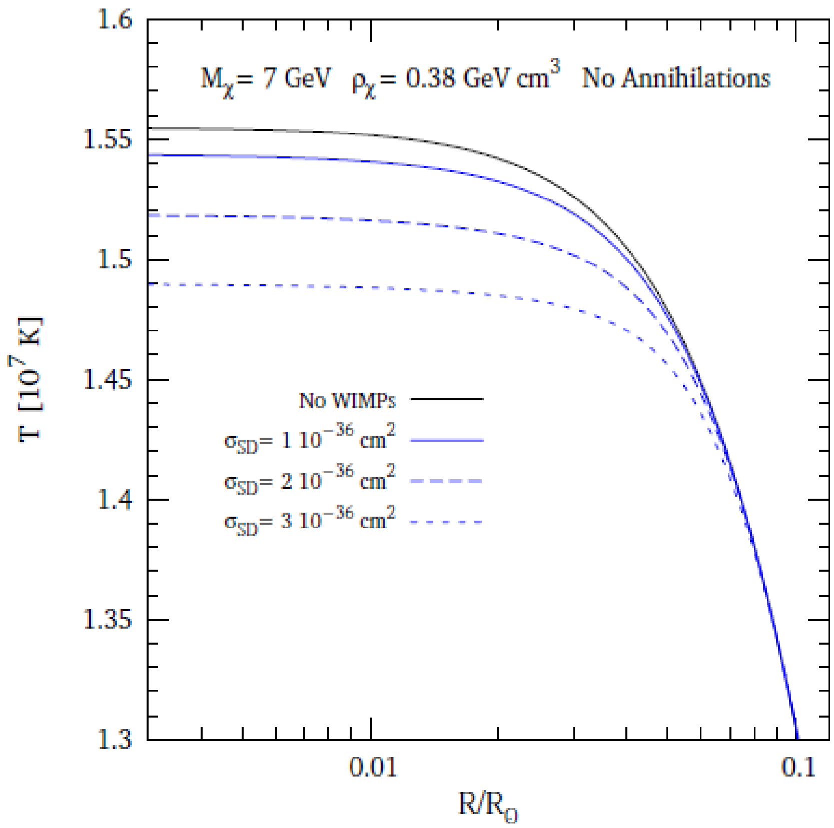
$N_\chi = C t_\odot$ with the age of the Sun $t_\odot = 4.57 \times 10^9 \mathrm{yr}$

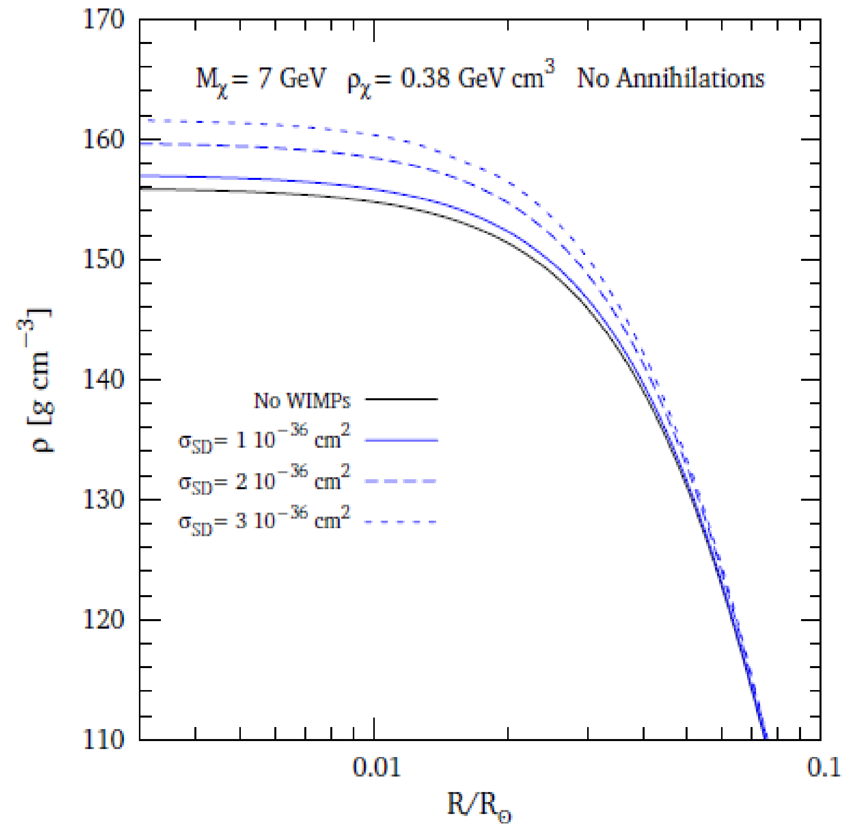
WIMPs orbiting inside the star and scattering off nuclei TRANSPORT ENERGY from the center of the Sun to the outer regions



Formalism in Gould et al. 1990, Spergel et al. 1985

Effects of the DM transport of energy inside the Sun.



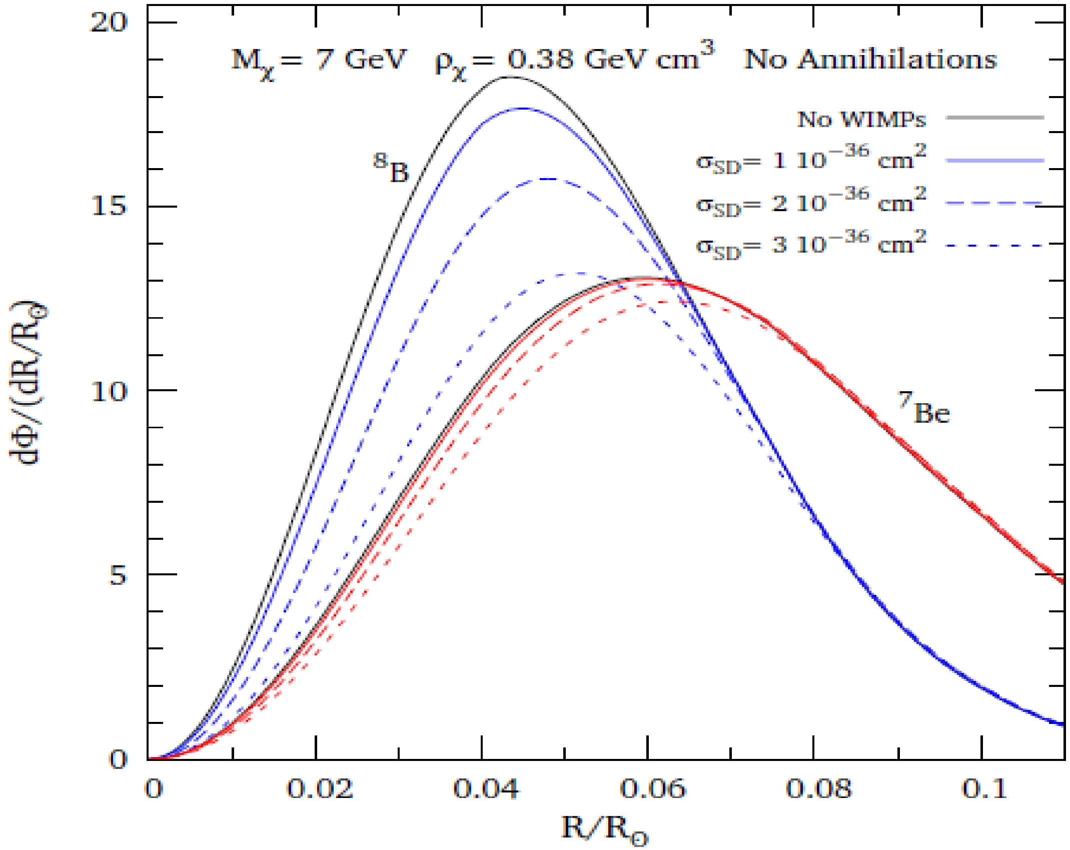


DM extracts energy from the center so the central temperature is decreased.

The baryon density is increased due to the contraction of the core

Look for solar observables modified by the presence of DM

Solar neutrinos are extremely sensitive to temperature of the Sun in the inner regions



Effects were studied in '80 in the context of cosmions to solve the solar neutrino problem!

Faulkener et al. 1985,
Dearborn et al 1991...

More recent analysis:

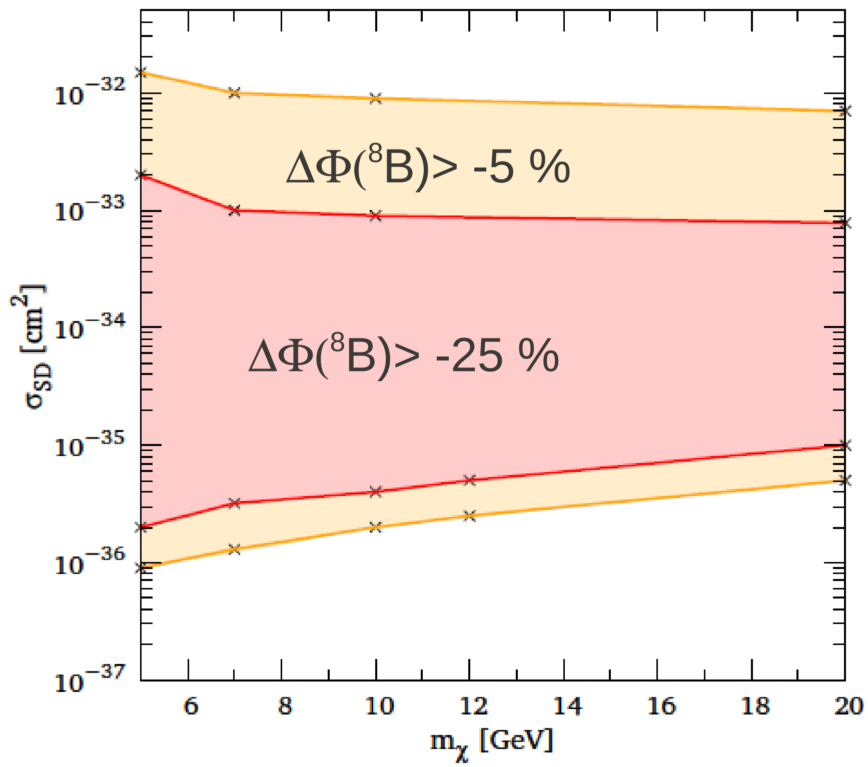
Bottino et al. 2002

^{8}B neutrinos are the most sensitive to the effecs of DM since they are the most “internal”

DM energy transport lowers the solar neutrinos fluxes ---> solar ν fluxes constraints DM

Geneva evolution code used to evolved the Sun from the ZAMS to the present age in presence of DM particles

Spin Dependent interactions



For masses below 4 GeV the evaporation is relevant and the effects are dramatcially reduced

Experimental + Theoretical uncertainty on $\Phi(^8B) \rightarrow$ 18-30 % decrease excluded @ 95% CL

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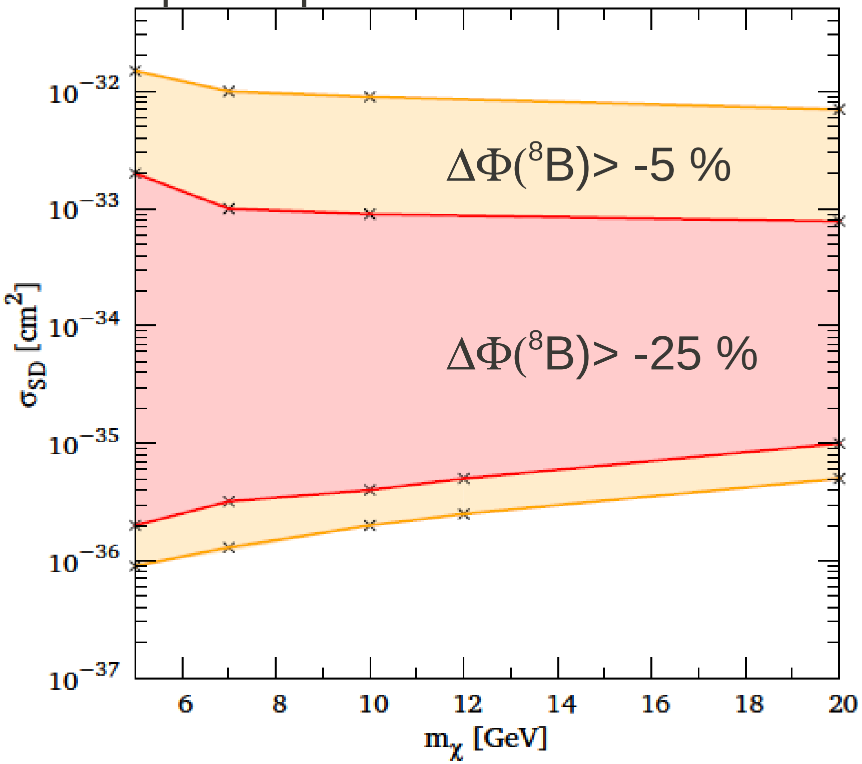
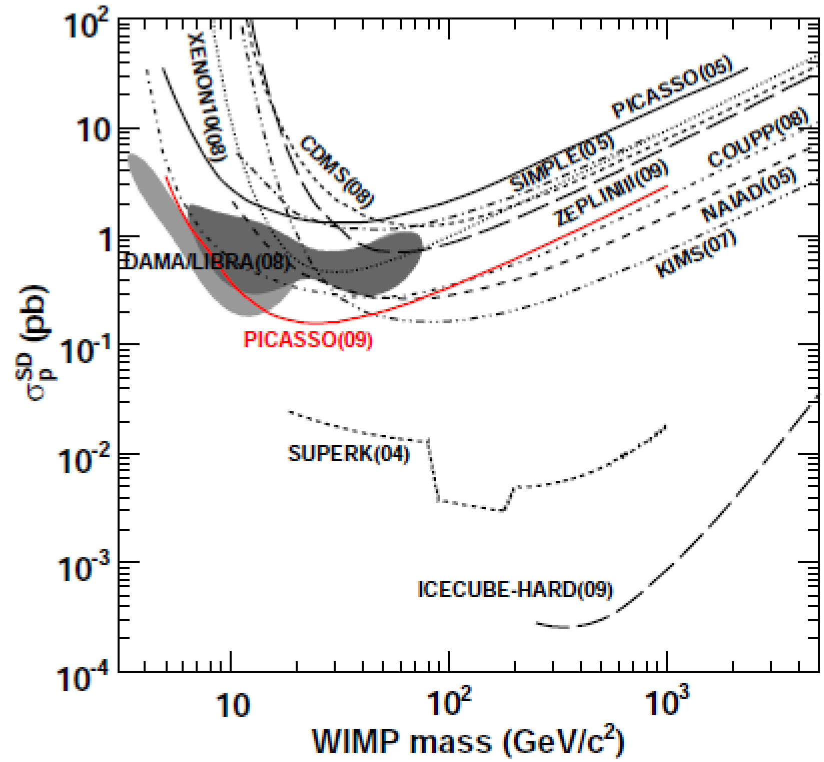




Experimental + Theoretical uncertainty on $\Phi(^8B)$ → 18-30 % decrease excluded @ 95% CL

DM transport from the center to the outer shell can be viewed like an effective decrease of the opacity → this may modify the helioseismology curves and the edge of the convective zone.

Can DM particles change helioseismology? Frandsen and Sarkar. 2010

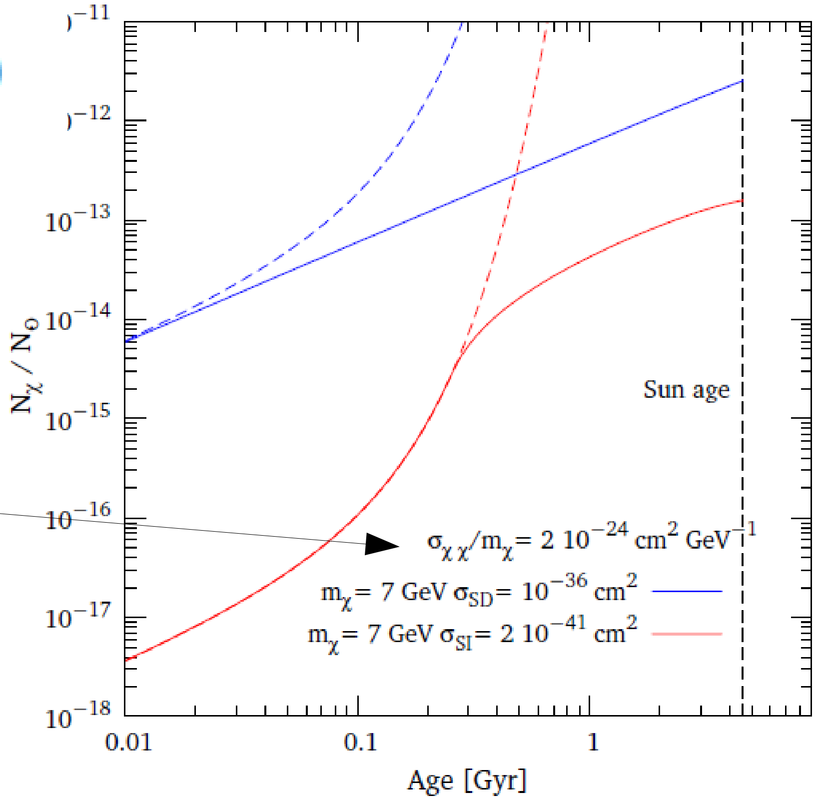
Self interacting DM in the Sun: the number of DM particles is largely increased!

$$N_\chi(t) = \frac{C}{C_{\chi\chi}} \left(e^{C_{\chi\chi} t} - 1\right)$$

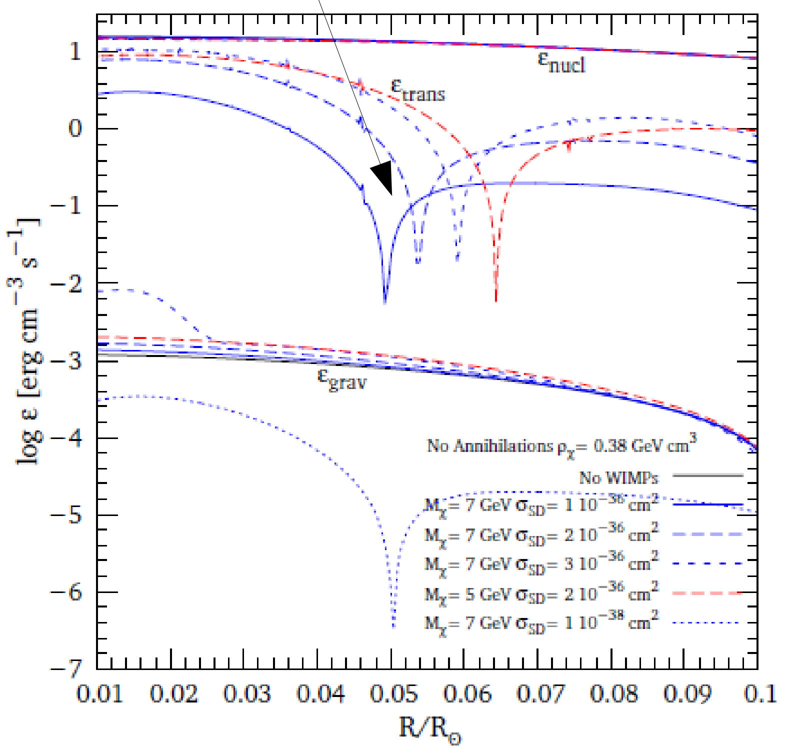
Upper limit on

DM self interactions

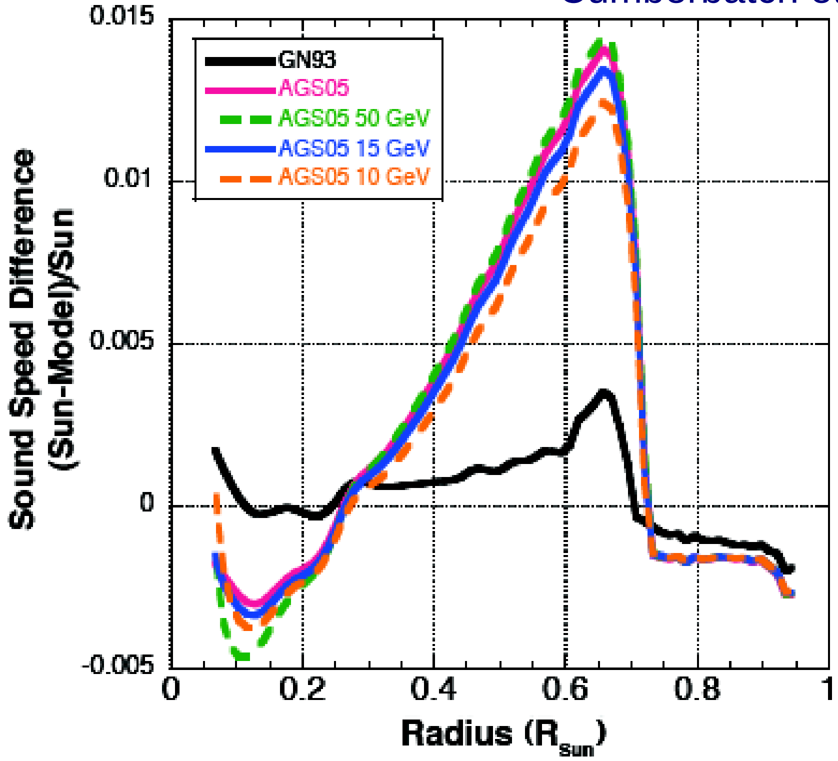
from the bullet cluster



Energy extracted from a a region smaller than the solar core and diluted in a > 1000 larger volume: effects of DM energy transport small outside the solar core.



Cumberbatch et al. 2010



Helioseismology curves almost unchanged outside the core.

Solar composition problem is not solved.

See J.Silk talk

CONCLUSIONS

Standard WIMPs model with efficient DM self-annihilations do not affect the Sun properties

Important effects may occour for stars at the GC, first stars,...

Solar neutrino fluxes can constraints the DM SD cross section off nuclei for Asymmetric Dark Matter models.

The constraints are competitive with those from direct detection for light DM.

DM modify only the internal structure of the Sun so the effects are not relevant to solve he solar composition problem.