Stellar convective cores as dark matter probes (Casanellas, Brandao, Lebreton, arXiv:1505.01362; Phys.Rev. accepted)

Jim Rich

SPP-IRFU
CEA-Saclay
91191 Gif-sur-Yvette

james.rich@cea.fr

May, 2015

The idea:

THE ASTROPHYSICAL JOURNAL, **294**: 663–673, 1985 July 15

EFFECT OF HYPOTHETICAL, WEAKLY INTERACTING, MASSIVE PARTICLES ON ENERGY TRANSPORT IN THE SOLAR INTERIOR

DAVID N. SPERGEL AND WILLIAM H. PRESS
Harvard-Smithsonian Center for Astrophysics
Received 1984 December 28; accepted 1985 January 28

ABSTRACT

A possible solution to the solar neutrino problem is to posit a massive, stable, neutral particle as part of the Sun's primordial composition. If that particle has a mass between 5 and 60 GeV, then it will populate only the inner "solar neutrino unit–producing" core and not the larger luminosity-producing region. If it has a scattering cross section on protons of 4×10^{-36} cm^2, then a fractional abundance of 10^{-12} will have order-unity effect on the Sun's thermal transport, in the direction of decreasing the expected neutrino signature. For smaller cross sections, the required abundance rises in inverse proportion, so that cross sections as small as 10^{-46} cm^2 are effective if the concentration is as large as $\sim 10^{-2}$. The photino is a possible candidate particle; mirror neutrinos may also be candidates.

Subject headings: elementary particles — neutrinos — nucleosynthesis — Sun: interior

Better idea:

THE ASTROPHYSICAL JOURNAL, **321**:571–585, 1987 October 1

RESONANT ENHANCEMENTS IN WEAKLY INTERACTING MASSIVE PARTICLE CAPTURE BY THE EARTH

ANDREW GOULD
Stanford Linear Accelerator Center, Stanford University
Received 1987 March 2; accepted 1987 March 17

ABSTRACT

The exact formulae for the capture of weakly interacting massive particles (WIMPs) by a massive body are derived. Capture by the Earth is found to be significantly enhanced whenever the WIMP mass is roughly equal to the nuclear mass of an element present in the Earth in large quantities. For Dirac neutrino WIMPs of mass 10–90 GeV, the capture rate is 10–300 times that previously believed. Capture rates for the Sun are also recalculated and found to be from 1.5 times higher to 3 times lower than previously believed, depending on the mass and type of WIMP. The Earth alone or the Earth in combination with the Sun is found to give a much stronger annihilation signal from Dirac neutrino WIMPs than the Sun alone over a very large mass range. This is particularly important in the neighborhood of the mass of iron where previous analyses could not set any significant limits.

Subject headings: elementary particles — neutrinos

First search:

VOLUME 65, NUMBER 11 PHYSICAL REVIEW LETTERS 10 SEPTEMBER 1990

Searching for the Cosmion by Scattering in Si Detectors

D. O. Caldwell, B. Magnusson, and M. S. Witherell
Physics Department, University of California, Santa Barbara, California 93106

A. Da Silva and B. Sadoulet
Physics Department, University of California, Berkeley, California 94720

C. Cork, F. S. Goulding, D. A. Landis, N. W. Madden, R. H. Pehl, and A. R. Smith
Lawrence Berkeley Laboratory, Berkeley, California 94720

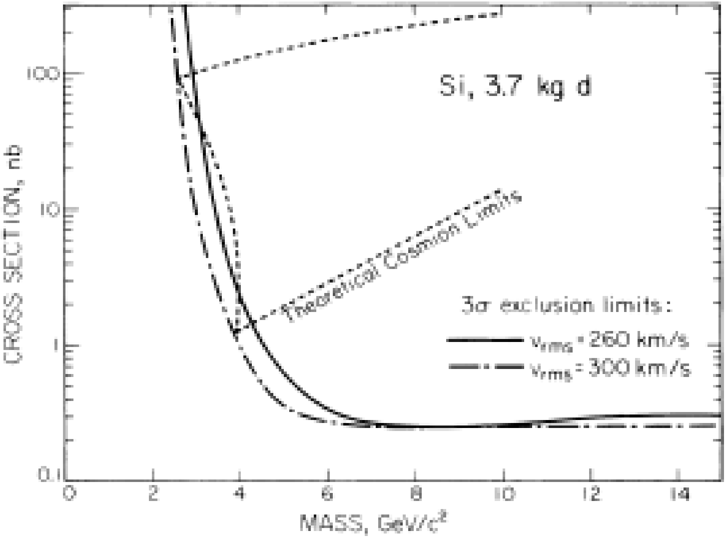
G. Gerbier, E. Lesquoy, J. Rich, M. Spiro, C. Tao, D. Yvon, and S. Zylberajch
Département de Physique des Particules Elémentaires, Centre d'Etudes Nucléaires de Saclay, F-91191 Gif-sur-Yvette CEDEX, France

(Received 5 June 1990)

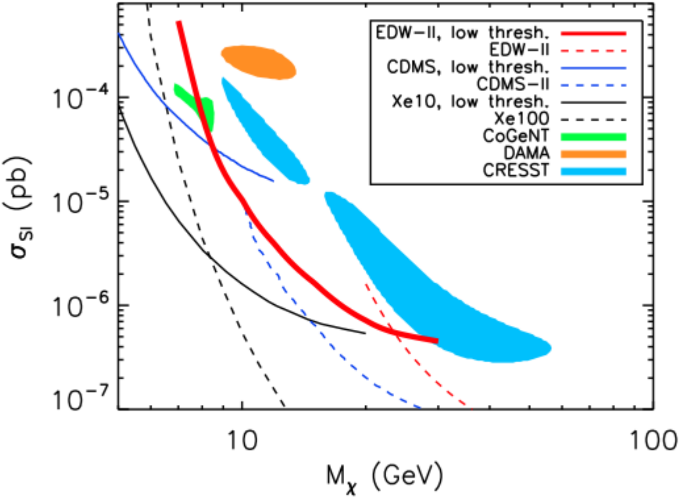
A new particle, the cosmion, has been proposed to be the dark matter of the Universe and to explain the solar ν deficit by cooling the solar core to reduce ^{8}B ν production. Such cosmions in the galactic halo would scatter from nuclei in terrestrial detectors. Measurements were made in Si ionization detectors in a very-low-background environment down to energies of 1.1 keV. These results exclude nearly all of the mass range possible for cosmions with coherent nuclear interactions.

PACS numbers: 95.30.Cq, 14.60.Gh, 14.80.Pb, 96.60.Kx

First search:



Present limits and detections



What happens

- Wimp scatters in star, looses energy resulting in bound orbit passing through the star.
- Repeated collisions in star result in wimp thermalization in core.
- Wimp abundance builds up with time until capture rate balanced by annihilation rate.

    Asymmetric wimps have suppressed annihilation
- Large mean-free-path of wimps efficiently conducts heat from center of star to outer regions

    $\Rightarrow$Lower central temperature

    solves "solar neutrino problem"

    $\Rightarrow$Reduced dT/dr prevents central convection ($M \sim 1.3M_{\odot}$)

    $\Rightarrow$modified pressure wave frequencies

Symmetric and asymmetric Dark Matter

- symmetric dark matter ($n_\chi = \bar{n}_\chi$)

  $n_{relic} \propto 1/\sigma_{annihilation}$

  $\Rightarrow$ low mass wimps have small abundances

  Example: symmetric e^+e^-: $n/n_\gamma \sim 10^{-16}$

  $\sigma_{e^+e^- \to \gamma\gamma} \sim \alpha^2/m_e^2$

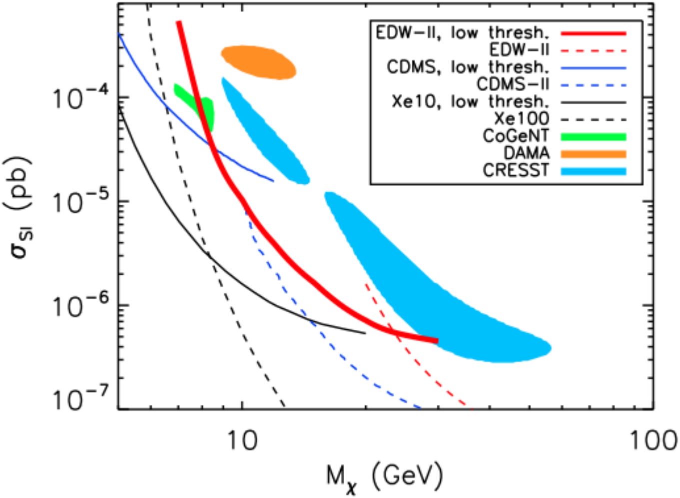
- asymmetric darkmetter ($n_\chi \neq \bar{n}_\chi$)

  n_{relic} determined by $(n - \bar{n})/n_\gamma$

  Example: asymmetric e^+e^-: $n/n_\gamma \sim 10^{-10}$

$\Rightarrow$ Low-mass wimps might be asymmetric

Low-mass wimps



Stellar acoustic vibrations

Fundamental frequency: $\nu \sim c_s/R$
$c_s^2 \sim kT/\langle m \rangle$
Sun: kT ~keV; m ~1GeV $\Rightarrow c_s \sim 10^{-3}c$
$R_\odot = 7 \times 10^8$m
$\Rightarrow \nu_\odot \sim 0.4$mHz

modes: $Y_{\ell m}(\theta, \phi) R_n(r) e^{i\nu(n,\ell)t/2\pi}$

Sun: Doppler imaging of solar surface$\Rightarrow$ many modes
Stars: low-ℓ modes seen in CoRoT and Kepler lightcurves (flux vs. time)

Stellar acoustic vibrations

$Y_{\ell m}(\theta,\phi)R_n(r)e^{i\nu t/2\pi}$: $\nu_{n\ell}$ depends mostly on $n+\ell/2$:

$$\nu_{n\ell} \simeq \Delta\nu\left(n+\frac{l}{2}+\epsilon\right) - \Delta\nu^2\left[\frac{A[\ell(\ell+1)]-B}{\nu_{n\ell}}\right], \qquad (1)$$

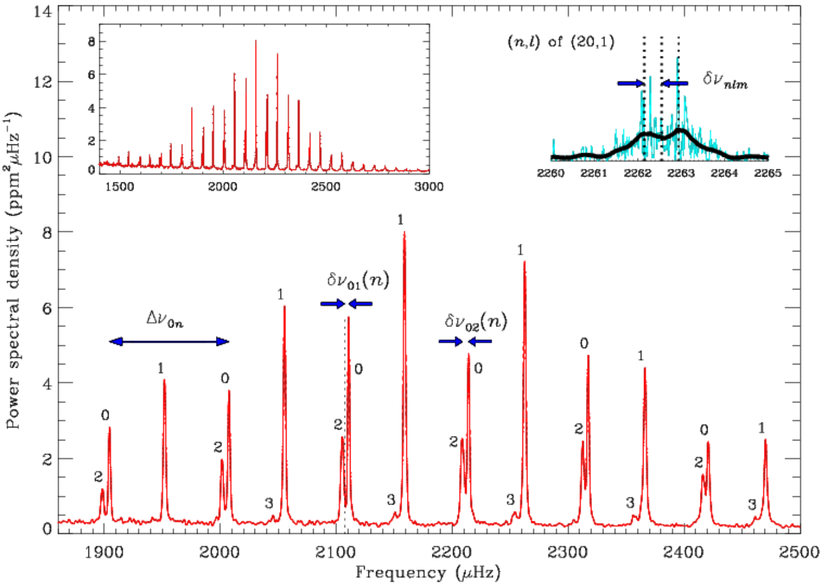
(ϵ and B depend on surface boundary conditions)

$$\Delta\nu = \left(2\int_0^R \frac{\mathrm{d}r}{c}\right)^{-1} \qquad (2)$$

$$A = \left(4\pi^2\Delta\nu\right)^{-1}\left[\frac{c(R)}{R} - \int_0^R \frac{\mathrm{d}c}{\mathrm{d}r}\frac{\mathrm{d}r}{r}\right], \qquad (3)$$

$\Rightarrow \nu_{n\ell} - \nu_{n-1\,\ell+2}$ sensitive to sound velocity gradient near center.

Observable modes have $n + \ell/2 \sim 20$, $\ell = 0, 1, 2$



$\nu_{n\ell}$ combinations sensitive to convective core

$$r_{010} = \{r_{01}(n), r_{10}(n), r_{01}(n+1), r_{10}(n+1), ...\}, \tag{4}$$

where:

$$r_{01}(n) = \frac{(\nu_{n-1,0} - 4\nu_{n-1,1} + 6\nu_{n,0} - 4\nu_{n,1} + \nu_{n+1,0})}{8(\nu_{n,1} - \nu_{n-1,1})}, \tag{5}$$

$$r_{10}(n) = \frac{-(\nu_{n-1,1} - 4\nu_{n,0} + 6\nu_{n,1} - 4\nu_{n+1,0} + \nu_{n+1,1})}{8(\nu_{n+1,0} - \nu_{n,0})}. \tag{6}$$

The frequency derivative of r_{010} may be used to diagnose the presence or the absence of a convective core in the star

Four models

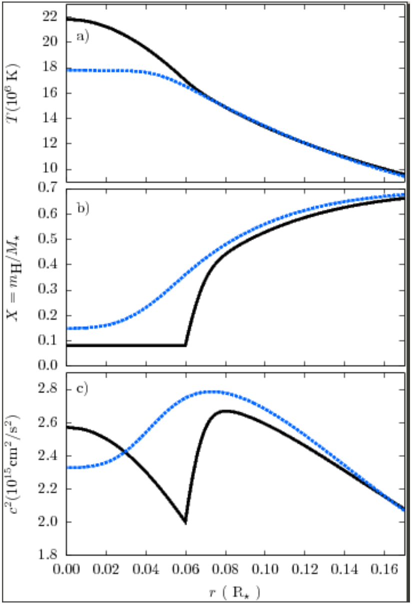
	m_χ (GeV)	σ_χ (cm^2)	Experiment
DM model 1	7	10^{-40}	DAMA+CDMS+CoGeNT [1]
DM model 2	13	10^{-36}	DAMA[2]
DM model 3	8	10^{-33}	CoGeNT[2]
DM model 4	10	10^{-32}	CDMS-Si[2]

Table: Characteristics of the models of dark matter particles tested in this work.

[1]interpreted in terms of SI WIMP-nucleon interactions [2014PDU.....5....1A]

[2]interpreted in term s of SD WIMP-proton interactions [2013PhRvD..88e6003B]

Profiles with and without Model 3 wimps

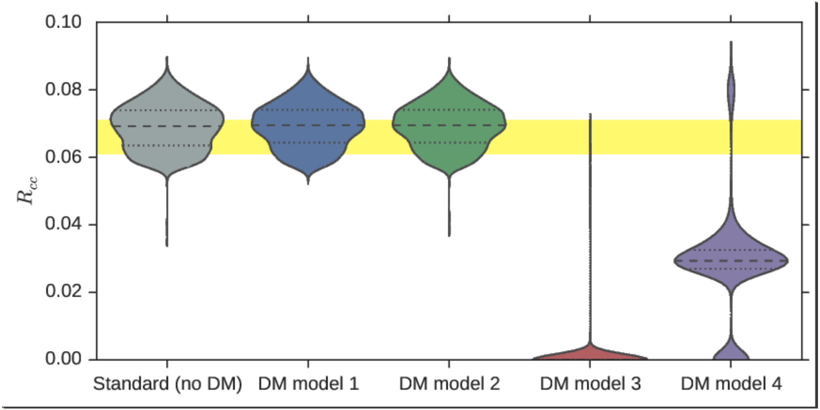


wimp transport lowers $T(r \sim 0)$
and $dT/dr(r \sim 0)$

Hydrogen fraction:
Convection $\Rightarrow d\langle m\rangle/dr(r \sim 0) \sim 0$

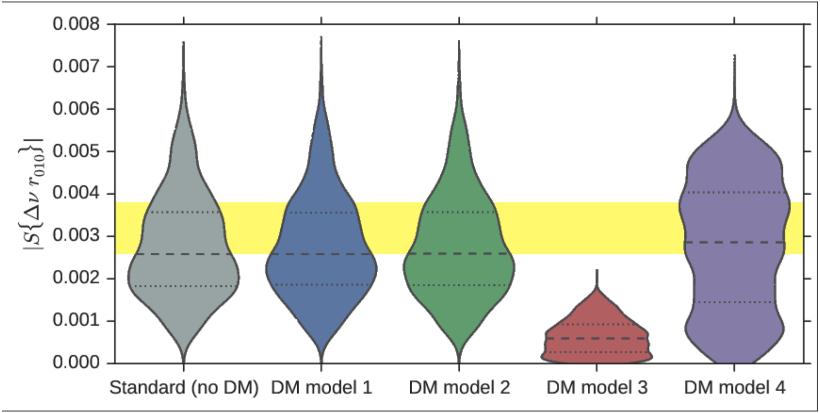
$c^2 \propto T/\langle m\rangle$
For $r < 0.06$:
$d\langle m\rangle/dr < 0 \;\Rightarrow dc/dr > 0$
$dT/dr < 0 \;\Rightarrow dc/dr < 0$

Model 3 has no convective core



Distribution of the radii of the convective core, $R_{\rm cc}$, in all the computed models that reproduce the observations of the star *Dushera*, The shapes of the distributions (violin plots) show the probability density...... The yellow area shows the range of the $R_{\rm cc}$ inferred for *Dushera* in [2013ApJ...769..141S].

Model 3 excluded by seismology



Distribution of the asteroseismic parameter $|S\{\Delta\nu\ r_{010}\}|$ in all the computed models that reproduce the observations of the star *Dushera*, The shapes of the distributions (violin plots) show the probability density. The yellow area shows the value of $|S\{\Delta\nu\ r_{010}\}|$ calculated from the observed frequencies with its uncertainty.

Four models

	m_χ (GeV)	σ_χ (cm^2)	Experiment
DM model 1	7	10^{-40}	DAMA+CDMS+CoGeNT
DM model 2	13	10^{-36}	DAMA
DM model 3	8	10^{-33}	CoGeNT
DM model 4	10	10^{-32}	CDMS-Si

- Models 1 and 2: low $\sigma \Rightarrow$ low capture rate
- Model 4: Wimp mean-free-path small $\Rightarrow$thermal structure not modified
- Model 3: Convection destroyed by wimp thermal conduction.