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DOES DARK MATTER AFFECT THE SOLAR ν FLUX?

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An observed deficit of high-energy (^8B) solar neutrinos¹ and the galactic dark mass problem² are both explained by Press and Spergel³ in terms of hypothetical particles: their "cosmions" must have masses m_c in the range 5-50 amu, a mean elastic scattering cross section per hydrogen nucleus in the sun of $\langle\sigma\rangle_s \sim 4 \cdot 10^{-36} \text{ cm}^2$, local mass density $\rho \sim 1 \text{ amu/cm}^3$, and cosmological velocity $v \sim 10^{-3} c$. Accumulated in the sun, they enhance its thermal conductivity so as to yield the measured solar luminosity with a lower central temperature than in standard models. We note that such particles, should they exist, can be detected and studied in the laboratory by bolometric procedures proposed originally by Cabrera, Krauss, and Wilczek⁴ for the purpose of measuring solar neutrinos. The event rates are so large that a definitive test of this cosmion hypothesis can be made, even with a relatively small bolometric detector.

According to Ref. 4, neutrinos from pp reactions in the sun produce recoil electrons in Si at the rate of $10^{-3} \text{ kg}^{-1} \text{ d}^{-1}$. Higher energy ^8B neutrinos scatter coherently from Si nuclei depositing several KeV of energy at a rate a seventh as large. Cabrera *et al.* propose an experiment utilizing tons of silicon to study these effects. Cosmions with properties specified in Ref. 3 also make elastic collisions with Si nuclei depositing up to 1.3 KeV (for $m_c = 5 \text{ amu}$) and up to 23 KeV (for $m_c = 50 \text{ amu}$). In general, the maximum energy transfer is $2 M m_c^2 v^2 (M + m_c)^{-2}$ where M is the mass of the target nucleus. Cosmion scattering is s-wave so that the distribution in recoil energy is uniform.

The cosmion cross-section on a nucleus is coherent since its de Broglie wavelength exceeds the nuclear size. For simplicity we take cosmion-nucleus scattering to be isospin independent, and comment later on the effects of relaxing this constraint.

For a cosmion with purely spin-dependent (SD) interactions, the non-relativistic scattering cross-section on element i is related to that on hydrogen by⁵:

$$\sigma_i(\text{SD}) \approx \left\langle \left(\frac{m_c + 1}{m_c + A} \right)^2 A^2 \frac{4}{3} J(J+1) \right\rangle_i \sigma_H(\text{SD})$$

where m_c is given in amu, A and J are the mass number and nuclear spin of an isotope of the element and the average is taken over the various isotopes according to their natural abundance. In the sun such cosmions scatter predominantly from hydrogen, so that cosmions can provide the link between the dark mass of the galactic halo and the solar (^8B) ν flux providing $\sigma_H(\text{SD}) \approx 4 \cdot 10^{-36} \text{ cm}^2$. This leads to an event rate per Kg per day in a bolometric detector of element i of

$$\sim 8300 \left\langle \frac{A}{m_c} \left(\frac{m_c + 1}{m_c + A} \right)^2 J(J+1) \right\rangle_i.$$

For this case, Si is a poorly chosen target; only 4.7% of naturally occurring Si has a nuclear spin, and these are only spin 1/2, giving an event rate of 53(70) per Kg per day for $m_c = 5(50)\text{amu}$. For a 5 amu cosmion, there are several elements which give event rates 200 times larger than Si: Li, B, Al, Sc, V, and Nb, while for a heavy cosmion (50 amu) these elements give event rates relative to Si which increase with atomic number ranging from 50 for Li to 800 for Nb.

For spin independent (SI) cosmion-nucleus scattering⁵

$$\sigma_i(\text{SI}) \approx \left(\frac{m_c + 1}{m_c + A} \right)^2 A^4 \sigma_H(\text{SI}),$$

where A is the dominant mass number for element i . The large growth of $\sigma_i(\text{SI})$ with A means that for all values of m_c of interest, cosmion scattering in the sun is dominated by He and the heavy elements rather

than by H. In order to obtain $\langle \sigma_S \rangle = 4 \cdot 10^{-36} \text{ cm}^2$, we find $\sigma_H(\text{SI}) \sim 2 \cdot 10^{-37} \text{ cm}^2$ for $m_c = 5 \text{ amu}$ and $\sim 2 \cdot 10^{-38} \text{ cm}^2$ for $m_c = 50 \text{ amu}$. Event rates per Kg per day are

$$\sim 1.6 \cdot 10^{39} \sigma_H(\text{SI}) \frac{A^3}{m_c} \left(\frac{m_c + 1}{m_c + A} \right)^2,$$

which for Si is $4.6 \cdot 10^4 (6 \cdot 10^3)$ for $m_c = 5(50) \text{ amu}$. A further enhancement by a factor of ten in rate is obtained with a target element of $A \sim 200$.

In particle physics models of the cosmion, it is quite likely that the scattering from nuclei will have some isospin dependence. This will change our numerical estimates but is unlikely to effect our conclusions.

Event rates for bolometric detection of various sources and targets is shown in the table. Entries relating to solar neutrinos or reactor antineutrinos near the core are taken from Ref. 4. They are to be compared with our estimates of cosmion-induced events. These event rates are so high that they will be observable with a small detector providing sensitivity to deposition energies of 1-20 KeV is obtained. A significant signal is still expected when probing incident cosmions with velocities near the galactic escape velocity of $2 \cdot 10^{-3} c$, in which case the recoil energies will be 4-80 KeV. These event rates also apply to superconducting colloid detectors⁶ which could also detect cosmions.

Cosmions present a far easier target for bolometric detection than do solar neutrinos. The Press-Spergel hypothesis is subject to decisive experimental test. Should the existence of cosmions be demonstrated, bolometric measurements (in Si, B, and possibly other materials) can yield their mass, local density, velocity distribution, and the magnitude and spin-dependence of cosmion-nucleon cross sections.

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TABLE

Event rates in a bolometric detector		(kg ⁻¹ day ⁻¹)	
Recoil electrons from solar pp ν 's on Si		1.10 ⁻³	
	Coherent scattering of solar ⁸ B ν 's on Si nuclei	1.5 10 ⁻⁴	
	$\bar{\nu}$ events on Si near a nuclear reactor core	40	
		m _c = 5 GeV	m _c = 50 GeV
Cosmion scattering on Si nuclei (spin dependent)		53	70
Cosmion scattering on B nuclei (spin dependent)		1.4 10 ⁴	1.7 10 ⁴
Cosmion scattering on B nuclei (spin independent)		1.2 10 ⁴	6.0 10 ²
Cosmion scattering on Si nuclei (spin independent)		4.6 10 ⁴	6.0 10 ³