The Photino, the Sun, and High-Energy Neutrinos

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If the Universe contains a nearly critical density of photinos which are also assumed to constitute the dark matter in our galactic halo, then gravitational trapping by the Sun and ensuing annihilation in the solar core yields a significant flux of ~250-MeV neutrinos. This results in about two neutrino-induced events per kiloton-year in an underground proton-decay detector.

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The photino, expected to be a stable, massive relic of supersymmetry, is a promising dark-matter candidate.[1] The photino mass range that may be relevant to interpretations[2] of CERN monojets (1–10 GeV) also can yield a critical closure density for the Universe.[3] A critical-density, spatially flat Friedmann cosmological model dominated by massive, weakly interacting particles reconciles several outstanding cosmological issues, including the isotropy of the microwave background,[4] the light-element abudances,[5] and predictions of inflationary cosmology.[6] However, a plausible weakly interacting dark-matter candidate is required, and the case for the photinos seems especially intriguing.

Two of us have recently noted[7] that if our galactic halo, known to consist largely of dark matter, is plausibly assumed to consist of the same dark matter that binds the Universe, then the identification of the photino as the dark-matter candidate leads to a unique, observable signature. For a photino mass $m_{\tilde{\gamma}} \sim 3$ GeV, photino annihilations in our halo were found to lead to a detectable flux of low-energy cosmic-ray antiprotons, below the kinematic threshold for secondary production by high-energy cosmic-ray interaction with interstellar matter.

In this Letter, we point out another signature of photino annihilations. The Sun gravitationally traps halo photinos,[8,9] which subsequently lose energy elastically and annihilate in the solar core. The yield of ~250-MeV neutrinos resulting from trapped-photino annihilations in the Sun is appreciable: it may be detectable in ongoing undergound experiments.

In the ensuing discussion, we will be interested in two cross sections involving photinos, the elastic-scattering cross section σ_E, and the annihilation cross section σ_A. The present mass density of photinos is basically determined by σ_A at the time annihilations freeze out. In order to achieve a cosmological mass density corresponding[10] to $\Omega = 1$, we need $\langle \sigma v \rangle_{A,F} \approx 10^{-26}$ cm^3 s^{-1} (for $h = \frac{1}{2}$) where $\langle \sigma v \rangle_{A,F}$ is the thermally averaged product of the annihilation cross section and relative velocity at the freezeout temperature. At lower velocities, the p-wave annihilation channel is suppressed and

$$\langle \sigma v_A \rangle = \langle \sigma v \rangle_{A,F} (1 + 0.04 m_{\tilde{\gamma}}^2)^{-1} \tag{1}$$

where $m_{\tilde{\gamma}}$ is in gigaelectronvolts and we have assumed that all scalar-quark and -lepton masses are equal. In terms of the low-energy annihilation cross section [Eq. (1)], we determine the elastic scattering cross section[11]:

$$\begin{aligned} \langle \sigma v \rangle_E &= 0.17 \beta \langle \sigma v \rangle_A \\ &= 1.7 \times 10^{-27} \beta (1 + 0.04 m_{\tilde{\gamma}}^2)^{-1} \text{ cm}^3 \text{ s}^{-1}, \end{aligned} \tag{2}$$

where $\beta = v/c$.

Photino annihilations in the Sun are, of course, subject to photinos first hitting the Sun and becoming trapped. Press and Spergel[9] have calculated the trapping rate and find that

$$\dot{N}_{\tilde{\gamma}}^{\text{trap}} = 9 \times 10^{28} n_{0.3} \sigma_{36} \bar{v}_{300}^{-1} m_{\tilde{\gamma}}^{-1} \text{ s}^{-1}, \tag{3}$$

where $n_{0.3} \simeq 0.3$ cm^{-3} and the average halo density of photinos $n_H = n_{0.3} m_{\tilde{\gamma}}^{-1}$, $\sigma_{36} = \sigma_E/(10^{-36}$ cm$^2)$ and $\bar{v}_{300} = \bar{v}/(300$ km s$^{-1}) \approx 0.9$ is the rms velocity of a halo photino in the solar neighborhood [$= (3/2)^{1/2} \times$ galactic rotation velocity in the solar neighborhood for an isothermal dark halo model].

The number of photinos in the Sun can diminish in one of two ways: evaporation and/or annihilation. Steigman *et al.*[8] and Press and Spergel[12] have shown that unless $m_{\tilde{\gamma}} \lesssim 5$ GeV, evaporation is not important. Given the annihilation cross section [Eq. (1)], the annihilation rate is

$$\dot{N}_{\tilde{\gamma}}^{\text{ann}} = (4/3)\pi R_{\odot}{}^3 n_{\tilde{\gamma}}^2 \langle \sigma v \rangle_A f$$
$$\approx 5\times 10^{54} (n_{\tilde{\gamma}}/n_p)^2 \langle \sigma v \rangle)_{A,26} f \text{ s}^{-1}, \qquad (4)$$

where $n_{\tilde{\gamma}}$ (n_p) is the mean photino (proton) density in the Sun, $\langle \sigma v \rangle_{A,26} = \langle \sigma v \rangle_A/(10^{-26} \text{ cm}^3 \text{ s}^{-1})$, and f is a density weighting factor ($f = \int n^2\, dV/n^{-2} V$). Hence trapping can maintain a mean solar photino abundance

$$\frac{n_{\tilde{\gamma}}}{n_p} \simeq 1.3\times 10^{-13} n_{0.3}^{1/2} \left(\frac{\sigma_{36}}{\langle \sigma v \rangle_{A,26}} \right)^{1/2}$$
$$\times m_{\tilde{\gamma}}^{-1/2} \bar{v}_{300}^{-1/2} f^{-1/2}. \qquad (5)$$

The annihilation rate is thus set by the trapping rate.

The only annihilation products that can escape from the solar interior are the high-energy neutrinos. These typically are expected[7] to have energies $\lesssim 0.05 m_{\tilde{\gamma}}$. It is now relatively straightforward to compute the expected flux of energetic neutrinos of type ν_i on earth:

$$\phi_{\nu_i} = \tfrac{1}{2} N_{\nu_i} \dot{N}_{\tilde{\gamma}}^{\text{trap}}/4\pi (1 \text{ AU})^2 \text{ cm}^{-2} \text{ s}^{-1}$$
$$\approx 16 N_{\nu_i} n_{0.3} \sigma_{36} \bar{v}_{300}^{-1} m_{\tilde{\gamma}}^{-1} \text{ cm}^{-2} \text{ s}^{-1}, \qquad (6)$$

where N_{ν_i} is the number of neutrinos of type ν_i produced in each annihilation.

The most easily detectable process is the reaction $\bar{\nu}_e + p \rightarrow n + e^+$ which has a cross section $\sigma = 7.5 \times 10^{-38} [E_\nu/(1 \text{ GeV})]^2 \text{ cm}^2$. Given the flux from Eq. (6) we estimate the number of events in a water detector per kiloton-year,

$$N_E = \phi \sigma N_p, \qquad (7)$$

where $N_p \simeq 6.7\times 10^{31}$ is the number of protons in one kiloton of H_2O. Thus we expect

$$N_E = 0.44 n_{0.3} \bar{v}_{300} m_{\tilde{\gamma}} \text{ events/kiloton year} \qquad (8)$$

for $\bar{\nu}_e$'s with energy $E_{\bar{\nu}} \simeq 0.05 m_{\tilde{\gamma}}$ where[7] $N_{\bar{\nu}_e} = 2.5$ and $\sigma_{36} = 0.028$. Hence for $m_{\tilde{\gamma}} > 5$ GeV we expect $N_E > 2.2$ events/kiloton year. This is comparable to the expected event rate from atmospheric neutrinos[13-15] for $E \sim 250$ MeV. We note that there has been reported an excess of neutrino events around the 100–200-MeV range by the Kamiokande group.[13] Other sources of high-energy neutrinos have been discussed by Dar.[14]

It has been suggested[8,9,12] that a population of weakly interacting particles inside the Sun could solve the solar neutrino problem. However, in the case of photinos, the elastic scattering cross section appears to be too small for this effect to work.[11,16]

In summary, we predict that the existence of a dark galactic halo consisting of photinos leads to an appreciable flux of high-energy neutrinos on Earth due to photino annihilations in the Sun. We have estimated the event rate in a proton-decay-type water detector and found that the predicted event rate is comparable to atmospheric backgrounds. This effect depends only on the existence of dark matter composed of heavy ($m > 5$ GeV) weakly interacting particles, in the galactic halo. Our results carry uncertainties primarily in the estimate of the cross section and the number of neutrinos per decay channel, both of which depend on the masses of scalar quarks and leptons. We consider this in more detail elsewhere.[11] Here we specialized by considering photinos in particular but these results can be generalized to other forms of dark matter such as scalar neutrinos where this effect may be enhanced. In a forthcoming publication[11] we look at these other possibilities as well as a more detailed examination of the capability of detection.

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