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# EXTINCTION OF THE TEV GAMMA-RAY BACKGROUND BY SUNLIGHT

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## ABSTRACT

I show that pair production on sunlight introduces a sizable anisotropy in the cosmic background of TeV gamma-rays. The anisotropy amplitude in the direction of the Sun exceeds the cosmic dipole anisotropy from the motion of the Sun relative to the cosmic rest-frame.

## 1. INTRODUCTION

Given its effective surface temperature of $T_{\rm eff} = 5.8 \times 10^3$ K, the Sun acts as a source of photons with a characteristic energy, $E_{\gamma\odot} \approx k_B T_{\rm eff} = 0.5$ eV. When these photons collide with the cosmic background of TeV photons (Inoue & Tanaka 2016; Yan-kun & Hou-dun 2022), they produce electron-positron pairs through the process: $\gamma_\odot + \gamma \rightarrow e^+ + e^-$. For pair creation to occur, the energy of the background photon, $E_\gamma$, must exceed the threshold value, $E_{\rm th}$ (Gould & Schréder 1967a),

$$E_\gamma > E_{\rm th} = \frac{2m_e^2c^4}{E_{\gamma\odot}\mu} \approx \frac{0.5 \text{ TeV}}{(\mu/2)}, \tag{1}$$

where $m_e = 5.11 \times 10^5$ eV is the electron rest-mass, $c$ is the speed of light and $\mu = (1 - \cos\theta)$ with $\theta$ being the angle between the momenta of the two photons in the observer's frame. The value of $E_{\rm th}$ is minimized for a head-on collision ($\mu = 2$) with a background photon of energy $E_\gamma \gtrsim 0.5$ TeV.

Above this threshold, the cross-section for pair production is given by,

$$\sigma_{\gamma\gamma} = 3.7 \times 10^{-25} \text{ cm}^2 \times (1 - \beta^2) \left[ (1 - \frac{1}{3}\beta^4) \ln \left( \frac{1+\beta}{1-\beta} \right) - \frac{2}{3}\beta(2 - \beta^2) \right], \tag{2}$$

where $\beta = (v/c)$, with $v$ being the speed of the electron or positron in the center-of-mass system. The value of $\beta$ depends on $E_\gamma$ and $\theta$ through the relation,

$$\beta = \sqrt{1 - \frac{E_{\rm th}}{E_\gamma}}. \tag{3}$$

The same pair-production process introduces a cosmic opacity to the TeV radiation background as a result of photon-photon collisions with the extragalactic background light (Gould & Schréder 1967b; Singh et al. 2021; Franceschini 2021). Here we focus on the imprint of Solar photons on the cosmic TeV background observable on Earth.

## 2. RESULTS

The number density of Solar photons at a distance $R$ from the Sun is given by,

$$n_{\gamma\odot} = \frac{L_\odot}{(4\pi c R^2 E_{\gamma\odot})} \approx 2.7 \times 10^{12} \text{ cm}^{-3} \left( \frac{R}{R_\odot} \right)^{-2}, \tag{4}$$

where $L_\odot = 4 \times 10^{33}$ erg s$^{-1}$ is the Solar luminosity. The Earth-Sun separation at $R = 1.5 \times 10^{13}$ cm is $2.14 \times 10^2$ times larger than the Solar radius $R_\odot = 7 \times 10^{10}$ cm. This photon density yields a local optical-depth for pair-production at an energy $E_\gamma \sim 1$ TeV, of magnitude,

$$\tau_{\gamma\gamma}(E_\gamma \sim 1 \text{ TeV}) = n_{\gamma\odot}\sigma_{\gamma\gamma}R \sim 7 \times 10^{-2} \left( \frac{R}{R_\odot} \right)^{-1}. \tag{5}$$

The resulting absorption of background photons produces a deficit in the gamma-ray background at the energy $\sim 1$ TeV with an anisotropy amplitude $\sim 7 \times 10^{-2}$ in the vicinity of the Sun and $\sim 3.3 \times 10^{-4}$ at the Earth's orbital radius, and an anisotropy angular dependence that reflects the position of the Sun in the sky at the observing time combined with the $\mu$ dependence of $\sigma_{\gamma\gamma}$ in equations (2-3).

## 3. IMPLICATIONS

Interestingly, the expected anisotropy amplitude is significant relative to the dipole associated with the motion of the Solar system relative to the cosmic rest-frame, $\sim 1.2 \times 10^{-3}$, as measured from the cosmic microwave background (Kogut et al. 1993).

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## REFERENCES

Franceschini, A. 2021, Universe, 7, 146, doi: 10.3390/universe7050146

Gould, R. J., & Schréder, G. P. 1967a, Physical Review, 155, 1404, doi: 10.1103/PhysRev.155.1404

—. 1967b, Physical Review, 155, 1408, doi: 10.1103/PhysRev.155.1408

Inoue, Y., & Tanaka, Y. T. 2016, ApJ, 818, 187, doi: 10.3847/0004-637X/818/2/187

Kogut, A., Lineweaver, C., Smoot, G. F., et al. 1993, ApJ, 419, 1, doi: 10.1086/173453

Singh, K. K., Yadav, K. K., & Meintjes, P. J. 2021, Ap&SS, 366, 51, doi: 10.1007/s10509-021-03957-z

Yan-kun, Q., & Hou-dun, Z. 2022, ChA&A, 46, 42, doi: 10.1016/j.chinastron.2022.05.003