Supernova bounds on axion-like particles coupled with nucleons and electrons

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Based on F. Calore, P. Carenza, M. Giannotti, J. Jaeckel, G. Lucente, A. Mirizzi ArXiv:2107.02186

WORK'S AIMS

In this work we focused on:

- Phenomenology of axion-like particles (ALPs) coupled with nucleons and electrons and produced in supernovae (SNe).
- Strong bounds from the measurement of 511 keV line photon flux and from the Cosmic X-ray Background (CXB)

MASSIVE ALPs

ALPs are pseudoscalar particles introduced in UV completion of the Standard Model. In this work, we consider heavy ALPs [$m_a < 30$ MeV] interacting with electrons and nucleons

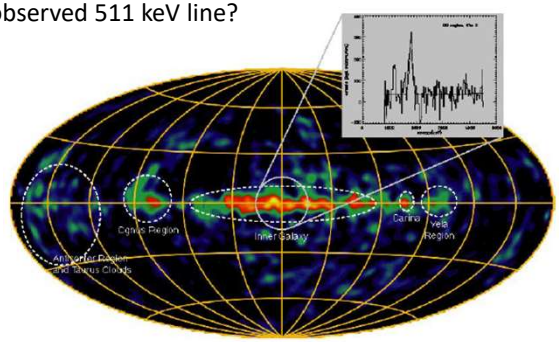
$$\mathcal{L}_{af} = \frac{g_{af}}{2m}\bar{\psi}\gamma_\mu\gamma_5\psi\partial^\mu a$$

In this mass range, SNe are efficient laboratories to probe the ALPs produced in SNe

THE 511 keV LINE

An X-ray flux at 511 keV is observed from the center of our Galaxy. It is originated by positrons annihilation with electrons in the Galactic medium. Positrons produced in explosive phenomena as SN Ia lose energy in Bhabha scatterings, annihilating at rest [Prantzos, Rev. Mod. Phys. 83 (2011)].

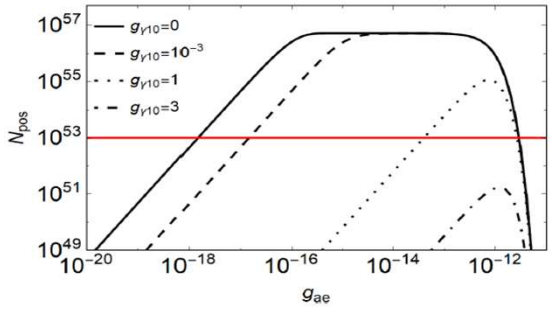
What is the impact of positrons produced in heavy ALP decays on the observed 511 keV line?



POSITRON PRODUCTION PROCESS

In a SN core, ALPs coupled with nucleons are produced by NN bremsstrahlung [Carenza, JCAP 10 (2019)].

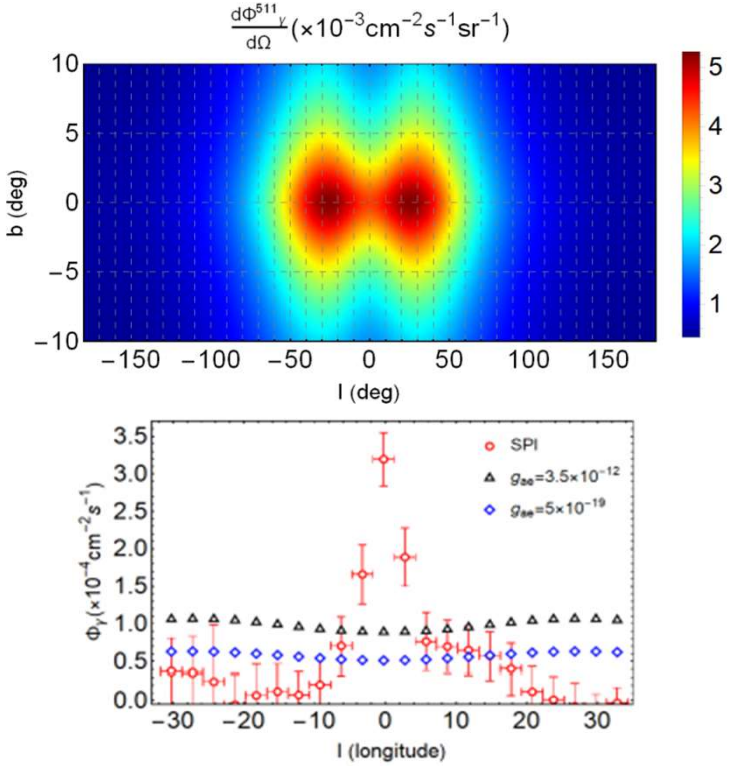
If ALPs decay outside the SN photosphere into electron-positron pairs, fast positrons are injected in the Galaxy. Weakly interacting ALPs decay far from the SN and positrons travel in the Galaxy for $10^6 - 10^7 yrs$ losing energy. Finally they annihilate at rest.



Number of positrons produced in a SN for $m_a = 30\,MeV$ and $g_{ap} = 10^{-9}$

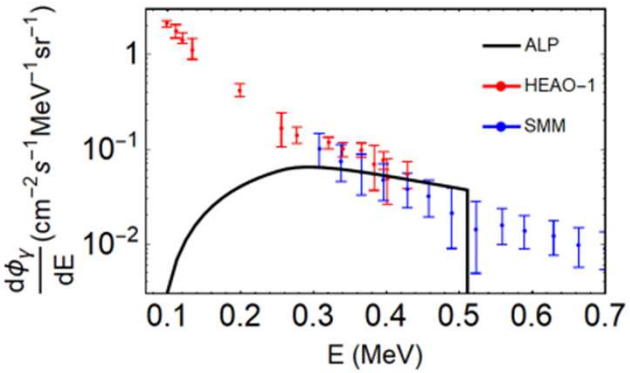
OBSERVABLE SIGNATURES

The 511 keV photon line produced in this way follows the shape of the SN distribution in the Galaxy, different from the observed morphology of the 511 keV flux signal.



Skymap of the photon flux for $m_a = 30\,MeV, g_{ap} = 10^{-9}$ and $g_{ae} = 5 \times 10^{-19}$ and comparison with the flux measured by SPI.

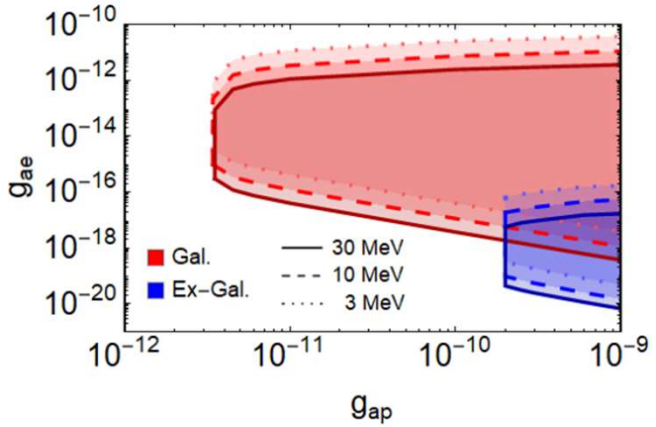
Long lived ALPs decay outside the Galaxy and positrons deposited in the intergalactic medium might lead to an X-ray diffuse flux. The energy distribution is no more a line because of the redshift.



Extragalactic photon flux for $m_a = 30\,MeV, g_{ap} = 10^{-9}$ and $g_{ae} = 7 \times 10^{-21}$ compared with measurements.

SUMMARY OF THE BOUNDS

The resulting bounds are obtained by requiring that the ALP-induced flux is smaller than the measured photon flux.



These bounds cover a large region of the parameter space and future experiments as eASTROGAM and AMEGO might improve these results.