Overview of feebly interacting particle in indirect detection searches

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Abstract. Axion-like particles (ALPs) as feebly interacting particles (FIPs) candidate have generated a lot of interest in the recent years. Stars are good FIPs factories and consequently those particle can be detected through their interaction with the interstellar medium or decay in standard particles. Briefly, I will illustrate how high-energy astrophysics observations can be exploited to set constraints to ALPs model and to the ASTRO-MeV gap problem.

1 Introduction

What likely makes up the 84% of the matter content in the Universe is called Dark Matter (DM). All evidence of DM is purely gravitational and covers larger and larger scales. Anyway, its identification still remains an unsolved problem of the physics Beyond the Standard Model (BSM). Indeed no SM particles match the inferred DM characteristics. In the last years, feebly interacting particles (FIPs) [1] have been representing an interesting alternative to the so-called WIMP, namely Weakly Interacting Massive Particles. The FIPs are relatively light particles (sub-GeV masses), with extremely suppressed interactions with SM bosons or fermions. They have sound theoretical motivations of particle physics and in particular they could be the manifestation of a complicated secluded sector, called *dark sector* connected with the visible sector by a "mediator" known as *portal*. The portal is representative of low-dimensional operators according to the nature of the new particle: i.e Axion-Like Particle (ALP).

2 Axion-Like Particles

An ALP is a light pseudoscalar particle arising from the spontaneous breaking of an approximate global symmetry, a pseudo-Goldstone boson. According to the quasi-exact global symmetry, it identifies a particular BSM particle, i.e. the QCD axion [2]. A peculiar characteristic is that the mass and the coupling constant of ALPs are independent parameters and, for this reason, they scan a wide mass range by direct and indirect detection techniques. The ALP plays the role of DM itself or as a mediator through the dark sector. An ALP is coupled to ordinary matter and radiation and the Lagrangians involving these fields enjoy an approximate shift symmetry under which $L_a \to a + const.$, which implies that their interactions has to proceed via derivative terms.

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2.1 Production in Astrophysical environment

The stars are very good factories of FIPs. For the ALPs, according to the interaction, the production processes inside the star could be: Primakoff $\gamma + Ze \rightarrow a + Ze$, Compton Scattering $\gamma + e \rightarrow e + a$, Electron Bremsstrahlung $e + Ze \rightarrow e + Ze + a$ and nucleon Bremsstrahlung $N_1 + N_2 \rightarrow N_3 + N_4 + a$. Each process is dominant in a particular stage of the star lifetime and ALP mass range [3].

After production, the FIPs can free stream and escape from the core inducing novel channel of energy-loss and impacting the stellar evolution or producing spectral signatures in cosmic background as in gamma-ray. Experiment as Fermi-LAT [4] are able to catch this kind of indirect detection signals.

According to the nature of the coupling, the signatures to search are different: *i)* for very light mass, conversion of ALPs into photons in the Galactic magnetic field can produce spectral irregularities in galactic and/or extragalactic source spectra, i.e. core collapse SNe [5] or diffusive gamma-ray background [6]; *ii)* for heavy mass, ALPs can be detected through their interaction with the interstellar medium or decay in SM particles inducing spectral features in the expected background [7] [8].

Unfortunately the MeV energy region, where many objects in the Universe emit, is never uncovered by any good performant instrument: COMPTEL reached a sensitivity at around $10^{-9}\frac{erg}{cm^2 \cdot sec}$, INTEGRAL hardly reaches the soft gamma-ray regime with an insufficient sensitivity, the FERMI pair vertex tracker telescope has an high energy threshold around 30 MeV and a bad point spread function below 100 MeV. Therefore the so-called ASTRO-MeV gap is empty by research. An intriguing and low-cost idea could be a crew of nano-satellites (1U=1 unit), i.e. COMCUBE [9], which detect energies from 100 keV to $\mathcal{O}(1)$ MeV, with very good instrument response functions (preliminarily the 4U COMCUBE sensitivity of $10^{-11}\frac{erg}{cm^2 \cdot sec}$ is obtained). The idea is to use COMCUBEs to detect observable fluxes of ALPs from pre-SN phase as Betelgeuse [10] and to scan the ALP parameter space in the MeV gap. The collaboration between Bari University Group and Roma Tor Vergata University is promoting that kind of analysis.

References

[1] P. Agrawal, *et al.* Eur. Phys. J. C **81** (2021) no.11, 1015
[2] R. D. Peccei and H. R. Quinn, Phys. Rev. Lett. **38** (1977), 1440-1443
[3] G. G. Raffelt, Lect. Notes Phys. **741** (2008), 51-71
[4] M. Meyer, M. Giannotti, A. Mirizzi, J. Conrad and M. A. Sánchez-Conde, Phys. Rev. Lett. **118** (2017) no.1, 011103
[5] M. Crnogorčević, R. Caputo, M. Meyer, N. Omodei and M. Gustafsson, Phys. Rev. D **104** (2021) no.10, 103001
[6] C. Eckner, F. Calore, P. Carenza, M. Giannotti, J. Jaeckel, F. Sivo and A. Mirizzi, PoS **ICRC2021** (2021), 543
[7] A. Caputo, H. T. Janka, G. Raffelt and E. Vitagliano, Phys. Rev. Lett. **128** (2022) no.22, 221103
[8] F. Calore, P. Carenza, M. Giannotti, J. Jaeckel, G. Lucente, L. Mastrototaro and A. Mirizzi, Phys. Rev. D **105** (2022) no.6, 063026
[9] A Laviron et al., *SF2A-2021: Proceedings of the Annual meeting of the French Society of Astronomy and Astrophysics. Eds.: A. Siebert* (2021) 105-108
[10] M. Xiao, K. M. Perez, M. Giannotti, O. Straniero, A. Mirizzi, B. W. Grefenstette, B. M. Roach and M. Nynka, Phys. Rev. Lett. **126** (2021) no.3, 031101