X-ray Constraints on Late Decaying Dark Matter Majorons (or Other Soft X-ray Emitting Candidates)*

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An attractive way to generate neutrino masses is through the spontaneous breaking of lepton number. The resulting majoron can acquire a mass and thereby be the dark matter. Structure formation requires the dark matter mass to be ≈ 0.15 keV. The majorons can decay into two photons providing a mono-energetic emission line. Observing 0.1 keV photons is challenging, but we have obtained constraints in the 0.07-4.0 keV interval, which have been combined with earlier results and compared to realistic particle physics models for the majoron mass and interactions. The constraints applies to a wide range of dark matter candidates with radiative decays.

1 Introduction

In the Standard Model of particle physics the neutrinos are exactly massless which is in contradiction to the experimental evidence for neutrino oscillations. An attractive way to generate the neutrino masses involves spontaneous breaking of the global lepton symmetry. In this case the Goldstone boson associated to the broken symmetry, the majoron, can acquire a mass through quantum gravity effects. The idea of explicit violation of global symmetries by gravitational effects was originally put forward by R. Holman et al. [2] in the context of axions. This idea was applied to majorons by Akhmedov *et al.* [3] who first explored the possibility of a decaying keV mass singlet majoron. This paper was followed by Berezinsky and Valle [4] who proposed the majorons to be an excellent dark matter candidate with an observational signature. The majorons are unstable, decaying mostly to neutrinos but also to photons, with very long lifetimes, which may be longer than the lifetime of the Universe. Majorons with mass in the keV range could then constitute the bulk or a large part of the dark matter in the Universe. If so, cosmological observations can place interesting bounds on the coupling of this special type of majorons to neutrinos and photons.

*This talk was based on the paper by F. Bazzocchi, M. Lattanzi, S. Riemer-Sorensen and J. W. F. Valle, given in Ref. [1] which at the time of the workshop was accepted for publishing in JCAP.

2 Astrophysical constraints

The dominating majoron decay is into neutrinos. Lattanzi *et al.* [5] have studied the bounds imposed by the cosmic microwave background radiation on decaying keV mass majorons. The result is that the mass must lie in the interval 0.11 keV$< m_J <$ 0.18 keV and the decay rate must be smaller than $\Gamma_{J\nu\nu} < 10^{-19} s^{-1}$ in the case where the majorons are in thermal equilibrium in the early Universe and decouple very early.

The majorons are also allowed to decay into two photons providing a possible astrophysical signature from dark matter dominated regions in the Universe in terms of a mono-energetic emission line with an energy of half the majoron rest mass.

Current day X-ray observatories *Chandra* and *XMM-Newton* are only directly sensitive down to 0.3 keV, but by combining the High Resolution Camera onboard *Chandra* with a grating, a sensitivity down to 0.07 keV was obtained. However, using a grating has some disadvantages: i) The information of the origin of the photon is lost so it is not possible to optimize the signal to noise ratio. ii) The extension of the dark matter halo reduces the otherwise extremely high spectral resolution of the grating. iii) Gratings requires bright sources, so no X-ray faint dark matter dominated regions have been observed. We used observations of the Seyfert 1 galaxy NGC 3227. It is known there is a lot of baryonic emission from this galaxy, but the received flux is nonetheless a conservative upper limit on the flux from decaying dark matter, and due to the effects of the grating, no better target exists. The mass of the dark matter within the field of view was approximated to be 10^{10} $M_\odot$ and we assumed only one kind of dark matter. The obtained constraints on the decay rate is shown in Figure 1.

Allowing for non-equilibrium of the majorons in the early Universe, later decoupling or other production mechanism introduces a mass shift. We have expressed this ignorance in the parameter β, where the value of $\beta = 1$ was chosen for the scenario with thermal equilibrium and early decoupling. The CMB mass constraint from [5] discussed above then becomes $0.11 < \beta m_J < 0.18$keV. For non-thermal production mechanisms $\beta < 1$ so the mass constraint form CMB shift towards higher masses. Consequently we have compared our constraints to earlier line emission searches from dark matter (mainly performed in the context of sterile neutrinos, but applies to all dark matter candidates with a radiative decay) [6]. The constraints on the decay rate of the majorons into photons in the covered energy range of 0.07-4000 keV is shown in Figure 1. This have been compared to realistic particle physics models for the majoron mass and interactions.

In Figure 2 the diagonal lines gives the dependence of $\Gamma_{J\gamma\gamma}$ on m_J for different values of the triplet vacuum expectation value, v_3, which is one of the parameters of the underlying particle physics model. They single out the allowed strip in the $\Gamma_{J\to\gamma\gamma} - m_J$ plane consistent with neutrino oscillation data [7] and with the cosmological bounds on neutrino mass [8]. The left panel is for hierarchal neutrino masses while the right panel is for degenerate masses. The vertical bands in the figure indicate the mass region singled out by the CMB observations, for two different values of β. In both scenarios small m_J and v_3 values lead to decay rates well below the observational bounds.

However, for large values of v_3, e.g. 5 GeV, roughly corresponding to the maximum compatible with precision measurements of electroweak parameters [9], the radiative rates fall within the sensitivities of the Milky Way observations, and are thereby observationally excluded. For lower masses the observational sensitivities needs to be improved by about 20 orders of magnitude requiring completely new techniques from what is available today.

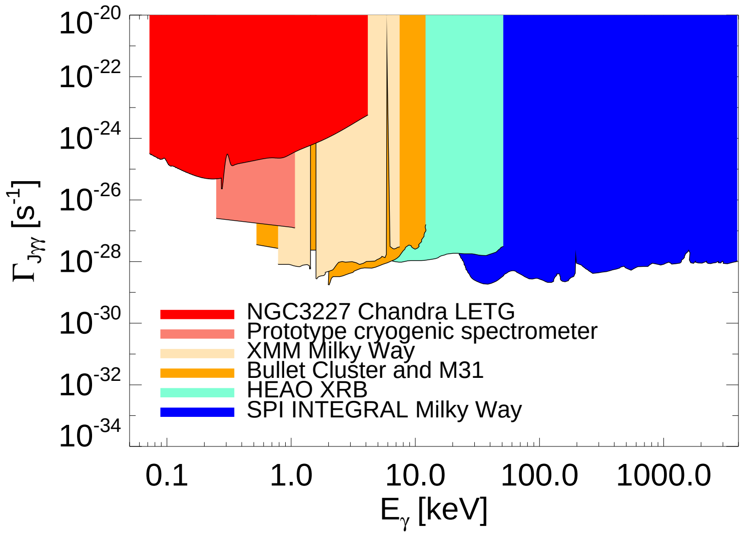

Figure 1: Upper limit on the decay rate (filled regions are excluded) from NGC3227 (red), the Milky Way halo observed with a prototype cryogenic spectrometer (salmon), *XMM* observations of the Milky Way (sand) and M31(orange), HEAO-1 observations of the diffuse x-ray background (aquamarine), INTEGRAL SPI line search in the Milky Way halo (blue) [6].

3 Summary

We have investigated the production of X-ray photons in the late-decaying dark matter scenario, and quantified the sensitivity of current observations to such a mono-energetic emission line. In particular, we have studied the constraints from the diffuse X-ray observations, as well as by considering the fluxes generated by dark matter dominated objects. These observations provide a probe of radiative dark matter decays and can be used as an *indirect detection* of the late decaying dark matter majoron scenario. We have illustrated this explicitly for the case where neutrinos get mass a la seesaw, where the majoron couples to photons through its Higgs triplet admixture. The constraints applies also to other dark matter candidates with radiative two-body decays emitting photons of energies of 0.07-4000 keV.

Acknowledgments

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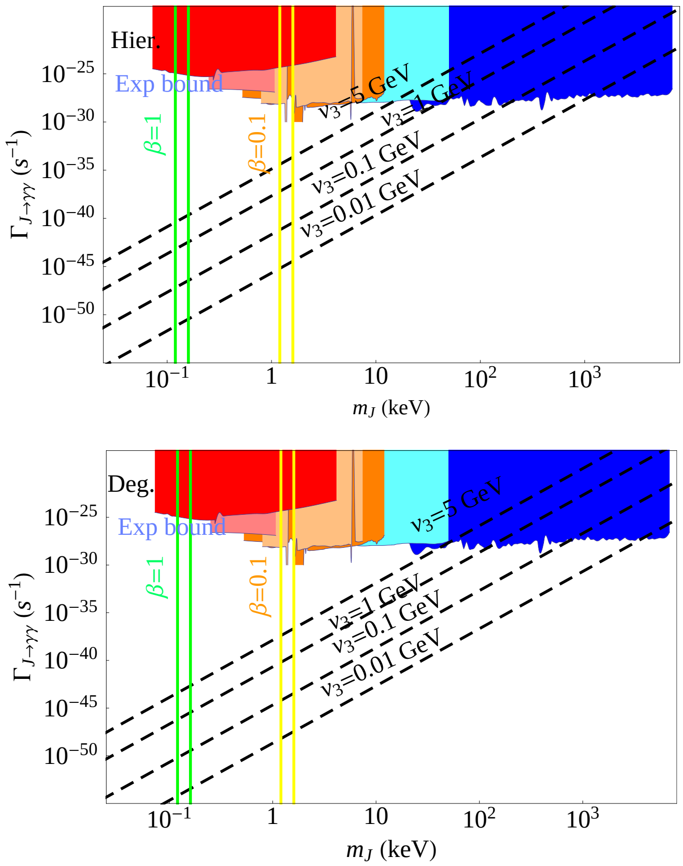

Figure 2: Majoron decay rate to photons as a function of the majoron mass m_J, for different values of the triplet vacuum expectation value, v_3. The left and right panels refer to hierarchical and degenerate neutrino mass spectra, respectively. The shaded regions are excluded by observations.

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