Effects of Hidden Photons during the Red Giant Branch (RGB) Phase

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DOI: http://dx.doi.org/10.3204/DESY-PROC-2015-02/ayala_adrian

Features in the globular cluster luminosity functions (LF) of the post-main sequence stellar evolution can be used to investigate modifications of standard stellar models and to look for new physics fingerprints, like axions or hidden photons. Here, we investigate the possible effects of hidden photons during the red giant branch (RGB) phase. In a follow-up analysis, these results will be applied to discuss signatures and observational effects in the globular cluster LF.

1 Introduction

For decades stars have represented very efficient laboratories for testing new models of physics beyond the standard model [1], providing bounds often superseding what achieved by terrestrial experiments. Recent examples include axions [2, 3, 4, 5, 6], anomalous neutrino magnetic moment [7, 8, 9], extradimensions [10], and hidden photons [11, 12, 13, 14].

Here, we consider the case of the hidden photons and study their effects on the red giant branch (RGB). Hidden photons (HP) are described by the Lagrangian [11]

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}^2 - \frac{1}{4}V_{\mu\nu}^2 - \frac{\chi}{2}F_{\mu\nu}V^{\mu\nu} + \frac{m_V^2}{2}V_{\mu\nu}V^{\mu\nu} \tag{1}$$

where F and V represent, respectively, the standard photon and the HP fields, m_V is the HP mass and χ is the coupling constant.

With the exception of [14], which studied the effects of low mass HP from the sun, all previous analyses of HP from stars have been performed on existent standard stellar models, therefore ignoring the feedback from the HP emission on the stellar evolution, particularly for RGB stars. In this case, the approach [12, 13] has been to consider a model of RGB near the He-flash and constraint the HP emission rate (averaged over the stellar core) to be less than 10 erg/g·s [13]. This simple criteria, however, ignores the possibility that the HP emission could modify the star evolution prior to the He-flash.

We present preliminary results of an attempt to study the full RGB evolution, including the new physics cooling channel in the evolutionary code.

2 Approach

In this first phase of the analysis, we plan to consider only HP masses from a few keV to a few 10 keV. This mass region seems to be the one where stars can overcome other constraints, particularly those derived from current dark matter experiments (see, e.g., [13]).

The HP emission rates (for transverse and longitudinal modes) can be found in [11, 12]. Here we consider only the longitudinal mode and use the emission rate in the resonant approximation [12]

$$\epsilon_L \simeq \frac{\chi^2 m_V^2}{4\pi\,\rho}\,\frac{\omega_{\rm pl}^2\sqrt{\omega_{\rm pl}^2 - m_V^2}}{e^{\omega_{\rm pl}/T}-1} \tag{2}$$

where $\omega_{\rm pl}$ is the plasma frequency. The resonant approximation represents an enormous simplification of the HP rate and, according to our numerical tests, is an excellent approximation of the longitudinal emission rate throughout the RGB evolution.

3 Preliminary Results

We have considered a model of a $0.82 M_\odot$ mass star, with metallicity $Z = 0.001$, representative of a typical globular cluster RGB star. The model has been evolved from pre-main sequence to the RGB *tip* (the point of maximum luminosity of the RGB phase, just before helium flash) using the FUNS (FUll Network Stellar evolution) stellar evolution code [15, 16, 17], with the additional cooling rate (2) for $m_V =$ 1 keV.

The HP emission plays no significant role during the main sequence evolution since, for the masses we are interested in, the resonant production of either transverse or longitudinal modes is forbidden in this early evolutionary stage.

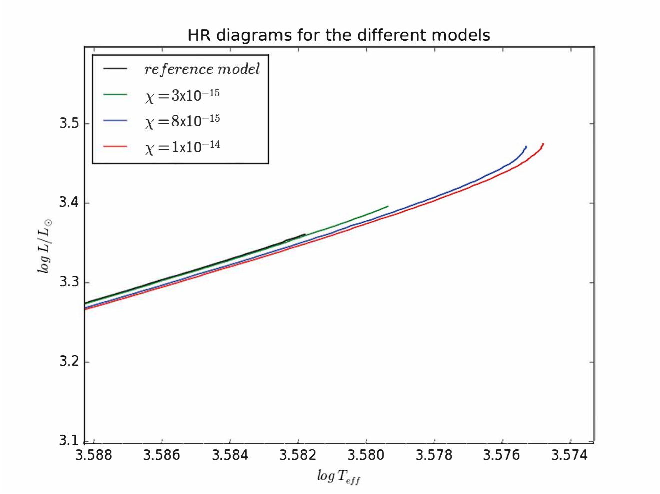

Figure 1: HR diagram for the RGB evolution for our reference models.

However, assuming couplings $\chi \sim$ a few 10^{-15}, the additional emission provides an effective energy sink during the RGB evolution, increasing the mass of the helium core and the RGB tip brightness. The results are shown in the table below, where we report the χ value for each model, helium core mass M_{HeC}, evolutionary time up to the tip, the effective surface temperature, the luminosity at the tip (the maximum value of the luminosity) measured in I band magnitude, M_I, the difference of I magnitude between the tip and the bump (a small local luminosity minimum) ΔM_I and the differences of ΔM_I with respect to the reference model without hidden photon. It is evident

χ	M_{HeC}	t_{TIP} (Gy)	log T_{eff}	RGB tip M_I	ΔM_I	$\Delta M_I - [\Delta M_I]_{ref}$
0	0.5034	13.21	3.581	-3.997	-3.294	0
3×10^{-15}	0.5072	13.19	3.579	-4.075	-3.395	-0.101
8×10^{-15}	0.5238	13.10	3.576	-4.247	-3.734	-0.440
1×10^{-14}	0.5303	13.07	3.575	-4.255	-3.841	-0.547

Table 1: Results from the simulation. The luminosity is measured in I band magnitude (M_I)

that larger HP couplings produce brighter RGB tips.

The actual value of the RGB tip luminosity is a useful observable to test physics beyond the standard model. This method has been used recently to constrain the neutrino magnetic moment [3] and the axion electron coupling [8].

Comparing the results from our table (Table 1) with the recent analysis in [3, 8], we see that a value of $\chi \sim 10^{-14}$ seems to be excluded, a result somewhat stronger than the bound in [13].

One of the problem with this methodology, however, is the experimental identification of the RGB tip luminosity which depends, among other parameters, on the stellar distance. Noticeable, this was the source of the largest uncertainties in the recent studies [3, 8].

We therefore investigate another possible method: to measure the luminosity differences between the *tip* and the *bump* of the RGB. As shown in table 1 and Fig. 2, this observable increases monotonically with the coupling and becomes more than 0.5 magnitudes in the I band for $\chi = 10^{-14}$.

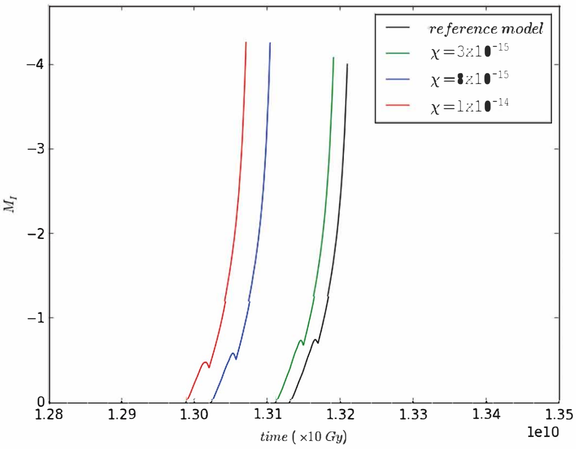

Figure 2: Luminosity (measured in I band magnitude) vs time, for the three models. Note the increase of the difference between the tip (maximum luminosity on the RGB band) and the bump (local luminosity decrease) with the coupling. See text for more explanation.

The exact threshold value for $\Delta M_I - [\Delta M_I]_{ref}$ to be confidently excluded has not been determined yet. Therefore, at this stage of the analysis, we are not ready to provide a clear constraint on the HP coupling. A complete study of this problem is currently in preparation.

4 Summary and conclusion

We reported on a preliminary study of the effects of HP emission on the evolution of RGB stars. In order to assess this impact, we modified the stellar evolution code to add the possibility of HP emission and studied the whole modified RGB evolution. At the moment, we have considered only an example, with HP mass 1 keV, and confined our analysis to the case of resonant emission of the longitudinal mode.

Our results show that the HP can change the pre-He-flash evolution, as clear from the time shifts of the tracks in Fig. 2, confirming the need to use the modified code throughout the whole evolution.

Finally, we identified a possible observable, the luminosity difference (ΔM_I) between the tip and the bump in the RGB evolutionary tracks, which is less subject to systematics than the absolute luminosity of the RGB tip. Comparing the predicted values of ΔM_I with the observations could provide a promising way to constrain HP and other new physics candidates during the RGB evolution.

A full analysis, which will include a scan of masses between 1-10 keV and the off-resonant (longitudinal) rate, is in preparation.

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