Nuclear Activity in Galaxies Across Cosmic Time
Proceedings IAU Symposium No. 356, 2019
M. Pović, P. Marziani, J. Masegosa, H. Netzer, S. H. Negu & S. B. Tessema, eds.
doi:10.1017/S1743921320003580

Mass-loss varying luminosity and its implication to the solar evolution

Negessa Tilahun Shukure,[1,2,3] Solomon Belay Tessema[1] and Endalkachew Mengistu[1]

[1]Astronomy and Astrophysics Research and Development Division, Entoto Observatory and Research Center, Ethiopian Space Science and Technology Institute, P.O.Box 33679, Addis Ababa, Ethiopia

[2]Addis Ababa University, P.O.Box 1176, Addis Ababa, Ethiopia

[3]Dilla University, P.O.Box 419, Dilla, Ethiopia
emails: nagessa2006@gmail.com; tessemabelay@gmail.com; 2fendalk@gmail.com

Abstract. Several models of the solar luminosity, $L_\odot$, in the evolutionary timescale, have been computed as a function of time. However, the solar mass-loss, $\dot{M}$, is one of the drivers of $L_\odot$ variation in this timescale. The purpose of this study is to model mass-loss varying solar luminosity, $L_\odot(\dot{M})$, and to predict the luminosity variation before it leaves the main sequence. We numerically computed the $\dot{M}$ up to 4.9 Gyrs from now. We used the $\dot{M}$ solution to compute the modeled $L_\odot(\dot{M})$. We then validated our model with the current solar standard model (SSM). The $L_\odot(\dot{M})$ shows consistency up to 8 Gyrs. At about 8.85 Gyrs, the Sun loses 28% of its mass and its luminosity increased to $2.2L_\odot$. The model suggests that the total main sequence lifetime is nearly 9 Gyrs. The model explains well the stage at which the Sun exhausts its central supply of hydrogen and when it will be ready to leave the main sequence. It may also explain the fate of the Sun by making some improvements in comparison to previous models.

Keywords. Sun; mass-loss; solar luminosity

1. Introduction

Understanding of the red giant evolution allows us to predict the final fate of the Sun during its final nuclear burning phase. Nowadays, numerical simulations make possible to test different evolutionary scenarios. Several models of solar luminosity, $L_\odot$, in the evolutionary timescale have been computed as a function of time (Gough 1981; Bahcall *et al.* 2001). However, the solar mass-loss, $\dot{M}$, is one of the drivers of $L_\odot$ variation. The purpose of this study is to model mass-loss varying solar luminosity, $L_\odot(\dot{M})$, to predict the magnitude of luminosity before it leaves the main sequence, and to estimate the solar mass-loss just before the red giant branch (RGB).

2. Mathematical formulation

The base of the formulation of our model is the equation of solar standard model (SSM) given by Gough (1981):

$$L(t) = \frac{L_\odot}{1 + \frac{2}{5}\left(1 - \frac{t}{t_\odot}\right)}, \tag{2.1}$$

where $t_\odot$ is the current solar age and $L_\odot$ is the solar luminosity at this time.

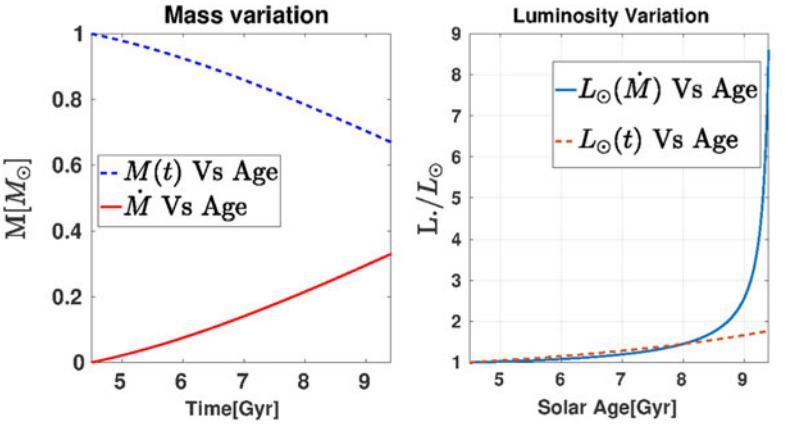

Figure 1. Panel A. The solar mass variation (dashed blue line) and mass-loss (solid red line) in relation to coming lifetime. **Panel B.** Solar luminosity variation in our model, using eq. 3.1 (blue solid line), and in SSM model, using eq. 2.1 (red dashed line).

3. Analysis

We modeled the solar mass variation with time as an exponential decay, $M(t) = M_\odot e^{-\delta t}$, and $\dot{M} = M_\odot - M(t)$, where $M_\odot$ is the current solar mass, δ is the reduction coefficient of mass of the Sun defined in the greatest interval $0 \leq \delta \ll 1$, and t is the age of the Sun. We modeled the $L_\odot(\dot{M})$ in the evolutionary time scale as:

$$L(\dot{M}) = \frac{L_\odot}{1 + \frac{2}{5} ln \left[1 + \frac{1}{\delta t_0} ln \left(1 - \frac{\dot{M}}{M_\odot}\right)\right]}, \tag{3.1}$$

where $L_\odot = 3.85 \times 10^{26}$ W and $t_\odot = 4.57$ Gyrs (Feulner 2012) are the current solar luminosity and solar age, respectively, $M_\odot = 1.9891 \times 10^{30}$ kg (Kaplan, 1981) is the current solar mass, and $0 \leq \delta \leq 10^{-10}$ is the input boundary condition to numerical solution.

4. Results and conclusions

We studied solar mass variation and mass-loss (Figure 1, A) and luminosity variation (Figure 1, B) along the solar coming lifetime. The $L_\odot(\dot{M})$ shows consistency up to 8 Gyrs (blue solid line in panel B) with the SSM (red dashed linein panel B). Our model suggests that Sun will enter RGB at about 8.85 Gyrs which approaches the time suggested by Kopp (2016). The Sun will lose about 28% of its mass and will have a luminosity of $2.2L_\odot$ at this age. At 9 Gyrs, the Sun will lose about 30% of its mass and the luminosity will raise by about $2.5L_\odot$. The model explains well the stage in which the Sun exhausts its central supply of hydrogen and is ready to leave the main sequence. This model contributes to previous studies and our knowledge about Solar evolution.

Acknowledgment

This research was partially supported by the International Science Program (ISP), grant code IPPS/AFRO5.

References

Bahcall, J. N., Pinsonneault, M. H., & Basu, S. 2001, *APJ*, 555(2), p. 990
Feulner, G. 2012, *Reviews of Geophysics*, 50 (2)
Gough, D. O. 1981, *Sol. Phys.*, 74, 21–34
Kaplan G. H. 1981, editor *US Naval Observatory*, No. 163
Kopp G. 2016, *Journal of space weather and space climate*, 6, p. A30

https://doi.org/10.1017/S1743921320003580 Published online by Cambridge University Press