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Ages as an attribute of planetary habitability

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Abstract. In the study of the climatic evolution of the planets and search for life, a key concept is the habitable zone (HZ). The standard definition of HZ is considered, a range of distances from a star to a planet for which liquid water could exist. Physically this corresponds to take into account temperature conditions of about 273 - 373 K for a specific static evolutionary point. Here, based on an evolutionary model, we investigate the evolution of the climate region of a hypothetical Earth around a solar analog star whose masses and metallicities are close to the solar values. We follow the luminosity and temperature model evolution as a function of time (age) for one solar mass star. Our first results used recently GAIA distance and luminosities measurements for a sample of analogs and twins and showing an HZ growing of approximately 20% in size from the Zero Age Main Sequence (ZAMS) to the current age of the Sun. In this study, we are presenting our HZ estimative for a sample of solar analogs and twins. The stability of life and habitability of planets like Earth around solar analogs seems to be a function of age.

Resumo. No estudo da evolução climática de planetas e busca por vida, um conceito fundamental é o de Zona Habitável (ZH). A definição de ZH considerada padrão é de uma faixa de distâncias da estrela em que um planeta pode sustentar água no estado líquido. Fisicamente isso corresponde a levar em consideração condições de temperatura entre 273-373 K para um específico estágio de evolução estelar. Aqui, baseado em um modelo de evolução estelar, nós investigamos a evolução da região climática de uma Terra hipotética ao redor de análogas solares nas quais a massa e a metalicidade são próximas dos valores do Sol. Nós seguimos modelos evolutivos de luminosidade e temperatura como função do tempo (idade) para estrelas de uma massa solar. Nossos resultados usam dados recentes do GAIA para distância e consequentemente luminosidade para uma amostra de gêmeas e análogas e mostram um crescimento da ZH de aproximadamente 20% em tamanho desde a ZAMS até a idade atual do Sol. Nesse poster nós apresentamos nossa estimativa de ZH para gêmeas e análogas. A estabilidade da vida e a habitabilidade de planetas como a Terra ao redor de estrelas como o Sol aparenta ser uma função da idade.

Keywords. (Stars): planetary systems – Stars: evolution

1. Introduction

In order to study planetary habitability we commonly use habitable zone (HZ) as the main parameter. Habitability is quantitatively defined as a measure of the ability of a specific planet orbiting a star develop and sustain life (Schulze-Makuch et al., 2011). However, this concept is under construction. The standard concept of habitable zone (HZ) is conservatively defined as a region where a planet can support liquid water on the surface (Huang 1959). G-type stars evolve along the first 100 Myr reaching the ZAMS, and it is well-known that first billion years of their life the activity is enhanced. The life conditions at this stage are hostile. At this phase, continuous flares, EUV radiation and much denser and faster stellar winds are present (do Nascimento *et al.* 2013). An example of this evolutionary effect driven by the Sun can be found in the Mars evolution. Mars has undergone three main climatic stages throughout its geological history. First, beginning with a water-rich epoch, followed by the Archean cold and semi-arid era. Third, transitioning into present-day arid and very cold desert conditions. These global climatic periods represent three different stages of planetary habitability. The evolution of the habitable zone as a function of stellar age is important and a fundamental step to study habitability. Age of a planet is a major attribute of the habitability status, along which, factors like liquid water or an equivalent solvent, rocky mantle and temperature and other can be considered. The sample selection is critical step to understand our own life evolution as a function of age. Local conditions for the developing of life are thought to include liquid water, magnetic and particles protection, rock, minerals and other aspects connected with the onset of biological requirements. Star-planetary age is a necessary condition and stars with the same properties as for the Sun, and in a range of ages it is one of the good choices to study the habitability evolution as a function of age. In this context, we used the sample composed by 81 solar analogs and twins as proposed by dos Santos et al. (2016). These stars have temperatures between 5662 and 5918K and ages ranging between 0.60 and 10.10 Gyrs.

2. Habitable zone and stellar age

In our approach, to study how HZ changes with the stellar evolution, we used a simple model, in which we consider the flux from a star of radius as $R = \sqrt{\frac{L}{4\pi\sigma T^4}}$, where T is the temperature due to the radiation of a point in the spherical surface of radius R centered in the star that has luminosity L. We use temperatures of 273 and 373 K to compute the internal and external limits of the HZ. These limits represent the temperatures at which water is liquid under a pressure of 1 atm.This is a rough first order approximation. We compare our numbers for the Sun with the ones obtained by Kopparapu et al. (2013), and we realized that they are in good agreement and could be used as a qualitative first study. Concerning distances and evolutionary status of our primary targets, we used information of distance obtained by the GAIA (ESA) mission. We computed luminosities by using the standard expression

$$\log\left(\frac{L}{L_\odot}\right) = \frac{M_\odot(BC + M_V)}{2.5} \qquad (1)$$

where BC is the bolometric correction and has been obtained as a function of the T_{eff} and mass, based on the expressions

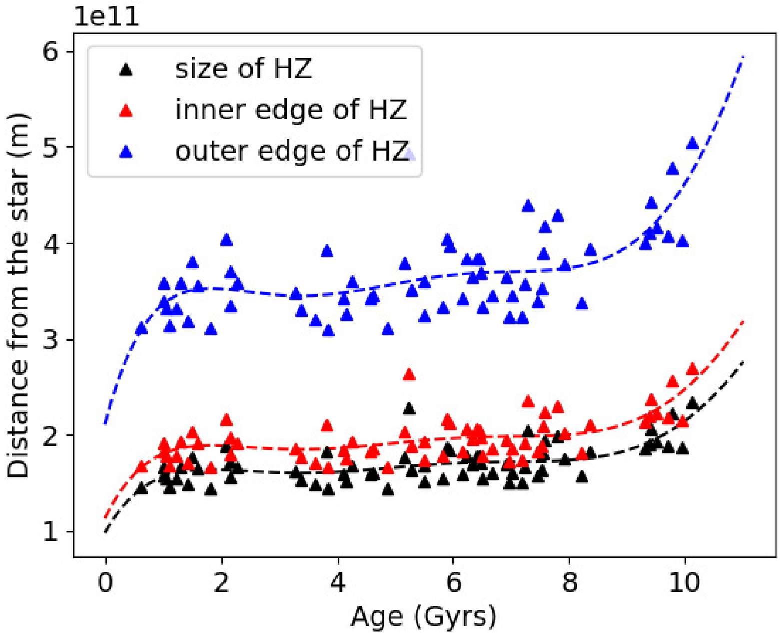

Figure 1. Distance as a function of age. Triangles represent solar analogs and twins which its age and habitable zone has been computed. The dotted lines are trend lines.

described by Flower (1996). The M_V is the visual magnitude and described by

$$M_V = V + 55 \log\left(\frac{1000}{\pi}\right) AV. \quad (2)$$

For close targets with low (π) parallaxes, we can consider absolute extinctions as zero. To understand how these properties vary in an evolving star, we used evolutionary models computed by the Toulouse-Geneva evolutionary code (TGEC), as described in Hui-Bon-Hoa (2008) and do Nascimento *et al.* (2013). These models used an initial composition as Grevesse & Noels (1993). Transport of chemicals and angular momentum due to rotation-induced mixing are computed as described in (Vauclair 2003). The angular momentum evolution follows the Kawaler (1988) prescription. We calibrated a solar model as in Richard *et al.* (1996). With this models, we computed the relation between HZ and some fundamental parameters. The resulting evolutionary model of the HZ as a function of age is shown in Fig. 1.

3. Results and Conclusions

The Figs. 1 show how the HZ evolve as a function of age. From our simple model, we determined a habitable zone size increase of 20% from the ZAMS to the current age of our sun. In this study, we used only stars with new GAIA parallaxes. This first results, allow us to conclude that our theoretical prevision is actually in agreement with the expected for G-type stars. The studies will be continuing to found a promising way to trace the habitability evolution on exoplanets.

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