Ecospheres around binary stars

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Scientific investigations concerning ecospheres of other stars are very important for understanding the posibilities of existence and evolution of extraterrestrial life. In several last years astronomers discovered hundreds of extrasolar planets. Identification of stars with ecospheres is the first step in selecting those planets which could be inhabited. Usually an ecosphere of a single star is considered but it may also exist in planetary systems with two suns. This possibility is very promising in search for life on other planets as more that 60 % of stars reside in binary or multiple systems.

Introduction

For many years astronomers have been investigating the possibility of life on other planets in our Solar System, as well as on planets in extrasolar planetary systems. The region around a star in which life-supporting planets can exist has been called the 'ecosphere' [1]. To determine ecosphere dimension and lifespan one have to know star's luminosity and its 'life-time' because the luminosity changes over time. Ecospheres vary in distance from the central star, width and lifespan depending on intrinsic parameters of planet hosting stars. The larger the luminosity (mass) of the planet hosting star the larger the orbital distance of the ecosphere. However, since many factors influence the exact size of ecosphere even for the Solar System the size of the ecosphere is a matter of dispute. Here we present very simplified considerations concerning ecospheres of binary star solar systems with roughly solar mass companions. We did not take into account the properties of the planet.

Ecospheres around binary stars

It is known that planets around binary star systems can exist. Protoplanetary disks can be observed around young stars. There are three types of planets around binary star systems:

- TYPE S — the planet orbiting one of the component of binary star system (stars are in large separation, over 100 AU)
- TYPE P — the planet orbiting both components of tight binary star system (below 1 AU)
- TYPE L — the planet orbiting Lagrange's points (L4, L5)

Protoplanetary disks were observed around individual components of wide binary systems [2]. Several planetary systems of TYPE S are known. Massive protoplanetary disks are very rare around binary stars with separation of $1 - 100$ AU. Also with the help of numerical simulations it is known that stable planetary orbits around binary stars cannot exist for stars with distances $1 - 100$ AU [3]. In the present work we are interested in TYPE-P planets orbiting close binary systems. Such systems are expected to exist since protoplanetary disks around close binaries are known (see e.g. [4]) for a review). In the present paper we assume that size and distance of an ecosphere depends only on luminosity and effective temperature of the stars. Ecosphere's distance and width is calculated from the barycenter of the binary system. We considered binary systems composed of one star with solar mass and a companion with mass ranging from 0.5 to 2 solar masses. We used Girardi's evolutionary tracks for stars with solar metallicity Z=0.019 (see e.g. [5]) (`http://pleiadi.pd.astro.it/`). We considered evolution of the ecosphere of a binary system over the lifetime of the more massive component. The ecosphere was calculated starting from its Zero Main Sequence

Age (beginning of thermonuclear reactions). We calculated a boundary of ecosphere using the equation for ecosphere of single star [6]:

$$a(T) = \frac{\sqrt{L}}{\sqrt{16\pi\sigma T^2}}, \tag{1}$$

where a, T, L and σ are the edge of the ecosphere (dependent on temperature), the effective temperature within ecosphere, the luminosity of a star and Stefan–Boltzmann constant, correspondingly. To determine the edges of the ecospheres of binary systems we simply added luminosities of two components:

$$a(T) = \frac{\sqrt{L_{s_1} + L_{s_2}}}{\sqrt{16\pi\sigma T^2}}, \tag{2}$$

where s_1 and s_2 are the numbers of components.
If we assume the highest temperature within ecosphere as 373 K and lowest one as 273 K then we have an equation for the width of the ecosphere:

$$\Delta a = a_o - a_i, \tag{3}$$

where a_o and a_i are the outer (273 K) and inner (373 K) boundaries of the ecosphere.

Results and conclusions

The size of the ecosphere during the main-sequence evolution is practically constant, but for a further period of time it expands and moves away from the star (see e.g. [9]) for a review). In Figure 1 the ecosphere for a system consisting of 1 solar mass primary component and 0.5 solar mass secondary component is presented. The ecosphere stretches from 0.67 to 0.89 AU during 8 billions years. The ecosphere location is constant for time long enough for life to develop. However, it is very thin, only 0.22 AU. If we compare this results to Sun's ecosphere (0.52 AU, according to [7]) we can see that it is much thinner. In Figure 2 the evolution of ecosphere for a binary system composed of two solar mass stars is presented. The ecosphere stretches from 0.93 to 1.22 AU during 8 billions years. However, the width is also very small (only 0.29 AU). In Figure 3 the results obtained for a system consisting of 1 solar mass secondary and 1.9 solar mass primary are presented. The width of such ecosphere is the largest. It results from high luminosity of both components. The ecosphere was found to extend from 2.5 to 4 AU during 1.2 billion years. The ecosphere is very wide (fully 1.5 AU) although it does not exist long enought for life to appear.

Detection of planet which orbit lies in ecosphere of a binary stars system does not guarantee that there is life on its surface. It only indicates that there can be liquid water. However, life that we know is carbon-based. So coincidence of planetary orbit with ecosphere is the first important factor for life to appear and evolve. Other factors are important, too. In this simplified approach we did not take them into account. The water on planet's surface can be at risk of evaporation when the planetary orbit is smaller than the inner edge of ecosphere. On the other hand, the water can freeze when the planetary orbit is outside the outer edge of ecosphere. A good example of planets on which life is not possible are Venus and Mars [8]. Another factor which we ignored is planet's atmosphere or albedo which depends on atmospheric structure of a planet and may vary in time.

References

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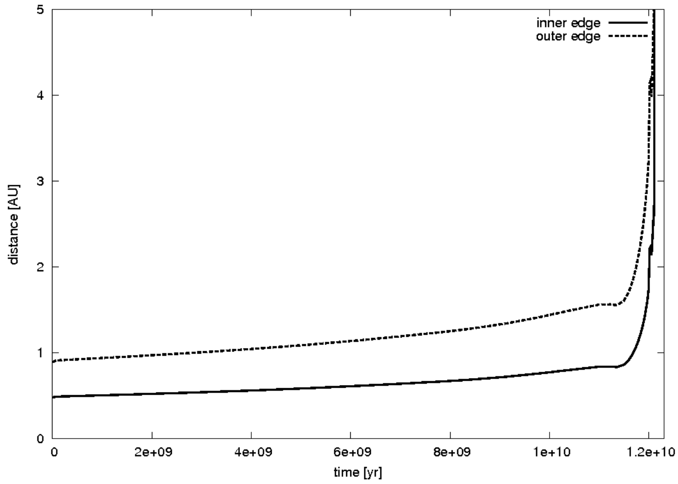

Figure 1: Time evolution for ecosphere's edges for close binary system consisting of stars with 1 and 0.5 solar masses.

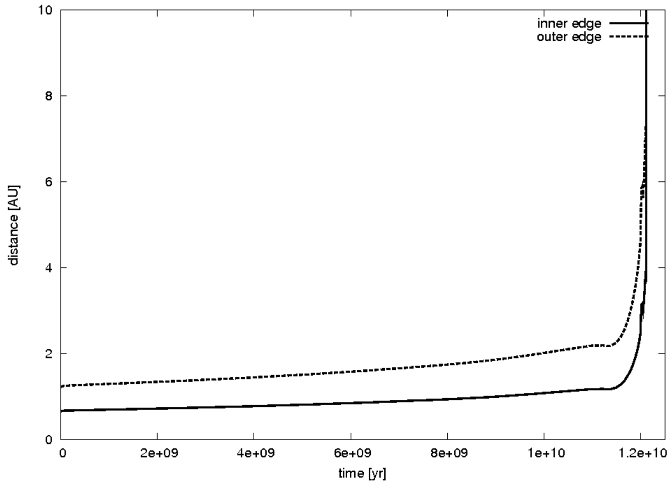

Figure 2: Time evolution for ecosphere's edges for close binary system consisting of two stars with solar masses.

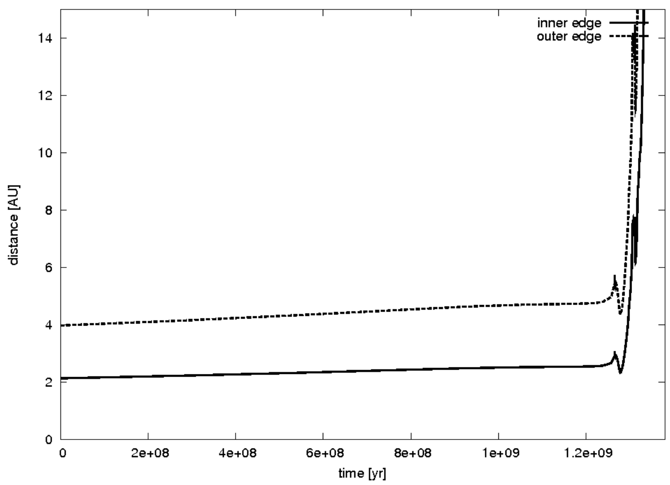

Figure 3: Time evolution for ecosphere's edges for close binary system consisting of stars with 1 and 1.9 solar masses