

Can Earth-Type Habitable Planets Exist Around 47 UMa?

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Abstract. We explore whether the existence of Earth-type habitable planets is in principle possible in the planetary system of 47 UMa. Our analysis assumes that Earth-type planets have successfully formed and are orbitally stable. Our study of habitability deliberately follows an Earth-based view while investigating the long-term possibility of photosynthetic biomass production. Here the stellar luminosity and the age of star/planet system are of fundamental importance for the existence of planetary habitability. We find that the likelihood of Earth-type habitable planets is increased if assumed that 47 UMa is relatively young ($\lesssim 6$ Gyr) and has a relatively small stellar luminosity.

1. Introduction

Planets have now been observed around nearly 100 solar-type stars. Based on the available observational techniques, most detected objects are giant (Jupiter-like) planets, although a few planets with sub-Saturn masses have also been identified. Nonetheless, the presence of terrestrial planets around other stars is suggested by various observational findings including the steep rise of the mass distribution of planets with decreasing mass — albeit different formation mechanisms for gas giants and terrestrial planets (e.g., Marcy & Butler 2000). The study of hypothetical terrestrial planets around 47 UMa is particularly interesting because this system resembles our own solar system relatively closely. First, 47 UMa hosts two Jupiter-mass planets in nearly circular orbits at respectable distances from the host star (i.e., 2.09 and 3.73 AU; see Butler & Marcy 1996; Fischer et al. 2002). Second, it is known that there are no Jupiter-mass planets in the inner region around the star. Third, it is found that the central star has properties very similar to the sun, including effective temperature, spectral type, and metallicity (e.g., Gonzalez 1998). A pivotal requirement for biological evolution of life, including intelligent life, is the long-term orbital stability of Earth-like planets, which is affected by the existence of the two giant planets. For recent results on the 47 UMa system based on different types of methods see Fischer et al. (2002), Noble, Musielak, & Cuntz (2002), Jones & Sleep (2002), and Goździewski (2002). These simulations seem to indicate an outer stability limit for terrestrial planets close to 1.25 AU.

2. Habitability of Earth-Type Planets

On Earth, the carbonate-silicate cycle is the crucial element for a long-term homeostasis under increasing solar luminosity. In most studies the cycling of carbon is related to the tectonic activities and to the present continental area as a snapshot of the Earth’s evolution. Such models are called geostatic models (GSM). On the other hand, on geological time-scales the deeper parts of the Earth are considerable sinks and sources for carbon. In addition, the tectonic activity and the continental area change noticeably. Therefore, we favor the so-called geodynamical models (GDM) that take into account both the growth of continental area and the decline in the spreading rate (Franck et al. 2000).

The habitable zone (HZ) around 47 UMa is defined as the spatial domain where the planetary surface temperature stays between 0°C and 100°C and where the atmospheric CO₂ partial pressure is higher than 10⁻⁵ bar to allow photosynthesis, which is equivalent to a non-vanishing biological productivity. In previous studies habitability for different types of stars has been assessed based on the work by Kasting, Whitmire, & Reynolds (1993), implying that the HZ is limited only by climatic constraints invoked by the stellar luminosity. In our method (“Integrated System Approach”), habitability is linked to the photosynthetic activity of the planet and furthermore to the planetary geodynamics. In principle, this leads to additional spatial and temporal limitations of habitability, as the stellar HZ (defined for a specific type of planet) becomes narrower with time due to the persistent decrease of the planetary CO₂ concentration. Consequently, the HZ of 47 UMa is determined by the stellar luminosity and the age of the star-planet system. The stellar luminosity essentially defines the planetary climate, whereas the age constrains the parameters of the GDM. As stellar luminosity, we assume $L = 1.54 \pm 0.13 L_{\odot}$, based on a parallax of $\pi_{\text{HIP}} = 71.04 \pm 0.66$ obtained by *Hipparcos* (Perryman et al. 1996). As stellar age, we assume 6.32 (+1.2, -1.0) Gyr based on stellar evolution computations (Ng & Bertelli 1998) and the Ca II age-activity relation (Henry et al. 2000).

3. Application to the 47 UMa Planetary System

We compute models for three different stellar luminosities, i.e., 1.41, 1.54, and 1.67 L_{\odot} , which reflect the lower limit, likely value, and upper limit of the 47 UMa luminosity. Concerning the Earth-type planet, we choose three different types of continental growth models in the context of the geodynamic model, which are: no growth, linear growth, and delayed growth (see Figure 1). For comparison, we also consider the geostatic model. Due to the action of geodynamic activity, resulting in the temporal decrease of the planetary atmospheric CO₂ concentration, the different types of geodynamic models are only able to sustain life up to a certain planetary evolutionary time. Life becomes impossible after 7.82 Gyr if the constant area (no growth) model is assumed, after 6.40 Gyr in case of the linear growth model, and after 5.97 Gyr in the delayed growth model. These results are found to be independent of the stellar luminosity, even though the HZs for the different growth models are positioned at different distances from the star. On the other hand, the position of the various HZs in the different models is extremely relevant, if the orbital stability of the terrestrial planet is

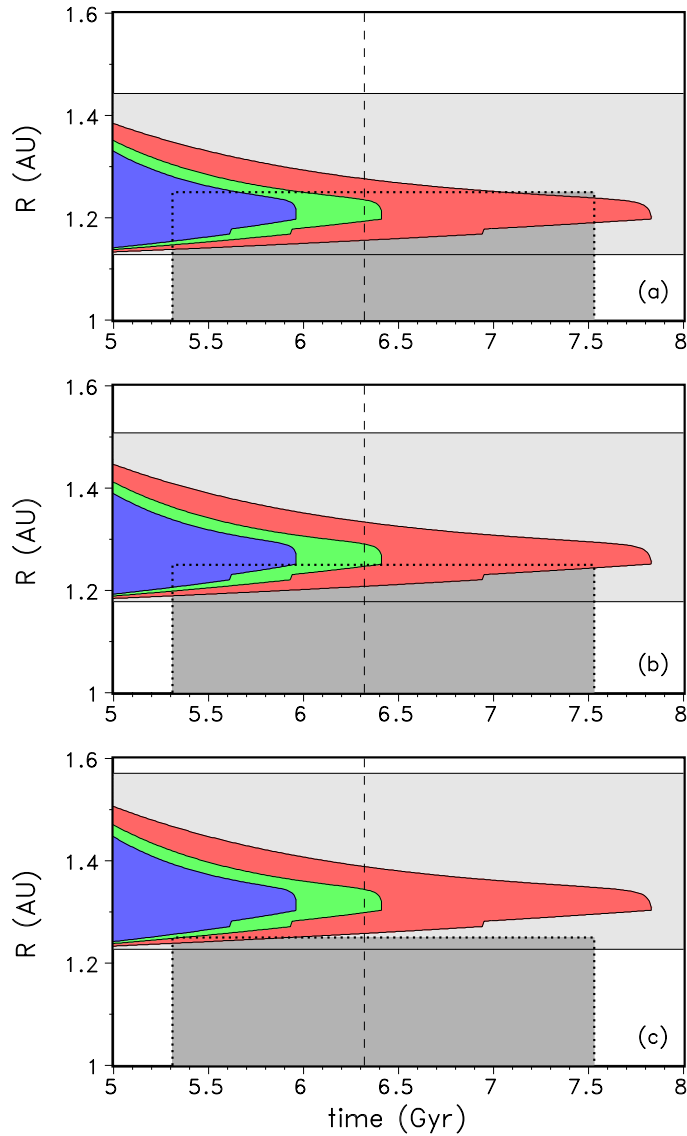


Figure 1. The figure panel shows the stellar HZ around 47 UMa for three different luminosities, which are: (a) 1.41 , (b) 1.54 , and (c) $1.67 L_{\odot}$. The dark gray, semi-light gray, and standard gray areas indicate the extent of the HZ assuming different types of continental growth models in the context of geodynamic models (GDM), which are: no growth (standard gray), linear growth (semi-light gray), and delayed growth (dark gray). The light gray areas (parallel to the x-axes) indicate the results for geostatic model (GSM). The dotted lines indicate the permissible parameter space as constraint by the stellar age and the orbital stability limit at 1.25 AU.

taken into account, as required. In case of $L = 1.41L_{\odot}$, the two giant planets do not heavily restrict the extent of the HZ for an Earth-type planet, which is essentially determined by the choice of the most appropriate continental growth model. On the other hand, for $L = 1.54L_{\odot}$ both the gravitational effects of the gas giants and the planetary continental growth model seriously limit the extent of the HZ around 47 UMa. In case of $L = 1.67L_{\odot}$, the effective HZ around 47 UMa is virtually non-existent.

In summary, the existence of Earth-type habitable planets around 47 UMa depends on the following conditions: First, these planets must have formed out of the planetary disk, despite the relatively close proximity of the two Jupiter-mass gas giants. This would imply that relatively massive planetary embryos accreted close to the host star prior to the formation of the Jupiter-type planets (see discussion by Laughlin, Chambers, & Fischer 2002). Second, 47 UMa must have a relatively low luminosity. Otherwise, the extent of the stellar HZ would be relatively narrow or non-existent as it would be “sliced off” by the gravitational influence of the two gas giants. Third, it would be advantageous if the 47 UMa star-planet system is relatively young ($\lesssim 6$ Gyr). If the age of the star-planet system is 6 Gyr or less, the existence of life would be consistent with all three continental growth models considered. In spite of those caveats, indicating that the 47 UMa system is “a much less than ideal candidate” for extraterrestrial life, it should be noted that 47 UMa is by far the most promising system out of the extrasolar planetary systems discovered to date. Clearly, 47 UMa should be worth serious attention in future terrestrial planet search missions.

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