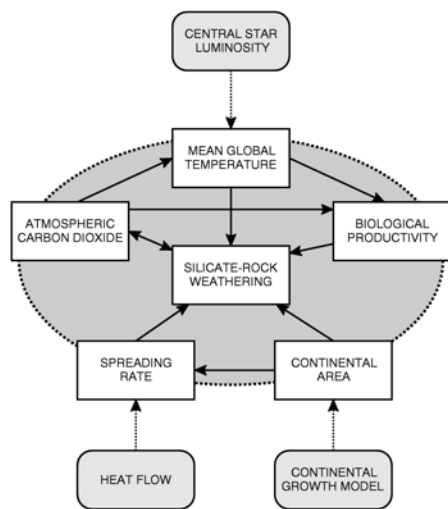


**HABITABLE ZONES IN EXTRASOLAR PLANETARY SYSTEMS: THE SEARCH FOR A SECOND EARTH.** S. Franck, W. von Bloh and C. Bounama, Potsdam Institute for Climate Impact Research, PF 601203, 14412 Potsdam, Germany ([franck@pik-potsdam.de](mailto:franck@pik-potsdam.de), [bloh@pik-potsdam.de](mailto:bloh@pik-potsdam.de), [bounama@pik-potsdam.de](mailto:bounama@pik-potsdam.de)).

**Introduction:** The search for extrasolar planets is one of the main goals of present research. Up to now, more than about 130 extrasolar giant planets are known to orbit around Sun-like stars including several multiple-planet systems. These giant planets, with hydrogen and helium as the main constituents, have atmospheres too turbulent to permit the emergence of life and have no underlying solid surfaces or oceans that could support a biosphere. The distribution of masses of all known exoplanets lets scientists suppose that there must be a multitude of planets with lower masses. Even if it is today beyond the technical feasibility to detect Earth-mass planets we can apply computer models to investigate known exoplanetary systems to determine whether they could host Earth-like planets with surface conditions sufficient for the emergence and maintenance of life on a stable orbit. Such a configuration is described as dynamically habitable.

In our approach habitability does not just depend on the parameters of the central star, but also on the planet itself. In particular, habitability is linked to the photosynthetic activity of the planet, which in turn depends on the mean global surface temperature and the planetary atmospheric CO<sub>2</sub> concentration. Our integrated systems approach is applied both to the solar system and to the extrasolar planetary systems 47 Ursae Majoris (UMa) and 55 Cancri (Cnc).

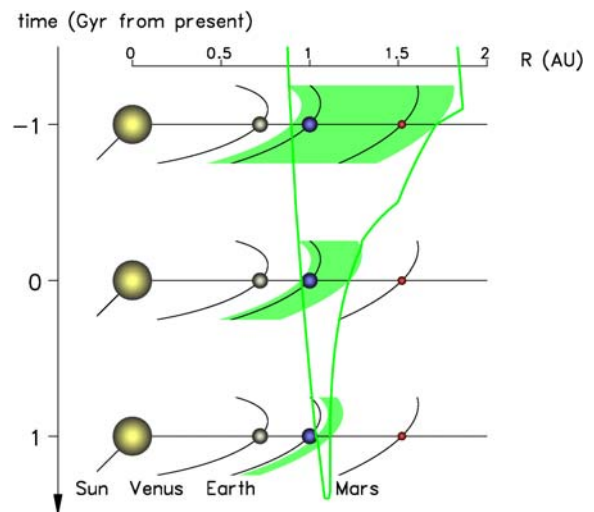


**Figure 1:** Box model of the integrated systems approach [1]. The arrows indicate the different forcings (dotted lines) and feedback mechanisms (solid lines).

**Model Description:** On Earth, the carbonate-silicate cycle is the crucial element for long-term homeostasis under increasing solar luminosity. Furthermore, 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 favour the so-called geodynamical models, which take into account both the growth of continental area and the decline in the spreading rate. Our numerical model couples the stellar luminosity, the silicate-rock weathering rate, and the global energy balance to allow estimates of the partial pressure of atmospheric and soil carbon dioxide, the mean global surface temperature, and the biological productivity as a function of time. The main point is the persistent balance between the CO<sub>2</sub> sink in the atmosphere-ocean system and the metamorphic (plate-tectonic) sources [2].

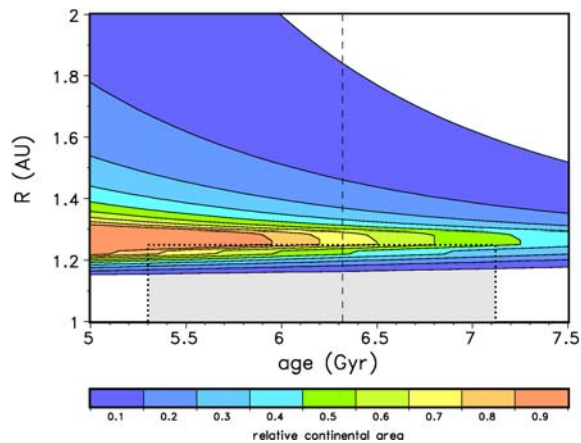
**Results for the Solar system:** The results for the estimation of the HZ for the solar system are summarized in Figure 2, where we have plotted the width and position of the HZ for three different points in time (past, present, future). In about 500 Myr the inner boundary reaches the Earth's position and the biosphere ceases to exist. The outer boundary decreases in a strongly non-linear way.



**Figure 2:** Habitable zone (green shading) for the solar system at three different time steps. The orbits of the three terrestrial planets, Venus, Earth, Mars, are shown. The solid green lines describe the evolution of the inner and outer boundary of the HZ [3].

**Results for extrasolar planetary systems:** The first system, 47 UMa, has been identified to host two Jupiter-mass planets at respectable distances from the host star, which has properties very similar to those of our Sun, including mass, effective temperature, spectral type, and metallicity. The star of the second system, 55 Cnc, has an outer planetary companion orbiting at Jupiter distance and two inner

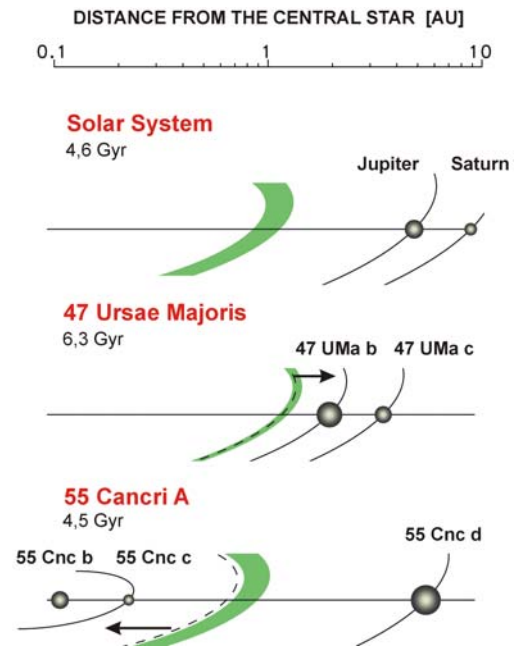
giant planets at very small orbits (hot Jupiters). We have investigated whether these extrasolar planetary systems could host Earth-like planets on stable orbits within the habitable zone. In Figure 3 we show the results of our calculations of the HZ for a likely value of the central star luminosity (color shaded) and the gray-shaded range of orbital stability. The intersection of the two areas describes the interesting parameter range where an Earth-like planet on a stable orbit can exist within the HZ. It is evident that an almost completely ocean-covered planet (“water world”) has the highest likelihood of being both habitable and orbital stable. If the planet is covered with more than 50% continental area, then habitability and orbital stability cannot be found for the entire assumed range of stellar age. For a continental area of more than 90% of the total surface, no habitable solutions also meeting the requirement of orbital stability exist.



**Figure 3:** The habitable zone around 47 UMa for the likely value of luminosity. The colored areas indicate the extend of the HZ for different relative continental areas. The gray shaded area indicates the permissible parameter space as constrained by the possible stellar age and the orbital limit at 1.25 AU [4].

Also in the case of 55 Cnc an almost completely ocean covered planet has the highest likelihood of being habitable [5]. In Figure 4 we show the HZ for the systems 47 UMa and 55 Cnc in comparison with the Solar system for an Earth model with constant continental area of about 30%.

**Conclusions:** In the present investigation we have shown that the existence of a dynamically habitable Earth-like planet is principally possible both in the system 47 UMa and in the system 55 Cnc. This likelihood depends critically on the percentage of the planetary land/ocean coverage and is significantly increased for planets with a high percentage of ocean surface (“water worlds”).



**Figure 4:** Habitable zones (green belts) in the Solar system and in the extrasolar planetary systems 47 UMa and 55 Cnc for an Earth model with constant continental area. The dashed lines indicate the limits of orbital stability of an Earth-like planet. The arrows point at the direction where the orbits of such planets are unstable.

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 [5] von Bloh W. et al. (2003) *Astrobiology*, 3 (4), 681-688.