ON THE HABITABILITY OF EARTH AND MARS

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ABSTRACT

The habitable zone (HZ) around the Sun is defined as the region within which an Earth-like planet might enjoy moderate surface temperatures needed for advanced life forms. Usually, this definition is equivalent to the existence of liquid water at the planet's surface. Our Earth system model consists of the components solid Earth, hydrosphere, atmosphere, and biosphere and couples the increasing solar luminosity, the silicate-rock weathering rate, and the global energy balance to estimate the partial pressure of atmospheric and soil carbon dioxide, mean global surface temperature, and the biological productivity as a function of time. We find that our Earth will leave the HZ in about 500 million years. The position of Venus was never in the HZ, but the Martian position was within the HZ up to about 500 million years ago. Furthermore, we have investigated an Earth model scaled down to Mars size with respect to ocean mass, continental area, oceanic area, plate tectonics etc. We find that an early Mars with plate tectonics and an ocean may have been habitable for some billion years.

1. MODEL DESCRIPTION

Our Earth system model [1,2,3] is a conceptual geosphere-biosphere model to analyse the evolution from the geological past to the planetary future in 1.5 billion years. It consists of the components solid Earth, hydrosphere, atmosphere, and biosphere and couples the increasing solar luminosity, the silicate-rock weathering rate, and the global energy balance to estimate the partial pressure of atmospheric and soil carbon dioxide, mean global surface temperature, and the biological productivity as a function of time. The crucial point is the long-term balance between the CO_2 sink in the atmosphere-ocean system and the metamorphic (plate-tectonic) source. In our approach, the HZ for an Earth-like planet is the region around the Sun within which the surface temperature of the planet stays between 0°C and 100°C and the atmospheric CO_2 content is higher than 10 ppm suitable for photosynthesis-based life.

2. RESULTS FOR AN EARTH-LIKE PLANET

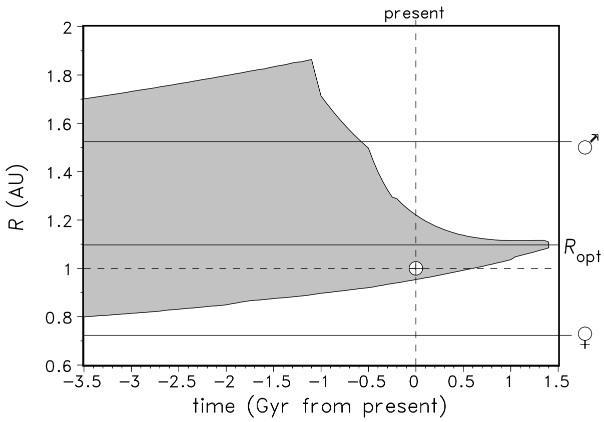

Figure 1: Evolution of the HZ for an Earth-like planet in the solar system with a total carbon amount of 10 bar and an optimum temperature of the biosphere of 50°C [2].

In Fig. 1 we show the evolution of the HZ for an Earth-like planet between 3.5 billion years in the past and 1.5 billion years in the future. We find that our Earth will leave the HZ in about 500 million years, while an optimum position with maximum life span of the biosphere would be at R_{opt}=1.08 AU. Furthermore, the position of Venus was never in the HZ, but the Martian position was within the HZ up to about 500 million years ago.

3. RESULTS FOR A MARS-SIZED EARTH

The results shown in Fig.1 refer to an Earth-like planet that is shifted to Venusian or Martian position, respectively. Up to now, we have no comprehensive model for the planetary evolution of Mars. Therefore, we have investigated an Earth model scaled down to Mars size with respect to ocean mass, continental area, oceanic area, plate tectonics, etc. (see Tab. 1). The results for these calculations of the HZ are shown in Fig. 2. We find that the HZ for a Mars-sized Earth generally vanishes earlier than for an Earth-like planet. Furthermore, the HZ depends strongly on the continental growth model (see Fig. 3).

Table 1: Parameters for the Earth and a Mars-sized Earth.

	EARTH	**MARS**
Radius	6371 km	3390 km
Mantle Radius	6271 km	3337 km
Core Radius	3485 km	1700 km
Mass	$5.9736 \cdot 10^{24}$ kg	$0.6419 \cdot 10^{24}$ kg
Surface temperature	273 K	210 K
Acceleration of gravity	$9.81\ \mathrm{m} \cdot \mathrm{s}^2$	$3.69\ \mathrm{m} \cdot \mathrm{s}^2$
Mantle heat flow	$70\ \mathrm{mW} \cdot \mathrm{m}^{-2}$	$35\ \mathrm{mW} \cdot \mathrm{m}^{-2}$
Mantle density	$4{,}400\ \mathrm{kg} \cdot \mathrm{m}^{-3}$	$3{,}469\ \mathrm{kg} \cdot \mathrm{m}^{-3}$
Mantle volume	$8.6 \cdot 10^{20}\ \mathrm{m}^3$	$1.35 \cdot 10^{20}\ \mathrm{m}^3$
Mantle mass	$4.0 \cdot 10^{24}$ kg	$4.7 \cdot 10^{23}$ kg
Ocean mass	$1.404 \cdot 10^{21}$ kg	$0.151 \cdot 10^{21}$ kg
Surface area	$5.1 \cdot 10^{14}\ \mathrm{m}^2$	$1.44 \cdot 10^{14}\ \mathrm{m}^2$
Continental area	$2.0 \cdot 10^{14}\ \mathrm{m}^2$	$0.565 \cdot 10^{14}\ \mathrm{m}^2$
Ocean area	$3.1 \cdot 10^{14}\ \mathrm{m}^2$	$0.875 \cdot 10^{14}\ \mathrm{m}^2$

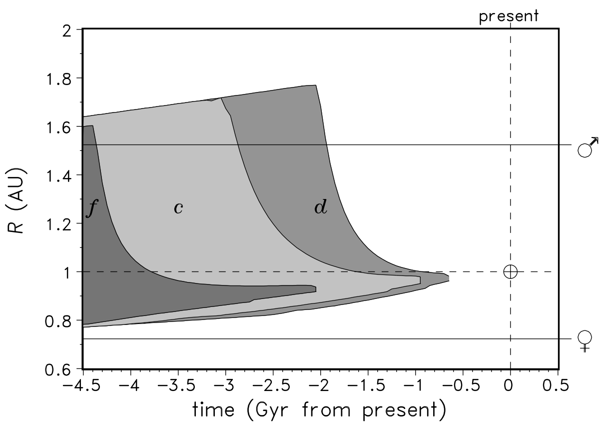

Figure 2: Evolution of the HZ for a Mars-sized Earth for three different continental growth models: fixed area (f), constant growth (c), and delayed growth (d).

4. CONCLUSIONS

We have found that an early Mars with plate tectonics and an ocean may have been habitable for some billion years. Recent investigations give hints for an early warmer and wetter Martian environment [4,5,6,7]. Furthermore, there exist speculations that plate tectonics may have operated on Mars [8]. This is in agreement with the general view that, because of Mars's smaller size, all geological processes caused by the internal cooling of the planet should go off much faster than on Earth. There is a strong influence of the applied continental growth model on the extent of the HZ. Our investigations show that Mars, at least with constant or delayed continental growth, should have been in the HZ long enough to allow the evolution of life. If so, signs of this past life forms should be detectable on planet Mars and future space missions will have to prove whether Mars was living or not.

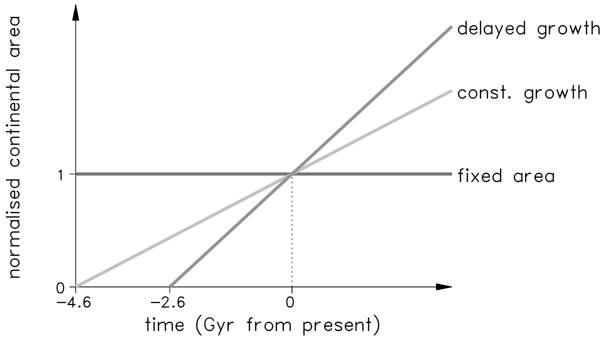

Figure 3: Various continental growth models and their extrapolation into the long-term future.

5. REFERENCES

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