**HABITABILITY OF SUPER-EARTH PLANETS.** S. Franck[1], C. Bounama[1], W. von Bloh[1],and M. Cuntz[2], [1]Potsdam Institute for Climate Impact Research, PF 601203, 14412 Potsdam, Germany (franck@pik-potsdam.de), [2]University of Texas at Arlington, Box 19059, Arlington, TX 76019, USA.

**Methodology:** Our numerical model couples the stellar luminosity, the silicate-rock weathering rate and the global energy balance to obtain estimates of the partial pressure of atmospheric 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 $CO_2$ sink in the atmosphere-ocean system and the metamorphic (plate-tectonic) sources. This is expressed through the dimensionless quantities

$$f_{wr}(t)\cdot f_A(t) = f_{sr}(t) \ ,$$

where $f_{wr}$(t) is the weathering rate, $f_A$(t)is the continental area, and $f_{sr}$(t) is the spreading rate, which are all normalized by their present values of Earth.The evolution of the surface temperature can be derived directly for known luminosity, distance to the central star and geophysical forcing ratio (GFR=$f_{sr}/f_A$). For the investigation of a super-Earth under external forcing, we adopt a model planet with a prescribed continental area. The fraction of continental area to the total planetary surface is varied between 0.1 and 0.9.

The thermal history and future of a super-Earth has to be determined to calculate the GFR values . Assuming conservation of energy, the average mantle temperature $T_m$ can be obtained as shown in Fig. 1.

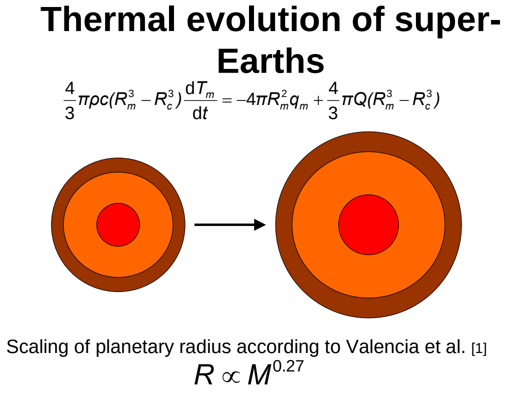


Fig. 1: Sketch of the thermal evolution and the scaling laws for super-Earth planets with radius *R* and mass *M*,where ρ is the density, *c* is the specific heat at constant pressure, qm is the heat flow from the mantle, *Q* is the energy production rate by decay of radiogenic heat sources in the mantle per unit volume, and $R_m$ and $R_c$ are the outer and inner radii of the mantle, respectively.

The photosynthesis-sustaining HZ (pHZ) is defined as the spatial domain of all distances *R* from the central star where the biological productivity is greater than zero, i.e.,

$$\text{pHZ} := \{R \mid \Pi(P_{\text{atm}}(R,t), T_{\text{surf}}(R,t)) > 0\}.$$

A photosynthetic-active biosphere can exist in this domain of sufficient surface conditions. It is possible to calculate the maximum time span that such a biosphere can be sustained.

**Results and discussion:** Very recently, Udry et al. [2] announced the detection of two super-Earth planets in this system, Gl 581c with 5.06 Earth masses with a semi-major axis of 0.073 AU, and Gl 581d with 8.3 $M_e$ and 0.25 AU. Both mass estimates are minimum masses uncorrected for the inclination term sin *i*.

According to Valencia et al. [1] super-Earths are rocky planets from one to ten Earth masses with the same chemicaland mineral composition as the Earth. We use scaling laws to obtain the total radius, mantle thickness and average density as a function of planetary mass. The pHZ around Gl 581 for super-Earths with five and eight Earth masses has been calculated for $L$=0.013$L_s$ (von Bloh et al. [3], Selsis et al. [4]).

The results are shown in Fig. 2.The planet Gl 581c is clearly outside the habitable zone.A planet with eight Earth masses has more volatiles than an Earth size planet to build up such a dense atmosphere. This prevents the atmosphere from freezing out due to tidal locking. In case of an eccentric orbit of Gl 581d (*e*=0.2), the planet is habitable for the entire luminosity range considered in this study, even if the maximum $CO_2$ pressure is assumed as low as 5 bar. In conclusion, one might expect that life may have originated on Gl 581d. The appearance of complex life, however, is unlikely due to the rather adverse environmental conditions. To get an ultimate answer to the profound question of life on Gl 581d, we have to await future space missions such as the TPF/ Darwin. They will allow for the first time to attempt the detection of biomarkers in the atmospheres of the two super-Earths around Gl 581.

We find that the maximum life span scales with planetary mass according to a power law with an exponent of about 0.14. The scaling law can be applied without restrictions to super-Earth planets orbiting K and M stars. Massive stars would limit the duration of habitable conditions through the end of their main-sequence evolution.

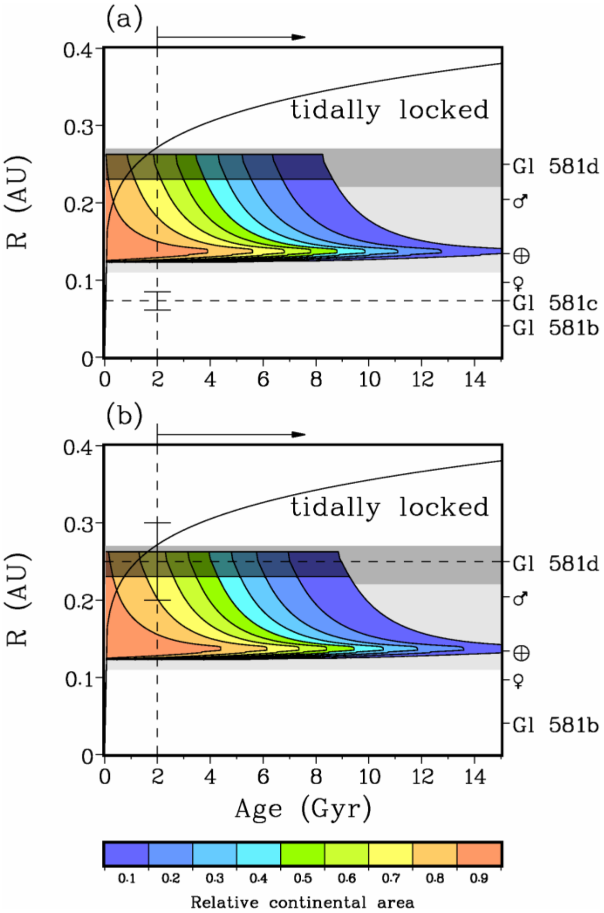


Figure 2: The pHZ of Gl 581 for super-Earth Gl 581c (a) and Gl 581d (b) with a relative continental area varied from 0.1 to 0.9 and a stellar luminosity of 0.013 $L_s$ as a function of planetary age. The light colours correspond to a maximum $CO_2$ pressure of 5 bar, whereas the dark colours correspond to 10 bar. For comparison, the positions of Venus, Earth and Mars are shown scaled to the luminosity of Gl 581. The light and dark grey shaded areas denote different approximations for the so-called stellar HZ. The vertical bar at 2 Gyr denotes the range of distances due to the (possibly) eccentric orbit. The area below the solid black curve is affected by tidal locking [3].

**References:** [1] Valencia D., O'Connell R. J., Sasselov D. (2006), *Icarus, 181*, 545. [2] Udry S., Bonfils X., Delfosse X., et al. (2007), *A&A, 469*, 43. [3] Von Bloh W., Bounama C., Cuntz M., Franck S. (2007), *A&A, 476,* 1365. [4] Selsis F., Kasting J. F., Levrard B., et al. (2007), *A&A, 476*, 1376.