5 Planets Suitable for Life

When searching for extraterrestrial life, and particularly intelligent life, elsewhere in the solar system or in our galaxy, the obvious places to look are habitable Earth-like planets. This is because most living organisms are quite vulnerable to harsh conditions, and thus the presence of life will be most likely when very favorable conditions occur. Here organisms that survive under extreme conditions on Earth represent no contradiction, because they have adapted to their way of life by the fierce battle of survival on the basis of Darwin's theory (discussed in Chap. 7). But what are the conditions that are favorable for life?

Clearly, one of the most important requirements is energy. The fundamental role of our Sun as a provider of energy, as a "source of life", has always been recognized by mankind. Too much sunlight, however, is life-threatening. In order to sustain life, therefore, a planet must orbit in the right distance range, the *habitable zone*, around its sun, and must have the right size. If, like Jupiter, it is too large, its surface will be entirely covered by a massive ocean of liquid hydrogen, where life is unable to form or survive. A planet also must not be too small – like our Moon, which, devoid of atmosphere and oceans, is likewise incapable of supporting life. In addition, the uninterrupted development of the present life forms needed billions of years of a relatively benign environment. The existence of extraterrestrial intelligent life therefore requires a substantial list of favorable conditions, and the question is: Do such Earth-like planets with benign environments exist elsewhere, and how many of them can be expected in our galaxy?

5.1 Habitable Zones

As far away as we can see in our universe, out to the most distant galaxies and quasars, everywhere matter is composed of the same chemical elements as found on Earth. Thus extraterrestrial life, if it exists, must also be composed of these elements. However, one element among the roughly 110 is outstanding: carbon. This element is exceptional because it forms large numbers of different compounds. Presently, more than 10 million carbon compounds are known, the so-called *organic compounds*, compared to only about 200 000 *inorganic compounds* composed of all the other elements.

In order to ensure the basic functions of life, even the most simple living organisms are made up of a large number of different building blocks of intricately designed form and complicated function. Only organic compounds have the huge variety, the different shapes and functions, required of such construction materials of life. It is thus no surprise that life on Earth is based on organic chemistry. Certainly, life could be imagined based on other types of chemistry; for instance, on silicon (see Chap. 9), which is used in the world of computers. However, it is most likely that on other planets the ready availability of a large variety of organic compounds will not be ignored and will invariably lead to organisms that employ a similar chemistry to that on Earth. Nature almost always attempts to take the easiest road to success. One must therefore assume that life on other worlds probably also started using organic chemistry.

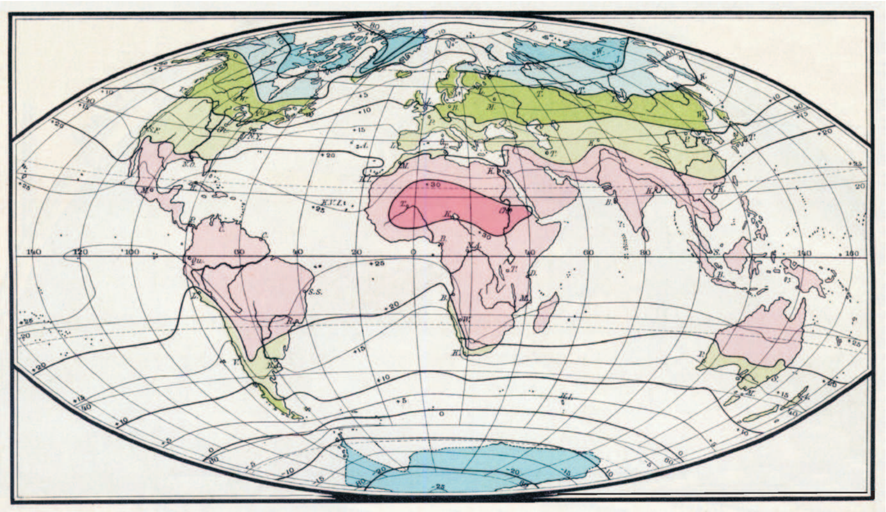

Fig. 5.1. Climatic zones on the Earth, with isotherms of the mean annual temperatures. The 30°C isotherm encloses the central Sahara, marked *dark red*, the 0°C and -10°C isotherms border Arctic and Antarctic regions, shown *light and dark blue*

5.1.1 The Solar Habitable Zone

The vast majority of biologically active organic compounds function best in a certain temperature range and under well defined conditions, like e.g. in solution of water. This temperature range can be seen from the variety of temperatures at which living organisms thrive. Figure 5.1 shows the habitable regions on Earth. In the very cold Arctic and Antarctic regions, where the mean annual isotherms fall below −10°C, little or no life exists. The same can be said for the extremely hot desert regions, where the mean annual isotherms rise above 30°C. While the −10°C annual isotherms correspond roughly to lines at about 60 degree northern and southern latitude, the 30°C isotherm roughly coincides with the central region of the Sahara close to the Equator. At a latitude of 60 degrees (see Fig. 5.2) the amount of solar energy received per cm^2 and sec, the so-called *solar radiative energy flux*, is only one half of that at the Equator (because $\cos 60° = 1/2$). Thus life needs a temperature range where the solar radiation flux is allowed to vary in a very narrow range of at most a factor of two.

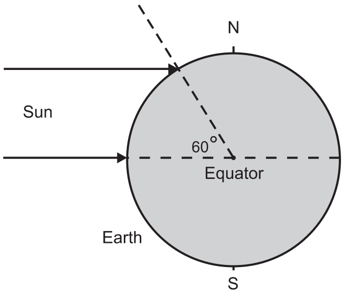

Fig. 5.2. The variation of the solar radiation flux with latitude on the Earth

Let us now conduct a thought-experiment. Assume that one could vary the distance of the Earth from the Sun (see Fig. 5.3). This distance is 149.5 million km, and is called one astronomical unit (AU). How close could one bring the Earth toward the Sun and still have life on it, and how far would one be able to move it away? Since the solar radiation flux varies with the square of the distance from the Sun and as the flux is allowed to increase or decrease by a factor of two, one could move the Earth inward as close as 0.7 AU (with $(0.7)^2 = 1/2$) or outward as far as 1.4 AU (with $(1.4)^2 = 2$). Therefore the distance from the Sun in which life is possible varies by a factor of two, and the solar radiation flux in this zone changes by a factor of four. These distances correspond roughly to the orbits of Venus and Mars (see Table 5.4). One calls the region where, in principle, life is possible the *ecosphere* or *habitable zone*. As the precise distances of the inner and outer boundaries of the solar habitable zone are determined from a number of time-dependent effects, it should be noted that the range of the solar habitable zone from 0.7 to 1.4 AU represents only a reasonable first estimate. More accurate values will be given later.

Moving the Earth to the inner boundary of that zone, the Sahara desert would extend essentially up to the poles and all land surfaces would become unbearably hot. On the outer boundary, the polar ice fields would extend all the way to the Equator and life would no longer be possible in a com-

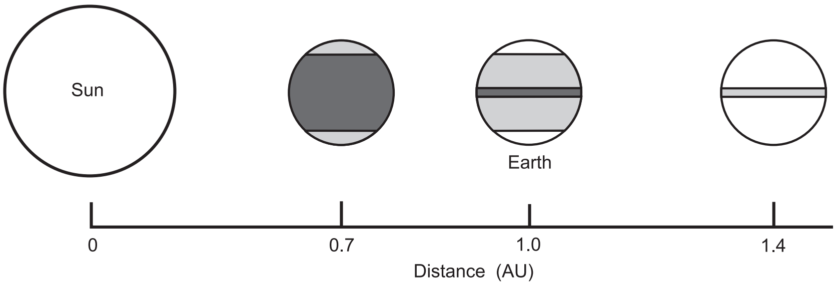

Fig. 5.3. Habitable regions (*light gray*) if Earth were at various distances from the Sun. Arctic regions are shown in *white* and desert regions in *dark gray*

pletely frozen world (Fig. 5.3). These two types of fate were essentially what happened to Venus and Mars.

5.1.2 Habitable Zones Around Other Stars

Now consider the habitable zones around other stars. Stars differ in size (there are giant and dwarf stars) and in surface temperature. Since the overwhelming majority of stars are dwarfs, or more precisely *main sequence stars* (see Chap. 1), and as the giant stars are late evolutionary stages of main sequence stars, we can exclude the few giants from our considerations. Table 5.1 displays the different types of main sequence stars.

For historical reasons, the stars are classified by the letters O to M (to be memorized by the famous phrase "Oh Be A Fine Girl (Guy) Kiss Me"). These

Table 5.1. The spectral class, effective temperature T_{eff}, luminosity, lifetime, abundance, range of habitable zone, and tidal lock radius of main sequence stars (after Landolt-Börnstein 1982)

Spectral class	T_{eff} (K)	Stellar luminosity ($L_\odot$)	Stellar lifetime (y)	Stellar abundance (%)	Habitable zone (AU)	Tidal lock radius (AU)
O6V	41 000	4.2×10^5	10^6	4×10^{-5}	450–900	1.9
B5V	15 400	830	8×10^7	0.1	20–40	1.1
A5V	8 200	14	1×10^9	0.7	2.6–5.2	0.8
F5V	6 400	3.2	4×10^9	4	1.3–2.5	0.7
G5V	5 800	1	2×10^{10}	9	0.7–1.4	0.6
K5V	4 400	0.15	7×10^{10}	14	0.3–0.5	0.5
M5V	3 200	1.1×10^{-3}	3×10^{11}	72	0.07–0.15	0.4