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Seminars and Public Lectures

Unless stated otherwise, the seminars summarized below are directed at a scientific audience. There are some overlaps in the contents of some of the lectures.

"Primary production by oxygenic photosynthesis: One of the most significant breakthroughs during the evolution of the biosphere"

During its early history, the development of life on Earth was restricted by the limited availability of both organic matter and energy: Only organic material that had been synthesized previously by non-biological reactions was available. Mounting evidence suggests that least part of this matter originated from interstellar space and might have been transported to Earth by comets or asteroids. Terminal electron acceptors for the generation of energy by oxidative reactions were in extremely short supply because the primordial atmosphere did not contain any oxygen. After the emergence of the first autotrophic bacteria the biosphere became capable of *de-novo* synthesis of organic matter by the reduction of carbon dioxide. However, the first photosynthetic organisms were dependent on reduced molecules as primary electron donors such as hydrogen sulphide whose availability was limited despite the lack of atmospheric molecular oxygen. Moreover, terminal electron acceptors continued to be rare. However, probably at least 3.5 billion years ago, the stromatolithes developed, cyanobacterial mats, that were capable of utilizing water as primary electron donor for the reduction of CO_2. Cleavage of the stable water molecule required the evolution of a second photosystem and the emergence of an effective enzyme system. Molecular oxygen was formed as a waste product that was released to the environment.

However, it took almost one and a half billion years for the first traces of oxygen to appear in the atmosphere. This had mainly two reasons:
(1) Most oxygen was consumed by the decomposition of organic matter that previously had been biologically synthesized. Only a small proportion of molecular oxygen remained behind, which corresponded to the proportions of organic matter that was deposited in sediments, instead of being decomposed.
(2) About 98% of the remaining oxygen led to the oxidation of minerals at the surface of the Earth. During that time, the first unicellular Eukaryotes evolved, the vast majority of which is aerobic.

The time-course of the rise in atmospheric oxygen is poorly known. However, there is some evidence that it occurred in pulses. The emergence of multi-cellular animals occurred only one billion years later. This can be explained by the great energy demands of multi-cellular organisms that could be met only by the utilization of oxygen as terminal electron acceptor. In fact, only about 700 million years ago, the first highly diverse community of multi-cellular marine organisms (the *Ediacara* fauna) had developed. Most of the animals had flat bodies, which can be interpreted as adaptation to increase the surface-to-volume ratio for enhanced respiratory gas exchange.

It is assumed that about 400 – 500 million years ago the atmospheric oxygen partial pressure had approximately reached its current level. During this time, first plants and shortly thereafter animals invaded terrestrial habitats. It is reasonable to assume that this only became possible after the stratospheric ozone layer had formed which absorbs most of the damaging solar ultraviolet radiation. In the water, ultraviolet is of minor importance, especially due to dissolved organic matter which mainly absorbs light at short wavelengths.

The development of terrestrial communities of animals and plants has been an enormous evolutionary breakthrough, comparable only to the developments of aerobic life und multi-cellular organisms. Within a relatively short time by geological standards, terrestrial primary production exceeded the productivity of the sea and the lush carboniferous forest developed. The superiority of terrestrial primary production is mainly due to the greater supply with radiant energy. This has two reasons:

(1) Water strongly absorbs red light. Therefore, only the blue absorption peak of photosynthetic antenna pigments is capable of harvesting photons.
(2) Water absorbs and scatters light much more than air. Therefore, in most aquatic habitats only small proportions of the light penetrating the water can be absorbed. By contrast in closed terrestrial plant stands virtually all impinging light is absorbed and harvested by photosynthetic tissue.

It is assumed that during the past 400 million years, atmospheric oxygen levels have remained relatively constant. Two mechanisms for stabilizing atmospheric oxygen have been proposed that are not mutually exclusive:

(1) Microbial nitrogen fixation is inhibited by oxygen. As a consequence, primary production is diminished by nitrogen limitation whenever oxygen concentrations in the environment rise.
(2) Elevated atmospheric oxygen partial pressure leads to the spontaneous ignition of organic matter, thus consuming oxygen.

However, the occurrence of insects with wingspans of up to 60 cm (Dragonflies and the extinct Paleodictyoptera) during the Carboniferous would strongly suggest atmospheric oxygen partial pressures significantly higher than at present during this period of extremely high terrestrial primary production. This can be inferred because the oxygen demands of flying insects of this size could not be met today due to the limited efficiency of the tracheal system for respiratory oxygen supply.

The current atmospheric oxygen content of ca. 21% apparently is optimal for the evolution and dispersal of life, both in the ocean and on the continents. It is the result of a large number of processes that closely interact which each other. The beginning of this chain of biogeochemical reactions, the cleavage of the water molecules by oxygenic phototrophs, was achieved by the first cyanobacteria in shallow waters. The communities responsible for this have persisted to the present day.

"Nutrient versus Energy Limitation in the Sea: The Red Sea and the Southern Ocean as extreme case-studies."

The Law of the Minimum states that the resource in shortest supply controls biological productivity. In general, nutrient supply restricts the accumulation of biomass (yield limitation), whereas energy supply controls the velocity of growth (rate limitation). In most marine systems energy supply is ample during summer, thus allowing the complete exhaustion of the least available nutrient, most frequently nitrogen: By contrast, during winter, deep mixing recharges the euphotic zone with nutrients which, however, cannot be fully utilized due to shortage of radiant energy. The study of mechanisms controlling the productivity of the sea is of interest for two reasons: (1) The use of marine living resources a food sources for the growing human population. (2) The role of the ocean as a potential carbon sink, both during Earth history and during the current period of increasing atmospheric CO_2-levels.

The Gulf of Aqaba at the Northern end of the Red Sea can serve as an example for a primarily nutrient-controlled system. During most years, radiant energy supply is sufficient for the complete exhaustion of nitrate within the mixed layer, even in winter. Because mixing depths vary between years owing to the extent of winter cooling, variable quantities of nutrient salts are introduced to the euphotic zone during winter mixing. As a consequence, phytoplankton development and productivity exhibit pronounced inter-annual variations. In other words: The deeper winter mixing, the more biomass can form during the ensuing growing season. Only when mixing depths exceed ca. 350 m during exceptionally cool winters, energy supply is insufficient for the complete exhaustion of nutrients. Then phytoplankton biomass cannot rise any further.

For years it has been hypothesized that energy supply in the Southern Ocean is insufficient to allow depletion of limiting nutrient salts for the build-up of phytoplankton biomass throughout the year (HNLC-Region). However, since the Equatorial Pacific and the Central North Pacific are also HNLC-Regions, low energy supply cannot serve as the only explanation for this pattern. Iron fertilization experiments in the Equatorial Pacific and, more recently, in the Southern Ocean suggest that also in the Southern Ocean, iron limitation might act at least as an additional mechanism controlling the primary production process.

These findings may serve as bases for two existing hypotheses to explain the co-variation of temperature and atmospheric CO_2 partial pressures during the glacial-interglacial cycles, as evident from the Vostok ice core: (1) The *mixing-depth-hypothesis* which contends that deep mixing during glacial periods has increased nutrient salt supply to the upper mixes layer, thus adding to the build-up of biomass. (2) The *iron-dust-hypothesis*, which states that fertilization by iron dust, is instrumental in enhancing oceanic production during cold periods.

Both scenarios should lead to an intensification of the biological carbon pump thus increasing the rate of CO_2 removal from the atmosphere. The two hypotheses are not mutually exclusive.

"Renewable but not inexhaustible: The global supply with freshwater for a growing human population"

This presentation is aimed at a general public and decision-makers.

It is estimated that ca. 1.2 billion people worldwide don't have access to sufficient freshwater of adequate quality. Over 50 % of the world population does not have hygienic toilet facilities. Only ca. 5 % of all sewage is treated worldwide. Every year, over 5 Million people die of diseases related to inadequate supply of freshwater. Infants are particularly affected. In order to meet the demands of the growing human population (annual growth rate currently 1.33 %), global freshwater withdrawal would have to increase by ca. 4 % annually.

Freshwater availability for any usage depends on both the amount of water available, and on its quality. Inadequate management of the global freshwater resources includes alteration of the hydrological cycle and the deterioration of water quality. Large reservoirs and irrigation projects usually lead to diminishing water availability for downstream users, mainly by increasing water losses by enhanced evaporation. The quality of inland water resources is adversely affected by over-fertilization (eutrophication), by pollution, mainly due to pesticides and heavy metals, by acidification, and due to non-sustainable use of living freshwater resources. The deterioration of water quality of rivers and lakes reduces their usability for human needs.

Enormous regional disparities in the quantities and the quality of available freshwater exist worldwide. In general, regions with limited supply of water for human consumption are also characterized by poor water quality. Moreover, in most of such cases the small quantities that would in principle be available are used only inefficiently. By the combination of these factors, the regional disparities in water availability are enormously amplified.

Because only water that is naturally regenerated by the hydrological cycle can be utilized in a sustainable fashion, the overall availability of fresh water cannot be increased. Only more efficient and effective water usage can provide a solution for the growing freshwater demand for the human population. Since on the average, 70 % of worldwide water consumption is for agricultural use, increased water economy in the agricultural sector has the greatest potential for the solution of the global freshwater crisis. The best strategies towards this goal are the use of recycled purified wastewater and the application of water-efficient irrigation techniques (in particular, drip irrigation). Since most irrigation water is used for the production of food, the global freshwater crisis is inseparably linked to the problem of global food production.

In order to resolve the global freshwater crisis the following goals have to be met: (1) To guarantee drinking water of adequate quality in sufficient quantities. (2) To secure enough water required for agricultural production (especially food and timber). (3) To secure enough water for industrial production, to maintain ecosystem health of inland waters, and (4) to meet the demands of all water users, in order to avoid conflicts of interest between different forms of water use by taking into consideration the needs of downstream water users. In order to meet this goal both technical and administrative measures are required.

“The Sixth Extinction:
Humanity as cause for a mass-Extinction of biological species of geologic proportions”

This seminar is aimed at undergraduate students

The natural life span of a biological species ranges from between 1 and 10 Million years. Species lost by extinction are assumed to be replaced by new ones, thus leaving the total species number unchanged. It is estimated that background extinction affects ca. 10 species annually. Brief episodes with ass extinctions, by contrast, are characterized by losses of a large number of species that are not immediately compensated for by the emergence of new species. Glaciations, trap volcanism, and asteroid impacts are considered to be the main causes for mass extinctions during Earth history. However, adaptive radiation following mass extinctions during Earth history has led to emergence of new forms of life during 2 – 5 million years following a major extinction event. Therefore, mass extinctions are considered to be major motors of evolution. The total number of biological species is assumed to have increased during Earth history, despite the repeated occurrence of mass extinctions, and is estimated to range from 10 to 80 million (However, only 1.7 million species are known to science).

Before our eyes but hardly noticed, a mass extinction takes place which is comparable to the major extinction events during Earth history. Estimates of current extinction rates vary widely, but are assumed to be in the range of 130 species per day. The main primary driving variable for the extinction of species is the combination of human population growth (currently 1.33 % per years, or 82.6 million), in conjunction with rising per capita resource consumption. The main immediate causes for the current losses of species are (1) loss of habitat due to ecosystem degradation or conversion for human use, (2) introduction of alien species, either on purpose, or by accident, and (3) over-exploitation of living resources. The susceptibility of organisms to extinction depends on (1) their geographic distribution (widely distributed species being less endangered than those living in restricted geographic ranges), (2) tolerance to environmental conditions and specialization with respect to food resources (generalists being less susceptible than specialists), and (3) mode of reproduction and abundance (small and abundant species having many offspring are less threatened by extinction than large and rare species with few natural enemies and small numbers of offspring).

The consequences of species loss for the functioning of ecosystems depend on their role in the respective ecosystems, which is not necessarily a function of their abundance. The need for species protection depends on their susceptibility to extinction and their “values”: Concerning the latter, a broad range of ethical positions exists which can be subdivided into anthropocentric positions (protection because a species is useful for humans), and biocentric positions (protection of species because of their roles in natural ecosystems and because of their intrinsic values).

"World population growth and sustainable development:
The greatest challenge for the Third Millennium"

This presentation is aimed at a general public and decision-makers.

By 1800, the world population had reached 1 billion. A second billion was added during the ensuing 120 years. Currently, one tenth of this time-span is required to add another billion to the world population. Almost 99 % of human population growth takes place in lesser-developed countries. At the same time, 80 % of the world's resources are exploited by 20 % of the world population, residing in the wealthy industrialized countries. Per-capita energy consumption (the D-index, as proposed by the Canadian ecologist Jack Vallentyne which defines per-capita energy consumption as multiples of physiological human energy demands of ca. 100 Watts) can be used as a convenient measure of overall resource consumption. The world average of per-capita energy consumption is 2,000 Watts (that is, 20 D-units), ranging from ca. 3 (Bangladesh, Ethiopia) to over 100 (USA and Canada). As a rough approximation, the human impact on the environment by any individual country can be related to the product of population size times per-capita resource consumption (the overall number of D-units).

For the development of strategies to achieve sustainability, both factors have to be considered. Neither population size and growth rate, nor per capita resource consumption alone will be sufficient to develop global strategies with the objective of achieving a sustainable and environmentally sound future development.

The combined effects of world population growth and rising per-capita resource demand are the main driving forces of man-made global change: The following global core problems can be defined:

- Loss of biological habitats and species,
- Man-made climate change,
- Shortage of freshwater and food, and
- Shortage of energy.

Because of the mismatch in the geographic distributions of population growth and wealth, the regional disparities between the rich and the poor countries are bound to continue to rise.

Within the industrial countries, the process of demographic transition during the past 200 years has led to a virtual cessation of population growth. The following three stages of demographic transition can be distinguished:

- Stage 1 (pre-industrial): Slow population growth due to high mortality despite high birth rates.
- Stage 2 (early industrial): Rapid population growth due to decreasing mortality but continuing high birth rates.
- Stage 3 (late industrial): Decelerating or stagnating population growth by the combination of low mortality (high life expectancy) with low birth rates. Population size decreases if the maintenance reproduction rate (2.1 children per woman) no longer is reached.

Lesser-developed countries currently are in Stage 2 of their demographic transition. However, it cannot be expected that in a large number of developing countries Stage 3 will be reached early enough to forestall catastrophic consequences of the current growth of the world’s population. The following reasons are responsible for this: (1) Decreasing fertility is the consequence of increasing wealth and education, both of which are not imminent in many of the poor countries because poverty is still on the rise. (2) The process of demographic transition is slow (at least 3 generations).

As a consequence of this, the following problems can be expected to get worse during the next few decades:

- Increasing food and water shortage,
- Increasing poverty in the lesser developed countries,
- Increasing incidence of epidemic diseases,
- High unemployment, especially among the young generation,
- Mass migrations from the poor to the rich countries,
- Rising political unrest and conflicts within underdeveloped regions (civil wars, ethnic cleansing)
- Rising conflicts ("asymmetric warfare" by terrorism) between the poor and the wealthy countries,
- Accelerated destruction of the natural habitats and, as a consequence, accelerated mass-extinction of species,
- Continued and rising human impacts on the world climate.

Political measures aimed at alleviating these problems are urgently needed. However, they will be bound to fail on the long run, unless the primary driving forces of anthropogenic global change are checked. Immediate and concerted political action is required which above all has to take into consideration the global disparities between the rich and the poor countries: (1) The rich countries have to curb their excessive resource consumption and provide massive aid to the poor countries to help them solve their own problems. (2) In the poor countries, all means available should be utilized to curb the excessive reproduction. The most effective means by which this can be achieved is by strengthening the position of women in society, including substantially improving their education. All of these strategies are urgently required to safeguard sustainable development and the survival of our planet during the 21st Century. In most countries, the chances for rapidly implementing the above-mentioned remedial strategies are slim.

"Will there be a new ice age, despite global warming?
Natural and anthropogenic climate variations and their consequences"

Since 1900, global mean air temperatures have risen by ca. 1°C. The year 1998 has been the warmest over the past 1,000 years. Moreover, seasonal weather patterns have changed in many regions. Global warming at least in part can be attributed to the increase in atmospheric levels of greenhouse gases, mainly carbon dioxide and methane, as a consequence of human activities. In this presentation the question will be raised whether this could possibly prevent the next glaciation, which is expected to reach its maximum in about 60.000 years. The conclusion will be that even in case of a continuation of the current warming trend due to the emission of greenhouse gases, it is unlikely that the next glaciation will not take place.

The climate is controlled by the solar energy input, the heat balance within the atmosphere, and the re-distribution of heat by global atmospheric and oceanic circulation patterns. Only during 3% of the entire history of the Earth, it was cold enough for ice to form in polar and high-altitude regions. Climate change over the course of Earth history has been caused by an array of mechanisms, which can be summarized as follows:

- Variations of the amount of radiation received by the Earth system (the solar constant) which are controlled by the intrinsic solar input (which has increased steadily by a total of ca. 30% since the formation of the solar system), and by variations of important elements of the Earth's orbit around the sun.
- Atmospheric and oceanic circulation patterns that shift on a long time-scale, mainly due to the changing distribution of continents and oceans and the formation of mountain ridges. In addition, ocean currents can undergo rapid rearrangements, thus leading to a destabilization of the climate.
- Variations in the natural greenhouse effect of the Earth's atmosphere (which at present causes an increase of global mean temperatures by 33 K) are caused by changes in atmospheric greenhouse gas partial pressures. The latter are due to shifts in the balance of greenhouse gases between the atmosphere on the one and oceans and continents on the other hand. About 75 % of the natural greenhouse effect is due to water vapour, 15% to CO_2 and the remainder to other trace gases such as methane, CFCs, and ozone.

It is most likely that regular variations in certain parameters characterizing the Earth's orbit around the sun (the Milankowitch Cycles), are the main causes for the alteration of glacial and interglacial periods with a periodicity of ca. 100,000 years over the past 900,000 years, as documented from the Vostok ice core and marine climate archives.

Since 1800, atmospheric CO_2 levels have risen by 30%, and methane levels have doubled. The current atmospheric CO_2 partial pressure represents the highest value during the past 300,000 to 400,000 years. Fossil fuel consumption contributes 77% and land use changes 23% to the anthropogenic rise in CO_2. It is estimated that roughly 50% of the CO_2 added by human interference, remains in the atmosphere.

Concern about global warming is due to the following possible consequences:

- Shifts in the global distribution of temperatures and vegetation boundaries: Although this might be desirable in some regions, thawing of permafrost could cause the release of additional greenhouse gases, thus enhancing the current warming trend.

- Changes in the regional patterns in the precipitation: Of particular concern is decreasing rainfall in regions that are already affected by draught such as the Sahel Region to the South of the Sahara Desert (desertification).
- Global sea level rise: By thermal expansion of upper layers of the sea and by melting of polar ice caps over the past century, the sea level has risen by between 10 and 25 cm since 1900. Predictions of the additional sea level rise until the year 2100 range from 20 to 100 cm, based on the assumption of a continuation of the current warming trend. The high degree of uncertainty in the predictions is in part is due to our limited capability of predicting the extent of sea level rise due to thermal expansion of near-surface layers of the ocean. The latter is estimated to contribute roughly 50% of the overall sea level rise. If all glacier ice would melt, this effect alone would lead to a sea level rise of 86 m. Rising sea levels are considered to represent particularly severe threats in view of the fact that growing proportions of the human population reside at low elevations in coastal regions.
- Increasing abundance of extreme weather events such as hurricanes and floods: The probability of severe natural disasters exhibits a skewed magnitude-frequency distribution. In other words, the larger an event, the less likely it is to occur. Due to the rarity of their occurrence, it is difficult to prove by statistical means whether extreme weather events have actually increased as a consequence of global warming, as is often stated. However, it has been convincingly demonstrated that the extent of property damage and death toll by weather-induced disasters has increased markedly during the 20th century. This at least in part can be attributed to the increased vulnerability of affected areas due to population growth and economic development.
- Destabilization of the climate: Modelling of ocean circulation patterns had suggested previously that global warming could lead to re-arrangements of ocean currents with the consequence of drastic short-term climate changes. It had been predicted that increased melt water influx to the North Atlantic could lead to a cessation of the convective sinking of cold surface water. As a consequence, the North Atlantic current could be shut down, thus leading to a rapid cooling. However, more recent calculations have suggested that this scenario is less likely than previously assumed. .

The Kyoto Protocol of 1997 has been an attempt to curb the release of greenhouse gases by the industrial nations by 5% in 2010 as compared to 1990, in with the aim of avoiding further global warming. Significant flaws of the Kyoto Protocol include the exemption of lesser-developed countries such as China and India from the obligation to reduce greenhouse gas emissions, and the accountability of reforestation efforts by which greenhouse gas sinks are established, for determining national emission targets. Trading of emission certificates, on the other hand, is considered a positive element of the Treaty. To date, the Kyoto Protocol is not yet binding because it has not been ratified by a sufficient number of countries. Despite the existing uncertainties in predicting future climate change and the obvious flaws of the Kyoto Protocol, its implementation would be highly desirable for the sake of environmental protection and disaster prevention.

“Extraterrestrial life:
Are we facing a reversal of the Copernican Revolution?”

The Heliocentric System, proposed by Nicolaus Copernicus has triggered one of the most significant changes of paradigm during the entire cultural history: Earth now no longer was considered to be the centre of the Universe. The corollary of this has been that there might be many worlds such us ours. It could be, however, that 460 years later, we have to return to the previous view that Earth after all in many respects is a truly unique place. This reversal of the Copernican Revolution could be derived from the fact that, despite intensive search, no evidence of extraterrestrial life whatsoever, not to mention intelligent one, has emerged. The proposed presentation is attempting to give an overview of our current views on the prospects of extraterrestrial life, and of our chances of getting into contact with alien intelligent civilizations.

The only basis for drawing conclusions concerning the possibility of extraterrestrial life is the analysis of conditions that allowed the emergence and evolution of life on Earth. The working hypothesis of this presentation is the Principle of Uniformitarianism, which assumes that at all times, and everywhere in the Universe, the same principles can be applied. Since we roughly know which conditions were met on Earth for life to emerge and spread, we can look at other planets and examine whether conditions there might also have the potential of supporting life. These conditions include the following: The existence of liquid water, the availability of all chemical elements required for life, and of energy sources that can be used by organisms. Moreover, life can only form and persist on solid surfaces such as rocky planets, at temperatures within a narrow range by cosmic standards, and the persistence of conditions allowing for life to persist over sufficiently long periods of time. The latter requires the existence of a single main-sequence star of approximately solar mass at the centre of a planetary system. The life expectancy of main-sequence stars is inversely proportional to the 3^{rd} power of their respective masses. It determines the overall time available for biological evolution on a planet orbiting this star. This is because their intrinsic luminosities (and hence, consumption of their hydrogen fuel) are proportional to the 4^{th} power of their mass. In fact, a star such as the sun has a life expectancy as main-sequence star of 10 billion years, whereas a star of 10 solar masses lives no longer than 10 million years.

Two basic approaches will be used to assess the possibility of extraterrestrial life and our chances to get into contact with intelligent civilizations:

1. **Defining habitable zones within the Universe:**
   The hypothesis is that life is only possible within relatively narrow regions:
   - **The solar system habitable zone:** Our neighbouring planets are inhospitable places: On Venus no water is available because water molecules were dissociated by solar ultraviolet radiation, which on Venus is almost twice as intense as on Earth. Due to the immense greenhouse effect by the massive Venusian atmosphere which consists almost entirely of carbon dioxide, the mean surface temperature on Venus is ca. 470°C. Mars, by contrast, has lost most of its atmosphere which escaped into space owing to the small mass of Mars. Mean temperatures, therefore, are ca. –60°C. There is some indirect evidence, however, that liquid water was present on Mars during its early

history. It cannot be excluded that primitive microbial life existed then. Earth is located within a narrow habitable zone within the solar system, which is mainly defined by the existence of liquid water. The occurrence of an ocean, ca. 100 km deep, on Jupiter's moon Europa recently has attracted attention. Europa was considered as a possible venue for harbouring life. However, the availability of energy that could be used by organisms is doubtful: Solar irradiance is only 3.7 % as strong as on Earth, and an ice cover several kilometres thick covers the ocean. The availability of other energy sources that could be used by organisms, for example for microbial chemosynthesis, is also doubtful at best.

- **The Galactic habitable zone:** Also within our Milky Way Galaxy, only a restricted doughnut-shaped zone can be considered to be potentially habitable. Near the galactic centre, new stars and planets form, thus causing high probabilities of meteorite and comet impacts. In addition, high intensities of ionizing radiation can be expected. At the periphery of our galaxy, ancient stars reside which lack the heavy elements required for life. It is estimated that altogether ca. 20% of the 10^{10} stars within our galaxy are at least potentially habitable. The solar system is located within this habitable zone.

2. The Statistical approach:

- **The chances for contacting civilizations:** In 1961, the American radio-astronomer Frank Drake has formulated an equation which should allow us to predict our chances to get into a radio contact with alien civilizations: This equation attempts to take into consideration all factors controlling the probability on life and the life expectancy of technical civilizations. Estimates thus obtained vary widely. The most optimistic assumption is 5 million technical civilizations within our Milky Way. Given the enormous size of our galaxy (diameter: 180,000 light-years) this would mean that, on average, such a civilization would be 185 light-years away. A pessimistic calculation, based on a life span of a technical civilization of 300 years, yields an estimate of between 2 and 3 civilizations within our galaxy. This would render radio contact during the entire life span of humanity completely out of the question.
- **Parallel Universes:** From models concerning the homogeneous structure of the observable Universe, it recently was concluded that homogeneity extends beyond the boundaries of observability. This would imply that, following the principles of random statistics; recurrent structures should exist at extremely large cosmic distances. Assuming that the Cosmos is infinite after all, one could infer that an infinite number of identical copies of Earth (and of each of us) should exist. However, these "replicas" of us would be at extremely large distances.

If that were true, we might be able to keep the Copernican view of the Universe. However, we still would not be able to get into contact with alien civilizations.

“Time-constants in the evolution of the Universe, the Earth system, the biosphere, and of humanity”

The time courses of historic processes are controlled by intrinsic (internal) time constants and external forcing. They exhibit three basic patterns: Recurrent (cyclic) events, one-directional (aperiodic) courses of events, and singular events. Due to the interactions between different influencing variables, not only the overall velocities of complex developments are controlled, but also their directions.

1. Time constants during the evolution of the Universe (cosmology)

An age of the Universe of 15 billion years is considered to be most likely. According to the Standard Model, time has begun with a Big Bang singularity. The course of events during the initial phase of the cosmic evolution was extremely rapid, but strongly decelerated with time. The beginning of the Universe whose structure in principal would have been accessible to our observation occurred ca. 300,000 years after the Big Bang when matter and energy separated and, hence, the Universe became transparent. During that time, the first neutral atoms formed at temperatures around 3,000 K. During the first billion years after this, the first generation of stars formed within globular clusters. Within massive first-generation stars all elements heavier than helium were synthesized which at present comprise ca. 2% of the matter of the Universe.

2. Time-constants of planetary evolution relevant for the conditions of Earth.

The initiation of the development of the solar system can be defined by the first occurrence of small cosmic dust particles. By accretion, thereafter, the planets were formed. By using several independent methods, based on the decay of heavy radioisotopes, the onset of the evolution of the solar system can be dated to 4.5263 – 4.5609 billion years before present. The accretion of the Earth took no longer than 30 million years. We thus are well informed about the age of our home planet.

The life expectancy of main-sequence stars is inversely proportional to their respective masses. A star such as the sun has a life expectancy as main-sequence star of 10 billion years, whereas a star of 10 solar masses lives no longer than 10 million years. The time-span during which a star persists under stable hydrogen-burning conditions determines the overall time available for biological evolution on a planet orbiting this star.

Fluctuations of the solar constant (the amount of solar radiation impinging onto the upper boundaries of the atmosphere) are due to regular fluctuations in important parameters of Earth’s orbit around the sun, as well as to variations in the intrinsic solar energy output. Orbital parameters of the Earth around the Sun exhibit periodicities of 100, 40, 23 and 21 thousand years, respectively. The Milankowitch cycles are considered to be the main causes for the alternations between glaciated and predominately ice-free conditions every 100,000 or years during the past 900,000 years. Quasi-periodic climate changes are related to variations of solar activity (mainly sunspot-frequency). They are responsible for comparatively small climate fluctuations as observed during the past 10,000 years (the Holocene), whose overall climate is exceptionally stable as compared to the preceding Pleistocene.

3. Time constants in the control of biological evolution

Adaptational responses of individual species or communities of species within ecosystems to external forcing variables are only possible if the time constant of external forcing is at least as great as the time constant of any biological responses (adaptations). Important processes causing long-term changes of climatic conditions include sea-floor spreading, continental drift, and faulting of mountain ridges. All of these processes have a strong influence on atmospheric and oceanic circulation patterns, which control the regional distribution of heat and moisture.

The rate of gene-pool-change (mutation rate) in organisms is relatively constant. This would suggest a steady pace of biological evolution (gradualism). The natural life expectancy of biological species ranges from 2 to 5 million years. Most species are short-lived whereas very few species survive long periods of time ("living fossils"). Mass extinctions of species occur when environmental conditions rapidly deteriorate, or in the aftermath of global catastrophes such as impacts of large meteorites, or massive volcanic eruptions (trap volcanism). Events such as these are characterized by a skewed magnitude-frequency distribution (the larger an event, the less frequently it occurs). As a consequence of mass extinctions, overall species numbers drop drastically within extremely brief time-spans. Evolutionary pulses frequently follow Mass extinctions. Prerequisites for such evolutionary pulses are favourable environmental conditions. As a general rule, replenishment of species inventories depleted by extinction events, takes between 2 and 5 million years.

4. Time constants in the developments of culture and technical civilization:

Philosophy and arts exhibit extended periods during which the levels of accomplishment rise only slowly, followed by brief episodes of blooming cultures, and thereafter by a rapid decline. Maximum cultural accomplishments in different fields of culture not necessarily are co-incident as has been, for example, during Greek Antiquity. Taken together, the patterns in the developments of philosophy and arts in principle follow similar temporal patterns as those of biological evolution, however, on completely different time-scales.

By contrast material culture mainly depends on the developments of natural sciences and technology. It is characterized by acceleration. The acceleration in the rates of development is mainly caused by the fact that relevant information can be transferred from one generation to the next which then can start off at a more advanced level than the preceding one. Also the growth rate of the human world population has accelerated during the past 200 years. The main reason for this has been the social and economic development that followed the Industrial Revolution. Thus the velocity of world population growth is closely linked to the socio-economic development.