Geophysical Research Abstracts, Vol. 7, 07943, 2005
SRef-ID: 1607-7962/gra/EGU05-A-07943

Solar Space Weather as a Factor in the Origin of the Biosphere

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Introduction

The first steps in the evolution of life on Earth may be safely assumed to have taken place before the first appearance of the earliest available microfossils. For the formation of the atmosphere and the biosphere, where the emergence of life took place, the Solar Space Weather (SSW) played a significant role in determining the specific environmental conditions on the early Earth (Tehrany et al., 2002). Therefore SSW is relevant even before the earliest stages of chemical evolution in the 'primordial soup'. Based on recent solar models and the derived time evolution of particle and photon fluxes (Guinan et al., 2003, Sackmann and Boothroyd, 2003), in this work we analyze the relevant effects at different stages of life evolution on the Earth.

Core

The evolution of the Earth atmosphere from anoxic to oxygenous, and the associated appearance as well as the chemical and organic evolution of life is driven by the solar UV radiation (e.g. Berces et al., 2003) via a set of processes whose intensity is proportional to the flux emitted by the Sun. We emphasize that the Standard Solar Model predicts that the solar flux of the young Sun was lower than the present one, whereas high-precision solar evolutionary models (Sackmann and Boothroyd, 2003) provide a value significantly higher than the present one. This factor should be ascertained by experimental evidences, as it plays a fundamental role in identifying, via reverse modeling, the environmental conditions (and their evolution) in the atmosphere and at the sea level which catalyzed or inhibited the chemical evolution of life and biased its biological evolution. Furthermore, observational evidence on solar-like stars at different evolutionary stages indicates that the early Sun might have experienced a highly active phase in its particle and radiation environment from 4.5 to 3.5 Gyr ago (Tehrany et al., 2002), i.e. during the whole time span relevant to the appearance of life on Earth.

In fact, by focusing on evidence based on various disciplines, ranging from geochronology, biogeochemistry to micropaleontology, there are at least three different time estimates (epochs) for the origin of life on Earth:

1) 4.4-4.2 Gyr. The final stages of asteroidal bombardment of the inner solar system have been imprinted on the surface of the Moon. Major impacts comparable to those that hit the Moon also hit the Earth during the same period (simply remembering that the Earth offers a more efficient gravitational sink for those projectiles than the Moon). Two interpretations of the lunar record are possible (Moorbath, 1994). The cratering pattern may represent the decaying remnants of planetary formation from 4,5-3.8 Gyr. If this were the case, the impact frustration of the origin of life may have ended by 4-4.2 Gyr, thus, in principle, allowing chemical evolution to enter the biological evolution stage, but care is needed with other conditions that may have been present at likely sites for the emergence of life such as hydrothermal vents (Maher, and Stevenson, 1988).

Alternatively, a late spike in the lunar cratering flux in 3.9-3.8 Gyr may have taken place after an interval spanning the period extending from the origin of the Earth at 4.5 Gyr till 3.9 Gyr. This period may have been characterized first by heavy bombardment of planetesimals during accretion, followed by the formation of rocks by solidification of molten magma and volcanism, two geologic processes that may have been undisturbed by intense bombardment. Then life that may have formed earlier during relatively long intervals between large impacts, would have been frustrated by the late lunar spike.

2) 3.8-3.9 Gyr. The 3,800 Myr-old metamorphosed sedimentary rocks from Isua, West Greenland span 85% of Earth history. It is for this reason that the possibility has been raised for the presence of bacterial ecosystems at this early date. Through a study of the isotopic fractionation of carbon biogeochemistry suggests that photosynthesis was imprinted in these rocks (Schidlowski, 1988). It may be argued that no definite conclusion may be reached about the original isotopic data due to the metamorphism to which the samples studied may have been subjected (Hayes et al., 1983).

3) 3.5-3.6 Gyr. The oldest microfossils represent a third epoch around 3.5 Gyr that may be taken as the signal for the origin of life. Microfossils representing taxa of cellular preserved prokaryotes were retrieved form Western Australia from 3.47 Gyr (Schopf, 1993; Schopf et al., 2002). However, more recently this evidence for a third epoch for the origin of life has been hotly debated (Brasier, et al., 2002) suggesting that

microfossil evidence may not be reliable from this early date. Such claims on this piece of evidence of the Western Australian microfossils would postpone its occurrence to a later period of the Archaean.

Increased UV, XUV and X solar radiation and fast solar wind particle streams on a time scale of 1 Gyr (Solar Space Paleoclimate) provided an increased energy input to the early atmosphere on a long-term basis and an increased energy input at the level of the sea, where the first chemical autocatalysis of biogenic elements is supposed to have occurred. At the present state of knowledge it is quite puzzling to determine if this augmented input played a catalytic or an inhibiting role due to the variety of initial biochemical processes.

The various models of solar UV radiation flux evolution in time are critical with respect to the time span when the atmosphere was anoxic, i.e., when both chemical and living forms where more subject to energetic radiation. A common assumption ranges from 3.8 to 2 Gyr ago (Berces et al., 2003) and the level of radiation determines the acting photo-reaction processes.

Conclusion

In the framework of Solar Space Weather, in the present paper we discussed which, if any of the considered time estimates (or 'epochs') for life appearance and evolution on the Earth may have been ruled out due to the adverse conditions provided by the early Sun, according to the most recent solar models. Assuming the biochemical processes accepted by current knowledge, the higher radiation flux and activity level assumed for the early Sun indicate that the oldest epochs can reasonably be excluded in favor of the most recent ones. We stress anyway that diachronic observations of Solar Space Weather associated with the study of the terrestrial climate at the present time can help in shedding light on this aspect, as they would refine the time-reverse modeling. In this context the E-STAR program plays a fundamental role.

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