ISSN 1845–8319

UV RADIATION OF THE YOUNG SUN AND ITS IMPLICATIONS FOR LIFE IN THE SOLAR SYSTEM

X. C. ABREVAYA[1]; A. HANSLMEIER[2] ; M. LEITZINGER[2] ; P. ODERT[2,3] ; P. J. D. MAUAS[1] and A. P. BUCCINO[1,4]

[1]*Instituto de Astronomía y Física del Espacio, UBA-CONICET, Pabelløn IAFE, CC 67, Suc. 28 (C1428ZAA), CABA, Argentina*
[2]*Institute of Physics, Univ. Platz 5, 8010 Graz, Austria*
[3]*Space Research Institute, Austrian Academy of Sciences, Schmiedlstr. 6, 8042 Graz, Austria*
[4] *Departamento de Física, FCEN, UBA, CABA, Argentina*

Abstract. UV radiation is thought to have played an important role in the origin of life on Earth. To estimate these levels of UV radiation, we computed the UVC fluxes from HST/STIS and IUE spectra of the young solar analogs κ^1 Cet and χ^1 Ori. In the future experiments with extremophilic microorganisms we will use these resulting UVC-levels to test the probability of the survival, and therefore, the existence of this kind of life at Early Earth, Early Mars and Early Europa.

Key words: Solar analogs - Astrobiology - origin of life

1. Introduction

The current answer about when life originated on the Earth comes from indirect evidences from the microbial fossil record. Accordingly, the first cells arose around 3.800-3.500 million years ago. However, there are some uncertainties about when first cells could have aroused. Since it is well known that radiation at certain doses could be very damaging for life, inducing damage to different cellular components which could lead to cell death, solar radiation could be an important constraint for the origin of life on Earth.

At the Early Earth ages, the Sun was different in several aspects to the present Sun. Solar analogs could provide relevant information about the conditions of the Young Sun (∼0.8 Gyr). According to Dorren and Guinan (1994) and Ribas et al. (2005), the early Sun emitted a proportionally higher UV flux than at present. In particular, the UV continuum flux density of the early Sun exceeded the present one by a factor of 2 to 10 shortward of 200 nm. However, at longer UV wavelengths, where the photospheric emission dominates over that of the chromosphere, the UV flux of the young Sun could have been even lower than at present due to its lower luminosity, as predicted by stellar models, even after accounting for chromospheric excess emission **?**. However, if the predicted lower luminosity, which is inconsistent with geological evidence (faint young Sun paradox), is mainly due to deficiencies in the standard stellar models, the UV fluxes would be higher (or at least comparable) to the present solar value.

In this work we use the UV fluxes of several solar analogs with different ages to simulate the radiation environment of planetary bodies which are relevant from an astrobiological point of view (Early Earth, Early Mars, Early Europa). These values will be used to conduct biological experiments with microorganisms, simulating the radiation environment on these planetary bodies in order to test the probability of the survival, and therefore, the existence of this kind of life at these ages on these planetary bodies.

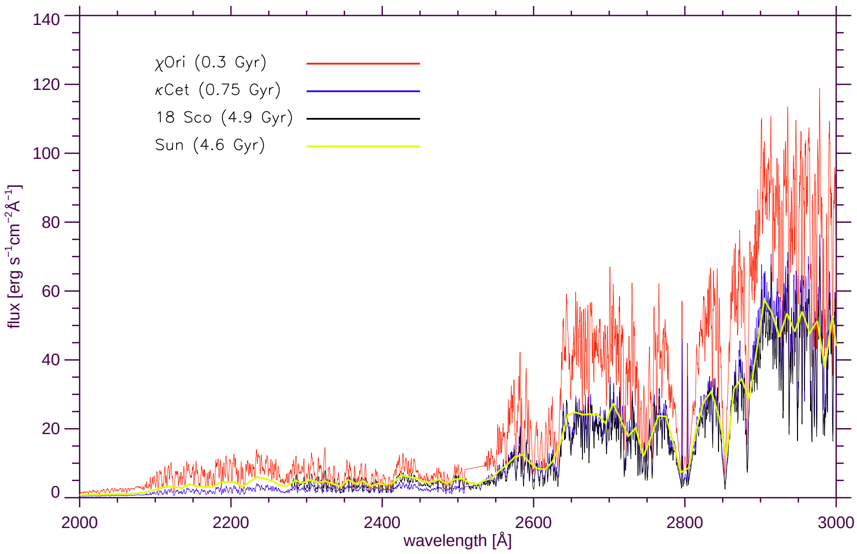

Figure 1: UV Spectra of the Sun and Solar Analogs.

2. Methodology

2.1. Solar analogs and UV fluxes

For the present study we calculated the UV fluxes of three stellar analogs with different ages. We selected the stars κ^1 Cet (G5 V) and χ^1 Ori (G1 V) because their ages of 0.3 Gyr and 0.75 Gyr respectively are representative of the Young Sun when life arose on Earth. We also included the best solar twin 18 Sco (G2V) in this study which has nearly the same age as the Sun. In a future analysis we will expand our sample based on the list of solar analogs from Güdel (2007). As we are interested in the UV radiation of these stars we will use data from the International Ultraviolet Explorer (IUE) and the Hubble Space Telescope (HST), especially from the Space Telescope Imaging Spectrograph (STIS) and the Cosmic Origins Spectrograph (COS). The obtained fluxes will then be scaled to the distances of Earth, Mars, and Europa. The shown spectra (Fig. 1) are scaled to a distance of 1AU and were taken from StarCat (see Ayres (2010)). The solar spectrum was recorded by the SORCE/Solstice instrument during solar quiescence.

In Fig. 2 we show the solar analogs selected in this work and the Sun in the context of the origin of life on Earth. In particular, UVC radiation (2000-2800 Å) is relevant on the Early Earth due to the absence of the ozone layer in the atmosphere.

In Fig. 3 we show the temporal evolution of stellar flux in different wavelength bands normalized to the present solar values. The evolution of the UVC fluxes was obtained by fitting a power law to the integrated fluxes in the UVC range derived from the spectra shown in Fig. 1, whereas the evolution of the fluxes in the shorter wavelength bands were calculated from the power laws given in Ribas et al. (2005). Here the UV-C band shows the weakest correlation with stellar age and is therefore not closely related to stellar activity. The UV-C wavelength band includes already a part of the continuum of our solar-like stars.

2.2. Irradiation experiments with microorganisms

The experiments with microorganisms will include extremophilic microorganisms such as different species of halophilic archaea or haloarchaea (organisms that live at very high salt concentrations as hypersaline environ-

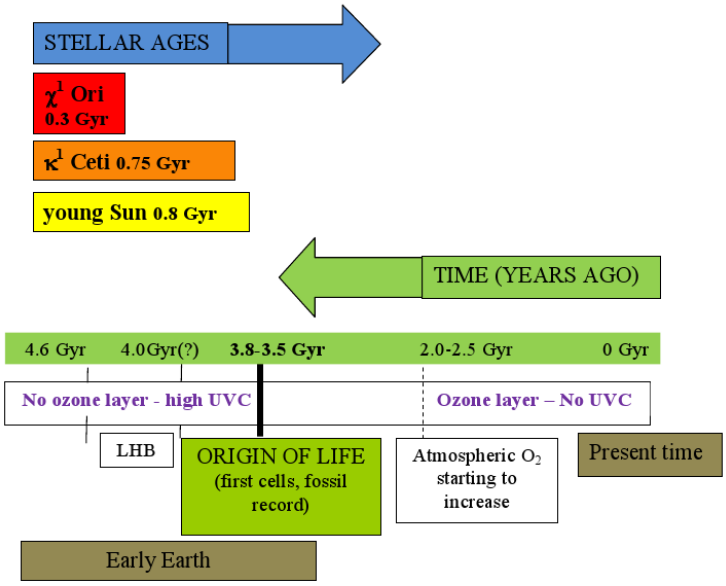

Figure 2: Solar analogues, stellar ages and timescale relevant to the origin of life (LHB: Late Heavy Bombardment period).

ments) and also several species of cyanobacteria (photosynthetic bacteria). The relevance of these microorganisms for this project is related to different facts:

- They are known as UV-tolerant (apart from other harsh conditions) (Garcia-Pichel, 1998; Abrevaya et al., 2010, 2011, 2012)

- Cyanobacterial group contains the oldest entries in the fossil record that can be assigned to any extant group of organisms

- Haloarchaea were found in old salt rocks (evaporites) of million years, dating from Permic and Triassic and this kind of evaporites have been detected in meteorites, including the martian meteorites (Gooding, 1992; Rieder et al., 2004), these organisms have been proposed as possible inhabitants of Mars or other planetary bodies with saline environments like the jovian moon Europa. Moreover, several species of haloarchaea were found in living stromatolites which are considered

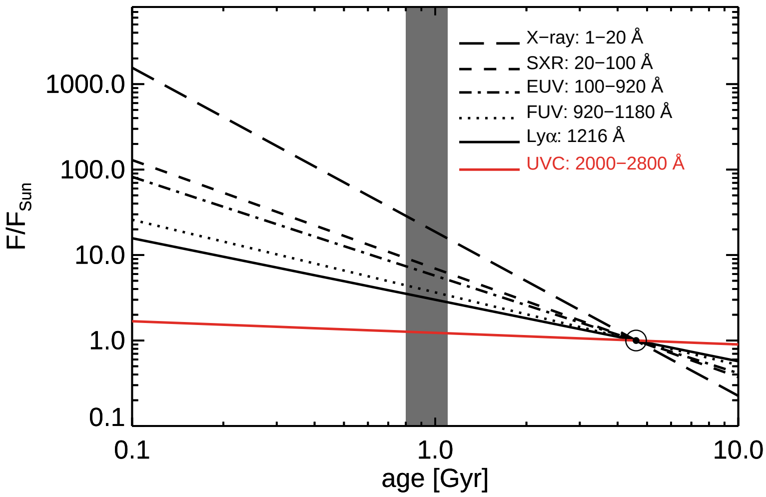

Figure 3: Temporal evolution of fluxes in different wavelength bands normalized to the present solar values.

analogs of the older stromatolites on the Earth (Burns et al., 2004).

As a first approach the microorganisms will be irradiated with UVC radiation (max. emission at 254nm). The doses will be obtained using the flux value for each star considering different intervals of time. The survival of the microorganisms will be measured using different techniques as differential fluorescent staining using specific dyes to detect live and dead cells and classical methods in parallel as growth curves and plate counting, if possible.

3. Expected results

Previous results obtained by Abrevaya et al. (2010, 2012) showed that some species of haloarchaea are capable to suvive UVC doses up to 13320 Jm^{-2}. If we consider the UVC fluxes calculated in this work it is possible to estimate that these microorganisms could survive up to 48 hours of continuous irradiation considering these fluxes. However, further experiments are required and future work will also consider the fluxes reaching the surface of the Early Earth, Mars and Europa and the effect of the atmosphere in the calculation of these fluxes.

4. Acknowledgments

M.L, P.O., and A.H. gratefully acknowledge FWF grant P22950-N16.

P.O. acknowledges the Helmholtz Association through the research alliance Planetary Evolution and Life.

X.C.A and A.P.B gratefully acknowledge MINCyT - BMWF bilateral cooperation grant.

All authors thank the Österreichischer Akademischer Austauschdienst (ÖAD) with grant 11/2011 for supporting this work.

References

Abrevaya, X. C., Cortón, E., and Mauas, P. J. D.: 2010, *in* A. G. Kosovichev, A. H. Andrei, and J.-P. Rozelot (eds), *IAU Symposium*, Vol. 264 of *IAU Symposium*, pp. 443–445.

Abrevaya, X. C., Cortón, E., and Mauas, P. J. D.: 2012, *in* C. H. Mandrini, and D. F. Webb (eds), *IAU Symposium*, Vol. 286 of *IAU Symposium*, pp. 405–409.

Abrevaya, X. C., Paulino-Lima, I. G., Galante, D., Rodrigues, F., Mauas, P. J. D., Cortón, E., and Lage, C. D. A. S.: 2011, *Astrobiology* **11**, 1034–1040.

Ayres, T. R.: 2010, *ApJS* **187**, 149–171.

Burns, B.P., Goh, F., Allen, M.A., Neilan, B.A.: 2004, *Environmental Microbiology* **6**, 1096–1101.

Claire, M. W., Sheets, J., Cohen, M., Ribas, I., Meadows, V. S. and Catling, D. C.: 2012, *ApJ* **757**, article id. 95, 12 pp.

Dorren, J. D., and Guinan, E. F.: 1994, *ApJ* **428**, 805–818.

Garcia-Pichel, F.: 1998, *Origins of Life and Evolution of the Biosphere* **28**, 321–347.

Gooding, J. L.: 1992, *Icarus* **99**, 28–41.

Güdel, M.: 2007, *Living Reviews in Solar Physics* **4**, 3.

Ribas, I., Guinan, E. F., Güdel, M., and Audard, M.: 2005, *ApJ* **622**, 680–694.

Rieder, R., Gellert, R., Anderson, R. C., Brückner, J., Clark, B. C., Dreibus, G., Economou, T., Klingelhöfer, G., Lugmair, G. W., Ming, D. W., Squyres, S. W., d'Uston, C., Wänke, H., Yen, A., and Zipfel, J.: 2004, *Science* **306**, 1746–1749.