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Flares and habitability

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Abstract. At present, dwarf M stars are being considered as potential hosts for habitable planets. However, an important fraction of these stars are flare stars, which among other kind of radiation, emit large amounts of UV radiation during flares, and it is unknown how this events can affect life, since biological systems are particularly vulnerable to UV. In this work we evaluate a well known dMe star, EV Lacertae (GJ 873) as a potential host for the emergence and evolution of life, focusing on the effects of the UV emission associated with flare activity. Since UV-C is particularly harmful for living organisms, we studied the effect of UV-C radiation on halophile archaea cultures. The halophile archaea or haloarchaea are extremophile microorganisms, which inhabit in hypersaline environments and which show several mechanisms to cope with UV radiation since they are naturally exposed to intense solar UV radiation on Earth. To select the irradiance to be tested, we considered a moderate flare on this star. We obtained the mean value for the UV-C irradiance integrating the IUE spectrum in the impulsive phase, and considering a hypothetical planet in the center of the liquid water habitability zone. To select the irradiation times we took the most frequent duration of flares on this star which is from 9 to 27 minutes. Our results show that even after considerable UV damage, the haloarchaeal cells survive at the tested doses, showing that this kind of life could survive in a relatively hostile UV environment.

Keywords. astrobiology, stars: activity, stars: flare, ultraviolet: stars

1. Introduction

Astrobiology is a multidisciplinary area of scientific research. Its main goal is to understand the origin, the evolution and the distribution of life on Earth and elsewhere in the universe. According to the "Mediocrity principle", which proposes that our planetary system, life on Earth, and technological civilizations are an average case in the universe (von Hoerner 1961), life as we know it could emerge in any place with conditions similar to Earth, and would develop following similar selection rules.

Based on this, we wish to study if exoplanets around dMe stars can be suitable places for the emergence and evolution of life. To this end it is necessary to consider the habitability criteria, which defines if a place is suitable for life for a significant period of time. Habitability is based on physical and chemical environmental factors (Cockell 2007) which are necessary for the existence of "life" as we know it on Earth, since it is the unique form of life that we know. Since terrestrial life is dependent on the existence of water usually the most important factor for habitability is the presence of liquid water in the planet's surface which is known as Liquid-Water Habitable Zone (LW-HZ) (Huang 1959; Dole 1964; Hart 1979).

However, other important environmental factors as UV radiation can play a significant role in habitability. On one hand, it is well known that UV radiation can be very damaging and even lethal for life (inducing damage to DNA and other cellular components). In particular, high exposure to UV-C results very damaging and even lethal to most terrestrial biological systems. On the other hand UV could be also a factor necessary for life origin and biological evolution. Therefore, UV radiation should also be considered as an habitability criteria (Buccino *et al.* 2006).

A paradigmatic case are dM stars since it is known that many dMe stars emit large amounts of UV radiation during flares and it is uncertain how these UV events can affect life (Buccino *et al.* 2007). Moreover they are the most common stars in the galaxy and around these stars is easier to detect terrestrial planets which would probably be in the LW-HZ. Therefore we should consider UV and to analyze flaring activity to set an habitability zone on these planets (UV-HZ).

To set this habitability zone we study UV radiation from dMe-stars and we performed biological experiments to see the effects of UV radiation on life. To this end we used extremophile microorganisms, because they are "model" organisms in Astrobiology (Cavicchioli 2002) due to their capacity to survive extreme physicochemical conditions that usually we can find in extraterrestrial environments. In particular the extremophiles the we used in this work are halophilic archaea (haloarchaea), microorganisms hat live at high salt concentrations (3-5 M NaCl; hypersaline environments) such as hypersaline lakes, salterns, etc., because the could be taken as models since they are considered UV resistant microorganisms. Because much halophilic archaea are exposed to intense solar UV radiation in their natural environments, so they are generally regarded as relatively UV tolerant, among other factors (DasSarma 2006; Abrevaya *et al.* 2011).

In this work we examine the effect of UV-C on *Natrialba magadii* and *Haloferax volcanii* two halophilic archaea with different physiological features, initially isolated from Magadi Lake in Kenya, Africa, and the Dead Sea in the Jordan Rift Valley, respectively.

Even though flares emit UV radiation of wide spectra we selected to use UV-C radiation, due it is potentially more damaging that other wavelengths, because DNA has their maximum of absorption at this wavelength range.

2. Methods

To select the irradiance values we considered the UV spectra from different flares on dM stars, from the International Ultraviolet Explorer (IUE) satellite. Using this data we choose as a mean case the dM-star EV Lacertae (EV Lac, M3.5 V) (GJ873). It is a star with frequent periods of high activity in which emits flares. We selected as a sample the flare from September 3rd, 1981. We calculate the mean value for UV-C during impulsive phase, resulting in 3.7 W m^{-2} in the center of the LW-HZ. From literature it is known that most flares last between 9 and 27 minutes Gerschberg, 2005.

Thereafter, cultures of *N. magadii* and *H. volcanii* were grown around an optical density (OD) related to mid-exponential phase, and diluted to an OD=0.5. Samples were divided in five groups: Control (non-irradiated culture), and irradiated for 10 and 30 minutes (doses: 2220 and 6660 J m^{-2}, respectively). Liquid culture was irradiated being exposed to a UV-C source (Phillips 15W Hg lamp $\lambda = 254$ nm, irradiance 3.7 W m^{-2}). Aliquots of the irradiated and control groups were diluted with fresh medium until to reach an OD=0.05 and withdrawn after different irradiation times. The biological effects of the UV treatment were assesed following the changes of the growth kinetics. To obtain growth curves, OD values for each sample were acquired at different times after irradiation and were plotted versus post-irradiation time.

3. Results

Figures 1 and 2 show the growth curves obtained for *H. volcanii* and *N. magadii* after irradiation. As can be observed for the irradiated groups, there is a delay in the growth that can be seen as a displacement of the growth curve, which is significantly different from non-irradiated group.

Additionally it can be observed that this delay is dose dependent for *N. magadii* (between 20 and 30 hours, for 2220 and 6660 J m^{-2} doses, respectively) (Fig. 2) and independent from the dose for *H. volcanii* (around 70 hours for both for 2220 and 6660 J m^{-2} doses) (Fig. 1).

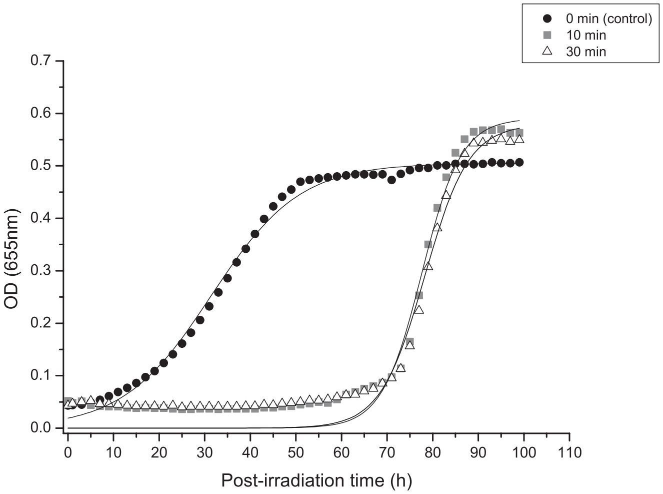

Figure 1. UV survival curves for *H. volcanii.* The black circles corresponds to the control group while the grey squares corresponds to 2220 J m^{-2} dose and the open triangles to the 6660 J m^{-2} dose. Each curve is the average of duplicates for each experimental group

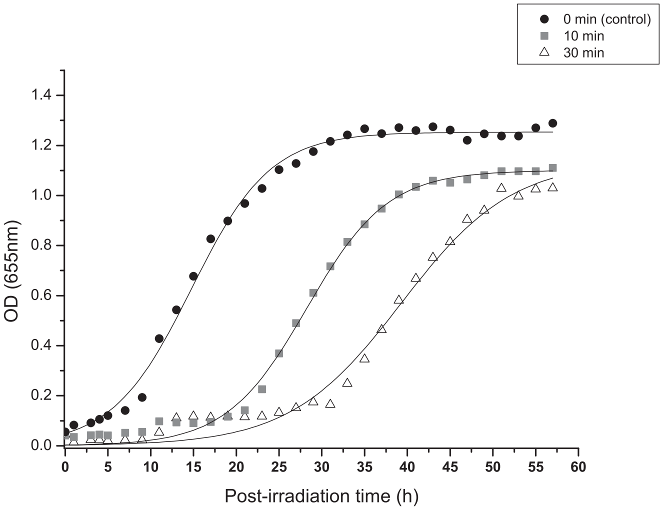

Figure 2. UV survival curves for *N. magadii.* The black circles corresponds to the control group while the grey squares corresponds to 2220 J m^{-2} dose and the open triangles to the 6660 J m^{-2} dose. Each curve is the average of duplicates for each experimental group

4. Conclusions

The tested doses used in this work are equivalent to the doses that life (in this case microorganisms) would receive from a flare of moderate intensity, not very high to sterilize the surface of the planet, considering a terrestrial planet orbiting a dMe star in the center of the LW-HZ.

On the other hand, it is well known that UV induces diverse kind of damage in cells. In particular UV-C is a potent inductor of DNA chemical modifications, mainly formation of cyclobutane pyrimidine dimers and 6-4 photoproducts, which eventually could lead to mutations or cell death if they are not repaired(Mitchell & Nairn 1989; Cadet *et al.* 2005). Growth delay could be explained by processes related to sublethal effects of this kind of cell damage, which can cause blockage of diverse cellular processes. In such cases cells stops to growth and bacterial population remain in lag phase, which is visualized as a displacement of the growth curve.

In our work even the microorganisms seems to be significantly damaged, as was observed by the delay in growth for 20 and 30 hours for *N. magadii* and 70 hours for *H. volcanii*, both species are able to survive at the tested doses. Moreover these results show that both species are capable to survive not only high UV radiation levels, but also UV-C radiation which is not present in their natural environments.

These preliminary results provide evidence that such “kind of life” could possibly survive in a relatively hostile environment from the point of view of UV radiation, in an hypothetical planet around dMe stars with moderate flaring activity.

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Discussion

MARK GIAMPAPA: The food source should have also survived the UV-irradiation. What is you comment on that?

XIMENA ABREVAYA: In our experiment we irradiated the haloarchaea on their own growth medium, but after irradiation we changed this medium putting a fresh one. That is because we suppose that UV could produce some chemical modifications on the “food source”. We didn’t study that point.

Jeffrey Linsky: (Comment) Observations of EUV flux are distorted through the interstellar medium. This needs to be corrected.

Ximena Abrevaya: It is an interesting observation but our work is focused on UV-C radiation. We should study that to reach a conclusion.