SOLAR IRRADIANCE CHANGES AND PHOTOBIOLOGICAL EFFECTS AT EARTH'S SURFACE FOLLOWING ASTROPHYSICAL IONIZING RADIATION EVENTS

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Introduction: Astrophysical ionizing radiation events have been recognized as a potential threat to life on Earth for decades. Although there is some direct biological damage on the surface from redistributed radiation [1,2] several studies have indicated that the greatest long term threat is from ozone depletion and subsequent heightened solar ultraviolet (UV) radiation [3,4,5,6]. Stratospheric ozone normally shields surface-dwelling life from harmful UV, particularly the UVB band, 280-315 nm. Atmospheric ionization, caused by high energy photons or cosmic ray particles, creates nitrogen oxides (most importantly NO and NO_2) which catalytically destroy ozone. Depending on the event's energy fluence and spectrum, this depletion can be severe and long lived, leading to greatly increased surface irradiation by solar UV [5,7]. It is known that organisms exposed to this irradiation experience harmful effects such as sunburn and even direct damage to DNA, proteins, or other cellular structures.

Simulations of the atmospheric effects of a variety of events (such as supernovae, gamma-ray bursts, and solar proton events) have been previously published, along with estimates of biological damage at Earth's surface [4,5,7,8]. In the present work, we employed the TUV radiative transfer model [9] to expand and improve calculations of surface-level irradiance and biological impacts following an ionizing radiation event. We considered changes in surface-level UVB, UVA, and photosynthetically active radiation (visible light) for clear-sky conditions and fixed aerosol parameter values.

Using biological weighting functions included in the TUV model we have considered a wide range of effects, including: erythema and skin cancer in humans; inhibition of photosynthesis in the diatom *Phaeodactylum* sp. and dinoflagellate *Prorocentrum micans*; inhibition of carbon fixation in Antarctic phytoplankton; inhibition of growth of oat (*Avena sativa* L. cv. Otana) seedlings; and cataracts.

We found that past work [5,7] overestimated UVB irradiance, but that relative estimates for increase in exposure to DNA damaging radiation are still similar to our improved calculations. We also found that the intensity of biologically damaging radiation varies widely with organism and specific impact considered; these results have implications for biosphere-level damage following astrophysical ionizing radiation events.

When considering changes in surface-level visible light irradiance, we found that, contrary to previous assumptions, a decrease in irradiance is only present for a short time in very limited geographical areas; instead we found a net increase for most of the modeled time-space region. This result has implications for proposed climate changes associated with ionizing radiation events [10].

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References: [1] Martin, O. et al. (2009) *Astrophys. Space Sci.* 321:161-167. [2] Peñate, L. et al. (2010) *Astrophys. Space Sci.* 330:211-217, doi:10.1007/s10509-010-0450-7. [3] Reid, G.C., and McAfee, J.R., Jr. (1978) *Nature* 275:489–492, doi: 10.1038/275489a0. [4] Gehrels, N. et al. (2003) *The Astrophysical Journal* 585:1169–1176, doi: 10.1086/346127. [5] Thomas B.C. et al. (2005) *Astrophysical Journal* 634:509-533. [6] Atri, D. et al. (2014) *International Journal of Astrobiology* 13:224-228, doi:10.1017/S1473550413000414. [7] Ejzak, L. et al. (2007) *The Astrophysical Journal* 654:373-348, doi: 10.1086/509106. [8] Thomas, B.C. et al. (2013) *Geophys. Res. Lett.* 40:1237-1240, doi:10.1002/grl.50222. [9] Madronich, S. and Flocke, S. (1997) Theoretical estimation of biologically effective UV radiation at the Earth's surface. In *Solar Ultraviolet Radiation – Modeling, Measurements and Effects*, edited by C. Zerefos, NATO ASI Series Vol. 52, Springer-Verlag, Berlin, pp 23-48. [10] Melott, A.L. et al. (2005) *Geophys. Res. Lett.* 32:L14808, doi:10.1029/2005GL023073.