Darwin-TPF Meeting 2006

Biomarker Response to Cosmic Rays on Planets orbiting in the Habitable Zone of M-Stars

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Introduction: Our model predicts that biomarkers from planets orbiting in the Habitable Zone (HZ) of M-Dwarf stars with Earthlike atmospheres (hereafter "M-star worlds") **may survive strong fluxes from Galactic Cosmic Rays** (GCRs). These calculations included the effects of (albeit weakened) magnetospheric shielding. Our result refers to the effect of cosmic rays producing nitrogen oxides, NO_x(=NO+NO_2) in earthlike atmospheres which perturb the atmospheric chemistry hence remove ozone. Ozone on the M-star world is resilient to GCR-induced NO_x because high methane levels favour the ozone-producing "smog" mechanism, which is catalysed by NO_x as discussed by Grenfell et al. (2006) (Astrobiology Special Issue, submitted). We have also performed an initial estimate of stellar cosmic ray (SCR) fluxes but these are currently upper estimate fluxes, based on our own Sun, assuming a completely unmagnetised planet scaled to 0.2 AU i.e. in the HZ. SCR results imply that up to 98% of the ozone column **may be removed by Cosmic Rays with the strength of Solar Proton Events (SPEs).** Other biomarkers are quite resilient even to strong SPE fluxes. Grieβmeier et al. (this session, poster) present related results which demonstrate that M-star worlds are subject to high levels of cosmic rays.

Models and Runs

GCR Fluxes from Cosmic Ray Proton Flux (CRPF) Model

References: Grieβmeier et al. (2005); Grieβmeier et al. (2006). Calculates proton fluxes through the magnetosphere. Simulates 7 million particle trajectories per energy interval over energy range: 100 MeV < E < 8 GeV (Figure 1). Magnetosphere radius calculated from balance of stellar wind ram pressure with magnetic pressure of planetary magnetic field.

OR

SCR Fluxes from solar observations (Smart and Shea, 2002) for Interplanetary Space scaled to 0.2AU

Cosmic Ray - Atmospheric NO_x Parameterisation

Protons produce secondary electrons (e^-) hence NO_x via:

N_2+e--->2N+e^-

N+O_2-->NO+O

Assume one NO_x produced per N_2 destroyed at all heights.
Assume third-power law for electron energy (Bichsel et al., 2005)
Assume proton penetration based on Gaisser and Hillas, (1977) (Figure 2).

T, P until convergence

Atmospheric Column Model

References: Segura et al. (2003); Kasting et al. (1984); Kasting et al. (1985).
Chemistry: 220 reactions for 55 species with kinetics from 02-25 JPL (2003).
HO_x, NO_x, O_x and ClO_x families as well as their major reservoirs.
Backwards Euler integration. Diurnal-mean photolysis diurnally-averaged for clear skies. AD Leo active M-star input stellar spectrum.
Radiation: Shortwave (incoming solar flux) code based on Toon et al. (1989).
Longwave (re-emitted IR flux) scheme based on Mlawer et al. (1997).

Biomarker Concentrations, Temperature Profiles (Figure 3)

About the Runs

All Runs: Atmosphere Model: Surface Albedo=0.207; CH_4 surface fluxes=600Tg/year
Other gas fluxes similar to Segura et al. (2003)

Run 1: M-star GCRs at 0.2AU from CRPF Model
Run 2: Observed Interplanetary GCRs (Beer et al. 1991)
Run 3: As for Run 2 but with observed mean Solar Minimum SCRs scaled to 0.2AU (Kuznetsov et al., 2003)
Run 4: As for Run 2 but for scaled Solar Maximum
Run 5: As for Run 2 but with Observed Solar Proton Event (SPE) (see Table 1, marked "GCR+SPE run") fluxes scaled to 0.2AU (Smart and Shea, 2002)

Note that that run 1 is for a weakly-magnetised planet, whereas runs 2 to 5 are for an unmagnetised planet.

Results

Figure 1: GCR fluxes (thin curves) peak around 700MeV and dominate >4096 MeV whereas the solar fluxes (thicker curves) dominate <512 MeV.
Figure 2: NO production rates peak in the troposphere at 14-16km. The M-world values (red) are about x5 those of the Earth (light blue). Interplanetary GCR values (green) are still higher by about 50%. The SPE flux values (orange) led to massively enhanced NO production by around two to four orders of magnitude.
Figure 3: The SPE-induced NO_x led to strong ozone loss (dotted line Figure 3a). For all other runs the biomarkers did not change greatly.
Table 1: The SPE run removed 98% of the ozone column. Other biomarkers did not change greatly.

Figure 1: Cosmic Ray Energy Fluxes

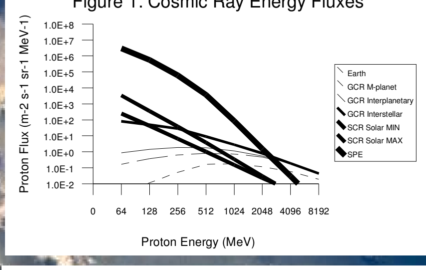

Figure 2: Cosmic Ray NO Production

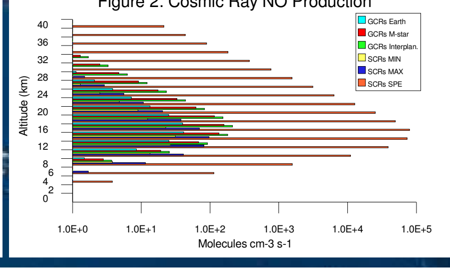

Figure 3: Effect of Cosmic Rays on Biomarkers (1×10^{-6}) vmr

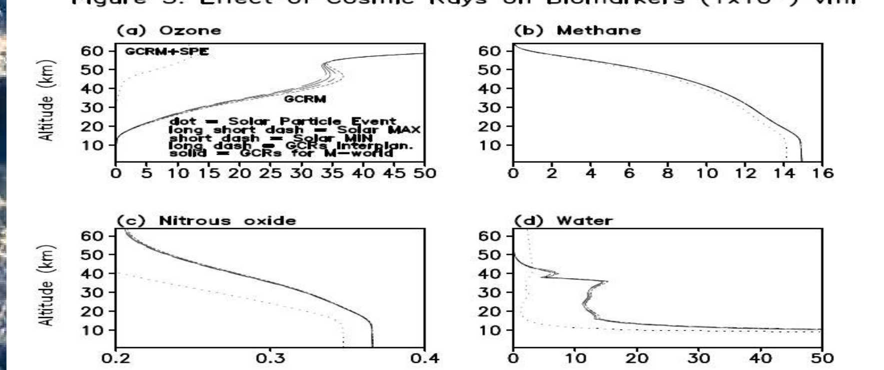

Table 1: Biomarker Columns (DU) for two Model Scenarios (a) No Cosmic Rays and (b) with strong SPEs and GCRs with no planetary magnetosphere protection.

RUN	Ozone	Methane	Chloromethane	Nitrous Oxide	Water
(a) No CRs	680	11731	20	290	3.1×10^6
(b) GCR+SPE	13	11158	19	274	2.4×10^6
% Decrease	98	3	5	6	23

Conclusions

All Biomarkers are resilient to GCR-induced NO_x increased in the HZ of M-star worlds
Ozone may not survive transient SPE-induced NO_x increases (Figure 3 and Table 1)
Non-ozone biomarkers are quite resilient even to the SPE effects (Table 1)

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