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New Insights into Cosmic Ray induced Biosignature Chemistry in Earth-like Atmospheres

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Abstract

With the recent discoveries of terrestrial planets around active M-dwarfs, better understanding of atmospheric responses to the stellar environment becomes of high importance. Destruction processes which mask the possible presence of life are getting large attention in the exoplanet community.

We investigate the habitability and potential biosignatures of planets having Earth-like (N_2-O_2 dominated) atmospheres orbiting in the habitable zone of the M-dwarf star AD Leo. Such atmospheres are strongly bombarded by high energetic particles which can create showers of secondary particles down to the surface. We apply our cloud-free 1D climate chemistry model to study the influence of key particle shower parameters and chemical efficiencies of NOx and HOx production from cosmic rays. We determine thereby the effect of stellar radiation and cosmic rays upon atmospheric composition, temperature, and spectral appearance. Results suggest that despite strong stratospheric O_3 destruction by cosmic rays, smog O_3 can significantly build up in the lower atmosphere of our modeled planet around AD Leo. We discuss the importance of the Sun's higher UVB flux compared to AD Leo to keep tropospheric O_3 abundances from building up on Earth. N_2O abundances first decrease with increasing flaring energies due to O_3 loss hence stronger photolytic destruction by UV. This decrease in abundance weakens however for the strongest flaring cases because a sink reaction for N_2O with excited oxygen becomes weaker. CH_4 is removed mainly by atomic chlorine in the upper atmosphere for strong flaring cases and not via removal with hydroxyl as is otherwise usually the case. Cosmic rays lead to lower CH_4 abundances which weakens the role of CH_4 in heating the middle atmosphere so that H_2O absorption can play a more important role. Our results additionally underline the importance of HNO_3 as a possible marker for strong stellar particle showers, which is especially apparent in the forward-modeled transmission spectra of our virtual Earth-like planet around AD Leo.

Summary

In a nutshell, uncertainty in the efficiencies of abiotic NOx and HOx production from cosmic rays in our model significantly influences biosignature abundances and their spectral appearances during transits of our modeled Earth-like planets around the M-dwarf star AD Leo.