Galactic and Stellar Cosmic-Ray Environments of Habitable Planets

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Galactic and solar cosmic rays affect the ionization fraction and chemistry of planetary atmospheres, and are coupled to climate and mutational evolution. We have studied the effect of astrospheric (analogue of heliospheric) modulaton of the Galactic cosmic-ray flux to a habitable-zone planet as planetary systems interact with the interstellar medium throughout their lives. Using a pressure-balance model for the astrosphere size and a convection-diffusion solution for cosmic-ray transport, we calculate the time history and statistics of these fluxes due to passage through interstellar structure, represented by high-resolution, 3-dimensional hydrodynamic simulations. Rapid fluctuations by orders of magnitude on timescales of 10^3 to 10^7 years are predicted. We also discuss longer-term variations due to star formation rate changes and cosmic-ray streaming instabilities. Taking into account the time dependence of the activity of the parent star, we compare the Galactic and stellar contribution to the planetary cosmic-ray flux as a function of time, using the Earth-Sun system as a prototype, and show that until recently solar cosmic rays were much more important than Galactic cosmic rays, a result that should apply to planets around other
stars. Finally we show how the recent history of the Sun's cosmic-ray environment could be reconstructed by observations of the local interstellar medium. Implications of these results for evolution of planetary atmospheres and climate are discussed.