The effect of spectral type of central star on climate and climatic evolution of the Earth-like planets in habitable zone

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The climate of the Earth depends on both insolation and the amount of greenhouse gases, especially CO_2, in the atmosphere. Owing to a negative feedback mechanism in carbonate-silicate geochemical cycle system (so called the "Walker feedback"), the amount of CO_2 in the atmosphere (pCO_2) is regulated so that the climate of the Earth may be warm (i.e., the climate is warm enough for liquid water to exist on the surface of the Earth). However, if the CO_2 degassing rate via volcanic activities is below some critical value, the Walker feedback mechanism cannot maintain a sufficient amount of CO_2, and the Earth becomes globally ice-covered. Here, the critical value of the CO_2 degassing rate is a critical condition under which the Earth becomes globally ice-covered owing to a large ice-cap instability. Since albedo of ice depends on the spectrum of the insolation, the critical condition for the Earth to be globally ice-covered is expected to be different from previous estimates when the central star is different from the Sun. The difference in the spectral type of the central star due to different mass also results in different evolutionary timescale of its luminosity which affects the habitable zone (HZ) around it. In this study, we examine the climate and the climatic evolution of the Earth-like planets around different-mass stars.
We use a one-dimensional energy balance model coupled with a carbon cycle model to estimate the climate, and the planetary albedo model is improved in order to examine the effect of the difference in the spectrum of the insolation from the central star. The evolution of the climate is examined based on the evolutions of CO_2 degassing rate and insolation, which are estimated by a parameterized convection model coupled with a mantle degassing model and a luminosity evolution model, respectively. Four types of stars (i.e., M-, K-, G-, and F-type stars) are considered.
Comparing stars with different mass (e.g., M- and G-type stars), pCO_2 of an Earth-like planet around a light star (i.e., the M-type star) tends to be lower than that of an Earth-like planet around a heavy star (i.e., G-type star) for the same luminosity and CO_2 degassing rate. This is because the peak wavelength of the insolation of the light star is longer than that of the heavy star, and because the ice absorbs longer-wavelength radiation more than shorter-wavelength radiation. As a result, the critical CO_2 degassing rate is less in the inner region of the HZ around the light star than in the region around the heavy star. However, when the Earth-planet is in the outer region of the HZ, and pCO_2 is high owing to the Walker feedback, the critical CO_2 degassing rate of the Earth around the light star is almost the same as that of the Earth around the heavy star especially in the outer region of the HZ because the surface albedo does not affect the planetary albedo owing to the dense atmosphere. Thus, regardless of the spectral type of the central star, the timescale for the warm climate of Earth-like planet is about 4 billion years which depends, not on the insolation, but strongly on the evolution of the CO_2 degassing rate of the planet. These results indicate that we should search for the inner region of the HZ around young stars to find Earth-like habitable planets.

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