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Habitability of planets on eccentric orbits: limits of the mean flux approximation

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A few of the planets found in the insolation habitable zone (region in which a planet with an atmosphere can sustain surface liquid water, Kasting et al. 1993) are on eccentric orbits, such as GJ 667Cc (eccentricity of < 0.3, Anglada-Escude et al. 2012) or HD 16175 b (eccentricity of 0.6, Peek et al. 2009). This raises the question of the potential habitability of planets that only spend a fraction of their orbit in the habitable zone.

Usually for a planet of semi-major axis a and eccentricity e, the averaged flux over one orbit received by the planet is considered. This averaged flux corresponds to the flux received by a planet on a circular orbit of radius $r = a(1 - e^2)^{1/4}$. If this orbital distance is within the habitable zone, the planet is said "habitable". However, for a hot star, for which the habitable zone is far from the star, the climate can be degraded when the planet is temporarily outside the habitable zone.

We investigate here the limits of validity of the mean flux approximation used to assess the potential habitability of eccentric planets. For this study, we consider ocean planets in synchronized rotation and planets with a rotation period of 24 hr. We investigate the influence of the type of host star and the eccentricity of the orbit on the climate of a planet. We do so by scaling the duration of its orbital period and its apastron and periastron distance to ensure that it receives in average the same incoming flux as Earth's. We performed sets of 3D simulations using the Global Climate Model LMDz (Wordsworth et al. 2011, Forget et al. 2013, Leconte et al. 2013). The atmosphere is composed of N_2, CO_2 and H_2O (gas, liquid, solid) in Earth-like proportions. First, we do not take into account the spectral difference between a low luminosity star and a Sun-like star. Second, the dependence of the albedo of ice and snow on the spectra of the host star is taken into account. This influences the positive ice-albedo feedback and can lead to a different climatic evolution.

We show that the higher the eccentricity and the higher the luminosity of the star, the less reliable the mean flux approximation.