EPSC Abstracts
Vol. 10, EPSC2015-172, 2015
European Planetary Science Congress 2015

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

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Abstract

We investigate here the limits of validity of the mean flux approximation used to assess the potential habitability of eccentric planets that only spend a fraction of their orbit in the habitable zone. For this study, we consider ocean planets in synchronized rotation.

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. The dependence of the albedo of ice and snow on the spectra of the host star is also taken into account.

1. Introduction

A few of the planets found in the insolation habitable zone (as defined by [3]) are on eccentric orbits, such as HD 136118 b (eccentricity of ~ 0.3, [12]) or HD 16175 b (eccentricity of 0.6, [6]). 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.

The influence of the orbital eccentricity of a planet on its climate has already been studied for Earth-like conditions (same star, same rotation period), with Global Climate Models (GCM) such as in [11] and [5]. [9] and [1] have also shown the effect of eccentricity for more diverse conditions with energy-balanced models. The influence of the host star type has also previously been considered for Earth-like planets on circular orbits (e.g., [7, 8]). [13] has studied the climate of GJ 581d orbiting a red dwarf for two different eccentricities (0 and 0.38).

We test here in a systematic way the influence of both the eccentricity and the type of host star on the habitability of a planet (i.e., survival of surface liquid water).

2. Method and results

We performed sets of 3D simulations using the Global Climate Model LMDz ([13], [2], [4]). We computed the climate of aqua planets in synchronous rotation receiving a mean flux equal to Earth's (1366 W/m^2), around stars of luminosity ranging from $L_\star = 1\ L_\odot$ to $10^{-4}\ L_\odot$ and of orbital eccentricity from 0 to 0.9. The atmosphere is composed of N_2, CO_2 and H_2O (gas, liquid, solid) in Earth-like proportions.

First, for the different eccentricities, we scaled the orbital period of the planet (the duration of the "year") to insure the planet receives 1366 W/m^2 in average. For a star of $L_\star = 1\ L_\odot$ and a planet on a circular orbit, the year is 365 days long and the planet has a slow rotation. If the planet is on a very eccentric orbit ($e = 0.9$), then the year is 681 days long and the planet has an even slower rotation. For a star of $L_\star = 10^{-4}\ L_\odot$ and a planet on a circular orbit, the year is ~ 2 days long (~ 4 days for $e = 0.9$) and the planet has a faster rotation. The brighter the star and the more eccentric the orbit, the longer the time spent by the planet outside the habitable zone. We monitor the global and local temperature of the planet as well as the extent of ice and liquid water to evaluate its habitability.

We also show the dependance of some parameters such as the thermal inertia of the oceans: they can help stabilize the climate when the planet is outside the habitable zone.

Second, an additional impact of the spectral type of the star is taken into account. We do not only scale the orbital period but we also consider the variation of the albedo of ice and snow.

For Sun-like stars the high value of the albedo of snow and ice can trigger a snow-ball phase due to the destabilizing ice-albedo feedback. For the redder stars, the albedo of snow and ice is much lower [10] and the feedback becomes stabilizing. We show the influence of this spectral dependance on our results for planets on eccentric orbits.

Acknowledgements

This work is part of the F.R.S.-FNRS "ExtraOrDynHa" research project. Computational resources have been provided by the Consortium des Équipements de Calcul Intensif (CÉCI), funded by the Fonds de la Recherche Scientifique de Belgique (F.R.S.-FNRS) under Grant No. 2.5020.11.

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