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Habitable Zone and Water World Regime around Main-Sequence Stars

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Habitable zone (HZ) around main-sequence stars is defined as an orbital region in which H2O may exist as liquid water on the surface of terrestrial planets. The inner and outer limits of HZ should correspond to the condition of total evaporation and total freezing of water, respectively. It is, however, assumed implicitly that the atmosphere has enough greenhouse effects due to greenhouse gasses, such as CO2, CH4, and NH3, to maintain the climate warm enough for H2O to be liquid phase. In this respect, HZ is not a sufficient condition but just a necessary condition for H2O to be liquid water. That is to say, if there is not enough greenhouse effect, liquid water on the planet should freeze totally even when the planet is orbiting within HZ.

The condition for the planets to have liquid water on the surface is affected not only by semi-major axis (distance from the central star) but also by other factors such as orbital eccentricity, obliquity, degassing rate of CO2 via volcanism, carbonate-silicate geochemical cycle, land-sea distribution, water abundance, and so on. It is therefore suggested that the concept of HZ should be extended to include these factors.

We also propose a sufficient condition for H2O to be liquid water if the planet has abundant H2O on the surface. This is an abusolutely habitable zone, and we name it a ”Water World Regime” (WWR). It is defined as an orbital condition which permits H2O as liquid phase unless there is no greenhouse gass other than water vapor in the atmosphere. If there is H2O on the planetary surface, it is in a liquid phase owing to the energy flux from the central star and greenhouse effect of water vapor without any other greenhouse gasses in the atmosphere. Ice giants and icy satellites around gas giants and/or ice giants, as well as terrestrial planets, are expected to have oceans if they are orbiting within the WWR.

Keywords: Extrasolar planetary system, habitable zone, habitable planet