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Free-floating planets as potential seats for aqueous and non-aqueous life

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ABSTRACT

Bodies with water, ammonia or ethane oceans are possible in interstellar space. This may happen for optically thick atmospheres of methane, ethane and carbon dioxide.

1. Introduction

Free-floating planets (FFP) (sometimes called interstellar planets or rogue planets) were first mentioned by Shapley (1958, 1962). Öpik (1964) hinted that FFPs might originate either around a star or in solitary fashion. The first general assessment of the existence of interstellar planets has been made by Fogg (1990) and a review has been presented by Taylor (2001). Fogg (2002) developed a systematic terminology taking into account the formation process. *Planetars* are those FFPs originating in interstellar space while *unbound planets* are those formed within the circumstellar space and subsequently lost to interstellar space. Early studies estimate the number of unbound planets may exceed the number of stars by two orders of magnitude (Fogg, 2002) while usage of Drake-type equations predicted about 7×10^8 free floating binary terrestrial planets in the Galaxy (Debes and Sigurdsson, 2007). Expected detections are as follows: one to a few FFPs, during the Herschel's PACS instrument mission and 10–100 Earth-mass FFPs, during a next-generation microlensing mission (Debes and Sigurdsson, 2007). The Galactic Exoplanet Survey Telescope might detect more than 20 FFPs within a distance of 1000 AU from Earth (Abbot and Switzer, 2011).

The existence of a solvent seems to be a pre-requisite when searching conditions for extra-terrestrial life (Bains, 2004; Schulze-Makuch and Irwin, 2006). Life-supporting solvents other than water are grouped in three categories (Baross et al., 2007): (i) polar solvents, (ii) non-polar solvents and (iii) cryosolvents.

In case of FFPs, which do not receive energy from an external source, keeping a solvent in liquid state a reasonable long time on its surface may require an optically thick atmosphere, able to diminish the loss of thermal energy and planet cooling. Stevenson (1999) identified a set of conditions which may ensure the existence of water-based life on Jovian type FFPs surrounded by a molecular hydrogen-rich atmosphere. The quoted study used a semi-analytical model. One question refers to the low opacity of the molecular hydrogen. In order for the body to be prevented from eliminating its internal radioactive heat by the pressure-induced far IR opacity of the molecular hydrogen one requires very high basal pressures, of the order of 10^2–10^4 bar (Stevenson, 1999). This is difficult to accommodate with liquid water. The question of water-based life conditions on Earth-size FFPs planets remained open.

Here we report results concerning the thermodynamic constraints allowing liquid solvents on FFPs surface. A numerical model for radiative energy transfer in the atmosphere is used. FFPs larger and smaller than the Earth are considered. Several non-polar and polar solvents (including water) are studied. A trial for atmospheric gases compatible with these solvents is performed.

2. Model

An optically dense atmosphere requires a sufficiently large planetary core and gas mass, able to induce large values of the atmospheric pressure. But the gas pressure on the planet surface should be sufficiently small to keep the given solvent in liquid state. These constraints inter-correlate the planet mass and chemical composition as well as the chemical and physical structure of the atmosphere. For better identification and proper conclusion an

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accurate treatment of the energy transfer through the atmosphere is required.

The models of radiative transfer in atmospheres are known as notoriously large consumers of computing time. This is mainly the result of the complex absorption line spectrum that star and planetary atmospheres exhibit. The simplest realistic possibility is to average the opacity over the whole spectrum. This reduces all the information to a single number, the mean opacity. Pretabulated mean opacity tables are often used when modeling the transfer of radiation through optically thick materials. Interpolation in those tables is performed at the time the opacities are required.

The discoveries of extrasolar giant planets and brown dwarfs in 1995 raised the problem of radiation absorption by molecules for rather low atmospheric temperatures (100–3000 K) and pressures (0.1 Pa to 10 MPa), that had not been considered before. These prompted some authors to report low-temperature opacity tables (Ferguson et al., 2005). Also, tables of Rosseland and Planck mean opacities were presented more recently (Freedman et al., 2008) to be used in studies of the atmospheres, interiors, and evolution of planets and brown dwarfs. We reported the preparation of Rosseland mean opacity tables (Badescu, 2010a) for several atmospheric gases at low temperatures (70–650 K).

The simplest planetar radiative transfer model refers to a steady state atmosphere with spherical symmetry. It consists of 1D ordinary differential equations for the hydrostatic equilibrium, the atmospheric mass conservation and the energy transfer through the atmosphere, respectively (Toma, 1980; Guillot, 2001). The energy balance is made at the ground surface, where the intrinsic luminosity leaving the solid core equals the energy flux entering the atmosphere. At some height above the ground the radiative gradient may become unstable. Then, the energy transfer mechanism turns to convection. Also, the theory involves a gas equation of state, the known dependence of the Rosseland and total mean opacities on pressure and temperature and the detailed description of the second adiabatic coefficient of the atmosphere (Badescu, 2011b).

There is a rather subtle aspect to be outlined. In common cases, for a given existing planet, with given planetary luminosity, atmospheric composition *and* atmospheric physical structure, the surface temperature is constrained. The situation changes when looking for appropriate conditions to keep liquid solvents on FFP's surface. The physical characteristics of the planet are known, as well as the planetary luminosity, the atmospheric composition *and* the surface temperature. The unknown is the physical structure of the atmosphere allowing compatibility between all these input quantities.

The most important heat source inside the FFP is the decay of the long-lived radionuclides ^{40}K, ^{232}Th, ^{235}U, ^{238}U and ^{87}Rb. Their present abundance in the Solar System has been determined from analysis of ordinary chondrites. It is (in ppm weight): 0.097, 0.04, 0.00009, 0.012 and 2.5, respectively. The half-life of ^{40}K is about 1.47 Gy (decay to ^{40}Ca) and 11.8 Gy (decay to ^{40}Ar). The half-lives of ^{232}Th, ^{235}U, ^{238}U and ^{87}Rb are 13.9 Gy, 0.72 Gy, 4.52 Gy and 50 Gy, respectively (Lewis and Prinn, 1984). Most of the planets in the Milky Way are significantly older than Earth in terms of their formation epoch, which is about 2 Gyr lower than Earth's. For FFPs older than the Earth, the largest heat release contribution will come from ^{87}Rb and ^{232}Th. Other smaller contributions will come from ^{40}K decaying to ^{40}Ar and ^{238}U. Taking into account the significant weight participation of ^{87}Rb, and its long half-live, one may expect a rather stable heat release for long periods of time, exceeding two or three times the present age of the Solar System.

The composition of FFPs might depend on the formation epoch and place in the Galaxy. This may induce variability on the amount of heat released by radio-nuclides and finally on FFP's luminosity. The luminosity derived from long-lived radio-nuclides of an interstellar Earth-size planet of solar origin would be at present epoch (4.6 Gy) around 4×10^{13} W if it is like Earth (mass density $\rho_E = 5500$ kg/m^3) and 2×10^{13} W if it is a 50–50% mixture of water ice and rock (mass density 3000 kg/m^3)^{12}. However, the uncertainties in the luminosity values have negligible influence of the results obtained for small FFPs, and reduced influence for the results corresponding to giant FFPs (Badescu, 2011a).

The composition of the atmosphere of FFPs is largely a matter of speculation. No single set of observations exist. Stevenson (1999) based his model on an atmosphere consisting of molecular hydrogen. Heavier gases are not appropriate since they condensate at the expected high pressures and (rather) low temperatures. Too light gases such as helium are not appropriate because they have a tendency to leave the atmosphere, especially for small size bodies. The ground level atmospheric pressure should be large enough to keep the solvent in liquid state but low enough to keep the atmosphere in gaseous state. These requirements remove some gases as potential atmospheric constituents. Evidence from terrestrial planets observations suggests that nitrogen, carbon dioxide, methane and ethane should be included on the list of candidate atmospheric gases for FFPs with liquid surface solvents (Badescu, 2011a). These gases may induce a higher atmospheric opacity than molecular hydrogen.

Two thermodynamic constraints should be considered: (i) the solvent on the FFP surface must be in liquid phase at the atmospheric pressure p_s and temperature T_s; (ii) the atmosphere near the body's surface must be in gaseous phase at p_s and T_s.

A third constraint can also be adopted: (iii) the atmosphere should have a low value of the photon mean free path near the surface. This constraint is a modeling approximation adopted to ensure that the energy transfer in the densest part of the atmosphere is by radiation diffusion and the usage of the Rosseland mean opacity is appropriate. For similar values of pressure and temperature the photon mean free path increases for gases in this order: ethane, methane and carbon dioxide (Badescu, 2010b, 2011a,b). The photon mean free path for nitrogen is very large for the range of pressure and temperature of interest and might exceed the expected size of the atmosphere (Badescu, 2010b). There are, however, atmospheric spectral windows that may allow more efficient surface cooling than that estimated by using the mean Rosseland opacity. These windows were analyses one by one, considering their wavelength-dependent opacity. It has been shown that the mean Rosseland opacity is a good approximation for spectral windows in carbon dioxide and ethane atmospheres and to a lesser extent in methane atmospheres (Badescu, 2011b).

Single component atmospheres are studied. This is inspired by the terrestrial planets and giant planets satellites whose atmospheres have always a major constituent. Note, however, that the thermal and radiative properties of these atmospheres are dominated by the fact that there are mixtures of gases. For example, the strong greenhouse of Titan requires methane and to some extent hydrogen in addition to the major constituent nitrogen to close the spectrum.

3. Liquid water

Because of the differences between the spatial distributions of electrons and protons, respectively, water is a polar solvent and it is able to dissolve many salts. An important aspect of Earth biochemistry is the reactivity of carbon–carbon and carbon–hydrogen bonds in molecules that also contain carbon–heteroatom bonds. In water, hydrogen–heteroatom bonds break and re-form dynamically but carbon–heteroatom bonds are rarely broken unless another bond is formed at the same time (Baross et al., 2007).