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Stellar C/O: Effects on Habitability of Exoplanet Systems

T. V. Johnson (1), G. S. Pekmezci (2), O. Mousis (3), J. I. Lunine (4) and N. Madhusudhan (5)
(1) Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, United States (Torrence.V.Johnson@jpl.nasa.gov), (2) Università Degli Studi di Roma "Tor Vergata", Italy, (3) Aix Marseille Université, CNRS, LAM (Laboratoire d'Astrophysique de Marseille) UMR 7326, 13388, Marseille, France, (4) Center for Radiophysics and Space Research, Cornell University, Ithaca, NY, United States, (5) Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK

Abstract

In this talk we assess how differences in the composition of exoplanet host stars might affect the availability of water in their systems, particularly the role of carbon and oxygen abundances. Water, one of the key chemical ingredients for habitability, may be in short supply in carbon-rich, oxygen-poor systems even if planets exist in the 'habitable zone'.

1. Introduction

The 'habitable zone' in the solar system is generally defined as the region around the Sun where liquid water can in principle exist on the surface of a planet-sized body given suitable atmospheric pressure – e.g. the Earth. In discussing exoplanet systems, the definition of the habitable zone has also to take into account the host star's history, size and luminosity as well. However, a key factor in assessing the habitability of exoplanets within the zone in a given system is not well constrained – the availability of significant amounts of water in the planetesimal building blocks from which the planets in the system were formed.

2. Role of C/O ratio in determining H_2O availability

For the solar system, C/O = 0.55 is particularly important in determining the refractory (silicate and metal) to volatile ice ratio expected in material condensed beyond the snow line [1],[2]. Our analysis of published compositions for a set of exoplanet host stars [3] showed that the amount of condensed water ice in those systems might range from as much as 50% by mass for sub-solar C/O = 0.35 to less than a few percent for super-solar C/O = 0.7 (Figure 1). For even higher C/O values (> 0.8), there is essentially no oxygen available for water if the major carbon gas phase in the nebula is CO, while in the inner nebula carbides might be a major refractory species, replacing oxides [2], [4].

A recent analysis [5] of a much larger stellar composition data set for 974 FGK stars [6] using similar techniques allows us to assess the possible range of water ice abundance in the circumstellar accretion disks of these 'solar-type' stars (of which 72 were known to have one or more planets as of 2011). Figure 2 shows the range of stellar C/O in a subset (457 stars) of this stellar database with reported C, O, Ni, and Fe abundances. The resulting computed water ice fraction and refractory (silicate + metal) fraction as a function of C/O are shown in Figure 3. Although some of the most extreme (>1) C/O values have been questioned, these results strongly suggest that while many exoplanet systems may have water volatile inventories similar to the Solar System or even more water-rich, many, perhaps 50% or more might well be very dry compared to our system.

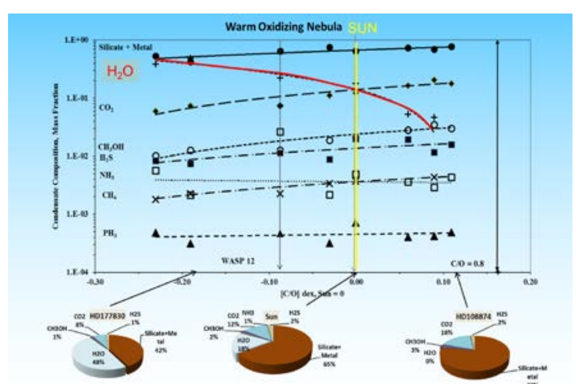

Figure 1: Mass fraction of condensates for exoplanet host stars with varying C/O, in dex (Solar value =0), after [3]

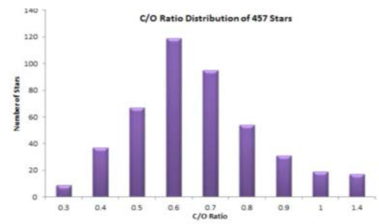

Figure 1.1. *The distribution of carbon-to-oxygen ratio among 457 stars given by Petigura and Marcy (2011), based on the adaption of the solar data from Asplund et al. (2009).*

Figure 2: From [5]

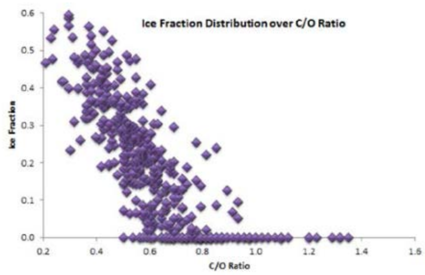

Figure 1.2. *The distribution of water ice fraction over total material available, on the basis of carbon-to-oxygen ratio of parent stars. Results are derived from the data provided by Petigura and Marcy (2011).*

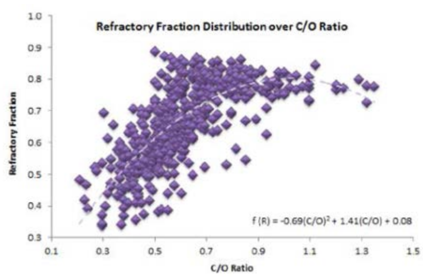

Figure 1.3. *The distribution of refractory (silicate and metallic) fraction over total material available, on the basis of carbon-to-oxygen ratio of the parent stars. Results are derived from the data provided by Petigura and Marcy (2011).*

Figure 3 a (above), b (below) from [5]

3. Summary and Conclusions

These results have implications for assessing the habitability of exoplanets since they constrain the amount of water available beyond the snow line for dynamical delivery to inner planets, depending on the host stars' C/O in the circumstellar nebula. As more and more exoplanets are discovered and characterized, we suggest that stellar composition studies of host stars are a useful way to assess the availability of water in their habitable zones.

Acknowledgements

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References

[1] Gaidos E. J. (2000) *Icarus* 145, 637.

[2] Wong M. H. et al. (2008) in Oxygen in the Solar System, G.J. MacPherson, Editor 2008, Mineralogical Society of America: Chantilly, VA, 241.

[3] Johnson T. V. et al. (2012) *Astrophys. J.* 757(2), 192.

[4] Bond J. C. et al. (2010) *Astrophys. J.* 715(2), 1050.

[5] Pekmezci G. S. (2014) Dottorato di Ricerca in Astronomia, Università Degli Studi di Roma "Tor Vergata".

[6] Petigura E. and Marcy G. (2011) *Journal of Astrophysics* 735.

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On the problem of searching for the life belts in the double stars systems

N. Perov (1, 2)
(1) Cultural and Educational Centre named after V.V. Tereshkova, Yaroslavl, Russian Federation, (2) State Pedagogical University named after K.D. Ushinskii,Yaroslavl, Russian Federation (perov@yarplaneta.ru / Fax: +7 (4852) 72-68-37)

1. Introduction

There are known dozen factors determined possible origin and evolution of exoplanetary life. For the life of the Earth's type these factors are - the temperature of the star, semi major axes and eccentricity of the planetary orbit, period of planet's rotation, the angle between plane of equator and planetary orbit plane, water on the surface and the vapor in the atmosphere, vulcans, mass of the planet, satellite of the planet, the dependence "energy–mass–food–size of the animals" [1], [3]. Below we consider the quasiisothermal orbits of the habitable planet m_3 in the binary system consisted of two stars with mass m_1 and m_2 in the frame of the restricted planar circle 3 body problem.

2. Fundamental Equation

In accordance with the work [2] we have the vector differential equation (1) of the particle m_3 motion in the uniformly rotating system

$$d^2\mathbf{r_3}/dt^2+Gm_1(\mathbf{r}_3-\mathbf{r}_1)/(|\mathbf{r}_3-\mathbf{r}_1|)^3 +$$

$$Gm_2(\mathbf{r}_3-\mathbf{r}_2)/(|\mathbf{r}_3-\mathbf{r}_2|)^3)-2[d\mathbf{r}_3/dt, \boldsymbol{\Omega}]-\Omega^2\mathbf{r}_3 = 0. \qquad (1)$$

Here, $\mathbf{r}_3$ is the radius-vector determined the position of the considered point m_3 in respect of the center mass of the system. $\mathbf{r}_1$ and $\mathbf{r}_2$ are radii – vectors in respect of the center mass of the system determined the positions of the star with mass m_1 and the star m_2 correspondingly. Ω is the angular velocity of uniformly rotation of the major bodies.

$$\mathbf{r}_1=-(m_2/(m_1+m_2))\mathbf{r}_{12}, \quad \mathbf{r}_2=(m_1/(m_1+m_2))\mathbf{r}_{12}, \qquad (2)$$

$$\Omega = \sqrt{\frac{G(m_1+m_2)}{r_{12}^3}}\ .$$

3. Examples

For the generating of the numerical experiments we put m_1/m_2 =50, m_3 is mass of a planet. In the process of the corresponding equation (1) solving we use the following units: m_1 is the unit of mass, r_{12} is the unit of length, the unit of time t is corresponded for the case G=1, where G is the gravitating constant. Moreover, we put for all considered cases the following *initial* conditions: $x_1 \neq 0$, $dx_1/dt=0$, $y_1=0$, $dy_1/dt=0$, $x_2 \neq 0$, $dx_2/dt=0$, $y_2=0$, $dy_2/dt=0$, $x_3 \neq 0$, $dx_3/dt=0$, $y_3=0$, $dy_3/dt \neq 0$. The results of the numerical experiments in intervals of time t motion corresponded to hundreds and thousands revolutions of major bodies are presented in Fig.1 – 5.

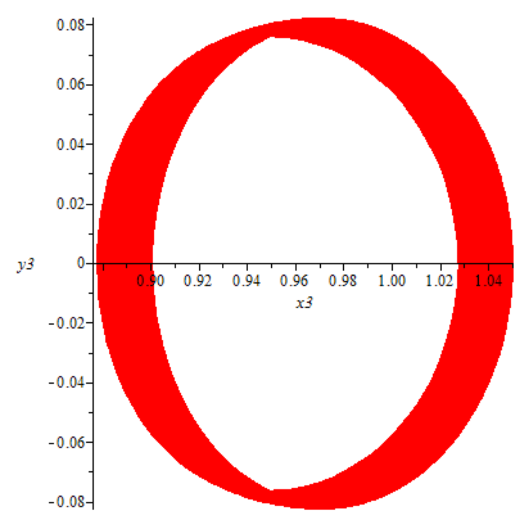

Figure 1: The habitable planet m_3 is moving near the star m_2. m_2/m_1 =1/50. x_{30}=1.05. $(dy_3/dt)_{t=0}$ = 0.5. t=1000. N=20000 (number of points).

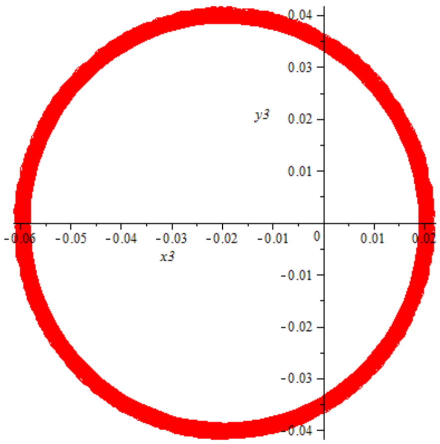

Figure 2: The habitable planet m_3 is moving near the star m_1. m_2/m_1 =1/50. x_{30}=0.02. $(dy_3/dt)_{t=0}$ = 5.05. t=200. N=2000 (number of points).

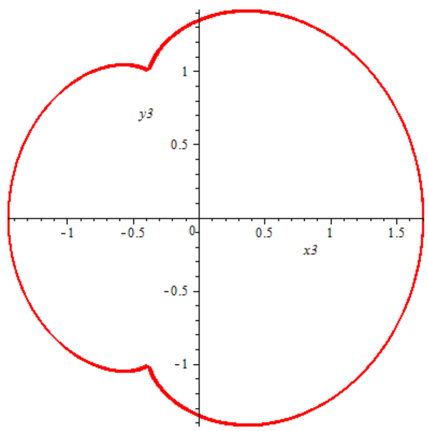

Figure 3: The habitable planet m_3 is moving near the stars m_1 and m_2. m_2/m_1 =1/50. x_{30}=-1.45. $(dy_3/dt)_{t=0}$ = 0.695. t=2000. N=20000 (number of points).

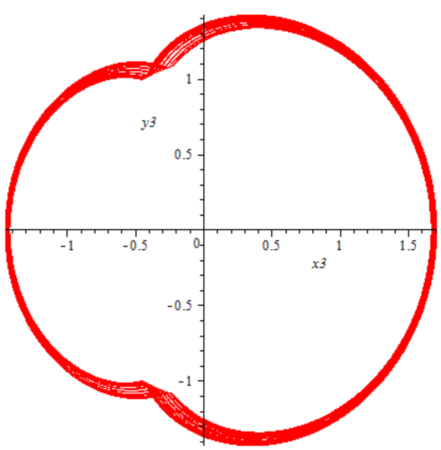

Figure 4: The habitable planet m_3 is moving near the stars $m_1$and m_2. m_2/m_1 =1/50. x_{30}=-1.45. $(dy_3/dt)_{t=0}$ = 0.69112. t=2000. N=20000 (number of points).

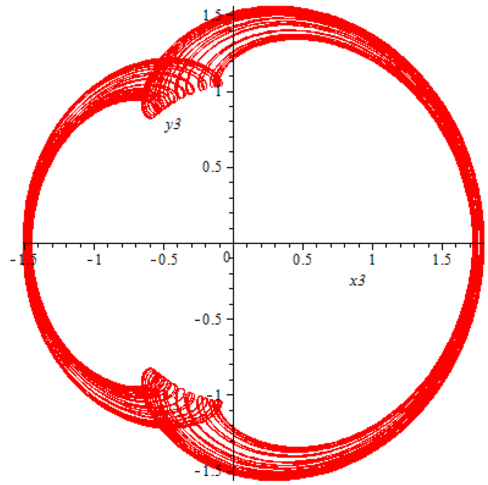

Figure 5: The habitable planet m_3 is moving near the stars m_1 and m_2. m_2/m_1 =1/50. x_{30}=-1.45. $(dy_3/dt)_{t=0}$ = 0.71. t=2000. N=20000 (number of points).

4. Conclusions

There are existed (theoretically) quasiisothermal trajectories (40°C<T<+40°C) for the habitable planets (in the binary systems of stars) in the form of the narrow rings – a) near the star – satellite; b) near the main star; c) near both stars (r_3>1). (Fig. 1. and Fig. 2.). Moreover, we found “strange” quasiisothermal trajectories of habitable planets (Fig. 3. – Fig. 5.). In the work [3] the life’ belts are considered for two body problem like “a star and a planet”.

References

[1] Gyndilis, L. M.: SETI: Searching for extraterrestrial intelligence. Moscow. Ed. of Physical and Mathematical Literatures. 648 pp. 2004. (In Russian).

[2] Szebehely, V.: Theory of orbits. The restricted problem of three bodies, Yale University. New Haven. Connecticut. Academic Press New York and London, 1967.

[3] Kane, S. R. and Gelino, D. M.: The Habitable Zone and Extreme Planetary Orbits. Astrobiology. October 2012, 12(10): pp. 940-945, 2012.

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Investigation of Enceladus' Topology and Underwater Exploration With a Robot

A. Süer, Division of Space Technology, Lulea University of Technology, Kiruna, Sweden (a.suer@hotmail.se)

Abstract

This is a proposal for a future mission with focus on orbital and in-situ exploration of Saturn's icy moon Enceladus, a good candidate for life-supporting celestial body. Enceladus is heated up due to the tidal effects by the gravity of Saturn, which results in an active surface where water plumes are present, but also a potentiality of an ocean of liquid water under the icy crust. By examining the water from the plumes and exploration of the environment under the surface, there might be a possibility to find life in form of microorganisms, present and/or remnants. This will give us a better understanding of the astrobiology and life conditions of bodies both inside and outside our Solar System. The mission will involve a robot that does observations in water. To be able to reach the waters, a nuclear power source will be onboard a vehicle, which permits it to access through the ice and travel downwards. This is due to the heat, melting the ice in the way. The vehicle will be installed on a mount**,** brought down with the aid of a sky crane. It is more stable to land a heavy spacecraft with radiative material with this method, especially since the landing will be done vertically. The robot will be automous and the problem of encountering possible collisions with surface obstacles will be resolved by using sensors on the robot, which will alert it in advance. The area where this process will occur shall be determined after surface observations of the carrier satellite, where it shall determine where the thinnest ice layer is situated. The data and images from the robot will be sent via a communication link between it, the mount and the carrier satellite. Additionally, the satellite in orbit will be equipped with a camera, which will create a heat map of the moon and send detailed images of its surface to the ground station on Earth.

1. Introduction

The search for life outside our planet has been a hot topic for years and one of the goals is to one day find living (or traces of) life, in form of microorganisms. This will give us an understanding of how common life is in other words besides our own planet. Except the planet Mars, the moons of Jupiter and Saturn are of great interest since they are active, with either volcanoes or liquid water under the surface. This mission is proposed to search for evidence of life, living or remnants, but also give information about Io's volcanic activity, atmospheric conditions and surface features.

1.1. Enceladus' plumes

One of the objectives of this mission is to study the water plumes for further detail regarding the moon. Below is an estimation of the composition of the plumes.

Table 1: The composition of Enceladus' plumes. Small amount of other species (Ch_3OH, N_2, ^{40}Ar, C_nH_n and C_nH_nO) exist, but their percentage is not indicated here. **[1]**

Molecule	Percentage [%]
H_2O	≈ 90
CO_2	≈ 5
CH_4	≈ 0.9
NH_3	≈ 0.8

As can be seen, the greatest proportion of the plume's composition is actual H_2O. This might suggest that the water is clean enough to support life as can be found here on Earth, or even other forms of life that we have not encountered yet.

2. Payload

To satisfy the goals of the mission, the satellite will carry the following instruments: A spectroscopic, optical and infrared remote imaging camera for taking images in the visible, near IR and near UV wavelengths. An instrument for radio science investigation, where the objective is to attain more knowledge about Enceladus' gravitational field, nucleus and its thermal properties. A spectrometer for visible, infrared and thermal imaging. This will allow a temperature mapping and it will likewise help to find the best landing site for the lander. Besides these, the lander will be equipped with cameras and lamps for detailed images of the area and give footage of the ice-melting process.

3. Spacecraft and Robot Design

Below is the preliminary design of the satellite, with the heat shield on-board, which has the skycrane and vehicle inside. A parachute will decrease the velocity of the heat shield as it enters the atmosphere of Enceladus. As mentioned, the satellite must take maps of the surface to find a site with ice that is relatively thin compared to the surrounding. It is worth to point out that the thickness might be ≈ 60 km. The vehicle has an edge around it so that the melted water can push it downwards faster.

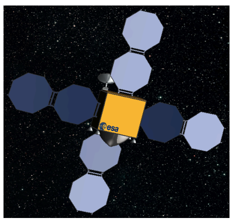

Figure 1: The satellite with the heat shield on-board.

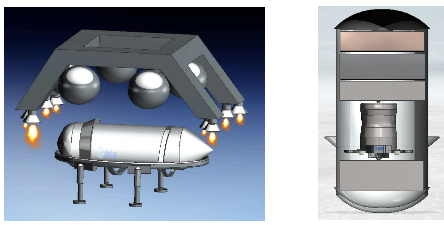

Figure 2: The skycrane leaving the vehicle on the decided site. Also, a cut-through of the vehicle with the robot inside can be seen.

From top we have a tether box for communication with the vehicle. The second is a nuclear power source, which was chosen due to the fact that the vehicle will be under the surface, where it is not possible to charge batteries with the aid of solar arrays. Beneath it is the on-board computer, followed by the robot. Lastly, the hot water pumps and jets for melting the ice and run through the ice. Note that the design of each instrument is not detailed in figure 2.

The vehicle will rest on a mount, which is equipped with a motor that moves the nose of the vehicle downwards to the surface in a ≈ 90° inclination.

Figure 3: The design of the robot. It will be equipped with two cameras, 5 lamps, a big turbine in the center for fast movement, and two smaller rotators that can move in 45° each side for sideways movement.

4. Launch and Orbital trajectory

This is a M-class (Medium size) mission and will be launched with a Soyuz rocket. The carrier satellite will reach its destination by the use of gravity assist after a bi-elliptic Hohmann transfer. That is, after the launch, the satellite will reach a LEO orbit (≈ 500 km), where it will perform an Earth flyby and move towards Venus. There, it will execute a Deep Space Maneuver (≈ 480 x 10^6 km), for a second Venus swing-by for a Hohmann transfer to reach Saturn. This technique will give enough of force and speed to send it on a trajectory towards Saturn. As the spacecraft approaches Saturn, it will use the gravity of the planet with the aid of a flyby (≈500 km), to reach the final destination, i.e. Enceladus. The entire flight will take approximately 7 years. The total mission time, i.e. the EOL stage, will be reached after 10 years (≈ 2-3 years of observation with the satellite and ≈ 1 week for the robot).

5. Summary and Conclusions

The mission proposed will provide a unique opportunity to study Enceladus, its plumes and the liquid ocean beneath its surface. The combination of topographic, magnetic, and gravity measurements will lead to a significant improvement of understanding active moons, which can be applied to exoplanets as well. That is, to and improvement in general understanding of planetary geophysics and evolution of terrestrial planets and moons.

References

[1] A. Bergantini, S. Pilling, B. G. Nair , N.J. Mason , and H.J. Fraser2, Processing of analogues of plume fallout in cold regions of Enceladus by energetic electrons, ESO 2014

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Volcanic Outgassing and In-situ Surface Observations of the Jovian Moon Io

A. Süer, Division of Space Technology, Lulea University of Technology, Kiruna, Sweden (a.suer@hotmail.se)

Abstract

This is a proposal for a future mission with focus on orbital and in-situ exploration of the Jovian moon Io. Io is heated up due to the tidal effects by the gravitational force of Jupiter, which results in an active surface where volcanoes are common. By collecting particles from volcanic eruptions in the atmosphere and surface samples, it is possible to understand the evolution of Io. There might also be a possibility to find evidence of past and present existence of life, e.g. remnants of microorganisms. This is a possibility since it has been detected on Earth that some life forms have the ability to live on for instance radioactive matter, near volcanoes, and also around hot springs where the temperature can reach 40–100° C. The mission will include a lander, which will be deployed from a carrier satellite, which will also perform observations in orbit. During the deployment, a high-altitude balloon will inflate and the lander will be able to collect dust samples from a volcano over a time period of ≈ 2-3 weeks. In the second stage, the lander will land on a site, far from a volcano, where it will examine the collected particles from the atmosphere. It shall also drill on Io's surface and perform chemical analysis of the samples with the aid of instruments. The site will be determined after a heat map analysis, where the ideal area is one far from a volcano and not hot enough. In addition, cameras will be mounted on the lander, where it will take panoramic images of its surrounding, but also the surface during the drilling process. The images will be used for scientific investigations, likewise for commercial and educational purposes. The orbiting satellite will also be equipped with a camera, which will create a heat map of the moon and send detailed images of its surface to the ground station on Earth.

1. Introduction

The search for life outside our planet has been a hot topic for years and one of the goals is to one day find life, in form of microorganisms, as remnants or living ones. This will give us an understanding of how common life is in other words besides our own planet. Besides the planet Mars, the moons of Jupiter and Saturn are of great interest since they are active, with either volcanoes or liquid water under the surface. The mission is proposed to search for evidence of life, living or remnants, but also give information about Io's volcanic activity, atmospheric conditions and surface features, important knowledge that can be applied to exoplanets as well.

1.1. Dust particles

Below are data for the dust particles collected by the Galileo and Cassini missions during their flybys.

Table 2: Data about the Jovian dust streams **[1]**

Dust data	
Density	1.35-1.75 g/cm^3
Dust stream speeds	220/450 km s^{-1}
Charge Potentials	5.5/6.5 V

The measured height of Io's atmosphere is ≈ 8 km, to wholly rarefied ≈100 km where the mean free path is >1 km **[2]**. Substantial atmospheric escape can happen above the exobase (which varies from 200-400 km **[3]**) because of collisional sputtering by energetic Jovian plasma.

2. Payload

To satisfy the goals of the mission, the satellite will carry the following instruments: A spectroscopic, optical and infrared remote imaging camera for imaging in the visible, near IR and near UV wavelengths. This will allow a temperature mapping and it will likewise help to find the best landing site for the lander. An instrument for radio science investigation, where the objective is to attain more knowledge about for instance Io's gravitational field, nucleus and its thermal properties. The lander will be equipped with a particle collector, which will perform chemical analysis (a mineralogy and chemistry lab*)* of the samples from Io's atmosphere as it orbits the moon with the aid of the high-altitude balloon. The objective is to search for organic and inorganic components in the samples. A microwave oven onboard the lander will be a part of this process. Additionally, a drill will help to collect and analyze samples from the surface. To be able to study these samples in an easy manner, a vibrating instrument will be used to break the samples into smaller pieces. A mass spectrometer, x-ray diffraction and gas analyzer is planned to study the samples. Lastly, an imaging system will take panoramic images of the lander's surrounding, but also smaller cameras close to the drill, which will be of great value when the digging process is started. The images will be used for not only scientific investigations, but also for educational and commercial purposes.

3. Spacecraft and Lander Design

Below are the **preliminary** design of both the carrier satellite and the lander. The internal instruments, for instance the OBC, are not shown.

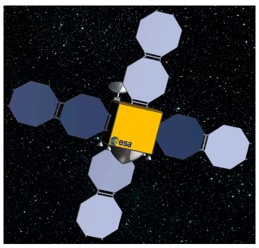

Figure 1: Satellite with the heat protective shell on the bottom

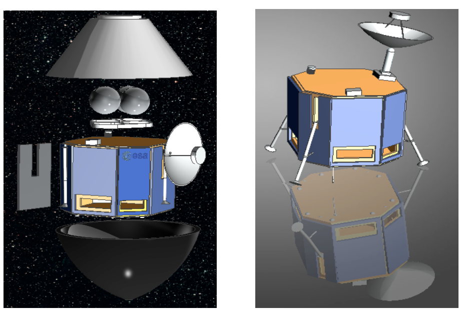

Figure 2: The satellite with the helium thanks for the high-altitude balloon, and heat protective panels on the side, which will be released automatically after the deployment of the lander from the balloon. Note that only one panel is shown in the figure, which is to decrease the image size. The holes on the structure of the lander are where the dust particles from the volcanoes will be collected in for later analysis.

4. Mission design: Launcher, Orbit and balloon

This is a M-class (Medium size) mission and will be launched with a Soyuz rocket. The carrier satellite will reach its destination by the use of gravity assist, after a bi-elliptic Hohmann transfer. That is, after the launch, the satellite will reach a LEO orbit (≈ 500 km), where it will perform an Earth swing-by. It will then perform a Deep Space Maneuver (≈ 480 x 10^6 km), and travel back to Earth for a second Earth flyby followed by a Hohmann transfer to send the satellite to Jupiter. This technique will give enough of force and speed to send it on a trajectory towards Jupiter. As the spacecraft approaches Jupiter, it will use the gravity of the planet with the aid of a flyby (≈500 km), to reach the final destination, i.e. Io. The entire flight will take approximately 7 years and 7 months. The total mission time, i.e. the EOL stage, will be reached after 10 years (≈ three years of observation of the satellite and between 1-2 years for the launcher).

5. Summary and Conclusions

The mission proposed here will provide a one of a kind opportunity to study Io and its topology. The combination of topographic, gravity, and magnetic field measurements will lead to an important improvement of understanding active moons and their geology, which can be applied to exoplanets as well. Additionally, the understanding of the method of using high-altitude balloons for observations will increase and can be applied for future planetary exploration. In conclusion, this mission is proposed to increase and develop a general understanding of planetary geophysics and evolution of terrestrial (or terrestrial like) planets and moons.

References

[1] Pearl et al., Io's Surface, Atmosphere and Volcanism, 1979

[2]-[3] Philip L.; Moore, Chris H.; Deng, Hao; Goldstein, David B.; Levin, Deborah; Varghese Trafton, Laurence M.; Stewart, Bénédicte D.; Walker, Andrew C, Simulation of Plasma Interaction with Io's Atmosphere, May 2011.

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Enceladus as a place of origin of the life in Solar System

Leszek Czechowski
University of Warsaw, Faculty of Physics, Institute of Geophysics, ul. Pasteura 7,02-093Poland (lczech@op.pl/Fax: +48-22-5546882)

Abstract

We consider the core of early Enceladus as a cradle of the life. The model of core origin indicates that for dozens of Myr there were conditions preferable for the origin of life. The simple organisms could be ejected in icy grains into space by the volcanic jets. A few mechanisms could be responsible for transport the grains to the early Earth.

1. Introduction

Enceladus is a medium sized icy satellite (MIS) of Saturn. MIS are built of mixtures of rocks and ices. Enceladus with its radius of 250 km is one of the smallest of MIS, however, contrary to the rest of them, it is geologically active. [2] considered the process of differentiation and core forming in Enceladus. He found that the result of differentiation is a relatively cold core of loosely packed grains with water between them. At that time, there was not mechanism of removing the water. The water and silicates make the process of serpentinization possible. After [4] the reaction of serpentinization could be:

Mg_2SiO_4 (forsterite) + $MgSiO_3$ (enstatite) + $2H_2O$ --> $Mg_3Si_2O_5(OH)_4$ (antigorite).

This reaction releases 241 000 J per kg of serpentine produced. A simple calculations (e.g. [2]) indicate that mass fraction of silicates f_{mas} in Enceladus is ~0.646, hence the total mass of its silicate is ~6.97 $\times 10^{19}$ kg. The serpentinization is believed to be a possible source of energy for primitive life. According to [1]: “For life to have emerged […], a sustained source of chemically transducible energy was essential. The serpentinization process is emerging as an increasingly likely source of that energy. Serpentinization of ultramafic crust would have continuously supplied hydrogen, methane, […] to off-ridge alkaline hydrothermal springs that interfaced with the metal-rich carbonic Hadean Ocean” (see also [3]).

2. Conditions in the early core

The pressure in the center of Enceladus is ~2.3 10^7 Pa that correspond to pressure on the depth 2300 m in the terrestrial ocean.

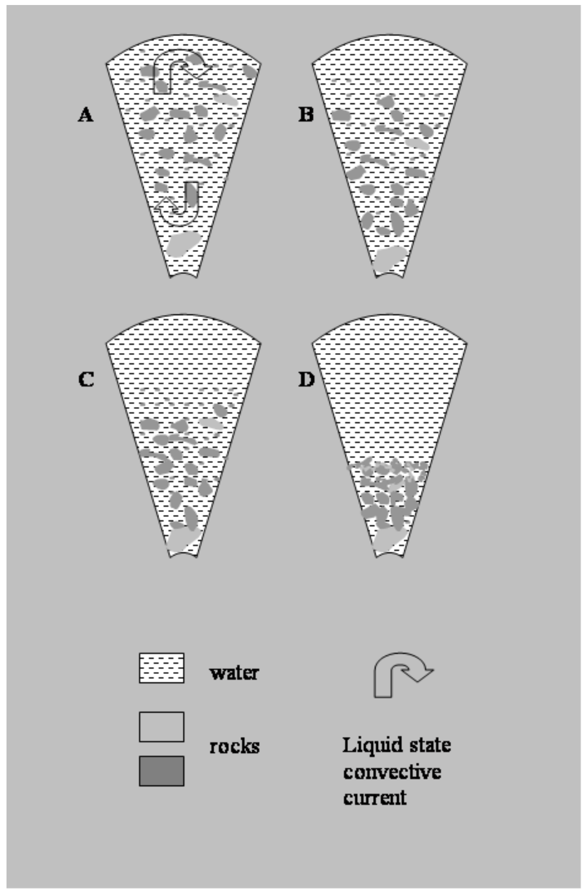

Fig. 1 A scheme of differentiation and formation of the core in Enceladus: A – silicate grains (typical size 0.1-1 mm) are suspended in liquid water. LSC mixing does not allow for setting the grains with exception of the largest ones (e.g. over 10 cm). B. LSC stops. The grains are setting. C – grains in hydrodynamic contact. D – grains in the physical contact. Further compaction requires significant pressure gradient. The core is permeable, so

hydrothermal convection could operate. The sizes of the grains are highly exaggerated.

The model of evolution of temperature in the Enceladus interior for the first a few hundreds Myr is calculated by [2]. It is found that for hundreds of Myr the conditions in the interior of Enceladus were favorable for origin of life. Presently, the life could exist in the underground sea just above the core

Since terrestrial rocks are permeable up to the pressure of ~300 MPa then the entire core of Enceladus was probably permeable for liquids and gases. This could lead to formation of extensive hydrothermal convective systems. Note that in Enceladus most of silicate could be serpentenized (contrary to the Earth). It suggests that total mass of serpentenized silicate in Enceladus could be even larger than on the Earth.

3. Proliferation of the life

3.1 From the core to the surface: The volcanic activity offers occasion to transport organisms from the core to the surface of early Enceladus. The form of this activity could be essentially the same as present.

3.2 From the surface to E-ring: The existence of E-ring is a prove that cryo-volcanic jets could eject gas and solid particles (possibly with primitive organism) into orbit around the Saturn.

3.3 From E-ring to orbit around Sun: The mechanism of gravity assist could be responsible for acceleration of some particles from the orbit around the Saturn into orbit around the Sun. The existence of several satellites of Saturn increases the probability of this mechanism.

3.4 Deceleration of particle: On the orbit around the Sun the small grains could decelerate as a result of Poynting-Robertson mechanism. Deceleration leads the particle to move closer to the Earth and other terrestrial planets.

3.5. Deceleration in the upper atmosphere: Small ratio of considered particles mass to their cross section makes possible to decelerate in upper atmospheres of terrestrial planets without substantial increase of temperature

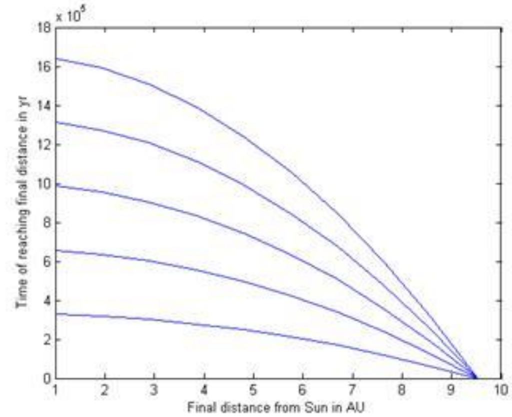

Fig. 1 Time of reaching a given orbit from the orbit at 9.5 AU from the Sun as a result of Poynting-Roberstson effect. The grains' radius: 5µm (the lowest line), 10 µm, 15µm, 20 µm, 25 µm (the uppermost line).

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3.6. Evolution in terrestrial condition: The primitive organism could evolve into present forms of life.

4. Summary and Conclusions

We indicate that the proliferation of life from Enceladus is possible [5]. Note that similar proliferation from the Earth is less probably because of high escape velocity from the Earth.

Acknowledgements

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References

[1] Russell, M. J., Hall, A. J., And Martin W. (2010). Geobiology (2010), 8, 355–371. [2] Czechowski L. (2013) Some remarks on the early evolution of Enceladus. Planet. Space Sci.11 (2014); 104. DOI: 10.1016/j.pss.2014.09.010

[3] Izawa M. R. M. et al. (2010). Planet. Space Sci. 58, 583–591. [4] Abramov, O., Mojzsis, S. J., (2011) Icarus **213**, 273–279.

[5] Czechowski, L. (2014) Enceladus, a cradle of life of the Solar System. Presented inEGU 2014, Vienna.

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

E. Bolmont (1), A.-S. Libert (1), J. Leconte (2) and F. Selsis (3)
(1) NaXys, Department of Mathematics, University of Namur, 8 Rempart de la Vierge, 5000 Namur, Belgium (2) Canadian Institute for Theoretical Astrophysics, 60st St George Street, University of Toronto, Toronto, ON, M5S3H8, Canada (3) Univ. Bordeaux, LAB, UMR 5804, F-33270, Floirac, France (emeline.bolmont@unamur.be)

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.

References

[1] Dressing, C. D., Spiegel, D. S., Scharf, C. A., Menou, K., Raymond, S. N.: Habitable Climates: The Influence of Eccentricity, The Astrophysical Journal, vol. 721, pp. 1295-1307, 2010.

[2] Forget, F., Wordsworth, R., Millour, E., Madeleine, J.-B., Kerber, L., Leconte, J., Marcq, E., Haberle, R. M.: 3D modelling of the early martian climate under a denser CO_2 atmosphere: Temperatures and CO_2 ice clouds, Icarus, vol. 222, pp. 81-99, 2013.

[3] Kasting, J. F., Whitmire, D. P., Reynolds, R. T.: Habitable Zones around Main Sequence Stars, Icarus, vol. 101, pp. 108-128, 1993.

[4] Leconte, J., Forget, F., Charnay, B., Wordsworth, R., Pottier, A.: Increased insolation threshold for runaway greenhouse processes on Earth-like planets, Nature, vol. 504, pp. 268-271, 2013.

[5] Linsenmeier, M., Pascale, S., Lucarini, V.: Climate of Earth-like planets with high obliquity and eccentric orbits: Implications for habitability conditions, Planetary and Space Science, vol. 105, pp. 43-59, 2015.

[6] Peek, K. M. G., and 12 colleagues: Old, Rich, and Eccentric: Two Jovian Planets Orbiting Evolved Metal-Rich Stars, Publications of the Astronomical Society of the Pacific, vol. 121, pp. 613-620, 2009.

[7] Shields, A. L., Meadows, V. S., Bitz, C. M., Pierrehumbert, R. T., Joshi, M. M., Robinson, T. D.: The Effect of Host Star Spectral Energy Distribution and Ice-Albedo Feedback on the Climate of Extrasolar Planets, Astrobiology, vol. 13, pp. 715-739, 2013.

[8] Shields, A. L., Bitz, C. M., Meadows, V. S., Joshi, M. M., Robinson, T. D.: Spectrum-driven Planetary Deglaciation due to Increases in Stellar Luminosity, The Astrophysical Journal, vol. 785, pp. L9, 2014.

[9] Spiegel, D. S., Raymond, S. N., Dressing, C. D., Scharf, C. A., Mitchell, J. L.: Generalized Milankovitch Cycles and Long-Term Climatic Habitability, The Astrophysical Journal, vol. 721, pp. 1308-1318, 2010.

[10] von Paris, P., Selsis, F., Kitzmann, D., Rauer, H.: The Dependence of the Ice-Albedo Feedback on Atmospheric Properties, Astrobiology, vol. 13, pp. 899-909, 2013.

[11] Williams, D. M., Pollard, D.: Habitable Planets on Eccentric Orbits. The Evolving Sun and its Influence on Planetary Environments, ASP Conference Proceedings, Vol. 269, pp. 201, 2002.

[12] Wittenmyer, R. A., Endl, M., Cochran, W. D., Levison, H. F., Henry, G. W.: A Search for Multi-Planet Systems Using the Hobby-Eberly Telescope, The Astrophysical Journal Supplement Series, vol. 182, pp. 97-119, 2009.

[13] Wordsworth, R. D., Forget, F., Selsis, F., Millour, E., Charnay, B., Madeleine, J.-B.: Gliese 581d is the First Discovered Terrestrial-mass Exoplanet in the Habitable Zone, The Astrophysical Journal, vol. 733, pp. L48, 2011.

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Rotation, Activity, and Flaring of Kepler's Habitable Planet Hosts

D. J. Armstrong, D. L. Pollacco
Department of Physics, University of Warwick, Coventry, CV4 7AL, UK, d.j.armstrong@warwick.ac.uk

Abstract

The Kepler satellite has discovered thousands of planetary candidates, and confirmed hundreds of those. Among these confirmed planets, several rank highly on scales of 'habitability', including well-known objects such as Kepler-22b, Kepler-61b and others. We have been studying the host stars of these habitable planets, with the aim of investigating the effects of the host on habitability. Here we will present studies of the activity levels, rotation periods, and flare properties of the hosts. These have been measured through the Kepler data, utilising several photometric proxies for magnetic activity. Two separate methods, the autocorrelation-function and a wavelet based analysis, are used to study stellar rotation, which is a necessary prerequisite to obtaining reliable measures of activity. These properties of the host star impact strongly on putative habitability, being an indication of the levels of radiation and coronal mass ejections experienced at the planet's orbit.

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Water-rich planets: how habitable is a water layer deeper than on Earth?

L. Noack (1), D. Höning (2), A. Rivoldini (1), C. Heistracher (3), (3), H. Lammer (4), T. Van Hoolst (1) and J.H. Bredehöft (5)
(1) Royal Observatory of Belgium, Belgium (lena.noack@oma.be), (2) German Aerospace Center (DLR), Institute of Planetary Research, Berlin, Germany, (3) Vienna Technical University, Austria, (4) Austrian Academy of Sciences, Space Research Institute, Graz, Austria, (5) University of Bremen, Institute for Applied and Physical Chemistry, Germany

Abstract

We study plausible constraints for the habitability of water-rich exoplanets and introduce a new habitability classification to be applied to water-rich planets from about Mars-size to almost Neptune-size planets with a deep water-ice layer.

1. Introduction

Water is necessary for the origin and survival of life as we know it. In the search for habitable worlds, water-rich planets therefore seem obvious candidates. The water layer on such planets could be hundreds of kilometers deep. Depending on the temperature profile and the pressure gradient, it is likely that at great depths a significant part of the water layer is solid high pressure ice. Whether the solid ice layer extends to the bottom of the water layer depends also on the thermal state of the planet. In this study we assess the depth of the liquid water layer as a function of the planet's mass, iron fraction and thermal state and determine the conditions for the ice layer to melt from beneath.

2. Model

A new ocean model has been developed including an interior structure model to infer the depth-dependent thermodynamic properties of high-pressure water and the possible formation of high-pressure ice [1]. In this study, we only consider pure water and neglect liquidus temperature depressing species like salts or ammonia. To determine the temperature profile in the water layer (where water is either liquid or in a high-pressure ice phase), we also need to know the heat flux out of the silicate mantle into the water layer. We therefore use a 1D parametrized model of the thermal evolution of core, silicate mantle and water layer, for either stagnant lid planets or plate tectonics mantles.

3. Results

3.1 Maximal ocean depth

Fig. 1 shows the maximal ocean depth and corresponding water weight fraction for varying planetary iron content or surface temperature as a function of planet mass.

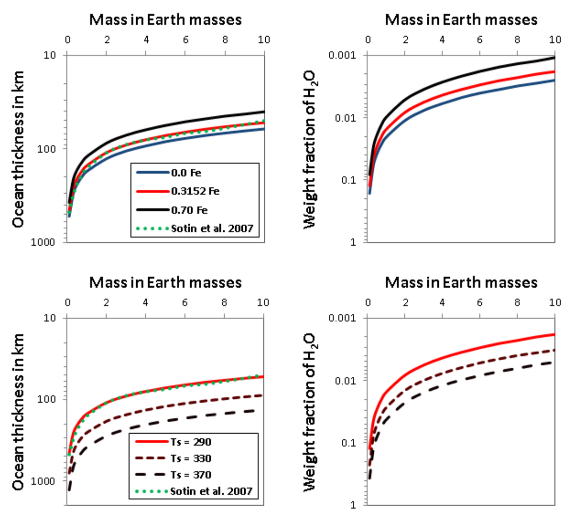

Figure 1: Maximal ocean depths and corresponding water weight fractions depending on iron content (top row) and surface temperature (bottom row) over planet mass. The green dotted line corresponds to the data published in [2] for an Earth-like composition and surface temperature. From [1]

We find that: 1) the depth of the liquid ocean increases with surface temperature, 2) an increasing planet mass reduces the maximum liquid ocean size due to the larger pressure gradient, and 3) a smaller iron content and thus average density of a planet (i.e. a larger planet radius for a fixed mass) slightly increases the depth of the liquid water layer.

3.2 Melting of high-pressure ice

Our results show that heat flowing out of the silicate mantle can melt an ice layer from below (maybe episodically), depending amongst others on the thickness of the ocean-ice shell and the mass of the planet, see Fig. 2. For thin ice layers, a steady lower ocean evolves. For increasing ice layer thicknesses, melting events become episodic, with fewer melting episodes for thicker ice shells.

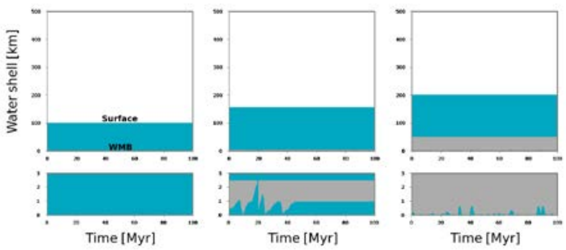

Figure 2: Thermal evolution of the water layer for a planet of one Earth mass with a surface temperature of 290K and water-ice layer thicknesses of 100km, 155 km and 200 km. The lower row shows the lowermost 3km of the water-ice layer. From [1]

3.3 Volcanism

Here we investigate how the planet mass influences the critical water/ice layer depth that would lead to a cessation of volcanism on stagnant lid planets and plate tectonics planets. We investigate the thermal evolution of the silicate mantle for varying water-mantle boundary (WMB) pressure and use upper mantle temperatures of either 2000 K or 2200 K.

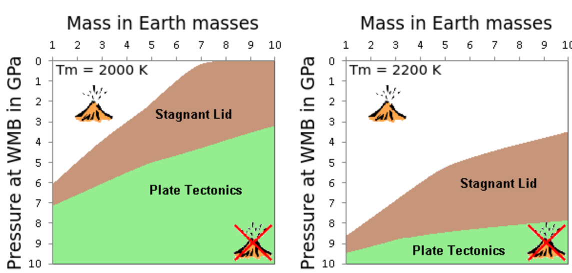

Figure 3: Example ocean depths, at which the WMB lithospheric pressure leads to cessation of volcanism. Brown regions show the area where no volcanism is expected for stagnant lid planets, and green for plate tectonics planets. From [1]

Fig. 3 shows that deep water-ice layers may hinder the existence of volcanism at the WMB due to the high WMB pressure for both stagnant lid and plate tectonics silicate shells. For the latter, volcanism is still possible for larger pressures than for stagnant-lid planets, since the warm mantle upwellings reach shallower depths. For even larger pressures, melt becomes denser than solids, and no volcanism is expected.

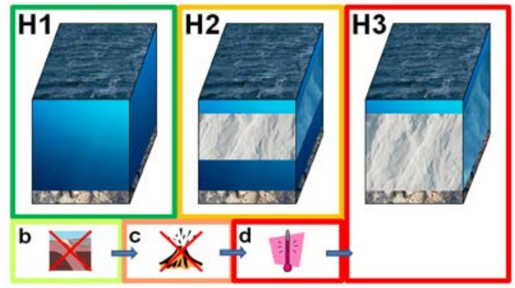

Figure 4: Our proposed new habitability classification for water-rich planets including subclasses (b-d), which consecutively reduce the habitability of classes H1 and H2. From [1]

4. Summary and Conclusions

Following the new habitability classification (Fig. 4), water-rich planets with a deep ocean, a large planet mass, a high average density or a low surface temperature are less habitable than a planet with an Earth-like ocean and might not be suitable candidates for the origin of life.

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References

[1] Noack et al.: Water-rich planets: how habitable is a water layer deeper than on Earth?, Icarus, in review.

[2] Sotin, C., Grasset, O., Mocquet, A.,: Mass radius curve for extrasolar Earth-like planets and ocean planets. Icarus, Vol. 191(1), pp. 337-351, 2007.

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Habitability and dynamical perturbations

E. Pilat-Lohinger (1), H. Lammer (2), C.P. Johnstone (1), N.V. Erkaev (3)
(1) Institute of Astrophysics, University of Vienna, Austria (elke.pilat-lohinger@univie.ac.at) (2) Space Research Institute, Austrian Academy of Sciences, Graz, Austria (3) Institute for Computational Modelling SB RAS, Krasnoyarsk, Russian Federation

Abstract

The search for an Exo-Earth is certainly a big challenge which needs maybe detections of planetary systems resembling our Solar system in order to find life like on Earth. Numerical investigations of Jupiter-Saturn like configurations indicate strong dynamical perturbations for the planetary motion in the habitable zone for certain systems. Therefore, we show the dynamical influence on the habitability of a planet.

1. Introduction

The search for planets outside the Solar system showed an unexpected diversity of planetary systems. Most of the planets indicate high eccentricity motion while the Solar system planets move in nearly circular orbits and nearly the same plane. Taking into account migration and other turbulent phases during the formation process, one could assume, that the instability phase in our planetary system was moderate and, therefore, advantageous for habitability of our Earth. From the numerous detected planets so far no terrestrial planet comparable to our planet has been discovered. However, even if we find Solar system analogues, it is not certain that a planet in Earth position will have similar circumstances as those of Earth. It is known, that small changes in the architecture of the giant planets can lead to orbital perturbations in the area of the terrestrial planets which could affect the habitability of a planet in the habitable zone.

2. Dynamical model

To study the dynamics of test-planets in the habitable zone we used the restricted problem which is commonly used for such investigations. In this model, the test-planets move in the gravitational field of the star and the giant planets without perturbing their orbits. As we study Solar system analogues, we use a G2 main sequence star like the Sun as host-star. From the four giant planets in the Solar system, we take only Jupiter and Saturn into account, as it was shown that Uranus and Neptune do not influence the area between Venus and Mars significantly [1]. To create Solar system-like configurations, we fix the orbit of Jupiter to its observed position one and vary Saturn's orbit. Planetary orbits are described by a set of orbital elements: semi-major axis, eccentricity, inclination, argument of perihelion, longitude of ascending node and mean anomaly. These parameter show variations due to gravitational perturbations as soon as more than two celestial bodies build a system. From studies of the Solar system it is known that resonant perturbations may influence the orbital motion significantly.

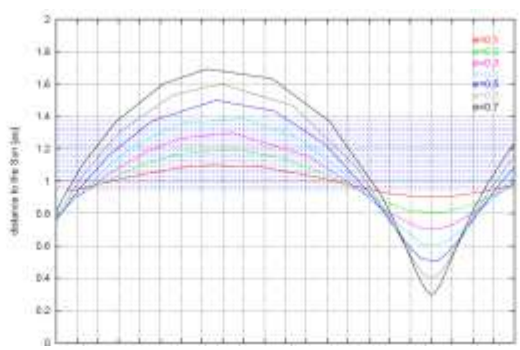

Figure 1: Variation of the distance to the Sun (y-axis) of a planet at 1au calculated for one orbital period. Different curves show the variation of the distance for various eccentricities of the planet.

3. Summary and Conclusions

Perturbations of the giant planets may increase the eccentricity of planets moving in the habitable zone. A higher eccentricity could influence the habitability of a planet significantly as such a planet would leave the habitable zone when orbiting its host-star more or less frequently, depending on the eccentricity and its variation.

In a previous study, it was shown that Earth remains habitable even for an eccentricity of 0.7 [2]. On such a highly eccentric orbit, the peri-center of Earth will be closer to the Sun than Mercury's orbit (see Fig. 1 black curve)

In our presentation we discuss the question whether eccentric planetary motion in the habitable zone can be habitable taking into account the early evolution the Sun and the planetary system.

Acknowledgements

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References

[1] Pilat-Lohinger, Robutel, P., Süli, A. and Freistetter: CeMD, 102, pp. 83-95, 2008.

[2] Williams, D.M. and Pollard, D.: 2002, IJAsB, 1, pp.61.

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Volcanics and chemotrophic life on Mars

F. Westall (1), K.A. Campbell (2), F. Foucher (1), J.G. Bréhéret (3), P. Gautret, (4), A. Hubert (1). (1) Centre de Biophysique Moléculaire-CNRS, Orléans, France; (2) Geology, University of Auckland, New Zealand ; (3) Géo-hydrosystèmes continentaux, University of Tours, France ; (4) Insitut des Sciences de la Terre d'Orléans-CNRS, France (frances.westall@cnrs-orleans.fr)

Abstract

One of the main objectives of the MSL, ExoMars 2018, and Mars 2020 missions is to search for traces of past life in Noachian-Early Hesperian terranes. Chemotrophic life in volcanic habitats will be sparsely distributed, unless fed by localised hydrothermal systems. Study of the distribution of anaerobic, chemotrophic life in a terrestrial analogue environment (early Earth) provides valuable information to help search for life on Mars.

1. Introduction

Mars is predominantly volcanic in composition, as are the majority of sediments deposited in the actual or potential landing sites of interest (with additional sulphate and oxide minerals concretions and veins). There is also evidence for hydrothermal siliceous deposits, although sparse [1]. These kinds of environments in the anaerobic conditions existing on early Mars could have hosted chemotrophic life forms, *i.e.* lithotrophic organisms living off inorganically produced energy (e.g. H2, Fe2+) or organotrophs using energy produced by the oxidation of organic matter, if it existed.

Similar to early Mars, the early Earth was an anaerobic, volcanic habitat. The main difference between the two planets was that the Earth was permanently habitable while Mars was sporadically and heterogeneously habitable. Other differences are that ocean waters on the early Earth were saltier and slightly acidic (pH 6-7) [2], and all aqueous environments were very much influenced by hydrothermal activity [3]. If interpretations of the orbital IR data for Mars are correct, the pH of early martian waters was neutral and there is only sporadic and possibly impact-related evidence for hydrothermal activity [1]. Nevertheless, on a microbial scale, there are great similarities between habitat types on both early planets [4].

The traces of life occurring in Early-Mid Archaean (3.5-3.33 Ga) sediments in Australia and South Africa occur as carbonaceous remains that have been preserved in a cement of hydrothermal silica. Note that, while the terrestrial volcanic sediments were almost permanently in contact with water, the very rapid obstruction of pore space by a silica cement (within the space of days to months) means that phyllosilicate alteration, although common, was not total.

2. Nature and distribution of life on the early Earth

Terrestrial carbonaceous remains include sometimes visibly identifiable colonies of chemotrophs coating volcanic sand grains or "floating" in hydrothermal silica gel [5,6]. Within the silty to sandy volcanic sediments (altered aqueously to phyllosilicates), the distribution of carbon coated particles is widespread but their colonisation is thin (Figs. 1A,B), presumably due to nutrient limitation. Nutrients here would have been obtained from redox reactions at the surfaces of volcanic particles, e.g. volcanic glass shards, pyroxenes, olivines and carbon from CO_2 dissolved in water. However, in the vicinity of hydrothermal sources, the abundant supply of nutrients in the form of H_2 and organic compounds facilitates the formation of mats or films of unsupported colonies or thickly colonised mineral or rock particles (Figs. 1C,D). Chemoorganotrophs also could have sourced their nutrients from the dead remains of lithotrophs.

Note that detrital carbon (of biological or abiological origin) is also a common component of these volcanic sediments, settling out with the finer volcanic particles.

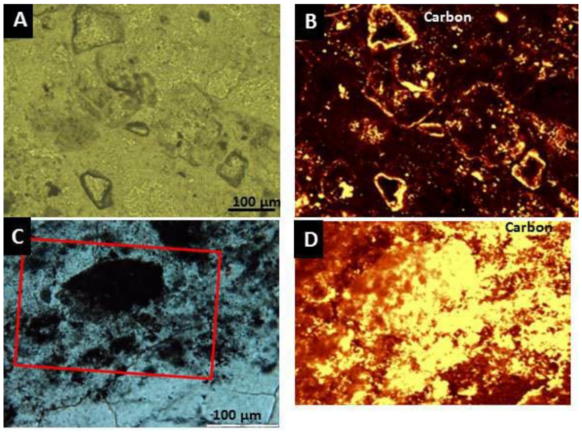

Figure 1. 3.5-3.33 Ga-old volcanic particles coated with the carbonaceous remains of chemotrophic microorganisms. (A,B) Thin films of carbon representing mono-layer colonies on volcanic grains. (C,D) Thickly coated volcanic particle in the vicinity of a hydrothermal vent.

3. Relevance for Mars

Study of the Early-Mid Archaean terrestrial sediments demonstrates that, even in an anaerobic setting, chemotrophic life can be widespread, if it is situated in or can reach the potentially habitable environment. However, without the input of hydrothermal nutrients, its development is limited. Nevertheless, it should still be detectable *in situ* on Mars with Raman or LD-GCMS-type instruments.

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References

[1] Skok, J.R. et al., Nature Geosc., 3, 838-841 [2] Westall, F., 2012. In Astrobiology (ed. J. Lunine et al.). Cambridge University Press, 89-114 [3] Hofmann, A. and Harris, C., 2008. Chemical Geology, v. 257, p. 221–239 [4] Westall, F., et al., 2013. Astrobiology, 13, 887-897. [5] Westall, F. et al., Planet. Space Sci., 59, 1093–1106 [6] Westall, F. et al., in press.