Planetary Simulation Chambers bring Mars to laboratory studies

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Abstract
Although space missions provide fundamental and unique knowledge for planetary exploration, they are always costly and extremely time-consuming. Due to the obvious technical and economical limitations of *in-situ* planetary exploration, laboratory simulations are among the most feasible research options for making advances in planetary exploration. Therefore, laboratory simulations of planetary environments are a necessary and complementary option to expensive space missions. Simulation chambers are economical, more versatile, and allow for a higher number of experiments than space missions. Laboratory-based facilities are able to mimic the conditions found in the atmospheres and on the surfaces of a majority of planetary objects. Number of relevant applications in Mars planetary exploration will be described in order to provide an understanding about the potential and flexibility of planetary simulation chambers systems: mainly, stability and presence of certain minerals on Mars surface; and microorganisms potential habitability under planetary environmental conditions would be studied. Therefore, simulation chambers will be a promising tools and necessary platform to design future planetary space mission and to validate in-situ measurements from orbital or rover observations.

Key words: Planetary Simulation Chambers; Planetary Atmosphere and Surfaces Chamber (PASC); Mars; habitability; spectroscopy; planetary exploration; vacuum.

Las Cámaras de Simulación Planetaria transfieren Marte a estudios en el laboratorio

Resumen
Las misiones espaciales dentro de la exploración planetaria aportan un conocimiento fundamental, único y primordial, pero implica una gran inversión y alto coste, tanto de tiempo dedicado al desarrollo de la instrumentación necesaria así como de medios económicos. Por consiguiente la simulación de condiciones planetarias en el laboratorio mediante cámaras de simulación se presenta como una necesaria y complementaria alternativa a las costosas misiones espaciales, ya que implica mayor accesibilidad, versatilidad, menor coste y la posibilidad de múltiples ensayos. Estas infraestructuras desarrolladas en el laboratorio son capaces de simular las condiciones encontradas en la atmosfera y superficies de la mayoría de los objetos planetarios. Numerosas y relevantes aplicaciones en exploración planetaria de Marte serán aquí descritas para proporcionar un conocimiento acerca de la capacidad y flexibilidad de sistemas experimentales como las cámara de simulación planetaria: principalmente, estabilidad y existencia de ciertos minerales en la superficie de Marte; potencial habitabilidad de microorganismos en condiciones de ambientes planetarios han sido también estudiados. Por

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consiguiente, las cámaras de simulación se posicionan como prometedoras herramientas y plataformas necesarias para el diseño de futuras misiones espaciales y planetarias, así como para la validación de medidas y observaciones realizadas in-situ desde orbitadores o robots en superficie.

Palabras clave: Cámaras de Simulación Planetaria; Cámara de Atmósfera y Superficies Planetarias; Marte; habitabilidad; espectroscopia; exploración planetaria, vacío.

Summary: Introduction 1. Experimental 2. Results and Discussion 3. Conclusions. Acknowledgments. References.

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Introduction

Within this decade, a central goal of Mars exploration programs of several nations is to search for evidence of extant or extinct life on Mars and to investigate the ability of that planet to sustain life. Just recently there has been an exponential increase in interest among international space agencies (NASA, ESA, Roscosmos, Indian Space Agency) to explore Mars. A common research goal of these missions is to study habitability conditions, including the detection of atmospheric traces of gases such as methane and unequivocal detection of organics on the surface soil. The NASA-Mars Science Laboratory (MSL) mission has been operating on Mars for more than four years now. The European mission ExoMars starts on 2016 with the TGO orbiter and EDM lander, as precursor mission for the 2020 ExoMars rover and surface platform. Both surface missions target, among other topics, habitability conditions studies.

The search for Martian biosignatures has become a high priority after the discovery that surface and near-surface aqueous environments existed on Mars at the same time when biological organic matter was being preserved in ancient aqueous sediments on Earth. Additionally, the recent detection of environmental conditions for transient liquid water stability on Mars (Martin-Torres et al., 2015; Zorzano et al., 2009; Ojha et al., 2015; Massé et al., 2016), has reopened the quest for the present day habitability of the Martian Surface. Biosignature identification needs to take into account a broad variety of geochemical and organic characteristics; furthermore the most detectable in-situ biosignatures will be organic molecules.

The limited knowledge that we possess concerning planetary environments has been gathered primarily from space missions. Although space missions provide fundamental, unique, and basic knowledge for planetary exploration, they are always costly and extremely time-consuming. Due to the obvious technical and economical limitations of in-situ planetary exploration, laboratory simulations are among the most feasible research options for making advances both in planetary science, and in developing a consistent description of the origin of life. Therefore, laboratory simulations of planetary environments are a necessary and complementary option to expensive space missions. Simulation chambers are economical, more versatile, and allow for a higher number of experiments than space missions.

Laboratory-based facilities are able to mimic the conditions found in the atmospheres and on the surfaces of a majority of planetary objects (e.g., Mars, Titan, Europa). Planetary simulation chambers have experienced extraordinary improvement from the first methodological models and instrumental designs in the 1960s to the present (Zhukova et al., 1965; Zill et al., 1979; Rannou et al., 2001; Sears et al., 2002; Galletta et al., 2006; Mateo-Martí et al., 2006; Jensen et al., 2008; Sobron and Wang, 2012; Sobrado et al., 2014). At first, the majority of these environmental simulation chambers consisted of uncomplicated systems, which reproduced a particular gas composition and temperature. The majority of simulation chambers simulate physical parameters at the surface or atmosphere of a planet (Figure 1). Actually, there exist few sophisticated chambers that include in situ gas analysis techniques for specific problems, such as gas chromatography mass spectrometry (GCMS) or quadrupole mass spectrometry (QMS). Among them, EXOCAM (Rannou et al., 2001) is devoted to the study of physical–chemical interactions between the atmospheres and the surface and subsurface in Mars conditions. Andromeda (Sears et al., 2002) planetary simulation chamber is mainly dedicated to simulate conditions on Mars. Furthermore, infrared and ultraviolet spectroscopies techniques implementation for in-situ characterization has been done at Planetary Atmospheres and Surfaces chamber (PASC) at the Astrobiology Centre (CAB) (Mateo-Martí et al., 2006) and at PEACh chamber (Sobron and Wang, 2012) which, provides two surface spectroscopies RAMAN-LIBS and Infrared (at Washington University).

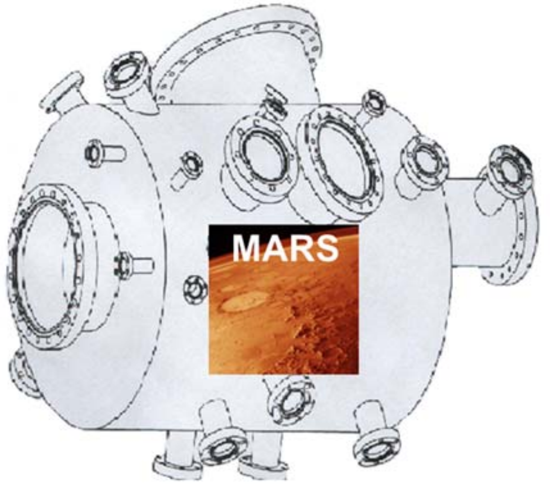


Figure 1. Scheme of a Mars planetary simulation chamber.

Planetary simulation chambers have become extremely useful tools for assessing analytical protocols for instruments and sensors that operate outside the Earth's environment, and for emulating various experiments that involve biological, geological and physico-chemical issues (Schuerger et al., 2003; Goetz et al., 2005; Muñoz-Caro et al., 2006; Zorzano et al., 2009; Mateo-Martí et al., 2009; Gomez et al., 2010; Sánchez Iñigo et al., 2012; Mateo-Martí et al., 2013; Mateo-Martí, 2014; Massé et al., 2016). The international community has focused in the last decade on characterizing and describing Mars geological processes, as well as the search for possible liquid water (Bullock et al., 2004; Zorzano et al., 2009; Ojha et al., 2015; Martin-Torres et al., 2015; Massé et al., 2016). The exploration of Mars is a target of space missions; therefore, experiments with long residence times for ATP on spacecraft materials exposed under martian conditions suggest that prelaunch cleaning protocols need to be more meticulous to mitigate against possible ATP contamination during life-detection experiments on mars landers (Schuerger et al., 2008).

When using a simulation chamber to test the survival of haloarchaea under conditions comparable to present-day Mars higher survival rates are indicated when cells are kept in liquid brines rather than dry conditions (Stan-Lotter et al., 2003).

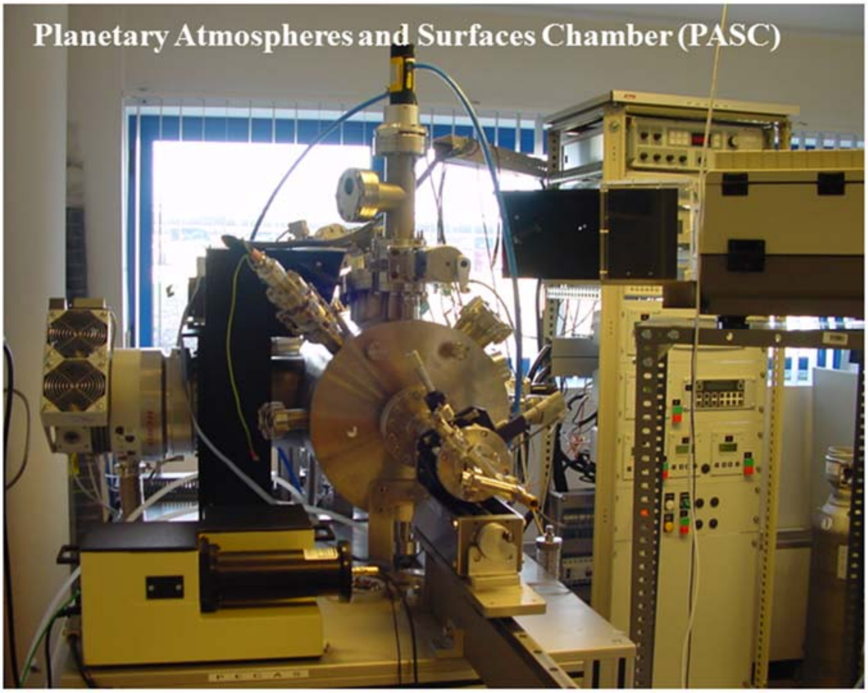
Nowadays, the actual challenge is to search for habitability conditions and organic compounds detection.

Multiple studies in many scientific and technological fields have confirmed the importance of simulation-chamber facilities, as an example the Planetary Atmosphere and Surfaces Chamber (PASC) at CAB is a promising instrumentation for the emulation of planetary conditions and the assessment of multidisciplinary, astrobiologically relevant scenarios.

1. Experimental

The Planetary Atmosphere and Surfaces Chamber (see Figure 2) (Mateo-Marti et al., 2006) is a versatile planetary-simulation chamber that is capable of producing environments with computer-controlled gas compositions, pressure in the atmosphere and sample temperatures that can be representative of most of the planets in the Solar System. This equipment was specifically developed to make feasible the in situ irradiation and physico-chemical characterization of samples.

The total pressure range of the chamber is from 7 mbar to 5×10^{-9} mbar, and the partial pressures of the gases in the chamber can be set with this precision. To simulate a particular atmosphere, the gases are mixed in a manifold to the required proportions, and the gas composition is constantly monitored by a residual gas analyzer mass spectrometer. The temperature of the sample is regulated by a commercial helium cryostat connected to the sample holder, and it can be adjusted from 4 K to 325 K. Standard sample size ranges are from 5 to 35 mm diameter; however other types of particular sample container are available for specific



requirements. Irradiation sources are set-up to perform ion (5 KeV), electron (5 KeV) and ultraviolet (UV) irradiation (from 200 to 500 nm).

Figure 2. Photograph of the Planetary Atmosphere and Surfaces Chamber (PASC).

To simulate Martian conditions, 7 mbar is used as the average atmospheric pressure of the planet, temperature cycles ranging from 150 to 280 K can be programmed (this could be particularly interesting to simulate seasonal cycles). To reach these values, we have to first set the partial pressures of the gases known for the Mars atmosphere (i.e., about 95% CO_2, 2.7% N_2, 1.6% Ar and 0.6% H_2O), with a total pressure of 7 mbar (Figure 3 Mars atmosphere). Once the partial pressure of all the gasses is stabilized, we cool down the surface to the desired temperature, in our case to 150 K. We get a stable temperature after 15 min (Figure 3 Mars atmosphere at 150 K). The fluctuations in the partial pressure of the gasses are due to the heating stage, which induces adsorption and desorption of the molecules around the sample holder. Finally, we switch on the ultraviolet radiation source, a deuterium lamp in the range of 200–400 nm.

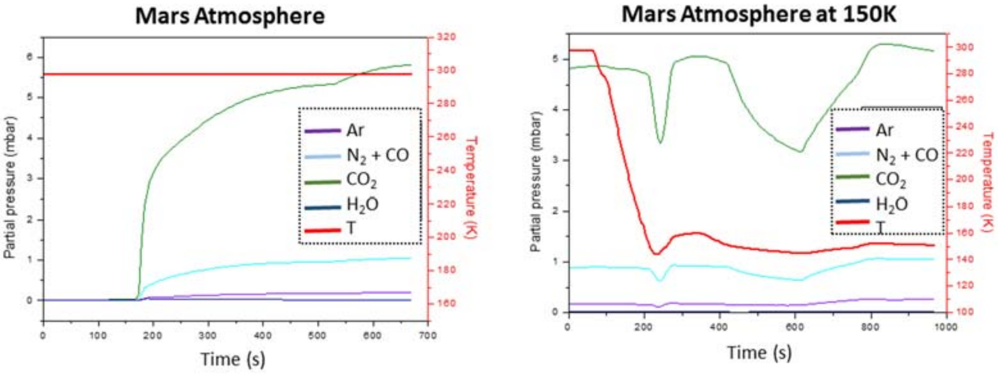


Figure 3. Mars surface and atmosphere environment: Evolution of the partial pressure of the different gasses at the Mars atmosphere (left side), Evolution of the partial pressure of the different gasses at the Mars atmosphere as the temperature is decreased to 150 K (right side).

2. Results and Discussion

PASC simulation facility was developed to be a useful tool in several scientific and technological areas of knowledge, such as engineering, chemistry, geology and biology among others. PASC has produced relevant scientific outcomes related to astrobiology and habitability research: The UV-absorbing properties of basaltic dust (Martian analog) have been evaluated as a function of its thickness and mass (Muñoz-Caro et al., 2006). The survival capability of specific bacteria exposed to simulated Mars conditions has been recently confirmed (Gomez et al., 2010), as have the high resistance and survival capability of eukaryotic symbiotic organisms (lichen) under simulated Mars and space conditions (Sánchez Iñigo et al., 2012). Furthermore, the photostability or molecular damage of nucleobases and peptide biomolecules under UV irradiation has also been investigated (Mateo-Marti et al., 2009; Mateo-Marti et al., 2013). Additionally, stability of saline water under Mars conditions have been studied; indicating that salty locations might allocate water to be periodically and locally liquid on Mars (Zorzano et al., 2009). These studies confirm the significance of simulation-chamber facilities as an emerging type of instrumentation for the emulation of planetary conditions and the assessment of various multidisciplinary, astrobiologically relevant scenarios.

Simulation chambers are essential tools for the assessment of the survival/adaptation of biological organisms under the harsh conditions of Mars planet (Gómez et al., 2010; Sánchez Íñigo et al., 2012). As an experimental case, studies of the survival capacity of lichens (eukaryotic and prokaryotic symbiotic organisms) under the conditions that prevail on the surface of Mars have been performed in PASC. After 120 h of exposure to simulated but representative Martian atmospheric, temperature, pressure and UV conditions, the photosynthetic performance of the lichen photobiont was unaltered, demonstrating its high resistance to these harsh conditions (Sánchez Iñigo et al., 2012). Because PASC is a unique instrument that is capable of simulating a wide variety of environmental conditions, it effectively facilitated the study of the high resistance of this specific lichen species to the harsh conditions on Mars (Sánchez Iñigo et al., 2012). Additionally, an acidophilic chemolithotroph isolated from Río Tinto and *Deinococcus radiodurans* microorganisms were exposed to simulated Mars environmental conditions in PASC under the protection of a layer of Mars regolith analogue. It was concluded that the presence of a thin layer of Mars regolith is critical to significantly reduce radiation doses and provide a shielding layer for microorganisms. Habitability increases considerably under only a few millimeters of regolith protection (Gómez et al., 2010). In conclusion, this experiment expanded the range of possibilities for extant life on Mars, meaning that a thin Mars regolith layer is enough to significantly reduce radiation doses and offers a shielding layer for these micro-organism species.

A crucial aim of the exploration of Mars was to determine whether liquid water exists there today, or existed in the past (Des Marais et al., 2008). It has been hypothesized that the existence of salts may depress the freezing point and permit liquid saline water to be occasionally stable on the Martian surface (Brass, 1980; Chevrier et al., 2009). Chloride salts have been found on the Meridiani and Gusev locations and in extensive deposits in the southern Martian hemisphere. Moreover, the Phoenix lander found perchlorate salts (mainly magnesium and sodium perchlorate) on Mars' arctic soil. The presence of these salts on the surface of Mars is important due to their capability to lower the freezing point of water, and they can absorb water vapor until they melt and form a liquid solution (deliquesce process, see in-set Figure 4). Our experiments performed in PASC conclude that deliquescent salts such as sodium perchlorate can form liquid water solutions on Mars on locations where salts are in contact with water vapor from the atmosphere or ice reservoirs (Zorzano et al., 2009). These results suggest a water cycle on Mars in which atmospheric vapor deliquesces salt particles into liquid solutions, freezes and sublimates. The deliquescent properties of perchlorate salts may thus play a significant role in controlling soil and atmospheric water content (Hecht et al., 2009). The probable existence of liquid saline water on the surface of Mars has important repercussions for the interpretation of Martian data, understanding of local water cycles, the selection of landing sites for future missions and planetary protection.

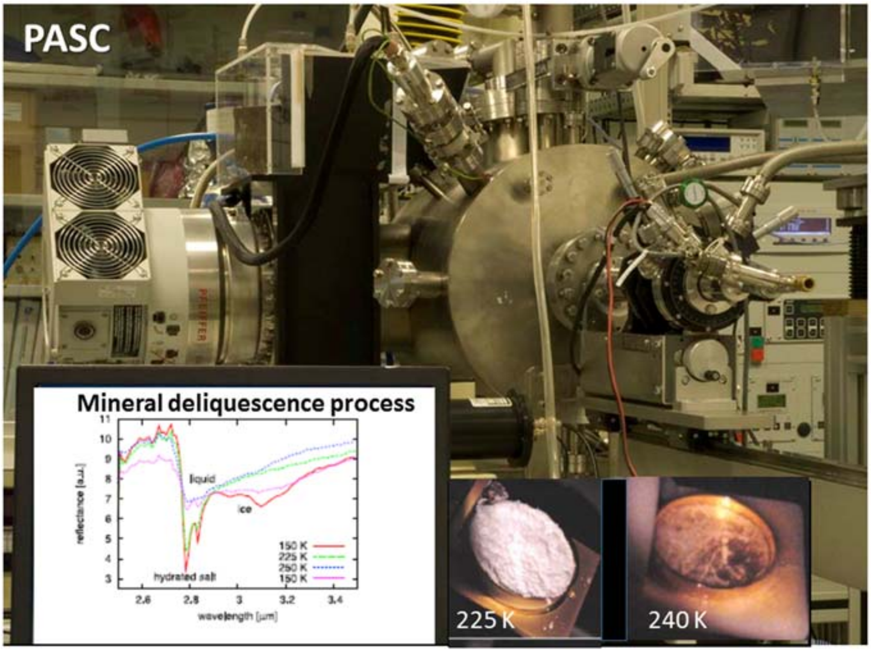


Figure 4. Infrared spectrum and two images of deliquescing dehydrated sodium perchlorate in a simulated Martian atmosphere at 7 mbar pressure at temperature of 225 K and 240 K respectively, in-situ data of experiment performed in PASC.

We have probed the potential of PASC to simulate Mars environmental conditions and some relevant experiments performed inside of it have been described. Therefore, this planetary simulation chamber is an accurate tool for contributing to the next space missions, to design successful scientific experiments under planetary environments to be further performed under real (in-situ mission) planetary bodies, and to validate in-situ measurements from orbital or rover observations on the Mars surface. The simulation chamber will contribute to the achievement of complementary knowledge regarding, mineralogy, habitability on Mars conditions and survival/adaptation aspects of microorganism at planetary extreme conditions.

3. Conclusions

Future planetary and space missions will be driven by innovative technology and challenging scientific experiments, the success of which will be ensured through preliminary tests in laboratory facilities. In this context, simulation chambers will play a crucial role in garnering complementary knowledge and exploring potential difficulties before such space missions are designed and launched. Even more, the findings of each space mission must be verified at terrestrial laboratories facilities in order to validate and confirm the in-situ measurements (rover) or from orbital observations of Mars surface. Therefore, planetary-simulation chambers are an ideal and accurate tool for contributing to future space research. In addition, several studies previously described confirm the significance of PASC simulation chamber facility as an established instrumentation to emulate Mars planetary conditions and assess different multidisciplinary astrobiological studies, which could contribute to a better evaluation of the habitability of the Mars planet's surface and expand the powerful capabilities of this planetary-environment simulation chamber.

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