

PPS002-01

会場:103

時間:5月25日 08:30-08:45

## MELOS 火星探査ミッションの概要 Mars Exploration Mission MELOS: An Overview

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While the scientists group continues discussion on the scientific target for Japan's Mars mission, a "sure" step of exploration needs to be followed from the engineering point of view. The idea is that we will achieve an orbital insertion plus entry-descent-landing (EDL) demonstration in MELOS1 mission. The EDL module will also carry a fair amount of science payload so it is not a mere demonstrator but also a platform of scientific mission. A upscale MELOS2 mission with a well-equipped lander will follow and enhance, together with MELOS1 and future MELOSX missions, our understanding about the red planet, Mars.

Currently, there are 2 proposals for the orbiter mission. One is Martian meteorology that complements the comparative study of terrestrial planet's meteorology. Unfortunately, Akatsuki's first attempt of Venus orbital insertion (December 2010) turned out to be unsuccessful, there is a good chance of another orbital insertion a few years later. The knowledge of the Earth meteorology will be improved by Akatsuki at Venus and by MELOS1 at Mars. Another is the escaping atmosphere that is thought to be a key process of today's tenuous atmosphere of Mars. To overcome NASA's MAVEN (launch in 2013), a group of people proposes a "2 orbiter" configuration for this mission. The mission needs to be around the maximum of 25th solar cycle (~2024). The lander group proposes 4 themes: the surface environment study with a rover; the interior study through seismology and rotation measurements that benefit most from a network of ground stations; astrobiological study that focuses Martian methane and related possible metabolism; and a "flyby" sample return mission that captures the dust and the atmosphere ~40-45 km altitude while flying.

Proposed ideas are all unique and valuable for the study of Martian system that produced today's dry/cold environment of Mars. We continue evaluation of proposals in 2011 and 2012. Will decide what we will do with MELOS1 (an orbiter and an EDL demo) by fall of 2012. The mission will then be proposed for launch in early 2020's that will be a similar time frame with NASA's MSR (Mars Sample Return) Orbiter and ESA's network lander mission.

Keywords: Mars exploration, system science, orbiter, lander, evolution history, habitability

PPS002-02

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## 火星におけるダスト輸送の地域的特徴 Regional characteristics of dust haze transport on Mars

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Regions favorable (FRs) for expansion of dust storms on Mars are identified. We performed many numerical simulations where, in the northern fall (Ls=180), dust was injected into the atmosphere artificially from dust sources located all over the planet. Such dust transport simulations provide global maps of dust expansibility (i.e. "dust expansion potential") and show that dust expansibility differs greatly between different regions on Mars. These global maps show that dust loaded from certain areas in the northern mid-latitudes tends to spread widely within a few days. Dust injected in the vast regions around Tharsis and the Sirenum-Aonia regions also tends to spread extensively depending on local time. On the other hand, dust injected at high latitudes in either hemisphere does not spread extensively. Such global maps indicating regions favorable for dust storm expansion are a clue to understanding expansion processes and climatology of great dust storms on Mars. Moreover, none of the approach described in the presentation to understanding expansion processes and climatology of great dust storms has been taken elsewhere. In our presentation, we present results of simulations for other seasons as well as Ls=180 and consider concrete mechanisms of dust expansion in and around each FR.

キーワード: 火星, ダストストーム, 物質輸送, 数値シミュレーション

Keywords: Mars, dust storm, transport, numerical simulation

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## 火星中層大気の大循環と力学 General circulation and dynamics of Martian middle atmosphere

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火星中層大気(高度 60~130km)の観測データは、地表面~下層大気(高度 0~60km)や上層大気・電離層(高度 130km以上)に比べその量は圧倒的に少ない。しかしその少ない観測データや数値シミュレーションによる最近の研究によると、この高度域の大気科学が火星の気候変動や大気散逸を探る上で重要視されている。

火星大気中のダストや水蒸気は、子午面循環により南北に輸送される。火星大気大循環モデル(MGCM)による計算結果によると、その南北循環の様子は太陽からの距離や太陽直下点の変化、および地形の効果により、大きな季節変化が存在する。特に近日点に近い南半球夏季では全球的に気温は北半球夏季よりも高めとなり、よって水蒸気がより高い高度に到達し、南半球から北半球への輸送が盛んに行われると考えられている。さらに南半球夏季には年によって全球規模のダストストームが発生し、その場合ダストによる放射加熱効果がさらに南北循環を強めることが示唆されている。中層大気の温度場・風速場を詳しく観測できれば、これらの現象を直接的に証明することができる。

Mars Express 搭載 SPICAM による星掩蔽観測は、中層大気におけるいくつかの鉛直温度プロファイルを導出している。この観測では高度 100km 前後で大気温度はしばしば CO<sub>2</sub> の凝結点を下回り、それにより高度 60~100km に CO<sub>2</sub> 氷雲が存在することを示唆している。CO<sub>2</sub> 氷雲は Mars Express や Mars Odyssey に搭載されたカメラからも観測され、雲追跡による中層大気の風速の導出も行われている。中層大気の流れについては、サブミリ波地上望遠鏡から見た吸収線の Doppler shift を用いた観測もある。現状の MGCM は中層大気の流れ場・風速場についてこれらの観測データをうまく再現できているとは言い難く、中間圏界面(高度 80~100km)の温度は観測より 10~30K 高く、また低緯度域の東風風速は観測より小さい。このような差異が生じる要因として、下層大気から伝播する重力波の効果が考慮されていないこと、CO<sub>2</sub> 赤外冷却の強さに影響を及ぼす O 原子の量がうまく再現できていないことなどが示唆されている。また下層大気の流れ場・水の循環や波動がはるか上の電離層に影響を及ぼすことを示唆する研究もあり、中層大気の流れ場・物質循環の解明が地表面から電離層までの一貫した理解につながることに期待は大きい。

我々は MELOS 気象オービタの検討にあたり、サブミリ波サウンダによる中層大気の流れ場・風速場・微量物質分布のマッピング、またカメラによる CO<sub>2</sub> 氷雲の撮像・追跡を通しての火星中層大気科学の解明に向けた観測を提案している。本発表ではこれまでに行われてきた火星中層大気の研究を紹介するとともに、その謎と観測計画の意義について議論する。

キーワード: 火星, 惑星大気, 大気力学, サブミリ波観測, 惑星探査, MELOS

Keywords: Mars, Planetary atmosphere, Atmospheric dynamics, Sub-millimeter observation, Space exploration, MELOS

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## 主成分の凝結を伴う大気対流

### Atmospheric convection with condensation of the major component

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火星大気では、主成分である CO<sub>2</sub> が凝結する。

現在の火星では、極域に CO<sub>2</sub> の氷雲が存在することが知られており、これらの雲は対流によって生じている可能性がある (Colaprete et al., 2003).

一方過去の火星では、厚い大気の下で多量の CO<sub>2</sub> 氷雲が存在し、その散乱温室効果が気候に大きな影響を及ぼしていたと考えられている (Forget and Pierrehumbert, 1997; Mitsuda, 2007).

主成分が凝結する系では過飽和が生じない場合に熱力学の変数に関する自由度が1つ少なくなる。

自由度が減ることで、雲層における上昇域と下降域の温度プロファイルが等しくなってしまう、空気塊は浮力を得られなくなってしまう。

その為、湿潤対流は発達できないと考えられてきた。

Colaprete et al.(2003) は鉛直1次元モデルを用いた数値計算により、臨界飽和比  $Sc_r$  が1.0を超える場合には温度分布が熱力学的平衡状態からずれる為、湿潤対流が生じることを示した。

しかし、鉛直1次元モデルでは、エントレインメントなどに関するパラメトリゼーションに不確定性が含まれている。

そこで本研究では、 $Sc_r = 1.0$  の場合の流れ場と雲の分布の特徴を掌握することを目的として、2次元の雲対流モデルを用いた主成分凝結系の雲対流の直接数値計算を実行する。

用いるモデルは様々な惑星大気の大気構造の理解を目指して我々が開発してきたものである (小高他, 2006; Sugiyama et al., 2009;

<http://www.gfd-dennou.org/library/deepconv/>).

モデルの基礎方程式は、準圧縮方程式 (Klemp and Wilhelmson, 1978) に主成分凝結の効果を検討したもの (Odaka et al., 2005) である。

雲粒の落下および雲粒の荷重の効果は考慮されていない。

雲微物理過程は、Tobie et al. (2003) と同様に、雲粒の拡散成長の式を用いて定式化する。

この定式化では、蒸気から雲への変換は有限のタイムスケールで生じる。

放射過程は陽に解かず、地表面付近に水平一様加熱、対流圏に水平一様冷却を与える。

初期状態として、下層で乾燥断熱、上層で飽和蒸気圧曲線に沿った温度分布を与える。

さらに、対流を駆動するために、モデル最下層に温位のランダムノイズを与える。積分時間は10日である。

計算結果は、Colaprete et al. (2003) の主張とは異なり、 $Sc_r = 1.0$  の場合においても湿潤対流が生じることを示す。

準平衡状態において、CO<sub>2</sub> 凝結高度の下方 (乾燥域) と上方 (雲層) の鉛直運

動は連続的である.

乾燥域からの上昇流は CO<sub>2</sub> 凝結高度を超えて雲層上端まで達し, 雲層上部からの下降流は下部境界まで達する.

上昇・下降流の最大値はともに約 15 m/sec である.

上昇する気塊は乾燥域では温度が高いために正の浮力を受け, 雲層内では温度が低いために負の浮力を受ける.

下降する気塊は上昇する気塊とは逆に, 雲層内では温度が高く, 乾燥域では温度が低い.

雲層内の温度分布が飽和温度からずれているのは, 蒸気から雲への変換に有限の時間がかかるためである.

湿潤対流が発達する理由は, 上昇流に対して乾燥域で働く正の浮力が雲層内で働く負の浮力よりも十分大きいためと考えられる.

キーワード: 大気主成分の凝結, CO<sub>2</sub> 氷雲, 雲対流モデル

Keywords: condensation of major atmospheric component, carbon dioxide ice cloud, cloud convection model

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## 火星メタンに関する最新の観測結果 Methane on Mars: Current observations and implication

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Since the simplest organic molecule, methane (CH<sub>4</sub>), was detected in the Martian atmosphere in 2004, this topic has caused a big interest in the solar system, because its discovery indicates the planet is either biologically or geologically active. Up to now, ground-based and space-born observations have confirmed its presence in the Martian atmosphere (Formisano et al., 2004; Krasnopolsky et al., 2004; Geminale et al., 2008; Mumma et al., 2009; Fonti and Marzo, 2010). However, its reservoirs, release mechanisms, circulation, and sink are still open questions. The high-spectral resolution observation from ground-based telescope indicated that CH<sub>4</sub> showed time variation, and non-uniform distribution, with plume-like features at discrete regions (Mumma et al., 2009). Using the Planetary Fourier Spectrometer (PFS) onboard Mars Express (MEX), Geminale et al. (2011) also reported maps of non-uniformed CH<sub>4</sub> distribution. Although the MEX/PFS and the ground-based observations were generally not collected at the same time nor did they cover identical areas of Mars, the characteristics of the observed CH<sub>4</sub> fields appear to be significantly different. In contrast, photochemistry as currently understood does not produce measurable variations in CH<sub>4</sub> concentrations [Lefevre et al., 2009]. Lefevre et al. (2009) suggested an atmospheric lifetime of less than 200 days is necessary to reproduce the local CH<sub>4</sub> enhancements similar to those recently reported, which implies an unidentified CH<sub>4</sub> loss process that is 600 times faster than predicted by standard photochemistry. In summary, current photochemical models cannot explain the observed presence of CH<sub>4</sub> in the atmosphere of Mars and its reported rapid variations in space and time. The origin and sink of CH<sub>4</sub> on Mars remains a puzzle. In the near future, the observations using heterodyne spectroscopy with an alternative CH<sub>4</sub> band near 7.8  $\mu$ m [Sonnabend et al., 2008] are begun to monitor CH<sub>4</sub> from the ground, and the tunable laser spectrometer measurements is carried out at the Martian surface on the 2011 Mars Science Laboratory (MSL) to identify the isotope of CH<sub>4</sub> [Webstar et al., 2011]. Joint orbiter mission being considered by ESA and NASA (JIDT) is also expected to provide the significant scientific progress on this issue by investigating the nature of the trace gas with measurements of temperature and aerosols (Zurek et al., 2011). Here we review the current observations of Martian CH<sub>4</sub> and their implications.

キーワード: 火星, メタン, 生命, 居住適性

Keywords: Mars, Methane, Life, Habitability

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## MEX/PFSによる火星大気中H<sub>2</sub>O<sub>2</sub>の導出 Search of H<sub>2</sub>O<sub>2</sub> in the Martian atmosphere by MEX/PFS

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Recently, a small amount of CH<sub>4</sub> was discovered in the Martian atmosphere. This discovery is remarkable because its sources are potentially biological or geological actives. However, its source, circulation and sink are still open questions. Recent observations showed the temporal and spatial variation of CH<sub>4</sub>, which requires fast loss, which might indicate strong oxidants. H<sub>2</sub>O<sub>2</sub> would be the best tracer for the amount of possible oxidants in the Martian atmosphere. However, past ground-based and space-born observations were very limited. Thus, the temporal and spatial variations of H<sub>2</sub>O<sub>2</sub> have not been understood yet.

H<sub>2</sub>O<sub>2</sub> has not detected from a Martian orbiter because it required high-spectral resolution in order to distinguish between weak absorption lines of H<sub>2</sub>O<sub>2</sub> (~0.1% of the background radiance) and stronger absorptions by H<sub>2</sub>O. At the moment, the Planetary Fourier Spectrometer (PFS) onboard Mars Express (MEX) is the best instrument for this objective, which has been successfully operated for seven years. It possesses the highest spectral resolution in the mid-IR range (~1.3 cm<sup>-1</sup>) in previous orbiters. However, even this resolution could not completely separate H<sub>2</sub>O<sub>2</sub> from H<sub>2</sub>O. We need careful treatment in the analysis.

In our study, we select the wavelength range from 360 to 385 cm<sup>-1</sup> where the contamination of H<sub>2</sub>O<sub>2</sub> by H<sub>2</sub>O is minimum. And, the sensitive calibration was performed: (1) FFT with the Hamming apodization, (2) characterization of a weak instrumental noise, and (3) careful averaging several thousands of measurements. In order to retrieve the mixing ratio of H<sub>2</sub>O<sub>2</sub>, the radiative transfer model for the Martian atmosphere has also been developed. By the comparison of the observed spectra with the model, we succeeded to determine the mixing ratio of Martian H<sub>2</sub>O<sub>2</sub> with the accuracy of several tens ppb. By this method, (1) total average, (2) annual variation, and (3) seasonal variation of the H<sub>2</sub>O<sub>2</sub> mixing ratio was obtained with the data observed 3 Martian years (Jan. 2004 - Dec. 2009). The main results are summarized as follows.

(1) Total average: Total averaged H<sub>2</sub>O<sub>2</sub> mixing ratios have been successfully determined to be 45 +- 21 ppb in the forward pendulum direction, and 25 +- 18 ppb in the reverse pendulum direction, respectively.

(2) Annual variation: The annual mean amount of H<sub>2</sub>O<sub>2</sub> in the three Martian years (MY 27, 28, and 29) was investigated. The mixing ratios of H<sub>2</sub>O<sub>2</sub> were 50 +- 27 ppb and 43 +- 26 ppb at the MY 27, 0 - 89 ppb and 0 - 74 ppb at the MY 28 (upper limits), and 46 +- 21 ppb and 28 +- 20 ppb at the MY 29, respectively

(3) Seasonal variation: It shows the variation from 0 to 120 ppb during the observational period, with an average of 39 +- 16 ppb in total data set.

In all results of (1)-(3), derived amount of H<sub>2</sub>O<sub>2</sub> is slightly larger than that predicted by the photochemical models and past observations. This discrepancy would be due to (1) the bias of data selection; the high Martian temperature (only 250-270K)> and the local time (only 10-16), and/or (2) the contribution of large but short enhancement in long-term average. In addition, it was noticed that the observational variations of CH<sub>4</sub> reported by previous works would not be explained by the process of photochemical loss even with our results.

キーワード: 火星, 大気, 赤外分光, メタン, 過酸化水素, 酸化

Keywords: Mars, Atmosphere, Infrared spectroscopy, Methane, Oxidation, Hydrogen peroxide

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## 火星の気象測器開発 Development of Martian meteorological Instruments

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We are developing weather observation instruments install on the lander of Mars of MELOS.

At now, there are some observation on Mars, but all observation are made with basic instruments.

Then, we are examining two kinds of instruments at the same time.

One of that is a set of basic instruments, the thermometer made of thermocouple or so, the manometer, these are always used for radiosonde. And a hot-film (similar to hot-wire) anemometer, this type is boarded on Viking.

The other instruments are mainly sonic anemometer, it improve high accuracy and high frequency in low electrical power.

Mars has a very low pressure of CO<sub>2</sub> atmosphere, sonic wave damping is very strong, so development has a difficulty.

However some reports say it will be possible, and we are examining a possibility, we report mainly around the progress of this possibility test.

キーワード: 火星, 気象, 風速計, ランダー, MELOS

Keywords: Mars, Meteorology, anemometer, Lander, MELOS



PPS002-08

会場:103

時間:5月25日 10:15-10:30

## 火星周回探査機搭載用サブミリ波サウンダ FIRE の開発状況 II FIRE: Submillimeter sounder for the Maratian atmospheric observations

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This paper describes the development status of a submillimeter atmospheric emission sounder FIRE which is proposed as an onboard payload of the Japanese Mars meteorological orbiter MELOS.

The submillimeter wavelength has potential advantages for the atmospheric remote sensing as there exist a large number of roto-vibrational transitions of many photochemically important species in the Martian atmosphere such as H<sub>2</sub>O, H<sub>2</sub>O<sub>2</sub>, HO<sub>2</sub>, CO, O<sub>2</sub>, O<sub>3</sub> and SO<sub>2</sub>. The vertical profiles of the atmospheric state (e.g., temperature, chemical compositions) can be retrieved by using the pressure dependency of the spectral line shape of those rotational transitions. Furthermore, thanks to high frequency resolution of the heterodyne technique, direct measurements of wind speed are realized through observing the Doppler shift of the molecular spectrum. Last but not least, the submillimeter observation is independent of dust opacity and local time. All these characteristics make the submillimeter instrument unique, and will provide a substantial progress on the Martian meteorological understanding.

We present the results of the measurement sensitivity study with respect to the key physical parameters such as H<sub>2</sub>O, temperature, HDO/H<sub>2</sub>O, and line-of-sight wind velocity, with assuming realistic instrumental parameters.

キーワード: Mars, sub-mm sounder

Keywords: Mars, sub-mm sounder

PPS002-09

会場:103

時間:5月25日 10:45-11:30

## Exploring the Martian Surface: Lessons Learned from Thirteen Rover-Years on Mars Exploring the Martian Surface: Lessons Learned from Thirteen Rover-Years on Mars

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The two Mars Exploration Rovers, Spirit and Opportunity, touched down on Mars in January 2004 and have been conducting extensive observations with the Athena science payload. Together the two rovers have traversed about 35 km. Spirit, located on the floor of Gusev crater, has investigated basaltic plains, as well as older materials in the Columbia Hills. The rocks of the Columbia Hills are granular in nature and have undergone significant alteration by water. They appear to be largely a mixture of altered impact ejecta and explosive volcanic materials. Spirit has discovered silica-rich deposits that may have formed in a hot spring or volcanic fumarole environment, as well as massive carbonate-rich rocks. Opportunity has carried out the first outcrop-scale investigation of ancient sedimentary rocks on Mars. The rocks are sandstones formed by wind and water erosion and re-deposition of "dirty evaporite" materials rich in sulfate salts. The stratigraphic section observed to date is dominated by wind-blown bedforms, with water-formed current ripples exposed locally near the top of the section. While liquid water was present at Meridiani below and occasionally at the surface, the ancient environmental conditions recorded there are dominantly arid, acidic and oxidizing, and would have posed some significant challenges to life.

In carrying out the rovers' mission, many lessons have been learned regarding the operation of robotic vehicles on the surface of Mars. These cover topics including flight system and mission design, traverse planning, science payload selection, flight software and autonomy, and team selection and training. Among the most important flight system capabilities are mobility, particularly in steep and rugged terrain, and a power system design that allows long mission life. Traverse planning benefits greatly from high resolution orbital imaging, and should take full advantage of topographic features, like impact craters, that provide access to important geologic materials. Important payload elements include instruments that can detect subtle compositional differences both remotely and in situ, and tools for getting below rock and soil surfaces. The most important flight software capabilities are ones that save time on the martian surface. Similarly, it is important to invest in the tools and team training necessary to minimize the duration of the uplink planning process.

Keywords: Mars Exploration Rover, Spirit, Opportunity, Operation, Science, Engineering

PPS002-10

会場:103

時間:5月25日 11:30-11:45

## 火星における流動地形と水の関係

### Possibly water-related active features on Mars: Their climatic and biological implications

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Currently active features on Mars include numerous flow-like features identified mostly in higher latitude areas. Although liquid water has long been considered impossible to stably exist under the current climate condition, origins of some flow-like features are proposed to be related to liquid water based on their morphologies and remaining chemical compositions. Because the presence of water ice in shallow subsurface and water vapor are known to exist on Mars, water-related active processes might be a part of the story of long-lasting slow circulations of water on the surface of Mars, which might be an intriguing target for synergetic observations between the orbiter and the lander of the future MELOS mission to Mars.

The lander group of the MELOS mission is actively discussing its mission concepts, which include a biological aspect. One of the biggest goals proposed is to critically discuss if certain types of bacteria are still alive on Mars. A tentative scenario drawn for this purpose is to explore source areas of putative discharge of Methane, which may include mud volcano-like features widely spread western side of Elysium. In this talk, I will review current understanding of the flow-like features as well as other features indicative of the previous presence of liquid at a little deeper depth, such as mud volcanoes, and discuss their implications to the mission concept of the MELOS mission.

キーワード: 火星複合探査, MELOS, 火星, 水, 周氷河地形

Keywords: Mars exploration, MELOS, Mars, water, periglacial area

## Sulphate-rich bedrocks at Meridiani Planum, Mars: Constraints and modelling Sulphate-rich bedrocks at Meridiani Planum, Mars: Constraints and modelling

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The sulphur-rich nature of Martian soils is known since the Viking missions [1]. Data from recent orbital and landed missions have confirmed the important role played by the sulphur cycle on Mars [2] by showing that sulphates were among the most abundant secondary minerals on the Martian surface. Understanding which geological processes led to their formation is of particular interest as it may yield important clues about the presence of water during Mars' geological history. In this context, data from the Mars Exploration Rover (MER) Opportunity provide crucial constraints on the conditions prevailing during the formation of Meridiani Planum sulphate-rich bedrocks. Terrains visited by Opportunity at Meridiani appear to be sulphur-rich (up to 25 % SO<sub>3</sub>) layered rocks covered by basaltic soils [3]. Outcrops are exposed by impact craters, allowing their analysis by the rover's instruments. Another notable feature of these plains is the ubiquitous presence of mm-sized spherules, containing hematite, observed in both the rocks and the soils. Some mafic constituents are also present in the rocks.

In addition to hypotheses formulated before the beginning of on-site observations, such as subaqueous sedimentary deposition [4], various formation scenarios have been proposed (or significantly refined) since the landing of the rover: impact surge [5], weathering of dust-ice deposits [6], alluvial deposition of exogenous materials [7], groundwater diagenesis of evaporitic sandstones [3,8], volcanic processes [9], and alteration of basaltic material through sulphur-bearing fluids [10,11]. It is worth to note that these models are not necessarily all mutually exclusive. Numerous constraints exist as regards these hypotheses, relative to the chemical/mineralogical compositions (including variations within the investigated layers), the provenance of the constituents involved in the formation scenario (including water, if needed), the textural observations, etc. The large-scale geological context, known from orbital data, has also to be taken into consideration [12], especially as the rock layers investigated by Opportunity only represent a small part of the full stratigraphic sequence of sulphate-bearing layers at Meridiani.

All the proposed scenarios have their own advantages and issues. The model of alteration of basaltic material through cold sulphur-bearing fluids [10,11], using a geochemical numerical simulator, provides particularly interesting results. Here, acidic fluids are assumed to originate from volcanic sour gas dissolution into pure water and the main parameter of the model is the quantity of added sulphur, expressed in terms of SO<sub>3</sub>/basalt mass ratio. The role of brine circulation is also taken into account. A good match with MER observations at Meridiani is obtained for a particular adjustment of the model parameters suggesting an alteration occurring in highly acidic brines and involving small amounts of water over a short period of time (or in an intermittent way). Additionally, the potential mineralogies obtained through this model over a wider range of initial conditions could also explain compositions encountered in other Martian regions.

References: [1] Clark et al. (1982), JGR, vol. 87. [2] King & McLennan (2010), Elements, vol. 6. [3] Squyres et al. (2004), Science, vol. 306. [4] Edgett & Parker (1997), GRL, vol. 24. [5] Knauth et al. (2005), Nature, vol. 438. [6] Niles & Michalski (2009), Nat. Geosc., vol. 438. [7] Fan et al. (2008), GRL, vol. 35. [8] McLennan et al. (2005), EPSL, vol. 240. [9] McCollom & Hynek (2005), Nature, vol. 438. [10] Treguier et al. (2008), JGR, vol. 113. [11] Berger et al. (2009), Am. Min., vol. 94. [12] Hynek & Phillips (2008), EPSL, vol. 274.

キーワード: Mars, Meridiani, alteration, sulfuric acid, Mars Exploration Rover, geochemical modelling  
Keywords: Mars, Meridiani, alteration, sulfuric acid, Mars Exploration Rover, geochemical modelling

PPS002-12

会場:103

時間:5月25日 12:00-12:15

## 火星隕石の多様性と火星探査によって得られたリモートセンシングデータとの関係 Diversity of Martian meteorites and its relationship to the remote sensing data as obtained by Mars exploration

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Recent recoveries of many hot and cold desert meteorites have drastically increased the number of Martian meteorites. We only had 10 samples in early 1990s, but now we have more than 50 unpaired samples. At the same time, the accumulation of remote sensing data by Mars mission has been considerably increasing for the past 15 years. Therefore, now is a good time to compare Martian meteorites and remote sensing data to construct the better view of the red planet.

In spite of the increase of recovered Martian meteorites, classic grouping as "SNC" (shergottite-nakhlite-chassignite) meteorites is still alive probably because many samples were transported to the earth by the same ejection event. Except for ALH84001, all other samples can be grouped as either of "SNC" with young crystallization ages (170-1300 Ma). Therefore, these samples probably originated from Tharsis or Elysium regions. It is still unexplained why ALH84001 is the only old sample possibly originating from the southern hemisphere. All Martian meteorites are igneous rocks, and no sedimentary rocks have been found yet, although both orbiters and rovers have found the wide distribution of sedimentary rocks. One of the explanations is that these altered rocks can not be ejected into the space because of fragile nature of the rock.

Shergottite is still the largest group of Martian meteorites that are generally divided into three subgroups (basaltic, thersizitic, and olivine-phyric) based on petrology and mineralogy. In recent years, geochemical studies have shown that shergottites can be divided into another three subgroups (enriched, depleted, and intermediate) based on distinct trace element and isotopic compositions, which is completely independent from petrological subgrouping. Their redox states are closely related to these geochemical characteristics, and interpreted to reflect the heterogeneity of the mantle reservoirs [e.g., 1]. These reservoirs formed about 4.5 Ga in a global magma ocean and kept separated because of the absence of active plate tectonics since the reservoirs formed. The second largest group is nakhlite that now consists of 8 samples. Because all nakhlites show similar mineralogy and ages, they probably originated from the same igneous body on Mars with possible layering by accumulation of crystallizing minerals. Each nakhlite is modeled to fit the location from near the surface to the depth of this igneous body. Nakhlites show minor evidence for secondary aqueous alteration that is related to the burial depth as inferred from igneous accumulation. There are a few alteration phases, but the presence of jarosite is important because it is one of the major alteration products on the surface as discovered by Mars Exploration Rover. Two chassignites are dunite rocks that have identical ages to nakhlites. The second chassignite shows black appearance because of the presence of Fe-rich nano-particles in olivine formed by shock metamorphism. ALH84001 is the only old Martian meteorite and the presence of possible biogenic magnetite is still under dispute.

Thus, Martian meteorites are important sources to deduce differentiation history of the planet. However, caution should be taken when we discuss a global view of the planet because of their young formation ages [2]. In fact, the chemical composition of the surface obtained by orbiters showed that the majority is tholeiitic basalts and Martian meteorites have distinct chemical compositions. Obviously Martian meteorites do not represent old crustal chemistry although they record that the planet's interior preserves distinctive regions that formed at 4.5 Ga.

References: [1] Borg L. E. et al. (2003) *GCA* 67, 3519-3536. [2] McSween H. Y. Jr. (2009) *Science* 324, 736-739.

キーワード: 火星隕石, 火星探査

Keywords: martian meteorites, mars exploration

PPS002-13

会場:103

時間:5月25日 12:15-12:30

## MELOS 火星着陸探査システムの検討 Mars Landing System for Surface Science in MELOS Mission

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Mars landing exploration system is being studied in MELOS, a Japanese Mars mission under study, including deployment from orbiter, entry into martian atmosphere, descending with aerodynamical control by heat shield, followed by parachute deceleration, landing with hazard avoidance, navigation and control, deployment of rover, and long-term operation on the Mars. Landing system and the following scientific observation as a long-lived station. Such landing and surface exploration system is briefly reported in this presentation.

Mars is among the extremely attractive planets to be explored in its nature: inner structure, surface processes, weather and climate system, and atmospheric escape. Furthermore, there are planned a sample return of dusts floating in the air and an exploration of life in the habitable zone showing aquifer or methane gas. In the MELOS mission, all of these aspects are studied and some of them will be selected as a united Mars mission to be proposed as a MELOS series.

Entry, descent and landing (EDL) as well as surface long-lived technology and surface rover technology are yet to be developed in Japan but essential for the missions of inner structure, surface processes, and life on Mars. Thus the EDL of a probe from Mars orbiter and the surface long-lived technology on the Mars are investigated in this study to clarify the technical problems and estimate the feasibility.

Three kinds of entry probes are assumed: A) a 700kg class probe to land a 500kg class lander with a 100kg class rover with 20 to 25 kg science payloads carried. B) two 350kg class probes to land 300kg class lander with 20 to 25 kg science payloads. C) 450kg and 250kg probes to land a 400kg and a 200kg landers, with 30kg class rover on the large one, and with 20 to 25 kg science payloads.

To start this study, we assumed that the launcher is H-2A-204, with 1.8t wet mass of the orbiter and landing system. The orbit of the orbiter is 300km x 10 Mars radius. The probe should survive during cruise using an internal heater.

The lander is a legged lander with aerodynamically decrease by heat shield and parachute, and controls its attitude for soft and smart landing by RCS (Reaction Control system) and reaction wheel (RW). The lander is expected to survive in the winter season for a long-lived station to investigate inner structure.

The lander instruments include seismometry, mass spectrometer, X-ray analyzer, landscape and macro imagers, magnetometer, space VLBI, meteorological package, atmospheric radio sounding in 25 kg. Rover is mounted on the lander. Communication system has X-band for direct link to the terrestrial station and UHF band for link to the orbiter. Battery and solar paddle for energy and thermal control are prepared for survivability even in the winter.

The feasibility of such EDL and long-lived technology has been examined to find a solution for a mission success as well as low cost in the spacecraft system.

キーワード: 火星, 着陸, 地質探査, 内部構造, 大気観測, ローバ

Keywords: Mars, Landing, Geological Survey, Inner structure, Atmosphere Observation, Rover

PPS002-14

会場:103

時間:5月25日 12:30-12:45

## MELOS 生命探査: 火星表面における微生物(メタン酸化菌)探査 MELOS Life Search plan: Search for microbes on the surface of Mars

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生命には水が必須である。もう一つ生命の維持に重要な因子としてギブス自由エネルギーがある。動物は食物と酸素無しには生存できないが、それは両者が自由エネルギーの獲得に必要なからである。火星で生命が誕生して現在もまだ生存し続けているとするならば、現在まで自由エネルギーが入手可能な場所でなければならない。

生物による自由エネルギー獲得方法としては、呼吸(動物)、光合成(植物)、化学合成(化学合成微生物)の三つが知られている。火星におけるメタンの発見と、地球におけるメタン酸化鉄還元細菌の発見(Bealら2009)から、我々は火星表面において現在もまだメタン酸化鉄還元細菌(化学合成微生物の一種)が生存しているのではないかと推定するに至った。

もし、火星に於いて生命が誕生し現在も生存しているとすれば、そこは生存にとって困難な条件をさける環境で無ければならない。火星の様々な環境の中で温度、気圧、重力等は地球の生命を考えた場合には十分に生存可能な環境である。放射線も生死に影響を与えるほどの強度は持っていない。唯一、紫外線が重要な致死要因となる。しかし、紫外線は様々な物質によって吸収されるので、薄い火星土壌に覆われるだけで、十分生育可能な環境となる。細胞内の液体の水は地球型生命にとって必須であるが、細胞外の液体の水は生存にとっては必須ではない。従って、メタンと酸化鉄のような酸化型物質の両者がある場所であれば、数センチメートル程度の深さでも微生物は生存している可能性があるかと推定している。

微生物探査の方法としては、蛍光色素をもちいた蛍光顕微鏡観察を自動的に行う。これまで多くの蛍光色素が開発されている。その中から、生命の定義に対応した色素を組み合わせて用いる。細胞の内外を区別する膜(境界)の存在を識別する色素、細胞の複製にひつような遺伝物質を識別する色素、細胞の代謝を司る酵素の存在を識別する色素を組み合わせて用いる。これらの色素の組み合わせから、「細胞」の特徴を抽出することができる。

さらに、その後「細胞」らしき粒子のアミノ酸分析を行う。地球の生物はすべて20種類のL型アミノ酸からなるタンパク質を持っている。火星の「細胞」らしき粒子が地球と同じアミノ酸かどうかを調べる事により、「細胞」の由来を知ることができる。その他、現在検討中の探査方法について報告する。

キーワード: 火星表面, 生命探査, 微生物, メタン酸化菌, 蛍光顕微鏡

Keywords: Surface of Mars, Life search, microbe, methane oxidizing bacteria, fluorescence microscope

# Japan Geoscience Union Meeting 2011

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PPS002-15

会場:103

時間:5月25日 14:15-14:30

## 火星の内部構造の解明に向けて What we have learned about the internal structure of Mars

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Mars has long been a target of exploration missions. Now we know the size and mass of Mars, that Mars has rarefied atmosphere and seasons, that Mars has obvious north-south dichotomy, and that Mars has the largest volcano in the solar system at the equator region. Then, what have we learned about internal structure of Mars?

The bulk density of Mars means that there is a dense core at the center of Mars. On the other hand Mars does not show intrinsic magnetic field, which means no vigorous convection in the core. According to the observation of gravity and topography the crustal structure of Mars shows contiguous thickening from north to south, which means long wave length mantle dynamics. The large volcanoes should have been supported by superplume.

In this talk, I will review what we have learned about the internal structure and thermal evolution model of Mars, and discuss what should be observed next to unveil the interior and history of Mars.

Keywords: Mars, internal structure, thermal evolution, mantle dynamics



PPS002-16

会場:103

時間:5月25日 14:30-14:45

## Numerical models of Martian mantle evolution induced by magmatism and solid-state convection

### Numerical models of Martian mantle evolution induced by magmatism and solid-state convection

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To consider the thermo-chemical evolution of Martian mantle, various studies have been performed, but most of them are based on parameterized convection models. Hence, they needed strong assumptions about the process of the evolution. Here we present numerical models of mantle evolution including magmatism in 2-D convecting mantle. By including magmatism, our models can reproduce compositionally layered mantle structure and surface crust spontaneously, and can treat the whole evolution process consistently. The viscosity is strongly temperature-dependent, and the lithosphere is stagnant. Magmatism is modeled as a permeable flow of basaltic magma generated by decompression melting. The effect of partitioning of heat producing elements into the melt is also included. When the initial mantle temperature is sufficiently high, a reminiscence of magma ocean develops to generate a thick basaltic crust and make the mantle compositionally layered. The upper layer consists of compositionally buoyant residue of the basaltic crust, while the lower layer consists of compositionally denser materials not depleted in the basaltic component. Hot plumes grow from the lower layer and make it thinner with time by erosion. The plume magmatism also keeps the mantle temperature below the solidus by efficiently extracting heat as soon as the mantle temperature exceeds the solidus. When the mantle is initially not so hot as to develop a sizable magma ocean, the compositional layering becomes milder, and a broad lateral heterogeneity temporally develops in deep mantle depending on the viscosity of the lithosphere. Martian mantle is likely to have evolved as a relaxation from a compositionally layered state formed by magma ocean, and plume magmatism probably has played a crucial role in the relaxation process.

Keywords: Mars, mantle evolution, magmatism, basaltic crust

## 宇宙測地学的手法による火星回転変動計測 Measurements of Martian rotational variations by space geodetic techniques

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一般に固体天体の表層環境の変化や内部構造は、その天体の回転（自転）変動に影響を及ぼし、その変動の振幅や位相は電波航法や VLBI などの宇宙測地学的手法により観測可能である。特に火星は、地球と類似の構成要素を有しながらも、過去から現在に至る進化やダイナミクスの様相は大いに異なっており、その相違を表層環境・内部構造から解き明かすことは比較惑星学的に重要である。

火星の回転変動は、従来は着陸機（ランダー）の追跡データ（2ウェイ測距・距離変化率計測：RARR など）を利用して計測されており、例えば Viking 1 および 2, Mars Pathfinder によって、歳差や自転速度変動が得られてきた。これらの計測手法には、地球・火星間の経路上および地上局の位相安定度等に起因すると考えられる測定精度の限界がある。そこで欧州の研究グループは、周回探査機（オービター）とランダー間の RARR を利用した電波航法による精度向上を提案しているが、現時点で採択には至っていない。

一方我が国では、オービターとランダー等の複数探査機を用いた火星複合探査（MELOS: Mars Exploration with Lander-Orbiter Synergy）の検討が開始された。そこで我々は、4ウェイドブラ計測（FWD）、逆 VLBI（iVLBI）等の新たな測地学的手法による、火星回転変動の高精度計測を提案する。4ウェイドブラ計測（FWD）は、宇宙機の位置・軌道の中継機を経由した4経路から決定する測地手法であり、我々は月周回衛星「かぐや」での月裏側の重力場観測という実績を有している。MELOS 計画では、宇宙機の構成は未定であるが、オービターとランダーという構成が一案である。この時、追跡局 オービター ランダー オービター 追跡局の経路でドブラ計測（距離変化率計測）を実施する。同時に、点線で示す経路で、オービターとランダーの2ウェイ RARR を実施する。本方式で期待される測定精度は従来の電波航法より向上し、オービター・ランダー間 RARR を利用した場合の精度に相当すると推定される。逆 VLBI（iVLBI）は、複数の宇宙機からの同期した信号の位相比較を行って、各々の相対位置を測定する手法であり、測定精度は周波数の逆数に比例し、地上と対象宇宙機の距離に依存しない高精度で決定できるという特徴を持つ [1]。MELOS 計画では、ランダーから地上への直接送信波と、オービターでコヒーレントに中継された信号を、追跡局で同時またはスイッチングにより計測する。ランダーの位置変化に対する原理的な感度は、想定される最も低い周波数である X 帯を用いた場合でも 0.3mm であり、FWD や RARR 等の従来手法と比べて著しく高精度である。一方、通信において従来手法より大電力を要すること、通信機経路内の高精度の位相補償を要することが、現状では技術課題である。

Reference: [1] Kawano et al. (1999) J. Geod. Soc. Japan, 45, 181-203.

キーワード: 火星, 自転, 宇宙測地, 逆 VLBI

Keywords: Mars, rotation, space geodesy, inverse VLBI

## 全火星地震波伝播モデリング 予備的研究 Global seismic waveform modeling in the whole Mars - a preliminary study -

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我々はこれまでに得られている火星内部構造モデルを用いて、火星の全球地震波動伝播のモデリングを行った。現在進行している日本の火星探査計画 MELOS では火星表面への地震計設置やそのデータによる内部構造探査を検討しており(小林他, 2009, 遊・星・人; Kurita et al., 2009, JPGU Meeting)、今回開発したスキームはその際のツールとしての役割が期待される。

火星は過去に地球とよく似た環境を持っていたと考えられ、その内部構造推定は地球や太陽系の形成史を明らかにする手がかりとして、地球惑星科学における長年の関心事となっている。これまでに提案されている火星内部構造モデルは、火星隕石の化学組成や、慣性モーメント等の物理学的パラメータの観測結果に基づいたものである。例えば Sohl & Spohn (1997, JGR) は極慣性モーメントの値と隕石から推定される Fe/Si 比をそれぞれ最もよく満たす 2 つの 1 次元火星内部構造モデル(モデル A とモデル B)を発表した。

地震学的手法を用いれば、さらに直接的かつ高解像度での全火星内部構造推定が可能となる。現時点で火星地震の記録と考えられる唯一のものは、1976 年に着陸したバイキング 2 号によるデータで特に精度が良い 640 時間分の記録のうちの 1 例だけであるが (Anderson et al., 1977, JGR)、マーズ・グローバル・サーベイヤーによる地形データの解析では火星表面に 8500 の断層が同定され、上限値として 1 年にマグニチュード 4 以上の地震が 572 個発生しているという予測がなされている (Knapmeyer et al., 2006, JGR)。MELOS 計画で高感度・広帯域な地震計が設置されれば十分に地震学的な内部構造推定が行える可能性がある。

地球での例を振り返ってみると、我々の地球内部構造についての理解は、良質なデータの蓄積とシミュレーション手法の発達が一歩一歩のように影響しあって発展してきたことがわかる。現在得られている火星内部構造モデルをもとに、火星の地震波伝播モデリングのためのスキームを準備することは、来るべき火星地震観測時代へ向けた理論面からのアプローチとして一定の意味を持つと思われる。

我々はこれまでモーメントテンソル点震源から励起され、現実的な全地球内部構造モデル中を伝播する地震波を精度と効率よくモデリングする手法の開発を行ってきた(例えば、Toyokuni et al., 2005, GRL; Toyokuni & Takenaka, 2006, EPS)。この手法は球座標系での 3 次元の地震波の支配方程式を、震源と観測点を含む地球の 2 次元断面について差分法で計算するものであり(球座標系 2.5 次元差分法)、断面のみに着目するため計算効率が良く、標準地球モデルを使った他手法との比較から精度も保証されている。今回は本手法を火星の地震波モデリングに応用した。地震学的な惑星内部構造推定の際には理論波形の繰り返し計算が必要であるため、計算効率の良さは本手法の大きなメリットである。発表では Sohl & Spohn (1997, JGR) の球対称構造モデル A・B の上に、現実的な火星地殻厚を乗せた非対称火星モデルによるシミュレーション結果等を紹介する。

キーワード: 火星, 地震学, 地震波伝播, 理論波形, グローバルモデリング, 差分法

Keywords: Mars, seismology, seismic wave propagation, synthetic seismogram, global modeling, finite-difference method (FDM)

PPS002-19

会場:103

時間:5月25日 15:15-15:30

## 火星環境における広帯域地震計測の検討 Consideration of broadband seismic observation on Mars.

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火星表面は過去の探査によって高解像度の画像をはじめとした多くの情報が蓄積されている。しかし火星の内部に関しては平均密度、モーメントや重力データなどの間接的な情報しか存在せず、コアのサイズや密度に関しても不確定要素が多い。その一方で火星の内部が散逸的であるという報告もなされており (Bills et al 2006) これは従来の '小さな天体は冷たくなるのが早い' という考えとは合わない。このような問題点を解決するため、火星の地震観測は必要である。

JAXA の火星探査計画 MELOS では複数の着陸機による内部構造探査案が提案されており、これには火星に地震計を設置する案も含まれている。火星は地震学的には未知の天体であるため、また一度に多数の観測点を設置することが困難なため、地震計で得られる地下深部からの微弱な地震波から様々な情報を余すことなく引き出したい。このため、設置する地震計は広帯域でなければならない。さらに地震計は非常に高感度である必要がある。その場合、もし観測点が一点に限定された場合でも常時自由振動が計測でき、コアの大きさや状態などの内部構造をより正確に決定することができるという利点もある。

しかし広帯域地震観測は傾斜や温度変化などの外部環境の影響を受けやすい。そのため、対策を講じなければならない。

地震計設置環境問題の中でも表層風は重要でかつ火星特有の問題である。我々は JAXA にある惑星環境風洞実験装置を借りて低圧および高風速下での風洞試験を行い、風洞試験結果とシミュレーションの比較を行った。

文献:

A.Khan and J.A.D.Connolly, Constraining the composition and thermal state of Mars from inversion of geophysical data, Journal of Geophysical Research, Vol. 133 E07003, 2008

C.F.Yoder et al., Fluid Core Size of Mars from Detection of the Solar Tide, Science, Vol.300 299, 2003

キーワード: 火震, 自由振動, 内部構造, コアサイズ

Keywords: Marsquake, free oscillations, inner structure, core size

# Japan Geoscience Union Meeting 2011

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PPS002-20

会場:103

時間:5月25日 15:30-15:45

## 火星地表における大気電気学 Atmospheric electricity on Mars surface

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No measurement of atmospheric electric field and electromagnetic waves on the ground in Mars has been made, though it could dedicated not only to understanding of the electric current research but also to the meteorology. DC electric field near surface is considered to play an important role in initiating dust devil. The electromagnetic wave measurement makes it possible to know the location and the quantitative strength of dust devils wind with few observation sites. Though only one observation site enables us to determine the discharging location, two or three sites improve the accuracy significantly. This measurement also contributes to the studies both on the crust and the upper atmosphere. We propose a very simple and promising instrumentation set for the DC and AC electromagnetic observation making use of MELOS lander.

キーワード: 火星, 地表, 大気電気, ダストデビル, 電磁波

Keywords: Mars, surface, atmospheric electricity, dust devil, electromagnetic wave

PPS002-21

会場:103

時間:5月25日 15:45-16:00

## Ionospheric Seasonal Variation in Martian Equatorial Region Ionospheric Seasonal Variation in Martian Equatorial Region

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Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) is a multi-frequency, synthetic-aperture, orbital sounding radar onboard Mars Express which was launched into an elliptic orbit with an inclination of 86.35 deg on 25 Nov 2003. By analyzing the surface echoes of MARSIS, Safaeinili proposed a method to calibrate the ionospheric effect and estimate the total electron content (TEC), peak electron density and neutral atmosphere scale height near the ionospheric peak properly. Using this method to collect TEC of Martian ionosphere over one Martian year from MARSIS, we have found TEC of ionosphere in Martian Equatorial Region is seasonal changed, and the changing trend is correlated with the seasonal cycle of carbon dioxide. As we know, in the lower ionosphere, photoelectron ionization is significant and makes a contribution of 20~30% to the total ionization rate [Nier and McElroy, 1977]. Even though CO<sub>2</sub> is the major atmospheric constituent of Mars at low altitudes and CO<sub>2</sub><sup>+</sup> ions are the primary ions produced below 100 km, O<sub>2</sub><sup>+</sup> ions are dominant at low altitudes (<260 km) because most of the CO<sub>2</sub><sup>+</sup> ions are broken down into O<sub>2</sub><sup>+</sup> ions through a subsequent ion-neutral reaction (CO<sub>2</sub><sup>+</sup> + O -> O<sub>2</sub><sup>+</sup> + CO). In a word, CO<sub>2</sub> is vaporized from polar cap, then photo-ionized to be CO<sub>2</sub><sup>+</sup>, O<sub>2</sub><sup>+</sup> etc. These charged particles are main ions of Martian ionosphere, and interact with solar wind directly. As solar wind flows past Mars, significant amounts of ions are taken away. It means that oxygen dissociated from CO<sub>2</sub> escape from Martian atmosphere. Based on MARSIS TEC data, the amplitude of TEC changing is about 10<sup>2</sup> per m<sup>2</sup> which affects the oxygen escape speed.

キーワード: Mars, TEC, Carbon Dioxide

Keywords: Mars, TEC, Carbon Dioxide

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PPS002-22

会場:103

時間:5月25日 16:00-16:15

## MHD simulations of the cold ion escape from the ionospheres of Mars and Venus MHD simulations of the cold ion escape from the ionospheres of Mars and Venus

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Ionospheric flow channels and escape of cold ions from the ionospheres of Mars and Venus are investigated using a comprehensive magnetohydrodynamic (MHD) model of the solar wind interaction with the ionospheres of Mars and Venus. The model successfully describes the structures, dynamics, and energetics of both the solar wind and the planetary ionosphere regions. The model shows a complex 3-D flow pattern of the ionospheric plasma, forming large-scale four vortex structures on the nightside and escape channels through the magnetotail region. We also compare our numerical results with recent observations of the Kelvin-Helmoltz wave-like signatures obtained by the magnetometer onboard Venus Express. We show the importance of the viscous process in forming a complex flow pattern in the ionosphere and subsequent escape channels.

キーワード: 太陽風相互作用, 火星, 金星

Keywords: Solar wind interaction, Mars, Venus