

U003-01

会場:304

時間:5月27日 08:30-08:45

## あかつき金星への帰還 AKATSUKI return to Venus

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金星探査の歴史は古く、アメリカ、旧ソビエト連邦が相次いで探査機を送り込んでいる。特にソビエト連邦のベネラシリーズはプローブを大気中に直接投入し、大気組成、圧力、温度などのデータをもたらした。そこで判った金星の表層環境は驚くべきことに地球とは似ても似つかぬもので、高い圧力を持つ高温の大気に覆われていた。海は存在せず、大気の組成も地球とは異なっている。これらの探査機により金星にまつわる幾つかの謎は解かれてきたが、しかし、いまだに金星には多くのサイエンステーマが残されている。

20世紀の最後に初の惑星探査機「のぞみ」を火星に向けて送り出した日本が、次のターゲットとして同じく地球型惑星である金星を目指すことは、ある意味で自然な流れである。そこでは今まで誰も手を付けなかった分野に進むことが求められた。ここで我々が選んだ回答が金星気象探査である。

欧州の宇宙機関 (ESA) は我々と同様の結論にたどり着き Venus Express を 2006 年 4 月から金星周回軌道で運用している。この探査機は以前に ESA が火星に送り込んだ Mar Express を下敷きとして建造された。この為、計画の立案は日本より遅かったが、速やかに計画を進めることが出来たのは幸いだった。この探査機は日本の「あかつき」とは異なり、主に大気の分光を行い、大気成分を詳細に調べる。軌道もこれに適した極軌道を取り、「あかつき」の赤道西向き軌道とは大きく異なる。この2つの探査機は互いに相補的な観測、言うなれば Venus Express は化学的観測、「あかつき」は物理的観測を行い、相互のデータを参照することにより、より多くの成果が生み出されるものである。

我が国初の金星探査機「あかつき」は2010年5月21日早朝、種子島から打ち上げられて金星を目指した。探査機は同年12月7日に金星に最接近する軌道を取り、近金点の前後で主推進器に点火して逆噴射を行う事により金星を回る軌道に投入されるはずだったが、点火後152秒前後に起きた軌道制御エンジン (OME) のトラブルにより探査機姿勢が乱れ、同158秒に自律制御でエンジンをシャットダウンし金星周回軌道への投入は断念された。現在「あかつき」は数年後に再び金星と会合する軌道にあり、最終的に軌道に投入される機会を待っている。

今回の金星軌道投入オペレーションでは12月5日には軌道投入に必要な命令を全て「あかつき」に送って、タイマーによる制御に移行した。12月6日にはこの命令に従って軌道制御エンジン噴射姿勢に遷移している。12月7日8時49分にエンジンの噴射が開始されたが103秒後、「あかつき」は地球から見て金星の裏側に入ってしまったために通信が途絶える。計画では9時1分0秒まで噴射が継続するはずであったが、「あかつき」に記録されたデータを再生してみると8時51分38秒に「あかつき」自身の判断で噴射を停止した事が解った。図には示していないが、その数秒前に何らかの大きな力が「あかつき」の姿勢を乱した事がその引き金となっている。「あかつき」が金星の陰から出てきた9時12分すぎ(地球では3分強の電波伝播遅延がある)には「あかつき」との通信を再開する予定だったが実際に「あかつき」からの電波を地球でとらえることが出来たのは10時26分前後であった。

このオペレーションで、計画の約2割の減速しか達成できなかったため、「あかつき」は金星を周回する軌道に入ることができず、太陽を周回する軌道に入った。現在の「あかつき」の軌道は公転周期約203日である。金星の公転周期は約225日であるため、「あかつき」は約6年後に再び金星と会合する可能性がある。その日に備えて、各搭載機器について、長期にわたる運用で問題になると考えられる課題の整理をし始めることとした。

「あかつき」から送られてくるテレメトリデータをもとに「あかつき」の現在の状態について調べた結果、すべてのサブシステムが正常値を示している。また姿勢系の制御モードも正常値に戻って姿勢も安定し、高利得アンテナを地球に向けて、正常な運用を続けている。また、地上局との通信も正常である。さらに観測機器の健全性を確かめるために、12月9日(金星周回軌道投入制御を実施した日の翌々日)には約60万kmの距離から金星の撮像を行った。

幸いな事に私たちはまだ「あかつき」をコントロールしている。ミッションは失われたわけではない。原因究明に全力を尽くし、続くミッションで同じ過ちを繰り返さない、そして、いまの「あかつき」を無事に飛行させ可能な限り多くの科学的・工学的成果を上げ、「あかつき」の弟、妹達を宇宙に旅立たせ、人類の知識の獲得に向けて邁進すること。これが我々宇宙科学に携わる者の使命だとプロジェクト一同考えている。金星探査の意義は今も決して失われてはいない。

キーワード: あかつき, 金星, 探査

Keywords: AKATSUKI, Venus, Exploration

# Japan Geoscience Union Meeting 2011

(May 22-27 2011 at Makuhari, Chiba, Japan)

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U003-02

会場:304

時間:5月27日 08:45-09:00

## あかつきの新たな科学的挑戦 Renewed science plan of Akatsuki

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金星周回軌道投入に失敗した「あかつき」は今、太陽の周りを回る軌道上にあり、6年後に再び金星に到達するチャンスを狙っている。この新たな可能性に望みを託し、「あかつき」は動作を最小限にして機器の劣化を抑え、再び始まった長い旅路を乗り切ろうとしている。「あかつき」が目指す科学そのものに関して近年大きな進展はなく、観測計画に大きな変更はありえないが、欧州の Venus Express がもたらした新たなデータや理論的研究の進展によって、より深く緻密な研究をなしうる状況が作られつつある。本講演では近年の金星大気研究の到達点とそこから導かれる「あかつき」の課題について論じるとともに、「あかつき」がクルージング中に実施する予定の科学観測についても紹介する。

キーワード: 金星, あかつき

Keywords: Venus, Akatsuki

U003-03

会場:304

時間:5月27日 09:00-09:15

## 中間赤外カメラ (LIR) の金星撮像 Venusian cloud top temperature obtained by LIR onboard Akatsuki

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Tetsuya Fukuhara<sup>1\*</sup>, Makoto Taguchi<sup>2</sup>, Masahiko Futaguchi<sup>2</sup>, Takeshi Imamura<sup>3</sup>, Masato Nakamura<sup>3</sup>, Munetaka Ueno<sup>3</sup>, Makoto Suzuki<sup>3</sup>, Naomoto Iwagami<sup>4</sup>, Mitsuteru Sato<sup>1</sup>, George HASHIMOTO<sup>5</sup>

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Venus orbit insertion of Akatsuki which has been launched on 21 May 2010 has been postponed until in six years. However, the Longwave Infrared Camera (LIR), which mounts an uncooled micro-bolometer array (UMBA), has succeeded in taking images of the Earth and the deep space immediately after the launch and during the cruise to Venus. Furthermore, It has succeeded in taking the image of Venus from six hundred thousand kilometers distance. LIR detects thermal emission from the top of the sulfur dioxide cloud of Venus in a wavelength region 8-12  $\mu\text{m}$  to map the cloud-top temperature which is typically as low as 230 K. The image of Venus which has been calibrated and verified using the earth or deep space images showed the obvious cold polar collars and zonal wave structures. These features have started to be compared with results of the ground observation. They also will be compared with images of the Ultraviolet Imager (UVI) onboard Akatsuki, or the Venus Monitoring Camera (VMC) onboard the Venus Express.

キーワード: 金星

Keywords: Venus

# Japan Geoscience Union Meeting 2011

(May 22-27 2011 at Makuhari, Chiba, Japan)

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U003-04

会場:304

時間:5月27日 09:15-09:30

## あかつき UVI による金星大気観測 Venus atmosphere observed by Akatsuki/UVI

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Shigeto Watanabe<sup>1\*</sup>, Atsushi Yamazaki<sup>2</sup>, Manabu Yamada<sup>2</sup>, Naoki Take<sup>1</sup>, Ko Hamamoto<sup>1</sup>, Yukihiro Takahashi<sup>1</sup>

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金星探査機あかつきに搭載された紫外イメージャ (UVI) は 365nm と 283nm の 2 波長で金星大気観測を実施した。365nm は未だ同定されていない物質による吸収であり, 283nm は SO<sub>2</sub> による吸収である。2 波長で撮像した画像から金星雲の分布, リム観測から金星雲の高度分布を推定した。本発表では初期解析結果を報告する。

キーワード: 金星大気, 紫外光画像, SO<sub>2</sub> 吸収, あかつき探査機

Keywords: Venus atmosphere, ultraviolet image, absorption by SO<sub>2</sub>, Akatsuki spacecraft

U003-05

会場:304

時間:5月27日 09:30-09:45

## あかつき搭載 1 $\mu$ mカメラ IR1 : 現状と展望 1 micro-m camera IR1 on board AKATSUKI: Current status and future view

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Venus crescent taken 2 days after the 1st fly-by  
at 600 thousand km away

The results of the imaging tests carried out during the cruising phase between the Earth and the Venus and after the fly-by by the IR1 camera on AKATSUKI are described. The troubles and/or problems found by those tests and the views for future operations are also discussed.

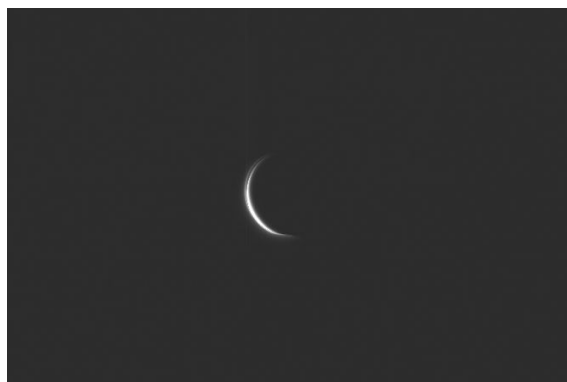
The imaging tests taken are the followings.

- (1) Earth imaging 10 hours after the launch on 21 May to check the normal performance of the camera
- (2) Star imaging to check the optical alignment between AKATSUKI and the IR1 camera. The focus and the absolute sensitivity are also checked
- (3) Venus imaging 2 days after the 1st fly-by at 600 thousand km away to check the normal operation of the camera for the right target.

The troubles and/or problems found so far are the followings.

- (1) Black and white noise
- (2) Missing line (?)
- (3) Blooming-like structure
- (4) Sensitivity decrease (?)
- (5) Attitude stability

Although there are some unsolved problems noted above, the camera seems to be working normally as seen in the image taken after the fly-by.



キーワード: 金星, あかつき, 赤外, 撮像  
Keywords: Venus, AKATSUKI, infrared, imaging

U003-06

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時間:5月27日 09:45-10:00

## 探査機と地上望遠鏡による金星雷放電及び大気光観測

### Lightning and airglow observation in Venus with spacecraft and ground-based telescope

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Lightning is potentially a good proxy of atmospheric circulation in planets, including Venus and Jupiter, where very limited in-situ measurements can be made. Recently it is reported that the magnetometer on board Venus Express detected whistler mode waves whose source could be lightning discharge occurring well below the spacecraft. On the other hand, night airglow is expected to provide an essential information on the atmospheric circulation in the upper atmosphere of Venus. But the number of consecutive images of airglow is limited and even the detail variations of most enhanced location is still unknown.

In order to identify the discharge phenomena in the atmosphere of Venus without ambiguity and to know the daily variation of airglow distribution in night-side disk, we sent a optical sensor to Venus, the lightning and airglow camera, LAC onboard Akatsuki. Though, unfortunately, its arrival will be delayed by several years, before the spacecraft measurement we plan to make a ground-based observation using 1.6 m telescope installed at Nayoro, Hokkaido, by Hokkaido University. In this presentation the strategies for investigation both for lightning and airglow, both with ground-based telescope and spacecrafts.

キーワード: 金星, 雷放電, 大気光, 探査機, 望遠鏡

Keywords: Venus, lightning, airglow, spacecraft, telescope

U003-07

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## 金星探査機あかつきのための雲追跡システムと VEx/VMC データを使ったテスト Cloud tracking system for Akatsuki data and its tests using VEx/VMC images

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A zonal retrograde super-rotation of the entire atmosphere is the most curious atmospheric phenomenon. The wind velocity increases with height and reaches ~100 m/s near the cloud top. This is very mysterious because the solid planet rotates very slowly with a period of 243 Earth days corresponding to an equatorial rotation speed of 1.6 m/s. Various theories have been suggested so far to explain mechanisms which maintain the super-rotation. However, none of them has been able to fully explain the mechanisms because of insufficient observational information on the meridional circulations crucial for the zonal momentum transport. Wind speed distributions obtained by previous missions were based on cloud tracking on only dayside. Therefore, it has been uncertain whether zonal mean of them approximates the actual meridional circulation. Akatsuki, Venus Climate Orbiter (VCO) has the potential to solve this problem. Cameras onboard Akatsuki image cloud features of both dayside and nightside at more than one vertical levels. IR1 visualizes the distribution of clouds illuminated by sunlight at ~50 km above the surface. IR2 can visualize the global cloud height distributions at 50-55 km by utilizing the 2.02  $\mu\text{m}$  filter on dayside and the 1.735  $\mu\text{m}$  filter on nightside. In addition, LIR is able to take images of both dayside and nightside with equal quality and accuracy. Tracking of cloud features in images taken by these instruments enable us to obtain three dimensional global wind distributions, which lead to understanding of the meridional circulation and the super-rotation.

We prepare images in longitude-latitude coordinate by coordinate transformation. This is not straightforward because Venus in each image is not a circle but an ellipse when the space-craft is near Venus. We fit an ellipse to the Venusian limb on images using many parameters of the orbit and the attitude to achieve this transformation. We track cloud features found on the images in longitude-latitude coordinate to obtain the distributions of horizontal wind. In our presentation, we explain a pipeline process for getting a global wind distribution from an image and present results of some kinds of tests for the pipeline process using images obtained by Venus Monitoring Camera on board Venus Express.

キーワード: 金星, スーパーローテーション, あかつき, データ処理, 雲追跡

Keywords: Venus, super-rotation, Akatsuki, data processing, cloud tracking



U003-08

会場:304

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## 地上赤外分光観測から迫る金星昼面大気波動現象 Venus' atmospheric waves indicated by ground-based dayside infrared spectroscopic observation

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In the Venus' atmosphere, waves of various scales transport angular momentum and play an important role in the atmosphere. For example, the mechanism of the super rotation may be explained by the equatorial Kelvin wave [Yamamoto & Tanaka, 1997] or by the thermal tides [Takagi & Matsuda, 2007].

Most of studies have focused on the ultraviolet region to observe atmospheric waves at 70 km [Del Genio et al., 1982, 1990]. Several studies have focused on the infrared region and analyzed thermal emission from the nightside to observe atmospheric waves at 50 km [Belton et al., 1991]. In contrast, we observed the dayside to derive the clouds structure at 60 - 65 km by quantifying CO<sub>2</sub> absorption. We performed infrared spectroscopic measurements at the NASA Infrared Telescope Facility (IRTF) with CSHELL spectrometer in May and November 2007, June 2009 and August 2010.

We derive the clouds structure from CO<sub>2</sub> absorption equivalent width above the clouds. We can compare data of different terms because equivalent width is unaffected by observation conditions. From the clouds structure, we estimated that the atmosphere rotates at 60 km with a period of 5 days in May 2007 and 5.5 days in August 2010. These periods are different from a period of 4 days at 70 km. It is found that the representative height in August 2010 was 2 km lower than that in May 2007. The changes suggest that the Venus' clouds descend gradually year by year. We derive the clouds structure by rigid body rotations like the past studies. We also derive that by differential rotation, made with wind speeds taken from Venus Express data.

キーワード: 金星, 惑星大気, 気象学, 波動現象, スーパーローテーション  
Keywords: Venus, Planetary atmosphere, atmospheric waves, super rotation

U003-09

会場:304

時間:5月27日 10:45-11:00

## 金星雲頂の惑星規模波動と背景風との関係

### Relationship between planetary-scale waves and the background wind field at the cloud top of Venus

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本研究では、Venus Express 搭載の Venus Monitoring Camera (VMC) により紫外波長 (365 nm) で撮像された金星雲画像データ (2006 年 4 月 ~ 2010 年 1 月) から雲頂高度の風速決定を行い、スーパーローテーションの時間変動と金星大気中を伝播する惑星スケールの波動を調べた。風速は画像相関を用いて雲の移動量を推定する手法により決定した。VMC は南半球の赤道域から中高緯度帯を広くかつ高頻度で撮像しており、これらの緯度帯の風速やその変動を調べることに適している。得られた風速場の解析から、赤道域において東西風速が 100 日程度で約  $20 \text{ m s}^{-1}$  加速し、また同様に 100 日程度で減速するという準周期的時間変動を示すことが分かった。そこで全観測期間のうち、赤道での東西風速が  $100 \text{ m s}^{-1}$  を超える速い時期 (F 期) と、 $90 \text{ m s}^{-1}$  を下回る遅い時期 (S 期) を選びフーリエ解析を行ったところ、それぞれの時期で周期や緯度構造の異なる数日周期の風速変動と雲の明るさの変動が見られた。

F 期では東西風速、南北風速、そして雲の明るさに約 5 日周期の規則的な変動が、低緯度帯から中・高緯度帯まで一体となって見られた。5 日周期の位相速度はこの時期の背景東西風速 ( $100 \text{ m s}^{-1}$ ) より遅い。それぞれの変動の位相関係から、この 5 日周期変動が作る風速場は明確な渦構造を示し、この渦によって雲の明るさが変化していることが示唆された。渦構造を持ち、スーパーローテーションに比べ位相速度が遅い特徴は、この変動がロスビー波によるものであることを示唆している。このような 5 日周期の風速変動が見られることは、Pioneer Venus 探査機での観測で見られた風速変動や雲の明るさ変動 (Del Genio and Rossow, 1990; Rossow et al., 1990) と調和的な結果である。一方 S 期では、低緯度帯で背景東西風速 ( $90 \text{ m s}^{-1}$ ) よりも位相速度が速い、約 4 日周期の変動が東西風速と雲の明るさ変動に見られた。この変動の位相速度、またその位相関係は Del Genio and Rossow, 1990 において赤道ケルビン波と予想される変動と整合的なものであった。

Yamamoto and Takahashi, 1997 による金星スーパーローテーションを再現する数値計算結果から、赤道ケルビン波は下層大気から運動量を汲み上げ雲層高度の東西風速を加速しうる一方、金星大気中、傾圧不安定で生じるロスビー波は励起される緯度帯から高緯度へ運動量を拡散し東西風速を減速させる働きを持ちうるということが知られている。これらの波は雲頂高度におけるスーパーローテーションの加減速に影響を持つことが予想される。本発表では観測から求められた 4 日、そして 5 日周期の風速変動パラメータを基に、赤道ケルビン波・ロスビー波が与える運動量輸送について定量的に議論する。

キーワード: 金星, スーパーローテーション, Venus Express, Venus Monitoring Camera, 大気波動

Keywords: Venus, super-rotation, Venus Express, Venus Monitoring Camera, atmospheric waves

U003-10

会場:304

時間:5月27日 11:00-11:15

## 金星中間圏・熱圏風速場への大気重力波の影響

## Effects of gravity waves on the wind velocity in the Venusian mesosphere and thermosphere

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金星中間圏・熱圏(高度 100km 以上) 大気大循環の理解にとって、雲層起源の大気重力波による運動量輸送効果は不可欠な要素と考えられている (e.g., Bougher et al. [2006]). Zhang et al. [1996] は重力波パラメタリゼーションを用いたシミュレーションを行い、高度約 140km 以上において、重力波運動量輸送効果により約 15-30m/s の西向き的高速東西風が駆動されることを示唆した。しかし、先行研究で用いられているパラメタリゼーションは、重力波同士の相互作用や分子粘性による重力波減衰などの物理過程を考慮できていない。本研究では、Medvedev et al. [2000] により開発された重力波パラメタリゼーション(以下 Medvedev スキーム)を用い、重力波の波動-波動相互作用や分子粘性による重力波減衰などの物理過程を考慮した数値実験から重力波が金星中間圏・熱圏風速場に与える影響を見積もった。

Medvedev スキームのパラメータはモデル下端における重力波の「典型的水平波長」と「鉛直波長スペクトル」である。本研究では、近年の Venus Express (VEX) による重力波観測結果 [Peralta et al. 2008] から、水平波長を 136 km、鉛直波長スペクトルを、波の内部位相速度 15m/s(鉛直波長に換算して 2 km) でピークをもつ分布とした。数値実験はモデルの下端風速 (1) 0 m/s, (2) 80 m/s の 2 ケースで計算をおこなった。(1) では、従来の重力波のパラメタリゼーション手法の一つであるレイリー摩擦を用いた数値実験結果との比較を行った。一方(2)では、重力波が熱圏高速東西風形成に与える影響を見積もった。

下端条件(1)による計算の結果、熱圏において最大風速約 290m/s の昼夜間対流が形成された。この結果は、レイリー摩擦を用いた結果に比べて最大風速が約 50 m/s 大きい。これは、本研究では分子拡散による重力波減衰により高度約 140 km 以上における wave drag 効果が小さくなるためと解釈できる。また、Medvedev スキームはレイリー摩擦に比べ、低高度における wave drag 効果が強く、高度約 120 km 付近に風速の減速層が生じた。条件(2)の計算の結果、重力波による運動量輸送により約 70 m/s の高速東西風が高度約 120 km 以上で形成された。高速東西風は高度約 100 km 以上で高度とともに強度が増加した。この高速東西風強度の鉛直勾配は過去の CO による熱圏風速観測の結果と整合的である。また本シミュレーションの結果、この高速東西風が O<sub>2</sub>-1.27 $\mu$ m 大気光の発光領域を 02:30 LT 付近までシフトさせることを示した。

キーワード: 金星, 中間圏, 熱圏, 重力波

Keywords: Venus, mesosphere, thermosphere, gravity wave

U003-11

会場:304

時間:5月27日 11:15-11:30

## 放射輸送を考慮したモデルで再現された金星下層大気の大循環

### General circulation of the Venus lower atmosphere simulated by a GCM with a new radiative transfer model

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The atmospheric superrotation is one of the most remarkable features of the Venus atmosphere. In recent years, several numerical experiments with general circulation models (GCMs) have been performed to investigate the generation mechanism of the Venus atmospheric superrotation (Yamamoto and Takahashi 2003; Takagi and Matsuda, 2007; Lee et al., 2007; Hollingsworth et al., 2007; Kido and Wakata, 2008). The results suggest that both the Gierasch mechanism (Gierasch, 1975; Matsuda, 1980) and the thermal tide mechanism (Fels and Lindzen, 1974; Plumb, 1975) may explain the atmospheric superrotation in dynamically consistent ways. However, in these studies, the radiative process is extremely simplified by Newtonian cooling. Since the Venus atmosphere is optically very thick in the infrared region, this simplification cannot be justified at all, especially in the Venus lower atmosphere. It has been also pointed out by Hollingsworth et al. (2007) that only extremely weak atmospheric superrotation is generated when realistic solar heating is adopted. In order to understand the real generation mechanism of the atmospheric superrotation, the radiative processes should be improved. Recently, Lebonnois et al. (2010) carried out numerical simulations by using a GCM combined with a radiative transfer model based on Eymet et al. (2009). Their results show that the atmospheric superrotation with about 70 m/s is obtained above about 40 km, while the mean zonal wind remains very weak below.

In the present study, a radiative transfer model applicable to the Venus atmosphere (Takagi et al., 2010) is incorporated into a three-dimensional general circulation model to investigate the generation mechanism of the atmospheric superrotation by focusing on the mean meridional circulation. A dynamical core of the GCM is the same as used by Takagi and Matsuda (2007). The model atmosphere extends from the ground to about 100 km, which is divided into 50 layers at a regular spacing of 2 km. The horizontal resolution is T10 (triangular truncation at wave number 10). Temperature dependence of the specific heat at constant pressure is taken into account (Staley, 1970). Horizontal eddy viscosity is represented by the second-order hyperviscosity with relaxation time of 1 Earth day for the maximum wave number component. Rayleigh friction is not used in the present model except at the lowest level, where the surface friction acts on horizontal winds. In addition, the dry convective adjustment scheme is used to restore the temperature lapse rate to the neutral one when an atmospheric layer becomes statically unstable. The solar heating is zonally averaged and prescribed in the present study. The vertical profile is based on the works of Tomasko et al. (1980) and Crisp (1986).

After numerical integration for 100 Earth years, it is found that the mean zonal flow with remarkable jets is generated in 30-70 km. Meridional temperature difference is only few K degrees near the cloud top level. This is consistent with the weak zonal flows obtained in this simulation in view of thermal wind balance. A weak local maximum (7-8 m/s) is observed in the equatorial region at 70 km. Weaker midlatitude jets are also found at about 40 km. Below 30 km, the mean zonal flow remains very weak. The temperature contrast between the equator and poles is less than 1 K at these levels. The mean meridional circulation splits into two cells which extend from 20 to 50 km and from 50 to 80 km. The maximum velocity of the mean meridional flow is about 12 m/s at about 67 km near 60 N/S. The mean meridional circulation simulated in the model splits into three parts. The upper two cells seem persistent. The present result implies that the atmospheric superrotation may be strongly affected by the mean meridional circulation in the lower atmosphere, and the Gierasch mechanism may not work in the Venus atmosphere.

キーワード: 金星, スーパーローテーション, 子午面循環, 大気放射

Keywords: Venus, superrotation, meridional circulation, radiative transfer

U003-12

会場:304

時間:5月27日 11:30-11:45

## 金星大気の対流調節および対流混合のマイクロスケールシミュレーション Microscale simulations of convective adjustment and mixing in the Venus atmosphere

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<sup>1</sup>RIAM, Kyushu Univ.

Heat, momentum and material transport processes caused by convective adjustment and mixing are important in subgrid-scale parameterization of the Venus general circulation model (VGCM). Recently, in order to investigate the thermal and material transport processes near the surface, Yamamoto (2011) conducted microscale atmospheric simulations near the Venusian surface by altering the astronomical and physical parameters in WRF (Weather Research and Forecasting model). When convective adjustment occurs, the heat and passive tracer are rapidly mixed into the upper stable layer with convective penetration. The convective adjustment and mixing produce high eddy diffusion coefficients of heat and passive tracer, which may explain the large eddy diffusion coefficients estimated in radiative-convective equilibrium models (Matsuda and Matsuno 1978; Takagi et al. 2010). In the case that values of surface heat flux  $Q_s$  is larger than a threshold, the convectively mixed layer with high eddy diffusion coefficients grows with time. In contrast, the mixed layer decays with time in the case of  $Q_s$  smaller than the threshold. The thermal structure near the surface is controlled not only by radiative processes with extremely long time scales (10,000 Earth days), but also by microscale dynamical processes with short time scales (a few hours). A mixed layer with high eddy diffusion coefficients may be maintained or grow with time in the regions where the surface heat flux is high (e.g., the volcanic hotspot and adjacent areas).

In the present study, I applied the abovementioned microscale atmospheric model of Yamamoto (2011) to dynamical processes in the unstable/neutral layer of the Venusian cloud (50-55 km), and examined the eddy mixing and its effective eddy diffusivity. Maximum magnitudes of eddy fluxes of momentum, heat and passive tracer become larger with increasing the vertical negative gradient of the initial potential temperature ( $\Gamma$ ) and the heat flux at the bottom of the lower cloud ( $Q_b$ ). In the unstable/neutral cloud layer, the eddy diffusion coefficients of  $10^3 \text{ m}^2 \text{ s}^{-1}$  are estimated for momentum, heat and passive tracer. In the cases that the vertical shear of the initial zonal wind is changed, although the flux magnitudes are somewhat different from those in the cases of the zero initial shear, the sensitivities to  $\Gamma$  and  $Q_b$  are qualitatively similar to those in the cases of the zero initial shear. Such microscale simulations are expected to contribute to physical interpretations of the balloon and radio science experiment data and improvements of the eddy diffusion coefficients in VGCM and chemical and aerosol transport models.

キーワード: 金星, 対流調節, 対流混合, マイクロスケール大気モデル, 渦拡散係数

Keywords: Venus, Convective adjustment, Convective mixing, Microscale atmospheric model, Eddy diffusion coefficient

U003-13

会場:304

時間:5月27日 11:45-12:00

## 金星 O<sub>2</sub> 夜間大気光にみられる大気波動の地上観測 Ground-based observations of atmospheric waves in Venus O<sub>2</sub> night airglow

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Venus 1.27-micron O<sub>2</sub> night airglow is the indicator of the general circulation at about 95 km in Venus. Recent observations reported that the airglow emission showed the temporal variations with a period of a few hours and days [e.g. Ohtsuki et al., 2008; Gerard et al., 2008]. The temporal variations are thought to be caused by the upward momentum transport and fluctuations by atmospheric waves. In recent years, the importance of planetary-scale waves on the general circulation of the Venus atmosphere has been recognized. Forbes and Konopliv [2007] suggested the propagation of planetary-scale waves originated in the cloud deck into the upper atmosphere. However, effects of planetary-scale waves on the Venus upper atmosphere has not been investigated yet. Now, GCM simulations considering the planetary-scale waves which are prominent at the cloud top (thermal tides, Kelvin wave and Rossby wave) is performing in order to understand effects of planetary-scale waves on the temporal night airglow variations and the general circulation in the Venus upper atmosphere. Our results show the Kelvin wave is the dominant wave in the planetary-scale waves. The Kelvin wave causes the shift the night airglow emission region between 00:00LT and 00:40LT and the large temporal intensity fluctuation of 0.7 to 1.0 MR (paper by Hoshino is in preparation).

In September 2010, we try to detect the atmospheric waves in the nightside upper atmosphere of Venus by 6-days monitoring the Venus 1.27-micron O<sub>2</sub> airglow and its rotational temperature. The cryogenic echelle spectrograph (CSHELL) of NASA's Infrared Telescope Facility is used for acquiring high-resolution spatially resolved spectra. Its resolution is high enough to show each emission line. The spatial resolution will achieve down to about 300km at the center of the Venus disk and be comparable with the planetary-scale waves (thermal tides, Kelvin wave and Rossby wave). These observations will provide us new information on the dynamics of the upper atmosphere.

In this presentation, we will report primary results of these observations.

U003-14

会場:304

時間:5月27日 12:00-12:15

## 新しい放射伝達モデルを用いた金星 AGCM によるスーパーローテーションの数値実験 Venus superrotation simulated by an AGCM with a new radiative transfer model

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A maintenance mechanism of the superrotation in the Venus atmosphere is investigated by using an atmospheric general circulation model (AGCM). We have constructed a new radiative transfer model for the Venus AGCM. This radiation model can treat absorption, scattering, and emission processes due to the gases and the atmospheric particles from short-wave to long-wave region. The surface temperature and temperature distribution close to observations can be reproduced in the radiative-convective equilibrium calculation; convection layer extends from the surface to about 40 km altitude. The role of various radiatively active gases is investigated by computing the radiative-convective equilibrium without each absorber. The results imply that the effect of each gas depends on treatments of line profile of gas absorption and the CO<sub>2</sub> continuum opacity.

The new radiation model has been incorporated into the CCSR/NIES/FRCGC AGCM. Zonal flow of about 50 m s<sup>-1</sup> is reproduced at the equatorial cloud top. Momentum transport associated with thermal tides play an important role in maintenance of the mean zonal flow in the cloud layer. The sensitivity to uncertainties in the distribution of the unknown UV absorber near the cloud top is examined. This test indicates that the superrotation in the middle atmosphere is affected by the distribution of the UV absorber. Although superrotational flow is maintained in the middle atmosphere, the zonal wind is much weaker than observations under the cloud layer. Although the mean meridional circulation contributes to the momentum balance of the superrotation in the middle atmosphere, it does not efficiently transport the angular momentum necessary to maintain the superrotation. It is suggested that the meridional circulation driven by this radiation model does not have sufficient strength to maintain the superrotation.

A simulation which includes momentum transport by small-scale gravity waves is performed to examine the maintenance mechanism of the superrotation below the cloud. Although greater energy flux of eastward gravity waves is required to assume, the superrotation in the lower atmosphere is maintained by critical level absorptions of gravity waves in this simulation.

キーワード: 金星, スーパーローテーション, 大気大循環モデル

Keywords: Venus, superrotation, AGCM

# Japan Geoscience Union Meeting 2011

(May 22-27 2011 at Makuhari, Chiba, Japan)

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U003-15

会場:304

時間:5月27日 12:15-12:30

## Latitudinal variation of UV reflectivity of Venus: VEX/VMC data analyses Latitudinal variation of UV reflectivity of Venus: VEX/VMC data analyses

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We examined a latitudinal variability of ultraviolet reflectivity of Venus using images obtained by the Venus Monitoring Camera (VMC) on board the Venus Express spacecraft. The Venus Express is orbiting around Venus, and the VMC observed a reflection of sunlight at 365 nm wavelength. To analyze the VMC images, we calculated a solar incidence angle and emission angle for each pixel of the image. Since the intensity of reflected light depends on the solar incidence angle and emission angle, we selected pixels which were observed in the same conditions. Our analysis indicated that the uv reflectivity increases with latitude on the Venus' southern hemisphere.

キーワード: Venus, atmosphere

Keywords: Venus, atmosphere



U003-16

会場:304

時間:5月27日 12:30-12:45

## Venus Express 電波掩蔽による金星の大気重力波の鉛直波数スペクトル Vertical wavenumber spectra of gravity waves in the Venus atmosphere from Venus Express radio occultation

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Hiroki Ando<sup>1\*</sup>, Takeshi Imamura<sup>2</sup>

<sup>1</sup> 東大・理, <sup>2</sup>ISAS/JAXA

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臼田局にて Venus Express からの電波を試験的に3回受信し、高度35kmから95kmまでの温度分布を計算した。その温度分布には鉛直波長の短い内部重力波によるものと思われる温度擾乱が含まれており、雲層の上と下それぞれの領域における鉛直波数スペクトルを得た。その結果、雲層より上の領域におけるスペクトルの傾きは高波数側ではおおよそ-3程度であり、そこでは内部重力波が飽和していると予想される。一方雲層より下の領域では、スペクトルの傾きは-3に至らずその強度も雲層の上におけるそれより小さい。これは雲層の下においては内部重力波が飽和していないことを示唆している。

キーワード: 電波掩蔽, Venus Express, 内部重力波, 鉛直波数スペクトル

Keywords: Radio occultation, Venus Express, Internal gravity wave, Vertical wavenumber spectra

U003-17

会場:304

時間:5月27日 14:15-14:30

## The Venus Express mission The Venus Express mission

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<sup>1</sup>ESA/ESTEC

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The ESA mission Venus Express was launched from Baikonur, Kazakhstan, on 9 November 2005. After a 5 months cruise phase, the spacecraft was inserted in a Venus orbit on 11 April 2006. The main objective of the mission is to carry out a detailed study of the atmosphere and the plasma environment and a number of properties of the surface of Venus, both on a global level and on a small scale level. The nominal duration of the mission was two Venus sidereal days (486 earth days) but the mission has been extending three times and is now funded until end of 2014, enabling data to be collected during a significant part of a full solar cycle.

The orbit is a highly elliptical polar orbit with 24 hours period and a pericentre located close to the North Pole. It is optimised for remote observations of the southern hemisphere at a global scale from high altitude, and for detailed studies of the northern hemisphere from low altitude, both at varying solar aspect angles. It also allows for in-situ plasma measurements covering a large range of distances from the planet. The payload is dedicated to studies of the physics and chemistry of the atmosphere and the clouds and the related processes. The interaction of the upper atmosphere with the solar wind will be investigated by dedicated instruments. With a time from the mission approval to the launch of just above three years this mission by far is the fastest scientific mission undertaken by ESA until now.

This talk will describe the main features of the mission and summarise the most important results from the different investigations as an introduction to the subsequent talks on the individual investigations.

キーワード: Venus, planetary atmosphere, planetary mission, spacecraft

Keywords: Venus, planetary atmosphere, planetary mission, spacecraft

# Japan Geoscience Union Meeting 2011

(May 22-27 2011 at Makuhari, Chiba, Japan)

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U003-18

会場:304

時間:5月27日 14:30-14:45

## Venus Express science operations and co-ordinated observation planning. Venus Express science operations and co-ordinated observation planning.

Colin Wilson<sup>1\*</sup>, Hakan Svedhem<sup>2</sup>, Dima Titov<sup>2</sup>, Raymond Hoofs<sup>2</sup>, Thomas Widemann<sup>3</sup>  
Colin Wilson<sup>1\*</sup>, Hakan Svedhem<sup>2</sup>, Dima Titov<sup>2</sup>, Raymond Hoofs<sup>2</sup>, Thomas Widemann<sup>3</sup>

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Venus Express has been in orbit around Venus since April 2006. Its orbit is highly elliptical, with altitude varying from 160-250 km at pericentre to 66,000 km at apocentre, and polar, with a pericentre near the North pole. The orbital period is 24 hours.

Science operations planning is undertaken to satisfy the many different goals and observation modes of the spacecraft - including nadir and limb imaging and spectroscopy, radio occultation, and solar and stellar occultation - as well as geometrical, thermal and other constraints.

In addition to science goals of the Venus Express science teams, the science operations planning also responds to requests for co-ordinated observations from ground-based or other spacecraft observations.

In this talk we will present an overview of the Venus Express Science operations planning process and constraints, and discuss opportunities for co-ordinated observations.

キーワード: Venus Express, Science operations

Keywords: Venus Express, Science operations

U003-19

会場:304

時間:5月27日 14:45-15:00

## An overview of SPICAV results on the atmosphere of Venus from Venus Express mission. An overview of SPICAV results on the atmosphere of Venus from Venus Express mission.

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SPICAV is a suite of three spectrometers in the UV and IR range flying on ESA Venus Express orbiter, dedicated to the study of the atmosphere of Venus : UV (110-320 nm), Vis-Nir (0.65-1.65 micron), and mid IR (2.3-4.4 micron), from ground level to the outermost hydrogen corona at more than 40,000 km.

The UV spectrometer is working in the stellar and solar occultation mode, and nadir or limb viewing, day and night. It has mapped on the night side the gamma and delta bands of NO produced by recombination of O and N atoms coming from the dayside thermosphere. They indicate a maximum at 115 km altitude and around 02:00 LT (influence of super-rotation), while the O<sub>2</sub> emission mapped simultaneously by Virtis peaking at 95 km altitude (~10 km below NO emission) is centered at midnight, a puzzle for general circulation models. Vertical profiles of CO<sub>2</sub>, temperature, SO<sub>2</sub>, clouds and aerosols are obtained with star occultations and ozone was detected for the first time. Haze extends up to 104 km, where a layer of SO<sub>2</sub> and SO is detected in solar occultation. Day side observations allows to monitor the distribution of SO<sub>2</sub> at cloud top.

The SPICAV VIS-IR sensor (0.7-1.7 micron, resolution 0.5-1.2 nm) employs a pioneering technology: acousto-optical tunable filter (AOTF). Day side observations indicate a variable latitude distribution of cloud top altitude (decreasing toward the pole) and water vapor mixing ratio. Night side observations of the thermal ground emission allows to retrieve low altitude H<sub>2</sub>O.

The mid IR (2.3-4.4 micron) spectrometer SOIR works in solar occultation. It achieves the highest spectral resolution  $R > 20,000$  ever flown in a planetary mission. Vertical profiles of CO, HDO, H<sub>2</sub>O, HCl, SO<sub>2</sub>, CO<sub>2</sub> isotopes and temperature are regularly retrieved, as well as aerosols.

キーワード: Venus, atmosphere, Venus Express, SO<sub>2</sub>, occultation

Keywords: Venus, atmosphere, Venus Express, SO<sub>2</sub>, occultation

U003-20

会場:304

時間:5月27日 15:00-15:15

## SPICAV-SOIR on board Venus Express: an instrument to probe the neutral atmosphere of Venus SPICAV-SOIR on board Venus Express: an instrument to probe the neutral atmosphere of Venus

Ann Carine Vandaele<sup>1\*</sup>, R. Drummond<sup>1</sup>, A. Mahieux<sup>1</sup>, S. Robert<sup>1</sup>, V. Wilquet<sup>1</sup>, J.-L. Bertaux<sup>2</sup>  
Ann Carine Vandaele<sup>1\*</sup>, R. Drummond<sup>1</sup>, A. Mahieux<sup>1</sup>, S. Robert<sup>1</sup>, V. Wilquet<sup>1</sup>, J.-L. Bertaux<sup>2</sup>

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The SOIR instrument performs solar occultation measurements in the IR region (2.2 - 4.3  $\mu\text{m}$ ) at a resolution of 0.12  $\text{cm}^{-1}$ , the highest on board Venus Express. It combines an echelle spectrometer and an AOTF (Acousto-Optical Tunable Filter) for the order selection.

The wavelength range probed by SOIR allows a detailed chemical inventory of the Venus atmosphere at the terminators in the upper mesosphere and lower thermosphere (80 to 180 km) with an emphasis on vertical distribution of gases, such as  $\text{CO}_2$ ,  $\text{H}_2\text{O}$ ,  $\text{HCl}$ ,  $\text{HF}$ ,  $\text{CO}$ , as well as their isotopologues, including  $\text{HDO}$ .

In particular, measurements of  $\text{CO}_2$  density and rotational temperature vertical profiles have been routinely performed allowing a better description of the mesosphere and lower thermosphere. This moreover improves the understanding of the processes ? chemical and dynamical ? that occur at the terminators.

We will present the instrument and describe its capabilities in terms of measurements possibilities and accuracy. We will illustrate it with retrieval examples of various gases and show the high variability of the Venus atmosphere.

キーワード: Venus, mesosphere, thermosphere, atmospheric composition, temperature profile

Keywords: Venus, mesosphere, thermosphere, atmospheric composition, temperature profile

U003-21

会場:304

時間:5月27日 15:15-15:30

## Results from VIRTIS on board Venus Express after five years in orbit Results from VIRTIS on board Venus Express after five years in orbit

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After five years since the orbit insertion, VIRTIS aboard the Venus Express spacecraft has addressed a significant amount of the planned scientific objectives and also other unexpected results, from the surface up to the upper atmosphere, in terms of mapping, composition, structure and dynamics.

The VIRTIS instrument consists of two channels: VIRTIS-M, an imaging spectrometer with moderate spectral resolution in the range from 0.25 to 5.2 microns and VIRTIS-H, a high spectral resolution spectrometer in the range from 2 to 5 microns coaligned with the field of view of VIRTIS-M. The resolution of VIRTIS-M is 2 nm from 0.25 to 1 microns, and 10 nm from 1 to 5.2 microns. The resolution of VIRTIS-H is about 2 nm.

The atmosphere above the clouds is regularly observed both on day and night sides, in solar reflection and thermal emission in nadir geometry. Limb observations provide O<sub>2</sub>, OH, NO, CO<sub>2</sub> and CO emissions, through nightglow and fluorescence observations. Spectroscopy of the 4-5 micron range gives access to the cloud structure in the 60-95 km altitude levels.

The deeper atmospheric windows, limited by CO<sub>2</sub> and H<sub>2</sub>O bands are accessible only in thermal emission on the night side. The sounded levels at 1.7 and 2.3 microns are limited respectively to 30-20 km altitude, while at shorter wavelengths (1.18, 1.10, 1.01, 0.9 and 0.85 microns), the hot surface of Venus is seen through the scattering clouds.

Multiwavelength clouds tracking and thermal fields allow to study the wind fields and the global dynamics. Automatic wind tracking procedures permit to study in detail the polar vortex dynamics.

A brief description of the instrument and some selected results achieved by VIRTIS on Venus Express are reported in this talk.

キーワード: Venus, Spectroscopy, Atmosphere, Surface

Keywords: Venus, Spectroscopy, Atmosphere, Surface

# Japan Geoscience Union Meeting 2011

(May 22-27 2011 at Makuhari, Chiba, Japan)

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U003-22

会場:304

時間:5月27日 15:30-15:45

1600 Earth days around Venus imaging with Venus Monitoring Camera on Venus Express

1600 Earth days around Venus imaging with Venus Monitoring Camera on Venus Express

Wojciech Markiewicz<sup>1\*</sup>, Dimitri Titov<sup>4</sup>, Elena Petrova<sup>2</sup>, Nikolay Ignatiev<sup>2</sup>, Igor Khatuntsev<sup>2</sup>, Sanjay S. Limaye<sup>3</sup>, Oksana Shalygina<sup>1</sup>, Miguel Almeida<sup>4</sup>

Wojciech Markiewicz<sup>1\*</sup>, Dimitri Titov<sup>4</sup>, Elena Petrova<sup>2</sup>, Nikolay Ignatiev<sup>2</sup>, Igor Khatuntsev<sup>2</sup>, Sanjay S. Limaye<sup>3</sup>, Oksana Shalygina<sup>1</sup>, Miguel Almeida<sup>4</sup>

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The Venus Monitoring Camera (VMC) on Venus Express (VEX) spacecraft has been observing the upper cloud layer of Venus since April 2006. To date nearly two hundred thousand images have been acquired. VEX has a highly elliptical orbit allowing for global as well as close up views with resolution down to 200 meter per pixel. In this talk we will show examples of obtained images emphasizing spatial and temporal variability as well as some quantitative results that were derived from them.

キーワード: Venus, Atmospheres, Clouds

Keywords: Venus, Atmospheres, Clouds

U003-23

会場:304

時間:5月27日 15:45-16:00

## Cloud morphology and atmospheric dynamics from the Venus Express observations Cloud morphology and atmospheric dynamics from the Venus Express observations

Dima Titov<sup>1\*</sup>, Nikolay Ignatiev<sup>2</sup>, Arianna Piccialli<sup>1</sup>, Igor Khatuntsev<sup>2</sup>, Yeon Joo Lee<sup>3</sup>, Silvia Tellmann<sup>4</sup>, Sanjay Limaye<sup>5</sup>, Wojciech Markiewicz<sup>3</sup>, Giuseppe Piccioni<sup>6</sup>, Pierre Drossart<sup>7</sup>, Martin Paetzold<sup>4</sup>, Bernd Haesler<sup>8</sup>

Dima Titov<sup>1\*</sup>, Nikolay Ignatiev<sup>2</sup>, Arianna Piccialli<sup>1</sup>, Igor Khatuntsev<sup>2</sup>, Yeon Joo Lee<sup>3</sup>, Silvia Tellmann<sup>4</sup>, Sanjay Limaye<sup>5</sup>, Wojciech Markiewicz<sup>3</sup>, Giuseppe Piccioni<sup>6</sup>, Pierre Drossart<sup>7</sup>, Martin Paetzold<sup>4</sup>, Bernd Haesler<sup>8</sup>

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Since its orbit insertion in April 2006 the ESA Venus Express spacecraft has been performing a global survey of the Venus atmosphere. The powerful suite of remote sensing instruments that includes cameras, spectrometers and radio occultation experiment provided the largest and the longest set of atmospheric data collected so far. Coordinated use of various observation techniques enables investigation of different aspects of the Venus atmospheric physics. This paper focuses on the study of the cloud morphology and dynamics of the Venus atmosphere by synergistic use of the data from the Venus Monitoring Camera (VMC), Visible and Infrared Thermal Imaging Spectrometer (VIRTIS), and radio science (VeRa) experiments.

The VMC camera investigates the cloud top morphology by imaging at 365 nm - characteristic wavelength of the unknown UV absorber. Low latitudes (< 40 deg) are dominated by relatively dark clouds that have mottled and fragmented appearance clearly indicating the presence of turbulence in the sub-solar region. At ~50 degrees latitude this pattern gives a way to streaky clouds suggesting that horizontal flow prevails here. Poleward from ~60 degrees the planet is covered by almost featureless bright hood crossed by dark thin (~300 km) spiral or circular structures. The features of the global UV pattern are qualitatively explained by changes in the temperature structure and atmospheric stability with latitude. Simultaneous imaging in the UV and thermal-IR ranges showed that the cloud patterns on the day and night sides are correlated.

Joint analysis of the VIRTIS spectro-imaging data and the VeRa temperature sounding revealed remarkable changes in the vertical structure of the Venus cloud tops. The cloud top altitude changes from 74+/-1 km in the low and middle latitudes to about 64 km in the polar region marking vast polar depression. The descent of the cloud top correlates with drastic changes in aerosol scale height from 3.8+/-1.6 km to 1.7+/-2.4 km. The altitude of the sharp cloud top inside and poleward from the cold collar region coincide with position of strong temperature inversion, thus indicating its radiative origin.

Tracking of cloud features in the VMC UV images allowed characterization of the mean state of the atmospheric circulation at the cloud tops as well as its variability. An almost constant zonal wind speed of 90+/-10 m/s at low and middle latitudes gives way to the wind that quickly vanishes with latitude. The meridional poleward wind ranges from 0 m/s to about 20 m/s. Thermal wind field derived from the VIRTIS and VeRa temperature sounding using cyclostrophic approximation is in good agreement with the cloud tracked wind pattern indicating validity of the cyclostrophic balance.

キーワード: Venus Express, Clouds, Atmospheric dynamics

Keywords: Venus Express, Clouds, Atmospheric dynamics



U003-24

会場:304

時間:5月27日 16:00-16:15

## The Venus Neutral Atmosphere and Ionosphere as seen by the Radio Science Experiment VeRa on Venus Express The Venus Neutral Atmosphere and Ionosphere as seen by the Radio Science Experiment VeRa on Venus Express

Silvia Tellmann<sup>1\*</sup>, Bernd Haeusler<sup>2</sup>, Martin Paetzold<sup>1</sup>, Michael K. Bird<sup>3</sup>, Takeshi Imamura<sup>4</sup>, Hiroki Ando<sup>5</sup>, G. Leonard Tyler<sup>6</sup>, Tom Andert<sup>2</sup>, Stefan Remus<sup>7</sup>

Silvia Tellmann<sup>1\*</sup>, Bernd Haeusler<sup>2</sup>, Martin Paetzold<sup>1</sup>, Michael K. Bird<sup>3</sup>, Takeshi Imamura<sup>4</sup>, Hiroki Ando<sup>5</sup>, G. Leonard Tyler<sup>6</sup>, Tom Andert<sup>2</sup>, Stefan Remus<sup>7</sup>

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The Venus Express Radio Science Experiment VeRa performs routinely radio-sounding measurements of the Venus atmosphere and ionosphere as part of the ESA Venus Express (VEX) mission since 2006. An Ultrastable Oscillator (USO) provides a high quality onboard frequency reference source for the derivation of electron density profiles in the ionosphere and profiles of pressure, temperature and neutral number density of the neutral atmosphere. A total of more than 350 vertical scans of the Venus ionosphere and atmosphere were obtained in the first nine occultation seasons until the end of 2010.

The polar orbit of Venus Express provides the opportunity to study the troposphere and mesosphere between 40 ? 90 km at almost all planetocentric latitudes under varying illumination conditions.

The Venus mesosphere shows a high variability resulting from atmospheric waves and turbulence. Small scale temperature fluctuations originating from internal gravity waves with vertical wavelengths of only a few kilometers are detectable in the VeRa profiles. Standard wave theory can be used to analyze the observed wave structures with regard to their vertical and horizontal structure as a function of latitude and local time.

The ionosphere consists of a two layer structure between 115 km to 160 km. The main layer V2 is dominantly formed by solar EUV photoionisation, the lower V1 is formed by solar X-ray and dominant secondary ionization. The V1 and V2 peak altitudes and peak density show a Chapman-like behaviour through the range of solar zenith angle. The topside is highly variable and the ionopause is located at extremely low altitudes (250 ? 330 km) during the declining phase of the solar cycle (2007-2008) and at solar minimum (2009-2010).

キーワード: Venus Express, VeRa, Venus Atmosphere, Venus Ionosphere, Atmospheric Waves, Radio Science

Keywords: Venus Express, VeRa, Venus Atmosphere, Venus Ionosphere, Atmospheric Waves, Radio Science

# Japan Geoscience Union Meeting 2011

(May 22-27 2011 at Makuhari, Chiba, Japan)

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U003-25

会場:304

時間:5月27日 16:30-16:45

## Five Years of Venus Express Magnetic Field Observations Five Years of Venus Express Magnetic Field Observations

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Since the Venus Express insertion into a highly elliptical polar orbit with a period of 24 h around the planet Venus, the magnetometer has operated continuously for about 5 years and obtained a wealth of data in the solar minimum at rather low altitude, which was not reached by earlier missions. In this paper, we review the magnetic field observations by Venus Express emphasizing on the solar wind interaction with Venus.

# Japan Geoscience Union Meeting 2011

(May 22-27 2011 at Makuhari, Chiba, Japan)

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U003-26

会場:304

時間:5月27日 16:45-17:00

## Review of results from the plasma package ASPERA-4 onboard Venus Express Review of results from the plasma package ASPERA-4 onboard Venus Express

Stas Barabash<sup>1\*</sup>, ASPERA-4 team<sup>1</sup>

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The plasma package ASPERA-4 (Analyzer of Space Plasmas and Energetic Neutral Atoms) is operational since the Venus orbit insertion in April 2006 and provides measurements of ions, electrons, and energetic neutral atoms in the range from a few eV to few tens keV. We provide basic introduction into the instrument design and review the main results of the experiment mainly in the field of electrodynamics of the ion population including the ion escape measurements.

キーワード: Venus Express, ASPERA-4, ion escape

Keywords: Venus Express, ASPERA-4, ion escape

U003-27

会場:304

時間:5月27日 17:00-17:15

## Ground-based observations of the mesosphere and lower thermosphere : Coordinated campaigns with Venus Express Ground-based observations of the mesosphere and lower thermosphere : Coordinated campaigns with Venus Express

Thomas Widemann<sup>1\*</sup>, Yukihiro Takahashi<sup>2</sup>, Shoko Ohtsuki<sup>3</sup>, Manuela Sornig<sup>4</sup>, Brad Sandor<sup>5</sup>, Eliot Young<sup>6</sup>, Constantine Tsang<sup>6</sup>, Tom Slanger<sup>7</sup>, Sanjay Limaye<sup>8</sup>  
Thomas Widemann<sup>1\*</sup>, Yukihiro Takahashi<sup>2</sup>, Shoko Ohtsuki<sup>3</sup>, Manuela Sornig<sup>4</sup>, Brad Sandor<sup>5</sup>, Eliot Young<sup>6</sup>, Constantine Tsang<sup>6</sup>, Tom Slanger<sup>7</sup>, Sanjay Limaye<sup>8</sup>

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Coordinated measurements with ground-based observations allow to (i) perform measurements not feasible by an orbiting spacecraft like Venus-Express or Akatsuki, (ii) obtain cross-validation and record different diagnostics of similar phenomena, (iii) obtain simultaneous measurements sampling a large range of altitudes and (iv) improve the temporal baseline on time-varying phenomena. The 2010 coordinated campaign was supported by several international teams from the ground : Ohtsuki et al. (IRTF/CSHELL, 1.27 um), Iwagami et al. (IRTF/CSHELL, 1.7-2.3 um), Young et al. (IRTF/SpEX, 2.26-2.52 um), Sornig et al. (Kitt Peak/THIS, ~10 um), Livengood et al. (IRTF/HIPWAC, ~10 um), Bailey et al. (AAT/IRIS2, APO/ARCES, 1.1-2.4 um), Sandor et al. (JCMT, 330-360 GHz CO, T(z), winds), Limaye et al. (2-m HCT/ HFOOSC 2.3 um), Widemann et al. (CFHT/EsPADOnS, 0.35-1.05 um), Slanger et al. (10-m Keck I/HIRES, APO, nIR O2 and Vis. airglow), Jessup et al. (Hubble Space Telescope/STIS), Encrenaz et al. (IRTF/EXES, 7-8 um). We will discuss science results obtained through coordination with VEx, and mention future ground-based instrumentation esp. in Japanese facilities. We will briefly introduce new balloon experiments proposed to observe Venus continuously in the near-IR, as well as specific projects in coordination for the observation of next year's Venus solar transit.

キーワード: Planetary Science, Planetary Atmospheres, Venus Atmospheric Dynamics, High Resolution Spectroscopy, Visible, Infrared, Millimeter-wave, Venus Atmospheric Chemistry

Keywords: Planetary Science, Planetary Atmospheres, Venus Atmospheric Dynamics, High Resolution Spectroscopy, Visible, Infrared, Millimeter-wave, Venus Atmospheric Chemistry

U003-28

会場:304

時間:5月27日 17:15-17:30

## Characterization of Venus' atmospheric dynamics with ground-based Doppler velocimetry

## Characterization of Venus' atmospheric dynamics with ground-based Doppler velocimetry

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We present an analysis of observations of Venus made with the Ultraviolet and Visual Echelle Spectrograph (UVES) instrument at ESO's Very Large Telescope. This instrument allows to perform Doppler velocimetry based on high-resolution spectra of solar Fraunhofer lines, probing an altitude close to cloud tops, where opacity in the visible reaches unity. Observations were made at a central wavelength of 580 nm.

The UVES instrument achieves both high spectral resolving power ( $R \sim 100000$ ) and high spatial resolution. The narrow slit width combined with the large angular size of the planet allows a direct determination of the latitudinal (slit perpendicular to equator) and longitudinal (slit parallel to equator) variation of the zonal winds in both hemispheres.

The circulation up to the cloud tops is characterized by a monotonically increasing zonal wind, reaching its maximum close to 70 km altitude. Cloud-top winds were measured from Doppler velocimetry, a technique which has been used previously to measure the winds of Titan from the Doppler shifts of the solar reflected spectrum (Luz et al. 2005, Icarus 179, 497; Luz et al., 2006, JGR 111, E08S90), and in Venus from Doppler shifts of solar Fraunhofer and CO<sub>2</sub> absorption lines (Widemann et al. 2007, PSS 55, 1741; 2008, PSS 56, 1320; Gaulme et al. 2008, PSS 56, 1335; Gabsi et al., 2008, PSS 56, 1454). The spatially-resolved velocity changes on the source are measured using the optimal weight of intensity variations along the spectra to perform absolute accelerometry, with respect to a reference spectrum.

The objective of this work is to measure zonal winds on Venus, in the context of the study of atmospheric super-rotation, in coordination with the effort under way with the European Space Agency's Venus Express mission (VEx). Major objectives are (1) to measure the latitudinal profile of the zonal winds in the cloud layer, mesosphere and in the thermosphere and to search for wave motions through ground-based spectroscopic observations, using Doppler velocimetry techniques; (2) to complement in-situ observations made by space missions (which use cloud tracking techniques or infer winds indirectly); (3) to improve our understanding of the nature of the processes governing super-rotation, in particular waves and wave-mean flow interactions, as well as the latitudinal extent of the cyclostrophic balance approximation at cloud top level.

The narrow slit width combined with the large angular size of the planet allows to characterize latitudinal and longitudinal variations of the wind. Relative Doppler shifts allow to retrieve relative variations in the latitudinal profile of the zonal wind and combined results of three nights of observation were used to deduce the variability of the circulation.

This technique allowed to create an approximate wind map in the case of observations obtained with the spectroscopic slit parallel to the equator and to estimate the hemispheric asymmetry of the zonal wind. We shall discuss these results in the light of previous spacecraft observations, in particular Venus Express observations by the VIRTIS and VMC instruments (Sanchez-Lavega et al. 2008, GRL 35, L13204; Moissl et al., 2009, JGR 114, E0031).

キーワード: Venus, Atmosphere dynamics, Ground based, Spectroscopy

Keywords: Venus, Atmosphere dynamics, Ground based, Spectroscopy

U003-29

会場:304

時間:5月27日 17:30-17:45

## Direct Wind and Temperature Measurements in Venus Upper Atmosphere by Ground-based Infrared Heterodyne Spectroscopy

### Direct Wind and Temperature Measurements in Venus Upper Atmosphere by Ground-based Infrared Heterodyne Spectroscopy

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Dynamics of the Venusian atmospheric transition zone between the sub-solar to anti-solar (SS-AS) flow dominated region above 120km and the superrotation dominated region below 90km is not yet fully understood. Temperatures in the same region are not very well constrained. Measurements are essential to gain a global understanding of the atmosphere and to validate global circulation models. Space based observations can provide temperatures but do not offer direct wind measurements at these altitudes and ground-based results lack in time coverage and spatial resolution. Hence measurements on various time scales and on different locations with sufficient spatial resolution on the planet are important.

The Tunable Infrared Heterodyne Spectrometer (THIS) was developed at the University of Cologne, I. Physikalisches Institut. The ground-based receiver is transportable and can be used at various telescopes. Beside high spectral resolution ( $R > 10^7$ ) this technique also guarantees high spatial resolution on the planet. Temperatures and winds in planetary atmospheres can be retrieved from detection of narrow non-LTE emission lines of CO<sub>2</sub> at 10  $\mu$ m. These emission lines are induced by solar radiation. Non-LTE emission can only occur within a narrow pressure/altitude region around 110km. Resolving the molecular features allow to retrieve temperatures and wind velocities. Temperatures with a precision of 5K can be calculated from the Doppler-width of emission lines and wind velocities can be determined from Doppler-shifts of emission lines with an precision up to 10 m/s.

We observed Venus at several characteristic orbital positions using the McMath-Pierce-Solar Telescope on Kitt Peak, Arizona, USA. Observations at maximum elongation in May and November 2007 and June 2009 and observations close to inferior conjunction in March and in April 2009 have been accomplished. These observing geometries allow investigations of wind velocities of different combinations of the superrotational component and the SS-AS flow component including investigations of temporal behavior on different time scales.

キーワード: Venus, atmosphere, heterodyne spectroscopy, dynamics, temperatures

Keywords: Venus, atmosphere, heterodyne spectroscopy, dynamics, temperatures

U003-30

会場:304

時間:5月27日 17:45-18:00

## 地上サブミリ波望遠鏡を利用した金星中間圏のリモートセンシング Ground based submillimeter observations of thermal structure, CO distribution, and wind in the Venus mesosphere

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<sup>1</sup>NICT

Heterodyne spectroscopy at the millimeter/submillimeter domain is a powerful tool to study the thermal structure, chemical compositions, and dynamics in the Venus mesosphere. A large number of roto-vibrational transitions of many photochemically important species in the Venus atmosphere such as H<sub>2</sub>O, HDO, CO, SO and SO<sub>2</sub> are found in this spectral region. 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, the high spectral resolving power of the submillimeter heterodyne technique achieves the detection of the Doppler shift of molecular lines, which provides the capability of direct measurements of the mesospheric wind as line-of-sight velocity. The spatial resolution of such observations can be improved by using the interferometer facilities.

This paper describes about the recent works on the ground-based submillimeter observations of Venus atmosphere using the Combined Array for Research in Millimeter-wave Astronomy, CARMA, and the Sub-Millimeter Array, SMA, in 2009. Disk-resolved wind field maps are obtained from these observations, and the results are suggesting that an intense spatial variability of the wind pattern in the Venus mesosphere.

U003-31

会場:304

時間:5月27日 18:00-18:15

## VEXAG and the Exploration of Venus in the next decade - the Decadal Survey Recommendations VEXAG and the Exploration of Venus in the next decade - the Decadal Survey Recommendations

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Venus remains an important exploration target as it provides insight into not only the future climate of Earth, but also for the conditions on terrestrial planets around other stars. At present ESA's Venus Express mission is providing valuable monitoring of the planet and yielding important discoveries about Venus and its atmosphere. JAXA's Akatsuki mission may go into orbit into Venus in 2015 and provide valuable data on the super rotating circulation of the Venus atmosphere. However, there are many other questions about Venus that will remain unanswered after these missions.

“Vision and Voyages for Planetary Science in the Decade 2013-2022” presents the results and recommendations of the Planetary Science Decadal Survey conducted by the US National Academies during the past two years upon a request from NASA. The recommendations of this survey serve as a guideline for NASA's planetary exploration and supporting activities. Among the tasks performed by the Steering Committee were - (1) A broad survey of the current state of knowledge of the solar system, (3) An inventory of the top-level science questions that should guide flight programs and supporting research programs, (4) Recommendations on the optimum balance among small, medium, and large missions and supporting activities (5) A discussion of strategic technology development needs and opportunities, and (6) A prioritized list of major flight investigations in the New Frontiers and larger classes recommended for initiation over the decade 2013-2022.

The Decadal Survey recommendations include a Venus Climate Mission as well as New Frontiers missions and Discovery Missions to Venus. The survey recognizes the value of international partnerships such as those between ESA and NASA. These guidelines are thus significant for prospects of future US missions to Venus, and also important for international collaborative efforts to explore Venus in the current. budgetary climates.

The current New Frontiers Opportunity (NASA) is undergoing evaluation of three concept studies, one of which includes a mission to Venus, and the Discovery Missions Opportunity is evaluating many proposals for missions to Venus. The outcome of these competitions should become known in the next few months and selection of Venus missions will accomplish some of the goals identified by the Decadal Survey and guide future exploration activities.

NASA's Venus Exploration Analysis Group (VEXAG) serves as a forum to identify scientific priorities and exploration strategies for Venus. It will hold a workshop during August 30 – 1 September in the Washington, D.C. metropolitan area to which all scientists interested in Venus exploration are welcome.

Keywords: Venus, exploration