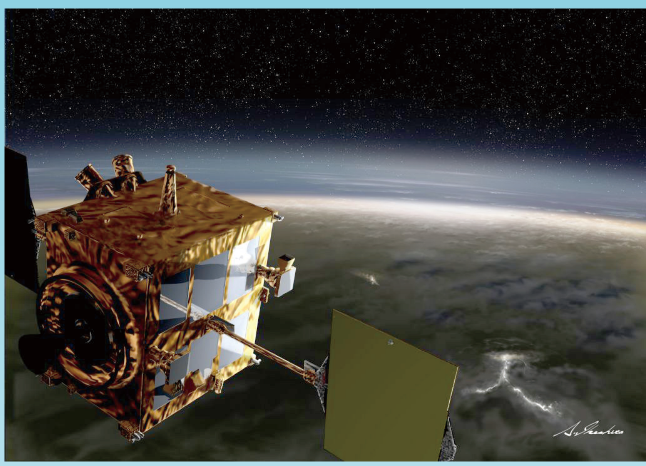
Earth, Planets and Space

Akatsuki at Venus: The First Year of Scientific Operation



A.Ikeshita

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PREFACE

Open Access

Special issue "Akatsuki at Venus: The First Year of Scientific Operation"

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The JAXA Venus explorer, which had been developed in Japan since 2001, was launched in 2010. The spacecraft was named "Akatsuki" after the Japanese word meaning dawn. Akatsuki was inserted into the Venus orbit and began its observation program in 2015, after 5 years wandering around the sun due to the failure of orbit insertion in 2010. Nakamura et al. (2016) described the orbit insertion as well as some initial results from the IR1, UVI, and LIR cameras.

In the twentieth century, well before the start of Akatsuki mission, the former Soviet Union and the USA had explored Venus and elucidated basic characteristics such as atmospheric temperature, pressure, composition, wind speed, surface topography and the plasma environment. However, the physical processes leading to the present state were still unclear. Among them, the Akatsuki mission focused on the study of atmospheric dynamics as a major goal of Venus exploration in the early twenty-first century. The Venusian atmosphere encircles the planet from east to west at all latitudes at a speed much faster than the solid planet. This wind system, called the super-rotation, is one of the biggest mysteries of planetary meteorology and should have a major effect on Venus' environment. Akatsuki is aimed at a comprehensive survey of the meteorological processes and a quantitative evaluation of the momentum transport sustaining the super-rotation. For this purpose, five cameras imaging the planet at different wavelengths are installed on the spacecraft to visualize atmospheric motions at different altitudes. Combined with a radio occultation instrument that probes the vertical structure, this suite of instruments can monitor the dynamics of the whole atmosphere in three dimensions.

The second attempt of the orbit insertion using attitude control thrusters in 2015 was perfectly successful. The first scientific discovery was made just 3 h after the arrival: the longwave infrared camera captured a planetary-scale atmospheric gravity wave that was stationary with respect to the surface topography. Starting with this discovery, many other scientific results have been accomplished.

This issue presents initial results of the Akatsuki mission. Iwagami et al. (2018) reported the initial results from Akatsuki/1-μm camera (IR1). More than 600 dayside and 150 night-side images have been obtained since the beginning of regular operation on April 2016. The night-side images are less numerous due to limitations related to the light scattered from the bright dayside. Satoh et al. (2017) reported the performance of Akatsuki/2-μm camera (IR2), and the results obtained with IR2 camera from December 2015 through November 2016. A total of 3091 images of Venus (1420 dayside images at 2.02 μm and 1671 night-side images at 1.735, 2.26, and 2.32 μm) were acquired in this period. Additionally, 159 images, including those of stars for calibration and dark images for the evaluation of dark levels, were obtained. Yamazaki et al. (2018) described the initial results from Akatsuki/Ultraviolet Imager (UVI) at 283 nm and 365 nm. The UV images provide the spatial distribution of SO_2 and the unknown absorber at the cloud tops and characterize the cloud-top morphologies and haze properties. Nominal sequential images with 2-h intervals are used to understand the dynamics of the Venusian atmosphere by deriving the wind velocity field from measured motion vectors at the cloud tops, as well as the mass transportation of UV absorbers. Fukuhara et al. (2017) described the calibration of the Akatsuki/longwave infrared camera (LIR). The brightness

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temperature derived from LIR images contained an unexpected bias related not to natural phenomena but to a thermal condition of the instrument. Deep-space images were acquired at different baffle temperatures, and a reference table for eliminating the bias from images was prepared. Takahashi et al. (2018) described the lightning search using the Akatsuki/lightning and airglow camera (LAC). LAC was designed to observe the light curve of possible flashes at a sufficiently high sampling rate to discriminate lightning from other sources and thereby perform a more definitive search for optical emissions. It was confirmed that the operational high voltage was achieved and that the triggering system functions correctly. LAC lightning search observations are planned to continue for several years.

Imamura et al. (2017) reported the initial results of the radio occultation experiments revealing the Venus atmosphere structure. The physical quantities retrieved include the pressure, the temperature, the H_2SO_4 vapor density, and the ionospheric electron density and their variations.

Archiving of the results of these observations is important. Ogohara et al. (2017) gave an overview of the data products. The level-2 images include calibrated radiances and geometry information. The level-3 data are global-grid data in a regular longitude–latitude coordinate system. The method of correcting the boresight pointing of each camera by fitting an ellipse to the observed Venusian limb is also described.

Three numerical modelling and theoretical works are included in this special issue. Horinouchi et al. (2018) studied the cloud-top wind field using images taken by the Ultraviolet Imager (UVI) at the wavelengths of 365 nm (unidentified absorber) and 283 nm (SO_2). These two wavelengths yield slightly different wind velocities, suggesting a difference in the altitude of the cloud features. The local-time dependence and an asymmetry with respect to the equator were observed. The geographic distribution of the zonal wind reported previously (Bertaux et al. 2016) was not seen in the data. McGouldrick (2017) studied the effects of variation in the coalescence efficiency of the Venus cloud particles on the structure of cloud using a one-dimensional cloud model. Specifically, they explored the consequence of allowing the coalescence efficiency of supercooled sulfuric acid in the upper clouds to tend to zero. The most significant result is the appearance of thick clouds of small particles near the transition between upper and middle clouds. Limaye et al. (2018) summarized the characteristics of Venus clouds seen in the multi-wavelength images taken by Akatsuki. The images reveal new and puzzling morphology of the complex cloud cover. The cloud morphologies provide some clues to the processes occurring in the atmosphere and are thus a key diagnostic tool when quantitative dynamical analysis is not feasible due to insufficient information.

In this special issue, you will find the history of the spacecraft development, the design of the observation instruments, the data processing procedure and the initial scientific results. We hope this special issue will familiarize readers with the outline of the JAXA Akatsuki mission that opened up a new era of Venus exploration. Akatsuki follow-up Venus missions are planned by some space agencies and are discussed by Glaze et al. (2018).

Authors' contributions
All authors read and approved the final manuscript.

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Competing interests
The authors declare they don't have any competing interests.

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FRONTIER LETTER **Open Access**

AKATSUKI returns to Venus

Masato Nakamura*, Takeshi Imamura, Nobuaki Ishii, Takumi Abe, Yasuhiro Kawakatsu, Chikako Hirose, Takehiko Satoh, Makoto Suzuki, Munetaka Ueno, Atsushi Yamazaki, Naomoto Iwagami, Shigeto Watanabe, Makoto Taguchi, Tetsuya Fukuhara, Yukihiro Takahashi, Manabu Yamada, Masataka Imai, Shoko Ohtsuki, Kazunori Uemizu, George L. Hashimoto, Masahiro Takagi, Yoshihisa Matsuda, Kazunori Ogohara, Naoki Sato, Yasumasa Kasaba, Toru Kouyama, Naru Hirata, Ryosuke Nakamura, Yukio Yamamoto, Takeshi Horinouchi, Masaru Yamamoto, Yoshi-Yuki Hayashi, Hiroki Kashimura, Ko-ichiro Sugiyama, Takeshi Sakanoi, Hiroki Ando, Shin-ya Murakami, Takao M. Sato, Seiko Takagi, Kensuke Nakajima, Javier Peralta, Yeon Joo Lee, Junichi Nakatsuka, Tsutomu Ichikawa, Kozaburo Inoue, Tomoaki Toda, Hiroyuki Toyota, Sumitaka Tachikawa, Shinichiro Narita, Tomoko Hayashiyama, Akiko Hasegawa and Yukio Kamata

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Abstract

AKATSUKI is the Japanese Venus Climate Orbiter that was designed to investigate the climate system of Venus. The orbiter was launched on May 21, 2010, and it reached Venus on December 7, 2010. Thrust was applied by the orbital maneuver engine in an attempt to put AKATSUKI into a westward equatorial orbit around Venus with a 30-h orbital period. However, this operation failed because of a malfunction in the propulsion system. After this failure, the spacecraft orbited the Sun for 5 years. On December 7, 2015, AKATSUKI once again approached Venus and the Venus orbit insertion was successful, whereby a westward equatorial orbit with apoapsis of ~440,000 km and orbital period of 14 days was initiated. Now that AKATSUKI's long journey to Venus has ended, it will provide scientific data on the Venusian climate system for two or more years. For the purpose of both decreasing the apoapsis altitude and avoiding a long eclipse during the orbit, a trim maneuver was performed at the first periapsis. The apoapsis altitude is now ~360,000 km with a periapsis altitude of 1000–8000 km, and the period is 10 days and 12 h. In this paper, we describe the details of the Venus orbit insertion-revenge 1 (VOI-R1) and the new orbit, the expected scientific information to be obtained at this orbit, and the Venus images captured by the onboard 1-μm infrared camera, ultraviolet imager, and long-wave infrared camera 2 h after the successful initiation of the VOI-R1.

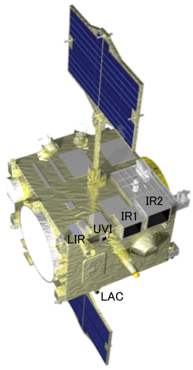

Fig. 1

Keywords: Venus, Atmosphere, Meteorology, Exploration, AKATSUKI

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FRONTIER LETTER **Open Access**

Performance of Akatsuki/IR2 in Venus orbit: the first year

Takehiko Satoh*, Takao M. Sato, Masato Nakamura, Yasumasa Kasaba, Munetaka Ueno, Makoto Suzuki, George L. Hashimoto, Takeshi Horinouchi, Takeshi Imamura, Atsushi Yamazaki, Takayuki Enomoto, Yuri Sakurai, Kosuke Takami, Kenta Sawai, Takashi Nakakushi, Takumi Abe, Nobuaki Ishii, Chikako Hirose, Naru Hirata, Manabu Yamada, Shin-ya Murakami, Yukio Yamamoto, Tetsuya Fukuhara, Kazunori Ogohara, Hiroki Ando, Ko-ichiro Sugiyama, Hiroki Kashimura and Shoko Ohtsuki

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Abstract

The first year (December 2015 to November 2016) of IR2 after Akatsuki's successful insertion to an elongated elliptical orbit around Venus is reported with performance evaluation and results of data acquisition. The single-stage Stirling-cycle cryo-cooler of IR2 has been operated with various driving voltages to achieve the best possible cooling under the given thermal environment. A total of 3091 images of Venus (1420 dayside images at 2.02 μm and 1671 night-side images at 1.735, 2.26, and 2.32 μm) were acquired in this period. Additionally, 159 images, including images of stars for calibration and dark images for the evaluation of noise levels, were captured. Low-frequency flat images (not available in pre-launch calibration data) have been constructed using the images of Venus acquired from near the pericenter to establish the procedure to correct for the IR2 flat-field response. It was noticed that multiple reflections of infrared light in the PtSi detector caused a weak but extended tail of the point-spread function (PSF), contaminating the night-side disk of Venus with light from the much brighter dayside crescent. This necessitated the construction of an empirical PSF to remove this contamination and also to improve the dayside data by deconvolution, and this work is also discussed. Detailed astrometry is performed on star-field images in the H-band (1.65 μm), hereby confirming that the geometrical distortion of IR2 images is negligible.

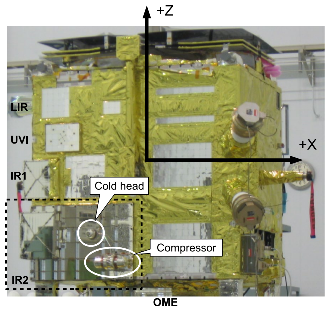

Fig. 1

Keywords: Venus, Atmosphere, Orbiter, Akatsuki, Near-infrared, Window, Cryo-cooler, Dynamics, Aerosols

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FULL PAPER **Open Access**

Initial performance of the radio occultation experiment in the Venus orbiter mission Akatsuki

Takeshi Imamura*, Hiroki Ando, Silvia Tellmann, Martin Pätzold, Bernd Häusler, Atsushi Yamazaki, Takao M. Sato, Katsuyuki Noguchi, Yoshifumi Futaana, Janusz Oschlisniok, Sanjay Limaye, R. K. Choudhary, Yasuhiro Murata, Hiroshi Takeuchi, Chikako Hirose, Tsutomu Ichikawa, Tomoaki Toda, Atsushi Tomiki, Takumi Abe, Zen-ichi Yamamoto, Hirotomo Noda, Takahiro Iwata, Shin-ya Murakami, Takehiko Satoh, Tetsuya Fukuhara, Kazunori Ogohara, Ko-ichiro Sugiyama, Hiroki Kashimura, Shoko Ohtsuki, Seiko Takagi, Yukio Yamamoto, Naru Hirata, George L. Hashimoto, Manabu Yamada, Makoto Suzuki, Nobuaki Ishii, Tomoko Hayashiyama, Yeon Joo Lee and Masato Nakamura

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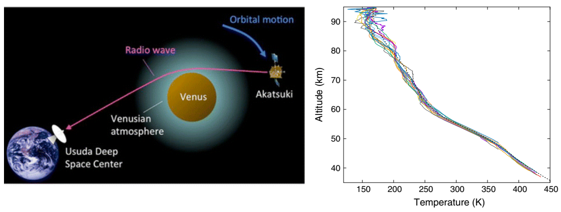
Abstract
After the arrival of Akatsuki spacecraft of Japan Aerospace Exploration Agency at Venus in December 2015, the radio occultation experiment, termed RS (Radio Science), obtained 19 vertical profiles of the Venusian atmosphere by April 2017. An onboard ultra-stable oscillator is used to generate stable X-band downlink signals needed for the experiment. The quantities to be retrieved are the atmospheric pressure, the temperature, the sulfuric acid vapor mixing ratio, and the electron density. Temperature profiles were successfully obtained down to ~ 38 km altitude and show distinct atmospheric structures depending on the altitude. The overall structure is close to the previous observations, suggesting a remarkable stability of the thermal structure. Local time-dependent features are seen within and above the clouds, which is located around 48–70 km altitude. The H_2SO_4 vapor density roughly follows the saturation curve at cloud heights, suggesting equilibrium with cloud particles. The ionospheric electron density profiles are also successfully retrieved, showing distinct local time dependence. Akatsuki RS mainly probes the low and middle latitude regions thanks to the near-equatorial orbit in contrast to the previous radio occultation experiments using polar orbiters. Studies based on combined analyses of RS and optical imaging data are ongoing.

Keywords: Venus, Radio occultation, Akatsuki



Graphical abstract

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FULL PAPER **Open Access**

Absolute calibration of brightness temperature of the Venus disk observed by the Longwave Infrared Camera onboard Akatsuki

Tetsuya Fukuhara*, Makoto Taguchi, Takeshi Imamura, Akane Hayashitani, Takeru Yamada, Masahiko Futaguchi, Toru Kouyama, Takao M. Sato, Mao Takamura, Naomoto Iwagami, Masato Nakamura, Makoto Suzuki, Munetaka Ueno, George L. Hashimoto, Mitsuteru Sato, Seiko Takagi, Atsushi Yamazaki, Manabu Yamada, Shin-ya Murakami, Yukio Yamamoto, Kazunori Ogohara, Hiroki Ando, Ko-ichiro Sugiyama, Hiroki Kashimura, Shoko Ohtsuki, Nobuaki Ishii, Takumi Abe, Takehiko Satoh, Chikako Hirose and Naru Hirata

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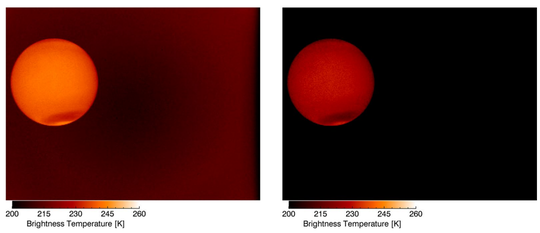
Abstract
The Venus Climate Orbiter Akatsuki arrived at Venus in December 2015, and the Longwave Infrared Camera (LIR) onboard the spacecraft started making observations. LIR has acquired more than 8000 images during the first two Venusian years since orbit insertion without any serious faults. However, brightness temperature derived from LIR images contained an unexpected bias that related not to natural phenomena but to a thermal condition of the instrument. The bias could be partially eliminated by keeping the power supply unit for LIR always active, while the residual bias was simply correlated with the baffle temperature. Therefore, deep-space images were acquired at different baffle temperatures on orbit, and a reference table for eliminating the bias from images was prepared. In the corrected images, the brightness temperature was ~ 230 K at the center of the Venus disk, where the effect of limb darkening is negligible. The result is independent of the baffle temperature and consistent with the results of previous studies. Later, a laboratory experiment with the proto model of LIR showed that when the germanium (Ge) lens was heated, its actual temperature was slightly higher than the temperature measured by a thermal sensor attached to the lens holder. The experiment confirmed that transitory baffle heating accounted for the background bias found in the brightness temperature observed by LIR.

Keywords: Venus, Thermal infrared, Akatsuki



a Original LIR image representing the brightness temperature of the Venus disk. It was acquired on 19 October 2016 with the baffle temperature being 334.6 K.

b The same image corrected for the background bias.

Graphical abstract

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FULL PAPER | Open Access

Effects of variation in coagulation and photochemistry parameters on the particle size distributions in the Venus clouds

Kevin McGouldrick

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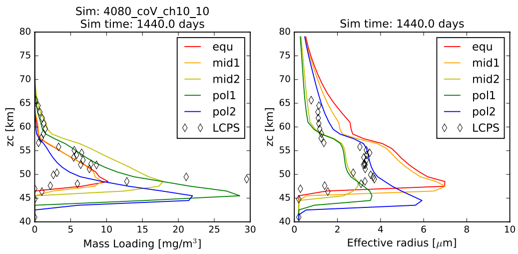
Abstract

This paper explores the effects that variation in the coalescence efficiency of the Venus cloud particles can have on the structure of the Venus cloud. It is motivated by the acknowledgment of uncertainties in the measured parameters—and the assumptions made to account for them—that define our present knowledge of the particle characteristics. Specifically, we explore the consequence of allowing the coalescence efficiency of supercooled sulfuric acid in the upper clouds to tend to zero. This produces a cloud that occasionally exhibits an enhancement of small particles at altitude (similar to the upper hazes observed by Pioneer Venus and subsequently shown to be somewhat transient). This simulated cloud occasionally exhibits a rapid growth of particle size near cloud base, exhibiting characteristics similar to those seen in the controversial Mode 3 particles. These results demonstrate that a subset of the variations observed as near-infrared opacity variations in the lower and middle clouds of Venus can be explained by microphysical, in addition to dynamical, variations. Furthermore, the existence of a population of particles exhibiting less efficient coalescence efficiencies would support the likelihood of conditions suitable for charge exchange, hence lightning, in the Venus clouds. We recommend future laboratory studies on the coalescence properties of sulfuric acid under the range of conditions experienced in the Venus clouds. We also recommend future in situ measurements to better characterize the properties of the cloud particles themselves, especially composition and particle habits (shapes).



Graphical abstract

Keywords: Venus, Atmosphere, Clouds, Meteorology, Dynamics

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Overview of Akatsuki data products: definition of data levels, method and accuracy of geometric correction

Kazunori Ogohara*, Masahiro Takagi, Shin-ya Murakami, Takeshi Horinouchi, Manabu Yamada, Toru Kouyama, George L. Hashimoto, Takeshi Imamura, Yukio Yamamoto, Hiroki Kashimura, Naru Hirata, Naoki Sato, Atsushi Yamazaki, Takehiko Satoh, Naomoto Iwagami, Makoto Taguchi, Shigeto Watanabe, Takao M. Sato, Shoko Ohtsuki, Tetsuya Fukuhara, Masahiko Futaguchi, Takeshi Sakanoi, Shingo Kameda, Ko-ichiro Sugiyama, Hiroki Ando, Yeon Joo Lee, Masato Nakamura, Makoto Suzuki, Chikako Hirose, Nobuaki Ishii and Takumi Abe

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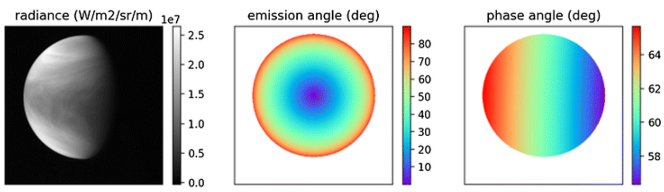
Abstract

We provide an overview of data products from observations by the Japanese Venus Climate Orbiter, Akatsuki, and describe the definition and content of each data-processing level. Levels 1 and 2 consist of non-calibrated and calibrated radiance (or brightness temperature), respectively, as well as geometry information (e.g., illumination angles). Level 3 data are global-grid data in the regular longitude–latitude coordinate system, produced from the contents of Level 2. Non-negligible errors in navigational data and instrumental alignment can result in serious errors in the geometry calculations. Such errors cause mismapping of the data and lead to inconsistencies between radiances and illumination angles, along with errors in cloud-motion vectors. Thus, we carefully correct the boresight pointing of each camera by fitting an ellipse to the observed Venusian limb to provide improved longitude–latitude maps for Level 3 products, if possible. The accuracy of the pointing correction is also estimated statistically by simulating observed limb distributions. The results show that our algorithm successfully corrects instrumental pointing and will enable a variety of studies on the Venusian atmosphere using Akatsuki data.



Graphical abstract

Keywords: Venus, Data product, Pointing correction, Ellipse-fitting technique

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Initial products of Akatsuki 1-μm camera

Naomoto Iwagami*, Takeshi Sakanoi, George L. Hashimoto, Kenta Sawai, Shoko Ohtsuki, Seiko Takagi, Kazunori Uemizu, Munetaka Ueno, Shingo Kameda, Shin-ya Murakami, Masato Nakamura, Nobuaki Ishii, Takumi Abe, Takehiko Satoh, Takeshi Imamura, Chikako Hirose, Makoto Suzuki, Naru Hirata, Atsushi Yamazaki, Takao M. Sato, Manabu Yamada, Yukio Yamamoto, Tetsuya Fukuhara, Kazunori Ogohara, Hiroki Ando, Ko-ichiro Sugiyama, Hiroki Kashimura and Toru Kouyama

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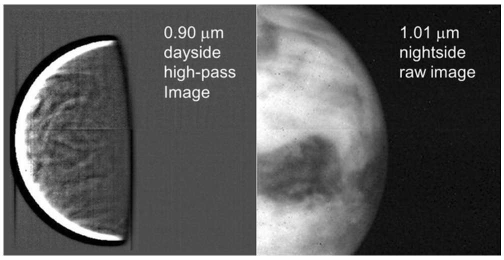
Abstract

The status and initial products of the 1-μm camera onboard the Akatsuki mission to Venus are presented. After the successful retrial of Venus' orbit insertion on Dec. 2015 (5 years after the failure in Dec. 2010), and after a long cruise under intense radiation, damage in the detector seems small and fortunately insignificant in the final quality of the images. More than 600 dayside images have been obtained since the beginning of regular operation on Apr. 2016 although nightside images are less numerous (about 150 in total at three wavelengths) due to the light scattered from the bright dayside. However, data acquisition stopped after December 07, 2016, due to malfunction of the electronics and has not been resumed since then. The 0.90-μm dayside images are of sufficient quality for the cloud-tracking procedure to retrieve wind field in the cloud region. The results appear to be similar to those reported by previous 1-μm imaging by Galileo and Venus Express. The representative altitude sampled for such dayside images is estimated to be 51–55 km. Also, the quality of the nightside 1.01-μm images is sufficient for a search for active volcanism, since interference due to cloud inhomogeneity appears to be insignificant. The quality of the 0.97-μm images may be insufficient to achieve the expected spatial resolution for the near-surface H_2O mixing ratio retrievals.

Keywords: Venus, Infrared, Dayside cloud, Nightside surface



Graphical abstract

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Mean winds at the cloud top of Venus obtained from two-wavelength UV imaging by Akatsuki

Takeshi Horinouchi*, Toru Kouyama, Yeon Joo Lee, Shin-ya Murakami, Kazunori Ogohara, Masahiro Takagi, Takeshi Imamura, Kensuke Nakajima, Javier Peralta, Atsushi Yamazaki, Manabu Yamada and Shigeto Watanabe

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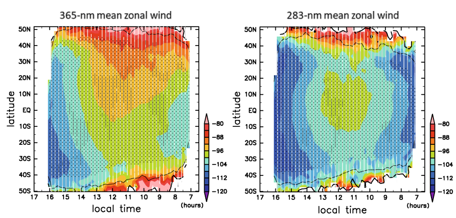
Abstract

Venus is covered with thick clouds. Ultraviolet (UV) images at 0.3–0.4 microns show detailed cloud features at the cloud-top level at about 70 km, which are created by an unknown UV-absorbing substance. Images acquired in this wavelength range have traditionally been used to measure winds at the cloud top. In this study, we report low-latitude winds obtained from the images taken by the UV imager, UVI, onboard the Akatsuki orbiter from December 2015 to March 2017. UVI provides images with two filters centered at 365 and 283 nm. While the 365-nm images enable continuation of traditional Venus observations, the 283-nm images visualize cloud features at an SO_2 absorption band, which is novel. We used a sophisticated automated cloud-tracking method and thorough quality control to estimate winds with high precision. Horizontal winds obtained from the 283-nm images are generally similar to those from the 365-nm images, but in many cases, westward winds from the former are faster than the latter by a few m/s. From previous studies, one can argue that the 283-nm images likely reflect cloud features at higher altitude than the 365-nm images. If this is the case, the superrotation of the Venusian atmosphere generally increases with height at the cloud-top level, where it has been thought to roughly peak. The mean winds obtained from the 365-nm images exhibit local time dependence consistent with known tidal features. Mean zonal winds exhibit asymmetry with respect to the equator in the latter half of the analysis period, significantly at 365 nm and weakly at 283 nm. This contrast indicates that the relative altitude may vary with time and latitude, and so are the observed altitudes. In contrast, mean meridional winds do not exhibit much long-term variability. A previous study suggested that the geographic distribution of temporal mean zonal winds obtained from UV images from the Venus Express orbiter during 2006–2012 can be interpreted as forced by topographically induced stationary gravity waves. However, the geographic distribution of temporal mean zonal winds we obtained is not consistent with that distribution, which suggests that the distribution may not be persistent.

Keywords: Venus, Planetary atmosphere, Planetary climatology, Cloud tracking, Image velocimetry, Superrotation, Aerosol, Wind shear, Cloud motion vector, SO_2



Graphical abstract

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FULL PAPER **Open Access**

Ultraviolet imager on Venus orbiter *Akatsuki* and its initial results

Atsushi Yamazaki*, Manabu Yamada, Yeon Joo Lee, Shigeto Watanabe, Takeshi Horinouchi, Shin-ya Murakami, Toru Kouyama, Kazunori Ogohara, Takeshi Imamura, Takao M. Sato, Yukio Yamamoto, Tetsuya Fukuhara, Hiroki Ando, Ko-ichiro Sugiyama, Seiko Takagi, Hiroki Kashimura, Shoko Ohtsuki, Naru Hirata, George L. Hashimoto, Makoto Suzuki, Chikako Hirose, Munetaka Ueno, Takehiko Satoh, Takumi Abe, Nobuaki Ishii and Masato Nakamura

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Abstract

The ultraviolet imager (UVI) has been developed for the *Akatsuki* spacecraft (Venus Climate Orbiter mission). The UVI takes ultraviolet (UV) images of the solar radiation reflected by the Venusian clouds with narrow bandpass filters centered at the 283 and 365 nm wavelengths. There are absorption bands of SO_2 and unknown absorbers in these wavelength regions. The UV images provide the spatial distribution of SO_2 and the unknown absorber around cloud top altitudes. The images also allow us to understand the cloud top morphologies and haze properties. Nominal sequential images with 2-h intervals are used to understand the dynamics of the Venusian atmosphere by estimating the wind vectors at the cloud top altitude, as well as the mass transportation of UV absorbers. The UVI is equipped with off-axial catadioptric optics, two bandpass filters, a diffuser installed in a filter wheel moving with a step motor, and a high sensitivity charge-coupled device with UV coating. The UVI images have spatial resolutions ranging from 200 m to 86 km at sub-spacecraft points. The UVI has been kept in good condition during the extended interplanetary cruise by carefully designed operations that have maintained its temperature maintenance and avoided solar radiation damage. The images have signal-to-noise ratios of over 100 after onboard desmear processing.

Keywords: Venus orbiter *Akatsuki*, Ultraviolet imager (UVI), UVI performance, UV images of Venus at the cloud top altitude, Initial results of cloud tracking

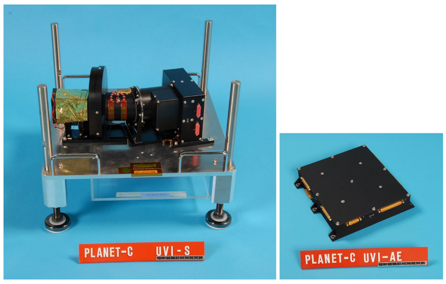

Fig. 1

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Venus looks different from day to night across wavelengths: morphology from Akatsuki multispectral images

Sanjay S. Limaye*, Shigeto Watanabe, Atsushi Yamazaki, Manabu Yamada, Takehiko Satoh, Takao M. Sato, Masato Nakamura, Makoto Taguchi, Tetsuya Fukuhara, Takeshi Imamura, Toru Kouyama, Yeon Joo Lee, Takeshi Horinouchi, Javier Peralta, Naomoto Iwagami, George L. Hashimoto, Seiko Takagi, Shoko Ohtsuki, Shin-ya Murakami, Yukio Yamamoto, Kazunori Ogohara, Hiroki Ando, Ko-ichiro Sugiyama, Nobuaki Ishii, Takumi Abe, Chikako Hirose, Makoto Suzuki, Naru Hirata, Eliot F. Young and Adriana C. Ocampo

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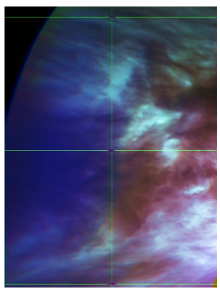
Abstract

Since insertion into orbit on December 7, 2015, the Akatsuki orbiter has returned global images of Venus from its four imaging cameras at eleven discrete wavelengths from ultraviolet (283 and 365 nm) and near infrared (0.9–2.3 μm), to the thermal infrared (8–12 μm) from a near-equatorial orbit. The Venus Express and Pioneer Venus Orbiter missions have also monitored the planet for long periods but from polar or near-polar orbits. The wavelength coverage and views of the planet also differ for all three missions. In reflected light, the images reveal features seen near the cloud tops (~ 70 km altitude), whereas in the near-infrared images of the nightside, features seen are at mid- to lower cloud levels (~ 48–60 km altitude). The dayside cloud cover imaged at the ultraviolet wavelengths shows morphologies similar to what was observed from Mariner 10, Pioneer Venus, Galileo, Venus Express and MESSENGER. The daytime images at 0.9 and 2.02 μm also reveal some interesting features which bear similarity to the ultraviolet images. The nighttime images at 1.74, 2.26 and 2.32 μm and at 8–12 μm reveal features not seen before and show new details of the nightside including narrow wavy ribbons, curved string-like features, long-scale waves, long dark streaks, isolated bright spots, sharp boundaries and even mesoscale vortices. Some features previously seen such as circum-equatorial belts (CEBs) and occasional areal brightenings at ultraviolet (seen in Venus Express observations) of the cloud cover at ultraviolet wavelengths have not been observed thus far. Evidence for the hemispheric vortex organization of the global circulation can be seen at all wavelengths on the day- and nightsides. Akatsuki images reveal new and puzzling morphology of the complex nightside cloud cover. The cloud morphologies provide some clues to the processes occurring in the atmosphere and are thus, a key diagnostic tool when quantitative dynamical analysis is not feasible due to insufficient information.

Keywords: Venus clouds, Morphology, Day, Night, Ultraviolet, Near infrared



Graphical abstract

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Initiation of a lightning search using the lightning and airglow camera onboard the Venus orbiter Akatsuki

Yukihiro Takahashi*, Mitsuteru Sato, Masataka Imai, Ralph Lorenz, Yoav Yair, Karen Aplin, Georg Fischer, Masato Nakamura, Nobuaki Ishii, Takumi Abe, Takehiko Satoh, Takeshi Imamura, Chikako Hirose, Makoto Suzuki, George L. Hashimoto, Naru Hirata, Atsushi Yamazaki, Takao M. Sato, Manabu Yamada, Shin-ya Murakami, Yukio Yamamoto, Tetsuya Fukuhara, Kazunori Ogohara, Hiroki Ando, Ko-ichiro Sugiyama, Hiroki Kashimura and Shoko Ohtsuki

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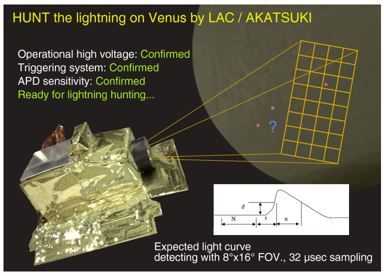
Abstract

The existence of lightning discharges in the Venus atmosphere has been controversial for more than 30 years, with many positive and negative reports published. The lightning and airglow camera (LAC) onboard the Venus orbiter, Akatsuki, was designed to observe the light curve of possible flashes at a sufficiently high sampling rate to discriminate lightning from other sources and can thereby perform a more definitive search for optical emissions. Akatsuki arrived at Venus during December 2016, 5 years following its launch. The initial operations of LAC through November 2016 have included a progressive increase in the high voltage applied to the avalanche photodiode detector. LAC began lightning survey observations in December 2016. It was confirmed that the operational high voltage was achieved and that the triggering system functions correctly. LAC lightning search observations are planned to continue for several years.

Keywords: Venus, Lightning, Flash, Akatsuki, Lightning and airglow camera



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Correspondence

If you have any questions, please contact editorial@earth-planets-space.com.

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