N93-14303 484013 P-1

IMAGE PROCESSING AND PRODUCTS FOR THE MAGELLAN MISSION TO VENUS. Jerry Clark, Doug Alexander, Paul Andres, Scott Lewicki, and Myche McAuley, Magellan Image Data Processing Team, Jet Propulsion Laboratory, Mail Stop 168-514, 4800 Oak Grove Drive, Pasadena CA 91109, USA.

The Magellan mission to Venus is providing planetary scientists with massive amounts of new data about the surface geology of Venus. Digital image processing is an integral part of the ground data system that provides data products to the investigators. The mosaicking of synthetic aperture radar (SAR) image data from the spacecraft is being performed at JPL's Multimission Image Processing Laboratory (MIPL). MIPL hosts and supports the Image Data Processing Subsystem (IDPS), which was developed in a VAXcluster environment of hardware and software that includes optical disk jukeboxes and the TAE-VICAR (Transportable Applications Executive-Video Image Communiation and Retrieval) system. The IDPS is being used by processing analysts of the Image Data Processing Team to produce Magellan image data products. Data arrive at the IDPS via the fiber optic Imaging Local Area Network from the SAR Data Processing Subsystem that correlates raw SAR data into image data. The input SAR image swaths, called F-BIDRs (Full-resolution Basic Image Data Record), are long, thin swaths of imagery covering an area on the surface about 20 km in width by about 17,000 km in length, extending from the north pole to near the south pole of Venus. Systematic procedures were written for the automatic mosaicking of multiple orbits of data into image frames covering predetermined regions of the planet. Algorithms were developed to perform such functions as the correction of radiometric differences at the edges of adjacent orbits and the automatic tiepointing of overlapping data to correct for navigational errors between orbits. After mosaicking, the images are contrast enhanced, annotated, and masked to create photo products for scientific analysis. Other versions of mosaics are created from reduced resolution image swaths. Depending on the product, the data are output from the MIPL as archive tapes; working WORM (Write-Once-Read-Many) optical disks; premastered tapes for stamping, by a vendor, of CD-ROMs (Compact-Disc-Read-Only-Memory) that are used to distribute mosaics and ancillary data to the scientific community; and exposed film that is used for the production of prints and copy negatives. Numerous special products have been made at the request of the investigators, including SAR mosaics merged with non-SAR data (such as altimetry and radiometric emissivity data) that are displayed as color composites and stereo anaglyphs that use SAR data collected at different look-angles to view surface topography through stereo parallax. In addition, mosaicked data are used to make other products, including terrain rendering that shows SAR mosaics combined with digital elevation data in perspective views and videos that use thousands of incremented rendered scenes to create simulated flights over the surface of Venus.

(This work is being performed at JPL, California Institute of Technology, under contract with NASA.)

N93-14307 484214 P-2

THE THERMOSPHERE AND IONOSPHERE OF VENUS. T. E. Cravens, Department of Physics and Astronomy, University of Kansas, Lawrence KS 66045, USA.

Our knowledge of the upper atmosphere and ionosphere of Venus and its interaction with the solar wind has advanced dramatically over the last decade, largely due to the data obtained during the Pioneer Venus mission and to the theoretical work that was motivated by this data. Most of this information was obtained during the period 1978 through 1981, when the periapsis of the Pioneer Venus Orbiter (PVO) was still in the measurable atmosphere. However, solar gravitational perturbations will again lower the PVO periapsis into the upper atmosphere in September 1992, prior to the destruction of the spacecraft toward the end of this year. The physics and chemistry of the thermosphere and ionosphere of Venus will be reviewed in this paper. The book entitled *Venus Aeronomy* [1] contains several chapters that together provide a good overview of this subject.

The neutral atmosphere is primarily composed of carbon dioxide, but for altitudes above about 160 km atomic oxygen, which is produced via photodissociation of CO_2 by solar photons, becomes the dominant neutral species. The PVO neutral mass spectrometer has provided most of our information on the composition of the Venus thermosphere. The thermosphere of Venus is quite cold in comparison with Earth's thermosphere with an exospheric temperature on the dayside of $T_{ex} \approx 300$ K, whereas at Earth $T_{ex} \approx 1500$ K. The nightside thermosphere of Venus is extremely cold with $T_{ex} \approx 100$ K; it has been suggested, in fact, that this region of the atmosphere be called the "cryosphere" rather than the thermosphere. It is not fully understood why the upper atmosphere of Venus is so cold, although part of the answer is contained in the CO_2 15-μm cooling mechanism and also in the nature of the thermosphere dynamics. Thermospheric wind speeds of several hundred meters per second have been theoretically calculated for altitudes above about 150 km, and indirect observational evidence, such as compositional gradients, supports the validity of these calculations.

The exobase of Venus is located at about 180 km; above this altitude, in the exosphere, neutral atoms and molecules largely follow ballistic trajectories. Both atomic oxygen and atomic hydrogen are abundant in the Venus exosphere. The H density is about 10^5 cm^{-3} on the dayside and about 10^7 cm^{-3} on the nightside. Two populations of exospheric H exist at Venus: (1) a cold thermal component and (2) a hot (i.e., an effective temperature of ≈1200 K) nonthermal component. The hot hydrogen is thought to be mainly produced by the charge exchange of hot H^+ ions with neutral H and O atoms. Both cold and hot populations of atomic oxygen also exist in the Venus exosphere, and the nonthermal hot population has a larger density than the cold population for altitudes above about 300 km. The hot oxygen corona, as it is called, was observed by the ultraviolet spectrometer onboard PVO via resonantly scattered solar 130.4-nm photons. The major source of hot oxygen is the dissociative recombination of ionospheric O_2^+ ions. Hot oxygen plays an important role in the solar wind interaction with Venus, because photoionization of oxygen atoms that are present out in the Venus magnetosheath creates heavy ions that "mass load," and thus slow down, the solar wind flow.

The ionosphere of Venus forms due to the ionization of neutrals. Photoionization by solar extreme ultraviolet (EUV) photons is the main ionization process, although some contribution is also made by electron impact ionization by photoelectrons on the dayside and by "auroral" electrons on the nightside. It should be noted that superthermal electrons appear to be precipitating into the nightside atmosphere of Venus, generating emissions observed by the PVO ultraviolet spectrometer and also creating ionization. However, the Venus aurora is very weak in comparison with the terrestrial aurora, and is thought to be caused by relatively low energy electrons (i.e., energies of ≈100 eV or less, whereas auroral electrons at Earth have energies of thousands of eV).

The ionization process for the major neutral species, CO_2 and O, in the ionosphere of Venus can be represented by the reactions

$$\begin{aligned} h\nu + CO_2 &\rightarrow CO_2^+ + e \\ &\rightarrow CO + O^+ + e \\ h\nu + O &\rightarrow O^+ + e \end{aligned}$$

where $h\nu$ represents an ultraviolet photon. h is Planck's constant and ν is the photon frequency. $h\nu$ must exceed the ionization potential of the molecule for these photochemical reactions to proceed.

A peak electron density in the Venus ionosphere of $\approx 6 \times 10^5$ cm^{-3} was observed on the dayside by the Pioneer Venus radio occultation experiment, as well as by the radio occultation experiments on other missions. The altitude of the peak is located at $z \approx 140$ km. The major ion species in the lower ionosphere of Venus was observed by the PVO ion mass spectrometer and by the retarding potential analyzer experiments to be O_2^+ and not CO_2^+, even though the abundance of neutral O_2 in the atmosphere of Venus is negligible, because of the following rapid ion-neutral reaction

$$CO_2^+ + O \rightarrow O_2^+ + CO$$

The O_2^+ ions are removed from the ionosphere by means of the following dissociative recombination reaction with ionospheric electrons

$$O_2^+ + e \rightarrow O + O$$

The neutral oxygen atoms produced by this reaction have energies of a few eV and are the source of the hot oxygen corona. The major ion species observed by instruments on PVO for altitudes above ≈ 160 km is O^+. Many minor ion species, including H^+, CO^+, N_2^+, CO_2^+, NO^+, He^+, C^+, and N^+, were observed by the PVO ion mass spectrometer.

Electron and ion temperatures of several thousand degrees were observed in the ionosphere of Venus by the PVO electron temperature probe and by the retarding potential analyzer. Theoretical models indicate that most of the energy required to heat the ionospheric plasma to these temperatures, which greatly exceed the neutral temperature, is derived from the solar wind interaction with the ionosphere.

The nightside ionosphere of Venus is quite variable, both spatially and temporally, with peak densities typically observed to be about 10^4 cm^{-3}. The main source of nightside ionization is thought to be transport of ions from the dayside to the nightside. O^+ ions drift upward on the dayside, then flow horizontally with speeds of several kilometers per second above 200 km, and then subside to lower altitudes on the nightside. Large ion drift speeds near the terminator of Venus were measured by the PVO retarding potential analyzer. Auroral ionization also contributes to the nightside ionosphere, especially during time periods of large solar wind dynamic pressure, when it is known that the nightside ionosphere at higher altitudes virtually disappears. A variety of other nightside ionospheric phenomena have also been observed, such as tall rays, ionospheric clouds, and ionospheric holes.

The solar wind interacts very strongly with the ionosphere of Venus. In fact, two types of ionosphere exist: (1) unmagnetized and (2) magnetized. The former ionospheric state is observed to be present whenever the solar wind dynamic pressure is low, and in this case large-scale magnetic fields are excluded from the ionosphere, although small-scale magnetic structures called flux ropes were observed to be present in the ionosphere by the PVO magnetometer. The boundary between the solar wind and ionosphere, called the ionopause, is rather narrow and is located at higher altitudes for unmagnetized ionosphere cases. However, the dayside ionosphere is observed to be permeated by large-scale magnetic fields during conditions of high solar wind dynamic pressure. In this case, electrical currents flow throughout the ionosphere and both the density structure and the dynamics of the ionosphere are strongly affected by the solar wind interaction. The ionopause in this case is located below about 300 km and is rather broad.

References: [1] Russell C. T., ed. (1991) *Venus Aeronomy*, Kluwer, Dordrecht.

S30-91

N93-14308

NEAR-INFRARED OXYGEN AIRGLOW FROM THE VENUS NIGHTSIDE.

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Groundbased imaging and spectroscopic observations of Venus reveal intense near-infrared oxygen airglow emission from the upper atmosphere [1,2] and provide new constraints on the oxygen photochemistry and dynamics near the mesopause (~100 km). Atomic oxygen is produced by the photolysis of CO_2 on the dayside of Venus. These atoms are transported by the general circulation, and eventually recombine to form molecular oxygen. Because this recombination reaction is exothermic, many of these molecules are created in an excited state known as $O_2(^1\Delta)$. The airglow is produced as these molecules emit a photon and return to their ground state. Connes et al. [1] found that the airglow intensity is comparable on the dayside (1.5×10^{12} photons/cm^2/s) and nightside (1.2×10^{12} photons/cm^2/s) of the planet. They concluded that the $O_2(^1\Delta)$ emission is spatially uniform, and that chemical reactions involving $O_2(^1\Delta)$ provide a major pathway for the recombination of oxygen atoms in the venusian atmosphere. The intensity and apparent uniformity of this emission has puzzled atmospheric chemists for more than a decade because these properties cannot be explained by existing models [3].

New imaging and spectroscopic observations acquired during the summer and fall of 1991 show unexpected spatial and temporal variations in the $O_2(^1\Delta)$ airglow [4,5]. High-resolution (0.4 cm^{-1}) spectra of selected regions of the dayside and nightside of Venus were obtained with the Fourier Transform Spectrometer on the Canada-France-Hawaii Telescope (Mauna Kea Hawaii) on 27 June and 1 July 1991 (Fig. 1). Individual oxygen emission lines of the $O_2(^1\Delta)$ band near 7880 cm^{-1} (1.269 µm) were resolved, allowing us to distinguish the airglow emission from the deep-atmosphere thermal emission peak near 7830 cm^{-1} (1.277 µm). The intensity of the nightside $O_2(^1\Delta)$ emission increased by a factor of 4 between 10N to 5S latitude on 27 June. The emission measured near 15S latitude on 1 July was almost six times brighter than that seen four days earlier, and about three times brighter than that reported by Connes et al. [1]. Comparisons of intensities of individual rotational transitions in the P and R branches of the emission spectrum indicate a rotational temperature of 186 ± 6 K (Fig. 2).

This temperature is comparable to that derived from the $O_2(^1\Delta)$ observations made in the mid 1970s [1]. When Pioneer Venus arrived in 1978, the Venus mesosphere was characterized by an anomalous thermal structure, with warm poles and a relatively cool equator. Dynamical models showed that this temperature structure was consistent with a rapid decrease in the amplitude of the cloud-