Venus Science Conference 2024
(Venus-SC 2024)
23-24 September 2024

Volume of Abstracts

Physical Research Laboratory

Ahmedabad, INDIA

Table of Contents

Oral Presentations

Session 1-A: Atmosphere and Ionosphere

Effects of magnetic fields on Venus and Mars' ionospheres

S. A. Haider[1] and Siddhi Y. Shah[2]
[1]Planetary Sciences Division, Physical Research Laboratory, Navrangpura, Ahmedabad
[2]Pandit Deendayal Energy University (PDEU), Gandhinagar, Gujarat
[1]E-mail: haider@prl.res.in

Mars and Venus do not have an indigenous dipole magnetic field. However, an induced magnetosphere exists as a result of the solar wind interaction with the ionospheres of Venus and Mars, which in turn results in several plasma boundaries: (1) magnetic pile-up boundary, (2) magnetic activity, (3) the ionopause[1]. In this paper we have studied the ionopauses of Venus and Mars in presence and absence of magnetic fields. We report that these planets should have three ionopause like boundaries viz. low, mid and high ionopases at altitude range 300-400 km, 600-700 km and 1000-1200 km respectively. These measurements are carried out from MAVEN and PVO in the upper ionospheres of Mars and Venus respectively, which demand a source mechanism to understand the physical, chemical and dynamic processes. In this measurement a steep ionopause like boundary is observed when MAVEN and PVO were passing from the magnetic pile-up region during the daytime ionosphere in presence of horizontal magnetic field of high strength, while their night side ionosphere did not show such boundary in presence of horizontal magnetic field of low strength. The night side ionospheres of both planets are produced by horizontal plasma transport from dayside ionosphere across the terminator.

We propose that the horizontal magnetic field can form such ionopause within the magnetic pile-up boundary during the daytime, if time and location of the magnetic anomaly coincide with the ion and electron density measurements. The modelling of the Mars' ionopause controlled by the induced magnetic field in terms of continuity equations, momentum equations and divergence term of horizontal velocity is also carried out[1,2]. There is a good agreement between model and Mars' ionopauses.

References: [1] Haider, S. A., Prasad, K. D. and Siddhi, Y. S., (2023), *Icarus*, 394, 115423.
[2] Shinagawa H. and T. E. Cravens, (1989), *J. Geophys. Res.*, 94 (A6), 6506-6516

Latest results from Akatsuki radio occultation

Takeshi Imamura*, Akatsuki Radio Science Team
Graduate School of Frontier Sciences, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba 277-8561, Japan
*E-mail: t_imamura@edu.k.u-tokyo.ac.jp

Radio occultation observations of the Venusian atmosphere in JAXA's Akatsuki mission have provided information on the vertical structure of the atmosphere over broad latitude, longitude and local time regions [1,2]. The measured quantities are the atmospheric pressure, temperature, sulfuric acid vapor mixing ratio and electron density. Recent studies conducted using Akatsuki radio occultation data include: meridional thermal cross section, characteristics of gravity waves revealed by radio holographic analysis, radio scintillation analysis for short vertical scale waves, fine vertical structures of the ionosphere, and solar corona. Selected results from Akatsuki radio occultation experiments will be introduced in the presentation.

Interaction of solar wind with Mars and Venus

Dibyendu Chakrabarty
Physical Research Laboratory, Ahmedabad, India
E-mail: dipu@prl.res.in

Venus and Mars, the two terrestrial planets have nearly negligible planetary dipole generated magnetic field. Interestingly, Mars has pockets of remnant magnetic field in the southern hemisphere. Therefore, although the interaction of solar wind generates induced magnetosphere at both Venus and Mars, the induced magnetosphere at Mars gets locally modulated wherein remnant magnetic field strength is significant. The interaction of solar wind also controls the atmospheric escape at both Mars and Venus. The differences in the duration of solar day/night over Mars and Venus also makes the evolution and sustenance of ionosphere different particularly on the nightside. The location and evolution of bow shock, variations in the magnetopause stand-off distance, as well as the structures of nightside ionotail of Mars and Venus also reveal important aspects of solar wind interaction with the ionospheres of non-magnetized planets. Some of these aspects will be discussed in this talk.

The Ionospheres of Venus and Mars: Similarities, Differences, and Future Prospects

N. V. Rao
National Atmospheric Research Laboratory, Gadanki, Andhra Pradesh, India
E-mail: nvrao@narl.gov.in

The ionospheres of Venus and Mars have been extensively studied by various spacecraft, including (for Venus) Venera, the Pioneer Venus Orbiter, Venus Express, Akatsuki, and (for Mars) the Mars Global Surveyor, Mars Express, MAVEN, and the Mars Orbiter Mission, among others. These missions have provided a wealth of data, significantly advancing our understanding of the ionospheres of these two CO_2-dominated planets, both of which lack intrinsic magnetic fields. Numerical simulations and general circulation models based on these spacecraft observations have further enriched our insights into their ionospheric dynamics. Given the substantial progress made over decades, a detailed comparison of the similarities and differences between the ionospheres of Venus and Mars is both timely and essential. This presentation will offer a comprehensive comparison, with a particular emphasis on radio remote sensing observations, focusing especially on the topside ionospheres. Additionally, we will identify potential knowledge gaps that can be addressed by future missions to these planets.

Radiative transfer model simulations of VSEAM observations

Satya P. Ojha*, Satadru Bhattacharya and Rajesh B. Upadhyaya
Space Applications Centre (ISRO)
Ahmedabad – 380015
*E-mail: satyaprakash.ojha@gmail.com

The proposed Venus Surface Emissivity and Atmospheric Mapper (VSEAM) instrument on Shukrayaan, is being designed for acquiring information about the surface emissivity and near surface atmosphere of Venus. VSEAM will be operating in the near infrared region of the electromagnetic spectrum. It has atmospheric windows located at 1.02, 1.10, 1.16 and 1.18 µm which are meant for surface sounding, while additional windows between 1.3 and 2.5 µm (the deep atmosphere windows) will sound the deep atmosphere around 20-40 km altitude. The measured radiance in the surface windows depends on the surface as well as on the atmospheric properties that must be derived from the deep atmospheric windows. The retrieval of surface emissivity and temperature requires the observations to be corrected for atmospheric effects. It demands a thorough understanding of the radiative transfer on Venus so that the coupling of the different atmospheric and surface parameters can be modelled. The development of radiative transfer (RT) model for Venus is the first step towards the retrieval of surface and near surface atmospheric parameters. RT model is an essential part of retrieval algorithms which involves the inversion of satellite radiances. The available RT models which are being used for Earth cannot be used as such for Venus. It requires significant customisation of the RT model according to the prevailing surface and atmospheric conditions of Venus. This study focuses on the development of atmospheric radiative transfer model for Venus. The complexities involved in the RT model simulations for Venus atmosphere are discussed.

Probing Microorganisms in Venus Clouds and Challenges

Rajagopal Shanmugasundaram
Department of Physics, PSG College of Arts & Science, Coimbatore – 641014, India
E-mail: s.rajagopal@psgcas.ac.in and raja2001s@gmail.com

It is believed that Venus has habitable situation and it changed slowly, with increase of hotness of the Sun. Along with the greenhouse effect in Venus, such hotness evaporates all water content and splits carbon dioxide and produced a very thick clouds approximately 48 Km above its surface. But luckily these clouds have very good temperature gradient with respect to the surface of the planet. In addition with that, clouds of Venus is mostly filled with sulfuric acid. Recent study shows the impression for phosphine and ammonia gases in Venus clouds. At this high temperature no chemicals possible as stable one. Though their amount may be less than ppm, it is till existing. It gives a hope that possibility of the living things that releases those gases at this temperature region.

In this present work, possibilities that favors for living microorganisms in Venus through its atmospheric condition are to be discussed. Experimental opportunities on the optical properties and chemical structure of atmospheric cloud are to be mainly addressed. Challenges on probes that identify and monitor microorganisms are also to be discussed.

References: [1] Nißler, R., Balder, O., Dohmen, M. et al. (2020), *Nat Commun*, 11, 5995(12). [2] Greaves, J. S., Richards, A. M. S., Bains, W. et al. (2021), *Nat Astron* 5, 655–664. [3] Clara Sousa S., Sara S., Sukrit R. et al. (2020), *Astrobiology*, 20(2), 235-268. [4] Alcolombri, U., Pioli, R., Stocker, R. et al. (2022), *Isme Commun.*, 2, 55(9). [5] Feng Z., Jing-Hang W., and Han-Qing Y. (2020), *Anal. Chem.*, 92(15), 10606–10612.

Planetary-scale waves and their dynamical effect on the general circulation in the Venusian cloud layer

Masahiro Takagi[1*], Hiroki Ando[1], Masataka Imai[2], Norihiko Sugimoto[3], Yoshihisa Matsuda[4]
[1]Faculty of Science, Kyoto Sangyo U. (Kamigamo Motoyama, Kita, Kyoto 603-8555, Japan)
[2]Institute of Astronomy, U. of Tokyo (Osawa, Mitaka, Tokyo 181-8588, Japan)
[3]Dept. of Physics, Keio U. (Hiyoshi, Yokohama, Kanagawa 223-8521, Japan)
[4]Dept. of Astronomy & Earth Science, Tokyo Gakugei U. (Koganei, Tokyo 184-8501, Japan)
*E-mail: takagi.masahiro@cc.kyoto-su.ac.jp

The atmospheric circulation of Venus is dominated by fast zonal winds of the entire atmosphere called superrotation (SR), which rotates in the same direction as the solid planet and extends from the ground to altitude of 80–90 km or higher[1]. Recently, observations by the 2-μm infrared camera (IR2) onboard Akatsuki found for the first time that a significant equatorial jet, which is a narrow band of zonal winds with a maximum rotational speed near the equator, could exist in the lower cloud layer at 47–57 km, significantly varying in time [2]. Using a Venusian general circulation model (GCM), we successfully reproduced the equatorial jet in the lower cloud layer and its quasi-periodic variation that could be consistent with the Akatsuki observation [3]. The equatorial jet is produced by the 5.8-day wave[4], which corresponds to the 5-day wave observed at the cloud top [5, 6, 7], and destroyed by the 7-day wave in the GCM. Its quasi-periodic variation with a timescale of about 280 Earth days is caused by the alternating development of these waves. The 5.8-day wave, which is excited by the Rossby-Kelvin instability, produces the equatorward angular momentum (AM) flux, and accelerates the zonal-mean zonal wind in the equatorial region [4]. The 7-day wave is a planetary-scale wave newly found in the GCM, whose structure is antisymmetric about the equator [3]. This wave is excited by the coupling among the lower-altitude equatorial Rossby wave, the mid-latitude Rossby wave, and the high-latitude Rossby wave. In the growth period of the 7-day wave, it produces the poleward (equatorward) AM flux around the equatorward (poleward) critical latitude, at which the zonal-mean zonal wind velocity equals to the zonal phase velocity of the 7-day wave. As a result, the zonal-mean zonal wind is decelerated (accelerated) in the equatorial region and high latitudes (mid-latitudes). The downward propagation of the high-latitude Rossby wave produces significant equatorward heat transport, which could affect the thermal structures in the polar region [8, 9]. The zonal and meridional winds near the cloud top could be also affected by these waves. It should be noted, however, that the existence of the equatorial jet in the lower cloud layer is not well established by observations. Also, the 7-day wave has not yet been observed. To understand the general circulation on Venus, these planetary-scale waves should be examined by further observations in the future.

References: [1] Schubert, G. et al. (1980), *JGR*, 85, 8007-8025. [2] Horinouchi, T. et al. (2017), *Nature Geoscience*, 10, 646-651. [3] Takagi, M. et al. (2023), *JGR: Planets,* 128, e2023JE007922. [4] Takagi, M. et al. (2022), *JGR: Planets*, 127, e2021JE007164. [5] Del Genio, A. D. and Rossow W. B. (1990), *JAS*, 47, 293-317. [6] Kouyama, T. et al. (2013), *JGR: Planets*, 118, 37-46. [7] Imai, M. et al. (2019), *JGR: Planets*, 126, e2021JE007047. [8] Ando, H. et al. (2020), *Scientific Reports*, 10, 3448. [9] Ando, H. et al. (2022), *JGR: Planets*, 127, e2021JE006957.

Session 2:
Surface Science and Exploration

Sedimentary Processes on Venus

Richard Ghail[1*], Philippa Mason[2], and the League of Venus Explorers
[1]Department of Earth Sciences, Royal Holloway, University of London, Egham, TW20 0EX, United Kingdom
[2]Department of Earth Science and Engineering, Imperial College London, South Kensington, SW7 2BP, United Kingdom
*E-mail: richard.ghail@rhul.ac.uk

Sedimentary features are rarely observed in Magellan data and so might be assumed to be unimportant on Venus. However, the four Venera lander panoramas reveal surfaces dominated by clastic rocks and mobile sediment. Rapid lithification can reconcile these contrasting observations. Magellan radiometric data indicate that sedimentary rocks might cover almost half the Venus surface, primarily in the plains, while Venera elemental abundance data and experimental data suggest that calcium and alkali sulphates are the most likely cementing agents. The main sediment sources appear to be upland erosion and the mass wasting of steep slopes, from which sand-sized granular material is transported globally to be deposited across the plains and lithified as thinly layered clastic rocks, but a range of other sedimentary features are evident on Venus [1]. Obscuration of lava flows and the rate of crater floor infilling may be used to bound modern sedimentation rates to between 0·01 and 1 mm a^{-1}, bracketing the global marine sedimentation rate. However, past sedimentation rates may have been very different. Many upland tessera terrains are more highly eroded than can be attributed to modern processes, with some evidence for dissection by fluvial erosion [2], consistent with Venus formerly having supported oceans.

Polarimetry: Polarimetric data are critical for understanding sedimentary features and deposits by distinguishing the backscatter mechanisms at work (single or double bounce, volumetric scattering) at the scale of the radar wavelength. These distinctions allow mapping of boundaries and flow structures not apparent in non-polar data (HH or VV). While the dual polarization (HH and HV) mode on EnVision will aid the mapping of boundaries, only the tripol (HH HV/VH VV) data from Shukrayaan will be able to fully distinguish scattering mechanisms that are of key importance in understanding sedimentary deposits and processes. With these data we anticipate resolving a host of sedimentary features in the uplands and their deposits across the plains.

References: [1] Carter, L. M. et al. (2023), *Space Sci. Rev.*, 219(8), 85. [2] Khawja, S. et al. (2020), *Nat. Commun*. 11, 5789.

Plume-Induced Dyke Swarms in Anala and Irnini Montes, Central Eistla Regio, Venus

Aastha Mishra[1*], Richard E. Ernst[2], Hafida El Bilali[2], Rajesh K Srivastava[3]
[1]School of Earth, Ocean and Climate Science, IIT Bhubaneshwar, Odisha 752050, India
[2] Department of Earth Sciences, Carleton University, Ottawa ON K1S5B6, Canada
[3]Department of Geology, Banaras Hindu University, Varanasi 221005, India
*E-mail: a24gg09006@iitbbs.ac.in

Venus lacks plate tectonics, and its surface is dominated by intraplate basaltic magmatism with the largest events comparable to terrestrial Large Igneous Provinces linked to mantle plumes. Owing to the lack of any significant erosion, the Venusian surface is dominated by lava flows and graben-fissure-fracture systems (which are typically the surface expression of mafic dyke swarms). Central Eistla Regio is an important mantle plume region on Venus with multiple magmatic centres. Here we focus on detailed 1:500,000 scale mapping (10X more than previous V-20 Quadrangle mapping [1]) of two important volcanic centres, Anala and Irnini Montes [1-5] and their surrounding regions, using radar data from the NASA Magellan mission. We have mapped more than 10,000 grabens, and grouped them into radiating, circumferential and linear dyke swarms.

Anala Mons (11.0°N 14.1°E, 525 km in diameter) is a complex volcanic centre with multiple radiating and circumferential swarms. About 300 km to the east, there is a broad circular feature (170 km in diameter) interpreted as an older corona, which has been filled by younger lava flows emanating from Anala Mons. These flows mostly cover the dyke swarm radiating to the east, but some Anala Mons grabens were apparently large enough that they were not completely filled by the younger flows and remain visible. One particular graben can be traced for >550 km, initially trending radially to the NE from Anala Mons; at a distance of about 350 km this dyke swings clockwise 45 degrees towards an ESE trend. A second partially flooded radial graben trends east from Anala Mons, and at approximately the same 350 km distance, also swings into an ESE trend. Additional smaller graben segments also support this pattern of a radial swarm swinging into a linear trend. Such a pattern can be used to estimate extent of the domal uplift which proxies the size of the underlying size of the plume head. In this case the graben (dyke swarm) pattern indicates an Anala plume head radius of about 350 km. The recognition of a linear ESE dyke trend beyond this distance indicates a regional ESE-WNW-trending maximum compressive stress in the region east of Anala Mons. Some grabens (dykes) in the interior of the other major centre, Irnini Mons (14.6°N 16.0°E, 475 km in diameter), also show a similar swing in trend at about the same 350 km distance away from Anala Mons, and we are investigating whether these could belong to a north-trending sector of the main Anala Mons radiating swarm.

Irnini Mons is also mapped for radiating and circumferential swarms. However, major linear sets of grabens on the western and northern sides of Irnini Mons are not linked to this Mons; instead, these dykes are provisionally interpreted to be part of a huge radiating swarm associated with Belet-ili Corona located more than 1000 km to the south [1,2].

References: [1] McGill (2000), USGS map i2637. [2] Chaddha et al. (2024), *Icarus* 410, 115893. [3] Singh et al. (2023), *LPSC* #1181. [4] Buczkowski et al. (2004), *LPSC* #1561. [5] Buczkowski (2006), *J. Struct. Geol.,* 28, 2156-2168.

The >3700 km long Great Dyke of Atla Regio (GDAR), Venus: Longest continuously traced individual mafic dyke in the Solar System

Hafida EL BILALI*, Richard E. ERNST
Department of Earth Sciences, Carleton University, Ottawa, Ontario, K1S 5B6, Canada
*E-mail: hafidaelbilali@cunet.carleton.ca

The Great Dyke of Atla Regio (GDAR) is traced for >3700 km on Venus, as surface graben interpreted to overlie a continuous, laterally-emplaced underlying mafic dyke (vertical magma-filled crack) [1]. The GDAR is part of a giant radiating graben/fissure/fracture system (dyke swarm) associated with the Ozza Mons volcano of the Atla Regio Superplume [2]. Based on our criteria for recognition and interpretation of dyke swarms on Venus, we suggest that the GDAR is the longest individually traced dyke so far recognized on Venus (and also in the Solar System). The GDAR is traced from an interpreted magma reservoir located ~600 km south of the Ozza Mons plume centre, which may have been fed initially from closer to the plume centre. A 50-degree counter-clockwise swing of the GDAR trend at 1200 km from the plume centre is consistent with 1200 km radius for the underlying Ozza Mons mantle plume head, and a stress link to the 10,000 km long Parga Chasmata rift system. Our discovery of the >3700 km long Great Dyke of Atla Regio, should spur the search for additional long continuous single dykes on Venus (and Earth), with implications for estimating plume head size, locating buffered magma reservoirs, mapping regional stress variation across large regions of Venus (and Earth) at a geological instant, and representing time markers that reveal relative ages (through cross-cutting relationships) over regional-scale distances.

References: [1] El Bilali, H. and Ernst, R. E. (2024), *Nat. Commun.*, 15, 1759. [2] El Bilali, H. et al. (2023), *Commun. Earth Environ.*, 4, 235.

Crustal extension due to mafic dyke swarms: Influence on Venusian surface topography including the formation of coronae

Richard E. ERNST[1*], Hafida EL BILALI[1], Kenneth L. BUCHAN[2], James W. HEAD[3].
[1]Department of Earth Sciences, Carleton University, Ottawa, ON, K1S 5B6, Canada
[2]273 Fifth Ave., Ottawa, Ontario, Canada.
[3]Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI, USA
*E-mail: Richard.Ernst@carleton.ca

Graben systems are extensive on Venus and have been interpreted both as purely structural features, and as underlain by mafic dykes. A dyke origin is often demonstrated by eruption of lava flows from the grabens. We consider the implications of crustal extension (mostly 1-5%, but ranging up to 10%) under the dyke swarm interpretation. Our analysis is based on field observations of dyke swarms on Earth, theoretical treatments of radial dyke swarms, and the mapping of graben patterns on Venus. Our analysis benefits from the unique opportunity that Venus offers to compare the primary surface topography (preserved in the absence of erosion) with crustal extension inferred from dyke swarm emplacement. We consider the effect on surface topography of crustal extension due to emplacement of swarms.

1) Formation of annular rims / troughs characteristic of coronae: Crustal extension associated with circumferential swarms (encircling most coronae) may explain the annular folding of corona rims / troughs, and complement other folding mechanisms based on modelling of plume dynamics.

2) Preservation of domal uplift above plumes/diapirs: Crustal extension due to emplacement of a radiating swarm above a plume/diapir contributes to preservation of the plume-generated domal uplift. On the other hand, in the absence of dyke emplacement, once the thermal anomaly fades the original topography could be restored.

3) Formation of arachnoids: Some magmatic centres have radiating ridge systems (termed arachnoids). Such radial compressional features could develop from collapse of dyke-extended domal uplift, with thrust faults partly utilizing preexisting radiating dykes.

4) Elevation of fracture belts (lineae, groove belts): Fracture belts are interpreted as older failed rifts, but often have elevated topography. Emplacement of rift-parallel dykes and the resulting crustal extension within a failed rift zone could represent a mechanism for linear uplift.

5) Formation of km-scale undulations in topography: Many areas on Venus display multiple cross-cutting graben sets, which appear analogous to regions of terrestrial Precambrian shields that exhibit multiple crosscutting dyke swarms of different ages. The superimposition of crustal extension from each of the multiple crosscutting trends is predicted to cause complicated patterns of km scale undulations in the surface topography.

AVENGERS (Analogs for VENus' Geologically Recent Surfaces) initiative: an investigation of terrestrial analog active volcano-tectonic areas for Venus exploration

J. Filiberto[1], P. D'Incecco[2], J. B. Garvin[3], G. N. Arney[3], S. A. Getty[3], E. Kohler[3], et al
[1]Astromaterials Research and Exploration Science (ARES) Division, NASA Johnson Space Center, Houston, TX, 77058, USA;
[2]National Institute for Astrophysics (INAF) – Astronomical Observatory of Abruzzo, Teramo, Italy;
[3]NASA Goddard Space Flight Center, 8800 Greenbelt Rd, Greenbelt, MD 20771, USA;
*E-mail: justin.r.filiberto@nasa.gov

One of the biggest scientific questions about Venus is related to its volcanic state; specifically, if it is still volcanically active, how active it is today, and what was the volcanic re-surfacing rate through time [e.g., 1]. It is important to constrain the volcanic activity and rate in order to understand the geodynamic state of Venus, its volatile budget, and its current tectonic operating model. In the next decade, we will have extensive new data for the surface of Venus from the upcoming accepted and potential missions to Venus – NASA's DAVINCI [2] and VERITAS [3] missions, ESA's EnVision mission [4], Roscosmos' Venera-D mission [5], China's VOICE mission [6], ISRO's Shukrayaan-I mission [7], and the privately funded Venus Life Finder mission [8]. In order to help prepare for this a new era of Venus exploration the "Analogs for VENus' GEologically Recent Surfaces" (AVENGERS) initiative aims at investigating several terrestrial analog sites for the comparative study of recent and possibly ongoing volcanic activity on Venus [9]. Besides its scientific importance, the AVENGERS initiative acts as a bridge for international scientific collaboration, including the leaderships and/or team members from all the currently selected missions to Venus. Our first site selection is Mt Etna [10] one of the most active and monitored volcanoes on Earth. We directly compared Mount Etna with Idunn Mons, which is a potentially active volcano on Venus [11, 12]. The two volcanic edifices show interesting points of comparison: a) comparable morpho-structural setting, since both volcanoes interact with a rift zone, and b) morphologically similar volcanic fields around both Mount Etna and Idunn Mons. Here we will discuss the main objectives of the project, and the preliminary criteria of selection that will be used to select the analog sites on Earth. We will then provide examples of active volcanic areas on Earth that we intend to use as endmembers volcanoes for the analysis of potential active volcanism on Venus. Finally, we will list the methodologies that will be used in our ongoing and future investigations.

References: [1] King S. D. (2022), *JGR: Planets*, 127, e2022JE007208. [2] Garvin J. B. et al. (2022), *PSJ*, 3, 117. [3] Smrekar S. et al. (2022), *IEEE*. [4] Ghail R. et al. (2021), *Envision Assessment Study Report. European Space Agency*, 1-111. [5] Zasova L. et al. (2019), *SSR*, 53, 506-510. [6] Wang C. et al. (2022), *Chinese Journ. Space Sci.*, 42, 514-518. [7] Sundararajan V. (2021), *ASCEND*, 4103. [8] Seager S. et al. (2022), *Aerospace*, 9, 385. [9] D'Incecco, P. et al. (submitted), *JGR: Planets*. [10] D'Incecco P. et al. (2024), *Icarus*, 411, 115959. [11] Smrekar S. E. et al. (2010), *Science*, 328, 605-608. [12] D'Incecco P. et al. (2021), *PSJ*, 2, 215.

Potential Science Enabled by a Long-Duration Venus Lander

Tibor Kremic[1*], Robert R. Herrick[2]

[1]NASA Glenn Research Center, (21000 Brookpark Road, Cleveland Ohio 44135, USA)
[2]University of Alaska, Fairbanks, (Fairbanks, AK 99775-5910, USA)
*E-mail: Tibor.Kremic@nasa.gov

Venus is a compellingly mysterious planet but a challenging exploration target. Its bulk properties are similar to Earth's but yet its surface, atmosphere, and habitability are dramatically different. The reasons for many of the differences are not clear despite Venus being Earth's nearest neighbor and the first planet to be visited by spacecraft. Several recent orbiters and the ten Soviet missions that have successful landed on Venus have not yet provided the crucial data required to unravel many of the puzzles. There is also growing sentiment that Venus may be a key to better understanding exoplanets, not to mention the recent press about potential habitability of its atmosphere. All these perhaps contribute to why the planetary Decadal Survey reports [1] continue to identify Venus as an important mission target.

Analysis of surface rocks and use of surface geophysical instruments is made challenging by the characteristics of the atmosphere and the hostile environment on the surface. Remote sensing of the surface and near surface environment on Venus is limited due to the layers of sulfuric acid clouds and the dense high-pressure CO2 based atmosphere. The surface temperature of ~460 C and the ~92 bar surface pressure has limited the ability of prior landers to survive beyond ~2 hours.

The National Aeronautics and Space Administration (NASA) is investing in technologies, undertaking experiments, and developing systems to overcome the challenges of exploring Venus to help unravel more of its mysteries. For example, recent technology advances in high-temperature sensors, electronics, power, and other systems have been funded. The work has resulted in maturation of critical capabilities bringing us closer to long-duration surface operations. Work has also been conducted to develop critical instruments, such as a high-temperature seismometer, that may return much needed data to help answer long-standing questions. The technology development work, combined with ground-based simulation capability such as NASA Glenn's GEER (Glenn Extreme Environment Rig) [2], are changing the paradigm for scientific exploration of Venus, especially its surface and interior.

The data that these long duration platforms may provide will allow, for the first time, temporal data to be collected at the surface. Data over time will provide new insights in Venus's climate, weather, seismic activity, as well as chemical weathering and the processes that are shaping its surface [3].

This presentation will provide a glimpse of the potential new science that may be achieved and a short summary of the recent technical progress on long-duration Venus lander capability.

A set of non-exhaustive examples of science contributions is provided in Table 1. The science goals in the table trace potential contributions to key planetary decadal surface [1] questions 3, 4, 5, 6, 10, and 12.

Science Theme	Science objectives for a long-duration lander	Measurements	Instrument Requirements
A) Solid Bodies (Questions 3, 4, and 5)	1) Determine if Venus is currently seismically active, characterize the rate and style of seismic activity	Measure waveforms of seismic waves Concurrent wind data at time of seismic measurement	3-axis seismometer operating for 90 days or more 3 axis wind sensor
	2) Determine the thickness and composition of the crust and lithosphere	Same as above	Two or more stations with instrumentation as noted above.
B) Atmospheres (Question 6)	3) Acquire temporal meteorological data	Measurement of pressure, temperature, wind speed and directions, and solar radiance	Temperature and pressure sensors, 3-axis wind speed measurements, orientation, radiance for 60 days or more
	4) Estimate momentum exchange between the surface and the atmosphere	Same as above	3-axis wind speed measurements, and orientation for 60 days or more
	5) Determine the key atmospheric species over time	Measure the abundance of gases in atmosphere over time	Chemical sensor measurements during descent and at surface over time
D) Past environments and habitability (Question 10)	6) Determine the composition of the crust and lithosphere, measure atmospheric chemistry over time	Same as above	Two or more stations with instrumentation as noted above, chemical sensor measurements at surface over time
E) Exoplanets (Question 12)	7) Determine the evolution of solid bodies and atmospheres	Assess spatial distribution of seismicity to constrain interior evolution and contrast with Earth Concurrent wind data at time of seismic measurements Use current abundance of gases in atmosphere to constrain its evolution	3-axis seismometer operating for 90 days or more, at 2 or more locations 3 axis wind sensor Chemical sensor measurements during descent and at surface over time

Table 1: Summary of potential science enabled by long-duration Venus landers.

References: [1] National Academies of Sciences, Engineering, and Medicine (2023), The National Academies Press. [2] GEER website: https://www1.grc.nasa.gov/space/geer/. [3] Kremic, T. et al. (2020), *PSS*, 190, 104961.

UPDATE ON ACTIVITIES OF THE INTERNATIONAL VENUS RESEARCH GROUP (IVRG): DETAILED MAPPING TO DEVELOP GEOLOGICAL HISTORIES OF 40+ AREAS OF VENUS.

J.W. Head[1], R. E. Ernst[2], and H. El Bilali[2]
[1]Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI, USA, [2]Department of Earth Sciences, Carleton University, Ottawa, Ontario, Canada,
*E-mail: james_head@brown.edu

In preparation for the flotilla of upcoming missions to Venus, the International Venus Research Group (IVRG) was founded by El Bilali, Ernst & Head. The majority are students (graduate and undergraduate), and they are being trained in planetary mapping. Their scientific results help sharpen the research questions and identify target areas for future Venus missions. IVRG members have produced detailed mapping (1:500,000) using Magellan mission data on >80 magmatic-tectonic features in >40 different areas (Fig. 1) which have already led to 6 abstracts in LPSC 2021, 34 in LPSC 2022, 28 in LPSC 2023 and 9 in LPSC2024, as well as 11 journal publications [2-12] and 5 in final preparation for journal submission. Our mapping builds on the global map of Venus [1] and USGS Quadrangle Series maps.

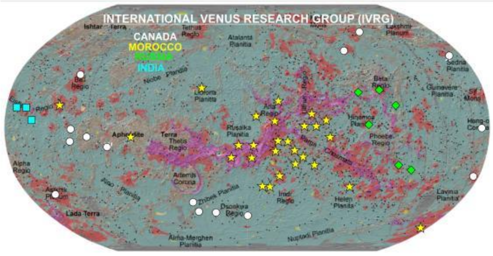


Figure 1. *Distribution of IVRG mapping areas*

Features Mapped: For each feature we list lead author (LPSC abstracts), and numbered references for journal publications. ***Regios.*** Atla Regio (El Bilali [2-3]), Beta Regio (Shimolina) Bell Regio (Riaz), Imdr Regio (western) Boussetta, Khadraoui), Eistla Regio (Chaddha, Singh) SE of Phoebe Regio (Matveev). ***Planitia and Planum.*** Wawalag, northern portion (Ounar), Nsomeka Planitia, eastern portion (Khadraoui), Sedna Planitia, northern portion (Stark), Astkhik Planum (MacLellan [4]). ***Mons.*** Atai (Budko), Atira (Braga [5]), Bagbartu (McAlpine), Kona (Rozhin), Maat (El Bilali), Mbokomu (Hannour [6]), Nyx (Riaz), Ozza (El Bilali), Ongwuti (El Bilali [2]), Polik-mana (Rozhin), Samodiva (Malyshev), Sapas (Ankach), Tepev (Riaz), Theia (Shimolina). ***Corona.*** Achall (Ousbih), Atahensik (Ait Lahna), Belet-Ili (Chaddha [7]), Coatlicue (McAlpine), Derceto (MacLellan [4]), Emegelji (Eloualda), Epona (Hadimi), Eve (Fardy), Gaya (Chaddha [7]), Feronia (McAlpine), Heng-o (Tessier [8]), Inacho (Eloualda) Ituana (Eloualda) Khabuchi (Mediany), Kolias (Oukhro), Kulimina (Ousbih), Latmikaik (Shackman), Lumimuut (El-Ouali), Oanuava (Ousbih), Maram (Mghazli), Nabuzana (Sanchez), Nefertiti (Riaz), Nehalennia (Singh), Nott (Hadimi), Ninmah (Hasanaine), Onenhste (Ben Marzoug [9]), Selu (MacLellan), Sith (Mediany), Xcacau (Shackman), Quetzalpetlatl and interior Boala (Ben Marzoug), corona-rich portion of Dali chasma (Hasanaine), corona cluster N of Atla Regio (Moutbir), characterizing portion of giant radiating swarm of Artemis to the south of Artemis (Bley). ***Flucti***. Itoki (Ouaskioud), Neago (Stark), in Astkhik planum (MacLellan [4]). ***Linea (Groove Belts).*** Jokwa (Oukhro), Thaukhud (El-Kamal). ***Rift zones (chasmata) and associated corona.*** Dali (Hasananaie, Ait

Lahna, Mediany), Devana (Shimolina), Hecate (Houane), Latona (Rozhin), Parga (Ben Marzoug, Eloualda, Hannour, Mghazli), Pinga (Budko), Tellervo (Shackman). ***Canali.*** linked to Fotla corona (Demorcy, Studd). linked to Nabuzana corona (Sanchez), Lo Shen, link to magmatic feeder systems (Singhal), Citlalpul system (Studd). ***Tesserae.*** Salus (Khawja [10]), Western Ovda Regio dyke swarm history (Dean) Eastern Ovda Regio (Hannour), link with proposed Great Climate Transition [10,11]. ***Anemone, Paterae and Tholi***. Cluster of Anemone south of Atla Regio (Najib), Ayrton Patera (Jabbour), Kupo Patera (Khadraoui), Libby Patera (Hadimi), Panina Patera (Matveev), Villepreux-Power Patera (Eloualda), Tursa Tholus (Hadimi), Vupar Tholus (Matveev). ***Meteorite airburst "splotch" chain***. (Antropova, [12]).

Broad theme: Links to LIPs [13-15], their dyke swarms [2,3, 13-16], magma reservoirs [4,15], and assessing influence on climate [10, 11, 17-18].

References: [1] Ivanov, M. and Head, J.W. (2011), *PSS*, 59, 1559. [2] El Bilali, H. et al. (2023), *Comm Earth Environ*, 4, 235, [3] El Bilali, H. and Ernst, R. E. (2024), *Nat Comm*, 15, 1759. [4] MacLellan, L. M. et al. (2021), *Earth-Sci. Rev.*, 220, 103619. [5] Braga, C. H. G. et al. (2024), *PSS*, 244, 105879. [6] Hannour, N. et al. (2024), *Icarus*, 423, 116268. [7] Chaddha, T. et al. (2024), *Icarus*, 410, 115893. [8] Tessier, A.D. et al. (2024), *Icarus*, 417, 116090. [9] Ben Marzoug, M. et al. (2024), *Icarus*, 424, 116269. [10] Khawja, S. et al. (2020), *Nat Comm*, 11, 5789. [11] Way, M. et al. (2022), *Planet. Sci. J.*, 3, 92. [12] Antropova, E. G. et al. (2023), *PSS*, 228, 105636. [13] Ernst, R. E. (2014), *Large Igneous Provinces. Cambridge U. Press.* [14] Buchan, K. L. and Ernst, R. E. (2021), *Gond. Res.*, 100, 25-43. [15] Ernst et al. (2022), *LPSC 53*, #1188. [16] Ernst et al. (2023), *LPSC 54*, #2603. [17] Way and Del Genio (2020), *JGR Planets*, 125, e2019JE006276. [18] Head, J. W. et al. (2021), *LPSC 52*, #2143.

Session 3:
Lightning and Habitability

Studying Venus using Balloon Probe

Kinsuk Acharyya
Physical Research Laboratory, Navrangpura, Ahmedabad - 380 009, India
E-mail: acharyya@prl.res.in

Venus is our closest planetary neighbour, and it is also a terrestrial planet with a dense atmosphere and having regions with conditions similar to Earth's atmosphere. It makes it an ideal target for balloon probes, providing a unique opportunity to conduct experiments for in-situ measurement. It can help us understand its atmosphere and may shed light on its surface processes, e.g., volcanic activity. Venus is likely to be formed from the ingredients of the solar nebula like Earth and, in many ways, similar to Earth's structure. It has a central core, a rocky mantle, and a solid crust. However, some significant differences between the two planets are also there. It includes Venus' slow retrograde rotation and the thick atmosphere surrounding it, which is nearly 95 % carbon dioxide and 3.5 % nitrogen, whereas, on Earth, nitrogen accounts for 78% of the atmosphere and oxygen 21%. Venus's atmosphere also lacks water but has sulfuric acid clouds. One of the fundamental questions is: Why is Venus so different from Earth, and how is it related to the evolution of terrestrial planets like Earth? Also, the discovery of Venus-like exoplanets assumes significance in this context. Although challenging the balloon probe in the Venusian atmosphere at the cloud altitude level can be the best bet to understand the present-day cloud-level Venus atmosphere to decipher the current climate and its evolution, which is crucial to understanding the climatic evolution of terrestrial planets, In this talk I will discuss the importance of a balloon probe in the atmosphere of Venus and its possible scientific outcome.

Venusian Lightning and possibility of ground based observation

S. Jitarwal[1]*, J. P. Pabari[1], S. Nambiar[1], N. J. S. S. V. Prasad[1], Rashmi[1], K. Acharyya[1], T. Upadhyaya[2] and Team
[1]Physical Research Laboratory, Ahmedabad, India
[2]Charusat, Changa, India
*E-mail: sonam@prl.res.in

Lightning on Earth is well studied but it is not yet fully understood in the case of Venus. Lightning in the atmosphere of Venus were discovered in several past missions like Venera landers [1], Pioneer Venus Orbiter (PVO) [2] Lightning and Airglow Camera (LAC) [3] and IR2 camera on-board Akatsuki [4]. These measurements are performed using detection of electromagnetic waves in radio and optical domain. Hansell et al. (1995) used 153 cm telescope located on Mt. Bigelow, Arizona for detection of 777.4 nm (OI line), which represents the excitation of neutral oxygen during the lightning flash. The measurements were carried out on night side of Venus and during the observation period, six flashes were detected in this line [5]. Lightning is a crucial phenomenon in planetary atmospheres, as it can generate unique physical conditions. For better understanding of this process, we propose to take observations in campaign mode to detect lightning on Venus using a similar test setup. We can utilize the PRL telescope facility at Mount Abu for this purpose.

In this work, we present about past measurements, development of Lightning Instrument and measurement concept for ground based observation of Venusian lightning.

References: [1] Ksanfomaliti L. V. (1980), *Nature*, 284, 244-246. [2] Scarf and Russell (1983), *GRL*, 10, 1192-1195. [3] Takahashi et. al. (2021), *Research Square*, Pre-print. [4] Ksanfomaliti L. V. (2023), *CR*, 62, 60-72. [5] Hansel et. al. (1995), *ICARUS*, 117, 345-351. 6] Borucki et. al. (1985), *ICARUS*, 64, 221-232. [7] Lorenz Ralph (2018), *PEPS*, 5:34.

Chemical impacts on the Venusian atmosphere by lightning-inducing discharges

Cheng-Ling Kuo[1*], Jayesh P. Pabari[2], Wing-Huen Ip[1,3]
[1]Department of Space Science and Engineering, National Central University, Taiwan
[2]Physical Research Laboratory, Ahmedabad, India
[3]Institute of Astronomy, National Central University, Taiwan
*E-mail: clkuo@g.ncu.edu.tw

Venus has the most massive atmosphere of the terrestrial planets, including Mercury, Earth, and Mars [1]. Venusian atmosphere is abundant with greenhouse gas and composed of 96.5% carbon dioxide and 3.5% nitrogen, with other chemical compounds (carbon monoxide, sulfur dioxide, water vapor, argon, and helium) present only in trace amounts. Here, we used the zero-dimensional plasma chemical model [2,3] to study the chemical effects on the middle atmosphere of Venus by lightning-inducing discharges. We adopted the Venus atmosphere model [4] as the background reference in the initial condition. We use the electric field calculation from the Venus lightning charge region [5], and estimate the possible discharge region at altitudes between 90 and 110 km. The Venusian ionosphere model [6] was also used for charged species involved in the plasma chemical reactions in the discharge region. In a hypothetical situation of a plasma streamer in the discharge region, the high electric field at the head of the plasma streamer will cause a series of plasma chemical reactions. We can use the simulation results to investigate the key parameters for the Venusian atmosphere electrostatic model in future work.

References: [1] O'Rourke, J. G., Wilson, C. F., Borrelli, M. E. et al. (2023), *Space SciRev,* 219, 10. [2] Kuo et al. (2011), *JGR,* 116, A01310 [3] Kuo et al. (2012), *JGR,* 117, A07320. [4] http://www-venus.lmd.jussieu.fr/vcd_python/. [5] Dinesh Kumar V. R. et al. (2021), *ICARUS,* 365, 114473. [6] Antoine Martinez et al., (2024), *ICARUS,* 415, 116035.

Session 1-B:
Atmosphere and Ionosphere

Signs of Heterogeneously Composed Aerosols in Pioneer Venus Mass Spectra

R. Mogul[1], M. Yu. Zolotov[2], M. J. Way[3], S. S. Limaye[4]
[1]California State Polytechnic University, Pomona. [2]Arizona State University. [3]NASA Goddard Institute of Space Studies. [4]University of Wisconsin, Madison.
E-mail:rmogul@cpp.edu

We present mass spectral evidence that the aerosols in Venus' clouds are composed of sulfuric acid (H_2SO_4), iron sulfates (*e.g.*, $Fe_2(SO_4)_3$), and substantial water (H_2O) from differing hydrates. This assessment was reached by re-analysis of in situ data acquired by the Pioneer Venus Large Probe (PVLP), which descended through Venus' atmosphere in 1978 [1-4]. Novel to our work is the interpretation of the PVLP data as an evolved gas analysis of heterogeneously composed aerosols from the middle and lower clouds. We propose that cloud aerosols inadvertently collected within the PVLP intake inlet assemblies and thermally and differentially decomposed across the temperature gradient of the atmosphere (~ –25 to 460 ˚C) during the PVLP descent (~ 64 km to the surface). Evolved gases and compounds that released into the PV Large Probe Neutral Mass Spectrometer (LNMS) included SO_2, H_2O, SO_3, O_2, and Fe_2O_3 (inferred from FeO^+). Release of these species is consistent with the thermal decomposition of aerosols containing H_2SO_4, ferric sulfates, and differing hydrates (Fig. 1). To obtain weight percent (w%) and mass loading (mg m^3), we converted ion counts to number density [2], extracted the LNMS inlet temperatures at each altitude, conducted peak fitting of the SO_2 and H_2O thermal profiles using Gauss functions, expressed peak areas from the fits as number densities for parent species using the stoichiometric relationships in Fig. 1, and identified the aerosol collection column as ~ 51-48 km. These considerations support an aerosol composition (Table 1) that includes near equivalent masses of H_2SO_4 and $Fe_2(SO_4)_3$ and ~ 3-fold higher abundances of hydrate-phase H_2O, likely arising from hydrated iron sulfates and other species (*e.g.*, $MgSO_4{\cdot}H_2O$; kieserite). Abundances in the volatile fraction (Table 1) and total aerosol mass loading (5.4 ± 0.5 mg m^{-3}) are consistent with all prior Venus measurements. Thus, this work reveals a potentially underestimated reservoir of water and cosmic materials (*e.g.*, Fe) in Venus' clouds, which could significantly impact cloud chemistry and cloud habitability models.

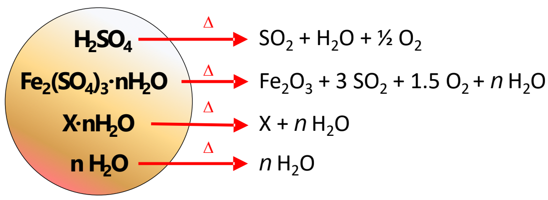


Figure 1. Thermal decomposition reactions for aerosol species captured in the LNMS inlets ($X{\cdot}H_2O$ = in/organic hydrates).

Table (A) Aerosol phase abundances; (B) partitioning of total aerosol H2O (~ 64 w%) across sources including hydrates exhibiting differing LNMS decomposition temperatures (TD); and (C) abundances in the volatile fraction of the aerosols.

Aerosol Weight Percentages (w%) & Mass Loading (mg m^{-3})						
(A) *Aerosol Constituents*			**(B) *Aerosol Water***		**(C) *Volatile Fraction***	
compounds	**w%**	**mg m^{-3}**	**sources**	**w%**	**compounds**	**w%**
H_2SO_4	21 ± 3	1.1 ± 0.2	hydrate species T_D ~ 300-460 ˚C	61 ± 9	H_2SO_4	87 ± 17
$Fe_2(SO_4)_3$	15 ± 2	0.8 ± 0.1	hydrate species T_D ~ 50-250 ˚C	3 ± 1	H_2O	13 ± 4
total H_2O	64 ± 9	3.5 ± 0.4	solution phase	0.2 ± 0.1		

References: [1] Mogul et al. (2023), *Icarus*, 393. [2] Mogul et al. (2023), *MethodsX*, 11. [3] Mogul et al (2021), *GRL*, 48. [4] Hoffman et al (1980), *JGR*, 85.

The Solar Wind Interaction with an Orbiting Venus

Stephen Ledvina
University of California, Berkeley, USA
E-mail: ledvina@ssl.berkeley.edu

Studies of large-scale interaction of the solar wind with planets has often been considered along the line of the sun to the planet, neglecting the planet's orbital motion. This talk describes a new refinement in the long history of Venus simulations, the addition of the planet's orbital motion. Simulations with this refinement have produced a change in the electromagnetic environment around Venus. This leads to dramatic changes in how the solar wind interacts with Venus, producing new channels of ion loss and altering the energy deposition of the solar wind into the upper atmosphere.

Observations of Venus' O_2 Airglow from Ground-Based Instruments

E.M. Royer[1*], S. Avina[1], E.F. Young[2], M.A. Bullock[3], T. Navarro[4]
[1]California State University, Los Angeles, 5151 University Dr., Los Angeles, CA 90032
[2]Southwest Research Institute, Boulder, CO
[3]Science and Technology Corporation, Boulder, CO
[4]Space Science Institute, Boulder, CO
*E-mail: eroyer@calstatela.edu

Airglow emissions from Venus' upper atmosphere serve as valuable indicators of the atmospheric dynamics at altitudes ranging from 90 to 120 km. Notably, the 1.27 μm O_2 airglow, which peaks around 95 km, is situated at the intersection of two distinct circulation patterns: a retrograde zonal super-rotating (RZS) flow beneath ~100 km and a sub-solar/anti-solar circulation (SSAS) above 100 km [1]. The Venus Express (VEX) mission, which operated from 2006 to 2014, provided extensive observations of the O_2 night side airglow on Venus, revealing the intricate dynamical behavior in Venus' thermosphere. Aside from the brighter anti-solar airglow main patch near the midnight equator, data from the Visible and Infrared Thermal Imaging Spectrometer (VIRTIS) highlighted a secondary localized peak near 50ºN and 30º N that current models fail to replicate [2]. Recent modeling efforts, however, have suggested that the brightness and latitudinal distribution of the airglow are influenced by a ~5-day period Kelvin wave [3].

In this study, we introduce a new method for retrieving the O_2 nightglow signal on Venus using the ground-based IRTF SpeX Instrument. This instrument has been capturing Venus observations since 2001 as part of a program focused on the planet's clouds, and it has also collected data on the 1.27 μm O_2 airglow (averaging two images per night). By scanning the SpeX slit across Venus' disk, we achieve the spatial coverage needed to observe nightglow features both at the limb and on the disk. This new approach enables the measurement of O_2 airglow intensity and distribution over several days around inferior conjunction. By utilizing IRTF SpeX observations from before, during, and after the VEX mission, we aim to enhance the spatial and temporal coverage, gain deeper insights into the O_2 airglow characteristics, and assess the effects of the predicted ~5-day Kelvin wave modulation on airglow morphology [3].

This unique dataset offers a fresh perspective on the 1.27 μm O_2 airglow at Venus, facilitating the analysis of short-term changes in nightglow morphology on nights with multiple images from SpeX. Additionally, the 23 years of data available provide essential information for a long-term analysis of airglow behavior, complementing existing mission data.

References: [1] Bougher, S. W., Alexander, M. J. and Mayr, H. G. (1997), *Venus II, Ch. 2.4* (U. of Arizona Press, Tucson, 1997), 259–292 [2] Gérard, J. C. et al. (2014), *Icarus*, 236, 93–103. [3] Navarro, T. et al. (2021), *Icarus*, *366*, 114400.

VASP - Venus Atmospheric Spectro-Polarimeter

Anand Jain, Swapnil Singh, Bhavesh Jaiswal, Brajpal Singh, Reenu Palawat, Ravishankar B T, Manju Sudhakar, Anuj Nandi
Space Astronomy Group, ISITE Campus, U. R. Rao Satellite Centre, ISRO, Bangalore-560037, India
*E-mail: anandj@ursc.gov.in

Venus has been explored by several space based instruments on-board various missions; however there are still uncertainties in the global understanding of Venusian atmosphere. We are interested in studying the cloud formation and related dynamics in the atmosphere of Venus which is known to be covered with the sulphuric acid clouds. Previous measurements have shown the size of the cloud particle size to be close to ~ 1 µm at low latitudes and ~ 0.2 µm at high latitudes. The complete study of scattered light which requires measuring the stokes parameter Q and U simultaneously, especially in an optically thick medium like Venus where multiple scattering can dominate, is one of the primary objectives of VASP. The spectro-polarimeter under development is designed in the near infrared wavelength range of 0.9 - 1.7 µm which is sensitive to linear polarization. It consists of Acousto-Optic Tunable Filters (AOTF), InGaAs detectors, Telescope optics and RF synthesizer unit. With this instrument, we can study the clouds in the Venusian atmosphere using polarization measurements of the scattered solar radiation. The design also enables spectroscopic measurements which can (a) quantify the water vapour (H2O) and carbon dioxide (CO2) present in the Venusian atmosphere, as well as (b) help study the cloud top altitude. Similar concept study has been carried out in Chandrayaan-3 mission, wherein an experimental payload titled Spectro-polarimeter for HAbitable Planet Earth (SHAPE) was successfully demonstrated.

References: [1] Nandi, A. et al. (2013), *ASI Conference Series*, 9, 101 [2] Agrawal, P. et al. (2015), *Experimental Astronomy*, [3] Jaiswal B. et al. (2022), *Journal of Astronomical Telescopes, Instruments, and Systems*, 8, 4, 044007 [4] Nandi, A. et al., (2024), *Journal of Aerospace Sciences and Technologies,* (Accepted)

Venera-D: A Mission For Comprehensive Study of Venus

L.M. Zelenyi[1], O.I. Korablev[1*], L.V. Zasova[1], M.V. Gerasimov[1], N.I. Ignatiev[1], D.S. Rodionov[1], D.V. Strelnikov[1], M.A. Ivanov[2], N.A. Eismont[1], D.A. Gorinov[1*]
[1]Space Research Institute RAS, Profsouznaya 84/32, Moscow 117997, Russia
[2]Vernadsky Institute of Geochemistry and Analytical Chemistry, Kosygina 19, Moscow 119991, Russia
*E-mail: dmitry_gorinov@cosmos.ru

Venera-D is a planned mission to study atmosphere, surface and surrounding plasma of Venus to resolve the fundamental questions of difference between climates of Venus and Earth. It can also help understand environments of the terrestrial planets of the Solar and extrasolar systems, as well as the shed light on the question of their potential habitability. The Venera-D mission architecture combines the orbiter, the lander and two airborne balloons to use different approaches to obtain knowledge about Venus.

The Orbiter on the polar orbit is focused on studying thermal structure, dynamics and the composition of the atmosphere (both above and below clouds) and magnetosphere.

The Lander is the primary element of the Venera-D mission, which distinguishes it from the other currently planned Venus missions [1]. It contains the scientific payload to study the elemental and mineralogical composition of the surface and near subsurface materials after drilling to a few cm depth and taking samples, as well as the structure and chemical composition of the atmosphere down to the surface, including the abundances and isotopic ratios of the trace and noble gases, direct chemical analysis of cloud aerosols, and the geomorphology of the landing site.

The mission will also include aerial platforms — paired balloons to operate for up to one month at the 53-55 km altitudes. Such modules can provide unique in situ information on the meteorological parameters, composition of the atmosphere, cloud structure, composition and microphysics, nature and distribution of the UV absorber. They will also investigate the potential cloud habitability.

The Venera-D project, which is planned to be launched in 2031, will be an important complementation to the other future Venus missions (VERITAS, DAVINCI, EnVision, and Indian Venus Orbiter). Venera-D has unique capabilities such as surface sampling and long-term in situ cloud measurements, and instrumentation that can work in synergy with the parallel missions. A coordination of efforts between missions and their scientific instruments is crucial to answer the most important fundamental questions about our mysterious neighbor planet.

References: [1] Widemann T. et al. (2023), *Space Science Reviews,* 219(56)

Experiment VIRAL to study Venus upper atmosphere: scientific concept

Denis Belyaev[1*], Andrey Patrakeev[1], Alexander Trokhimovskiy[1], Oleg Korablev[1], Franck Montmessin[2], Anna Fedorova[1]
[1]Space Research Institute of the Russian Academy of Sciences (IKI), Profsoyusnaya str., 84/32, Moscow, 117997, Russia
[2]LATMOS/IPSL, UVSQ Université Paris-Saclay, Sorbonne Université, CNRS, 11 BD D'Alembert Guyancourt, 78280 France
*E-mail: dbelyaev@cosmos.ru

In this paper we present a concept of the VIRAL experiment that was chosen by the Indian Space Research Organisation (ISRO) as a scientific payload on board their Venus Orbiter Mission. VIRAL (Venus InfraRed Atmospheric gases Linker) is a remote sensing infrared (IR) spectrometer to study the composition and structure of the atmosphere at the top and above the cloud layer of Venus in the altitude range 65 to 180 km, with the solar occultation technique. VIRAL will cover the IR range from 2.3 to 4.3 μm with spectral resolving power above 22000 and will sound the atmosphere with high vertical resolution (around 1 km at the limb, depending on the mission orbital configuration). These facilities will allow retrieving the upper atmospheric structure and its composition like as CO_2 and its main isotopes (with related temperature), H_2O and HDO (related to the evolution of water on Venus), as well as other minor species (CO, SO_2, HCl, HF), and layers of H_2SO_4 droplets. VIRAL's enhanced sensitivity will also allow establishing refined upper limits or new detections for a number of trace gasses, such as OCS, H_2S, H_2CO, C_2H_2, phosphine.

VIRAL employs a combination of an echelle spectrometer and an acousto-optic tunable filter (AOTF) serving for the selection of diffraction orders. This concept relies on a series of new-generation instruments that have orbited and operated around Venus and Mars for the last more than decade years, in particular the ACS instrument onboard ExoMars TGO mission [1], and the previous SOIR experiment onboard the Venus Express orbiter [2]. The AOTF-echelle combination allows the sequential acquiring of several diffraction orders during one measurement. They can be located at any required spectral interval within the accessible spectral range thanks to the AOTF flexibility and high-speed performance. This makes VIRAL both an extremely capable and a versatile instrument efficiently packed in a <7 kg housing, requiring less than 20W (peak power) and implementing onboard intelligence to limit telemetry to <100 Mbits/orbit. The mechanical requirements are restrained to an envelope of 12×40×25 cm^3.

References: [1] Korablev, O. I. et al. (2018), *SSR,* 214(7) [2] Nevejans, D. et al. (2006), *Applied Optics,* 45(21)*,* 5191-5206.

Session 4:
Short Oral Presentation

Sporadic Nature of Meteor Layer in Planetary Atmosphere

S. Nambiar*, J. P. Pabari, S. Jitarwal and Rashmi
Physical Research Laboratory, Navrangpura, Ahmedabad, India-380009
*Email: srirag@prl.res.in

Interplanetary dust particles, spread throughout our solar system, constantly interact with planetary bodies and get ablated in presence of atmosphere. During the ablation process, neutral and ionized atoms get deposited in the atmosphere, leading to formation of a meteor layer as observed in atmospheres of Earth, Mars and Venus [1-4]. The density, altitude of peak density and shape of the layer depends on several factors of incoming particles as well as the atmosphere. An ablation model was developed to simulate this process and the derived results of production rate profiles of metallic ions and atoms, computed from the model, will be presented [5]. Radio occultation technique provides us electron density profiles in the atmosphere and has played a key role in establishing the meteor layer in the planetary atmosphere. Past observation using this technique has shown variation in the peak altitude and peak density of meteor layer over time and planetary location [6]. The possible reasons behind this sporadic nature of meteor layer is explored.

References: [1] Plane J. M. C. (2012), *Chem. Soc. Rev.,* 41, 6507–6518. [2] Pätzold, M. et al. (2005), *Science*, 310, 837–839. [3] M. Pätzold et al. (2009), *GRL*, 36, L05203. [4] Carrillo-Sanchez J. D. et al. (2020), *Icarus*, 335, 113395. [5] Pabari J. P. et al. (2023), *PSS*, 226, 105617. [6] P. Withers et al. (2008), *JGR*, 113, A12314.

Estimation of the H_2SO_4 and SO_2 vapor concentrations below the Clouds of Venus using Radio Occultation Technique by the Akatsuki Spacecraft

S. Banerjee[1*], R. K. Choudhary[1], K. R. Tripathi[2], A. A. Potdar[1], T. Imamura[2]
[1]Space Physics Laboratory, VSSC, Trivandrum, Kerala, India 695022
[2]The University of Tokyo (Graduate School of Frontier Sciences, The University of Tokyo, Kashiwa, Chiba 277-8561, Japan)
*E-mail: soumyaneal08@gmail.com

The Radio Science (RS) payload onboard the Akatsuki spacecraft has been used to probe the atmosphere of Venus from 2016 to 2024. The Radio Occultation (RO) technique is implemented to study the sulfuric acid vapors present typically between the altitudes of 35-50 km, just below the base of the clouds of Venus. The X-band radio signal (~8.41 GHz) transmitted by a stable radio source from the RS payload was used for the experiments. Radio signals get attenuated due to refractive effects and the absorption by the Venus atmosphere. The primary absorber is H_2SO_4 vapors present below the clouds of Venus. The attenuation due to refractive effects and the absorption of the signal by the other X-band absorbers in the Venus atmosphere like CO_2, N_2, and SO_2, is subtracted from the total signal loss. The residual attenuation, caused by the H_2SO_4 vapors, is converted into absorptivity through an Abel inversion. Finally we get the mixing ratio values from the absorptivity, thereby providing the abundance of the sulfuric acid vapors in the region. This is the first study conducted using the Akatsuki datasets to study H_2SO_4 below the clouds of Venus. The initial results suggest that the H_2SO_4 vapor concentration matches with the studies conducted during previous missions (VEX and PVO). The vapor concentration typically increases from zero ppm at an altitude of 50 km up to 6-13 ppm, peaking in the 44-46 km region, and again decreasing to a few ppms further down.

Additionally, SO_2 concentrations from 55-35 km have also been estimated using our present understanding that H_2SO_4 vapor concentration exponentially decreases to zero above 50 km altitudes, following its saturation vapor pressure curve. This gives us estimated SO_2 values in the range of a few tens to a few hundred ppms, which also agree with the existing studies. In the talk, various results concerning measurements of H_2SO_4 and SO_2 will be presented and discussed.

References: [1] T. Imamura et al. (2017), *EPS*, 69, 137. [2] J. Oschlisniok et al. (2021), *Icarus* 362, 114405. [3] J. M. Jenkins and P. G. Steffes (1991), *Icarus* 90 (1), 129-138. [4] W. Ho et al. (1966), *J. Geophys. Res.* 71 (21), 5091-5108. [5] A. K. Fahd and P. G. Steffes (1991), *JGR* 96, 471-476. [6] M. A. Kolodner and P. G. Steffes (1998), *Icarus* 132 (1), 151-169. [7] G. P. Ayers et al. (1980), *Geophys. Res Lett.* 7 (6), 433-436.

Observations of Stationary Waves in Venusian Clouds

Ramdayal Singh*, Abhineet Shyam and Rajesh Upadhyaya
Planetary Science Division, PGSG, EPSA, Space Applications Centre, Ahmedabad
*E-mail: ram@sac.isro.gov.in

Observations of Venus cloud-top temperature have been conducted by Akatsuki using a Longwave Infrared Camera, LIR [1]. We have further investigated the presence of large stationary gravity waves seen in Venus cloud-top brightness temperature images of LIR data [2] (see figure 1 white ellipses on the disk as well as their corresponding topographic locations, extracted from Magellan data [3], marked as A, B, C & D) for the four dates in the year 2016 & 2017 as a precursor to follow-up investigations towards unravelling stationary wave features at various locations of Venus. For this, VIRTIS (VEX mission) images are also currently planned to be utilized owing to its availability over regions not covered by Akatsuki.

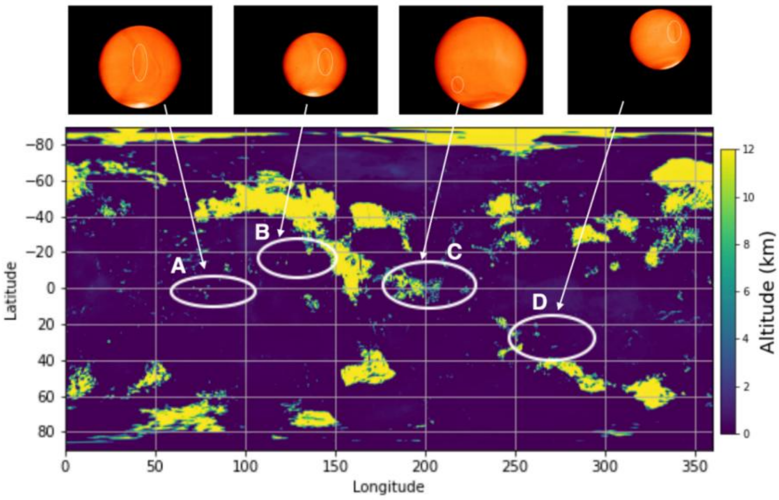


Figure 1: Examples of large stationary gravity waves seen in brightness temperature images of the Venus disk taken by LIR (A. 03 Aug 2017, B. 14 Aug 2016, C. 23 Dec 2016, D. 14 Jan 2017), corresponding to highland locations of four regions (A. Ovdio Regio, B. Thetis Regio, C. Atla Regio and D. Beta Regio) on the Venus topography map.

The study is significant to understand the propagation and dissipation effects of stationary waves in the thermosphere as they are likely to have strong implications on momentum shift of the planet, thereby, causing decrease in the length of Venusian day [4]. Significant changes in temperature may be evident also [5]. The study is a preparation prior to ISRO’s Venus mission with proposed Venus Thermal Camera (VTC) instrument by Space Applications Centre (SAC). The instrument shall operate in the 8-12 µm spectral range and has a high-temperature sensitivity. VTC is designed to have an NEdT of 0.1 K at 230 K and will have approximately 0.5 km resolution from the periapsis and 60 km from the apoapsis for an elliptical orbit of 500 km x 60,000 km, known from ISRO’s initial proposal as on date.

References: [1] Fukuhara, T., (2011), *Earth, Planets and Space*, 63. [2] Taguchi, M., SIS for VCO LIR Camera Data Products, (2024). [3] Ford, P. & Pettengill, G., *JGR*, 97, 13103-13114. [4] Navarro et al., (2018). *Nature Geoscience*, 11, 487-491. [5] Hickey et al., (2022). *Icarus*, 377, 114922.

Cyclostrophic Wind retrieval using Akatsuki Radio Occultation data in the middle atmosphere of planet Venus

Ancy Jerald[1*], T Maria Antonita[2], Deepa V[1]
[1]Department of Physics, Mahatma Gandhi College, Thiruvananthapuram, Kerala, India
[2]Science Program Office, ISRO Headquarters, Bangalore-560094, Karnataka, India
*E-mail: ancyjerald06@gmail.com

The phenomenon of super-rotation in the Venusian atmosphere, where winds significantly outpace the planet's rotation, remains a key area of scientific investigation. This intriguing feature, with winds reaching speeds of hundreds of kilometers per hour, has sparked significant scientific curiosity, driving the need for comprehensive wind measurements. Understanding the dynamics of Venus's atmosphere, especially the super-rotation, requires precise wind measurements in the middle atmosphere. However, only a few direct space-based techniques are currently available to measure winds. Cloud motion vectors (CMV) are commonly used to study circulation in Venus's middle atmosphere.In this work, a novel technique is introduced to estimate zonal winds from temperature profiles using the cyclostrophic approximation. This approximation suggests that global zonal circulation results from the balance between the pressure gradient force and the centripetal force on a slowly rotating planet, in the absence of Coriolis forces. The temperature profiles utilized are from the Radio Science (RS) experiment of the Japan Aerospace Exploration Agency's (JAXA) Akatsuki, or Venus Climate Orbiter (VCO) mission. Radio occultation has proven to be a powerful technique for studying atmospheric conditions. This method relies on the bending or refraction of radio signals as they pass through the atmosphere to derive state vectors like density, temperature, pressure, and total electron density in the ionosphere. Temperature profiles from 2018 to 2022 are used to estimate zonal wind fields in Venus's middle atmosphere. The estimated winds are compared with the Venus Climate Database and Akatsuki UVI wind data at the cloud levels. These derived zonal winds are key to understanding the dynamic nature of Venus's middle atmosphere, and detailed results will be presented at the conference.

References: [1] Horinouchi, T. et al. (2017), *Nature geoscience*, 10(9), 646-651. [2] Imamura, T. et al. (2011) *Earth, planets and space*, 63, 493-501. [3] Piccialli, A. et al. (2012), *Icarus*, 217(2), 669-681.

Prototype Development for future Airglow Photometer Experiments on-board terrestrial and planetary missions

R. Pathak
Physical Research Laboratory, Ahmedabad, India
Email: rpathak@prl.res.in

A number of Airglow Photometer (AP) experiments are being planned for future ISRO missions (Earth, Venus and Mars) to detect oxygen emission lines by limiting the spectral bandwidth (to enhance SNR) and field of view (to capture even small-scale spatial variations in the emission). The selection of an optical detector for detecting these wavelengths is crucial, as it determines the overall performance and capability of the system. Therefore, the choice of detector is based on an extensive calculation of Signal-to-Noise Ratio (SNR), considering the optimization of the field of view (FOV), spectral bandwidth, dark noise, readout noise, pixel size, etc. We have explored various bare CMOS chips, such as the C650 chip, CAPELLA-CIS120 chip, and CMV4000-3E12M1PP, to design a working prototype of the airglow payload. This prototype consists of front-end, processing, and ground checkout systems. The C650 chip has already been used in the HySIS payload (Chandrayaan-1 mission) and the LiVHySI payload (YouthSat mission). The CMV4000-3E12M1PP has been used in the Mars Colour Camera (MCC) payload in Mars Mission. In this talk, I will present the initial results obtained using SCMOS chips, explain the rationale behind selecting SCMOS detector chips, and discuss their development.

Lightning generated whistler wave propagation through ionosphere of Venus

Ankita[1] and R.S. Pandey[1*]
[1]Department of Physics, Amity Institute of Applied Sciences, Amity University, Sector - 125 Noida, Uttar Pradesh, India
*E-mail: rspandey@amity.edu

In the present study whistler mode waves are studied with parallel DC electric field for generalized distribution function in the Jupiter's magnetosphere. This work is examined for generalized distribution function which are reducible in bi-Maxwellian for $j = 0$ and loss-cone distribution function for $j = 1$. We have analysed the effect of various plasma parameters on the growth rate of waves by utilizing the approach of kinetic theory and method of characteristics solutions. The growth rate has enhanced by increasing the magnitude of electric field, temperature anisotropy, energy density, and particle number density. The analysis shows that temperature anisotropy, the increase of magnitude of DC electric field, the growth rate of whistler wave increases with significant change of wave number. This result is of great significance for analyzing the very low frequency radiation observed in ionosphere of Venus a wide frequency of range.

Development of ionospheric model for the Venus ionosphere

K.M Ambili
Space Physics Laboratory, VSSC, ISRO, India
*E-mail: ambili_km@vssc.gov.in, ambilisadasivan@gmail.com

Venus, being the closest planet to Earth, has been a subject of numerous planetary missions aimed at studying its atmospheric and ionospheric composition and density. The Venus ionosphere is formed by the photoionization of the neutral atmosphere by solar EUV and X-ray radiations and, as a secondary effect, by photo-electron impact ionization at lower altitudes. In addition to the V2 layer, Venus is known to have the presence of a secondary layer of enhanced ionization at the lower height (~125 km) as well [1,2]. Though Venus has been thoroughly explored in the past various missions, there are still outstanding questions even related to the formation of the different layers. Physics based ionospheric model is a potential tool to understand Venus ionosphere in detail.

Since the Venus is devoid of magnetic field, the dynamics of the plasma is different from the Earth's ionosphere. Venus ionosphere is in photo-chemical equilibrium below 200 km where the production and loss plasma controls the net electron density profile. In Space Physics Laboratory, we developed a One Dimensional Venus Ionospheric Model (1D-VIM), which includes the production and loss of 11 ions and the diffusion of plasma in the vertical direction. 1D-VIM considered a thermosphere composed of six major neutrals. Model also explains the role of minor neutrals in the Venus ionosphere and the impact on the net electron density profile. Model has been used successfully to understand various physical problesm related to V2, V1 and the V0 layer of the Venusian ionosphere.

References:

[1] Cravens, T., Kliore, A., Kozyra, J., Nagy, A., 1981. The ionospheric peak on the venus dayside. J. Geophys. Res. 86, 11323–11329. [2] Girazian, Z., Withers, P., Häusler, B., Pätzold, M., Tellmann, S. and Peter, K., 2015. Characterization of the lower layer in the dayside Venus ionosphere and comparisons with Mars. Planetary and Space Science, 117, pp.146-158. [3] Imamura, T., Ando, H., Tellmann, S., Pätzold, M., Häusler, B., Yamazaki, A., Sato, T.M., Noguchi, K., Futaana, Y., Oschlisniok, J. and Limaye, S., 2017. Initial performance of the radio occultation experiment in the Venus orbiter mission Akatsuki. Earth, Planets and Space, 69(1), pp.1-11. [4] Ambili, K.M., Babu, S.S. and Choudhary, R.K., 2019. On the relative roles of the neutral density and photo chemistry on the solar zenith angle variations in the V2 layer characteristics of the Venus ionosphere under different solar activity conditions. Icarus, 321, pp.661-670.

Venusian Ionosphere as Observed by Akatsuki Radio Science Experiments

Keshav R. Tripathi[1*], T. Imamura[1], R.K. Choudhary[2], and Ambili KM[2]
[1]Graduate School of Frontier Sciences, The University of Tokyo, Japan.
[2]Space Physics Laboratory, VSSC, Trivandrum, Kerala, India.
[*]Email: tripathikr95@gmail.com

During the deep solar minimum of solar cycle 24, the distinct characteristics of various layers within the Venusian ionosphere were investigated through a radio science experiment conducted aboard the Akatsuki spacecraft. Tracking of radio signals from the spacecraft took place at multiple locations: the Indian deep space network in Bangalore, the Usuda Deep Space Center in Japan, and the DLR Ground station in Weilheim, Germany [1]. The unique orbital geometry of the spacecraft presented rare opportunities for exploring the equatorial region of the Venusian ionosphere and atmosphere at low solar zenith angles (SZAs).

Throughout the observation period spanning from 2016 to 2024, the peak of electron density consistently occurs at an altitude of approximately 141 km, maintaining stability for solar zenith angles ≤ 90°. The associated plasma density recorded during this period ranks among the lowest reported in existing literature. Furthermore, we emphasize that the Venusian ionosphere differs from the Chapman variation observed on Earth.

Examining secondary ionospheric features, the V1 layer (~125 km altitudes) aligns well with the previous measurements. Akatsuki observations identified all three types of V1 layers and sporadic occurrences of the V0 layer (~110 km altitudes) in approximately 15% of cases. The presence of the V0 layer was observed independently of SZA and geographical constraints [2, 3]. The role of different physical processes such as impact of the solar energetic particle events and forcing from the lower atmosphere has also been explored [4]. Despite regular observations, nighttime occurrences of the ionosphere were limited. The significant findings from Akatsuki's observations of the Venusian ionosphere will be presented during the conference.

References: [1] Tripathi, K. R., et al. (2023) *JGR-Planets*, 128, e2023JE007768. [2] Ambili, K. M., Tripathi, K. R., Choudhary, R. K., & Imamura, T. (2022), MNRS, 516(4), 5555–5562. [3] Tripathi, K. et al. (2022). *Geo. Res. Letters*, 49(7), e2022GL097824. [4] Tripathi, K.R., Imamura, T. et al., (2024) *Geophysical Research Letters*, 51(14), p.e2024GL109724.

Venus Express IMA measurements on precipitating solar wind proton

Xu Huang[1,2*], Xiao-Dong Wang[2], Yoshifumi Futaana[2], and Jun Cui[1]
[1] Planetary Environmental and Astrobiological Research Laboratory (PEARL), School of Atmospheric Sciences, Sun Yat-Sen University, Zhuhai, China
[2] Swedish Institute of Space Physics, Kiruna, SE981 28, Sweden
*E-mail: huangx279@mail2.sysu.edu.cn

A fraction of solar wind protons (both upstream and magnetosheath) can be neutralized before they encounter the induced magnetosphere of Venus by charge exchange, allowing them to penetrate the induced magnetosphere as neutral solar wind hydrogen atoms. These hydrogen atoms are partially re-ionized, precipitating onto the upper atmosphere. This process is a channel for mass and momentum deposit to planet that cannot be assessed by collisionless plasma theories. We utilized Venus Express IMA data to identify the signatures of re-ionized solar wind and magnetosheath protons. Our survey has shown no detection of penetrating upstream solar wind protons, while signatures of shocked solar wind protons have been found. We will discuss the characteristics of these protons.

One-Dimensional Photochemical Venusian Ionosphere Model

Satyandra M. Sharma[1,2*], Varun Sheel[1], Tirtha J. Kalita[1]
[1] Physical Research Laboratory, Ahmedabad-380009, India
[2] Indian Institute of Technology Gandhinagar, Gandhinagar-382055, India.
*E-mail: smsharma@prl.res.in

The ionosphere of a planet forms due to the ionization of its neutral atmosphere by various ionizing radiations, including Solar EUV (15-122 nm), soft X-rays (1-15 nm), hard X-rays (1-8 nm), stellar radiations, cosmic rays, and solar energetic particles. These radiations deposit their energy at different altitudes within the ionosphere, depending on their energy and the ionization/absorption cross-sections of the neutral particles.

Our study focuses on the ionospheric features produced by solar photons. Specifically, the photoionization by Solar EUV and soft X-rays is responsible for forming the dayside ionosphere. These processes create the V2 (~140 km) and V1 (~125 km) layers in the Venusian ionosphere. Additionally, a sporadic layer, V0 (~113 km), observed below the V1 layer, is hypothesized to be of non - photochemical origin, though its exact source remains unidentified [1].

We have developed a one-dimensional photochemical model of the dayside Venusian ionosphere, validated against electron density profiles from the Venus Radio Science (VeRa) experiment onboard the Venus Express (VEX). This model is used to study the Venus ionosphere's response to solar cycle variations, with comparisons made to VeRa observations spanning the solar minimum of Solar Cycle 23 to the near-maximum of Solar Cycle 24 (2006-2014).

Our in-house model considers the production and loss of 12 ions: CO_2^+, CO^+, C^+, O_2^+, $O^+(4S)$, $O^+(2D)$, $O^+(2P)$, N_2^+, N^+, NO^+, H_2^+, and H^+. We use background neutrals from VCD v2.3 [2]. By incorporating various ionization sources (e.g., solar X-rays, Lyman-alpha) and examining the background neutral atmosphere, we aim to deepen our understanding of the ionization processes in the lower ionosphere. Furthermore, this model can be applied in future investigations of the Venus thermosphere and ionosphere at altitudes below 150 km, where observational data remain limited.

References: [1] Pätzold, M et al., (2009) *Geo. Res. Letters*, 36(5), L05203. [2] Martinez, A. et al. (2023), Icarus, 389, 115272.

Energetic neutral atom and ion precipitation at Venus

L. Obersnel[1*], Y. Futaana[2], X.-D. Wang[2], M. Holmström[2]
[1]Physikalisches Institut, Universität Bern, Sidlerstrasse 5, 3012 Bern, Switzerland
[2]Swedish Institute of Space Physics, Bengt Hultqvists väg 1, 981 92 Kiruna, Sweden
*E-mail: lorenzo.obersnel@unibe.ch

Venus does not have an intrinsic magnetic field. The interplanetary magnetic field (IMF) carried by the solar wind induces electric currents in the conductive ionosphere that exclude the IMF near to the planet, separating the planetary ions from the solar wind, and creating what is called induced magnetosphere [1]. Solar wind hydrogen ions and energetic neutral atoms can precipitate onto the atmosphere of Venus and be a source of mass, momentum and energy for the planet. Planetary species can precipitate after being picked up by the solar wind and energise the upper atmosphere and lead to loss of atmospheric compounds. Oxygen precipitation appears to be linked to the loss of water from the atmosphere of Venus [2].

We study the solar wind hydrogen ions and planetary oxygen ions precipitating in the upper atmosphere of Venus, as well as the energetic neutral atoms produced by charge exchange between the energetic ions and the neutral exosphere. We calculate the spatial and direction distribution and the spectra of the precipitating ions and neutrals using a global hybrid model for the solar wind-Venus interaction and a solar zenith angle dependent model for the neutral atmosphere.

According to our model results, about 5% of the solar wind hydrogen ions precipitates in the upper atmosphere of Venus, but only *<1%* of the solar wind hydrogen ions precipitates as energetic neutral atom. The hydrogen ion precipitation is solar zenith angle dependent and peaks in the subsolar region. The solar zenith angle dependency is relevant to infer the total precipitation rate from single point observations.

The oxygen ion precipitation rate showed a light North-South asymmetry in the Venus Solar Electric frame. Particularly, a non-negligible flux of oxygen ions is found to precipitate onto the high-latitude nightside. In absence of solar irradiation, oxygen precipitation may cause local effects on the upper atmosphere and ionosphere of Venus.

The ASPERA-4 package on board of the Venus Express spacecraft investigated the plasma environment and the energetic atoms near the terminator. The precipitating hydrogen flux that we calculated close to the terminator is approximately one order of magnitude higher than the flux observed [3]. Calculated angular distribution of energetic neutral atom observations are consistent with ASPERA-4 observations [4].

References: [1] Futaana Y. et al. (2017), *Space Science Reviews*, 212, 1453-1509. [2] Luhmann. J. G. and Kozyra J. U. (1991), *JGR: Space Physics*, 96(A4), 5457-5467. [3] Stenberg Wieser G. et al. (2015), *PSS*, 113, 369-377. [4] Galli A. et al. (2008) *Journal of Geo. Res.*: *Planets*, 113(E9).

Comprehensive Venus boundaries model

Umberto Rollero[1*], Yoshifumi Futaana[1], and Sebastián Rojas Mata[2]
[1] Swedish Institute for Space Physics (IRF), Kiruna, Sweden
[2] Royal Institute of Technology, Stockholm, Sweden
[*]E-mail: umberto.rollero@irf.se

Venus lacks an intrinsic magnetic field, exposing the atmosphere directly to the solar wind. Its upper part, the ionosphere, deflects the solar wind around the planet, resulting in the formation of an induced magnetosphere [1]. The induced magnetosphere contains different plasma boundaries, for example, the bow shock (BS), where the solar wind is slowed, heated and deflected. Another boundary, the ion composition boundary (ICB) marks the separation between solar wind and planetary ions [2]. These boundaries vary in response to upstream conditions. The BS and the ICB are influenced by the solar cycle phase, the magnetosonic Mach number, the solar wind dynamic pressure, and Interplanetary Magnetic Field (IMF) direction and magnitude [3][4][5], but an analytical model which quantitatively describes the boundaries variation with respect to upstream conditions is missing. In this study, we seeked to develop this analytical model which, given a set of upstream conditions, determines the BS and ICB locations.

We used boundary crossings and upstream conditions recorded by the ion mass analyzer (IMA), the electron spectrometer (ELS), and the magnetometer (MAG) onboard the Venus Express spacecraft [6]. We modelled the BS with a conic section curve, symmetrical around the longitudinal axis, and the dayside ICB with a half sphere. We studied the boundaries' variation with respect to different upstream conditions, and developed our final BS and ICB model by combining upstream conditions that minimized errors in predicting the boundaries' positions and shapes. Our BS model shows that the boundary expands with increasing IMF magnitude and shrinks with increasing solar wind mass flux, while the shock normal angle generates a quasi-perpendicular/quasi-parallel shock asymmetry, with the quasi-parallel side of the shock which tends to be closer to the planet. The ICB model shows a boundary expansion with increasing solar Extreme UltraViolet flux and a shrinkage with increasing mass flux. Our models improve the boundary prediction accuracy by 16% and 6%, for the BS and ICB respectively, compared to the average statistical models which disregard upstream conditions. Our findings indicate that the BS is more variable than the ICB as well as more sensitive to upstream conditions.

References: [1] Futaana, Y. et al. (2017), *SSRv*, 212, 1453. [2] Martinecz, C., Fr¨anz, M., Woch, J., et al. (2008), *PSS*, 56, 780. [3] Alexander, C. J., & Russell, C. T. (1985), *Geophys. Res. Lett*., 12, 369. [4] Russell, C. T., Chou, E., Luhmann, J. G., et al. (1988), *JGRA*, 93, 5461. [5] Zhang, T.-L., Schwingenschuh, K., et al. (1991) *Geophys. Res. Lett*., 18, 127. [6] Signoles, C., Persson, M., Futaana, Y., et al. (2023), *ApJ*, 954, 95.

Flux ropes observations near Venus

Aarti Yadav* and Jayesh Pabari
Physical Research Laboratory, Ahmedabad, India
*E-mail: aarti@prl.res.in

A flux rope is a helical structure consisting of magnetic field lines that are twisted around a central axis. These structures are found in various astrophysical and space environments, including the solar corona and planetary magnetospheres [1]. The flux ropes have been observed near Venus by the Pioneer Venus Orbiter (PVO) [2] and the Venus Express (VEX) [3]. The VEX has provided its measurements during the solar minimum [4]. Some giant flux ropes were found near the terminator [4], in the ionosphere, from the VEX observations[5]. Analyzing the data further, one can study the scale size of the flux rope, magnetic flux and its orientation. Such characteristics of the flux rope are useful to understand its origin and evolution[5]. We have carried out similar analysis[6] of the VEX data at different times and found few additional flux ropes near Venus. We shall present new results along with the derived characteristics of flux ropes. The analysis technique for obtaining the axial orientation of the flux rope will also be discussed. Further work is ongoing.

References: [1] Moldwin, M. B. & Hughes, W. J. (1991), 96(A8), 14051– 14064. [2] Elphic, R. C. & Russell, C. T. (1983), , *JGR: Space Physics,* 88(A1), 58–72. [3] Zhang, T. L., Lu, Q. M.(2012), *Science,* 336(6081), 567–570. [4] Zhang, T. L., Baumjohann, W.(2012), *GRL,* 39(23). [5] Slavin, J. A., Acu˜na, M. H. (2009), *GRL,* 36(9). [6] Sonnerup, B. U. O. & Scheible, M. (1998), *ISSI Scientific Reports Series* 1, 185–220.

Acquisition and analysis of lightning generated signals captured by Lightning Instrument for VEnus (LIVE)

Rashmi*, Jayesh Pabari, Sonam Jitarwal, and Srirag Nambiar
Physical Research Laboratory, Ahmedabad, India - 380009
*E-mail: rashmi@prl.res.in

Lightning is a natural phenomenon of large electric discharge for very short duration. It occurs very frequently in Earth’s cloud and also in other planetary atmosphere. Lightning on planet like Venus is yet not confirmed and is still debated. As it evolves additional atmospheric chemistry of the planet, it is important to study the lightning [1]. At PRL, we are developing an instrument “Lightning Instrument for VEnus (LIVE)”, proposed for future Venus mission, to detect lightning in the Venusian atmosphere [2].

In LIVE, the signals from Front-End Electronics (FEE) are digitized and processed using processing electronics. The FEE has two configurations, where the first configuration is PVO OEFD like architecture [4] having six channels for six different frequencies and the second configuration has a wide band filter (Hz-kHz). In this work, second configuration will be discussed where data is processed using Fourier Transform technique.

References: [1] Lorenz, Ralph D. (2018), *PEPS*, 34, 2197-4284. [2] Pabari et al. (2018), *LPSC*, #1391 [3] S. Jitarwal et al. (2020), *VEXAG*, #8010. [4] Scarf F. L. Et al. (1980), *J. Geophys. Res.*, 85(A13), 8158–8166.

The response of the Venusian upper atmosphere during the passage of interplanetary coronal mass ejections

Diptiranjan Rout[1], S. V. Thampi[2], Y. Miyoshi[3], T. Pant[2], A. Bhardwaj[4]
[1]National Atmospheric Research Laboratory, Gadanki, India
[2]Space Physics Laboratory, Vikram Sarabhai Space Center, Kerala, India
[3]Institute for Space-Earth Environmental Research, Nagoya University, Nagoya, Japan
[4]Physical Research Laboratory, Ahmedabad, India
*E-mail: diptiprl89@gmail.com

The study explores the dynamic interaction between Interplanetary coronal mass ejections (ICMEs) and the induced magnetosphere of Venus, utilizing measurements from the Venus Express (VEX) mission. We have investigated 16 ICME events during the period 2006-2013. The altitude of the inbound bow shock and ionopause at Venus are comprehensively studied during the passage of these ICMEs. The ionosphere is found to be highly magnetized due to the very high magnetic pressure of the induced magnetosphere. Remarkably, the altitude of the ionopause is found to be significantly changed as compared to the previous quiet day due to the increased solar wind dynamic pressure. The ratio of the altitude of ionopause and magnitude of the magnetic field at ionopause on the event days to the quiet days shows a strong anti-correlation which indicates the ionopause height is inversely related to the magnetic field. Intriguingly, the position of the bow shock exhibited minimal deviations compared to typical quiet days, underscoring that, during ICME events, the ionopause location is more responsive to solar wind pressure fluctuations than the bow shock location. Additionally, the heavy-ion density near and above the ionopause is found to be significantly higher than that observed on previous quiet days. This substantial increase implies that ICMEs can induce atmospheric loss in Venus's atmosphere and also cause a significant reduction in the ionopause location.

IMAGE ANALYSIS OF DUST RING IN THE ORBIT OF VENUS

Harshita[1] and J. P. Pabari[2]
[1]University of Delhi, Delhi -110007, INDIA.
[2]Physical Research Laboratory, Navrangpura, Ahmedabad - 380009, INDIA.
*E-mail: hkindia03@gmail.com

Venus, the second planet from the sun, has long fascinated scientists due to its unique atmosphere and surface. In addition to other features within the planet Venus, there exists a dust ring [1, 2, 3, 4] in the orbit of Venus, which has recently attracted the attention for its in depth study. The present work focuses on the image analysis of this dust ring. Utilizing advanced image processing [5, 6] techniques in Python, we aimed to determine the velocity and momentum of dust particles within the dust ring. Our methodology involved analysing high-resolution images taken by Wide-Field Imager for Parker Solar Probe (WISPR) on the Parker Solar Probe Mission [3, 7]. The results of our study provide information for characterization of the dust ring. Understanding dust dynamics in the dust ring is crucial for predicting its future existence and stability. Future research could expand on our findings to explore whether the ring will persist or gradually diminish over time.

References : [1] Krasnopolsky, V., Krysko, A. (1979), 951–957. [2] M. H. Jones, D. Bewsher, D. S. Brown 2013, *Science*, 342, 960. [3] Stenborg, G., Gallagher, B., Howard, R. A., Hess, P., Raouafi, N. E. (2021). *The Astrophysical Journal*, 910(2), 157. [4] Jones, M., Bewsher, D., Brown, D. (2017). *Icarus*, 288, 172–185. [5] Gonzalez, R. C., Woods ,R. E., (2002), *Digital Image Processing*. Prentice Hall. [6] Jain A. K., 1989. [7] Source of Dust Ring Images, Online 9 August, 2024.

Terrestrial Analogue studies from ISRO's Venus mission perspective: Polarimetric radar properties of Hawaiian Lava Flows

Sriram S. Bhiravarasu[1*], P. D'Incecco[2], J. Filiberto[3], D. A. Gorinov[4], S. Bhattacharya[1], T. Chakraborty[1], Rajesh B. Upadhyaya[1], D. Putrevu[1], and G. Di Achille[2]
[1]Space Applications Centre, Indian Space Research Organization, Ahmedabad 380015, India;
[2]National Institute for Astrophysics (INAF) - Astronomical Observatory of Abruzzo, Teramo, Italy;
[3]Astromaterials Research and Exploration Science (ARES) Division, NASA Johnson Space Center, Houston, TX, 77058, USA;
[4]Space Research Institute of the Russian Academy of Sciences, Moscow, Russia
*E-mail: sriram.saran@sac.isro.gov.in

Detection of present and past volcanism on Venus is one of the major goals of the proposed ISRO's Venus orbiter mission. The S-band, high-resolution (40 m/pixel) fully Polarimetric Synthetic Aperture Radar (PolSAR) instrument on this mission [1] may have the capabilities to detect recently active volcanism within the mission lifetime using repeated PolSAR imagery, and possibly SAR Interferometry (InSAR, experimental mode). The global mapping efforts of Venus by Magellan mission has enabled comprehensive mapping of lava flows and indicated that Venus has an extensive history of volcanism, the ages of which are largely unknown (e.g. [2]). While Magellan radar emissivity data (e.g. [3, 4]) and Near Infrared emissivity data from VIRTIS [5] suggested the occurrence of recent episodes of volcanic activity (e.g. Maat Mons and Ganis Chasma), as well as the presence of stratigraphically young lava flows (e.g. Idunn Mons), measuring changes in radar backscatter amplitude alone to identify lava flows has many challenges. Although very large changes in the shape of the terrain can be observed in radar backscatter amplitude changes (e.g. [6]), smaller, or relatively flat lava flows are difficult to detect. Previous terrestrial studies suggest that PolSAR and InSAR techniques are very effective for mapping lava flows (e.g. [7-9]), and can be used when changes cannot be distinguished in radar backscatter images.

We use the unvegetated lava flows on Hawai'i island as a terrestrial analogue to study Venus lava flows for the following reasons: (a) It is extensively studied at several wavelengths commonly used in remote sensing studies (including PolSAR and InSAR methods); and (b) it is a volcanically active area with new lava flows frequently covering older emplaced flows. To investigate the surface roughness, texture, and fine-grained mantling associated with Mauna Loa and Kilauea lava flows, we utilize C- and L-band PolSAR datasets obtained from RISAT-1A (EOS-4) and ALOS PALSAR missions respectively.

In particular, we will use the quad-polarized backscatter and polarimetric parameters to characterize the texture of the terrestrial lava flows to understand whether the Venus crust is continuously disrupted during flow emplacement. While some previous studies (e.g. [10, 11]) suggested that surface roughness of most of the Venus flows is comparable to that of terrestrial pāhoehoe flows, other studies indicated that fractal dimensions of some large lava flows on Venus imply high eruption rates which favour the formation of a'a flows (e.g. [12]). We will also analyse the terrestrial flows for the presence/absence of pyroclastic mantling as radar-bright diffuse deposits near the summit regions of some coronae on Venus have been proposed to be young pyroclastics, and possible evidence of a renewed epoch of mantle volcanism that taps into deeper volatiles [13]. A recent study using EOS-4 RISAT-1 data of a part of fresh Mauna Loa lava flows (2022 eruption) emphasizes the ability of fully polarimetric SAR data to understand the diversity of physical properties (e.g. texture and morphology) associated with them [14]; and we will apply similar methods to the PolSAR data obtained from ISRO's Venus mission for our proposed objectives.

References: **[1]** Widemann, T. et al. (2023), *Space Sci. Rev*., 219:56. **[2]** Head, J. W. et al. (1992), *JGR*, Planets, 97(E8), 13153–13197. **[3]** Brossier, J. et al. (2022), *Geophys. Res. Lett*., 49:e2022GL099765. **[4]** Brossier, J. et al. (2021), *J Geophys. Res*., Planets, 126(3), e2020JE006722. **[5]** Smrekar, S. E. et al. (2010), *Science,* 328, 605–608. **[6]** Herrick, R. R., Hensley, S. (2023), *Science,* 379(6638), 1205–1208. **[7]** Campbell, B. A., Shepard, M. K. (1996), *J Geophys. Res., Planets*, 101, 18941–18952. **[8]** Dietterich, H. R. et al. (2012), *Geochemistry, Geophysics, Geosystems*, 13(5). **[9]** Poland, M. P. (2022), *Bulletin of Volcanology*, 84(3), 32. **[10]** Campbell, B. A., Campbell, D. B. (1992), *J Geophys. Res., Planets* 97:162935. [11] Kratter, K. M., Carter, L. M., Campbell, D. B. (2007) *J Geophys Res, Planets* 112:E04008 [12] Bruno, B. C. et al. (1992), *Geophys. Res. Lett*., 19:305. [13] Campbell, B. A. et al. (2017), *J Geophys. Res*., Planets 122:1580. [14] Sreejith, K. M. et al. (2024), *Current Science* 126, Special Section: EOS-04.

ANORTHOSITE ROCKS OF THE HOLENARASIPURA GREENSTONE BELT, KARNATAKA, INDIA: A COMPARATIVE ANALYSIS FOR PLANETARY ANALOGUES ON THE MOON, MARS, AND VENUS.

Manasa M. J[1], B. R. Manjunatha[2],
[1,2]Department Of Marine Geology
Mangalore University, Mangalagangothri Konaje-574199, Karnataka, India.
manasa964@gmail.com

The Holenarasipura Greenstone Belt in Karnataka, India, is host to a unique suite of anorthositic rocks that provide valuable insights into early Earth processes and serve as analogues for planetary geology on the Moon, Mars, and Venus. These anorthosites, distinct from other terrestrial counterparts, are primarily composed of plagioclase (Anorthite), hornblende, and garnet, with minor accessory minerals such as apatite, sphene, and magnetite. The plagioclase crystals exhibit varied grain sizes and complex textures, indicative of dynamic geological processes. Geochemical analysis reveals higher Na, O, and SiO_2 content in these anorthosites compared to typical Archaean anorthosites, closely resembling compositions found in the Limpopo Belt. The study of these rocks not only enhances our understanding of the early chemical evolution of Earth's crust but also offers a comparative framework for understanding the geological history of other planetary bodies. The anorthosites from the Holenarasipura Greenstone Belt are, therefore, critical in advancing our knowledge of planetary geology and the early history of the solar system.

Introduction: Plate tectonics have shaped Earth, while the Moon remains a dry and inactive desert. Mars likely became geologically dormant within its first bil lion years, and Venus, despite being internally active, has a surface engulfed in a scorching inferno[1]. During the first million years of solar system history, planetes imals underwent extensive melting, driven by the radi oactive decay of (26Al)[2].The Holenarasipura anor thositic rocks are distinctly different from other terres trial anorthosites in both their characteristics and com positional aspects [3].

Geological Setting: The southern part of the Holenarasipura greenstone belt is composed of mafic ultramafic rocks, including tremolite-actinolite-talc schists, followed by metaperidotitic komatiites, serpen tinites, basaltic komatiites (high-magnesium basalts), garnetiferous amphibolitic schists, kyanite-staurolite schists, and iron formations [3].

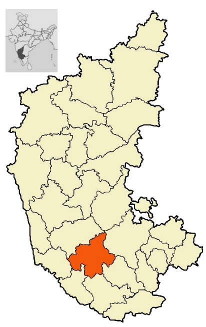


Fig.1. Map of Hasana District

Petrology: The Holenarasipura anorthosites consist predominantly of plagioclase (Anorthite), hornblende, and garnet, with minor amounts of apatite, sphene, magnetite, ilmenite, spinel, scapolite, and quartz. The grain size of plagioclase ranges from 0.016 to 41.1 mm. The plagioclase crystals are mostly subidiomorphic (partially well-formed) and equant (having roughly equal dimensions). These crystals can exhibit polyhedral granular or sub-idiomorphic granular textures and sometimes display flow and poikilitic textures (where larger crystals contain smaller inclusions) [3].

Geochemistry: The Na, O, and SiO_2 content of these anorthosites is higher than that of typical Archaean anortho sites from Sittampudi and Fiskenaesset, but closely resembles the composition of those from the Limpopo Belt.The Na,O, and Si02 content of these anorthosites is higher than the typi cal Archaean anorthosites from Sittampudi and Fiskenaesset, but almost similar to those from the Limpopo belt.

Conclusion: Anorthosites from greenstone belts and high-grade supra crustals may play an important role in the understanding of the early chemical evolution of the earth's crust. The occurrence of anorthosite in sheet form. This Anorthosite is best suitable to understanding planetary geology.

References: [1] Albarède, Francis, and Janne Blichert-Toft. Comptes Rendus. *Géoscience* 339.14-15 (2007): 917-927. [2] Lee, T., Papanastassiou, D., Wasserburg, G. (1977) *Astrophysical Journal* 211, L107-L110. [3] Naqvi, S. M., and S. M. Hussain, *Canadian Journal of Earth Sciences,* 16.6 (1979): 1254-1264.

Micro-spectroscopic characterization of alunite from the Puga hot springs, Ladakh (UT), India: Implications for future rover-based IR-spectroscopy of altered Venusian basalts

KVNG Vikram, Satadru Bhattacharya*, Sriram Saran Bhiravarasu, Aditya Dagar and Rajesh Upadhyaya
Space Applications Centre (ISRO), Ahmedabad – 380 015
*E-mail: satadru@sac.isro.gov.in

A state-of-the-art planetary spectroscopy laboratory (PSL) has recently been developed at Space Applications Centre (ISRO), Ahmedabad primarily for characterization of planetary analogues and meteorites in a wide spectral range from 400-25000 cm^{-1}. The integrated Vertex80V FT-IR spctrometer and HYPERION 3000 FT-IR imaging microscope from M/s. Bruker Optik GmbH, Germany is being used for analyzing the samples collected from the Puga Geothermal Field situated within the Indus-Tsangpo Suture Zone (ITSZ) in the eastern Ladakh, India from the perspective of astrobiological and mineralogical analogues to the terrestrial planets, in particular, the Venus and the Mars. The Puga hot spring deposits represent unique association of hydrated sodium borates and a suite of hydrous sulfates including acid sulfates such as jarosite, alunite, and copiapite along with tamarugite, native sulfur and gypsum. We conducted spectral measurements at an elevated temperature (that is expected at the Venusian surface) on the alunite sample collected from the Puga hot springs. Because of the elevated SO_2 fugacity as expected in the Venusian atmosphere due to recent volcanic activities as suggested by recent studies, the possibility of development of weathering rinds comprising acid sulfates cannot be ignored.

The spectral measurements at the PSL have been carried out using LINKAM stage that is connected with the HYPERION3000 microscope and can vary temperature from ~-196°C to 600°C. Here, we present NIR spectra of alunite at 6 different temperatures, i.e., 50°C, 100°C, 200°C, 300°C, 400°C and 450°C in the spectral range of 1.0-2.5 µm. It is evident from the present study that as the alunite sample is raised from lower to a higher temperature, the spectral band center of the 2.2-µm doublet feature systematically shifts towards the longer wavelength and also the band strength of the longer wavelength minimum of the 2.2-µm doublet and the 2.3-µm (single and more or less symmetric) features diminishes as alunite loses its crystalline OH/H_2O at elevated temperatures that one expects at the surface of the Venus. Based on these preliminary observations, we would conduct experiments at simulated Venusian surface temperature for a suite of acid sulfates collected from the Puga Geothermal Field in the VNIR-Mid-IR region as a pre-investment study for future rover-based IR-spectroscopy of selected Venusian science targets. Additionally, we will analyze polarimetric radar data (C-/L-band) of this region to understand the diverse compositional variations within the hot spring deposits as a function of their dielectric properties.

Radar imaging of Venus surface characteristics

Lomash Relia[1], Sandhya K Nair[2*]
[1]Devang Patel Institute of Advance Technology and Research, CHARUSAT, Anand, Gujarat, India
[2]Space Physics Laboratory, Vikram Sarabhai Space Centre, Trivandrum. Kerala, India
*E-mail: sandymad@gmail.com

Venus is the second planet from the Sun, and considered in many ways to be a twin planet of Earth. It has a similar size, mass, density and gravity, as well as a very similar chemical composition. In other ways, Venus is very different than Earth, with its high surface temperature, crushing pressure, and CO2 dominant atmosphere. Venus covered with clouds which are mostly formed due to the chemical reaction of SO2. The objective of the present study is to explore and visualize the surface of Venus using Synthetic Aperture Radar (SAR) data captured by the Magellan mission. The Image data, contains radar cross-section in an 8-bit unsigned integer format [1]. The relative brightness of pixels or pixel neighborhoods in these images can be interpreted as indicative of surface roughness, material composition, and slope orientation, with brighter pixels representing areas with higher radar reflectivity and darker pixels representing areas with lower radar reflectivity [2], [3]. However, since the values are processed and scaled using the Muhleman Law [4], the interpretations should focus on relative contrasts and patterns rather than absolute measurements. The DN values in the SAR data are directly related to the radar backscatter, with higher values indicating rougher or more reflective surfaces [3]. More details of this linking with Venus volcanic activity will be addressed with more data and images.

References: [1] “Planetary Data System Magellan Mosaicked Image Data Record (MIDR).” [Online]. [2] R. A. Lotufo etal., *Microscope Image Processing*, Elsevier, 2023, pp. 75–117. [3] P. H. Richard Bamler, *Synthetic aperture radar interferometry*. [Online]. [4] “Data Set Information: MGN V RDRS COMPRESSED BASIC IMAGE DATA RECORD CD ARCHIVE, Muhleman Law and Scaling expression.” [Online].

Comparative Analysis of the Magnetic Fields of Venus and Mars

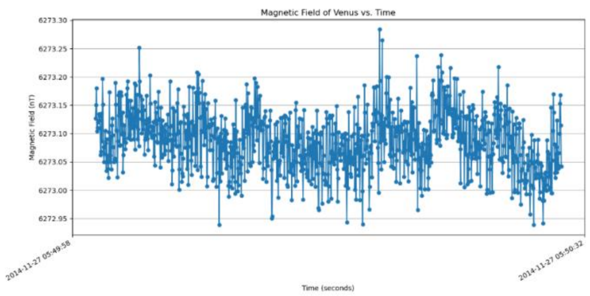
Akshita Gaba[1], Vanshika Batosiya[2],
[1]E-mail: akshita01gaba@gmail.com

Introduction: Mars retains weak crustal fields, whereas Venus lacks a global field, affecting atmospheric and habitability aspects [1]. Magnetic fields influence atmospheric interactions with solar wind and ionosphere formation; Mars' field weakened due to core cooling [2], while Venus' ionosphere forms a magnetic barrier and comet-like magnetotail depending on solar wind pressure [3][4].

Research Gap and Importance of the Work: The research gap in directly comparing Venus and Mars arises from their differing magnetic characteristics, with Venus lacking a global magnetic field and Mars possessing only weak remnant fields. Addressing this gap is crucial for understanding the impact of these differences on atmospheric retention, solar wind interactions, and ionosphere dynamics.

Methodology: Data from the Planetary Data System (PDS) was used for the Venus Express and Rosetta-Lander missions, which collected total magnetic field measurements using their respective instruments: MAG and ROMAP [5]. For Venus, the total magnetic field was sampled at a rate of one data point per second for two hours and 40 minutes. For Mars, the total magnetic field was sampled at a rate of one data point per second for two hours. The collected data for both planets was plotted on graphs with time in seconds on the x-axis and magnetic field strength in nano Tesla's (nT) on the y-axis.

Results and conclusion: The analysis revealed distinct magnetic behaviors for Venus and Mars. Venus's induced magnetic field fluctuates significantly due to solar wind interactions, with an average strength of 5−15nT, while Mars's more stable magnetic field, driven by remnant crustal magnetism, averages 50−200nT. These findings highlight how magnetic field differences influence atmospheric retention and solar wind interactions, providing crucial insights for future planetary exploration and understanding the habitability of terrestrial planets.



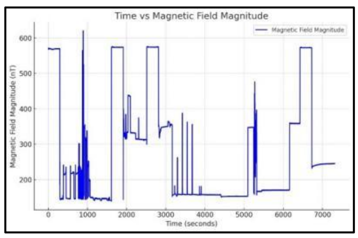


Figure 1: Total Magnetic Fields of Venus vs Time (in seconds). Figure 2: Total Magnetic Fields of Mars vs Time (in seconds)

References: [1] Stevenson, D. J. (2003), *Earth and Planetary Science Letters*, 208(1-2), 1-11. [2] Russell, C. T. (1993), *Scientific American*, 267(4), 36-43. [3] Acuña MH et al.(2001), *Journal of Geophysical Research: Planets,* 106 (E10):23403-17. [4] Luhmann JG, Cravens TE (1991), *Space Science Reviews*, 55(1):201-74.

Dyke Swarm History of the Eve Corona Region on the Southern Side of Alpha Regio, Venus, and Potential Implications for the Upcoming DAVINCI Mission.

I. J. Fardy[1], R. E. Ernst[1], and H. El Bilali1[1]
[1]Department of Earth Sciences, Carleton University, Ottawa, Ontario, Canada,
*E-mail: ikefardy1@gmail.com

Introduction: Detailed mapping (1:500,000 scale) and geological interpretation was conducted on the Eve Corona region, located on the southern side of Alpha Regio tesserae [1,2] (Figs., 1,2), which is the proposed final impact region of the upcoming NASA DAVINCI mission.

Eve Corona area: A total of 26,265 extensional lineaments (grabens) were mapped, which are interpreted as the surface expression of mafic dykes (and which are common on Venus due to the absence of erosion). These grabens (dykes) are grouped into radiating, circumferential and linear swarms and linked to magmatic centres where possible. In total five magmatic centres are identified and found to be the source of 18 of the mapped swarms. Analysis of the cross-cutting relationships of swarms reveals an evolutionary history, with initial centres located on the southern side of Eve Corona, before magmatic centres shift to the north and then outward, to both the northeast and northwest.

Alpha Regio Tesserae: Mapping of graben (ribbon fabric and other extensional lineaments) within the Alpha Regio tesserae, on the north side of Eve Corona (Figs. 1, 2), is currently underway. Two groups are being identified: those which represent the continuations of swarms from outside the tesserae, and those which are restricted to the tesserae (interpreted as forming during a pre-plains history). Thus far, several of the externally sourced linear swarms identified in the Eve Corona region appear to be present in the Alpha Regio tesserae as well. There appears to be minimal extension of the Eve Corona swarms to the Alpha Regio tesserae. The geologic history derived from this dyke swarm study of Eve corona and surrounding plains [1], and those from within Alpha Regio tesserae will be useful ground-truthing for the interpretation of images to be taken of Alpha Regio Tesserae region during the descent of the DAVINCI spacecraft through the atmosphere.

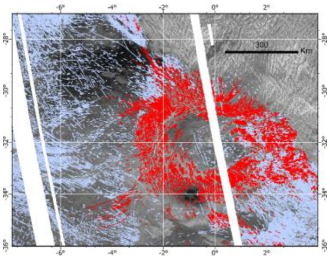


Figure 1

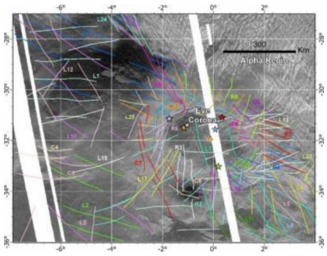


Figure 2

Figure 1. Distribution of 26,265 extensional lineaments (grabens, fissures and fractures) mapped in the study area. Those associated with Eve Corona are in red, and those linked to other centres or of unknown linkage are in light blue (After [1]).

Figure 2. Generalized distribution of graben-fissure systems (interpreted as dyke swarms) distinguished by colour and labels. Linear systems are labelled L. Stars and triangles locate the centres, respectively, of radiating (labelled R) and circumferential (labelled C) systems. (After [1])

References: [1] Fardy, I. J., et al. (2024) *LPSC 55*, abstr. #1479. [2] Fardy I. J., et al. (2024) Manuscript in prep.

Graben systems of Mbokomu Mons region, SE of Atla Regio along Parga Chasmata, Venus: Detailed mapping and geological history.

Naima Hannour[1*], Hafida El Bilali[1], Richard E. Ernst[1], Kenneth L. Buchan[2], James W. Head[3], Mohamed Ben Marzoug[1]
[1]Department of Earth Sciences, Carleton University, Ottawa, ON, Canada
[2]273 Fifth Ave, Ottawa, ON, Canada
[3]Department of Earth, Environmental and Planetary Sciences Brown University, RI, USA
*E-mail: hannournaima83@gmail.com

Introduction: The relationship between chasmata (rift zones) and spatially associated volcanism (mons and coronae) on Venus has been extensively discussed but remains enigmatic. One region where these features are prominently displayed is along 10,000 km long, NW trending, Parga Chasmata, which connects Atla Regio with Themis Regio. We have selected the Mbokomu Mons area (located about 2200 km SE of Atla Regio) for the current detailed study [1].

Results: More than 39,000 extensional lineaments (grabens, fissures and fractures) were mapped at 1:500,000 scale using full resolution Magellan SAR (radar) images and grouped into radiating, circumferential and linear systems [1]. They are (except where noted) interpreted to represent the surface expression of underlying mafic dyke swarms. Radiating and/or circumferential swarms are associated with Mbokomu Mons and the four coronae in the surrounding area, Among Corona (AC), Repa Corona (RC) and unnamed coronae (UC1-UC2). In addition to its cicumferential graben, Mbokomu Mons displays other features, such as an elevated rim, that are characteristic of coronae.

Mbokomu Mons: Mbokomu Mons is unique among the tectono-magmatic features in this region of Parga Chasmata, in having both corona and mons characteristics [1]. The initial Corona Phase consists of radiating and circumferential systems mainly preserved in an unflooded annular uplift, while the Mons Phase includes a second radiating swarm associated with a central edifice, and smaller circumferential fracture pattern near the summit that could overlie a magma reservoir. The plume or diapir that is interpreted to have been responsible for the initial Corona Phase is estimated to have had a radius of ~150. The radiating swarm associated with the Mons Phase (interpreted as being the youngest stage of Mbokomu Mons) spills out lava flows on both the eastern and western flanks at the same elevation (~1700 m). Further downslope the radiating dykes of the Mons Phase mostly disappear and lava flows dominate. If the 1700 m elevation indicates the depth of a magma reservoir (that laterally fed the radiating dyke swarm), then the magma reservoir should be located at a depth of ~400 m below the summit.

Age relationships: Cross-cutting relationships indicate that Mbokomu Mons is younger than three other large nearby magmatic centres, - Among Corona in the study area, Oduduwa and Onenhtse coronae outside the study area to the NW and SE respectively [1]. In addition, Mbokomu Mons appears to be younger than the Parga Chasmata rift system and the parallel Penthesilia Fossa (PF) (Great dyke of Atla Regio) [2]), as well as the NE trending Jokwa Linea branch of Parga Chasmata. We propose that the alignment of the four magmatic centres of Mbokomu Mons, Among, Oduduwa and Onenhtse coronae reveals an underlying zone of lithospheric weakness parallel to and likely part of the Parga rift system [1].

References: [1] Hannour. N, Bilali. El, H. et al. (2024), *Icarus,* 423 116268. [2] Bilali, H. Ernst. R.E. (2024), *Nat. Comm*. 15 1759.

Dyke swarms of Onenhste and nearby coronae within Parga Chasmata, SE of Atla Regio, Venus: An in-depth analysis of mapping, interactions within the swarms, and geological history

Mohamed Ben Marzoug[1]*, Hafida El Bilali[1], Richard E. Ernst[1], Kenneth L. Buchan[2], James W. Head[3], Naima Hannour[1]
[1]Department of Earth Sciences, Carleton University, Ottawa, ON, Canada
[2]273 Fifth Ave, Ottawa, ON, Canada
[3]Department of Earth, Environmental and Planetary Sciences Brown University, Providence, RI, USA
*E-mail: marzoug375@gmail.com

Introduction: Parga Chasmata is a rift system on Venus extending 10,000 km, known for its numerous coronae (mysterious circular tectono-magmatic structures). To explore the relationship between the rift and these coronae, detailed geological mapping at a scale of 1:500,000 was conducted in the Onenhste Corona area and its surroundings [1]. This area contains many coronae that formed within the Parga Chasmata rift system and the nearby Wawalag Planitia to the south.

Goals: The objectives of the current study [1] are: 1) To create detailed map at a scale of 1:500,000 of the various grabens, fissures, and fractures, and to connect them to magmatic centers, 2) To analyze how Onenhste and nearby coronae relate to the Parga Chasmata rift zone and the intersecting rift segments, and 3) To clarify the relationships and geological history of the coronae within the rift zone.

Results: Over 46,000 extensional lineaments were mapped and grouped into 50 groups: 17 radiating, 28 circumferential, and 5 linear sets (which are interpreted to overlay mafic dyke swarms) [1]. The radiating and circumferential swarms are associated with Onenhste Corona (OC), Momu Coronae (MC), Ulgen-ekhe Coronae (UEC), Rzhanitsa Corona (RzC located just outside the study area), and five unnamed coronae (UC1–5), as well as Malibran Patera (MP) and Fedchenko Patera (FP). By examining the crosscutting relationships among the graben sets (dyke swarms), we determined the relative ages of the magmatic centers. We also used an additional method involving the swinging or deflection of radiating and circumferential dyke swarms to understand stress interactions between coeval centers [1]. The relative ages of the magmatic centers, from oldest to youngest, are UC2 > RzC > MC ≥ OC = UC1 = UEC ≥ MP > UC5, and FP > UC3. This detailed data provides valuable insights into the timing, evolution, and relationship of coronae to rift zones, forming a foundation for future quantitative studies of lithospheric and mantle evolution, and the interplay of rifting and mantle diapiric upwelling.

Several centers (RzC, UC2, MC, UC3, and FP) are aligned along a trend that parallels Parga Chasmata but is offset about 900 km south of the main rifting zone. This alignment is likely related to a weakness zone associated with rift extension.

Coronae MC, OC, UC1, and UEC are aligned along the NNE-trending P13 Linea, which is perpendicular to the main Parga Chasmata rift. Onenhste is contemporaneous with UC1, which is also contemporaneous with UEC. Additional age relationships show that the later stage of OC was active simultaneously with MP, MC, and the UC2–9 center of UC2. Linea P13 is older than Chondi Chasma (a branch of Parga Chasmata rift zone).

Conclusion: The development of the geological relationships and insights in this study underscore the importance of continued detailed geological mapping and analysis for the longer-term development of an integrated geological history that includes the main WNW-trending Parga Chasmata rift zone, the orthogonal trends of rifting and the numerous magmatic centres (mainly coronae) distributed along both trends.

References: [1] Ben Marzoug M., El Bilali H., Ernst R. E., Buchan K. L., Head J. W., Hannour N. (2024), *Icarus*, v. 424, 116269.

Dyke swarm and mantle plume/diapir history of the Tefnut Mons region, east of Themis Regio, Venus

E. Druxbury*, H. El Bilali, R. E. Ernst
Department of Earth Sciences, Carleton University, Ottawa, ON, Canada
*E-mail:erinduxbury@cmail.carleton.ca

Introduction: Detailed geological mapping at 1:500,000 by the International Venus Research Group (IVRG; [1]) is 10X more detailed that regional Quadrangle mapping and is providing new insights into regional geological histories of a range of geological features on Venus. The present study (290-310°E, 30-50°S) is focused on producing a detailed dyke swarm and mantle plume/diapir history of a portion of the Themis Regio. This marks a corner of the triangular-shaped Beta Atla Themis (BAT) region of Venus which is notable for its major mantle plume centres with associated long connecting rift zones (up to >8000 km in length). Other studies by the IVRG have been focused on the two other corners of BAT, Atla Regio [2,3] and Beta Regio [4]. This present study is an opportunity to develop an improved understanding of the Themis Regio corner of the BAT region, located at the end of the long Parga Chasmata (rift zone). The western portion of the study area was mapped by [5] as part of Quadrangle Map V-53. The eastern part of the area lies in Quadrangle V-54 for which initial mapping was been begun [6-7] but not yet completed. Some preliminary detailed mapping of graben-fissure-fracture systems was also done in the eastern part of the study area [8].

Methodology: Data from the 1989-1994 NASA Magellan mission was used: mainly the 75m per pixel resolution Synthetic Aperture Radar data and also the 4.6 km per pixel altimetry data. Mapping is being done using ArcPro, and also JMARS is used to reconnaissance work. The focus of the current mapping is extensional lineaments (grabens, fissures and fractures) which are mainly inferred to represent the surface expression of mafic dyke swarms. The goal is producing 1:500,000 scale mapping of dyke swarms, grouping them into radiating, circumferential and linear which can be linked to the known magmatic centres and also used to identifying previously unknown centres. Cross-cutting relationships between graben systems can also reveal the relative ages of the different magmatic centres to which graben systems (dyke swarms) belong. Magmatic centres include Mons [large shield volcanoes] and Coronae [circular-elliptical tectono-magmatic features]. The present research will be followed by a subsequent study on lava flows, which will build on the geological history developed through study of the dyke swarms.

Progress Report: The present mapping is focused on the area 295-310°E, 30-45°S; so far 19,114 extensional lineaments (interpreted as dykes) have been mapped. These are in the process of being grouped into radiating, circumferential and linear swarms and linked to magmatic centres. So far, major circumferential swarms have been linked with Tunehakwe Corona, and radiating swarms linked with Tefnut Mons, Tamiyo Corona and Ukemochi Corona. At the time of the conference we will show an updated map and geological interpretation. Initial interpretations from the current map are concerned with the complex interplay between the grabens (dykes) of the major magmatic centers. Radiating swarms linked with Tunehakwe Corona, Tamiya Corona and Ukemochi Corona tend to swing towards each other's centres, suggesting a similarity in age. Any further conclusions drawn using cross-cutting relations will be presented at the conference.

References: [1] Ernst et al. (2024), *Ann. Mtg Planet. Geol. Mappers Flagstaff*, USA. [2] El Bilali et al. (2023), *Comm. Earth Env.* [3] El Bilali & Ernst (2024), *Nat. Comm.* [4] Shimolina et al. (in review) *Icarus*. [5] Stofan & Brian (2012), *Sci. Map* 3165 USGS. [6] Bridges (2001), *LPSC* XXXII, abstr. #1376. [7] Bridges (2008), *Ann. Mtg Planet. Geol. Mappers Flagstaff*, USA. [8] Blair & Ernst (2002), *LPSC XXXIII*, abstr. #1628.

Venusian cloud features. Imaging from UV to IR

Sandhya K Nair*, Tarun Kumar Pant, Madhusoodanan MS
Space Physics Laboratory, Vikram Sarabhai Space Centre, Trivandrum
Amity University, Noida
*E-mail: sandhya_nair@vssc.gov.in

Venus, often dubbed Earth’s "sister planet," boasts a distinctly more massive atmosphere and a surface pressure approximately 92 times greater than Earth's. Composed predominantly of carbon dioxide (about 96.5%), the planet's thick atmosphere generates intense greenhouse effects, leading to surface temperatures that can reach up to 467 degrees Celsius. Furthermore, Venus's high albedo, which surpasses that of Earth, reveals its dense cloud layers that reflect much of the sunlight. This study aims to illuminate the reflectance properties of Venus across various spectral intervals, from the ultraviolet (UV) to the infrared (IR), and to probe into its atmospheric dynamics by examining wind velocity variations in both horizontal and vertical orientations. Observations from the Ultraviolet Imager (UVI) at wavelengths of 283 nm and 365 nm, along with data from the Long-wave Infrared Camera (LIR) (Taguchi et al. 2007; Fukuhara et al. 2011, 2017), the 1 µm camera (IR1) (Iwagami et al. 2011, 2018), and the 2 µm camera (IR2) (Satoh et al. 2016, 2017) have been utilized. Additionally, the wind vectors obtained from UVI images are incorporated into the current study. Significant differences have been noted in the ultraviolet (UV) images obtained, with distinct features varying considerably from one another. The radiance observed in the 365-nm image is approximately ten times greater than that of the 283-nm image. The 365-nm image reveals enhanced contrast and brighter areas in the equatorial region near the center. These variations in UV images indicate that the spatial distributions of sulfur dioxide (SO2) and unidentified UV absorbers are influenced, at least in part, by differing chemical and/or dynamical processes. Additionally, UV images are utilized to estimate horizontal winds by monitoring cloud features. This study leverages the winds derived from cloud features to analyze the underlying dynamics. The typical radiance magnitude for the 1 µm camera ranges from 10 to 20 $mW/cm^2/\mu m/sr$, while the 2 µm camera ranges from -0.05 to +0.05 $W/m^2/\mu m/sr$. The typical brightness temperature in the equatorial belt varies from 230 to 234 K. The infrared radiance captured by the 1 µm camera exhibits a significant gradient along the equatorial region. In equatorial latitudes, the zonal wind demonstrates super-rotation at approximately 70 to 80 m/s. Ongoing work involves the inter-comparison of cloud features across various spectral intervals.spectral intervals.

Session 5:
Interplanetary Dust Science

Comparative Analysis of Dust Phenomena and Electromagnetic Discharge Processes on Venus and Mars

Mohamad Abdelaal
Moscow Institute of Physics and Technology
E-mail: mohamad.essam@phystech.edu

The study of dust phenomena and electromagnetic discharge processes on planetary surfaces provides crucial insights into planetary atmospheres and surface interactions. While Mars has been extensively studied for its dust storms and associated electrical discharge phenomena, the exploration of Venusian dust activity and its potential electromagnetic effects remains less understood. This research aims to conduct a comparative analysis of the dust phenomena on Venus and Mars, focusing on the similarities and differences in their discharge processes.

Venus's dense atmosphere, with its high concentration of sulfuric acid clouds and active volcanic surface, presents a unique environment where electrostatic charging of particles could occur differently than on Mars. The Martian atmosphere, characterized by its thin CO2-rich composition and frequent global dust storms, provides a stark contrast in terms of particle dynamics and discharge mechanisms. This presentation will explore the role of solar wind interactions, atmospheric composition, and surface conditions in influencing dust electrification and discharge processes on both planets. By examining data from past missions and developing conceptual models, we aim to highlight the implications of these phenomena for future exploration and instrumentation design for Venus.

On Cometary-Ion-Tail-Disconnection-Like Events on Mars and Venus

Wing-Huen Ip
Institute of Astronomy, National Central University, Taiwan
E-mail: wingip@astro.ncu.edu.tw

In the early days of the study of solar wind interactions with Mars and Venus, it was customary to consider the physical process was similar to that of comet-solar wind interaction, hence the popular term of cometlike interaction. In this respect, the so-called cometary ion tail disconnection is particularly noteworthy because it might signal the encountering of a comet with the heliospheric current sheet where the interplanetary magnetic field changes polarity abruptly. Alternatively, the ion tail disruption could be triggered by the interaction of solar wind structures of high dynamic pressure. However, not much attention has been given to the analogous effects at Mars and Venus even though the dynamical nature of solar wind interaction with their ionospheres have been elucidated because of spacecraft in-situ measurements. The recent discovery of the sinuous aurora features in FUV in 130.4 and 135.6 nm oxygen emissions by the EMM Hope Orbiter that might be associated with the nightside current sheet prompted the idea that energetic electron acceleration could take place therein (Lillis et al., JGR, 2024). While no similar observations were available at Venus, it is interesting to note that a possible correlation of the 557.7 nm OI oxygen green line aurora at Venus with the crossing of the heliospheric current sheet (Gray et al., 2023, BAAS, DPS55 abstract #507.08) could be indicative of such a process. Even though the information is still scanty, it points to the exciting prospect of FUV spectroscopic imaging to monitor auroral activities at Venus modulated by the solar wind conditions including sector boundary crossing.

Interplanetary dust in inner solar system and its detection

Jayesh Pabari*, Srirag Nambiar, Rashmi, Sonam Jitarwal and Team
Physical Research Laboratory, Navrangpura, Ahmedabad - 380009, INDIA
*E-mail: jayesh@prl.res.in

Interplanetary Dust Particles (IDPs) are found everywhere in solar system. The dust is an important constituent in the formation of solar system. The IDP may originate from sources like Asteroid belt, Kuiper belt and comets. They evolve dynamically in the solar system under the effect of various forces [1, 2]. Though there are some measurements of IDP near Earth and also, in the interplanetary space; the flux and other parameters of IDP at some planets are not understood fully [3]. Further, the dust particles in the solar system may enter a planetary object and affect it in different ways [3-5]. The results [3, 6, 7] of IDP flux in inner solar system will be presented. Also, the Venus Orbiter Dust EXperiment (VODEX) is proposed for Venus mission to measure the IDP at Venus and the detector is based on the impact ionization principle [6, 8, 9]. For the demonstration of dust detector, the Dust EXperiment (DEX) was flown on PS4 of PSLV C-52 (XpoSat) mission. From the dust observations in near Earth orbit, the DEX was found working successfully in space. The results obtained from DEX will be also be presented.

References: [1] Gor'kavyi, N. N., Ozernoy, L. M. and Mather, J. C. (1997), *APJ (Acta Pathol. Jpn.)*, 474, 496. [2] Mann, I., Meyer-Vernet, N., Czechowski, A. (2014), *Phys. Rep.*, 536, 1-39. [3] Pabari, J. P., Nambiar, S. N., Rashmi and Jitarwal, S. (2023), *PSS*, 226, 105617, 1-11. [4] Plane J. M. C. (2012), *Chem. Soc. Rev.*, 2012, 41, 6507-6518. [5] Carrillo-Sanchez J. D. et al. (2020), *Icarus*, 335, 113395. [6] Pabari, J. P.et al. (2022), *PSS*, 215, 105452. [7] Pabari, J. P. and Bhalodi, P. J. (2017), *Icarus*, 288, 1-9. [8] Pabari et al. (2018), *PSS*, 161, 68-75. [9] Pabari et al. (2021), *43rd COSPAR Scientific Assembly*, C3.2-0030-21.