MEETING REPORT

Venus science conference*

The second conference on Venus Science (Venus-SC-2022; online), organized recently, focused on modelling, observations, data analysis, conceptual instrument design and scientific experiments related to Venus science and exploration, considering the upcoming Venus mission of India. It included speakers from various parts of the globe and benefitted researchers and students regarding new Venusian science opportunities in the coming years.

The first session on 'Surface science and exploration' had nine talks. The first talk was delivered by James Head (Brown University, USA). He elaborated upon the great climatic transition, the origin of the atmosphere, the abundance of volatiles derived from the interior and the effect of recent volcanism on the atmosphere. Siddharth Krishnamoorthy (JPL, USA) spoke on infrasonic remote sensing for seismic detection, short-range airborne infrasound detection, balloons for measuring seismic signals and significant ground tests. Gaurav Seth (SAC, Ahmedabad) talked on subsurface radar operating at 9–30 MHz, first planned for the Indian mission. Justin Filiberto (ARES, USA) discussed present-day volcanism on the Idunn Mons. The Earth rock alkali basalt and olivine are used for analogue studies for oxidation experiments. Richard Ghail (University of London, UK) described Venus as a key to understanding the Earth-sized planets by fragmented lithosphere. Masatoshi Yamauchi (SISP, Sweden) presented a Venus dynamics tracer, which is a proposal for multi-balloon mission to look for the global dynamics of ions.

Takehiko Satoh (JAXA, Japan) presented major results from 11 Venusian years of observation, including a possible signature of lighting observed on 1 March 2020. Arya Pratap Singh (IIRS, Dehradun) spoke about machine learning for noise removal in the VIRTIS data. Tathagata Chakraborty (SAC, Ahmedabad) spoke on the potential of polarimetric SAR for surface characterization and utilization of Chandrayaan-2 DFSAR acquisitions.

The 'Session on atmosphere and ionosphere' covered 11 talks, split over two days. Takeshi Imamura (University of Tokyo, Japan) showed the presence of temperature inversion layers and mean thermal structure of the sub-cloud atmosphere from the Akatsuki Radio Occultation (RO) experiment. He presented semi-diurnal tides and the usefulness of radio holographic analysis to obtain fine structures in the atmosphere. Wing-Huen Ip (NCU, Taiwan) proposed a fleet of orbiters, including the Indian Venus Orbiter, to provide a unique opportunity for multi-point radio sounding. Martin Pätzold (Cologne University, Germany) delivered a talk on important aspects of a successful RO experiment, which included link budget analysis from power and antenna size. Mao Persson (IRAP, France) presented a view of planetary ion flows in the induced magnetosphere using data from ASPERA-4 and MAG instruments. She showed an unexpected result of dusk-to-dawn ion flow to very low altitudes and also recent measurements of proton flows of the subsolar magnetosheath, provided by BepiColombo during its second Venus flyby in August 2021. Using Akatsuki RO data and a one-dimensional photochemical model, Ambili (SPL, Thiruvananthapuram) showed that the V1 layer can appear as a slope change below the V2 layer with O_2^+ as the dominant ion and a clear, prominent layer peak with NO^+ as major ions.

Eliot Young (SWRI, USA) showed spectral image cubes from ground-based observations constraining the cloud properties and mapping the trace gas distributions. The observations revealed persistent cloud discontinuities with 4–5 day periods and their recurrence over a 16-day span. The 1.25–1.27 μm signature showed oxygen airglow originating from ~95 km, and the 5.1 μm images showed thermal maps, possibly due to mountain waves from the surface. Parkinson (SSI, USA) presented photochemistry/dynamics of the middle atmosphere, modelling SO_2/aerosol distribution and occurrence of precipitation (rain cycle) in the equator. Masahiro Takagi (Kyoto Sangyo University, Japan) discussed planetary-scale atmospheric waves and equatorward angular momentum flux contributing to the super-rotation. Norihiko Sugimoto (Keio University, Japan) talked about AFES-Venus, a general circulation model for Venus, and developing a data-assimilation system based on a local ensemble transform Kalman filter. From a campaign involving three spacecraft and six ground-based telescopes, Yeon Joo Lee (IBS, South Korea) presented the reflectivity of a dayside disk. Considerable absorption was found in the 350–450 nm range, for which the corresponding optical depth by the unknown absorber was retrieved. Tirtha Jyoti Kalita (Dibrugarh University) showed dayside/nightside distribution of SO_2 absorption (190–230 nm) using SPICAV–UV data.

The session on 'Lightning and habitability' covered seven talks. Dipen Sahu (PRL, Ahmedabad) discussed the astro-physical/chemical connection of early planetary atmospheres with phosphine on Venus. Trushit Upadhyaya (CHARUSAT, Changa) spoke on *in situ* emulation of lightning and detection for future planetary missions. He discussed the development of a lightning test set-up with a Venus atmosphere-like environment, which was carried out in collaboration with PRL, Ahmedabad. R. S. Pandey (Amity University) talked about whistler-mode waves with an electric field for the ionosphere. Marc Pulupa (University of California, USA) spoke on the non-detection of radio signatures of lightning during spacecraft flybys from the available instrument. He mentioned that the Venusian lightning could be emitting very low frequencies. Richard Hart (UCLA, USA) presented the confirmation of lightning on Venus by low-altitude whistler-mode waves. He showed ~17 cumulative hours of whistler-mode observations and occasional continuous activity for over 2 min, with a connection to an electrical storm, using VEX data during 2006–14. Rachana Agrawal (MIT, USA) discussed atmospheric and cloud-particle sample returns for astrobiology investigations. Sara Seager (MIT, USA) discussed *in situ* missions to study Venus as a potentially habitable planet. The controversial detection of phosphine has renewed interest in both the atmosphere in general and in the speculative possibility of life in the clouds.

The session on 'Venus–solar wind interaction' covered five talks. D. Chakrabarty (PRL, Ahmedabad) discussed solar wind interaction with Venus, providing a perspective of oxygen airglow. Haider (PRL, Ahmedabad) showed escape flux and density of O^+ on Venus/Mars in the presence of charge

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separation electric fields. N. V. Rao (NARL, Gadanki) presented the probing of Venusian plasma, magnetic boundaries and its topside ionosphere through a radio sounder. Yoshifumi Futaana (SISP, Sweden) reviewed the findings by Analyser of Space Plasma and EneRgetic Atoms (ASPERA-4) on VEX. Sakshi Gupta (IISER, Kolkata) talked about understanding the environments of Venus-like exo-planets crafted by evolving stellar magnetic activity.

The session on 'Interplanetary dust science' had four talks. Apostolos Christou (Armagh Observatory, UK) showed that Venusian meteors tend to be brighter but shorter-lived than terrestrial meteors. Jayesh Pabari (PRL, Ahmedabad) delivered a talk on the heliocentric dependence of interplanetary dust particle density in light of the latest Solar Orbiter observations. He showed the momentum of ring particles in the orbit of Venus and also the comet as a possible source of particles detected by Solar Orbiter. Yanwei Li (University of Stuttgart, Germany) talked about interplanetary dust particles, various types of dust detectors and a calibration facility of 2 MV Van-de-Graaff dust accelerator at Institute of Space Systems (Stuttgart). Ingrid Mann (AUN, Norway) discussed interplanetary dust inside 1 AU, and presented model calculations for smaller-sized, charged particles which are affected by solar radiation pressure as well as Lorentz force.

There was a session covering short video presentations by 18 participants. Another session had three talks on Venusian data analysis, more important in context to the future Indian mission to Venus. Dinesh Kumar (SWRI, USA) talked about detecting lightning signatures using PVO and VEX datasets. Tripathi (SPL, Thiruvananthapuram) spoke on Akatsuki RO data analysis, time-domain analysis, Doppler as well as power analysis and frequency residuals. Sinha (PRL, Ahmedabad) discussed the emplacement pattern of lava-flow channels in the Henwen Fluctus region.

There were open sessions at the end of each major session, where the experts discussed various topics, including the following.

- Several research areas related to Venusian science emerge, like the evolution of the surface, unknown UV absorber, lightning, super-rotation, interplanetary dust/ring and space weather.
- Possibility of subsequent work on great climate transition, remote seismology and surface study was deliberated.
- Research on SO_2 content, unknown absorbers, possibilities of ballooning experiments and difficulties of multiple altitude measurements was debated.
- The methods of lightning detection, instruments needed and requirements of *in situ* measurements of the middle atmosphere were discussed.
- The effect of interplanetary dust on the atmosphere, characterization of dust ring, atmospheric escape and solar wind interaction with Venus were discussed.

In summary, despite some similarities regarding certain aspects of research on different planets, Venus has been of interest to space scientists for different reasons. Its exploration started from the time of Venera missions (1960s), and subsequently, many other missions like Mariner, Pioneer Venus, Vega, Magellan, Venus Express, Akatsuki and IKAROS have provided a wealth of information about the planet. Unintended missions like Galileo, Cassini, MESSENGER, Parker Solar Probe, BepiColombo and Solar Orbiter have also provided flyby observations. The Venus-SC-2022 conference covered diversified research areas from the surface to the upper atmosphere and beyond. More than 172 delegates had registered for the conference, and there were 24 oral presentations from institutions outside India as well as 15 oral presentations from Indian institutions. Such a gathering provides research avenues to students and an opportunity for the research community to interact/collaborate.

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COMMENTARY

Climate change impacts on the coastal regions

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In recent years, the Intergovernmental Panel on Climate Change (IPCC) has brought out three reports, including chapters that deal with assessments of climate change and its impacts on the coastal regions. They include a chapter in SROCC; in the IPCC *Special Report on Oceans and Cryosphere in a Changing Climate* (ref. 1, chapter 4) and two chapters in the Sixth Assessment Report (AR6) of IPCC (ref. 2, chapter 9 and ref. 3, chapter 3 respectively). These reports provided assessments of the changes and projections of global mean sea-level rise and extreme sea level and their impacts in the coastal regions.

More than 90% of the heat generated by global warming gets absorbed in the ocean. One of the significant changes in the ocean is the increase in marine heat waves (MHWs). These are large increases in temperature over a region, which persist for a few weeks or longer. For instance, using sea surface temperature (SST) data, Chatterjee and Shenoy[4] showed an increase in the occurrence of MHWs in the Arabian Sea during the period 1982–2019. MHWs cause coral bleaching, and they are harmful to other marine organisms. Besides, ocean acidification due to the increased absorption of carbon dioxide in the ocean also affects the marine ecosystem.

Warming of the ocean causes an increase in the mean sea level. Thermal expansion, as well as melting of glaciers and ice sheets (Antarctica and Greenland) are the main contributors to sea-level rise. The global mean sea level rose by 0.20 m from 1901 to 2018. Projections for global mean sea-level rise for 2100 (relative to 1995–2014) could vary from 0.28 to 0.55 m for a very low greenhouse gas emission scenario and by 0.63–1.01 m for a high emission scenario[2].

A major concern is the increase extreme sea-level events in the coastal regions worldwide. They occur mainly due to storm surges generated by cyclones. Assessments in SROCC[1] and AR6 (refs 2, 3), based on studies of statistical projections using historical tide-gauge records and assuming a uniform sea-level rise, showed that extreme