Platinum Jubilee

Physical Research Laboratory
MetMeSS-2022

2nd Symposium On

"Meteoroids, Meteors and Meteorites: Messengers from Space"

25th November, Thursday

Session-III: Science from Meteor Radars, Radiation processing of organic matter and Space Weathering.

Session Chairs: Varun Sheel and Umesh Kadhane

Abstract #	Time	Speaker	Title of talk
Invited	09:30-10:00	K Kishore Kumar	A Decade of Meteor Radar Observations of the Low Latitude Mesosphere Lower Thermosphere Dynamics.
Invited	10:00-10:30	Umesh Kadhane	A molecular physics prospective of high energy radiation processing of organic matter in our solar system
S3-01	10:40-10:50	S. S. Prijith	Meteor radar observations of quasi-two-day waves and weakening of diurnal tides in the mesosphere lower thermosphere
S3-02	10:50-11:00	Eswar Sunkara	Advances in Meteor Radar Application for Upper Atmosphere Studies during Sudden Stratosphere Warnings
S3-03	11:00-11:10	M V Vinitha	Differentiation of Trapped $C_{16}H_{10}^{+}$ isomer using Low-energy collisions and Visible/VUV Photons; Murchison meteorite as a case study
S3-04	11:10-11:20	Pramitha M	Stratospheric Quasi Biennial Oscillation Modulations of Migrating Diurnal Tide in the Mesosphere and Lower Thermosphere Over the Low and Equatorial Latitudes
S3-05	11:20-11:30	Veena C.P	Study of aerosol analogue of Titan: Tholin
S3-06	11:30-11:40	Surya Snata Rout	Laboratory Simulations of Space Weathering: Pulsed Laser and H^{+}-, He^{2+}- and Ar^{+}- ion Irradiation of Low-Fe Olivine
S3-07	11:40-11:45	Priyal Singhal	Science behind meteor echoes

Meteor radar observations of quasi-two-day waves and weakening of diurnal tides in the mesosphere lower thermosphere

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Atmosphere tides in the mesosphere-lower thermosphere (MLT) region are important in controlling atmosphere-ionosphere coupling [1] and modulating ionosphere composition and processes [2, 3]. Day to day variation of migrating diurnal tidal characteristics and effects of quasi-two-day waves on tidal amplitudes are examined in the present study. The analysis is carried out using wind measurements in the MLT region, by meteor wind radar at Thumba, for a period of 10years from 2006 to 2015. Diurnal tidal amplitudes are extracted using harmonic analysis, by employing least square best fit method [4], on a composite diurnal cycle of winds, generated by considering a moving window period of 4days [5].

The analysis shows events of anomalous tidal weakening, in February 2010 and January 2012. Mean amplitude of diurnal tide at 91km is observed to be weakening by $13ms^{-1}$ (former event) and $16ms^{-1}$ (latter event), compared to that during the pre-event period. Fourier analysis shows occurrence of strong quasi-two-day waves, during the anomalous events of tidal weakening. Compared to pre-event periods, increase in quasi-two-day wave amplitude is observed to be $35ms^{-1}$ and $53ms^{-1}$ during the former and latter events, respectively. However, mechanisms leading to the weakening of diurnal tides by quasi-two-day waves are found to be different in both the events. In the first event, parametric excitation of phase locked two day waves occurs, by extracting energy from diurnal tides, and causes tidal weakening [6]. However, in the second event, non linear interaction between diurnal tide and quasi-two-day wave leads to generation of secondary quasi-16hour waves at the expense of tidal energy and hence leads to tidal weakening [7]. Thus, the present study provides observational evidence for different pathways through which quasi two day waves affect tidal amplitudes and hence atmosphere-ionosphere coupling.

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Advances in Meteor Radar Application for Upper Atmosphere Studies during Sudden Stratosphere Warnings

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Abstract:

Recent days Meteor Radars are playing a key role in understanding the upper atmosphere structure and dynamics by providing the continuous observations through meteor detection. Made a systematic study in understanding mesospheric dynamics in both the polar region and in low-latitude region using the KSS meteor radar in Antarctica (62° S, 59° W) and Advanced meteor radar at Tirupati (13.63°N, 79.4°E). We have investigated Antarctic mesospheric structure and dynamics during 2010, 2019 minor sudden stratosphere warming (SSW) events. Further using advanced meteor radar network observations along with ERA5 data, we report observational evidence of polar to tropical mesospheric teleconnections during the 2018 major sudden stratosphere warming (SSW) event in the northern hemisphere. A peak SSW on February 14, 2018, characterized by a ~ 45 K rise in polar stratosphere temperature and a zonal wind reversal of ~ (–25) m/s at 60°N and 10 hPa, is observed. In the tropical lower mesosphere, a maximum zonal wind reversal (–24 m/s) compared with that identified in the extra-tropical regions was observed. Moreover, a time delay in the wind reversal between the tropical/polar stations and the mid-latitudes was detected. The wind reversal in the mesosphere is due to the propagation of dominant intra-seasonal oscillations (ISOs) of 30–60-days and the presence and superposition of 8-day period planetary waves (PWs). The ISOs phase propagation is observed from the high- to low-latitudes (60°N to 20°N) in contrast to 8-day PWs phase propagation, indicating the change in the meridional propagation of winds during SSW. However, the superposition of dominant ISOs and weak 8-day PWs could be responsible for the delay of the wind reversal in the tropical mesosphere. Therefore, this study has strong implications for understanding the reversed (polar to tropical) mesospheric meridional circulation during SSW.

Differentiation of Trapped $C_{16}H_{10}^+$ isomer using Low-energy collisions and Visible/VUV Photons; Murchison meteorite as a case study

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Polycyclic aromatic hydrocarbons (PAHs) are key species in carbonaceous chondrites (CC) and these molecules are believed to be synthesized well before the accretion of meteoritic bodies [1]. Identification of the structural isomers of these indigenous molecules can bring further information about the physical conditions at which they were formed and evolved. Molecular analysis of the PAH content in CC meteorites shows a dominant peak at m/z 202.078 corresponding to $C_{16}H_{10}$ [2]. Obtaining information on the associated isomeric structures is a challenge for the molecular analysis of samples available in very small quantities (mg or less). We showed that coupling laser desorption ionization mass spectrometry with ion trapping opens up the possibility of unraveling isomers by activating ion fragmentation via collisions or photon absorption [3]. In this study, we reported the best criteria for differentiating isomers with comparable dissociation energies, namely Pyrene (Pyr), Fluoranthene (Flu), and 9-Ethynylphenanthrene (Etp), on the basis of the parent dissociation curve and the ratio of dehydrogenation channels. Photoabsorption schemes, multiple photon absorption (MPD) in the visible range and single photon absorption at 10.5 eV are found to be more effective in differentiating these isomers than activation by low energy collisions. That led us to implement the MPD scheme in the molecular analyzer setup, AROMA [2], which is dedicated to molecular analysis of complex samples by using two-step laser desorption laser ionization (L2MS) mass spectrometry. We present here the results obtained with MPD on AROMA on the $C_{16}H_{10}^+$ species produced from Pyr and Flu pure samples, their mixtures and the Murchison meteorite. The results indicate an abundance of ~50%/50% of Pyr and Flu in Murchison, which is in good agreement with the composition of $C_{16}H_{10}$ isomers derived from gas chromatography mass spectrometry [1, 4] (See Figure 1).

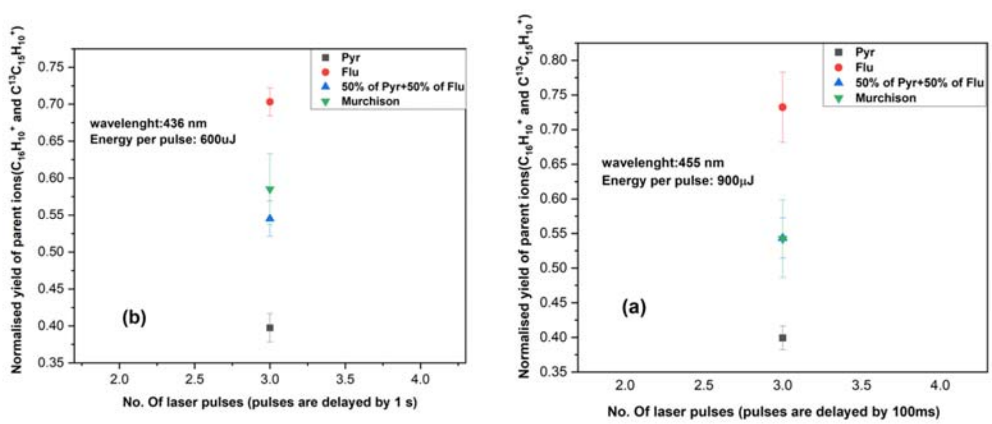

Figure 1. Calibration and test results for the Murchison meteorite for m/z 202.078. Measurements performed using MPD on AROMA at two different laser wavelengths (a). 436 nm and (b). 455nm.

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Stratospheric Quasi Biennial Oscillation Modulations of Migrating Diurnal Tide in the Mesosphere and Lower Thermosphere Over the Low and Equatorial Latitudes

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Atmospheric tides are global scale oscillations having periods that are harmonics of solar day (24, 12, 8h, etc.) and play a significant role in coupling lower and middle/upper atmosphere. Even though tides are well represented in numerical models, time-to-time evaluation of these models against observations from several ground based measurements is needed to employ them in day-to-day research applications.In the present study, horizontal wind measurements using meteor radars located at Thumba (8.5^{0}N, 77^{0}E; 2006–2015) Kototabang (0.2^{0}S, 100.3^{0}E; 2002–2017) and Tirupati (13.63^{0}N, 79.4^{0}E; 2013–2017) in the mesosphere-lower thermosphere (MLT) and Specified Dynamics Whole Atmosphere Community Climate Model (SD-WACCM) simulations are employed for investigating the diurnal tide variability at quasi-biennial scales. The model simulations are evaluated using the meteor radar observations at three tropical locations. WACCM simulations could reproduce the seasonal evolution of diurnal tides very well over Thumba and Tirupati but there are small discrepancies over Kototabang. In order to investigate the modulation of the diurnal tide amplitudes in the MLT region by the stratospheric quasi-biennial oscillation (SQBO), deseasonalized perturbations of diurnal tides and stratospheric winds are analyzed. A very good correspondence is found between meridional diurnal tide perturbation amplitudes and the SQBO with positive tidal perturbations during the eastward phase of SQBO and negative perturbations during the westward phase over Thumba and Tirupati. SQBO modulations of diurnal tides at global scales exhibits a positive correlation between the meridional diurnal tide perturbation with SQBO winds at 20hPa and a negative correlation with SQBO winds at 70 hPa within ±40^0 latitude, except over the equator. It is also noted that the equatorial electrojet strength, is modulated by the SQBO over the Thumba, which is a dip equatorial location. The significance of present study lies in evaluating WACCM simulations at tropical locations using meteor radar measurements and in investigating the SQBO modulations of diurnal tides at global scales.

Study of aerosol analogue of Titan: Tholin

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Radiation processes in the planetary atmosphere lead to the formation of many interesting molecules. Pluto, Saturn's moon Titan and comets like 67P/Churyumov-Geransimeko contain complex organic molecules formed due to such processes. Among these objects of interest in the solar system, Titan is unique as it is considered as a proxy of early earth. Titan has nitrogen and methane rich atmosphere. Exposure of Titan's upper atmosphere (>700 km) to external energy sources, mainly solar photons and magnetospheric electrons from Saturn leads to ionization and dissociation of the most abundant molecular species. Complex organic compounds are observed at the lower altitudes, which are identified to be the basis of the aerosol [1]. We have considered Titan's aerosol analogue "Tholin" for our study.

Study of organic chemistry on Titan involves: (1) Direct observation and in-situ sampling of Titan's atmosphere and surface (2) laboratory simulation of the atmospheric condition and (3) modelling Titan's atmosphere and surface using data from 1 and 2 [2]. We are interested in the laboratory simulation and analysis of products formed in the Titan reactor. We have developed our experimental set-up to create the Titan's ionospheric condition in the lab using 13.56 MHz RF inductively coupled plasma in a gas mixture of 96% Nitrogen and 4% Methane (similar composition as in Titan). Experimental set up consists of a plasma reactor with an inductive coil connected to the RF power supply and provisions for gas supply. In addition, provisions for mass spectrometric studies of stable intermediates are also made. To understand the tholin formation, there are two different and complementary approaches. The first is a bottom-up approach in which focus is towards the study of gas phase reactions leading to tholin formation and second is a top-bottom approach in which tholin's properties and composition are studied to infer their formation process. We use both the approaches: Real-time mass spectrometric measurements for examining the stable intermediates and characterization techniques like FTIR, SEM for understanding the tholin formed.

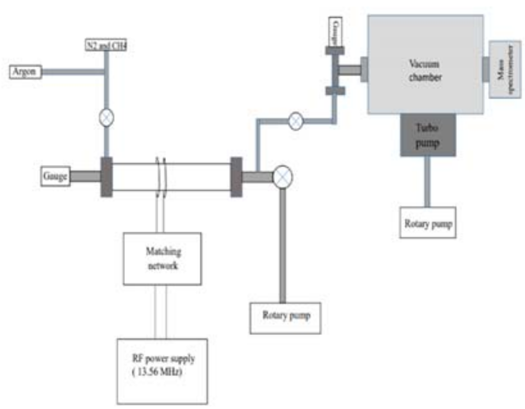

Fig1. Schematic of experimental set-up

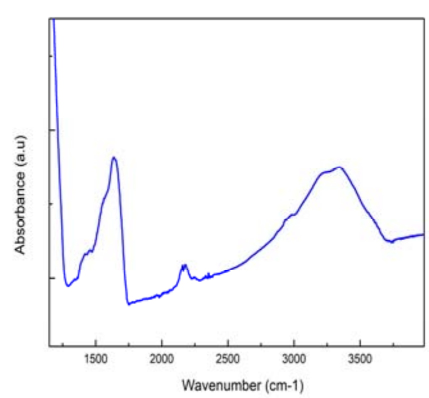

Fig 2. FTIR spectra of tholin

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Laboratory Simulations of Space Weathering: Pulsed Laser and H^+-, He^{2+}- and Ar^+- ion Irradiation of Low-Fe Olivine

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Introduction:

Space weathering (SW) leads to structural, chemical, mineralogical and optical changes with time of the surface/regolith of different bodies in the solar system that are exposed to impact of micron-sized dust particles (micrometeorites) and solar wind and solar flare ions [1]. The dominant information about the surface of different solar system bodies is acquired using reflectance spectroscopy in the UV-vis-NIR and to accurately determine the surface composition of an airless body it is extremely important to understand the mechanism of SW. It is now well known that reddening and darkening of spectra in the visible-near-infrared range (VNIR) due to lunar-like SW is caused by <40 nm sized metallic iron ($npFe^0$) present within 20-200 nm thick amorphous film/coating around the grains in the lunar regolith [1,2]. SW occurring on other bodies except the S(IV) subclass of asteroids and Itokawa is not well understood. Except for the samples from the Moon and the asteroid Itokawa, our direct understanding of SW comes from laboratory ion and laser irradiation experiments simulating solar wind and micrometeorite impacts respectively. The heating and shock effects due to micrometeorite impact is simulated by an infrared nanosecond pulsed laser beam and a femtosecond pulsed laser beam respectively whereas solar wind implantation is simulated by irradiation of samples with 1-500 keV H^+, He^+ and Ar^+ ions [3,4]. The interaction of pulsed laser beam and energetic ions with different types of minerals and the variability of SW with temporal locations and different space environment is not well understood. Additionally, many artificially space weathered samples show reddening in VNIR but the causes of reddening has not been studied. Here, I study the nanometer scales changes in the surface of an olivine crystal after irradiation with a pulsed laser beam and with H^+, He^{2+} and Ar^+ ions in order to understand the cause of reddening in VNIR spectra of Fe-bearing samples after ion and laser irradiation.

Samples and Methods: An olivine crystal with ~4wt% FeO was selected for the study and polished slices were prepared from the crystal fragment. Single a nanosecond (6 nsec) pulse of an infrared laser (1064 nm) with pulse energy of 30 mJ was used to irradiate the surface of an olivine crystal. The total energy deposited was 10^9 W/cm^2 which has been shown to simulate the impact of dust particles on the surface of planetary bodies. Other olivine crystals were irradiated with 1 keV H^+ (fluence = 1×10^{18} ions/cm^2), 4-40 keV He^{2+} (5×10^{16}-10^{18}ions/cm^2) and 40-400 keV Ar^+ (5×10^{16} ions/cm^2) ions using two different ion implanters. The ion beam current was kept at <1 μA/cm^2 to prevent excessive heating of the samples. After irradiation of the sample TEM lamellas were prepared using a focused ion beam instrument and then studied in a 200 keV Thermo Scientific Talos TEM.

Results and Discussions: Lamella prepared from olivine irradiated with a pulsed laser beam show a thick melt layer on top of the crystalline olivine and contains numerous $npFe^0$ inclusions (Fig.1). These inclusions are the cause of reddening of VNIR spectra of laser irradiated samples. Sample irradiated with 1 keV H^+ ions has a 50-60 nm amorphous layer with many bubbles most likely filled with H (Fig. 2). The amorphous layer on olivine sample irradiated with 40 keV He^{2+} and 200 keV Ar^+-ions is 250 nm and 280 nm thick (Fig. 3,4). None of the ion irradiated samples have $npFe^0$ inclusions within their top amorphous layers but they show depletion of O, Mg and Si along with implantation of Ar-ions.

Conclusion and Future Work: Redenning of VNIR spectra in laser irradiated samples is due to presence of $npFe^0$ inclusions within the melted layer but ion irradiated samples do not have any $npFe^0$ inclusions and it not clear why ion irradiated samples show reddening in the VNIR. More coordinated TEM and VNIR spectroscopy studies of ion irradiation samples need to be done.

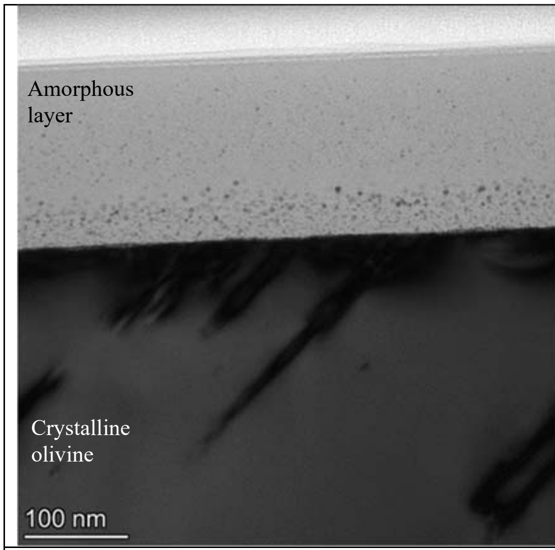

Fig. 1: Bright-field TEM image of olivine irradiated with a nanosecond pulsed laser. The dark inclusions in the amorphous layer are $npFe^0$ inclusions.

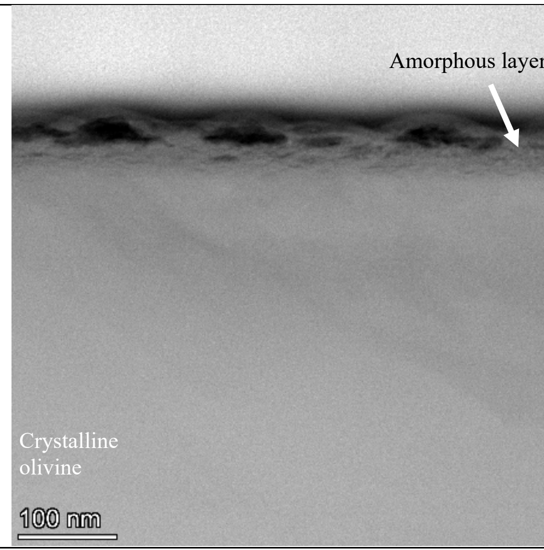

Fig. 2: Bright-field TEM image of lamella prepared from olivine irradiated with 1 keV H^+ ions.

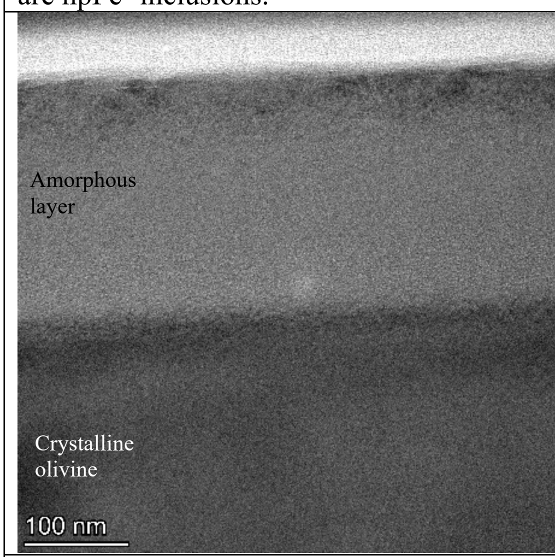

Fig. 2: Bright-field TEM image of lamella prepared from olivine irradiated with 40 keV He^{2+} ions.

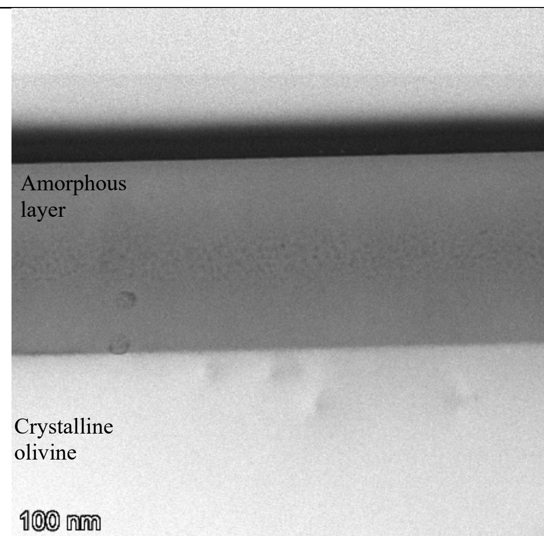

Fig. 2: Bright-field TEM image of lamella prepared from olivine irradiated with 200 keV Ar^+ ions.

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Science behind meteor echoes

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By studying the radio waves originating from astronomical sources, astronomers can learn about their composition, structure, and motion. Recently, high altitude radar meteors up to 148 km have been confirmed by the MU radar meteor echo data set. [1] Here, we focus on meteor showers like zeta Perseids, which are mainly due to dust particles released on its orbit by a comet when it approaches the Sun and use forward scattering on radio signals to detect and characterize meteoroids falling into the Earth's atmosphere. The incident radio wave is reflected on the ionized trail left behind the meteoroid when it falls into the atmosphere. The receiver then records radio signals reflected off meteor trails (hereafter called meteor echoes). Meteor echoes are used to predict activity curves, to estimate the mass index of meteor shower and to compute trajectories of meteoroids. [2] We are currently analyzing meteor echoes data for 'Radio Meteor Zoo Project' which collects radio signals from BRAMS.

References: [1] https://academic.oup.com/mnras/article/517/2/3024/6731793
[2] https://www.zooniverse.org/projects/zooniverse/radio-meteor-zoo/about/research