MetMeSS-2021

Symposium

Meteoroids, Meteors and Meteorites: Messengers from Space

Physical Research Laboratory, Ahmedabad

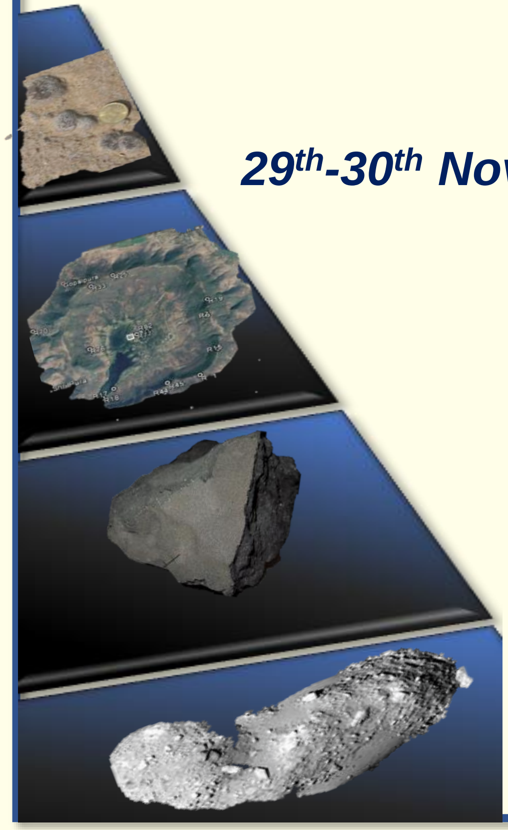
29th-30th November 2021

Platinum Jubilee

Physical Research Laboratory, Ahmedabad

Symposium on Meteoroids, Meteor, Meteorites: Messenger from Space

MetMeSS-2021



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“Meteoroids, Meteors and Meteorites: Messengers from Space”

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“Meteoroids, Meteors and Meteorites: Messengers from Space”

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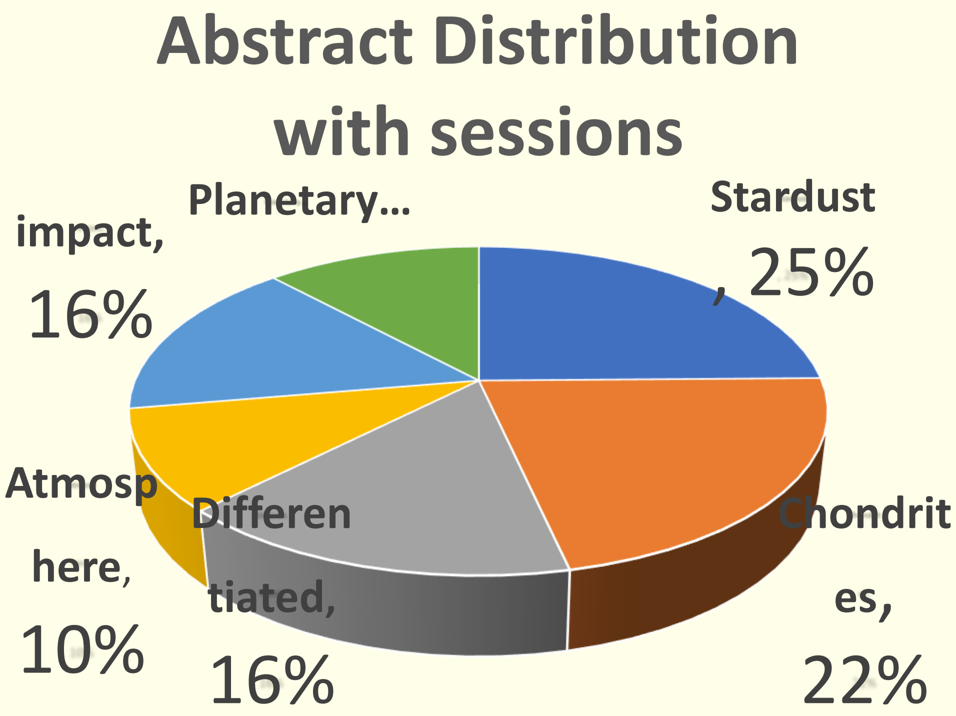

Platinum Jubilee

Physical Research Laboratory
MetMeSS-2021

Symposium on *Meteoroids, Meteors and Meteorites: Messengers from Space*

Programme

29 November, Monday

Session-1: Stardusts & Starbits!

(Pre-Solar Grains, Interplanetary Dust Particles, Early Solar System Solids)

Session Chair: Sandeep Sahijpal & Kinsuk Acharyya

Abstract #	Time	Speaker	Title of talk
	11:00-11:15	Kuljeet K. Marhas	Overview of Pre-solar dust, early solar system sloid
S1-01	11:15-11:30	Ritesh K. Mishra	Meteoritic evidence of multiple superflares during the birth of the Solar system
S1-02	11:30-11:40	Kinsuk Acharyya	Dust-grains: Journey from the interstellar medium to planetary bodies as a catalytic agent to form the simple through complex organic molecules
S1-03	11:40-11:50	Jayesh Pabari	Interplanetary Dust at Mars in Light of MAVEN Observations
S1-05	11:50-11:58	Manish Sanghani*	Evidence of a Population II Star as a Stellar Source of a Presolar SiC Grain?
S1-06	11:58-12:06	Arijit Roy*	Minerals in the ISM are Made in an Instant
S1-07	12:06-12:14	Chaitanya Giri	Sequestered Graphene in CAIs of Allende and QUE 94366 CV3 meteorites: Implications for future asteroid sample-return and in-situ sampling missions.
S1-08	12:14-12:22	Sana Ahmed*	Interstellar Comet 2I/Borisov: Complex Organics in the Primordial Disk?
S1-09	12:22-12:27	Advait Unnithan *	Interaction of Silicate grains with Galactic Cosmic Rays in Interstellar medium.
S1-10	12:27-12:32	S. V. Singh*	A possible explanation for the microstructures observed in meteorites
S1-11	12:32-12:37	Malaidevan P.	Microcontroller based Automated Freeze-Thaw Instrument.

Meteoritic evidence of multiple superflares during the birth of the Solar system.

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Astronomical observations of young stellar objects by NASA Kepler, K2 and other astronomical missions provide evidences of multiple, high energy flaring events during the pre-main sequence stages of the Sun-like stars [1,2]. These highly energetic events that emanate copious amount of energy, radiation, mass dramatically alter the physical, chemical, isotopic composition of the matter in the protoplanetary disk thereby resetting the dynamics of formation and growth of planetesimals in the protoplanetary disk. The nature, intensity, and chronology of such events for our Sun during its birth is a key missing information that could potentially be the defining determinant for the unique grand architecture of the Solar system hosting a habitable planet (Earth). Studies of fossilized records of short-lived now-extinct radionuclides in various components of meteorites provide opportunities to understand events, processes and their chronology during the formation and early evolution of the solar system [3-7]. In particular, lithium-beryllium-boron isotope systematics study in the early solar system solids provide a unique possibility to simultaneously study two distinct radioactive decay systematics [3,4]. The short-lived now-extinct radionuclides ^{7}Be and ^{10}Be decay to ^{7}Li and ^{10}B with characteristic half-lives of (53.12±0.07) days [8] and (1.386±0.016) million years [9], respectively.

Li-Be-B isotope systematics study of a Calcium-aluminum-rich inclusion (CAI) in Vigarano (carbonaceous chondrite; petrographic type 3.1) (Vig-1) was carried out to: (1) search for evidence of flaring activity during the birth of the Solar system (2) ascertain irradiation of gas and solids in the protoplanetary disk by the solar flares as the source of some of the short-lived radionuclie (3) infer cosmochemical conditions, processes and their duration. Secondary ion mass spectrometer ims 1270 at CRPG-CNRS, Nancy, France was used to analyse melilite phase present in the central regions and at the outer periphery (Wark-Lovering rim) of the CAI. The in-situ isotopic study yielded evidences of a range of excesses in $^{7}Li/^{6}Li$ and $^{10}B/^{11}B$ ratios that positively correlate with abundance of Beryllium (Be). Hence can be most appositely ascribed due to the decay of ^{7}Be and ^{10}Be, respectively. The linear regression of the obtained data give isochrons corresponding to $^{7}Be/^{9}Be$ of $(5.4\pm3.7)\times10^{-3}$ (2σ) and $^{10}Be/^{9}Be$ ratio of $(3.9\pm4.2)\times10^{-3}$ (95% conf.). Previous ^{26}Al-^{26}Mg isotope systematics of this CAI ($^{26}Al/^{27}Al = (4.89\pm0.38)\times10^{-5}$) suggests its formation at 0.07±0.08Ma [7]. The very short-half-life of ^{7}Be of 53 days implies its production locally before incorporation into the CAI. Since production of ^{7}Be, ^{10}Be by spallation reactions have same targets (oxygen, carbon nuclie), very similar reaction cross-sections over the range of energies, the production of the two nuclides in irradiation scenario are coupled with the production ratio of the two nuclides being governed by the rigidity of the spectrum of energy of the flux of incident particle and duration of irradiation. Therefore, the observed ^{10}Be in the CAI is also mostly co-genetic with ^{7}Be. The observed mean abundance of $^{7}Be/^{9}Be$ in Vigarano CAI 1 is about 5 times the observed abundance in Efremovka CAI 40 [4] and similar to Allende 3529-41 CAI [3]. A range of $^{7}Be/^{9}Be$ in these 3 CAIs forming at 0.07±0.08, 0.24±0.33 and 0.42±0.34 Ma, respectively after the fiducial origin of solar system therefore provides evidence of multiple episodes of Solar flare of varying intensity occurring during the pre-main sequence stages (0-~2.5Ma) of our Sun.

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Dust-grains: Journey from the interstellar medium to planetary bodies as a catalytic agent to form the simple through complex organic molecules

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Dust-grains are solid particles and an integral component of the interstellar medium (ISM) and proto-planetary disks around young stars. By mass, they are only about 1 % of the total mass budget of ISM, despite playing a crucial role in the physical and chemical evolution of ISM. They are the fundamental building block of planets - they grow from small sub-micron sizes to planetesimals that have sufficient gravitational attraction and end up in planetary embryos and planets. In addition, they provide a surface for the chemical reactions to occur, in fact, even the formation of the most abundant molecule H_2 cannot happen in ISM without the dust-grains. Starting from diffuse ISM to its incorporation in the planetary bodies, it encounters a variety of physical environments which influences the formation of molecules on them. At low temperature (~10 K), building block molecules like H_2O, CH_4, NH_3, HCN are produced due to hydrogenation reaction via grain surface chemistry, when the temperature starts to increase due to the process of star formation various radicals such as OH, CH, CH_2, CH_3, NH, NH_2, CN, which are produced due to photo-dissociation and chemical reactions combine to form complex organics such as organic acids, aldehydes, alcohols etc. Dust-grains are mixed with gasses. In an astrochemical simulation, they are evolved simultaneously which is coupled with physical conditions. Typical gas-phase models include about 750 species connected with about 8000 reactions and around 300 species on the grain surface connected with about 3000 reactions. To study chemical evolution one needs to evolve stiff differential equations of the form for each species:

$$\frac{dn_g(i)}{dt} = \sum_i \sum_j K_{ij} n_g(l) n_g(j) - n(i) \sum_i K_{ij} n_g(j) - r_{acc}(i) + r_{des}(i) n_s(i),$$

The left-Hand side describes the time evolution of any given species in the gas phase. The first term on the right-hand side represents its formation paths, 2nd term is its destruction paths, 3rd term represents species that accrete on the dust-grains and finally, the last term represents the desorption of species from dust-grains. In this presentation, I will discuss how dust grains play an important role in the chemical evolution in the various phases of star and planet formation, starting from the formation of H_2 in the diffuse ISM to the formation of H_2O, CH_4, NH_3, HCN, simple organic acids/aldehydes/alcohols in the dense molecular clouds and protoplanetary disks.

Interplanetary Dust at Mars in Light of MAVEN Observations

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Abstract: Interplanetary Dust Particles (IDPs) or cosmic dust is found everywhere in our Solar system and Mars is not the exception. Modelling results [1] show that the Martian moons, Phobos and Deimos provide dust around Mars due to ejected particles due to incoming micrometeorites. Though a thin dust ring is expected around Mars, its experimental evidence is awaited [2]. IDPs originate from sources like Asteroid belt or Kuiper belt and they encounter various planets during their motion in the solar system. The impact rate of IDP was observed by LPW on board MAVEN, earlier for the particle size of 1-5 μm or 5-25 μm [3]. The observed impact rate is used to obtain the IDP flux at Mars for the possible particle size and, it is presented here. Also, a range of possible particle velocity at Mars provides the range of particle number density, which are presented and compared with the assumed velocity of 18 km/s at Mars. Study of dust at Mars is important for the ablation study in atmosphere.

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Evidence of a Population II Star as a Stellar Source of a Presolar SiC Grain?

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Introduction: Presolar grains found in primitive meteorites condensed in the outflows of red giant or asymptotic giant branch (AGB) stars and in the stellar explosions before the formation of our solar system. These tiny dust grains survived isotopic homogenization in the early solar system, carrying nucleosynthetic signatures of their parent stars [1]. Chromium (Cr) isotopic anomalies identified in meteorites are thought to have carried by presolar silicon carbide (SiC) grains [2], majority of which are mainstream grains condensed in ~1.5- 3 $M_{\odot}$ AGB stars of near solar metallicity [3]. Following their condensation in the inner shells of pre-supernova stars, Cr isotopes are inherited by AGB stars and reprocessed by slow-neutron capture (s) process. Isotopically anomalous 16 presolar SiC grains were identified by [4] with the Cr abundance ranging from ~0.5-9 ppm, of which a grain with $\delta^{54}Cr$ ~647±412 ‰ was found, with its C and N isotopic composition pointing towards an AGB origin. The present study aims to provide constraints on the mass and metallicity of the parent AGB star using C, N and Cr isotopic compositions, by applying F.R.U.I.T.Y. (FUll-Network Repository of Updated Isotopic Tables & Yields) model.

Model Calculations: The initial nucleosynthetic calculations for s-process in AGB stars predicted overproduction of ^{54}Cr isotopes of only up to ~110 ‰ in $\delta^{54}Cr$ values [2]. Calculations by [5] shows that the ^{54}Cr enrichment for 1.5 $M_{\odot}$ and solar metallicity ($Z_{\odot}$) is found to be insufficient to explain our grain data, however, the model predicts substantial ^{54}Cr enrichment when $Z = Z_{\odot}/3$. Present study explored several possible scenarios that can explain ^{54}Cr enrichment, with the C and N isotopic compositions of the grain using FRUITY model.

Results and Conclusions: The modelling calculations show that the metallicity of the parent star should be very low to match the observed grain data. For instance, a 1.3 $M_{\odot}$ star with low metallicity can closely reproduce ^{54}Cr enrichment and $^{12}C/^{13}C$ ratio with ~little higher $^{14}N/^{15}N$ ratio than the reported ratio for the grain. The parent star of the grain is likely a low metallicity star belong to the population II (metal-poor) stars in the early universe which might have reaccreted heavy metals from the population III stars. Alternatively, the parent star might have evolved from the gas clouds externally enriched by a first generation type-II supernovae as has been discussed for the Zn enrichment in the star HE1327–2326 [7].

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Minerals in the ISM are Made in an Instant

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Dusts, especially silicate type, are detected in different astrophysical regions using the characteristic IR spectral features [1]. Similar spectral signatures are also observed in different comets, asteroids, and Interplanetary Dust Particles (IDP) and meteorites [1, 2]. A significant amount of interstellar dust is assumed to produce via gas-phase condensation processes in presence of winds of Asymptotic Giant Branch (AGB) stars [3]. In order to understand the formation pathways of minerals in the Interstellar Medium (ISM) as well as in our Solar system various experimental and theoretical methods have been proposed by various groups. These are like Sol - Gel technique [4], melting and quenching technique [5], gas phase condensation [6], laser pyrolysis [7] and ion irradiation [8].

Shock waves are known to play vital role in the chemical enrichment of ISM as well as on the surface of the air less planetary bodies [9]. Shock waves of various intensities has been observed at different parts of the ISM [10]. The high velocity shock waves (> 50 km s^{-1}) are known to contribute to different dust destruction processes like sputtering, grain charging, shattering etc., [9]. On the other hand, low velocity shock waves (1-10 km s^{-1}) has been proposed to chemically enrich the propagating medium [11].

Owing the importance of the shock waves in the interstellar chemistry we have investigated shock induced formation pathway of mineral dust. To do so, we used the High Intensity Shock Tube for Astrochemistry (HISTA) housed at PRL, Ahmedabad, that can simulate shock waves up to 6 Mach. We prepared stoichiometric mixtures of Mg, Fe, and SiO_2 and subjected the mixture to high intensity shock (~ 7000 K, 2 ms). The processed samples were collected and examined using spectroscopic and imaging techniques. Preliminary results will be discussed in this meeting.

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Sequestered Graphene in CAIs of Allende and QUE 94366 CV3 meteorites: Implications for future asteroid sample-return and in-situ sampling missions

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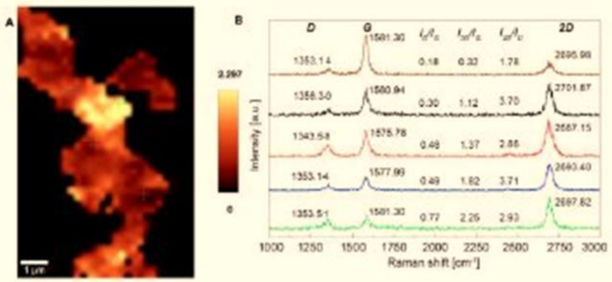
Contents of Abstract: Nanoscale graphene morphologies are reported in the Allende and QUE 94366 CV3-type carbonaceous chondrites via Confocal Raman Imaging Spectroscopy [1]. These morphologies are found embedded in the refractory calcium-aluminum-rich inclusion (CAI) rims in Allende and within a chondrule inclusion in QUE 94366. Earlier investigation already revealed graphite whiskers (GWs) presence in both these meteorites [2]. Further inspection of the meteoritic sections, coupled with advancements in the knowledge of carbon materials [3], reveal a re-interpretation of Raman features of a subset of the reported GWs and newer analysed features as graphene. This meteoritic graphene perhaps originated from the same protosolar carbon reservoir that synthesized the GWs. The graphene was most likely synthesized concurrent to the inclusions and CAIs, in a high-temperature zone near the proto-Sun and during the solar system's earliest eon [4]. However, in the case of Allende we cannot totally rule out synthesis during later aqueous alteration of the original mineral CAI assemblage. The possibility of exploring similar carbon allotropes will be crucial for the scientific and economic rationale of *in situ* and sample-return space missions bound for carbonaceous asteroids near Earth, those in the Main Belt, and those that are Greeks and Trojans.



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Interstellar Comet 2I/Borisov: Complex Organics in the Primordial Disk?

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Abstract:

Understanding the chemical evolution of protoplanetary disks and the origin of the primordial compositions of planetary systems like ours is a fundamental question in astrochemistry. Comets, made up of left-over material that formed the planets, are also the least-altered objects surviving from the protoplanetary disk that formed the Solar System. Therefore they can preserve the signature of the physical processes and the chemical stratification that prevailed due to the spatial and temporal variation of volatiles in the disk. While comets in the Solar System provide an understanding of the Solar System formation, recent observation of the interstellar comet 2I/Borisov provides a unique opportunity to understand the physical conditions that prevailed in a distant unknown planetary system.

Comet 2I/Borisov was discovered by G. Borisov on 30 August 2019. Observations of the comet show that the CO/H_2O ratio is higher than what has been observed in Solar System comets at a heliocentric distance < 2.5 AU. We studied the gas-phase coma of comet 2I/Borisov using a multi-fluid chemical-hydrodynamical model. The gas-phase model includes a host of chemical reactions, with the neutrals, ions and electrons treated as three separate fluids. Energy exchange between the three fluids due to elastic and inelastic scattering, and radiative losses are also considered. Our model results give an understanding of the coma composition of comet 2I/Borisov. We see from our results that there is high abundance of CO^+ and HCO^+ ions in the coma of comet 2I/Borisov, and we show how these two ions affect the creation/destruction rates of other ions such as H_2O^+, H_3O^+, N-bearing ions and large organic ions. We find that the presence of CO leads to a higher abundance of large organic ions and neutrals such as $CH_3OH_2^+$, $CH_3OCH_4^+$ and CH_3OCH_3, as compared to a typical H_2O-rich Solar System comet.

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Interaction of Silicate grains with Galactic Cosmic Rays in Interstellar medium

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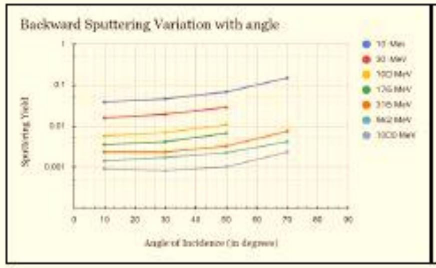
Abstract: Dust grains in the interstellar medium can play a vital role in our understanding of how interstellar material (ISM) is processed once they have been ejected out from stellar interiors. Studying the environment of their origins and their formation, destruction and re-accretion processes provide crucial constraints on the properties of stellar interiors, molecular clouds and the chemical evolutionary history of our galaxy [1]. In our understanding of dust destruction processes in the ISM, the role of ice-mantles is a relatively novel addition. They have been theorized to protect presolar grains from being shattered in grain-grain collisions and have even been thought to shield grains from Galactic Cosmic Rays in the ISM [2]. In this project, we have quantified the amount of atoms which will be sputtered (ejected) from an Iron rich Olivine silicate grain when a beam of Galactic Cosmic Rays (GCRs) hits it. We conducted the study by simulating the sputtering process using the software SDTrimSP, which allows us to define a target with given thickness and composition and simulate a beam of ions hitting the target at some incident energy and angle. We used a grain size of 2 μm and an ice-mantle thickness of 0.01μm. The grain composition was obtained by averaging out the compositions of 50 Fe-rich olivine silicate grains. The ice-mantle composition is characteristic of the molecular cloud being considered. We have chosen a Young Stellar Object: R CrA IRS1, a Herbig Haro object roughly 130 parsecs from Earth [3]. It has very weak energy processing. GCR energies taken into consideration range from 10 MeV to 1 GeV, and assumed the lifetime of our grain as 1 billion years. The sputtering yields (number of atoms sputtered per GCR hit) show an exponential relation with the angle of incidence, with more atoms being sputtered by GCRs hitting at large angles of incidence. GCRs of lower energies are more likely to sputter atoms (Figure 1 and 2). Sputtering yields for angles higher than 70 degrees are still in progress. Combining the results for all angles of incidence and energies, we can determine the percentage destruction of ice-mantle due to sputtering by GCRs. Further, the effects of different molecular environment and grain-mantle thicknesses and compositions have yet to be studied, although previous results show negligible changes in yield for SiC grains [4]. It would be interesting to quantify the amount of amorphisation that takes place in case of silicates with respect to SiCs as laboratory observations in meteorites indicate presolar silicates to be largely amorphous.



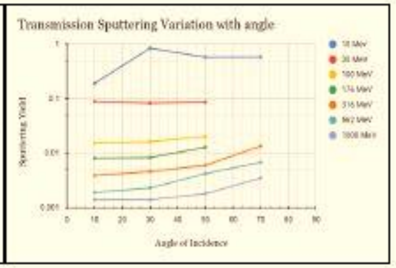


Figure 1 and 2 (left to right): Variation in Backward Sputtering Yield and transmission sputtering yield respectively.

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A possible explanation for the microstructures observed in meteorites

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Abstract:

A variety of microstructures have been found in various meteorites [1, 2]. These microstructures were titled as "organized elements" by Claus and Nagy [1], which resembled biological forms, but their biogenic origin was unknown and they were also excluded as being of terrestrial contamination [3]. Further studies identified these structures as microfossil remains [1, 4, 5]. Hoover [6] also deciphered these elements as microfossils of extraterrestrial life forms, indigenous to the meteorite, by comparing these structures with living and fossilized cyanobacteria. However, no convincing evidence was found concerning their origin [7-11]. We performed shock experiments on amino acids, which shows that when amino acids were shock processed, they resulted in the formation of a variety of complex structures [11]. Our results on the synthesis of microstructures in shock processed amino acids give a more plausible explanation for the formation of these structures in meteorites when they are subjected to impact induced shock events. A comparison of the structures we have observed with similar structures in several meteorites is shown in Figure 1. The striking similarities between the two suggest that shock induced processing of amino acids, known to be present in meteorites, can lead to the formation of microstructures.

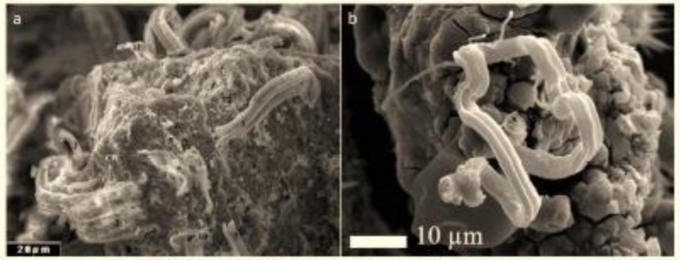

Figure 1: (a) Microstructures observed in Orgueil meteorite and (b) structures observed in shock processed amino acids.

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Microcontroller based Automated Freeze-Thaw Instrument

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Grains of several nanometers to a few microns in size are found within the fine-grained matrix of primitive meteorites, having highly anomalous isotopic compositions and very low abundances. These dust grains condensed in the outer envelopes of a red giant or asymptotic giant branch stars and in the ejecta of novae and supernovae explosions before the solar system was formed, and hence called *presolar grains*. These stardust grains survived high energy processes and isotopic homogenization in the early solar system and preserved their initial isotopic compositions, which are inherited from the nucleosynthetic processes of their parent stars. Laboratory analyses of presolar grains provide an excellent opportunity to better understand stellar nucleosynthesis, grain formation, alteration, and the chemical evolution of the galaxy [1]. Refractory presolar phases such as silicon carbide and oxide are isolated from primitive meteorite matrix by *chemical separation* of presolar grains [2], where harsh acids etch the grain surfaces and alter grain morphology and surface chemical composition. An alternative non-destructive method for isolating presolar grains is *Freeze-Thaw desegregation*, where grains are gently separated from the meteorite matrix, avoiding the strong acid treatment [3].

Here we report the development of an Automated Freeze-Thaw (AFT) instrument for the separation of minerals and grains by desegregating meteorite samples. Conceptually, the instrument uses natural expansion and contraction of solid samples by applying temperature variation. The AFT instrument automatically moves the sample from the heating element (hot bath) to a cooling element (liquid nitrogen) with a certain time gap. The mineral edges within the sample act as flaws through which the ultrapure water flows and the periodic pressure produced by contraction and expansion leads to the breakage of minerals from the edges. Multiple freeze-thaw cycles defragment the meteorite sample into very fine pieces, and different minerals are further separated using heavy liquids of different densities. This instrument is operated over a number of cycles using a dual-phase industrial grade stepper motor and its corresponding motor driver and is controlled by a 32-bit microcontroller (ATmega2560). We have successfully desegregated the Dhajala meteorite sample using the AFT instrument developed at PRL and isolated graphite grains from the matrix of Dhajala meteorite using the density separation method.

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Platinum Jubilee

Physical Research Laboratory
MetMeSS-2021

Symposium on *Meteoroids, Meteors and Meteorites: Messengers from Space*

Programme

29th November, Monday

Session-2: Chondrites & Micrometeorites: Events and Processes

Session Chairs: Sujoy Ghosh & Anil D. Shukla

Abstract #	Time	Speaker	Title of talk
Invited	13:50-14:05	Sandeep Sahijpal	Chondrites overview.
S2-01	14:05-14:15	Sujoy Ghosh	Natural bridgmanite in the Katol meteorite
S2-02	14:15-14:25	N.G Rudraswami	Micrometeorites: samples of chondritic components.
S2-03	14:25-14:33	Dipak K. Panda	AOA (Amoeboid olivine aggregates): Nebular and Parent body Processes in Mukundpura.
S2-04	14:33-14:41	Arindam. Dutta	Petrochemical and shock characterization of four Indian meteorite (chondrite) finds / falls
S2-05	14:41-14:49	Dafilgo Fernandes*	Investigating micrometeorites from Antarctica and deep-sea sediments of the Indian Ocean: Particulate asteroid and comet matter on the Earth.
S2-06	14:49-14:57	Mayank Pandey*	Preliminary results of micrometeorites collected From Maitri Station Antarctica
S2-07	14:57-15:05	Dipankar Pathak*	Understanding impact volatilization events in meteorites and their parent bodies, through volatile stable isotope systematics.
S2-08	15:05-15:13	Shristi Sharma*	Calcium Isotopic Compositions of Ordinary Chondrites.
S2-09	15:13-15:21	Shreeya Natrajan	The origin and evolution of insoluble organic matter in CMs- A NanoSIMS study.
S2-10	15:21-15:29	Shivani Baliyan*	Carbonates in meteorites and asteroids: Implications for aqueous alteration.
S2-11	15:29-15:37	Kishan Tiwari*	Shocked induced phase transformations and melting textures in Kamargaon L6 chondrite:

			Evidence for multiple impacts and constraints on shock conditions and thermal history
S2-12	15:37-15:42	Avadh Kumar	Meteorite-Asteroid relation using Cosmic ray exposure ages in Ordinary chondrites
S2-13	15:42-15:47	Malika Singhal*	Luminescence Characterization of Minerals from Murchison and Murray

S2-01

Natural bridgmanite in the Katol meteorite

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Bridgmanite, the most abundant mineral of the Earth's lower mantle, has been reported in only a few shocked chondritic meteorites; however, the compositions of these instances differ from that expected in the terrestrial bridgmanite. Here, we report the first natural occurrence of Fe-bearing aluminous bridgmanite in shockinduced melt veins within the Katol L6 chondrite with a composition that closely matches those synthesized in high-pressure and temperature experiments over the last three decades. The Katol bridgmanite coexists with majorite and metal-sulfide intergrowths. We found that the natural Fe-bearing aluminous bridgmanite in the Katol L6 chondrite has a significantly higher $Fe3+/\Sigma Fe$ ratio (0.69 ± 0.08) than coexisting majorite (0.37 ± 0.10), which agrees with experimental studies. The Katol bridgmanite is arguably the closest natural analog for the bridgmanite composition expected to be present in the Earth's lower mantle. Textural observations and comparison with laboratory experiments suggest that the Katol bridgmanite formed at pressures of ~23 to 25 gigapascals directly from the chondritic melt generated by the shock event. Thus, the Katol L6 sample may also serve as a unique analog for crystallization of bridgmanite during the final stages of magma ocean crystallization during Earth's formation.

S2-02

Micrometeorites: samples of chondritic components

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Micrometeorites (MMs) are extraterrestrial material in the size range of ~50–2000 µm collected by various methodology in deep sea, Polar Regions and space. These particles get detached from their parent bodies as dust and eventually spiral inwards towards the Sun over geologically timescales [1-6]. The unmelted micrometeorites (UMMs) as the name suggest preserve the mineral phases similar to that prior to atmospheric entry. The study of these UNMs has the potential to provide direct insights into the astrophysical conditions operating during the early solar system and the geological history of their parent bodies [1-3]. In spite of the benefits of studying UMMs, there are far fewer research on unmelted particles than on cosmic spherules [3]. This is predominantly due to highly friable nature of UMMs as well as the effort in recognizing UMMs and the challenges associated with analyzing the small particles.

The present study report high-precision analyses using secondary ion mass spectrometer for oxygen isotope systematics on micrometeorites collected from Antarctica. The study population focuses on unmelted coarse-grained (Cg) varieties. The study also analyzed relict minerals in porphyritic cosmic spherules and the relict matrix in a single scoriaceous fine-grained (Fg) MM. The minerals investigated are olivine and spinel. The textural, chemical and isotopic data on the mineral phases of MMs confirm that both olivine and spinel grains have retained their pre-atmospheric O-isotope compositions, indicating about their history beginning from breaking up with parent bodies, followed by Earth's entry and parent body affinities.

The olivine grains in spinel-free MMs have oxygen isotope composition that follow a slope-1 line on oxygen three isotope plot. They may represent most probable fragmented chondrules, with both type I and type II. The observed Mg#–$\Delta^{17}O$ distribution is best explained by a mixture of CM and CR chondrules, Tagish Lake chondrules or WILD2 cometary particles [3]. One of these chondrule-like MMs has oxygen isotope composition that are heterogeneous that are ^{16}O-rich linking it to relict silicate fragment of AOA material probably fused into the chondrule precursor or CAI type material [1]. The present work supports earlier O-isotope studies signifying that small MMs significantly sample material from CC parent bodies and that CgMMs sample from chondrules and, to a lesser extent, CAI material. The further studies will provide insights into the primitive O-isotope reservoirs of the early solar system.

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AOA (Amoeboid olivine aggregates): Nebular and Parent body Processes in Mukundpura.

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Introduction: Amoeboid olivine aggregates (AOAs) are the most common type of refractory inclusions in chondritic meteorite. It looks like AOAs have escaped extensive heating/melting and hence must have preserved the evidence for condensation from solar nebula gas [1,2]. In primitive carbonaceous chondrites, AOAs are mostly consisting of forsterite, Fe, Ni-metal, Al-diopside, spinel, anorthite, and very rare melilite. Mukunpura is a highly altered CM2 type meteorite. The present work aims to study the mineralogy of AOA in Mukundpura to understand the physiochemical condition of nebular gas.

Analytical Techniques: X-Ray mapping and mineral composition for the thick section of Mukundpura were carried out with JEOL IT300 scanning electron microscope coupled with an OXFORD EDS operated at 20 keV 500pA.

Results: The petrography study shows that all the chondrule and the matrix of in the meteorite are highly altered. Few partially altered chondrule with isolated olivine grains are fayalitic in composition [3]. The matrix is mainly clast of phyllosilicates or poorly crystallized phases (PCP) along with presence of carbonates and very rare presence of refractory inclusion [3, 4]. Only in two thick sections, presence of AOA has been observed. The EDS analysis shows the AOA are mainly composed of forsterite ($Fa_{<3}$), high Ca-pyroxene with average Wo 48.7, En 48.4 and Fs 2.8, low Ca pyroxene with average Wo 0.8, En 93.5 and Fs 5.7, Al-rich pyroxene (Al_2O_3 12-16 wt %) with average Wo 46.8, En 47.6 and Fs 5.6, Fe-Ni metal (Fe 92 wt %, Ni 6 wt %, Co ~1 %). AOA's in Mukundpura are mostly aggregates of irregular shaped olivine arranged in band like structure. The metal droplets are within the Ca-Al rich pyroxene. The high_ca pyroxene are coupled within the forsterite grains while low_Ca pyroxenes are occurring as individual grain. Spinel are also occurring as individual grain in AOA.

Discussion: From the geochemical analysis, it appears that Mukundpura is poor in refractory inclusion with highly altered matrix [4]. Only two AOA observed in two thick section (one in each section). AOA's in Mukundpura are mainly composed of forsterite, hi_Ca pyroxene, CAI (Al-rich pyroxene, Spinel), Fe-Ni metal. Forsterite in AOA of Mukundpura are coarse-grained and compact which indicate the possibility of thermal processing but may not be complete melting. Presence of CAI (Ca_Al- rich pyroxene) within olivine suggests that melilite was not physically isolated from the nebular gas. Hence, it can be implicit that during fast cooling the melilite might have altered to Al-Ca pyroxene [5].

Conclusion: AOA are common refractory found in chondritic meteorite and only two AOA observed in Mukundpura. AOA's in Mukundpura are consist of forsterite ($Fa_{<3}$), CAI (in the form of spine, Ca-Al-diopside), Fe-Ni metal. CAI (malilite) might have altered to Ca-Al pyroxene during the fast cooling in AOA of Mukundpura.

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Petrochemical and shock characterization of four Indian meteorite (chondrite) finds / falls

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In this study four (04 nos.) Indian meteorite (chondrite) finds / falls, e.g. *Bhanupratappur (L4)*, *Jalangi (L5/6)*, *Karimati (L5)* and *Natun Balijan (L4)* (earlier referred as Sadiya by [1]), have been registered in the Meteoritical Bulletin Database (http://www.lpi.usra.edu/meteor/metbull) for the first time based on their chemical and petrological types [2,3]. These ordinary chondrites of varying petrologic types (L4 to L5/6) with shock grades/stages ranging from S2 – S5 have been studied to evaluate relative degree of shock metamorphism and its characteristic features. Moreover, relatively higher equilibration temperatures (720-1109°C) have been estimated for these L-Group chondrites which can be correlated with their shock stages with increasing petrologic types, though at many instances the shock effects have been annealed to some extent with increasing temperature. Characteristic Raman peaks exclusively represent the presence of wadsleyite (718 cm^{-1} and 917 cm^{-1}) and ringwoodite (795 cm^{-1} and 842 cm^{-1}) fragments confined within shock melt veins (SMVs) as observed in *Jalangi (L5/6)* and *Bhanupratappur (L4)* chondrites. Presence of plagioclase melt glass along the interstitial /intergranular spaces of olivine and pyroxene chondrules, and within matrices suggests escalation of shock pressures at above ~ 45 GPa, involved in volume expansion and generating radial cracks in *Jalangi (L5/6)* chondrite. These recent fall / find, e.g., *Jalangi (L5/6)*, *Karimati (L5)*, *Bhanupratappur (L4)* and *Natun Balijan (L4)* chondrites exhibit comparable mineralogy, textures, and mineral chemical data (see Table -1), suggesting similar parental source component.

Table-1: Mineral chemical data, textural variants, and shock grade of studied chondrites

Chondrite	Mineralogy*	Textural variants	Chondrule: Matrix	X_{Mg}	Equilibration T in °C#	Shock Stages
Bhanupratappur (L4)	Olivine ($Fa_{25-29}Fo_{71-75}$)	PO, GO, POP chondrules and matrix component	~ 70 : 30	0.71 – 0.75	720-1020	S4 – S5
	Opx ($En_{72-77.5}Fs_{20.6-26.3}Wo_{1-4}$)	PP, POP, GP chondrules and matrix component		0.72 – 0.775		
	Cpx	Present as matrix component, rarely as mesostasis within PO and POP chondrules		$Wo_{42.7-48.3}En_{44.5-47}Fs_{7-12}$		
Jalangi (L5/6)	Olivine ($Fa_{24-27}Fo_{73-76}$)	BO, PO, GO, POP chondrules and matrix component	~ 60 : 40	0.73 – 0.76	825-1109	S4 – S5
	Opx ($En_{74.8-77}Fs_{21-23.4}Wo_{1-2}$)	PP and POP chondrules and matrix component		0.748 – 0.770		
Karimati (L5)	Olivine ($Fa_{24-26}Fo_{74-76}$)	BO, PO, GO, POP chondrules and matrix component	~ 60 : 40	0.74 – 0.76	720-950	S2 – S3
	Opx ($En_{74-77.1}Fs_{21.4-25.8}Wo_{\leq 2}$)	GP and POP chondrules and matrix component		0.748 – 0.771		
Natun Balijan (L4)	Olivine ($Fo_{73-75}Fa_{25-27}$)	BO, PO, POP, GO chondrules and matrix component	~ 70 : 30	0.73 – 0.75	750-930	S2 – S3
	Opx ($En_{69-76.7}Fs_{22-30}Wo_{1-4}$)	PP, POP chondrules and matrix component		0.689 – 0.767		
	Cpx	Present as matrix component, within mesostasis of BO and POP chondrules and rarely as rock/mineral clasts		$Wo_{27-48.8}En_{43.7-59}Fs_{7.3-13.4}$		

* Apart from olivine, orthopyroxene, clinopyroxene and feldspathic glass, Fe-Ni metals (kamacite and taenite), ± magnetite ± troilite ± chromite ± merrillite ± apatite are also present in these studied chondrites.
# Equilibration temperatures of studied chondrites have been calculated after Brey and Köhler (1990); Witt Eickschen and Seck (1991); Wood and Banno (1973); Lindsley and Anderson (1983) and others, compiled with PTMAFIC data. Calculation error limit in PTMAFIC software: ± 25-60°C.

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Investigating micrometeorites from Antarctica and deep-sea sediments of the Indian Ocean: Particulate asteroid and comet matter on the Earth

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Micrometeorites are micrometers to millimeters in size heated extraterrestrial particles and are primarily derived from asteroid bodies and comets that are collected from the Earth's surface [1,2,3,4,5]. Extraterrestrial dust, estimated to be ~40,000 tonnes per year, enters the atmosphere and is by far the most abundant extraterrestrial material accreting to the Earth [6]. Although 90% of the dust that directly enters the atmosphere is lost due to ablation during the entry process only 10% is recovered as micrometeorite on the surface of the Earth [7]. Micrometeorites have undergone significant chemical changes as a result of heating and ablation, making it difficult to determine their precursors [8]. Despite this, the previous study shows their chondritic elemental ratios preserved with the least changes [9]. For this study micrometeorites, were obtained from Antarctica ice and deep-sea sediments of the Central Indian Ocean Basin [10,11]. Scanning electron microscope and electron microprobe were used to examine and investigate the petrology and chemical composition of micrometeorites. The texture, mineralogy, and chemical composition of partially melted micrometeorites and unmelted Antarctica fine-grained micrometeorites indicate dominant fine-grained carbonaceous chondritic precursors. Some of the relict grains found in micrometeorites appear to represent type I and type II chondrule fragments from carbonaceous and ordinary chondrites. The major and minor elements for relict olivine and pyroxenes are compared with those from carbonaceous and ordinary chondrites to assert the nature of chondritic precursors that contribute to relict grains in micrometeorites. Unmelted Antarctica coarse-grained micrometeorites that are studied are similar to chondrules from many carbonaceous chondrites. In addition, evidence of intact subspherical domains of chondrules has been found in a few composite micrometeorites, which constraints the chondrule features of micrometeorites parent bodies [12]. The petrology, mineralogy, and chemical composition of these Antarctic and deep-sea micrometeorites suggests carbonaceous chondrites as the dominant source, with a modest fraction of ordinary chondrite-like parent bodies contributing a minimal fraction.

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Preliminary results of micrometeorites collected From Maitri Station Antarctica

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Micrometeorites are the largest fraction of extraterrestrial material reaching to the earth's surface and represent a broader spectrum of Solar System bodies as compared to meteorites. Here we will discuss preliminary results obtained from ~3000 cosmic spherules collected from Antarctica Blue ice region located approximately 8 km from the permanent Indian station Maitri (70°45S and 11°44E) [1]. These cosmic spherules are classified based on the scheme given in [2]. All the selected particles were mounted in epoxy, carbon-coated, examined, and analysed using SEM and EPMA respectively. The MMs are dominated by porphyritic (~36.9%) and barred (~36.5%). The other textural types comprises cryptocrystalline ~7.4%, glass-4.5%, RGB ~2.9%, scoriaceous ~4.5%, I-type ~6.1%, and G-type ~1.2%. When compared with particles collected from deep sea it is found that they are better preserved as lots of particles are lost due to interaction with sea water. Bulk major oxide data is obtained and elemental ratios of non-volatile elements shows that majority of them align with carbonaceous chondrites. Also lack of chondrules in majority of the particles impose important question on the nature of progenitors. We have also started to separate and analyze unmelted particles and some of which are also included here. They can be broadly divided into Coarse grained and fine grained and provide direct window to their precursors. Their mineralogy is also discussed briefly. Further analysis of Antarctica samples is continuing, and preliminary findings indicate that both melted and unmelted micrometeorites could be recovered. In the future, a thorough examination will be carried out to elucidate the sources of cosmic dust and better understand the early solar system

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Understanding impact volatilization events in meteorites and their parent bodies, through volatile stable isotope systematics

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Introduction: Impact events on terrestrial planets and other rocky bodies like asteroids are crucial in understanding their geological past. Impact events were responsible for delivering materials toward inner solar system, during the late heavy bombardment period that provides an insight to the lunar evolution. Such processes are also considered to be important in delivering volatiles to Earth at different times during its formation, and shortly or during its early differentiation. In this abstract, we present K and Sn stable isotope data of two ordinary chondrite falls from India, Dergaon (H5) and Mahadevpur (H4/5), to 1) Explain the anomalously low potassium content of Dergaon amongst ordinary chondrite [1], and 2) Constrain a probable impact event in the history of Mahadevpur parent body that could have caused a disturbance in the $^{87}Rb/^{86}Sr$, due to Rb volatilization [2].

Method: The major and trace elements data for both Dergaon and Mahadevpur fragments, together with the Nd and Sr isotope data were obtained using a quadrupole ICP-MS (X-Series II, Thermo Scientific) and a TIMS (Triton plus, Thermo Scientific) at the Center for Earth Sciences, Indian Institute of Science, India, respectively. The K and Sn stable isotopes were measured with a MC-ICP-MS at the Department of Earth and Planetary Sciences, Washington University in St. Louis, USA and Institute of Geological Sciences, University of Bern, Switzerland, respectively.

Result and Conclusion: Two fragments of Mahadevpur (one collected from Mahadevpur, and other from Pengeri) shows almost identical major and trace elements pattern, including $^{143}Nd/^{144}Nd$, suggesting that they are paired meteorites belonging to the same parent-body. However, the fragments show distinct elemental Rb/Sr and $^{87}Sr/^{86}Sr$. Based on the calculation of initial $^{87}Sr/^{86}Sr$ and a modelled Rb loss age ($\Delta t \rightarrow$ time since formation of CAIs), such an impact volatilization event is estimated to have occurred on the Mahadevpur parent body between 4.09-4.137 Ga. Given this hypothesis is correct, the same differences should be observed in the isotopic composition of volatile elements. The $\delta^{41}K$ as well as their $\delta^{122}Sn$ analysis shows a distinct isotope composition, indicating a possible change due to evaporation/condensation processes. Sn being more volatile compared to K, shows a much greater degree of fractionation by a factor of ~0.6 ‰ between the two fragments of Mahadevpur.

The Dergaon meteorite shows a normal Nd and Sr isotope ratios, and the calculated initial $^{87}Sr/^{86}Sr$ shows a composition similar to ordinary chondrites. The $\delta^{41}K$ isotopes composition of Dergaon meteorite is unique amongst the other ordinary chondrites [3].

Here, we evaluate the possibility of evaporative or condensation processes at kinetic or equilibrium conditions (Fig.1). The δ^{41}K of Dergaon falls under a $P_i/P_{i,sat} < 1$ (0.97-0.98) while both the fragments of Mahadevpur falls under the region where $P_i/P_{i,sat} > 1$. Here, $P_i/P_{i,sat}$ is the saturation pressure of a species i. The magnitude of K isotope fractionation in Dergaon is equivalent to HED groups of meteorites, however the Ca/K doesn't explain a K loss due to evaporation or condensation process.

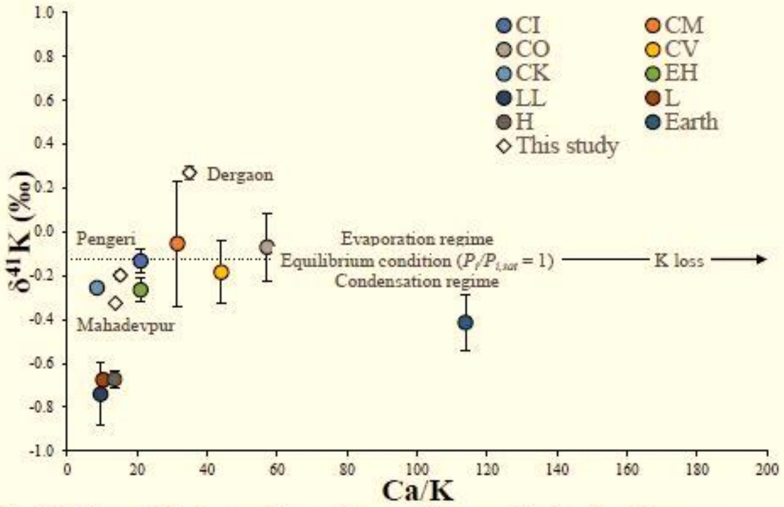

Fig. 1 Relation of K isotope variation with a possible evaporation/condensation process.

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Calcium Isotopic Compositions of Ordinary Chondrites

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Abstract: Mass-dependent isotopic differences between bulk meteorite samples can provide an insight into initial heterogeneity, processes within the disk that fractionated isotopes during nebular condensation and planetary accretion, and/or differentiation processes within the planets after they formed.[1] Calcium is an abundant refractory lithophile element (RLE) and therefore, can provide information about high-temperature condensation processes and the initial heterogeneity of the early solar system.[2]

In this study, we measured the calcium isotopic composition of 16 ordinary chondrites using a Thermo Scientific™ Triton Plus Thermal Ionization Mass Spectrometer (TIMS) at CEaS, IISc.[3] The measured data is compared to literature data for ordinary chondrites and different meteorite groups in Figures 1 and 2, respectively.

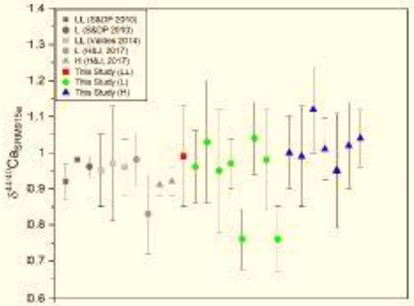

Fig. 1. Mass-dependent δ^{44}Ca/^{40}Ca compositions of ordinary chondrites measured in this study along with literature data.[2,4,5]

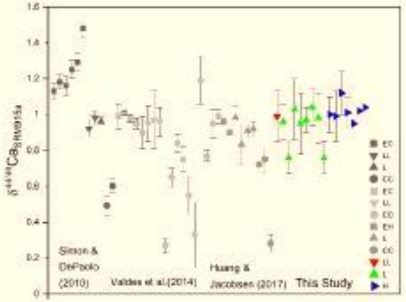

Fig. 2. δ^{44}Ca/^{40}Ca compositions of ordinary chondrites compared to different chondrite groups.[2,4,5]

Earlier studies have shown some variation in δ^{44}Ca/^{40}Ca between chondrite groups and Earth, at the <0.1‰ level of precision. The maximum variability was observed in carbonaceous chondrites (+0.10‰ to +1.19‰), and least variability in ordinary chondrites (+0.91‰ to +1.16‰). We show however, that variability in ordinary chondrites is larger than previously measured and that resolvable differences also exist between same meteorite samples measured by different groups-indicating sample heterogeneity. The isotopic composition does not seem to correlate with degree of thermal alteration in the samples. Previous studies have postulated that parent body aqueous alteration [6] and low-temperature alteration [7] play a significant role in establishing variability in calcium isotopic composition. Future studies therefore require a greater number of samples belonging to chondrite groups displaying different stages of alteration.

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The origin and evolution of insoluble organic matter in CMs- A NanoSIMS study

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The majority of carbon and nitrogen abundances found in chondrites is usually associated with macromolecular organic component. The fraction of this component that survives acid demineralization is termed as "insoluble" organic matter (IOM). The ^{13}C and ^{15}N isotopic ratios measured in IOM extracted from carbonaceous chondrites generally show large enrichments [1,2]. These provide clues to the origin , formation and the effects of nebular and parent body processing on the organic matter

^{15}N anomalies of the order of ~2000–3000‰ have been reported in carbonaceous chondrites[3,4,5,6]. These enrichments termed as hotspots are reported to be a result of ion molecule reactions at very low temperatures in the outer portion of the nascent solar nebula or the ISM [7,8]. Alternatively, these enrichments can also be explained by UV irradiation self-shielding similar to that of oxygen, self-shielding model [9,10,11] indicating they could have occurred in the outer solar nebula.

On the other hand, ^{15}N isotopic anomalies also manifest in terms of 15N poor signatures, termed as "cold-spots". Although not commonly observed they have been reported in Sahara 97096 [12] , DOM 08006 [13] and Maribo[14]. They are an intriguing feature as the organic matter in primitive chondrites as well as IDPs are predominantly enriched. The local ISM [15,16] and several molecular clouds [17,18,19] show depleted nitrogen isotopic ratios. Moreover the solar value of $\delta^{15}N_{air}$~ -380 ‰ calculated based on the data from Genesis [20] and atmospheric composition of Jupiter [21] also indicated a lower abundance of ^{15}N.

As advanced analytical techniques are used to study these samples the case for both nebular and ISM origin of organic matter becomes stronger. Thus in order to add to the understanding of C, N isotopic anomalies and their link to the origin of organic matter we performed a nanoSIMS analysis on IOM extracted from Murchison, Murray and Mukundpura. We observed a large variation in $\delta^{13}C$ and $\delta^{15}N$ ranging from hotspots to coldspots. Another interesting observation was that a contrast was seen in the ^{15}N isotopic anomalies between samples extracted in air as compared to the samples extracted in argon (inert) environment, which could be a result of contamination due to atmospheric nitrogen during the extraction.

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Carbonates in meteorites and asteroids: Implications for aqueous alteration

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Carbonates, even though occurring as a minor phase (generally < 3%) in primitive Carbonaceous (C) chondrites (commonly in CM (Mighei like) and CI (Ivuna like) chondrites), is ubiquitously present in meteoritic matrix. The carbonates are also important because they are the direct precipitate from the aqueous fluid and thus provide insights on the geologic history (first 5 Ma) of the early Solar System [1]. Carbonates are detected in exposure scale in the surface of asteroids Bennu and Ceres, while majority of carbonates are micron to sub-micron sized (rare veins and vein fragments) within the C-chondrites. The nature of carbonate minerals also varies with the extent of alteration; e.g. complex carbonates are generally common in the highly altered chondrite types. The activity of ion also has a fair control on carbonate chemistry, e.g. in higher aqueously altered meteorite due to decreasing Mg^{2+} activity, dolomite destabilises and facilitate precipitation of calcite. The carbonate mineral chemical composition also varies within a single meteorite and corroborate changes in the microenvironment. This also endorses precipitation of carbonate due to multiple events rather single episode. Thereof, the microstructure, texture and chemical composition of carbonate potentially record the diverse scenarios of aqueous alterations in the parent body.

Carbonates in B-type asteroid Bennu occur as centimetre-thick, meter-long vein suggesting for fluid-flow into the fractures conducive for open system, hydrothermal alteration [2]. The carbonates appear to be more abundant and complex in Ceres as compared to CM/CI chondrites and thus arguing for advanced and pervasive alteration [3].

Future scopes include *in situ* VIS-NIR spectroscopy of carbonate in C-chondrite to better understand the intricacy of spectra obtained remotely from the carbonates on asteroidal surface. The in situ C-O isotopic study of chemically zoned carbonates are also prerequisite to understand crystal growth and isotopic evolution of aqueous fluid.

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Shocked induced phase transformations and melting textures in Kamargaon L6 chondrite: Evidence for multiple impacts and constraints on shock conditions and thermal history

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Contents of Abstract: We report high-pressure mineral assemblages and microtextures in a up to 1.6 mm-wide shock melt vein (SMV) in heavily shocked Kamargaon L6 chondrite to constrain the shock conditions and thermal history. The chondritic portion mainly consists of olivine ($Fo_{73\text{-}74}$), low-calcium pyroxene ($En_{77\text{-}80}Fs_{19\text{-}22}Wo_{1\text{-}2}$), high-calcium pyroxene ($En_{45\text{-}46}Fs_{9\text{-}10}Wo_{44\text{-}46}$), plagioclase ($Ab_{62\text{-}70}An_{18\text{-}23}Or_{12\text{-}15}$), Fe-Ni metal alloy (kamacite and taenite), troilite and a minor amount of phosphate and chromite. The feldspar grains in the SMV have been transformed into maskelynite and lingunite and their texture and heterogenous composition suggest that they crystallized from isolated feldspar melt pockets at high-pressure. The parental pyroxene around some of the maskelynite grains are transformed into majorite. We also observed three distinct textures in olivine grains from the SMV: (i) segmented texture; (ii) vesicular texture; and (iii) dissociated texture. The segmentation may have developed due to the formation of sub-grain boundaries during the recovery process when the grains were subjected to localized shear stress. Many textural and compositional features indicate that the polycrystalline assemblage of segmented olivine is the product of back transformation from ringwoodite or wadsleyite. Dissociation of olivine has been proposed to be the result of incongruent melting of olivine into magnesiowüstite and liquid. We propose that the vesicular texture possibly formed due to localized melting during a shock event and subsequent degassing of volatiles after decompression when the post shock temperature was sufficiently high. Our finding is the first report of vesicular olivine and pyroxene grains in an ordinary chondrite.

Based on textures, melting features and high-pressure polymorphs, we have estimated average shock pressure and temperature in the shock-melt veins of Kamargaon L6 chondrite to be ~19-22 GPa and ~2433-2633 K. The maskelynization of feldspar ($An_{18\text{-}23}$) in the SMV indicates that the Kamargaon L6 chondrite has experienced peak pressure of up to ~30 GPa. Taking the peak thermal metamorphic temperature of 1073 K as initial temperature, the calculated shock and post shock temperature are ~1390 K and ~1226 K, respectively. The thermal model to estimate the cooling history of the shock-melt vein gives the crystallization time of ~50 ms. The SMV reaches the temperature of 1226 K in ~2 s. The shock pulse duration must have been less than ~2 s for the back transformation of high-pressure polymorphs to occur. Calculated values of impact velocity and the parent body size of the Kamargaon L6 meteorite, using these shock conditions, is envisaged ~2.06-2.3 km/s and at least ~6.4 km across respectively. Textures observed in the investigated sample indicate that they were formed as a result of multiple impact events on the parent body of Kamargaon L6 chondrite.

Meteorite-Asteroid relation using Cosmic ray exposure ages in Ordinary chondrites

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Abstract: Meteorites are the space rocks that coming from the outer space due to continuum impacts, collisions and gravitational perturbation on its parent asteroid body. Class of meteorites can be categorized into two types, on the basis of the genesis: *Chondrites* (undifferentiated) and *Achondrites* (differentiated). Further Chondrites can be subdivided as- *Ordinary*, *Carbonaceous* and *Enstatite* based on mineralogy and petrological properties. The ordinary chondrites are the largest class of meteorites in our collection; it had almost 87% of available meteorites. The group of H chondrites (high iron content, approx. 28%), L chondrites (low iron content, approx. 22%) and LL chondrites (low iron and low metallic iron) are together known as Ordinary chondrites. The cosmic ray exposure age of the meteorite is defined as how much time it spends after ejection from parent body. It is also known as ejection age [1].

After ejection from its parent body to their fall on the Earth as meteorites, as they are in continuum exposed to the Solar Wind(SW), Solar cosmic rays (SCR) and Galactic cosmic rays(GCR). During this process interaction of Galatic Cosmic Rays (GCR, energy in GeV range) with the ejected material, resulting in the production of cosmogenic nuclides [2,3]. We calculated ^{21}Ne cosmic ray exposure ages of these meteorites to understand the number of meteorite producing ejection events and constraints of its parent asteroid body. After analyzing the histogram of exposure age of the ordinary chondrites, it depicts influx of meteorite to Earth and its time dependence. Number of peaks also constraint the number of parent bodies which depicts Meteorites-Asteroid relations. [4,5].

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Luminescence Characterization of Minerals from Murchison and Murray

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Thermoluminescence (TL) and optically stimulated luminescence (OSL) are widely used to study the terrestrial and extra-terrestrial materials. Natural TL and OSL signals reveal the thermal, radiation and terrestrial history of meteorites[1]. Additionally, investigating the induced luminescence signals can decode the metamorphic history of the meteorites. However, most of the techniques used are framed for quartz and feldspar. In the present study, we are trying to explore the luminescence properties of new minerals.The luminescence properties of minerals as olivine, spinel, and quartz are being explored which are separated from Murchison and Murray meteorites. The measurements were done on single grains hand picked under optical microscope after physical[2] and chemical processing[3]. The traps responsible for luminescence are characterized using UV and BG-39 filters and stimulated with Blue, Infrared LED and heat[4]. The analyzed grains of olivine show only a low-temperature TL peak near 80-100°C, a significant BSL signal in UV emission. A very feeble IRSL response was observed in UV emission. Spinel also showed a dim luminescence signal and will be subjected to further studies. OSL results of quartz are similar to terrestrial quartz but the TL results are very feeble.

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Platinum Jubilee

Physical Research Laboratory

MetMeSS-2021

Symposium on *Meteoroids, Meteors and Meteorites: Messengers from Space*

Programme

29th November, Monday

Session-3: Journey to Differentiated Worlds

(Earth-Mars-Moon-Asteroids)

Session Chairs: Nachiketa Rai & Amit Basu

Abstract #	Time	Speaker	Title of talk
Invited	16:15-16:30	Ramananda Chakrabarti	Overview of differentiated planets.
S3-01	16:30-16:45	G. Srinivasan	Compositional Constraints on Late Veneer from Chalcogen Elements
S3-02	16:45- 16:55	Narendra Bhandari	Evidence and Consequence of presence of Niobium-94 in Gebel Kamil iron meteorite
S3-03	16:55-17:05	Amit Basu	Compositional Constraints on the Origin of Volcanism on Mars
S3-09	17:05-17:15	Gurpreet K. Bhatia	Early thermal evolution of Earth's embryos due to heat of ^{26}Al and impact-generated steam atmosphere
S3-04	17:15-17:23	Yash Srivastava *	Petrogenesis of A-881757: A non-KREEP Low Ti Lunar Meteorite Basalts
S3-05	17:23-17:31	Vishal Goyal*	Early Evolution of Mass-Averaged Temperature of the Moon
S3-06	17:31-17:39	P. Layak*	Constraining the composition of the parent planetisimal for the acapulcoite and Lodranite suite of meteorites- A trace element approach
S3-07	17:39-17:44	Rahul Das Gupta*	Formation of carbonate-sulfide association in the martian meteorite ALH84001 and implications for the nature of water-rock interactions on the martian surface in the Noachian Era
S3-08	17:44-17:49	Satvika Jaiswal*	Light noble gas study in Eucrites and diogenites

Compositional Constraints on Late Veneer from Chalcogen Elements.

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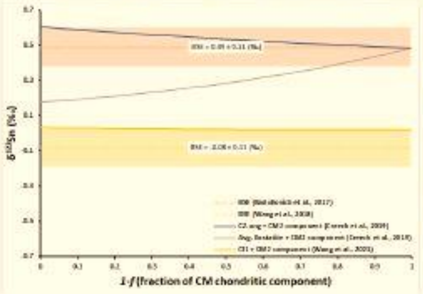
The composition of terrestrial planets is a function of their respective building blocks. The diversity of chemical and isotopic composition of Earth, Moon, Mars and meteorites is product of the varied physical and chemical conditions leading to their accretion. Dynamical modelling suggests that Earth accreted through collisional interactions of diverse material originating from a wide variety of heliocentric distances (Morbidelli et al. 2000). The composition of CI carbonaceous chondrites is a proxy for the primordial material from which the solar system formed. The composition of the Earth is very different from CI chondrites. One of the unresolved enigmas is that the Earth chemically resembles the carbonaceous chondrites (CC) while isotopically it is most similar to enstatite (NC) chondrites (Dauphas 2017). There is no exact equivalent meteorite composition which can be a source material for Earth. One wa.y to constrain the building blocks for the Earth is to compare and contrast the various elemental budgets based on volatility. There is no consensus on the sources of the volatiles or their mass fractions delivered towards the final stages of accretion. The obstacles in determining volatile inventory is that these elements have been redistributed due to core formation and or lost due to high temperatures generated by impact and accretion (Wang and Becker 2013). The elemental abundances of primitive meteorites and Earth decrease relative to CI chondrite composition as volatility increases. It was also observed that volatile element abundances may level off (Takahashi et al. 1978). More recent measurements by (Braukmüller et al. 2019) reveal that that volatile element abundances (e.g., S, Se, Te) do not fall off monotonically but level off into a plateau.

The building blocks for Earth perhaps had varying volatile element abundancs and redox state. The Earth building process could be subdivided into three primary simple steps a) accretion of 85% Earth mass material; b) followed by a Moon forming giant impact (~14 % of Earth Mass); c) late veneer with 1% Earth Mass. These steps could be further subdivided for compositional diversity and sequence vis-à-vis mile stone in Earth evolution (e.g., core-mantle formation). In this simplified scenario, in the first step matter could be dominated by enstatite like material while subsequent accretionary material may have been very different. The moon forming giant impact or material may have ranged in composition from a homogeneous (CC or NC) end member to a heterogeneous mixture of both. It could involve a primary event followed by a secondary event, or could be more exotic compositional equivalent of a reduced planet like Mercury (e.g., Wang et al.2021). This was followed by the impactor constituting the late veneer, 1% of total Earth mass, which is used to explain the abundance of highly siderophile elements (HSE) such as the platinum group elements and Re and Au. Similar to the HSEs, the abundance of volatile chalcogen elements, e.g., Se, Te, and Sn, with a 50% condensation temperature between 700K-500K are in depleted in BSE by core formation. If we assume that all the inventory of these elements in BSE is due to late veneer, we can use mass balance equation to calculate the composition of the impactor - a mixture of various CC type meteorite composition. Using mass balance equation it was shown (Varas-Reus et al 2019) e.g., that ~ 85% CI meteorite and ~ 15% CM meteorite material with nearly 1% Earth mass could contaminate the pre-late veneer silicate mantle to recreate suitable Se isotope composition. If we use this proportion of CI and CM material with measured □$^{122/118}Sn$ isotope composition (Wang et al. 2021) one can generate



BSE like composition with suitable Sn isotope composition. This is a useful constraint in the chalcogen element budget as their values converge towards BSE composition (Figure).

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Evidence and Consequence of presence of Niobium-94 in Gebel Kamil iron meteorite

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We have measured spectrum of coincident gamma rays emitted by two large fragments of Gebel Kamil iron meteorite, found in 2009-10 near an impact crater, using a low background, highly specific gamma-gamma coincidence spectrometer in the underground laboratory of Monte dei Cappuccini in Torino, Italy. The results of ^{26}Al (mean life ~ 1million years), published earlier (Taricco et al, 2019), indicate a highly asymmetric ablation. The data also show a feeble but clear presence of ^{94}Nb (mean life ~ 30,000 years), identified by its characteriusctic coincident two decay gamma rays in the fragment exposed near the surface in the interplanetary space. The other fragment, located much deeper within the meteoroid, gives no such signal indicating that ^{94}Nb activity is steeply depth dependent, and this fragment can serve as an ideal background control, mimicking all the known and unknown processes. The results can be re-confirmed using radiochemical methods, and measurement in additional shallow fragments.

^{94}Nb, is known to be synthesised only in r-process in supernovae and giant stars and its presence in the meteorite demands a very special, multi step, scenario, in which, after being produced in the interstellar neighbourhood, ^{94}Nb is accelerated to very high (>GeV) energies while propagating through the interstellar medium, enter with galactic cosmic rays in the heliosphere by crossing the heliomagnetic field and then get implanted in the meteorite orbiting in the interplanetary space. The plausability of these steps, and their time scales considering the half life of the niobium radioisotope is discussed. No other mechanism appears probable. If confirmed, these results will provide new information about the supernovae events in solar neighbourhood in the recent past (<10^5 years). Plausibility of mechanisms and problems involved in these steps will be discussed.

We are indebted to S. Mohanty and K.K.Marhas for discussions.

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Compositional Constraints on the Origin of Volcanism on Mars

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Mars surface is thought of basaltic composition on an average. However, there are ample pieces of evidence of heterogeneous compositions. The martian surface displays a wide range from olivine-enriched basalt to felsic material material-rich dacite composition on a local scale. The olivine-enriched basalts, found from the eastern part of Valles Marineris, were interpreted as an eruptive event consisting of compositionally uniform flood lavas originating from a primitive mantle source region associated with the initiation of Tharsis volcanism. The presence of granitoid bodies at the central peaks of Syrtis Major might indicate mechanisms that produce highly differentiated /fractionated magmas.

Arabia Paterae is a unique and recently recognized Noachian volcanic province on Mars [1-4]. Relative abundances of different elements in Arabia Paterae relative to other volcanic regions on Mars can help to understand the mantle source composition and the petrogenesis during the oldest volcanic. The Hesperian volcanic domains on Mars are Syrtis Major, Tyrrhena Patera, Syria Planum, while the Amazonian volcanic domains are Olympus Mons, Alba Patera, Elysium Mons. If a gradational relation exists between compositional and spatial parameters, it will reflect the mantle heterogeneity and evolution of the mantle through geologic time. Being the Noachian age, Arabia Paterae volcanism was definitely influenced by more water activity and a better oxidation state than the later volcanic events.

SNC martian meteorites are formed volcanically. The range of their composition also varies from most Fe-Mg rich ultramafic dunite-pyroxenite to permafic and mafic basaltic types to silicic clasts in brecciated rocks. The shergottites are of the late Amazonian age. Phase equilibria experiments indicate that these rock compositions represent multiply saturated magmas with olivine + orthopyroxene ± spinel at 1.0–1.2 GPa, corresponding to depths of 85–100 km [5-8]. This mineral assemblage is predicted as a partial melting residue for the Mars upper mantle. Noteworthy, martian surface rocks are higher in aluminum and alkali content than the martian meteorites, the bulk of which indicates late crystallization of plagioclase and abundant phosphates. The difference in rock compositions between old rocks on the martian surface and young martian meteorites is striking and suggests global magmatic evolution through time. Several explanations for this difference in composition have been offered, including melting and fractionation at different pressures, under different redox conditions, or with different water contents.

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Early thermal evolution of Earth's embryos due to heat of ^{26}Al and impact-generated steam atmosphere

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Earth and the Enstatite chondrite meteorites (dry) are known to have similar isotopic abundance [1]. Previous isotopic studies have suggested that the Earth initial accreted the reduced Enstatite material [2]. The volatile rich material was delivered from large heliocentric distances possibly through the moon forming giant impact [3]. However, recent studies have shown that the Enstatite chondrites are not depleted in volatiles [4]. These contain adequate hydrogen to deliver significant amount of water to Earth. It implies to the formation of an impact-generated steam atmosphere on the surface of Earth's embryos (building blocks) during their growth [5]. Further, the recent planet formation theories and isotopic measurements suggest that the embryos of Earth accreted very rapidly during the initial ~2 Ma of the formation of solar system [6-7]. The early accretion implies the role played by the short-lived radionuclide (SLR) ^{26}Al in the large-scale heating of embryo's interiors [8-9]. Based on these new finding, we performed numerical simulations to study the early thermal evolution and core-mantle separation of Earth's embryos ($0.2M_E$-$0.6M_E$) due to significant heating by short-lived radionuclide ^{26}Al and blanketing effect of the impact-generated steam atmosphere during accretion [10]. We also incorporated the heat energies of SLR ^{60}Fe along with long-lived radionuclides ^{40}K, ^{235}U, ^{238}U and ^{232}U. The bulk composition of the embryos was considered to be Enstatite type [5,9]. The initial water content (X_{wp}) of the accreting planetesimals was considered to be in the range of 0.1 – 0.54% H_2O by weight [4]. The results of numerical simulations show the formation of the magma ocean on the surface of embryos during accretion because of significant blanketing by the impact-generated steam atmosphere. Further, the core-mantle segregation in the interior was complete within the initial ~5 Ma of the formation of the solar system if the embryos accreted in the initial ~1.3-1.5 Ma after the formation of CAIs. The early segregation of massive embryos ($0.4M_E$-$0.6M_E$) at lower melt fraction of silicates was essential for complete core-mantle differentiation within the initial 5 Ma. These results seem to be consistent with the results of new finding for the rapid accretion and differentiation of main accretion phase of Earth within the initial ~5 Ma of the solar system [11]. The outcomes of the present works could be used to explain the anomalously high concentration of siderophile elements and Platinum group elements in the mantle of Earth.

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PETROGENESIS OF A-881757: A NON-KREEP LOW Ti LUNAR METEORITE BASALTS

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Low-Ti basalts spans over wider lunar volcanic history, with the oldest low Ti basalt age of ~ 4.39 Ga (Kalahari 009;[1]) to recently sampled Chang'E 5 low Ti basalt (~2.0 Ga;[2]). Asuka-881757 is a coarse, holocrystalline (grains more than 5 mm in length), low-Ti, high Fe (Mg# 38), unbrecciated mare basalt with pyroxene and plagioclase as the primary constituents. Similarity in textural, chemical and isotopic signature of A-881757 with lunar meteorites including Y-793169, MIL 05035 and MET 01210 led [3] collectively referred them as YAMM group of meteorites. Compared to the other lunar meteorites and returned VLT/Low-Ti samples, YAMM basalts with ~ 3.8-3.9 Ga age [4,5,6] are older and have fairly evolved (Mg# (32-41) bulk composition with low bulk concentration of REEs and other incompatible trace elements (e.g., 0.48 ppm Th). It is generally believed that the generation of mare basalts is assisted by the assimilation of KREEP components [7]. However, low Rb/Sr (Sr_I=0.69908 - 0.6991), high ε_{Nd}= 7.2-7.4 and unusually low U-Pb (μ = 11-20) suggest a non-KREEP (high Rb/Sr and low ε_{Nd}) related origin of these meteorite clan and also imply a distinct source than other lunar basalts [4]. Thus, it becomes important to understand as well as assess the role of KREEP and early impacts in ancient volcanism.

In this study, we have revisited the petrogenesis of YAMM basalts with special emphasis on A-881757 to understand the ancient lunar volcanism. We show that detailed petrology of A- 881757 provides insight into the generation of VLT/low Ti basalts and their source chemistry, as well as highlight the importance of trapped residual components in generating trace element variations in lunar basaltic magmas.

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Early Evolution of Mass-Averaged Temperature of the Moon

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The Moon is considered to have formed as a result of the giant collision of proto-planetary body 'Theia' with proto-Earth [1]. The event happened after the exhaustion of short-lived radionuclides ^{26}Al and ^{60}Fe [2-3]. In the absence of short-lived radionuclides, the thermal energy comes from only the initial energy of accreting moonlets and impact-induced heating. In this study, we have analyzed the evolution of mass-average of lunar thermal profile based on numerical simulations.

We have run several models with the initial temperature of accreting moonlets, T_{ini} in the range of 1700-2100 K, and efficiency of impact-induced heating (h-parameter) in the range of 0.01-0.5. After capturing the thermal profile at several time points, mass-average was computed thereafter.

Fig. 1 shows the evolution of mass-averaged lunar temperature for our 14 models. The general trend among the models show that temperature increase for the initial 200 years on account of impact-induced heating due to dependence on surface gravity. After that, a sharp decline for about 10000-20000 years on account of liquid-state convection followed by slow cooling by remnant convection and conduction. Fig. 1 starts at time t = 1.0 years when the Moon was already formed 1280 km in radius by then, making temperature different for the same T_{ini} at that time-point. For all the models, the averaged temperature rises to different levels at t = 200 years, i.e., at the end of accretion. Except in T_{ini} = 2000 K and h = 0.5, sharp decline due to rapid convection completes in nearly same time interval whereas it is double for the former. Furthermore, the final temperature at the end of 2 Myr is in a narrow band 1650-1700 K except for T_{ini} = 1700 K

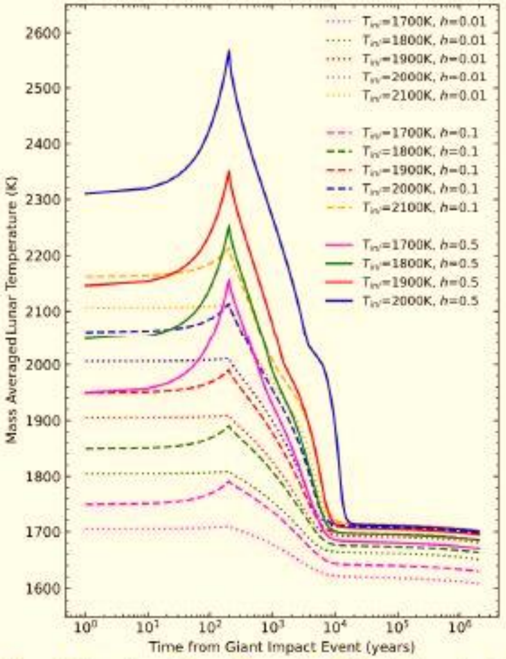

Figure 1: *Mass-Averaged Lunar Temperature*. Different colours show the different values for initial temperature of accreting moonlets, T_{ini}. Different linestyles epresents distinct values for *h*-parameter. The figure startes at t=1.0 year, when the Moon was accreted to 1280 km.

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CONSTRAINING THE COMPOSITION OF THE PARENT PLANETESIMAL FOR THE ACAPULCOITE AND LODRANITE SUITE OF METEORITES - A TRACE ELEMENT APPROACH.

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In spite of the detailed petrogenetic history of the Acapulcoite-Lodranite (A-L) suite of meteorites, its original parent body composition still remains an unsettled question. In this study, we have compared the source composition of the A-L suite of meteorites to a host of chondritic compositions [1-6, 8-9] viz. ordinary (H) chondrites, Carbonaceous Bencubbinites (CB), Carbonaceous Renazzo (CR) and Kakangari (K) chondrites, as possible representatives of the source materials of the A-Lsuite using the trace element systematics for lithophile and siderophile elements to shortlist the most plausible parent body composition for the A-L suite of meteorites.

The A-L source material has undergone 1-4% partial melting without the loss of a metallic melt to give rise to the acapulcoites (A). Thus, a compositional homogeneity in terms of their bulk trace element concentration is expected between A and H, CB, CR and K chondrites. It is observed that the CI normalized values for refractory lithophiles (Al, Ca, V, La, Sm, Mg, Cr, Na and K) and siderophiles (Ru, Os, Ir, Fe, Co, Ni, Ga, As and Au) for K chondrites, H chondrites and CR chondrites lie within ±1σ of A. But, the CB chondrites show depletion in lithophiles (0.4±0.1×A) and enrichment in siderophiles (3.4±0.2×A) (Figure 1) as compared to acapulcoites, owing to which it is ruled out from the list of possible source materials for the A-L suite of meteorites. Despite the mineralogical and geochemical similarities of the H chondrites with ALs, isotopic signatures rule out the H-chondrites. On the other hand, the K chondrites satisfy both the trace element criterion with matching isotope signatures to the A-L suite. From the analysis of all chondritic compositions (H, CB, CR and K chondrites), the K chondrites offer best correlations with the A-Ls.

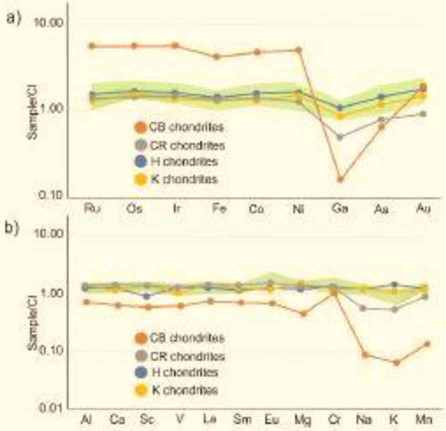

Figure 1: CI normalized plots showing element depletion patterns for H, CB, CR and K chondrites. The CI normalized values for ±1σ for acapulcoites is calculated, which marks the upper and lower limit, demarcated by green zone.

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Formation of carbonate-sulfide association in the martian meteorite ALH84001 and implications for the nature of water-rock interactions on the martian surface in the Noachian Era

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Introduction: The geologic evolution of Mars is characterized by a shift from wet to dry surface conditions due to the loss of the martian atmosphere, resulting from the loss of its magnetic field before 4 Ga [1]. In addition, the transition from neutral-pH fluids during Noachian to acidic fluids during Hesperian led to the formation of distinctive mineral assemblages in martian meteorites [2]. The martian meteorite, ALH 84001 is an orthopyroxenite cumulate rock, which represents the oldest igneous rock among the martian meteorites [3-5]. The crystallization age of this rock is estimated to be 4.091 ± 0.03 Ga based on Lu-Hf isotopic ratios, whereas the other martian meteorites formed later than 2.5 Ga [3]. Hence the secondary minerals formed in ALH 84001 records the conditions of aqueous alteration on Mars in the Noachian Era.

Research gap and significance of this study: The presence of phyllosilicates, sulfates in the SNC meteorites indicate oxidizing conditions on Mars, particularly during the Hesperian era following the loss of the martian atmosphere [6-7]. In contrast, the presence of Mg-Fe carbonates, sulfides, magnetites in ALH 84001 suggest reducing conditions on Mars before 4 Ga [2, 8]. The carbonates and sulfides are likely to have formed during hydrothermal alteration on Mars [9]. The enriched sulfur isotopic compositions of the pyrites in ALH 84001 have been explained by mixing of sulfur from the martian mantle with the isotopically heavy sulfur from the martian atmosphere [9-10]. This implies that the formation of these sulfides is likely to be related to impact driven hydrothermal alteration. The formation of the carbonates has also been attributed to hydrothermal alteration based on their oxygen isotopic compositions [11]. Hence, the isotopic compositions of the carbonates and sulfides along with their textural association suggests a possible genetic relationship.

Preliminary results and future work: Polished and gold-coated epoxy mounts of several pieces of ALH 84001 were studied using the JEOL JSM-IT300 SEM at Physical Research Laboratory. In addition to the orthopyroxenes, formed by igneous processes, this meteorite shows presence of veins of Na, Al-rich maskelynite, grains of chromites, Ca-phosphate, carbonates and sulfides. The concentrations of Mg, Fe and Ca in the carbonates show significant heterogeneity, suggesting these have been modified after their precipitation. The relationship of these zoned carbonates with the formation of the sulfides will be investigated in this study based on their elemental and isotopic compositions. The measurement of oxygen isotopes in the carbonates and sulfur isotopes in the coexisting sulfides would help us to better understand their possible formation from hydrothermal fluids.

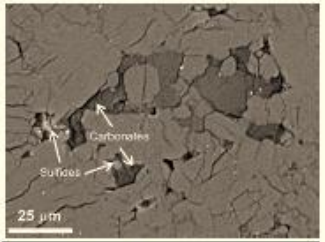

Fig. 1: Representative image of the association of carbonates and sulfides in ALH 84001

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S3-08

Light noble gas study in Eucrites and diogenites

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HED is a group of differentiated meteorites believed to be derived from asteroid Vesta. Eucrites, howardites and diogenites represent different parts of Vesta and hence we can learn the geology and the processes that occurred deep within and on the surface of this asteroid. Eucrites and diogenites are achondrite meteorites and are the products of igneous processes. Eucrites are mafic igneous rocks of pyroxene plagioclase rich. They are likely derived from subsurface. Diogenites are coarse-grained monomict orthopyroxene-rich cumulates that likely formed from a fractionally crystallizing magma. Noble gas study is a tool to understand the history of volatile degassing from the interior and to constrain the types of precursor materials.

Neon shows widely differing isotopic compositions in different reservoirs. The isotopes of neon are used widely to understand the trapped component, cosmic ray exposure age and many other scientific aspects. The present study, which has been carried out to assess the abundance and isotopic composition of light noble gas neon in the Eucrites and diogenites based on bulk samples compiled from literature. The bulk dataset is used to identify the major trapped component in the HED parent body.

The three-isotope plot of $^{20}Ne/^{22}Ne$ vs. $^{21}Ne/^{22}Ne$ ratios of eucrites and diogenites indicates that all the samples are lie in the spallation component line and there is no evidence of solar wind gases. We than compare the concentrations of trapped noble gases with Chassigny, a representative of interior of Mars, carbonaceous chondrites, the accreting material of the parent bodies and MORB, the representative of interior of Earth.There is variation in abundances of neon gas, which is imprint of the different geological evolution of objects.

Platinum Jubilee

Physical Research Laboratory

MetMeSS-2021

Symposium on "Meteoroids, Meteors and Meteorites: Messengers from Space"

Programme

30th November, Tuesday

Session-4: Atmosphere and Meteors

Session Chairs: Amit K. Patra & Varun Sheel

Abstract #	Time	Speaker	Title
Invited	10:40-10:55	K. Kishore Kumar	Overview of atmosphere and Meteors
S4-01	10:55-11:10	G. Kishore Kumar	Tropical Mesospheric Semi-annual Oscillation using Meteor radar observations
S4-02	11:10- 11:20	Keshav Tripathi	V0 layer in the Venus ionosphere: is it of meteoric origin?
S4-03	11:20-11:30	M. Pramitha	Meteor Radar Estimations of Gravity Wave Momentum Fluxes in the Mesosphere –Lower Thermosphere and their source spectra characterisation using Ray tracing modelling
S4-04	111:30-11:40	N. Koushik	Tropical Signatures of Sudden Stratospheric Warming Events as Observed by Meteor Wind Radars
S4-05	11:40 - 11:48	Masoom Jethwa *	Study of meteor induced metallic ions in the Martian atmosphere

S4-01

Tropical Mesospheric Semi-annual Oscillation using Meteor radar observations

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Two long-period oscillations dominate Earth's equatorial atmosphere, viz., Quasi-biennial and semi-annual oscillations (QBO and SAO) in the stratosphere as well as the mesosphere. These two prominent oscillations have modulated many equatorial atmospheric processes. Among QBO and SAO, the latter is relatively less explored. The SAO is clearly observed in zonal winds and temperature with peaks in the stratosphere and mesosphere. The Mesospheric SAO (MSAO) is in the opposite phase with stratospheric SAO (SSAO). Besides the winds and temperature, the SAO signature is prominently observed in gravity wave (GW) activity and tidal activity. However, the SAO amplitudes obtained from different observations showed significant differences in amplitudes. This could be due to the differences in local time sampling. Most of the measurements in the middle atmosphere didn't comprise a full diurnal cycle. For example, the lidar measurements are limited to night-time, the MST radar observations are limited to daytime observations, and the rocket measurements are mostly limited to a selective time of the Day. In this study, we attempt to estimate the possible biases in the SAO amplitude due to the difference in the local time sampling by using the round-the-clock measurements of meteor radar observations. We estimated the semi-annual amplitudes in zonal winds for different local times in addition to the diurnal mean zonal winds. The differences between SAO amplitudes from a particular hour to a diurnal mean showed systematic differences. The significance of the present study lies in estimating the SAO amplitude as a function of local time and comparing the same with that obtained from diurnal mean winds. It is envisaged that the present results will address the differences in SAO amplitudes estimated using different observational platforms and will shed light on local time dependency in SAO forcing mechanism.

V_0 layer in the Venus ionosphere: is it of meteoric origin?

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Radio Occultation (RO) experiments are being conducted over Venus by the Akatsuki spacecraft since 2016. Total 34 electron density profiles of the Venus ionosphere have been obtained using this experiment among which six profiles show an enhancement in the electron density below 120 km altitude (below V1 base). This distinct layer below 120 km altitude has been named as V0 layer. The orbital geometry of spacecraft has enabled us to observe (1) the first V0 layers near the subsolar point (SZA = 5 degrees), (2) the first V0 layers well past the terminator (SZA=108 degrees), and (3) the first V0 layers at the equator.

The origin of V0 layer has traditionally been associated with the ablation of meteoric dust at a given altitude (Patzold et al 2009). Recent studies however suggest alternative origins for the enhancement in electron density profile at lower altitudes in the different planetary ionosphere, notable among them are :

1. Precipitation of solar energetic particles (SEP) can enhance the electron number density at lower altitudes by chemical reaction (charge exchange processes). Sheel et al., (2012) has modelled the SEP events and predicted that 50 MeV solar particles can penetrate the martian atmosphere up to 50 km altitude. Such an event can also be anticipated for the origin of V0 layer in the Venusian ionosphere.
2. Recent observations by MAVEN have demonstrated that the enhancement in transient electron density profile below 100 km altitude in the martian ionosphere (Mm layer) could be due to the occurrence of proton aurora (Crismani et al 2019). They suspect that such an enhancement could be the permanent feature of the planetary ionosphere.
3. Peter et. al. 2021 demonstrated that the enhancement in solar X-ray radiation (< 2 nm) can ionize the available NO molecules which will enhance the electron number density below 100 km altitude in the martian ionosphere (Mm Layer). Though there is no direct observation of NO molecules in the Venusian ionosphere, indirect evidence of meteor chemistry is ultraviolet night glow detection in which nitric oxide (NO) emissions were seen along with what might have been an extended meteor trail (Huestis & Slanger, 1993).
4. The local perturbation in the planetary atmosphere (internal gravity wave) can also enhance the electron density in the Earth ionosphere (Yiğit et al., 2016). Such enhancements are seen in the planetary ionosphere as well.

Due to the lack of supporting observations (other than RO investigation), we can not ignore the possibility of any of the above four reasons and ensure the meteoric origin of V0 layer. More details of all possibilities for the formation of V0 layer will be discussed during the presentation.

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S4-03

Meteor Radar Estimations of Gravity Wave Momentum Fluxes in the Mesosphere –Lower Thermosphere and their source spectra characterisation using Ray tracing modelling

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Atmospheric gravity waves play a vital role in coupling the various layers of the atmosphere. Meteor radars are widely used to study gravity wave (GW) variances and their momentum fluxes at the altitudes where meteor counts are sufficient to yield good statistical fits to the data (Mesosphere-Lower Thermosphere). Hocking's matrix inversion method is widely used for obtaining GW momentum flux from meteor radar, but in this method GW perturbation obtained after the removal of background winds are contributed by tides and planetary waves.So, a modified composite day (MCD) analysis of Hocking Method is adopted to estimate the GW momentum fluxes, which accounts for the tidal and planetary wave contributions.The present study evaluates the meteor radar observations of GW momentum fluxes obtained from Thumba (8.5°N, 77°E; 2006–2015), Kototabang (0.2°S, 100.3°E; 2002–2017), and Tirupati (13.63°N, 79.4°E; 2013–2018) using three-dimensional wind field simulations, which include specified tidal, planetary and GW fields in MCD analysis. The results showed that the retrieved and specified GW momentum fluxes agree very well over Tirupati followed by Thumba and Kototabang which is depend on the number of meteor detections used in the analysis.

Being a sub-grid process, the gravity waves are parameterized in the global atmospheric models. One of the important aspects of the gravity wave parameterisation is to identify the source spectrum in the lower atmosphere. Earlier studies employed the GROGRAT (Gravity-wave Regional Or Global Ray Tracer) model to fine tune the source spectrum by comparing model results with the observations. An attempt is made in the present study to identify the best fit source spectra for the gravity waves which are observed at mesospheric altitude using GROGRAT model and meteor radar located at Tirupati. In this regard, monthly mean climatologies of background atmosphere are developed (using SD-WACCM,TIMED/SABER & Radiosonde) in and around $\pm 5^0$ at Tirupati. Considering this as background atmosphere for GROGRAT model and by considering different source spectra (isotropic as well as anisotropic, symmetric as well as antisymmetric) with various combinations of spectral width, horizontal wavelength, spectral amplitude, model runs were carried out at different altitudes and zonal momentum fluxes are obtained. These simulated fluxes are compared with that of the meteor radar observed monthly mean gravity wave momentum flux to get the best fit source spectra at Tirupati. The significance of the present study lies in identifying the best fit source spectra of gravity waves by tuning it with gravity wave momentum flux observations from meteor radar in the mesosphere and lower thermosphere region.

S4-04

Tropical Signatures of Sudden Stratospheric Warming Events as Observed by Meteor Wind Radars

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Spectacular meteorological phenomena in the winter polar stratosphere called Sudden Stratospheric Warming (SSW) events are found to exhibit coupling across a wide range of spatial and temporal scales. In high and midlatitudes, these events often result in severe weather episodes at the surface in weeks or months to follow. In the low latitudes, SSW events are found to cause significant day to day variabilities in the upper atmosphere/ionosphere. Key to understanding there variabilities are the processes taking place in the Mesosphere Lower Thermosphere (MLT) region which acts as a gateway between the neutral atmosphere below and the ionosphere above. Meteor Wind Radars serve as one of the most versatile tools for probing the MLT region with high temporal and spatial resolution. In this study, we use meteor wind radars to understand the dynamics of the MLT region in association with SSW events in terms of mean winds, tidal and planetary wave variability. Significant enhancements in solar semidiurnal tides and quasi-two day waves are observed in the tropical MLT during major SSW events. Apart from this, certain events exhibited enhancements in lunar semidiurnal tides which are purely gravitational in original. This observation is further discussed in the light of planetary wave-tidal interactions, wherein lunar tidal amplitudes can be potentially contaminated by secondary tidal components resulting from the interaction of solar semidiurnal tides and the quasi-16 day planetary waves. We present classical examples for atmosphere-ionosphere coupling present in the low latitudes through lunar tidal signatures in the Equatorial Electrojet (EEJ) intensities. Further, we provide evidences for the equatorward propagation of secondary planetary waves in the mid/high latitude MLT following SSW events. These results highlight the importance of using state of the art meteor wind radars to study short term variabilities in the middle atmosphere.

Study of meteor induced metallic ions in the Martian atmosphere

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Abstract:

The primary source of metallic species in the Martian atmosphere is an influx from meteors. The assessment of metallic ion/neutral species, their chemistry and physics of the upper and middle atmosphere amalgamates meteoric and atmospheric research. This work aims to study the impact of meteoroid influx in the ionospheric of Mars [1]. Recent prediction of cosmic dust particles mass input is approximately two tons per day for Mars [2]. We present evidence of the metallic ion layer produced by meteoric ablation in the upper atmosphere using Neutral Gas and Ion Mass Spectrometer (NGIMS) onboard MAVEN spacecraft [3]. We report observations that span more than an Earth year, showing enhancement of metallic ions during the predicted meteor showers, at least by a factor of two. This work will help us validate/improve densities from PRL Neutral & Ion Reactivities Upon Atmospheric Meteoroid Ablation (NIRUPAMA) model. In future, there is a scope to model the airglow emissions from the metallic ions [4].

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Platinum Jubilee

Physical Research Laboratory

MetMeSS-2021

Symposium on *Meteoroids, Meteors and Meteorites: Messengers from Space*

Programme

30th November, Tuesday

Session-5: Impact Shocking and Shattering!!!

Session Chairs: Deepak Dhingra & Dwijesh Ray

Abstract #	Time	Speaker	Title
Invited	13:30-13:45	Jayanta K. Pati	Overview of impact crater/structure
S5-01	13:45-13:55	Dwijesh Ray	The Ramgarh structure is 2.4 km or 10 km in size? Not settled yet!
S5-02	13:55- 14:03	Saranya R. Chandran*	Quantifying erosion rate for terrestrial meteorite (simple) impact craters using paleoclimate and other parameters
S5-03	14:03-14:11	Anuj kumar singh*	Fabric disposition of granitoid clasts in monomict breccia from the Dhala Structure, India
S5-04	14:11-14:19	Rahul Das Gupta *	Constraints on the age and diameter of the Dhala crater based on the provenance of the sedimentary rocks on the Central Elevated Area and the morphological characteristics of the crater
S5-05	14:19-14:27	S. James*	Terrestrial Impact Craters as Potential Sites for Exploration of Economic Resources
S5-06	14.27-14.35	Asif Iqbal Kakkassery	A Geomorphologic Study of Possible Glacio-Fluvial Landforms in An Unnamed Impact Structure in Xanthe Terra, Mars
S5-07	14.35-14.43	P. M. Thesniya*	Morphology and Ejecta Emplacement Dynamics of the Das Crater on the Lunar Farside: Insights into the Impact Dynamics and Cratering Mechanics of the Moon
S5-08	14:43-14:48	Harshal Ponekar	Numerical Modelling of Lonar Impact Crater

The Ramgarh structure is 2.4 km or 10 km in size? Not settled yet!

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The Impact-cratering is a fundamental geological process in our Solar System for shaping the surfaces of planetary solid bodies. When asteroids or comets struck on the planetary surface, it generates ellipsoidal/spherical depressions called impact craters with fracturing and finally melting of the target rocks [1]. The severity of impact process could include global biological mass extinction (e.g. Chicxulub crater in 66 Ma) and often produces valuable mineral (Sudbury Cu-Ni-PGE deposit) or a suitable reservoir for petroleum and groundwater reserves. Though the result of large impacts on Earth is devastating, the impact has also important implications for space exploration and could hold clues on understanding the origin of life [2].

The Ramgarh structure (centred at 25°20′N, 76° 38′E) in Rajasthan, India is the only known confirmed asteroid impact crater in India that excavated the sedimentary target-rock [3,4,5]. The target-rock includes Mesoproterozoic Vindhyan Supergroup of sedimentary rocks. Recent field investigation, palaeontological studies, along with studies on the high-resolution satellite images suggest that this complex crater formed in a shallow water environment during the Callovian (Upper-Middle Jurassic) by an oblique impact along SW to NE [4]. Further, in-situ microprobe analyses on the relict native iron globules present in glassy pieces recovered from the soil formed on the outer slope of the crater's rim suggest that the impactor could be a Cu-rich iron meteorite [5]. This structure is the third known confirmed asteroid impact crater in the Indian sub-continent after the Lonar crater and Dhala crater.

There is an ambiguity exists on the actual size of this complex, degraded, impact crater and currently two alternative opinions exist. It has been suggested that the Ramgarh crater is a ring-like prominently rectangular structure with a rim-to-rim diameter of ~2.4 km, it has a small conical peak of ~6 m and a diameter/depth ration of ~12 [5]. The alternative idea suggests that the structure has an apparent diameter of ~10 km, and its present exposed morphology actually represents its eroded central uplift [4]. However, the actual rim is hardly recognizable, and boundary of this ~10 km structure is mainly inferred based on a few discontinuous, arcuate shaped, concentric lineaments identified in satellite images to the northern part of the present exposed morphology of the Ramgarh crater [4]. Future drilling is necessary to resolve this issue and also to better understand the impact process and products at Ramgarh.

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Quantifying erosion rate for terrestrial meteorite (simple) impact craters using paleoclimate and other parameters

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Abstract

The surface of the earth is sculptured by the erosional activities of various geological agents. In the process of erosional landscaping several morphological features are continuously modified for ages. Hergarten and Kenkmann[1] have estimated the long term erosion rate on the surface of earth as a function of present-day topography and climate using the impact-crater inventory. Influence of erosion is most often manifested in positive relief features. The erosion rate of excessive erosive regimes such as shield, orogeny and igneous province are expressed through a linear relationship, $r = \Delta s$, connecting topographic relief and erosional efficacy[1]. The study aims to estimate the long-term erosion rate of thirteen terrestrial simple impact craters by taking into account the influence of various climatic zones experienced by the crater and the geological province in which the crater is located. Simple impact craters formed by hypervelocity meteorite impact events are chosen since they constitute immaculate geological formations preserving original morphology in most cases. The temporal range of each crater in distinct paleoclimatic zones is identified and analyzed in this study[2] for a better understanding of the influence of climatic zones on erosion. The erosion rate of the regional geological province hosting the impact craters and the erosion rate of the individual crater are estimated separately using two methods. The first method considers the relief of the geological province where the crater was originally formed and the second method calculated the initial relief of the transient impact crater using a set of crater morphological parameters. The relief calculated using these independent methods is substituted to the equation $r = \Delta s$ to identify the rate of long-term erosion. The estimated values of long term erosion rates are correlated with the erosion rates of craters reported in past literature. The variations observed between the actual and estimated erosion rates of some impact craters are attributed to dynamic evolutionary trends of terrestrial simple impact craters.

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Fabric disposition of granitoid clasts in monomict breccia from the Dhala Structure, India

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The ~11 km wide Paleoproterozoic Dhala impact structure, north-central India comprises distinctive concentric domain of monomict granitoid breccia in the outermost annular region of the structure [1, 2]. This morpho-lithological unit holds a ring of more than 200 outcrops of irregular shape and elevation which are discontinuously exposed around the central elevated area (CEA) covering an annulus of about 28 km^2 areal extent [3]. These monomict breccias consist of granitoid clasts, larger grains of K-feldspar, and rare quartz fragments embedded in a clastic matrix of nearly similar composition. In the present study, we have carried out a comprehensive study of shape, size and orientation of granitoid clasts at various monomict breccia outcrops. The measurement was recorded for about six thousand clasts, generally of fine- to coarse-grained texture. The result shows that the clasts are of variable shapes (e.g., square, angular to sub-angular, rectangular to sub-rectangular, triangular, pentagonal etc.) and sizes (<1 cm to 2.81 m). These granitoid clasts originated during the brittle failure of the target rocks. The aspect ratios of clasts vary between 1 and 12.68. Their average aspect ratios also vary from one outcrop to the other in each of these eight zones (Zone-1: 1.000-4.435; Zone-2: 1.016-12.676; Zone-3: 1.100-4.800; Zone-4: 1.032-7.667; Zone-5: 1.026-5.125; Zone-6:1.000-4.159; Zone-7: 1.000-1.703; Zone-8: 1.040-8.333) classified at 45° angular interval with respect to the centre of the CEA. However, the frequency distributions of granitoid clasts measured in these zones are also variable (1091, 239, 267, 363, 266, 281, 2338, and 1175, respectively) depending upon the number of exposed monomict breccia outcrops and their areal extent. The outcrops as well as the size of clasts are relatively larger in the N-NNW direction with respect to the CEA. The long axes of granitoid clasts show random orientation indicating minor effect of post-impact tectonic deformation on monomict breccia bodies.

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Constraints on the age and diameter of the Dhala crater based on the provenance of the sedimentary rocks on the Central Elevated Area and the morphological characteristics of the crater

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Introduction: The Dhala structure near Jhansi, Madhya Pradesh, is a rare terrestrial impact crater formed in the Proterozoic Era [1]. This crater is hosted within the Bundelkhand granitoid rocks and its age is estimated to be 2.24 - 2.44 Ga, based on $^{207}Pb/^{206}Pb$ ratios of zircons in quartz reefs, near the rim of the Dhala crater [2]. The only large-scale identifiable feature of this complex crater in the field is a Central Elevated Area (CEA). The CEA is likely to be the central peak, which forms due to basement rebound in complex craters [1].

Research gap and significance of this work: The CEA comprises a sequence of sandstone and shale, which belong to the Vindhyan Supergroup of sedimentary rocks. The presence of shocked quartz grains in sandstone from the CEA has been attributed to fluvial deposition of crater ejecta into the crater cavity [3]. However, geochemical studies on these sedimentary rocks have not been done. In this study, the provenance of these sedimentary rocks from the CEA is further investigated using Nd isotopic compositions.

Results and Discussion: The distinctly radiogenic $\varepsilon_{Nd(0)}$ of the DH-CEA samples suggest their source is not linked to the brecciated granitoids in the Dhala crater (Fig. 1). The DH-CEA sample, DH-6, which is a shale from the base of the CEA, shows the least radiogenic $\varepsilon_{Nd(0)}$ and the oldest T_{DM} of 3.6 Ga (Fig. 1). In contrast, the sandstone sample, DH-8, collected near the top of the CEA, shows a younger T_{DM} of 2 Ga and the most radiogenic $\varepsilon_{Nd(0)}$ (Fig. 1). These results suggest that the sedimentary rocks in the CEA were derived from both the Lower Vindhyan and the Upper Vindhyan Supergroup, which implies that the Dhala crater formed before the deposition of the Vindhyan Supergroup ~ 1700 Ma ago [3]

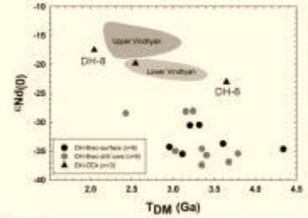

Fig. 1: Plot of T_{DM} versus $\varepsilon_{Nd}(0)$ for all samples from the Dhala crater. The data for the Vindhyan Supergroup rocks are taken from Chakrabarti et al. 2007.

The diameter of the CEA (D_{cp}) at Dhala is 2.5 Km and its altitude (h_{cp}) is 426 m [1]. Based on morphometric measurements of 15 complex craters, the diameter of the central uplift is 0.228 times the crater diameter [5]. Based on this relationship the diameter of the Dhala crater is 8.9 Km, which is similar to the estimate of 11 Km [1]. However, the altitude of 426 m is much less than the expected structural uplift, given by $h_{su} = 0.1D_c$ [6]. This discrepancy is due to deposition and erosion of sedimentary rocks, after the formation of the crater (Fig. 2).

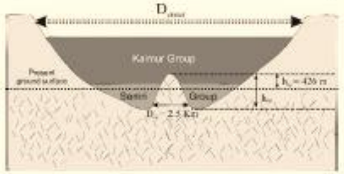

Fig. 2: Schematic representation of the morphological features of the Dhala crater

Conclusions: The origin of the sediments in the CEA from the Vindhyan Supergroup is consistent with the formation of the Dhala crater nearly 2.5 Ga ago. The morphology of the CEA and its relationship with the crater, confirms that this is the central uplift that typically forms in complex craters.

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Terrestrial Impact Craters as Potential Sites for Exploration of Economic Resources

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Contents of Abstract: Among the 210 terrestrial impact craters, 60 house economically significant natural resources. The resources range from metals such as iron, lead, zinc, nickel, copper and cobalt to uranium, coal and hydrocarbons, along with notable hydropower resources. The above resources are specifically critical to the energy industry today, given the growing stress on the demand-supply owing to continued global population growth. Impact craters catalyze the discoveries of associated resources/deposits, while mineral deposits help the identification of impact craters.

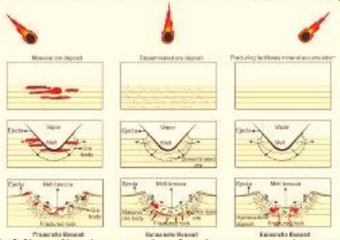

Fig1: Mineralization associated to impact cratering event

Fig2: Hydrocarbon centered at CEA of Red Wing crater

Terrestrial craters aid the exposure, formation and preservation of mineral resources, as signified by diverse modes of genesis of resources (Fig1). The progenetic deposits occur when the impact event exposes pre-established ore deposits which until the moment of the impact, was present at near/sub-surface levels. Gold and uranium ores at Vredefort (South Africa), iron ores at Ternovka (Ukraine) and uranium mineralization at Carswell (Canada) are major examples of progenetic mineralization [1,2]. The syngenetic deposits form due to contributions of the impact melt in enriching and mobilizing elements present in target to economically significant quantities. Syngenetic mineralization mainly occurs during the mid to late excavation stages of the impact cratering event have produced the Ni-Cu and PGE deposits at Sudbury. Lastly, epigenetic deposits include the hydrocarbon deposits at craters such as Avak and Ames (USA), wherein the morphological and structural units of caters aid both the maturation and importantly, the preservation of the hydrocarbons. Mineral deposits associated with craters show two characteristics which are reflected as (1) circular/semi-circular/arcuate deposit distribution and orientation and (2) deposit associations with proximal impact derivatives such as ejecta deposits, melt units, brecciated target rock fragments and shatter cones. The application of remote sensing techniques will accelerate the discoveries of craters and mineral resources as shown in hydrocarbon field at Red Wing crater's CEA (Fig2). The study showcases the potential of remote sensing in reducing the time delay to provide the energy resources associated with impact craters, to the market supply chains.

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A Geomorphologic Study of Possible Glacio- Fluvial Landforms in An Unnamed Impact Structure in Xanthe Terra, Mars

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Impact craters on Mars are remnants of late heavy bombardment events that occurred at around 3.9 Gyr ago. The records of the geologic history of the surface are still preserved within Martian craters. Whereas from the impact craters of the Earth, little geological history is known due to active erosion [1]. This study focuses on the unnamed crater located in the Xanthe Terra (3° S 52° W) at around 200 km northwest of the Ganges Chasma region of Valles Marineris. The study area is an isolated depression in the region having an average depth of 3 km. Fluvial features like interior layered deposits (ILDs) [3], lakes[4], alluvial fans or deltas[5], massive landslides[6], valley network, and outflow channels[7] have been reported in the surrounding regions of the crater (e.g., Ganges, Juventus, Capri, Eos Chasmata of VM) where possible involvement of subsurface processes has been proposed. Therefore, similar features are expected to be present in the crater. Due to the great depth of the crater, it is likely to have preserved the evidence for the subsurface fluvial features. The study investigates the presence of fluvial or glacial features in the crater and attempts to address the associated subsurface processes using high-resolution imagery from Context Camera (CTX) and HiRISE onboard Mars Reconnaissance Orbiter combined with MOLA DEM,. The study area is a fairly large complex crater with an average diameter of 78 km, with a discontinuous peak ring complex around a central peak mound, terraced walls, and floor deposits. The crater floor is highly rugged in nature with aeolian features like Transverse Aeolian Ridges (TARs) and Large Dark Dunes (LDDs). The Theater-head valleys show fluvial activity, which emerged from the southern crater wall and spread out as alluvial fans to the crater floor. Similar alluvial fans are observed on the west wall and in the region between the central peak mound and the arc of the peak ring massif on the east part of the crater. Braided sinuous ridges are observed to be formed at the confluence of alluvial fans. At the terminus of alluvial fans, bench-cut-like eroded platforms are also noticed. The tongue-shaped flows observed on the hill slopes of peak ring complexes are interpreted as glacial flows with lateral and end moraines [10]. Large massive flows are encountered on the north, west, and east crater walls. Linear ridges, grooves, and the layered lobate base resemble the massive glacial flows seen on Earth. Hence, the flows observed in the study area are inferred as Geliflucion lobes which can be compared with the flows observed on the Taylor valley of McMurdo DryValleys, Antarctica, [11] [12]. Small scale overlapping viscous flow features noticed on the troughs of east and west crater walls have tongue-like shapes. These features are similar to the debris covered glaciers in the Mullins glacier, Antarctica [11]. The study put forward possible evidence for fluvial and glacial features resulted from an impact event that occurred in the Xanthe terra region where subsurface water is preserved.

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Morphology and Ejecta Emplacement Dynamics of the Das Crater on the Lunar Farside: Insights into the Impact Dynamics and Cratering Mechanics of the Moon

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Abstract

Impact cratering is considered to be the most fundamental geologic process in our solar system. The Copernican impact craters on the Moon are the best sites to study the lunar impact cratering mechanics. The present study attempted to carry out an in-depth mapping of the morphological units and ejecta facies of the Copernican Das crater on the lunar farside to get better insights into the cratering processes associated with projectile impacts on the Moon.

The morphological mapping interior to the crater cavity revealed the characteristic geological features of this complex impact crater, starting from the sharp and scalloped rim, an alcove of wall terraces, the distinct scarp-tread system with steep slopes on the scarp, wall slumping, impact melt deposits, flat floor with hummocky texture, slump hillocks on the floor, melt platform, and central mounds with bedrock exposures. These distinct morphological units suggest that the Das crater was originally formed as a simple bowl-shaped crater, which later modified to become a complex crater. The excavation of the transient crater cavity for the Das crater took place in less than 4 seconds. The maximum depth of excavation is estimated to be 3 km. The transient crater diameter is projected to be 30.4 km, and the transient crater depth ranges between 7.6-9.12 km. The crater excavation was concurrent with the ejection of shocked and melted debris outward as impact ejecta. The modification of the crater began even before the central mounds rose from depths of maximally compressed rocks at around 3.2 km. The subsequent gravitational collapse of the rim produced terraced, steeper walls resulting in a slight widening of the crater rim along W-E and enlargement of the final diameter to 38 km. The wall slumping occurred at a larger scale on the western inner wall, and the slumped materials slid down to form heaps of hillocks, mainly in the western section of the floor. The

rotational slumping of the inner wall with their toes reaching the base of the crater to form a small plug has partly contributed to a segment of rising central mounds. The eastern crater floor has undergone subsidence, likely due to structural failure and/or cooling of the initial melt column. The impact melts line the transient crater cavity throughout its growth and are emplaced in a variety of topographic settings ranging from ponds in the wall terraces to extensive melt sheets along the inner wall slopes and the melt-draped floor units. The melt breccia, fractured impact melt deposits with boulders at their margins, and distinctive flow features appearing as melt fronts or flow lobes concentrated on the inner wall of the crater are diagnostic in determining their origin as impact-generated melts. Exterior to the crater cavity, solid and melt phase ejecta are distributed around the crater, with the highly shocked debris materials occurring at radial distances beyond the rim and melted debris preferentially occupying the topographic lows and slopes both inward and outward the crater rim.

Four distinct ejecta facies identified around the crater exhibit similarity in physical characteristics, spatial distribution and maximum radial extents. The ballistic ejecta facies are emplaced as continuous ejecta blanket (proximal to the crater rim) and discontinuous ejecta (beyond the extent of contiguous ejecta blanket), both distributed at varying radial distances from the rim. The onset of discontinuous ejecta blanket is marked by the appearance of the herringbone pattern consisting of linear clusters of elongated secondary craters or V-shaped depressions pointing back to the crater. The radial facies showed a slight deviation from their expected orientation as a result of interaction with the underlying topography controlled by remnant ridges of the SPA basin ring. The emplacement of the radial ejecta facies, including the contiguous blanket and the secondary crater chains, occurred concurrently during the mixing of fallen ejecta with the surface materials. The resulting ground-hugging flow of mixed materials caused infilling of the secondary crater chains and subsequent overprinting by the contiguous ejecta blanket. The melt-bearing ejecta is distributed as rim veneer deposits and ponded melt and lobate deposits within 7 km radial extents from the rim crest, and they completely overlie the contiguous ejecta blanket.

The non-uniform distribution of ballistic ejecta facies around the crater and maximum radial extents to the northwestern and southeastern quadrants than the less extensive deposits towards the southwest and NNE indicates overall asymmetric ejecta with a bilateral symmetry along the line running NNE-SSW through the centre of the crater. The presence of a forbidden zone devoid of distal ejecta rays and secondary crater chains to the NNE suggests that the direction of the impact was NNE-SSW. The near circular form of the crater, along with a clearly defined forbidden zone in the uprange, indicate that the impact occurred at an angle between 15°-25° to the horizontal. The interpretations from the present study demonstrate that studying Copernican craters are crucial for expanding our knowledge on the impact dynamics and cratering mechanics of the Moon.

Numerical Modeling of Lonar Impact Crater

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Abstract:

Lonar Lake is one of the kind hyper velocity impact crater formed in basaltic terrain in Buldhana district of Maharashtra, India. It has radius of 915 m and maximum depth of 150 m [1]. There have been a few attempts to model the impact event and estimate the diameter and type of incoming meteor. These results are summarized in the Table 1. However most of these simulations are either empirical or use fairly crude approximations of the impact event. Moreover none of the studies so far have taken in to account the underlying granitic basement below the Deccan Traps. Here we investigate the role of granite gneiss serving as sub surface to basalt lavas at Lonar and finding size and impact velocity of meteorite that has produced the Lonar crater. We have numerically modeled and simulated impact event using both basalt only and basalt-gneiss target surface combinations, with help of state-of-art iSALE2D shock physics code [6]. Our analysis concludes that the crater is formed by the iron meteor of 55m radius with impact velocity of 60 km/s. We estimate that during the impact the transient crater reached the depth of 414m before settling to 154m within 4 seconds.

Meteorite Radius (m)	Meteorite Velocity (km/s)	Reference
17.5	20	[2]
20	50	[3]
27.5	20	[3]
30	25	[4]
50	18	[5]
55	60	Present study

Table 1. Summary of Meteorite Parameters from Previous Studies

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Platinum Jubilee

Physical Research Laboratory

MetMeSS-2021

Symposium on *Meteoroids, Meteors and Meteorites: Messengers from Space*

Programme

30th November, Tuesday

Session-6: Planetary Analogue:
Similar Environment of Dissimilar World!

Session Chairs: V. J. Rajesh & Satadru Bhattacharya

Abstract #	Time	Speaker	Title
Invited	15:00-15:15	Saibal Gupta	Overview of Planetary analogue
S6-01	15:15-15:25	Sarajit SenSarma	Origin of the extremely high-silica terrestrial igneous rocks: Implications to understanding Lunar and Martian high silicic magmatism
S6-03	15:25- 15:33	Souvik Mitra	Jarosite formation at Kachchh provides water-limited weathering window onto Mars.
S6-04	15:33-15:41	Anil Chavan*	Theatre headed valleys in Deccan traps: a potential analogue for the Martian studies.
S6-05	15:41-15:46	Subham Sarkar *	Characterizing Tapovan Hot Spring from a Martian Analogue Perspective.
S6-02	15:46-15:51	Anindita Das	Application of a Modified Drake-Seagre Equation to Microbes in Astrobiological Systems – Some Contributions to Impact Process Analogues.

Origin of the extremely high-silica terrestrial igneous rocks: Implications to understanding Lunar and Martian high silicic magmatism

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Introduction: Understanding silicic magmatism in the Moon and Mars are of immense interest. The crystallized zircon-hosted melt inclusions in lunar meteorite (NWA 10049) dated at ~4.38 Ga are silica rich and iron poor (~80–90 wt% SiO_2), suggest presence of silicic magmatism [1]. Density calculation on the hackle fracture pattern in quartz and the volume of quartz and fracture space in granitoid fragment in lunar regolith indicate a molar volume contraction from tridymite/cristobalite, suggestive of low pressure-high temperature SiO_2 polymorph crystallization in lunar granitoid. Granitic fragments from the Apollo rocks containing up to 0.7 wt % TiO_2, is consistent with high-temperature origin [2]. Presence of tridymite (>870°C) in a drill sample in Gale crater, Mars is the first in-situ mineralogical evidence for Martian silicic volcanism, with tridymite (14%) occur as ~40 wt% crystalline and ~60 wt% amorphous material, and has minor TiO_2 and $Fe_2O_3^t$ (~5 wt%) [3].
Significance of work: The study of origin of high-silica (SiO_2 >73 wt%) terrestrial igneous rocks though debated, i.e., whether fractional crystallization of basalts or crustal partial melting or some other processes(s), may be useful analogues to bring important constraints on Martian and lunar silicic magmatism. Although melts ultra-rich in SiO_2 (>80 wt.%) are extremely rare in terrestrial record too, few exceptions include quenched silicic glass in melt inclusions (SiO_2 81.10 wt%) in quartz-rich xenoliths in lavas/pyroclastic rocks in the Vulcano Island, Italy [4], rhyolitic glass (SiO_2 >80 wt%, TiO_2 0.19 wt%, FeO^t 0.31 wt%) in the ~2.5 Ga high silica rhyolites (HSR) in the Dongargarh-Kotri (D-K) bimodal LIP, India [5], and the ~2.15 Ga 'quartz reefs' (SiO_2 83.7 – 95.5 wt%), having positive topographic relief in the Bundelkhand craton, India [6].
Main text; Qualitative Raman observations on the Vulcano glass confirm extremely high-silica melts were formed at high temperature (980°-1100°C) and pressures in presence of water, at middle-lower crust, by melting of basement metamorphic rocks and entrapped at different times within quartz grains. In the Bundelkhand 'quartz reefs', few data show elevated Ti (TiO_2 1.07 wt%, 0.67 wt%) and variations in $Fe_2O_3^t$ (3.6-0.34 wt%), and Al_2O_3 (<3 wt.%), attributed to tectonically controlled polyphase hydrothermal silica-rich fluid, though fluid source(s) remain unclear. Sporadic high Ti-content might indicate higher temperatures too. Interestingly, despite being extremely SiO_2-rich, the samples show up to 20 times chondritic flat REE pattern to LREE/HREE >1 and could be co-genetic to micrograniites. The low-grade metamorphosed deformed extremely HSR in the D-K LIP comprise quartz+K-feldspar+albite±anorthoclase+biotite+zircon+Fe-oxides; high Fe/Mg, Zr, Ga, Y, and REE (except Eu), low CaO, Ba, Sr contents and high Ga/Al; temperature of ~900°C is estimated. The REE patterns broadly similar, yet sometimes cross each other, unique to the HSR. Interaction of mantle-derived mafic and deeper crustal melts better explains $\delta^{18}O$ (4.4 to 7.6 ‰) and low initial $^{87}Sr/^{86}Sr$ (0.7031 and 0.7057) in the HSR, though limited UCC input seem plausible. So, basaltic magmas are involved in the origin of the HSR, both physically and chemically. Fluid introduction likely occurred during brittle fracturing of the crust and/or crust-mantle interaction in a caldera setting ([7]). Secondary silicification, on the other hand, may have led to HSR (SiO_2 77–80 wt%) in the Amalia tuff (USA) in the Questa caldera [8].
Conclusion: Diverse petrogenetic processes suggested for terrestrial HSR origins may provide important constraints and clues to understanding silicic lunar and Martian rocks.

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Application of a Modified Drake-Seagre Equation to Microbes in Astrobiological Systems – Some Contributions to Impact Process Analogues

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Quantification of several astrobiological and geobiological issues, often require substantial bridging between apparently unrelated branches. Linking genomics data to geophysical or astronomical issues has always been challenging, though not impossible. Deep-abyssal red clays of the Central Indian Basin exhibited strange linkage to ocean floor heat-flux, possible photonic emission and abundance of phototrophic microbial genera [1, 2]. While attempting to solve the complex model by a compartmentalized approach, the Drake and Drake-Seagre Equations were modified and applied. The Drake equation is the famous extraterrestrial intelligence equation [3]. Sara Seagre modified this to detect habitable zones in space and detect biosignatures in space. Frank and Sullivan altered the Drake's equation to find out the probability of technological species in cosmic history [4, 5]. Both of these work removed the 'length of time component' for reasons defended as appropriate. In this work, 'number of stars' and their subsets are replaced by 'number of microbial genes in sediments' and their subsets. The common analogy between stars and microbes is the large astronomical scale of numbers in both cases, allowing the possible modification. The present work proposes to modify the Drake-Seagre Equation with and without the time component. Uncertainty levels are high in the Intelligence Equation. Nevertheless, it serves as an adequate starting point to connect the absolutely dark gaps between geophysical and geomicrobial scales. The original Drake equation, the Drake-Seager equation and the modified Drake-Seager equation (this work) are:

a. **Drake equation** $N = R_*.\, f_p.n_e.\, f_l.\, f_i.f_c.\, l$
b. **Drake-Seager equation** $N = N^*.F_Q.\, F_{HZ}.\, F_O.\, F_L.\, F_S$
c. The Present Work:- **Modified Drake-Seager Equation** to estimate microbial phototrophic potential in abyssal ocean floor

$N' = N^{*\prime}.F_Q'.\, F_{HZ}'.\, F_O'.\, F_L'.\, F_S'$ **Or,** $N' = N^{*\prime}.F_Q'.\, F_{HZ}'.\, F_O'.\, F_L'.\, F_S' L'$

N' = Number of photon absorbing OTUs (Operational Taxonomical Units)
$N^{*\prime}$ = Total Number of OTUs
F_Q' = Number of quiet OTUs that perform no photon absorption
F_{HZ}' = Fraction of OTUs contributing to photon absorption
F_O' = Fraction of observed genera contributing to photon absorption
F_L' = Fraction of cells that may absorb photons
F_S' = Fraction of biomass that could actually signal absorption of photons
L' = the Length of time for which such microbial communities release photons

Impact related processes are liable to show a time-release factor for geobiological energy. Utilization of probability, uncertainty and fractal concepts would help to quantify outcomes of extreme pulsed or continuous cascade processes like Microbial Response or Resilience to Impact events and theoretically calculate Primordial Origin of Life situations just after an impact.

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Jarosite formation at Kachchh provides water-limited weathering window onto Mars

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Abstract:
The hydrous sulfate mineral jarosite is believed to be formed in a highly acidic and oxidizing condition [1]. Its presence on Mars was first confirmed from the Opportunity rover data [2] that indicated the restricted environment and surface water activity on past Martian environment [3]. Understanding the possible geochemical conditions for restricted environment appropriate terrestrial analog locations are suitable and economical. Recent studies reported the analog site of mars with similar basaltic setting in association with acidic hydrous sulfate mineral 'jarosite' on the overlying sediments at Kachchh [4]. The mode of occurrences and stratigraphic units of jarosite occurrences varies with pre- and post-Deccan eruption era in different localities at Kachchh. Plaeocene succession appears to have dominance of jarosite layers in turn early and mid Eocene successions contains small lenticular patches [5]. Subsequent ages of stratigraphic successions don't have any signature of jarosite. In Matanumadh area jarosite is found in association with alunite and gypsum [4], in rest of the locations gypsum is common. Identifications of these hydrous sulfates were performed with FTIR and VNIR analyses and supplemented with XRD results [4]. Geochemical analyses corroborate the hydrous sulfates formation and the weathering of basalt has been occurred in restricted condition. XRF and ICPMS analyses were conducted for both basalt and hydrous sulfate samples to understand the major and trace element pattern and their source for formation [5]. Sulfur isotope analysis has been conducted to understand the source of sulfur for different hydrous sulfate minerals. Considering the different parameters the Kachchh localities therefore can be inferred an appropriate terrestrial analog to understand the geochemical environment of mars in particular jarosite in basaltic setting.

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Theatre headed valleys in Deccan traps: a potential analogue for the Martian studies

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Abstract

The comprehensive mapping of Mars has almost concluded, and studies focusing on detailed analysis at the regional to outcrop level have started to come up. Martian geology and surface geomorphic features are grouped under Noachian, Hesperian, and Amazonian eras, based on the crater retention ages and resurfacing ages by crater densities. Understanding that the Martian surface is carved by the changes in climatic, tectonic, and volcanic conditions through hydrological and geomorphic investigations of the landscape and further comparing the same with the analogues on Earth and in particular with the analogues from Deccan traps gives us confirmative answers as to how the Martian surface was sculpted. Comparing the similarities and differences between Martian and terrestrial analogues promotes an understanding of how surface processes operated on both planets.

The geological history of an area, including information of the structures and surficial conditions, can be deciphered from the study of drainage patterns [1]. In the present study, basic morphometric analysis for the Terrestrial basin and the Martian basin has been performed to understand the terrain modulation and probable causes of the differential geomorphic features. The valley observed on the Deccan plateau has similarities with the valleys carved within the Echus plateau on the Martian surface. The rock types are similar at both places, i.e., basalt [2]. The basic morphometric parameters are calculated based on the dataset discussed above, for the terrestrial and Martian valleys. These parameters include qualitative analysis such as stream ordering (Strahler method for ordering drainages), bifurcation ratios, drainage densities, total stream length for main streams, river sinuosity, basin asymmetry factor, valley floor width to height ratios, rose diagram for the first, second and third-order stream. The analysis was done based on the ratios and magnitude-dependent parameters calculated for both the valleys on Earth and Mars to understand the detailed morphological characterization of an area. The ground-truthing of the geomorphic features was done by extensive fieldwork in the analogue valley. On a broader scale, both the basins have experienced tectonism and catastrophic flooding through time. This leads us to believe that variation in climate, subsequent volcanic activity, and tectonics, which have played a significant role in shaping the present-day scenarios on Earth, can aid in assessing Martian geomorphology.

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Characterizing Tapovan Hot Spring from a Martian Analogue Perspective

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Terrestrial Hot Spring localities provide all the necessary components useful for existence of life and are thus considered to be the cradle for primordial life on Earth [1]. However, the process of origin of life and ecological constraints affecting the stability and sustainability of high temperature microbiomes at these harsh conditions have not been fully understood till date. In this context, proper understanding and thorough characterization of different terrestrial Hot Springs will provide us an insight about the life forming processes and aid the search for extraterrestrial life on different planetary bodies.

Figure: Field photograph of collection of temperature data from one of the hot spring conduit

In this study, we are presenting Visible Near Infrared spectroscopic characterization of mineral assemblages found in the vicinity of Tapovan Hot spring located on Malari-Joshimath Road, around 15 km south-east of the Joshimath town in the state of Uttarakhand, India [2]. It is part of numerous circum neutral hydrothermal vents situated within Dhauliganga valley in the Garhwal Himalayas [2].

Continuously boiling water is emerging from the conduits (as shown in Figure) with temperature of the water measured to be as high as 86 °C. The average altitude of the region is around 1900 m and thus lower atmospheric pressure at such high altitudes causes the water to continuously boil. The main minerals found at this area are different phyllosilicates (muscovite, biotite), clay minerals (montmorillonite, kaolinite) and calcite. These secondary minerals are formed due to alteration of the granitic host rock caused by the hydrothermal fluid Various spectroscopic studies already suggest the presence of these altered minerals on Mars. Thus, these characterization can help us to formulate the paleo-environmental and geochemical conditions leading to their formation and to find similar hydrothermal deposits on the surface of the Red planet.

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VAIDURYA- Conceptualized Igneous Microbial Processes contemporary to Tarantian Age

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The enigmatic Sanskrit/Pali word "Vaidurya" embraces mysticism, mystery, message and medicine, with puzzling dictionary answers like peridot, olivine, tourmaline, chrysoberyl, emerald, lapis lazuli and more. Gemstone nomenclature of Victorian Age remained confused in the elegant green-yellow radiance of chrysoberyl, beryl (containing Beryllium) and chrysolite (olivine), much of which is overcome by modernity. The Microbial lessons are very different!

The Serpentinization reactions (olivine group), spilitization/albitization reactions (basalt group) and mixed reactions (gabbro group) are associated with the origin of primodial archaea, bacteria and the methylotrophs, respectively, since the Last Universal Common Ancestor (LUCA). The simple signatures often go unnoticed, in our anxiety for natural wealth extraction.

Evolutionary complexities of synthetic and degradative processes have overlapped with extreme geological events including impact catastrophes. In this work, igneous microbial processes contemporary to two very interesting stages of the Tarantian Age are highlighted. The first stage, the Sangamonian Interglacial stage overlaps with the termination Eemian Last Interglacial and onset of the Wisconsin Glacial, from 85,000-75,000 years before present [1]. Here, the potential of eccentric throw of mantle derivatives laterally [2] and the superimposition of the Bruhnes-Matuyama Magnetic reversal [3, 4] marks the beryllium enriched interval with high Be/Al ratio common in Marine isotope stage 5. The apparent lack of biological indicators is due to a subtle sequence of cascading primordial microbial processes. A window-pane to the mantle-derivatives and a witness of Toba super-explosion, this interval is an analogue of meteorite impact on sea-floor. The spin of the mantle fluids fuels the microbial niche dominant HC-degrading methylotrophic microbes and methanogens since the last interglacial stage.

The second stage occurred around 50,000 years ago, marking the culmination of the late Wisconsin Glaciation. Understanding microbial proxies at 50,000 years interval could demarcate a mini-ice age microbial behavior. The scrutiny in the case of the Central Indian basin is more challenging. We thus followed a multi-directional comparison and analysis involving samples from absolutely different spots from the same Age. The hot springs and paleolakes of Ladakh with an active sulphur cycle were examined. These sub-environments hold microbial mosaics that explain multiple planetary analogues of Lunar, Mars, Venus and Meteorite Impacts.

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S6-06

VAIDURYA- Conceptualized Igneous Microbial Processes contemporary to Tarantian Age

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The enigmatic Sanskrit/Pali word "Vaidurya" embraces mysticism, mystery, message and medicine, with puzzling dictionary answers like peridot, olivine, tourmaline, chrysoberyl, emerald, lapis lazuli and more. Gemstone nomenclature of Victorian Age remained confused in the elegant green-yellow radiance of chrysoberyl, beryl (containing Beryllium) and chrysolite (olivine), much of which is overcome by modernity. The Microbial lessons are very different!

The Serpentinization reactions (olivine group), spilitization/albitization reactions (basalt group) and mixed reactions (gabbro group) are associated with the origin of primodial archaea, bacteria and the methylotrophs, respectively, since the Last Universal Common Ancestor (LUCA). The simple signatures often go unnoticed, in our anxiety for natural wealth extraction.

Evolutionary complexities of synthetic and degradative processes have overlapped with extreme geological events including impact catastrophes. In this work, igneous microbial processes contemporary to two very interesting stages of the Tarantian Age are highlighted. The first stage, the Sangamonian Interglacial stage overlaps with the termination Eemian Last Interglacial and onset of the Wisconsin Glacial, from 85,000-75,000 years before present [1]. Here, the potential of eccentric throw of mantle derivatives laterally [2] and the superimposition of the Bruhnes-Matuyama Magnetic reversal [3, 4] marks the beryllium enriched interval with high Be/Al ratio common in Marine isotope stage 5. The apparent lack of biological indicators is due to a subtle sequence of cascading primordial microbial processes. A window-pane to the mantle-derivatives and a witness of Toba super-explosion, this interval is an analogue of meteorite impact on sea-floor. The spin of the mantle fluids fuels the microbial niche dominant HC-degrading methylotrophic microbes and methanogens since the last interglacial stage.

The second stage occurred around 50,000 years ago, marking the culmination of the late Wisconsin Glaciation. Understanding microbial proxies at 50,000 years interval could demarcate a mini-ice age microbial behavior. The scrutiny in the case of the Central Indian basin is more challenging. We thus followed a multi-directional comparison and analysis involving samples from absolutely different spots from the same Age. The hot springs and paleolakes of Ladakh with an active sulphur cycle were examined. These sub-environments hold microbial mosaics that explain multiple planetary analogues of Lunar, Mars, Venus and Meteorite Impacts.

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S6-07

Secret Gorges of Clay-Carbonate interaction from sediment cores to meteoritic chondrites (SHALIGRAM)

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Earth's deepest gorge, the Kali Gandaki valley, Central Himalayan belt, Nepal [1], hosts the K-Pg boundary ammonite fossils largely venerated as the Shaligram. The witness of a massive geocatastrophe and age transition, the Shaligram is an embodiment of mysterious reverence, making mankind surrender to Nature while seeking the Origins.

The geochemical mechanisms of clay-carbonate interactions are widespread, from marine sediments, to mantle pipes, interstellar dust and meteorite chondrites, across sedimentary, igneous and metamorphic systems, with system-distinct signatures and some unified principles. Extremes of habitability are investigated by many routes. They include interaction of mantle/core derivatives with clay-materials, dissolution of olivine and other serpentine alterations, deposition of carbonate/phosphate globules in low temperature near neutral to alkaline waters [2], replacements of silicates, carbonates and sulphates and many more. Geochemically, Formose or Butlerov reaction which form sugars from formaldehyde, Haber-Bosch *ab intio* synthesizing ammonia, hydrogenation of calcium carbonate in presence of Palladium (Pd) or Iridium (Ir), dissolution of carbonates by weak organic acids like formic or acetic acid, are some very important reactions participation in these processes [3-6].

Carbonaceous oozes from a seamount-top near Calcite Compensation Depth (CCD) of Central Indian Basin were examined for clay-carbonate interactions. Siliceous oozes and ooze-free pelagic red clays both below the CCD were cross-examined. Carbonaceous veins in Opliolitic systems of Nidar, and hot and cold near-neutral to alkaline systems of hotsprings, palaeolakes lakes, evaporates were all analyzed to understand glimpses of the complex mechanism. The Mukundapura Carbonaceous Chondrite data and its impact-related mechanisms [7-8] are utilized as reference data substantiating the interactions.

Microbial Carbon fixation and Adenosine Triphosphate (ATP) were measured in seamount cores TVBC-37 (2005) SVBC-37 (2007). The core recorded chronological signatures up to Marine Isotope Stage 11, along with interglacials MIS 5 and 9 [9]. The Microbial parameters mentioned were measured differentially as whole sediments, and clay and shell-fractions separated centripetally by light vortexing, a simple in-vitro technique mimicking impact rebounds that form many stratified paleo-structures. Surprisingly, the clay and shell-fractions individually neither summed-up nor subtracted from one another to quantify the whole sediment reading. At the interglacial interval the clays sequestered more carbon and carbonates did reverse. The carbonaceous shell fraction produced one order more ATP than the clay fraction expect at the onset of MIS 9, where the situation reversed. This behavior is unclear as yet. The dissolution and bioreactor mechanisms of new microbial origins are ample at such extreme intervals and other types of samples mentioned. The signature awaits more critical understanding comparatively with celestial entities like Mukundapur chondrite.

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S6-08

Microbial Resilience to Impact Triggers of Toba, Uncertainties of Jaramillo and Astronomy-Climate Interactions (MRITTUNJAI)

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The voyage of the Wilson Cycle transfers mass and energy in dual directions, both synthetic and degradative, through the same path, but in opposite directions of the redox continuum. In oligotrophic or organic-C depleted systems, hydrothermal signatures become distinct even in cryptic quantities with distinct chemolithotrophic proliferations. Astrobiologists have been hypothesizing the resilience of chemolithotrophic microbial communities during catastrophic geophysical or astrophysical events and the resilience of microbes is well established [1, 2, 3]. We discuss the response of microbes to multiple astronomical, climatic and impact induced events.

Multiple astrobiological sites were examined from the abyssal Central Indian Basin (CIB) siliceous oozes, sediments/ mats associated to alkaline hotsprings, paleolakes and ophiolitic biosignatures from Ladakh, India, and ilmenite placers, Ratnagiri, India. The data from **Mahadeva meteorite, India,** is being used as a reference data here to understand analogous impact related processes. The cosmogenic radionuclides activities were found consistent and matched with the production rate and solar cycle activity [4]. The CIB microbial systems exhibit interesting snapshots of Microbial responses to sunspot cycle, magnetic reversals, mass extinctions, catastrophic impacts and astronomical cycles, all inter-woven in a complex microbial matrix. The study of analogies between the hyperthermal successions in the seafloor sediment cores and meteorites thus seems feasible.

The CIB sediments clearly showed that chemolithotrophic proliferations related closely with Holocene anoxic event, two most recent mass extinctions, magnetic reversals and astronomical cycles including the sunspot cycle. The hotsprings in Ladakh spread over Panamik, Puga, Chumathang show different stages of microbial colonization post-propulsion of hotspring water-jets. Mutualistic succession between iron bacteria and diatoms had been observed in mesocosm experiments with ilmenite-rich placers minerals from Ratnagiri, Maharashtra, India. In diverse geothermal and hydrothermal systems, hyperthermia is succeeded by anoxia followed by productivity and finally oxygenic successions. The pivotal role of primitive microbes like methanogenic archaea and sulfur-oxidizers in regulating the 'sand-clock behaviour' of acidic/alkaline, oxic/anoxic and glacial/interglacial cycles is re-iterated once again. The interiors of meteors, the time of flight of meteors, the contact zone of meteorite impacts, the abrupt 'centripetal brakes' in crater lakes and paleolakes might be targeted as regular study objectives to understand bioreactor processes in meteorite associated samples, locations and events.

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