Physical Research Laboratory
MetMeSS-2023

3rd Symposium on "Meteoroids, Meteors and Meteorites: Messengers from Space"

1–3 November 2023

Physical Research Laboratory
MetMeSS-23

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"Meteoroids, Meteors and Meteorites:
Messengers from Space

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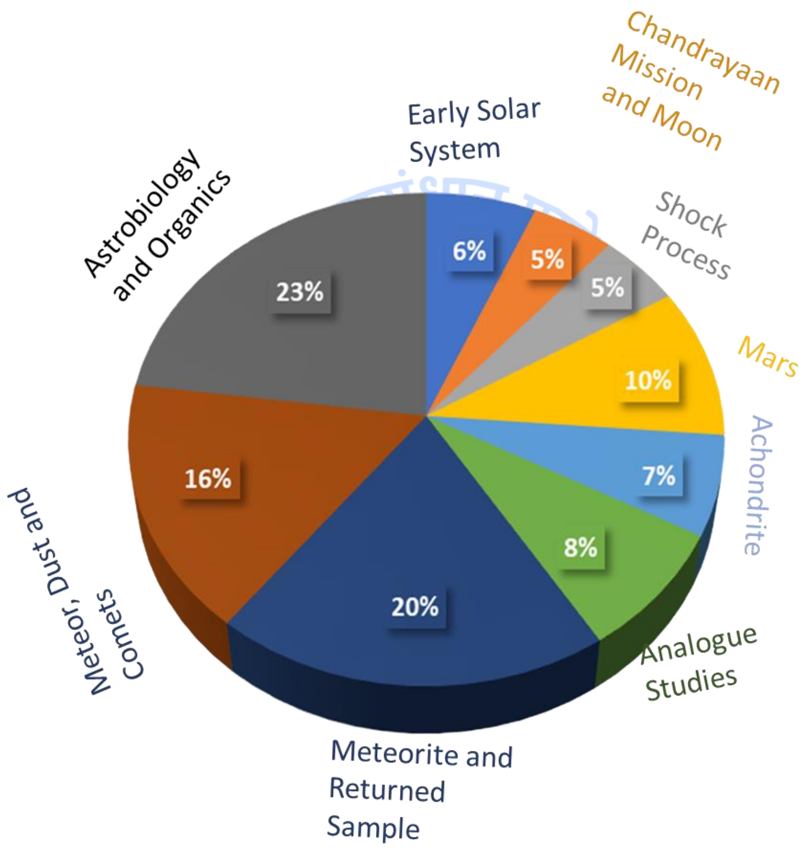

Physical Research Laboratory
MetMeSS-2023

1st November, Wednesday

Session- I: Early Solar System
Session Chair: Dr. G. Srinivasan and Dr. Ritesh Mishra

Abstract#	Time	Speaker	Title	Affiliation
Invited	11:15 – 11:35	Kuljeet K Marhas	Interstellar heritage and birth of the Early solar system.	PRL, Ahmedabad
S1-01	11:35 – 11:50	Ritesh Mishra	Superflares during pre-main sequence stage of the Sun recorded in meteorites.	National Museum of Natural History, Smithsonian Institution, Washington DC USA
S1-02	11:50 12:00	Advait Unnithan	The Role of Volatile-rich Reservoirs in Production of ^{36}Cl in Solar Protoplanetary Disk.	PRL Ahmedabad
S1-03	12:00 – 12:10	Ankit P Singh	Asteroidal heritage of CV3 chondrite through Mid-IR spectroscopy of matrix and Calcium Aluminum-rich inclusions.	PRL Ahmedabad

S1-01

Superflares during pre-main sequence stage of the Sun recorded in meteorites

Ritesh Kumar Mishra[1]* Kuljeet Kaur Marhas[2] and Marc Chaussidon[3]
[1]National Museum of Natural History, Smithsonian Institution, Washington DC USA.
[2]Planetary Sciences Division, Physical Research Laboratory, Navrangpura, Ahmedabad, Gujarat, 360009 India.[3]Université de Paris, Institut de Physique du Globe de Paris (IPGP) 1 rue Jussieu 75238 Paris, France.
*Corresponding author email: riteshkumarmishra@gmail.com

Young stellar objects during the pre-main sequence stages are highly dynamic [1,2] that influence and determine the physical- chemical characteristics of the proto-planetary disk. These early stochastic and ergodic events and processes determine the grand architecture of the planetary system around stars. Understanding the chronology of these events for stellar systems, in particular for the solar system, during the pre-main sequence stage, lasting a few million years, is therefore essential to not only understand the unique architecture of our Solar system but also the formation and evolution of protoplanetary disk into planets and planetoids. Presently the records of irradiation and flaring from the nascent Sun is constrained at million year time scale even though astronomical observations of young Sun like stars in the solar neighbourhood document these sporadic events varying by several orders of magnitude in intensity in a median time of a few fortnight. Short-lived now-extinct radionuclides (SLNs) extant during the origin and early evolution of the Solar system can be gainfully utilized to study the early solar system event and processes. Lithium-beryllium-boron (Li-Be-B) isotopic studies of a CAI was carried out to trace records of irradiation of solar nebula from the nascent Sun. Li-Be-B isotope systematics study allow to track simultaneously records of decay of ^{7}Be into ^{7}Li (half-life 53.12±0.07 days) [3] and decay of ^{10}Be into ^{10}B (half-life 1.386±0.016 million years) [4]. The low binding energy per nucleon of lithium and beryllium in the range of 5.3-6.5 MeV/nucleon primary restricts its synthesis in the core of the stars. Instead, Lithium, beryllium, boron are produced by spallation reactions in the interstellar medium or in the outer envelopes of the stars. Hence, these two short-lived now- extinct radionuclides that are primarily produced by spallation reactions are useful tracers for investigating the intensity and variation of irradiance of the nascent Sun. A previous study showed evidence of former presence of ^{7}Be in the first forming solar system solid called calcium, aluminium- rich inclusion (CAI) [5,6]. The fossil evidence of ^{7}Be along with ^{10}Be in the CAI that had formed at 0.42±0.34 Ma was attributed to a late superflare from the Sun during the class II of the pre-main sequence stage [5,7]. To understand and trace records of solar activity at the during the earlier stages (viz class 0, class I) at the fiducial time of the birth of the solar system a Li-Be-B isotope systematics study was carried out in a pristine CAI. The selected type A CAI from the Vigarano (Vigarano CAI 1) consists primarily of melilite and spinel and has Wark-Lovering rim. In situ isotopic studies carried out using secondary ion mass spectrometer within melilite show a range of lithium isotope ratios (^{7}Li/^{6}Li) from 12.02 (chondritic) to 18 [7,8]. The radiogenic excess ranging up to 520 permil (^{7}Li/^{6}Li = 18.28) correlate linearly with ^{9}Be/^{6}Li ratio to yield an isochron corresponding to ^{7}Be/^{9}Be of $(5.4\pm3.7)\times10^{-3}$ (2σ) (MSWD = 1; IsoplotR Model 3). Within the CAI the beryllium-boron isotope system yield ^{10}Be/^{9}Be ratio of $(3.9\pm4.2)\times10^{-3}$ (95% conf.). The implications of the result towards chronology of the early solar events and processes will be presented.

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S1-02

The Role of Volatile-rich Reservoirs in Production of ^{36}Cl in Solar Protoplanetary Disk

Advait Unnithan*, Kuljeet Kaur Marhas
Physical Research Laboratory, Ahmedabad
*advait.unnithan@gmail.com

Any study on the production of a particular short-lived radionuclide (SLR) in a protoplanetary disk is incomplete if discussed in isolation from other SLRs. Injection of material from a nearby supernova or spallation products from solar energetic particles and disk material could easily explain the abundance of one SLR, but the scenario might be invalid for another SLR, which ends up being either over or under-produced. Recent studies of ^{36}Cl showed that the excess of ^{36}S found in aqueously altered secondary minerals like sodalite and wadalite in Calcium-Aluminium rich Inclusions cannot be correlated with a ^{36}S/^{34}S vs ^{35}Cl/^{34}S Isochron, but rather as a mixing line of irradiated-chlorine and solar composition-sulfur [1]. In an older study, the simulated production of ^{36}Cl in an environment rich in refractory elements resulted in an overproduction of ^{26}Al [2]. Using better estimates of volatile abundances in the ice-composition target sizes smaller than that assumed in previous studies, we simulate the flux densities required to produce the observed abundances of ^{36}S with SEP-induced spallation in a volatile-rich environment 2-3.6 AU from the sun, about 1-2 Myr after the formation of CAIs, which can reconcile with the abundances of other SLRs such as ^{26}Al.

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S1-03

Asteroidal heritage of CV3 chondrite through Mid-IR spectroscopy of matrix and Calcium Aluminum-rich inclusions

Ankit Prakash Singh[1,2], Kuljeet Kaur Marhas[1*]
[1]Physical Research Laboratory, Ahmedabad
[2]Gujarat University, Ahmedabad
*Corresponding author E-mail: kkmarhas@prl.res.in

Abstract: Calcium aluminium-rich inclusions are one of the first formed solids in the solar system with an age of 4568.7 ma [1]. These CAIs are formed by condensation from gas in the protostellar nebula and their subsequent partial melting or by crystallisation from melt. This gives rise to CAIs of varying petrographic types [2], which contain different minerals and trace element signatures. Carbonaceous Chondrites of the Vigarano type are considered to be primitive in nature as they have undergone a lesser degree of postprocessing alteration, and they also contain a fairly large number of CAIs by volume [3]. The CV3 chondrites are further divided into two groups: oxidised (Allende, Bali, Mokoia, etc.) and reduced (Vigarano, Leoville, Effremovka, etc.). This research deals with 6 CAI samples of 3 such meteorite types, namely Leoville, Allende and Effremovka. These CV3 meteorites have undergone thermal alteration, whose timescale is ambiguous [4], which is evident to some extent from their petrography.

EPMA was used to determine the mineralogy of these CAIs, and further, their mid-IR spectra have been obtained using Fourier Transform IR at resolution 4 cm^{-1} and a range of 500-1500 cm^{-1}. EPMA data has been used to categorise the petrographic type of the samples, using which a ternary diagram [5] has been plotted to follow their evolution path. The mid-IR spectra have been used to determine the postprocessing thermal or other events that the minerals could have undergone; for e.g., as the akermanite content in melilites increases, the shoulder of the mid-IR peak becomes thinner [6] or the wavelength of IR peaks increases when the mineral undergoes thermal alteration like in spinels [7]as they are altered to hercynites. Therefore, these evidences are used to postulate the evolution history of these CAIs compared to their meteorite matrix. Further, an attempt has been made to compare the spectra of the CAIs and meteorite matrix with asteroids [8] [9] in order to find the similarities. Future studies are being planned to obtain the whole range of IR spectra, including near-IR and far-IR; efforts will be made to find and identify the CAI-forming regions in circumstellar disks of protostars[10] to understand our early solar system processes.

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P-01

Contribution of ^{3}He irradiation in the production of Short-lived radionuclides

Vikram Goyal[1*], Kuljeet K Marhas[2],
[1]Physical Research Laboratory, Ahmedabad (vikram@prl.res.in)
[2]Physical Research Laboratory, Ahmedabad (kkmarhas@prl.res.in)
*Corresponding author E-mail:vikram@prl.res.in

Introduction: Isotopic studies of meteorites provide sufficient evidence of short-lived radionuclides (SLRs), having half-lives of a few Myr, incorporated in early solar system solids at the time of the solar system's formation. SLRs are useful chronometers and can be utilised in understanding the astrophysical processes occurring during solar system formation. Stellar injection and irradiation from energetic particles can both produce these short-lived radionuclides. Early solar system solids with evidence of extinct ^{7}Be and ^{10}Be (irradiation products) indicate intense irradiation in earlier times. On the other hand, the presence of ^{60}Fe (product of stellar environment) suggests the contribution of other stellar sources in the Solar System's parent molecular cloud. Neither of these scenarios has been able to provide the production of all SLR abundances together as experimentally observed in meteorites.
Many researchers have attempted an irradiation model to explain the maximum amount of SLR production. The production rates of most of the SLRs are majorly based on the irradiation of dust particles in protoplanetary disk with solar energetic proton and alpha particles [1-3]. A few models have reported SLR production with ^{3}He contributions [3]. Recent evidence of superflare from the nascent sun via ^{7}Be measurements in early solar system solids indicates a definite contribution of local irradiation [4-5]. In this study, we check the earlier local irradiation model given by Goswami [2] with the latest abundances, thoroughly comparing experimental and model cross-sections, and include ^{3}He (earlier, it was not considered in the model).

Calculation: To study the irradiation of precursor material of CAIs by Solar Energetic Particle (SEP), we will calculate the production rate of short-lived radio nuclide using the following expression:

$$P_i = \sum_j \int F(E) \times N_j \times \sigma(j \to i, E)\ dE$$

Where Pi represents the production rate of radionuclide i, F(E) is the flux of the solar energetic particles as a function of energy, N_j is used for the number of target nuclide j, and $\sigma(E)$ is the relevant nuclear reaction cross-section as a function of energy [2]. For the nuclear cross-section, we will use data from the TALYS code [6], a program written to predict the nuclear cross-section for energy range starting from 1 KeV to 200 MeV. A power law represents SEP flux in kinetic energy $dN \propto E^{-\gamma} dE$ where $\boldsymbol{\gamma}$ is the spectral index. The flux of incident energetic particles depends on the value of $\boldsymbol{\gamma}$. For higher values of spectral index, the flux decreases very steeply, so their contribution decreases in the case of higher energies. The target dust grains are assumed to be following a power-law size distribution ($dn/dr\ \alpha\ r^{-\beta}$; $\beta = 4$) where r varies from 10 µm to 1 cm. Wolk [7] spectroscopically observed that particle flux for YSOs is 10^{5} times more than the active sun. The enhanced solar flux values are calculated using the SLR production values obtained.

Discussion: After adding ^{3}He in the incident particles, there is a significant change in the production of SLRs. The abundance of ^{3}He/^{4}He is ~1000-fold [8] enhanced during the impulsive flares, which are generally at higher energies. During the gradual flares, proton and alpha particles contribute more at lower energies. For ^{7}Be production, the contribution of higher energy (>200MeV) incident particles is less than 7%.

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1st November, Wednesday

Session- II: Chandrayaan Mission and Moon
Session Chair: Dr. T.P Das and Mr. Satadru Bhattacharya

Abstract#	Time	Speaker	Title	Affiliation
Invited	14:00 – 14:20	Neeraj Srivastava	Overview of Lunar geology	PRL, Ahmedabad
	14:20 – 14:40	T. P. Das	Overview of Lunar exploration from Chandrayaan mission.	SSPO, Bangalore
	14:40 – 14:55	M. Shanmugam	The first in-situ elemental composition measurement on lunar south pole with APXS onboard Chandrayaan-3 Rover	PRL, Ahmedabad
	14:55 - 15:10	Satadru Bhattacharya	Constraining lunar crustal composition and hydration through imaging spectroscopy from recent lunar missions.	SAC, Ahmedabad
	15:10 - 15:25	Nizy Mathew	ChaSTE: Precise Probing.	SPL, Kerla
	15:25 - 15:40	Manju G.	Lunar ionosphere: A true plasma laboratory?	SPL, Kerla
	16:00 - 16:15	Netra	Mapping Lunar Surface Chemistry with CLASS	URSC, Kerla
	16:15 - 16:30	Durga Prasad	Perspective of Lunar Thermo-physics and Volatiles	PRL, Ahmedabad
S2-01	16:30 - 16:45	Souvik Mitra	Was Lunar nearside thicker than farside?: A spectroscopic approach	Presidency university

S2-01

Was Lunar nearside thicker than farside?: A spectroscopic approach

Souvik Mitra[1,*]
[1] Department of Geology Presidency University, Kolkata, 700003, India
*Corresponding author E-mail: Souvik.geol@presiuniv.ac.in

Abstract

Lunar magma ocean theory postulates the early crystallized heavy minerals e.g., olivine, pyroxene sink to the interior of moon to form metallic core and light weighted plagioclase formed floated crust[1]. Silicate mantle with olivine, orthopyroxene, clinopyroxene is assumed to be rest in between[2]. Subsequent large impacts induced the subsurface magma to spill out on the basin and surface of the moon and therefore lunar Impact Craters could be the windows to study its mantle and lower crust[3]. In addition, radiogenic heat on Oceanus Procellarum imposed to form Lunar dichotomy with thin crusted nearside and highland of farside[4]. However, studies on mineralogical composition across several lunar basins could not reveal unambiguous composition expected to be derived from mantle from either side[5].

In this study an attempt has been made to get unambiguous mantle mineralogy across the near side deep basin of Mare Tranquillitatis using Moon Mineralogy Mapper (M^3) data finding the compositional variation along north south strip. In available M^3 data no records are found for southern hemisphere, therefore the strip is limited to ~1 N to ~53N for study. In this stretch numerous small craters are observed with increasing density from south to north, possibly resulted from younger impacts. Few large craters with 5-40 km in diameter present in scene. Spectral signatures of the small craters appear with smooth absorption bands reflecting invariable dominance of HCP (High Ca Pyroxene) in association with plagioclase, although a few have appeared with Low Ca Pyroxene (LCP) in composition. In contrast the spectral signatures for the larger craters' surface are unsmooth possibly due to space weathering except in some rim areas and central peaks. Several spectral curves are unclassified and need to be further study. An absorption band with 2800-3000 nm persistent in all across the strip indicates presence of H_2O/OH in the region. In addition, a very small portion of the rim of Grove crater reflects LCP with the presence of Plagioclase implying lower crustal noritic rocks. However, no unequivocal spectral signature of pure olivine has been observed in this study. Nevertheless, Impact Models postulates a possible excavation of crust with ~60-85 km in Mare regions[6], therefore mantle materials are strongly expected in mare regions. Cumulates of Olivine, LCP and HCP with negligible plagioclase are expected as a possible mantle mineralogy[2], which is lack in any spectral signature all across the strip. Does it imply the near could have more thicker crust?

References:

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S2-02

Investigating Lunar Polar Water Ice Distribution: Insights from Depth-to-Diameter Ratios and Topographical Analysis

Sachana Sathyan[1, 2], Megha U Bhatt[1 *], Sajin Kumar K.S.[2]
[1]Physical Research Laboratory, Ahmedabad-380059 (sachana@prl.res.in)
[2]University of Kerala, Thiruvananthapuram-Kerala. 695581

Corresponding author E-mail: megha@prl.res.in

Presence of water ice in an atmosphere-less planetary body like Moon is considered as one of the most intriguing discoveries [1]. The low obliquity of Moon (~1.5°) can cast permanent shadows in the topographic depressions of poles and if they are sufficiently cold enough they can trap water ice [2]. The remote observations from radar [3], neutron spectroscopic [4], and UV-VIS-NIR spectroscopic measurements [5] [6] [7] [8] [9] all hinted in this direction. The Apollo samples analysis using new sophisticated techniques confirmed presence of water in ppb level even at equatorial regions on otherwise considered borne dry Moon [10]. In spite of having handful of observational evidences supporting the existence of water ice on lunar surface, the idea behind its origin, transport and sequestration mechanisms is yet to be understood fully and demands for a systematic study using the new set of high-resolution satellite based cameras and hyperspectral imagers, specially designed for polar measurements [11] [12] [13].

A recent study led by [14] found a decrease in depth to diameter ratio of Necterian age craters as moving from equator to lunar poles. This intriguing phenomenon hints at crater infilling, potentially facilitated by water ice. Furthermore, this reduction in depth to diameter of craters with increasing latitudes manifests itself with greater prominence in the lunar south pole compared to the north, accentuating an anomalous distribution also noted by previous studies [15] [16].

While it is widely acknowledged that topography plays a pivotal role in creating permanently shadowed regions where water ice can accumulate, the precise connection between this topographical influence and the observed variation in depth-to-diameter (d/D) ratios between the north and south poles remains uncharted. Remarkably, no prior research has sought to establish a link between these two critical factors. We are taking this research gap as our main motivation for the present work that involves the detailed comparison of depth to diameter ratio of craters of north and south poles (50°N/S-90°N/S) of the Moon integrating with the local scale topography of poles. Our objective is to understand the underlying reasons behind the divergent distribution of water ice in these polar regions. The diameter of the craters chosen for the study is restricted to diameter range of 2.5-15 km similar to [14]. Our analysis of d/D ratio using the highest resolution images of the poles is integrated with, the radar measurements and the VIS-NIR reflectance measurements of Chandrayaan-1 mission will be useful in understanding the polar water ice distribution dichotomy among north and south poles of the Moon.

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P-02

Lunar Volcanic Glasses: Compositional Analysis of Lunar Dark Mantle Deposits

Dibyendu Misra[1,2,*] and Megha Bhatt[1]
[1]Physical Research Laboratory, Ahmedabad-380009, India
[2]Indian Institute of Technology Gandhinagar, Gandhinagar-382055, India
*Corresponding author E-mail: dibyendu@prl.res.in

Dark mantle deposits (DMD), one of the lunar lithological units, are generally composed of pyroclasts in the form of partially crystallized droplets of Fe-Ti-bearing glasses [1]. It has a relatively low albedo and homogeneous texture with similar composition, and spectral characteristics to the surrounding early mare regions [2]. Pyroclastics are a key to understand source region characteristics related to ancient volcanism. Additionally, DMDs are important for understanding volatile concentrations on the surface by examining the spectral characteristics of these glasses. Several recent works, suggest the existence of volatile-enriched primary magma reservoirs within the Moon [2]. However, differentiating volcanic glasses from other lunar minerals and impact glasses is challenging due to the overlapping spectral characteristics of volcanic glasses with common major minerals present on the Lunar surface [2,3,4,5,6]. In addition to spectral characteristics, it's important to understand the geomorphology of DMDs for discriminating them in the UV-VIS-NIR wavelength range.

The main objective of this work is to establish a framework for studying pyroclastics on the global scale for understanding the origin and evolution of lunar basaltic magmatism. Our approach is based on the high-resolution level 2 data products from various orbiter missions. In this work, we present the methodology developed by considering two well-studied local and regional DMDs of Schlüter [5.93˚ S, 84˚ W] and Aristarchus [23.73˚ N, 47.49˚ W], respectively [4,6]. In the search for pyroclastic materials, these two regions are being reexamined, using the Moon Mineralogical Mapper (M^3) [7] data of Chandrayaan-1. Our careful assessment suggests that the interplay between the band center around 2 μm and the band center around 1 μm holds a significant role in classifying pyroclastics along with the associated mineralogy. We found that a coordinate search using a set of spectral parameters extracted from hyperspectral imager operating in the VIS-NIR wavelength range should be fully utilized because relying solely on a single band parameter falls short of identifying pyroclasts accurately. We identify spectral parameters; band area and band depth at the band center around 1 μm as crucial parameters to distinguish volcanic glasses from the local minerals.

In summary, a comprehensive assessment involving multiple spectral parameters is essential for the accurate identification and classification of mineralogical variations among the DMDs. In future, we also plan to integrate telescope-based polarimetric images for understanding grain size variations present around DMDs.

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Physical Research Laboratory
MetMeSS-2023

1st November, Wednesday

Session- III: Shock effects
Session Chair: Dr. Dwijesh ray

Abstract#	Time	Speaker	Title	Affiliation
S3-01	16:55 – 17:05	Rajesh K Behera	Formation mechanism of ringwoodite and dissociation of olivine in Bori L6 chondrite	IIT, KHARAGPUR
S3-02	17:05 – 17:15	Priyanka Pandit	Phase stability of MgSiO3 silicate minerals at the mantle transition zone (MTZ)	IISER Kolkata

S3-01

Formation mechanism of ringwoodite and dissociation of olivine in Bori L6 chondrite

Rajesh Kumar Behera[1, *], Sujoy Ghosh[1], Kishan Tiwari[1], Dwijesh Ray[2], Kuljeet K Marhas[2]

1. Department of Geology and Geophysics, Indian Institute of Technology, Kharagpur-721302, India
2. Planetary Sciences Division, Physical Research Laboratory, Ahmedabad 380059, India

*Corresponding author E-mail: rajeshkb@iitkgp.ac.in

Introduction: Shocked meteorites are the major natural source of high-pressure minerals, which are the framework constituents of the planetary interiors. Shocked meteorites are those that have experienced high pressure and temperature conditions due to the collision between celestial bodies in space. These collisions cause deformation and fracturing. The friction along these fractures results in high-temperature conditions and subsequent melting. Such fractures are known as shock melt veins. The minerals in and around the shock melt vein are transformed into their high-pressure polymorphs due to high pressure and temperature. These high-pressure phases are rare in terrestrial rocks but are abundant in the Earth's mantle. Olivine is one of the most important constituents of Earth's mantle. Hence, it is very important to study the transformation mechanisms of olivine to ringwoodite and the dissociation of the olivine which are expected to be the major transformation process of olivine at the lower mantle. Several high-pressure experiments have been performed to study the behaviors of olivine under extreme pressure and temperature conditions. Near the transition zone at 410 km, olivine transforms into wadsleyite, and at 520 km it transforms into ringwoodite. Hence the study of the high-pressure phases found in the meteorites provides clues about phase transformation mechanisms. The Bori meteorite fell in 1894 in Bori village, Madhya Pradesh, India.

Significance of the work: The study of the dissociation of olivine and the olivine-ringwoodite transformation mechanism is very important to better understand the composition, structure, and dynamics processes and the behavior of materials under extreme pressure and temperature conditions within the planetary interior. Here we are going to report the dissociation of olivine and the different modes of occurrence of ringwoodite inside the SMV and also in the host rock direct contact with the SMV in Bori L6 chondrite, which are completely different from the previous report in shocked ordinary chondrite. We will discuss in detail the different transformation mechanisms, constraints pressure-temperature conditions, and shock history.

Results: Bori L6 chondrite, consists of the shock melt vein (SMV) and the melt pockets (MP). In the host rock, olivine, low-Ca pyroxene, high-Ca pyroxene, plagioclase (mostly transformed to maskelynite), chromite, apatite, Fe-Ni, and troilite are present. High-pressure polymorphs present inside or close to the SMV and MP include ringwoodite, akimotoite, majorite, lingunite, jadeite and coesite, tuite, and the matrix of SMV contains the majorite-pyrope solid solution. Several olivine grains inside the SMV have a fine dissociation texture, similar to the host rock olivine. According to earlier research, olivine may be dissociated into assemblages of magnesiowüstite and orthoenstatite or ferroan-periclase and clinopyroxene or magnesiowüstite and bridgmanite [1]. Olivine grains inside the SMV show the segmentation texture which represents the sub-grain boundaries. Numerous crystal defects develop in the olivine as a result of the thermal stress caused by shear and the sub-grain boundary is then produced by the subsequent diffusion of the crystal defects. When the thermal activation of defects commences at a high temperature, the olivine grain segments [2].

Different mode of occurrences of ringwoodite is observed in Bori L6 chondrite. A fine dendritic and acicular texture can be seen in one of the ringwoodite grains inside the SMV, on the other hand, polycrystalline to dendritic texture can be found in another ringwoodite grain inside the MP. Both have compositions similar to the host rock olivine, suggesting ringwoodite may be formed by the solid-state transformation mechanism [3]. However, the presence of dendritic texture may be due to the partial melting of the olivine grains followed a by rapid cooling event under high-pressure conditions, which inhibit the kinetics of back-transformation from metastable ringwoodite to olivine.

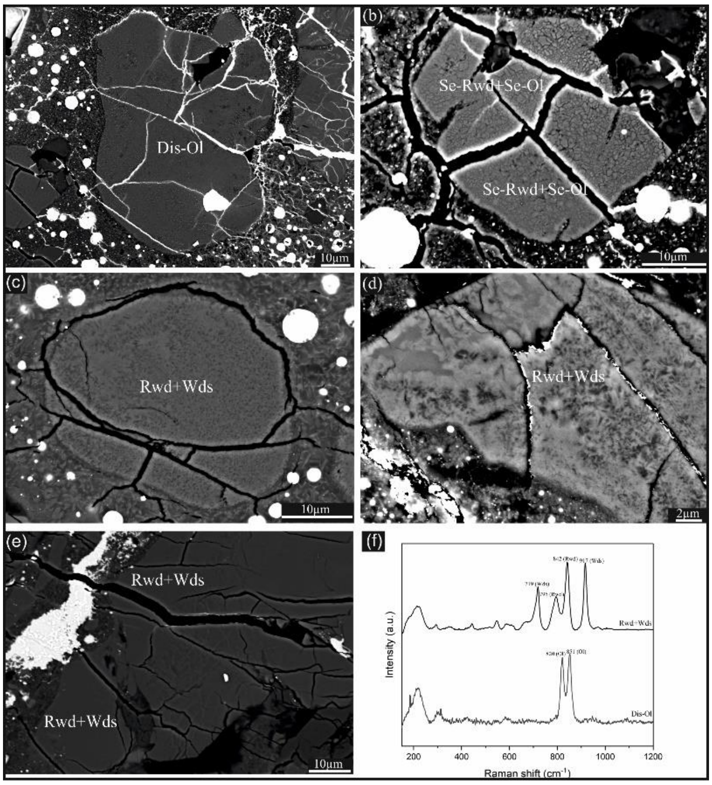

Fig. 1. Back-scattered electron (BSE) images of (a) Dissociated olivine, (b) Assemblages of segmented ringwoodite and segmented olivine, in (c) and (d), Ringwoodite grains consist of dendritic to acicular texture, (e) polycrystalline to lamellar ringwoodite. (f) Representative Raman spectra of dissociated olivine (lower spectrum) and ringwoodite and wadsleyite (upper spectrum). Dis-Ol: dissociated olivine, Se-Ol: segmented olivine: Se-Rwd: segmented ringwoodite, Ol: olivine, Rwd: ringwoodite, Wds: wadsleyite

Other types of ringwoodite appear as polycrystalline ringwoodite close to the SMV, followed by randomly oriented lamellar ringwoodite that grows farther away from the SMV and finally disappears from the host rock. This textural variance may have been created by an incoherent transformation mechanism and implies a temperature gradient from the edge toward the host rock. Based on the high-pressure phase diagrams and the presence of high-pressure polymorphs in Bori L6 chondrite suggest that it should have been exposed to pressure of at least 18 to 23 GPa.

Future work: Transmitted electron microscope (TEM) studies will be carried out for a detailed study of different phases on a submicron scale.

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S3-02

Phase stability of MgSiO3 silicate minerals at the mantle transition zone (MTZ)

Priyanka Pandit[1], Prathibha Chandrashekar[1], Gaurav Shukla[1,2*]
[1]Department of Earth Sciences, Indian Institute of Science Education and Research, Kolkata, India. (pp21rs054@iiserkol.ac.in)
[1]Department of Earth Sciences, Indian Institute of Science Education and Research, Kolkata, India. (prathu496@iiserkol.ac.in)
[1]Department of Earth Sciences, Indian Institute of Science Education and Research, Kolkata, India
[2]National Center for High Pressure Studies, Kolkata, India. (gshukla@iiserkol.ac.in)
*Corresponding author E-mail: gshukla@iiserkol.ac.in

Contents of Abstract:

The post-spinel phase transition from ringwoodite to bridgmanite and ferropericlase is generally attributed to the seismic discontinuity at 660km depth [1]. However, seismic observations reveal multiple discontinuities and depressions by ~30 to ~90 km at this boundary in the cold subduction zones (e.g., Tonga subduction, Mariana slab, etc.) [2,3,4]. Several high-pressure experimental and first-principles studies suggest that the akimotoite to bridgmanite phase transition may play a significant role in unravelling the complexity of the 660 km boundary [5,6,7]. The recent discovery of iron-rich natural analogues of akimotoite and bridgmanite in the Suizhou L6 chondrite raises the possibility that iron incorporation in akimotoite and bridgmanite may have a significant impact on the phase stability of these minerals [8,9]. Using first-principles computational methods, we investigated the stability field of iron-rich analogues of akimotoite and bridgmanite, $(Mg_{1-x}Fe_x^{2+})SiO_3$. The static transition pressure decreases significantly with the incorporation of iron. We find that at the transition point, the contrast in compressional velocity decreases, whereas the shear velocity contrast increases with increasing concentration of Fe from x = 0 to 0.5. We also investigated the effects of temperature on the transition within the quasiharmonic approximation and found that the overall steepness of the clapeyronslope increases with an increase in iron concentration.

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P-03

Akimotoite formation mechanisms in the Bori L6 chondrite: Insights from high-pressure shock events

Ghosh S[1], Behera R[1], Tiwari K[1], Ray D[2], Marhas K[2]

[1]Department of Geology and Geophysics, Indian Institute of Technology, Kharagpur-721302, India
[2]Planetary Science Division, Physical Research Laboratory, Ahmedabad- 380059, India
Corresponding author E-mail: sujoy.ghosh@gg.iitkgp.ac.in

Akimotoite, a high-pressure polymorph of $(Mg,Fe)SiO_3$ with an ilmenite structure, is a valuable indicator of high-grade shock states in mafic-rich chondrites like L chondrites. Its formation mechanisms provide crucial insights into the processes during high-grade shock events and contribute to our understanding of planetary body origin and evolution. This study investigates the Bori L6 chondrite, a heavily shocked meteorite, to unveil various modes of akimotoite occurrence. The findings reveal net-like growth of akimotoite lamellae along the margin of shock-induced melt veins (SMVs), intracrystalline growth within enstatite grains entrained in SMVs, and grain boundary nucleation and intracrystalline growth within an enstatite grain inside an SMV. The chemical composition of lamellar akimotoite resembles that of host rock enstatite, suggesting a solid-state transformation. This transformation is estimated to occur at temperatures exceeding 1550 °C at 22 GPa. These observations enhance our knowledge of akimotoite formation in heavily shocked chondrites and its significance in deciphering planetary processes.

Physical Research Laboratory
MetMeSS-2023

2nd November, Thursday

Session- IV: Mars
Session Chair: Dr Amit Basu Sarbadhikari and Dr. Megha U Bhatt

Abstract#	Time	Speaker	Title	Affiliation
Invited	9:30 - 9:50	Amit Basu	Geological history/formation of Mars	PRL, Ahmedabad
Invited	9:50 - 10:30	Sujoy Mukhopadhyay	Noble gases in Martian Meteorites	UC Davis, California
S4-01	11:05 - 11:20	Gurpreet Kaur Bhatia	Early thermal evolution and core-mantle differentiation of Mars: Implications for its volatile rich core	Maharishi Markandeshwar University, Mullana
S4-02	11:20 – 11:30	Subham Sarkar	Smectite Detection on Jezero Delta front using Perseverance’s SuperCam instruments	PRL, Ahmedabad
S4-03	11:30 – 11:40	Aditya Das	Martian crustal alteration: A perspective from meteorite and terrestrial sample	PRL, Ahmedabad
S4-04	11:40 – 11:50	Varsha M. Nair	Unveiling Mars' Magmatic History through Geochemical Analysis of Enriched to Intermediate Poikilitic Shergottites	PRL, Ahmedabad

S4-01

Early thermal evolution and core-mantle differentiation of Mars: Implications for its volatile rich core

Gurpreet Kaur Bhatia
Department of Physics, Maharishi Markandeshwar (Deemed to be University), Mullana, India 133207
gurpreetkaur@pu.ac.in ; gurpreet.kaur@mmumullana.org

Results of the recent InSight mission to Mars suggested its volatile rich core [1]. Further, the recent planet formation theories suggested early formation of Mars either before the dissipation of primordial solar nebula or its accretion from the volatile rich impacting planetesimals [2]. We ran numerical simulations for Mars' thermal history and core formation during the first 10 Ma (million years) of the solar system's origin in order to explain its volatile-rich core [3]. The heat sources include the decay energy of the SLR ^{26}Al along with the blanketing effect of both primordial and impact-generated H_2O+CO_2+CO+H_2 atmosphere. The impact generated atmosphere was grey, radiative, and plane-parallel [3-4]. The results of this study recommend complete core formation of Mars for accretion timescales <2Ma. During the differentiation process, the volatiles dissolved in the magma ocean from the overlying atmosphere could partition to the core. For models with longer duration of accretion, the interior of Mars experienced incomplete differentiation. However, in these models, complete core formation might be triggered by Rayleigh-Taylor instability. The outcomes of present study have implication to explain the volatile rich core of Mars.

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S4-02

Smectite Detection on Jezero Delta front using Perseverance's SuperCam instruments

Subham Sarkar[1], Sushanta Ghosh[2], Anik Mukherjee[3], Dwijesh Ray[1],
[1]Physical Research Laboratory, Ahmedabad, India
[2]Indian Institute of Technology (Indian School of Mines), Dhanbad
Dhanbad (India)
[3]Department of Geology and Geophysics, Indian Institute of Technology Kharagpur,
*Corresponding author E-mail: subham@prl.res.in

The Perseverance rover landed in the Jezero crater in February 2021 as part of the Mars 2020 mission, with the primary goal of searching for habitability on Mars and collecting samples for Earth return [1]. The paleolake basin of the Jezero crater hosts carbonate along with Fe-/Mg-smectite minerals [2]. In this study, we have characterized the mineralogy of a specific locale within the Jezero crater, positioned along the Delta Lake boundary using Visible (VIS), InfraRed (IR), and Laser Induced Breakdown Spectroscopy (LIBS) instruments of SuperCam suite onboard Perseverance rover [3,4]. LIBS uses a 1064-nm laser to generate data for the 243-843 nm spectral range. The spectral ranges of the VIS and IR spectroscopic instruments are 400 - 900 nm and 1.3 - 2.6 µm, respectively [3,4]. Thus, these instruments can be used for precise elemental and mineralogical identifications. Preliminary observations on the study area show the presence of nontronite, saponite, sepiolite, and montmorillonite minerals. Although all these minerals can form due to aqueous alteration of the primary basaltic floor, the water:rock ratio and pH condition of the aqueous solution vary for each alteration product. Thus, a detailed study of their formation mechanism and distribution can help us to model paleoenvironmental conditions that prevailed on the red planet. However, the presence of smectites in the Jezero crater is well-known from the orbiter-based observations. The exact mineral diversity can be deciphered by in-situ detection only.

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S4-03

Martian crustal alteration: A perspective from meteorite and terrestrial sample

Aditya Das[1,2*], Dwijesh Ray[1]

[1]Planetary Science Division, Physical Research Laboratory, Ahmedabad, Gujarat 380009
[2]Indian Institute of Technology Gandhinagar, Gujarat 382355

*Corresponding Author E-mail: [1]adityadas@prl.res.in

Like Earth, olivine, the major ferromagnesian mineral, was discovered in mafic rocks/ crust on Mars via orbital and or rover missions [1,2,3]. The alteration of olivine in the Martian crust unequivocally suggests the active role of the water-rock interaction and provides an important constraint on the hydrology; these findings have led to the planning of Martian landing missions, given that clays offer the highest potential for preserving biosignatures. We pursued comparative planetology using secondary minerals from Mars (nakhlite) and Earth from the Deccan volcanic province to complement our study, where similar alterations are observed along olivine fractures. Based on the petrochemical study, this study aims to gain insights into the physicochemical conditions of the aqueous evolution of the planetary crust.

During the analysis, several similarities have emerged between the Deccan and Martian samples, potentially suggesting an analogical relationship between the early Mars and Earth. Both the Martian and terrestrial olivine grains show irregular fractures containing secondary minerals. Detailed examination through high-resolution Backscattered Electron (BSE) images exhibits a serrated appearance with prominent teeth and notches, indicating low-temperature alteration-induced dissolution and precipitation of secondary minerals (saponite). The Octahedral/Tetrahedral coordination of Martian and terrestrial saponite yield similar values (0.612, 0.683 respectively). The chemical index of alteration (CIA) of secondary minerals suggested that the weathering vector will continue along the A-CN join in the A-CN-K ternary diagram. The mafic index of alteration (MIA) and CIA of secondary minerals are linearly correlated, arguing the similar bulk weathering behaviour of Mg, Ca, and Na. The overall correlation of Martian olivine's secondary minerals is relatively poorer than its terrestrial counterpart. This could indicate a slightly different behaviour of Mg, Ca, and Na during the formation of phyllosilicates in the intermediate weathering stages. Fe and Mg are continuously available in a closed system and may interact with Si, while the terrestrial olivine shows a slight Al enrichment (open system). However, the silica-bearing phases are underreported. A low-temperature weathering process also expects a relatively iron enrichment trend for Martian secondary minerals under a dense CO2 atmosphere.

Hence, gaining insight into the alteration processes in Martian and samples Earth could provide valuable information about water-rock interactions and past climatic conditions.

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S4-04

Unveiling Mars' Magmatic History through Geochemical Analysis of Enriched to Intermediate Poikilitic Shergottites.

V.M. Nair[1,2,*], A. Basu Sarbadhikari[1], Y. Srivastava[1,2]

[1]Physical Research Laboratory, Ahmedabad 380009, India.
[2]Indian Institute of Technology Gandhinagar, Gujarat 382355, India.
***E-mail:** varsha@prl.res.in

In recent decades, Mars exploration missions, including Landers, Rovers, and Orbiters, have provided valuable insights into the chemical and mineralogical properties of the Martian surface. However, the instruments used on Mars lack the precision of Earth's laboratories and cannot analyze multiple sample parameters crucial for understanding the planet's evolution. Martian meteorites are the primary source for in-depth laboratory studies without sample return missions, offering valuable information on diverse geological processes and Mars' evolutionary history.

Shergottites, the most common type of Martian meteorites, comprise approximately 90% of the collection. Based on texture and mineralogy, they are classified into different categories, including basaltic, olivine-phyric, poikilitic, and gabbroic [1]. Among them, poikilitic shergottites are the most abundant, accounting for over 20% of the collection. Poikilitic shergottites are distinguished by their unique bimodal texture [2], [3]. This provides insights into their evolution, with an early slow-cooling poikilitic stage and a later, rapidly cooled interstitial stage [2]. They may constitute a significant portion of the Martian crust, making them crucial for studying Martian magmatism. These meteorites are geochemically categorized based on the variations in Incompatible Trace Elements [4], [5] and radiogenic isotopic compositions [6] into enriched, intermediate, and depleted varieties, revealing insights into their mantle sources and the planet's geological history.

In this study, we will be discussing the mineralogy, trace element mineral chemistry, and petrology of two suits of Poikilitic Shergottites, NWA 7397 (Enriched) and NWA 1950 (Intermediate), to constraints the Martian mantle dynamics and source reservoirs for shergottites as a whole, advancing our understanding of Martian igneous processes.

References:

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P-19

Martian ionospheric disturbances induced by consecutive solar eclipse and strong solar flare

Authors' names: Sayanee Haldar[*1,3], Samadrita Basu[2,3]

[1]CSSTEAP - Space and Atmospheric Sciences, Physical Research Laboratory (PRL), Ahmedabad 380009, Gujarat

[2]CSSTEAP – Satellite Meteorology, Space Application Centre (SAC) – ISRO, Ahmedabad 380058, Gujarat

[3]National Institute of Technology Rourkela, Sector 1, Rourkela 769008, Odisha

[*]Corresponding author's email id: sayanee.nitrkl@gmail.com

Abstract

On 30 April 2022, irradiance from a magnitude X class solar flare impacted Mars topside ionosphere while the Mars Atmosphere and Volatile EvolutioN (MAVEN) orbiter was characterizing Mars upper atmosphere. On 27 April 2022, a solar eclipse by Phobos on Mars also was observed by the rover Perseverance near the equatorial region. On Mars, solar flares induce ionization and heat the upper atmosphere in a manner akin to terrestrial processes. Initially, the irradiance induced by solar flares elevates the rate of photoionization within the ionosphere, with the most substantial elevation observed at an altitude of approximately 100 kilometers. Following this, highly energetic photoelectrons proceed to augment atmospheric ionization through impact ionization mechanisms. Consequently, there is a corresponding increase in the plasma density within the ionosphere, mirroring the enhancement in irradiance caused by the solar flare. In contrast, when a solar eclipse occurs on Mars, there is a reduction in the number of electrons that are present in the atmosphere of the planet. Since Mars has a weak and concentrated magnetic force, there are fewer noticeable shifts in the flow of current on the planet. Changes in plasma densities between two different solar events are required in order to distinguish the solar-event-induced phenomena that occur in the upper atmosphere of Mars.

Keywords: Martian Ionosphere, plasma density, solar flares, solar eclipse.

Reference:

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Physical Research Laboratory
MetMeSS-2023

2nd November, Thursday

Session- V: Achondrites
Session Chair: Prof. D. Banerjee and Dr. Nachiketa Rai

Abstract#	Time	Speaker	Title	Affiliation
Invited	11:50 - 12:10	Nachiketa Rai	Ureilites: An end member model for Planetesimal formation	PRL, Ahmedabad
S5-01	12:10 - 12:25	G. Srinivasan	Constraints on Heterogeneous Earth Accretion Model	Centre for Space Sciences and Earth Habitability, Bhopal
Invited	12:25 – 12:45	Sujoy Ghosh	High-pressure mineral assemblages in shocked chondrites.	IIT Kharagpur
S5-02	12:45 – 13:00	Yogita Kadlag	Diyodar is Aubrite: Confirmation from Cr isotopes	PRL, Ahmedabad
S5-03	13:00 – 13:10	Yash Srivastava	Petrogenesis of Diyodar aubrite: Implication to origin of aubrite parent body	PRL, Ahmedabad
S5-03	13:10 - 13:20	Nikita Saji	Neodymium isotope constraints on the structure of the early solar system and accretionary history of Earth	USA

S5-01

Constraints on Heterogeneous Earth Accretion Model

G. Srinivasan

Centre for Space Sciences and Earth Habitability E5-11 Arera Colony, Bhopal 462016
gopalan.srinivasan@gmail.com:

The planetary bodies (terrestrial planets, asteroids, giant planets) in the solar system are made of the material that constituted the solar nebula. The CI chondrites, e.g., Orgeuil, Ivuna, are the most primitive or pristine meteorites with a composition similar to the solar photosphere [1-2]. However, there is significant variation in chemical and isotopic composition amongst various groups of meteorites [3-4] and CI meteorites vis-à-vis the terrestrial planets. Compositional variation amongst the planetary bodies forming from the same nebula implies unique pathways of accretion, both in time and space. Temporal information regarding absolute and/ or relative timing and duration of processes leading to formation and evolution of bodies is preserved in their chemical composition, and they can be inferred for example, from radioactive parent-daughter decay systems. Alternatively, resolving the various potential pathways that led to specific chemical composition of bodies can provide us with constraints on nature of nebular processes that led to formation of a planetary body and its subsequent evolution via chemical differentiation. For example, the chemical and isotopic composition of the bulk silicate Earth (BSE) can be used to narrow down the most probable pathways for accretionary sequence of material, the physical and chemical conditions of chemical differentiation (e.g., oxygen fugacity, temperature, pressure) leading to formation of metallic core and silicate mantle. These principle are applicable to all terrestrial planets and planetesimals. The systematic measurements of chemical composition of the accessible part of the Earth, i.e., the silicate Earth has shown that the abundances of refractory lithophile elements in BSE (primitive upper mantle) are similar to CI chondrite ratios [5-6], implying refractory element abundances regardless of their geochemical affinities are similar to those of solar composition represented by CI chondrites. Further, the depletion of refractory siderophile / chalcophile elements in the silicate mantle is an outcome of their geochemical affinity leading to their sequestration in the Earth's core [7] during a large planetary scale melting event due to high energy impacts, release of gravitational potential energy, heat from radioactive decay of ^{26}Al [8, 9]. Using a simple mass balance calculation early on it was shown that the Earth's mantle had a higher than expected abundance of Ni, Co and Cu [10].

Several workers over the years have attempted to explain the near chondritic Ni/Co ratio in the mantle. The accumulation of mass for growth of the proto-Earth to its current mass can be broadly divided as homogeneous and heterogeneous accretion models. The former as the name suggests composition of the material that accreted remained homogeneous through time while in case of the latter it was not. In the context of homogeneous models using low pressure partitioning coefficients for Ni or Co between liquid metal alloy and silicate the explanation for this excess Ni or Co was attributed to several scenarios such as equilibrium between S-rich core and mantle [11], high temperature equilibrium [12] or disequilibrium [7] between core and mantle. Alternatively, the first heterogeneous accretion model [13] suggested accretion of volatile poor reduced material followed by volatile -rich oxidized material. Heterogeneous accretion models [14] propose initial growth from accretion of highly reduced bodies (60-70% by mass) followed by more oxidized bodies (30-40% by mass). The large differentiated impactor core merge with the Earth's core without equilibrating with mantle to reproduce Ni and Co abundances observed in BSE. On the other hand another model [15] uses the radioactive decays system - ^{53}Mn-^{53}Cr, ^{107}Pd-^{107}Ag, ^{87}Rb-^{87}Sr and ^{182}Hf-^{182}W model calculation data to infer the requirement of volatile depleted precursor for ^{53}Mn-^{53}Cr and ^{87}Rb-^{87}Sr system, whereas a volatile rich precursor for ^{107}Pd-^{107}Ag system to match with the ^{182}Hf-^{182}W systematics derived age models. This conundrum is overcome by a heterogeneous accretion scenario of 90% mass accumulation by 30 Mys followed by 9% mass accretion of volatile-rich material through Moon forming giant impact around 60 Mys. Such a scenario also accounts for similarities in W isotope composition with differing Hf/W ratios for Earth and Moon [16].

In the following a scenario is explored which is parsed into three main epochs [e.g., 17]. A primary growth of proto-Earth (80-85% of bulk Earth mass) from reduced volatile poor material which ends with a major milestone in Earth's history i.e., core-mantle formation. This is followed by a second major mass accumulation of about 15% which is enriched or less depleted in volatile material via the Moon forming impact of Theia. This step results in accumulation of 99% of the mass and is followed by segregation of sulfide melt known as "*Hadean matte*" [18-20] which may also explain the relatively low abundance of sulfur in the silicate Earth [21]. The remainder of Earth mass was aggregated later and is popularly labelled as "*late veneer*" [22-23] which accounts for the abundances of siderophile elements in chondritic proportions. For calculations meteorite analogue of reduced material in the first epoch is enstatite chondrite and in the second epoch the meteorite analogue is CI and or CM material. The abundances of Ni are calculated after each step and this is compared with present day Earth abundance of Ni. We use Ni partition coefficients [24] metal-silicate portioning in first epoch and Ni partitioning coefficient [21, 25] for sulfide-silicate melt for second epoch to calculate the distribution of Ni between the various reservoirs following two epochs. We will explore the changing Ni abundance distribution by varying considering an impactor as mixture of CI and CM chondrites in the second epoch.

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S5-02

Diyodar is Aubrite: Confirmation from Cr isotopes

Yogita Kadlag[1,*], Amit Basu Sarbadhikari[2], Yash Srivastava[2], and Varsha M. Nair[2]
[1]Geosciences Division, Physical Research Laboratory, Navrangpura, 380009, Ahmedabad, Gujarat, India.
[2]Planetary Sciences Division, Physical Research Laboratory, Navrangpura, 380009, Ahmedabad, Gujarat, India
*Corresponding author E-mail: yogita@prl.res.in

On August 17, 2022, the Diyodar meteorite fell in Gujarat, India. Preliminary examination of Diyodar indicates it is an aubrite [1]. However, detailed chemical and isotopic studies are still needed to classify this meteorite and establish its genetic linkage. Here, we carried out mass-independent Cr isotope studies of Diyodar to determine the group and genetic linkage of this meteorite.

Two aliquots (each 50 mg) of homogenized powder of Diyodar and terrestrial reference material BHVO-2 are dissolved in microwave digestion system at temperature ~ 200^{o}C and pressures ~ 90 bars. Three stages column chromatography involving anion and cation exchange is performed to separate Cr from other matrix elements. Purified Cr loaded on the Re filaments and measured on Triton TIMS situated at Physical Research Laboratory. Detailed separation and analysis procedure is described in [2, 3]. The ε^{53}Cr and ε^{54}Cr of BHVO-2 reference standard are 0.06 ± 0.03 (2SE, n =16) and 0.08 ± 0.06, respectively, consistent with the literature data [3, 4, 5]. The ε^{53}Cr of two Diyodar aliquots are 0.97 ± 0.03 (2SE, n =7) and 0.97 ± 0.02 (n =19). The ε^{54}Cr of two Diyodar aliquots are 0.14 ± 0.05 (n =7) and 0.12 ± 0.06 (n =19). The ^{55}Mn/^{52}Cr (4.12), ε^{53}Cr and ε^{54}Cr values of Diyodar fall in the range of enstatite achondrites, i.e., Aubrites [Figure 1]. It is another independent evidence that Diyodar originated from Aubrite parent body, making it 11th 'fall' Aubrite, which are most reduced and rare class of differentiated meteorites from inner solar system.

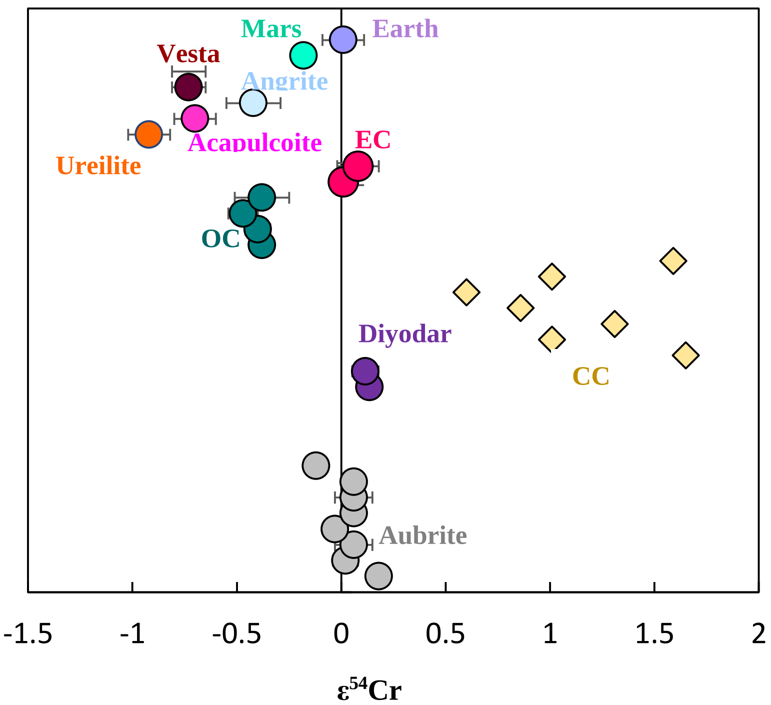

Fig. 1: ε^{54}Cr of chondrites, achondrites, differentiated meteorites, Mars, and Earth. ε^{54}Cr value of Diyodar is similar to enstatite Achondrites/chondrites. Literature data is from different sources complied in [3] and Aubrite data from [6].

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S5-03

Petrogenesis of Diyodar aubrite: Implication to origin of aubrite parent body

Y. Srivastava[1], V.M. Nair[1,2], A. Basu Sarbadhikari[1]
[1]Physical Research Laboratory, Ahmedabad, India, [2]Indian Institute of Technology, Gandhinagar, India, E-mail: yash@prl.res.in

Aubrites (enstatite achondrites) are differentiated bodies formed under extremely low oxygen fugacities (fO_2: IW-2 to -6), making them most reduced rocks in our sample collection [1]. Under such reduced conditions distinct chemical preference give rise to exotic minerals, such as oldhamite [Ca, Mg] S, alabandite [Mn, Fe] S, heideite $FeTi_2S_4$ etc, which are not typically observed in other extraterrestrial bodies. In contrast to other primitive achondrites, the aubrites show convincing chemical and isotopic evidences of having derived from early differentiation of enstatite chondrite like precursor with their parent body (or bodies) accreting close to the solar nebula [2-5]. These unique features of rare aubrites (~30 classified) highlight their importance in studying reduced magmatism in our solar system.

In this work, we study recently fallen, second aubrite meteorite of India, Diyodar meteorite. The meteorite has been classified as fragmental breccia dominated by nearly FeO-free enstatite (~90 vol. %), with minor to nearly FeO-free diopside and forsterite, metallic Fe, Ni, troilites with other common exotic sulfides [6]. Our detailed mineralogical, petrological investigation and bulk rock chemistry ($[Th/Sm]_N = 3.52$; $[La/Sm]_N = 1.39$ and $[Eu/Eu^*]_N = 0.16$) suggests that Diyodar meteorite is related to the igneous-origin main group aubrites.

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S5-04

Neodymium isotope constraints on the structure of the early solar system and accretionary history of Earth

Nikitha Saji[1,2*], Kirsten Larsen[1], Martin Schiller[1], Martin Bizzarro[1]
[1]Centre for Star and Planet Formation, Globe Institute, University of Copenhagen, 1350 Copenhagen K, Denmark
[2]College of Science and Engineering, Central State University, Wilberforce, 45384 Ohio, USA
*Corresponding author Email: nsaji@centralstate.edu

There exists abundant evidence today, from meteorites and their components, for the heterogeneous distribution of diverse presolar carries of nucleosynthetic isotope anomalies in the solar protoplanetary disk [1, 2]. The observed isotopic variations testify to the differential incorporation of presolar dust by accreting planets and planetesimals, although the exact mechanism behind their heterogeneous distribution in the early solar system is highly debated. Two contrasting models exist currently, the first invoking a change in the composition of the infalling molecular cloud material during the cloud collapse phase [3], and the second arguing for thermal processing in the disk leading to unmixing of distinct dust populations [4, 5]. Of the large number of elements for which nucleosynthetic anomalies have been documented so far, the isotopic variations in light elements such as Ca, Ti, Cr, Ni, and Fe are generally attributed to variable admixture of material derived from supernovae [1]. On the other hand, for heavy elements such as Mo, Ru, Zr, Sr, Ba, Nd and Sm, the isotopic variations are mainly governed by heterogenous distribution of material produced by slow neutron capture (s-process) in asymptotic giant branch (AGB) stars [5]. It is unclear how these two distinct isotopic heterogeneity trends relate to each other, with existing models of nucleosynthetic variations often focusing on one or the other. Additionally, considerable correlated variations exist between s-process isotope anomalies and those in light elements for different subsets of meteorites and their components [6, 7]. The origin of these correlations that involve both refractory (Ti, Zr, Mo) and non-refractory (Cr, Ni) elements with a wide range of volatilities remains elusive considering that the presolar carrier phases of the two sets of isotope anomalies originate from distinct stellar environments.

Neodymium is a refractory lithophile element useful for investigating the origin of nucleosynthetic isotope variations in the early solar system. Although planetary-scale Nd isotope variations are typically understood to be driven by s-process dust [8, 9] evidence for an apparent dichotomy between carbonaceous and non-carbonaceous meteorites related to non-classical s-process or intermediate neutron capture (i-process) has been reported for its most neutron-rich nuclide - ^{150}Nd [10]. Carbonaceous chondrites that accreted in the outer solar system are characterized by a marked deficit in ^{150}Nd relative to most bodies that accreted in the inner solar system. This peculiar distribution of ^{150}Nd is reminiscent of the carbonaceous (C) - non-carbonaceous (NC) dichotomy observed for neutron-rich nuclides such as ^{48}Ca, ^{50}Ti, ^{54}Cr, and ^{95}Mo [1, 2]. However, the enrichment direction for the neutron-rich ^{150}Nd is opposite to that defined by other neutron-rich nuclides with non-carbonaceous meteorites having an enhanced ^{150}Nd abundance relative to carbonaceous meteorites. This distinction becomes even more pronounced when one considers that the refractory inclusions that carry the largest depletions in ^{150}Nd represent the solar system materials most enriched in ^{48}Ca, ^{50}Ti, ^{54}Cr, and

^{95}Mo [2, 3]. In addition to the broader C-NC dichotomy apparent in ^{150}Nd, the classical s-process variations reflected in other Nd isotopes (e.g., ^{148}Nd) are known to show intriguing correlations with anomalies in neutron-rich nuclides such as ^{54}Cr for different meteorite subgroups [9]. In this work, we investigate the full extent and significance of these inter-element correlations using available and newly acquired high precision neodymium isotope data for primitive and differentiated meteorites, as well as their components. Our overall objective is to investigate the relative role of disk processes and heterogeneous infall in delineating the multitude of nucleosynthetic isotope heterogeneity trends observed in solar system materials, including the s-process heterogeneity and the apparent C-NC dichotomy. We find that divergent distribution of distinct dust populations as a function of thermal processing as well as some degree of inherited molecular cloud heterogeneity is necessary to explain the full spectrum of solar system nucleosynthetic isotope variations. In the context of our new comprehensive model for the origin of planetary-scale isotope variations, we also explore the nucleosynthetic makeup of the material precursors of Earth and Mars in order to pinpoint the processes that control the accretionary history of solar system terrestrial planets.

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Terrestrial analogs: The Similarity between dissimilarities

Dwijesh Ray
Physical Research Laboratory, Ahmedabad 380009, India
E-mail: dwijesh@prl.res.in

There are no perfect analogs on Earth. However, terrestrial analogs are commonly used in planetary geology because of their likelihood of satisfying conditions. *In situ* exploration and analyses in space involve limited scopes, e.g. the energy and mass constraint of spacecraft, sensitivity, precision and incompatibility with the specification of any mission. The analog sites also help to select the future landing sites on the Moon, Mars, Asteroids and beyond. Also, the remote sensing data collected during the sojourn of orbiter instruments lacks the proper geologic context. The validation of different protocols before any planetary mission is crucial for scientific relevance and for training scientific teams to follow a procedure of investigation. Ideally, the validation and testing phase must be carried out in a terrestrial laboratory prior to any mission similar to those anticipated or will be analysed during the mission. Analog sites can also be used to train astronauts, test instruments or payload and/or assist in the interpretation of observations made during space missions.

The Earth's materials and various geological processes are considered as potential Planetary, Mineralogical, Astrobiological and Engineering analogs. Despite the larger similarity, some disparity also exists. Last but not least, I will discuss a few analog sites from the Indian Geological Record.

Recent advances in astronomy hold many prospects for the discovery of exoplanets, and potential habitats for life. Until it proves feasible for geological studies, we can still advance the science of these Earth-like planetary surfaces through the application of geological/analogical reasoning. This relatively evolving subject also helps and creates new opportunities for scientists to work in the interface of traditional subjects like geobiology, astrobiology, etc.

Physical Research Laboratory
MetMeSS-2023

2nd November, Thursday

Session- VI: Analogue studies
Session Chair: Prof. Sujoy Ghosh and Dr. Naveen Chauhan

Abstract#	Time	Speaker	Title	Affiliation
Key Note	14:00 - 14:20	Dwijesh Ray	Analogue studies and their importance	PRL, Ahmedabad
S6-01	14:20 - 14:30	V. Deepchand	Comparative Spectrochemical Analysis of Lodestones of Southern India and Martian Meteorites: Exploring Potential Functional Analogues	University of Kerala, Thiruvananthapuram
S6-02	14:30 – 14:40	M. Singhal	Luminescence Characteristics of terrestrial Jarosite from Kachchh, India:A Martian Analogue	PRL, Ahmedabad
S6-03	14:40 - 14:50	Preeti Kumari	Thenardite and Mirabilite of Hypersaline Lake, Rajasthan: Implications to Martian analogue and Astrobiology.	IIST, Thiruvananthapuram
S6-04	14:50-15:00	Saptarshi Lohia	Spectral Characterization of Red Sands from Muttom, Tamil Nadu, India: Implications to Mars	IIST, Thiruvananthapuram
S6-05	15:00 – 15:10	Hariharan P.K.	3D printing of Martian and Lunar analogue rocks	
	16:00 – 16-30		1300 HR SIMS and its application	Ameket
	16:30 – 17:30	Keisuke Okayama	TEM and its application in earth and planetary Science.	Jeol, Japan

S6-01

Comparative Spectrochemical Analysis of Lodestones of Southern India and Martian Meteorites: Exploring Potential Functional Analogues

V. Deepchand[1,*], V. J. Rajesh[2], R. B. Binoj Kumar[1]
[1]Department of Geology, University of Kerala, Thiruvananthapuram-695581
[2]Department of Earth and Space Sciences, Indian Institute of Space Science and Technology, Thiruvananthapuram-695547
*Corresponding author E-mail: deepchandgeology@gmail.com

The spectral and chemical analysis of Martian meteorites enables us to comprehend the mineralogy and processes associated with the origin and evolution of the Martian crust. Meteorites can also be used as planetary analogues to examine mineral-forming processes and compare spectral data with Mars mission results [1]. Comparing the spectrochemical properties of Martian meteorites to those of terrestrial materials validates and improves planetary exploration. The present study compares the spectrochemical and mineralogical characteristics of Martian meteorite EETA79001 to lodestone deposits in southern peninsular India to understand their similarities and explore the potential of lodestones as functional analogues to understand mineral paragenetic mechanisms and magnetism on Mars.

Lodestones are naturally magnetized ore bodies commonly found as lenses or bands within mafic-ultramafic rocks [2]. Lodestones retain natural remanent magnetism due to their varied mineralogy, microtextural characteristics, and unusual chemical composition [3]. The Kanthampara lodestone deposit is a chromiferous vanadiferous titanomagnetite deposit near Periye village and is a recognized naturally magnetized lodestone deposit in the northern part of Kerala [4]. This study uses petrographic, spectroscopic, and mineralogical methods to characterize the lodestone deposit. The samples primarily consist of titanomagnetite and ilmenite, with a minor amount of chromite, hematite, pleonaste, and ulvöspinel. Ti-magnetite displays a variety of micro-intergrowth textures that reflect exsolution characteristics developed from solid-solution compositions under varying oxygen fugacities. Exsolution and oxidation at different temperatures during sub-solidus magma cooling produce crystallographic intergrowths. In mineral chemistry, magnetite grains have 74.8 to 76.9% FeO(t), 12.9 to 15.8 % Cr_2O_3, and 2.6 to 3.9% Al_2O_3, while ilmenite grains have 37.8 to 41.3% FeO(t) and 53.1 to 53.6% TiO_2. Chromium spinels are also found with 18.4-29.6% Cr_2O_3. The magnetite-ilmenite geothermometric constraints show a temperature range of 479.7 to 673 °C and a fugacity range of -26 to -15.9. The range of fugacity values indicates that the lodestone layers were formed or cooled in an environment with variable oxygen fugacity conditions. The negative fugacity values suggest that the lodestones were formed in a higher oxidizing environment. Raman spectral features indicate the presence of magnetite, ilmenite, hematite, chromite, and ulvöspinel and their solid solutions. A major peak in the range 600-800 cm^{-1} and a few minor peaks at lower wavenumbers observed correspond to A_{1g}, T_{2g} (1), E_g, T_{2g} (2), and T_{2g} (3) modes of vibration. The region 600-800 cm^{-1} is the most useful for discriminating Fe-Ti-Cr-Al substitutions in the magnetite-ulvöspinel, ulvöspinel-chromite, ilmenite-hematite, and chromite-spinel series, minor peaks observed in the range 300-600 cm^{-1} also helps in discrimination.

EETA79001 is an extensively studied Martian basaltic shergottite meteorite, notable for its two distinct lithologies (A and B) separated by either an igneous or impact-melt contact [5]. Mineralogical and Raman spectral studies on EETA79001 [6] and [7] reveal the presence of various Fe-Ti-Cr oxides, including chromite, ulvöspinel, magnetite, ilmenite, and hematite. Chromite, with its regular spinel structure, exhibits five distinct Raman-active vibrational modes. Key Raman peaks for chromite appear at approximately 675 cm^{-1}, 659 cm^{-1}, and 1305 cm^{-1}. Ulvöspinel displays major Raman peak positions around 224 cm^{-1}, 303 cm^{-1}, and 527 cm^{-1}. Magnetite, distinguishable by its specific Raman peaks, is recognized by major Raman peak positions at approximately 665 cm^{-1}, 289 cm^{-1}, and 404 cm^{-1}. Ilmenite showcases specific Raman peaks, with major positions around 491 cm^{-1}, 608 cm^{-1}, and 223 cm^{-1} [6]. Hematite exhibits characteristic Raman peaks, including major positions at approximately 218 cm^{-1}, 595 cm^{-1}, and 497 cm^{-1}. Titanomagnetite phases from EETA79001 vary in composition, with 67.38% FeO(t), 4.6% Cr_2O_3, and 15.09 % TiO_2. Chromite phases range from 20.3% to 49.79% FeO(t) and 21.99% to 66.51% Cr_2O_3. Ilmenite phases have compositional variability, with FeO(t) ranging from 27.18 to 46.97 % and TiO_2 from 51.69 to 52.54% [7].

A comparative investigation in mineralogy, chemistry, and spectral signatures between lodestones from southern India and the Martian meteorite EETA79001 has shown a significant range of overlap between them. In both the lodestone and the meteorite sample, the Fe-Ti-Cr oxides present, which include chromite, magnetite, ilmenite, and ulvospinel, were mainly formed during the early stages of crystallization from their Fe-rich parent melt. This overlap highlights the usefulness of lodestones as functioning Martian analogue materials for researching the mineral paragenetic mechanisms of materials similar to those found on Mars. Our research highlights the significance of such comparison studies, which offer insight into the intricate geological history and mineralogical diversity of the Martian surface while also improving the accuracy of analytical procedures used in planetary exploration.

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S6-02

Luminescence Characteristics of terrestrial Jarosite from Kachchh, India: A Martian Analogue

M. Singhal[1,2*], S. Mitra[3], S. Gupta[4], N. Chauhan[1] and A.K. Singhvi[1]
[1]Atomic and Molecular Physics Division, Physical Research Laboratory, Ahmedabad, 380009, India
[2] Indian Institute of Technology, Gandhinagar, Palaj, 382355, India
[3] Department of Geology Presidency University, Kolkata, 700003, India
[4]Department of Geology and Geophysics, Indian Institute of Technology, Kharagpur, 721302, India
*Corresponding author E-mail: malikasinghal97@gmail.com

Abstract

Luminescence of natural minerals is now established as an effective tool for understanding the evolution of landforms and related Earth's surface processes[1]. This is made possible due to ubiquity of natural minerals that are sensitive recorders of natural radiation, robust sample-strata correlation, relative ease of precise measurements and that the method does not need external standards for calibration. The method has also been extensively used to understand thermal and radiation history of meteorites and the radiation processes on the lunar regolith[2,3.] Considerable effort has been spent to study radiation fluxes and the properties of Martian analog rocks. Instruments for in-situ analysis of Martian rocks have also been developed[4–7].

This study reports on the luminescence based radiation dosimetry properties of terrestrial Jarosite, which is considered to be a Martian analog mineral. Its presence on the surface of Mars has been confirmed by various missions[8,9]. As jarosite precipitates under wet acidic conditions, its occurrence indicates the presence of water on Mars, in the past[10]. Thermoluminescence (TL) and optically stimulated luminescence (OSL) of six jarosite samples from Kachchh, India were analyzed for their potential for radiation dosimetry and chronometry using luminescence techniques. The samples had a broadly similar luminescence response but their sensitivities varying by two orders of magnitude.

A key factor of concern was decomposition of jarosite to yavapaiite, hematite and water on heating to 450°C and its effect on its luminescence. On heating marginal (~20-30%) change in luminescence sensitivity were seen, although the shape of glow curves remained same, suggesting that even after decomposition, the luminescing phase was largely unaffected.

Jarosite TL comprised glow peaks at 80, 150, 300 and 375°C, and on repeated heating and irradiation, the luminescence yield was reproducible to within 6%. TL emission in both blue and UV regions were seen and the saturation dose for both the emission was ~1600 Gy. Fractional glow analysis gave an activation energy of 1.35 eV for 350°C glow peak, suggesting life time of 0.3 Ma.

Blue light stimulated luminescence (BLSL) in the UV window at 200°C was also reproducible and the saturation dose was 1800 Gy. The samples satisfied criterion for single aliquot regeneration (SAR) protocol[11]. However, this BLSL did exhibit athermal fading with a “g” value of 7.6%/decade.

Jarosite also exhibited Infrared stimulated luminescence (IRSL) and the emission in the blue window was also amenable to a SAR protocol. The saturation doses of IRSL at 50°C was 1200

Gy. The athermal fading was 7.4%/decade. It is noteworthy that IR stimulation at 225°C did not exhibit any fading.

Given this, it seems reasonable to suggest the future missions to Mars that carry TL/OSL dating system for in-situ dating on the Martian surface would need to integrate systems to measure post infrared IR signals at elevated temperatures[12]. Considering the earlier studies on cosmic ray flux on the Martian surface gives a working estimate of a cosmic dose rate ~65 m Gy/a . This coupled to luminescence efficiency of alpha particles in luminescence production, and as yet estimated internal dose, we surmise an effective dose rate of ~55 -60 m Gy/a for jarosite luminescence [6]. These would imply a maximum dating limit of ~30 ka for jarosite. This is a useful time range to understand the paleoenvironment and the time scales of aeolian processes on the Mars.

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S6-03

Thenardite and Mirabilite of Hypersaline Lake, Rajasthan: Implications to Martian analogue and Astrobiology.

Preeti Kumari*, Kavish Madhan, V.J. Rajesh

Department of Earth and Space Sciences, Indian Institute of Space Science and Technology, Valiamala P.O., Thiruvananthapuram, 695547, India
*preetikumari.22@res.iist.ac.in

Advancements in technology and numerous Mars missions have unveiled a diverse array of sulfate minerals on the Martian surface, including gypsum, Kieserite, alunite, jarosite, thenardite, and mirabilite. These minerals, when found in contemporary terrestrial environments, have been shown to host a wide range of extremophiles within their crystal structures. The study focuses on the sodium sulfates group of minerals thenardite and mirabilite from the hypersaline environment of Sambhar Lake, Jaipur, Rajasthan which boasts highly saline water and where the conditions are extreme with temperatures as high as 45-49º C. The geological condition of the region, characterized by the rain-shadowed Sandmata Gneissic complex overlain by the arkose-pelite-graywacke suite of the Ajmer formation within the South Delhi fold belt, makes Sambhar Lake an ideal site for the formation of diverse evaporite deposits, encompassing sulfates, chlorides, and carbonates [1]. The lake also serves as a habitat for various extremophiles residing in the water and brine-saturated sediments in and around the hypersaline lake. Mirabilite is highly unstable mineral which transforms to thenardite by losing its water molecule during progressive evaporation. While the evaporation facilitates these two minerals to crystalize consecutively it also causes extremophilic organisms and biomolecules to get trapped within the crystal during the process. A detailed characterization of these minerals guides us in understanding the geological process for their presence, formation, and evolution. Spectrochemical characterization provided detailed information about their molecular structure and chemical composition that helped in understanding the physio-chemical environment under which a particular mineral is formed and evolved. The combination of FTIR (Fourier-transform infrared) spectroscopy, Laser Raman spectroscopy, and Hyperspectral imaging revealed the presence of thenardite closely associated with halite and polyhalite. The absorption bands near 1.79 in VNIR (Visible and Near-Infrared) spectroscopy indicated the presence of sulfate minerals, a result corroborated by FTIR spectroscopy. The absorption peaks between 3650-3100 cm^{-1}, 1575-1700 $^{cm-1}$, 1000-1300 cm^{-1} and 580-670 cm^{-1} in several samples helped us understand the transformation sequence from mirabilite to thenardite. Laser raman analysis further complemented the results confirming the presence of range of sodium sulfate minerals (mirabilite to heptahydrate to thenardite). The existence of comparable evaporitic deposits, dunes, and mud cracks in Sambhar Lake, reminiscent of those found on Mars, already makes this region a possible terrestrial Martian analogue with both mineralogical and geomorphological significance. Minerals such as mirabilite and thenardite, which have hitherto received limited attention, have demonstrated the presence of biomolecular signatures along with other groups of minerals making it important for astrobiological research as well.

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S6-04

Spectral Characterization of Red Sands from Muttom, Tamil Nadu, India: Implications to Mars

Saptarshi Lohia[1, *], V.J. Rajesh[1]
[1]Department of Earth and Space Sciences, Indian Institute of Space Science and Technology, Valiamala P.O., Thiruvananthapuram, 695547, India
*Corresponding author E-mail: saptarshilohia@gmail.com

Mars, the farthest terrestrial planet from the Sun, has garnered significant research interest in recent years. This is primarily because it boasts substantial evidence suggesting the existence of early life and the occurrence of fluvial flows in its past. Exploring the genetic mechanisms of iron oxide-rich sand and dust on the Martian surface necessitates the search for terrestrial counterparts, therefore, this study. The study area is located in Muttom (Teri sands), a dune complex rich in iron-bearing minerals peculiar to some parts in southeastern region of Tamil Nadu. Numerous sedimentary features such as gullies, channels, polygonal mud cracks, erosion pits, and dunes were found in the Muttom region, resembling those seen on the Martian terrain.[1] The primary aim is to characterize Muttom red sands using sophisticated spectral techniques and thus draw comparative studies with the Martian regolith (red soil) which can be used for future studies and martian missions.

Initially, the samples were subject to hyperspectral spectrometer, which functions in the 350-2500 nm band and is observed for noticeable absorption bands. Absorption bands at wavelengths of 550 nm, 650 nm, and 890 nm indicate the characteristic features of hematite and goethite. Additionally, absorption bands observed at 1450 nm (in the form of a doublet), 1900 nm, and 2200 nm (in the form of a doublet) can be attributed to the existence of molecular to surficial water within the samples. Moreover, the absorption band at 2350 nm signifies the presence of altered Iron hydroxide phases, such as goethite, within the sample. Additionally, Raman laser spectroscopic studies confirmed the presence of the minerals found in the initial spectroscopic studies, which yielded goethite, hematite, quartz, and ilmenite.[2] XRD and FTIR (Fourier Transform InfraRed) spectroscopic analysis were also done for the samples, which again gave Quartz, Goethite, Hematite, Ilmenite and also Rutile. Finally, all the data is being compared with the spectral data of martian soil recorded by the rovers and orbiters, to assess its compatibility. Geomorphological features like gullies and polygonal mud cracks have also been observed on mars same as found in the study area. Additionally, spectral analysis for these samples shows the signature of minerals like the ones present on Mars, making this region one of the probable martian terrestrial analogue sites.

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S6-05

3D printing of Martian and Lunar analogue rocks

Hariharan P.K.[1], Bhalamurugan Sivaraman[2], Vijayan Sivaprahasam[2], Vijay Thiruvenkatam[3], Vinoth Srinivasan[4], Thirukumaran Venugopal[1]
1 Government Arts College (Autonomous), Salem-636007, Tamil Nadu
2 Physical Research Laboratory, Ahamadabad, Gujarat
3 IIT Gandhinagar, Gujarat
4 NIT, Surathkal, Karnataka
e-mail: mailkumaran75@gmail.com

Abstract

The near-future colonisation of Mars and the Moon warrants suitable construction materials to be prearranged. Selecting appropriate and readily available rocks, as well as obtaining a cementing medium to make the rocks feasible for 3D printing, provide obstacles that must be overcome before preparing for Martian and Lunar surface colonisation. Olivine, a mineral of significant presence, is widely distributed across the planetary surface of Mars. However, it is noteworthy that Nili Fossae, a region encompassing Noachian-aged rocks, exhibits particularly prominent accumulations of this material. A notable occurrence of a substantial olivine-rich outcrop can be observed in Ganges Chasma, which is situated on the eastern side of Valles Marineris (Linda M.V. Martel 2007). Calcium or iron carbonates were identified within a crater situated on the rim of Huygens Crater, which is situated in the Iapygia quadrangle. The excavation of material resulting from the impact event that formed Huygens has led to the exposure of rim materials (NASA JPL 2011). The calcium carbonate may be used as a raw material for cement. The terrestrial analogue of the olivine mineral is collected from the ultramafic complex of Chalk Hills, Salem, Tamil Nadu. The monomineralic rock Dunite is pulverised in a jaw crusher and sieved using a mechanical sieve shaker. Two different types of cement are intended for making cubical blocks of 4 cm in size. Pulverised sedimentary Marly lime stones were collected from sedimentary deposits in Ariyalur district, Tamil Nadu, which may be an analogue of the sedimentary sequence reported from Gale crater. The pulverised and sieved fractions are mixed in equal proportions to use it as cement. Heated marly lime stones (calcined lime) resembling a possible cement we can prepare from CaCO3 under the effects of an ionising radiation dose at a minimum power of absorbed radiation equal to 0.5 Mrad/s (United States Paten 3,940,324) The calcined lime is used as the binding material of olivine for making 4 cm3 blocks. The blocks are made with olivine (dunite) and limestone powder in five different proportions ranging from 50:50 to 90:10. Similar proportions are maintained for the olivine and calcined lime mixtures. But the due to colloidal nature of calcined lime clay like observed when mixed with water. Eventually shrinkage cracks appeared during curing process. So, the proportions are changed and ranging from 75:25 to 95:05.

With the possibility of microbial-induced calcite precipitation (Rashmi Dikshit et al., 2021), taking up a limestone medium as a binder for Lunar soil will enhance the possibility of building a robust structure. Lunar analogue soil is made from the anorthosite rocks from the Sittampundi anorthosite complex, located in South India (Venugopal et al., 2020). The anorthosite is pulverised and sieved using a mechanical sieve shaker. Eleven different size fractions are separated, viz., ASTM 230+, ASTM 230, ASTM 180, etc. The different size fractions are taken in equal proportions and thoroughly mixed with marly limestone powder in different ratios, like 50:50 to 90:10. Similarly anorthosites are mixed with calcined lime in the ratio ranging from 75:25 to 95:05.

After 14 days of curing and drying under nominal atmospheric conditions, the blocks will be treated in liquid nitrogen and Thermovac lab to simulate temperature and pressure variations in space before being tested for engineering properties.

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P-04

Rann of Kutch a potential Astrobiological Analogue for Mars

Kanak Sharma, J.G. Gokula Krishnan, Gourisankar Sahoo, Kimi KB, Anil Chavan,
Bhalamurugan S, and Vijayan S
Kanakpvt.astropaleo@gmail.com and vijayan@prl.res.in

The survival capabilities of primitive life on Mars are of profound interest in astrobiology research, seeking to unravel the potential habitability and resilience of microorganisms in extreme Martian conditions **[1]**. Extensive literature has documented microorganism's ability to endure high salt concentrations in various analogues, providing essential insights into their potential survival mechanisms in Martian-like conditions **[2][3]**.

The Martian surface is characterized by high salinity, particularly sodium chloride (NaCl), making it crucial to understand how microorganisms adapt to and withstand such extreme environments. Through controlled experiments simulating Martian parameters **[4] [5]**, this study will investigate the response of microorganisms from the Rann of Kutch to high salt concentrations, shedding light on their resilience and potential survival strategies in Martian environments **[6]**. Apart from saline conditions, the Martian regolith is known to contain a maximum of 0.5% (w/v) perchlorate (ClO_4^-) **[7]** that is toxic for most living organisms. In such case if any biological events tend to occur on Mars, it has to be perchlorate resistant **[8] [9]**.

To understand and find life supporting biosignatures on Mars, its important to study microorganisms that generate chemical biosignatures in environments characterized by extreme conditions as in Rann of Kutch. This study will employ a comparative analogue approach, focusing on the survivability of microorganisms **[10] [11]** found in the Rann of Kutch, under simulated Martian conditions **[12] [13]**. This study also aims to search and understand perchlorate resistant microorganisms from Rann of Kutch.

Keywords: Mars, astrobiology, analogue study, Rann of Kutch, extreme environments, survival capabilities, microorganisms, salt tolerance, perchlorate, Martian surface, simulated conditions.

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Physical Research Laboratory
MetMeSS-2023

3rd November, Friday

Session- VII: Meteorites and Returned Sample
Session Chair: Dr. Arindam Dutta and Dr. Neeraj Srivastava

Abstract#	Time	Speaker	Title	Affiliation
Invited	9:30 – 9:50	ARINDAM DUTTA	Meteorite field studies, collection and characterization at GSI	GSI, Kolkata
S7-01	9:50 - 10:05	Anil Shukla	Overview of New meteorites study	PRL, Ahmedabad
S7-02	10:05 – 10:15	Dipak Panda	National Curation facility at PRL	PRL, Ahmedabad
S7-03	10:15 - 10:25	Neeraj Srivastava	Reflectance spectroscopy of Diyodar meteorite	PRL, Ahmedabad
S7-04	10:25 - 10:35	Swarna Prava Das	Peak Metamorphic Temperature of CI/CM-type clasts, CM and CV chondrites	NISER, Bhubaneswar
S7-05	10:35 - 10:45	Subhasmita Swain	Correlating cosmic ray track density and exposure ages of chromite grains from regolith breccia meteorites	NISER, Bhubaneswar
S7-06	10:45 -10:55	Ramakant Mahajan	Future Sample return mission	PRL, Ahmedabad
S7-07	10:55 - 11::05	Abhishek Verma	Planetary Core Drilling technique	PRL, Ahmedabad

S7-03

Reflectance spectroscopy of Diyodar meteorite

Neeraj Srivastava, Neha Panwar, Abhishek J. Verma, Ramakant R. Mahajan
PRSS, PSDN, Physical Research Laboratory (PRL), Ahmedabad
Email: sneeraj@prl.res.in

Reflectance spectroscopy is a quick and non-destructive tool to classify meteorites on the basis study of light scattered from their surface. Here, we have carried out reflectance spectroscopy of Diyodar meteorite, which fell in the Banaskantha district, Gujarat, India on 17th August, 2022. The reflectance spectra of a hand specimen of bulk sample of Diyodar meteorite were acquired in Planetary Remote Sensing Laboratory, PRL Thaltej Campus, Ahmedabad using ASD FieldSpec 4-Hires spectroradiometer over the wavelength range of 350–2500 nm. The measurements were made at a 0° phase angle and the calibration was done relative to a Spectralon white reference target. The reflectance spectra of the Diyodar meteorite specimen exhibit two broad absorption bands centred at ~930 nm and ~1900 nm, implying the dominant presence of orthopyroxene, possibly enstatite, in the meteorite sample. The absorption bands are shallow and show a blue slope beyond 1000 nm, indicating that the meteorite is an enstatite achondrite. Further, the spectral characteristics indicate that the Diyodar specimen belong to Xe-type meteorites. The spectra of Diyodar meteorite is also unique compared to the spectra of some of the typical aubrites such as Norton County, Shallowater, Aubres, Mayo Belwa, and Khor Temiki. A comparatively prominent 1000 and 2000 nm absorption bands indicate relative enrichment of iron in the Mg-pyroxene of Diyodar specimen compared to the other aubrites.

S7-04

Peak Metamorphic Temperature of CI/CM-type clasts, CM and CV chondrites

Swarna Prava Das[1]*, Priyadarshi Chowdhury[1], Dipak Kumar Panda[2], Markus Patzek[3], Surya Snata Rout[1], Guneshwar Thangjam[1]

[1]School of Earth and Planetary Sciences, NISER, HBNI, Bhubaneswar-752050, India
[2]Planetary Science Division, Physical Research Laboratory, Navrangpura, Ahmedabad, India
[3]Institute of Planetology, University Muenster, Muenster, Germany

*swarnaprava.das@niser.ac.in

Introduction:

Carbonaceous chondrites, a class of primitive meteorites, exhibit complex mineralogical transformations due to brecciation, aqueous alteration, and thermal metamorphism [1]. These processes, particularly thermal metamorphism, significantly impact the mineral composition and provide valuable insights into the early evolution of the parent asteroid of the meteorites [2]. To comprehend the thermal history of their parent asteroids, it is essential to determine the peak metamorphic temperatures (PMT), which is the highest temperature reached during metamorphism in the parent asteroid. To distinguish between traits that predate and postdate the accretion of their parent celestial bodies, precise quantification of the thermal history of meteorites is necessary. While earlier research used Raman spectroscopy to examine the organic materials in meteorites and calculate PMT, there are some inconsistencies in calculated temperature when compared to other methods [3,4,5]. In this study, we determine PMT of CV, CM and CI/CM-like clasts in HED meteorites from the Raman signature of organic matter and correlate it with the temperature determined from diffusion profiles of Fe-Mg within olivine and pyroxene grains.

Samples and Methods:

We used polished thin sections of different meteorites: Allende (CV3), Vigarano (CV3), Murchison (CM2), Jbilet Winselwan (CM2), Aguas Zarcas (CM2), NWA 7542 (Polymict Eucrite) and Saricicek (Howardite). A Raman spectrometer (LabRAM HR Evolution, Horiba Scientific) is used with an excitation wavelength of 532 nm, laser energy of <1mW. With the aid of 4-pseudo-Voigt/2-Lorentzian profiles and a linear baseline correction, we examined the peak center positions and full-width half-maximum (FWHM) of each Raman band. We used three different equations as mentioned in three different studies to calculate PMT [3,4,5]. We used the CM chondrite Murchison, as investigated by an earlier study [6], as a standard reference for cross-laboratory calibration and to confirm the accuracy of our peak fitting method.

Result and Discussions:

The calculated temperature using the approaches shows large variations for NWA 7542 like <140 ^{0}C by [3] approach while >220 ^{0}C by [4] approach. The three approaches use Raman signature of insoluble organic matter separated from different meteorites to establish the equation for calculating PMT. Our result show that it is uncertain to know which method can be used to accurately measure PMT of any meteorite directly from Raman signatures of organics in polished thin sections. However, to select the right equation for calculating PMT another geothermometer needs to be used. Many of the studied meteorites (e.g., Allende, CM-clasts) have olivine fragments in the matrix and chondrules which show zonation in Fe. The interdiffusion of Fe-Mg in these olivine grains will be used as a geothermometer to calculate PMT and then compare it with the PMT calculated from Raman signature of the organic matter.

Conclusions:

We calculated PMT of different CV, CM and CI/CM-like clasts in HED meteorites using three previously established approaches. The calculated temperature shows large variations. In order to select the right method to calculate PMT the interdiffusion of Fe-Mg in zoned olivine crystals will be used as a complementary approach.

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S7-05

Correlating cosmic ray track density and exposure ages of chromite grains from regolith breccia meteorites

Subhasmita Swain[1*], Dipak Kumar Panda[2], Ramakant Mahajan[2], Birger Schmitz[3], Surya Snata Rout[1]
[1]School of Earth & Planetary Sciences, NISER, HBNI, 752050-Odisha, India
[2]Planetary Science Division, PRL, Navrangpura, 380009 Ahmedabad, India
[3]Astrogeobiology Laboratory, Lund University, Sweden
*subhasmita.swain@niser.ac.in

Introduction: Chromite is a minor component in many meteorites (0.05-0.5 wt%) but they are resistant to weathering and can be found as relict phases in fossil meteorites and micrometeorites [1]. Some of these sediment dispersed extraterrestrial chromite (SEC) grains contain inclusions of silicate minerals [2] and can preserve cosmic ray tracks if the whole SEC grain was exposed to solar wind/cosmic rays. Studying the cosmic ray track density within these silicate mineral inclusions is useful in understanding the variation in cosmic ray flux over time. In this study the SEC grains extracted from sediments of different time periods will be used for reconstructing the variation in the flux of cosmic rays in the last 500 Myrs. The size of the silicate inclusions generally ranges from <1 to 15 µm. To find these inclusions and understand their distribution we used X-ray tomography of micrometeorites from Antarctica.

As a preliminary proof of concept study we have taken the L5 ordinary chondrite regolith breccia, Ghubara, for which noble gas concentration is available [3]. The studied Ghubara sample has two types of clasts: light and dark clasts with difference in cosmic ray exposure age [3]. Here, we are studying chromite grains with silicate inclusions from the two clasts to look for correlation between their cosmic ray exposure history and density of cosmic ray tracks (CRT).

Samples & Methods: Micrometeorites (MMs) bearing sediment were provided by Vrije Universiteit Brussel (Brussels, Belgium). It was collected at Walnumfjellet (~2450 meter above sea level; S72˚ 07.188’, E24˚ 12.525’) located in the Sør Rondane Mountains within Dronning Maud Land of East Antarctica. MMs were magnetically separated and then hand picked under an optical microscope. Some of the MMs (40) were studied using the micro-CT facility at NTNU, Trondheim (2 micron voxel size, 54 µA tube current, 130 kV voltage). A portion of these micrometeorite samples were dissolved in 40% HF to separate chromite grains. Scanning electron microscopy - energy dispersive spectroscopy (SEM-EDX) elemental analysis was done to identify the extraterrestrial chromites. The grains were mounted in epoxy and polished to search for the silicate inclusions.

A part of the Ghubara meteorite (dark clast) was dissolved in 40% HF and subsequently with 68% HNO_3 to obtain chromite grains. Chromite grains were embedded in epoxy and then searched for the silicate inclusions using optical microscope & SEM-EDX.

Results and Discussion: The X-ray tomographic images show different types of MMs: cryptocrystalline, scoriaceous, and I-type spherules rich in Fe. We did not find any chromite grains within the studied MMs. With the dissolution technique we found 11 chromite grains in 2 kg sediment samples. The elemental composition of the chromite grains are: Cr2O3 ~ 32-60 wt%, FeO ~ 26-35 wt%, Al2O3 ~ 1-29 wt %, MgO ~ 0.6-8.5 wt%, V2O3 ~ 0.2- 0.5 wt%, TiO2 ~ 0.4-2.8 wt%. None of the chromite grains contain inclusions.

In the Ghubara meteorite cosmic ray tracks are found in very few silicate grains. Between the lighter and darker clast there is a difference in CRT density: ~ 3.6×10^4 cm^{-2} for light clast, 3.7×10^5 cm^{-2} for darker clast. The dissolved chromite grains are being searched for presence of silicate mineral inclusions. The CRT density within the silicate inclusions from the two clasts will then be compared.

Conclusions: Chromite grains are rare in the studied Antarctic MMs and more samples need to be studied to find them. In addition, finding silicate mineral inclusions within the chromite grains is also challenging. Difference in cosmic ray track density within the two studied clasts from Ghubara shows a difference in exposure history. Any chromite grains within mineral inclusions should also show variation in cosmic ray track density, if present in the top 1-2 m of the regolith of its parent asteroid.

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S7-07

Automated Core Drilling for future in-situ analysis and sample return missions from planetary bodies

Abhishek J. Verma, Neeraj Srivastava, Nirbhay K. Upadhyay, Ramakant R. Mahajan, K. Durga Prasad, M. Shanmugham, Sanjay Mishra, Varun Sheel, Anil Bhardwaj
Planetary Sciences Division,
Physical Research Laboratory, Ahmedabad

As a follow-up to the landmark Moon landing, roving and lander hop-up exercise during the Chandrayan-3 mission, it is logical to say that the next step in the ISRO's lunar exploration programme will be a sample acquisition and return mission. In fact, rover/lander based in-situ missions and sample return missions are imperative in the next few decades to further our understanding of the formation and evolution of our solar system. The key to the success of these futuristic endeavours largely depends upon our ability to robotically acquire desired rock and soil samples from planetary surfaces and sub-surfaces under a gamut of challenging environments. These include acquiring and processing samples under low gravity (Moon, comet, and asteroids), low pressure (6 millibar on Mars to UHV on the Moon), and temperature as low as ~100 K in the lunar permanently shadowed regions (PSRs). Among the several technological developments required to achieve the aforesaid endeavour, development of an automated core drilling system is the most challenging but scientifically fruitful.

In this presentation, we provide an account of the scientific objectives, international scenario, requirements for design and development, criticalities and challenges involved, and a possible option for design of a drilling system acquiring powdered samples from the Moon for future in-situ sampling and sample return mission of ISRO .

P-05

Mineralogical Studies of Calcium-Aluminum Inclusion in Mukundpura (CM2) Chondrite

Anjana Shaju[1 *], Dipak Kumar Panda[2]
[1]Indian Institute of Science Education and Research, Mohali
[2]Planetary Science Division, Physical Research Laboratory, Ahmedabad
*ms20181@iisermohali.ac.in

Introduction: The refractory inclusions (Calcium- Aluminum inclusions (CAI) and Amoeboid Olivine Aggregates (AOA)) are commonly observed in carbonaceous type meteorites. The CAIs that are found in the CM chondrites are of smaller in size (mostly less than 0.5 mm). In case of the unaltered CAIs found in these types of chondrites, the central region mostly consists of spinel and melilite while the Wark- Lovering rims contain Aluminous diopside and anorthosites. But in altered CAIs, these inclusions are porous aggregates and the secondary mineralization results in the formation of hydrous phases [1]. This study aims to understand the aqueous alteration of CAIs by the mineralogical studies of Mukundpura (CM2) chondrite.

Methodology: In this study, we used one polished thick section of Mukundpura sample. The Back Scattered Electron (BSE) images and the quantitative chemical composition of the sample was obtained using Electron Probe Micro Analyser (model CAMECA SX 100) with three Wavelength Dispersive Spectrometers (WDS). The elemental composition maps (Ca, Mg and Al) of the whole area of CAI were also obtained using their respective X-ray images.

Results: From the backscattered images, we can observe that the CAI present in the Mukundpura (CM2) sample is subcircular with a few dark patches in the interior region and the rim can be nearly identified separately. Analysis of the chemical composition of the CAI shows the presence of few unaltered spinel ($MgAl_2O_4$) in the interior regions. This region also has patches consisting of Mg and Al (Al_2O_3 around 13 %) along with Si, Fe and S (SiO_2 around 29 wt%, FeO~ 16.7 wt% and S up to 3 wt%). These patches are be thought to contain the partially altered products from spinel. Calcite which is a secondary phase is also found in the interior region. Towards the rim region contains the Al, Ti- rich pyroxenes with FeO content upto 6.7 wt%. The matrix region immediately outside the CAI consists of phyllosilicates such as Fe- serpentines and cronstedite.

Discussion: This CAI under study can be interpreted as a spinel- pyroxene inclusion since the subcircular core which consists mostly of spinel is rimmed by the layer of diopside [2]. The dark patches mostly consist of unaltered spinel, and some partially altered form of spinel where the Al is thought to be progressively replaced by Si, Fe and S. This indicates the process of secondary mineralization. The calcite, which are present almost near to the rim region of the inclusion, is a product of aqueous alteration of the parent body where this carbonate phase is precipitated from the fluid phase [3]. These calcites might have formed either from high-calcium pyroxene or melilite. The phyllosilicates present in the matrix region immediately outside the rim can be interpreted to be the products of the aqueous alteration of the parent body [2]. By focusing on the aqueous alterations within the Calcium- Aluminum inclusions, we seek to understand the processes that occurred during the early stages of the solar system's history.

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P-06

Neutron and X-ray tomography of three CM chondrites

Anusha G[1], Richi Kumar[2], Surya Snata Rout[3]
[1]Madras Christian College-East Tambaram, Chennai-600059
[2]Helmholtz-Zentrum Hereon, Geesthacht, Germany
[3]School of Earth and Planetary Sciences, NISER Bhubaneswar, Jatani, Khorda, 752050-Odisha
*anushaanu16902@gmail.com

Introduction:CM chondrites are a type of carbonaceous meteorite characterized by their high carbon content and rich organic material. The components that are primarily present in a CM chondrite are chondrules, matrix with abundant aqueously altered minerals (e.g. Tochilinite, cronstedite, serpentine), Fe-oxide, and tochilinite-cronstedite intergrowths (TCIs) [1].Although various studies have provided a detailed understanding of the aqueous alteration process in CM chondrites and its evolution, there are several open questions: (a)what is the macroscale distribution and nature of aqueous alteration in 3D? (b) How does shock affects the meteorite in 3D? (c) What were the physical conditions in the region of the proto solar nebula where the CM chondrite parent body accreted? Neutron and X-ray tomography (NXCT) are nondestructive techniques and can help in answering the above questions by providing a three-dimensional view of the meteorites' interior [2,3,4]. They are complementary techniques: Attenuation of X-rays is proportional to atomic number (Z) but neutrons are strongly attenuated by H, Cl, Fe and Ni. Here, we are studying three CM chondrites using NXCT to understand the 3D distribution of aqueous alteration phases.

Samples and Methods: The study examines three meteorites: Murchison, Mighei, and Acfer 331.Samples were imaged using thermal neutron tomography at the NEUTRA instrument at PSI.A ikon-L camera with Gadox scintillator, and a pixel size of 32 µm was used for imaging. Additionally, X-ray tomography was also done using the XTRA opetion at NEUTRA using a 320kV source and the same detectors.
The samples were placed together on the sample stage and three set of 626 projections were acquired by rotating samples 360º with an exposure time of 30 seconds, 30 open beam (radiograph without sample) and 30 dark images (radiograph without neutron beam) were also acquired with the same exposure time.
The XCT and NCT datasets of different meteorites under study are imported to dragonfly software, this software provides 3D and three orthogonal views (X, Y, Z) with the dataset voxels having different values in a grayscale. Datasets can be visualized as a series of 2D images(slices) that can be loaded and 'stacked' into a 3D volume. And through different visualization techniques like is surfacing and volume rendering the chondrules can be manually segmented. Different ROIs are also used to define chondrules in the 3D view. Segmentation data is exported into the Blob3D software and chondrule size is measured. Blob3D provides a rich set of object-based measurements including size, shape, surface area.

Results and Discussions: Different components in the 3 meteorites can be resolved using the NXCT data. Chondrules appear dark in both XCT and NCT images but the level of darkness is high in the latter due to the low interaction cross section of neutrons compared to X-rays for Mg, Si and O. Fe, Ni-metal and Fe-sulphide appear bright in both the images. Some chondrules/fragments appear bright in XCT but dark in NCT images. This phase should be rich in high Z elements and the most likely phase is Fe-rich phyllosilicates. However, Fe-rich phyllosilicates should also be bright in NCT image. The identity of such phases needs to be verified by a detailed elemental mapping and phase characterization using a scanning electron microscope - energy dispersive spectroscopy or by electron microprobe. Rims around chondrules in Murchison and other two meteorites are poor in phyllosilicates and TCIs. In NCT the rims therefore look darker than the matrix which is rich in water hearing phases.

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P-07

Neon composition Study in bulk Carbonaceous Chondrites

Shehzade M K[1,*], Ramakant R Mahajan[2]
[1] National Institute of Science Education and Research Bhubaneswar P.O. Jatni, Khurda 752050, Odisha, India
[2]Planetary Sciences Division, Physical Research Laboratory, Ahmedabad, Gujarat, India, 380009
* Corresponding author: Email: manzoor.khan@niser.ac.in

Carbonaceous chondrites are one of the most primitive and unaltered meteorites in the solar system [1]. As noble gases are rare in meteorites, we can distinguish different noble gas components. The study of noble gases can help understand the evolution of meteorite and their parent bodies. [2]. Because they are volatile and unreactive, they did not entirely condense in even the most primordial meteorites and are thus even prevalent on the Sun [3]. In this work we collected data from various literature for carbonaceous chondrites and plotted the neon three-isotope diagram of $^{20}Ne/^{22}Ne$ versus $^{21}Ne/^{22}Ne$ and calculated the trapped ^{20}Ne component for different type of carbonaceous chondrites. In the neon 3 isotope plot we plot the various end member components, Solar Wind (SW), Ne Q and HL which have specific signatures [4]. From the calculation of trapped component it can be seen that CM have large amount of trapped gases, this may be due to the fact that most CM chondrites have high regolith component and are regolith breccias[5].Most regolith breccias are rich in solar-wind gases.CV chondrites show regolith breccias and the high amount of trapped gases may be due impact related mixing [6].From the Neon 3 isotope plot it can be seen there is domination of GCR due to its higher penetration depth. In Neon isotope plot for CI chondrites. we can see a clustering near NeQ, and HL components. In Neon 3 isotope plot CI chondrites shows isotopic signatures for planetesimal trapped noble gases. HL component is of presolar origin suggesting presence of presolar noble gases in CI chondrites.CV chondrites show signature of both GCR and SCR. The study of noble gases can shed more light on the solar nebula and the formation of the solar system as well as the nucleosynthesis process.

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Type of Carbonaceous meteorite	Trapped Ne component	^{20}Ne trapped x 10^{-8} cm3STP/g		
		Maximum	Minimum	Average
CM	Ne Q	3107.54	0.828	111.997
	SW	3109.55	0.586	130.797
CV	Ne Q	11001	0.354	216.023
	SW	11004.3	0.355	216.093
CR	Ne Q	212.599	0.686	35.087
	SW	3.294	0.392	2.23
CO	NeQ	21.451	0.733	6.451
CL	Ne Q	2.618	1.851	2.284
CI	Ne Q	1105.06	3.556	55.682
CK	Ne Q	30.237	0.0971	1.9

P-08

Collisional History of parent bodies of Ordinary Chondrites using Cosmic-Ray Exposure (CRE) Ages

Avadh Kumar[1*], R. R. Mahajan[1]
[1]Physical Research Laboratory, Ahmedabad, India-380009
*Corresponding author E-mail: avadh@prl.res.in
Keywords: Neon Isotopic study, Meteorites, Ordinary chondrites, CRE ages

Abstract: Meteorites are pieces of rock and metal, which are segment came from asteroids due to various impacts and collisions. Meteorites are important because meteorites are the only physical materials available on Earth that give direct access to the earliest material formed in the Solar system. Meteorites are of two type *Achondrites* and *Chondrites*. Chondrites are the largest class of available meteorites, almost 86% are chondrites, and rest are achondrites [1, 2]. Further chondrites can be divided into three (carbonaceous, ordinary and Enstatite) subgroups.

Ordinary chondrites can be subdivided into three groups based on its chemical composition [3]. H group (high iron content, 28%), L group (low iron content, 22%), and LL group (low iron content, low metallic iron).

In this work, we have collected as much as possible Neon gas isotopic data from the published work of literature [5]. This work may conclude to understand the parent body history of different ordinary chondrites and the major trapped component of noble gas (Ne) in it. We also calculated CRE ages for H, L and LL group chondrites. After compiling abundance of all stable isotopes of Neon gas from published literature of ordinary chondrites. We calculated the CRE age of these meteorites based on Neon abundance. We discuss about meteoroid ejection from its parent asteroid body. [6]

Significance of CRE ages:

The scientific significance of CRE ages of meteorites in advancing our understanding of the solar system. Its contributions to unraveling the chronology and dynamic processes in the solar system. Cosmic rays, predominantly high-energy particles from outer space, constantly bombard the surfaces of celestial bodies, including meteoroids and asteroids. [7]

Results and Conclusion:

Chronology of Events- By determining the cosmic ray exposure ages of meteorites, we can establish a chronology of events in parent asteroid body. The CRE ages of different meteorites provide insights into the timing and duration of various processes, such as asteroid fragmentation, collisional evolution, and transport in the solar system. [8]

Regolith Evolution of Asteroids- Study of the CRE age of meteorites can help in understanding the regolith evolution of asteroids.

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P-10

Understanding building blocks of terrestrial planets: A case for Asteroid sample Return

G. Srinivasan[1,*], R. Mahajan[2], N. Bhandari[3]
[1]Centre for Space Sciences and Earth Habitability, E5-11 Arera Colony, Bhopal
[2]Physical Research Laboratory, Ahmedabad 380009
[3]Science and Spirituality Research Institute, Navrangpura, Ahmedabad 380009.
*gopalan.srinivasan@gmail.com

Introduction: The remnants of precursors bodies that formed the terrestrial planets and cores of giant planets have survived as planetesimals/asteroids in the asteroid belt [1,2]. Some of these asteroids have escaped major post-accretion alteration, aqueous or thermal, and preserve their pristine characteristics. Others have experienced intermediate levels of alteration or chemical differentiations, erasing original signatures. The primitive asteroids also carry organic molecules and volatiles, including water, perhaps the two most important ingredients for origin of life. The physical and chemical properties are also modified by collisions and sometimes bodies are reaggregated from diverse mixtures, a case in point is asteroid TC3 [3].

Fragments of asteroids delivered to the Earth by natural processes represent an extremely diverse suite of extraterrestrial samples. Meteorites collected from various locations around the world, particularly the finds from the hot and cold deserts [e.g., 4]. have significantly augmented the collections in the last forty years. These have yielded important information about the formation and evolution of these rocks and the. environment in which they formed [e.g., 5]. In addition, the collection of smaller samples like IDPs and micrometeorites from stratosphere, polar regions and deep oceans [6-9], have enhanced our understanding of solar system formation and evolution, although their place of origin remains unknown. A missing link in meteorite analyses is the lack of definitive identification of meteorite to a specific asteroid. This missing part of the puzzle compromises the understanding of asteroids.

A significant advancement in planetary sciences was achieved through the success of lunar samples from Apollo and Luna Missions in the 70s [10] and recently the China's Chang'E 5 mission [11]. Small quantities of samples have been returned from asteroid (25143) Itokawa [12], C class asteroids (162173) Ryugu [13] using space craft Hayabusa, and samples are anticipated shortly from (101955) Bennu using OSIRIS Rex spacecraft [14]. Comet particles from Stardust mission to comet 81P/Wild (Wild 2) [e.g., 15] and solar wind particles have been returned using Genesis mission [16]. Asteroid Itokawa, an S type asteroid, is more like an ordinary chondrite, while Ryugu and Bennu resemble C-complex type asteroids that have low albedos with absorption features indicative of hydrated silicates, generally associated with carbonaceous chondrites. Missions in the past like NEAR Shoemaker flyby to asteroid Mathilde [17] and then EROS [e.g., 18], and more recent fly-by missions of asteroid 2867 Steins (E-type asteroid) by the ESA's Rosetta spacecraft [19] have given insight into their physical and chemical properties.

The asteroid flybys, rendezvous and sample return missions have provided us with valuable understanding of planetary formation and evolution and their compositions. For example, magma ocean on Moon [20], and more recently the constraint on the volatile content of Moon [21], and the high H ion implantation on lunar soils from North Eastern Oceanus Porcellarum returned by Chang'E-5 [22]; mixing of innermost and peripheral regions of solar nebula were deciphered from Stardust return samples [23]; ordinary chondrite composition of S-type asteroid was determined from asteroid Itokawa samples [24]; and the extremely 16-Oxygen rich composition of the Sun was determined from Genesis solar wind samples [25]. The returned samples from asteroid Ryugu have a composition similar to CI Ivuna [26]. The samples consist predominantly of minerals which appear to be products of aqueous alteration on the parent body occurringat low temperatures (<50^{o}C). Based on ^{53}Mn-^{53}Cr studies these alterations appear to have taken place with in ~ 5 My of the formation of solar system [26]. The investigation of O, Ti and Cr isotopes [26] show that Ryugu samples originated from the same reservoir as CC group of meteorites.

Notwithstanding all the progress made through remote sensing studies and return samples from asteroids and meteorite and related studies of extra-terrestrial samples our understanding is limited only to surface characteristics and almost none about an asteroid's deep interior. Further, surface of airless bodies in space are subject to space weathering which changes their properties. To have a better understanding of asteroids we need to study a body in space and its sample in more detail in laboratory. Situations like that of meteorite Almahata Sitta and asteroid TC3 [3] are rare and have also shown the unexpected and unusual mixture of both NC and CC type of meteorite types in the asteroid body [27-28].

The primary aim of asteroid research apart from understanding their formation and evolution is to connect them with the chemical composition of terrestrial planets, in particular with volatiles and organics. The anticipated outcome of such connection between asteroids, meteorites and terrestrial planet will enable us to get some clues about origin of life. Given the success of GSLV launch vehicle and the Chandrayaan 3 module ISRO could consider the possibility of a sample return mission from NEAs, e.g., E type which is considered as an Earth analog and return pristine samples after studying its surface features with various remote sensing techniques such as optical and gamma spectrometry. We suggest potential sample asteroids for investigations and return sample.

Table: Potential asteroids for sample return (list not exhaustive)

Name	NEO#	q (AU)	Q (AU)	a (AU)	Tholen/ SMASSII*	diameter (km)	Analog (planet/ met)
3103 Eger	Apollo	0.90	1.9	1.4	E/Xe	1.5	Earth/ Enstatite
1862 Apollo	Apollo	0.64	2.29	1.47	Q/Q	1.5	L/LL/H
1981 Midas	Apollo	0.62	2.93	1.77	-/V	3.4	Vesta/HED
2100 RaShalom	Aten	0.46	1.19	0.83	C/Xc	2.3	carbonaceous
3552DonQuixote	Amor	1.2	7.2	4.2	D/D	19	Jupiter Trojan/

							Tagish Lake
Data from Solar System Dynamics Website hosted by JPL (small bodies data base lookup)							

Classification [29] [; q (perihelion); Q (aphelion); a (semimajor axis) (* Spectral Class [30,31])

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Physical Research Laboratory
MetMeSS-2023

3rd November, Friday

Session- VIII: Meteors, Dust, Comet
Session Chair: Prof Varun Sheel and Dr. Yogita Kadlag

Abstract#	Time	Speaker	Title	Affiliation
Invited	11:30 - 11:50	N. G. Rudraswami	Cosmic dust from sky	PRL, Ahmedabad
S8-01	11:50 - 12:00	M. Pandey	Geochemical appraisal of unmelted micrometeorites collected from Maitri Station Antarctica	Nio, Goa
S8-02	12:00 – 12:10	Goldy Ahuja	Monitoring of a long-period comet C/2020 V2 (ZTF) from Indian telescopes	PRL, Ahmedabad
S8-03	12:10 - 12:20	Sreekuttan S.	Deep sea: Largest repository of extraterrestrial dust	NIO, Goa
S8-04	12:20 – 12:30	V. P. Singh	Control of precursor composition and atmospheric entry on the texture of micrometeorites	PRL, Ahmedabad
S8-05	12:30-12:40	Balaji Prasath S	CSTERC Meteor Activity Monitoring System: Raspberry Pi Built 720px Low-Light Camera	Open Space Foundation, Tamilnadu.
S8-06	12:40-12:50	Kanak Patel	A Novel Approach to Meteoroid and Meteorite Detection and Recovery for Planetary Exploration	Ddu, Nadia

S8-01

Geochemical appraisal of unmelted micrometeorites collected from Maitri Station Antarctica

M. Pandey [1,2*] and N.G Rudraswami[1]

[1]National Institute of Oceanography (Council of Scientific and Industrial Research),

Dona Paula, Goa 403004, India

[2]School of Earth, Ocean and Atmospheric Sciences, Goa University, Taleigao Plateau,

Goa 403 206, India

*Corresponding author E-mail: mayank.pandeybhu@gmail.com

A significant portion of extraterrestrial material that is received by the Earth comes in the form of dust generated by collision in asteroidal belt and sublimation of comets and represents a wide range of precursors in contrast to the known meteorites [1]. The incoming dust fraction suffers severe heating during entering into the terrestrial atmosphere resulting into textural as well as chemical alteration. Extant of heating depends upon several parameters such as entry velocity, entry angle and particle size [2]. In contrast to melted micrometeorites known as cosmic spherules, unmelted ones preserve their original nature and experiences minimal alteration. Their original chemistry remains largely preserved, making it possible to identify the particle's pre-entry mineralogy that provides a direct window for the study of their parent body. Here brief account of geochemical properties of unmelted particles collected from Maitri station, Antarctica have been discussed. Based upon elemental chemistry they show affinity towards carbonaceous chondrites which are amongst the most primitive material of the solar system. In addition these particles can be broadly divided into fine grained and coarse grained. Most olivines in studied unmelted particles are forsteritic (FeO poor) with a strong provenance with type 1 chondrule that predominate in carbonaceous chondrites as compared to Ordinary chondrites. Bulk composition of fine grained unmelted micrometeorites show affinity towards matrices of CI and CM chondrites. Here we have discussed preliminary results and further detailed investigation is underway for robust linkage of these particles towards their parent body.

Key words: Micrometeorites, Chondrules, Atmosphere

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S8-02

Monitoring of a long-period comet C/2020 V2 (ZTF) from Indian telescopes

Goldy Ahuja[1,2,*], K Aravind[1], Shashikiran Ganesh[1]
[1]Physical Research Laboratory, Ahmedabad – 380009
[2]Indian Institute of Technology, Gandhinagar – 382355

*Corresponding author E-mail: goldy@prl.res.in

Contents of Abstract: Comet C/2020 V2 (ZTF) was observed on Dec 2022 from the Mount Abu Observatory using the LISA instrument on PRL 1.2m telescope. The comet has also been observed from the Himalayan Chandran Telescope (HCT) to monitor its activity during pre- and post-perihelion. The perihelion of the comet was on 8 May 2023, with a perihelion distance of 2.23 AU.

Comets are made up of volatile ice and dust since they are primarily found in reservoirs far from the Sun. Because of that, only a thin layer is removed every time comets approach perihelion. The comets' composition would not change much during their lifetime. Solid ice starts sublimating when it approaches the Sun, and we observe the cloud of gas and dust, known as a coma [1]. The Cometary Emissions, such as CN, C3, and C2, are the significant emissions present in the cometary coma. These emissions are the daughter/granddaughter molecules that formed during the sublimation of the icy material in the comet.

In the talk, I will briefly describe the observed trend in the relative abundances of different gas molecules and dust as the comet went around the Sun.

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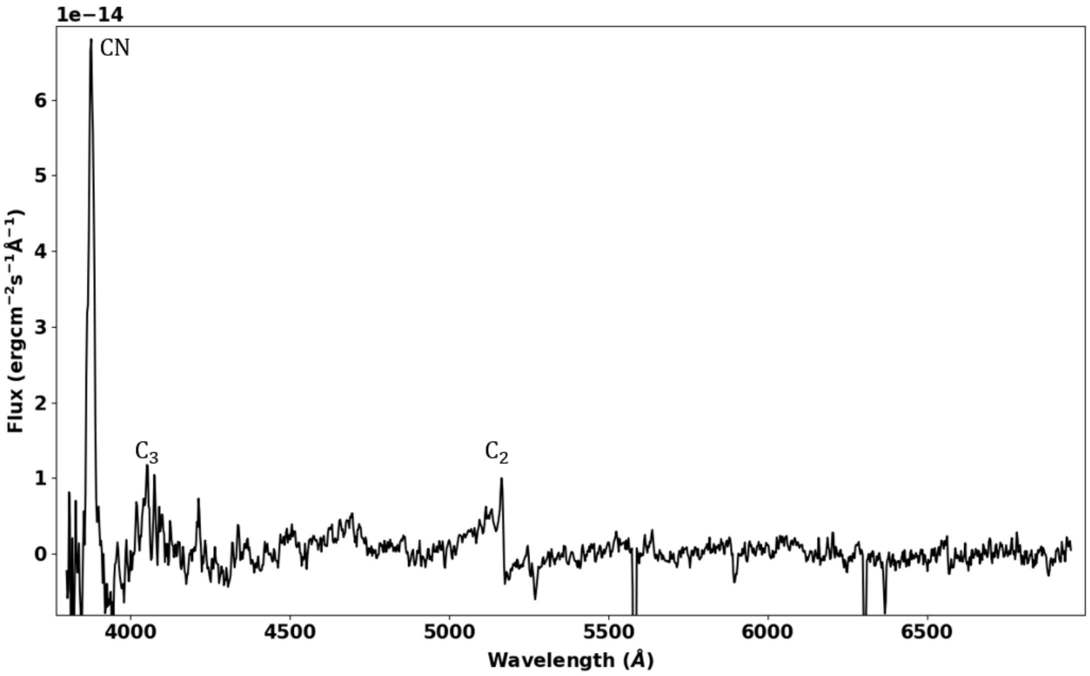

Figure 1: Optical Spectrum of the comet C/2020 V2 (ZTF) observed from PRL 1.2m telescope.

S8-03

Deep sea: Largest repository of extraterrestrial dust.

Sreekuttan S. [1,2,*] and Rudraswami N.G [1,2], V. P. Singh [1,2]
[1]National Institute of Oceanography (Council of Scientific and Industrial Research),

Dona Paula, Goa 403004, India

[2]Academy of Scientific and Innovative Research (AcSIR),

Ghaziabad 201002, India

*Corresponding author E-mail: sreesidh17@gmail.com

Abstract:
It is estimated that ~40,000 tons of extraterrestrial dust annually fall on the Earth's surface [1]. Dust particles are mostly produced either by asteroid collisions or comet sublimation. P-R drag governs the movement of these small dust particles in space. These extraterrestrial dust particles ranging in size from 10's of µm to few mm that enter the Earth's atmosphere at a velocity of >11 km/s and undergo heating due to friction with atmospheric air molecules. The particles that survive the atmospheric entry heating and reach the Earth's surface are called micrometeorites [2]. Melted particles attain spherical geometry and are defined as cosmic spherules, whereas those that do not melt are defined as unmelted micrometeorites. Micrometeorites are crucial direct evidence that allows us to investigate the solar system materials in the laboratory.
Micrometeorite presence is ubiquitous in all terrestrial environments. However, the deep sea and the polar areas are the principal locations for their collection due to the lower terrestrial sedimentation rate. Deep sea sediments provide the first extensive collection of micrometeorites and still are a valuable source of cosmic spherules, especially understanding the weathering, etching and biogeochemistry. Deep sea basins with larger surface areas provide the largest reservoir site for cosmic dust. Considering the meagre sedimentation rate and relatively stable condition for millions of years, deep sea sediments provide a suitable collection site for extra-terrestrial dust and act as a storehouse of valuable information that unveils the mystery of the formation and evolution of our solar system. However, the flux calculation of micrometeorites from deep sea regions gives lesser value than the polar areas, probably due to the harsher conditions, dissolution and etching of the particles [3]. Moreover, extra-terrestrial dust is an important source of bioavailable iron in the marine environment and contributes to the primary productivity of phytoplankton [4]. Here, we discuss the characteristics of micrometeorites from the Central Indian Ocean Basin and the role of deep-sea conditions in the preservation, flux calculation, and alteration of cosmic dust.

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S8-04

Control of precursor composition and atmospheric entry on the texture of micrometeorites.

V. P. Singh [1,2,*] and N.G Rudraswami[1,2]

[1]National Institute of Oceanography (Council of Scientific and Industrial Research),

Dona Paula, Goa 403004, India

[2]Academy of Scientific and Innovative Research (AcSIR),

Ghaziabad 201002, India

*Corresponding author E-mail: vijaypratap865@gmail.com

Abstract:
The dynamic evolution of asteroidal belt, planetary bodies' collision and comet's sublimation produces cosmic dust. Under the effect of P-R drag, this dust travels toward the Sun and enters the Earth's atmosphere on that course while crossing the Earth's orbital path. These dust suffer extreme heating and melting during atmospheric entry and gets modified in term of morphology, texture and compositions. Annually, ~40000 tonnes of extraterrestrial dust material bombard the upper Earth's atmosphere, out of which ~10% survive the atmospheric heating and reach the Earth's surface [1]. These survived particles, collected from the various terrestrial environment, are called micrometeorites [2]. The melted micrometeorites attain a spherical morphology called cosmic spherules, whereas some particles escape atmospheric heating and preserve in irregular morphology, called unmelted micrometeorites. The degree of heating of cosmic dust depends on its entry speed, angle, and composition [3]. Cosmic spherules, based on their composition, are classified as S-type (silicate), I-type (Fe-dominated), and G-type (mixed). Further, S-types based on texture are classified as scoriaceous, porphyritic, barred, cryptocrystalline, and glass [4]. Porphyritic and barred spherules show various textural and compositional patterns resembling their variable origin source and atmospheric entry modification. This article discusses the relationship and control of precursor composition and atmospheric entry parameters in developing various barred and porphyritic textural patterns in cosmic spherules.

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S8-05

CSTERC Meteor Activity Monitoring System: Raspberry Pi Built 720px Low-Light Camera

Balaji Prasath S[1,*], Surender Ponnalagar[1], Bharathkumar Velusamy[1], Aazhimukilan G[1], Krithika Krishnan G[1], Anupama Pradeepan[1]
[1]Open Space Foundation, Kadaiveethi Street, Lower Camp, Periyar Project, Theni, Tamilnadu—625525, India.
*Corresponding author E-mail: contact@openspacefoundation.in
Key words: Meteor detection, Astroimaging, Image processing.

Abstract:

Networks of traditional video surveillance systems, operated by professionals such as CAMS (Camera for Allsky Surveillance cameras), validate the IAU working list of Meteor Showers [1]. The data from these camera networks enable researchers to catalog meteor showers, differentiate minor meteor showers, and establish the remaining showers on the IAU working list [2]. The CSTERC Meteor Activity Monitoring System is an amateur effort to capture meteor activities using Raspberry Pi connected, f/1.0 8mm focal length 720px low light cameras. The FreeTure software, designed for capturing meteors, records the data[3]. This research effort enables us to better understand meteor showers and share data among connected researchers to produce scientific results. In the first phase of this project, CSTERC - Center for Science & Technology Education Research and Communication, built a pilot system in Coimbatore, Tamilnadu, India, to evaluate the functional attributes needed to scale the monitoring network.

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S8-06

A Novel Approach to Meteoroid and Meteorite Detection and Recovery for Planetary Exploration

Kanak Patel1[1], Amit Kumar[2], H.S.Mazumdar[3]

[1,2] PhD Scholar, Dharmsinh Desai University Nadiad, Gujrat India (kanakpatel.rnd@ddu.ac.in)

[3]Retired PRL, Active H.O.D R&D Centre Dharmsinh Desai University Nadiad, Gujrat India(hsmazumdar@ddu.ac.in)

1. Introduction:

Exploring the vast cosmos beyond our planet has always been a subject of fascination and scientific inquiry. In the realm of celestial objects, meteoroids, meteorites, and meteors play a crucial role in shedding light on the mysteries of our solar system's origin and evolution. These fragments of space rock carry invaluable information about the conditions and materials present in the early stages of our celestial neighbourhood. However, locating and recovering meteorites on Earth or other celestial bodies like Mars has been a challenging endeavour. This research proposal introduces a ground-breaking approach: the development of a Meteoroids/Meteorite/Meteors locator system, which aims to use advanced imaging technology artificial intelligence and robotics to precisely identify, characterize and recover these celestial remnants.

2. Research Gap:

The exploration and recovery of meteorites represent an essential aspect of planetary science, yet it has faced significant challenges and limitations. Existing methodologies rely on observations from telescopes and meteorological data, often providing imprecise information about the meteorites' landing locations. This research gap is particularly critical when considering the exploration of celestial bodies with an atmosphere, such as Earth or Mars.

Current meteorite recovery efforts are hindered by the lack of real-time, accurate, and proactive tracking and identification systems. The proposed research addresses this gap by introducing a novel approach that utilizes fisheye lenses with high-resolution cameras synchronized across multiple distant locations. This system will not only capture detailed images of the night sky but also employ neural network image processing to detect meteorite trails accurately, determine their direction, velocity, and time of entry, and, ultimately, pinpoint their probable landing locations.

3. Significance and Plan:

The significance of this research proposal extends far beyond the realms of astronomy and planetary science. Accurately locating and recovering meteorites can provide invaluable insights into the early history of our solar system. These celestial fragments contain preserved records of ancient cosmic events, material compositions, and even the potential for extra-terrestrial life. The project's two-phased approach, involving advanced simulations and the deployment of meteorite detector stations, promises to revolutionize the field of meteorite recovery.

Phase-1, by simulating the night sky and meteorite dynamics, this project lays the foundation for a robust data generation system, this will help meteorite locator system.

Meteorite Trajectory Simulation: to simulate meteorite trajectories in the night sky, we will employ the following equation:

$$r(t) = r_0 + v_0\, t + a\, t^2$$

Where:

- $r(t)$ represents the position vector of the meteorite at time t.
- r_0 is the initial position vector of the meteorite.

- v_0 is the initial velocity vector of the meteorite.
- a is the acceleration vector due to gravity.

Neural Network Image Analysis: In the data analysis phase, we will leverage deep learning neural networks to analyse both simulated and real meteorite data obtained from various observatories. The neural network model can be represented as follows:

$$Y = \sigma (W \cdot X + b)$$

Where:

- Y represents the output vector (meteorite detection and characteristics).
- σ is the activation function (e.g., ReLU, sigmoid).
- W is the weight matrix.
- X is the input data vector (meteorite images and relevant parameters).
- b is the bias vector.

This neural network will learn to recognize meteorite trails in images, determine their direction, estimate their velocity, and record the time of entry into the atmosphere. The network will be trained on a diverse dataset of simulated and real meteorite images to ensure accuracy and effectiveness.

These equations will enable us to accurately model the motion of meteorites as they enter the Earth's atmosphere or the atmosphere of other celestial bodies

The use of deep learning neural networks to analyse simulated meteorite and real-meteorite data from different observatories ensures the system's accuracy and effectiveness. Here is the explanation of the triangulation process to determine the 3D location of a target point using three images:

1. Camera Projection Matrices and Image Coordinates
    - Each camera has a projection matrix (P_i) that relates 3D world coordinates (X) to 2D image coordinates (x_i).
    - P_i combines camera intrinsic (calibration) and extrinsic (position and orientation) parameters.
    - x_i are the measured 2D coordinates of the target point in each image.

2. Triangulation and Linear Least Squares
    - Set up equations:
        - From the first camera: $X = P_1^{-1} x_1$
        - From the second camera: $X = P_2^{-1} x_2$
        - From the third camera: $X = P_3^{-1} x_3$
    - Formulate a linear system of equations: $AX=0$.
    - Solve for X using techniques like Singular Value Decomposition (SVD).
    - De-homogenize X to obtain 3D coordinates: $X_{\text{de-homogenized}} = \frac{X}{X[3]}$

3. **Accuracy and Considerations**:
    - Accuracy depends on camera resolution, calibration, measurement precision, and setup geometry.
    - The objective function in bundle adjustment is to minimize the sum of squared residuals. Mathematically, it can be expressed as: Bundle adjustment can refine the solution and account for errors if needed.

      $\min_{X,P} \sum_i \|x_i - \text{project}(X_{est}, P_{est})\|^2$

This process allows us to calculate the 3D location of a point based on its appearance in three images taken from different camera positions.

Phase-2 takes the project to planetary surfaces, offering a real-world implementation of the meteorite locator technology. The establishment of meteorite detector stations, linked with series of wireless sensor networks shown in figure-1, promises to provide timely and precise data on incoming meteorites. Coupled with drones capable of close-up imaging and robotic recovery, this system opens up new avenues for the efficient retrieval of meteorites.
In Phase-2 of project, where we take the meteorite locator technology to planetary surfaces, we will associate with the ambitious science projects of ISRO to enhance the overall science goals. Here's a list of activities for Phase-2:

1. Site Selection:
    - Identify suitable locations on the planetary surface (Earth and Mars) for setting up meteorite detector stations.
    - Consider factors like accessibility, safety, and the likelihood of meteorite impacts.

2. Meteorite Detector and WSN Station Setup for Mars:
    - Use of Drone to transport the 'All Sky Camera' payloads for setting up meteorite detector 3 stations.
    - Setting up WSN nodes to link 'All Sky Camera' stations and Lander module

3. System Integration, Calibration and Testing:
    - Integrate the meteorite locator technology with the detector stations and wireless sensor network.
    - Develop software for real-time data collection, analysis, and communication.
    - Calibrate the meteorite detection system to accurately identify meteorites based on sensor data.
    - Conduct thorough testing and validation to ensure the system's accuracy and reliability.

4. Drones and Robotics Deployment:
    - Deploy drones equipped with imaging capabilities to capture close-up images of meteorite impact sites.
    - Implement robotic systems capable of safely recovering meteorites.

5. Remote Operation:
    - Develop remote operation procedures to control the meteorite locator system from a central command centre.
    - Train personnel to operate the system remotely and troubleshoot issues.

6. Data Analysis and Reporting:
    - Establish protocols for data analysis, including meteorite trajectory reconstruction, impact point prediction, and characterization.
    - Generate reports on incoming meteorites, including their size, composition, and potential scientific significance.

7. Security and Maintenance:
    - Implement security measures to protect the equipment from environmental factors and unauthorized access.
    - Develop a maintenance schedule to ensure the ongoing functionality of the system.

8. Scientific Collaboration:

- Collaborate with planetary scientists and research institutions (PRL) to share data and findings.
- Contribute to the broader understanding of planetary science through the meteorite recovery and analysis process.

9. University Outreach and Education:
   - Engage in public outreach and education initiatives to raise awareness about the project's goals and outcomes.
   - Share discoveries and promote interest in planetary science among young students (DDU).

10. Documentation and Reporting:
    - Maintain comprehensive documentation of all activities, data, and findings.
    - Regularly report progress and results to project stakeholders and funding agencies.

These activities will help ensure the successful deployment and operation of the meteorite locator system on planetary surfaces, advancing the field of planetary science and meteorite recovery.

4. Conclusion:

In conclusion, "A Novel Approach to Meteoroid and Meteorite Detection and Recovery for Planetary Exploration" represents an ambitious yet achievable mission to revolutionize meteorite recovery and planetary science. By combining advanced imaging technology, machine learning, and the deployment of detector stations on planetary surfaces, we aim to close the existing research gap in accurately locating and recovering meteorites. The potential discoveries that lie within these celestial remnants are not only scientifically significant but also have the power to reshape our understanding of the solar system's formation and evolution. This proposal represents a crucial step forward in unlocking the secrets of our cosmic neighbourhood and advancing the field of planetary science.

5. Images:

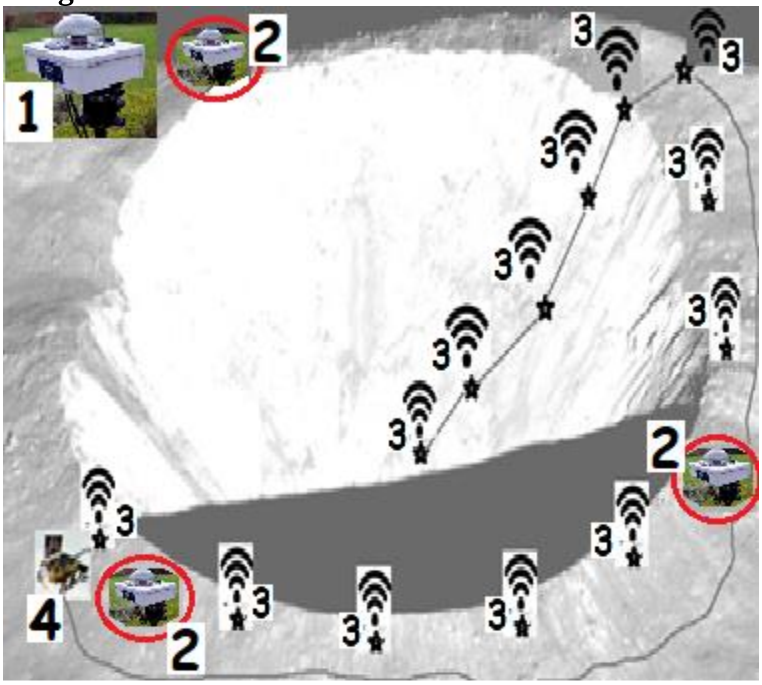

Figure-1 illustrates the suggested arrangement, which involves the placement of three All Sky Cameras, alongside Wireless Sensor Network nodes, accompanied by a Data Sink Station acting as a mobile unit (Rover) (4). Image (1) provides a closer look at one of the All Sky Cameras equipped with an automated surface penetration device. It's worth noting that these three installed cameras possess the capability to not only capture dynamic star imagery but also accurately detect surface seismic activities, achieving a precision of 5 to 10 arc seconds.

An Image of a Fish Eye Lens


An Image of an All Sky Camera with a captured image


An Image of a Drone capturing view image

6. References:

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Note: In view of language upgradation, assistance from ChatGpt has been taken.

P-09

Quantitative and qualitative analysis of effect of etching on Micrometeorites.

S.K.T. Basil [1,2,*], N.G Rudraswami[1], and V. P. Singh[1]

[1]National Institute of Oceanography (Council of Scientific and Industrial Research), Dona Paula, Goa 403004, India

[2]Indian Institute of Science Education and Research,

Kolkata, West Bengal 741246, India

*Corresponding author E-mail: basilsaleemphy@gmail.com

Abstract:

Micrometeorites (MMs) are minute cosmic particles that have reached Earth's surface and can be collected in significant quantities from unique locales, such as deep ocean sediments and polar ice [1]. While they exist ubiquitously, their concentration is less in areas with a high influx of terrestrial particles. These micrometeorites serve as valuable specimens from asteroids and comets, affording us an opportunity to investigate diverse samples of the solar system. MM data offers a less biased representation of asteroids or comets due to their substantial arrival rate on Earth compared to traditional meteorites [2].

This study demonstrates the qualitative and quantitative effect of etching on the preservation of MMs in deep sea and polar regions. Here, we employed the sieving processes to selectively isolate the particles coarser than 220 µm from deep sea sediments and coarser than 50 µm from polar ice [3,4]. Subsequently, magnetic separation is employed to distinguish between magnetic and non-magnetic particles. Spherical particles have been picked from the magnetic fraction under the binocular microscope, mounted in epoxy and polished to expose the internal features. Carbon coated polished samples has been analysed under the Scanning Electron Microscopy (SEM) and Electron Probe Micro Analyser (EPMA) for textural and chemical characteristics.

SEM imagery reveals a broad spectrum of etching, indicative of alteration, with varying degrees of etching observed for different chemical types of MMs. Among the S Type MMs, Barred Olivine exhibits the most extensive etching, followed by other S Type MMs like Porphyritic Olivine and Glass Spherules. G Type spherules display intermediate levels of etching, while I Type spherules exhibit the least extent of weathering. Notably, interstitial silicate glass is particularly susceptible to etching, as evidenced in Barred Olivine and Porphyritic Olivine MMs. Furthermore, scoriaceous MMs display comparatively lower levels of etching, which probably not the true representation, as scoriaceous MM has least preservation chances and readily crumbles with smaller degree of etching. Therefore, the analysed scoriaceous MMs are those which experience least etching. The chemical composition of MMs demonstrates a strong correlation with the degree of etching, with MMs retrieved from deep-sea sediments exhibiting more pronounced weathering compared to those collected from Antarctic ice. This underscores the influence of terrestrial storage conditions on the etching phenomenon.

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P-11

Understanding the Micrometeorites entry heating through CI chondrite

N. G. Rudraswami*
[1]National Institute of Oceanography (Council of Scientific and Industrial Research),
Dona Paula, Goa 403004, India
Corresponding Author: rudra@nio.org

Micrometeorites has played an important role in unravelling the chemical and isotopic composition of Extraterrestrial that is reaching Earth's surface [1-7]. The heterogeneity of precursor of extraterrestrial dust displays a broad range of textural, chemical and oxygen isotopic isotope compositions, apart from their heating during entry [2, 5]. The experimental heating has provided an opportunity to explore the association between thermal processing and micrometeorite composition [3]. An experimental investigation on the chemical and isotopic properties of the interplanetary dust as it enter the Earth's atmosphere provide strong constraints to decipher the variation in chemical and isotopic composition. The experimental procedures encompasses heating chondritic particles for short duration of time and to document the variation in chemical and isotopic properties which is analogous to the micrometeorites (MMs) during their entry into the Earth's atmosphere [4, 5, 7]. Carrying out heating experiment (400–1600°C) of CI chondrite particles followed by chemical and in-situ oxygen isotopic analyses prepare the ground for future investigation associated with atmospheric exchange, isotopic fractionation, and chemical alteration during entry which will be crucial to decipher precursor properties. The textural variation due to heating produced fine-grained, coarse-grained, scoriaceous particles similar to those found in MMs. The temperature and texture relation indicate that large number of extraterrestrial particles either enter at high velocity or low zenith angle indicating high temperature events [4]. The variation or change in $\Delta^{17}O$ during heating is < 3 ‰ indicate MMs do not exchange atmospheric oxygen considerably as perceived earlier. These results demonstrate oxygen isotopic alteration during atmospheric entry is nearly a closed system. We conclude that the extraterrestrial dust particles has oxygen isotopic composition that demonstrate wide diversity than anticipated when compared with meteorites.

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P-20

1 Title: Study the impact of El Niño case study with Biporjoy over A S during 2023.

Nagalakshmi, Susmitha Joseph

The main aim of this study is to understand the impact of El Niño case study with Biporjoy over Arabian Sea, in the past, India has experienced below-average rainfall during most El Nino years, sometimes leading to severe drought that destroyed crops and forced authorities to limit the export of some food grains. When the onset of cyclones and monsoons coincides, they impact each other. We have taken wind, sea level pressure, SST, air temperature at 2m, geopotential height, cloud cover from NCEP/NCAR Reanalysis data for the study period before, during and after the Biporjoy in June month 2023. Results indicating that during the Biporjoy over A S, location of wind at 850 hPa and 200 hPa has been changed. The position of the easterly jet controls the location of monsoonal rains, which occur ahead and to the left of the strongest winds and behind them and to the right. Cyclone Biporjoy, which developed over the Arabian Sea on June 7, has influenced the progress. This is because westerly winds, which pull the monsoon towards the Indian mainland. Along with this remaining parameter will be discussed.

Physical Research Laboratory
MetMeSS-2023

3rd November, Friday

Session- IX: Astrobiology and Organics
Session Chair: Prof. Kuljeet K Marhas and Prof. Vijay Thiruvenkatam

Abstract#	Time	Speaker	Title	Affiliation
Invited	14:00 - 14:20	Vijay Thiruvenkatam	Exploring the Metabolomic Diversity in microorganisms identified in the International Space Station and Rann of Kutch.	IIT, Gandhinagar
	14:20 -14:35	Kinsuk Acharrya	Organics in Comets	PRL, Ahmedabad
S9-01	14:35 - 14:50	Shreeya Natrajan	Compositional diversity in type 1 & 2 chondrites: An insight into evolution of Ryugu like planetesimals.	PRL, Ahmedabad
S9-02	14:50 -15:05	Arijit Roy	Shock Processing of Smaller PAHs	PRL, Ahmedabad
S9-03	15:05 - 15:15	Rachana Singh	Conformational and Electro-Optical analysis of Interstellar Cyanopropene at Different Temperatures	University of Lucknow
S9-04	15:15 - 15:25	W. Khan	Mid-IR spectroscopy of pure phenylacetylene at low temperature	PRL, Ahmedabad
S-9-05	15:25-15:35	Deep Thakkar	Crystallographic analysis of different layers of Haematite bearing concretions from the Laiari riverbed, Kutch, India	IIT, Gandhinagar
S9-06	15:35 - 15:50	Alka Misra	Effect of Solvents in Protonation of Dicyanoacetylene: A Computational approach	University of Lucknow

S9-01

Compositional diversity in type 1&2 chondrites: An insight into evolution of Ryugu like planetesimals.

S.Natrajan [1,*], K.K. Marhas [1]
[1]Physical Research Laboratory, Ahmedabad-380009
*Corresponding author email: shreeya@prl.res.in

Chondritic meteorites of the type 1&2 are suggested to have water rich parent bodies that formed in the early stages of the solar system formation. These primitive samples show evidences for prograde alteration with an early period at lower temperatures (<150℃) and later affected by short lived thermal metamorphism at~200℃ to >750 ℃ [1]. They record significant interaction between alteration fluid, silicate rocks and organic content. The exact conditions of these hydrothermal alterations are very crucial in understanding the formation and evolution of hydrous asteroids. The extent of aqueous alteration has been quantified through various techniques some of which indicates that it may have been driven primarily by impact rather than by radiogenic heating [2]. Moreover, the wide range of hydrothermal conditions affect the formation, destruction and transformation of the organic content within. The influence of water and related activity on the organics encased in meteorites makes their origin inextricably linked. Furthermore, the recent study of Bennu and Ryugu and the presence of primitive chondritic material embedded in other meteorites implies that the parent body was disrupted and could have supplied material to Earth. Their similarity makes the analysis of type 1&2 chondrites essential to the interpretation of these enigmatic bodies.

In this study we have performed a multi-technique study of IOM extracted from 18 carbonaceous (CI, CM, CR) meteorite samples with an aim to understand the parent body evolution using FTIR, Raman and XANES analyses. We observe that altered samples have low N content and high aromaticity which could stem from the loss of C, N as CH_4, NH_3 that are evolved from organic material during asteroidal hydrothermal reactions [3-5]. We propose a state of chemical equilibrium that is reached between IOM and SOM during hydrothermal alteration in water rich planetesimals where IOM could have evolved from SOM modification and organo-mineral interactions.

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S9-02

Shock Processing of Smaller PAHs

Arijit Roy[1, *], S.V. Singh[1], J. K Meka[1], R. Ramachandran[1], D. Sahu[1], S. Gupta[1], V Venkataraman[2], V. Jayaram[3], J. Cami[4], B.N. Rajasekhar[5], A. Bhardwaj[1], H. Hill[6], N.J. Mason[7], B. Sivaraman[1, *]
[1]Physical Research Laboratory, Ahmedabad, India.
[2] Space Physics Laboratory, Vikram Sarabhai Space Centre, Thiruvananthapuram, India.
[3] Indian Institute of Science, Bangalore, India.
[4] Western University, Ontario, Canada.
[5] Bhaba Atomic Research Centre, Mumbai, India.
[6]International Space University, Strasburg, France.
[7] University of Kent, Canterbury, UK.
*Corresponding author E-mail: arijit@prl.res.in, bhala@prl.res.in .

The Polycyclic Aromatic Hydrocarbon (PAH) molecules, which is made of many fused benzene rings, are considered potential carrier of the Unidentified Infrared Emission (UIE) bands, peaking around 3.3, 6.2, 7.7-7.9, 8.6, 11.3, and 12.7 µm, observed in different parts of ISM [1,2,3]. Almost 20 % of the interstellar carbon is proposed to be locked up in PAHs [2,3]. However, detecting specific PAHs in the Interstellar Medium (ISM) has been difficult, at least until recently, when benzonitrile was discovered in the dark molecular cloud TMC-1[4]. Since then, a barrage of smaller PAHs (< 24 C atoms) have been reported in the different parts of the ISM (CDMS). Not only in the ISM, but the smaller PAHs are also known to be present in various solar system objects, such as comets, asteroids, and the atmosphere of Jupiter and Titan [5]. These smaller PAHs are also an important building block of the insoluble organic matter, often found in carbonaceous chondrites such as Murchison [5]. The role of these smaller PAHs in the interstellar chemical enrichment processes and their impact on the structures of the resulting cosmic dust grains have been least explored to date. Vacuum Ultraviolet (VUV) irradiation on the benzene ice showed the formation of refractory residue with different geometrical structures such as cubes, rods, prisms, and T-shaped structures[6]. The residue made from the VUV irradiation of the benzonitrile ice showed the presence of various carbon allotropes such as graphene, nanodiamonds, and graphene quantum dots [7]. Results from these studies suggest that smaller PAHs can play a key role in shaping the physical structures of the interstellar dust and showing the astrochemistry community the urge to carry out robust experimental work/network to probe the physio-chemical evolution of the cosmic smaller PAHs analogues.

Shock waves are ubiquitous in the ISM and contribute to the interstellar chemical enrichment processes [8]. The high-velocity shock waves (> 100 km s^{-1}) generated by the violent supernova explosion destroy the molecules and dust grains in its path. The low-velocity shock waves (3-10 M) detected around Mira Variable can process the dust thermally and produce new molecular species [8]. These low-velocity shock waves can be created using a shock tube in the lab. In this work, we carried out shock processing of the smaller interstellar PAH analogues such as naphthalene, anthracene, pyrene, 1-cyanonaphthalene (1-$C_{10}H_7CN$, 1-CNN) and 2-cyanonaphthalene (2-$C_{10}H_7CN$, 2-CNN) using the High-Intensity Shock Tube for Astrochemistry (HISTA) house at PRL. These molecules are subjected to shock waves with Mach ~ 5.6 (1.8 km s^{-1}) and reflected shock temperature ~ 7300 K for 2 ms. The shock-processed samples are analyzed using IR spectroscopy, Raman Spectroscopy, and HR-TEM imaging techniques. In this meeting, we will discuss some initial results of this experiment and its importance in the interstellar dust enrichment processes.

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S9-03

Conformational and Electro-Optical analysis of Interstellar Cyanopropene at Different Temperatures

Rachana Singh[1, 2], Manisha Yadav[1, 2], Shivani[2], Parmanand Pandey[1, 2], Aftab Ahamad[2], Pravi Mishra[1, 2] Alka Misra*[1] and Poonam Tandon[2]
[1]Department of Mathematics and Astronomy, University of Lucknow, Lucknow, India
[2]Department of Physics, University of Lucknow, Lucknow, India
*Corresponding author email: alkamisra99@gmail.com

Abstract:

The cyano derivatives of propene are highly abundant in the interstellar medium. The trans and cis-crotononitrile (t-$CH_3CHCHCN$, c-$CH_3CHCHCN$), methacrylonitrile ($CH_2C(CH_3)CN$), and gauche and cis-allyl cyanide (g-CH_2CHCH_2CN and c-CH_2CHCH_2CN) are the five isomers of cyanopropene detected towards the cold dark clouds TMC-1[1]. In this study, we investigate the conformational dynamics and electro-optical properties of interstellar cyanopropene across a range of temperatures to gain deeper insights into its behavior in extreme environments. We employed density functional theory (DFT) with B3LYP/aug-cc-pVDZ and CAM-B3LYP/aug-cc-pVDZ methods using Gaussian 16 program package[2], to optimize the electronic structures of isomers of cyanopropene. The electro-optical properties, including HOMO, LUMO, and molecular electrostatic potential (MEP) surfaces, are computed to elucidate the optical behavior and chemical reactivity of these interstellar molecules. Furthermore, Frontier molecular orbital (FMO) analysis provides valuable insights into the reactivity of cyanopropene in the interstellar medium. Our findings reveal distinct conformational changes in response to temperature variations, shedding light on the molecule's adaptability to interstellar conditions. This comprehensive investigation contributes not only to our understanding of cyanopropene but also to the broader field of astrochemistry, providing essential insights into the behavior of complex organic molecules.

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S9-04

Mid-IR spectroscopy of pure phenylacetylene at low temperature

W Khan [1,2], R Ramachandran[1*], S Gupta[1], JK Meka[1], Anil Bhardwaj[1] , N J Mason[3], B Sivaraman[1*]

[1] Physical Research Laboratory, Ahmedabad, India,
[2] Indian Institute of Technology (IIT) Gandhinagar, India,
[3] University of Kent, Kent, UK
*Corresponding author E-mail: ragav.kasak@gmail.com, bhala@prl.res.in

Aromatic molecules are of great interest in the field of astrochemistry because of their link to the formation of Polycyclic Aromatic Hydrocarbons (PAHs). Ring-containing molecules and their derivatives, like cationic, substituted PAH species, can serve as a foundation for the creation of PAHs. These ring-based structures can subsequently grow and form molecules with hundreds of carbon atoms [1,2]. These PAHs are believed to contribute to the emissions in the unidentified infrared emission (UIR) bands [3]. The IR emission signifies a broad category of molecules, but the exact forms of the PAH responsible for the UIR bands are still challenging in astronomy.

One of the PAH molecules, phenylacetylene, was recently identified in the TMC-1 in ISM [2,4]. However, the laboratory analog experiments of phenylacetylene molecules at ISM cold dust conditions are still not present in the literature. Hence, in this study, we have carried out the temperature-dependent mid-IR spectroscopy of phenylacetylene from 8 K until its sublimation. The experiments were conducted at the Simulator for Astromolecules at Low Temperature (SALT) setup, housed at the Physical Research Laboratory (PRL). The molecular ice deposited at low temperature (~8 K) and ultra-high vacuum, were warmed to higher temperatures at a constant rate until its sublimation. The behavior of the ice was studied *in situ* using FTIR spectroscopic technique in the mid-IR region. The detailed experimental setup can be found in [1].

The mid IR spectra of phenylacetylene at different temperatures is shown in Figure 1. The molecule on deposition at 8 K formed an amorphous ice. Upon warming to higher temperatures, the ice starts compacting after 100 K and crystallizes at ~150 K. The sharpening and splitting of the lines can be observed upon crystallization. The ice sublimates ~193 K. The reactivity of molecular ice depends on its phase, with amorphous ice being more reactive because of its porosity [5]. This study gives an understanding of the reactivity and stability of phenylacetylene molecules in the interstellar medium. Along with this, such an IR study of the PAH molecules can also be used for its unambiguous identification in the ISM and other planetary bodies.

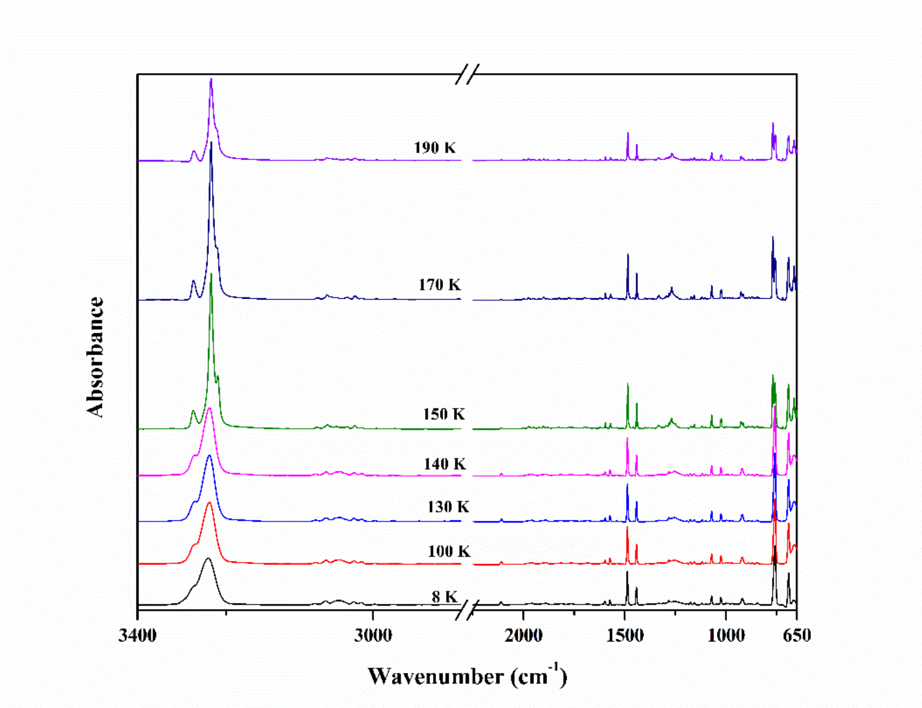

Fig-1 IR spectra of Phenylacetylene deposited at 8 K and warmed to higher temperatures.

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S9-05

Crystallographic analysis of different layers of Haematite bearing concretions from the Laiari riverbed, Kutch, India

Deep Thakkar[1], Dr. Vijay Thiruvenkatam[2]
[1] Department of Chemical Engineering and Computer Science and Engineering, Indian Institute of Technology, Gandhinagar
[2]Department of Biological Sciences and Engineering, Indian Institute of Technology, Gandhinagar

The instruments aboard the Opportunity Rover confirmed the presence of Fe_2O_3 by identifying hematite bearing iron concretions which was suggested from the data of the Mars Global Surveyor Thermal Emission Spectrometer instrument[1]. Researchers believe that the discovery of iron concretions on the Martian surface is a strong evidence for presence of flowing surface water of Mars[3]. In the search for Martian analogues on Earth, the presence of haematite bearing concretions have been a very important indicator[2]. The iron spherules are of great Astro-biological importance as not only they indicate the presence of water but also because they can indicators of past life on Mars. It is hypothesized that iron bacteria and filamentous fungi play a significant role in the formation of haematite concretions on earth[4,5].

The haematite concretions were collected from the dried river bed of Laiari river, Kutch, Gujarat, India. (Ray et al., 2021b) proposed the Laiari riverbed as a Mars analogue site for petrography, mineralogy, and geochemistry comparisons. It also reports hematite bearing concretions from the site[6]. Haematite bearing concretions are multilayered strictures with a rind (dark brown in colour) and a brittle outer (Light brown in colour) and inner layer (white in colour). Our study involves performing, SEM, EDX, Powder XRD (PXRD), and Single Crystal XRD (SC-XRD) of different layers of iron concretions to understand the process of formation of Iron concretions on Mars. Picking up crystals from different layers and elucidating the crystal parameters from SC-XRD results would share further light on the processes involved in formation of hematite bearing concretions and role of water on Mars in the process.

Image: Left the cross-section of an iron concretion found from the river bed of Layari river, right – an intact iron concretion with a dark blue almost purple crust

Image (Iron concretion from Laiari riverbed)

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P-12

Thermochemical analysis of the reaction mechanism that leads to the formation of the propargyl radical (CH_2CCH) using Quantum Chemistry.

Parmanand Pandey[1, 2], Rachana Singh[1, 2], Manisha Yadav[1, 2], Shivani[2], Aftab Ahamad[2], Pravi Mishra[1, 2] Alka Misra*[1] and Poonam Tandon[2]

[1]Department of Mathematics and Astronomy, University of Lucknow, Lucknow, India
[2]Department of Physics, University of Lucknow, Lucknow, India
*Corresponding Author email: alkamisra99@gmail.com
Phone: 9305666576, 9415580700

Abstract: The Propargyl radical (CH2CCH) has been abundantly detected in cold dark cloud TMC-1 using the Yebes 40 m telescope. This radical is a potentially crucial intermediate step in the creation of complex organic molecules, including aromatic rings. A significant portion of neutral species and closed-shell molecules have been detected in cold dark clouds among which, the long known unsaturated carbon chains stand out as the most prevalent type of molecules [1]. However complex organic molecules (COMs) has also been found in cold dark clouds, ranging from the nearly saturated propylene [2], various isomers of the partially saturated molecules C_4H_4, C_5H_4, C_4H_3N and C_5H_3N [3-7] the five-membered ring C_5H_5CN [8], and the aromatic ring C_6H_5CN [9,10].

This theoretical study presents thermochemical analysis of the reaction mechanisms that leads to the formation of the Propargyl radical (CH_2CCH) with the help of molecules which are primarily detected in the interstellar medium. All the computational work has been done using Density Functional Theory (DFT) with B3LYP functional and 6-311 G++ (2d, 2p) basis set . The process of formation of complex organic molecules involves reactions that include radicals and ions. These radicals play a crucial role in the formation of more complex organic molecules. Therefore, studying the reactions between such radicals, molecules and ions through computational chemistry is extremely important. This study helps to understand the synthetic pathways, or the steps involved in the formation of various interstellar species.

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P-13

A Theoretical Study of Formation of Methane in Interstellar ice

Manisha Yadav[1, 2], Rachana Singh[1, 2], Shivani[2], Parmanand Pandey[1, 2], Aftab Ahamad[2], Pravi Mishra[1, 2] Alka Misra*[1] and Poonam Tandon[2]

[1]Department of Mathematics and Astronomy, University of Lucknow, Lucknow, Bharat
[2]Department of Physics, University of Lucknow, Lucknow, Bharat
*Corresponding Author email: alkamisra99@gmail.com
Phone: 9305666576, 9415580700

The formation of Methane (CH_4) by successive hydrogenation of carbon in interstellar ices has been investigated theoretically in conditions close to those encountered in the interstellar medium. Carbon and hydrogen atom have been reacted in interstellar ice at 10K. This first theoretical investigation of CH_4 by the reaction of C and H atoms is essential to understanding the formation of methane in the molecular cloud environments. This study shows that CH_4 is expected to be formed by the hydrogenation of C in interstellar ice and that CH_4 ice is strongly correlated with solid H_2O.

Such work also provides the formation yields, rates, temperature and reactant dependencies. The release in energy in the formation of Methane shows the exothermicity of reaction. All the calculations have been done using quantum chemical method, Viz Density Functional Theory (DFT). Via successive hydrogenation of Carbon atom: CH, CH_2, CH_3 and the product Methane (CH_4) has been formed. All these species have been detected in interstellar medium and methane is also detected in comets [1-5]. Methane's widespread presence in various environments, both on Earth and in space, makes it a molecule of scientific interest in fields ranging from planetary science to astrobiology to astrophysics.

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P-14

Organic Derived Temperature Calculation of Parent body Metamorphism through X-Ray Absorption Near Edge Structure Spectroscopy of Enstatite Achondrites

Neha[1,*], S. Natrajan[2], Kuljeet K. Marhas[2]
[1, 2] Planetary Sciences Division, Physical Research Laboratory, Ahmedabad, Gujarat 380009, India
*neha.thakran02@gmail.com

The organics observed within meteorites have inherited the record of prehistoric processes including various events of aqueous alteration and metamorphism. As these alterations are easily modified by the temperature, study of organics can provide clue to certain dynamics of the solar nebula and the planetesimals disk. The presence of organics is observed in various extraterrestrial objects like chondrites, achondrites and presolar interstellar grains [3].The organic material within differentiated meteorite is commonly assumed to be a product of thermal alteration of the pre-existing organic material, during or after the formation of the meteorite parent body as they typically contain less organic material than chondrites. The objective of this study is to investigate the widespread existence of the organic matter within the planetesimals disk and understanding the early dynamic events altering them.

To achieve this, the isolated organics from the aubrites or enstatite achondrites have been analyzed for C-, N- and O- XANES spectroscopy. Here, the degree of absorption is measured as the energy of a monochromatic beam of X-rays scanned across an element's absorption edge. A prominent features '1s-σ*' the exciton intensity obtained through C-XANES spectra has been used to calculate effective temperature which has been reported to correlated with parent body metamorphism [1]. On the basis of this exciton intensity found in IOM, the temperature ranges from 324 to 516 degree Celsius in the aubrites. Furthermore, the XANES provides quantative analysis of organics and light element [2]. We have calculated the atomic ratio (i.e. O/C and N/C ratio) using the intensity of absorption from the spectra. Thus, the XANES provides a detailed functional group information and chemical complexity within the organics that insight for their origins.

The future work involves the analyzing the sample by Raman Spectroscopy and correlating with the XANES data.

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P-15

A Reaction Pathway for the formation of Interstellar Allylimine: Theoretical Approach

Pravi Mishra[1,2], Shivani[1,2], Aftab Ahamad[1,2], Manisha Yadav[1,2], Rachana Singh[1,2], Parmanand Pandey[1,2], Alka Misra*[,1] & Poonam Tandon[2]
[1]Department of Mathematics & Astronomy, University of Lucknow (mathematics@lkouniv.ac.in)
[2]Department of Physics, University of Lucknow (physics@lkouniv.ac.in)
*Email: alkamisra99@gmail.com

Many of the complex molecules have been identified in the ISM. The diverse range of environmental conditions and processes involved with chemistry in space produce complex populations of materials, and many of these elements also organic in nature such as H, C, O, and N are most abundant in the universe, including some of direct astrobiological significance [1]. Much of this chemistry occurs in "dense" interstellar clouds and protostellar disks surrounding forming stars from which planets, comets, asteroids, and other macroscopic bodies eventually form. Some of the chemical species made in these environments are expected to be delivered to the surfaces of planets where they can potentially play important roles in the origin of life. These chemical processes are ubiquitous and should take place in these environments wherever they are found, this implies that some of the starting materials for life are likely to be widely distributed throughout the universe [2].

Amines are one such molecular family which is important in astrobiology due to the presence of HCNH moiety [3]. Guided by new laboratory data [4], Allylimine was searched for in space using a sensitive spectral survey of the G+0.693-0.027 molecular cloud, located at the Galactic centre. Allylimine is an important precursor of amines. A theoretical approach to studying the formation of Allylimine in ISM confirms the possibility of the amines-containing extra-terrestrial life. As Allylimine structural isomers with amines bond are stable and has great relevance in the formation of life. This type of research motivates researchers to find the interstellar chemistry responsible for the formation of complex molecules in the ISM, beginning with the synthesis of chemical elements within stars and continuing with a summary of the various processes that lead to the formation of complex molecules within interstellar space.

A three-step formation pathway has been proposed for Allylimine in interstellar medium via detected molecule in ISM such as CH_2, CH and NH radical by radical-neutral interactions in the gaseous phase using rigorous quantum-chemical calculations [5]. Density functional theory at B2PLYPD/aug-cc-pVQZ level of theory is utilized to explore the proposed pathway [6].

Our proposed pathway is found to be very efficient. CH_2 is the starting reactant in our proposed path for Allylimine. The reaction energies and the structures of all the geometries involved in the reaction path shows that proposed reaction paths of Allylimine formation is possible in interstellar space.

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P-16

Thermal and electron induced chemistry of the three-ringed PAH under astrochemical conditions

R. Ramachandran[1,*], A. Corrigan[2], D. V. Mifsud[2], S. -L. Chou[3], Y. -J. Wu[3], M. Srivastava[4], B. N. Rajashekar[5], Anil Bhardwaj[1], N. J. Mason[2], B. Sivaraman[1,*]
[1]Physical Research Laboratory, Ahmedabad, India.
[2]School of Physical Sciences, University of Kent, CT2 7NH, Canterbury, UK.
[3]National Synchrotron Radiation Research Center, Hsinchu, Taiwan.
[4]Department of Chemistry, Dayalbagh Educational Institute, Dayalbagh, Agra 282005, India.
[5]Atomic and Molecular Physics Division, Bhabha Atomic Research Centre, Mumbai, India.

*Corresponding author E-mail: ragav@prl.res.in ; bhala@prl.res.in

A recent study showed that irradiating benzonitrile ice with photons and warming created nanostructures including quantum dots and N-graphene, and suggested that graphene can be synthesized in cold dust grains in the interstellar medium (ISM), which can then lead to the synthesis of larger polycyclic aromatic hydrocarbon (PAH) molecules in hydrogen-rich environments [1]. Further, experiments on the formation and photochemistry of large covalently bonded PAH clusters provided a model for the evolution of large molecular clusters in space. Photo processing of these clusters can also lead to the formation of larger PAHs or smaller monomer PAHs [2]. Even though many ionized PAHs have been identified in the ISM, neutral PAHs have been quite elusive as the the contribution of neutral PAHs to the unidentified infrared bands (UIB) in the ISM has been difficult to determine due to a lack of infrared spectral data [3]. Therefore, studying such PAHs are ineluctable and will provide an understanding of grain evolution processes in the interstellar medium [4].

Anthracene, in particular, is a leading candidate for the source of interstellar blue luminescence [5]. Neutral anthracene is most likely to play a role in the photochemistry of interstellar regions where it would be well-shielded from UV photons [6]. Unfortunately, the infrared absorption data which are required for the identification and physico-chemical characterization of the interstellar PAHs is mostly unknown. Mid-infrared spectral data for anthracene in particular are currently limited [3][7]. Therefore, in this work, we investigated the temperature-dependent mid-infrared absorption spectra of pure neutral anthracene ice and the effect of electron irradiation on such ice under astrochemical conditions.

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P-17
Understanding the limits of Life: Extremophiles from potholes in Khari, Gorge, Kutch

Deep Thakkar[1], Dr. Vijay Thiruvenkatam[2]
[1] Department of Chemical Engineering and Computer Science and Engineering, Indian Institute of Technology, Gandhinagar
[2]Department of Biological Sciences and Engineering, Indian Institute of Technology, Gandhinagar

Potholes are formed by erosion of bedrock channels. With change sin flow of stream over a period of time. Water would get collected in these potholes. Kahri Gorge has formed over Mesozoic Sandstone and due to erosion potholes of varying sizes have been observed[1,2]. The evaporation due to the high temperatures especially in the arid Kutch regions would result in concentration of molecules, and ions resulting in extreme conditions. Furthermore during the wet season there would be a dilution in these molecules resulting in an unique environment.
In the present study water samples, were collected from the running stream and potholes at a distance from the stream. The water samples were screened for various chemical components and plating was done on bacterial growth medium to isolate microbes from these conditions[3]. The microbes isolated from the running stream and the potholes at different distances from the stream will be compared. Previous studies from dessert potholes have resulted in isolation of extremophiles from these environments. Due to high temperatures the potholes would be generally dry during the summer seasons and would get replenished by water during precipitation. These can be a hotspot for identifying microbes which might have adapted to become resistant or dormant during the dry seasons[4]. Extremophiles are of great Astro-biological importance as they help understand how life may exits in similar extreme environments of extraterrestrial origin.

Image: Left – running stream from Khari Gorge, right - 30 cm wide potholes in Khari Gorge

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P-18

Title: "Origin of Complex Organics in Presolar (Protostellar) Stages and Comets as Witnesses"

by Dr. Dipen Sahu and collaborators

The presence of complex organic molecules (COMs) is often found in protostellar or young stellar sources, known as 'hot corinos.' Low-mass protostellar sources can later evolve into a Solar-type system. Therefore, exploring the origin of COMs in hot corinos and their connection to planetary bodies' organics is very important for understanding our chemical heritage. However, roughly 2-3 years ago, hot corinos were thought to be rarely found in the interstellar medium; but, recent survey results have found dozens of hot corinos. Hot corinos are identified by the emission signature of COMs, but what is the origin of the COMs towards the protostellar sources? Based on our recent results, I will discuss the origin of COMs in the protostellar phase quantitatively. In this connection, I will also briefly discuss how we should understand cometary organics and whether they are inherited from the protostellar phase.

PLAS (Planetary Laboratory Analyses Section) under Planetary Science Division of Physical Research Laboratory was constituted in July 2021

One of the objectives of planetary Science research at PRL is to understand the origin and evolution of the solar system by laboratory analyses of the extra terrestrial material (meteorites or mission returned samples). The Laboratory analyses (chemical and mineralogical characterization, spectroscopy and isotopic compositions) are also backed with the observational as well as theoretical work. In addition, research areas also include terrestrial impact craters and Moon-Mars analogue studies on Earth. PLAS group hosts an assembly of state-of-the-art instruments under one roof, like, XRD, XRF, FE-EPMA, LA-ICP-MS, NG-MS, Nano-SIMS.

Research Areas

<u>Meteorites</u>

Meteorites, the most abundant astromaterial are also known as messenger from space. Any eye-witnessed new Meteorite fall and find are important to a meteoricist or, to a cosmochemist for its dynamically active scientific data. A new meteorite not only adds to the meteorite database but also offers a unique opportunity to examine origin and formation history of Solar System. Our group actively participated in meteorite collection if there is any fresh fall in India and also involves in the laboratory studies of the extra-terrestrial samples from Asteroids, Moon and Mars.

<u>Sample return</u>

Returned sample from the planetary mission brought back samples to the Earth from Asteroids, Comets and other Celestial bodies for high precision studies in the laboratory. Laboratory Analysis of samples obtained from missions like Hayabusa (JAXA), Apollo (NASA) are currently ongoing.

<u>Analogue studies</u>

A near perfect terrestrial analogue localities to Moon and Mars that mimics the concretions is still elusive on Earth. No single terrestrial analogue can account for all attributes found either on Moon and Mars. However, continued research on terrestrial analogue sites helps to better understand the possible geologic evolution and near-surface processes on Moon and Mars. Continued research on analogue sites on Moon and Mars also serve as testing beds for performance test validation of the payloads and help us to explore the possibilities of future landing sites.

Impact Cratering Studies

The hypervelocity Impact process is one of the fundamental geological processes since the birth of the Solar System at ~4.56 Ga. Despite the good and bad of the impact process, terrestrial impact craters hold many fundamental insights of planetray science including emergence of life in the extreme environment. India so far has three identified, confirmed impact craters, viz. Lonar, Maharashtra Dhala, M.P and Ramgarh structure in Rajasthan formed due to asteroidal impact. Searching for oldest impact craters to find possible evidence of late heavy bombardment is currently ongoing.

State of the art, in-house Analytical Equipment Facilities in PLAS-PSDN, PRL

NanoSIMS (Nanoscale Secondary Ion Mass Spectrometry)

- High spatial resolution: (~50 nm for Cs^+ and ~200 nm for O^-) Capable of analyzing sub micrometre-size sample.
- High mass resolution: Interferences can be resolved with MRP (m/Δm) = 10,000 to 15,000.
- High Transmission: ~ 30 x IMS-4f, better precision.
  Multi-isotope detection facility, saves sample analyses time. Less destructive technique: Few Å.

Noble Gas Mass Spectrometer (NGMS)

NGMS is a multi-collector mass spectrometer for isotope ratio measurement of noble gases and nitrogen.

Field Emission Electron Probe Micro Analyzer (FE-EPMA)

HR-EPMA is principally used for the major element analysis of minerals. The main advantage is to analyse micro-sized sample area and it is a non-destructive technique and the same sample can be used for other analytical purpose as well.

- Five channels WDS for faster quantitative analyses and X-ray mapping

- Capable of capturing the images up to sub-micron level
- Non flat surface analysis and trace elements analysis
- Chemical age dating

Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS)

LA-ICPMS is capable of analyzing highly accurate quantitative analysis of elemental concentrations through digestion of solid samples. The coupling of LA with the ICPMS has resulted in the development of in-situ analysis capability. This is especially very important for planetary sample research, where sample size is tiny and amount is very small.

X-ray Fluorescence Spectrometer (XRF)

XRF is widely used for analytical technique in the determination of major and trace element chemistry of rock samples. The nature of analyses is non-destructive and wavelength dispersive technique is used for quantification.

- Accurate, precise, faster and robust analyses of multielement composition of rocks/ sediments
- High sample throughput for pressed pellet and fused glass bead samples

X-ray Diffraction (XRD)

X-ray diffraction is used to obtain the information on the structures of crystalline materials.

- Portable, benchtop
- Accuracy: ± 0.02° throughout the entire measuring range
- No external cooling water supply

Invitation

JEOL INDIA
2ND NOVEMBER 2023
VENUE: PHYSICAL RESEARCH LABORATORY AHMEDABAD

Dear MetMeSS Symposium 2023 Delegates,

Greetings from JEOL TEAM!!
We cordially invite you to attend to our TEM meet during **MetMeSS Symposium -2023**. It will take place at Physical Research Laboratory Ahmedabad.

It is our pleasure to inform that TEM user delegates about latest developments in Solution of TEM technologies for planetary science research.

welcoming any queries on info@jeolindia.com

Presentations:

"JEOL INDIA "

Time- 02:00 – 3:00 Hrs

"Recent Developments in Field of JEOL TEM "

By
Dr. Oikawa San

Contact details:

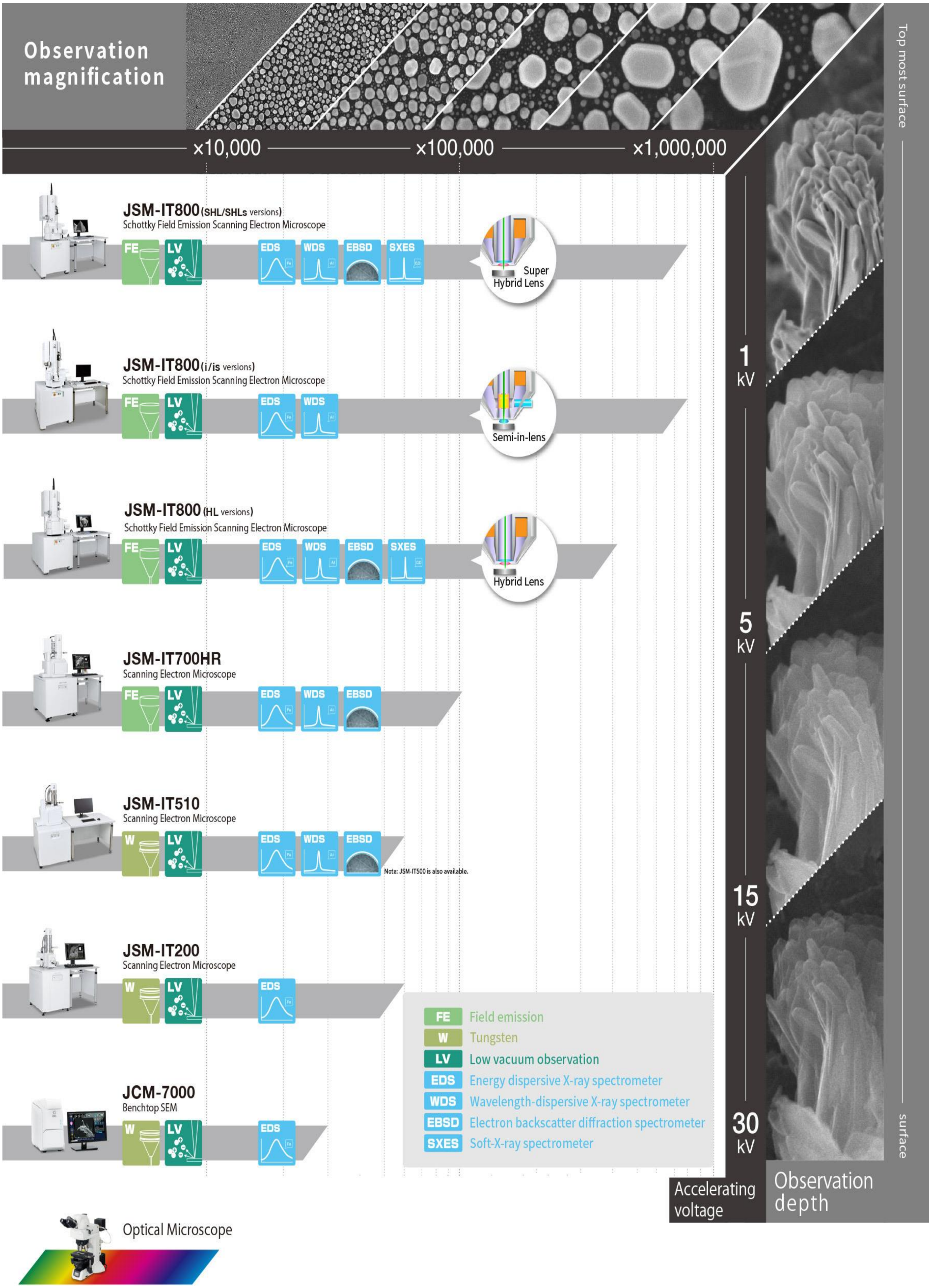
JEOL INDIA PVT. LTD.

Unit No 305, Level 3, Elegance Towers

Jasola District Centre,

New Delhi-110025

+91-11-64722578, 45958005


Observation magnification
×10,000
×100,000
×1,000,000
Top most surface
surface
JSM-IT800(SHL/SHLs versions)
Schottky Field Emission Scanning Electron Microscope
FE
LV
EDS
WDS
EBSD
SXES
Super Hybrid Lens
JSM-IT800(i/is versions)
Schottky Field Emission Scanning Electron Microscope
FE
LV
EDS
WDS
Semi-in-lens
JSM-IT800(HL versions)
Schottky Field Emission Scanning Electron Microscope
FE
LV
EDS
WDS
EBSD
SXES
Hybrid Lens
JSM-IT700HR
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FE
LV
EDS
WDS
EBSD
JSM-IT510
Scanning Electron Microscope
W
LV
EDS
WDS
EBSD
Note: JSM-IT500 is also available.
JSM-IT200
Scanning Electron Microscope
W
LV
EDS
JCM-7000
Benchtop SEM
W
LV
EDS
FE Field emission
W Tungsten
LV Low vacuum observation
EDS Energy dispersive X-ray spectrometer
WDS Wavelength-dispersive X-ray spectrometer
EBSD Electron backscatter diffraction spectrometer
SXES Soft-X-ray spectrometer
1 kV
5 kV
15 kV
30 kV
Accelerating voltage
Observation depth
Optical Microscope

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