International Conference
on
Meteoroids, Meteors and Meteorites : Messengers from Space

20-22 November 2024

Volume of Abstracts

Physical Research Laboratory, Ahmedabad

Director's Note

I am pleased and honored to extend a warm welcome to all the participants of the International Conference on Meteoroids, Meteors, and Meteorites (MetMeSS-2024), which is being hosted by the Physical Research Laboratory in Ahmedabad from November 20 to 22, 2024. As the Director of the Institute and the Chair of the Scientific Organizing Committee, I am delighted to be a part of this assembly of distinguished delegates, scholars, and experts from across the globe.

In an effort to promote planetary science across the nation, and building on the success of the previous three annual symposia held from 2021 to 2023, MetMESS'24 seeks to broaden its global outreach by inviting participation from international experts and researchers.

The goal of the MetMeSS-2024 conference is to bring together diverse multidisciplinary communities to explore a broad range of topics, including early solar systems, meteors and space weathering, extraterrestrial organics in the interstellar medium, and meteorites, as well as surface and subsurface processes of moons, Mars, Venus, small bodies, astrochemistry, astrobiology, and terrestrial analogues. I anticipate and firmly believe that the upcoming days will be filled with engaging presentations, discussions, and opportunities to connect with fellow experts and researchers.

Following the success of Chandrayaan 3, ISRO is gearing up for an ambitious sample return mission from the Moon. PRL, with its extensive scientific expertise and heritage, will play a pivotal role in analysing those returned samples and producing top-notch research in the coming years. PRL is proud to be the host of this international conference, and we're grateful to everyone who has been working tirelessly to make the MetMeSS-2024 a success. A big thank you to the organizing committee, sponsors, and everyone involved.

I hope this conference proves to be a memorable and enriching experience for all the participants. I thank each one of you for being a part of MetMeSS-2024, and wish you a fulfilling, enjoyable, and a memorable experience ahead.

Best regards,

Prof. Anil Bhardwaj
Distinguished Professor
FNA, FASc, FNASc, J.C. Bose Fellow, AOGS Fellow
Academician, International Academy of Astronautics
Director, PRL

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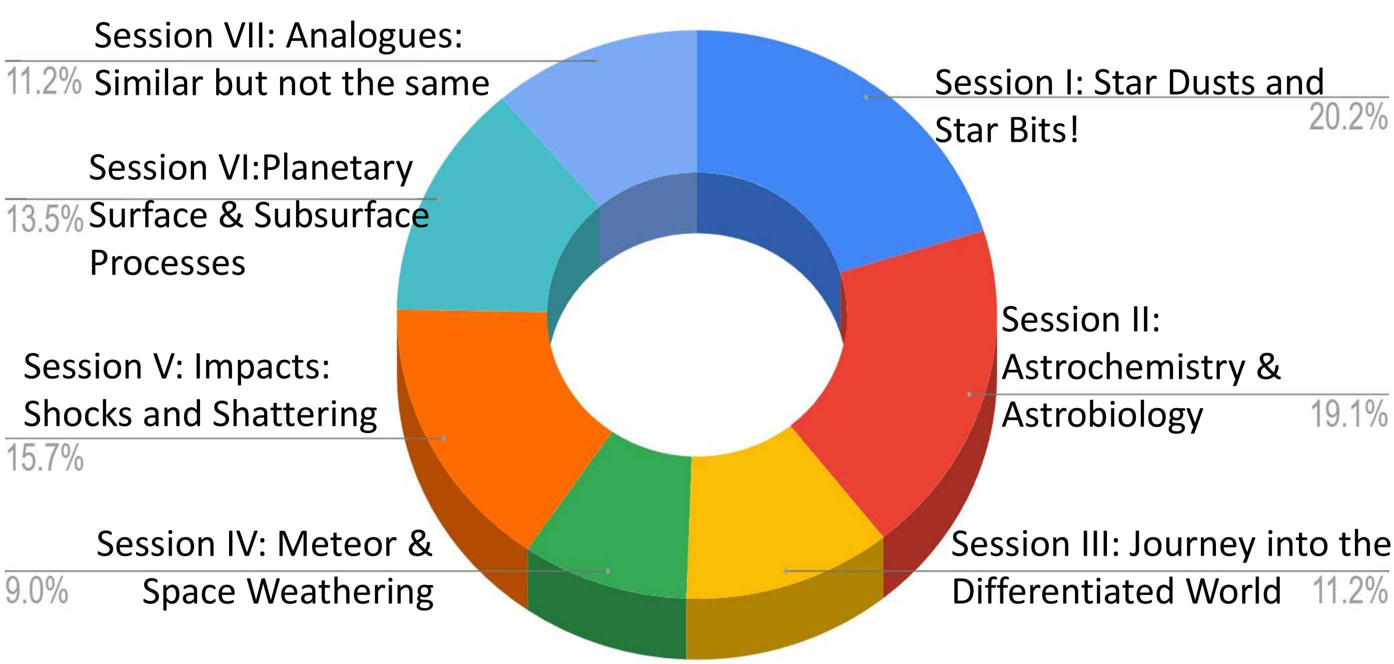
Overview

Total abstracts received	89
Oral	45
Poster	44



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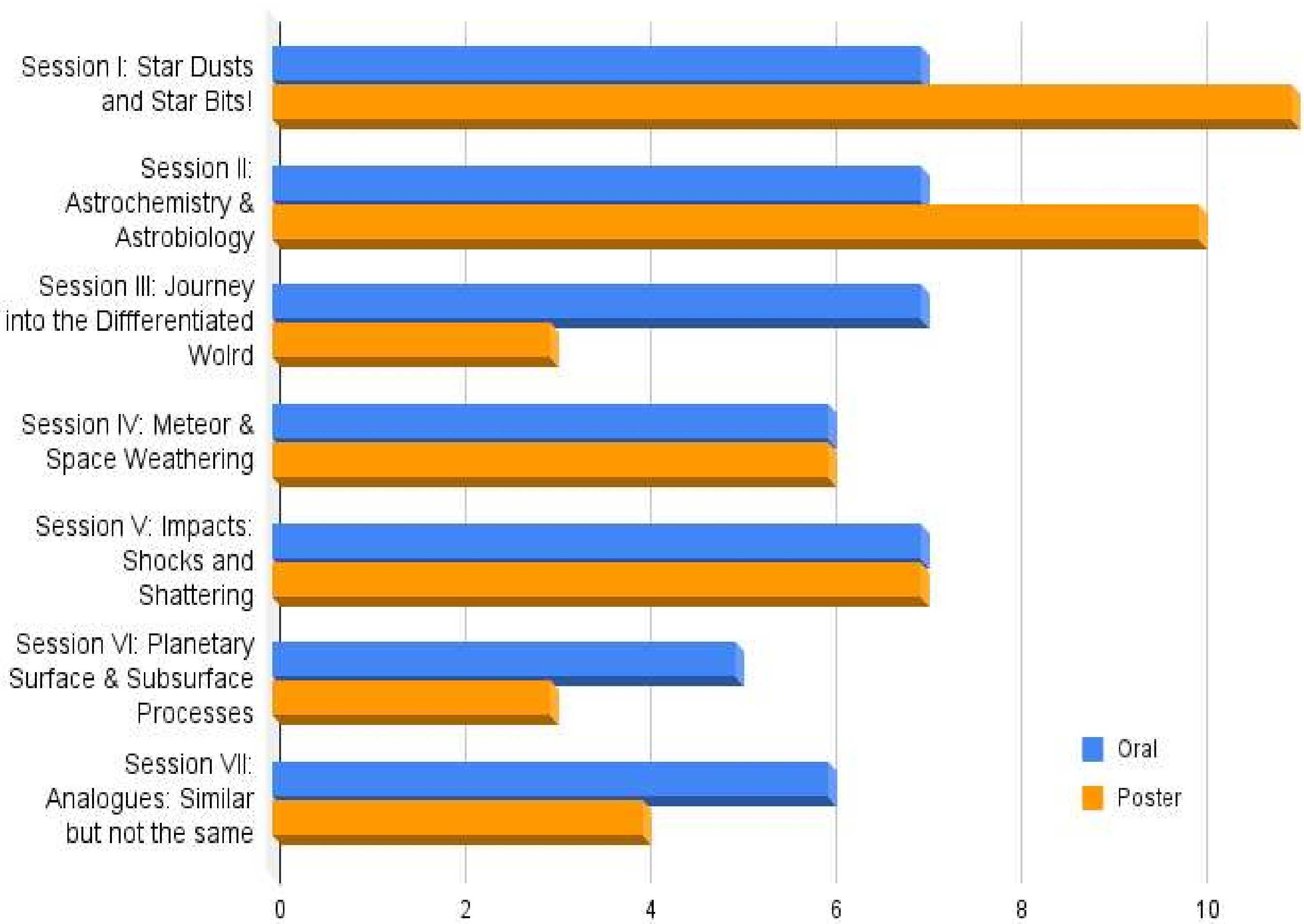
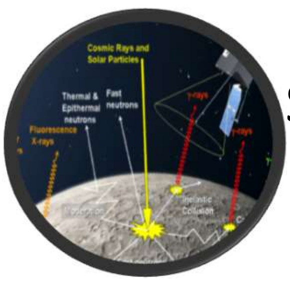


Sessions

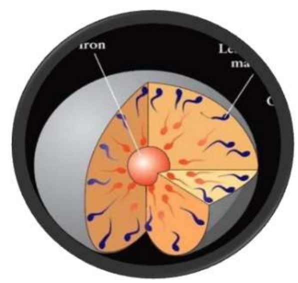
Session I: Star Dusts and Star Bits!

Session II: Astrochemistry & Astrobiology



Session III: Planetary Surface & Subsurface Processes

Session IV: Meteor & Space Weathering



Session V: Impacts: Shocks and Shattering

Session VI: Journey into the Differentiated World

Session VII: Analogues: Similar but not the same

Session -I: Star Dusts and Start Bits!

Abstract ID	Title	Author	Oral/ Poster
SDS-01	Meteoritic perspectives of the origin and early evolution of the Solar system.	Ritesh Kumar Mishra VKSU, ARA, Bihar	Invited talk
SDS-02	Experimental heating of chondrite particles to stimulate micrometeorite heating during atmospheric entry	Rudraswami NG NIO, Goa	Oral
SDS-03	Laboratory evidence of p-nuclide nucleosynthesis in core-collapse supernovae	Manavi Jadhav Department of physics, University of Louisiana at Lafayette, la	Oral
SDS-04	A novel spectroscopic approach to determine alteration histories of Carbonaceous Chondrites	Shreeya PRL, Ahmedabad	Oral
SDS-05	Trace elements in refractory phases of primitive CAIs: implications for formation and understanding the cosmochemical conditions in the early solar system perspective	Ankit Prakash Singh PRL, Ahmedabad	Oral
SDS-06	Organic Diversity in Differentiated Bodies: Unveiling Indigenous Origin and Impact Dynamics	Neha PRL, Ahmedabad	Oral
SDS-07	The Impact of Cosmic Dust on the Cretaceous-Paleogene Boundary	Vijay Pratap Singh NIO, Goa	Oral
SDS-08	Estimation of cosmic radiation flux received by meteorites from their thermoluminescence study	Vinayak Kumar PRL, Ahmedabad	Oral
SDS-09	Secondary alterations in calcium aluminium inclusions	Mahananda Sengupta IIT khargpur	Poster
SDS-010	Modeling H and N isotope fractionation in molecular cloud and comparison	Subhasmita Swain NISER, Bhubaneswar	Poster
SDS-011	Mineralogy and Nobel gas study in chondrule	Dipak Panda PRL, Ahmedabad	Poster
SDS-012	Galactic Chemical Evolution Simulations for Sulphur Isotopes	Antariksha Mitra PRL, Ahmedabad	Poster
SDS-013	Early solar system: events & processes	Anjani Pachauri Gautam Budh University, Noida	Poster
SDS-014	Decoding meteorites with reflectance spectroscopy	Roshan Nath IISER, Bhopal	Poster
SDS-015	Estimation of Mineral Abundance in Meteorites using Reflectance Spectroscopy	Soham D Mali, Iist, Trivandrum	Poster
SDS-016	Unraveling the mystery of probable micrometeorite characteristics from jonnagiri area, kurnool dist, A.P, india	P V Sunder Raju NGRI, Hyderabad	Poster
SDS-017	Linking Kopargaon chondrite meteorite with s – type asteroid Itokawa, a combined spectral – geochemical approach	Subham Sarkar PRL, Ahmedabad	Poster
SDS-018	Thermal Metamorphic Effects in CI- and CM-like Clasts in HED Meteorites: Insights from Raman Spectroscopy	Swarna Prava Das NISER, Bhubaneswar	Poster

SDS-019	Relative chronology of a large CAI from chainpur ordinary chondrite	Ritesh Kumar Mishra	Poster

Experimental heating of chondrite particles to stimulate micrometeorite heating during atmospheric entry

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Abstract: Micrometeorites demonstrate a much more comprehensive range of textural, chemical and oxygen isotopic compositions owing to the heterogeneity in precursors and diverse levels of alteration during atmospheric entry. We have performed a heating experiment on small-size particles that permits us to examine the association between thermal processing and micrometeorite composition for a known precursor material. We conducted experiments to simulate the atmospheric entry of micrometeorites (MMs) using controlled, short-duration flash heating at a temperature range from ~400 to 1600 °C of CI chondrite chips (<1500 μm) in atmospheric air (1 bar, 21% O2) combined with microanalysis (textures, chemical and isotopic compositions) of the experimental products. The parameters used for this approach are similar to those of micrometeorite entry conditions [1-3]. The MM entry heating process is complex but can be experimentally reproduced in the laboratory, allowing us to study the relationship between heating and particle evolution [2,3]. The heated chips closely resemble materials analogous to unmelted MMs, partially melted (scoriaceous) MMs and entirely melted cosmic spherules. We reproduced vital features such as dehydration cracks, magnetite rims, volatile gas release, vesicle formation and coalescence, melting and quench cooling. From this study, O-isotope measurement allows petrographic effects (such as volatile degassing and melting) to be correlated against bulk O-isotope evolution. At the onset of melting (~1000-1200°C), O-isotope compositions evolve through mass-dependent evaporation and mixing with atmospheric air, producing a complex combined signal. Evidence suggests that evaporative loss may dominate once bulk compositions plot on the TFL. The total change in Δ17O during heating up to 1600 °C is <3 ‰ and in most scenarios <2 ‰, indicating that the variation is modest.

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LABORATORY EVIDENCE OF *P*-NUCLIDE NUCLEOSYNTHESIS IN CORE-COLLAPSE SUPERNOVAE

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Introduction: There are currently about 40 known *p*-nuclides, i.e. nuclides heavier than Fe that are proton-enriched or neutron-deficient. The most common process used to explain the synthesis of *p*-nuclides is the γ-process or photodisintegration where heavier nuclei disintegrate into lighter nuclei in the presence of gamma photons in high-energy environments, such as supernovae (SNe) [1]. The main astrophysical site for the synthesis of *p*-nuclides remains ambiguous because the γ-process can occur in Type II core collapse supernovae (CCSNe) [2,3] and also in Type 1a Chandrashekar-mass thermonuclear SNe [4,5]. As the isotopic abundances of a majority of the *p*-nuclides are a very minor fraction of the total abundances of elements, it is impossible to identify these nuclides in stellar spectra, making determining the main astrophysical site that produces *p*-nuclides very difficult. The only method that can be used to determine the abundances of *p*-nuclei is the laboratory analysis of physical samples. Excesses in the *p*-nuclide of Sr (^{84}Sr) have been reported in meteorites by multiple studies [e.g.,6,7]. One of these studies, attribute the anomalous signatures to presolar phases that are enriched in *p*-nuclides within the meteoritic bodies [7].

Here we present Sr isotope measurements on presolar graphite grains and report the presence of enrichments of the *p*-process nuclide, ^{84}Sr (compared to solar abundance), in some grains.

Methods: We conducted light and heavy element isotopic analysis on 49 high-density (HD) presolar graphite grains from the KFB1 HD fraction (2.10 – 2.15 g/cm^3) of the Murchison Meteorite. Light elements, carbon and nitrogen were measured using the NanoSIMS 50 at Washington University St. Louis, while oxygen was measured at the CAMECA IMS-1280 at the University of Wisconsin Madison [8]. Post light element measurement, the grains were re-documented using Scanning Electron Microscope. Using a Focused Ion Beam, the grains were C welded to the gold mount and the mount was etched to better locate the grains. Heavy elements Sr, Zr, and Mo isotopes were measured using Resonance Ionization Mass Spectrometry at the Laser Ionization of Neutrals (LION) facility of the Lawrence Livermore National Laboratory [9].

Results & Discussion: Five grains demonstrate statistically significant excesses in ^{84}Sr, compared to the solar isotopic value. We also present evidence that these anomalies originate in internal subgrains within the graphites. A majority of HD graphites are known to originate in low-metallicity Asymptotic Giant Branch stars [e.g., 10]. However, the *s*-process which is the dominant neutron capture nucleosynthesis process in these stars produces depletions in ^{84}Sr and not excesses. We present evidence that the grains reported in this study originated in CCSNe. Mixing calculations of material from the inner-most zones of CCSNe with material from the C-rich He shell reproduce the anomalies observed in the five grains reported in this study.

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A novel spectroscopic approach to determine alteration histories of Carbonaceous Chondrites.

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Meteorites, remnants from the early solar system, harbor a rich abundance of organic compounds which provides valuable insights into the evolution of parent body The refractory portion i.e., insoluble organic matter (IOM), makes up for 75% of the organic matter, whereas the labile component i.e., soluble organic matter (SOM) contributes the remaining 25% [1].

In this study, we present a novel approach for the calculation of duration of alteration. Insoluble organic matter extracted from seventeen carbonaceous chondrites with varying petrographic types have been analyzed using spectroscopic techniques such as FTIR and Raman to understand their evolutionary histories. The average temperatures of alteration for our suite of sample vary from 36-91℃. On the basis of these temperatures, duration of alteration was calculated which divides our suite of samples into 2 regions i.e, short duration alteration <500years, extended alteration Fig. 1. Furthermore, we attempt to link the origin of these samples to different parent bodies based on the correlation between the duration of alteration and parent body size [2]. This suggests that the majority of our samples could have originated from a small parent body (<50km) or a rubble pile of these (Fig. 1, region B). Interestingly, Ryugu parameters plot right into the rubble pile region which in turn supports our interpretations.

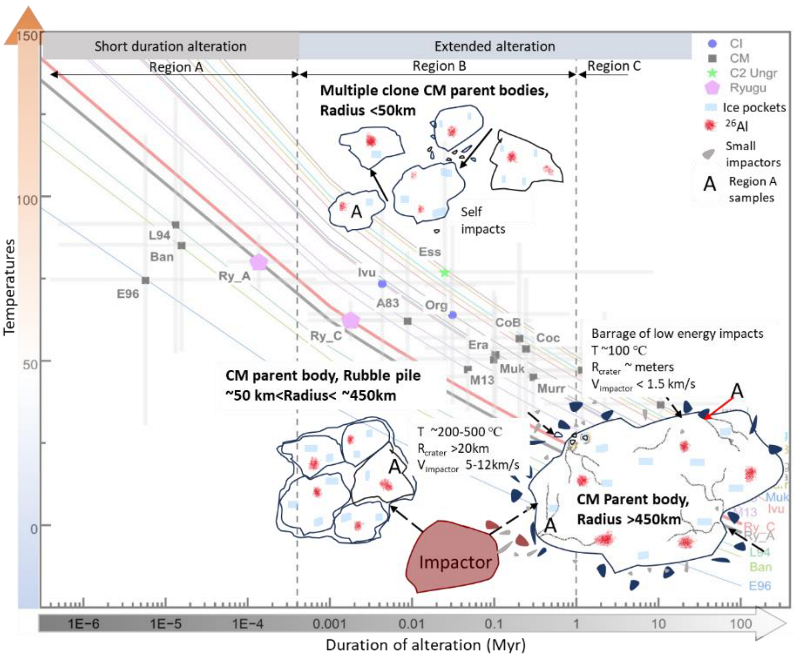

Figure 1: A schematic of the correlation between temperature, duration of alteration and parent body size.

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TRACE ELEMENTS IN REFRACTORY PHASES OF PRIMITIVE CAIS: UNDERSTANDING THE COSMOCHEMICAL CONDITIONS IN THE EARLY SOLAR SYSTEM.

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Introduction: Formation of the first Solar system solids called calcium, aluminium,-rich inclusions (CAIs) by condensation, aggregation, evaporation and melting is a major event in the hot protoplanetary disk. Rare earth elements (REE), most of which are refractory (and lithophile) in nature are incorporated in trace amounts within various mineral phases (pervoskite, spinel, melilite) of the CAIs. The REEs can substitute for a large number of elements, including Ca, Mn, Fe, and Na, due to the similar ion sizes and ionic charged states. The partitioning of REE within various constituent minerals of a CAI depends on the prevalent cosmochemical environment, primarily on the fractionation factor and fugacity. The REE abundances observed in CAIs, therefore, reflect differences in their volatilities, solid-melt partition coefficients, and diffusion behaviours experienced by CAIs during formation in the protoplanetary disk. The REE patterns in CAIs are not governed in the same way as they are for the terrestrial minerals and are, therefore, classified into 6 major groups [1,2]. The abundance of REE in CAIs is uncertain due to the heterogeneous nature of the phases in CAIs, but the primitive or rather refractory ones are primarily characterised by group II patterns. The group II pattern in CAIs results from fractional condensation of refractory REEs like Gd, Tb, Dy, Ho, Er, and Lu identified in ultra-refractory phases of perovskite and hibonites [3-5].

The abundance of REE in meteorites over the years has been determined by various analytical techniques like INAA, ICPMS, and SIMS. The abundance and relative variation in concentration of the trace elements with respect to the major refractory elements of the host phases in CAIs is higher. This high-fidelity behaviour makes them a unique indicator/messenger of the spatial and temporal diversity of the physicochemical conditions of the protoplanetary disk. The electron probe microanalyser quantifies the abundances of various elements in the solid samples in situ at micrometre scale by measuring the normalised intensities of the characteristic X-rays (Kα, Kβ, L and M series) emitted when bombarded with energised/accelerated e- beam. The non-destructive in situ analyses at micron-scale spatial resolution with plausible detection limits at ppm level allow us to compare and co-relate variations within the mineral phases of a CAI to understand their petrogenesis and cosmochemical processes experienced by CAIs.

Result and discussion: A few Type B CAIs from unequilibrated carbonaceous chondrites (CV) type, namely Efremovka, Leoville and Allende, have been analysed using EPMA to study the refractory trace elements. The results show that refractory trace elements tend to partition preferentially in response to the local processes faced by the CAIs. The refractory lithophile trace elements (RLTEs viz. here, Sr, Y Zr, Nb and Ba) are more associated near the zones enriched in refractory Ti; this zone also shows enrichment of LREE>HREE. The zones within the CAI that have experienced significant alteration are enriched in HREE> LREE. The sample shows zonal variation in the enrichment of LREE and HREE with respect to individual phases like melilite, fassaites, spinel, etc. Further work is being carried out to understand the relationship of trace elements with individual phases rather than bulk analysis in order to understand the correlation between the fractionation of a trace element and phases in the CAI.

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Organic Diversity in Differentiated Bodies: Unveiling Indigenous Origin and Impact Dynamics

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Abstract: Aubrites, unique enstatite achondrites formed in a reducing environment intrigued with organic matter presence, seem to have partially defied thermally harsh processes. The aubrites and enstatite chondrites ECs have linked heritage with complex thermal histories with multiple impacts, fragmentation and re-accretion [1,2]. Organics accreted within the aubrite parent body might have registered these complex formation events, providing clues to their impact and peak metamorphic temperatures.

Although organic carbon has been reported in enstatite chondrite (ECs) in previous studies [3,4,5], the same has never been reported in aubrites, probably due to their low abundances. In this study we attempt to compare the organics in aubrites and enstatite chondrites with an objective to understand the extent (widespread occurrence) of the organics within the protoplanetary disk and the physiochemical process providing essential clues to their parent body evolution.

In essence to these investigations, we carried out spectroscopic measurements (Raman, FTIR and XANES spectroscopy) on the chemically extracted Insoluble Organic Matter (IOM) from six aubrites and four enstatite chondrites. The Raman parameter and FTIR data imply different carbon phases present in aubrites and ECs, i.e. carbonized and graphitized organic components. Raman thermometry is utilized to deduce temperatures of their alteration correlating with the FWHM of G Band of IOM. It is worth noting that the temperature deduced for extensively graphitized IOM (∼ 1000 °C) in aubrites are similar to that reported earlier by the silicate thermometry [6,7]. On the other hand, lower temperature obtained for organics near to chondrites, indicates heterogeneity in the organic content that either it is (1) indigenous organics preserved during partial melting of Aubrite Parent Body (AuPB) or (2) the source of organics is exogenous or impact introduction of organics in aubrites. Furthermore, absence of exciton intensity in XANES spectra of IOM and temperature deduced for aubrites suggest that these alterations might be caused by impacts on Aubrite Parent Body (AuPB).

Although some studies have investigated foreign clasts within aubrites, this is unprecedented examination of organics in aubrites, provides a new insight into thermal evolution and impact history of aubrites. Also, it sheds light on the potential impactor (i.e. OCs or CCs) for these events, enhancing our understanding of their formation and alteration processes.

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The Impact of Cosmic Dust on the Cretaceous-Paleogene Boundary

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Abstract: Micrometeorites, tiny particles of extraterrestrial matter, have been a constant source of material to Earth for billions of years. Their flux has varied over time and has been influenced by extraterrestrial activity in the solar system. The K-Pg boundary, marking a major mass extinction event, is characterized by a significantly higher concentration of extraterrestrial material than other periods in Earth's Phanerozoic history [1]. This study presents the first discovery of micrometeorites in Deccan intertrappean sediments, dating back to the K-Pg boundary. These spherules, including silicate-dominated and iron-nickel types, are exceptionally well-preserved due to a favourable depositional environment with rapid sedimentation and favourable climatic conditions. The Deccan age range (67 to 64 Ma) and the presence of impact spherules with their resemblance to Chicxulub impact spherules suggests a potential connection to the Chicxulub asteroid impact and K-Pg boundary [2]. The carbonaceous chondritic nature of these micrometeorites aligns with the composition of the Chicxulub impactor, indicating an active collisional period for carbonaceous chondrites. Their inherent fragility may have contributed to increased dust production in interplanetary space, leading to a higher-than-normal cosmic dust flux to Earth. This elevated dust flux, combined with the effects of Deccan volcanism and the Chicxulub impact, likely exacerbated the environmental conditions at the K-Pg boundary. Additionally, the bioavailable iron in micrometeorites may have played a role in the subsequent recovery of life, providing essential nutrients for organisms [3].

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ESTIMATION OF COSMIC RADIATION FLUX RECEIVED BY METEORITES FROM THEIR THERMOLUMINESCENCE STUDY

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Meteorites acquire their luminescence due to cosmic ray exposure and their thermoluminescence (TL) reaches an equilibrium state due to their long exposure ages and the temperature they experience in space. Typically, meteorite thermoluminescence glow has several peaks and each has a different stability. It therefore implies that due to their inherent stability, these peaks integrate cosmic ray exposure that is limited to their life time. This fact, coupled with the dependence of equilibrium level of TL on the ambient temperature a meteorite experiences in its orbit around the sun, has been used to construct a time-temperature history of a meteorite. A method to invert this time-temperature history record to deduce average cosmic ray exposure over the lifetime of each of these peaks and convert those to time average changes in CR fluxes through time is discussed. A mathematical model to simulate the variation in TL peaks corresponding to irradiation at different temperatures is also constructed. Kinetic parameters which govern the shape of a TL peak were found by applying the initial-rise method on coarse grain samples extracted from *Dhajala* meteorite. Kinetic parameters of the prominent TL peaks typically observed in meteorites TL were calculated. The possibility of estimating the last bleaching event that a meteorite experienced using the model is also explored. The strategy required for the computation of the model, its limitations, the possibility of extending its application to other celestial objects, and the testing of the hypothesis on real meteorite samples is discussed.

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SECONDARY ALTERATIONS IN CALCIUM ALUMINIUM INCLUSIONS

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Introduction: Calcium Aluminium Inclusions are the refractory oxides and silicates of calcium,magnesium,aluminium and titanium found in carbonaceous chondrites and they are the early formed condensates of our Solar system.The CAI's consists of primary mineral phases such as spinel($MgAl_2O_4$),melilite solid solution($Ca_2Al_2SiO_7$-$Ca_2MgSi_2O_7$),hibonite($CaMgxTixAl_{12}$-$2xO_{19}$, where x<1),primary anorthite($CaAl_2Si_2O_8$) and perovskite($CaTiO_2$).The primary minerals in CAI's show evidence of secondary aqueous alterations which are present as rims,veins and pseudomorph primary mineral phases.The secondary minerals are sodalite[$Na_8(Al_6Si_6O_{24})Cl_2$],wadalite,grossular[$Ca_3Al_2(SiO_4)_3$].The CAI's contain shortlived radionuclide having very short half lives such as ^{26}Al-^{26}Mg having ($t_{1/2}$=0.73 Ma) concentrated mainly in the primary mineral phases and ^{36}Cl-^{36}S having ($t_{1/2}$ = 0.3 Ma) concentrated in secondary sodalites and wadalites formed by metasomatic alterations.The ^{26}Al-^{26}Mg and ^{36}Cl-^{36}S systematics can be used as geochronometers to study the processes of early solar system and demarcate the time of formation of this inclusions and its alterations.This study aims at finding out the secondary alteration minerals and their possible formation mechanism in Allende meteorite using Electron Probe Micro Analyser to study the ^{26}Al-^{26}Mg and ^{36}Cl-^{36}S systematics using NanoSIMS.The ^{36}Cl-^{36}S systematics can be performed on sodalite grains(as sodalite is a feldspathoid mineral,a chloride containing sodium aluminosilicate) to determine the time of aqueous alteration and determine the possible source of ^{36}Cl to find out the activity of early Sun. ^{26}Al-^{26}Mg systematics can be performed on grossular(garnet) which forms co-genetically with sodalites and contains Al.

Results:

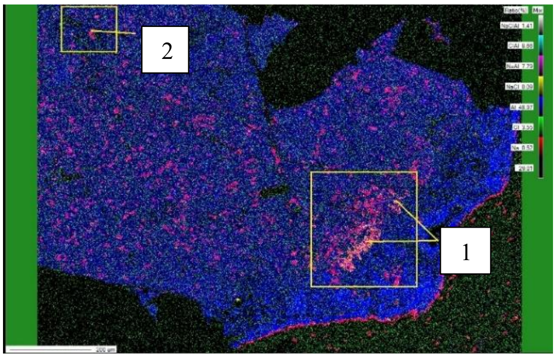

Fig 1

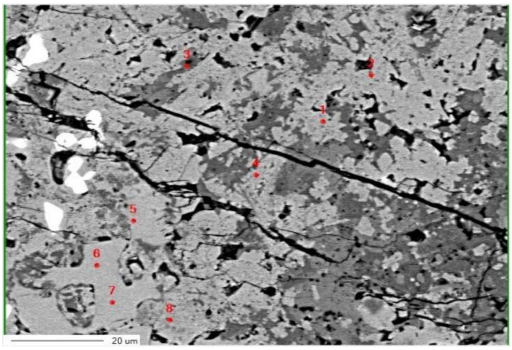

Fig 2

Fig 1 represents presence of Sodalite grains in point 1 and 2 in (Na-Cl-Al) X-ray elemental map.Fig 2 is the BSE image represents presence of Grossular grains in points 1,2,3 and 4.These are parts of Allende meteorite and were named as CAI 15.These are the points on which further analysis will be done on NanoSIMS to determine ^{26}Al-^{26}Mg systematics on grossular grains and ^{36}Cl-^{36}S systematics on sodalite grains.

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Modeling H and N isotope fractionation in molecular cloud and comparison with meteoritic data

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Introduction: Extraterrestrial samples like meteorites, IDPs, comets help us understand the Early solar system history. Isotopically heavier; the so-called hotspots in them are considered to be formed in colder molecular clouds <10K [1, 2, 3]. These hotspots show an extreme 15N enrichment of ~5169‰ in Isheyevo meteorite clasts [4], and D enrichment ~ 24800‰ in an IDP 'Dragonfly' [1]. We are trying to understand the variation in the isotopic values, what conditions in the molecular cloud and the precursor molecules can give rise to these higher values. We are simulating such ratios in precursor molecules using cloud modeling.

Methods: To simulate cloud chemistry, we use a three-phase gas-grain chemical code called "DNautilus" [5] that solves time dependent rate equations and gives time dependent abundances. The network is based on the KIDA database and is extended to include both Deuterated species and ^{15}N species. The rate coefficients of the isotopic reactions are defined based on the statistical branching ratios. The cloud is assumed to have TMC1 physical conditions where T ~ 5K, nH ~ 2.4×10^4 cm^{-3}, visual extinction ~ 10 mag and Cosmic ray ionization ~ 1.3×10^{-17} s^{-1}. The simulation is done for 10 Myr and the results are presented. To understand the effect of temperature on the isotopic ratios observed in meteoritic hotspots, we considered temperatures of 10K, 20K, 50K and 100K for our simulation and their results have also been presented.

Results: Directly understanding the isotopic ratios in the organic molecules is difficult. Here we are considering the N & H containing abundant molecules and the C molecules to be the precursor organic molecules. The models were run for a time period of 10 Myr. At a lower temperature of 5K the most abundant molecule in the gas phase is H_2. In the ice phases H_2 and H_2O are the most abundant molecules. NH_3, N_2 are abundant N containing molecules but with a much lesser abundance than H containing molecules. With higher temperatures there is a tendency to reach steady state abundance. The ice species molecules show a larger heavier isotope ratio than gas species. CH_4 and C_2H_2, CH_3 are the most abundant hydrocarbon molecules. The δD values taking the VSMOW standard value are much lower for these Hydrocarbons. $\delta^{15}N$ of the NH, C_3N, N_2O molecules at a lower temperature of 5K falls in the range of the meteoritic hotspot values. With higher temperatures the delta values are much lower, for the same molecules.

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Mineralogy and Nobel gas study in chondrule

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Introduction: Calcium Aluminium Inclusion and chondrules are the first formed solid in the solar system. Therefore, the study on these objects will provide the information about the early history of origin and evolution of solar system. The chemical and isotopic study of these objects. The chondrites are mainly composed of chondrule, matrix, refractory inclusion, Fe-Ni metal, or metal sulfides. The chondrule is a sub-mm to mm size ferromagnesian spherical objects, formed by melting predecessor material and fast cooling and crystallization These chondrules are classified as porphyritic, granular, barred, radial, or cryptocrystalline, depending on the igneous texture. The classification depends on several factors like different cooling rates, type of precursor material, maximum temperature of molten material. Noble gases are extremely rare in meteorites and can be helpful in understanding the evolutionary processes of early solar system due to their chemical inertness and extremely volatile nature, are. The chondrites meteorites contain the primordial noble gases trapped at the time of formation. Chondrules, the early formed objects in solar system, are major constituents of the chondritic meteorites and hence mineralogical details of chondrules are used in combination of the cosmic ray effect to understand their exposure history and trapped gas variation in the chondrule due to manifestation of cooling period. Different mineral phases can carry distinct trapped noble gas compositions, which require knowledge of both mineral composition and noble gas composition in the same chondrule.
Therefore, a combined study of mineralogy and noble gas (concentration and isotope) study can provide an idea of how noble gas trapping also depends on types of chondrule and mineralogy chondrule [1,2,3]. In this paper preliminary results of mineralogy and noble gas isotopes of chondrules from different types of chondritic meteorite will be discussed

Separated chondrules from different type of chondrite (CM, CV, Ordinary) has been chosen for this study. Each chondrules are broken into two parts. One part is for Mineralogical study and another part is used for Noble gas study. The mineralogical study will be carried out by Electron Probe Micro Analyser (EPMA) whereas the isotopic analysis and concentration of noble gas along with Nitrogen will be analysed with Noble gas Mass Spectrometer (NGMS). Preliminary results from EPMA and Noble gas Mass Spectrometer will be discussed.

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Galactic Chemical Evolution Simulations for Sulphur Isotopes

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Introduction: Sulphur is one of the ten most abundant elements in the universe, primarily produced in massive stars through stellar nucleosynthesis. The presence of Sulphur and its isotopes in different astrophysical environments, such as interstellar medium (ISM), stellar atmospheres, and planetary bodies, makes it a crucial element in tracing chemical evolution. It plays a vital role in Galactic Chemical Evolution (GCE) studies, providing insights into the nucleosynthesis processes and stellar evolution that shape the chemical composition of the galaxy. Sulphur is primarily produced in supernovae, particularly in Type II and, to a lesser extent, Type Ia supernovae, which enrich the interstellar medium (ISM) [1,4]. The isotopic ratios of sulphur, especially $^{33}S/^{32}S$ and $^{34}S/^{32}S$, serve as tracers of various stellar sources and nucleosynthetic environments, making them essential diagnostics in GCE simulations[1]. These ratios help refine stellar yield models and enhance our understanding of galactic mixing and chemical enrichment over time.

Sample analysis, including the study of meteorites and returned samples from asteroids, offers direct evidence of sulphur isotopic compositions predating the solar system[2]. These samples provide critical insights into the nucleosynthetic origins of presolar grains and local chemical environments at the time of their formation. Differences between extraterrestrial sulphur isotopic ratios and those observed in the solar system help to unravel the history of galactic chemical evolution and the conditions prevalent in the protosolar nebula. The integration of high-precision sulphur isotope measurements with GCE simulations and observational data from stellar spectra, supernova remnants, and ISM clouds is essential for advancing our understanding of galactic chemical processes[1,4].

In this study, we examine various GCE models incorporating sulphur isotopes and provide a detailed analysis of their predictive capabilities. We explore how different models handle sulphur production from supernovae, the incorporation of isotopic ratios into simulations, and the resulting implications for our understanding of stellar contributions to the ISM. Using the model by Kobayashi et al. [1], we find that the relationship between $\delta^{33}S$ and $\delta^{34}S$ exhibits a slope of approximately 1.1318, which aligns well with existing GCE models. However, analyses of presolar grains show discrepancies in isotopic ratios due to the effects of thermal pulses in asymptotic giant branch (AGB) stars and the decay of radionuclides that form sulphur isotopes. These processes are not currently accounted for in standard GCE models, presenting an opportunity for future research to explore these aspects and refine the models further.

Hence, we assess the accuracy and limitations of current GCE models by comparing model predictions with empirical data from sulphur isotopic measurements in meteorites, planetary samples, and stellar observations[3,4]. This comprehensive evaluation highlights the strengths of different modelling approaches and identifies critical areas where improvements are needed to enhance our understanding of sulphur's role in galactic evolution.

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Early Solar System: Events & Processes

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Introduction:

The early solar system was a complex and dynamic environment, shaped by a series of intricate processes that ultimately led to the formation and evolution of the planetary bodies we observe today. (Dotti et al., 2019) (Wild, 2015) (Russell, 2007) The current paradigm suggests that the solar system formed from the collapse of an interstellar molecular cloud under its own gravity, around 4.56 billion years ago. This initial collapse led to the formation of a dusty protoplanetary disk, from which the building blocks of the planets, known as planetesimals, began to accrete.

The aggregation of dust and gas into these planetesimals was a crucial step, as it marked the initiation of core formation, magnetic field generation, and the development of planetary atmospheres and oceans (Russell, 2007). The migration of giant planets and the influx of volatile-rich material also played pivotal roles in shaping the composition and habitability of the emerging terrestrial planets. (Kwok, 2009) Furthermore, the clustered environment in which the solar system formed may have had significant impacts on the evolution of protoplanetary disks, as encounters with neighboring stars could have perturbed the disks (Dotti et al., 2019).

Recent advancements in observational, experimental, and theoretical research have shed new light on the key events and mechanisms that governed the early solar system. Studies of meteorites and other extraterrestrial materials, as well as astronomical observations of star-forming regions, have provided valuable insights into the processes that shaped the solar system's formation and evolution. (Russell, 2007)(Dotti et al., 2019)(Wild, 2015)

This period witnessed the aggregation of dust and gas into planetesimals, the initiation of core formation and magnetic field generation, and the development of atmospheres and oceans. Additionally, the migration of giant planets and the influx of volatile-rich material played crucial roles in shaping the composition and habitability of emerging terrestrial planets. Understanding these processes is essential to reconstructing the conditions that led to the formation of the solar system as we observe it today. This abstract discusses recent advancements in observational, experimental, and theoretical research that elucidate the key events and mechanisms in the early solar system, offering new perspectives on planetary formation and the origins of habitable environments.

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Returned Samples: Planetary Missions and Instrumentation

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Introduction:

Planetary sample return missions have revolutionized our understanding of the solar system by providing direct, pristine material from various celestial bodies for detailed analysis on Earth. Missions such as Apollo, Hayabusa, Stardust, and OSIRIS-REx have successfully collected samples from the Moon, asteroids, and comets, enabling comprehensive studies of their composition, isotopic signatures, and formation histories (Newman et al., 2007). These samples offer unique insights into the processes of planetary differentiation, space weathering, and the presence of volatiles, organics, and water in early solar system materials. (Dhingra, 2018) The development of sophisticated instrumentation and analytical techniques, including high-resolution mass spectrometry, synchrotron radiation, and nano-scale imaging, has further enhanced our ability to probe these samples at unprecedented levels of precision.

The analysis of returned samples has yielded significant insights into the formation, evolution, and maturation of the Earth-Moon system, as well as many other planetary bodies in both the inner and outer solar system (Zeigler et al., 2019). For instance, studies of the Apollo samples have provided evidence that the Moon formed from the debris of a giant impact between the proto-Earth and a large bolide early in the solar system history. This abstract discusses the scientific achievements of past and ongoing sample return missions, the challenges in sample collection and preservation, and the future directions in mission planning and instrumentation development aimed at unlocking the secrets of planetary evolution and the potential for life beyond Earth.

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DECODING METEORITES WITH REFLECTANCE SPECTROSCOPY AND DEEP LEARNING

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Meteorites, remnants of asteroids that successfully survive their passage through the Earth's atmosphere, hold critical information about the evolution and history of the Solar System [1]. Traditional methods of analysing these rare and precious specimens often involve destructive geochemical techniques, which can deplete the sample and limit subsequent analyses. Accurate classification of meteorites, typically determined through petrological examination, is crucial before any further analytical steps. Reflectance spectroscopy, which interprets a sample's characteristics by analysing reflected light, has emerged as a non-destructive alternative with significant potential for meteorite classification [2, 3, 4, 5, 6]. This technique allows for the examination of spectral features such as absorption bands, symmetry, band centres, inflection points, and overall slope [2]. In this study, we employed spectral reflectance data from 1505 meteorite samples to develop and fine-tune a deep learning model capable of accurate classification. The model was trained on 80% of the dataset and validated on the remaining 20%, achieving a validation accuracy of 95.17%. These results demonstrate the efficacy of using deep learning and reflectance spectroscopy for meteorite classification, offering a non-destructive and accurate alternative to traditional methods.

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Estimation of Mineral Abundance in Meteorites using Reflectance Spectroscopy

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Traditionally, mineral abundance estimation has relied on destructive techniques like XRD (X-ray diffraction), XRF (X-ray fluorescence), electron probe micro analyzer (EPMA), Laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) etc. However, these methods can damage precious samples and are not always suitable for planetary materials. This study focuses on Reflectance spectroscopy, a non-destructive analytical technique as an alternative to these methods by allowing for the identification and quantification of minerals.

This study focuses on the estimation of modal abundance (wt%) of minerals, specifically Olivine (Ol), Low-Calcium Pyroxenes (LCP) and High-Calcium Pyroxenes (HCP) using the Band Area Ratio (BAR) as the spectral parameter; and application of this methodology on ordinary chondrites. The methodology involves analyzing spectral parameters of known mineral mixtures to estimate the fraction and modal abundance (wt%) of minerals. The method is derived using sample mixtures where the sample consists only of Olivine, HCP and LCP mixtures. Hence, further a specific error reduction framework is required depending on sample type, when applying it to actual samples containing other minerals, impurities, etc. In this study, we focus on ordinary chondrites, discussing the procedures to minimize errors and improve the accuracy of mineral abundance estimations.

When applied to a set of almost 50 ordinary chondrites, the worst-case difference between actual and estimated weight percentage abundances was 6.88, with an average error of 6.08%. Hence, the results demonstrate that this methodology along with appropriate error correction is effective in initial determination within reliable errors ranges, without sample destruction. Moreover, the methodology and steps developed in this study demonstrate how this can be extended to other meteorites, as well as terrestrial and extraterrestrial samples, making it a versatile approach for mineral abundance estimation across a wide range of geological materials In conclusion, this research underscores the significance of reflectance spectroscopy as a powerful and non-destructive tool for studying the mineralogical compositions, offering a reliable alternative to traditional methods and broadening the scope of planetary science research.

UNRAVELING THE MYSTERY OF PROBABLE MICROMETEORITE CHARACTERISTICS FROM JONNAGIRI AREA, KURNOOL DIST, A.P, INDIA

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Introduction: During a reconnaissance survey for gold in the Jonnagiri area in Kurnool district, AP, we accidentally found a unique rock specimen suspected to be a meteorite. The sample is 5 cm long and exhibits characteristic regmaglypts with minute depressions, indicating its entry into the atmosphere. It is magnetic and has a glassy appearance with a vitreous luster. The sample was subjected to PXRD, EDXRF, and basic petrological studies. A typical Widmanstätten pattern (Fig 1a) was found, indicating the presence of interlocking crystals of two minerals, nickel-poor kamacite and nickel-rich taenite, which combine to form a characteristic arrangement that suggests the relatively low pressure at which iron meteorites are formed. The chondrule sizes vary from 1mm to <10 um (Fig 1b), varying from precursor to molten stage and finally to a chondrule. Under reflected light, chondrites show rims with undulations, with shapes varying from circular to semicircular (Fig 1c). The PXRD analysis revealed the presence of Mg-rich olivine typical of meteorites as fayalite ,while the EDXRF analysis of the whole rock with Fe_2O_3- ~ 46%, Cr -~70 ppm, V -~100 ppm, Pb -~120 ppm, classifies it as an Iron chondrite. The microscopic study shows Fe-Ni-S phases, and perfect round to surrounded grains of titanite, NiS, Cobalt, and probable bright phases of native metals like Platinum and Gold (Fig 1d). The Jonnagiri area is a well-known area for the hunt of micro to macro diamonds, along with black diamonds and is assumed to have been formed due to meteoritic impact. Studying the geochemistry of kimberlite pipe rocks and conducting mineralogical studies to identify high-pressure minerals can be a valuable way to understand if diamonds and other carbonaceous materials are created as a result of impact-generated magmatism. The research conducted by Parthasarathy and his group at NGRI, presented in the abstracts of papers from the India-US conference on Space Science in Bangalore on June 21-25, 2004, is particularly interesting .[1] suggests almost circular regional gravity 'low' and the residual gravity 'high' with an amplitude of 55 mgal and uses this to support the impact origin for the basin. Our preliminary studies cannot rule out the possibility of this meteorite and the significance of mineralization is similar to impact sites such as the Sudbury structure in Canada and the Vredefort dome in South Africa, which host the world's largest nickel, uranium, and gold deposits around their impact sites. The Benganapalli formation also shows reverse magnetization in the entire Kurnool Group, indicating that such phenomena can only occur due to a meteoritic impact. Hence, this sample specimen, with isotopic and other advanced studies, can pave the way for understanding the significance of extraterrestrial materials and their link to early primordial mineral Earth processes.

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Fig 1 a

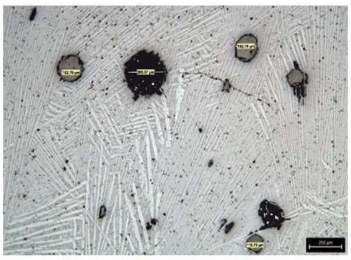

Fig 1b

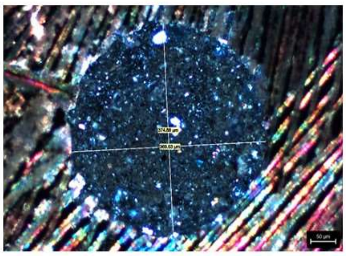

Fig 1c

Fig 1d

LINKING KOPARGAON CHONDRITE METEORITE WITH S – TYPE ASTEROID ITOKAWA, A COMBINED SPECTRAL – GEOCHEMICAL APPROACH

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Undifferentiated asteroids, remain in a pristine state after their formation during the accretion of early solid objects. Thus, they offer crucial insights into the early Solar System's formation. They are the parent bodies of chondrite meteorites, the most common type found on Earth. Studying these meteorites helps reconstruct early Solar System events, such as shock-thermal processes and cosmic-ray interactions. Most of the analysis and classification of the meteorites have been done using various geochemical analyses. But, for their parent bodies, the asteroids, classification is primarily based on Visible and Near Infra-Red spectra. Recent asteroid missions have provided valuable geochemical data, suggesting a combined geochemical and spectral approach for classifying meteorites and their parent bodies. Both chondrite meteorites and s-type asteroids can be easily identified using VNIR spectroscopy due to the presence of the strong 1 μm and 2 μm absorption bands indicative of olivine and pyroxene [1]. In this study, we are using geochemical and reflectance spectroscopic data of the Kopargaon meteorite, the most recent fall of India. After preliminary mineralogical and geochemical study, it has been classified as an LL-type ordinary chondrite of petrologic group 5 [2]. LL chondrites are often associated with S-type asteroids in the Main Asteroid Belt due to their spectral similarities [3,4]. The Hayabusa-1 mission provided valuable samples and data from the S-type asteroid 25143 Itokawa using Near Infrared Spectrometer (NIRS) and X-Ray Fluorescence Spectrometer (XRS) [5,6,7]. In this context, we aim to explore Kopargaon's possible association with S-type asteroid using both lab-based and remotely sensed data.

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Thermal Metamorphic Effects in CI- and CM-like Clasts in HED Meteorites: Insights from Raman Spectroscopy

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Introduction: Meteorite breccias are crucial for understanding early Solar System processes and the evolution of their parent bodies [1]. Volatile-rich clasts found in various chondrites (CH, CR, CB, O, R) and other achondrite types like HEDs and ureilites offer valuable insights into primitive solar system material, including some that are not yet present in our meteorite collection [2,3]. Carbonaceous matter within carbonaceous meteorites undergoes significant structural and chemical changes due to thermal metamorphism on the parent asteroid, leading to irreversible maturation [4-7]. To gain insights into the history of thermal alteration in the parent bodies of these volatile-rich clasts, it is essential to determine the peak metamorphic temperature (PMT). Raman spectroscopy is a key method for estimating PMT, though the process involves considerable uncertainties [4-7]. This study examines the PMT of volatile-rich clasts in a polymict eucrite and a howardite, comparing the efficacy of two thermometric approaches [6,7].

Samples and Methods: We analyzed polished thin sections of meteorites, including Allende (CV3), Vigarano (CV3), Jbilet Winselwan (CM2), Aguas Zarcas (CM2), and Murchison (CM2), as well as NWA7542 (polymict eucrite), and Saricicek (howardite). Raman spectra were acquired using a LabRAM HR Evolution Spectrometer with a 532 nm excitation wavelength at low laser power (≤0.3 mW) to prevent thermal effects on organics. We also recorded spectra at laser energies varying between approximately 0.05 mW and 1.5 mW to understand the potential progressive degradation of organics under laser exposure. After applying linear baseline corrections, the peak positions and full width at half maximum (FWHM) of the Raman peaks were determined by fitting the spectra using 4-pseudo-Voigt or 2-Lorentzian profiles. PMT was estimated using the equations provided by [6,7].

Results and Discussion: Temperature estimates derived from Raman spectra of matrix organics in Murchison exhibit variability with respect to laser power depending on whether the calculations use the Homma method [6] or the Schmidt method [7]. Reproducible temperatures were achieved only at lower laser powers (<0.3 mW). For the CM-like clasts in the polymict eucrite NWA7542 (clast number: 13,14,15,211), PMT ranged from 95°C to 202°C using equation from [6], and from 74°C to 100°C using that of [7]. In contrast, for a CI-like clast (B2), the temperatures were 188±42°C [6] and 48±18°C [7]. The discrepancies between these methods arise from their use of different full width at half maximum (FWHM) values: the D-band for Homma [6] and the G-band for Schmidt [7]. The Homma method is sensitive to FWHM-D band variations, where a 1 cm^{-1} difference can lead to a 7% change in the estimated PMT. We are also studying 10 more clasts. In an olivine-rich clast (X-9A, X-9B), shows forsterite grains with thick fayalitic rims were observed without evidence of prior aqueous alteration, indicating either transformation of all secondary phases to olivine during heating or minimal aqueous alteration before heating.

Conclusions: Determining PMT from Raman spectra of matrix organics in volatile-rich meteorites or clasts is challenging, with significant dependence on laser power selection and data processing parameters. Volatile-rich clasts in NWA7542 polymict eucrite show similarities to CI and CM chondrites, with evidence of strong heating in one clast. However, further research is required to clarify the history of aqueous alteration before heating events. Accurate PMT estimation, especially at low temperatures (<200°C), required careful spectral fitting and laser power control to ensure reproducibility.

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RELATIVE CHRONOLOGY OF A LARGE CAI FROM CHAINPUR ORDINARY CHONDRITE.

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Introduction: The birth of Sun, 4.56 $\times 10^9$ years ago, is accompanied by formation of an alpha (α) shaped protoplanetary disk. The protoplanetary disk quickly develops a gradient (variable with time and state of nascent Sun) in several parameters including temperature, density, composition (even isotopic), flux of radiation, and number abundance of solid particles. In the cooling parcel of a gas of solar composition in the protoplanetary disk, the first solids of the Solar system are formed.

The first forming Solar system solids are refractory oxides and silicates of calcium, aluminium, titanium and magnesium which give them their eponymous name Calcium, Aluminium-rich Inclusions (CAIs) [1,2]. The abundance, mean size, mineral composition and normative mineral phases abundance of CAIs are distinct characteristics of different chondrite groups. Carbonaceous chondrites have preponderance of CAIs up to ~3 volume % in Vigarano (CV e.g., Efremovka, Vigarano) type with a large range of size varying from few microns to a few centimetres. Ordinary chondrites (OC), however, very sparsely (<0.02-0.2 vol. %) have CAIs [1-8]. Only a few (~50), mostly very small (~20-50 microns) have been found in ordinary chondrites compared to several large, few 10,000 in the carbonaceous chondrites. Owing to this dichotomous fact, the information about the earliest phase derived from CAIs is probably a representative and generalized view of the carbonaceous reservoir [1-12].

To validate the similarity or differences, it is of significant importance to find large CAIs (very rare) in ordinary chondrite (preferably of the lowest petrographic grade ~3.0) for analogous petrographic, morphological, isotopic and chronology studies. Our extensive, systematic search in the lowest petrographic grade Ordinary chondrite led to finding a few large CAIs.

Results and discussion: A large type A CAI of 1500×1200 µm found in Chainpur consists of a central elongated spinel free melilite region that is surrounded by more gehlenitic (Al-rich) melilite that is peppered with spinels of different size [13]. It is the *largest sized* CAI in the ordinary chondrite reported so far; the second largest (600×400 µm) being a recent 'find' of spinel- melilite bearing CAI from NWA 8276 (LL3.00) [11]. Here we present preliminary results of ^{26}Al-^{26}Mg isotope systematics (relative high-precision chronology) and oxygen isotope in a large CAI from Chainpur (LL3.4). An O^- primary beam of ~10×15 microns size and carrying a current of ~5.3 nA was used to obtained positive secondary ions of ^{24,25,26}Mg, and ^{27}Al. The secondary ions were measured simultaneously in multi-collection mode using faraday cups. Multiple analysis within melilite and spinel have yielded a ^{26}Al isochron corresponding to ^{26}Al/^{27}Al of $(4.83\pm0.14)\times 10^{-5}$ (2σ) with an initial $\Delta^{26}Mg_0$ intercept of -0.30 ± 0.09 permil (2σ). Results and implications of ^{26}Al-^{26}Mg and oxygen isotope for the origin and evolution of the Solar system will be discussed.

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Session- II: Astrochemisty & Astrobiology

Abstract ID	Title	Author	ORAL /POSTER
AA-01	Searching for the origins of life; From Meteorites to Mars.	Nigel Mason Open University, UK	Invited Talk
AA-02	Tardigrades on icy moons – investigating their survivability using SALT	Bhala Sivaraman PRL, Ahmedabad	Oral
AA-03	A study of the origin and distribution of dissolved organics in highaltitude hotsprings of Ladakh	A. H. Ansari et. al. BSIP, Lucknow	Oral
AA-04	Theoretical Study of Chemical Pathways to Propanol synthesis in Interstellar Medium	A. Mishra et al. Phy. Dept, Lucknow University	Oral
AA-05	Shock Processing of smaller PAHs and its consequences on interstellar chemistry	A. Roy et al. PRL, Ahmedabad	Oral
AA-06	Low-Energy Electron Impact Dynamics on Astrochemically Relevant Molecules.	M. Vinodkumar et. al. V. P. & R. P. T. P. Science College, Vallabh Vidyanagar	Oral
AA-07	Formation of water ice at 200 k: a result of hydrogen Bonding between diols and water	W. Khan et al. PRL, Ahmedabad	Oral
AA-08	N_2D^+ as an evolutionary indicator of starless cores- the parent cloud of Solar type of system and our chemical origin	Dipen Sahu et. al. PRL, Ahmedabad	Oral
AA-09	Molecular processes driven by positron interaction with H_2CO, NO_2 and O_3	Barad Nehaben Devchandbhai	Poster
AA-010	Making the interstellar minerals behind the shock front	Dr. Arijit Roy PRL, Ahmedabad	Poster
AA-011	Interstellar Formation 1, 4-pentadiyne (HCCCH2CCH): A DFT Study	Parmanand Pandey Lucknow University	Poster
AA-012	Proton Transfer Reaction of NCCNH+ in the Interstellar Medium (ISM)	Rachana Singh Lucknow University	Poster
AA-013	Electron impact ionization cross section of ethyl amine and propyl amine	Nirali Rajubhai Bhavsar Govt College, Surat	Poster
AA-014	Electron and positron interaction with molecule of astrophysical Importance	Pinalben Chandrakantbhai Mer M.S. Baroda	Poster
AA-015	Insights into plausible reaction pathway for the formation of Interstellar Allylimine: Theoretical Approach	Pravi Mishra Lucknow University	Poster
AA-016	Investigating astrochemical ices containing intramolecular hydrogen bond - 1,4 butanediol ice	Shivanshi Gupta PRL, Ahmedabad	Poster
AA-017	Mid-infrared spectroscopic investigation of a sample of near earth asteroids	Allena George	Poster
AA-018	Tentative's detetction of Amines on Jupiter's moon Callisto	Ganapathy	Poster

TARDIGRADES ON ICY MOONS – INVESTIGATING THEIR SURVIVABILITY USING SALT

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Tardigrades are known to be resilient tiny creatures, size ranging from 100 - 500 micron, that can even survive non equilibrium conditions. Capsules loaded with Tardigrades were sent to the lunar surface and analogues in laboratory experiments showed that the Tardigrades can survive the hypervelocity impact events. Different species of tardigrades had been subjected to a range of cold / heat conditions and chemical environments, where certain varieties of tardigrades were found to survive. Though Tardigrades were subjected to extreme conditions, they are yet to be subjected to a combination of extreme conditions especially the subsequent reduction in pressure and temperature conditions, such as those experienced on the icy moons.

This year, via the Govt Arts College (Ooty) and PRL, collaborative effort we are able to find a new species of tardigrade. However, the survivability of this newly identified tardigrade in extreme conditions, especially icy moon conditions, are not known to-date. In addition, other tardigrades are also subjected to similar conditions to understand their survivability on the surface of the icy moons.

Tardigrades isolated form the mosses and lichens from the Nilgri hills were loaded on to an oxygen free high conductivity (OFHC) copper sample holder before they turn to the tun state. The OFHC copper holder was then mounted to the tip of a cold head cooled using closed cycle helium refrigerator. The chamber was evacuated using a combination of turbo and backup pumps to reach ultrahigh vacuum (UHV) pressures. Once UHV conditions were reached then the tardigrades were left for a few hours at room temperature. The chamber was then decompressed to remove the tardigrade to test for survivability.

Similar conditions to those above were repeated and once the UHV conditions were reached then the cold head was turned on in order to reduce the temperature from 300 K to 100 K in about 30 minutes. Tardigrades were left at 100 K for about 2 - 6 hours before rising the temperature back to 300 K at the rate of 5 K per minute. Tardigrades were then removed to test for survivability.

The preliminary results on the survivability of tardigrades at icy moon conditions, which are not known to-date, will be presented in this meeting.

A study of the origin and distribution of dissolved organics in high-altitude hotsprings of Ladakh.

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Ladakh's high-altitude hotsprings are long thought to provide therapeutic benefits. These hotsprings, however, have recently drawn interest from astrobiological researchers as they roughly replicate several extreme environmental factors present on the early Earth and early Mars. Thus, the research focussing on such hotspring's depositional environment could provide us with some novel biomarker tools to investigate Earth's early life and look for potential evidence of extinct life on Mars. The origin and distribution of dissolved organic compounds in the Ladakh hotspring waters were examined in this study for the first time. During the investigation, the thermal water temperatures and pH values of the Chumathang, Panamik, Changlung, and Puga hotspring locations ranged from 50.4° to 84.9°C and from 7.01 to 8.08, respectively. The results suggest that bacterially-produced organic molecules, primarily n-alkanes, esters, alcohols, carboxylic acids, and alkenes, predominated at these locations. Low molecular weight n-alkanes (C12 and C14) may include minor amounts of indistinguishable thermogenic abiotic chemical molecules.

Theoretical Study of Chemical Pathways to Propanol synthesis in Interstellar Medium

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The search to understand the origin of life and the possibility of extraterrestrial life remains a major focus of scientific research. The discovery of various organic molecules in the interstellar medium (ISM) indicates that the basic building blocks necessary for life are widely distributed throughout space, having been synthesized from simpler interstellar molecules[1]. Numerous physical and chemical processes have been suggested to explain the formation of these organic compounds in the ISM[2]. The study of possible reaction mechanisms, that may be responsible for the formation of molecules detected in outer space, may provide a better understanding of the origin of life. Several studies have been performed to predict the possible route to the formation of molecules of biological importance such as glycine, alanine, amines and imines, nitriles, glycoldehyde, cyanide, carbodimide, etc[3–13]. Alcohols are considered essential precursors for the formation of more complex organic molecules, making their detection in the interstellar medium particularly significant for understanding the origins of life and the chemical reactions taking place in space. In the present work, we proposed potential reaction pathways for the formation of two isomers of propanol viz., i-propanol and n-propanol in the interstellar medium. The presence of i-Propanol has been observed in interstellar space near Sgr B2(N2), while n-Propanol has been identified in hot cores, with an abundance ratio of 0.6 [14]. The proposed reaction pathways for the formation of both iso-propanol and n-propanol in the interstellar medium are based on the utilization of molecules that have been predominantly detected in interstellar environments. These pathways are carefully constructed by considering the known chemical species present in space and the conditions under which they interact. By examining the potential reactions among these interstellar molecules, we aim to identify the specific mechanisms through which i-Propanol and n-Propanol can be synthesized. The study not only proposes these reaction pathways but also analyzes the underlying chemical processes, providing insights into how these alcohols could form naturally in the vast, cold regions of space where stars and planetary systems are born. This investigation enhances our understanding of the complex chemistry that occurs in the interstellar medium and its role in the potential origins of life.

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Shock Processing of smaller PAHs and its consequences on interstellar chemistry

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The Polycyclic Aromatic Hydrocarbon (PAH) molecules are made of many fused benzene rings and are considered an important reservoir of cosmic carbon. These molecules have been proposed to be a potential carrier of many interstellar emission and absorption features, the Unidentified Infrared Emission (UIE), Diffuse Interstellar Bands (DIB), and interstellar extinction features [1,2,3]. 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). Well before their detection in the ISM, these smaller PAHs have been 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 interstellar dust. Therefore, a growing need exists for 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 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]. In recent years' shock tubes have emerged as a new tool to mimic interstellar low velocity (3< M< 10) shocks in the laboratory [9]. By utilizing the High-Intensity Shock Tube for Astrochemistry (HISTA) housed at the Physical Research Laboratory, we studied the shock processing of the smaller interstellar PAH analogues such as naphthalene, anthracene, 1-cyano naphthalene (1-$C_{10}H_7CN$, 1-CNN) and naphthalene-2-carbonitrile (2-$C_{10}H_7CN$, 2-CNN), acridine ($C_{13}H_9N$). These molecules were subjected to shock fronts with Mach ~ 5.6 (1.8 km s^{-1}) and reflected shock temperature ~ 7300 K for 2 ms. The shock-processed samples were analyzed using IR spectroscopy, Raman Spectroscopy, and HR-TEM imaging techniques. The analysis of the shocked samples showed two important features: shock survival of PAHs and the dependence of produced dust morphology on the precursors' structure. In this meeting, we shall discuss the above-described results in detail and their importance in cosmic dust chemistry.

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Low-Energy Electron Impact Dynamics on Astrochemically Relevant Molecules.

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Introduction: Electron-molecule scattering processes are integral to a wide range of scientific disciplines, including astrophysics, astrochemistry, biophysics, plasma physics, nanotechnology, and atmospheric science [1]. These interactions are crucial for understanding the distribution of electron energy and the subsequent chemical reactions that occur in various environments, from interstellar space to planetary atmospheres. Cyanopolyacetylenes (HCnN, where n = 3, 5, 7) are particularly significant in this context, as they are believed to participate in the intricate photochemical reactions taking place within the atmosphere of Titan, Saturn's largest moon [2]. These molecules are also hypothesized to be key components of cometary nuclei, contributing to the complex chemistry of comets [3]. Moreover, cyanopolyacetylenes have been detected in a variety of astronomical environments, including the circumstellar envelope of IRC+10216 [4], the dense molecular clouds of TMC-1 [5], and regions such as Heiles 2 and TMC-2 [6].

Investigating how electrons interact with these interstellar molecules is vital for advancing our understanding of fundamental processes such as ionization, chemical reactions, and electronic excitation. The present study employs the R-matrix method [7], a sophisticated computational approach, facilitated by Quantemol-N software [8], to explore the scattering dynamics of three cyanopolyacetylene molecules: HC_3N, HC_5N, and HC_7N. This study provides a comprehensive analysis of target properties, including structural data and vibrational frequencies. Additionally, it offers detailed cross-sectional data encompassing symmetric decomposed elastic, total elastic, differential, momentum transfer, discrete electronic excitation, and ionization cross-sections [9]. A representative result illustrating the elastic cross-section is presented in Fig 1. The full spectrum of findings from this study will be elaborated upon during the conference presentation.

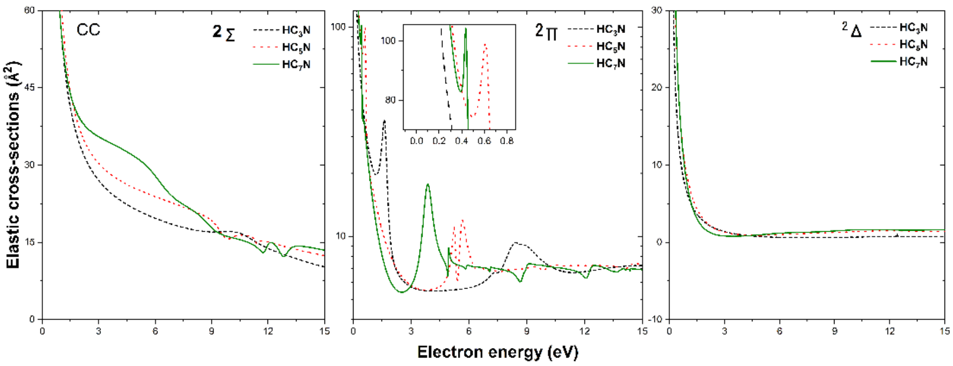

Figure 1. Symmetric decomposed elastic cross-section: black short dash line for HC3N; red dot line for HC5N; green solid line for HC7N.

Acknowledgment: Minaxi Vinodkumar and **Chetan Limbachiya** acknowledges DST-SERB, New Delhi for the Major research project [CRG/2021/000253] for financial support.

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FORMATION OF WATER ICE AT 200 K: A RESULT OF HYDROGEN BONDING BETWEEN DIOLS AND WATER.

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Introduction: Water ice, being the most abundant ice in the solar system and in the interstellar medium (ISM) [1] plays an important role in the formation and evolution of molecules in low-temperature, low-pressure astrochemical conditions. In the protoplanetary disk, the formation of water ice on the dust grains occurs by colliding the water molecules onto the dust grains below 160 K [2], also known as the snowline temperature of water in astrochemical conditions. The laboratory studies also suggest that the sublimation temperature of water ice in the astrochemical conditions is 180 K [1,3]. Hence the condensation of water ice on the dust grains at a temperature above 180 K is impossible in such scenarios. In this work, we present the condensation of water ice at a temperature of 200 K onto the diol molecular ice (Sublimation temperature > 230 K) grains due to H-bonding between diols and water at these extreme conditions. It is important to note that the protoplanetary disk contains a large number of simple to complex molecules; in fact, complex organic molecules are considered as the byproduct of the protoplanetary disk evolution [4].

Methodology: 1,3 Propanediol (PD) / ethylene glycol (EG) and D_2O, available in liquid state, were used. The experiments have been carried out under low temperature (8 K - 300 K) and pressure (~10^{-9} mbar) conditions using the SALT (Simulator for Astro-molecules at Low Temperature) setup [5] housed at the Physical Research Laboratory, India. Vapors of diols were deposited onto a Zinc Selenide (ZnSe) substrate at 200 K, on top of the resultant ice, D_2O was deposited at 200 K. The ices were probed *in situ* by FTIR spectroscopy using Thermo Scientific Nicolet iS 50 FTIR Spectrometer. D_2O is chosen instead of H_2O to avoid the overlap in the OH peaks of diols and water.

Results and Discussions: While we tried to deposit pure D_2O at 200 K on the ZnSe substrate for 1 hour by allowing D_2O molecules into the UHV chamber at a pressure 10^{-8}~10^{-9} mbar, no signature of D_2O was observed in the IR spectrum. In other experiments, we first deposited 1,3 PD (or EG) at 200 K and used the spectra of the resultant ice as a background. Then we deposited D_2O (at the same base pressure range 10^{-8}~10^{-9} mbar) on top of the previously deposited 1,3 PD/EG ice. Here we could observe the appearance of OD stretching band where the intensity of the band increased over deposition time. We attribute this is due to the hydrogen bonding between the molecules of 1,3 PD/EG and D_2O which significantly increased the binding energy of D_2O with the diols even at this temperature and resulted in the formation of D_2O molecular ice layers on top of PD/EG. The growth of the OD stretching peak was quite faster at the beginning of the D_2O deposition and then slowed down over time. This could be due to the number of available PD molecules to form hydrogen bonding being more at the beginning of deposition and the reduction in the available sites due to hydrogen bonding as deposition time increases. The deposited D_2O ice over PD was kept in isothermal condition at 200 K for 1 hour to check for any D_2O desorption at 200 K; however, the peak appears to be the same even at isotherm. The results clearly demonstrate a strong hydrogen bonding between the PD and D_2O molecules responsible for the condensation of water ice at a temperature above its sublimation. This result has significant implications in the chemistry involving water ice in such protoplanetary disks.

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N_2D^+ as an evolutionary indicator of starless cores- the parent cloud of Solar type of system and our chemical origin

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We present ALMA Band 6 observations of 29 starless cores which targets 72 single dish identified cores. After thorough analysis, we focus on the chemical properties of the starless cores, as well as detection statistics using ALMA. Among the 29 cores, 14 are considered detected in ALMA ACA array (beam~2000 au scale) observations. Our findings suggest that ACA-detected cores are more evolved than their non-detected counterparts. To further investigate this, we extracted radial density profiles and fitted them using the prestellar core density model, revealing that detected cores typically have flat region sizes of 10″ or less and peak densities of 10^6 cm^{-3} or greater. We compare these detections with previous surveys to evaluate core lifetimes and find that all ACA-detected cores are likely gravitationally bound and on the verge of collapse based on virial analysis. We also analyzed molecular maps primarily using N_2D+ and DCO^+, **finding that N_2D^+ emission closely traces core evolution**, while DCO^+ is detected in both ACA-detected and non-detected cores.

The significance of this result is that, for the first time, we have revealed how starless cores, which is the parent core of a Solar type system evolve to form a Solar type of star and explored the chemical nature of the cores. This further helps us to gauge the isotopic fractionation and origin of complex organics molecules in the Solar type of protostars. Based on the published results and ongoing work, we will briefly discuss the early evolution of the solar type system and our chemical origin.

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Molecular processes driven by positron interaction with H_2CO, NO_2 and O_3.

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Introduction: Electron and Positron driven molecular processes are a fascinating area of research that bridges atomic physics and chemistry [1]. The atmosphere of Planets is dynamic and a sphere of constant activities, where numerous processes occur to influence weather patterns, air quality, and ultimately, life on Planets [2]. In this work, we report results of comprehensive study of positron driven molecular chemistry for atmospheric compounds, H_2CO, NO_2 and O_3. These molecules are pervasive in atmosphere of Planets and have a considerable effect on climate change. We have quantified various molecular processes initiated due to positron interaction by evaluating elastic (Q_{el}), inelastic (Q_{inel}), direct ionization ($Q_{D\text{-}ion}$), total ionization (Q_{ion}) and positronium formation (Q_{Ps}) and total cross-sections (Q_{tot}) from the respective threshold energy of the molecular process to 5000 eV using modified Spherical Complex Optical Potential (SCOP) method [3]. Positron driven ionization is investigated using Complex Scattering Potential – ionization contribution (CSP-ic) method [3]. This study aims to find probabilities for different positron assisted processes of these molecules using the quantum chemical treatment that can contribute to improve various models of astro-chemistry.

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Making the interstellar minerals behind the shock front

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Solid matter in the Interstellar Medium (ISM) has been detected in different astrophysical environments, and our solar system is typically classified into three categories: silicate-type minerals, carbonaceous dust, and ices [1]. A significant amount of interstellar minerals is thought to be produced via the gas phase condensation process in the extended envelope of the Asymptotic Giant Branch (AGB) stars [2]. The elemental abundance of these stars greatly affects these minerals' chemical compositions, especially the C/O abundance ratio. For the case of C/O <1, the dust grains are mostly oxides like olivine, pyroxene, spinel, etc.; for C/O >1, dust grains are carbonaceous like SiC, C_{60}, and other carbon allotropes [2]. However, our understanding of the formation pathways of these dust grains, especially for mineral dusts like olivine and SiC in stellar environments, is limited.

Shock waves are widely observed in different parts of ISM and, depending on its strength, can induce various events such as sputtering and shattering while interacting with dust grains [3]. The low-velocity shocks (3< M< 10) can enrich its propagating medium through thermal processing and enhance the molecular complexity of the ISM [3]. The low-velocity nebular shocks have also been proposed to be responsible for the formation of crystalline mineral dust in the comets [4]. In recent years' shock tubes have emerged as a new tool to mimic interstellar low velocity (3< M< 10) shocks in the laboratory [5]. By utilizing the High-Intensity Shock Tube for Astrochemistry (HISTA) housed at the Physical Research Laboratory, we studied the shock processing of cosmic silicate, and SiC dust precursors. The processed samples have been analyzed using IR spectroscopy, XRD, FE-SEM, and HR-TEM imaging techniques. In this meeting, we will discuss some of the preliminary results of this experiment and their importance in cosmic mineral chemistry.

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Interstellar Formation 1, 4-pentadiyne ($HCCCH_2CCH$): A DFT Study

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Abstract:

Cold dark molecular clouds in Interstellar medium are especially valuable for studying interstellar chemistry as their physical properties are better understood than those of heterogeneous, complicated huge molecular clouds [1]. One such dark cloud TMC-1 has advanced our knowledge of the chemistry of the interstellar medium to new dimension. Due to its carbon rich composition, a large number of novel molecules have been found recently using the Green Bank 100 m telescope via the GOTHAM2 line survey [2] and the Yebes 40 m radio telescope via the QUIJOTE1 line survey [3]. A significant part of dark cloud reactions is governed by pure hydrocarbons. Their low dipole moment has made their feeble rotational transitions difficult to examine. Since the formation of some molecules are not yet fully predicted by existing models, studying this source and providing new formation pathways is essential for developing chemical networks and producing correct processes.

In present work, a fresh insight into the formation of $HCCCH_2CCH$ isomer of C_5H_4 family is investigated at sophisticated levels of theory. 1, 4-pentadiyne ($HCCCH_2CCH$) has been recently detected towards TMC-1 via the QUIJOTE line survey in the 31–50 GHz range [4] with a column density of $(5.0 \pm 0.5) \times 10^{12}$ cm^{-2}. Our proposed formation pathway for this molecule is based on radical addition reaction. Optimizations were performed and Zero-point corrected relative energetics were predicted using both density functional methodologies and coupled cluster. For this purpose, we performed all geometry optimization calculations using the Gaussian 16 program package [5] and the WB97XD [6] hybrid density functional with the Dunning's correlation consistent polarized valence triple-(ζ) (cc-pVTZ) [7]. Computations with both methodologies agree qualitatively with previous theoretical results.

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Proton Transfer Reaction of $NCCNH^+$ in the Interstellar Medium (ISM)

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Approximately, more than 300 molecules have been detected so far in the interstellar medium. Most of the detected molecules are organic, several of them served as precursors of sugar, amino acids, nucleobases[1,2] and other prebiotic molecules. Astronomical observation indicates that, approximately 15% of the total molecules detected so far are cations. Protonated nitrogen (N_2H^+), protonated carbon dioxide ($HOCO^+$), protonated hydrogen cyanide ($HCNH^+$), protonated formaldehyde (H_2COH^+), protonated isocyanic acid (H_2NCO^+), protonated cyanogen ($NCCNH^+$) protonated tricarbon monoxide (HC_3O^+), protonated tricarbon sulfide (HC_3S^+), protonated cyanoacetylene (HC_3NH^+), protonated cyanodiacetylene (HC_5NH^+), protonated cyanotriacetylene (HC_7NH^+), protonated isocynoacetylene ($HCCNCH^+$) and protonated dicyanoacetylene (NC_4NH^+), are some of the significantly detected protonated molecules. Most of the protonated molecules detected in interstellar medium are suggested to be formed via proton transfer [3].The protonation is a very important process and many studies have supported the proton transfer reaction undergoing in the interstellar space [4]. The study of reaction processes for the formation of molecules of biological importance detected in the interstellar medium viz., nitriles, glycine, glycoldehyde, alanine, carbodimide, amines and imines, etc. [5–9], plays a vital role in study of the terrestrial origin of life. In present work, we have theoretically studied proton transfer reactions mechanisms of $NCCNH^+$ for the formation of some of the key protonated molecules viz., hydrogen cyanide ($HCNH^+$), protonated cyanoacetylene (HC_3NH^+), protonated cyanodiacetylene (HC_5NH^+), protonated cyanotriacetylene (HC_7NH^+), and protonated isocynoacetylene ($HCCNCH^+$).

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Electron impact ionization cross section of ethyl amine and propyl amine

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Introduction: In this study, we investigate the electron impact ionization cross section from ionization energy to 5000 eV using two formalisms, CSP – ic [1] and BEB [2]. The findings presented herein shed light on fundamental electron-amine interactions, offering valuable insights for diverse fields ranging from chemical kinetics to astrophysics.

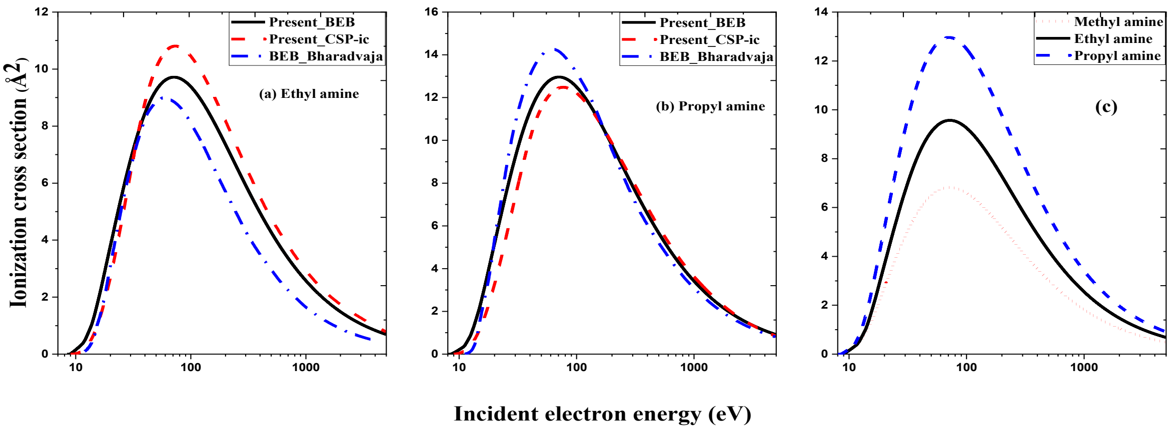

Figure 1. Ionization cross section (ICS) In the figure (a) and (b) Black solid line represents the calculated ICS with BEB, red dash line represents the calculated ICS with CSP-ic, blue dash dot line represent the BEB results of Bharadvaja et al.[3] for ethyl amine and propyl amine. Figure (c) represents the comparison of ICS among three amines methylamine (red short dot line), ethylamine (black solid line) and propyl amine (red dash line) obtained using BEB method.

Figure 1 (a, b) depicts the ICS for ethyl amine and propyl amine spanning from the IP to 5 KeV, computed using two distinct methodologies: BEB and CSP-ic. The ICS obtained through two distinct methodologies namely BEB and CSP-ic exhibit overall good consistency. Focusing on the ICS of ethyl amine, a comparison of the ICS values obtained from the CSP-ic and BEB methods indicates a general consistency across the energy range, although there is a minor deviation in the peak ICS.

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Electron and positron interaction with molecule of astrophysical Importance

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Introduction: The interaction of cosmic rays with astrochemical compounds offers a rich area of research. High-energy particles from space engage in various processes upon colliding with atmospheric gases. Understanding these interactions is crucial for advancing our search for life beyond Earth. The detection of vinylamine ($C_2H_3NH_2$) in the interstellar medium (ISM) marks a significant breakthrough in astrochemistry. As a prebiotic molecule, vinylamine contains the amino ($-NH_2$) group, essential for forming complex organic compounds vital for life. It has a C=C-N backbone, which is a fundamental component of imidazole, a critical structure in biochemistry. In this study, we conduct a comparative analysis of scattering cross-sections over a broad range of impact energies, from threshold to 5 keV. Utilizing the Spherical Complex Optical Potential (SCOP) and Complex Scattering Potential-ionization contribution (CSP-ic) methods, we quantify probabilities of various charged particle-driven molecular processes. These processes include elastic cross-section (Q_{el}), inelastic cross-sections (Q_{inel}), direct inelastic cross-sections ($Q_{D\text{-}inel}$), total cross-section (Q_T), total ionization cross-sections (Q_{ion}), direct ionization cross-sections ($Q_{D\text{-}ion}$), and positronium formation (Qps) for $C_2H_3NH_2$.

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Insights into plausible reaction pathway for the formation of Interstellar Allylimine: Theoretical Approach.

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The interstellar medium (ISM) is a complex environment containing more than 300 identified compounds, many of which are organic in nature and abundant throughout the interstellar space. These molecules hold significant astrobiological interest as they serve as potential precursors to life [1]. Dense interstellar clouds and protostellar disks, the birthplaces of stars and their planetary systems, are dynamic environments for complex chemical reactions. The prevalence of these conditions suggests a widespread distribution of prebiotic molecules [2]. Imines, characterized by the HCNH functional group, represent a critical molecular family in astrobiology [3]. In the recent laboratory findings [4], a detailed spectroscopic analysis of the G+0.693-0.027 molecular cloud in the Galactic center was conducted, confirming the tentative detection of Allylimine, a key imine precursor.

In this work, we proposed a formation pathway involving radical-neutral interactions of pre-detected molecules in the gas phase using quantum chemical techniques. Density functional theory calculations are employed with CAM-B3LYP/6-311++G(2d,2p) methods using Gaussian 16 program package [6] to explore the proposed pathway. The proposed pathway is found to be very efficient. The calculated reaction energies and geometries indicate the feasibility of Allylimine synthesis under interstellar conditions, with CH_2 serving as the initial reactant in the proposed mechanism. This study gives an understanding of the reactivity and stability of Allylimine in the interstellar medium. This theoretical investigation supports the hypothesis of Allylimine formation in the ISM. That could contribute to the emergence of extraterrestrial life due to the molecule's structural similarity and stability relative to imines [5]. 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.

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INVESTIGATING ASTROCHEMICAL ICES CONTAINING INTRAMOLECULAR HYDROGEN BOND - 1,4 BUTANEDIOL ICE

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Introduction: In this study, we present the mid-infrared (MIR) absorption spectra of 1,4-butanediol (1,4-BD) ice under laboratory conditions designed to simulate the low temperature (~10 - 300 K) and low pressure (~ 10^{-11} mbar) environments characteristic of cold interstellar molecular clouds. To the best of our knowledge, this is the first report of the MIR spectra of pure 1,4-BD under these specific conditions. This research is part of our broader effort to investigate the influence of hydrogen bonding between water ice and the ices of various diols on the sublimation temperature (and, consequently, the snowline) of water ice in the interstellar medium [1]. Given that 1,4-BD is the smallest diol featuring intramolecular hydrogen bonding [2], it is expected to offer valuable insights into the extent to which diol ice affects the condensation of water molecules onto dust grain surfaces.

Methodology: For these experiments, 99% pure 1,4-BD, procured from Sigma-Aldrich, was used. The experiments were carried out using the SALT (Simulator for Astro-molecules at Low Temperature) setup [3] at the Physical Research Laboratory in India. The vapor of 1,4-BD was deposited onto a ZnSe substrate maintained at a temperature of 10 K within a chamber under ultra-high vacuum conditions (~10^{-11} mbar). The MIR spectrum of the resulting ice was recorded using an FTIR spectrometer. The ice was then gradually warmed at a ramp rate of 5 K/min, with spectra recorded at regular intervals until the ice completely sublimated.

Results and Discussions: The spectrum recorded at 10 K revealed that the 1,4-BD ice is amorphous at this temperature, as indicated by the broad full width at half maximum (FWHM) of the peaks corresponding to O-H stretching. Signs of crystallinity began to appear in the spectrum at around 180 K, where the peaks started to narrow and split. The ice became fully crystalline at approximately 185 K. By 270 K, the ice had completely sublimated from the substrate. We then deposited the ice at higher temperatures, specifically at 220 K, 230 K, and 235 K. Contrary to our expectations, the spectral morphology of the ice deposited at these temperatures differed significantly from that of the ice deposited at 10 K and subsequently warmed to these temperatures. Notably, the spectral morphology remained unchanged even after cooling the ice back down to 10 K and reheating it to these higher temperatures. This indicates that the morphology of the ice deposited at these higher temperatures is stable. Thus, our experiments reveal that 1,4 BD ice has two different stable crystalline forms. We now aim to deposit water ice on top of 1,4 BD ice to study the influence of hydrogen bonding between the two substances on the sublimation temperature and stability of the water ice.

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Mid-Infrared Spectroscopic Investigation of a sample of Near Earth Asteroids

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Asteroids orbiting the Sun with perihelion distance $q < 1.3$ AU and aphelion distance $Q > 0.983$ AU are usually called near-Earth Asteroids (NEAs). These asteroids have sizes ranging from meters to tens of kilometers. They are believed to have originated in the Main Asteroid Belt, located between Mars and Jupiter. These asteroids are believed to contain less processed material and are hence considered remnants of our early Solar system. For this reason, they are considered prime targets for various sample return space missions. In the present study, the surface properties of a sample of Near Earth Asteroid were investigated from the Spitzer mid-infrared spectroscopic observations in the wavelengths between 5 to 38 μm. Near-Earth asteroid thermal model (NEATM) was used to model the observed spectral energy distribution. The preliminary results obtained from the model on the size, composition, and temperature distribution of the asteroids will be presented.

Tentative detection of Amines in Jupiter's Moon Callisto

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The detection of ozone in Jupiter's moon Callisto [1] motivates the search for life in the icy moons of Jupiter. While the nitrogen-bearing molecules are considered to play a vital role in the formation of biomolecules and hence the origin of life itself, they remain largely unexplored in the icy moon environment of Jupiter. The ammonia (NH_3) present in Jupiter's environment [2] can induce the formation of other N-H bearing molecules in its surroundings. For instance, irradiation of NH_3-O_2 ices with electrons/VUV photon under astrochemical icy conditions forms hydroxylamine (NH_2OH), which is considered to be a precursor for glycine [4,5].

The Hubble Space Telescope (HST) Faint Object Spectrograph (FOS) revealed the presence of SO_2 in Jupiter's moon Callisto from its characteristic band at 280 nm [3]. In the HST spectra used for the detection of SO_2, which has a wide range of wavelengths ranging from 200 nm - 400 nm, the 200-240 nm and 240-260 nm band remains unidentified.

In this study, We reinvestigate the VUV irradiation experiments done by [5] and compare the results with that of the HST spectra. On comparing the VUV spectra of NH_2OH with the HST-FOS spectra of Callisto [3], we have tentatively detected the presence of amine substituted compounds on callisto. The tentative detection warrants a closer look into the Jovian satellites for N-bearing compounds (including amino acids) in the ongoing and upcoming missions. Details and significance of the work will be discussed in the presentation.

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Petrogenesis of Angrites: Insights from Chondritic Precursor Materials.

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Angrites, pristine basaltic meteorites, offer a unique window into the earliest stages of the thermochemical evolution and differentiation of rocky bodies in our solar system. These enigmatic achondrites form the largest group of extraterrestrial basalts after those from the Moon, Mars, and asteroid 4-Vesta. Several studies have even suggested that angrites might have originated from Mercury [1,4].

Angrites are classified as differentiated achondrites and are subdivided into two categories: rapidly cooled volcanic or quenched angrites, and slowly cooled plutonic angrites. These meteorites are characterized by enrichment in refractory elements such as aluminum (Al) and calcium (Ca), and depletion in volatile elements like sodium (Na) and potassium (K). With an age of approximately 4564 Ma, only 4 Ma younger than Calcium-Aluminum-rich Inclusions (CAIs), which are among the earliest solids formed in the solar system [3], angrites are exceptionally valuable for studying early solar system processes.

The nature and composition of the parental magma from which angrites evolved remain largely unconstrained. The partial melting and fractional crystallization behavior of the Angrite Parent Body (APB), leading to the formation of angrites, have been investigated here. The bulk composition of angrite meteorites have been compared with the resultant compositions derived from this investigation to identify the most plausible parent body composition for angrites. Previous studies have proposed Allende CV3 chondrites [2] as analogues for the bulk composition of the APB. A modified CV composition, adjusted for metal-silicate differentiation in the APB [5], was selected as a potential composition for the APB. Findings from this work suggest that the melt component after approximately 70% equilibrium crystallization (1130°C) provides the closest match, in terms of major oxides, to the range of bulk compositions observed in angrite meteorites. Our results show that the angrites formed through a complex multi-stage crystallization mechanism in a molten chondritic body that had already undergone core-mantle differentiation. We will present models for the detailed petrogenesis of these different achondrites.

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MAKING A FELSIC VOLCANIC CONSTRUCT ON THE MOON: THE WOLF CRATER COMPLEX

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Viscous granitic melts form most of the continental crust on Earth. However, they are relatively rare on other planets in our solar system, because these magmas are products of either prolonged fractionation of a basaltic magma or remelting of the planet's mafic crust, processes requiring considerable heat budgets. On the Moon, only twelve locales have been detected so far where constructs made of such viscous silicic magmas have been confirmed [1]. The Wolf crater complex on Mare Nubium on the lunar nearside is one such construct [1, 2]. In this study, we have characterized the Wolf crater as a silicic volcanic caldera that was later filled by mare basalts that erupted at the same site. For this, detailed morphological, compositional, chronological and gravity anomaly analyses were accomplished using remotely sensed data from multiple lunar missions. The results show that near-anhydrous, silicic volcanism occurred in this region between 3.6-3.7 Ga before the caldera collapsed; this was followed by episodic mafic volcanism that continued till about 2.0 Ga. Gravity studies reveal the presence of high-density anomalies (mafic intrusions) surrounding the low density (silicic) Wolf crater complex, where the low-density signature is persistent for the entire crustal thickness of the region. Finally, based on all these observations and the modest Fe-contents interpreted for the exposures of mafic minerals like pyroxene and Mg-spinel, we conclude that crustal melting triggered by mafic intrusions may have generated the silicic magma at the Wolf crater complex [3].

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Variations of stable Sn isotopes constrain early differentiation of planetary bodies

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Introduction: The abundance and distribution of volatile elements in planetary bodies can serve as useful markers in understanding the formation and growth of planetary bodies. Elemental volatility is defined on the basis of condensation temperature (T_c) at which 50% of the mass of the element in nebular gas at pressure 10^{-4} bars condenses (e.g., Lodders, 2003). Elements with 50% T_c < 665 K (the 50% T_c of sulfur) are labelled as highly volatile, whereas elements with 665 < 50% T_c < 1335 (the 50% T_c of Mg, Fe, Si; Lodders, 2003) are labelled as moderately volatile. It has been known since the 1960s that the upper mantle and the crust of the Earth are depleted in moderately volatile elements (e.g., Wasserburg et al., 1964) in comparison to CI chondrites. Further the inner rocky planets and 4-Vesta have been shown to be depleted in volatile elements like K compared to CI chondrites. Later studies showed that the terrestrial planets, including Earth, the Moon, Mars and Mercury, and asteroids, such as 4-Vesta, are all depleted in K relative to the bulk Solar System composition, represented by CI chondrites (e.g., Palme et al. 1993). This depletion is manifested across the inner solar system and is reflected in the bulk chemical composition of planetary bodies. The reasons for this volatile loss or depletion can be attributed to either nebular or planetary processes. This study reports the results of Sn elemental abundances and isotopic compositions for a range of meteorites, including chondritic and differentiated meteorites.

Tin is a moderately volatile element (50% T_c of 704 K) (Lodders, 2003), that tends to show both chalcophile and siderophile behavior. It is therefore a very useful element that can serve as a proxy to understand the origin of volatile constituents in rocky planets, the composition of the materials incorporated at different stages of planetary accretion, and also to acquire information about planetary core formation.

Previous studies on Sn isotopes have analysed komatiites and peridotites to estimate the bulk silicate Earth (BSE) Sn isotope composition (e.g., Badullovich et al. 2017), that is incoherent with a carbonaceous chondrite (CC) like sources (Creech and Moynier, 2019; Wang et al. 2021). In this study, several terrestrial ultramafic rocks (including both komatiites and peridotites) are investigated to better constrain the Sn BSE composition, ii) several chondrites and achondrites are also measured with an overall aim to determine the nature of the components that contributed to this budget.

Methodology and samples: A wet chemistry based method was developed at the Institut für Geologie, Universität Bern, to determine mass dependent Sn isotope fractionation and concentration with high precision, using double spike MC-ICP-MS in terrestrial rocks and chondritic meteorites (Pathak and Mezger, 2024). The technique is useful in determining precise isotope ratios relative to NIST SRM 3161a in samples containing very small amounts of Sn (~20-100 ng), as most planetary materials are highly depleted in Sn compared to other similarly volatile elements. This study presents the $\delta^{122/118}$Sn of bulk Howardites (NWA 11551 and 8736), Diogenites (Tatahouine and Johnstown), Aubrites (Mt. Egerton, Norton County and Khor Temiki), Canyon Diablo Fe meteorite, along with some Lunar (NWA 12604, 11273 and SaU 169), Martian meteorites (Nakhla and NWA 2737) and the summary results $\delta^{122/118}Sn_{NIST\ SRM\ 3161a}$ of several bulk chondrites.

Results: Based on the data obtained for mafic rock standards (BCR-2, BHVO-2, BIR-1a, BRP-1) the Sn elemental abundances in these rocks range from 0.66-2.24 µg/g and $\delta^{122/118}Sn_{NIST\ SRM\ 3161a}$ values range from 0.316 to 0.384 ‰ (Pathak and Mezger, 2024) which is similar in quality to ratios reported by earlier studies (e.g., Wang et al. 2022 and She et al. 2023)

The range in variations of δ^{122}Sn (i.e. difference between most and least fractionated sample) is largest in bulk ordinary chondrites (OCs) (1.3 ‰; n = 12), while that range is least in enstatite chondrites (ECs) (0.24 ‰; n = 9) and with CCs showing an intermediate range (0.54 ‰; n = 15). For Sn elemental abundance (mean ± 2s.d. in µg/g) - the OCs are the most depleted (0.33 ± 0.13), while CCs show an intermediate abundance

(0.77 ± 0.59) and ECs are the least depleted (1.77 ± 0.59). In addition to CCs, ECs also overlap with the estimated δ^{122}Sn BSE value (δ^{122}Sn = 0.49 ± 0.11 ‰ 2s.d.) (Creech and Moynier, 2019; Wang et al. 2021).

Data were obtained on several silicate end members of differentiated meteorites – from the HED clan and the aubrites. Amongst the HED members, the Howardites and Diogenites show δ^{122}Sn values ranging from 0.8 -1.9 ‰, although one diogenite has a much lower value of 0.22 ‰. The abundance of Sn in these HEDs ranges from 0.012 to 0.052 µg/g. In case of the differentiated counterpart of the ECs the aubrites have Sn elemental abundance from 0.02 to 0.120 µg/g and δ^{122}Sn values from 0.25 to 0.4 ‰. In sharp contrast the Fe meteorites have much higher Sn elemental abundances from 0.47 to 4.2 µg/g and δ^{122}Sn from 0.49 to 0.87 ‰. Similar to the HEDs, the lunar and Martian meteorites show extremely depleted Sn elemental abundances ranging from 0.03 to 0.06 µg/g; and δ^{122}Sn values from 0.23 to 0.29 ‰ for Martian meteorites and 0.4 to 2.0 ‰ for lunar meteorites.

Discussion: From these results some inferences that can be made using the ranges of reported values. The Fe meteorites show significantly enhanced Sn elemental abundances compared to chondrites. This is expected because of the siderophile behavior of Sn. Further they do not show uniformly elevated δ^{122}Sn values compared to chondrites. They are elevated with respect to CCs and ECs but lower compared to OCs. The silicate-rich end members of HEDs and the Aubrites have extremely depleted Sn elemental abundances compared to chondrites – which is indicative of loss of Sn to the metallic core due to planetary differentiation process on their respective parent body. While the Howardites, which are a mixture and breccia of eucrites and diogenites, show elevated values in δ^{122}Sn compared to CCs and ECs they are lower compared to OCs. In contrast, the aubrites have δ^{122}Sn values that are similar to the ECs, which are considered as the parent prototype of aubrites. The lunar and Martian meteorites are depleted in Sn elemental abundance compared to chondrites and they are lower even compared to Earth's mantle.

This study will explore the depletion of Sn in silicate mantle of differentiated meteorites, Moon, Mars and Earth and compares it to Fe meteorites for various conditions on the planet. The depletion of siderophile /chalcophile elements tends to follow volatility as exhibited by volatile lithophile elements. All depletions of siderophile and chalcophile elements subsequent to planet accretion are an outcome of scavenging by core formation process via exchange between silicates and Fe-Ni±S with redox equilibration between mantle-core forming materials. One of the enigmatic phenomena about Sn is that it is not as depleted in the mantle of the Earth as it should be, given its high partition coefficients under high P-T conditions during core-mantle differentiation (e.g., Ballhaus et al. 2017).

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Nakhlites and Water-Rock Interaction: Alteration Processes in Martian Meteorites

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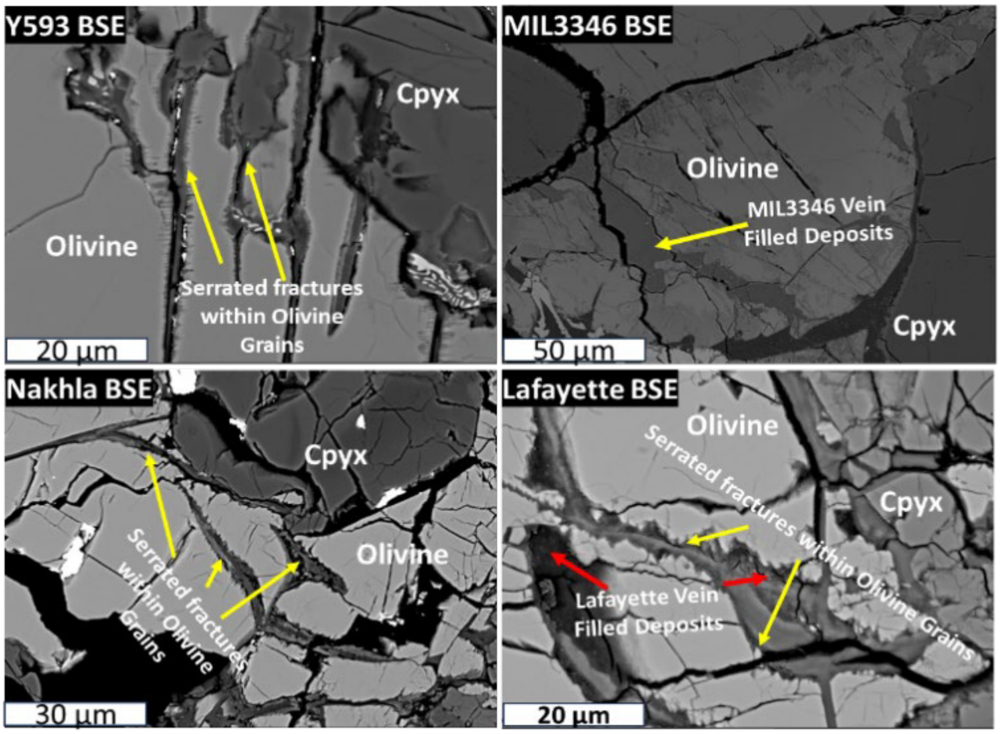
Introduction: Phyllosilicate-rich regions on Mars are prioritized by rover missions for their potential to preserve biosignatures and reveal Mars's paleoclimatic conditions. Information on Martian phyllosilicates is constrained by data from orbiters [1] or by the presence of secondary minerals in meteorites, notably Nakhlites [2], in which altered products are found along fractures of primary olivine. In this study, the chemical nature of these altered products is examined

Methodology: The investigation utilized polished thin sections of various Nakhlite meteorites viz: Yamato 593, Miller 3346, and Lafayette that are placed at different depths of the Nakhlite profile [3,4] to analyze the secondary altered products. The study involved mineral chemical analyses and imaging using a field emission electron probe microanalyzer (FE-EPMA; JEOL JXA-8530F, Japan) at the Physical Research Laboratory, Ahmedabad. The study employed a 15 KeV accelerating voltage, a 15 nA beam current, and a beam diameter of approximately 1μm, with five wavelength dispersive X-ray spectrometers.

Results: BSE images of various Nakhlite meteorites reveal fractures with serrated edges and 'high relief' serrations. Altered products are mainly found within the fractures of olivine grains. Based on the O'/T' ratios, the chemical composition of these altered products is identified as saponite [5,6]. Bi-variant plots of Nakhlites provide valuable insights into how the nature



of the altered product changes along the established Nakhlite depth profile. Compared to terrestrial olivine, unaltered Martian olivine contains a higher concentration of iron (Fe). However, during the alteration process, terrestrial olivine shows an increase in iron content, while Martian olivine shifts towards a higher silicon (Si) content."

Discussion: Deposition along fractures suggests a fracture-controlled type of deposition. The pronounced relief of the serrated fissures within Nakhlite grains indicates a low-temperature alteration mode, aligning with the geochemical composition of the altered phase. This is further supported by the characterization of secondary products as saponite, based on the O'/T' ratios. The consistent alteration pattern in the serrated fissures provides insights into the geological history of Nakhlites, pointing to reduced temperature conditions. The Si enrichment in the Nakhlite alteration products suggests a relatively acidic environment. Additionally, the different alteration pathways observed in Martian and terrestrial samples highlight distinct conditions necessary for alteration during early Mars.

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INSIGHTS IN TO THE MAGMA EVOLUTION OF ENRICHED TO INTERMEDIATE SHERGOTTITES FROM MELT INCLUSIONS

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Introduction: In recent decades, Mars exploration missions, encompassing landers, rovers, and orbiters, have furnished valuable insights into the chemical and mineralogical attributes of the Martian surface. However, the instruments deployed on Mars lack the precision of Earth's laboratories and are limited in their ability to analyze multiple sample parameters essential for comprehending the planet's evolutionary processes. Martian meteorites, particularly shergottites, serve as a primary avenue for in-depth laboratory investigations in the absence of sample return missions, offering crucial information on diverse geological phenomena and Mars' evolutionary timeline.

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]. Poikilitic shergottites are distinguished by their unique bimodal texture [2], [3]. This texture provides insights into their evolution, with an early slow-cooling poikilitic stage (PA) and a later, rapidly cooled interstitial stage (NPA) [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.

Melt inclusions (MI) in each texture are olivine-hosted, with olivine being the earliest crystallizing mineral in the poikilitic shergottites. Thus, the MI can be representative of the compositions at the time of their formation [7]. This study delves into the mineralogy, trace element mineral chemistry, and petrology of two sets of poikilitic shergottites, namely NWA 7397 (enriched) and NWA 1950 (intermediate) with a major focus on the major and trace element MI analyses on mineral phases located in olivine hosted MI of the PA And NPA textural areas, to better constrain parental magma compositions, as well as the magmatic evolution through these different textural domains.

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ARGUIN 002: A UNIQUE LUNAR NORITE

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Introduction: A total of ten norites from Apollo 14, 15, and 17 [1] have been collected. Alongside these Apollo samples, 51 lunar meteorites have been classified and reported to contain noritic clasts in the Meteoritical Bulletin (as of September 2024). However, of these samples, only Arguin 002, a lunar meteorite found in Mauritania, is reported to be unbrecciated [2]. Lunar norites are classified as Mg-suite rocks that contain Ca-rich plagioclase along with Mg-rich orthopyroxene (OPX). These samples are representative of the deeper lunar crust and can constrain the nature and timing of Mg-suite magmatism. Apollo norite, 78238, records a crystallisation age of 4332 ± 18 Ma [3]. However, due to the highly shocked and brecciated nature of lunar norites, there remains uncertainty regarding their formation. The unbrecciated nature of Arguin 002 provides a unique opportunity to investigate the timing and formation of secondary lunar crust beyond returned samples.

Materials and Methods: A Zeiss EVO MA10 LaB6 scanning electron microscope (SEM) at the University of Portsmouth and a Zeiss Crossbeam 550 SEM at The Open University were used for initial chemical and structural investigations, following the methodology of [4]. Mineral chemistry was acquired using a JEOL Field Emission Gun JXA-IHP200F electron probe micro-analyzer (EPMA) at the University of Cambridge following the methodology of [5]. Pb-Pb isotopic analyses were carried out using a CAMECA IMS1280 large-geometry ion microprobe at the NordSIMS facility, Swedish Museum of Natural History, following the methodology of [4].

Results: Arguin 002 reveals an unbrecciated, plutonic/cumulate-like texture (~2 mm grain size). The two dominant minerals are OPX ($En_{60.9}Fs_{32.8}Wo_{6.2}$; n = 31) and anorthitic plagioclase ($An_{92.6}$; n = 18) along with minor amounts of augite ($En_{40.4}Fs_{18.5}Wo_{41.3}$; n = 2), chromite, troilite, silica polymorphs, monazite, zircon and phosphates. All plagioclase occurs as amorphous maskelynite. Phosphates are highly crystalline and display low degrees of internal deformation (< 6°). No olivine was identified in the studied sample. Based on regression through Canyon Diablo troilite (CDT) Pb isotope composition, Arguin 002 phosphates and zircons yield a Pb-Pb isochron date of 4332.6 ± 3 Ma, with a mean squared weighted deviation (MSWD) of 1.13. Regression through Stacey & Kramers (S & K) modern terrestrial Pb isotope composition yields an identical date.

Discussion: The OPX in Arguin 002 displays relatively low Mg# (63-73) compared with samples from the Apollo collections and noritic clasts within lunar meteorites (Mg# = 71-84) [1, 6]). This lower Mg# in Arguin 002 OPX may be linked to the fractionated nature of the parental melt as indicated by the higher abundances of REE-rich minerals in this sample (e.g. monazite) [7]. On an Mg# vs. An# plot, Arguin 002 plots barely within the uncertainty of the existing geochemical field for Mg-suite Apollo samples. The Pb-Pb age of Arguin 002 (4332 ± 6 Ma) collected from minimally-deformed phosphates, unlikely to have experienced secondary Pb loss, is within the uncertainty of U-Pb ages of accessory minerals within many other Apollo Mg-suite lithologies. These include norites 78238 (4332 ± 18 Ma; [3]) and 15455 (4332 ± 6 Ma; [8]), and troctolite 76535 (4334 ± 4 Ma; [9]), as well as in agreement with Rb-Sr, Pb-Pb and Sm-Nd ages for 15445, 67667, and 78238 [e.g. 10]. Interestingly, data from other lunar meteorites [6] and the recent results from the Chandrayaan-3 APXS instrument [11] highlight the existence of lunar lithologies that plot outside the typical FAN or Mg-suite fields, all of which were derived from Apollo samples on the lunar nearside. This highlights crustal diversity on the Moon and the need for a greater sampling of the lunar surface. The preponderance of c. 4332 Ma ages from secondary lunar crustal rocks suggests a common event is recorded across a wide range of lunar lithologies. In contrast, geochemical analysis of Arguin 002 suggests complex crustal formation mechanisms occurred early in the Moon's history.

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Application of clinopyroxene-liquid thermobarometers to low-Ti Apollo 15 mare basalts.

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Introduction: Understanding P-T conditions of crystallization using thermobarometers is a possible solution to address the uncertainty of lunar magma storage and crystallization. Existing mineral-melt thermobarometer models rely on empirical relationships between minerals and melts and are calibrated on terrestrial systems. We examine the applicability of existing clinopyroxene-liquid (cpx-liq) thermobarometers to lunar cpx from Apollo 15 (A-15) mare basalts and interpret our results with previous interpretations of crystallization history of A-15 mare basalts.

Methodology: We used the chemistry of cpx from seven A-15 mare basalts from the olivine normative (ON) and quartz normative (QN) suites [1]. We chose the Al exchange between cpx and liq barometer (Eq. 32c [2]) and Jd-DiHd exchange thermometer (Eq. 33 [2]) to calculate P-T conditions of cpx crystallization. We chose these equations as they are calibrated on cpx compositions that are closely matched with the A-15 cpx. To test for equilibrium between cpx and putative melt compositions, we iteratively matched the chemistry of cpx grains with A-15 yellow glass [3], olivine hosted melt inclusions from A-15 mare basalts [4] and A-15 ON and QN whole rock chemistry [3]. We performed equilibrium tests on cpx-liq pairs using the above equations. We also used a Monte Carlo (MC) approach to propagate analytical EPMA errors of a cpx core and rim composition onto the calculated P-T estimates [5].

Results: The A-15 QN whole rock compositions returned 37 cpx-liq pairs upon matching with QN cpx cores and 19 pairs with QN cpx rim compositions using the Al exchange barometer (Eq. 32c [2]) and the Jd-DiHd thermometer (Eq. 33 [2]). Our calculations returned crystallization pressures for the A-15 cpx in the range 0-0.6 GPa, corresponding to lunar depths of 0-120 km. The QN cpx cores show a mean crystallization pressure of 0.4 GPa (80 km) while QN cpx rims return a mean crystallization of 0.3 GPa. At any given pressure, the QN cores return higher T (1200-1300°C) than the QN rims (1150-1200°C). The ON cpxs returned no cpx-liq pairs that passed the equilibrium filters after application of Al exchange barometer and Jd-DiHd exchange thermometer. The 2σ confidence ellipse derived from the MC simulation parallels the trajectory observed for the estimated P-T values.

Discussion: Although our calculations yield a P range of 0-0.6 GPa for QN cps, we cannot consider these estimates at face value as our MC error propagation (Fig. 1) highlights that the 95% confidence ellipse for a single analysis spans the entire output P range. However, the QN cpx core and rim temperatures are significantly different (Fig. 1) suggesting two different crystallization environments of cpx crystallization. This could occur either through cooling within a single magma reservoir or through crystal transfer whereby cores grew in a hotter deeper reservoir and rims grew in a cooler, shallower reservoir. The latter interpretation aligns with previous interpretations that QN basalts experienced multiple stages of fractionation in the lunar crust [6]. We therefore cannot be certain whether our output P-T ranges reflect real geological processes or are con-trolled by propagated analytical uncertainties. For example, although previous experimental studies on QN basalts suggest that they crystallized within lunar lava flows [7], Fig. 1 shows that our cpx core and rim populations returned mean pressures within the crust. Individual matches returning crystallization pressures close to the lunar surface could be real or could be artefacts of propagated analytical uncertainties. The overlap of P-T estimates from simulated analytical errors with actual measurements underscores the necessity for refined analytical techniques [5, 8] and bespoke lunar specific calibrations of cpx-liq thermobarometer models to ensure robustness of P-T assessments in understanding the mechanisms of magma storage and crystallization on the Moon.

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RAMAN ANALYSIS OF ZIRCON GRAINS IN THE EUCRITE DaG 647

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Introduction: Eucrites, the members of the howardite-eucrite-diogenite (HED) clan of meteorites, constitute surface or shallow level basaltic melt or cumulates from the melt generated on a parent body, presumably asteroid 4 Vesta [1]. Eucrites are amongst the prime sources for meteoritic zircon, besides Lunar and Martian meteorites [2-4]. Zircon is a refractory mineral which is chemically inert and has a tendency of incorporating various short- and long-lived radionuclides [4,5]. Here, we study the structural state and thermal history of zircon grains in a monomict eucrite Dar al Gani (DaG) 647.

Samples and Methods: An analysis was conducted on a polished thin section (PTS) of the monomict eucrite DaG 647. Twenty zircon grains in all, ranging in size from 6 to 15 µm, were discovered. The LabRAM HR Evolution spectrometer was utilized to get the Raman spectra of these grains, using an excitation wavelength of 532 nm and a laser intensity of ~1.5 mW. After fitting the spectra using 2 (or) 3-pseudo-Voigt profiles and carrying out linear baseline adjustments, the peak center positions (Raman shift) and full-width half-maximum (FWHM) were determined. Using the formula in [6], the FWHM value was adjusted for the instrumental profile function. For non-metamict zircon, the Raman spectra of a zircon grain from Mud Tank, Australia, was utilized as a standard.

Result and Discussions: The 900–1075 cm^{-1} spectral region was the focus of our Raman research, and it had two notable peaks: $\nu_1(SiO_4)$ near 975 cm^{-1} and $\nu_3(SiO_4)$ near 1008 cm^{-1}, which are related to the symmetric and antisymmetric stretching modes, respectively. The $\nu_3(SiO_4)$ peak is susceptible to structural deterioration. Peak shifts to lower values are caused by varying degrees of metamictization, and the associated FWHM broadening follows. In Fig. 1, the Raman shift v/s FWHM of $\nu_3(SiO_4)$ for our present data is shown against the previous data from different meteoritic zircon sources. The radiation trend zone [2] is followed by our data. Two grains with mean FWHM for $\nu_3(SiO_4)$ of 19.3 and 18.5, respectively, were captured in CL images; these grains exhibit high single intensity from dark regions in backscatter electron (BSE) images.

Conclusions and Future work: Within DaG 647, analysis of 20 zircon grains indicates a high level of metamictization. There are two zircon grains in the fusion crust that exhibit annealed spectral fingerprints. Utilizing a transmission electron microscope, more research is being done on the microstructure of the zircon grains.

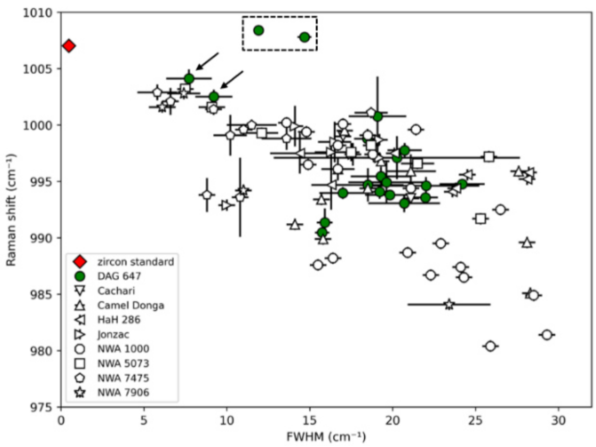

Fig. 1: Raman shift of the $\nu_3(SiO_4)$ band for 20 zircons of DaG 647 v/s FWHM of the same band. Information derived from extant meteoritic zircons is sourced from [2]. The current study's data is indicated in green. For every zircon, the error bars represent the 2σ standard deviation of the acquired data. The data for the non-metamict zircon standard is indicated in red. Two zircons that were discovered in the fusing crust are indicated by arrows, and the two zircons inside the dotted rectangle exhibit abruptly high Raman shift values.

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Textural and thermodynamic evaluation of Ureilite NWA 14072

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Meteorite NWA 14072, formally described by Irving and Carpenter [1], is a ureilite dominated by highly magnesian olivine (cores $Fa_{7.9\pm0.0}$, rims $Fa_{1.7}$-$Fa_{3.9}$) and a low-Ca pyroxene reported as pigeonite. It is unusual among ureilites in containing exsolution lamellae of subcalcic augite ($Fs_{4.5\pm0.0}Wo_{34.7\pm0.0}$) hosted in pigeonite ($Fs_{6.9\pm0.0}Wo_{10.6\text{-}10.7}$) [1]. More typically, ureilites contain clinopyroxenes that lack detectable exsolution lamellae even when the growth of such lamellae would have been thermodynamically stable, implying that cooling took place too fast to allow exsolution [2].

We present new EPMA data confirming the existence of multiple generations of exsolution lamellae of augite hosted in low-Ca pyroxene, and of low-Ca pyroxene hosted in augite. Application of olivine–low-Ca pyroxene Cr-partitioning thermometry [3] yields an estimated equilibration temperature of 1230±30ºC. This relatively high temperature estimate is consistent with the highly magnesian compositions of the silicate phases, the broad (width ~10 µm) exsolution lamellae, and other textures suggesting that NWA 14072, in common with other ureilite meteorites, has undergone silicate partial melting and melt extraction (e.g. [4]).

NWA 14072's well-developed exsolution lamellae, the result of an atypically slow cooling history for a ureilite, make it a valuable target for thermobarometry. Following [4] in interpreting ureilites as members of a Pigeonite metamorphic facies, we present progress towards the development of a more precise modelling of pyroxene phase relations in the pyroxene quadrilateral ([5] and experimental studies cited therein). In this modelling we aim to resolve (1) the composition of coexisting pyroxenes as a sensitive function of pressure and temperature, and (2) the equilibrium Wo ranges of the low-Ca pyroxene phases pigeonite (C2/*c*), protopyroxene (P*bcn*) and orthopyroxene (P*bca*).

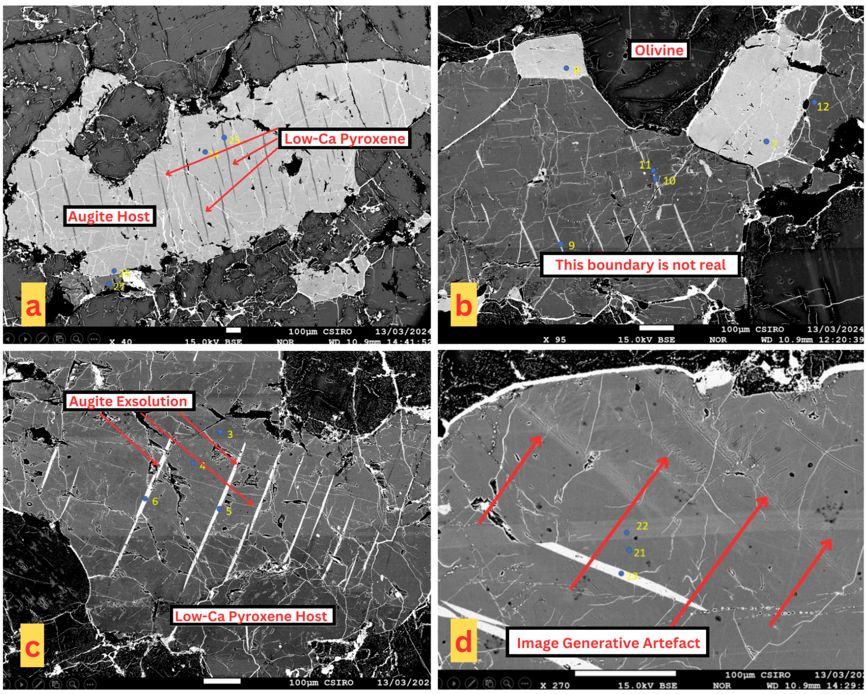

Fig.1. EPMA results. (a) Low-Ca pyroxene (dark bars) within an augite host (light shading). (b) Black grains represent olivine; light grains are high-Ca pyroxene (pre-sumed augite), and intermediate grains are low-Ca pyroxene. (c) Au-gite exsolution lamel-lae (light bars) in a low-Ca pyroxene host (intermediate shading). (d) The presence of a second generation of lamellae is uncertain (conceivably an image generative artifact).

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Granite: Earth's Blueprint for Planetary Geology

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There is different level of planetary exploration for each of the terrestrial planets, among which Mars and the Moon being the most studied bodies so far. These telluric planetary bodies have the same internal structure with metallic inner core and silicate outer shell and there is a large room for doubt concerning continental crustal growth on the terrestrial planets other than the Earth. Therefore, understanding the geological evolution of Earth's continental crust should be very important. For understanding the planetary crustal evolution, the comprehensive picture of the granite petrogenesis is important as it is the major sustainable and most abundant component of earth's continental crust. The reported evidences of granitic components from Martian and Lunar bodies gives valuable insight into the geological evolution of such planetary crusts, although these planetary bodies are unlikely to have produced enough granite to make continents.

The study is keen to explain the petrogenesis of diverse assortment of silicic quartzo-feldspathic plutonic rocks in terms of "Granite". This term is restricted to the range of quartz-alkali feldspar-plagioclase feldspar proportions in the IUGS classification. For the betterment of understanding the quartzo-feldspathic assemblages, the term "Granitoids" may be used as a cumulative one. Such a broad spectrum of rock types has broad range of source and genetic processes of magmatism and geodynamics. This work is focused on systematic petrographic, geochemical analysis of various Precambrian aged granitoids from Aravalli -Delhi Protocontinent of Northwestern Indian Shield to understand the Earth's continental crust formation over time, and thereby trying to correlate the mode of occurrence of granitic component in planetary bodies and to point light on the probable existence of continental type crusts in planetary history.

Session - IV: Meteor &Space Weathering

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MSW-01			Invited talk
MSW-02	Laboratory Simulations of Solar Wind-Induced Space Weathering on Mercury and Other Solar System Bodies	Surya Snata Rout NISER, Bhubanewsar	Oral
MSW-03	Spectral modeling of 269 justitia: investigating the formation and evolutionary pathways of ultra-red asteroids for the upcoming emirates mission to the asteroid belt (EMA)	Harish Laboratory for Atmospheric and Space Physics, CU, Boulder	Oral
MSW-04	Observational Evidence of Two-Step Nonlinear Interactions Involving Zonally Symmetric Waves During Major Sudden Stratospheric Warmings	Gourav Mitra PRL, Ahmedabad	Oral
MSW-05	Lunar PSRs: Electric breakdown and its implications	Trinesh Sana PRL, Ahmedabad	Oral
MSW-06	A study on mesospheric temperature at 90 km altitude using meteor radars and satellite observations at conjugate high latitudes	Borukote Sangadeep Osmania University, Hydrabad	Oral
MSW-07	study of lunar dust lofting during the total lunar eclipse of 27-28 july, 2018 using polarised lunar eclipse spectra	Aman H. Singh University of Mumbai	Poster
MSW-08	Cosmic and Solar Energetic Particle Tracks in Regolith Breccia Meteorites	Neetha Thomas IISER, Berhmpur	Poster
MSW-09	MAVEN observations of the Martian Gravity Waves and their Variability with the Phase of the Solar Cycle	Sunil Kumar NCPOR, GOA	Poster

Laboratory Simulations of Solar Wind-Induced Space Weathering on Mercury and Other Solar System Bodies

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Introduction: Space weathering (SW) is an active process on various airless planetary bodies and its effect depends on surface composition, exposure time, resurfacing rates, location in the solar system, temperature, and strength of the magnetic field [1]. While SW is well-studied on the Moon and near-Earth S-type asteroids, less is known about its effects on other planetary bodies. For instance, the surface of Mercury is highly space weathered due to its weak magnetic field and high flux of dust particles [2]. This is exhibited by its visible-to-near-infrared (VNIR) reflectance spectrum which is red-sloped, featureless, and has low albedo [3]. In addition, the day side temperature on the surface of Mercury goes up to 450°C in the equatorial regions [4]. A lunar-like SW is not applicable to Mercury due to the very low iron within its silicate minerals and higher abundances of opaque phases. In this study, we investigate the chemical and structural changes induced by ion irradiation in low-iron bearing silicate minerals at high temperatures, simulating conditions on Mercury's day side, to understand the formation of iron nanoparticles.

Samples and Method: Here we experimentally simulate the interaction of solar wind ions with low-iron (~3 wt% Fe) bearing olivine grains that is taken as an analog component of the surface of Mercury. The sample is irradiated with 4 keV He^+, 1 keV H^+, and 200 keV Ar^+ ions. The sample irradiated with He^+ was done both under ambient conditions and also heated to 450°C during the ion irradiation to directly simulate the daytime conditions in the equatorial regions of Mercury. After the irradiation experiment, lamellas for transmission electron microscope (TEM) study were prepared using a Helios Nanolab G3 UC focused ion beam (FIB) from Thermo Scientific. TEM study was done with a Talos F200 TEM from Thermo Scientific.

Result and Discussion: The sample irradiated with He^+ under ambient conditions shows ~140 nm thick amorphous layer on top of the grain with high concentrations of bubbles and cavities. However, the sample irradiated at 450°C has an irregular 110-140 nm thick nano polycrystalline layer with 1-5 nm sized nanoparticles of iron. Mg is preferentially sputtered and oxygen atoms are reimplanted in the 140 nm thick amorphous layer present on the sample irradiated under ambient conditions but no preferential sputtering or difference in composition is seen between the crystalline substrate olivine and the ion-damaged layer in the sample irradiated at 450°C. Our results show that solar wind irradiation of low-iron bearing olivine in the equatorial regions of Mercury will produce nanoparticles of iron whose sizes will be larger than that on the surface of the Moon and the sizes will further increase due to flash heating during dust impacts. Study of other ion irradiated samples are ongoing.

Conclusion: Ion irradiation of olivine with ~3wt% Fe in the equatorial regions of Mercury should have nanoparticles of iron around them and their concentration and size should change with latitude due to the latitudinal variation of temperature. In addition, flash heating of the ion-irradiated olivine grains due to impacting dust particles should further increase the size of nanoparticles of Fe. Ostwald ripening of iron nanoparticles must also be active on the surface of Mercury but to understand the process experimental measurements of the diffusion coefficient of Fe within an amorphous silicate matrix are needed. The solar wind implanted He within the surface materials of Mercury should diffuse out of the grains due to high temperatures during the daytime and escape to the exosphere through desorption.

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SPECTRAL MODELING OF 269 JUSTITIA: INVESTIGATING THE FORMATION AND EVOLUTIONARY PATHWAYS OF ULTRA-RED ASTEROIDS FOR THE UPCOMING EMIRATES MISSION TO THE ASTEROID BELT (EMA)

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In early 2028, the Emirates Mission to Asteroids (EMA) spacecraft is planned to launch with the goal of studying seven main belt asteroids: (10253) Westerwald, (623) Chimaera, (13294) Rockox, 88055 (2000 VA2), 23871 (1998 RC76), 59980 (1999 SG6), and (269) Justitia, the latter of which is the target of a planned rendezvous [1]. Justitia is spectrally classified as an ultra-red asteroid in the visible and near-infrared region (VNIR), due to its exceptionally red spectral slope, which raises questions about its formation in the main belt [2,3]. Composition is vital for understanding asteroid formation and evolution, providing insights into their original locations in the early solar system and the history of planetary migration, as seen with Ceres [4]. Thus, Justitia presents a compelling case for exploring asteroid formation through the study of surface composition. Its anomalously ultra-red spectral slope in visible and near infrared region, reminiscent of Trans-Neptunian Objects (TNOs) or possibly the result of space weathering processes [2,3], and absorptions near 3.0 and 3.4 µm, reminiscent of CM2-type carbonaceous chondrites [5], raises a few crucial questions: Does Justitia share a common origin with TNOs or CM2? Is Justitia's anomalous reddening a consequence of space-weathering? Or could a combination of other endmembers and processes explain Justitia's spectral character?

This study aims to decipher the composition of ultra-red asteroids, focusing on Justitia, by employing linear and non-linear spectral mixing models. Reflectance and emissivity spectra, with their distinct absorption/emission features and spectral gradients, are particularly useful for identifying surface mineralogy. In this study, hemispheric albedo spectra were derived using the delta-Eddington two-stream method [6] for granular surfaces, with individual mineral albedo calculated from Mie parameters obtained through Mie theory, using optical constants. To estimate the albedo of mineral mixtures, we employed Maxwell-Garnett theory for mixing optical constants. We used endmembers from complex organics such as Triton tholin [7], to silicates such as orthopyroxene [8] and the CM2 Murray meteorite. To incorporate space weathering effects, we modeled mixtures of these endmembers with micron-size iron-metals [9].

We have computed model albedo spectra for both individual components varying their particle sizes and their mixtures, where endmembers are mixed linearly as well as non-linearly. We seek to identify possible compositional endmembers for Justitia in the VNIR and mid-IR to improve our understanding of its formation and evolutionary pathways. Our results hint at potentially CM2-like material mixed with space weathered silicates, considering current thermal conditions on Justitia [10] which makes several ices unstable on its surface. The results of this research are anticipated to be instrumental for EMA, offering valuable test cases for developing observational strategies and guiding post-encounter analyses of the expected hyperspectral mid-wave infrared (2–5 µm) and thermal infrared (6–100 µm) datasets [1].

Acknowledgement: Funding of the Emirates Mission to the Asteroid Belt is provided by the UAE Space Agency with support from the University of Colorado Boulder's Laboratory for Atmospheric and Space Physics as its main knowledge partner.

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Observational Evidence of Two-Step Nonlinear Interactions Involving Zonally Symmetric Waves During Major Sudden Stratospheric Warmings

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ABSTRACT

The study investigates atmospheric tides and related dynamics during two major boreal sudden stratospheric warmings (SSWs). Using evolutionary Lomb-Scargle and wavelet spectral analysis of hourly winds derived from specular meteor radar (SMR), we find evidence of nonlinear interactions between the semidiurnal solar tide and the quasi-20-day wave (Q20DW) in the high latitude mesosphere and lower thermosphere (MLT) during SSWs. Diagnoses of zonal wavenumber (ZWN) suggest that the dominant migrating semidiurnal tide (SW2) may nonlinearly interact with the zonally symmetric 20-day wave (20DW0) component, leading to the generation of secondary waves. Additionally, the source of the 20DW0 is found to be associated with the interaction between the ZWN 2 component of the stationary planetary wave (SPW2) and the westward propagating 20-day wave (20dWW2) in the stratosphere. As seen in the SMR-derived wind spectra, on excitation, the 20DW0 likely propagates to the MLT and further interacts nonlinearly with SW2, forming secondary waves. This study, therefore, provides the first observational evidence of a two-step nonlinear interaction involving zonally symmetric planetary waves during major SSWs.

LUNAR PSRs: ELECTRIC BREAKDOWN AND ITS IMPLICATIONS

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Introduction: Lunar Permanently Shadowed Regions (PSRs) are certain areas near the poles of the Moon that lack direct sunlight, experience extremely cold temperatures, and exhibit a complex thermal, chemical, and electrical environment [1]. The surface and sub-surface charging of the PSRs is a crucial aspect of space weathering, with implications for both scientific exploration and future lunar missions. The surface charging of the PSR is primarily driven by the dynamic interaction of solar wind /ambient plasma with the PSR's surface and local plasma effects. Due to dominant electron accretion from the solar wind/ambient plasma, the top layer of the PSR's regolith becomes negatively charged. However, the degree of charging significantly depends on the surface topography [2-3]. The presence of extreme inhomogeneous surface topography results in extreme surface charging within lunar PSRs [4].

The Moon is also exposed to the flux of energetic charged particles in the form of galactic cosmic rays(GCRs) and solar energetic particles (SEPs). These particles penetrate the lunar surface and deposit their charge beneath the top layer of the regolith. Due to the insulating nature of the lunar regolith, in the extreme cold of PSRs, the mobility of these trapped charges is significantly reduced, leading to the buildup of large electric fields within the sub-surface layers. GCRs, primarily composed of protons with a flux of ~ 2 - 4 particles $cm^{-2}s^{-1}$ (peaking around ~ 200 MeV), can penetrate and charge the regolith to depths up to ten centimeters [5-6]. It can create a persistent electric field of ~ 700 Vm^{-1} [7-8]. On the other hand, SEPs with higher flux can generate electric fields $> 10^{6}\, Vm^{-1}$ within the top millimeter of regolith [7-8]. These episodic strong subsurface electric fields can induce the dielectric breakdown of the regolith, exceeding the material's dielectric strength. Apart from GCR/SEP fluxes, the electrical properties of the lunar regolith play a significant role in the deep charging and breakdown process. The low electrical conductivity of the cold (~ 50 K) PSRs slows down the charge dissipation. As a result, significant charge buildup leads to a substantial increase in the subsurface electric field. In addition to that, the size and shape of the grains, porosity, and trapped gasses can influence the local electric fields and subsequent breakdown. The repeated breakdown events can fragment regolith grains and make the regolith porous, which is an important aspect of space weathering [9-10].

This presentation introduces underlying physics and the current understanding of the surface and sub-surface charging of the lunar polar region. We also discuss ideas for test experiments for future lunar polar exploration missions based on our present knowledge.

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A study on mesospheric temperature at 90 km altitude using meteor radars and satellite observations at conjugate high latitudes

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Abstract:

The long-term and continuous observations of mesospheric temperature are rare, but they are important to investigate climatological changes at these altitude regions on time scales of several years, covering a complete solar cycle and longer. Such long-time series are a natural heritage of the mesospheric climate change, and they are valuable to compare climatology models. We present here the variation of mesospheric temperatures at 90 km altitude using all-sky meteor radars located at conjugate high latitudes. The daily mesospheric temperatures are computed using ambipolar diffusion coefficient data from all-sky meteor radars at Esrange (69.6°N, 19.2°E), in the Arctic and Rothera (68.6°S, 77.9°E), in Antarctica. We have compared radar-derived temperatures with Sounding the Atmosphere using Broadband Emission Radiometry instrument onboard the TIMED satellite (TIMED/SABER) measurements. The meteor radar derived temperatures are fairly in good agreement with the space borne measurements. This study focuses on a detailed evaluation and inter-hemisphere comparison of temperatures derived from different measurement techniques. Inter-hemispheric observations indicate that the mesospheric temperatures at the opposite high-latitude regions show a clear seasonal asymmetry. Seasonal variations in mesospheric temperature estimated from two meteor radars and satellites indicate that there are inter-hemispheric differences in seasonal characteristics.

STUDY OF LUNAR DUST LOFTING DURING THE TOTAL LUNAR ECLIPSE OF 27-28 JULY, 2018 USING POLARISED LUNAR ECLIPSE SPECTRA.

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The lunar dust fountain model (DFM) near the day-night terminator has been variously described in the literature as arising from thermal desorption, photon stimulated desorption, sputtering of solar wind ions, and meteorite impact vaporization, etc. [1,2,4,5,6,9]. The day side of the moon facing the sun is constantly bombarded by solar photons causing photoelectric electron emission. This results in the development of a positive potential on the day side of the lunar surface [1, 4]. The electrostatic like charges are redistributed along the surface and to and dust particles, eventually causing them to repel each other, such that under certain conditions the dust grains are lifted above the surface upto heights of around 100 km above the surface near the terminator region [9]. In this paper, we propose that a lunar eclipse induces an effect similar to what occurs at the day-night terminator on the lunar day side, which we refer to as the "Eclipse Terminator" (ET). The ET represents the boundary separating the illuminated and eclipsed regions of the lunar surface. During a lunar eclipse, the rapid progression of the ET across the lunar day side results in regions of differential charging, leading to the vertical uplift and horizontal transport of charged lunar dust.

We present an analysis of imaging and spectroscopy observations of the moon during various stages of a total lunar eclipse (27 July 2018). During the eclipse, filtered images of the moon (broad-band, IR, H-alpha, H-beta) were captured during various phases of the lunar eclipse using a 90mm Galilean Refractor and an ATIK 11000 Monochrome CCD. Simultaneously, moon spectra were captured using a 104mm MAK-Cassegrian telescope, equipped with a grism-mounted ALPY600 Spectrometer, polarizer, and a DMK 41AU02 CCD. The spectra were captured with three different polarizer orientations.

The lunar surface is cited to exhibit a significant abundance of Na and K, in multiple studies [3,7,8,10], while additional elements such as Al, Ti, Ca, Fe, and Mg have been detected through various methodologies, including ground-based spectroscopy and missions like LADEE, LACE, and LRO (see e.g. ref [3]).

Analysis of standard spectral lines (Ca, Na, H-alpha, H-beta) reveals greater absorption of the radiating dipole moment normal to the ET compared to the tangential direction. The observed ratios of our polarised spectra are consistent with basic dipole radiation theory [11, 12], considering the polarized orientation of lunar dust particles in the electric field as described in the DFM. Details will be presented. In a broader context, these findings could also contribute to understanding the dynamics of dust in planetary exospheres and their interactions with the stellar wind.

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Cosmic and Solar Energetic Particle Tracks in Regolith Breccia Meteorites

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Introduction: Regolith breccia meteorites contain high concentrations of solar wind implanted gases and therefore sample some component of regolith of their parent asteroid. During the exposure of regolith material on the surface they are exposed to solar energetic particles and cosmic rays which produce trail of damage within the grains and are called solar flare tracks (SFTs) or cosmic ray tracks (CRTs) [1]. The analysis of etched tracks helps to reconstruct activity over millions of years and provides insights into regolith characteristics and exposure ages [1,2]. Here, we show the results of our search for SFT and CRT in grains present within regolith breccia meteorites.

Samples and Methods: For the studies, we have used different meteorite samples: Khor Temiki and Kapoeta to look for SFTs and Ghubara & NWA 869 for CRTs. The bulk sample was prepared by embedding the meteorite in epoxy followed by several stages of polishing. Chemical etching is done for the samples to visualize SFT and CRT. For etching pyroxene NaOH and Milli-Q water solution (6:4 ratio) is heated to 120–160°C with a refluxing system, etching is done for 5 minutes, and in the case of olivine, WN solution made from 1g oxalic acid, 1ml orthophosphoric acid (85%), and 40g disodium salt of EDTA in 100ml distilled water (pH adjusted to 8.0 ± 0.3 using NaOH) is heated to 105°C and etched for 3-4 hours using a reflux system to maintain solution concentration. Etching is made to stop with the help of running water, then the sample is rinsed with methanol and finally dried. Both optical and scanning electron microscopy are utilized to visualize the density and distribution of the tracks.

Result and Discussions: 5 mounts containing 850 grains (100-200µm) and 6 mounts containing 2700 grains in total (40-60µm) were prepared to look for SFTs. Out of these, the 5 mounts (100-200µm) were etched using boiling NaOH solution. We did not find SFTs in any of the grains. Many of the grains darkened during the etching process and the fractures and imperfections on some grains increased in size. The absence of SFTs in the studied samples shows that these grains were never exposed to the solar wind or the experimental parameters were not optimum. Two specimens from Ghubara and NWA 869 were etched with WN solution but no tracks were found within olivine grains. More studies are undergoing.

Conclusions and Future work: Estimating surface exposure ages through SEP tracks provides direct information about the surface processes and the dynamics of regolith on the surface of asteroids. This information helps in reconstructing the geological history and understanding the surface weathering processes. We studied one regolith breccia meteorite with high concentrations of solar wind gases to look for SFTs in enstatite and olivine grains from the matrix. The absence of SFTs in the 100-200 micron-sized grains shows that more grains needs to be studied. The etching of the other 6 epoxy mounts (3 from Khor Temiki and 3 from Kapoeta) containing grains of the size 40-60µm is being carried out. As for cosmic ray tracks, chromite grains have been located with the help of SEM and these mounts are yet to be etched for further studies.

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MAVEN observations of the Martian Gravity Waves and their Variability with the Phase of the Solar Cycle

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ABSTRACT

Gravity waves (GWs) or (buoyancy waves) are ubiquitous in the planetary atmosphere. GWs are generated in various ways in the lower atmosphere, for example, due to the orographic barriers, cyclonic activity, jets, etc. These waves may propagate to the lower thermosphere and play a crucial role in the region's dynamics.

The current study focuses on the GWs in the Martian thermosphere. Mars and Antarctica offer unique advantages for studying gravity waves due to their extreme and stable atmospheric conditions. Antarctica offers a controlled environment on Earth with minimal atmospheric disturbances. Because of its location, the Antarctic upper atmosphere constantly interacts with the solar wind and corresponding space weather activities. As a result, the upper atmospheric GW activity is modulated by energy and momentum deposition during intense space weather events. Similar conditions are also found on Mars. As opposed to Earth, Mars lacks a global magnetic field. Consequently, its atmosphere is highly influenced by the solar wind, mimicking conditions similar to Antarctica to some extent. Understanding the GW dynamics over Mars under constantly varying space weather conditions may help us understand the same over Antarctica.

This study uses the reference data from Mars's atmospheric measurement by the Neutral Gas and Ions Mass Spectrometer (NGIMS) onboard the Mars Atmosphere and Volatile EvolutioN (MAVEN) satellite. The MAVEN satellite continues to measure the atmospheric constituents from the peak of solar cycle 24. The transient solar activity, varying with the solar cycle phases, will likely affect the tenuous Martian atmosphere to different degrees. The characterisation of the GWs in the Martian atmosphere has been carried out. Moreover, the comparison of the GW activity with the solar cycle phase shall be discussed.

Keywords: Gravity Waves, solar cycle, Thermospheric region, density, etc.

Session -V: Impacts: Shocks and Shattering

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Akimotoite-bridgmanite formation in shocked chondrite

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Introduction: Akimotoite, with its ilmenite structure, is stable between 23 and 25 GPa and at temperatures ranging from 900 to 2200 K, while bridgmanite, which has a perovskite structure, remains stable at pressures above 24 GPa and at temperatures between 1800 and 2800 K [1,2]. The formation mechanisms of these minerals provide valuable insights into the processes occurring during high-grade shock events in mafic-rich chondrites, improving our understanding of the origin and evolution of planetary bodies.

Results and discussion: The Bori meteorite, a heavily shocked L6 chondrite that fell near the Bori district in Madhya Pradesh, India, in 1894, is primarily composed of olivine, low-Ca pyroxene, high-Ca pyroxene, plagioclase, chromite, apatite, Fe-Ni metal, and troilite. This study reports various modes of akimotoite and bridgmanite occurrences within the Bori chondrite. Low-Ca pyroxene grains ($En_{77}Fs_{20}Wo_2$) within the shock melt vein (SMV) have been partially transformed into akimotoite ($En_{75}Fs_{24}Wo_2$), coexisting with pyroxene glass. The chemical composition of lamellar akimotoite [$(Mg_{0.75}Fe_{0.24}Al_{0.01}Ca_{0.02})_{1.01}Si_{0.99}O_3$] is similar to that of the host enstatite, indicating a solid-state transformation from enstatite to akimotoite. Akimotoite in Bori meteorite exhibits two morphologies: one is columnar-shaped (50 to 600 nm) with random orientations, and the other is granular, with grain sizes ranging from 50 to 100 nm. Bridgmanite was also identified in the center of equant glassy grains, coexisting with akimotoite and metal. Bridgmanite grains were idiomorphic and microcrystalline, with grain sizes ranging from 50 to 70 nm. The chemical composition of bridgmanite from the Bori L6 chondrite is $(Mg_{0.74}Fe_{0.21}Al_{0.01}Ca_{0.02})_{0.97}(Si_{1.03}O_3)$. Also, it was found that Bori bridgmanite has a significantly lower Fe^{3+}/Fe_{Total} ratio (0.29) compared to the previously reported Fe-bearing aluminous bridgmanite (0.69) from Katol [3]. The $Fe^{3+}/\sum Fe$ ratio of akimotoite from Bori is ~0.21, much lower than that of Al-bearing akimotoite (0.67) from Sixiangkou L6 chondrite. These bridgmanites were crystallized at pressures above 25 GPa from pyroxene melt generated by the shock event, while akimotoite formed at pressures from 19 to 23 GPa by the solid-state transformation of orthoenstatite.

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MARS' STRUCTURE AND EVOLUTION AS SEEN BY IMPACT CRATERS

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Introduction: All planetary surfaces have been exposed to impact bombardment by rocks from space, altering their crusts and surfaces and forming craters [1]. Impact craters have different geological, geophysical, and remote sensing signatures depending on the materials they form in. By studying impact craters, i.e., the mechanics of their formation and geological crater record, we can infer the structure and the changes in the crust they formed into. This overview presentation introduces how we use impact craters to understand the structure and evolution of planetary surfaces and interiors across geological epochs (specifically Mars) through impact crater simulations, remote sensing space data analyses and applications to resource identification for future in-situ exploitation.

Methods: Our team focuses on the cratering process from several aspects: impact physics, high-pressure shock physics process, numerical simulation of crater formation (using the iSALE shock physics code [2]), visible and spectral remote sensing (MRO CRISM, CTX and HiRISE datasets), geological and geophysical surveying [3]. In doing so, we strive to provide a complete investigation of how the cratering process could have changed planetary surfaces and/or how the cratering process can uncover information about the crustal structure. Part of our work builds on the engagement with the NASA InSight mission and its legacy to understand the interior of the Red Planet better.

Impact basins on Mars and early Mars geological history: In this work, we investigate Mars's early geological evolution through large impacts (so-called impact basins) that formed within the first billion years following Mars's formation. The large bombardment shaped the early crust on Mars and has likely played a role in its thermal evolution. Signatures of impact basins are captured differently depending on the crustal thickness and thermal conditions they formed into [4-5]. Similarities with the Moon's early bombardment [6] provide a fundamental analysis of impact bombardment rates/history. Here, we discuss the latest understanding of the early impacts on Mars, building on the most recent understanding of the Martian interior after the NASA InSight mission.

Tracing water signatures in recent Mars' crust: We also investigate hydrothermal products observed through spectral surveys [3] in complex craters on Mars to identify whether they could have been impact-generated or impact-excavated. Our work suggests that complex craters on Mars (20-80 km in diameter) could be ideal candidates. Numerical simulations can discern from depths heated by an impact vs excavation to the surface without impact-related alteration [7]. In doing so, we strive to unravel the water/ice/climate history of Mars.

Ice-exposing craters and near-surface ice deposits: We also interrogate the conditions and properties of the underground water/ice. NASA InSight and MRO CTX/HiRISE observed the largest ever ice-exposing impact crater (~150 m in diameter) that happened to be located in the most southern latitudes of all ice-exposing craters ever, providing a window to investigate ice deposits at lower latitudes and deeper depths [8]. Numerical impact simulations suggested the ice layer in the top 10 m [9]. Additional work on the excavation of near-surface ice in smaller, meter-size craters is presented here by Mendonca et al. [10].

Conclusions: In this presentation, we present our extensive numerical and remote sensing work to understand Mars's structure and evolution through the cratering process. This leads to a better understanding of the interior structure and planetary evolution of Mars and its potential habitability. Our results inform future space mission planning. We show how this project can assist with near-future human space exploration targets where water as a resource is key.

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Potential target for early Earth impact-related studies from the Singhbhum Craton, India

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Archaean impact ejecta units (e.g. spherule bearing layers) have provided vital information about early bolide impacts on our young Earth. Spherule beds related to global events have often been cited for assessment of the projectile flux early in Earth's history. Tracing their chemical affiliation to objects in the asteroid belt may plausibly unravel the timing of the dynamical mixing. Over the past few decades, high-resolution geochemical studies of impact horizons predominantly from the geologic record of the Kaapvaal and Pilbara Cratons (Lowe, 2024) have improved our understanding of these impact events. In recent times, the geological evolution of the Singhbhum Craton of India has been compared to those of the Kaapvaal and Pilbara Cratons (Hofmann et al. 2022; Jodder et al. 2023; Lowe, 2024). Well-preserved Archaean sedimentary units in the Singhbhum Craton provide novel prospects for investigating potential impact-related units. In this pilot study, we evaluate petrological and geochemical characteristics of event units from the Archaean record of the Singhbhum Craton in terms of their highly siderophile elements (HSE) and triple oxygen isotope composition and compare them with existing data from the Kaapvaal and Pilbara Cratons to test their potential impact origin. The first unit investigated from the Palaeoarchaean Daitari greenstone belt is represented by rip-chert clasts set within their host rock (i.e. silicified clastic layer) that indicate high-energy depositional settings (e.g. tsunamis). Another interesting sandstone unit found interlayered within shales and banded iron formations of the Neoarchaean Koira Group of the Singhbhum Craton suggests deposition in a high-energy event in the epicontinental sea. This unit is suggestive of a major storm event giving rise to sandstone interbedded with offshore shale (Jodder et al. submitted). Through this comparative study, we intend to expand our frontiers in terms of early Earth impact-related research from the Singhbhum Craton of India.

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NONTRADITIONAL STABLE Sr ISOTOPIC VARIATIONS IN THE IMPACTITES OF LONAR IMPACT STRUCTURE, INDIA: IMPLICATIONS FOR MELTING, MIXING AND IMPACT VOLATILIZATION

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Introduction: The ~1.88 km diameter Lonar crater is a ~0.57-Myr old simple impact structure hosted in the ~66 Ma old Deccan Traps in India [1]. It is the best-preserved impact structure hosted in basalts, providing unique opportunities to study processes of impact cratering in basaltic targets. Variations in radiogenic isotope ratios of Nd, Sr, Pb in the Lonar impactites were explained by melting of the sub-basaltic basement at Lonar upon impact while analyses of selected Platinum Group Elements in the Lonar spherules have indicated a chondritic impactor [2,3]. Here we present preliminary nontraditional stable Sr isotopic variations coupled with radiogenic Sr isotopic variations for the target basalts and impactites (impact breccias and tektites) from the Lonar area.

Samples and Methods: 6 samples sampled across the Lonar impact structure have been selected for this study. The samples include 1 host Deccan basalt, 3 impact melt breccias sampled from the upper crater wall and 2 tektites sampled from the distal ejecta blanket extending up to ~1.6 km from the crater rim [2]. These samples were analyzed for their stable and radiogenic Sr isotopic compositions. All measurements were performed using thermal ionization mass spectrometry (TIMS, Thermo Triton Plus) at the Centre for Earth Sciences, IISc. The analytical uncertainties for $\delta^{88/86}$Sr, measured using an ^{84}Sr-^{87}Sr double-spike technique [4], are <0.05 ‰ (2SD), based on multiple analyses of NIST SRM 987 (n=6).

Results: The stable Sr isotopic variations for the selected impact lithologies are the first reported for any impact crater. The impactites display significant variations in measured $\delta^{88/86}$Sr values ranging from 0.144 to 0.518 ‰ which are both higher and lower than the target basalt while their ^{87}Sr/^{86}Sr range from 0.707241 to 0.708713 (Fig 1).

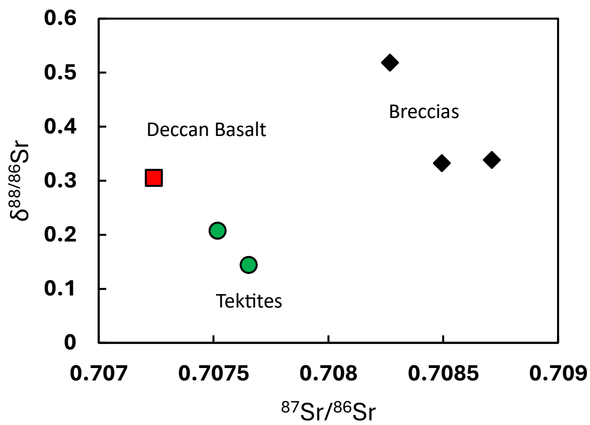

Fig 1. $\delta^{88/86}$Sr vs ^{87}Sr/^{86}Sr of Lonar impactites

Discussion and conclusions: The $\delta^{88/86}$Sr value for the host deccan basalt is 0.305 ± 0.014 ‰ which overlaps with restricted $\delta^{88/86}$Sr values reported for globally distributed terrestrial basalts 0.30 ± 0.07 ‰ [5]. The impact melt breccia samples show a significant range from 0.332 ± 0.009 ‰ to 0.518 ± 0.015 ‰, suggesting loss of the lighter isotopes of Sr likely due to impact volatilization. The 2 tektites sampled from the distal ejecta blanket show the lowest $\delta^{88/86}$Sr values (0.144 ± 0.013 ‰ to 0.207 ± 0.012 ‰), which might represent the condensates from the impact vapour plume sampling the comparatively lighter isotopic compositions. On the other hand, the ^{87}Sr/^{86}Sr of impactites are all more radiogenic than the target basalt; the impact breccias show the most radiogenic Sr isotope ratios ranging from 0.708269 to 0.708713, distinctively radiogenic from the host basalt ^{87}Sr/^{86}Sr value of 0.707241, while the tektites show intermediate ^{87}Sr/^{86}Sr values between the host basalt and the breccias. The ^{87}Sr/^{86}Sr highlights mixing of the host basalt with the radiogenic granitic basement, which melted upon impact, with possible contribution from the impactor. The results indicate that coupled measurements of radiogenic and stable isotopes of Sr can reveal important insights into processes associated with impact cratering.

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SHOCK-PRODUCED TEXTURES AND PHASES IN INDIAN METEORITES

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Introduction: Meteorites are broken pieces of the asteroids or some planet that got dislodged from the asteroid's surface when two celestial bodies collide with each other. These broken pieces are later get sucked in by the Earth's gravity and fall on the Earth's surface as meteorites. These collisions result in the formation of shock waves. The main property of these waves is that they deform the rocks and immensely increase the pressure. Furthermore, such collisions give rise to the formation of numerous fractures in the parent body. During the collision, the friction produced as the surface of these fractures moves past each other, causes temperature spike and subsequent melting. Therefore, these fractures become localized zones of high-pressure and high-temperature and are called shock-melt veins (SMVs). These high-pressure and high-temperature conditions are similar to the condition prevailing at depths of ~400-700 km on Earth resulting in formation of high-pressure phases in and around these SMVs.

Kamargaon: Asteroids are mostly made up of a mineral called olivine which is also a major constituent of the Earth. Consequently, understanding the behavior of olivine at high pressure and temperature becomes important to unravel the secrets of Earth's deep interior. Olivine becomes unstable at around pressure of ~23-25 GPa, which is equivalent to the depth of ~660 km on Earth, and breaks down into bridgmanite + magnesiowüstite. Bridgmanite is the most abundant mineral on Earth, which makes this one of the most important reactions that control the physical and chemical properties of the Earth's interior. This breakdown may occur where the olivine remains in the solid state or may also form by melting of the olivine. The breakdown assemblage of bridgmanite and magnesiowüstite formed by both of these mechanisms has been reported in few Martian meteorites. However, no such assemblage formed by melting has been found in meteorites originated from the asteroid belt. We studied a meteorite named 'Kamargaon' that fell on November 13, 2015, near the town of Kamargaon, Assam, India [1]. We, for the first time, reported the possible occurrence of bridgmanite and magnesiowüstite formed by the melting of olivine in Kamargaon meteorite, a meteorite that came from the asteroid belt [2]. This assemblage may have formed at pressure and temperature of ~25 GPa (equivalent to the depth of ~660 km on Earth) and ~2500 °C [2]. These observations suggest that the breakdown of olivine in the natural systems can also take place by the melting of olivine.

Katol: Additionally, we studied another meteorite that originated in the asteroid belt named 'Katol' that fell near the town of Katol in the Nagpur district of India after a large meteor shower occurred on May 22, 2012 [3]. We tried to understand and decipher the composition and formation mechanisms of various minerals that are present in the shock-melt veins of Katol meteorite. We found that the bridgmanite is present as a very fine-grained (100-1000 nanometer in size) assemblage in the shock-melt veins [4]. Natural bridgmanite has been reported in only a few meteorites; however, the composition of these specimens differs from the plausible composition of bridgmanite that is expected to be present in the Earth's interior. This study reports the first natural occurrence of bridgmanite, observed in Katol meteorite, with a composition closest to the bridgmanite present in the Earth's mantle. The bridgmanite in the Katol chondrite has high Fe^{3+} and other compositional traits that agree with experimental predictions. Additionally, the pressure we have estimated (~25 GPa) based on the occurrence of bridgmanite and the duration for which such conditions persisted can be used to calculate the impact velocity and parent body size of these meteorites. According to our calculations, Katol meteorite was produced during an impact where impact velocity was ~2.54 km/s and the parent body from which it broke off was at least ~3 km in diameter [4]. For Kamargaon meteorite, our calculations suggest that it is a result of impact velocity of ~2.3 km/s and the parent body size was ~6.4 km in diameter [2].

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Shock-induced Majorite and Majorite-pyrope solid solution in the Bori L6 chondrite

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Introduction: The high-pressure minerals are mostly found inside the Earth's interior. These are rarely seen in terrestrial rocks and sometimes appear as an inclusion in diamonds. However, shocked meteorites are the primary natural source of these high-pressure minerals. Shocked meteorites experienced high-pressure and temperature conditions due to the collision of the celestial bodies in outer space. The friction along the fractures results in high-temperature conditions, and the subsequent melting happens to produce the shock melt veins (SMV). The formation mechanism of the high-pressure phases mainly involves two types of mechanisms. (a) solid-state transformation mechanism in which the chemical composition of the high-pressure phase will be similar to the host rock mineral [1]. (b) crystallization from the melt in which the high-pressure phases directly crystallized with enrichment of Al_2O_3, CaO, and Na_2O present in the SMV compared to the host rock minerals [2]. Pyroxene progressively transforms into a garnet structure with increasing pressure and temperature, forming an Al-deficient garnet called majorite [3]. However, the dissolution of pyroxene in a garnet structure forms the majorite-pyrope solid solution [4]. These high-pressure phases are present in the mantle and affect the seismic velocity and the compositional heterogeneities occurring in the mantle. Hence, studying these high-pressure minerals in the shocked meteorite gives information about the mechanisms operating inside the planetary interiors.

Results and discussion: The Bori meteorite fell in 1894 in the Bori village of Madhya Pradesh. The SMV, melt pockets, and high-pressure minerals indicate the heavy impact event. The host rock minerals include olivine, low Ca-pyroxene, high Ca-pyroxene, plagioclase (mostly maskelyinite), chromite, apatite Fe-Ni, and troilite. The high-pressure minerals include ringwoodite, wadsleyite, asimowite, bridgmanite, akimotoite, majorite, lingunite, jadeite, coesite, stishovite, xieite, and tuite. This study discusses the formation mechanism of majorite and majorite-pyrope solid solution inside the SMV. Some of the low Ca-pyroxene grains inside the SMV transform into the polycrystalline majorite with the inclusion of platy minerals and metals. The chemical composition of the majorite $(Mg_{0.76}Ca_{0.02}Fe_{0.22})Si_{1.00}O_3$ is similar to the host rock low Ca-pyroxene $(Mg_{0.77}Ca_{0.02}Fe_{0.19})Si_{1.00}O_3$ indicates that it is formed by the solid-state transformation of the low Ca-pyroxene. Furthermore, the majorite-pyrope solid solution occurs as very fine grains coexisting with Mg-rich and Fe-rich wadsleyite, albite, and Fe-alloy in the matrix portion inside the SMV. The majorite-pyrope solid solution, $(Mg_{0.59}Ca_{0.05}Na_{0.07}Al_{0.09}Fe_{0.22})Si_{1.00}O_3$ is enriched in Al_2O_3 (4.12 wt %), Na_2O (1.97 wt %), CaO (2.45 wt %) as compared to the host rock low-Ca pyroxene indicates that it is directly crystallized from the chondritic melt under high-pressure and temperature conditions. The polycrystalline majorite may be formed in the pressure range from 17 to 20 GPa and a temperature range from 1900 to 2000 ° C. However, the coexistence of the majorite-pyrope solid solution with albite and wadsleyite in the matrix of the SMV suggests the comparatively lower pressure and temperature conditions of crystallization of majorite-pyrope solid solution than the polycrystalline majorite formed by the solid-state transformation mechanism.

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Luna Impact Crater: cosmic fingerprint on Harappan Civilization

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Introduction: Luna structure (23°42′39.16′′ N, 69°15′39.35′′ E), located in the Kutch region of western India, is a simple, high velocity impact crater with an average diameter of 1.8 km. It is considered as the largest Holocene impact crater noted till date and potentially resulted from an iron/stony-iron bolide [1], [2]. The significance of Luna is amplified in a geo-archaeological perspective by its proximity to the archaeological sites belonging to the Harappan Civilization, a Bronze Age culture that thrived in the Kutch region. Numerous Harappan settlements have been uncovered in the Kutch Peninsula [3], [4], [5], [6] and the civilization went into a 'sudden decline' from the Kutch region around 1900 BCE [7]. While various explanations have been proposed for this decline, including natural disasters like droughts [8] and earthquake [9], the potential impact of a cosmic event has not been thoroughly investigated.

Impact events can be regarded as biologically 'resetting' events. They render the immediate area of the impact sterile as a result of the intense heat and pressures reached at the point of contact of the impactor with the target planet [10]. These cataclysmic events, often accompanied by earthquakes and widespread fires, lead to the destructions at local scale. Surprisingly, such localized catastrophes can have far-reaching consequences on a broader scale. By dramatically altering environmental conditions, these impact events can act as catalysts for significant evolutionary changes, leaving enduring traces in the fossil record [11]. How such an impact event would affect the human civilization is an interesting aspect that have not been studied in detail.

This study aims to investigate the possibility that the formation of the Luna impact crater contributed to the abrupt disappearance of the Harappan civilization from the Kutch region. We will present this ongoing work that is based on extensive field study, and age dating of archaeological samples and impact melt collected from the Luna region. Five trenches were excavated in the different morphologic units of the crater, from which the pottery and human bone fragments as well as impact melt samples were collected. Confinement of both pottery pieces and bones within the ejecta layer suggests that the civilization might have been affected by Luna impact. The age of impact melt samples was estimated by Optically Stimulated Luminescence (OSL) dating method, which yielded an age estimate of 4.045±0.182 ka for the impact event. Though this age coincides with the decline of Harappan Civilization in this region, we will be presenting the age estimates from pottery and bone samples and the subsequent environmental changes post impact so as to reaffirm the consequences of the Luna impact event on the decline of Harappan Civilization in Kutch region.

Funding Support: This work is supported by the *Meteoritical Society Research Grant (July 2024)* awarded to S. Sathyan for the topic 'Luna impact crater; cosmic fingerprint on Harappan Civilization.

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GEOMORPHIC AND RELATED SIGNIFICANT OBSERVATIONS ON KAVERI CRATER

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Kaveri Crater, a new extraterrestrial hypervelocity impact structure has been discovered in the Southern Indian Peninsula [1]. This Crater, with a diameter of about 120 kilometers, is the fourth largest on the surface of the Earth. It is nearly circular in shape and surrounded by hills of high relief. Rock type in the circular depression is mainly composed of granitic gneisses/migmatites. This is surrounded by charnockite. The quartz grains show the presence of PDF and PF, which are definitive evidence of impact origin. Plagioclase grains show a variety of features which point to impact. Among them are: PDF and PF; checkerboard; evidences of melting and isotropism; increase in clouding of feldspars towards the Crater; remagnetisation. PDF and PF in quartz and plagioclase, taken together, indicate that the hypervelocity impact was subjected to pressure in the range of 10 to 30 GPa. Region surrounding the Crater has many outcrops of Pseudotachylite, which is more abundant in the northeast. A detailed study of the slope map shows an outward sloping ring nearly concentric with the rim. Two arcs in the NE direction, point to gravitational collapse of crater wall. These taken together indicate that the region beyond the Northeast direction of the Crater has been subjected to maximum deformation.

Topographic analysis shows a circular depression which is more pronounced in the northern, southern and western direction. It is subdued in the eastern direction as the Peninsula as a whole has an easterly tilt. The prominent geomorphic units identified in the study area are Bajada; high, moderate, and low dissected hills; valleys and plateaus, pediment pediplain complex, and flood plain. The major landform that covers the crater is the pediment pediplain complex. The crater is surrounded by highly dissected hills and valleys, with Bajada at its foothill.

The crater region has tributaries of river Kaveri which also define the boundaries. The drainage map of the study area has been prepared using georeferenced topographic sheets from the Survey of India with the help of GIS software. The entire study area has been divided into 5 major river basins: Moyar-Bhavani, Kaveri, Thirumanimuthar, Noyyal, and Amaravathi. The rivers Moyar, Bhavani together with the Kaveri, cover the north and north east portions of the crater rim. The river Amaravathi (Amaravathi basin) raises in the Anaimalai/Kodaikanal hills, flows from the south to the depression in the centre of the crater, and fills the crater’s southern half. The crater basin is fully covered by the pediplain landform of Alfisol (Al + Fe) class of Rhodustalfs, and Pellusterts (mixed red & black soils) surrounded by dissected structural hills.

Geophysical analysis gives supportive evidences. The study area shows an elliptical positive Bouger gravity anomaly, below the Crater. This positive anomaly can be partly due to elastic rebound and partly due to isostatic adjustment, as the topography in the Crater region is deeper, density of the gneissic rock is lower compared to surrounding charnockite. The magnetic basement is deeper by 1 km and approximately coincides with the Crater. All of these evidences, taken together, confirm the earlier study that the Kaveri Crater is an extraterrestrial hypervelocity impact.

Available geochronological data [2] provides a narrow window on the age of impact: Sivamalai syenite whose age of emplacement is 623 ± 21 Ma has quartz and pegmatite veins. Quartz in these, have developed PDF and PF, indicating that impact is younger than 623 Ma. Oddanchatram anorthosite whose age of intrusion is 560 ± 12 Ma has PDF developed in plagioclase. A huge impact normally creates large quantity of melt. It has been seen that within the crater and also within the apparent crater rim, there are innumerable emplacements of granitic bodies. Ages of these range from 580 to 510 Ma with a mean of 545 Ma. Metamorphic age of Paleoproterozoic rocks (~2.5 Ga) within and close to the Crater, range in age from 576 to 512 with a mean of 548 Ma. These age data indicates that the impact could have occurred at the Proterozoic – Paleozoic boundary. Whether the impact has contributed to Cambrian Explosion is worthy of investigation.

Key words: Kaveri Crater, PDF, Pseudotachylytes, Extraterrestrial, Hypervelocity, Cambrian Explosion

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High Pressure Mineral Phases in Katol and Kamargaon Meteorites

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Introduction: The study of shock metamorphism in extraterrestrial planetary materials, provides insights into impact processes in the early history of the solar system. Here we studied samples from the highly shocked Katol L6 and Kamargaon L6 chondrites. These L6 chondrites show presence of high pressure polymorphs, which are unique crystal structures formed under extreme pressure conditions. High pressure polymorphs are different crystal structures that form when minerals in meteorites are subjected to intense pressure.

Samples and Methods: For the study, we prepared three polished sections from Katol (2) and Kamargaon (1) specimens. The sample was carbon coated of thickness 15-20 nm to cover non-conducting samples with a conducting layer for use inside a Scanning Electron Microscope (SEM). Two shock melt veins, ranging in thickness 1.6- 20 µm were discovered in the Katol L6 sample. The SEM was utilized to get the images of the melt veins using electron high tension of 20.00 kV.

Results and Discussions: In this work, SEM study of Katol L6 sample revealed shock melt vein formations various rounded fragments in the host rock entrained in a finer matrix. The silicate portion of the chondrite is highly recrystallized, with very few recognizable chondrules. The presence of shock melt veins could suggest that the meteorite experienced a significant impact event. The extreme heat and pressure from the impact could create these veins.

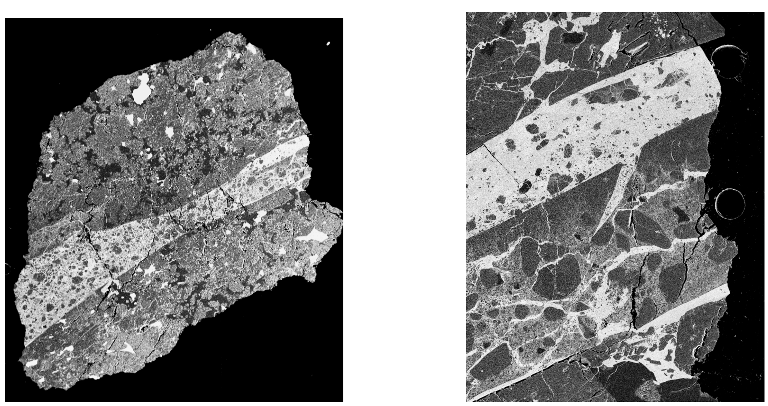

Fig. Scanning Electron Microscope image of Katol L6 chondrite

Conclusion and Future work: With the discovery of shock melt veins in the Katol L6 sample, we intend to identify the high-pressure mineral phases using Raman Spectroscopy.

Keywords: High pressure minerals, Shock metamorphism, Shock melt veins, SEM, Raman Spectroscopy

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Post Impact Aqueous Alteration of Basaltic Target Rocks: Implications for Mars and Earth

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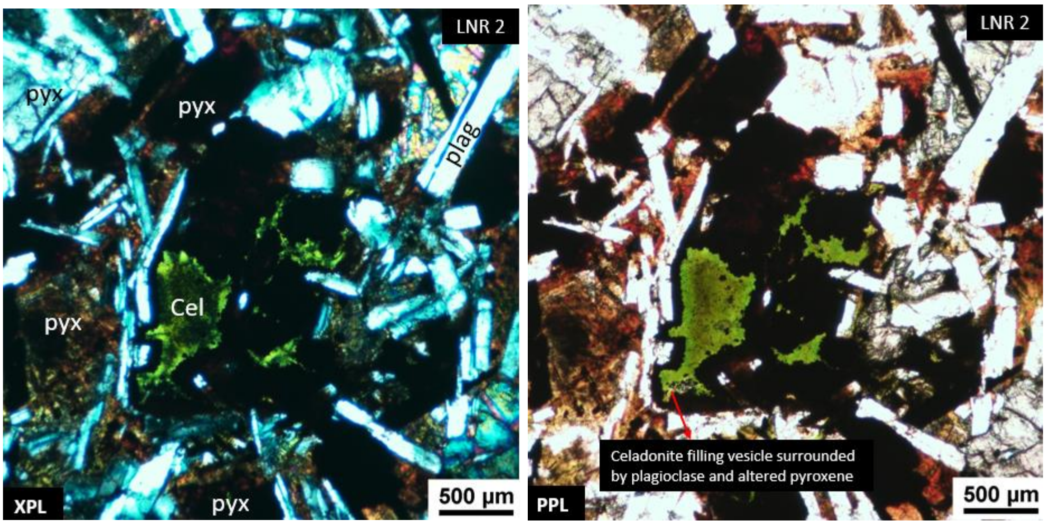
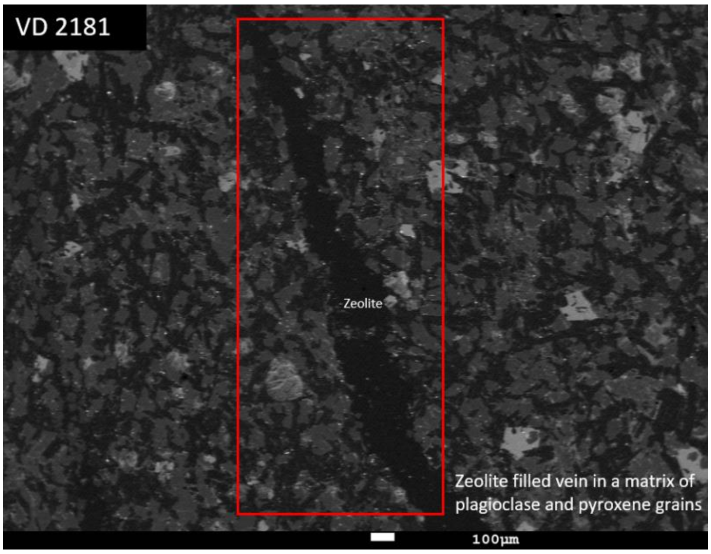
Introduction: Impact craters serve as geological signatures, revealing information about the planetary surface and sub-surface. Additionally, impacts on water-bearing target rocks can trigger hydrothermal systems, leading to the formation of new minerals and potentially habitable conditions for organic matter [1, 2]. Study of such impact craters specifically on basaltic lithology of Earth can serve as ideal terrestrial analogues for planetary bodies like Moon and Mars. Following on that, three terrestrial impact craters of varying size namely Lonar Crater (India), Vargeão Dome (Brazil) and Vista Alegre Impact Structure (Brazil) formed in basaltic lithology were studied and analyzed for signs of any post impact hydrothermal activity. Lonar Crater is a relatively small 1.88 km diameter depression formed in purely basaltic rocks of the Deccan Traps and serves as an ideal terrestrial analogue [3, 4]. Vargeão Dome and the Vista Alegre structure are bigger impact craters excavated in the Parana Basin of South Brazil that were formed on a mixed lithology of basalts and sandstones [5, 6].

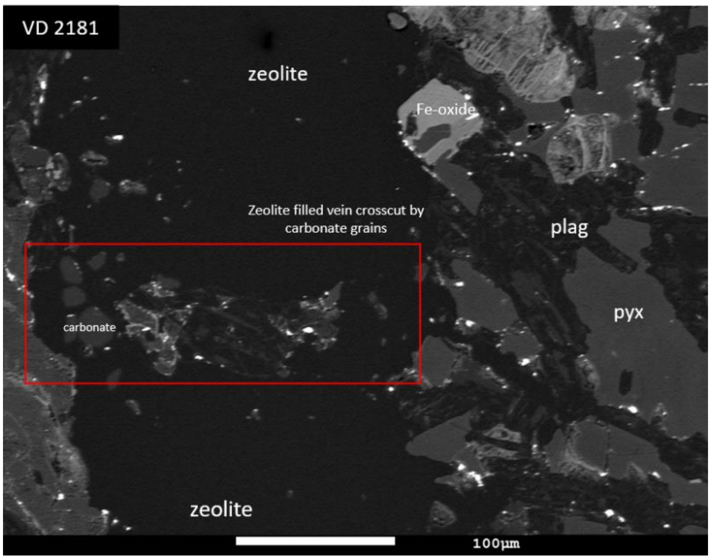
Methodology: This study was done on polished thin sections sampled from the interior of the three craters and involves petrography using Nikon Lv100 polarizing microscope at Physical Research Laboratory (PRL), Ahmedabad, India. Both plane polarized and cross polarized light was used to identify and image secondary mineral phases and their occurrence using NIS-Elements F 5.42.01 image analysis software. For a more detailed and accurate understanding, BSE imaging and mineral chemical analysis was conducted using JEOL 8530F FE-EPMA, also at Physical Research Laboratory (PRL), Ahmedabad, India. The operating conditions were set at a typical accelerating voltage of 15 keV, a 15 nA sample current and a beam size of 1 micron with 5 wavelength dispersive X-ray spectrometers. Accuracy and precision of results was monitored through analyses of mineral standards.

Results: The investigation revealed evidence of low to moderate temperature clay minerals replacing primary phases, as well as their presence in veins and pockets. Additionally, zeolites



and carbonates were also identified, as illustrated in the provided figures. Along with this, data collected by the Perseverance rover while exploring Mars' Jezero Crater's floor was taken to check for any hydrothermal alteration assemblages [7]. The type of clay minerals (smectites) in both Jezero Crater and the terrestrial analogues have been found to show similarities.





Discussion: The formation of such hydrothermal secondary phases in this scenario is only possible due to instant heating of the rocks post impact, given the presence of a water source. Moreover, the similarities between clay minerals of Jezero Crater and the terrestrial analogues hint towards a possible hydrothermal system on Martian craters generated by the presence of an aqueous source, an indication of organic activity. Through this study, the aim is not only to detect presence of such hydrothermal systems on Mars that could have acted as hosts for life but also to analyze the observed variations in secondary hydrothermal mineralogy with respect to size of the impact crater formed, which could again play a role in determining possible sites for microbial activity on Mars.

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Numerical Analysis of Rotating Ejecta Stability and Morphologies in Terrestrial and Lunar Impact Craters: Simulations Using iSALE and FE-SPH

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Understanding the formation and stability of ejecta shapes resulting from planetary impacts is crucial for interpreting cratering processes. This study focuses on simulating rotating ejecta to explore the dynamics behind their morphologies, such as spheres, ellipsoids, and tear-drops, using the iSALE shock physics code and FE-Smoothed Particle Hydrodynamics (FE-SPH). The novelty lies in the detailed examination of how gravity and aerodynamic stresses influence these shapes during and after impact events, with applications to both terrestrial and lunar craters.

In this project, We are focusing on numerically analyzing the stability and morphology of rotating ejecta formed during impact events on terrestrial and lunar surfaces. The primary goal is to explore the possible causes of different ejecta shapes, such as elongated, ellipsoidal, spherical, and tear-drop forms, while examining the effects of gravity and aerodynamic stresses on their stability.

Research Focus:

★ **Rotational Stability and Morphology:** Utilizing the iSALE shock physics code and FE-Smoothed Particle Hydrodynamics (FE-SPH), I am simulating the formation and evolution of rotating ejecta. The study will investigate how factors like rotational speed and material properties influence the formation of stable shapes, drawing upon the work of Elkins-Tanton et al. [1], who modeled the dynamics of spinning fluid drops. The stability of these shapes will be assessed based on the interplay between centrifugal forces and surface tension, as suggested by Melosh's hydrocode models [2].

★ **Impact of Aerodynamic Stresses:** Another aspect of this research involves exploring the aerodynamic stresses acting on ejecta during flight, which can lead to shape distortions or fragmentation. This will involve examining the breakup dynamics of ejecta as they travel through the atmosphere, utilizing Weber and Reynolds number analysis as outlined by Melosh and Vickery [3].

★ **Applications to Terrestrial and Lunar Impact Craters:** The simulations will be applied to both terrestrial and lunar craters, aiming to predict the range of stable morphologies under varying gravitational and atmospheric conditions. This approach builds upon the laboratory models developed by Elkins-Tanton et al. [1], where similar shapes were reproduced under controlled conditions, providing a basis for comparison with the simulation results.

★ **Ongoing Work:** This project is currently ongoing, with preliminary results indicating that the interaction between rotation and aerodynamic stresses plays a significant role in ejecta shape evolution. Further simulations are planned to refine these models, and I hope that soon, more detailed and accurate results will emerge, offering a clearer understanding of the mechanisms at play.

Mathematical Framework:

The dynamics of rotating ejecta will be governed by the following key equations:

- **Drop Stability Equation:**

$$\Sigma = \frac{\Delta\rho\Omega^2 R^2}{\rho_a \Delta U^2}$$

where Σ is the ratio of dynamic pressures due to rotation and translation, $\Delta\rho$ is the density difference, Ω is the angular velocity, R is the radius, and ΔU is the relative velocity between the drop and the surrounding air [1].

- **Weber Number (We):**

$$We = \frac{\rho_a \Delta U^2 R}{\sigma}$$

which characterizes the stability of the drops against aerodynamic breakup, with σ representing surface tension [2].

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High-pressure mineral phases in the melt rock from the Luna Crater, Gujarat, India

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Introduction: The impact origin of the Luna crater in India has been a subject of debate due to its distinct morphology, with the recent studies providing conclusive evidence of an impact origin, supported by geological data [1]. The Luna Crater, with a diameter of 1.5–1.8 km, exhibits rocks with high specific gravity and diverse magnetic properties and the region has a circular morphology with a faint rim in the low-lying Banni Plains of the tectonically active Kutch Basin [1]. However, no high-pressure phases have been found in the collected samples from the region. We propose to address this gap by searching for high-pressure mineral phases and shock deformation features in new rock samples collected from the Luna crater [2].

Methodology: We prepared 12 polished thin sections (PTS) from rock samples collected from six different locations of the Luna crater (Fig: 1b). A reflected light microscope was used to study the PTS (Fig: 1c). A few samples were crushed to powder and studied using an X-ray diffractometer (Fig: 1d).

Results and Discussions: X-ray diffraction (XRD) analysis revealed the presence of wüstite (FeO) as the predominant mineral component (Fig. 1d). The reflected light images from the PTS also show dominant presence of a metallic phase. We are carrying out scanning electron microscope imaging, electron microprobe and Raman spectroscopy study of the samples to understand the origin of the wüstite phase and to search for presence of high-pressure mineral phases.

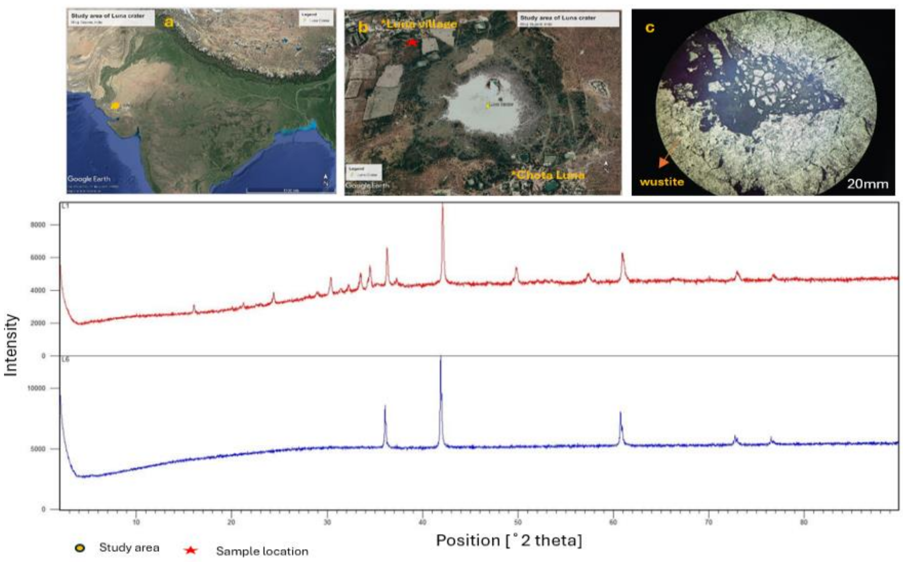

Fig.1: (a) Location map of the Luna crater in Gujarat, India. (b) Regional view of Luna crater. (c) Photomicrograph of the melt-rock under reflected light showing wustite as a major component. (d) X-ray diffraction spectra acquired from two samples from the Luna structure. The dominant peaks correspond to wustite.

Conclusion and Future Plans: The identification of wüstite as a major component in the Luna Crater, which could shed light on the crater's impact history and mantle processes, needs further investigation on associated high pressure mineral. More studies are ongoing to explore the characteristics of high-pressure mineral phases in the melted rock samples.

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U-Th-Pb Chemical dating of shock-recrystallized monazite to decode the timing of asteroid impact: a future planetary exploratory tool

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Throughout geologic time, Impact cratering is one of the fundamental processes that modify the surfaces of planets, satellites and asteroid bodies in our solar *(French, 1998)*. A precise and accurate dating of impact cratering event is important to correlate the geological events (e.g. the Chicxulub crater is likely associated with the Cretaceous-Paleogene mass extinction; *Chulate et al. 2010*), and in some cases, the determination of the influence of impact cratering on human civilization (e.g. *Masse 2007; Hmacher and Goldsmith 2013*). Additionally, the dating of impact craters is crucial to determine the impact flux on Earth (e.g., *Bland and Artemieva 2006*).

Chemical U-Th-Pb dating of newly crystallized monazite from the impact melt can provide a clue of the timing of asteroid impact. Chemical dating of Th/U rich minerals using electron probe microanalysis (EPMA) has been proved in the last few years to be a powerful and fast technique (*Suzuki and Adachi 1991, Montel et al. 1996, Rhede et al. 1996, Vlach et al. 1999*).As an *in-situ,* non-destructive dating method, EPMA chemical dating of monazite has a higher spatial resolution (~1µm) and faster analytical speed *(Williams et al. 2017)*.

This study aims to formulate a suitable protocol for high-precision rare earth elements (REE), U, Th and Pb abundance measurement, and quantify the conditions of U–Th–Pb chemical dating of monazite using the Field Emission (FE) EPMA. We have applied the CHIME dating method *(Suzuki and Adachi, 1991a, 1991b; Suzuki et al., 1991)* for neoblastic monazites from the impactite (monomict breccia) of the Araguainha impact crater, Brazil and yields an average age of 250±26 Ma, which is consistent with the published LA-ICP-MS and SHRIMP data (*Tohver et al. 2012; Erickson et al. 2017; Hauser et al. 2019).* Additionally, the probability distribution and average weighted age computations were performed using Ludwig, K. R. (2003)'s Isoplot program. This technique involves minimal sample damage and is also capable of analyzing smaller Earth and Planetary materials and thus can be useful and appropriate for dating the returned samples from the Moon, Mars and Asteroids.

Petrography and geochemistry of Martian basaltic impact structures analogues (Vargeão Dome, Vista Alegre, Brazil; Lonar Crater, India)

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Impact cratering is a fundamental process in the Solar System, with collisions strongly influencing both the evolution of planets and the development of life throughout their evolution history. Impact structures and craters resulting from these collisions are preserved on all rocky and icy bodies and represent the most common geological landform at their surfaces. Nevertheless, processes such as erosion, tectonic deformation or burial tend to reduce the number of impact structures on Earth, leaving gaps in the impact cratering record of the terrestrial surface. In contrast, the surface of Mars is covered by 60% of early, ancient Noachian crust and the impact cratering history of Mars is well preserved. The Martian crust is currently the centre of interest of the NASA-ESA Mars Sample Return missions, drilling and collecting samples from Jezero crater. As the majority of the Martian surface is covered in volcanic or volcanically sourced sedimentary units, terrestrial impact craters and structures formed in basaltic target rocks represent excellent analogues to study Martian planetary surface processes and products, although such sites remain relatively rare on Earth.

This work focuses on three basaltic impact structures: Vargeão Dome (Brazil, 12.4km diameter), Vista Alegre (Brazil, 9.5 km diameter), and the Lonar crater (India, 1.88 km, 570 ± 47 kyr[3]), with the aim to understand impact-related processes affecting basaltic targets based on detailed petrographic, bulk geochemical, and isotopic analyses.

The different types of impactites (monomict and polymict impact breccias) have been petrographically studied to trace impact-induced processes such as shock, melting and mixing of the targets to better understand how impact events affect basaltic target rocks and their associated minerals. Bulk geochemical compositions (major and trace elements) have also been determined to trace variations induced by impact processes, but also to evaluate the level of post-impact alteration (impact-induced or not).

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MINERALOGICAL AND GEOCHEMICAL CHARACTERIZATION OF SUSPECTED IMPACTITES FROM THE LUNA STRUCTURE, WESTERN INDIA

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Meteorite impacts are known to have played significant role in the evolution of the Earth as well as of the other planets in the solar system, including the delivery of volatiles, formation of ore deposits, biological mass extinction events and extreme climate changes [1]. Identification of impact structures is often hampered by post-impact geological processes including tectono-thermal events, weathering, and erosion. The Luna structure in the Banni Plains of Western India (in Gujarat) was a suspected impact structure [2], however, no concrete evidence was observed to confirm it. In a recent study, the impact origin of Luna structure was proposed based on the circular shape of the structure, peculiar mineralogy and elevated concentration of highly siderophile elements in the suspected impactites [3].

We investigated the texture, mineralogy and bulk chemical compositions of the suspected impactites from the Luna structure. Major composition is wüstite, kirschsteinite and glassy matrix constitutes the mineral assemblages, with wüstite forming blobs and dendrites and kirschsteinite occupying the interstitial space (Fig. 1a). Though the studied samples are iron rich ($Fe_2O_3^T$ = 42.3–63.3 wt.%), the observed mineralogy, lack of Widmanstätten pattern as well as the low Ni concentration (<74 μg/g) rule out them to be the fragments of the iron meteorites.

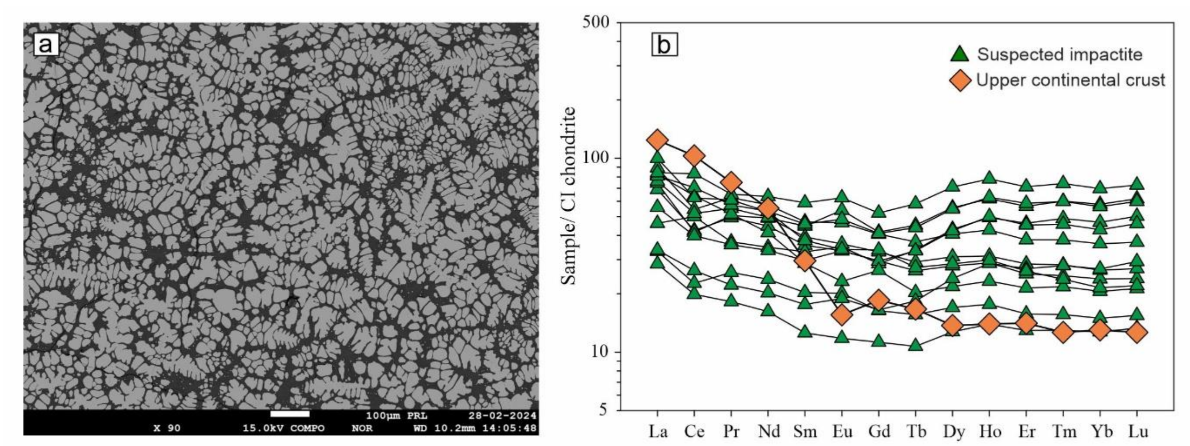

Figure 1: (a) Backscattered electron (BSE) image of the suspected impactite sample and (b) CI chondrite normalized REE abundances of the Luna samples and upper continental crust (UCC). UCC and CI chondrite values from [4] and [5].

During a meteoritic impact, impactites largely incorporates the target rocks with only ~1-2% input from the projectile. Unconsolidated soft sediments such as sand, clay and clayey silt are the common lithounits in the Luna structure and the Banni Plains, which is likely similar in composition to the upper continental crust. However, the chondrite normalized rare earth element compositions of suspected Luna impactites display a flat pattern without any europium anomaly (Fig. 1b). When compared with the upper continental crust, these samples are depleted in trace elements such as Rb, Th, La, Ce, Nd, Zr, Hf and Pb. These observations negate any contribution from felsic crustal sources. Consolidating the textural, mineralogical and geochemical evidence, an impact origin for the Luna structure clearly needs to be relooked with additional geochemical and isotopic data.

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Session – VI: Planetary Surface & Subsurface Processes

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Investigation of gravity signatures of crustal structures in the Mare Humboldtianum and adjoining regions, Moon

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Mare Humboldtinaum is Nectarian aged multi-ring basin located in the northern hemisphere of the Moon. Compton-Belkovich Volcanic Complex (CBVC) is located in the NE part of the basin, on the Lunar far side, which is characterized by high Thorium concentration and high silica content. Recently, compositional and morphological studies were carried out in the CBVC region using remote sensing data sets of Lunar Prospector, Chandrayaan-1 and Lunar Reconnaissance Orbiter etc. In this study, analysis of gravity anomalies (Gravity model: ggrx900c) obtained from GRAIL mission is carried out for the Mare Humboldtaimum and adjoining regions (56^0E-134^0E and 44^0N -75^0N), using different interpretation techniques such as Bouguer correction density estimation based on fractals approach, estimation of plausible depths to sub-surface layers using radial power spectrum of Bouguer gravity anomalies, regional and residual gravity anomaly separation in Fourier and spherical harmonic domain. Morphological mapping of this region using the Chandrayaan-2/1 Terrain Mapping Camera (TMC) and contemporary global data sets is in progress. Results obtained from the analysis of gravity anomalies are interpreted vis-à-vis correlation with topography, crustal thickness maps and results from recent remote sensing-based studies to understand the crustal structure and evolution of this region. Mapping of rims of the basin and structural features of the region is carried out based on residual gravity anomaly maps.

Chandrayaan-3 landing site evolution by South Pole-Aitken basin and other impact craters

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Introduction: The Chandrayaan-3 mission with a Vikram-lander and a Pragyan-rover landed in the High latitude highland region near the south pole of the Moon. The landing site is located ~350 km from the South Pole-Aitken basin rim, an ancient and highly cratered terrain. This site has undergone the complex emplacement sequence of SPA basin ejecta followed by the nearby and distant impact basins and crater ejecta materials. To evaluate the source of individual basin and crater ejecta emplacement over this landing site, we carefully demarcated the nearby and far basins and craters, contributing to the source regolith material [1,2,3,4]. We found that the SPA basin is the major contributor, which deposited nearly ~1400 m of ejecta materials, and 11 other basins deposited ~580 m of ejecta, and other complex craters contributed up to ~90 m of ejecta. Meanwhile, secondary clusters of a few km in diameter located adjacent to the landing site contributed to ~0.5 m ejecta, which are crucial target materials for the Pragyan rover insitu analysis. Pragyan rover images revealed the landing site is devoid of big boulders along the traverse revealing typical highland terrain. The Pragyan rover Navcam insitu and OHRC regional images co-ordinately revealed linear distal ejecta rays possibly from the distant impacts as insitu evidence of foreign material at the CH-3 landing site. We found a semi-circular, heavily degraded structure encompassed around the landing site, which is interpreted as a buried impact crater probably formed before the SPA basins. The erasure of pre-SPA basin craters is caused by both the direct burial of SPA basin ejecta, high seismic shaking during SPA formation and then followed by various post-SPA craters and its associated some of the degradation processes. Overall, Chandrayaan-3 landed within an ancient region, which hosts one of the most deeply excavated materials on the Moon.

The goal of this study is to understand the role of basin-forming impact and complex craters influence in and around the Chandrayaan-3 landing site. This study also evaluates the results of small-size crater density derived from the Navigation Camera on the Pragyan rover (Navcam) along its traversed path, comparing these findings with data from the Orbiter High-Resolution Camera (OHRC) on board the Chandrayaan 2 orbiter. We expect that the crater morphological comparison with high latitude in-situ exploration will provide clues to their degradation and state of retention. This paper presents a workflow to coordinate and analyse the orbiter and rover derived images for the crater distribution around the Chandrayaan-3 landing site.

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METEORITE IMPACTS OR SHALLOW MOONQUAKES: WHAT TRIGGERED THE BIGGEST BOULDER-FALL ON THE MOON?

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Introduction: Boulder-falls are ubiquitous on the Moon [1-2]. To understand the role of meteorite impacts and shallow moonquakes in triggering boulder-falls, we conducted detailed investigation of previously undocumented boulder-fall activity in the Vitello crater (diameter= ~42.5 km; centered at 30.4° S, 37.5° W) region situated around the southern rim of the Mare Humorum basin. Images and topography data from Chandrayaan-2, Lunar Reconnaissance Orbiter and Kaguya missions were used to characterize the morphology and morphometry of boulder-fall trails.

Observations: We found more than a thousand boulder-fall trails of length between 10 and 3200 m over an average slope of 20-30°. The trails are characterized by fresh and faded morphologies, and exhibit cross-cutting relationships. The majority of boulders have length between 3 and 10 m, but we found 8 boulders having length in between 26-35 m [Figure 1] and one of the boulders is of 55 m, which is the biggest boulder-fall ever observed on the Moon.

The southern region of Vitello crater is surrounded by one of the longest (330 km) clusters of thrust fault lobate scarps on the Moon. Moreover, the lobate scarps surrounding the crater are found to be within 30 km of the epicenter of a potential shallow moonquake recorded during the Apollo missions. Additionally, a previous study has revealed that the faults in this region have likely envisaged the most recent activity on the Moon [3].

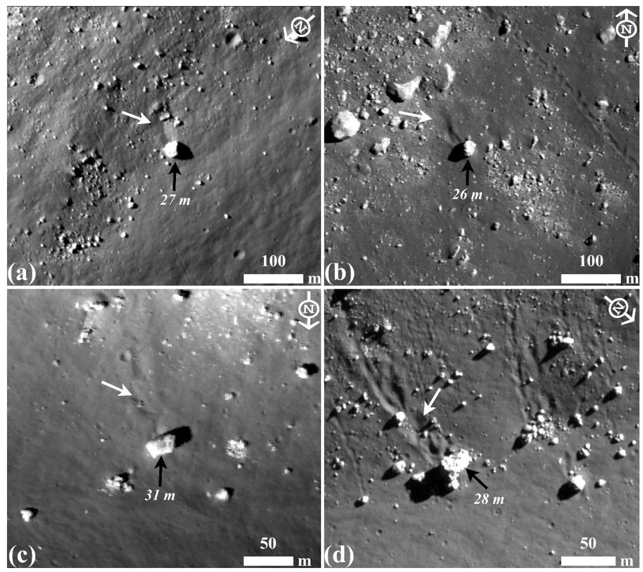

Figure 1: *LRO NAC image based examples of fallen boulders (black arrows) having length in between 26-35 m. Their respective tracks are shown by white arrows.*

Implications: While some boulder-fall sites on the Moon are near fresh meteorite impacts, others show no such nearby evidence. However, we have found morphological signs of fresh boulder fields on the majority of lobate scarps, suggesting recent activity. This indicates that the scarps around the Vitello crater may have been seismically active in the recent past (~50 Ma). These scarps could have generated episodic shallow moonquakes that likely triggered nearby boulder falls. Nevertheless, the presence of boulder falls on the steep slopes of older, possibly seismically inactive scarps and grabens related to the Mare Humorum basin presents a contrasting scenario, suggesting that the role of fresh meteorite impacts cannot be entirely ruled out.

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First-ever in-situ temperatures from a high-latitude location of the Moon – Insight from ChaSTE onboard Chandrayaan-3

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ABSTRACT

Understanding the thermophysical behavior of the lunar surface is essential for resource prospecting and future lunar exploration. Earlier studies have interpreted the surface temperatures and certain thermophysical properties from Apollo landings and remote sensing datasets. But the realistic characterisation of thermophysical environment at local scales (within few meters to kilometers) is not yet available. India's third Moon mission, Chandrayaan-3, has successfully deployed a lander and a rover at a high latitude location of the Moon and provided first ever in-situ science investigations of such a pristine location that will potentially improve our understanding about our nearest neighbour. Chandra's Surface Thermophysical Experiment (ChaSTE) is one of the payloads flown onboard Chandrayaan-3 lander, which is developed jointly by the Physical Research Laboratory, Ahmedabad and Space Physics Laboratory (SPL) in collaboration with the various entities of VSSC, Trivandrum. The objective of the experiment is in-situ investigation of thermal behaviour of outermost 100 mm layer of the lunar surface by deploying a thermal probe. The probe consists of 10 temperature sensors (Platinum RTDs) mounted at different locations along the length of the probe to measure lunar soil temperatures as a function of depth.

ChaSTE experiment operated flawlessly throughout the mission operation lifetime thus providing the first ever in-situ temperature measurements of high-latitude surficial layer of the Moon. ChaSTE observations have been thoroughly analysed considering all the relevant aspects to arrive at more realistic temperatures for the surface and subsurface. Results from ChaSTE seem to be intriguing with an indicative of relatively higher temperatures than that of earlier predictions and observations. An insight into these intriguing results from ChaSTE, its possible explanation and implications towards a comprehensive understanding of thermophysical behaviour of lunar high latitudes as a whole will be discussed.

Understanding Thermophysical Environment of Lunar Poles: Implications to Volatile Stability.

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Introduction: The thermophysical environment of the Moon has been extensively studied over the past decades, particularly in the context of scientific advancements and future human exploration. Since the surface and subsurface temperatures on the Moon vary with latitude, local time, and topography, each site offers a unique insight into the lunar thermal regime [1]. The polar regions, in particular, exhibit distinct thermal behavior compared to equatorial and mid-latitude areas, with polar temperatures varying both diurnally and seasonally [2]. These temperature fluctuations significantly impact the stability and transport of volatiles, such as water ice, as surface temperature determines their residence time [3, 4]. Although equatorial and high-latitude regions have been studied through ground-truth measurements, numerical modeling and remote sensing [5, 6], the polar regions require more detailed investigation and modeling with specific parameters, particularly at regional or local scales. This study focuses on the numerical modeling of key sites at the lunar poles to better understand their thermophysical environment and, consequently, the stability of volatiles in these regions.

Methodology: The modelling has been carried out using a 3D finite element thermophysical model. The actual topography with the highest possible resolution is used for each site. Since the solar illumination is almost at grazing angle over lunar poles, the solar flux is calculated using complex and realistic illumination, varying over time. The thermophysical parameters such as thermal conductivity, bulk density etc. are given as depth and temperature dependent functions and the surface, subsurface temperatures are calculated.

Conclusions: All the sites exhibited distinct variations in surface and subsurface temperatures, due to variation in local topography and regolith structure. The temperatures are also compared with remote sensing datasets and are validated. The major results of this study will be presented and discussed.

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Spectrophotometric Analysis of Dwarf Planet Ceres Using Disk-Resolved Observations from NASA Dawn VIR data

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Introduction: We present a detailed analysis of the spectrophotometric properties of dwarf planet Ceres, utilizing disk-resolved observations in the visual-to-infrared (VIS-IR) spectral range. The data, acquired by the VIR imaging spectrometer onboard NASA's Dawn mission spans a phase angle range of 0° to 133°. Photometric corrections were performed using Hapke's model [1] to standardize observation geometry, enabling the creation of albedo maps of Ceres' surface.

Methods: Our analysis incorporates data from five key mission phases: Ceres Approach (CSA), Rotational Characterization 3 (RC3), Ceres Transfer to Survey (CTS), Ceres Survey (CSS) and Extended Mission Phase (XMO4). To enhance the accuracy of phase curve modeling, we introduced a per-phase angle filtering process to exclude outliers. The low phase angle coverage provided by XMO4 data enabled us to model the shadow-hiding opposition effect (SHOE) parameters within Hapke's framework. Additionally, asymmetry factors were derived using the two-term Henyey-Greenstein (2HG) single-particle phase function [2].

The phase curves were fitted across the 0.465–4.05 micrometer range [3] in a two-step process. Initially, a wavelength-independent roughness parameter was determined, followed by the fitting of wavelength-dependent parameters with the roughness value held constant [4]. We also derived parameters by fixing SHOE to previously reported literature values and compared these results with existing photometric studies.

Results: At 555 nm, the derived parameters are as follows: roughness parameter - 18.6 ± 2.67, single-scattering albedo (w) - 0.087 ± 1.2e-7, 2-HG parameters, b - 1.86 ± 1e-6 and c - 0.69 ± 3.76e-05, SHOE amplitude (Bs_0) - 3.4 ± 7.4e-4, and SHOE width (hs) - 0.06 ± 1.76e-7. When SHOE is fixed, the parameters are w - 0.105 ± 3.23e-8, b - 0.39 ± 8.54e-8, and c - 0.39 ± 1.4e-5. The estimated parameters are in good agreement with literatures. Further analysis and validation of the parameters are in progress.

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Advanced Thermal Modeling of Asteroid Ryugu: Insights into Subsurface Temperature Profiles and Structural Properties

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The C-type asteroid Ryugu, classified as a rubble-pile body, offers a significant opportunity to investigate the thermal and structural evolution of small celestial bodies. This study presents an advanced thermal modeling analysis of Ryugu's subsurface, leveraging a sophisticated partial differential equation solver (PDEPE) in MATLAB. The model simulates temperature profiles under varying rotational periods, which are crucial for understanding the thermal behavior and internal dynamics of Ryugu.

Key parameters, such as albedo, solar azimuth, thermal conductivity, and thermal inertia, were incorporated into the model. The thermal conductivity of the boulders, found to be notably low, is crucial in understanding heat transfer within the asteroid [1]. For instance, Grott et al. [1] observed that the thermal conductivity of Ryugu's surface boulders is as low as 0.06–0.08 W m^{-1} K^{-1}, which significantly influences the subsurface temperature distribution. Our model also considers the porosity of these boulders, which impacts the thermal inertia—a critical parameter for determining the surface and subsurface thermal response to solar radiation.

The analysis of temperature-depth profiles revealed substantial variations due to the loose boundaries and heterogeneous composition of Ryugu, highlighting the effect of its rubble-pile structure. Anomalously porous boulders, as reported by Hamm et al. [2], contribute to the asteroid's unique thermal characteristics. Specifically, the porosity, which can reach up to 70%, plays a vital role in determining the effective thermal inertia, thereby influencing the depth to which solar heat penetrates.

Mathematically, the heat conduction in Ryugu's subsurface is governed by the one-dimensional heat conduction equation:

$$\rho c \left(\frac{\partial T}{\partial t}\right) = \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial Z}\right)$$

where ρ is the density, c is the specific heat capacity, k is the thermal conductivity, T is the temperature, and z is the depth below the surface. By solving this equation under various boundary conditions that account for diurnal temperature variations and the asteroid's rotation, the study provides detailed insights into subsurface temperature profiles.

Furthermore, structural properties such as vertical and horizontal fractures, boulder sizes, and changes in effective porosity were evaluated. These factors are critical in understanding the asteroid's thermal inertia, which ranges from 150 to 300 J m^{-2} $s^{0.5}$ K^{-1} [3], and how it affects surface evolution over time.

The findings from this study provide a deeper understanding of the surface and subsurface thermal dynamics of Ryugu, offering valuable data that could guide future space missions. Future work will aim to refine the thermal models by including the effects of subsurface fractures and assessing potential long-term surface evolution.

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ICE-EXPOSING IMPACT CRATERS: A WINDOW INTO THE CURRENT NATURE, DEPTH AND THICKNESS OF SUBSURFACE ICE ON MARS

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Introduction: Fresh impact craters have been discovered on Mars in the past two decades using orbital imaging. Some craters have exposed bright patches, confirmed to be H_2O ice in composition [1]. This ice, buried at shallow depths, was excavated during impact and exposed as ejecta or streaks on the surface. The ice-exposing craters are commonly detected in mid to high-latitude regions and almost across all longitudes, indicating the presence of a global subsurface ice table buried underneath the surface of Mars. Previous studies on fresh ice-exposing impact craters have relied on thermal models [2] and geomorphological investigations [3] to predict the pre-impact conditions of this buried ice. However, they do not account for local heterogeneities that arise in the ice table, providing an incomplete picture.

In this paper, remote sensing observations are complemented by numerical modelling. We made numerical impact simulations of the ice-exposing crater formation using the iSALE2D shock physics code [4]. By focusing on terrain and impact morphology, new insights can be derived into the depth, thickness and mechanical nature of subsurface ice on Mars.

Method: Single ice-exposing craters were the target of this study. Out of 23 identified craters, 17 were chosen, and observations were carried out using JMARS software. Several parameters, such as crater diameter, radial distance of ice exposure, etc., were recorded from the HiRISE image of the respective craters (e.g., Figure 1). The iSALE2D shock physics code [4] was used to visualize different impact scenarios. A three-layer model (composed of regolith, ice and bedrock) inspired by [5] was implemented in the simulations. The thickness and material strength of ice and regolith were varied to analyze the cratering process and final crater morphology.

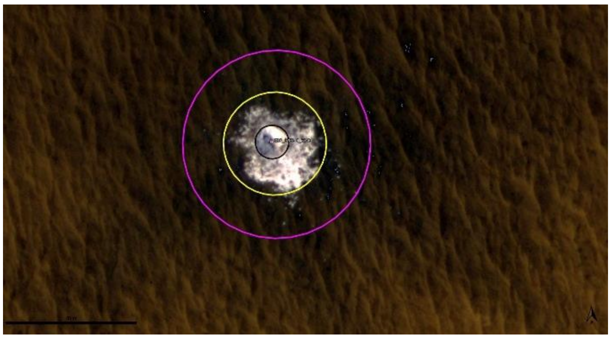

Fig. 1: Ice-exposing crater (HiRISE ID: ESP_025840_2240). Black, yellow and pink circles indicate the radial boundaries of the crater rim and continuous and discontinuous ejecta, respectively. (Scale bar = 50 m).

Results and conclusions: Preliminary results focused on impact simulations that made a ~10-m in diameter crater, which is the most common crater size observed through remote sensing. For this crater, simulations suggest that the excavation depth is ~80 cm. Mapping of ice-exposing craters in the Dundas et al. (2021) database suggests ice deposits are distributed majorly within the crater and up to a radius of 25 m from the crater. Additionally, the craters are situated in terrains that geomorphologically depict an interaction between ice and subsurface materials (e.g. thermal polygons). Numerical impact modelling work is underway and is expected to complement the observations and provide some information about the ice properties. Furthermore, the properties of the ice table can help decipher past climatic conditions and be potential sites of interest for future robotic and human exploration.

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Unnamed crater in Terra Sirenum: Mars' Volcanic Mystery – Hot magma or Muddy Mischief?

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Abstract: Mars exhibits a variety of conical formations that have stimulated ongoing debate regarding their origin and significance in understanding Martian geological history. This study investigates a comprehensive collection of prominent cones located within an unnamed crater in the Terra Sirenum region. The morphological mapping of this crater reveals approximately 73 cones, which are arranged in relation to three primary faults that have led to the development of graben structures within the crater. Additionally, the crater floor is characterized by a complex assemblage of at least five distinct geological units. The cones observed within this crater can be classified into two main types based on their morphological characteristics: domical cones and pitted cones. Morphometric analyses of the pitted cones show size distributions comparable to those of both terrestrial and Martian scoria cones. The cumulative size-frequency distribution (CSFD) analysis of these cones indicates that the formation of the cone field likely occurred between approximately 1.26 billion years ago (Ga) and 1 billion years ago, which aligns with the Mid-Amazonian epoch. This investigation is limited by the availability of high-resolution CRISM (Compact Reconnaissance Imaging Spectrometer for Mars) data for the crater. Spectral analysis of the crater's composition has identified the presence of kaolinite and both low-calcium and high-calcium pyroxene minerals. These findings suggest a potential igneous volcanic origin for the cones. However, the influence of aqueous processes on the formation and alteration of these features cannot be entirely ruled out, necessitating further investigation to fully understand the origins of these Martian conical structures.

Acknowledgment: The authors wish to acknowledge the HiRISE, CTX, MOLA and CRISM teams. Authors Shreekumari Patel and M. R. El-Maarry acknowledge financial support from Khalifa University's Space and Planetary Science Center (Abu Dhabi, UAE) under Grant no. KU-SPSC-8474000336.

Lunar Pyroclastics: A novel way of detection, characterization and validation

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Dark Mantle Deposits (DMDs) are one of the lunar lithological units characterized by their low albedo and association with volcanic features such as wrinkle ridges, vents, rilles, etc. [1]. These deposits are predominantly composed of Fe-Ti bearing volcanic glasses or pyroclasts, which are closely associated with mafic minerals like olivine and pyroxene [2]. These volcanic glasses are of particular interest as they carry signatures of primitive lunar mantle [1].

The spectral characteristics of volcanic glasses is challenging to detect using orbiter's hyper spectral imaging techniques because of its overlapping spectral signatures with those of major mafic minerals [3,4]. This limits the pyroclastics detection to site specific studies [5]. In this study, for the first time, we used 'Extra Tree Classifier' methodology, a machine learning approach to the global coverage of the Moon (level-2 OP2C reflectance data) obtained using the Moon Mineralogy Mapper (M^3) [6] onboard Chandrayaan-1. This novel approach identified several new sites as potential pyroclastic deposit spread across the Moon. However, manual validation of these potential sites is required for further improving on model by removing false positive detections.

To ensure the accuracy of our newly developed pyroclastic detection model, we carried out a systematic evaluation of newly detected pyroclastics from the Oriental Basin (19.2° S, 95° W). This multiring basin host a few already known pyroclastics [5] thus providing a test bench for validation of our methodology. We found that the newly detected pyroclastic deposits are associated with known morphological features and enriched in volcanic glasses, which are co-located with common mafic minerals. In addition to morphological and mineralogical characterization, we will present compositional analysis of extended region leading to a better understanding of the geology of the Oriental basin.

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LUNAR CRATERING CHRONOLOGY - IMPLICATIONS.

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Lunar Cratering Chronology: Models that correlate crater densities measured on the surface of the Moon and ages of lunar rock samples derived with isotope geochemistry provide temporal constraints globally to assess lunar and planetary evolution. Recently we [1-3] have mapped the lunar sampling sites using Moon Mineralogical Mapper (M3) near-infrared spectral data over Apollo, Luna and Chang'e 5 landing sites. We not only outlined homogeneous geological units, but also identified based on sample spectral features the dominating mineralogy at these sites. This allowed to identify better than before the relevant sample and thus the age that should be used for the chronology model calibration of the specific landing site. Furthermore, assessing the crater count units not only by morphology, but also spectrally we identified more confidently the outline for the surface unit in reference to the crater statistics needed to provide reliable pairs of age and crater density. Crater statistics is a method that by deriving size-resolved and area-normalised crater frequencies globally assesses times and rates of the geological evolution of the respective planetary body. We [2] provided a new lunar cratering chronology that changes previous timelines significantly and sets some events such as the Imbrium and Orientale formation event at different times than previous studies [3].

Implications: The calibration of the impactor flux before 3.9 Ga remains challenging. The heterogeneous nature of breccia samples challenges the definition of homogeneous units and suitable reference samples to establish appropriate sample-unit links. The 'Late Heavy Bombardment' concept captures rather the last large basin formation event, Orientale, as a marker horizon, instead of the subsequent formation of several basins in a short timeperiod. Compared to previous models, the new calibration pairs (frequency vs. age) suggest a monotonically decaying and, more importantly, lower throughout projectile flux. This lower flux is NOT the result of a systematic shift related to the derivation of the crater frequencies but relates to different outlines of counting units and modern sample ages. Applying the new model to crater counts across the Moon suggests much older surfaces (by at least by 200 million years) than any of the current cratering-chronology models. This has implications for the interpretation of evolutionary events on the Moon. Transferring this model to other solid-surface planetary bodies implies the ageing of these surfaces, too.

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Investigation of Kovalevskaya Crater: Insights from M3 and LRO-MiniRF.

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Abstract: Lunar highland crust dominated by anorthosites [1,2] is highly cratered and reworked by impact processes. Having a better preservation potential than mare regions, highland craters offer a good understanding of the genesis of this ancient crust. Kovalevskaya (30° 43' 21"N, 129° 33' 37"W) is a complex, well preserved ~115 km diameter crater in the lunar far side. The central peaks show a varied mineralogy with mafics in and around the crater [3]. Using Chandrayaan-1 M3[4] data the preliminary findings in this study indicate the presence of both chromite and Mg-Spinel. Spectral indices such as Pyroxene, Spinel and Plagioclase Anorthite (PAN) ratios [5] were used to identify the plagioclase bearing exposures (blue polygons in fig-1a) chromite (red and green polygons in fig-1a) was located by combining the chromite parameter [6] with PAN and Pyroxene ratios. Chromite being a part of spinel group of mineral shows similar spectral properties in which the diagnostic band for Mg-spinel is present at <2.1 µm and for Cr-rich endmember, the band shifts past 2.1 µm (Cr-1&Cr2 in fig-1b) [7]. Plagioclase feldspar occurs along with spinel (PSP in fig-1b) showing two band minima, one around 1.25 µm indicating crystalline plagioclase [8] and other around 2 µm with band minimum occurring around 2.0 µm suggesting Mg-Spinel. To understand the surface of the crater, the RGB composite of M-Chi decomposition [9] using LRO-MiniRF reveals that the crater floor majorly exhibits combination of double bounce and surface scattering which is an indicative of mix regolith of varying dielectric properties, generally well-mixed and can include material from various depths. Whereas the crater rim is showing volume scattering as indicated by the green color. The smaller impacts on the floor showing surface scattering indicated by the blue color (fig-1c). Overall, the nature of the crater is complex, and can have mixture of material derived from impact as well as subsurface. The current study also attempts to identify additional ambiguous spectral features having band minima around 2.8 and 3.0 µm, attributed to H_2O/OH [10]. Further analysis will assess the presence of H_2O/OH by characterizing the 3.0 µm absorption features using Chandrayaan-2 IIRS datasets along with M3 data.

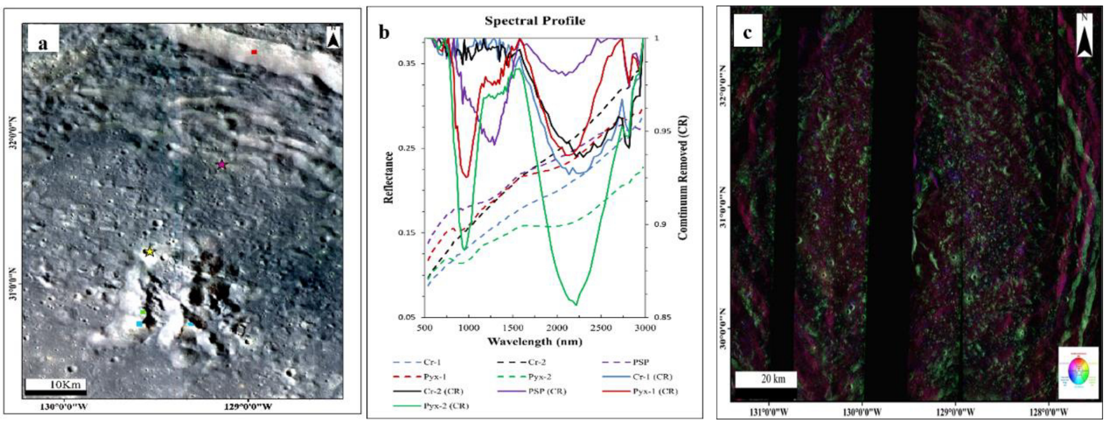

Figure-1: (a) M3 false color composite (FCC) (R= 0.93µm, G=1.21µm, B= 1.81µm) mosaic of Kovalevskaya crater. Locations- yellow and pink stars for Pyroxene (Pyx-1 and Pyx-2 respectively) spectra, blue polygon for Plagioclase+Spinel (PSP) spectra, red and green polygons for Chromite spectra (Cr-1 and Cr-2 respectively). (b) Spectral profiles of the identified minerals. (c) RGB composite of M-chi decomposition showing double bounce (red) volume scattering (green) and surface scattering (blue).

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Investigating Amazonian Fluvial Activity: The Geomorphological Impact of Catastrophic Floods in Jovis Tholus Outflow Channels on Mars

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The outflow channels have been prominent features on Mars since the Hesperian period [1]. Among these, the outflow channels formed during the Amazonian period are particularly relevant as they offer insights into recent changes due to fluvial processes on Mars. To understand the role of catastrophic floods in shaping Martian landscapes, concepts like stream power per unit boundary and channel boundary shear stress are useful for investigating the geomorphic responses in Martian fluvial systems [2]. The study zone lies northwest of the Jovis Tholus volcano, two outflow channels originates from a single graben [3].

The geomorphological features have been identified using high-resolution Context Camera (CXT) and High-Resolution Imaging Science Experiment (HiRISE) imageries. A sequential geological history of the study area was portrayed to analyse the origin and mechanism of the flood. To describe the geomorphic features carved out by fluvial processes in Jovis Tholus outflow channels, a hydraulic modeling was performed using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) software. Flood parameters such as peak discharge, flow velocity, water surface elevation (WSE), stream power index (SPI), shear stress, and Froude number were analysed. The best-fit discharge for the Jovis Tholus region is estimated to be 1×10^6 m^3s^{-1} and the mean flow velocity obtained from the channel is 11.31 ms^{-1}. SPI of the channels (Channel 1 (Ch1) and Channel 2 (Ch2)) is 2963 to 121469 kgm^2s^{-3} and 245 to 14475 kgm^2s^{-3}, respectively. The shear stress of Ch1 and Ch2 is 3517.538 Pa and 92.428 Pa, respectively. Such SPI and shear stress are enough to sculpt such an outflow channel. The particle size has been identified from the corresponding flow shear stress of the channels, which is 0.31 mm in Ch1 and 0.084 mm in Ch2, respectively. The presence of pools and bars, phase analysis, and Froude number from 0.01 to 0.53 (for Ch1) and from 0.09 to 0.82 (for Ch2) describe the intense dynamic nature of the flow. Overall, this study reveals the intensity and the carving nature of an Amazonian-aged catastrophic flood.

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Session -7: Analogues: Similar but not the Same.

Abstract ID	Title	Author	ORAL/ POSTER
ASS-01	Planetary Analogues – An Indian 'INSIDE' Story	Saibal Gupta IIT, Khargpur	Invited
ASS-02	The habitat conditions of early Mars and Earth were revealed by clumped isotopic analysis of carbonate precipitates in the meteorites and sedimentary archives	R. Ghosh et al. IISc, Bangalore	ORAL
ASS-03	Spectroscopic characterisation of Nidar ophiolite complex and its implications	S. Bhattacharya et al. SAC, Ahmedabad	ORAL
ASS-04	Retrieval of abundance in particulate mixture using spectro-goniometric measurements at PRSL, PRL	N. Srivastava et al. PRL, Ahmedabad	ORAL
ASS-05	Dosimetric investigation of Jarosite: A martian analogue	M. Singhal PRL, Ahmedabad	ORAL
AISS-06	Characterisation of hydrous sulphate in Matanomadh formation-A Martian analog	N. Saha and A.S. Majumdar IIT(ISM) Dhanbad	ORAL
ASS-011	Planetary Analogue Study	V.J. Rajesh, IIST Trivenrum	Oral
ASS-07	Comparative study of columnar joints: Insights from Mars and St. Mary's island as a terrestrial analogue	Manasa M.J. and B.R. Manjunatha Mangalore University	Poster
ASS-08	Deccan volcanic bole layers: An under investigated Martian soil analogue	A Dhiman and S. Singh Punjab University	POSTER
ASS-09	Laboratory study of regolith analogues-relevance to recent asteroid sample return mission	R. Gupta IUCAA, Pune	POSTER
ASS-010	Reflectance spectroscopy of lunar soil simulants: A comparative study of LSS-ISAC-1 and JSC 1A basalt	D. Karunakaran et al.	POSTER

PLANETARY ANALOGUES – AN INDIAN 'INSIDE' STORY

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Planetary analogues are vital to the study of planetary bodies. Their study is vital for a number of reasons – they can help understand and explain observed features and phenomena on other celestial bodies; they can help test mission instruments; they can help plan for, and target future mission areas; and finally, once identified, they can help train astronauts for upcoming missions. Identification of terrestrial analogues to other planetary bodies is therefore critical. These analogue localities are primarily geological in nature – and one specific locality will necessarily not represent a perfect analogy to any extra-terrestrial setting. Training of astronauts for the Apollo missions, for instance, were conducted in localities as diverse as Hawaii, the Grand Canyon and Iceland, among many others. While analogue localities are particularly important for astronaut training and instrument testing, they are also key indicators for understanding extra-terrestrial processes. Given India's drive towards making an international mark in Space Science and Technology, it is very important to identify analogue localities within India. This talk will discuss a few localities in the country where such analogue studies have been conducted, and which can serve as templates for future planetary exploration. These include mineralogical and morphological analogues, and also some localities that can serve as astrobiological parallels. Interestingly, only some of these localities can be considered as present-day extreme environments, indicating that the dynamic nature of the terrestrial planetary surface may be responsible for creating transient environments that may resemble some extra-terrestrial settings, but also erasing of many past signatures that may have been good planetary analogues.

The habitat conditions of Early Mars and Earth were revealed by clumped isotopic analysis of carbonate precipitates in the meteorites and sedimentary archives.

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Recent results of rover-based carbon isotopic composition of in-situ sedimentary rocks revealed the Martian carbon cycle modes [1]. During the analysis, a distinct carbon isotopic compositional pattern in methane released from the sediment revealed three compelling thoughts on methanogenesis generating anomalous lighter composition. However, one of the propositions on the photodissociation of organic molecules yielding lighter carbon isotope ratios in methane caught significant attention [1, 2]. We will show geochemical evidence of Early Mar's climate in the geological record with an environment of deposition denoting wet, warm conditions like lacustrine setting or isolated basinal environment for the life to diversify. Such a near-surface aqueous environment during the Noachian epoch was predicted from the analysis of carbonates in the ALH84001 [3].

We will draw parallels and display the temperature evolution of the microbial environment from carbonate precipitates from strata as old as 2.8 b.y. to 645 m.y. These carbonates originate from multiple green stone belts and offer only a piece of documentary evidence to draw a comparison between the hydrological reservoirs of both these terrestrial planets. The present study addresses the evolution of temperature and oxygen isotopic composition ($\delta^{18}O_{Seawater}$) th the hydrosphere during the Precambrian era based on a Clumped isotope thermometry study. Sedimentary carbonates with features of algal growth were surveyed from multiple time windows to reveal the pattern of temperature and freshwater fluxes into the environment responsible for the commencement and evolution of early life during the Precambrian era. Present and previous observations have shown a systematic drop in the water temperature from Archean to Neoproterozoic time [4,5], analogous or consistent with the low-temperature carbonates from ALH84001. In summary, this study has shown an exponential drop in the maximum temperature and relatively near-consistent minimum temperature of carbonate precipitation.

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Spectroscopic characterization of Nidar Ophiolite Complex and its planetary implications

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To reckon the chemical composition of minerals on planetary surfaces from indirect spectroscopic data, it is required to establish the link between mineralogy, spectroscopy and chemical composition of rock forming minerals on Earth. To meet this requirement, integrated mineralogical and spectroscopic (Visible-Near Infrared and micro Raman) characterisation of suitable lunar and martian analogue minerals from different parts of Earth is highly needed.

A through spectral stratigraphy of Nidar Ophiolite sequence is constructed by collecting VNIR spectra from systematically collected samples from different stratigraphic layers of that particular ophiolite sequence. Ophiolites are actually obducted oceanic crust and upper mantle sequence during collisional orogeny. Preliminary study reveals that the samples contain magnesium rich serpentine minerals mixed with other iron bearing minerals and chlorites. Spectra of the finely grained samples also suggest the presence of hydrous minerals, possibly phyllosilicates. Various absorption features in the instrument range (0.35-2.5 µm) are identified. For convenience and to better interpret and determine the band features, the visible and near infrared region, were together divided into 3 regions, 0.35-1.3, 1.2-2 and 2-2.5 µm, each part is characterized and discussed independently and refers to a particular mechanism. The minerals were sorted according to spectra and composition. Possible reason for their variation are discussed below.

The presence of serpentinites and carbonates at Nidar ophiolite complex resembles Mgcarbonate and Mgserpentinite discovered at Nilli Fossae, Mars. Olivine-rich ultrmafic crust and low water/rock ratios of Nidar serpentinite suggests similar process might have prevailed and invoked sepentinisation on Mars. This could be a potential site for exploring abiogenic methane and to understand Martian habitability.

RETRIEVAL OF ABUNDANCE IN A PARTICULATE MIXTURE USING SPECTRO-GONIOMETERIC MEASUREMENTS AT PRSL, PRL.

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This study investigates the application of the Hapke model [1] for photometric analysis and estimation of component abundance within a particulate mixture using the Spectro-Goniometer facility at the Planetary Remote Sensing Laboratory, PRL. The Sittampundi Anorthosite sample [2] with a grain size range of 100-200 microns was magnetically separated into its magnetic (M) and non-magnetic (NM) components. These components were then recombined in various proportions to create a series of samples: Sample A (100% M), Sample B (80% M, 20% NM), Sample C (60% M, 40% NM), Sample D (50% M, 50% NM), Sample E (20% M, 80% NM), and Sample R (100% NM).

Reflectance spectra for each sample were acquired across multiple phase angles in the spectral range of 350 nm - 2500 nm. The inverse photometric modeling of the Hapke radiative transfer equation was performed on the spectral data to derive key photometric parameters, including the single scattering albedo (w), and phase function coefficients (b, c). Subsequently, the derived single scattering albedo was utilized to invert and calculate the extinction coefficient (k) for each sample [2, 3, and 4].

It is found that the extinction coefficient exhibits a linear relationship with the proportion of the end members viz M and NM in this case, with a correlation coefficient (R^2) of 0.99, indicating a very strong correlation. This linear relationship enabled the prediction of the abundance of an unknown sample by analyzing its extinction coefficient. The predicted k spectra for a mixture containing 60% M and 40% NM were plotted alongside the measured k spectra, showing a strong agreement. These findings suggest that with a known k spectra of the endmembers (M and NM in this case), it was possible to accurately estimate the k spectra for a given mixture composition and vice-versa, thereby, showcasing the application of the Hapke model in compositional analysis of particulate mixtures using the spectro-goniometric measurements at Planetary Remote Sensing Laboratory (PRSL), PRL.

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DOSIMETRIC INVESTIGATION OF JAROSITE: A MARTIAN ANALOGUE

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Luminescence dosimetry of natural minerals is now an effective tool to understand the timescales over which planetary landforms and surface processes occur [1]. The use of luminescence to understand the radiation fluxes on the Martian surface has been explored and some Martian analogue rocks have been examined for their potential use to study the time scales of surface processes on Mars [2–5].

The present study characterizes the luminescence dosimetric properties of terrestrial jarosite – a Martian analogue mineral as its presence on Mars has been confirmed by various Mars missions [6,7]. Its occurrence indicates presence of water-limited, acidic and oxidizing conditions[8].

Six natural jarosite samples from Kachchh, India were analysed for the thermoluminescence (TL) and optically stimulated luminescence (OSL) and associated chronometry and radiation dosimetry parameters. Thermoluminescence of samples had a similar glow curves but with varied luminescence sensitivities. Their TL comprised glow peaks at 80, 150, 300 and 375°C. In respect of optical stimulation, the samples also gave both blue light and infrared stimulated luminescence. Fractional glow analysis gave an activation energy of 1.35 eV for 300°C glow peak, suggesting life time of 0.3 Ma. Near zero athermal fading was observed for blue and UV emission from infrared stimulation (IRSL) at a readout temperature of 225°C. However, at 50°C readout temperature, IRSL signal shows a fading of g ~7% per decade in blue emission and the UV emission with blue stimulation showed a fading of g ~6.4% per decade. The saturation dose for TL, BSLUV and IRSL50Blue, PIRIR225Blue and PIRIR225UV were 1590±122, 867±85, 1180±181, 817±95, 685±35 Gy respectively.

Considering the estimated cosmic ray dose rate ~63 m Gy/a[4] and internal dose rate estimate ~ 1.6 m Gy/a , suggests that jarosite can be used to understand the most recent to 25 ka of surface processes on Mars. The decomposition of jarosite into yavapaiite, hematite, and water at 450°C and its impact on luminescence properties is a key concern. Upon heating, a marginal change in luminescence properties is observed. Additional characterization of natural jarosites, and its breakdown products after annealing at 450°C using Fourier Transform Infrared Spectrometry is currently being attempted.

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CHARACTERIZATION OF HYDROUS SULPHATE IN MATANOMADH FORMATION – A MARTIAN ANALOG.

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Introduction: The recent Mars Mission have given suitable evidences of the presence of hydrous sulphate group of minerals (e.g. Jarosite, Alunite etc.) in the Meridiani Planum, of the Mars[1]. To understand the origin of these hydrous sulfosalts, potentially in early Martian condition, terrestrial analog sites of same mineral deposits can be explored in details. The Kachchh geoheritage site in Gujarat, India exposes such a well preserved analog site, which may help to better constrain paleo-environmental condition during Martian alterations [2]. Of Martian sulphate group minerals, jarosite-alunite group minerals are mainly found in the Matanomadh Formation and the Harudi Formation of Kachchh, Gujarat, in association with grey carbonaceous shale, weathered basalt and gypsum and they commonly occur as lenses of variable width, as interconnected veins and/or as veinlets.

Methodology: Pure jarosite samples were collected after detailed field investigation from the Matanomadh and the Harudi Formation, but no pure jarosite-group minerals can be sampled from the Naredi Formation. Samples were characterized by X-Ray Diffraction (XRD), X-Ray Photoelectron Spectroscopy (XPS) and Field Emission Scanning Electron Microscopy (FE-SEM) analyses.

Result: All the XRD patterns were analyzed using FullProf program and employing Rietveld refinement technique. Peak refinements were performed using the R-3m space group. The average a and c cell dimensions calculated to be for jarosite a= 7.3028 Å, c =16.6376 Å, for alunite a=6.9920 Å, c= 16.7575 Å. XRD diffractogram showing distinct peak at (006) at 2θ=32.29°. During FE-SEM image analysis, jarosite and alunite crystal display perfectly pseudohexagonal crystal forms with well-defined faces and edges. Jarosite XPS analysis gave prominent peaks of Fe2p3/2 and S2p at binding energies of ~713.4eV and ~169.9eV respectively. Also S2p peaks were present in jarosite hosting shale.

Discussion: The a and c cell dimensions of XRD data are consistent with the literature data [3, 4, 5] and it is confirmed as Natrojarosite and/or Natroalunite. The peak position of (006) reflection in natrojarosite differ in position from jarosite [5]. In these Jarosite-Alunite group samples, Fe is present in +3 oxidation state as confirmed from XPS analysis [6]. Based on the parallel presence of sulfur (S^{-1}) XPS peaks in associated shale, it is inferred that shale has a potential to act as a source of sulfur for natrojarosite-natroalunite formation in present study area under acidic oxidizing condition.

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Comparative Study of Columnar Joints: Insights from Mars and St. Mary's Island as a Terrestrial analogue

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Abstract
Columnar jointing, a geological feature commonly observed in various rock formations on Earth, is rare and sparsely distributed on Mars. Identifying such structures on Mars, particularly those formed through interactions between lava and water, could provide valuable insights into the planet's history of near-surface water. This research focuses on the columnar jointing within the Marte Vallis Crater, where mafic lava and liquid water may have interacted over extended periods ranging from several years to decades. By examining terrestrial analogues, such as the Madagascar flood basalt province and the St. Mary's Island (SMI) volcanics, which are linked to volcanic activity during the breakup of Greater India and Madagascar in the Upper Cretaceous (88 Ma), we aim to draw parallels that can enhance our understanding of Martian geologic processes. This study highlights the importance of terrestrial analogues in planetary science and offers new perspectives on the potential for past liquid water on Mars, contributing to the broader search for habitable environments beyond Earth. This study aimed to explore the similarities between the columnar jointing on Mars, particularly in Marte Vallis, and the well-preserved columnar basalts on St. Mary's Island.

Keywords: Mars analogue, Columnar joint, flood basalt, Marte Vallis, St. Mary Island.

Columnar basalts serve as evidence of past lava-water interactions, providing terrestrial analogies to help comprehend comparable processes on Mars[1].HiRISE found multi-tiered columnar jointing on Mars. In areas with inferred histories of flood volcanism, the lavas that cooled in the presence of water depended on the specifics of joint formation and occurred in the uplifted walls of impact craters. These are interpreted as columnar basalts based on the local geologic history[2]. Numerous locations on Mars have seen the observation of additional columns since the discovery[3].The separation is thought to have begun during or soon after a recognized episode of Late Cretaceous basic and felsic magmatism from Madagascar. Numerous plate reconstructions suggest a strong connection between Madagascar and Greater India from the late Precambrian to the Cretaceous eras[4]. Although comparable Cretaceous volcanism is not extensively known from western India, the western edge of India likely rifted off the eastern edge of Madagascar during this late Cretaceous break-up episode. The acid volcanic rocks of the St. Mary's Islands and the mafic dykes of mainland southwest India are two potential outliers[5,6].

Geological Setting

In the South Kanara district of Karnataka, St. Mary Island is situated roughly 6 km to the northwest of the port of Maple and 670 km to the south of Bombay. At 130 28' latitude, the St. Marys Islands group of Udupi Islands is positioned almost exactly parallel to the coast. The island has a total area of roughly 500 meters (1640.77 feet). The islands aligned north-south form a noncontinuous chain. The St. Marys Islands are a group of small islands that stretch roughly 6 kilometers off the western coast of central India, close to the seaside community of Maple. The islands are oriented NW-SE. All of the felsic volcanic rocks found on the islands are flat-lying and undeformed; these rocks include dacites and rayodacites[7,8]. Some of which have remarkably developed columnar jointing. The St. Marys Islands group consists of four significant islands: North Island, Coconut Island, Darya Bahadurgari Island, and South Island. Of the four islands, the northernmost island, St. Marys Islands, contains a hexagon-shaped basaltic rock formation—the only one of its kind in India[9,10].

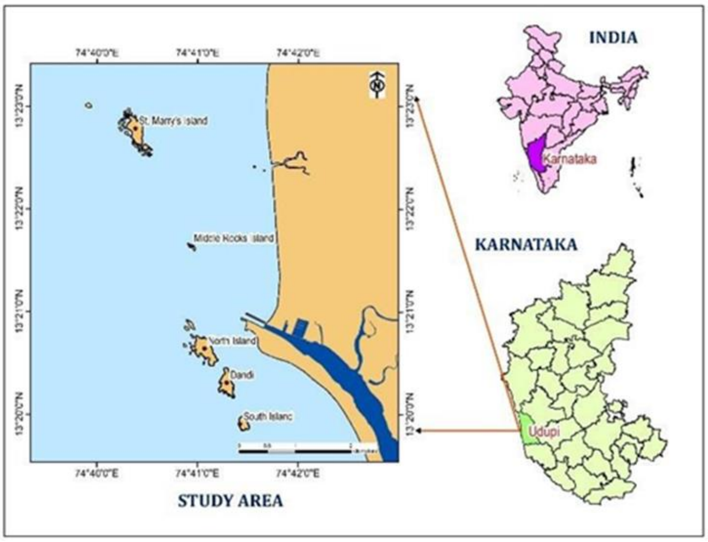

Fig.1. Study Area of St Mary's Island (SMI).

The Karnataka state government donated the island to the Geological Survey of India, which designated the rocks as a national geological monument due to their exceptionally well-developed columnar joints. The island is roughly 500 meters (1640.4 feet) long and 100 meters (328.1 feet) wide. The farthest island from the coast, Coconut Island, is located roughly 2.5 kilometers west of the mainland. The two northern islands, Northern Island and Coconut Island, are larger than the other two and have roughly identical areas (0.14 km2 and 0.13 km2, respectively). At approximately 11.38 meters on Coconut Island, 16.6 meters on North Island, and 11.5 meters on Darya Bahadurgari Island, the topography rises above the present-day sea level[11]. Marte Vallis, located between 170-190 ° W longitude and 0-20 ° N latitude, is a region characterized primarily by channels of possible fluvial origin[15].

Data and Sources of Data

The High-Resolution Imaging Science Experiment (HiRISE) on the Mars Reconnaissance Orbiter (MRO) discovered multi-tiered columnar jointing on Mars[2]. For this study, we choose PSP_007341_2020, PSP_006774_2020 Marte Vallis Lat:21.6^0 Lon:184.3^0, credited to NASA/JPL-Caltech/Arizona publicly access. For Fig.1.SMI Map Georeferenced using RS & Arc GIS software.

Research Methodology

Geomorphology of St Mary's Island

The St. Mary's islands were sub-aerial as Madagascar was still attached to India. The rifting of Madagascar from India took place around 88 M.Y[9,10].The landforms in the study area are primarily of depositional nature. The volcanic activity which gave rise to the St.Marys Islands was sub-aerial in nature as that of in Madagascar was still attached to India. The topography of the island is highly irregular and rugged and the islands, except the coconut islands are mainly rocky. Coconut Island has a maximum elevation of 10m above mean sea level compared to the other Islands, which is greater. The Coconut Island has a patchy layer of wave-worn rhyodacite pebbles and cobbles covering the +3m surface. To the west of the pebble bed is the shell deposit, of nearly at 2.5m is observed. Most parts of the Coconut Island most have an elevation of about 6m which represents a dissected marine terrace. St.Marys has just a few coconut trees for vegetation. There are several morphologies identified in the field i.e. columnar basalt[12-14].

Formation of Columnar Lavas

Fig.1.Study Area of St Mary's Island (SMI). Fig.2.Columnar Basalts in SMI. Fig.3. Columns seen in the wall of the impact crater in the Marte Vallis between Elysium and Amazonis planitia. Observation ID: 2020(NASA/JPL-Caltech/Arizona) II. PSP 006985 Formation of Columnar Lavas In terrestrial lavas, narrow (less than a meter to several meters wide), constant-width colonnades form when still-hot lavas are inundated by liquid water[7]. This inundation greatly increases the cooling rate compared with conduction alone, causing rapid contraction of the nearly solid lavas, which results in stress fracturing perpendicular to the cooling front. The spacing of the contraction fractures (joints) is inversely proportional to the cooling rate[8].

Fig.2. Columnar Basalts in SMI.

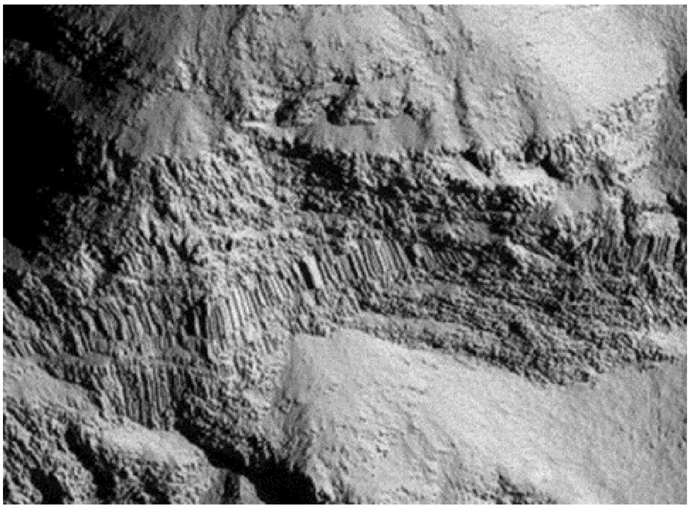

Fig.3. Columns seen in the wall of the impact crater in the Marte Vallis between Elysium and Amazonis planitia. Observation ID: PSP 006985 2020(NASA/JPL-Caltech/Arizona)

Comparison of the Models

Morphology of Columnar Joint on Mars

The volcanic activity, in the form of flood basalts and long lava flows, utilized the channels to transport lava distances as great as five hundred kilometers or more[16] flows share many similar characteristics of long, terrestrial-like basaltic flows Columnar jointing often forms when basalt lava cools[17,18]. The Columnar Joint occurs in the uplifted wall of the uneroded impact craters on Mars[1].

Fig.4.PSP_007341_2020MarteVallis Lat:21.6^{0}Lon:184.3^0(NASA/JPL-Caltech/Arizona)

Fig.5.PSP_006774_2020(NASA/JPLCaltech/Arizona)

Fig.6. Feild Visit to SMI Columnar joint.

Result and Discussion

Lava flow emplacement is a fundamental geologic process on Mars and other planetary bodies. By morphological comparison studying the surface morphology of lava flows The study area exhibits distinct geomorphological characteristics, particularly on St. Marys Island, where features like high beach deposits and wave-cut terraces suggest ongoing uplift processes. The island's geological composition is predominantly acidic, with basic regions also present, including formations such as granophyres, dacites, rhyodacites, and rhyolites. Notably, each major island within the St. Mary Islands group displays a unique rock type, with Coconut Island stands out due to its well-developed columnar joints. The sediments on

Coconut Island consist primarily of medium-sized sand particles, ranging from coarse to fine grains. Interestingly, despite being collected from both the northern and southern edges of St. Marys Island, the sediments share almost identical characteristics across the entire area[11].

Conclusion

•This study explored the similarities between the columnar jointing on Mars, particularly in Marte Vallis, and the well-preserved columnar basalts on St. Mary's Island.
•Our analysis revealed striking morphological parallels, suggesting that similar geological processes may have occurred on both Mars and Earth. The identification of columnar jointing on Mars not only enhances our understanding of Martian volcanic activity but also provides valuable clues about the planet's past interactions with water.
•These insights are critical in the ongoing search for evidence of habitable environments on Mars.
•While this study provides significant insights, further research is needed to confirm the presence of similar geological features across different Martian regions. Future missions with advanced imaging and sampling capabilities could offer more detailed data, enabling a deeper understanding of Mars's volcanic history and its implications for past water activity.

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ACKNOWLEDGMENT: We would like to thank NASA/JPL Caltech/Arizona for HiRISE image of Mars. We thank the anonymous reviewers for their constructive comments and suggestions.

Deccan volcanic bole layers: An under investigated Martian soil analogue

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The surficial rock record of terrestrial planets is intricate yet integrated. Buried regolith carry significant traces of surficial processes which are consequence of geologic, in particular geomorphic processes that operated in planet's evolutionary history. Researchers have shown that Deccan Continental Flood Basalts (CFBs) at the K-T boundary (~65-67Ma) may represent analogue of Martian crust. Therein, conspicuous red colored, interbasaltic layers in the extensive Deccan Volcanic Igneous Province (DVIP) of India provides an exceptional preservation of buried regoliths. These are termed 'bole beds' and are investigated popularly for their debated origin and as Martian soil analogues. In fact, amongst terrestrial planets, other than the blue planet Earth, Martian surface is actively studied in the realm of planetary sciences for its potential inhabitability. Deccan CFB regolith weathering profiles and weathering pathways may provide significant deal of information to understand weathering profiles of Martian regolith. Therefore, we carried out an extensive review to delineate gaps in these studies. It has been noticed that the hydrated group of silicates known as phyllosilicates is the most commonly used proxy to compare the weathering processes of Martian surface with Earth. This is because phyllosilicates form an important indicator for weathering processes and the most common phyllosilicates on Mars are similar to those identified in the Deccan CFB, in particular with those in bole bed paleosols. Though characteristic identification of phyllosilicates has been done using varied tools and techniques but still lack a robust correlation. Presumably, due to limited identification of Deccan bole bed paleosols. This may further be attributed due to lack of detailed and systematic micromorphological studies in these Deccan volcanic bole layers. On the contrary, such micromorphological studies form an integral part of global studies involving intravolcanic layers at worldwide volcanic occurrences. Thus, it can be concluded from the review that there is an immediate necessity to ensure inclusivity of such studies in Indian counterparts, more specifically in Deccan volcanic bole layers.

Laboratory Study of Regolith Analogues - relevance to recent Asteroid sample return missions

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Abstract:

The talk describes new studies carried out at Assam University, Silchar using a Goniometer developed in collaboration with IUCAA for reflectivity measurements of planetary regoliths. Historically, this experiment was conceptualized during our early visits (2000-2004) to Kobe University, Kobe, Japan where Prof. T. Mukai and his team were using similar Goniometers. The samples of regoliths were of industrial and natural origin and simulate the kind of dust expected tobe on planetary surfaces. The measurements match quite well with model estimates and provide a platform to remotely infer the physical properties of solar system regoliths which will be very useful for future asteroid sample return and landing missions on planets.

REFLECTANCE SPECTROSCOPY OF LUNAR SOIL SIMULANTS: A COMPARATIVE STUDY OF LSS-ISAC-1 AND JSC 1A BASALT.

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The accurate characterization of lunar surface materials is essential for advancing our understanding of lunar geology and improving the interpretation of remote sensing data from lunar missions. This study investigates the scattering properties of ISRO's Lunar Highland Soil Simulant (LSS-ISAC-1)[1] and NASA's JSC 1A Basalt [2], a well-established Lunar Mare Soil Simulant, through detailed reflectance spectroscopy. Samples of LSS, provided by Periyar University, were comprehensively examined across various grain sizes and viewing geometries. Bidirectional reflectance spectra were acquired for LSS in four distinct grain size fractions (20–45 µm, 45–100 µm, 100–150 µm, and 150–200 µm) using an ASD Fieldspec4 Hi-Res spectroradiometer mounted on a custom-built goniometer at the Planetary Remote Sensing Laboratory (PRSL), Physical Research Laboratory (PRL), Ahmedabad. Spectral data acquisition was performed with a spectral resolution of 1 nm within the wavelength range of 0.35 to 2.5 µm, with the incident angle fixed at -45° and emergence angles varying from -30° to 60° within the principal plane under controlled laboratory conditions.

The optical properties of LSS were derived using the Hapke model [3], which enabled the extraction of key parameters such as single scattering albedo (w), phase function coefficients, and the extinction coefficient (k) across the Visible and Near-Infrared (VNIR) range. These parameters were then utilized to model the reflectance spectra, allowing for a detailed analysis of the scattering behavior as a function of grain size and viewing geometry.

We also investigated the scattering behavior of JSC 1A Basalt, received from SIMPEX Lab, PRL. Our results indicate that JSC 1A Basalt exhibits a predominantly forward-scattering behavior, consistent with the prior studies [4]. Additionally, LSS demonstrated a relatively back-scattering behavior compared to JSC 1A, consistent with the scattering behavior observed in Apollo samples [4].

These findings underscore the significance of LSS as a lunar highland soil analog, providing critical insights into the scattering behavior of lunar surface materials. The derived optical constants and observed scattering behavior will not only enhance our understanding of lunar surface processes but also contribute to the refinement of models used in the analysis of remote sensing data from current and future lunar missions.

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Developing Modular Construction Block for Lunar and Martian Habitats using 3D Printing through Analogue Studies

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Abstract

Moon and Mars will serve as land for near-future colonization as humans aim to be an inter-planetary species. To establish self-sustaining habitats on these terrestrial bodies, it's crucial to leverage analogue samples readily available on Earth. Designing a modular construction block via 3D printing for Lunar and Martian conditions following standardized interfaces with appropriate structural stability would serve as an integral building unit in these conditions. Considering how concrete is manufactured in Earth-based conditions, to prepare such a construction block, aggregate mix along with a binding medium using local resources is required.

To emulate the extraterrestrial environment, terrestrial analogues of lunar and Martian materials can be utilized. Anorthosite, abundant in lunar highlands, and basalt, prevalent in lunar maria, can serve as potential aggregates. The Sittampundi Anorthosite Complex in Namakkal, Tamil Nadu (Budholiya, S., et al) and the Anjar region in Gujarat provide terrestrial sources for these materials respectively. For the preparation of Martian soil simulant, Dunite from the ultramafic complex in Salem (Hariharan, et al), banded and vein type deposits of Gypsum from Ariyalur district, Tamil Nadu (Prabhakaran, R., et al) are to be used. Limestone, one of the major constituents in Ordinary Portland Cement, can be used as the binding medium. Two types of limestone, both crystalline and sedimentary are to be sampled from Tirunelveli and Ariyalur districts of Tamil Nadu respectively.

The initial geotechnical characterization of the analogue samples showed good agreement with existing Lunar and Martian simulants. By comparing different formulations of binder, fine and coarse aggregates as outlined by Reches, 2019, we aim to optimize the mechanical properties for structural integrity. IS 516 (1959) is to be followed while preparation of these 3D-printed cubical construction blocks of sides 150mm each. Once done, a batch of the most structurally stable blocks will then undergo multiple freeze-thaw cycles that simulate extraterrestrial environmental conditions. This process aims to analyze engineering properties and assess how temperature fluctuations impact structural strength. A heat map profile using thermal sensors will be generated when the blocks are laid as a stacked wall unit to understand the thermal response and insulation properties. A complete dataset of how each material contributes at different proportions of mixing will also be developed.

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About PRL

Physical Research Laboratory

The Physical Research Laboratory (PRL; भौतिक अनुसंधान प्रयोगशाला) located in Ahmedabad, founded by Dr. Vikram Sarabhai on 11 November 1947 is a premier scientific institution dedicated to research in various areas of physics, supported mainly by Department of Space, Government of India. Key areas of research at PRL include astronomy & astrophysics, space & atmospheric sciences, planetary and geosciences, atomic-molecular & optical physics, solar physics and theoretical physics. The laboratory has been involved in several important space missions and research projects, contributing significantly to India's advancements in space science & technology and scientific research.

PRL operates several observational facilities and laboratories, including the Gurushikhar Observatory in Mount Abu, which is one of the highest astronomical observatories in India and also Solar observatory in Udaipur, the Udaipur Solar Observatory. The institution also collaborates extensively with national and international scientific institutions to further its research goals.

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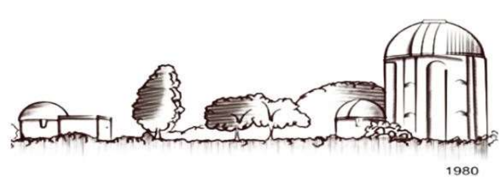

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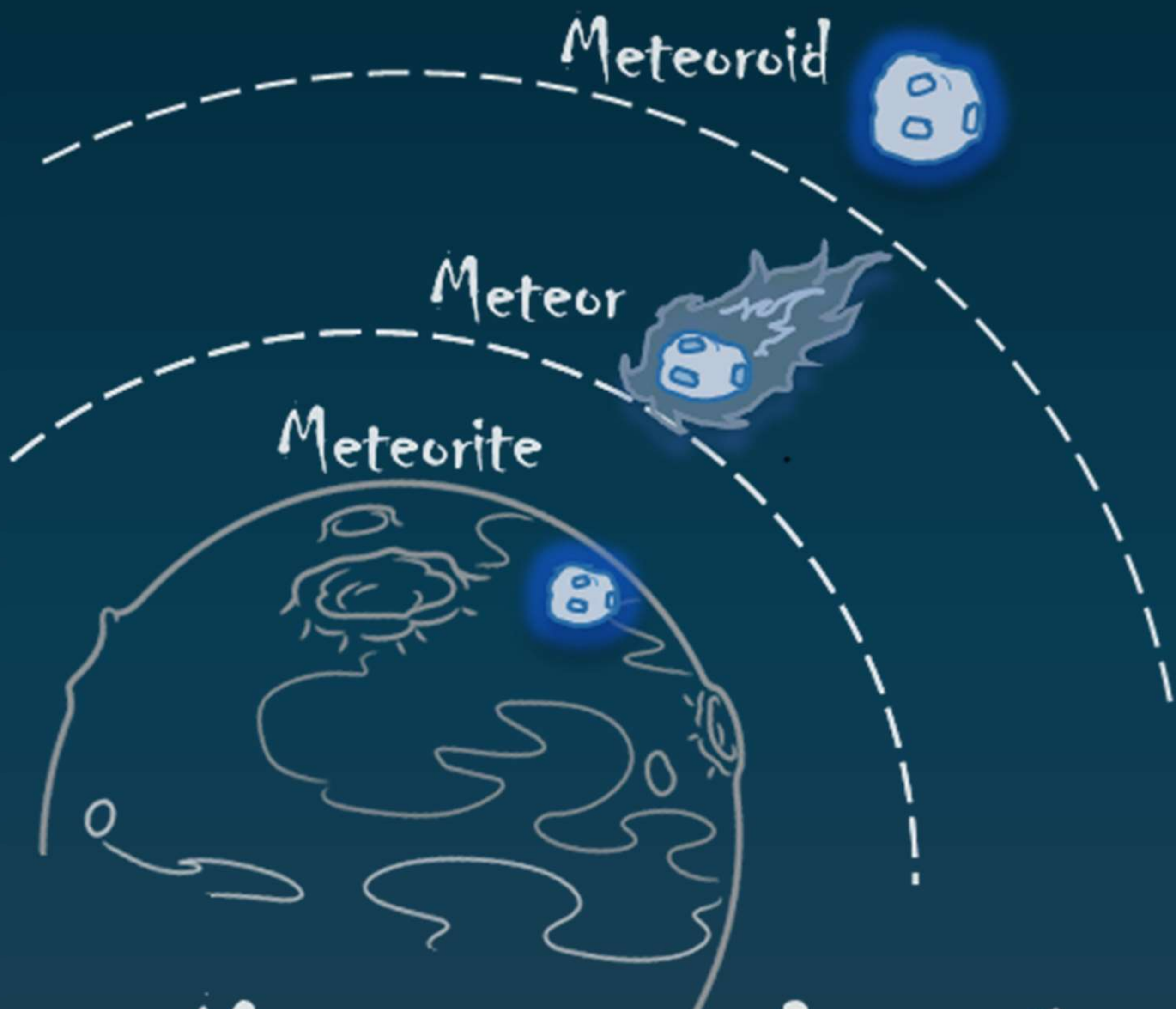

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