Platinum Jubilee

Physical Research Laboratory
MetMeSS-2022

2nd Symposium On

"Meteoroids, Meteors and Meteorites: Messengers from Space"

24th November, Thursday

Session-I: The First few million years of the Solar System: Many a little makes a mickle!

Session Chair: Debabrata Banerjee and Yogita Kadlag

Abstract #	Time	Speaker	Title of talk
S1-01	10:30-10:40	Yogita Kadlag	Quantification of physical properties and average atomic number of chondrules using micro-CT
S1-02	10:40-10:50	Mohammad Tauseef	^{14}C activity concentration and $^{14}C/^{10}Be$ activity ratios in ordinary chondrites
S1-03	12.00-12:10	Aditya Patkar	Water concentration and oxygen isotope compositions in olivines from CM2 chondrites
S1-04	12:10-12:20	Shreeya Natrajan	D/H systematics in Insoluble organic matter in CM chondrites
S1-05	12:20-12:30	Indhu Varatharajan	UV to FIR Reflectance Spectroscopy of Mukundpura (CM2) Meteorite at varying phase angles: A Potential Analogue to Ryugu and Bennu
S1-06	12:30-12:40	Dipak K. Panda	Thermal metamorphic history of unequilibrated chondrites.
S1-07	12:40-12:50	Subhasmita Swain	Thermal Metamorphism of Rumuruti Chondrite
Invited	14.00-14.30	NG Rudraswami	Extraterrestrial dust reaching the Earth Surface
S1-08	14.30-14.40	Swarna Prava Das	Thermal Properties of Organic Matter in CM Chondrites using Raman Spectroscopy
S1-09	14.40-14.50	Rishant Prakash	Geochemical studies of AOA (Amoeboid Olivine Aggregates) in Mukundpura (CM) and Allende (CV3) chondrites
S1-10	14.50-15.00	Avadh Kumar	Trapped 20Ne in LL chondrites
S1-11	15.00-15.10	Arindam Dutta	Microdiamonds from ordinary chondrites and its cosmogenic significance
S1-12	15.10-15.15	Richeek Debnath	Dark Matter - Matter That Can't Be Touched

Quantification of physical properties and average atomic number of chondrules using micro-CT

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Computed tomography is a fast and non-destructive technique for studying 3D physical characteristics and volumetric modal abundances of silicates and opaque phases in meteorites and their components [1, 2]. This study explores micro-CT imaging technique to determine the textural, physical, and qualitative chemical properties (based on the average atomic numbers) of chondrules from unequilibrated ordinary, carbonaceous, and enstatite chondrites. Thirty eight chondrules are selected for this study from Allende (CV3.6), Ningqiang (C3-ung), NWA 11241 (CV3), NWA 1665 (CK3-an), NWA 10507 (CO3.0), NWA 7892 (CO3.0), NWA 8276 (L3.00), NWA 12692 (LL3.00), and Qingzhen (EH3). Chondrules are separated using freeze-thaw and gentle scratching by needles and tweezers. The 3D tomographs of chondrules are obtained using Bruker SkyScan 1272 high-resolution micro-CT (isometric voxel size of 1.65 µm) and the 3D porphyritic and non-porphyritic textures, shape, variable porosity and mineral grain size, and linear attenuation coefficient (LAC) values of the chondrules are determined.
Many chondrules deviate from their spherical shape, implying that they were affected by a strain during cooling and prior to complete solidification. The modal abundances of silicates and metal are calculated from the grayscale differences. The relationship between LAC and grayscale of reference materials such as BHVO-2, BCR, synthetic glass, albite, San Carlos olivine, clinopyroxene, and Fe-Ni metal is used to calculate the linear attenuation coefficient of the bulk chondrules. LAC values of bulk chondrules ranges from 9 to 16, indicating the variable proportions of Fe-rich phases, such as fayalite, Fe-Ni metal and FeS in the chondrules. The total (closed and open) porosity of the studied chondrules ranges from 0.04% to 5.3%. Chondrules from carbonaceous chondrites show the highest porosity and the largest voids. In some chondrules, pores are associated with opaque phases, suggesting the formation during solidification of metal phases and/or during parent body alteration. Except in Allende and NWA 1665, where smaller chondrules show more deformation than larger chondrules, there is no consistent variation between the degree of deformation, chondrule diameter, and open and closed porosity among the chondrules from different groups, suggesting that the processes responsible for changes in the different physical properties of the chondrules are decoupled from each other and are likely universal to all chondrules.

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^{14}C activity concentration and $^{14}C/^{10}Be$ activity ratios in ordinary chondrites

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Introduction: The Meteoritical Bulletin Database statistics for the meteorites that have been authorized and listed to date show that 97% of meteorites are finds and 3% are falls. Determining terrestrial ages of such a large number of meteorites find aids in (i) comprehending the meteorites accumulation on Earth over time, (ii) studying meteorite weathering and erosion rates in specific areas, (iii) helps in meteorite pairing. Terrestrial age of meteorites are determine by comparison of present concentration of a cosmogenic nuclide in the meteorite to the concentration the meteorite had when it landed on Earth. Cosmogenic ^{14}C-dating of meteorites is a robust technique for terrestrial age determination up to ~50 ka. For such studies, it is necessary to know the ^{14}C activity concertation at the time of fall, which is not straightforward. ^{14}C production in meteorites depend on the chemical composition of the meteorite, pre-atmospheric radius of meteorite, and depth of the sample in meteorite body before it enters the Earth [1]. To alleviate such problems, $^{14}C/^{10}Be$ production ratio is often applied instead of ^{14}C production alone, which is less dependent on chemical composition and shielding depth [1]. Nonetheless, in order to apply this ratio, ^{10}Be must be saturated, i.e., the cosmic ray exposure (CRE) age of meteorites must be >5–6 Ma [1]. However, these values are not well constrained for different meteorite types. For a reliable application of ^{14}C–^{10}Be terrestrial age dating system, the ^{14}C production rate and the $^{14}C/^{10}Be$ production rate ratio in different meteorite types and shielding depth needs more detail investigation. In this study, we aim to determine the ^{14}C production rate and $^{14}C/^{10}Be$ production rate ratio in freshly fallen meteorites. This investigation will help to better constrain existing data, and expand our comprehension of the dynamics of the small bodies in the solar system.

Methodology: With our updated Bernese–^{14}C line, we can qualitatively and reproducibly measure up to 15 samples without hindering the vacuum of the system, thereby ending with lower blanks and higher sample throughput [2]. We have selected 4 ordinary chondrites; Bensour (LL6), Boumdeid (L6), Mt. Tazerzait (L5) and SaU 606 (H5). CO_2 gas from meteorites extracted in our laboratory at the University of Bern [2,3], and the $^{14}C/^{12}C$ ratios are measured in the MICADAS system at the LARA laboratory, University of Bern, Switzerland [4]. ^{10}Be measurements carried out at the ASTER-AMS facility at CEREGE, Aix-en-Provence, France [5]. In addition, we also measure cosmogenic isotopes of noble gases He, Ne and Ar in our laboratory at the University of Bern, in order to determine the CRE age of samples [6].

Results: Calculated CRE ages using $^{20}Ne_{cos}$ of the samples, SaU 606 (8.5 ± 0.53 Ma), Boumdeid (10.9 ± 0.66 Ma), Mt. Tazerzait (21.8 ± 1.29 Ma) and Bensour (7.4 ± 0.43 Ma), are adequate to have ^{10}Be in saturation, i.e., $^{14}C/^{10}Be$ ratios are applicable for our samples. The preliminary results of the ^{14}C activity concentration and $^{14}C/^{10}Be$ activity ratios show significant variation (Fig. 1). The ^{14}C activity concentration varies from 15.0 ± 0.19 dpm/kg in SaU 606 (H5) to 46.3 ± 0.41 dpm/kg in Bensour (LL6). Similar variation reflected in the $^{14}C/^{10}Be$ ratio (Fig. 1).

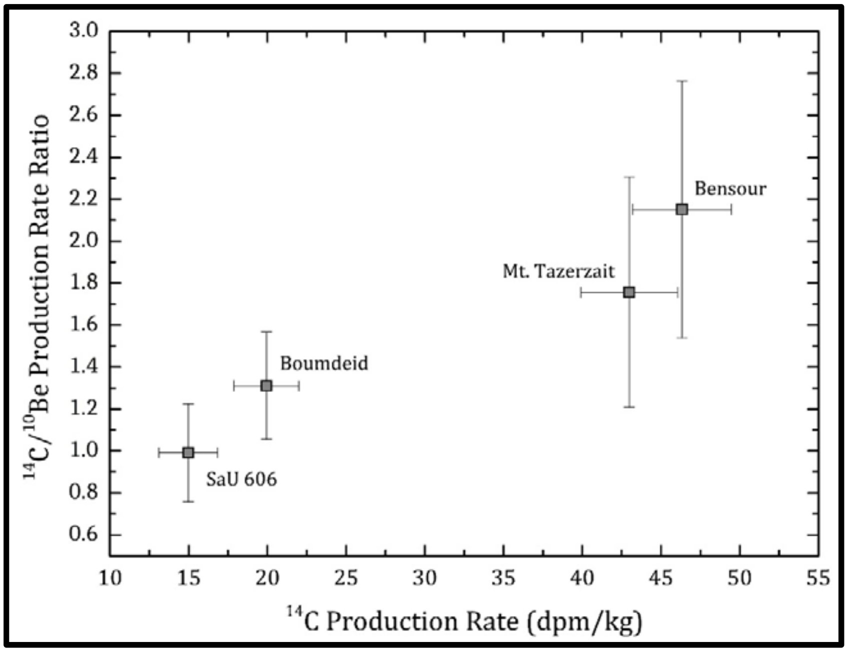

Fig. 1. $^{14}C/^{10}Be$ ratio against ^{14}C production rate in freshly fallen meteorites

Conclusions: $^{14}C/^{10}Be$ corrects for shielding effect, thus more robust than ^{14}C alone. Our samples have suitable exposure age (>7 Ma) to imply $^{14}C/^{10}Be$. However, we are not so sure about such high variation in ^{14}C activities, also reflected in the $^{14}C/^{10}Be$ ratios, are whether due to the chemistry and shielding. We doubt that the crucible in our extraction line was getting full with addition of more samples, and we might have ended with incomplete extraction. We have already started measuring next batch of the same samples and might be able to discuss new data in the meeting. Nevertheless, measurement of large number of meteorite samples could better comprehend the ^{14}C production rate and $^{14}C/^{10}Be$ ratio in different meteorite groups.

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Water concentration and oxygen isotope compositions in olivines from CM2 chondrites

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Introduction: Robert Clayton discovered large anomalies in oxygen isotopic compositions of CAIs from the CV3 Allende in the order of ~5% compared to terrestrial materials [1]. Much work has gone into studying the mechanisms leading to this non-mass-dependent oxygen isotope exchange in the solar nebula. [2] suggested the possible role of water in this isotopic exchange in the hydrous matrix from some carbonaceous chondrite groups and also in the nominally anhydrous phases from chondrules and CAIs.

Low-level water measurements in nominally anhydrous minerals (NAMs) like olivine are fundamental in understanding the ambient P-T conditions during their formation and volatile inventories in the early solar system. Many recent studies have attempted in situ measurements of water concentration in NAMs using SIMS (e.g. [3-5]). However, the reported range of ~8 to ~10000 ppm is highly variable and still debated. Here, we report water concentration and oxygen isotope composition ($\delta^{18}O$ normalised to SMOW) in olivines from three CM2 chondrites using a new grain mounting method.

Methods: Small (~0.5 cm) chips of CM2 Murchison, Mighei and Jbilet Winselwan were crushed, and olivine grains were isolated before mounting in Bi-Sn alloy, a mounting method developed for analysing trace amounts of water. Following anhydrous polishing and cleaning, they were analysed using the Sensitive High Resolution Ion Micro Probe Stable Isotope (SHRIMP SI) at RSES, Australian National University. A Cs^+ primary ion source and an electron gun were used to sputter ~25 µm spots and simultaneously acquire ^{16}O, $^{16}O^1H^-$ and $^{18}O^-$ secondary ions.

Raw $^{16}O^1H^-/^{16}O^-$ ratios were converted to water concentration in ppm using three standards: Suprasil Glass (SiO_2; ≤ 1 ppm water), San Carlos Olivine (SCO; 15±2 ppm), Russian Cr-diopside (100±10 ppm) [6]. All the standards were mounted and polished along with the CM2 olivines on the same section to ensure similar treatment for the standards and the unknowns. A polynomial regression fit was used to calibrate the unknown water concentrations (linear fit R^2=0.99). SCO was used as the reference for $\delta^{18}O$ measurements.

Results: Over 60 olivine anhedral to subhedral grains ranging from ~50 to ~350 µm on their longest axis were analysed. About half of them appear to be from Type I chondrules as evident from their Mg# ≥99 and the other half are from Type II chondrules (Mg# ~50-90).

One to five spots (median = 3) were analysed per grain depending on the grain size. Type I olivines show ~2 to 8 ppm water (median = 4 ppm). Type II olivines show ~10 to 25 ppm water (median = 15 ppm). 10% uncertainty is considered for all water measurements as in [6], however, the maximum analytical uncertainty (2σ) in our measurements is ~8%.

$\delta^{18}O$ compositions for olivines are consistent with the values reported previously from CM chondrites [7] and range from -8.9±0.3‰ to -4.0±0.2‰ for Type I olivines and -0.8±0.4‰ to 5.6±0.2‰ for Type II olivines. Isotope compositions have been corrected for matrix bias using procedures followed by [8].

Discussion and Conclusions: Water concentrations in olivines are consistent in the grains analysed and are significantly lower than previously reported values from meteorites. The primary reason seems to be the sample preparation and mounting techniques employed in different studies as shown in [9]. Terrestrial alteration does not seem to have affected the water content in olivines as evident from the olivine separates from Jbilet Winselwan which is a find.

The observed $\delta^{18}O$ and Mg# bimodality in olivines is reflected in their water content as well with forsterites (Mg# >99) showing markedly lower water content than fayalites (Mg# <90) in all three CM chondrites. However, there is no apparent correlation between the Mg#, $\delta^{18}O$ and water content within Type II olivines despite the considerable range in Mg#. Thus, it appears that the two chondrule types sampled different isotopic reservoirs with the Type II olivines forming in an oxidizing, more water-bearing environment resulting in their heavier isotopic ratios and higher water concentrations as supported by [10].

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D/H systematics in Insoluble organic matter in CM chondrites

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Abstract: Insoluble organic matter (IOM) makes up to 90% of the organic inventory in the most primitive class of meteorite samples i.e. the carbonaceous chondrites. Insights into their chemical evolution can help elucidate the physical and chemical processes that occurred on their asteroidal parent bodies and with that, the organic chemistry that occurred prior to and/or early in the solar system's evolution and the potential for specific organic syntheses to occur in other stellar systems. The ratio of heavy-to-light isotopes in a compound can constrains its formation history: a reaction's substrates, mechanisms, and physiochemical conditions impact isotope ratios. The solar system consists of reservoirs containing water with an extremely wide range of D/H ratios. The variation in D/H ratios partly reflects the primordial gradient of water and other volatiles through the solar system as a function of distance from the Sun (Fig. 1). The similar D/H ratios among CI-CM carbonaceous chondrite meteorites, JFCs, and Earth may support the hypothesis of a common source region for the water of these celestial objects [1,2,3].

CI and CM chondrites have long been thought of as potential sources for the volatiles in the terrestrial planets [e.g., 4,5,6] Their bulk D/H and $^{15}N/^{14}N$ ratios are some of the most robust constraints that favor a CI-CM origin for Earth's and Mar's volatile elements [4,5,7]. IOM in these meteorites are the major carriers of D and N enrichments. Deuterium enrichment is inversely related to both a compound class's water solubility Which suggest that ISM-sourced compounds reacted to form deuterium-enriched molecules on meteorites' parent bodies and the enrichments were attenuated through exchange with water during aqueous alteration on the parent body and subsequent terrestrial processing [8,9,10]

In order to further constrain the parameters of alterations and to obtain insights into the pre accretionary processing of IOMs, we carried out NanoSIMS analysis of CM chondrites using the D/H schematics. In our preliminary analysis we observe wide range of delta values with hotspots as high as ~4000 ‰ and spanning every class of CCs Fig.1 which suggests the enrichments could have taken place in the outer solar system at the surface of the protosolar disk.

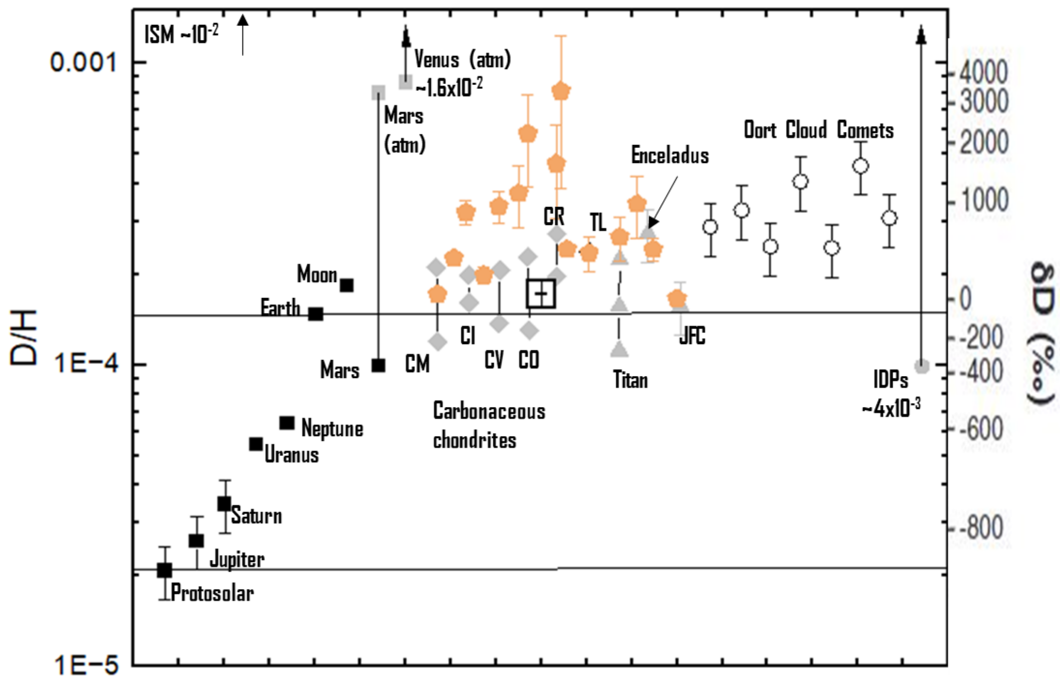

***Fig 1**: D/H ratios for all solar system objects. The protosolar nebula is a characterized by deuterium depletion, whereas the outer solar system, such as in the Oort cloud comets, is enriched in D/H ratios by a factor of 2 or more over terrestrial values. The enrichments are directly related with distance from the Sun. The data from this study (plotted in orange) shows enrichments of the order of outer solar system and higher.*

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UV to FIR Reflectance Spectroscopy of Mukundpura (CM2) Meteorite at varying phase angles: A Potential Analogue to Ryugu and Bennu

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Introduction: Carbonaceous chondrites include most primitive known meteorites. Although carbonaceous chondrites occupy a major fraction (75%) among asteroids, they are rare [4.6%] in Earth's meteorite inventory [1,2]. This limits us in understanding the diversity in mineralogy and composition of this asteroid class. Two of the sample return missions to NEAs which include JAXA Hayabusa 2 mission to Ryugu and NASA OSIRIS-REX mission to Bennu are both C-type asteroids. For remote sensing classification and mapping of C-type asteroids, it's important to perform detailed spectroscopic investigation of this meteorite class at wide spectral range [3] (from ultraviolet to far-infrared) at varying phase angle combinations. In this study, we investigated the mineralogy of the fresh carbonaceous chondrite fall, Mukundpura, through reflectance spectroscopy at wide spectral range (0.2-100 μm) of varying phase angle combinations with phase angles varies from 26° to 100°.

Sample: On June 6, 2017, a meteorite weighing ~2 kg fell in Mukundpura village (26° 52' 53''N, 75° 39' 54''E) at Rajasthan, India. This impact formed a nearly circular crater of ~40 cm diameter with a depth of ~15 cm and impactor shattered into several large pieces and numerous small pieces which weigh from gram to subgram-sized fragments. This meteorite is then classified as CM2 class of carbonaceous chondrites [4-6]. We collected multiple fragments from the Mukundpura impact site one amongst them shown in Fig. 1. The broken piece consists of 5 separate faces (Fig.1A a), and one among them is the fusion crust (Fig.1; A). Therefore, this study further allows us to do understand the spectral nature of fusion crust and the sample itself.

Planetary Spectroscopy Laboratory (PSL): In this study, the reflectance spectroscopy of the Mukundpura sample in wide spectral range covering from ultraviolet (UV) to far-infrared (FIR) spectral regions (0.2μm – 100μm) is carried out at varying phase angle combinations using two Bruker Vertex 80V instruments hosted at PSL Planetary Spectroscopy Laboratory (PSL) facility located at the Institute of Planetary Research (PF) at the German Aerospace Center (DLR), Berlin.

Methodology: In this study, we collectively measured the spectral reflectance at vacuum of all the faces of the sample (A-E) at wide spectral range (0.2-100 µm) at nine different phase angle combinations such as where the incidence (I°) and reflectance angles (R°) of each measurements (I°-R°) are 13°-13°, 13°-20°, 13°-30°, 13°-40°, 13°-50°, 20°-20°, 30°-30°, 40°-40°, 50°-50° (Fig.1A b).

Results: The visible-mid infrared (0.5-16 μm) spectra of the fusion crust (Fig. 1B (a,b)) and the sample face E (Fig. 1B (c,d)) measured at all phase angles. In the visible-nearinfrared (VNIR) region, the fresh meteorite surface spectra is nearly flat or not having any significant distinguishable absorption (Fig. 1B c), however, the spectra of the fusion crust shows a broad convex shape from end to end (Fig. 1B a). The presence of OH bond in the meteorite is represented by the 2.8 μm absorption feature as shown in (Fig. 1B b,d). In the spectra of the fusion crust (Fig. 1B b), the 2.8 μm absorption feature is highly subdued which could be explained by the loss of water within the mineral matrix during the atmospheric descent of the impactor. The shape and positions of absorption features near 9 and 13 µm for the fusion crust (Fig. 1B b) and the sample (Fig. 1B d), is different suggesting the thermal weathering of the sample during the atmospheric descent.

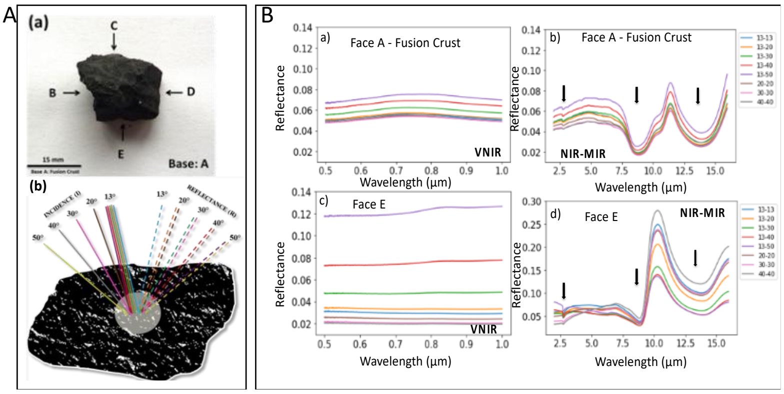

Figure 1. A) Mukundpura meteorite and the representation of varying phase angles studied B) Visible – Mid IR spectra (0.5 – 16 µm) of Mukundupura meteorite at varying phase angle combinations.

Comparison to Ryugu and Bennu: Usually, spectroscopy of all the CM or C-class meteorites studied are powdered samples because most solar system target possess a fine dusty surface and therefore studying the spectral properties of fine grained analogue materials were well-suited. However, Ryugu surprised us with a very rocky surface with no “smooth” surface to land. This compels us to understand the spectral nature of the rocky undulated analogues such as our Mukundpura meteorite sample itself. Comparison of Mukundpura fusion crust and average intrinsic surface spectra compared with the Ryugu and Bennu spectra [7-8] respectively is shown in Fig. 2. The results reveal that the thermally metamorphosed and shocked Mukundpura fusion curst with diagnostic 2.72 µm absorption is comparable to the Ryugu. Therefore, supporting that Ryugu surface has experienced extensive heating in its geologic past. The asymmetric 3 µm band of Bennu is significantly comparable to the strong asymmetric absorption band of intrinsic Mukundpura surfaces, which further supports that Bennu’s upper layer had not undergone heating compared to Ryugu surface.

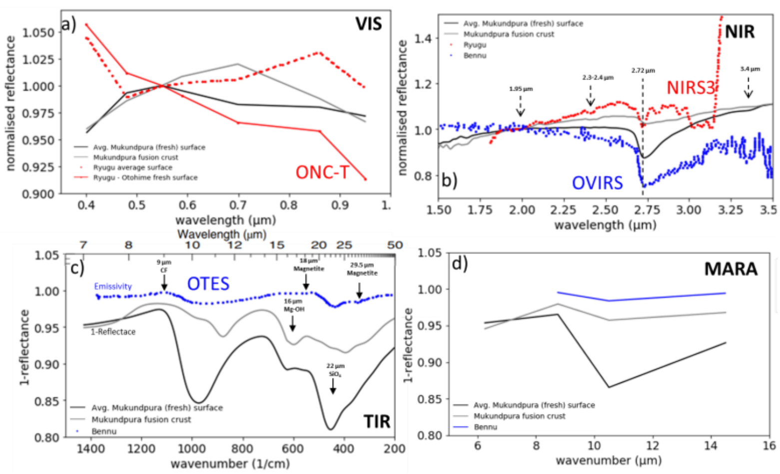

Figure 2. Comparison of Mukundpura fusion crust and average intrinsic surface spectra compared with the extracted Ryugu and Bennu spectra respectively.

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Thermal metamorphic history of unequilibrated chondrites.

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Chondritic meteorites are classified mainly on the basis of their texture and bulk composition. In chondritic meteorite, ordinary chondrites are classified as H, L and LL type. These meteorites are altered due to the thermal metamorphism as they are exposed to temperatures upto 1200^o C. We present an application of thermoluminescence (TL) where TL sensitivity from laboratory induced thermoluminescence is used to measure the degree of metamorphism chondritic meteorite [1,2]. Thermoluminescence sensitivity is defined as the amount of TL induced in a sample by a standard radiation dose. Our study focusses the new idea of using OSL sensitivity for normalizing the TL signals obtained from chondritic meteorite to understand their thermal metamorphic history. Results are presented from two ordinary meteorite Dhajala (H4) and Kamargaon (L-6). The naturally accumulated TL is removed by annealing the sample to 400^o C, following which meteorite aliquots were exposed to a test dose of ~ 132 Gy and the TL signal was measured. This was followed by the measurement of OSL signal in the same manner. The peak temperature for the laboratory induced TL signal for Dhajala and Kamargaon are 119^o and 121^{o}C respectively. The TL/OSL for Dhajala and Kamargaon are estimated to be ~21.3 ± 2.7 and 8.9 ± 2.6 respectively. Assuming Dhajala as the normalization standard (TL/OSL =1), Kamargaon is estimated to have a TL/OSL sensitivity ratio of 0.42. This is an order of magnitude lower than mass normalized TL sensitivity ratios observed previously from LL6 chondrites (Appley Bridge and Mangwendi) which provided estimates of 14 and 6 respectively [1].

Reference:

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Thermal Metamorphism of Rumuruti Chondrite

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Introduction: Rumuruti (R) chondrites are a unique group of chondritic meteorite having the highest $\Delta^{17}O$ of ~2.7 among all chondritic groups [1]. Many of the R chondrites are regolith breccias and have a variety of clasts embedded within an olivine-rich clastic matrix. All of the studied R chondrites show effects of thermal equilibration and the matrix olivine in unequilibrated lithologies show fayalite contents of ~45–60 mol%. Such high fayalite content points to a possible fluid source and using mineralogical parameters to understand the petrologic grade can provide unreliable results. The maturity of organic matters in matrix of various chondritic meteorites has been reliably used as an indicator for petrologic type [2]. In this study we are studying the structural order of polyaromatic carbonaceous matter present in matrix of different R chondrites to understand their thermal history.

Samples and Methods: We have studied polished thin sections of 7 R chondrites including the Rumuruti meteorite, the only R chondrite fall. A WITec alphaR 300 Raman microscope at the Hawaii Institute of Geophysics and Planetology (HIGP) was used with an excitation wavelength of 532 nm, laser energy of <1mW. From the acquired spectra, a linear background from 1000-1800 cm^{-1} has been subtracted. Fitting of the peaks has been done using a Python code: Lorentzian function for G Band and BWF for D Band.

Results and Discussions: The Raman spectra from the organic matter in the matrix of the studied meteorites shows the characteristic G (~1600 cm^{-1}) and D (~1350 cm^{-1}) bands due to first-order Raman scattering effect. In a plot for FWHM of D band ($FWHM_D$) against ratio of intensity of D and G band (I_D/I_G) all the previously studied CV3, ordinary chondrites (OC), CO and Antarctic meteorites show a trend with the most unequilibrated chondrite Semarkona having the highest $FWHM_D$ value and the more metamorphosed Parnallee having the lowest $FWHM_D$ (Fig. 1). The R chondrites have $FWHM_D$ <125 plot towards the more metamorphosed meteorites (e.g. Allende, Parnallee, etc). However, they do not plot along the trend followed by the studied CV3, OC and CO chondrites. All the previously studied meteorites belong to petrologic type 3.0-3.6 and all the studied R chondrites are petrologic type 3.6 or higher. The structural order of polyaromatic carbonaceous matter of highly metamorphosed meteorites (>3.6) may have different properties compared to low metamorphosed meteorites. This needs to be investigated further by studying more ordinary chondrite meteorites of petrologic type >3.8.

Conclusions: All our studied R chondrites are metamorphosed and are of petrologic type >3.6. The properties of polyaromatic carbonaceous matter in metamorphosed meteorites is different than less metamorphosed meteorites and this needs further investigation by studying highly metamorphosed meteorites.

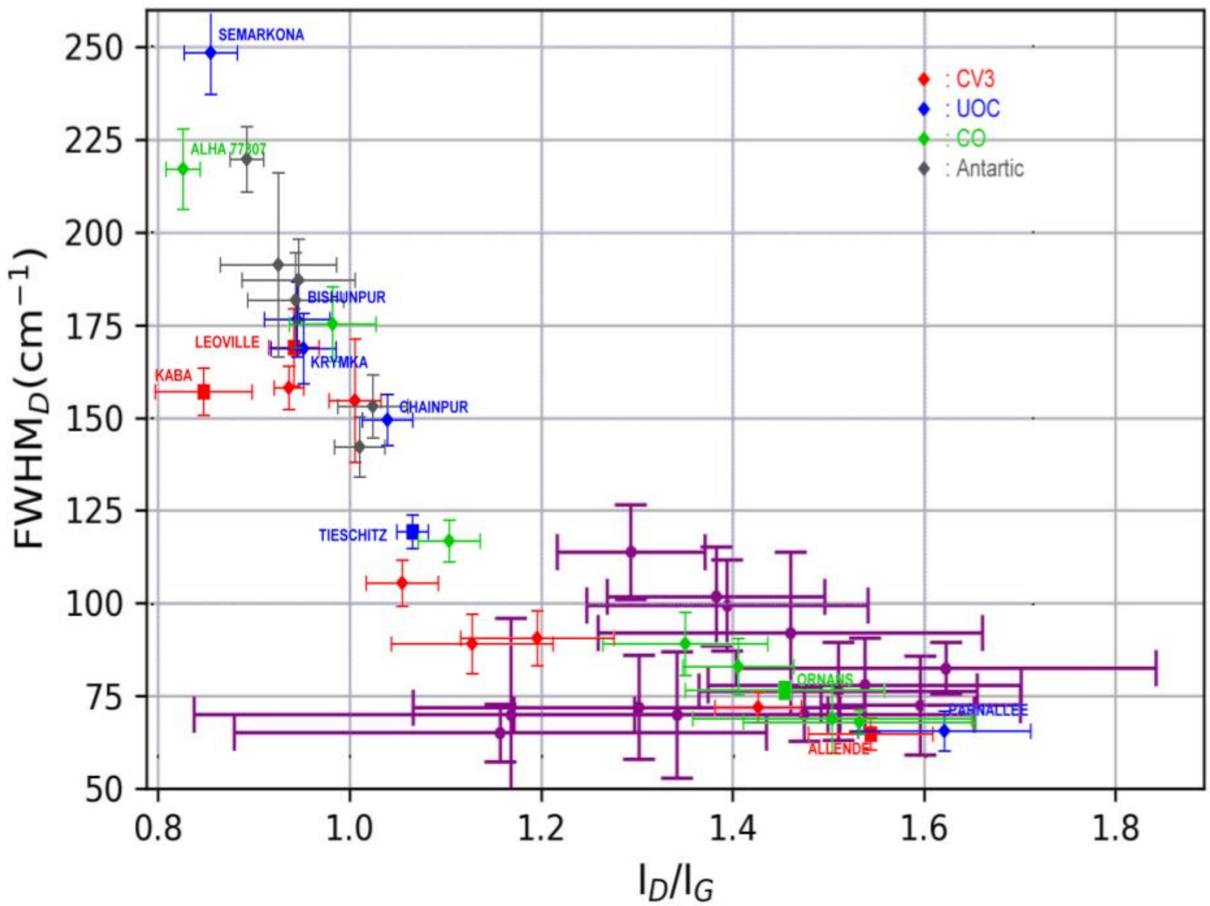

Fig. 1: FWHM$_D$ vs. I_D/I_G of Raman bands of carbonaceous matter in different chondritic meteorites. The data from the studied R chondrites is also shown.

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Thermal Properties of Organic Matter in CM Chondrites using Raman Spectroscopy

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Introduction: CM chondrites are complex group of primitive meteorites that underwent brecciation as well as aqueous alteration to different degrees [1]. In spite of the alteration, CM chondrites preserve signatures of early solar history [2] and could be major carriers of water and organics to Earth [3]. Various studies have shown that after accretion of the CM chondrite parent body, most of the silicate minerals and metals were transformed into secondary phases because of the aqueous alteration process [4]. In addition, some of the CM chondrites are also thermally metamorphosed causing further phase changes, especially the hydrated minerals [5]. In order to understand the primary nebular record preserved in CM chondrites, it is essential to have a proper understanding of the effects of aqueous and thermal alteration. The porous matrix of CM chondrites containing fine-grained mixture of phyllosilicates and organics are the primary regions of alteration. However, the degree of aqueous alteration and thermal metamorphism in CM chondrites and subsequently the phase changes in their mineralogy remain poorly understood [1,5]. Here we are working on to understand the aqueous alteration and thermal metamorphism of selected CM chondrites using Raman spectroscopy, X-Ray Diffraction (XRD), and Field Emission Scanning Electron Microscopy (FESEM). This particular work presents our results on Peak Metamorphic Temperature (PMT) using Raman. Peak metamorphic temperature (PMT) is the highest temperature reached during metamorphism in CM chondrites [6].

Samples and Methods: The samples used in this work are thin sections of two CM chondrites: Jbilet Winselwan/JW (CM 2.4–2.9) [5] and Murchison (CM 2.5) [7]. The Raman spectrometer (LabRAM HR Evolution, Horiba Scientific) is used with an excitation wavelength of 532 nm, laser energy of <1mW. The peak center positions and full-width half-maximum (FWHM) of each Raman band were calculated using 4-pseudo-Voigt profiles following a linear baseline correction method [8]. PMT was estimated using the geothermometry approach provided by [9]. The CM chondrite Murchison studied by [9] is used for cross-laboratory calibration and as a standard to verify the accuracy of our peak fitting procedure.

Result and Summary: The PMT calculated here are 94 ± 16 ^{0}C and 76 ± 15 ^{0}C for JW and Murchison, respectively. The PMT calculated here for Murchison is comparable to earlier finding of 65 ± 25 ^{0}C by [8]. However, the PMT of JW is inconsistent with earlier report of 305.5 ± 4.7 ^{0}C by [10]. Further analysis is in progress investigating the difference in PMT values. It could be because of the different curve fitting procedures and the geothermometry approach [11]. It is also worth mentioning that the JW meteorite is quite heterogeneous, which could indicate a complex aqueous and thermal alteration process.

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Geochemical studies of AOA (Amoeboid Olivine Aggregates) in Mukundpura (CM) and Allende (CV3) chondrites

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Introduction: Amoeboid olivine aggregates (AOAs) are one of the three major components of carbonaceous chondrite. The mineral and textural composition of AOAs does not vary much within the sub-groups of chondrites. AOAs consist mainly of olivine of varying composition, mostly forsterite>96 % (but in some cases fo_65-96 %), Ca-Al-rich inclusions and their recondensed products after remelting, and low-Ca pyroxenes [1]. The present study aims at delineating the formation environment of AOAs by the geochemical studies of Allende (CV3) and Mukundpura (CM2) chondrites.

Analytical technique: This study uses two polished thick sections of the Mukundpura and one thick section of the Allende sample. The high-resolution BSE images and chemical composition of these samples were obtained from Fe-EPMA (model JEOL 8530F, Japan) equipped with five WDS and EDS, operated at 15 Kev and 15nA current, and beam size of 1μm.

Results: From the BSE images, it can be observed that the AOAs from the Allende (CV3) and Mukundpura (CM 2.5) are irregular in shape and size, approximately 900μm and 150-200μm, respectively. The chemical compositions indicate that the AOA's in Allende are dominant by olivine with Fo_{64-99}, peak touching around $Fo_{80-85;}$ other minerals found are high-Ca,Ti- pyroxene with up to 9.2 wt% Al_2O_3 and <6 wt% TiO_2; low-Ca pyroxene plagioclase and a tiny grain of nepheline [$(Na,K)AlSiO_4$] surrounded by anorthite within the AOA. However, in the case of Mukundpura, AOA consists of nearly pure forsterite (Fo_{96-97}) and Mg-rich pyroxenes (En_{96-91}). Isolated olivine grains (Fo_{98}) and chondrules in Mukundpura shows thick rims of fine-grained phyllosilicate dominated by Fe-rich phases that demonstrate abundant aqueous phases.

Discussion: The geochemical analysis of AOA in Allende and Mukundpura reveals a sequence of condensation reactions indicating the formation environment of these minerals. The minerals formed are of both high- and relatively low-temperature environments. AOAs are genetically related to CAIs and have chemical similarities to magnesium type I chondrule [2]. The forsterite grains in AOAs in Allende are fayalitic in composition, whereas AOAs in Mukundpura are dominantly forsterite in composition (fo>96). The Al-Ti-rich pyroxene and anorthite might have formed from the reaction of CAI-rich minerals with SiO and Mg-rich gas, which indicates the formation of these minerals at extremely high temperatures in a ^{16}O-rich gaseous environment [3]. However, the presence of low-Ca pyroxene on the periphery of AOA in Allende suggests otherwise, i.e., the formation environment is like Magnesium-type I chondrules, which are poor in ^{16}O gas [3]. The uniqueness of this AOA study is that it gives the wholesome story between the formation of CAIs and chondrules in a chondritic meteorite, thus acting as an information bridge between the two.

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Trapped ^{20}Ne in LL chondrites

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Introduction:

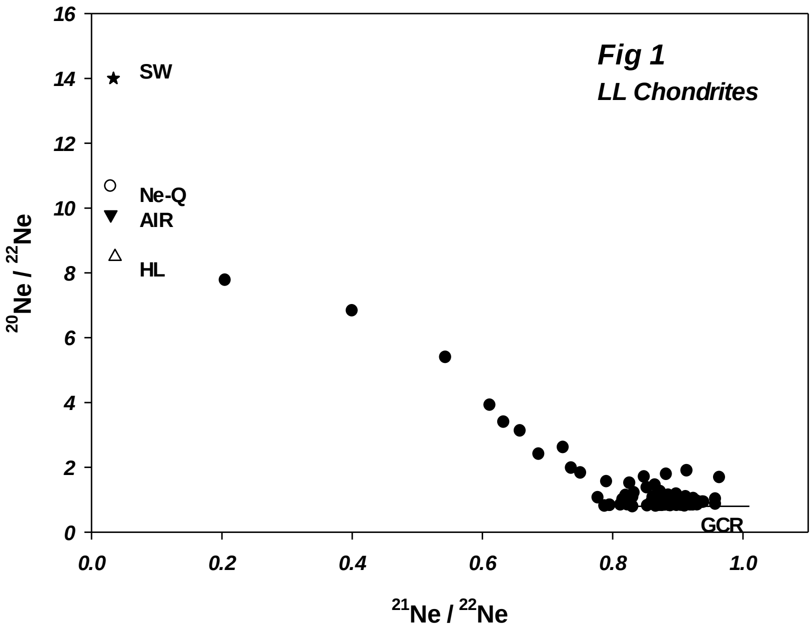
Meteorites are space rocks that comes from outer space to Earth. It gives us window to understand the Early solar system processes and formation. Almost ~86% of existing meteorites are chondrites while rest are achondrites. Ordinary chondrites are subdivided based on chemical compositions, as: group H chondrites (high iron, ~28%), L chondrites (low iron, ~22%) and LL Chondrites (low iron and low metallic iron) are collectively known as Ordinary Chondrites. [1]

Petrologic Grid:

Higher petrologic nature of LL chondrites shows the higher degree of the thermal metamorphism. This work has compilation of around 100 bulk LL chondrites neon data. Some of these meteorites had been analysed more than one time, where the average of these is used. We choose noble gases for study because of its properties like it is very low in abundance, highly volatile, inert or non-reactive, different reservoir has the distinct isotopic ratios for noble gases. [2,3]

Three Neon Isotopic Plot for LL chondrites:

Neon three isotopic plots for LL chondrites with different end member components are shown in Figure 1. The end-member components are: Solar wind (SW) [4], Ne-Q [5], Air [6], HL [7]



Regolith Modification:

Due to collision and gravitational perturbation between asteroid parent bodies leads ejection of meteoroid from its parent asteroid body. So these fragments of meteoroids are interacting continuously by exposure of Solar wind (SW, ~KeV range energy), Solar Cosmic Rays (SCR, ~MeV range energy) and Galactic Cosmic Rays (GCR, ~GeV range). From figure 1 we can infer that some of LL chondrites shows Ne-Q as trapped component but mostly LL chondrites fall near the GCR region due to its high penetration depth (1-2 meter range).

Results and Discussion:

In this work we calculated concentration of trapped ^{20}Ne of LL chondrites. The cosmogenic neon is subtracted from measured gas amount, adopting Q-phase neon characteristics (fig,1). The trapped ^{20}Ne in LL chondrites ranges from 0.064 10^{-8} cm^3 STP/g to 141.50 10^{-8} cm^3 STP/g. The average value of ^{20}Ne for LL chondrites is 5.81 x 10^{-8} cm^3 STP/g.

Concentration of trapped ^{20}Ne in individual petrographic grade is calculated for LL chondrites (Table 1).

Here we can also see that the average ^{20}Ne trapped concentration decreases as the petrographic nature of LL chondrites increases. The possible main reason is thought to be due to higher degree of thermal metamorphism from 3-6 petrographic grade. [8,9]

Table 1. ^{20}Ne trapped Concentration (in 10^{-8} cm^3 STP/g) of bulk LL subgroup chondrites.

Serial no.	LL Chondrites	Minima	Maxima	Average
1	LL (without Subgroup)	-	-	-
2	LL3 Subgroup	0.43	141.55	12.51
3	LL4 Subgroup	0.21	4.41	1.51
4	LL5 Subgroup	0.06	6.54	1.15
5	LL6 Subgroup	0.15	2.95	0.81
6	LL7 Subgroup	0.31	1.47	0.89

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Microdiamonds from ordinary chondrites and its cosmogenic significance

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Presence of nano to micro-diamonds have been reported from different types of meteorites like carbonaceous chondrites, ordinary chondrites, iron meteorites and ureilites ([1], [2]). The presence of microdiamonds (size ~ 1 – 3 μm) and different allotropic forms of carbon (C) are being reported from Quenggouk (H4), Bluff (L5) and Assam (L5) ordinary chondrites (Indian and foreign meteorites). This is to characterize the incidence of extra-terrestrial diamonds and diamond diversity in ordinary chondrites with an aim to focus on the origin of microdiamonds. Laser Raman Spectroscopy (LRS) aided by Scanning Electron Microscopy (SEM) and Cathodoluminescence (CL) study had been the most useful tool for identifying the different carbon phases along with diamond polytypes in ordinary chondrites. These ordinary chondrites in general contain 0.03 - 0.2 wt% carbon in the matrices and this amount decreases slightly with increasing petrologic types [3]. These ordinary chondrites (viz. Quenggouk, Bluff and Assam) of varying chemical and petrologic types (H4 and L5) with different shock grades (S3 – S6) display the presence of different diamond polytypes with Raman peak values ranging from 1309 cm^{-1} to 1357 cm^{-1}. Estimated equilibration temperatures calculated from partitioning of Ca and Mg-Ca in Cpx and Opx-Cpx mineral pair show 825-1220ºC ([4], [5]; calculation error limit in PTMAFIC software: ± 25-60ºC). The carbon (C) concentration in these diamond polytypes varies from 19 – 86 wt% as revealed by SEM – EDS study. Micro-diamonds within these shocked chondrites have bimodal occurrences which are mainly present adjacent to the shock/melt veins and rarely as inclusions within shocked olivine and pyroxene. The intergranular spaces of major modal minerals and matrix are also occupied by amorphous carbon and graphitic material along with diamond polytypes. These microdiamonds appear as bright yellow/whitish yellow/pink coloured spots under CL study, while olivine and orthopyroxene exhibits red or blue colour. Isotropic shock melt veins also contain microdiamonds. Different diamond polytypes have been identified from their characteristic Raman peaks at 1309 cm^{-1}, 1311 cm^{-1}, 1355 cm^{-1} and 1357 cm^{-1}, corresponding to diamond polytype of B-C phase. The Raman shift towards smaller wavenumber at 1315 cm^{-1} indicates the presence of lonsdaleite with more ordered carbon structure and hexagonal symmetry. The 1315 cm^{-1} peak of lonsdaleite – 2H diamond polytype was attributed to the LO (Longitudinal-Optical) mode of the diamond-like B–C phase transformed under high pressure – temperature conditions [2]. The presence of microdiamonds within shock veins indicates High Pressure High Temperature (HPHT) impact genesis at P – T of 45 GPa and 2230 ± 140 K [6]. Microdiamonds of different polytypes were observed in these ordinary chondrites with a wide range of Raman shifts from 1306 cm^{-1} to 1343 cm^{-1}. Classical microdiamond (3C – cubic structure) with Raman peak at 1332 cm^{-1}, is comparable to diamonds of terrestrial kimberlite origin [7]. The Full Width at Half Maximum (FWHM) parameter has also been assessed to semi-quantify the shock deformation in ordinary chondrites (mostly from olivine and orthopyroxene), and it ranges from 12 cm^{-1} to 32 cm^{-1}, implies the values at higher side indicate more disordered mineral structure. Diamond is an abundant phase in space and also exists in meteorites, inside the planets, interplanetary dust particles (IDPs), comet dusts and stars. Though there are many existing theories which explains the origin of extraterrestrial microdiamonds, the presence of different microdiamond polytypes in these ordinary chondrites either within shock melt veins/veinlets or as inclusions within olivine and pyroxene which may indicate its origin from (HPHT) impact processes. Moreover, these microdiamonds have been formed under varied shock stages (S3-S6) escalating shock pressures at ~ 30-50 GPa [8].

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Dark Matter - Matter That Can't Be Touched

Team Astrophysics

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Abstract

During the last century many observations have been made to peep into the DARK MATTER in the universe and many astonishing behaviours of Galaxy clusters have been found which do not fit to any theories formulated before. However, Optical Spectroscopic observation has been initially used to measure the rotational velocity of the Andromeda Galaxy as a function of distance found in contrast to the Law of Gravitation. Another observation of X-ray of luminous gas of an Elliptical Galaxy has been carried where bending of light emitted from a cluster's gravitational field was studied. Since the 1950s, the Big Bang cosmology scenario has held the leading position as the most successful model for the origin and evolution of the Universe. Due to the expansion of space, electromagnetic radiation emitted in the distant Universe is redshifted on its path towards us which can be used to determine the distances of astronomical objects.

The lingering radiation from the Big Bang that permeates the whole Universe is the CMB or cosmic microwave background, which can be utilised to 'travel back in time the farthest'. The cosmologists tried to find out nature and the content of the Dark Matter which was found to be 98.3% of the Low speed mass and only 1.67%. Moreover, most of the Dark Matter contribution came out from Non baryonic nature.

Different models have been proposed to see its nature and its time evolution viz Cold, Warm, Mixed Dark Matter Models, Self Interacting and Self Annihilating, Fuzzy and Modified Gravity models. Its constituent particles include few Baryonic and some Non-Baryonic particles. And finally detections were made, though no direct evidence are available but strong indirect evidence of its presence have been confirmed. This paper is an attempt to look into the aforesaid perspectives of Dark Matter and make predictions to connect the observed properties of galaxies.

Keywords: Dark Matter, Big Bang, Cosmic Microwave Background (CMB), Baryonic, Non-Baryonic, Galactic Collisions, Gravitational Lensing, Weakly Interacting Massive Particles (WIMPs).