Platinum Jubilee

Physical Research Laboratory
MetMeSS-2021

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

Programme

29 November, Monday

Session-1: Stardusts & Starbits!

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

Session Chair: Sandeep Sahijpal & Kinsuk Acharyya

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

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

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

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

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

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

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

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

Interplanetary Dust at Mars in Light of MAVEN Observations

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

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

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

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

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

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Minerals in the ISM are Made in an Instant

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

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

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

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

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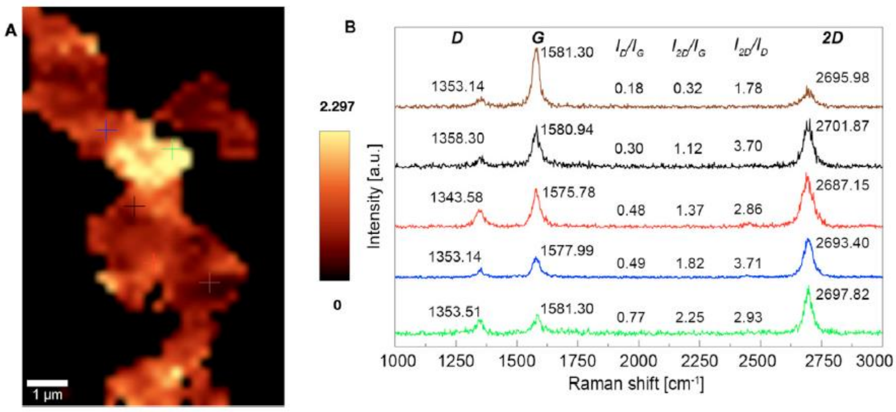
Contents of Abstract: Nanoscale graphene morphologies are reported in the Allende and QUE 94366 CV3-type carbonaceous chondrites via Confocal Raman Imaging Spectroscopy [1]. These morphologies are found embedded in the refractory calcium-aluminum-rich inclusion (CAI) rims in Allende and within a chondrule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



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

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Abstract:

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

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

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Interaction of Silicate grains with Galactic Cosmic Rays in Interstellar medium

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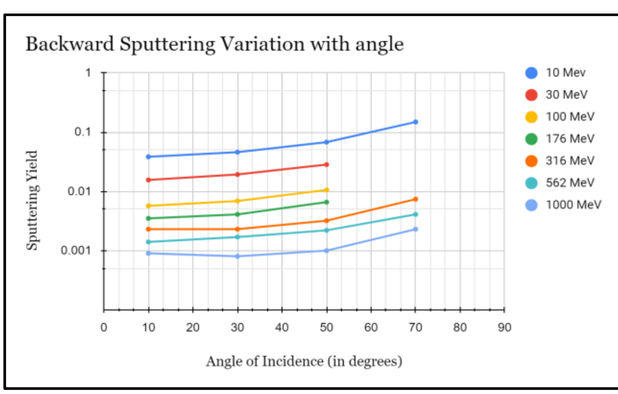
Abstract: Dust grains in the interstellar medium can play a vital role in our understanding of how interstellar material (ISM) is processed once they have been ejected out from stellar interiors. Studying the environment of their origins and their formation, destruction and re-accretion processes provide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



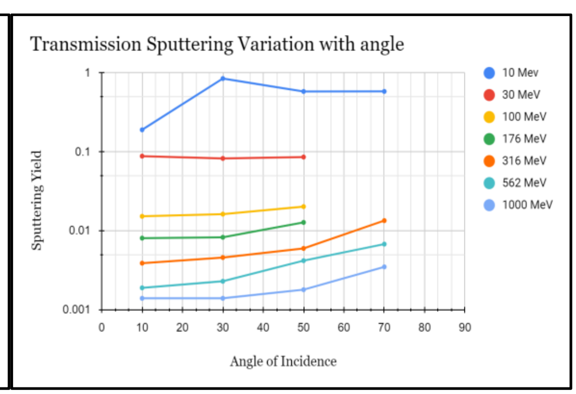


Figure 1 and 2 (left to right): Variation in Backward Sputtering Yield and transmission sputtering yield respectively.

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A possible explanation for the microstructures observed in meteorites

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Abstract:

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

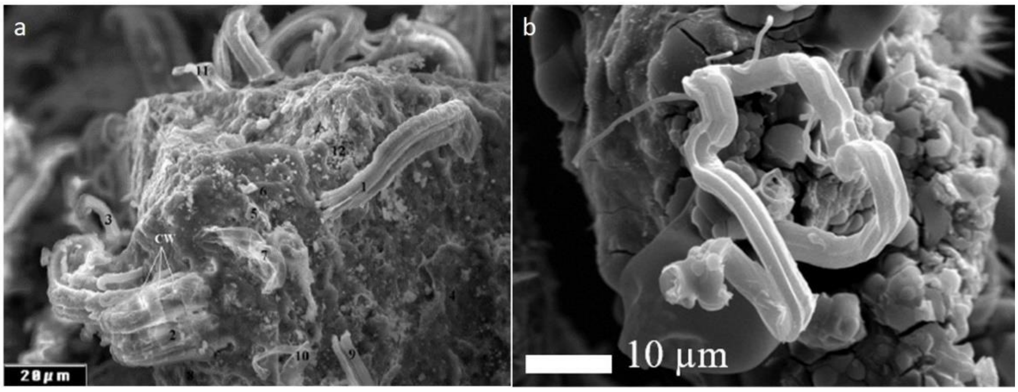

Figure 1: (a) Microstructures observed in Orgueil meteorite and (b) structures observed in shock processed amino acids.

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Microcontroller based Automated Freeze-Thaw Instrument

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

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

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