Report on the outcomes of a Short-Term Scientific Mission[1]

Action number: **CA21126**

Grantee name: **Nour HARIKA**

Details of the STSM

Title: **Synthesis and Characterisation of Porous Carbonaceous Dust Analogue Films for Astrochemical Surface Experiments.**

Description of the work carried out during the STSM

The experiments were performed at the Analytical Mineralogy Group, Friedrich Schiller University (FSU) Jena, with Dr. Alexey Potapov's team, using the Jena Dust Machine [1] — a setup equipped with a pulsed laser for target ablation, a skimmer directing the generated nanoparticles toward a cryogenically cooled substrate, a quartz crystal microbalance (QCM) for in-situ monitoring of dust layer thickness, and a Fourier transform infrared (FTIR) spectrometer for spectral characterisation.

The first part of the visit was dedicated to learning and actively participating in the production of porous dust analogue films via laser ablation. Amorphous carbonaceous films: both ^{12}C and ^{13}C; and magnesium silicate ($MgSiO_3$) nanoparticle films were synthesised. Depending on the target material, different carrier gases were introduced into the ablation chamber: helium was used for carbonaceous dust production, while oxygen was employed for silicate synthesis. Prior to each deposition run, laser alignment and power were carefully adjusted, and the deposited mass and nominal thickness were monitored in situ via the QCM. Occasionally, the skimmer became partially obstructed by deposited material; a cleaning procedure using a thin needle inserted through an access port was developed to minimize interruptions and preserve vacuum conditions.

The second part of the visit was dedicated to participation in experiments on diffusion-driven chemistry under astrophysically relevant conditions [2]. Layered "sandwich" samples were subsequently prepared by depositing nanoparticles and molecular ices onto substrates cooled to 10 K — one of the distinctive capabilities of the Jena Dust Machine. A typical configuration consisted of a bottom layer of $^{13}CO_2$, followed by an intermediate porous dust layer, and finally an upper layer of NH_3, ensuring complete spatial separation of the two molecular reactants by the dust matrix from the outset. After deposition, isothermal kinetics experiments leading to the CO_2+NH_3 reaction were performed.

Six ^{13}C carbonaceous samples of varying thickness were brought back to LIRA-CY Cergy-Paris University for follow-up diffusion and characterisation experiments carried out on FORMALISM. The use of ^{13}C isotopically labelled carbon is particularly important as it allows unambiguous discrimination between experimental signals and ^{12}C background contamination in subsequent infrared spectroscopic measurements. These samples will be used not only for surface characterisation but also for depth-

[1] This report is submitted by the grantee to the Action MC for approval and for claiming payment of the awarded grant. The Grant Awarding Coordinator coordinates the evaluation of this report on behalf of the Action MC and instructs the Grant Holder Manager to verify the grant documents compliance and proceed with the payment.

profile studies, enabling investigation of how molecular species penetrate and interact with the porous carbonaceous matrix at different depths.

Description of the STSM main achievements and planned follow-up activities

The STSM successfully delivered its primary objectives. Hands-on expertise in pulsed-laser ablation and porous dust analogue film synthesis was acquired, a capability not available at LIRA. The production of both carbonaceous (^{12}C and ^{13}C) and silicate ($MgSiO_3$) analogue films was mastered for the first time in collaboration with the FSU Jena team. These achievements directly expand the experimental capabilities of the LIRA group and establish a reproducible joint production protocol for future campaigns.

Preliminary characterisation of the ^{13}C samples at LIRA has already yielded significant results. A highly developed surface area was identified, originating primarily from the porous structure of the deposited films prior to any thermal processing. Thermal annealing was found to modify not only the morphology of the carbonaceous analogue but also its adsorption properties and its capacity to retain molecules at low temperatures. These findings suggest that thermal history plays a critical role in determining the chemical reactivity of carbonaceous dust grains in astrophysical environments, a result of direct relevance to the understanding of grain evolution in protostellar envelopes and protoplanetary disc midplanes. The acquired data on existing samples are currently under analysis and may provide evidence for additional reaction pathways and the formation of new molecular species. These results are intended for presentation at the ECLA conference in September 2026 and for a future publication.

The six ^{13}C samples brought back to LIRA will be used in a series of upcoming experiments on molecular diffusion on carbonaceous dust analogues, including adsorption, desorption, and depth-profile characterization, which also will help collect data for the previous result. These experiments form a core part of the ongoing PhD research on molecule–grain interactions in astrophysical environments, with a particular focus on how grain porosity and morphology govern molecular mobility and surface reactivity.

After this successful mission, a second research stay at FSU Jena is being planned for September 2026 to continue and extend these studies. The planned activities include deeper investigation of diffusion processes within layered sandwich samples, with particular focus on formaldehyde (H_2CO) diffusion and the physico-chemical mechanisms governing its formation via dust-mediated pathways. Training in Transmission Electron Microscopy (TEM) is also anticipated during this second visit, which would enable direct imaging of the porous sample morphology and structural modifications of the actual sample in FORMALISM induced by thermal processing and molecular exposure.

In parallel, participation in the analysis of near- and mid-infrared spectra obtained with the James Webb Space Telescope (JWST) is planned, in collaboration with Dr. Alexey Potapov's team [3]. By comparing laboratory spectra of dust analogues with astronomical observations, this work aims to constrain the molecular composition of protoplanetary discs and improve understanding of the chemistry occurring in star- and planet-forming regions.

Finally, these joint studies are expected to contribute to future collaborative publications within the NanoSpace network.

[1] Potapov, A., et al. 2019, ApJ, 880,12
[2] Potapov, A., & McCoustra, M. R. S. 2021, Int. Rev. Phys. Chem., 40, 299
[3] Ptapov, A., Kalambkar, P., et al., A&A, 2026, DOI: 10.1051/0004-6361/202659525