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

Action number: CA21126

Grantee name: Alexey Potapov

Details of the STSM

Title: Formation of molecular hydrogen on the surface of carbonaceous analogues of cosmic dust grains

Start and end date: 29/06/2025 to 12/07/2025

Description of the work carried out during the STSM

Description of the activities carried out during the STSM. Any deviations from the initial working plan shall also be described in this section.

(max. 500 words)

We followed the initial working plan described in the grant application. Using the FORMOLISM setup (Mohamed Ibrahim et al. 2022) comprising an ultrahigh vacuum (UHV) chamber, a Fourier transform infrared (FTIR) spectrometer, a closed-cycle He cryostat, a gas inlet system, H and D-atom beamlines, and a quadrupole mass spectrometer (QMS):

- We performed temperature programmed desorption experiments on H_2 and CH_4 to estimate the surface area of amorphous carbon grains produced in the Jena laboratory.
- We produced H/D atoms by dissociation of H_2/D_2 in microwave discharge and measured the H_2 and D_2 dissociation efficiencies.
- We measured the formation of D_2 and H_2 (D + D and H + H recombination) on the surface of the amorphous carbon grains. In our experiments, we followed the experimental protocol described in (Grieco et al. 2023). For the D_2/H_2 formation experiments, the beamline containing D_2/H_2 was aimed towards the surface of the carbon sample. The QMS was placed in front of the surface and mostly measured what is coming off the surface (plus some unavoidable background contribution from the the chamber). D + D and H + H recombination were measured in the temperature range from 10 to 350 K.
- Directly from the measurements, we calculated recombination efficiencies of H_2 and D_2 and compared our values with the values previously obtained for various surfaces.

[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 GH for payment of the Grant.

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

Description and assessment of whether the STSM achieved its planned goals and expected outcomes, including specific contribution to Action objective and deliverables, or publications resulting from the STSM. Agreed plans for future follow-up collaborations shall also be described in this section.

(max. 500 words)

Various studies of the H_2 formation on silicate and carbon surfaces by H atom recombination have illustrated that the reaction efficiency is highlight dependent on the surface properties (Wakelam et al. 2017). An important result was recently obtained (Grieco, et al. 2023). In contradiction to both laboratory experiments and theoretical models suggesting that H_2 cannot form on grains at temperatures above 100 K, new laboratory measurements provided evidence for the highly efficient formation of H_2 at temperatures up to 250 K on the surface of coronene ($C_{24}H_{12}$), a polycyclic aromatic hydrocarbon mimicking carbonaceous cosmic dust.

In our study, we obtained recombination efficiencies of molecular hydrogen on amorphous carbon grains, reliable analogues of carbonaceous cosmic dust, in the temperature range of 10 – 350 K, broader than any temperature range considered before in laboratory experiments. We observed efficient formation of molecular hydrogen in the whole temperature range. This result:

- reinforces the previous result for coronene that, contrary to what was previously thought, hydrogen atoms chemisorb easily on carbonaceous surfaces,
- shows efficient high-temperature formation of H_2 on the most reliable analogues of the carbonaceous cosmic dust – porous amorphous carbon grains,
- demonstrates a very important role of cosmic nanocarbons in surface processes,
- opens a door to future research on the diffusion and formation of key astrophysical species on the surface of cosmic dust grain analogues.

Our results will be presented at international conferences. A publication in a highly ranked journal is expected. Our next step will be to study the formation of molecular hydrogen on amorphous carbon grains irradiated by energetic ions (analogues of cosmic rays). Interaction with ions can induce chemical activation of the grain surfaces, thus, improving the ability of the grains to adsorb and store volatiles and to catalyse reactions between them.

References

Grieco, F., Theule, P., De Looze, I., & Dulieu, F., Enhanced star formation through the high-temperature formation of H2 on carbonaceous dust grains. 2023, Nat Astron, 7, 541, 10.1038/s41550-023-01902-4

Mohamed Ibrahim, A. S., Morisset, S., Baouche, S., & Dulieu, F., Desorption of physisorbed molecular oxygen from coronene films and graphite surfaces. 2022, J Chem Phys, 156, 194307, 10.1063/5.0087870

Wakelam, V., et al., H-2 formation on interstellar dust grains: The viewpoints of theory, experiments, models and observations. 2017, Molecular Astrophysics, 9, 1, 10.1016/j.molap.2017.11.001