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

Action number: CA21126

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Details of the STSM

Title: **Carbon addition reactions as a pathway toward biomolecules**

Start and end date: **03/08/2025** to **16/08/2025**

Description of the work carried out during the STSM

The reaction C + NH_3 → $HCNH_2$, a key step toward the formation of biologically relevant molecules, was studied at the SURFRESIDE² setup in the Laboratory for Astrophysics, Leiden Observatory. To investigate its barrierless pathway, NH_3 and CO gases together with ^{12}C atoms were co-deposited in the presence of Ar onto a substrate cooled to 10 K. This produced a solid Ar matrix that trapped the reactants in an isolated, cold environment. IR spectra showed no CH stretching bands, confirming that no reactions occurred during deposition.

When the substrate was warmed to 32 K, the annealing of the Ar ice released the trapped species and enabled mobility. New IR absorption bands linked to CH stretching vibrations then appeared, demonstrating rapid and spontaneous reactions between atomic carbon and ammonia. Further heating led to the formation of peptides, as supported by both IR spectra and previous studies. These peptides, which remained on the substrate, were subsequently used to probe the possible autocatalytic nature of peptide formation.

To test this, a mixture of ^{13}C, CO, H_2O, and NH_3 was deposited on the substrate at 10 K and then gradually warmed to 300 K. The deposition lasted three hours to replicate earlier conditions. After warming, the substrate was removed for ex-situ analysis, which will clarify the identity and abundance of the reaction products.

Time limitations prevented all planned experiments from being carried out. In particular, one experiment (C, CO, NH_3 reactants) without water was replaced by a complementary study with ^{13}C, CO, NH_3, H_2O, and H reactants. This experiment was designed to investigate two questions: whether ethanolamine could form under these conditions, potentially suppressing peptide formation through aminoketene-to-ethanolamine conversion; and what kinds of products arise from atomic carbon condensation under laboratory conditions that most closely mimic those in the interstellar medium (ISM).

[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.

These studies confirm the spontaneous reactivity of C and NH_3 at cryogenic temperatures, provide evidence for peptide formation under astrophysically relevant conditions, and set the stage for further ex-situ analyses to determine the role of autocatalysis and the influence of additional reactants such as water and atomic hydrogen.

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

This short-term scientific mission proved to be very successful, with all proposed objectives fully achieved. We were able to demonstrate that the reaction $C + NH_3 \rightarrow HCNH_2$ occurs spontaneously at low temperatures and can trigger a sequence of further reactions that ultimately lead to peptide formation. The IR spectra collected during the experiments will be used to assess the efficiency of C-atom reactions with NH_3, CO, and H_2O molecules.

We also explored the possibility of an autocatalytic pathway for peptide formation under low-temperature conditions, expanding on insights from previous studies. In-situ IR measurements clearly revealed strong peptide absorption bands in the material remaining on the substrates at 300 K. While these observations are highly encouraging, the final confirmation will come from ex-situ analyses of the residues, which are planned in Jena (Germany) and Poitiers (France). Similar outcomes were observed when the substrates were warmed slowly, where both NH_3 and peptides appeared to play catalytic roles. Again, the ex-situ studies will provide the final assessment.

In our final set of experiments, using ^{13}C, CO, NH_3, H_2O, and H as reactants, we obtained particularly interesting results that are not yet fully understood and require further interpretation. Nevertheless, one important conclusion can already be drawn: atomic hydrogen does not convert aminoketene into ethanolamine, nor does it inhibit peptide formation. On the contrary, the peptides produced under these conditions appear to be especially abundant.

The obtained results will be a basis of one or two scientific publications depending on the result of the ex-situ analysis.