Research Networking Programmes

Short Visit Grant ☐ or Exchange Visit Grant ☒

(please tick the relevant box)

Scientific Report

Scientific report (one single document in WORD or PDF file) should be submitted online within one month of the event. It should not exceed eight A4 pages.

Proposal Title: Laboratory investigation of streamers under upper atmosphere conditions: development of the spectroscopic method for analysis of real transient luminous events

Application Reference N°: 4219

1) Purpose of the visit

The purpose of the visit was to deepen the knowledge on the transient luminous events (TLEs) that takes place in the upper atmosphere by studying scaled streamer discharges in the laboratory. By placing scaled TLE phenomenon (generating streamer discharges in air at lower pressures and temperatures in barrier discharge arrangement) into the controlled conditions of a well equipped plasma-diagnostic laboratory we planned to get an access to the basic plasma parameters (electric field, rotational and vibrational temperatures or vibrational distribution functions, i.e. VDF) as well as to the spectral signatures from the ultraviolet (UV) to the near infrared (NIR) parts of spectrum of these events. Especially we wanted to have a complete time and space resolved overview of the spectral output of laboratory TLE-analogs. Furthermore, we planned to improve the spectroscopic methods and approaches towards the estimation of these parameters also in real TLEs which is a much more complicated task due to the short duration, accidental nature of real TLEs and low signal-to-noise ratio. Special focus was given on the high-resolved (in time and space)

estimation of the electric field evolution in streamers under TLE conditions.

2) Description of the work carried out during the visit

The work on the above planned topics was divided into the following measurement campaigns performed during the stay at IPP:

- firstly we have undertaken a large scanning of time-resolved streamer spectra for several low pressures (pressures between 0.16 to 9 torr, approx. 60 to 30 km altitude, respectively) at 300 K temperature - spectral intervals were chosen to cover the relevant radiative electronic transitions (to cover the VDFs of excited states) and more importantly to have an overview and understanding of the complete streamer emission (from UV to NIR interval) and its temporal development at given pressures. Additionally, we tried adding trace admixtures of Helium in order to improve our diagnostics by atomic line and Stark spectroscopy - however due to the very weak signal of helium lines comparing to N2 emission this attempt was not successful.

- secondly, we have undertaken first experiments in a cooled system down to reach temperatures below minus 50 degrees of Celsius to recognise the temperature effects on the spectra - i.e. by fitting the rotational temperature. In this part we faced technical problems with our cooling apparatus, which were finally solved, however the newly manufactured part solving this issue was not prepared until the end of the visit.

- thirdly, we focused in our experiments on the recognition of the Meinel spectral system of ionised nitrogen - in these measurements, according to our previous expertise on barrier discharges, we resolved the active part of the discharge, the streamer part, and the post discharge phase where no significant excitation is present, and compared these spectra. Meinel spectral system is expected to appear during the active streamer part of spectra and much suppresed in the second one. In this case, in order to recognize and identify the Meinel emission, we undertook also experiments at higher pressures (up to 15 torr) and in pure nitrogen as well.

- as the next step we focused on the estimation of the streamer velocities at given pressures. This was done by detecting the emission of propagating streamer time-resolved in more axial positions using fast PMT. Here, a very localised emission had to be detected which was managed by long thin capillary connected prior the entrance of PMT.

- finally, a systematic measurement campaign was devoted to the radially-, axially- and time-resolved detection of discharge emission for determination of the electric field in streamers under TLE pressures. This was done for pressures corresponding to the above mentioned altitudes. We scanned the streamer discharge emission

using the capillary-PMT system radially and axially. This was done for selected spectral wavelengths of the second positive and first negative systems of molecular nitrogen using selected band-pass spectral filters. Precise spectral and transmission calibration of all used optical components was done additionally to obtain a relevant electric field values in the future after careful data processing.

3) Description of the main results obtained

From the undertaken experiments the following main results were obtained and are in evaluation:

- a novel approach to determine the electric field from nitrogen spectral bands using spectral filters based on modelling of the streamer emission spectra was developed
- spatially and temporally resolved development of the discharge emission was obtained for estimation of the electric field in streamers under different pressures (corresponding to above mentioned interval of altitudes)
- time resolved molecular and atomic spectra (interval UV to NIR) registered with medium spectral resolution (better than 1nm) were obtained in streamer spectra under given conditions
- important experimental information required to evaluate contribution of the N2+ Meinel emission to the NIR spectra produced under TLE-like conditions were acquired
- having the temporal spectral scan of the discharge development from UV to NIR interval a complete VDF of N2(C3Pi) state of molecular nitrogen and partial VDF (1-12) of N2(B3Pi) for first positive system of molecular nitrogen will be more precisely estimated for the development in real TLEs
- also electrical data were obtained for power and current evolution determination within TLE-analogs - these development were correlated in time with spectrally resolved measurements to have simultaneous record of the streamer discharge emission and its electrical characteristics

4) Future collaboration with host institution (if applicable)

The team around Dr. Milan Šimek at the host institution IPP Prague (CZ) continues working on the topic in the frame of project granted by Academy of Science of Czech Republic: M100431201 „Laboratory discharges for simulating and investigating Transient Luminous Events“. Further new scientific questions and ideas arised during the time of this Exchange Grant and will be followed in the future. Especially, the combination of the LIF, PMT spectroscopic measurements from Prague with additional analysis made by Cross-correlation Spectroscopy in collaboration with INP Greifswald (DE) is planned. The study of the streamer development at different pressures

and temperatures remains further in the focus for the second half of 2014 and first half of 2015.

5) Projected publications / articles resulting or to result from the grant *(ESF must be acknowledged in publications resulting from the grantee's work in relation with the grant)*

Recently, based on the first results we submitted contributions with the acknowledgment to ESF grant to the following conferences:

- T. Hoder, V. Prukner, F. J. Gordillo-Vázquez, M. Šimek, Laboratory streamers under TLE conditions: spectroscopic analysis with emphasis on the determination of the electric field strength - TEA-IS Summer school, 2nd, Collioure, France, June 23 - 27, 2014.
- M. Šimek, T. Hoder, F.C. Parra-Rojas, V. Prukner and F.J. Gordillo-Vázquez, Spectroscopic investigations of laboratory streamer discharges generated under TLE-like conditions - ESCAMPIG XXII, Greifswald, Germany, July 15-19, 2014.
- T. Hoder, V. Prukner, M. Šimek, Radially resolved spectroscopic analysis of positive streamers under Transient Luminous Event conditions - HAKONE XIV, Greifswald, Germany, September 21 - 26, 2014.

Furthermore, at this moment several publications are planned according to the main obtained results as written in point 3. of this report:

- topic 01: On the two-dimensional electric field development of the streamers under TLE-like conditions
- topic 02: On the development of the molecular and atomic emissions within TLEs
- topic 03: On the detection of N2+ Meinel system under TLE-like conditions
- topic 04: On the vibrational kinetics in streamers under TLE-like conditions

6) Other comments (if any)

Note that a huge experimental data amount was obtained for several pressures and radially and axially resolved scans were permorfed for several spectral filters. Each scan was done with resolution of 1 mm on several cm large streamer discharge. The complete data processing of all data sets will include spectral calibration and also, in the case of radial scans, inverse Abel transformation to get radial dependences and therefore the completion of this process will take several months of intense work. Thus, the results will be published with certain delay, planned to the end of 2014, first half of 2015.