Training on theoretical phase curve modeling in support of possible future time applications for Europlanet network telescopes.

As we stated in our proposal for this grant, one of the most important characteristics to examine in the field of asteroid studies, are the phase curves (variation of the asteroid's brightness as it moves along its orbit around the Sun). For a high-quality fit of these models, it is necessary to have a good sampling of the phase angle space, especially at angles close to opposition (~0°). Combining data from different telescopes (ground-based and space-based) becomes crucial here. One issue we might encounter in this procedure is that the same asteroid observed at different epochs may present different rotational phases. This is because these objects are usually not perfectly spherical, do not have a uniform albedo over their entire surface, and as they rotate around the sun, their aspect angle (the angle between the axis of rotation of the object and the observer's view) changes. Therefore, to obtain accurate phase curves by combining data from different epochs/observatories, it is strictly necessary to consider all these effects. This requires complex mathematical models to correct for these variations.

During this visit, we began a project consisting of deriving accurate phase curves by combining data obtained from ground-based observations obtained with European telescopes and the ATLAS database. For this purpose, the applicant learnt to use a software written by Muinonen et al., (2020) and refined by Martikanien et al., (2021) and Muinonen et al., (2022). This tool can account for brightness changes due to shape, rotation, and aspect changes by moving to a reference phase function. The use of reference phase function allow us to compare the behavior of several asteroids in a consistent way. Previously, Ms. Milagros Colazo has worked with phase curve parameter determination for large catalogs of observations. For this reason, she has used a simplified approach for this problem, which allows to find a first estimate of the parameters. However, as mentioned, the goal of the current project is to derive phase curves of high accuracy for a small number of objects. Therefore, the first task of the participant was to study the theoretical background on light curve inversion, light curve inversion with Bayesian technique and reference phase curves. After a careful reading of important papers focused on these topics, it was possible to proceed to the use of the software. This was the first time Ms. Colazo used this program, which is why one day of the visit was dedicated to hands-on practice and testing.

Once the participant succeeded in the correct handling of the software, the calculation of the phase curves for 77 asteroids was started. The first tests were performed on personal computers. Soon, we noticed that the calculations for each asteroid would take at least 2 days. Therefore, we decided that the software runs would be performed on a supercomputer. For this purpose we turned to the “Poznań Supercomputing and Networking Center”. As this was the first time the group worked with this tool, we had to learn quickly how to use it. Fortunately, we managed to start the calculations on the cluster and obtained the first results for asteroid 281.

Finally, while the calculations for the following asteroids were submitted, the applicant started writing the paper that we plan to publish in the next months.

In addition, Ms. Colazo gave a talk on her doctoral work at the Institute. This event paved the way for future collaborations between the institutions involved.

The main goal of the visit was to provide training on theoretical phase curve modeling in support of possible future time applications for Europlanet network telescopes. Fortunately, this objective was successfully achieved. The visit was an idyllic opportunity, combining the applicant's knowledge of large database management with the knowledge of theoretical modeling of phase curves provided by the Poznan working group. In spite of the short stay, we were able to lay the foundations of the project and start it. On her side, Ms. Colazo was able to learn how to use various tools, learn

theoretical concepts of great importance for her scientific career and work efficiently in a new working environment. It is important to note that this opportunity has been the kick-off for a collaboration that we hope will bear fruit in several papers that will provide important advances in the study of phase curves and the combination of dense and sparse data catalogs.