Europlanet Expert Exchange Programme Report

Developing synergies between exoplanet research and Solar-System analyses
(Óscar Carrión-González – 18th to 23rd, December 2022)

Motivation of the visit
Before the end of this decade, the first direct-imaging observations of exoplanets in reflected starlight will become available with the launch of the Nancy Grace Roman Space Telescope. A number of additional direct-imaging instruments observing in reflected starlight both on the ground and in space will become available in the next decades. This will enable the detection and atmospheric characterization of a population of planets significantly different from that analysed to date. In particular, this technique will be sensitive to cold and temperate exoplanets with orbital periods similar or longer than that of the Earth. Part of the preparatory work for these missions is to determine the scientific output of direct-imaging measurements in reflected starlight.

With this visit, we aimed at combining the expertise of the visitor on direct-imaging observations of exoplanets with that of the host institution (the Planetary Sciences Group of the University of the Basque Country) on the atmospheric characterization of Solar-System planets. Solar-System observations and atmospheric retrievals using Solar-System data will be informative for similar analyses focused on cold and temperate exoplanets.

Scientific output of the visit
Our broad goal in this visit was to bridge our current knowledge on remote-sensing of Solar-System planets and the preparatory science for exoplanet-imaging missions. We focused on the analysis of Neptune's atmospheric perturbations as an analogue of the variability that might be present in cold exoplanets imaged in reflected starlight.

During this five-day visit, we selected a number of imaging observations of Neptune taken with the Hubble Space Telescope's Wide Field Camera 3 (WFC3) in the visible and near-IR range, similar to that in which future exoplanet-imaging missions will operate.

We processed publicly available models of Neptune's atmosphere in this similar wavelength range. We used the supplementary data published by Irwin et al. 2022 (JGRE, 127, 6, 07189) for their analysis of the unperturbed atmosphere of Neptune (hereon referred to as nominal atmosphere). We will use this information as the starting point from which we will study the atmospheric variations when bright-spot perturbations are present in the planet.

The host Santiago Pérez-Hoyos and the host group have a vast expertise on the use of the NEMESIS radiative-transfer and retrieval code (Irwin et al. 2008, JQSRT, 109, 6, 1136). In this visit the host taught the visitor on how to initialise this code to produce synthetic spectra of the nominal atmosphere of Neptune with the models by Irwin et al. 2022. This included a discussion on the relevant planetary parameters and input files needed for the modelisation.

The visitor had developed during his PhD thesis an MCMC retrieval code for future direct-imaging observations of exoplanets in reflected starlight. During the visit, a strategy to couple the NEMESIS code with an MCMC retrieval methodology was discussed. This will benefit from the efficiency of MCMC methods to sample multi-dimensional spaces of parameters and the accuracy of NEMESIS computations for complex light scattering processes which take place in planetary atmospheres.

The visitor also gave a seminar to the host group on the topic of direct-imaging observations of cold and temperate exoplanets in order to explain the fundamentals of the technique, and foster discussion on possible Solar-System synergies.

The work developed during the visit is being continued and is expected to result in a scientific publication in a peer-reviewed journal. This ongoing work includes:

- Carrying out atmospheric retrievals of Hubble images of Neptune in which bright-spot perturbations are present. For this, the coupled code of NEMESIS radiative-transfer calculator with an MCMC sampler is applied.
- This methodology produces synthetic spectra of Neptune (with NEMESIS) that need to be convolved with the transmittance of Hubble's WFC3 filters. These synthetic Hubble-like observations will be compared with the actual measurements using the MCMC sampler. This will yield a range of atmospheric configurations (particularly, the abundance and vertical distribution of cloud aerosols) consistent with the measurements.
- With this, we will be able to reproduce the variability in reflected-starlight observations when a bright-spot storm appears on the atmosphere. We will also be able to determine which filters are more sensitive to this detection.
- If this is converted to disk-integrated observations, it will be possible to establish similarities with cold long-period exoplanets observed in reflected starlight. Future direct-imaging telescopes will not achieve spatial resolution and thus exoplanets will appear as a single pixel.
- Furthermore, the prospects to detect atmospheric perturbations with disk-integrated observations will be useful for the monitoring of Neptune itself. Spatially resolved images of Neptune require large ground-based telescopes or space-borne facilities, all of which are very demanded and thus difficult to access. With this study we expect to determine the capability of smaller telescopes and amateur facilities to monitor the atmospheric activity of Neptune with disk-integrated measurements in the optical and near-IR