MW-Gaia STSM

Synergies between astrometric, radial velocity and future direct imaging measurements of exoplanets

Óscar Carrión González, PhD student at the Technische Universität Berlin spent 13 days (17-29/11/2019) at the Instituto de Astrofísica e Ciências do Espaço (IA), Universidade do Porto, CAUP thanks to a GP1 STSM grant to collaborate with Dr. Nuno C. Santos.

The goal of this Short-Term Scientific Mission (STSM) is to get to collaborate with European groups working on RV and astrometry, in order to build a catalogue of exoplanets observable with future direct imaging missions. Within the proposed 2-week STSM to IA in Porto (Portugal), Óscar Carrion attended the MWGaia WG3 Workshop “Exoplanets in the era of Gaia” (18-20 November, 2019). There, he learned about synergies between Gaia data and other exoplanet-focused missions, and to get familiar to the use of Gaia databases and data analysis techniques. Afterwards, the stay at IA is dedicated to know more about their expertise on radial velocity measurements (e.g. Santos et al. 2016) and stellar physics (e.g. Adibekyan et al. 2018). This would be a great counterpart to the knowledge that the group at TU Berlin and DLR Berlin has on transit observations (e.g. Rauer et al. 2014) and phase curves of exoplanets (e.g. García Muñoz & Cabrera, 2018).

The work during this STSM was divided as follows:

- WP-1: 18-20 November, 2019: Attendance to MW-Gaia WG3 Workshop “Exoplanets in the era of Gaia” (IA, Porto, Portugal). Óscar Carrion learned about how Gaia give a big picture on exoplanet populations, detecting hundreds to thousands of long-orbiting exoplanets. He also was able to discuss with some of the speakers the chances to detect transits of exoplanets in GAIA data.
- WP-2: 21-22 November, 2019: Accessing and handling RV exoplanet databases. (IA, Porto, Portugal). Ó. Carrión got familiar with exoplanet databases and developed code to download the data and process it. The most interesting properties of confirmed exoplanets were selected for further study.
- WP-3: 25-27 November, 2019: Cross-check with direct-imaging requirements. (IA, Porto, Portugal). The observability conditions for a coronagraphic direct-imaging mission like LUVOIR or WFIRST were established. The work focused on the following limiting factors:
    - Instrument’s Inner Working Angle (IWA)
    - Instrument’s Outer Working Angle (OWA)
    - Instrument’s minimum contrast (Cmin)

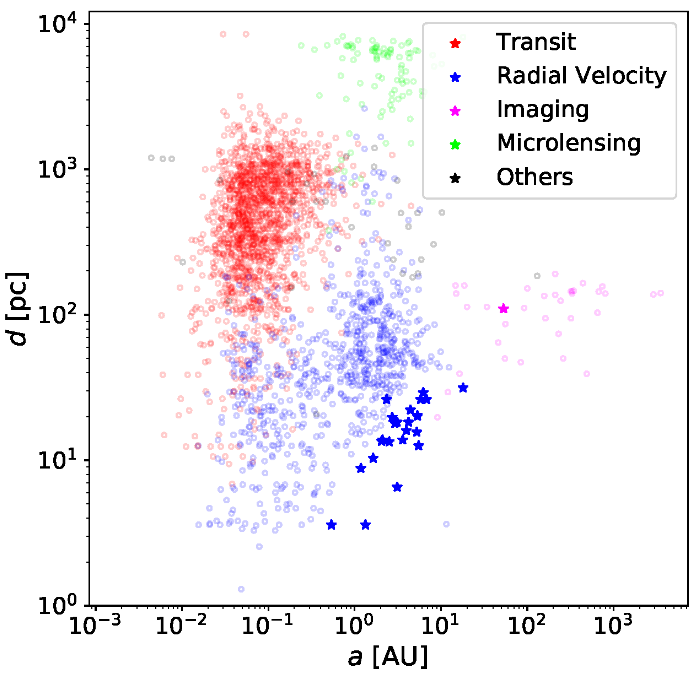
  An exoplanet will therefore be detectable if it is orbiting at a planet-to-star angular separation (θ) such that it falls within the operating range between the IWA and the OWA. The albedo of the planet will define how many starlight photons are reflected towards the observer, yielding a certain planet/star contrast, C. We could start analysing which of the several limiting factors will play a bigger role.
- ✓ WP-4: 28-29 November, 2019: Target selection and future work outline. (IA, Porto, Portugal). Selection of interesting targets for in-depth study. Study of which

statistical analysis should be applied on the database and which properties to further study over the whole sample of exoplanets (e.g., equilibrium temperature, metallicity of the host star...).

Main achievements

Showed that, since transit detection is a very fruitful method to discover exoplanets, there is an observational bias towards hot, short-period planets. These exoplanets, with greater probability to transit due to the geometry of their orbit, will be too close to their host star and will not be observed by coronagraphs like those on board of WFIRST or LUVOIR.

The Inner Working Angle, therefore, was proved to be a very limiting factor for a direct imaging mission, discarding most of the currently-known confirmed exoplanets. Only planets with a maximum angular separation along the orbit (θmax) bigger than the IWA limit will be observable. Indeed, we computed that this factor alone would leave as observable only 3.2% of the confirmed population of exoplanets for a mission like WFIRST. A mission with improved specifications, as LUVOIR, could detect up to 7% of the known exoplanets if considering only the IWA limitation.



Semi-transparent dots: confirmed exoplanets for which we know the distance from Earth d and can derive the semi-major axis a. Solid stars: confirmed exoplanetsthat we find Roman-accessible in the optimistic CGI configuration, with Paccess > 25% and orbiting stars brighter than V=7 mag. Colour code indicates the corresponding discovery technique (that by which the planet was first identified), as detailed in the legend. "Others" refers to all other possible discovery techniques considered in the NASA Exoplanet Archive. HD 100546 b appears as the only Romana ccessible discovered in Imaging, although its existence is marked as controversial in the NASA Archive.

The following paper was published as a direct result:

- ✓ "Catalogue of exoplanets accessible in reflected starlight to the Nancy Grace Roman Space Telescope. A population study and prospects for phase-curve measurements" Ó.Carrión-González, A.García Muñoz, J.Cabrera, S.Csizmadia, N.C. Santos, H. Rauer https://arxiv.org/abs/2104.04296 A&A 651, A7 (2021)

The method developed in that paper has been later applied to compute the detectability of certain exoplanets in subsequent publications not directly linked to the STSM:

- ✓ "Doppler wind measurements in Neptune's stratosphere with ALMA" Ó. Carrión-González et al. https://arxiv.org/abs/2305.06787 A&A 674, L3 (2023)

- ✓ “Large Interferometer For Exoplanets (LIFE). X. Detectability of currently known exoplanets and synergies with future IR/O/UV reflected-starlight imaging missions” Ó. Carrión-González et al. https://arxiv.org/abs/2308.09646 A&A accepted (2023)

After the STSM the collaboration with the host continues on the topic initiated there. they developed a statistical methodology to compute the detectability of exoplanets with direct-imaging facilities. They analysed how multi-technique measurements (radial velocity, astrometry, transits) will help in refining the orbital characterization of known exoplanets and thus the detectability prospects in direct imaging. This new methodology was presented in the already mention scientific paper, where they applied it to the Coronagraph Instrument of the Nancy Grace Roman Space Telescope (to be launched in 2026 or 2027). It shows how precise astrometric measurements are a key to accurately determine which exoplanets will be observable in direct imaging and to prioritize the targets. After this, the collaboration with the host in other works not directly linked to the STSM is ongoing.