Statement of Research Interests and Experience

Pierrot Lamontagne

Radial Velocity Analysis

During my M.Sc. at Université de Montréal under Prof. David Lafrenière, I focused on detecting and characterizing exoplanets around M-dwarf stars using radial velocity (RV) data from state-of-the-art echelle spectrographs such as NIRPS (infrared) and HARPS (optical). Both these spectrographs demonstrate RV precision at the $1\,m/s$ level.

Many methods exist to reduce high-resolution spectra into radial velocity measurements. Historically, the most used methods are CCF and template matching, but these algorithms often suffer from outliers. A new reduction method has been developed by Étienne Artigau, a member of my research institute at Université de Montréal: The Line-by-line method [1]. It is outlier-resistant since it performs summations on small spectral domains (”lines”). For example, applying LBL to ESPRESSO data of LHS 1140 improved the semi-amplitudes estimates of the signals from LHS 1140 b and c by 50% and 70%, respectively, compared to previous estimates using CCF [2]. During my master, I have used LBL extensively to reduce the spectra of my targets and I have participated in testing and troubleshooting its algorithm. I believe this expertise would be immensely valuable for the `THIRSTEE` team.

At this new level of RV precision, stellar activity becomes the main source of noise in the data. It produces quasi-periodic signals that can mimic planetary signals and so it must be taken into account when analysing RV measurements. A big part of my master’s project involves finding ways of modeling stellar activity on complex datasets involving simultaneous infrared and optical measurements of the same target, since NIRPS and HARPS usually observe at the same time. After trying various methods on different targets, I finally focused on the state-of-the-art method of multi-dimensional Gaussian Processes which originates from the principles described in [3] and [4] which states that stellar activity signals can be modeled jointly across multiple time series (such as radial velocities and activity indicators) using a single underlying Gaussian Process framework. I learned to use the `S+LEAF` package [5] directly from its developer Jean-Baptiste Delisle at the University of Geneva through our remote collaboration in the NIRPS consortium. I became the first of the Trottier Institute for Research on Exoplanets to be able to carry out multi-dimensional analysis on RV measurements. This gave me the opportunity to help some of my colleagues in their respective research by bringing this new method to the table. I would also be bringing this valuable expertise to the `THIRSTEE` team.

My paper on GJ 3090

At this stage of my master’s program, I am nearing completion of a first author paper on the GJ 3090 system, which shares key similarities with the types of planets targeted by the THIRSTEE project. GJ 3090 b is a mini-Neptune orbiting an M2 dwarf consistent with a volatile-rich composition [6]. These properties make it an excellent analog for investigating the formation and structure of sub-Neptunes, a central focus of THIRSTEE. My analysis makes an update on the mass constraints of GJ 3090 b and uncovers a new planetary candidate in the system.

To extract these planetary signals, I applied multi-dimensional Gaussian Process analysis to the dataset, modeling stellar activity across multiple indicators and disentangling it from planetary signals. I will also include the results of an interior structure model analysis of GJ 3090 b conducted by collaborators, which will provide insights into its potential core composition and atmospheric properties. Similarly, a stellar abundance analysis on NIRPS spectra by a PhD student in my team is underway, which will contextualize the planet's formation environment by linking the host star's metallicity to planetary composition. These methodologies, while performed by collaborators, are techniques I am familiar with and have interpreted extensively in my work.

The combination of precise RV analysis, planetary modeling, and host star characterization aligns directly with THIRSTEE's multi-technique objectives. By integrating these approaches, my work on GJ 3090 contributes to the broader understanding of sub-Neptunes.

As the next step in my master's research, I will lead the development of a Python package called `SCARVS` (Statistical tools for Combined Analysis of Radial Velocity Signals). Building on my expertise in stellar activity modeling, the aim is to create a user-friendly tool designed for advanced radial velocity (RV) analysis. The backend will be implemented in `jax` [7], enabling fast and efficient Bayesian inference computations with the added advantage of pre-computed gradients. `SCARVS` is expected to offer a versatile suite of features, including N-planet + GP fits, semi-shared Gaussian processes (GPs), multi-dimensional GPs, transit + keplerian fits, astrometry + keplerian fits, stellar surface visualization using `starry`, and rotation evolution analysis. This tool's user-friendly interface will make it an accessible and valuable resource for the THIRSTEE team and potential interns, simplifying complex RV analyses and promoting efficient workflows.

Transit Photometry and Atmospheric Characterization

During my time at the Trottier Institute for Research on Exoplanets (iREx), I also worked and gained experience in many other exoplanet projects, beyond RV analysis. This includes contributing to the development of the data reduction pipeline for the SOSS mode of the JWST NIRISS instrument [8]. Additionally, I submitted an observing proposal as Principal Investigator for JWST Cycle 4 to study the atmosphere of the brown dwarf LHS 6343 C [9] using emission spectroscopy and eclipse mapping techniques. I have also performed joint RV and transit fits of photometry and radial velocity data using the `juliet` package [10], allowing for a comprehensive characterization of planetary systems.

Relevance to the Position

The skills I have developed align closely with the objectives of the THIRSTEE project. My expertise in analyzing multi-planetary systems like GJ 3090, applying advanced RV extraction methods, and using joint RV-transit modeling directly supports the project's aim of measuring precise bulk densities for sub-Neptunes. The application of multi-dimensional Gaussian Processes to correct stellar activity and uncover planetary signals demonstrates my ability to address the challenges inherent in high-precision RV analysis. These capabilities position me to contribute meaningfully to the THIRSTEE team's efforts in characterizing small planets and understanding their formation and evolution.

Sincerely,

Pierrot Lamontagne

References

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