 Research Progress

B1.

i. Aims of your higher degree research program:

Radial velocity observations have been widely used, and highly successful, in the search for exoplanets. They trace the spectral Doppler shift resulting from the barycentric reflex motion of a star with gravitationally bound companions (e.g. planets). However, surface inhomogeneities on a star (e.g. arising from stellar activity) can modify the shape of a spectral line-profile, and if those changes are asymmetric, they will introduce an apparent radial velocity shift. This “noise”

variability can be on timescales and amplitudes similar to those of planetary signals, hindering the detection of exoplanets.

We aim to develop robust techniques to parametrize spectral line shapes (and especially line asymmetries) and their variation, so as to quantify and remove the Doppler impact of stellar variability (i.e. jitter) and other surface inhomogeneities from radial velocity planet search data. We will utilise both least squares deconvolution (LSD) and cross-correlation techniques to generate high-signal-to-noise stellar line profiles from observed planet search data on an epoch-by-epoch basis, and then explore the quantification of the resulting profiles using suitable sets of orthogonal basis functions (like the Gauss-Hermite series). The aim is to develop techniques for robustly quantifying line-profile shapes, and their symmetric and anti-symmetric components.

B2.

1. Progress over the last 12 months (or since last review):

Main progress:

We used the SOAP 2.0 (Spot Oscillation And Planet 2.0) code to generate simulated line-profiles that included the effects of both dark spots and bright plages on the stellar surface, and then tested line-profile quantification metrics using these simulated data.

The metrics that we used here were the Gauss-Hermite functions. They are a set of orthonormal basis - Hermite polynomials weighted by a Gaussian term. Among them, even orders are even functions and represent the symmetric part of a line-profile; odd orders are odd functions and represent the anti-symmetric components. The Gauss-Hermite functions provide a natural and robust way to quantify the symmetric and asymmetric terms of a line-profile.

We found, in the SOAP 2.0 simulation data, that the odd order coefficients demonstrated a semi-linear trend against the jitter-induced radial velocity. Applying this relation in the end-to-end simulations, we managed to recover the planet signal in the presence of stellar noise.

Our further periodogram analysis of the time series of Gauss-Hermite coefficients showed that

1. the stellar rotation period, responsible for some of the activities’ period, was present in the periodogram of both odd- and even- order coefficients, however, this has not yet been effectively convincing in the real observation data;
2. the planet orbital period was traceable in the periodogram of odd-order coefficients, when a zero reference point was fixed for the Gauss-Hermite. It has been tested successfully in both the simulation and observation data from HARPS (High Accuracy Radial Velocity Planet Searcher). This finding may lead to a new and more robust method to discovery exoplanets in the presence of stellar noise.

Other progress:

Activity indicators in prominent spectral lines, such as H alpha, are associated with chromospheric activities of a star. Periodic variations in its FWHM (full width at half maximum) indicate that Doppler variability at that period is more likely to be due to activity than the presence of planets.

The continuum normalization plays an important role in delivering an accurate FWHM. We improved the normalization procedure in our UCLES (University College London Echelle Spectrograph) data by implementing more sophisticated techniques (including constructing high-signal-to-noise template to be more resistant to outliers, exclude telluric line absorption regions, etc.). With this improvement, we negated a planet candidate orbiting HD 29399 because the H alpha FWHM was found to correlate with the detected Doppler velocity; we also supported the detection of three new planets orbiting the K giants HD 86950, HD 222076 and HD 76920.

B3.

1. List written reports, publications, exhibitions/performances, conference presentations or other achievements in the last 12 months:

* Exoplanet Workshop Talk at Monash University: Gauss-Hermite Decomposition of Spectral Line Profile in an effort to Quantify Intrinsic Radial Velocity
* Publication: THE PAN-PACIFIC PLANET SEARCH. VI. GIANT PLANETS ORBITING HD 86950 AND HD 222076

Robert A. Wittenmyer, M. I. Jones, **Jinglin Zhao**, J. P. Marshall, R. P. Butler, C. G. Tinney, Liang Wang, and John Asher Johnson

* Publication (in preparation): THE PAN-PACIFIC PLANET SEARCH VII: THE MOST ECCENTRIC PLANET ORBITING A GIANT STAR

Robert A. Wittenmyer, M.I. Jones, Jonathan Horner, Stephen R. Kane, J.P. Marshall, **Jinglin Zhao**, Eva Villaver, R.P. Butler

* First chapter of the PhD thesis

B4.

1. Goals for the next 12 months:

* The Gauss-Hermite decomposition has been successfully tested in the simulation data. It is now at the stage of being tested by more HARPS archival. We would like to see extensively how this technique performs in the presence of real-world noise.
* While the Gauss-Hermite decomposition turns out to trace planet orbital period, there is not yet obvious detection of the stellar variability period. It may be because the true line centre (the shift of which is a pure effect of orbiting planets) cannot be precisely determined as the line-profile is distorted. Implementing the Gauss-Hermite decomposition was intended to tackle this problem. One of the ideas to be further investigated is introduce the line centre as a free parameter and determining the true line centre becomes an optimization problem.
* We currently use the cross-correlation function (CCF) to approximate an averaged spectral line-profile. It has the disadvantages of being affected by blended lines for late type stars. To solve this problem, we eventually opt to use the least squares deconvolution (LSD) technique to construct the mean profile. We will need to seek external cooperation, because LSD codes are proprietary, while developing our own LSD codes is out of the scope of the thesis.

B5.

1. Have any issues that you raised in your last progress review been addressed?

N/A

B6.

**i. Please indicate if any of the following problems affected progress over the past year:**

Academic background

English language/comprehension and/or writing

Settling in

Access to resources

Experimentation

Understanding work expected

Communication

Health/Personal

Financial

Interruption to supervision

Other

**OR**

No issues have affected my research progress

ii. Please elaborate on specific issues identified and indicate what steps have been taken to address these issues:

B7.

i. Are you on track for an on-time completion?

Yes

No

ii. Indicate your projected submission date:

B8.

**i. Please provide details of any completed coursework required for the degree or courses related to the degree in the table below:**

I have not completed any courses or coursework required for the degree.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Institution** | **Course ID** | **Course Name** | **Term - Year** | **Result** | **Action** |
|  |  |  |  |  | Add |

ii. Provide additional information regarding courses listed above or any other coursework info not listed above:

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**You may need to check sections of the form in red before submitting.**