

Preface

Since the discovery of the first planet orbiting another star than our Sun, just over twenty years ago, hundreds of new extra-solar planets have been identified, and thousands of more discoveries are awaiting confirmation. The first exoplanets that were detected had sizes similar to those of Jupiter and Saturn, the giants in our solar system. In recent years, instrument precision and telescope power have improved so much that discovering and characterising planets as small as the Earth is now a reality. The search for worlds similar to our own is one of the fastest growing fields in astronomy; it is a young and exciting field and captivates the interest of the public like no other.

One of the most successful ways to find extra-solar planets is to look for stars that wobble. As a planet orbits around its parent star, it exerts a tiny pull on the star. This causes the starlight to periodically stretch and compress, making the star appear redder and bluer. This effect, known as the Doppler shift, is the same effect that makes the siren of an ambulance sound high-pitched then low-pitched as it drives past. These minuscule changes in the colour of the star's light, which reflect the variations of the star's velocity along our line of sight, can be detected by current state-of-the-art spectrographs.

There are still several challenges to be overcome in the quest for other Earths. One major difficulty arises from the intrinsic magnetic activity of the host stars themselves. Indeed, the correlated noise that arises from their natural radial-velocity variability can easily mimic or conceal the orbital signals of super-Earth and Earth-mass exoplanets, and there is currently no reliable method to untangle the signal of a planet from this stellar “noise”.

The work I undertook as part of my thesis was intended to tackle this issue via a twofold approach. First, I developed an intuitive and robust data analysis framework in which the activity-induced variations are modelled with a Gaussian process that has the frequency structure of the photometric variations of the star, thus allowing me to determine precise and reliable planetary masses (Chap. 2); and second, I explored the physical origin of stellar-induced Doppler variations through the study of our best-known star, the Sun (Chap. 4).

I applied my new data-modelling technique to three recently discovered planetary systems: CoRoT-7, Kepler-78, and Kepler-10 (Chap. 3). I determined the masses of the transiting super-Earth CoRoT-7b and the small Neptune CoRoT-7c to be $4.73 \pm 0.95 M_{\oplus}$ and $13.56 \pm 1.08 M_{\oplus}$, respectively. The density of CoRoT-7b is $6.61 \pm 1.72 \text{ g cm}^{-3}$, which is compatible with a rocky composition. I carried out Bayesian model comparison to assess the nature of a previously identified signal at 9 days and found that it is best interpreted as stellar activity. Despite the high levels of activity of its host star, I determined the mass of the Earth-sized planet Kepler-78b to be $1.76 \pm 0.18 M_{\oplus}$. With a density of $6.2^{+1.8}_{-1.4} \text{ g cm}^{-3}$, it is also a rocky planet. I found the masses of Kepler-10b and Kepler-10c to be $3.31 \pm 0.32 M_{\oplus}$ and $16.25 \pm 3.66 M_{\oplus}$, respectively. Their densities, of $6.4^{+1.1}_{-0.7} \text{ g cm}^{-3}$ and $8.1 \pm 1.8 \text{ g cm}^{-3}$, imply that they are both of rocky composition—even the 2 Earth-radius planet Kepler-10c!

In parallel, I deepened our understanding of the physical origin of stellar radial-velocity variability through the study of the Sun, which is the only star whose surface can be imaged at high resolution. I found that the full-disc magnetic flux is an excellent proxy for activity-induced radial-velocity variations; this result may become key to breaking the activity barrier in coming years.

I also found that in the case of CoRoT-7, the suppression of convective blueshift leads to radial-velocity variations with an RMS of 1.82 m s^{-1} , while the modulation induced by the presence of dark spots on the rotating stellar disc has an RMS of 0.46 m s^{-1} . For the Sun, I found these contributions to be 2.22 m s^{-1} and 0.14 m s^{-1} , respectively. These results suggest that for slowly rotating stars, the suppression of convective blueshift is the dominant contributor to the activity-modulated radial-velocity signal, rather than the rotational Doppler shift of the flux blocked by starspots.

Gaining a deeper understanding of the physics at the heart of activity-driven RV variability will ultimately enable us to better model and remove this contribution from RV observations, thus revealing the planetary signals.

Cambridge, MA, USA

Dr. Raphaëlle D. Haywood

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Haywood, R.D.

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