Correcting Astrophysical Noise in HARPS-N RV Measurements

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Abstract

Radial velocity instrumental precision has improved to the degree that measurements are now limited in part by the noise intrinsic to the host star, or stellar 'jitter'. Several different phenomena contribute to the observed jitter, including pressure waves, granulation, magnetic features caused by stellar activity, and solar-like magnetic cycles. The amplitude of these effects ranges from 10 to 400 cm/s, depending on stellar type, and pose a significant limitation to detecting Earth analogues. We carry out a survey of bright, quiet stars with the new HARPS-N instrument, an ultra-stabilized R=115,000 cross-dispersed spectrograph located on the 3.6m Telescopio Nazionale Galileo on the island of La Palma. We look for correlations between these radial velocity measurements and known activity indicators, including line bisector measurements and the CaII index. We will correct for the presence of starspots by locating and removing quasi-periodic signals consistent with stellar rotation rate. We also investigate new correlations between radial velocity measurements and other observables, including variations in line depth ratios. By correcting for these combined effects, we can improve the radial velocity precision, enabling the detection of low-mass planets.

Introduction

Stellar activity can generate radial velocity (RV) signals of up to a few m/s that can mimic or hide the signal of a planet. With the sub-m/s precision of HARPS-N, stellar 'jitter' becomes one of the primary restrictions in detecting low mass planets. We use the observations taken as part of the guaranteed time Rocky Planet Search (RPS) focusing on bright, quiet stars to look for correlations between radial velocity measurements an other observables, such that stellar activity effects can be modeled and corrected.

The observing cadence of the survey is designed to mitigate the effects of stellar activity with a timescale of minutes to hours, using 15 minute observations to average pressure waves and well-spaced multiple exposures to minimize granulation noise (Dumusque et al. 2011). Over the course of years, the stellar magnetic cycle causes RV variations that correlate linearly with R'_{HK} and can so be removed (Lovis et al. 2011).

On the scale of days to weeks, rotational modulation due to starspot activity can cause planetary false positives, as observed by Queloz et al. (2001). A negative correlation between RVs and line bisectors is a hallmark of this effect, though its absence is not sufficient to rule out activity contamination. Both Bonfils et al. (2007) and Isaacson & Fischer (2010) observe correlations between RV and chromospheric indices, though of different forms (Figs. 1 & 2). Another method for removing the effects of starspots is to fit and subtract sinusoids at the stellar rotation period and its harmonics (e.g. Queloz et al. 2009). Finally, Catalano et al. (2002) find that variations in stellar temperature due to starspots can be measured to within 5K by examining variations in line depth ratios.

This poster describes one effort led by S. Gettel and D. Charbonneau at the Harvard-Smithsonian Center for Astrophysics to study these markers of stellar activity and further develop correlations with radial velocity; there are several parallel efforts across the HARPS-N collaboration. We will model and correct for the effects of activity, minimizing stellar jitter and further improving our radial velocity precision.

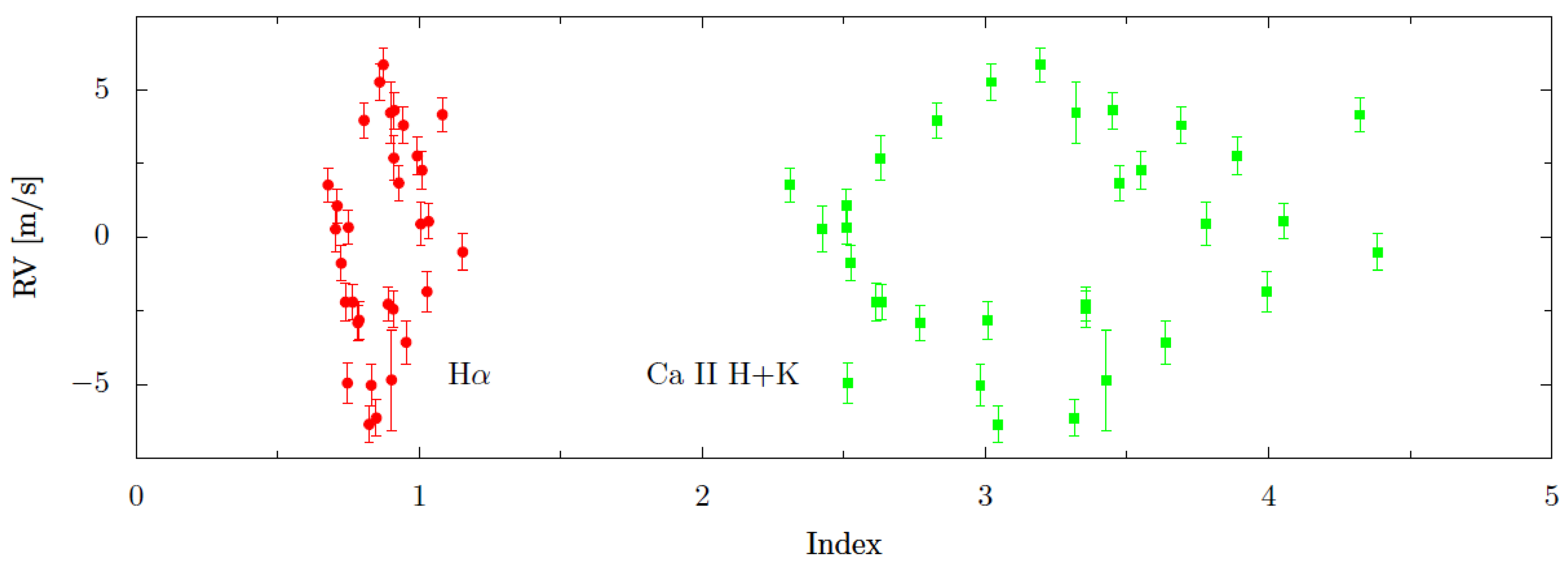
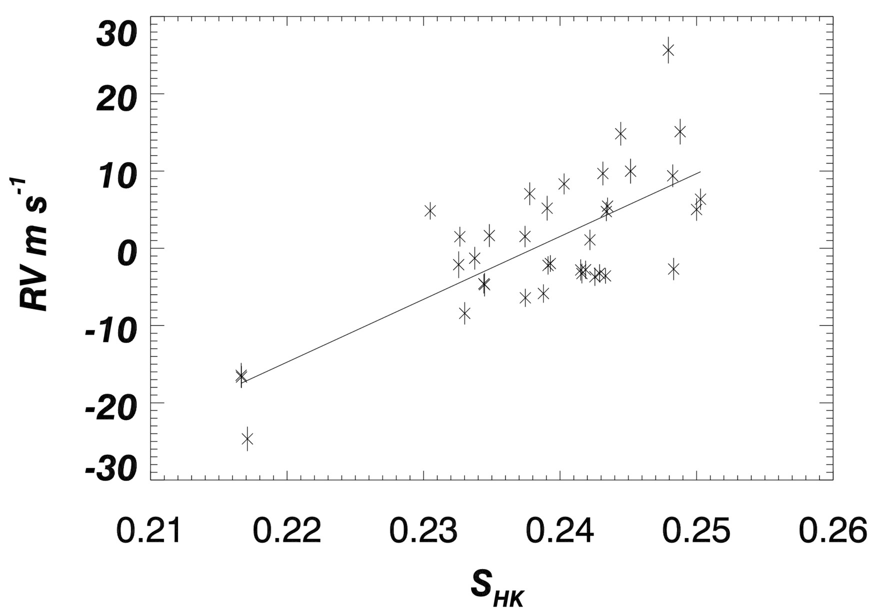


Fig. 1: *From Bonfils et al. 2007 – RVs of GJ 674 as a function of Hα (red circles) and Ca II H & K index (green squares). The presence of a starspot passing across the visible hemisphere of the star causes the spectral indices to trace a closed diamond shape as a function of radial velocity.*

Fig. 2: *From Isaacson & Fischer 2010: RVs of HD143174 show a correlation with activity index S_{HK} that is present over the course of one observing season but not in later measurements.*



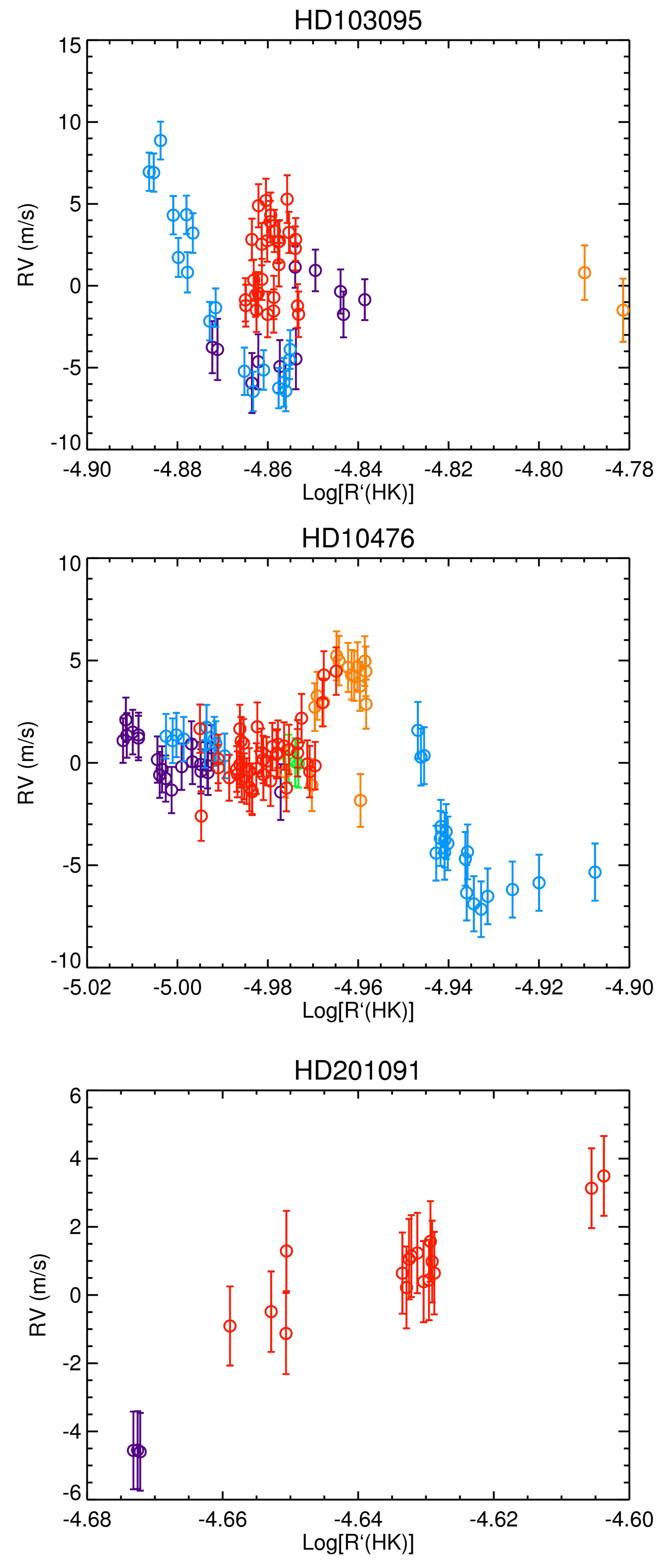


Fig. 3: *Several of the RPS targets show temporary correlations between RV and Log[R'_{HK}]. Observations are broken into segments of 50 days each and ordered by color – purple, blue, green, orange and red, with red being the most recent group of measurements.*

Measurements

We utilize measurements taken as part of the HARPS-N guaranteed time survey for planets around bright, quiet stars. These observations are 15 minutes each and made two times a night, separated by at least two hours. This cadence averages over pressure waves and reduces noise due to stellar granulation. For further details of this survey see poster by F. Motalebi.

We measure the chromospheric activity as Log[R'_{HK}], the ratio of re-emission in the Ca II H & K lines relative to the continuum, in a manner similar to Lovis et al. (2011). We measure line depth ratios using the Fe I/II and VI linelist of Catalano et al. (2002), which are sensitive to temperature and easily observable with HARPS-N.

Results & Future Work

Several targets show temporary correlations between RV and Log[R'_{HK}], as shown in Fig. 3. We will generate models of the correlation between RV and chromospheric activity due to starspots. We will continue to monitor these results as more observations are made and investigate correcting the RV measurements by removing these correlations.

The line depth ratios do not show correlations with radial velocity at our current level of precision, as shown in the example in Fig. 4. These ratios should be able to detect disk-integrated temperature variations due to starspots and may become an indicator of spot contamination as our precision increases.

As spot activity can produce RV signals of 0.4-1.4 m/s, any orbit solutions of this magnitude will require a multi-parameter fit that includes a correlation with activity indicators.

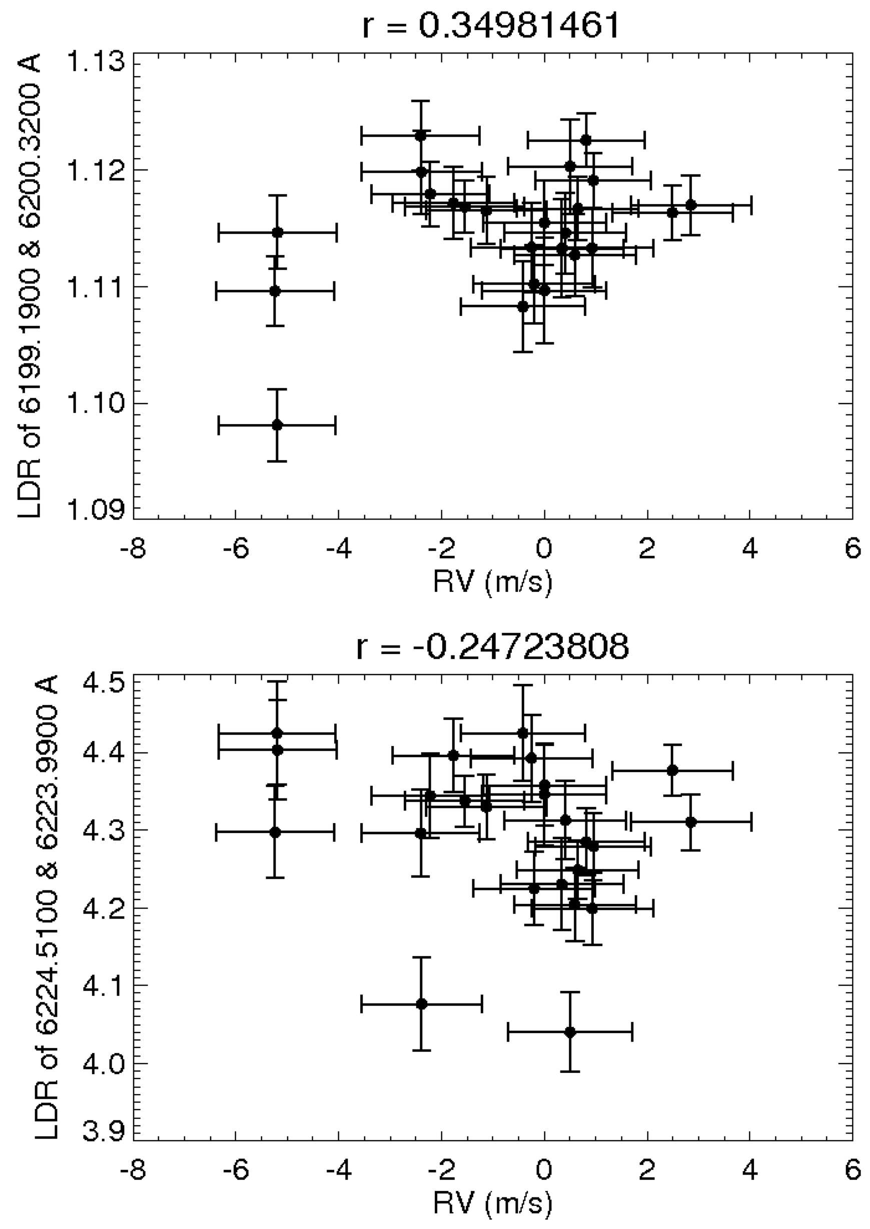


Fig. 4: *Line depth ratios versus radial velocity for HD201091, which are representative of those seen for the most frequently observed stars. Errors are determined from photon noise. 'r' is the Pearson correlation coefficient, indicating weak correlations.*

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