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Correcting HIRES radial-velocities for systematic errors

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Abstract

We use publicly-available radial velocities (RVs) from the HIRES spectrograph to identify and correct for minute (~1 m/s) systematic RV variations. By averaging the RVs of different quiet stars that were observed each night, we calculate instrumental nightly zero-point RVs, and find small but significant variations on three different timescales. In addition, we find an average small intra-night RV drift. We correct the HIRES RVs for the systematic effects, and investigate the impact of the correction. Our findings highlight the importance of observing quiet stars on a nightly basis, even in the era of self-calibrated and stabilized RV spectrographs.

1. Introduction

The HIRES spectrograph on the 10-m Keck telescope in Hawaii belongs to a small family of radial-velocity (RV) instruments that can produce stellar RVs with internal precision and long-term stability down to ~1 m/s. For the last two decades it was extensively used to monitor F, G, K, and M dwarf stars in search for exoplanets. Last year, the HIRES team made public ~65,000 RVs of ~1,700 stars that were collected with HIRES between 1996 and 2014 [1]. In what follows, we use these RVs to identify and correct for minute systematic instrumental RV variations.

2. Four different systmatic effects

To identify the systematic effects, we select a sub-sample of ~800 stars whose RV scatter is < 10 m/s (RV-quiet stars). By averaging the RVs of the different stars that were observed each night, we calculate a nightly zero-point RV (NZP) for ~900 nights in which at least three different RV-quiet stars were observed. Using the NZPs we find that the two most significant systematic effects are a discontinuous jump, which was caused by major modifications of the instrument in Aug 2004, and a slow NZP variation, with a typical timescale of a few years. We find the Aug 2004 jump to be 1.5 ± 0.1 m/s, and the magnitude of the slow variation to be ~1 m/s. Periodogram analysis of the NZPs reveals yet another systematic effect of ~0.5 m/s with a period of ~30 days, which is probably related to the bright-time scheduling of the observations. On top of that, we find a significant correlation between RVs and the time from local midnight, indicative of an average nightly drift of the RVs of 0.049 ± 0.003 m/s/hr.

3. Correcting the RVs

We correct the public HIRES RVs for the systematic effects we find. The night-to-night variations are corrected by subtracting a moving (50-day window) weighted-average filter applied to the NZPs. The intra-night drift is corrected by using the observation's time from local midnight. The median absolute value of the total correction is ~0.7 m/s. The corrected RVs will be soon made public alongside a dedicated publication [3].

The median RV rms scatter per star in the public HIRES data is ~5 m/s, while the most RV-quiet stars have an rms of ~2 m/s. This scatter contains both the intrinsic stellar RV variations, which come from orbital motions and photospheric activity, and the instrumental RV errors, which can be further divided to internal RV precision and systematic errors. Therefore, correcting for ~1 m/s systematic effects does not change significantly each-star's RV rms. However, the correction is important when analyzing low amplitude signals. In particular, it suppresses spurious signals of a few planet candidates that were listed by [1]. Moreover, the correction makes the HIRES data slightly more self-consistent over timescales of years, which can facilitate combining it with data from other precision RV instruments in search for low-amplitude long-period orbital signatures of low mass planets.

4. Figures

Figure 1 demonstrates our NZP correction method of HIRES RVs. The NZPs have an STD of ~1.3 m/s and a median uncertainty of ~0.9 m/s, which shows that the NZPs reveal an additional source of systematic RV scatter, on top of the internal RV uncertainties. The Aug 2004 jump can be seen at JD~2453225.

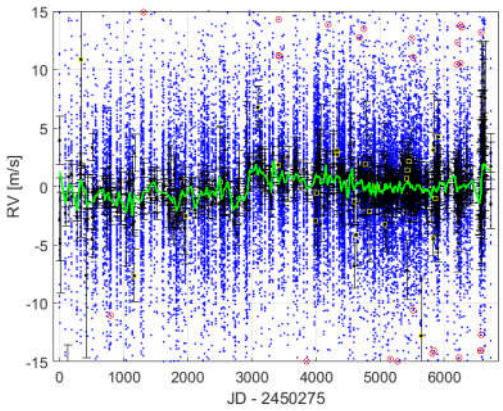

Figure 1: HIRES NZP correction. RV-quiet star RVs are shown as blue points. Black errorbars show the NZPs, while NZPs that were derived from less than three RVs are marked with yellow boxes. Outliers are marked in red. The green line shows our adopted NZP model: a moving (50-day window) weighted-average filter. Aug 2004 is at JD ~ 2453225.

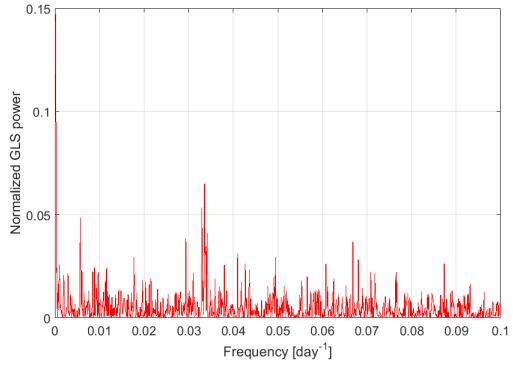

Figure 2: GLS periodogram of the HIRES NZPs.

Figure 2 shows a GLS periodogram of the NZPs. The two highest peaks belong to periods of ~6000 and ~30 days. The low frequency peak originates from the Aug 2004 jump, combined with a slow decay of the NZPs back to their median value. The 30-day peak naturally emerges from the bright-time scheduling of HIRES observations.

Figure 3 shows the small intra-night drift of HIRES RVs. The linear correlation has a p(F_{test})-value of ~$5 \cdot 10^{-7}$, which shows that it is significant.

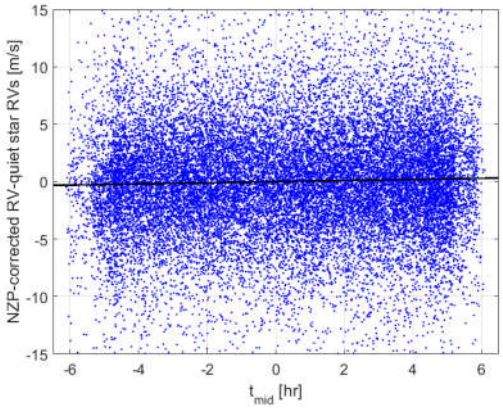

Figure 3: HIRES RVs of RV-quiet stars versus the time from local midnight.

5. Conclusions

Observing RV standard stars to correct for systematic errors is a technique that was in use ever since the RV method was invented. However, in the era of self-calibrated and stabilized RV spectrographs it was largely abandoned, while sophisticated calibration methods were adopted instead. We show here that repeated observations of RV-quiet stars is still important, and can reveal systematic errors well below the noise level of the instrument. As more and more precision RV instruments become operational, and as the precision is being pushed to the ~0.1 m/s limit [2], we urge the observatories to keep observing RV-quiet stars on a nightly basis, in order to identify and correct for instrumental systematic RV errors.

References

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