Affordable echelle spectroscopy of the eccentric HAT-P-2, WASP-14, and XO-3 planetary systems with a sub-meter-class telescope

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Abstract

A new off-the-shelf, low-cost echelle spectrograph eShel was installed recently on the 0.6m telescope at the Stará Lesná Observatory (SLO) – G1 (Slovakia). We describe the radial velocity (RV) analysis of the first three transiting planetary systems, namely HAT-P-2, WASP-14, and XO-3, observed with this instrument. First, we reduced and analyzed our RV observations. Subsequently, we compared our data with previously published RV data. We were curious about the precision of our measurements in comparison to that of the RV data achieved with echelle spectrographs of other sub-meter-, meter- and 2-m-class telescopes. Another question was the applicability of our RV data for modeling orbital parameters. For this purpose, we previously published data were analyzed in the same way as our RV data in order to determine and compare the parameters. Finally, we combined and analyzed all used RV data per object.

The RV observations were performed at SLO-G1 with a 0.6 m, D125 Zeiss Cassegrain telescope (see figure left). The fiber injection and photometric Fabry-Pérot (FP) of the echelle spectrograph itself in the cellar below the dome (see figure lower right). The collimated beam is dispensed by a high-efficiency RZ echelle grating with 79 grooves/mm. The maximum resolution of the echelle spectrograph reaches ≥ 12 000 (Pribulla et al. 2015).

Properties of the instrumentation at SLO-G1

The objects selected according to the RV amplitude, brightness, and the sky position. All three systems are, however, very interesting because they are characterized by close-in, but apparently eccentric orbits, and therefore represent potentially important systems to constrain the migration as well as tidal and thermal evolution of gas giant planets (Bakos et al., 2005; Johns-Krull et al., 2008; Joshi et al., 2009). Using our instrumentation, we obtained 20 RV measurements per planetary system. The data were reduced using IRAF package tasks, Linux shell scripts, and FORTRAN programs as described in Pribulla et al. (2013). We then used the code JKTEBOP (Southworth, Mastick, & Smalley, 2004). This code can fit RVs simultaneously with a light curve; hence the orbital parameters of the three transiting planets were calculated from the RV data, together with the photometric data. The used transit light curve of HAT-P-2, WASP-14b, and XO-3 is depicted on left panel (taken from the HATNet archive), middle panel (taken from Raetz et al., 2014), and right panel (observed at the Izael Observatory, respectively). We fitted RV data from different sources simultaneously with exactly the same photometric data per object. First, we fitted only our GI RV data with the photometric data. Subsequently, we fitted previously published RV data from other sub-meter-, meter- and 2-m-class telescopes, simultaneously with the photometric data, in the same way as we described above, in order to compare the results. In the case of HAT-P-2, we used the RV data published by Csák et al. (2014). Observations were carried out at the Coudé Astrophysical Observatory (GAO) ± 0.6 m telescope), Smithsonian, and at the Piskëstëinë Mountain Station (PO, ± 1 m telescope) with the same echelle spectrograph. For WASP-14, we adopted the RV data published by Joshi et al. (2009), which were collected with the FIES instrument in medium-resolution mode (Telleng et al., 2014), mounted on the 2.5 m Nordic Optical Telescope (NOT) and with the SOPHIE spectrograph in high-resolution mode (Pernicka et al., 2014). In the case of XO-3, we used the RV data published by Hébrard et al. (2008), which were collected with the SOPHIE in high-resolution mode. Finally, we combined and analyzed all used data per object.

Results: the best fit parameters and spectroscopic models

In the case of HAT-P-2 we worked with 39 (∼ 20) RV measurements (upper left panel). The resulting GI RVs show an average scatter of about 170 m/s. First, we fitted only our GI RV data simultaneously with the photometric data. The best fit parameters are summarized in the table. In the next step, we fitted NOT and OHP RV data, simultaneously with the photometric data. In this case, the average scatter is only about 10 m/s. Finally, we simultaneously fitted the photometric and all RV data. The resulting parameter values are very similar, for example, in the case of the systemic velocity. The parameter A is more inconsistent. The value of the RV semi-amplitude derived from GI RVs is, from the parameter R, derived from NOT/HP RVs, however, if we consider 1σ error limits, these values are also in agreement. The situation is very similar if we compare the best fit parameter values derived from GI RV data and the literature parameter values. Furthermore, we can also easily see that the parameter values derived from GI RVs are, in general, more uncertain. The value of the RV semi-amplitude derived from GI RVs is, from the parameter R, derived from NOT/HP RVs, however, if we consider 1σ error limits, these values are also in agreement. The situation is very similar if we compare the best fit parameter values derived from GI RV data and the literature parameter values. Furthermore, we can also easily see that the parameter values derived from GI RVs are, in general, more uncertain. The value of the RV semi-amplitude derived from GI RVs is, from the parameter R, derived from NOT/HP RVs, however, if we consider 1σ error limits, these values are also in agreement. The situation is very similar if we compare the best fit parameter values derived from GI RV data and the literature parameter values.

In the case of WASP-14 we worked with 47 (∼27) RV measurements (upper middle panel). Our RVs show an average scatter of about 220 m/s. First, we fitted only our GI RV data, simultaneously with the photometric data. The best fit parameters are summarized in the table. Subsequently, we fitted OHP RV data, simultaneously with the photometric data. The average scatter of OHP RVs is about 35 m/s. As a final step, we simultaneously fitted photometric and all RV data. The best fit parameters are also summarized in the table. We can compare, for example, the semi-amplitude, the systemic velocity, or the eccentricity. The parameter values derived from our GI RV data are, however, more uncertain. The best fit parameter results from GI RVs are also, in general, consistent with the literature values, however, we can see, again, that the literature values are given with better accuracy. We did not confirm only the ratio of the radii.

Expected RV precision as a function of the telescope diameter and the spectrograph resolution is depicted in the figure in this panel. The precision curve assume the worst cases time, telescope–spectrograph throughput, and the same object. The expected precision reasonably matches the observed uncertainty.

Conclusions

Based on our results, we can conclude that the spectrograph is a useful instrument for the study of objects with a relatively small RV amplitude. We achieved an average precision of about 170 m/s in the case of HAT-P-2, 220 m/s in the case of WASP-14, and 280 m/s in the case of the XO-3 system. These values are sufficient for exoplanet RV detections and spectroscopic follow-up measurements of massive exoplanets on close-in orbits. The accuracy is well comparable with the average RV scatter achieved with other sub-meter and meter-class telescopes. In comparison with 2-meter-class spectrographs, our instrumentation gives an RV scatter of about one order of magnitude. This difference is primarily due to the telescope diameter size.

On the other hand, our best fit results show that RV data obtained with our instrumentation can be used to determine orbital parameters of massive close-in exoplanets. In general, we can conclude that the best fit parameters resulting from the GI RV data are in good agreement with the published parameters. Literature parameter values are, however, given with better accuracy.

Furthermore, in comparison with NOT/OHP RV data, due to the relatively lower RV accuracy of GI RV data, we can determine the system parameters with larger error interval only. This is also the reason why parameters derived from NOT/OHP RV data and from combined GI and NOT/OHP observations are very similar (see the table). Since data obtained at GI have lower accuracy, these are weighted-down during the model-fitting procedure when we combined GI and NOT/OHP observations, and have minimal influence on parameter determinations.

Recently, we published our results in the journal Astronomical Notes (Gárai et al., 2017, AN 338, 55). For other details see the published paper at the web-page http://adsabs.harvard.edu/abs/2017A&A...598A..45G.

Acknowledgements

The authors thank V. Kollar for technical assistance, B. Csák for the RV data, and J. Budaj for comments and discussion. This work was supported by the VEGA grant of the Slovak Academy of Sciences (No. 2014/13), the Slovak Research and Development Agency (Contract No. APVV-15-0811), the Slovak Central Observatory, and the realization of the Project EÚ (No. 26220120209), based on the Supporting Operational Research and Development Program financed from the European Regional Development Fund. M.S. thanks onyxosyros.gr, for financial support.

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