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# WASP-4 IS ACCELERATING TOWARDS THE EARTH

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In recent work we showed that the TESS mission observed the hot Jupiter WASP-4b transit $\approx 82$ seconds earlier than expected, under the assumption of a constant orbital period (Bouma et al. 2019). This result was based on transit times[1] acquired since 2007 (CITE ALL). We pointed out that the transit times were best fit by a timing model with a constant period derivative, and reported a best-fit decay rate of $\dot{P} = -12.6 \pm 1.2\,\mathrm{ms}$ per year. Our interpretation was that the apparent period change could be caused by any of three scenarios: a decaying orbit, a precessing orbit, and an orbit being gravitationally perturbed by an outer companion.

Thereafter, Southworth et al. (2019) reported 22 new transit times for the system, and also found that the entire series of transit times was consistent with a quadratic ephemeris. Their interpretation of the timing variations did not differ in any major aspects from our own. A separate follow-up study by Baluev et al. (2019) also reported new light curves, and analyzed these plus light curves that were purposefully omitted from our analysis due to systematic uncertainties in the absolute time system. Baluev et al. found that when they used all the available TTV data, the need for a quadratic ephemeris was present "at the high $\sim 5-7$ sigma level". However, they pointed out that if they used lower-precision subsets of the available timing data, the necessity for the quadratic term decreased. Baluev et al. also pointed out that the precise transit times reported by Huitson et al. (2017) were quite important in the time-series. Overall, Baluev et al. were not convinced.

We, too, wanted to confirm and understand the timing variation. One of the lines of follow-up we originally mentioned was the need for additional radial velocity observations. We acquired them this past season with Keck HIRES. After fitting out the hot Jupiter, the residuals now show a strong linear trend (Figure 1). Specifically, the best-fit radial velocity derivative, $\dot{v}_\mathrm{r}$, is

$$\dot{v}_\mathrm{r} = -X.XX \pm Y.YY\,\mathrm{m\,s^{-1}\,day^{-1}}. \tag{1}$$

This acceleration towards our line of sight is XXX times faster than reported from the 5 points available during the Friends of Hot Jupiters project (Knutson et al. 2014). The updated radial velocity values are available in the data-behind-the-figure online version of this *Note*.

Under the assumption of constant acceleration, the implied period derivative is $\dot{P} = \dot{v}_\mathrm{r} P/c$, yielding X.XX milliseconds per year for WASP-4.

With respect to WASP-4b's quadratic ephemeris, it seems rather likely that this line of sight acceleration is at fault. Further radial velocity observations of the system should help in resolving the nature of the companion.

This paper includes data collected by the TESS mission, which are publicly available from the Mikulski Archive for Space Telescopes (MAST). Funding for the TESS mission is provided by NASA's Science Mission directorate. This research has made use of the NASA Exoplanet Archive, which is operated by the California Institute of Technology, under contract with the National Aeronautics and Space Administration under the Exoplanet Exploration Program. This work made use of NASA's Astrophysics Data System Bibliographic Services. This research has made use of the VizieR catalogue access tool, CDS, Strasbourg, France.

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[1] Our timing analysis included data from peer-reviewed literature for which the times were measured from a single transit, and for which the midpoint was allowed to be a free parameter. We also required that the time system be clearly documented. In other words, we needed to know whether any heliocentric/barycentric corrections had been performed, and whether the absolute time system was UTC or TDB.

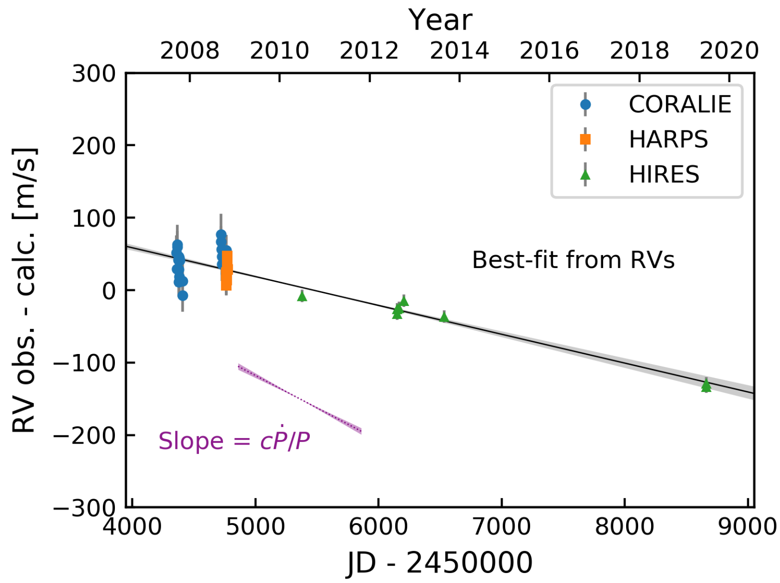


**Figure 1. Radial velocity observations of WASP-4.** The orbit of WASP-4b has been subtracted.

The original description of the VizieR service was published in A&AS 143, 23. This work has made use of data from the European Space Agency (ESA) mission *Gaia* (https://www.cosmos.esa.int/gaia), processed by the *Gaia* Data Processing and Analysis Consortium (DPAC, https://www.cosmos.esa.int/web/gaia/dpac/consortium). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the *Gaia* Multilateral Agreement.

*Software:* `radvel` (Fulton et al. 2018),

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