RadVel: A Radial Velocity Fitting Toolkit

http://radvel.readthedocs.io

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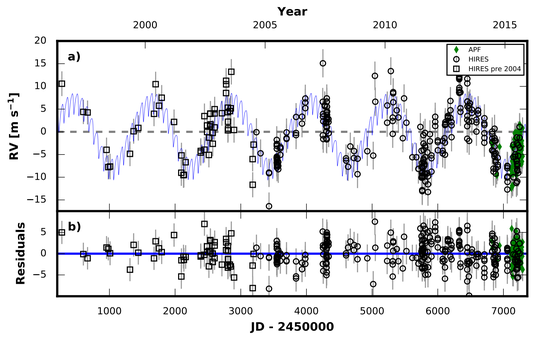
Abstract

RadVel[1] is a radial velocity (RV) modeling toolkit written in object-oriented Python designed to extract accurate parameters and associated uncertainties in complex multi-planet, multi-instrument RV datasets. It is designed to be highly extensible and easily modified to cater to a wide variety of maximum-likelihood and MCMC modeling applications. The package is well-documented, highly portable, and open source. The affine-invariant MCMC sampling (via `emcee`[2]) is parallelized and the Kepler equation solver is written in C for maximum speed on modest computing platforms.

Publication-Ready Plots and Tables



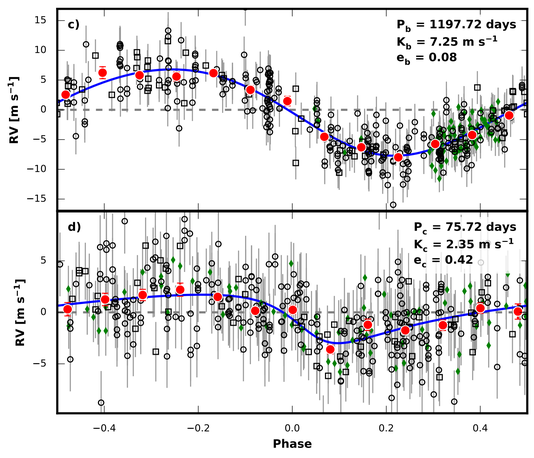


TABLE 2
MCMC Posteriors

Parameter	Credible Interval	Maximum Likelihood	Units
Modified MCMC Step Parameters			
$\sqrt{e}\cos\omega_b$	$-0.227\ ^{+0.08}_{-0.064}$	-0.241	
$\sqrt{e}\sin\omega_b$	$0.16\ ^{+0.1}_{-0.14}$	0.16	
$\ln K_b$	$1.977\ ^{+0.034}_{-0.037}$	1.98	$\ln(\mathrm{m\ s^{-1}})$
$\sqrt{e}\cos\omega_c$	$-0.26\ ^{+0.32}_{-0.24}$	-0.3	
$\sqrt{e}\sin\omega_c$	$0.44\ ^{+0.1}_{-0.14}$	0.47	
$\ln K_c$	$0.79\ ^{+0.15}_{-0.13}$	0.81	$\ln(\mathrm{m\ s^{-1}})$
Orbital Parameters			
P_b	$1198.1\ ^{+4.3}_{-3.9}$	1198.0	days
$T\mathrm{conj_b}$	$2456769\ ^{+15}_{-14}$	2456770	JD
e_b	$0.087\ ^{+0.036}_{-0.035}$	0.085	
ω_b	$2.55\ ^{+0.52}_{-0.4}$	2.55	radians
K_b	$7.22\ ^{+0.25}_{-0.26}$	7.25	$\mathrm{m\ s^{-1}}$
P_c	$75.729\ ^{+0.043}_{-0.038}$	75.72	days
$T\mathrm{conj_c}$	$2456279.5\ ^{+3.1}_{-2.8}$	2456280.0	JD
e_c	$0.29\ ^{+0.21}_{-0.13}$	0.31	
ω_c	$2.12\ ^{+0.35}_{-0.69}$	2.13	radians
K_c	$2.2\ ^{+0.34}_{-0.27}$	2.24	$\mathrm{m\ s^{-1}}$
Other Parameters			
γ_k	0.18 ± 0.44	0.21	m s−1
γ_j	0.16 ± 0.21	0.19	m s−1
γ_a	1.1 ± 0.44	1.11	m s−1
$\dot{\gamma}$	$\equiv 0.0$	$\equiv 0.0$	$\mathrm{m\ s^{-1}\ day^{-1}}$
$\ddot{\gamma}$	$\equiv 0.0$	$\equiv 0.0$	$\mathrm{m\ s^{-1}\ day^{-2}}$
σ_k	$2.68\ ^{+0.41}_{-0.33}$	2.5	$\mathrm{m\ s^{-1}}$
σ_j	2.94 ± 0.15	2.89	$\mathrm{m\ s^{-1}}$
σ_a	$1.08\ ^{+0.4}_{-0.43}$	1.0	$\mathrm{m\ s^{-1}}$

240000 links saved
Reference epoch for $\gamma,\dot{\gamma},\ddot{\gamma}$: 2456778.0

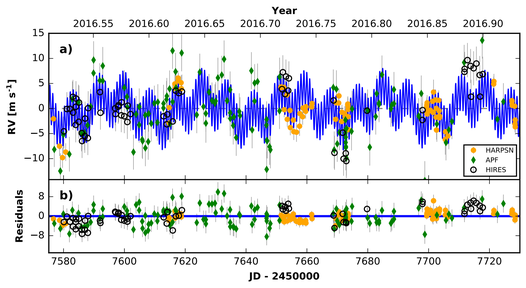
References

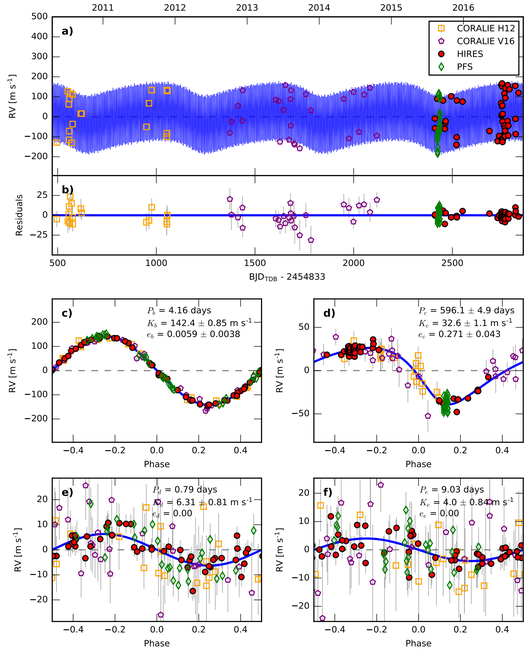
1. Fulton, B. and Petigura, E. Radvel: Radial velocity fitting toolkit, , May (2017).
2. Foreman-Mackey, D., Hogg, D. W., Lang, D., and Goodman, J. emcee: The MCMC Hammer. *PASP* **125**, 306, March (2013).
3. Sinukoff, E., Howard, A. W., Petigura, E. A., et al. Mass Constraints of the WASP-47 Planetary System from Radial Velocities. *Astronomical Journal* **153**, 70, February (2017).
4. Christiansen, J. L., Vanderburg, A., Burt, J., et al. Three's Company: An additional non-transiting super-Earth in the bright HD 3167 system, and masses for all three planets. *ArXiv e-prints* , June (2017).
5. Petigura, E. A., Sinukoff, E., Lopez, E. D., et al. Four Sub-Saturns with Dissimilar Densities: Windows into Planetary Cores and Envelopes. *Astronomical Journal* **153**, 142, April (2017).
6. Sinukoff, E., Howard, A. W., Petigura, E. A., et al. K2-66b and K2-106b: Two Extremely Hot Sub-Neptune-size Planets with High Densities. *Astronomical Journal* **153**, 271, June (2017).

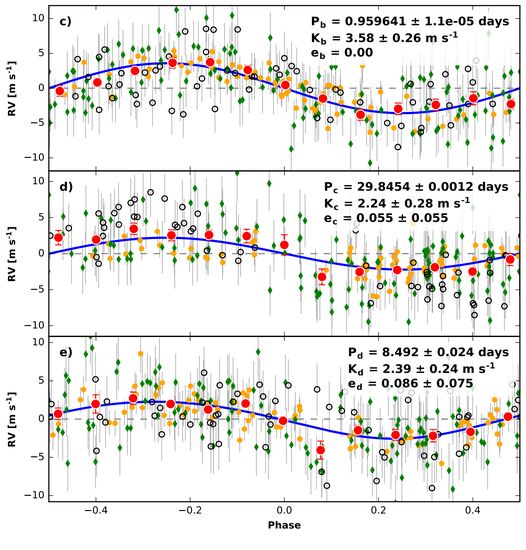
Features

- Model multi-instrument, multi-planet RV datasets out of the box
- Robust MCMC convergence criteria
- Scriptable using the well-documented API for industrial-scale RV modeling
- Easy to implement many different types of priors
- Written primarily in object-oriented Python
- Can incorporate decorrelation against nuisance parameters and activity indices
- Ongoing efforts by collaborators to incorporate gaussian process noise model
- Open source (https://github.com/California-Planet-Search/radvel)
- Coded according to the PEP 8 style guide for Python code
- Easily adapted to a wide variety of specialized applications
- Painless installation using PyPI (pip) on any unix-based machine

Publications using RadVel







RadVel has already been used in several publications. For example, Sinukoff et al. (2017a)[3] used it to model the 4-planet WASP-47 system with RVs collected from 4 different instruments. Christiansen et al. (2017)[4] used RadVel to model the three planet system orbiting HD 3167 with velocities collected on Keck/HIRES, HARPS-N, and APF. Several other studies have made use of RadVel including Petigura et al. (2017)[5], and Sinukoff et al. (2017b)[6].