



The Solar Neighborhood XLVIII: Nine Giant Planets Orbiting Nearby K Dwarfs, and the CHIRON Spectrograph’s Radial Velocity Performance

Leonardo A. Paredes¹ , Todd J. Henry² , Samuel N. Quinn³ , Douglas R. Gies¹ , Rodrigo Hinojosa-Góni⁴,
Hodari-Sadiki James¹ , Wei-Chun Jao¹ , and Russel J. White¹

¹ Department of Physics and Astronomy, Georgia State University, Atlanta, GA 30302-4106, USA; lparedes@astro.gsu.edu, gies@chara.gsu.edu,
james@astro.gsu.edu, jao@astro.gsu.edu, white@astro.gsu.edu

² RECONS Institute, Chambersburg, PA 17201, USA; toddhenry28@gmail.com

³ Center for Astrophysics, Harvard and Smithsonian, 60 Garden Street, Cambridge, MA 02138, USA; squinn@cfa.harvard.edu

⁴ Cerro Tololo Inter-American Observatory, CTIO/AURA Inc., La Serena, Chile; rodrigo.hinojosa@noirlab.edu

Received 2021 January 6; revised 2021 May 31; accepted 2021 June 2; published 2021 October 4

Abstract

We report initial results of a large radial velocity survey of K dwarfs up to a distance of 50 pc from the solar system, to look for stellar, brown dwarf, and Jovian planets using radial velocities from the CHIRON spectrograph on the CTIO/SMARTS 1.5 m telescope. We identify three new exoplanet candidates orbiting host stars in the K dwarf survey and confirm a hot Jupiter from TESS orbiting TOI 129. Our techniques are confirmed via five additional known exoplanet orbiting K dwarfs, bringing the number of orbital solutions presented here to 9, each hosting an exoplanet candidate with a minimum mass of 0.5–3.0 M_{Jup} . In addition, we provide a list of 186 nearby K dwarfs with no detected close companions that are ideal for more sensitive searches for lower-mass planets. This set of stars is used to determine CHIRON’s efficiency, stability, and performance for radial velocity work. For K dwarfs with $V = 7\text{--}12$, we reach radial velocity precisions of 5–20 ms^{-1} under a wide range of observing conditions. We demonstrate the stability of CHIRON over hours, weeks, and years using radial velocity standards, and describe instrumental capabilities and operation modes available for potential users.

Unified Astronomy Thesaurus concepts: [Astronomical techniques \(1684\)](#); [Extrasolar gaseous giant planets \(509\)](#); [Radial velocity \(1332\)](#); [Solar neighborhood \(1509\)](#); [Surveys \(1671\)](#)

1. Introduction

The field of exoplanet discovery has advanced quickly, from the first detections of planets (Latham et al. 1989; Wolszczan & Frail 1992; Mayor & Queloz 1995) to large-scale transit surveys from space transits such as Kepler (Borucki et al. 2010), CoRoT (Baglin et al. 2006), and TESS (Ricker et al. 2014). This paper is concerned primarily with large scale radial velocity (RV) surveys targeting 1000 stars or more, such as the Lick/Keck survey (Butler et al. 2017) and the CORAVEL/HARPS survey (Mayor et al. 2011), which provide key statistics about the formation of stellar and planetary systems. Such large surveys enable ensemble studies to complement individual discoveries, but they are also valuable in the evaluation of observing facilities, techniques, and results. In this spirit, here we provide results from the CHIRON spectrograph on the CTIO/SMARTS 1.5 m (Tokovinin et al. 2013), which is being used as part of a multifaceted survey of more than 5000 of the nearest K dwarfs.

High-resolution spectrographs used for precise RV work are critical components of exoplanet surveys and are particularly relevant now owing to their symbiosis with transit survey instruments on both the ground and in space that are used to detect and characterize planetary systems. In the southern hemisphere there have been at least eight spectrographs precise enough to detect giant planets, operated in various mixtures of classical and queue observations, with or without assistance from the instruments’ Principal Investigators (PIs). These instruments include HARPS (Mayor et al. 2003) at ESO La Silla 3.6 m Telescope, FEROS (Kaufer & Pasquini 1998) and CORALIE (former ELODIE; Baranne et al. 1996) at ESO La Silla Swiss 1.2 m Leonhard Euler Telescope, PFS (Crane et al. 2006) and MIKE (Bernstein et al. 2003) at Las Campanas

Observatory 6.5 m Magellan II Telescope, FIDEOS (Tala et al. 2014) at ESO La Silla 1 m Telescope, and Veloce Rosso (Gilbert et al. 2018) at the Anglo-Australian Telescope. In this paper, we describe initial science results from our RV search for companions orbiting the nearest K dwarfs carried out at the Cerro Tololo Inter-American Observatory (CTIO) in Chile and provide details about CHIRON operations that are useful for those searching for exoplanets, driven in particular by NASA’s TESS mission.

Since 1994, the RECONS group has been studying the nearest stars (Henry et al. 1997), with various scientific investigations focused on horizons spanning 10–100 pc. One of the key results is that the population of stars in the solar neighborhood is dominated by stars smaller than the Sun, with M dwarfs accounting for 75% of all stars, followed by K dwarfs at 12% (Henry et al. 2006, 2018, with updates at www.recons.org). The K dwarfs are the focus of this paper, as they lie in a sweet spot in between the shorter-lived, rarer G dwarfs (5% of the population) and the magnetically active M dwarfs, making them arguably the most suitable hosts for long-term, biologically active planets (Cuntz & Guinan 2016).

In this paper we discuss first results of a survey of several hundred K dwarfs using the CHIRON instrument on the CTIO/SMARTS 1.5 m telescope. CHIRON is being used as part of NASA’s efforts to follow-up TESS exoplanet detections and for individual PI spectroscopic surveys of nearby K and M dwarfs. We provide key statistics on the capabilities of CHIRON for K dwarfs with magnitudes of $\sim 8\text{--}11$ using a set of presumably single stars, resulting in typical RV precisions of 5–20 ms^{-1} . In addition, we present results for giant planets detected orbiting K dwarfs, including (a) five previously known planets used to check our observing

Table 1
Modes Available for Observing with CHIRON

Slit Mode	Binning	R	Throughput	Element Size
Fiber	4×4	28,000	1.00	4000 ms^{-1}
Slicer	3×1	80,000	0.75	1000 ms^{-1}
Slit	3×1	90,000	0.40	1000 ms^{-1}
Narrow slit	3×1	136,000	0.20	1000 ms^{-1}

Note. The K dwarf survey described in this paper uses slicer mode.

protocols, reduction techniques, and overall CHIRON performance; (b) a detection of a planet orbiting NLTT 58744 (hereafter HIP 65) from TESS (TOI 129); and (c) three candidate planets orbiting the K dwarfs HIP 5763, HIP 34222, and HIP 86221 in our larger survey.

2. CHIRON Operations

The CTIO/SMARTS 1.5 m telescope has been operated by the SMARTS Consortium (Subasavage et al. 2010) since 2003. The telescope is primarily operated by on-site CTIO/SMARTS staff observers, although occasional runs are done by individual SMARTS Consortium members. The 1.5 m has had a few different instruments available since SMARTS began, but the primary instrument over the past decade, and the only one operating since 2015, is the CHIRON high-resolution spectrograph (Tokovinin et al. 2013). CHIRON has been operational since 2011, it was upgraded in 2012, and it was used until the 1.5 m closed in 2016, when the primary observing program at the time ended. The 1.5 m was reopened in 2017 June via an effort by RECONS team members Paredes and Henry working closely with CTIO staff members, and the 1.5 m has now been operating exclusively with CHIRON for 3 yr.

2.1. Observing Queue Management

Since 2017 June, the RECONS team has overseen the management and operations of the 1.5 m and CHIRON. This includes scientific support, the construction of observing queues, data processing, and data distribution. Queue management is carried out via a web-based platform chiron.astro.gsu.edu, in which time allocations, target requests, desired observing cadences, and on-site telescope operations are fully integrated. Programs from users who purchase observing time and those awarded time via the NOAO/NOIRLab and Chilean TACs are scheduled simultaneously.

Once observing time is allocated, PIs and their collaborators access the queue management platform to submit their targets and observing requirements, managing the use of the observing time that they have been granted. Our queue management team then sorts the various observing requests from multiple PIs to create the nightly schedule, and the observing sequence is executed by a CTIO/SMARTS observer using the same web-based platform. The observer is able to add, remove, or re-sequence observations as sky conditions permit and can complete the arc of some science programs through a seven-night shift or prepare the next shift's observer to carry on longer programs. From 2017 October through 2019 July, the facility was operated every other week; beginning in 2019 August, operations expanded to full-time nightly coverage.

2.2. Telescope Operations

A typical night of CHIRON operations starts with a fixed set of calibrations for all observing modes, detailed in Table 1, that commence in the afternoon. At astronomical twilight, the on-site observer accesses the night's observing schedule using the web platform and executes the plan, reporting back the status and/or any issues that may affect the observations. For some programs, an Atlanta-based team member at Georgia State University is available in real time to assist in interpretation of the science requirements. The web platform is directly connected with the instrument controller; therefore, on each target acquired the requested instrument setup is passed directly and efficiently to the instrument and telescope control system (TCS), minimizing time spent and configuration errors. At the end of the night, another fixed set of calibrations is secured. More details are explained in Brewer et al. (2014).

2.3. Data Reduction and Distribution

The raw data and calibration files are backed up and transferred for processing daily to computer facilities in Atlanta. The files consist of 2D CCD frames containing the echelle orders and header information, where telescope, ephemerides, spectrograph, and exposure meter (EM) data are recorded. The default data processing consists of bias and flat-field corrections, cosmic-ray removal, echelle order extractions, and wavelength calibrations using ThAr comparison lamps.⁵ The algorithms used are based on the REDUCE IDL package (Piskunov & Valenti 2002) and were adapted to CHIRON data with the application of deriving precise RV measurements. Reduced data are produced in FITS file format, containing for each extracted order the flux in photoelectrons and topocentric wavelength in angstroms per pixel. Additional specifics of the data reduction process are described in detail in Tokovinin et al. (2013). Once a night of observations is fully processed, calibration files, raw data, logs, and reduced data are grouped into individual PI programs and placed in secure directories on servers in Atlanta. PIs are then notified and instructed on how to retrieve their data products. Under normal operating conditions, the entire process from raw data acquisition to the delivery of fully processed data products is completed within a few days.

3. CHIRON Capabilities

Over the years, the CHIRON spectrograph on the 1.5 m has been used to pursue a wide variety of scientific goals, but it was envisioned as an instrument to measure RVs precise enough to detect planets orbiting bright stars (Giguere et al. 2015). Other science goals accomplished with CHIRON data have involved optical spectral characterization of a variety of astrophysical objects, such as the atmospheres of bright stars and novae (Giguere et al. 2016; Munari & Walter 2016). The results we present here aim to describe the performance capabilities of CHIRON for measuring RVs.

3.1. Specifications and Setup Options

CHIRON is able to cover an optical wavelength range between 415 and 880 nm divided into spectral orders from 136

⁵ An iodine cell is available, but few CHIRON PIs have used the iodine cell since reopening and wavelength calibrations based on iodine lines are not part of routine operations.

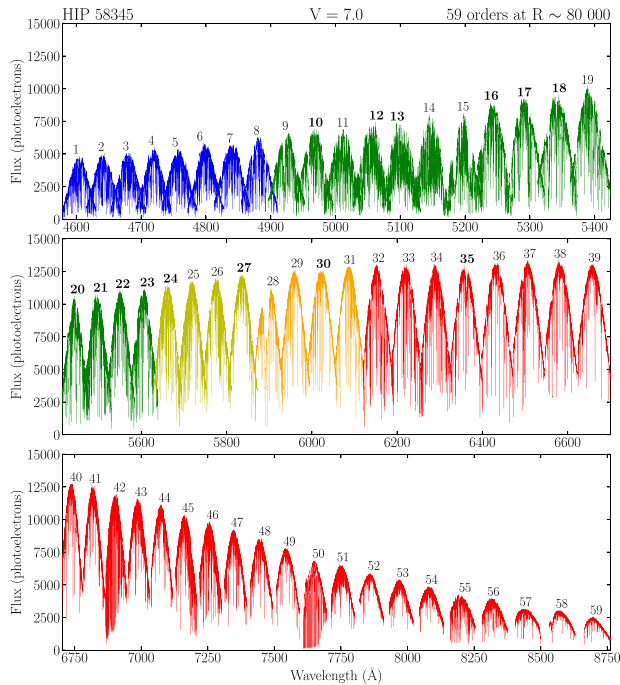


Figure 1. 59 echelle spectral orders in slicer mode ($R \sim 80,000$) for the K dwarf HIP 58345 extracted by the CHIRON basic reduction pipeline. A fixed set of 14 of these orders (highlighted) are used to derive our RVs.

to 66 and is able to acquire targets up to ~ 18 mag through a fiber that is $2''7$ in diameter in the sky. The primary resource for details about CHIRON is Tokovinin et al. (2013), which outlines the four different slit setups available, ranging in resolution from 28,000 to 136,000 (details given in Table 1). A user’s choice of setup is dependent on science goals and target brightnesses.

CHIRON offers two wavelength calibration options: a ThAr comparison lamp and an iodine cell. The latter can be used to achieve instrumental precision below 5 ms^{-1} on targets brighter than $V \sim 6$, at the expense of requiring large amounts of observing time to reach a sufficient signal-to-noise ratio (S/N) for such precision. The work we present here utilizes the ThAr lamp for wavelength calibration, which is more versatile than the iodine cell and is the most popular among users.

3.2. CHIRON Setup for the K Dwarf Program

The K dwarfs are being observed with CHIRON in slicer mode, which provides a resolution of 80,000 and spreads the spectrum into 59 orders. Integration times are uniformly set to 900 s, except for a few stars brighter than $V \sim 6$, for which the exposure is typically stopped when the S/N reaches 100 at 5500 Å. After each science exposure, a single ThAr lamp exposure of 0.4 s is taken to use for wavelength calibration. In poor seeing or partial cloud cover, the 900 s integration time is maintained in an effort to permit coverage of targets in the large program and to provide insight into how precision changes under various sky conditions. The consistent 900 s integration times for stars with $V \sim 6$ –12 also enable straightforward evaluations of the changes in RV precision with magnitude, as well as permitting direct comparisons of fluxes received for individual stars throughout their coverage during the survey.

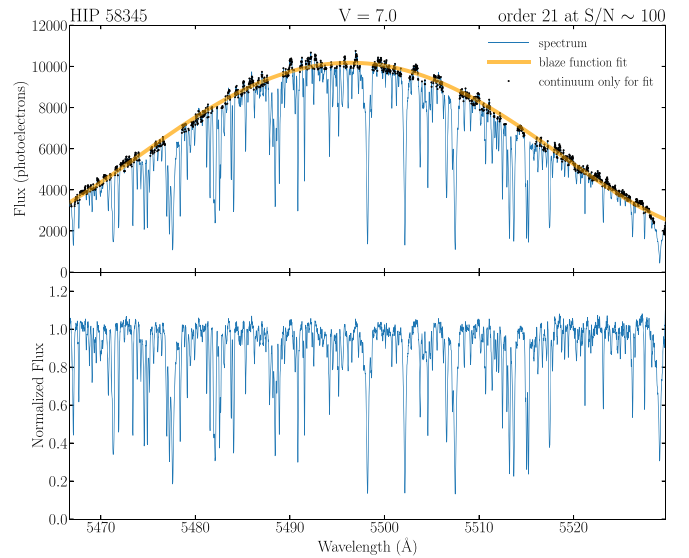


Figure 2. Spectrum of order 21 (~ 5460 – 5530 Å) of HIP 58345 taken in slicer mode ($R \sim 80,000$) at S/N ~ 100 . Top: spectrum before the removal of the blaze function, where the black circles are the data points from the original spectrum (blue line) used to fit the blaze function (yellow line). Bottom: normalized spectrum after the removal of the blaze function.

3.3. Radial Velocity Pipeline

A pipeline (hereafter the RV pipeline) was developed in Python by this group to process uniformly large volumes of spectra taken with CHIRON to extract RVs. It was optimized specifically for our K dwarf survey at the 1.5 m and follows a recipe that has nine steps.

1. *Input spectra.* Each wavelength-calibrated spectrum (Figure 1) enters the RV pipeline once it has been confirmed to have the proper target identification, as well as correct observational parameters, such as coordinates, hour angle, time of exposure, and air mass.
2. *Flattening spectra.* The removal of the blaze function embedded on each order of echelle spectra is crucial for extracting precise RVs. The Doppler information contained in the spectrum is most valuable in regions where changes in the slope of the flux per wavelength are steepest, i.e., for sharp lines. The flattening process starts with a recursive sigma clipping algorithm to remove the spectral lines over subsections of the order to be able to map the continuum. Subsequently, a fifth-order polynomial is fitted using the remaining data points of the order. Finally, the original unfiltered spectral order is divided by the fitted blaze function to get the flattened normalized version (Figure 2). Removing the blaze function to flatten each order ensures that Doppler shifts are the result of shifting lines due to a star’s velocity, rather than from changes in the instrument response along the order. Figure 3 illustrates three spectral regions after removing the blaze function and normalization. These spectral regions include many key features found in K dwarf spectra: Cr I, Fe I, H α , Li I, Na I, and Ti I.
3. *Barycentric correction.* The motion of Earth around the barycenter of the solar system produces a large ($\pm 30 \text{ km s}^{-1}$) Doppler oscillation present in all sequences of spectra. These variations must be removed with high precision to derive the final RVs for a targeted star. We use the algorithm “barycorr” by Wright & Eastman (2014),

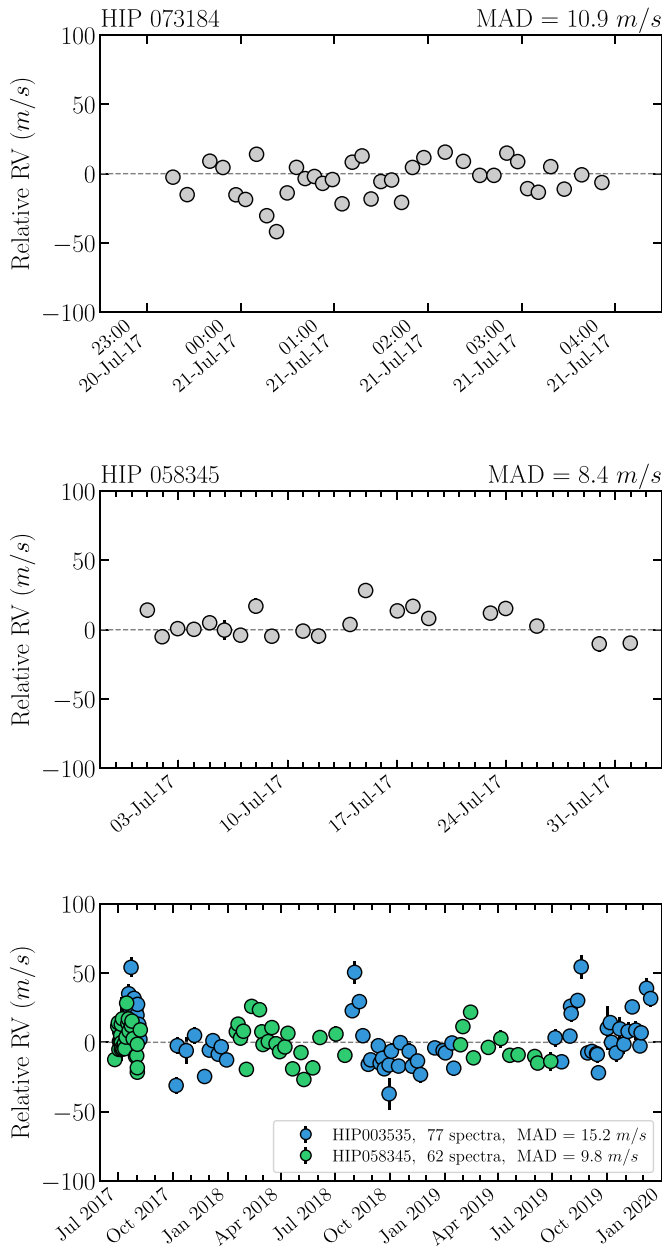


Figure 4. Three K dwarfs used as RV standards to monitor the stability of CHIRON. Top: HIP 73184 observed for ~ 4.5 hr on a single night. Middle: HIP 58345 observed roughly once per night for a month; skipped nights were due to unfavorable weather conditions. Bottom: HIP 3535 and HIP 58345 observed between 2017 June and 2019 December with a typical cadence of one observation every 7–10 days.

were selected because they had data from previous RV programs indicating that they have variations of only $3\text{--}7\text{ ms}^{-1}$ over years (Butler et al. 2017), sufficiently low for our purposes to consider them RV standard stars. Results for all three stars are shown in Figure 4 and with RV data listed in Table A1. There are occasional outlier points, in particular for HIP 3535, the faintest of the three standards.

The error associated with each RV measured on a night is tightly correlated with the photon flux received by the CHIRON detector and relates to the variance across the 14 orders for which individual RVs are extracted, but as can be seen in the time series for HIP 3535, for example, the dispersion as measured by the mean absolute deviation (MAD)

of the points overall (15 ms^{-1}) is larger than errors on most of the individual points (typically $3\text{--}10\text{ ms}^{-1}$). The roughly factor of two difference is presumably due to systematic errors, with the leading culprits being changes in the focus of lines on the CCD and temperature fluctuations inside the chamber that houses the CHIRON instrument.

Once multiple spectra are available for a given star, the MAD is calculated for all available spectra, which is ~ 0.8 times the standard deviation of normally distributed data. It is the MAD values for various stars that are given in the panels of Figure 4 and reported henceforth in this paper. We emphasize that these results are for K dwarfs observed during our survey; other types of stars will not necessarily provide similar results, i.e., hotter stars with fewer lines available for RV extraction, or rapidly rotating stars with broad lines.

1. *Stability over hours:* HIP 73184 was observed 36 times on the night of 2017 July 17 to test the stability of CHIRON over a period of ~ 4.5 hr. Observations were taken on a clear night with seeing of $0''.7\text{--}1''.0$, while the air mass changed from 1.012 to 1.674. The top panel of Figure 4 shows that the MAD is 10.9 ms^{-1} during the series of observations.
2. *Stability over 1 month:* As shown in the middle panel of Figure 4, HIP 58345 was observed on 21 nights over a 1 month period in 2017. There are few RV measurements lying far from the mean value, with a resulting MAD of 9.8 ms^{-1} for the data series. This MAD is likely lower than that for HIP 3535 on a single night simply because HIP 58345 is a magnitude brighter in V.
3. *Stability over 2+ yr:* The bottom panel of Figure 4 includes data sequences for HIP 3535 (77 spectra, MAD value 15.2 ms^{-1}) and HIP 58345 (62 spectra, MAD 9.8 ms^{-1}) together, as observations are dovetailed throughout the year to provide an unbroken series of RV standard observations. It is evident that there are several stretches of time when RV offsets are found in the HIP 3535 data sequence. We have examined various quantities in an attempt to reveal the cause(s) of the offsets for individual measurements. It appears that the drifts in the HIP 3535 data are *not* caused solely by (a) varying S/N in the spectra (primarily because nearly all spectra, 62 out of 77, have $S/N > 50$; out of the 15 RVs where the S/N is below 50, only four deviate by more than 15 ms^{-1} from the mean), (b) air mass, and (c) temperature changes in the coudé room where CHIRON is housed. We suspect that the poorer precision is due to shifts in the final spectral resolution: values computed from the individual spectra indicate that when the resolution dips by more than $\sim 1\%$, the final RV points are offset. Resolution offsets occur when the focus of the spectrum onto the CCD drifts slightly, and this shows that it is critical to keep the lines consistently as narrow as possible on the chip. In addition, we find a correlation between the most deviated RVs from the mean ($>15\text{ ms}^{-1}$) and their individual uncertainties. This is consistent with the fact that our error bars reflect mostly photon noise in combination with instrumental errors, but having bright stars in this case, the latter reason seems to dominate.

In summary, for K dwarfs with $V = 7\text{--}12$, the data indicate that CHIRON is stable to $5\text{--}20\text{ ms}^{-1}$ over timescales of hours, 1 month, and more than 2 yr.

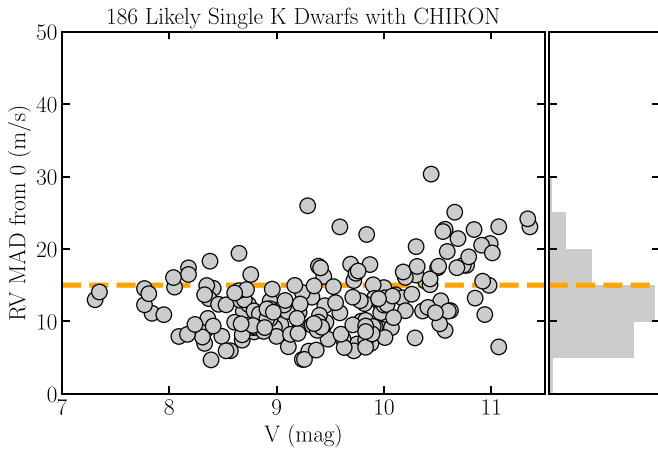


Figure 5. Dependence of the scatter in the RV time series on the V magnitude for each of the 186 K dwarfs with no Keplerian RV signal (Table A3). The right panel groups data points in bins of 5 ms^{-1} , indicating that 75% of RV MADs are below 15 ms^{-1} (dashed line), with the best series as low as 5 ms^{-1} .

4. K Dwarf Survey and Observations

4.1. Sample

The observed stars are a portion of an effort targeting more than 5000 K dwarfs within 50 pc; details about the full sample will be given in a future paper in this series. The particular subset observed here includes 190 stars selected from Hipparcos (van Leeuwen 2007) to have parallaxes of at least 30 mas, placing them within 33 pc of the Sun, and that have decl. between $+30^\circ$ and -30° . This equatorial sample has been selected so that each star can be observed from major observatories in both hemispheres. Sample star observations began before Gaia Data Release 2 (Evans et al. 2018) results were available; hence, stars closer than the sample horizon entered the observing list using Hipparcos parallaxes.

Stars of spectral type K were chosen using an assessment of the regions where dividing lines between the G/K and K/M spectral types are found, with types determined by Gray & Corbally (2009) and RECONS. To define the blue and red ends of the K dwarf sequence, stars with spectral types were matched to members of the RECONS 25 pc sample that have been carefully vetted for close companions, enabling us to use presumably single stars uncorrupted by close companions to map K dwarf spectral types to $V-K$ colors. We find that K dwarfs span $V-K=1.90-3.70$, and we apply an additional constraint of $M_V=5.80-8.80$ to eliminate evolved stars and white dwarfs. The $V-K$ values were accumulated for the sample stars using V from Tycho (Høg et al. 2000) and K from the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006). The resulting list of 300 stars includes 110 that have stellar companions (either published by others or to be published by us) and/or have at least 10 RV measurements found in the data archives of HARPS (Mayor et al. 2003) and HIRES (Vogt et al. 1994). The remaining 190 stars compose the sample discussed here and are (a) within 33 pc, (b) located in the equatorial region of the sky, (c) have colors and absolute magnitudes of K dwarfs, and (d) have not been observed extensively, if at all, in previous RV programs.

The sample is presented in Table A3, including 186 K dwarfs for which no companion has been detected with RV and four stars with new Jovian exoplanet candidates. In addition, we provide results for nine more stars: one K dwarf from TESS

discovered to have a planet, five K dwarfs with previously known planet candidates used as checks on our observing and reduction methodologies, and the three K dwarfs used as RV standards discussed in Section 3.4. For all 199 stars, Table A3 provides names, coordinates, V photometry from Tycho (Høg et al. 2000), K_s photometry from 2MASS (Skrutskie et al. 2006), B_g and R_g photometry from Gaia (Evans et al. 2018), the number and time coverage of the RV observations, and the MAD values for the RV series.

4.2. Observations and Radial Velocity Precision

Our RV search is designed to perform a systematic reconnaissance for companions, so each K dwarf in our sample gets at least six, and ideally nine, observations using the slicer instrument setup described in Section 3.2. The observing cadence goal is to secure two to three spectra within 7 days, then repeat the sequence after a month, and then repeat it again after a year. The MAD values for the sequences of spectra for 186 stars for which we do not find periodic RV variations with CHIRON are illustrated in Figure 5 and listed in Table A3. Given that Jupiter-mass planets in (edge-on) orbits with periods of 10–100 days around K dwarfs cause RV variations of $\sim 40-100 \text{ ms}^{-1}$, it is clear that CHIRON is precise enough to detect Jupiter-mass exoplanets orbiting virtually all of the targeted K dwarfs.

For observational planning, it is useful to examine CHIRON’s precision as a function of target brightness. Figure 5 illustrates the dependence of the scatter for the RV time series using the MAD values versus V magnitudes of the K dwarfs whose RV curve is flat, i.e., they do not show periodic variation or a trend in their RVs over time. For our observing and data reduction protocols, we reach precisions of $5-15 \text{ ms}^{-1}$ for $V=7.0-10.5$, with slightly poorer precision for $V=10.5-11.5$; therefore, the points above $\sim 20 \text{ ms}^{-1}$ in the plot may, in fact, be as-yet-unidentified perturbations or young active stars, and they may be worthy of a closer look; additional observations are planned for these stars.

In addition to mapping the dependence of RV precision with target brightness, because sky conditions and telescope tracking vary, it is useful to map the precision as a function of the S/N for individual spectra (as measured by CHIRON’s exposure meter during an observation). Figure 6 relates the S/N values for 1784 individual spectra of the 186 K dwarfs to the resulting RV uncertainties. Overall, for S/N values of at least 40, the uncertainties are less than 15 ms^{-1} , whereas for S/N ~ 20 , the uncertainties increase to 30 ms^{-1} and above. It is therefore recommended that to reach a precision of 15 ms^{-1} in slicer mode with CHIRON, observers targeting K dwarfs or similar stars anticipate exposure times of 900 s (our standard exposure time) for stars with $V \lesssim 10.5$. As a rule of thumb, to obtain a single measurement error in RV of $\sim 5 \text{ ms}^{-1}$, it is necessary to reach S/N ~ 100 at $5500 \text{ \AA}$. This is possible for a K dwarf brighter than $V \sim 9$ in 900 s exposure in slicer mode. Overall, for stars like those observed in our program, the expected precision can be predicted using

$$\sigma_{\text{RV}} \sim \frac{10,000}{\text{S/N}^2} + 4 \text{ ms}^{-1}. \quad (1)$$

The S/N of each spectrum is computed using the counts from the exposure meter, which picks off about 1% of the collimated light at $5450 \text{ \AA}$ with a bandwidth of $900 \text{ \AA}$ (Tokovinin et al. 2013). This S/N value maps directly to the

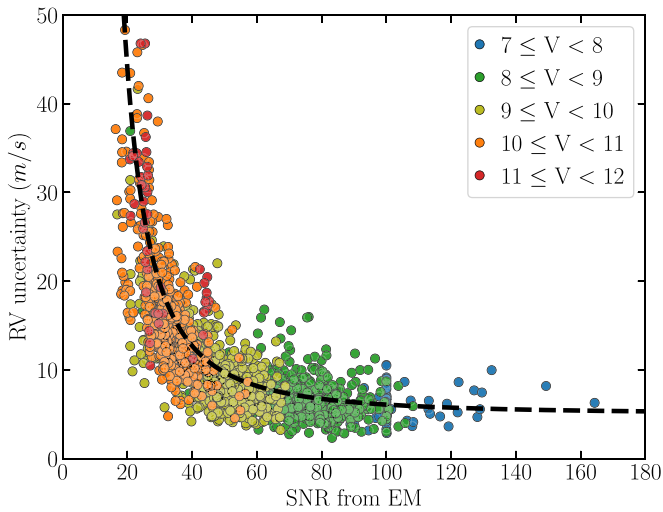


Figure 6. S/N calculated from CHIRON’s exposure meter (EM) vs. RV uncertainty for individual spectra, color-coded by stellar V magnitude. Each of the 1784 data points represents a single spectrum. The dashed line is described by Equation (1) and is derived using observations with exposure times of 900 s. The slight overabundance of points at $S/N = 100$ is the result of observations that were stopped before 900 s, when the S/N reached 100.

S/N of the raw spectra and provides a straightforward method to evaluate individual exposures. Importantly, the S/N can be tracked by an observer during an exposure to compensate for cloud cover, seeing, and telescope tracking, all of which can affect how much light is injected into the fiber. As a result, an observer can actively stop or extend an integration to reach a desired S/N . For example, the collection of vertical points at $S/N = 100$ represents observations of relatively bright stars for which exposures were stopped before 900 s. The relation to convert from exposure meter counts to S/N is given by

$$S/N = \sqrt{\frac{EMNUMSMP \times EMAVG - 7401.973}{57.909}}, \quad (2)$$

where $EMNUMSMP$ is the number of samples of a tenth of a second during the exposure and $EMAVG$ is the average instant number of photon counts during the exposure; both are recorded as header entries with these names for each spectrum taken.

As outlined in Section 3.3, the individual RV measurements have been determined using the weighted standard error of the RVs measured for the 14 orders adopted in the pipeline. While there are other errors, such as systematic instrumental offsets to be considered in future work when larger data sets are available, for this characterization of our K dwarf survey prospects we report errors that are only the result of the statistical results based on individual RVs extracted from the 14 different orders. As expected, the RV errors are lower for brighter stars and higher- S/N spectra.

Finally, because our sample stars span $\text{decl.} = -30^\circ$ to $+30^\circ$, we observe stars with air masses of 1.0–2.0 from CTIO. Although not every observation is timed precisely when a star passes through the meridian, most observations occur near transit, and a plot of air mass versus RV uncertainty is useful to understand whether or not high air-mass observations yield lower RV precision. Figure 7 illustrates that the RV uncertainty is independent of the air mass, a result that is particularly encouraging because stars north of $\text{decl.} = 0$ can be observed with CHIRON as effectively as more southern stars. This also bodes well for individual targets for which many observations

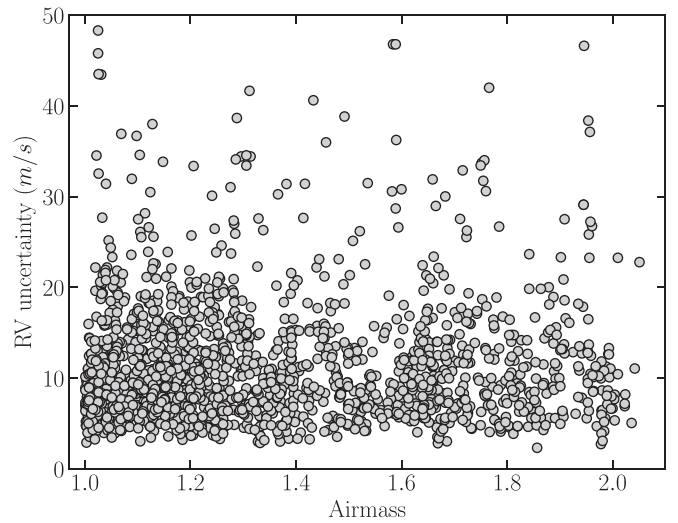


Figure 7. Air mass versus RV uncertainty per spectrum. Typically, targets are observed when they are close to the meridian passage, but this is not always possible owing to scheduling constraints. It is clear that RV uncertainty is not systematically affected by the air mass at which the K dwarfs have been observed.

are desired over the span of a single night, given that RV uncertainties are consistent over a large range of air mass.

5. Results

Over the past two decades, more than 4300 planets orbiting other stars have been detected and confirmed (as listed in the NASA Exoplanet Archive, exoplanetarchive.ipac.caltech.edu as of 2021 May), including more than 3300 revealed via the exoplanet transit method. The greatest contributor of transiting exoplanets has been the Kepler mission (Borucki et al. 2010), which was extended via the K2 effort (Howell et al. 2014). Together, Kepler and K2 have revealed thousands of exoplanet candidates, and TESS continues to add to the candidate list. Among the finds are terrestrial, ice giant, and gas giant planets, with orbital periods ranging from hours to years. Most relevant to the work presented here, given the precision of CHIRON and the duration of the survey, are planet candidates with masses of $0.3 M_{\text{Jup}} < m \sin i < 10 M_{\text{Jup}}$ and orbital periods of $P < 180$ days. As of 23) 2021 May, a search of the NASA Exoplanet Archive yields 93 stellar hosts within 100 pc with at least one confirmed exoplanet that meets these criteria.

Many of the exoplanets revealed during the transit surveys are followed up using RVs to confirm that the object is, indeed, a planet orbiting the star identified to exhibit the transit. In addition, there have been more than 800 candidates detected during RV surveys that do not transit. Here we discuss nine K dwarfs that are orbited by low-mass companions that are exoplanet candidates. A total of 240 individual measured RVs from CHIRON are given for these nine stars in Table A2, ordered by Hipparcos number.

The orbital fits for all nine systems are shown in Figure 8. Our orbits have been derived using the code *Systemic2* (Meschiari et al. 2009),⁶ which provides a functional interface that can be used to calculate Lomb–Scargle periodograms and to explore orbital fits interactively given a set of RV data. All plots have zero phase defined to be at the epoch of periastron. Our calculated RVs are input into the code, and the

⁶ github.com/stefano-meschiari/Systemic2

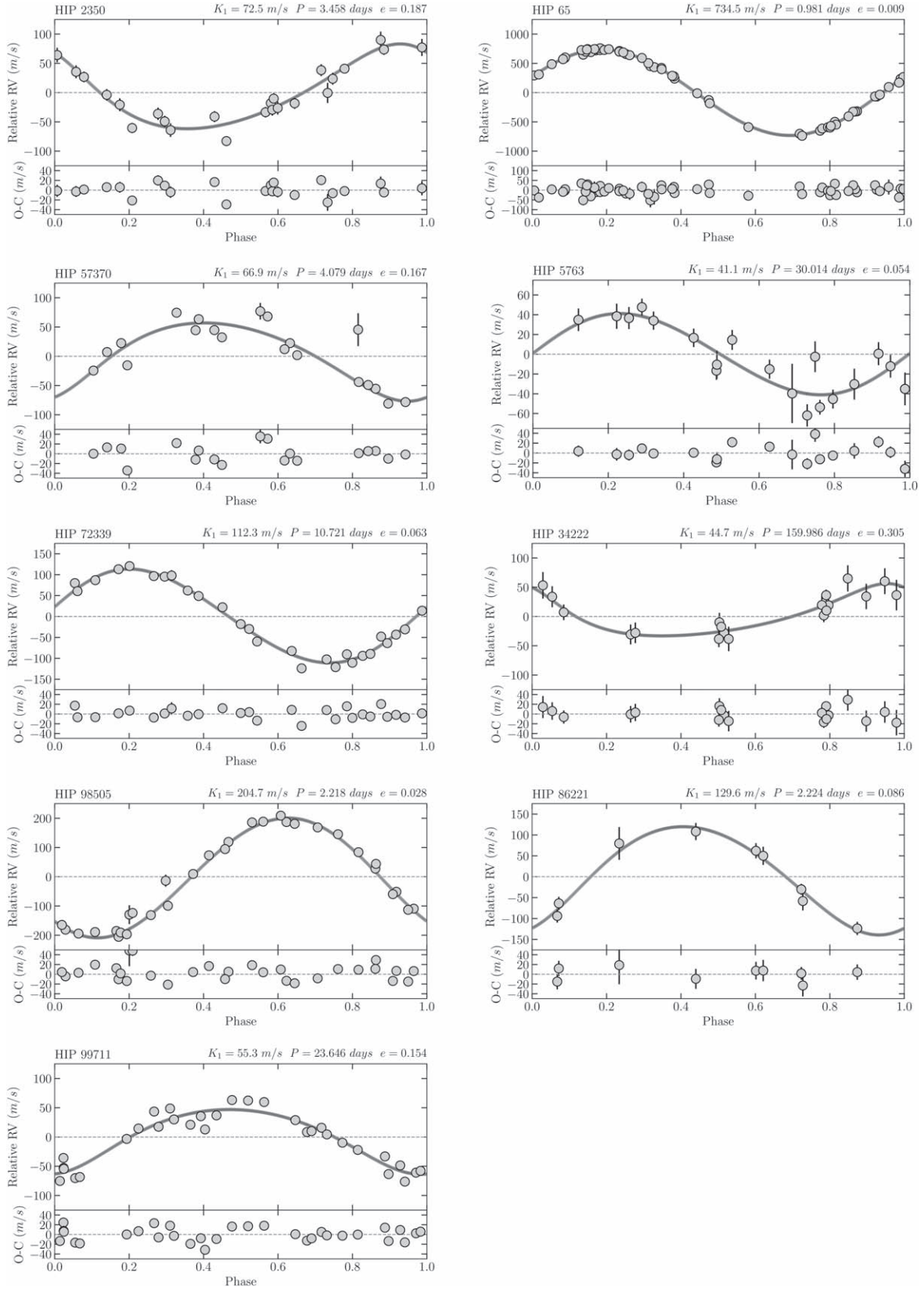


Figure 8. Phase-folded RV curves and residuals derived from CHIRON spectra. Phase zero indicates the time of the periastron passage (T_p). Left column: five planets known to orbit K dwarfs. Right column: four new planet candidates around K dwarfs.

periodogram is inspected for prominent peaks above the 10% false-alarm probability (FAP) level. We avoid those peaks that match the nightly cadence and total baseline of the observations

because they are caused by sampling aliases. Keplerian orbits are then fit for each of ~ 5 strongest peaks and the results inspected by eye. Initial fits are made using circular orbits in

Table 2
Orbital Parameters of Exoplanet Candidates

Star	M_* $M_\odot$	Period (days)	$m \sin i$ (M_{Jup})	e	ω (deg)	K (ms^{-1})	a (au)	T_p (JD $-2,450,000$)	rms (ms^{-1})	Data Points	References
Previously Known Exoplanet Systems											
HIP 2350	0.92	$3.458^{+0.0081}_{-0.0083}$	0.50	0.187	37.28	$72.5^{+4.6}_{-4.4}$	0.044	7948.482	12.8	24	this work
	0.93	3.444	0.48	0.000	126.90	67.4	0.044	3323.206	...	28	Moutou et al. (2005)
HIP 57370	0.92	$4.079^{+0.0142}_{-0.0146}$	0.49	0.167	206.16	$66.9^{+3.5}_{-3.3}$	0.049	7933.659	26.1	20	this work
	0.93	4.114	0.49	<0.140	143.40	63.4	0.049	3732.700	16.0	59	Ge et al. (2006)
HIP 72339	0.85	$10.721^{+0.0033}_{-0.0031}$	1.09	0.063	281.05	$112.3^{+4.6}_{-4.5}$	0.090	7928.965	9.9	28	this work
	0.79	10.720	1.02	0.044	203.63	115.0	0.088	1287.380	15.4	118	Udry et al. (2000)
HIP 98505	0.84	$2.218^{+0.0010}_{-0.0009}$	1.17	0.028	136.42	$204.7^{+2.6}_{-2.5}$	0.031	7929.288	21.5	31	this work
	0.82	2.219	1.15	0 (fix)	...	205.0	0.031	...	...	35	Bouchy et al. (2005)
HIP 99711	0.74	$23.646^{+0.2304}_{-0.2082}$	0.63	0.154	188.21	$55.3^{+2.1}_{-2.2}$	0.146	7912.820	13.5	32	this work
	0.75	24.348	0.72	0 (fix)	0.00	61.0	0.150	...	...	182	Santos et al. (2003)
TESS Exoplanet System											
HIP 65	0.74	0.981 (fix)	2.95	0.009	291.42	$734.6^{+4.6}_{-4.5}$	0.017	8368.833	20.4	58	this work
	0.78	0.981	3.21	0 (fix)	...	753.7	0.017	...	...	34	Nielsen et al. (2020)
New Candidate Exoplanet Systems											
HIP 5763	0.72	$30.014^{+0.1528}_{-0.2842}$	0.51	0.054	271.08	$41.1^{+8.8}_{-11.2}$	0.170	8056.731	16.2	19	this work
HIP 34222	0.62	$159.986^{+2.6753}_{-2.9256}$	0.83	0.305	31.80	$44.7^{+9.1}_{-8.3}$	0.492	8023.220	12.7	19	this work
HIP 86221	0.79	$2.224^{+0.0004}_{-0.0005}$	0.71	0.086	208.93	$129.6^{+34.5}_{-19.6}$	0.031	7947.283	12.8	9	this work

order to avoid very high eccentricity orbits that may fit the data sets but are astrophysically unlikely. Step sizes of 0.001 days are used to fine-tune the orbital period, while the fitting process is carried out using chi-square minimization until each orbit fit converges, determined when the rms of the fit reaches $\sim 20 \text{ ms}^{-1}$. We have chosen this limit given the typical RV scatter and uncertainties seen for the 186 K dwarfs with no detected companions, as shown in Figures 5 and 6. As a final step in the orbital parameter determinations, we derive the intervals of confidence for parameters using MCMC simulations also included in the Systemic2 code, starting with the model best fitted, a total of $\sim 10,000$ steps, in two chains, and skipping the first 1000 iterations. Errors are not listed for previous orbital parameters because they are a mix of different types of errors.

Table 2 includes the orbital parameters and errors for all nine K dwarf + exoplanet systems highlighted here. To estimate the companion $m \sin i$ values, masses for the primary stars have been derived using V magnitudes converted from V_T magnitudes (Høg et al. 2000) and the mass–luminosity relation in M_V of Henry & McCarthy (1993). A future paper is planned to provide a much-needed update to the mass–luminosity relation for K dwarfs using empirically determined masses.

5.1. Known Planets Orbiting K Dwarfs

Here we provide five examples of previously known planet candidates orbiting K dwarfs revealed via RVs. All five are (presumed) single-planet systems chosen during the initial reopening of the CTIO/SMARTS 1.5 m in 2017 June to serve as test targets to verify the efficacy of CHIRON under typical observing protocols. The instrument setup, data reduction, and RV calculation methods were as described in Sections 3.1–3.3 for all of the stars. Each of the new orbital solutions presented here has been calculated solely based on the CHIRON observations and therefore is independent of previously reported solutions found in the literature.

5.1.1. HIP 2350

This star ($V=9.37$, K1V) was reported by Moutou et al. (2005) to have a hot Jupiter of minimum mass $0.48 M_{\text{Jup}}$ with an orbital period of 3.444 days. We obtained 24 spectra of HIP 2350 between 2017 July 16 and August 08 and confirm a $0.50 M_{\text{Jup}}$ minimum-mass planet with an orbital period of 3.458 days, consistent with the previous result. The 73 ms^{-1} RV semiamplitude is ~ 7 times larger than the typical uncertainty for K dwarfs in our program, indicating that hot Jupiters of this type are easily revealed by CHIRON. HIP 2350 has a lower-mass stellar companion detected with RoboAO at Palomar (Baranec et al. 2012) at a separation of $0''.5$ and fainter by 3.3 mag at 754 nm (Sloan i' filter) by Riddle et al. (2015) and Roberts et al. (2015). The companion was confirmed with DSSI at Gemini North (Horch et al. 2009) at a separation of $0''.5$ and fainter by 3.8 mag at 692 nm (Wittrock et al. 2016). The companion is likely an M1V with an estimated orbital period of ~ 130 yr from the projected separation, and it should not pose a serious threat to the detection, nor the orbital stability of the planet. Shaya & Olling (2011) and later Oh et al. (2017) reported HIP 2350 to be part of a comoving wide pair where the primary component is HIP 2292, another solar-type star, at projected separation of $897''$ (~ 0.2 pc). While the system could still be a wide multiple, Oh et al. (2017) also discuss the possibility that systems such as these could have formed together but are now drifting apart.

5.1.2. HIP 57370

This star ($V=8.05$, K0V) was reported by Ge et al. (2006) to have a hot Jupiter with a minimum mass $0.49 M_{\text{Jup}}$ in an orbit with a period of 4.114 days. We obtained 20 spectra of HIP 57370 between 2017 June 29 and 2017 July 26, and with the same minimum mass of $0.49 M_{\text{Jup}}$ in an orbital period of 4.079 days. The single point with a large error near phase 0.8 in the panel for this star in Figure 8 was taken at the beginning of the

night on 2017 July 26, when clouds were present and the seeing expanded to $2''.5$, resulting in poor S/N for this observation. This data point is included to illustrate the relative quality of a poor observation suffering from high photon noise error compared to more typical measurements. The lack of speckle companions (Nusdeo et al. 2018) or any known visual stellar companions makes this detection robust. Despite being a nontransiting planet, Guilluy et al. (2019) use this hot Jupiter (HD 102195 b) to demonstrate the feasibility of detailed studies of exoplanet atmospheres using the GIANO spectrograph (Oliva et al. 2006) mounted at Telescopio Nazionale Galileo (TNG), a 4 m class telescope.

5.1.3. HIP 72339

This star ($V = 8.04$, K0V) is near the celestial equator, but at $V - K_s = 1.81$ it is slightly bluer than the blue cutoff we used for our K dwarf sample; thus, it is not part of the larger survey but was observed strictly as a benchmark. This star has a known hot Jupiter with minimum mass $1.02 M_{\text{Jup}}$ and orbital period 10.720 days (Udry et al. 2000). We confirm the companion via 28 spectra to have a somewhat larger minimum mass of $1.02 M_{\text{Jup}}$ and a virtually identical orbital period of 10.721 days. Our phased RV curve spans 3.5 full orbits for data taken in 2017 from June 24 to August 7, and this is the star with a known planet for which we have the longest time coverage at 42 days. Given the RV variation caused by the companion of $K = 112 \text{ ms}^{-1}$, this Jupiter-like planet is clearly detected, indicating that CHIRON reveals such candidates easily. No visual stellar companions are known in the system, and the planet is not found to be transiting. While this system has been revisited by Wittenmyer et al. (2009) and Hinkel et al. (2015), the candidate exoplanet’s properties have not changed significantly since the initial discovery.

5.1.4. HIP 98505

We obtained 31 observations of HIP 98505 ($V = 7.66$, K2V) between 2017 June 24 and August 4, spanning 40 days, to reveal a companion with minimum mass $1.17 M_{\text{Jup}}$ in a 2.218-day orbit. This planet (HD 189733 b) was discovered by Bouchy et al. (2005) and reported to have a minimum mass of $1.15 M_{\text{Jup}}$ in a 2.219-day orbit; the system has been extensively studied since then with no significant changes in the orbital parameters. At an orbital inclination of $\sim 85^\circ$, the exoplanet transits its host star, allowing detailed determination of its fundamental parameters, which, combined with the proximity and brightness of the star, have made the system an ideal laboratory for exoplanet atmosphere studies (e.g., Redfield et al. 2008; Guilluy et al. 2020, and references therein). Bakos et al. (2006) report a lower-mass companion $11''.2$ from HIP 98505 that is 3.7 mag fainter in K_s . Using astrometry, proper motion, RV, and photometry, they derive an orbit for the stellar companion nearly perpendicular to the planet’s transiting orbit, i.e., nearly face-on. However, at a projected separation of 218 au and orbital period of 3200 yr, the orbit is highly uncertain.

5.1.5. HIP 99711

We found for this star ($V = 7.76$, K2V) a $0.63 M_{\text{Jup}}$ companion with the longest orbital period (23.646 days) and the smallest RV amplitude (55.3 ms^{-1}) of the five selected benchmark stars. Nonetheless, the RV perturbation is clear in the CHIRON data, and the values are close-enough matches to

those in the discovery paper (Santos et al. 2000). The companion (HD 192263 b) is among the earliest exoplanet candidates but was called into question by Henry et al. (2002), who argued that the RV signal detected is due to stellar magnetic activity rather than the stellar reflex motion caused by a companion. However, Santos et al. (2003) then provided further proof to improve the planet’s orbit and confirmed the discovery, which is also supported by our measurements. We suspect that the difference in the orbital solution we found is due to contamination of the RV signal by the same stellar magnetic activity that initially disputed the discovery.

5.2. New Planets Orbiting K Dwarfs

Here we discuss four candidates for giant planets orbiting nearby K dwarfs, including a contemporaneous detection of a transiting exoplanet from TESS and three new candidate exoplanets from our survey.

5.2.1. TESS Target HIP 65 (NLTT 57844)

A possible low-mass companion was found to transit HIP 65 (TOI 129, $V = 11.13$, K4V) in the first set of data released from TESS in sector 2, and later in sectors 28 and 29. At 61.9 pc, this star is beyond the 50 pc cutoff of our K dwarf survey but was observed as an early possible discovery by TESS that could be quickly verified with CHIRON data. Initial RVs were collected with CHIRON starting on 2018 September 8, and within 2 weeks of the first TESS data release.⁷ The quick turnaround was possible because of the nimble system established to acquire CHIRON observations. A total of 58 spectroscopic observations have been secured between 2018 September 8 and 2020 January 12, and we find an RV signal consistent with the TESS transit signal detected. Our analysis yields a giant planet companion with mass $2.95 M_{\text{Jup}}$ in an orbital period of 0.981 days, consistent with the orbit published by Nielsen et al. (2020). The properties of the ~ 1 day orbit and massive planet make this an excellent candidate for detailed exoplanet atmospheric studies.

5.2.2. HIP 5763

This K dwarf survey star ($V = 9.86$, K6V) shows a perturbation with a period of 30 days in the RVs due to a companion with minimum mass $0.51 M_{\text{Jup}}$. A total of 19 observations spanning 2 yr were secured between 2017 November 20 and 2019 December 17. This planet candidate has the smallest RV amplitude (41.1 ms^{-1}) of the four new detections reported here, but this amplitude is clearly offset from results for stars of similar brightness in Figure 5, indicating that the companion is likely real. In addition, the rms of the residuals to the orbital fit (16.2 ms^{-1}) is similar to the rms values we find after fitting orbits for the five known planetary systems. HIP 5763 is not known to have visual stellar companions reported in the Washington Double Star Catalog (WDS; Mason et al. 2001), nor any spectroscopic binary companions reported in The Ninth Catalogue of Spectroscopic Binary Orbits (SB9; Pourbaix et al. 2004). TESS observed this target in sector 17 from 2019 October 8 to 2019 November 2 (25 days) at 2-minute cadence; the TESS SPOC (Science Processing Operations Center) pipeline does not report transit events.

⁷ An orbit was published at www.recons.org on 2018 September 10.

5.2.3. HIP 34222

At $V = 10.23$, this K7V star is one of the fainter K dwarfs in the sample, which is reflected in the relatively large error bars on individual points. We obtained 19 spectra spread over 2 yr between 2017 December 15 and 2019 December 18. The data set indicates a possible companion with minimum mass $0.83 M_{\text{Jup}}$ in an orbit with $e = 0.301$, which is the most eccentric of the nine systems discussed here. With a derived orbital period of 160 days, the relatively high eccentricity is not precluded by tidal circularization, which happens only for systems with orbital periods less than a few weeks (Halbwachs et al. 2005); nonetheless, we consider this to be the least precise orbit presented here. The WDS reports WDS J07057+2728B as a visual companion 4.6 mag fainter at $13.5''$, but no parallax or reliable proper motion is available to confirm that it is bound to HIP 34222. Although WDS lists five stars as nearby, none are physical companions. No spectroscopic companion is listed in the SB9 catalog.

5.2.4. HIP 86221

This star ($V = 9.20$, K5V) is among the most northern in our equatorial sample, with decl. $\sim +28^\circ$. We find a classic hot Jupiter candidate in a 2.2-day orbit with minimum mass $0.71 M_{\text{Jup}}$. Although we have only nine observations to date for this star, the semiamplitude of the orbital fit, 130 ms^{-1} , is more than 10 times CHIRON’s typical MAD value for K dwarfs of this brightness, so we consider the detection secure. The HIP 86221 system is known to be a stellar triple. The AB components are separated by a few tenths of an arcsecond, with B fainter than A by 0.59 mag in the optical. A visual binary orbit has been determined for AB using astrometry and speckle interferometry, yielding a period of 23.991 yr, semimajor axis of $0''.2884$, and eccentricity 0.2053 (Mason et al. 1999; Söderhjelm 1999; Malkov et al. 2012). No spectroscopic companion is listed in the SB9 catalog. Thus, the companion we detect is not the stellar secondary and presumably orbits the primary given that the flux in the spectra is heavily weighted to the brighter primary component. The third star in the system is NLTT 45161 at a distance of $9''.4$ and is 2.26 mag fainter in the V band than the combined AB pair (Mason et al. 2001; Gould & Chanamé 2004). Among FGK dwarf systems, 12% are triple-star systems (Raghavan et al. 2010; Tokovinin 2014), and as of 37) 2021 May the NASA Exoplanet Archive reports 3260 stellar systems hosting at least one confirmed exoplanet, of which 41 are triple-star systems, making this detection rare among the known exoplanet population.

Table 2 summarizes the orbital elements for the nine systems discussed here. The values listed include the first orbits from the discovery references and our orbit. We have not added any points from other efforts to ours from CHIRON to enable direct comparisons between results. For the five stars used to check the veracity of our observing and reduction efforts with CHIRON, we find that our orbits are in good agreement with those found in the discovery papers. We note that we have been able to reach similar orbital solutions with less data compared to the discovery papers, primarily because of CHIRON’s RV precision for this type of star.

5.3. K Dwarfs for Future Low-mass Planet Surveys

In Table A3, we also provide details for the 186 K dwarfs within 50 pc for which no companion down to our sensitivity

and time coverage has been detected. In addition to names and epoch/equinox 2000.0 coordinates, each star’s parallax from Gaia DR2, V and K photometry, $V - K$ color, and M_V magnitude are given, as well as the number of observations and time span of our CHIRON observations.

Note that companions farther than a few au from their primaries are beyond the sensitivity limit of our RV survey to date—we hope to reveal most stellar companions at these separations through our high-resolution speckle survey of the same stars. The 186 stars listed should become high-priority targets for terrestrial planet searches because we now know that they do not have stellar or brown dwarf companions within a few au. In fact, cross-checks of the NASA Exoplanet Archive as of 2021 May have revealed that none of the 186 stars have confirmed planets. However, additional checks of K2 and TESS reveal that four—HIP 5286, HIP 11707, HIP 12493, and HIP 74981—have recently been added to the TESS TOI list. Still, none of these stars have significant numbers of observations in the HARPS and HIRES data archives, so each remains a promising new target for deeper and more precise searches for terrestrial planets.

6. Conclusions

We have presented the first results of our ongoing RV survey of nearby K dwarfs with the CHIRON spectrograph. Three K dwarf RV standard stars and a set of 186 stars with no detected companions have been used to determine the stability level of CHIRON over 2.5 yr to be $5\text{--}20 \text{ ms}^{-1}$ for K dwarf stars with magnitudes of $V = 7\text{--}12$. Previously known planets around five K dwarfs have been independently detected with CHIRON and produced orbital solutions consistent with previous efforts. We have independently confirmed a giant planet around a K dwarf initially discovered by TESS, taking data with CHIRON within a few days of the first TESS data release. Three K dwarfs in our survey show RV variations consistent with planets of minimum masses from $0.5\text{--}0.9 M_{\text{Jup}}$ in orbital periods of 2–160 days. We provide details for 186 K dwarfs within 50 pc that do not show significant variations in RV indicative of close stellar or substellar companions in orbits with periods less than a year. Vetting stars for close brown dwarf and Jovian companions is a time-consuming and expensive effort in the search for terrestrial exoplanets; thus, we provide this list of K dwarfs as ideal targets for extreme precision RV programs.

All of the K dwarfs in our survey are also being examined for stellar companions; as promising new multiple stellar systems show up in our data with larger RV variations, long-term RV linear trends, and fully resolved orbits, we are preparing them for the next publication. Moreover, beyond the few au regime sampled by the RV effort, both high-resolution speckle imaging and wide-field companion searches are being done to provide a comprehensive assessment of stellar companions from 0 to 1000 au, which will ultimately provide a detailed understanding of where stellar companions form around K dwarfs and what their orbital architectures look like. Because of its sensitivity, the RV survey probes beyond stellar companions to brown dwarf and massive planetary companions, providing an opportunity to evaluate architectures for all three classes of companions.

Via a carefully defined sample with systematic coverage in three spatial regimes, we will be able to reveal the results of the stellar, brown dwarf, and Jovian planetary formation processes, with an ultimate expansion to the regime of terrestrial planets.

In the end, we will then understand the populations of companions spanning a factor of ~ 1000 in mass for many of the nearest K dwarfs to the Sun.

This work has been supported by the National Science Foundation via grants AST-1517413 and AST-1910130. We are indebted to members of the SMARTS Consortium and NSF's National Optical-Infrared Astronomy Research Laboratory, particularly the staff at CTIO, for efforts to keep the 1.5 m and the CHIRON spectrograph in operation. At CTIO, Rodrigo Hinojosa, Roberto Aviles, Hernan Tirado, Manuel Hernandez, David Rojas, Javier Rojas, Humberto Orrego, Esteban Parkes, Marco Bonati, Peter Moore, Nicole David, Mauricio Rojas, Andrei Tokovinin, Steve Heathcote, Ximena Herreros, Luz Pinto, Rodrigo Hernandez, Jacqueline Seron, Fernando Cortes, Carlos Corco, Alberto Miranda, Jorge Briones, Jorge Lopez, Pedro Ramos, Alfonso Rojas, Hector Pasten, Juan Paleo, Marco Nunez, and so many others. We also want to thank Eric Mamajek for his insightful comments on this work. 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 publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. This work has made use of data from the European Space Agency's Hipparcos mission and Gaia (cosmos.esa.int/gaia) mission, the latter processed by the Gaia Data Processing and Analysis Consortium (DPAC, 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.

Facilities: CTIO:1.5 m, TESS, Exoplanet Archive.

Appendix

Additional tables.

Table A1
CHIRON Radial Velocities of K-Dwarf Radial-velocity Standards

BJD – 2,450,000 (days)	RV (ms^{-1})	σ_{RV} (ms^{-1})
HIP 003535		
7937.93779	3.6	4.5
7952.91229	31.3	6.9
7953.91139	12.0	3.6
7955.89438	19.4	4.3
7956.89693	50.4	7.1
7957.88705	4.0	3.4
7958.89154	21.0	4.9
7959.89157	3.1	3.4
7960.90567	16.3	3.5
7961.89886	28.0	5.5
7964.86529	15.7	4.7
7964.87851	–5.1	4.8
7964.89314	19.3	8.3
7966.88038	15.9	4.7
7967.87161	23.6	2.5
7968.84481	5.6	3.4
7969.84934	9.2	4.1
7971.82710	–1.6	2.9
8032.72070	–34.9	6.1
8034.70148	–6.1	5.8
8049.70544	–9.7	9.4
8063.66741	1.3	6.0
8080.58239	–28.4	3.3
8088.55321	–9.4	3.9
8094.56871	–2.5	4.4
8103.56055	–12.4	4.1
8108.56269	–7.0	5.7
8117.53255	–16.5	4.8
8328.87868	19.0	3.5
8332.81382	46.8	8.0
8340.85366	25.6	2.2

Table A1
(Continued)

BJD – 2,450,000 (days)	RV (ms ⁻¹)	σ_{RV} (ms ⁻¹)
8346.74116*	1.0	4.9
8355.76342	-19.6	1.8
8359.77765	-16.4	3.9
8372.74307	-6.2	5.0
8375.74388	-18.8	3.8
8379.71874	-15.3	4.3
8382.68316	-22.9	4.4
8390.75122	-40.9	11.2
8390.75869	-20.1	5.6
8394.64051	-10.2	5.8
8406.71501	-20.9	4.7
8409.75878	-4.0	4.7
8424.58772	-10.3	6.9
8429.60039	-21.0	4.2
8438.58231	-17.2	4.6
8443.57756	-27.0	5.4
8467.56317	-7.8	4.5
8481.54435	-9.7	5.6
8485.53214	-11.4	2.8
8496.54465	-4.2	4.3
8499.54251	-22.4	5.2
8669.94105	-0.5	6.4
8680.87636	-17.8	5.0
8694.86469	0.7	4.4
8695.91882	22.3	3.8
8696.94116	17.0	6.1
8707.83373	26.4	3.0
8713.74162	50.7	8.4
8724.73160	-11.4	4.7
8731.76619	-10.3	5.3
8739.66745	-11.9	5.1
8740.78399	-12.6	5.7
8742.76074	-25.7	5.1
8757.72640	6.4	15.9
8762.72234	10.5	5.6
8764.74822	-3.8	5.2
8772.63562	-11.4	6.8
8778.72172	6.0	8.3
8785.64313	-5.1	6.6
8792.64111	4.1	6.2
8799.66675	21.8	4.6
8805.59900	5.1	6.6
8812.59844	-6.4	4.5
8814.58366	3.1	5.1
8823.64221	35.2	7.5
8830.56459	27.9	6.1

HIP 058345

7929.47227	-23.1	3.4
7934.51183	1.0	4.1
7935.50558	3.5	5.3
7936.45360	-15.7	3.3
7937.44903	-9.9	3.4
7938.49311	-10.4	2.0
7939.50140	-5.7	3.9
7940.44767	-10.9	7.0
7940.46230	-15.7	8.0
7940.47513	2.4	19.6
7941.48157	-14.6	2.7
7942.46453	6.3	5.5
7943.48651	-15.4	4.2
7945.48714	-11.6	4.1
7946.48332	-15.2	5.3
7948.50122	-6.9	2.6

Table A1
(Continued)

BJD – 2,450,000 (days)	RV (ms ⁻¹)	σ_{RV} (ms ⁻¹)
7949.50256	17.6	4.5
7951.53332	3.0	3.3
7952.53421	6.2	3.9
7953.54595	-2.5	2.7
7957.50429	1.3	3.7
7958.48138	4.7	5.2
7960.48108	-8.0	3.0
7964.47982	-20.9	5.7
7966.46944	-20.3	3.9
7967.46667	-32.2	5.0
7967.47976	-12.0	3.5
7967.48817	-29.0	5.9
7972.46397	-1.7	3.8
8133.86703	-3.0	4.2
8136.84237	2.5	4.7
8140.87425	-7.6	3.4
8145.87504	-2.6	4.7
8150.85799	-30.2	3.3
8159.74411	15.3	3.6
8172.86354	12.9	3.6
8176.73761	-3.1	5.2
8178.79027	-12.2	2.2
8187.69472	-10.1	2.7
8193.71248*	0.0	3.9
8200.71629	-11.7	1.0
8206.66241	-17.4	4.6
8215.63786	-14.0	2.4
8220.62637	-4.1	1.2
8228.64657	-29.8	2.0
8242.64360	-18.0	3.4
8247.53488	-37.5	4.4
8262.54488	-29.1	5.2
8274.55207	-7.2	4.8
8301.49704	-4.7	6.0
8316.45984	-20.0	4.5
8510.82843	-12.4	3.7
8514.89015	0.7	3.0
8527.80571	11.1	1.6
8532.69755	-21.8	4.4
8557.64528	-14.3	2.6
8578.67044	-7.9	6.3
8593.76299	-20.0	3.4
8607.69268	-19.6	4.1
8635.68290	-20.9	3.4
8640.58051	-25.6	3.9
8662.59434	-24.4	6.5

HIP 073184

7929.57864	4.1	1.6
7934.58382	0.1	4.1
7935.59031	26.6	3.6
7936.56410	10.1	2.1
7937.55489	14.3	3.2
7938.57440	-7.3	2.6
7939.58877	16.4	3.0
7941.51141	19.2	0.4
7942.55522	-17.4	1.2
7943.54831	-26.7	2.2
7945.53189	4.8	4.3
7946.54298	27.8	2.4
7948.57620	6.0	3.6
7949.53540	11.7	2.1
7951.61597	-11.5	2.7
7952.57729	-1.2	2.0

Table A1
(Continued)

BJD – 2,450,000 (days)	RV (ms ⁻¹)	σ_{RV} (ms ⁻¹)
7954.50028	9.3	2.4
7954.54084	10.5	2.6
7954.57675	-14.6	0.9
7954.61224	-21.6	4.5
7954.64590	11.3	1.6
7954.68161	-7.5	0.5
7955.61843*	7.5	2.3
7957.53453	-4.9	1.7
7958.51432	-10.0	2.7
7959.52758	6.3	3.8
7960.52905	4.1	2.8
7964.50926	-8.3	1.2
7966.50109	-25.1	1.8
7969.53070	14.6	4.2
7971.52182	2.9	2.3
7971.52730	-0.8	3.3
7972.57029	-24.3	1.2
7972.57641	-1.5	3.3
7973.49741	-11.6	3.3
7974.59661	-14.3	2.8
7984.46368	19.0	2.2
7985.47296	-14.6	3.4
7986.46875	-7.7	2.3
HIP 073184 within a Night		
7955.46977	-9.8	2.1
7955.47611	-22.4	0.3
7955.48620	1.7	2.6
7955.49203	-2.8	3.6
7955.49781	-22.5	1.7
7955.50210	-25.9	2.7
7955.50700	6.7	0.1
7955.51153	-37.6	3.4
7955.51589	-49.1	2.9
7955.52064	-21.2	0.7
7955.52477	-2.7	0.8
7955.52862	-10.8	3.0
7955.53277	-9.3	0.7
7955.53641	-14.3	2.3
7955.54078	-11.5	0.7
7955.54507	-29.0	3.0
7955.54961	1.0	1.4
7955.55396	5.5	2.2
7955.55799	-25.5	3.0
7955.56236	-12.9	1.6
7955.56714	-11.8	1.0
7955.57157	-28.1	2.3
7955.57642	-2.8	1.7
7955.58148	4.3	2.2
7955.59099	8.3	1.5
7955.59910	1.6	1.8
7955.60639	-8.5	1.0
7955.61269	-8.5	0.9
7955.61843*	7.5	2.3
7955.62327	1.4	1.6
7955.62768	-18.1	1.8
7955.63247	-20.7	3.2
7955.63798	-2.2	0.8
7955.64400	-18.4	2.5
7955.65179	-8.1	2.7
7955.66077	-13.7	1.3

Note. (*) marks the reference epoch.**Table A2**
CHIRON Radial Velocities of Known and New Planet Candidates

BJD – 2,450,000 (days)	RV (ms ⁻¹)	σ_{RV} (ms ⁻¹)
HIP 002350		
7951.89442	77.2	14.5
7952.90012	-36.1	10.6
7953.89963	-33.5	9.0
7955.88144	-3.8	10.0
7956.88370	-41.0	9.4
7957.87499	38.4	10.2
7958.87913	64.3	12.4
7959.87877	-49.2	9.6
7960.86503	-17.9	9.3
7960.87869*	-29.3	10.1
7960.89144	-10.2	9.2
7961.88615	90.1	14.1
7964.85088	-0.5	17.2
7966.84962	-64.1	11.6
7967.84517	-26.3	11.2
7968.83282	73.7	9.2
7969.83590	-20.7	11.0
7970.82671	-82.8	8.5
7971.81477	23.7	10.2
7972.88795	35.6	11.1
7974.91900	-18.2	9.5
7983.78358	-60.5	8.7
7985.75744	40.9	7.1
7986.79379	26.8	9.1
HIP 057370		
7934.45458	-15.5	6.1
7935.49137	32.3	8.2
7937.50350	-78.3	5.4
7938.46593	22.5	6.4
7939.48726	44.7	7.2
7944.47423	1.9	6.0
7945.47259	-81.0	6.4
7946.46890	7.2	5.7
7947.47382	63.4	5.3
7948.47416	22.4	5.0
7951.51847	44.5	6.1
7952.49357	12.0	6.2
7953.49230*	-55.5	6.1
7954.47789	-24.5	4.6
7957.48911	-49.1	7.6
7959.46760	74.5	5.8
7960.46572	68.0	6.6
7961.45805	45.5	28.2
7961.46449	-44.0	5.4
7964.46424	76.9	14.2
HIP 072339		
7929.54565	79.9	7.2
7934.56758	-29.9	6.7
7936.54942*	-108.8	6.2
7937.54107	-110.7	5.8
7938.54737	-63.7	4.8
7939.54678	13.8	5.2
7941.52488	113.1	4.5
7942.54093	96.7	5.1
7943.51842	62.1	4.6
7944.52069	22.1	6.6
7945.51703	-59.8	7.3
7946.51391	-82.3	5.4
7947.52004	-102.7	6.5
7948.56045	-94.2	5.0

Table A2
(Continued)

BJD – 2,450,000 (days)	RV (ms ⁻¹)	σ_{RV} (ms ⁻¹)
7949.51980	-43.4	5.7
7951.57622	87.0	6.1
7952.56338	120.6	5.6
7953.57462	95.4	5.3
7954.55280	49.0	4.1
7957.52048	-124.1	7.1
7958.49852	-121.2	7.1
7959.50038	-89.5	6.9
7960.49920	-30.8	8.0
7964.49635	98.0	12.8
7966.48701	-18.1	5.5
7969.54572	-90.4	5.4
7970.53248	-48.1	7.5
7972.50529	60.7	5.7
HIP 098505		
7929.73335	-129.5	32.4
7933.78957	-180.9	5.2
7934.76108	119.0	6.5
7935.76221	-51.3	4.9
7936.76874	9.5	5.7
7937.75467	84.0	5.4
7941.76233	187.0	5.9
7942.74095	-194.3	6.6
7943.77564	185.7	5.0
7944.73933	-109.1	4.4
7945.73698	73.3	6.5
7946.72916	27.8	3.9
7947.69775	-13.5	20.6
7948.72484	145.3	6.2
7949.71869	-123.7	10.7
7951.71345	-189.0	7.5
7952.71563	188.3	4.7
7953.73393	-164.7	5.0
7954.70688	94.6	5.8
7955.70707	-59.6	4.7
7958.70140	-131.2	3.3
7959.69553	168.6	4.3
7960.71401	-185.4	3.8
7960.72722*	-205.4	5.3
7960.73934	-190.8	3.3
7961.69405	208.8	5.7
7964.67201	-113.0	2.9
7966.69832	43.9	6.5
7967.67659	-99.1	4.3
7969.64983	-196.7	5.9
7970.65065	180.9	4.5
HIP 099711		
7928.85159	8.4	5.8
7929.77375	15.8	5.3
7933.80559	-33.2	3.6
7934.77486	-48.6	3.5
7935.77614	-60.9	4.1
7936.79664	-75.1	5.2
7937.76887	-70.3	3.4
7941.78987	14.5	3.3
7942.78353	43.5	4.6
7943.79578	48.7	4.1
7945.75133	35.5	3.5
7946.74455	37.0	6.3
7947.73203	63.2	4.5
7948.75327	62.3	4.0

Table A2
(Continued)

BJD – 2,450,000 (days)	RV (ms ⁻¹)	σ_{RV} (ms ⁻¹)
7949.77388	59.7	4.0
7951.75601	28.8	6.8
7952.78594	10.0	5.2
7953.76042	4.4	4.9
7954.74812	-9.8	5.5
7955.72372	-22.1	4.3
7957.68199	-63.4	4.8
7958.71591	-76.3	4.0
7959.71218	-57.9	2.7
7960.66741	-35.8	2.2
7960.67976	-52.9	3.4
7960.69186*	-54.5	4.1
7961.70835	-68.4	3.9
7964.68627	-3.3	5.7
7966.71242	17.5	3.4
7967.69067	30.0	4.3
7968.73616	20.9	4.4
7969.66455	12.9	3.6
HIP 000065		
8369.59230	-650.8	16.5
8369.68969	-319.3	12.2
8369.74174	-67.4	11.9
8369.81965	293.6	13.4
8370.57894	-613.7	11.7
8370.66590	-323.7	12.9
8370.71827*	-65.7	16.7
8370.78546	234.8	15.2
8371.57496	-591.1	15.4
8371.64147	-326.5	16.7
8371.77372	265.9	11.8
8371.82794	486.0	10.1
8371.92226	744.7	15.3
8372.56158	-597.2	22.3
8372.69277	-36.1	9.6
8372.84314	590.3	7.0
8372.92524	722.9	20.5
8373.55514	-499.4	19.9
8373.69723	96.9	38.4
8375.55321	-406.1	16.5
8375.78704	600.6	16.4
8375.86988	742.4	14.0
8379.61043	171.5	19.8
8379.78845	740.0	15.7
8380.62274	309.9	16.9
8380.78421	726.7	12.0
8380.91677	453.0	35.9
8381.90793	435.4	39.1
8382.90787	423.1	19.0
8383.88954	399.8	19.0
8385.88544	240.0	16.7
8390.59432	758.4	21.6
8390.78867	278.6	25.0
8392.68328	504.0	13.5
8393.51258	692.4	17.6
8393.58814	712.3	10.7
8394.50312	743.9	31.1
8394.58626	659.7	15.1
8394.80467	-127.8	13.8
8395.51021	729.3	22.2
8404.71885	-589.5	15.9
8509.54996	-11.6	11.6
8799.62251	648.2	26.2

Table A2
(Continued)

BJD – 2,450,000 (days)	RV (ms ⁻¹)	σ_{RV} (ms ⁻¹)
8800.55031	571.3	19.0
8800.72591	639.8	31.6
8801.59100	700.8	23.0
8802.56096	727.4	16.3
8802.63289	742.6	20.2
8804.53716	736.6	15.0
8804.62272	700.5	10.8
8812.53006	592.9	26.9
8812.61004	287.6	29.5
8817.61384	–182.2	19.5
8832.56591	–703.8	21.0
8833.55323	–737.5	24.9
8833.64288	–546.5	20.6
8835.59108	–569.5	20.0
8861.53040	688.1	15.7
HIP 005763		
8078.56772*	–61.9	11.3
8079.58427	–53.6	7.5
8080.62024	–45.4	9.6
8453.58523	38.4	12.8
8454.56220	36.6	11.2
8455.59389	47.7	8.6
8480.55554	34.9	11.4
8486.53386	34.0	9.2
8699.82914	16.6	9.3
8702.89324	14.5	10.1
8705.86816	–15.1	9.7
8761.66765	–16.6	9.3
8761.70735	–10.6	14.1
8767.69761	–39.7	30.0
8772.64876	–30.3	15.7
8776.67979	–35.1	16.6
8804.59023	0.5	11.7
8829.55582	–2.5	15.6

Table A2
(Continued)

BJD – 2,450,000 (days)	RV (ms ⁻¹)	σ_{RV} (ms ⁻¹)
8835.55624	–12.1	11.5
HIP 034222		
8103.73297*	–9.8	16.1
8105.74962	–28.0	10.2
8107.73982	–38.4	20.9
8148.64093	1.8	11.4
8149.62949	36.4	9.5
8150.66532	19.3	14.2
8467.76467	19.6	15.2
8469.73676	10.2	11.9
8545.54512	–30.7	17.0
8547.55476	–27.9	17.6
8583.47349	–38.5	13.9
8584.48261	–17.5	11.5
8798.86694	65.1	22.3
8806.81245	34.2	21.7
8814.78550	60.3	22.1
8819.80890	36.6	26.1
8827.77791	53.3	22.6
8831.77616	33.8	18.0
8836.74275	7.2	13.4
HIP 086221		
7948.62058*	62.1	18.2
8299.68175	108.2	20.5
8303.67192	79.7	39.2
8709.57041	–58.1	22.5
8712.55082	–93.9	15.9
8716.56836	–123.7	15.8
8738.47559	–30.1	13.1
8740.47209	50.1	21.8
8741.47443	–63.6	15.5

Note. (*) marks the reference epoch.

Table A3
Sample of 198 K Dwarfs with RV Curves

HIP	R.A. (hh:mm:ss.sss)	Decl. (°:':")	Parallax (mas)	V (mag)	K (mag)	V − K (mag)	M_V (mag)	MAD_{RV} (ms ^{−1})	No. Obs.	Time Span (days)
K Dwarf RV Standards										
3535	00:45:04.894	+01:47:07.88	46.37	8.01	5.74	2.26	6.34	15.2	77	892
58345	11:57:56.207	−27:42:25.37	98.45	6.97	4.53	2.44	6.93	9.8	62	733
73184	14:57:28.001	−21:24:55.71	171.22	5.75	3.80	1.94	6.91	10.3	77	56
K Dwarfs with Known Planets										
2350	00:29:59.873	−05:45:50.40	20.03	9.37	7.31	2.06	5.88	39.5	24	34
57370	11:45:42.292	+02:49:17.33	33.74	8.05	6.15	1.90	5.70	42.0	20	30
72339	14:47:32.727	−00:16:53.31	31.54	8.04	6.23	1.81	5.53	75.6	27	42
98505	20:00:43.713	+22:42:39.06	51.41	7.66	5.54	2.12	6.22	129.0	31	40
99711	20:13:59.846	−00:52:00.77	51.77	7.76	5.54	2.22	6.33	40.4	32	40
K Dwarfs with New Planet Candidates										
65	00:00:44.905	−54:49:49.85	18.28	11.13	8.29	2.84	7.44	430.3	58	491
5763	01:13:58.867	+16:29:40.27	34.16	9.86	6.91	2.95	7.53	28.7	19	756
34222	07:05:42.243	+27:28:14.99	41.89	10.23	6.78	3.45	8.34	29.0	19	733
86221	17:37:10.761	+27:53:47.12	33.91	9.20	6.30	2.90	6.85	72.2	9	792
K Dwarfs with Flat RV Curves										
112	00:01:25.840	−16:56:54.40	31.13	10.53	7.22	3.31	7.99	12.5	8	377
897	00:11:04.612	−05:47:02.30	39.15	10.77	7.12	3.65	8.74	18.6	17	855
974	00:12:04.024	+27:05:56.23	37.93	8.69	6.30	2.39	6.58	12.0	8	379
1539	00:19:12.397	−03:03:13.01	32.31	10.99	7.46	3.53	8.54	24.4	12	758
3493	00:44:37.150	−18:56:48.20	31.81	10.69	7.12	3.56	8.20	26.3	10	404
3998	00:51:21.754	+18:44:21.31	46.79	9.21	6.24	2.97	7.56	11.3	13	408
4022	00:51:34.020	−22:54:36.24	63.96	8.94	5.74	3.21	7.97	12.1	16	408
4061	00:52:00.062	+20:34:58.32	31.37	11.36	7.63	3.74	8.85	23.0	12	788
4353	00:55:49.255	−29:40:33.44	32.82	9.44	6.57	2.87	7.02	9.8	7	378
4691	01:00:18.490	−25:36:52.74	31.70	9.92	7.21	2.71	7.43	8.0	9	368
4824	01:01:57.040	−09:53:08.01	30.55	10.39	7.29	3.10	7.82	16.9	13	751
5027	01:04:24.152	−25:36:17.99	41.66	9.84	6.84	3.00	7.94	7.8	16	400
5286	01:07:37.872	+22:57:17.92	47.50	8.41	5.76	2.65	6.79	15.6	13	399
5957	01:16:39.357	+25:19:53.30	42.31	10.11	6.66	3.46	8.24	14.9	9	394
6037	01:17:34.025	−15:30:11.96	33.19	9.75	7.17	2.58	7.36	6.5	7	407
6342	01:21:29.379	+24:19:50.04	38.54	10.62	7.11	3.51	8.55	7.0	8	394
6390	01:22:07.613	−26:53:35.17	33.83	8.74	6.50	2.24	6.39	12.2	9	486
6558	01:24:16.527	+12:54:27.12	30.67	9.46	7.06	2.40	6.89	9.7	7	379
6639	01:25:09.490	−01:03:34.84	30.76	9.44	6.92	2.52	6.88	16.8	12	724
7228	01:33:09.124	−24:54:51.62	30.00	10.00	7.17	2.84	7.39	14.5	9	380
7500	01:36:39.523	+21:33:47.21	30.92	9.29	6.88	2.41	6.74	25.9	11	729
8043	01:43:15.973	+27:50:31.56	47.23	10.30	6.60	3.70	8.67	16.1	13	845
8543	01:50:07.880	+29:27:52.47	39.04	8.05	6.11	1.95	6.01	14.9	8	392
9716	02:04:59.327	−15:40:41.17	39.06	7.77	5.88	1.88	5.72	14.4	9	380
10312	02:12:51.011	−17:41:12.21	37.24	10.74	7.34	3.40	8.59	26.8	9	344
11083	02:22:41.647	+18:24:38.35	30.55	8.79	6.63	2.16	6.21	8.1	8	298
11707	02:31:03.278	+08:22:55.16	30.37	10.91	7.55	3.35	8.32	22.2	8	781
11759	02:31:42.472	−15:16:24.45	35.86	8.66	6.40	2.26	6.43	13.7	8	391
12493	02:40:42.873	+01:11:55.24	42.91	9.53	6.50	3.03	7.69	14.0	6	387
13065	02:47:55.873	+28:42:44.20	36.46	10.84	7.48	3.36	8.65	27.6	8	746
13079	02:48:06.530	−11:45:47.39	33.76	10.85	7.22	3.62	8.49	15.0	8	367
14445	03:06:26.737	+01:57:54.63	68.94	9.04	5.65	3.39	8.23	9.4	11	377
16242	03:29:19.795	−11:40:42.12	45.28	9.98	6.45	3.54	8.26	9.0	7	300
17496	03:44:51.125	+11:55:12.01	44.32	9.12	6.20	2.91	7.35	12.4	8	350
19441	04:09:49.349	+09:18:19.79	32.27	10.17	7.26	2.91	7.72	14.0	7	366
20232	04:20:10.586	−14:45:39.85	34.58	9.88	6.83	3.05	7.58	8.1	7	380
20240	04:20:14.241	−09:02:13.46	31.88	9.69	7.13	2.56	7.20	18.7	9	781
21489	04:36:54.310	−14:53:12.16	30.44	9.95	7.20	2.75	7.36	13.3	15	423
22715	04:53:04.731	+22:14:06.62	37.68	8.78	6.29	2.49	6.66	9.4	7	379
23431	05:02:09.831	+14:04:53.63	33.33	8.18	6.32	1.86	5.80	18.8	8	768
24454	05:14:48.133	+00:39:43.08	37.47	10.02	6.99	3.02	7.88	10.3	6	395
24783	05:18:47.191	−21:23:37.55	50.28	9.33	6.15	3.18	7.84	13.9	11	434
24819	05:19:12.658	−03:04:25.72	64.73	7.84	5.05	2.79	6.89	11.1	16	517

Table A3
(Continued)

HIP	R.A. (hh:mm:ss.sss)	Decl. (°:':")	Parallax (mas)	<i>V</i> (mag)	<i>K</i> (mag)	<i>V</i> − <i>K</i> (mag)	<i>M_V</i> (mag)	MAD _{RV} (ms ^{−1})	No. Obs.	Time Span (days)
24874	05:19:59.577	−15:50:22.72	41.15	8.70	6.21	2.50	6.78	14.2	10	375
26175	05:34:48.620	−23:28:08.34	37.56	8.79	6.48	2.31	6.67	11.5	9	423
26844	05:41:58.867	+15:20:14.01	46.83	10.57	6.88	3.69	8.92	19.3	9	376
26907	05:42:45.836	+02:40:44.55	30.31	8.57	6.43	2.14	5.98	5.9	6	396
27397	05:48:17.139	−11:08:04.64	37.39	10.94	7.28	3.66	8.81	10.5	12	368
28494	06:00:53.972	+21:01:15.58	32.79	9.97	7.00	2.97	7.54	10.5	5	394
28921	06:06:16.615	−27:54:20.99	31.15	8.98	6.78	2.20	6.45	9.1	8	367
29132	06:08:40.712	+09:28:41.69	30.41	10.36	7.33	3.03	7.78	12.2	13	380
29208	06:09:35.911	+05:40:08.03	34.73	8.37	6.27	2.10	6.08	13.5	10	380
29875	06:17:25.837	+17:59:21.13	30.18	10.41	7.17	3.24	7.80	12.8	9	337
30893	06:29:05.528	+27:00:31.96	33.66	8.61	6.36	2.25	6.24	9.3	9	368
31069	06:31:11.083	+05:52:36.96	32.17	8.94	6.74	2.20	6.47	10.8	10	367
32530	06:47:15.778	−18:15:31.39	31.17	10.57	7.20	3.37	8.04	9.6	9	355
34317	07:06:52.109	+23:58:08.25	31.32	10.07	7.13	2.94	7.55	10.2	8	362
34414	07:08:04.238	+29:50:04.18	44.93	8.33	6.06	2.28	6.60	9.0	9	423
34423	07:08:09.306	−09:58:07.32	35.17	8.84	6.51	2.33	6.57	10.9	10	407
34673	07:10:49.579	−14:25:58.93	40.58	9.90	6.63	3.27	7.94	15.0	8	436
34950	07:13:53.112	+25:00:40.97	40.56	8.38	6.22	2.16	6.42	19.6	7	785
35851	07:23:29.253	−20:01:24.23	32.12	9.84	6.94	2.90	7.37	9.7	9	410
35872	07:23:47.066	+12:57:52.99	41.72	8.18	5.89	2.30	6.28	17.6	9	449
38492	07:52:59.602	+22:33:22.99	31.60	11.07	7.60	3.47	8.57	23.1	24	396
38702	07:55:23.921	−15:29:53.20	31.20	10.68	7.66	3.02	8.15	16.7	7	404
38992	07:58:50.384	+10:07:47.13	33.05	8.09	6.18	1.91	5.69	8.5	9	396
39068	07:59:35.632	+12:58:59.04	30.43	8.33	6.46	1.87	5.75	6.9	8	404
39826	08:08:13.186	+21:06:18.26	60.09	9.45	6.08	3.36	8.34	13.2	11	408
42074	08:34:31.651	−00:43:33.83	47.31	7.31	5.42	1.88	5.68	13.2	33	517
43233	08:48:26.156	+06:28:06.08	39.55	10.59	6.99	3.60	8.58	20.8	12	410
43771	08:54:57.243	−24:23:39.44	32.11	8.65	6.46	2.19	6.18	13.9	10	406
44072	08:58:38.181	+20:32:48.29	47.85	9.24	...	...	7.64	14.3	8	396
44109	08:59:02.245	+01:51:52.89	32.28	10.44	7.19	3.25	7.99	29.9	11	396
44526	09:04:20.694	−15:54:51.30	35.34	8.76	6.39	2.37	6.50	16.7	13	424
44920	09:09:03.265	+27:25:55.35	32.71	10.29	7.20	3.09	7.87	7.8	8	396
46549	09:29:35.053	−05:22:21.74	41.24	9.79	6.52	3.27	7.87	10.4	7	369
47201	09:37:11.340	+22:41:38.92	45.57	9.40	6.34	3.06	7.69	12.0	9	411
47261	09:37:58.332	+22:31:23.18	31.05	9.72	6.85	2.86	7.18	16.8	16	424
48016	09:47:16.685	+01:34:36.95	32.70	10.98	7.56	3.42	8.55	17.4	12	412
48024	09:47:22.400	+26:18:12.56	30.95	10.92	7.34	3.58	8.38	17.8	10	395
48447	09:52:39.162	+03:07:48.58	43.96	10.52	7.08	3.45	8.74	9.8	10	414
49127	10:01:37.295	−15:25:29.24	37.13	8.65	6.21	2.44	6.50	20.0	11	466
49429	10:05:26.519	+26:29:16.10	34.13	9.10	6.65	2.45	6.77	11.6	8	429
49544	10:06:56.863	+02:57:51.88	44.33	9.92	6.39	3.53	8.16	11.1	9	432
50657	10:20:43.406	−01:28:11.38	31.11	9.39	6.76	2.63	6.85	9.5	11	412
50782	10:22:09.488	+11:18:36.86	37.97	7.77	5.91	1.86	5.67	11.9	11	424
51254	10:28:10.444	+06:44:06.45	39.67	8.49	6.26	2.23	6.48	8.1	9	412
51931	10:36:30.792	−13:50:35.82	31.01	8.72	6.57	2.15	6.18	14.9	10	375
52708	10:46:36.902	−24:35:07.74	46.49	9.33	6.44	2.89	7.67	9.3	9	378
52765	10:47:19.207	+21:29:51.06	30.43	10.00	7.16	2.84	7.42	12.0	7	335
53486	10:56:30.798	+07:23:18.51	57.79	7.35	5.20	2.15	6.16	14.4	9	412
54651	11:11:10.701	−10:57:03.19	49.38	9.24	6.33	2.91	7.71	4.5	9	401
54810	11:13:13.235	+04:28:56.43	54.70	8.68	5.85	2.82	7.37	8.2	10	408
54922	11:14:48.171	−23:06:17.72	43.39	9.00	6.03	2.97	7.18	8.3	8	446
55066	11:16:22.146	−14:41:36.13	55.82	10.01	6.46	3.56	8.75	14.0	7	469
55119	11:17:07.508	−27:48:48.71	56.52	9.72	6.20	3.52	8.48	5.5	7	406
55772	11:25:39.948	+20:00:07.68	32.19	8.31	6.35	1.96	5.85	7.7	9	348
55988	11:28:27.748	+07:31:02.19	36.50	10.20	7.06	3.14	8.02	10.6	9	383
56570	11:35:49.367	+24:36:42.53	30.21	9.35	6.87	2.48	6.75	15.8	6	432
56578	11:35:59.172	+16:58:05.72	31.40	9.48	6.84	2.64	6.97	7.6	5	52
56838	11:39:08.164	−27:41:46.37	32.73	9.91	6.91	3.00	7.49	12.7	5	66
57866	11:52:08.338	+18:45:18.66	37.95	8.39	6.27	2.12	6.28	6.1	7	444
58293	11:57:16.291	−26:08:29.02	37.13	8.91	6.41	2.50	6.76	10.2	5	66
58374	11:58:11.705	−23:55:25.99	39.02	8.68	6.31	2.36	6.63	8.0	7	382
58863	12:04:17.458	+09:11:35.00	30.84	9.83	7.06	2.77	7.28	7.9	3	2
58949	12:05:12.529	−01:30:32.53	30.97	8.17	6.32	1.85	5.62	8.1	3	4

Table A3
(Continued)

HIP	R.A. (hh:mm:ss.sss)	Decl. (°:':")	Parallax (mas)	V (mag)	K (mag)	$V - K$ (mag)	M_V (mag)	MAD_{RV} (ms^{-1})	No. Obs.	Time Span (days)
60207	12:20:46.831	-19:53:45.83	34.43	8.96	6.59	2.37	6.65	14.9	8	345
60343	12:22:21.273	+25:10:11.89	33.43	11.07	7.60	3.47	8.69	4.5	3	4
61329	12:33:59.744	-14:38:19.19	38.21	9.11	6.44	2.67	7.02	6.6	7	299
63467	13:00:16.996	-02:42:17.22	37.89	9.74	6.77	2.97	7.63	16.4	14	307
65574	13:26:39.557	-24:17:36.14	33.08	8.81	6.56	2.25	6.41	10.1	6	56
66675	13:40:07.131	-04:11:09.96	67.58	9.59	6.04	3.56	8.74	11.0	9	347
67092	13:45:05.340	-04:37:13.23	39.84	10.50	7.20	3.30	8.50	19.7	8	355
67105	13:45:14.717	+08:50:09.52	47.65	8.46	5.97	2.49	6.85	13.2	8	395
67211	13:46:19.025	-00:27:29.04	30.75	9.30	6.91	2.39	6.74	6.2	5	51
67291	13:47:28.801	+06:18:56.36	32.49	10.03	7.01	3.01	7.59	12.9	8	408
67344	13:48:10.056	-10:47:19.50	32.05	8.35	6.43	1.92	5.87	15.0	6	54
69410	14:12:41.562	+23:48:51.49	30.03	8.88	6.44	2.43	6.26	9.0	10	373
69485	14:13:31.194	-06:57:32.33	51.64	10.08	6.57	3.51	8.64	15.3	8	369
70218	14:21:57.216	+29:37:46.63	69.70	8.53	5.42	3.10	7.74	11.8	9	424
70472	14:24:49.861	-17:27:08.09	31.38	10.79	7.28	3.51	8.27	18.3	8	417
70529	14:25:43.475	+23:37:01.51	61.11	9.62	5.97	3.65	8.56	8.8	16	277
70956	14:30:47.718	-08:38:46.81	58.87	9.38	5.77	3.61	8.22	7.8	8	392
71190	14:33:34.902	+09:20:03.76	30.88	8.78	6.59	2.19	6.23	9.5	6	54
71914	14:42:33.648	+19:28:47.22	46.34	9.07	5.82	3.24	7.40	12.1	16	270
72044	14:44:11.991	+22:11:07.16	38.54	9.82	6.90	2.92	7.75	12.8	10	410
72200	14:46:03.072	+27:30:44.45	39.73	7.95	5.98	1.97	5.94	11.3	7	353
72237	14:46:23.282	+16:29:48.14	58.00	9.20	6.06	3.13	8.01	8.1	16	313
73066	14:55:55.019	-27:07:38.25	36.36	8.94	6.48	2.46	6.74	12.2	18	318
73457	15:00:43.411	-11:08:06.47	51.70	9.42	5.99	3.43	7.98	9.9	8	325
73512	15:01:29.974	+15:52:07.99	32.99	9.13	6.58	2.55	6.72	8.0	5	40
73786	15:04:53.525	+05:38:17.19	53.80	9.83	6.47	3.37	8.49	9.8	18	314
74555	15:13:59.641	-03:47:52.79	37.04	9.87	6.91	2.97	7.72	19.6	7	381
74981	15:19:21.154	+29:12:22.25	38.02	10.30	7.10	3.20	8.20	21.4	4	417
75201	15:22:04.101	-04:46:38.82	52.92	9.39	6.18	3.21	8.01	18.8	8	324
75672	15:27:38.020	+10:35:39.08	39.01	9.83	6.65	3.18	7.79	6.4	5	316
75686	15:27:42.697	+02:35:51.93	37.96	10.26	6.90	3.36	8.16	16.0	6	326
76779	15:40:34.570	-18:02:56.50	64.28	8.91	5.69	3.23	7.95	12.0	9	283
77908	15:54:38.429	-26:00:15.03	41.00	9.20	6.24	2.96	7.26	8.6	13	333
78336	15:59:42.293	-05:04:34.50	30.27	9.08	6.83	2.24	6.48	13.4	8	413
79066	16:08:24.487	-13:08:07.81	35.43	8.67	6.38	2.29	6.41	10.5	5	333
80366	16:24:19.810	-13:38:29.97	46.46	8.33	6.00	2.33	6.67	14.1	14	327
80539	16:26:33.482	+15:39:53.83	37.09	10.55	7.20	3.35	8.40	23.1	6	329
80597	16:27:20.393	+00:55:29.68	32.82	9.95	6.79	3.16	7.53	10.5	6	313
81030	16:32:57.882	-12:35:30.23	30.53	10.60	7.25	3.35	8.03	10.0	7	417
84487	17:16:20.234	-12:10:41.36	36.73	10.20	6.91	3.29	8.03	15.3	10	798
85561	17:29:06.558	-23:50:10.02	53.02	9.63	6.39	3.24	8.26	6.3	16	328
87464	17:52:16.606	-07:33:37.46	33.35	10.01	6.97	3.03	7.62	8.3	6	36
87745	17:55:24.781	+03:45:16.22	38.13	10.18	6.82	3.36	8.09	16.0	9	799
87768	17:55:44.899	+18:30:01.41	39.93	9.22	6.30	2.92	7.23	11.8	7	822
88961	18:09:32.246	-00:19:37.66	33.40	8.97	6.54	2.42	6.58	12.3	14	802
88962	18:09:33.263	-12:02:20.01	36.29	10.43	6.99	3.44	8.23	20.1	10	799
89517	18:16:02.252	+13:54:48.19	55.01	10.09	6.56	3.53	8.79	12.3	18	328
89656	18:17:49.804	+26:40:16.70	31.74	9.59	6.95	2.64	7.10	23.6	5	31
89728	18:18:40.679	-06:42:03.73	32.42	9.26	6.72	2.54	6.82	6.4	7	339
89825	18:19:50.842	-01:56:18.98	51.12	9.60	6.28	3.32	8.15	8.8	19	329
90611	18:29:22.303	-27:58:19.02	33.90	9.37	6.49	2.88	7.02	7.6	5	29
90626	18:29:31.914	+09:03:43.52	36.20	8.61	6.33	2.28	6.40	11.1	10	789
90959	18:33:17.760	+22:18:51.30	43.53	8.89	6.16	2.73	7.08	9.4	19	329
92311	18:48:51.872	+17:26:20.22	58.82	9.17	5.92	3.25	8.01	14.0	16	355
93195	18:58:56.491	-00:30:14.34	32.41	8.36	6.38	1.97	5.91	10.6	8	758
93731	19:05:07.515	+23:04:40.06	31.46	8.53	6.62	1.91	6.02	5.7	6	66
94650	19:15:35.054	+11:33:16.98	38.07	8.04	5.94	2.10	5.95	16.3	7	727
95299	19:23:16.463	-06:35:07.32	34.72	9.71	6.81	2.90	7.42	9.4	7	745
95429	19:24:42.094	+08:32:59.76	30.30	11.34	7.73	3.61	8.75	27.6	8	501
95730	19:28:15.396	+12:32:09.24	35.69	9.19	6.35	2.84	6.95	11.0	6	405
95890	19:30:05.478	+21:40:34.01	32.67	9.90	7.07	2.83	7.47	8.2	4	44
96121	19:32:37.919	+00:34:39.05	44.52	10.43	6.81	3.62	8.67	14.0	18	412
96285	19:34:39.841	+04:34:57.05	69.32	9.35	5.92	3.43	8.55	10.5	17	412

Table A3
(Continued)

HIP	R.A. (hh:mm:ss.sss)	Decl. (°:′:″)	Parallax (mas)	<i>V</i> (mag)	<i>K</i> (mag)	<i>V</i> − <i>K</i> (mag)	<i>M_V</i> (mag)	MAD _{RV} (ms ^{−1})	No. Obs.	Time Span (days)
97805	19:52:29.915	−23:56:57.06	36.77	9.41	6.61	2.81	7.24	16.8	6	488
98828	20:04:10.046	+25:47:24.82	45.56	7.81	5.64	2.17	6.10	13.3	15	430
99205	20:08:24.367	+06:40:43.46	39.23	9.84	6.93	2.91	7.80	22.3	8	208
99332	20:09:41.013	−03:07:44.43	30.94	9.55	6.74	2.81	7.01	14.3	9	165
102115	20:41:40.697	−05:29:34.25	31.53	10.66	7.23	3.42	8.15	27.0	8	439
102226	20:42:49.360	+20:50:40.61	39.93	8.24	6.01	2.23	6.25	11.2	5	460
102332	20:44:00.655	−21:21:20.87	40.05	9.89	6.75	3.14	7.90	10.5	14	345
102582	20:47:16.841	+10:51:36.47	31.94	9.78	7.00	2.78	7.31	11.6	9	540
104329	21:08:01.902	+25:10:34.44	30.59	9.83	7.06	2.77	7.26	12.4	7	507
109807	22:14:26.748	+02:42:24.12	34.12	10.31	7.49	2.82	7.98	18.7	10	736
112918	22:52:02.520	+23:24:47.67	38.17	9.76	6.82	2.94	7.67	16.6	13	811
113333	22:57:07.357	+28:00:07.03	36.03	9.83	7.02	2.81	7.62	10.1	5	339
114941	23:16:51.829	+05:41:45.59	39.59	10.51	6.80	3.71	8.49	18.3	12	896
115752	23:27:04.836	−01:17:10.58	32.98	10.48	7.01	3.46	8.07	12.4	12	514
117463	23:49:01.159	+03:10:52.20	38.94	8.41	6.17	2.24	6.36	9.4	13	464
117779	23:53:08.595	+29:01:05.05	44.41	9.71	6.39	3.32	7.95	13.9	19	412
118086	23:57:14.381	−16:30:27.37	32.61	11.01	7.60	3.41	8.57	17.7	10	878

ORCID iDs

Leonardo A. Paredes  <https://orcid.org/0000-0003-1324-0495>
 Todd J. Henry  <https://orcid.org/0000-0002-9061-2865>
 Samuel N. Quinn  <https://orcid.org/0000-0002-8964-8377>
 Douglas R. Gies  <https://orcid.org/0000-0001-8537-3583>
 Hodari-Sadiki James  <https://orcid.org/0000-0003-4568-2079>
 Wei-Chun Jao  <https://orcid.org/0000-0003-0193-2187>
 Russel J. White  <https://orcid.org/0000-0001-5313-7498>

References

- Baglin, A., Auvergne, M., Barge, P., et al. 2006, in The CoRoT Mission Pre-Launch Status—Stellar Seismology and Planet Finding, ESA Special Publication, Vol. 1306, ed. M. Fridlund et al. (Noordwijk: ESA Publications), 33
- Bakos, G. Á., Pál, A., Latham, D. W., Noyes, R. W., & Stefanik, R. P. 2006, *ApJL*, 641, L57
- Baranec, C., Riddle, R., Ramaprakash, A. N., et al. 2012, *Proc. SPIE*, 8447, 844704
- Baranne, A., Queloz, D., Mayor, M., et al. 1996, *A&AS*, 119, 373
- Bernstein, R., Shtetman, S. A., Gunnels, S. M., Mochnacki, S., & Athey, A. E. 2003, *Proc. SPIE*, 4841, 1694
- Borucki, W. J., Koch, D., Basri, G., et al. 2010, *Sci*, 327, 977
- Bouchy, F., Udry, S., Mayor, M., et al. 2005, *A&A*, 444, L15
- Brewer, J. M., Giguere, M., & Fischer, D. A. 2014, *PASP*, 126, 48
- Butler, R. P., Vogt, S. S., Laughlin, G., et al. 2017, *AJ*, 153, 208
- Crane, J. D., Shtetman, S. A., & Butler, R. P. 2006, *Proc. SPIE*, 6269, 626931
- Cuntz, M., & Guinan, E. F. 2016, *ApJ*, 827, 79
- Evans, D. W., Riello, M., De Angeli, F., et al. 2018, *A&A*, 616, A4
- Ge, J., van Eyken, J., Mahadevan, S., et al. 2006, *ApJ*, 648, 683
- Giguere, M. J., Fischer, D. A., Payne, M. J., et al. 2015, *ApJ*, 799, 89
- Giguere, M. J., Fischer, D. A., Zhang, C. X. Y., et al. 2016, *ApJ*, 824, 150
- Gilbert, J., Bergmann, C., Bloxham, G., et al. 2018, *Proc. SPIE*, 10702, 107020Y
- Gould, A., & Chanamé, J. 2004, *ApJS*, 150, 455
- Gray, R. O., & Corbally, Christopher J. 2009, *Stellar Spectral Classification* (Princeton, NJ: Princeton Univ. Press)
- Guilluy, G., Andretta, V., Borsa, F., et al. 2020, *A&A*, 639, A49
- Guilluy, G., Sozzetti, A., Brogi, M., et al. 2019, *A&A*, 625, A107
- Halbwachs, J. L., Mayor, M., & Udry, S. 2005, *A&A*, 431, 1129
- Henry, G. W., Donahue, R. A., & Baliunas, S. L. 2002, *ApJL*, 577, L111
- Henry, T. J., Ianna, P. A., Kirkpatrick, J. D., & Jahreiss, H. 1997, *AJ*, 114, 388
- Henry, T. J., Jao, W.-C., Subasavage, J. P., et al. 2006, *AJ*, 132, 2360
- Henry, T. J., Jao, W.-C., Winters, J. G., et al. 2018, *AJ*, 155, 265
- Henry, T. J., & McCarthy, Donald W., Jr. 1993, *AJ*, 106, 773
- Hinkel, N. R., Kane, S. R., Henry, G. W., et al. 2015, *ApJ*, 803, 8
- Høg, E., Fabricius, C., Makarov, V. V., et al. 2000, *A&A*, 355, L27
- Horch, E. P., Veilleux, D. R., Baena Gallé, R., et al. 2009, *AJ*, 137, 5057
- Howell, S. B., Sobek, C., Haas, M., et al. 2014, *PASP*, 126, 398
- Kaufer, A., & Pasquini, L. 1998, *Proc. SPIE*, 3355, 844
- Latham, D. W., Mazeh, T., Stefanik, R. P., Mayor, M., & Burki, G. 1989, *Natur*, 339, 38
- Malkov, O. Y., Tamazian, V. S., Docobo, J. A., & Chulkov, D. A. 2012, *A&A*, 546, A69
- Mamajek, E. E. 2012, arXiv:1210.1616
- Mason, B. D., Douglass, G. G., & Hartkopf, W. I. 1999, *AJ*, 117, 1023
- Mason, B. D., Wycoff, G. L., Hartkopf, W. I., Douglass, G. G., & Worley, C. E. 2001, *AJ*, 122, 3466
- Mayor, M., Marmier, M., Lovis, C., et al. 2011, arXiv:1109.2497
- Mayor, M., Pepe, F., Queloz, D., et al. 2003, *Msngr*, 114, 20
- Mayor, M., & Queloz, D. 1995, *Natur*, 378, 355
- Meschiari, S., Wolf, A. S., Rivera, E., et al. 2009, *PASP*, 121, 1016
- Moutou, C., Mayor, M., Bouchy, F., et al. 2005, *A&A*, 439, 367
- Munari, U., & Walter, F. M. 2016, *MNRAS*, 455, L57
- Nielsen, L. D., Brahm, R., Bouchy, F., et al. 2020, *A&A*, 639, A76
- Nusdeo, Daniel A. 2018, in AAS Meeting, 231, 244.13
- Oh, S., Price-Whelan, A. M., Hogg, D. W., Morton, T. D., & Spergel, D. N. 2017, *AJ*, 153, 257
- Oliya, E., Origlia, L., Baffa, C., et al. 2006, *Proc. SPIE*, 6269, 626919
- Piskunov, N. E., & Valenti, J. A. 2002, *A&A*, 385, 1095
- Pourbaix, D., Tokovinin, A. A., Batten, A. H., et al. 2004, *A&A*, 424, 727
- Raghavan, D., McAlister, H. A., Henry, T. J., et al. 2010, *ApJS*, 190, 1
- Redfield, S., Endl, M., Cochran, W. D., & Koesterke, L. 2008, *ApJL*, 673, L87
- Ricker, G. R., Winn, J. N., Vanderspek, R., et al. 2014, *Proc. SPIE*, 9143, 914320
- Riddle, R. L., Tokovinin, A., Mason, B. D., et al. 2015, *ApJ*, 799, 4
- Roberts, Lewis C., J., Tokovinin, A., Mason, B. D., et al. 2015, *AJ*, 149, 118
- Santos, N. C., Mayor, M., Naef, D., et al. 2000, *A&A*, 356, 599
- Santos, N. C., Udry, S., Mayor, M., et al. 2003, *A&A*, 406, 373
- Skrutskie, M. F., Cutri, R. M., Stiening, R., et al. 2006, *AJ*, 131, 1163
- Shaya, E. J., & Olling, R. P. 2011, *ApJS*, 192, 2
- Söderhjelm, S. 1999, *A&A*, 341, 121
- Subasavage, J. P., Bailyn, C. D., Smith, R. C., et al. 2010, *Proc. SPIE*, 7737, 77371C
- Tala, M., Berdja, A., Jones, M., et al. 2014, *Proc. SPIE*, 9147, 914789
- Tokovinin, A. 2014, *AJ*, 147, 87
- Tokovinin, A., Fischer, D. A., Bonati, M., et al. 2013, *PASP*, 125, 1336
- Udry, S., Mayor, M., Naef, D., et al. 2000, *A&A*, 356, 590
- van Leeuwen, F. 2007, *A&A*, 474, 653
- Vogt, S. S., Allen, S. L., Bigelow, B. C., et al. 1994, *Proc. SPIE*, 2198, 362
- Wittenmyer, R. A., Endl, M., Cochran, W. D., Levison, H. F., & Henry, G. W. 2009, *ApJS*, 182, 97
- Wittrock, J. M., Kane, S. R., Horch, E. P., et al. 2016, *AJ*, 152, 149
- Wolszczan, A., & Frail, D. A. 1992, *Natur*, 355, 145
- Wright, J. T., & Eastman, J. D. 2014, *PASP*, 126, 838
- Zucker, S. 2003, *MNRAS*, 342, 1291