Adventures in J and H Band Photometry of Evolved Stars

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Abstract Among the classes of objects optimized for angular diameter measurements by current generation astronomical interferometers are nearby red giant stars. Precision diameters can help constrain atmospheric and evolution models thereof, but many of these stars are intrinsically variable and thus must be monitored during intervals when interferometry is planned. Using an Optec SSP-4 photometer, we obtained the J and H band magnitudes of a sample of such stars being studied by the Palomar Testbed Interferometer, and report results here.

1. Introduction

Van Belle and Hart (2007 private communication) have proposed measuring the angular diameters of a selection of evolved stars and unresolved comparators using the Palomar Testbed Interferometer [PTI, Colavita et al. 1999]. In order to realize milli-arcsecond angular accuracy, the brightness of each star at or near the time of PTI observation needs to be monitored, ideally in or near the 2.2 micron K band wavelengths used by PTI. Our photometric targets were selected on the basis of priority for PTI observation and accessibility during summer 2007. The comparison stars reported here serve as unresolved point sources for PTI to use to calibrate angular diameters of the target stars.

2. Procedure

Our instrumentation involved the south 0.72 m telescope of the University of Denver's Meyer-Womble Observatory atop Mt. Evans (Stencel 1999), as well as an Optec (http://www.optecinc.com) SSP-4 photometer (Henden 2002). The data collection was performed in a differential manner following a method described by Hopkins (2006). This method requires determining the brightness of the PTI Target stars and PTI Calibrator Stars, as well as Near-IR Primary Standard Stars (Standard Stars), in both the near infrared 1.2 micron J band and the 1.6 micron H band.

The instrumental magnitude in both the J and H bands is determined for a Standard Star, by star minus sky subtraction, and -2.5 log (net counts). The Standard Star has a known magnitude in the two bands, from catalog sources discussed below. Next, the instrumental magnitude of a PTI Target star and/or a PTI calibrator star is determined in both the J and H bands. Finally, the instrumental magnitude of the Standard Star is re-observed. This provides a bracketing of the PTI Target or PTI calibrator with known Standard Stars. This method can also be adapted to include multiple PTI Targets and PTI Calibrator Stars between Standard Stars.

Table 2 shows the measurements for the Standard Stars. First, a correction factor was found from all of the Standard Stars observed on a given night. This correction factor was used to convert instrumental magnitudes to the known, catalog values. One problem with this approach is that the night sky conditions change, both spatially and temporally. Because we are using a differential method, these changes have a large impact on our data analysis. Therefore, we modified this approach to bracket the PTI Target stars and PTI Calibrator Stars between Standard Stars in right ascension, declination, and time, which yielded the results reported below. By doing so, we could minimize the changes in the atmosphere, thereby achieving more reliable results.

One area of interest was the effect of air mass on the observed counts of Standard Stars. Air mass refers to the line of sight column of air that varies with angle from zenith. Most magnitude measurements were taken as close to the meridian as possible, at air mass values between 1.00 and 1.15. Henden (2002) suggests typical extinction values of 0.10 mag per unit airmass in the J band, and 0.06 mag per unit airmass in the H band. One would expect airmass correction of less than 0.01 mag over the majority of our observed range of airmasses, which is less than our quoted errors (see below). Therefore, no air mass corrections have been applied to the results from the data analysis. As a check, a few large airmass readings were made and the extinction found to be consistent with Henden (2002).

Dark counts are used as an offset and are recorded when there is no light incident on the detector. According to Optec, the electrometer amplifier may drift slightly, and if the offset drops below zero, the unit will not display any value for the counts. Thus a positive dark count is necessary (Optec 2007). In general, we found that the dark count tends to decrease as the night goes on, consistent with the cooling of the detector. The dark counts decrease ~5% in the first few minutes of the detector being on, and then slowly recover on a scale of hours. For this reason, we did not take data during the first 15-30 minutes. Because the dark counts are small relative to the counts from the stars, there has been no correction made for the drift.

Any cloud cover or atmospheric disturbance will affect the readings on the SSP4. It has been found that visible cloud cover will decrease the counts of a star from what would have been seen without the clouds. Light leak has also been a possible source of error in the SSP4 – either having a light shining directly on the SSP4 casing, or not moving a bright star sufficiently far out of the field of view when taking a sky reading. Additionally, the gain setting on the photometer might not provide a perfectly linear multiplication of the signal. When going from a gain of 10 to a gain of 100 for the same target, the counts increase more than 10 times, which is less than a 1% effect. The high amplification is the root cause of the nonlinearity in the gain setting (Hopkins 2007).

3. Results

The list of stars that were observed is found in Table 1. Standard Star instrumental and catalog magnitudes are found in Table 2, while the observed magnitudes for the PTI Target and PTI Calibrator Stars are in Table 3. In Table 1, the columns reflect the category of star reported, HD number and spectral type from SIMBAD, catalog value for J and H magnitudes from Henden, et al. (2002), or 2MASS. The columns in Tables 2 and 3 include star identifier, Reduced Julian Day observed (RJD is JD – 2,450,000), air mass at time of observation, instrumental magnitudes in the J and H Bands, and the conversion factor to calculate the catalog magnitude in both the J and H Bands. Table 3 also includes two columns that contain the calculated catalog values for the PTI Targets and the PTI Calibrator Stars. It is important to note that Henden claims approximately 0.050 mag all-sky accuracy is possible using these Standard Stars. Since we are working in a very limited air mass region, we have assumed an accuracy of 0.025 mag on all catalog values for the magnitudes of the Standard Stars used (Henden 2002).

During 2007 July, the 0.72m mirrors in both tubes of the Meyer Womble Binocular Telescope were resilvered. The mirrors were removed from the telescope on RJD 4293, and were back in service by RJD 4335. Because we used a differential procedure, the subsequent change in instrumental magnitude due to the resilvered mirrors was accounted for by the change in correction factor, as can be seen, for example, with HD 172167 in Table 2.

This particular observational sample does not feature any large amplitude variables, and that is consistent with the measurements and the errors derived here. These measurements provide a baseline against which parallel interferometric observations can be calibrated. In this paper we have demonstrated the utility of the SSP4 photometer in support of this and other ground based astronomical measurements.

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Table 1. A list of stars observed. PTI Target Stars and PTI Calibrator Stars from Van Belle and Hart (2007), Near-IR Primary Standard Stars from Henden (2002).

Object Type[1]	**HD**	**Spectral Type**	$\mathbf{J_{cat} / \sigma_{cat}}$	$\mathbf{H_{cat} / \sigma_{cat}}$	**Notes**[2]
Standard	358	B8 IVmnp…	2.30 ±0.025	2.33 ±0.025	H, alp And
Standard	886	B2 IV	3.50 ±0.26	3.64 ±0.20	2M, gam Peg
Standard	1013	M2 III	1.63 ±0.025	0.81 ±0.025	H, chi Peg
PTI Cal	1364	M3.5 IIIa	3.16 ±0.24	2.16 ±0.19	2M
PTI Cal	3268	F7 V	5.34 ±0.02	5.16 ±0.04	2M
Standard	6860	M0 III	-0.92 ±0.025	-1.73 ±0.025	H, bet And
Standard	34085	B8 Iab:	0.23 ±0.025	0.22 ±0.025	H, Rigel
Standard	121370	G0 IV	1.71 ±0.025	1.41 ±0.025	H, eta Boo
Standard	124897	K1 III	-2.21 ±0.025	-2.90 ±0.025	H, alpha Boo
Standard	128167	F3 Vwvar	3.70 ±0.025	3.51 ±0.025	H, sig Boo
PTI Target	133208	G8 IIIa	1.80 ±0.31	1.27 ±0.12	2M, bet Boo
PTI Target	139153	M1.5 III	2.00 ±0.23	1.14 ±0.14	2M, mu CrB
PTI Cal	139761	K0	4.33 ±0.24	3.85 ±0.21	2M
PTI Cal	142908	F0 IV	4.69 ±0.037	4.48 ±0.036	3, lam CrB
Standard	147394	B5 IV	4.20 ±0.025	4.27 ±0.025	H, tau Her
Standard	156014	M5 Ib	-2.29 ±0.025	-3.14 ±0.025	H, alpha Her
Standard	164136	F2 II	3.46 ±0.025	3.25 ±0.025	H, nu Her
PTI Cal	166229	K2.5 III	3.65 ±0.30	3.05 ±0.26	2M
PTI Target	168775	K2 III	2.58 ±0.28	1.99 ±0.16	2M, kap Lyr
PTI Cal	169702	A3 IVn	4.92 ±0.04	4.95 ±0.04	2M, mu Lyr
PTI Target	170970	M8+…	3.56 ±0.26	2.69 ±0.20	2M, V530 Lyr
Standard	172167	A0 V	0.00 ±0.025	0.00 ±0.025	H, Vega
PTI Cal	173417	F1 III-IV	4.90 ±0.04	4.84 ±0.04	2M
PTI Cal	174368	A0	8.46 ±0.03	8.43 ±0.03	2M
PTI Cal	184385	G5 V	5.57 ±0.02	5.25 ±0.04	2M
PTI Target	186675	G7 III	3.45 ±0.27	2.94 ±0.22	2M, 15 Cyg
PTI Target	186776	M4 III	2.72 ±0.25	1.85 ±0.20	2M, V973 Cyg
PTI Cal	187013	F7 V	4.05 ±0.3	3.98 ±0.3	2M
Standard	188947	K0 III	2.16 ±0.025	1.70 ±0.025	H, eta Cyg
PTI Cal	190771	G5 IV	4.92 ±0.3	4.74 ±0.3	2M
PTI Target	192004	K3 Iab:	3.27 ±0.30	2.59 ±0.26	2M, 19 Vul
Standard	197345	A2 Iae	0.99 ±0.025	0.91 ±0.025	H, Deneb
Standard	197989	K0 III	0.73 ±0.025	0.19 ±0.025	H, eps Cyg
PTI Cal	200527	M4s…	2.27 ±0.33	1.41 ±0.18	2M, V1981 Cyg
PTI Cal	200723	F3 IV	5.55 ±0.02	5.40 ±0.04	2M
PTI Target	205435	G8 III	2.49 ±0.26	2.01 ±0.26	2M, rho Cyg
PTI Target	206330	M1 III	2.14 ±0.24	1.23 ±0.16	2M, 75 Cyg
PTI Cal	206749	M2 III	2.52 ±0.31	1.70 ±0.19	2M

Table 1, continued

Object Type	**HD**	**Spectral Type**	**J_{cat} / σ_{cat}**	**H_{cat} / σ_{cat}**	**Notes**
Standard	217906	M2.5 II-III	-1.19 ±0.025	-2.05 ±0.025	H, bet Peg
PTI Target	339034	K3 Iab:	3.25 ±0.27	2.14 ±0.22	2M, NR Vul

[1] Targets and comps from Van Belle and Hart (2007), Primary Standard Stars from Henden (2002).
[2] H indicates that the magnitudes were taken from Henden (2002), and 2M indicates that the magnitudes were taken from the 2Mass All Sky Catalog. Where no uncertainty was given, a maximum value is assumed.
[3] For HD 142908 (lam CrB), no 2Mass magnitudes were available, so we report our Table 3 result here.

Table 2. Results for the near-IR primary standard stars

HD	RJD	Air Mass	$J_{inst} \pm \sigma_{inst}$	ΔJ	$H_{inst} \pm \sigma_{inst}$	ΔH
358	4334.8472	1.03	-8.17 ±0.003	10.47 ±0.025	-8.33 ±0.005	10.66 ±0.025
6860	4334.8819	1.02	-11.43 ±0.006	10.51 ±0.026	-12.42 ±0.006	10.69 ±0.026
121370	4270.6631	1.09	-8.74 ±0.003	10.45 ±0.025	-9.20 ±0.004	10.61 ±0.025
121370	4270.7326	1.23	-8.72 ±0.010	10.43 ±0.027	-9.16 ±0.003	10.57 ±0.025
121370	4271.6562	1.09	-8.73 ±0.005	10.44 ±0.025	-9.18 ±0.003	10.59 ±0.025
124897	4270.6458	1.08	-12.70 ±0.004	10.49 ±0.025	-13.57 ±0.005	10.67 ±0.025
124897	4270.7430	1.22	-12.67 ±0.030	10.46 ±0.039	-13.54 ±0.011	10.64 ±0.027
124897	4271.6319	1.08	-12.70 ±0.005	10.49 ±0.025	-13.57 ±0.005	10.67 ±0.025
124897	4271.6666	1.08	-12.68 ±0.005	10.47 ±0.025	-13.55 ±0.005	10.65 ±0.025
124897	4271.7708	1.36	-12.64 ±0.008	10.43 ±0.026	-13.51 ±0.011	10.61 ±0.027
128167	4271.6770	1.02	-6.68 ±0.001	10.38 ±0.025	-7.09 ±0.002	10.60 ±0.025
147394	4271.7256	1.01	-6.19 ±0.001	10.39 ±0.025	-6.35 ±0.003	10.62 ±0.025
147394	4272.7430	1.01	-6.17 ±0.003	10.37 ±0.025	-6.35 ±0.003	10.62 ±0.025
156014	4270.9027	1.40	-12.69 ±0.030	10.40 ±0.039	-13.80 ±0.013	10.66 ±0.028
156014	4271.6458	1.52	-12.66 ±0.010	10.37 ±0.027	-13.76 ±0.020	10.62 ±0.032
156014	4271.6944	1.22	-12.66 ±0.013	10.37 ±0.028	-13.77 ±0.011	10.63 ±0.027
156014	4271.7326	1.14	-12.69 ±0.005	10.40 ±0.025	-13.79 ±0.004	10.65 ±0.025
156014	4272.7604	1.11	-12.66 ±0.005	10.37 ±0.025	-13.75 ±0.009	10.61 ±0.027
156014	4335.6562	1.16	-12.77 ±0.009	10.48 ±0.027	-13.84 ±0.005	10.70 ±0.025
164136	4271.7430	1.07	-6.90 ±0.002	10.36 ±0.025	-7.35 ±0.003	10.60 ±0.025
164136	4272.7708	1.03	-6.86 ±0.002	10.32 ±0.025	-7.29 ±0.008	10.54 ±0.026
164136	4272.8055	1.02	-6.88 ±0.001	10.34 ±0.025	-7.33 ±0.002	10.58 ±0.025
164136	4277.8159	1.03	-6.87 ±0.002	10.33 ±0.025	-7.33 ±0.002	10.58 ±0.025
164136	4290.7500	1.02	-6.83 ±0.005	10.29 ±0.025	-7.29 ±0.007	10.54 ±0.026

Table 2, continued

HD	RJD	Air Mass	$J_{inst} \pm \sigma_{inst}$	ΔJ	$H_{inst} \pm \sigma_{inst}$	ΔH
172167	4270.8819	1.02	-10.38 ±0.002	10.38 ±0.025	-10.60 ±0.005	10.60 ±0.025
172167	4271.7013	1.22	-10.34 ±0.001	10.34 ±0.025	-10.58 ±0.001	10.58 ±0.025
172167	4271.7812	1.03	-10.36 ±0.005	10.36 ±0.025	-10.59 ±0.006	10.59 ±0.026
172167	4271.8159	1.00	-10.38 ±0.006	10.38 ±0.026	-10.61 ±0.003	10.61 ±0.025
172167	4272.7916	1.01	-10.35 ±0.001	10.35 ±0.025	-10.58 ±0.004	10.58 ±0.025
172167	4277.8055	1.00	-10.36 ±0.002	10.36 ±0.025	-10.59 ±0.002	10.59 ±0.025
172167	4277.8437	1.02	-10.35 ±0.006	10.35 ±0.026	-10.58 ±0.005	10.58 ±0.025
172167	4277.8819	1.06	-10.32 ±0.016	10.32 ±0.030	-10.57 ±0.004	10.57 ±0.025
172167	4280.9062	1.14	-10.34 ±0.004	10.34 ±0.025	-10.56 ±0.006	10.56 ±0.026
172167	4290.7812	1.00	-10.33 ±0.004	10.33 ±0.025	-10.56 ±0.006	10.56 ±0.026
172167	4333.7083	1.02	-10.45 ±0.004	10.45 ±0.025	-10.67 ±0.002	10.67 ±0.025
172167	4333.7500	1.11	-10.45 ±0.003	10.45 ±0.025	-10.66 ±0.003	10.66 ±0.025
172167	4335.6944	1.02	-10.44 ±0.013	10.44 ±0.028	-10.67 ±0.008	10.67 ±0.026
172167	4335.7013	1.03	-10.44 ±0.005	10.44 ±0.025	-10.66 ±0.003	10.66 ±0.025
172167	4335.7152	1.05	-10.45 ±0.006	10.45 ±0.026	-10.67 ±0.013	10.67 ±0.028
172167	4335.7222	1.07	-10.44 ±0.004	10.44 ±0.025	-10.66 ±0.005	10.66 ±0.025
172167	4343.6875	1.04	-10.45 ±0.008	10.45 ±0.026	-10.66 ±0.006	10.66 ±0.026
172167	4343.7361	1.15	-10.41 ±0.007	10.41 ±0.026	-10.65 ±0.005	10.65 ±0.025
188947	4272.8159	1.06	-8.17 ±0.010	10.33 ±0.027	-8.87 ±0.006	10.57 ±0.026
188947	4272.8750	1.00	-8.20 ±0.003	10.36 ±0.025	-8.89 ±0.010	10.59 ±0.027
188947	4277.8888	1.01	-8.20 ±0.002	10.36 ±0.025	-8.89 ±0.003	10.59 ±0.025
188947	4277.9236	1.05	-8.18 ±0.006	10.34 ±0.026	-8.88 ±0.002	10.58 ±0.025
188947	4290.8437	1.01	-8.15 ±0.010	10.31 ±0.027	-8.85 ±0.005	10.55 ±0.025
188947	4291.8125	1.01	-8.17 ±0.002	10.33 ±0.025	-8.87 ±0.002	10.57 ±0.025
188947	4333.7916	1.07	-8.30 ±0.008	10.46 ±0.026	-8.97 ±0.007	10.57 ±0.026
188947	4335.7534	1.03	-8.30 ±0.003	10.46 ±0.025	-8.99 ±0.004	10.59 ±0.025
188947	4335.7673	1.05	-8.30 ±0.004	10.46 ±0.025	-8.99 ±0.006	10.59 ±0.026
197345	4272.8958	1.01	-9.39 ±0.004	10.38 ±0.025	-9.69 ±0.004	10.60 ±0.025
197345	4291.8750	1.01	-9.34 ±0.013	10.33 ±0.028	-9.65 ±0.007	10.56 ±0.026

Table 2, continued

HD	RJD	Air Mass	$J_{inst} \pm \sigma_{inst}$	ΔJ	$H_{inst} \pm \sigma_{inst}$	ΔH
197345	4333.8229	1.07	-9.50 ±0.006	10.49 ±0.026	-9.78 ±0.003	10.69 ±0.025
197345	4335.7708	1.02	-9.51 ±0.006	10.50 ±0.026	-9.79 ±0.005	10.70 ±0.025
197345	4335.7777	1.02	-9.50 ±0.003	10.49 ±0.025	-9.77 ±0.004	10.68 ±0.025
197345	4343.7138	1.00	-9.47 ±0.009	10.46 ±0.027	-9.76 ±0.002	10.67 ±0.025
197345	4343.7569	1.02	-9.49 ±0.004	10.48 ±0.025	-9.76 ±0.004	10.67 ±0.025
197345	4343.7812	1.05	-9.48 ±0.007	10.47 ±0.026	-9.76 ±0.002	10.67 ±0.025
197345	4343.8055	1.09	-9.47 ±0.010	10.46 ±0.027	-9.76 ±0.004	10.67 ±0.025
197989	4272.8854	1.01	-9.68 ±0.005	10.41 ±0.025	-10.40 ±0.004	10.59 ±0.025
197989	4291.9097	1.04	-9.66 ±0.005	10.39 ±0.025	-10.40 ±0.003	10.59 ±0.025
197989	4335.7812	1.02	-9.78 ±0.007	10.51 ±0.026	-10.50 ±0.005	10.69 ±0.025
217906	4333.9166	1.03	-11.74 ±0.004	10.55 ±0.025	-12.79 ±0.006	10.74 ±0.026
217906	4334.8090	1.03	-11.74 ±0.005	10.55 ±0.025	-12.78 ±0.009	10.73 ±0.027

*RJD = JD – 2,450,000

Table 3. Results for the PTI Target and PTI Calibrator stars

HD	RJD	$J_{inst} \pm \sigma_{inst}$	ΔJ	$J \pm \sigma_J$	$H_{inst} \pm \sigma_{inst}$	ΔH	$H \pm \sigma_H$
1364	4334.8611	-7.62 ±0.002	10.46 ±0.036	2.84 ±0.036	-8.64 ±0.002	10.66 ±0.036	2.02 ±0.036
3268	4334.8715	-5.08 ±0.001	10.41 ±0.036	5.33 ±0.036	-5.53 ±0.001	10.62 ±0.036	5.09 ±0.036
133208	4270.6806	-8.50 ±0.004	10.41 ±0.037	1.91 ±0.037	-9.11 ±0.042	10.60 ±0.036	1.49 ±0.055
133208	4271.6875	-8.49 ±0.006	10.38 ±0.038	1.89 ±0.038	-9.14 ±0.004	10.60 ±0.037	1.46 ±0.037
139153	4270.7014	-8.38 ±0.002	10.41 ±0.037	2.03 ±0.037	-9.42 ±0.004	10.60 ±0.036	1.18 ±0.036
139153	4271.7153	-8.38 ±0.005	10.38 ±0.036	2.00 ±0.036	-9.41 ±0.004	10.61 ±0.036	1.20 ±0.036
139761	4270.6909	-6.08 ±0.001	10.39 ±0.037	4.31 ±0.037	-6.82 ±0.003	10.57 ±0.036	3.75 ±0.036
139761	4270.7083	-6.08 ±0.001	10.39 ±0.037	4.31 ±0.037	-6.82 ±0.003	10.57 ±0.036	3.75 ±0.036
142908	4270.7153	-5.70 ±0.003	10.39 ±0.037	4.69 ±0.037	-6.08 ±0.002	10.56 ±0.036	4.48 ±0.036
166229	4270.7813	-6.82 ±0.001	10.40 ±0.046	3.58 ±0.046	-7.55 ±0.001	10.58 ±0.037	3.03 ±0.037
166229	4335.6875	-6.89 ±0.003	10.49 ±0.039	3.60 ±0.039	-7.62 ±0.004	10.69 ±0.037	3.07 ±0.037
166229	4335.6924	-6.89 ±0.004	10.49 ±0.039	3.60 ±0.039	-7.63 ±0.009	10.69 ±0.037	3.06 ±0.038
168775	4270.7881	-8.01 ±0.002	10.31 ±0.046	2.30 ±0.046	-8.76 ±0.003	10.55 ±0.037	1.79 ±0.037
168775	4271.7500	-8.02 ±0.005	10.41 ±0.036	2.39 ±0.037	-8.77 ±0.006	10.60 ±0.037	1.83 ±0.038
168775	4277.8299	-7.98 ±0.003	10.35 ±0.036	2.37 ±0.036	-8.73 ±0.006	10.58 ±0.036	1.85 ±0.036
168775	4290.7569	-7.95 ±0.001	10.21 ±0.036	2.26 ±0.036	-8.70 ±0.003	10.45 ±0.036	1.75 ±0.037
168775	4333.7222	-8.08 ±0.004	10.45 ±0.036	2.37 ±0.036	-8.80 ±0.006	10.66 ±0.036	1.86 ±0.036
168775	4335.7083	-8.07 ±0.009	10.48 ±0.036	2.41 ±0.037	-8.82 ±0.007	10.68 ±0.038	1.86 ±0.038
169702	4270.8056	-5.48 ±0.001	10.39 ±0.046	4.91 ±0.046	-5.74 ±0.001	10.56 ±0.037	4.82 ±0.037
169702	4271.7916	-5.47 ±0.001	10.36 ±0.036	4.89 ±0.036	-5.72 ±0.001	10.58 ±0.036	4.86 ±0.036
169702	4277.8542	-5.47 ±0.001	10.30 ±0.039	4.83 ±0.039	-5.74 ±0.001	10.44±0.036	4.70 ±0.036
169702	4290.7917	-5.39 ±0.001	10.28 ±0.037	4.89 ±0.037	-5.63 ±0.002	10.53 ±0.036	4.90 ±0.036

Table 3, continued

HD	RJD	$J_{inst} \pm \sigma_{inst}$	ΔJ	$J \pm \sigma_J$	$H_{inst} \pm \sigma_{inst}$	ΔH	$H \pm \sigma_H$
170970	4270.7986	-6.87 ±0.001	10.40 ±0.46	3.53 ±0.046	-7.90 ±0.024	10.58 ±0.037	2.68 ±0.044
170970	4271.7569	-6.89 ±0.002	10.37 ±0.036	3.48 ±0.036	-7.91 ±0.001	10.60 ±0.037	2.69 ±0.037
170970	4272.7847	-6.86 ±0.002	10.35 ±0.035	3.49 ±0.003	-7.89 ±0.004	10.58 ±0.036	2.69 ±0.037
170970	4277.8368	-6.85 ±0.002	10.32 ±0.036	3.47 ±0.036	-7.88 ±0.003	10.54 ±0.036	2.66 ±0.036
170970	4290.7708	-6.83 ±0.002	10.29 ±0.036	3.46 ±0.036	-7.86 ±0.004	10.54 ±0.036	2.68 ±0.037
170970	4333.7396	-6.96 ±0.003	10.43 ±0.036	3.47 ±0.036	-7.97 ±0.002	10.64 ±0.036	2.67 ±0.036
170970	4335.7083	-6.95 ±0.005	10.49 ±0.036	3.54 ±0.036	-7.97 ±0.016	10.69 ±0.038	2.72 ±0.041
170970	4343.6979	-6.94 ±0.012	10.56 ±0.037	3.62 ±0.039	-7.97 ±0.004	10.71 ±0.036	2.74 ±0.036
173417	4270.8368	-5.42 ±0.001	10.39 ±0.046	4.97 ±0.046	-5.80 ±0.001	10.56 ±0.037	4.76 ±0.037
173417	4271.8090	-5.40 ±0.002	10.36 ±0.036	4.96 ±0.036	-5.79 ±0.001	10.58 ±0.036	4.79 ±0.036
173417	4277.8750	-5.44 ±0.001	10.30 ±0.039	4.86 ±0.039	-5.79 ±0.002	10.44 ±0.036	4.65 ±0.036
173417	4291.7778	-5.36 ±0.002	10.44 ±0.037	5.08 ±0.037	-5.77 ±0.001	10.68 ±0.035	4.91 ±0.035
174368	4270.8159	-1.86 ±0.001	10.36 ±0.046	8.50 ±0.047	-2.15 ±0.001	10.51 ±0.037	8.36 ±0.037
184385	4343.7292	-4.83 ±0.002	10.64 ±0.037	5.81 ±0.037	-5.39 ±0.001	10.77 ±0.036	5.38 ±0.036
186675	4270.8472	-7.14 ±0.002	10.40 ±0.046	3.26 ±0.046	-7.80 ±0.007	10.58 ±0.037	2.78 ±0.038
186675	4272.8229	-7.09 ±0.004	10.35 ±0.037	3.26 ±0.037	-7.73 ±0.006	10.58 ±0.037	2.85 ±0.038
186675	4290.8125	-7.08 ±0.005	10.30 ±0.037	3.22 ±0.037	-7.74 ±0.003	10.54 ±0.036	2.80 ±0.036
186675	4291.7986	-7.07 ±0.003	10.39 ±0.038	3.32 ±0.038	-7.73 ±0.005	10.61 ±0.036	2.88 ±0.036
186675	4333.7674	-7.20 ±0.002	10.43 ±0.036	3.23 ±0.036	-7.84 ±0.001	10.64 ±0.036	2.80 ±0.036
186675	4335.7396	-7.21 ±0.003	10.49 ±0.036	3.28 ±0.036	-7.85 ±0.003	10.69 ±0.036	2.84 ±0.036
186675	4343.7014	-7.17 ±0.007	10.55 ±0.037	3.38 ±0.038	-7.82 ±0.004	10.72 ±0.036	2.90 ±0.036
186776	4270.8542	-7.85 ±0.002	10.40 ±0.046	2.55 ±0.046	-8.91 ±0.002	10.60 ±0.037	1.69 ±0.037
186776	4272.8333	-7.80 ±0.004	10.35 ±0.037	2.55 ±0.037	-8.86 ±0.005	10.58 ±0.037	1.72 ±0.038
186776	4277.9063	-7.79 ±0.004	10.33 ±0.036	2.54 ±0.036	-8.85 ±0.005	10.58 ±0.036	1.73 ±0.036
186776	4291.8194	-7.78 ±0.022	10.37 ±0.038	2.59 ±0.044	-8.84 ±0.009	10.58 ±0.036	1.74 ±0.037

Table 3, continued

HD	RJD	$J_{inst} \pm \sigma_{inst}$	ΔJ	$J \pm \sigma_J$	$H_{inst} \pm \sigma_{inst}$	ΔH	$H \pm \sigma_H$
186776	4333.7812	-7.93 ±0.003	10.45 ±0.036	2.52 ±0.036	-8.96 ±0.002	10.66 ±0.036	1.70 ±0.036
186776	4335.7431	-7.93 ±0.007	10.48 ±0.036	2.55 ±0.036	-8.97 ±0.005	10.68 ±0.036	1.71 ±0.036
186776	4343.7049	-7.89 ±0.007	10.53 ±0.037	2.64 ±0.038	-8.94 ±0.003	10.69 ±0.036	1.75 ±0.036
190771	4270.8681	-5.40 ±0.002	10.39 ±0.046	4.99 ±0.046	-5.90 ±0.002	10.56 ±0.037	4.66 ±0.037
190771	4277.9236	-5.35 ±0.002	10.30 ±0.036	4.95 ±0.036	-5.86 ±0.002	10.44 ±0.036	4.58 ±0.036
190771	4335.7604	-5.46 ±0.001	10.51 ±0.036	5.05 ±0.036	-5.96 ±0.001	10.69 ±0.036	4.73 ±0.036
192004	4272.8681	-7.21 ±0.002	10.35 ±0.037	3.14 ±0.037	-8.06 ±0.003	10.58 ±0.037	2.52 ±0.037
192004	4334.8125	-7.31 ±0.002	10.44 ±0.037	3.13 ±0.037	-8.14 ±0.002	10.65 ±0.036	2.51 ±0.036
192004	4335.7639	-7.31 ±0.004	10.49 ±0.036	3.18 ±0.036	-8.15 ±0.006	10.69 ±0.036	2.54 ±0.037
200527	4335.7917	-8.47 ±0.006	10.48 ±0.036	2.01 ±0.037	-9.51 ±0.008	10.68 ±0.036	1.17 ±0.037
200527	4343.7625	-8.43 ±0.005	10.51 ±0.036	2.08 ±0.037	-9.49 ±0.004	10.68 ±0.036	1.19 ±0.036
200723	4335.7951	-4.86 ±0.002	10.64 ±0.036	5.78 ±0.036	-5.28 ±0.001	10.70 ±0.036	5.42 ±0.036
205435	4272.9062	-7.92 ±0.005	10.35 ±0.036	2.43 ±0.036	-8.58 ±0.004	10.58 ±0.036	2.00 ±0.036
205435	4291.8889	-7.90 ±0.014	10.37 ±0.038	2.47 ±0.040	-8.56 ±0.004	10.59 ±0.036	2.03 ±0.036
205435	4335.7882	-8.04 ±0.006	10.48 ±0.036	2.44 ±0.037	-8.68 ±0.004	10.68 ±0.036	2.00 ±0.036
206330	4272.9132	-8.35 ±0.007	10.36 ±0.036	2.01 ±0.037	-9.34 ±0.006	10.58 ±0.036	1.24 ±0.036
206330	4291.9028	-8.35 ±0.002	10.36 ±0.038	2.01 ±0.038	-9.32 ±0.016	10.56 ±0.036	1.24 ±0.040
206330	4333.8646	-8.46 ±0.011	10.46 ±0.036	2.00 ±0.038	-9.43 ±0.005	10.67 ±0.036	1.24 ±0.036
206330	4335.7986	-8.46 ±0.010	10.48 ±0.036	2.02 ±0.038	-9.43 ±0.010	10.68 ±0.036	1.25 ±0.037
206749	4335.8035	-8.18 ±0.011	10.48 ±0.036	2.30 ±0.038	-9.16 ±0.007	10.68 ±0.036	1.52 ±0.037
206749	4343.7778	-8.16 ±0.004	10.52 ±0.036	2.36 ±0.036	-9.14 ±0.004	10.69 ±0.036	1.55 ±0.036
339034	4272.8611	-7.29 ±0.002	10.35 ±0.037	3.06 ±0.037	-8.43 ±0.001	10.58 ±0.037	2.15 ±0.037
339034	4291.8541	-7.27 ±0.002	10.39 ±0.038	3.12 ±0.038	-8.39 ±0.004	10.59 ±0.036	2.20 ±0.036
339034	4343.7083	-7.36 ±0.011	10.55 ±0.038	3.19 ±0.039	-8.47 ±0.001	10.70 ±0.036	2.23 ±0.036

*RJD = JD – 2,450,000