The Astronomical Journal, 127:2931–2935, 2004 May

CHROMOSPHERICALLY ACTIVE STARS. XXIII. THE TRIPLE SYSTEM HD 7205 = QU ANDROMEDAE

Francis C. Fekel[1]
Center of Excellence in Information Systems, Tennessee State University, 330 10th Avenue North, Nashville, TN 37203; fekel@evans.tsuniv.edu
Received 2004 January 27; accepted 2004 February 11

ABSTRACT

HD 7205 is a recently discovered visual binary. The primary star is a chromospherically active, single-lined binary, making the system triple. From spectroscopic observations, the orbit of the primary has a period of 18.01335 days and a moderate eccentricity of 0.197. The primary's spectral type is G8 IV–V. The unseen secondary of the short-period binary is likely an M dwarf, while the visual binary secondary is probably a K3 dwarf. From solar-abundance evolutionary tracks, the primary has a mass of $\sim 1.0\ M_\odot$ and an age of about 10 Gyr. It has evolved off the main sequence and is approaching the base of the red giant branch. Its rotation period of 21.3 days is significantly different from its pseudosynchronous rotation period of 14.6 days, making it an asynchronous rotator.

Key words: binaries: spectroscopic — stars: late-type

1. INTRODUCTION

Reporting initial results from a northern sky objective-prism survey, Bidelman (1985) noted the detection of weak Ca II H and K emission in the spectrum of HD 7205 = QU Andromedae ($\alpha = 01^{\rm h}13^{\rm m}06^{\rm s}.1$, $\delta = 41°39'15''.5$ [J2000], $V = 7.2$ mag). In addition, he classified the spectrum as Gp and concluded that it was slightly weak lined. Halliwell (1979) had earlier suggested that HD 7205 is a nearby star, which has been confirmed by its *Hipparcos* parallax (ESA 1997). As part of a survey of high proper motion stars, Sandage & Kowal (1986) obtained *UBV* photometry of it, while Olsen (1993) observed it in the Strömgren photometric system. From a half-dozen Reticon spectra Fouts (1987) concluded that the star is a single-lined spectroscopic binary. Following this flurry of interest, Strassmeier et al. (1993) included HD 7205 as a candidate star in their catalog of chromospherically active binaries. Henry, Fekel, & Hall (1995) acquired photometric observations of it during one season. They analyzed the data from the portion of that season that showed the most coherent variability, determining a period of 21.3 days and a *V* amplitude of 0.03 mag. They also obtained three spectrograms from which they confirmed the velocity variability announced by Fouts (1987), classified the star as G8 V, and estimated a $v \sin i$ value of ≤ 3 km s^{-1}. As part of a search for Doppler-imaging candidates, Strassmeier et al. (2000) confirmed the Ca II H and K emission of HD 7205 as well as its photometric period, finding 21.08 days. More recently, Horch et al. (2002) conducted a speckle-interferometry survey of a number of A, F, and G dwarfs. They discovered that HD 7205 is a visual double with a separation of $1''.27$ and a magnitude difference of ~ 2.8. Thus, HD 7205 is a triple system, consisting of a visual binary, components A and B, the primary of which is also a short-period, single-lined spectroscopic binary. Of the three stars in the system only the lines of the short-period primary, component Aa, are visible spectroscopically.

In this paper the short-period orbital elements are determined. In addition, some of the basic properties of component Aa are computed and its evolutionary status is discussed.

2. SPECTROSCOPIC OBSERVATIONS AND REDUCTIONS

From 1994 November to 2003 September we obtained 38 high-resolution spectrograms of HD 7205. The observations were acquired with the Kitt Peak National Observatory (KPNO) coudé feed telescope, coudé spectrograph, and a TI CCD detector. Nearly all of the spectrograms are centered in the red at 6430 Å, cover a wavelength range of about 80 Å, and have a resolution of 0.21 Å. Three spectrograms were obtained at other wavelengths. One was of the Hα region and a second was of the lithium region around 6708 Å. In addition, a blue-wavelength spectrogram was acquired that included the Ca II H and K lines. Those three spectrograms have wavelength ranges and resolutions similar to the observations obtained in the 6430 Å region. Typical signal-to-noise ratios are 150–200.

Radial velocities for the 37 red-wavelength observations were determined with the IRAF cross-correlation program FXCOR (Fitzpatrick 1993). The primary cross-correlation reference star was β Aql, while a few observations were measured relative to the IAU velocity standard 10 Tau. For β Aql a velocity of -40.2 km s^{-1}, measured relative to the IAU velocity standard HR 7560, was adopted from unpublished results. The velocity used for 10 Tau was 29.7 km s^{-1} (Scarfe, Batten, & Fletcher 1990).

3. ORBIT

An initial spectroscopic period of 18.014 days was determined by fitting a sine curve to the 37 KPNO velocities (Table 1) for trial periods between 1.0 and 50 days with a step size of 0.001 days. For each period the sum of the squared residuals was computed, and the period with the smallest value of that sum was identified as the preliminary value of the orbital period. Initial orbital elements were then computed with BISP (Wolfe, Horak, & Storer 1967), a computer program that implements a slightly modified version of the Wilsing-Russell

[1] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

TABLE 1
RADIAL VELOCITIES OF HD 7205

Heliocentric Julian Date (2,400,000+)	Phase	Velocity (km s^{-1})	$O - C$ (km s^{-1})	Weight	Source[a]
44,948.636	0.456	65.0	0.9	0.0	MtW
45,208.969	0.908	32.9	−4.5	0.0	MtW
45,632.805	0.437	69.6	4.3	0.0	MtW
45,935.991	0.269	92.8	20.6	0.0	MtW
45,936.999	0.325	79.2	8.3	0.0	MtW
45,938.017	0.381	82.6	14.1	0.0	MtW
49,676.678	0.930	38.8	−0.1	1.0	KPNO
49,901.962	0.437	65.3	0.0	1.0	KPNO
49,902.963	0.493	61.5	−0.1	1.0	KPNO
49,968.875	0.152	68.9	0.2	1.0	KPNO
49,969.984	0.213	72.1	0.3	1.0	KPNO
49,970.869	0.262	72.0	−0.2	1.0	KPNO
49,971.875	0.318	71.1	0.0	1.0	KPNO
49,972.914	0.376	68.3[b]	−0.4	1.0	KPNO
49,972.978	0.379	68.8[c]	0.2	1.0	KPNO
49,973.727	0.421	66.4	0.1	1.0	KPNO
50,361.786	0.964	42.7	0.3	1.0	KPNO
50,362.768	0.018	50.4	−0.2	1.0	KPNO
50,363.748	0.073	59.6	0.1	1.0	KPNO
50,364.747	0.128	66.2	−0.4	1.0	KPNO
50,365.778	0.185	71.0	0.2	1.0	KPNO
50,366.727	0.238	72.1	−0.1	1.0	KPNO
50,401.686	0.179	70.5	0.0	1.0	KPNO
50,719.864	0.842	36.5	−0.2	1.0	KPNO
50,720.936	0.902	37.4	0.3	1.0	KPNO
50,753.768	0.724	43.2	−0.2	1.0	KPNO
50,754.760	0.780	39.2	−0.3	1.0	KPNO
50,755.818	0.838	37.0	0.2	1.0	KPNO
51,003.987	0.615	52.6	0.4	1.0	KPNO
51,004.974	0.670	47.6	−0.1	1.0	KPNO
51,089.831	0.381	68.5	0.0	1.0	KPNO
51,092.747	0.543	58.1	0.2	1.0	KPNO
51,093.866	0.605	52.9	−0.1	1.0	KPNO
51,094.758	0.654	49.1	0.1	1.0	KPNO
51,352.991	0.990	45.9	−0.1	1.0	KPNO
51,731.994	0.030	52.2	−0.3	1.0	KPNO
51,803.915	0.023	51.3	0.0	1.0	KPNO
52,181.826	0.002	47.8	−0.1	1.0	KPNO
52,326.594	0.039	54.4	0.4	1.0	KPNO
52,327.585	0.094	62.8	0.3	1.0	KPNO
52,542.889	0.046	55.2	−0.1	1.0	KPNO
52,902.816	0.028	52.0	−0.1	1.0	KPNO
52,903.826	0.084	61.2	0.1	1.0	KPNO

[a] (MtW) Mount Wilson Observatory; (KPNO) Kitt Peak National Observatory.
[b] Hα region, central wavelength 6560 Å.
[c] Lithium region, central wavelength 6700 Å.

method. The orbit was then refined with SB1 (Barker, Evans, & Laing 1967), a program that uses differential corrections.

In the early 1980s Fouts (1987) obtained six radial velocities at Mount Wilson Observatory. An SB1 solution was obtained that included those six older velocities, which were given weights of 0.04 relative to the KPNO velocities. The Mount Wilson velocities have large internal errors, $\sigma = 4.7$ km s^{-1} (Fouts 1987), as well as a somewhat uncertain zero point. Their inclusion did not improve the orbital solution, and three of the six velocities have large systematic residuals (Table 1). Thus, the SB1 orbital-element solution for the KPNO velocities alone is given in Table 2. The orbit is clearly eccentric with $e = 0.197 \pm 0.003$. The phases of all 43 velocities and the residuals to the computed curve are given in Table 1. In Figure 1 the computed velocity curve is compared with the KPNO velocities. Zero phase is a time of periastron passage.

4. SPECTRAL TYPE AND ABUNDANCE

Strassmeier & Fekel (1990) identified several luminosity-sensitive and temperature-sensitive line ratios in the 6430–6465 Å region. Those critical line ratios and the general appearance of the spectrum were employed as spectral-type criteria. Using some of our spectra, Henry, Fekel, & Hall (1995) classified HD 7205 as G8 V. Since that time additional reference star spectra, covering a wider range of iron abundances, have been obtained. Thus, the spectrum of HD 7205 was compared with those of late-G and early-K dwarfs and subgiants from the lists of Keenan & McNeil (1989) and Fekel (1997). Spectra of the reference stars were obtained at KPNO

TABLE 2
Orbital Elements of HD 7205 Aa

Parameter	Value
P (days)	18.01335 ± 0.00014
T (HJD)	2,448,921.370 ± 0.055
γ (km s^{-1})	55.662 ± 0.042
K (km s^{-1})	17.938 ± 0.062
e	0.1971 ± 0.0031
ω (deg)	247.9 ± 1.0
$a \sin i$ (km)	4.356 ± 0.015 × 10^6
$f(m)$ ($M_\odot$)	0.01018 ± 0.00011
Standard error of an observation of unit weight (km s^{-1})	0.2

with the same telescope, spectrograph, and detector as our spectra of HD 7205. In the 6430 Å region the overall spectrum of HD 7205 appears to be most similar to that of HR 5544 A, G8 V (Johnson & Morgan 1953) and mean [Fe/H] = −0.19 (Taylor 2003). However, two of the critical line ratios are more like those in the spectrum of β Aql, G8 IV (Keenan & McNeil 1989), and mean [Fe/H] = −0.17 (Taylor 1999). Thus, HD 7205 is classified as G8 IV–V. Comparison of its spectrum in the 6430 Å region with that of τ Ceti, G8 V (Keenan & McNeil 1989), and mean [Fe/H] = −0.45 (Taylor 2003) shows that while the spectra of the two have strong lines of similar strength, the weak lines of HD 7205 are significantly stronger than those of τ Cet. So HD 7205 is likely not as metal-poor as τ Cet, although it may be slightly metal-poor relative to the Sun.

5. BASIC PROPERTIES

The brightest known V magnitude and bluest $B-V$ of HD 7205 are 7.24 and 0.77 mag, respectively (ESA 1997). The 2.8 mag difference between components A and B (Horch et al. 2002) makes component Aa, the only one visible spectroscopically, 0.08 mag fainter than the combined magnitude. Thus, a V magnitude of 7.32 was adopted as the unspotted magnitude of the primary. When this was combined with the *Hipparcos* parallax of 0."02236 ± 0."00079 (ESA 1997), it produced $M_V = 4.07 \pm 0.08$ mag. At a distance of 44.7 ± 1.6 pc from the Sun, HD 7205 is presumed to be unaffected by interstellar extinction. A $B-V$ value of 0.75, adjusted for the contribution of component B, was used in conjunction with Table 3 of Flower (1996) to obtain a bolometric correction and effective temperature of component Aa. These values were used to compute a luminosity $L = 2.2 \pm 0.2\ L_\odot$ and a radius $R = 1.7 \pm 0.1\ R_\odot$. The uncertainties in the computed quantities are dominated by the uncertainty in the parallax and, to a lesser extent, in the effective temperature, with the latter uncertainty estimated to be ±100 K. Most chromospherically active dwarfs have small photometric amplitudes, typically less than 0.1 mag, and are not believed to be heavily spotted (e.g., Henry, Fekel, & Hall 1995). However, if the true unspotted V magnitude were 0.1 mag brighter than our adopted value, the luminosity would be increased by 10% and the radius by 5%. Those increases are approximately equal to the respective uncertainties of the luminosity and radius. The basic properties of component Aa are summarized in Table 3.

The star's minimum radius, computed from $v \sin i = 2.7$ km s^{-1} (Fekel 1997) and the rotation period of 21.3 days (Henry, Fekel, & Hall 1995), is 1.1 $R_\odot$. Comparison with the radius from the Stefan-Boltzmann law results in a rotational inclination of ~40°. The luminosity and effective temperature of HD 7205, compared with the solar abundance evolutionary tracks of Charbonnel et al. (1999), suggest a mass of ~1.0 $M_\odot$ for component Aa. This mass, combined with the mass function, results in a minimum mass of 0.25 $M_\odot$ for the spectroscopic secondary, component Ab. If the rotational and orbital axes are aligned, the mass of Ab increases to 0.39 $M_\odot$. These masses suggest that the short-period secondary is likely a mid- or early-M dwarf (Gray 1992). This is consistent with its lack of detection in our red wavelength spectra.

The visual secondary, component B, is about 2.8 mag fainter than the primary (Horch et al. 2002). Thus, its $M_V \simeq$ 6.8 mag corresponds to a K3 V star, which has a canonical mass of 0.74 $M_\odot$ (Gray 1992).

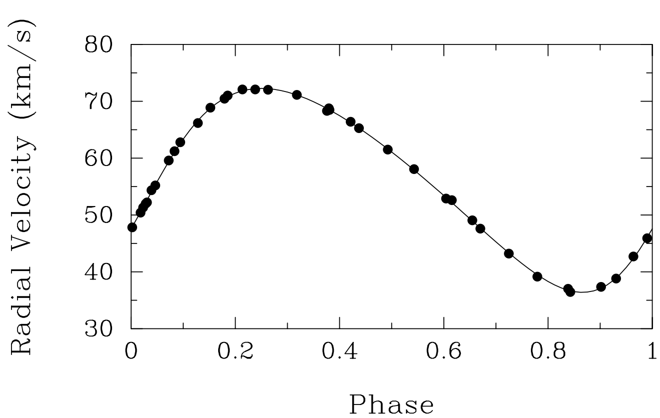

Fig. 1.—Plot of the computed radial-velocity curve of HD 7205 Aa compared with the KPNO velocities. Zero phase is a time of periastron passage.

6. DISCUSSION

In 2000 August Horch et al. (2002) discovered a faint visual companion to HD 7205 that had a separation of 1."27.

TABLE 3
Fundamental Properties of HD 7205 Aa

Parameter	Value	Reference
V (mag)	7.32	1
$B-V$ (mag)	0.75	1
π (arcsec)	0.02236 ± 0.00079	2
Spectral type	G8 IV–V	1
$v \sin i$ (km s^{-1})	2.7 ± 1.0	3
M_V (mag)	4.07 ± 0.08	1
L ($L_\odot$)	2.2 ± 0.2	1
R ($R_\odot$)	1.7 ± 0.1	1

References.—(1) This paper; (2) ESA 1997; (3) Fekel 1997.

Although in principle *Hipparcos* could resolve components with separations >0″.1 and magnitude differences up to 4 mag (Lindegren et al. 1997), HD 7205 was not identified as a binary in that catalog (ESA 1997). Only systems that have magnitude differences less than ~2 mag can be detected with the Tycho instrument of the *Hipparcos* satellite. Thus, it is not surprising that a new reduction of that data (Fabricius et al. 2002) did not detect the duplicity of HD 7205.

If the visual secondary is a physical companion, which is likely given the small angular separation of the components, then HD 7205 is a triple system. The orbit of the spectroscopic subsystem has an 18 day period. One can estimate the period of the visual system using Kepler's third law. The angular separation measured by Horch et al. (2002) divided by the *Hipparcos* parallax (ESA 1997) results in a projected separation of 57 astronomical units. Adopting this as the semimajor axis of the orbit and 2.13 $M_\odot$ as the sum of the masses for the three stars produces a period of 295 yr for the AB system.

Is there any evidence in the radial velocities of component Aa for the presence of the visual companion, component B? The center-of-mass velocity, obtained between 1994 and 2003 from the spectroscopic observations, is quite constant, 55.66 ± 0.04 km s^{-1}. However, the six earlier velocities of Fouts (1987) suggest a different story. Three of those radial velocities were obtained between 1981 December and 1983 October and have a mean velocity residual of 0.2 km s^{-1} when compared to the computed spectroscopic orbit. The other three velocities were acquired on consecutive nights in 1984 August and have a mean residual of 14.3 km s^{-1}. This large velocity difference suggests a change in the short-period binary's center-of-mass velocity, which if real, would indicate that in 1984 the AB pair was going through a very rapid nodal and periastron passage. Stockton & Fekel (1992) determined orbits from KPNO velocities for three systems in common with Fouts (1987). When compared with those orbits, velocity residuals greater than 15 km s^{-1} were found for several of the velocities of Fouts (1987), indicating that such large residuals are not unusual. In addition, the referee has noted that for an orbital period greater than 200 yr no combination of semimajor axis and eccentricity can produce the suggested rapid periastron passage. Thus, the radial-velocity evidence for such a passage appears to be spurious. Additional visual observations will be useful to confirm the physical nature of the visual system.

Strassmeier et al. (2000) presented a spectrum of the Ca II H and K lines of HD 7205. It showed modest emission features that rise less than halfway to the continuum. Our spectrum of this wavelength region shows the Ca II emission lines to be slightly weaker. Strassmeier et al. (2000) calculated the chromospheric radiative loss in the H and K lines normalized to the total surface luminosity of the star, log R'(HK) = −4.1. For comparison, most chromospherically active stars have values of log R'(HK) > −4.0 (Fig. 5b, Strassmeier et al. 1990).

Attempting to identify new subdwarfs, Sandage & Kowal (1986) included HD 7205 in their photometric survey of high proper motion stars. Combining its *Hipparcos* parallax and proper motion with the center-of-mass velocity of component A, in a right-handed coordinate system the U, V, W Galactic space-velocity components relative to the Sun are −84.7, −0.4, and −21.0 km s^{-1}, respectively. Adjusting these velocities for the standard solar motion (Mihalas & Routly 1968) decreases the U velocity by 10 km s^{-1}. Nevertheless, HD 7205 is a high-velocity star with a large velocity toward the Galactic anticenter, which argues that the system is old rather than young.

The strength of the primary's Li I line at 6707.8 Å is also inconsistent with youth. If HD 7205 Aa were a very young star, its Li I line would have a large equivalent width. For example, late-G and early-K dwarf Pleiades stars, a benchmark cluster for zero-age main-sequence stars, have equivalent widths of 80–180 mÅ (Ford, Jeffries, & Smalley 2002). However, Strassmeier et al. (2000) measured an equivalent width of just 14 mÅ for the 6707.8 Å line. Our KPNO spectrum of this region gives an upper limit of 16 mÅ for this lithium line.

Comparison with the solar-abundance evolutionary tracks of Charbonnel et al. (1999) leads to a mass of ~1.0 $M_\odot$ for the primary of HD 7205. That star is positioned in the "relatively rapid" crossing phase between the end of the main sequence and the base of the first-ascent red giant branch. Although low-mass pre–main-sequence stars are also found in this region (Charbonnel et al. 1999), the properties of HD 7205 indicate that its primary is a post–main-sequence star.

The two main theories of orbital circularization and rotational synchronization (e.g., Zahn 1977; Tassoul & Tassoul 1992) disagree significantly on absolute timescales but do agree that synchronization should occur first. Hut (1981) has shown that in an eccentric orbit a star's rotational angular velocity will tend to synchronize with that of the orbital motion at periastron, a condition called pseudosynchronous rotation. With equation (42) of Hut (1981) we calculated a predicted pseudosynchronous period of 14.6 days for the primary compared to the observed photometric period of 21.3 days. The asynchronous-rotation situation apparently is a product of the rather large binary separation and the primary's relatively small radius.

The primary of HD 7205 has spent most of its life as a dwarf star and, even now at an age of about 10 billion years (Charbonnel et al. 1999), is still approaching the base of the red giant branch. Fekel, Henry, & Alston (2004) noted that of the 205 systems listed in the second edition of A Catalog of Chromospherically Active Binary Stars (Strassmeier et al. 1993), 68 are dwarf systems, binaries in which both components are dwarfs or, if the system's spectrum is single-lined, presumed dwarfs. Twelve of those systems have orbital periods ≥10 days. One star, HD 116378, appears to be rather similar to HD 7205. It is a single-lined binary with a G5 primary, an orbital period of 17.76 days, and an eccentricity of 0.122 (Griffin 1983). Its *Hipparcos* parallax and $B-V$ color (ESA 1997) produce a radius of 2.3 $R_\odot$, about 25% larger than that of component Aa of HD 7205. No ground-based search for photometric variability in HD 116378 has been made. Photometric results given in the *Hipparcos* catalog (ESA 1997) show a range of 0.06 mag, but the variability column is blank, indicating that the *Hipparcos* team was unable to determine whether HD 116378 is a variable star. Given its similarity to HD 7205, it is likely that the system does indeed have low-amplitude light variations.

I thank D. Pourbaix for helpful discussions and the referee for comments that improved the paper. This research at Tennessee State University was supported in part by NASA grant NCC5-511 and NSF grant HRD-9706268.

REFERENCES

Barker, E. S., Evans, D. S., & Laing, J. D. 1967, R. Obs. Bull., 130
Bidelman, W. P. 1985, AJ, 90, 341
Charbonnel, C., Däppen, W., Schaerer, D., Bernasconi, P. A., Maeder, A. Meynet, G., & Mowlavi, N. 1999, A&AS, 135, 405
ESA. 1997, The Hipparcos and Tycho Catalogues (ESA SP-1200) (Noordwijk: ESA)
Fabricius, C., Hog, E., Makarov, V. V., Mason, B. D., Wycoff, G. L., & Urban, S. E. 2002, A&A, 384, 180
Fekel, F. C. 1997, PASP, 109, 514
Fekel, F. C., Henry, G. W., & Alston, F. M. 2004, AJ, 127, 2303
Fitzpatrick, M. J. 1993, in ASP Conf. Ser. 52, Astronomical Data Analysis Software and Systems II, ed. R. J. Hanisch, R. V. J. Brissenden, & J. Barnes (San Francisco: ASP), 472
Flower, P. J. 1996, ApJ, 469, 355
Ford, A., Jeffries, R. D., & Smalley, B. 2002, A&A, 391, 253
Fouts, G. 1987, PASP, 99, 986
Gray, D. F. 1992, The Observation and Analysis of Stellar Photospheres (Cambridge: Cambridge Univ. Press)
Griffin, R. F. 1983, J. Astrophys. Astron., 4, 171
Halliwell, M. J. 1979, ApJS, 41, 173
Henry, G. W., Fekel, F. C., & Hall, D. S. 1995, AJ, 110, 2926
Horch, E. P., Robinson, S. E., Ninkov, Z., van Altena, W. F., Meyer, R. D., & Mason, B. D. 2002, AJ, 124, 2245
Hut, P. 1981, A&A, 99, 126
Johnson, H. L., & Morgan, W. W. 1953, ApJ, 117, 313
Keenan, P. C., & McNeil, R. C. 1989, ApJS, 71, 245
Lindegren, L., et al. 1997, A&A, 323, L53
Mihalas, D., & Routly, P. M. 1968, Galactic Astronomy (San Francisco: Freeman), 101
Olsen, E. H. 1993, A&AS, 102, 89
Sandage, A., & Kowal, C. 1986, AJ, 91, 1140
Scarfe, C. D., Batten, A. H., & Fletcher, J. M. 1990, Publ. Dominion Astrophy. Obs., 18, 21
Stockton, R. A., & Fekel, F. C. 1992, MNRAS, 256, 575
Strassmeier, K. G., & Fekel, F. C. 1990, A&A, 230, 389
Strassmeier, K. G., Fekel, F. C., Bopp, B. W., Dempsey, R. C., & Henry, G. W. 1990, ApJS, 72, 191
Strassmeier, K. G., Hall, D. S., Fekel, F. C., & Scheck, M. 1993, A&AS, 100, 173
Strassmeier, K. G., Washuettl, A., Granzer, T., Scheck, M., & Weber, M. 2000, A&AS, 142, 275
Tassoul, J.-L., & Tassoul, M. 1992, ApJ, 395, 259
Taylor, B. J. 1999, A&AS, 134, 523
———. 2003, A&A, 398, 731
Wolfe, R. H., Horak, H. G., & Storer, N. W. 1967, in Modern Astrophysics, ed. M. Hack (New York: Gordon & Breach), 251
Zahn, J.-P. 1977, A&A, 57, 383