Publications of the Astronomical Society of the Pacific
108: 894–899, 1996 October

Orbital Periods of the Dwarf Novae AR Andromedae, AM Cassiopeiae, and PY Persei[1]

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Received 1996 June 24; accepted 1996 July 26

ABSTRACT. We present time-resolved spectroscopy of the dwarf novae AR And, AM Cas, and PY Per. From velocities of Hα emission lines, we determine orbital periods of 0.16302$\pm$0.00032 d (= 3.91 hr) for AR And and 0.15480$\pm$0.00017 d (= 3.72 hr) for PY Per. Our period determination for AR And resolves a daily cycle-count ambiguity in a previous determination by Shafter et al. (1995, ApJ, 440, 853). No orbital period for PY Per has previously been published. The orbital period of AM Cas, determined here for the first time, is constrained over a 46-night baseline to one of several precise values near 0.165 d (= 3.96 hr), the best of which are 0.16490$\pm$0.00001 d and 0.16551$\pm$0.00001 d. For PY Per, we use a single direct CCD exposure to extend the magnitude sequence of Misselt (1996, PASP, 108, 146). A comparison with the Downes and Shara atlas (1993, PASP, 105, 127) shows that PY Per had $V\sim$19.8 when the Downes and Shara image was obtained, which is much fainter than the minimum listed in the *General Catalogue of Variable Stars* [Kholopov 1987 (Nakua, Moscow)]. Our averaged spectra of all appear typical for dwarf novae, except that the Fe II λ5169 in AR And is unusually strong and weak features at λ5230, λ5270, and λ5322 (which we attribute to Fe II) also appear.

1. INTRODUCTION

AM Cas (mag 12.3–15.2 p), AR And (mag 11.0–16.9 v), and PY Per (mag 13.8–16.5 p) are among the brightest dwarf novae in the northern sky with unknown or ambigious orbital periods (Downes and Shara 1993–hereafter D&S). The coordinates and finding charts are found in D&S (but Misselt 1996 points out that PY Per is marked incorrectly in their atlas). The orbital period of a cataclysmic binary is correlated with the secondary star mass and outburst type (Shafter 1992), and it is easily measurable to high precision.

The outbursts of AR And show it to be a U Gem star. However, the orbital period predicted from the Bailey relation (between orbital period and decline from outburst) is 2.03 hr, which is considerably shorter than expected in U Gem-type dwarf novae and would suggest an SU Ursae Majoris classification (Szkody and Mattei 1984). Based on variations in the light curve, Szkody (1985) suggested a candidate orbital period of 2.25 hours. Szkody et al. (1990) cite from Shafter orbital periods of 237 min (0.165 d) or 280 min (0.194 d) and, using velocities of Hγ absorption lines during outburst, they detected the same periodicity but did not make a final determination. Shafter et al. (1995—hereafter SVR) remeasured the orbital period, using radial velocities from both quiescent Hα emission lines and outburst Hγ emission lines, and again found an orbital period of 0.1640$\pm$0.0005 d, but could not rule out daily cycle count aliases. SVR pointed out the unusual consistency of velocity amplitude with outburst state.

AM Cas, first classified as a dwarf nova by Bond in 1981 (private communication 1996), is a Z Cam star with an unusually short mean outburst cycle of 8.2 days (Richter et al. 1988). Richter and Rössiger (1989) predicted the orbital period to be 0.1–0.2 d based on the Kukarkin–Parenago relation. They noticed a roughly 2 mag minimum lasting 40 min, but doubted whether it was due to an eclipse since the minimum was observed only once. Spectroscopic observations by Downes et al. (1995) showed a typical dwarf-nova spectrum.

PY Per is classified as a Z Cam-type dwarf nova in the *General Catalogue of Variable Stars* (Kholopov 1987—hereafter GCVS). Zwitter and Munari (1994) published a spectrum and confirmed Bond's (1978) description of diffuse hydrogen emission lines on a blue continuum. We are not aware of any published orbital period.

2. OBSERVATIONS AND REDUCTIONS

We used the Michigan–Dartmouth–MIT (MDM) Observatory on Kitt Peak, during three observing runs—1994 December, 1995 January, and 1995 October. Table 1 lists the different combinations of telescopes and spectrographs, as well as the spectral resolution (FWHM). All observations used a Loral 2048^2 chip and the exposure times ranged from 6 to 10 min. The exact dates of observation are implicit in the radial-velocity time series (Tables 2–4). To avoid daily

TABLE 1
Observation Log

Dates (UT)	Stars	Telescope (m)	Spectr.	λ range (Å)	FWHM (Å)
1994 Dec.	AM Cas	1.3	MkIII	4270–7070	5
1995 Jan.	AM Cas	2.4	modular	4300–6850	3
1995 Oct.	AR And, PY Per	2.4	modular	4300–7000	3

[1]Based in part on observations obtained at MDM Observatory, operated by the University of Michigan, Dartmouth College, and the Massachusetts Institute of Technology.

TABLE 2
AR And Hα Radial Velocities

HJD[a]	V (km s^{-1})	HJD[a]	V (km s^{-1})	HJD[a]	V (km s^{-1})	HJD[a]	V (km s^{-1})
50002.8658	−95	50005.6550	−158	50006.0045	−66	50006.6881	29
50002.8705	−95	50005.6638	−36	50006.0180	−1	50006.6969	73
50003.6932	−126	50005.6727	−30	50006.6056	−60	50006.7058	79
50003.7020	−115	50005.8353	−63	50006.6145	−81	50006.7155	85
50003.7109	−83	50005.8441	−30	50006.6233	−57	50006.8283	−17
50003.7197	−85	50005.8530	11	50006.6322	−82	50006.8371	27
50005.6047	−11	50005.8618	40	50006.6463	−60		
50005.6225	−19	50005.9779	−114	50006.6551	−47		
50005.6313	11	50005.9868	−77	50006.6640	−66		
50005.6461	−153	50005.9956	−82	50006.6729	−18		

[a]Heliocentric JD of midintegration minus 2400000.

cycle count ambiguity, the targets were observed over a wide range of hour angle. The wavelength scale was derived from comparison lamp spectra bracketing each observation as the telescope tracked.

The data reductions were done with standard IRAF routines.[2] The pixel-to-wavelength transformations had rms residuals of ~0.05 Å. The stability of the 5577.350 Å night-sky line in the reduced data was approximately 1 km s^{-1} rms for the 1994 December and 1995 January data (AM Cas) and 6 km s^{-1} rms for the 1995 October data (AR And and PY Per).

Radial velocities of the Hα emission line (Tables 2–4) were measured using algorithms described by Schneider and Young (1980). One algorithm convolves the line with the derivative of a Gaussian and takes the line center to be the zero of the convolution. The other algorithm is similar but convolves the line with two narrow Gaussians of opposite sign, one offset to the red and the other to the blue. Parameters were chosen by examining the line profile and the algorithm was selected by the signal to noise of the result. We did not search exhaustively to optimize the parameters. The times and velocities were corrected to the solar system barycenter.

We searched for periods in the radial velocities by creating a dense grid of evenly spaced trial frequencies and fitting least-squares sinusoids at each frequency. We then plotted $1/\sigma^2$, where σ is the standard deviation of the fit, as a function of trial frequency (Figs. 1 and 2). At periods selected by this method we fit least-squares sinusoids

$$v(t)=\gamma+K\sin[2\pi(t-T_0)/P].$$

Table 5 gives the fit parameters and their formal 1σ uncertainties. Figure 3 shows the velocities folded on the best-fit periods with the sinusoidal fits superposed. To assess the reliability of the cycle count choice, we used the Monte-Carlo technique of Thorstensen and Freed (1985). The spectra were flux calibrated using IRAF routines (Figs. 4–6) and observations of white dwarfs.

[2]IRAF is distributed by the National Optical Astronomy Observatories. IRAF routines were used for bias subtraction, flat fielding, extraction of one-dimensional spectra, determination of wavelength scale, and rebinning to a uniform wavelength scale.

3. NOTES ON INDIVIDUAL OBJECTS

3.1 AR And

We used the derivative of a Gaussian with a FWHM of 1140 km s^{-1} to measure the radial velocities. The periodogram (Fig. 1, top curve) shows a preferred frequency near 6 cycles day^{-1}. In 1000 Monte-Carlo simulations, the best-fit period for AR And was chosen all 1000 times. The alias choice is therefore secure, especially since our period is consistent (within 1.7σ) with that of SVR.

The spectrum of AR And (Fig. 4) looks typical, except for three broad, weak lines which we tenatively label as Fe II. Their wavelengths, equivalent widths, and FWHM are listed in Table 6. We also noticed that the Fe II λ5169 appeared unusually strong.

3.2 AM Cas

To measure the radial velocities, we used the derivative of Gaussians with a FWHM of 710 km s^{-1} (1994 December data) and 860 km s^{-1} (1995 January data). The periodogram, Fig. 2, shows that a frequency near 6 cycles day^{-1} is strongly preferred over other frequencies separated by ±1 cycle day^{-1}. However, there is aliasing at intervals of 1/46 d^{-1} due to uncertainty in the cycle counts between the December and January runs. Four periods appeared plausible, with 0.16490 and 0.16551 d the most likely.

We first used the Monte-Carlo technique to verify the daily cycle count. In 1000 simulations, the top 6 cycles d^{-1} period was chosen 1000 times over the top 5 cycles d^{-1} and 7 cycles d^{-1} periods. Then we ran 1000 simulations on the top four periods listed in Table 5. When the best-fit period (0.16490 d) was the true period in the simulation, it was chosen 932 times, the second-best period (0.16551 d) was chosen 41 times, the third-best period (0.16431 d) was chosen 27 times, and the fourth-best period (0.16612 d) was not chosen at all. Based on the definitions in Thorstensen and Freed (1985), the data have a discriminatory power of 932/1000 and a correctness likelihood of approximately 0.95 on the 1/46 d^{-1} aliasing.

The spectrum of AM Cas (Fig. 5) shows it is well above minimum light for the 1994 December run and on 1995 January 21 and 23. On 1995 January 20 it was quiescent,

1996PASP..108..894T

TABLE 3
AM Cas Hα Radial Velocities

HJD[a]	V (km s^{-1})	HJD[a]	V (km s^{-1})	HJD[a]	V (km s^{-1})	HJD[a]	V (km s^{-1})
49689.6475	−75	49695.6323	−78	49738.7680	60	49740.6434	−25
49689.6618	108	49695.6397	−101	49738.7740	81	49740.6495	−48
49689.8566	−13	49695.7878	−29	49738.7800	44	49740.6619	−56
49689.8640	−126	49695.7952	−27	49738.7861	26	49740.6679	−68
49689.8714	−67	49695.8027	−88	49738.7921	18	49740.6740	−105
49689.8788	−95	49695.8101	−103	49738.7982	9	49740.6800	−111
49690.6923	−11	49695.8175	−91	49739.5826	57	49740.6861	−91
49690.6998	−31	49695.8486	−28	49739.6216	51	49740.6921	−67
49690.7072	−58	49695.8560	−14	49739.7803	63	49740.6982	−37
49690.7971	90	49695.8635	−3	49739.7863	62	49740.7137	−5
49690.8621	−58	49695.8709	−24	49739.7925	78	49740.7198	23
49690.8695	−78	49736.8157	50	49739.7985	23	49740.7258	26
49690.8769	−78	49736.8204	53	49739.8046	22	49740.7318	32
49695.5784	86	49736.8250	65	49739.8106	27	49740.7379	35
49695.5859	47	49737.6060	86	49740.6132	64	49740.7439	49
49695.5933	91	49737.6140	63	49740.6192	46		
49695.6007	74	49737.6200	107	49740.6253	34		
49695.6105	46	49737.6261	84	49740.6313	21		
49695.6249	−58	49737.6321	74	49740.6374	8		

[a]Heliocentric JD of midintegration minus 2400000.

though the absolute flux is uncertain due to cloudy conditions. A fit to the continuum of the form $f_\lambda = k\lambda^{-\alpha}$ for the 1994 December and 1995 January 21 and 23 data yielded $\alpha = 2$, while the 1995 January 20 data gave $\alpha = 0.4$, and the equivalent width (Table 6) of the Hα line went from 14 Å (1995 January 21 and 23) to 28 Å (1995 January 20). Thus the apparently decreased flux on 1995 January 20 is a real change in the star, not simply due to the cloudy conditions. Note that the Na I absorption doublet appears in the 1994 December and 1995 January 21 and 23 spectra. Since the equivalent widths of both λ5889 and λ5896 remain constant at 0.2 Å for both the 1994 December and 1995 January 21 and 23 data, they are most likely interstellar.

3.3 PY Per

We used two Gaussians with a FWHM of 400 km s^{-1} and a separation of 1880 km s^{-1} to measure the radial velocities. The periodogram, Fig. 2 (bottom curve), shows a frequency of roughly 6.5 cycles d^{-1}. In the Monte Carlo simulations, the best-fit period was chosen all 1000 times. The spectrum is unremarkable for a dwarf nova (Fig. 6).

TABLE 4
PY Per Hα Radial Velocities

HJD[a]	V (km s^{-1})	HJD[a]	V (km s^{-1})	HJD[a]	V (km s^{-1})	HJD[a]	V (km s^{-1})
49998.6816	−16	50002.7241	−29	50002.9988	36	50003.8982	−89
49998.6877	29	50002.7288	40	50003.0035	49	50003.9057	−40
49998.6937	−25	50002.7373	40	50003.0082	67	50003.9132	−40
49998.6998	−70	50002.7420	72	50003.0128	77	50005.6908	−85
49998.7059	61	50002.7467	19	50003.0175	108	50005.6983	−29
49999.8065	−25	50002.7513	7	50003.0222	67	50005.7057	−74
49999.8129	−24	50002.7560	−123	50003.0269	69	50005.7232	−160
49999.8190	−36	50002.7607	−96	50003.7404	−77	50005.7306	−168
50001.9191	10	50002.7654	−61	50003.7479	−49	50005.7381	−155
50001.9252	53	50002.7700	−95	50003.7554	−23	50006.7651	51
50001.9312	64	50002.7788	−48	50003.7628	−22	50006.7726	23
50001.9373	115	50002.7835	−175	50003.7732	72	50006.7828	−90
50002.6960	−32	50002.7882	−164	50003.7806	42	50006.7951	−108
50002.7007	25	50002.7929	−102	50003.7881	63	50006.8026	−161
50002.7053	154	50002.7976	−146	50003.7955	58	50006.8100	−156
50002.7100	131	50002.8022	−124	50003.8457	−99		
50002.7147	−5	50002.8069	−102	50003.8833	−143		
50002.7194	65	50002.8116	−68	50003.8907	−110		

[a]Heliocentric JD of midintegration minus 2400000.

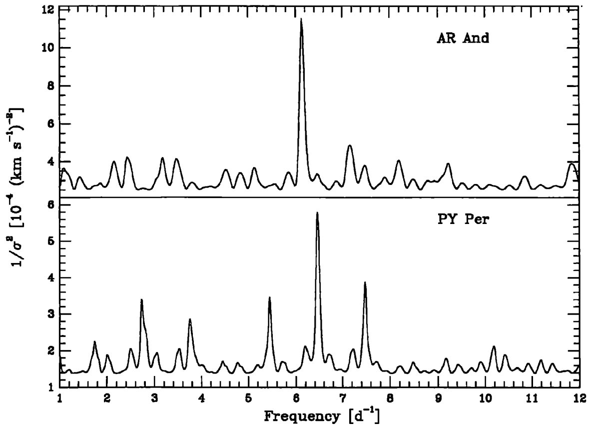

FIG. 1—Periodogram of velocities of AR And (top curve) and PY Per (bottom curve).

Misselt (1996) pointed out that PY Per was misidentified in D&S and from time-resolved photometry determined that the southeast object of a pair is PY Per. We have a 60-s, V-band CCD image of PY Per taken 1994 November 30.385 UT with the MDM 1.3-m and a Loral 2048^2 chip with 15 μm pixels, binned 2×2, yielding 0".63 per pixel. An astrometric fit to eight *HST Guide Star Catalogue* stars gave a rms error of 0".34 and yielded new coordinates for PY Per: $\alpha=2^h50^m00^s.16$ $\delta=+37°39'22''.3$, J2000. This agrees closely with values determined by Downes (private communication 1996) using the *HST Guide Star Calalogue* plates.

We used the IRAF *imexamine* task to measure instrumental magnitudes for seven of Misselt's (1996) secondary photometric standards in our picture; the rms scatter in the resulting zero-point offsets was only 0.03 mag. From this, we determined that PY Per had $V=$ 15.55 and the misidentified D&S star had $V\sim 18.67$ in our image. Examination of the D&S image showed the "real" PY Per to be still fainter than this. We looked for stars of similar appearance on the D&S chart, measured them on our CCD picture, and from this estimate that PY Per has $V=19.8\pm0.5$ (estimated error) on the D&S image. We were unable to determine when the image in D&S was obtained. Nonetheless, it appears that PY Per can become remarkably faint, much fainter than the GCVS magnitude range of 13.8–16.5 p. We searched our spectra for evidence of eclipses and found none—though a more thorough search for eclipses is warranted. Since the true minimum of PY Per appears to be so faint, it seems likely that most of our data were taken in a standstill state.

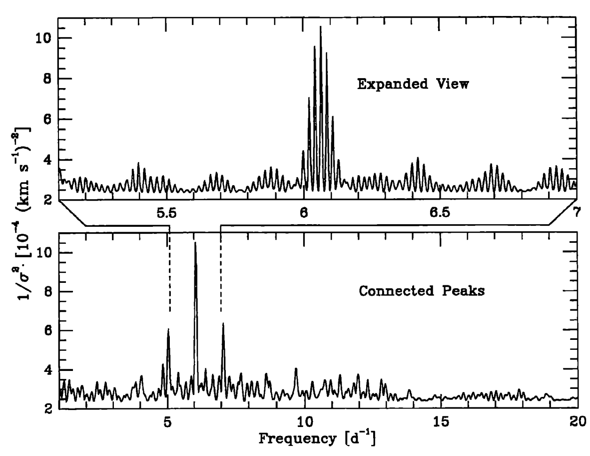

FIG. 2—Periodogram of velocities of AM Cas. Two observing runs are analyzed jointly, which creates fine-scale ringing in the periodogram. The lower panel shows the upper envelope of the periodogram, created by joining local maxima with straight lines, while the upper shows a magnified view of the region of the highest peak.

TABLE 5
Fits to Radial Velocities

T_0 (HJD−2400000)	P (d)	K (km s^{-1})	γ (km s^{-1})	σ (km s^{-1})
AR And:				
50005.6924±0.0021	0.16302±0.00032	91±7	−5±5	30
AM Cas:				
49720.2699±0.0019	0.16490±0.00001	76±5	−4±4	31
49720.3619±0.0019	0.16551±0.00001	77±5	−3±4	32
49720.3416±0.0018	0.16431±0.00001	79±5	−9±4	33
49720.2907±0.0021	0.16612±0.00001	77±7	−4±5	38
PY Per:				
50002.9830±0.0019	0.15480±0.00017	98±7	−4±5	41

4. CONCLUSION

AR And has an orbital period of 0.16302±0.00032 days (3.91 hr) which confirms the most likely alias choice of SVR. The orbital period of AM Cas is most likely 0.16490 ±0.00001 days (3.96 hr), but periods of 0.16551±0.00001 days (3.97 hr) and 0.16431±0.00001 days (3.94 hr) are not

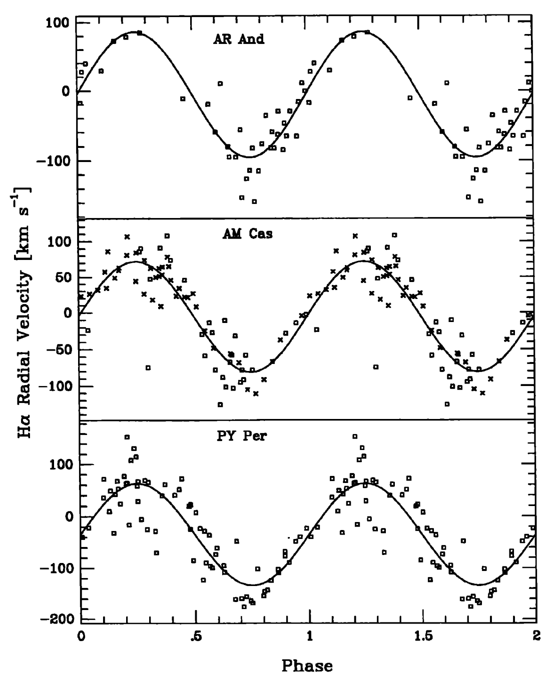

FIG. 3—Hα radial velocities folded on the ephemerides given in Table 5 for AR And (top), AM Cas (middle), and PY Per (bottom). Two cycles are plotted for continuity, and the best-fit sinusoid is shown. For AM Cas, the squares are 1994 December values and the crosses are 1995 January values.

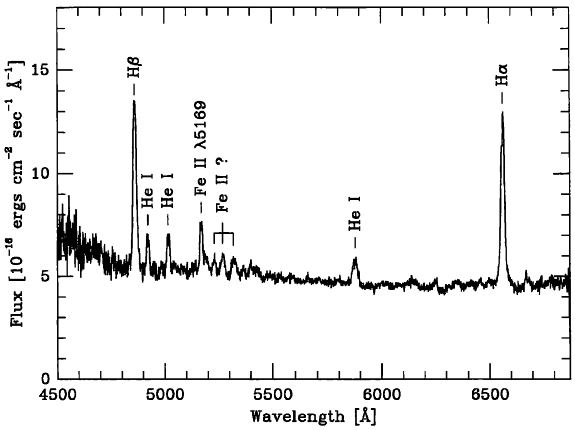

FIG. 4—Average spectrum of AR And obtained in 1995 October. Note the unusual strength of Fe II λ5169 and the presence of three weak lines at λ5230, λ5270, and λ5322 that we attribute to Fe II.

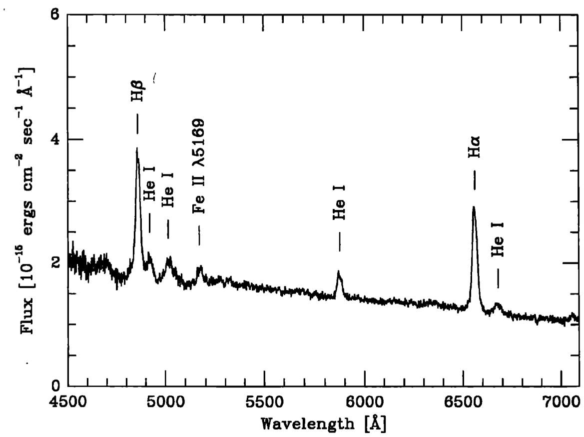

FIG. 6—Average spectrum of PY Per.

excluded. PY Per has an orbital period of 0.15480±0.00017 days (3.72 hr). These periods appear typical for U Gem and Z Cam types (Shafter 1992). The spectra appear typical except for the three weak features in AR And that we attribute to Fe II. In our spectral range, we do not see any contribution from the secondary star, though none is expected at these orbital periods.

Using a single direct CCD exposure of PY Per, we extended the magnitude sequence of Misselt (1996) and measured $V=15.55$. Comparing our image with the D&S atlas, we estimate that PY Per had $V\sim 19.8$ at the time the D&S image was obtained. This is much fainter than the magnitudes listed in GCVS and suggest that most of our data were taken in a standstill state.

We gratefully acknowledge support through NSF Grant No. AST 93-14787. This research made use of the SIMBAD data base, operated at CDS, Strasbourg, France.

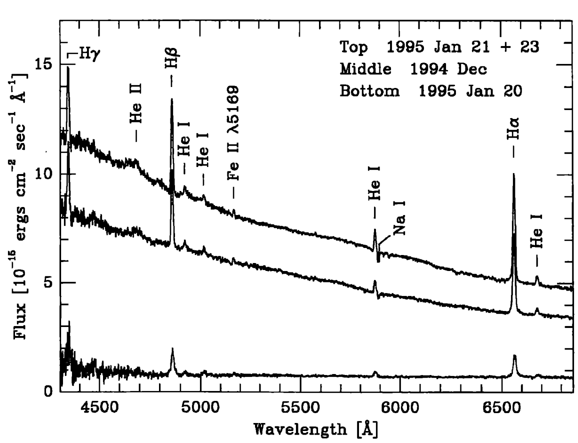

FIG. 5—Average spectra of AM Cas. Both the top spectrum (averaged 1995 January 21 and 23 data) and the middle spectrum (averaged 1994 December data) appear to be above minimum light. Bottom spectrum is averaged 1995 January 20 data, which were obtained in cloudy conditions. Note the prescence of the Na I doublet in the two upper spectra.

TABLE 6
Line Measurements

Star	Lines	EW (Å)	FWHM (km s^{-1})
AR And	Hα	39	920
	Hβ	29	1070
	Hγ	17	...
	He I λ6678	2.4	1350
	He I λ5876	7.4	1700
	He I λ5015	4.5	950
	He I λ4920	4.5	1150
	Fe II λ5169	6.0	930
	Fe II? λ5230	2.5	916
	Fe II? λ5270	4.1	1160
	Fe II? λ5322	3.9	1369
AM Cas	1995 Jan. 21 and 23[a]		
	Hα	14	610
	Hβ	5.7	680
	Hγ	3.6	780
	He I λ6678	1.1	600
	He I λ5876	1.8	510
	He I λ5015	0.5	700
	He I λ4920	0.5	710
	Fe II λ5169	0.4	560
AM Cas	1995 Jan. 20		
	Hα	28	810
	Hβ	32	1190
	Hγ	12	...
	He I λ6678	4.0	980
	He I λ5876	5.4	870
	He I λ5015	3.1	1010
	He I λ4920	3.4	1190
	Fe II λ5169	1.7	680
PY Per	Hα	36	1360
	Hβ	23	1600
	Hγ	13	1680
	He I λ6678	3.1	1470
	He I λ5876	5.9	1510
	He I λ5015	4.2	...
	He I λ4920	2.6	1660
	Fe II λ5169	2.7	1550

[a]1994 December data yielded similar values.

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