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Binary Nature and Long-Term Variations of γ Cassiopeiae

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ABSTRACT. We present the results of high-resolution spectroscopic observations of the bright Be star γ Cas obtained at the Ritter Observatory of the University of Toledo in 1993–2002. Two components in the emission-line profile variations, a long-term and a periodic one, are found. The periodic component is represented by changes of the mean radial velocity of the Hα line with a period of 205 days, which is most likely related to the orbital motion in a binary system. This finding confirms a recently reported result of Harmanec et al., although our data suggest a circular orbit rather than the eccentric one they derived. The zero eccentricity favors a nondegenerate nature of the secondary and supports a hypothesis that the companion is not connected with the X-ray generation. The long-term variations are represented by changes in the peak intensities and radial velocities of the spectral lines on a timescale of a few years and include a continuous decrease of the line intensities in 1993–2001. We also found a different behavior of the Hα line profile shape and those of nonhydrogen lines. This suggests the presence of an additional component in the Hα line profile that may originate in the outer regions of the primary's disk. This might manifest the beginning of a new phase in the evolution of γ Cas, which could lead to a new normal B star phase.

1. INTRODUCTION

γ Cas is one of the brightest Be stars ($V \simeq 2$ mag) and one of the most frequently observed objects. Many studies have been devoted to analysis of the variations of its different characteristics on various timescales. The most recent of them are Telting & Kaper (1994): long-term spectroscopic and photometric variations; Horaguchi et al. (1994): short-term spectroscopic and X-ray flux variations; and Moujtahid et al. (1998): long-term spectrophotometric variations. Briefly summarizing the published results, we highlight the following: pronounced variations of the Balmer lines violet-to-red (V/R) peak ratios with a characteristic period of 5–7 yr, a steady increase of the visual and near-IR brightness by about 30% between ~1970 and ~1993, and a similar strengthening of the emission-line spectrum during the same period of time.

Recently, Harmanec et al. (2000, hereafter H2000) reported the first detection of the regular radial velocity (RV) variations of the Hα and He I 6678 Å lines with a period of 203.59 days and attributed them to the orbital motion in a binary system. These authors used medium-resolution spectra (4 pixels Å^{-1}) obtained between 1993 and 2000. Their orbital solution shows a relatively high eccentricity ($e = 0.26 \pm 0.04$), which is usually observed in Be/X-ray binaries with a compact (white dwarf or neutron star) secondary (e.g., Okazaki & Negueruela 2001) rather than in Be systems with a normal-star secondary. The secondary mass estimate by H2000 (0.7–1.9 $M_{\odot}$) cannot exclude either possibility for its nature. γ Cas is known as an X-ray source, with flux a few times stronger than in other Be stars but a factor of ~20 weaker than in Be/X-ray binaries. If the secondary is degenerate, it can be responsible for the X-ray emission. However, the X-ray flux was found to show cyclical variations on timescales of 55–93 days and no correlation with the orbital phase, suggesting that the X-ray generation is not associated with the secondary (see Robinson, Smith, & Henry 2002). These authors discuss X-ray studies of γ Cas and propose a magnetic dynamo located in the inner parts of the primary's disk to explain these results. Thus, studies of the spectral variations of γ Cas are of importance in order to further constrain the system's properties.

We started our high-resolution spectroscopic observations of γ Cas at Ritter Observatory in 1993, although the bulk of the data were obtained between 1997 and 2002. In this paper, we present the results of our observations (§ 2), describe the line-profile variations on different timescales (§ 3), and discuss possible sources of circumstellar emission responsible for the line-profile formation and variations (§ 4).

2. OBSERVATIONS AND DATA REDUCTION

The high-resolution spectroscopic observations of γ Cas were made in 1993–2002 with a fiber-fed echelle spectrograph at the 1 m telescope of the Ritter Observatory of the University

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of Toledo. The observations cover nine nonoverlapping parts of the spectral region 5285–6597 Å with a resolving power $R \simeq 26{,}000$ (16 pixels or four resolution elements per Å near Hα). In total, 179 spectra were obtained during 164 nights. Additionally, one spectrum was obtained on 1993 October 14 in the range 3980–5360 Å (15 nonoverlapping orders, $R \simeq 31{,}500$). The exposure time varied from 5 to 20 minutes depending on the weather conditions. Most of the spectra have a signal-to-noise ratio ≥100. The data were reduced with IRAF.[4] The wavelength calibration was controlled by observations of the RV standards (mainly α Cas) and by using the telluric water vapor lines.

In the 1993 October 14 spectrum, we detected a number of Fe II emission lines (including the one at 5317 Å) and Hβ. In the Hα-region spectra, we detected the following lines: Fe II 5317 and 6383, He I 5876, Si II 6347 and 6371 Å, Hα (emission), and Na I D1,2 5889 and 5895 Å (absorption). Among them, the Si lines and Fe II 6383 Å are the weakest, and measurements of their characteristics are most uncertain. However, they show the same qualitative behavior as the Fe II 5317 and He I 5876 Å lines. Our results for the latter are discussed below in addition to those for Hα. The results include measurements of the line peak RVs (fitted to a Gaussian), the centroid line RVs, the line equivalent widths (EWs; measured from the continuum level), and V/R ratios.

Additionally, the Hα mean velocities (RV$_{\rm mean}$) were determined by matching the linear parts of the original and mirrored profiles. The same method, which basically determines an average bisector velocity calculated within a certain intensity region, was also used by H2000. The most reliable results can obviously be obtained for linear and symmetric parts of the profile. In practice, RV$_{\rm mean}$ can be measured manually. However, the result may depend on personal experience and other unreliable factors, such as the plot scale used to display the data. To avoid personal errors, we designed an automated procedure that calculated RV$_{\rm mean}$ between specified values of the normalized intensity levels (I_c) and returned the most accurate one.

This method has a potential problem of shrinking the working region too much, so the results obtained in different regions would have close accuracies but noticeably different values. Fortunately, this is not the case for γ Cas. Most of our RV$_{\rm mean}$ values were derived from a region (1.7–2.8)I_c, while nearly half of them, measured in the 2000–2002 data, were from a region (1.6–3.0)I_c. Comparison of the RV$_{\rm mean}$ derived in close intensity regions shows that their difference does not exceed a 1 σ uncertainty (~2 km s^{-1}) of the most accurate value. This intensity region is slightly affected by telluric water vapor lines, which were avoided in the RV$_{\rm mean}$ measurements. The mean RVs were not measured for the Fe II and He I lines because they are much weaker, making the region of appropriate intensities significantly smaller.

Another estimate of the RV accuracy can be derived from the measurements of Na I D lines, which seem to have a purely interstellar origin. The mean RV of the stronger (D2) line, which is also less contaminated by telluric lines than the D1 line, is -3.7 ± 0.9 km s^{-1}. Its central residual intensity is also very stable (0.33 ± 0.01) in all our spectra of γ Cas. The D2/D1 intensity ratio is close to 2, which is characteristic of interstellar sodium at low optical depths (Munari & Zwitter 1997). Our measurements of the Na I D2 and Hα line in ~100 spectra of α Cas obtained in 1997–2002 show the same accuracy. Only a few RVs of the D2 line in the spectra of γ Cas were found outside the 3 σ range, which is most likely the result of CCD-chip shifts after liquid nitrogen fillings. In these cases, we corrected the Hα RVs using the difference between the measured D2 line RV and the mean value.

The V/R ratios are accurate to 0.1 and the EWs to about 5%. Multiple observations during the same night revealed no significant variations of the line profiles on a timescale from tens of minutes to a few hours. For example, the Hα line parameters measured in five spectra, obtained on 2000 December 26 within 2.5 hr, are as follows: EW $= 24.0 \pm 0.1$ Å, RV$_{\rm mean} = -11.1 \pm 0.3$ km s^{-1}, RV$_{\rm peak} = -57.9 \pm 1.1$ km s^{-1}.

3. RESULTS

All the emission lines have double-peaked profiles (Fig. 1). In Hα, this structure is veiled by the presence of a strong emission peak at RVs between +20 and −60 km s^{-1}. The strongest peak of Hα as well as both peaks of the Fe and He lines display long-term RV variations, which are correlated with the V/R variations (see Figs. 1 and 2). Additionally, the Hα's RV$_{\rm mean}$ varies on both a long-term and a shorter term scale. These two types of variations are discussed separately in this section.

3.1. Long-Term Variations

According to Doazan et al. (1987), the current Be phase of γ Cas began in the mid-1940s after a normal B star phase. The quasi-regular V/R variations have been observed since the late 1960s. The Hβ line usually serves as their tracer, because the Hα peaks were not always resolved. Four subsequent cycles, with lengths increasing with time (~4, 5, 7, and ~10 yr), have been observed since 1970. The lack of published data for the beginning of the first and end of the fourth cycle hampers better estimates of the cycle lengths. Nevertheless, it is seen that they become longer with time. The last known published data on the Hβ line for γ Cas (Galkina 1995) show that it passed through the $V/R = 1$ phase at the end of 1990. Berio et al. (1999) extrapolated available V/R data and predicted the beginning of the fifth (current) cycle in 1993 (V/R minimum).

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[4] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

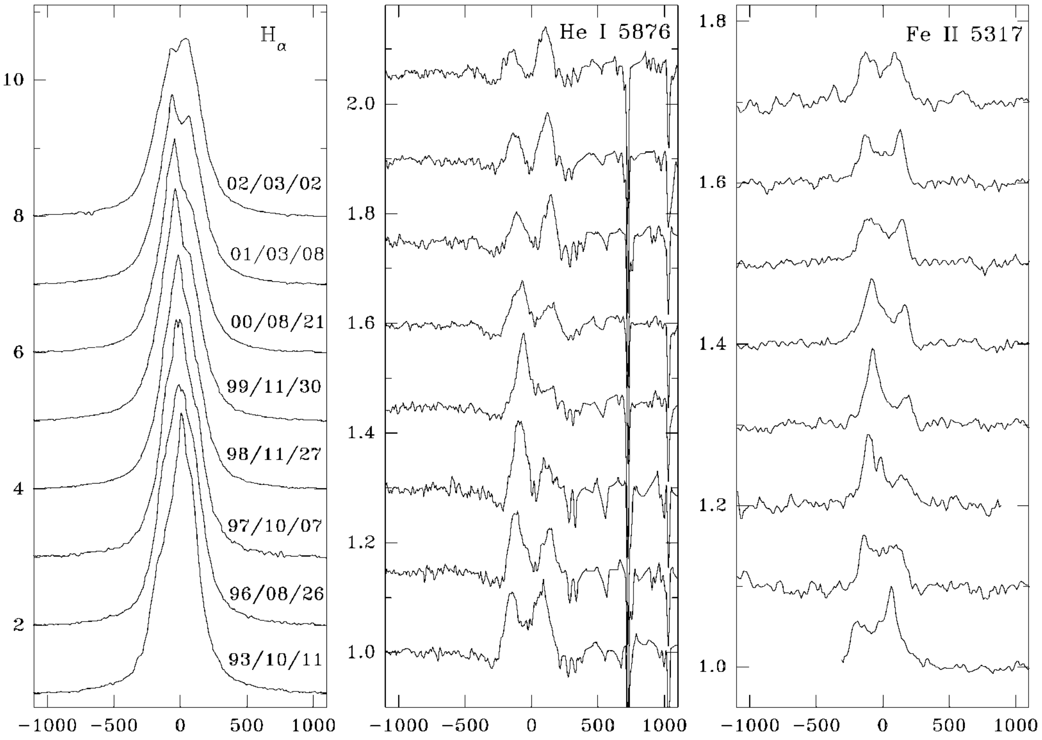

FIG. 1.—Sample line profiles in 1993–2002 in RV space. The heliocentric velocities are given in km s^{-1}, while the intensities are in units of the underlying continuum. The dates shown for the Hα line also refer to the other corresponding profiles, except for the last one of Fe II 5317 Å, which was obtained on 1993 October 14.

Our short-wavelength spectrum of 1993 October shows the Hβ $V/R = 0.52$, in agreement with this prediction. Other emission lines detected in this spectrum show similar V/R values. This fact suggests that the observed line profiles were formed by almost the same density distribution pattern at the cycle beginning time.

Taking into account the cycle length progression, one would predict the next $V/R = 1$ phase in 1995/1996 and the next maximum in 1999/2000. Our Hα data show that the strongest peak was close to the red wing of the profile in 1993 (i.e., $V/R \lesssim 1$) and to the blue wing in 2000/2001 ($V/R \gtrsim 1$). Thus, if we consider it a part of the double-peaked structure (as was done in previous studies, e.g., Doazan et al. 1984) and use it to estimate the V/R ratio, the latter agrees well with the above predictions. At the same time, the He I 5876 Å line V/R ratio was close to 1 in 1995, passed maximum in 1998, and approached a new minimum in 2001/2002 (see Figs. 1, 2*c*, and 2*d*). The Fe I 5317Å line V/R varies qualitatively in the same way, except that it is closer to 1 in 2001/2002. Such different behavior might imply the presence of an additional component in the circumstellar density structure contributing to the Hα line (and perhaps other Balmer lines) formation.

The peak velocity variations of the Fe and He lines displayed a correlation with the V/R variations. Both peaks (blue and red) were shifting to positive velocities when V/R was increasing and to negative ones when V/R was decreasing. The peak separation of ∼220–230 km s^{-1} appeared approximately constant. The strongest peak of Hα was continuously moving toward negative velocities in 1995–2001. The positive shift might have occurred in 1993/1994, as our data and those of H2000 for the Hα RV_{mean} suggested. In any case, the peak RV behavior is different from those of the Fe and He lines. We should note here that in the course of the gradual Hα profile changes, the strongest peak has not been clearly recognizable since 2001 September. The RVs during this period, shown in Figure 2*a*, refer to the blue peak. During this later period, there is a better correlation with the periodic variations (see § 3.2) than before.

All the changes described above occurred along with the continuous decrease of all the line EWs in 1993–2001, followed by their stabilization in 2002. Despite a rather large dispersion in the published Hα EWs, their behavior in the 1970s and 1980s was positively correlated with the V/R variations (see Fig. 3). Additionally, a continuous increase of the mean Hα EW was observed during this period. However, this is not the case since ∼1993. Thus, this phenomenon might represent a new phase in the evolution of the system.

3.2. Periodic Variations

In addition to the long-term variations, the Hα RV_{mean} in our spectra show regular changes with an amplitude of ≃10 km s^{-1}.

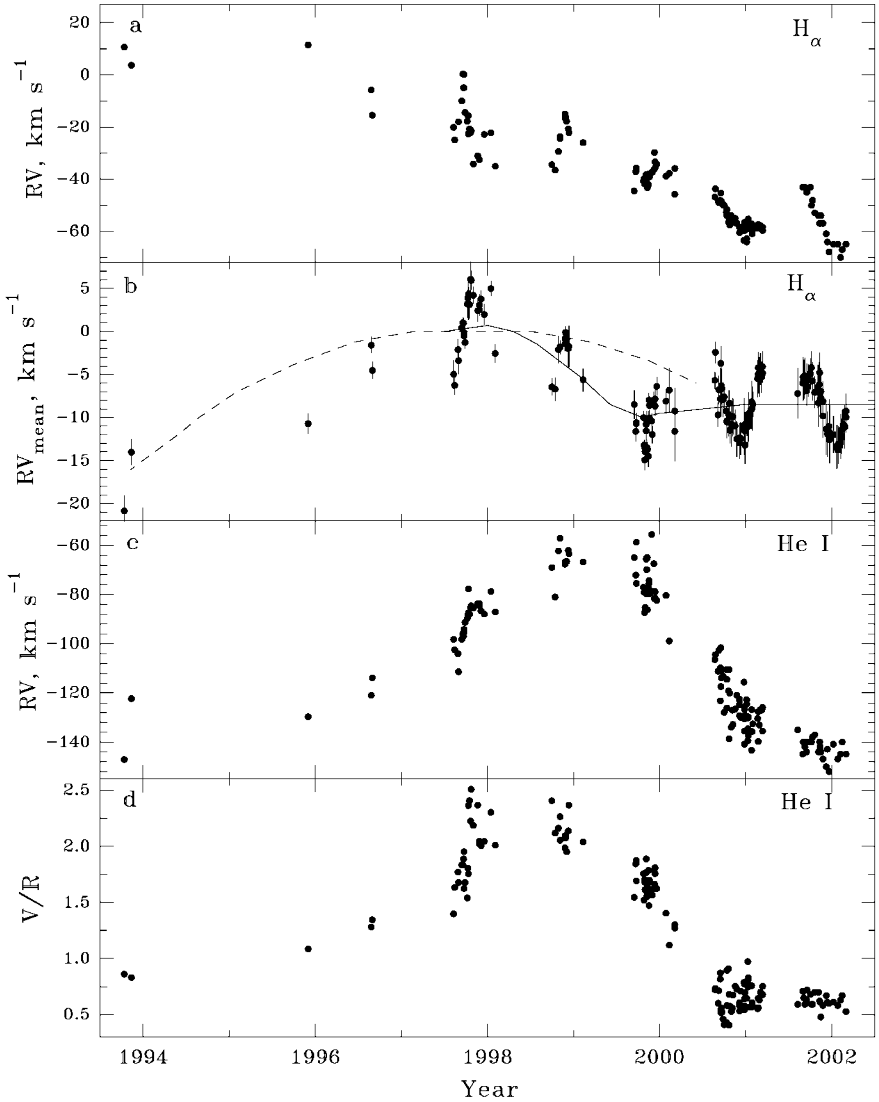

FIG. 2.—Variations of the RVs and *V*/*R*. (*a*) RVs of Hα's central peak; (*b*) RV$_{\rm mean}$ of Hα with uncertainties; (*c*) RVs of the blue peak of the He I 5876 Å line; and (*d*) *V*/*R* of the He I 5876 Å line. The solid line in (*b*) represents the mean curve we used for the long-term removal, and the dashed line is the mean curve used by H2000. The heliocentric velocities are given in km s^{-1}.

This is most clearly seen during the observing season of 2000/2001, when a total of 56 spectra were obtained, and 2001/2002 (50 spectra) (see Fig. 2*b*). Analysis of these changes suggests that they are regular with a period close to the one found by H2000, who attributed them to the binary orbital rotation. In order to derive orbital parameters from these data, one must remove the long-term trend. For this purpose, H2000 used a spline smoothing method of Vondrák (1977), and their resulting trend in 1993–2000 resembles the long-term changes of the Fe and He lines *V*/*R* ratios and the peak RVs (see Figs. 2*c* and 2*d*). Although our observations covered essentially the same period as that of H2000, the observing date distribution is different. Most of their data were obtained in 1993–1997. This has led to a different trend removal in our data, although a qualitative comparison of the two data sets before the removal suggests no systematic difference in our RV$_{\rm mean}$ measurements. It turns out that the RV$_{\rm mean}$ change due to the trend does not exceed the measurement accuracy within one orbital period. This is why we simply shifted our RV$_{\rm mean}$ obtained during different orbital periods to a common mean level. The mean curves representing the long-term trend used by H2000 and us are shown in Fig. 2*b*.

After the trend removal, we performed a least-squares fitting of our data for RV$_{\rm mean}$ to Keplerian RV curves with the following free parameters: orbital period (P), periastron passage time ($T_{\rm per}$), eccentricity (e), periastron longitude (ω), and RV semiamplitude (K_1). Because of the uncertainty of the long-term trend removal for our data obtained prior to 1997, we

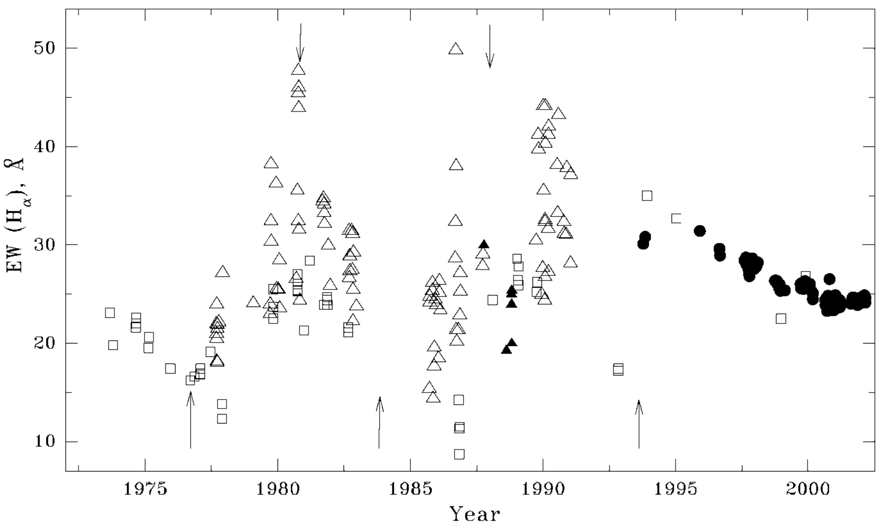

FIG. 3.—Long-term EW variations of the Hα line. Filled circles show the Ritter data, filled triangles show the photographic data by Krugov (1998), open triangles show the Crimean photographic data set reported by Galkina (1995), while open squares represent other, mostly photoelectric, data collected from the literature.

have not used them in this analysis. The fitting was performed using the Interactive Data Language (IDL) procedure CURVEFIT (Bevington 1969). Nine RV$_{\rm mean}$ with the largest deviations from the fit were removed. This did not change the best-fit parameters, but it reduced the rms error. The results are presented in Table 1.

The orbital period that we found from the analysis of our entire data set is not significantly different from that of H2000 (see col. [4] in Table 1). The larger period found from our 2000/2002 data has a larger uncertainty due to the smaller time interval. At the same time, the other parameters are different. A lower value of K_1 reflects our higher spectral resolution in comparison with the data of H2000. The main difference is that our data suggest a circular orbit for the binary. In this case, we list an epoch of RV$_{\rm mean}$ maximum in Table 1, while ω is not relevant.

The solution discrepancy is partly due to the different trend removal. Application of the fitting procedure to the data set of 106 spectra obtained between 2000 August 8 and 2002 March 2 yields the same result for *e*. Our best fits for the complete data set, along with the H2000 phase curve, are presented in Figure 4. The best-fit phase curve and $O - C$ deviations for our circular and for the H2000 solution are shown in Figure 5. It is seen that the $O - C$ distribution is much more uniform for the circular orbit. The rms error from our solution is also noticeably smaller than that from the H2000 solution (0.936 vs. 1.511 km s^{-1}, respectively). Thus, our data do not show evidence for the large eccentricity found by H2000.

4. DISCUSSION

One of the main results of our observations is the confirmation of the periodic RV variations in the spectrum of γ Cas. They are most likely related to orbital motion in a binary sys-

TABLE 1
ORBITAL SOLUTIONS FOR γ CAS

	THIS WORK			
ELEMENT	1997–2002	2000–2002 Only	Period 203.59 days Fixed	H2000
P (days)	205.50 ± 0.38	206.36 ± 1.21	203.59	203.59 ± 0.29
$T_{\rm per}$	…	…	…	2,450,578.7 ± 4.2
$T_{\rm max}$	2,450,541.2 ± 2.5	2,450,534.1 ± 2.0	2,450,552.5 ± 2.5	…
e	0	0	0	0.260 ± 0.035
ω (deg)	…	…	…	47.9 ± 8.0
K_1 (km s^{-1})	3.80 ± 0.12	3.87 ± 0.14	3.80 ± 0.12	4.68 ± 0.25
rms (km s^{-1})	0.936	0.627	1.053	1.455
Number of spectra used	162	104	162	272

NOTE.—A periastron epoch and that of the maximum RV$_{\rm mean}$ in HJD$-$2,400,000 are given in rows (2) and (3), respectively; rms errors per one observation are given row (6).

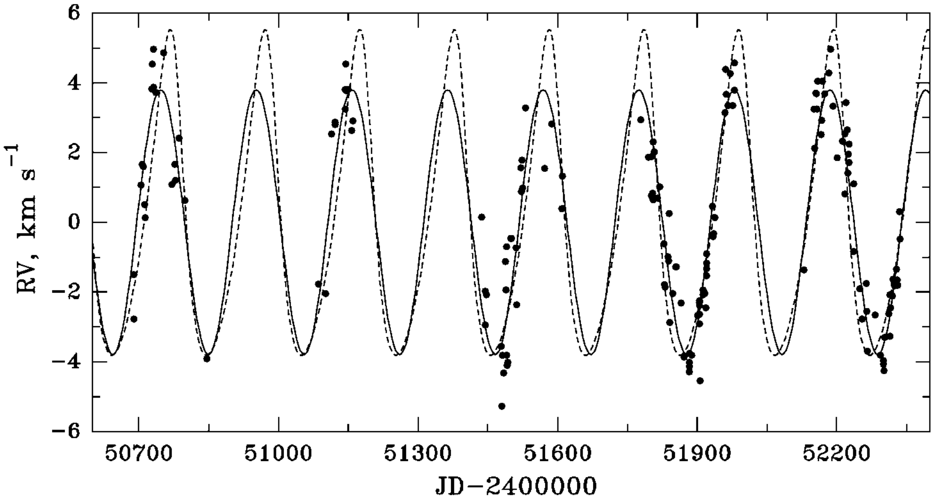

FIG. 4.—Hα line RV$_{\rm mean}$ variations. Filled circles show the Ritter data obtained between 1997 August and 2002 March with the temporal trend removed. The solid line represents our orbital solution, and the dashed line represents the H2000 solution.

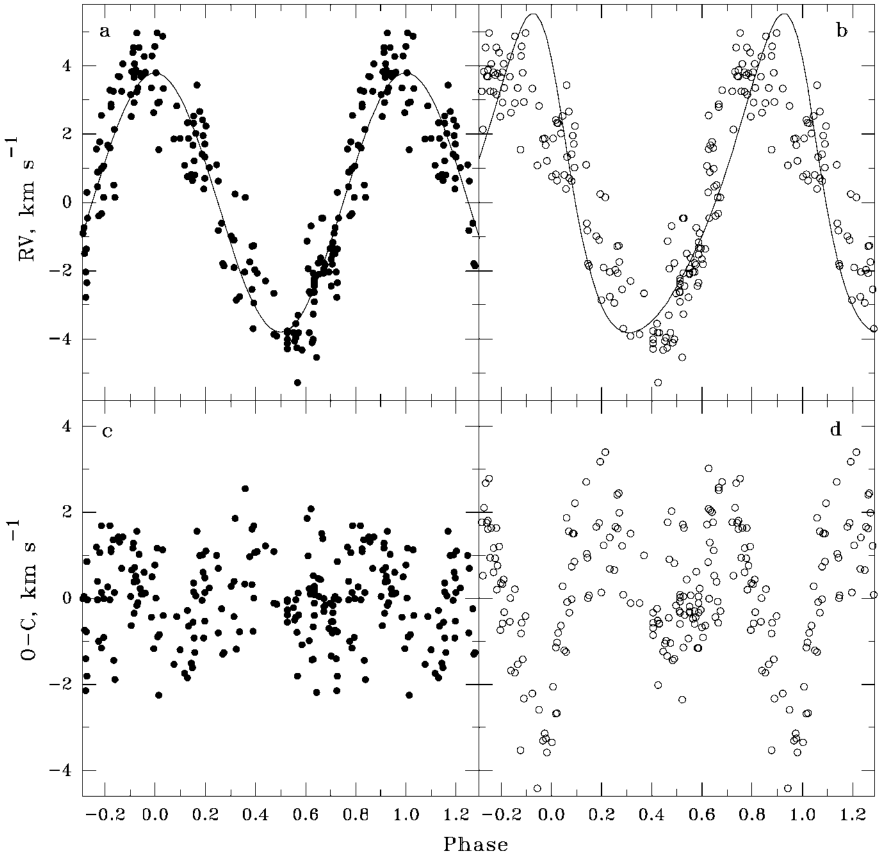

FIG. 5.—Phase curve of the Hα's RV$_{\rm mean}$ variations and $O-C$ differences for the circular ([*a*] and [*c*], respectively) and H2000 ([*b*] and [*d*], respectively) solutions. The solid lines represent corresponding solutions for the whole our data set.

tem. However, our orbital elements (except for P) differ from those of H2000. It is relevant to discuss possible causes of this discrepancy in more detail.

First, it is not clear whether the method of trend removal is applicable in this case. The line-profile dynamics appear to be very complicated and include at least three components that might contribute to the observed RVs. They are the orbital motion, the long-term profile variations seen in the Fe and He lines, and the apparently independent variations of Hα's strongest peak. The method developed by Vondrák (1977) is a purely mathematical model, based on smoothing the actual data set using cubic spline functions, and does not include any additional information about other possible contributing factors. Our method of the trend removal is simpler but has the same problem. For example, since the strongest peak in Hα displays a long-term RV trend different from that of the lines, which have the usual double-peaked profiles (Figs. 2*a* and 2*c*), and since the Hα's $\mathrm{RV}_{\mathrm{mean}}$ is probably related to the veiled double-peaked structure, a trend similar to that shown in Figure 2*c* might be present in the Hα's $\mathrm{RV}_{\mathrm{mean}}$. It is not obvious how to take it into account, but it might affect the phase-curve shape.

Another possible source of the uncertainties in the $\mathrm{RV}_{\mathrm{mean}}$ measurements is the intensity region used to match the original and mirrored profiles. As seen in Figure 1, the top part of the Hα profiles is dominated by an asymmetric single peak and therefore cannot be used to measure $\mathrm{RV}_{\mathrm{mean}}$. Furthermore, during the period of both our and H2000's observations, the Hα line intensity was decreasing. This may change the potential working region and perhaps make it time dependent. H2000 did explicitly mention their working intensity region, and they showed only an example of a 1993 profile, where the region between ~1.8 and ~3.3 in continuum units (I_c) was used. Finally, additional undiscovered processes might affect the profile dynamics. At present, we can only confirm the H2000 finding of the periodic RV variations, but the question about eccentricity needs further study.

Our high-resolution spectroscopic monitoring of γ Cas revealed that apparently several processes in its circumstellar envelope are responsible for the line-profile dynamics. Various observations point to the presence of a circumstellar disk, which is viewed at an intermediate inclination angle (~45°; Quirrenbach et al. 1997) and is extended up to ~17 stellar radii (Stee et al. 1995). The disk obviously surrounds the primary star of the binary system, since the secondary seems to be much less massive (H2000). The different *V*/*R* cycle lengths for the Hα line on one side and the Fe and He lines on the other side might suggest either different formation regions inside the primary's disk or the presence of a contribution from material surrounding the secondary. A closer inspection of the high-resolution Hα profiles of γ Cas (e.g., Doazan et al. 1984; this paper) suggests that the highest emission peak veils a double-peaked structure, similar to that of the other emission lines. Since its RV is usually smaller than those of the Fe and He line peaks (see Fig. 2), one can argue that it is formed further away from the star, where the disk rotates more slowly. This may be a region close to the primary's Roche lobe boundary, where the matter can be accumulated before it is transferred into the secondary's Roche lobe. In fact, a ringlike region of an enhanced circumstellar matter concentration was recently suspected in several Be stars by Rivinius et al. (2001).

The continuous decrease of the line EWs in the spectrum of γ Cas observed in 1993–2001 (also reported by Pollmann 2001) may mark a coming end to the current Be phase. A similar event was recently observed for another Be star, π Aqr (Bjorkman et al. 2002), whose Hα profile has had the same appearance as that of γ Cas. π Aqr lost its highest Hα peak within a few months in 1989 and revealed a usual double-peaked structure, which then faded for 6 more years. This object has been in a normal B-star phase since 1996. Our study of its spectra during this phase showed the presence of a faint emission component, variable in RV, within the photospheric Hα line profile. Measurements of the RVs of both emission-line and absorption-line components resulted in detection of antiphased periodic variations, suggesting that π Aqr is a binary system. A similar study of γ Cas during a possible future normal B-star phase could help to constrain the nature and parameters of both stellar components.

Our findings can be briefly summarized as follows:

1. A regular component with a period of ~205 days was detected in the variations of the Hα $\mathrm{RV}_{\mathrm{mean}}$. Thus, we confirm the earlier discovery by H2000, who attributed it to orbital motion in a binary system. However, our orbital solution implies a circular orbit rather than the eccentric one ($e = 0.26$) found by H2000. One of the possible reasons for this discrepancy is the uncertain removal of the long-term RV variations. While our results cannot completely rule out that the binary orbit is eccentric, they favor a nondegenerate nature of the secondary and are consistent with the conclusion of Robinson et al. (2002) about the X-ray generation connected with the primary.
2. A continuous decrease of line EWs was detected in 1993–2001. This phenomenon most likely heralds the onset of a new phase in the object's evolution, which may end with another normal B-star phase.
3. We found that the *V*/*R* ratios of the Hα and nonhydrogen lines varied nonsimultaneously. The Hα *V*/*R* cycle was apparently longer than that of the other observed lines. Such a behavior might be explained by the presence of one or more additional components in the Hα (Balmer lines) profile on top of the double-peaked structure seen in other lines.

The observed emission-line behavior raised a number of questions to be answered by future observations. They include refinement of the binary orbital elements, the nature of the secondary, the presence of circumstellar matter around the secondary and the significance of its contribution to the line profiles, and further evolution of the overall emission-line spectrum. To answer these questions, further frequent and high-resolution spectroscopy is important. The resolving power of such observations should be higher than ~15,000 in order to measure RVs with the required accuracy. However, a resolving power of ∼40,000 and higher is needed to study the line-profile structure in detail. We also suggest observing a number of spectral lines of different species and monitoring the star frequently. Additional photometry and polarimetry would be of benefit to constrain the circumstellar distribution and parameters of the binary.

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REFERENCES

Berio, P., et al. 1999, A&A, 345, 203
Bevington, P. R. 1969, Data Reduction and Error Analysis for the Physical Sciences (New York: McGraw-Hill)
Bjorkman, K. S., Miroshnichenko, A. S., McDavid, D. A., & Pogrosheva, T. M. 2002, ApJ, 573, 812
Doazan, V., Franco, M., Ruskoni, L., Sedmak, G., & Stalio, R. 1984, A&AS, 55, 1
Doazan, V., Ruskoni, L., Sedmak, G., Thomas, R. N., & Bourdonneau, B. 1987, A&A, 182, L25
Galkina, T. S. 1995, Izv. Krymskoi Astrofiz. Obs., 93, 102
Harmanec, P., et al. 2000, A&A, 364, L85 (H2000)
Horaguchi, T., et al. 1994, PASJ, 46, 9
Krugov, V. D. 1998, Kinemat. Fiz. Nebesn. Tel., 14, 268
Moujtahid, A., Zorec, J., Hubet, A.-M., Garcia, A., & Burki, G. 1998, A&AS, 129, 289
Munari, U., & Zwitter, T. 1997, A&A, 318, 269
Okazaki, A. T., & Negueruela, I. 2001, A&A, 377, 161
Pollmann, E. 2001, Be Star Newsl., No. 35
Quirrenbach, A., et al. 1997, ApJ, 479, 477
Rivinius, Th., Baade, D., Stefl, S., & Maintz, M. 2001, A&A, 379, 257
Robinson, R. D., Smith, M. A., & Henry, G. W. 2002, ApJ, 575, 435
Stee, P., de Araujo, F. X., Vakili, F., Mourard, D., Arnold, L., Bonneau, D., Morand, F., & Tallon-Bosc, I. 1995, A&A, 300, 219
Telting, J. H., & Kaper, L. 1994, A&A, 284, 515
Vondrák, J. 1977, Bull. Astron. Inst. Czechoslovakia, 28, 84