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γ Per: Bright, but Ill-Understood

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Abstract.
γ Per looks like an unexceptional composite–spectrum binary, and has habitually been classified as G8 III+A3 V. Nevertheless, previous studies have produced conflicting results, of component masses that are uncomfortably high, or luminosities that are too large, or (most recently) showing that there is nothing abnormal about the components after all. However, new high-precision CCD spectroscopy and isolation of the secondary spectrum finds that mass of the giant is 3.9 $M_{\odot}$, which is indeed greater than would be expected from its published spectral type, and that both components have somewhat enhanced luminosities, thus re-opening the question of the origin and evolution of this somewhat unusual system.

1. Introduction

Superficial consideration of the high frequency of oddities among the brightest stars (Arcturus, Vega, Capella, Sirius, *o* Leo, ...) and extrapolation to fainter ones leads to the conclusion that *all* stars are odd in some way. We can add another bright star to the collection of known stellar oddities: γ Per ($V = 2^{\rm m}.9$).

γ Per is a well-observed spectroscopic binary, and I'm not the first to claim that it is baffling. McLaughlin (1948) reported that the component masses seem to be too high, but 40 years later Popper & McAlister (1987) concluded that, on the contrary, the components are over–luminous rather than over-massive. Then Pourbaix (1999) said that everyone else was quite wrong and that, with some conditioning of the data by stellar–evolution theory, everything hangs together nearly as well as the textbooks would have us believe. This paper is based on new high-resolution CCD spectra, and offers results that mesh more closely with the two earlier papers than with anything towards which stellar–evolution theory would propel us.

2. Observations and their Analyses

2.1. *Eclipses*

The period of γ Per is about 14.5 years, and eclipses were not discovered until 1990 by R.F. Griffin (making it the second-brightest known eclipsing binary, the brightest being none other than β Per!). Analysis of eclipse photometry (Figure 1) gives us the radii of the components and the "latitude" of the trajectory. Knowing the duration of the eclipse, and the relative tangential velocity of the components from the single-lined orbit, we can derive limits for those radii by fitting the slopes of the ingress and egress light curves: 3.0 $R_{\odot} <$ R$_2$ $<$ 3.4 $R_{\odot}$ for the hot star, and 21 $R_{\odot} <$ R$_1$ $<$ 25 $R_{\odot}$ for the cool one.

2.2. *Parallax, Distance and Absolute Magnitude*

The *Hipparcos* parallax corresponds to a distance of 78.6 ± 4.3 pc, i.e., $M_V = -1^{\rm m}.55 \pm 0^{\rm m}.12$. The eclipse photometry gives us the values of ΔV, ΔB and ΔU, and a photometric model can then be constructed which reproduces the observed colours. It also gives $M_{V,1} = -1^{\rm m}.27 \pm 0^{\rm m}.12$, $M_{V,2} = +0^{\rm m}.06 \pm 0^{\rm m}.12$ (see Table 1).

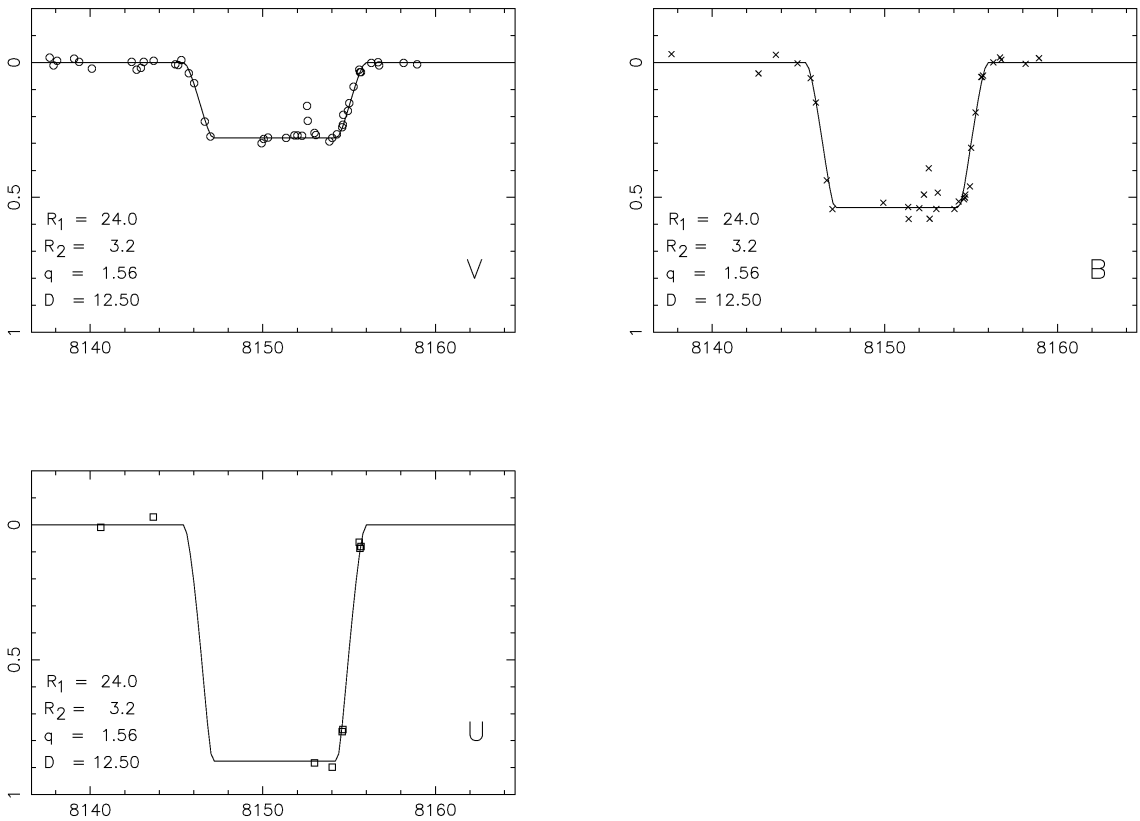

Figure 1. Three-colour eclipse photometry of γ Per, fitted with a model. The changes observed during eclipse are $\Delta V = 0^{\rm m}.28$, $\Delta B = 0^{\rm m}.54$, $\Delta U = 0^{\rm m}.88$.

2.3. *Spectroscopy and a Double-Lined Orbit*

About two dozen high-resolution CCD spectra were recorded in 2005 with the DAO 1.2-m telescope and coudé spectrograph, at phases that were either during or near eclipse or at the node of large radial-velocity (RV) excursion (see Figure 2). Spectra of the hot component were isolated by subtracting the giant's spectrum observed during totality. By measuring the RV displacements between the components and correcting for the known RV of the giant, RV measurements of the secondary were obtained and were fed into a double-lined orbit. The solution (Figure 2) gives a mass ratio (m_1/m_2) of 1.56, which is substantially higher than has been derived from other composite-spectrum binaries with comparable component types.

2.4. *Spectroscopy, Physical Parameters and a Photometric Model*

Comparisons between synthetic spectra and the spectra of the hot component of γ Per were reasonable but not fully satisfactory, as it proved difficult to fit the observed strength of the K line with the same model as also fitted the Balmer-line profiles well. A compromise (illustrated in Figure 3) suggested an effective temperature $T_{\rm eff}$ = 9,500 $\pm$ 300 K and a slightly raised luminosity: log $g = 3.8 \pm 0.2$. Those parameters yield a luminosity close to 100, and a radius for the secondary of $R_2 = 3.4\ R_\odot$; the latter is consistent with the analysis of the eclipse photometry. However, those parameters are much more characteristic of ~AO V than the A3 V that has been claimed in the literature.

The spectrum of the hot component in γ Per could be matched better with that of θ Leo, particularly at the K line (Figure 4). However, the precise status of θ Leo itself is

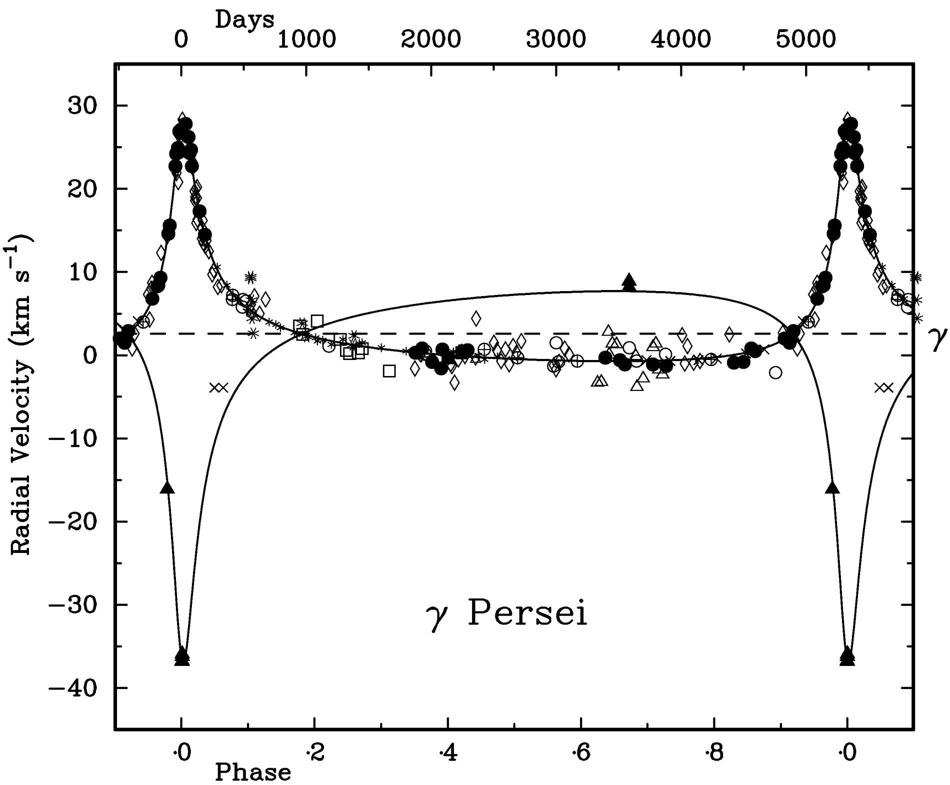

Figure 2. This orbit solution yields $q = m_1/m_2 = 1.56$, with $m_1 = 3.9\ M_\odot$ and $m_2 = 2.5\ M_\odot$. (I am grateful for R.F. Griffin's assistance and advice in running his orbit programme.)

a little unclear. Its $(B - V)$ of -0.06 is too blue for its assigned spectral type of A2 V, although that luminosity classification may need revising, since the M_V derived from its *Hipparcos* parallax is $-0^m.33$. While the M_V for the hot component of γ Per is also somewhat brighter than tabulations suggest for an early A dwarf, it is not as luminous as θ Leo even at the extreme of the *Hipparcos* uncertainty, namely $M_V = -0^m.18$.

For the giant component, the temperature of 5100 ± 150 K, selected on the basis of comparisons with standard spectra which have been analysed in detail, indicates $R_1 = 23\ R_\odot$ and thus agrees comfortably with the value derived from the eclipse photometry. But that value of R_1 and the corresponding value of $M_{V,1}$ (see Table 1) indicate that the giant too has a raised luminosity; rather than the class III that has previously been assigned, it is more probably class II–III.

Table 1. Photometric model for γ Per

Object	M_V m	$(B - V)$ m	$(U - B)$ m
Primary (∼G8 II–III)	−1.27	0.96	0.79
Secondary (∼A1 IV)	+0.06	0.11	0.07
Combined	−1.55	0.70	0.45
γ Per (observed)	−1.55 ±0.12	0.70	0.45

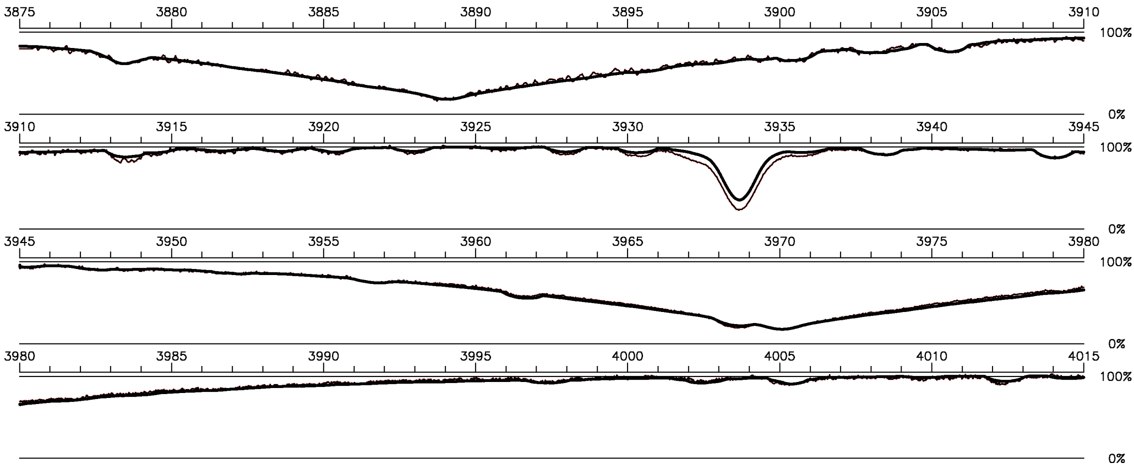

Figure 3. The spectrum of the hot component of γ Per (red), isolated from the composite one by subtracting that of the giant (observed during total eclipse), is overplotted (in black) with a synthetic spectrum calculated for [T_{eff} = 9500 K, log g = 4.0]. The latter has been blurred by 50 km s^{-1} to mimic the widths of the lines in the star.

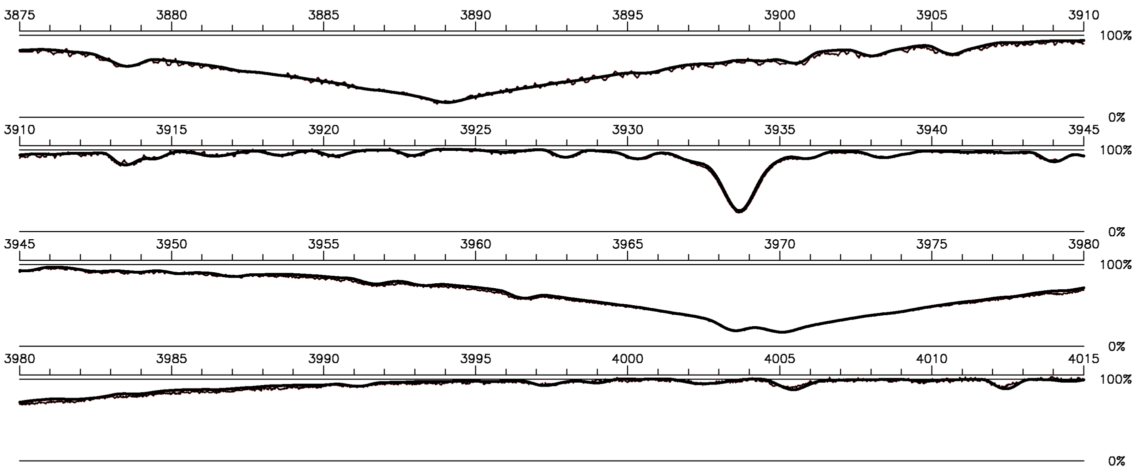

Figure 4. Again the spectrum of the early-A star in γ Per is in red; in black is the spectrum of θ Leo (A2 IV), which has been blurred by 40 km s^{-1} to mimic the line-widths in the γ Per star.

3. Stellar Evolution

The [log T_{eff}, log L] positions of the two components of γ Per in the H-R diagram were compared to evolutionary tracks computed for the corresponding masses as determined from the orbit solution; computations were carried out with Dr. O. Pols' software described by Pols et al. (1998) and now in the public domain. Overshooting was included, as recommended by those authors for stellar masses of the sizes involved here. Interestingly, although the mass of 2.5 $M_\odot$ determined for the hot component is unexceptional, its H-R diagram position and corresponding evolutionary track could only be reconciled if a reduction in metallicity by a factor of 2 was accepted. No such reduction was necessary in the case of the cool component, for which the deduced [log T_{eff}, log L] positions match well the corresponding evolutionary track for 3.9 $M_\odot$ (Figure 5).

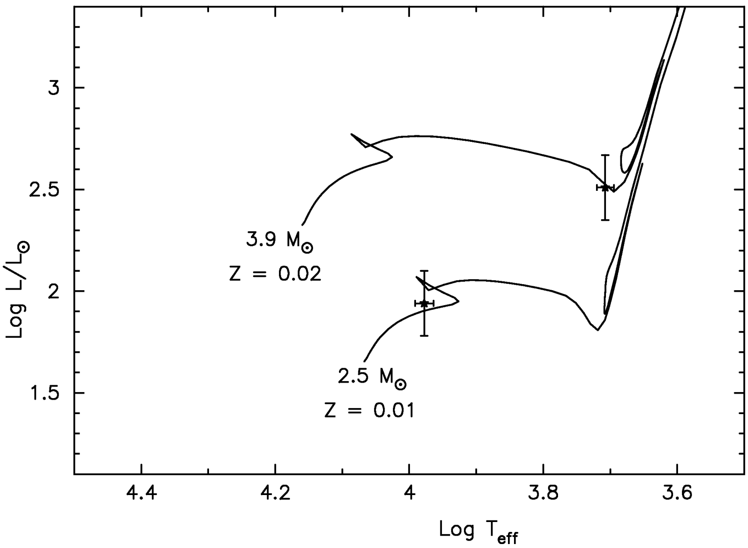

Figure 5. Evolutionary tracks, from Pols et al. (1998), for models corresponding to the masses of the two component stars in γ Per. The model for the cool-giant primary has solar metallicity, but for the hot secondary the metallicity has had to be reduced by a factor of 2.

4. The Conundrum

Somewhat contrary to the assertion by Popper & McAlister (1987) that γ Per is "not overmassive but overluminous", our conclusion is that it is *both*.

Analysis of more than 25 composite-spectrum systems by spectrum subtraction has now produced enough results that a picture is beginning to emerge – and it is an unexpected one: like γ Per, many other systems also have secondary stars that have started to evolve away from the main-sequence, thereby challenging details of our models through the requirement that the component stars have the same age.

The ages corresponding to the two evolutionary tracks illustrated in Figure 5 disagree by a factor of 2.5, the giant's apparent age being the shorter because of its high mass. The implication is that the system which we now detect as a binary must have undergone some fundamental alteration since its main-sequence life. Could the system have once been triple, and that the primary acquired surplus mass by absorbing the third star? What evidence needs to be produced to test that hypothesis?

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