The stellar mass ratio of GK Persei

L. Morales-Rueda, M. D. Still, P. Roche, J. H. Wood, J. J. Lockley

ABSTRACT
We study the absorption lines present in the spectra of the long-period cataclysmic variable GK Per during its quiescent state, which are associated with the secondary star. By comparing quiescent data with outburst spectra we infer that the donor star appears identical during the two states and the inner face of the secondary star is not noticeably irradiated by flux from the accreting regions. We obtain new values for the radial velocity semi-amplitude of the secondary star, $K_K = 120.5 \pm 0.7 \, \text{km s}^{-1}$, a projected rotational velocity, $V_K \sin i = 61.5 \pm 11.8 \, \text{km s}^{-1}$ and consequently a measurement of the stellar mass ratio of GK Per, $q = M_K/M_{WD} = 0.55 \pm 0.21$. The inferred white dwarf radial velocities are greater than those measured traditionally using the wings of Doppler-broadened emission lines suspected to originate in an accretion disk, highlighting the unsuitability of emission lines for mass determinations in cataclysmic variables. We determine mass limits for both components in the binary, $M_K \geq 0.48 \pm 0.32 M_\odot$ and $M_{WD} \geq 0.87 \pm 0.24 M_\odot$.

Key words: binaries: close – stars: cataclysmic variables – stars: fundamental parameters – stars: individual: GK Per.

1 INTRODUCTION
GK Per (Nova Per 1901; Campbell 1903), is a cataclysmic variable (CV) that undergoes dwarf nova outbursts every 2–3 years, brightening from 13th to 10th magnitude (Sabbadin & Bianchini 1983). Its spectrum is a composite of broad emission lines and narrow absorption lines that move sinusoidally in wavelength over the orbital cycle, but 180 degrees out of phase, indicating origins associated with both stars. The absorption lines are generally photospheric and from the secondary star (Kraft, 1964), while the emission lines are probably from an accretion disc around the compact object (we explore this further in a future paper). Within the sample of known CVs, GK Per has the longest orbital period, $P_{\text{orb}} = 1.996803 \, \text{d}(0.000007)$, (Crampton, Cowley & Fisher 1986). This makes observing the orbital cycle from the ground difficult unless observations are separated over several observing seasons or a number of observatories are employed contemporaneously at varying longitudes.

Previously, (Morales-Rueda, Still & Roche 1996, 1999; hereafter MSR96 and MSR99), we have presented spectrophotometric observations of GK Per taken during its 1996 outburst (Mattei et al.1996). In the current paper we present spectroscopic observations of GK Per during its quiescence state and focus mainly on the behaviour of the secondary star absorption lines, searching for signs of heating on the inner surface of the companion. Furthermore we measure the radial velocity of the secondary star and combine this with previously published velocities. With all the data, covering from 1964 to 1995, we calculate a new ephemeris for GK Per and a more accurate value for the radial velocity semi-amplitude of the companion star, $K_K$. We measure $V_K \sin i$ and consequently the mass ratio $q$ for GK Per. A lower limit for the white dwarf mass is derived from these values which is significantly different to the mass inferred by emission line measurements. This provides a further example of the general unsuitability of emission line for measuring stellar masses in CVs (Dhillon, Marsh & Jones, 1991).

2 OBSERVATIONS
Spectra of GK Per during its quiescent state were acquired in 1995, from October 11 to 13, and from October 31 to November 2. The first set of spectra was taken at the 2.5 m
Table 1. Journal of observations. The orbital phases were calculated using the ephemeris obtained in Section 3.2. Phase 0 corresponds to superior conjunction of the white dwarf. Labels (1) and (2) indicate which observation campaign the data were taken at: (1) INT, (2) McDonald.

| Date (1995) | Start Time (UT) | End Time (UT) | Start Phase | End Phase | No. of Spectra |
|-------------|-----------------|---------------|-------------|-----------|----------------|
| 11 Oct (1)  | 22.27           | 4.58          | 0.027       | 0.158     | 129            |
| 12 Oct (1)  | 22.91           | 6.48          | 0.541       | 0.699     | 165            |
| 13 Oct (1)  | 3.62            | 6.59          | 0.140       | 0.202     | 57             |
| 31 Oct (2)  | 5.76            | 9.67          | 0.199       | 0.281     | 30             |
| 1 Nov (2)   | 5.22            | 11.71         | 0.689       | 0.824     | 51             |
| 2 Nov (2)   | 4.88            | 8.96          | 0.183       | 0.268     | 32             |

Isaac Newton Telescope (INT) on La Palma using the Intermediate Dispersion Spectrograph. The standard readout mode was used with the Tektronix CCD TEK4 windowed to 1024 x 340 pixels. Exposure times were 35 s with 90 s dead time, and the spectral resolution at H$\beta$ was 110 km s$^{-1}$. The R1200B grating with 1200 lines mm$^{-1}$ covered the wavelength range from $\lambda\lambda$4363 – 5000 $\AA$. 351 spectra of GK Per and 8 spectra of K-type template stars were obtained during this observing run. Several bias and flatfield frames were obtained each night to correct for the bias level and the pixel-to-pixel response variations of the chip, and a CuAr frame was taken every 15 frames of the target to calibrate the spectra in wavelength. A wide slit exposure of the standard HD19445 (Oke & Gunn, 1983) was taken every night to calibrate the detector’s larger scale response variations. A spectrograph slit orientation of PA 249.1$^\circ$ allowed a 15th magnitude nearby star approximately 25 arcsec ENE of GK Per to be employed as calibration for light losses on the slit. A wide slit spectrum of GK Per and the comparison star was also taken to calibrate the absolute flux scale. After debiasing and flat-fielding the frames, spectral extraction proceeded according to the optimal algorithm of Horne (1986).

The second set of spectra was taken using the low-to-moderate resolution spectrograph ES2 mounted on the 2.1 m telescope at McDonald Observatory in Texas. The TI1 CCD camera and a grating ruled at 1200 lines mm$^{-1}$ were used, covering wavelengths $\lambda\lambda$4196 – 4894 $\AA$. Exposure times were 350 s with 40 s readout time, and the resolution at H$\beta$ was 130 km s$^{-1}$. Bias and flatfield frames were taken each night with regularly-spaced arc lamp exposures. The standard Feige 110 (Stone, 1977) was observed to flux calibrate the data. Simultaneous photometry of GK Per was taken during the campaign at the McDonald 36-inch telescope with the Stiening Photometer (Zhang et al., 1991) using UBVRI filters (see Skidmore et al. 1997, for a description of the filters). The exposure times for the photometry were 1 s. The combination of the spectroscopy and the photometry yielded 113 spectra of GK Per calibrated in flux. Spectra of 7 K-type template stars were also obtained. Tables 1 and 2 give a journal of the GK Per observations and a list of the K-type templates observed during both campaigns and their spectral classes respectively.

### 3 RESULTS

#### 3.1 Spectral classification of the donor star

In 1964 Kraft noticed the presence of absorption features characteristic of K-type stars in the optical spectrum of GK Per. Kraft (1964), Gallagher & Oinas (1974), Crampton et al. (1986) and Reinsch (1994) carried out temporal studies of these absorption lines and concluded that their origin was the mass-donating secondary star of the binary system. These authors classified the donor star by comparing its absorption features with the same features seen in K-type template stars. Kraft (1964), Gallagher & Oinas (1974) and Reinsch (1994) obtained consistent classifications; K2,vp - K2,v and K2,v or K3,v respectively. Kraft (1964) and Gallagher & Oinas (1974) noted changes in the line ratios from spectrum to spectrum throughout their observing campaign and the classification they gave was the mean spectral type of all the observations. The spectral type of the secondary as measured by Crampton et al. (1986) (K0II – K0IV) is not consistent with those of the authors mentioned above. Moreover, Crampton et al. (1986) conclude that phase-related spectral changes seen by previous authors are not present in their own data.

The spectra of GK Per and the K-type templates presented here were binned into constant velocity bins. We used the fit to the orbital radial velocity of the secondary calculated in Section 3.2 (systemic velocity $\gamma=40.8$ km s$^{-1}$, radial velocity semi-amplitude of the companion $K_2=120.5$ km s$^{-1}$) to shift out the orbital motion of the absorption lines with a quadratic rebinning algorithm. The GK Per spectra from each night were then binned into two orbital phase intervals to investigate the possible changes in spectral and luminosity classes of the secondary at different orbital phases. We selected the regions where there were mostly-uncontaminated absorption features, i.e. regions containing obvious emission lines (e.g. $\lambda\lambda$4265–4399 $\AA$, $\lambda\lambda$4345–4384 $\AA$, $\lambda\lambda$4503–4553 $\AA$, $\lambda\lambda$4620–4727 $\AA$, $\lambda\lambda$4842–4878 $\AA$, and $\lambda\lambda$4910–4935 $\AA$) were masked out from the data.

In order to classify the secondary star, an optimal subtraction method (Marsh, Robinson & Wood 1994) was applied. The K star templates are individually subtracted from the total spectrum. The residual is compared to a smoothed version of itself, produced by convolving the residual with a Gaussian of FWHM = 13 $\AA$ using the $\chi^2$ statistic. For each K star, this procedure is iterative, where the template is scaled by a multiplicative free parameter which is determined by

Table 2. K star templates observed, with their corresponding spectral classification. (a) Houk & Smith-Moore (1988); (b) Nassau & van Albada (1947); (c) Yoss (1961); (d) Roman (1952); (e) Georgelin (1967), (f) Griffin & Redman (1960), (g) Hoffleit & Warren (1991).

| Name         | SpType | Ref. | Name         | SpType | Ref. |
|--------------|--------|------|--------------|--------|------|
| October 1995 |        |      | November 1995|        |      |
| HR190        | K1 III | a    | K0 III       | d, f   |      |
| HR86688      | K1 III | b    | K1 III       | d, f   |      |
| HR84156      | K2 III | c    | K2 III       | d      |      |
| HR86526      | K3 III | d    | K3 III       | d      |      |
| HR89741      | K1 IV  | d    | K2.5 IV      | g      |      |
| HR88811      | K1 V   | e    | K0 IV        | d, f   |      |
| HR222        | K2 V   | f    | HD197964     | K1 IV  | g    |
| HR88832      | K3 V   | d, f |              |        |      |
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Figure 1. The top spectrum is an average of the spectra of GK Per obtained during the first night of observations on the October 1995 campaign at the INT. The middle spectrum corresponds to the K1 IV template HD197964 multiplied by a constant, $0.3 \times 10^{-3}$. The bottom spectrum is the residual resulting from the subtraction of the template from the averaged GK Per spectrum and probably resembles the spectrum of the accretion flow during quiescence. Some absorption and emission lines present in the spectra have been labelled. Most of the absorption lines were identified by Crampton et al. (1986).

minimising $\chi^2$. The assumption is that the correctly-scaled template spectrum is a good representation of the secondary star and the most intrinsically-smooth residual is a good representation of the accretion flow spectrum. The template providing the smallest minimum-$\chi^2$ is considered the best match to the secondary star spectrum. A plot of the minimum-$\chi^2$ per degree of freedom found for each template for the two orbital phase intervals observed each night can be found in Fig. 2.

The best-fit template is a K1 IV star (HD197964) in all cases. The companion star contributes 69 percent of the total light at 4550 Å, in contrast with 13 percent measured during outburst (MSR99). Fig. 1 presents the total spectrum of GK Per before (top panel) and after (bottom panel) the subtraction of the scaled K1 IV star template (middle panel). Identified emission and absorption lines are labelled. This spectral classification of the secondary is close to previous studies of GK Per during quiescence. This result does not fit within the spectral class-orbital period relation fit by Smith & Dhillon (1998). This may indicate that the secondary star in GK Per is not a main-sequence star, which is not surprising as basic evolutionary theories tell us that one should not find a main-sequence star in a CV with an orbital period much longer than ~9 hours (Patterson 1984).

The INT data covers approximately the same orbital phases as the 1996 outburst data analysed in MSR96 and MSR99. The template star nearest in spectral class to the donor during outburst at phases, $\phi \sim 0.14–0.18$ and $\phi \sim 0.64–0.68$ is also a K1 IV star (MSR99). The secondary star shows the same spectral class during both outburst and quiescence at those particular phases. Furthermore, there is no convincing evidence for the rapid spectral changes reported by Kraft (1964) and Gallagher & Oinas (1974).

### 3.2 Radial velocity of the secondary star

The continuum was subtracted from individual spectra by masking wavelength regions with major emission lines, fitting a spline with 3 knots and subtracting the fits from the GK Per spectra. For the template, a two-knot spline fit was subtracted. The spectra were binned in velocity to ensure that all covered the same wavelength region and had the same logarithmic dispersion. Emission line regions remained masked out and the absorption lines of GK Per were
cross-correlated (Tonry & Davis 1979) against those of the K1iv template. The template spectrum was broadened by the value of $V_K \sin i$ obtained in Section 3.4 before cross-correlation was carried out. This is an iterative process because to measure $V_K \sin i$ we need to know $K_K$. We carried out three iterations after which the values of $K_K$ and $V_K \sin i$ were stable.

Cross-correlation of the absorption lines of GK Per and the broadened template yielded the radial velocities of the secondary star in the binary, relative to that of the K1iv template used. The radial velocities obtained were then shifted to account for the radial velocity of HD197964; $-6.5 \text{ km s}^{-1}$ (Evans 1979).

We combined these results with previously published radial velocities (Kraft 1964, Crampton et al. 1986, and Reinsch 1994), all obtained during quiescence and carried out a search for periodicities using the Lomb-Scargle algorithm (Scargle 1982). Based on this period search we obtained a new ephemeris for GK Per:

$$T_0(HJD) = 2450022.3465(0.0006) + 1.9968(0.0008)E$$  \hspace{1cm} (1)

We plot the radial velocities folded using this ephemeris in Fig. 3. We did not include the radial velocities measured during outburst because they show increases and decreases steeper than those seen during quiescence (see MSR99 for a comparison between radial velocities measured during quiescence and outburst). Although we do not have an explanation for this behaviour, we decided not to include the outburst data for consistency. The errors on individual measurements previous to this study were assumed to be equal to the mean error of 20 km s$^{-1}$ (Reinsch 1994). We fitted all the combined data with a sinusoid:

$$V = \gamma + K_K \sin 2\pi(\phi - \phi_0)$$  \hspace{1cm} (2)

and plot it with a solid line in Fig. 3. The best fit provides $\gamma = 37.9 \pm 0.3 \text{ km s}^{-1}$, and $K_K = 119.3 \pm 0.6 \text{ km s}^{-1}$. For comparison, we fitted only the radial velocities previous to this work with a circular function obtaining $\gamma = 22.5 \pm 1.7$, and $K_K = 129.0 \pm 2.7 \text{ km s}^{-1}$. The uncertainties of the fit parameters from the combined data are smaller than those of the published data, and the two solutions for $K_K$ are consistent within 3-$\sigma$. We also fitted a sinusoidal to our data only and obtained $\gamma = 40.8 \pm 0.7 \text{ km s}^{-1}$ and $K_K = 120.5 \pm 0.7 \text{ km s}^{-1}$. This value for $K_K$ is consistent within 1-$\sigma$ with that obtained from the combined data. For clarity we plot two orbits in Fig. 3. Our data is plotted only once so it is easier to see how good the fit is for previously published data.

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Figure 2. $\chi^2$ per degree of freedom for each template, each night after applying optimal subtraction to the quiescent data. Note that the $\chi^2$ for the two orbital bins for each night is given. $\phi$ is the orbital phase range of each bin.
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Figure 3. Radial velocity curve obtained by cross-correlating the absorption features of the companion star for the quiescent data sets against suitable templates. The radial velocities measured by Kraft (1964), Crampton et al. (1986), and Reinsch (1994) are also plotted. The solid line is the circular fit to all the data. The dashed line is the fit to the data previous to this study. The dotted line is a fit to the data presented in this paper. Note that although two orbits are plotted, our data is only plotted once for clarity.

We noticed that between orbital phases 0.4 – 0.8 the previously published data shows large deviations from the fit to all the data. This is not surprising considering that the radial velocity measurements were done using different radial velocity standards, of different spectral types in some cases. We mentioned before that Kraft (1964) had noticed spectral changes in the secondary during his observations which could have been caused by irradiation of the secondary. This would explain the deviations from the fit observed. For this reason we have decided to adopt as the best solution the fit to only our data, as it was obtained from a consistent dataset.

A second-order sinusoidal fit has been found in the past to provide a statistically more-significant fit than a circular one. This results from the irradiation of a fraction of the stellar surface (Friend et al. 1990). Such a fit in this case provides no significant eccentricity, verifying we have not detected an irradiated atmosphere in this data.

3.3 Emission line velocities

Crampton et al. (1986) measured the radial velocity semi-amplitudes of the wings of Hβ to be 34 ± 5 km s⁻¹ and combined with their absorption line measurements reported a mass ratio $q (M_K/M_{WD})$ of 0.28, where $M_{WD}$ and $M_K$ are the masses of the primary and secondary star respectively. Although they used only Hβ because the variations in the radial velocities for the other emission lines showed more scatter, it is clear from their Fig. 3 that even the scatter in Hβ gives a very unreliable fit. Adopting the emission line velocity to be the same as the white dwarf requires the assumption that the disc emits axisymmetrically, however there are many examples where this is not the case (Kaitchuck et al. 1994). Axisymmetry can generally be minimised by sampling the velocities of the high velocity line wings only since the inner disk is expected to be more axisymmetric than the outer (Marsh 1988) and we apply this method to GK Per.

We use the double-gaussian convolution technique of Schneider & Young (1980). This convolves each continuum-subtracted, logarithmically-rebinned spectrum with two Gaussians of identical width, FWHM = 200 km s⁻¹, and of separations varying systematically between 400 and 3000 km s⁻¹. The resulting radial velocities were fitted using:

$$V = \gamma - K_{em} \sin 2\pi[\phi - \phi_0]$$

(3)
and the parameters of the fit are plotted in the diagnostic diagram (Shafter, Szkody & Thorstensen 1986) shown in Fig. 3. Faster gas velocities are sampled as the Gaussian separation increases. The value of \( K_{\text{em}} \) depends sensitively on the segment of line that is sampled. Commonly, \( K_{\text{WD}} \) is considered to coincide with \( K_{\text{em}} \) when \( K_{\text{em}} \) is stable over a range of Gaussian separations, i.e. \( 36 \pm 13 \ \text{km s}^{-1} \) in this case, or at the point just before \( \sigma_K/K_{\text{em}} \) increases sharply, i.e. at a Gaussian separation of \( \sim 900 \ \text{km s}^{-1} \) which corresponds to \( \sim 40 \ \text{km s}^{-1} \) in this instance. The actual radial velocities and the fits obtained are plotted in Fig. 3 for measurements taken when the Gaussian separation is \( 900 \ \text{km s}^{-1} \). Another approach to the diagnostic diagram is the light centres method (Marsh 1988) in which we plot the radial velocities measured in velocity space, extrapolate the line of points obtained to the \( K_y \) axis and read off the value. Using this method we find \( K_{\text{em}} \sim 30 \ \text{km s}^{-1} \) for \( \text{H}\beta \) and \( 0 \ \text{km s}^{-1} \) for \( \text{H} \gamma \) (see Fig. 3).

However, both approaches are not particularly justified and we find it impossible to determine \( K_{\text{WD}} \) from these measurements.

### 3.4 Rotational line broadening

Fortunately, if we make the assumption that the secondary stars rotation is tidally-locked to the orbital period we can determine the mass ratio of the binary using only the projected radial velocity semi-amplitude and rotational velocity of the secondary (Section 3.5). This rotational quantity can be measured from the width of the absorption lines. Calculation of the masses of the components of binary systems from \( V_K \sin i \) measurements is considered a more accurate method than measuring the emission line velocities, although Bleach et al. (2000) provide some caveats.

We used the radial velocity fit obtained in Section 3.2 to subtract the orbital velocity of the absorption features.

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**Figure 4.** Diagnostic diagram of the Balmer lines, showing the radial velocity semi-amplitude \( K_{\text{em}} \) and its fractional error, \( \sigma_K/K_{\text{em}} \), as well as the systemic velocity, \( \gamma \), and the zero phase, \( \phi_0 \). The zero phase is relative to the ephemeris derived in Section 3.2. The dashed and dash-dotted lines represent the results obtained after applying the Schneider & Young (1980) method to \( \text{H}\beta \) and \( \text{H}\gamma \) respectively whereas the solid line presents the results for the sum of both lines.

**Figure 5.** The radial velocity curves for \( \text{H}\beta \) and \( \text{H}\gamma \) from measurements with a double Gaussian separation of \( 900 \ \text{km s}^{-1} \).

**Figure 6.** The light centres of the disc deduced from the radial velocity fits of \( \text{H}\beta \) and \( \text{H}\gamma \). The position moves from left to right as the Gaussian separation increases which is equivalent to measuring the velocities closer to the white dwarf. For \( \text{H}\beta \) the Gaussian separations go from 400 to 1400 \( \text{km s}^{-1} \) in 100 \( \text{km s}^{-1} \) steps whereas for \( \text{H}\gamma \) they go from 600 to 1200 \( \text{km s}^{-1} \) in 100 \( \text{km s}^{-1} \) steps. In \( \text{H}\beta \) we have ignored separations above 900 \( \text{km s}^{-1} \) in the extrapolation to the \( K_y \) axis as they start departing from \( K_x=0 \).
in GK Per, and averaged the continuum subtracted spectra for each night. We convolved the K11v template spectrum with a broadening function in which we include a linear limb-darkening coefficient of 0.53 (Gray 1992; van Hamme, 1993), obtaining a series of templates corresponding to \( V_K \sin i = 5\text{–}150 \text{ km s}^{-1} \). Then we applied the same optimal subtraction technique as in Section 3.1 to find which broadened templates best matched the lines in the average spectrum. This technique has been applied by many authors to close binary systems (e.g. Southwell et al., 1995; Marsh et al., 1994; Drew, Jones & Woods, 1993; Friend et al., 1990).

The INT and McDonald spectra yielded \( V_K \sin i = 64.3 \pm 11.0 \text{ km s}^{-1} \), and \( 58.7 \pm 14.2 \text{ km s}^{-1} \) respectively. We adopt \( V_K \sin i = 61.5 \pm 11.8 \text{ km s}^{-1} \), the mean of the values found for the quiescent data.

## 3.5 Stellar masses

From \( K_K = 120.5 \pm 0.7 \text{ km s}^{-1} \), measured in Section 3.2, we can obtain a value for the mass function of white dwarf of 0.362 \( \pm 0.006 \text{ M}_\odot \) using:

\[
\frac{M_{WD} \sin^3 i}{(1+q)^2} = \frac{K_K^3 P}{2 G} \tag{4}
\]

In Section 3.3 we defined the stellar mass ratio \( q \), where

\[
q = \frac{M_2}{M_{WD}} = \frac{K_{WD}}{K_K} \tag{5}
\]

The rotational, \( V_K \sin i \), and radial velocity semi-amplitude, \( K_K \), of the secondary star are related by

\[
V_K \sin i = K_K (1+q) R_{L_K} (q) \tag{6}
\]

where \( R_{L_K} (q) \) is the spherically-averaged Roche lobe radius of the companion star, scaled to the stellar separation. Eggleton (1983) has supplied an analytical approximation for this, correct to \( 1\% \):

\[
R_{L_K} (q) = \frac{0.49 q^{2/3}}{0.6 q^{2/3} + \ln(1+q^{1/3})} \quad 0 < q < \infty \tag{7}
\]

Consequently \( q = 0.55 \pm 0.21 \). This value does not agree with \( q = 0.28 \) measured by combining absorption and emission line velocities by Crampton et al. (1986) and the implied velocity semi-amplitude for the white dwarf is \( K_{WD} = 66.3 \pm 25.3 \text{ km s}^{-1} \).

Substituting \( q \) into Eq. 4, we obtain a lower limit for the mass of the white dwarf of \( M_{WD} = 0.87 \pm 0.24 \text{M}_\odot \). Combining this value with \( q \) we then have a lower limit on \( M_K \) of \( 0.48 \pm 0.32 \text{M}_\odot \).

Reinsch (1949) observed GK Per at orbital phases during which potential eclipses would happen but did not measure any eclipse effects in the line wings. This implies that the white dwarf and inner accretion region are not eclipsed. Eclipses of the compact object and inner accretion regions require an orbital inclination \( i > \cos^{-1} R_{L_K} \), where \( R_{L_K} \) is the spherically-averaged Roche lobe radius of the secondary star, scaled to the stellar separation, defined in Eq. 6.

Assuming a value for \( q = 0.55 \pm 0.21 \), we obtain that eclipses would occur if \( i \) was greater than 73°. Fig. 7 represents the possible values for the mass of the components of the system depending on the mass ratio \( q \) and the inclination \( i \) of the binary. Solutions are presented between the mass function value of 0.362M\(_\odot\), and the Chandrasekhar white dwarf mass M\(_{WD} = 1.44 \text{M}_\odot\). The grey-shaded regions give the possible solutions to the mass of the system (see figure caption for more details).

## 4 CONCLUSION

We have measured the mass ratio of GK Per, \( q = 0.55 \pm 0.21 \), using the width and orbital velocity of absorption lines from the secondary star, and determine lower limits for the stellar masses, \( M_{WD} \geq 0.87 \pm 0.24 \) and \( M_K \geq 0.48 \pm 0.32 \text{M}_\odot \), without using dubious measurements of \( K_{WD} \). The spectral type of the secondary star remains constant over the orbital cycle indicating that the inner face of the companion is not significantly irradiated by accretion radiation.

## ACKNOWLEDGEMENTS

MDS was supported by PPARC grant K46019. PDR acknowledges the support of the Nuffield Foundation via a grant to newly qualified lecturers in science to assist collaborative research. The reduction and analysis of the data were carried out on the Sussex node of the STARLINK network. We thank Tom Marsh for providing his reduction software. The Isaac Newton Telescope is operated on the island of La Palma by the Isaac Newton Group in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias.

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Figure 7. Possible values for $M_K$ and $M_{WD}$ from the calculated mass function. Since the system does not show eclipses, $i$ must be smaller than 73° (limit obtained from the maximum value of $q$ we calculate). The minimum value possible for $M_K$ found from this work is $0.48 \pm 0.32 \, M_\odot$. This implies a minimum value for $M_{WD}$ of $0.87 \pm 0.24 \, M_\odot$. The maximum possible value for $M_{WD}$ is the Chandrasekhar limit (1.44 $M_\odot$). The light grey-shaded region gives the possible mass solutions for GK Per. The limits of this region are the minimum and maximum possible value of $M_{WD}$ and the minimum and maximum values of $q$ found from this work. The dark grey-shaded region includes the limit imposed by the inclination of the system. Several mass ratio curves are also plotted.

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