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IK Peg – a nearby, short-period, Sirius-like system

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ABSTRACT

The system IK Peg has been known to be a binary for over 60 years but the secondary has never been identified. The detection of this system in the British Wide Field Camera All-Sky Survey in the EUV has enabled the secondary to be positively identified as a white dwarf. Fits to EUV survey data, the first *IUE* spectrum, and archival X-ray data indicate that the system contains a high-mass (~ 1 $M_{\odot}$) white dwarf and that it is very close to edge-on. The evolutionary status of this system is discussed; it is shown to be the result of a common-envelope phase, and it is expected to evolve into a Type I supernova or a cataclysmic variable.

Key words: binaries: close – stars: evolution – stars: fundamental parameters – stars: individual: IK Peg – white dwarfs.

1 INTRODUCTION

Known binary systems composed of a degenerate star and a non-degenerate companion are relatively rare. Those that interact (the cataclysmic variables) do so spectacularly, but their precursors are difficult to find because of the contrast between the white dwarf and its considerably brighter companion. For late-type companions (e.g. Feige 24 or V471 Tauri), the separation of the individual spectra is straightforward, but this situation worsens for non-degenerate companions of increasingly early type as the spectra overlap more and more in the blue.

Cowley et al. (1969) identified IK Peg as a marginally metallic-lined A star in a survey of A stars and allocated it A8m: as its spectral type. Cowley & Aikman (1980) showed that IK Peg A is a few tenths of a dex underabundant in manganese, yttrium and iron, and strongly depleted in chromium ([Cr/Fe] ~ -0.97). These abundances are ~ 0.8 dex *below* the expected abundances for Am and evolved Am stars (Kurtz 1976), making the identification with the metallic-lined group very uncertain. Guthrie (1987) found that the calcium abundance in IK Peg A is [Ca/H] $= +0.08$, flatly contradicting the Am classification as these stars are characterized by '...an apparent surface *under*abundance of calcium...' (Conti 1970). The corrected 'age' parameter $\delta' c_0 = -0.026$ for IK Peg A was also derived, making it the youngest of the stars in that sample of 57 Am stars and indicating that it is very close to the main sequence where $\delta' c_0 = 0$.

The earliest (and only) orbit determination for IK Peg (HR 8210, HD 204188) is due to Harper (1927), who found a 21.7-d period and a small but non-zero eccentricity ($e = 0.027$). The same author later revised the period downwards slightly (Harper 1935). To date, this is the only determination of the orbital parameters of this system. From the *same* data, Lucy & Sweeny (1971) estimated that the probability that the orbit is in fact circular ($e = 0$) is ~ 56 per cent, and adjusted the orbital parameters accordingly.

Trimble & Thorne (1969) proposed that a number of single-lined spectroscopic binary systems (including the 6th-magnitude A star IK Peg) have compact companions, based on the values of the known mass functions.

2 IDENTIFYING THE COMPANION

Several pieces of evidence from different spectral regions lead to the conclusion that IK Peg B is a white dwarf. Given that, because of the presence of the A star, a white dwarf companion could never be sighted in the visual region or at longer wavelengths, the three sets of data below comprise the most complete coverage of the white dwarf currently available.

2.1 The extreme ultraviolet

In 1990 November, the British Wide Field Camera (WFC) All-Sky Survey detected a strong source of extreme-ultraviolet radiation at the position RA(2000) $= 21^{h}26^{m}24\overset{s}{.}3$, Dec.(2000) $= +19°23'04''$, with a 99 per cent error circle of 9 arcsec. Cross-correlation with known catalogues identified the Am star IK Peg as the nearest (and by far the brightest) candidate. Although the source is 47.1 arcsec from the predicted epoch J2000 position of IK Peg (Hoffleit 1982), it should be borne in mind that the current pointing accuracy in *some* parts of the WFC sky reconstruction (as opposed to the precision with which a source can be located on an image, as given above) can be as large as ~40 arcsec, and the typical width of the WFC point spread function is 3–4 arcmin.

The source was observed over approximately five days (three in one filter and two in the other) for periods of up to 80 s once every orbit ($P_{orb}\sim96$ min). The count rates were obtained by extracting the count data (source-plus-background and a separate background displaced by approximately 3 s of time along the scan direction) and exposure-time data as time series, summing the number of detected photons and exposure times over all orbital passes, and dividing the two. Subtraction of the source-plus-background and the background data gives the required source counts. This method of extraction was adopted for two reasons. First, the exposure times as a function of clock time should have the functional form of a parabola (equivalent to the chord length across a circular field of view at varying 'impact parameters'), and this provides a consistency check on the performance of the satellite and the software. Secondly, when the source enters and leaves the field of view it follows a very short chord, and this can adversely affect the observed counts if the sky reconstruction is not performed with sufficient accuracy (as may be the case for the preliminary survey data), as well as adding to the photon noise. To circumvent this problem, the first and last four orbits of data (amounting to a total of ~80 s of data) have been removed from the statistics prior to the analysis, giving a minimum exposure time per orbit of approximately 20 s. The errors on the count rates have been derived using the Bayesian statistics of Kraft, Burrows & Nousek (1991), and a 10 per cent (1σ) uncertainty in the WFC calibration (Barstow et al. 1993) has been added in quadrature (after multiplication by 2.57 to correct it to the 99 per cent limit). The count rates are also corrected for the decrease in detector efficiency through the survey by the addition of 27.3 and 12.6 per cent to S1a and S2a count rates respectively. The integrated mean count rates and their 99 per cent limits are given in Table 1.

The appearance of this system in the WFC All-Sky Survey and the very soft filter ratio (strongly implying that the source is a white dwarf) seem to vindicate the prediction of Trimble & Thorne (1969). The possibility of a non-negligible contribution to the observed signal from the A star can be ruled out by comparison with the absence of signals from other well-known and nearby A stars (Wonnacott et al. 1992).

2.2 The *Einstein* HRI observation

A search of the *Einstein* X-ray data base at Leicester University showed that the *Einstein* HRI detected a bright X-ray source in the vicinity of IK Peg. The count rate was high at 0.223 ± 0.016 count s^{-1} for an exposure of 1398.74 s. A re-analysis of these data using Bayesian statistics, with a vignetting correction of 2 per cent and a scattering correction of 3.5 per cent (Seward, private communication) at the very soft wavelengths at which the flux dominates ($\lambda\gtrsim50$ Å), gives a count rate and 99 per cent limits of $0.206^{+0.034}_{-0.031}$ count s^{-1}, in good agreement with the standard reduction. The latter value is used in the following analysis.

This observation is confirmed by the German XRT experiment, also on board the *ROSAT* observatory, which detected a strong X-ray source at RA(2000) = 21^{h}26^{m}26^s.4, Dec.(2000) = +19°22′19″, with a 90 per cent error circle of 4.1 arcsec (Schmitt, private communication). This is offset from the epoch J2000 position by 13.3 arcsec. (Note that the XRT and WFC sky coordinate systems are assembled separately and small offsets between them are not uncommon at the moment.)

2.3 The ultraviolet spectrum

The large values of the WFC and *Einstein* HRI detections suggested that a white dwarf, if responsible, would be an easy target for the *International Ultraviolet Explorer* (*IUE*) cameras (Boggess et al. 1978). One of us (DJS) acquired a low-resolution (~7 Å) *IUE* spectrum of IK Peg in the short-wavelength region ($\lambda\lambda$1150–2000) of the ultraviolet. The exposure time was 1800 s. The spectrum was extracted and calibrated using the IUEDR software (Rees 1987) supplied by Starlink. The spectrum (shown in Fig. 1) is saturated longwards of ~1650 Å because of the presence of the A star in the *IUE* large aperture. Nevertheless, in the region to the blue of this wavelength where the A star flux falls rapidly, the rising continuum of a white dwarf is clearly seen. The low-resolution spectrum of 51 Tau (spectral type F0 V), chosen to fit the non-metallic-lined spectral type of IK Peg and retrieved from the Uniform Low-Dispersion Archive (ULDA) at RAL (Murray 1990), is shown (scaled to IK Peg) for comparison. A comparison of IK Peg with the late-Am star 15 UMa (spectral type kA2hF2mF2 ~ F0 IV–Vm; Gray & Garrison 1989) is identical to this, indicating that the metallicity or otherwise of IK Peg does not affect this result.

3 THE WHITE DWARF PARAMETERS

Breger (1979), using a *ubvyβ* calibration due to Crawford, gives the absolute magnitude of IK Peg A as $M_V=+2.70$. With the observed $m_V=+6.07$ (Hoffleit 1982), this gives a distance of 47.2 pc if there is negligible absorption ($A_V\sim0.0$ mag) and 45.1 pc if $A_V=0.1$ mag. The former is adopted for

Table 1. Passbands, exposure times, count rates and 99 per cent errors from the WFC Sky Survey observations of IK Peg.

Filter	Effective wavelength (Å)[a]	Bandwidth (Å)[a]	Total exposure time (sec)	Mean count-rate (counts/sec)
S1a	100.0	70.8	1460	$0.250^{+0.075}_{-0.071}$
S2a	137.9	88.3	1485	$0.760^{+0.21}_{-0.20}$

[a]Data taken from the *ROSAT* A0-2 document.

the following analysis and will be tested a posteriori. It is expected that this assumption will be validated, as IK Peg is very bright, even though extreme-ultraviolet (EUV) radiation is very sensitive to the hydrogen column.

3.1 The ultraviolet constraint

The spectrum of a distant white dwarf *longward* of 912 Å is relatively insensitive either to the presence of helium or metals in the white-dwarf photosphere or to an absorbing interstellar column of neutral gas. This permits the relationship between the white dwarf's temperature ($T_{\rm eff}$) and its radius ($R_{\rm WD}$) to be found from model fits to the *IUE* data alone. Data at wavelengths longer than 1450 Å were not used because the primary was also in the *IUE* aperture during the observation and may be contributing light at these wavelengths. The region around Lyα was also excluded to remove the geocoronal contamination of this line. The ($T_{\rm eff}$, $R_{\rm WD}$) solution is shown in Fig. 2.

It should, in principle, also be possible to use the width of the Lyα wings and the line depth to restrict the range of possible temperatures of the white dwarf, but a close examination of the profile shows it to be contaminated by 'features' in the wings, particularly to the redward side, as well as by the geocoronal emission in its core. This permits only rather weak limits to be set such that $30\,000 \lesssim T_{\rm eff} \lesssim 70\,000$ K. This lower limit is in concordance with the strong constraint imposed by the sensitivity of the WFC, which only detects white dwarfs if they are hotter than ~ 25 000 K.

3.2 The EUV and X-ray solution

To incorporate the WFC and *Einstein* HRI information, a grid of white dwarf models is required. Those used were based on the pure hydrogen (LTE and hydrogen line-blanketed) $\log g = 8.0$ model atmospheres of Wesemael et al. (1980), extended into the EUV and X-ray region, with corrections for trace helium (Petre, Shipman & Canizares 1986). The models were normalized using the radius–distance ratio. They were convolved with the WFC and HRI instrumental efficiencies and filter passbands to produce a set of solution contours in the temperature–column plane for each value of the helium abundance. The final solution is obtained by iterating between the temperature and radius (adjusting the normalization each time) until the solution contours move less than 0.5 per cent of their current value.

4 RESULTS

Initial tests for possible fits were run with the helium abundance fixed at zero. The orientation of the solution contours for each filter is such that an increase in the amount of helium present in the photosphere would strongly decrease the likelihood of obtaining a solution. Fig. 3 gives the full graphical solution to the fits and the best-fitting parameters are given in Table 2.

Aside from the obvious sources of error, such as photon noise which is accounted for, there are also calibration errors present in the WFC and HRI: those in the WFC have been

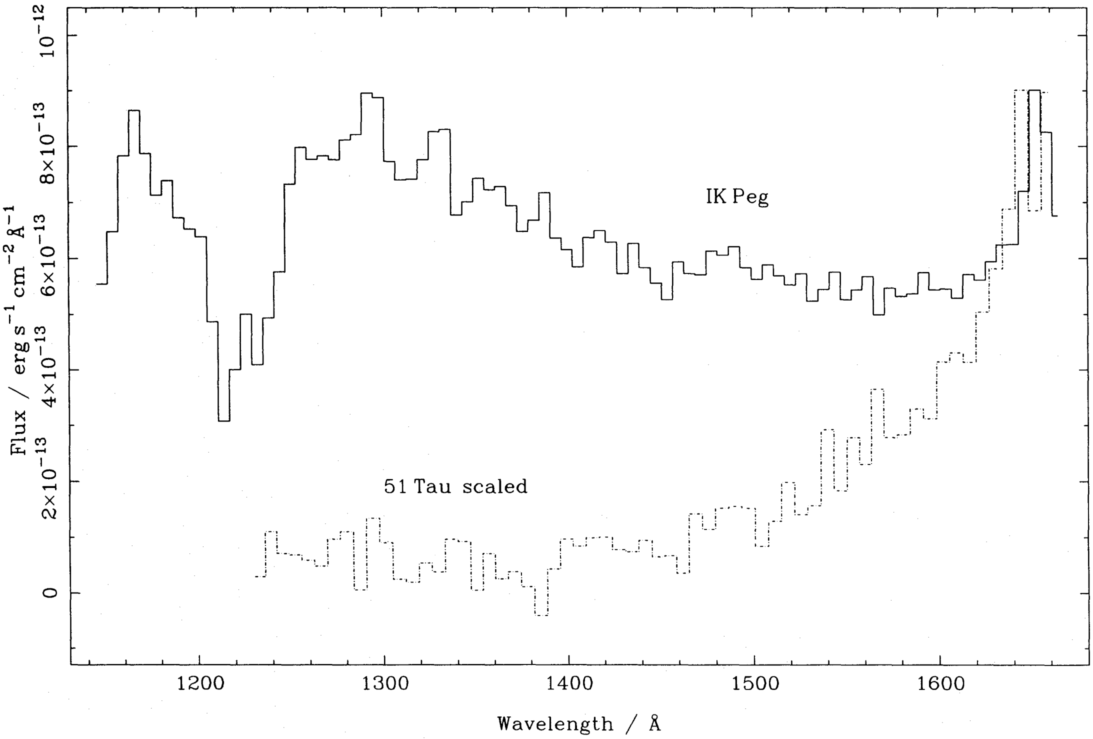

Figure 1. First *IUE* spectrum of IK Peg clearly showing the presence of a white dwarf companion. The F0 V star 51 Tau is also shown to indicate the flux expected from a *single* F0 star. (51 Tau has been scaled to IK Peg at the longest wavelength available.)

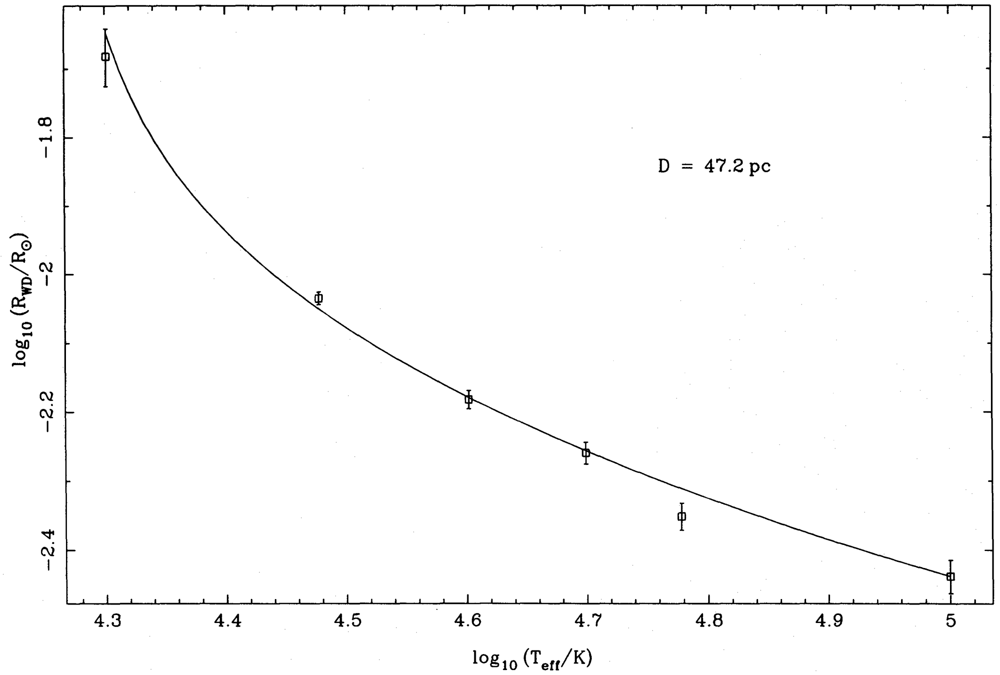

Figure 2. Polynomial fit to the temperature–radius relation derived from model fits to the *IUE* data in Fig. 1 assuming a distance of 47.2 pc. The errors are derived from fits that lie at the limits of the noise in the *IUE* spectrum.

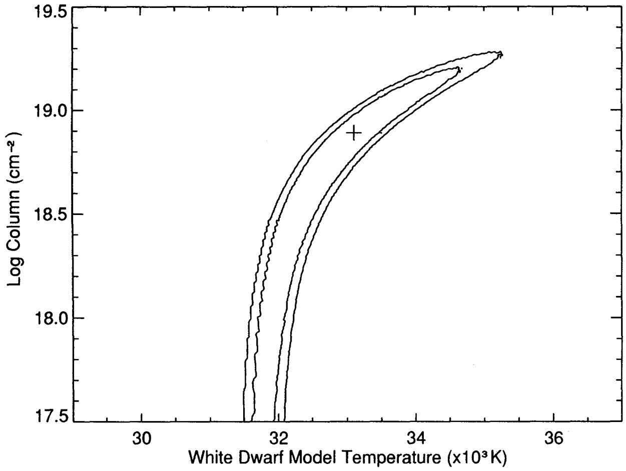

Figure 3. Analysis of the X-ray/EUV photometry of IK Peg showing the formal solution (assuming a distance of 47.2 pc). The solutions are bracketed by their 90 and 99 per cent error contours.

included in the preceding analysis, but the shortest wavelength calibration point for the HRI is at ~66 Å and consequently the effective area for this instrument had to be extrapolated down into the hard X-ray region. Variation of this extrapolation as much as possible within reasonable limits (i.e. such that no unreasonable distortions were introduced into the HRI effective area–energy relation) produced fluctuations in the model fits of the order of 300 K. These extra contributions to the errors are not included in the results of Fig. 3, but should be convolved into error estimates based on this figure.

Table 2. Derived best parameters describing IK Peg B.

T_{eff}	=	33 000 K
$\log g$	=	8.0 (assumed)
R_{WD}	=	$0.0080 \pm 0.0002\,R_\odot$
M_{WD}	=	$0.985 \pm 0.03\,M_\odot$
n(He)/n(H)	<	10^{-5}
$\log(N_H/cm^{-2})$	=	18.90

As a consistency check, the derived column can be converted to a visual absorption using the formulae of Zombeck (1990), giving $A_V = 0.005$ mag, a result entirely consistent with the assumption of zero visual absorption and a distance of 47.2 pc.

5 WHITE DWARF MASS

If one nominally assigns 99 per cent errors of ±500 K to the effective temperature of IK Peg B (equivalent to ±400 K from the widest part of the 99 per cent contour and ±300 K from the HRI calibration uncertainty added in quadrature), the relationship displayed in Fig. 2 yields equivalent errors on the radius of $\pm 0.00013\,R_\odot$. The Hamada–Salpeter zero-temperature mass for a carbon core (Hamada & Salpeter 1961) is then $0.985 \pm 0.03\,M_\odot$. This constitutes quite a strong lower limit, as this relationship underestimates the true mass of white dwarfs by as much as $0.08\,M_\odot$ for very hot white dwarfs. This effect is reduced if the objects are more massive than on average (Bergeron, Saffer & Liebert 1992). The derived mass and radius give $\log g = 8.6$. A comparison of *un*blanketed $\log g = 8.0$ and $\log g = 9.0$ models shows little significant difference and gives values for the derived parameters which agree to well within the quoted errors. The effect of the inclusion of blanketing is more difficult to gauge as there are no blanketed models available in the literature with $\log g > 8.0$. However, large effects *on the continuum* due to the presence of lines redward of several hundred ångströms diminish rapidly at shorter wavelengths. Only the line profiles in the EUV region remain sensitive to $\log g$, whereas the broad-band photometry and continuum slope analyses used here are predominantly sensitive to temperature and abundance effects. It is expected, therefore, that the derived results will *not* be significantly affected by fixing the gravity too low by a factor of 4 during the modelling.

This derived mass is considerably higher than the observed mean for white dwarfs of $\langle M_{\rm WD} \rangle = 0.562 \pm 0.137$ $M_\odot$ (Bergeron et al. 1992). The mass function of IK Peg [$f(M_\odot) = 0.16106$ $M_\odot$; Harper 1927], however, is such that for white dwarf masses near this mean it is *impossible* to reconcile the calculated mass of the primary with its observed spectral type. This lends confidence to the large mass derived for IK Peg B.

6 THE TIME SERIES

The WFC EUV time series of IK Peg is shown in Fig. 4. (The preliminary survey data contain a drop in the S1a count rate near MJD 48210.88 which was due to a fault in the telescope pointing reconstruction and has been corrected for the present analysis.) The errors are 99 per cent probability limits constructed, as before, from the raw count and background data using a Poisson distribution, Bayesian statistics and a slow exponential prior (Kraft et al. 1991). The same correction factors as described in Section 2.1 have been applied.

The best estimate of the systemic parameters, including the primary radius ~ 1.25 $R_\odot$ from Allen (1973) based on the derived mass, yields a maximum eclipse duration of 4.75 h. This should have been clearly observable with the WFC if it had occurred.

The three ephemerides mentioned in Section 1 were used to derive the expected times of secondary conjunction (i.e. the times of the white dwarf eclipse assuming that $i \sim 90°$). The prediction of the revised ephemeris of Harper (1935) lies outside the WFC observation window, but the remaining two (Harper 1927; Lucy & Sweeny 1971) predict conjunctions which are labelled 'H27' and 'LS71' respectively in Fig. 4. It is clear that there is *no* eclipse at either of these times.

There are six possibilities to account for this. First, the accumulation of the quoted period error in the 65 years since the orbit determination may be large enough to move the predicted conjunction times outside the WFC window. This can be rejected, as the slippage amounts to between 0.11 and 0.55 d which is too small to produce the required effect. Secondly, the period may have changed sufficiently to do the same: a total period change of ± 1–4 d in 65 yr yields a value for $d \ln(P)/dt \sim (0.7$–$2.8) \times 10^{-3}$ yr^{-1}. This is an implausibly

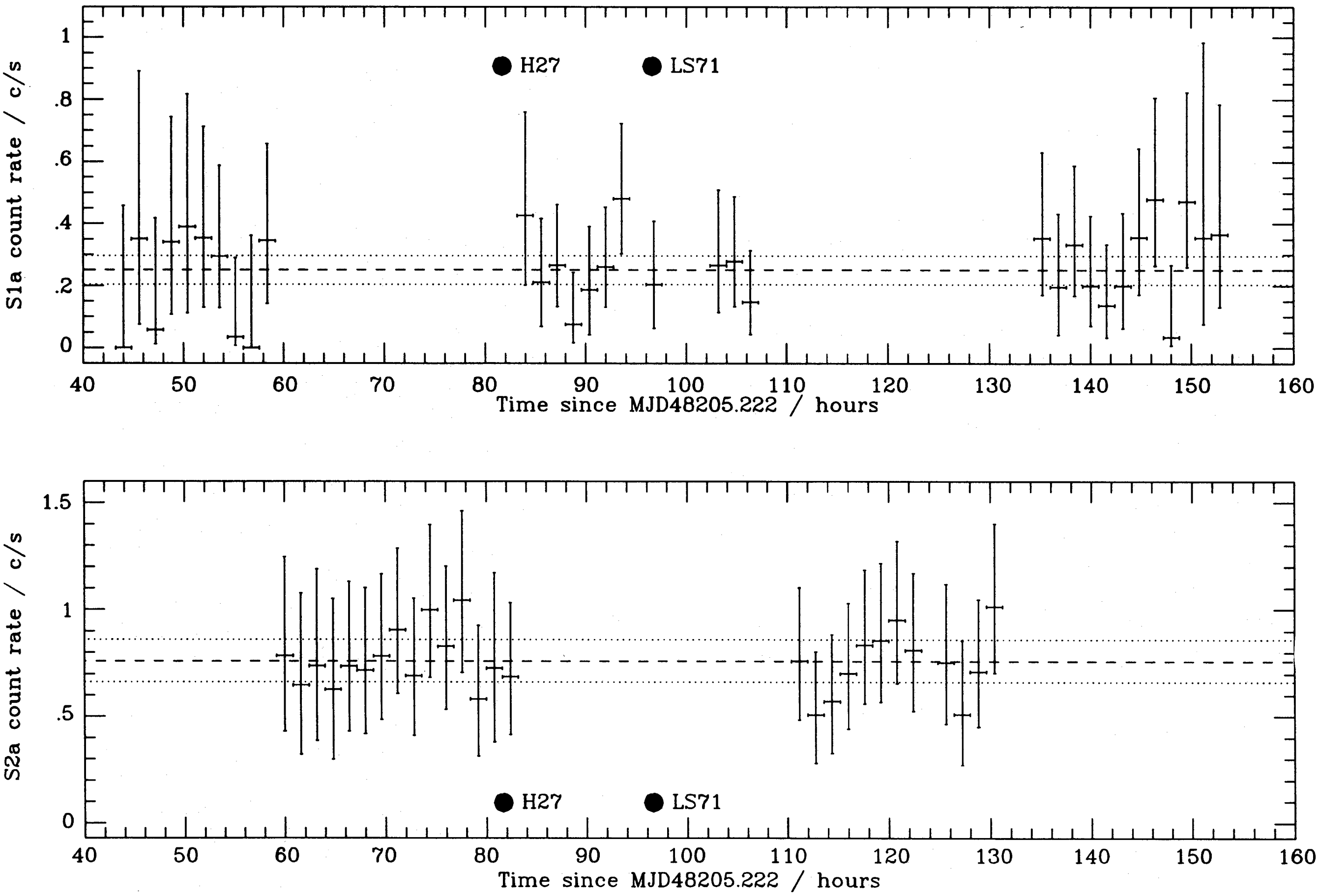

Figure 4. WFC time series showing the positions of the conjunction predictions of Harper (H27) and of Lucy & Sweeny (LS71). There are *no* eclipses and the time series is consistent with a constant count-rate at the 99 per cent level.

large value. The high-rate mass-transfer system β Lyr has $d\ln(P)/dt \sim 2.0 \times 10^{-5}\ \mathrm{yr}^{-1}$ (Plavec 1990), and the magnetically active binaries in the RS CVn class typically have $d\ln(P)/dt$ of the same order of magnitude (Strassmeier et al. 1988). It is hard (if not impossible) to see how such a sizeable period change could have occurred in a binary with a period of a few weeks. Thirdly, apsidal motion can cause shifts in the expected times of eclipse. However, the low eccentricity, long period and central condensation of the white dwarf give an apsidal period (from equations 18.17 and 18.18 of Schwarzschild 1965) in excess of 10^6 yr, which is far too long to have the desired effect in a mere 65 yr. Fourthly, there is still the possibility that Harper's revised orbit is correct. For the moment, without a modern estimate of the phase of this system, it is not possible to reject this hypothesis. The fifth possibility is that the eclipse is sufficiently short to fall *between* two passes of the WFC. Given the stellar parameters derived here and elsewhere, this requires that the inclination of the system lies in the narrow range $88\overset{\circ}{.}37 \lesssim i \lesssim 88\overset{\circ}{.}47$. Along with the requirement that the WFC does, indeed, miss the eclipse, it is not considered that this is a likely set of circumstances. The final option is, of course, that the system does not eclipse. The system cannot be viewed from too high an inclination, however, as the $v \sin i$ of IK Peg A is quite large (83 km s^{-1}; Hoffleit 1982). The metallic-lined phenomenon occurs only in stars below the observational limit of $v \sin i \sim 100$ km s^{-1} (Charbonneau & Michaud 1991 and references therein), and this implies that the system must be seen from an inclination $i \gtrsim 56°$. (This is only a suggestive observation, as the metallic lines may have a different origin from the classical metallicity.) If the white dwarf does *not* eclipse, this places a weak upper limit on the inclination: $i \lesssim 88\overset{\circ}{.}37$.

Given the mass function of Harper (1927), and the mass of the white dwarf from Section 5, the primary mass can be estimated to lie between 0.85 and 1.45 $\mathrm{M}_\odot$ (corresponding to $56° < i < 90°$) if it is still on or near the main sequence. To be consistent with the observed spectral type of the primary, the inclination is, again, required to be very close to 90°, for which Allen (1973) gives a spectral type of F2 V. This is entirely consistent with the nominal type A8m: quoted elsewhere, as the metal lines can substantially modify the spectral distribution. Rotation has no appreciable effect on the classification of stars of this spectral type (Gray & Garrison 1989).

It can be seen from Fig. 4 that the count rates derived from each pass are consistent with the constant rate derived from the whole data stream at the 99 per cent level. There is less than one chance in a hundred, therefore, that the system exhibits variations in the extreme ultraviolet.

The absence of (periodic) changes in the EUV is good evidence either that the white dwarf is non-magnetic or that there is practically no material being swept up by an intrinsic magnetic field. The latter is more likely to be the explanation, as A stars are notorious for their lack of mass loss (Brown et al. 1990; Wonnacott & Kellett 1992 and references therein).

7 DISCUSSION

There are many different evolutionary pathways along which a binary system can evolve, dependent on the initial masses and separation. Most, if not all of the systems with relatively 'short' periods ($P \lesssim 500$–1000 d) have undergone some exchange of mass, conservatively or otherwise, at rates which vary from $\lesssim 10^{-16}\ \mathrm{M}_\odot\ \mathrm{yr}^{-1}$ for white dwarfs to $\sim 10^{-2}\ \mathrm{M}_\odot\ \mathrm{yr}^{-1}$ for the rapid Roche lobe overflow which leads to a common-envelope (CE) system. The understanding of the processes which go on in these evolutionary stages requires that several good candidates which have undergone such changes are found and well understood. Only then are they testable against the theory.

The system IK Peg seems to be a good example of common-envelope evolution, for the following reason. The present mass of the white dwarf provides a lower limit to the mass of the core remnant which was exposed when its precursor ejected its outer layers to form a nebula. The core mass–luminosity relation from Livio & Soker (1984) indicates that the luminosity of the precursor would be of the order of $\log(L/\mathrm{L}_\odot) \sim 4.8$, and hence the star would have a radius of $\sim 840\ \mathrm{R}_\odot$ near the red giant tip. This is much greater than the current size of the binary orbit, and so during this phase the companion (now seen as the late A–early FV star) was well within the supergiant's envelope – this is the classical common-envelope configuration.

The supergiant state demands that the star evolved from an initial mass $M \gtrsim 5\ \mathrm{M}_\odot$. The upper limit for stars to become white dwarfs (as opposed to neutron stars or black holes), however, is 8 $\mathrm{M}_\odot$ (Maeder & Meynet 1989). The precursor to IK Peg B must, therefore, lie in this range. The nuclear lifetime of such an object lies in the range $(4.5\text{–}12.6) \times 10^7$ yr (Maeder & Meynet 1989). The addition of the white dwarf cooling time ($\sim 1.8 \times 10^7$ yr; Koester & Schönberner 1986) brings the current age of the system to $(6.3\text{–}14.4) \times 10^7$ yr, and this constrains the companion to be less massive than 6.0 $\mathrm{M}_\odot$ and 4.3 $\mathrm{M}_\odot$ (for IK Peg B initial masses of 8 and 5 $\mathrm{M}_\odot$ respectively) if it is to be currently unevolved. These are quite stringent upper limits, as IK Peg A is observed to be still very close to the main sequence. The CE phase is, in fact, expected to transfer little or no mass to the companion (Iben 1991) (but may be responsible for the abundance anomalies noted in Section 1). Its initial mass is, therefore, unchanged from its present value of 1.45 $\mathrm{M}_\odot$, in agreement with the aforementioned limits and the initial mass ratio of IK Peg, $q_0 \sim 0.25$.

With this information in hand, the evolution of IK Peg is likely to have proceeded as follows. The system probably originated as a binary composed of a 5- and a 1.5-$\mathrm{M}_\odot$ star with an orbital separation of order 500 solar radii ($P_0 \sim 450$ d). The more massive star evolved into a red supergiant and the system entered a CE phase before shedding the outer envelope and most of the mass of the system as a nebula. This nebula dispersed into invisibility over the next 18×10^6 yr and, assuming a typical expansion velocity of 20 km s^{-1} (Pottasch 1984), it now has a radius of ~ 370 pc and envelops the Earth.

If no other interaction occurs, the time-scale for braking by gravitational radiation is $\tau_{\mathrm{GR}} \sim 1.9 \times 10^9$ yr (Landau & Lifshitz 1962). This implies that the orbital separation will, in all probability, have shrunk dramatically before the main-sequence star becomes a giant ($R \sim 110\ \mathrm{R}_\odot$) sometime in the next 5×10^9 yr ($= \tau_{\mathrm{evol}}$). Two scenarios can ensue. If $\tau_{\mathrm{evol}} < \tau_{\mathrm{GR}}$, the system will enter a second CE phase and emerge as a double degenerate system. This binary configuration will spiral inwards due to further gravitational radiation but, unless a substantial fraction of the current mass is lost in the second CE phase, the system will be too massive to merge within a Hubble time (Iben 1991). If $\tau_{evol} > \tau_{GR}$, the Roche lobe around IK Peg A will eventually contract on to it and initiate mass transfer. The system will have $P \sim 13$ h and $A \sim 4$ $R_\odot$, not unlike a wide cataclysmic variable (CV). A short-lived third CE phase begins when the transferred hydrogen ignites on the white dwarf and mass transfer continues until $M_{MS} < 0.8$ M_{WD}. The system then dispels the CE, becomes a normal CV, and follows the usual evolution for such a system, either to explode as a Type I supernova if the white dwarf can accrete enough mass to reach the Chandrasekhar limit, or to evolve across the period gap, where mass transfer continues until the donor is totally absorbed (Iben 1991). The resulting object will either explode (again as a Type I supernova) or cool to invisibility, dependent on the final mass as before.

Similarities exist between IK Peg and other classes of object, for example, the Ba II stars (e.g. Lambert 1985) where an evolved giant orbits a cool (~15 000 K) white dwarf. The late-type giant (G0–K0II–III) has an excess of s-process elements, notably barium and other lanthanides. These objects probably differ from IK Peg in that their initial separation was sufficiently wide to prevent the rapid mass transfer which leads to a CE stage, and produce instead a milder ($\sim 10^{-7}$–10^{-8} $M_\odot$ yr^{-1}) Algol-type mass transfer. It would be expected that, as in the case of IK Peg, the white dwarf companions should be more massive than 0.6 $M_\odot$.

Sirius, the system that springs most readily to mind when looking for comparisons, would have been (and still is) far too wide ($P = 50.1$ yr) to have interacted significantly, and constitutes a system with an extreme value of the initial separation. Systems which are born much closer together will interact more strongly in their youth, but will almost certainly all pass through a CE stage like IK Peg at some point. The major difference is that they are substantially more likely to merge into a single object.

A more recent discovery, also a product of the WFC All-Sky Survey, is β Crt (Fleming et al. 1991) which is thought to consist of a main-sequence A2 IV star and a white dwarf which is slightly cooler (and hence older) than that in IK Peg. The radial velocity data for this system are sparse at best (comprising 15 measurements over eight years), but the last seven points, covering 19 days, are capable of constraining the period to between 3 d and 1 yr. A modern estimate of the period of β Crt would be most useful. It seems that there are at least two systems of this type within 50 pc of the Sun: this particular evolutionary pathway therefore appears to be quite favoured.

Another system of direct interest to an analysis of IK Peg is V651 Mon. This binary is composed of a very hot (100 000 K) compact object and an A5 V star, and the period is only 16 d. More interesting is that it lies at the centre of the planetary nebula NGC 2346, and is only ~6000 yr old (Walsh 1983). Every indication is that it is a younger version of IK Peg. A comparative analysis, particularly of the elemental abundances, would be of great use in establishing any relationships between these two objects.

8 CONCLUSION

One of the major benefits of the first All-Sky Survey in the EUV is that it will help to extend the range covered by the currently complete sample of WDs (in particular, the DA-types) from ~10 pc (Jahreiß 1987), perhaps out as far as ~100 pc. As demonstrated here, the WFC is particularly good at picking out white dwarfs that are hidden in short-period binary systems and would otherwise remain unseen.

Observations of the nearby binary IK Peg have demonstrated it to be a system composed of a massive white dwarf and a main-sequence star. This is most likely to be the result of a common-envelope phase in a moderately wide binary of intermediate mass. A great deal remains uncertain about this nearby but relatively unstudied system.

Of primary importance is the determination of a modern ephemeris for this system. This would cast light on 60 yr of weak mass loss. A full and detailed abundance analysis of IK Peg A would be of enormous benefit in deciding how much influence the CE phase has had on the main-sequence companion, and whether a companion really does gain or lose a significant amount of mass during the CE phase. Forthcoming EUVE observations of the white dwarf will permit a determination of how contaminated the remnant is, either by material left over from the nebular phase, or by accretion from the interstellar medium or a wind from the A star.

It is clear that the study of these systems, which are of intermediate type between the better known classes of CVs, PNN, post-Algols or double degenerates, can provide tests of the theory of stellar evolution where the objects concerned have evolved rapidly across the HR diagram.

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REFERENCES

Allen C. W., 1973, Astrophysical Quantities. Athlone Press, London
Barstow M. A., Fleming T. A., Finley D. S., Koester D., Diamond C. J., 1993, MNRAS, 260, 631
Bergeron P., Saffer R. A., Liebert J., 1992, ApJ, 394, 228
Boggess A. et al., 1978, Nat, 275, 377
Breger M., 1979, PASP, 91, 5
Brown A., Vealé A., Judge P., Bookbinder J. A., Hubeny I., 1990, ApJ, 331, 220
Charbonneau P., Michaud G., 1991, ApJ, 370, 693
Conti P. S., 1970, PASP, 82, 781

Cowley C. R., Aikman G. C. L., 1980, ApJ, 242, 684
Cowley A., Cowley C., Jaschek H., Jaschek C., 1969, AJ, 74, 375
Fleming T. A., Schmitt J. H. M. M., Barstow M. A., Mittaz J. P. D., 1991, A&A, 246, L47
Gray R. O., Garrison R. F., 1989, ApJS, 69, 301
Guthrie B. N. G., 1987, MNRAS, 226, 361
Hamada T., Salpeter E. E., 1961, ApJ, 134, 683
Harper W. E., 1927, Publ. Dom. Astrophys. Obs., 4, 167
Harper W. E., 1935, Publ. Dom. Astrophys. Obs., 6, 249
Hoffleit D., 1982, Bright Star Catalogue, Yale University Observatory, Connecticut
Iben I., 1991, ApJS, 55, 76
Jahreiß H., 1987, Mem. Soc. Astron. Ital., 358, 53
Koester D., Schönberner D., 1986, A&A, 154, 125
Kraft R. P., Burrows D. N., Nousek J. A., 1991, ApJ, 374, 344
Kurtz D. W., 1976, ApJS, 32, 651
Lambert D. L., 1985, in Jaschek M., Keenan P. C., eds, Cool Stars with Excesses of Heavy Elements. Reidel, Dordrecht, p. 191
Landau L. D., Lifshitz E., 1962, The Classical Theory of Fields. Pergamon Press, London
Livio M., Soker N., 1984, MNRAS, 208, 783
Lucy L. B., Sweeny M. A., 1971, AJ, 76, 544
Maeder A., Meynet G., 1989, A&A, 210, 155
Murray J., 1990, SERC Starlink User Note, No. 20
Petre R., Shipman H. L., Canizares C. R., 1986, ApJ, 304, 356
Plavec M. J., 1990, in İbanoğlu C., ed., NATO ASI 41, Active Close Binaries. Kluwer, Dordrecht
Pottasch S. R., 1984, Astrophys. Space Sci. Library Vol. 107, Planetary Nebulae. Reidel, Dordrecht, p. 294
Rees P. C. T., 1987, SERC Starlink User Note, No. 37
Schwarzschild M., 1965, The Structure and Evolution of Stars. Dover Publications Inc., New York, p. 154
Strassmeier K., Hall D. S., Zeilik M., Nelson E., Eker Z., Fekel F. C., 1988, A&AS, 72, 291
Trimble V. L., Thorne K. S., 1969, ApJ, 156, 1013
Walsh J. R., 1983, MNRAS, 202, 303
Wesemael F., Auer L. H., van Horn H. M., Savedoff M. P., 1980, ApJS, 43, 159
Wonnacott D., Kellett B. J., 1992, in Barstow M. A., ed., White Dwarfs: Advances in Observation and Theory. Kluwer, Dordrecht, in press
Wonnacott D., Kellett B. J., Matthews L., Clayton C., Bromage G. E., Lloyd C., Sumner T. J., Sidher S. D., 1992, MNRAS, 259, 251
Zombeck M. V., 1990, Handbook of Space Astronomy and Astrophysics. Cambridge Univ. Press, Cambridge, p. 103