Spectropolarimetry of the dwarf nova IP Peg

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Abstract

We present spectropolarimetric observations of the eclipsing dwarf nova IP Peg in quiescence. The data show linear polarizations with a mean value of 0.10 ± 0.06 per cent. There are no significant differences between the continuum and line polarizations and no significant variations with wavelength or binary phase. We argue that the measured polarization may be attributed to scattering in the interstellar medium and hence conclude that there is no evidence of polarization intrinsic to IP Peg.

Key words: accretion, accretion discs – polarization – binaries: eclipsing – binaries: spectroscopic – stars: individual: IP Peg – novae, cataclysmic variables.

1 INTRODUCTION

Cataclysmic variables (CVs) are interacting binary systems in which a white dwarf primary accretes material from a red dwarf secondary via an accretion disc (see the review by Wade & Ward 1985). IP Peg is an eclipsing member of the dwarf nova subclass, with an orbital period of 3.8 h (Goranskij et al. 1985) and an outburst cycle of approximately 3 months (Marsh & Horne 1990; Harlaftis et al. 1994). Since its discovery (Lipovetskij & Stepanyan 1981), IP Peg has been the subject of extensive photometric studies (Szkody & Mateo 1986; Wood & Crawford 1986; Wood et al. 1989; Wolf et al. 1993) and spectroscopic studies (Martin, Jones & Smith 1987; Marsh 1988; Hessman 1989; Martin et al. 1989) studies. However, to the best of our knowledge, IP Peg has never been studied in polarized light.

We consider two processes which could produce linear polarization in a dwarf nova. The first is through the asymmetric distribution of electron-scattering material relative to a source of illuminating radiation, and the second is through the presence of magnetic fields. Let us first consider magnetic fields: given the supposedly low field strength of the white dwarf in dwarf novae (Wickramasinghe, Wu & Ferrario 1991), polarization due to accreting material flowing along magnetic field lines, as is observed in magnetic CVs (e.g. Wu & Chattamugam 1989), is unlikely to occur or be detectable in dwarf novae. Horne & Saar (1991) have, however, suggested that dynamo-generated magnetic fields in the accretion disc may be responsible for (part of) the emission line flux from quiescent accretion discs; these might then result in measurable polarization, depending on the geometry of the field. A more likely source of polarization is through the above-mentioned scattering process, since dwarf novae are clearly asymmetric (compared to, say, isolated stars). For example, if a bipolar accretion disc wind illuminated by disc emission were present one might expect to detect linear polarization (Rutten & Dhillon 1992). Given their lack of circular symmetry, inclined accretion discs, gas streams and secondary stars filling their Roche lobes might be expected to produce measurable linear polarization (see Cheng et al. 1988). One might also expect the level of linear polarization to vary in a dwarf nova. This might be due to the changing orientation due to orbital motion (Rudy & Kemp 1978), the changing structure of the disc due to outbursts (Cheng & Lin 1992), or, in eclipsing systems, the obscuration of the central parts of the disc by the secondary (Cheng et al. 1988) or the destruction of the circular symmetry of the secondary’s limb by the occultation by the disc (see Dolan 1986). There are very few linear polarimetric studies of dwarf novae in the literature. Perhaps the two most detailed studies of recent years were performed by Szkody, Michalsky & Stokes (1982) and Cropper (1986), although neither of them observed IP Peg. Szkody et al. (1982) found very low polarization levels, of a few tenths of a per cent, which did not vary with outburst cycle. Much of this polarization could be attributed to interstellar absorption, although Szkody et al. (1982) found a dependence on wavelength and orbital phase which suggested that at least part of the measured polarization was intrinsic. All of these studies used broad-band filtered or unfiltered polarization measurements, which do not allow one to separate the contributions from spectral lines and the continuum. This is unfortunate, since strongly polarized line emission might be diluted by any unpolarized continuum in broad-band polarimetry, making it difficult to determine whether an intrinsic component is present, especially if interstellar polarization is dominant. Spectro-
polarimetry permits a separation of the line and continuum regions, providing a more accurate way of studying polarization and its variability. In this paper we present such a study of IP Peg.

2 OBSERVATIONS AND DATA REDUCTION

IP Peg was observed on the night of 1993 July 26–27 with the 4.2-m William Herschel Telescope on La Palma. The blue arm of the ISIS triple spectrograph (see Carter et al. 1993) was used, equipped with a thinned Tektronix CCD detector. A 158 line mm$^{-1}$ grating gave a dispersion of 2.88 Å pixel$^{-1}$ and a wavelength range of λ 3800–6700 Å. The ISIS spectrograph is fitted with polarization optics for conducting linear spectropolarimetry (see Tinbergen & Rutten 1992). The optics consist of a half-wave plate located above the slit and a calcite plate analyser immediately below the slit. The calcite plate produces two slit images: the ordinary (o) and the extraordinary (e) rays, which are slightly offset in the spatial direction. A comb-type dekker mask with 4-arcsec apertures was used to allow simultaneous detection of object and sky without confusion between the o and e rays from different parts of the slit.

One component of the polarization vector of the incoming beam (e.g. the Stokes Q parameter in some instrumental reference frame) is converted to a contrast in the intensities of the o and e ray spectra. Since both the o and e spectra are taken under exactly the same conditions, the ratio of the normally extracted spectra is independent of sky transparency, seeing, image wander and variations in shutter timing. In order to account for differences in the response of the spectrograph and the detector to the polarized o and e rays, a second exposure with the half-wave plate rotated by 45° is required. This offset results in a rotation of the incoming polarization vector by 90°, which inverts the contrast between the o and e rays; the spectrograph response is then removed by taking the ratio of these two exposures. To measure the full polarization vector (i.e. both Stokes Q and U), a second set of exposures is required with the half-wave plate set at 22.5° and 67.5°. Sky is removed by subtracting the mean spectrum of the sky regions on either side of the object spectra. This, to first order, also eliminates the influence of scattered light from the object (see Tinbergen & Rutten 1992 for details). Comparison arc spectra were taken between each set of polarization measurements in order to calibrate the wavelength scale and instrumental flexure.

The next step in the data reduction is to remove the instrumental zero-point from the polarization spectrum. This was achieved by observing the unpolarized calibration star HD 154892 (Turnshek et al. 1990). We found no evidence for instrumental polarization at a level of greater than 0.01 per cent and therefore did not apply any correction. Similarly, by observing a calibration lamp through a Polaroid polarization filter we determined the efficiency of the system to be greater than 99 per cent and therefore applied no correction to the degree-of-polarization scale. As an independent verification of the above, we observed the polarized standard star HD 154445 (Hsu & Breger 1982) and found its measured polarization and wavelength dependence to be in excellent agreement with its tabulated values. We are therefore confident of the quality of the observational and reduction techniques.

<table>
<thead>
<tr>
<th>HWP Exposure UTC</th>
<th>UTC Phase</th>
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</tr>
<tr>
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<tr>
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<tr>
<td>4 4x600 04:09 04:53</td>
<td>22630.305 22630.477</td>
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</table>

The upper panel of Fig. 1 displays the summed spectrum of IP Peg. Note that the eclipse spectrum has not been included in the sum and the orbital motion has not been removed. No corrections for instrumental response and atmospheric losses have been made and therefore the shape and level of the continuum remain uncalibrated. The summed spectrum exhibits similar features to the one displayed by Marsh (1988) – strong, double-peaked Balmer, He i, Ca ii and Fe ii emission lines from the accretion disc. As observed by Marsh (1988), the Balmer lines exhibit a ~10 per cent blue–red asymmetry in the peaks due to the bright spot. The spectrum also exhibits absorption features of Na i and TiO, believed to originate from the red dwarf component (see Martin et al. 1987).

The lower panel of Fig. 1 displays the mean linear polarization spectrum of IP Peg, calculated from the same data set as was used to produce the summed spectrum displayed in the upper panel. As stated above, the eclipse has not been included in this mean. This is because there is a great deal of spurious polarization induced by the extremely low signal in the blue during eclipse. Two curves are presented in Fig. 1 and care should be taken in their interpretation. The solid curve has been binned to yield identical errors of 0.3 per cent in each interval. This ensures that the major emission lines each occupy at least one bin. By taking into account the large error bars, this curve indicates that there are no significant differences between the line and continuum polarizations and there are no gross variations with wavelength. Since the noise associated with the normalized Stokes parameters always enhances the polarization values, however, the mean level is biased towards a higher value [see Clarke & Stewart (1986) for a review of the statistics of polarization measurement]. To determine the mean level we therefore binned the data to yield a single bin spanning the entire wavelength range (with a polarization error of 0.06 per cent). The result is shown by the dotted curve in Fig. 1, which gives a mean polarization for IP Peg in this wavelength range of
0.10 ± 0.06 per cent. To within the measurement errors, the polarization values of the individual half-wave plate cycles are consistent with this value, and hence there is no evidence for any dependence on binary phase.

4 DISCUSSION

The results of our observations show that there is evidence for only very low levels (if any) of polarization in the spectrum of IP Peg. The question naturally arises: is the polarization we measure intrinsic to the system? It is well known that interstellar absorption by dust grains aligned in the galactic magnetic field causes linear polarization, and several techniques for estimating the fraction of the measured polarization due to this interstellar effect have been developed (see McLean & Clarke 1979). To estimate this fraction in our observations of IP Peg, we retrieved low-resolution International Ultraviolet Explorer (IUE) spectra from the archive in order to inspect the broad and shallow interstellar absorption bands around 2200 Å. We followed the method of Verbunt (1987) and applied the wavelength-dependent UV extinction correction of Seaton (1979) for a number of colour excess $E(B-V)$ values. The spectra were judged by eye for the presence of the absorption feature. Although the IUE spectra available to us are not of sufficient quality to estimate $E(B-V)$ accurately, they are at least good enough to signal the presence of substantial interstellar absorption; we find that IP Peg provides only marginal evidence for interstellar absorption and we adopt a value for $E(B-V)$ of between 0.0 and 0.1. This value is in agreement with the estimate provided by calculating $E(B-V)$ from the distance of IP Peg (150 pc; Marsh 1988), which gives $E(B-V) < 0.05$ (Scheffler 1967). The polarization survey by Serkowski, Mathewson & Ford (1975) provides an estimate of the maximum level of interstellar polarization as a function of colour excess: $P_{\text{max}} < 9.0 E(B-V)$. For IP Peg, this yields $P_{\text{max}} = 0.45$ per cent (assuming $E(B-V) = 0.05$), which is sufficiently high to explain some, if not all, of the observed polarization. From the dependence of interstellar polarization on wavelength (Serkowski et al. 1975), the polarizations at 3900 Å and 6000 Å are expected to be approximately 87 and 96 per cent, respectively, of $P_{\text{max}}$ at ~5500 Å, which is in general agreement with the observed data (see Fig. 1). In conjunction with the fact that there is no evidence of orbital variability in the polarization signal, the above arguments lead us to conclude that the low level of linear polarization we have measured in IP Peg is consistent with the expected behaviour of the interstellar medium and hence that there is no evidence for any polarized emission intrinsic to IP Peg.

This result is in agreement with broad-band polarimetric observations of other dwarf novae (e.g. Szkody et al. 1982),
which show linear polarization at a similarly low level. The lack of intrinsic polarization in these systems does not, however, mean that the polarization mechanisms outlined in Section 1 do not operate - it is possible that other mechanisms act to weaken the measured signal. For example, magnetic fields may still be important in the disc of IP Peg (Horne & Saar 1991), but one might expect a variety of field-line orientations and hence no (or little) net linear polarization. Similarly, photons may still be electron-scattered by asymmetrically distributed material in IP Peg, but the action of small-scale variations from a smooth geometry, multiple scatterings and the fact that scattering is not the only source of opacity in CVs, will all act to weaken the polarization signal (see Cheng et al. 1988). Finally, it should be noted that our observations do not completely rule out the possibility of variable polarization from IP Peg, since the observational technique we employed to measure linear spectropolarimetry smears out the polarization signal due to the long time interval required to make a measurement (approximately 40 min; see Table 1).

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