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Long term disc variability in the Be star *o* Andromedae

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Abstract. We present 18 years of high resolution and S/N Hα spectroscopy of the Be shell star *o* And, obtained between 1985–2002. Spectra taken during late 1985 show a pure photospheric profile, with disc re-formation commencing in 1986; a process that is found to occur over long timescales ($\sim 10^3$ days). Analysis of the evolution of the properties of the Hα shell profile suggest that the disc kinematics are dominated by rotational motion. It has been shown that disc loss in *o* And occurs "inside out"; we find that the disc also appears to be rebuilt in a similar manner, with disc material gradually diffusing to larger radii. The long timescale for changes in the bulk properties of the disc, domination of rotational over radial velocities and manner of disc loss and formation are all consistent with the predictions of the viscous decretion disc model for Be star discs.

Key words. stars: circumstellar matter – stars: early type – stars: individual: *o* Andromedae

1. Introduction

While Oe/Be stars – defined as non supergiant OB stars which have at one time shown emission lines in their spectrum – have been intensively observed for over a century currently no consensus exists as to the cause of the phenomenon. Observationally, Be stars are found to have a fast polar wind with terminal velocities of $\sim$1–2000 km s^{-1}, similar to the radiation driven winds of normal early type stars. However a pronounced near-IR – radio continuum excess and rich recombination line spectrum are also observed. It is assumed that these arise in a dense equatorially concentrated disc, a hypothesis confirmed by optical and radio interferometric observations (Quirrenbach et al. 1994; Stee et al. 1995; Dougherty & Taylor 1992); however to date no complete theory for the formation and dynamics of such discs exists.

One promising avenue of investigation is the treatment of the equatorial disc as a viscous decretion disc, with angular momentum and material transported radially outwards. This idea was first proposed by Lee et al. (1991) and has subsequently been explored by Porter (1999) and Okazaki (2001). Such a model appears promising in that it naturally explains the small outflow velocity and quasi-Keplerian nature of the equatorial disc (e.g. Dachs et al. 1986; Hanuschik 1989, 1996) and can also naturally accommodate the cyclical variability observed in the line profiles of some Be stars as the precession of a one armed density wave within the disc (Okazaki 1997).

However the weakness of the viscous disc model at present is that while it describes the dynamics of the circumstellar disc the input of angular momentum at the stellar surface required to support the disc is treated on an ad hoc basis. Several mechanisms (e.g. magnetic fields, non-radial pulsations) have been suggested to supply the required angular momentum to the disc. However, since a few Be stars show extreme photometric and spectroscopic variability, reflecting disc loss and re-formation, the physical mechanism for the supply of angular momentum is apparently transient. Recently, observations of μ Cen by Rivinius et al. (1998a) have revealed a number of "outbursts", characterised by rapid variability in the emission line profiles. They interpret these as rapid discrete mass ejection events, possibly initiated by non radial pulsations (Rivinius et al. 1998b) – potentially providing a mechanism for the transfer of both angular momentum and material from star to disc.

Given that under the viscous disc model, changes in the input of angular momentum significantly affect the evolution of the radial density gradient, it is to be hoped that by modeling the emission from the disc over time it will be possible to not only test the hypothesis but also infer the properties of the mechanism by which angular momentum is supplied. Since the disc is assumed to vary on the viscous timescale – which can be of the order of 10^2–10^3 days – long term monitoring of Be stars is essential. Here we present the results of such a campaign on the Be shell star *o* And, and a *qualitative* interpretation of the results under the viscous disc paradigm. Comparison of the dataset to a detailed hydrodynamical simulation of the circumstellar disc will reported in a future paper (Porter et al., in prep.).

1.1. The Be shell star *o* And

o And (HD 217675, HR 8762, HIP 113726) is a well studied, bright ($V \sim 3.6$ m) Be star of relatively late spectral type (B6IIIpe) that has shown shell-phases. Shell phases,

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characterised by the presence of deep central absorption features in the emission lines present have been observed in a subset of of ~10–20% of classical Be stars (Hanuschik 1996; Porter 1996 and refs. therein). These are understood as being due to obscuration of the stellar disc by the circumstellar disc in systems seen ~equator on. Since this implies that *o* And is observed at high inclination, the observed $v \sin i = 200$ km s^{-1} (Abt et al. 2002) implies that it rotates at ~50 per cent of its critical velocity (Porter 1996). We note however, that Abt et al. (2002) infer the projected rotational velocity using the FWHM of the He I 4471 Å and Mg II 4481 Å lines, both of which may be subject to perturbation from circumstellar material during a Be shell phases.

o And belongs to a quadruple stellar system (Hill et al. 1988). Okazaki & Negueruela (2001) have demonstrated that for the Be/X-ray binary systems the presence of the neutron star in a close eccentric orbit can significantly truncate the circumstellar disc via tidal interaction. However the closest component in the system orbits *o* And in 4 yrs, so we have confidence that the circumstellar disc will evolve essentially unperturbed by any other system components.

Despite the apparent lack of interaction with other system components, the photometric lightcurve of *o* And shows considerable variability; indeed, it was the first of the short period variable Be stars identified (~1.57 days; Guthnick 1941). This period was also identified in the long period photometry of Harmanec (1983; see also Pavlovski et al. 1997), and the *Hipparcos* dataset (Hubert & Floquet 1998; Percy et al. 2002), suggesting that it is stable over long periods (although with an evolution in amplitude). Explanations in terms of rotational modulation and pulsations have been advanced but as yet no consensus exists on the origin of the short term variability (see for example Sareyan et al. 1998).

Longer term (~3000 days) variability is also observed in the lightcurve (Harmanec 1983) which is accompanied with changes in the colour of the system (Pavlovski et al. 1997). Similar variability in other Be stars is attributed to a variable contribution to the continuum from the circumstellar envelope; indeed Harmanec (1984) claim a similar origin for the variability in this system. Additional evidence for bulk variability in the circumstellar envelope is provided by observations of the H I, He I and metallic lines, which have shown considerable variability over the last century (summarised in Gulliver et al. 1980; GBP80).

Of particular interest are the number of transitions between B-normal→B-shell→Be-shell phases (GBP80). The last of the episodes documented by GBP80 occurred between 1973–78. While observations during this period are sparse – indeed both the disc formation and the critical final disc loss phases are unsampled in Hα, sufficient data existed for Poeckert et al. (1982; PGM82) to construct a model to follow the physical parameter of the disc during its loss; the conclusions drawn from this will be returned to in Sect. 3. Subsequent shell episodes have been reported during 1983, 1988 (Sareyan et al. 1992; note the dates given are for the reported maxima of each episode rather than the onset) and 1994 (Harmanec 1994; although it is clear from the data presented in Sect. 2 that this is a continuation of the shell episode that began in 1987).

2. Data reduction and spectra

Observations of the Hα line in *o* And have been compiled over a 18 year period between 1985 August–2002 July, from the 2.6 m telescope of the Crimean Astrophysical Observatory, Ukraine with the GEC P8600 CCD array (pre-1995) and the EEV CCD array (post-1995), mounted at the Coudé focus. The observations were performed in the first and second orders of a diffraction grating with reciprocal dispersions of 6 and 3 Å/mm and corresponding spectral resolutions of 25–30 000. A single exposure typically lasted between 5–30 mins and resulted in a S/N ratio of 100–200 over the 60 Å long spectrum. Since *o* And is a late type B star, given the small wavelength range of our spectra we were not able to determine the continuum level free of contamination from the photospheric profile. Consequently line parameters were measured against the pseudo-continuum ~14 Å (~650 km s^{-1}) from the Hα line core for all spectra; sufficiently far that contamination from the emission components of the line profile are negligible.

The equivalent widths (EWs) were measured for the whole line profile and no attempt was made to deconvolve the profile into emission and absorption components. The strength of the central absorption, is also measured against this continuum; in Fig. 3 we plot the residual (1–$I_{\rm o}$) intensity. Finally the width of the central absorption feature and the positions of the emission peaks were measured directly from the spectra; Gaussian fits to the profiles were not attempted since there is no a priori physical reason for assuming that components of the line profile should correspond to Gaussian profiles.

A subset (~30 per cent) of the spectra illustrating the phase changes and evolution of the circumstellar disc of *o* And are plotted in Figs. 1, 2 while in Fig. 3 we present a summary of the evolution of the properties of the complete dataset.

We also performed limited linear-polarization studies of *o* And (Fig. 3) with the 1.25 m Crimean Astrophyical Observatory telescope using the five-channel *UBVRI* photometer/polarimeter of Piirola (Korhonen et al. 1983). Since *o* And is visually bright ($V \sim 3.5$ mag) we used a neutral density filter to reduce the flux from the star. Standard data reduction procedures were followed, which included correction for instrumental polarization and reduction of the zero point of the position angle to the standard coordinate system, using standard stars from list of Serkowski (1974) and Hsu & Breger (1982). These results, along with the more extensive dataset of McDavid (1999) are presented in Fig. 3.

3. Discussion

Figures 1–3 clearly indicate that the circumstellar disc has varied significantly between 1985 August–2002 July, with the principal variations occurring over long (~10^3 day) timescales. For the purposes of the discussion we define 3 different phases for *o* And, based on the morphology of the Hα line: (i) B-normal when no trace of line emission or additional absorption are present (i.e. a pure photospheric profile is present), (ii) B-shell when additional absorption is present at line centre but no excess emission is present and (iii) Be-shell when both additional absorption and excess emission in the line wings is

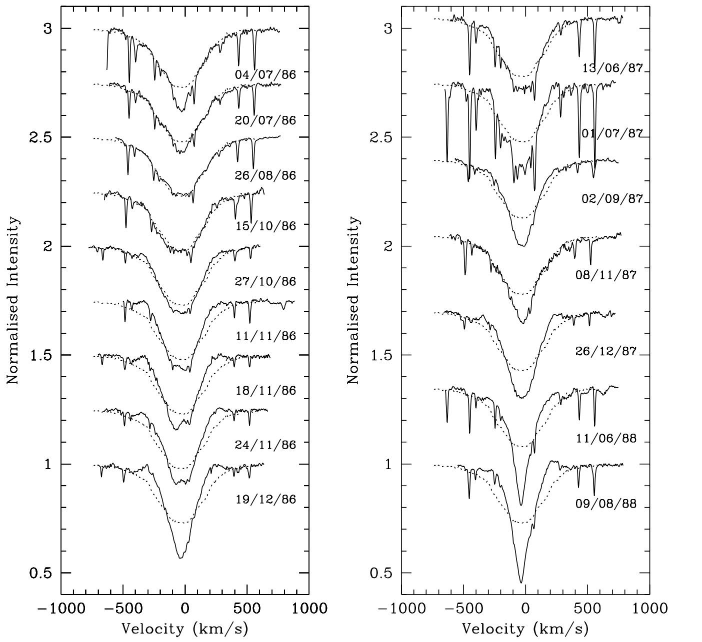

Fig. 1. Representative Hα profiles. Left panel: 1986 July–December, showing the transition from B-normal to B/Be-shell phases. Right panel: 1987 June–1988 August, showing the transition from B-shell to Be-shell phases after an unobserved Be-shell to B-shell transition during the first half of 1997. Note the superposition of the mean pure photospheric profile derived from the 5 spectra obtained during the 1985 B-normal phase (dotted line) on the profiles presented.

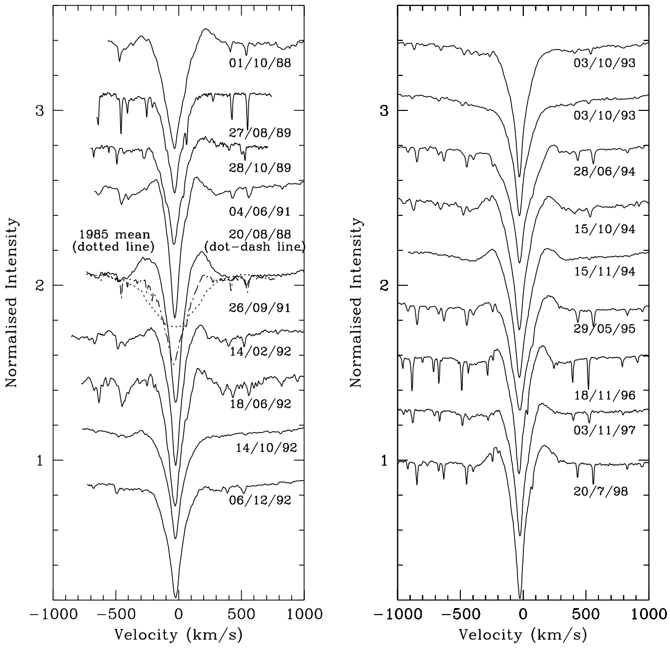

Fig. 2. Representative Hα profiles. Left panel: 1988 October–1992 December, showing continuous disc growth until 1991 September 26. The pure photospheric profile obtained during disc loss (1985 mean; dotted line) and a second profile obtained during disc re-formation (1988 August 20; dot-dashed line) have been over-plotted on the spectrum obtained on 1991 September 26 to illustrate the effects of disc growth; an increase in emission in the line wings and in the strength of the central absorption feature.

observed. These definitions allow us to subdivide the long term spectral behaviour of *o* And into 3 distinct periods.

During the 104 days of observations between 1985 August 24–December 8 the Hα profile appears to be purely photospheric in origin, implying a B normal phase (Sect. 3.1.1). Following this, during the 770 days between 1986 July 4–1988 September 9, *o* And underwent a transition from B-normal to Be-shell (via B-shell) phase (Sect. 3.1.2). During the remaining ~4350 day period of observations *o* And was found to be continually in a Be-shell phase, signifying the continuous presence of circumstellar material (Sect. 3.1.3). We summarise this behaviour in Table 1.

3.1. Hα variability

3.1.1. B-normal phase: 1985

During the 1985 observing season *o* And was observed 5 times between August 24 and December 12. Throughout this period the Hα profile was stable, with no evidence for excess emission or absorption in the line core; a mean of the 5 spectra is overplotted (dotted lines) in Fig. 1. To determine if these spectra corresponded to a B-normal phase, fits to broadened Kurucz models were made. The results of these fits – $T_{\rm eff}$ = 15 kK, $\log g$ = 3.5 and $V \sin i$ = 225 km s^{-1} – were found to be consistent with the stellar parameters reported in Sect. 1.1 for *o* And. We therefore conclude that the Hα profile during 1985 is consistent with a purely photospheric origin[1]. To test this conclusion Kurucz fits were also made to spectra obtained between 1986–87 that showed no evidence for excess emission. It was found that the best fit parameters from the spectra obtained in 1986–87 were not consistent with the expectations of a purely photospheric profile based on the stellar parameters of *o* And. In each case the results imply the presence of a more extended, diffuse atmosphere (with mean results of $T_{\rm eff}$ = 12 kK, log g = 2.0 and $V \sin i$ = 100 km s^{-1} for the spectra obtained during this period). We attribute this effect to the presence of circumstellar material contaminating the photospheric profile at this time and *not* to a variation in stellar parameters (see below).

3.1.2. Phase changes: 1986–1988

Figures 1 and 3 plot the evolution of the Hα profile between 1986–88, which we find to be the genesis of the current Be-shell phase. The phase transition is first apparent in the spectra obtained between 1986 July–August, where we find a strengthening in the central absorption component of the line profile, indicating that *o* And has entered a B-shell like phase. As described above, while we find no evidence for excess emission

[1] Note that we do not try to determine the phyiscal properties of *o* And from these data since Hα is a poor choice of transition for this goal; rather we have the more limited goal of simply demonstrating consistency between the profiles at this time and the expectations for a photospheric profile uncontaminated by circumstellar material.

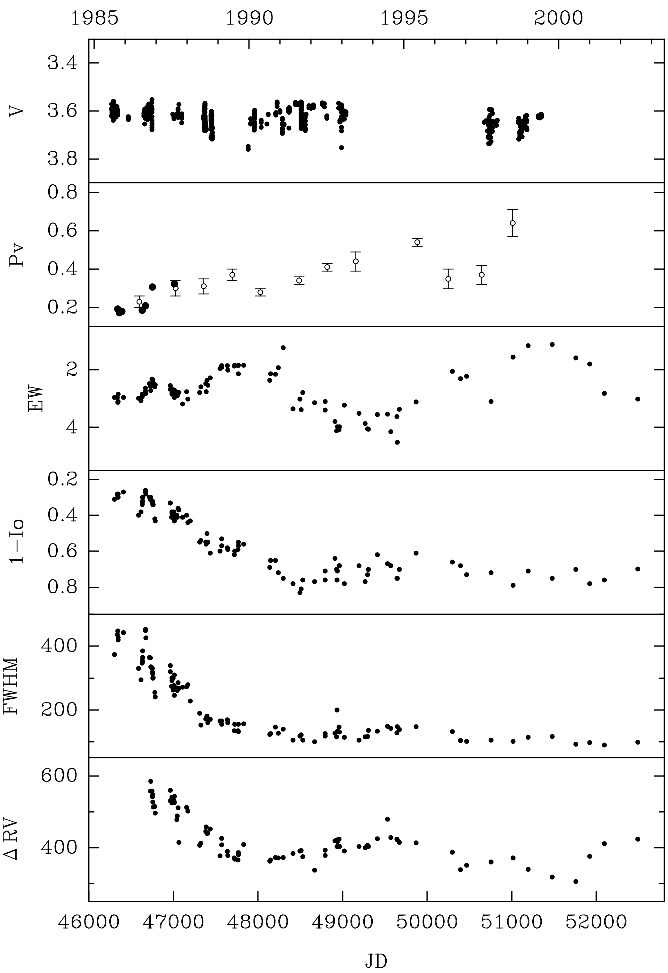

Fig. 3. Summary of line parameters 1985–2002. Top panel: *V* band photometric lightcurve. Second panel: *V* band continuum polarisation (closed symbols: Crimean data, open symbols:data from McDavid 1999). Third panel: Hα EW (Å). Fourth panel: Intensity of the central absorption feature normalised to the continuum level. Fifth panel: FWHM of the central absorption feature (km s^{-1}). Sixth panel: Peak separation (km s^{-1}).

Table 1. Summary of the timing of the phase changes observed for *o* And following the definitions in Sect. 3.0. The discontinuities in the start and end dates of consecutive phases are due to lack of data during these periods. Note that between 26/12/87–11/6/88 there is some evidence for weak emission in the line wings; hence the B/Be-shell phase classification.

Date	Phase
24/8/85–/12/85	B normal
4/7/86–11/11/86	B shell
11/11/86–19/12/86	Be shell
13/6/87–8/11/87	B shell
26/12/87–11/6/88	B/Be shell
9/8/88–4/7/00	Be shell

or an increase in continuum polarisation, Kurucz fits to the profiles imply a more extended atmosphere at this time, which we attribute to the presence of a circumstellar envelope with a small spatial extent. Subsequently, between 1986 October–December, weak emission is observed in the line wings,

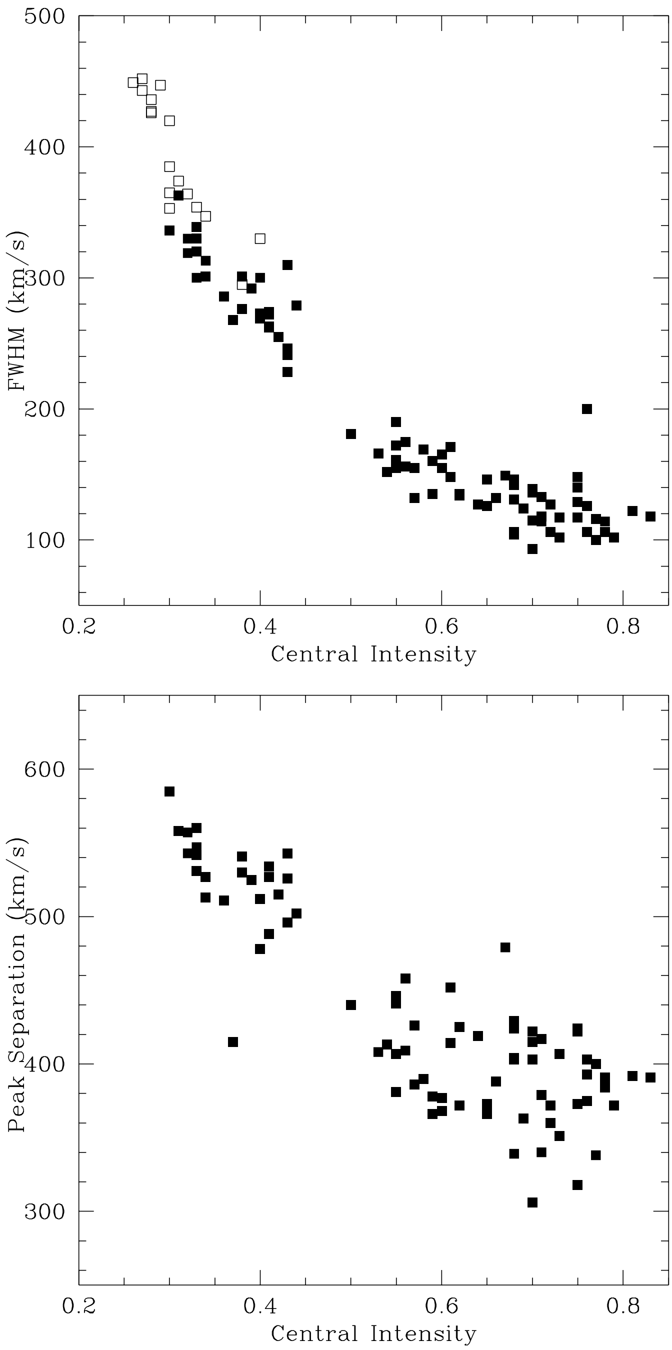

Fig. 4. Plot of the intensity of the central absorption trough of the Hα profile against the FWHM of the feature (top panel) and peak separation (bottom panel). Open squares correspond to data obtained prior to 1986 October (i.e. during disc loss), filled squares to data taken thereafter (i.e. during disc re-formation).

followed by an increase in continuum polarisation. Both observations are consistent with the continued injection of material into the circumstellar environment. Since PGM82 find that the inner regions of the disc ($<4\ R_*$) are responsible for polarisation, the observed increase in *V* band continuum polarisation reinforces the suposition of a relatively compact envelope at this time.

Throughout this initial ~770 day period the Hα profile appears unstable, with apparently random fluctuations in the strength of the emission and central absorption components.

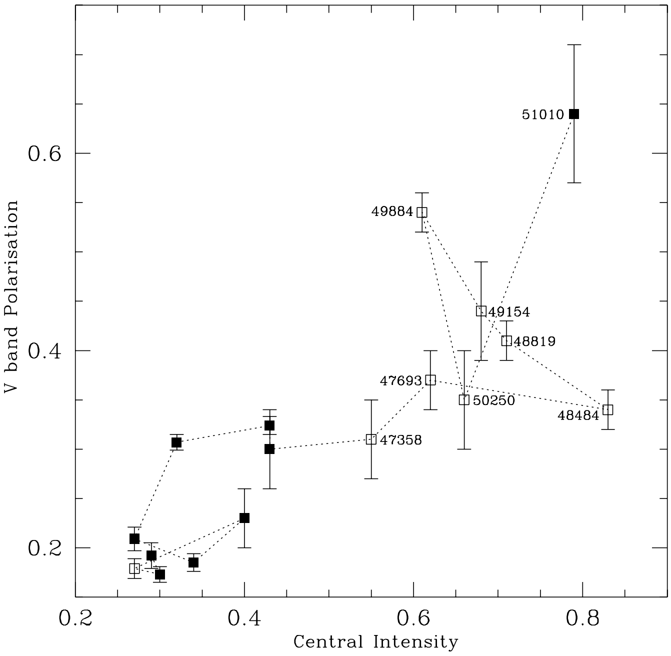

Fig. 5. Plot of the intensity of the central absorption trough against the *V* band polarisation. Solid squares correspond to pairs of measurements taken ≤10 days apart, while open symbols correspond to pairs of data between ≤40 days apart. The dotted line and the truncated Julian dates of the latter data indicate the evolution of both parameters.

However, despite these variations, at no stage was *o* And observed to change directly from B-normal to Be-shell phases without passing through a B-shell phase (Table 1). Indeed the continuum polarisation and Hα line profiles (Figs. 1 and 3) indicate the continued presence of circumstellar material during this time. Finally, by late 1988 significant emission was observed in the line wings, marking the onset of the current Be-shell phase.

There appear to be significant differences between the onset of the Be phase between early type stars (such as μ Cen; Rivinius et al. 1998a) and late type Be like *o* And. During disc formation, variability in early type stars appears to be characterised by short-lived flares where line emission is immediately seen (i.e. transiting directly from B-normal to Be phases), whereas in the late type Be stars such outbursts appear to be absent; indeed *o* And has one of the latest spectral types for which outbursts have been observed (Rivinius et al. 2001). Instead, disc growth in late spectral type Be stars appears to be characterised by a very slow development of the disc, visible first as a strengthening of the absorption profile (appearing as a "pseudo" photosphere) and only later producing weak emission in the line wings.

3.1.3. Disc Growth: 1988 – present

From 1988 onwards *o* And has remained continuously in a Be-shell phase. Between 1988 January–1991 September we observed a steady growth in the intensity of the central absorption feature. This is consistent with the continuous addition of material to the circumstellar envelope, leading to a greater optical depth along the lines of sight that intersect the stellar disc (Figs. 2 and 3). Such a scenario is supported by the decrease in the peak separation observed at this time, which is naturally explained by a growth in the radius of maximum emissivity of the disk in Hα as a result of an increasing disc density and/or outer radius (under the assumption of a disc dominated by rotational motion; see below).

Note that due to the interplay between the increasing strength of the emission and absorption components of the line profile no simple correlation is observed between the line EW and these parameters. This suggests that the intensity of the shell feature (a function of the disc density integrated along the line of sight) rather than the total EW provides a better indication of the mass content of the circumstellar disc for *o* And.

This process continued for ~1300 days until 1991 September, after which both the strength of the central absorption feature and line emission in the wings decreased and the separation between the emission peaks in the line wings increased. This suggests that a loss or redistribution (see Sect. 3.2) of material occured in the disc at this time such that material was lost from the outer regions responsible for both line emission and the shell absorption. However, the presence of a deep shell profile, transient emission in the line wings and significant continuum polarisation clearly indicates the presence of substantial disc material at this time; thus we are not witnessing a phase transition from Be-shell to either B-shell or B-normal phases during this time.

This behaviour ceased during a 400 day period between 1995 June and 1996 July (unfortunately, lack of observations prevent us from providing a more stringent constraint), after which the increase in the intensity of the shell feature and emission components of the line suggest a renewed input of material into the disc that has continued uninterupted to this day

Examination of the spectral dataset reveals that there are no consistent blue or red asymmetries in the line profiles. Such asymmetries would be expected if there were significant radial motion in the disc (see Sect. 3.4 and PGM02); we therefore conclude that a significant radial component to the disc kinematics is absent during the period of observations. Furthermore, no evidence for the presence of long period coherent variability in the peak ratio was found. Such cyclic V/R variability is attributed to the precession of a one armed density wave within the circumstellar disc. We therefore conclude that the circumstellar disc around *o* And appeared to be axisymmetric throughout the process of re-formation.

3.2. Comparison to photometric and polarimetric variability

While variability is clearly present in the *V* band lightcurve during the period of the observations we find no correlation between line and continuum emission (Fig. 3). While a variable optical excess (and associated colour changes) originating in the circumstellar envelope is seen for some systems (e.g. HD 245770; Clark et al. 1999), the optical continuum and associated rapid variability in *o* And are likely to be photospheric in origin (e.g. Sareyan et al. 1998).

Variation in the *V* band continuum polarisation is also present during the period of the observations and appears to be correlated with the development of the circumstellar envelope. In Fig. 5 we plot the strength of the central shell feature and the *V* band polarisation and find the 2 parameters to be correlated. Given that both are functions of disc density this is not unexpected and implies a broad correlation between the inner (polarisation) and outer (shell absorption) disc. A similar correlation between continuum polarisation and 12 micron excess – which is also expected to sample larger disc radii than polarisation measurements – was found for a large sample of Be stars by Waters & Marlborough (1992).

However close inspection of the evolution of continuum polarisation reveals that between 1991 August–1994 May the two parameters appear to be anticorrelated. This occurred during the period where reduced emission in the line wings was observed, which we attributed to a reduction in the disc density at radii responsible for line formation (Sect. 3.1.3). However it appears clear from these results that the variability at this time does not represent a simple global reduction in disc density, but rather a steepening of the density gradient, resulting in an increase in polarisation due to an increase in density in the inner regions of the disc.

3.3. The timescale of bulk variability.

When combined with previous observations, our spectroscopic dataset suggest that bulk variability in the properties of the circumstellar disc in *o* And occur over very long timescales; of the order of $\sim 10^3$ days. The transition between Be-shell to B-normal phases reported by PGM82 occured over 700 days, almost identical to the length of time required for the transition back from B-normal to Be-shell via the B-shell phase. The subsequent development of the present Be-shell phase proceded over a period of 1300 days, while the reduction in line emission between 1991–1995 occured over a minimum period of 1400 days. Finally, the recovery from this behaviour has occured continuously over a period of ~1900 days.

Any theory of disc loss and re-formation for Be stars clearly must explain these long characteristic timescales. To date the only theory governing the dynamics of the circumstellar discs of Be stars to provide such a prediction is the viscous decretion disc model (Porter 1999; Okazaki 2001). In this theory, bulk redistribution of material in the disc can only occur as rapidly as viscous torque can redistribute angular momentum within the disc. This results in a characteristic viscous timescale for the variability of Be stars discs.

The viscous timscale for Be star circumstellar discs is expected to be ~constant across the range of parameters expected for B stars (Porter, priv. comm., 2002); varying from $73/\alpha \rightarrow 55/\alpha$ days for B0 → B9 stars (where α characterises viscosity, which we assume does not vary as a function of spectral type; Shakura & Sunyaev 1973). As expected, the viscous timescale is highly dependant on α, which is at present poorly observationally constrained. However Okazaki & Negueruela (2001) are able to demonstrate that truncation of the circumstellar discs in Be/X-ray binaries – required to reproduce the transient nature of their X-ray emission – requires $\alpha \sim 0.1$. Likewise studies of accretion discs in binaries suggest small values $\alpha \leq 0.1$ are required (e.g. Blondin 2000; Matsumo 1999). For a value of $\alpha = 0.1$ we obtain a characteristic timescale of the order of 700 days for *o* And, entirely consistent with the timescale of long term variability observed.

Under the alternative assumption that the Be star disc is a collimated, outflowing stellar wind with a significant radial velocity component, any changes in the bulk properties of the disc will occur on the flow timescale of the wind. This is expected to be ≥order of magnitude shorter than the viscous timescale (e.g. PGM82 and Sect. 3.4); therefore the long timescales of variability observed for *o* And are inconsistent with such a theory.

Note that the viscous redistribution of material and angular momentum within the disc is an entirely different physical process from that which transports material from the stellar surface into the disc in the first place and hence one should not a priori expect both processes to occur over identical timescales. Indeed it has been speculated that the rapid (~few days) transient flaring episodes reported by e.g. Rivinius et al. (2001) represent the "explosive" injection of material into the circumstellar disc, although no physical process has yet been identified with this behaviour.

3.4. Modeling the 1978 shell episode

A combination of spectroscopic and polarimetric data allowed PGM82 to investigate the evolution of the disc parameters of *o* And during 1978. Their *static* model consisted of an axisymmetric disc with a rotational velocity that was Keplerian in the inner ($r < 8\,R_*$) disc and angular momentum conserving in the outer disc. The expansion velocity varied with radius and constrained the density gradient via conservation of mass, leaving the base density (and hence mass loss rate) of the disc a free parameter.

During the Be-shell phase their best fit model suggested the presence of a disc with a zero or low expansion velocity in the inner ($\sim 3\,R_*$) regions of the disc followed by a rapid radial acceleration, resulting in a terminal velocity of ~few 100 km s^{-1} at large radii ($r \sim 20\,R_*$). Without the acceleration too much emission and too narrow a peak separation was observed due to the presence of an excess of material in the outer, slowly rotating regions of the disc.

A reduction in mass loss rate by a factor of 100 was required to replicate the transition from Be-shell to B-normal phase. The reduced mass loss rate propagating outwards initially removed material in the inner regions of the disc responsible for the continuum polarisation. Subsequently Hα emission was lost and then the shell lines faded as the effect of the reduced mass loss rate propagated to larger radii, qualatatively reproducing the observations. However the quantitative timing of the observed changes could not be reproduced without introducing a time variable expansion velocity; in particular simply reducing the mass loss rate resulted in the disappearance of the shell lines 50 days after the reduction in polarisation – on the characteristic wind flow timescale – rather than the 700 days observed (PGM82). Despite the successes of the PGM82 model in qualitatively reproducing the behaviour of *o* And during disc loss, clearly a model incorporating a substantial radial outflow velocity results in problems in reproducing both the symmetric line profiles in the static disc approximation and the timescale of disc variability.

However, it is instructive to re-examine the results of PGM82 under the assumption that the disc is governed by viscous redistribution of angular momentum. As shown by Porter (1999) and Okazaki (2001) isothermal viscous disc models are quasi-Keplerian with a rather low expansion velocity (~few km s^{-1}) and steep density gradient ($\rho \propto r^{-5/2}$) without the requirement of a rapid acceleration of disc material to reduce the density in the outer disc. The low expansion velocity explains the symmetric line profiles observed and changes in the bulk disc parameters will occur on a viscous timescale (Sect. 3.3) rather than the flow timescale of the wind (~10 s days; PGM82). Finally, once the supply of angular momentum at the stellar surface required to support the quasi-Keplerian disc is removed, material begins to reaccrete, a process which progressively occurs at larger radii. This produces a flatter density gradient in the inner regions of the disc which *propagates outwards* on the viscous timescale as material is removed (reaccreted) from the disc – exactly the process PGM82 find is required to explain the disc loss in *o* And.

4. Conclusions

The results of an 18 year (1985–2002) monitoring campaign of the Be shell star *o* And have identified the re-formation of the circumstellar disc following the end of the B-normal phase observed in 1985. This process is found to occur over very long timescales (~10^3 days). The initial transition from B-normal to B-shell phase is marked by an increase in the depth of the central absorption profile, suggesting the presence of a very compact circumstellar envelope. Subsequently, emission at large (projected) velocities (~±300 km s^{-1}) and an increase in continuum polarisation was observed. These observations serve to emphasise that the circumstellar disc is rather compact at this time. The subsequent evolution of the Hα line profiles suggest that the disc kinematics are rotationally dominated, with the re-formation characterised by a slow increase in the radius of maximum emissivity of the disc in Hα (note that this is not necessarily equivalent to the "outer edge" of the circumstellar disc). These observations are consistent with the predictions of the viscous decretion disc model, which suggest that the continuous input of angular momentum (and matter) at the disc/stellar surface interface will result in a gradual radial diffusion of material within the disc to larger radii.

PGM82 find that disc loss also occurs over similarly long timescales; some ~700 days separate the initial reduction in continuum polarisation from the final loss of the shell absorption features (and reversion to purely photospheric profiles) in the 1978 disc loss event. They demonstrated that these observations can be qualitatively understood as a reduction in the density of the inner regions of the disc which slowly propagates to larger radii – the disc is effectively lost inside out. Such behaviour is also consistent with the expectations of a viscous decretion disc if the supply of angular momentum is "turned off" at the base of the disc. Without the angular momentum required to maintain disc matter in stable Keplerian orbits, material in the inner regions of the disc is re-accreted onto the stellar surface, effectively creating a "hole" in the inner disc. As more material is reaccreted the radius of the hole increases, mirroring the behaviour seen during disc loss in *o* And.

Therefore, we conclude that the viscous decretion disc model for Be star discs can *qualitatively* reproduce the rotationally dominated kinematics, timescale of variability and behaviour of the disc during disc loss and reformation in *o* And. In a future paper we will present a quantitative comparison of these data to the predictions of a hydrodynamical simulation of disc loss and formation (Porter et al., in prep.).

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