θ^1 Ori C through the eyes of the MuSiCoS spectropolarimeter

G.A. Wade[a], J.-F. Donati[b]

a Department of Astronomy, University of Toronto at Mississauga, Mississauga, Ontario, Canada L5L 1C6
b Observatoire Midi-Pyrenees, 14 Avenue Edouard Belin, 31400 Toulouse, France

Abstract.
We describe recent circular spectropolarimetric observations of the young 07 star θ^1 Ori C, as well as current and future investigations aimed at exploring the photosphere, envelope and wind of this enigmatic object.

Key words: magnetic fields, early-type stars, polarisation

1. Introduction

θ^1 Ori C is a young 07 star and represents the main source of ionizing photons for the Orion nebula. Walborn (1981) discovered cyclic variability of the broad Hα emission profile of this star, and subsequent studies have revealed that the Hα and He II (468.6 nm) emission, ultraviolet C IV (154.8 and 155.0 nm) wind lines, photospheric absorption lines, and ROSAT X-ray emission all appear to vary with a single well-defined period of 15.426 ± 0.002 d (Stahl et al., 1993, 1996; Gagné et al., 1997; Stahl, 1998). Such strictly periodic behaviour is observed only in magnetic rotators on the upper main sequence, and strongly suggests that the root cause of the variability of θ^1 Ori C may be a magnetic field.

Following this reasoning, Babel & Montmerle (1997b) applied to θ^1 Ori C their new Magnetically-Confined Wind Shock (MCWS) model originally developed to explain the X-ray emission of some Ap/Bp stars (Babel & Montmerle, 1997a). The model reproduces the X-ray variability of θ^1 Ori C very well, and predicts a magnetic field extending through the photosphere and wind which is approximately dipolar in configuration, with polar strength $B_d \sim 300$ G.

The goal of this study was to test the MCWS model by searching for direct observational evidence (via the Zeeman effect) of a magnetic field in the photosphere and/or envelope of θ^1 Ori C, and furthermore to determine the characteristics of such a field. Many of the details of this study are described by Donati & Wade (1999). In this paper we review those results, discuss recent insights, and provide a preview of upcoming observing strategies.

2. Observations

High-resolution circular polarisation observations of θ^1 Ori C were obtained using the MuSiCoS spectropolarimeter (Donati et al., 1999) mounted on the 2 metre Bernard Lyot telescope at Pic du Midi observatory. Five observations were obtained during February 1997, two observations in February 1998, and one observation in 1999. The data were analysed using the Least-Squares Deconvolution (LSD) procedure (Donati et al., 1997). The best effective signal-to-noise ratio (as computed from the inverse error bar in the LSD mean profiles) obtained was about 1250:1, for a single 40-minute exposure. Examples of LSD Stokes I and V profiles of θ^1 Ori C are shown in Fig. 1.

3. Magnetic field

No Stokes V signatures were detected in any of the LSD profiles. To determine an upper limit on the strength of the longitudinal component of any magnetic field present in the photosphere of θ^1 Ori C we employed two different procedures. The first involved synthesizing of the mean Stokes profiles and searching for the weakest longitudinal field which could be detected above the Stokes V noise level. The second involved straightforward measurement of the longitudinal field from the first moment of the Stokes V profile. Both methods produced null detections with 1σ uncertainties on the longitudinal field of about 250 G. These results constrain any MCWS-consistent magnetic field in the photosphere of this star to be weaker than 1.6 to 2 kG, with a confidence of 87%.

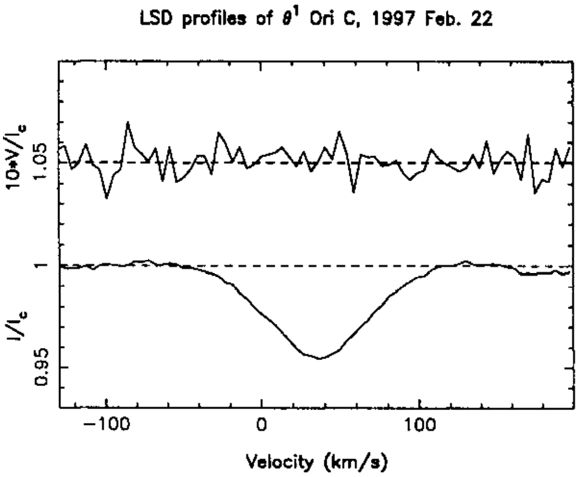

Figure 1: *LSD Stokes V (upper curve) and I (lower curve) profiles of θ^1 Ori C on 1997 Feb. 22. Note that the Stokes V profile was expanded by a factor of 10 and shifted upwards by 1.05 for graphics purposes.*

4. Continuum polarisation and depolasisation features

Some of our circular polarisation spectra of θ^1 Ori C displayed remarkably high levels of continuum polarisation (as large as 3.8% on 1997 Feb. 20). The continuum polarisation level varied on a nightly basis, although the MuSiCoS data as well as recent photopolarimetric observations (Romanyuk, 1998, priv. comm.) indicate that it does not strictly vary according to the 15.426 d period (i.e. there appears episodic variability in addition to possible rotational modulation). More remarkably, all nebular emission lines in the *V/I* spectra displayed depolarisation features, suggesting that the continuum polarisation is not spurious. The depolarisation features deepen with Stokes *I* line-to-continuum flux ratio and are consistent with a constant absolute level of continuum polarisation. This suggests that the nebular flux is essentially unpolarized, implying that the continuum polarisation is produced in the immediate circumstellar environment (e.g. by a disc similar to that proposed by the MCWS model). The continuum polarisation and depolarisation features associated with Hª in the spectrum of θ^1 Ori C are shown in Fig. 2.

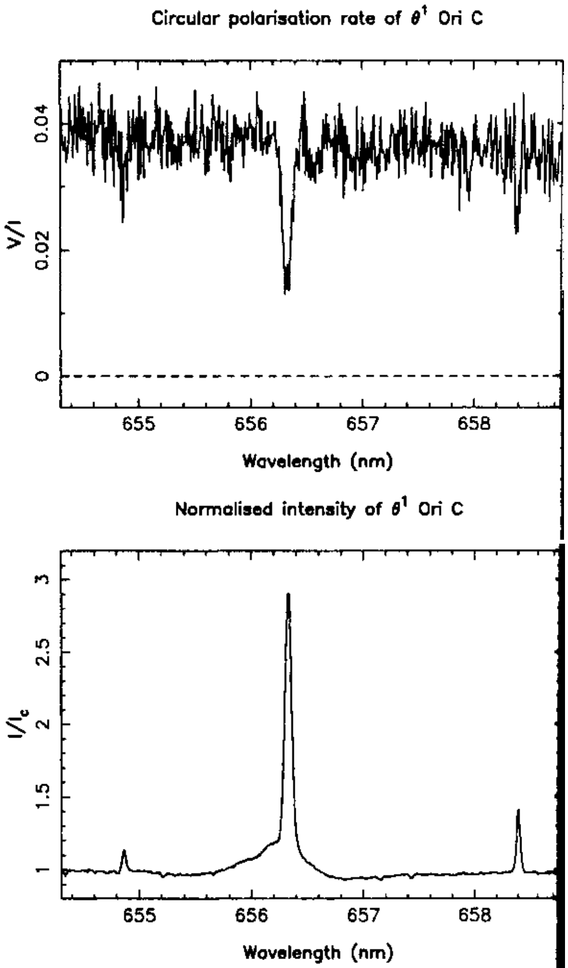

Figure 2: *Circular polarisation rate (V/I; top panel) and normalised intensity (bottom panel) of θ^1 Ori C at Hα wavelengths, on 1997 Feb. 20. Note that the depolarisation feature is associated only with the* nebular *component of the emission*

5. Discussion

5.1. Magnetic field

Clearly our 1.6 to 2 kG constraint on the field strength does not provide a useful test of the MCWS model. However, it does constrain somewhat models developed recently by Shore (1999) which require fields "at least a kilogauss" in strength to reproduce the width of the Hª emission profile. These observations also provide us with the ability to estimate the best possible constraint on the magnetic field of this star obtainable using the MuSiCoS spectropolarimeter. Its equatorial location positions it advantageously for long exposures. A 6-hour integration (equivalent to less than 2% of the presumed rotational period) under good observing conditions would provide some 9 times more photons than our best 40-minute exposure, resulting in an improvement of a factor of 3 in the LSD effective signal-to-noise ratio. Because the detection threshold scales are approximately as the noise level, this should allow us to achieve an upper limit on the longitudinal field of about 85 G (1σ)

By coadding two such exposures obtained at similar phases, this is reduced to 60 G. Such measurements would allow us to constrain any MCWS-consistent surface field to less than 385-480 G, a much more stringent constraint on the model.

5.2. Continuum polarisation

Wade & Donati (1999) noted that the observed continuum circular polarisation is difficult to explain in light of the small (~ 0.4%; Leroy & Leborgne, 1987) continuum linear polarisation observed in this object. They tentatively attributed this phenomenon to multiple scattering in the MCWS cooling disc. The cooling disc is speculated to undergo episodic density enhancements (while remaining optically thin) which result in an increase in the amount of scattered light continuum polarisation for a short time. This was supported by their observation (see Fig. 3) that, during epochs of enhanced continuum polarisation, *excess absorption* occurs in the LSD mean profiles at phases when the disc is seen edge-on.

It has been recently suggested (Moffat, 1999) that the continuum circular polarisation observed in the spectrum of θ^1 Ori C is *instrumental* in nature. Moffat argues that, due to small sensitivity variations across the fibre entrance, fibre-feb spectropolarimeters "see" point sources somewhat differently than extended sources. He proposes that this difference in response can produce both spurious continuum polarisation (this is known and well accepted) as well as spurious depolarisation features. An evaluation of this pfoposal awaits its publication.

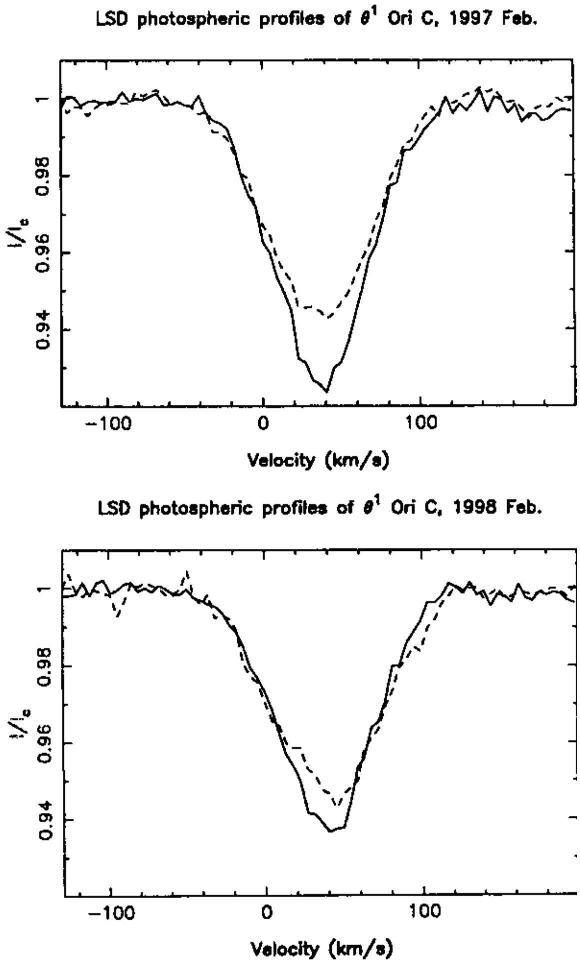

Figure 3: ***LSD profiles of the photospheric spectral lines of θ^1 Ori C in Feb. 1997 (top panel) and 1998 Feb. (bottom panel), closest to rotational phase 0.0 (solid line) and 0.5 (dashed line).***

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