Astron. Astrophys. 358, 572–574 (2000)

ASTRONOMY
AND
ASTROPHYSICS

Continuum optical circular polarisation in the young O star Θ^1 Orionis C?

A.F.J. Moffat[*] **and T. Eversberg**[**]

Département de Physique, Université de Montréal, C.P.6128, Succ. Centre Ville, Montréal H3C 3J7, Canada and Observatoire du Mont Mégantic (moffat@astro.umontreal.ca)

Received 29 October 1999 / Accepted 3 February 2000

Abstract. Recently, Donati & Wade (1999) have claimed rather spectacular, large, variable circular polarisation in the optical continuum of Θ^1 Orionis C, obtained with the échelle spectropolarimeter MuSiCoS. However, based on experience with the William-Wehlau spectropolarimeter, a similar unit using two fiber feeds, we suggest that this is the spurious result of instrumental effects. We propose a remedy to eliminate the effect.

Key words: instrumentation: polarimeters – methods: observational – techniques: polarimetric – stars: individual: θ^1 Ori C stars: magnetic fields – stars: early-type

1. Background

Θ^1 Ori C is the brightest and hottest member of the Orion Trapezium cluster at the heart of the bright HII nebula M42. Previous optical/UV observations going back many years (Conti 1972; Walborn 1981; Walborn & Panek 1984; Stahl et al. 1993; Walborn & Nichols 1994; Stahl et al. 1996) have shown that Θ^1 Ori C may be the O-star equivalent of a magnetic oblique rotator. Recent X-ray observations (Gagné et al. 1997; Babel & Montmerle 1997) indicate a modulation in the 15.4 day rotation cycle, with a likely surface magnetic field of several 100 G. In an attempt to detect the magnetic field via Zeeman splitting using high resolution optical spectropolarimetry in circular mode, Donati & Wade (1999) have reported null detections with 250 G 1σ error bars for any longitudinal component of a surface magnetic field averaged over the stellar disk. If the field is a dipole, the pole strength must be below some 1800 G. This null result is in agreement with the estimation of an upper threshold for B_e by Eversberg et al. (1998).

Donati & Wade (1999) also noted the unexpected discovery of strong, time-variable continuum circular polarisation in the optical spectrum of Θ^1 Ori C, reaching values as high as 3.8%! As support for the reliability of this result, they note the presence of depolarisation structure associated with the strong nebular emission lines. They conclude that the continuum polarisation must be produced within the immediate (spatially unresolved) circumstellar (CS) environment of the star. Eversberg et al. (1998) failed to detect any depolarisation in the strong Hα nebular line, although they possibly could have, had they had higher resolution and S/N.

Among the possible causes of this unusual continuum polarisation, Donati & Wade invoked some kind of CS disk as the most likely explanation. However, the level of *linear* continuum polarisation should be even larger, contrary to the previous observations of Leroy & Leborgne (1987), despite the latter authors' reporting of variability.

2. Instrumental problems?

The MuSiCoS échelle spectropolarimeter (Baudrand & Böhm 1992; Donati et al. 1999) used in Donati & Wade's (1999) investigation uses twin fibers to transfer the double split beam emerging from the polariser, to the spectrograph. The star is imaged directly onto each of the twin fibers. From beam ratios at the detector in the spectrograph, the wavelength-dependent Stokes' parameters can be derived. From an appropriate choice of *double* ratios (e.g. Eversberg et al. 1998; Tinbergen 1996), the fractional values of $q(\lambda) \equiv Q(\lambda)/I(\lambda)$, $u(\lambda) \equiv U(\lambda)/I(\lambda)$ and $v(\lambda) \equiv V(\lambda)/I(\lambda)$ can attain very high precision in principle, limited mainly to photon statistics and nearly impervious to pixel-to-pixel sensitivity variations.

Eversberg et al. (1998, 1999) used a similar setup in their recently built William-Wehlau (WW) spectropolarimeter. The major difference between the two apparati is that the WW instrument employs two quarter-wave plates (QWPs) simultaneously to measure q, u or v, while MuSiCoS uses either a QWP to measure v or no plate at all, but instrument rotation to measure q and u. In addition, as with MuSiCoS, Eversberg et al. (1998) find a scatter in continuum (i.e. broadband) polarisation from one measure to another, when stars are observed (see their Fig. 4). Typically, the scatter is $\sim$1% in q, u or v from one exposure to another independent of the telescope, somewhat worse in the blue. However, the instrument can still be used very well for high precision, *relative* line polarisation work, since the deviations in a given measurement vary only slowly with wavelength.

Send offprint requests to: A.F.J. Moffat

[*] Killam Fellow of the Canada Council for the Arts

[**] now at Leibnizstraße 37, 30827 Garbsen, Germany (T_Eversberg@feinfocus.com)

The MuSiCoS instrument, being very similar in general concept, leads to a similar scatter of 0.8% in broadband q, u or v (Donati et al. 1999). However, details between the two instruments differ, so that the quantitatively similar scatter in continuum polarisation may be a coincidence. For example, the ratio of analyser splitting angle to fiber core diameter is quite different in the two instruments, leading to possibly stronger chromaticity in the WW instrument; on the other hand, MuSiCoS has fibers that are twice as small in core diameter as those in the WW polarimeter, and thus being more sensitive to positioning errors. Note that this continuum effect is completely independent of the Donati & Wade (1999) magnetic field upper limit and does not affect that result.

While small in the context of transmission at the fiber interface, this $\sim$ 1% scatter is large (even fatal in most cases) for astronomical work on continuum or absolute line polarisation. In the case of the WW spectropolarimeter, Eversberg et al. (1998) have shown that the scatter is most likely due to small inhomogeneities in spatial surface sensitivity across the face of the fibers, combined with varying average position of the star on the fibers from one exposure to the next. This causes the beam intensities (and their ratios) to fluctuate, depending on exactly where the star is focussed on the fibers. It has nothing to do with intrinsic polarisation of the source. Presumably, small guiding errors are the main cause of the star's average position on the fibers changing from one exposure to another. Even a small change in position is apparently enough to cause this effect.

In contrast to stellar light, Eversberg et al. (1998) find that extended sources (e.g. flat fields) do not fluctuate by more than 0.02% (!) and are of much lower residual value (especially in v, where the source polarisation is less likely to be significantly different from zero; see their Fig. 5). Since fiber transmission generally falls off towards shorter wavelengths, the effect becomes gradually worse towards the blue. Note that it is not important whether the extended source is local or at "infinity" (i.e. astronomical); what is important is the uniform illumination of the fibers.

Based on the above experience of Eversberg et al. (1998), it appears very likely that the continuum circular polarisation observed by Donati & Wade (1999) is spurious: The continuum + photospheric-line polarisation (in circular mode v) is a result of the stellar light (i.e. a point-spread function), which with a 2-fiber system is known to fluctuate, as discussed above. As can be seen from the data of Donati & Wade (1999), the continuum circular polarisation in Θ^1 Ori C fluctuates by close to 1% rms, even including the freak 3.8% deviation observed near Hα 1997 on Feb 20[1]. The component of narrow emission line flux on the other hand is dominated by the nebular light of the Orion Nebula, which is an extended source. It therefore behaves like a flat field source, which as Eversberg et al. (1998) have shown for their similar apparatus, shows little fluctuation and lower polarisation. Of course, in the case of Θ^1 Ori C, about 1/3 of the light at the peak of Hα at Donati & Wade's (1999) spectral resolution is stellar (continuum + emission + absorption), so the polarisation does not necessarily fall to zero at line peak. In fact, for zero intrinsic and instrumental polarisation of nebular Hα (the normal case), one expects the observed circular polarisation, based on the relative line to continuum flux at line peak, to fall to c. 1/3 of the continuum value (regardless of its origin), as seen. Eversberg et al. (1998) failed to see any significant instrumental depolarisation in Hα probably because of their much lower spectral resolution.

As a first check of the spurious nature of the continuum circular polarisation in Θ^1 Orionis C, one should use MuSiCoS to measure simultaneous circular *and* linear polarisation across the Hα line. If the above explanation is correct, as already appears highly likely based on our experience with the WW spectropolarimeter, one would expect the same to occur as in circular polarisation, i.e. one would expect to find (spurious) variable continuum linear polarisation. In fact, Eversberg et al. (1998) already showed the same spurious continuum polarisation in any of q, u and v in their data using the WW spectropolarimeter. A more definitive check would be to compare observations of astronomical sources (rather than local dome-flats) that are uniform and extended (e.g. planets in this context) with point-like stellar light.

3. Remedy

In the WW spectropolarimeter, we have already eliminated the problem of rotation-angle dependence of the retardance in the achromatic QWPs, as noted by Eversberg et al. (1998), by providing better mountings for the two QWPs. The next step is to eliminate the illumination problem of the fibers (the same procedure could be applied to MuSiCoS). One possibility, in principle, would be to add a lenslet in front of each fiber, to image the entrance pupil instead of the star onto the fibers. This is however a very awkward solution, given that the instrument is built already; such lenslets would also have to be extremely small and precisely mounted in the two beams.

We believe that a much simpler solution to try is to mount a polished, highly uniform interface plate onto the fiber input ends, using a cement of similar index of refraction. In this way, the coupling of the beams to the fibers will be much less susceptible to sensitivity variations across the fiber faces. This is being explored on the WW spectropolarimeter and could be done on MuSiCoS, as well as the new ultra-efficient spectropolarimeter ESPaDOnS planned for use at the Canada-France-Hawaii telescope in the near future. If 1% fluctuations are important, this should also be considered for any other type of fiber-fed device.

Acknowledgements. A.F.J.M. thanks NSERC (Canada), FCAR (Québec), and the Killam program of the Canada Council for the Arts for financial support. T.E. is grateful for full financial aid from the Evangelisches Studienwerk/Germany which is supported by the German Government, as well as an extended bursary from the astronomy

---

[1] Donati & Wade (1999) note that polarisation spectra of other stars obtained on the same nights as Θ^1 Ori C show no similar high continuum polarisation levels as seen in Θ^1 Ori C. However, they also note that the fiber-fed MuSiCoS spectropolarimeter can measure the continuum polarisation with an accuracy of about 0.8%. We understand this to mean that the extreme value of 3.8% for Θ^1 Ori C is simply a statistical fluke.

group at the Université de Montréal. Both authors acknowledge useful discussions with J.-F. Donati and G. Wade. We are grateful to M. Cohen, the referee, for useful comments.

References

Babel J., Montmerle T., 1997, ApJ 485, 29
Baudrand J., Böhm T., 1992, A&A 259, 711
Conti P.S., 1972, ApJ 174, 79
Donati J.-F., Wade G.A., 1999, A&A 341, 216
Donati J.-F., Catala C., Wade G.A., et al., 1999 A&AS 134, 149
Eversberg T., Moffat A.F.J., Debruyne M., et al., 1998, PASP 110, 1356
Eversberg T., Moffat A.F.J., Debruyne M., et al., 1999, In: Variable and Non-spherical Stellar Winds in Luminous Hot Stars: Proceedings of IAU Coll. No. 169, Springer, Heidelberg, p. 107
Gagné M., Caillault J.-P., Stauffer J.R., Linsky J.L., 1997, ApJ 478, 87
Leroy J.L., Leborgne J.F., 1987, A&A 186, 322
Stahl O., Wolf B., Gäng T., et al., 1993, A&A 274, 29
Stahl O., Kaufer A., Rivinius T., et al., 1996, A&A 312, 539
Tinbergen J., 1996, Astronomical polarimetry. Cambridge Univ. Press, Cambridge
Walborn N.R., 1981, ApJ 243, 37
Walborn N.R., Panek R.J., 1984, ApJ 286, 718
Walborn N.R., Nichols J.S., 1994, ApJ 425, 29