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3 μm Spectropolarimetry of H_2O Ice in Young Stellar Objects

Antonio Chrysostomou and J. H. Hough

Division of Physical Sciences, University of Hertfordshire, College Lane, Hatfield, Herts AL10 9AB, UK

David W. Messinger and D. C. B. Whittet

Dept. of Physics, Applied Physics & Astronomy, Rensselaer Polytechnic Institute, Troy, NY 12180, USA

David K. Aitken

Visiting Fellow, Royal Observatory Edinburgh, Blackford Hill, Edinburgh EH9 3HJ, UK

Patrick F. Roche

Dept. of Astrophysics, University of Oxford, Keble Road, Oxford, OX1 3RH, UK

Abstract. Spectropolarimetry of the water-ice feature at 3.1 μm towards a number of YSOs is presented. The data show that excesses of polarization and changes in position angle across the feature are common. The polarization excess is due to dichroic absorption which means that the *water-ice mantled grains are aligned.* This may pose problems for current alignment theories. We interpret the change of position angle across the feature to mean that the magnetic field aligning the grains must be twisting along the line of sight and the ice-mantled grains must be fractionated, i.e., not evenly distributed along the line of sight.

1. Introduction

Spectropolarimetric observations of solid state features due to dust grains in the interstellar medium provide unique information on the optical and alignment properties of the carrier materials (for reviews, see Aitken 1989 and Aitken 1996). Polarization excesses in the 3.1 μm ice feature have been detected in several young embedded stars and also in Elias 16, a highly reddened late-type field star behind the Taurus dark cloud (Hough et al. 1988, 1989). Their absorption spectra display a range of profile shapes which is attributed to variations in the ice temperature (Smith et al. 1989). However, to explain the entire profile additional absorbers are required, most likely from C-H resonances in carbonaceous materials. Prior to the observations presented here, all spectropolarimetry data were taken with relatively broad band CVFs. Our data show that there is a clear

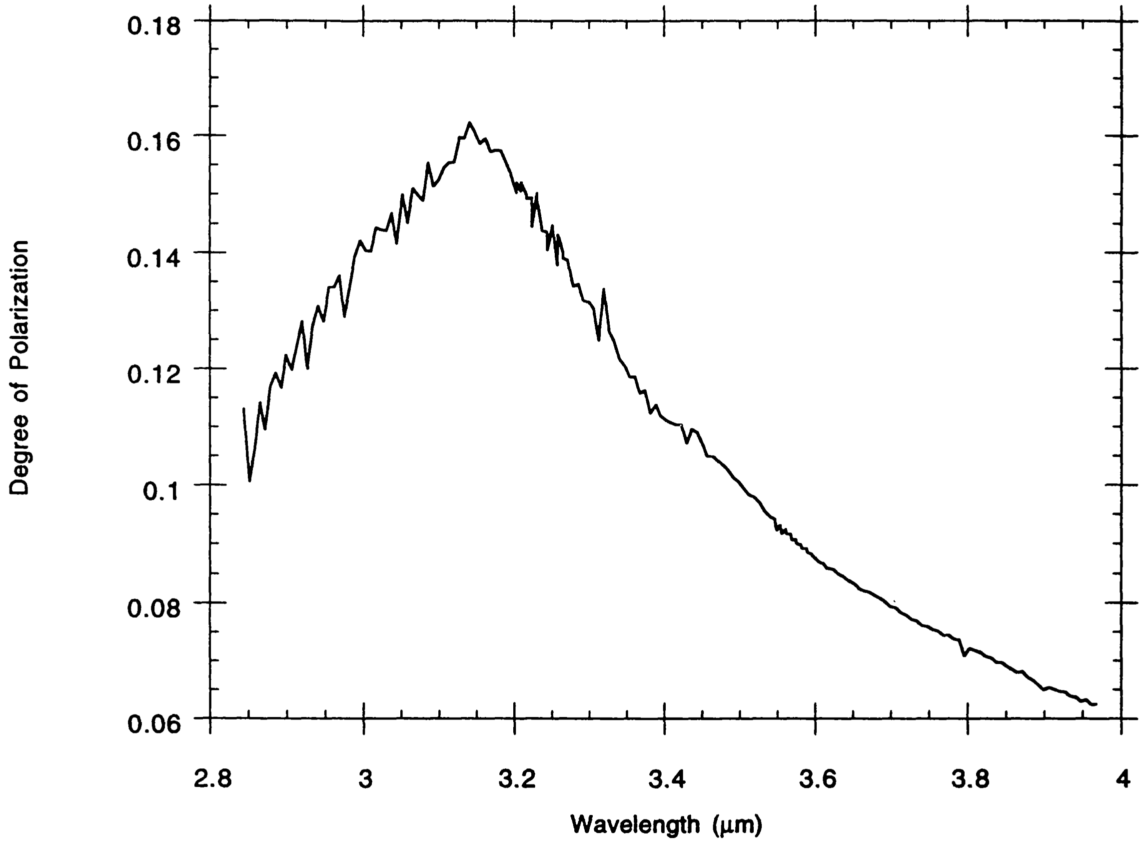


Figure 1. Degree of polarization spectrum of the water-ice feature in BN.

advantage to be gained from array spectrographs, not only from multiplexing but also from increased spectral resolution.

The data were taken with the UKIRT infrared spectrometer, CGS4, coupled with the IRPOL polarimetry module. It is a single-beam system with a cold wire-grid for an analyser and a rotating half waveplate. Three positions of the grating (resolving power ~580) were used to give coverage between 2.85 and 3.95 μm.

2. Common Observational Features

2.1. Polarization Excess

Six objects were observed: BN, GL989, GL490, GL896, MONR2 IRS3 and SVS13. In Fig. 1, the polarization spectrum of the ice feature in BN is shown. This should be compared to a similar spectrum given in Hough et al. (1989).

An excess in polarization above the continuum is seen across the feature for all the objects listed above (apart from SVS13, where the data are too noisy). To determine whether the excess polarizations observed are due to dichroism, the wavelengths of the peaks of extinction and polarization need to be compared. The extinction coefficient of elongated grains has different values for radiation

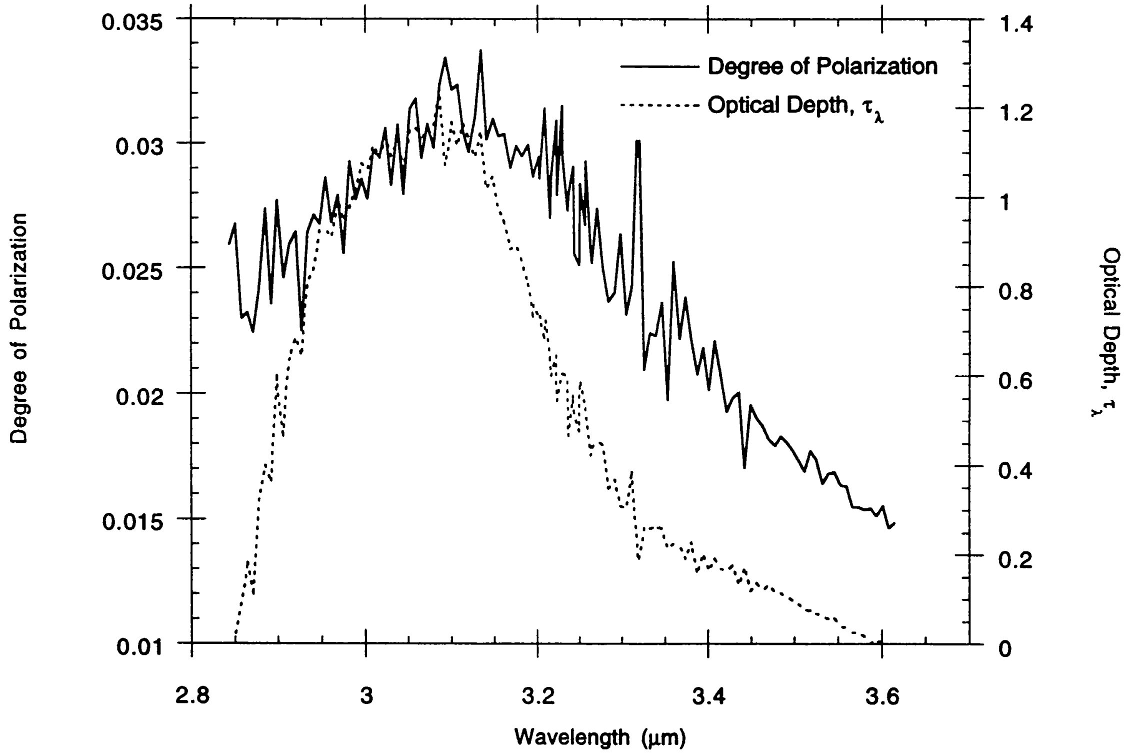


Figure 2. Degree of excess polarization plotted with the optical depth of the water-ice feature in GL989. Note the shift in wavelength between the two indicating that the polarization is caused by dichroism.

perpendicular and parallel to the grain axis, shifting the polarization maximum to longer wavelengths relative to the extinction (Kobayashi et al. 1980). Fig. 2 demonstrates this for GL989 and this is also seen for all our other objects (apart from MONR2 IRS3, where the excess is probably caused by dilution in the feature of scattered radiation).

This observational result could well pose a problem for current alignment theories. In the cold physical conditions where ice mantles can form on grains, the gas and grain temperatures are presumably closely coupled, ruling out the Davis-Greenstein and superparamagnetic alignment mechanisms. This leaves the possibility of suprathermal spin-up, which relies on the formation of H_2 on active sites on the grain surface. However, the ice mantle will have covered or "poisoned" the active sites rendering the suprathermal mechanism ineffective (Lazarian, private communication), notwithstanding the fact that the gas is already molecular. Our observations clearly demonstrate that the *ice mantled grains are aligned*; however, a theoretical explanation as to the physical process by which the ice-mantled grains are aligned is lacking.

2.2. Position Angle Rotation

Hough et al. (1989) first reported a rotation of position angle (~12°) across the feature for GL2136. At the time, this behaviour was not thought to be common. However, due to the high quality of our data, we have found that position angle changes across the feature may in fact be commonplace. For example, we see for the first time a rotation of just 4° across the feature for BN, while a change of 50° is seen for GL896 (Fig. 3).

These changes in position angle are most simply explained if we assume that the magnetic field that is aligning the ice-mantled grains twists along the line of sight. This would also mean that the ice-mantled grains cannot be evenly distributed along the line of sight with the bare grains, i.e., there is fractionation of mantle material.

2.3. Broad Red Wing

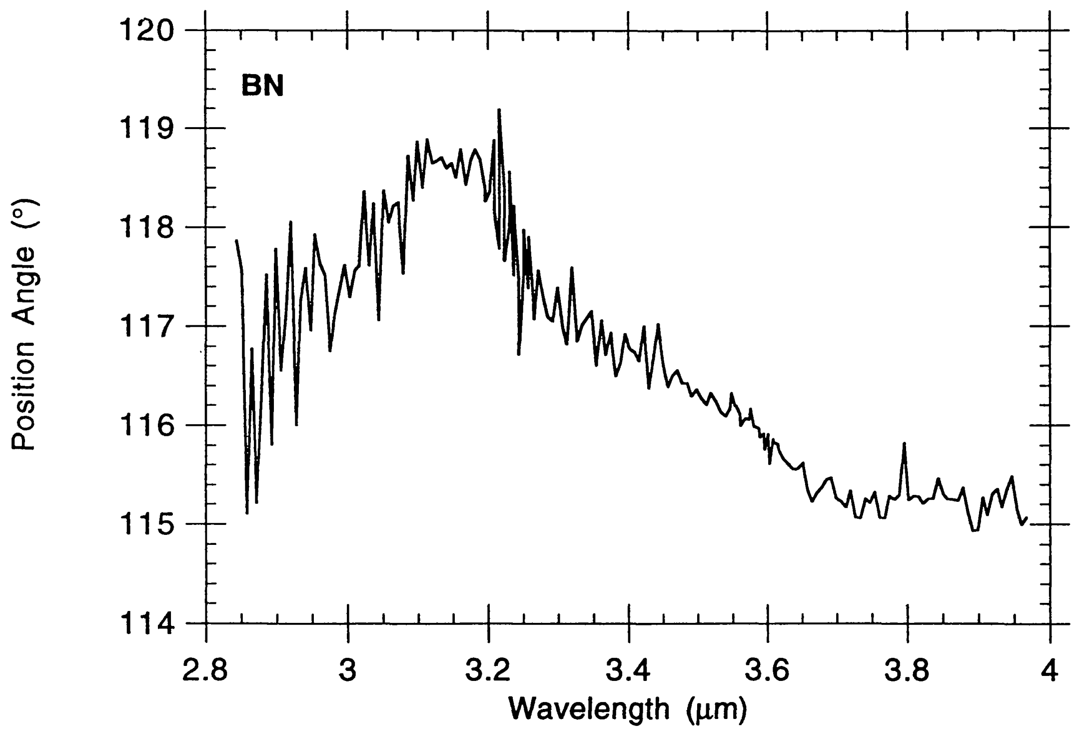
The red wing of the feature is very broad in absorption and polarization. The existence of the broad absorption feature has been documented for some time (e.g., see Smith et al. 1989); however, the breadth of the polarization wing has not been so. For BN, definite signs of a small and broad feature are seen between 3.3 and 3.6 μm. This feature corresponds quite closely in position and width to the 3.47 μm feature discovered spectroscopically by Allamandola et al. (1992). They attributed this structure to carbonaceous material with a "diamond-like" structure. This is the first time that this feature has been detected in BN and the first time for any object in polarization. For further information and modelling of the polarization spectrum of BN, see Messinger et al. (1996).

3. Future Prospects and Measurements

The future is very near! Currently all spectropolarimetric observations are based on single-beam systems. These are very susceptible to weather and super-photometric conditions are necessary for accuracy. A Wollaston prism has recently been installed into the upgraded version of CGS4, which will provide a dual-beam facility for near-infrared spectropolarimetry. From our previous experience on the AAT, we would hope to achieve an order of magnitude improvement on previous observations.

The increased wavelength coverage, resolution, and polarization accuracy from this system will benefit spectropolarimetric measurements of the structure in the broad red wing of the ice feature in objects other than BN. Better continuum measurements can be made between 1 and 5 μm, which will not only help to accurately ascertain the polarization excess in the feature, but also the non-Serkowski behaviour of dichroism in the near-infrared. Along with accuracy, an increased sensitivity will allow us to measure the polarization of objects with exceptionally deep water-ice features. A very important measurement will be to determine whether there exists an excess of polarization in the 4.67 μm CO-ice absorption feature due to dichroism. This will indicate that even some of the coldest grains (T $\sim$ 10 K) deeply embedded within molecular clouds are aligned. Such a measurement will serve as a severe and critical test of grain alignment theories, especially with concern as to the environmental conditions in which grains can align.

Quite clearly, the quality of data and the rate of data gathering are increasing quite remarkably. Very shortly we shall be coming to a position where we will be able to challenge and provide severe tests of our understanding of grain chemistry and alignment processes.



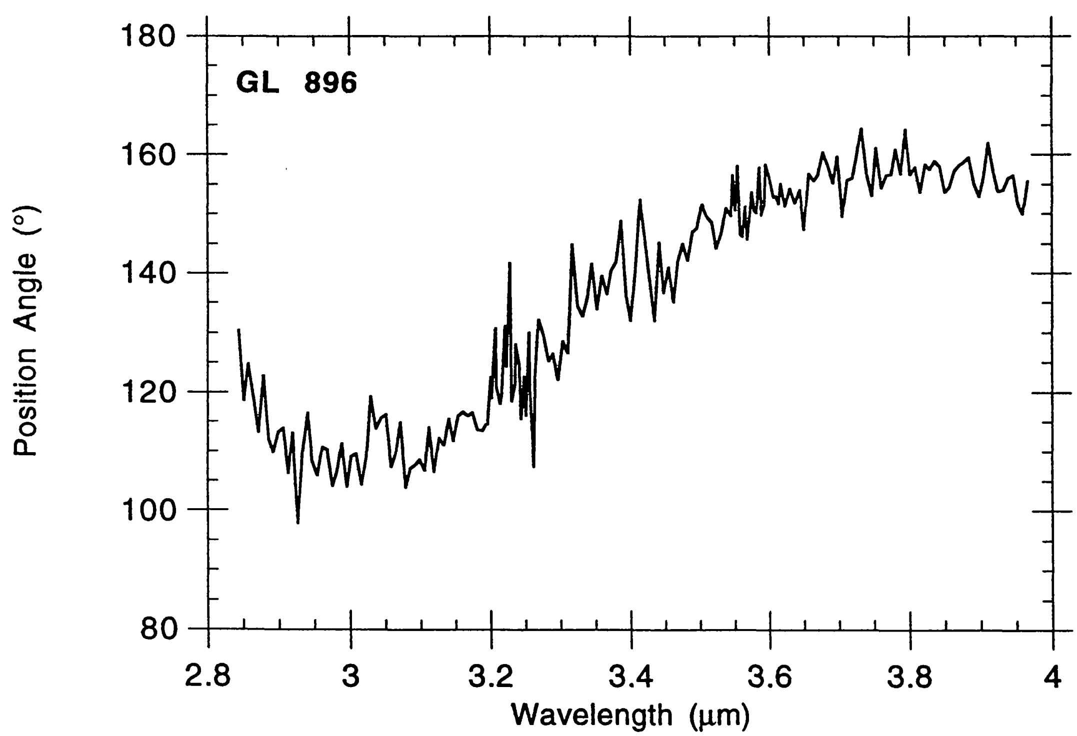


Figure 3. Changes in position angle seen across the water-ice feature for BN and GL896.

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