Astronomical Polarimetry: Current Status and Future Directions
ASP Conference Series, Vol. 343, 2005
Adamson, Aspin, Davis, and Fujiyoshi

The Hanle Effect in P Cygni Wind Lines

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Abstract. The Hanle Effect is a weak Zeeman effect that applies to resonance line scattering and operates in the range of 1–300 Gauss. So far, it has been used only in solar astrophysics. In this paper, we describe how the Hanle effect might be used to measure circumstellar magnetic fields in hot stars by presenting models and simulated data of polarimetric profiles of stellar wind lines.

1. Theory

The Hanle Effect describes how a magnetic field modifies the polarization from resonance line scattering. In a classical description of resonance scattering that treats the atom as a damped harmonic oscillator, the oscillating electron experiences precession in the presence of a magnetic field. This precession alters the distribution of scattered light with direction as well as the degree of polarization of the scattered light. The importance of this effect is determined by the ratio of the Larmor precessional rate for the electron to the radiative rate of the line transition. We define the "Hanle field" B_{Han} as the field at which resonance scattering line polarization is significantly altered. It is given by

$$B_{Han} = m_e\, c\, A_{ul}/2\, e\, g_L$$

where A_{ul} is the Einstein A-value of the upper level and g_L is the Landé factor. Typical values of B_{Han} for the strong doublet resonance lines from Lithium-like ions range from 3 Gauss for NaI (λ5890) to 15 Gauss for NV (λ1239). As a first application of the Hanle Effect to extra-solar astrophysics, we propose using the Hanle Effect polarization of the P Cygni lines in hot stars to allow us to detect magnetic fields in their winds. The Zeeman Effect is insensitive to these fields because of the very large Doppler width of the lines.

Ignace, Nordsieck, & Cassinelli (2004) describe our model for the polarized emission that arises in P Cygni wind lines. We adopt standard Sobolev theory in conjunction with a variation of the last scattering approximation. We assume that polarized line emission comes only from regions that are optically thin (i.e., $\tau_\ell < 1$), whereas optically thick regions do not contribute to the line polarization. As a result, the Hanle effect at different positions in the line profile is sensitive to the circumstellar magnetic field B_{wind} at different distances from the star.

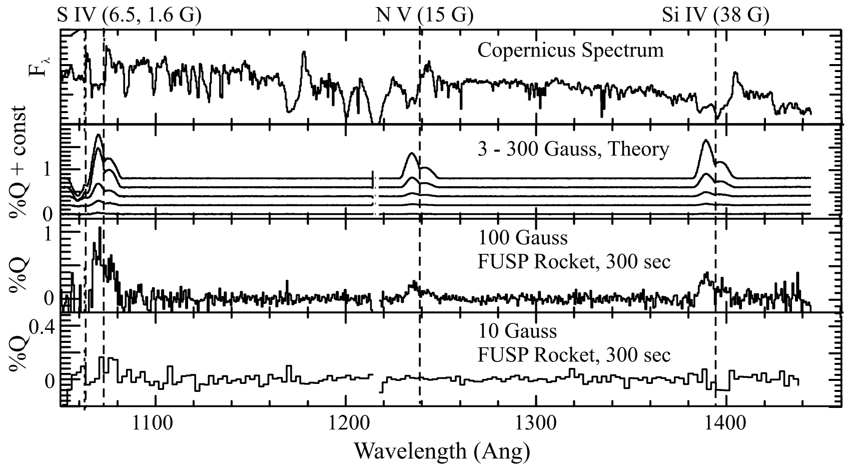

Figure 1. A simulated FUSP observation of ζ Ori. Top: Copernicus spectrum. Second panel: theoretical polarization profiles for three resonance lines, B_{Han} listed at top. Bottom panels: simulated 300 sec FUSP observations for base wind fields of 100 Gauss (unbinned) and 10 Gauss (binned to 2.4$\AA$)

For the magnetic field, we adopt a slow magnetic rotator "WCFields" model, where the field is weak enough and the rotation is slow enough that a standard β law spherical wind is still applicable. The Hanle Effect depends on the presence of a non-radial component of the field, so that as the rotation is increased, the Hanle polarization increases as the toroidal field increases. We find that line polarizations on the order of 1% should be seen for modest fields.

2. Observational Prospects

Since the P-Cygni wind lines in hot stars are all in the ultraviolet, we will require a UV polarimeter. The Far Ultraviolet SpectroPolarimeter (Nordsieck et al. 2003) is a sounding rocket payload designed to obtain the first spectropolarimetry in the far ultraviolet. It will cover wavelengths 1050–1500Å with a velocity resolution of 180 km/sec. FUSP has a telescope aperture of 50 cm, a rotating halfwave plate of stressed lithium fluoride, a 10 mm square artificial diamond brewster angle polarizer, and a spherical aberration-corrected holographic grating. A two-stage rocket will carry the payload to an apogee of 400 km, giving a total usable science time of 400 sec. The scheduled first launch is in 2005, with a "Hanle Effect" launch targeting ζ Ori (O9.5Ia) and the rapid rotator ξ Per (O7e) in 2006. Figure 1 shows a simulated observation of ζ Ori. We assume a wind with $\beta = 1$ and terminal velocity $v_{inf} = 2500$ km/sec, $v_{rot}/v_{inf} = 0.08$, $\tau_\ell = 1$, and inclination $i = 90$ deg. A base field $B_* > 30$ Gauss ($B_{wind} > 3$ Gauss) is easily detected in 300 seconds.

References

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