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Polarimetric Variability

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Invited Talk

Abstract. I present new observations of galactic and extra-galactic polarized variable sources, and demonstrate the science that one can obtain with the appropriate instrumentation.

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1. Magnetic Cataclysmic Variables

Intermediate polars (IPs) consist of a red dwarf (known as the secondary or the donor star) that is filling its Roche lobe, and an accreting white dwarf (the primary; WD). They are sub-classes of the magnetic Cataclysmic Variables (mCVs) which in turn constitute about 20% of the known CV population. IPs show a large variety of observational properties which still need to be understood in terms of accretion and evolutionary state. In contrast to polars, the white dwarfs in IPs are not phase locked to the orbital period but instead spin at a different rate (asynchronous). A wide range of WD asynchronism seems to characterize this class, and has been discussed in terms of spin equilibrium driven by magnetic accretion (Norton & Wynn 2004) which can take place in a variety of ways ranging from magnetized accretion streams to extended accretion disks.

In a few systems the presence of a soft X-ray emission component, similar to that observed in the polars (Buckley 2000), raises the question of evolution: are these soft X-ray IPs the progenitors of the polars? Our understanding of the evolutionary relationships among mCVs and in particular of IPs is unfortunately still very poor, but the addition of new systems and the study of their properties in new ways has great potential to alleviate the problem.

The study of IPs not only advances our understanding of this class of object in its own right, but also provides an opportunity to explore a broad range of astrophysical phenomena, the most obvious being accretion. CVs have been pivotal in the development of accretion-disk theory, largely because they are nearby (and hence bright), they evolve on short time-scales (hours to weeks) and are therefore ideal for micro-arc-second imaging techniques such as Doppler tomography. The additional ingredient of a magnetic field in IPs adds a further dimension to the exploration of accretion.

IPs are also a source of gamma-ray, X-ray and cyclotron optical emission. The reason is that the accretion material is eventually magnetically channelled onto the surface of the WD, where a small shock region forms. The material in the shock becomes highly ionized, very dense and very hot (several 10s of KeV), leading to the emission of X-ray radiation (by Bremsstrahlung) and cyclotron radiation (optically polarized). The white dwarfs in intermediate polars typically rotate every 10–20 minutes, thus permitting an almost 180° probe of the shocks on short time-scales.

An additional recent surprise is the discovery of planets in CV systems (Potter *et al.* 2011, in press; Beuerman *et al.* 2011), which has certainly expanded the types of environments in which planet formation is thought to take place.

Fig. 1 demonstrates the importance of using the correct polarimetric instrumentation. It shows two sets of observations of the same target—the intermediate polar NY Lup.

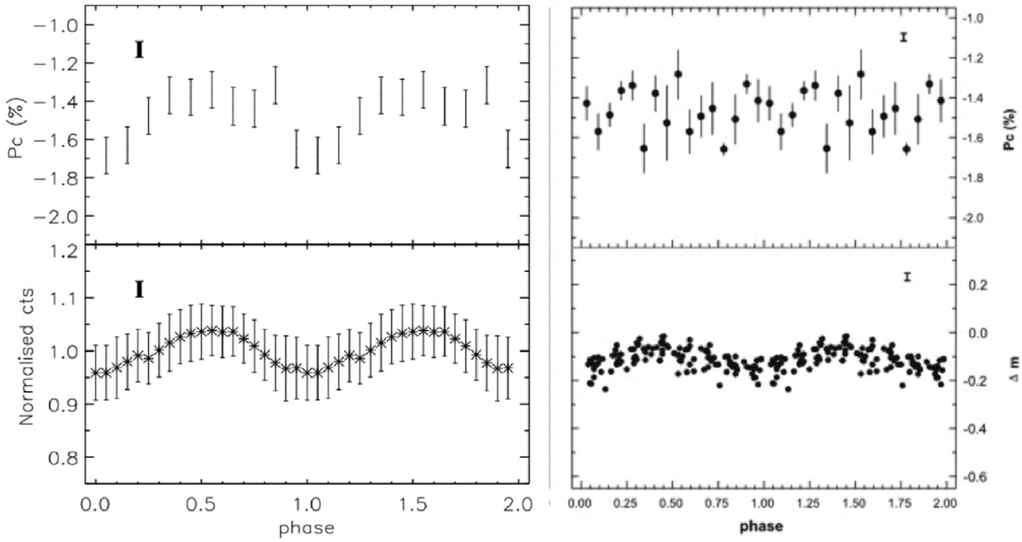

Figure 1. Photo-polarimetric observations of the IP NY Lup. The top and the bottom panels are the phase-spin-folded circular polarization and photometry, respectively. The left and right panels were made with the SAAO 1.9-m telescope and the VLT, respectively.

The upper and lower panels show spin-phase-folded circular polarization and photometry, respectively. Both data sets (left and right) show a detection of the spin period in the photometry; however, only the left data set shows a clear spin modulation in the circular polarization. Contrary to expectations, the superior data on the left were obtained with a 1.9-m telescope whereas those on the right were observed with the VLT. Moreover, the 1.9-m polarimeter (Potter *et al.* 2010) used photomultiplier detectors, which are several times lower in sensitivity compared to the CCD detector used on the VLT. The 1.9-m polarimeter also measured circular AND linear polarization simultaneously in two filters (not shown). The reason why the 1.9-m polarimeter does so well is because it is optimised to measure polarization variability. The exposure readout times of the photomultiplier tubes are very fast (sub-second), thus enabling polarization measurements to be made on a much shorter time-scale than the intrinsic variability of the polarization. The CCD readout times on the VLT were too slow, and led to the variability becoming smeared.

2. Blazars

Another source of polarimetric variability are blazars. Blazars, or BL Lacertae objects (BL Lacs), are radio-loud active galactic nuclei (AGNs) in which the relativistic jets are aligned close to the line-of-sight of the observer. They are characterised by intense and rapid variability across the electromagnetic spectrum; many of these objects demonstrate rapid and intense flaring episodes. For example, Aharonian *et al.* (2007) reported that during 2006 July PKS2155 experienced an outburst that corresponded to a Very High Energy (VHE, for $E > 200\,GeV$) flux increase of 35 times its quiescent level, some 20% Crab, i.e. 0.2 times the flux observed from the Crab Nebula (Abramowski *et al.* 2010). It has been shown that the radio and optical polarisation features of blazars are correlated (Gabuzda *et al.* 2006). The optical polarization can therefore be used as a tracer of the resolved radio state, but on time-scales relevant to VHE measurements. That implies

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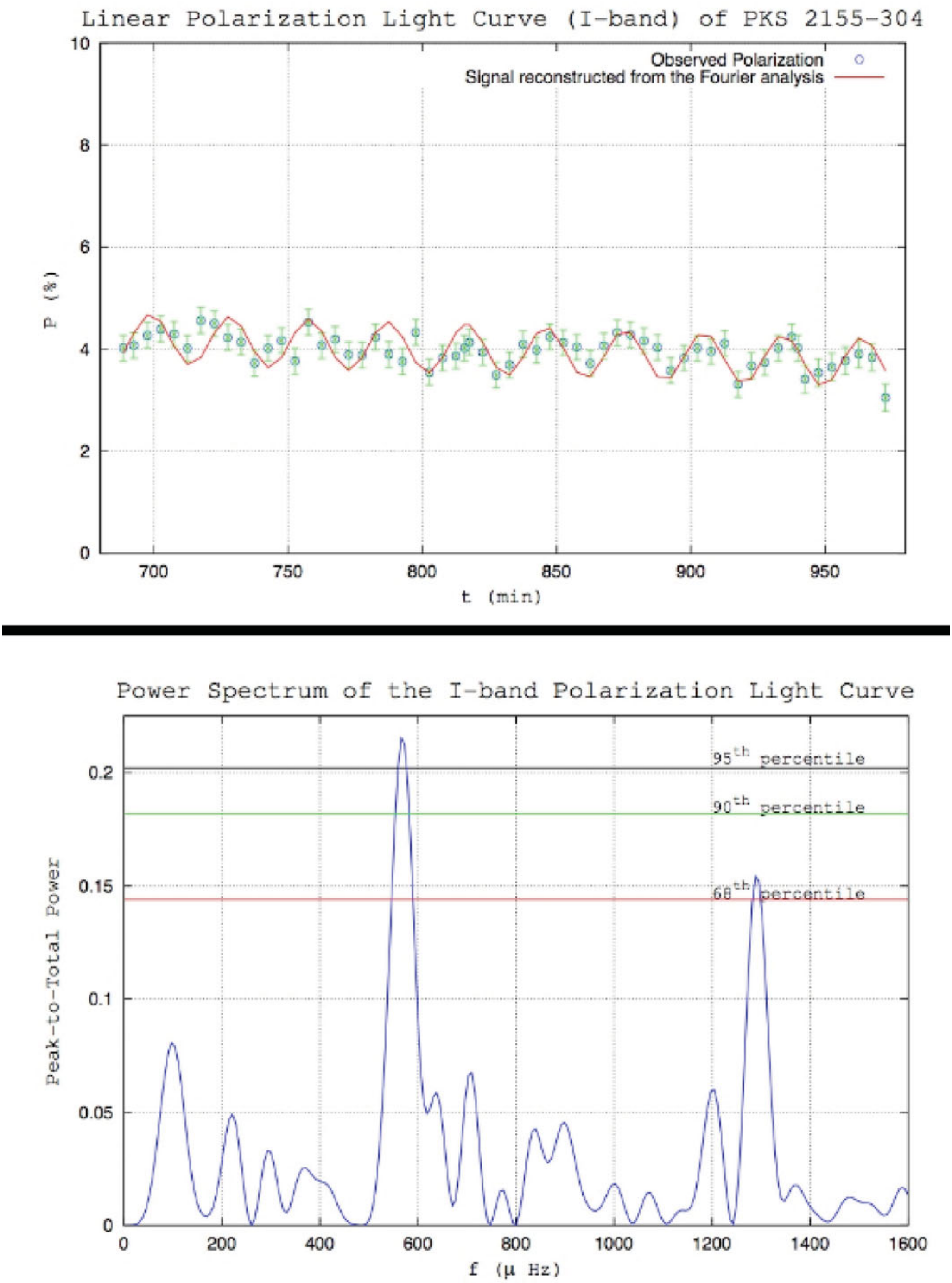

Figure 2. Variable linear polarization from the blazar PKS2155. The upper and lower panels show the linear polarization and corresponding Fourier analysis, respectively.

that we should be able to constrain the location of the emitting region in the jet as well as gaining information on the strength and orientation of the magnetic field of the jet; those are all important parameters for modelling blazar physics.

Fig. 2 shows new observations of PKS2155 taken with the polarimeter on the SAAO 1.9-m telescope. The observations were made during the 2009 flare event. The top panel shows the I-band linear polarization spanning $\sim$5 hours. What is immediately apparent is a possible quasi-periodic oscillation of $\sim$30 minutes as traced out by the solid curve. The lower plot shows the corresponding Fourier transform of the data, and indicates a strong peak at $\sim$30 minutes. Unfortunately the data do not continue long enough to confirm unambiguously that PKS2155 is a QPO, and are not some chance variability. However the time variability is intrinsic to PKS2155, and the time-scales can be used to put constraints on the sizes of emission regions, etc. These observations can also be combined with gamma-ray observations, particularly where various competing shocked-jet models (Holmes *et al.* 1984; Valtaoja *et al.* 1991) make different predictions.

3. Summary

With the correct polarimetric instrumentation, significant discoveries can be made with even a small telescope. Indeed, the polarimeter on the SAAO 1.9-m telescope outperforms the polarimeter on the VLT in high-time-domain polarimetry. In fact the VLT observations of the IP NY Lup did not detect the polarimetric spin modulation due to the spinning white dwarf.

The next step will be to obtain high-speed spectropolarimetry, and that will require high-speed CCD detectors on a 10-m-class telescope. The Robert Stobie Spectrograph on the Southern African Large Telescope has that capability, and is currently undergoing its commissioning phase.

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