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POLARIMETRIC SIGNATURES OF INFRARED JETS IN X-RAY BINARIES

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RESUMEN

Presentamos espectro-polarimetría en el cercano infrarrojo de una muestra de estrellas binarias de rayos-X persistentes, Sco X–1, Cyg X–2 y GRS 1915+105. Para Sco X–1 y Cyg X–2 los niveles de polarización a 2.4 μm son de 1.3±0.10% y 5.4±0.7%, respectivamente, mayores a los niveles de polarización a 1.65 μm. Esto no puede ser explicado por polarización interestelar o dispersión electrónica en el ambiente anisotrópico del flujo de acreción. Proponemos que la explicación más probable es que se trate de la firma de la emisión sincrotrón proveniente de cerca de la base del chorro. Para Sco X–1, el ángulo en el cielo del chorro en radio es aproximadamente perpendicular al ángulo de posición en el infrarrojo cercano (vector eléctrico), sugiriendo que el campo magnético está alineado con el chorro. Estas observaciones pueden ser un primer paso para el sondeo del ordenamiento, alineamiento y variabilidad del flujo magnético, en una región más cercana a la fuente central que lo observado en el radio.

ABSTRACT

We present near-infrared linear spectropolarimetry of a sample of persistent X-ray binaries, Sco X–1, Cyg X–2 and GRS 1915+105. For Sco X–1 and Cyg X–2, the polarization levels at 2.4 μm are 1.3±0.10% and 5.4±0.7%, respectively, which is greater than the polarization level at 1.65 μm. This cannot be explained by interstellar polarization or electron scattering in the anisotropic environment of the accretion flow. We propose that the most likely explanation is that this is the polarimetric signature of synchrotron emission arising from close to the base of the jet. For Sco X–1 the position angle of the radio jet on the sky is approximately perpendicular to the near-infrared position angle (electric vector), suggesting that the magnetic field is aligned with the jet. These observations may be a first step towards probing the ordering, alignment, and variability of the outflow magnetic field, in a region closer to the central accreting object than is observed in the radio band.

Key Words: X-rays: binaries

1. INTRODUCTION

In the past decade or so overwhelming evidence has pointed to a clear coupling between accretion and the formation of relativistic jets in galactic X-ray binary systems (see Fender 2006). Accretion states associated with hard X-ray spectra appear to be associated with the production of a relatively steady, continuously replenished and partially self-absorbed outflow, while major outbursts are associated with more discrete ejection events which may be resolved and tracked with radio interferometers (e.g. Mirabel & Rodriguez 1994).

In the radio band, the steady jets observed during the hard X-ray states have a flat spectrum ($\alpha \sim 0$, where $S_\nu \propto \nu^\alpha$), probably resulting from self-absorption in a self-similar outflow (e.g. Blandford & Konigl 1979). Above certain frequency this flat spectral component should break into an optically thin spectrum ($\alpha \sim -0.6$) corresponding to the point at which the entire jet becomes transparent. There is some evidence from some black hole X-ray binaries that this break occurs around the near-infrared spectral region (e.g. Corbel & Fender 2002), something which can be well fit by jet models (Markoff et al. 2001; Markoff et al. 2003). Thus the case is strong, that there is a significant contribution of synchrotron emission, probably optically thin, in the near-infrared spectral regimes of X-ray binaries. However, one key test which is yet to be reported is a measurement of the linear polarization in this regime. Here we present near-infrared spectropolarimetry for a sample of luminous X-ray binaries (Shahbaz et al. 2008), all of which can be confidently identified as jet sources based on radio observations.

2. OBSERVATIONS AND DATA REDUCTION

We obtained HK spectropolarimetry of three X-ray binaries Sco X–1, Cyg X–2 and GRS 1915+105

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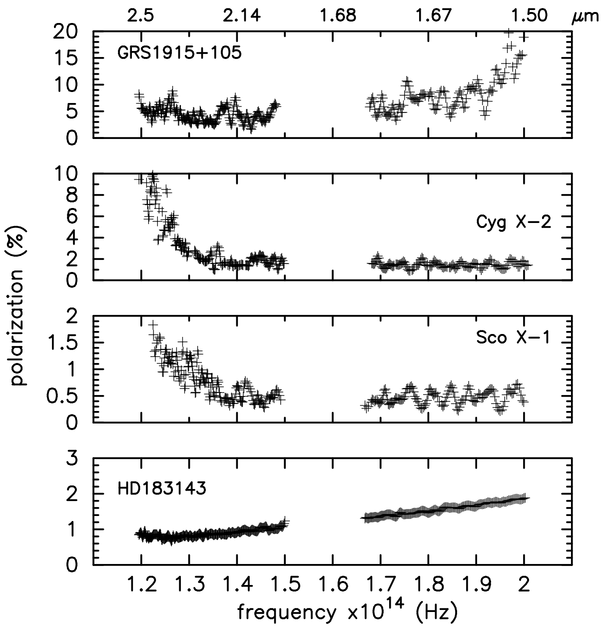

Fig. 1. From top to bottom: the HK linear polarization spectrum of GRS 1915+05, Cyg X–2, Sco X–1 and the polarized standard star HD184143.

with UKIRT during the nights of 18, 19, 22 and 23 July 2004. UIST was used with the HK (1.4 μm–2.5 μm) grism and the IRPOL2 polarimetry module. Rotating the half-wave retarder to 0.0°, 45°, 22.5° and 67.5° allowed us to obtained spectropolarimetry. The normalized Stokes parameters were then determined.

3. RESULTS

Sco X–1: The mean linear polarization for Sco X–1 is 0.47±0.05% and 1.3±0.10%, at 1.65 μm and 2.4 μm, respectively, which cannot be described as interstellar. The overall optical and near-infrared polarization spectrum can be described by two components: an interstellar polarization spectrum in the optical, and another component which dominates the H and K-band polarization spectrum (Figure 1). It should be noted that recent broad-band JHK measurements of polarization of Sco X-1 agree with the values we obtain here (Russell & Fender 2008). Given that Sco X–1 is known to be a powerful and variable jet source (Fomalont et al. 2001) the component in the IR is most likely due to optically thin synchrotron emission from the jet. We can compare the near-infrared position angles with the position angle in the radio images of Sco X–1. The mean position angle of the radio jet on the sky is 54 degrees (Fomalont et al. 2001). This is approximately perpendicular to the near-infrared electric vector position angle which implies that the magnetic field is aligned with the jet (assuming optically thin synchrotron emission).

Cyg X–2: Our IR linear polarization measurements of 1.7% and 5.4%, at 1.65 μm and 2.4 μm, respectively, show a considerable excess in the near-infrared compared to the optical.

GRS 1915+105: Our near-infrared linear polarization measurements of 7.5% and 5.0%, at 1.65 μm and 2.4 μm, may in fact be consistent with interstellar polarization, given the very high degree of extinction. However, we can estimate the maximum amount of interstellar polarization (Jones 1989). For GRS 1915+105 the extinction of $E(B-V)$=6.3 (Chapuis & Corbel 2004) gives a maximum interstellar polarization of 3.3% at 2.2 μm. The observed polarization at 2.2 μm of 3.7±1.1% suggests that the observed polarization may in fact be consistent with interstellar polarization.

4. POLARIZATION FROM JETS?

The near-infrared "excess" polarization is due to synchrotron emission from jets. Two polarization signatures are expected from the jet, depending on whether the synchrotron emission is optically thick or thin or not. Above some frequency this flat spectral component should break to an optically thin spectrum ($\alpha \sim -0.6$; $S_\nu \propto \nu^\alpha$) corresponding to the point at which the entire jet becomes transparent. For the optically thick part of the spectrum, which results in the flat spectral component ($\alpha \sim 0$) observed in the hard X-ray state, no more than a few % polarization is expected.

There exists the possibility of a large fractional polarization level from optically thin synchrotron emission. While, it is by no means firmly established, a small number of observational and theoretical results suggest a break between optically thick and thin emission should occur around the near-infrared band (e.g. see Corbel & Fender 2002). Optically thick synchrotron emission has a maximum linear polarization of ∼10% (Blandford et al. 2002), whereas optically thin synchrotron emission can have a fractional linear polarization as high as 70% (Blandford et al. 2002), Figure 2 illustrates in more detail our expectation for the intrinsic (i.e. before interstellar scattering) linear polarization signature in the near-infrared and optical regimes, based on spectral energy distributions published in Corbel & Fender (2002) and Homan et al. (2005) and the simple ideas outlined above. At long wavelengths (maybe in the mid-infrared) there will only be ∼ 1% polarization from the self-absorbed jet; at

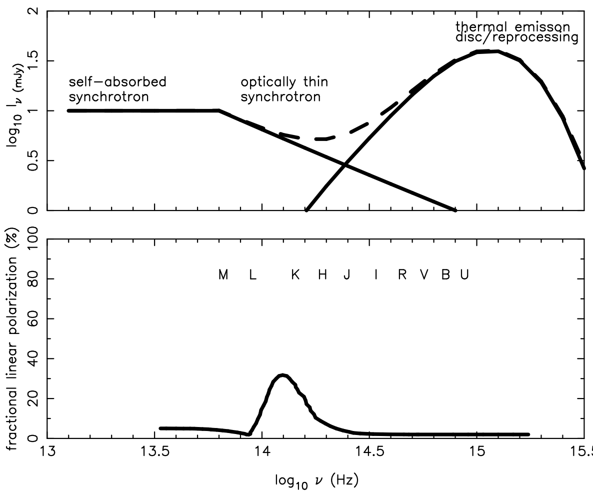

Fig. 2. Expectations for the linear polarization signature in the near-infrared and optical regimes of X-ray binaries. A narrow spectral region with relatively high linear polarization arising from close to the base of the jet is expected.

short wavelengths a comparable level will be measured due to scattering in the accretion flow. However, in the relatively narrow spectral region in which optically thin synchrotron emission dominates, we may expect a strong signature which initially rises to longer wavelengths as the relative jet to disc fraction increases (Shahbaz et al. 2008).

For Sco X–1 we find that the magnetic field is aligned with the jet. Both parallel and perpendicular magnetic fields are seen in radio jets. In the radio polarization maps of Cir X–1 one observes the polarization vector rotate through 90 degrees between the core and the jet (Fender et al., in prep.). Parallel magnetic fields are related to the intrinsic jet structure, perhaps helping to collimate the flow, whereas perpendicular magnetic fields indicate shocks, where the outflow is compressed along the jets axis (Saikia & Salter 1988). Measurements of the linear polarization of the compact jet in the near-infrared can probe a region closer to the central black hole or neutron star than the radio band, and reveal the degree or ordering of the magnetic field close to the jets's base. Furthermore, Faraday rotation (which is proportional to λ^2) is insignificant at near-infrared wavelengths, so that the linear polarization electric vector position angle tells us directly about the orientation of the magnetic field (the two are perpendicular). The three measurements reported here, at least two of which indicate a significant contribution of synchrotron emission in the near-infrared, should be the beginning of a highly useful line of inquiry in the near future.

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