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Outflows and jets from low mass protostars in Bok globules: the case of CB230

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Abstract. We have been investigating the low-mass star forming process in the Bok globule CB230 through NIR and mm wavelengths observations. A bright hot jet component emanating from a deeply embedded YSO has been found in the 1.64 μm line of [FeII], suggesting the presence of dissociative J-type shocks. The jet is composed of two well-defined knots and is located at the base of a larger scale, cold, molecular outflow. The [FeII] emission has been confirmed by the detection of several bright lines towards the jet as well as towards the driving YSO. These results allow us to investigate how the mass loss activity from YSOs affects the high-density medium hosting the newly-born low-mass stars.

Key words. stars: formation – ISM: jets and outflows – infrared: ISM

1. Introduction

Outflow and infall are inextricably associated with the very earliest stages of star formation. The present flow activity is represented by a fast, hot component traced by H_2 and/or [FeII] near-Infrared (NIR) lines, arising under a range of physical conditions leading to C- and J-shocks, respectively. Bok globules are a very good place to study the jet component: cold (10 K), nearby ($\sim$ a few 100 pc), small ($\sim$ 0.7 pc) and relatively isolated molecular clouds, often with dense cores and embedded protostars (Clemens & Barvainis 1988, and references therein). Globules form low-mass stars in small numbers and are therefore without the observational confusion found in regions like Orion or Ophiuchus. We are carrying out a survey of a sample of Bok globules searching for jet signatures through observations in the narrow-band filters centred on the 2.12 μm and the 1.64 μm lines of H_2 and [FeII], respectively. When these are found, follow-up spectral observations both in the NIR (to sample the physical conditions in the shocked gas) and in the mm (to probe

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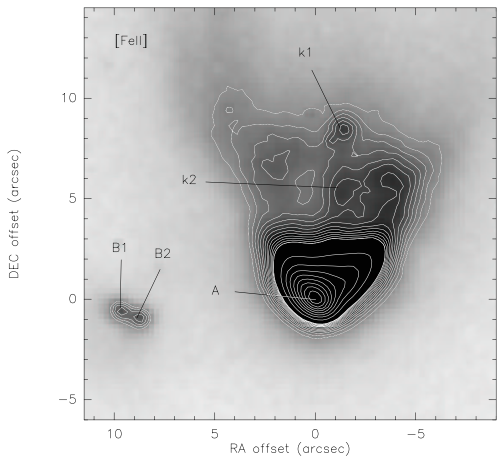

Fig. 1. TNG/NICS observations of CB230 in the [FeII] filter (still including continuum emission). The brightest YSO is indicated by A. On the left, note the smaller object, which contains two sources (B1 and B2). The diffuse emission north of A suggests the occurrence of two knots (called k1 and k2), which are clearly detected in [FeII] pure line emission (see Fig. 2).

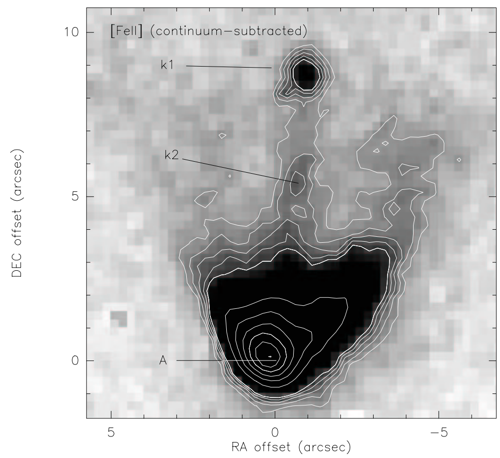

Fig. 2. Image of CB230 in the [FeII] 1.64 μm line (i. e., after continuum subtraction). The knots k1 and k2 are now evident, tracing a jet-like structure departing from A. Note that A is still visible in the line emission.

the cold molecular outflow) are carried out. The aim is to study the interaction between the jet-component, the outflows and the ambient cloud. In the following we present a summary of the results for the Bok globule CB230 ($d \sim 450$ pc), which hosts a NIR object classified as a Class 0/Class I protostar. Froebrich (2004) quotes a bolometric luminosity of 7.7 $L_\odot$ and an envelope mass of 0.56 $M_\odot$, deriving an age of $2 \times 10^4 - 10^5$ yrs. This makes CB230 an ideal laboratory to study the early stages of low-mass star forming processes.

2. Observations

Observations (Massi et al. 2004) were carried out with the 3.58-m Italian Telescopio Nazionale Galileo (TNG) at La Palma (Canary Islands, Spain) in July 2002 (imaging) and August 2004 (spectra). The images were obtained with the Near Infrared Camera Spectrometer (NICS) through narrow-band filters centred on the 1.644 μm [FeII] $a^4D_{7/2} - a^4F_{9/2}$ and 2.122 μm H_2 v=$1-0$ S(1) lines and on the adjacent continuum at 1.57 μm (H_{cont}) and 2.28 μm (K_{cont}). The spectra were also obtained with NICS through the grisms JH ($1.15 - 1.75$ μm) and HK ($1.40 - 2.50$ μm), using a 1 arcsec-wide slit and with a spectral resolution $R \sim 500$. The slit was aligned along the jet detected in [FeII] (see following text and Fig. 2). The molecular outflow has been investigated with the 15-m JCMT (Hawaii, USA) and the 30-m IRAM (Pico Veleta, Spain) antennas through mm-observations of emission lines of various CO isotopomers and other molecular species; maps of the dust continuum emission were made with SCUBA at the JCMT (Brand et al., in preparation).

3. Results

In Fig. 1, a zoom-in on the central part of the globule is shown in the [FeII] filter (still including continuum). Most of the emission seen in Fig. 1 is due to dust-reflected light

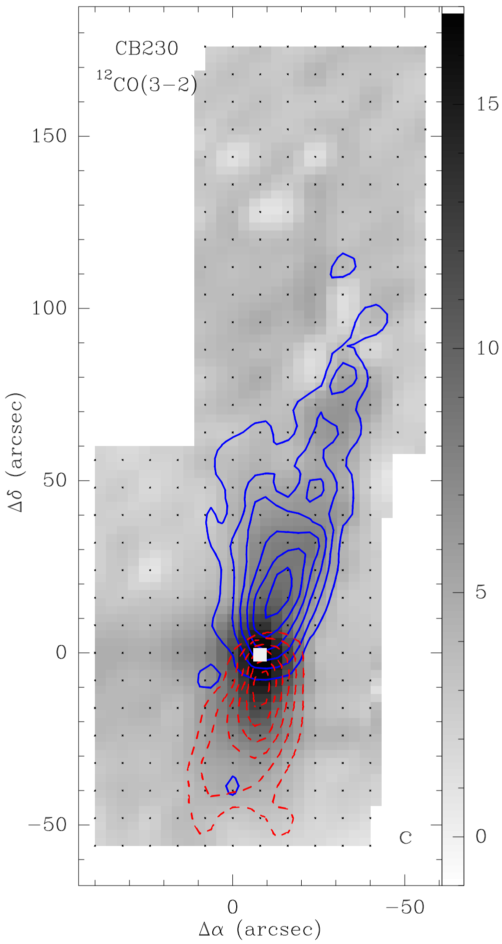

Fig. 3. CB230, outflow in CO(3–2) obtained with the JCMT antenna. The blue and red lobes are shown by drawn and dashed contours, respectively. The grey scale indicates the emission of the quiescent bulk of the gas. Observed positions are shown as small dots; the filled square indicates the SCUBA 450 and 850μm peaks (Brand et al., in preparation).

from an object (labeled as A) hidden in a cloud cavity, open to the North. Images with only H_2 and [FeII] line emission were obtained by a careful subtraction of the underlying continuum, scaling the H_{cont} and K_{cont} images. They reveal a spectacular jet in [FeII] (Fig. 2), which is traced also by a weaker structure in H_2 (Massi et al. 2004). The presence of strong [FeII] and weaker H_2 emission suggests the presence of fast, dissociative J-shocks. The jet is oriented in the N-S direction and has two knots (k1 and k2 in Fig. 2) superimposed on a fainter elongated emission feature. It lies at the base of the blue lobe of a large-scale molecular outflow shown in Fig. 3 through a preliminary CO(3–2) map. The main axis of the outflow also has an almost N-S orientation and has its origin at the YSO embedded at the apex of the bright nebulosity. Another interesting new finding from the TNG observations is that the small nebulous emission to the East, previously thought to be a single object which together with source A represents an embedded binary system (Yun & Clemens 1994), is seen to contain two sources (labeled B1 and B2 in Fig. 1), making this a triple system.

The low-resolution NIR spectra of the knot k1, located at the tip of the jet (see Fig. 4), and of source A (see Fig. 5) confirm the presence of the [FeII] lines. The spectra show an intense emission not only from the knot, but also from the YSO driving the jet. We note that also bright H_2 emission in the 2.12 μm line has been detected from source A (the K spectra are not shown here). Its continuum emission is characterized by a rising flux with wavelength (Fig. 5), typical of embedded objects. By using the ratio between the [FeII] lines at 1.25 and 1.64 μm, it is possible to estimate the extinction which ranges from $A_V \sim 16$ mag towards source A to $A_V \sim 14$ mag towards the knot k1.

The large scale outflow (see Fig. 3) extends roughly for 0.3 pc, suggesting a dynamical time of order $\sim$(1–5)$\times 10^4$ yrs (with gas velocities of $\sim$ 5–10 km s^{-1} inferred from the spread of the red- and blue-wings of the CO spectral profile). Our multi-transition observations indicate that the core where the driving source is embedded is quite cold ($\sim$ 20 K).

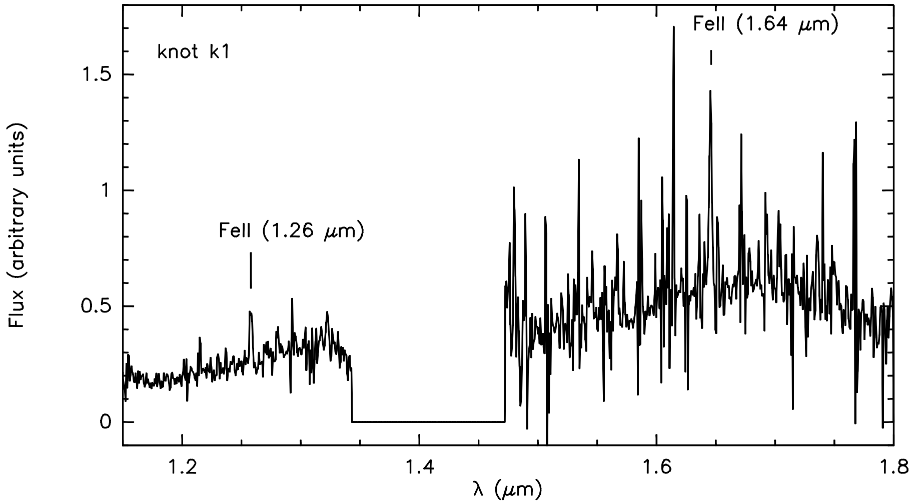

Fig. 4. TNG/NICS low-resolution spectrum of the knot k1 in the J and H bands, clearly showing [FeII] emission lines.

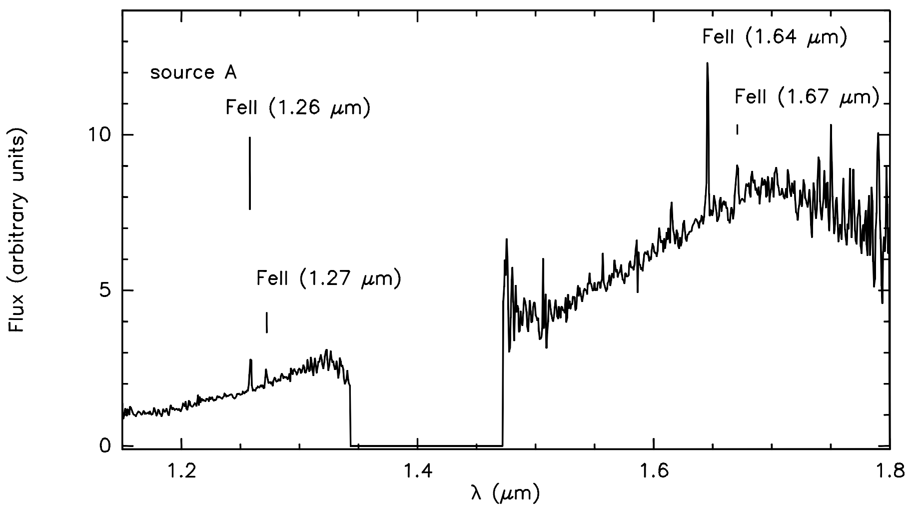

Fig. 5. TNG/NICS low-resolution spectrum of the embedded source A in the J and H bands. Note that [FeII] emission lines are still visible, as suggested by Fig. 2.

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