The infrared properties of the new outburst star
IRAS 05436−0007 in quiescent phase

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Received date; accepted date

Abstract. We compiled and investigated the infrared/sub-mm/mm SED of the new outburst star IRAS 05436−0007 in quiescent phase. The star is a flat-spectrum source, with an estimated total luminosity of $L_{\text{bol}} \approx 5.6 \, L_{\odot}$, typical of low-mass T Tauri stars. The derived circumstellar mass of 0.5 $M_{\odot}$ is rather high among low-mass YSOs. The observed SED differs from the SEDs of typical T Tauri stars and of 4 well-known EXors, and resembles more the SEDs of FU Orionis objects indicating the presence of a circumstellar envelope. IRAS 05436−0007 seems to be a Class II source with an age of approximately $4 \times 10^7$ yr. In this evolutionary stage an accretion disc is already fully developed, yet a circumstellar envelope may also be present. Observations of the present outburst will provide additional knowledge on the source.

Key words. Stars: formation – stars: circumstellar matter – Stars: individual: IRAS 05436−0007 – infrared: stars

1. Introduction

On 23 Jan 2004 the amateur astronomer J.W. McNeil discovered a new nebula towards the Orion B molecular cloud, close to the diffuse nebulosity Messier 78 (McNeil et al. 2004). The object was not visible in either of the two Palomar Surveys (1951, 1990), but a photograph taken in 1966 for the book “The Messier Album” (Mallas & Kreimer 1978) shows a bright nebulosity very similar to the one of today. Also in the very deep [SII] image of Eislöffel and Mundt (1997), taken in October 1995, parts of the nebula are clearly visible though fainter than in 1966. The alternation of active and quiescent periods, suggested by these earlier observations, indicates that the event, probably the eruption of a pre-main sequence star, may be similar to the well-known EXor-type outbursts.

At infrared and sub-millimetre wavelengths, however, the source was observable also during the quiescent periods (IRAS, 2MASS, Lis et al. 1999, Mitchell et al. 2001). At these wavelengths the emission is due to thermal radiation of circumstellar dust. The infrared/sub-mm/mm data offer a possibility to study the circumstellar matter – which is likely responsible for the explosion via a sudden rise of the accretion onto the star (Hartmann & Kenyon 1996) – prior to an outburst.

In this paper we collect all infrared/sub-mm observations available in the literature and compile a spectral energy distribution (SED) representative of the quiescent phase. The SED will be analysed, and compared with SEDs of pre-main sequence stars, including several known FUORs and EXors.

2. Infrared/sub-mm/mm data

From the literature one can collect several infrared and sub-mm/mm flux values for the new outburst star:

The 2MASS All-Sky Catalog of Point Sources (Cutri et al. 2003) contains a source coinciding with the optical position of the new star. We adopt the coordinates of this source,

Table 1. Infrared/sub-mm/mm observations of IRAS 05436−0007 collected from the literature (Sect.\textsuperscript{2}). No reddening correction was applied. We adopt the coordinates of the 2MASS source, $\alpha_{2000} = 5^{h}46^{m}13^{s}13$ $\delta_{2000} = -0^\circ6^\prime4^\prime\prime8$, as the position of the outburst star.
J05461313−0006048, as the position of the outburst object: 
\[ \alpha_{2000} = 5^{h}46^{m}13^{s}, \delta_{2000} = -0^\circ6'4''8. \]
Table 1 presents the 
2MASS JHK \_S fluxes, which are all flagged as high quality data in the catalogue.

In the ISO Data Archive there are two mid-infrared maps, taken by the ISOCAM instrument, which covers the position of the star. Checking the source lists available in the FITS file headers, it was possible to identify a point source coinciding with the 2MASS source. Its flux densities (produced by ISO’s automatic off-line processing software) are also given in Table 1.

The outburst star was identified with the IRAS source 05436−0007 by Eisloffel & Mundt (1997). We adopted the 12 and 25 \( \mu \)m flux densities from the IRAS Point Source Catalogue (Tab. 1). At longer wavelengths the PSC gives only upper limit, therefore we determined new IRAS fluxes using the SCANPI Processing Tool at IPAC. At 60 \( \mu \)m it was possible to extract an estimated in both plates). The total integrated fluxes, taken from the papers, as well as the names the authors gave to the object are given in Table 1.

Near-infrared: the unusually high \( J−H \) and \( H−K \) indices indicate that the central source is heavily extincted. Figure 2 shows the location of the star on a \( J−H \) vs. \( H−K \) diagram. A backward projection parallel to the reddening path onto the locus of the classical T Tauri stars (Meyer et al. 1997) gives a reddened colour indices of \( (J−H) = 1.15 \) magnitude and \( (H−K) = 1.08 \) magnitude. The near-infrared reddening is \( E(J−H) = 1.43 \) mag, and using the relationship of Rieke & Lebofsky (1985) this result gives a visual interstellar extinction of \( A_V \approx 13 \) magnitude. One should keep in mind that the observed near-infrared colours could be affected by scattering and extinction value (and also the result of the reddening correction in Fig. 5) should be taken with some caution. The \( (J−H) \) and \( (H−K) \) values indicate the presence of a significant amount of circumstellar matter.

Mid-infrared (7−25 \( \mu \)m): Based on the IRAS and sub-mm data points, Lis et al. (1999, their Fig. 6) modelled the SED as a sum of two modified Planck functions with \( T = 165 \) K and \( T = 30 \) K. The inclusion of the ISOCAM fluxes, however, does not support this simple model, but indicates that IRAS 05436−0007 is a flat-spectrum source at infrared wavelengths. Such a SED requires a less steep radial temperature profile than expected from an optically thick, geometrically thin circumstellar disk, and can be the result either of a flared disk (Adams et al. 1988) or of an extended envelope. Detailed modelling of FU Ori-type objects (Turner et al. 1997) showed that flared disks alone may not be able to produce a flat spec-
Fig. 2. The location of IRAS 05436−0007 (star) on a near-infrared colour-colour diagram. Overplotted are the unreddened main sequence (solid line) and giant sequence (dotted line), the reddening path of the main sequence (dashed line), and also the locus of the dereddened classical T Tauri stars (dashed-dot line, Meyer et al. 1997).

Spectral energy distributions of IRAS 05436−0007 after correcting for an interstellar extinction of AV = 13 magnitude.

5. Discussion

5.1. Comparison with pre-main sequence stars

In this section we compare the SED of IRAS 05436−0007 with a sample of SEDs of pre-main sequence stars. We focus on the λ ≥ 10 µm spectral range, because at optical/near-infrared wavelengths the variation of circumstellar extinction with inclination angle introduces a diversity in the spectral shapes.

T Tauri stars. The median SED of 39 young stars from the Taurus-Auriga star-forming region was constructed by D’Alessio et al. (1999). Their Fig. 5 reveals that the median SED declines towards longer wavelengths in the 10−100 µm range, which is clearly inconsistent with the flat spectrum of IRAS 05436−0007.

EXors. The infrared SEDs of 4 well-known EXor-type objects (EX Lup, DR Tau, UZ Tau, VY Tau) in quiescent phase were derived from ISOPHOT observations by Stringfellow et al. (2004). Similarly to the T Tauri stars, these objects also exhibit SEDs declining towards longer wavelengths, significantly differing from the SED of IRAS 05436−0007. On the other hand, the intermediate-mass young star PV Cephei, which is sometimes classified as an eruptive EXor-like variable (e.g. Teodorani et al. 1999) shows an approximately flat SED (Ábrahám et al. 2000).

FUORs. In Fig. 4 we collected the infrared SEDs of 6 FU Ori-type objects published in Kóspál et al. (2004), which are in the post-outburst phase. All these SEDs are flat (νFν ~ const.) or even raising with increasing wavelength in the 10−100 µm spectral range. These SEDs resemble more the SED of the new outburst star (Fig. 1) than do either the SEDs of the T Tau-stars or the EXors. Especially the 3 sources with flat mid-infrared
lutionary stage of the source, we followed the method of Chen et al. (1995) and computed the bolometric temperature $T_{bol}$ according to their Eq. 1. The resulting $T_{bol} = 830 \text{ K}$ and the bolometric luminosity $L_{bol} \approx 5.6 L_\odot$ was then compared with the distribution of corresponding values among YSOs in the Taurus and $\rho$ Oph star forming regions (Chen et al. 1995). From this check we can conclude that IRAS 05436$-0007$ seems to be a Class II object (close to the Class I/Class II boundary), and its age – according to Fig. 4 of Chen et al. (1995) – is approximately $4 \times 10^5 \text{ yr}$.

6. Conclusions

We compiled and investigated the infrared/sub-mm/mm SED of the new outburst star IRAS 05436$-0007$ in quiescent phase. The star is a flat-spectrum source, with an estimated total luminosity of $L_{bol} \approx 5.6 L_\odot$, typical of low-mass T Tauri stars. The derived circumstellar mass of $0.5 M_\odot$ is rather high among low-mass YSOs. The observed SED differs from the SEDs of typical T Tauri stars and of 4 well-known EXors, and resembles more the SEDs of FU Orionis objects indicating the presence of a circumstellar envelope. IRAS 05436$-0007$ seems to be a Class II source with an age of approximately $4 \times 10^5 \text{ yr}$.

In this evolutionary stage an accretion disk is already fully developed, though a circumstellar envelope may also be present. Observations of the present outburst will provide additional knowledge on the source.

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Fig. 4. Spectral energy distributions of 6 FUORs (from Kóspál et al. 2004). The presented data are based on observations obtained by ISOPHOT, the photometer on-board the Infrared Space Observatory, supplemented by IRAS, MSX, 2MASS, and sub-mm/mm data. In case the SED changed between 1983 and 1997 (Kóspál et al. 2004) only the more recent data set was plotted.

spectra: V346 Nor, V1057 Cyg, and Z CMa, look similar to IRAS 05436$-0007$ (though in the case of Z CMa the companion, a Herbig Ae/Be star, might also contribute to the SED).

The fact that IRAS 05436$-0007$ was bright also in 1966 (Sect. 3) suggests multiple active periods, i.e. an EXor-like nature. Its luminosity of $5.6 L_\odot$ (Sect. 4) is also more typical for the T Tau-like EXors than for the 5–100 times more luminous FUORs (Sandell & Weintraub 2001). However, on the basis of the shape of the spectral energy distribution, IRAS 05436$-0007$ is more similar to the FU Orionis objects. The flat spectra of the FUORs are usually interpreted in terms of extended circumstellar envelopes (Kenyon & Hartmann 1991, Turner et al. 1997), whose material is falling onto the outer parts of the accretion disk. Thus IRAS 05436$-0007$ might also be surrounded by an envelope, which – together with the unusually large circumstellar mass of $\approx 0.5 M_\odot$ (Sect. 4) – would make this object relatively unique among the known EXors. Observations of the present outburst, including measurements of the infrared SED with the Spitzer Space Telescope, will provide more data to compute detailed models of the circumstellar structure.

5.2. Evolutionary stage of IRAS 05436$-0007$

Based on the submillimetre-to-bolometric luminosity ratio Lis et al. (1999) proposed that IRAS 05436$-0007$ is a relatively young and embedded Class 0 source, though some observations (e.g. the lack of molecular outflow) seemed to indicate that the source was more evolved. In order to estimate the evo-