

# THE LONG-TERM EVOLUTION OF 7 FU ORIONIS-TYPE STARS AT INFRARED WAVELENGTHS

Á. Kóspál<sup>1</sup>, P. Ábrahám<sup>2</sup>,  
Sz. Csizmadia<sup>2</sup>, M. Kun<sup>2</sup>, A. Moór<sup>2</sup> and T. Prusti<sup>3</sup>

<sup>1</sup>Eötvös University, Dept. of Astronomy,  
H-1518 Budapest, P.O. Box 32., Hungary

<sup>2</sup>Konkoly Observatory,  
H-1525 Budapest, P.O. Box 67., Hungary

<sup>3</sup>ESTEC/SCI-SAF,  
Postbus 299, 2200 AG Noordwijk, The Netherlands  
E-mail: [kospal@szofi.elte.hu](mailto:kospal@szofi.elte.hu)

## Abstract

We investigate the brightness evolution of 7 FU Orionis systems in the 1–100  $\mu\text{m}$  wavelength range using data from the *Infrared Space Observatory*, 2MASS and MSX. The spectral energy distributions (SEDs) based on these data points are representative of the period 1996–2000. These SEDs were compared with earlier ones derived from the IRAS photometry and from ground-based observations carried out around 1983, in order to look for long-term evolution. Our data show that three objects have become fainter, while the others remained constant. We investigate the case of V1057 Cyg and discuss whether its observed fading could be understood in the framework of the existing models.

KEYWORDS: *pre-main sequence stars, circumstellar matter, infrared astronomy, V1057 Cyg*

## 1. Introduction

FU Orionis objects are low mass pre-main sequence stars undergoing outburst in optical light of 4 mag or more, followed by a fading phase on the timescale of several decades. According to the most widely accepted picture the FU Orionis outburst is a consequence of a rapid temporal increase of the disk accretion rate (for a review see Hartmann & Kenyon 1996). Predictions of these types of models have to be confronted with multiwavelength monitoring observations of the outburst period and of the post-outburst phase. The fading phase is well documented in the optical/near-infrared, but very few data have been available so far at mid- and far-infrared wavelengths where thermal emission of the disk and of the circumstellar envelope can be observed. Recently the *Infrared Space Observatory* (ISO) provided new photometric data on FU Orionis-type stars

Instrument	Wavelengths [ $\mu\text{m}$ ]	Aperture	Active period
ground-based	J, H, K, L, M, N, Q	$\leq 6''$	1970s –
IRAS	12, 25, 60, 100	1 – 3'	1983
MSX	4.25, 4.29, 8.28, 12.13, 14.65, 21.34	18''	1996 – 1997
2MASS	J, H, Ks		1997 – 2001
ISOPHOT	4.8, 12, 25, 60, 100, 120, 200	43'' – 180''	1995 – 1998

Table 1: Sources of infrared photometric data used in our study.

in the 4.8–200  $\mu\text{m}$  range. In our study we search, for the first time, for systematic brightness variations during the post-outburst phases of 7 FU Orionis objects (V1515 Cyg, V1735 Cyg, V346 Nor, Z CMa, Parsamian 21, V1331 Cyg, V1057 Cyg) at mid- and far-IR wavelengths.

## 2. Observations and data reduction

Tab.1 lists the infrared photometric data used in this study. The time distribution of the active periods of the instruments/projects offers a possibility to check for long-term variations of the infrared fluxes between  $\sim$ 1983 (IRAS, ground-based data) and 1996–2000 (ISO, MSX, 2MASS).

We compiled a list of all confirmed/candidate FU Orionis objects from the literature and selected those 7 objects for further study where sufficient data were available at both epochs (1983 and 1996–2000) to create complete mid/far-infrared SEDs.

The data reduction was performed using the ISOPHOT Interactive Analysis Software Package V10.0 (PIA, Gabriel *et al.* 1997). After the corrections for non-linearities of the integration ramps, the signals were transformed to a standard reset interval. Then an orbital dependent dark current was subtracted and cosmic ray hits were removed. In case the signal did not fully stabilise during the measurement time due to detector transients, only the last part of the data stream was used. The calibration of the measurements was performed by using the default responsivity. As an error estimate we adopted an absolute calibration uncertainty of 25%, which represents well the sum of the random and systematic uncertainties. Colour corrections were applied for each measurement by convolving the observed SED with the ISOPHOT filter profiles in an iterative way.

### 3. Results

Our main results, the comparison of SEDs at the two different epochs, are presented in Fig. 1 and Fig. 2. The figures show that the sources exhibit wavelength dependent temporal behaviour, as summarised below:

- **Near-IR** ( $\lambda \leq 5 \mu\text{m}$ ): the sources show various trends: Par 21, V1331 Cyg and Z CMa are unchanged, V1057 Cyg, V1515 Cyg and V1735 Cyg have faded, V346 Nor have become slightly brighter.
- **Mid-IR** ( $5 \leq \lambda \leq 20 \mu\text{m}$ ): only V1057 Cyg shows systematic flux change: it faded by a factor of 2 during the period.
- **Far-IR** ( $\lambda \geq 60 \mu\text{m}$ ): five stars (V1057 Cyg, V1735 Cyg and Z CMa, Par 21 and V1515 Cyg) remained constant while V346 Nor seem to have become fainter. For V1331 Cyg there are no FIR data other than IRAS.

### 4. Discussion: the case of V1057 Cyg

In this section we investigate in details the case of V1057 Cyg, which shows the fastest evolution, and which has the best documented multiwavelength flux evolution following its outburst in 1970. There are two models of the circumstellar environment of this star to fit the complete 1–100  $\mu\text{m}$  infrared SED. Kenyon & Hartmann (1991, hereafter KH) assume that a flat disk is embedded in a spherically symmetric envelope with a wind-driven polar hole. The envelope reprocesses the radiation from regions close to the central star. Turner et al. (1997, hereafter TBB) fitted the SED of V1057 Cyg by computing outbursting flared disk models in which the mass flux varies with radius. This model includes reprocessing of disk emission by other parts of the disk and an envelope of uniform thickness with a central hole exposing the inner disk. In the following we compare our observations with the theoretical results.

#### At $\lambda \leq 2.2 \mu\text{m}$

Both models claim that emission of the central source (the star plus the innermost part of the accretion disk) dominates the observed flux. After the outburst the accretion rate close to the star decreases leading to a flux decrease in this wavelength range.

Our data confirm that the flux decay was observable between 1983 and 2000, too. The data reveal that in the R, J, H, and K bands the flux

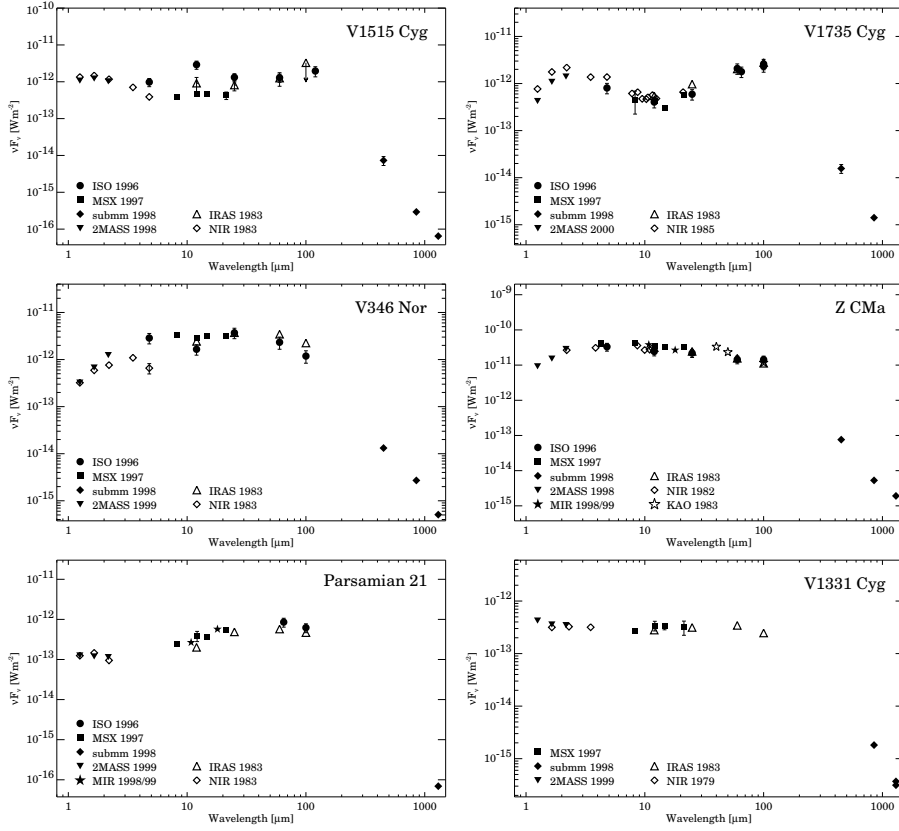


Figure 1: SEDs of FU Orionis objects. Open symbols represent data from  $\sim 1983$  while filled symbols correspond to the epoch 1996–2000. The data are presented with no reddening correction. Error bars smaller than the symbol size were not plotted.

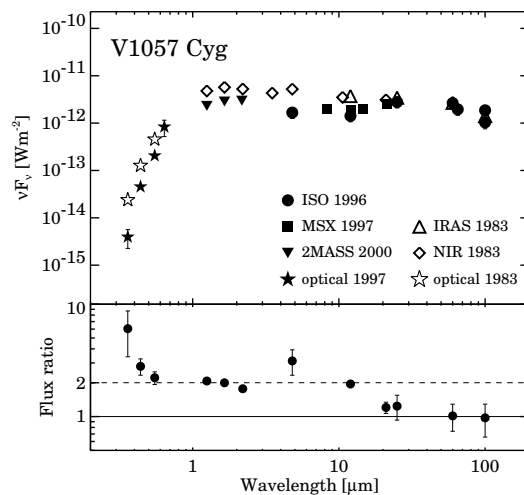


Figure 2: SED of V1057 Cyg at the two different epochs (1983 with open symbols and 1996–2000 with filled symbols). No reddening correction was performed. The lower panel shows the ratios of fluxes obtained in 1983 and in 1996–2000.

dropped by a constant factor of 2, while at B and V a larger decay was observed (lower panel of Fig. 2). This wavelength dependence may reflect the drop of effective temperature leading to a shift in the peak of the emission of the central source towards longer wavelengths.

### At $3 \leq \lambda \leq 10 \mu\text{m}$

According to the models the origin of the emission at these wavelengths is the release of accretion energy in the disk (KH, timescale:  $\tau_{dyn} \sim$  several years at  $\sim 1$  AU, Pringle 1981), and also starlight reprocessed in the same part of the disk and in an envelope (TBB, timescale:  $\tau_{th} \sim$  several years at  $\sim 1$  AU, Chiang & Goldreich 1997). Thus the prediction is that decreasing accretion rate at the centre would cause the drop of emission of all three components.

Since our temporal baseline (1983–1998) significantly exceeds the mentioned timescales and since the post-outburst evolution started already in the seventies, the model prediction is that the 3–10  $\mu\text{m}$  emission is decreasing synchronised with the rate of the optical/near-IR decay in a

wavelength independent way. Our measurements are fully consistent with these predictions.

#### At $\lambda \geq 10 \mu\text{m}$

In both models the emission is reprocessed starlight. The infrared radiation emerges from an envelope where dust particles are in radiative equilibrium with the illumination from the central region. The temporal evolution implied by the models is similar to the predicted trend at shorter wavelengths: a wavelength independent fading at the same rate as the fading of the central illuminating source.

Our results are not fully consistent with this picture. Though at  $10 \mu\text{m}$  the flux dropped between 1983 and 1997 by a factor of 2 similarly to the optical/near-IR rate, at far-IR wavelengths ( $\lambda \geq 60 \mu\text{m}$ ) the flux of V1057 Cyg remained constant. The comparison of the IRAS 60 and  $100 \mu\text{m}$  photometric points with our new ISOPHOT data at the same wavelengths clearly demonstrates that the far-infrared fluxes of V1057 Cyg showed no variation between 1983 and 1997.

Our results indicate that – unlike in the mentioned models – at  $\lambda \geq 10 \mu\text{m}$  two important emission components have to be taken into consideration. Between 10 and  $25 \mu\text{m}$  we probably observe the envelope, while at longer wavelengths the emission cannot be explained this way. In the following we discuss the possible nature of this second emission component.

The material responsible for the  $\lambda > 25 \mu\text{m}$  emission apparently has the following properties: (1) relatively cold; (2) *not* reprocessing, *not* optically thin medium; and (3) has a flat spectrum below  $100 \mu\text{m}$ , suggesting a  $T \sim r^{-0.5}$  radial temperature profile. The first possibility for the source of emission would be an optically thick reprocessing medium (e.g. a flared disk), and its time-lag behind the fading of the central source significantly exceeds our temporal baseline. For certain reasons, however, both KH and TBB rejected this possibility.

The second possibility is that the energy source of the far-IR emission is accretion in the outer disk, where the accretion rate is constant and unrelated to the outburst of the central region. The spectral shape of such a standard accretion disk would follow the canonical  $\nu F_\nu \sim \lambda^{-4/3}$  law, in contradiction with the observed flat spectrum (Fig. 2).

A solution for this problem could be if the temperature profile of the accretion disk differs from the standard one. Lodato & Bertin (2001) suggested

that in a self-gravitating protostellar disk the non-Keplerian rotation curve may result in a flat spectrum in the far-IR.

The last possibility would be to assume that the origin of the far-IR emission is unrelated to V1057 Cyg. Such a source could be a – so far undetected – embedded IR companion. Future infrared observations, like the ones expected from the Spitzer Space Observatory, will help to clarify the exact nature of the circumstellar environment of the FU Orionis stars.

### Acknowledgments

The ISOPHOT data presented in this paper were reduced using the ISOPHOT Interactive Analysis package PIA, which is a joint development by the ESA Astrophysics Division and the ISOPHOT Consortium, lead by the Max-Planck-Institut für Astronomie (MPIA). The work was partly supported by the grant OTKA T 037508 of the Hungarian Scientific Research Fund. P.Á. acknowledges the support of the Bolyai Fellowship.

### References

- Chiang, E.I., Goldreich, P. 1997, in *Spectral energy distributions of T Tauri stars with passive circumstellar disks*, *ApJ* , 490, 368
- Gabriel, C. et al. 1999, in *The ISOPHOT Interactive Analysis PIA, a calibration and scientific analysis tool*, Proceedings of the ADASS VI conference, ASP Conf. Ser. 125, p. 108
- Kenyon, S.J., Hartmann, L. 1991, in *The dusty envelopes of FU Orionis variables*, *ApJ* , 383, 664 (KH)
- Lodato, G., Bertin, G. 2001, in *The spectral energy distribution of self-gravitation protostellar disks*, *A&A* , 375, 455
- Pringle, J.E. 1981, in *Accretion disks in astrophysics*, *Ann. Rev. Astron. Astrophys.* , 19, 137
- Turner, N.J.J., Bodenheimer, P., Bell, K.R. 1997, in *Models of the spectral energy distributions of FU Orionis stars*, *ApJ* , 480, 754 (TBB)