A deep K-band variability study in Serpens – searching for the faint low-mass objects

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Abstract. A study of the applicability of K-band variability as a means of finding young stellar objects (YSOs) has been made. Deep K-band imaging of the central region of the Serpens Cloud Core was made at several epochs in 1995 and 1996. Variability is detectable with an amplitude as small as $\Delta m_{\mathrm{K}} = 0.15$ at a conservative 3σ level for sources brighter than $K = 15$. For fainter sources the 3σ level increases accordingly. In this paper 15 new YSO candidates, found to vary over a timescale of 1 year, are presented. In addition, it is shown that variability is detected in 14 known YSOs, classified on the basis of IR excess. The faint new YSO candidates are probably very low mass stars and brown dwarfs deeply embedded in the parental cloud of this young and active star formation region.

1. Introduction

The quest for very low mass stars and brown dwarfs is strongly motivated by one of the fundamental problems in astrophysics: understanding the origin of the stellar Initial Mass Function (IMF). Improvements of the IMF is almost always a matter of sampling lower mass objects. Very young clusters in active star formation regions have the advantage that the low-mass objects are relatively bright during contraction down the Hayashi track. Separating between stars belonging to the cluster and field stars is, however, critical and rather cumbersome. A standard method has been to assign cluster membership to sources with intrinsic IR-excess from their position in near-IR colour diagrammes (e.g. Rydgren & Cohen 1985, Lada & Adams 1992). In the commonly used $J-H/H-K$ diagramme field stars fall along the reddening band of giants, supergiants and main-sequence stars, while young stellar objects (YSOs) *might* stand out with excesses in H-K. One should not forget, however, that using this criterion alone may lead to a systematic underestimate of the young stellar population due to several reasons: 1) deeply embedded faint sources are often undetectable in J due to extinction, 2) intrinsic IR excess is not easily disentangled from reddening in these colours, and 3) young stars without near-IR excesses are not sampled. Additional approaches are therefore needed to ensure that a more complete census of the stellar population in young clusters is obtained.

For deeply embedded and faint YSOs the optimal window from ground is the K-band (2.2 μm) both with regards to sensitivity and extinction. Kaas et al. (1995) made a test study of the Serpens Cloud Core using K-variability as an indication of youth. Young stars are known to vary, periodically as well as irregularly. The results showed that variability in K would be as efficient as the $J-H/H-K$ colour diagramme at the sensitivity limit of the available JHK data, using several epochs obtained from the literature. In a similar study Horrobin et al. (1997) found that 28 % of the stars in a small field centered on the Serpens Cloud Core had varied over a timescale of 6 years. In this paper the first results of a deeper and more systematic K-band variability investigation in the Serpens Cloud Core are presented.

2. Observations and data reduction

The observations were performed at the Nordic Optical Telescope (NOT), La Palma in Aug/Sep 1995 and Aug 1996 with the ARcetri Near Infrared CAmera (ARNICA), a NICMOS-3 detector (Hunt et al. 1996, Lisi et al. 1996). With a pixel scale of $0\overset{''}{.}54$ a field of 8×6 arc minutes was covered with a 4×3 mosaic at several epochs in the K filter, and at one epoch in J and H. Repeated raster scans with random dithering were made such that the object frames themselves could be used for the sky subtraction. Skyflats were obtained continuously during twilight, yielding differential flats with the thermal and stray light contributions eliminated. Photometric standard stars were selected from the UKIRT faint standard system (Casali & Hawarden 1992) and from Northern JHK standard stars provided by Hunt et al. (1998).

Data reduction was performed using IRAF and a set of own programs. The images were corrected for bad pixels, rotated, sky subtracted and flat fielded. The median image of a sequence of ~ 10 properly scaled frames (excluding frames with nebulosity) was calculated and used to subtract the sky level. All integrations for each epoch were median combined rather than average combined in order to avoid that bad pixels would influence source photometry. For each epoch a 4×3 mosaic was constructed and source detection performed. Photometry was made with small aperture radii, and a proper aperture correction was applied based on measured values of several fairly bright and isolated stars.

3. Results and discussion

While ~ 1200 sources were detected in K, only 274 were detected in J, H and K, using total integration times of 2, 7 and 8 minutes, respectively. The standard $J-H/H-K$ diagramme is shown in Fig. 1 with the loci of giant, supergiant and main-sequence stars indicated with bold curves. The reddening line of an A0 star using the $A_\lambda \propto \lambda^{-1.7}$ extinction law is given as a dashed line (slope is 1.56) with every step of 10 A_V marked. Sources to the right of the reddening line have intrinsic excess in their $H-K$ colour due to the presence of circumstellar dust, possibly in the form of a disk. These are classified as young stellar objects (YSOs). Serpens is located at $b^{\rm II} = 5\overset{\circ}{.}3$ and $l^{\rm II} = 31\overset{\circ}{.}6$ at a distance of 259 ± 37 pc (Straižys et al. 1996), and contamination of the field by reddened background sources is expected to be high. Sources known to be YSOs from their mid-IR excess found by ISOCAM[1] (Nordh et al. 1996, Kaas et al. 1999) are indicated with large circles. These are found to the left as well as to the right of the reddening line, however, and demonstrate the limitation of the $J-H/H-K$ diagramme in extracting YSOs with IR-excess. Sources known from ISOCAM to be free of mid-IR excess are given as large triangles.

In Fig. 2 we show photometric variability in the K-band over the two epochs 1995 and 1996. The total integration times are 28 and 20 minutes, respectively. Variability is detectable at an amplitude as small as $\Delta m_{\rm K} = 0.15$ at a 3σ level (dotted lines) for sources brighter than $K = 15$. We define σ to be the standard deviation of the photometric repeatability, i.e. the empirical scatter from one night to the next. This

[1] The camera aboard the Infrared Space Observatory was used to survey the major nearby star formation regions (PIs: Nordh & Olofsson)

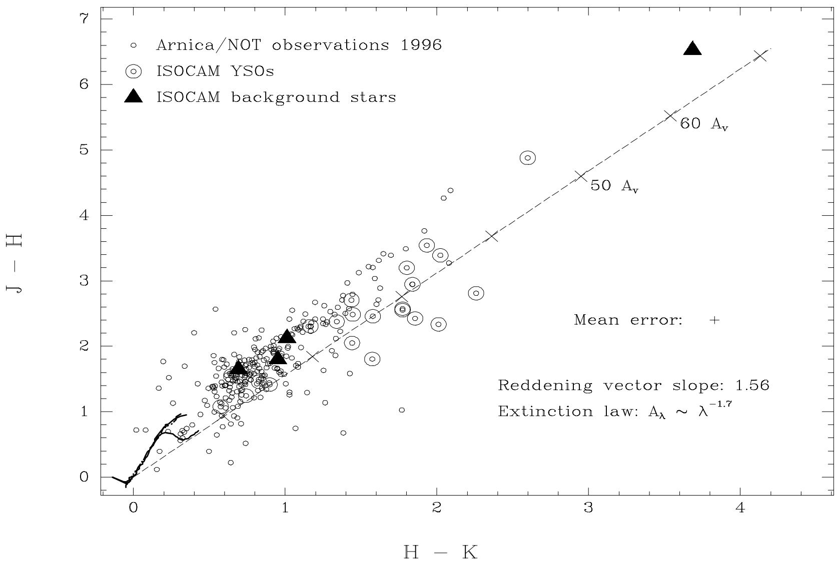

Figure 1. *J-H/H-K diagramme for the Serpens Cloud Core. See text.*

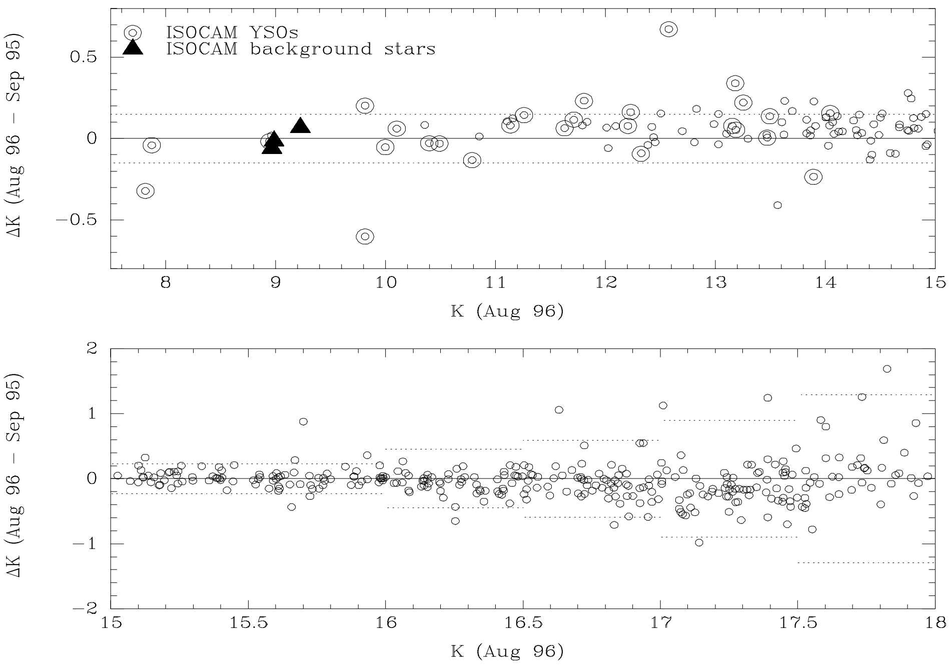

Figure 2. *Variability in K plotted as ΔK versus K. Dotted lines give the empirical 3 σ level. See text for details.*

σ amounts to roughly 4 times the uncertainties calculated from photon statistics. For stars with $K > 15$ the 3σ level increases accordingly as indicated in Fig. 2. For the fainter part of the sample σ is only about twice the photon statistics uncertainties. The brighter sources found to be variable are all already known YSOs, classified from having near-IR (Eiroa & Casali 1992, Sogawa et al. 1997, Giovannetti et al. 1998) and/or mid-IR (Kaas et al. 1999) excess. Large circles give the ISOCAM YSOs. In addition, we have found 15 new candidate YSOs. See Kaas (1999) for a source list including more epochs and details.

4. Conclusions

Preliminary results on the K-variability study yield 15 new YSO candidates in the Serpens Cloud Core. If these are confirmed spectroscopically, the current sample of YSOs within the observed field is increased by 23 %. The 14 brightest of the total sample of 29 variables are confirmed YSOs by IR excess. The 15 fainter candidates are probably lower mass cluster members. Assuming an age of 10^6 yr and an average extinction of 30 A_V, current evolutionary models of pre-main-sequence stars place these candidates in the mass range down to 0.02 $M_\odot$. Thus, even with conservative assumptions, more than half of them would be young brown dwarfs. Since 37 % of the ISOCAM YSOs are found to have varied over the timescale of 1 year, it is concluded that this method is an efficient supplement to the criteria already in use in order to distinguish YSOs from field stars.

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