*Triggered Star Formation in a Turbulent ISM*
*Proceedings IAU Symposium No. 237, 2006*
*B. G. Elmegreen & J. Palouš, eds.*

doi:10.1017/S1743921307001445

# Protostars in the Elephant Trunk Nebula

**William T. Reach**

Spitzer Science Center, MS 220-6, Caltech, Pasadena, CA, UAS
email: reach@ipac.caltech.edu

**Abstract.** Extremely red objects were identified in the early *Spitzer* Space Telescope observations of the bright-rimmed globule IC 1396A; they were classified as Class I protostars Class II T Tauri stars with disks based on their colors. New spectroscopic observations covering 5.5–38 $\mu$m confirm this identification. The Class I sources have extremely red continua, still rising at 38 $\mu$m, with a deep silicate absorption at 9–11 $\mu$m, weaker silicate absorption around 18 $\mu$m, and weak ice features including $CO_2$ at 15.2 $\mu$m and $H_2O$ at 6 $\mu$m. The Class II sources have warm, luminous disks, with a silicate emission feature at 9–11 $\mu$m. Optical spectra with the Palomar Hale 200-inch telescope show the Class II sources to be actively accreting, classical T Tauri stars with bright H$\alpha$ and other emission lines. The Class I sources are located within the molecular globule, while the Class II sources are more widely scattered. This suggests two phases of star formation occurred in the region, the first one leading to the Class II sources including LkH$\alpha$ 349a,c that are located in the center of the globule, and a very recent one (less than 100,000 yr ago) that is occurring within the globule. This second phase was likely triggered by the wind and radiation of the central O star of the IC 1396 H II region, with possible additional contributions from the outflows of LkH$\alpha$ 349a,c and some nearby B stars.

**Keywords.** stars: formation, stars: pre-main-sequence, ISM: globules

## 1. Introduction

A set of mid-infrared-bright sources was identified from early *Spitzer* (Werner *et al.* 2004) observations of the bright-rimmed globule IC 1396A (Reach *et al.* 2004). These sources were previously unknown, and their nature was determined by comparing broad-band colors to those of young stellar objects in nearby star-forming regions. Eight sources were identified based on their spectral energy distributions as 'Class I' protostars, while 30 were identified as 'Class II'. We have now followed up these sources using mid-infrared, optical, and radio spectroscopy to further elucidate their properties. Here we present some mid-infrared spectra obtained with the *Spitzer* Infrared Spectrograph (Houck *et al.* 2004) and optical spectra obtained with the Palomar double-spectroscope (Oke & Gunn 1982).

## 2. Class I Sources

Figure 1 shows the mid-infrared spectra of the sources whose broad-band colors indicated there were Class I protostars. The spectral shapes are characterized by deep 9–11 $\mu$m silicate absorption, moderately deep 15–20 $\mu$m silicate absorption, weak 6.0 $\mu$m $H_2O$ and 15.2 $CO_2$ ice absorption, and a dominant, rapidly-rising, infrared continuum. By far the bulk of the luminosity arises in the mid- to far-infrared. These spectra require a source with a centrally-heated core surrounded by a cold envelope that is opaque in the mid-infrared. This is precisely the configuration of a contracting protostar, before reaching the birth-line. Thus we confirm that the photometrically identified Class I sources are indeed protostars.

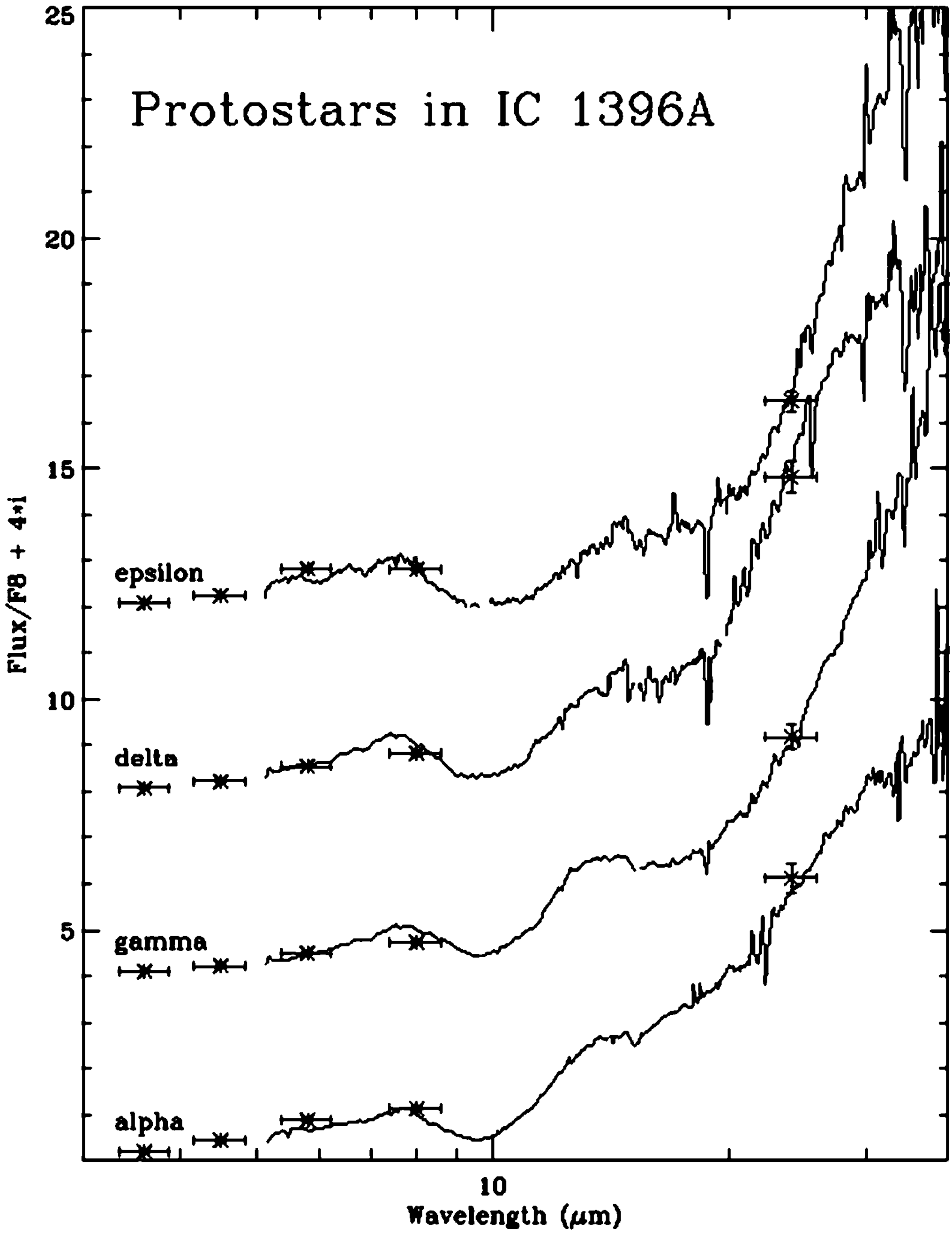


**Figure 1.** *Spitzer* IRS spectra of the Class I sources in IC 1396A.

## 3. Class II Sources

Figure 2 shows the mid-infrared spectra of the sources whose broad-band colors indicated there were Class II protostars. The spectral shapes are characterized by bright, rounded 9–11 $\mu$m silicate emission and a 'hump' that rises into the mid-infrared then is declining longward of 30 $\mu$m. These stars are all optically visible, with optical luminosity

https://doi.org/10.1017/S1743921307001445 Published online by Cambridge University Press

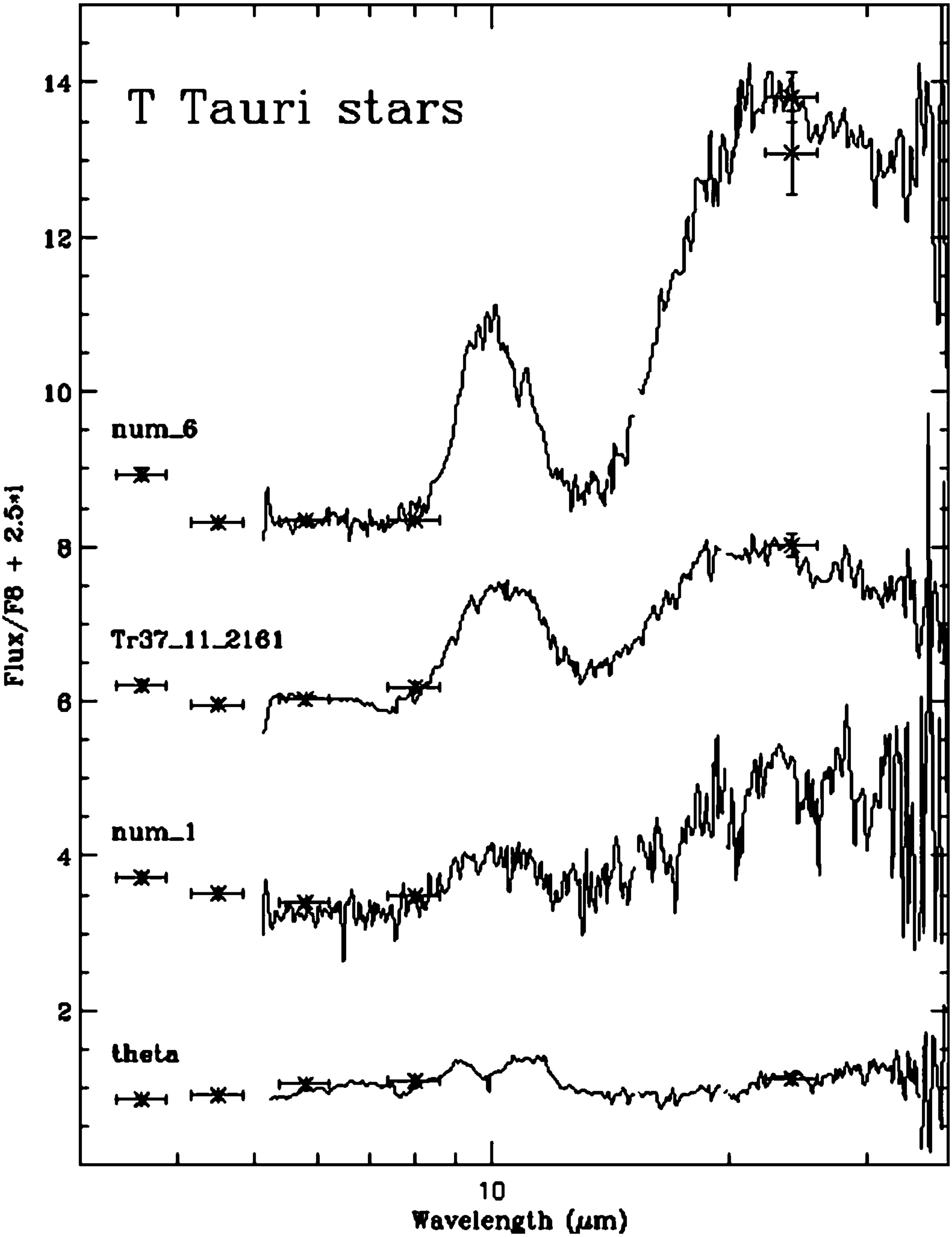


**Figure 2.** *Spitzer* IRS spectra of the Class II sources in IC 1396A.

comparable to the infrared. The optical spectra show bright emission lines, including H$\alpha$ with equivalent width $> 50$ Å and N II, O I, and S II. The infrared emission requires an optically thin region heated far warmer than achieved by the interstellar radiation field, more typical of the environment within 10's of astronomical units of stars. This is precisely the configuration of a young star, already born, with a dusty disk, before planet

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formation. The optical spectra meet the criteria for 'classical' T Tauri stars. Thus we confirm that the photometrically identified Class II sources are indeed classical T Tauri stars with disks.

## 4. Star Formation in IC 1396A

The presence of 8 Class I sources and 30 Class II sources within IC 1396A is consistent with their estimated lifetimes of $10^5$ and $10^6$ yr. The rim of the dense globule is an over-density due to the pressure of the H II region compressing the dense gas in the globule. The location of the Class I sources near the globule rims suggests they were very recently formed due to that compression, e.g. as predicted for radiative-driven implosion (Lefloch & Lazareff 1994).

### Acknowledgements

This work is based in part on observations made with the *Spitzer Space Telescope*, which is operated by the Jet Propulsion Laboratory, California Institute of Technology under NASA contract 1407.

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### Discussion

de Vries: The presence of dense gas in the globule is confirmed by out observations of $N_2H^+$ (presented at this conference).

Reach: Observations of the dense gas are important to determine the current state of the globule due to the effect of the H II region and the conditions for potentially ongoing star formation.