An Infrared Search for Young Stellar Objects in IC 1396

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Abstract

About 900 parsecs from Earth, IC1396 lies along the galactic plane, in the direction of the constellation Cepheus, and includes many dark nebulae, including the Elephant's Trunk Nebula. IC 1396A has been examined with a variety of telescopes, including *Spitzer, 2MASS, IPHAS, Chandra,* and *WISE*. The YSOVAR project (Rebull et al. 2014) also has Spitzer monitoring data in this region at 3.6 and 4.5 microns. Our team has merged these catalogs and identified candidate YSOs using IR color selection, X-ray detection, and variability metrics. In order to interpret the YSOVAR light curves, it is critical to understand which of the 700+ YSO candidates in this region are likely YSOs, and which are foreground/ background stars or are extragalactic objects. As a first attempt to confirm these candidate YSOs, we created spectral energy distributions (SEDs) for wavelengths from *IPHAS* r band to 24 microns, which we use, coupled with image inspection, to confirm (or refute) YSO candidates from this list of identified point sources. The goal of this study is to identify candidate YSO sources, as well as support the greater understanding of the variety, evolution and variability of young stars. Our next steps will include comparing our vetted list of YSO candidates to the lists of YSO candidates already identified in the literature of this region, see references below.

This project is a collaborative effort of high school students from three states. We analyzed data individually and later collaborated online to compare results. It is the result of many years of work with the NASA/IPAC Teacher Archive Research Program (NITARP).

Methods

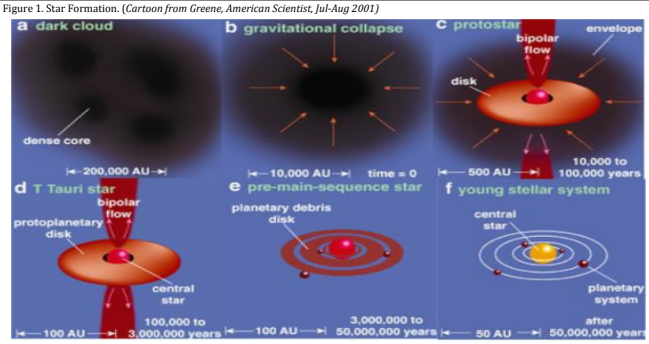
Selection of Sources

- Over 57,000 sources have been identified in IC1396. We took this list and culled through three methods:
  - Gutermuth IRAC color selection,
  - X-ray detection plus a star-like SED, and
  - Variability.
- The final source list included 756 objects. We analyzed the first 300. Sources with incomplete datasets (only 2-3 bands) or that were obviously not point sources were eliminated.
- We fit a slope to the SED between 2 and 24 microns for each "good" candidate.

Visual Inspection

- Although an algorithm can be written to do this, a visual inspection offers greater reliability. We used Finder Chart to inspect *2MASS* and *WISE* images. The *Spitzer Heritage Archive* was consulted for *IRAC* and *MIPS* data.
- We ensured sources were matched properly across bands, keeping in mind that telescopeshave very different spatial resolutions.
- We made sure that every source had a detection in the catalog.
- We checked image morphology to make sure that we are not looking at spiral or elliptical galaxies, but really point sources.

Figure 1. Star Formation. (*Cartoon from Greene, American Scientist, Jul-Aug 2001)*



Sample SEDs

Figure 3. SED of Class I YSO. Source #212. Note the rising slope.

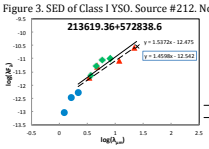


Figure 4. SED of Class Flat YSO. Source #119. Note the flatslope.

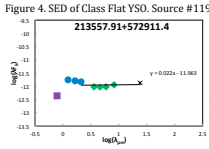


Figure 5. SED of Class Flat YSO. Source #63. Note the transition disk.

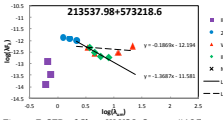


Figure 6. SED of Class II YSO. Source #51.

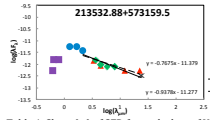


Figure 7. SED of Class III YSO. Source #195.

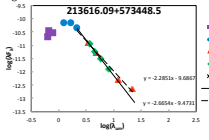
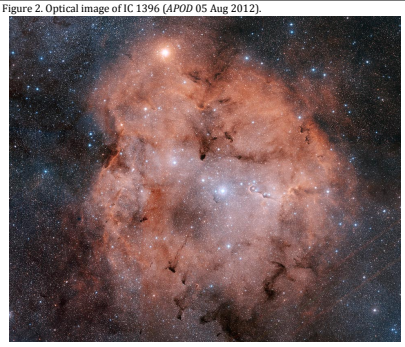


Table 1. Slope (α) of SED for each class of YSO.

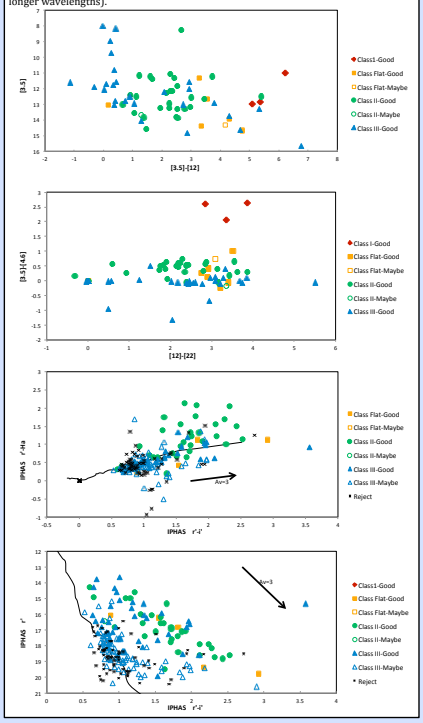
Class 0 source	undetectable at 20 μm
Class I source	α > 0.3
Flat spectrum source	0.3 > α > -0.3
Class II source	-0.3 > α > 1.6
Class III source	α < −1.6

Figure 2. Optical image of IC 1396 (*APOD* 05 Aug 2012).



Color-Color Diagrams & Color-Magnitude Diagrams

Figures 8-11 Filled points represent good YSO candidates, empty points represent maybes, rejects are marked with an X. Colors represent SED class: red=Class I, yellow=flat, green=Class II, blue=Class III. In Figures 10-11, a purple line indicates the locations of main sequence (MS) stars (at the distance of IC 1396, where relevant) and the reddening vectors are as shown (Av affects shorter wavelengths much more than longer wavelengths).



Beltran 2009. *A&A* 504, 97–107.
Barentsen 2011. *MNRAS* 415, 103-132.
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Getman 2012. *MNRAS* 426, 2917-1943.
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Matthews 1978. *A&A* 75: 345-350.
Nakano 2012 *ApJ* 143:61-76.
Ogura 2002 *AJ* 123, 2597-2626.
Rebull 2014 *AJ* 148: 92-119.
Schwartz 1991 *ApJ* 370: 263-272.

Results & Conclusions

- After thorough analysis and vetting, the conclusion was made that of the 300 stars analyzed, 208 YSO candidates would remain.
- These candidates were divided into two categories: good or maybe.
- Often during the analysis of the stars, different techniques disagreed. For example, the SED of a star might have indicated a YSO candidate, but the star's lack of data or quality of data placed it as questionable. This left us relying heavily on visual inspection of the stars.
- While Class III stars dominated with 49.4% of the good and 71.5% of the maybe, stars were found for all four classes including 4 stars that were class I.
- Incomplete data was problematic throughout the project and for future work, a larger set of data would be helpful in accurately identifying more YSO candidates.

Figure 12. Percentages of Good, Maybe and Rejected Sources (N=300).

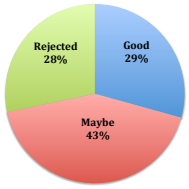
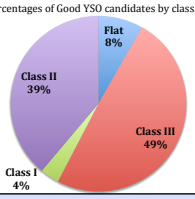


Figure 13. Percentages of Good YSO candidates by class. (N=85). Maybes not plotted.



Future Work

This is a work in progress.

- Our next step is to continue vetting the remaining 400+ sources. The students will compare their results with one another with the goal of one agreed upon, final vetted list of YSOs.
- We will be comparing our vetted listed of YSOs to the literature.
- We will be adding *Herschel* data.
- We will be examining each light curve tagged variable from the YSOVAR data, comparing each to the YSOVAR images themselves.