Cataloging and Analysis of Young Stellar Objects in the Spider Nebula (IC 417) Using Archival Visible and Infrared Data

V. Urbanowski[1], R. Anderson[2], B. Rodriguez[3], B. Senson[4], L. Rebull[5], M. Austin[2], A. Lichtenberg[1], H. Rodriguez[6], Z. Rodriguez[6], K. Fleischer[1], N. Roosa[3], N. Bendre[1], S. Samuel[1], K. Blood[3], J. Long[2]

[1]Academy of Information Technology & Engineering, Stamford, CT; [2]J.L. Mann High School, Academy of Mathematics, Science and Technology, Greenville, SC; [3]Crescenta Valley High School, La Crescenta, CA; [4]Madison Metropolitan School District, Madison, WI; [5]Caltech, Pasadena, CA; [6] Esperanza College Prep, Los Angeles, CA

Abstract & Overview

The Spider Nebula (IC417) is a star-forming region (SFR) at ~2.3 kpc away, in the direction of the galactic anticenter. The structure of the nebulosity in IC417 is striking (see Fig. 1); there is a "stream" of texture in the nebulosity, known as the "Nebulous Stream" (NS), first noted in the NIR by Jose et al. (2008). Particularly in the infrared (Fig. 1), four clumps of red point sources are immediately obvious in the NS.

A 2015 NITARP team began work in this region, selecting new young stellar object candidates (YSOc) based on WISE infrared (IR) excess and assessing the IR properties of the literature YSOc. (The literature YSOc have been identified based on IR excess, Hα excess, variability, or prior identification as O/B stars.) In 2020, we updated the list of literature YSOc to reflect more recent papers, and selected red sources from the NS based on projected position in the sky. For literature YSOc and for YSOc in the NS, we assembled available optical and infrared photometric data from up to 27 bands (including PanSTARRS, Gaia, IPHAS, 2MASS, Spitzer/IRAC, WISE, plus optical from Jose et al. 2008), and assessed images and spectral energy distributions (SEDs) of those YSOc (see Fig. 2).

In 2021, we have now included more literature YSOc and continued to assess our confidence in the YSOc, now including position in numerous color-color and color-magnitude diagrams (Fig. 3) and Gaia distances. We now have a list of 710 YSOc which we have ranked in terms of how confident we are that they are YSOs in IC417; we regard 512 of them (72%) as likely YSOs.

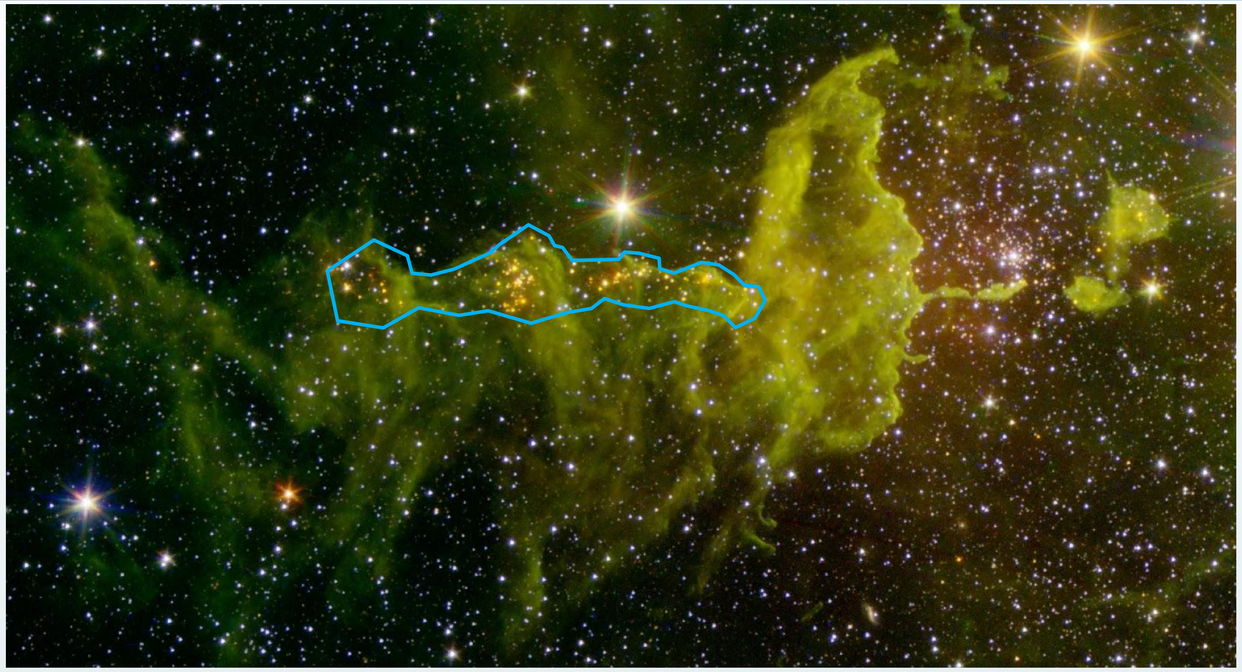


Figure 1. *Press release image from Spitzer (2016, sig16-008, NASA/JPL-Caltech) using 1.3 μm (2MASS, blue), 3.6 μm (IRAC, green), and 4.5 μm (IRAC, red) with the Nebulous Stream (NS) outlined in blue. There are four obvious clusters of red stars within the knots, which inspired us to look here for young stellar object candidates (YSOc).*

Vetting

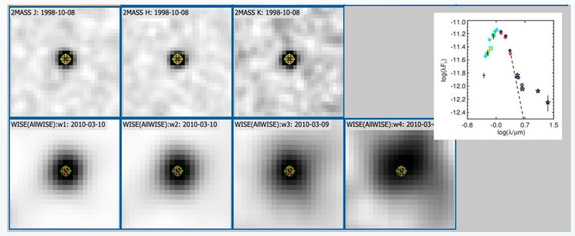
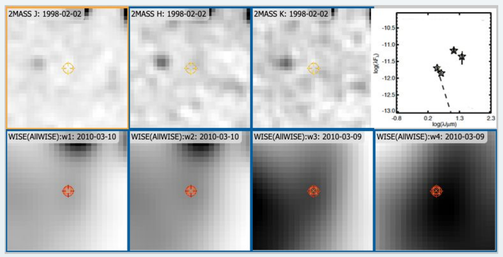
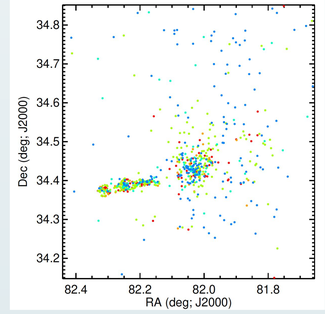
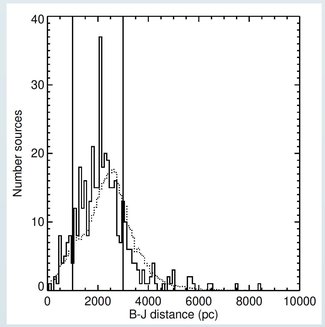


Figure 2. *Example of target vetting with images and SEDs. Above, a high-quality YSO candidate is a point source in multiple wavelengths and has an SED with an IR excess (different colors and points in SED correspond to different surveys). Below, a rejected object, where the image morphology plus the SED shape (and the fact that no counterparts can be found in any of the other catalogs we used) suggest that it is a nebular knot, and not a YSO.*





← **Figure 4**. Distribution on the sky of the YSOc, with color coding according to YSO confidence, as in Fig. 3. The NS and Stock 8 are both obvious by eye because of the way we constructed the list of YSOc.



→ **Figure 5**. Histogram of distances (Bailer Jones et al. 2018) to the YSOc and to the rest of the stars in this direction (scaled; dotted line); two vertical lines at 1 and 3 kpc are the range of distances we accepted as members of IC417.

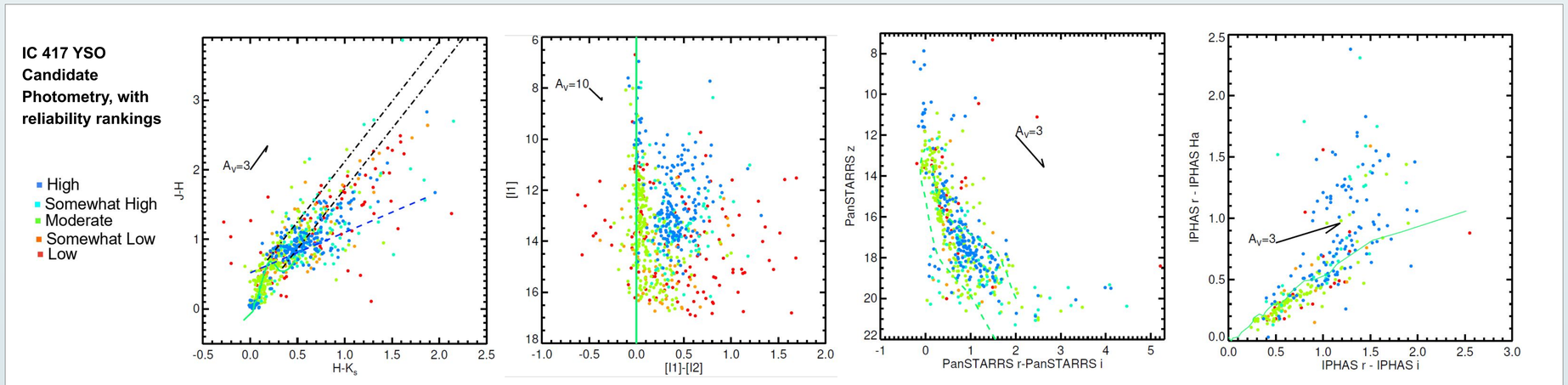


Figure 3. Color-color and color-magnitude diagrams, with candidate objects color coded by our confidence in their likelihood to be actual YSOs (basically, the bluer the better). Green solid lines are the expected (empirical) ZAMS relationship (Pecaut & Mamajek 2013, Drew et al. 2005). Reddening vectors (following the reddening law from Indebetouw et al. 2008 & Mathis 1990) are as shown, additionally extending from the ZAMS in the JHK plot. The dashed blue line is the Meyer et al. (1997) T Tauri locus. The green dashed lines in the PanSTARRS plot are 6 Myr and 9 Myr isochrones from PARSEC models (Bressan et al. 2012). **Higher confidence objects end up dominating regions consistent with YSO processes**: high mass O and B stars, NIR excesses, reddened colors, MIR excesses, near the 6 Myr isochrone, and Hα excesses. We ranked the YSOc based on image morphology, SED shape (some objects were downgraded if their SED had fewer than ~8 pts), distance (from Gaia DR2), and color-color and color-magnitude diagrams like this (more than are shown).

Results

	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	**Rank 3-5**
SED class I	41	4	0	10	11	**21 (4%)**
SED class flat	14	2	3	14	18	**35 (7%)**
SED class II	40	30	45	44	116	**205 (40%)**
SED class III	42	24	185	18	48	**251 (49%)**
Totals	137	60	233	86	193	**512**

Our result is summarized in the table at left and Figure 4. Out of our initial 710 YSOc, we're fairly confident that at least 512 are likely to be YSOs. Nearly all of them are SED class II or III, consistent with literature age estimates of ~10 Myr.

We are in the process of writing this up for submission to AAS journals in early 2022.

We used the 710 sources here as an input target list for our companion poster, Rodriguez et al., which explores optical and IR variability among these YSOc.

This research was made possible through the NASA/IPAC Teacher Archive Research Program (NITARP) and was funded by NASA Astrophysics Data Program. Support from the administrators of participating schools is greatly appreciated.