Finding Young Stars in IC 417

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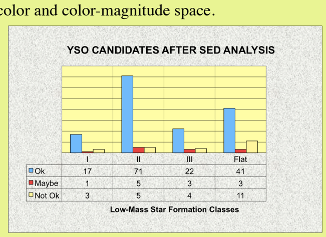
Abstract and Background

IC 417 is a young cluster in the constellation Auriga, towards the Galactic anti-center in the Perseus arm, at a distance of ~2.3 kpc. Previous studies suggested that there are young stars in this region; **Camargo et al. (2012) identified several few-Myr-old clusters in this region** from 2MASS clustering, and Jose et al. (2008) identified Hα excess sources. Since stars form from clouds of interstellar dust and gas, a signature of star formation is excess infrared (IR) emission, which is interpreted as evidence for circumstellar dust around young stars. We **identified new candidate young stellar objects** (YSOs) in IC 417 by incorporating near- and mid-infrared observations from the Wide-field Infrared Survey Explorer (WISE) and the Two Micron All-Sky Survey (2MASS). Infrared excess sources were identified by using a series of color cuts in various 2MASS/WISE color-magnitude and color-color diagrams following Koenig & Leisawitz (2014). We also assembled a list of OB and Hα stars from the literature, including those from Jose et al. (2008), and Hα bright stars from the IPHAS survey (Witham et al. 2008). Starting with this compiled list of approximately 200 interesting objects in the region, we then set about **checking their reliability in three ways**. We inspected the POSS, 2MASS, and WISE images of the sources. We assembled and inspected spectral energy distributions (SEDs) from archival data ranging from wavelengths of 0.7 to 22 µm. Finally, we created and inspected color-color and color-magnitude diagrams. We find more than 100 new YSO candidates, more than doubling the number yet identified in the IC 417 region. This research was made possible through the NASA/IPAC Teacher Archive Research Program (NITARP) and was funded by NASA Astrophysics Data Program.

Process

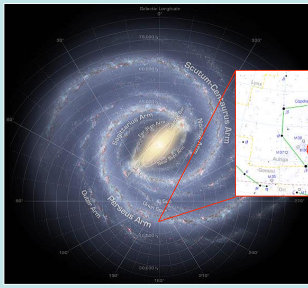
- Beginning with an initial sample of over 30,000 sources in the region, we identified 186 sources of interest.
- We inspected images of each source in Finder Chart at IRSA.
- We generated SEDs using photometry from Jose et al. (2008), 2MASS (JHK_s), UKIDSS (JHK), WISE (3.4-22 µm), IPHAS ($riH\alpha$), and IRAC (3.6, 4.5 µm).
- We assessed locations of individual sources in color-color and color-magnitude space.



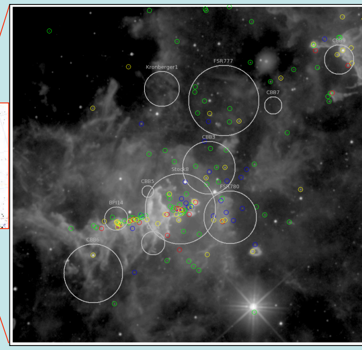
Histogram showing the results of the vetting process. After analysis, 151 of the original 186 sources remain in the OK category, meaning they passed the visual inspection as being point sources, have physically reasonable SEDs (meaning that they look like plausible YSOs) and are reasonably placed in color-color and color-magnitude space to be YSOs at the distance of IC417. 23 sources are rejected from the sample.

We gratefully acknowledge funding via NASA Astrophysics Data Program funds.

Where is IC 417?



Artist's rendering of the Milky Way Galaxy with the approximate location of IC 417 shown. It is ~2.3 kpc away from us, in the direction away from the galactic center. *(Image from NASA/JPL-Caltech/R. Hurt, SSC press release ssc2008-10b.)*

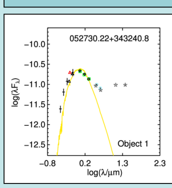


WISE 4 image showing the locations of the identified sample of YSOs in the region (small circles) as well as clusters identified by Camargo et al. (2012) in the large circles. Small blue circles = Class III SEDs; green circles = Class II SEDs, yellow circles = Flat Class SEDs, and red circles indicate Class I SEDs.

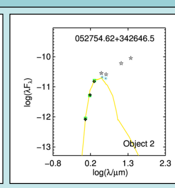
Zoom-in on the heart of IC417. This is a 3-color J / [3.6] / [4.5] composite image. *(Image from NASA/JPL-Caltech/R. Hurt)*

Sample SEDs

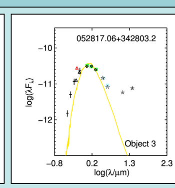
The SEDs shown below are a sampling of the SEDs we assembled for 186 identified objects of interest in the region; these 6 are identified in the CMDs below. Five have clear IR excesses and one is an O star. λF_λ is in units of ergs/s/cm^2 and λ is in units of microns. Crosses = Jose et al. (2008) optical photometry; triangles = IPHAS *ri Hα* (the latter in red); green squares = UKIDSS *JHK*; diamonds = 2MASS JHK_s; stars = WISE; blue circles = IRAC. Arrows are upper limits where available. Vertical bars in center of symbol (often seen as a dot and much smaller than the symbol) are the error bars associated with the point. Yellow lines are *notional* stellar models *solely* to guide the eye -- we do not have spectral types available for most sources, so we assumed a spectral type of G0 for those stars and estimated reddening (A_v) to fit the available data. Objects 2 and 5 require substantial reddening. For Object 6, there is a spectral type available; it is O9. Reddening is not well constrained for Object 6, but a few tenths of reddening is needed to fit the slope through JHK_s.



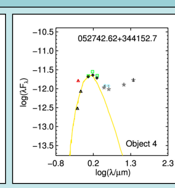
Object 1 was identified solely by the Koenig & Leisawitz color selection method. It also exhibits an ultraviolet excess (see below).



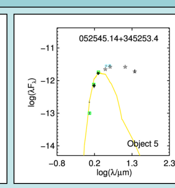
Object 2 was identified solely by the Koenig & Leisawitz color selection method. It is also substantially reddened.



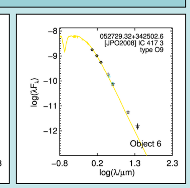
Object 3 was identified as an IPHAS Hα bright source, and it was also selected by the Koenig & Leisawitz method. It exhibits an ultraviolet excess.



Object 4 was identified solely as an IPHAS Hα bright source. However, it also exhibits an infrared excess.



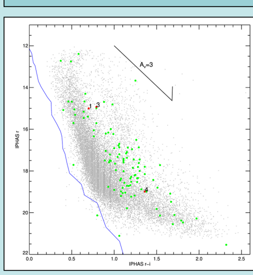
Object 5 is an embedded source that is not detected at optical wavelengths. It is substantially reddened and has an infrared excess.



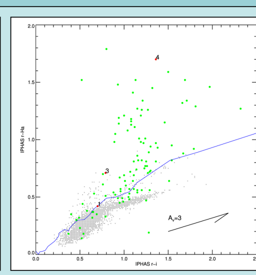
Object 6 is an example of an OB star. It was also identified by Jose et al. (2008). It is type O9 and does not appear to have a significant IR excess.

Color-Magnitude and Color-Color Plots

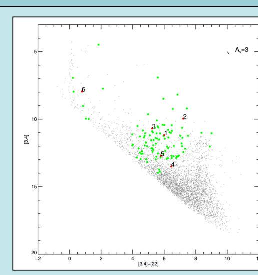
After inspecting the sources in our sample by direct examination of images and SEDs, we further vetted our sample by assessing the locations of the individual sources color-color and color-magnitude plots. A representative sample is shown below. Grey points represent all sources in the region with photometry to appear in the diagram. Green dots are our final set of YSO candidates. Numbered red dots correspond to sources with SEDs shown on this poster (above). The blue lines are the relation expected for the main sequence. A_v=3 vectors provided in all cases. (Apparent quantization in certain plots are a result of roundoff error in the contributing catalog.)



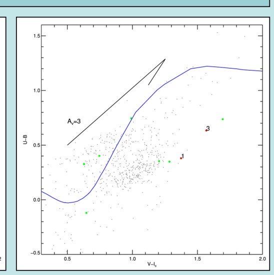
Color-Magnitude Plot showing IPHAS *r* versus IPHAS *r-i*. Sources to the upper right are more likely to be young stars because they are above the main sequence expected for a cluster at the distance of IC417. The three green points located near the main sequence line are (reddened) OB stars and may not be members of IC417.



Color-Color Plot showing IPHAS *r-Hα* versus *r-i*. H-α bright sources will be closer to the top of the plot. Source 4 exhibits particularly strong Hα excess, and also has an IR excess.



Color-Magnitude Plot showing WISE [3.4] versus [3.4]-[22]. Sources 1-5 show strong evidence of infrared excess. Source 6 is an OB star and probably does not have a significant IR excess.



Color-Color Plot showing Jose et al. (2008) *U-B* versus V-I_c. (These data are not available over our whole field, so there are many fewer points than in the other plots to the left.) Sources 1 and 3 show strong evidence of ultraviolet excess. These sources also display strong Hα as well as infrared excess, making them very strong YSO candidates.

Results

Starting from 186 objects selected from IR excess, Hα, or known OB stars: **163 we believe to be YSO candidates, 106 of which are newly identified YSO candidates.** Of the 163: 18 Class Is, 44 Flat Class, 76 Class IIs, and 25 Class IIIs. We expected to find YSOs clustered on the sky, following the Camargo et al. (2012) clusters, but our YSO candidates do not appear to be as clustered as expected. Stock 8 is clustered enough to identify by eye, and there are several YSOs in the "sinuous tail" of dust associated with BPI14. There are YSO candidates distributed through the field, but no very obvious clustering with the rest of the clusters from Camargo et al. (2012), and some clusters have no YSO candidates at all. Follow-up spectroscopy is needed to establish whether these YSO candidates are true YSOs.