Studying Young Stars in L1688 Using Submillimeter, Infrared, and Optical Data

L. Orr[1], L.M. Rebull[2], N. Coster[3], D. Morgan[4], L. Wommack[5], B. Sharpe[6], V. Park[1], B. Coster[3], S. Nannenga[3], D. Schurman[3], B. Jolley[4], J. Erickson[4]

[1]Ukiah High School, Ukiah, OR; [2]Caltech, Pasadena, CA; [3]Kankakee Valley High School, Wheatfield, IN; [4]South Sevier High School, Monroe, UT; [5]Lakeside Jr-Sr High School, Plummer, ID; [6]Echo High School, Echo, OR

Abstract

We looked for new candidate young stellar objects (YSOs) within 10 arcminutes of the heart of the Rho Ophiuchi (L1688) cluster using Herschel Space Telescope far-infrared (FIR) data. The goal of our study was to identify new YSOs as well as measure FIR brightnesses for literature-identified YSOs. The purpose of our work is to support the greater understanding of the variety and evolution of young stars.

Target Region: L1688

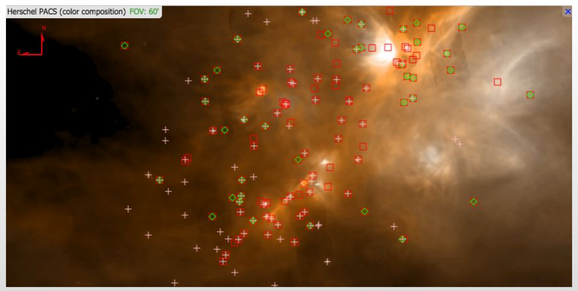


Image 1. Herschel/PACS HiPS composite image of the L1688 region. This region shown is a degree across, a larger region than we studied; we focused on the filament in the center of this image. Pink crosses: PACS Point Source Catalog (PPSC) 70 micron sources; we investigated all of these sources in the region as possible YSOs. Literature YSOs are given by green diamonds (sources from Ribas et. al. 2017, which reported Herschel fluxes) and red squares (sources from McClure et. al. 2010, which is a Spitzer/IRS investigation of known YSOs). Not shown: Cluster members from Wilking et al. (2008) sources, because they are numerous (making the rest of this hard to see) and largely detected solely at shorter wavelengths. There are many pink crosses that do not have a red square or a green diamond; these are either new sources (possible YSOs) or erroneous detections in the catalog.

Methods

- Identified 155 sources that were literature YSOs and/or long wavelength (70, 100, and/or 160 micron) detections in the Herschel PACS Point Source Catalog (PSC).
- Incorporated multiwavelength data from PanSTARRS, UKIDSS, Gaia DR2, 2MASS, Spitzer/IRAC & MIPS, WISE, AKARI, and Herschel/PACS & SPIRE. Also included variability statistics from YSOVAR (Rebull et al. 2014, Guenther et al. 2014).
- Cross-matched initial catalog by position.
- Inspected available images for each of these sources to ensure correct matching across bands.
- Constructed and inspected spectral energy distributions (SEDs).
- Obtained photometry for the Herschel bands for sources that could be seen in the images, but did not have corresponding catalog entries in the PACS or SPIRE PSCs. These data were added to the SEDs.
- Constructed color-color and color-magnitude diagrams to check that the properties of these YSO candidates matched those of other known YSOs.

Analysis

SEDs for new YSO candidates detected solely at Herschel bands.

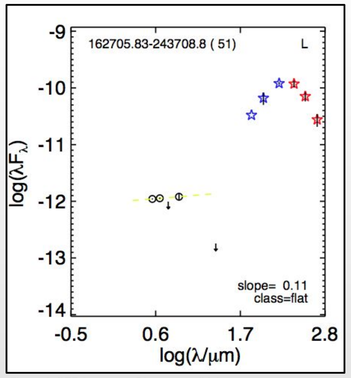


Figure 1. SED for source 51, new candidate.

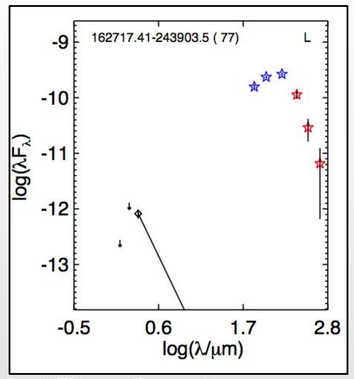


Figure 2. SED for source 77, new candidate.

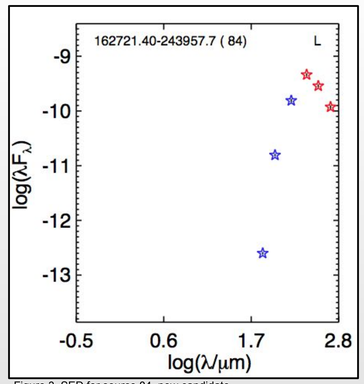
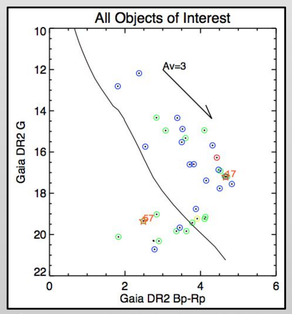


Figure 3. SED for source 84, new candidate.

Color-magnitude and color-color diagrams for sources studied.



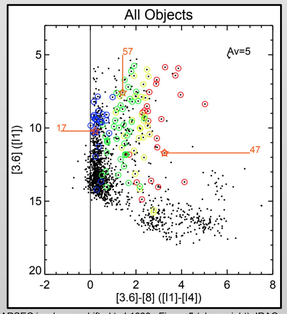


Figure 4 (above, left): Gaia DR2 G vs. Gaia DR2 Bp-Rp. Black line=PARSEC isochrone, shifted to L1688. Figure 5 (above right): IRAC 1 (3.6 um) vs. IRAC2-IRAC4 (3.6-8 um). In both, reddening vector is shown; colored points correspond to SED class (red=I, yellow=flat, green=II, blue=III); orange numbers correspond to highlighted SEDs below.

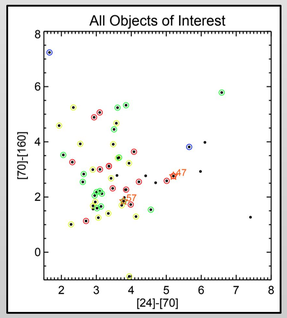


Figure 6. PACS 70-PACS 160 vs. MIPS 24-PACS 70. Notation is as in prior figure.

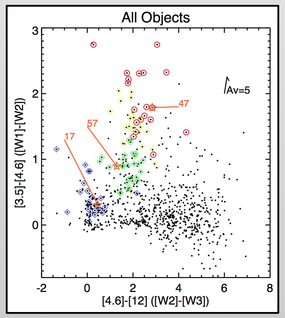


Figure 7. W1-W2 vs. W2-W3. Notation is as in prior figure.

Example SEDs of class I, II, and III YSOs for comparison.

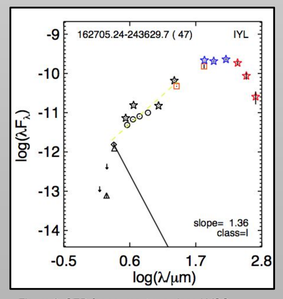


Figure 8. SED for source 47, a class I YSO.

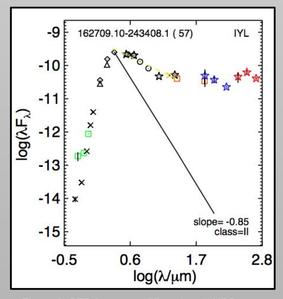


Figure 9. SED for source 57, a class II YSO.

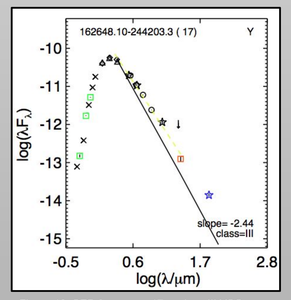
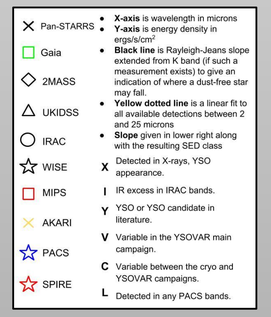


Figure 10. SED for source 17, a class III YSO.

SED Notation



Literature Cited

Guenther, H., et al., 2014, AJ, 148, 122
Rebull, L., et al., 2014, AJ, 148, 92
Ribas, A., et al., 2017, AJ, 849, 63
McClure, M. K., et al., 2010, ApJS, 188, 75
Wilking, B., et al., et al., 2008, in Handbook of Star Forming Regions, Volume II: The Southern Sky ASP Monograph Publications, Vol. 5. Edited by Bo Reipurth, p.351 (arXiv:0811.0005)

Acknowledgements

We gratefully acknowledge that this research was made possible through the NASA/IPAC Teacher Archive Research Program (NITARP) and was funded by the NASA Astrophysics Data Program.

Results

Sources

Total number of sources	155
New YSO candidates detected solely at Herschel bands	3
Unlikely point sources	21
Known or new YSO candidates with new Herschel measurements in at least one band	87

Spectral Energy Distribution Classes

Class I or 0	Flats	Class II	Class III
14	9	46	6

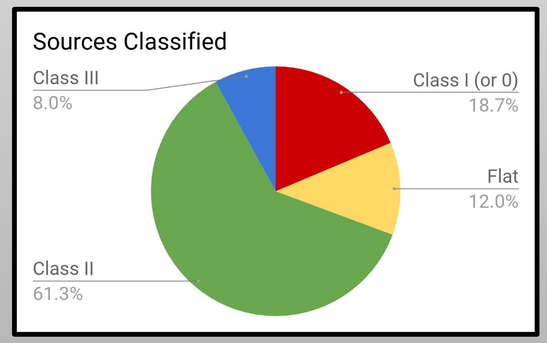


Figure 11. Sources classified according to slope of SEDs (between 2-25 microns.).

Future Work

- Further investigation could be done regarding the three new objects (sources 51, 77, and 84) identified in this study since there are still questions about their identities as real YSOs or simply dense knots of nebulosity.
- More studies could be conducted on the bright YSO (source 37) that appears to be binary in the IRAC bands, but does not appear documented in the literature as such. Possibly, a SOFIA observation could tell us more.
- Improved photometry of crowded sources with point-spread function (PSF) fitting would also be beneficial.

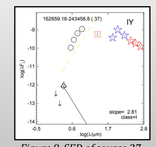


Figure 8. SED of source 37

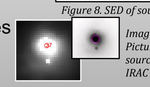


Image 2. Pictures of source 37 in IRAC 4 band.