The Effects of Authentic Science Research on High School Students Engaged in an Independent Astronomy Program

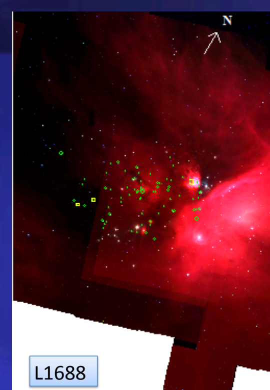
Mike Martinson[1], Marcella Linahan[1], Elizabeth Gutierrez[1], Adam Neidbalec[1], Holly Sprow[1], Luisa M. Rebull[2]
[1]Carmel Catholic High School (Mundelein, IL), [2]SSC/IPAC/Caltech (Pasadena, CA)

Four high school students were engaged in an independent research project searching for young stellar objects in Rho Ophiuchus (L1688). Students used the Spitzer Heritage Archive to obtain data under the guidance of their science teacher. The goal of this research project was to expose students to authentic scientific research, something that can rarely be recreated in the classroom. Compared to the linear path of the science classroom, this project allowed students to develop critical thinking skills which resulted in a deeper understanding of astronomy. Additionally, this project allowed for the spread of scientific research by making posters and giving scientific presentations. This program also exposes students to possible careers and future learning in the fields of science, technology, engineering, and math. This work was based on observations made with the Spitzer Space Telescope, obtained from the NASA/ IPAC Infrared Science Archive, both of which are operated by the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration.

BACKGROUND

- Within the Rho Ophiuchi cloud complex lies the dense dark cloud of Lynds 1688 (L1688). The Rho Ophiuchi cloud is a "dark" cloud, letting no visible light pass though it, making it hard for young stellar objects (YSOs) in the cloud to be seen. This is why the cloud must be studied in X-ray, near infrared (IR), and/or IR wavelengths (Greene and Meyer 1995, ApJ, 450, 233).
- Over the past couple of decades, L1688 (16h27m38.5s -24h29m34s) has been the most well-studied portion within the Rho Ophiuchi cloud complex.
- The Rho Ophiuchi cloud complex is estimated to be 130 parsecs away (Wilking et al. 2008, HSF, 351).
- Starless condensations have been found in the cloud, indicating the initial stages of star formation (Andre et al. 2007, A&A, 472, 519).
- Star formation in L1688 starts in the northwestern region of the cloud, which strongly indicates that ionization fronts from Upper Sco fuels star formation (Zhang and Wang 2009, 138, 1830).
- The young stellar objects in L1688 generally are low mass, pre-main sequence stars, averaging an age of 3 x10^5 years (Greene and Meyer 1995) and tend to form in clusters close to the core (Bontemps et al 2001, A&A, 372, 173).
- Bontemps et al. (2001) identified 425 IR sources using ISOCAM spectrographic data. From those initial sources, 16 were classified as Class I YSOs, 123 as Class II YSOs, and 77 as Class III YSOs.
- Using IRAC images from the Spitzer c2d data, Zhang and Wang (2009) found 13 new H_2 outflows in the mid-IR, showing the majority of the infrared outflows to be found in L1688's core, where YSOs are also likely to be found.
- Wilking et al. (2008) reviewed star formation in L1688 by detailing previous methods, catalogs, discoveries, and L1688's relationship to Upper Sco.

	Previously Known YSOs	Candidate YSOs	Total
Class I	7	0	7 (~9%)
Flat	18	0	18 (~22%)
Class II	41	2	43 (~53%)
Class III	12	1	13 (~16%)



Previously known stars are in green circles
Candidate YSO's are indicated with yellow squares.
The composite image (right) was made using IRAC-4 (red, 8 um), IRAC-2 (green, 4.5 um), and IRAC 1 (blue, 3.6 um) images. The images come from an early c2d reduction.

METHODS

Data for this project were obtained through the Spitzer Heritage Archive (SHA) and the NASA/IPAC Infrared Science Archive. Initially, we searched outward from the center of L1688 within a ~20 arcminute radius, using the c2d Fall '07 Candidate Young Stellar Objects (YSOc) catalog. We also searched other smaller regions in this vicinity, but most of our sources are within ~20 arcmin of L1688.

Two programs, Aperture Photometry Tool (APT, Laher et al. 2012 PASP, 124, 737; also see poster 256.09 Laher et al.) and ds9 were used to view the Spitzer mosaic images for each source, and to create the three-color image to the left. Sources from the c2d YSOc catalog were matched with sources from the literature on L1688, specifically the catalog compiled by Wilking et al. (2008).

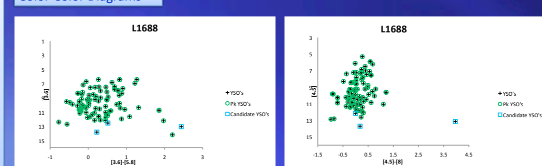
We imported the c2d YSOc catalog into Excel and converted the provided flux densities into energy densities to create spectral energy distributions (SEDs). To create the color-color diagrams, we calculated the magnitudes from the flux densities using zero points found on the web.

Three sources in the YSOc catalog are not in the literature. We looked to see if these sources were similar or different from the literature sources in image morphology, SED, or location in color-color or color-magnitude diagrams.

Color-Color Diagrams

These kinds of color-color plots were what c2d used to identify their YSO candidates from the rest of the catalog. Color-color plots allow one to separate the YSOs from the galaxies by looking at where known objects typically fall -- YSOs are generally bright and red and galaxies are typically faint and red. In our plots here, the literature-identified previously-known YSOs are in green circles and the candidate YSOs are in teal squares. Two of the candidate YSOs fell consistently into the appropriate range for young stars. As indicated in our results section, one of the candidate YSOs data may be affected by a nearby bright point source. The right color-color diagram shows this candidate in the far right where galaxies would typically occur.

Color-Color Diagrams



RESULTS and CONCLUSIONS

L1688 is replete with YSOs. From an initial 82 c2d sources gathered over our region, we threw out one of the initial c2d sources as a potential galaxy (based on the image morphology and SED). We matched 78 sources to the literature as YSOs, and 3 more sources were retained as candidate YSOs. Examination of the three candidate's SEDs, images, and color-color diagrams indicated that they are consistent with being YSOs. Additional data such as spectroscopy will be needed to confirm that these three sources are indeed YSOs.

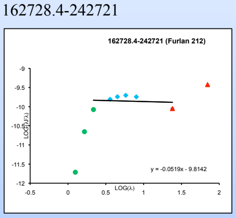
Of the 78 reconfirmed YSOs and 3 candidate YSOs, 7 were found to be Class I (~9%), 43 were found to be Class II (~53%), 18 were found to be Flat (~22%), and 13 were found to be Class III (~16%). There were no Class 0s. Candidate YSO 162758.9-243515 had a slope of -0.62, indicative of Class II. Candidate YSO 162811.6-243730 had a slope of -1.00 indicative of a Class II. However, the third candidate YSO 162636.5-242317 may be contaminated by a nearby bright point source; further analysis is needed.

Bontemps et al. (2001) reported on 216 YSOs in this region according to their mid-IR excess from ISOCAM data, while our data analyzed only 81 objects. Our selection methods, region, and data sources were different from Bontemps et al. (2001). For example Bontemps et al. (2001) studied not only L1688 but also studied L1689N and L1689S. However, the fraction by Class appeared comparable with that from Bontemps et al. (2001), who reported 7% Class I, 57% Class II, and 36% Class III. Our data suggest a much lower fraction of Class III stars (~16%) than Bontemps et al. (2001), who did not account for the Flat class, though our Class III sample is incomplete because we searched for things a priori using IR excess.

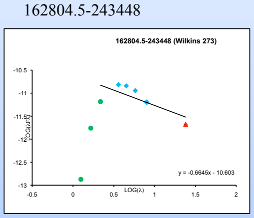
Example Spectral Energy Diagrams (SEDs)

SEDs allow us to assess the size of the infrared excess above photospheric levels, which corresponds to the class of YSO. The SED Class is thought to represent the degree of "embeddedness", which suggests an approximate age of the YSO. There are five classes of SEDs (0, I, Flat, II, III). Class 0 and I YSOs are thought to be the youngest and have the highest IR excess and the largest circumstellar accretion disk/envelope. Flat and Class II YSOs have a lower IR excess than Class I and are thought to have smaller circumstellar disks. Class III protostars are thought to be the oldest and have the smallest IR excess, potentially forming planets at this stage.

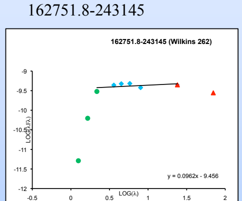
Class I
162728.4-242721



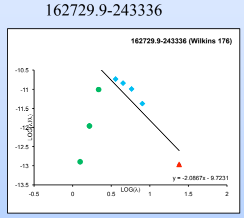
Class II
162804.5-243448



Flat
162751.8-243145



Class III
162729.9-243336



Examples of SEDs from L1688. The green circles are the J, H, and K bands, the blue diamonds are the four IRAC bands, and the red triangles are MIPS 24 and MIPS 70. In all figures, λFλ is in ergs/s/cm^2, and λ is in microns

EDUCATIONAL ASPECTS

This research project has provided the students with higher-level thinking skills not normally fostered in a typical high school astronomy course. Students achieved real insight on how authentic science research is conducted by professionals. This independent astronomy class has inspired these students to pursue careers in STEM and participate in similar projects that promote STEM careers. Teacher M. Linahan was part of the NITARP 2011 class, where she learned this kind of analysis.