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

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1. Abstract

This study will be looking for new candidate young stars within the star-forming region of Rho Ophiuchus, more specifically in a sub-region of this molecular cloud called L1688, or Lynds Dark Nebula 1688. The goal of our study is to identify candidate young stellar object (YSO) sources from Herschel Space Observatory data, as well as support the greater understanding of the variety, evolution, and variability of young stars. Our search for young stars will focus on optical, infrared (IR), and submillimeter data from PanSTARRS, 2MASS, Spitzer/IRAC & MIPS, WISE, and Herschel/PACS & SPIRE. We will merge the catalogs across all available wavelengths but focus our efforts on mid-IR, far-IR, and submillimeter wavelengths. The bulk of our efforts will focus on incorporating the recently released Herschel High Level Data Products (HHLDP), taking the photometry measurements and merging this work with the existing catalog. We will still need to do our own photometry in many cases, because the sources are not in the released catalogs. We will make color-color and color magnitude diagrams for the objects to identify candidate YSOs. We will inspect images (where possible) to ensure good matches across wavelengths and compare our photometry work to existing catalogs to better ensure quality data. We will also construct spectral energy distributions (SEDs) for each candidate YSO in order to better assess whether or not the objects are likely reliable YSOs, and to compare them to the literature inventory of YSOs in this region. This work is important in the greater context of understanding stellar evolution and the physical processes that drive star formation. Because the earliest phases of star formation are comparatively brief, relatively few objects are known from the earliest phases of star formation. This work will look for these objects in particular, as well as support further studies with an expanded candidate young star list in L1688, incorporating Herschel data into existing catalogs.

2.0 Science Introduction and Context

2.1 Low-Mass Star Formation

As described in many articles (e.g., Dunham et al. 2014), low-mass stars form from clouds of interstellar gas and dust that have slowly coalesced due to gravity over long periods of time. Stars usually form in clusters because they originate in large clouds that produce many stars. Turbulence within the nebulae from stellar winds and ultraviolet (UV) light, and/or shock fronts from the deaths of larger, older stars, gives rise to these coalescing masses. When enough material begins to collect, the matter begins to collapse in on itself under the influence of gravity.

This inward gravitational collapse, combined with the angular momentum of the cloud, forms a cocoon and then a disk around the central mass (see Fig. 1). As the cloud collapses and the matter accretes onto the central object, jets of matter are ejected from the magnetic poles. The central mass is accreting high amounts of material, has an active chromosphere and complex magnetic fields, and emits high energy X-rays. The heat generated from this gravitational collapse and continued accretion radiates outward, heating the surrounding dust cloud, which then emits in the IR, giving the central source the appearance of having more IR emission than a typical main sequence star (by definition the end result of star formation). Creating a spectral energy distribution (SED) for the source by plotting observed energy versus wavelength shows this excess of infrared energy.

As the evolution of the young stellar object (YSO) continues, the dust cloud continues to flatten out and accrete or disperse, and the star becomes less embedded. This changes the amount of IR excess measured. The SEDs of the earliest phases look like a cool blackbody spectrum; see Fig. 1. As the central mass accretes and heats up, the peak of the stellar SED moves towards the blue (shorter wavelengths), and the excess IR emission from the dust means that the net SED does not look like a single blackbody. By the time the circumstellar dust is accreted and/or dissipated, the SED looks more like a warmer blackbody spectrum. The dusty disks near the end of the star formation process can be dispersed from around the star entirely, but most likely many of these disks form protoplanets. By the time hydrogen ignites in the star and it alights onto the main sequence, planets are forming.

For completeness, we note that more massive stars probably experience these same star formation processes, just much faster.

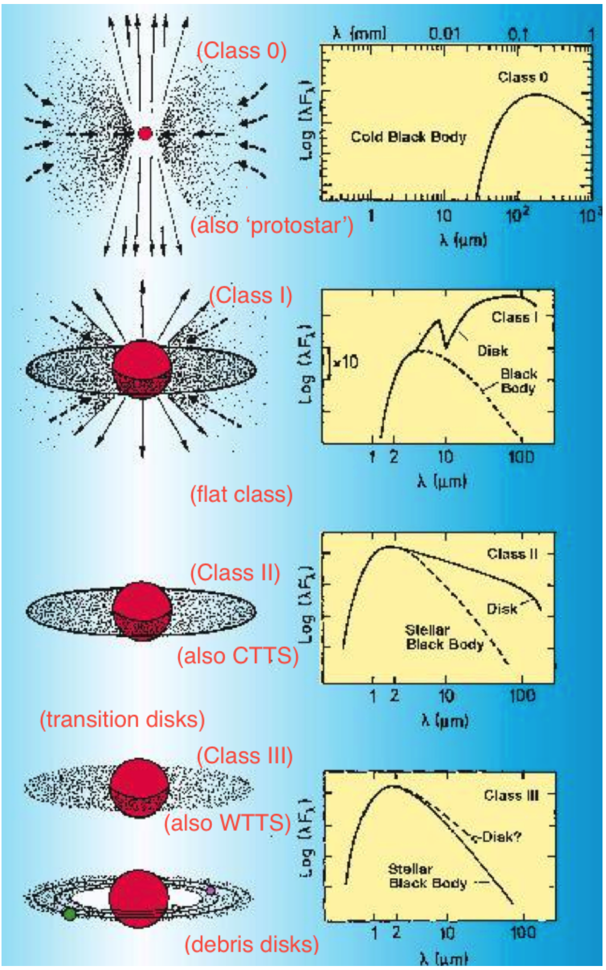

Figure 1: *Low-mass star formation with SEDs. (Figure adapted from Bachiller 1996 and Andre & Montmerle 1994.) In the class 0 phase, the protostar is a small core surrounded by an amorphous cloud of gas. By class I, the cloud is settling into a disk. (Flat class is intermediate between class I and II, and was introduced as a transition stage after this figure was made.) Class II protostars have thinner disks and less IR excess. By the time class III is reached, the disk is more dispersed. By the time the star begins to fuse hydrogen into helium, the material surrounding the disk has begun to condense into protoplanets.*

For YSOs, the shape of the SED can be empirically evaluated to help determine the YSO class. Young star classes are interpreted as how embedded the young star is in its formation dust cloud, and by extension, to a relative age. By comparing the observed SEDs, young stars can be classified in terms of the amounts of excess IR energy above the typical blackbody curve. The slope of SED curve in the near to mid IR region (2.2 μm - 25 μm) allows us to place the objects in SED classes: Class 0, I, Flat, II, and III (see Fig. 1 and Wilking et al. 2001).

These classes were established when most of the available IR data on young stars were between 2 and 25 μm. The earliest definitions of the youngest classes included non-detection at 2 μm, but this no longer works as a functional definition because the 2 μm data now reach faint flux limits. Now, especially with data available from missions like the Spitzer Space Telescope (bands at 3.6, 4.5, 5.8, 8, and 24 μm) the Herschel Space Observatory (bands at 70, 160, 250, 350, and 500 μm), YSO SEDs can be assembled out to at least 500 μm. As can be seen in the SEDs in Figure 1, the earliest (most embedded) classes are the brightest near ~100 μm. By observing with Herschel, we are most likely to detect these most embedded classes. The cartoons in Figure 1 do not show SEDs much past 100 μm. Assembled YSO SEDs should be continuous between 2 and 500 μm, but the slope at shorter bands (2-25 μm) may be substantially different than the slope at the longer bands (70-500 μm). We need to bear this in mind when interpreting SEDs.

The identification and classification of YSOs is important to the further understanding of stellar evolution. Because young stars are embedded in dust and gas, they are more difficult to see in the optical than those on the main sequence. The very youngest YSOs are even more embedded and more challenging to find, and they are not in this phase for very long, so fewer are known. All additional data gathered, tested, and evaluated provides important new pieces to further develop the understanding of the physical processes that drive and contribute to stellar evolution and even planet formation. To better understand these processes, more information from more sources at all stages of evolution need to be found and studied.

2.2 A few notes on nomenclature in star formation

Nomenclature in astronomy can be difficult, because often categories or kinds of objects are named before they are understood. Star formation nomenclature can be particularly muddled, in part because many new things have been learned in the last 15-20 years. There is a "Diskionary" (Evans et al. 2009) published specifically to try to clarify the terminology that is used by the star formation community. In the context of our work, we use the term "young stellar object" (YSO) to refer to young stars in any stage before hydrogen fusion begins (whereupon it becomes a fully-fledge star). "Protostar" is often used to refer to the earliest stages of star formation (Class 0 and I), but could apply to all YSOs. We will endeavor to be very clear and define our terms before we use them consistently.

The SED classes described above are assigned based on the empirical shape of the SED, but that SED shape is very likely substantially affected by the inclination of the rotation axis to us – a relatively old YSO that still has a substantial dust disk, seen edge-on, may seem to be a much more embedded (younger) YSO. Moreover, accretion is unlikely to be a smooth, slow, and steady process; YSOs may appear to have different SED shapes as a function of accretion rate (see, e.g., Dunham et al. 2014 and references therein). For all of these reasons, Dunham et al. (2014) and Robitaille et al. (2006), among others, have advocated for "stage" as a separate entity from "class"; "stage" is to be used when describing the physical or evolutionary state, and "class" remains an empirical definition based on the SED shape. We will use "class" for what we are doing here, because we are working primarily with observations and not models.

Time variability of YSOs has been known for decades – variability was one of the original defining characteristics of young stars (Joy 1945; Herbig 1952). However, studying variability of YSOs in the IR is a relatively new endeavor (see Rebull et al. 2014, Rebull 2011, and references therein). The best information we have available (Billot et al. 2012) shows that very young YSOs vary to at least the 20% level (in flux density) at Herschel bands on timescales of weeks. There are not enough literature-identified Class 0 objects in the YSOVAR clusters yet analyzed to characterize their variability on timescales of days/months at 3.6 & 4.5 μm (see, e.g., Rebull et al. 2015). YSOs are known to vary on all timescales, but the amplitudes (on human timescales) are typically tenths of magnitudes, not magnitudes. As such, it is rare for the SEDs (which are log-log plots) to change shape substantially on human timescales, though changes visible on an SED can happen (see, e.g., Meng et al. 2015).

2.3 Science Background: Our Target

The Ophiuchus molecular cloud (found ~1° south of the star ρ Ophiuchi of the the constellation Ophiuchus; see Fig. 2), at 120 pc away from us (see distance discussion in Rebull et al. 2014), is one of the nearest star forming regions to our Solar System. It is often used in popular images such as posters (see Fig. 3) because of its proximity to Earth and colorful nature. The entire star forming complex is enormous (Fig. 3); we will focus on just a piece of it (see below).

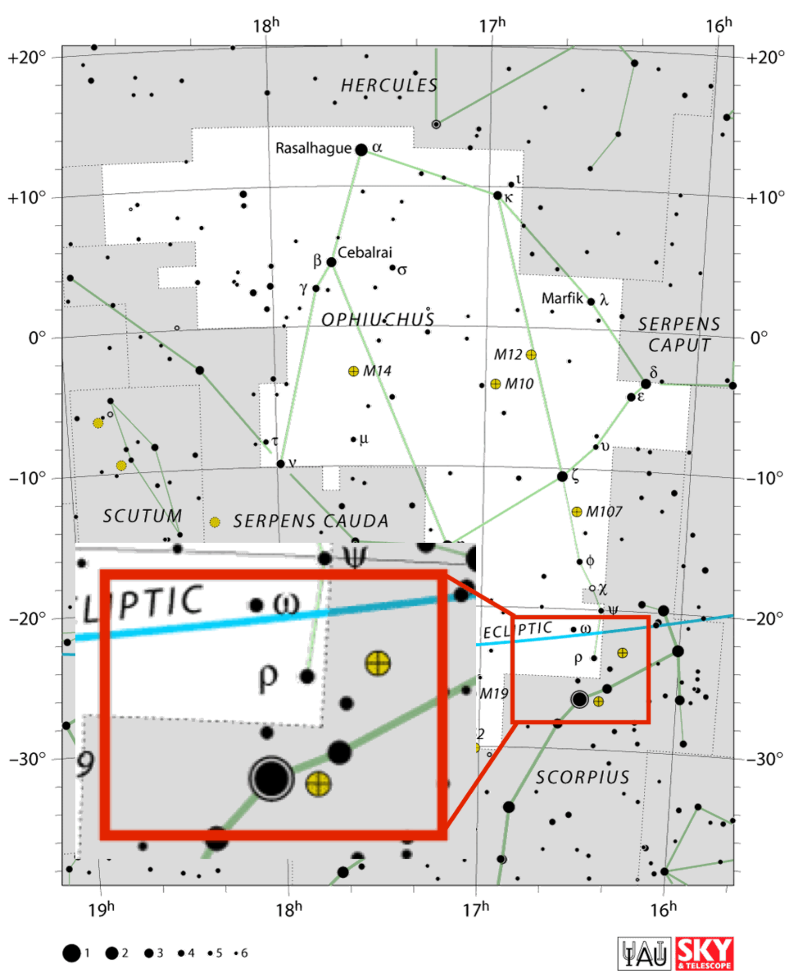

Figure 2: *Location of the Ophiuchus molecular cloud (red square), about 1° south of the star ρ Ophiuchi, near the constellation Ophiuchus, in relation to the ecliptic and other familiar constellations. Image source: International Astronomical Union, public use image.*

Figure 3: *Color (optical) ground-based image of the Ophiuchus region in optical from Wikipedia – this shows both the nebulosity and potential star forming regions of Ophiuchus. North is* ***not*** *up; it's roughly to the left, and east is down. This image spans the entire Ophiuchus cloud complex, a very large region – 16 degrees across side-to-side and 9 degrees top-to-bottom. We will be focusing our studies on a much smaller region, one of the more dense regions, seen here as dark filaments.*

Ophiuchus is likely the site of triggered star formation due to the interaction of the molecular cloud and nearby B2V star HD147889 (Wilking et al. 2008). The active stellar winds and ultraviolet radiation create a shock front that moves through the molecular cloud, providing the energy to aid gravity in star formation. Because of its proximity, this region has been the focus of many studies over several decades; there is a wide range of ancillary data. There are several individual sub-clouds within the greater cloud. We will be focusing our study on the L1688 area.

The Ophiuchus star-forming region is well studied (see, e.g., Wilking et al. 2008 and references therein). Studies performed in the 1970s and early 1980s showed large numbers of infrared sources in L1688 (see, e.g., Wilking et al. 2008). There are over 90 known YSOs in this region. Some of the youngest YSOs (Class 0s and Is) are known to be located here; Wilking et al. (2008) list 35 embedded objects, but there may be more. Ages are difficult to determine with any confidence, but with many embedded objects, the cluster can be no more than a few million years old; Wilking et al. (2008) cite a median age of 0.3 Myr.

There are two recent studies with direct relevance to our work. McClure et al. (2010) presented a detailed spectroscopic study of 136 YSOs in the Ophiuchus star-forming region, but many of their sources are in L1688. The longest wavelength they worked with, however, was ~25 μm, because they did not use Herschel data. They have assembled a lot of literature information and present new characterizations of their sources. Ribas et al. (2017) studied 83 YSOs in the Ophiuchus star-forming region (not just L1688) using Herschel images and spectra, some of the same data we plan to explore. However, Ribas et al. deliberately limited their study; they focused on the less embedded objects that were also away from the nebulosity as seen in the Herschel images.

However, there are more sources detected by Herschel than there are identified YSOs in the region when considering the catalogs from Wilking et al. (2008), McClure et al. (2010), and/or Ribas et al. (2017). Figure 4 includes, for reference, the L1688 region seen in a Herschel/PACS HiPS composite image with several catalogs overlaid (this figure is discussed more in the next section). While this figure depicts a larger region than we intend to study (see next section below), the relative densities of sources from the literature and the Herschel catalog can be seen. There are many Herschel sources that have not yet been explored, much less identified as YSO candidates; these are some of the sources we plan to investigate in detail. These could be new additional Class 0 and I sources that have not yet been discovered or characterized. We will begin this process by identifying these candidates and combining multiwavelength data to obtain SED classifications.

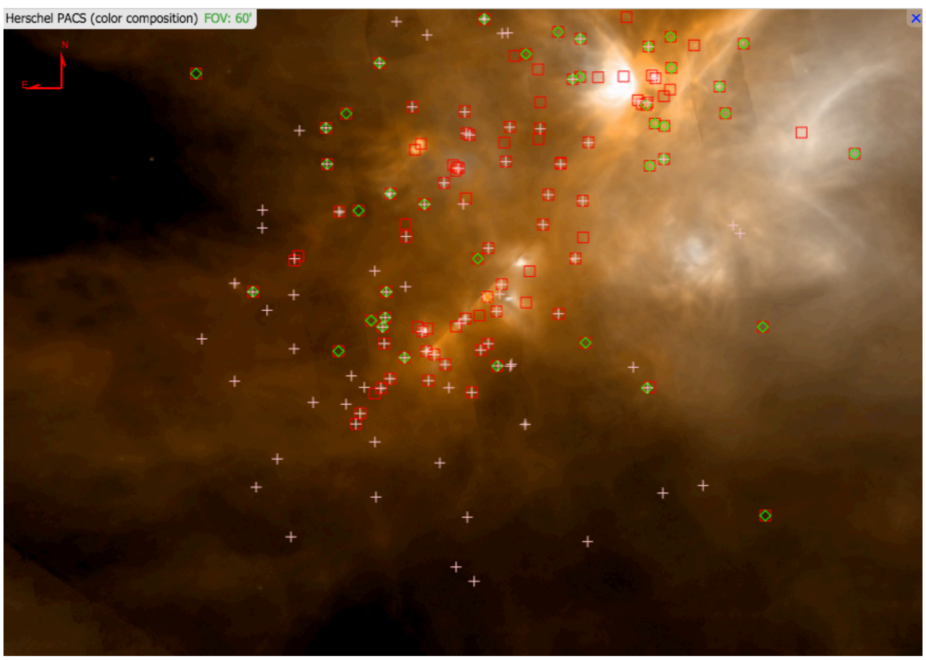

Figure 4: *Herschel/PACS HiPS composite image of the L1688 region. This region shown is a degree across, a larger region than we will study; we will focus on the filament in the center of this image. Pink crosses: HHLDP PACS-70 sources; green diamonds: Ribas et al. (2017) sources; red squares: McClure et al. (2010) sources. Not shown: Wilking et al. 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 errors in the catalog. This is one of the things we plan to investigate.*

3.0 Analysis Plan

3.1 Notes on nomenclature and "big picture" issues

The observations that we will work with are largely already processed for us – that is, there is a pipeline (set of computer software) that has been run on the data. For the most part, the images are flux-calibrated (so the values in the image pixels correspond directly to measured brightnesses), and the catalogs already exist (so there is a large table with the photometry, which is quantitative measurements of the brightness of each source in the image). Each row of the catalog carries with it the measurement of the source and various other parameters, sort of like a "baseball card" with the stats of the player on the back of the card. Sometimes catalogs are called "source lists" – the word "catalog" connotes more reliability, whereas "source lists" may not be as complete or reliable.

The catalogs (or source lists) for each survey are generated separately. Each row in the 2MASS catalog, for example, has almost 130 parameters for each source, including (but not limited to):

- the source position and a unique name generated from the position;
- measurements of brightnesses at that location in each of the 2MASS bands (J, H, and K_s), and their error estimates; and
- data quality flags from the computer which tells us how confident the computer is that it has measured those values correctly.

The computer running the 2MASS pipeline looks for sources at all three bands; it knows about the source's properties in all three bands at once. If it, say, detects a source at 2 of the 3 bands, it knows to look for it in the 3rd band, even if it doesn't detect the source there initially or independently. However, it doesn't know anything about any survey outside of 2MASS. It doesn't know what this source looks like in Pan-STARRS (optical) or Spitzer (longer wavelength IR than 2MASS).

The process of merging source measurements across wavelength bands is sometimes called "bandmerging." This process identifies unique, real sources and attaches all of the measurements properly to that source. (Continuing the baseball card analogy above, this could be like collecting all the stats for that player from every league/team he played for.)

Further complicating matters, however, the existing Herschel catalogs are reduced separately for each channel. The Herschel High Level Data Products (HHLDP) are the most recently released products. The HHLDP includes catalogs for each band of PACS and SPIRE, but each band was measured in isolation, without knowledge even of other Herschel bands, much less any other bands. These catalogs, therefore, are known to be incomplete, especially in star-forming regions where the nebulosity is clumpy and complicated, and the computer can have a hard time distinguishing between sources and nebulosity.

The initial matches between catalogs can be made with a computer, just looking for position matches within a small search radius, typically 1-3 arcseconds. But, it's important to look at all the images wherever possible before declaring a secure match between catalogs, especially in situations like L1688 where the computer might be fooled by complicated backgrounds and sources close together. Moreover, these various surveys are rarely the same sensitivity or spatial resolution, so matching sources can be complicated – a source in one wavelength may not be detected at all at another wavelength, or it might break into 2 or more pieces at another wavelength. (Again, attempting to continue the baseball card analogy above, one could not search on all instances of a player number to find all the instances of a given player on every team he ever played, because his number may change on each team, even if he likes having a particular number since his Little League years. One could attempt an initial match by having a computer look for matches of the last name plus the number, but a human would still need to look at it to confirm the match [turns out there are ~20 players named González in MLB], or to incorporate the knowledge that he was #8 on this team but #18 on this other team.)

3.2 Existing catalogs

Our mentor scientist has studied this region as part of YSOVAR (Young Stellar Object VARiability; Rebull et al. 2014); YSOVAR monitored the young stars in a dozen star forming regions to probe the variability of young stars in the IR. The existing YSOVAR catalog, assembled in the context of Guenther et al. (2014), has bandmerged together Chandra/ACIS (X-ray), UKIDSS (*zyJHK*, 0.88-2.2 μm), 2MASS (JHK_s, 1.2-2.2 μm), and Spitzer, both IRAC (3.6, 4.5, 5.8, 8 μm) and MIPS (24 μm). Since the time of publication of Guenther et al., PanSTARRS (*grizy* filters, 0.48-0.91 μm) has been released. There are also WISE data (3.4, 4.6, 12, and 22 μm) and AKARI data (9, 18, 60, and 160 μm); both of these satellites conducted all-sky surveys, but both are lower spatial resolution and sensitivity than Spitzer. The initial YSOVAR work did not incorporate WISE or AKARI data into the catalog due to limited scope and time. In our study, we plan to remedy that by merging in WISE and AKARI. Even though WISE and AKARI have lower spatial resolution and sensitivity, they still provide useful constraints on the SED for those sources that can be securely matched to WISE and AKARI counterparts.

The catalog assembled in the context of YSOVAR covered the whole L1688 region, but the YSOVAR study did not monitor this whole region; it monitored a region described by complicated polygons (see discussion and figures in Rebull et al. 2014). Where we can, we will match our sources to those with light curves from YSOVAR. Because there are so few Class 0 or I objects that have been monitored, even light curves for a few more would be important for characterizing the variability properties at 3.6 & 4.5 μm of these most embedded objects.

In our study, however, we will focus most of our work on the data from Herschel (PACS: 70 μm, 160 μm; SPIRE: 250 μm, 300 μm, 500 μm). HHLDP catalogs are available for all 5 of those bands, but as noted above, they are single-channel-only catalogs, and they are not bandmerged across wavelengths or instruments. Moreover, large patches of sky, including this region, were omitted from the initial SPIRE release because they were too complicated. We have obtained pre-release second generation catalogs from the SPIRE team (B. Schulz, private communication) that include this region. Since not all of the sources that we know are there (because we can see them by eye) have corresponding measurements in the HHLDP catalogs, we will have to make these additional measurements (do additional photometry) where they are missing from the HHLDP catalogs. We will thus focus most of our attention on getting high-quality bandmerged catalogs for the ~75 sources seen in PACS and SPIRE in L1688.

3.3 Our region

We are going to focus on a square that is 20 arcminutes on a side, in the heart of L1688, centered on 16:27:10 -24:37:30. This is also centered on a dark filament in the optical, which is bright in the infrared, with IR-bright sources along the filament (see Figure 4). We picked this region to focus on the heart of L1688, specifically to include new sources, but also to limit the project to something that is doable in the allotted time. If we move faster than expected, we may extend our region; if we are slower than expected, we may reduce the region. This region has many existing sources in the various constituent catalogs; see Table 1 for a summary of the number of sources in this region from each survey. There are several sources from Wilking et al. (2008), McClure et al. (2010), and Ribas et al. (2017) in this region; see Figure 4 and Table 1. There are more Herschel sources than literature sources; there are 50 PACS-70 sources and 44 PACS-160 sources listed in the public catalogs. Therefore, we know we will have new sources to investigate as part of this project. We will primarily work with these Herschel sources.

Table 1: Existing data – ~16,000 unique sources within a 20 arcmin square centered on 16:27:10 −24:37:30.

Instrument/ Catalog	Wavelengths	Source	Reduction done by	Number of Sources
Chandra/ACIS	X-Ray (~0.001μm)	collabo-rators	YSOVAR Team	47
Pan-STARRS	Optical, grizy (0.48–0.91 μm)	Pan-STARRS1 archive	Pan-STARRS1 archive	~500
UKIDSS	zyJHK (0.88–2.2 μm)	UKIDSS archive	UKIDSS archive	176
2MASS	JHK (1.2–2.2 μm)	2MASS archive	2MASS archive	357
Spitzer/IRAC and MIPS	Mid IR (3.6, 4.5, 5.8, 8.0, 24, 70 μm)	collabo-rators	YSOVAR team	~2,800
Spitzer/IRAC and MIPS	Mid IR (3.6, 4.5, 5.8, 8.0, 24, 70 μm)	c2d team	c2d team	~16,000 objects, ~4,000 with detections at all 4 IRAC bands
WISE	Mid IR (3.4, 4.6, 12, 22 μm)	WISE archive	WISE archive	~500 *(not merged yet)*
AKARI	Mid IR (9, 18, 60, 160 μm)	AKARI archive	AKARI archive	34 *(not merged yet)*
Herschel/ PACS and SPIRE	Far IR (70, 160, 250, 300, 500 μm)	Herschel archive	NHSC	~75 (*)
YSOVAR	Mid IR (3.6, 4.5 μm)	collabo-rators	YSOVAR team	~400
Wilking et al. (2008) sources	Multi-wavelength	Wilking+	Wilking+	114

McClure et al. (2010) sources	Multi-wavelength, to ~24 microns	McClure+	McClure+	56
Ribas et al. (2017) sources	Multi-wavelength, includes Herschel	Ribas+	Ribas+	12

(*) One can see several sources in the Herschel images, but detailed numbers await a more careful data reduction.

3.4 Our Plan

We will start with the position-matched but vetted catalog assembled for Guenther et al. (2014), and then merge WISE and AKARI to it by position. We will take the public HHLDP PACS catalogs and merge those in by position, along with the pre-release second generation SPIRE catalogs. Finally, we will merge by position this net catalog with the literature sources from Wilking et al. (2008), McClure et al. (2010), and Ribas et al. (2017).

Then, for each of the ~75 sources with Herschel detections in our 20 arcminute box, we will examine images (using IRSA tools such as Finder Chart and IRSA Viewer) and construct SEDs (using Excel) to see if the sources are matched correctly across bands. We will compare our SEDs with those published in the literature from McClure et al. (2010) and Ribas et al. (2017).

When we assemble the SEDs with all the data, objects could have data points from many wavelengths between 2 and 500 μm. As mentioned above, SEDs should be continuous between 2-500 μm, so outlying points or discontinuous changes are indicative of a source mis-match or errors in photometry. By comparing images and SEDs, we can identify whether this is due to sources being matched incorrectly across wavelengths. The class (0/I/flat/II/III) is defined as the slope of the SED between 2 and 22 μm. By adding points out to 500 μm, we will be able to investigate how the slope of the SED changes at the longer wavelengths. Ribas et al. (2017) investigated the distributions of SED slopes in these longer wavelengths. Since we will be working with sources that are more embedded, we will be able to extend those results to include more embedded sources.

We will identify sources whose Herschel photometry is missing and fill in those gaps. Once we are sure that we have a well-vetted catalog, we will make color-color and color-magnitude diagrams (using Excel) to assess whether or not the sources we have identified (or discovered) have qualities similar to known YSOs.

Our region is relatively small compared to the molecular cloud, and centered on one of the denser parts of the cloud. The cloud itself is likely dense enough in this region to block most of the sources behind the cloud. Most of the sources we see in the images are clustered and bright, and thus are likely to be either YSOs or foreground objects. However, by examining the color-color and color-magnitude diagrams, coupled with the SED shapes, we should be able to rule out most of the foreground stars and background galaxies.

In order to do our own photometry, the tool we will use is the Aperture Photometry Tool (APT), developed in the context of pre-NITARP teacher teams. While aperture photometry may not be ideal for sources close together with complicated backgrounds, we do not have access to user-friendly PSF-fitting routines. APT will allow us to make customized selection of apertures and annuli for each source, so we can assess each source individually. We will do aperture photometry for several sources that are already in Ribas et al. and the existing PACS and SPIRE catalogs to calibrate our results and assure we are doing photometry correctly. Then we can carefully do aperture photometry, individually, on deeply embedded and/or potentially confused sources.

4.0 Education & Outreach

The team of educators working on this project represent a wide range of backgrounds and locations; however, all the schools are rural, so some challenges across the schools are similar. While their teaching experiences and assignments might be very different, they share an appreciation for the effects science research like this has on their students, the school, and community as a whole. As this project develops, the team proposes to develop a qualitative study into the effects, reach, and influence of the NITARP experience on their students and schools. The study will include teacher observations, media activity and response, student comments and level of involvement in science research as a whole.

Ukiah High School, Ukiah, OR - L.Orr

For this project, students in Ukiah School and Stanfield will be given the opportunity to participate in the NITARP L1688 research as part of an extracurricular project. The bulk of our group work and student participation will be based on remote meeting with several in person workshop type sessions as needed. Over the course of the project, students will gain a greater understanding of star formation, but also experience in the research process, data analysis, and scientific communication. In addition to the core components of the NITARP experience, students will present their work to the school boards of each school, at a community library public outreach night, and to the local 4H astronomy club.

Laura Orr, as a NITARP researcher, will use the experience to gain better understanding of astronomical research as well as the process of proposing, conducting, and presenting authentic research. Authentic research on the effect of this type of program on teachers and students will be conducted. She will share the experience and skills with other middle and high school teachers in her region and state via workshops and professional development presentations (2018 NSTA National Convention, Oregon State Teachers Association annual convention, regional Intermountain Educational Service District Board meeting) as well as in print articles and radio interviews (Oregon School Board Association's 'Small Talk' publication and others).

Lakeside Jr-Sr High School, Plummer, ID – L. Wommack

Students and community members will be included in the NITARP program. Student volunteers were identified to participate in the program. Other students in high school math and science classes and support staff will be invited to learn about the research as interest allows. Students and the instructor will gain a better understanding of authentic research as well as star formation and basic astronomy. The participating students and instructor will also gain knowledge in multiple fields of astronomy from the AAS. The NITARP program will be shared with school board members and administration both before the summer session as well as after the January AAS meeting. Our school's participation in this program will also be shared with local media.

Kankakee Valley High School, Wheatfield, IN – N. Coster

Students at Kankakee Valley will have multiple opportunities to participate in the NITARP L1688 research project. Students can apply to be teaching assistants, enroll in AP Physics, or participate through the Kankakee Valley High School Science Club. During this experience, students will gain a deeper understanding of star formation, data analysis, scientific communication, and electromagnetic waves. Students will also improve their presentation skills by presenting NITARP information at 8th grade night, DeMotte Elementary School's Science Night, the local school board meeting, and other outreach opportunities.

Nancy Coster, as a NITARP researcher, will gain expertise in astronomy techniques related to waves in order to incorporate them into the real world application parameters of AP Physics 1 as well as enhancing her research skills. Nancy will share her experiences with high school and middle school teachers by sharing through professional development opportunities and publicizing the NITARP program.

South Sevier High School, Monroe, UT – D. Morgan

Several South Sevier High School students will have the opportunity to participate in the NITARP L1688 research project during a calendar-year-long investigation science course. Student objectives for this course include developing a research topic, conducting an experiment, and presenting results. The purpose of this course is to enhance students' experience with the scientific process, develop scientific reasoning skills, increase scientific vocabulary, and communicate scientific learning. The NITARP L1688 research project offers the perfect opportunity for students to meet these objectives and develop these critical skills through a collaborative effort with other peers, teachers, and mentor scientist. Additionally, students will present their results to their classmates, the local school board, the community at a school sponsored science night.

As a NITARP researcher, Deborah Morgan will use the opportunity to gain valuable experience in astronomy research--specifically young stellar objects, collaborate with other educators on best teaching practices in astronomy and physics, and provide students with authentic data for science activities in the classroom. She will present at the Utah Science Teachers Association (USTA) conference in February of 2019, host an online teacher edchat through Twitter, highlight the work of NITARP teachers in her blog, and teach professional development sessions at both district and regional conferences.

5.0 Resource list

Andre, P., & Montmerle, T., 1994, ApJ, 420, 837

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