Identifying Candidate Young Stellar Objects in the Spider Nebula (IC 417) Using Archival Visible and Infrared Data

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1.0 Abstract

The Spider Nebula (IC 417) is a star-forming region about 2.3 kpc away, in the direction of the Galactic anti-center. While not in the outer reaches of the Galaxy by any means, IC 417 is still further towards the outer reaches of the Galaxy than most of the well-studied star-forming regions. If star formation there is significantly different from star formation elsewhere (perhaps due to metallicity or stellar density), it might manifest in a different distribution of masses (initial mass function). The first step to understanding whether star formation is different there is to take an inventory of the cluster member stars. We will be working towards a complete list of members of IC 417. This region was studied by a NITARP team in 2015, and we are continuing and enhancing their investigation, adding new data released after their work, most notably Gaia DR2 and PanSTARRS. Between the prior NITARP team and the rest of the literature, there are several hundred known young stellar objects (YSOs) and candidate YSOs. There is a somewhat overlooked portion of IC 417 called the Nebulous Stream (NS) that is most obvious in the mid-IR (3.6, 4.5 μm). Our first goal is to explore the stellar content of the NS and add to the list of candidate YSOs. Our second goal is to apply the new data sources to the prior list of YSOs and assess whether or not we still believe them to be YSOs. We will use optical through far-infrared data, construct spectral energy distributions (SEDs), inspect images where possible to ensure isolated point sources, and create color-color and color-magnitude diagrams to help us identify YSO candidates.

2.0 Science Background

2.1 Star Formation

Stars form in clouds of gas and dust called nebulae, which act as incubators for newborn stars; see Figure 1, which depicts key stages of low-mass star formation.

An initial concentration of matter can be triggered into collapse by a supernova shockwave, winds and ultraviolet (UV) light from O and B stars, passing galactic spiral arm density waves, and/or through its gravitational pull. Initially in a cloud that can be thought of as roughly spherical shape, (Fig. 1b), the matter collapses inward, creating a rotating disk as it conserves angular momentum. Spiralling matter accretes onto the central object until it condenses under gravity. Matter from the original spherical envelope continues to fall toward the disk, and from there, flow inward toward the star. Some of this matter is ejected to form bipolar jets along the magnetic axis (which is thought to be most commonly roughly parallel to the rotation axis, Fig 1c).

Eventually the envelope is depleted, leaving a protoplanetary disk of primordial material (Fig 1d). As accretion slows, the disk thins out and the jets stop, and proto-planets form a planetary system in the same plane (and orbiting in the same direction) as the disk. Eventually, the pressure and density in the core ignites nuclear fusion, and it becomes a star.

Nomenclature is complicated in the study of young stars (Evans et al. 2009), but we refer to all of these stages as young stellar objects (YSOs). “Protostar” is often (but not always) used to refer to the central object in its earliest stages.

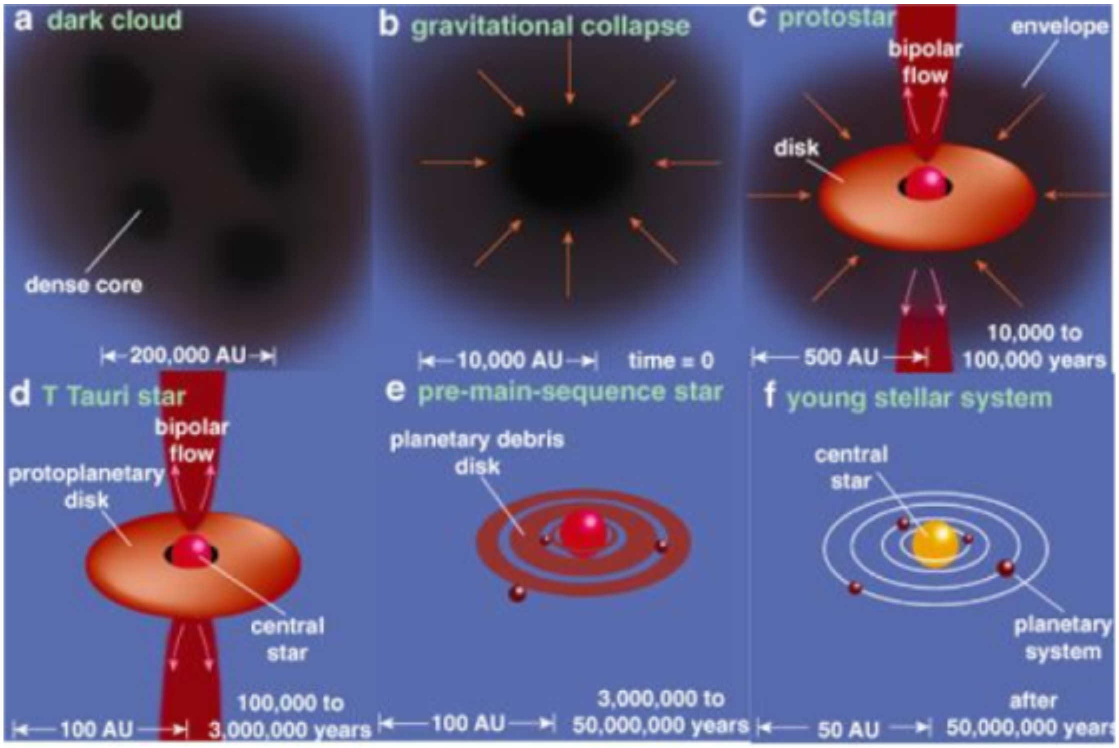

Figure 1: *The process of low-mass star formation. (Green 2001)*

During most of this process, the YSO has a dusty envelope or disk around it. This intercepts and absorbs radiation from the YSO, then re-emits it in the infrared (IR). Therefore, we can identify YSOs by looking for stars with excess IR emission, e.g., more IR emission than expected for a star without a dusty disk or envelope. IR excess can be used to differentiate the YSO from foreground and background stars that are not dusty.

Other objects with apparent IR excesses can seem to be YSOs. The primary example of such a contaminant (the primary one we need to worry about in our work here) is asymptotic giant branch (AGB) stars. These stars nearing the end of their lives produce copious dust in their atmospheres and are therefore very bright stars with an IR excess. If they are sufficiently far behind a cluster of YSOs, they will be faint enough to resemble YSOs in the cluster.

With distances from Gaia (not always available for everything) we can identify and include or eliminate objects from our candidate pool.

As YSOs age, their IR excess diminishes (Fig 1e) to trace amounts (Fig 1f).

IR excesses in YSOs are revealed in a spectral energy distribution (SED) plot. An SED is a graph of the energy density emitted by an object as a function of wavelength.

As seen in Figure 2, the SED for the youngest YSOs resembles that of a cold blackbody. This is because the object’s emission is absorbed by the gas and dust envelope which re-radiates the energy as heat like a simple blackbody. As the envelope collapses and the central source warms up, emission from the central source becomes more apparent. We see this as YSO progresses from Class 0 to Class I and the peak of the SED curve moves to the left (blue-ward) as the forming star warms up. Still, the remnant of the dusty cocoon (and the disk) continues to glow in IR, lifting the right side of the curve off from that of an isolated blackbody - this is the IR excess.

The IR excess continues to decrease as circumstellar dust decreases and the YSO progresses to Class II (also known as a classical TTauri star, or CTTS). When the YSO reaches Class III (also known as a weak-lined TTauri star, or WTTS), the IR excess has almost vanished.

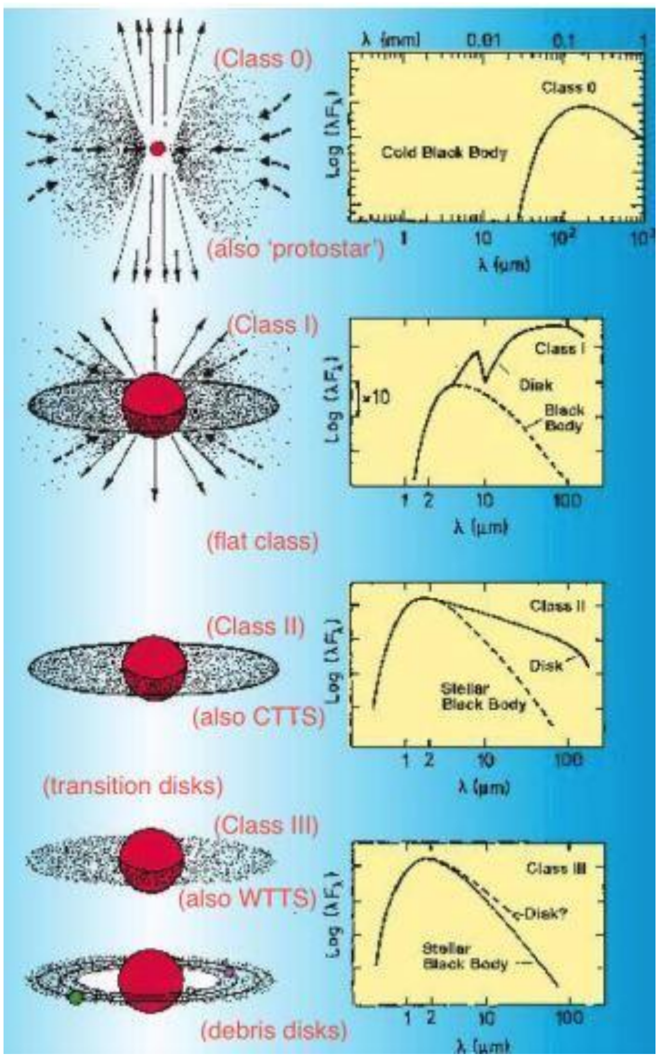

Figure 2: *Low-mass star formation with SEDs illustrating IR excess. Adapted from Bachiller (1996).*

YSOs can be identified in other ways as well. As matter accretes onto the YSO, where it hits the star, it creates a shock that produces a UV excess, which is also apparent in an SED. However, UV data from YSOs are harder to obtain than IR data because UV light is easily scattered/attenuated by circumstellar and interstellar dust (whereas IR light penetrates the dust). Very large UV excesses are strong enough to "spill over" into blue optical bands, such as *g* band in Pan-STARRS. Using optical bands, from Pan-STARRS and Gaia, we can construct color-magnitude diagrams in which YSOs will appear above the Zero-Age Main Sequence (ZAMS).

YSOs tend to rotate quickly because angular momentum is conserved during formation. The star ends up being much smaller than the initial cloud, and so even a small initial rotation can result in a very fast rotating star. Fast rotation is accompanied by high stellar activity -- strong magnetic fields, spots, and flares. Flares are associated with excess X-ray emissions and strong emission lines, most prominently in Hα. In Figure 3, a Class II star is shown with typical sources of electromagnetic emissions.

Note that accretion likely varies substantially as a function of time, flare brightness changes with time (by definition), star spots in young stars are often large and may be long lived, thus creating surface features that rotate into and out of view, and the disk is unlikely to be smooth and featureless (even if flared). All of these things together mean that young stars are also highly variable, pretty much on any timescale, at any wavelength (see, e.g., Rebull 2011).

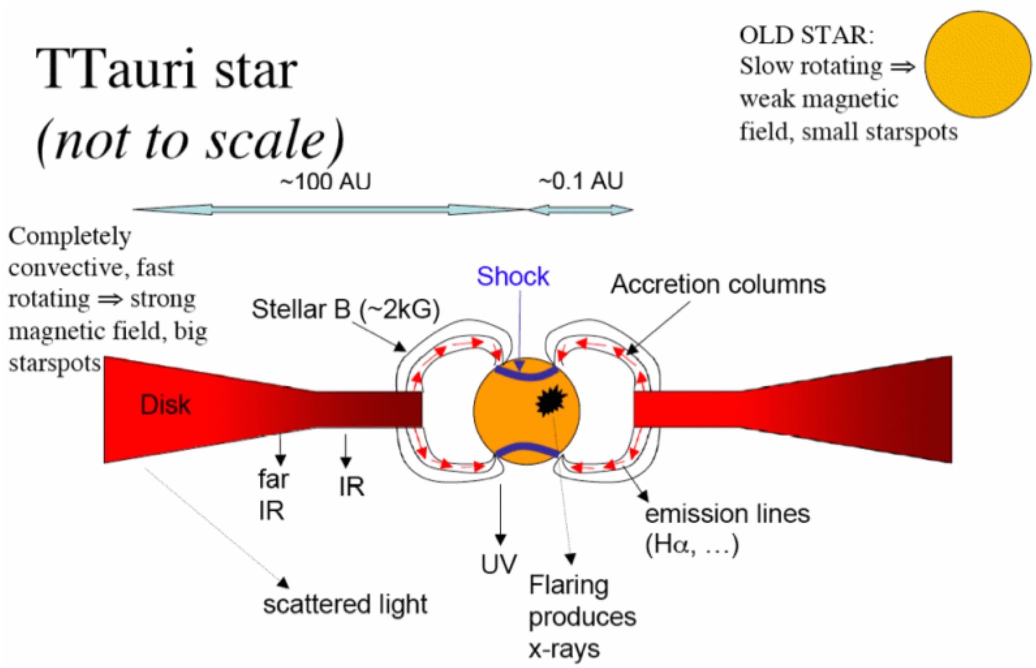

Figure 3: *Class II YSO (not to scale) illustrating origin of emissions making YSOs different from older stars (Rebull 2011). Typical magnetic field (B) strengths in young stars are on the order of 2 kiloGauss, much stronger than what is found in older stars like our Sun. The magnetic field truncates the disk before it reaches the star; matter crawls along the field lines and crashes down onto the star, creating a hot, shocked spot or ring on the stellar surface.*

Our understanding of (low-mass) star formation is shaped largely by the star formation regions (SFRs) closest to us, most notably the Taurus SFR (relatively low density star formation, no or few high-mass stars; only 140 pc away, see, e.g., Torres et al. 2007) and the Orion SFR (high gas and stellar density, including many O and B stars; 400 pc, and the closest SFR with O and B stars; see, e.g., Muench et al. 2008).

Figure 4 is a representation of our Galaxy. The origin of the galactic coordinate system is our Solar System. When we look out across the plane of the Galaxy, we see more SFRs between longitude 90° and 270° (the top ~half of the graphic, including the Galactic center) than between 270° and 90° (bottom ~half of graphic). It remains an open question whether variations in initial metallicity (e.g., elements aside from H and He) and stellar density play a significant role in determining the initial mass function of a star forming region. Therefore, characterizing star forming regions in all parts of the Milky Way is an important research goal.

We have decided to study IC 417, which is a region almost exactly opposite the galactic center (the galactic anti-center). Metallicity and average stellar density are uncertain, as is whether star formation here is significantly different from star formation elsewhere. This might manifest in a different distribution of masses (initial mass function, IMF).

The first step to understanding whether star formation is different here is to take an inventory of the cluster stars. **We will be working towards a complete list of members of IC 417.**

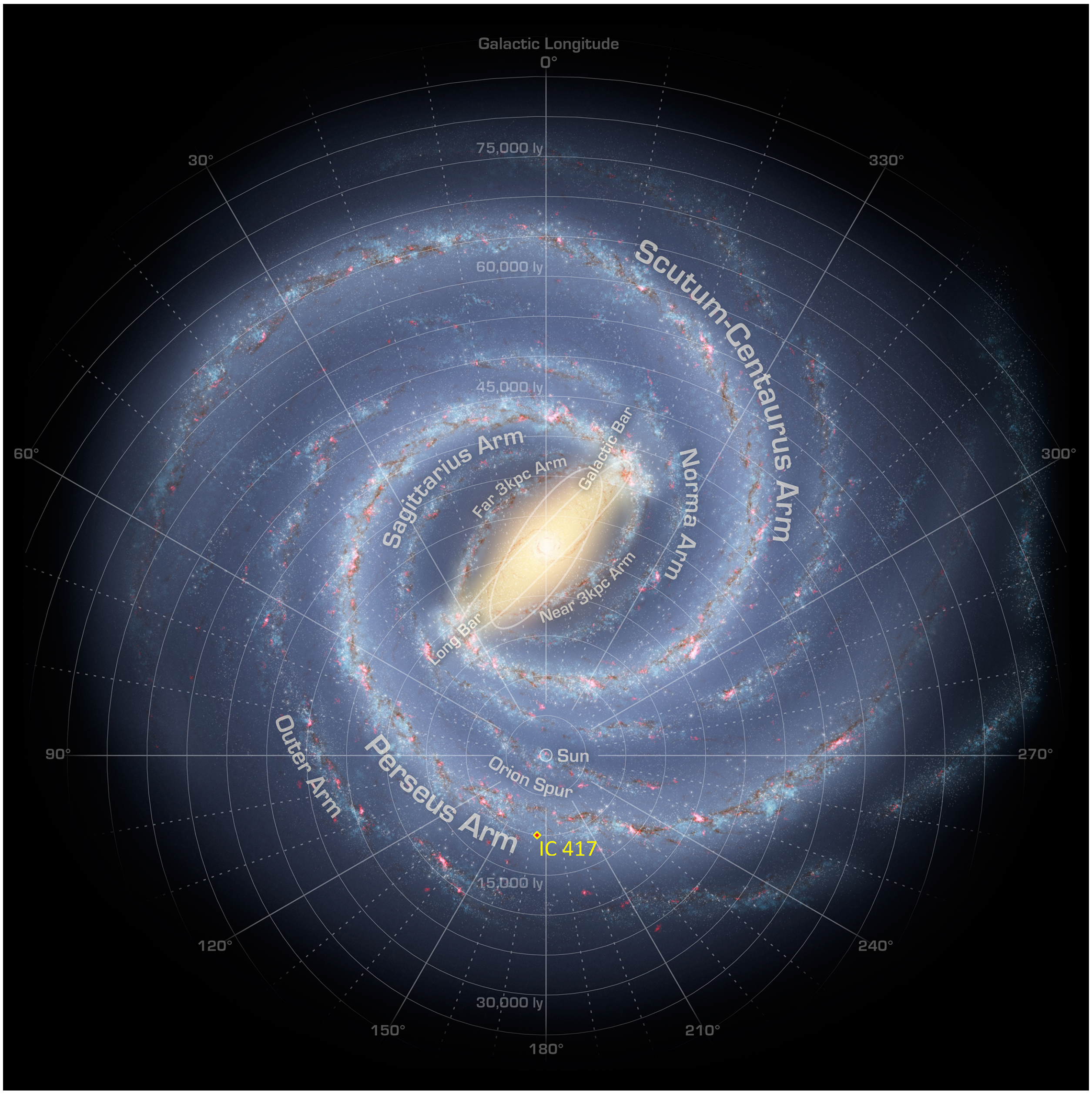

Figure 4: *Artist's impression of a top-down view of the Milky Way Galaxy (Image from NASA/JPL---Caltech/R. Hurt, SSC press release ssc2008---10b). Our Solar System is located in the Orion Spur of the Perseus Arm, at the origin of the coordinate system*

shown. IC 417 is located at 173° longitude (and 00.20° latitude), and a distance of 2.3 kpc, in the direction of the Galactic anti-center.

2.2 The IC 417 Region

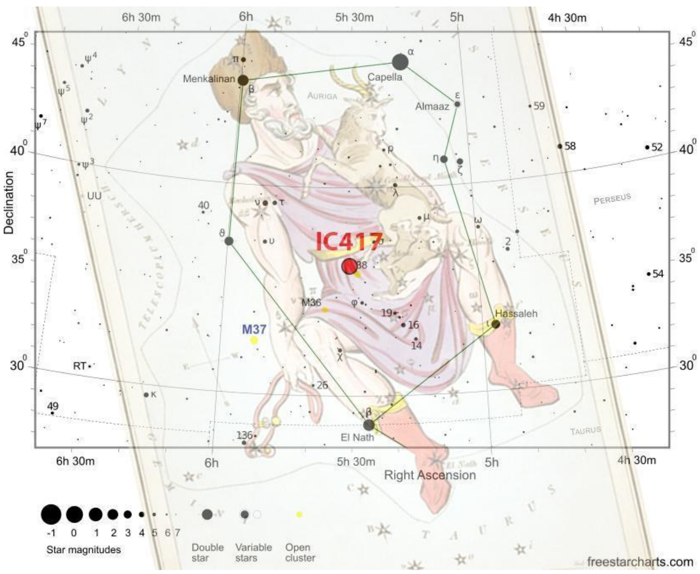

Figure 5: *The location of IC 417 in the constellation of Auriga. (Senson 2020; original constellation artwork Hall 1824)*

IC 417 (also known as Sh2-234 or the Spider Nebula) is located approximately 2.3 kpc away from Earth (Jose et al. 2008) within the constellation of Auriga at J2000 RA 05:28:11, Dec 34:25:28 (Figure 5), and at a galactic longitude, latitude (l,b) of 173.38, --00.20 degrees. IC 417 was studied by a 2015 NITARP team (see Fig. 6 for a visually striking IRAC-2MASS color image emerging in part from that work). We will continue with this analysis, including most notably additional data released since the 2015 team's work. This section summarizes the literature of IC 417, including specifically the 2015 NITARP team's contribution.

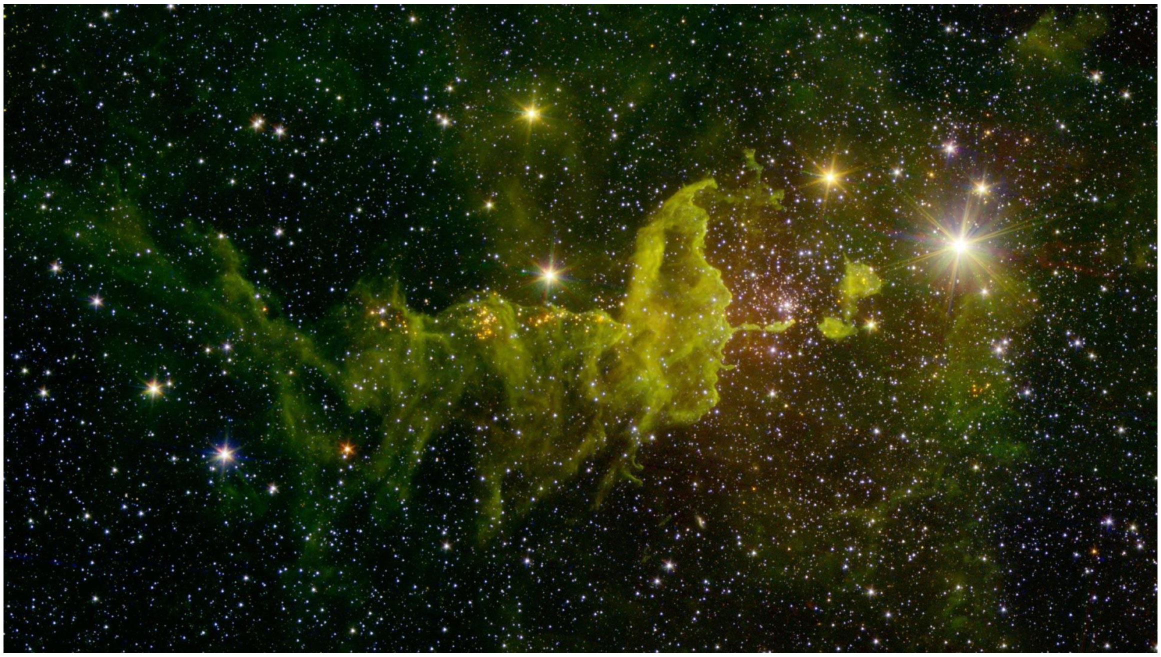

Figure 6: *IC 417 from an image release (2016-04-14/sig16-008; NASA/JPL-Caltech). Red=IRAC-2 (4.5 μm), green=IRAC-1 (3.6 μm), blue=2MASS J (1.3 μm). The text accompanying this image release mentions the 2015 NITARP team. The cluster Stock 8 is held in the "bowl" of nebulosity near the center of the image; the sinuous, "braided" tail to the left (East) of the "bowl" is called the Nebulous Stream (NS), and is where we will focus most of our work. North is very nearly up; see Figure 7.*

The earliest work in this region dates from the 1970s-1980s and largely consists of identification of the brightest stars (Georgelin & Georgelin et S. Roux 1973; Vetesnik 1978; Malysheva 1990; Efremov & Sitnik 1988). These are largely O and B stars, but include OP Aur, a carbon star. Kohoutek & Wehmeyer (1999) noted some Hα-bright stars here.

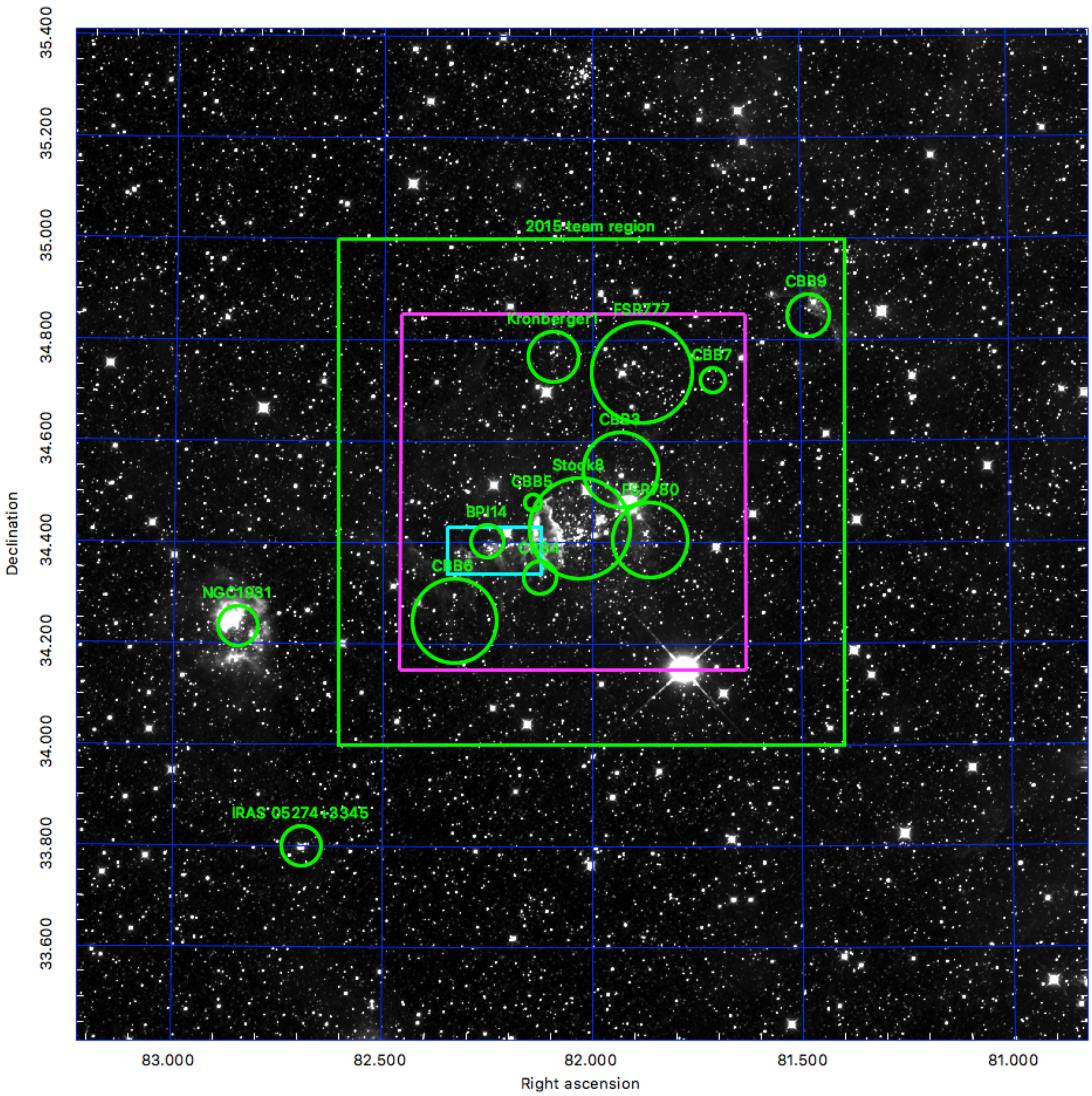

Figure 7: *Image of the greater IC 417 region in WISE-1 (4.5 μm) in grayscale with important annotations overlaid. (IC 417, the "Spider," is the center here; NGC1931 is the "Fly.") Equatorial (J2000) coordinates are provided; North is up. The 2015 NITARP team studied the region denoted by the large green square, focusing on WISE-selected YSO candidates. All clusters marked with circles inside this green square are clusters mentioned in Camargo et al. (2012) and identified in the literature from 2MASS data; see text. The small cyan rectangle encompasses the Nebulous Stream (NS) originally identified in Jose et al. (2008), and is where we will start our work (Goal #1). The larger magenta square is the region we will explore as part of Goal #2 and all the stretch goals. (For more on our Goals, see Section 3.)*

The next significant advance in this region was the release of the Two Micron All-Sky Survey (2MASS; Skrutskie et al. 2006). In the process of identifying clusters in various regions of the galactic plane, several authors used 2MASS derived star count data to identify clusters in the IC 417 region. All known clusters in the IC 417 region are identified in Figure 7 within the large green square.

Bica et al. (2003) identified the entire region, listing it as identical to IC 417. Borissova et al. (2003) identified BPI 14 (see Fig. 7). Ivanov et al. (2005) also calls attention to this region, labeling it CC 14. Kronberger et al. (2006) contributed the cluster marked Kronberger 1 in Fig. 7. Camargo et al. (2012) identified the clusters tagged “CBB” in Fig. 7 and provided the regional map on which our Fig. 7 is based (see their Fig. 19). An independent analysis by Marco & Negueruela (2016) identified some of the same clusters from Camargo et al. (2012), to which they added additional deep optical and NIR photometry and some classification spectra.

Jose et al. (2008) was the first extensive survey of IC 417 itself (as opposed to as “one more cluster” in a set of many). They included 2MASS data and deep optical imaging, and were primarily focused on the cluster Stock 8, which appears to sit within the “bowl” of nebulosity in Fig. 6. Jose et al. (2008) is the first paper to identify the sinuous structure in the IRAC bands in Fig. 6. They dubbed this the “Nebulous Stream.” This is the name which we will also use, and abbreviate it “NS.” Jose et al. (2008) did not investigate the NS in much detail, perhaps because it is not nearly so pronounced in the NIR as it is in IRAC bands. Borissova et al. (2003) identified the most prominent sub-cluster of the NS as BPI 14 (Fig. 7). This same region was called out as CC14 in Ivanov et al. (2005).

Jose et al. (2017) returned to Stock 8, analysing the IMF of Stock 8 with deep optical, near-IR (UKIDSS, 2MASS), and mid-IR (Spitzer/IRAC) data. However, nothing beyond Stock 8 was discussed; the NS was not mentioned at all.

Dewangan et al. (2018) had an extensive discussion of the filamentary structures in IC 417 as well as other clusters nearby in projected distance. While largely focused on far-IR (≥70 μm) and radio wavelengths and the distribution of gas/dust, a section of the paper includes figures with “selected YSOs,” however, no data table was provided.

Most recently, Lata et al. (2019) presented a variability analysis of stars in Stock 8, finding more than 100 short-period variables. No analysis of the non-periodic sources is included in this paper.

The NITARP 2015 team had access to all data published prior to 2015. That is to say they did not have Marco & Negueruela (2016), Jose et al. (2017), or Lata et al. (2019). (See Table 1 in section 3 below for a compact listing of what data the prior NITARP team used.)

As part of their work (see https://nitarp.ipac.caltech.edu/team/64-IC-417-Rebull), they (a) assembled a list of all YSOs or YSO candidates identified in the literature to that point, and (b) identified new YSO candidates based on IR excesses in WISE data in the large green square in Fig. 7. The literature sample largely consisted of stars identified using 2MASS JHK_s but also a few O and B stars, and some Hα-bright stars.

Given this literature sample, the 2015 NITARP team used WISE to identify YSO candidates. They used a series of cuts to filter out contaminants and select YSOs in 2MASS/WISE color-color and color-magnitude diagrams per Koenig & Leisawitz (2014). Koenig et al. (2015) suggests that this method is at least ~80% successful; that is, this approach is largely successful but there are still some contaminants left.

The NITARP 2015 team worked with the AllWISE catalog (reliable but perhaps not complete) as well as an independent data reduction provided by X. Koenig (private communication) that is more complete and less reliable. The NITARP team inspected all of the WISE images of the candidates to rule out those that did not look like point sources (e.g., were likely artifacts). They started with nearly 200 YSO candidates (from the literature or the Koenig reduction), and concluded that 163 were likely YSOs or candidates, 106 of which they discovered. They did not focus on the NS; their YSOs and YSO candidates are scattered throughout the large green square in Fig. 7, though more are aggregated near the clusters identified in Fig. 7. (This is, in part, affected by the inclusion of literature YSOs, and past work focused on the clusters identified in the literature.)

Our plan includes concentrated work on the NS, as yet neglected in the literature. Since the 2015 NITARP team's work, new literature on this region has appeared, along with additional large catalogs, most notably Gaia DR2 (Gaia Collaboration et al. 2019) and Pan-STARRS (Chambers et al. 2016), both multi-band optical surveys. We will be including these data and focusing work on the NS; see next section.

3.0 Analysis plan

3.1 Goals

This project has two main goals which we plan to complete by January 2021. We also have several “stretch goals,” which we will investigate as time permits.

The region on which we are focusing is shown as the large magenta square in Figure 7, and is given by the box defined by RA=05:29:50.0 to 05:26:31.5 (82.458333 to 81.631250 degrees), Dec=+34:08:50.6 to +34:51:05 (34.147389 to 34.851389 degrees).

Goal #1: The Nebulous Stream (NS), first identified by Jose et al. (2008), has not been thoroughly explored in the literature. We will focus on identifying new YSO candidates in this region (approximately the small cyan rectangle in Fig. 7). We expect to investigate about 400 targets for this goal, about 20 of which are in the literature as previously identified YSOs or candidates.

Goal #2: The 2015 NITARP team and the literature summarized in section 2.2 have identified a total of about 400 YSO candidates. We will explore the properties of these stars in the new data sets now available to see if they should still be considered YSO candidates.

Stretch goal #1: (a) Explore the properties of the previously identified clusters in this region, (b) Use multi-wavelength properties to refine membership.

Stretch goal #2: (a) Explore the properties of any long-wavelength sources detected but not yet explored in this region (Akari/IRC 9 and 18 μm, Herschel/PACS 70 and 160 μm, MSX (8.28, 12.13, 14.65, and 21.3 μm) as part of Goal 1 or 2, use multi-wavelength properties to refine membership.

Stretch goal #3: Explore the variability of our YSOs and candidates.

3.2 Assembled Data and the Master Catalog.

Because the IC 417 region is in the galactic plane, it has been serendipitously observed by several different surveys. A list of the largest of those surveys, along with data from the literature, is in Table 1.

Table 1: *Summary of data sets included in master catalog*

Survey or literature source	Bands	Fraction of sample	Was it in 2015 NITARP team's work?
2MASS (Skrutskie et al. 2006)	NIR: JHK_s	~40%	yes
Spitzer/ GLIMPSE (Werner et al. 2004; Churchwell et al. 2009)	MIR: IRAC-1 and 2	~86%	yes
WISE/AllWISE (Wright et al. 2010)	MIR: WISE-1,2,3,4	~30%	yes
PanSTARRS (Chambers et al. 2016)	Optical: grizy	~85%	**no**
UKIDSS (Lucas et al. 2008)	NIR: JHK	~70%	yes
IPHAS (Barentsen et al. 2014)	Optical: r', i', Ha	~50%	yes
Gaia DR2 (Gaia Collaboration et al. 2019)	Optical: G, Bp, Rp; parallaxes (distances from Bailer-Jones et al. 2018)	~66%	**no**
Herschel/ PACS (Pilbratt et al. 2010; Marton et al. 2017)	FIR: 70 and 160 µm	(less than a dozen sources)	**no**
Akari/IRC (Murakami et al. 2007)	MIR: 9 and 8 µm	(less than 20 sources)	**no**
MSX (Egan et al. 2003)	MIR: 8-21 µm	(less than 40 sources)	**no**
Jose et al. (2008)	Optical: UBVIc, spty; 2MASS	~20%	yes
Marco et al. (2016)	Optical: stromgren photometry, spty; NIR: JHK	~3%	**no**
Jose et al. (2017)	Optical: VI, NIR: JHK, MIR: I1I2	~4% (just in Stock 8)	**no**
Lata et al. (2019)	Optical: variability and rotation periods	(just 130 sources in Stock 8)	**no**
ZTF (for stretch goal 3; Masci et al. 2019)	Optical: variability	Not yet constrained	**no**

We have assembled the master catalog by merging by position across all of the available bands, in the order in which the surveys appear in Table 1. 2MASS and Spitzer/GLIMPSE are likely to have the most accurate coordinates and include most of the stars we expect to study in detail, which is why it forms the core of our master catalog. To that, we added measurements from a wide variety of additional surveys. Our master catalog thus spans 0.48 μm (PanSTARRS *g* band) through 160 μm (Herschel/PACS). There are ~30,000 objects currently in this master catalog.

The 2015 NITARP team focused on the WISE data and the data available to them at the time (2MASS, Spitzer, WISE, IPHAS, UKIDSS, Jose et al. 2008; see Table 1). We will now include (see Table 1) PanSTARRS, Gaia, Herschel, Akari, MSX, Jose et al. (2017), and Lata et al. (2019). For our third stretch goal, we can explore the optical variability (via the Zwicky Transient Facility, ZTF) of the subset of YSOs and YSO candidates identified here. Since we haven't yet established this list, we don't yet know the fraction of those sources with a ZTF counterpart.

3.3 Planned Scope

The NS is identified in Jose et al. (2008) but is not really explored in detail in the literature at any band. It is prominent in the IRAC image of the region (Fig. 6 above), with at least 4 clumps of sources that are obviously red even in the press release image. The cluster known as BPI 14 overlaps with the most prominent of these clumps (Fig. 7). Since this region has not yet been explored in detail, much less with the new data now available, identifying YSOs in the NS is our primary goal (Goal #1). Based on the master catalog and initial inspection of the images, we estimate that we will need to work with about 300-400 sources. We will refine this list using color-color and color-magnitude diagrams, and explore specific properties of individual sources (appearance in images, SEDs) for our final set of newly identified YSOs.

The 2015 NITARP team identified 141 targets in our region they thought were YSOs based primarily on WISE colors. Including those and the additional YSO candidates discussed in the literature since 2015, there are 384 literature YSOs. This forms the core of Goal #2 - to explore the properties of the previously identified YSOs and candidates based on the new data now included (primarily PanSTARRS and Gaia). We will refine the YSO list by omitting targets suggested by the data not to be associated with this region.

We highlight again that the 2015 NITARP team looked for YSOs using WISE IR excesses. We only have IRAC-1 and -2 from Spitzer, so using the available Spitzer bands to look for IR excesses will not identify IR excesses that start at wavelengths longer than 5 μm. Thus, our new candidate YSOs in the NS will be identified based on IRAC-1 and -2 colors, but assessed including optical properties. That is, we will look for large UV excesses that spill over into Pan-STARRS *g* band use distances from Gaia DR2 (Bailer-Jones et al. 2018) and construct optical/NIR/MIR color-color and color-magnitude diagrams.

3.4 Specific list of tasks

1. Assemble master catalog (completed in process of writing this proposal).
2. Identify (based on position) possible members of the literature clusters (also completed).
3. Decide on the specific region around the NS that we will explore. (Goal #1)
4. Create color-color and color-magnitude diagrams of the stars in the NS using Topcat or Microsoft Excel. Compare NS to similar diagrams in the literature of other star-forming regions and literature YSOs in this region. (Goal #1)
5. Using color-color and color-magnitude diagrams, winnow down the initial list of objects in the NS to a subset to explore in more detail. (Goal #1)
6. Identify which of those sources are already in the list of 384 literature YSOs. (Goals #1 and 2)
7. Use IRSA's Finder Chart and IRSA Viewer to visually inspect images of each of our targets in the NS to assess whether they are likely YSOs (single point sources, merged across bands correctly). (Goal #1)
8. Use the master catalog and Microsoft Excel to create SEDs for each of our targets in the NS to further assess whether they are likely YSOs and matched correctly across bands. We will include distances from Gaia (specifically those from Bailer-Jones et al. 2018) in this assessment. (Goal #1)
9. Refine list of NS YSOs. (Goal #1)
10. For each of the literature YSOs in the region beyond the NS, do similar image checking, SED assembly and checking, and color-color/color-magnitude diagram assessment (including distances from Gaia when possible) to decide if we agree that they are likely YSOs belonging to this region. (Goal #2)
11. For each of the clusters identified in this region, assemble color-color and color-magnitude diagrams to explore how they are similar or different from clusters in the NS. (Stretch Goal #1a)
12. For each of the clusters identified in this region, use color-color and color-magnitude diagrams to attempt to identify members of these clusters. (Stretch Goal #1b)
13. For each of the targets with long-wavelength detections not already captured to this point, assemble SEDs, check images, and make color-color and color-magnitude diagrams to assess whether they should be added to the list of YSOs and candidates in this region. (Stretch Goal #2)

14. For each of the YSOs or YSO candidates, identify any multi-epoch observations in ZTF and assess whether or not the YSOs/candidates are variable. (Stretch Goal #3)

3.5 Contamination

We are working in the Galactic plane, so contamination is likely, both in front of and behind IC 417. Foreground stars are likely to be bright and thus easily identified; they are also likely to have Gaia distances that will help us omit them from our final list of YSO candidates. Background stars are our most likely contaminant, particularly reddened AGB stars, which will appear as dusty stars with the right IR brightnesses to be YSOs in IC 417.

Gaia distances will help to some extent, but not everything in our master catalog has a Gaia counterpart, so it is likely that some of the sources we explore in the context of looking for YSOs will also lack distances. We have optical data from other sources for a substantial fraction of the sources in this region. By constructing SEDs and color-color/color-magnitude diagrams, some of the most obvious reddened AGB stars can be omitted. Background active galactic nuclei (AGN), if any are included by our color selections, are likely to be omitted as part of this process as well.

If any of our candidate YSOs have detections solely between 2 and 5 microns, we are unlikely to be able to distinguish them from contaminants. However, the optical data typically go past 20th mag, so any candidate YSO too faint for optical or NIR detection is more likely to be a contaminant. We will assemble grades of confidence for our YSO candidate list, e.g., those that we are very certain are YSOs and those that we are much less certain are YSOs. All of our YSO candidates will await follow-up classification spectra to confirm their youth.

4.0 Educational Outreach Plan

In order to maximize our educational impact, our outreach plan will consist of two parts: student-led peer-to-peer delivery of infrared astronomy, and a teacher-led educator professional development workshop series. The implementation of these components will be determined by the respective resources and skill sets of the participating teachers aligned to the proposal, as detailed below.

4.1 Robert Anderson

Students at JL Mann High School will present the research to peers and faculty to summarize what they have learned both about academic research and the underlying science. Presenting such an experience would indicate both a desire and need to provide more opportunities to engage in academic research to better prepare them to research at the university level.

Professional development sessions will be held at the school district level to peer astronomy educators on how to incorporate SIMBAD, IRSA, and other methods learned during the NITARP experience. These will focus on how to incorporate student-led research within normal classroom operations. The information provided to peer educators will also be integrated into my own classroom curriculum

A Cultural Life Program (CLP) held in conjunction with the education and physics department at Furman University, will be held to recount the entire NITARP experience from the perspectives of both the educator (myself) and from my students involved in the process. CLP events are held to enhance the liberal arts experience by engaging students in a variety of issues, ideas, and fine art events across multiple disciplines and cultures. CLP events are not restricted to Furman students and are frequently attended by alumni, peers within the field providing the event, and the general public.

In partnership with the Roper Mountain Science Center, two planetarium shows will be developed for use within the school district. The first show will be targeted to the general public audience. It will focus on the process of star formation, IC 417, and the NITARP experience with professional astronomers, teachers, and students. The second show will be for internal use by Greenville County Schools to share with students learning about star formation.

A presentation will be held at the Roper Mountain Astronomers (RMA) monthly club meeting. The mission statement of RMA is to promote astronomy and science for families, schools, and the community within the Greenville, South Carolina region. RMA meetings are held monthly and open to the public. The presentation and question and answer session will detail the NITARP, from the selection process to the post experience education outreach and the ability to start alumni projects.

4.2 Brandon Rodriguez

Students at Crescenta Valley High School will present several activities and lessons created by NASA and JPL, such as those identified on the NITARP website (NITARP 2020) and those found at JPL Education (JPL 2020a). Shared with their peers in both chemistry and physics class, student voice will allow for an opportunity for other young potential scientists to communicate with their peers on an authentic and likely more compelling wavelength, differentiating it from another ‘business-as-usual’ instructional day from their instructor.

Through the use of a small survey and content-specific assessment, the students will be able to determine what, if any, changes in content understanding and perception towards astronomy were observed as a result of the student-led nature of the delivery.

The collection and analysis of this data would present an interesting opportunity for the presentation of a poster at the upcoming AAS Meeting in Phoenix, AZ in 2021.

A series of professional development seminars will be scheduled in the community to allow for both the sharing of the results of the research on IC 417, but also providing for promotion of the NITARP program overall to audiences who may not have been exposed to the opportunity. By leveraging existing educator-friendly venues, such as the von Karman Auditorium at NASA's Jet Propulsion Laboratory, several educator workshops will be organized focusing on infrared astronomy. These hands-on workshops will consist of half of a day of professional development offered to K-12 teachers, led not just by the NITARP teachers, but also by invited educators with similar passions and expertise for sharing astronomical resources (ex. Airborne Astronomy Ambassadors Program (SETI 2020) alumni). A pilot of such a workshop has already been given at the Jet Propulsion Laboratory for fifty teachers in Southern California on March 7th 2020. (JPL 2020b)

4.3 Benjamin J. Senson

Students from James Madison Memorial High School will design and deliver a range of informational and educational presentations regarding the NITARP research process as well as the specifics for this proposal's goals, processes, data acquisition, analysis and presentation outcomes. These summative presentations will be made to audiences that include the Madison Metropolitan School Districts Board of Education as well as the high school's Astronomy Club and Astronomy course, Madison College's astronomy course sections taught by Mr. Senson, and at a regular meeting of the Madison Astronomical Society.

A revision and update to our existing "Exploring the Invisible Universe" planetarium program will be completed and made available for one of our monthly public shows as well as, by request, any school group from south central Wisconsin requesting the program. This revision will be made so as to highlight the work of the 2019 NITARP group as well as the current 2020 group with young stellar objects in IC 417 as a centerpiece for the script and visuals.

The lessons learned through our research with NITARP will be integrated in the form of lesson(s), activity(ies), or a lab experience in the curricular experiences of the JMM High School Astronomy Course and the Madison College "Astronomy: The Solar System" and/or "Astronomy: Stars & Galaxies" courses.

Professional development sessions will also be developed for delivery within the JMM science department, across the Madison Metropolitan School District and potentially for the Wisconsin Society of Science Teachers annual conference.

4.4 Vin Urbanowski

Participating AITE students will mentor new students in the establishment of a "professional" astronomy club along with the Science faculty. While there is significant interest in astronomy, the challenges of creating a telescope-based astronomy club have been daunting over the years. We plan to remain connected to NITARP and will use prior proposals to develop skills and activities around the professional tools we learned with NITARP.

Students will also present their work and methods at various community events including our "Out of the Box Night," a festival of "out of the box" STEM thinking, our "International Evening" which is designed to celebrate everyone's immigrant roots and which includes a showcase of all kinds of student achievements, the community STEMFest, a city-sponsored carnival of STEM fun, and our TechFest, a teacher-driven community evening showcase of student work.

Math that seems counterintuitive in the classroom becomes intuitive in the context of astronomy. The use of scientific notation and logs, for example, makes calculation and estimation straightforward in astronomical problems. The NITARP experience will be used to create contextualized problems to improve mathematics teaching and learning.

Astronomy also leverages the power of data and graphical display. Because of NITARP, the use of spreadsheets to automate calculations and sort data, along with data display software will be significantly increased in the classroom, making students more data literate and empowered.

The math insights and lessons inspired by NITARP will form the core of a set of PD offerings for regional and national conferences of the National Science Teaching Association (NSTA), National Council of Teachers of Mathematics (NCTM) and American Association of Physics Teachers (AAPT)

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