Searching For Young Stellar Object Candidates in Two Potential Star-Forming Regions In Cassiopeia

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1.0 Abstract

Our research will focus on identifying young stellar object (YSO) candidates in two regions along the northern galactic plane in the constellation Cassiopeia: One region we've called SCR 1 (centered around 01:23:46.48 +61:42:26.4, also known as "New SFR 3" from Wilson et al. 2023, and portions of which are also known as Sh 2-187) and one we've called SCR 2 (centered around 00:29:32.05 +65:26:35.9). These regions have also been included in previous studies of the galactic plane looking for YSOs; over both these regions, Frata et al. (2021) found 19 YSO candidates using Hα-excess, Winston et al. (2020) discovered 52 YSO candidates using infrared excess, Zari et al. (2018) identified 8 candidates using proper motion, and Wilson et al. (2023) located 30 Class II YSOs using a machine learning algorithm that looked at multiple search criteria. In our study, we will combine archival data from multiple wavelengths to further assess each previously published YSO candidate, as well as discover new, previously unidentified candidates using IR excess. We will use infrared data from 2MASS, WISE, Spitzer, and Herschel, as well as optical data from Gaia, IPHAS, and PanSTARRS to create a band-merged catalog that we will use to identify and evaluate YSO candidates using color-color diagrams, color-magnitude diagrams, spectral energy distributions (SEDs), and visual inspection of images. By using more data than any previous individual study of our two regions, we aspire to be able to make an up-to-date assessment of whether the previously identified YSO candidates are really YSOs, as well as identify new candidates that have been overlooked in prior studies.

2.0 Science Background

2.1 Star Formation

Star formation happens in interstellar molecular clouds. Molecular clouds are massive clouds in interstellar space, primarily composed of molecular hydrogen (H_2) along with other trace elements. These clouds form through a combination of cooling, gravitational compression, magnetic field influences, and turbulent motions in the interstellar medium.

Molecular clouds are subject to their own gravitational forces that act to collapse them. Fluctuations in density and temperature within the cloud can lead to regions that become gravitationally unstable. As a result, these regions start to contract through their own gravitational forces. Within the collapsing region, a central core begins to form.

As the cloud collapses, the cloud has some initial rotation due to it being a part of the rotating galaxy. As it contracts, this rotation rate increases and the material closest to the central object flattens out into a disk due to the conservation of angular momentum. This structure is known as a circumstellar (or protostellar) disk. Matter flows from the circumstellar disk onto the central object. When the accretion rate is high, simultaneously, powerful outflows of matter are ejected along the magnetic axis. These outflows play a crucial role in regulating the accretion process and removing excess angular momentum from the system, as well as blowing away the envelope surrounding the forming star. The outflows shape the surrounding environment and influence nearby star-formation. The central core becomes increasingly dense and hot as material accretes onto it. Eventually the disk dissipates and the outflows turn off. As the protostar continues to accrete mass, it evolves toward the main sequence phase, where it will spend the majority of its lifetime fusing hydrogen into helium and the protostar becomes a stable star.

The forming star throughout this process can be referred to as a young stellar object (YSO). Because observations of YSOs often cannot resolve the star (central object), disk, and envelope, sometimes the term "YSO" refers to the entire system. The process described here refers to YSOs that will become low-mass stars, that is G, K, and M stars.

2.2 Spectral Energy Distributions

A spectral energy distribution (SED) is a graph of the energy density emitted by an object as a function of wavelength. By plotting the energy density from an astronomical object, we can compare at a glance the emission across a broad range of wavelengths. The SEDs of main sequence, dust-free stars can be approximated by blackbody curves. The SED of our Sun, for example, can be represented by a blackbody with an effective temperature of ~5800 K. As circumstellar dust is added to a YSO, that dust intercepts some of the radiation that is emitted by the YSO. The dust heats up as a result and re-emits that radiation as IR light. The net SED of the star and the circumstellar dust, therefore, has an IR excess with respect to a star without dust. The inner disk, which is closer to the YSO, is warmer than the outer disk, and so the inner disk contributes more near-IR, and the outer disk contributes more far-IR and sub-millimeter emission; see Figure 1.

The SED of a YSO differs from that of a blackbody curve in other ways beyond just an IR excess. If the YSO is actively accreting gas or dust, where matter crashes onto the photosphere of the YSO, it creates a shock, which creates more ultraviolet than would be expected without accretion, i.e., an ultraviolet excess. This can sometimes spill over into slightly longer wavelength blue light.

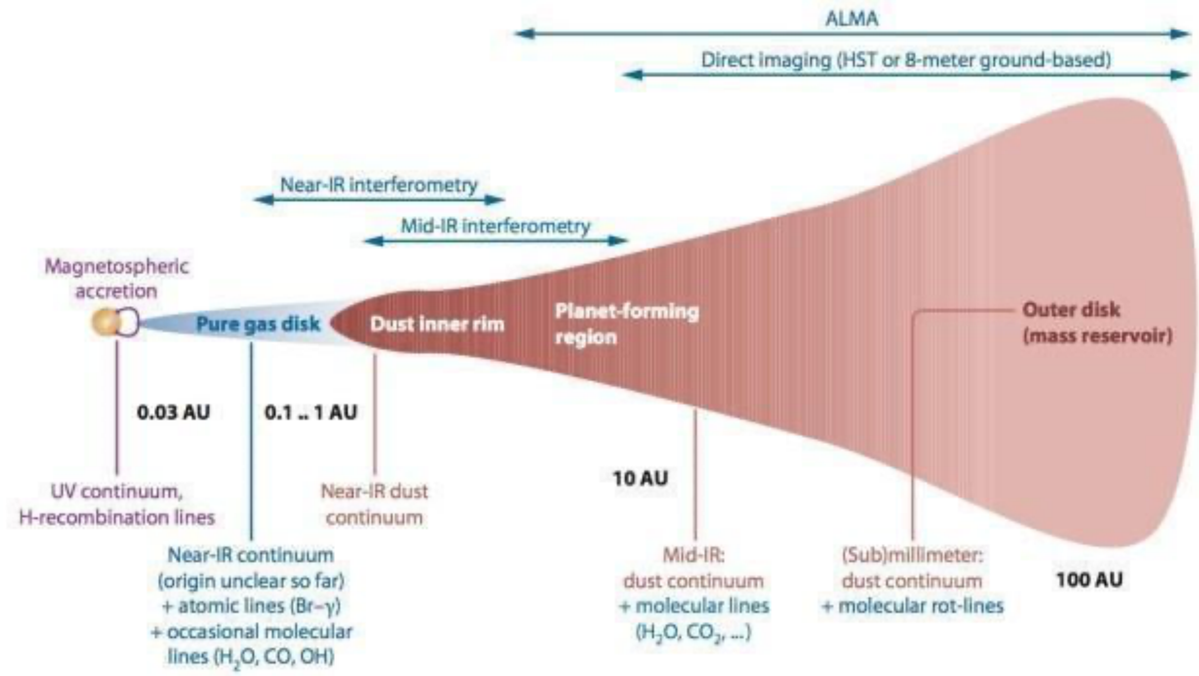


Figure 1: Schematic of a YSO showing its protoplanetary disk and accretion streams, with an indication of typical length scales (an AU is an astronomical unit, the distance between the Earth and the Sun) and emission lines. (Figure from Dullemond & Monnier, 2010.)

2.3 YSO SED Classes

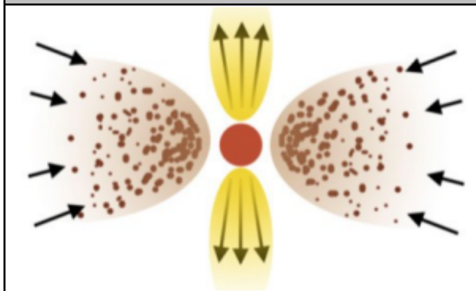
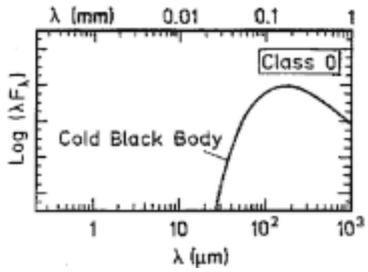
Early researchers, when attempting to understand star formation, defined classes of YSOs based on the empirical shapes of their SEDs between 2 and 25 microns. The sequence of SED shapes was interpreted as an evolutionary sequence from more embedded to less embedded. In this section, we discuss this sequence and its interpretation.

Class 0 YSOs.

A Class 0 YSO contains a protostar that is deeply embedded in its nebula. The protostar gains most of its mass during this stage, even though the surrounding nebula still contains more mass than the forming protostar (left panel, Table 1). As mass accretes, energy is released, warming the protostar to temperatures less than 30 K (Barsony, 1994). This can be seen in a smooth SED corresponding to a classical blackbody, as shown in the middle panel of Table 1 below. Class 0s are the shortest lived of these phases, lasting only 10,000 years or so before advancing to Class I. As such, Class 0 YSOs are rare.

Class 0s are typically observed in the far infrared, at wavelengths greater than 10 microns. Although the rate of accretion is prodigious, significant amounts of matter are also lost to powerful outflows along the poles of the protostar. When the outflows collide with the interstellar medium, it creates shocks that emit visible light, forming Herbig-Haro objects, as shown in the right panel of Table 1 below.

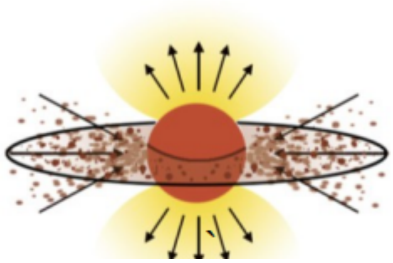
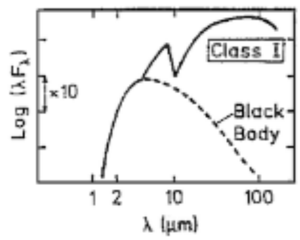
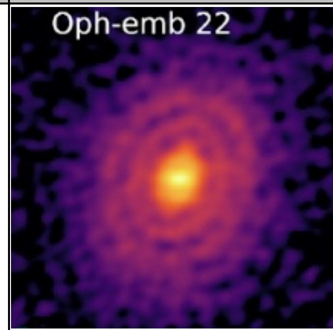
Table 1: A Class 0 YSO.

Illustration	SED	Image
		
Class 0 YSOs are marked by massive inflows and accretion from the disk, even though the disk still contains more mass than the forming protostar. Powerful outflows blast material into space along the poles of the protostar. (https://www.ira.inaf.it/~ddallaca/RadioA_5.pdf)	Spectral energy diagrams of Class 0 YSOs show a smooth black body curve in the far infrared corresponding to a temperature of about 30 K (Bachiller, 1996).	A Class 0 YSO is deeply embedded in its nebula and is invisible in optical light. The outflows, however, produce Herbig-Haro objects when the fast-moving gas collides with the interstellar medium, heating it and causing it to emit visible light. (This image is from JWST, of HH 211: ESA/Webb, NASA, CSA, T. Ray. https://esawebb.org/images/weic2322b/)

Class I YSOs.

In the Class I phase, the protostar has significantly accreted or dispersed most (~90%) of the material from the nebula and, as a result, is more exposed (left panel of Table 2). Accretion has slowed and, with it, the outflows have slowed or stopped. There is still a substantial circumstellar disk. The SED (middle panel, Table 2) has shifted toward shorter wavelengths than Class 0, corresponding to a warmer central protostar. Most of the Class I's energy, however, is radiated by the surrounding dust disk. Class I YSOs have a rising SED, such that there is an increasing IR excess as a function of wavelength through the mid- or far-IR, where it turns over. Class I YSOs typically exist for several hundreds of thousands of years before transitioning into a later phase.

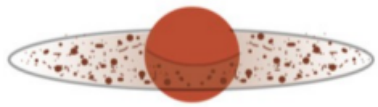
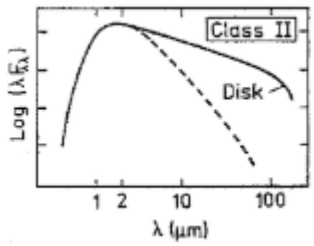
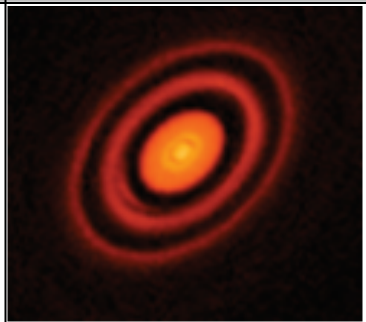
Table 2: A Class I YSO.

Illustration	SED	Image
		
Class I YSOs have already accreted most of their material onto the protostar. The rate of accretion slows, as does the outflows. (https://www.ira.inaf.it/~ddallaca/RadioA_5.pdf)	SEDs of Class I YSOs have shifted to shorter wavelengths but are marked by a rising infrared excess from the surrounding disk. (Bachiller, 1996).	As seen in this image of a face-on disk from ALMA, the protostar is now clearly visible, having emerged from its reduced cocoon. The disk is clearly visible, and outflows have slowed or stopped. (“Early Evolution of Planetary Disk Structures Seen for the First Time” NRAO, 1/8/2024, https://public.nrao.edu/news/early-evolution-of-planetary-disk-structures-seen-for-the-first-time/ .)

Class II YSOs.

In Class II YSOs, which are also called T Tauri stars, accretion is nearly complete, with the surrounding disk containing only about 1% of the mass of the central YSO. The disk is optically thick, and gaps due to planet formation may be visible. Accretion has slowed and outflows have stopped. Class II YSOs last a few millions of years. Their SEDs are marked by an infrared excess due to the disk, but most of the energy is coming from the central object, not the circumstellar dust. Noticeably, the slope of the Rayleigh-Jeans side (longer wavelengths) of the SED is always decreasing, as opposed to the increasing, positive slope of Class I YSOs. The YSO has warmed and the peak emission is now at shorter wavelengths than the Class I protostar.

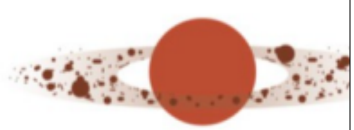
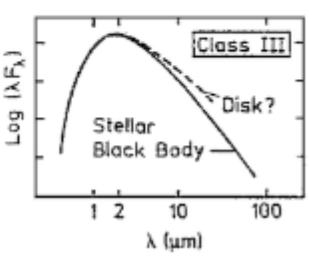
Table 3: A Class II YSO.

Illustration	SED	Image
		
Class II YSOs have slowed their accretion and their outflows have stopped. The remaining nebula has collapsed to an optically thick disk, with possible protoplanets being formed. (https://www.ira.inaf.it/~ddallaca/RadioA_5.pdf)	The peak emission of the SEDs of Class II YSOs have shifted to even shorter wavelengths and the Rayleigh-Jeans side shows a clear infrared excess with a negative slope corresponding to the warmed disk. (Bachiller, 1996).	The disk (with gaps) and its pre-main sequence star at its center are both clearly visible in this image from ALMA (Huang, 2018).

Class III YSOs.

The final stage before becoming a main sequence star is a Class III YSO. The surrounding protoplanetary disk has become optically thin, with only a fraction of the mass of the clearly-visible pre-main sequence star in its center (left panel, Table 3). The SED of a Class III YSOs shows a weak infrared excess due to the more tenuous disk. Class III YSOs survive the longest, lasting for tens of millions of years before fusion begins in its core and it becomes a main sequence star.

Table 4: A Class III YSO.

Illustration	SED	Image
		
Class III YSOs are characterized by an optically thin disk.	SEDs of Class III YSOs are characterized by a much fainter IR excess and a steep negative slope on the Rayleigh-Jeans side. (Bachiller, 1996).	Artists' rendition of a Class III YSO. Credit: NASA/JPL-Caltech/T. Pyle (IPAC)

Additional SED Information.

Sometimes astronomers insert another class in between I and II called “Flat class” which refers to SEDs that are indeed flat. The slope between 2 and 24 microns in an observed SED can be determined by a linear fit to all available points in the SED (between 2 and 24 microns) ; then, following Wilking et al. (2001):

- if the slope > 0.3, then the class = I
- if the slope < 0.3 and the slope > -0.3, then the class = Flat
- if the slope < -0.3 and the slope > -1.6, then class = II
- if the slope < -1.6, then class = III

The relative populations of stars in each of the classes provide information about the lifetime of each of the classes and the relative age of the population you are studying.

As described above, this sequence of Class 0 to I to II to III is often interpreted as an age sequence, so a Class I object is younger than a Class II object, etc. However, some evidence suggests that maybe the connection to age is more confusing than one might wish. For example, an edge-on Class II might look like a Class I. Additionally, we can find YSOs of nearly all classes in close physical proximity to each other (and no one knows how to form stars very close to each other that are not all the same age). So, astronomers still work under the assumption that the Class 0 to III is an evolutionary sequence but realize that there are uncertainties in this.

2.4 Identifying YSOs

There are several different ways to identify YSOs as distinct from the general population of main sequence stars in the Galaxy.

Another important aspect to include in studying electromagnetic radiation from YSOs is reddening, which occurs when light from a source is scattered and absorbed by dust grains along the line of sight. This scattering preferentially affects shorter wavelengths of light, reddening the net emission from an object. Reddening will change the location of objects in color-color and color-magnitude diagrams and change the shapes of their SEDs. It can make an early-type star look like a late-type star. However, reddening will not create an IR or large Hα excess where there is none.

We can attempt to limit these sources of contamination by bringing in additional information. Optical data can help further delineate the SED and constrain whether or not the object is a galaxy or a star or a heavily reddened star. Spectra could immediately reveal redshifts or how much reddening there is, whereas broadband photometry can only constrain it; we do not have spectra of our targets, nor will we have time to get any during our NITARP year.

Infrared Excess.

IR excess can be used to identify YSOs in circumstances where they are surrounded by dusty circumstellar disks or envelopes. IR excesses are obvious when plotted in SEDs, but objects with IR excess also appear as outliers when plotted in color-color diagrams.

Infrared data from the Spitzer Space Telescope (Werner et al. 2004), the Wide-field Infrared Survey Explorer (WISE) (Wright et al. 2010), and the Herschel Space Observatory (Pilbratt et al., 2010) are ideal for this. Spitzer and Herschel, despite being pointed observatories, conducted large surveys of the Galactic Plane, where a lot of star formation happens in our Galaxy. WISE is lower spatial resolution, but available all over the sky.

This method is not without its drawbacks, however. Foreground and background sources can emit infrared radiation, contaminating the source of interest. Star formation has the same colors whether it is near or far, so distant luminous star-forming galaxies can look like nearby YSOs. Old stars, specifically asymptotic giant branch (AGB) stars, can produce dust in their outer atmospheres, and these old dusty stars can therefore look like young dusty stars. Sometimes clumps of interstellar dust can also have colors like star formation.

Hα-excess.

Another method for looking for YSOs is to look for Hα excess. Hα emission is produced when the electron in atomic hydrogen (H) transitions from its third to second energy level, emitting light with a wavelength of 656.28 nm. Because there is so much hydrogen in the universe, there is plenty of Hα emission as well. Young stars also often have an Hα excess. In the case of YSOs, the Hα comes either from accretion streams between the disk and the star, or from activity (flares) on the YSO itself.

Main sequence stars that are rotating quickly (and therefore have higher than normal activity levels) can also be bright in Hα, and thus the baseline level expected for Hα emissions is a strong function of mass, especially when considering M stars which take a long time to slow down after settling onto the main sequence. As a result, the cutoff between “this is a quiescent level of Hα” and “this is an Hα excess” is mass-dependent. For our targets in our study, we won’t have masses because we won’t have spectra, so we will need to be conservative, and only take the most extreme Hα levels as true Hα excesses. However, Hα is relatively unaffected by reddening, such that no amount of reddening will remove a large Hα excess.

Spatial Motion.

Another method of searching for YSOs is looking for groups of stars moving together through space. Obtaining the 3D motions of stars can take a long time because you need to wait for the stars to move. With the recent Gaia mission, accurate positions and proper motions (and thus 3D space motions) have been obtained to more than a kiloparsec away. This approach has both revealed new clusters and increased our list of members for known clusters (see, e.g., Cantat-Gaudin et al., 2020).

Other Ways.

There are other ways of finding YSOs as well, including methods that are somewhat less relevant to our task at hand. As previously stated, actively accreting YSOs can have a UV excess that can spill over into a blue excess. The flaring that produces an Hα excess also produces large amounts of X-rays, such that sometimes simple detection of a star using X-rays is taken as an indication of youth. Accretion and activity both make YSOs highly variable at pretty much all wavelengths and all timescales, as long as you can make observations with high accuracy. The outflows that can be found in the earliest SED Classes sometimes are used as signposts to find YSOs. For more information on any of these methods, including specific examples, see appendix C in Rebull et al. (2023) and references therein.

2.5 Our Regions

Wilson et al. (2023) used a machine learning algorithm (a “naive Bayes classifier”), to identify 6,504 candidate Class II YSOs in the Northern Galactic Plane (Figure 2). They combined several indications of youth to identify their YSO candidates: IR excess, Hα excess, optical variability, and position in optical color-magnitude diagrams, but they limited themselves to targets with good Gaia distances and looked for Class II YSOs only. Mapping the locations of their candidate YSOs, they also identified, based on clustering of their YSO candidates, three potential star-forming regions (SFRs) that they could not tie to known SFRs.

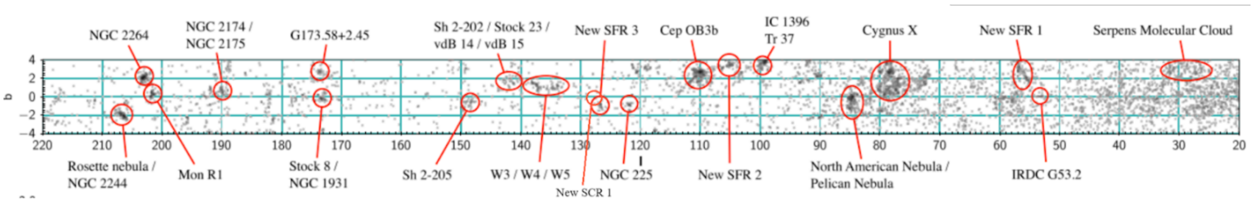


Figure 2: A map (copied from Wilson et al. 2023 and lightly annotated) of the 6,504 Class II YSO candidates identified by Wilson et al. (2023), in galactic coordinates. Known star-forming regions are labeled, as well as Wilson's 3 new, previously unidentified SFR's, labeled as "New SFR". This study looks at “New SFR3”= “New SCR1” (l,b = 128, -1), as well as a second region near SCR1.

We looked at the location of these three new SFRs in WISE data to see if it would be worth further study in those locations for more YSO candidates. Wilson’s SFR1 is in a region where the star surface density on the sky is relatively high, and it seemed likely that it would be hard for us to deal with source confusion. Wilson’s SFR2 partially overlaps with LDN 1188, which is about 900 pc away, and part of the Cep OB2 association (see, e.g., Marton et al., 2013). It would be possible, but challenging, to separate new targets from those in LDN 1188, which has already been rather extensively researched for IR excess sources. For these reasons, we opted not to investigate either SFR1 or 2 further.

However, Wilson’s third SFR seemed to be more of an ideal target: it has a reasonable number of YSO candidates, some literature but not so much that untangling it will be challenging, and the source surface density is not so high that source confusion will not be pervasive. We’ve denoted this region as SCR1 (StarChaser Region 1) for our purposes.

Moreover, part of this region turned out to be Sh 2-187, which was studied by one of last year’s NITARP teams (Kuper, et al., 2024). It is an entry in Stewart Sharpless’ catalog of HII regions (likely star forming regions) that he compiled from the Palomar Optical Sky Survey in Sharpless (1959). Sh 2-187 is viewable in Cassiopeia by a modest astrophotography setup (Figure 3), contrasting well with the dark nebula, LDN 1317, that partially obscures it (Jardine). Sh 2-187 has very little in the literature; Kang, et al. (2017) mention using WISE data to look for YSOs but did not publish a target list. Richards, et al. (2012) derive a distance of 1.44 ± 0.26 kpc, but again did not publish a list of YSO candidates. Last year’s NITARP team began work to look for YSO candidates using IR excesses, similar to our plans (see below), so we will incorporate their work (Kuper et al., 2024).

Figure 3: Sh 2-187. The dark nebula LDN 1377 can be seen partially obscuring the emission nebula Sh 2-187. (Coles, 2018)

When we were examining the WISE sky near SCR1, we noticed a nearby region of the sky that is likely to harbor YSOs because there is a darker region with bright sources at 12 and 22 microns. (Other, famous SFRs have this kind of morphology.) This region, near 00:29h32.05m, +65:26:35.9, is also located in Cassiopeia. There does not seem to be very much literature available on this region. We have christened this region SCR2.

Wilson et al. (2023) is not the only program that is looking for YSOs over large fractions of the sky. There are three other papers whose survey area overlaps with SCR1 and/or 2. Zari et al. (2018) used Gaia data release 2 positions and proper motions to identify nearby young stars that are moving together over the whole sky. Winston et al. (2019, 2020) used Spitzer and WISE data to look for IR excess sources in the Galactic plane. Fratta et al. (2021) used Gaia and IPHAS data to locate stars with Hα excesses, also in the Galactic plane. These four papers (Zari et al., 2018; Winston et al., 2020; Fratta et al., 2021; Wilson et al., 2023) represent the bulk of the literature YSO candidates reported in our two target regions.

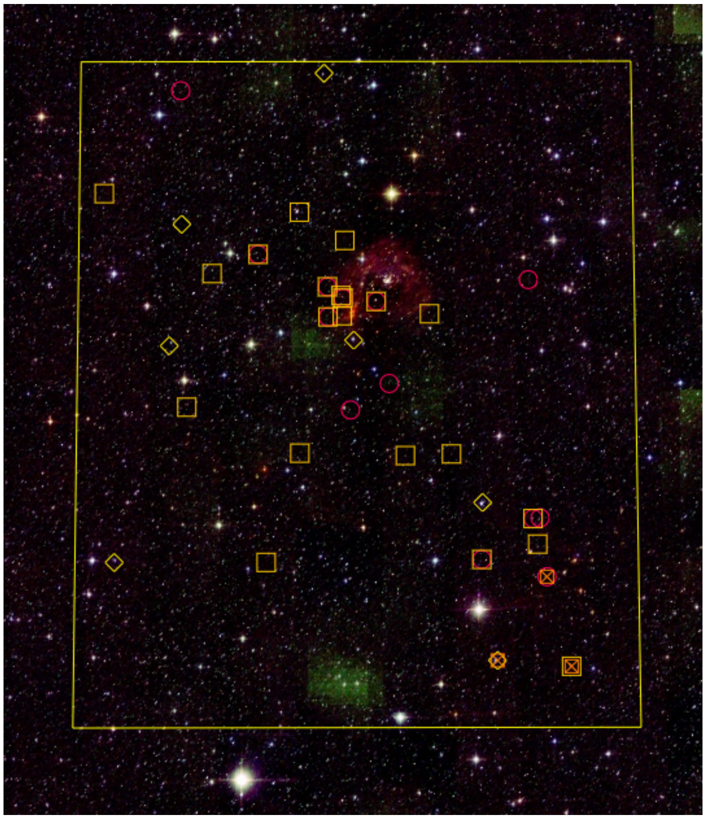
We defined polygons on the sky to encompass the clustered stars from these four papers as well as any nebulosity that we see in the WISE images; see Table 5. Table 5 also includes the number of YSO candidates from Zari et al., Winston et al., Fratta et al., and Wilson et al. that are encompassed by that polygon. Note how many sources (52) from Winston et al. are in SCR2 – consistent with our expectation that the 'dark river' with bright 12 and 22 micron sources is likely to harbor YSOs!

The Koenig column in Table 5 is defined in more detail in section 3 below, but in summary, it identifies new possible YSOs based on WISE colors. The last column in Table 5 is the maximum possible number of YSO candidates we would need to inspect in each region. Because these four papers are looking for YSOs in different ways, and the Koenig approach is yet a fifth method, they don't necessarily find the same stars, though of course some stars will be the same. We haven't yet done the detailed work to do the source matching to be able to identify which sources are the same, so the last column is the maximum number possible that we would need to explore as part of our project. We did this as a way to scope the size of the project.

Table 5: Our regions, with numbers of YSO candidates

	Polygon (decimal degrees, J2000)	Fratta+	Wilson+	Winston+	Zari+	Koenig	Total (max possible)
SCR1	21.8 62.2, 19.96 62.2, 19.96 61.16, 21.8 61.16	13	21	0	7	192	233
SCR2	7.798 65.54, 6.62 65.54, 6.62 65.37, 7.798 65.37	6	9	52	1	101	169

An image of SCR1 is in Figure 4, with the Zari et al., Fratta et al., and Wilson et al. catalogs (there are no sources from Winston et al. here) overlaid on the AllWISE HiPS image. Figure 5 is the same for SCR2, this time with all four catalogs: Zari et al., Winston et al., Fratta et al., and Wilson et al.



Fratta	Color	Symbol
Wilson	Color	Symbol
Zari	Color	Symbol

Figure 4: SCR1 with the four relevant literature catalogs overlaid (see text). The background image is the AllWISE HiPS image. North is up and east is to the left.

Fratta	Symbol
Wilson	Symbol
Winston	Symbol
Zari	Symbol

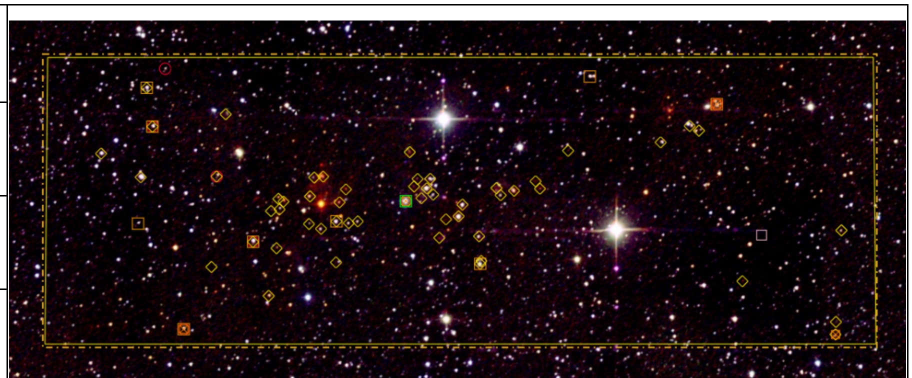


Figure 5: SCR2 with the four relevant literature catalogs overlaid (see text). The background image is the AllWISE HiPS image. North is up and east is to the left.

3.0 Analysis Plan

3.1 Goal

The goal of our research project is to (a) investigate the YSO candidates put forth in the literature in both of our regions, and (b) identify new YSO candidates in both of our regions using IR excesses. Because both of our regions of interest lie within the Galactic plane, both have a wealth of archived optical and infrared data, including catalogs from PanSTARRS, Gaia, IPHAS, 2MASS, Spitzer/GLIMPSE, Spitzer/SEIP, WISE (AllWISE, CatWISE, and unWISE), and Herschel, as shown in Table 6 below. (For completeness, we note that the publicly released eROSITA X-ray data do not include our regions.)

Previous studies of our regions, including those of Zari et al. (2018), Winston et al. (2020), Fratta et al. (2021), and Wilson et al. (2023), used data from only a subset of the data we plan to use. By using all the available data from the catalogs listed in our proposal, we'll attempt to make a better assessment via composite data sets than any previous assessments made to date as to whether targets are YSOs, to the best of our knowledge.

Table 6: Archival data we will use

	Spectrum Band	Wavelength (microns)	Mission
Visible	g	0.481	PanSTARRS
	B	0.511	Gaia
	r	0.617	PanSTARRS
	G	0.622	Gaia
	R	0.624	IPHAS
	Hα	0.6568	IPHAS
	I	0.752	PanSTARRS
	i	0.7743	IPHAS
	R	0.777	Gaia
Near Infrared	z	0.866	PanSTARRS
	y	0.962	PanSTARRS
	J	1.235	2MASS
	H	1.662	2MASS
	K	2.159	2MASS
Mid Infrared	W1	3.4	WISE
	I1	3.6	Spitzer
	I2	4.5	Spitzer
	W2	4.6	WISE
	I3	5.8	Spitzer
	I4	8.0	Spitzer

	Spectrum Band	Wavelength (microns)	Mission
	W3	12	WISE
	W4	22	WISE
Far Infrared	70	70	Herschel
	160	160	Herschel

3.2 Assembly of Master Catalog

We will begin by merging by position the catalogs from 2MASS, WISE (AllWISE, CatWISE, and unWISE), and Spitzer (GLIMPSE and SEIP); all of these are on the same coordinate system, so merging them with a tolerance of 1 arcsecond works well. If there are any Herschel point sources, we can merge them easily by position to the other IR catalogs at this point.

Gaia, IPHAS, and PanSTARRS are all optical and all are higher spatial resolution than 2MASS. We could simply merge those catalogs into our master catalog. Since our regions are in the Galactic plane, the number of stars detected per square arcsec goes up substantially as we move to shorter wavelengths, however, which makes the catalogs so large as to be difficult to work with. At the same time, though, essentially none of the stars in which we are most interested are likely to be detected solely in the optical. So, we will merge Gaia, IPHAS, and PanSTARRS into our master IR-based catalog, again with a tolerance of 1 arcsecond, but retain only those sources that have matches in the IR; that is, we will not retain optical-only sources.

After we have the master catalog, we will look for matches between our master catalog and the literature-identified YSO candidates from Zari et al. (2018), Winston et al. (2020), Fratta et al. (2021), and Wilson et al. (2023). If there are sources from the literature that are identified as YSO candidates but that for some reason are missing from our master catalog because of our decision to drop optical-only sources, we will manually retrieve the optical measurements for them and include them in our final master catalog.

3.3 New Candidate YSOs

With our master catalog complete to this point, we will then begin to search for new candidate YSOs. We will do this by using IR excesses via the Koenig & Leisawitz (2014) approach, since we have WISE data covering both regions. In the portion of one region where we have IRAC data, we will also apply the Gutermuth et al. (2009, 2010) approach. Both of these studies used a series of color cuts in either 2MASS+WISE (Koenig, 2014) or 2MASS+IRAC (Gutermuth, 2009) color spaces to attempt to select YSO candidates as distinct from background galaxies and other contaminants. These well-tested approaches have been used by many investigators (within NITARP and in the community at large) to select YSO candidates. However, they only use IR data between 2 and at most 24 microns. We have access to quite a bit of additional data which will allow us to continue to further disaggregate the information.

Our primary method will be IR excess. With that stated there are additional ways to pick out YSOs from the general stellar population beyond just IR excess, including ultraviolet/blue excess, extreme Hα excess, and variability. Given our constraints of data and time, however, each of these methods have their limitations. NITARP teams in the past have had mixed luck in using g-band excesses as spillover from accretion, so we are less inclined to believe that this will work well for us. Although we have Hα data, we will only be able to find the most extreme Hα excesses: because we don't have spectra for our targets, we cannot set tight, mass-dependent Hα boundaries between expected chromospheric levels and that due to accretion. We will explore using variability (in ZTF or NEOWISE data) to identify YSOs if time permits.

3.4 YSO Vetting

After we have a list of literature-selected YSO candidates plus IR-selected YSO candidates that we selected via the Koenig and/or Gutermuth approaches, we will take that merged list and construct SEDs for them using data from as many wavelengths as possible. By inspecting SEDs for each of our YSO candidates, we will be able to check that we did the bandmerging (catalog construction) correctly (by looking for, e.g., discontinuities), and check that the sources have SEDs that look like YSOs (as opposed to galaxies or nebular knots). Sources that have discontinuities will send us back to bandmerging to resolve those conflicts, and sources that have irregular (non-YSO) SEDs will be dropped from our list of YSO candidates.

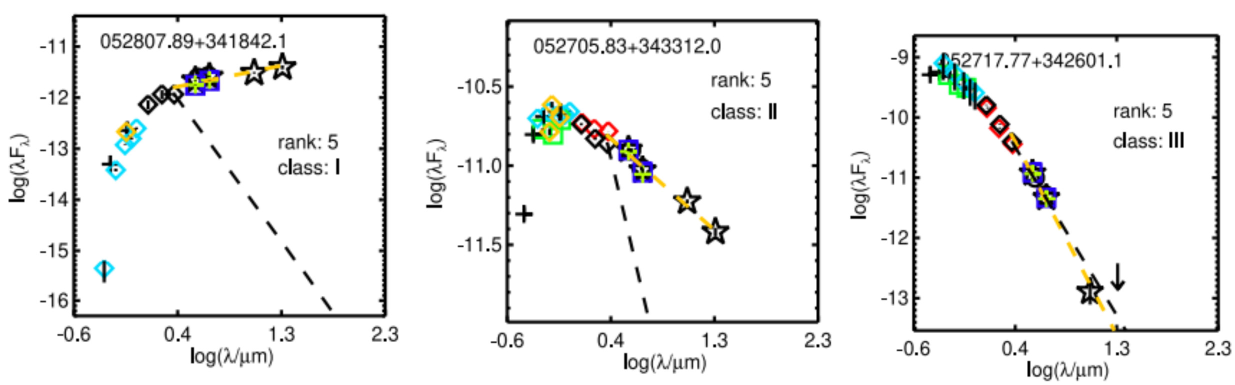


Figure 6. Sample SEDs demonstrating the features of Class I (left), II (middle), and III (right) YSO candidates from the star forming region IC 417, from Rebull et al. (2023). Each point in the SEDs corresponds to a photometric point. The rank corresponds to the confidence in the YSO identification (5 is the highest). The black dashed line is where the photosphere of a dust-free star would be, assuming that the K band is on the photosphere. The orange dashed line is a best-fit line to all the points between 2 and 25 microns; the slope of this line is what places the SED in class I, II, or III.

Example SEDs from IC417 (Rebull et al., 2023) are shown in Figure 6 for context, where many of the data sets are similar between IC417 and our regions. These three YSO candidates from IC417 also show the range of YSO SED shapes we are expecting to find in our regions. As described in Section 2 above, the slope of the SED between 2 and 25 microns can be used to identify the SED class of the YSO.

Another important assessment of YSO properties is checking position in color-color and color-magnitude spaces. This is useful for three reasons. First, while the objects selected via IR colors will necessarily be in the “right place” in IR color-color diagrams, they may not be in the “right place” in optical color-magnitude diagrams; alternatively, their placement in optical color-color diagrams can support their classification as YSOs. Second, we have objects from the literature that were not selected based on IR colors; seeing where they fall in IR color-color diagrams will be useful. Lastly, we can use JHK color-color diagrams to estimate reddening, which may aid in our interpretation of optical color-magnitude diagrams. We will do all of these things based on the multi-wavelength catalog we have assembled, constructing color-magnitude and color-color diagrams for each of our YSO candidates and using their placement on the diagrams to assess each candidate separately.

Lastly, visual inspection of all remaining sources will be made using archived images, such as those available through IRSA Viewer and IRSA’s Finder Chart. Sources that show source contamination, excessive nebulosity, or detector artifacts will be assessed individually. Photometric points may be removed or entire sources may be removed, depending on what we find. Figure 7a, taken from Rebull et al. (2023), shows a set of 2MASS and WISE images that indicate a high-quality source: the source is bright, present at all bands, and has the reticle (source location) centered in the source at all bands. This source was retained in their YSO search. Figure 7b, however, shows a poor-quality source: there appears to be some source confusion as the reticle is not at all centered on a source. This source was identified as a likely nebular knot and was rejected from the YSO catalog.

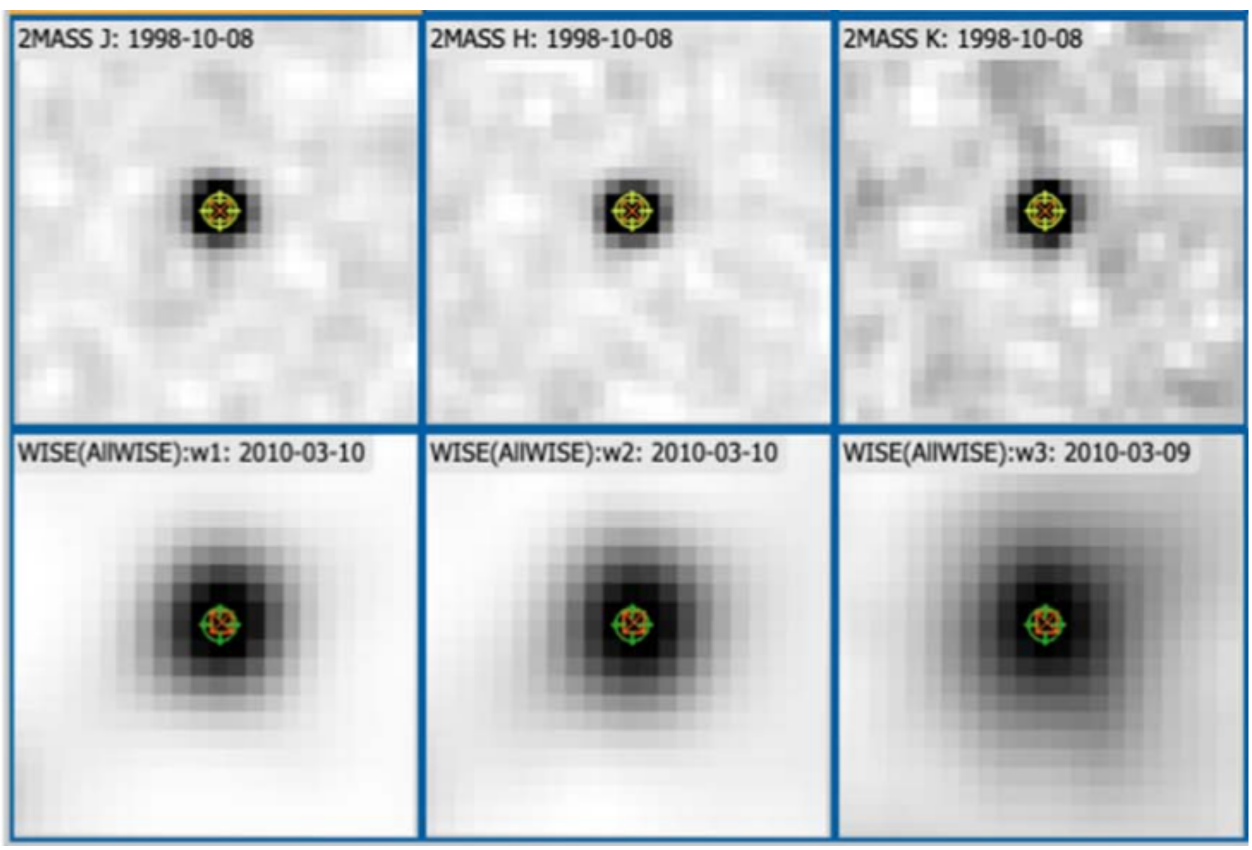


Figure 7a: A high quality source showing a well-defined object and a reticle centered on the source. This source was kept in a similar YSO study (Rebull et al., 2023).

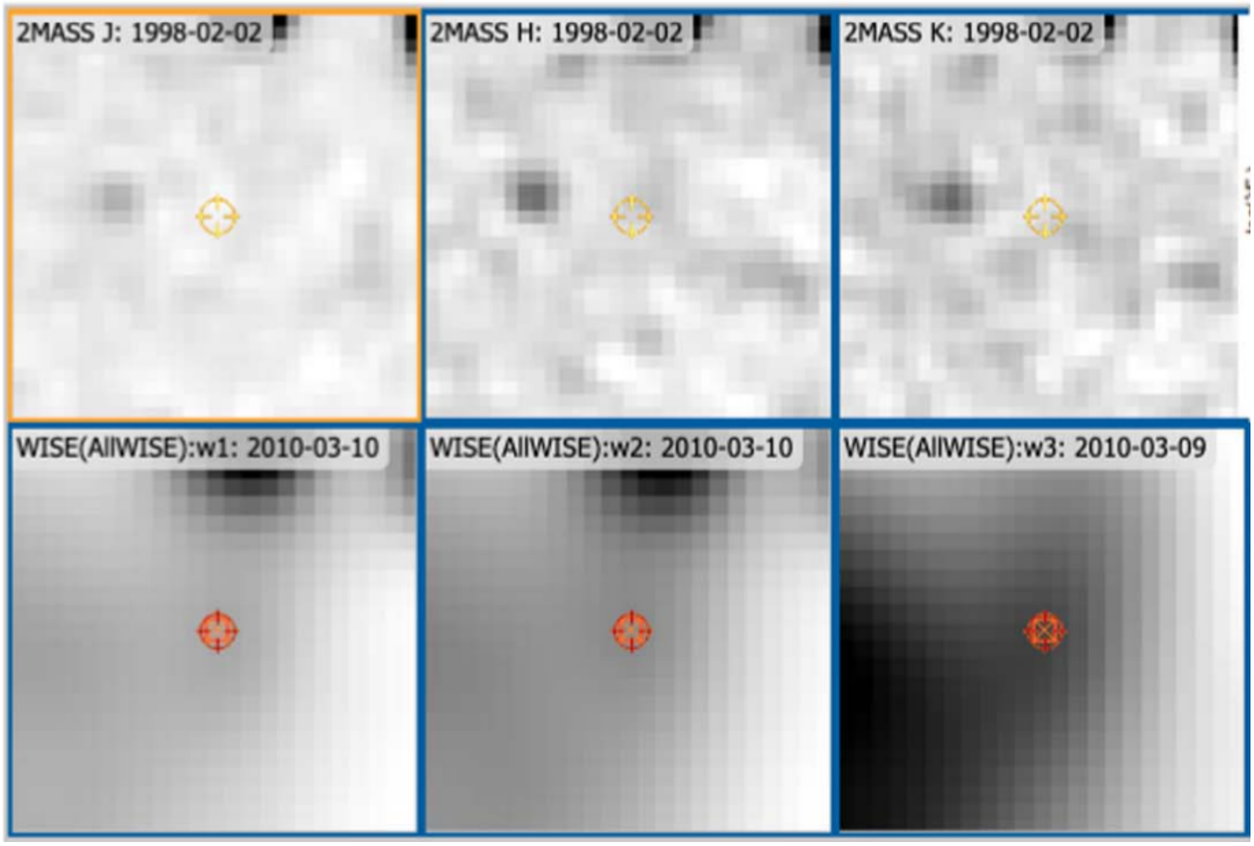


Figure 7b. A poor quality source rejected by Rebull et al. (2023). A source is not found near the reticle at any wavelength. The investigators identified this as a likely nebular knot, not a YSO.

For those sources that have distances provided for us by Gaia, we can attempt to assess whether they are at the right distance to be members. This is challenging because we don't really know the distance of the clusters we're examining to an exact precision, and Gaia DR3 distances are not very reliable after 1.5-2 kpc due to the limits of observation. We will do the best we can with what we have.

On the basis of all three pieces of evidence (color-color diagrams, SEDs, and images), each YSO candidate (literature and our newly selected ones) will be placed in a "confidence bin" based on the composition of the SED and how sure we are that it is really a YSO. When we get to this point, we will be able to say which of the literature YSOs and which of the Koenig- and Gutermuth-identified YSOs we believe.

4.0 Education and Outreach Plan

As our work progresses, it is important not to overlook the impact the work will have beyond the expected scientific contribution. As educators, we have a responsibility to identify opportunities to develop new and relevant classroom and outreach material as well as to contribute to the body of knowledge of educational theory and practice as a whole. We must plan ahead for outreach, education, and research so that these tools can be developed and the necessary data can be collected along the way as we work through our YSO analysis.

4.1 Classroom Materials.

Project 1:Excel and Python Applications.

We will develop a series of activities for high school physics and astronomy classes that engage students in working with real data and modeling using Excel and Python. These tools, in particular, were chosen due to their ease of access, versatility, and accessible learning curves. By using these tools to visualize and manipulate data, high school students and introductory level college students will gain practical skills and develop a strong understanding of the process of astrophysics research and the underlying physical concepts. NITARP students will help to create these lessons and we will be using them with physics and astronomy classes in the fall. The lessons will be shared with all current NITARP teachers as well as alumni.

Project 2: Earth and Space Science Standardized Curriculum.

We will also create a laboratory investigation that aligns to parts of the High School Earth and Space Sciences Standard 1A (HS-ESS1) and specifically the HS-ESS1:A. These standards read as follows (National Academies of Sciences, Engineering, and Medicine, 2012, p 173 – 174):

> The performance expectations in ESS1: Earth's Place in the Universe, help students formulate an answer to the question: "What is the universe, and what is Earth's place in it?" The ESS1 Disciplinary Core Idea from the NRC Framework is broken down into three sub-ideas: the universe and its stars, Earth and the solar system and the history of planet Earth. Students examine the processes governing the formation, evolution, and workings of the solar system and universe. Some concepts studied are fundamental to science, such as understanding how the matter of our world formed during the Big Bang and within the cores of stars. Others concepts are practical, such as understanding how short-term changes in the behavior of our sun directly affect humans. Engineering and technology play a large role here in obtaining and analyzing the data that support the theories of the formation of the solar system and universe. The crosscutting concepts of patterns, scale, proportion, and quantity, energy and matter, and stability and change are called out as organizing concepts for these disciplinary core ideas. In the ESS1 performance expectations, students are expected to demonstrate proficiency in developing and using models, using mathematical and computational thinking, constructing explanations and designing solutions, engaging in argument, and obtaining, evaluating and communicating information; and to use these practices to demonstrate understanding of the core ideas. [p.94]

> Students who demonstrate understanding can: Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy that eventually reaches Earth in the form of radiation. [Clarification Statement: Emphasis is on the energy transfer mechanisms that allow energy from nuclear fusion in the sun's core to reach Earth. Examples of evidence for the model include observations of the masses and lifetimes of other stars, as well as the ways that the sun's radiation varies due to sudden solar flares ("space weather"), the 11-year sunspot cycle, and non-cyclic variations over centuries.] [p.96]

Using the data obtained from our research, we aim to align it with the performance level outlined in Space Systems HS-ESS1-1. This standard involves developing and evaluating models, grounded in evidence, to depict the lifespan of celestial bodies such as the Sun or other stars, including YSOs. Additionally, it encompasses understanding the pivotal role of nuclear fusion and elucidating how the energy emanating from stars reaches Earth in the form of electromagnetic radiation. To accomplish this, we employ concepts of scale, proportion, and quantity to assess the validity and constraints of these models, thereby refining them. Our exploration will particularly delve into the early stages of stellar existence, examining the processes of collapse and formation observable in star systems.

By using the data from multiple telescopes and surveys, the laboratory investigation will focus on the significance of the fact that different telescopes have specific frequencies of electromagnetic energy that they study. More specifically, students will be guided to learn that these observations can be pieced together to create a mosaic of observations in a large electromagnetic spectrum to identify YSOs. Through existing research, students will learn which telescopes measure what band of electromagnetic radiation and how archival data can be used to find new discoveries. Additionally, students will discover that where there is excess electromagnetic radiation, there may be stars at the beginning of the process of collapse and ignition.

Students at the end of the investigation will demonstrate understanding of a composite SED graph using supplied data from multiple telescopes and frequencies of electromagnetic energy in an investigation that has a streamlined process to what will be done during our own investigation. Students will also be able to construct a model of a star's formation, identify some of the boundaries during its formation, and identify the difficulties observing this phenomena from earth. This activity and investigation will be practiced with one of our classes in the 24-25 school year and refined after being used in the classroom.

4.2 Education Research: Imposter Syndrome

Clance and Imes (1978) were the first to coin the phrase "imposter syndrome" and defined it as an "internal experience of intellectual phoniness" (p. 241). Their work focused on high-achieving women with high academic and professional accomplishment, but imposter syndrome has also been documented in men (September et al., 2001; Cowman & Ferrari, 2002; Cozzarelii & Major, 1990). Over time, imposter syndrome has been recognized and cataloged in many populations, such as college students, ethnic minorities, and professionals in a variety of careers (Peteet, 2015; Bernard et al., 2017; Byrnes & Lester, 1995; Cromwell et al., 1990; Kolligian & Sternberg, 1991; Hutchins & Rainbolt, 2017; King & Cooley, 1995).

Our study seeks to learn if the NITARP experience can impact Imposter Phenomenon (IP) of participating students. For our study, we will use the Clance Impostor Phenomenon Scale (CIPS) (Clance, 1985), shown by Chrisman et al. (1995) to be more consistent and reliable than the Perceived Fraudulence Scale (Kolligian & Sternberg, 1991) and consistent with other measures. The scale has 20 items rated on a five-point Likert scale, with 1 being “not true at all” and 5 being “very true,” with no reverse-scored items.

This scale is independent of the experience itself, so is not specific to astronomy. Sample questions include from Clance (1985) include:

- I can give the impression that I'm more competent than I really am.
- Sometimes I feel or believe that my success in my life or in my job has been the result of some kind of error.
- Sometimes I'm afraid others will discover how much knowledge or ability I really lack.
- If I receive a great deal of praise and recognition for something I've accomplished, I tend to discount the importance of what I've done.

We will also collect free-response data at the end of the study with questions tailored to determine the value of the experience of both the intervention and the scientific experience overall.

The study will proceed via the following steps:

- Spring:
    - Release forms will be collected from all interested students.
    - CIPS Survey data will be collected anonymously from student participants via the Internet.
- Late Fall:
    - CIPS Survey data will be collected anonymously from student participants via the Internet.
    - Responses to open-ended questions about imposter syndrome will be collected anonymously from student participants via the Internet.
    - Individual data will be destroyed upon the completion of the study, and only summaries in the form of charts and tables will be kept.

When the analysis has been completed, we will seek an appropriate journal for publication.

This study has been reviewed and approved by the Institutional Review Board at McLennan Community College, study numbers 2024.001 and 2024.002.

4.3 Public Outreach

David Dahari will be taking on the director role of the Dixon Observatory at Berkshire School, a small private boarding school in western, MA. As part of his work in that role, he will conduct several outreach sessions related to the work at NITARP for the school community and the general public. Some of these sessions will be recorded and shared on YouTube or Live Streamed.

Joseph Perry will present the team's work locally and at regional and state science conferences such as New York State Master Teacher Program and the Science Teachers Association of New York State (STANYS) conference. Both of these organizations connect with thousands of teachers across New York State. In the process, he will share information and offer training to teachers who themselves are turnkey trainers within their regions and school districts. Joe will share the NITARP experience, the project's findings and the lab investigation developed.

Jeff Benter will host six weekly workshops in the spring semester on foundational astronomy ideas, such as light, measurements, star formation, and star classification. Participants will include high school and middle school students from both his home district and the neighboring communities. High school students who complete the series will be eligible to visit Caltech in Pasadena, California, and attend the American Astronomical Society Conference in January 2025. Additionally, as a part-time presenter at the local community college planetarium, Jeff will incorporate information from this project into his presentations there.

April Andreas plans to share the results of both the YSO study and the related educational materials with the American Society for Engineering Education (ASEE) at their annual conference in 2025 and seek publication for papers about the experience. She has a strong following on her YouTube channel and will publish some "How To" videos about the techniques developed by the team.

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