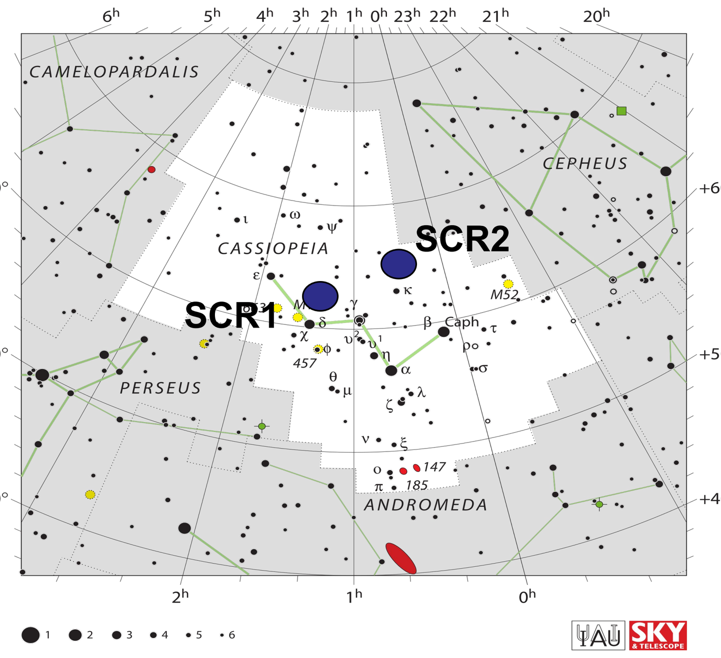
Combing a Cosmic Cradle in Cassiopeia: A Multiband Search for Young Stellar Objects

Jeff Benter[1], April Andreas[2], Kivan Andreas[2], Jack Benter[3], David Dahari[4], Gabriel Dahari[4], Tanner Hurliman[1], Andres Mar[2], Peter Newcomer[2], Joseph C. Perry[5], Richard J. Perry[5], Luisa Rebull[6], Jackson Ritchie[1], Madeleine Sullivan[5], Sahar Sultani[4], Mickayla Tosch[2], Bo Zeleznik[3],

[1]Tri-Valley High School, Downs, IL; [2]McLennan Community College, Waco, TX; [3]Le Roy High School, Le Roy, IL; [4]Berkshire School, Sheffield, MA; [5]Palmyra - Macedon CSD Palmyra, NY; [6]Caltech-IPAC/IRSA, Pasadena, CA

Project Goals



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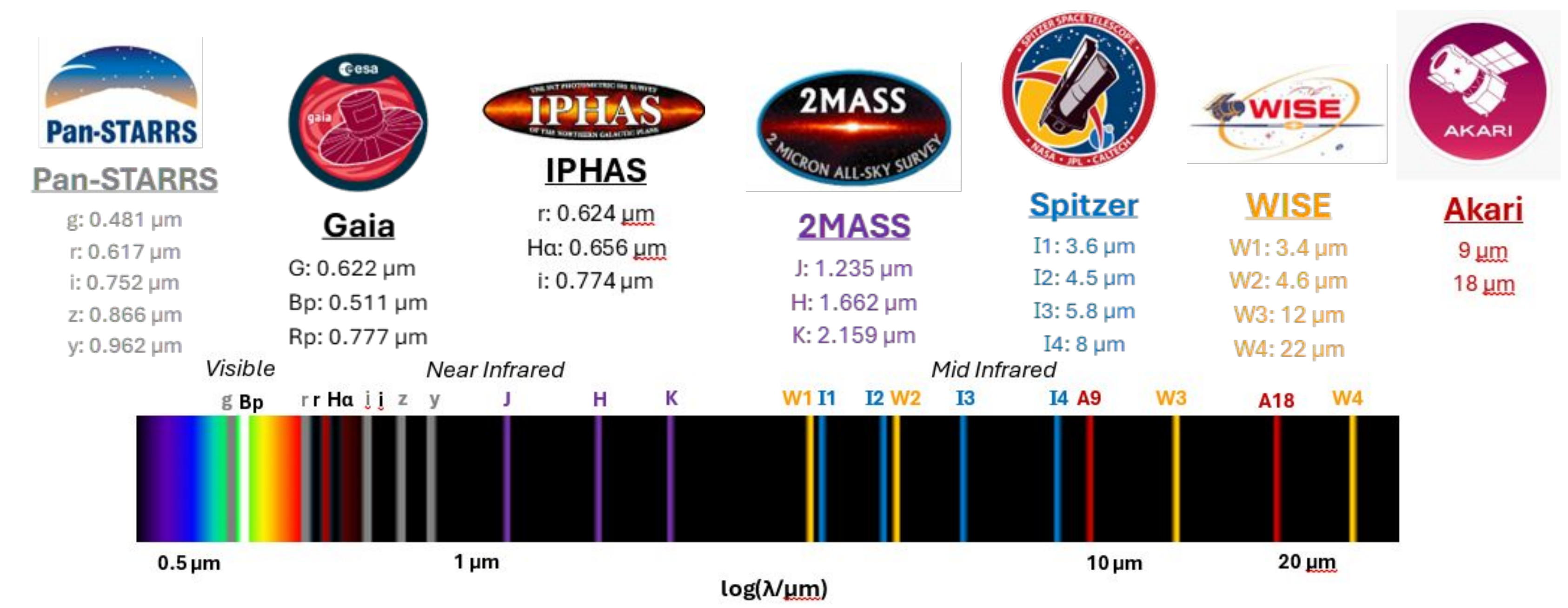
Our group seeks to identify young stellar object candidates (YSOs) in two regions (SCR1 and SCR2) along the northern galactic plane in the constellation Cassiopeia.

By using more data than any previous individual study of our two regions, we can make a more accurate assessment of whether the previously identified YSOs are really YSOs, as well as identify new candidates that have been overlooked in prior studies.

Data Matters

In our study, we combined archival data from a range of wavelengths to further assess each previously published YSO, as well as discover new, previously unidentified YSOs.

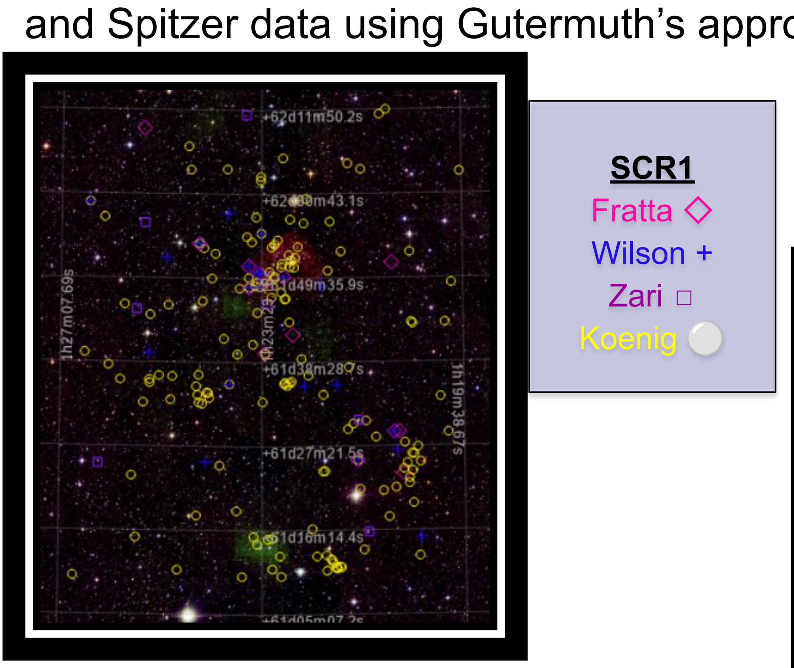


Why These Regions? & How to Find YSOs?

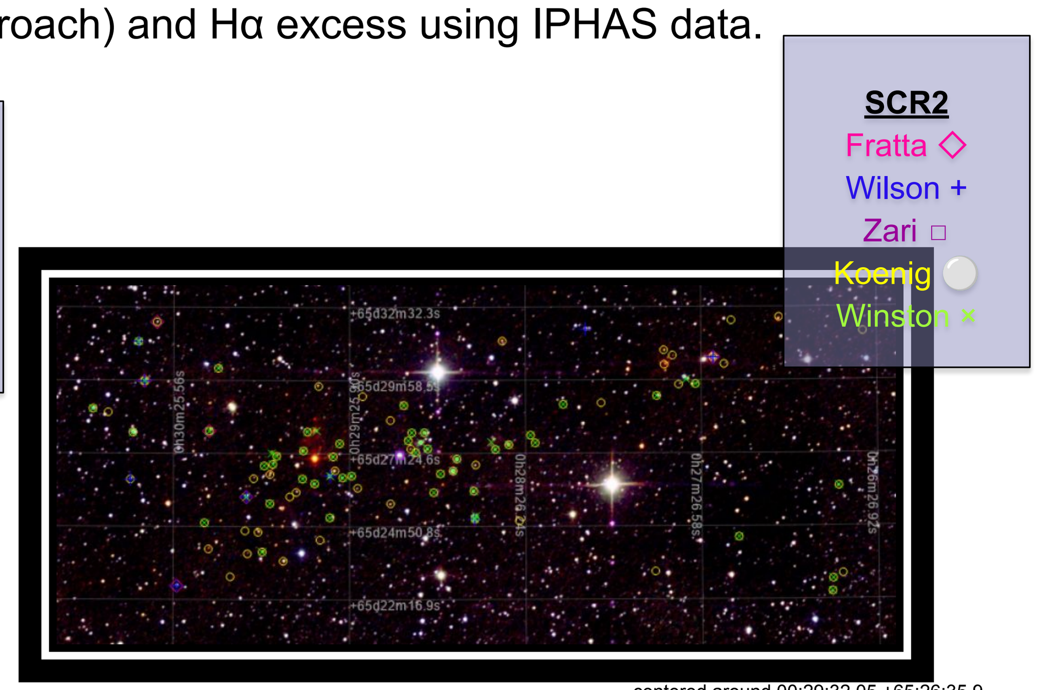
SCR1 and SCR2 are two promising regions we chose to study. SCR1 contains Wilson's SFR3 (a newly identified clustering of YSOs) and Sharpless 2-187; SCR2 has a dark river and bright sources at WISE-3 & 4. Both regions have been included as part of prior large-scale surveys to find YSO candidates:

- **Fratta** – used Gaia and IPHAS data to locate stars with Hα excesses;
- **Wilson** – looked for Class II YSOs using a naive Bayes classifier (machine learning) based on IR excess, Hα excess, optical variability, and position in optical color-magnitude diagrams;
- **Zari** – used Gaia Data Release 2 positions and proper motions to identify nearby young stars that are moving together;
- **Winston** – used WISE and Spitzer IR excesses;
- **ASAS-SN** – looked for optical variables (not just YSOs).

In addition, we identified new YSOs using IR excess (from WISE data using Koenig's approach and Spitzer data using Gutermuth's approach) and Hα excess using IPHAS data.



centered around 01:23:46.48 +61:42:26.4
portions of which are also known as Sh 2-187

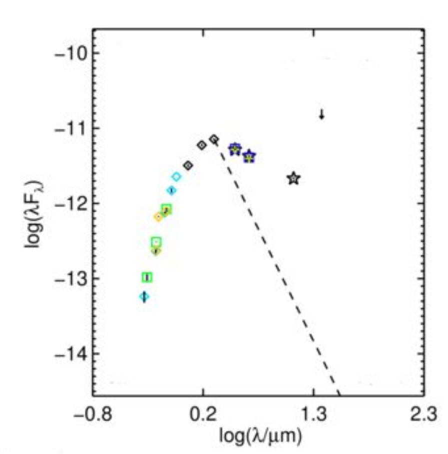


centered around 00:29:32.05 +65:26:35.9

Analysis: Sifting Through the Indicators

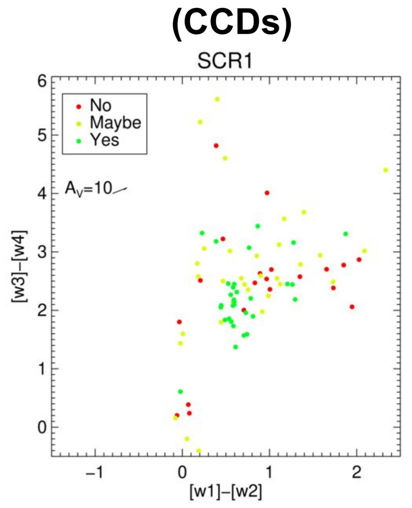
Using all available bands of data, spectral energy distributions, color-color diagrams, and color-magnitude diagrams were created for each source to identify any excess in infrared or Hα.

Spectral Energy Distributions (SEDs)



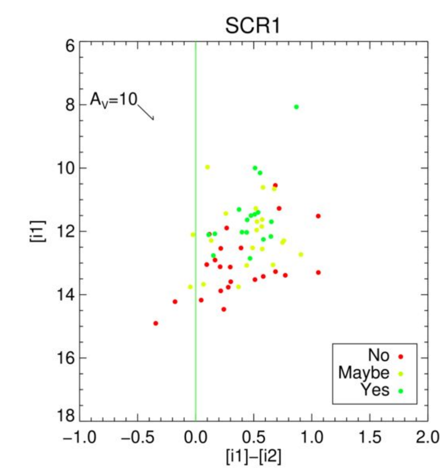
SED (symbols indicate origin); RJ line extended from K guides the eye; star has an IR excess starting by 3.5 um. Star was identified in the literature by Winston+; we identified it as having an IR excess and an Ha excess.

Color-Color Diagrams (CCDs)



Example WISE color-color plot. This identifies stars with IR excess; a star with no IR excess (dust-free) would be near (0,0). The no/maybe/yes code refers to how confident we are in whether the object is a YSO. Reddening vector is as shown.

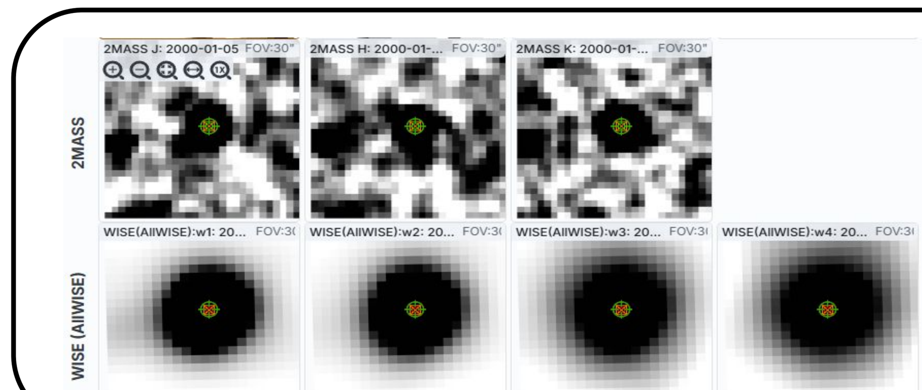
Color-Magnitude Diagrams (CMDs)



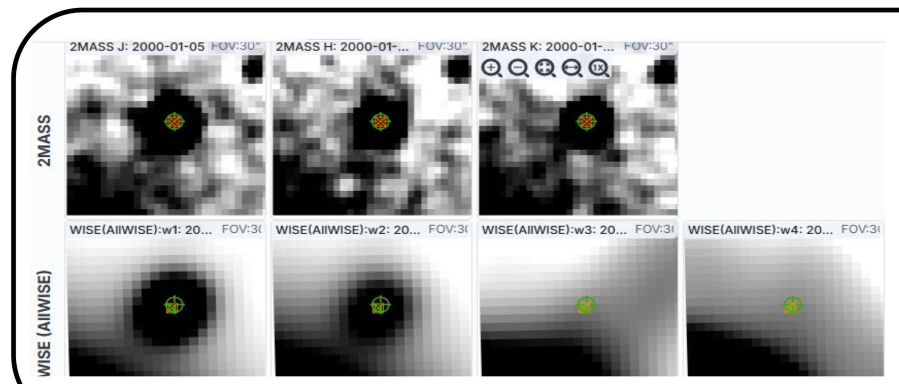
Example Spitzer color-mag diagram. Sources to the right of the green line show an IR excess. Reddening vector is as shown.

Visual Inspection of Images

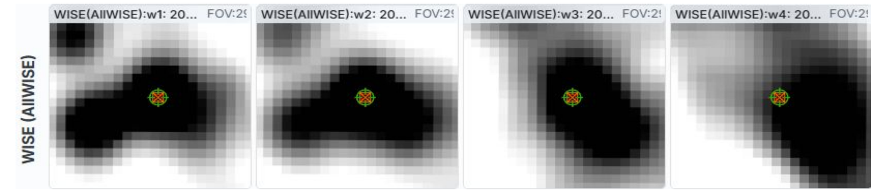
Multiple images of each source were then viewed to confirm the detection of a single, reliable source. Reviewing images helped catch cases where the pipeline confused objects or mistook artifacts or nebulosity for actual sources.



A "good" source: a discrete source is centered in each band.



Although clearly visible in 2MASS, W1, and W2, this source is lost in the background brightness in W3 and W4. W3 and W4 can only be assigned a "limit", or maximum brightness.



Multiple, overlapping sources mean it's not clear which source is creating the observed IR excess. The reticle is at the same position in each image but the sources appear to shift.

http://k2clusters.ipac.caltech.edu/scr2/html/029.html

Potential Indicators We Used to FInd YSOs

Infrared Excess

Detectable if YSO is surrounded by dusty circumstellar disk or envelope.

Hα-Excess

Produced when the electron in H transitions from 3rd to 2nd energy level; in YSOs, often occurs during accretion and stellar activity.

Optical Variability

Changes in brightness can be related to accretion, spot activity, circumstellar dust, and flares.

Gaia Proper Motions

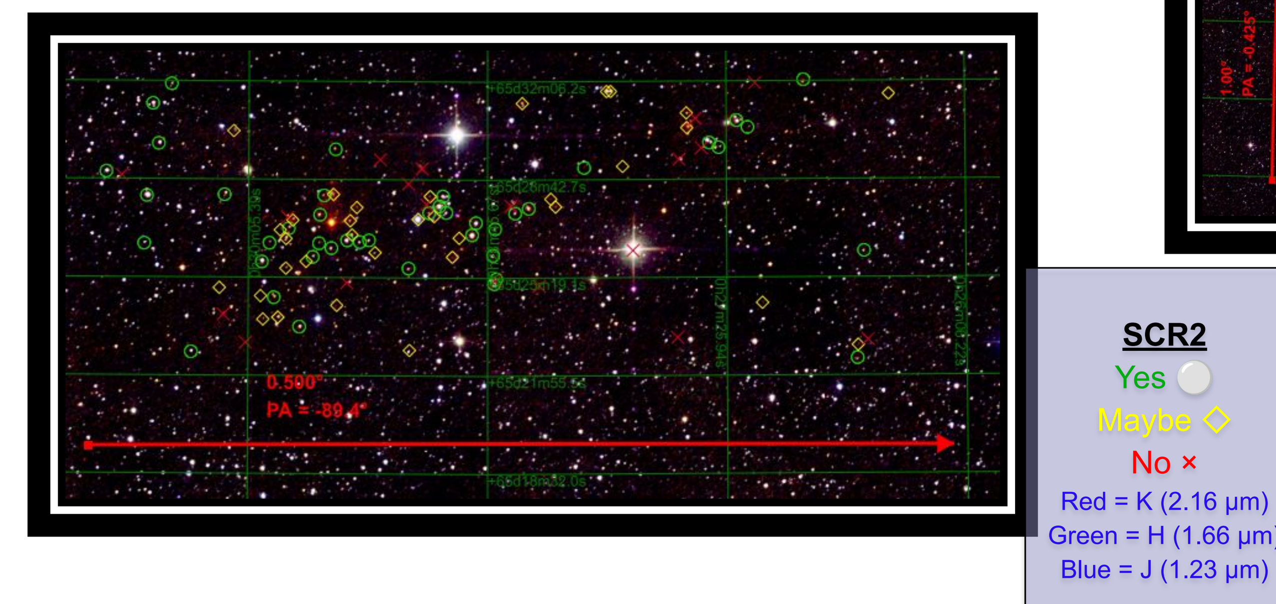
Groups of stars moving together through space. YSOs birthed in the same nebula often travel together through space before dispersing.

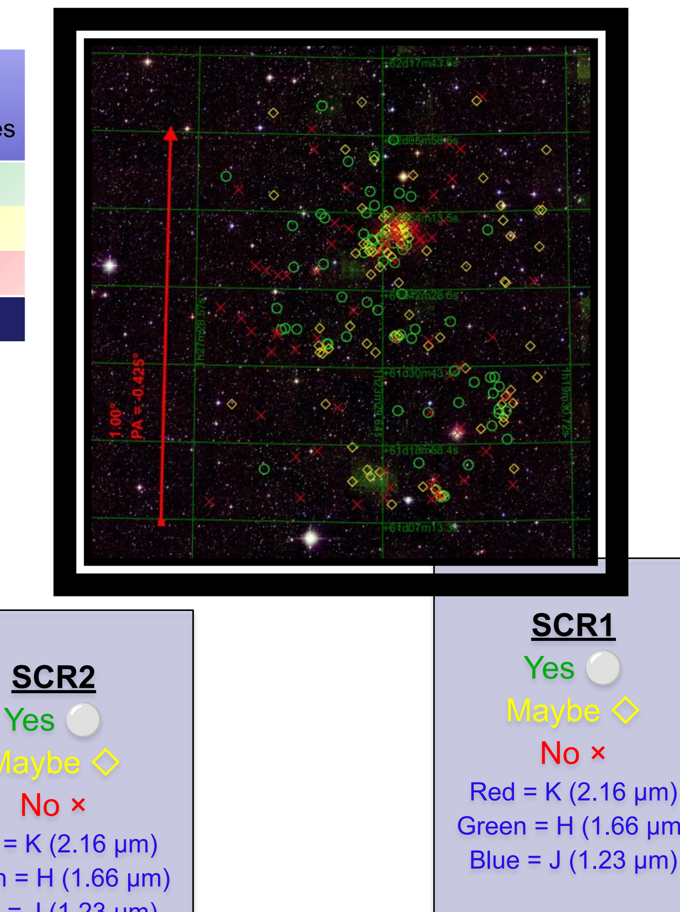
Results

Comparison of Counts in SCR1 vs. SCR2

After inspection of all available data, 80 (32%) of the 248 identified YSO candidates in SCR1 were identified as likely YSOs. As shown in the image, most likely YSOs are clustered in the illuminated nebula that is known as Sh 2-187. In SCR2, 43 (45%) of the 95 candidates were identified as likely YSOs, mainly located within the dark nebula that stretches horizontally across the image.

	SCR1		SCR2	
	Counts	% of All Sources	Counts	% of All Sources
Yes	80	32%	43	45%
Maybe	88	36%	33	35%
No	80	32%	19	20%
Totals	248	100%	95	100%





YSOs are classified by their amount of IR excess, determined by the slope of their SEDs on the longer wavelength (Rayleigh-Jeans) side. Class Is are the most embedded YSOs with the greatest IR excess (believed to be the youngest), while Class IIIs are the most exposed YSOs with the least IR excess (believed to be the oldest).

	SCR1		SCR2	
	Counts	% of All Yes's	Counts	% of All Yes's
Class I	6	8%	7	16%
Flat	12	15%	6	14%
Class II	49	61%	29	68%
Class III	12	15%	1	2%
Class X	1	1%	0	0%
Totals	80	100%	95	100%

SCR2, with its greater abundance of earlier classes and its dark nebula, is therefore likely to be the younger of the two regions.

Method Accuracy

	SCR1			SCR2		
	# of Sources Identified	"Confirmed"	Success Rate	# of Sources Identified	"Confirmed"	Success Rate
Koenig	147	49	33%	80	37	46%
Guter	56	15	27%	0	0	-
Maybe Hα	26	15	58%	10	9	90%
Asassn	13	2	15%	1	0	0%
Fratta	13	12	92%	6	6	100%
Wilson	21	15	71%	9	8	89%
Winston	0	0	0%	52	28	54%
Zari	7	1	14%	1	0	0%
Total	0	109		159	88	

Totals are >100% because several sources were flagged by multiple methods

The most reliable method of identifying likely YSOs was H-alpha excess, as used by both Fratta and our own "Maybe Hα" cut. Wilson's use of machine learning to cull through multiple parameters was also highly successful.

Future Opportunities

We still have to regard these YSO candidates as merely "candidates" because we don't have spectra for them. The most obvious next step would be to get follow-up spectroscopy to confirm that these YSOs are, in fact, stars, and to constrain their masses by getting spectral classifications for them. In the absence of additional telescope time, we could extend this analysis to other regions in the Galactic Plane and see if we can improve the statistics for some of the literature samples where we only had a few stars to work with. If we have more stars for those small samples, it would make our analysis more reliable.