A More Complete List of Young Stellar Object Candidates in AFGL 490

Rita Ciambra[1], Maxemilyan Kuhnle[1], David Friedlander-Holm[2], Cecilia Brady[2], Leila Eshaghpour-Silberman[2], Moya Herrera[2], Taylor Swanson[2], Kathy Gustavson[3], Ellee Tabak[4], Mary Swigert[5], Ethan Van Winkle[6], Julia Johnson[6], Dr. Luisa M. Rebull[7]

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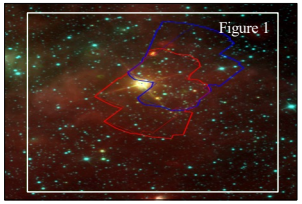
ABSTRACT AND OVERVIEW

AFGL 490 is an embedded cluster of low-mass stars around the high-mass (8-10 M☉) star AFGL 490 (Straižys & Laugalys 2008), located within the plane of the galaxy in the Cam OB1 association. Within this cluster are many young stellar objects (YSOs) emerging from the dust cloud surrounding AFGL 490. Starting with 517 YSO candidates from the literature or identified anew using H-alpha or infrared variability, each source was analyzed using image inspection, spectral energy distributions, color-color/color-magnitude diagrams and light curves to identify which targets were strong YSO candidates. This project successfully narrowed down the final list to 500 candidate YSOs in AFGL 490.

YSO CANDIDATE DISTRIBUTION IN AFGL 490



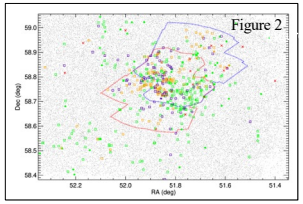
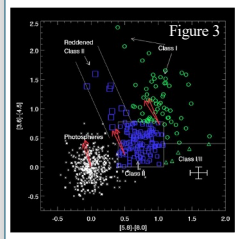


Figure 1 is an AllWISE color image; the white box is the region we studied. Red is W4 (22 μm), green is W2 (4.6 μm), and blue is W1 (3.4 μm). The blue outline is the region monitored in IRAC-1 (3.6 μm) and the red outline is the same for IRAC-2 (4.5 μm). Figure 2 is the location of the YSO candidates in AFGL 490. The legend is listed below.

YSO CANDIDATE CLASSES IN AFGL 490



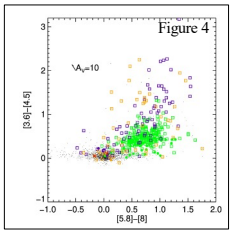


Figure 3 (Megeath et al. 2004) is a color-color diagram reference that displays established locations of YSO classes. The white dots in Figure 3 are photospheres.

Figure 4 displays our YSO candidates in AFGL 490 on the same color-color diagram as Fig. 3. The legend to the right represents our ranking of each candidate being a YSO.

- Object in catalog
- Likely YSO, with Gaia distance
- Likely YSO, without Gaia distance
- Probably YSO, with Gaia distance
- Probably YSO, without Gaia distance
- Maybe YSO, with Gaia distance
- Maybe YSO, without Gaia distance
- Reject

RESULTS

After analysis of the SEDs, color-color diagrams, and color-magnitude diagrams (CMD), we ranked the sources by our confidence in their being a YSO and sorted them into 4 bins: Likely YSO (LYSO), Probably YSO (PYSO), Maybe YSO (MYSO), and Reject. This is shown below in Table 1. These sources were also placed in the established YSO classes (I, flat, II, III) shown in Table 2. The analysis for the confidence ranking is explained in the following sections.

Table 1: YSO Candidate Results

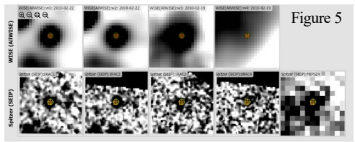
Bin	YSO Candidates (N=517)	Percent of YSO Candidate List	YSO Variables (N=249)	Percent of Variability YSO Candidates	YSO Periodic (N=22)	Percent of Periodic YSO Candidates
LYSO	287	55.5	106	42.6	14	63.6
PYSO	95	18.4	47	18.6	4	18.2
MYSO	118	22.8	92	36.9	4	18.2
Reject	17	3.3	4	1.6	0	0.0

Table 2: Percent of YSO Classes (N=500)

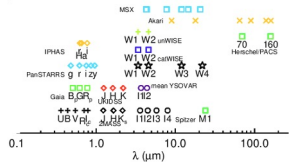
I	flat	II	III
14.6	15.8	54.6	15.0

DATA ANALYSIS: IMAGE INSPECTION AND SED CONSTRUCTION

Step 1: Using the NASA/IPAC Infrared Science Archive (IRSA) tools, we vetted each object on available images in order to determine if the object was a real point source in AFGL 490. Source 2 (LYSO) in Figure 5, is an example of an excellent point source.



Step 2: We are the first group to carefully analyze these sources in AFGL 490 using all of the bands shown below in the spectral energy distribution key. We organized the YSO candidates based on IR excess, examples of which are shown in color-coded Table 3.



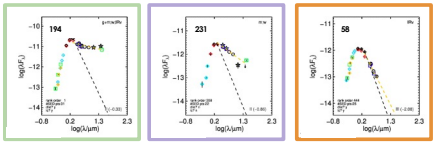
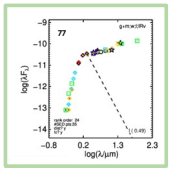


Table 3: SED Exemplars of Bins

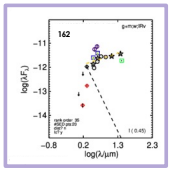
Source	IR Excess	Bin Abbreviation
194	High	LYSO
231	Moderate	PYSO
58	Low	MYSO

The following SEDs are examples of interesting sources.

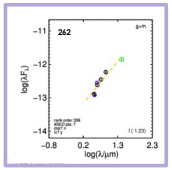
Source 77 is a bright source with large IR excess.



Source 162 shows variability even on the scale of the SED.



Source 262 is an embedded source, but lacks data.



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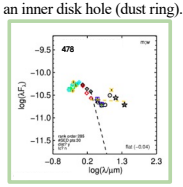
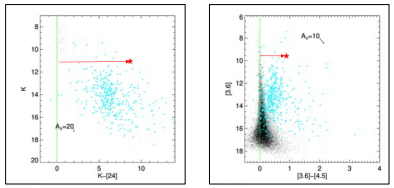


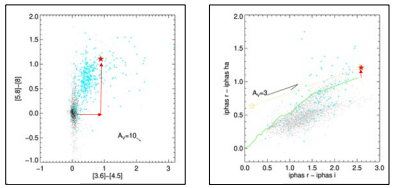
DATA ANALYSIS: COLOR-COLOR DIAGRAM, CMD, AND DISTANCE

Step 3: We inspected the position of each object in multiple color-color and color-magnitude diagrams. Where possible and relevant, we estimated reddening from JHK$_s$ and corrected for it. We assessed our confidence in each source being a YSO candidate. In the following figures, the red arrows indicate IR excess or H-alpha excess.

SOURCE 77
COLOR MAGNITUDE DIAGRAM

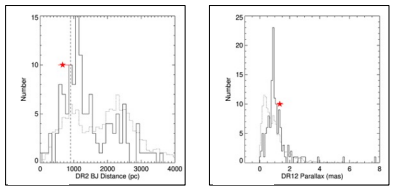


SOURCE 77
COLOR COLOR DIAGRAM



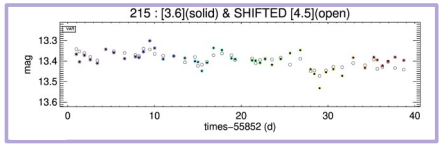
Step 4: We used Gaia DR3 distances where possible to see if the source is a part of AFGL 490, which has an estimated distance of 900 pc (Snell et al. 1984).

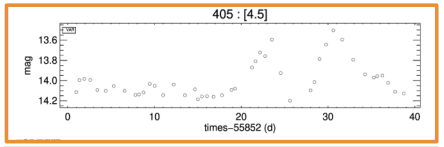
SOURCE 77
DISTANCE AND PARALLAX HISTOGRAM

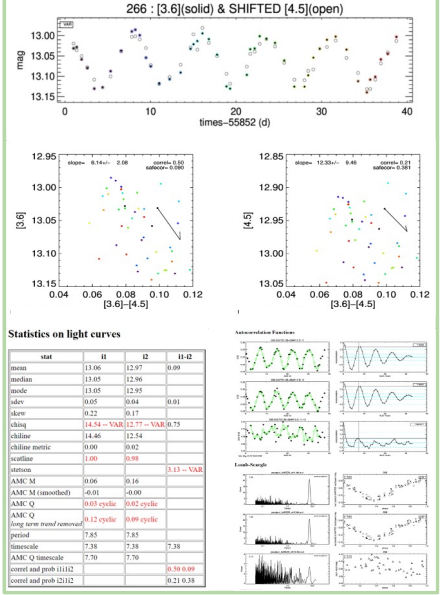


DATA ANALYSIS: VARIABILITY AND PERIODICITY

Step 5: With the YSO candidate list completed, we looked at the 312 YSO candidates that had Spitzer light curves to determine variability and periodicity. We used several statistics following the rest of the YSOVAR work (Rebull et al. 2014); we analyzed periodicity using the IRSA time series tools. Examples of light curves are shown below.







stat	i1	i2	i1-i2
mean	13.06	12.97	0.09
median	13.05	12.96	
mode	13.05	12.95	
sdev	0.05	0.04	0.01
skew	0.22	0.17	
chinj	14.54 → VAR	12.77 → VAR	0.75
chilne	14.46	12.54	
chilne metric	0.00	0.02	
scatline	1.00	0.98	
stetson			3.13 → VAR
AMC M	0.06	0.16	
AMC M (smoothed)	-0.01	-0.00	
AMC Q	0.03 cyclic	0.02 cyclic	
AMC Q *long term trend removed*	0.12 cyclic	0.09 cyclic	
period	7.85	7.85	
timescale	7.38	7.38	7.38
AMC Q timescale	7.70	7.70	
correl and prob i1i12			0.50 0.09
correl and prob i2i12			0.21 0.38

ACKNOWLEDGEMENTS

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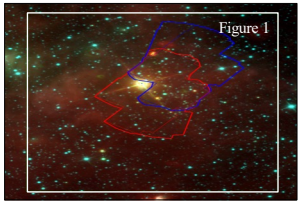

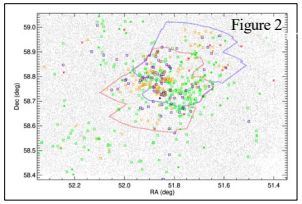

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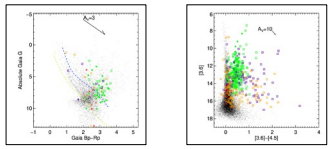

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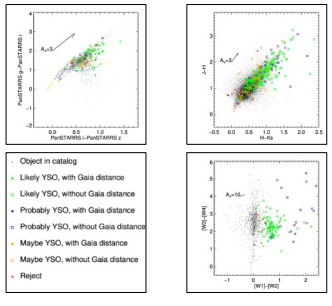

RESULTS

After analysis of the SEDs, color-color diagrams and CMDs, we collectively ranked the sources in bins of likelihood to be a YSO: Likely YSO (LYSO), Probably YSO (PYSO), Maybe YSO (MYSO) and Reject. This is shown below in Table 1. These sources were also placed in the accepted YSO classes (I,flat,II,III) shown in Table 2. The analysis for the likelihood ranking is explained in the following sections.

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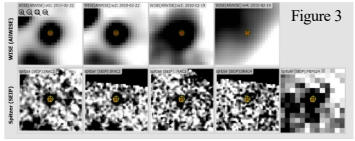

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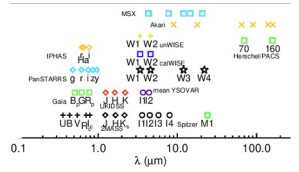

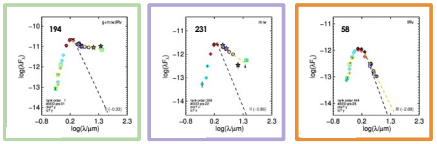

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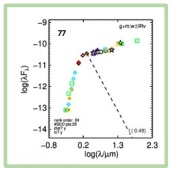

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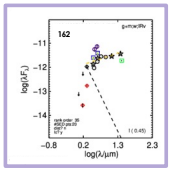

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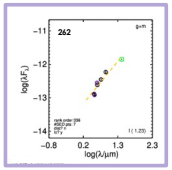

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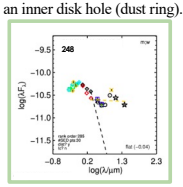

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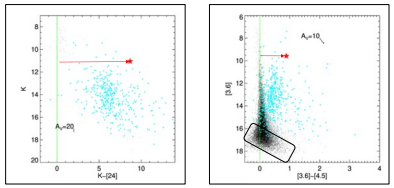
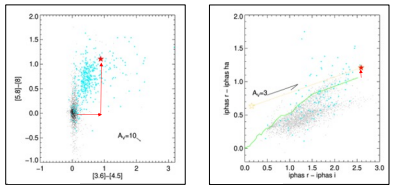


SOURCE 77
COLOR COLOR DIAGRAM



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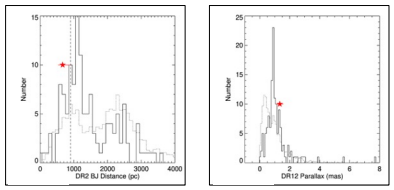
SOURCE 77
DISTANCE AND PARALLAX HISTOGRAM



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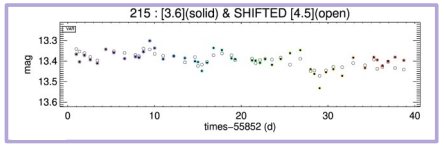

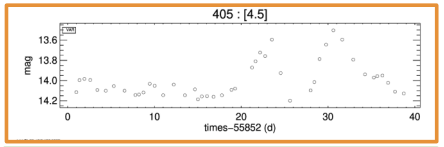

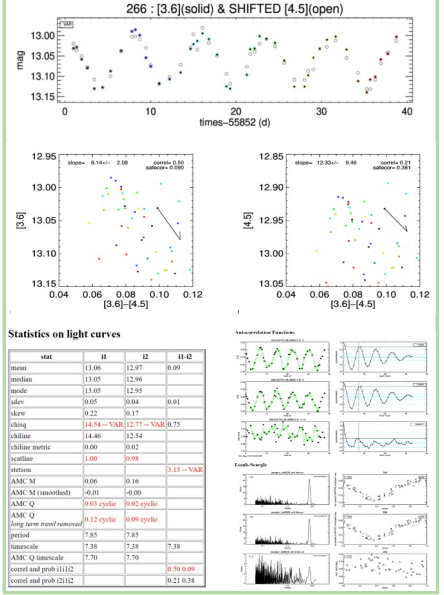

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