Looking for Young Stellar Objects in Obscure Sharpless Regions

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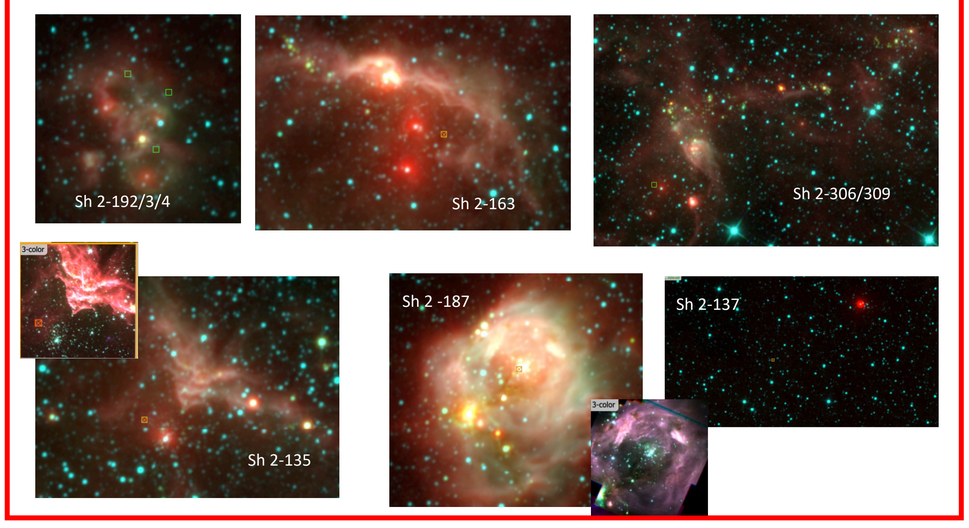
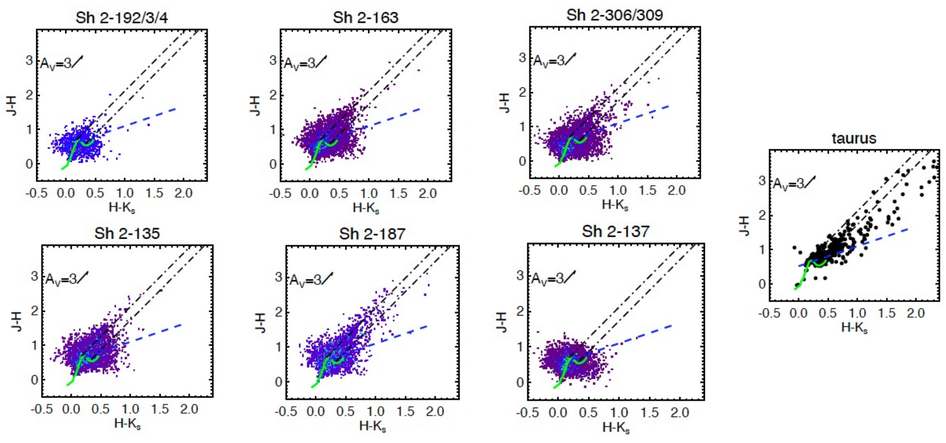
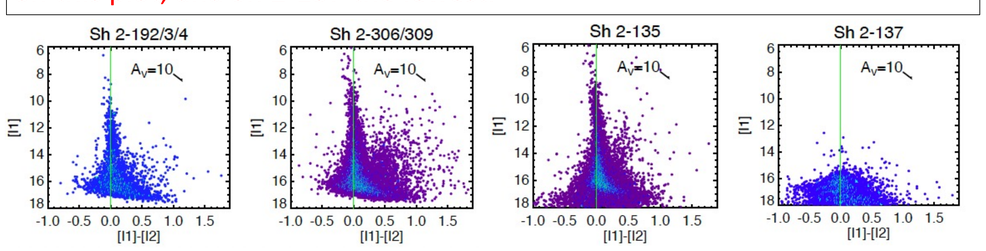
Which do YOU think will yield more YSOs?



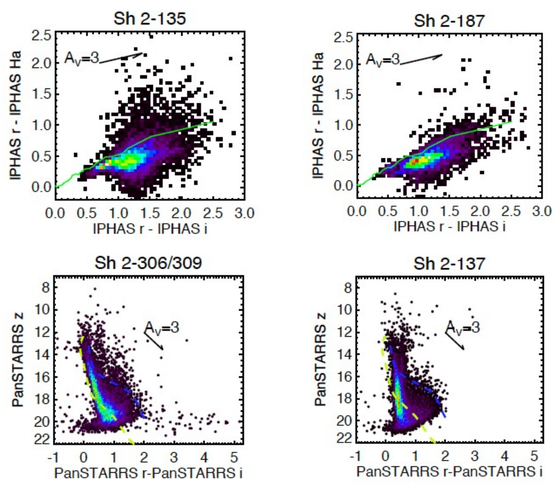


↑ J-H vs. H-K for all 6 regions. *The green line is the main sequence (MS), and the dot-dashed lines are reddened MS stars (reddening vector also shown); the blue dashed line is where YSOs with NIR excesses are found. Points are shown as density plots, e.g., green is a higher density of points. (Taurus YSOs are shown as black dots in a small plot for comparison.)* Sh 2-187 and Sh 2-306/309 seem to have the most YSO candidates based on this plot, and Sh 2-137 the fewest.



↑ [I1] vs. [I1]—[I2]. Only four clusters have widely available IRAC data. *The green line is the MS. (YSOs should be bright and red, e.g., upper right.) Points are shown as density plots, e.g., green is a higher density of points.* Sh 2-306/309 has the most YSO candidates based on this plot, and Sh 2-137 by far the fewest. (Sh 2-187 has IRAC data but not SEIP photometry, so we did our own for the subset of objects we cared about.)

Region (Sh 2-xxx)	# YSO lit candidates	# YSO candidates we identified	# YSO candidates to check	# YSO candidates surviving checks
192/3/4	12	5	16	8
163	0	37, +12 more based on optical CMDs	49	31
306/309	138	110	193	119
135	177	108	236	130
187	0	51, +11 more based on optical CMDs	62	45
137	0	33	33	2



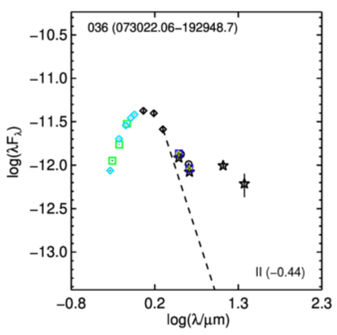
← Example of IPHAS (optical) color-color diagrams exploring Hα excess sources. *Green line is ZAMS, and reddening vector is shown; point colors reflect point density.* Sh 2-135 has significantly more stars with Hα excesses (= significantly above the green line) than Sh 2-187.

← Example of PanSTARRS (optical) color-magnitude diagrams exploring whether these targets look like they may be YSOs. *Dashed lines are 6 (blue) and 9 (yellow) Myr isochrones shifted arbitrarily to ~3 kpc; point colors reflect point density.* Sh 2-306/309 has stars that are clumping parallel to the isochrones, whereas Sh 2-137 is distinctly not parallel to the isochrones, which is more consistent with random background sources at a variety of distances.

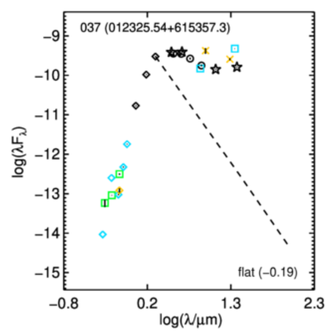
What did we do? *We searched for young stellar objects (YSOs) in places no one had yet really looked. Where would be good places to do this?*

- Sharpless (1953, 1959) published a catalog of HII regions based on POSS plates (optical).
- He identified 313 objects, many of which are now famous (e.g., Sh 2-49=M16, the Eagle Nebula).
- Some are huge (Sh 2-276=Barnard's Loop!) and some are not (Sh 2-4 is a 5' random IRAS source).
- A few aren't HII regions (Sh 2-191=Maffei 1, a galaxy; Sh 2-274=Medusa Nebula, a PN).
- We took the whole Sharpless catalog, compared it to Simbad, rejected non-SFRs & SFRs (famous and not) where someone already used IR to find YSOs there.
- We took the remaining Sharpless objects, uploaded them to IRSA tools, and looked at regions in WISE. In WISE, it was easy to see things that look like SFRs. Using IRSA tools, it was easy to quickly inspect a long list of possible SFRs.
- At this point, we had ~60 Sharpless regions where there could feasibly be YSOs but no one had really yet invested the time to look closely.
- We noticed patterns in the image morphology…
  - Fields close enough to the Galactic Center such that source confusion with WISE (~6 arcsec spatial resolution) renders analysis essentially impossible. We dropped these regions because they are too difficult to work with.
  - Effectively blank fields – what did Sharpless have in mind as the HII region? Can't easily tell in POSS or WISE. We dropped these because it was too hard to figure out/find YSOs.
  - ★ Targets where there was obvious IR nebulosity and likely YSOs.
  - ★ Targets with small, largely circular clumps of blue stars (only clear in Spitzer!).
  - ★ Targets with dispersed apparently red stars.
- Based on the IR image morphology, we picked regions that looked like they were likely to have YSOs.
- Did another more focused literature search to make sure no one had yet used IR to look for YSOs.
- Added Sh 2-137 for comparison, because it was one of the 'effectively blank fields.'
- Pulled archival data to explore point sources in these 6 regions to look for YSOs. Data we used:
  - From IRSA: 2MASS, WISE (AllWISE, CatWISE, unWISE), Spitzer*, Gaia, Herschel*, MSX*, Akari
  - From MAST: PanSTARRS
  - From VizieR: IPHAS*

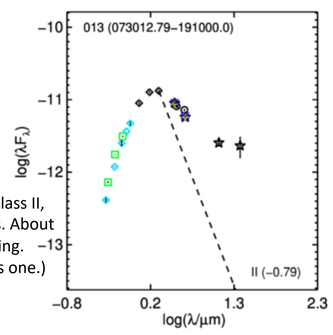
  ** Not every region has these data*
- We looked in the literature for any published YSO candidates. Found a few, primarily based on large-scale surveys of the Galactic Plane for Hα or IR excesses.
- We used Spitzer (Gutermuth et al. 2008, 2009) and WISE (Koenig & Leisawitz 2014) colors to identify YSO candidates from IR excesses. We explored identifying more candidates based on position in optical color-mag and color-color diagrams but did not find many candidates this way.
- We constructed SEDs for each candidate, and, following, e.g., Rebull et al. (2023), (a) inspected each candidate in all available images to make sure the source was isolated and circular and that photometry existed for each band where the source was visible; (b) inspected each SED to make sure that the source matching across catalogs was done correctly and that the SED looked like that of a YSO; (c) constructed several color-color and color-magnitude diagrams in the optical and IR to ensure that the source appeared in positions consistent with youthful stars.
- Gaia distances are not widely available for most targets in these regions; we conclude from this that these YSO candidates are largely >2.5 or 3 kpc away. A Gaia analysis will have to wait until DR4 or later.
- We explored color-color and color-mag diagrams for subsets of the images to see if we could distinguish subsets of the images as more or less likely to harbor YSOs.
- We were surprised by which regions had more YSO candidates! Sh 2-306/309 is the best, with Sh 2-135 and 187 both very promising as well. The red source in Sh 2-137 is an AGB star. The "blue clusters" have very few optical counterparts, so making optical CMDs is very much harder than we expected.
- More work is needed to continue to refine the list of YSO candidates.



← Nice SED, Class II; clear IR excess, likely dusty ring; identified in the literature as a YSO candidate. Essentially no reddening.



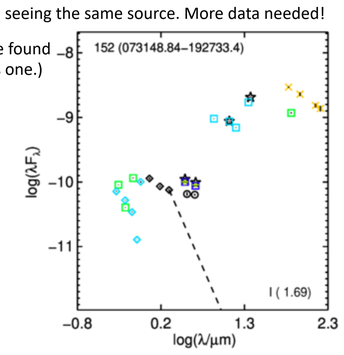
← Nice SED, Flat Class, with many IR missions agreeing in the long wavelengths. Considerable reddening (Av~16!!). (We found this one.)



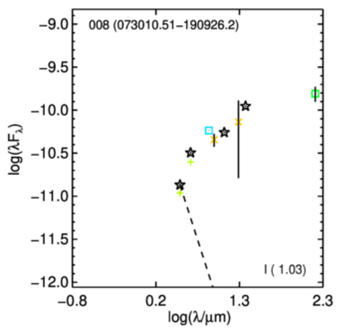
→ Nice SED, Class II, clear IR excess. About 3 mag reddening. (We found this one.)

↓ What is happening here? SED suggests Class I. *Very* bright point source in IR, with many unambiguous detections. Optical has considerable scatter and it is unclear if Gaia and PanSTARRS are seeing the same source. More data needed!

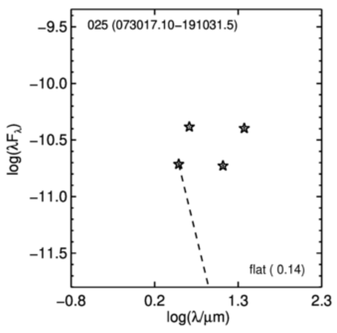
(We found this one.)



↓ Curiouser and curiouser! SED suggests Class I. *Very* bright in IR. No optical or even NIR to help interpret. Galaxy? More data needed! (We found this one.)



↓ This is likely an artifact. It was identified in the literature as a YSO candidate. However, the only detections are in WISE, and images look awful. We threw this out.



"Zoo" of SEDs, energy density in cgs units (erg/s/cm²) and wavelength in microns. Green short-wavelength square= Gaia; cyan diamond =PanSTARRS; yellow diamond =IPHAS; black diamond=2MASS; black circle= IRAC; black star=WISE; dk blue square=CatWISE; lt green =unWISE; cyan square=MSX; green long-wavelength square=PACS; yellow =Akari; black dashed line is where the photosphere would be, assuming K band is on the photosphere (or 3.5 μm if there is no K band).

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