New Young Stars in the North America Nebula Complex
(with a special emphasis on SOFIA results!)

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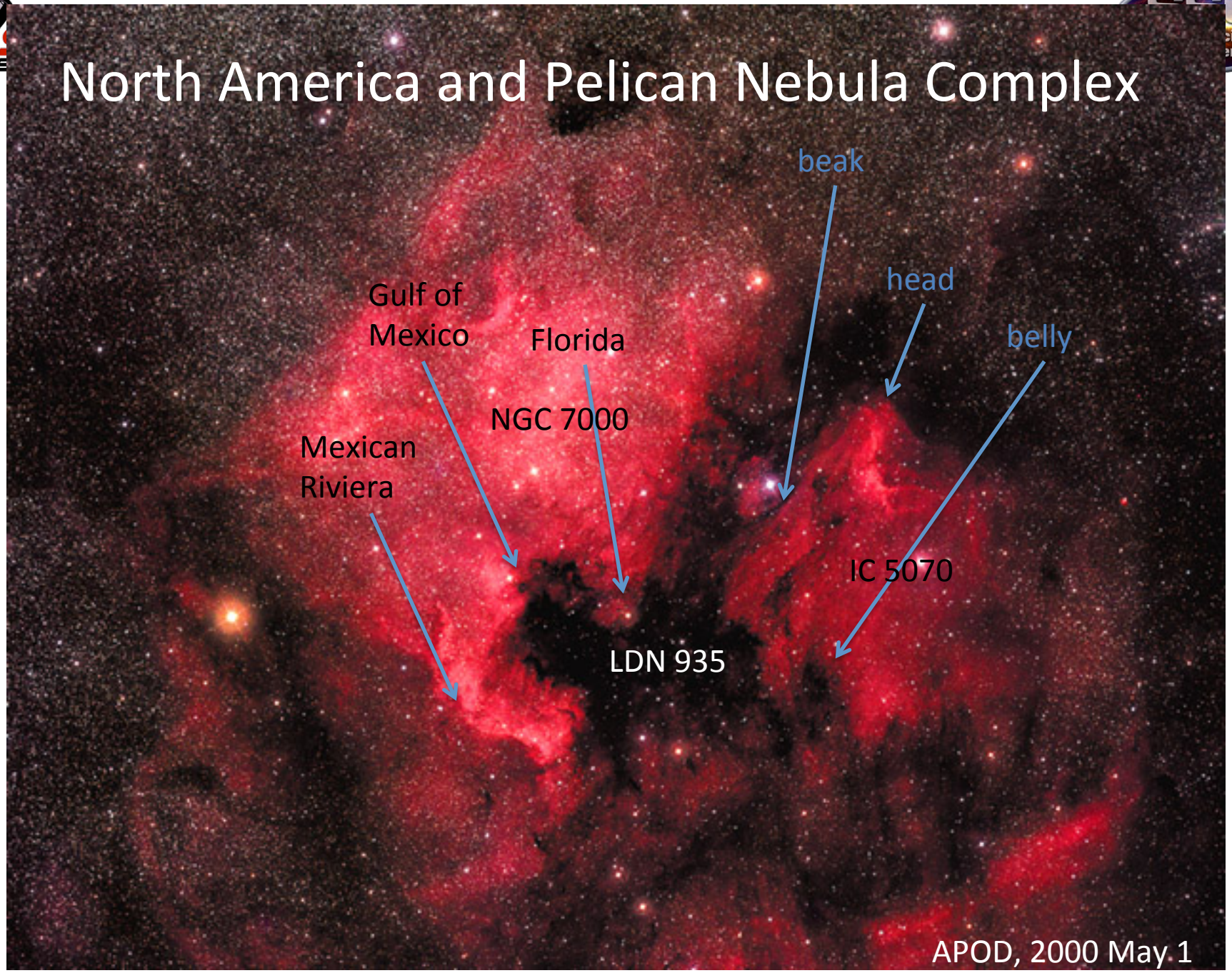
Including results from Guieu et al. 2009, ApJ, 697, 787; Rebull et al. 2011, ApJS, 193, 25

Outline

- FAST overview of the North America Nebula +Pelican Nebula complex
- FAST (& pretty!) overview of our Spitzer data, plus a 4-slide summary of two papers
- More on the Gulf of Mexico cluster
- SOFIA observations and results
- SOFIA hopes

North America and Pelican Nebula Complex



Why study "yet another SFR"

- (Because it's beautiful?)
- Environment matters – mass distribution, rotation distribution, disk lifetimes, …
- Orion is the prototypical SFR of its kind.
- At only ~520 pc, the North America Nebula complex is the next closest high-mass SFR.
- Is it different?

What is this region?

- The North America Nebula (NGC 7000) and Pelican Nebula (IC 5070) complex (NAN) appears to exhibit “mixed mode” star formation, eg., low and high mass, clusters and distributed populations.
- ~10^5 Msun in molecular gas, ~10^4 Msun in stars (?)
- Ages <~1 Myr to several Myr (?)
- ~520 pc away, only ~70 articles in ADS. (ONC is at 470 pc, and 400+ articles in ADS)
- Why hasn’t it been better studied to date?
- It’s in the galactic plane (b~-0.53 deg) and along a spiral arm!
- Contamination is …problematic. IR (Spitzer) helps!

Earlier NAN studies

- Between 1949 and 2009, deliberate studies of the NAN have yielded prior identifications/ data of some sort for ~3600 objects here.
- **~200 are identified as YSOs**.
- The rest are either known contaminants (AGBs) or just “things in this direction.”

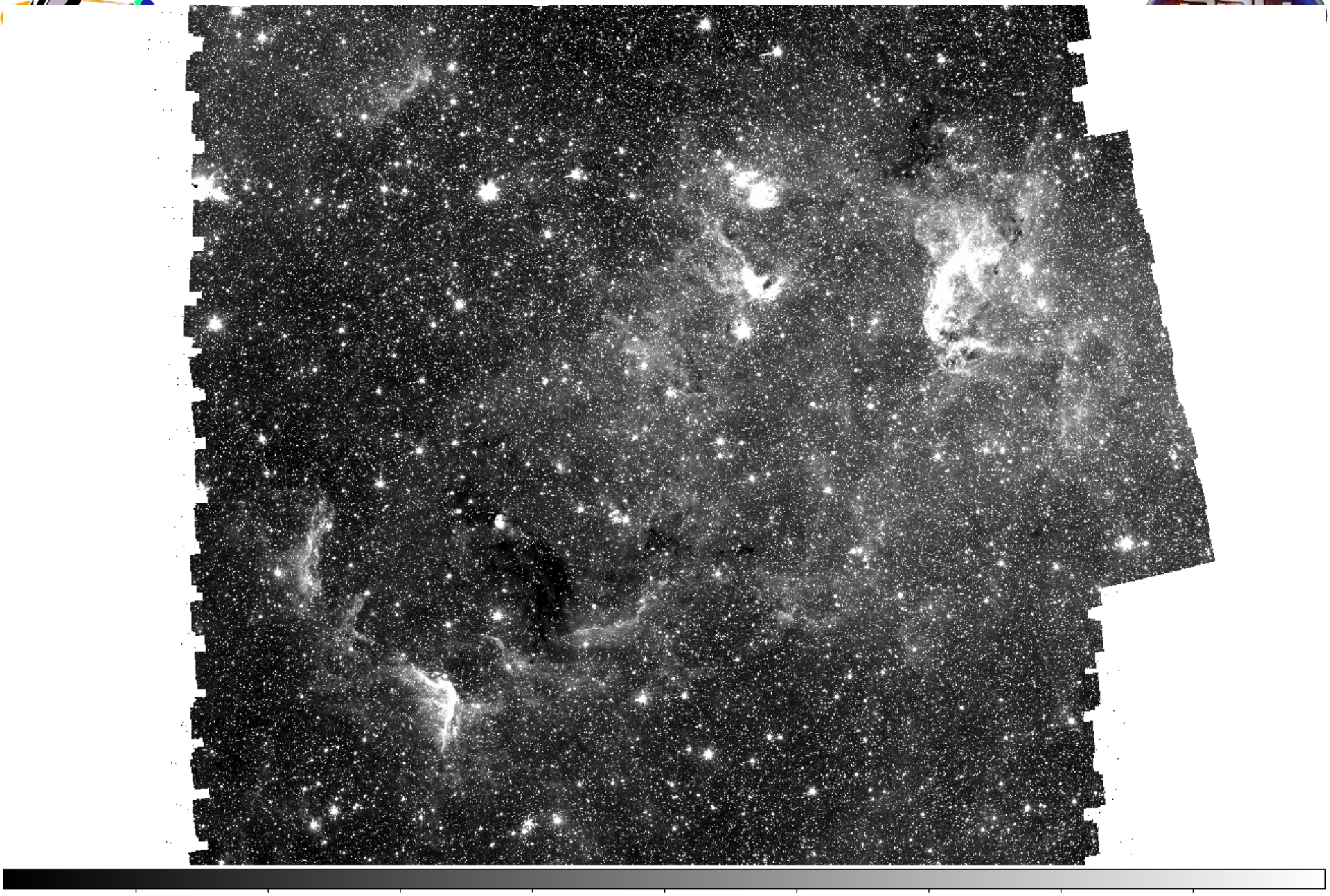
Some earlier surveys

- 2MASS (Cambresy et al. 2002) – millions of sources, Av up to 30(!), several subclusters, contamination rate up to 1900 stars/sq deg(!).
- To separate YSOs from contaminants, need IR!
- IRAS covered most of the sky … except for a few missing wedges, including here!
- MSX, Akari, & WISE ... But low spatial resolution and very shallow.
- Need high spatial resolution, deep IR obs over a large region to look for YSOs. (Spitzer, and in portions, SOFIA!!)
- Need optical data to help weed out contaminants – KPNO (BVI); Vilnius (UPXYZVS); IPHAS (r',i',Ha). SDSS (ugriz) has some coverage; UKIDSS (JHK), deeper than 2MASS!

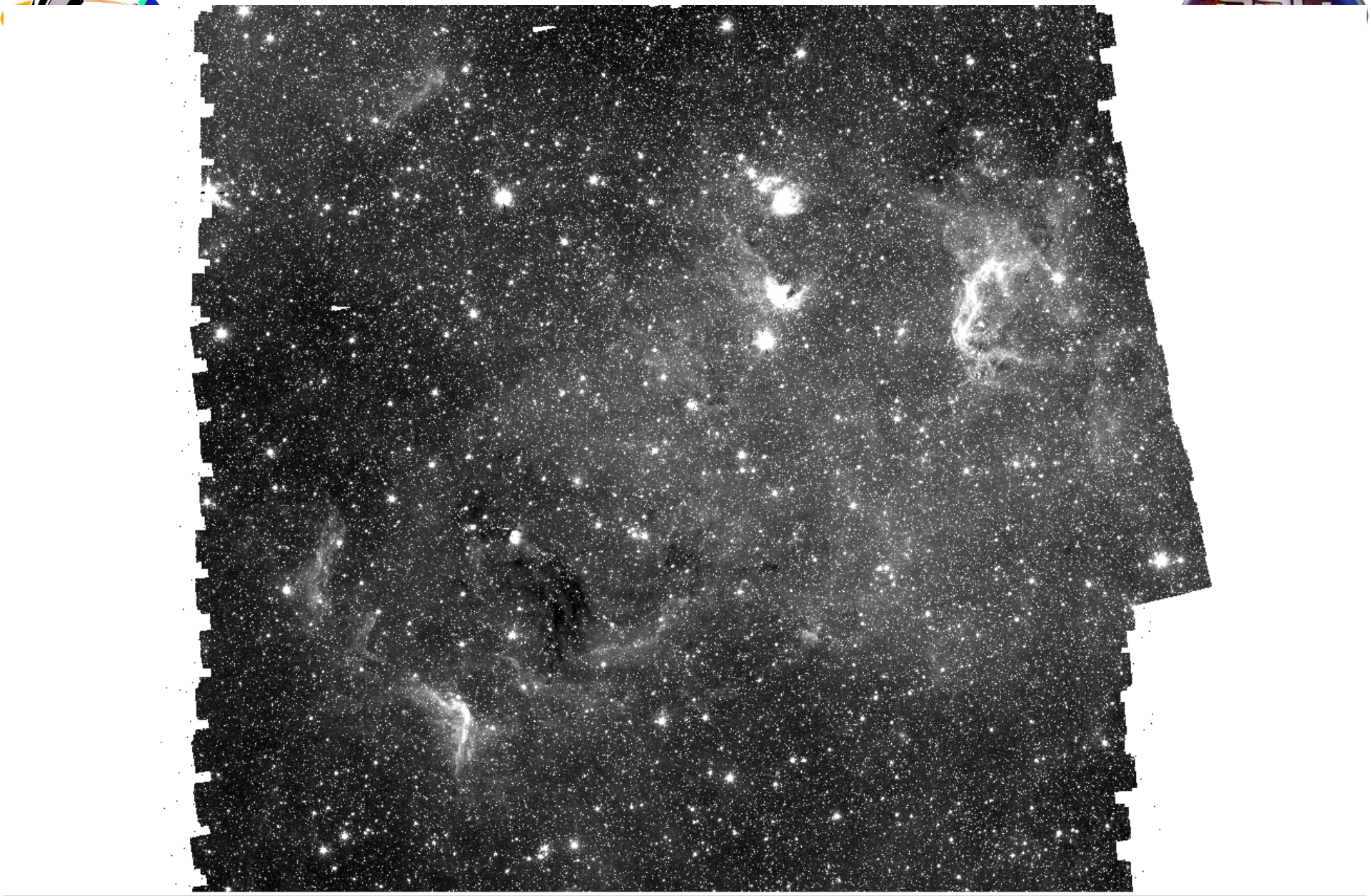
Our Spitzer Data

- IRAC (3.6, 4.5, 5.8, 8 microns) and MIPS (24, 70, 160 microns) maps of ~7 sq. deg.
- Obtained 2006, 2008
- ~0.5 million sources!
- Most of those have fluxes at >1 IRAC band
- 4300 MIPS-24 sources
- 97 MIPS-70 sources
- Images are very complex …

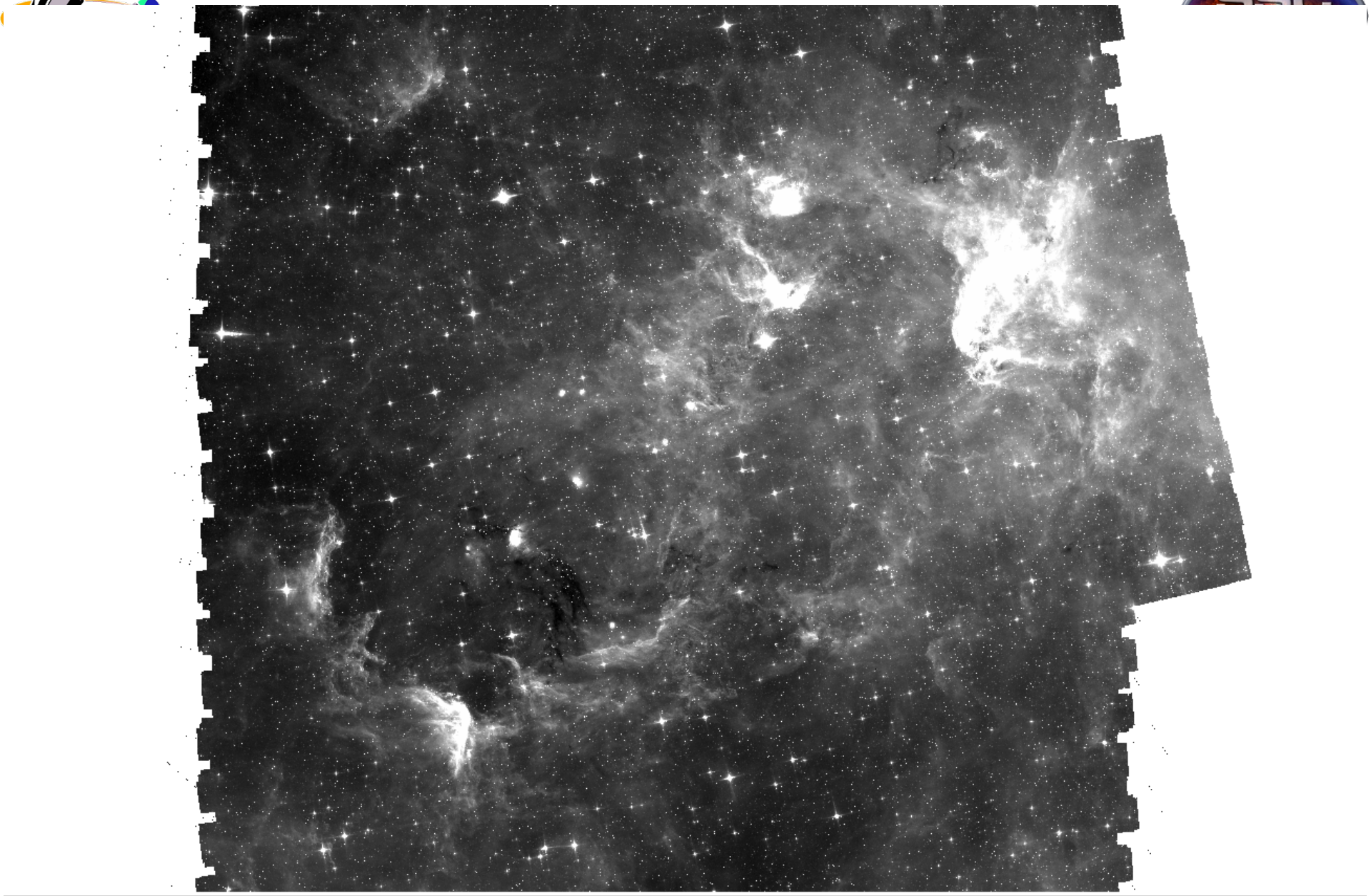
POSS (optical)



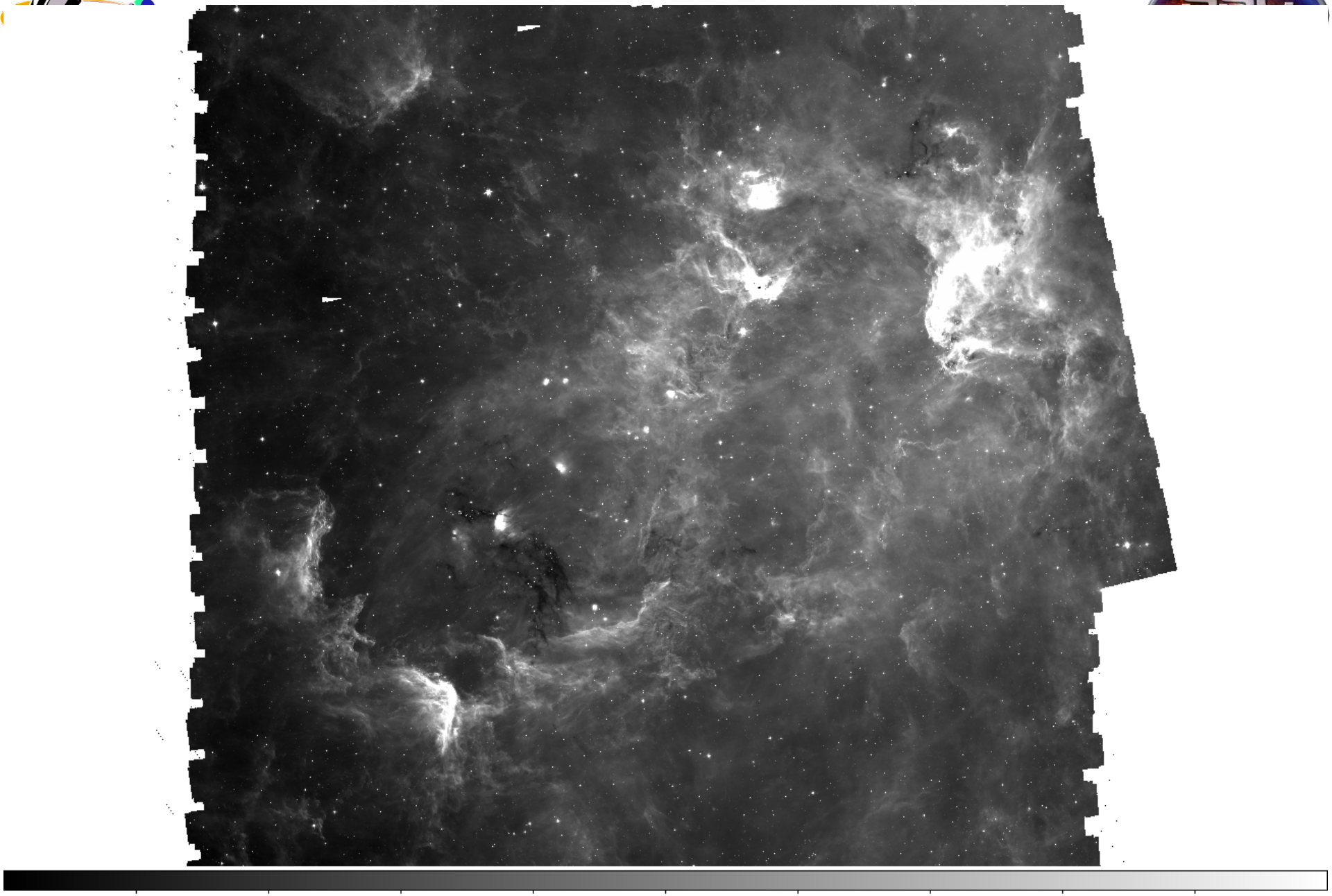
IRAC-1 (3.6 microns)



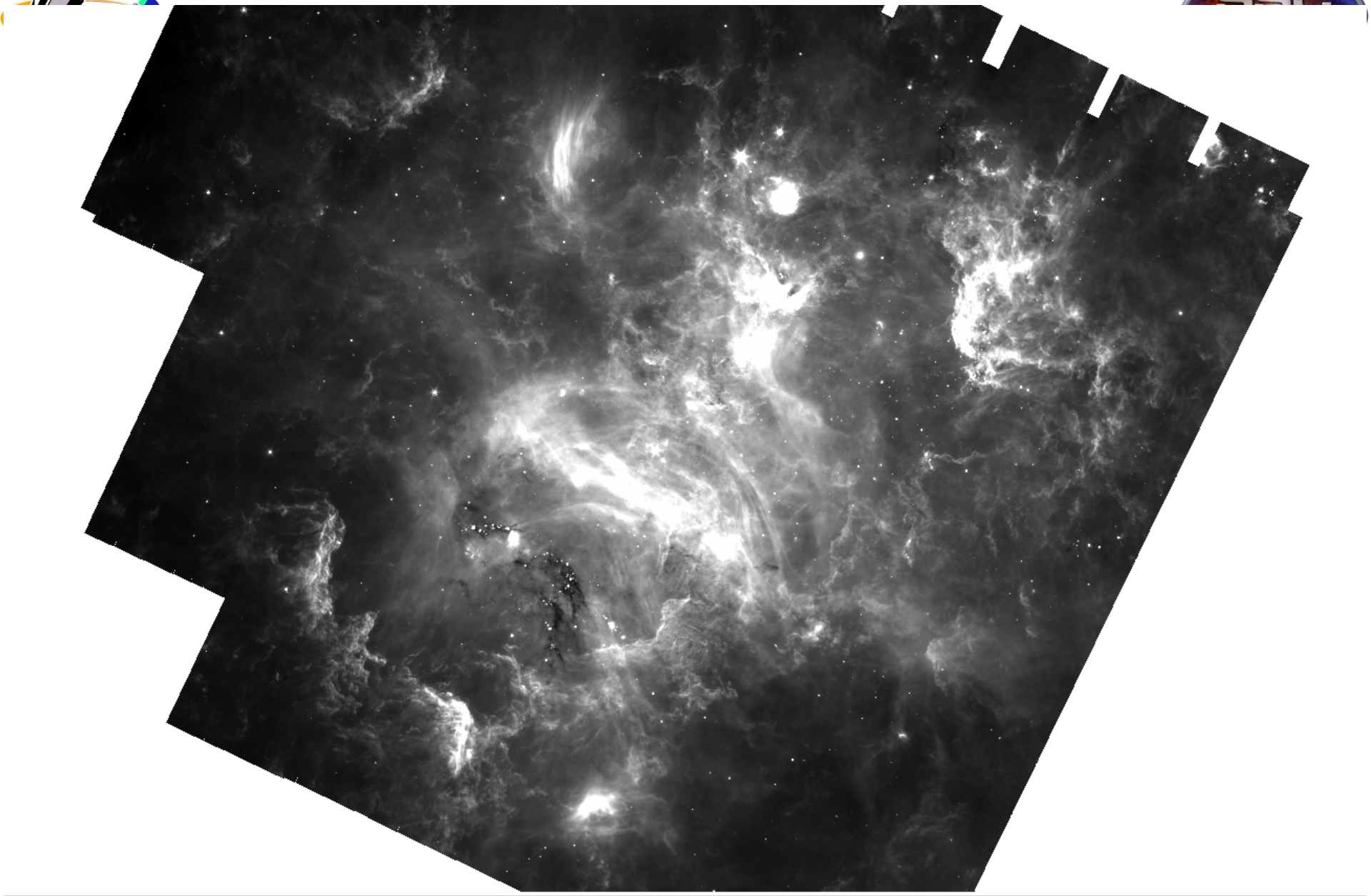
IRAC-2 (4.5 microns)



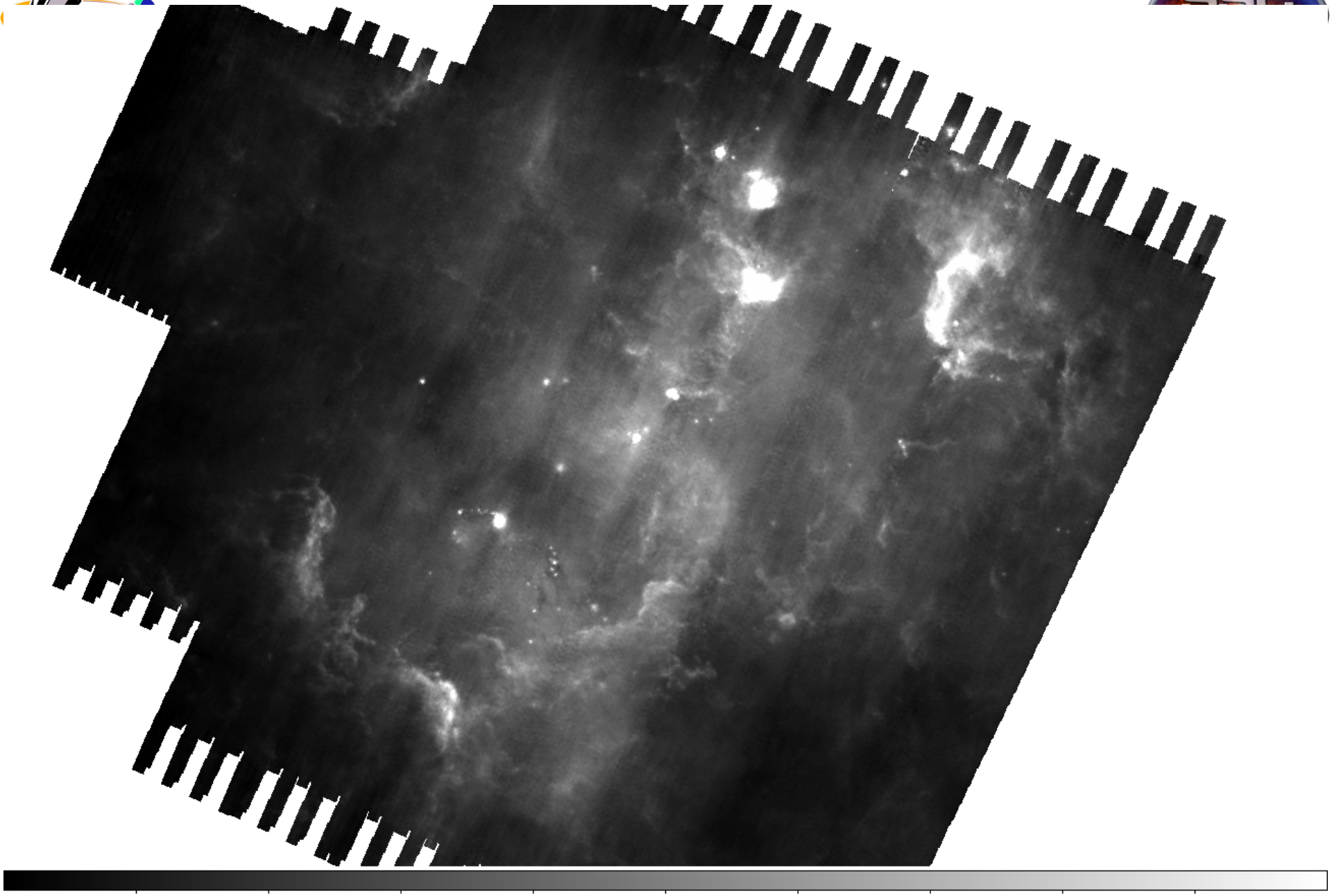
IRAC-3 (5.8 microns)



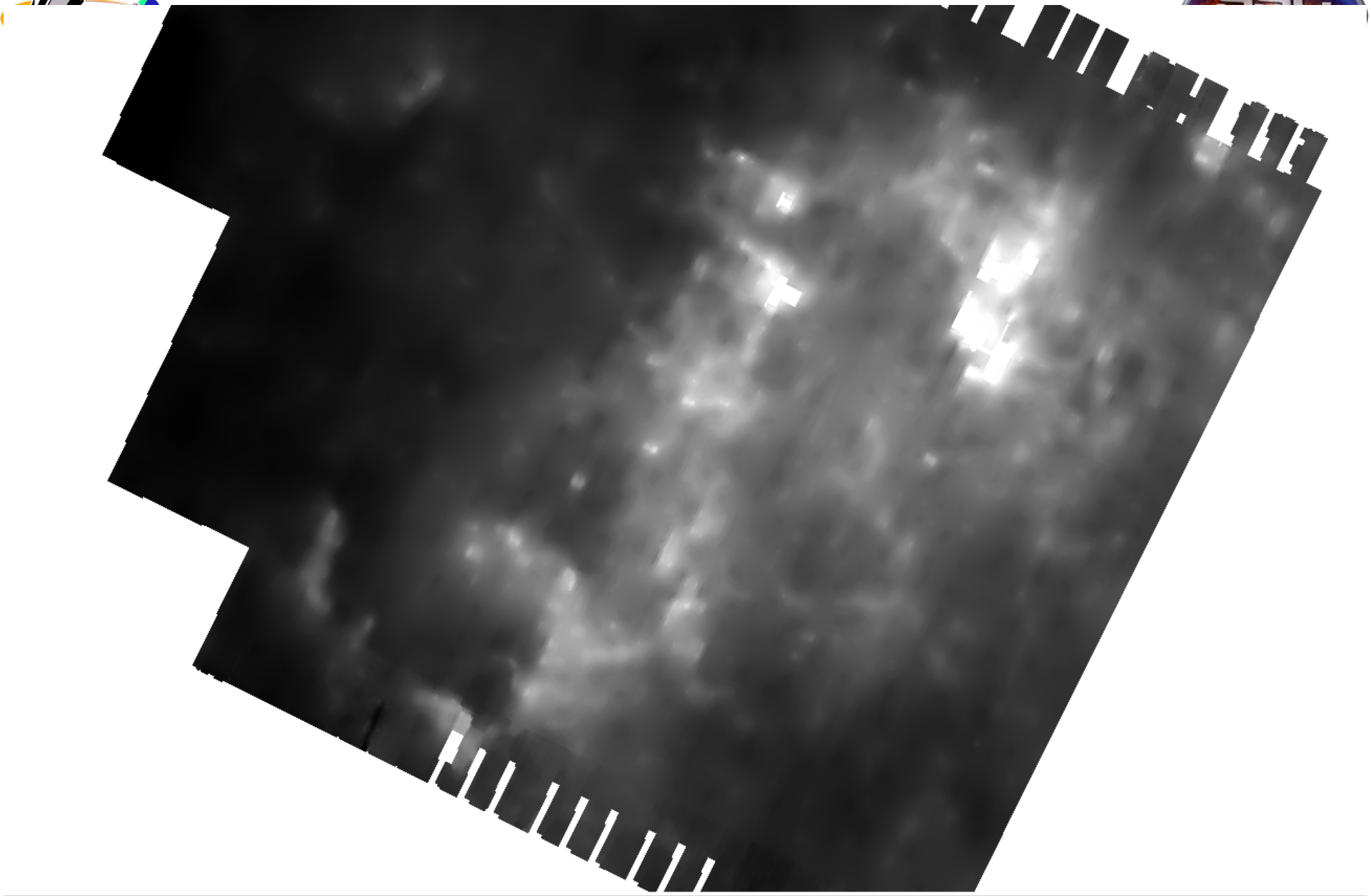
IRAC-4 (8 microns)



MIPS-1 (24 microns)



MIPS-2 (70 microns)



MIPS-3 (160 microns)

6 bands:
POSS +
IRAC (3.6-8
um)

4 bands:
IRAC (3.6-8 um)

5 bands: IRAC (3.6-8 um) and MIPS (24 um)

Multi-wavelength movie here

Now, how do you find the YSOs?

- Over the whole field, IR-driven color selection, because we will pick out things with (apparent) IR excesses against the (substantial) background.
- Many color selections in the literature. None perfect. *Always* will have contamination.
- **Use the known YSOs and known contaminants (here and elsewhere) to delineate properties**.
- Then use ancillary data to continue to weed.

Rebull et al. 2011, ApJS, 193, 25; Guieu et al. 2009, ApJ, 697, 787

Lots of checks

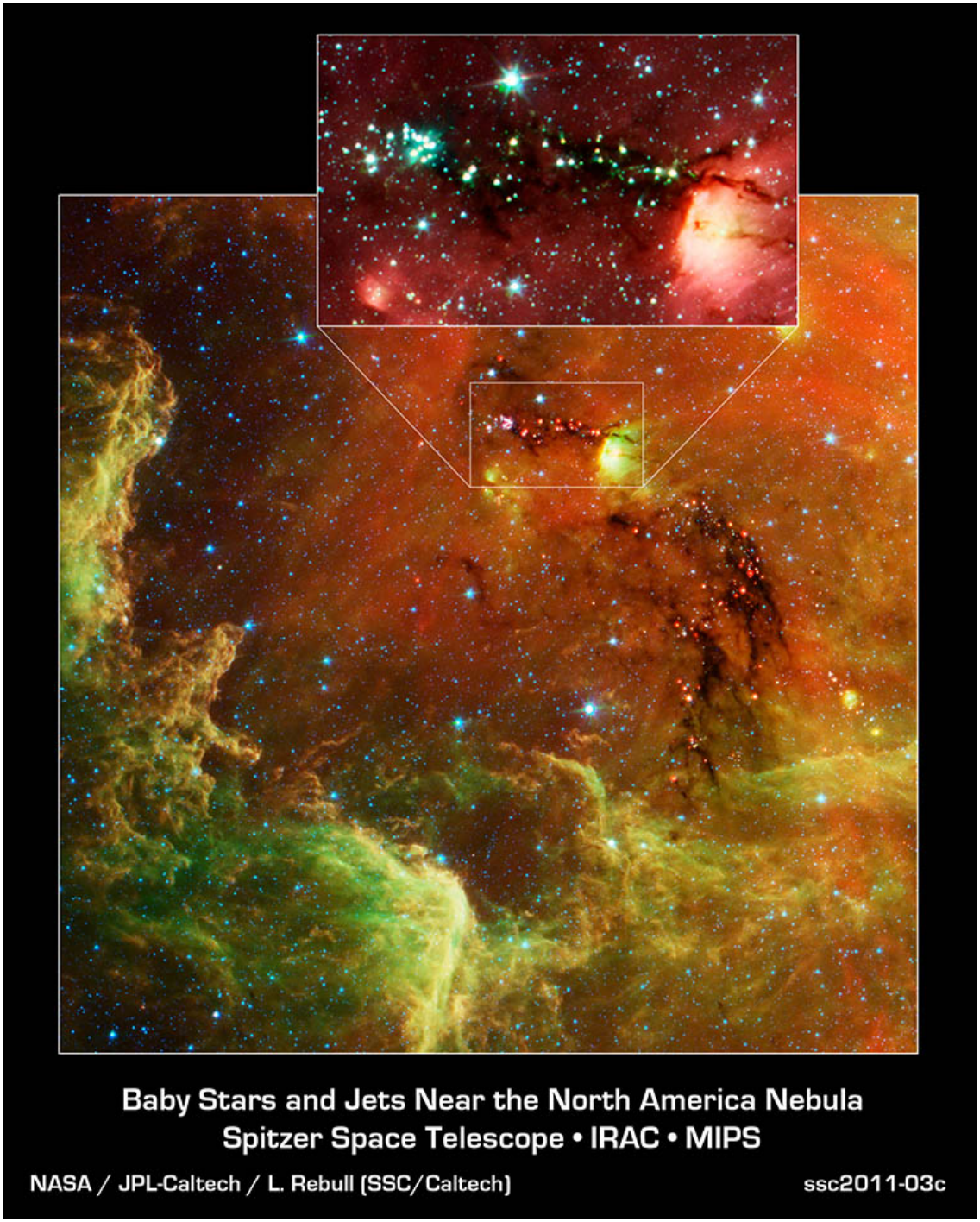
- Is it in the 'right place' in [3.6] vs. [3.6]-[24]? Is it bright or faint?
- Is it in the 'right place' in K vs. K-[24]? Is it bright or faint?
- Is it seen at 70 um?
- Did someone find it before using other bands?
- Was it selected using our "just IRAC" selection (G09)?
- Is it near other YSOs? REALLY near other YSOs (clustered)?
- Is it in the right place in an optical color-mag (I/V-I, r' vs. r'-i') or color-color (r'-Ha vs. r'-i') diagram?
- …Plus a manual sanity check (location, appearance in image, SED shape).
- (and then, even still, need a spectrum to confirm)

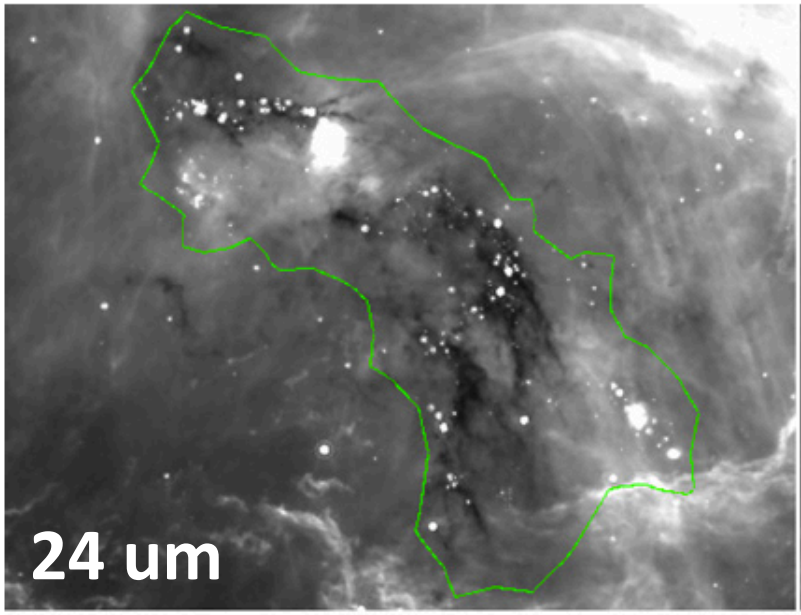
Rebull et al. 2011, ApJS, 193, 25; Guieu et al. 2009, ApJ, 697, 787

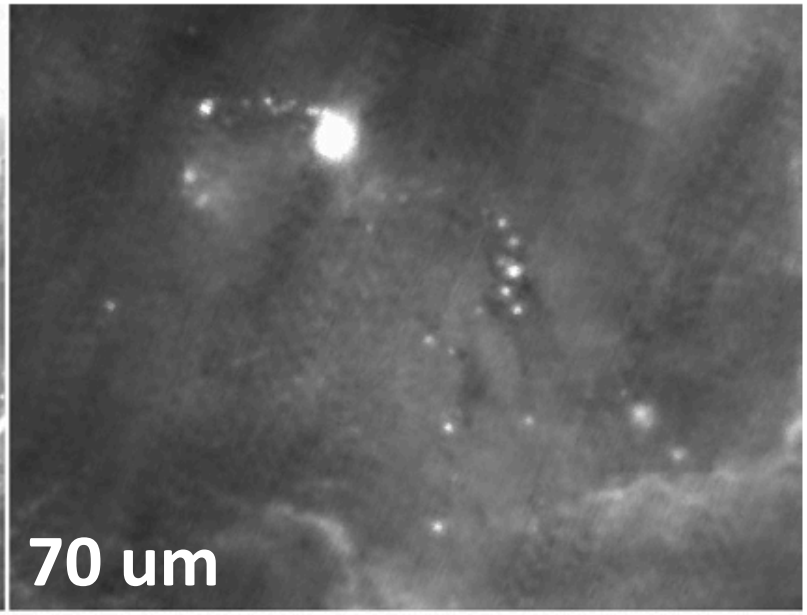
Yields …

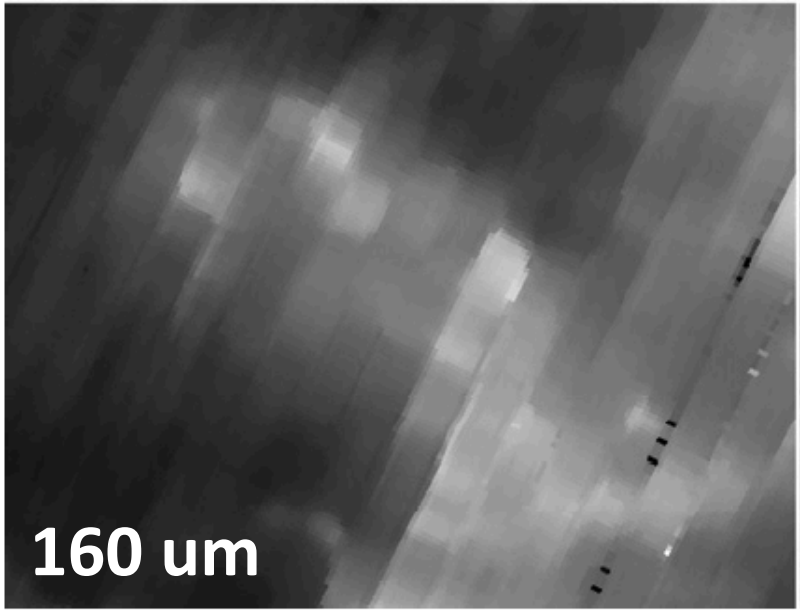
- (out of ~0.5 million sources)
- ~1300 MIPS-selected YSOs
- ~800 IRAC-selected (but not MIPS-recovered) MORE YSOs. [MIPS is effectively shallower.]
- **2076 new YSOs**. (~10x more than previously known!)
- Only ~half of the previously-identified YSOs recovered – rest are saturated or do NOT have an IR excess!
- ~Half of the ~2000 are Class II YSOs.
- 3 clear clusters appear: Gulf of Mexico, Pelican, Pelican's Hat

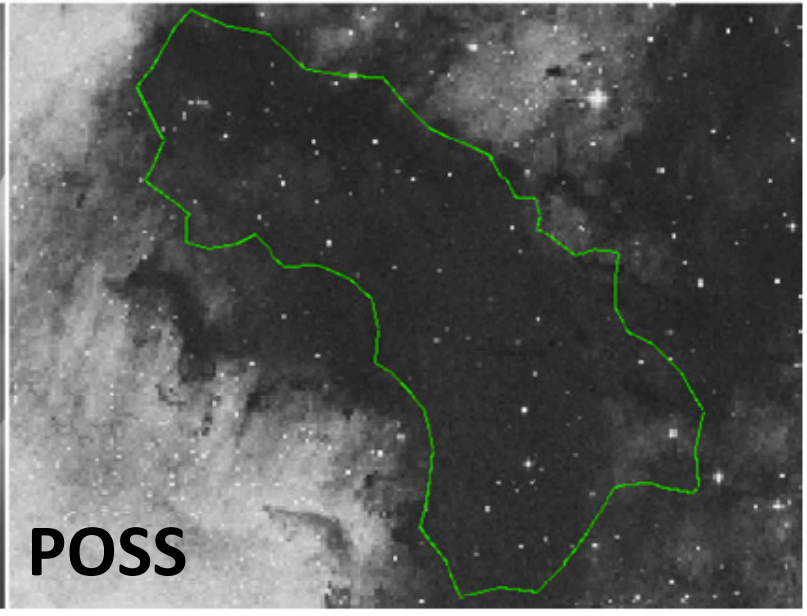
Rebull et al. 2011, ApJS, 193, 25; Guieu et al. 2009, ApJ, 697, 787

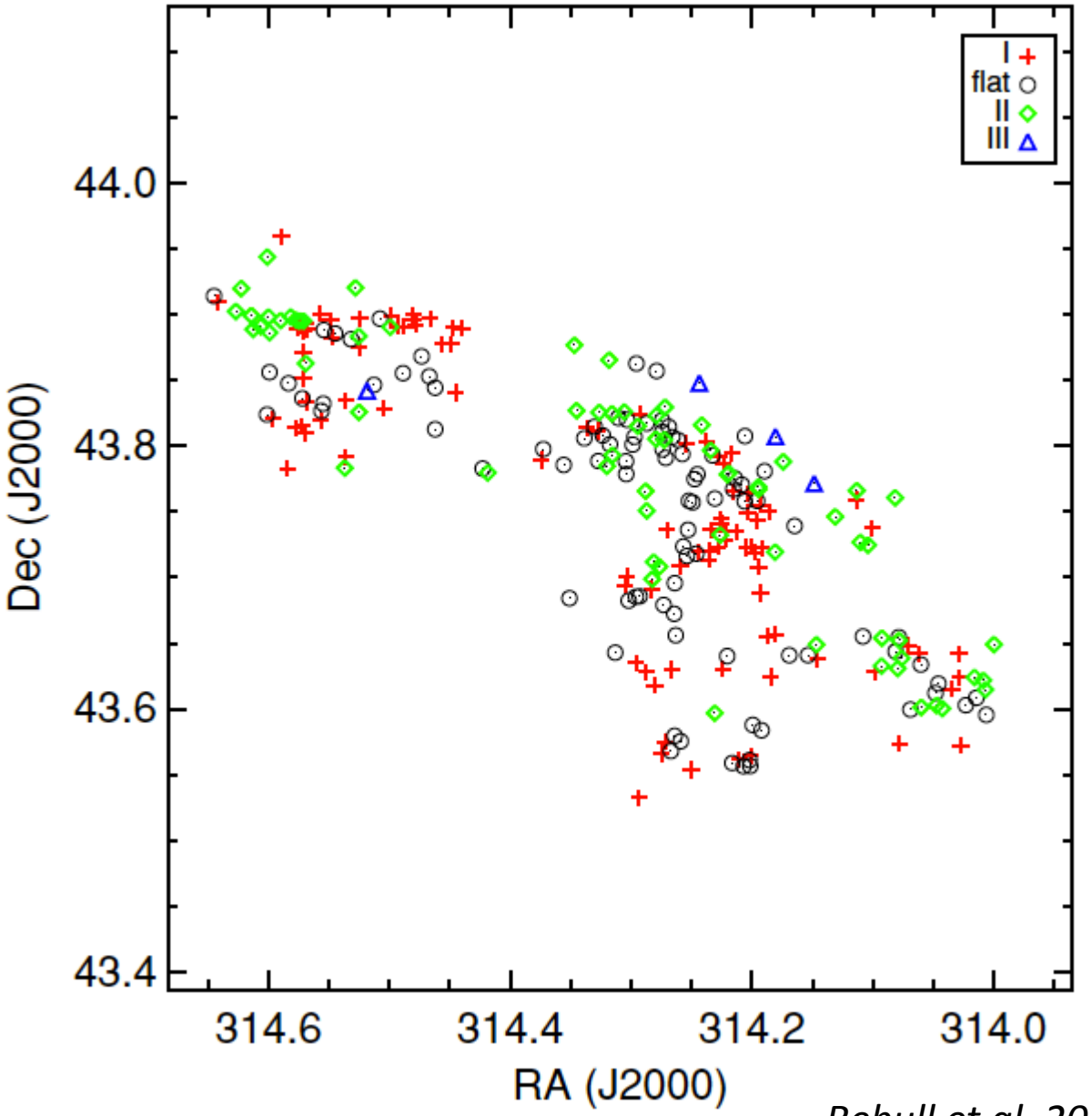

Baby Stars and Jets Near the North America Nebula
Spitzer Space Telescope • IRAC • MIPS
NASA / JPL-Caltech / L. Rebull (SSC/Caltech)
ssc2011-03c


24 um


70 um


160 um


POSS



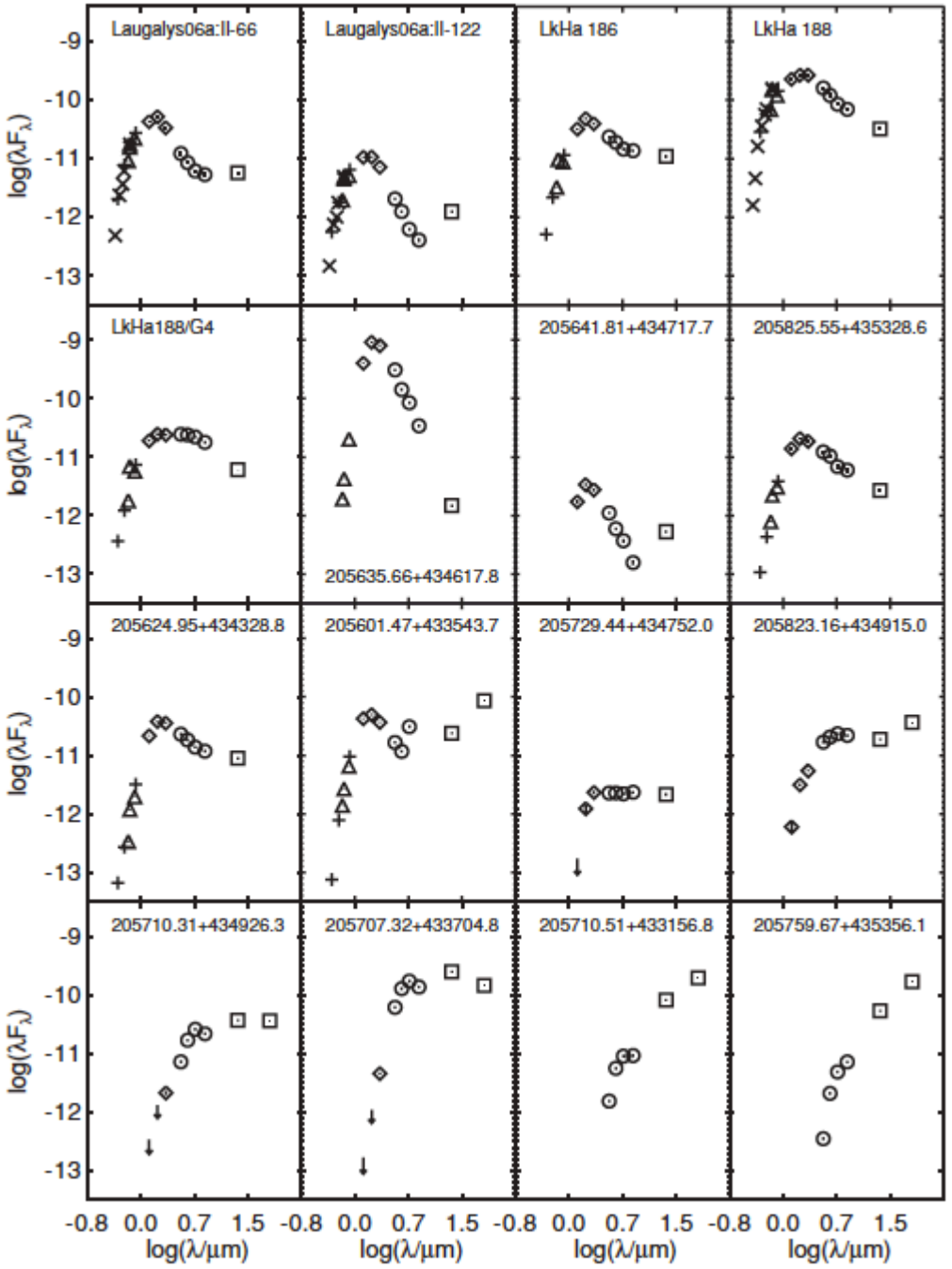
Rebull et al. 2011, ApJS, 193, 25

+ or x or Δ = optical

= 2MASS

¢ = IRAC

= MIPS



Rebull et al. 2011, ApJS, 193, 25

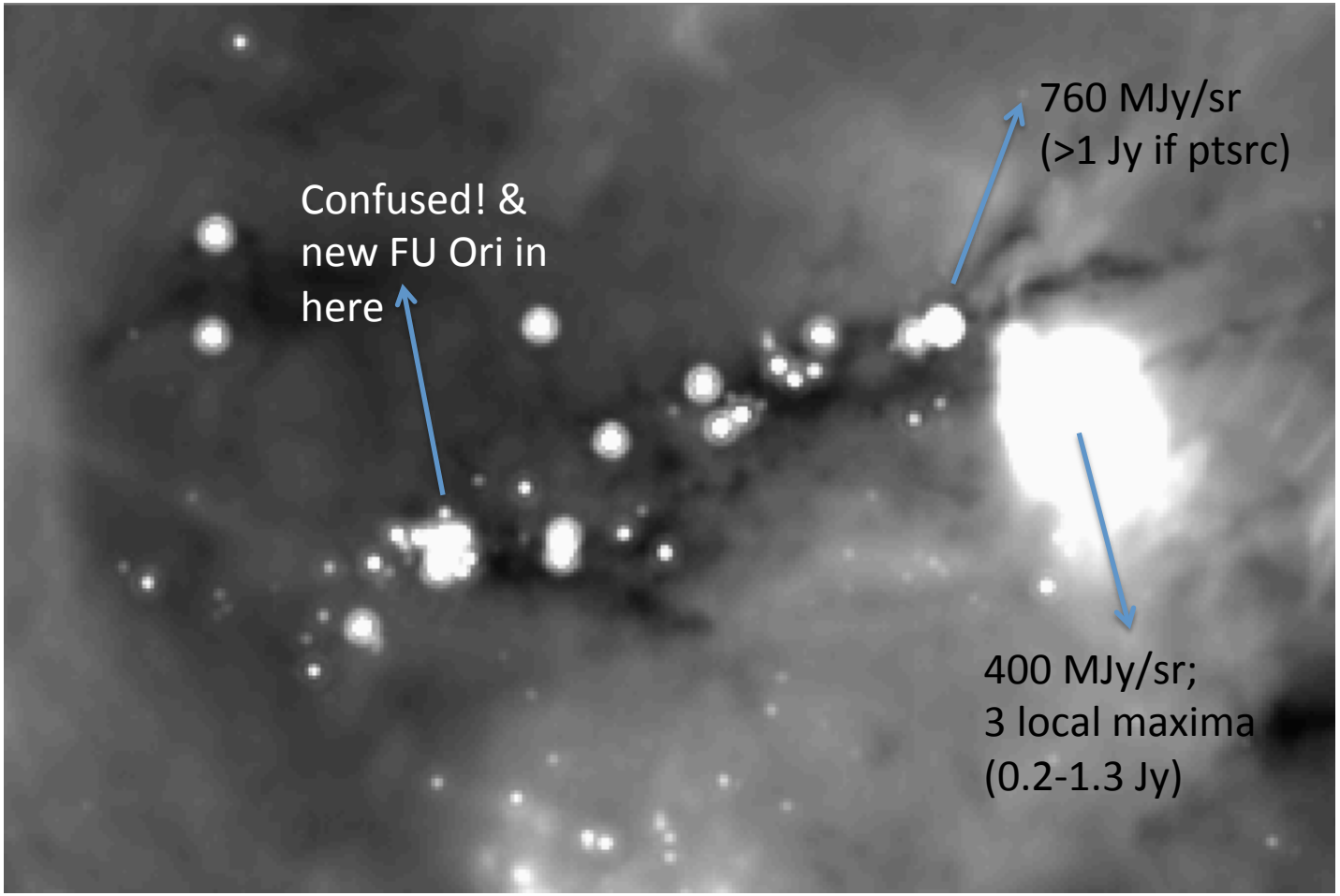
Gulf of Mexico

- Av peaks at ~30 here (from 2MASS, low-res).
- Av~10 contour matches the cluster contour well.
- 30’ across at widest part; 4.5 pc.
- 375 members of cluster!
- Most of the NAN 70 um point sources here.
- Many very embedded things.
- 11 previously known YSOs, all in North.
- Also jets, PTF outburster.

Recent NAN data

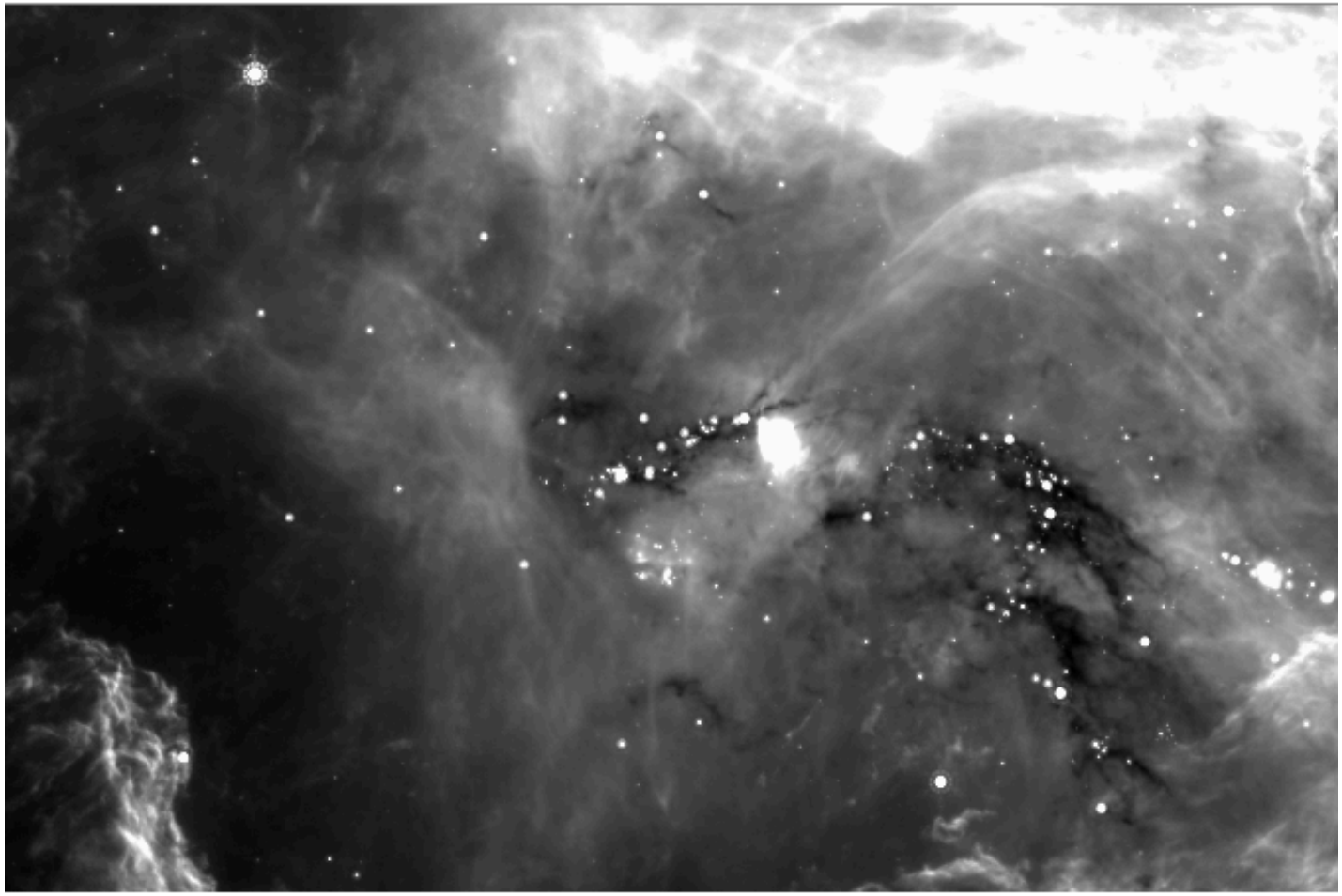
- Need to confirm, classify candidates: KPNO, Palomar spectroscopy obtained, being reduced and classified. More needed.
- FCRAO data obtained 1998 (Carpenter & Hillenbrand), messy (complex)!
- Folding in SDSS, UKIDSS data (source confusion means have to do this carefully).
- PTF monitoring (Hillenbrand et al.) 2010, 2011, 2012; two outbursters already published.
- Herschel observations (hopefully) as part of HiGal3 (Noriega-Crespo et al.).
- SOFIA (FORCAST) flights 5/19, 5/27!! (BaSc 4 and 7; 24.2 and 34.8 microns)

Northern Gulf

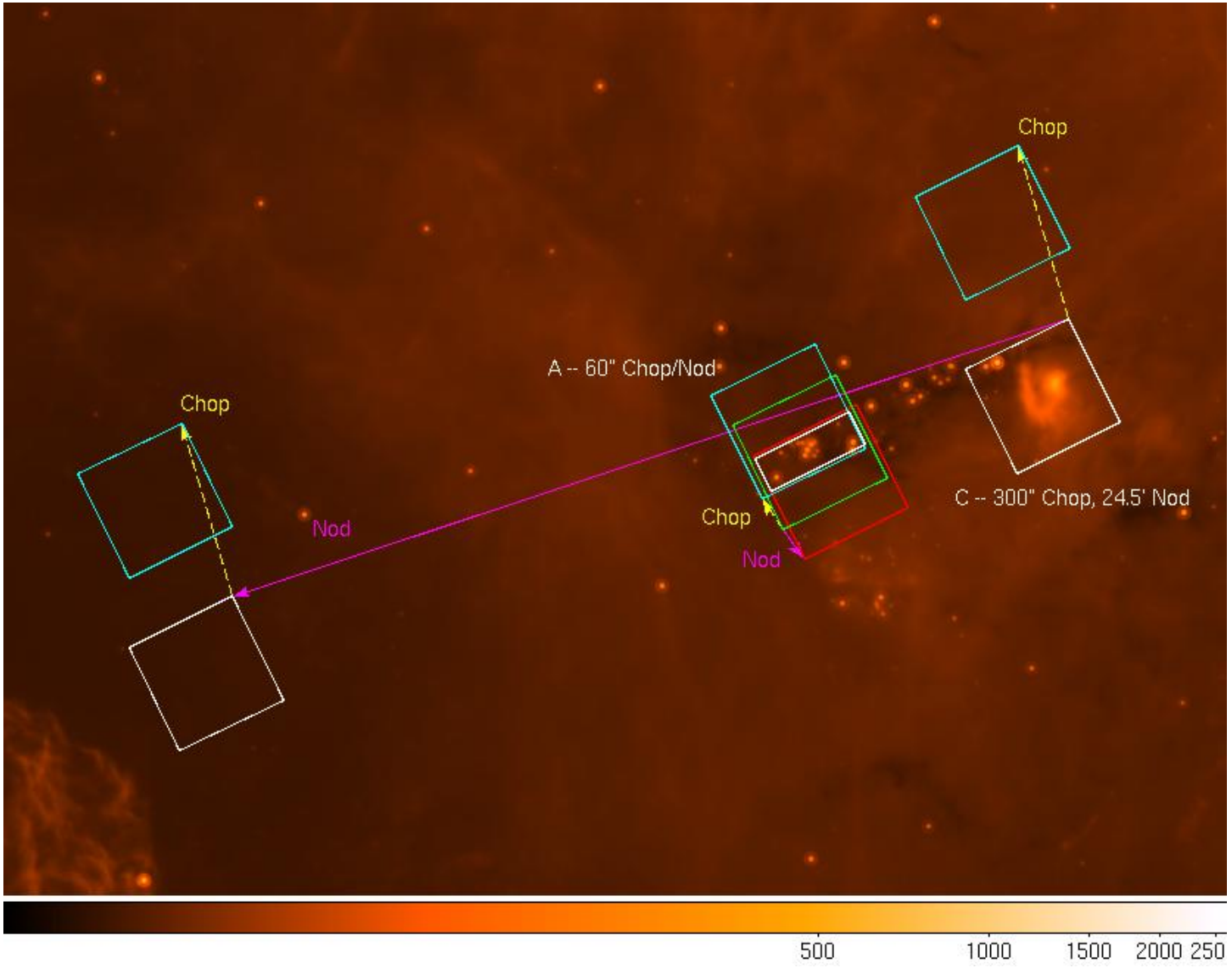


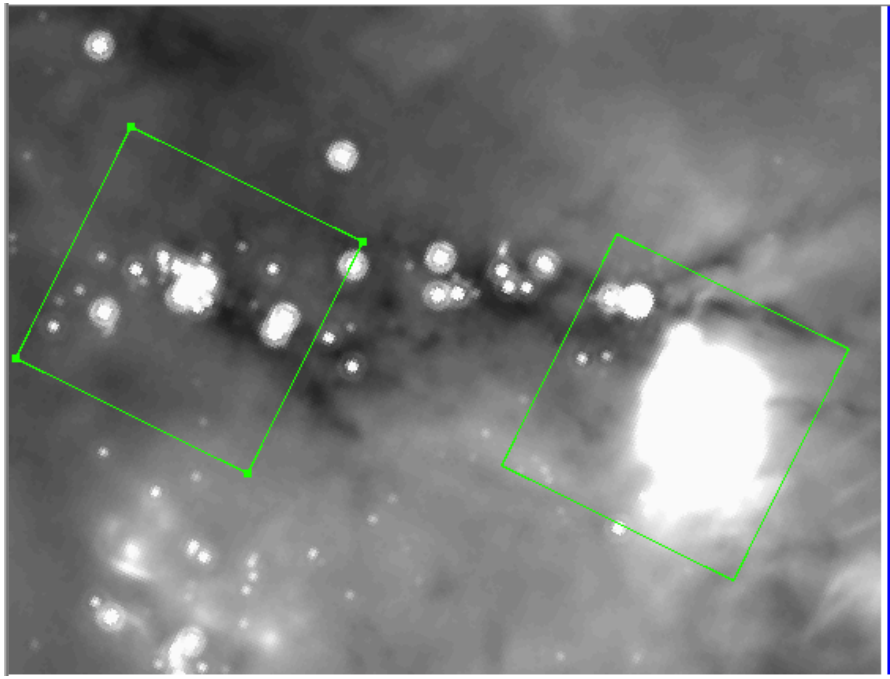
Bright enough for SOFIA, and can benefit from higher spatial resolution

Where, exactly, to place the ‘off’ field?

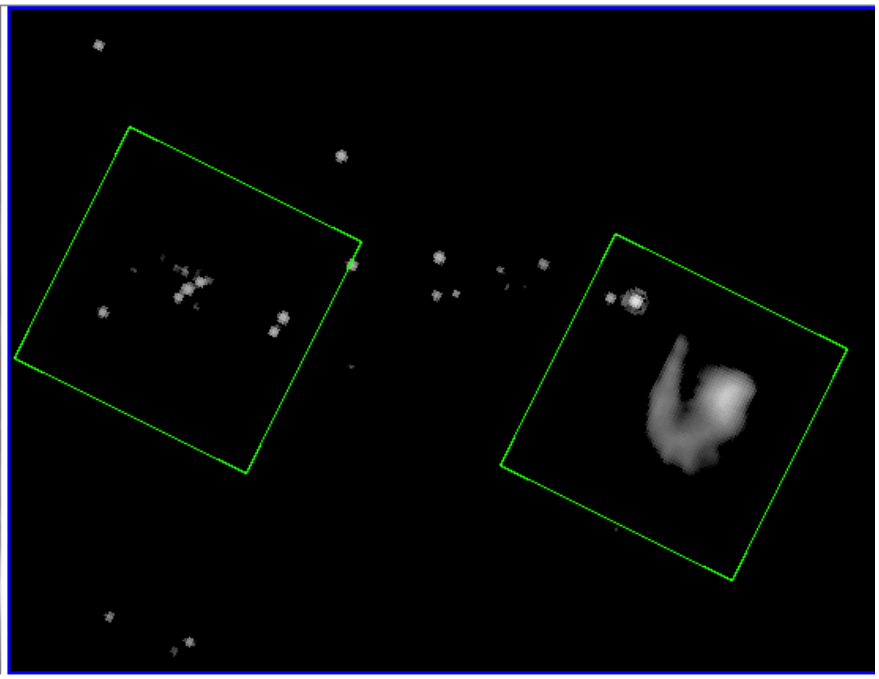


Going-in Observing Plan

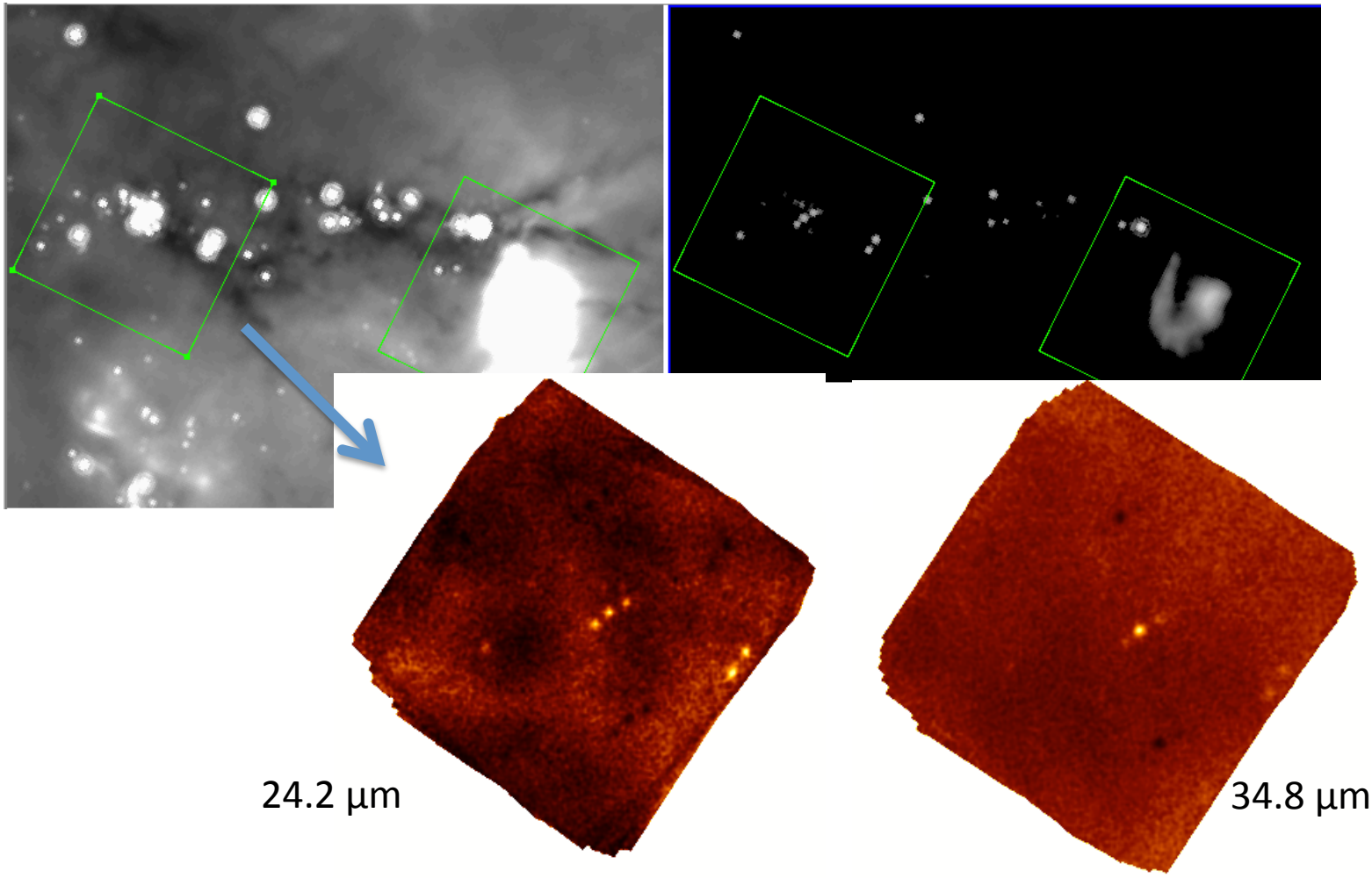


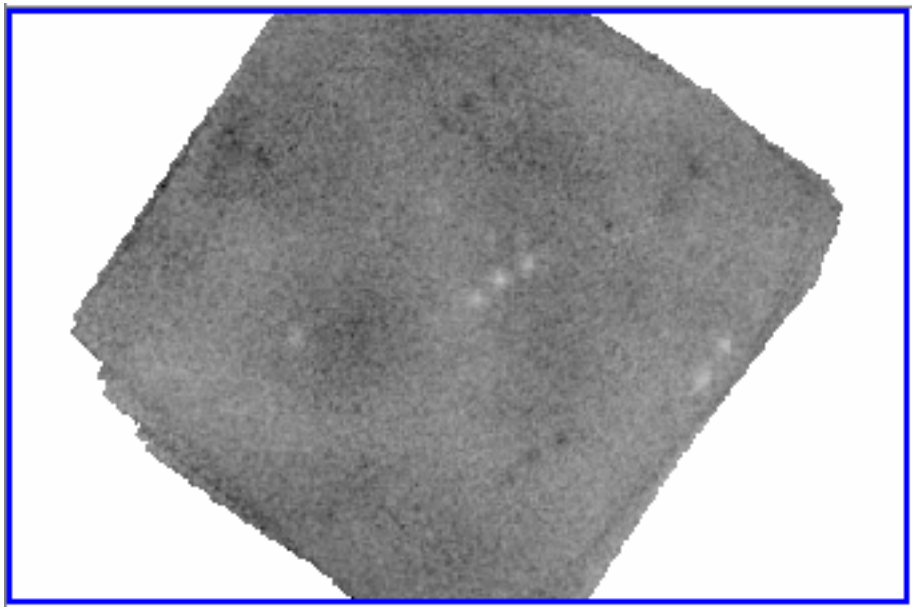


Full MIPS image; planned FORCAST observation FOVs in green

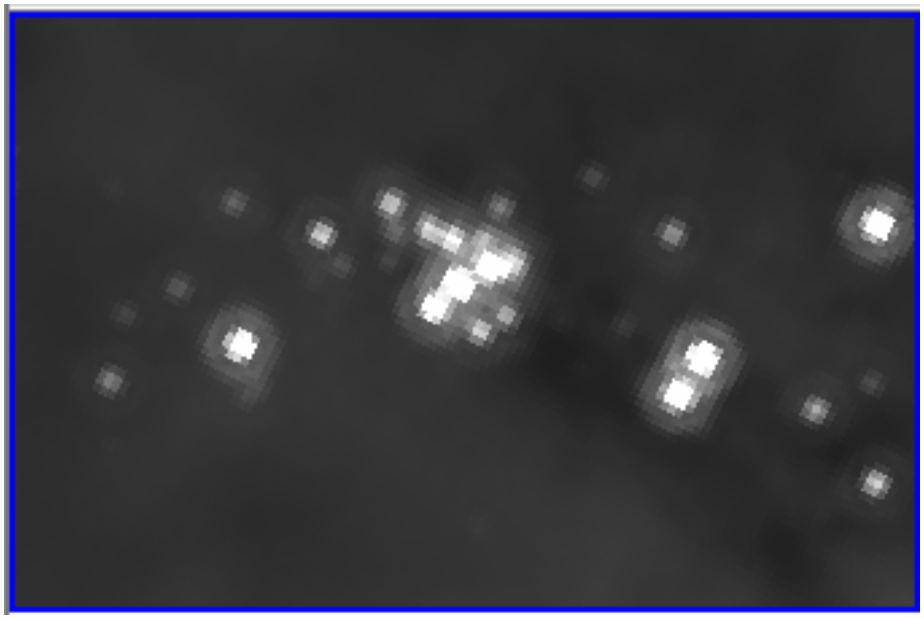


MIPS image, truncated to the expected FORCAST sensitivities.

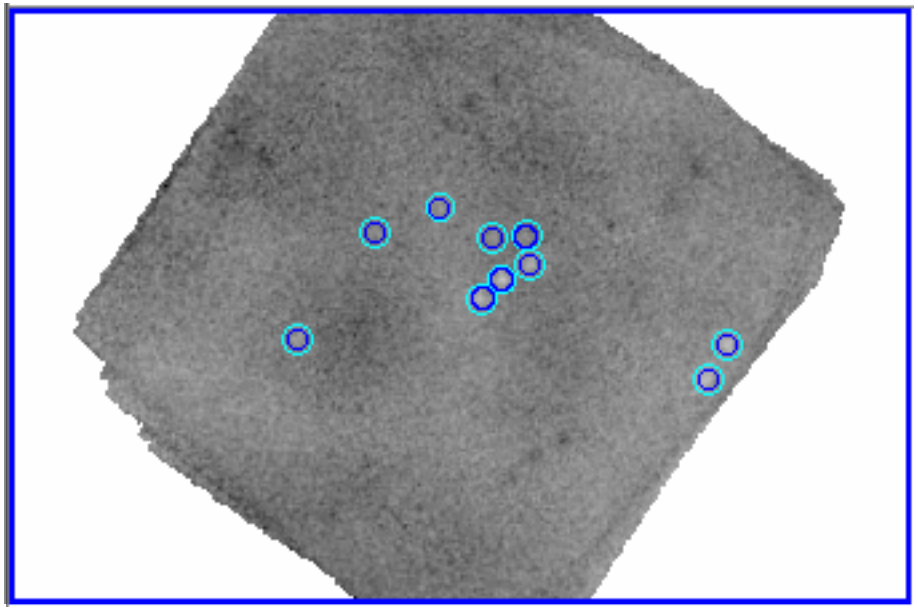

24.2 µm
34.8 µm



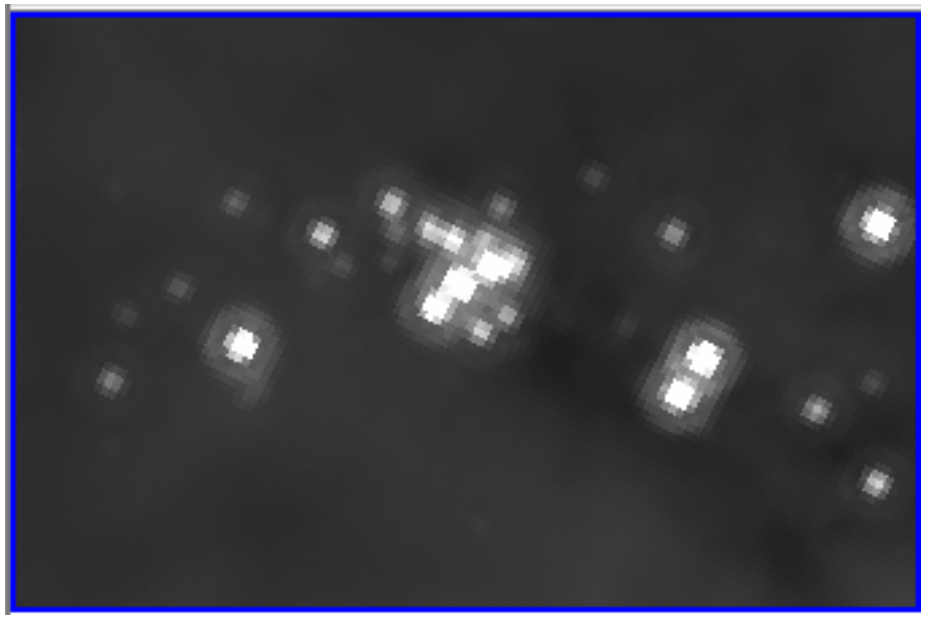
24.2 µm (SOFIA)



24 µm (MIPS)

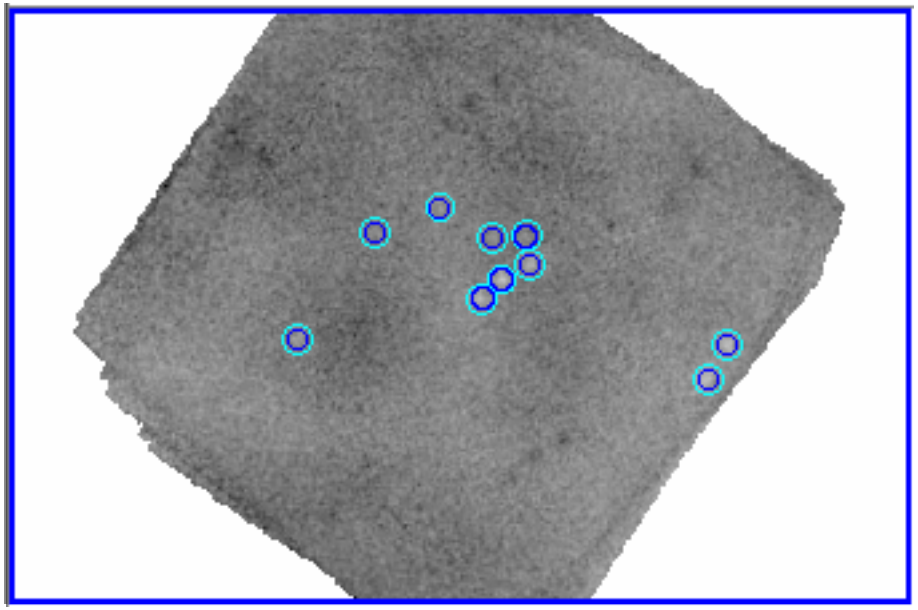


24.2 µm (SOFIA)

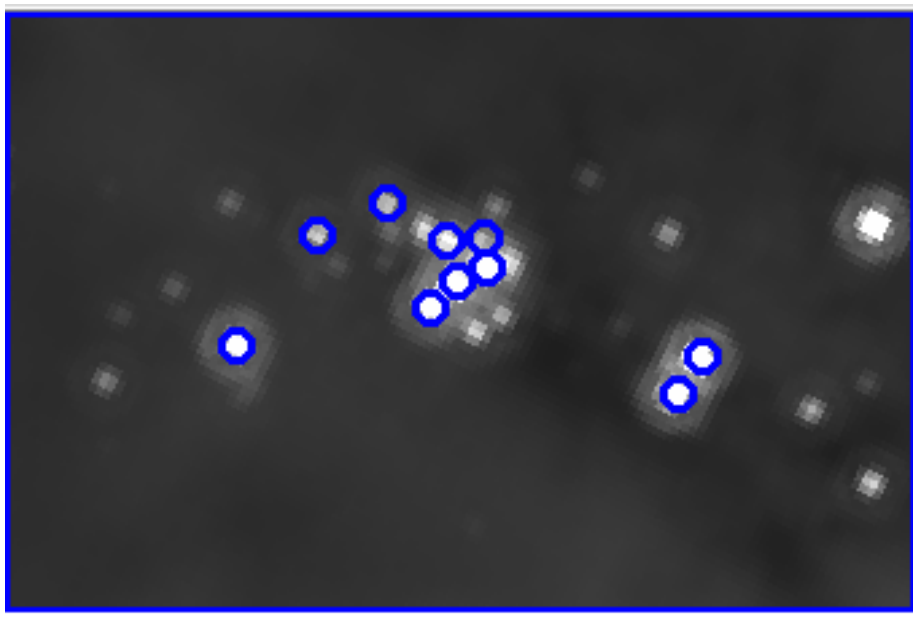


24 µm (MIPS)

SOFIA sources indicated in blue…

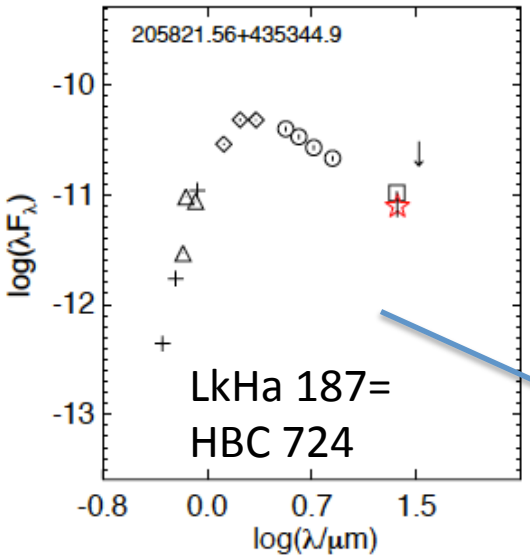


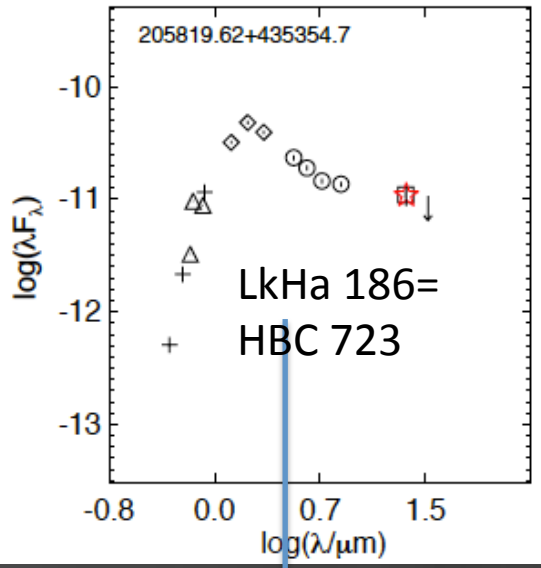
24.2 µm (SOFIA)

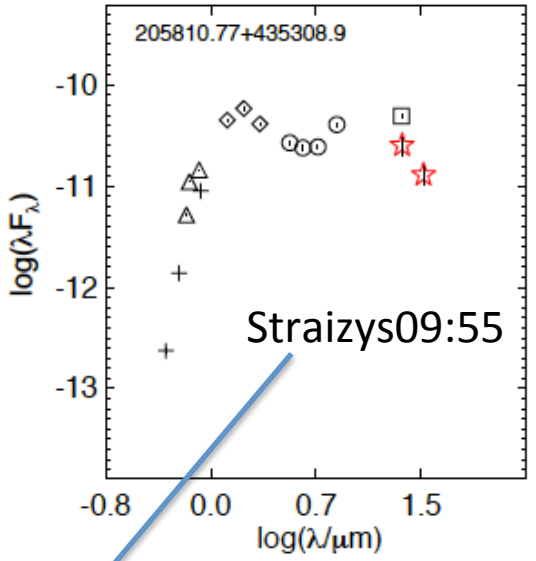


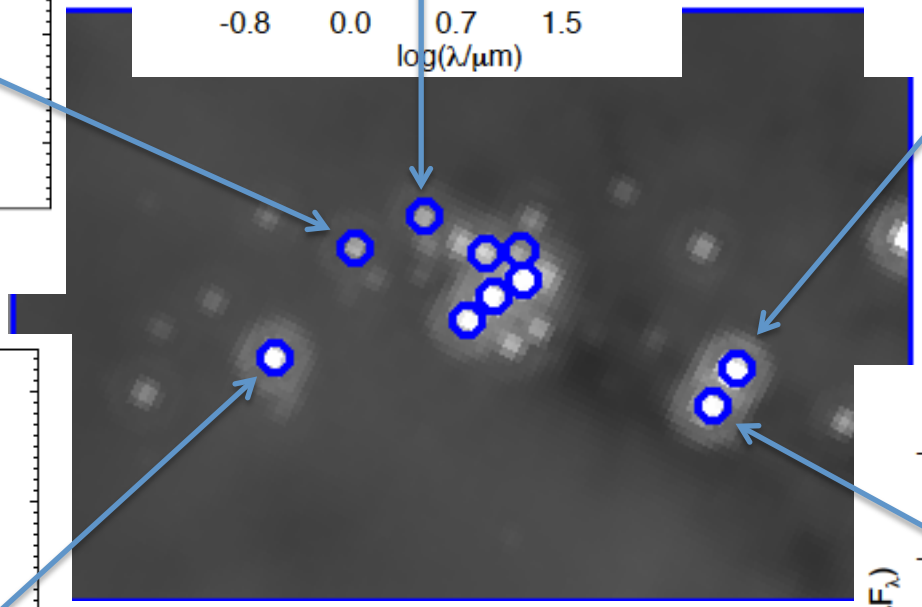
24 µm (MIPS)

Making the easy matches 2MASS SEDs…

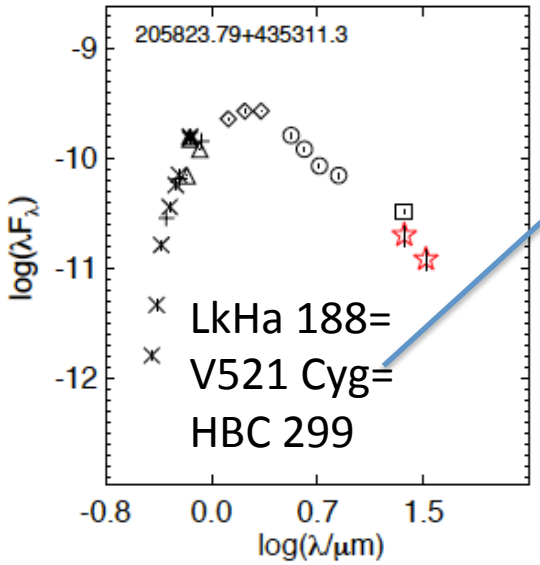


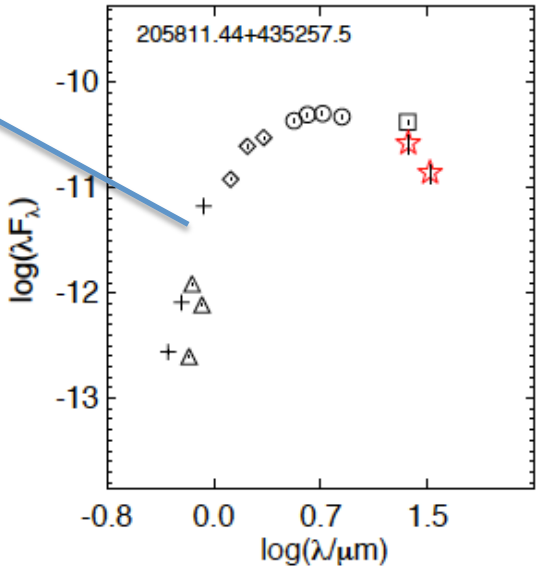






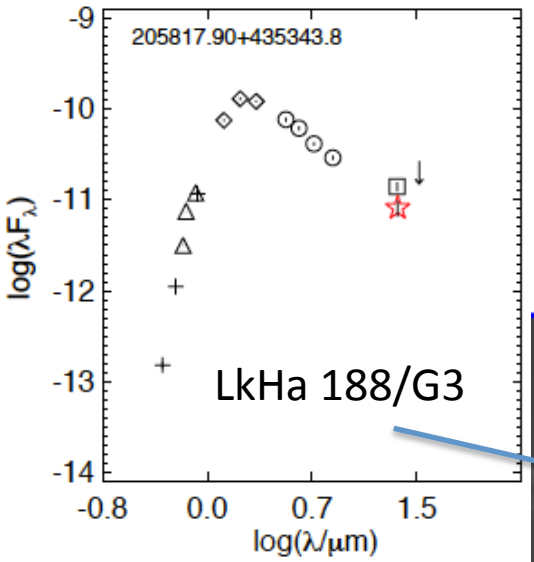
SOFIA is the longest wavelength detection in many of these!



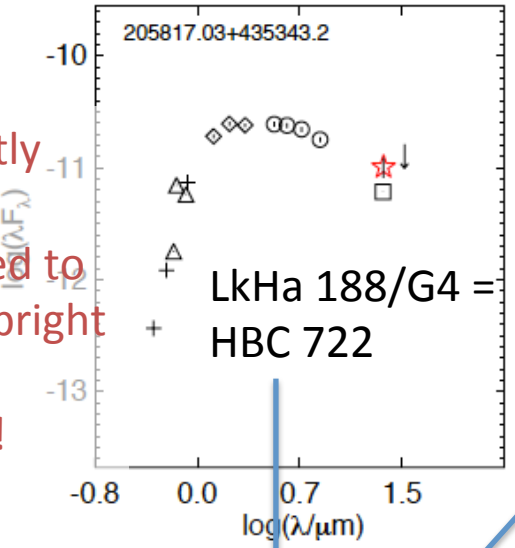


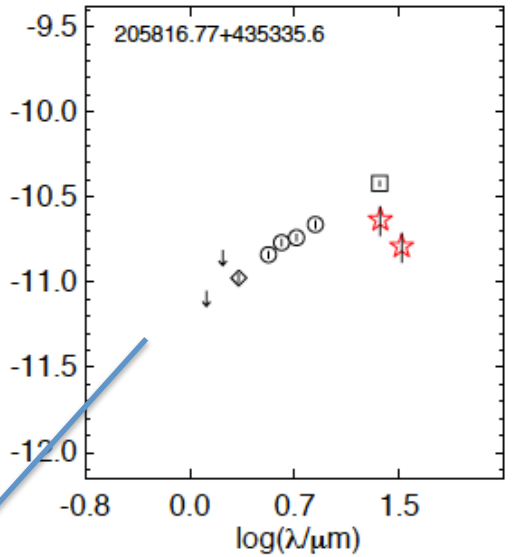
+ or x or Δ = optical; 2MASS;
¢ = IRAC; MIPS;
★ = SOFIA; arrows=limits

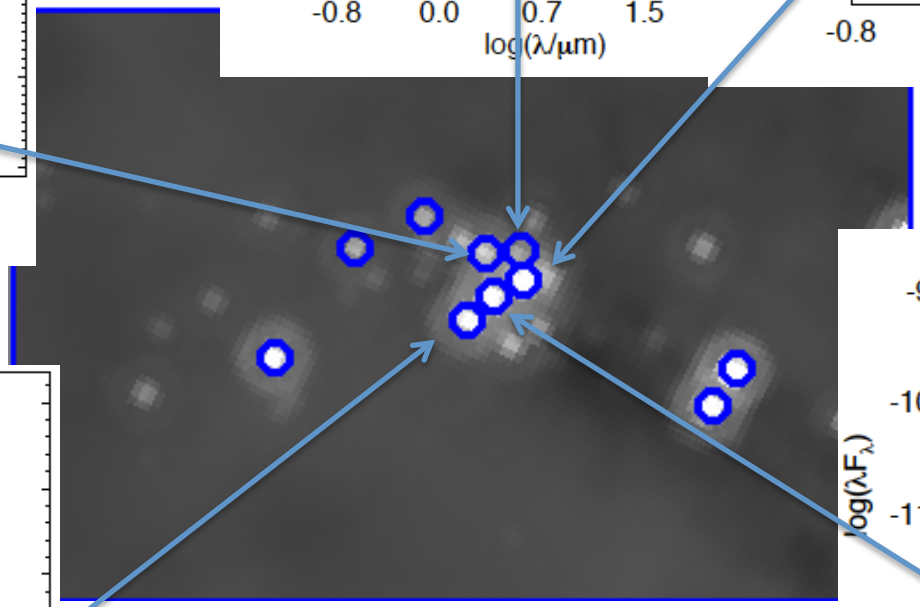
Now, it gets messier…

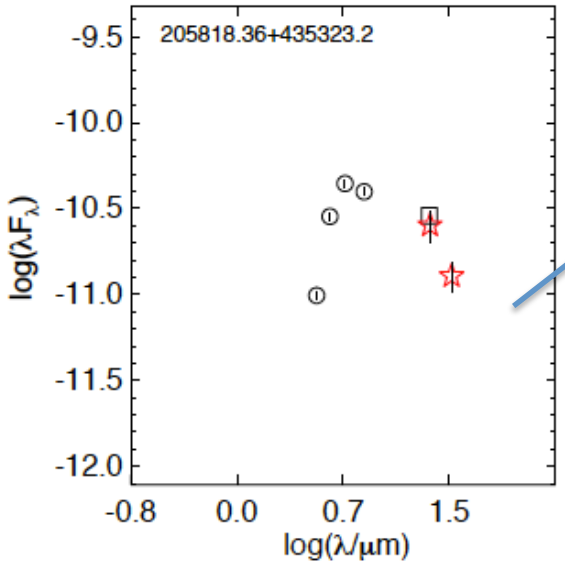


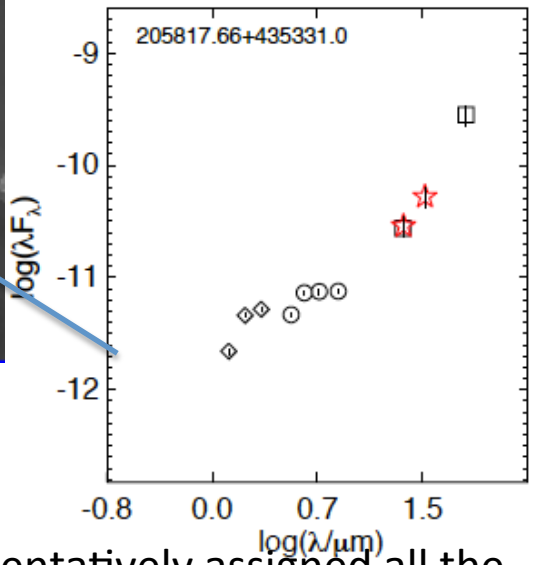
Distinctly NOT matched to a very bright MIPS source!











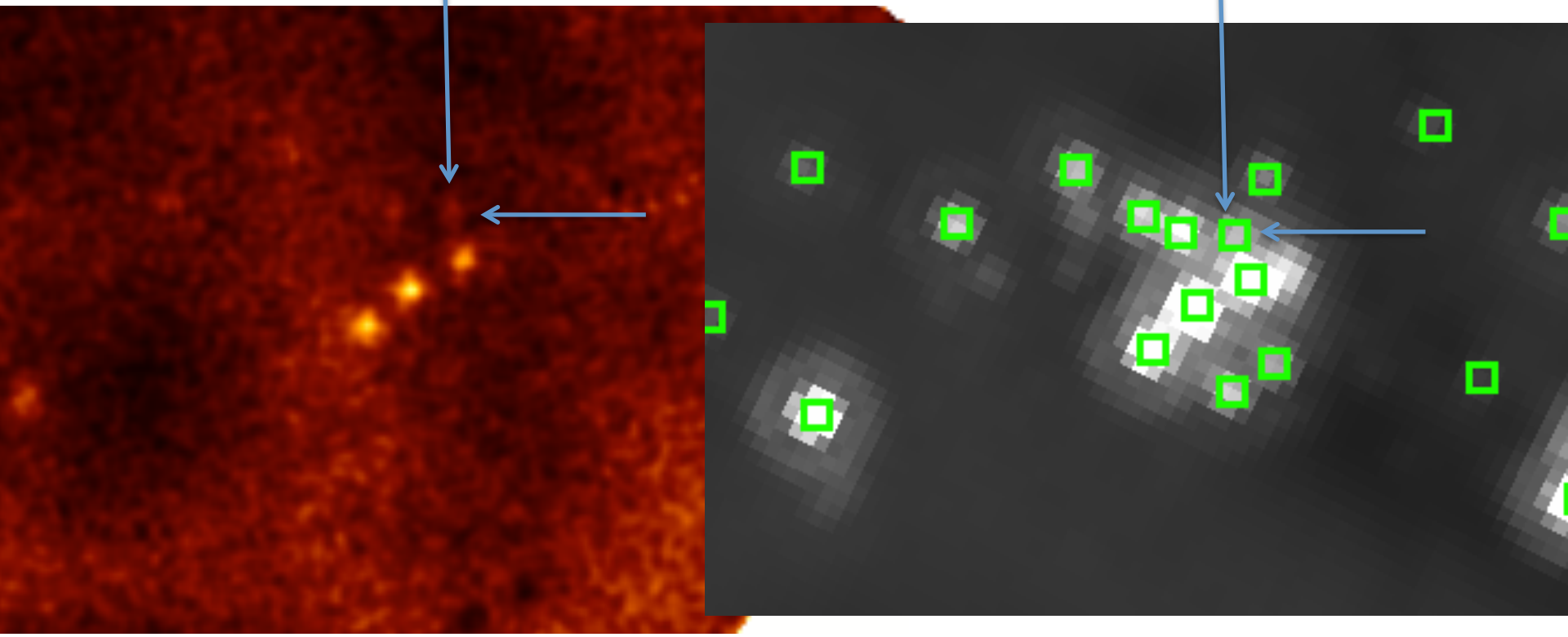
+ or x or Δ = optical; [illegible] = 2MASS;
¢ = IRAC; [illegible] = MIPS;
★ = SOFIA; arrows=limits

Tentatively assigned all the 70 um flux density

Hmmm…

Seems to really be there in SOFIA…

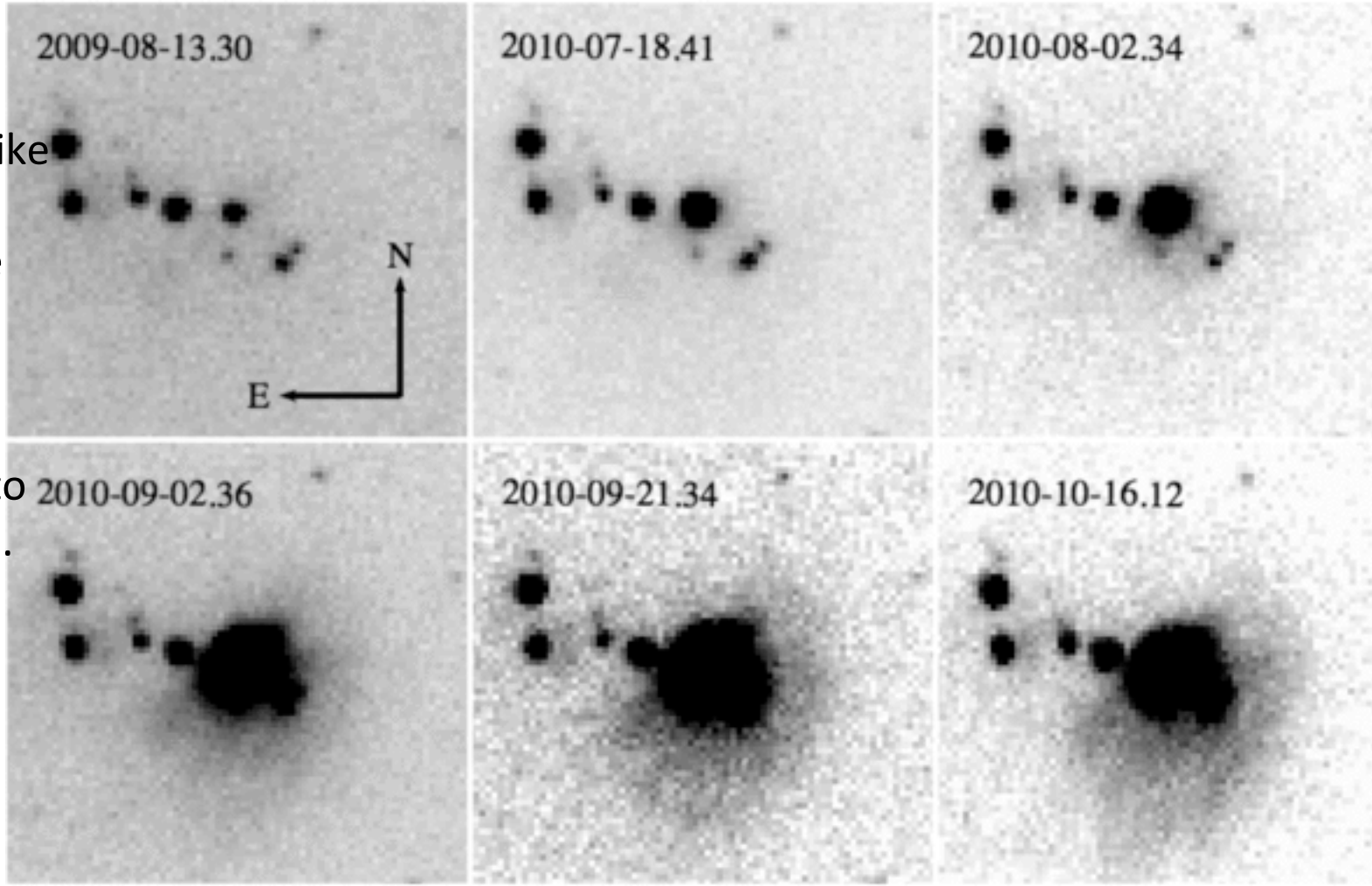
…But really not bright (as a point source anyway) in MIPS



Green squares = in the Spitzer catalog

PTF 10qpf

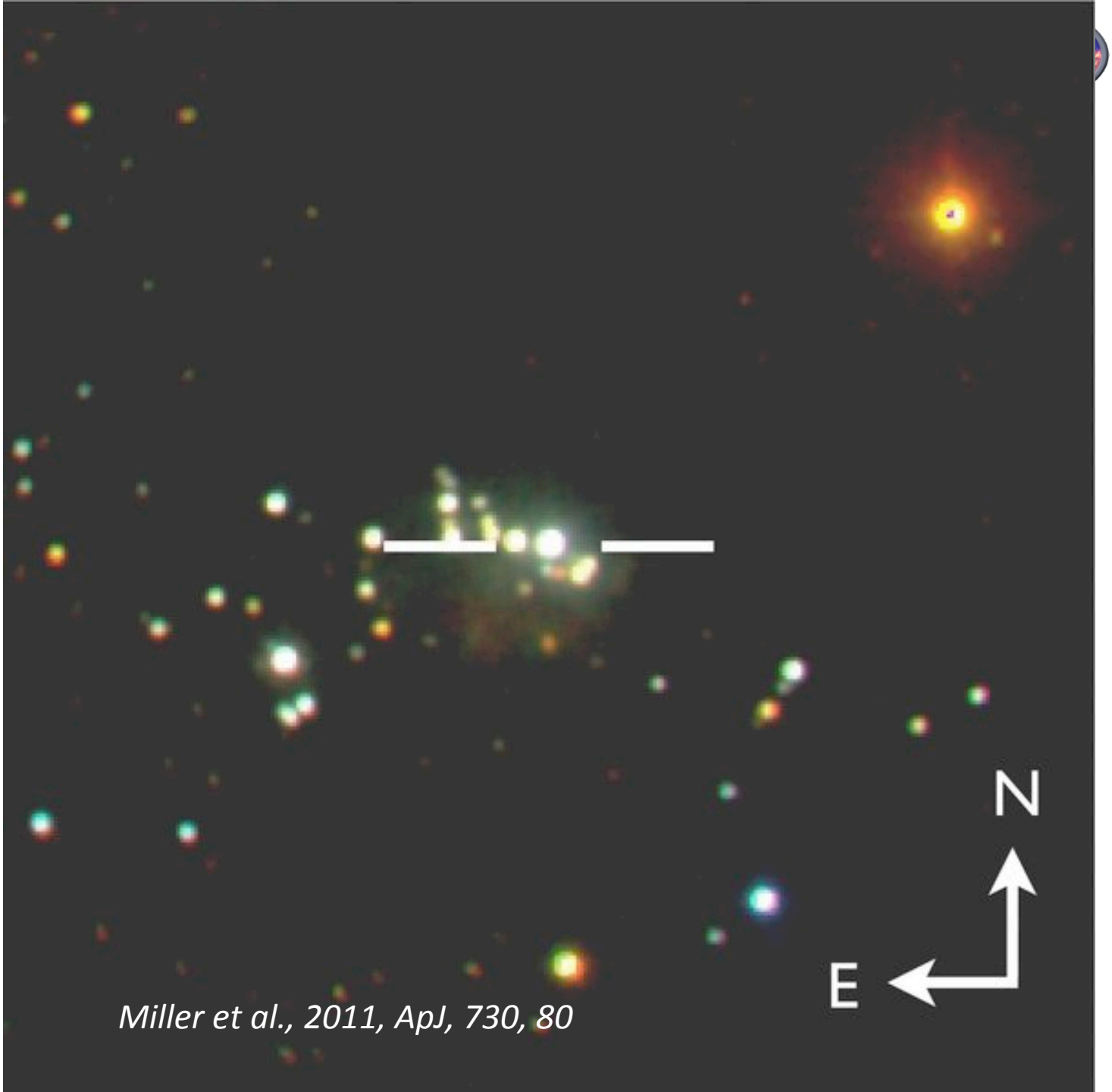
- R-band images, 75” on a side.
- FU Orionis-like outburst
- Many of the IR-bright sources are too deeply embedded to appear here.



Miller et al., 2011, ApJ, 730, 80

JHK composite, 5’ on a side.

Starting to see familiar pattern in the stars…



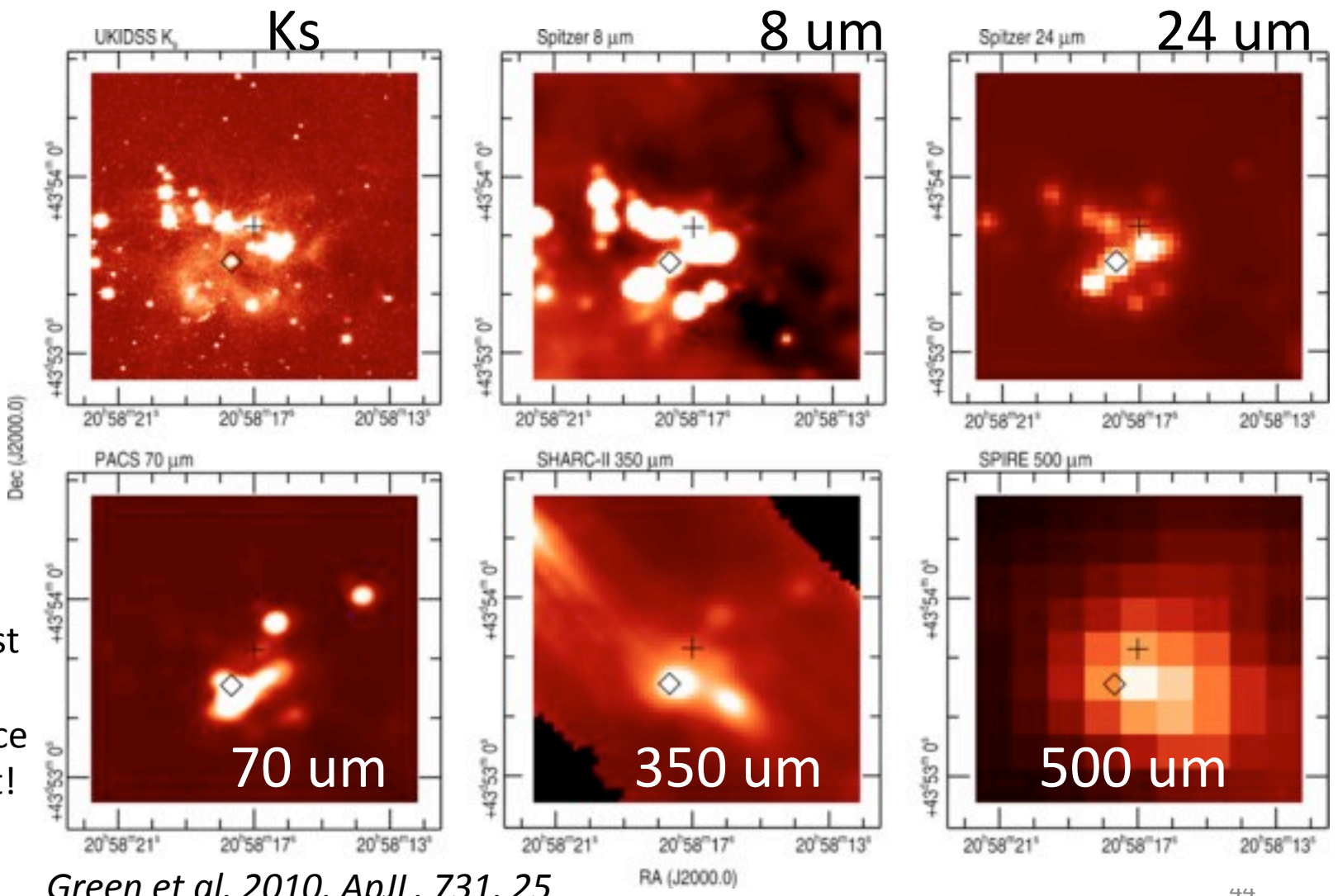
Miller et al., 2011, ApJ, 730, 80

More stuff is changing

Pre-outburst

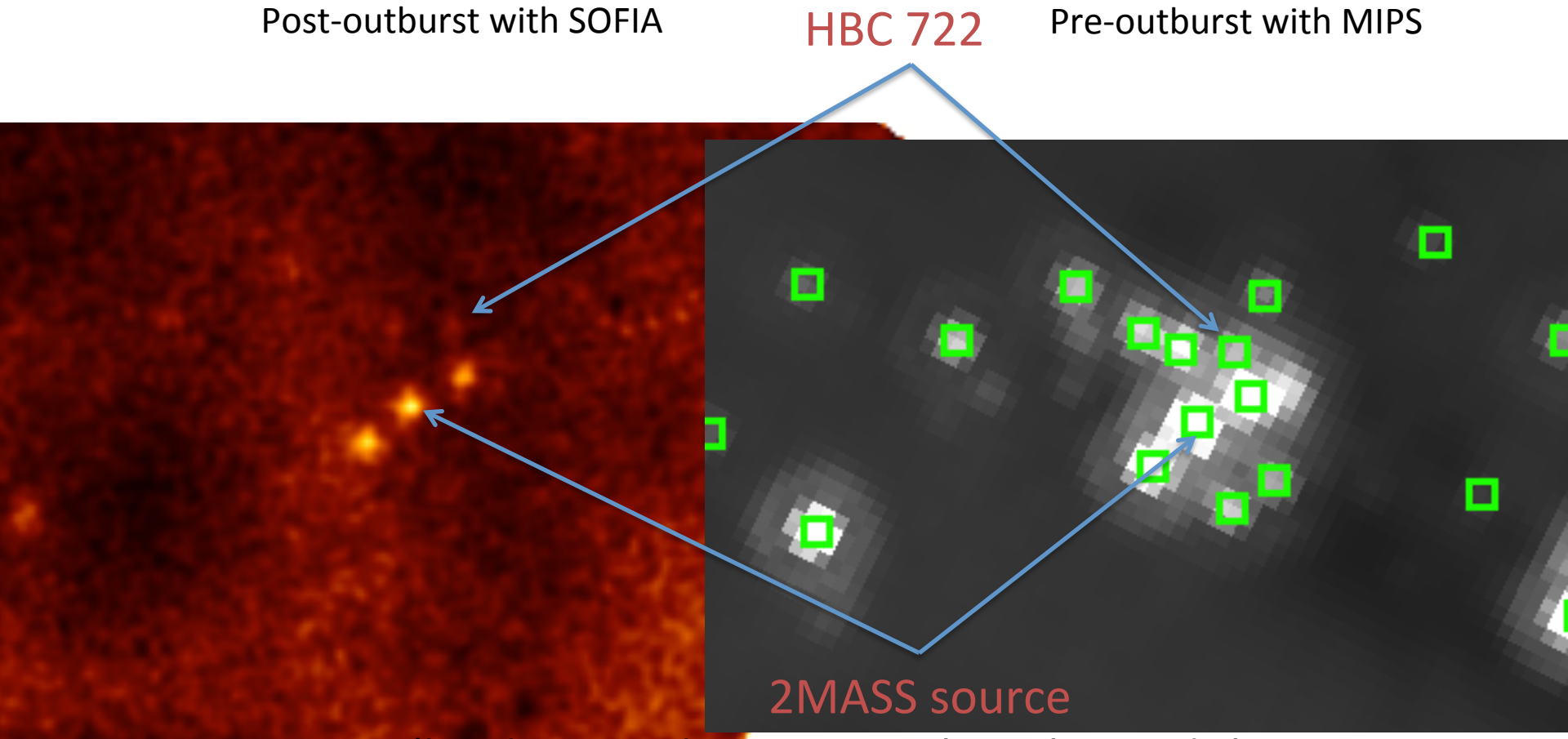
+= HBC 722
=2MASS 20581767+4353310

Post-outburst – it's the 2MASS source that is bright!



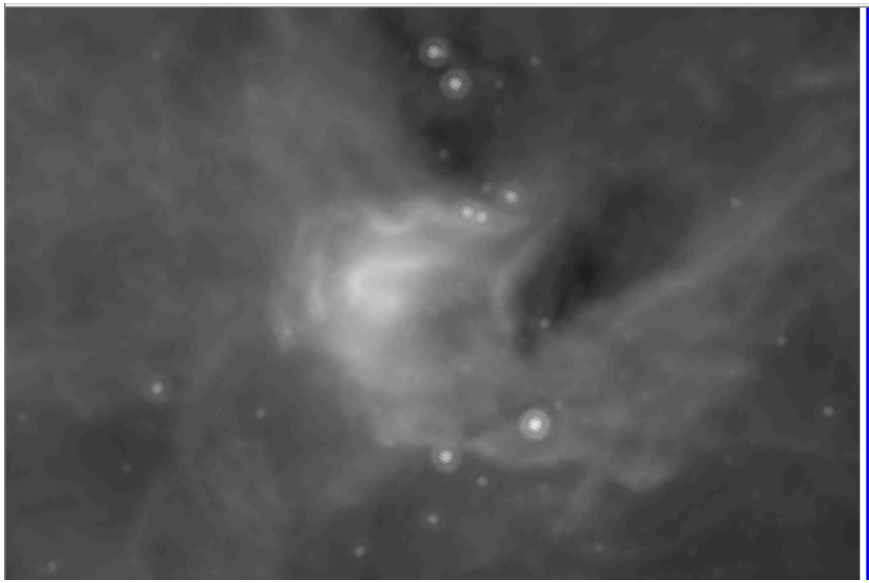
Green et al. 2010, ApJL, 731, 25

SOFIA recovered the FU Orionis object

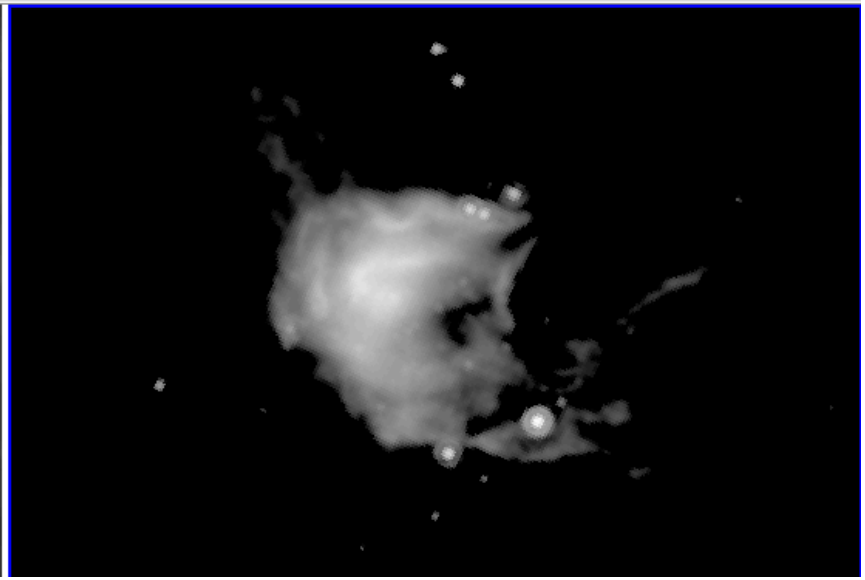


(brightest at longer wavelengths, and the one to which I assigned all the 70 um flux earlier!)

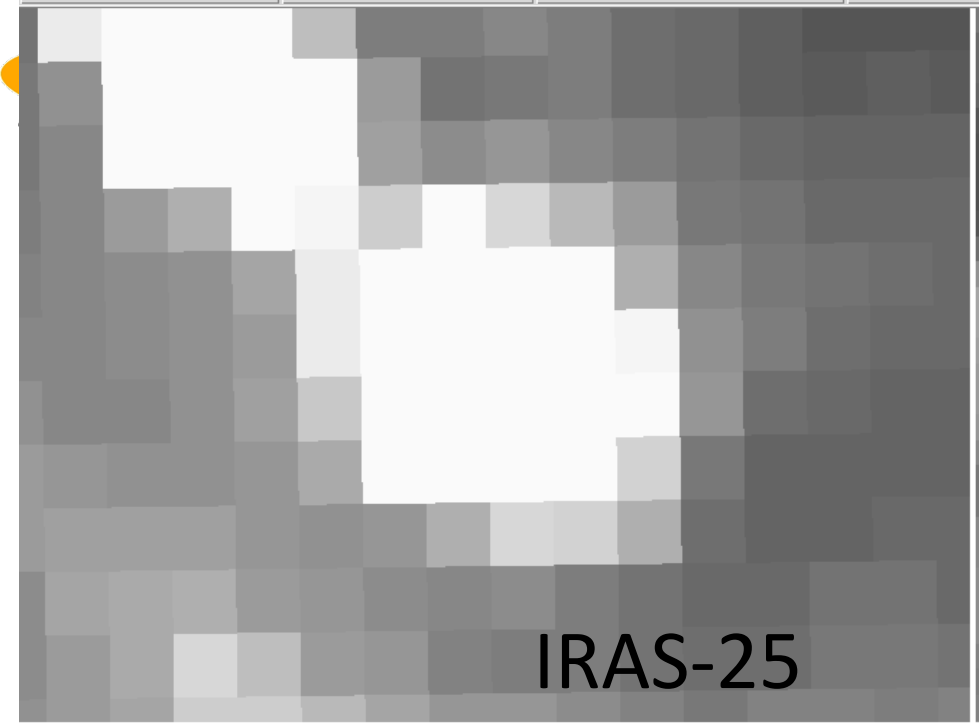
…And we only successfully observed one of our two fields
Cy1 proposal to do three bright patches in NAN

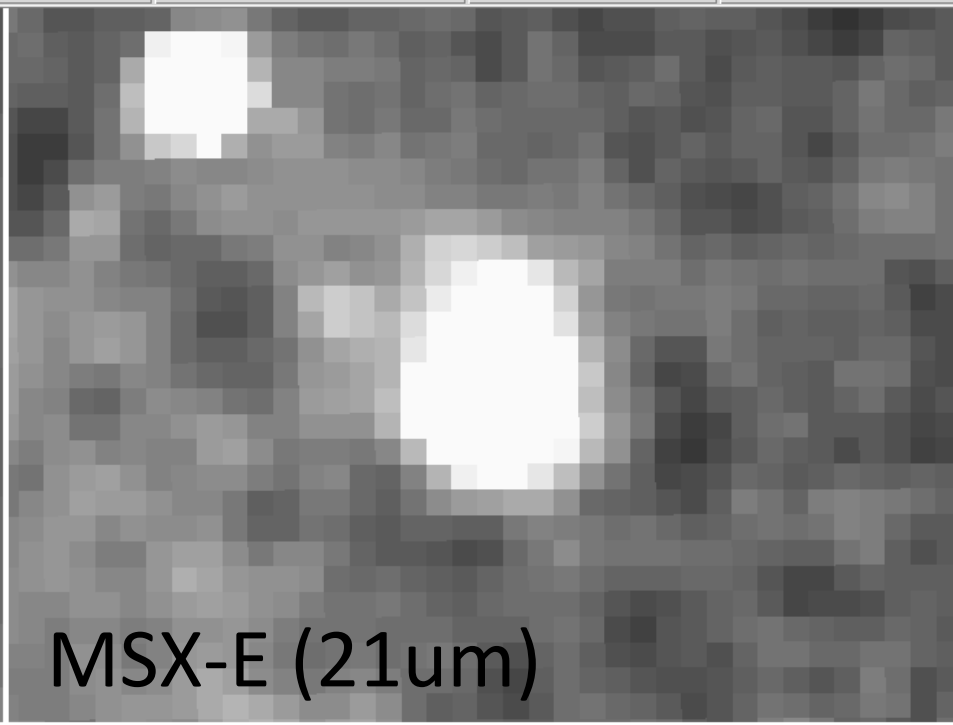


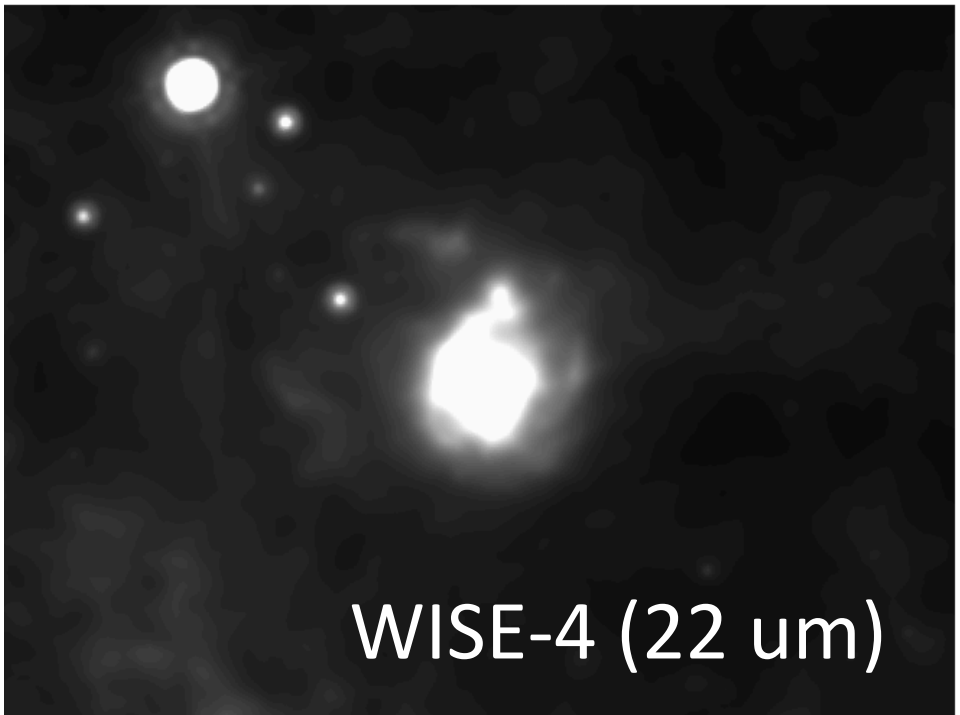
Full MIPS image

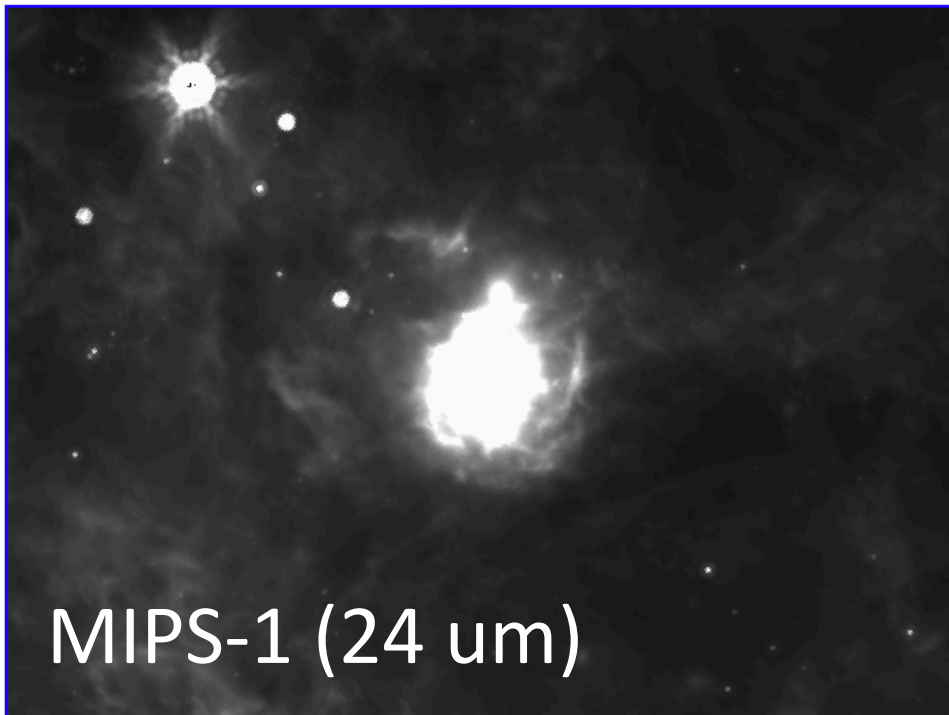


MIPS image, truncated to the expected FORCAST sensitivities.


IRAS-25

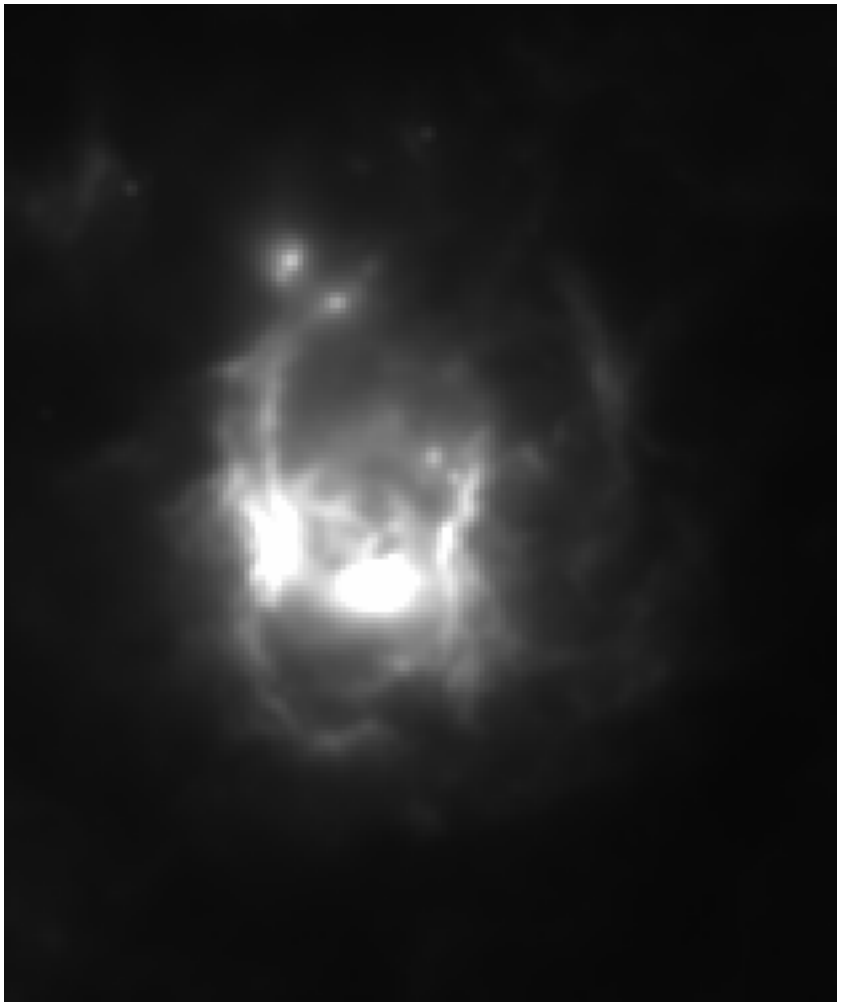

MSX-E (21um)


WISE-4 (22 um)


MIPS-1 (24 um)

MIPS-24, different stretch.

What will we see with SOFIA, if we get the time?



Conclusions

- The NAN provides a similar laboratory to Orion and not that much further away, enabling tests of environmental effects.
- Spitzer data have enabled tremendous headway in identifying the YSO population in this complex, increasing the candidate YSOs by a factor of 10 (~200  ~2000).
- There are three sub-clusters here, including clumps of extended emission and/or bright sources too close together for Spitzer to easily separate.
- SOFIA can resolve these confused sources, provide the longest wavelength SED point in several cases, & contribute to our understanding of the YSOs in this region.