



# Spectroscopy of Massive Protostars in Cygnus X

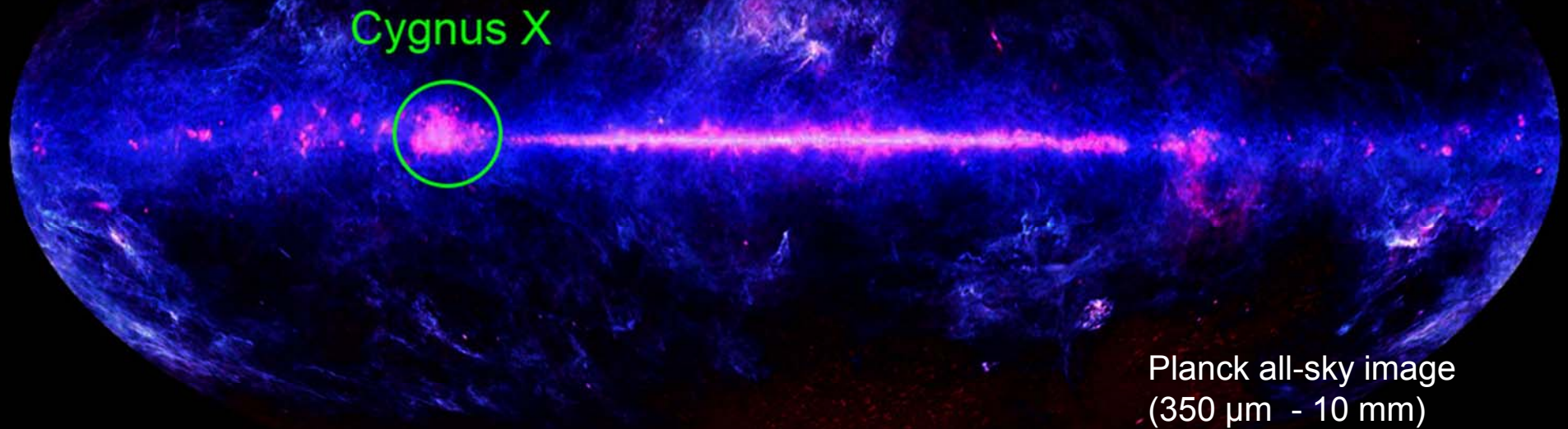
Joseph L. Hora  
SCTF Teletalk

July 10, 2013

# Cygnus-X SOFIA Project Team

- CfA:
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  - Howard Smith
  - Giovanni Fazio
  - Eric Keto
- Xavier Koenig (Yale)
- Sylvain Bontemps (Obs. Bordeaux)
- Nicola Schneider (CEA/Saclay)
- Frédérique Motte (CEA/Saclay)
- Kathleen Kraemer (Boston Univ)
- Tom Megeath (Univ. of Toledo)
- Rob Gutermuth (Smith College)
- Joseph Adams (Cornell)
- Sean Carey (Spitzer SC)
- Robert Simon (Univ. Cologne)
- Lori Allen (NOAO)

# What is Cygnus X?



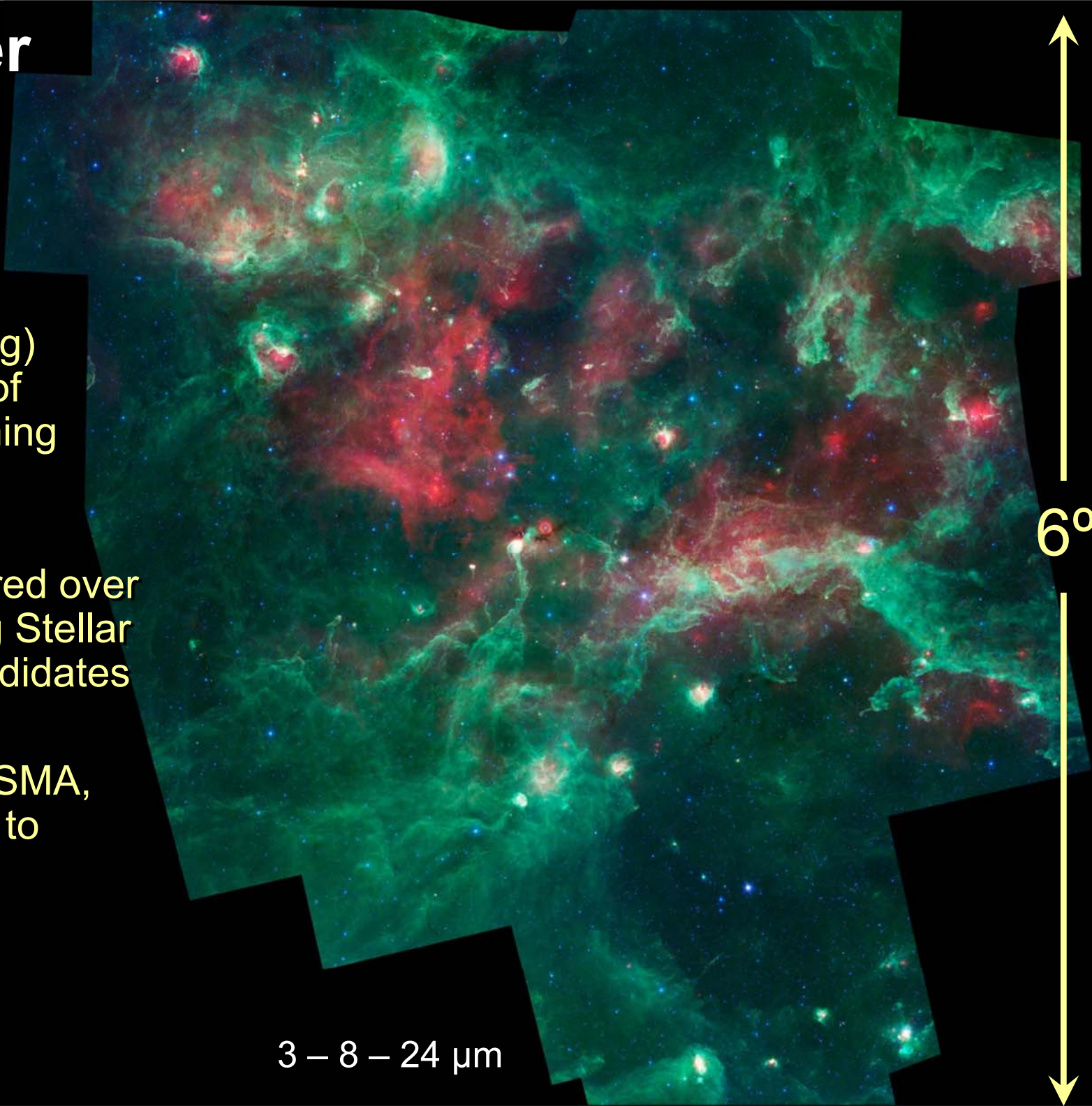
- Cygnus X is one of the brightest regions of the sky at all wavelengths, prominent in early radio and IR surveys
- It is one of the richest known star formation regions in the Galaxy, and the closest one of this size (1.4 kpc)
- Cygnus X is a  $\sim 150$  pc diameter massive star-forming complex ( $3 \times 10^6 M_{\odot}$ , 10x larger than Orion)

# The Spitzer Cygnus X Survey

Large (~25 sq. deg)  
unbiased survey of  
massive star-forming  
region

We have discovered over  
28000 new Young Stellar  
Object (YSO) candidates

Now using MMT, SMA,  
Herschel, SOFIA to  
investigate YSOs



6°

3 – 8 – 24  $\mu\text{m}$

# The Cygnus-X Legacy Survey

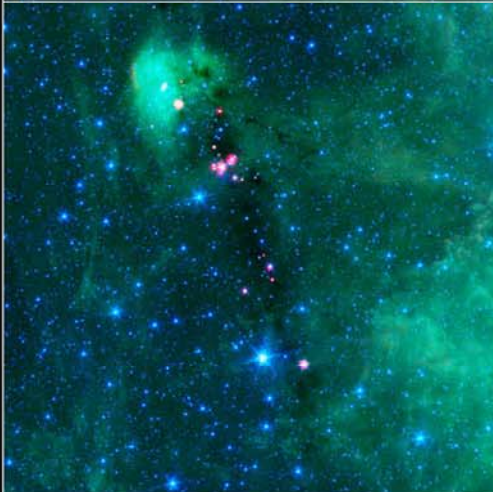
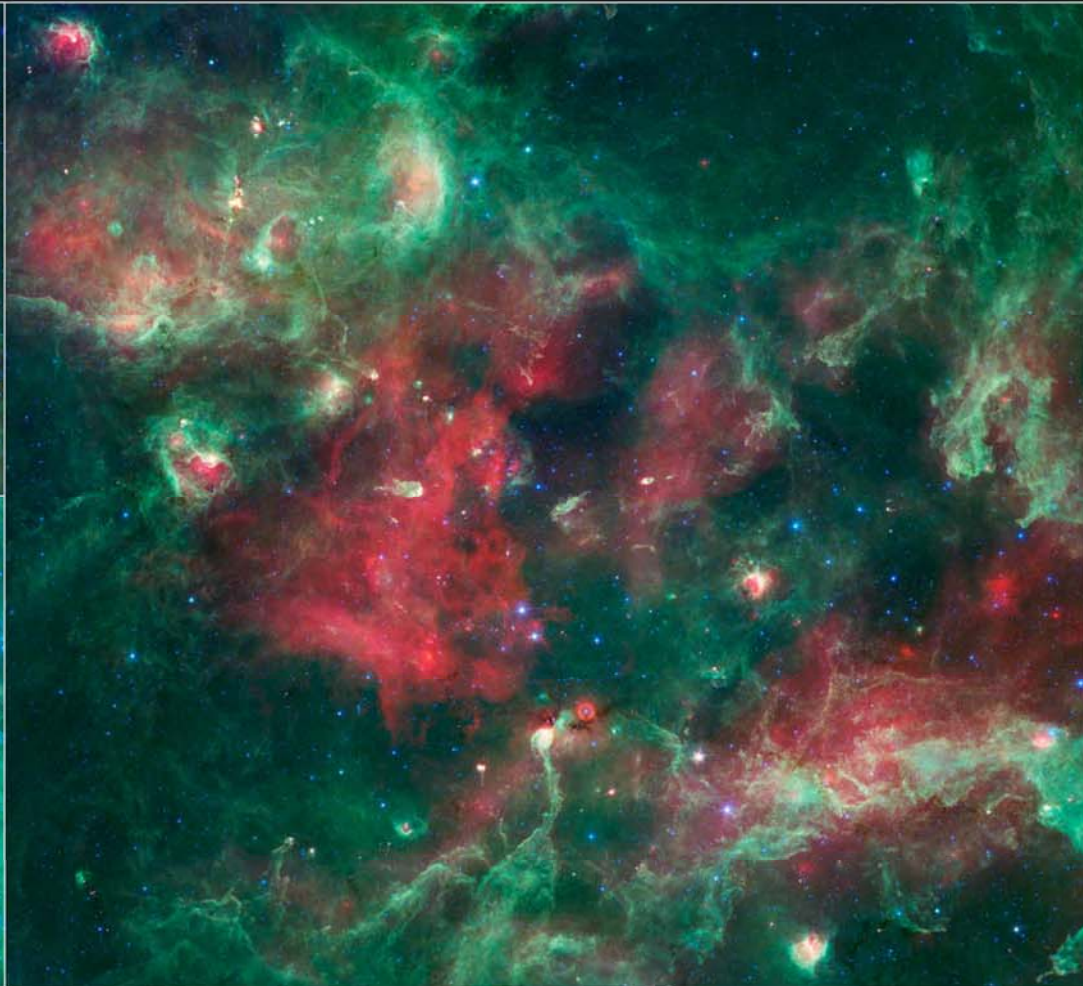
- Used Spitzer/IRAC and MIPS instruments to survey ~25 square degrees in the Cygnus-X region from 3 – 70  $\mu\text{m}$
- Survey is ~10x more sensitive than Spitzer observations in GLIMPSE survey (3x12s HDR coverage)
- ~4 million sources detected in the survey
- Mosaics and point source catalog are now on IRSA
- We have discovered many young stellar object candidates (YSOs)
  - 1200 deeply embedded objects,
  - 2600 Class I (YSOs with envelopes)
  - 24000 Class II (YSOs with disks)

Team web site: <http://www.cfa.harvard.edu/cygnusX>

# Some Highlights in Cygnus X

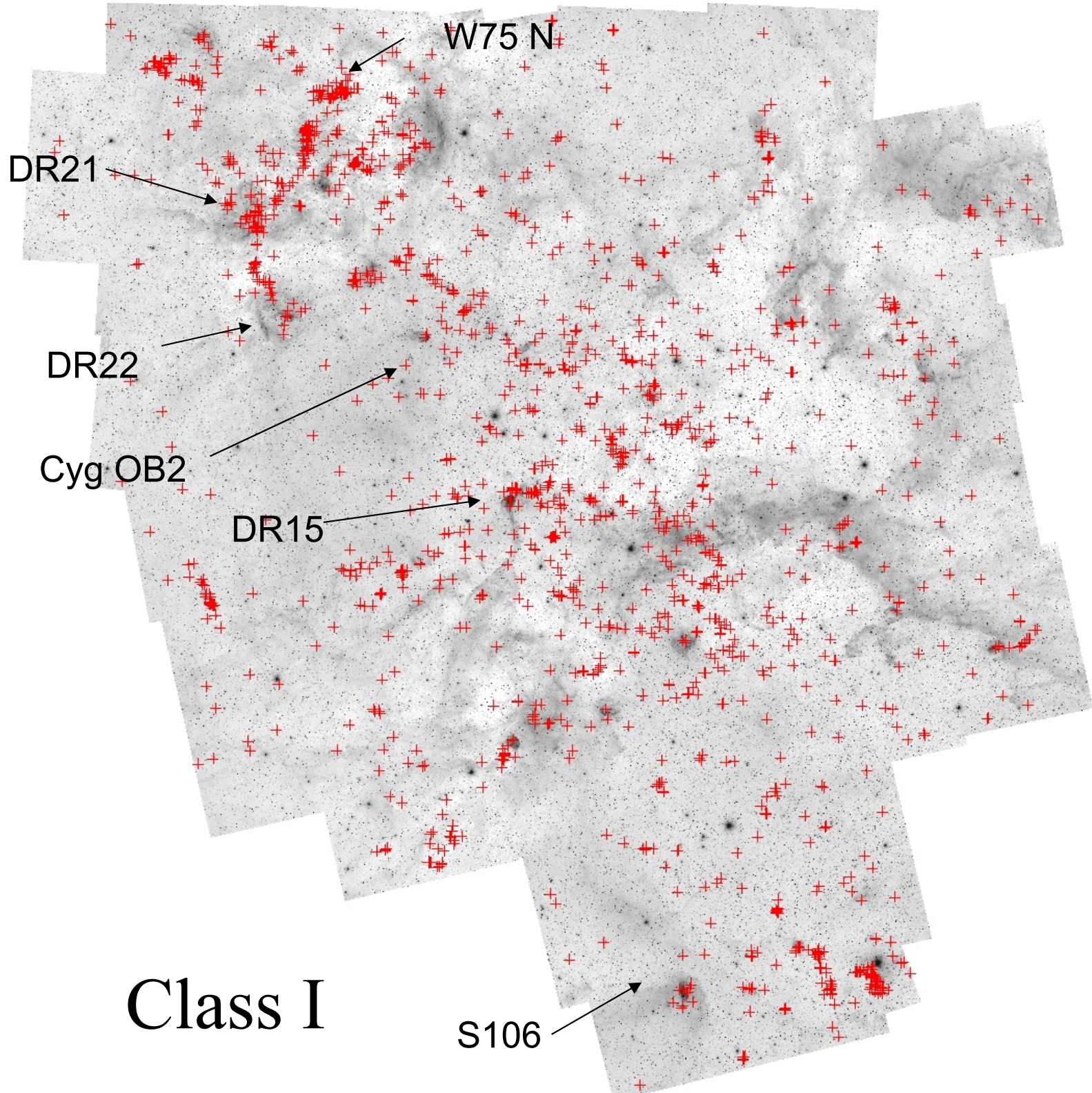
AFGL 2636

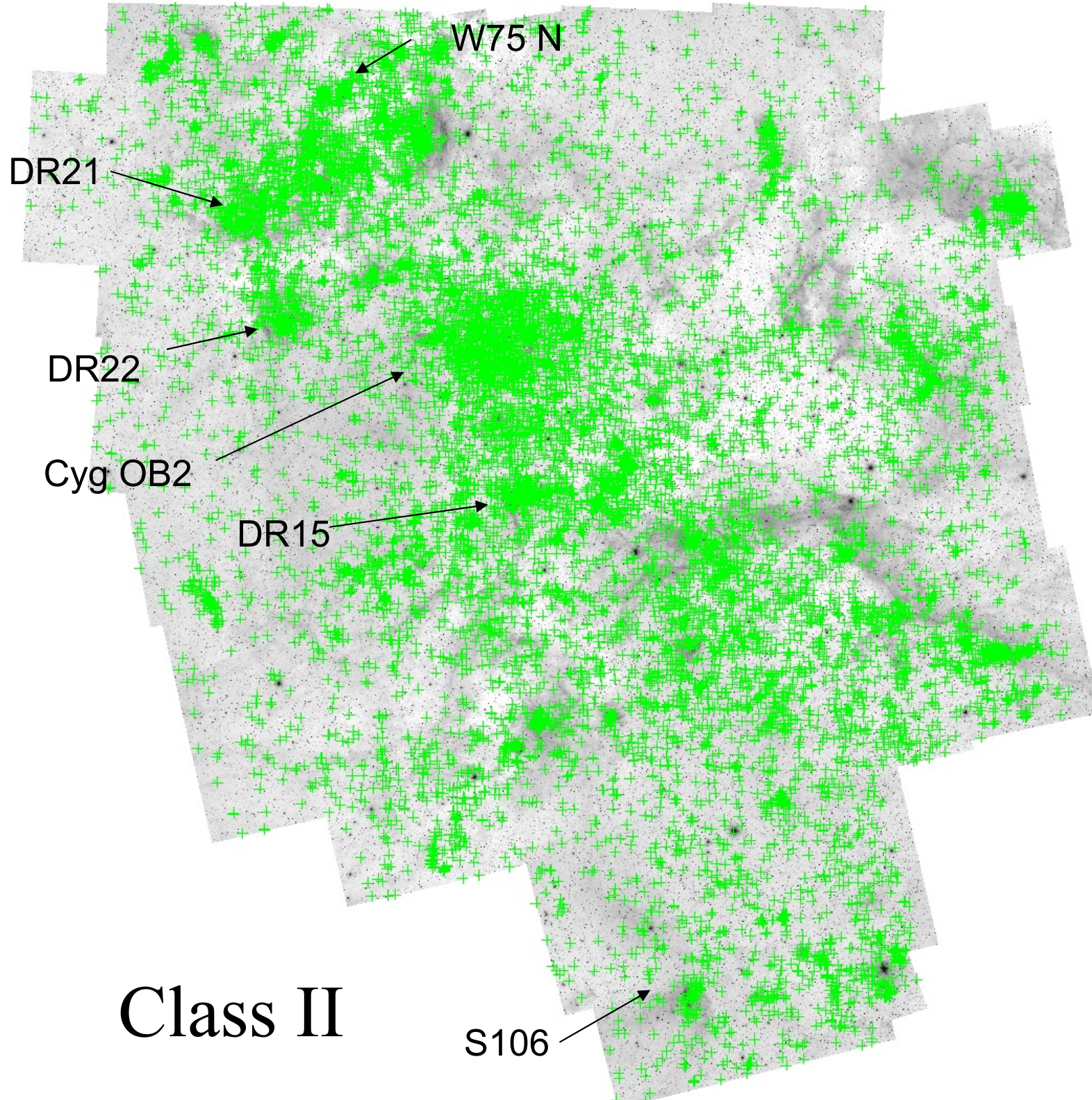
DR 22



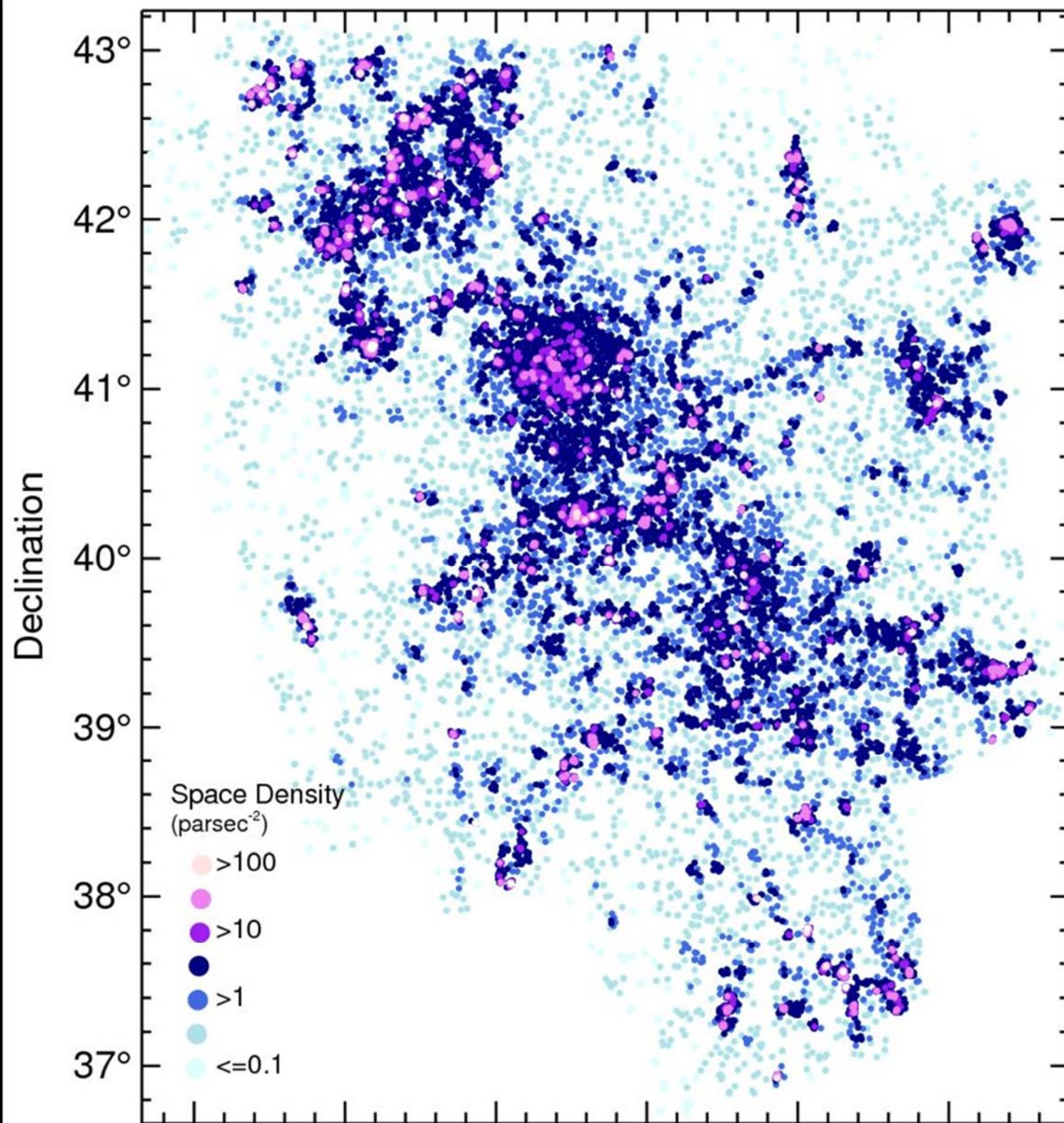
Lynds 896

DR 15



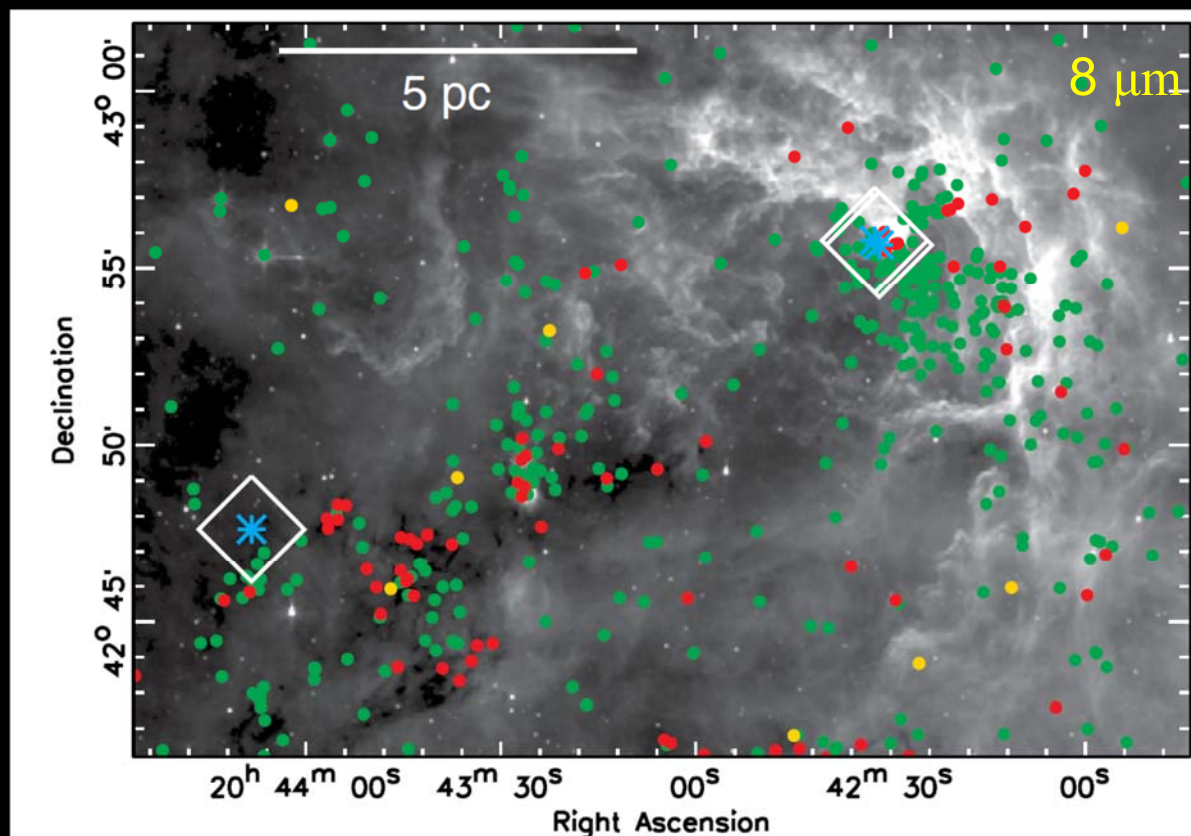






# Multiple Generations of Star Formation in AFGL 2636

- B stars identified with FAST spectra
- Clusters of YSO candidates
- In cavity, Class II objects in central region, Class I objects in rim of compressed material
- Near IRDC, Class I objects forming in filaments, Class II YSOs in more dispersed cluster
- Now using MMT and IR spectroscopy to classify YSOs, determine ages and masses, cluster mass function

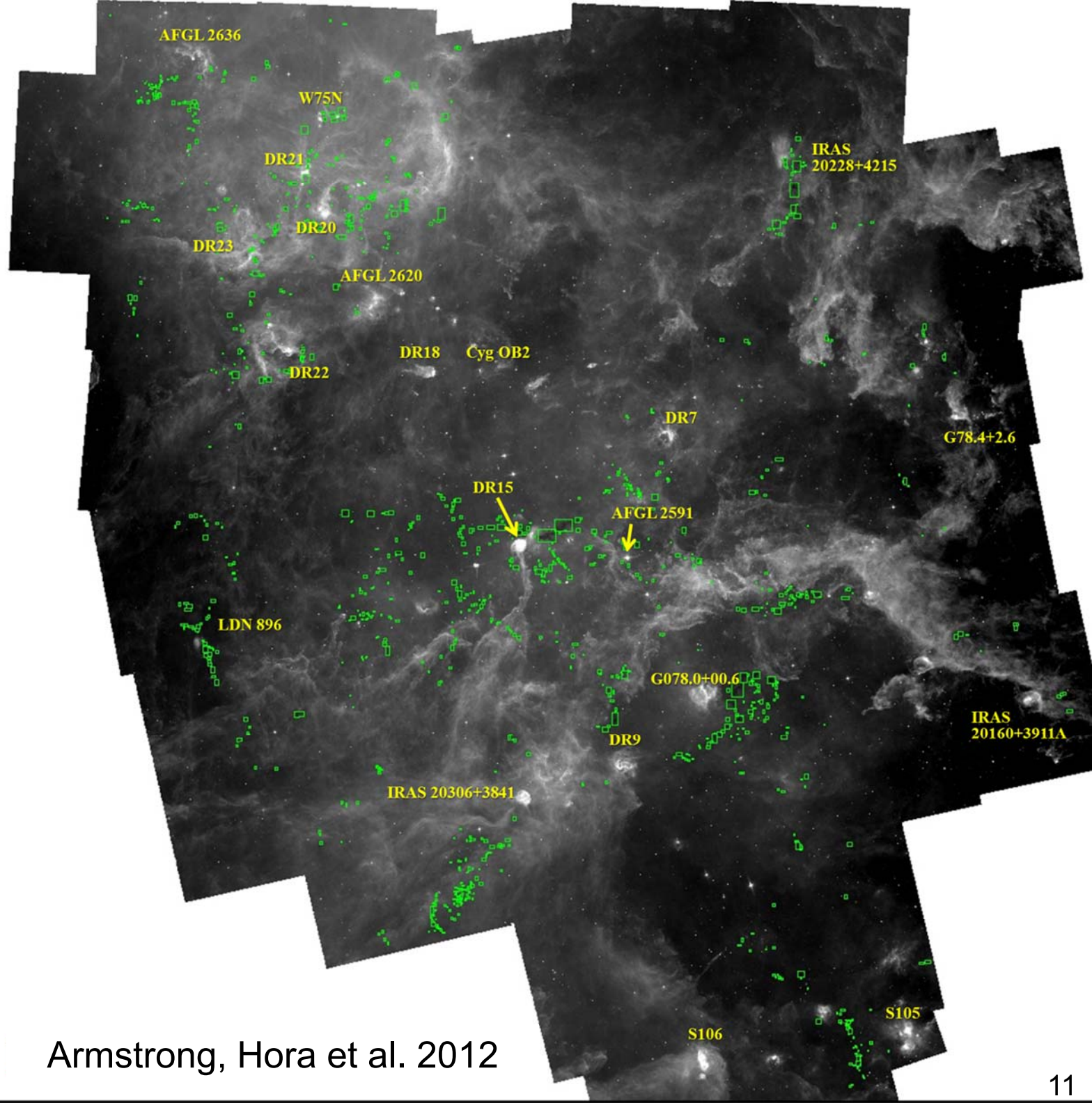


Beerer et al. 2010

B stars  
Class I  
Class II  
Class III

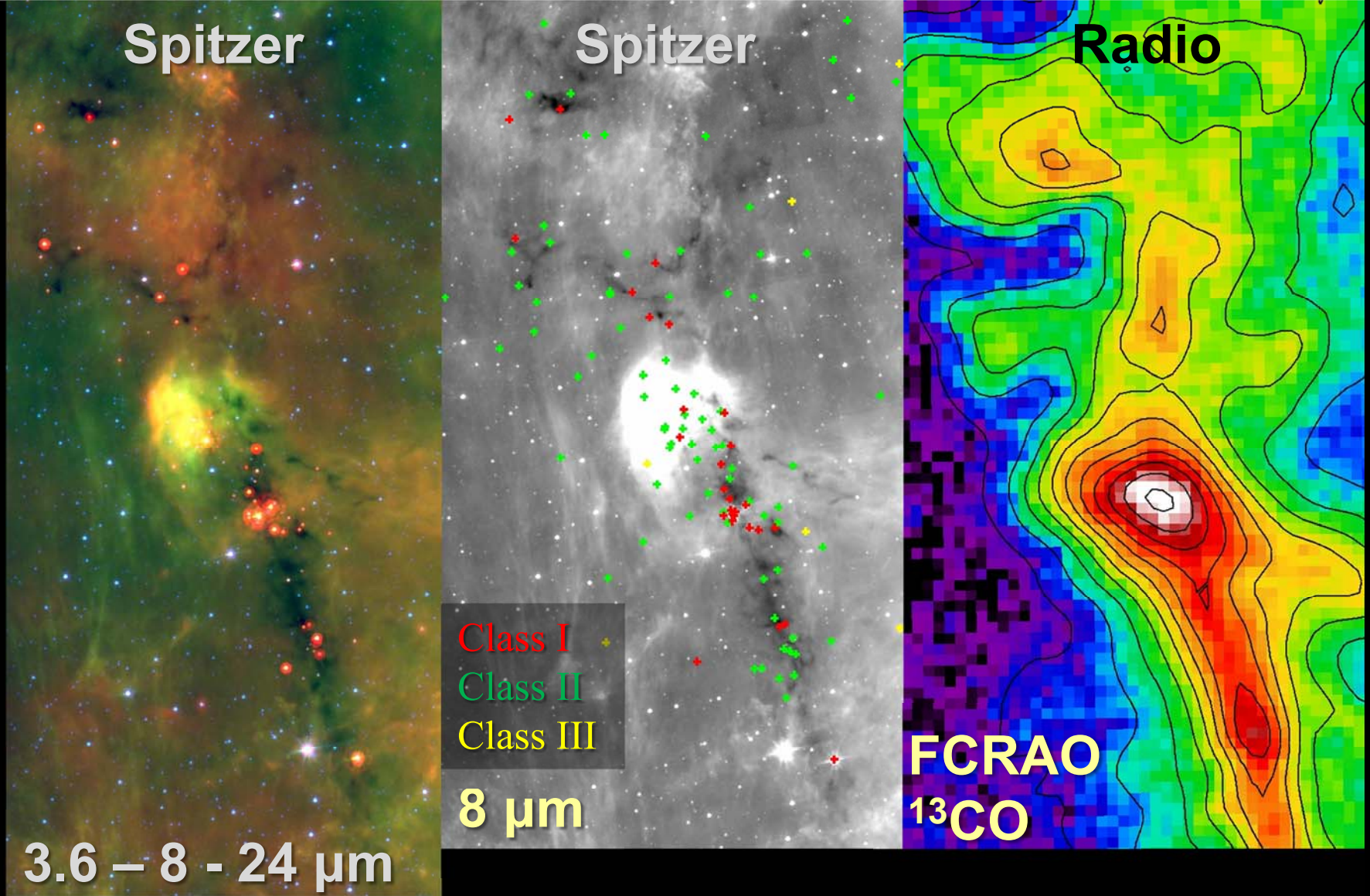
# Infrared Dark Clouds in Cygnus-X

- 42 complexes contain most of the ~1200 cloud fragments
- 13 large cloud complexes
- Youngest YSOs are located in densest parts of IRDCs
- Star formation is possibly being triggered by effects of massive stars



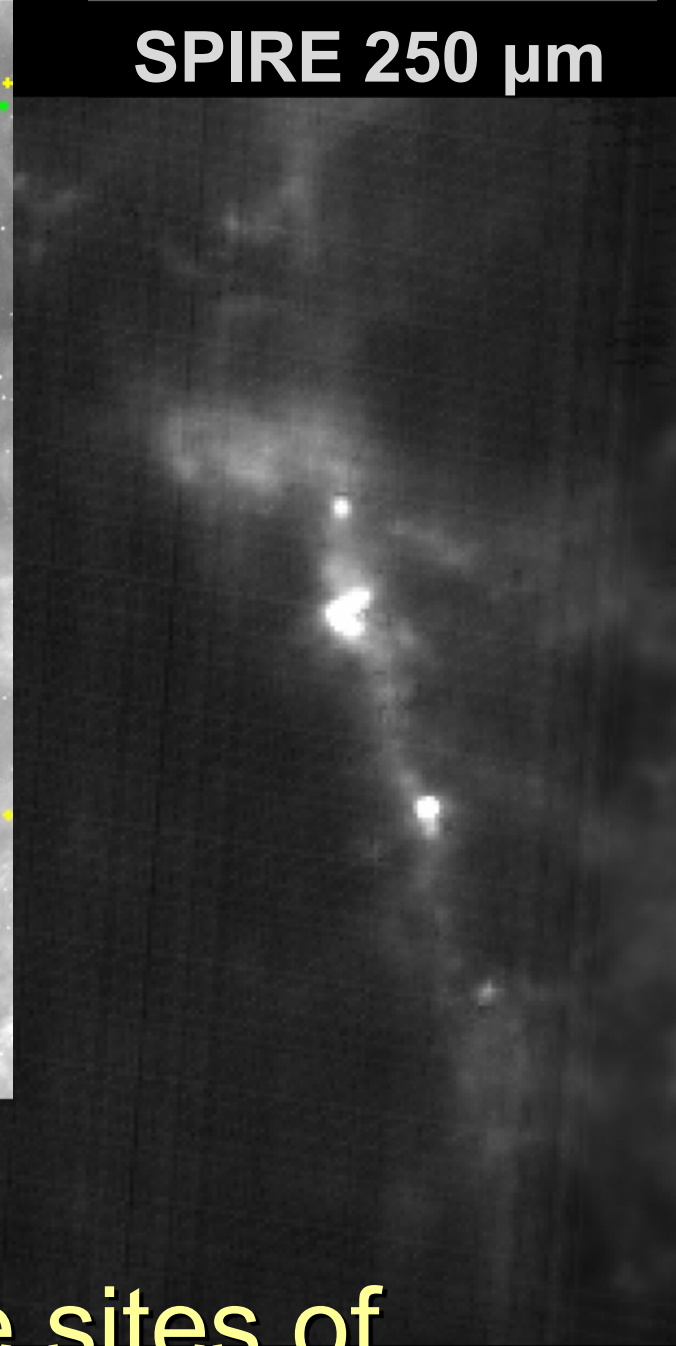
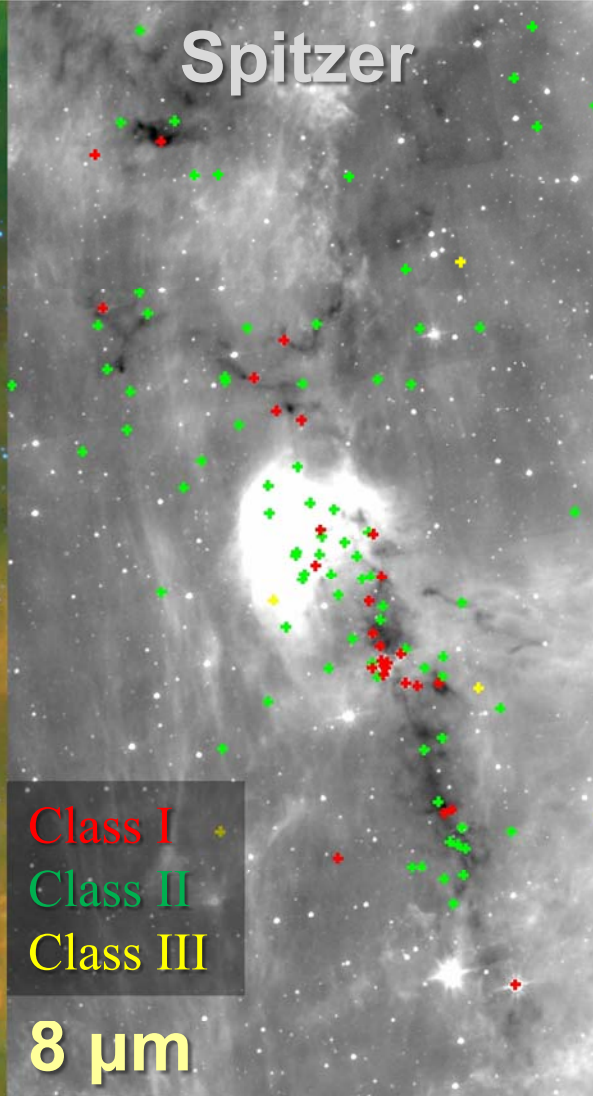
Armstrong, Hora et al. 2012

# LDN 896



Infrared Dark Clouds are sites of  
current star formation

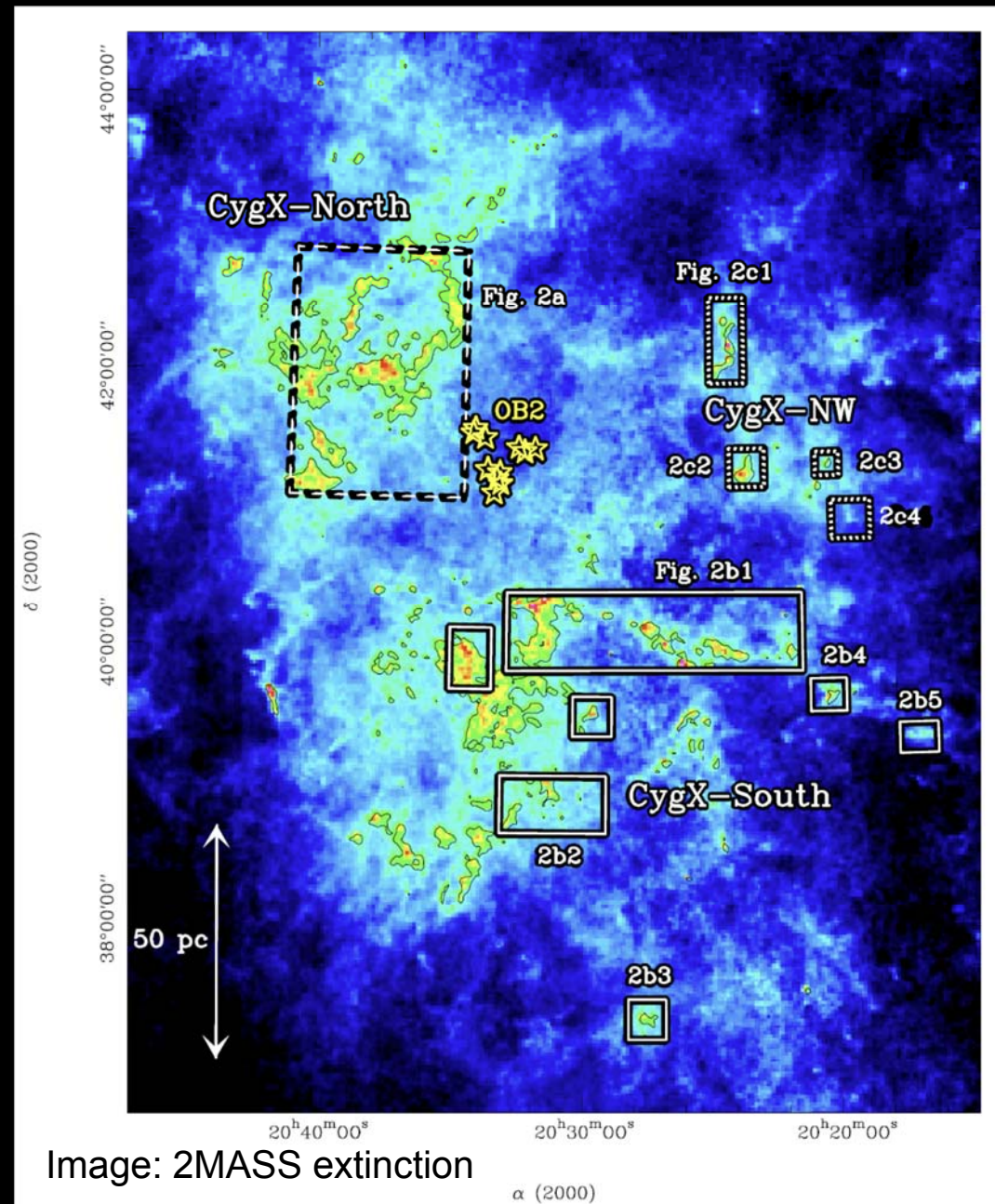
# LDN 896



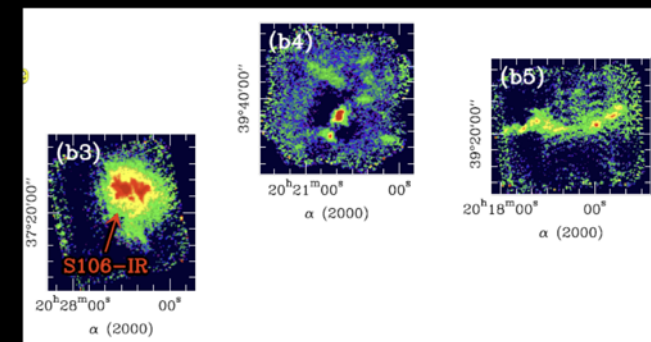
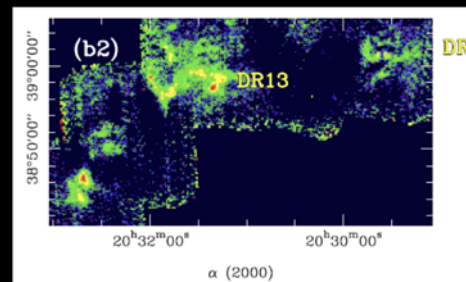
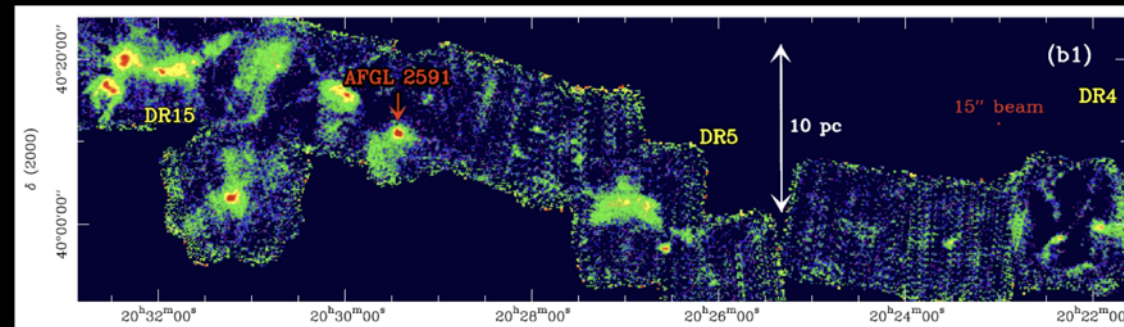
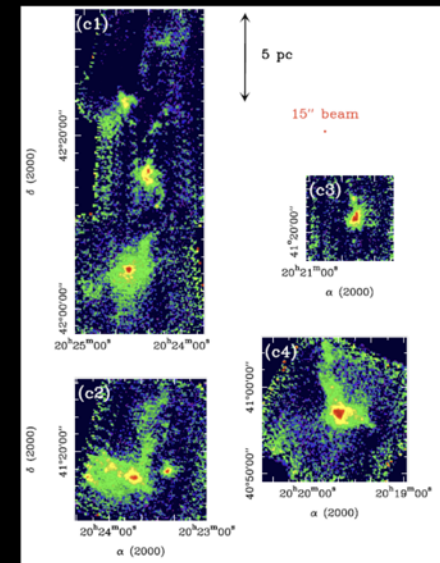
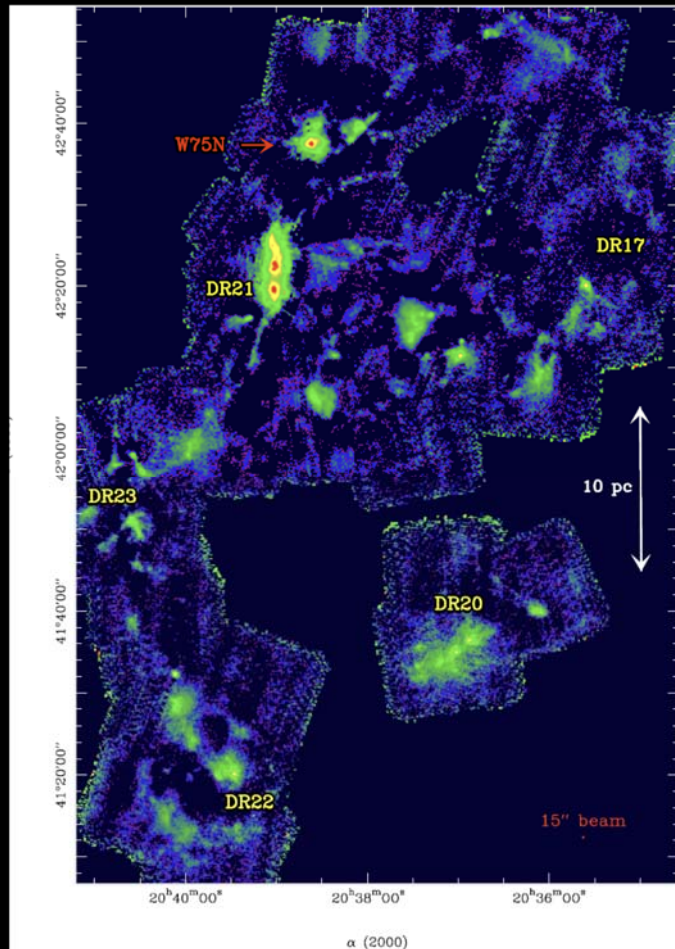
Infrared Dark Clouds are sites of  
current star formation

# 1.2mm Continuum mapping of Cygnus-X (Motte et al. 2007)

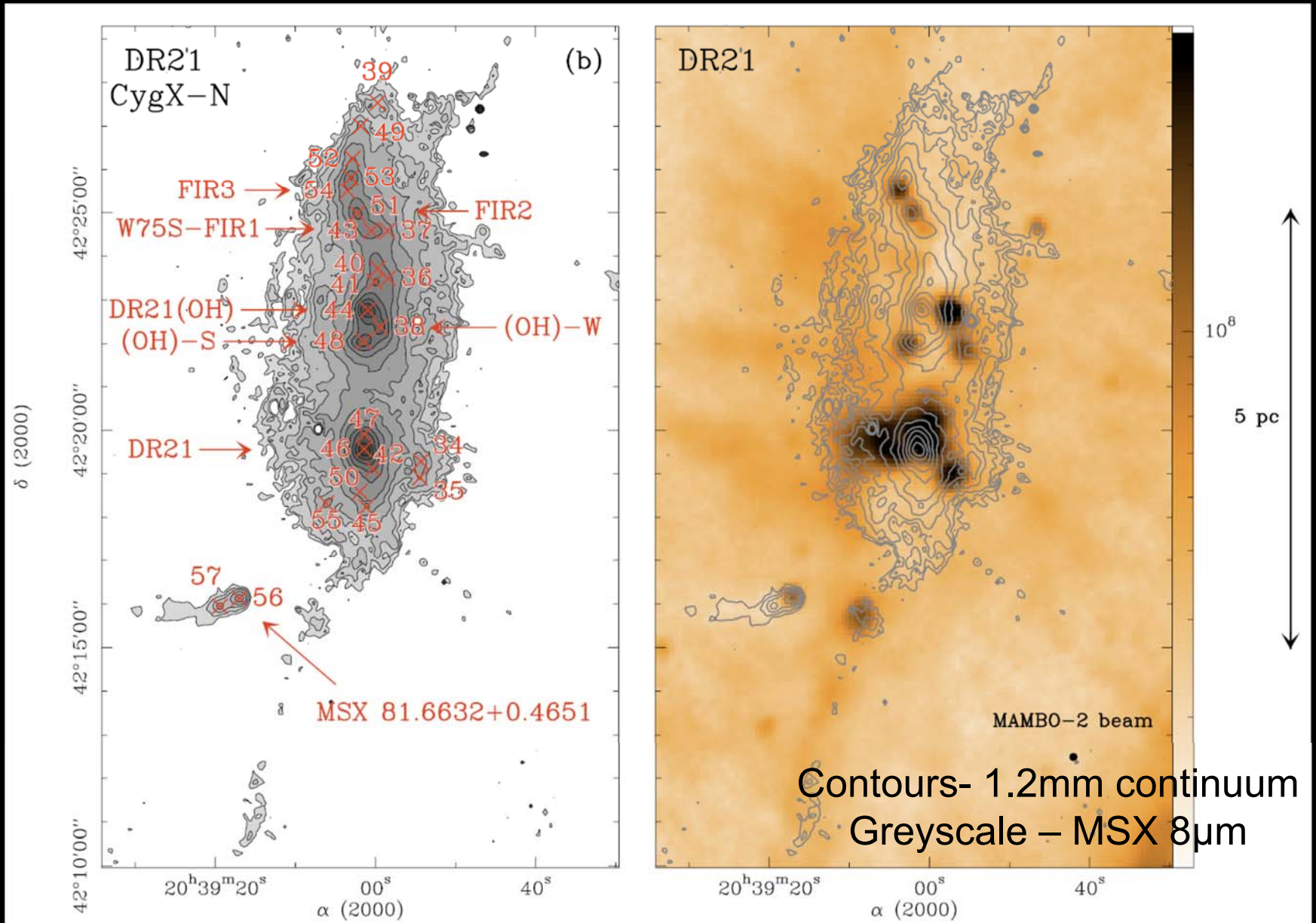
- Found 129 cores, ~40 identified as high-mass stellar precursors
- About 2/3 are “IR-quiet” (MSX) cores; massive ( $\geq 40 M_{\odot}$ ), molecular outflows common
- Many sources located in dark clouds and filaments



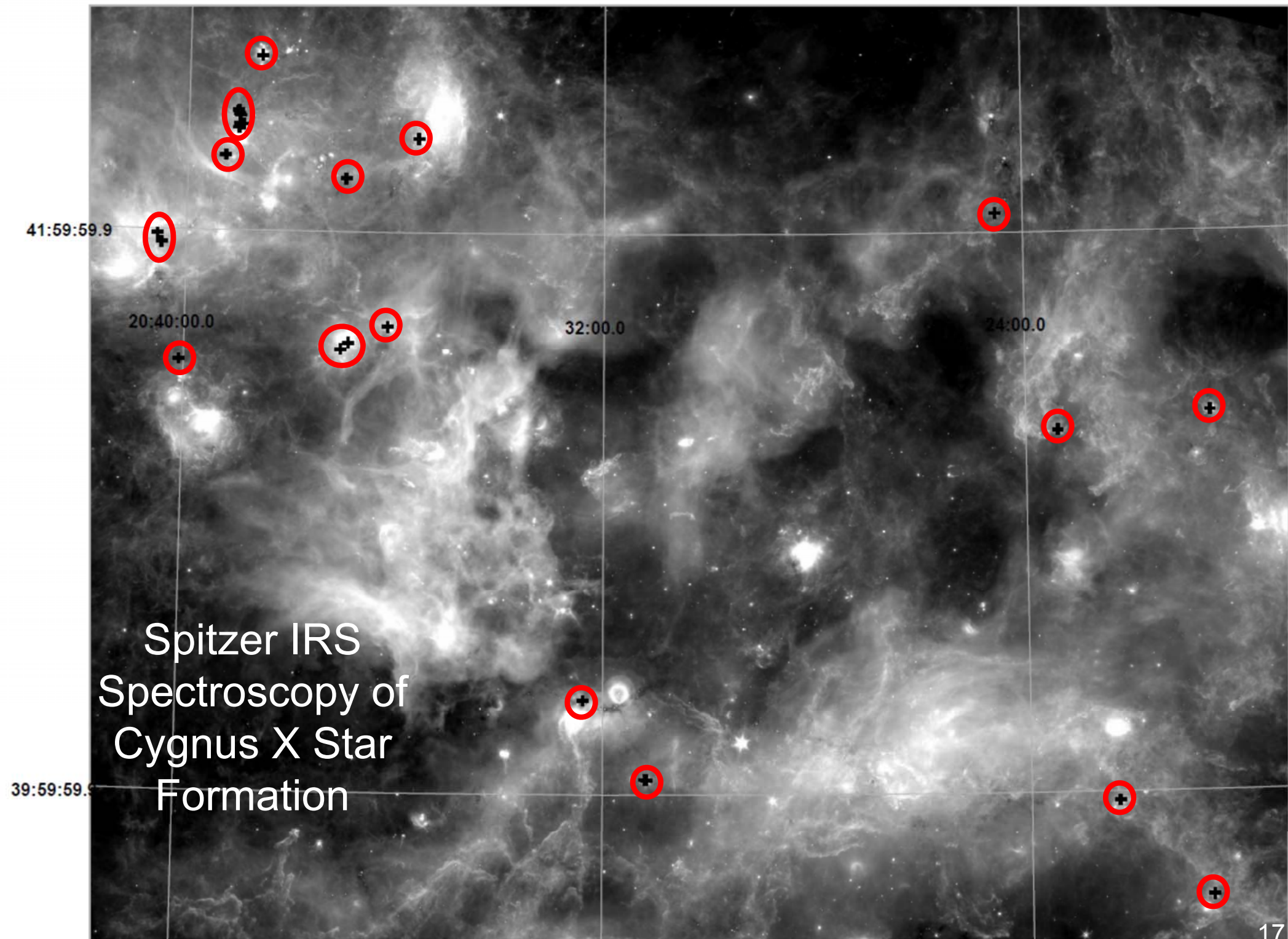
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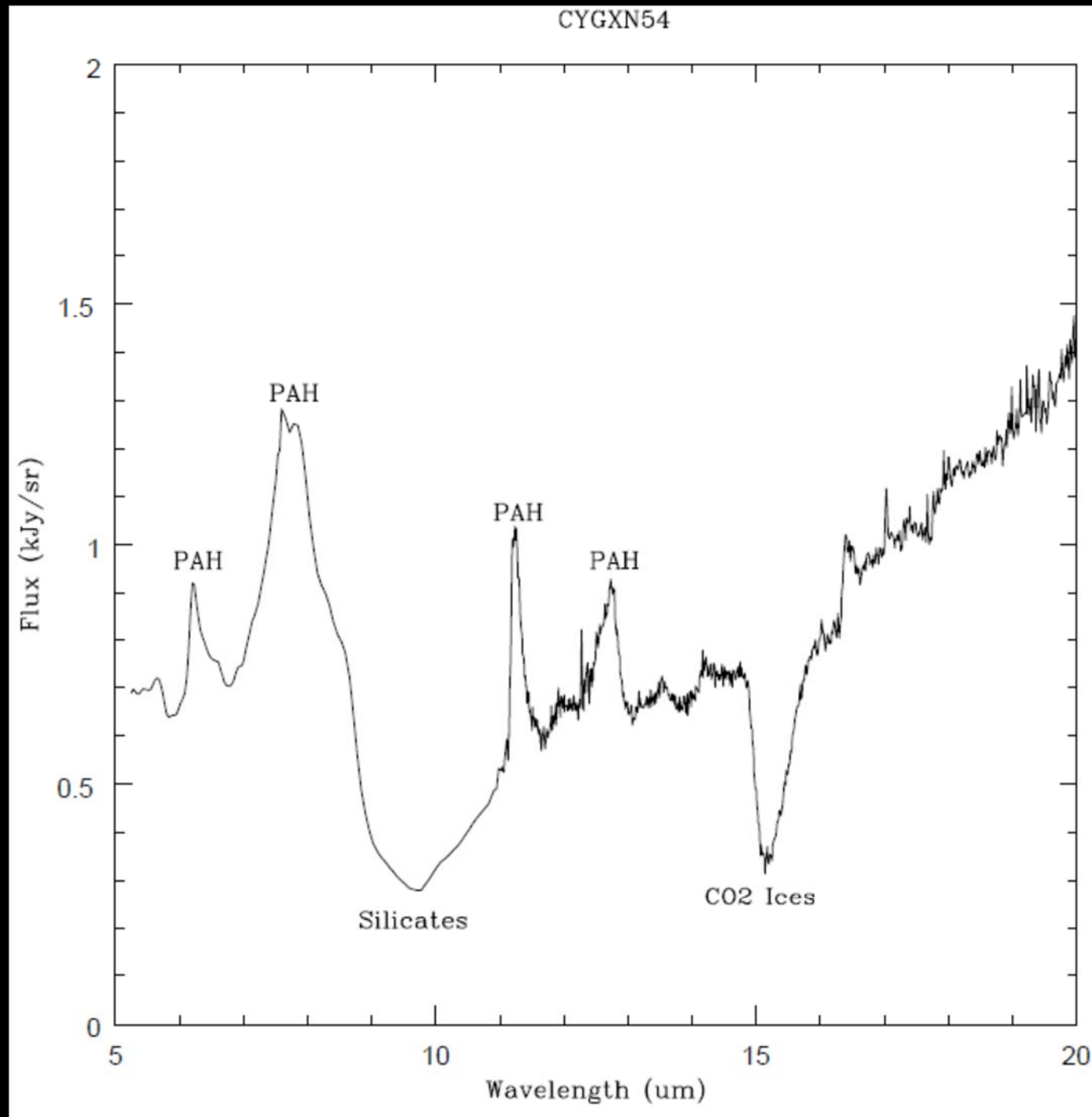




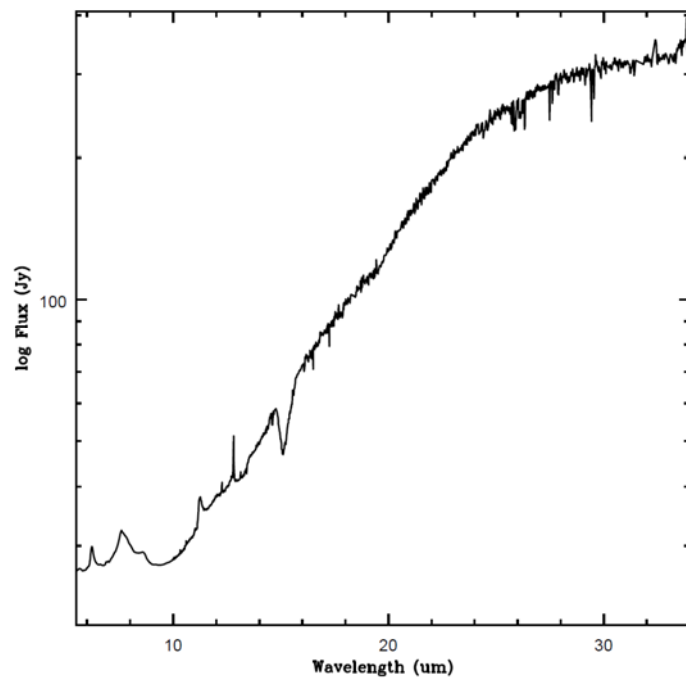
# Spitzer IRS Spectroscopy of Cygnus X Star Formation

(Segura-Cox et al. 2013)

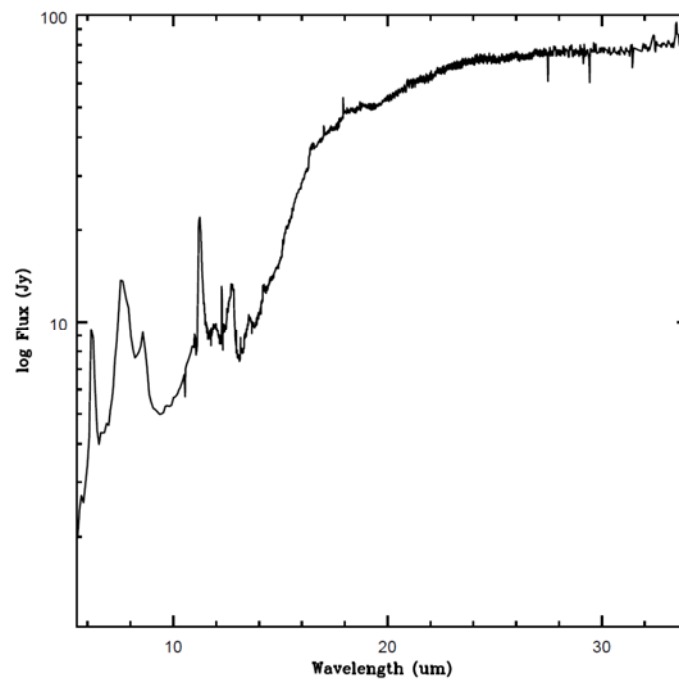
Features detected  
include PAHs, silicate  
and CO<sub>2</sub> absorption,  
and emission lines of  
H<sub>2</sub>, [Ne II], [Ne III],  
[S III]



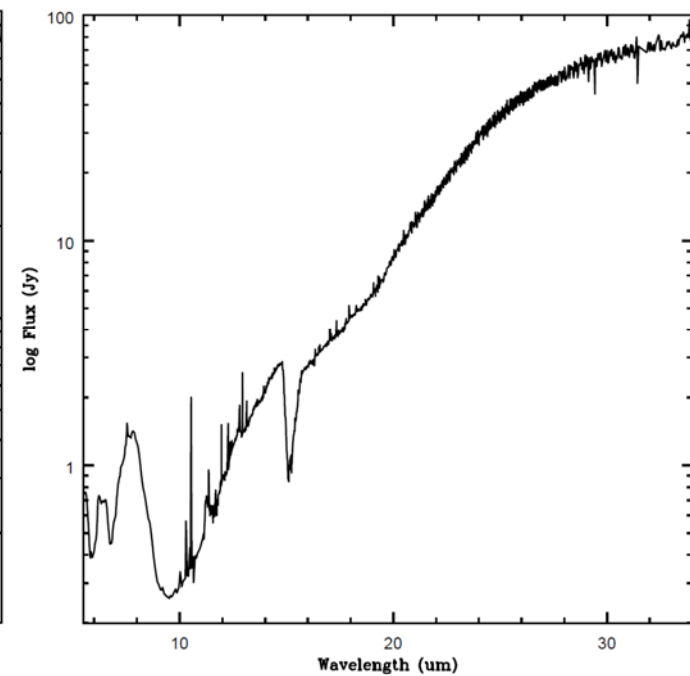
CYGXS8



CYGXS38

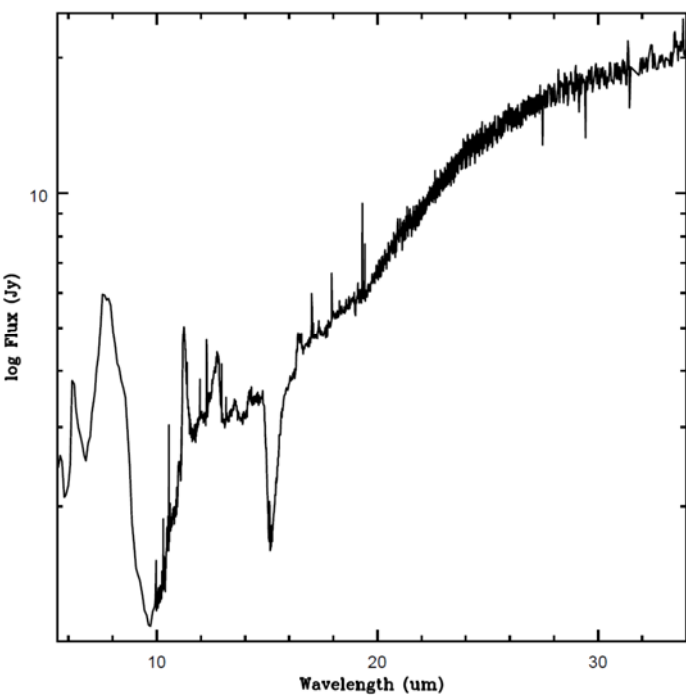


CYGXS43

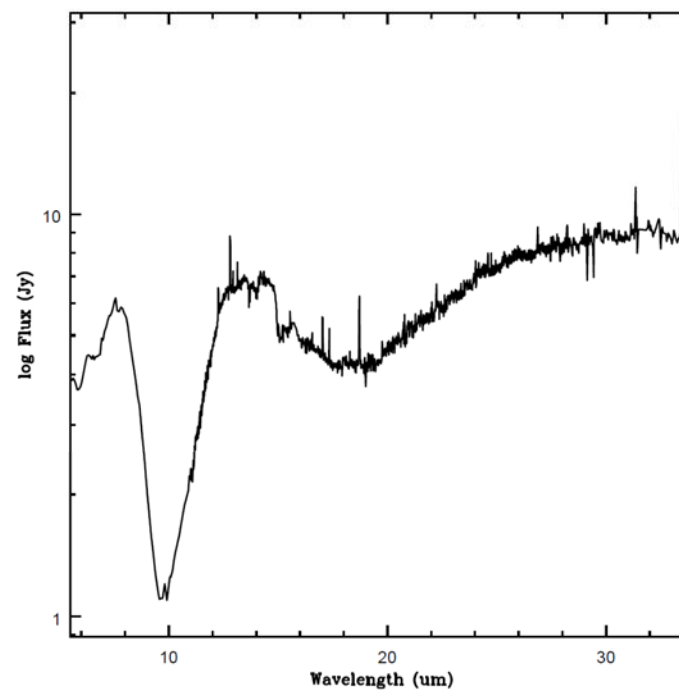


## Sample IRS Spectra of Cygnus X YSOs (Segura-Cox et al. 2013)

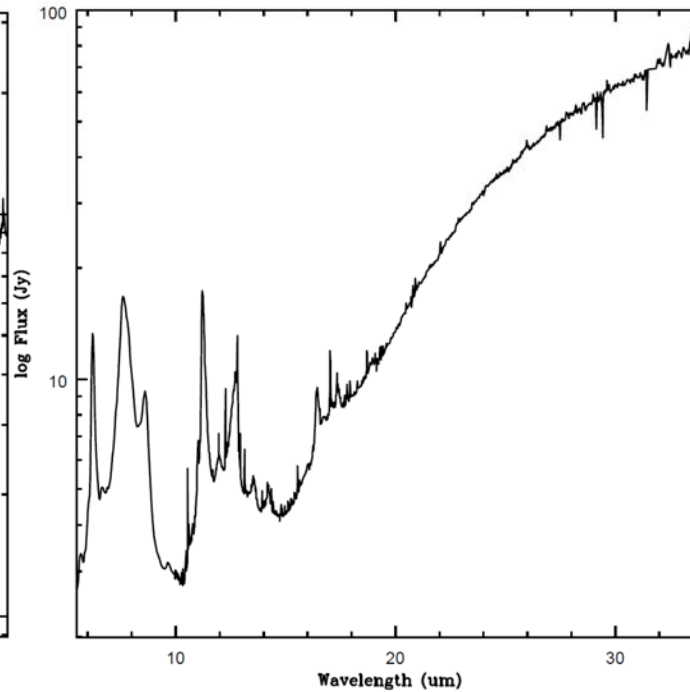
CYGXS54



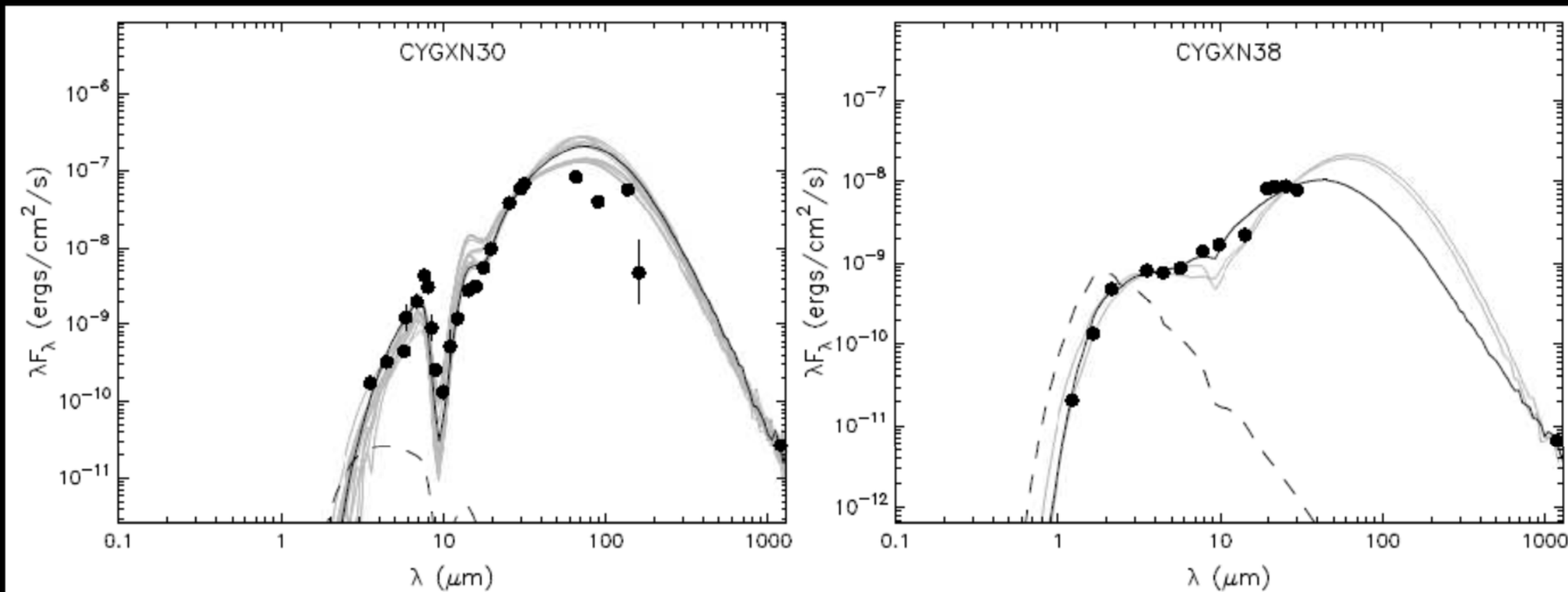
CYGXS56



IRAS 20205+3948



# YSO SED Fitting

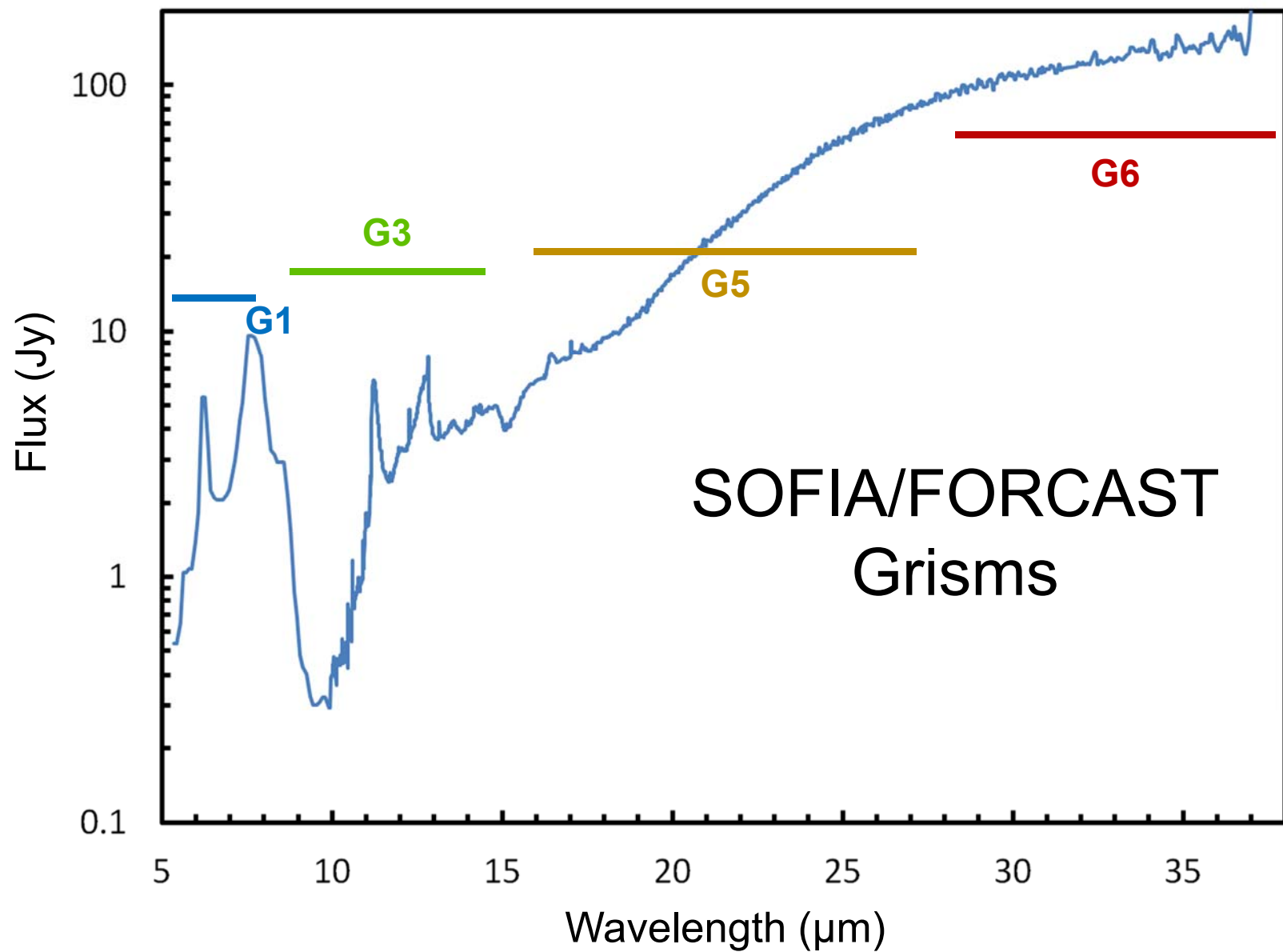


# SOFIA/FORCAST CygX Program

- We proposed to use FORCAST to obtain 5-40  $\mu\text{m}$  spectra of a sample of massive stars in the Cygnus-X region
  - Sample is selected from IR-bright and previously detected (Motte et al. 2007) mm continuum sources
  - Contain objects with a range of masses and at various stages of evolution
- These data along with Spitzer/IRS sample will enable us to determine how the properties of the massive stars change as they evolve towards the main sequence

# SOFIA/FORCAST CygX Program

- YSO model fitting of SED
- Use emission lines if present, e.g. [Ne II], [S IV], to determine the exciting star's temperature
- PAH feature ratios will provide information on relative grain sizes and ionization fraction
- Continuum emission and silicate absorption depth can provide model constraints to estimate
  - masses of the gas and dust
  - the column densities of the absorbing material
  - luminosities of the objects



# FORCAST Source List

Object <sup>1</sup>	RA	Dec	MSX 21 $\mu\text{m}$ flux <sup>1</sup> (Jy)	Other name(s)
N46	20:39:01.25	+42:19:53.8	272	DR21
N58	20:39:25.88	+41:20:01.8	634	IRAS20375+4109
S28	20:29:36.70	+39:01:21.0	204	IRAS20277+3851
NW1	20:19:39.27	+40:56:36.4	401	IRAS20178+4046
S18	20:27:26.85	+37:22:52.9	414	S106-IR

<sup>1</sup>Motte et al. 2007



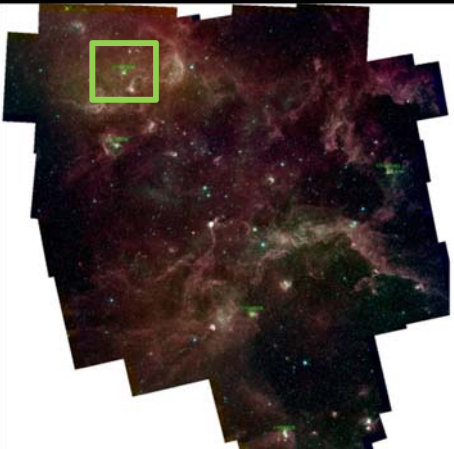
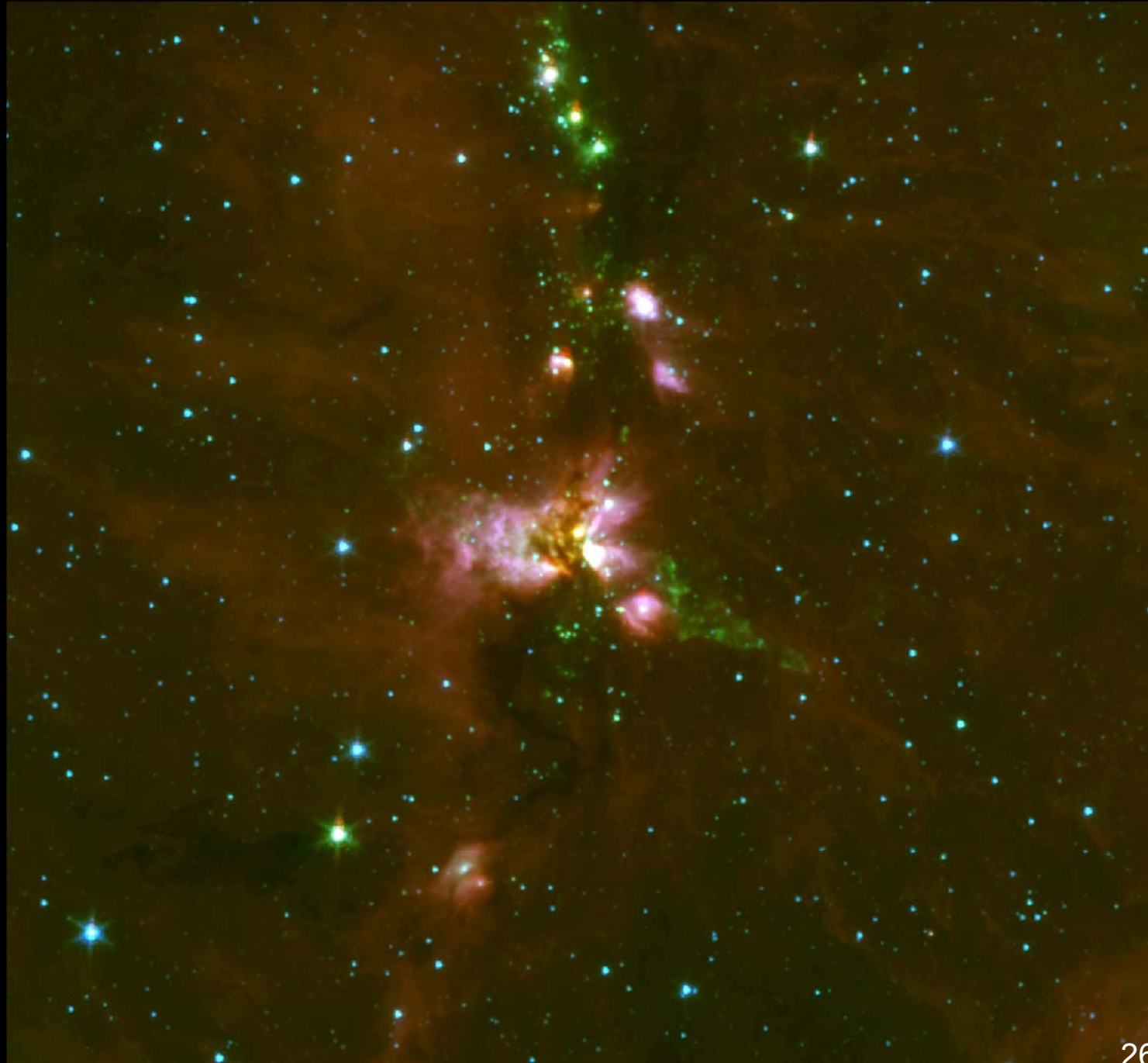
# SOFIA Project Status

- CYGXS18 scheduled for OC1-B Flight 5.
  - Take off date June 27 (PDT) - **CANCELED** 😞
- **Can be scheduled for Sept. 2013 FORCAST flights**

# CYGXNW46 (DR 21)

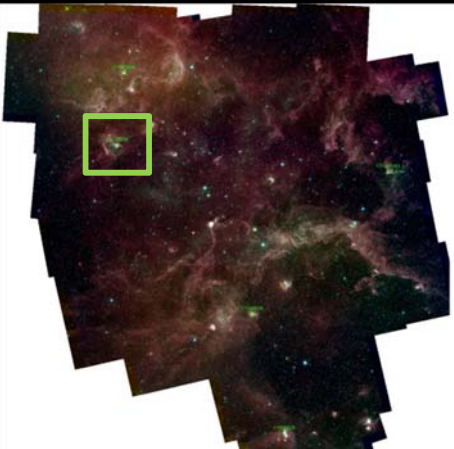
Massive ( $3 \cdot 10^4 M_{\odot}$ )  
filament containing  
many HII regions,  
outflows, massive  
stars, masers, IRDC

DR21 source  
possibly cluster of  
O stars



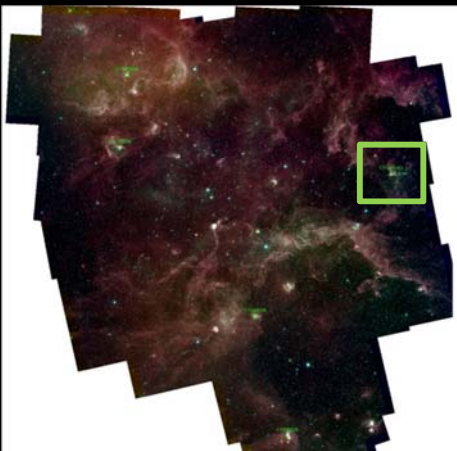
# CYGXNW58 (DR 22)

Bright protostar on  
edge of Bright-  
Rimmed Cloud,  
containing cluster of  
YSOs in the center



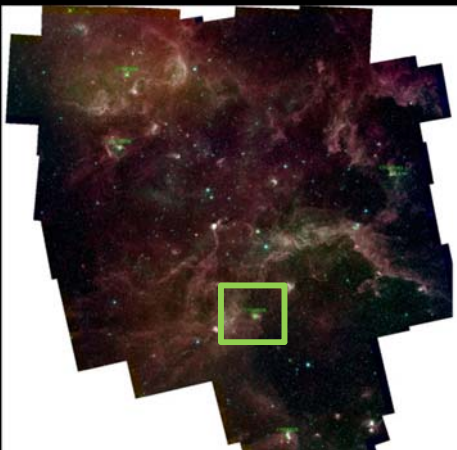
# CYGXNW1

Protostar in filament  
in western part of  
Cygnus-X complex



# CYGXS28

YSO at tip of  
feature extending  
into the center of  
the BRC containing  
cluster

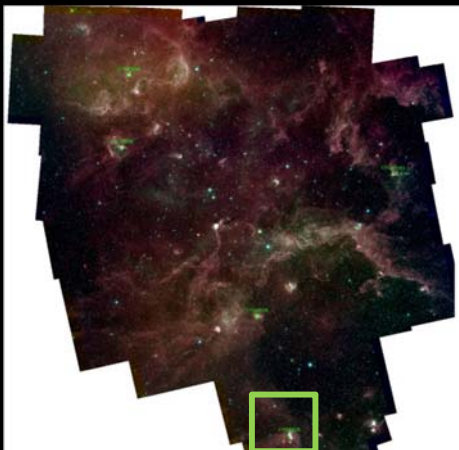


Object on edge of  
region cleared by  
Cyg OB1/9

Bipolar nebula with  
dark central lane,  
powered by O7-O9  
star

Simon et al. (2012)  
used GREAT to  
resolve complex  
kinematics of  
 $158\mu\text{m}$  [C II] and  
CO 11 $\rightarrow$ 10 lines

## CYGXS18 (S106)



# SOFIA Cygnus X Summary

- Our Previous Spitzer/IRS program observed a sample of massive YSOs
- The SOFIA observing program will obtain similar data on the brightest massive stars in Cygnus-X
- This will enable us to determine the properties of these massive stars and how they change as they evolve towards the main sequence
- We will also be able to examine their effects on their surroundings, including outflows into the nearby ISM and also in triggering further star formation.

Find images and links to the Spitzer CygnusX data:  
<http://www.cfa.harvard.edu/cygnusX>