Chandra and NIR Observations of Galactic HII Regions

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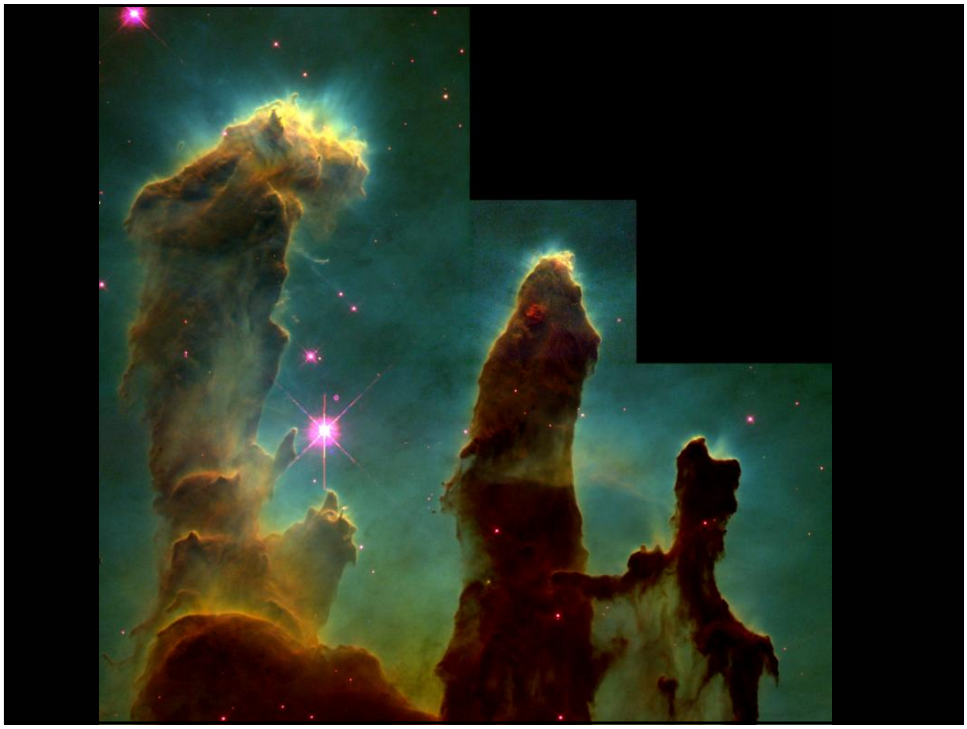
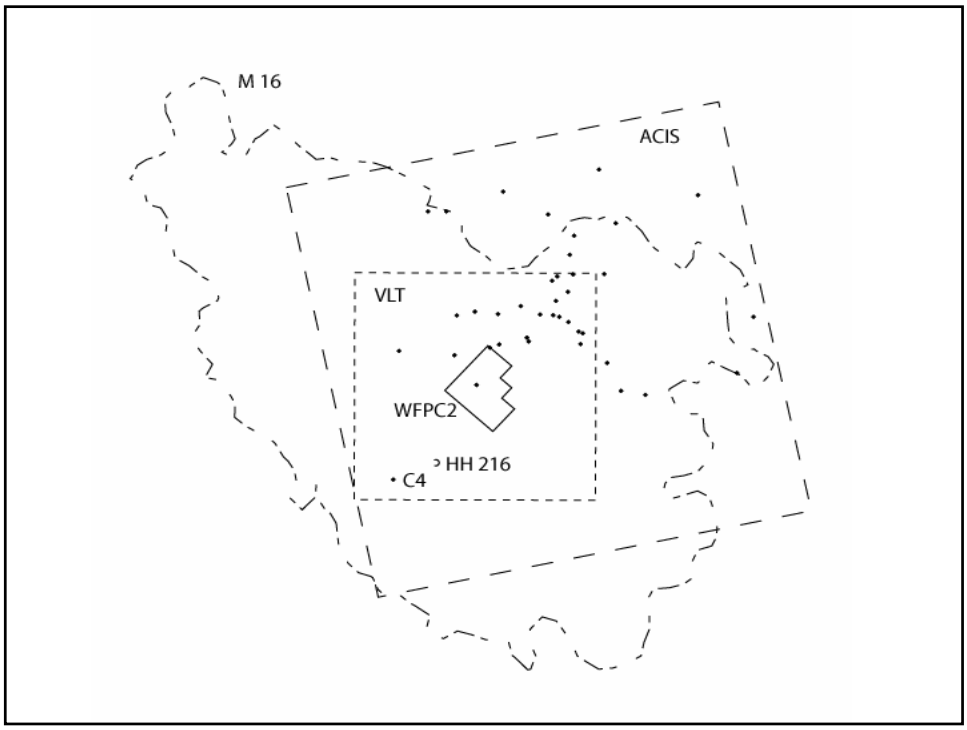
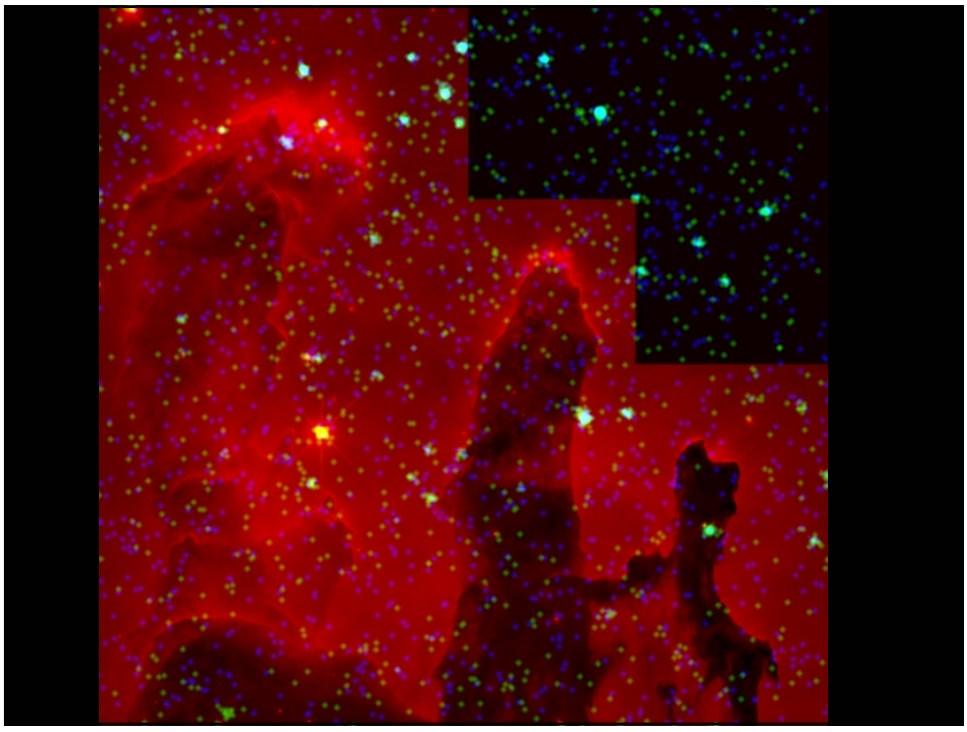


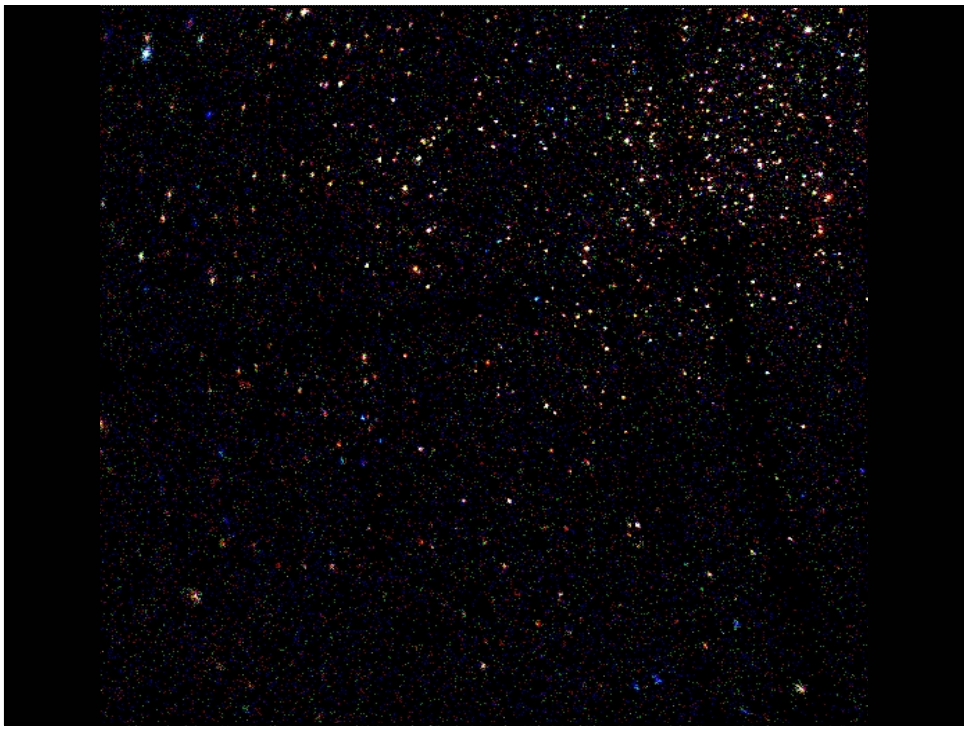

M 16
ACIS
VLT
WFPC2
HH 216
C4

78-ks *Chandra* ACIS-I RGB image of M16 and NGC 6611.

Red: 0.5-1.5 keV, green: 1.5-2.5 keV, blue: 2.5-7 keV.

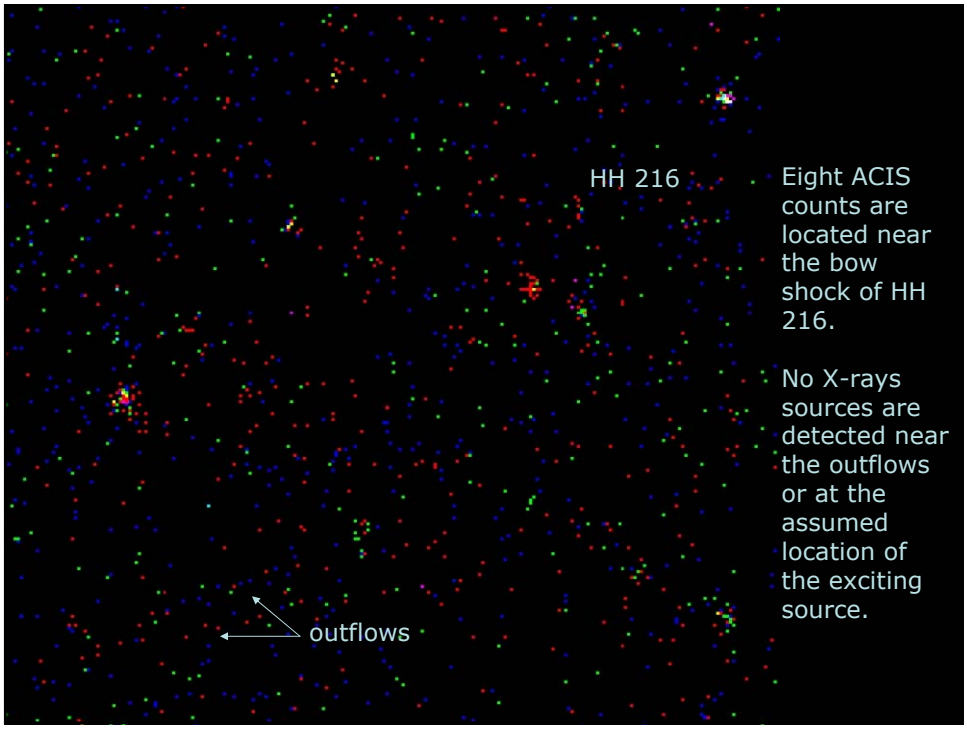
1103 X-ray sources, 959 with 2MASS or VLT counterparts.





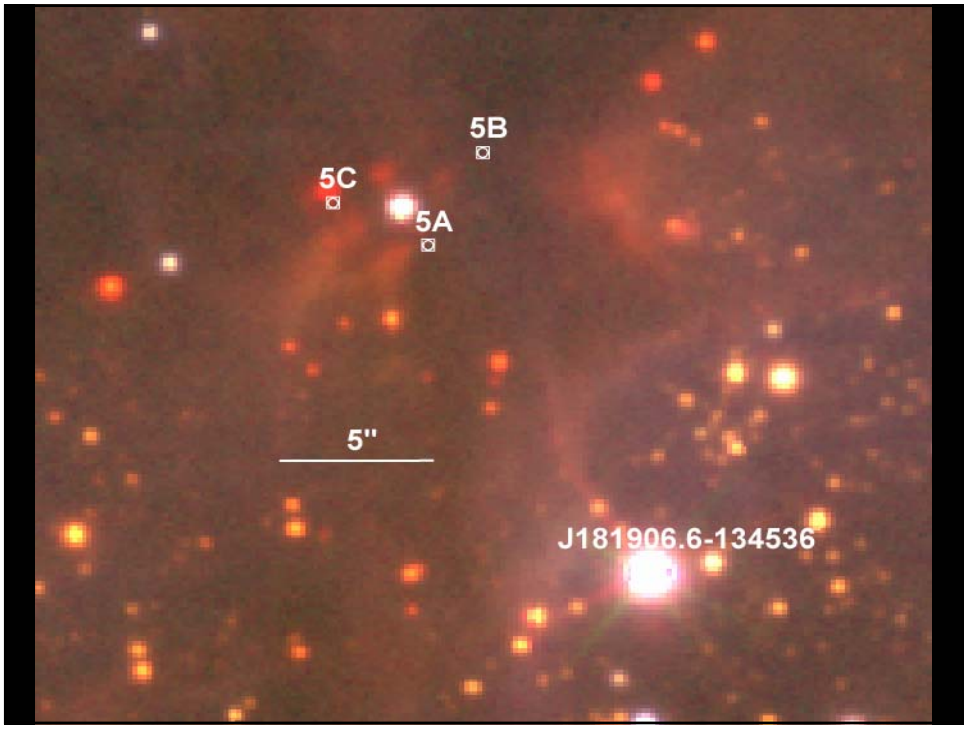
1.5′ × 1.125′ VLT J_sHK_s image of the top of Column 1. M16ES-1=YSO1 (Thompson, Smith & Hester 2002; McCaughrean & Andersen 2002) is a ~10 M_o YSO. No strong flares are seen in the *Chandra* light curve. M16-ES1's temperature and column density are kT ~ 3 keV and N_H ~ 4.5×10^{22} cm^{-2} (A_V ~ 27 mag).

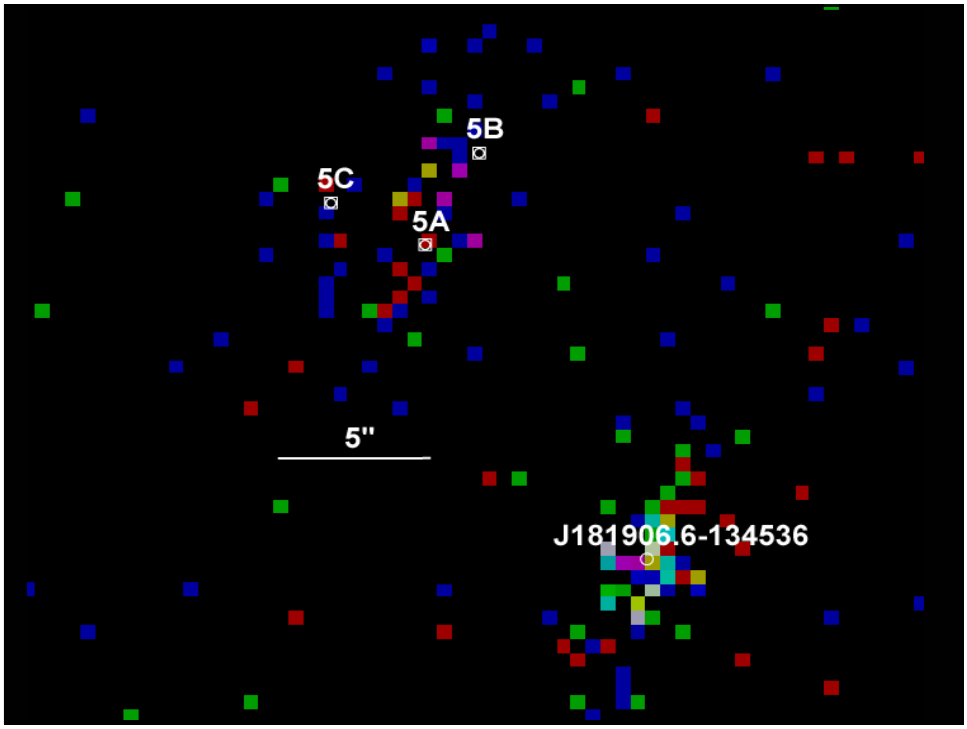
HH 216 and two outflows in column 4 (McCaughrean & Andersen).

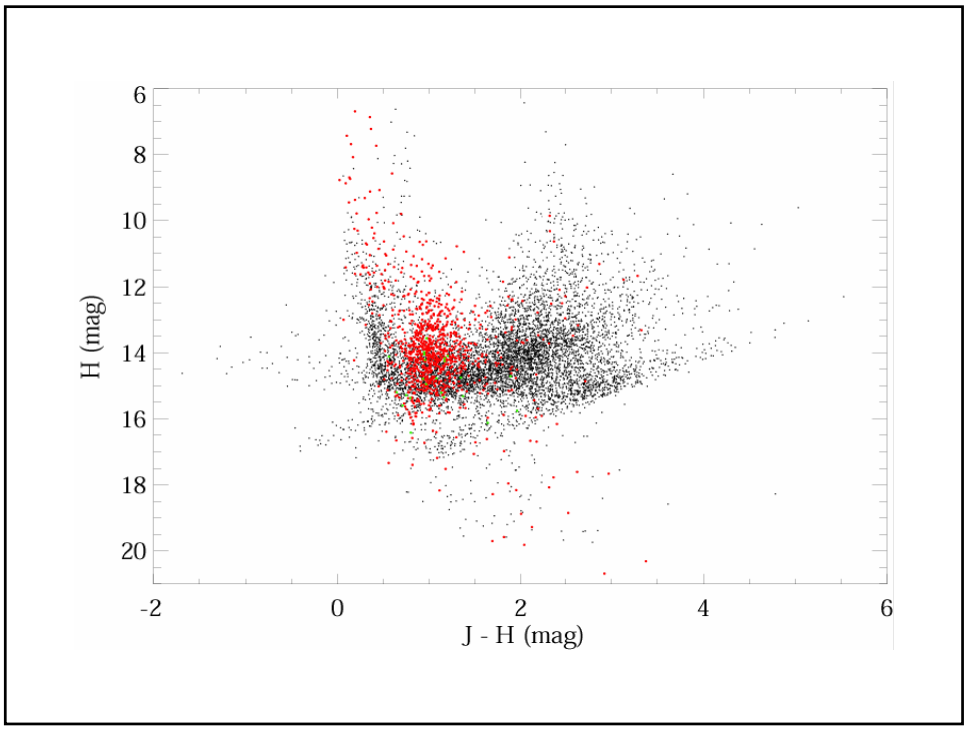


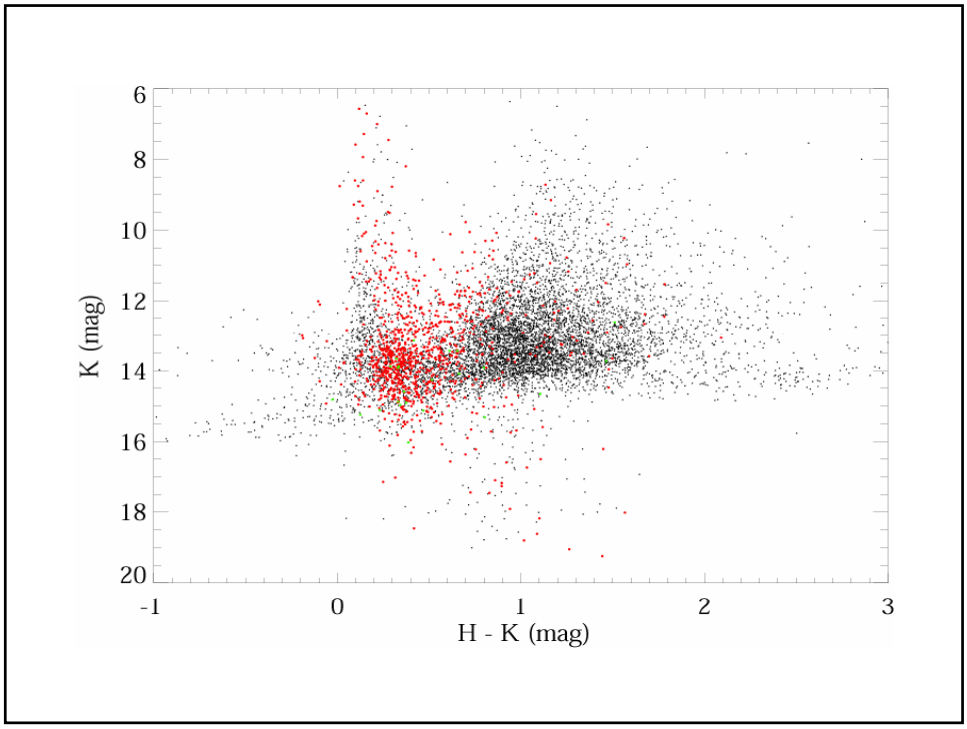
Eight ACIS counts are located near the bow shock of HH 216.

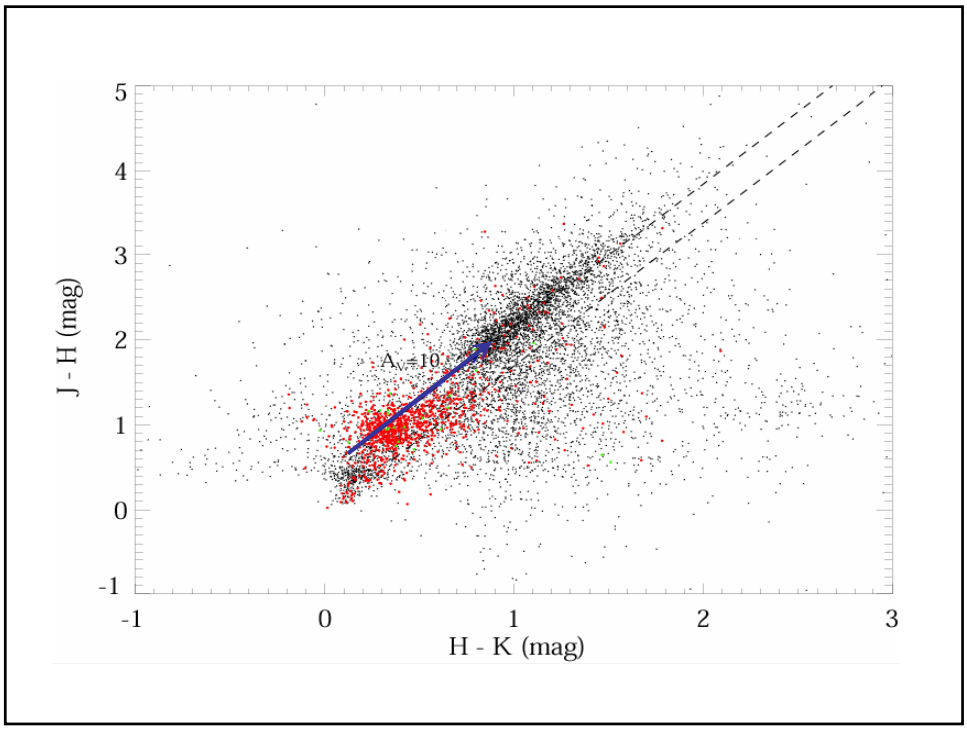
No X-rays sources are detected near the outflows or at the assumed location of the exciting source.




5B
5C
5A
5"
J181906.6-134536


H (mag)
J - H (mag)
6
8
10
12
14
16
18
20
-2
0
2
4
6


K (mag)
H - K (mag)
6
8
10
12
14
16
18
20
-1
0
1
2
3

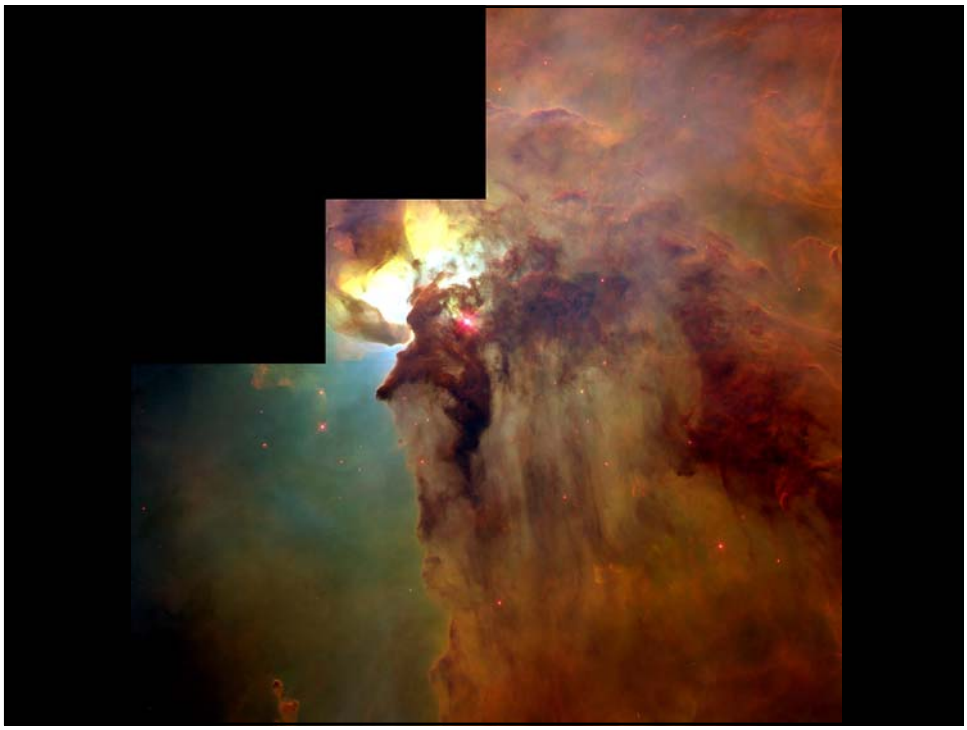

J - H (mag)
H - K (mag)
A_V = 10
5
4
3
2
1
0
-1
-1
0
1
2
3

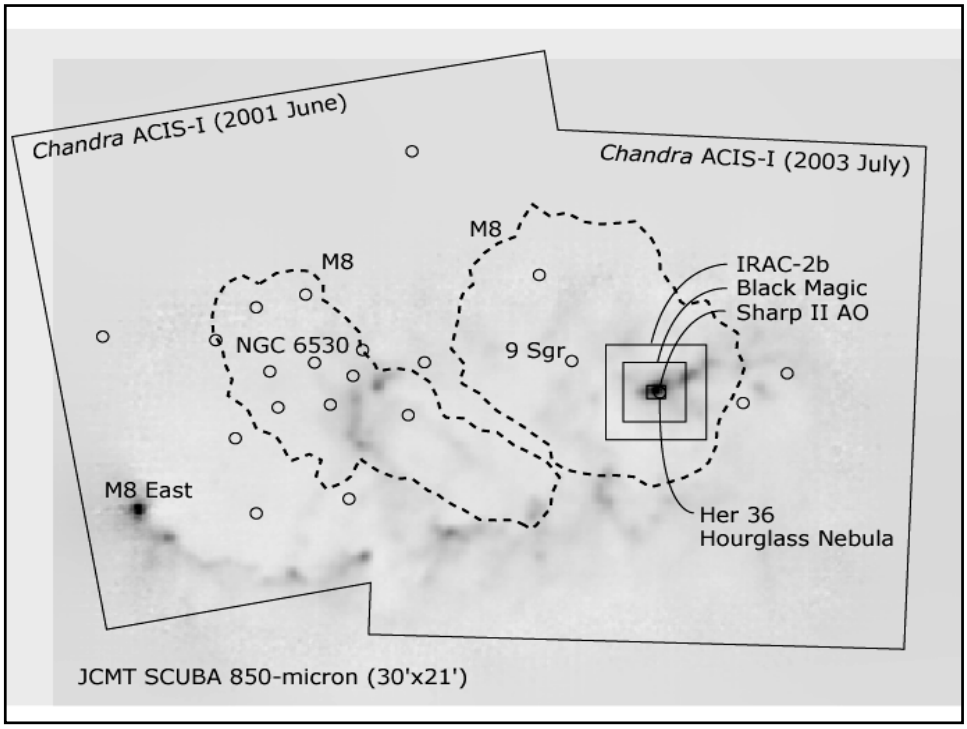
Massive Stars in M16

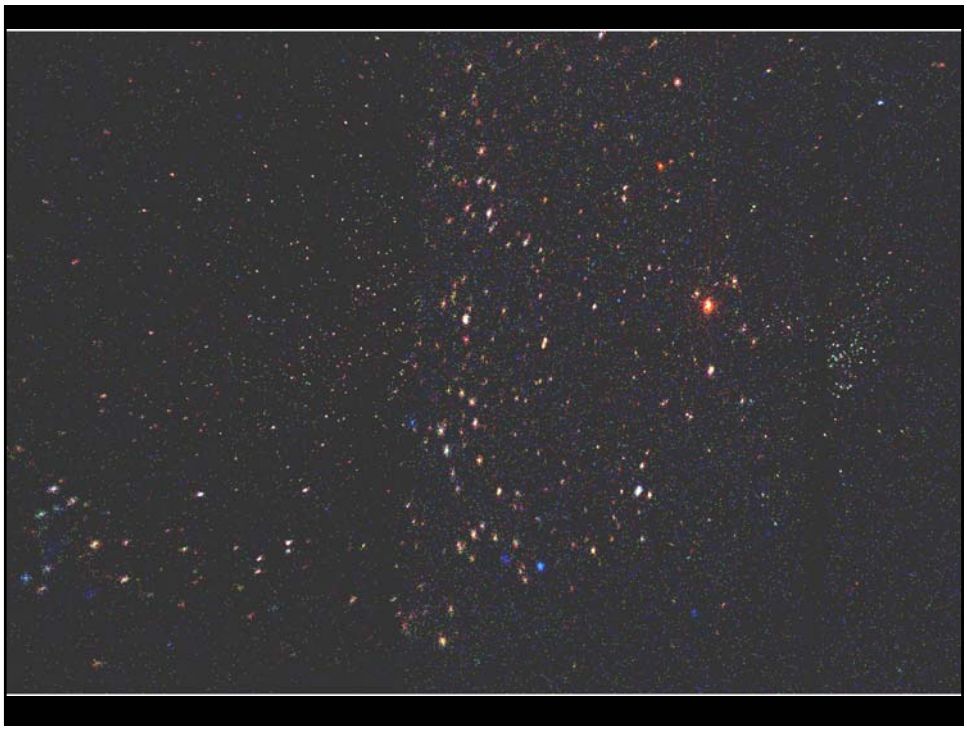
- The 11 O5 V - O9.5 V stars in NGC 6611 are all detected with *Chandra*, with L_X in the range $5.3´10^{30}$ – $1.8x10^{32}$ ergs s-1, L_X/L_{bol} in the range $1.4x10^{-8}$ – $6.8x10^{-8}$, and kT from 0.49–0.96 keV.
- The 2-Myr old O stars in NGC 6611 have relatively soft X-ray spectra and low L_X/L_{bol} , like many nearby O stars whose winds are thought to drive instabilities and X-ray emitting shocks.
- The O stars in NGC 6611 are to be contrasted with those in the younger Orion Nebula Cluster with hard, time-variable X-rays and higher L_X/L_{bol}, most likely produced by magnetic activity.

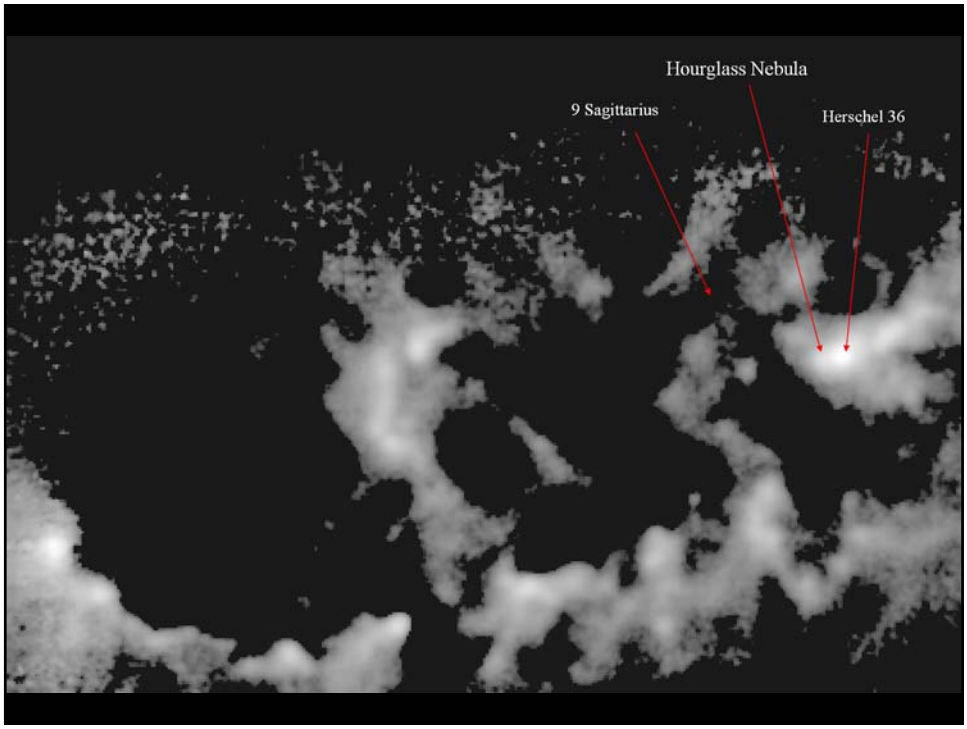
Star Formation in M16

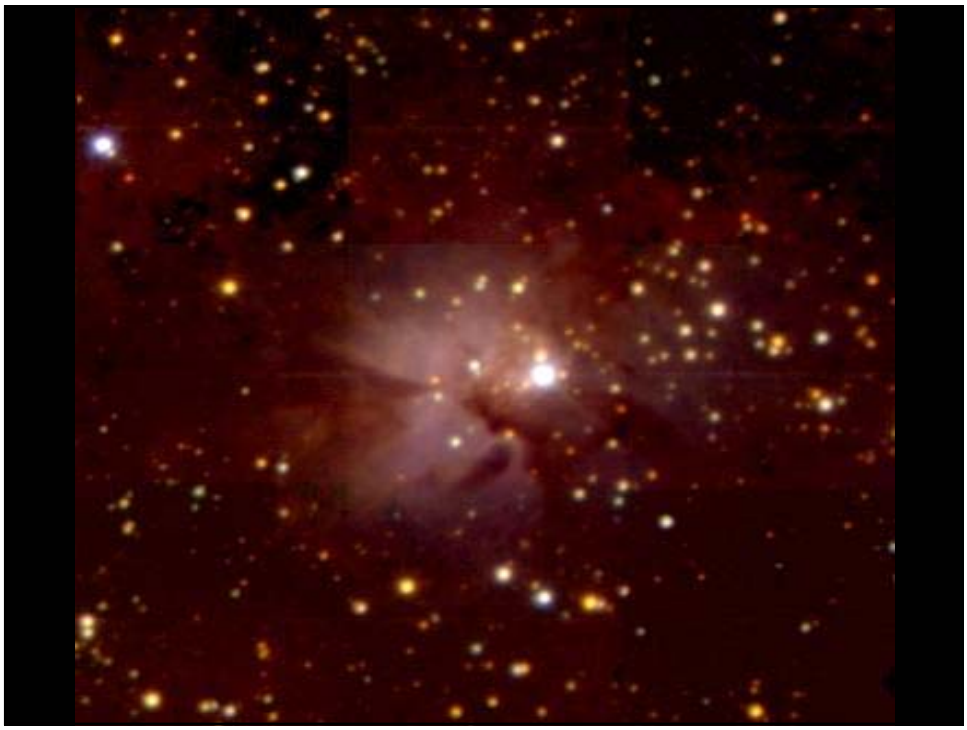
- Most stars in NGC 6611 formed ~2 Myr ago. High-mass stars and low-mass Class II and Class III YSOs appear to have properties like those in clusters of similar ages.
- Limiting 2-8 keV X-ray luminosity is log L_X ~ 29.8 ergs s^{-1}.
- With ~950 detected members, we thus estimate ~5300 cluster members in NGC 6611.
- Although some star formation is occurring in the columns of M16, few X-ray sources.
- The EGGs appear not to contain X-ray bright YSOs.
- Few signs of recently triggered star formation.

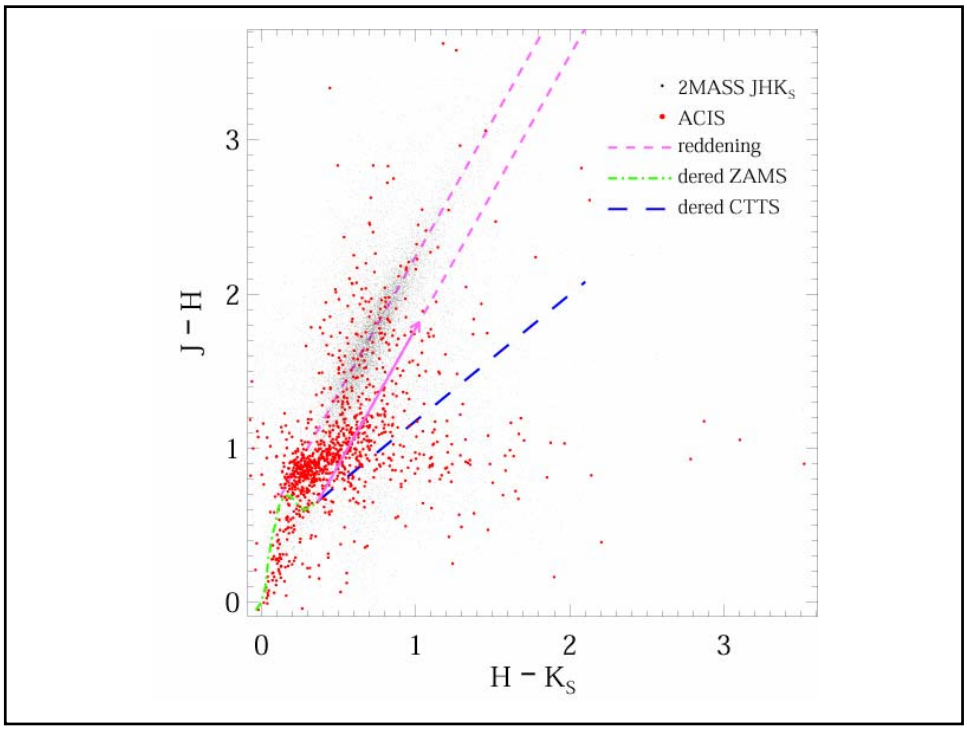


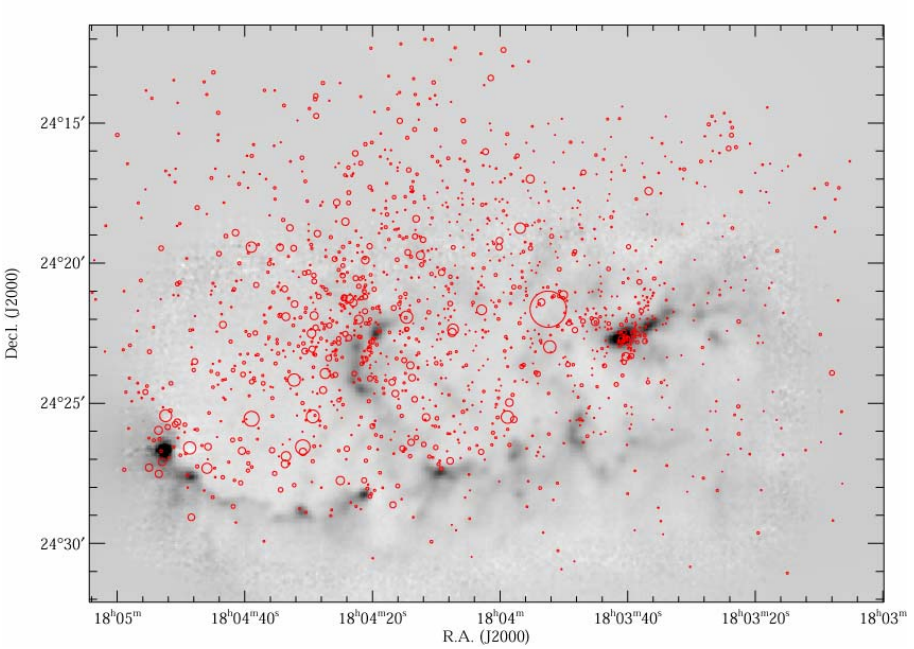

Chandra ACIS-I (2001 June)
Chandra ACIS-I (2003 July)
M8
M8
IRAC-2b
Black Magic
Sharp II AO
NGC 6530
9 Sgr
M8 East
Her 36
Hourglass Nebula
JCMT SCUBA 850-micron (30'x21')

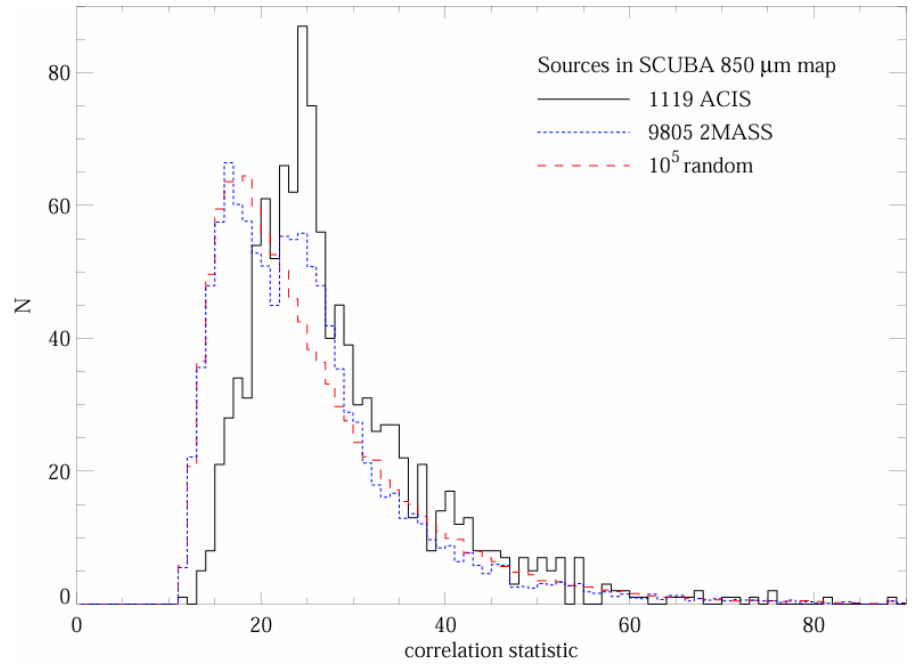


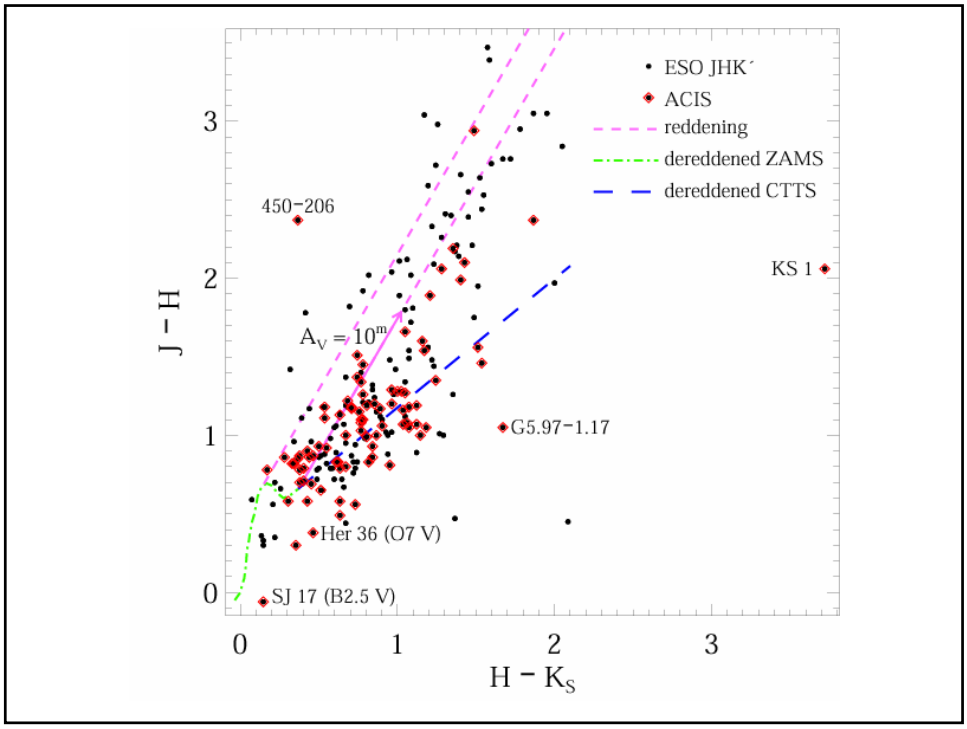

Hourglass Nebula
9 Sagittarius
Herschel 36

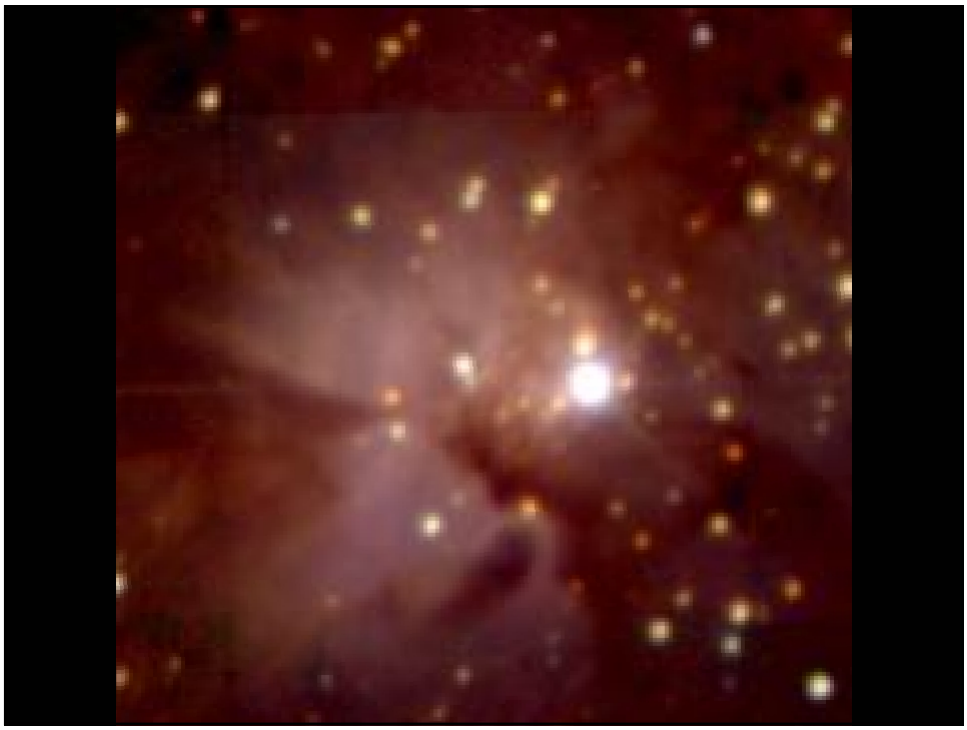


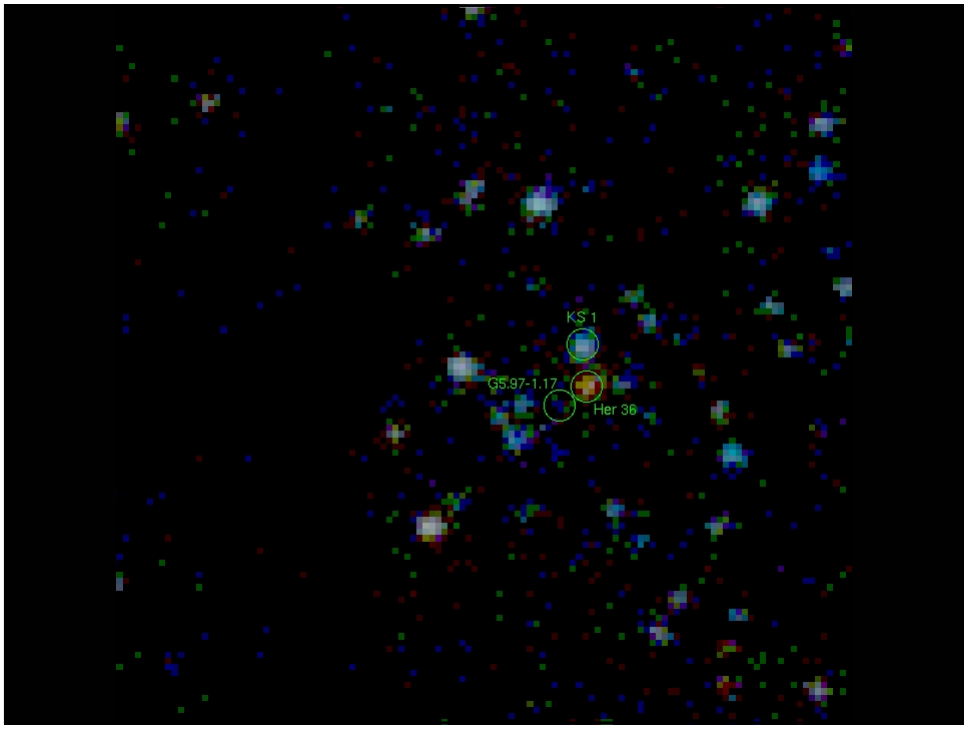

2MASS JHK$_S$
ACIS
reddening
dered ZAMS
dered CTTS
J − H
H − K$_S$
0
1
2
3


24°15′
24°20′
24°25′
24°30′
Decl. (J2000)
18h05m
18h04m40s
18h04m20s
18h04m
18h03m40s
18h03m20s
18h03m
R.A. (J2000)


Sources in SCUBA 850 μm map
1119 ACIS
9805 2MASS
10^5 random
N
0
20
40
60
80
correlation statistic


ESO JHK´
ACIS
reddening
dereddened ZAMS
dereddened CTTS
450−206
KS 1
$A_V = 10^m$
G5.97−1.17
Her 36 (O7 V)
SJ 17 (B2.5 V)
J − H
H − K_S
0
1
2
3





Massive Stars in M8

- The OB stars in the 2-Myr old NGC 6530 cluster, including the O4 I star 9 Sgr, are soft X-ray sources with normal X-ray to bolometric luminosity ratios.
- The young mid-O star Herschel 36 at the center of the newly discovered Hourglass Nebula cluster is a soft, steady X-ray source, again suggesting wind-driven X-ray emission.
- The massive YSO M8E is a hard, variable X-ray source.

Star Formation in M8

- Most stars in NGC 6530 formed ~2 Myr ago. High-mass stars and low-mass Class II and Class III YSOs have typical X-ray properties.
- SCUBA 850μm emission spatially correlated with many hard, variable X-ray sources near Her 36, M8E and the central ridge.
- Hourglass Nebula Cluster is denser, younger cluster including the O7 V star Her 36 and the ultracompact HII region G5.97-1.17.
- Limiting 2-8 keV X-ray luminosity near Her 36 is log L_X=29.4 ergs s^{-1}.
- XLF suggests 3000 NGC 6530 members, 400 in the Hourglass Nebula Cluster, and 1000 in M8E and the central ridge.

Star Formation in M17, M20 and the Rosette Nebula

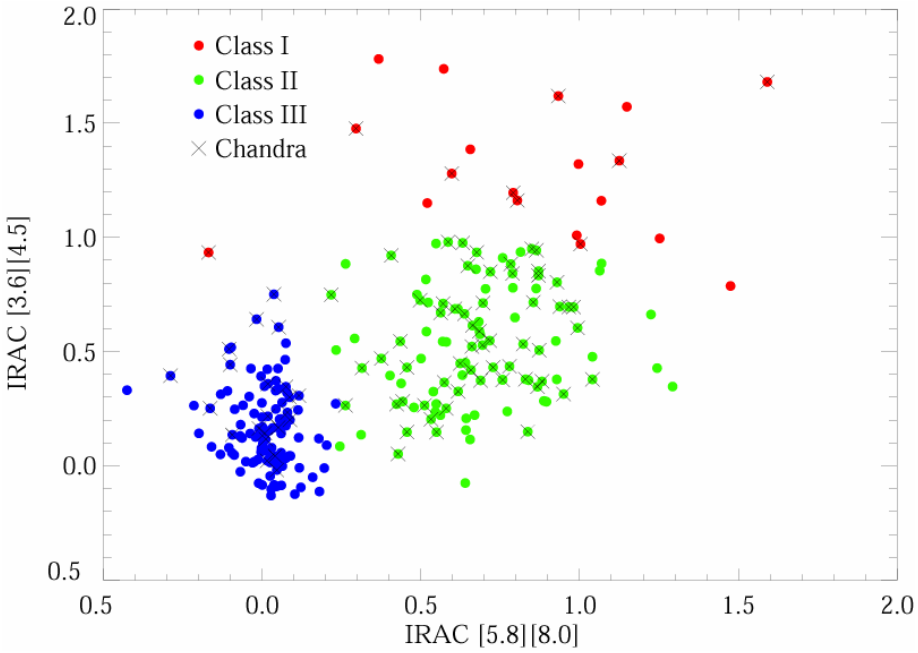
- Diffuse, soft X-rays spatially and spectrally distinct from stellar populations in Rosette, RCW 38, RCW 49, M17, and W51A (Townsley et al. 2003, 2004)
- Also in giant HII regions: Arches, NGC 3603, Carina, 30 Dor
- 304 X-ray sources in 58-ks ACIS exposure of M20 (Rho et al. 2004).

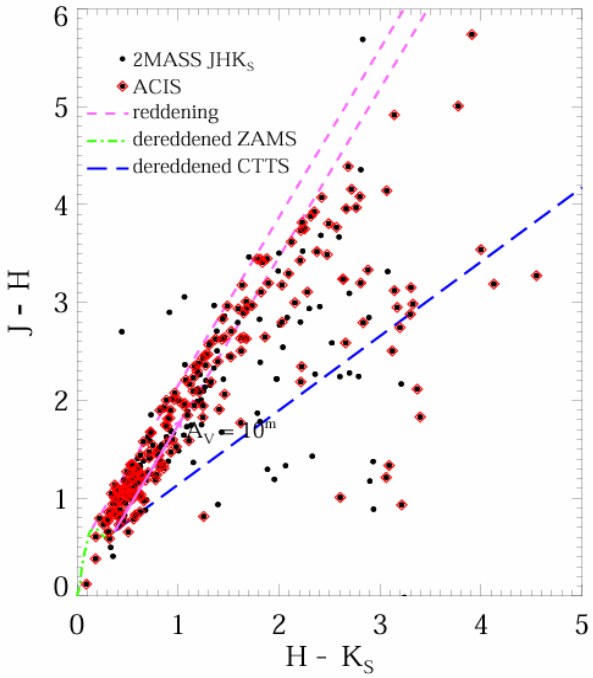
Future Prospects

- *Spitzer* IRAC and MIPS photometry needed to classify low-mass YSOs.
- Deeper *Chandra* observations needed while ACIS still operational to identify cluster populations. Future X-ray observatories will not resolve distant, young galactic cluster stars.
- At 2 kpc and $A_V \sim 4$, a 600 ks ACIS-I exposure is needed to achieve a 2-8 keV log Lx ~ 28.8, thereby detecting *half* of all stellar cluster members.

Update on ρ Oph

- *Chandra* (Imanishi et al., Gagné et al., Grosso et al.), XMM (Ozawa et al.) and *Spitzer* (Allen et al.) surveys bring census of L1688 cloud members to 356: 318 in 2MASS, 38 additional Class 0/I.
- Only 219 detected with *Chandra* or XMM.





In ρ Oph (120-140 pc), some moderately reddenned (A_V<30) YSOs are not detected with Chandra or XMM. These lie outside cloud cores A, E and F.

New cloud members are still being detected (Wilking et al. 2005).