X-ray Observations of Massive Star Formation and Feedback

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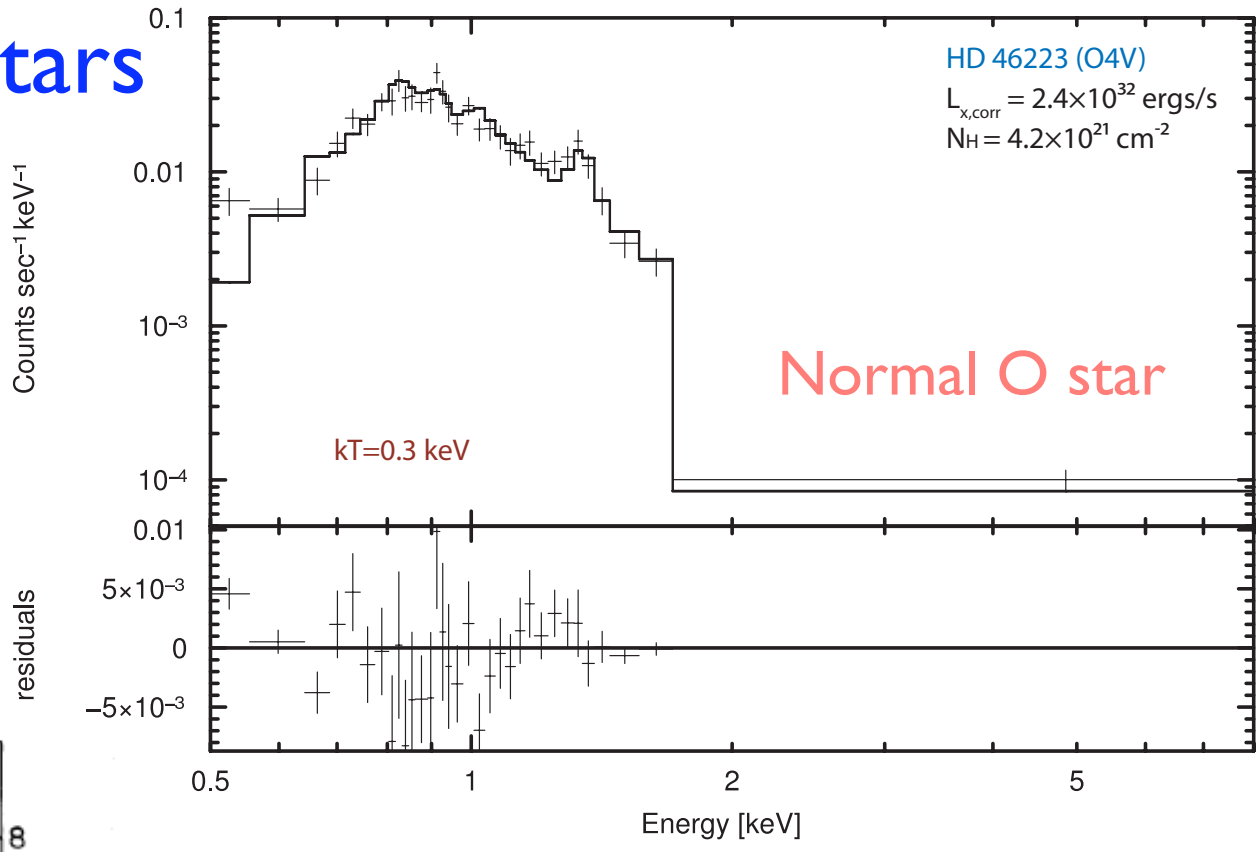
Penn State is the PI institution for ACIS (the Advanced CCD Imaging Spectrometer) on the *Chandra X-ray Observatory*.

X-rays from Massive Stars

Minishocks in fast winds
(Lucy & White 1980) ⇨
soft, constant X-rays (<1 keV).



Then these powerful winds encounter the ISM...

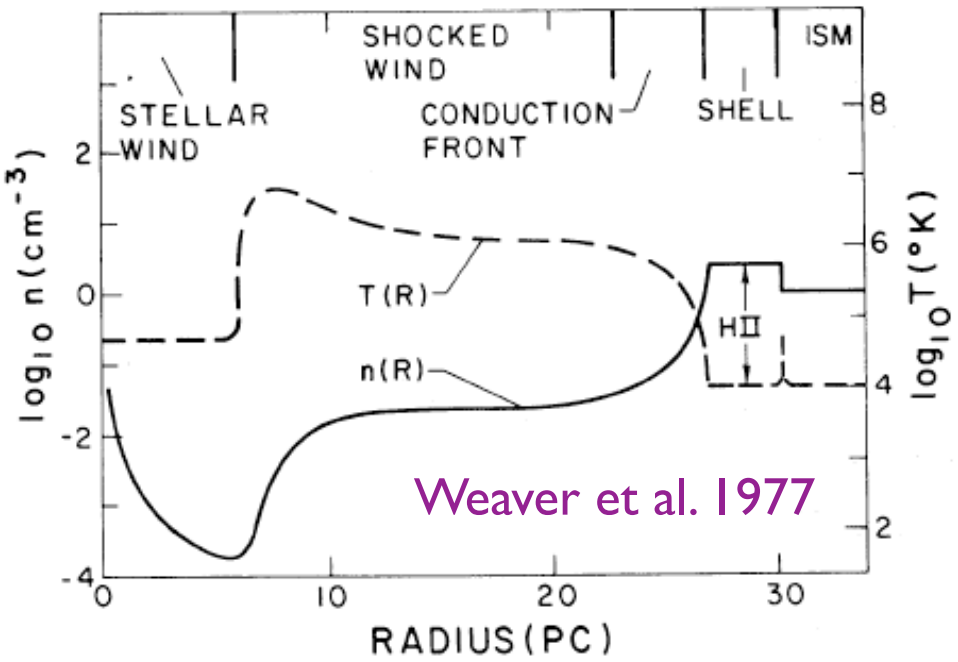


FIG. 3.—The large-scale features of the temperature and density structure of an interstellar bubble for which L_w = 1.27 × 10^{36} ergs s^{-1}, n_0 = 1 cm^{-3}, and t = 10^6 yr. ISM means ambient interstellar medium. For a typical O7 I star, the H II region would extend to ~3 R_2.

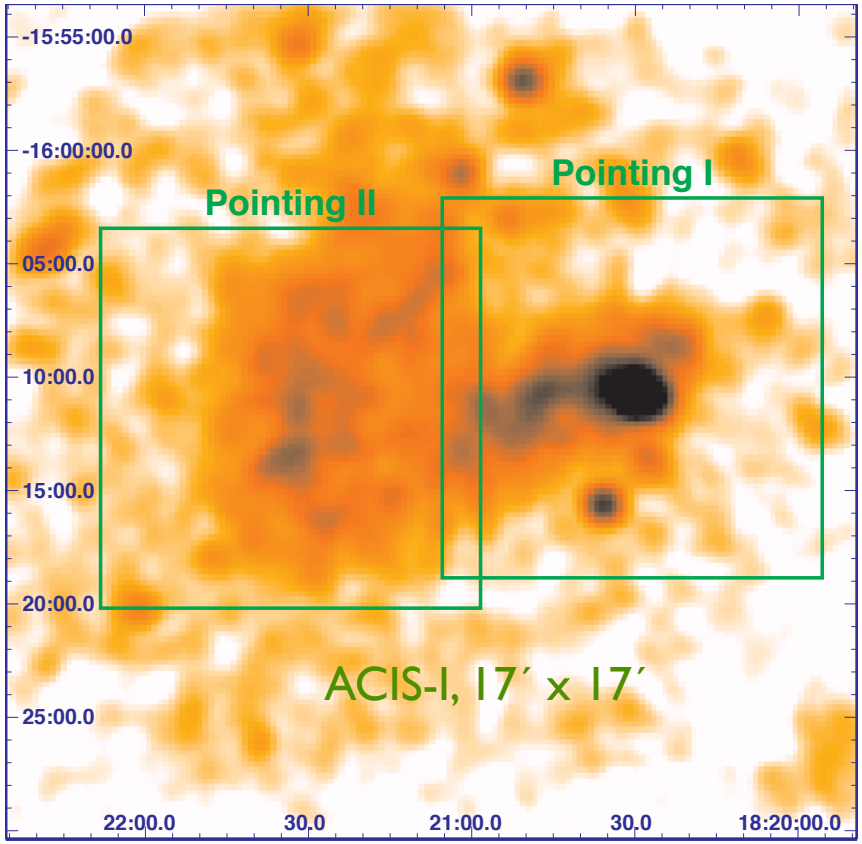
Historically, these diffuse X-rays were not seen.

The problem: limited spatial resolution confuses any diffuse X-ray emission with the point source population in a young cluster; also L_x < theory.

M17, The Omega Nebula: A Fire-breathing Dragon

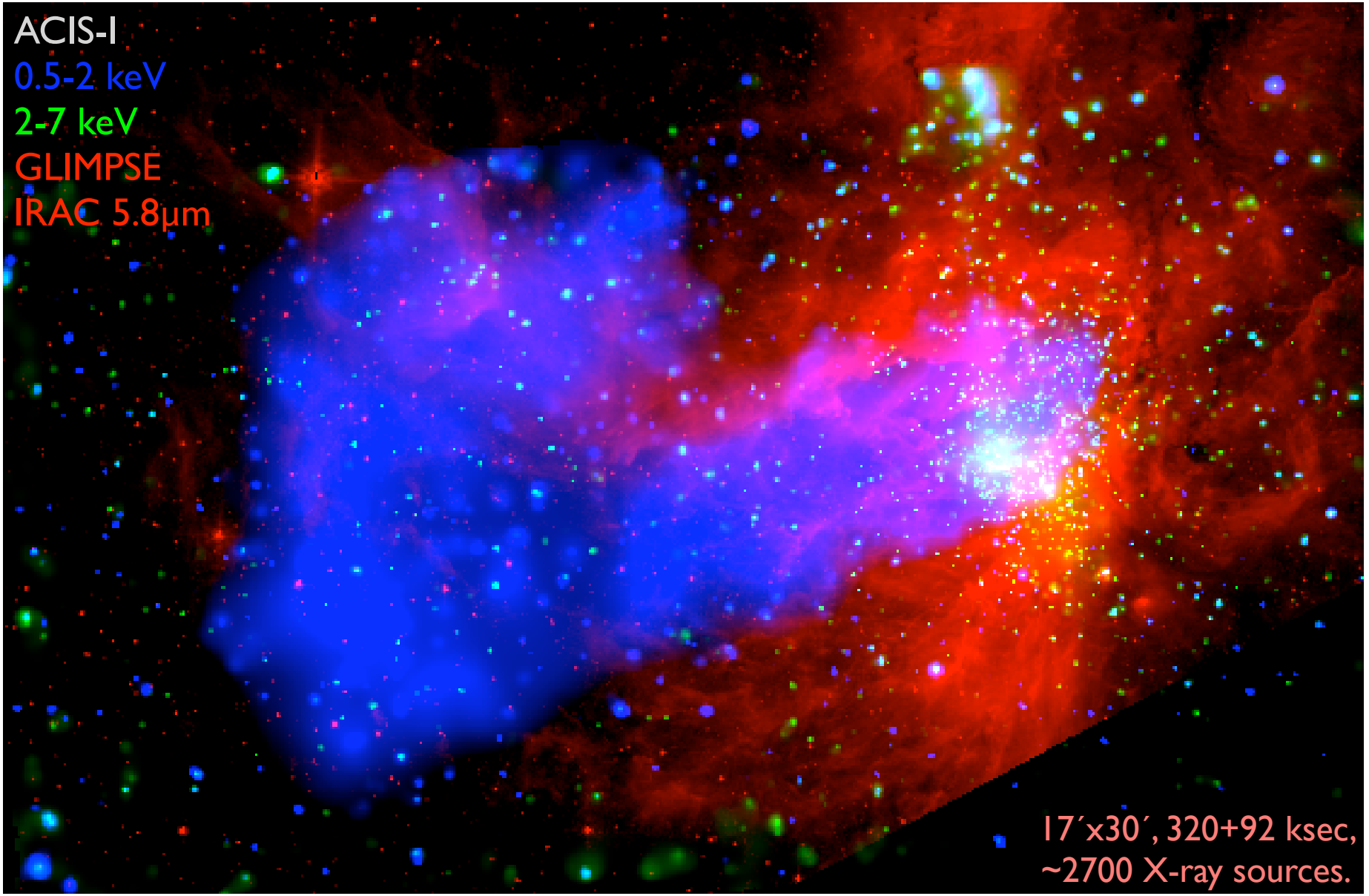
2MASS JHK atlas image, 15′×15′

- D ~2.2 kpc; 10′ ~6.4 pc.
- Closest giant HII region.
- Main cluster age ~0.5 Myr.



ROSAT PSPC image, ~35′×35′.
Point sources or diffuse emission?

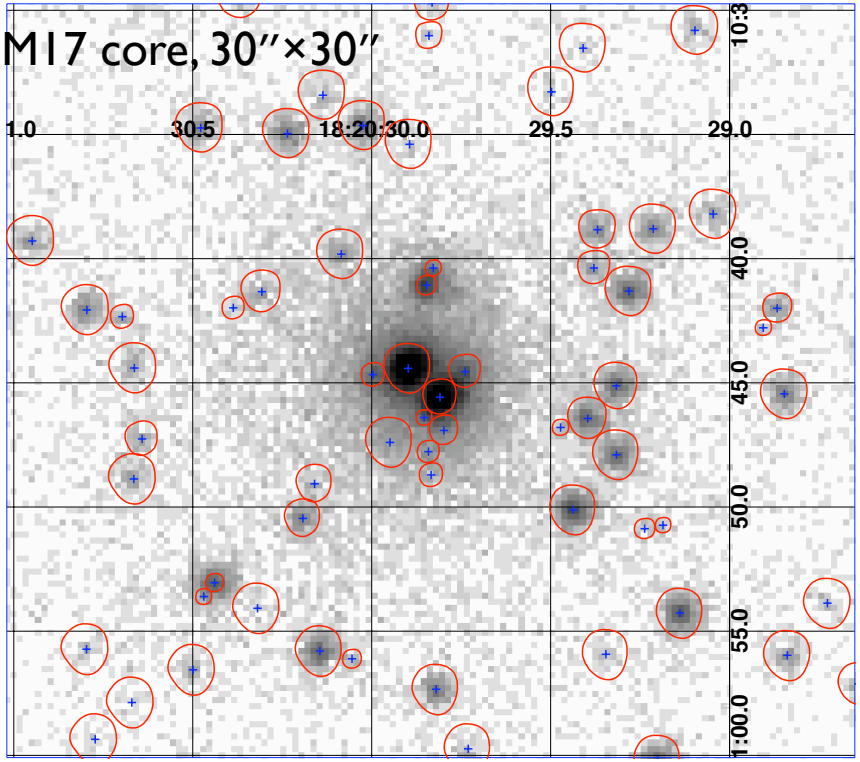
The dragon's breath: Chandra clearly detects diffuse X-ray emission and separates it from the stellar population.

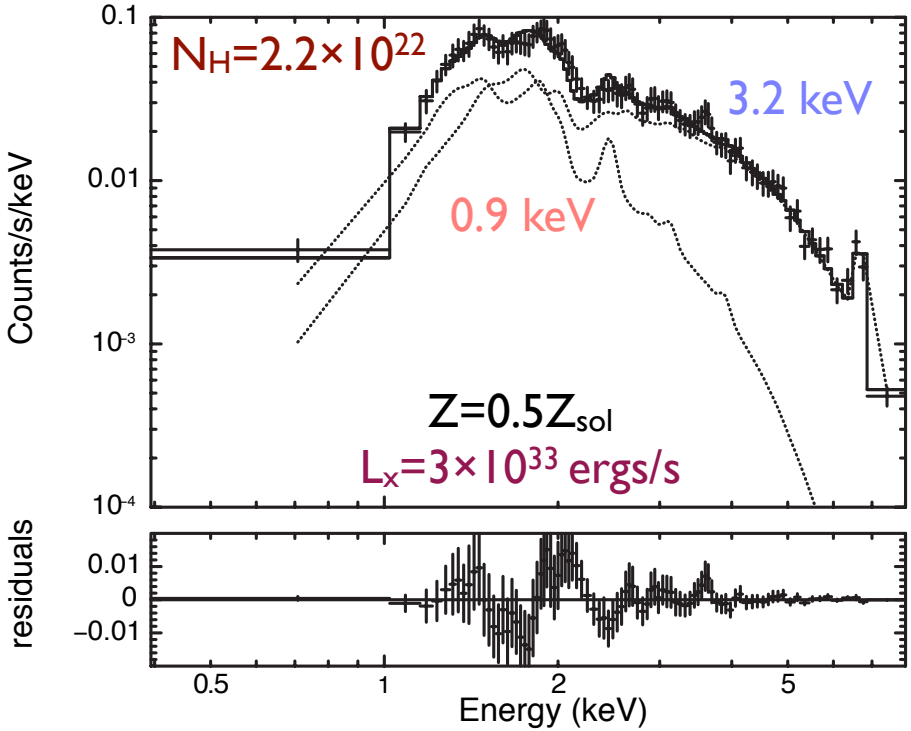


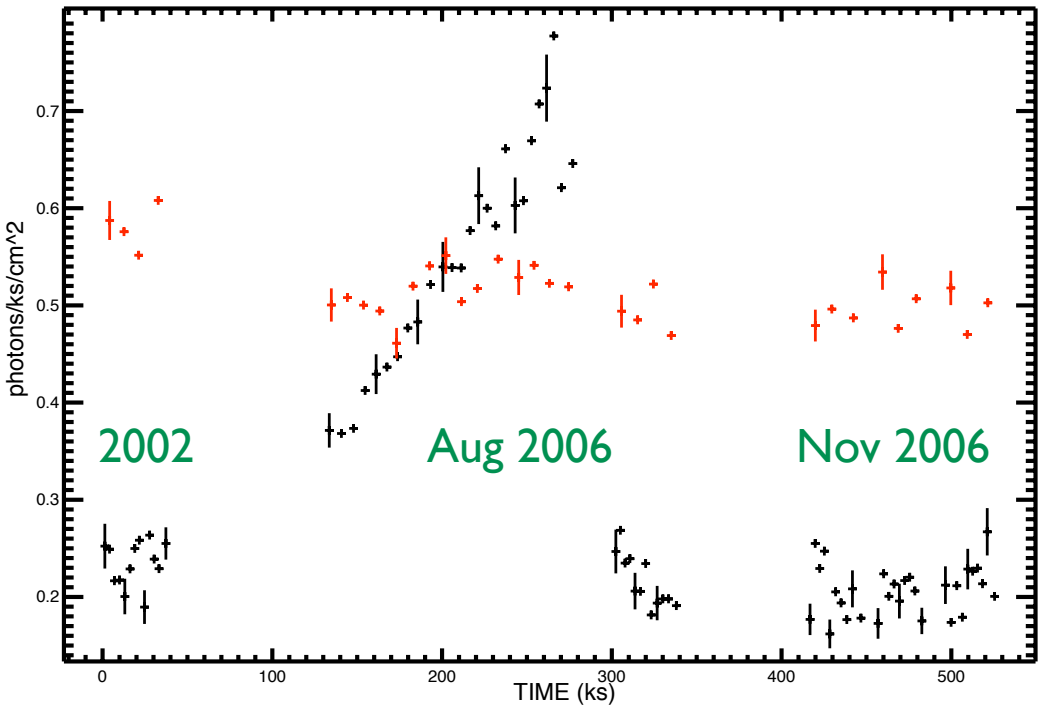
A combined Spitzer/Chandra view of M17.

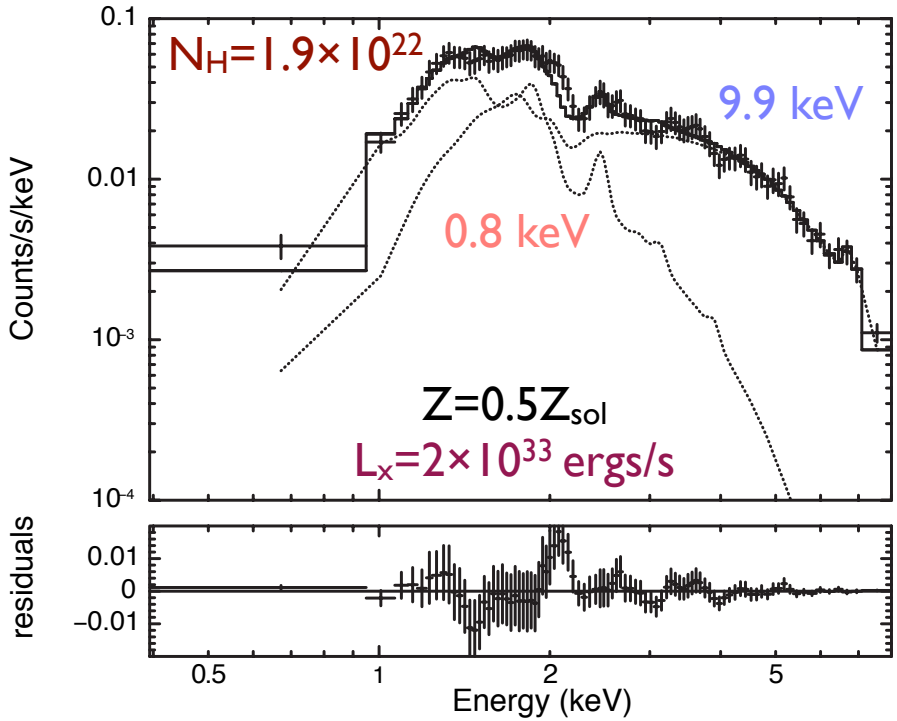
Townsley et al. 2003: diffuse emission has kT = 0.6 keV, $L_x = 3 \times 10^{33}$ ergs/s.

M17's O4-O4 Binary: The Eyes of the Dragon



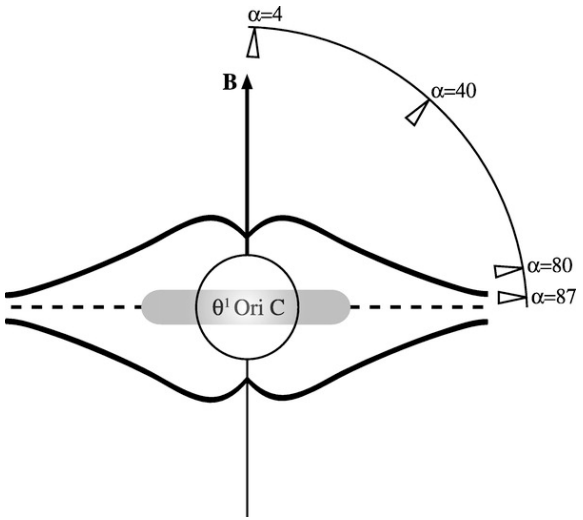






New from Chandra: Hard X-rays from Massive Stars

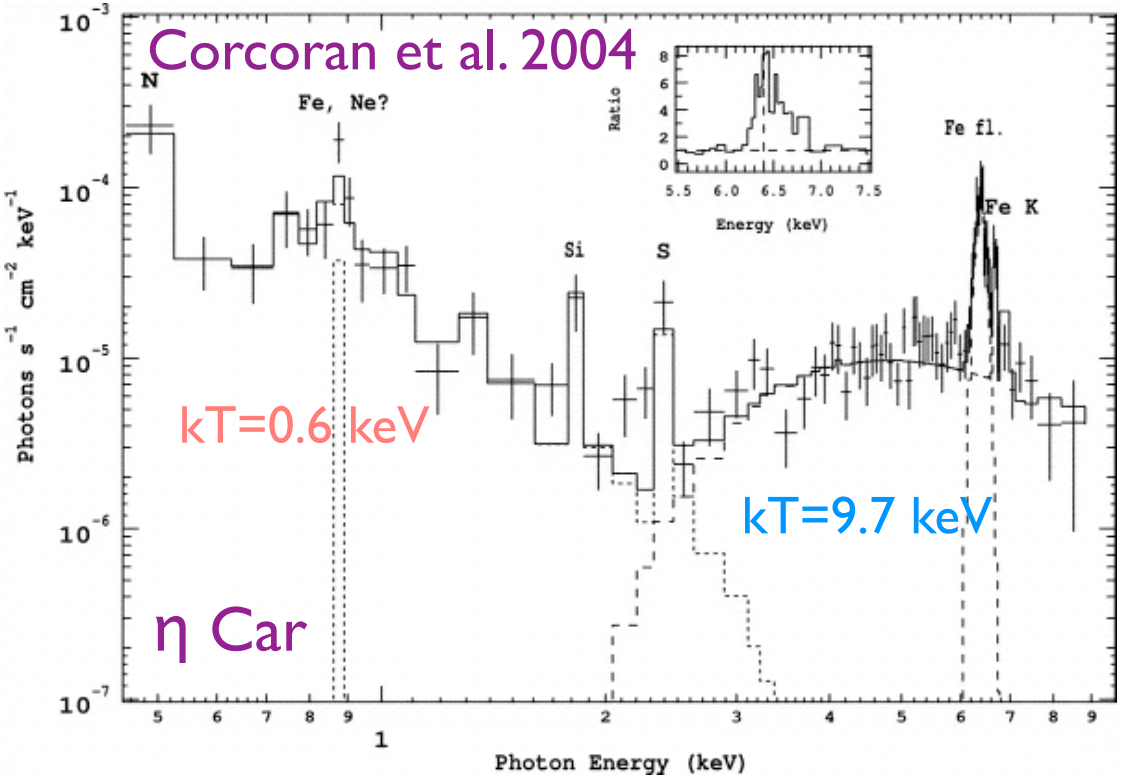
Magnetically-channeled wind shocks (Babel & Montmerle 1997) ⇨ medium X-rays (~1-4 keV).



Gagné et al. 2005

Colliding winds in close binaries ⇨ really hard X-rays (~6 keV), sometimes variable.

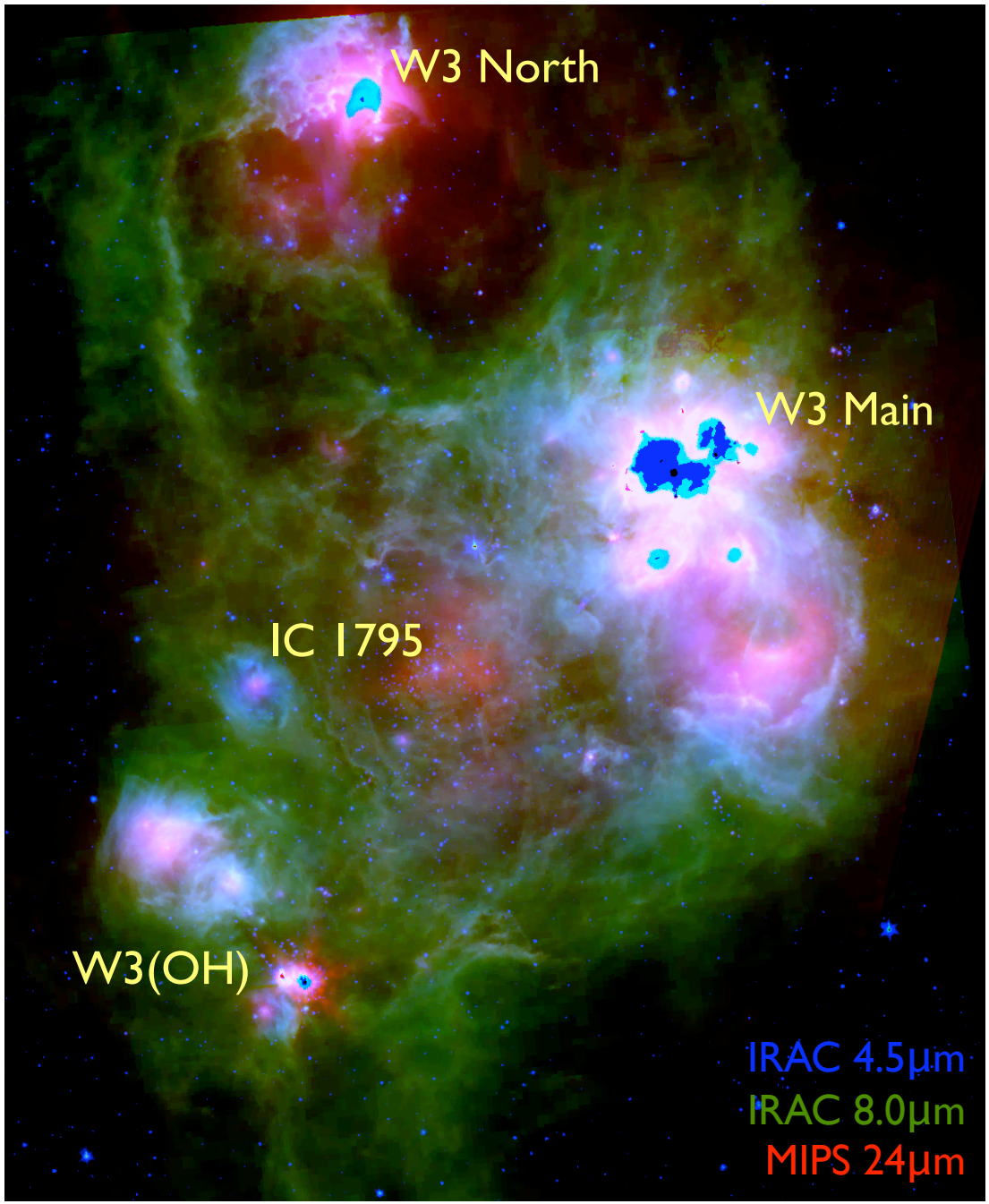
Hoffmeister et al. 2008 find M17 O4 stars (both) to be spectroscopic binaries!



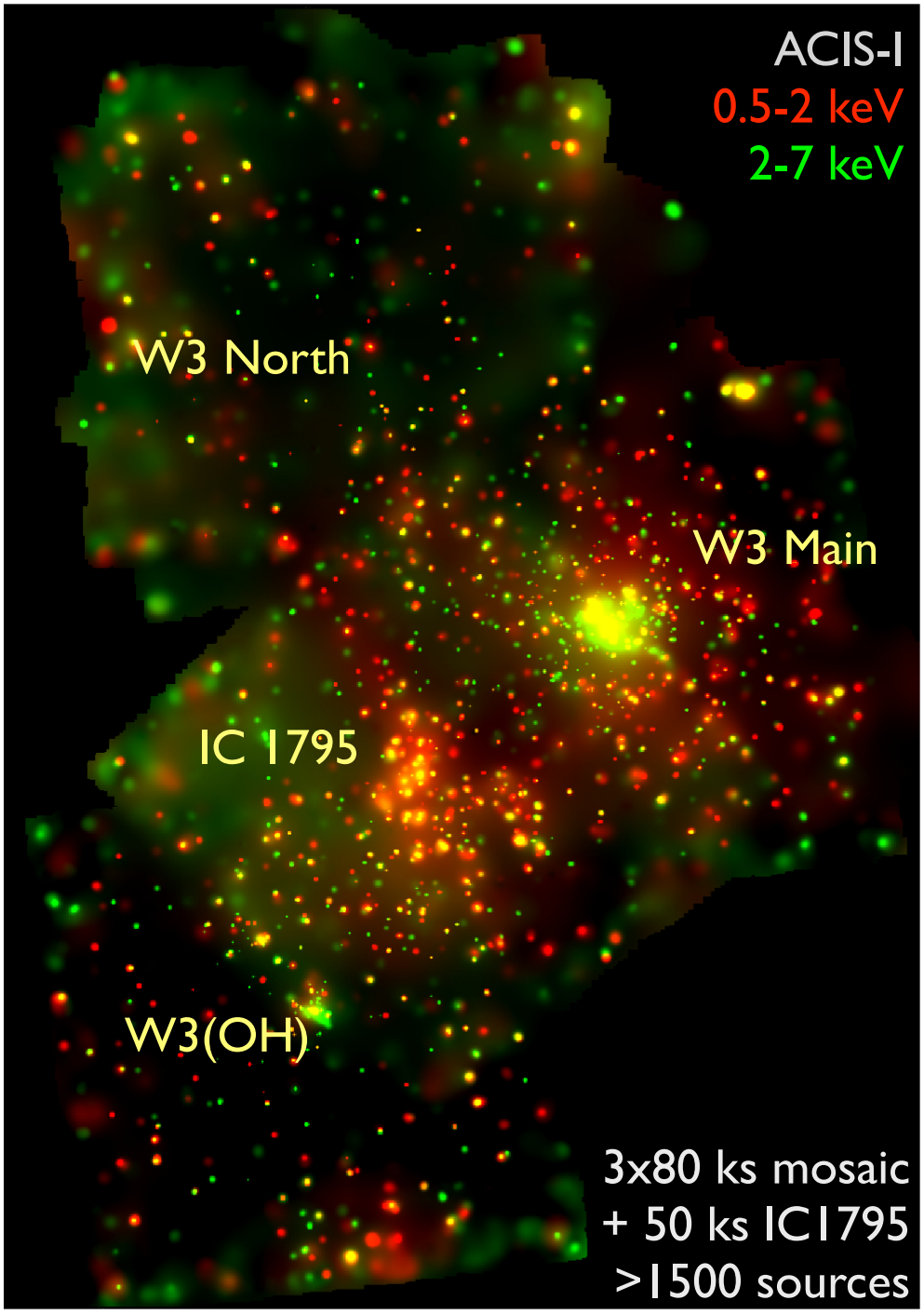
The kicker: these hard X-rays are gone by ~2 Myr!

Perhaps fossil B fields die away or binaries are disrupted.

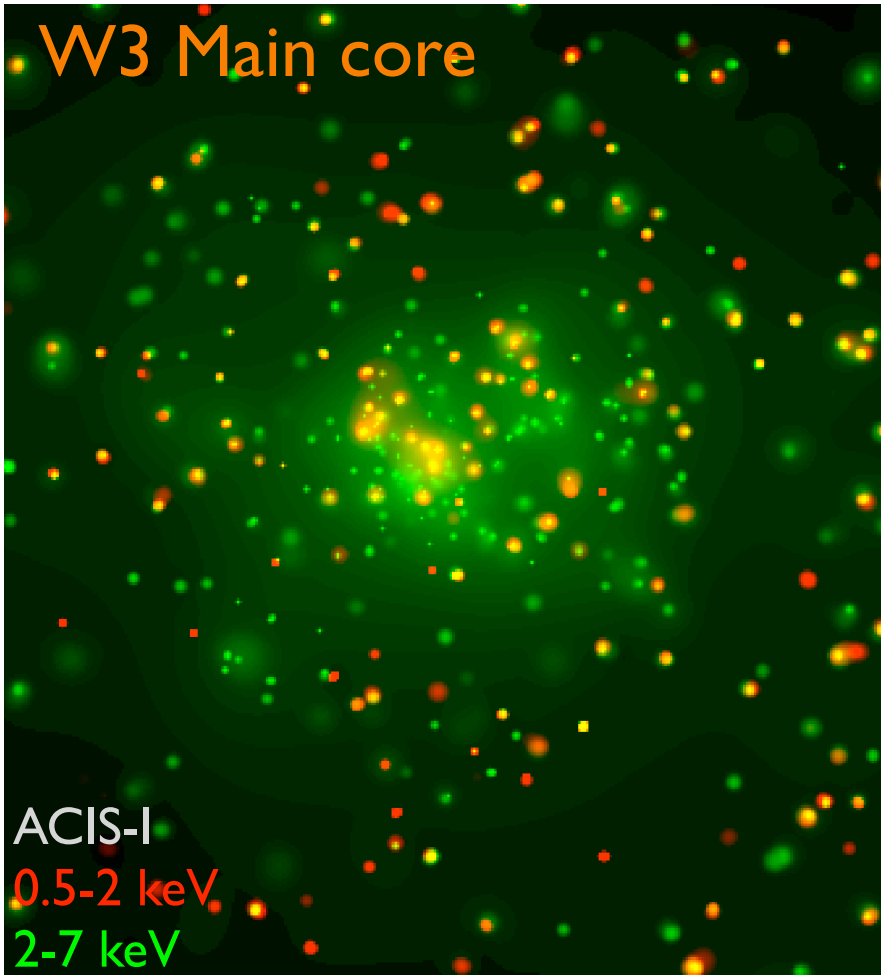
W3: A Cluster of Clusters



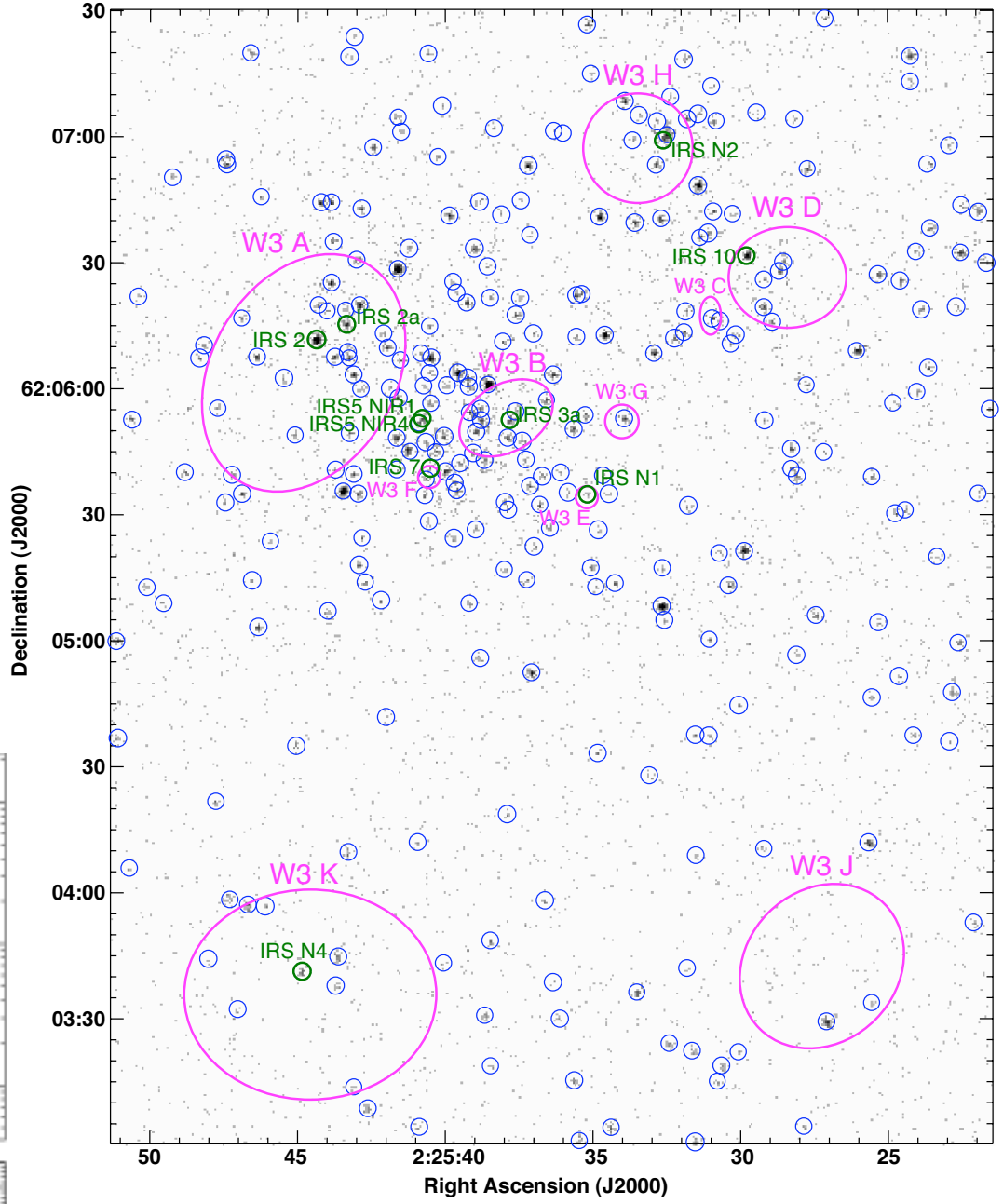
D = 2.0 kpc; 10′ ~5.8 pc.



Feigelson & Townsley 2008



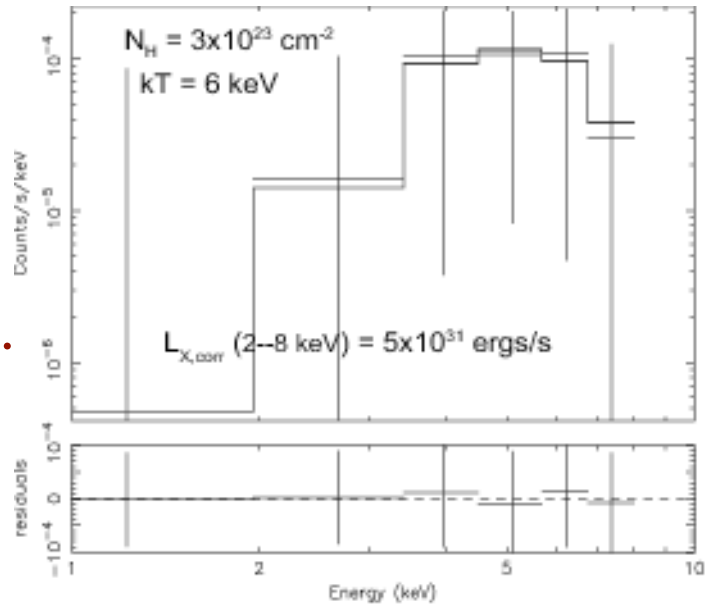
X-rays trace massive stars that ionize young HII regions.



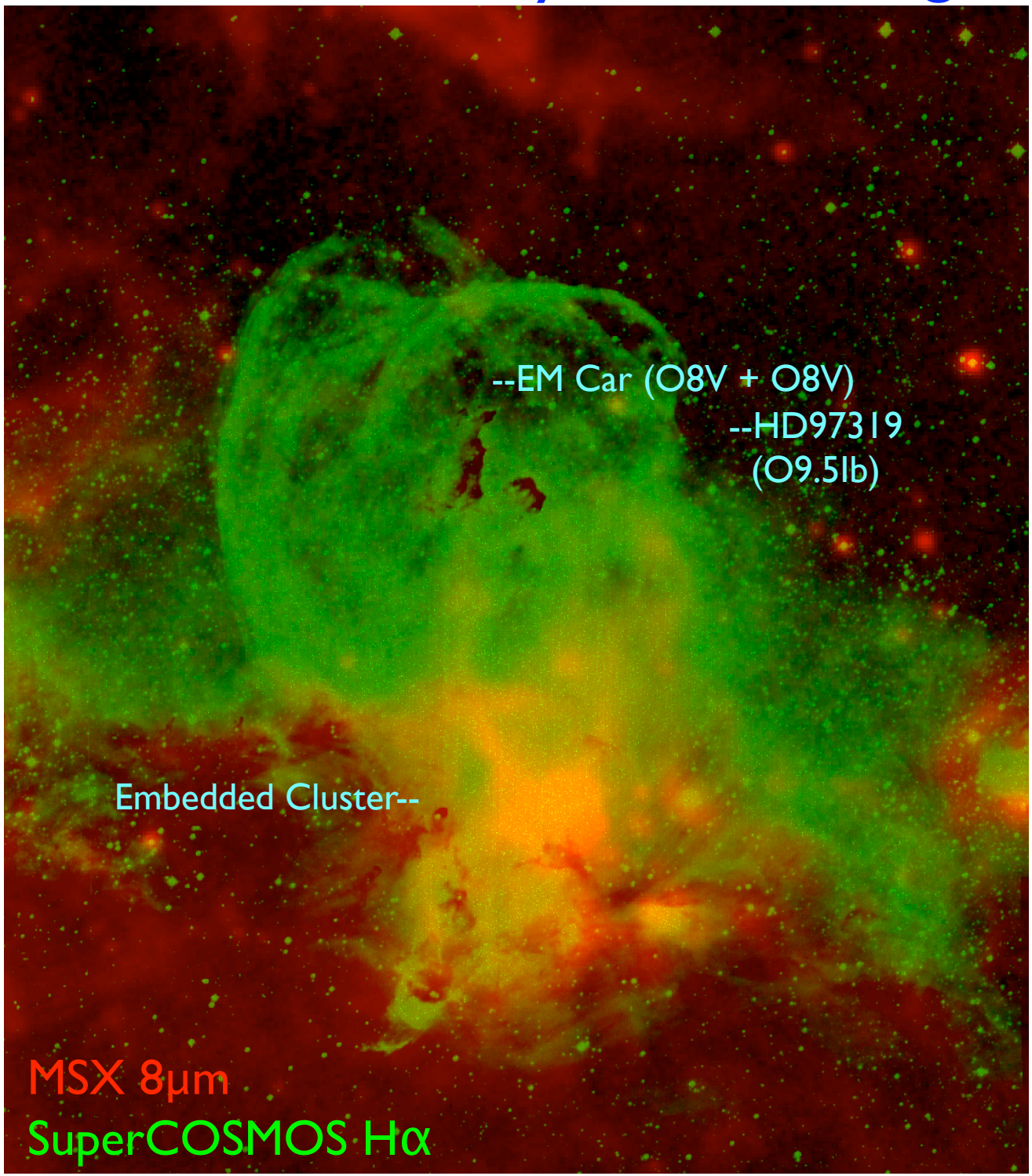
A new O star ionizing a HCHIIR: IRS5 NIR1

$N_H \rightarrow A_V$=150.

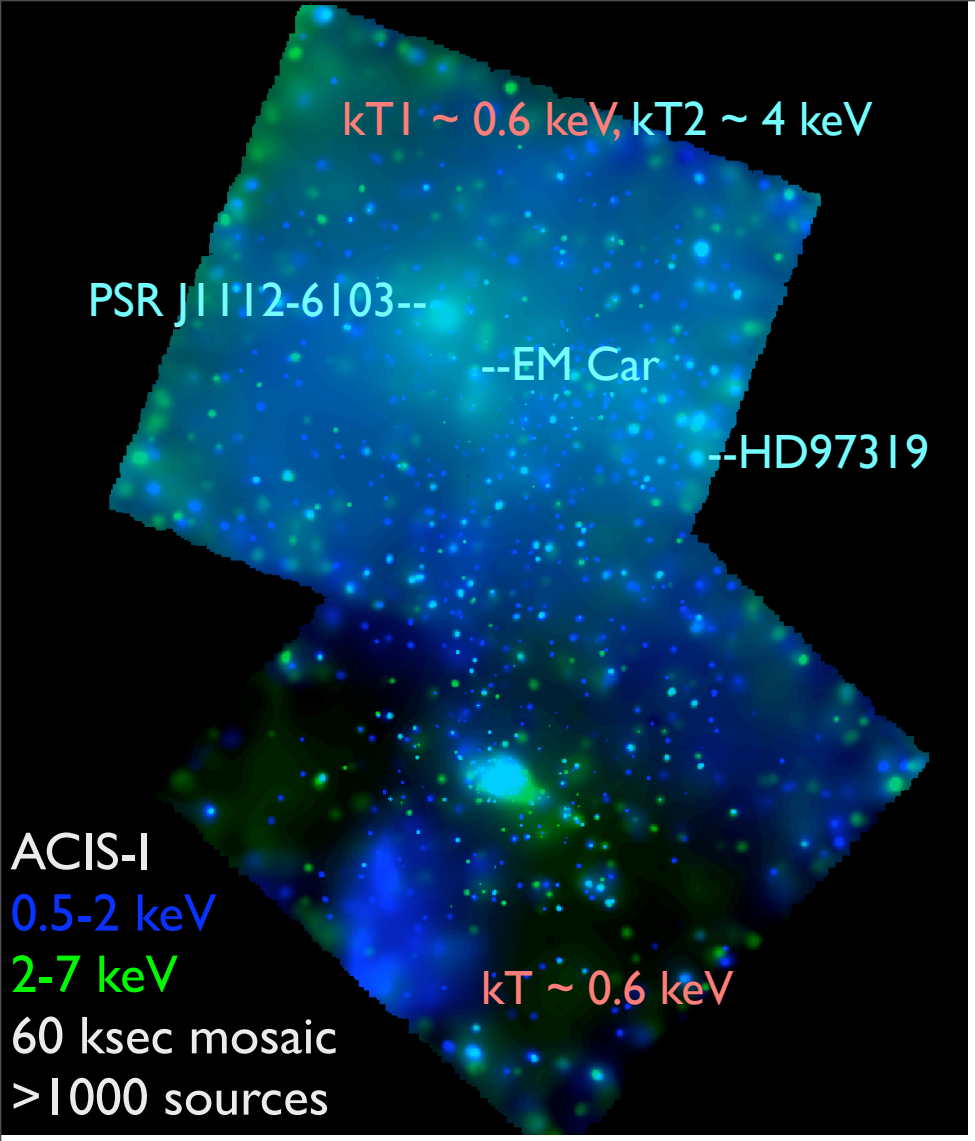
W3(OH) is similar.

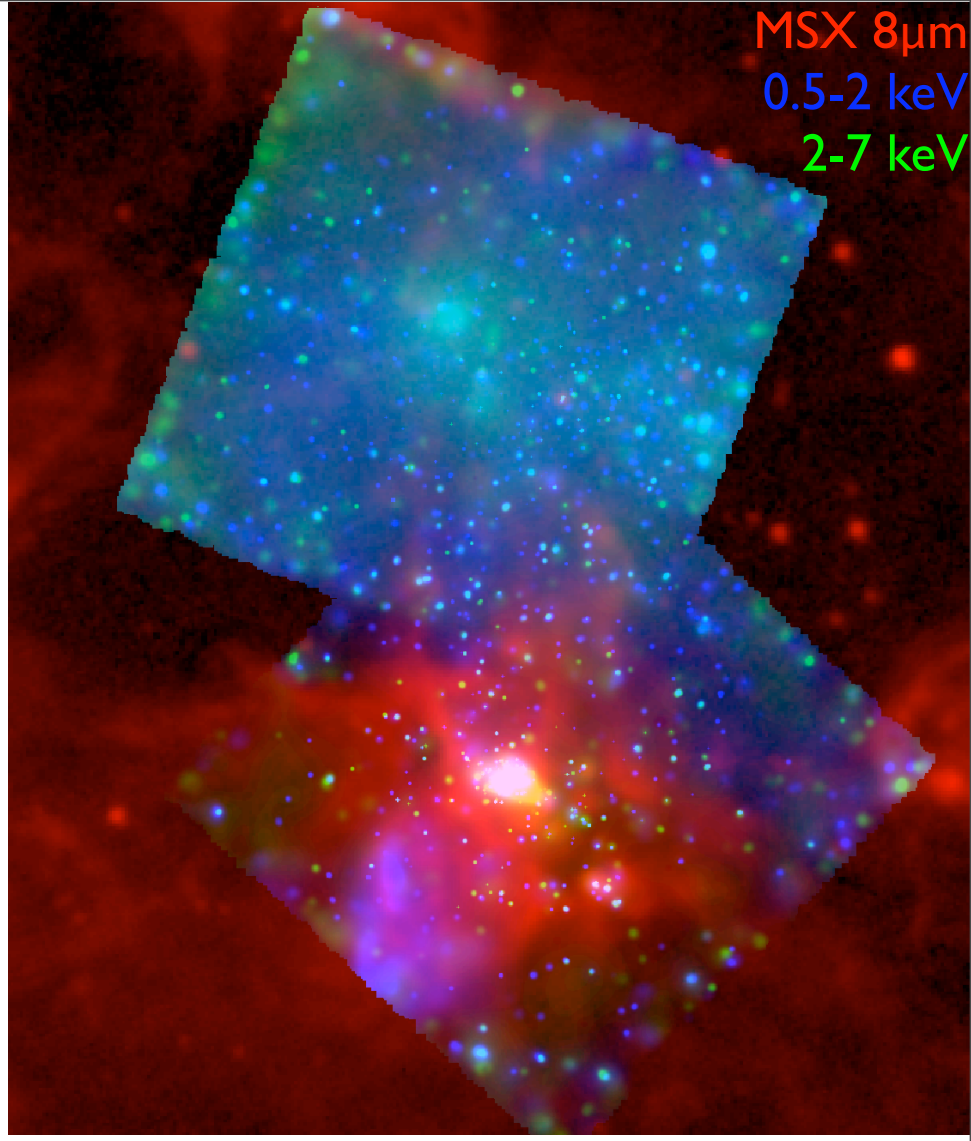


NGC 3576: X-rays Give Strong Evidence for Triggering

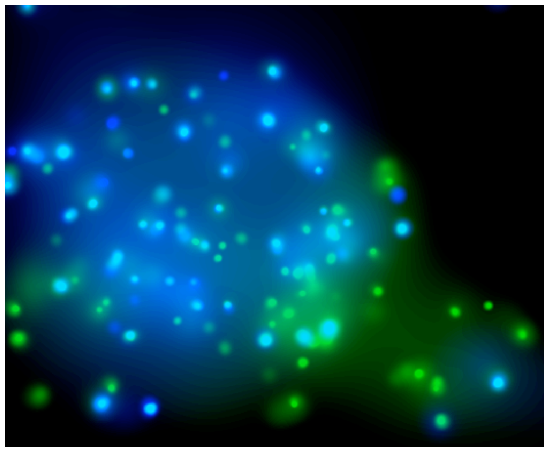


- D ~ 2.8 kpc; 10′ ~8.1 pc.
- Age <1 Myr.
- Second closest giant HII region, still forming stars.
- Two massive stars sit in a dust cavity north of GMC.





The embedded cluster: due to hard X-rays, ACIS finds the ionizing sources!



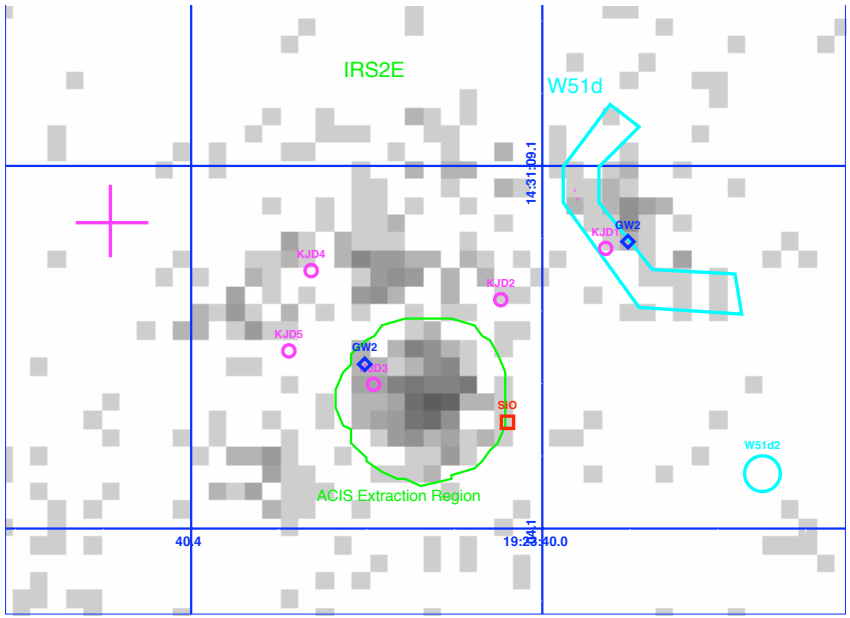
X-ray surprises:

* PSR J1112-6103 has a pulsar wind nebula.
* There is a large young stellar cluster in the dust cavity.
* Diffuse emission fills the cavity (note shadowing), hard X-rays may be signature of a cavity SNR.
* Southern outflow looks like M17's.

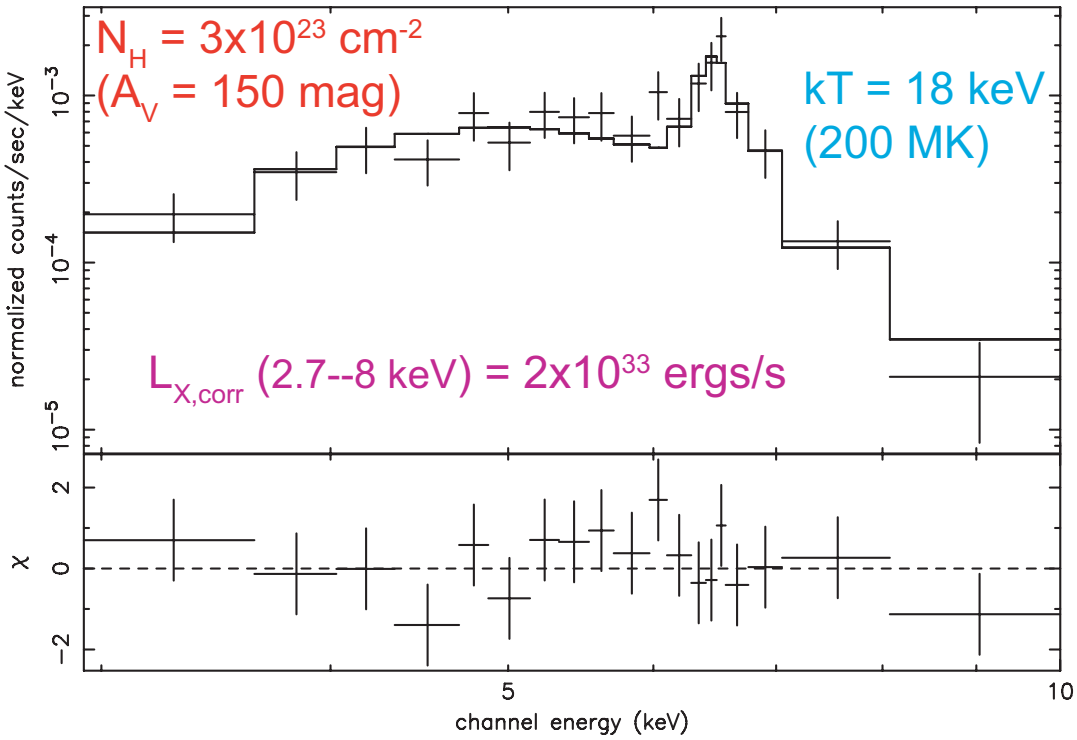
Hard O star emission allows Chandra to access massive star formation, giant HII regions across the Galaxy.

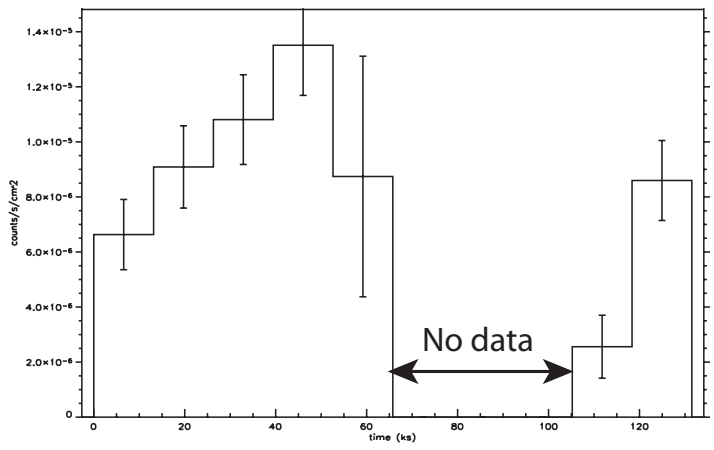
W51A is a giant HII region complex at ~7 kpc.

W51 IRS2 complex, 8" x 12"



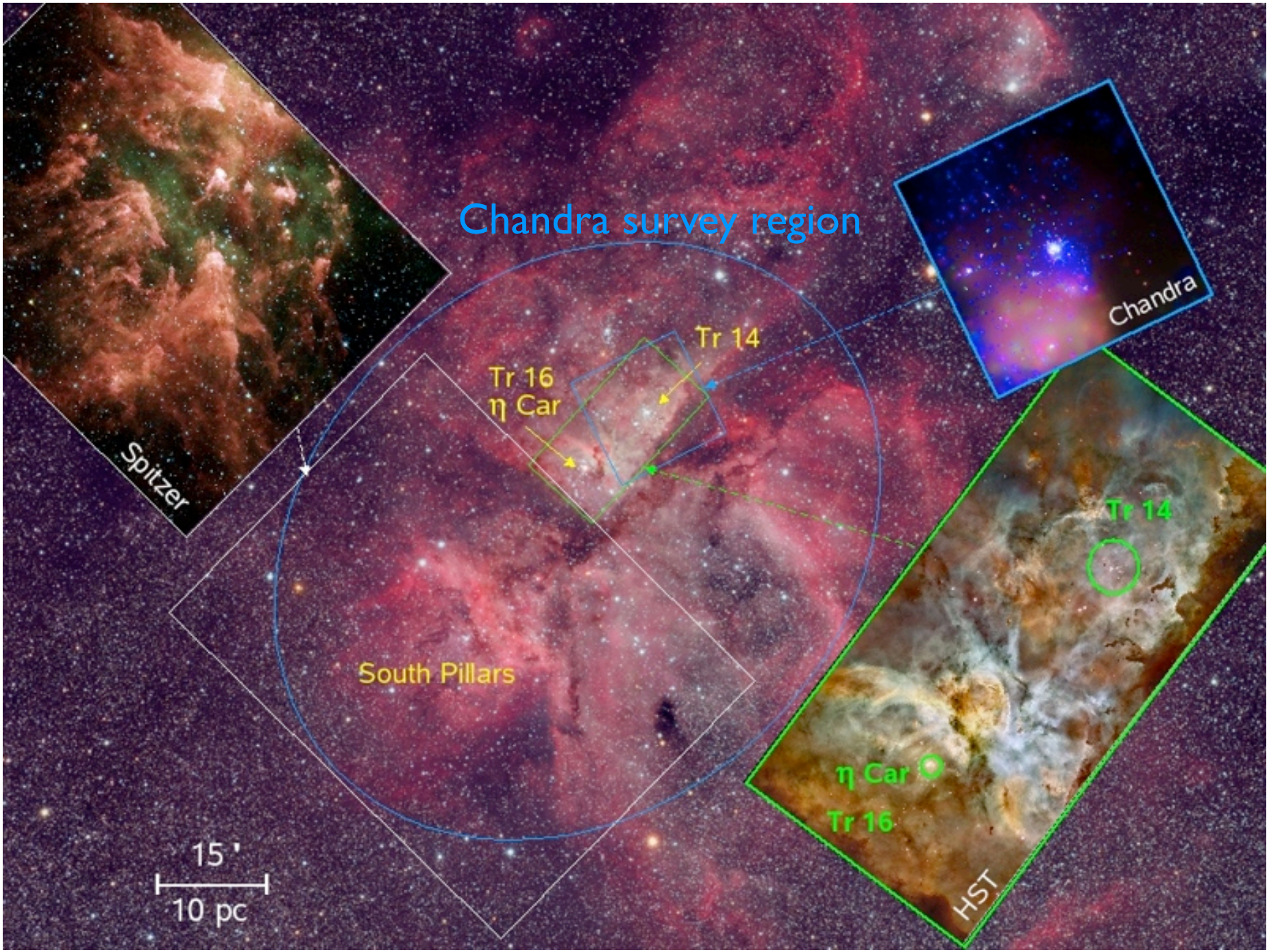
W51 IRS2E, 1 apec + gaussian at 6.5 keV



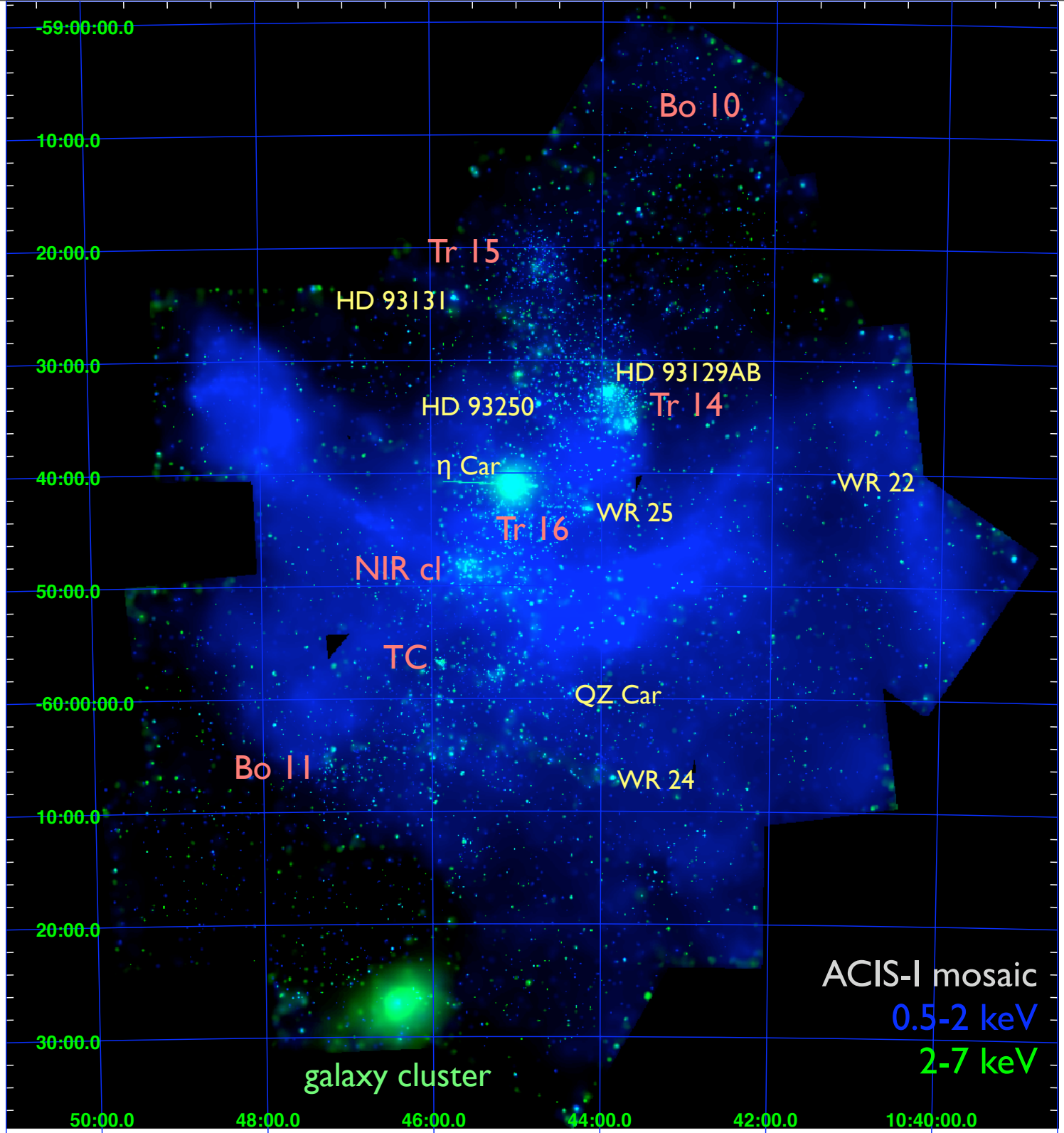


IRS2E is also likely to be a massive binary!

The Great Observatories Focus on Carina



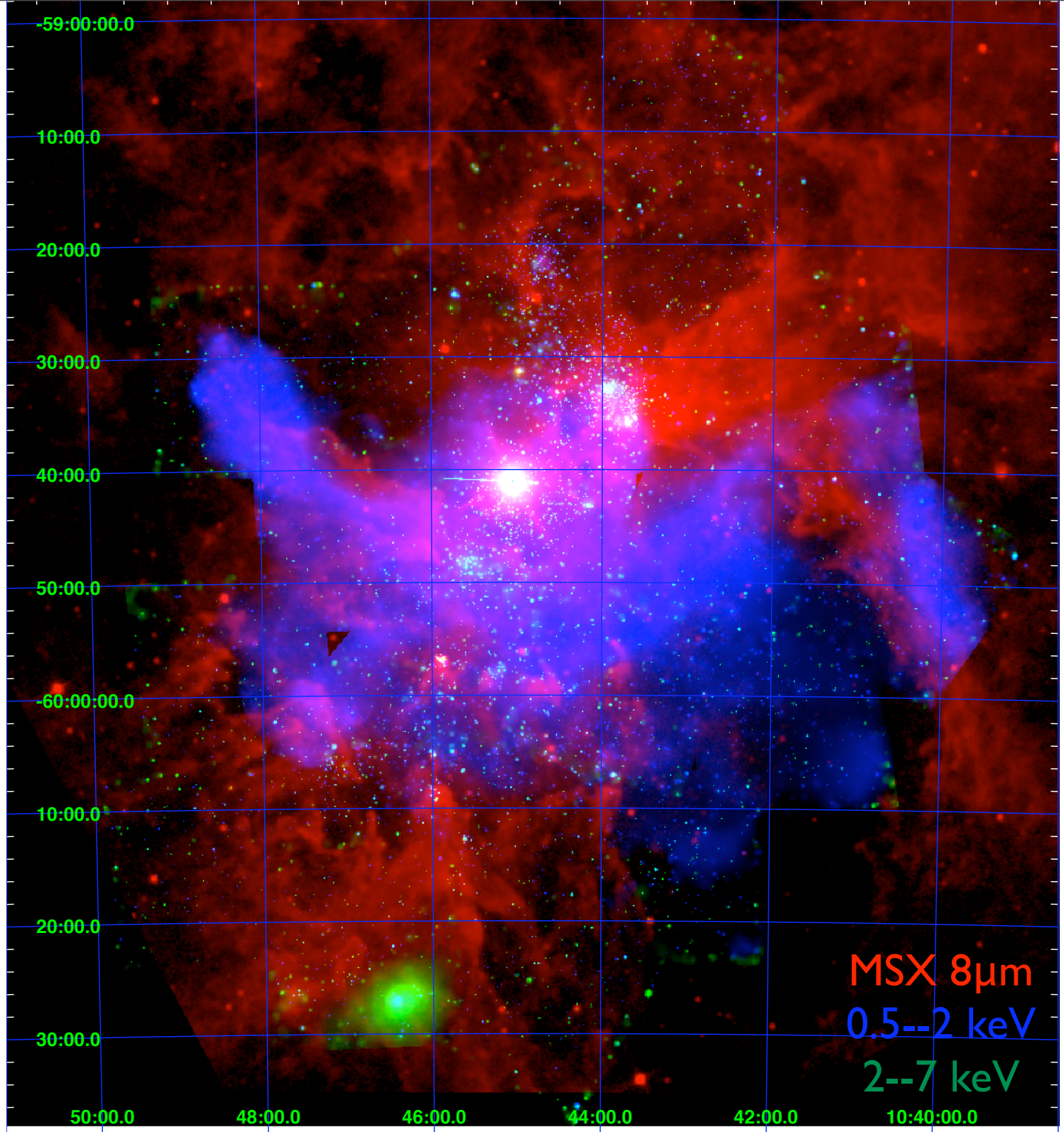
Composite image by Thomas Preibisch



Chandra 1.2 Ms survey: 22 ACIS-I pointings covering ~1 square degree; all but one observed.

Current tally ~14,000 point sources with 0.2″--0.4″ positions.

Field covers ~50 known O, WR stars.


-59:00:00.0
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20:00.0
30:00.0
40:00.0
50:00.0
-60:00:00.0
10:00.0
20:00.0
30:00.0
50:00.0
48:00.0
46:00.0
44:00.0
42:00.0
10:40:00.0
MSX 8μm
0.5--2 keV
2--7 keV

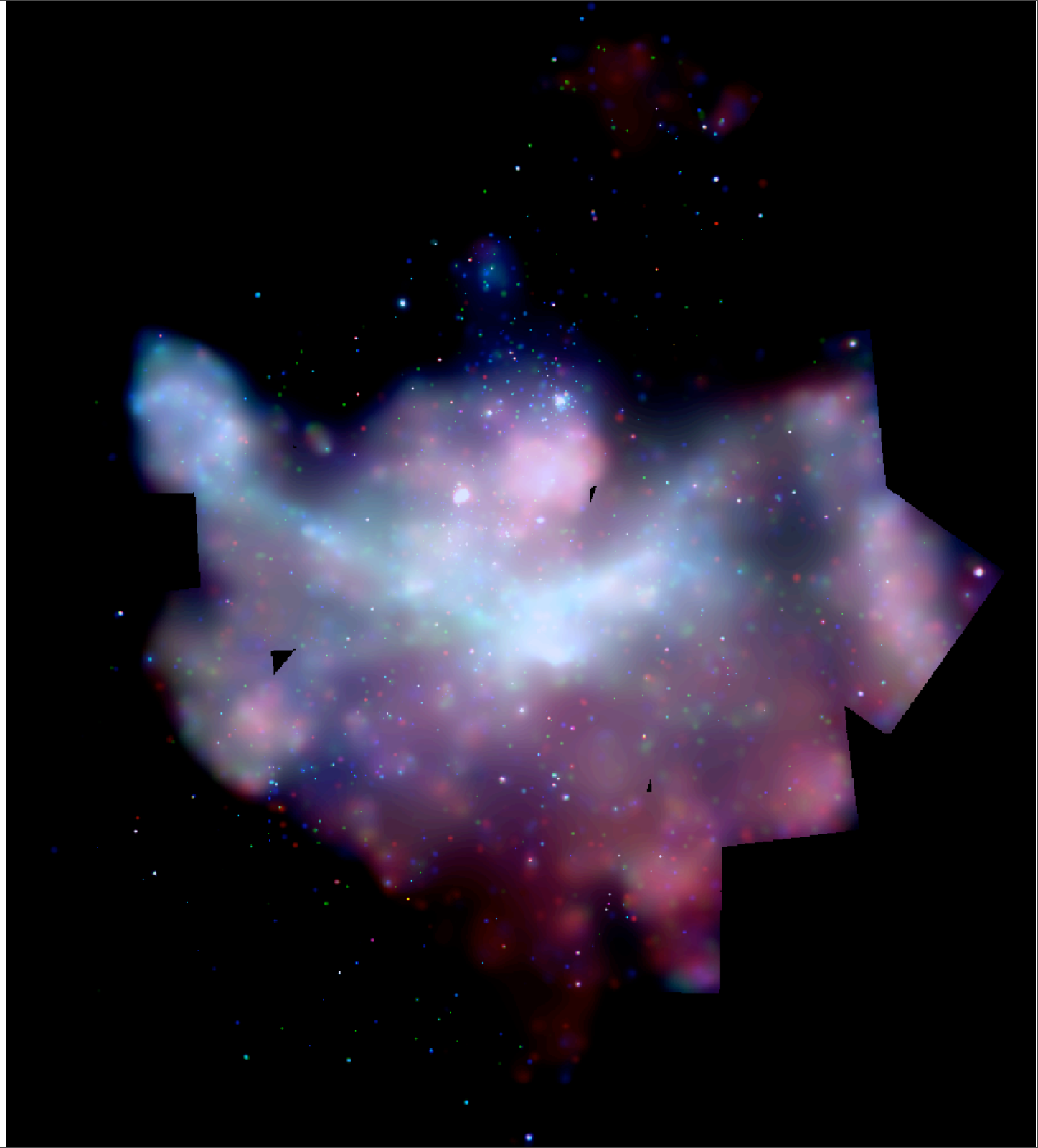
Soft diffuse X-rays:

500--700 eV

700--860 eV

860--960 eV

Brightness (total $L_x \sim 10^{35}$ ergs/s), spectra, and complexity may indicate a cavity SNR.



Blowhards and Windbags: A Summary

Some of your favorite ALMA targets are immersed in 10-100 MK X-ray plasmas!

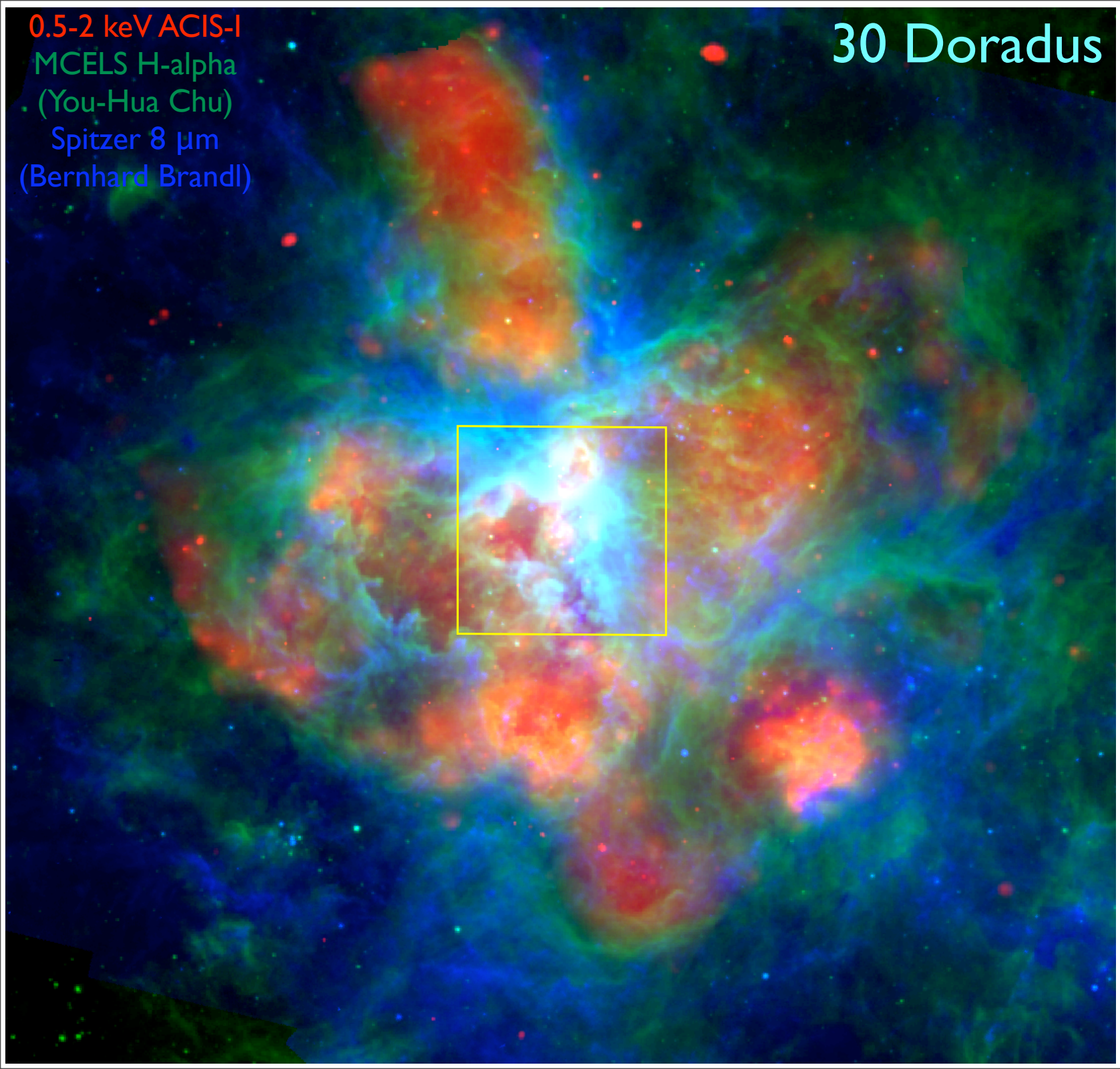
* O star - ISM interactions lead to parsec-scale soft X-ray emission; this may pervade the Galactic plane but is hard to detect.

* The 10^4K Strömgren Sphere is really a Strömgren shell filled with 10^7K plasma in many cases; Chandra sometimes sees X-ray outflows in edge-on blister HII regions.

* Wind-wind interactions and/or B fields lead to harder X-rays close to star(s) -- this may be a way to determine close binarity or detect embedded massive clusters.

* This unexpected emission is gone by 2 Myr -- binary evolution or decaying fossil fields?

* BRIGHT diffuse soft X-rays are usually due to cavity SNRs.



Plans for 2009

Carina as a microcosm of starburst astrophysics:

the Chandra Carina mosaic in context.