PARSEC-SCALE X-RAY FLOWS IN HIGH-MASS STAR-FORMING REGIONS

Leisa Townsley[1]
Eric Feigelson[1]
Thierry Montmerle[2]
Patrick Broos[1]
You-Hua Chu[3]
Gordon Garmire[1]
Konstantin Getman[1]

[1]*Penn State University, Department of Astronomy & Astrophysics*

[2]*Grenoble Observatory*

[3]*University of Illinois, Department of Astronomy*

Support provided by NASA contract NAS8-38252 to Gordon Garmire, the ACIS Principal Investigator, and by the Chandra X-ray Observatory GO2 grant G01-2008X.

INTRODUCTION

Massive star-forming regions present a microcosm of starburst astrophysics, where stellar winds compete with supernovae to carve up their natal clouds and to return processed material to the ISM.

Radio observations opened up studies of embedded star formation, revealing ionized gas despite large absorbing columns and the earliest stages of high-mass star formation through masers.

Chandra gives us the sensitivity, spatial resolution, and broad bandpass to detect diffuse X-ray emission and to separate it from the hundreds of X-ray-emitting stars in these fields.

My question to you:
How is the radio/IR picture of star formation impacted by the presence of 10^6–10^8 *K gas around the most massive stars?*

OVERVIEW

- What lurks within the Strömgren Sphere?

- M17, the Omega Nebula: an X-ray champagne flow.
- RCW 49: OB/Wolf-Rayet detente.
- W51: X-rays from virtually every radio HII region.

- After all that (and more), where do we stand?

X-ray details:
"Ten Million Degree Gas in M17 and the Rosette Nebula: X-ray Flows in Galactic HII Regions," Townsley et al. 2003, ApJ 593, 874

ISM BUBBLES & HOLLOW HII REGIONS

- Morton 1967: UV P Cygni profiles in Orion supergiants. Can't ignore O star winds anymore!

- Weaver et al. 1977: O7 star, steady wind, uniform ambient ISM $\leadsto$ *interstellar bubble*, $R > 20$ pc, filled with 10^{6-7} degree gas.

- Dorland & Montmerle 1987: Conduction $\leadsto$ smaller region, harder X-rays.

- Dyson and collaborators (1986 - present): dense clumps close to star $\leadsto$ "mass-loaded" winds, bubbles center-filled with X-rays.

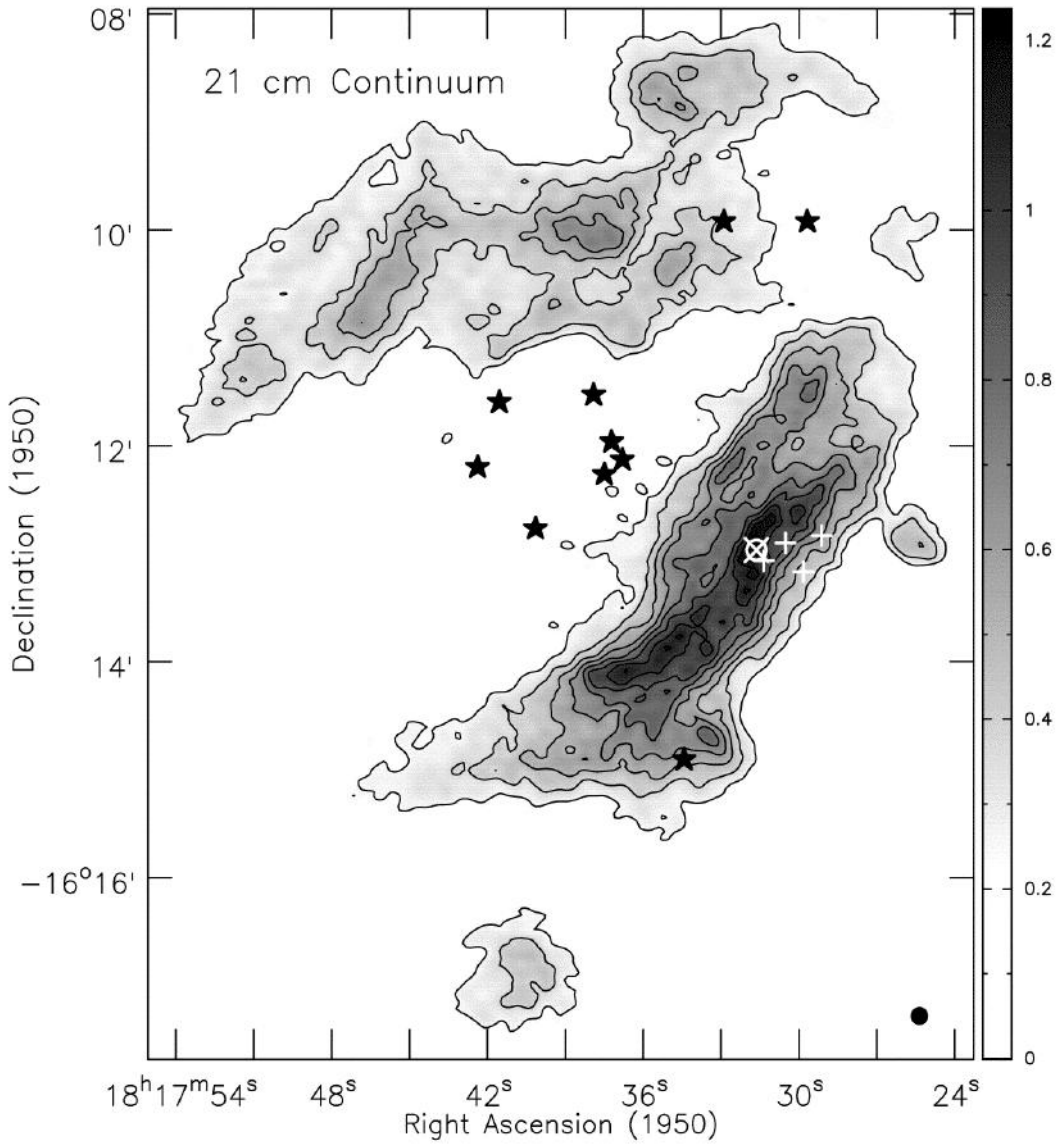
- Strickland & Stevens 1998: Ultracompact HII Regions $\leadsto$ hard X-rays, $L_x \sim 10^{35}$ ergs/s.

- Cantó, Raga, & Rodríguez 2000: Compact clusters of O stars: wind collisions $\leadsto$ hard X-rays, $L_x \sim 10^{35}$ ergs/s.

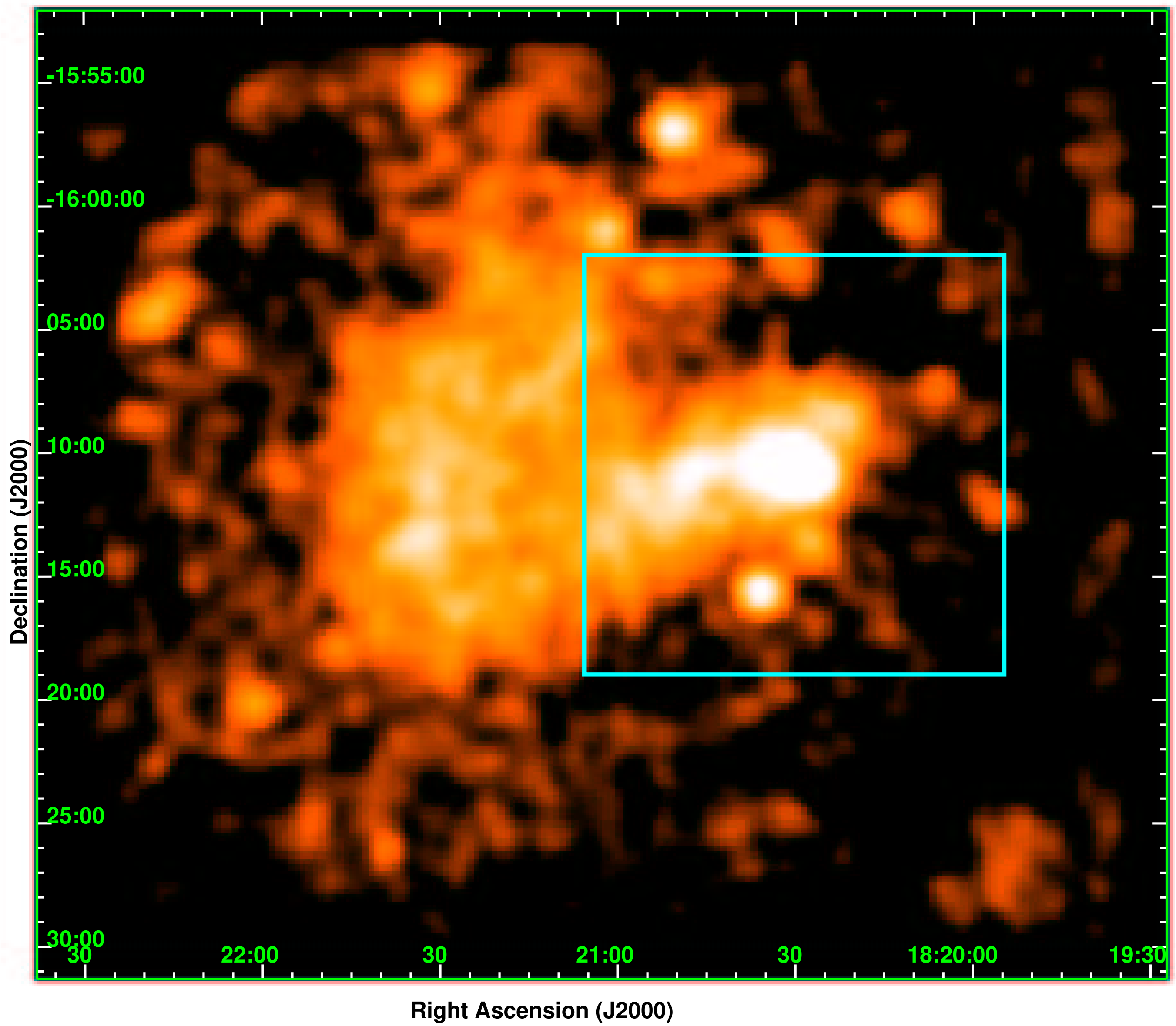
M17, THE OMEGA NEBULA

$15' \times 15'$ 2MASS image

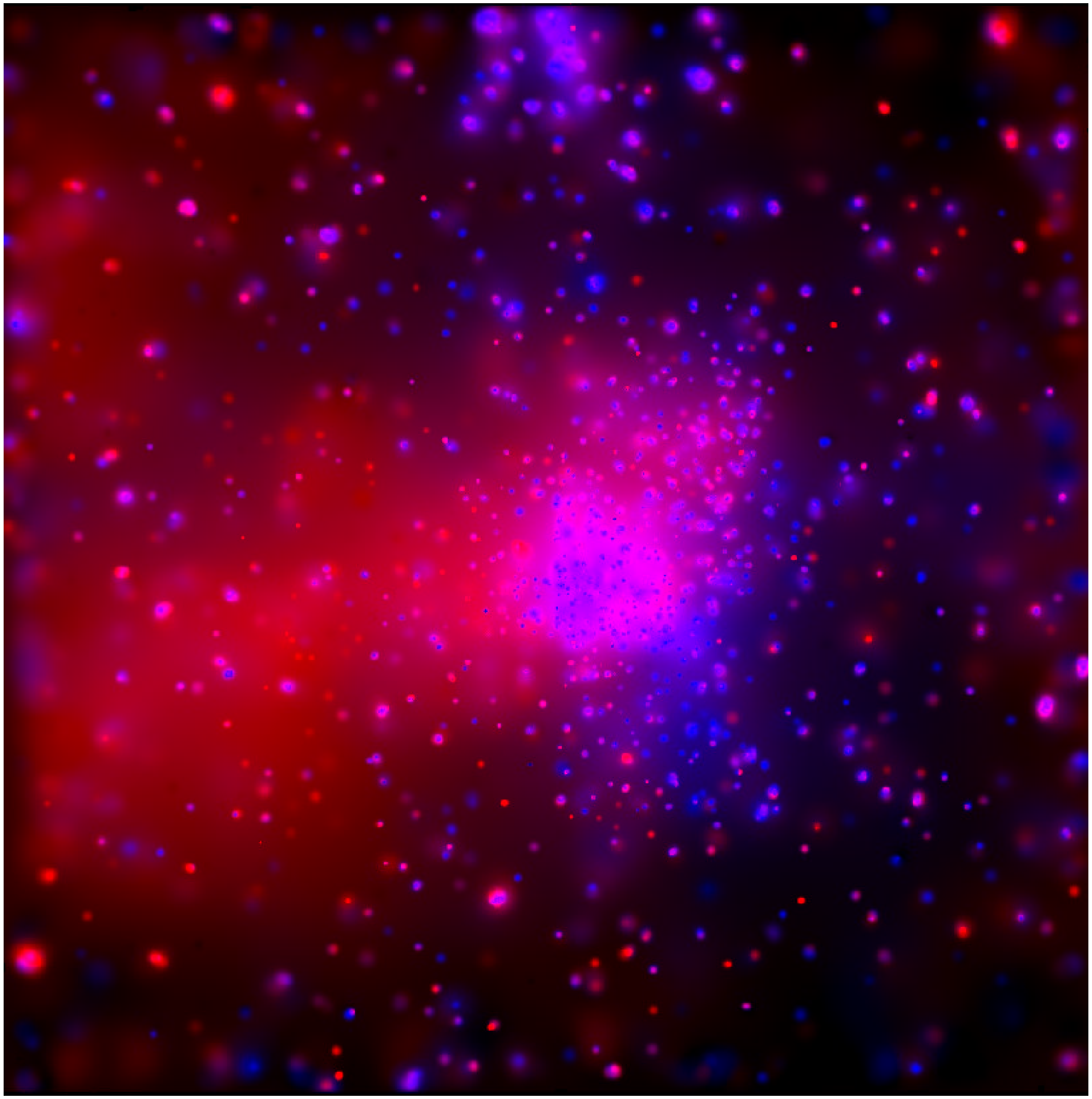
- D = 1.6 kpc; $10' \sim$ 4.7 pc.
- Age $\sim$ 1 Myr.
- Edge-on version of Orion K-L: blister on the edge of a GMC with UCHIIR, water masers, massive core M17SW.
- 100 stars earlier than B9 (Orion has 8).
  14 O stars, several form a $\sim 1'$ ring.



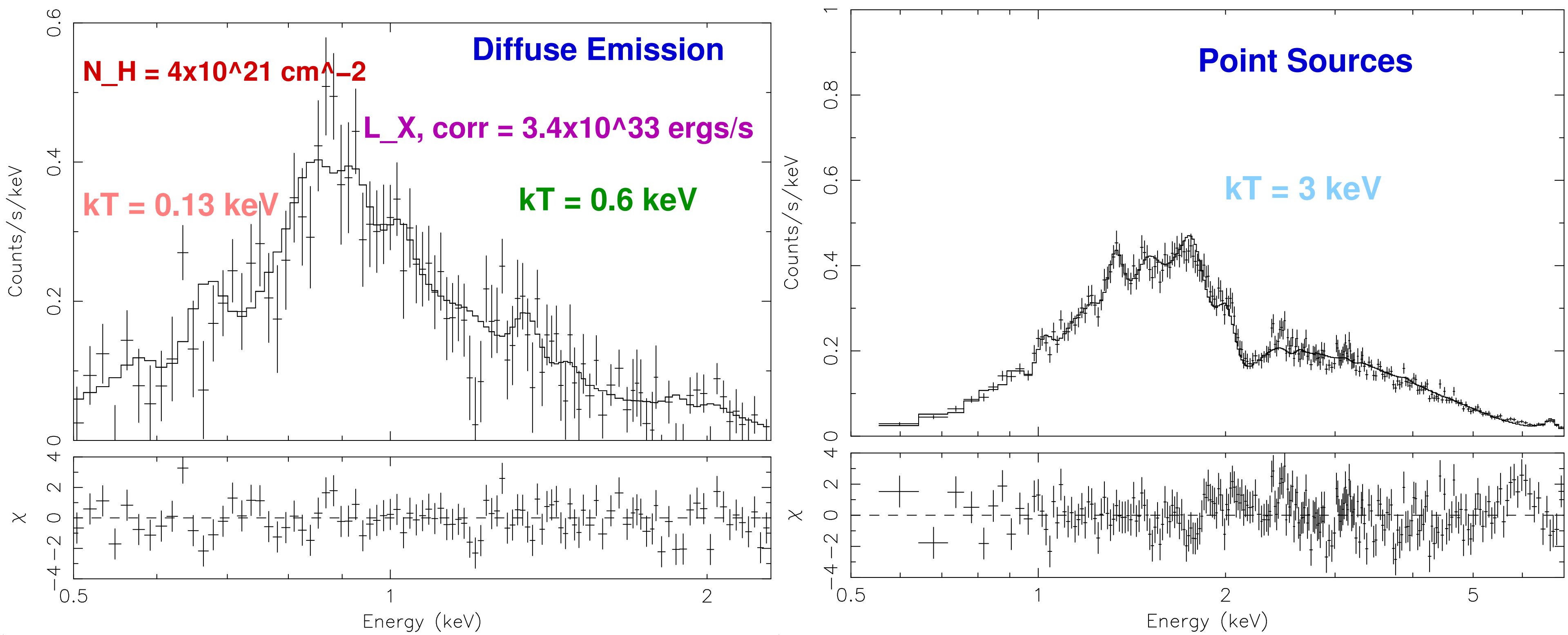
Radio image of M17 showing the photodissociation regions, from Brogan & Troland 2001 (ApJ 560, 821). M17 is a strong thermal radio source with high ionization.



Smoothed ROSAT PSPC (soft X-ray) image of M17. ACIS FoV.
See Dunne et al. 2003, ApJ 590, 306.



The 40-ksec ACIS-I observation of M17 ($17' \times 17'$). Red = soft (0.5–2 keV) emission; blue = hard (2–8 keV) emission. We see over 900 point sources + diffuse emission.

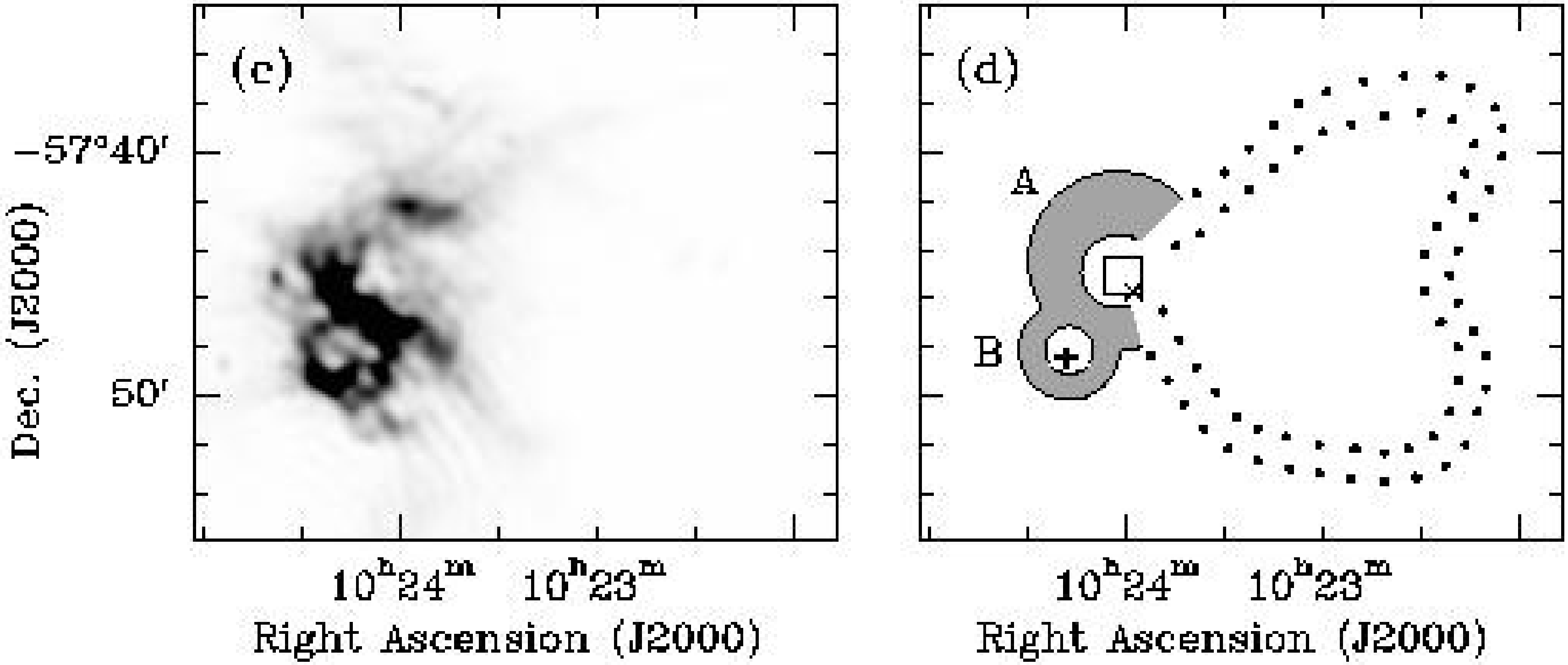


M17 spectra: comparison shows that the diffuse emission is not likely to be composed primarily of unresolved point sources.

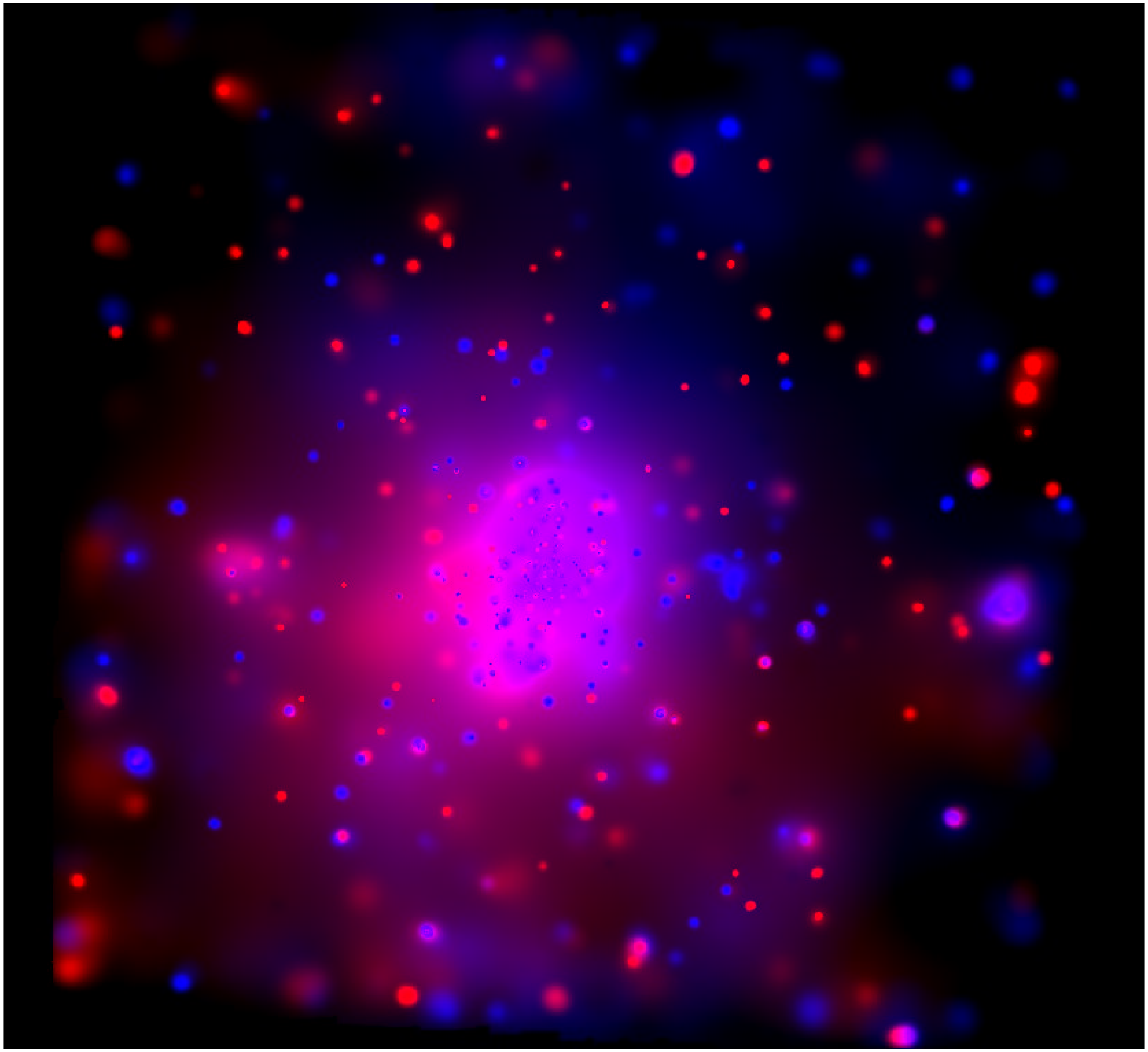
RCW 49 and Westerlund 2

RCW 49, $16' \times 16'$.

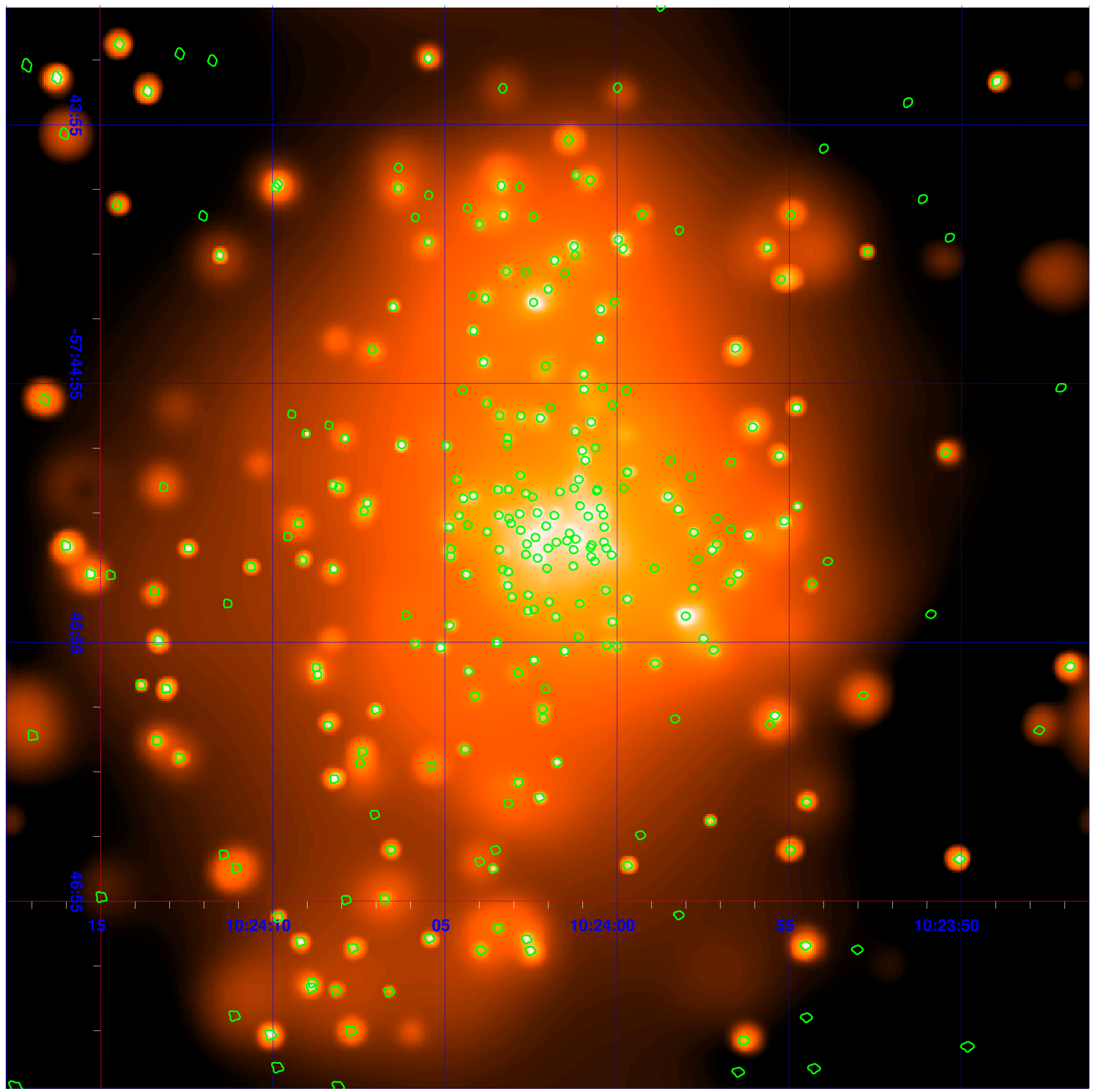
- Westerlund 2 is the young, very compact cluster ionizing the massive southern star-forming complex RCW 49.
- $D = 2.3$ kpc; $10' \sim 6.7$ pc.
- Age of Wd 2 is 2–3 Myr.
- 6 O7 stars, 2 Wolf-Rayet stars.
- ROSAT found 3 point sources + diffuse emission.
- Morphology dominated by two wind-blown shells: (Westerlund 2 + WR20a) & WR20b.



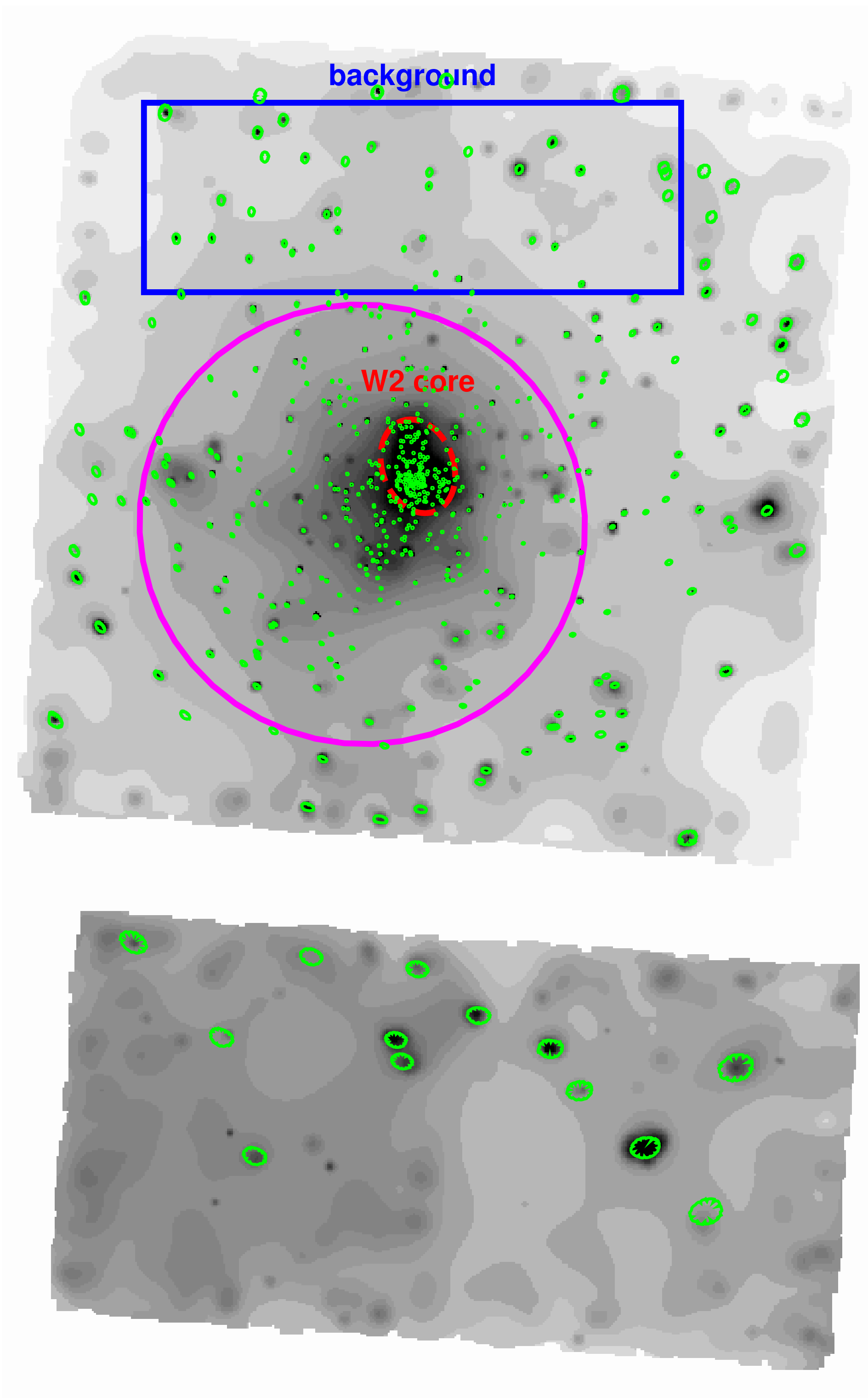
A radio image and model of RCW 49, from Whiteoak and Uchida 1997, A&A 317, 563. QUIZ TIME: What will Chandra show?



The 36-ksec ACIS-I observation of RCW 49 ($17' \times 17'$), (0.5–2 keV), (2–8 keV). Diffuse emission centered on dense cluster, not obviously associated with the Wolf-Rayet stars.

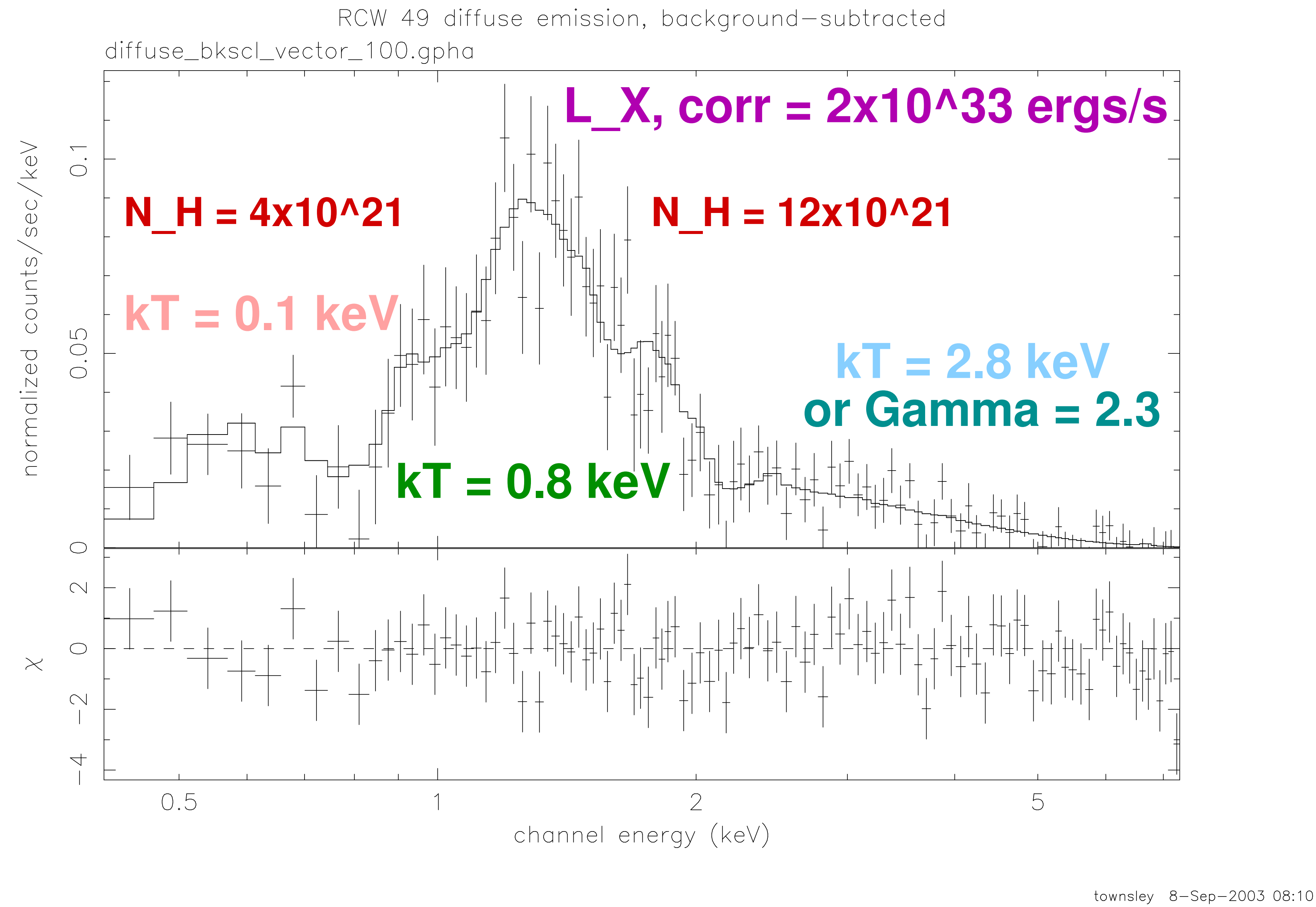


Central $\sim 4' \times 4'$ of ACIS image of RCW 49; point sources outlined in green. Note high source density in Westerlund 2.



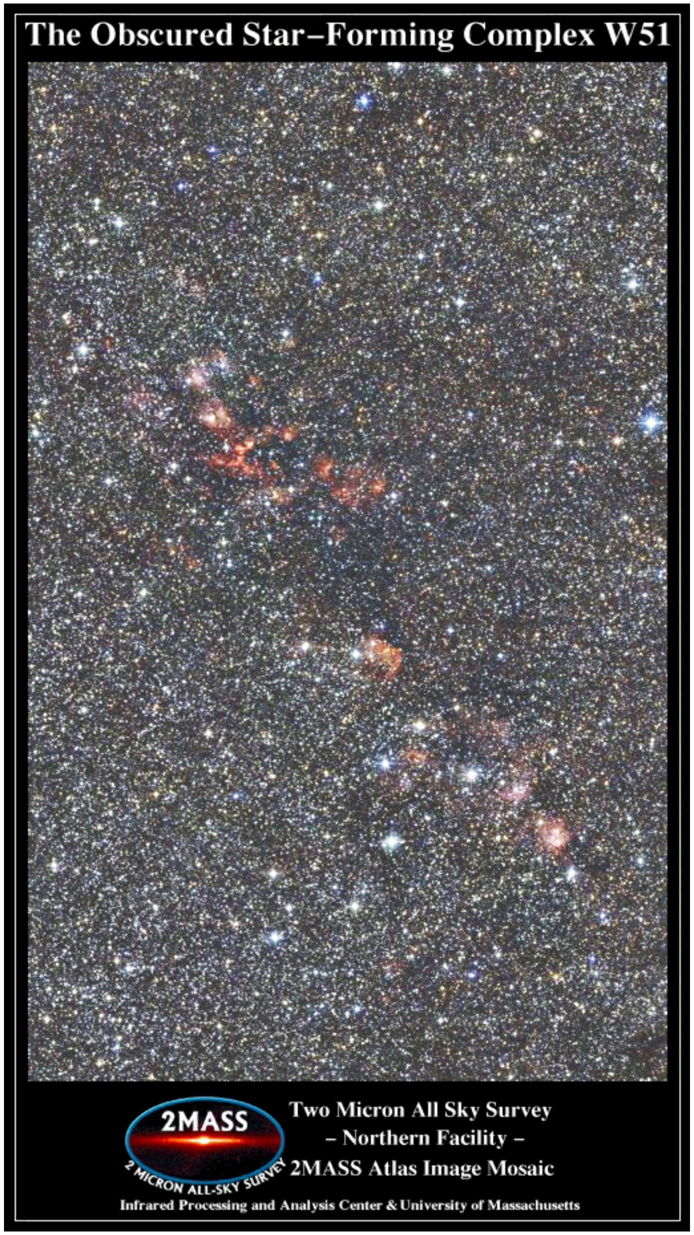
A full-band smoothed ACIS image of RCW 49 with over 500 detected point sources.

Spectral fitting: diffuse spectrum, Wd2 core excluded, point sources excluded, background.



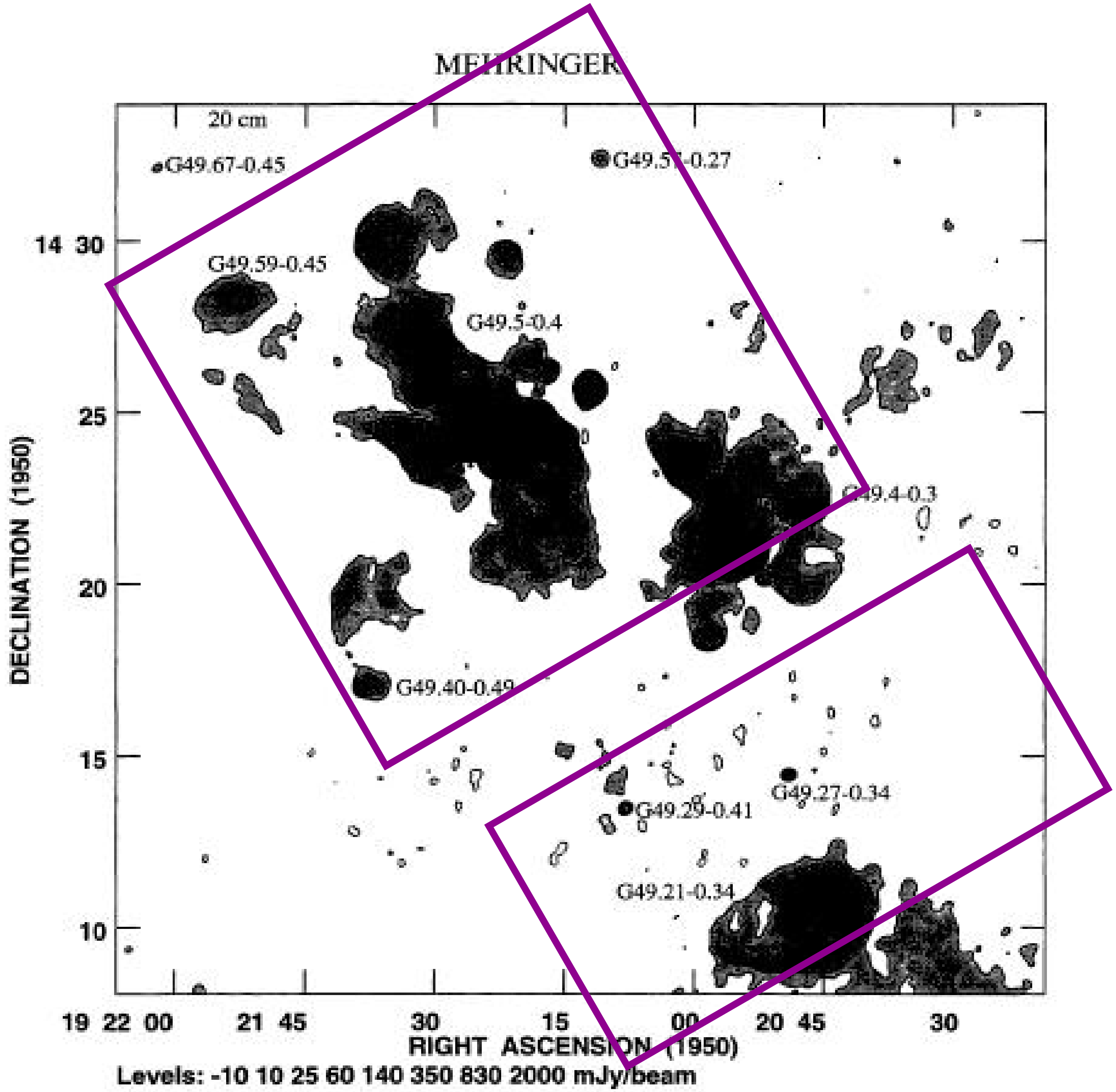
RCW 49 diffuse emission: a transition example? Hard component not well-constrained: thermal plasma or power law give acceptable fits.

W51

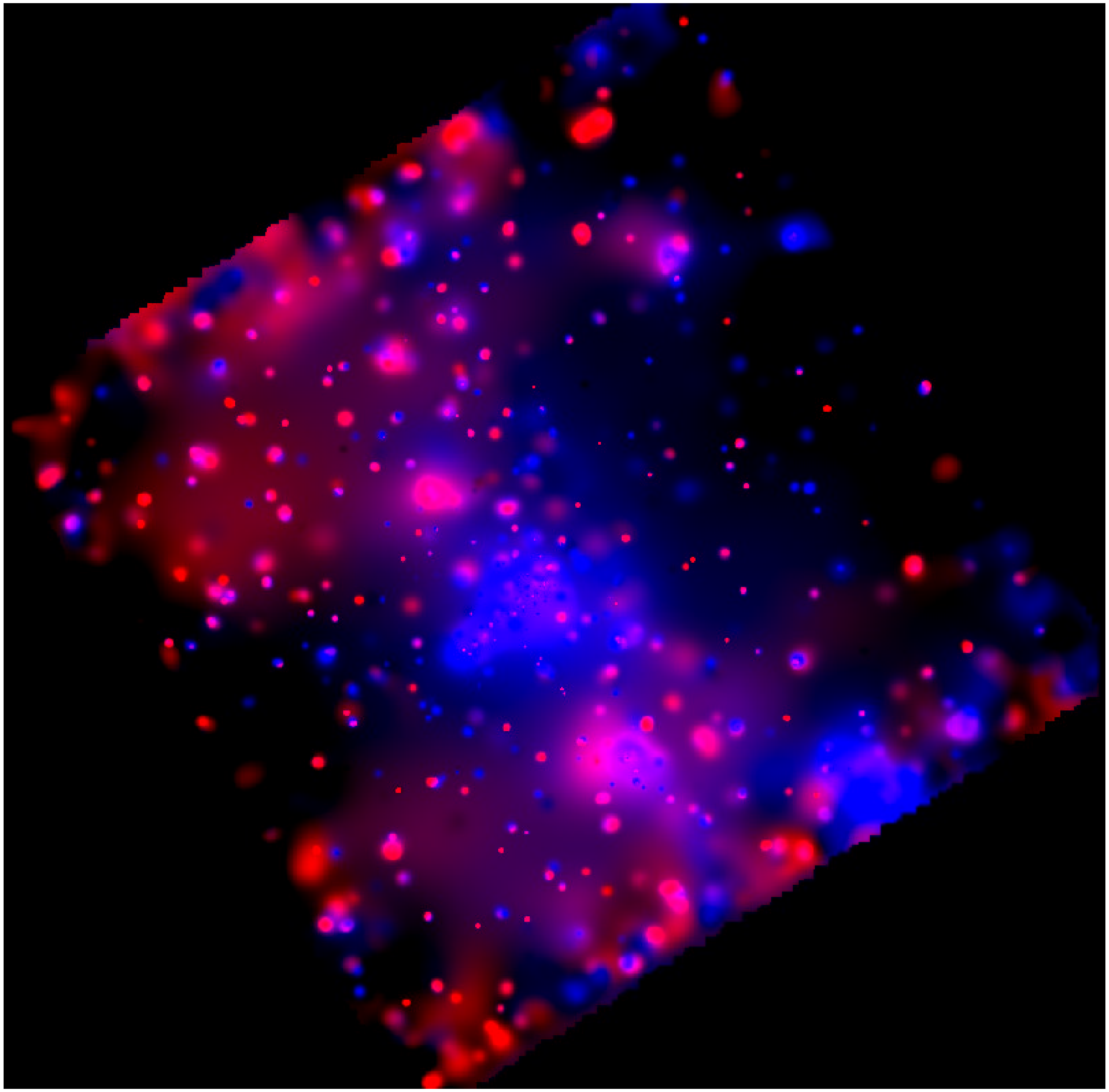


W51 complex, $43' \times 71'$.

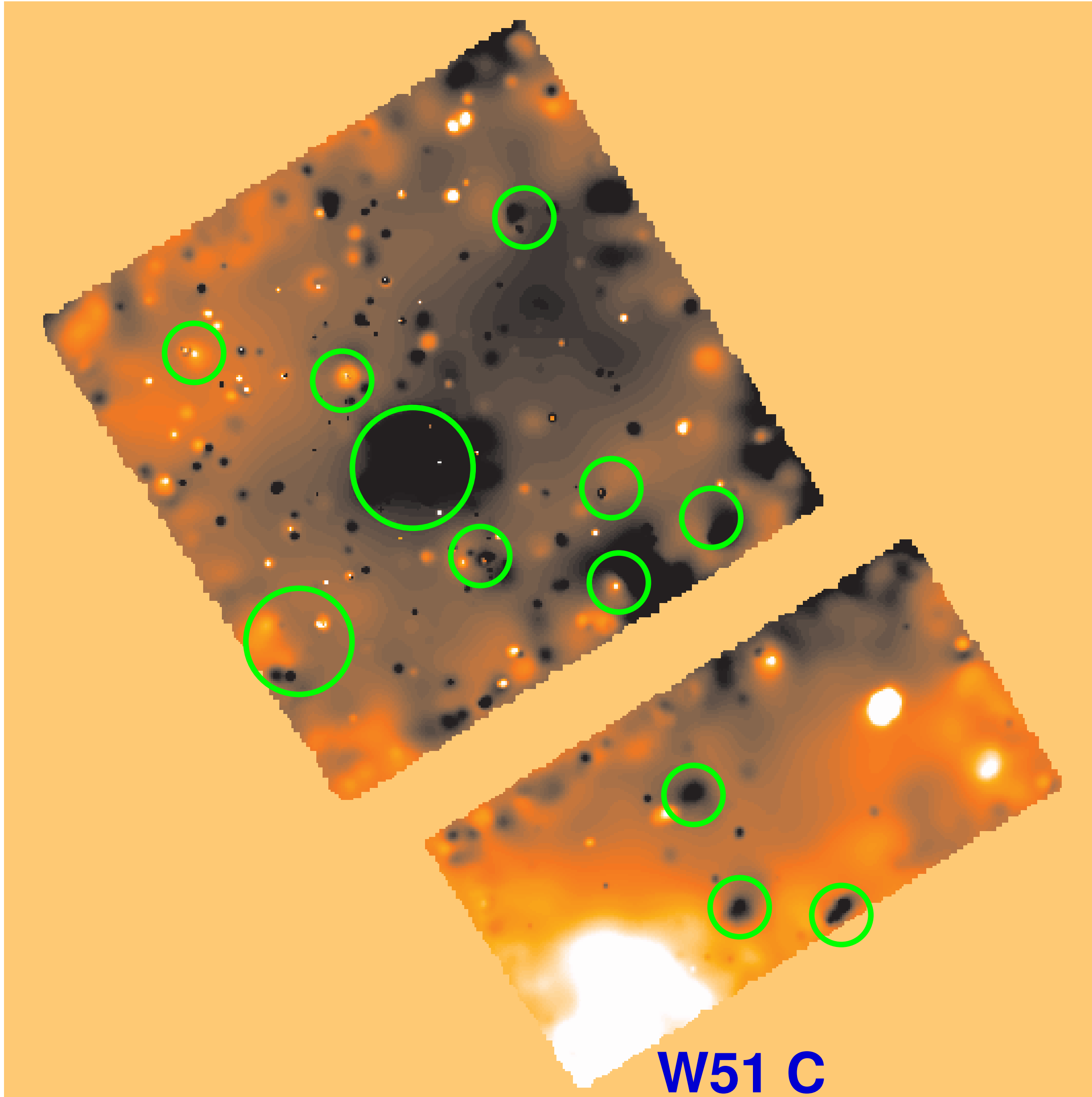
- One of the most luminous star-forming complexes in the Galaxy; its GMC is in top 10% by mass and top 1% by size.
- $D = 7.5$ kpc; $10' \sim 21.8$ pc.
- Cluster ages range from 0.4 to 2.3 Myr.
- At the tangent point of the Sagittarius Arm, star formation triggered by collisions of huge molecular clouds, perhaps due to spiral density wave.
- Just the complex G49.5-0.4 has 35 O stars (earliest O4); two are supergiants.



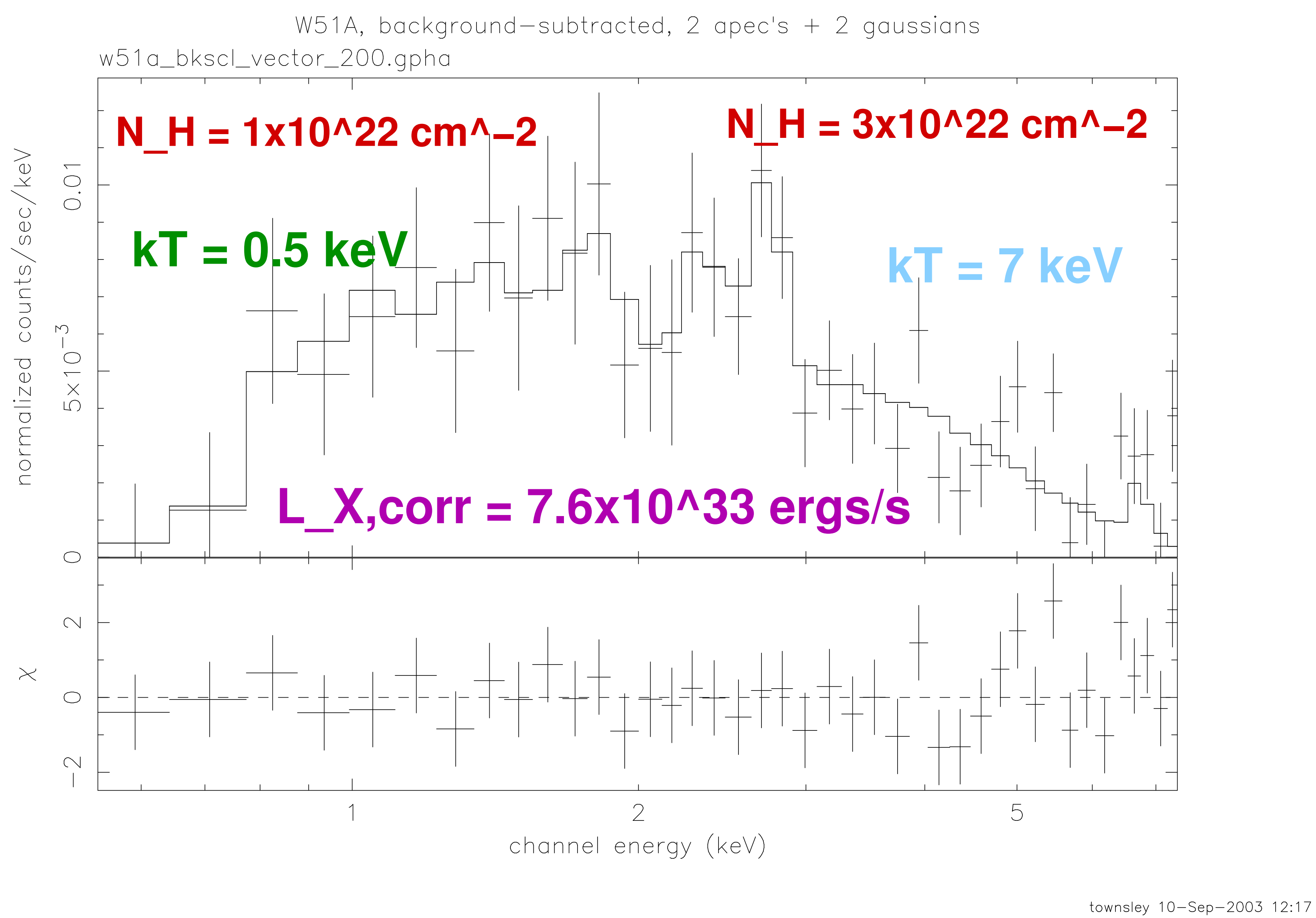
Radio continuum (Mehringer 1994, ApJS 91, 713) showing many HII regions, UC to diffuse. Masers everywhere too. ACIS FoV.



The 72-ksec ACIS-I observation of W51A. Over 450 X-ray point sources are detected. Diffuse emission is associated with most of the radio HII regions.



A hardness-ratio image of W51A: lighter regions are soft, darker regions are hard. Radio HII regions. W51C is a supernova remnant.



Diffuse emission in G49.5-0.4. Two thermal components plus two gaussians (at 2.3 and 2.7 keV) are needed.

Table 1. Diffuse X-rays from High-Mass Star-Forming Regions

Region	Diffuse Area (pc^2)	N_H 10^{21} cm^{-2}	kT (keV)	L_x, *corrected* 10^{33} ergs s^{-1}
Orion Nebula	⋯	⋯	⋯	$< 10^{-3}$
Eagle Nebula	⋯	⋯	⋯	$< 10^{-3}$
Lagoon – NGC 6530	⋯	⋯	⋯	$< 10^{-2}$
Lagoon – Hourglass	0.04	11.1	0.63	≤ 0.7
Rosette Nebula	47	2	0.06, 0.8	≤ 0.6
RCW 38	2	9.5	0.2, $\Gamma = 1.6$	1.6
RCW 49	39	4, 12	0.1, 0.8, 2.8 or $\Gamma = 2.3$	2
Omega Nebula	42	4	0.13, 0.6	3.4
W51A	140	10, 28	0.5, 7	7.6
Arches Cluster	14	100	5.7	16
NGC 3603	50	7	3.1	20
Carina Nebula	1270	3–40	0.8:	200:

WHERE WE STAND

- *Chandra* has resolved diffuse emission from stellar populations in several Galactic high-mass star-forming regions.

- *These are the first unambiguous detections of OB "windswept bubbles."*

- The Strömgren Sphere is really a Strömgren Shell in many cases.

- Diffuse emission may require early and/or multiple O stars (but not necessarily WR stars). Unclear whether emission is from individual stars or wind-wind interactions.

- Theories have to deal with $kT \sim 0.8$ keV and ~ 5 keV (or $\Gamma \sim 2$), $L_x \sim 10^{32-34}$ ergs/s, center-filled morphologies, parsec scales.

- Our L_X's are lower limits. *The Galactic Plane likely contains a LOT of soft X-ray emission from massive star-forming complexes!*

- PHYSICS: only a small portion of the wind energy and mass appears in the observed diffuse X-ray plasma. Could be dissipated via turbulence, mass-loading, fissures...

- X-ray flows from HII regions may contribute to the Galactic Ridge, diffuse emission in galaxies, starburst superwinds.

- Once again:
  How is the radio/IR picture of star formation impacted by the presence of 10^6–10^8 *K gas around the most massive stars?*

STAY TUNED FOR MORE DATA AND DISCOVERIES!

Already observed:

- NGC 6514 (Trifid) • M 8 (Lagoon) • W 3 Main
- Trumpler 16 (eta Carinae) • M 16 (Eagle)
- NGC 6334 (Bear Claw) • Cepheus B • Cygnus OB2
- Rosette Molecular Cloud, NGC 2244 • Orion

Coming in the next year:

- RCW 108 • Arches Cluster • NGC 6357, Pismis 24
- Trumpler 14 in Carina • XMM Carina mosaic
- NGC 3576 (M 17 analog)