The Future of Our Past
Star Formation & Feedback with X-ray Surveyor

Leisa Townsley

NASA's Big Questions

How did we get here?

Goal: Explore the origin and evolution of the galaxies, stars, and planets that make up our universe.

``Though astronomers have been studying stars for thousands of years, it is only in the past 35 or so years that they have been able to employ instruments that detect light across the entire electromagnetic spectrum...to peer into the dusty clouds where stars are born in our own Galaxy.

If we are to comprehend how the universe makes stars–and planets that orbit them today–we must continue these studies with ever more powerful telescopes."

X-ray Observables

All young stars emit X-rays:
- magnetic reconnection flaring in low-mass stars
- microshocks in the strong winds of massive stars
- X-rays correlated with stellar mass
- emission is always variable, eventually.

Colliding-wind binaries or strong fossil B fields in massive stars generate brighter, harder X-rays.

X-rays: Not just a good idea anymore...

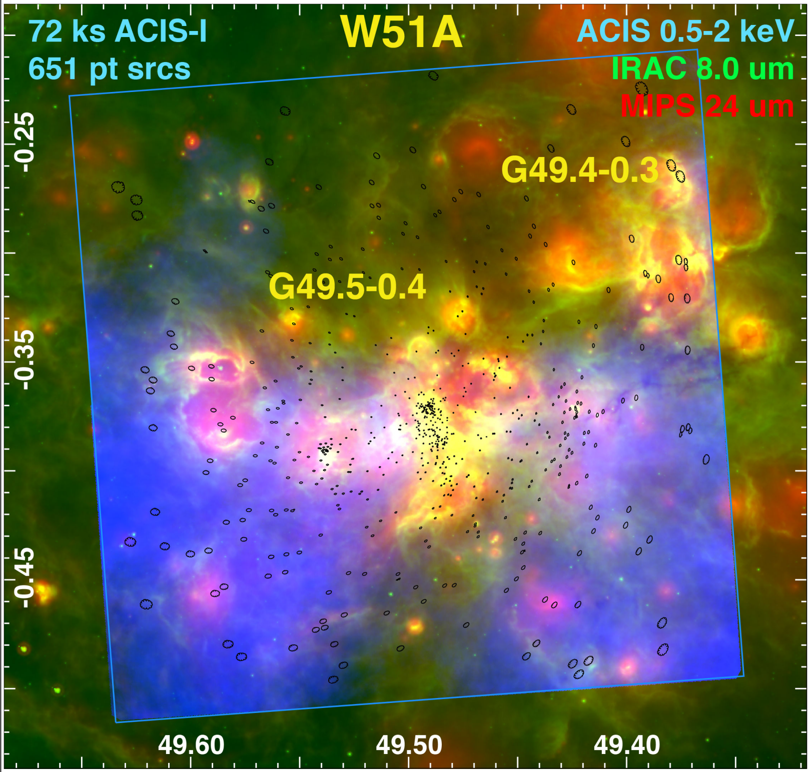
Star formation builds a strong bridge between NASA PCOS and COR:
- X-rays see just the young stars, give hot ISM energetics
- the best stellar census in a young cluster comes from X-ray + IR
- long wavelengths give stellar properties, warm and cold ISM

Chandra gives us many great examples of this partnership.

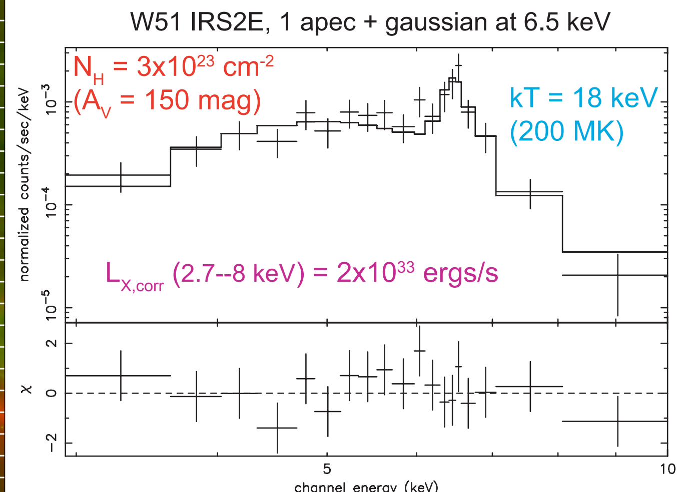
X-ray Surveyor (XRS) will bring the sensitivity and sky coverage necessary to make X-rays integral to every star formation study.

Buried Treasure
Hyper- and Ultra-Compact HII Regions

Chandra finds the ionizing sources in famous UCHIIRs -- many have strange, hard spectra penetrating 100-200 mags of extinction, but few photons make it through.

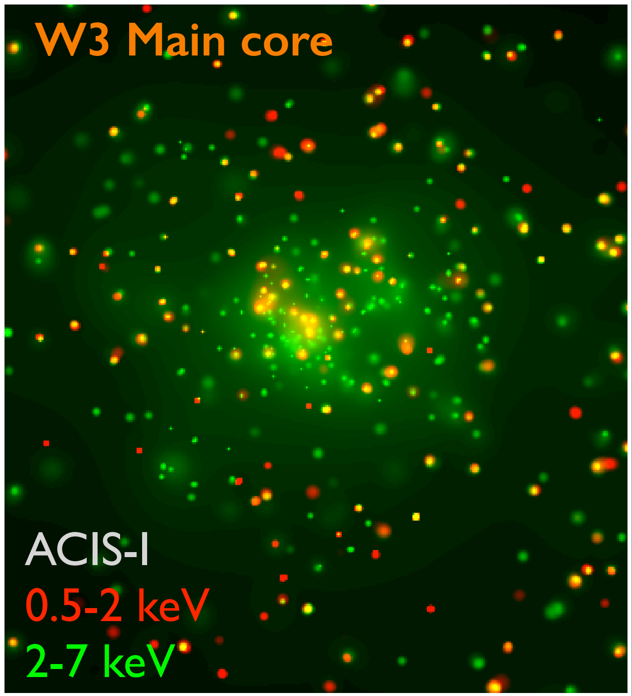


Cold Fe fluorescence:

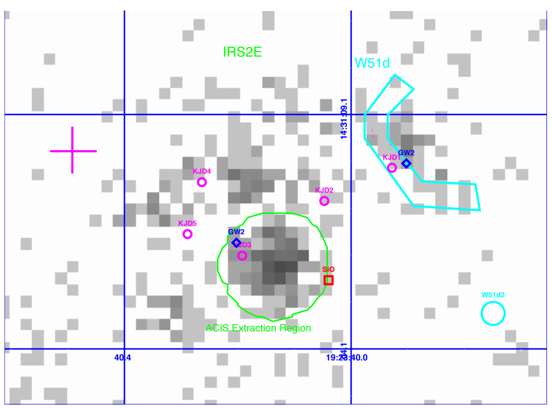


W51 IRS2E is a massive (early-O) star probably surrounded by a "quenched" HII region (Keto06).

ALMA chemistry should not ignore a 200 MK emitter!

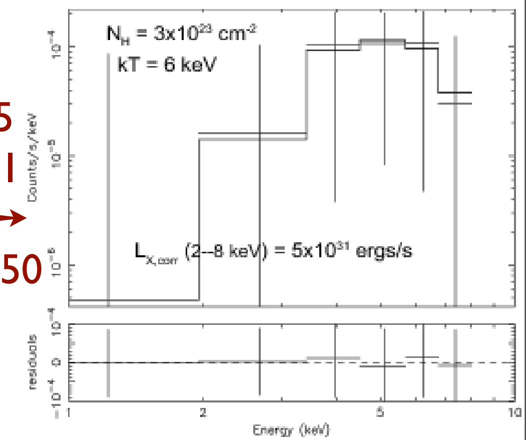


W51 IRS2, 8"x12", ACIS



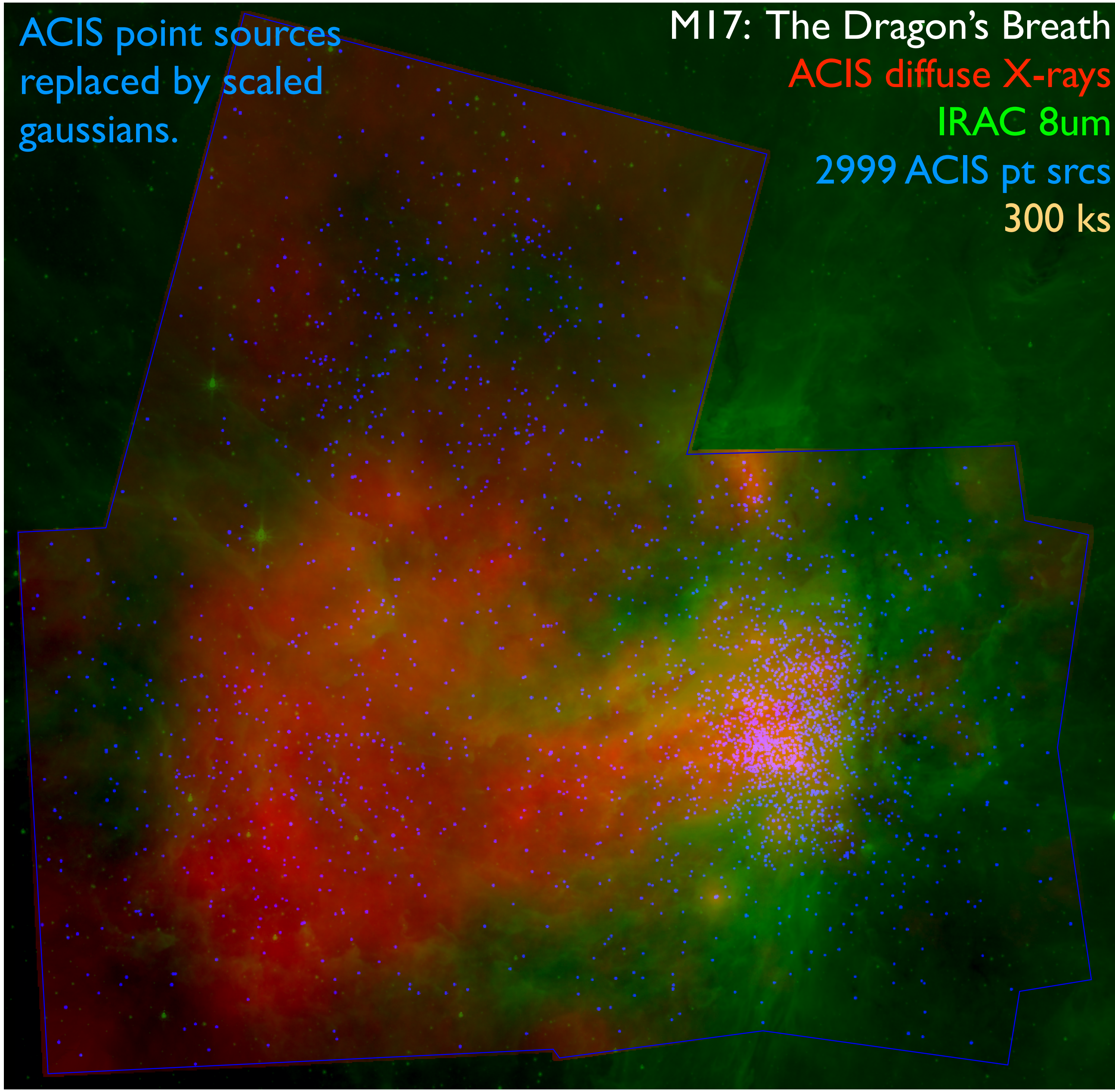
XRS: ~5000 cts in IRS2E, >1000 in many other UCHIIRs. Study their wind shocks, plus trace full XLF for surrounding young clusters.

IRS5
NIR1
N_H →
A_V=150

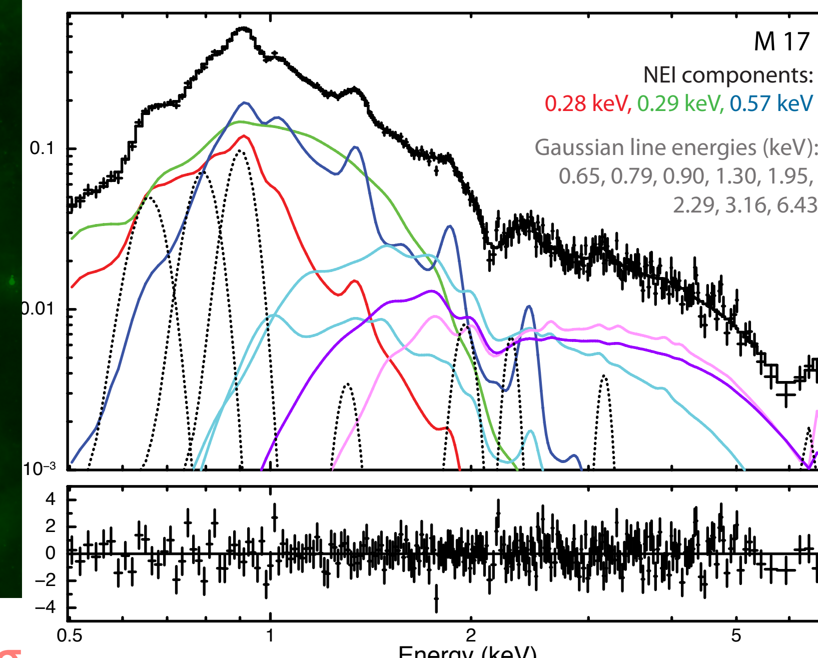


Birth of the Hot ISM

Chandra's spatial resolution lets us separate young stars from the faint diffuse X-rays surrounding them, tracing hot plasma generated by O star winds. We see this emission in essentially all young clusters, as predicted 45 years ago.



The Dragon's Breathalyzer



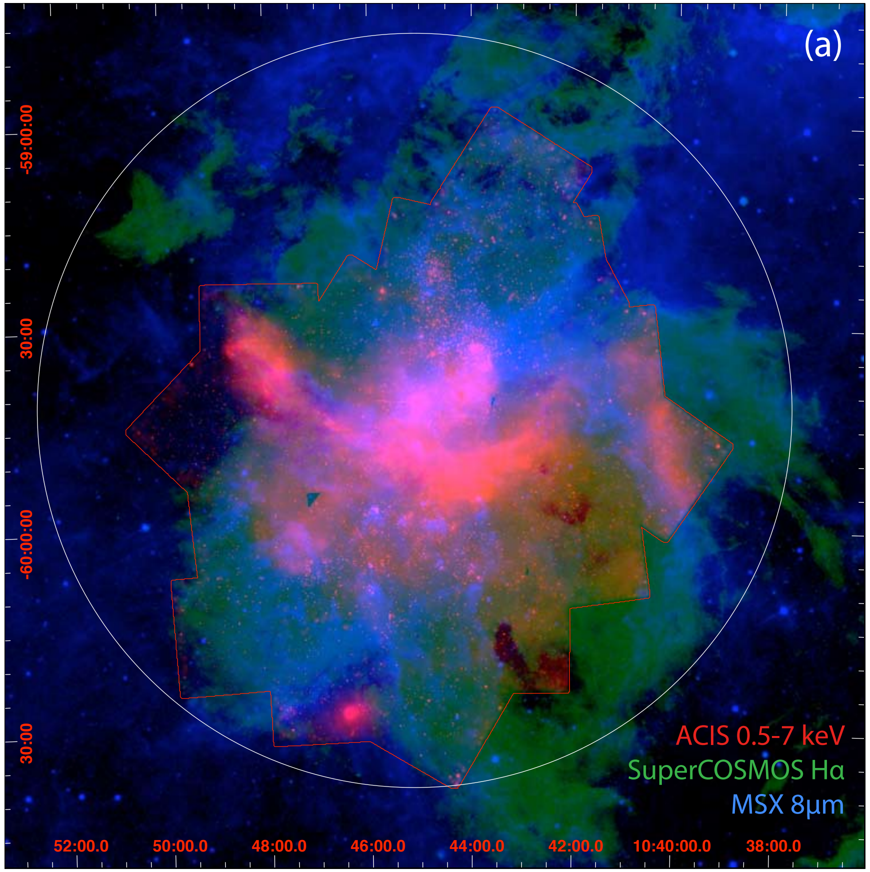
XRS could capture this scene in ~1 30-ks pointing. In 300 ks, trace entire XLF, spatial distribution of older populations, get spectra for embedded MYSOs, monitor variability in all OB stars, ...

3% of L_x in gaussian lines -- possible evidence for HII Region Charge Exchange (HIICX) -- or maybe just the wrong model.

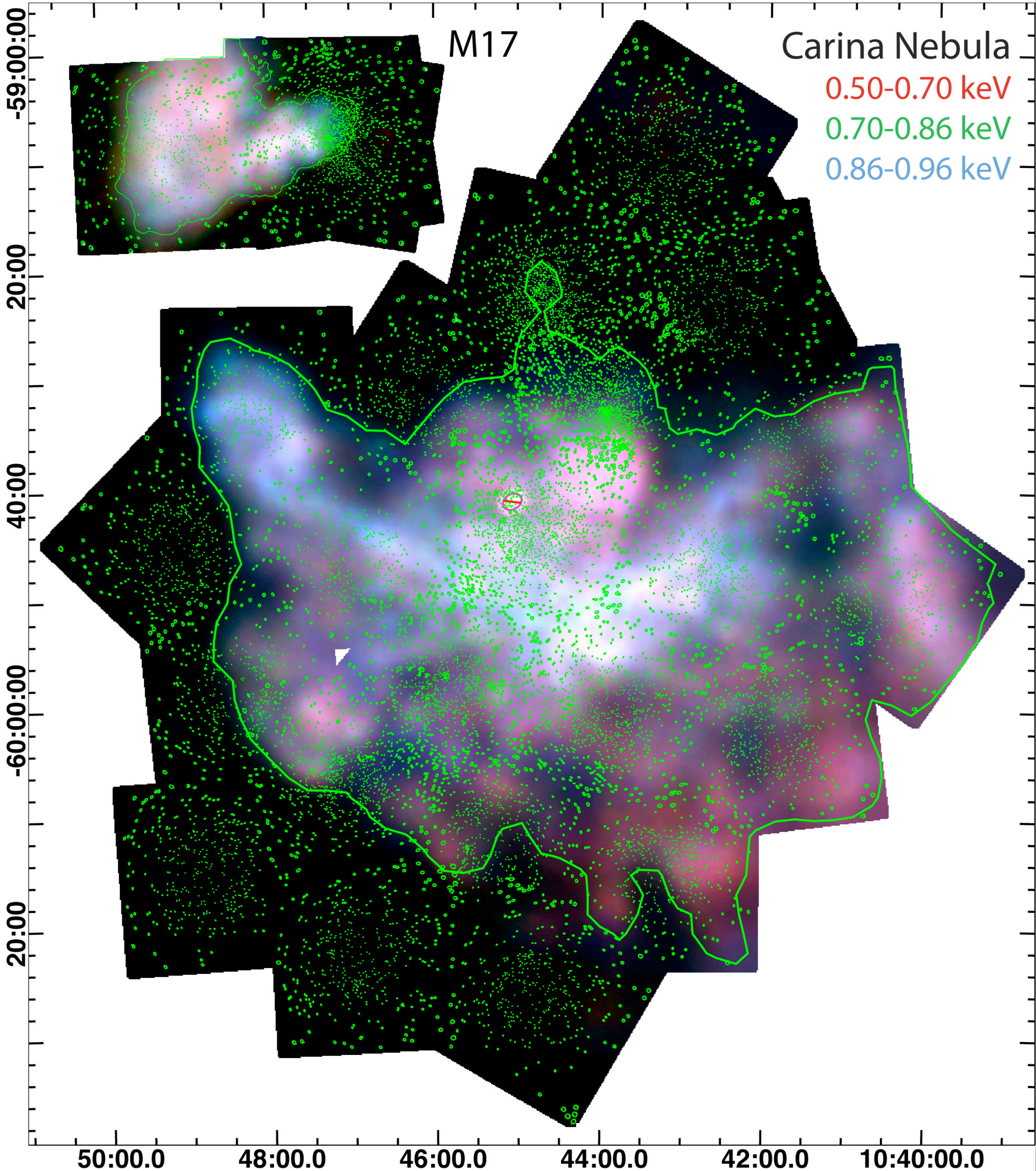
A Cluster of Clusters: CCCP

1.2 Ms Chandra VLP

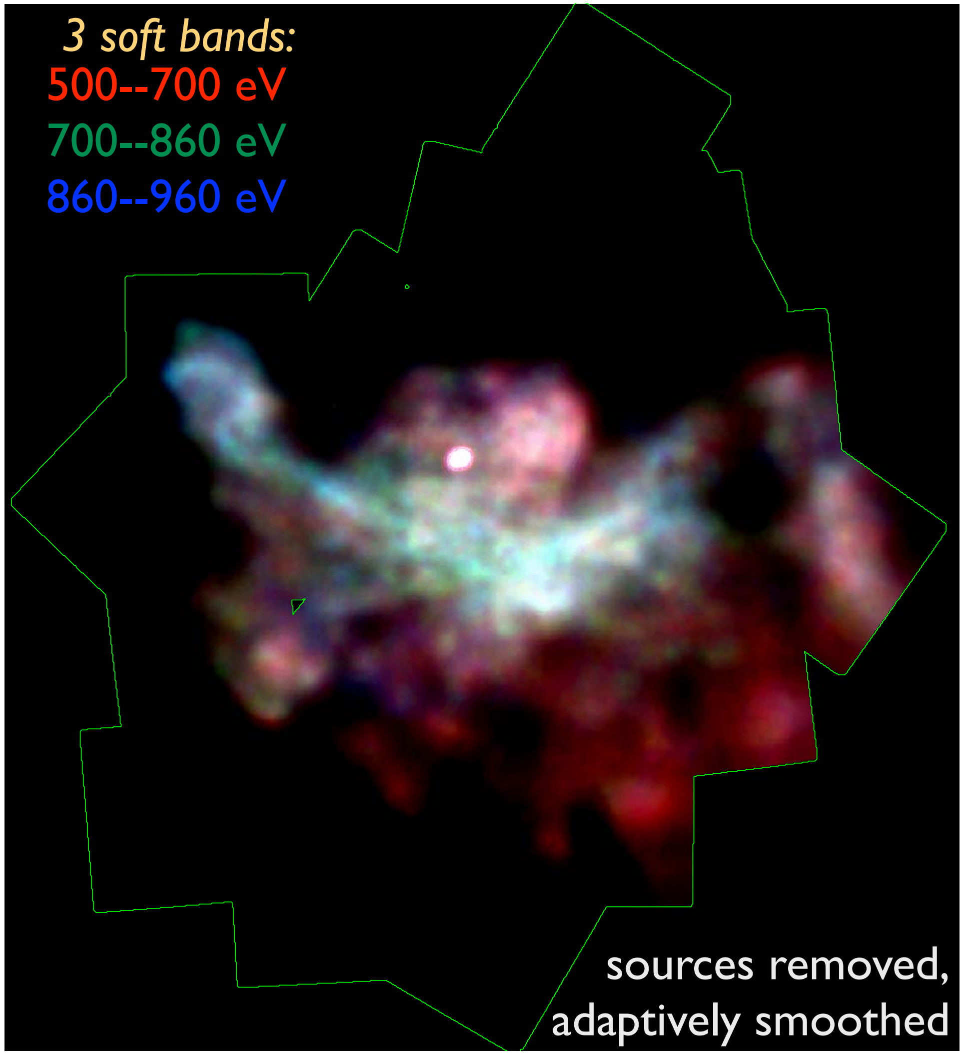
7 young clusters
22 ACIS-I pointings,
60 ks each

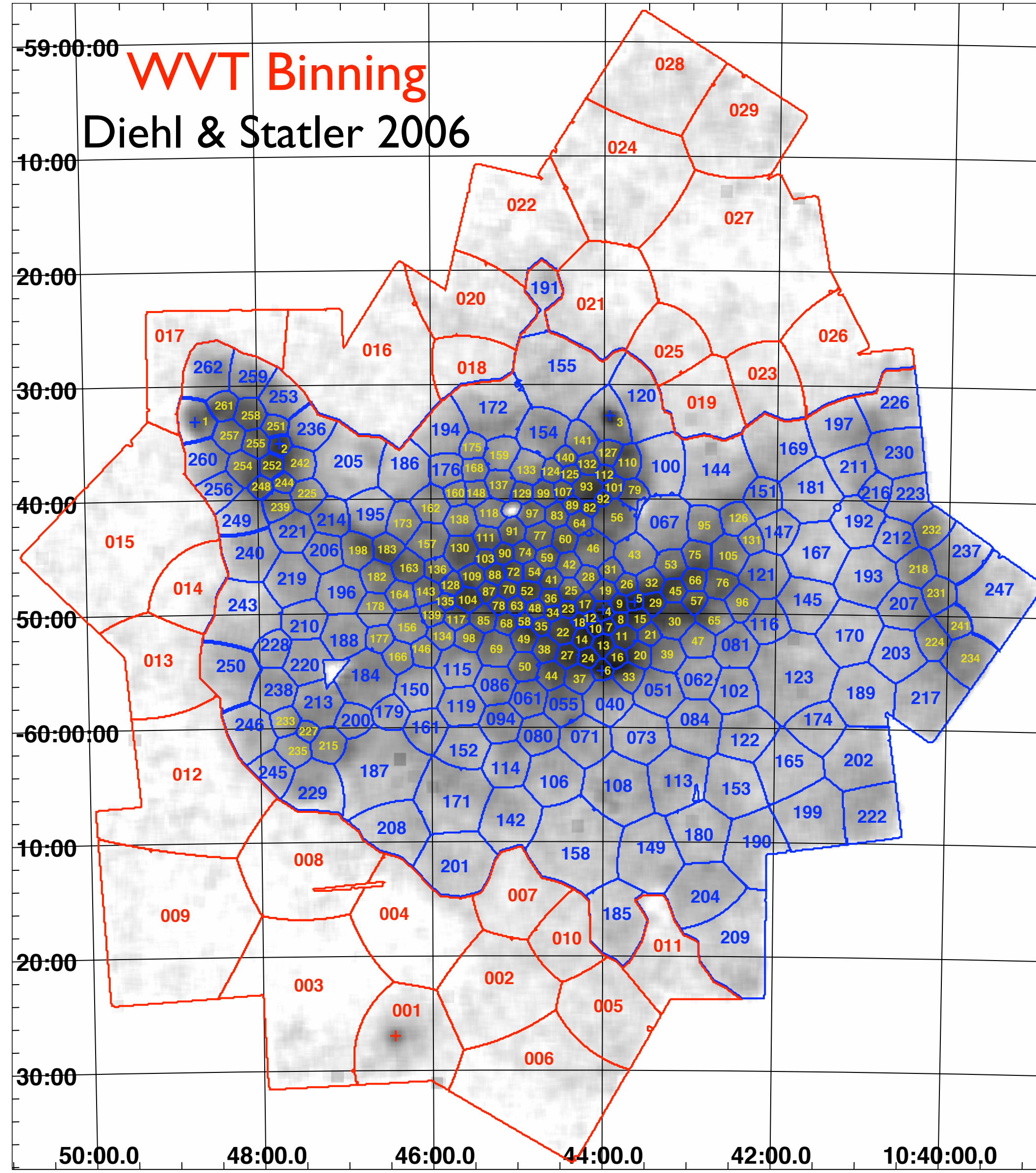


XRS: 1" resolution across entire field, minimize "egg crate effect." Repeat CCCP in 100 ks, see mostly a different set of stars. Build up 1.2 Ms to see full XLF down to ~0.2 Msolar. Trace structure, monitor 100+ OB stars.



CCCP Soft Diffuse Emission



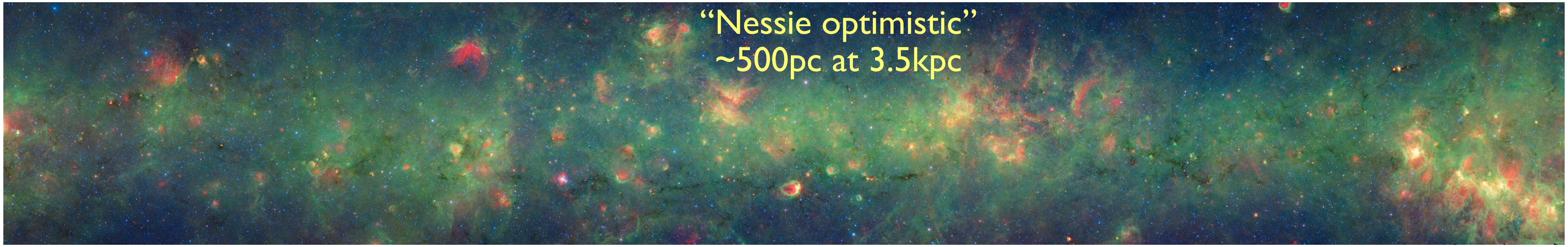


Chandra diffuse analysis: remove pt srcs, tessellate. Spectral fits yield maps of N_H, kT's, abund variations, intrinsic surface brightness => pressures, densities => HII region dynamics.

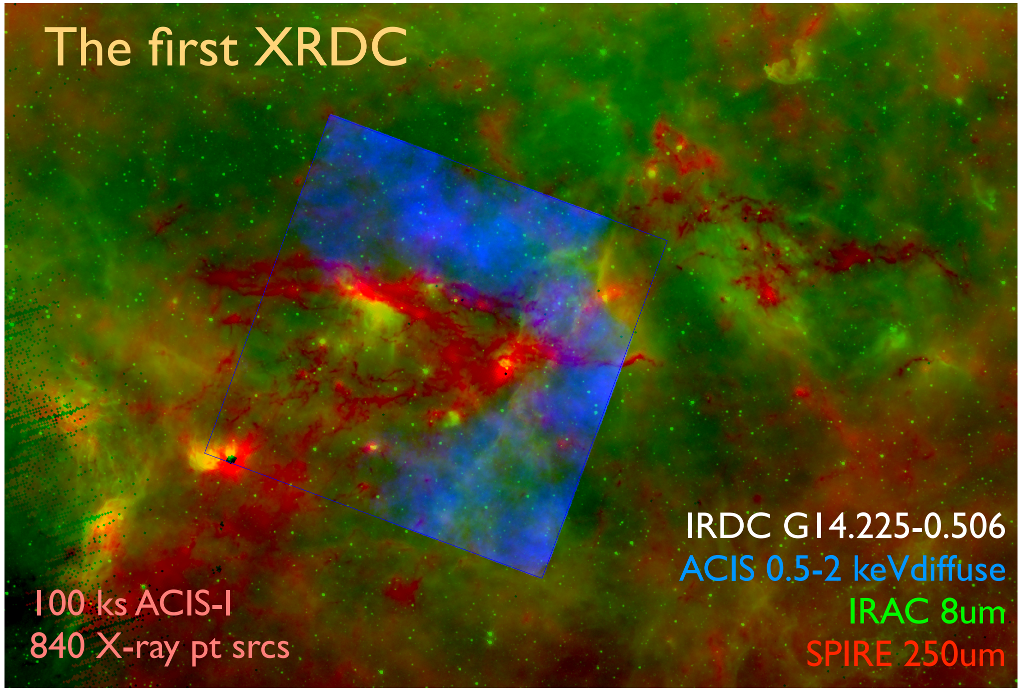
XRS: exploit high resolution with enough photons to fill cells -- 10x sensitivity => 10x more tessellates. Need fine probe to separate spectral features, HIICX variations.

X-raying the Bones of the Milky Way

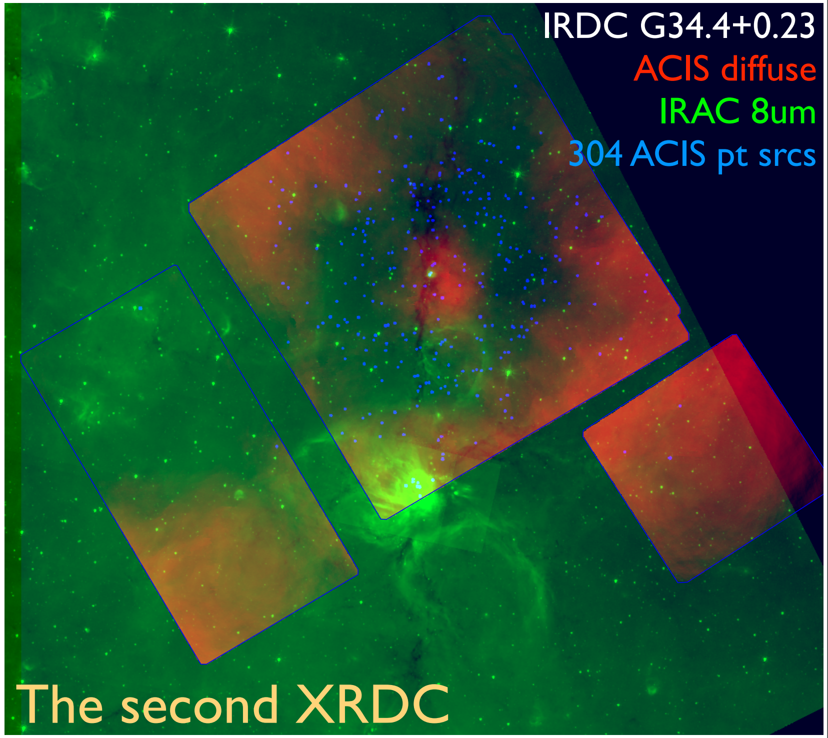
Goodman14: major Infrared Dark Cloud (IRDC) filaments form structures that extend for hundreds of parsecs and form the "spines" of the spiral arms.



Chandra is characterizing the history and extent of star formation in just a couple of individual small IRDCs.

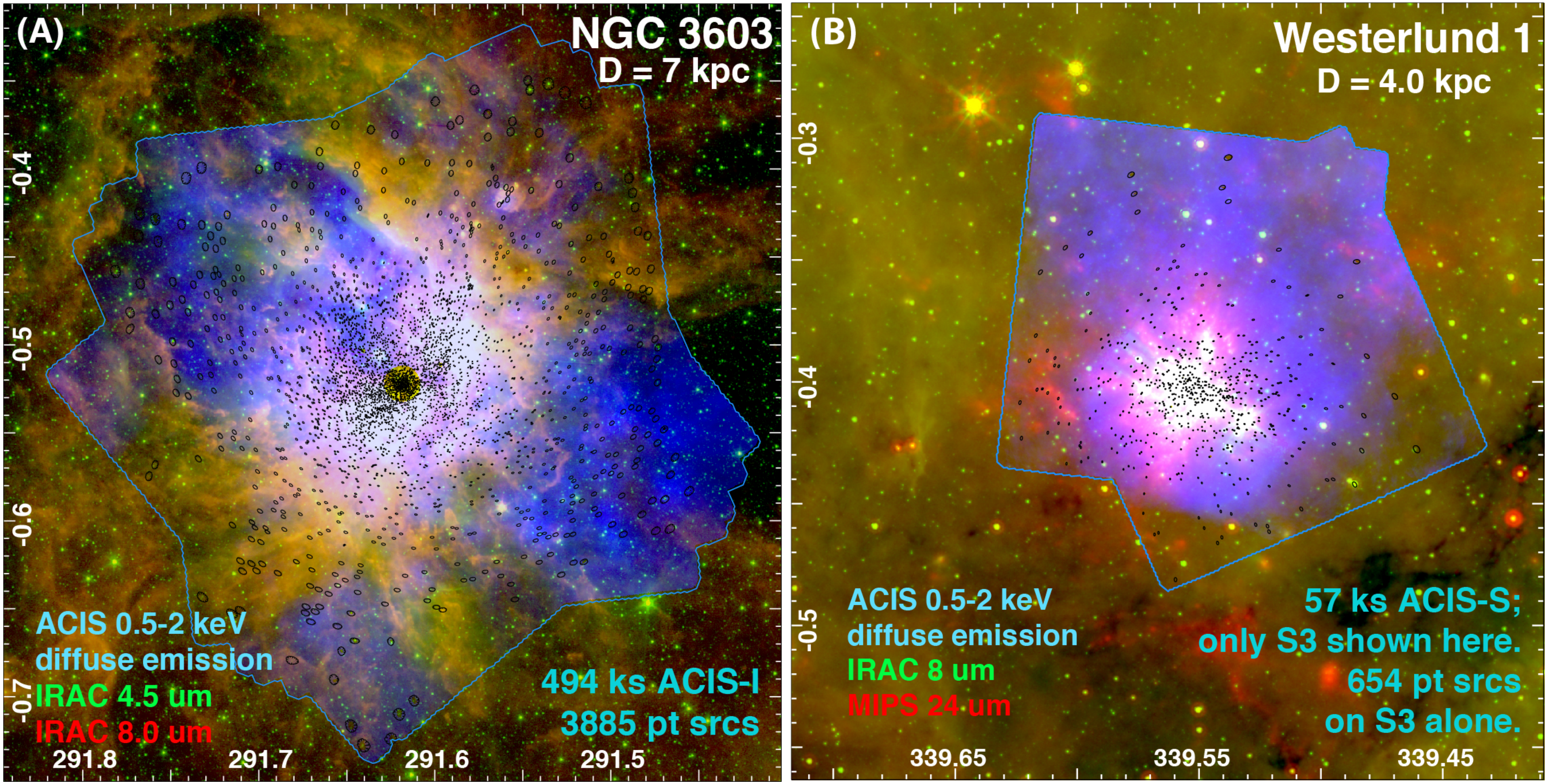


Povich15: *Rapid Circumstellar Disk Evolution and a High Rate of Distributed Star Formation in the IRDC M17 SWex*



XRS's sensitivity, large FoV, and compact PSF over wide fields are needed to map these huge structures, building an unprecedented picture of the major skeletons supporting star formation in the Galactic Plane.

Star Formation Powerhouses: Young Massive Clusters



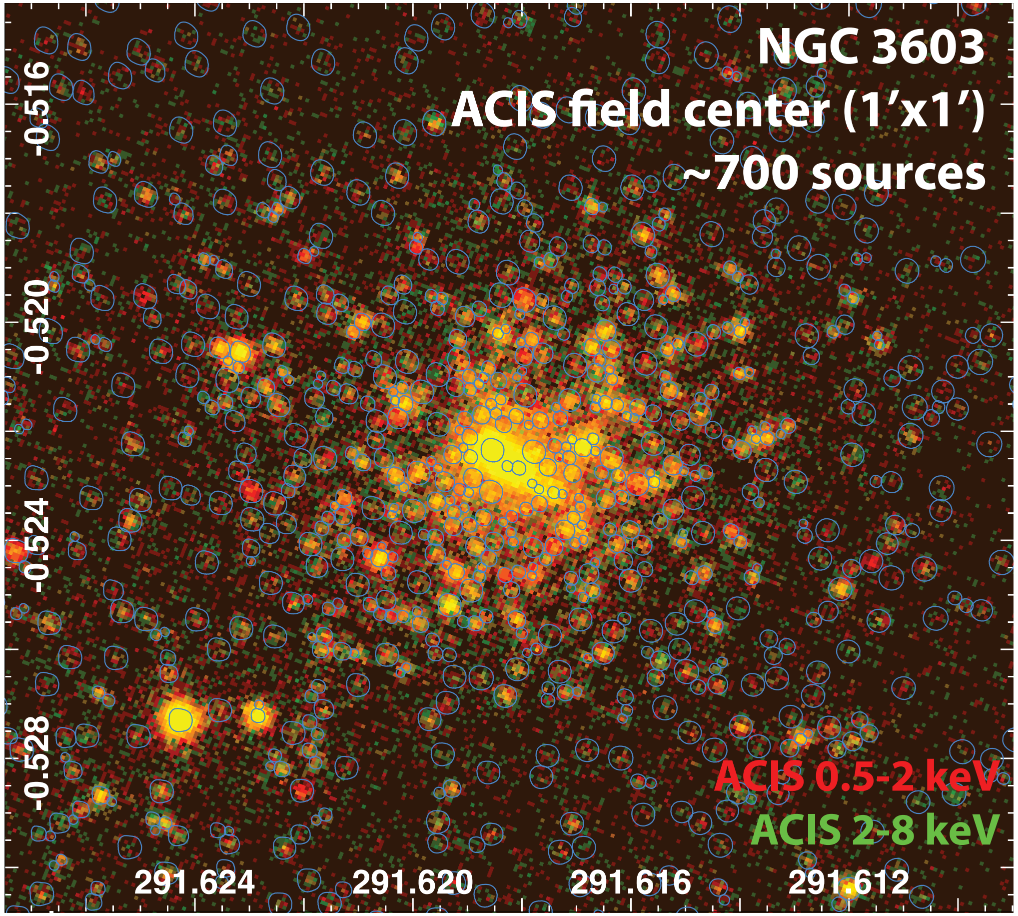
NGC 3603:
~2 Myr old,
13,000 Msolar
diffuse X-rays
from
wind shocks

YMCs shape galaxies, fuel the hot ISM, give birth to XRBs, SNRs, pulsars, gamma rays, etc.

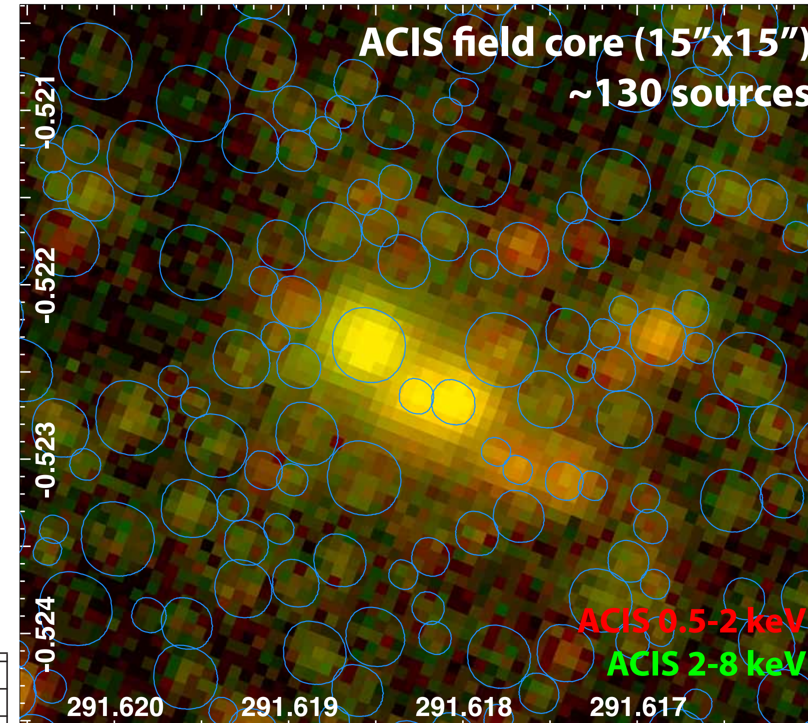
Chandra: only time for a few (often short) studies so far.

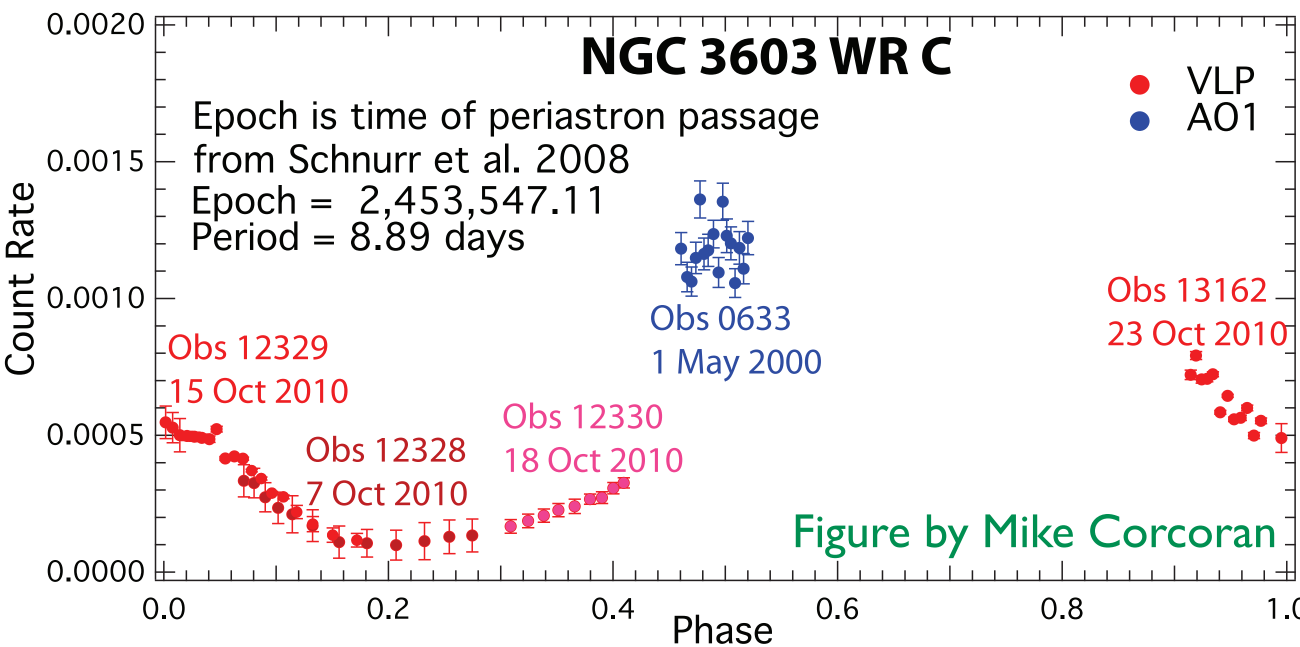
XRS: eROSITA and WFIRST will provide hundreds of YMC candidates in the Milky Way and beyond. A comprehensive study is only plausible with XRS efficiency.

Wd1:
4 Myr old,
50,000 Msolar
diffuse X-rays
mainly from
cavity SNRs



Chandra/XRS resolution is essential for YMC science.

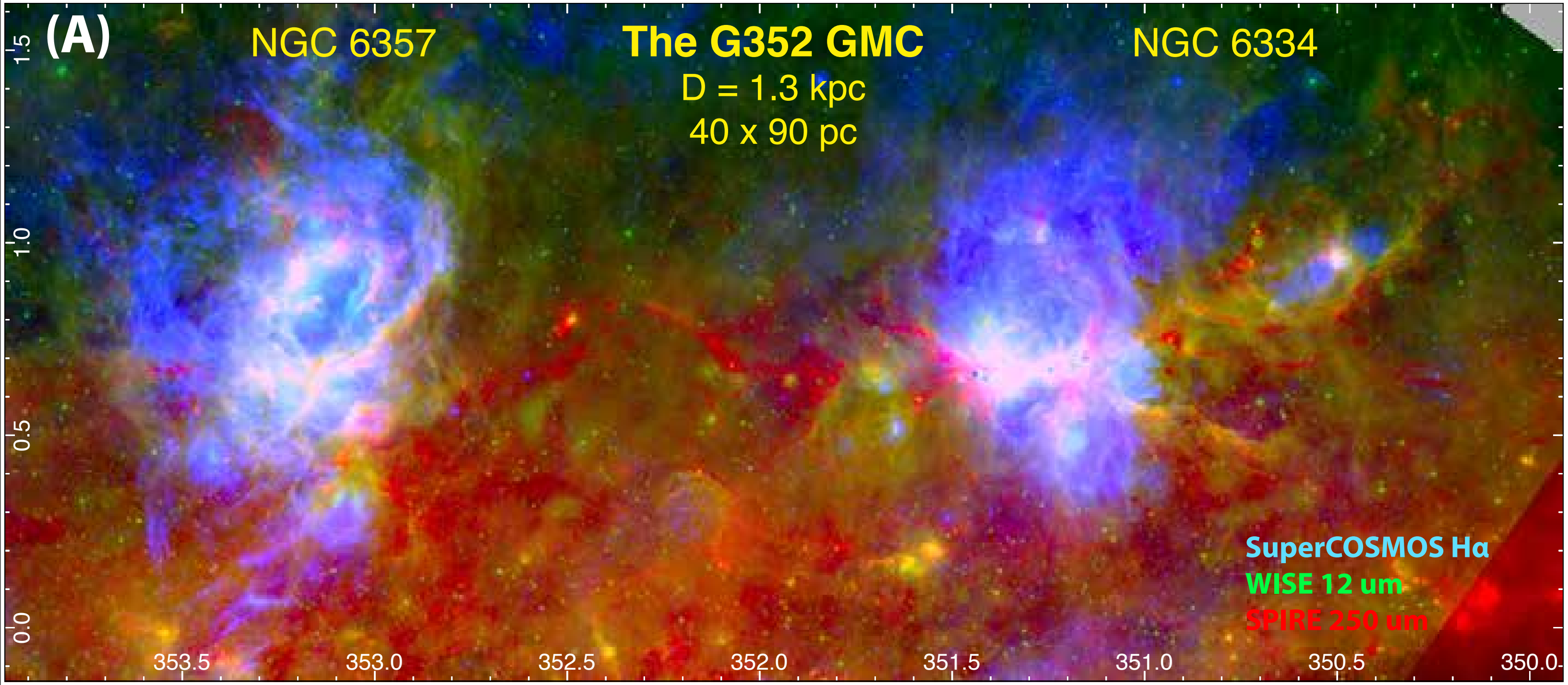


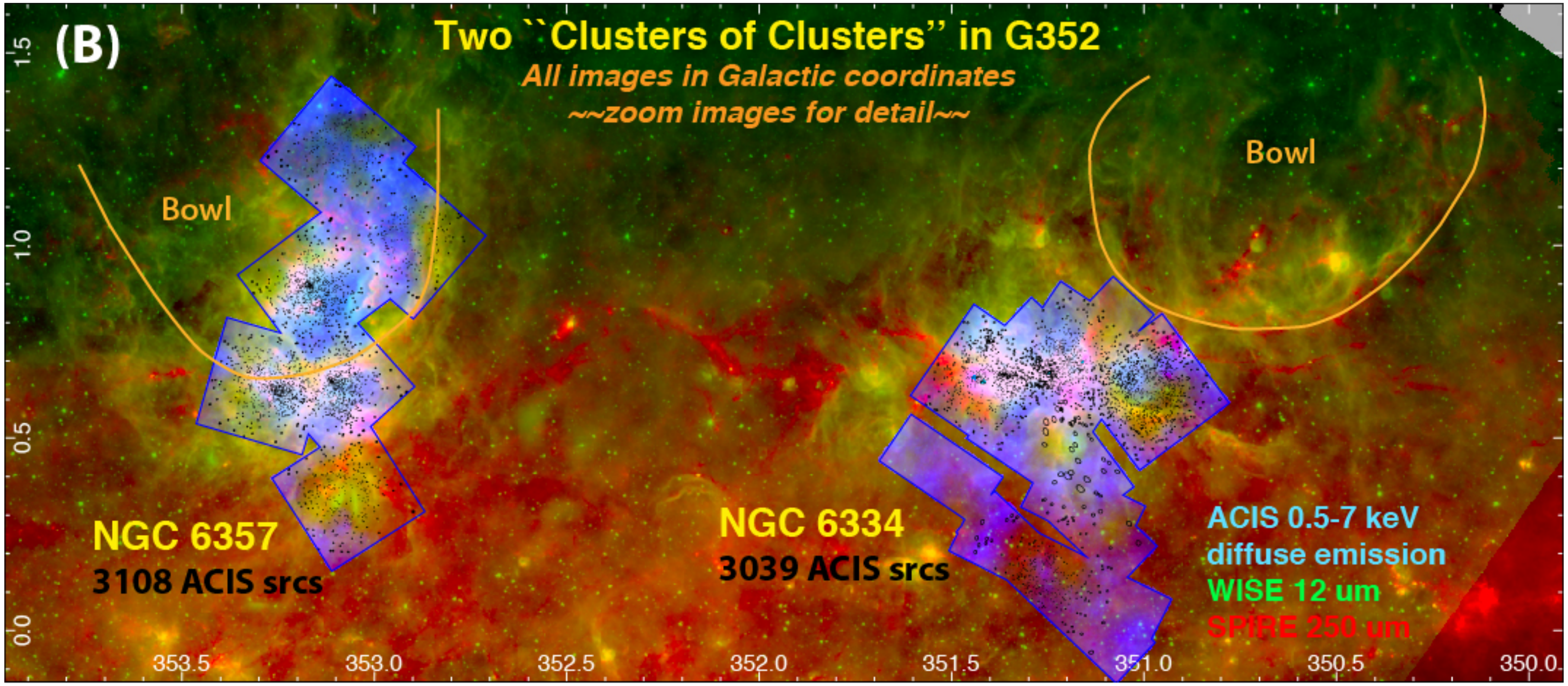


Other WR stars in NGC 3603 are doing a similar dance.

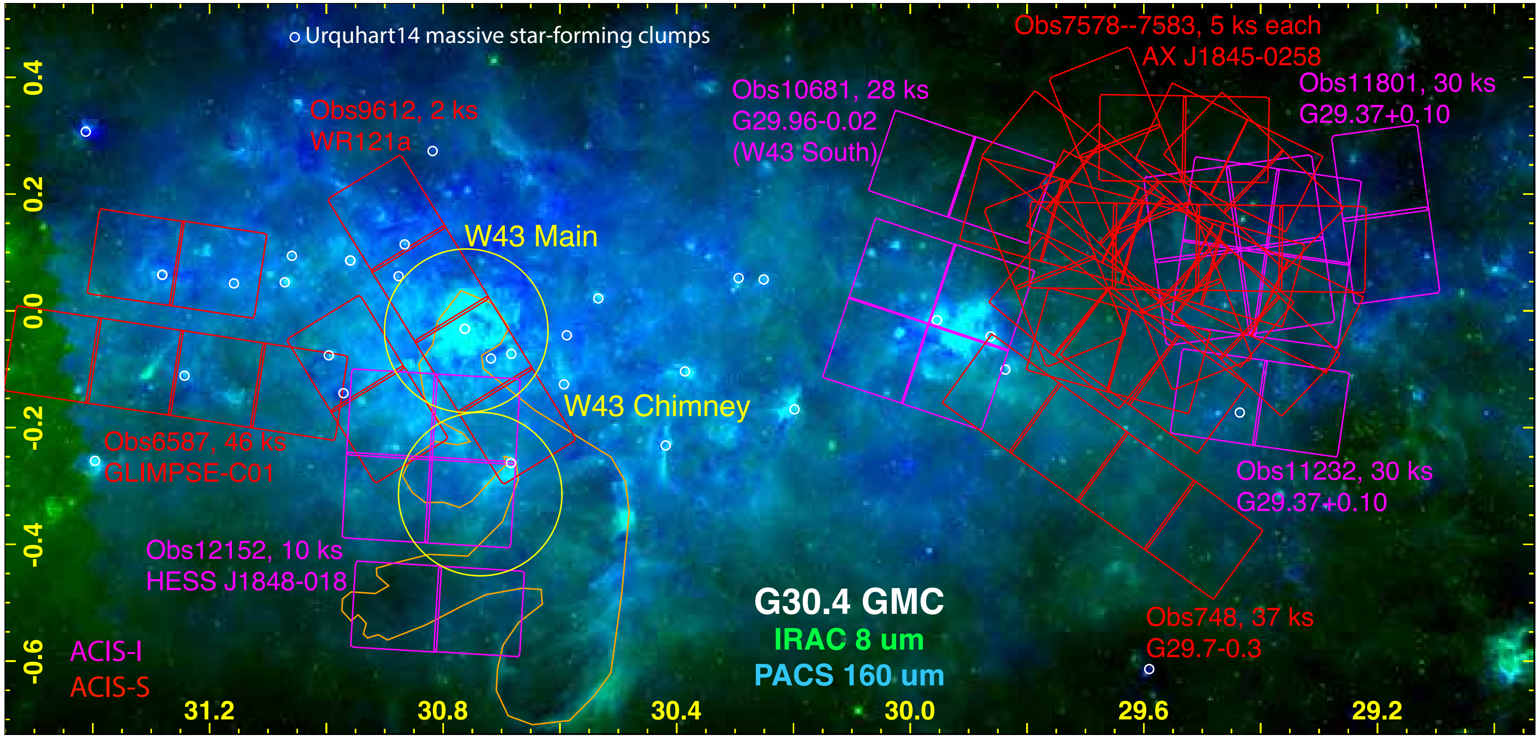
This appears to be the norm for a young starburst cluster.

For the Big Picture, Survey Whole Giant Molecular Clouds



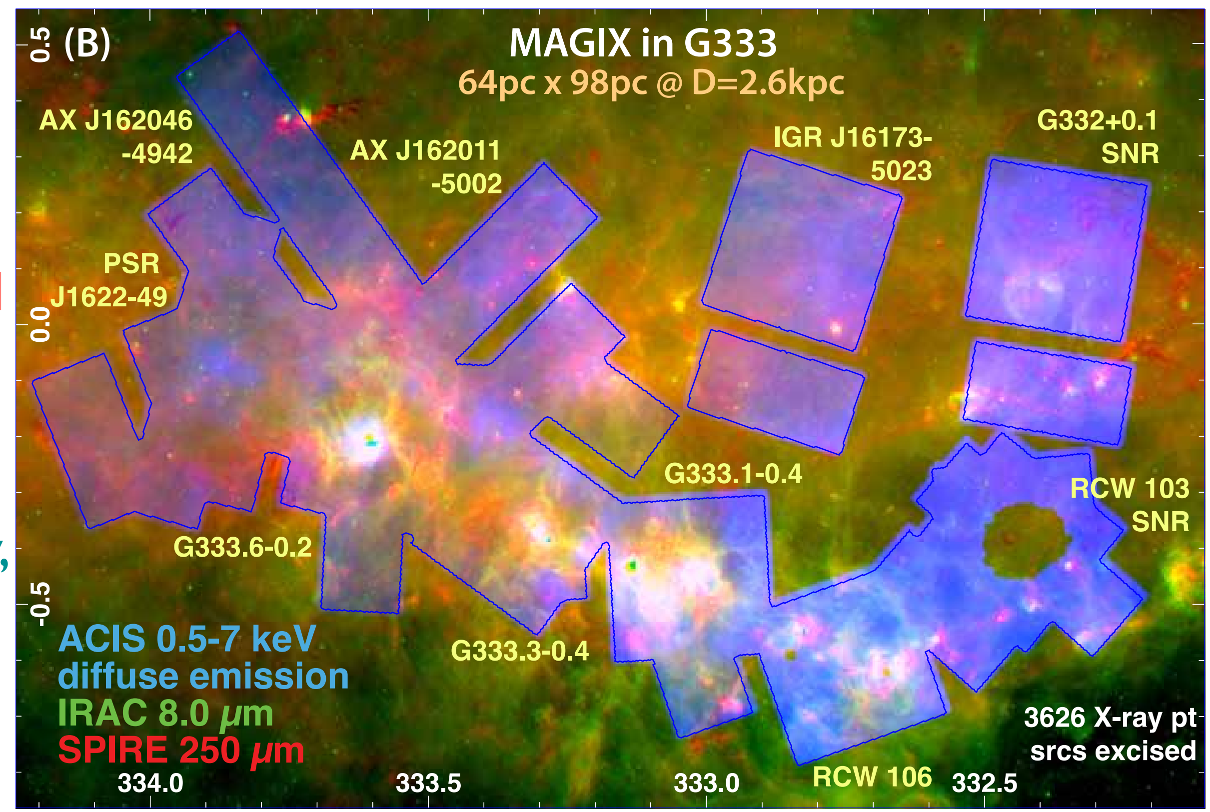


Chandra can piece together some structures (young clusters, SNRs) that make up major star-forming complexes, but it takes many separate programs.



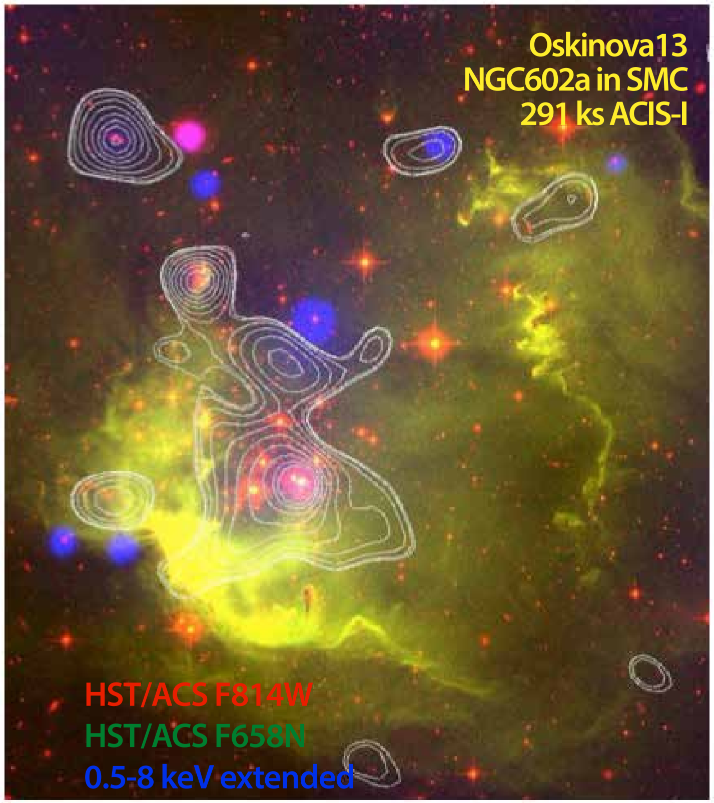
XRS LP's could survey whole GMCs, covering all major filaments, clusters, distributed young stars, SNRs, collapsed objects, hot plasmas, etc.

First comprehensive X-ray study of a whole GMC -- study the forest ecology, not just the butterflies and tigers.



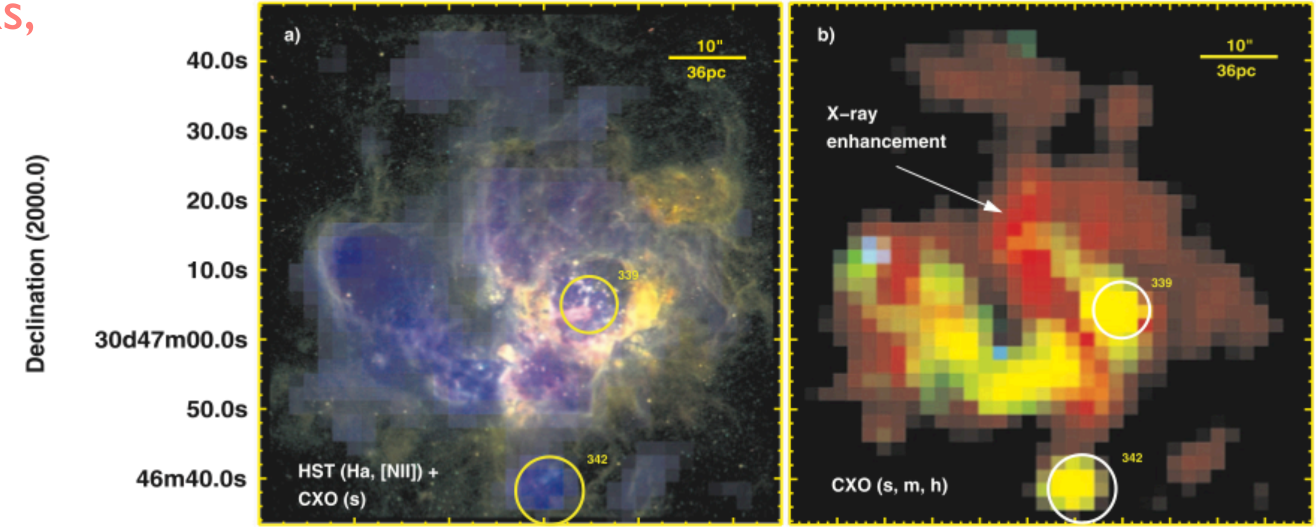
Beyond the Milky Way

XRS sensitivity and spatial resolution are critical for progress on Local Group YMCs, superbubbles, SNRs, XRBs -- all are found together!

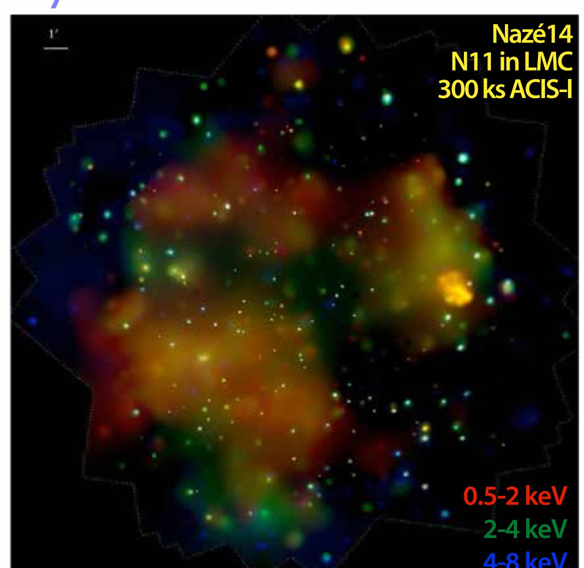


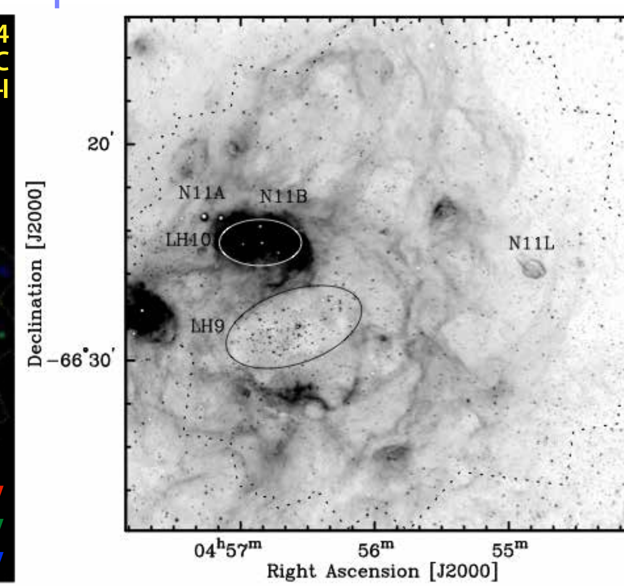
Oskinova13: NGC 602a in SMC (60 kpc)
9 pt srcs, plus unresolved emission with kT ~ 2 keV, likely the pre-MS populations of the SFRs.
If so, SMC pre-MS stars are comparable X-ray emitters to Galactic pre-MS stars.

Tullman08: NGC 604 in M33 (817 kpc) This appears to be a multi-generational complex with wind-generated plasma on one side, cavity SNR shocks on shell walls providing diffuse X-rays on the other side. Many unresolved stars.



Naze'14: N11 in LMC (50 kpc) 165 pt srcs, (14 OB + fg stars + AGN) plus unresolved emission with kT ~ 0.2 keV and an extra kT>1 keV near main SFRs. Likely hot plasma from feedback plus unresolved young stars. X-ray emission from O stars comparable to Galactic levels.





The **T**arantula--***Re****vealed by* ***X****-rays* (***T-ReX***)

An ongoing 2Ms Chandra XVP

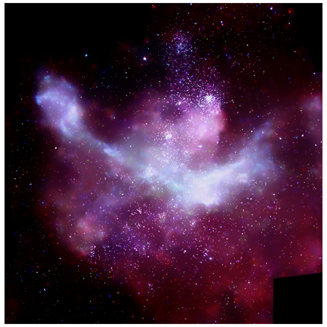
log Lx (lim) = 31.2 erg/s will reach all massive stars O8 & earlier, IMPS, brightest pre-MS

Complete dataset should yield ~3000 point sources.

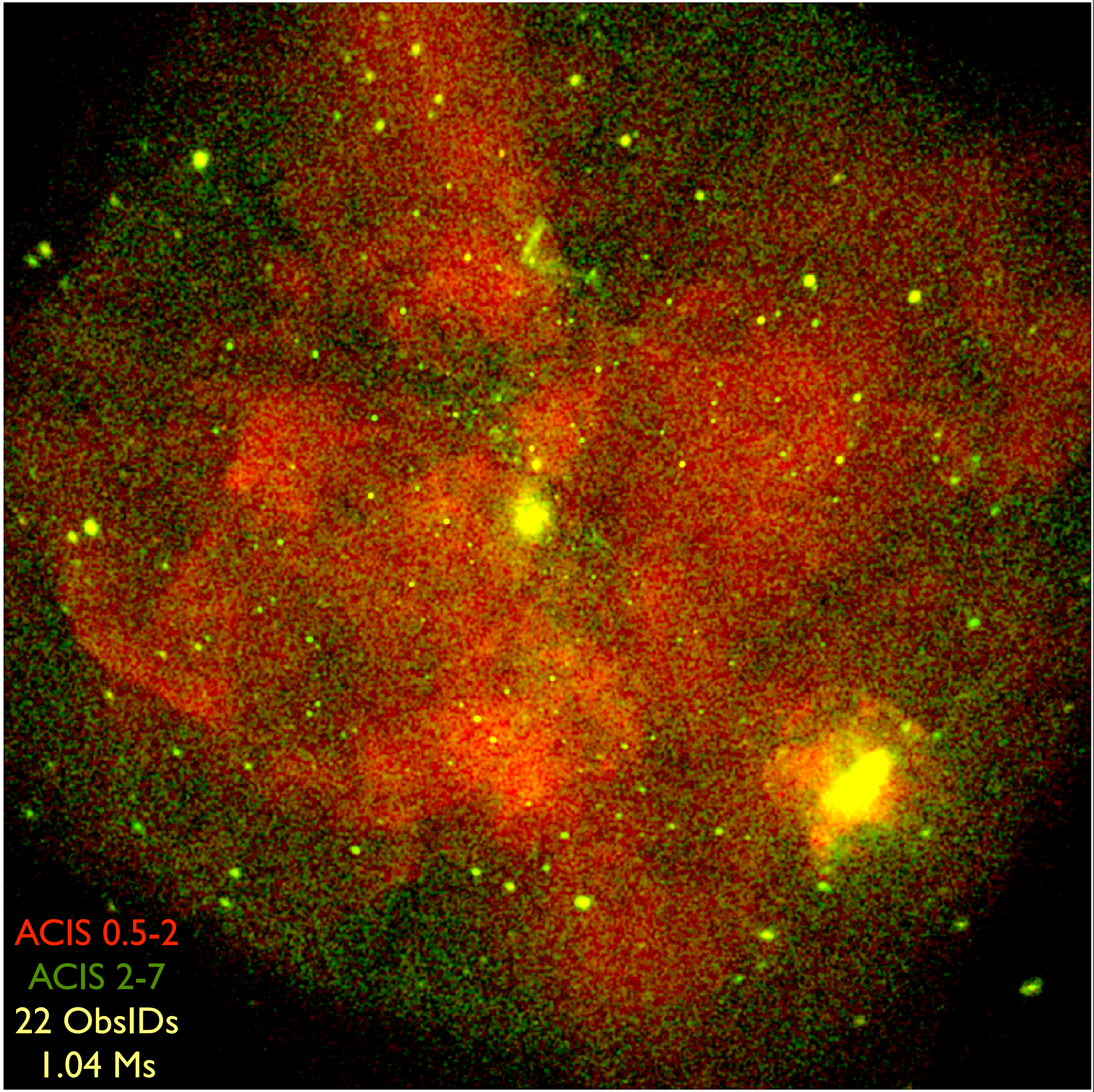
Extensive, highly-structured hot ISM: multiple thermal plasmas with kT~0.1-0.9 keV.

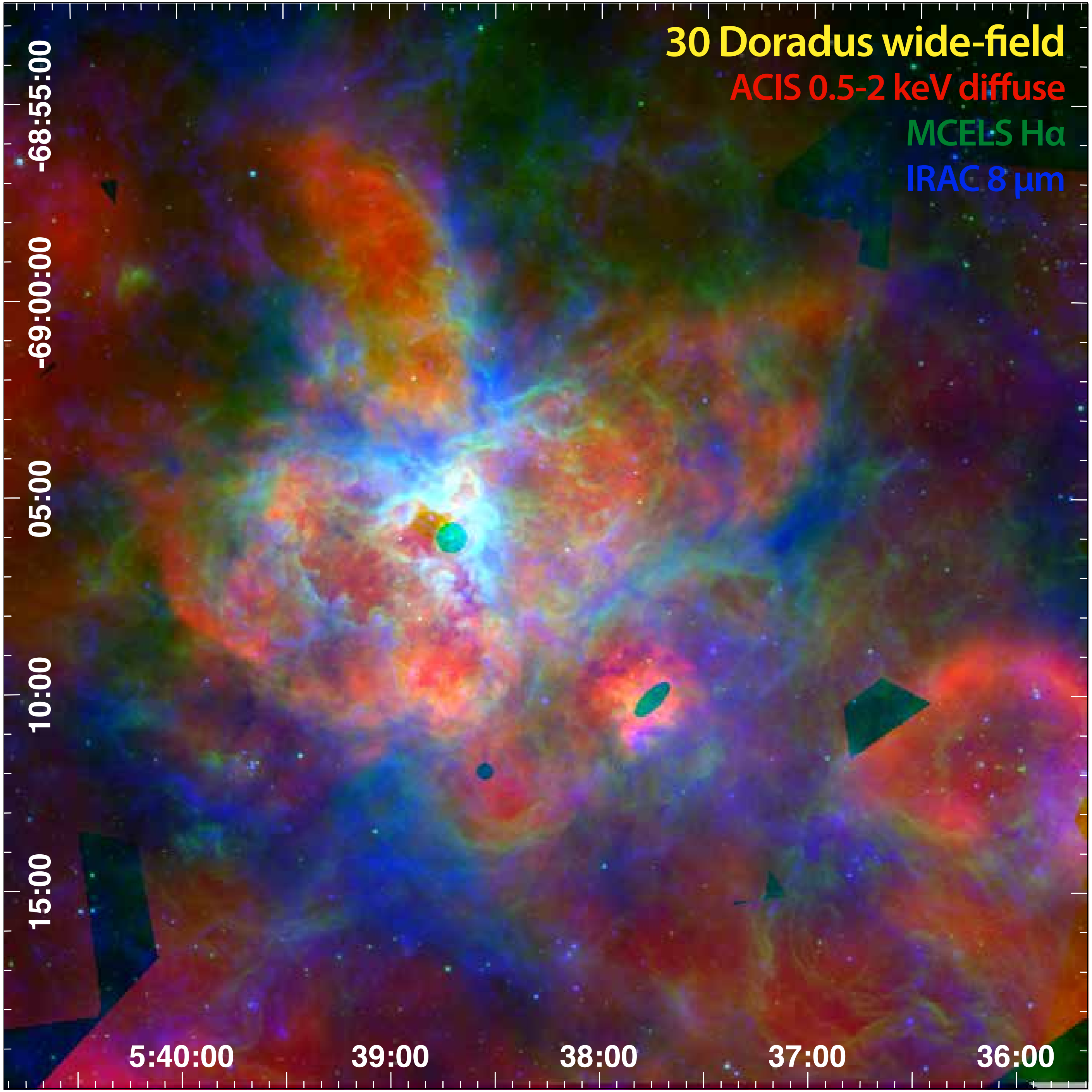
Non-thermal features too.

Strong shadowing, displacement by cold ISM.

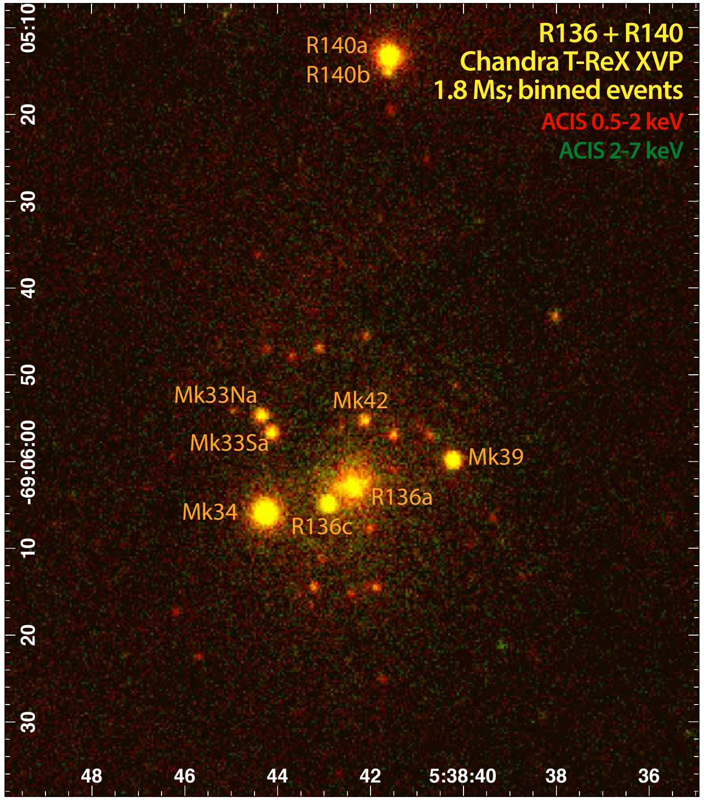


Carina might have 100,000 young stars. How many are in 30 Dor?

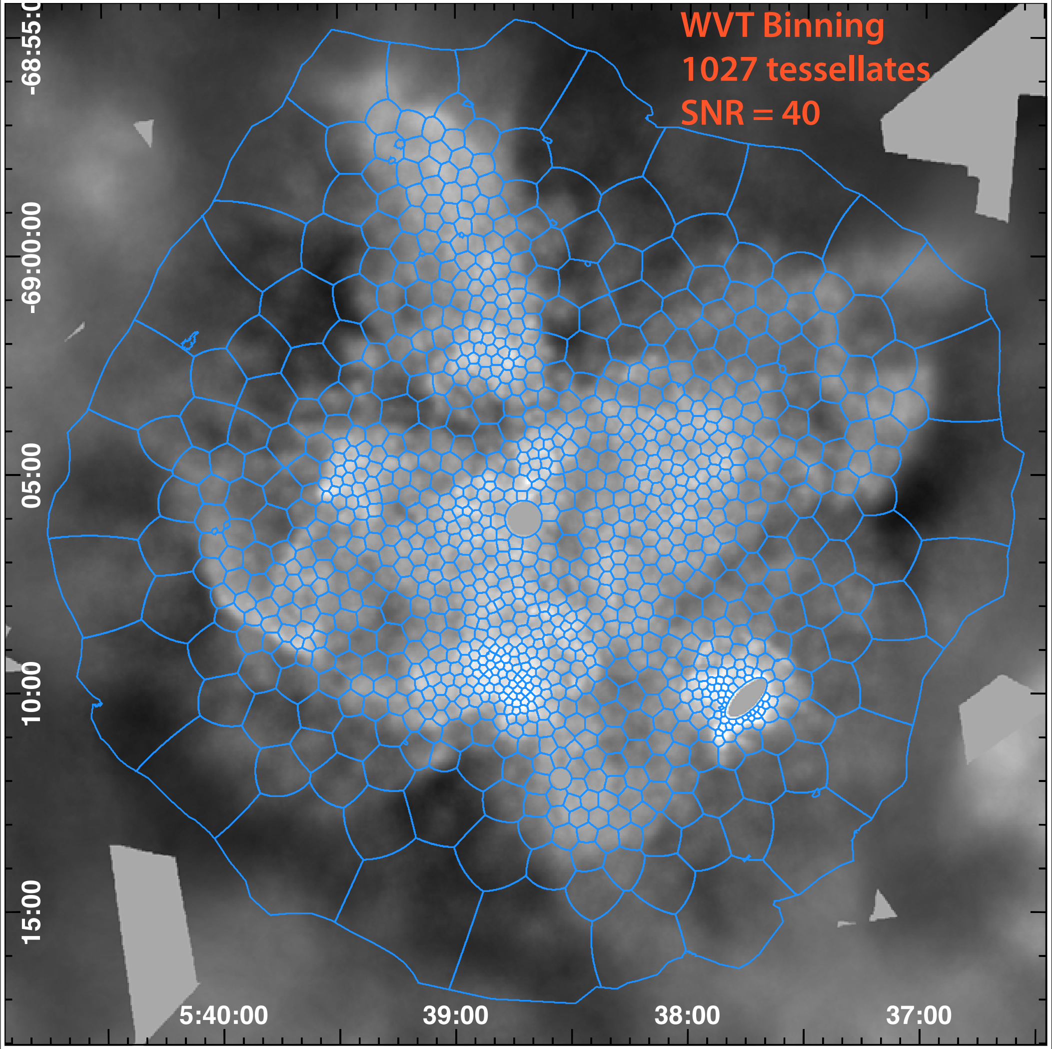




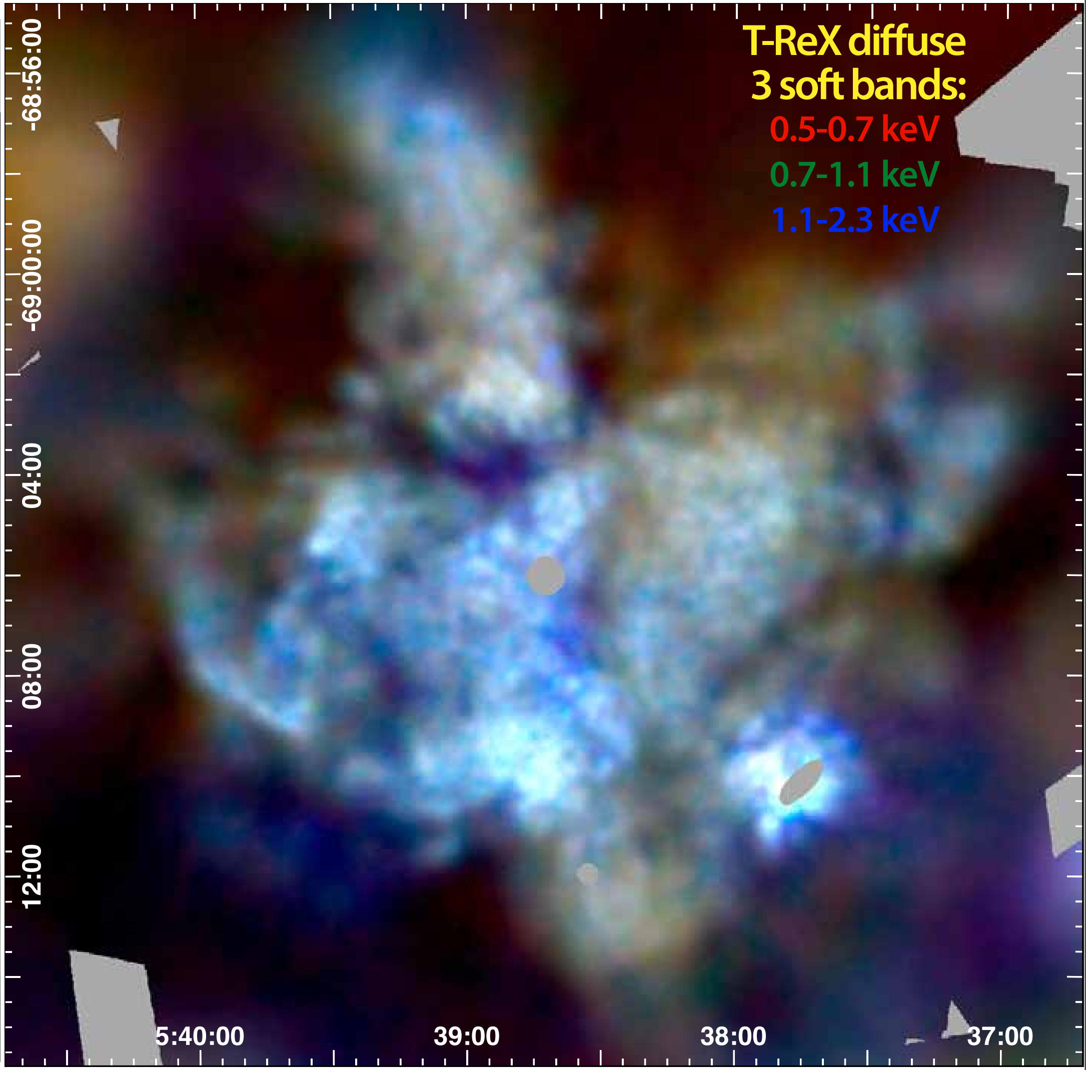
39 srcs with >1000 counts
210 srcs with >100 counts
1038 srcs with >10 counts
18/25 WR stars



Spectral fitting of tessellates yields maps of N_H, kT, intrinsic surface brightness. Can infer densities, pressures.



So far, more photons => more structure.



XRS would provide a huge leap forward in understanding the physics of a starburst cluster:

- revealing the pre-MS population down to <0.5 Msolar
- diffuse structures (and dynamics) on sub-pc scales
- a new population of faint XRBs, individual SNRs.

Star Formation Science Prospects for X-ray Surveyor

30 Doradus: could do T-ReX in 200 ks.
- With an XVP, could build up a sub-pc map of the hot ISM.
- Monitoring -- do 10ks/month for several years to measure the heartbeat of a starburst cluster.

Could survey the whole SMC+LMC as XMM is doing now, but with 1" spatial resolution and much better sensitivity. Do it a few times -- measure the heartbeat of a galaxy.

Comprehensive studies/comparisons of whole GMCs, 500-pc-long filaments -- reveal Galactic structure by X-raying the Milky Way.

Population studies (OB/WR stars, pre-MS stars, SNRs, XRBs, ...) in
- embedded massive star-forming regions (UCHIIRs)
- nearby young clusters (full XLF)
- all major Galactic YMCs
- the biggest Local Group star-forming complexes.

The hot ISM in all of these settings, from single O-star winds up to multiple cavity SNRs.