HOT STARS, THEIR WINDS AND FEEDBACK

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Chandra Science for the Next Decade 2016

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MASSIVE STARS

$M_i > 8\ M_\odot$

Depending on their initial masses (and other parameters…)

O-type star → **Red Supergiant (RSG)** / **Luminous Blue Variable (LBV)** / **Yellow Supergiant (YSG)** → **Wolf-Rayet (WR)**

(10^6 yr)	(10^5 yr)	(10^4 yr)
$V_\infty = 1000$ km s^{-1}	$V_\infty = 10$-100 km s^{-1}	$V_\infty = 1500$ km s^{-1}

$\dot{M} = 10^{-9}$–$10^{-3}\ M_\odot\ \mathrm{yr}^{-1}$

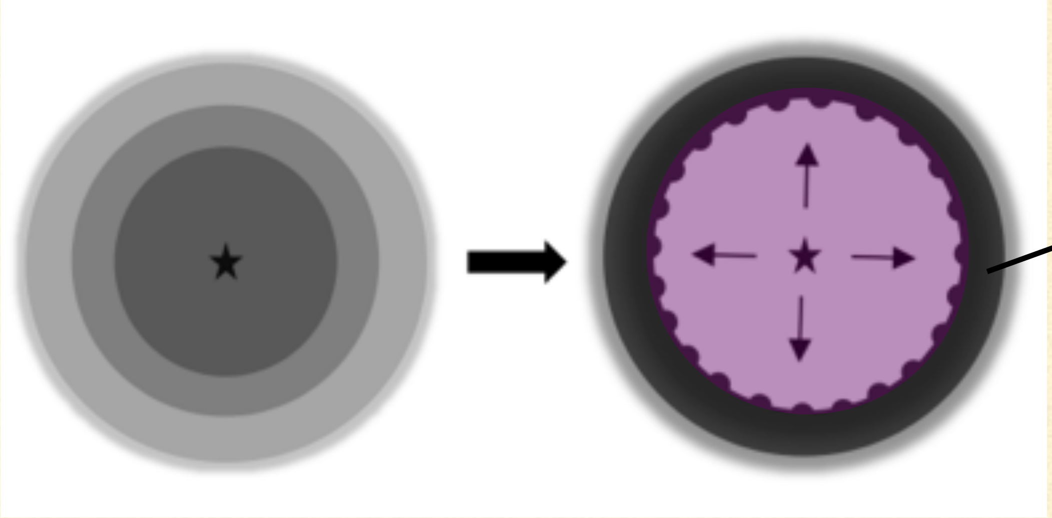
Feedback

Hubble Space Telescope (*HST*) Heritage 2016

- UV flux
- Proper motions

- Strong stellar winds ($V_\infty > 1000$ km/s)
- Supernova (SN) explosions

Stellar Feedback



Dense Material vs. **Current Fast WR wind**

Adiabatically shocked wind
(e.g., Dyson & Williams 1997):

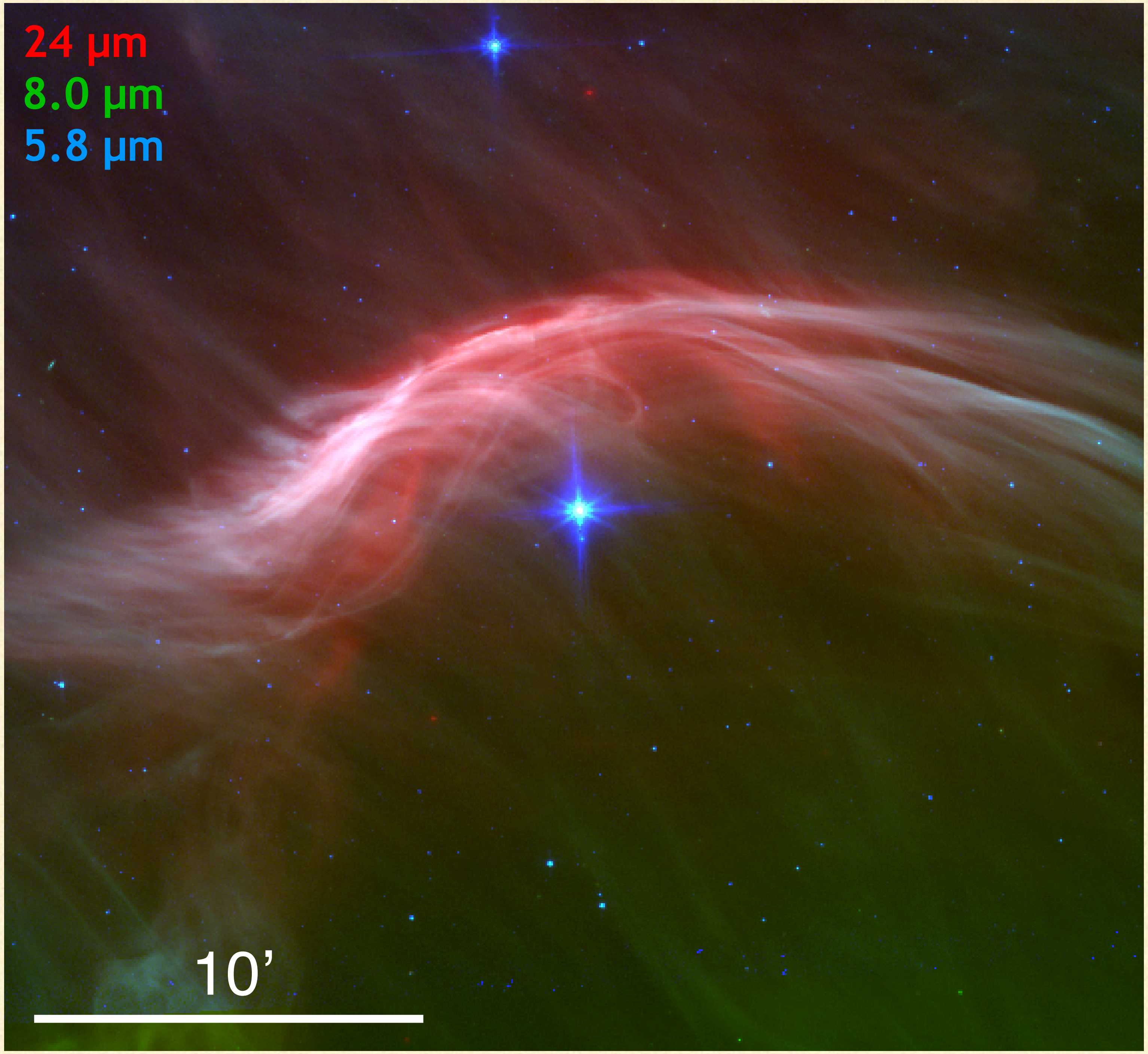
$$T = \frac{3}{16}\frac{\mu}{k_{\rm B}} m_{\rm H} v_\infty^2$$

$$= 2.3 \times 10^7 \mu \left(\frac{v_\infty}{1000\,{\rm km\,s^{-1}}} \right)^2 \,[{\rm K}]$$

i.e., for v_∞ = 1000 - 2000 km s^{-1}

Produce diffuse and Hot Bubbles!
$T = 10^7 - 10^8$ K
$n = 0.001 - 0.01\ cm^{-3}$

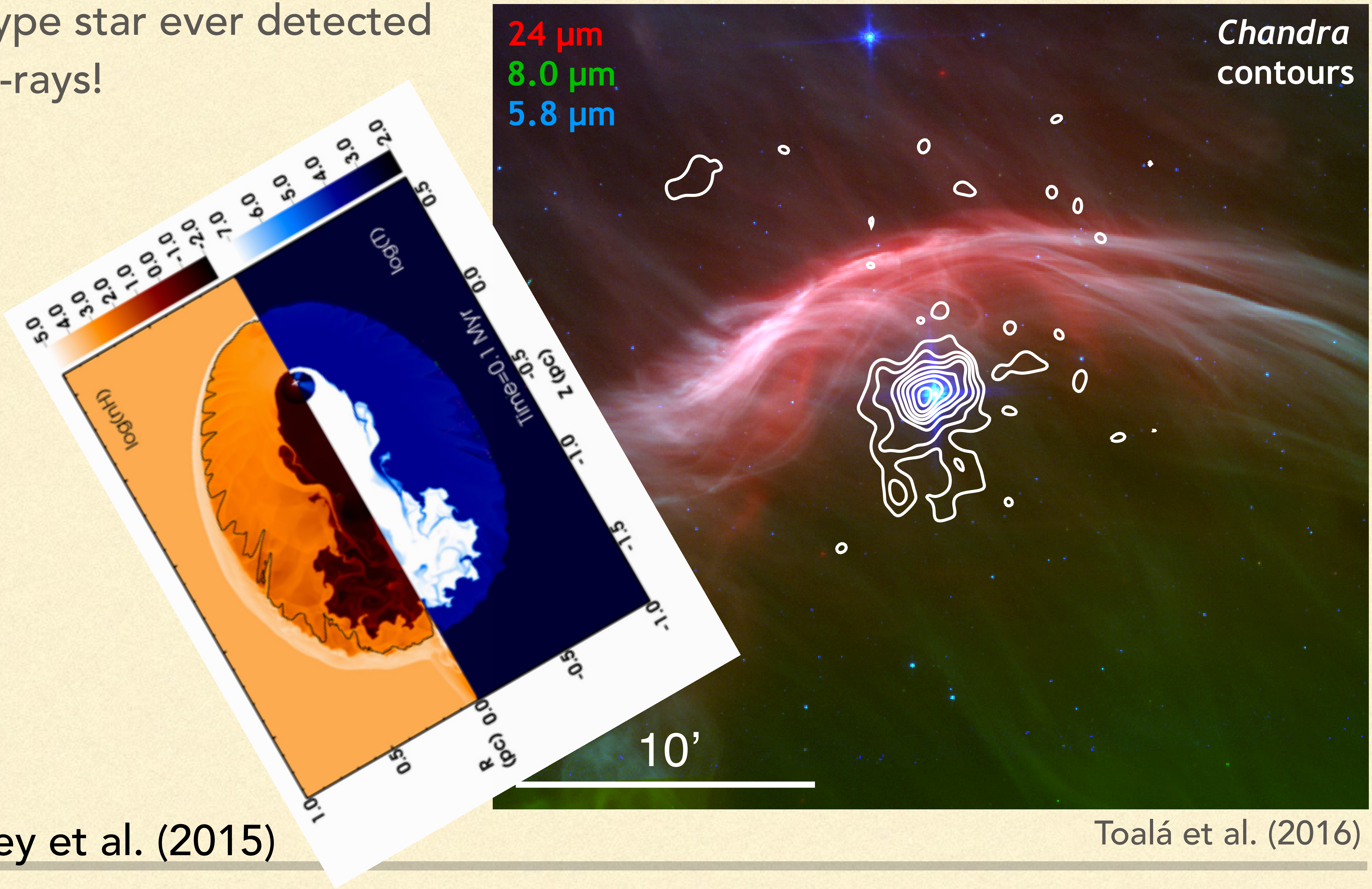
ζ Oph (O9.2 IV)



Toalá et al. (2016)

ζ Oph (O9.2 IV)

The first Hot Bubble around a single O-type star ever detected in X-rays!



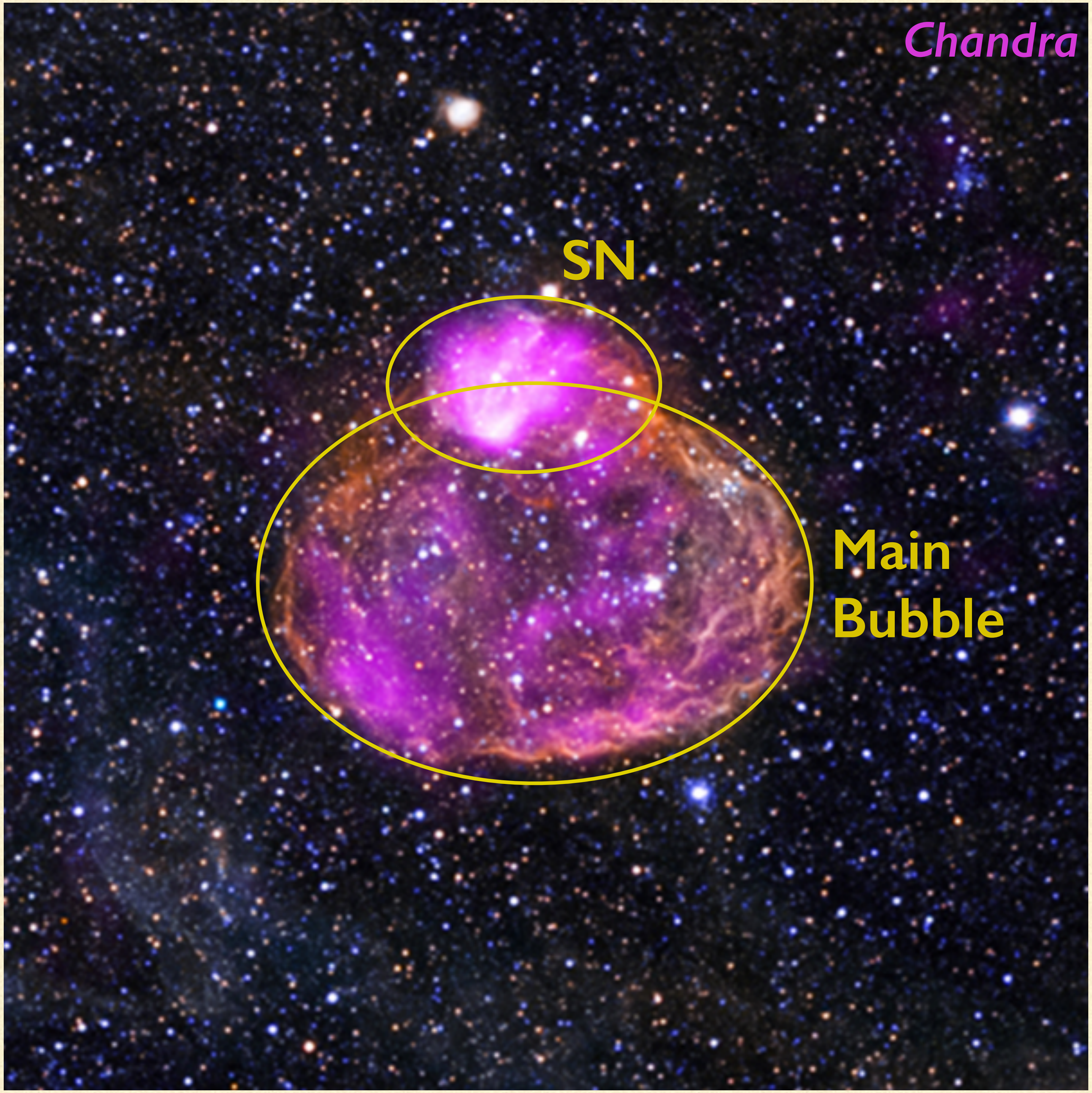
Mackey et al. (2015)

Toalá et al. (2016)

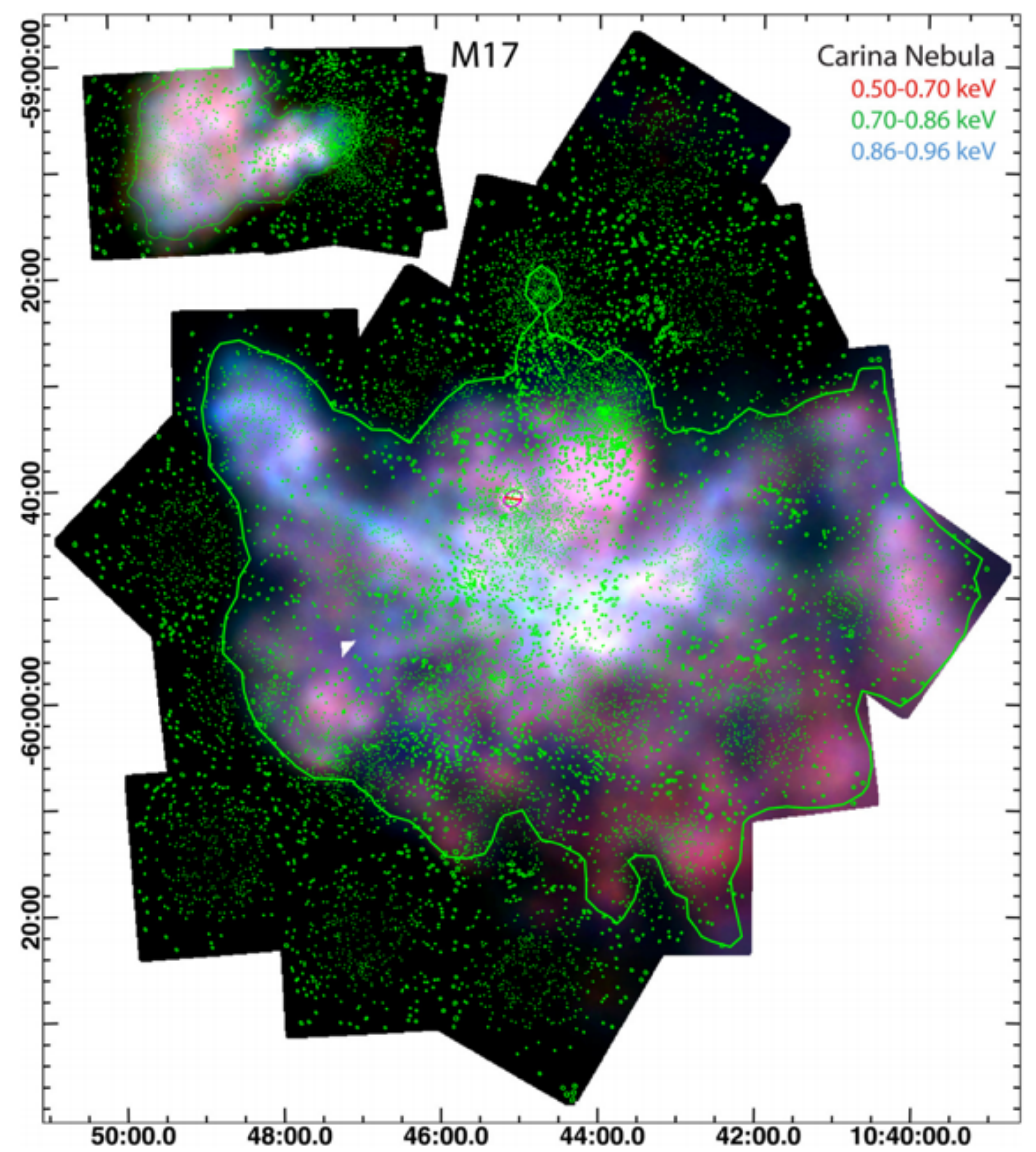
DEM L50 - Superbubble

Superbubble in the LMC
- Stellar winds
- Supernova (SN) explosions

Jaskot et al. (2011)
- Mixing with the ISM
- SN impacts dominant sources powering X-ray emission!



Superbubbles



Superbubbles

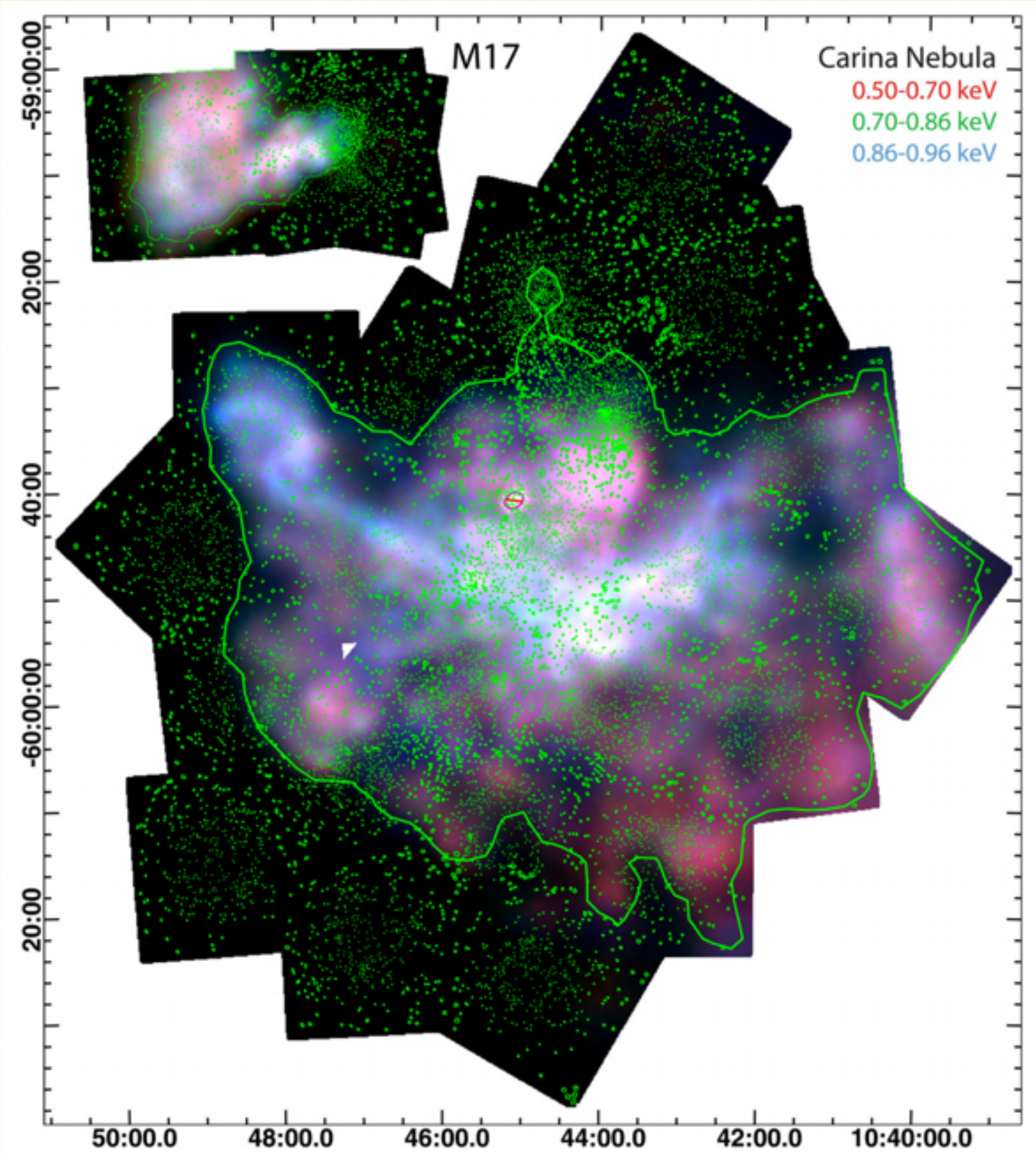
e.g., Townsley et al. (2011,2014)
Kuhn et al. (2013)
….

Large projects:

- The Chandra Carina Complex
- The OMNIBUS X-ray catalog
- The massive Young star-forming Complex Study in IR and X-ray (MYStIX)

Targets:

30 Doc
G29.96-0.02
G333.6-0.2
M 16
M 17
NGC 3576
NGC 3603
NGC 6334
NGC 6354
W3
W4
W51A
…..

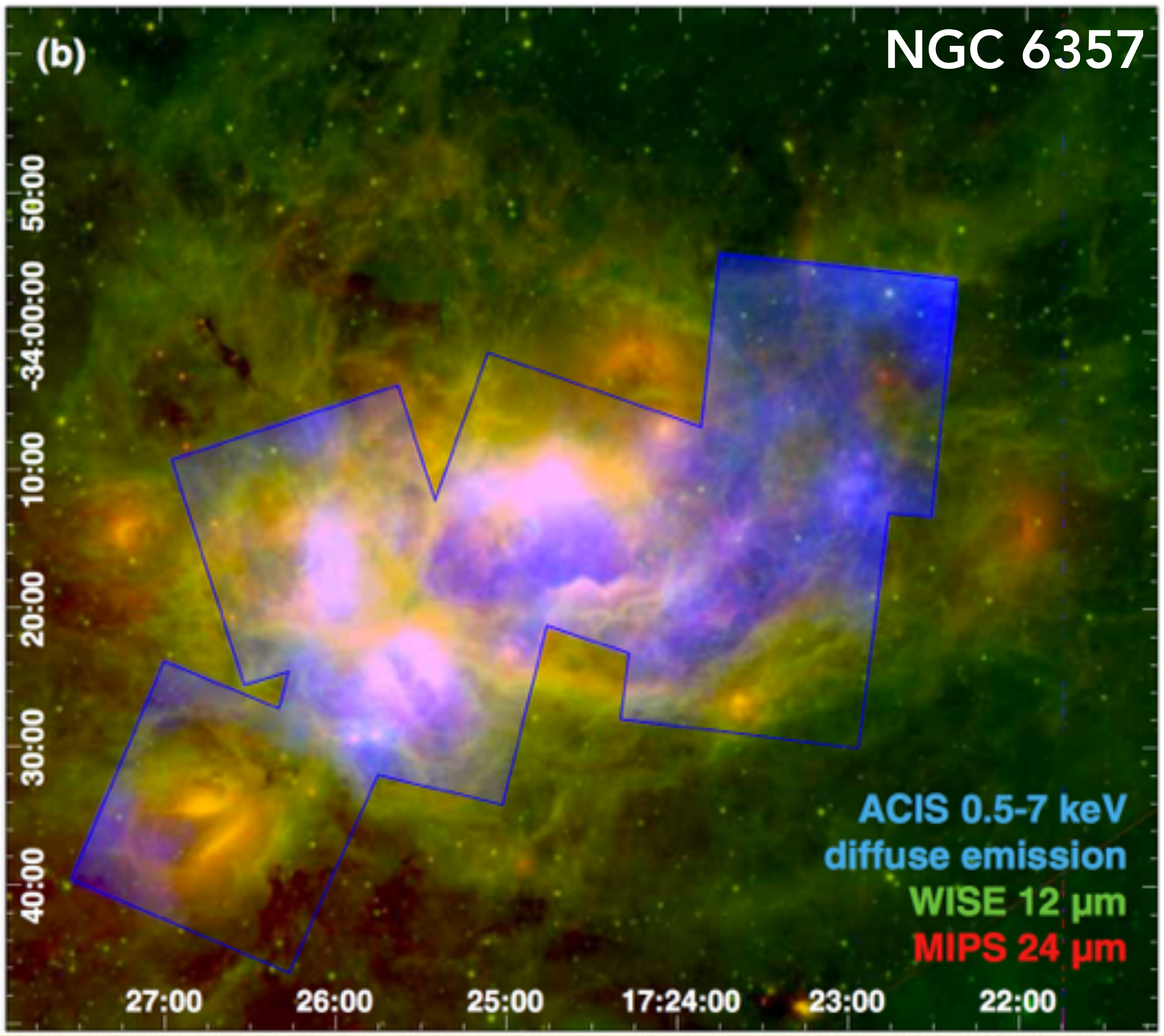


Superbubbles

The violent impact of Massive Stars!

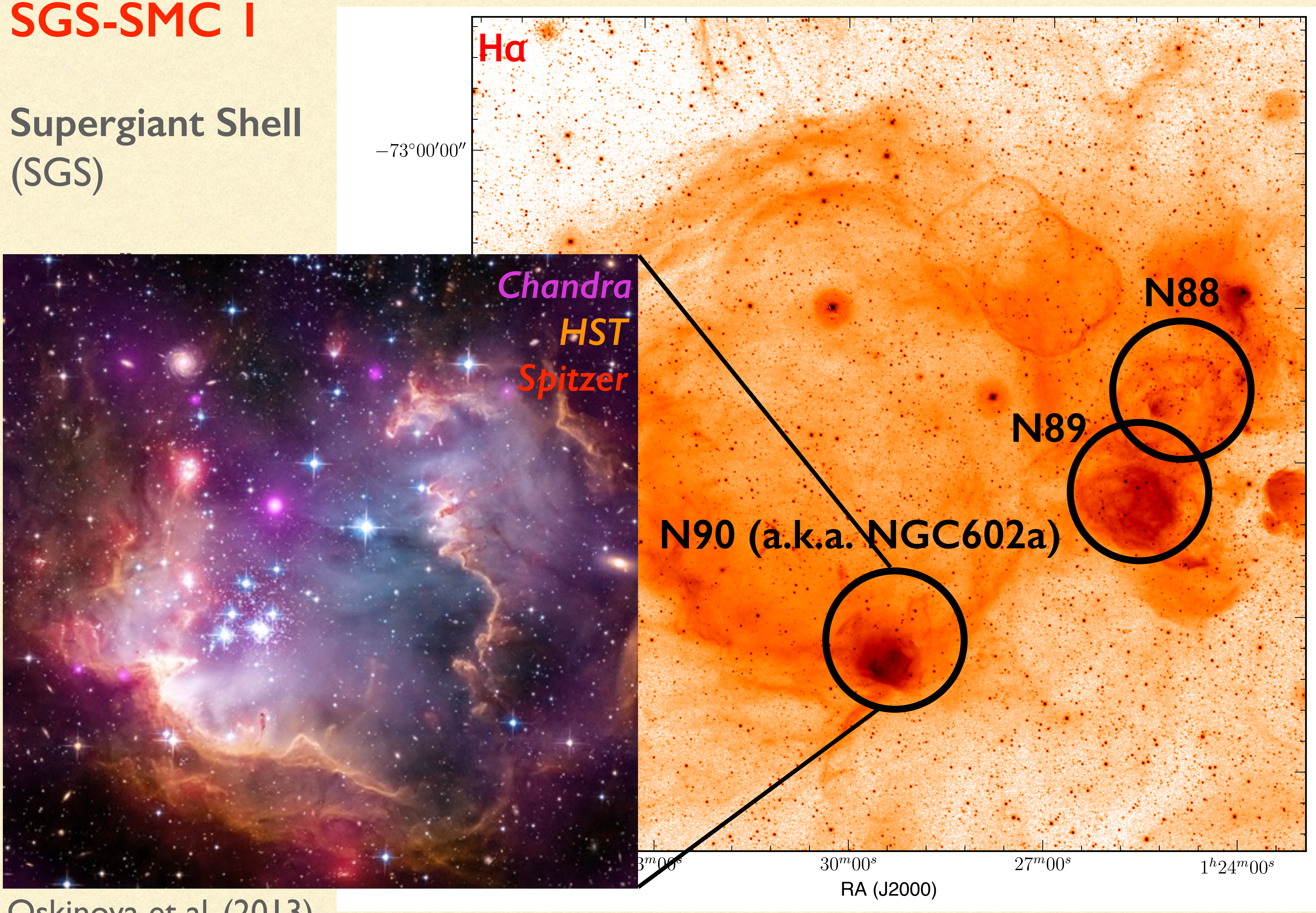
- Hot gas permeates the Galaxy
- Recent shocks
- charge exchange reactions with the cold, dense molecular material

Townsley et al. (2014)



SGS-SMC 1

Supergiant Shell (SGS)



Oskinova et al. (2013)

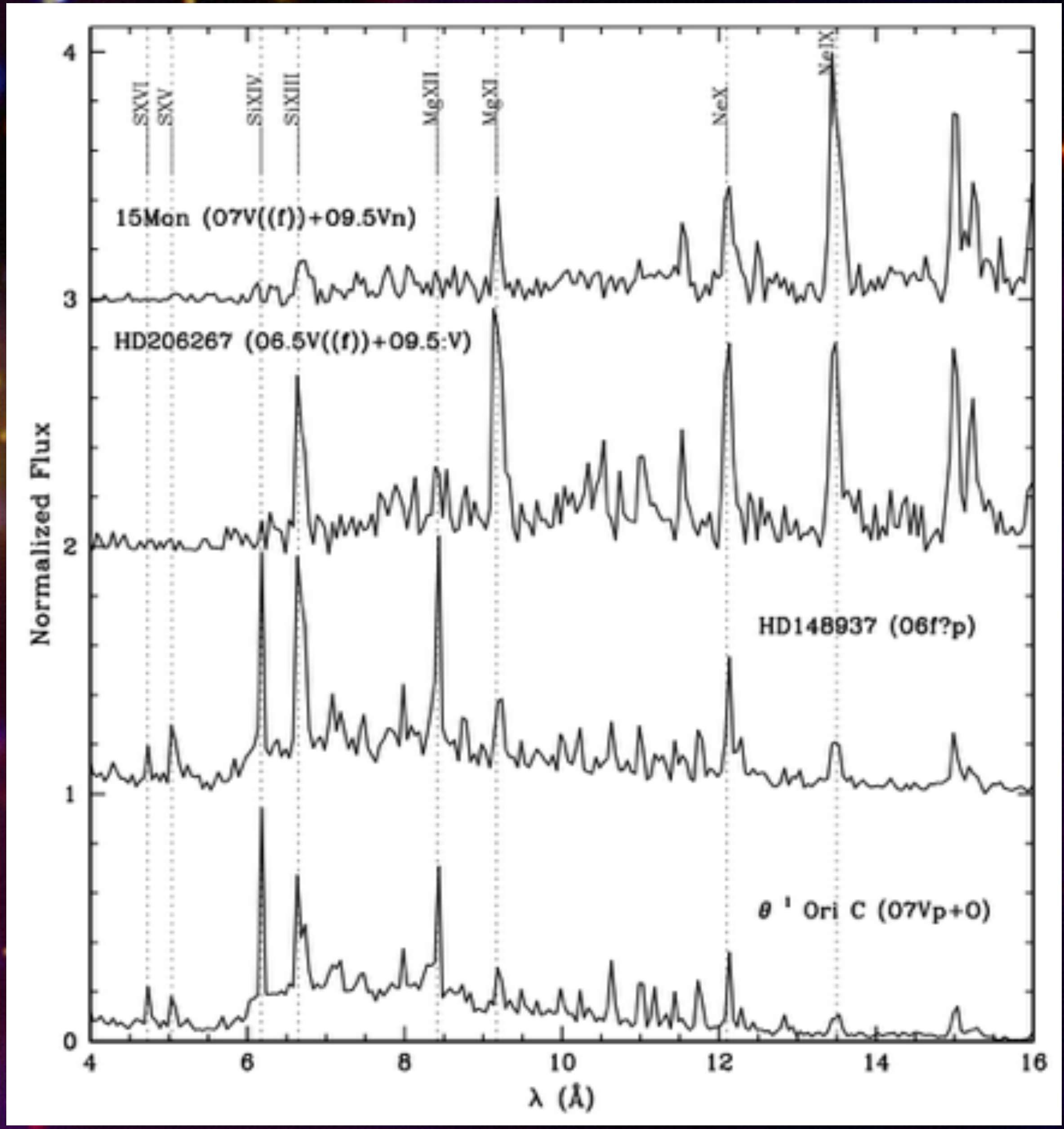
X-RAYS FROM MASSIVE HOT STARS

Thanks to the *Chandra* analysis of high-resolution spectra of hot stars, we now know that:

- The X-ray-emitting plasma around hot stars is very close to the photosphere
- It has a thermal origin
- X-ray lines are broad (well resolved by *Chandra*)
- Multi-temperature plasmas (up to 10 MK)
- X-ray variability

\+

state-of-the-art nonLTE stellar atmosphere codes, such as PoWR & CMFGEN
(e.g., Shenar et al. 2015; Puebla et al. 2016)

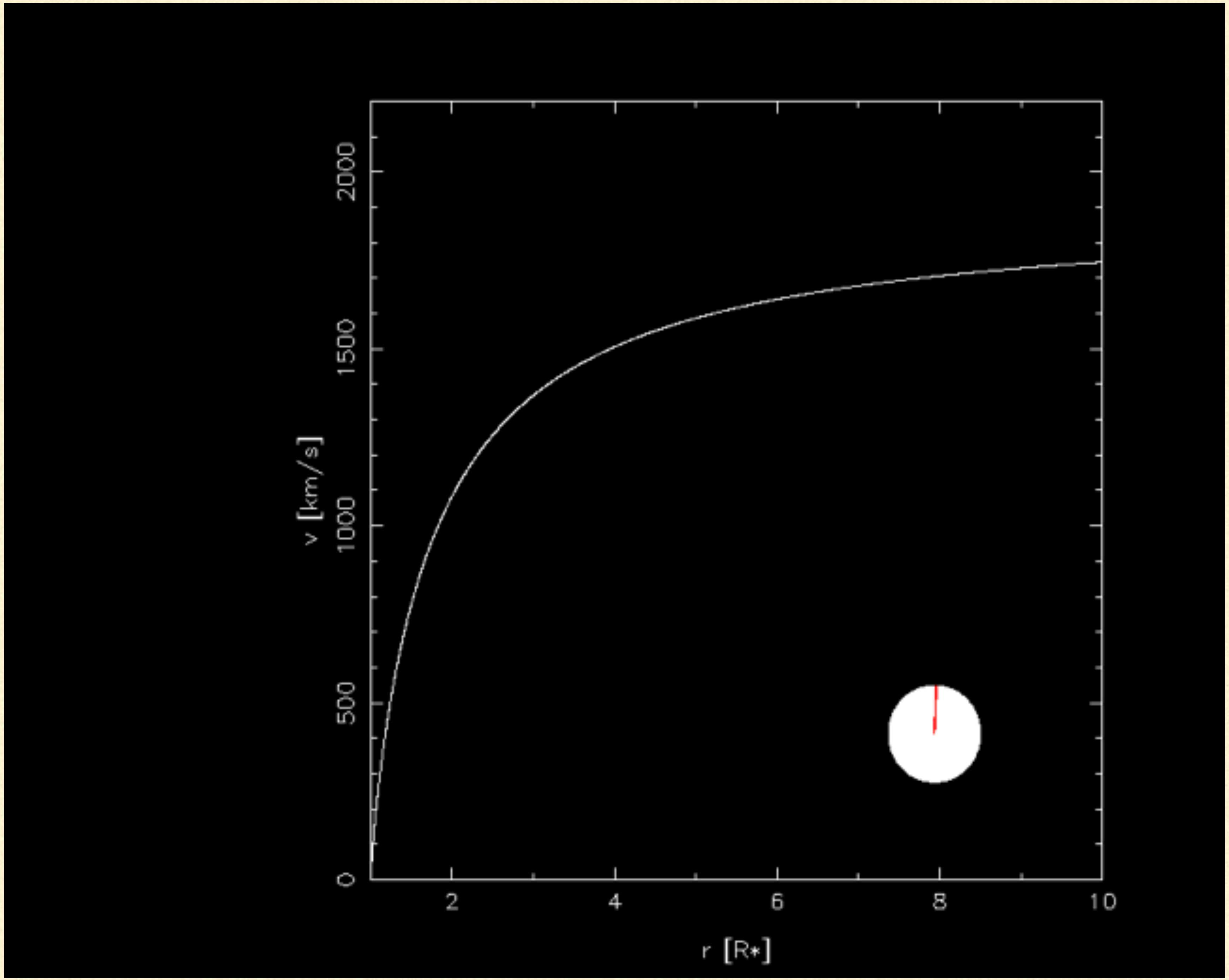


e.g., Naze et al. (2012) MEG/*Chandra*

X-RAYS FROM MASSIVE HOT STARS

Single stars:
1) Shock heating due to line-driven wind instabilities

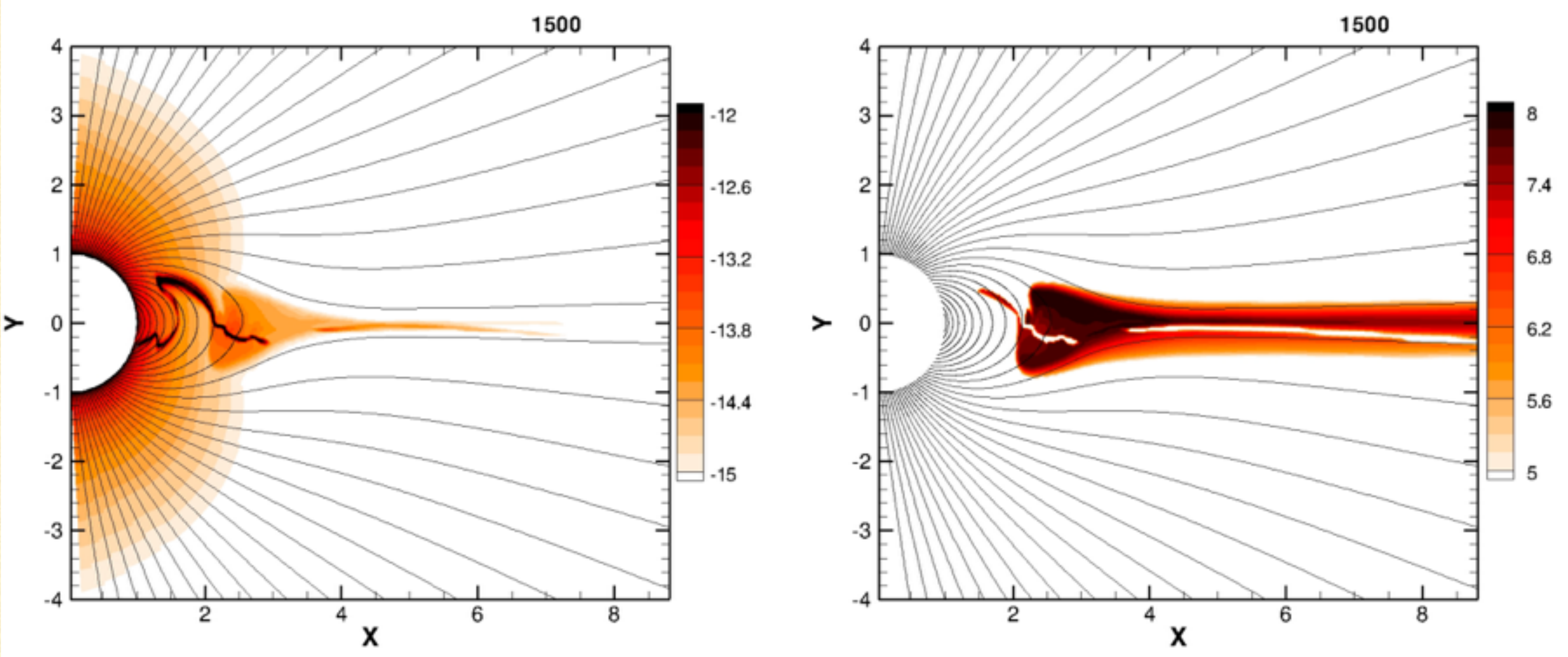
$L_X/L_{bol} \sim 10^{-7}$



e.g. Feldmeier et al. (1997)

X-RAYS FROM MASSIVE HOT STARS

Single stars:
2) Magnetically Confined Wind Shocks



Density

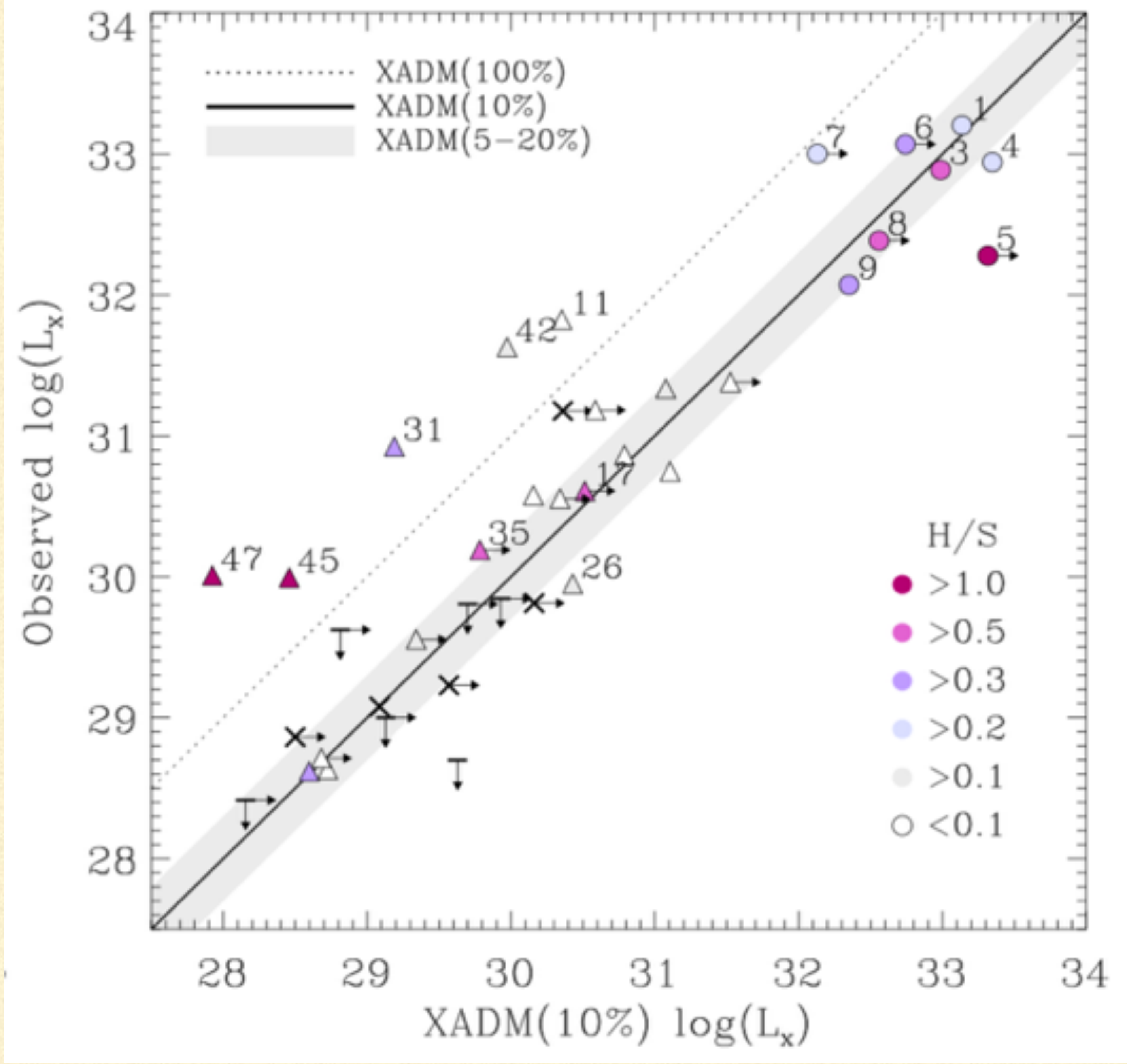
Temperature

e.g., ud-Doula et al. (2014)

X-RAYS FROM MASSIVE HOT STARS

Single stars:
2) Magnetically Confined Wind Shocks

X-ray Analytic Dynamical Magnetosphere (XADM) scaling law

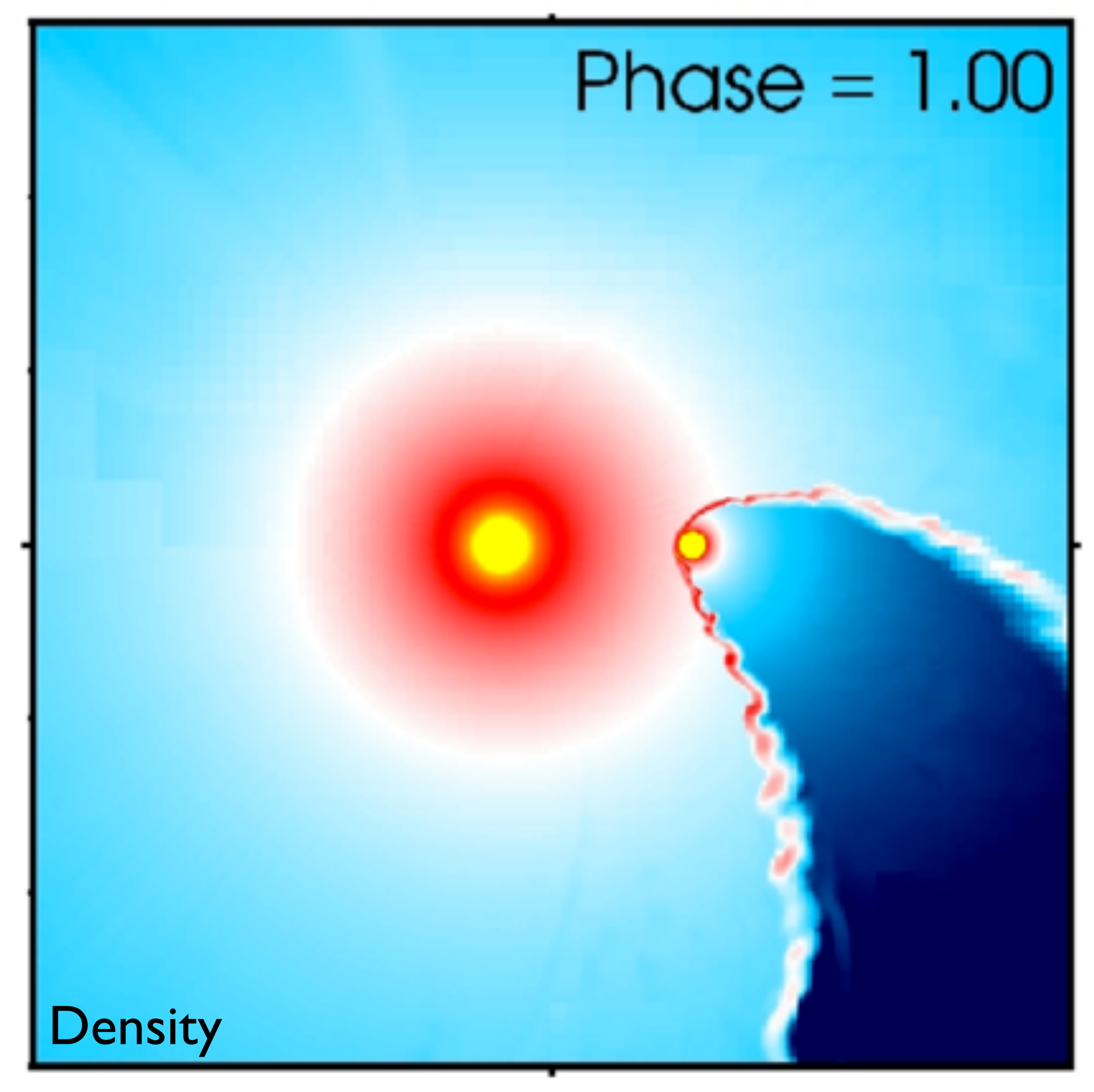


e.g., ud-Doula & Nazé (2016)
Petit et al. (2013)
Nazé et al. (2014)

X-RAYS FROM MASSIVE HOT STARS

Binaries
3) Colliding Wind Binaries (CWB)

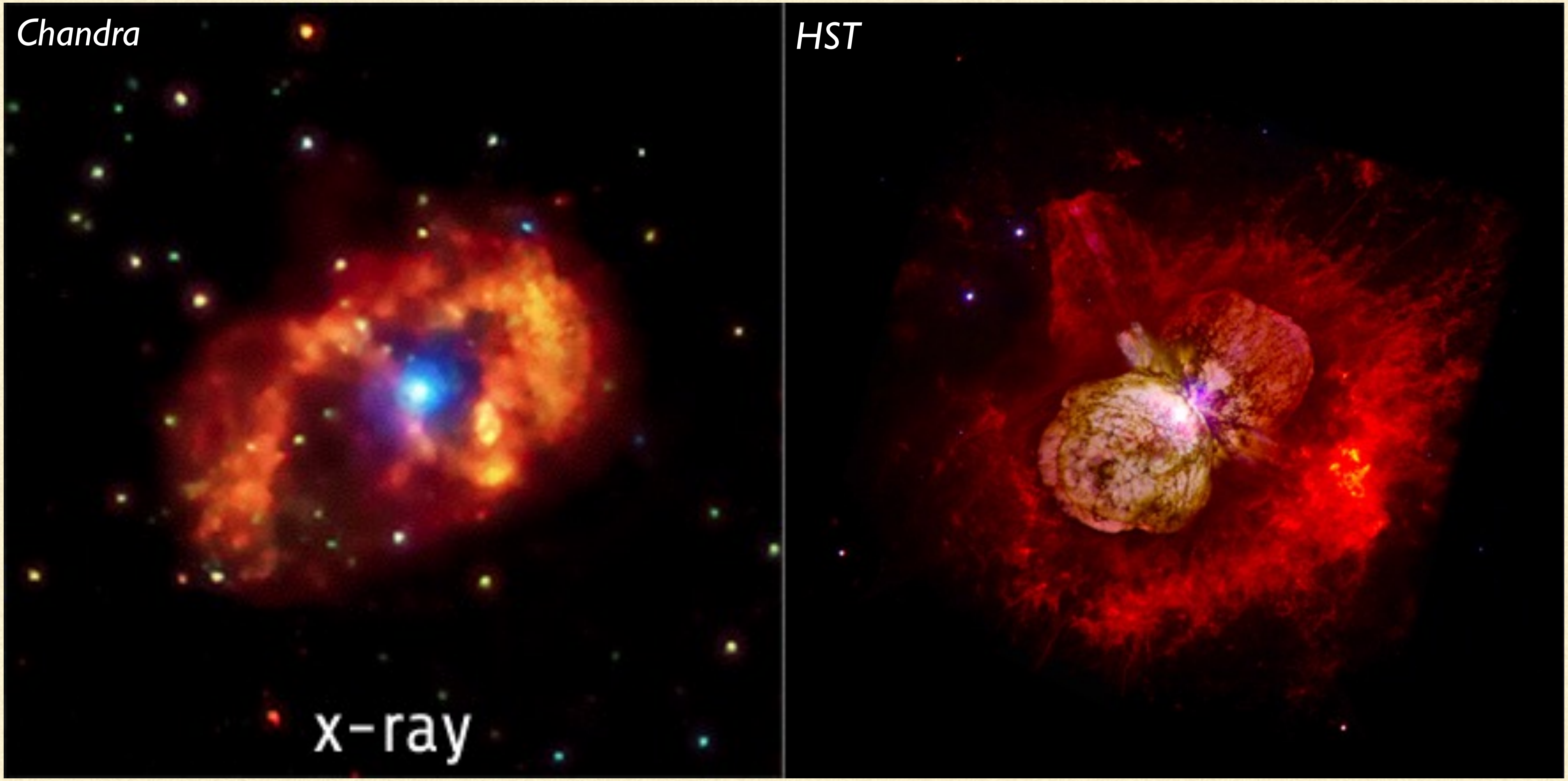
Credit: NASA/C. Reed



e.g. Parking et al. (2011)

η Car (LBV - Binary)
The most luminous star in the Galaxy!

More than 1.47 Ms



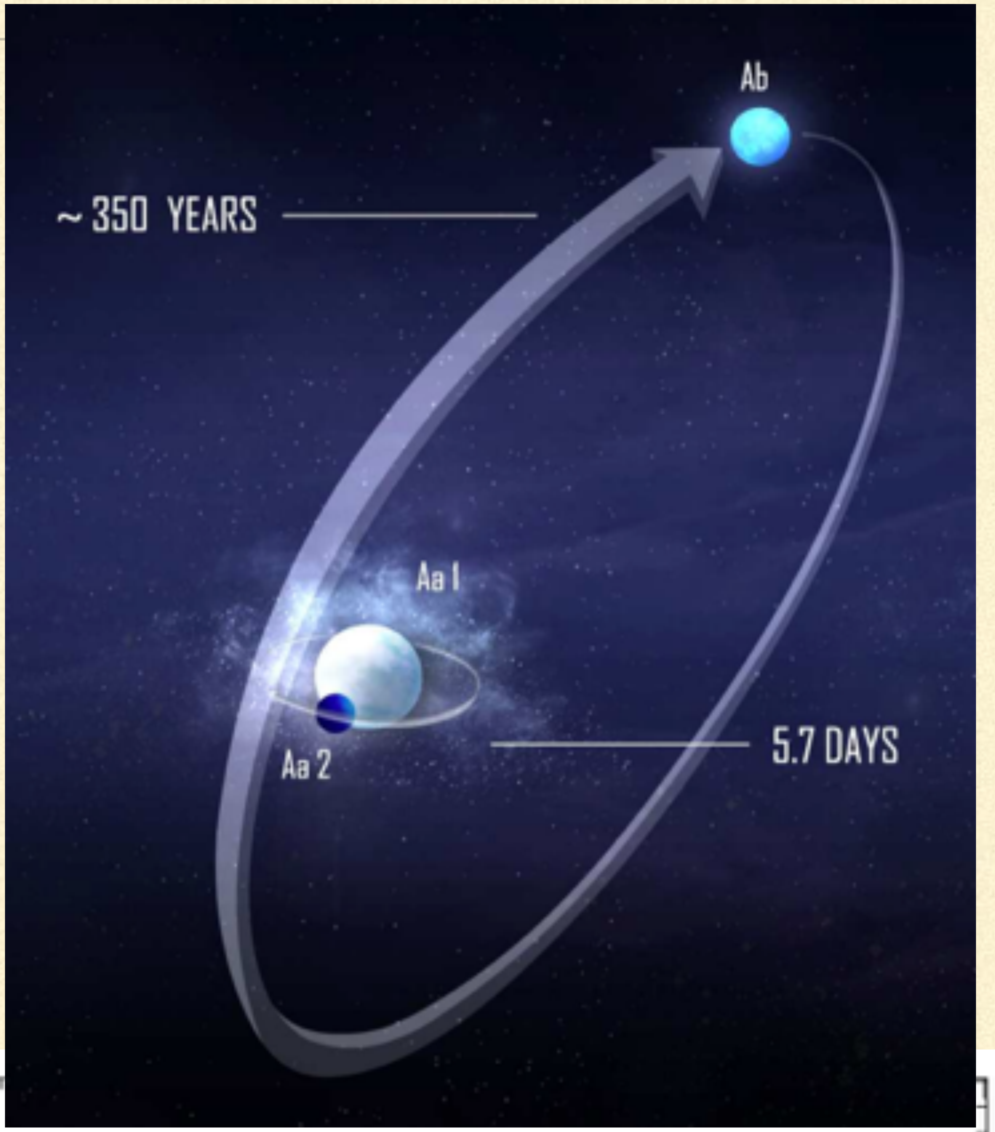
Hamaguchi et al. (2014)

δ Ori (O9.5 II) - Large Program

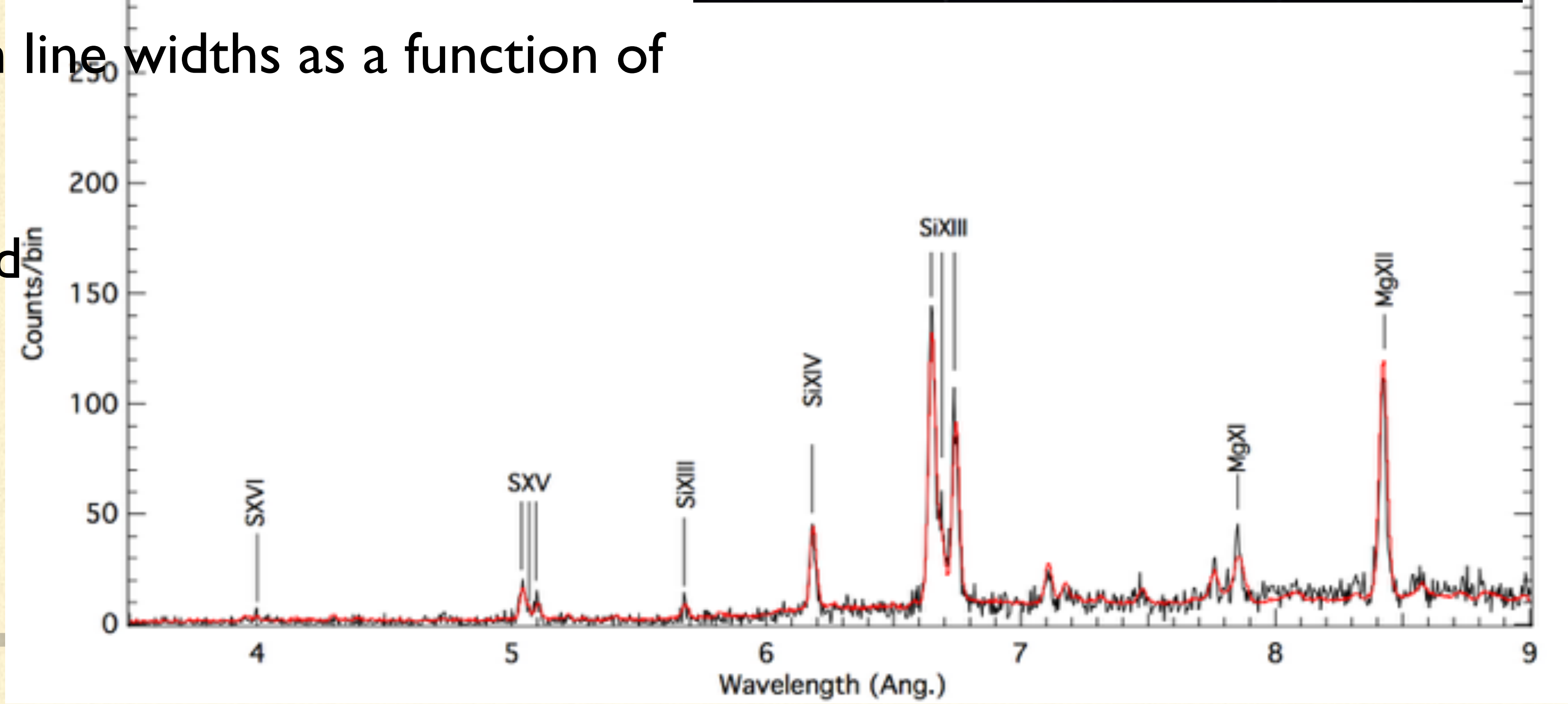
480 ks

Chandra HETGS & ACIS-S

Corcoran et al. (2015)
Nichols et al. (2015)
Pablo et al. (2015)
Shenar et al. (2015)



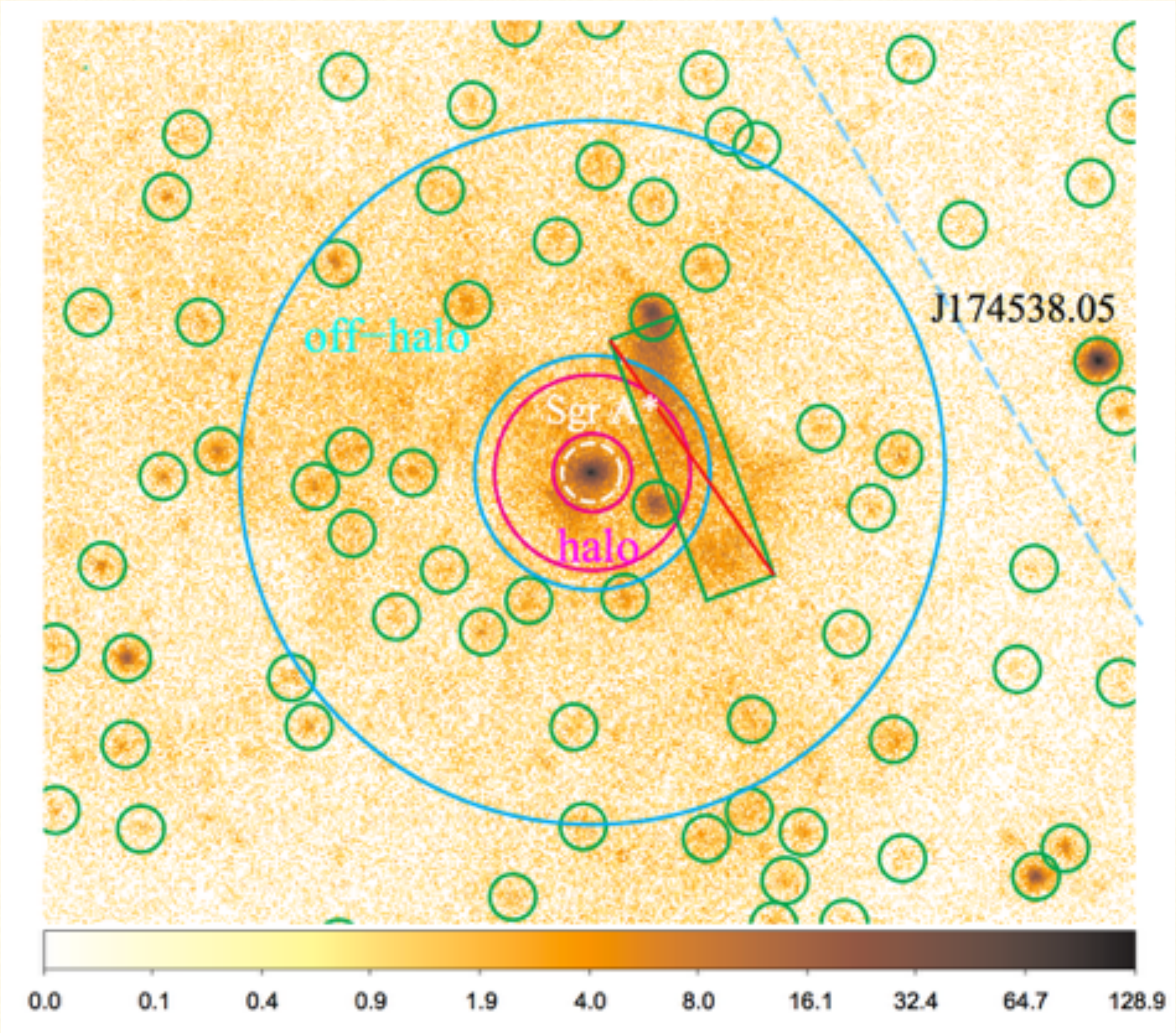
- The X-ray emission is dominated by embedded wind shock emission from Aa1
- Variations of the emission line widths as a function of binary phase are found
- Modelling : turbulent velocities (200 km s^{-1}) and wind inhomogeneities



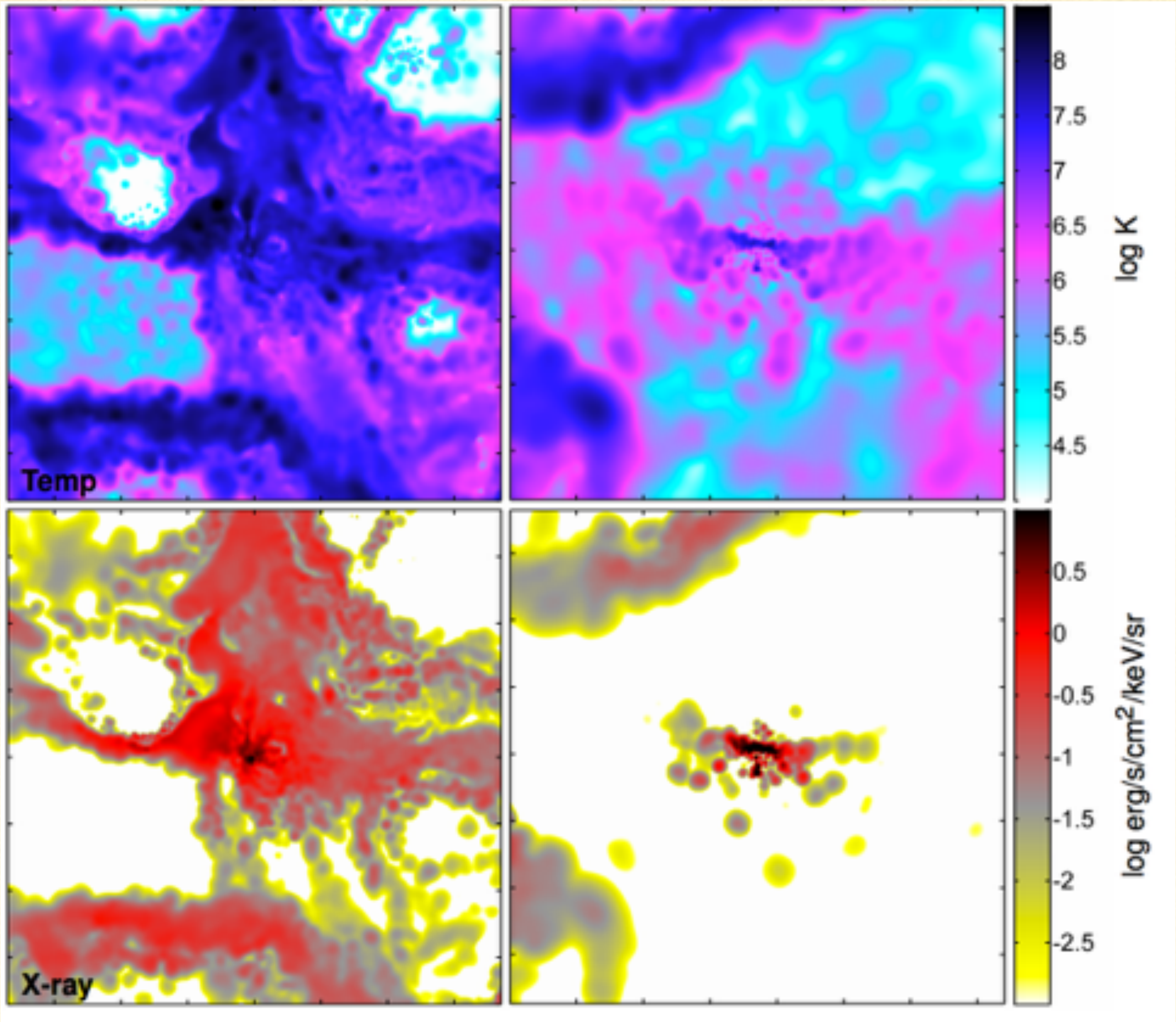
The Sgr A* X-ray Visionary Program

3 Ms *Chandra* Observations

Wang et al. (2013)



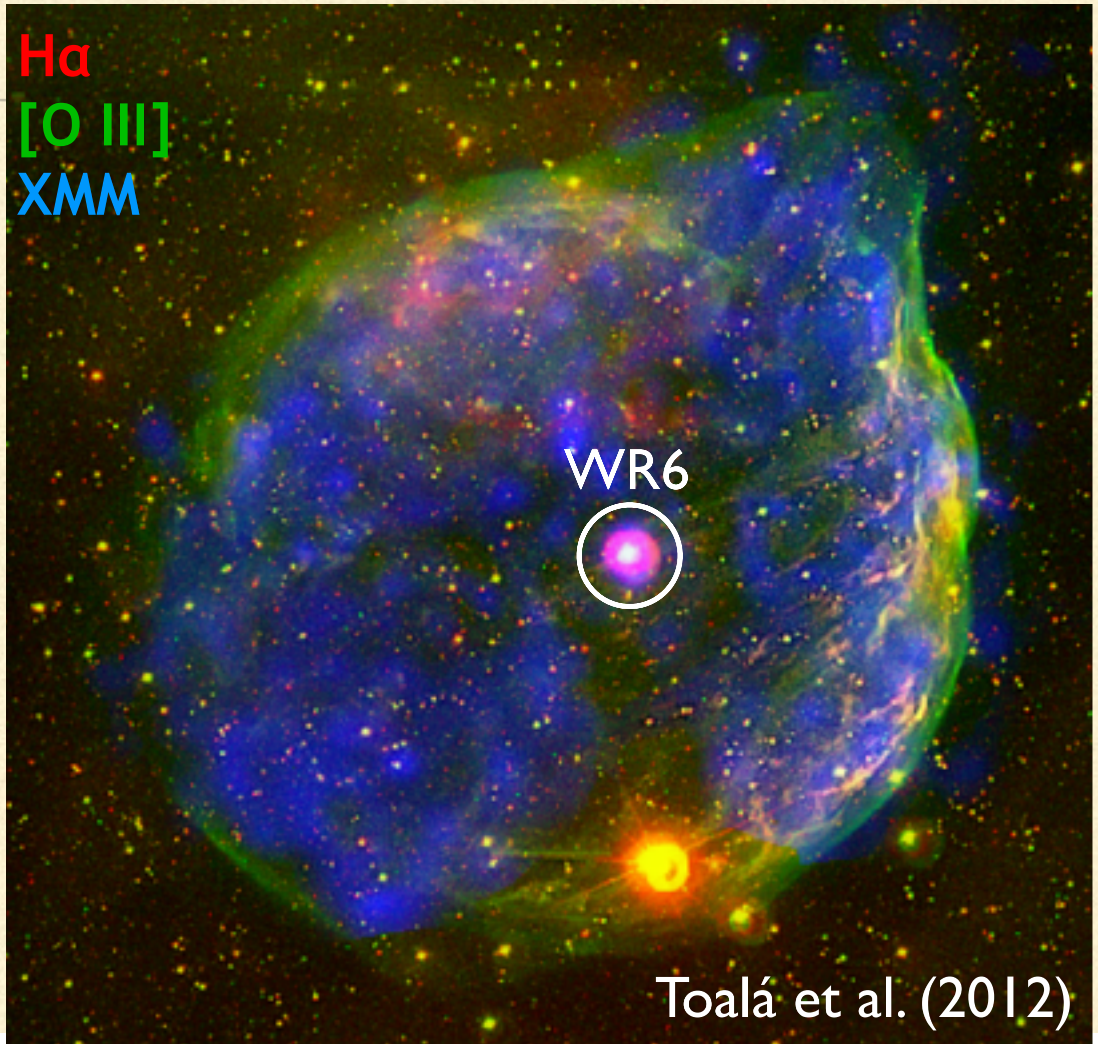
Cuadra et al. (2015)
Russell et al. (2015)



CWB feeding SgA* ..!

Wolf-Rayet (WR) stars

Chandra has devoted large time in studying WR stars: single and binaries!
(See review by Oskinova 2016)



Toalá et al. (2012)

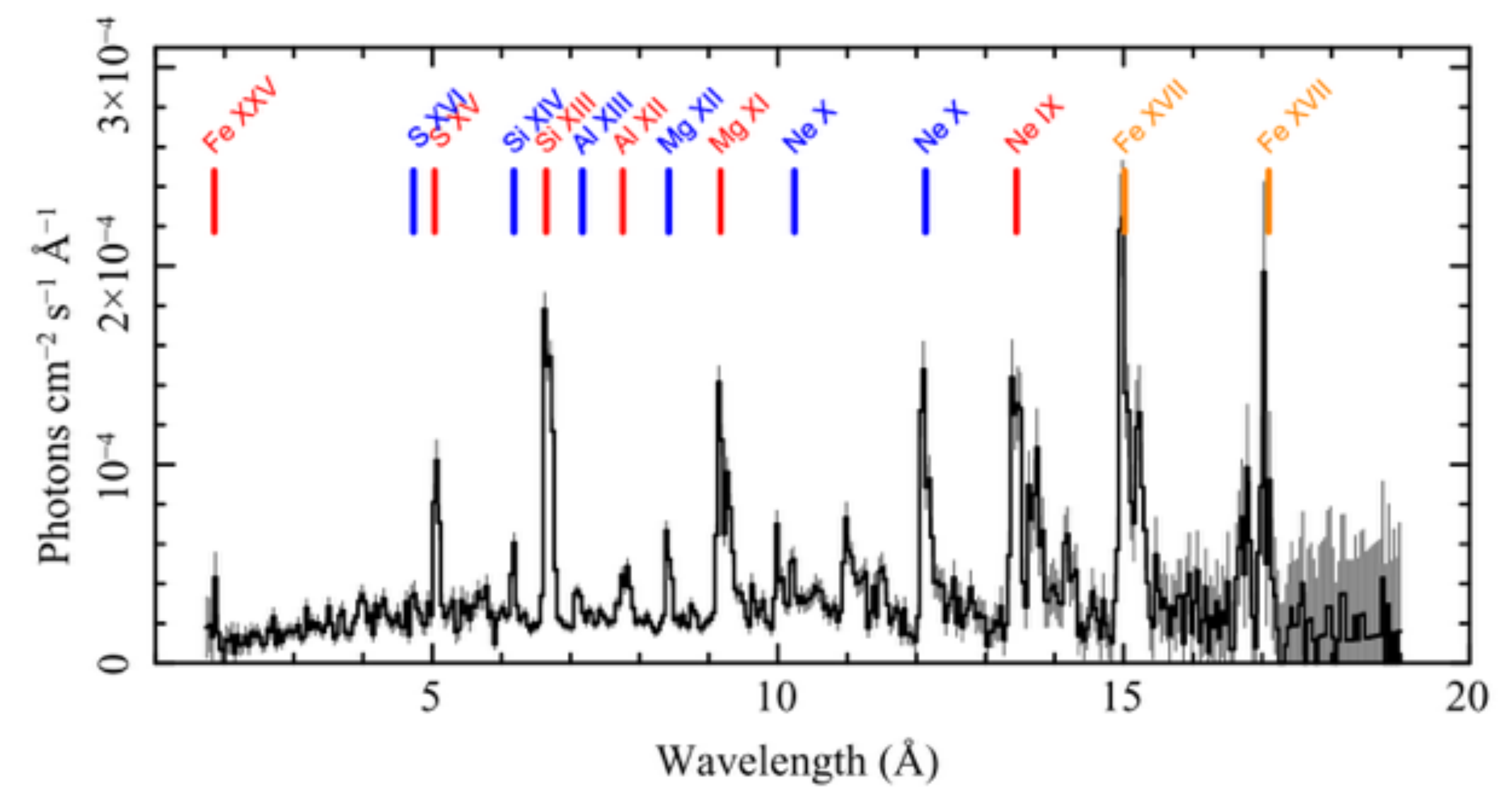
WR6

450 ks *Chandra*/HETG

The most detailed X-ray spectrum and analysis of a (single) WR star

- No Oxygen lines are detected
- X-rays-emitting is form out in the wind (He-like ions)
- X-rays between 10-100 R*

DIFFICULT TO RECONCILE TO THE LDW . . !



Huenemoerder el at. (2015)

Planetary Nebulae

PNe are also hot!

Central Stars are also
Hot Stars with fast winds:
500 - 4000 km s^{-1}
(Guerrero & De Marco 2013)

Chandra

Planetary Nebulae

PNe are also hot!

The *Chandra*
Planetary Nebulae Survey
(CHANPLANS)

~1.5 Ms

All PNe close to the Sun
(d < 2 kpc)

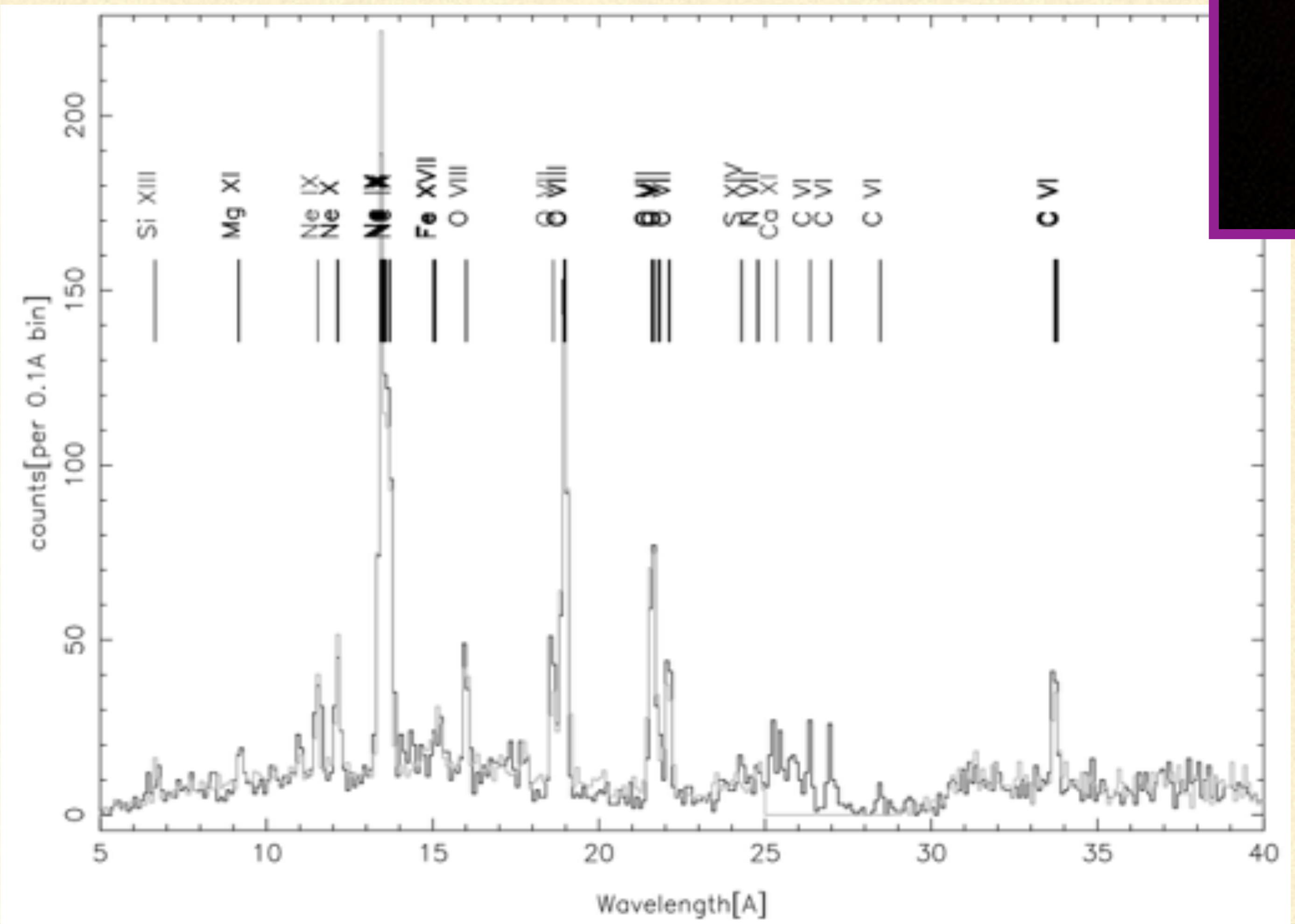
Kastner et al. (2012)
Freeman et al. (2014)
Montez et al. (2015)

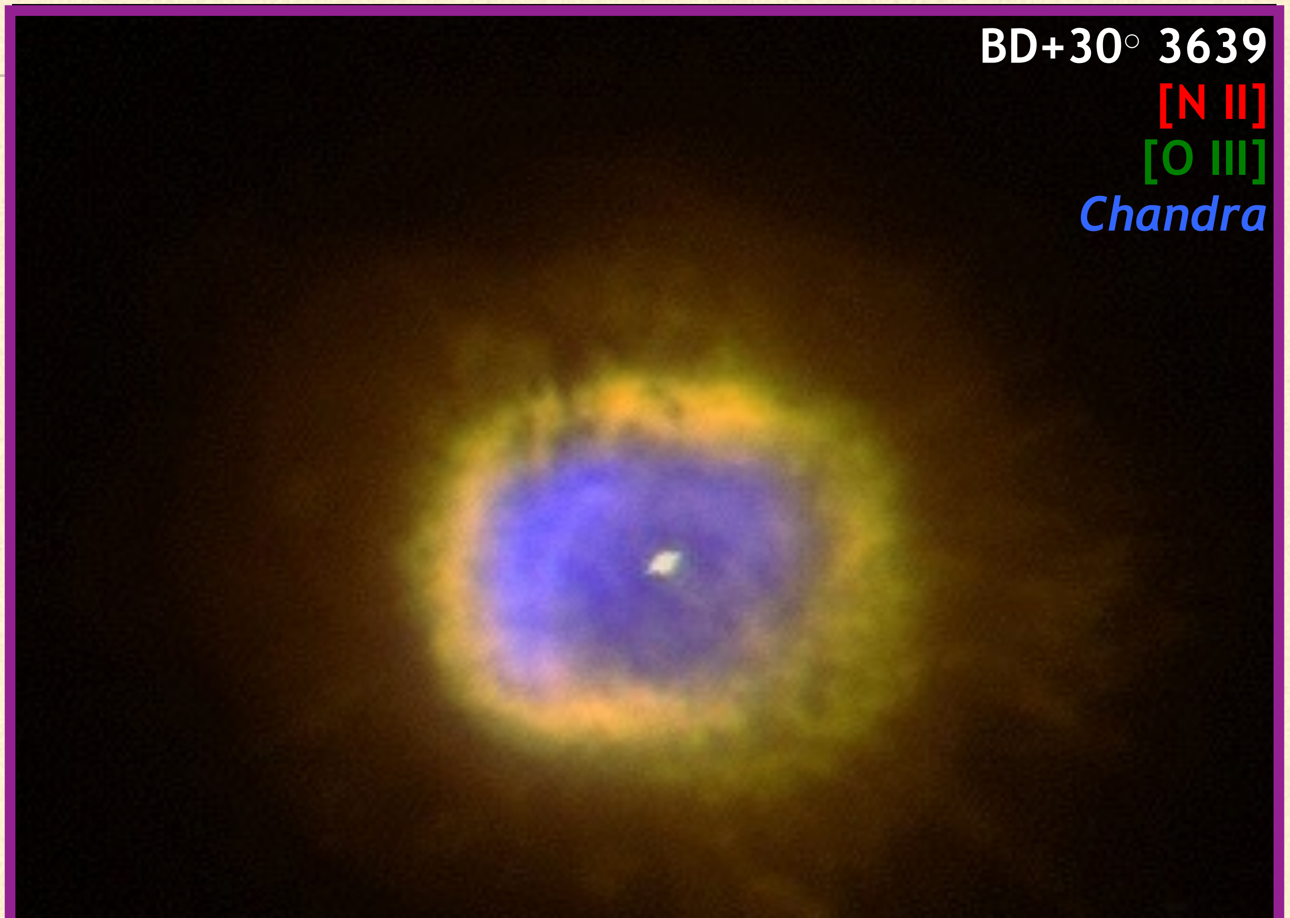
BD+30°3639

Yu et al. (2009)
LEGT/ACIS-S

The highest-resolution spectrum of a Hot bubble

$T_X = [1.7 - 2.9] \times 10^6$ K





SUMMARY

- *Chandra* has played a major role in advancing our understanding of X-ray emission from Hot Stars and their Feedback.

- X-ray spectra from Hot Stars have helped constrains and test radiatively-driven stellar winds with the help of sophisticated non-LTE stellar atmospheres codes (e.g., PoWR & CMFGEN)

- TGCat archive of *Chandra* grating spectra - a great legacy to X-ray Astronomy (Huenemoerder et al. 2011)
  more than 400 objects!

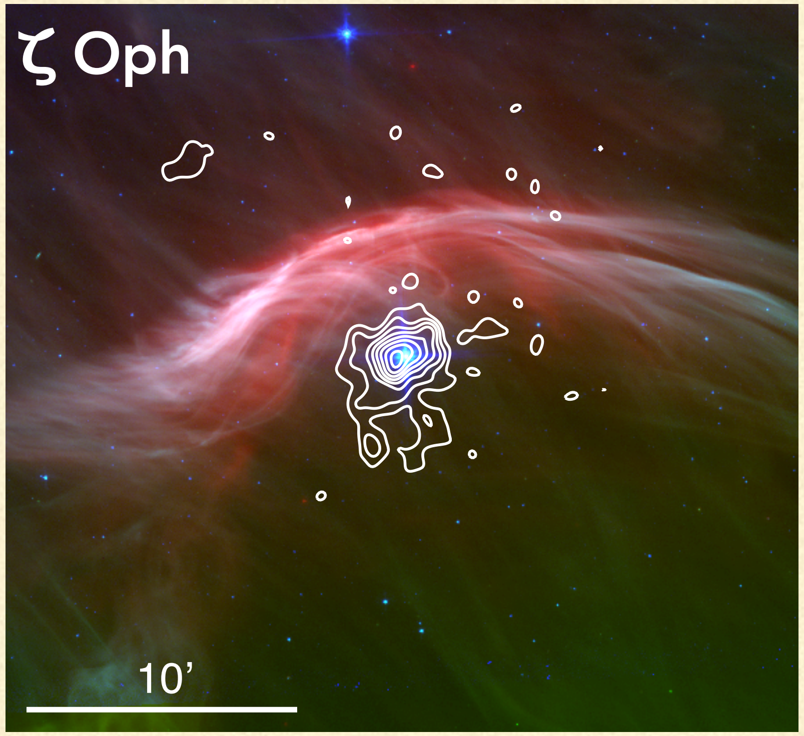
- *Chandra* the perfect satellite to study star forming regions and compact objects (e.g., PNe)

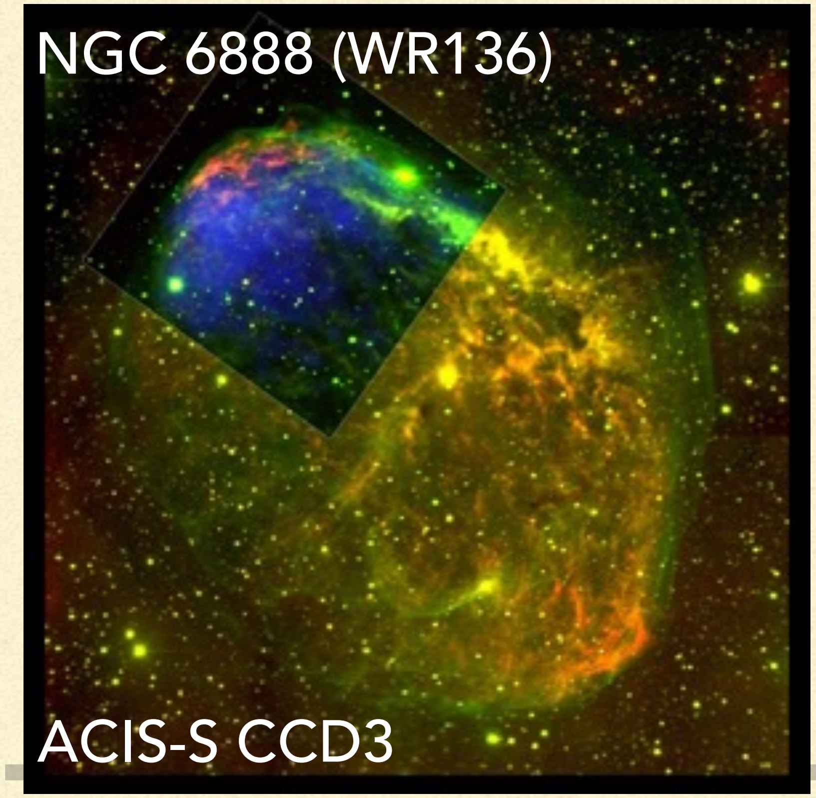
Chandra & Hot Stars in the Next Decade (I/V)

- We need *Chandra* "sharp eyes" to unveil stellar feedback for low-metallicity media
- We need to invest large time (~Ms) studying stellar feedback in the SMC
- A large proposal will be submitted again next year

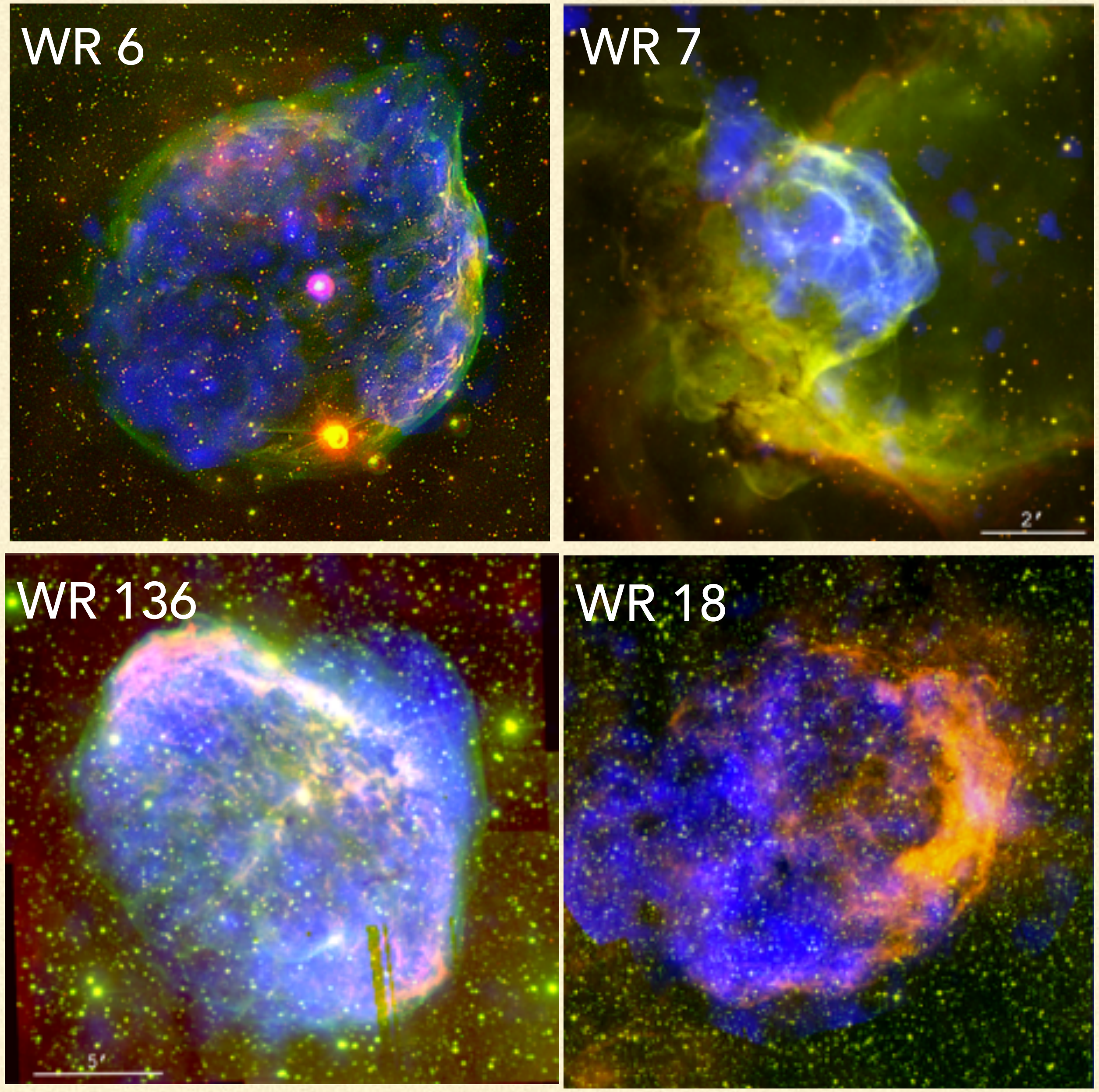
Chandra & Hot Stars in the Next Decade (II/V)

Diffuse X-ray emission around single O and WR stars





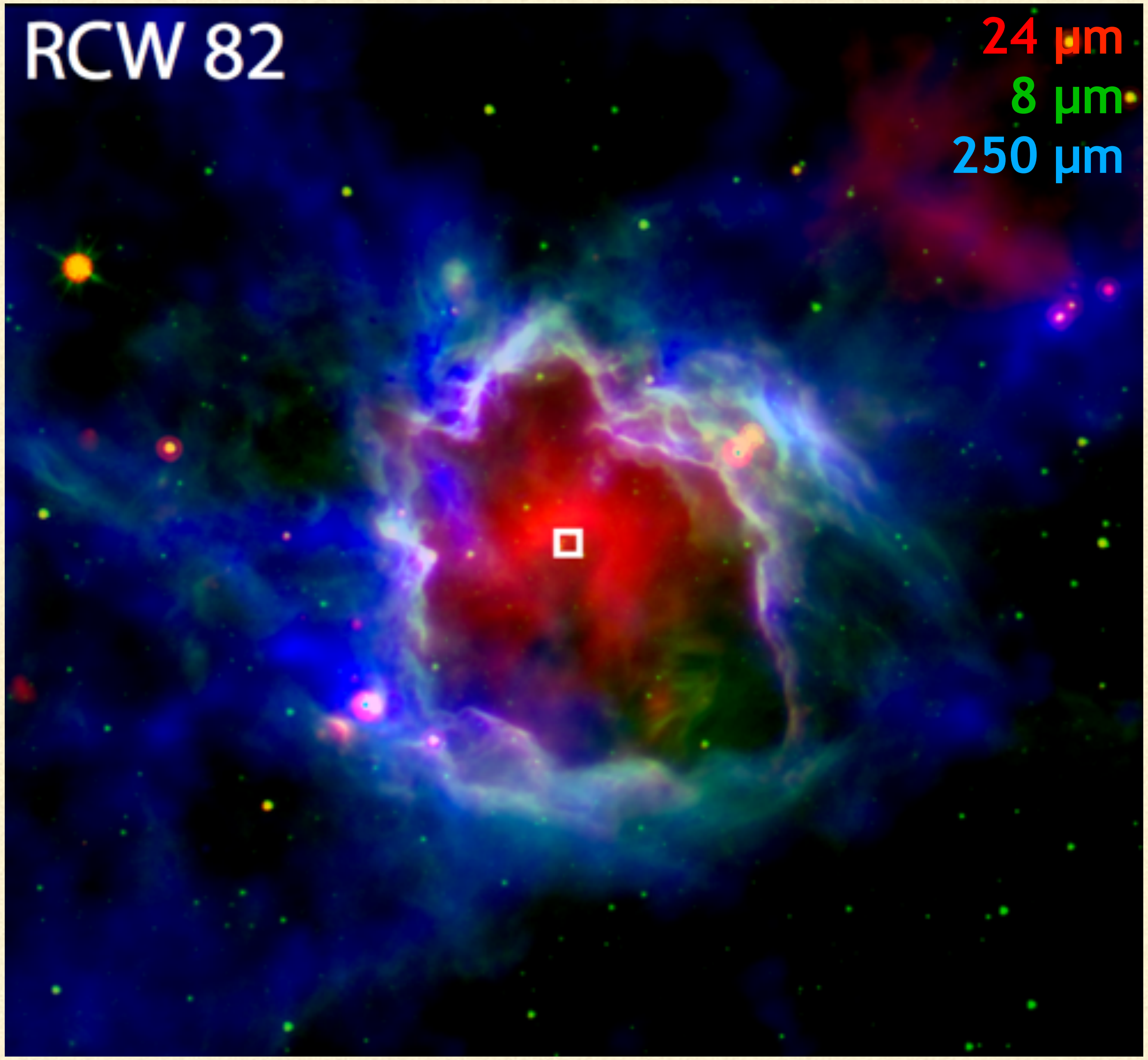
XMM-Newton



Toalá et al. (2012, 2015, 2016)

Chandra & Hot Stars in the Next Decade (III/V)

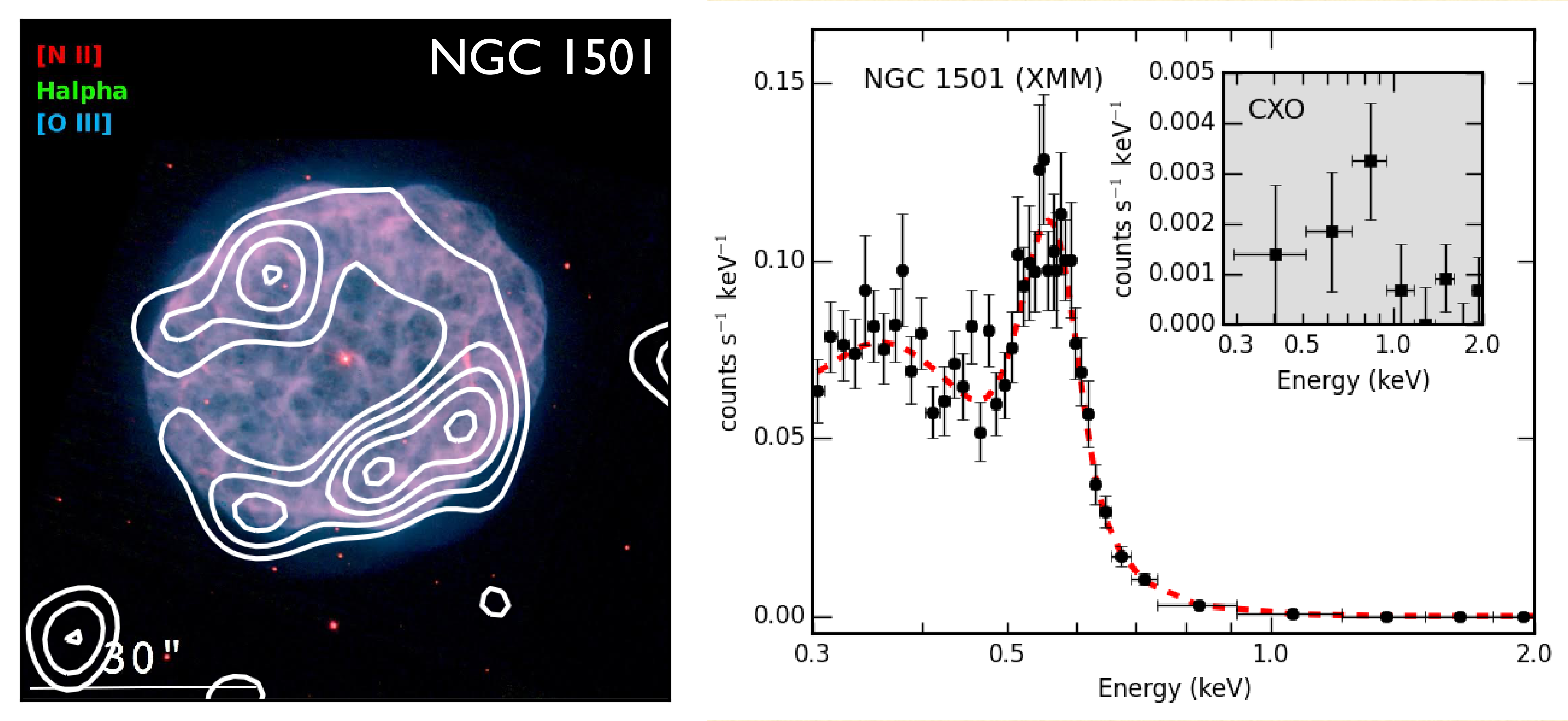
The weak-wind problem around late O and B-type stars - challenge the radiation-driven winds model
(e.g., Puls et al. 2008; Najarro et al. 2011)



Ochsendorf et al. (2014)

Chandra & Hot Stars in the Next Decade (IV/V)

The future of the ChanPlaNS project
Chandra HRC and *XMM-Newton* EPIC for a better understanding of PNe
(Improve plasma temperatures, abundances, electron densities, X-ray-emitting gas distribution…)



Chandra & Hot Stars in the Next Decade (V/V)

WR stars

- WR6 is *shaking* our understanding of the X-ray emission from WR stars

- Deep, high-resolution X-ray spectra for different spectral types (WN, WC, WO) !!

THANK YOU

Chandra in the future . . .

Still some discoveries to make!

Searching for a monster lurking in a WR nebula
WR+NS??
Chandra observations accepted
(PI: Oskinova)