13 268 X-ray sources in the Carina Nebula: the young stellar population revealed by the *Chandra Carina Complex Project*

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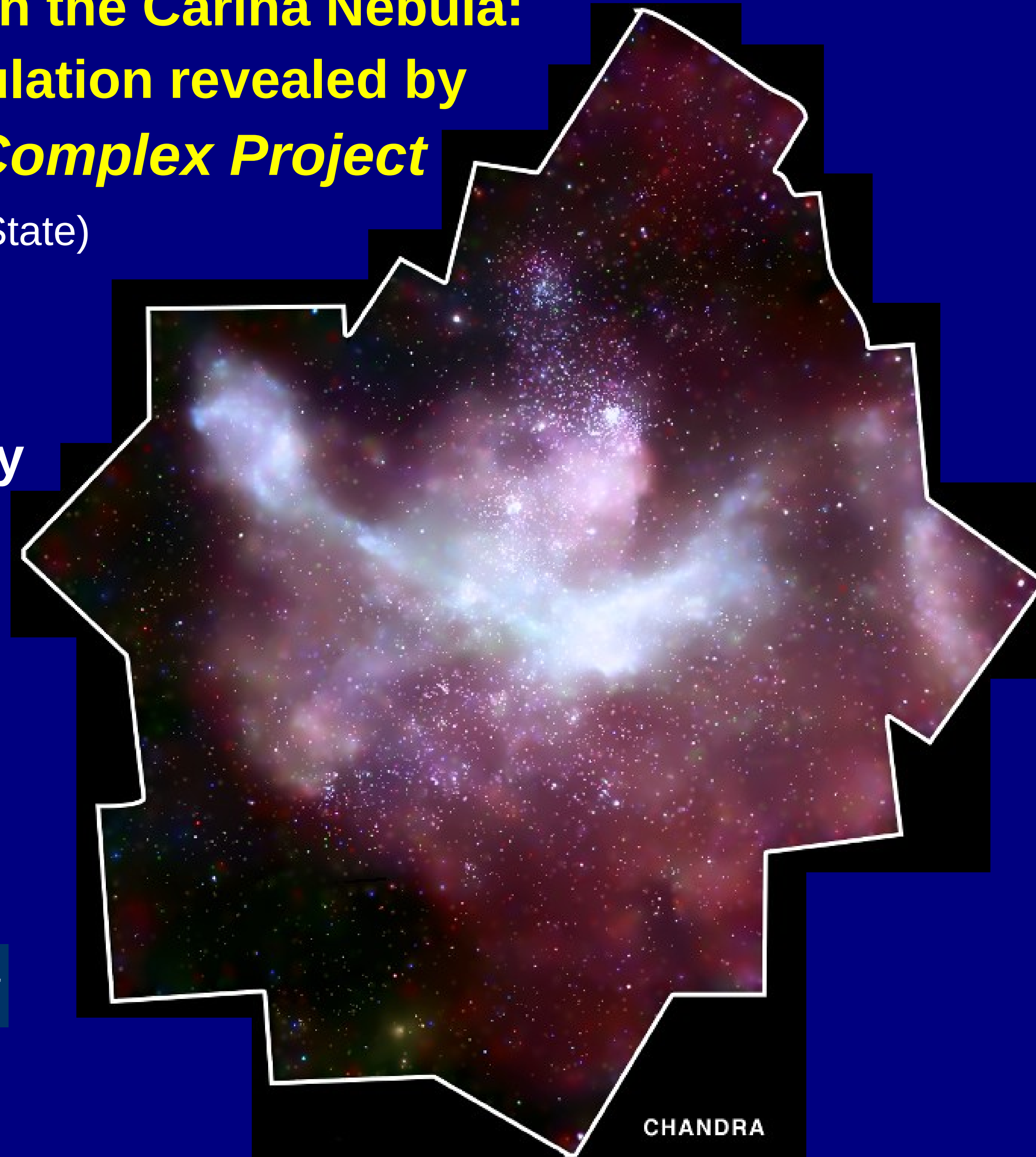

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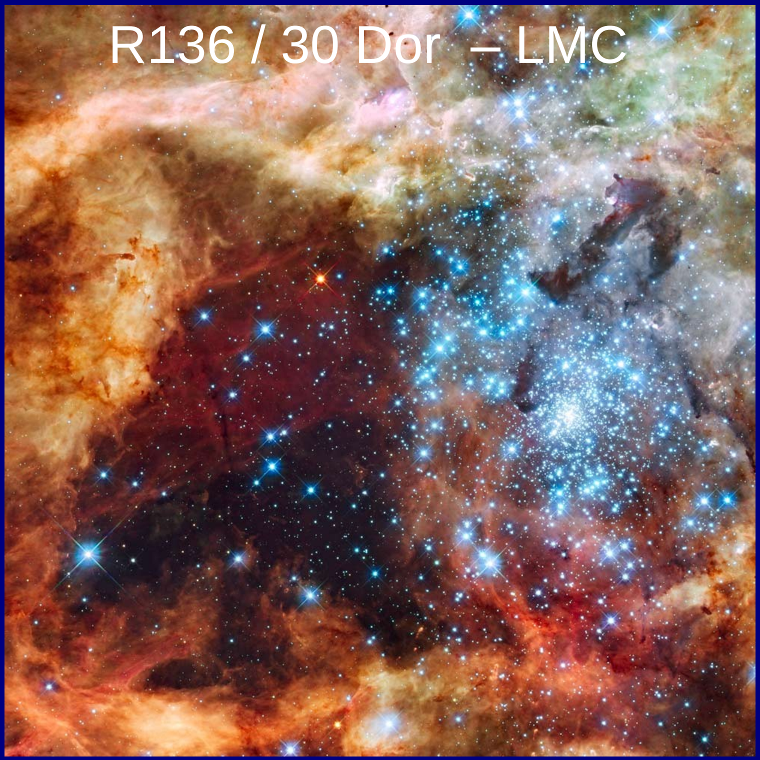
Science Context: How important is feedback from massive stars ?



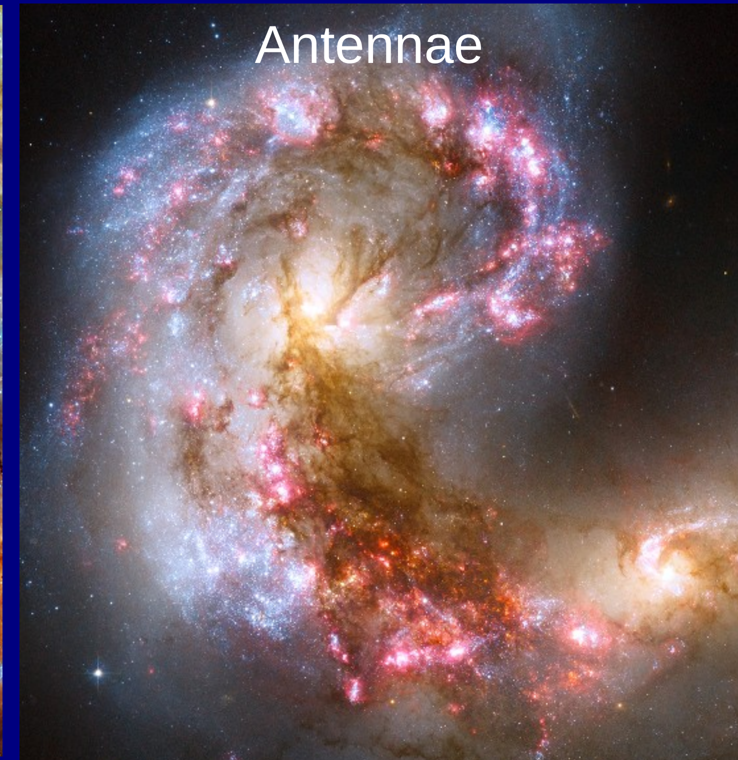
- Radiative feedback → less fragmentation → higher stellar masses ?

  → *top-heavy IMF ? deficit of low-mass stars* in massive clusters ?

- *Cloud dispersal* ? OR *triggered star formation ?*

- Destruction of protoplanetary disks ? Consequences for planet formation ?

Science Context: How important is feedback from massive stars ?



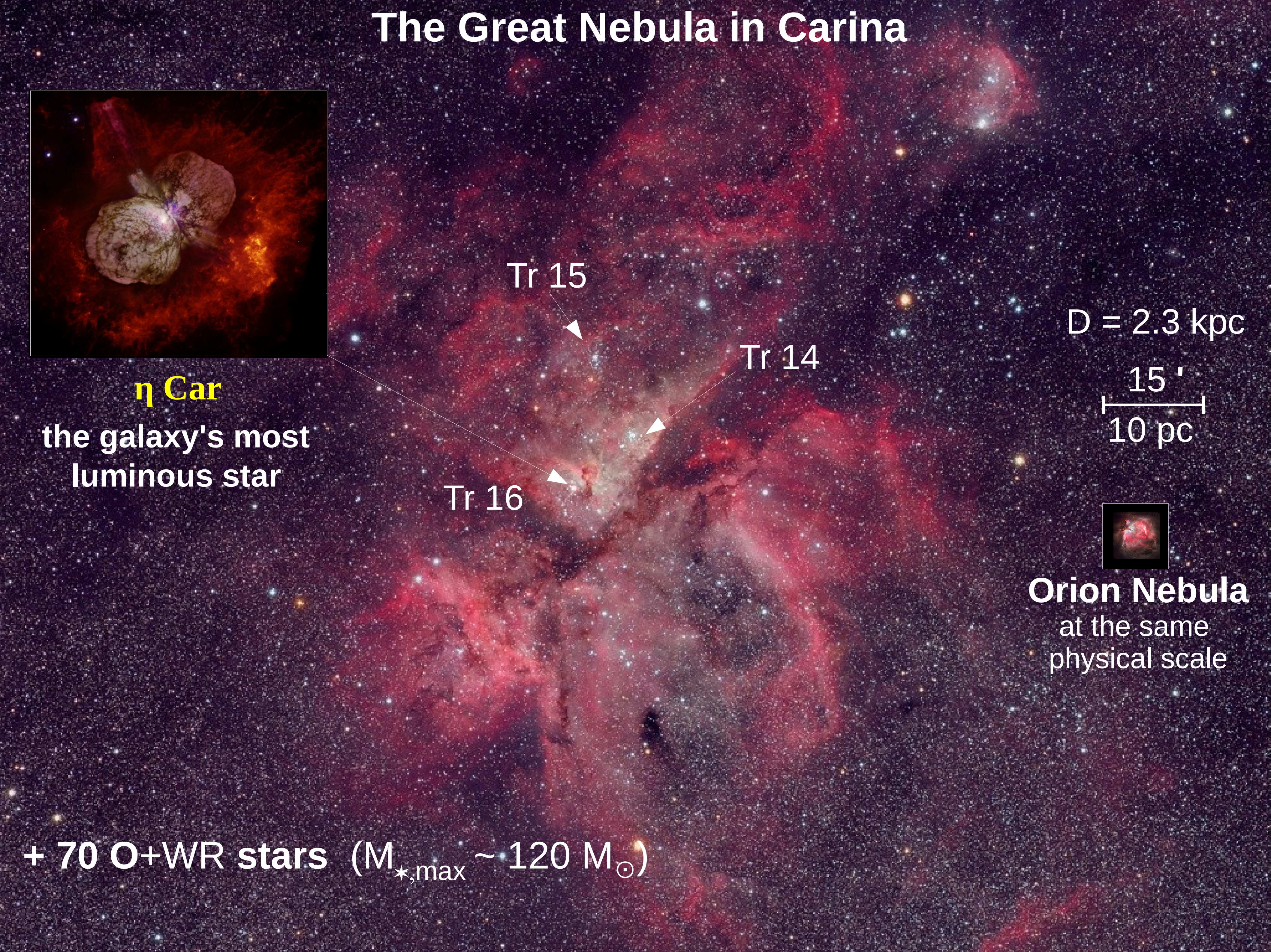
θ^1C Ori: SpT = O6
M = 36 $M_\odot$
$Q_{EUV} \approx 10^{49}\ s^{-1}$
$P_{wind} \approx 100\ L_\odot$

→ *Feedback is not very important in this cluster*

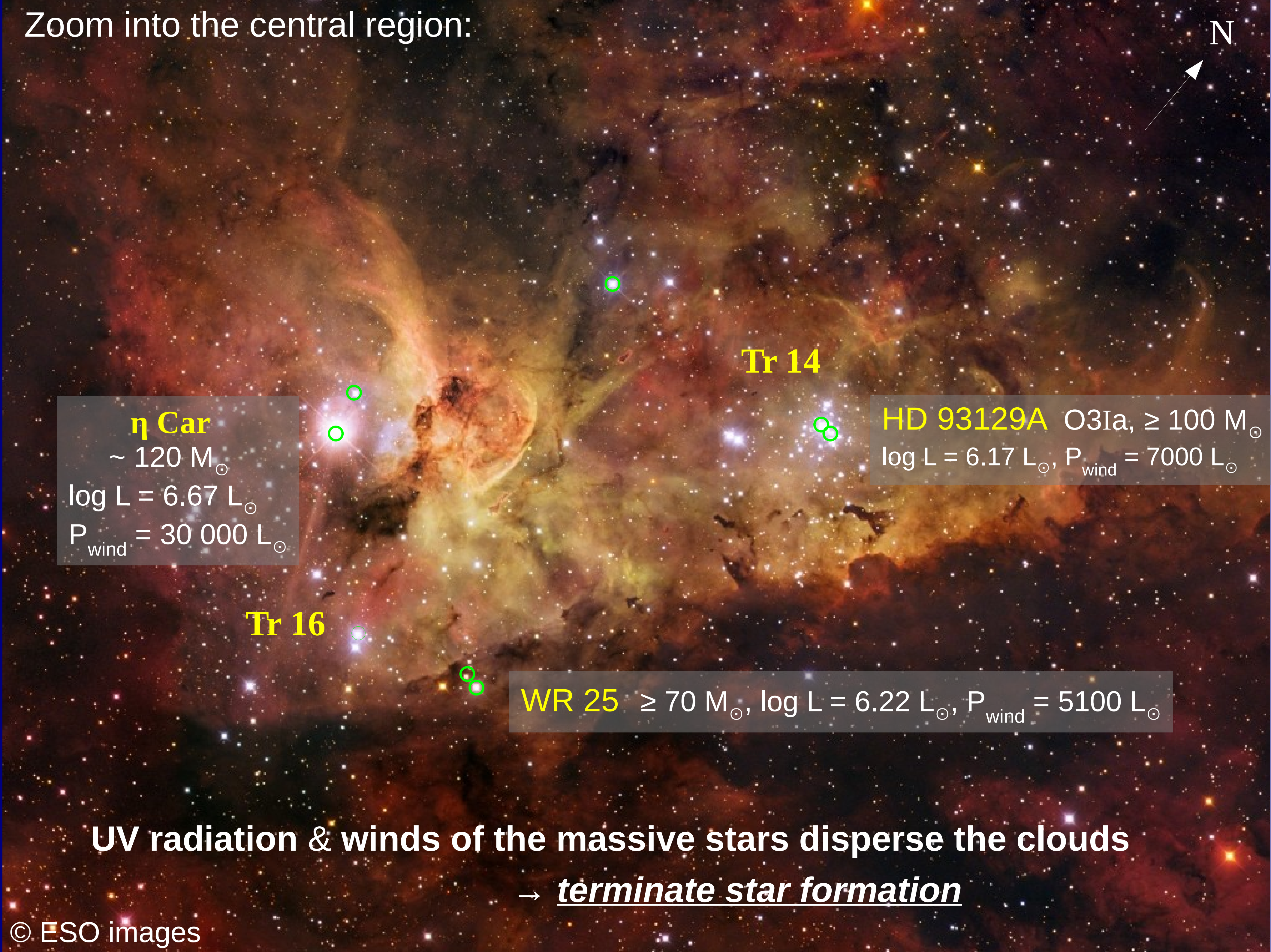
The *most massive stars* in starburst clusters produce ***much*** stronger feedback:

SpT = O3
$M_\star \sim 100\ M_\odot$
$Q_{EUV} \sim 10^{50}\ s^{-1}$
$P_{wind} \sim 10\,000\ L_\odot$

To study the effect of massive star feedback,
we need to look at *more massive = more distant* regions
→ requires observations with high resolution & sensitivity


The Great Nebula in Carina
η Car
the galaxy's most luminous star
Tr 15
Tr 14
Tr 16
D = 2.3 kpc
15 '
10 pc
Orion Nebula
at the same physical scale
+ 70 O+WR stars ($M_{\star,max}$ ~ 120 $M_\odot$)

Zoom into the central region:



UV radiation & winds of the massive stars disperse the clouds

→ ***terminate star formation***

Orion Nebula	**Carina Nebula**	**30 Doradus**
2 O stars	**70 O**+WR **stars**	**~1000 O stars**
$M_{\star,max} = 36\ M_\odot$	$M_{\star,max} \sim 120\ M_\odot$	$M_{\star,max} \sim 150\ M_\odot$

large enough to sample the *top of the IMF* →

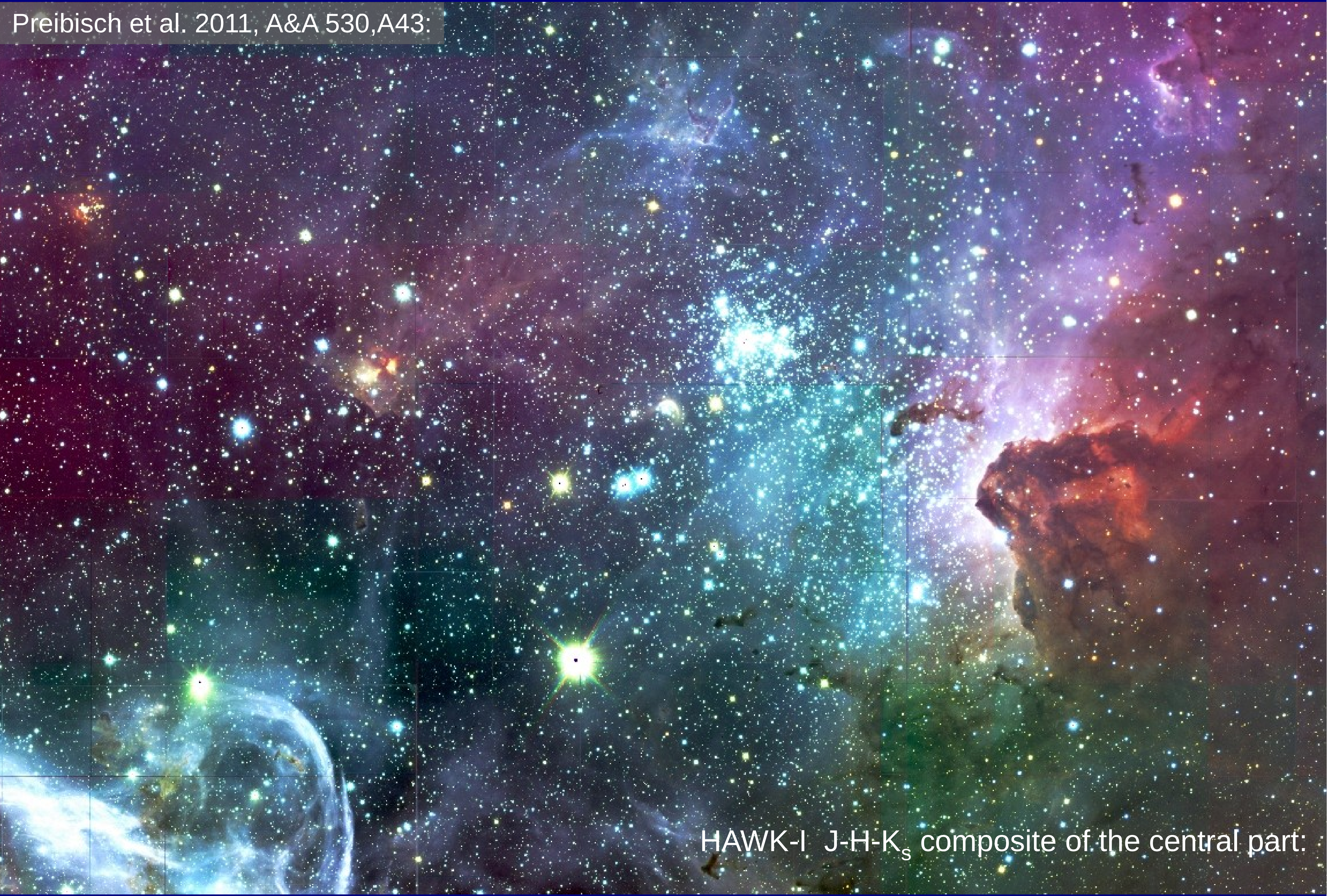
← **close enough to study low-mass stars**

1" = 420 AU = 0.002 pc	1" = 2300 AU = 0.01 pc	1" = 52 000 AU = 0.25 pc

Carina is the best bridge between
detailed studies of **nearby regions** and
more massive but more distant extragalactic **starburst regions**


• Evidence for on-going and triggered star formation
Spitzer IRAC map
3.6, 4.5, 8.0 µm
Many dust columns contain young stellar objects in their heads
Treasure Chest
BUT: The sample of the ~ 1500 known young low-mass stars is highly incomplete

HAWK-I survey: 600 336 infrared sources in Carina Nebula



galactic latitude = -0.6° → > 95% of these are unrelated background objects !

Chandra Carina Complex Project (CCCP)

team of ~ 30 X-ray astronomers
PI: L. Townsley (Penn State)

- 22 pointing mosaic covering **1.4 square-deg**

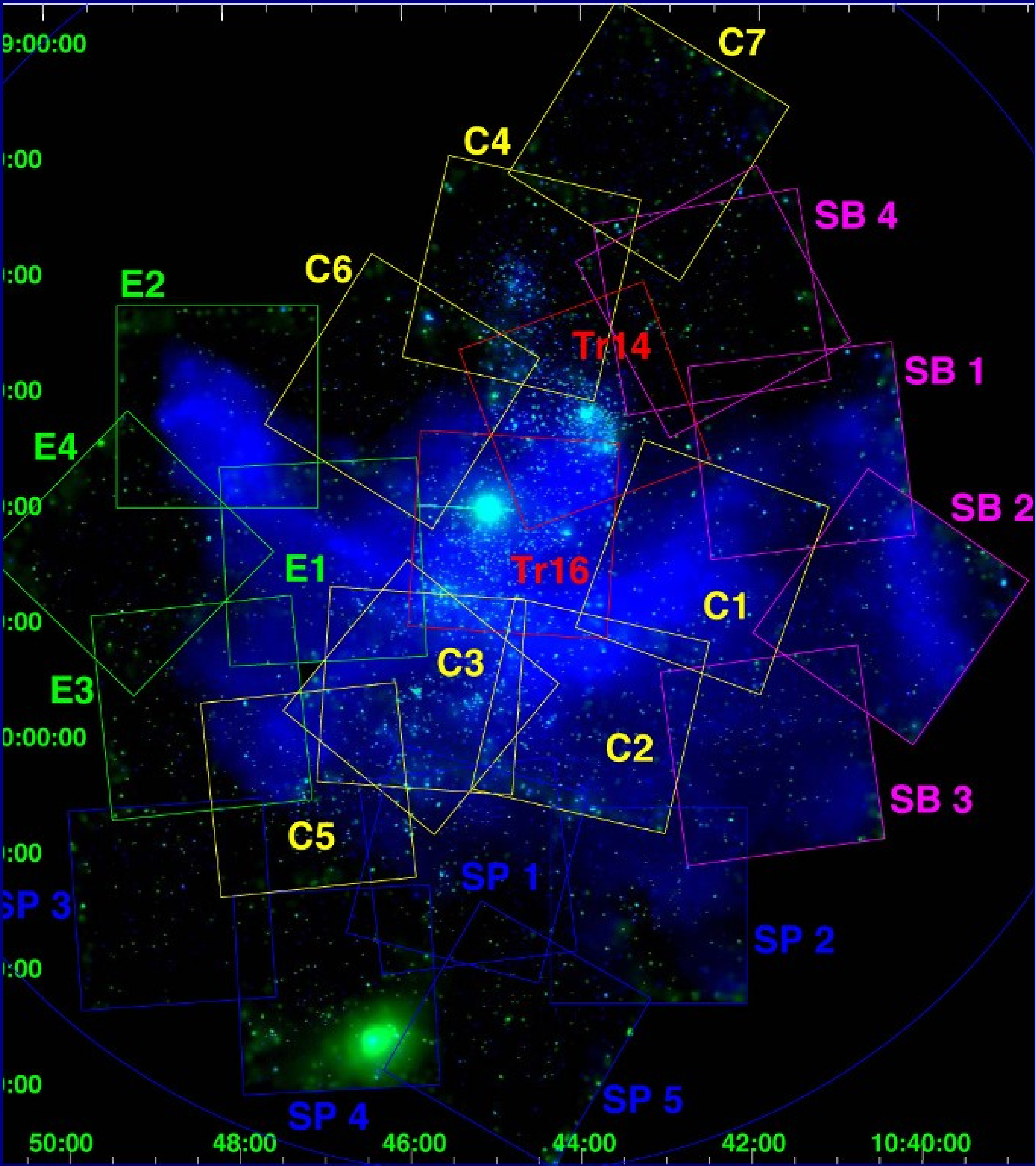
- Exposure time ≥ 60 ksec

- Total observing time: **1.34 Msec** = 15.6 days

Detection limit: $10^{29.9}$ erg/sec
Completeness limit: $10^{30.5}$ erg/sec

The first unbiased sample of the low-mass stellar population.

≥ 80% complete at ~ 1 $M_\odot$
~50% complete at ~ 0.5 $M_\odot$

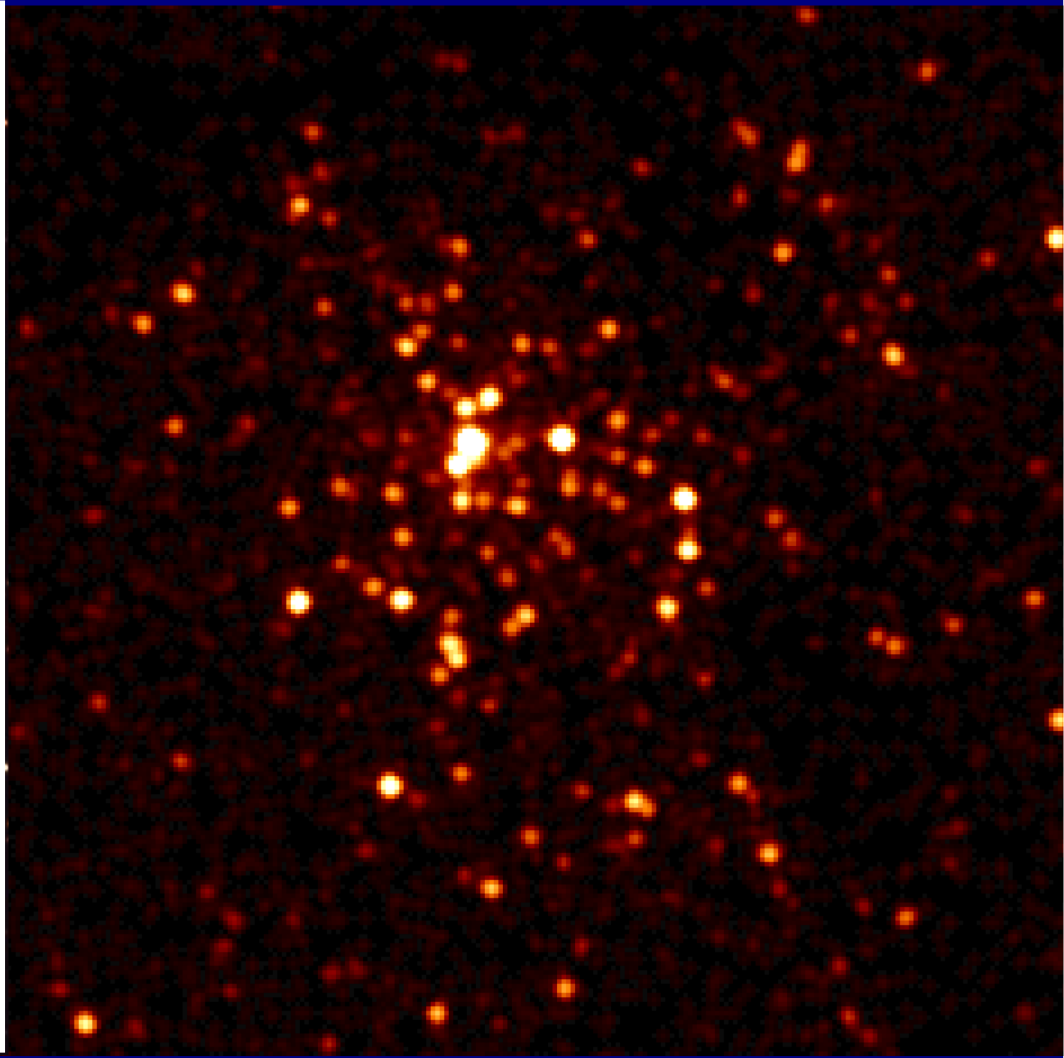


1) **Image Quality**   Example: the compact cluster Tr 14

HAWK-I J-H-K

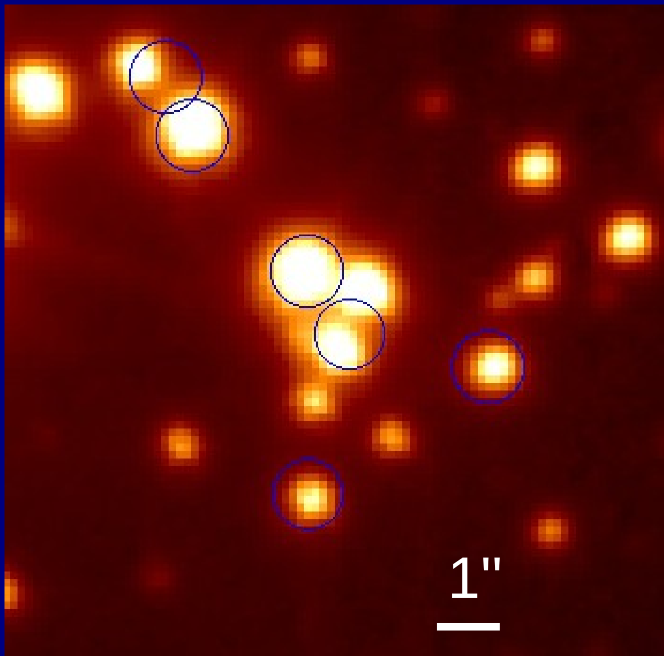
FWHM ≈ 0.6''

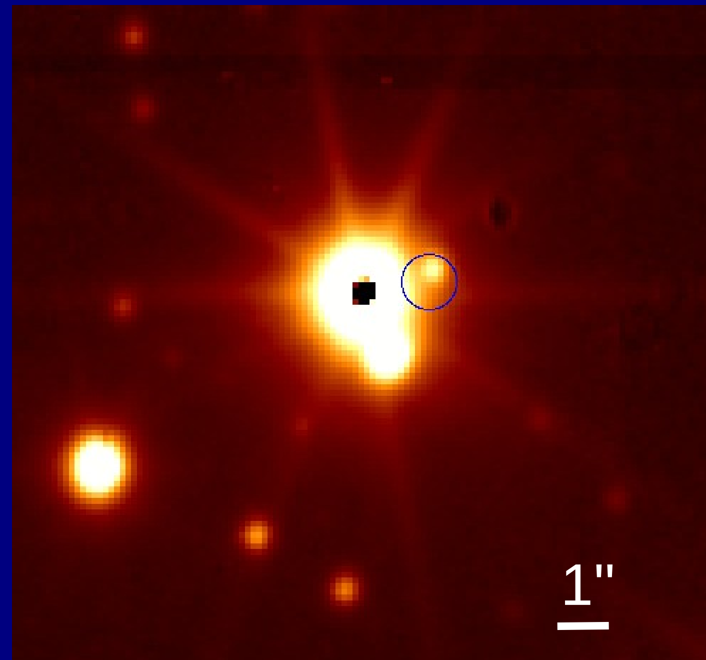
Chandra X-ray

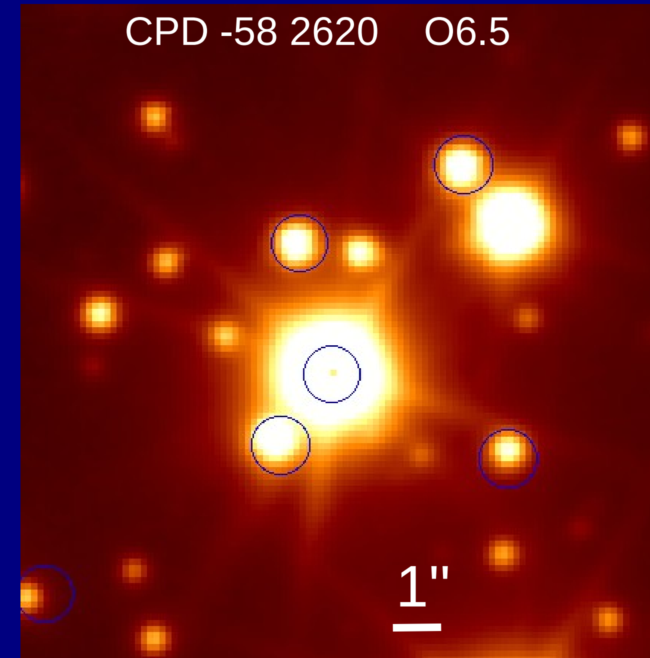


FWHM ≈ 0.8''

2) X-ray – Infrared Source Identification Examples



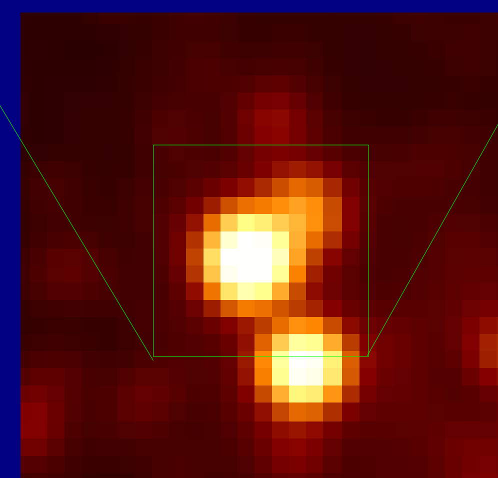




X-ray error circle radius ≈ 0.5''

HAWK-I image: FWHM = 0.6''

2MASS image



Sub-arcsecond resolution is essential for a proper identification of the Chandra X-ray sources !

3) Classification of X-ray sources

Broos et al. 2011, ApJS 194, 4

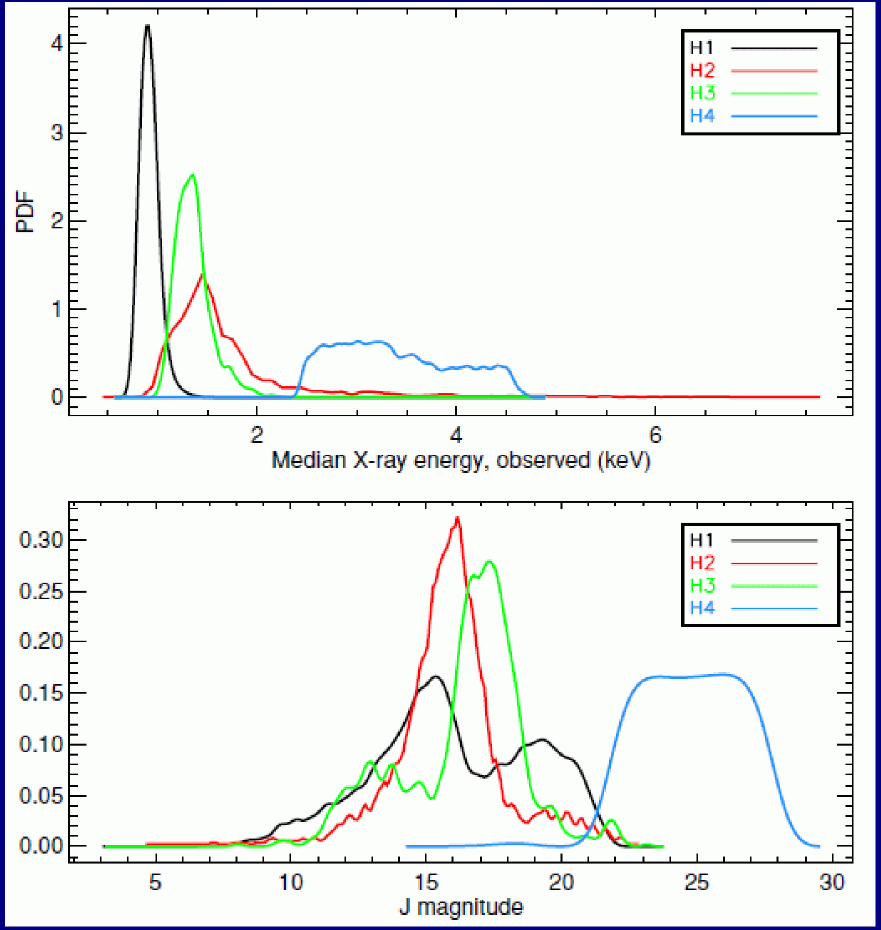
Object Classes:

H1: Foreground stars

H2: *Young Stars in Carina*

H3: Background Stars

H4: Extragalactic (AGN)



14 368 X-ray point sources

Properties D_1, D_2, … D_N :

- *median photon energy*
- *variability*
- *optical spectral type*
- *J-band flux*
- *infrared excess*

Bayes Source Classifier:

$$p(\mathrm{H} \mid D_1, D_2, \ldots, D_N) \propto p(D_1, D_2, \ldots, D_N \mid \mathrm{H})\ p(\mathrm{H})$$

posterior ∝ likelihood × prior.

10 714 Carina members

716 foreground stars, 16 background stars, 877 AGN, 2045 no classification

4) Spatial distribution

Only the 30% brightest X-ray members are shown:

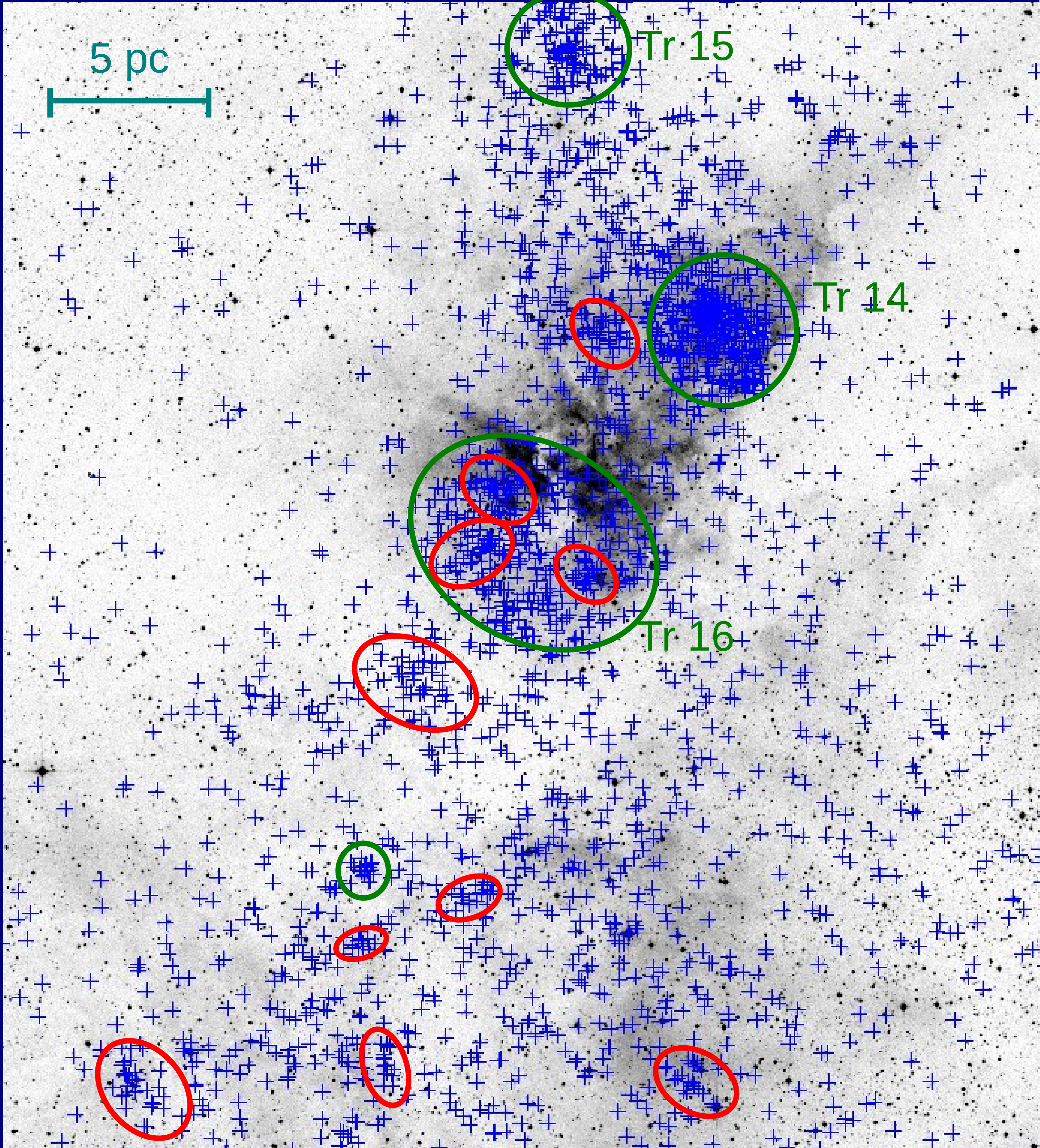
Clustering analysis:

Feigelson et al. 2011, ApJS 194, 9

- 20 principal clusters (mostly known before) +31 small groups

→ **5457** X-ray sources in a **clustered** population

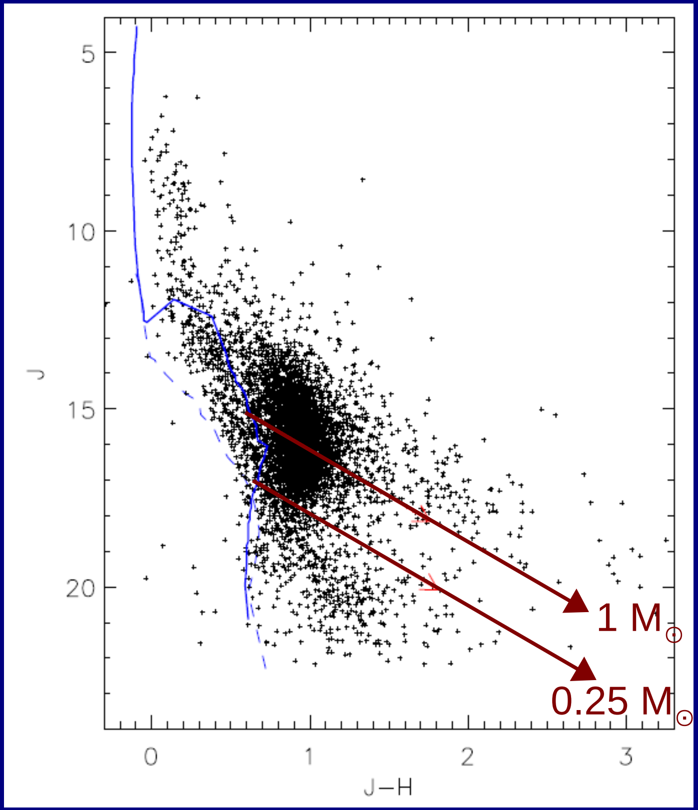
- **5271** X-ray sources in a **distributed** population (previously unknown)



5) The size of the low-mass stellar population

Preibisch et al. 2011, A&A 530, A34

- Number of X-ray detected stars with mass estimate (from CMD) $\geq 1\ M_\odot$: 3185



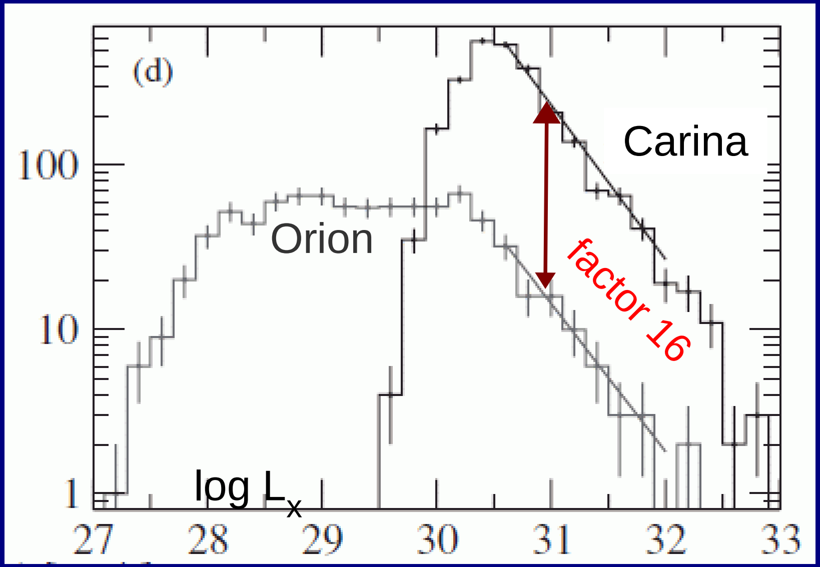
- 78 stars with $M > 20\ M_\odot$
  Field-star IMF (Kroupa 2002) prediction
  $N(M \geq 1\ M_\odot)_{expected} \approx 3500$

There is clearly
<u>no deficit of low-mass stars</u>

IMF(Carina Nebula) ≈ IMF(field) down to $1\ M_\odot$

Field IMF extrapolated down to $0.1\ M_\odot$:

$N_* \geq 45\ 000$, $M_{*,tot} \geq 30\ 000\ M_\odot$



The Carina Nebula is one of the most massive clusters known in our Galaxy!

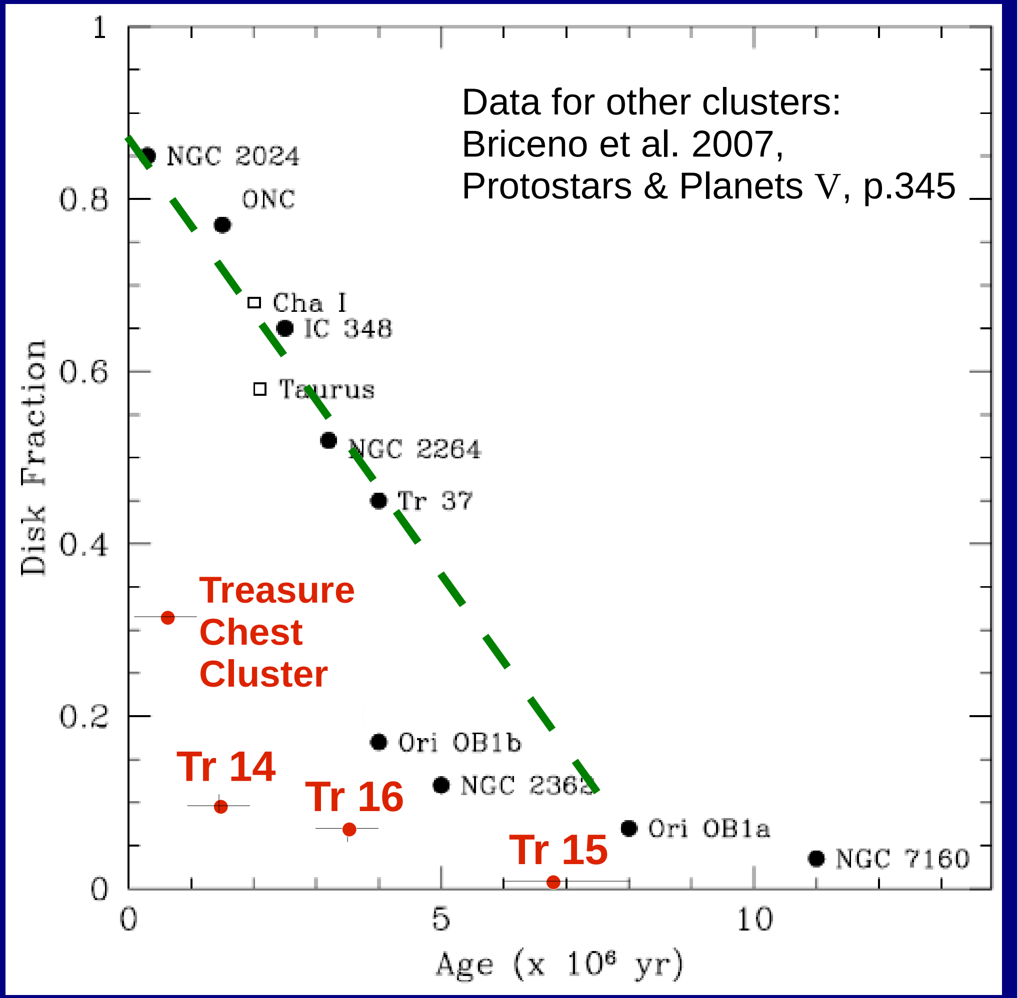
Carina Nebula > NHC 3603, Arches Cluster
≈ Westerlund 1

6) Ages and circumstellar disk fractions of clusters in Carina

IR color-color/color-magnitude diagrams of the X-ray selected populations:
Ages and **infrared excess fractions**

Tr 16:	~ 3-4 Myr	(7 ± 1) %
Tr 14:	~ 1-2 Myr	(10 ± 1) %
Tr 15:	~ 5-8 Myr	(2 ± 1) %
TCC:	< 1 Myr	(32 ± 5) %

Preibisch et al. 2011, A&A 530, A34



The infrared excess (= disk) fractions in the clusters in the Carina Nebula are considerably lower than in other clusters of similar ages!
→ ***fast dispersal of circumstellar disks due to the harsh environment***

see also: Wang et al. 2011, ApJS 194, 11; Wolk et al. 2011, ApJS 194, 12

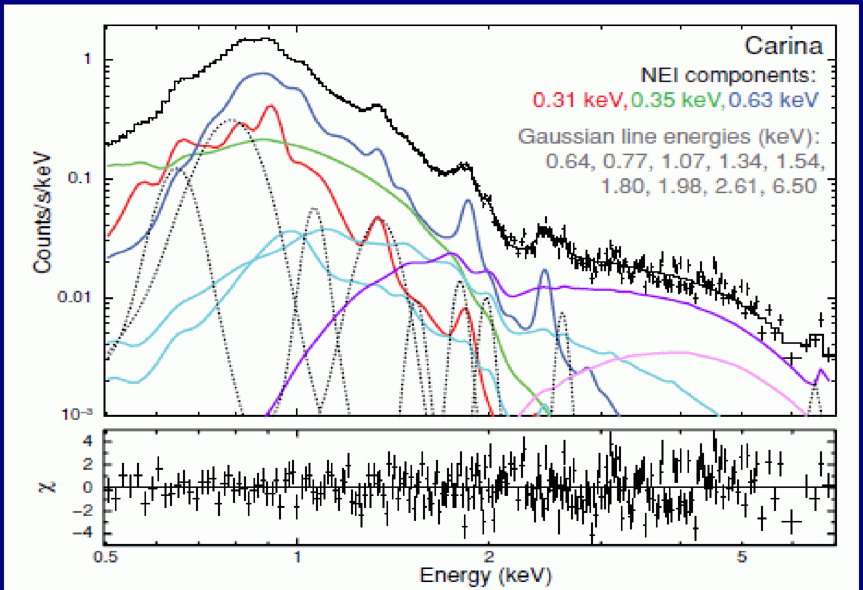
7) Diffuse X-ray emission

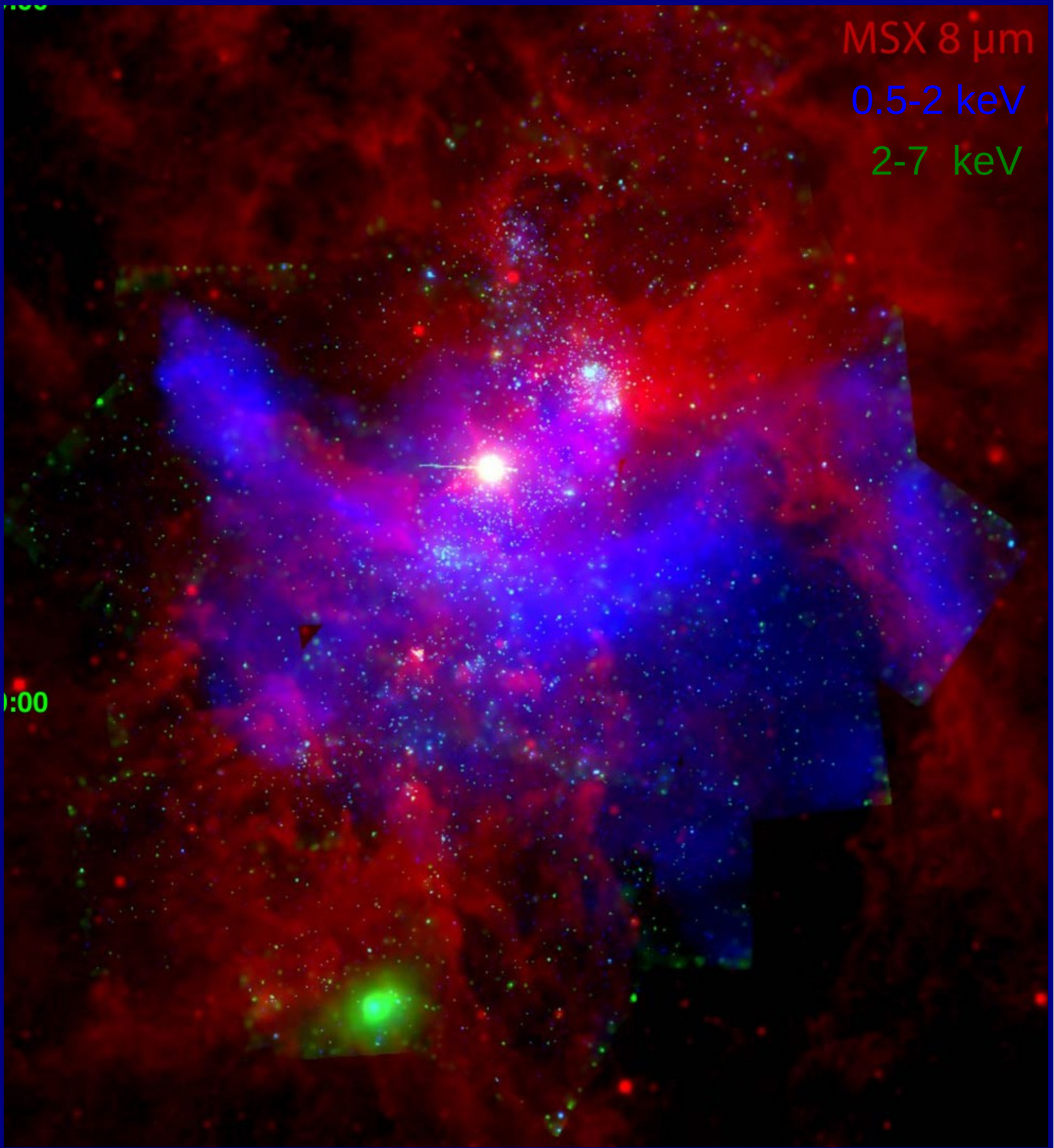
Townsley et al. 2011, ApJS 194, 16

Stellar winds (+ supernovae ?) have filled the super-bubble with hot plasma.

$L_{X,diff} = 3 \cdot 10^{35}$ erg/sec
$T_X = 4$ MK + 7 MK

Orion:
$L_{X,diff} = 5 \cdot 10^{31}$ erg/sec
$T_X \leq 2$ MK



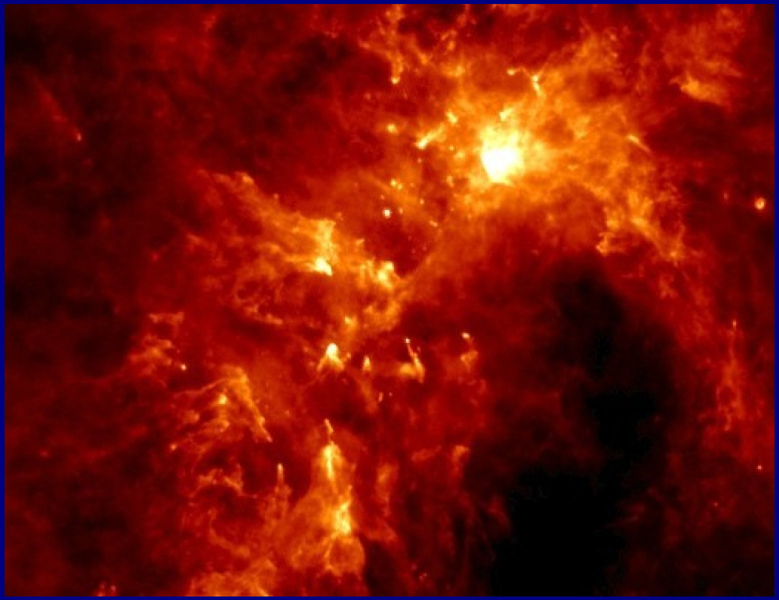


Ongoing/future studies: Multi-wavelength analysis of the interaction between the massive stars and the surrounding clouds

optical

Chandra
X-ray

Herschel
250 μm



Spitzer
3.6 – 8 μm

The End