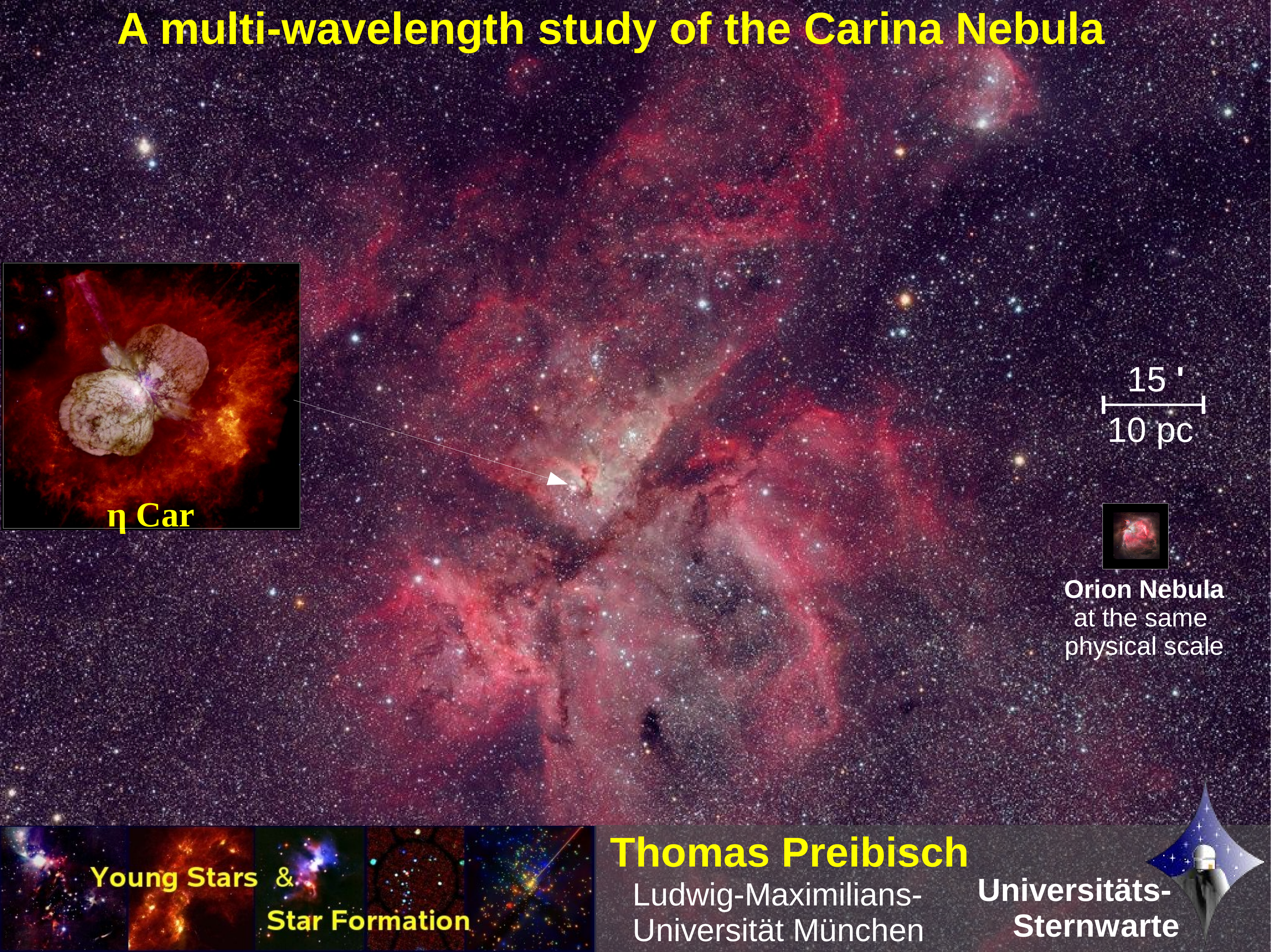
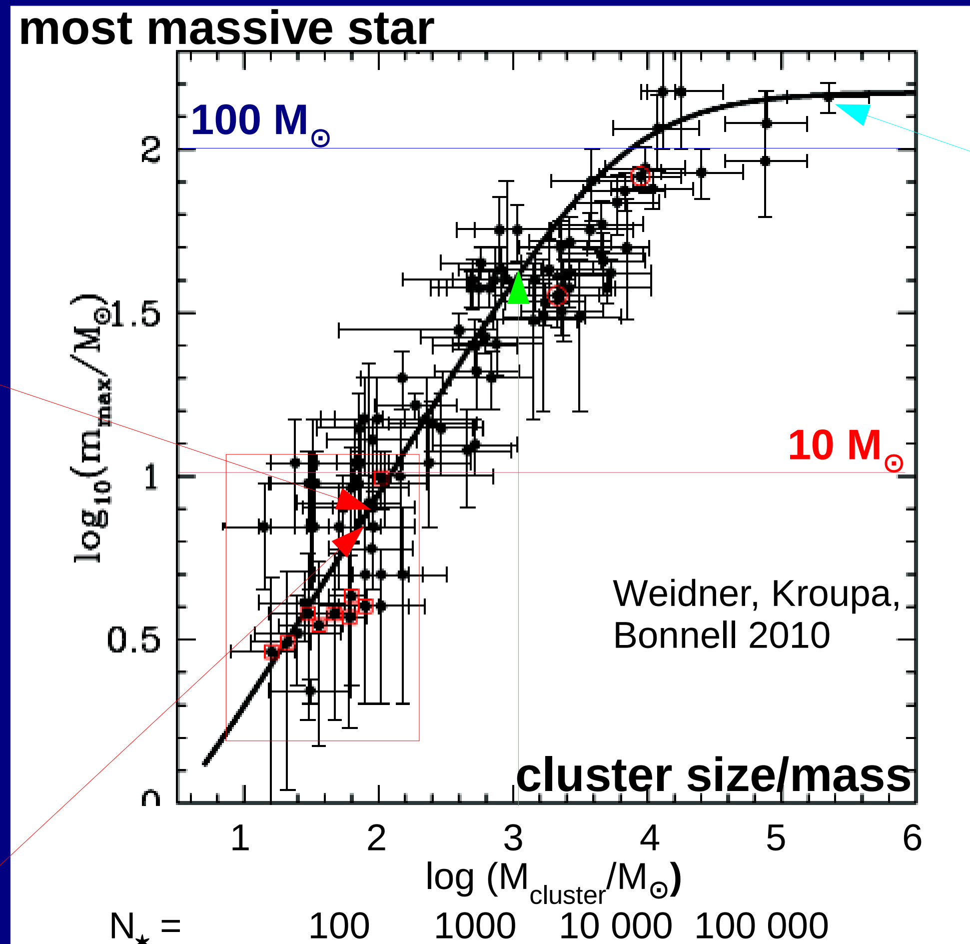

A multi-wavelength study of the Carina Nebula
η Car
15 '
10 pc
Orion Nebula
at the same
physical scale
Young Stars &
Star Formation
Thomas Preibisch
Ludwig-Maximilians-
Universität München
Universitäts-
Sternwarte

Star Cluster Populations and Massive Star Feedback

Taurus / IC348: no massive stars



R136/ 30 Dor in LMC

SpT = O3

$M_\star \sim 100\ M_\odot$

$Q_{EUV} \sim 10^{50}\ s^{-1}$

$P_{wind} \sim 10\,000\ L_\odot$

Orion Nebula Cluster

θ^1C Ori: SpT = O6

$M = 36\ M_\odot$

$Q_{EUV} \approx 10^{49}\ s^{-1}$

$P_{wind} \approx 100\ L_\odot$

Most star formation in the universe occurs in massive (starburst) clusters, containing 100s to 1000s of high-mass stars.

ULIRGS: SFR up to ~ 300 $M_\odot$/yr

Suggested effects of massive star feedback:

- Radiative cloud heating → higher Jeans mass
  → higher stellar masses → **deficit of low-mass stars** ***?***

- Massive star feedback disperses clouds, terminates star formation
  → Low-mass stars form first, high-mass stars later ***?***

- Strong radiation fields: Fast destruction of proto-planetary disks ***?***

Orion Nebula

2 O stars

$M_{\star,max} = 36 M_\odot$

Carina Nebula

66 O+ 4 WR **stars**

$M_{\star,max} \sim 120 M_\odot$

30 Doradus

~1000 O stars

$M_{\star,max} \sim 150 M_\odot$

large enough to sample the *top of the IMF*

strong feedback

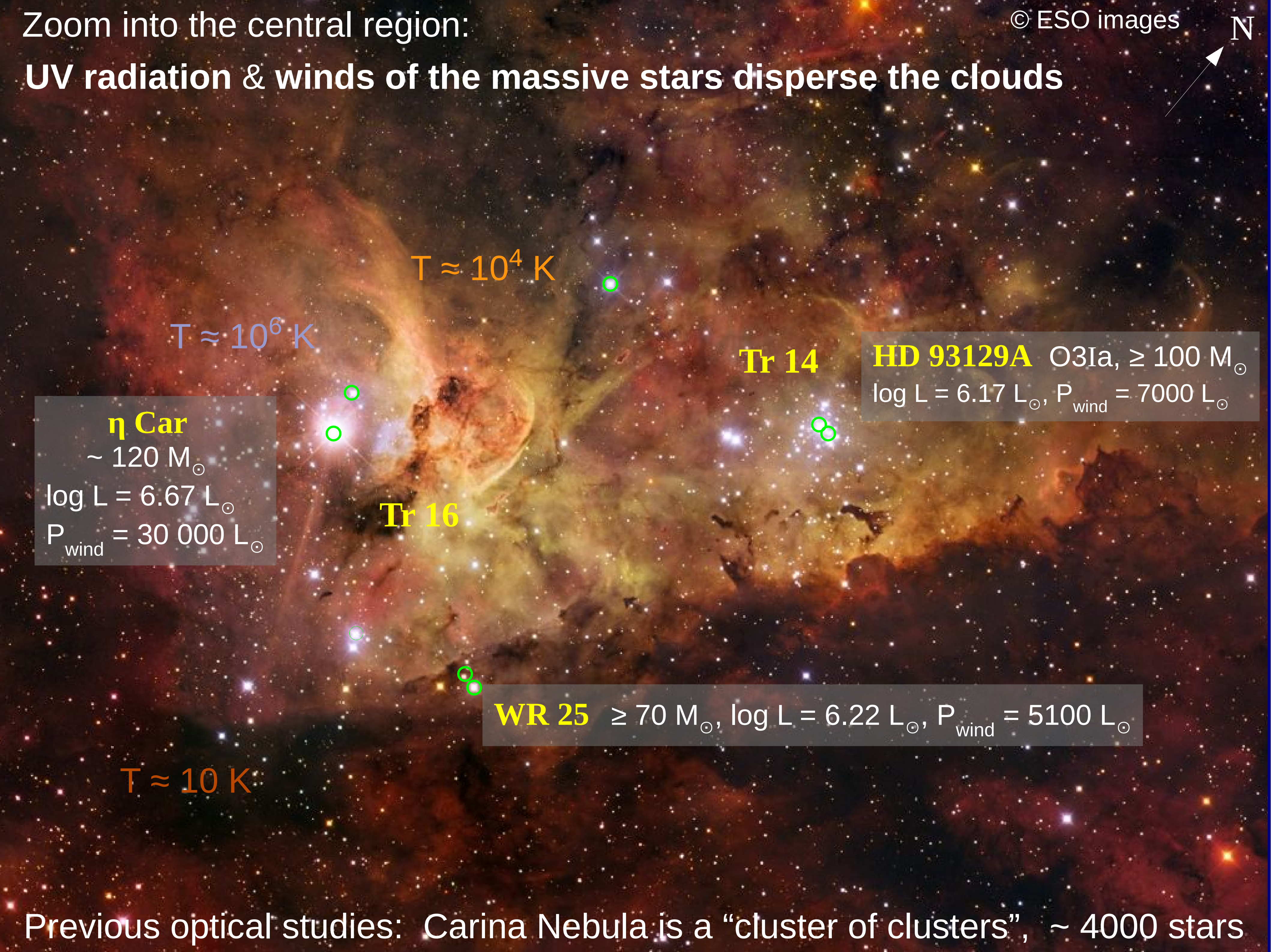
close enough to study low-mass stars

1" = 420 AU = 0.002 pc

1" = 2300 AU = 0.01 pc

1" = 52 000 AU = 0.25 pc

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


Zoom into the central region:
UV radiation & winds of the massive stars disperse the clouds
© ESO images
N
T ≈ 10^4 K
T ≈ 10^6 K
Tr 14
HD 93129A O3Ia, ≥ 100 $M_\odot$
log L = 6.17 $L_\odot$, P_{wind} = 7000 $L_\odot$
η Car
~ 120 $M_\odot$
log L = 6.67 $L_\odot$
P_{wind} = 30 000 $L_\odot$
Tr 16
WR 25 ≥ 70 $M_\odot$, log L = 6.22 $L_\odot$, P_{wind} = 5100 $L_\odot$
T ≈ 10 K
Previous optical studies: Carina Nebula is a “cluster of clusters”, ~ 4000 stars

STEP 1: Detecting the young stellar population

Preibisch et al. 2011
A&A 530,A43

Deep NIR survey with HAWK-I
at the ESO Very Large Telescope

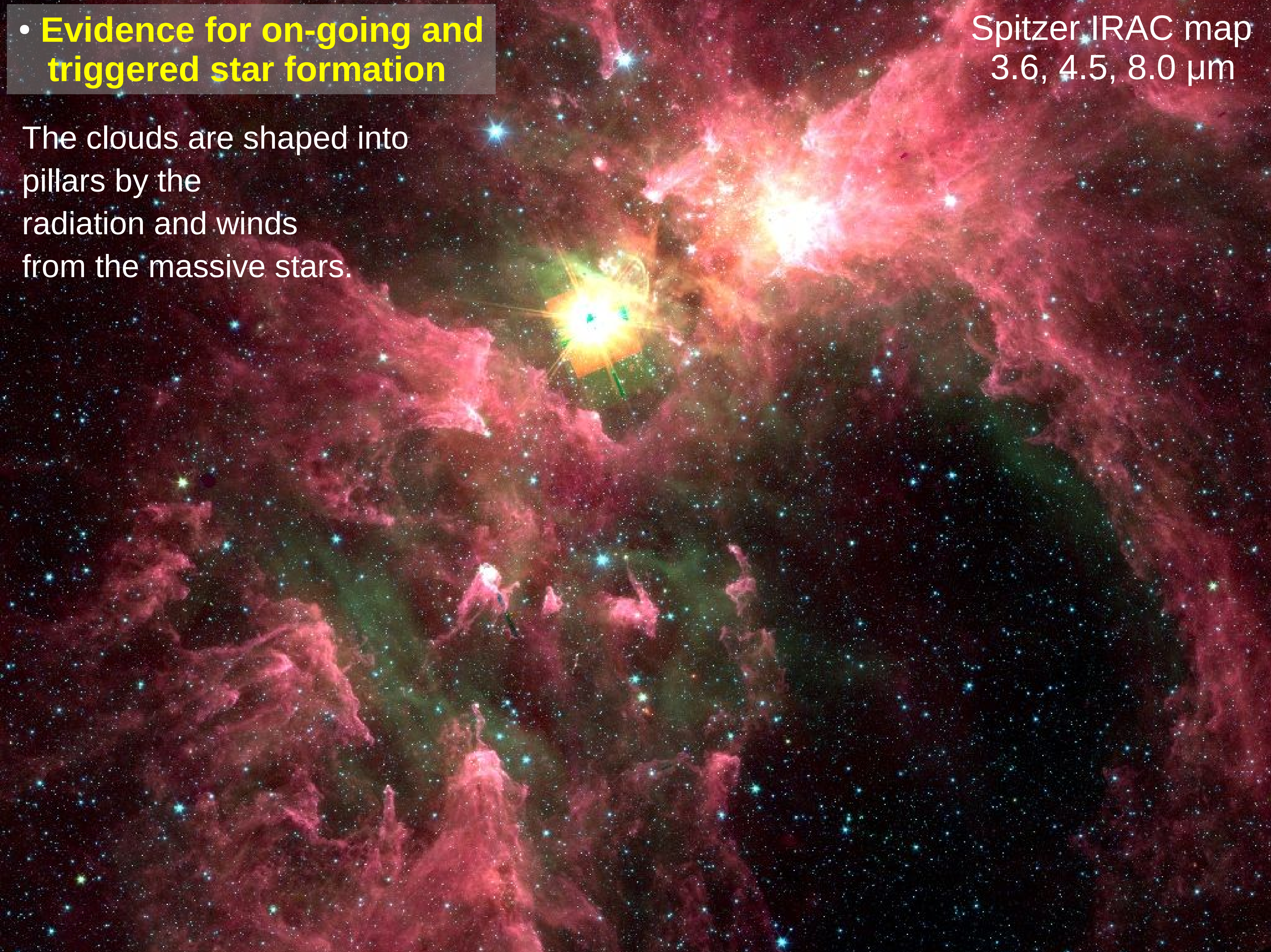
3"

Edge-on disk
Preibisch et al. 2011,
A&A 530, A40

→ Carina Nebula contains ~ 60 000 young stars

- **Evidence for on-going and triggered star formation**

The clouds are shaped into pillars by the radiation and winds from the massive stars.

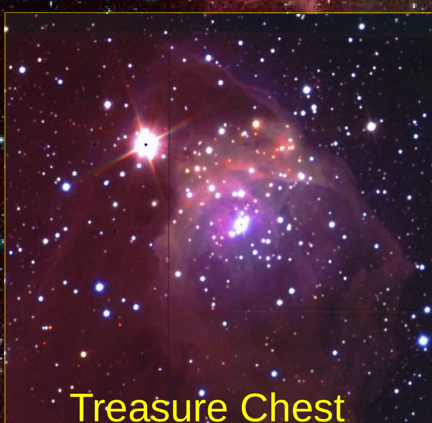


• Evidence for on-going and triggered star formation

Spitzer IRAC map
3.6, 4.5, 8.0 µm

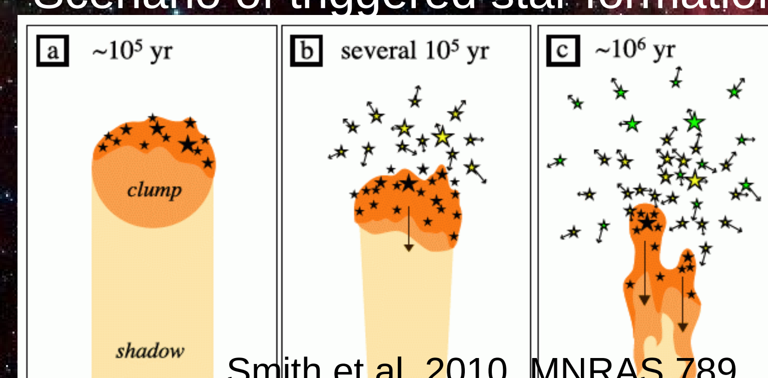
The clouds are shaped into pillars by the radiation and winds from the massive stars.

Many pillars contain young stellar objects in their heads.



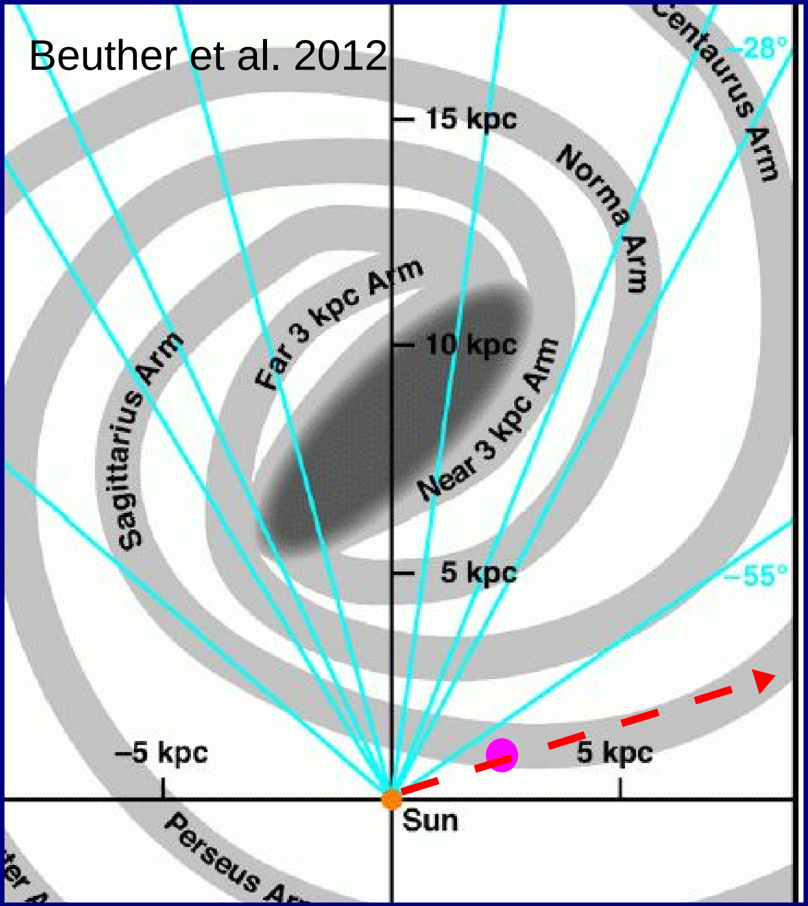
Treasure Chest
HAWK-I J,H,K image
Preibisch et al 2011, A&A 530,A34

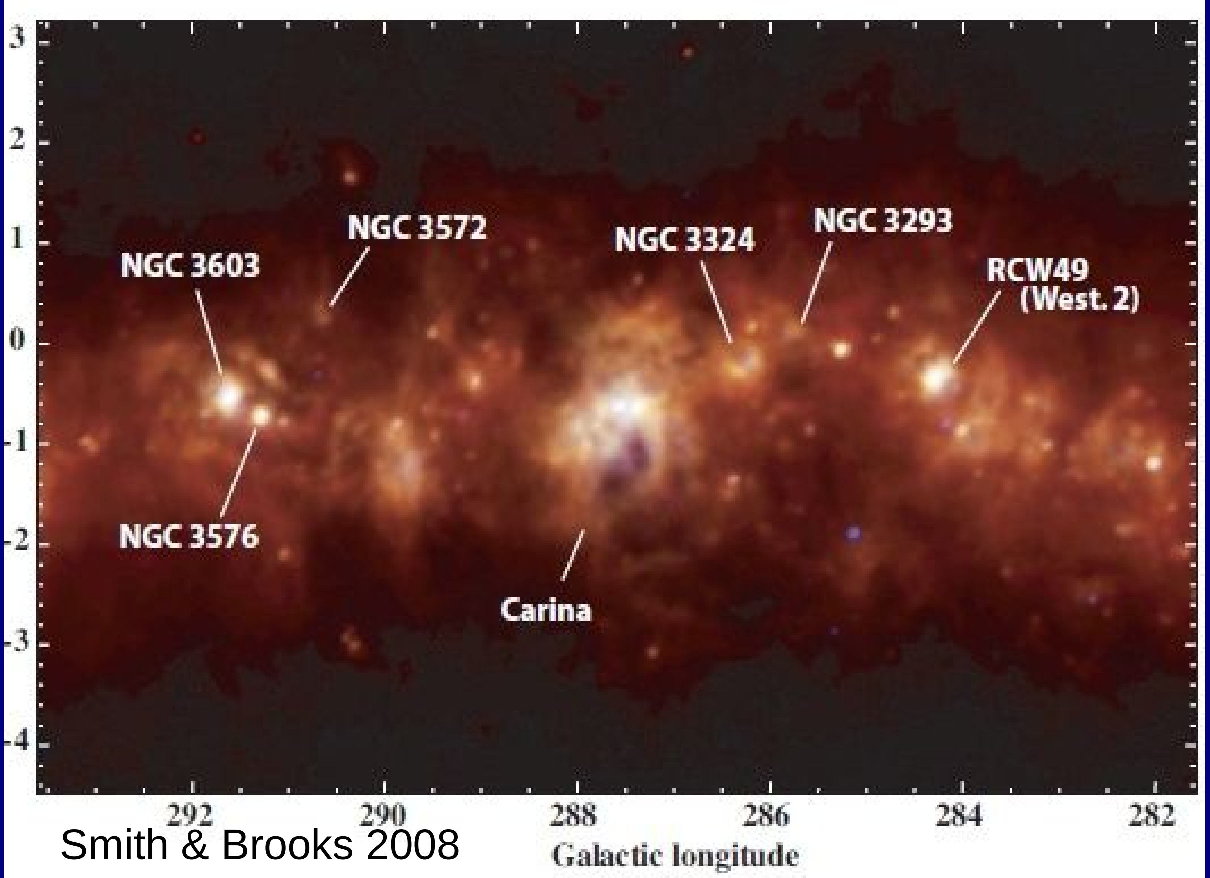
Scenario of triggered star formation



Smith et al. 2010, MNRAS 789

Galactic Position: l = 287.6° (-72.4°), b = -0.6°





igure 5. The Milky Way in Carina observed by IRAS at 25 μm (blue), 60 μm green), and 100 μm (red). Several other well-known regions are labeled.

→ strong Galactic background contamination

STEP2: Revealing the young stellar population

PI: Leisa Townsley (Penn State)

The *Chandra Carina Complex Project*

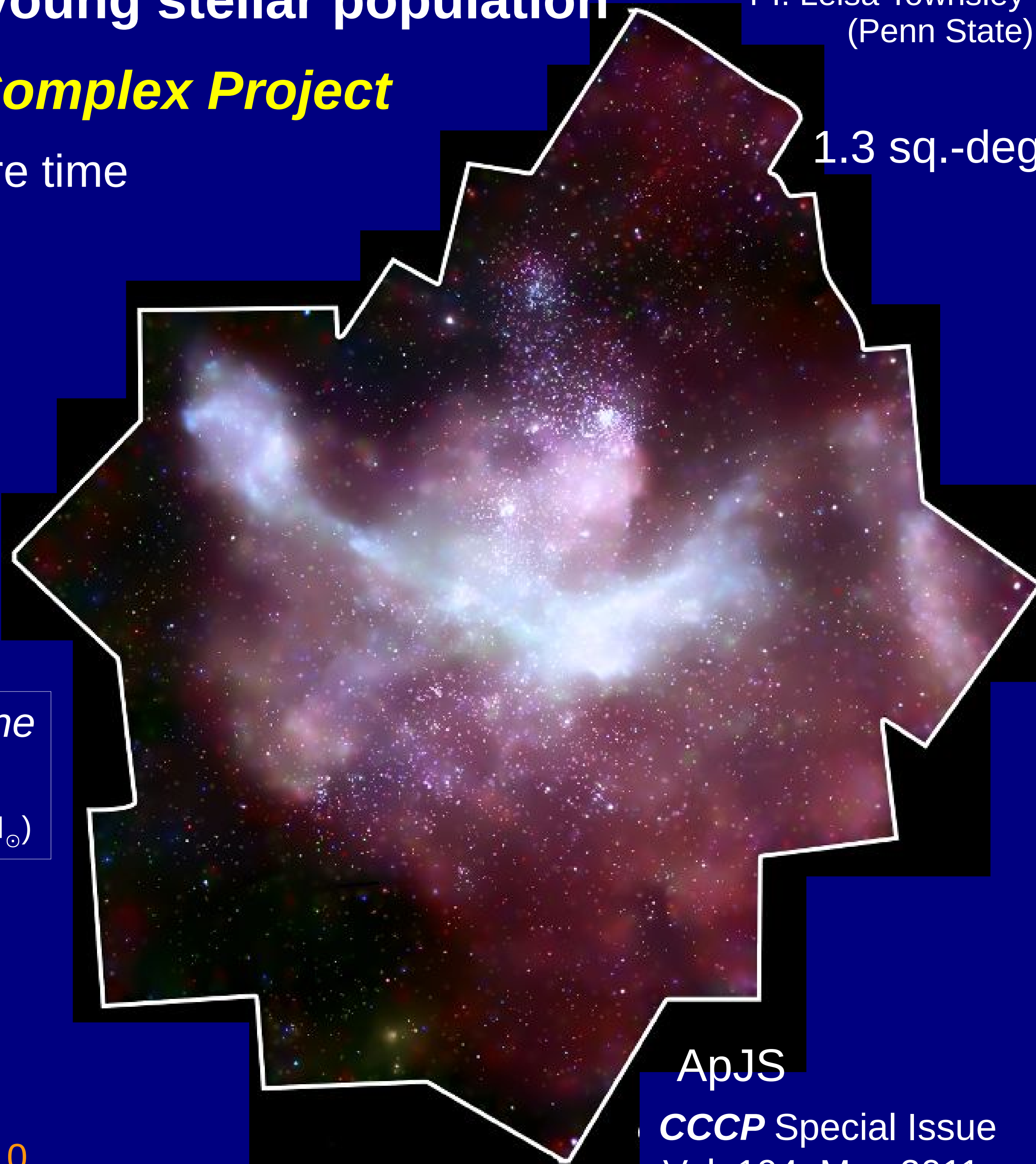
15.6 days exposure time

- 14 368 X-ray point sources

↓

- **10 714 Carina members**

The first unbiased sample of the low-mass stellar population.
≥ 80% (50%) complete at ~ 1 $M_\odot$ (0.5 $M_\odot$)



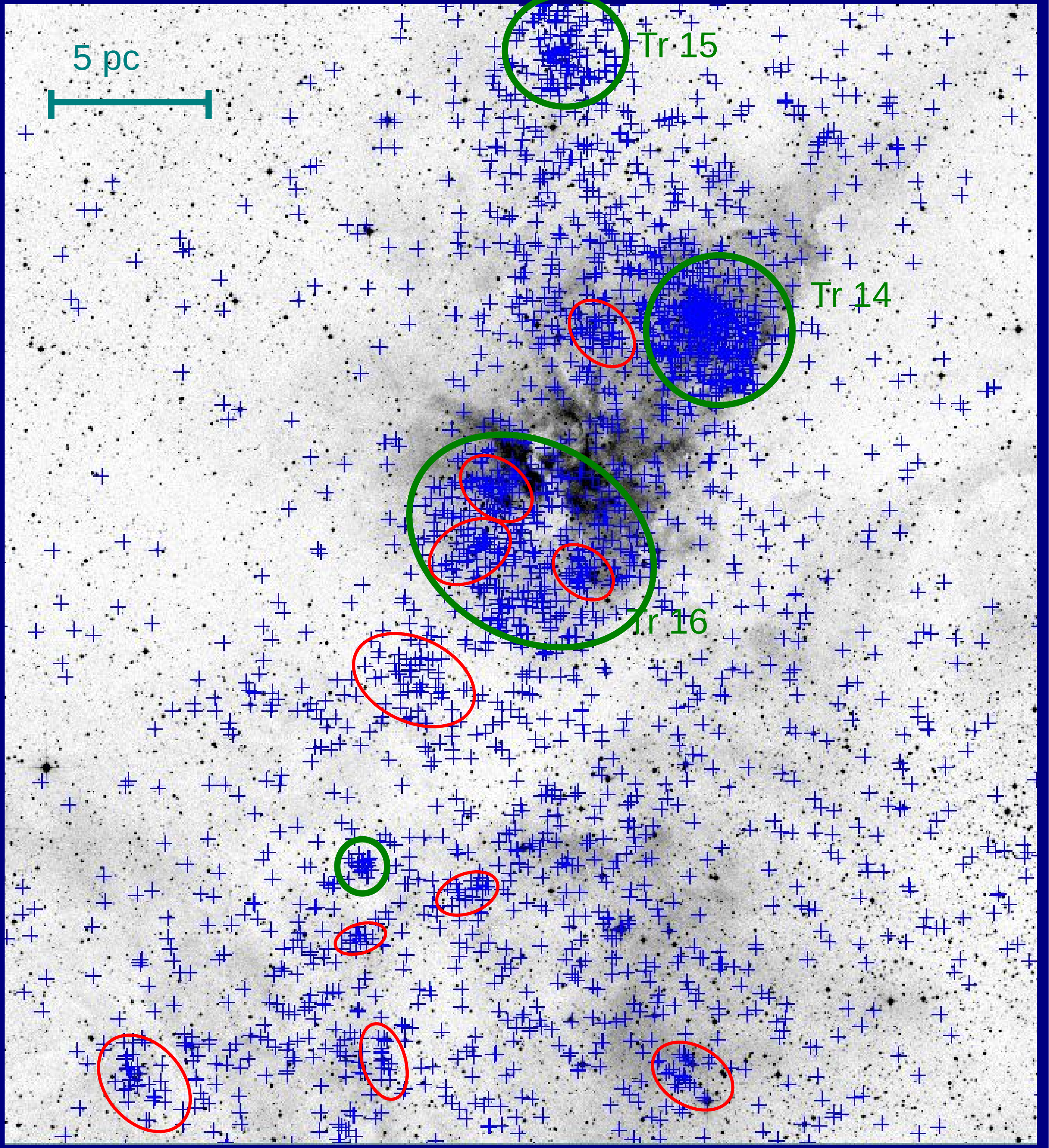
1.3 sq.-deg.

ApJS
CCCP Special Issue
Vol. 194, May 2011

Preibisch et al. 2011, ApJS 194, 10

STEP 3: Characterizing the stellar populations

- **Spatial distribution:**
  - **5457** X-ray sources in a **clustered** population
  - **5271** X-ray sources in a **distributed** population



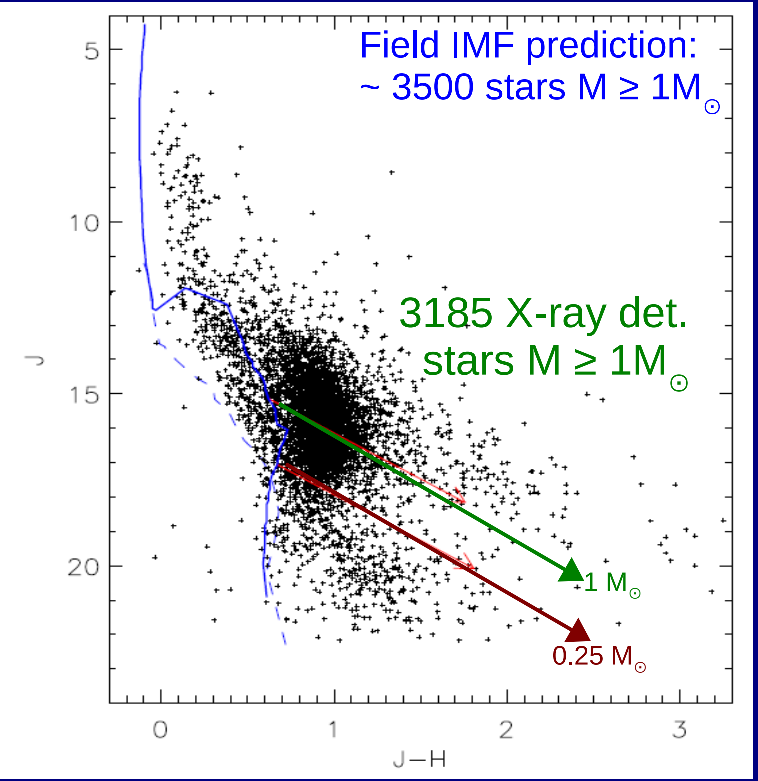
→ The Carina Nebula Complex is an ***association***, not a “cluster of clusters”

- **Initial mass function (IMF):**

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

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

<u>no deficit of low-mass stars</u>



- **Total mass:**

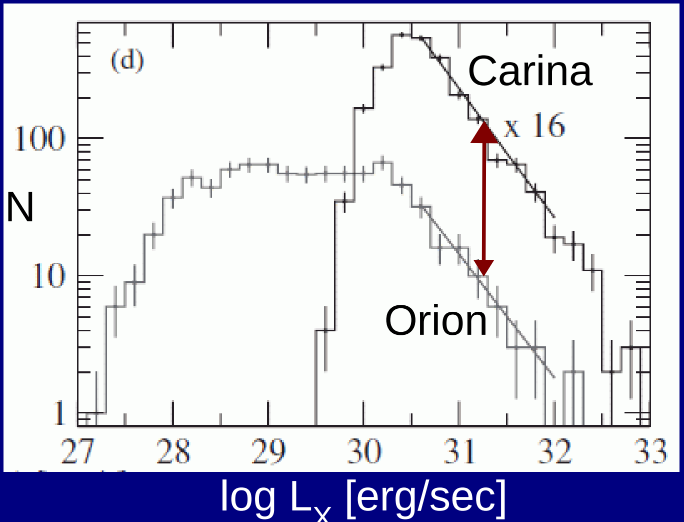
Field IMF extrapolated down to 0.1 $M_\odot$:

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

Carina Nebula is one of the most massive star forming complexes known in our Galaxy!

Carina Nebula $\gtrsim$ NGC 3603, Arches Cluster

≈ Westerlund 1



Feigelson et al. 2012

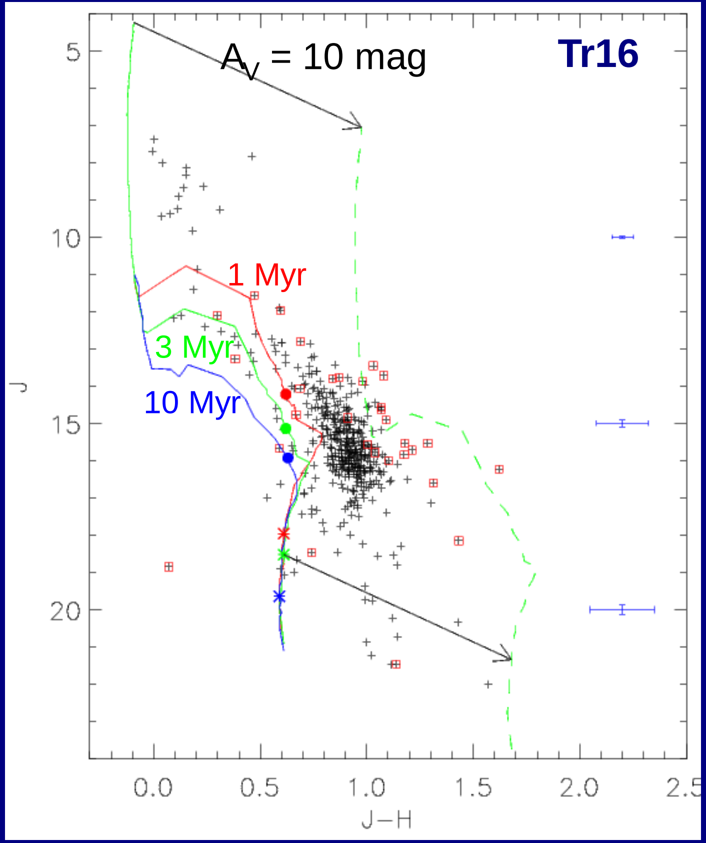
- **Stellar ages and disk fractions of the different populations**

Example: **central open cluster Tr 16**

Typical age of the low-mass stars: **~ 3-4 Myr**

consistent with the assumption of
coeval formation of high- & low-mass stars

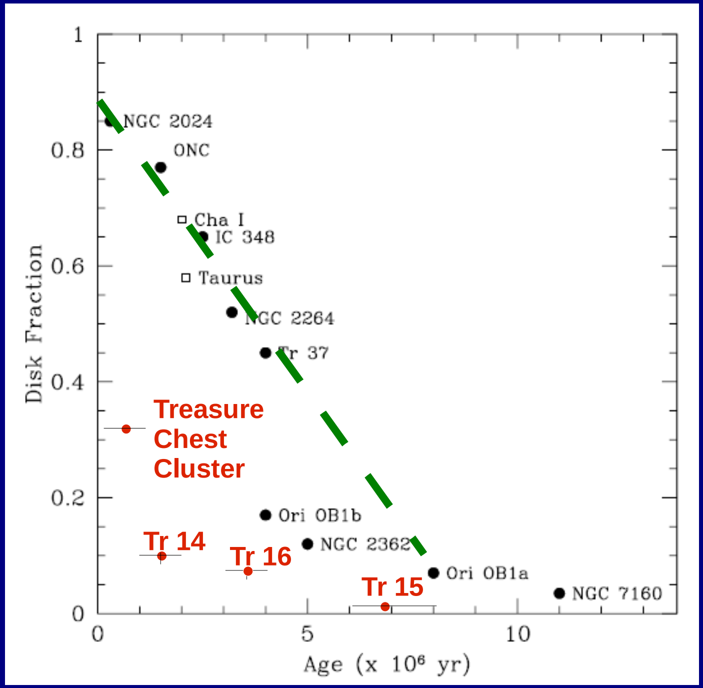
Widely distributed population:
range of ages [0 … ~5] Myr



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

Near-Infrared excess fractions
in the X-ray selected populations:

The harsh environment leads to faster disk dispersal in Carina.



STEP 4: Investigation of the molecular clouds

LABOCA

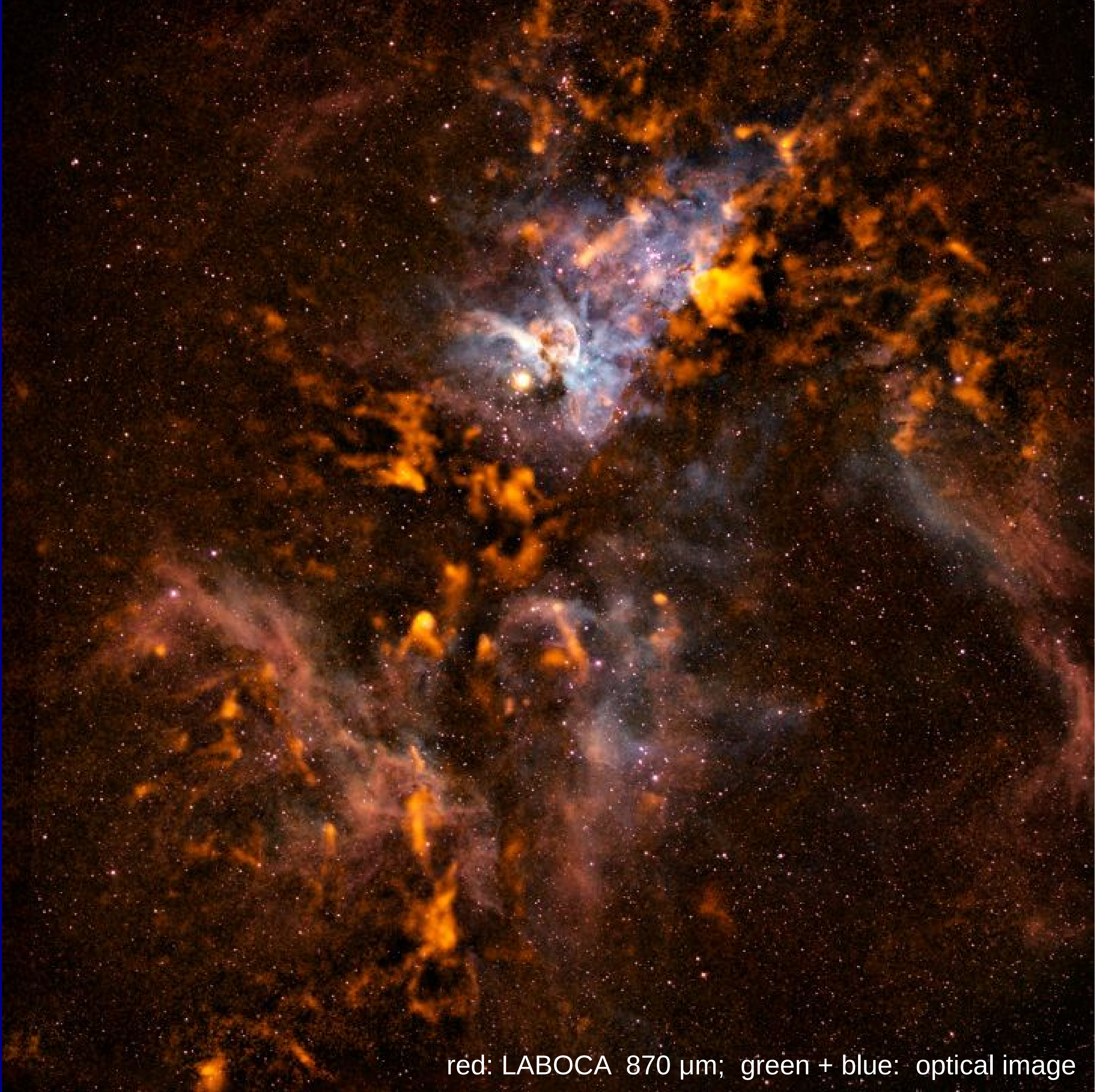
870 μm survey

(1.2 square-degrees)

reveals the cold, dense clouds

- Dense massive clouds still exist close (~ 5 pc) to the OB stars
- Total mass in dense clouds: **~ 60 000 $M_\odot$**
- $N_{H2} \leq 5 \cdot 10^{22}$ cm^{-2} too low for massive star formation (?)

Preibisch et al. 2011, A&A 525,A92



red: LABOCA 870 μm; green + blue: optical image

Herschel

far-infrared survey

70 / 170 / 250 / 350 / 500 µm

6 square-degrees

- Cloud temperatures: $T \approx 20 \ldots 40$ K
- Total cloud mass: $\geq 840\,000\ M_{\odot}$
- Detection of 642 point-sources

Preibisch et al. 2012, A&A 541, A132

Global Properties of the Carina Nebula: Cloud Mass Budget

Total stellar mass: $M_{\ast,tot} \geq$ 30 000 $M_\odot$

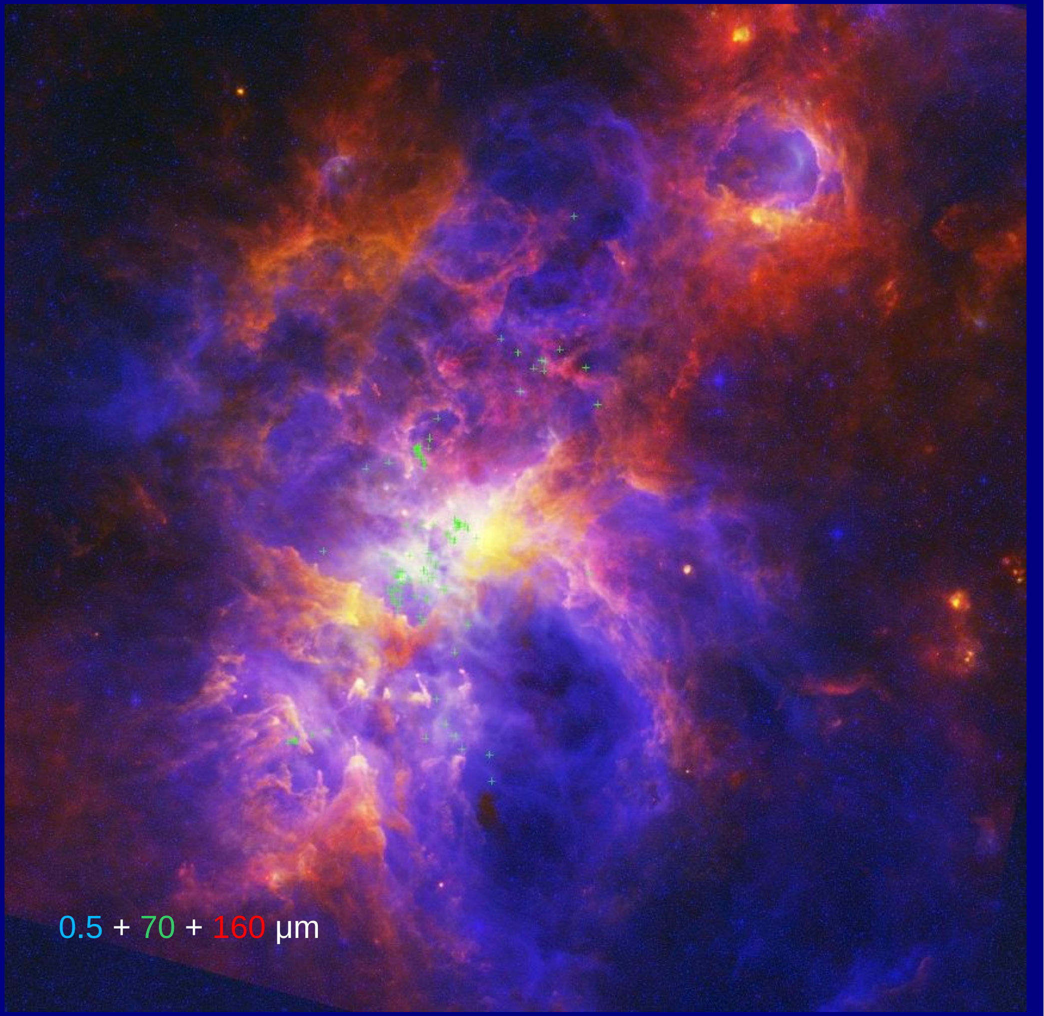
Cloud mass: $M_{tot} \approx$ 1 150 000 $M_\odot$

Cool/cold clouds seen by Herschel: $M_{cool} \approx$ 840 000 $M_\odot$

Molecular clouds : (Yonekura et al. 2005) $M_{CO} \approx$ 326 000 $M_\odot$

Dense clouds : (A_V > 3 mag) $M_{>3} \approx$ 120 000 $M_\odot$

Very dense clouds : (A_V > 7 mag) $M_{>7} \approx$ 30 000 $M_\odot$



***Star Formation Efficiency*: ~ 3 … 5 %**

Evidence for **triggered star formation**

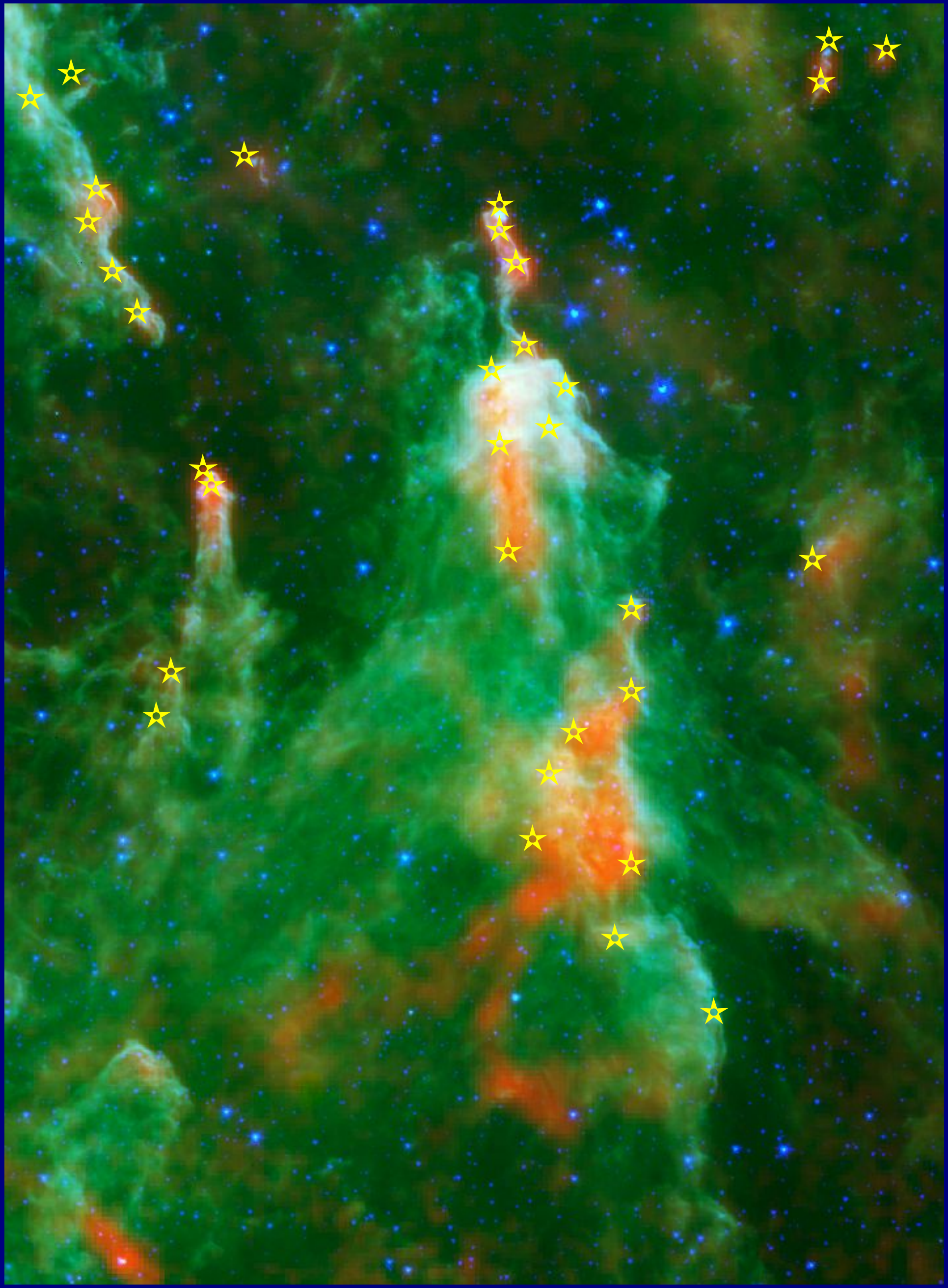
~ 3 million year old high-mass stars

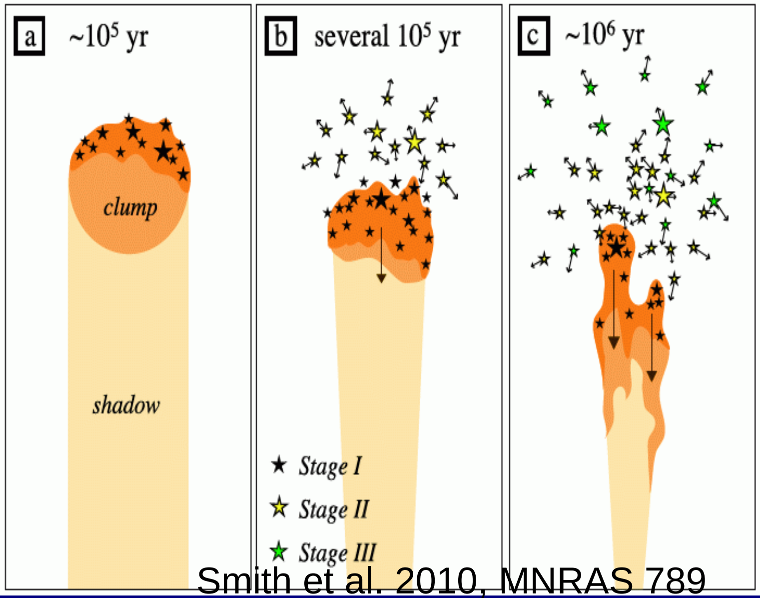
Spitzer
3.6 µm
Young Stars

Herschel
70 µm
Cool Clouds

APEX
870 µm
Cold Cloud Clumps

☆ *Herschel* detected protostars



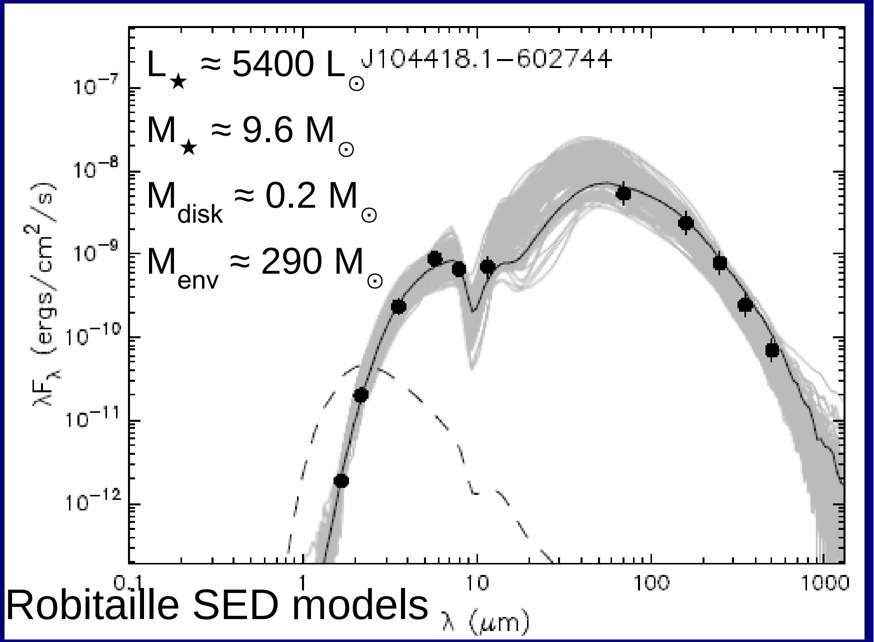


Smith et al. 2010, MNRAS 789

642 Herschel point-like sources

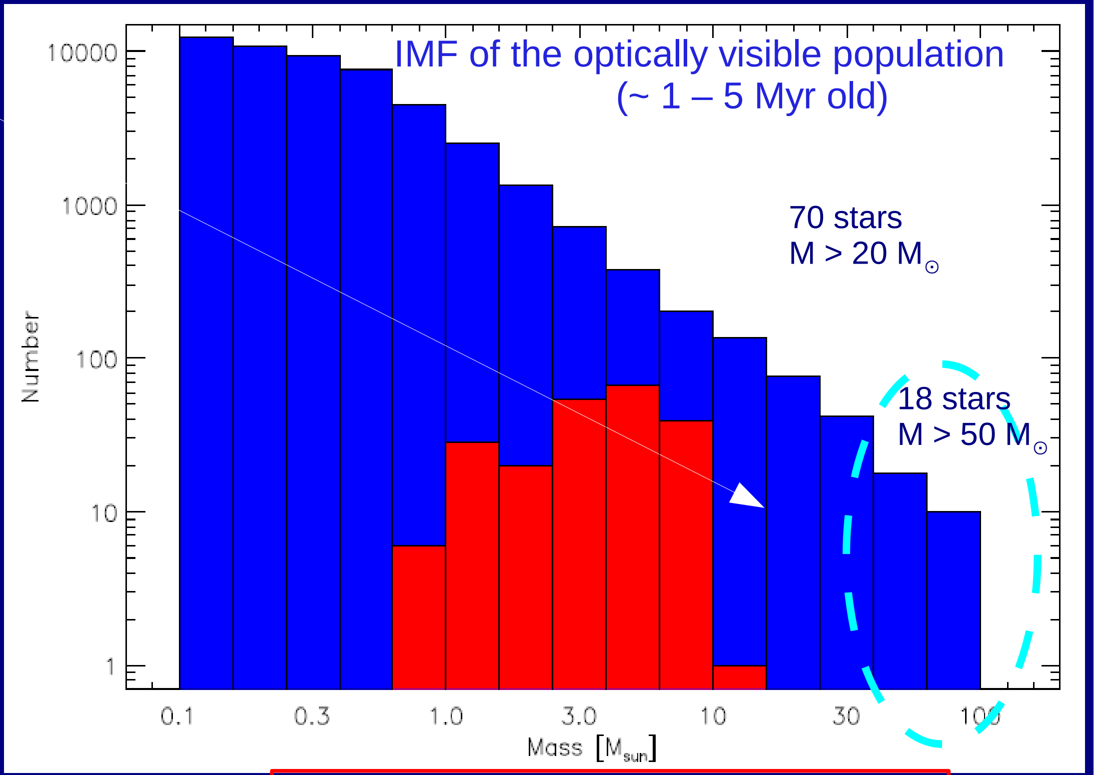
75% are protostars ($L_{submm}/L_{tot} > 0.005$)

Detection / completeness limits
for protostars: ~ 1 $M_\odot$ / ~ 3 $M_\odot$



Robitaille SED models

No luminous ($L > 10^4\ L_\odot$)
massive ($M > 20\ M_\odot$)
protostars are seen!



MF of the currently forming generation (protostars seen by Herschel)

The currently ongoing process of radiatively triggered star formation is fundamentally different from the formation process of the earlier stellar generation.

Protostellar mass function extrapolated down to 0.1 $M_\odot$:

→ ~ 4300 protostars

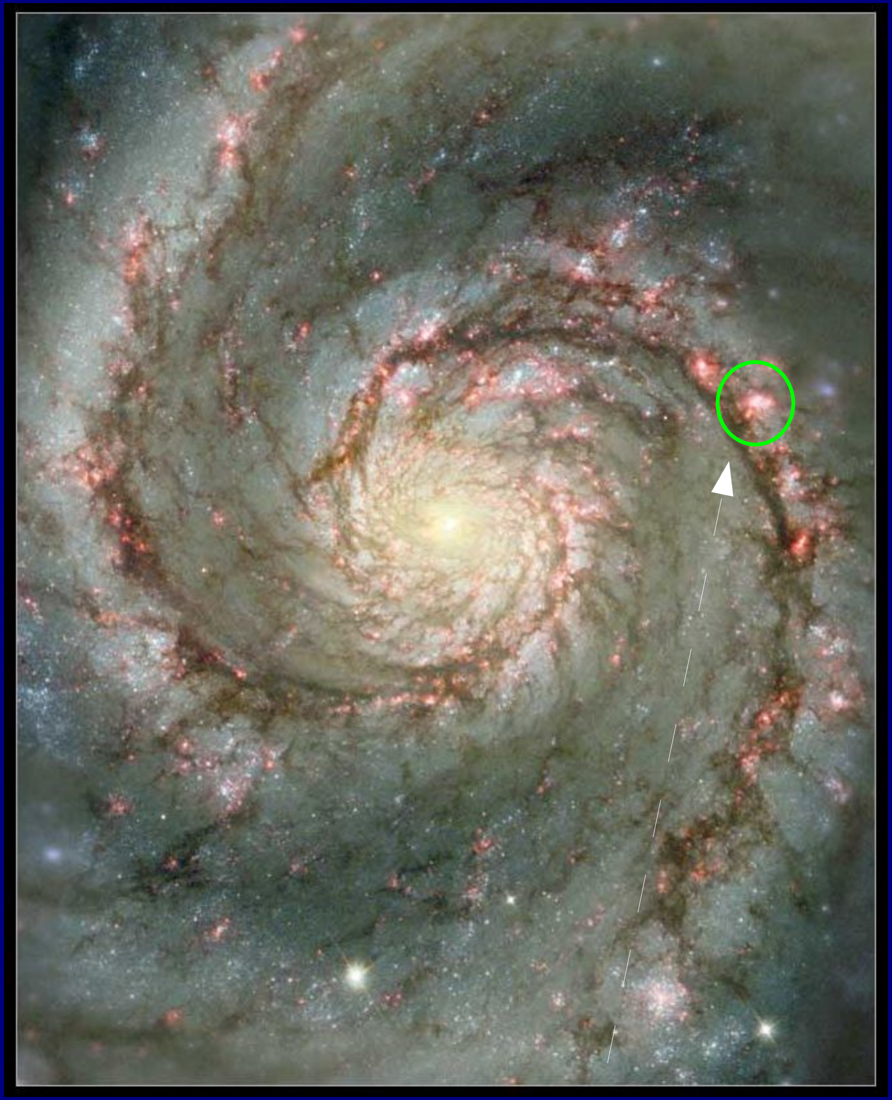
Assuming 10^5 years for the duration of protostellar phase:

Star Formation Rate ~ 0.02 $M_\odot$/yr

Povich et al. 2011:
≥ 0.008 $M_\odot$/yr averaged over last 5 Myr

Carina Nebula contributes ~ 1 % of the total Galactic Star Formation Rate !
(≈ 2 $M_\odot$/yr)

If *this* were the Milky Way ...



… the Carina Nebula would look ≈ like *this*

Carina Nebula: SFR ~ 0.02 $M_\odot$ / yr, M_{gas} ~ 10^6 $M_\odot$

Σ_{SFR} ~ 10 $M_\odot$ / yr / kpc^2, Σ_{gas} ~ 575 $M_\odot$ / pc^2

THE ASTROPHYSICAL JOURNAL, 745:190 (6pp), 2012 February 1

Lada et al. 2012

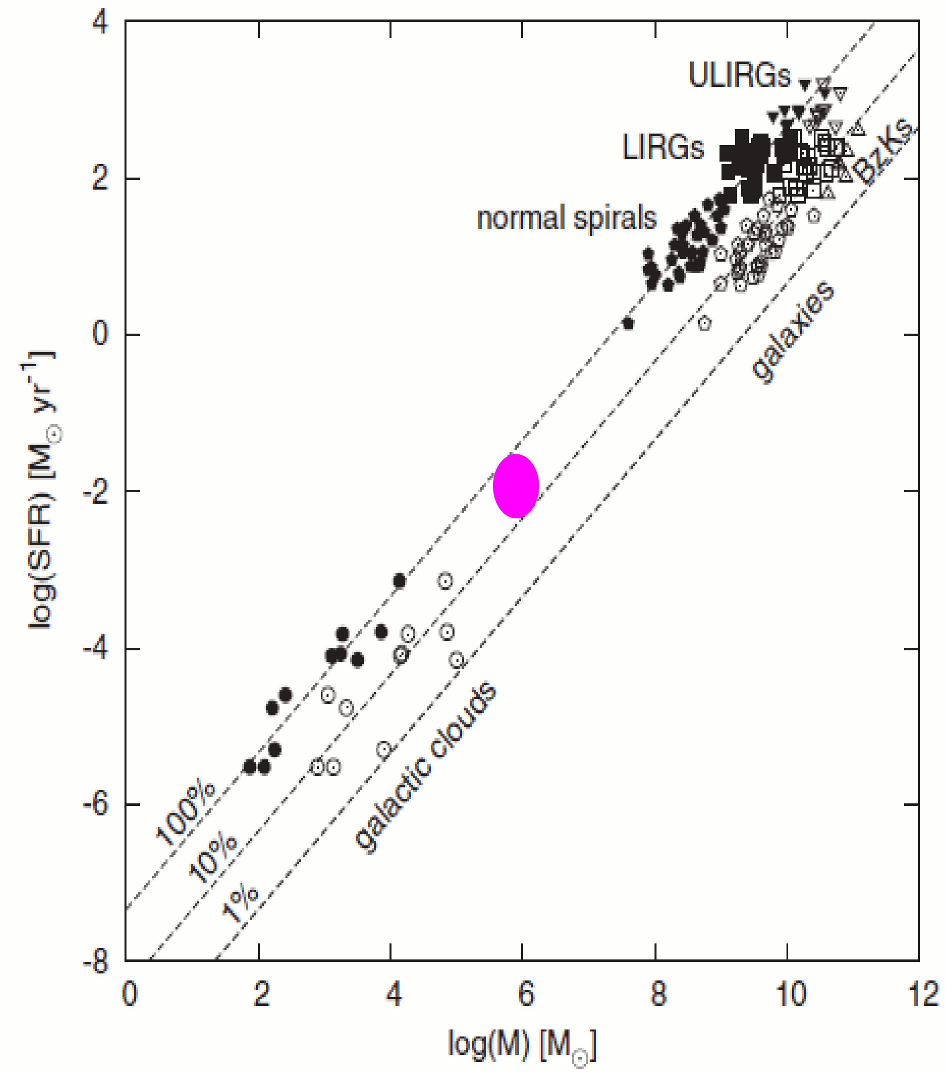
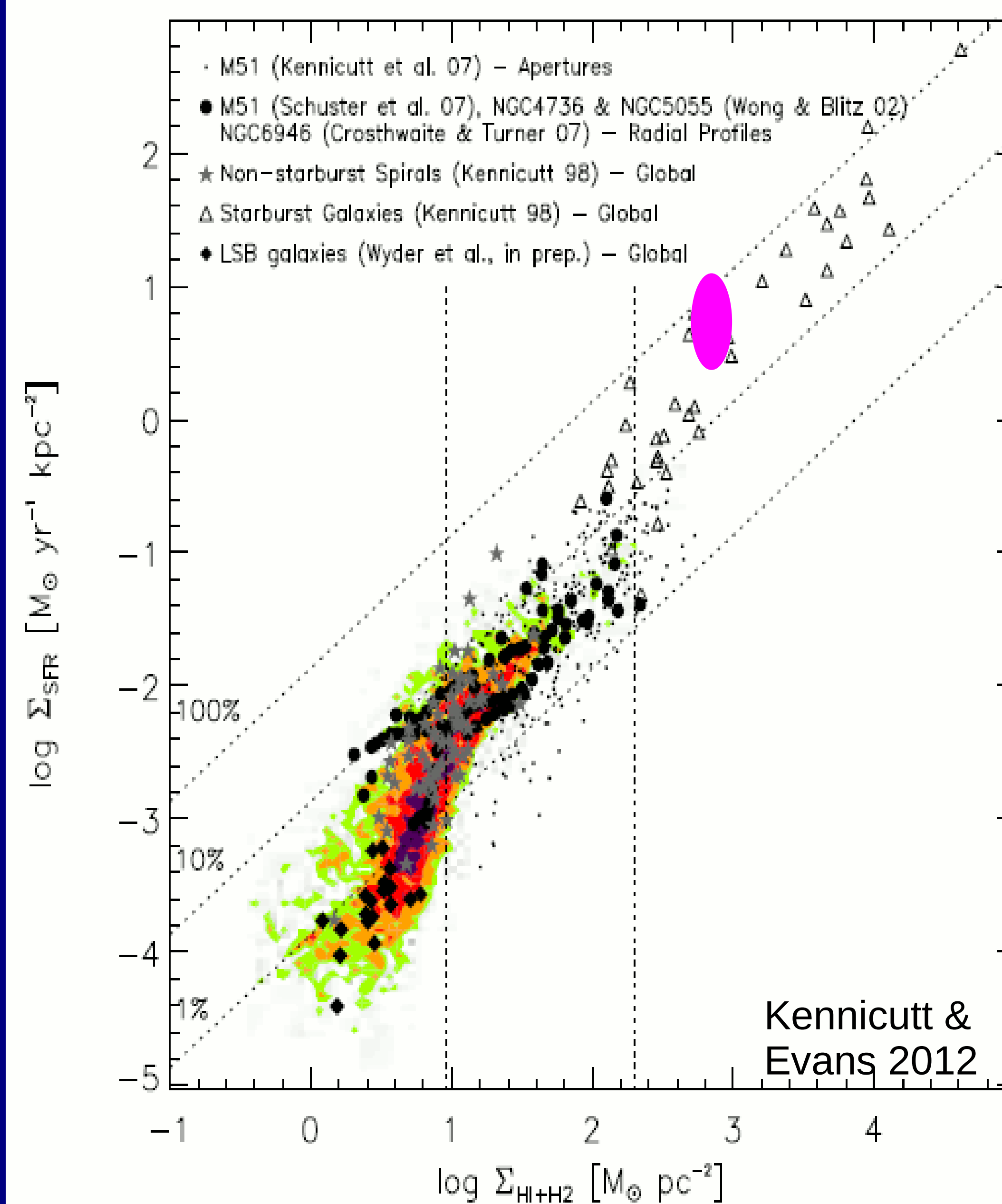


Figure 2. SFR–molecular-mass diagram for local molecular clouds and galaxies from the Gao & Solomon (2004a) sample. The solid symbols correspond to



Carina Nebula at ~800 kpc (M31):

1 pixel = 1 pc

Carina Nebula at ~7 Mpc (M51):

1 pixel = 5 pc