Feedback from Massive Stars:
Triggering in Orion, Carina, & W3/4/5

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Feedback from Massive Stars

Feedback: As stellar mass grows ….

Outflows ($M_* < 8\ M_o$) Inject

Non-ionizing UV ($M_* > 3\ M_o$ "scalar momentum"

Ionizing UV ($M_* > 8\ M_o$) into core, ISM, …

As stars age ….

winds, SN (main sequence, post-main-sequence)

"super-bubbles" => "super-shells" => "super-rings"

Destructive: (negative feedback)

Fast shocks, "excessive" heating,

positive ("spreading") shock curvature

Compressive: (positive feedback)

Slow shocks, negative ("compressive") curvature

Spreading Velocity < V_{escape}

Feedback: (Massive YSOs)

Feedback: Does ionizing UV stop growth?

Spherical accretion:

Trapped I-fronts: $R_{Stromgren} < R_G = GM/c_{II}^2$

Ionization does NOT halt growth (Keto 03)

Disk Accretion:

Disk photo-abblation < Accretion onto star.

Ionization does NOT halt growth

As M grows, eventually, $R_{Stromgren} > R_G$

HII region "blow-out" …. Disrupt core.

Triggered (vs. "spontaneous") Cloud & Star Formation

Collect & Collapse (make clumps) (Whitworth+ 94; Dale+ 07)

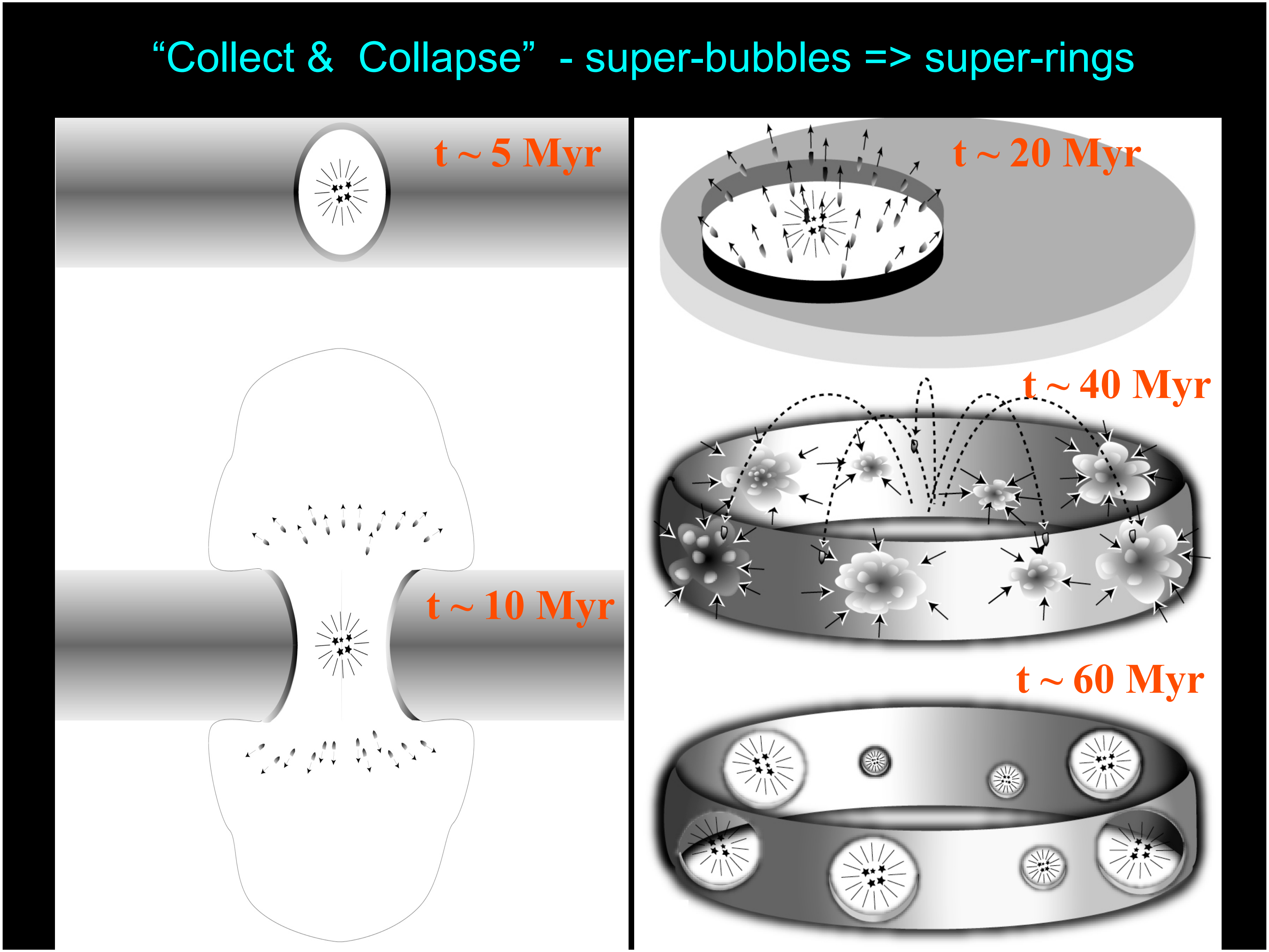
- Spiral arms (Elmegreen & Palous 07, …)
- HII regions (Elmegreen & Lada 77, …)
- Supernovae (Gerola & Seiden 78, …)
- Super-shells / rings (Elmegreen+ 79,82, 92, …)

Compression Driven Implosion (expose, compress clumps):

- HII pressure driven (Stutski+ 88)
- Radiation-driven (McKee & Klein 88)
- Shock-driven

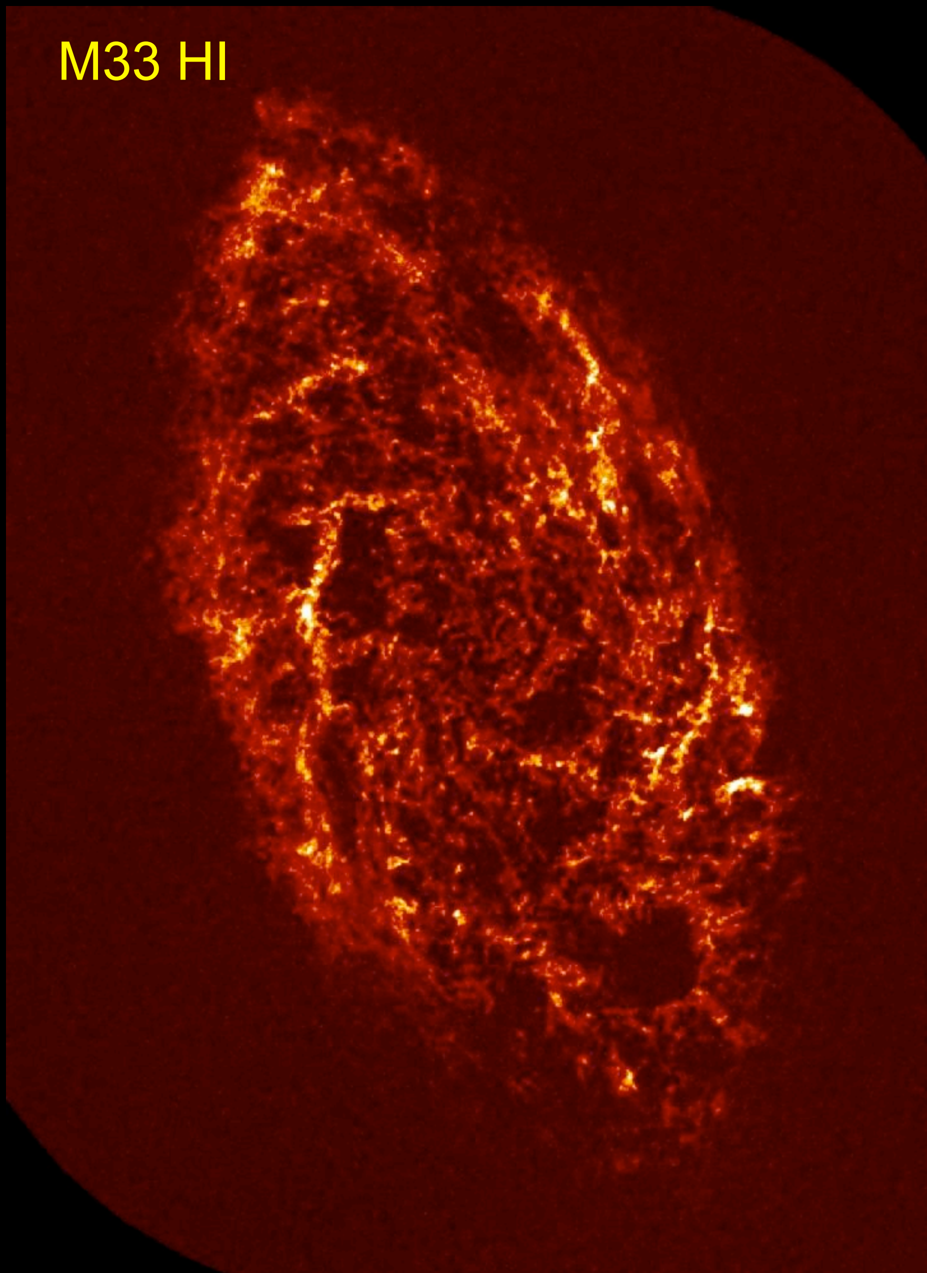
=> Need accurate chronometers!

$t_{core} = M_{core} / (dM_{core}/dt)$ & chemistry	Core (pre-YSO)
$t_{YSO} = M^* / (dM_{acc}/dt)$	Class I, II ($<10^5$ yr)
t_{PMS} = track-fitting of spectra	PMS stars



“Collect & Collapse” - super-bubbles => super-rings
t ~ 5 Myr
t ~ 10 Myr
t ~ 20 Myr
t ~ 40 Myr
t ~ 60 Myr

Super-bubbles, super-rings



Feedback: Triggering

Gravitational instability:

Escape speed > Velocity spread

$$V_{esc} > \sigma$$

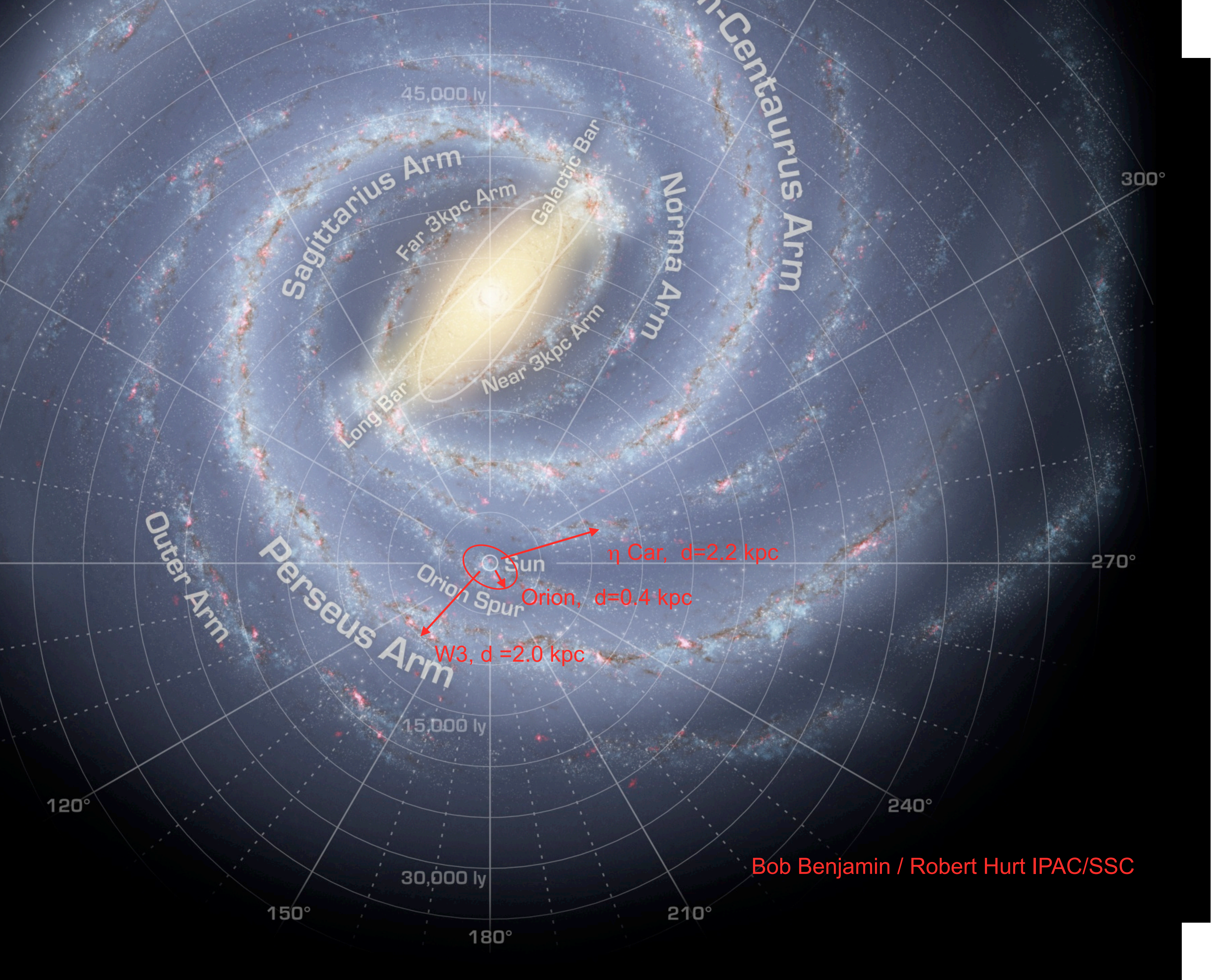
$$GM / r > \sigma^2$$

$$M = (4/3)\, \pi\, \rho\, r^3$$

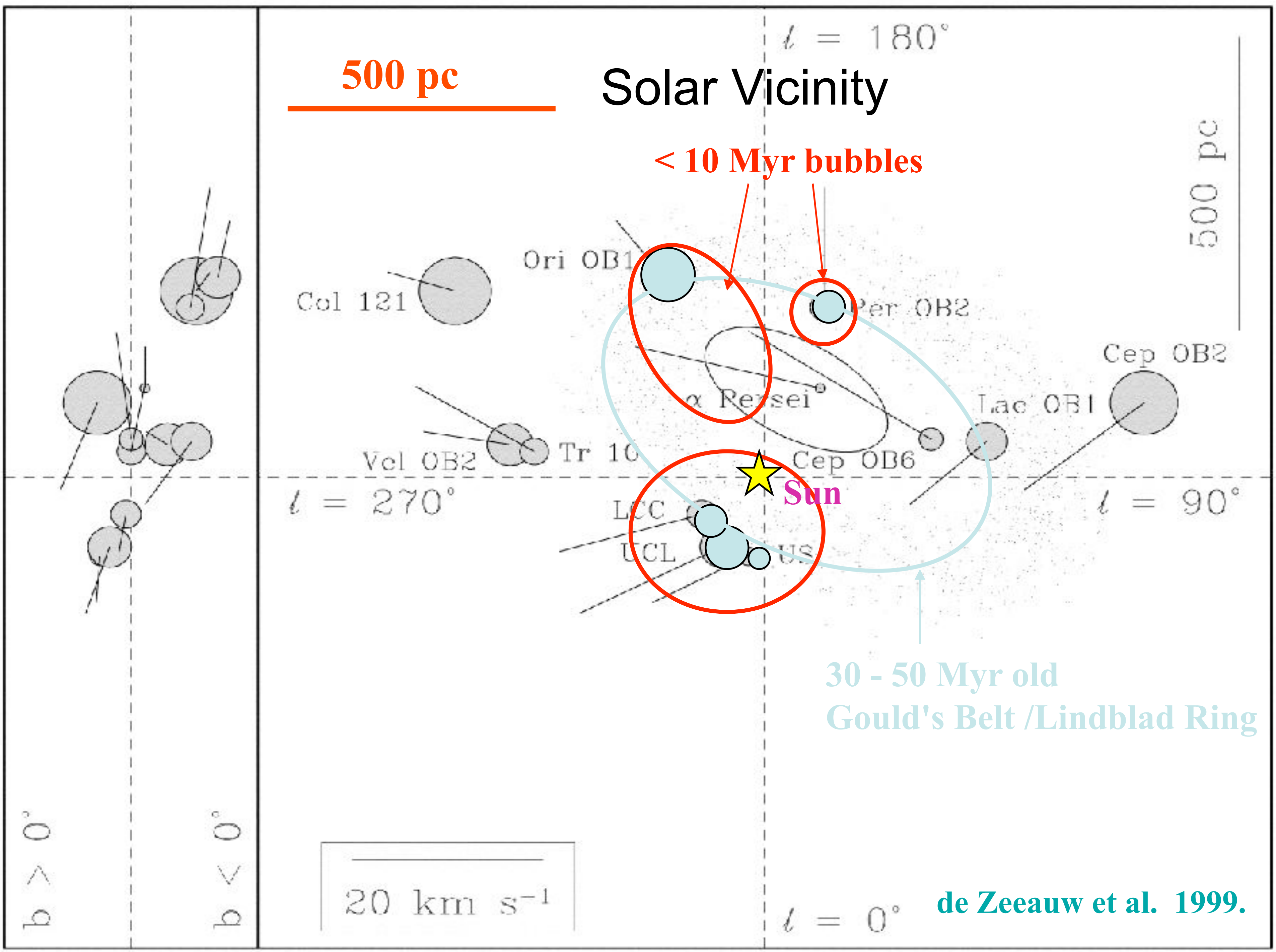
$$(4/3)\, \pi\, G\, \rho\, r^2 > \sigma^2$$

Let $\Sigma = \rho\, r$, $\kappa = \sigma / r$

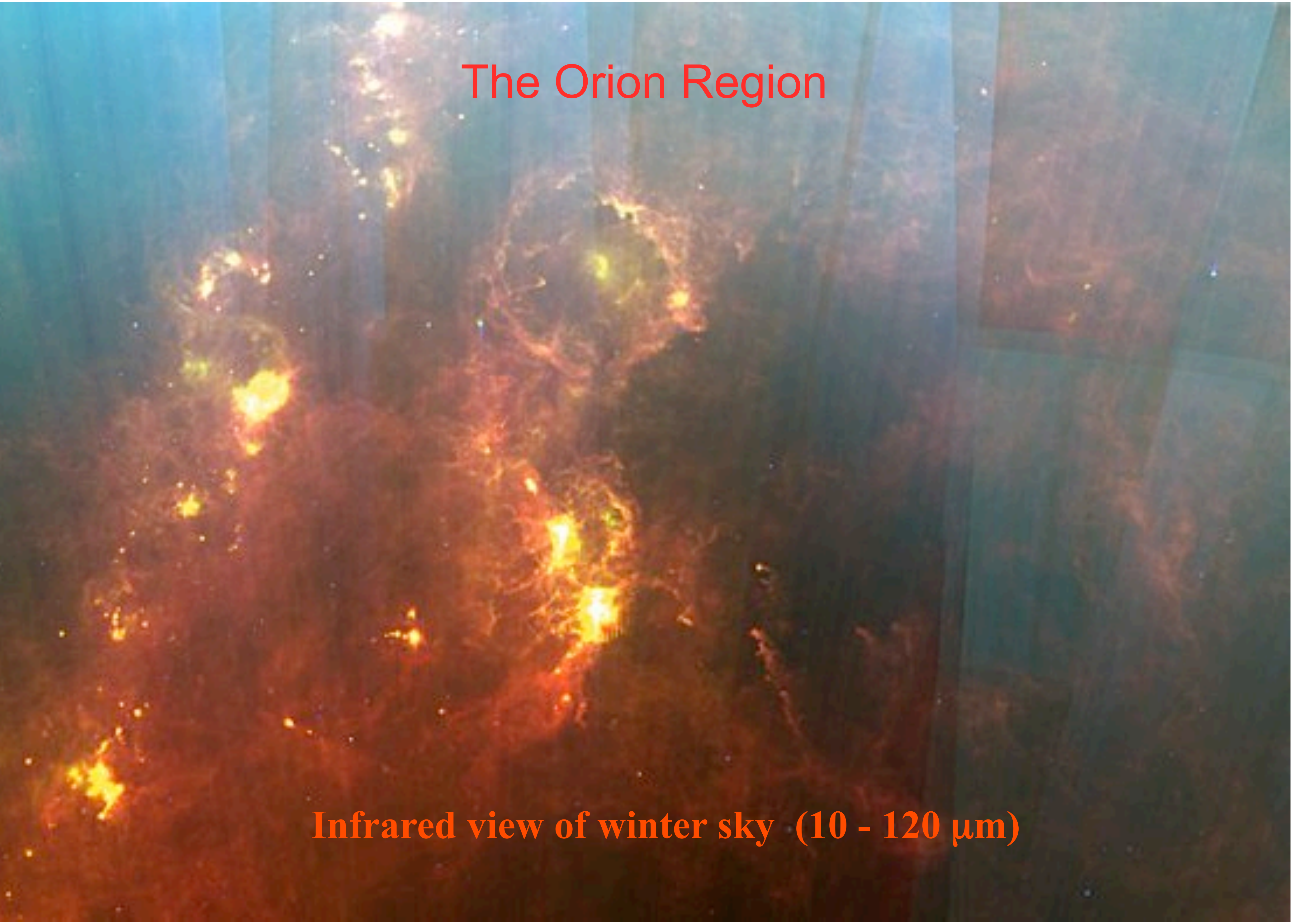
$Q' = (4/3)\, \pi\, G\, \Sigma / \kappa\, \sigma > 1$ (similar to Toomre Q)



-Centaurus Arm
Sagittarius Arm
Far 3kpc Arm
Galactic Bar
Norma Arm
Near 3kpc Arm
Long Bar
45,000 ly
300°
270°
240°
210°
180°
150°
120°
15,000 ly
30,000 ly
Outer Arm
Perseus Arm
Orion Spur
Sun
η Car, d=2.2 kpc
Orion, d=0.4 kpc
W3, d =2.0 kpc
Bob Benjamin / Robert Hurt IPAC/SSC

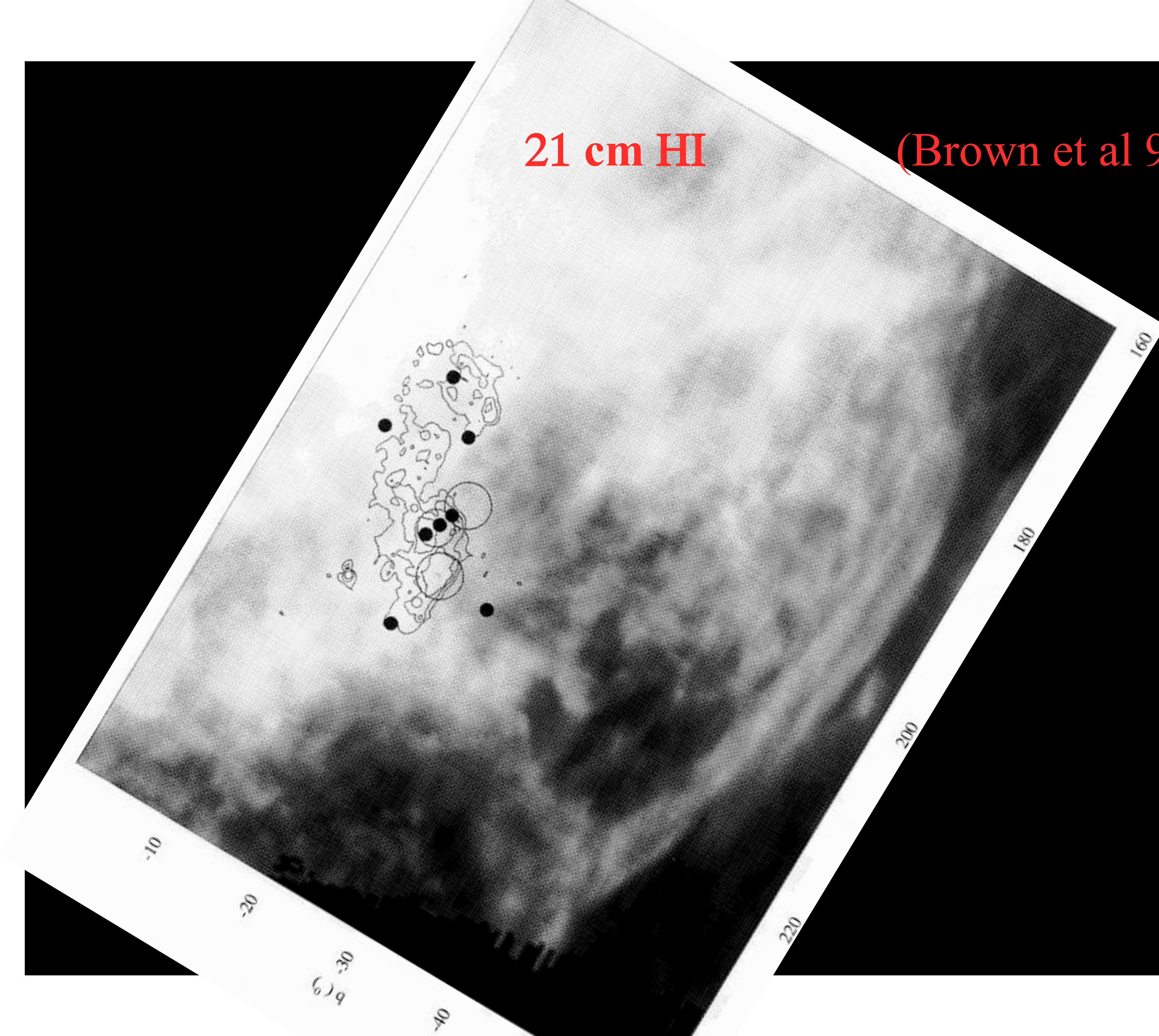


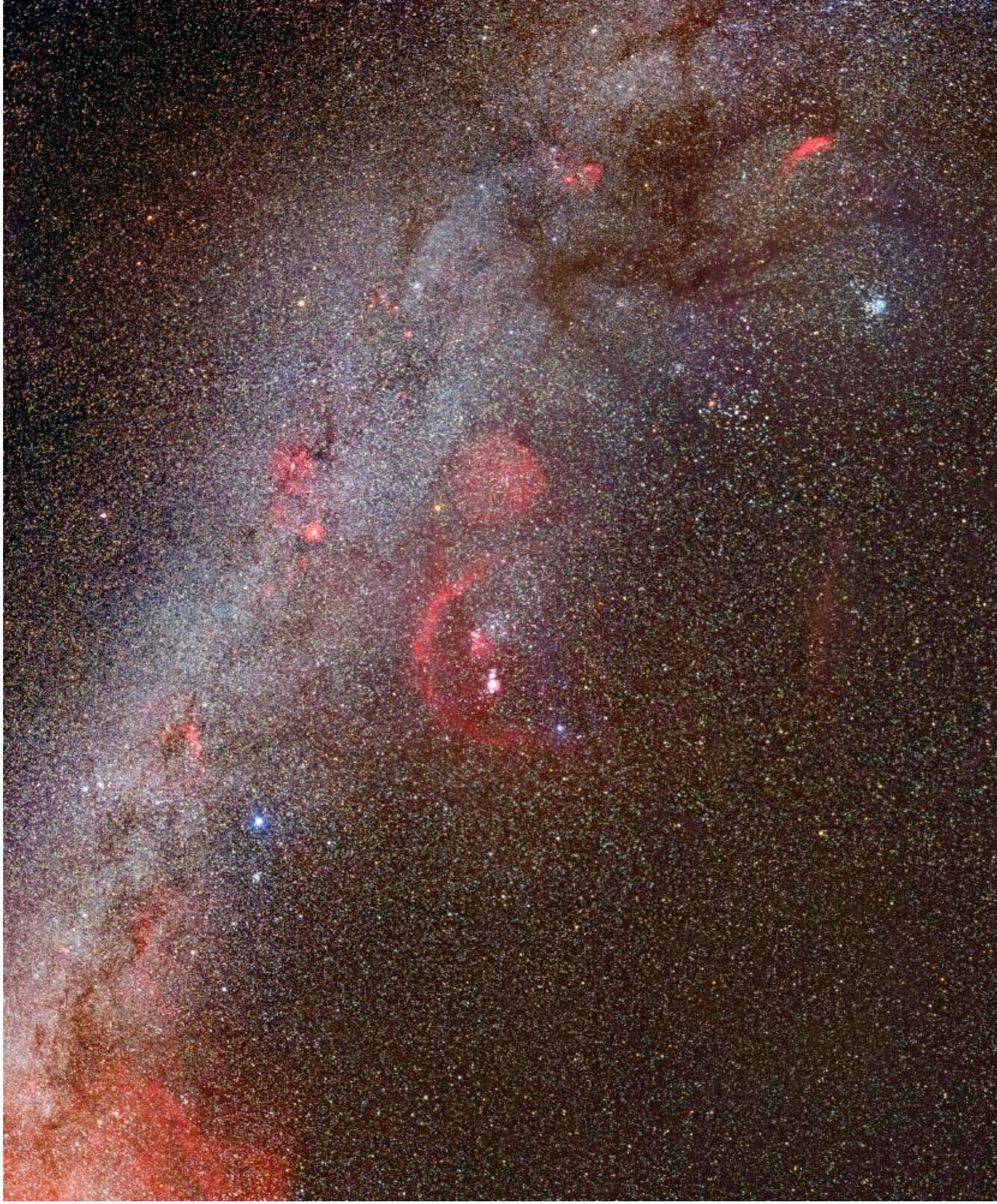
500 pc
Solar Vicinity
< 10 Myr bubbles
l = 180°
500 pc
Ori OB1
Col 121
Per OB2
Cep OB2
α Persei
Lac OB1
Vel OB2
Tr 10
Cep OB6
Sun
l = 270°
l = 90°
LCC
UCL
US
30 - 50 Myr old
Gould's Belt /Lindblad Ring
b > 0°
b < 0°
20 km s^{-1}
l = 0°
de Zeeauw et al. 1999.

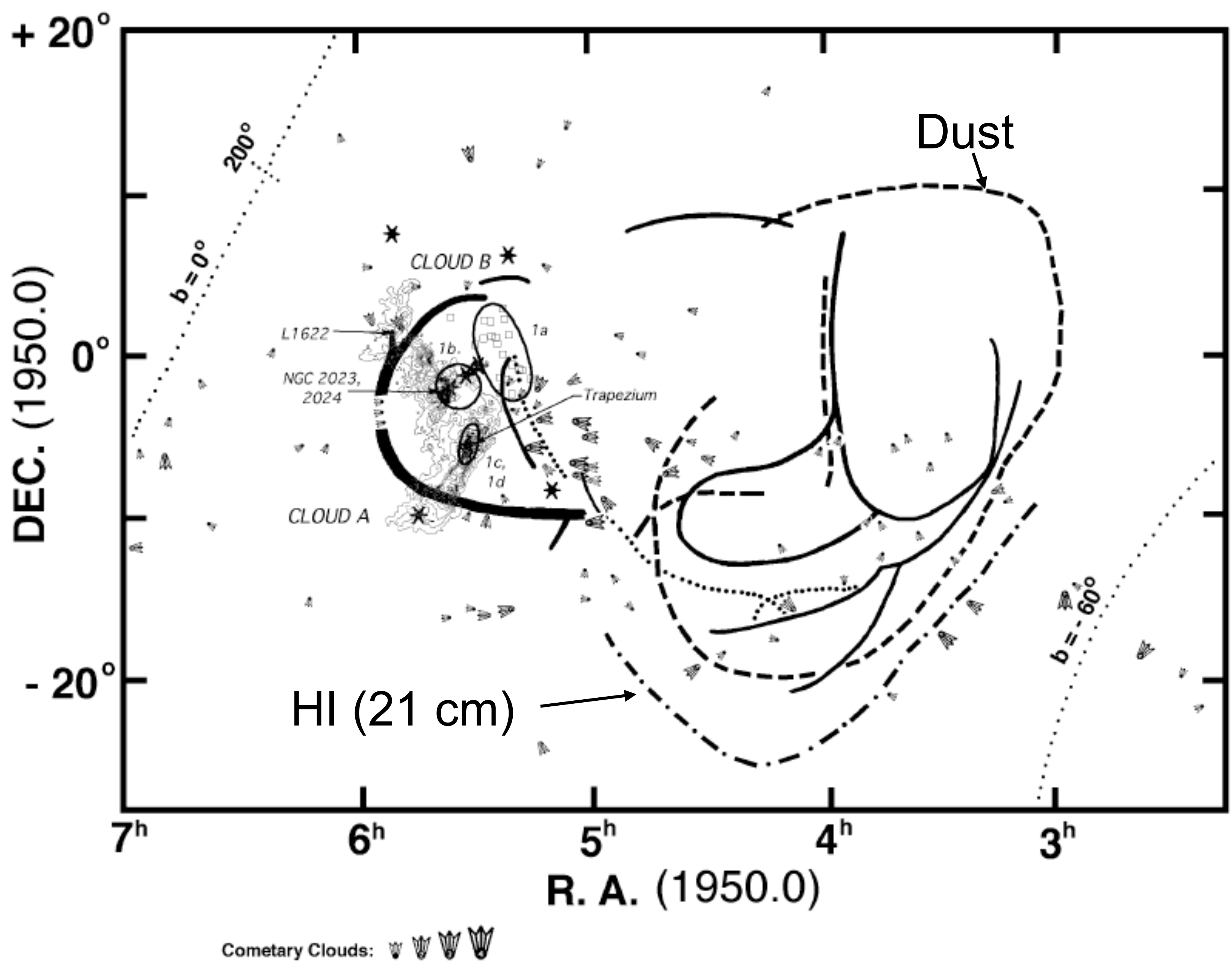

The Orion Region
Infrared view of winter sky (10 - 120 μm)

The Orion Region (Hα)

21 cm HI (Brown et al 94)

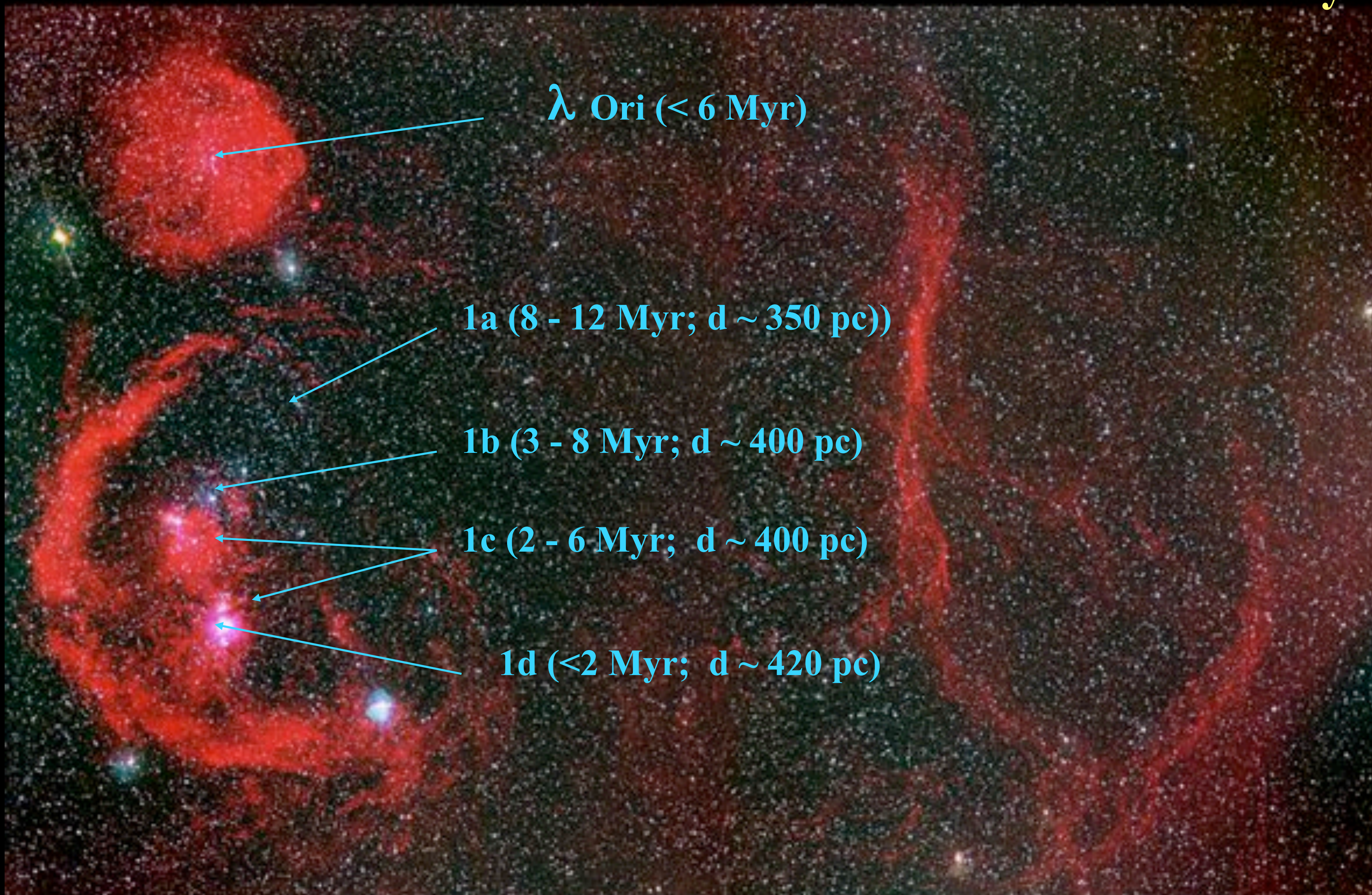





+ 20°
0°
- 20°
DEC. (1950.0)
7h
6h
5h
4h
3h
R. A. (1950.0)
200°
b = 0°
b = - 60°
Dust
HI (21 cm)
CLOUD B
CLOUD A
L1622
NGC 2023,
2024
Trapezium
1a
1b.
1c,
1d
Cometary Clouds:

The Orion/Eridanus Bubble ($H\alpha$): d=180 to 450pc; l > 300 pc

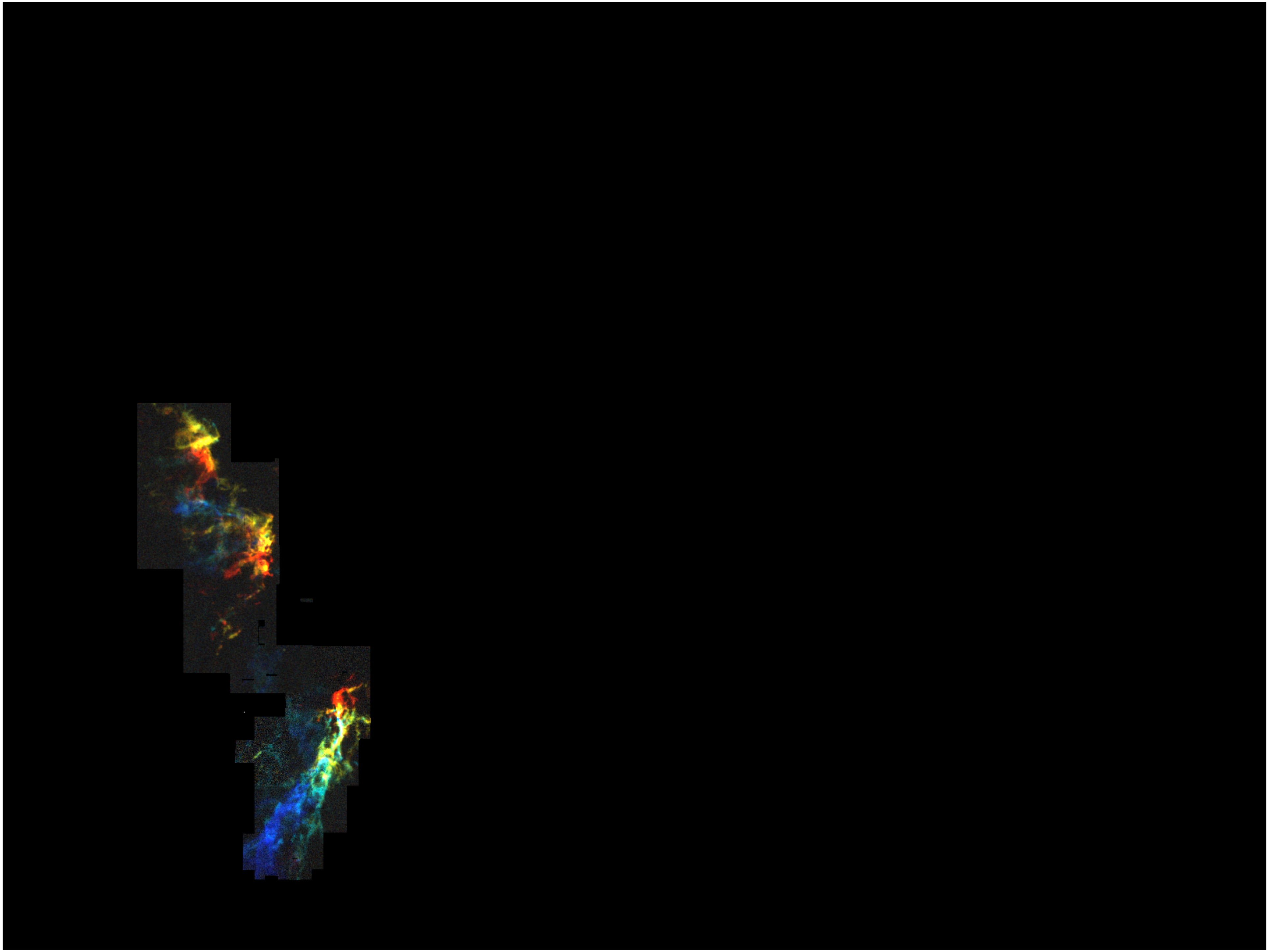
Orion OB1 Association: ~ 40 > 8 M stars: ~ 20 SN in 10 Myr



Barnards's Loop

Eridanus Loop


α Ori: 20 km/s
D = 136 - 260 pc
β Ori:
D = 236 pc




The Carina Region (Spitzer/IRAC : Nathan Smith)

η Carinae Nebula:
Trumpler 14 region

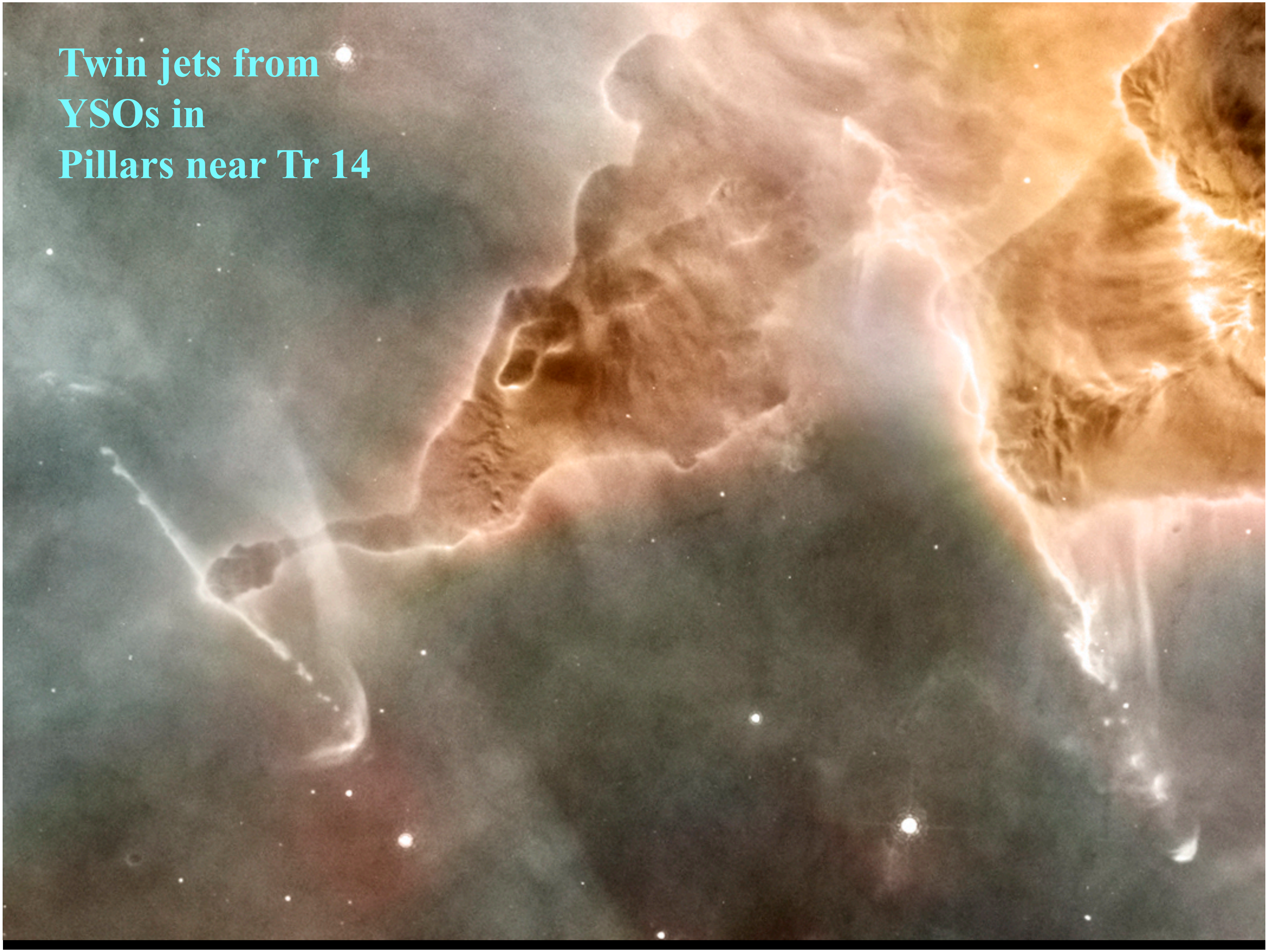
Pillars with jets

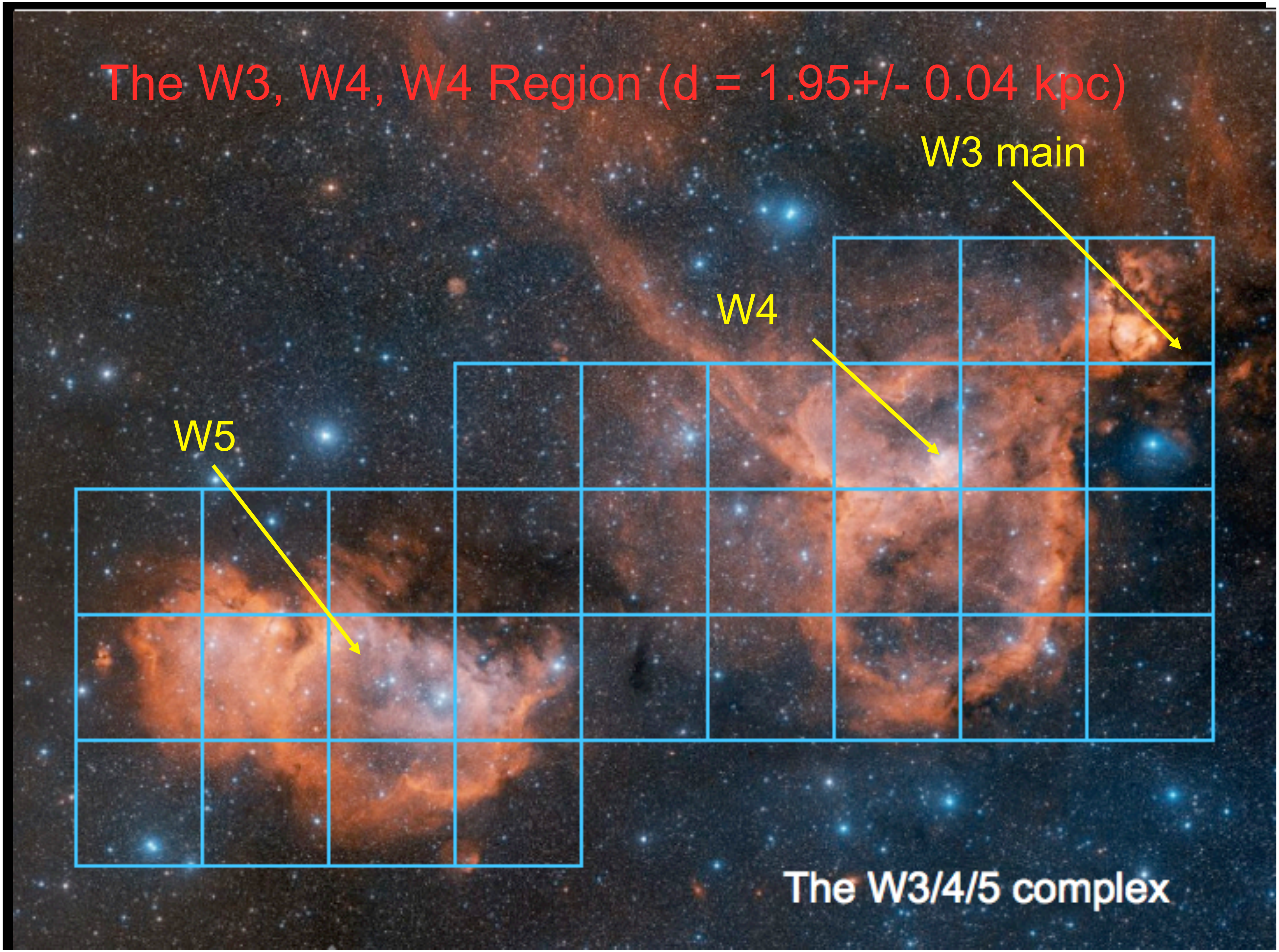
Tr 14 cluster
(< 3 Myr)

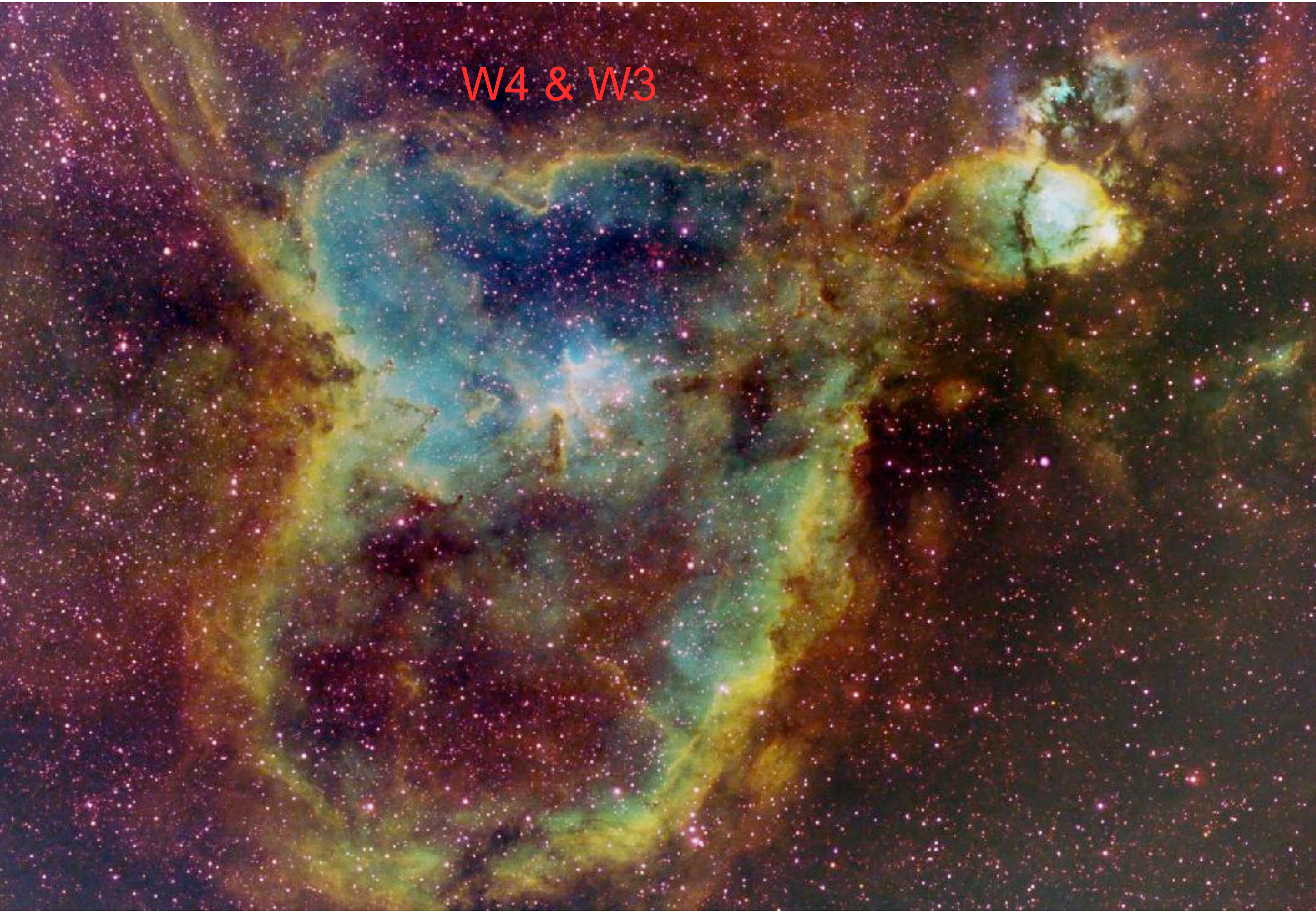
Trumpler 14

Dark globule:
faces η Car

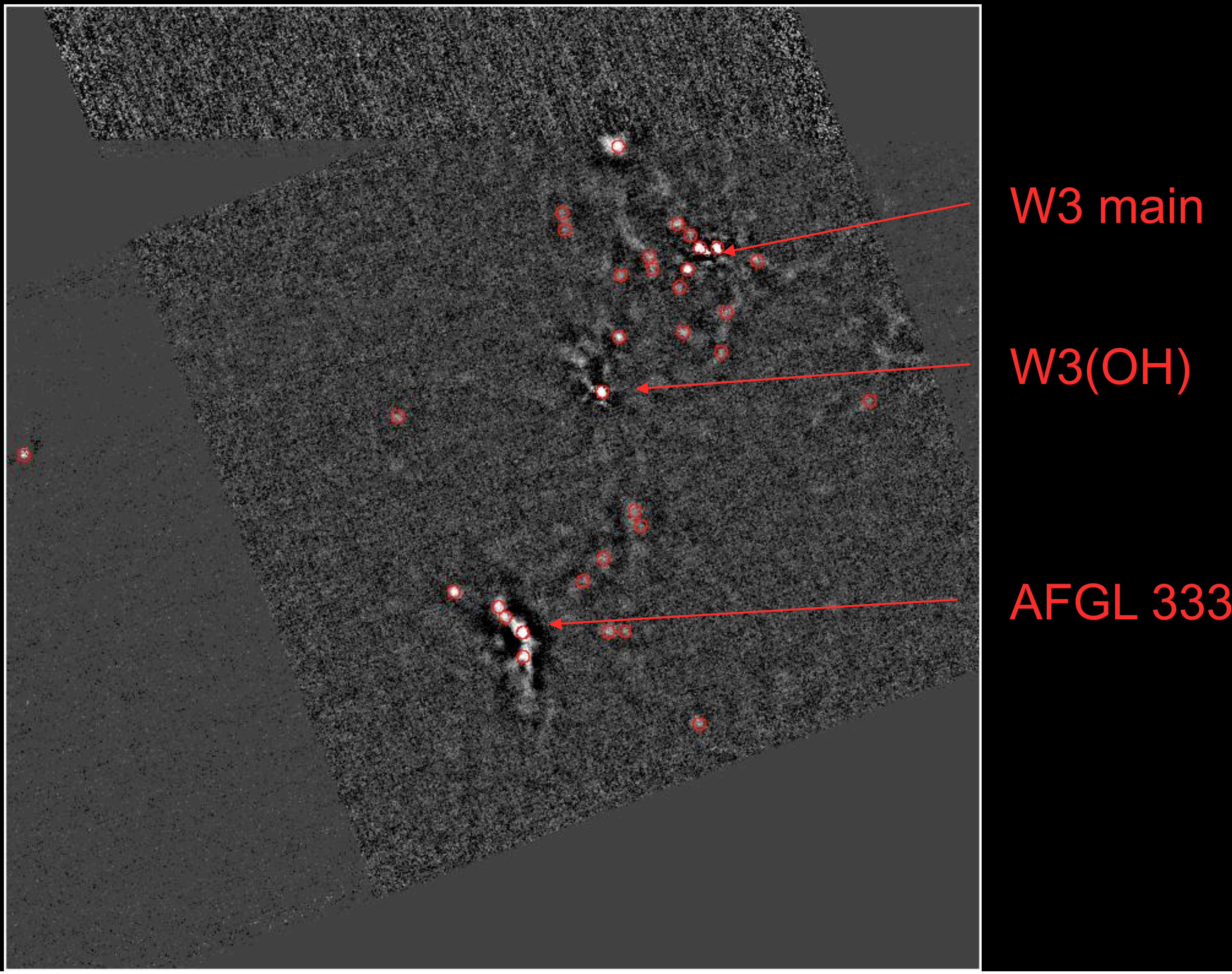
Jet ?


Twin jets from
YSOs in
Pillars near Tr 14


The W3, W4, W4 Region (d = 1.95+/- 0.04 kpc)
W3 main
W4
W5
The W3/4/5 complex

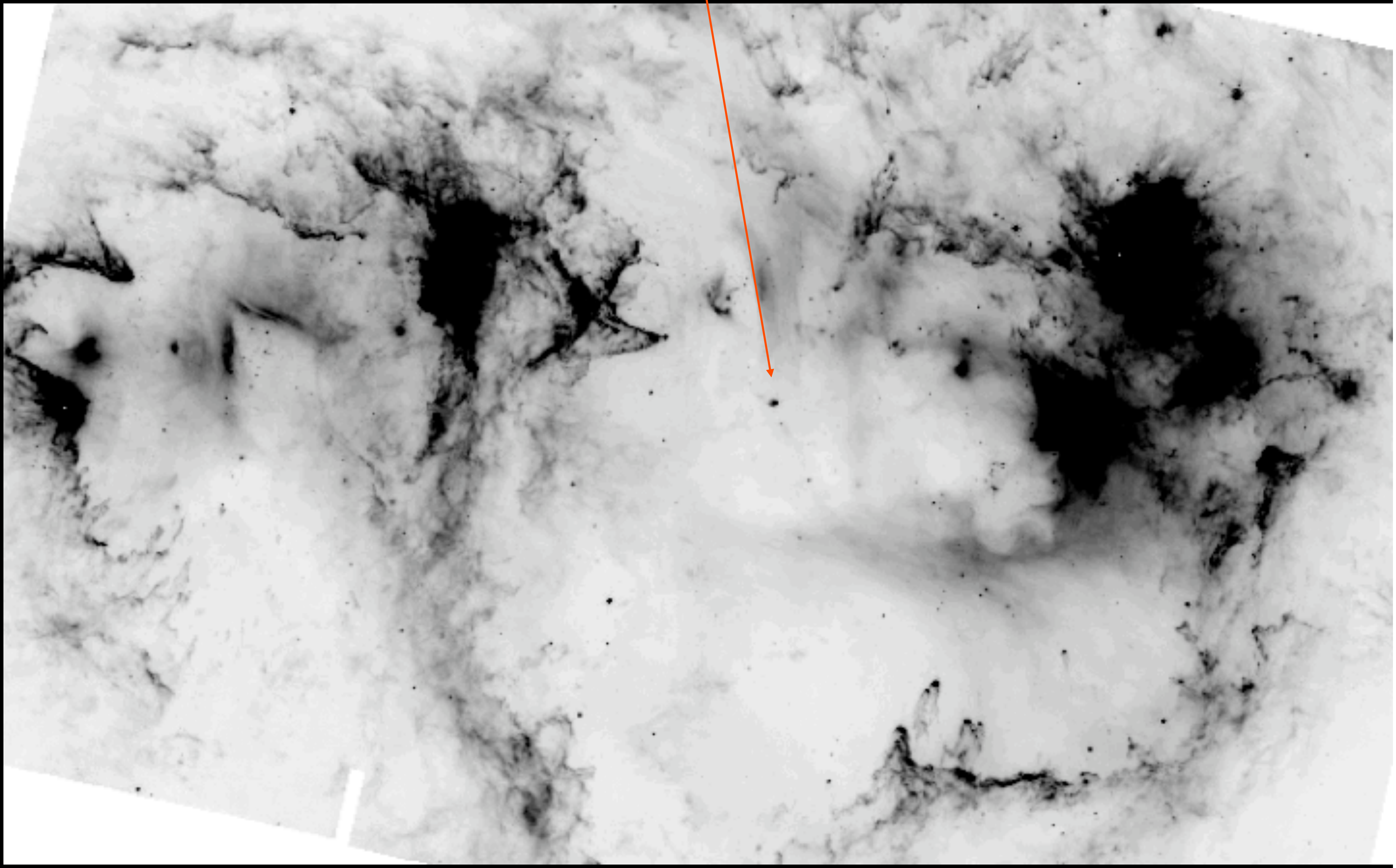

W4 & W3

Bolocam 1.1 mm: 1 square degree near W3



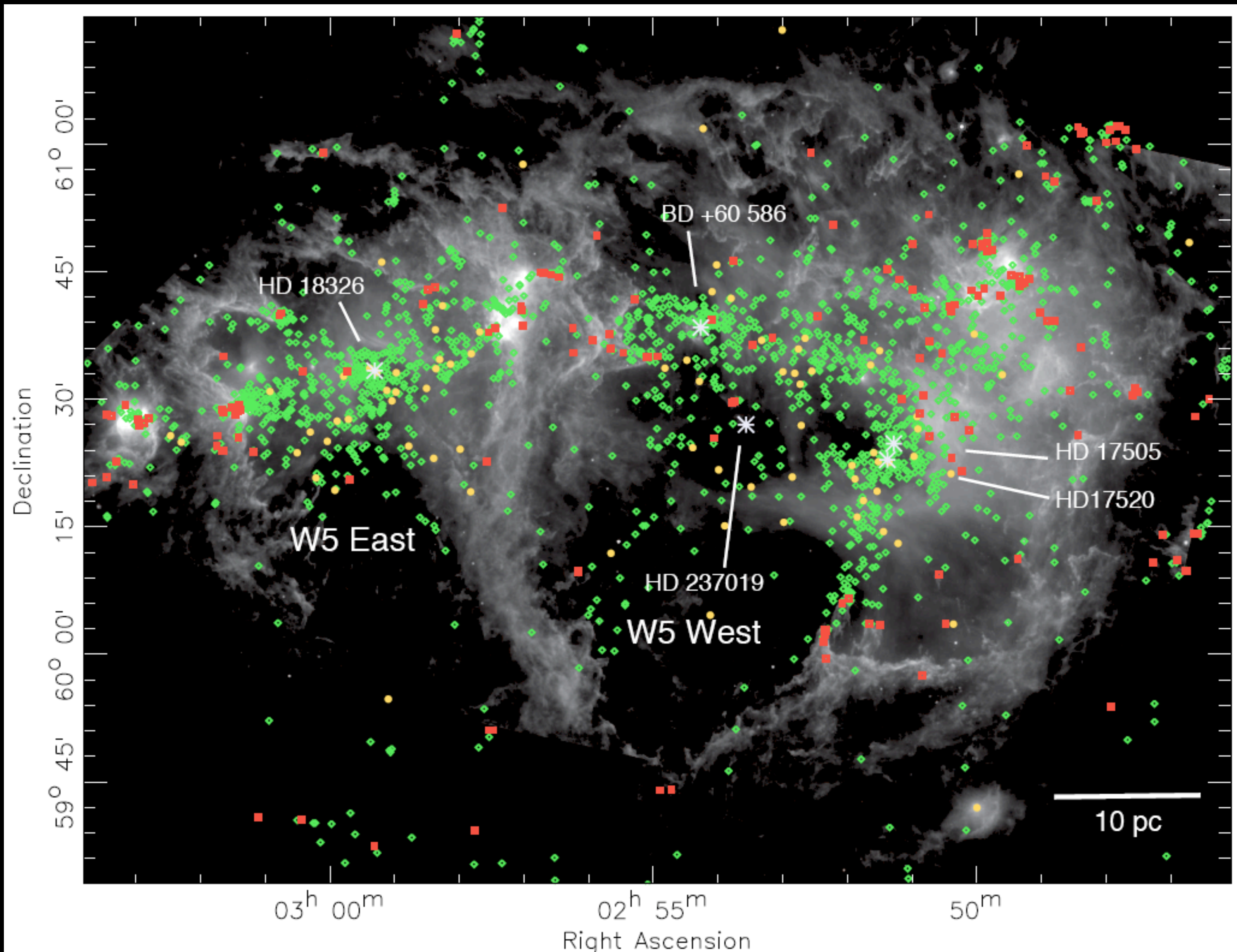
W5 IRAS 02497+6018

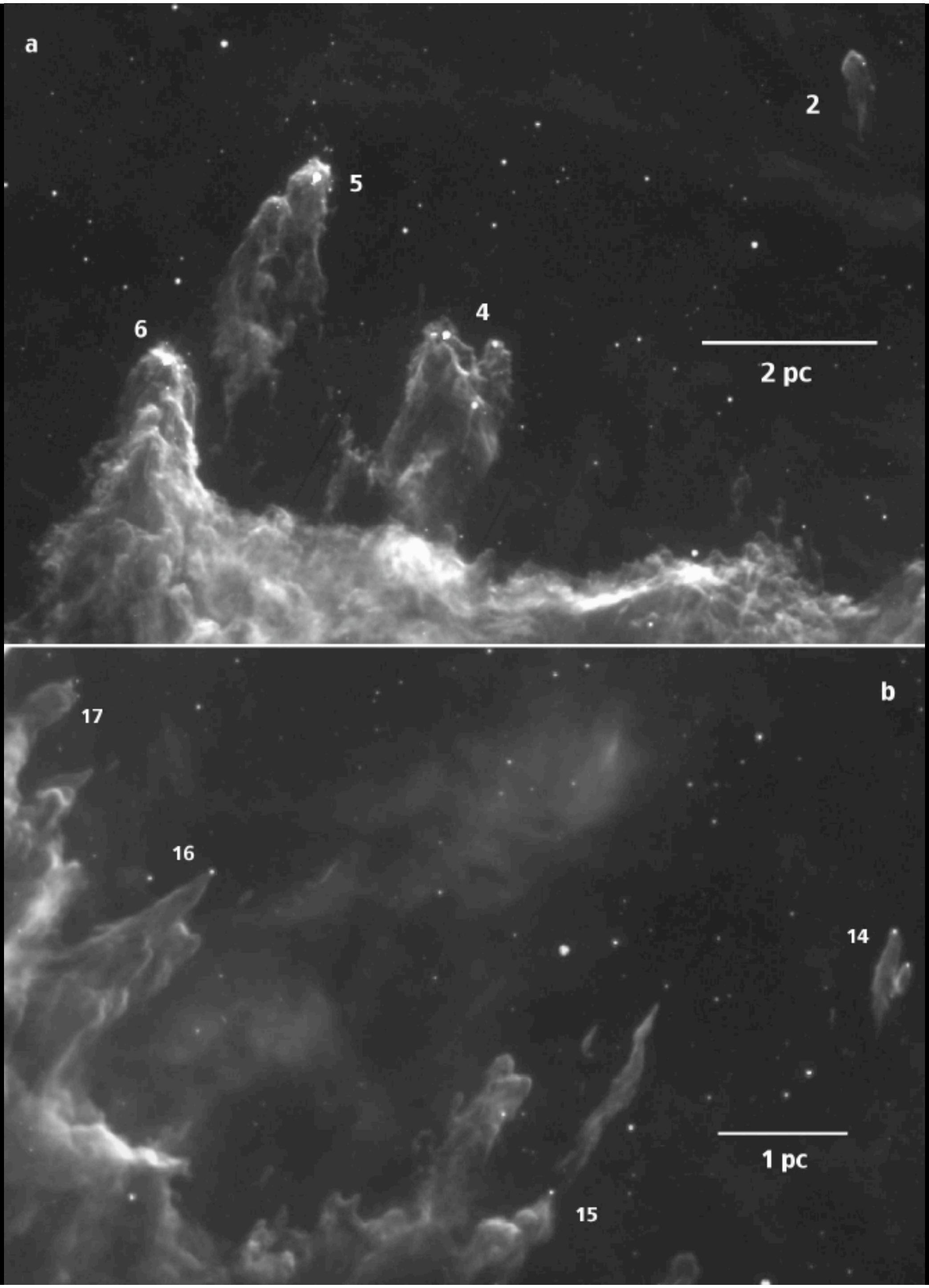
(Xavier Koenig PhD, Koenig et al. 2008)



W5 Spitzer Class I, Class I/II, Class II YSOs

(Xavier Koenig PhD, Koenig et al. 2008)

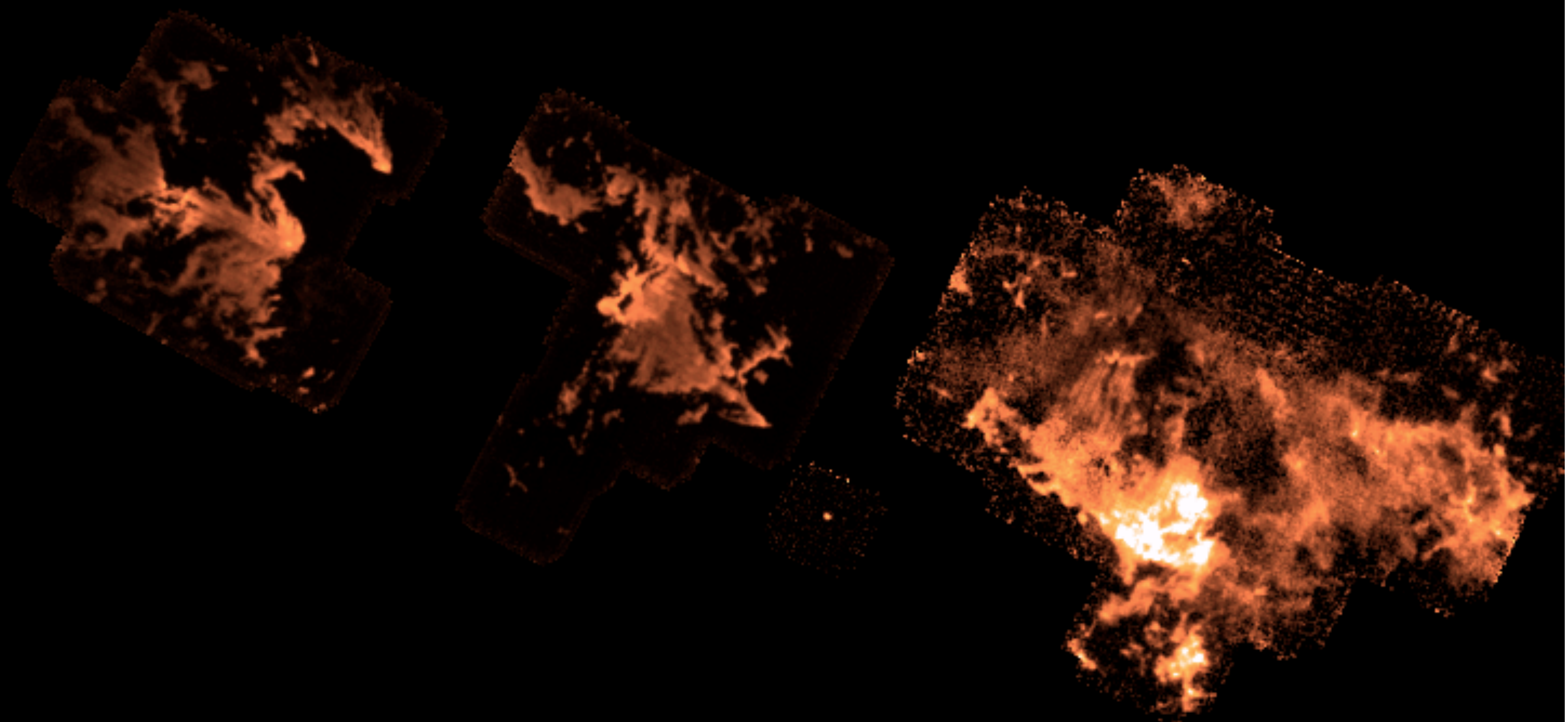


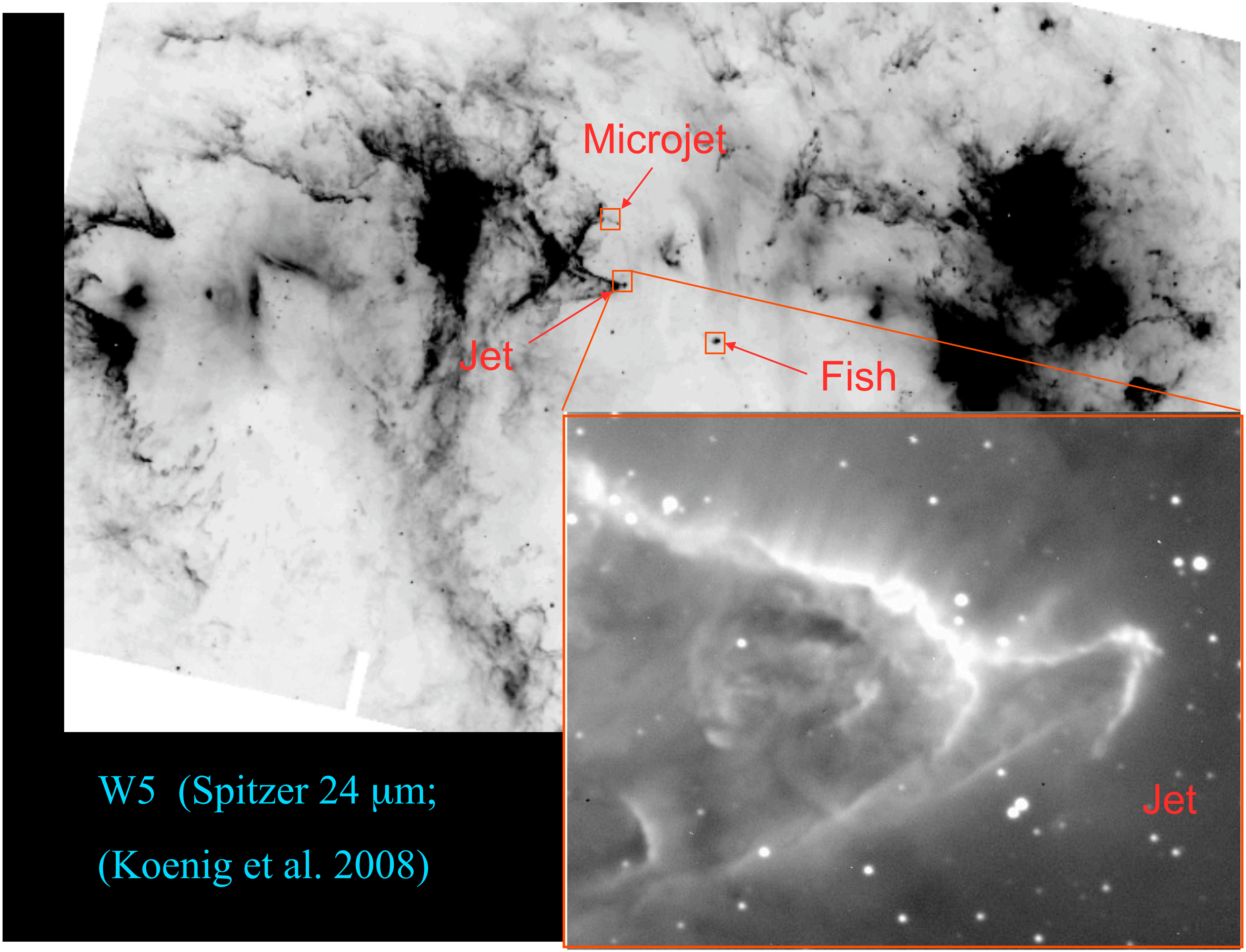


W5 Spitzer YSOs
8 μm
(Xavier Koenig PhD, Koenig et al. 2008)

CO J=3-2 integrated intensity W5

(Adam Ginsburg & Jonathan Williams, JCMT: Dec 07)

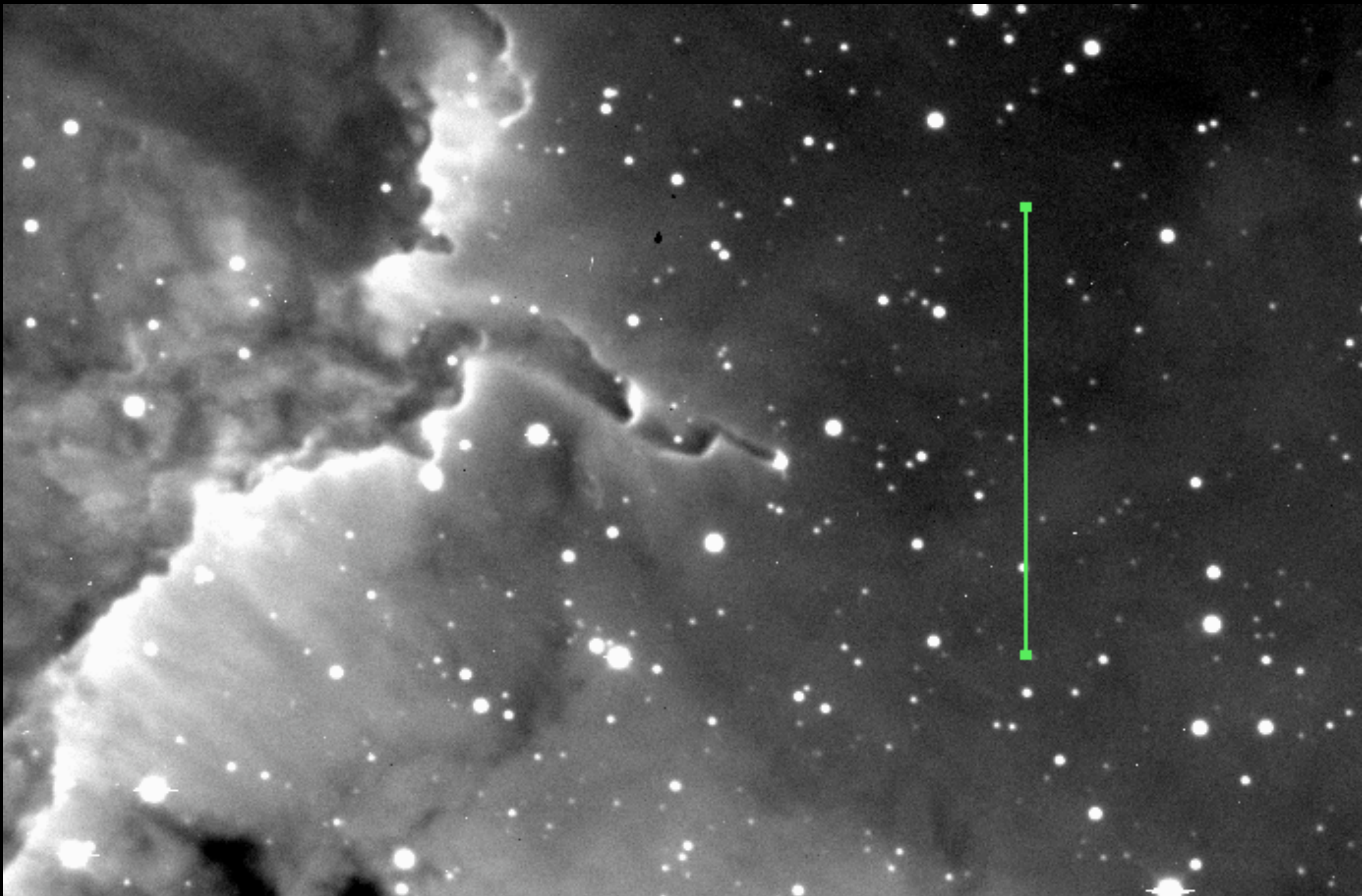




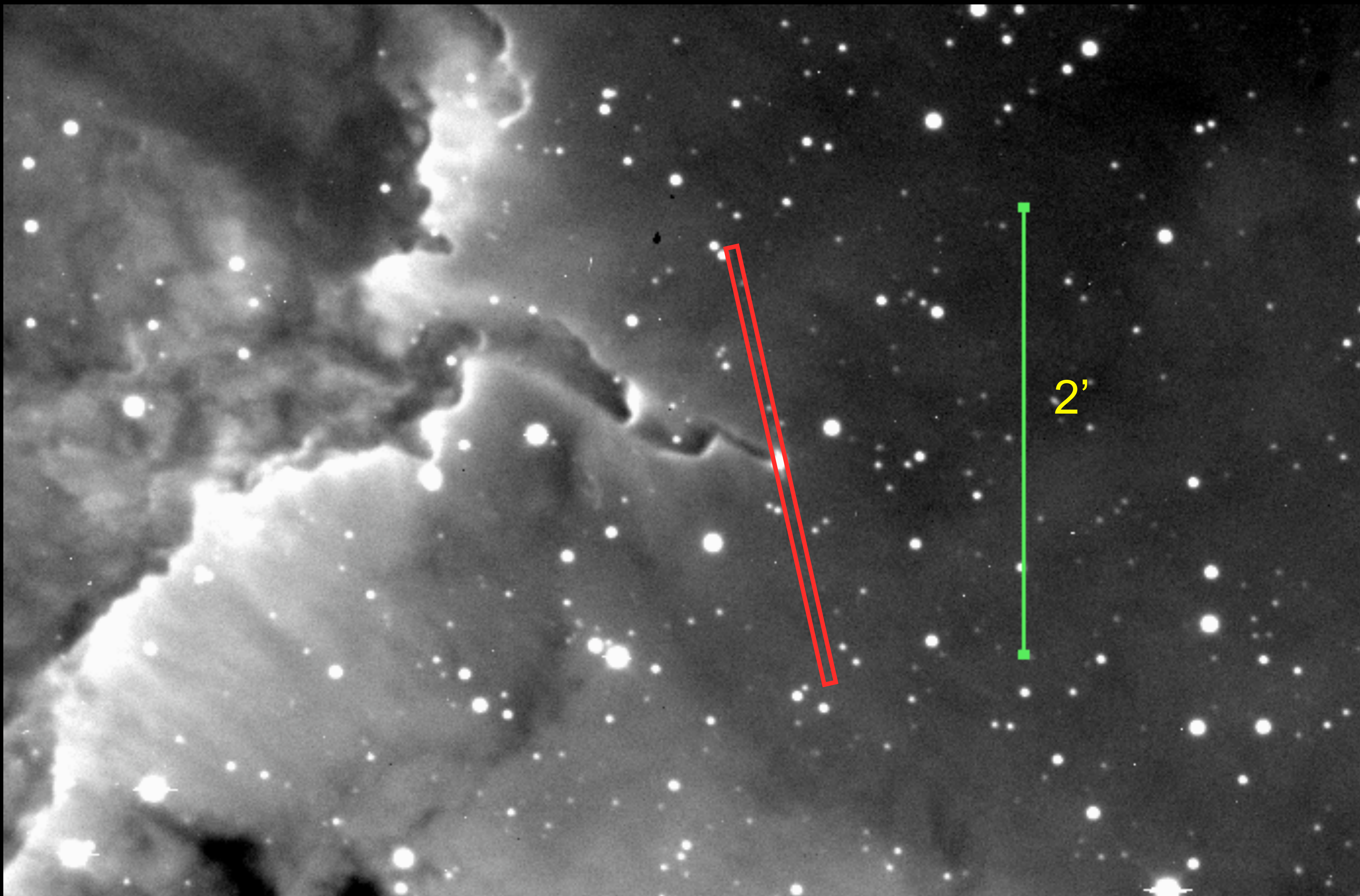
W5 (Spitzer 24 µm;

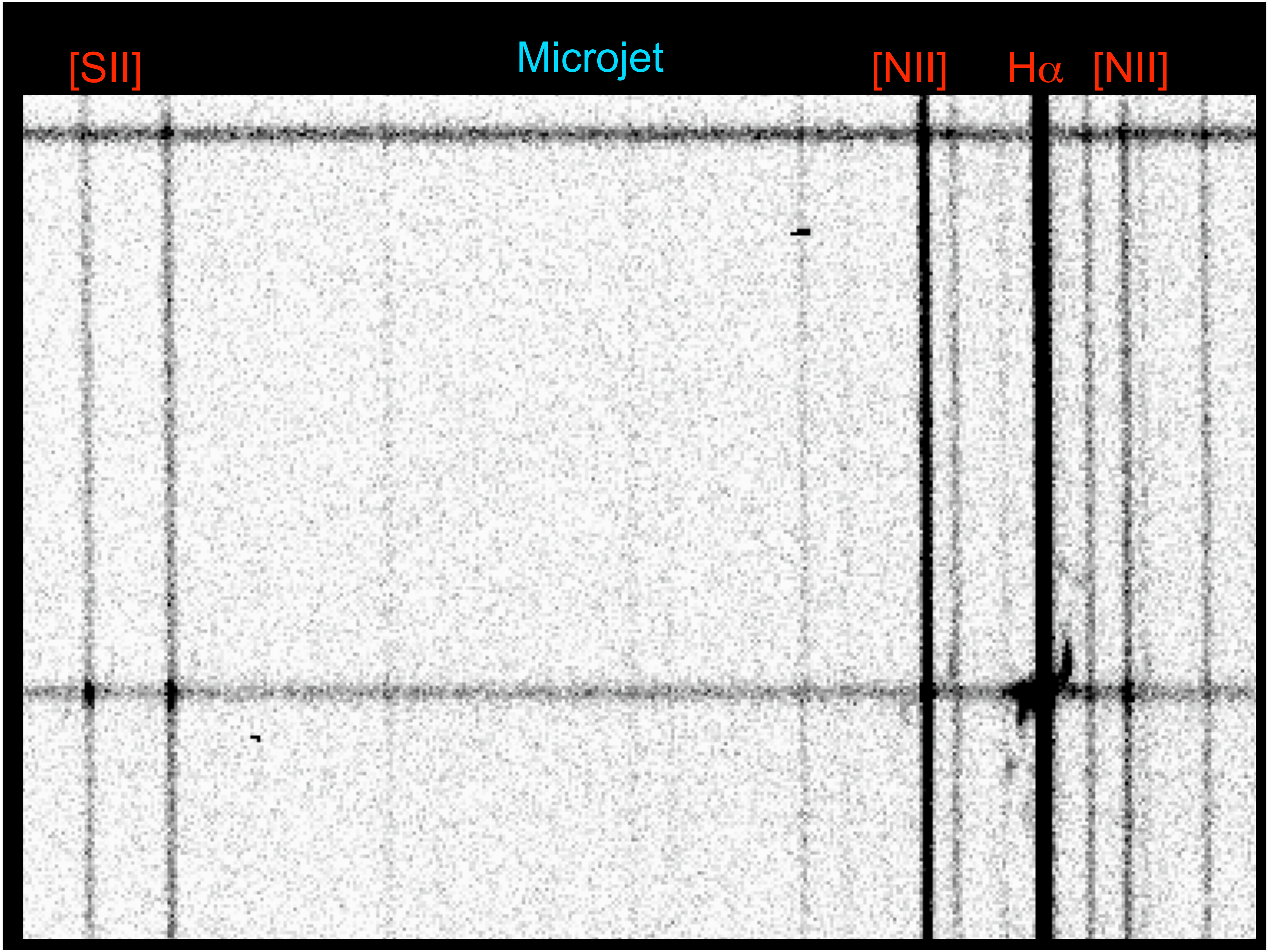
(Koenig et al. 2008)

Microjet (Hα)

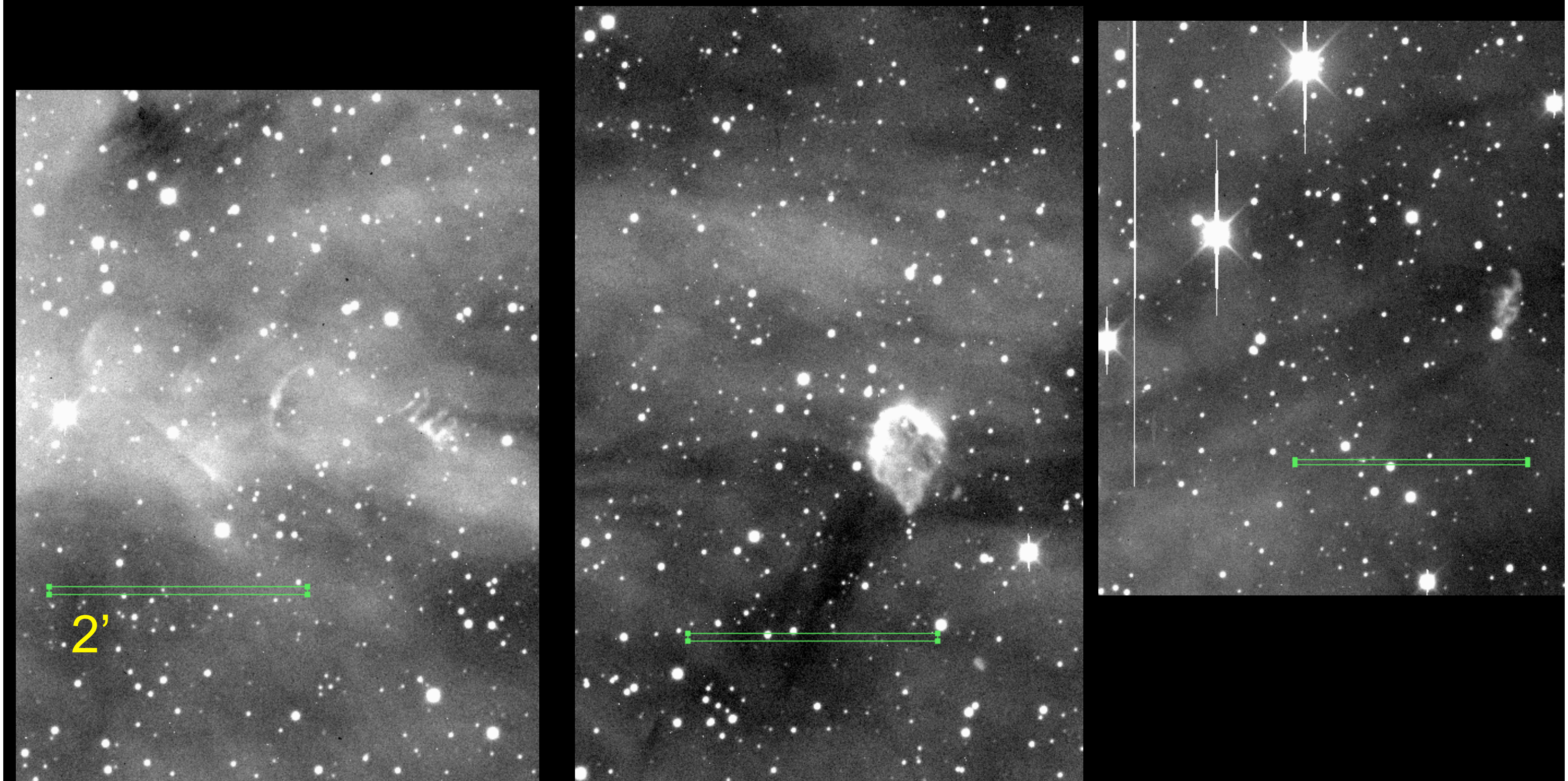


Microjet (Hα)




[SII]
Microjet
[NII]
Hα
[NII]

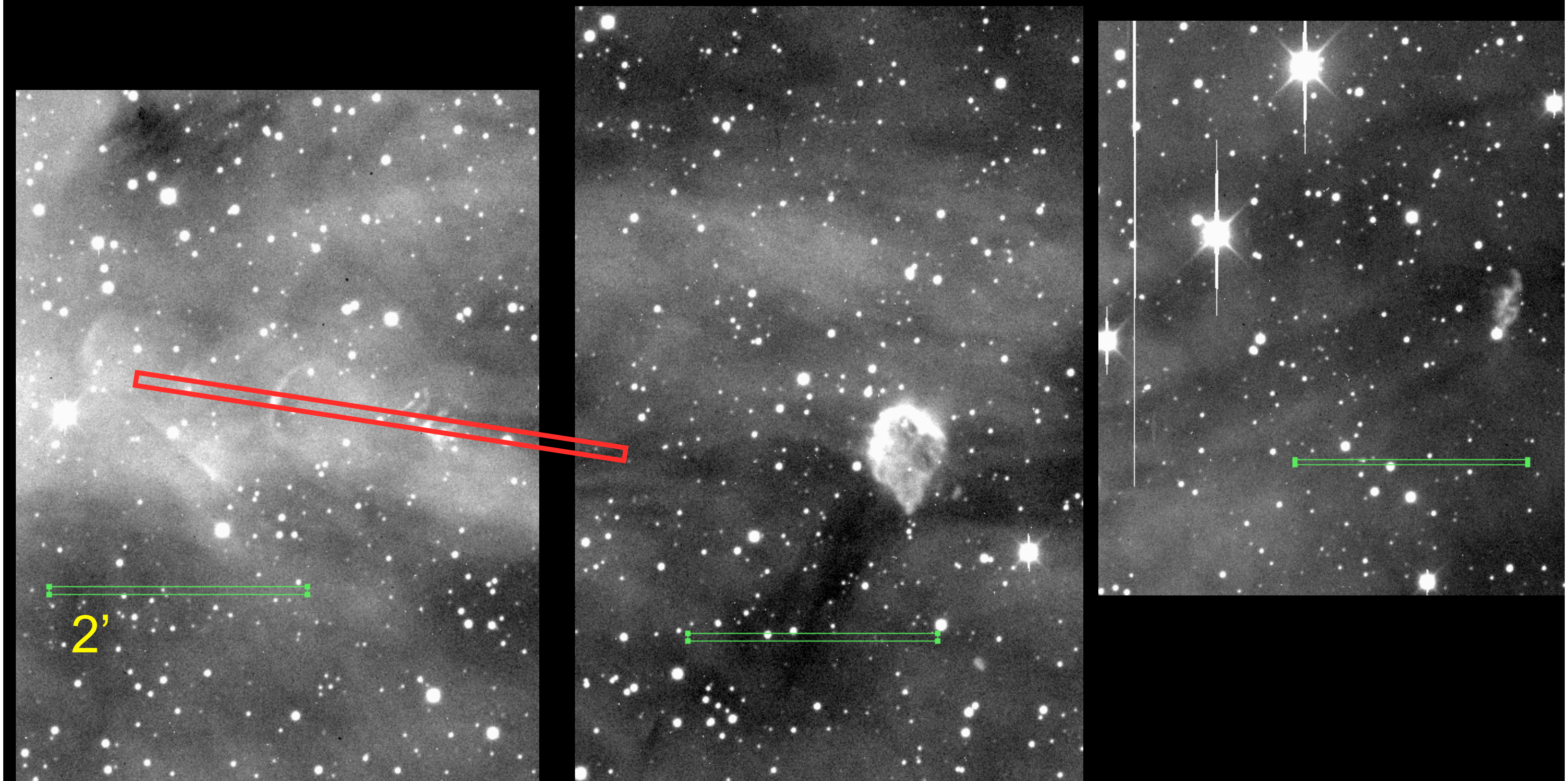
“Fish” North
Bow shocks (Hα)



North

South

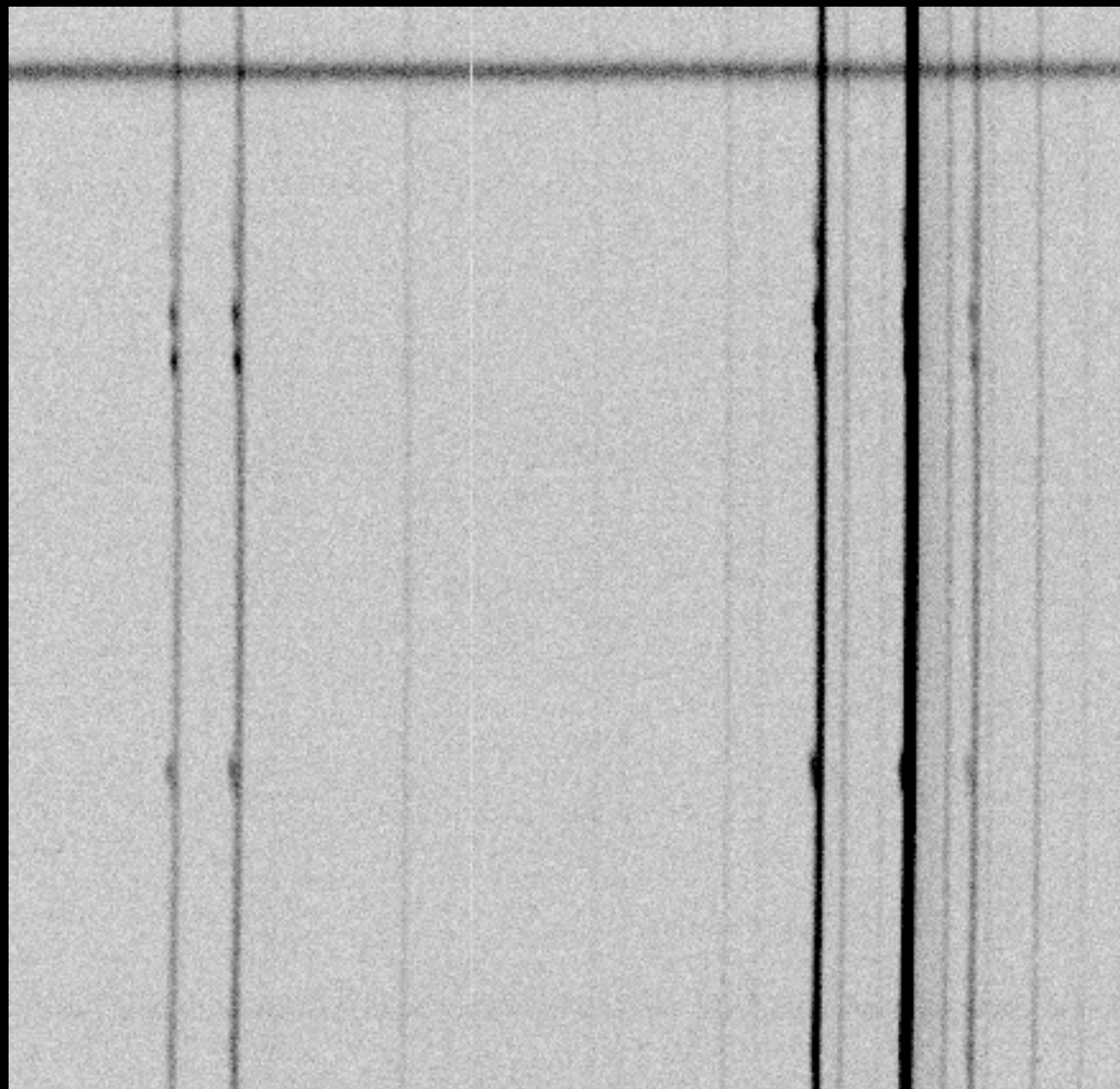
“Fish” North
Bow shocks

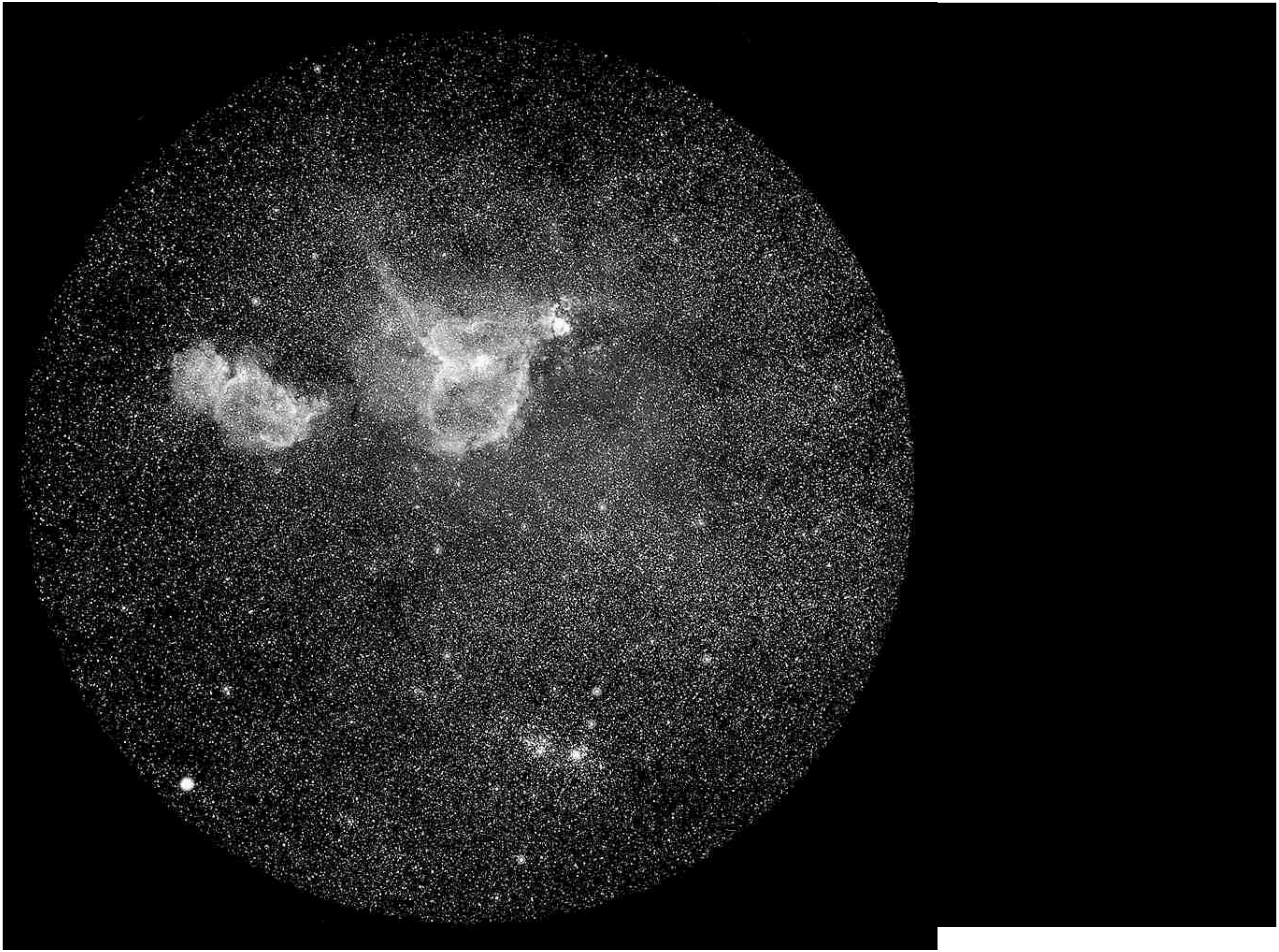


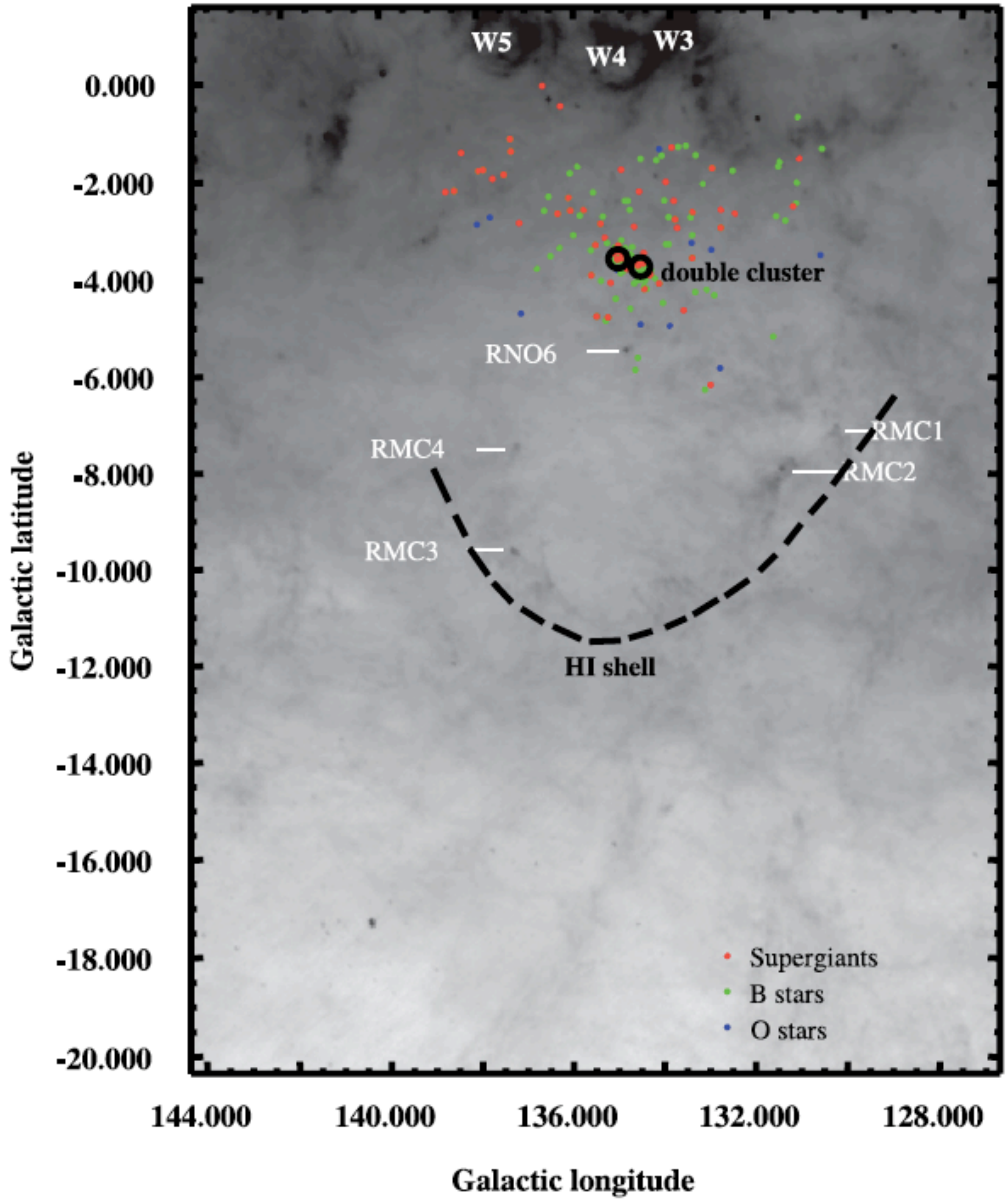
North

South

“Fish” North
Bow shocks







Per OB1, h & χ Per

O, B, & supergiants

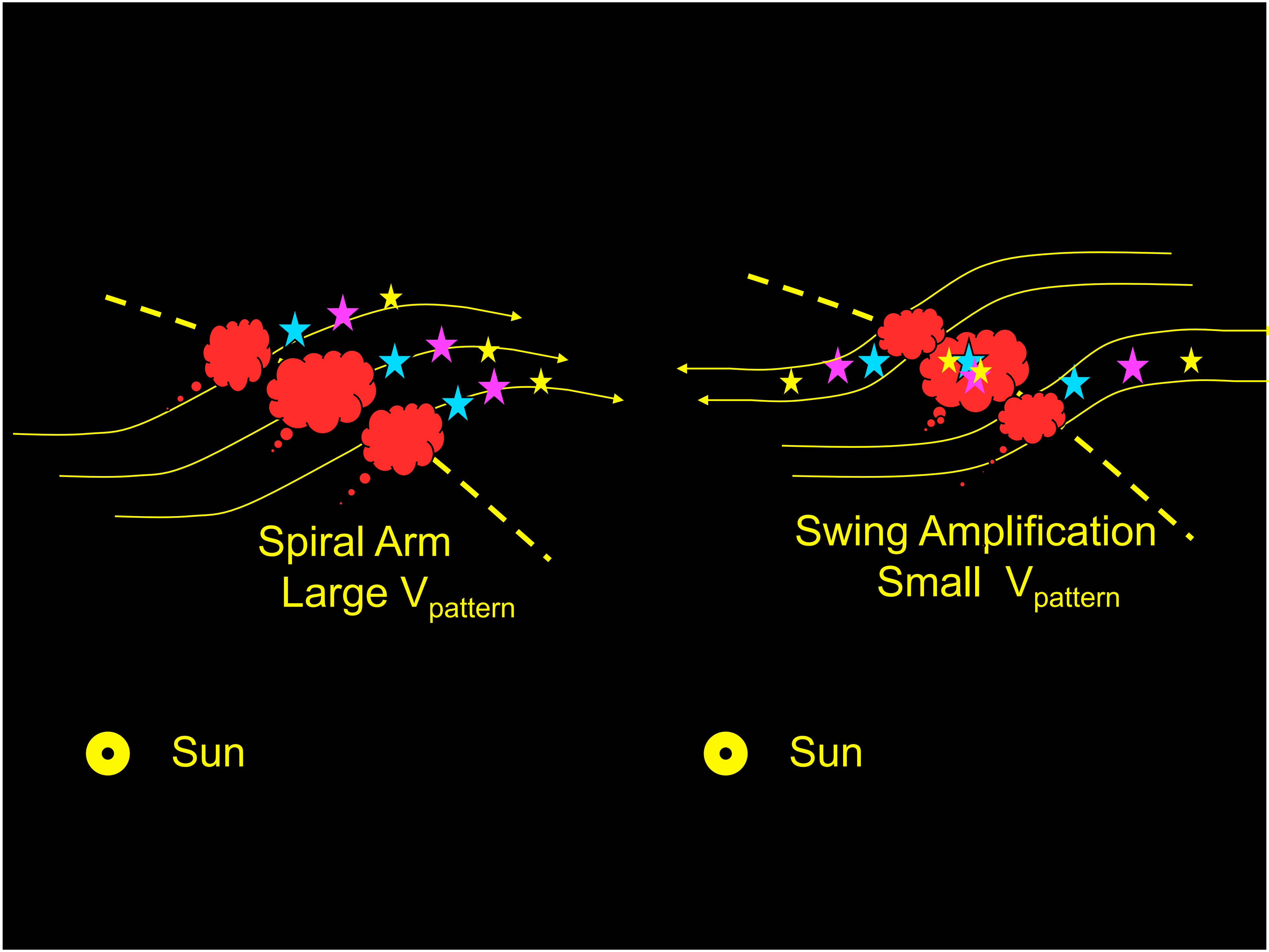
d = 2.35+/-0.05 kpc

t = 10 - 20 Myr

(Lee & Lim 08; Slesnick[+] 02)

Stars (Garmany &Stencel 92)

HI (Capps & Herbstmeier 00)



Spiral Arm
Large $V_{pattern}$
Swing Amplification
Small $V_{pattern}$
Sun
Sun

What can ALMA do?

Feedback from Massive YSOs:

- High resolution maps (line, continuum)
  - cores, hot cores, outflows, hypercompact HII regions
    - Orion, Cep A, ….

Triggered vs. Spontaneous SF:

- Image GMCs & SFRs in neabry Galaxies
- Relate to stellar populations (JST, JWST, SOFIA)
  - SMC, LMC, M83, NGC 253, …

=> Need accurate chronometers!

Velocity gradients:	$t \sim R / \Delta V$	Cores in cometary clouds
Accretion ages	$t_{core} = M_{core} / (dM_{core}/dt)$	Infall rates
chemical ages		Core (pre-YSO)
YSO accretion	$t_{YSO} = M^* / (dM_{acc}/dt)$	Class 0,I, II ($<10^5$ yr)
Young star age	t_{PMS} = track-fitting of spectra	PMS stars

Conclusions

Massive YSOs: Massive-star feedback limits star formation

Outflows

=> soft-UV

=> ionizing UV

=> Winds

=> SN

Massive stars:

Disruption of GMCs ($V > V_{escape}$; positive shock radius)

Compressive Triggers: ($V < V_{escape}$; negative shock radius)

Spiral arms, HII regions, super-rings

- Collect collapse
- $V < V_{escape}$ => triggered star, cluster formation on cluster, HII, & super-shell scales
- W3/4/5: "Carina of the North"

Need accurate chronometry


The End