Massive-star formation triggered by Galactic HII regions

NGC3324 (Spitzer 24 μm modified)

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→ Determine what kind of stars is formed at the peripheries of HII regions, and how. Are massive stars formed there?

The different processes triggering star formation at the borders of HII regions

Can several processes be at work in the same region?

Does the collect and collapse process work in an inhomogeneous medium?

The masses of the second-generation stars: how massive can they be?

Different processes triggering star formation

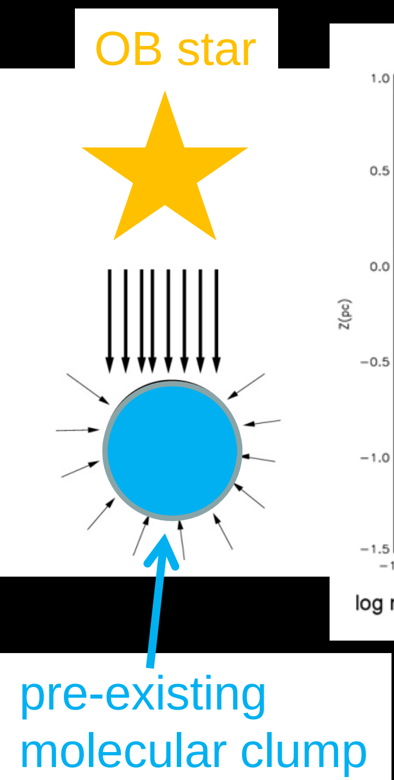
at the peripheries of HII regions

Review: *Elmegreen 1998*

The **radiation driven implosion** of a molecular condensation (RDI)
Formation and evolution of “cometary globules”, surrounded by “bright rims”

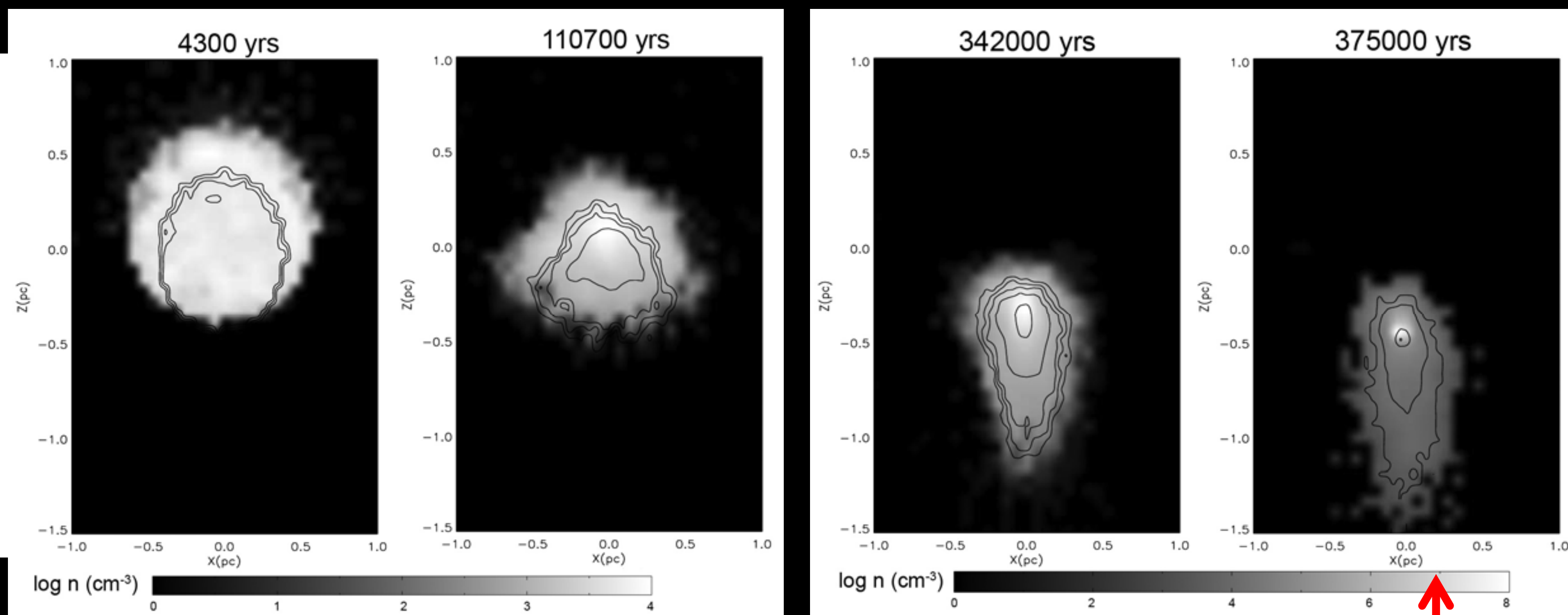
Analytical analysis and simulations:

Lefloch & Lazareff 1994
Kessel-Deynet & Burkert 2003
Miao et al. 2006



68 Msun
60 K
uniform density
R=0.4 pc

Miao et al. 2006



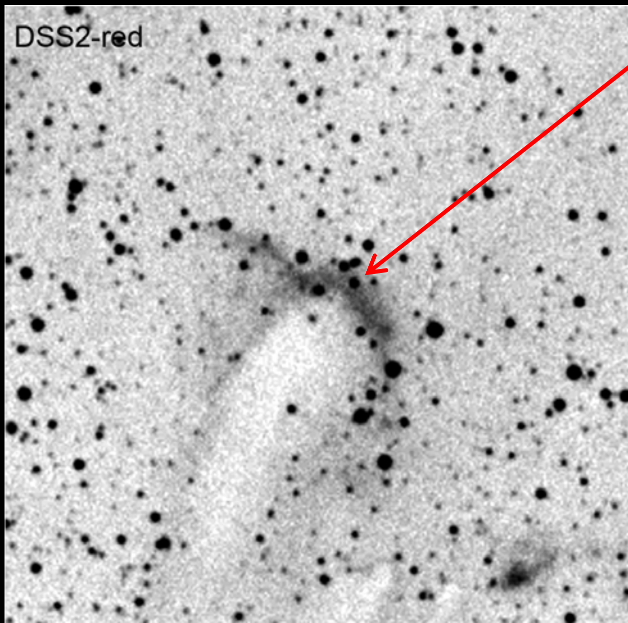
formation of a flat core

formation of an elongated finger
core + elongated tail

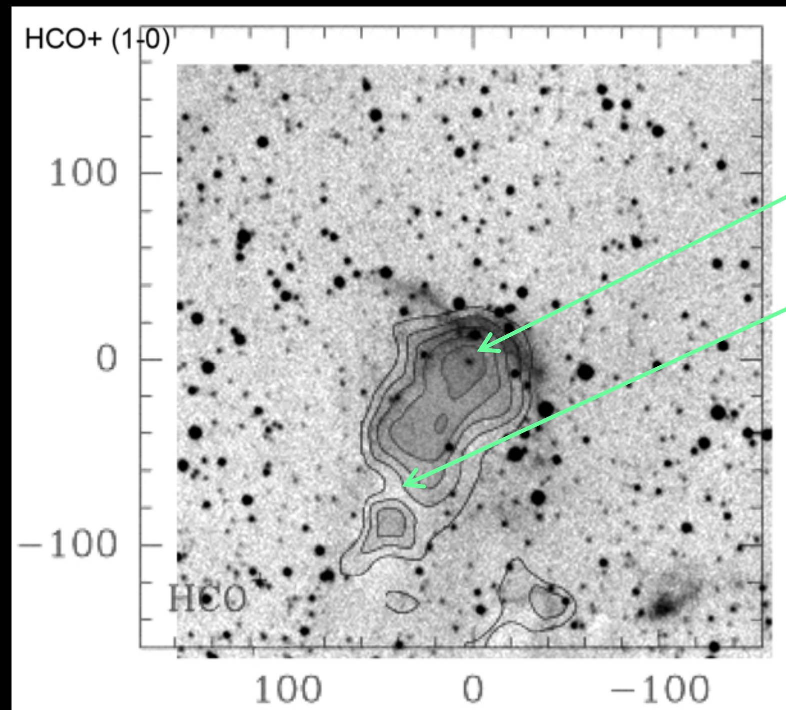
implosion &
star formation ?

Signatures of RDI: example BRC37

Duvert et al. 1990,
Sugitani et al. 1995, 1997, 2000,
De Vries et al. 2002, Ogura et al. 2002

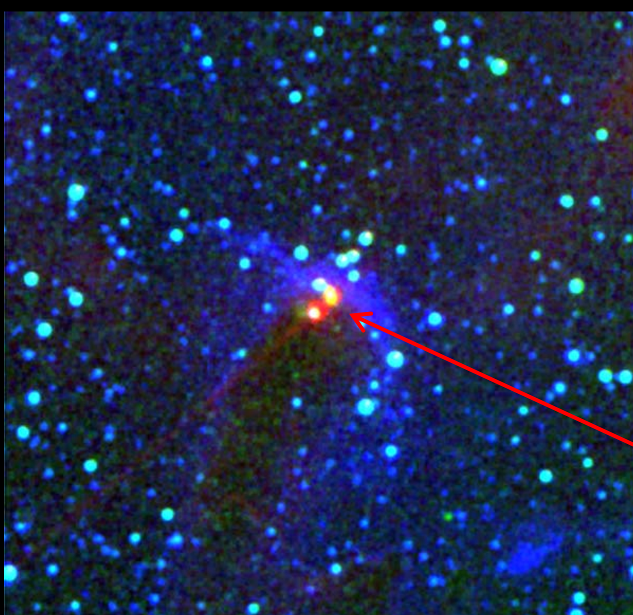


Presence of a bright rim
seen in Hα



dense molecular core
18 M⊙

& tail

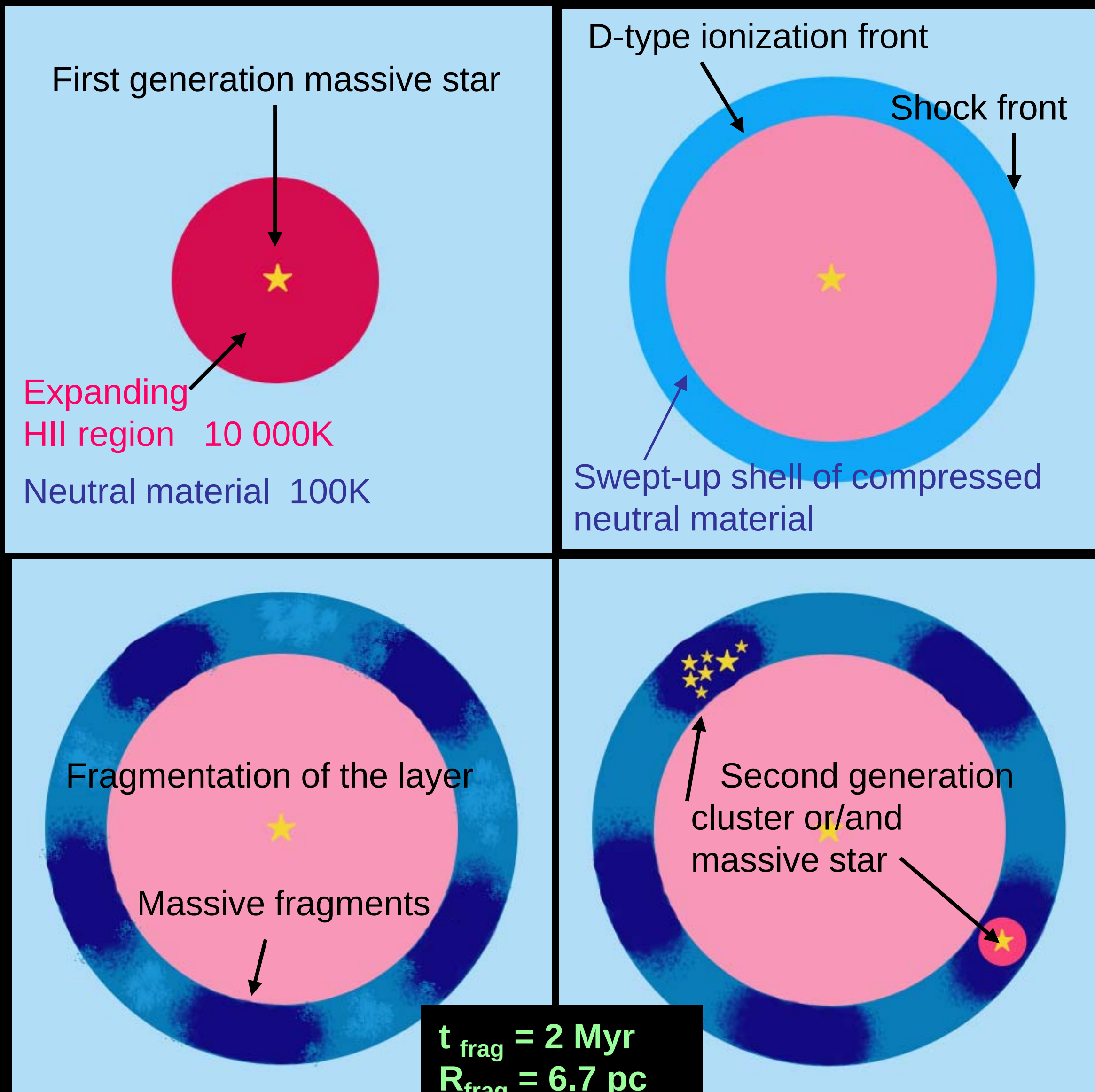


Star formation in the core
IRAS 21389+5622 110 L⊙

Hα K Spitzer 8.0 μm

? Sequential
star-formation

The collect and collapse process, or how to make massive fragments out of an homogeneous medium



t_{frag} = 2 Myr
R_{frag} = 6.7 pc
M_{frag} = 100 $M_\odot$

First proposed by
Elmegreen & Lada 1977

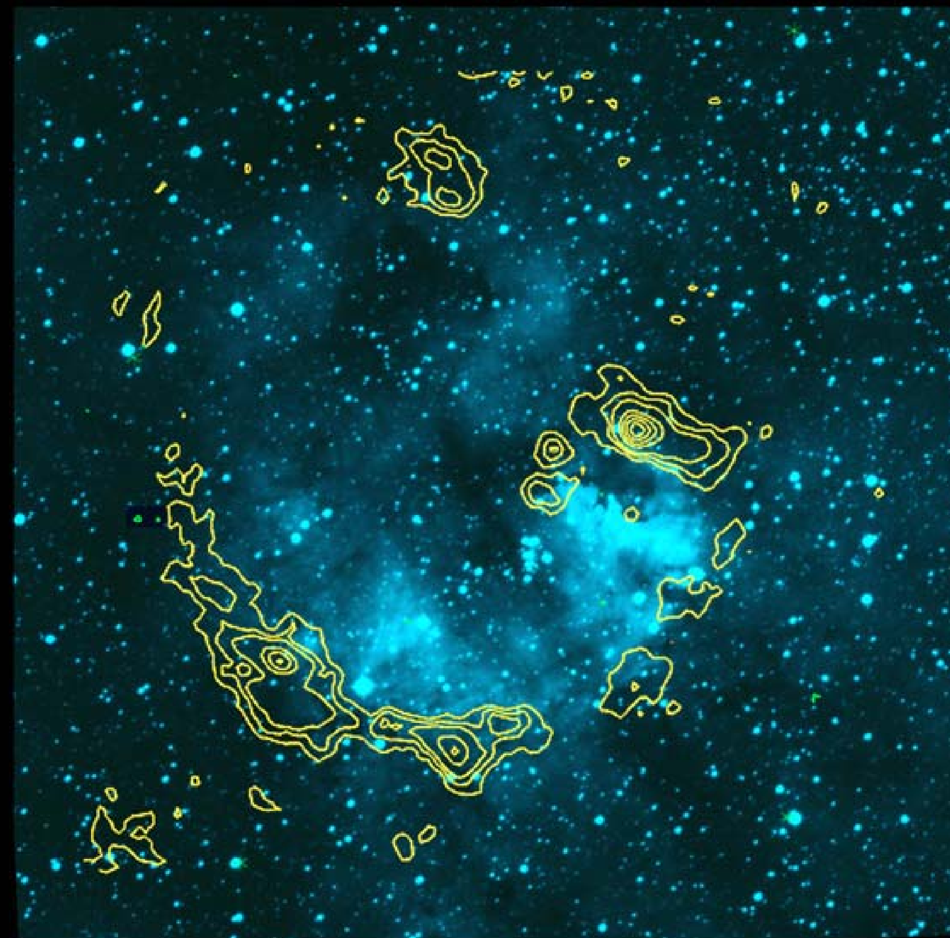
Analytical formulation
Whitworth et al. 1994

10^3 cm^{-3}
O6V
turbulence in the collected layer 0.3 km/s

Simulations
Hosokawa & Inutsuka 2005, 2006
Dale et al. 2007

Signatures of C&C: for example RCW 79

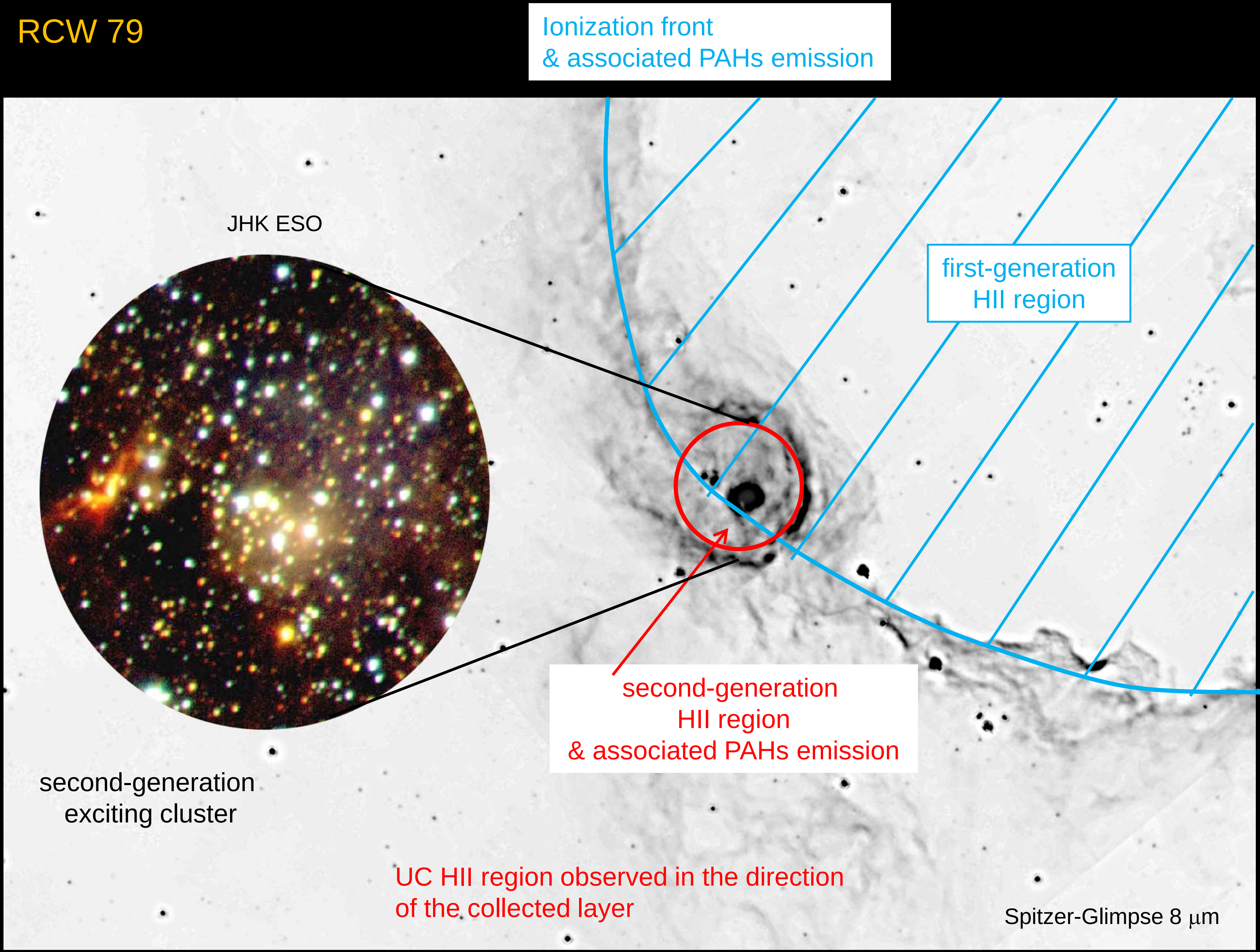
Spitzer-GLIMPSE 8μm Hα SuperCOSMOS



1.2mm continuum emission Hα SuperCOSMOS

Fragmented collected layer
surrounding the ionized gas

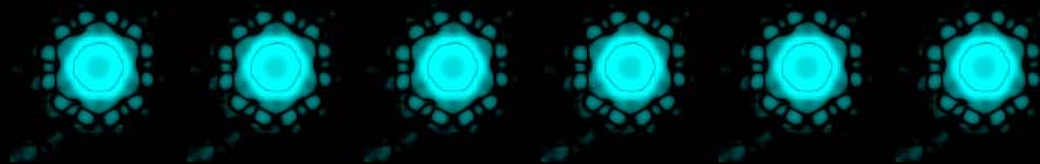
RCW 79


Ionization front
& associated PAHs emission
JHK ESO
first-generation
HII region
second-generation
HII region
& associated PAHs emission
second-generation
exciting cluster
UC HII region observed in the direction
of the collected layer
Spitzer-Glimpse 8 µm

Dense molecular condensations, potential sites of star formation, can also be formed by

Dynamical instabilities of the ionization front
Garcia-Segura & Franco 1996
Mizuta et al. 2006

or by
Turbulence
Elmegreen, Kimura & Tosa 1995
Dale et al. 2005
Gritschneder, Heitsch & Burkert 2006



Can several processes be at work

in the same region ?

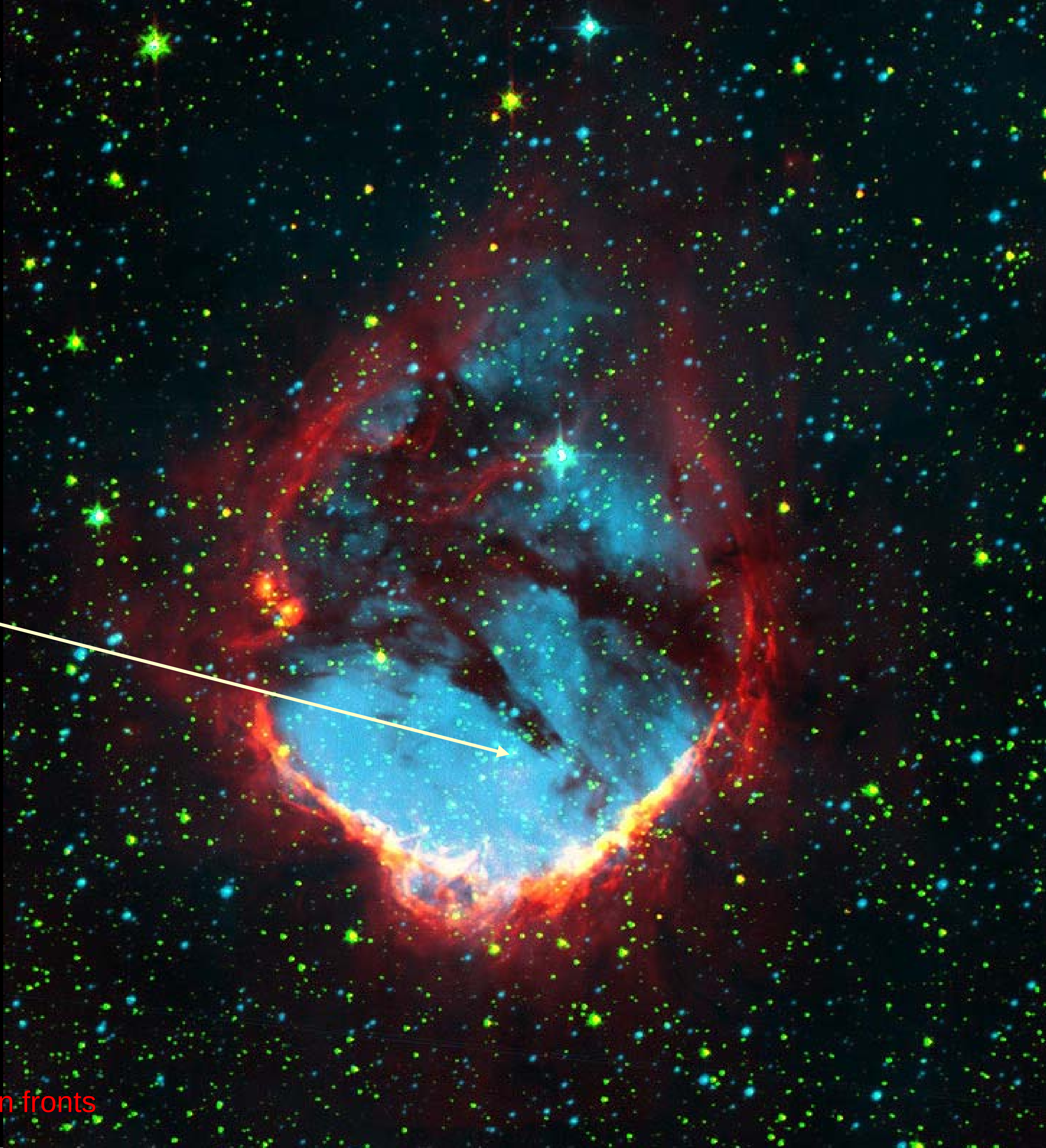
RCW120

Zavagno et al. 2007, A&A in press
details in poster M. Pomares

Distance = 1.3 kpc

Exciting star O8V

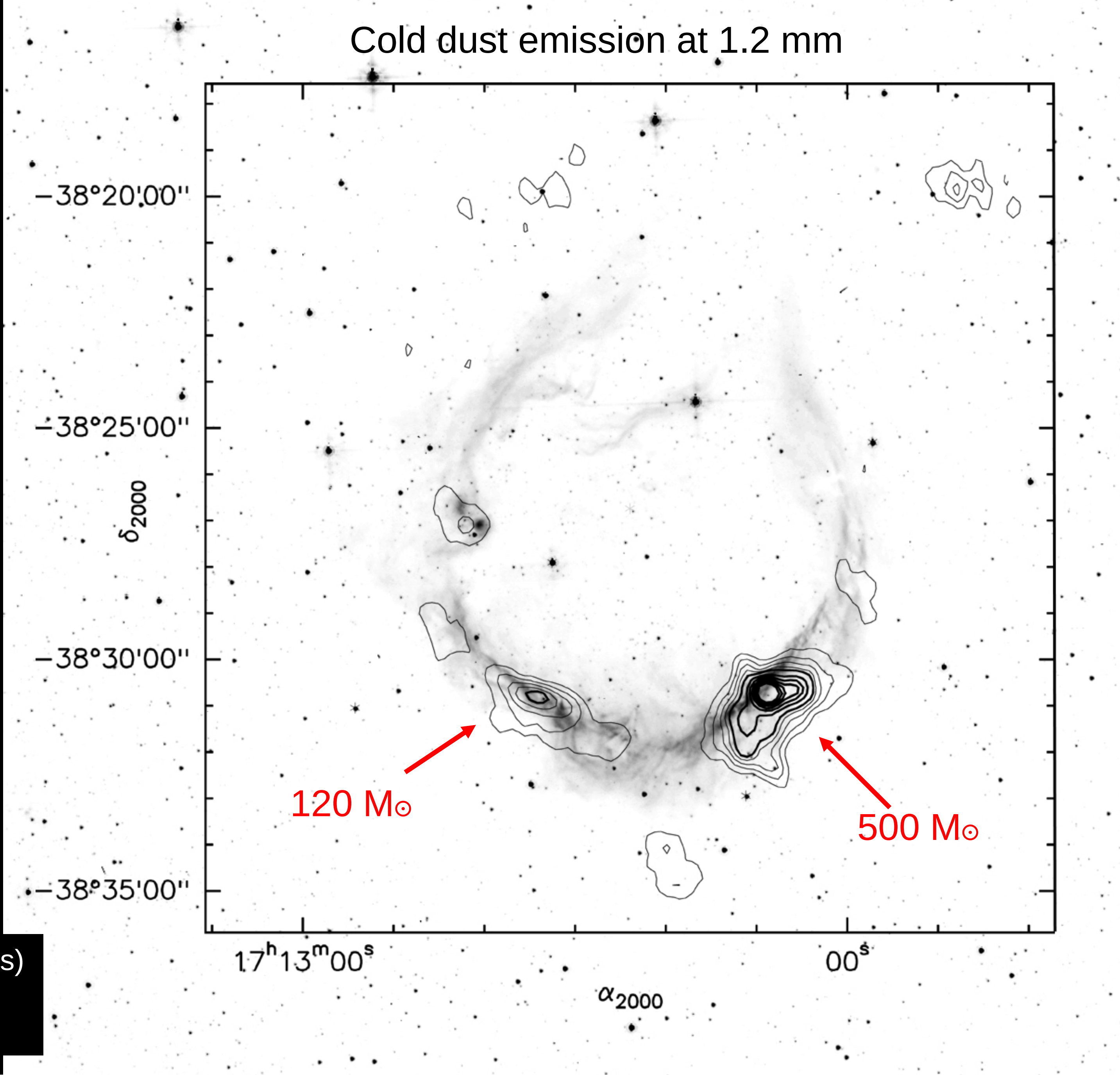
Diameter = 3.2 pc



Hα Supercosmos
ionized gas
Spitzer-GLIMPSE 4.5 μm
Spitzer-GLIMPSE 8.0 μm
PAH emission indicative of ionization fronts

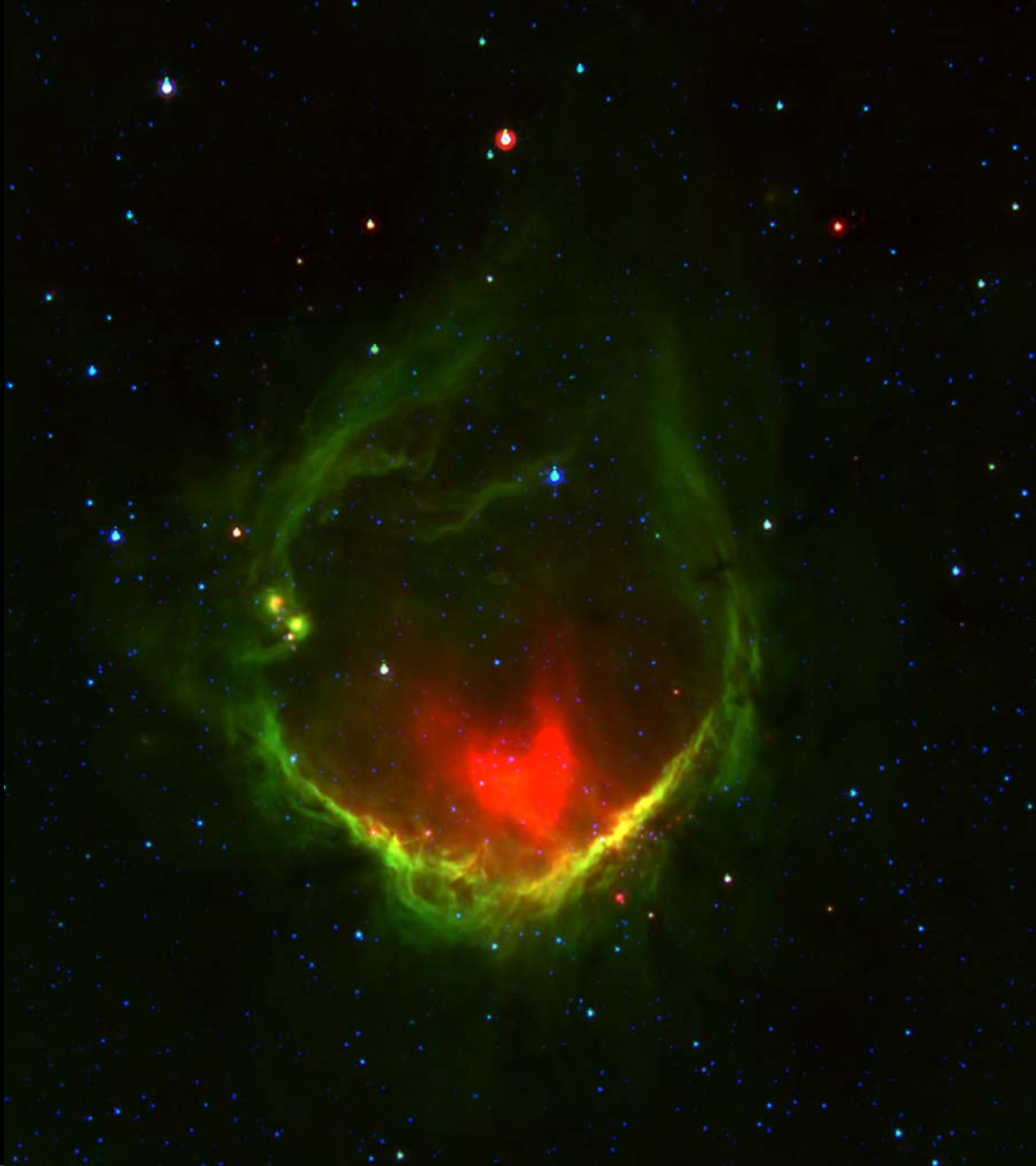
RCW120

→ **a layer of collected material and massive fragments**

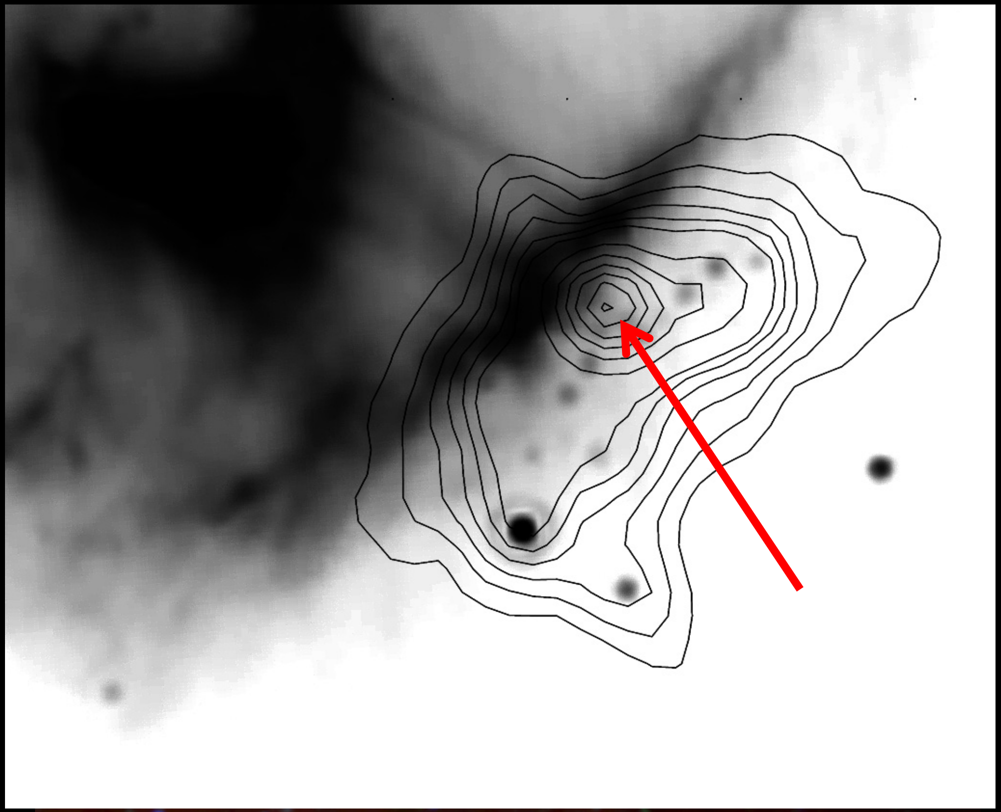


ESO SEST 1.2 mm (contours)
+
Spitzer GLIMPSE 5.8 μm

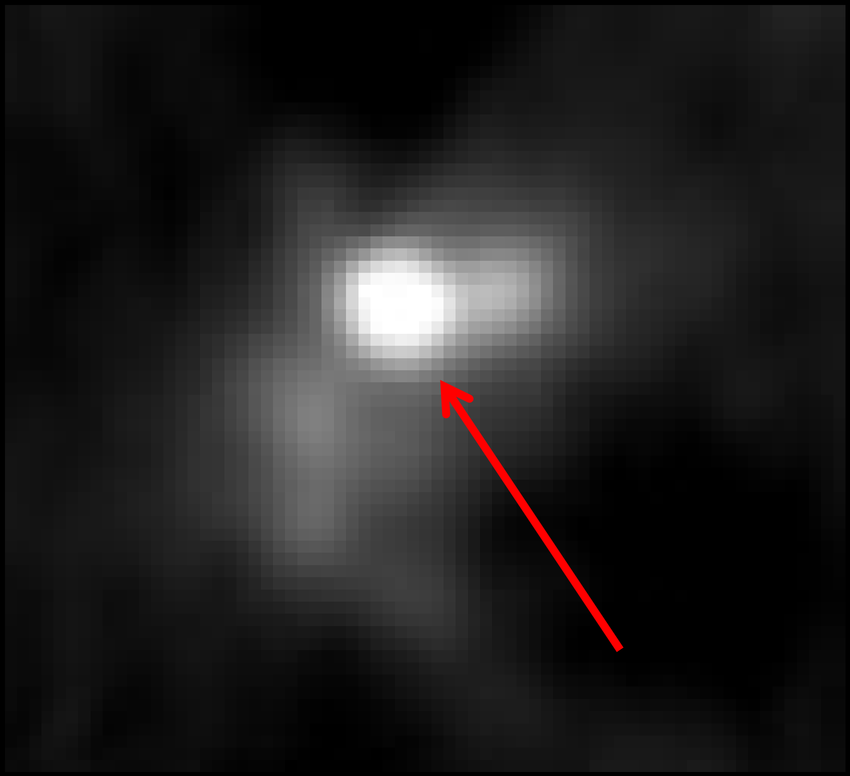
Star formation in RCW 120 with Spitzer



Spitzer-GLIMPSE 8 μm
Spitzer-MIPS 24 μm



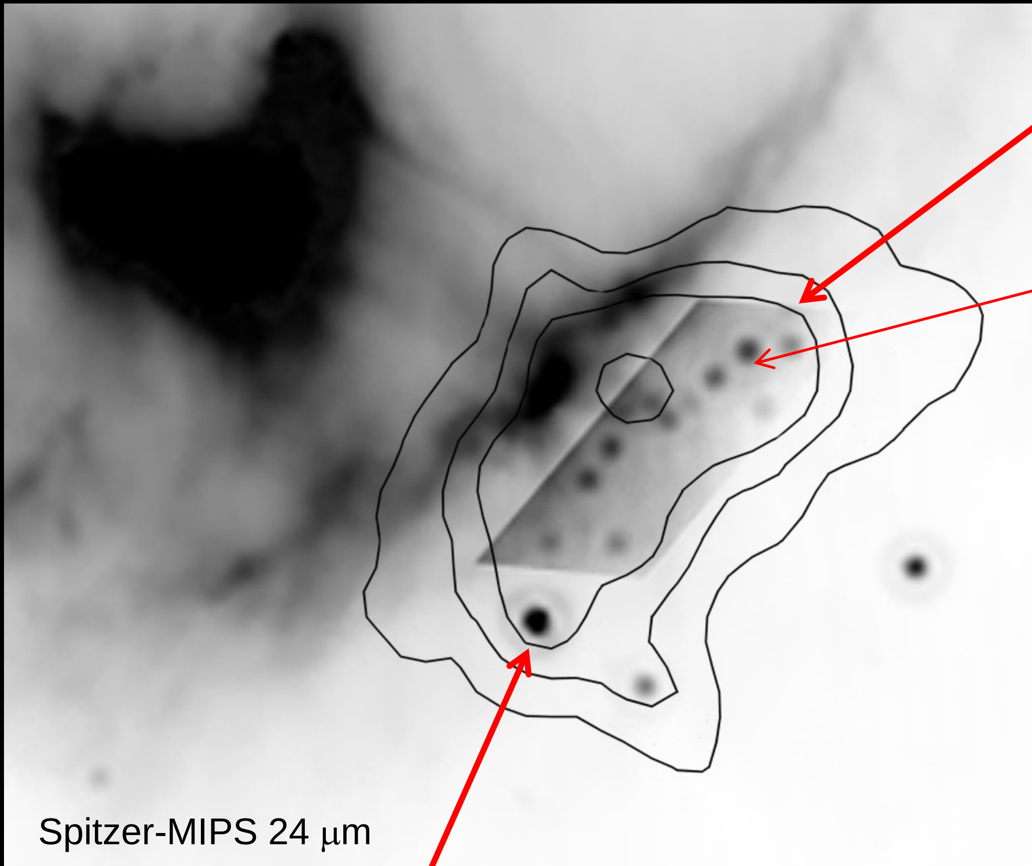
Spitzer MIPS 24 µm + SEST 1.2 mm (contours)



SEST 1.2 mm

Condensation 1: 500M⊙
No massive object at the 1.2 mm emission peak

Potential site of massive-star formation: the 1.2 mm column density indicates A_V > 200mag



Aligment of low luminosity sources **regularly spaced** (separation: 0.09 pc)

➔ Formed by dynamical instabilities?

SED ➔ class I sources

low mass ~ 0.5 $M_\odot$

Temperature ~ 3700 K

luminosity ~ 7 $L_\odot$

high extinction ~ 120 mag

Low mass stars are formed in the collected layer

IRAC colors and SED (*Robitaille et al. 2007, SED fitting tool)*

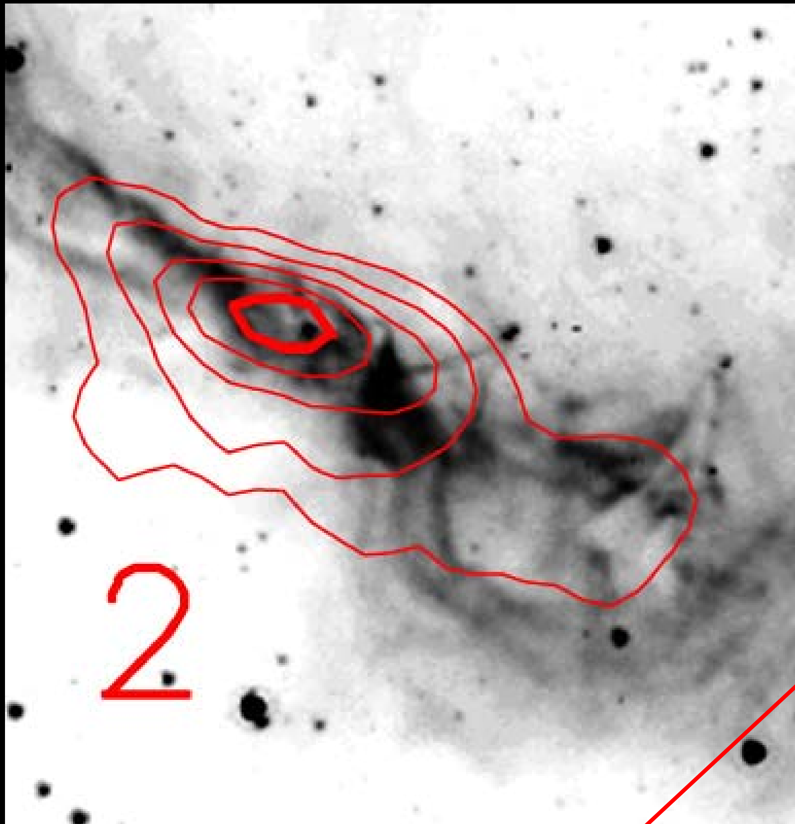
➔ Class I source

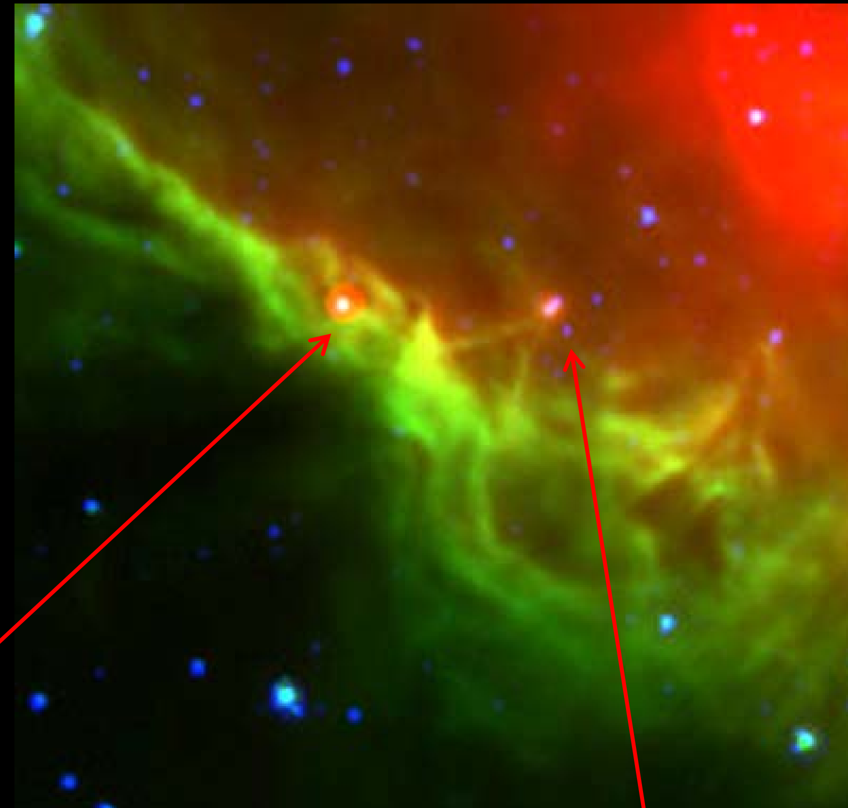
~ 3 $M_\odot$

~ 4400 K

~ 100 $L_\odot$

extinction ~ 94 mag





At the peak of condensation 2
➔possibly formed by collect and collapse

IRAC colors and SED (*Robitaille et al. 2007)*
➔ Class I source
~4 $M_\odot$
~ 4400 K
~ 120 $L_\odot$
Extinction ~ 67 mag

Possibly formed by RDI
At the top of a triangular bright rim, in a region of dynamical instability between two condensations
➔possibly formed by dynamical unstabilities.

IRAC colors ➔ Class II source

- Star formation far from the ionization front, outside the collected layer,

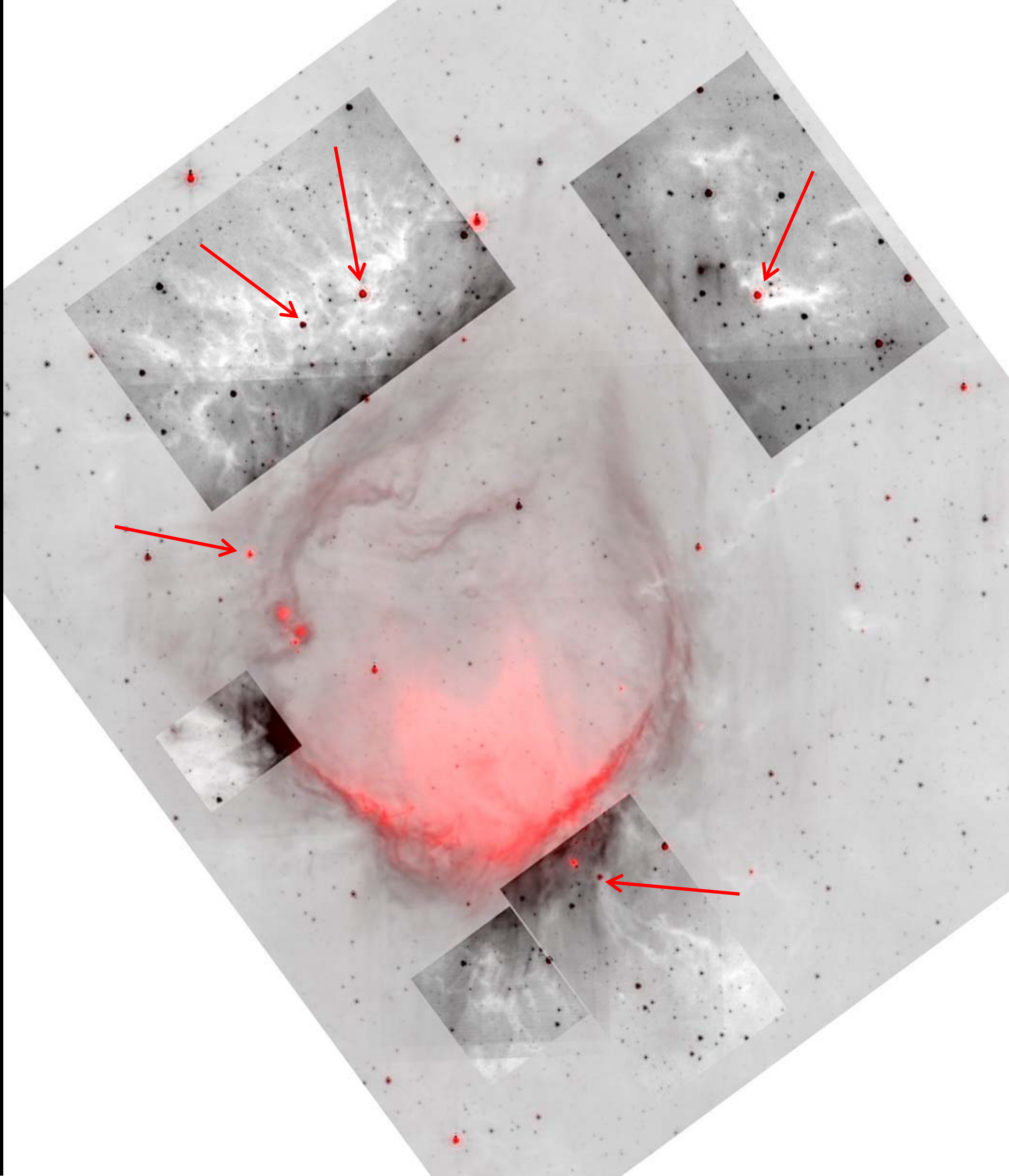
- Class I – class II objects

? spontaneous or triggered star formation

- Observed in the direction of IRDCs

- The IRDCs present radial structures

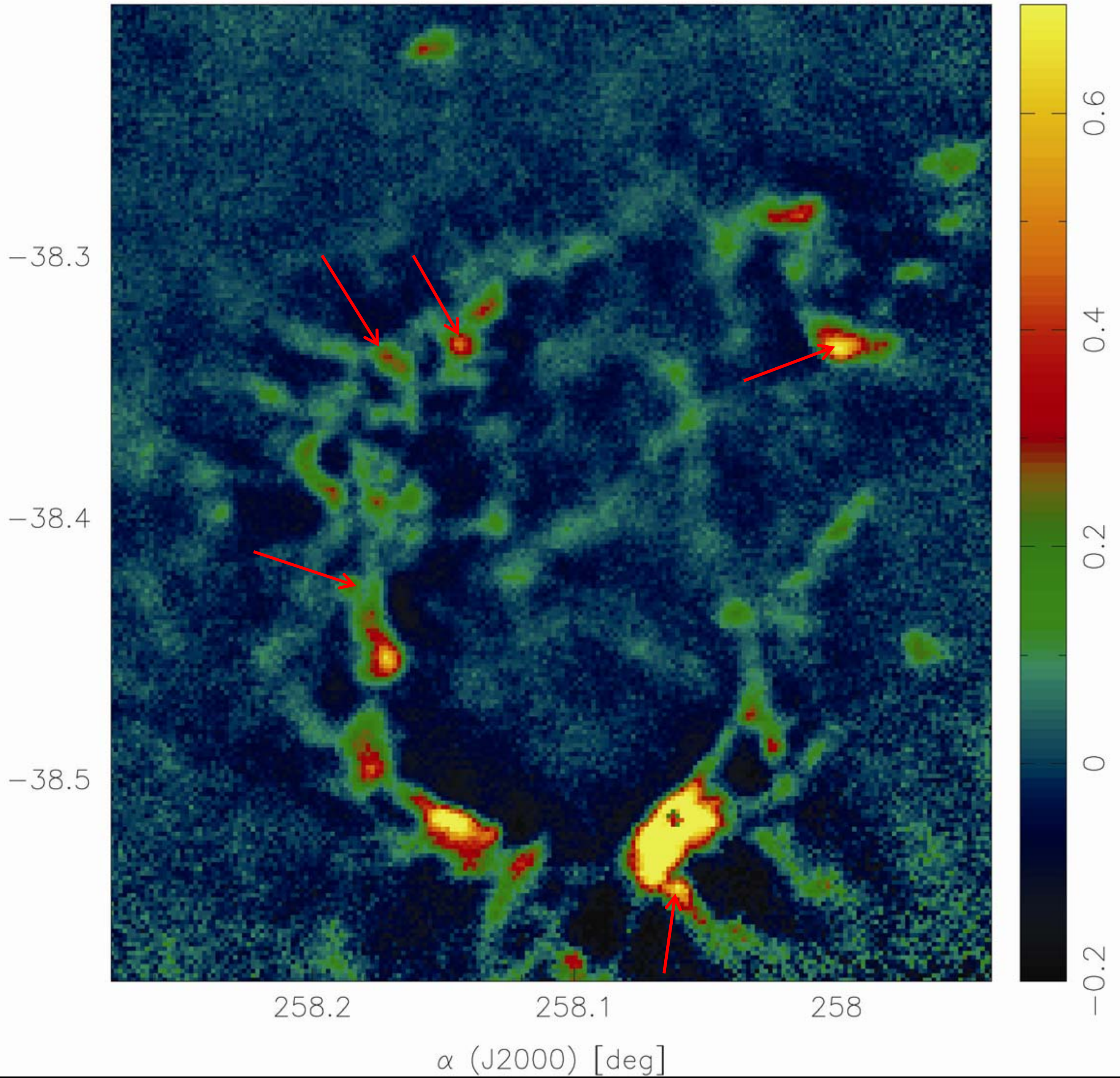
? Influence of the radiation of the central object

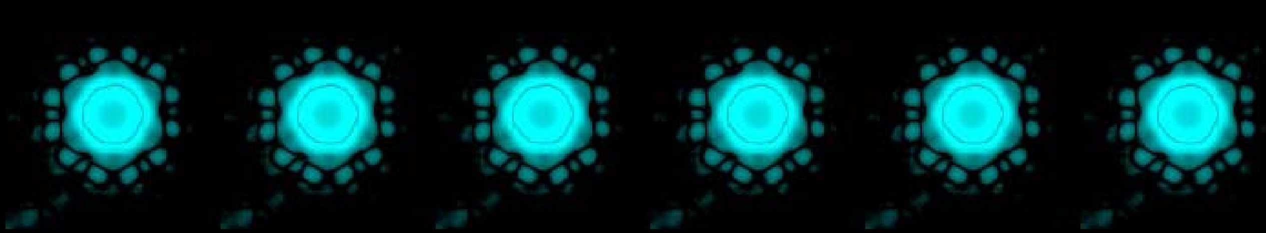


Spitzer 8.0 μm
MIPS 24 μm

APEX Laboca

870 μm
Science Verification
July 2007





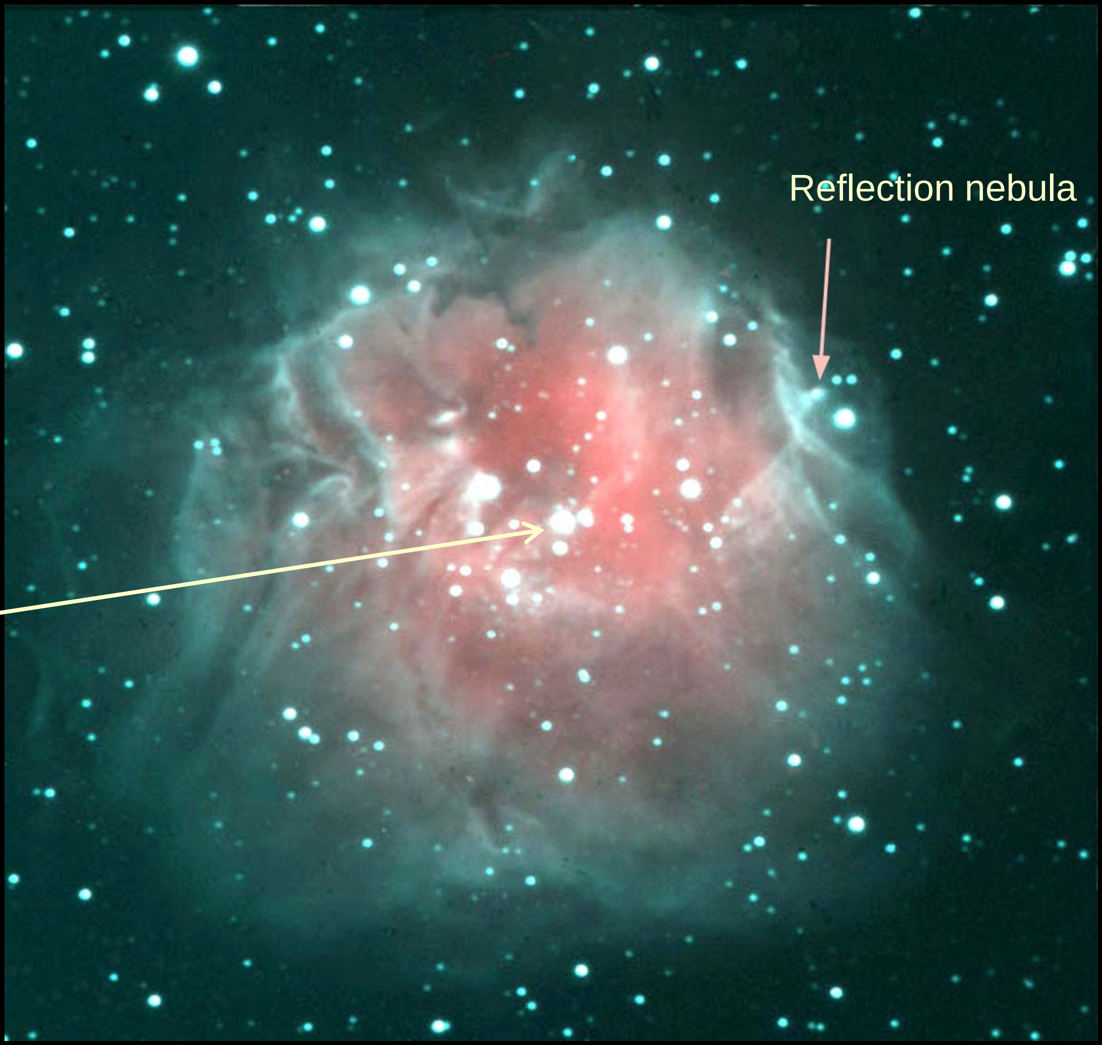
Does the collect and collapse process work

in an inhomogeneous medium?

Sh 212

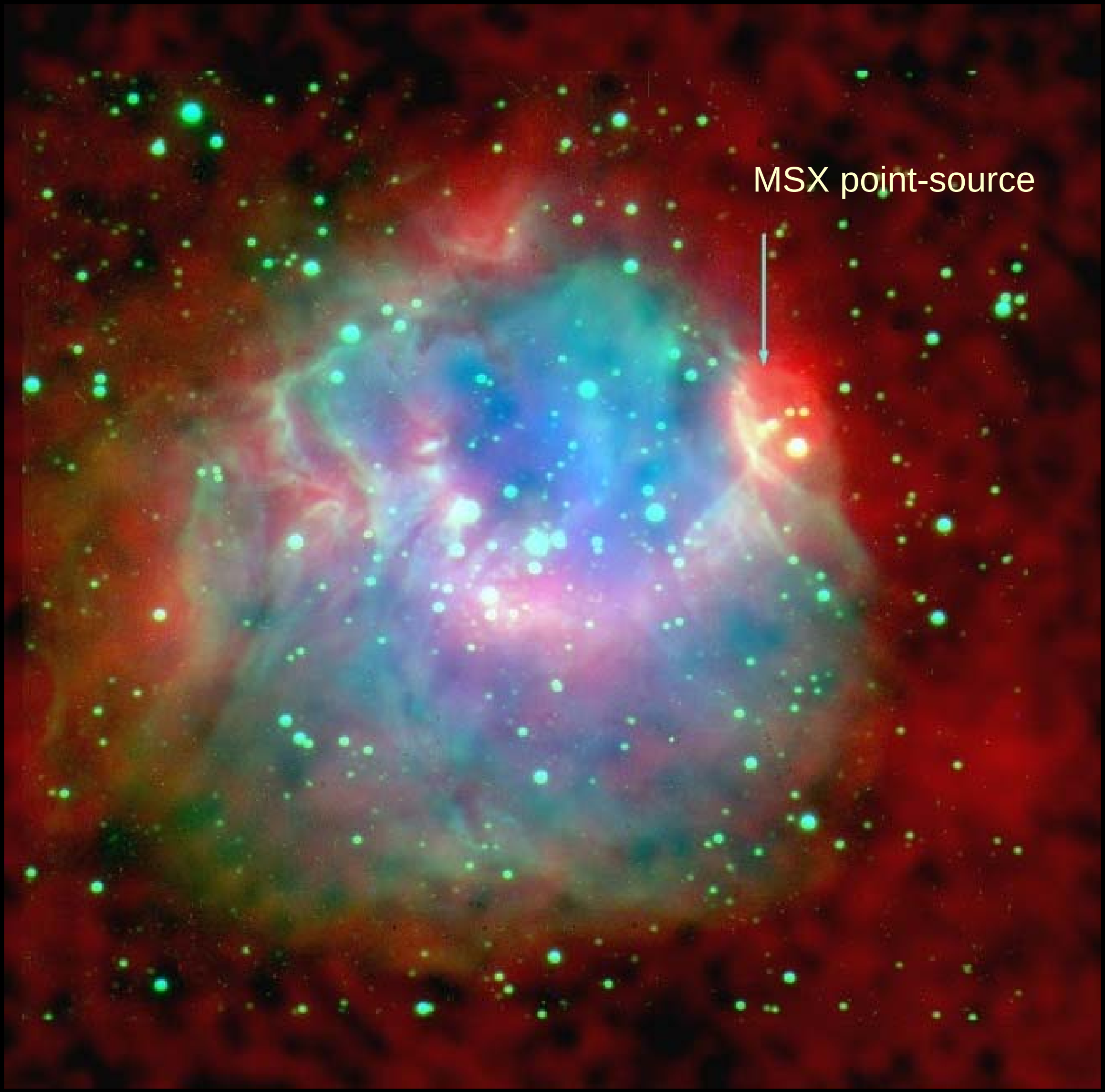
D=6.5 kpc
Φ = 9.5 pc

Exciting star O5.5



Hα [SII] ionization fronts Observatoire de Haute Provence

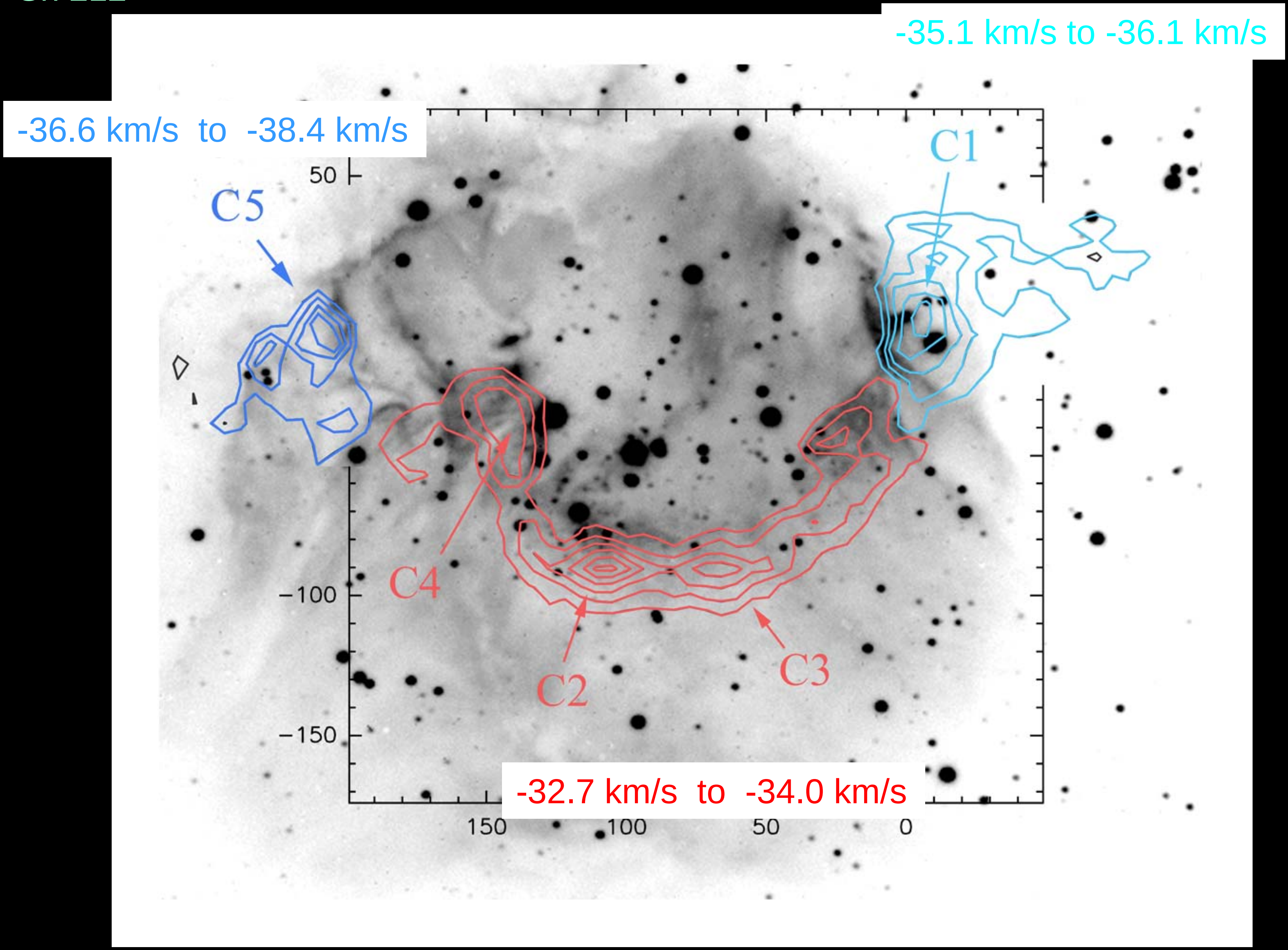
Sh 212



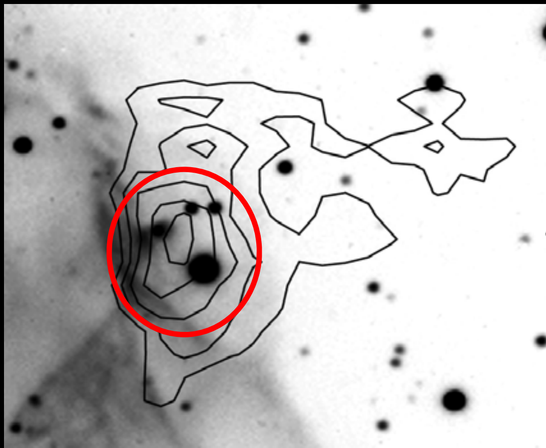
MSX 8.3 μm

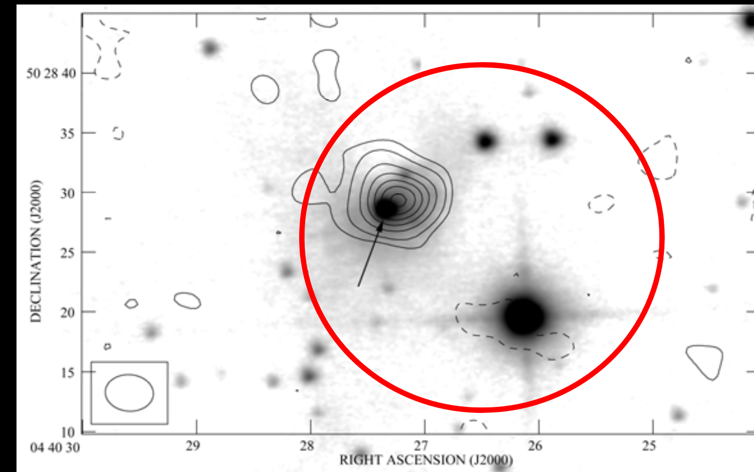
Sh 212

^{13}CO observations IRAM *Deharveng et al. in preparation*



Sh 212

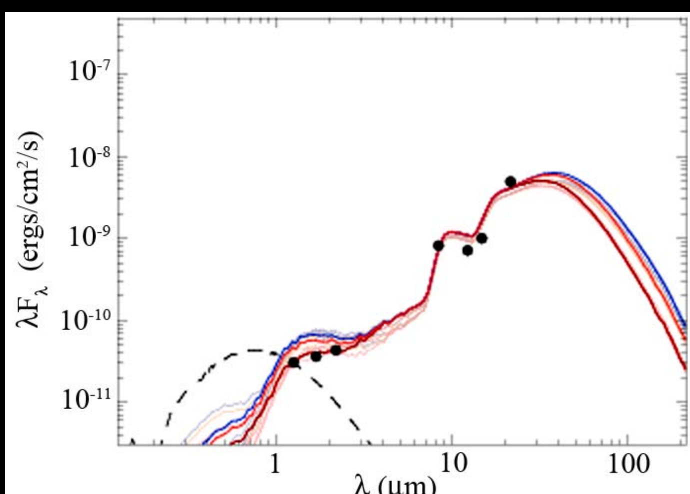




Condensation 1 13CO
200 $M_{\odot}$

JHK CFHT
near-IR excess

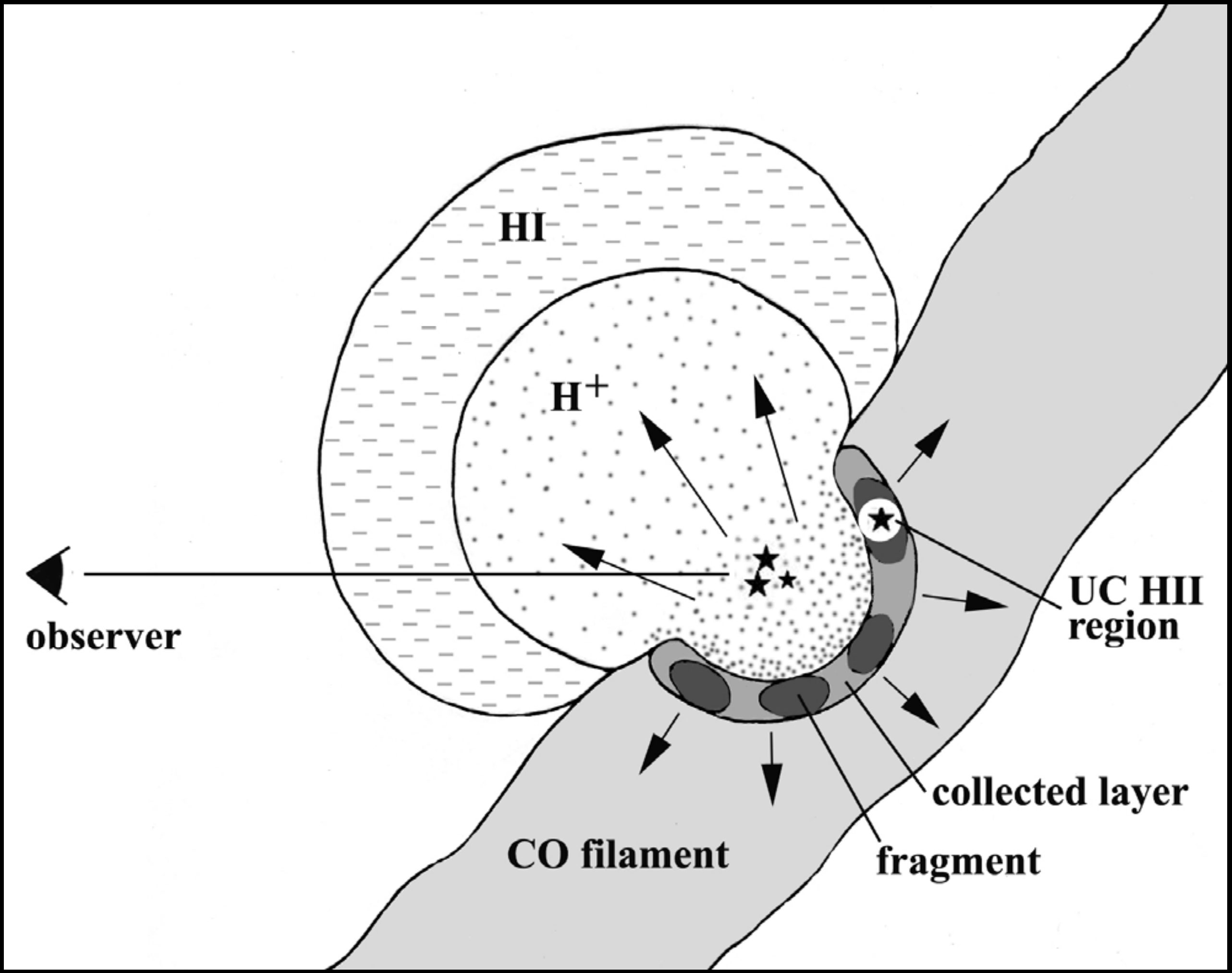
radio-continuum 1.3 cm VLA
UC HII region dynamical age ~15000 yr
B1 exciting star or earlier



SED fitting tool *Robitaille et al. 2007*

central source ~14 $M_{\odot}$
30000 K
~18000 $L_{\odot}$
envelope+disk view edge on

Sh 212



The collect & collapse process forms massive stars out of an inhomogeneous medium

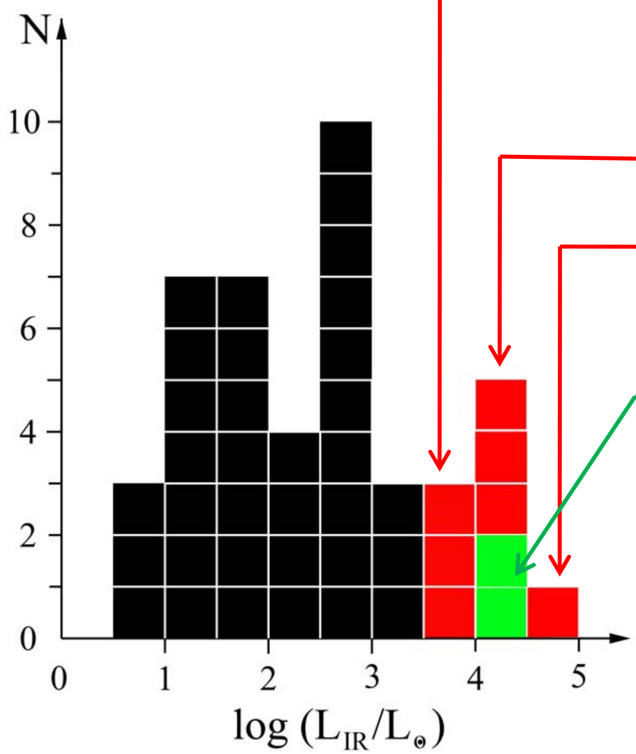
Two other such cases: Sh 217 and Sh 241 associated with various masers

The masses of the second-generation stars

How massive can they be?

Massive-star formation in Bright Rims Clouds

89 BRCs with IRAS point-sources: *Sugitani, Fukui & Ogura 1991* *Sugitani & Ogura 1994*

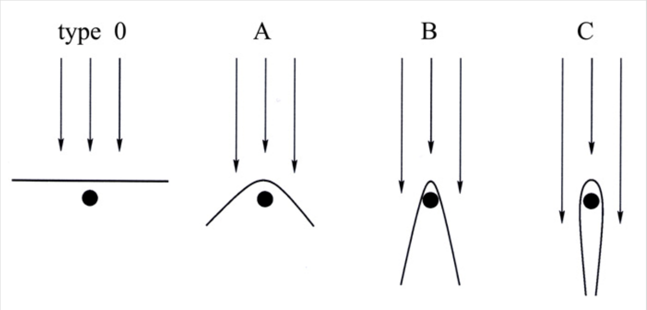


with UC or C HII regions

SFO 14	type A	*Deharveng et al. 1997*
SFO 74	A	*Thompson , Urquhart & White 2004*
SFO 79	0	*Urquhart et al. 2004*
SFO 59	A	*Thompson , Urquhart & White 2004*
SFO 62	A	*Thompson , Urquhart & White 2004*
SFO 85	A	*Thompson , Urquhart & White 2004*
Treasure chest		*Smith, Stassun & Bally 2005*

several IR sources, no HII regions — Spitzer images, and

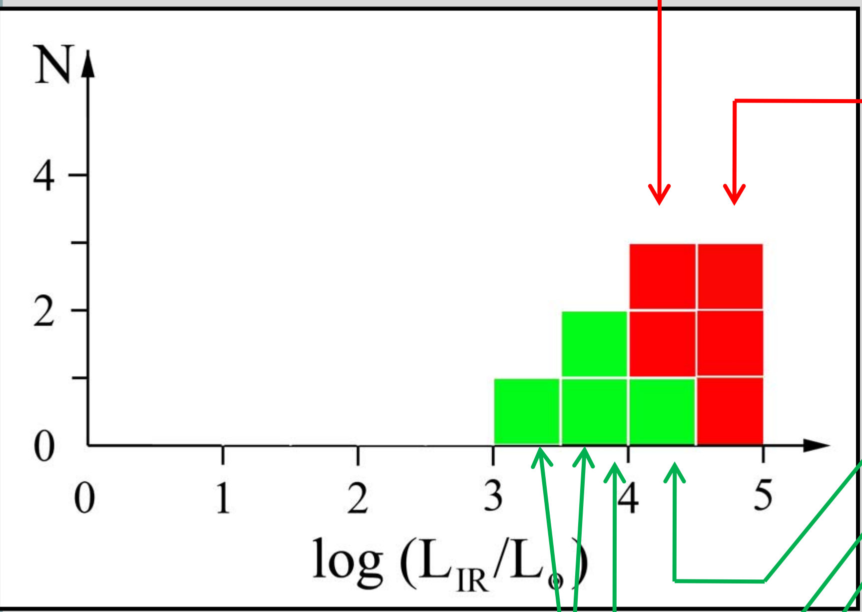
SFO 64	type A	*Thompson, Urquhart & White 2004*
SFO 75	A	*Urquhart et al. 2007*



Several BCRs harbor small HII regions. They are of type A, around a massive molecular cloud *(Yamaguchi et al., 1997).*

No second-generation star more massive than O8 (in SFO 59).

Massive-star formation by collect & collapse



with UC or C HII regions

Sh 104	*Deharveng et al. 2003*
Sh 217	*Brand et al. in preparation*
Sh 212	*Deharveng et al. in preparation*
RCW 79	*Zavagno et al. 2006*
G 332.54-0.13a	*Roman-Lopez & Abraham 2004, Hoare et al. 2007*

clusters without associated HII regions

Sh 241	*Pomarès et al. in preparation*
RCW 82a	*Pomarès et al. in preparation*
RCW 82b	*Pomarès et al. in preparation*
G 332.54-0.13b	*Roman-Lopez & Abraham 2004,*

Until now, no second-generation star formed by C&C more massive than O7.5

Conclusions

Several different processes are at work at forming stars in a given region; the RDI process should not be the only one put forward to explain triggered star-formation.

The “collect” part of collect and collapse is at work almost everywhere at the periphery of the ionized gas. The processes which trigger star formation in the collected layer are many, and are often difficult to identify even in HII regions with simple morphologies.

No second-generation stars more massive than O7-O8… but it does not mean that they do not exist. We are still looking for them.