Stellar feedback from a super star cluster in the Antennae overlap region

Herrera & Boulanger 2017, A&A, 600,139

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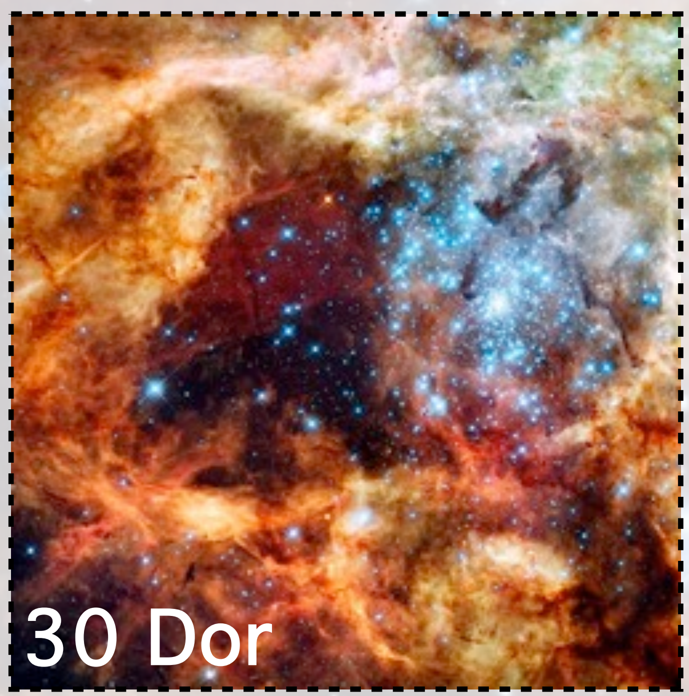
EWASS 2017, S05 High mass stars, their feedback and massive star clusters
June 30th, 2017

Super Star Clusters (SSCs)

One of the most extreme forms of star formation

- Massive ($>10^5\ M_\odot$) star clusters
- Compact (a few parsec)
- Thousands of O stars

... likely the progenitors of Globular Clusters



The number of such objects greatly increases in **galaxy interactions and mergers**, common phenomenon in the Universe.

How do they form and early evolve?

Star formation... and inefficient process

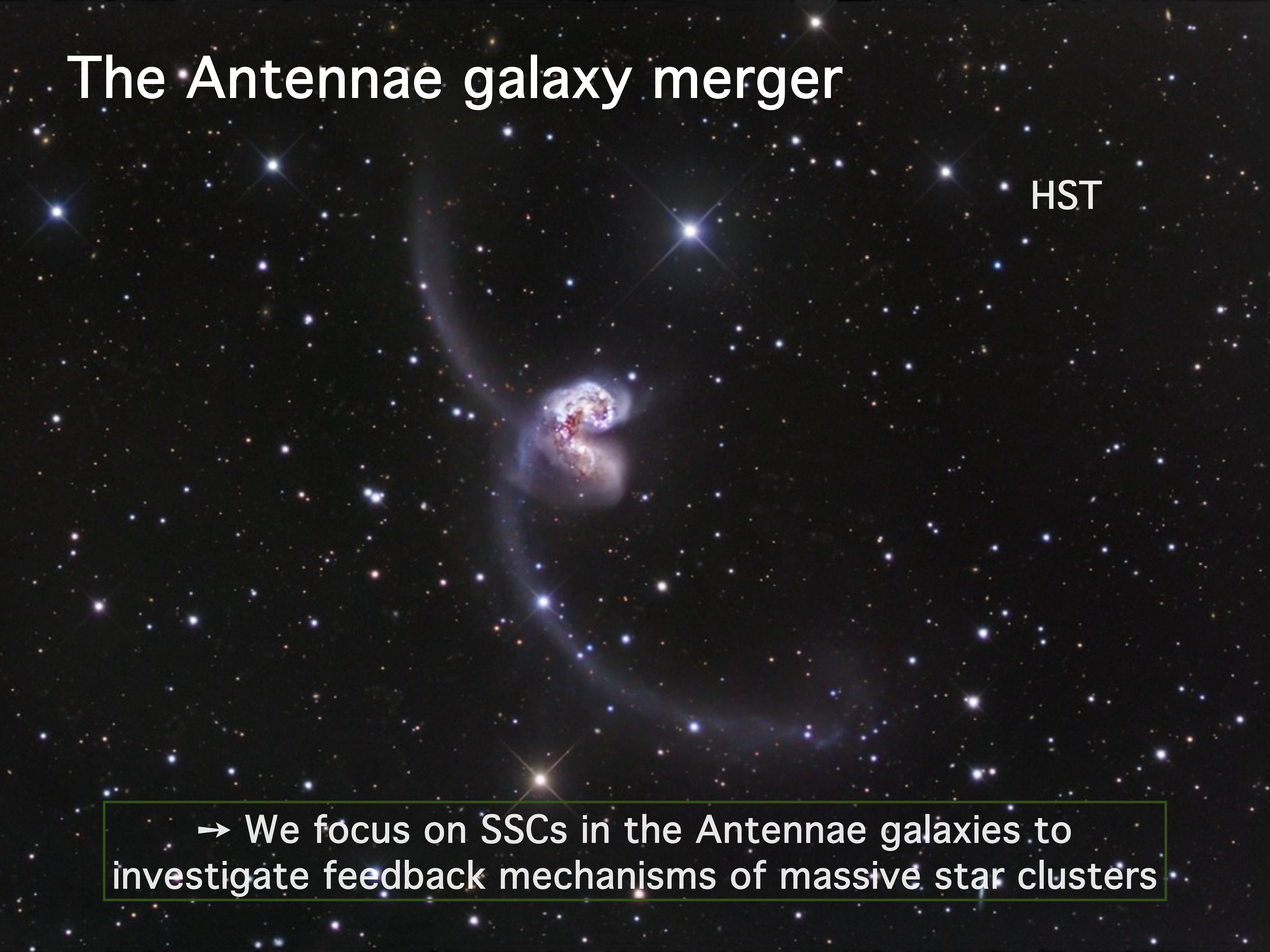
Massive star feedback is vital to galaxy evolution and star formation history in the Universe. Radiation pressure and stellar winds are important in unbinding, dispersing and disrupting large molecular clouds (e.g. Murray et al. 2010, Lopez et al. 2010).

Theory: Massive star formation needs high external pressures (10^7-10^8 k_B cm^{-3}) (Elmegreen & Efremov 1997; Ashman & Zepf 2001).

The dynamical timescale of their parent clouds must be shorter than their disruption timescale to have high SFE.

But.... lack of observational support to understand the details

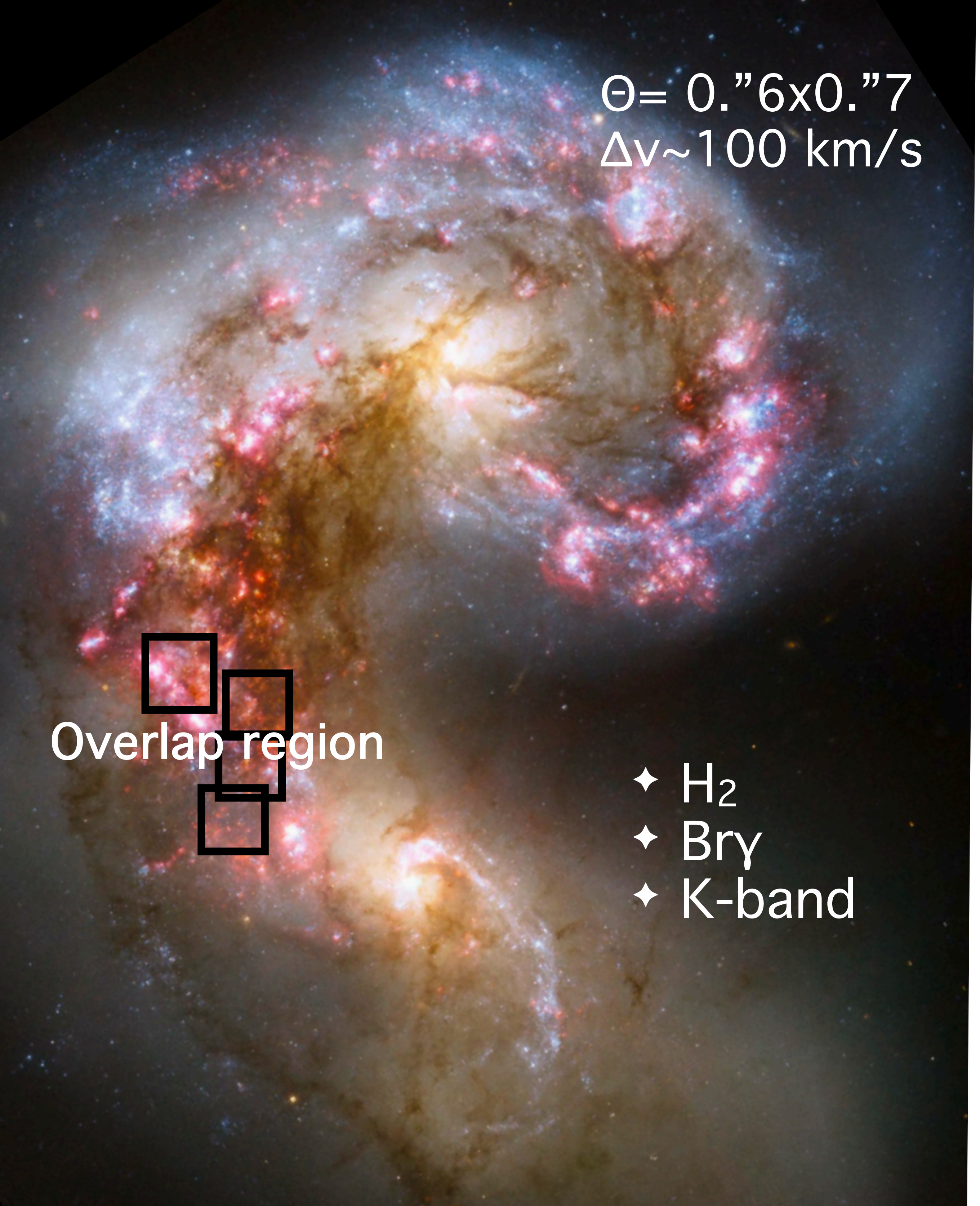
The Antennae galaxy merger



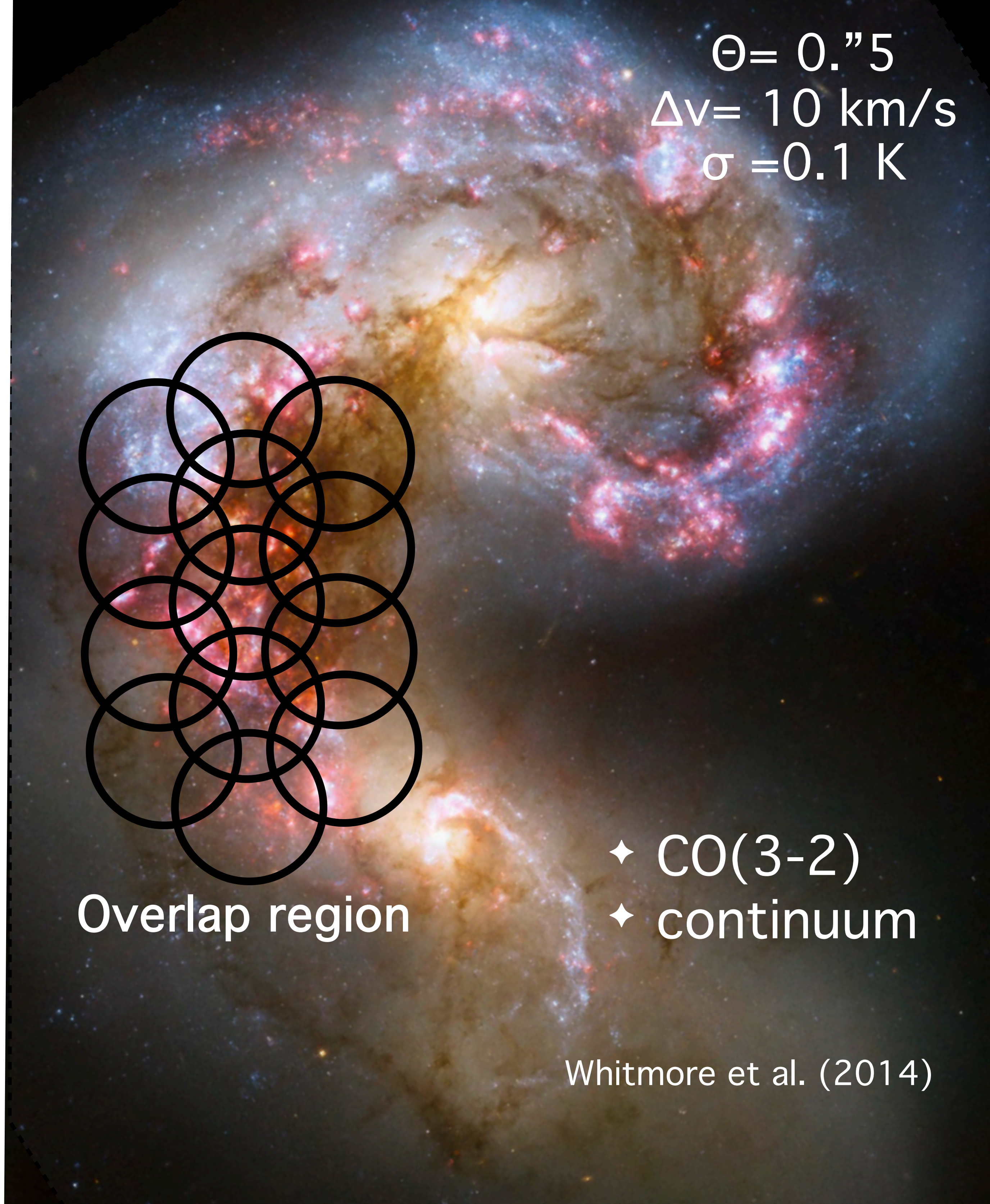
→ We focus on SSCs in the Antennae galaxies to investigate feedback mechanisms of massive star clusters

Observations

SINFONI/VLT (IFU) in the K-band



ALMA Cycle 0 (arch.) obs.



Search for embedded SSCs

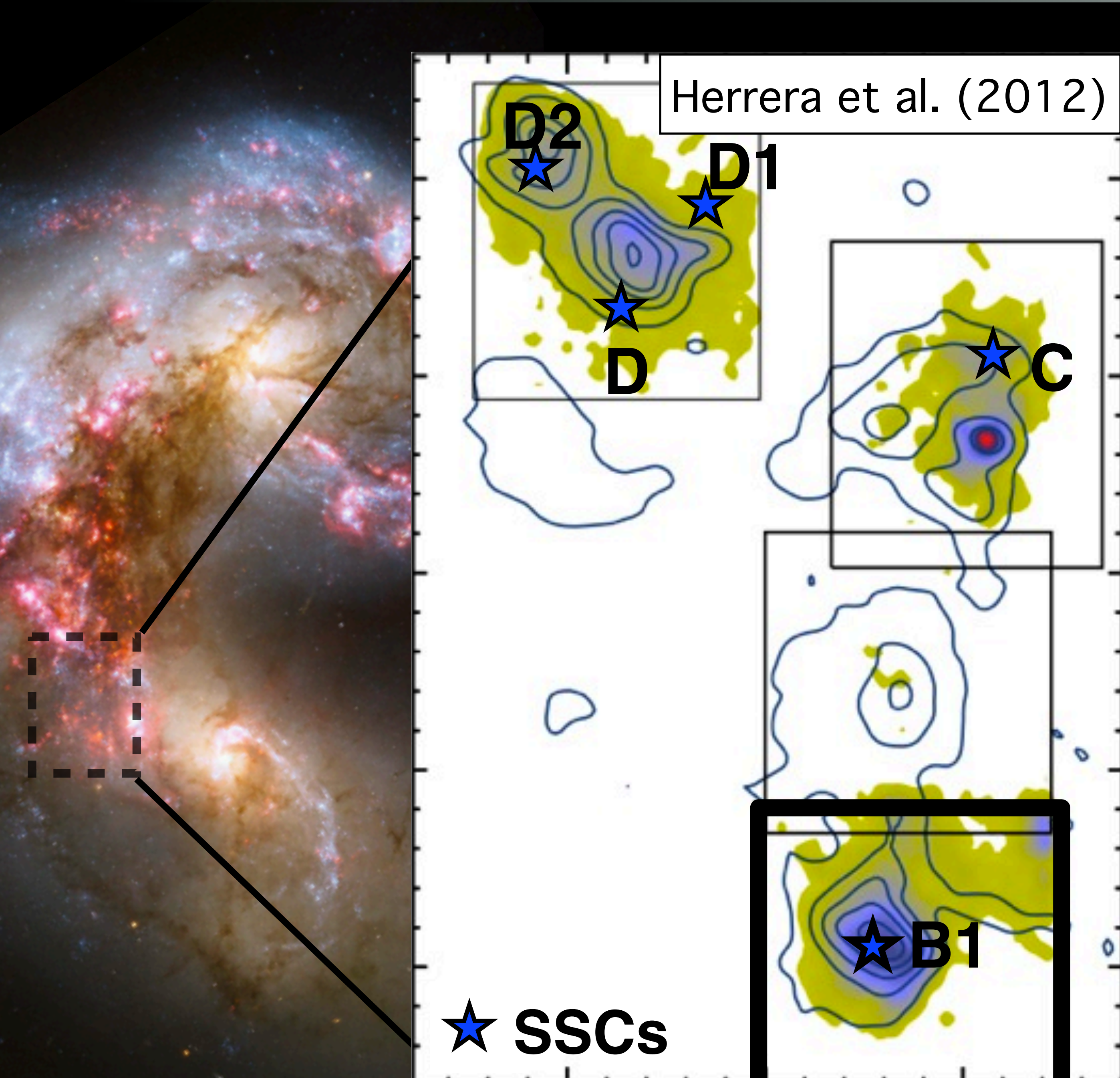
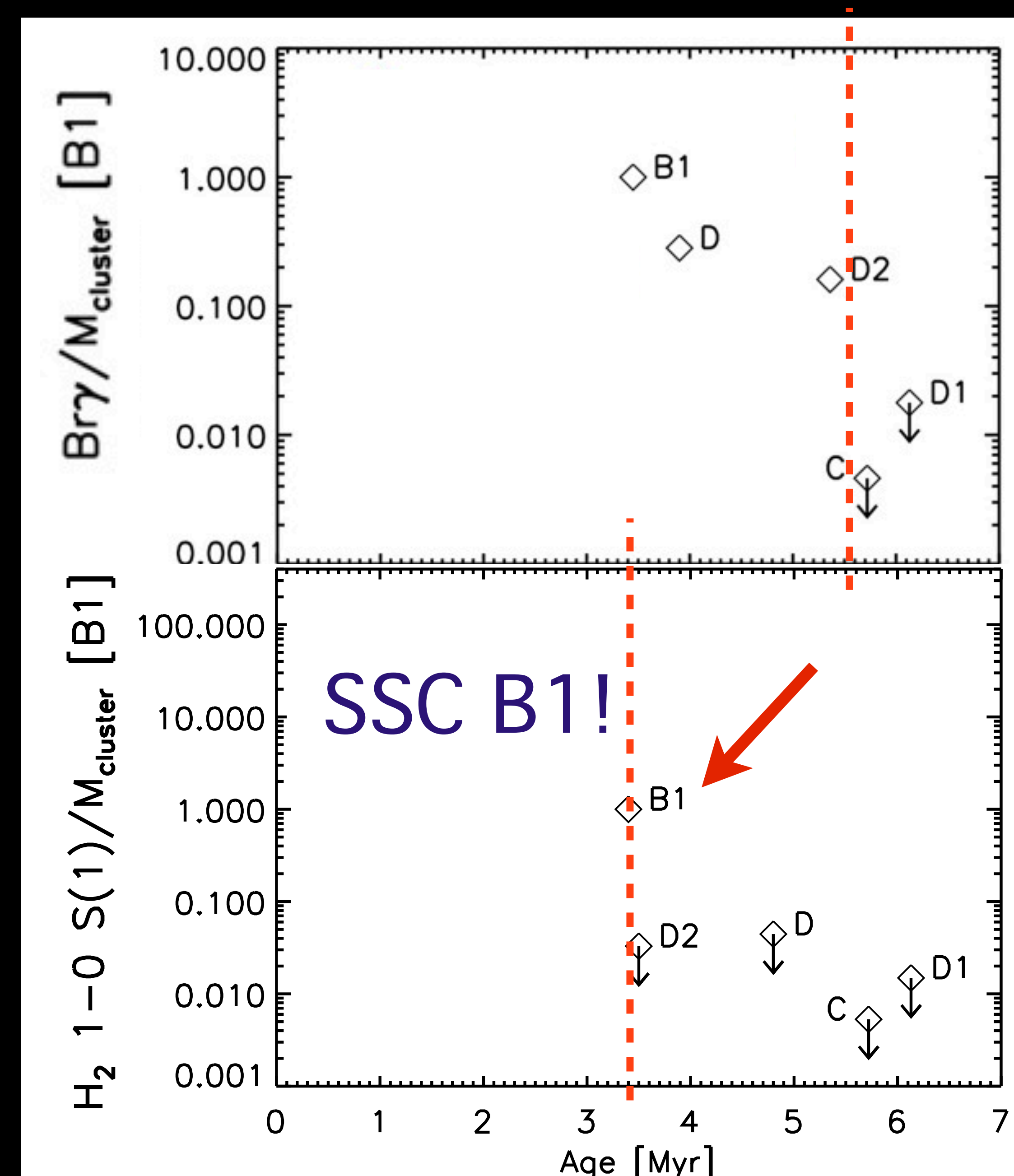


Image: H_2 1-0 S(1)
Contours: CO(3-2)

Look for SSCs associated with compact molecular and ionized gas emission.

We focus on SSCs isolated from others (SSCs: D, D1, D2, C, B1)



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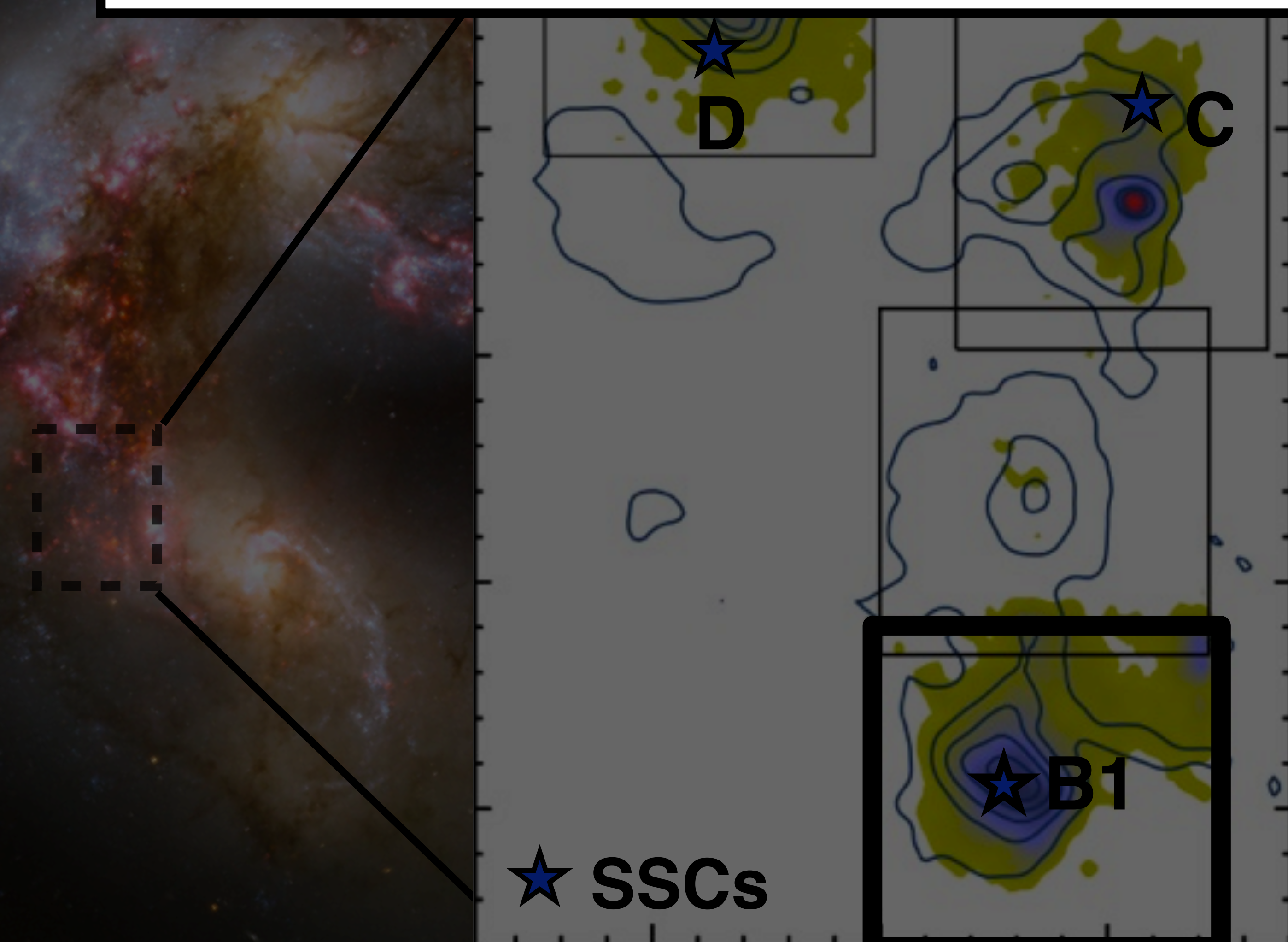
SSC B1 is associated with compact molecular and ionized emission.
Hypothesis: SSC B1 is still embedded in its parent molecular cloud.

➜ We investigate the impact of the stellar feedback from SSC B1 on its surrounding matter.



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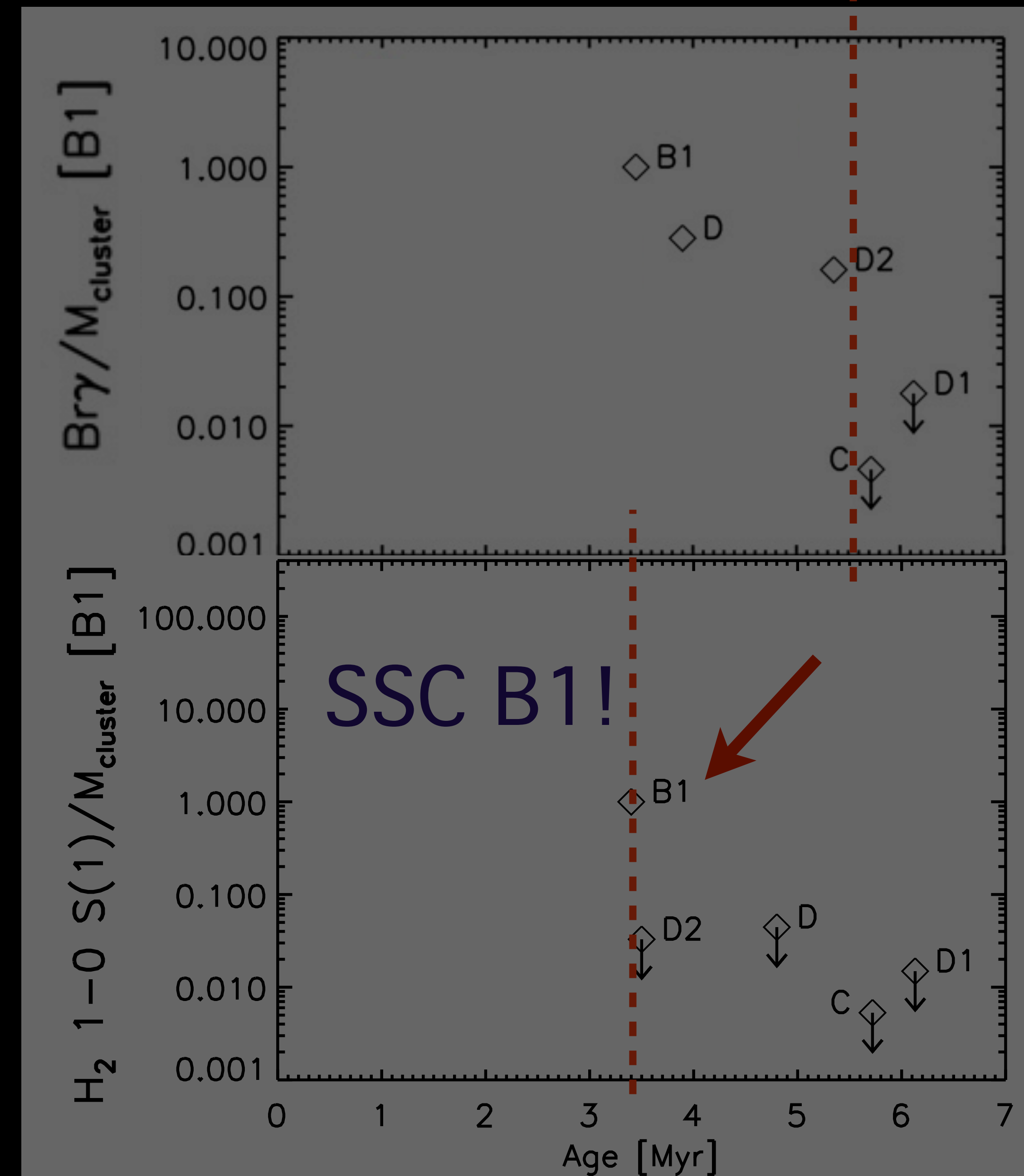

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Properties of SSC B1

Well known SSC! 15% of flux 8-15μm (ISO, 1.”5).
(Whitmore & Shweizer 95, Mirabel et al. 98)

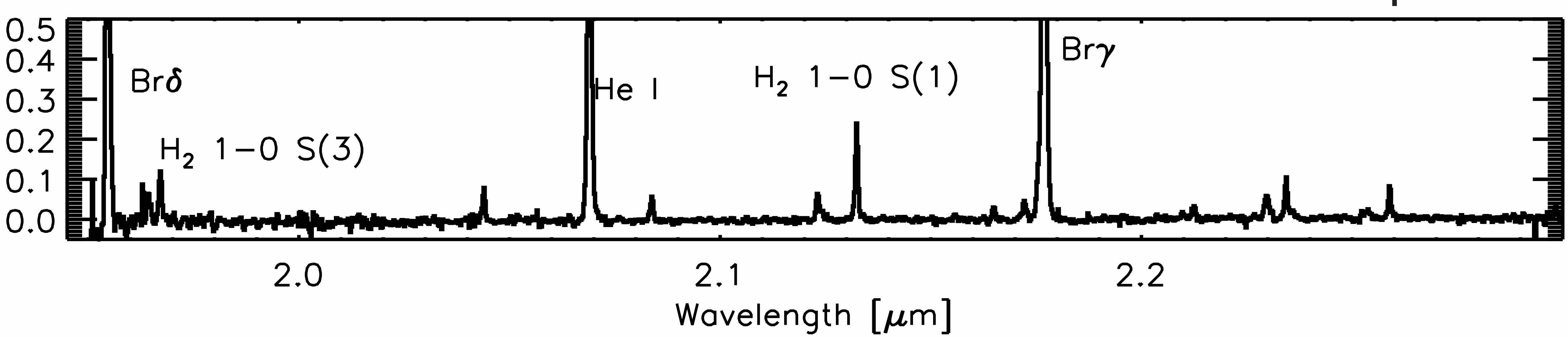
N_{Lyc} = 2.2×10^{53} phot. s^{-1}
(Neff & Ulvestad 2000)

Stellar age = 1 Myr (3.5 Myr)
(Whitmore+10: UBVIHα photometry; Brγ EW our work)

Stellar mass = 6.8×10^{6} $M_{\odot}$
(Whitmore+10: UBVIHα photometry)

Molecular mass = 4.6×10^{7} $M_{\odot}$
(dust emission, our work)

K-band spectrum



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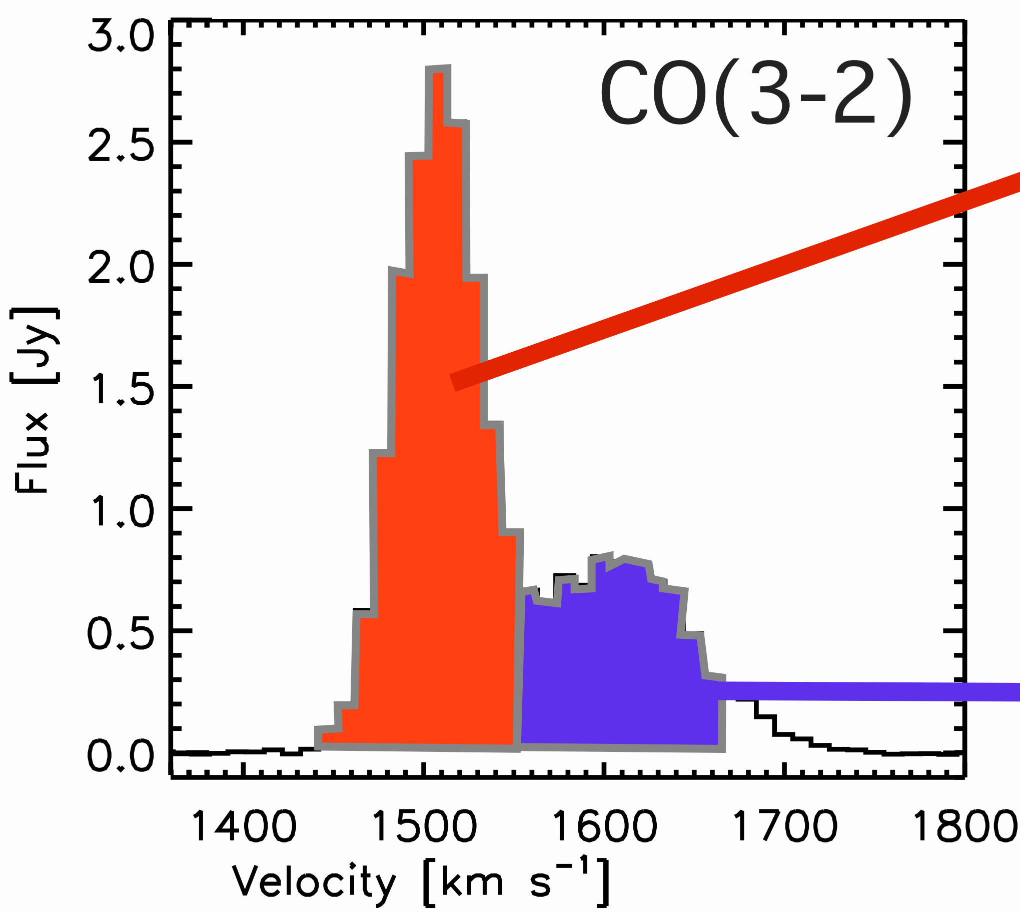
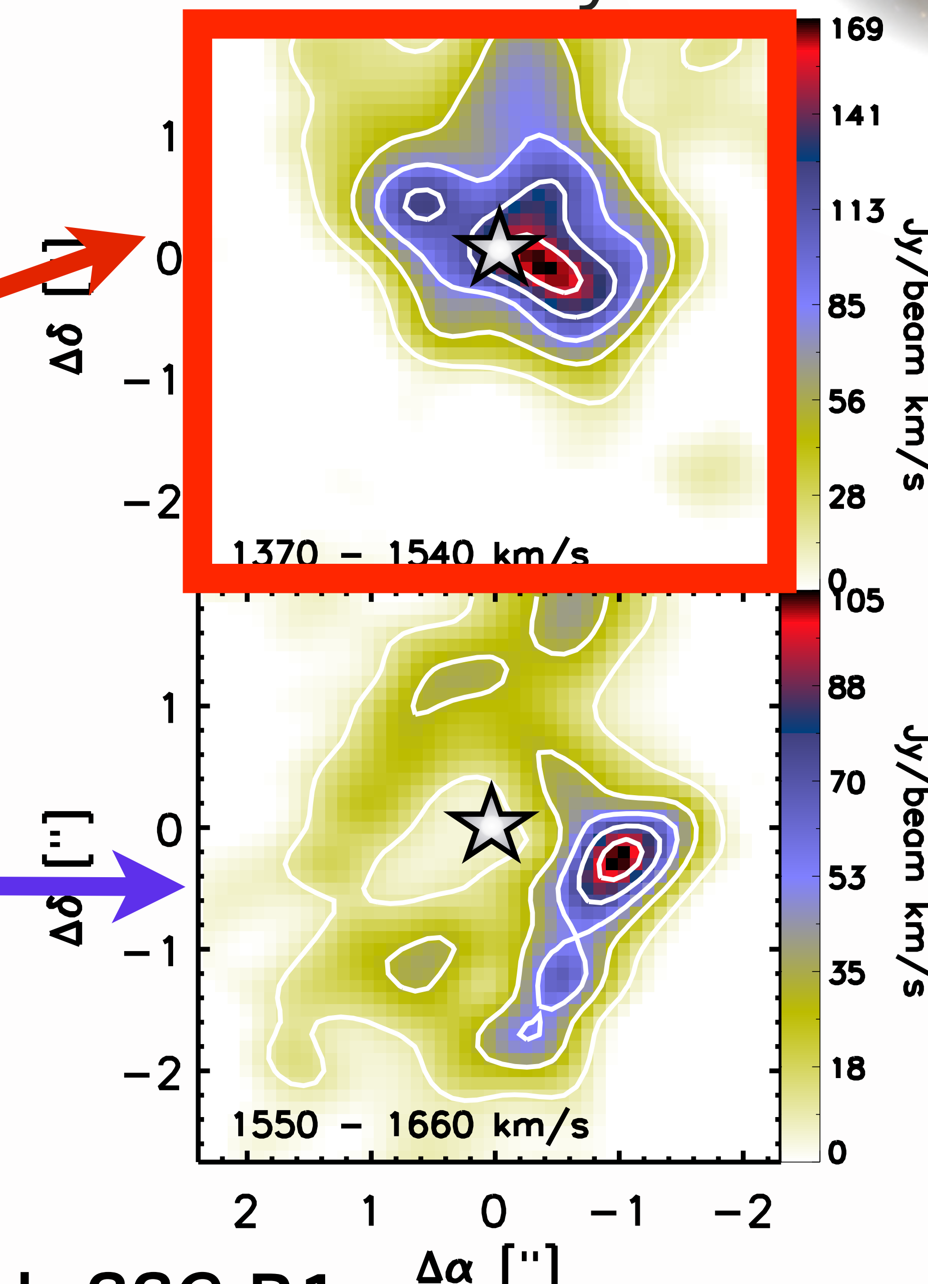
Properties of SSC B1

Two molecular gas velocity components observed in the CO gas



Velocity integrated intensity



- Low velocity component associated with SSC B1
- High velocity component associated with SGMC4/5

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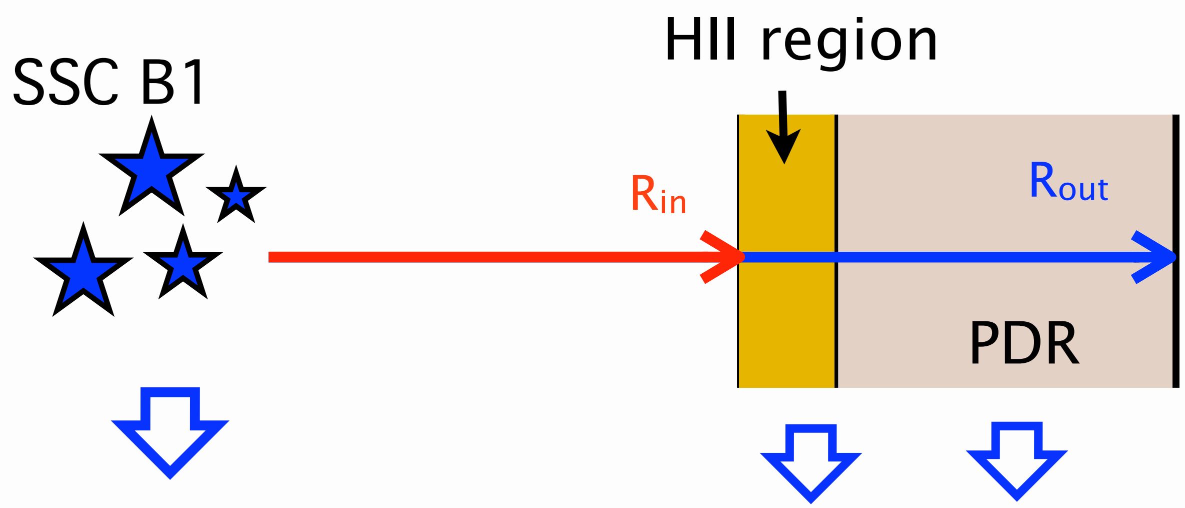
Physical Structure

Modeling of the physical environment (SSC, HII region, PDR)



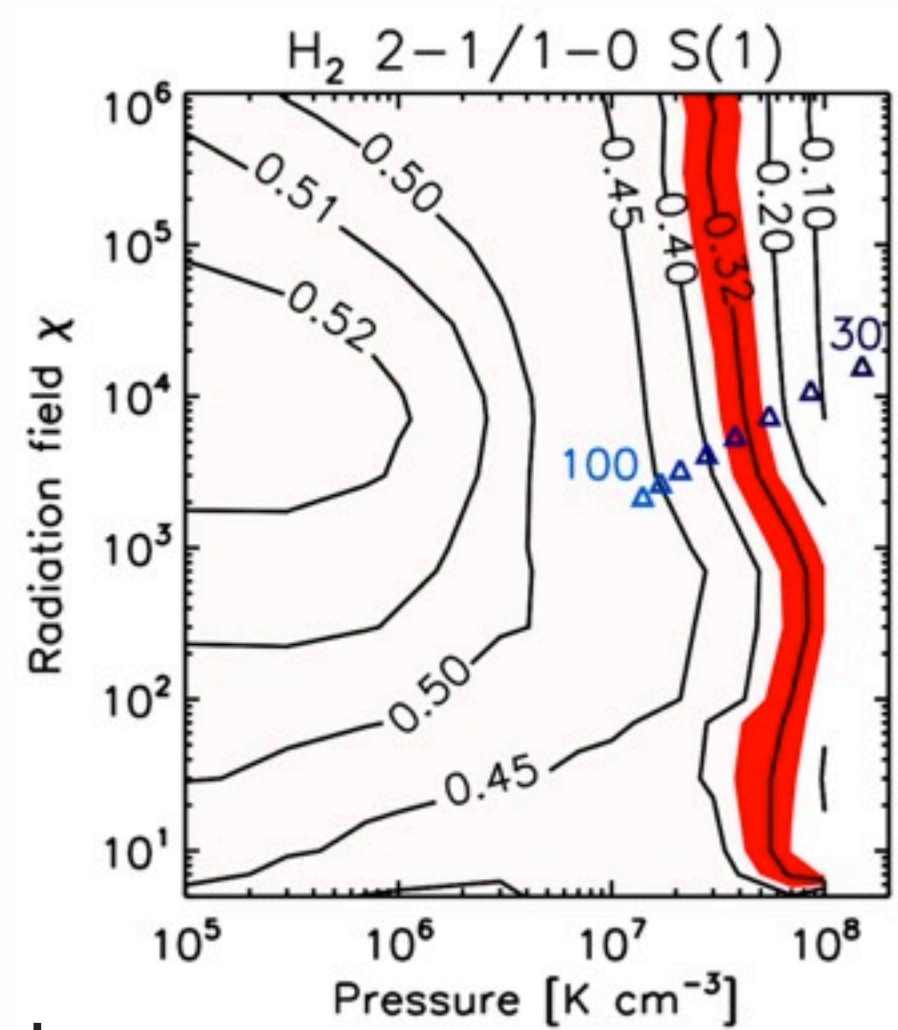
Starburst99

Age, Stellar mass

HII Model

PDR Meudon Code

(Isobaric models)



The observed H_2 lines can be modeled by a PDR with a gas pressure of ~ 10^8 K cm^{-3} .

△ R_{in} values

P_{gas} ~ $3x10^7$ - 10^8 K cm^{-3}

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Physical Structure

- **Gas pressure in molecular gas**

$$\frac{P_{\rm rad}}{k_{\rm B}} = 3.4 \times 10^{7} \times (1 + \langle \tau_{\rm rad} \rangle) \times \left(\frac{[35\ {\rm pc}]}{R_{\rm in}} \right)^{2}\ {\rm K\ cm^{-3}}$$

$$P_{\rm rad} = (1 + \langle \tau_{\rm rad} \rangle) \frac{L_{\rm cl}}{4\pi R_{\rm in}^{2}\, c}$$

Measurement of the cloud's opacity

Pressure agrees with that obtained from the PDR models, supporting very low values of $\tau_{\rm rad}$.

- **Gas pressure in hot gas**

$$\frac{P_{\rm hot,X}}{k_{\rm B}} = 1.2 \pm 0.4 \times 10^{7} \times \left(\frac{[35\ {\rm pc}]}{R_{\rm in}} \right)^{3/2}\ {\rm K\ cm^{-3}}$$

$$P_{\rm hot,X} = 1.9\, n_e\, k_{\rm B}\, T$$

SSC B1 is a compact X-ray source (Zezas et al. 2006)

Three times weaker than $P_{\rm rad}$ and 50 times smaller than the theoretical value estimated from the mechanical energy input of the SSC.

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Physical Structure

- Gas pressure in molecular gas

$$\frac{P_{\rm rad}}{k_{\rm B}} = 3.4 \times 10^{7} \times (1 + \langle \tau_{\rm rad} \rangle) \times \left(\frac{[35 \text{ pc}]}{R_{\rm in}} \right)^{2} \text{ K cm}^{-3}$$

$P_{\rm rad} = (1 + \langle\tau$ … hat … odels, … of $\tau_{\rm rad}$.

Measurement … cloud's c…

- Gas …

$P_{\rm hot,X} = 1.9$ … than $P_{\rm rad}$ … n the … rom the … the SSC.

SSC B1 is a co… source (Zezas …

- There is a leak out of the plasma. The shell around the cluster must be clumpy with moderate column density lines-of-sight through which radiation can escape.
- $P_{\rm rad}$ is not enough to push away the matter surrounding the cluster. There will be no further acceleration of the matter by $P_{\rm rad}$.
- This component probably did not participate in the formation of SSC B1.

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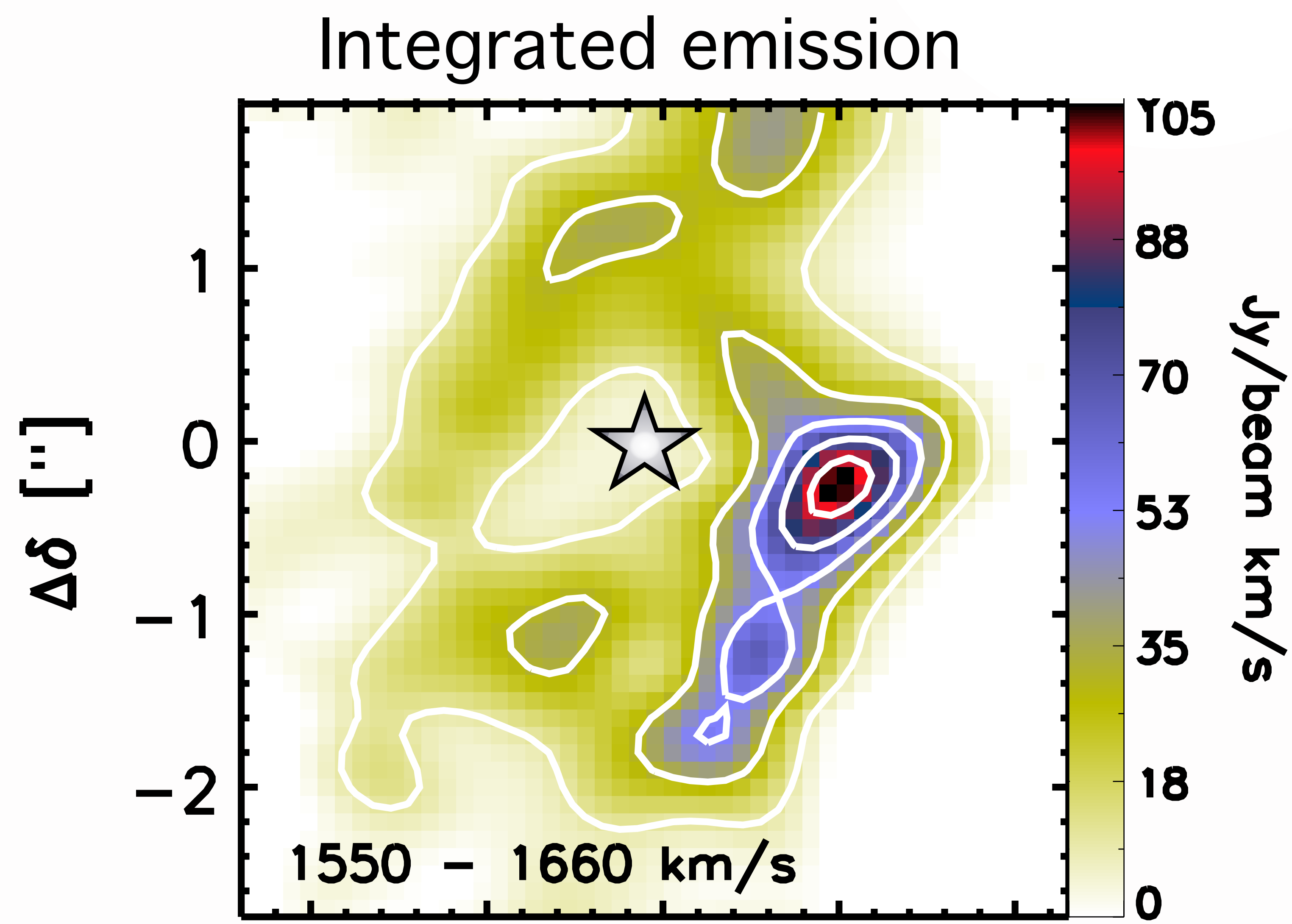
Dynamics of the molecular gas

Broad, high velocity component (associated with SGMC)

Δv = 100 km/s
V_{LSR} = 1594 km/s

It can trace outflowing gas with a v_{exp} of 80 km/s. This molecular gas could have been accelerated at earlier stages of the cluster evolution.



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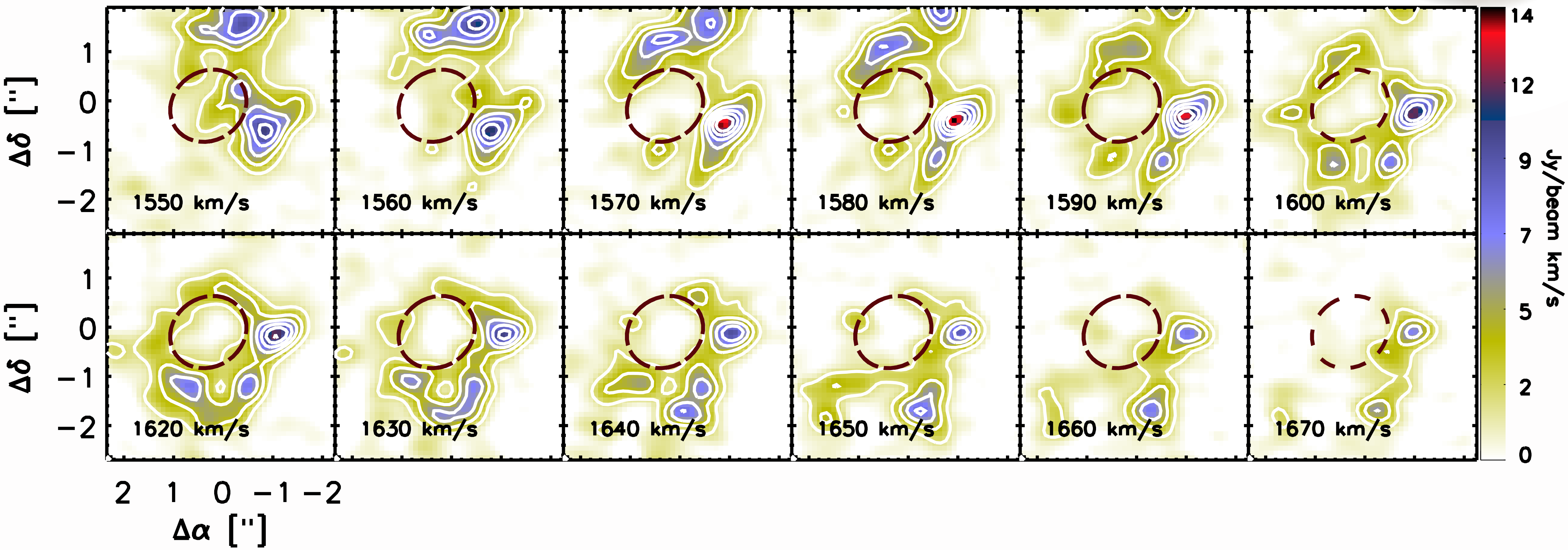
Dynamics of the molecular gas

CO(3-2) high velocity component channel maps



Supper bubble

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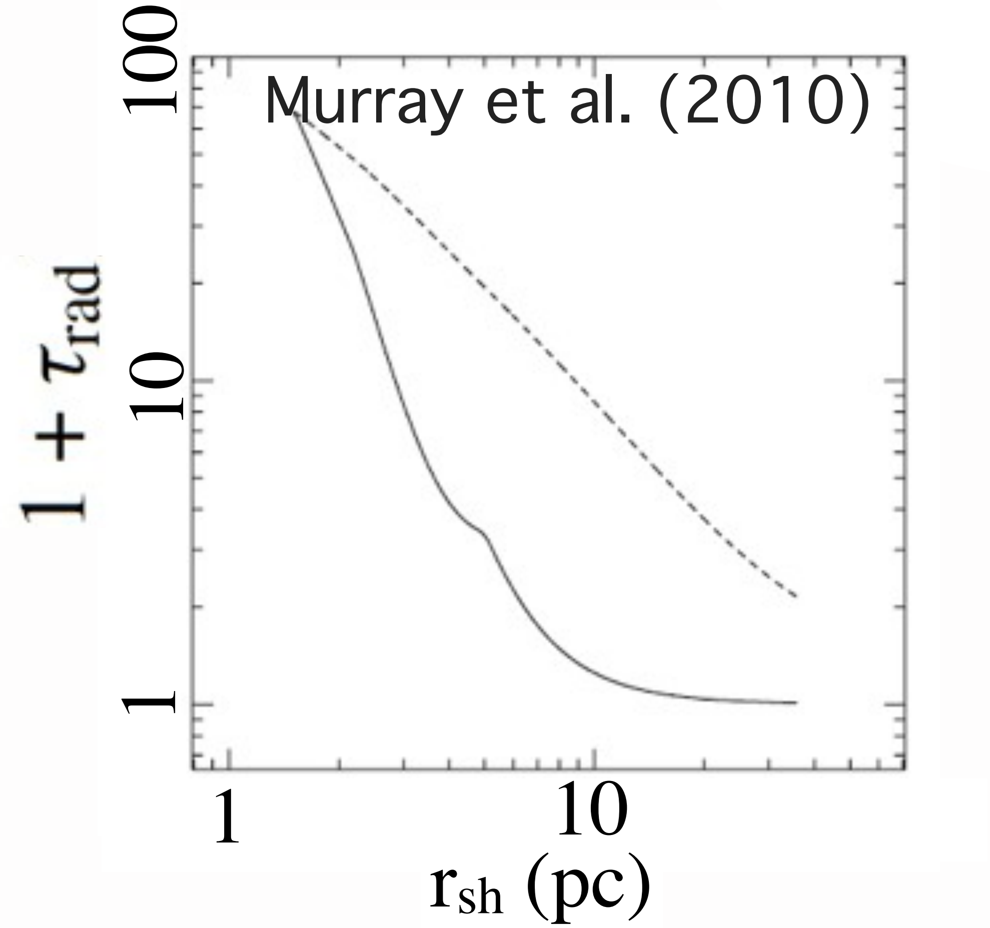
Dynamics of the molecular gas

At the beginning of the expansion, radiation pressure must have been much higher than today.

$$F_{\rm rad} = (1 + \tau_{\rm rad})\frac{L}{c}$$

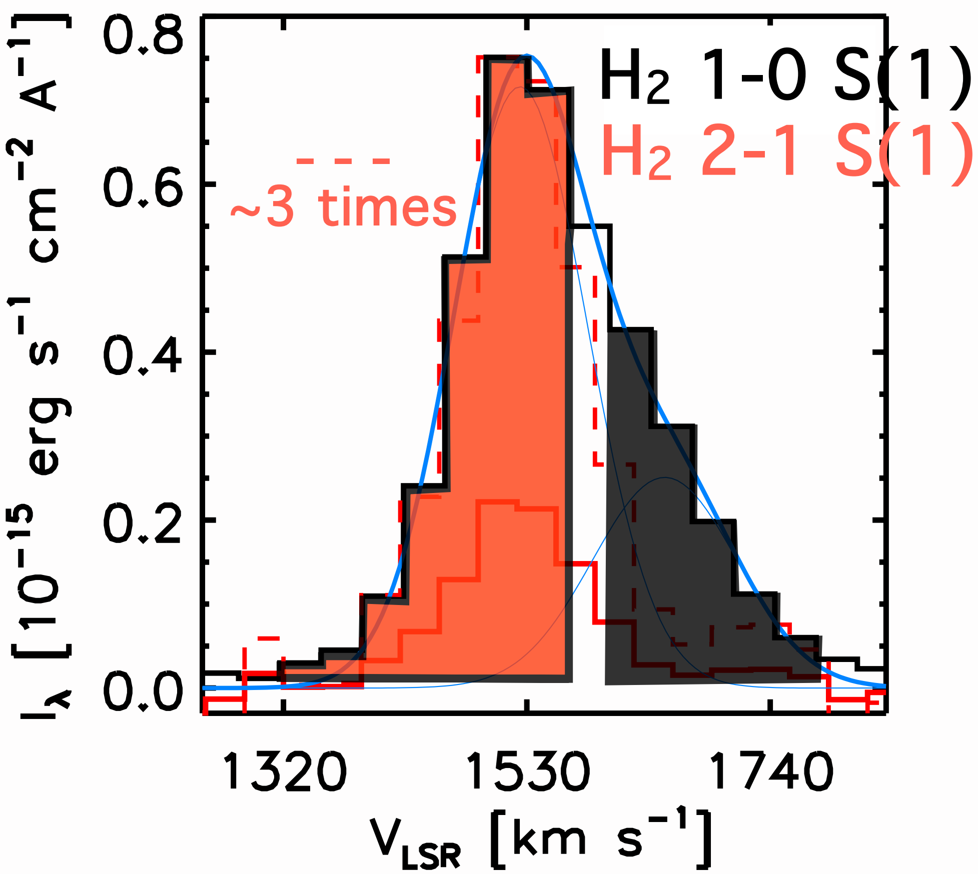
Murray et al. 2010: model the disruption of an environment with similar characteristics to SSC B1. The disruption of the parent cloud occurs in less than 1 Myr.



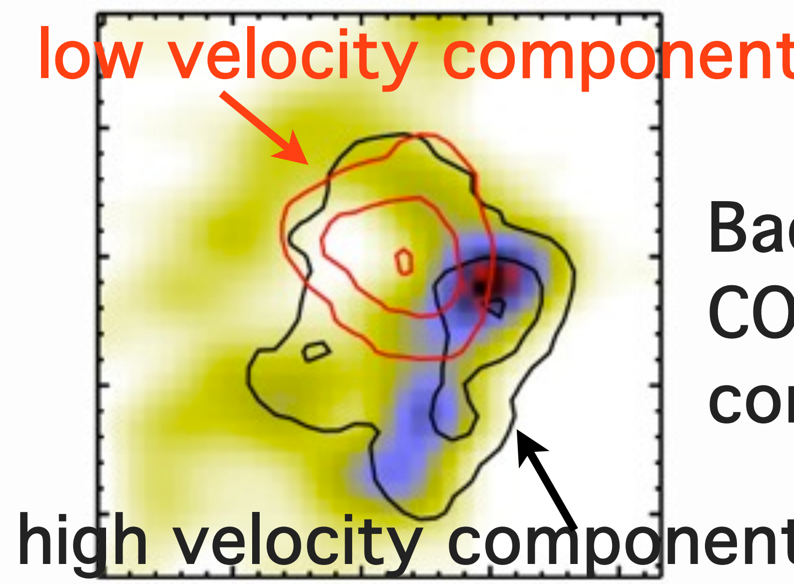
→ Gas from the parent cloud of SSC B1 was accelerated at the beginning of the cluster formation by radiation pressure and now it is expanding, leaving the cluster environment.

Outflowing gas

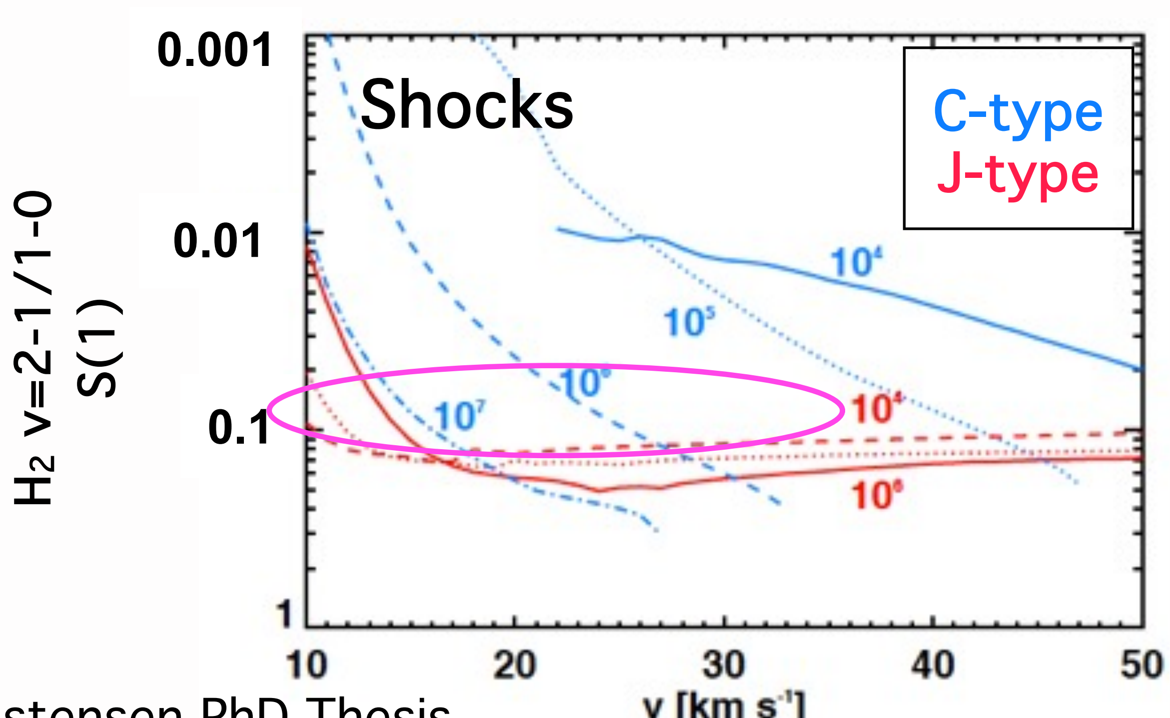
H2 spectra of SGMC 4/5



Contours H2:



Background image:
CO high velocity
component



J. Kristensen PhD Thesis

For high velocity component:
H_2 2-1/1-0 S(1) <0.18
➜ Indicates shocks

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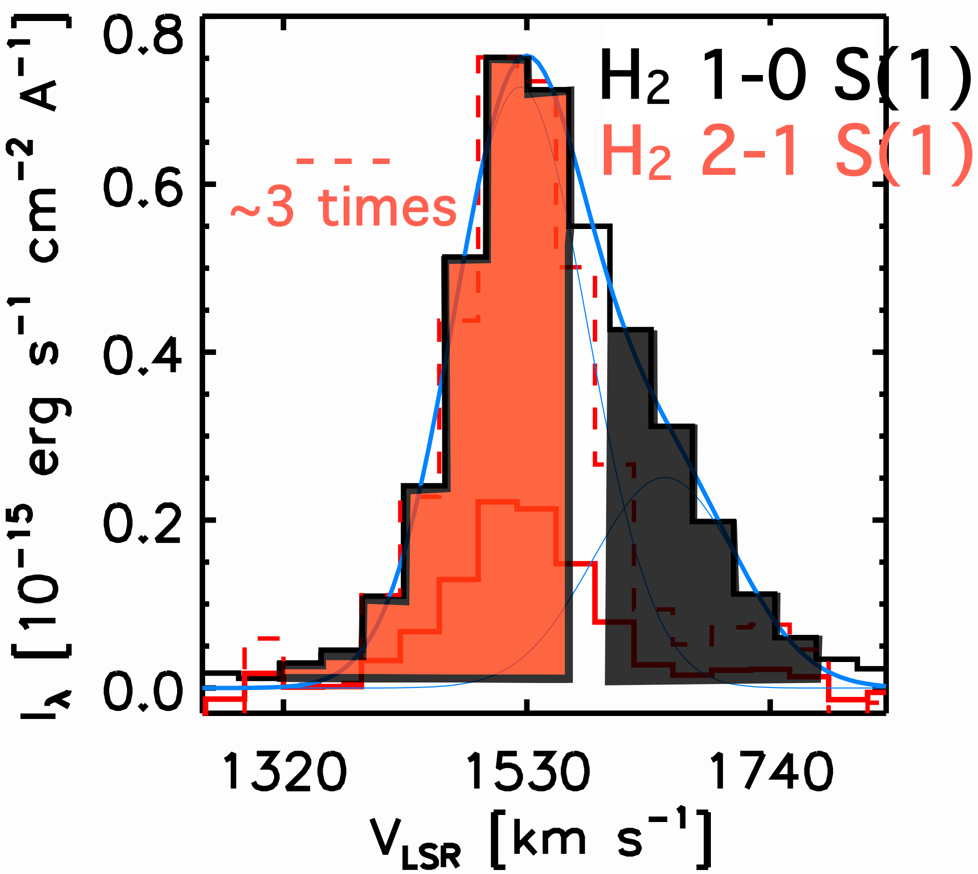
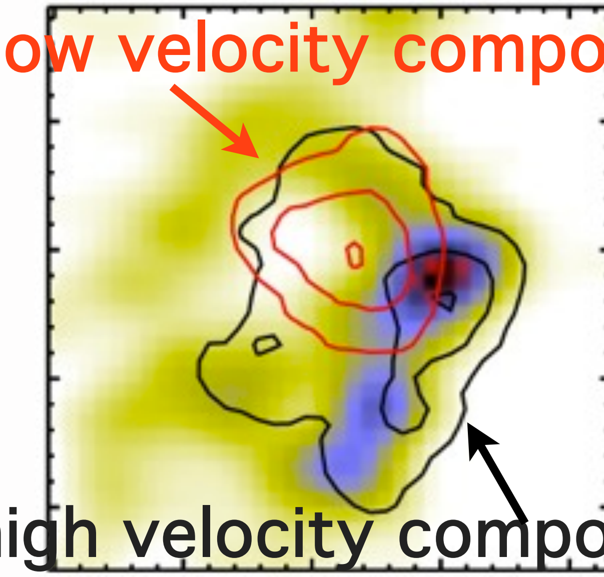
Outflowing gas

H_2 spectra of SGMC 4/5



Contours H_2:

low velocity component



high velocity component

Background image:
CO high velocity component

$\Rightarrow$ $t_{\rm feedback} \simeq R_{\rm high}/v_{\rm exp} \simeq 1.2\,{\rm Myr}$

$\Rightarrow$ $\dot{M}_{\rm outflow} = M_{\rm high}/t_{\rm feedback} \sim 30\ M_{\odot}/{\rm yr}$

SFE (within 100 pc) ≥ 17%

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Conclusions

- The parent molecular gas of SSC B1 is already disrupted and to witness the early stages of the cloud disruption we have to focus on clusters < 1 Myr.

- There are evidence of gas being pushed away by the stellar feedback in the high velocity gas component.

- We need higher angular resolution observation in order to understand the origin of the low velocity component

  ➜ ALMA Cycle 3 observations of the CO(3-2) line emission and dust continuum emission at 0.”15 resolution (~15 pc) will reveal the morphology and kinematics of the gas in the vicinity of the cluster (Data analysis!!).