Stellar feedback and triggered star formation in the prototypical bubble RCW 120

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SOFIA Tele-Talk
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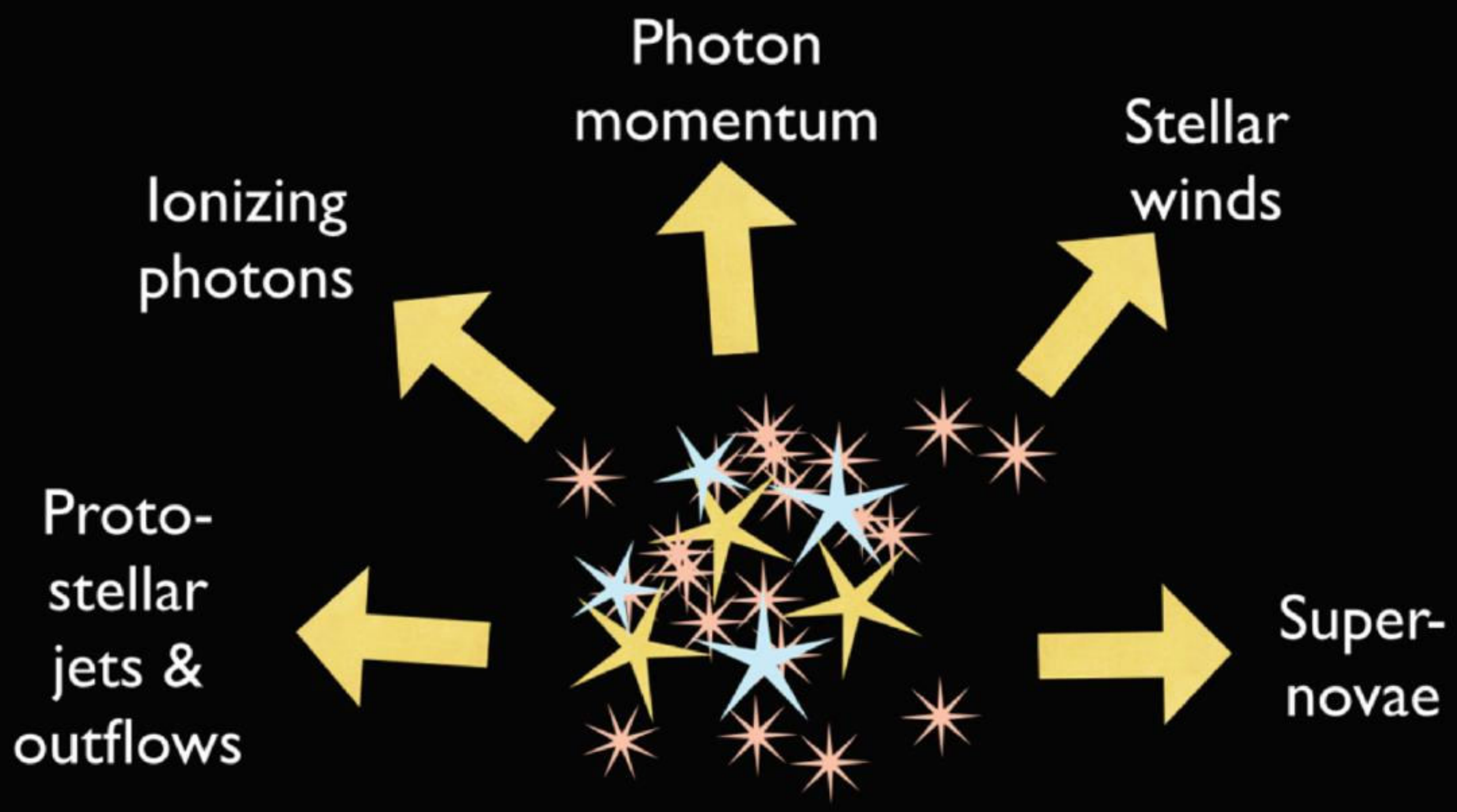
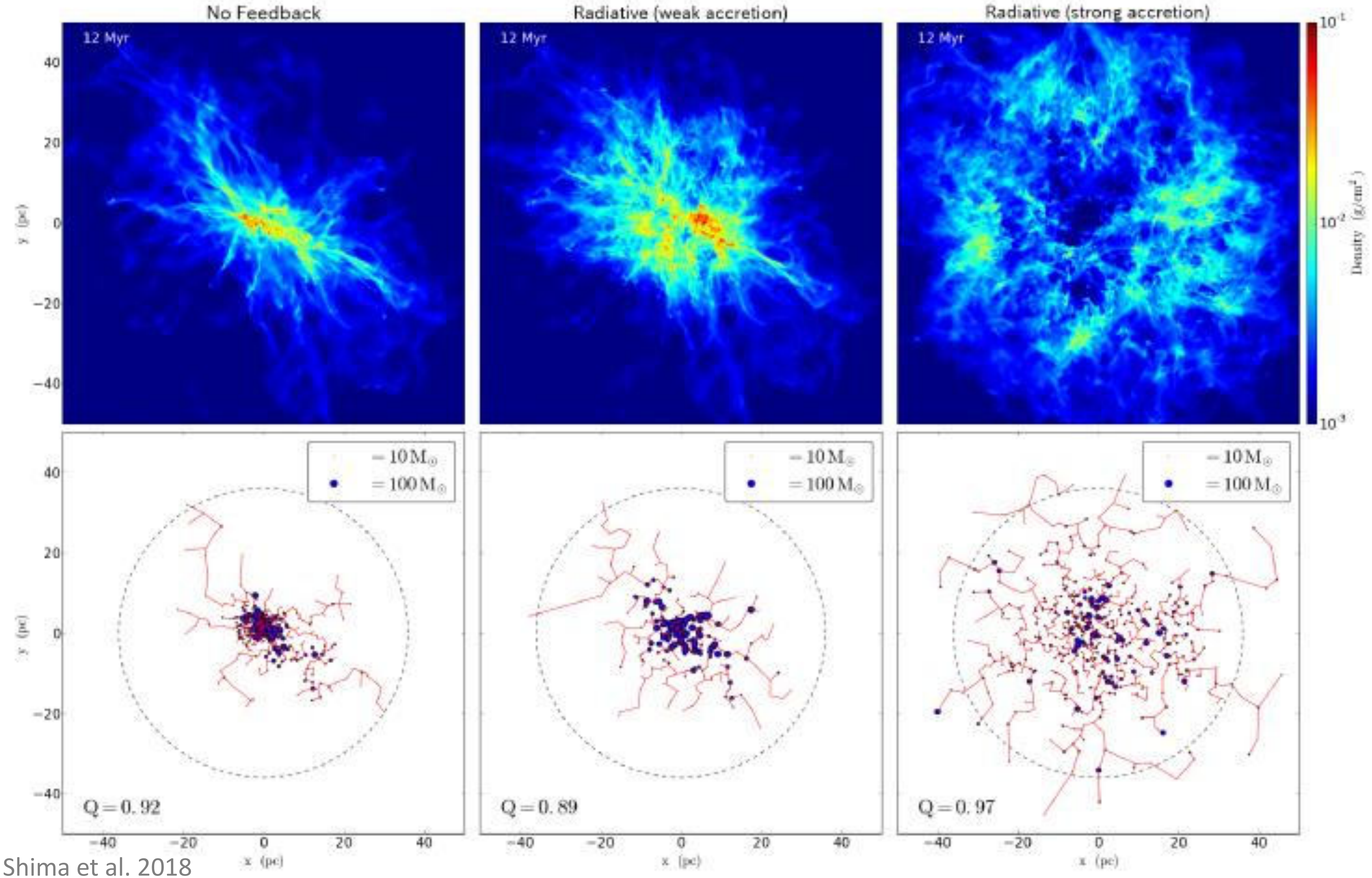
Background: Spitzer (blue: 3.6μm, green: 8μm, red: 24μm)

Stellar **feedback**



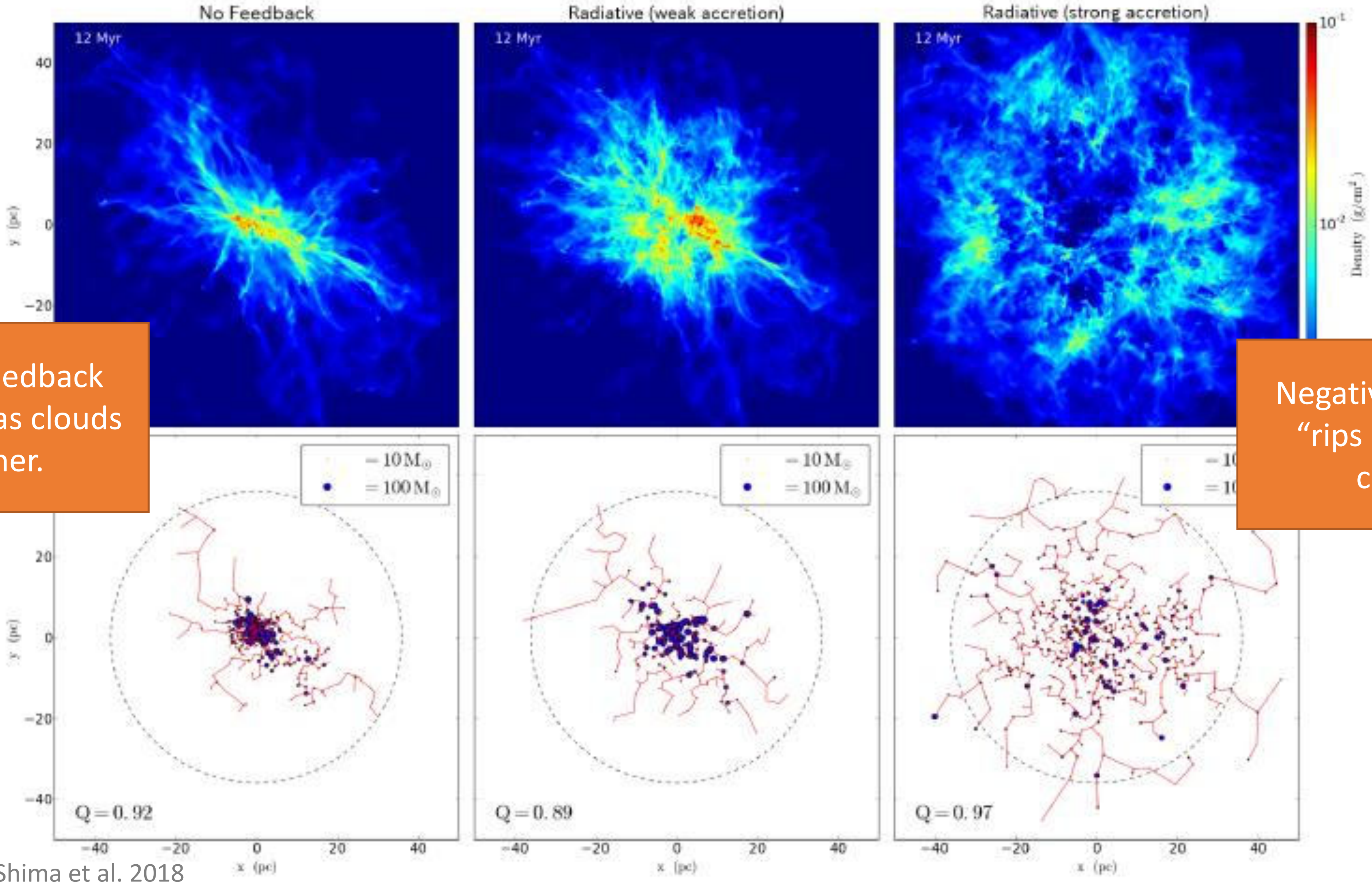
Credit:Matzner

Stellar feedback can be positive or negative



Shima et al. 2018

Stellar feedback can be positive or negative

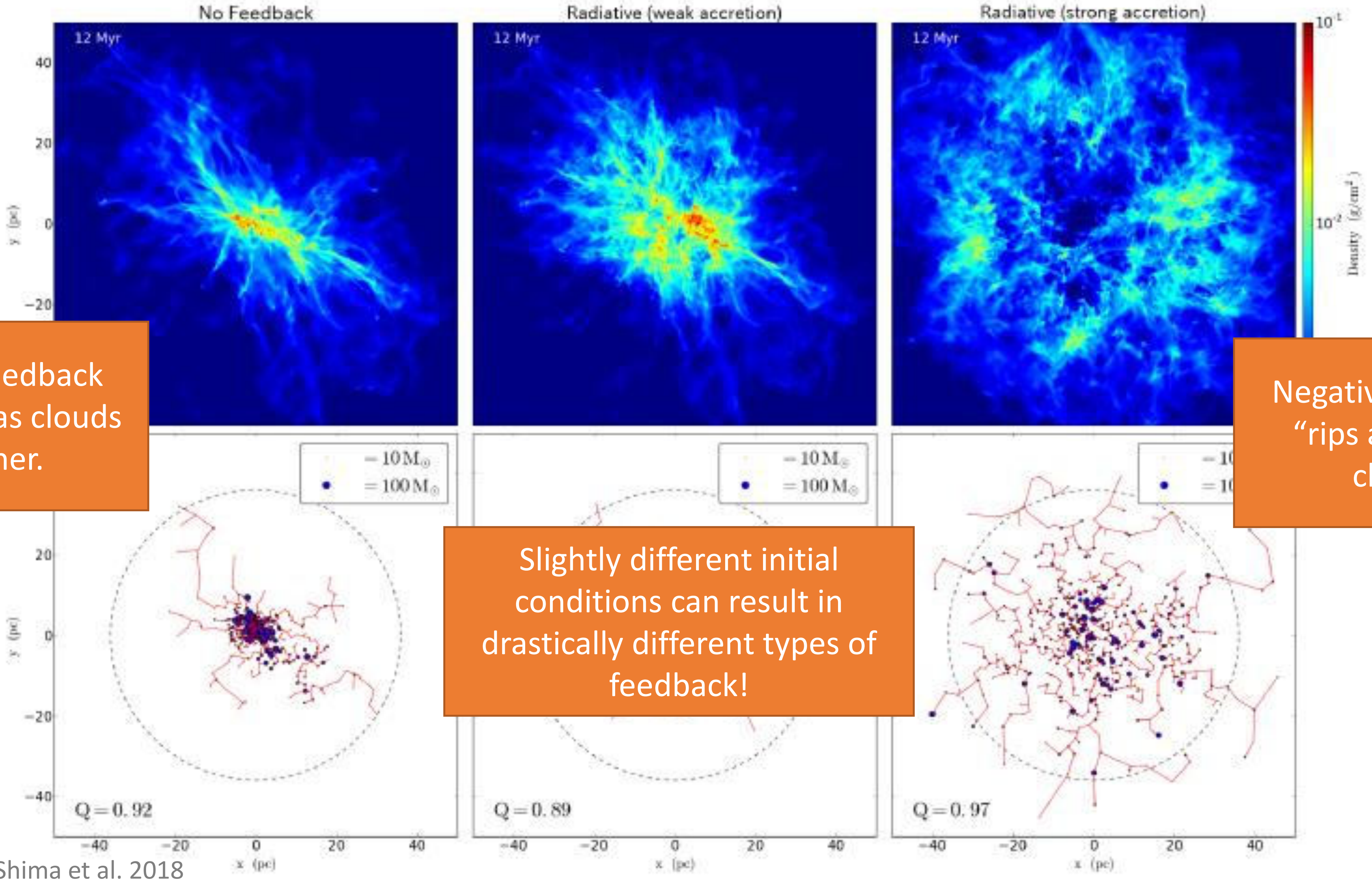


Positive feedback "pushes" gas clouds together.

Negative feedback "rips apart" gas clouds.

Shima et al. 2018

Stellar feedback can be positive or negative



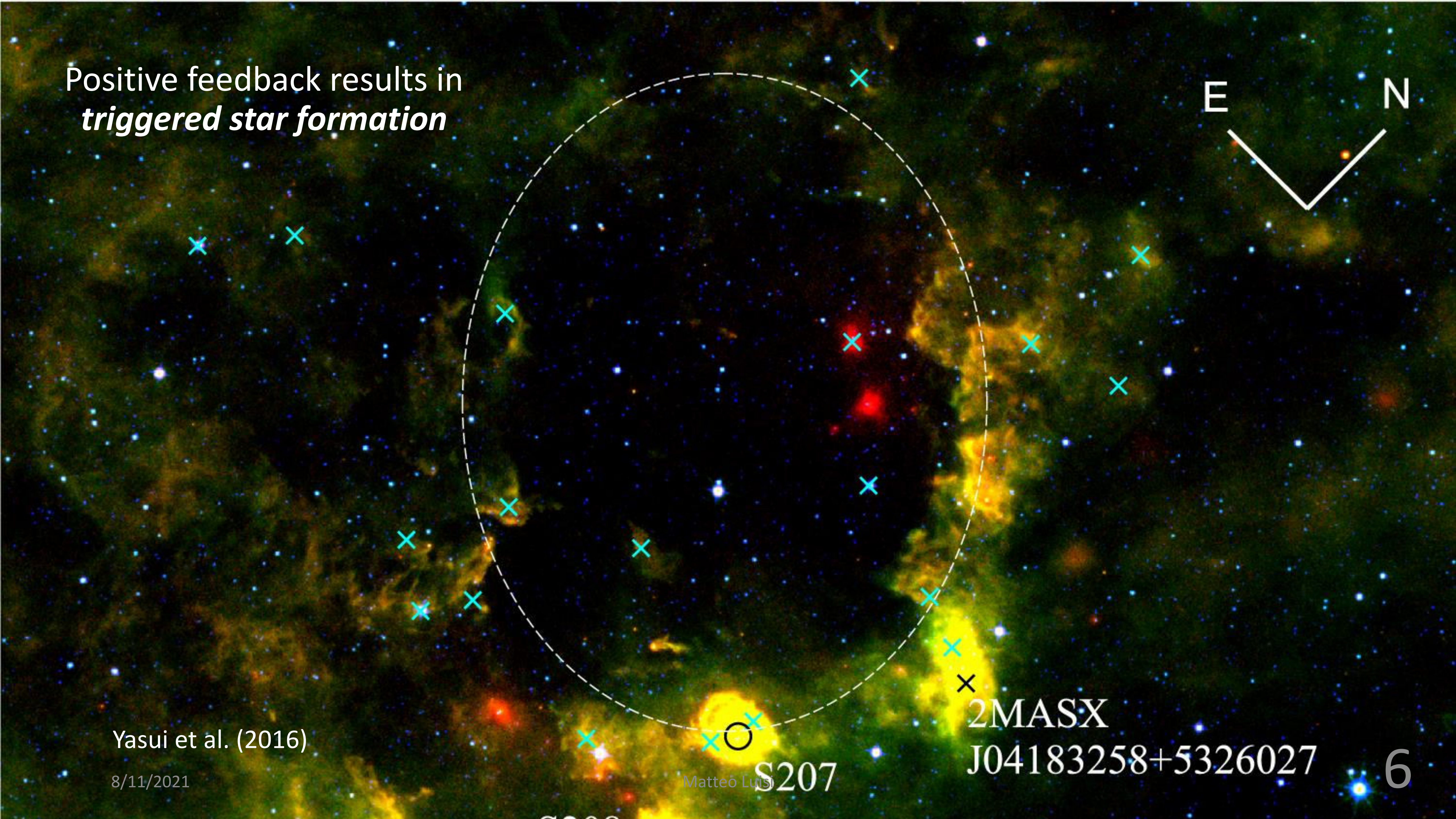
Positive feedback "pushes" gas clouds together.

Slightly different initial conditions can result in drastically different types of feedback!

Negative feedback "rips apart" gas clouds.

Shima et al. 2018

Positive feedback results in
triggered star formation



Yasui et al. (2016)

RCW 120

RCW 120 is the poster child for triggered star formation

Blue: Hα emission
Green: 8.0 μm emission
Red: 24 μm emission

Image from Deharveng et al. (2009)

RCW 120

RCW 120 is the poster child for triggered star formation

Blue: Hα emission
Green: 8.0 μm emission
Red: 24 μm emission

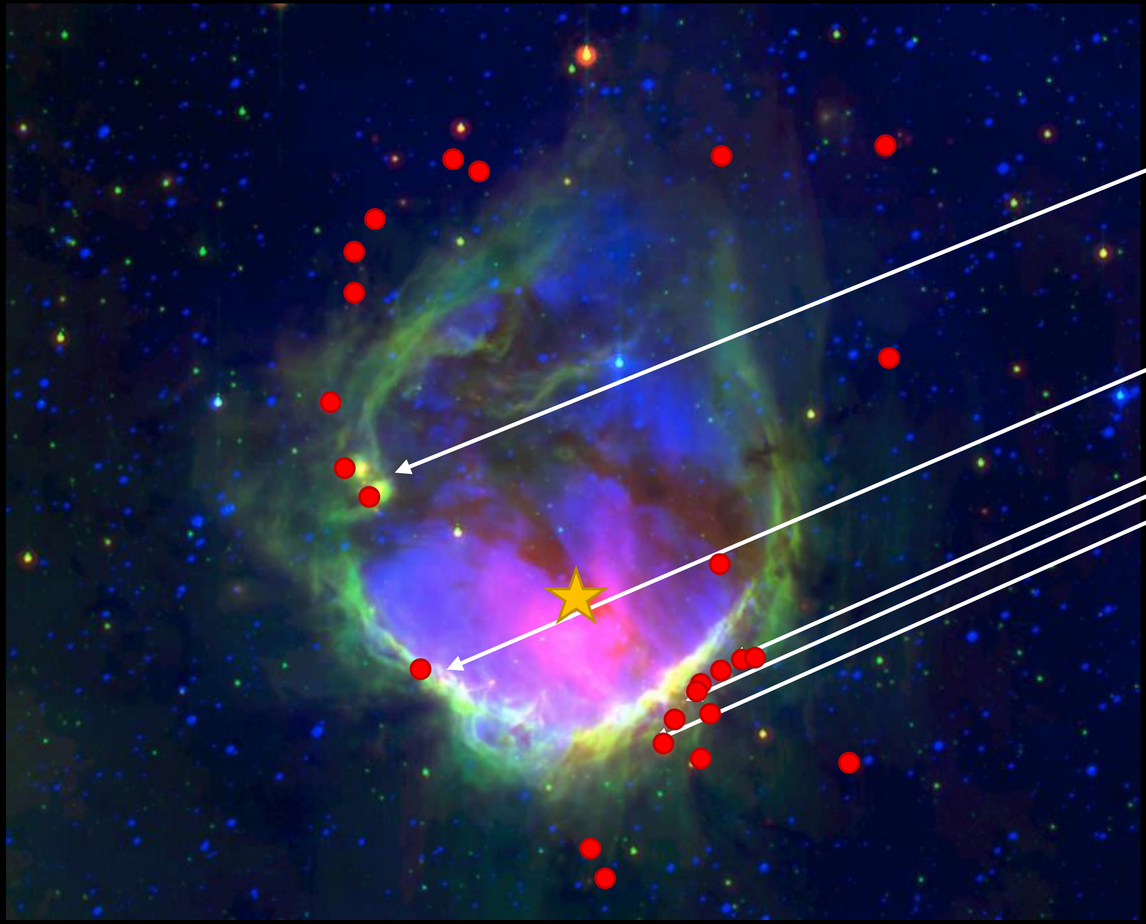
Image from Deharveng et al. (2009)

- RCW 120 is relatively nearby (~1.7 kpc)
- Physical radius ~2.25 pc
- Single ionizing source of type O8

RCW 120

RCW 120 is the poster child for triggered star formation

Blue: Hα emission
Green: 8.0 μm emission
Red: 24 μm emission



YSOs and mm-clumps indicative of recent triggered star formation

Image from Deharveng et al. (2009)

FEEDBACK

- We observed RCW 120 in [CII] 158 μm emission as part of the *SOFIA* FEEDBACK legacy program
  - [CII] transition is a reliable tracer of SFR (on larger scales) and PDRs

NASA photo / Jim Ross

- Also observed RCW 120 in CO J=3-2 emission with APEX

Xander Tielens

FEEDBACK

Nicola Schneider

- Goal: To study the interaction between massive stars with their environment.
- Full survey includes 11 Galactic sources, ranging from single OB stars to small starbursts.
  → Aim to quantify injection of mechanical and radiative energy from different processes (stellar winds, thermal expansion, radiation pressure).
- Total observing time of 96 hours; will produce fully sampled [CII] maps covering a total of ~6000 arcmin^2.
- [CII] line is dominant coolant in the ISM and traces the transition between ionized and neutral/molecular hydrogen.
- FEEDBACK survey paper is published: Schneider et al., PASP **132**, 104301 (2020)

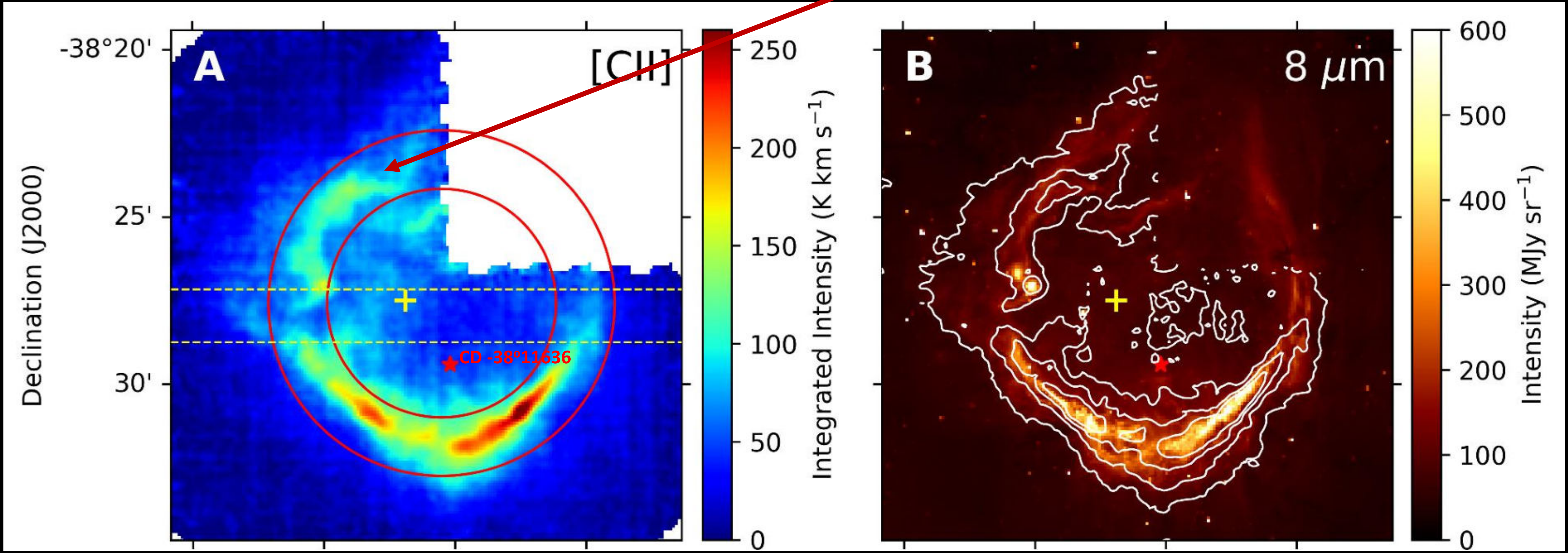
upGREAT

- Major advantage of FEEDBACK is fast velocity-resolved mapping of [CII].
- Would not be possible without upGREAT!
- High spatial (14.1”) and spectral (0.2 km/s) resolution, allowing us to disentangle different gas components and probe the dynamics of HII regions.

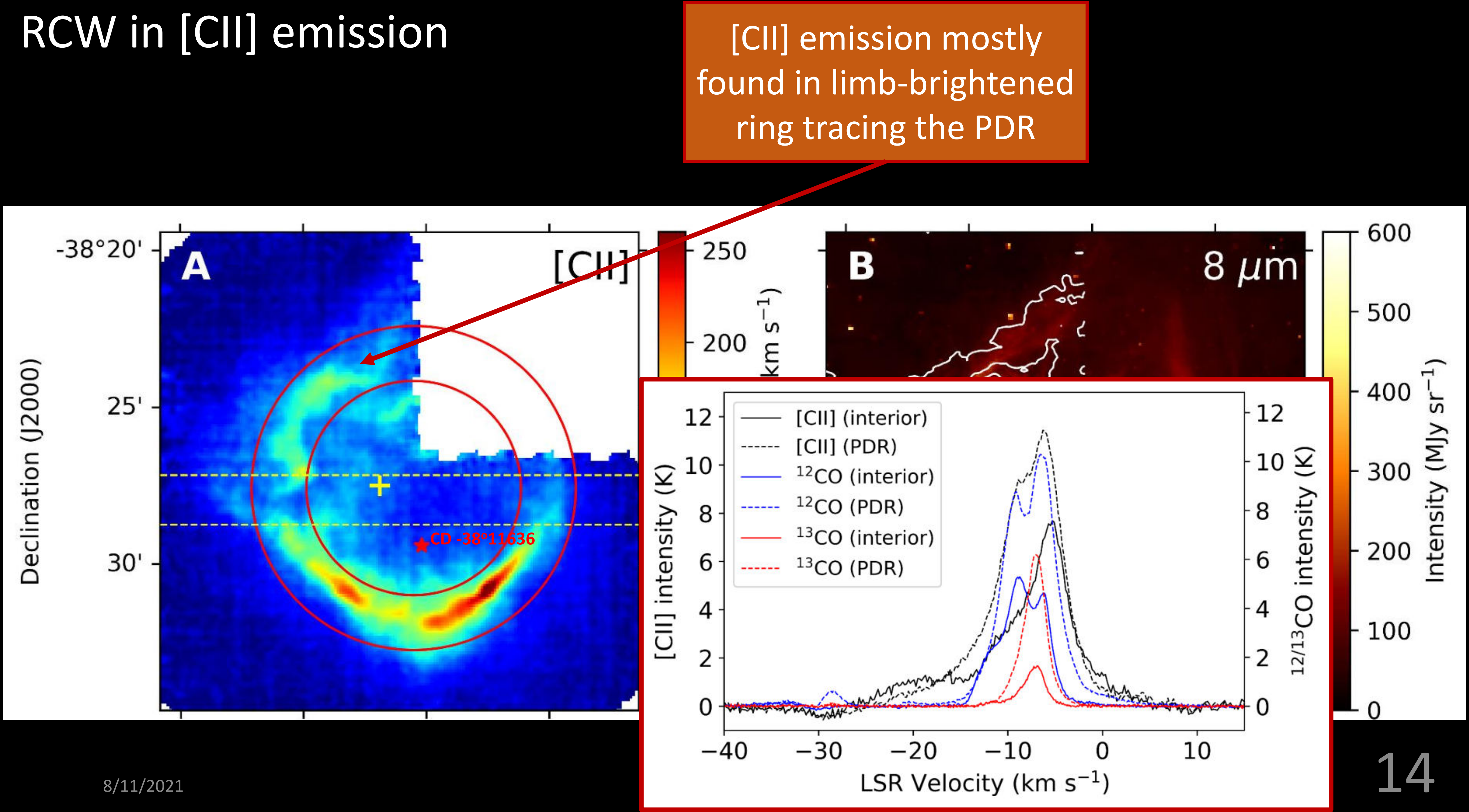
German REceiver for Astronomy at Terahertz Frequencies (GREAT)

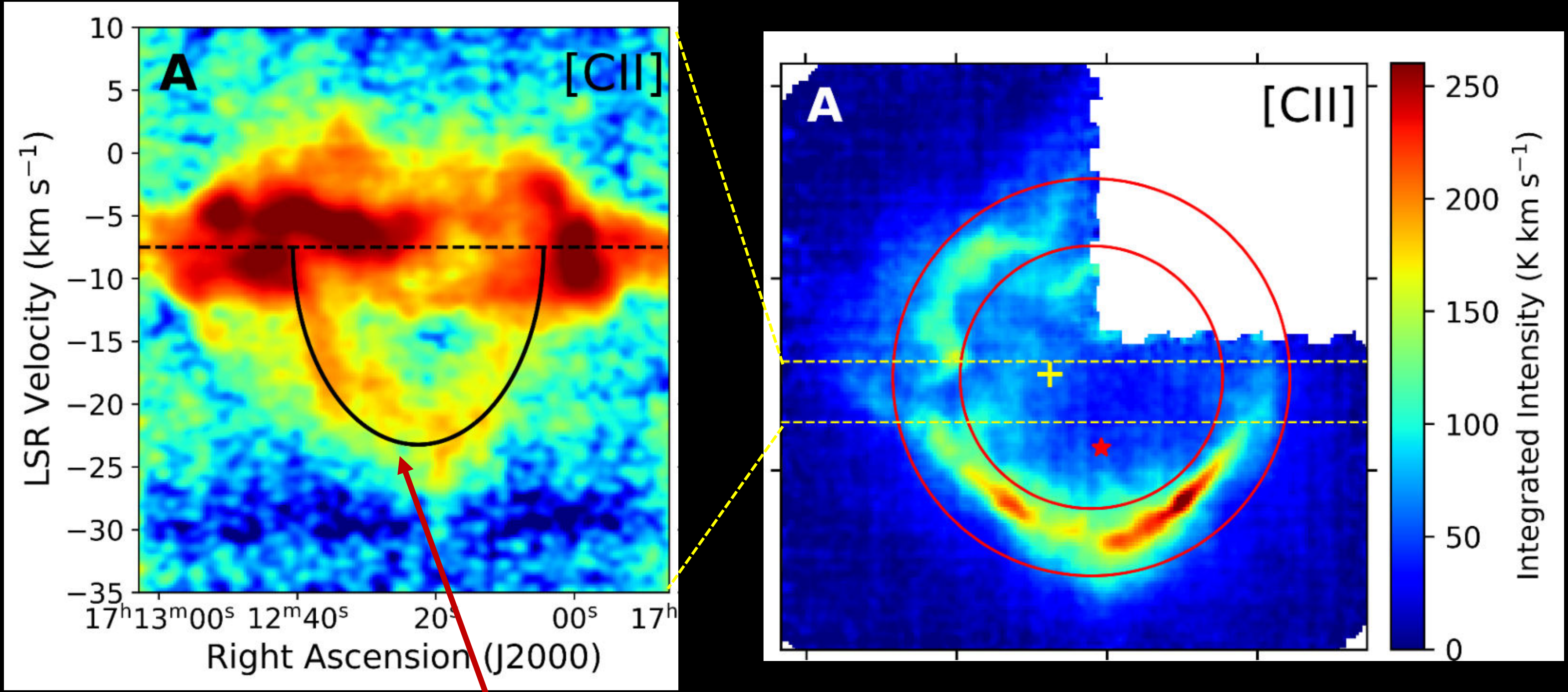
RCW in [CII] emission

[CII] emission mostly found in limb-brightened ring tracing the PDR

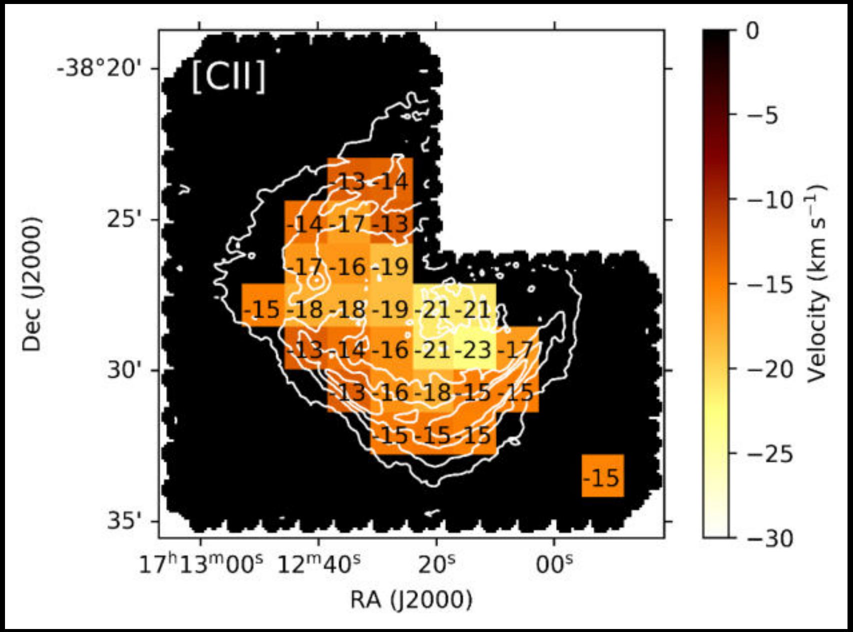


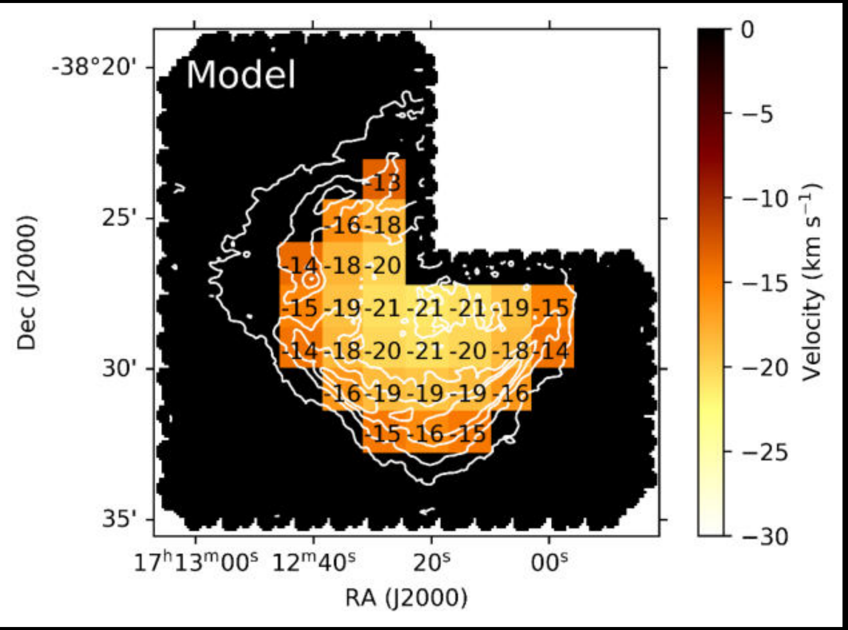
RCW in [CII] emission



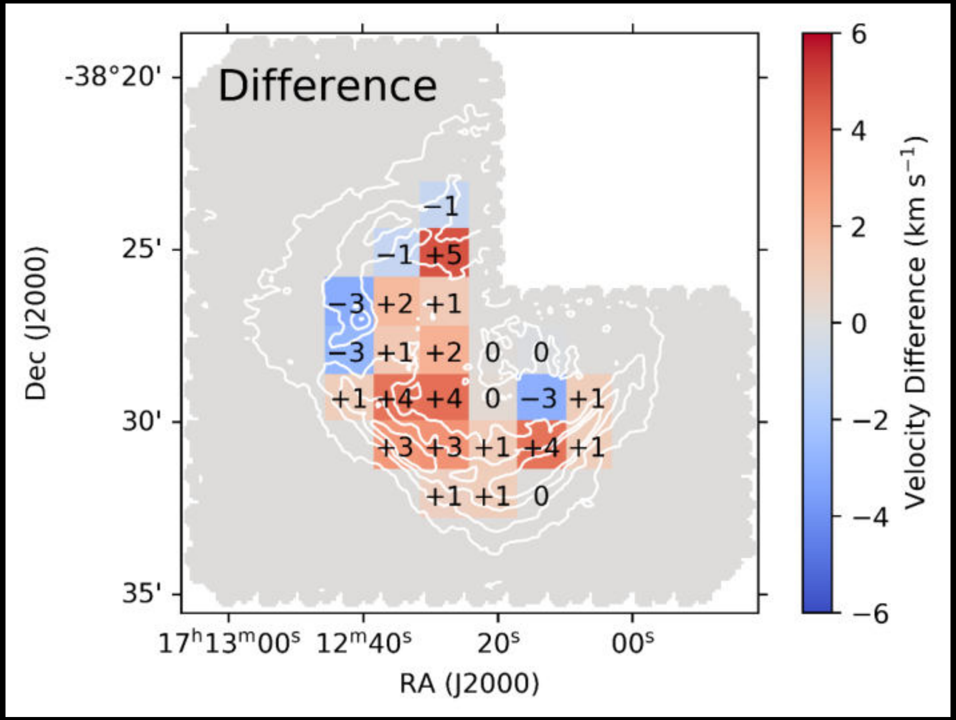


Position-velocity diagram reveals blue-shifted expansion signature in [CII], (V_{exp}~15 km/s)!

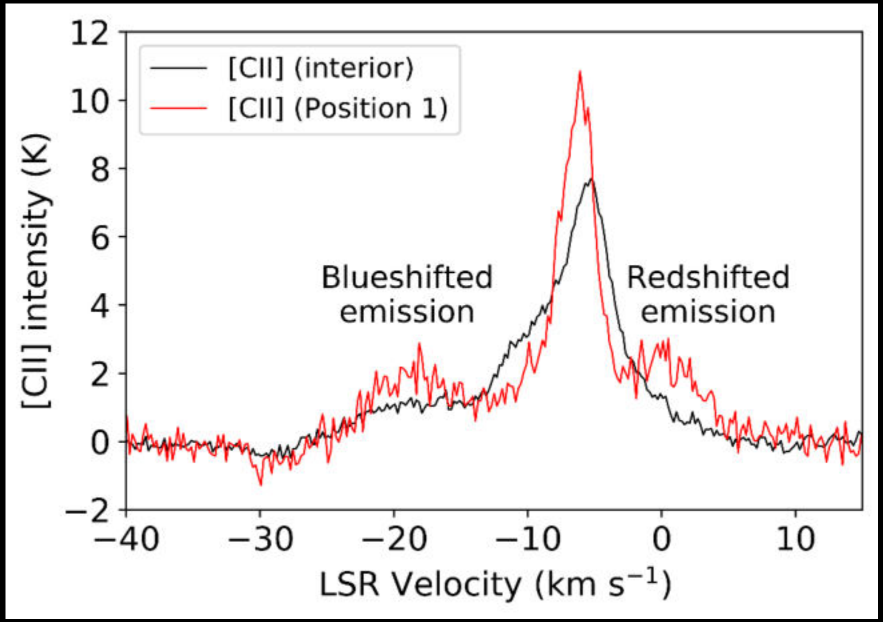


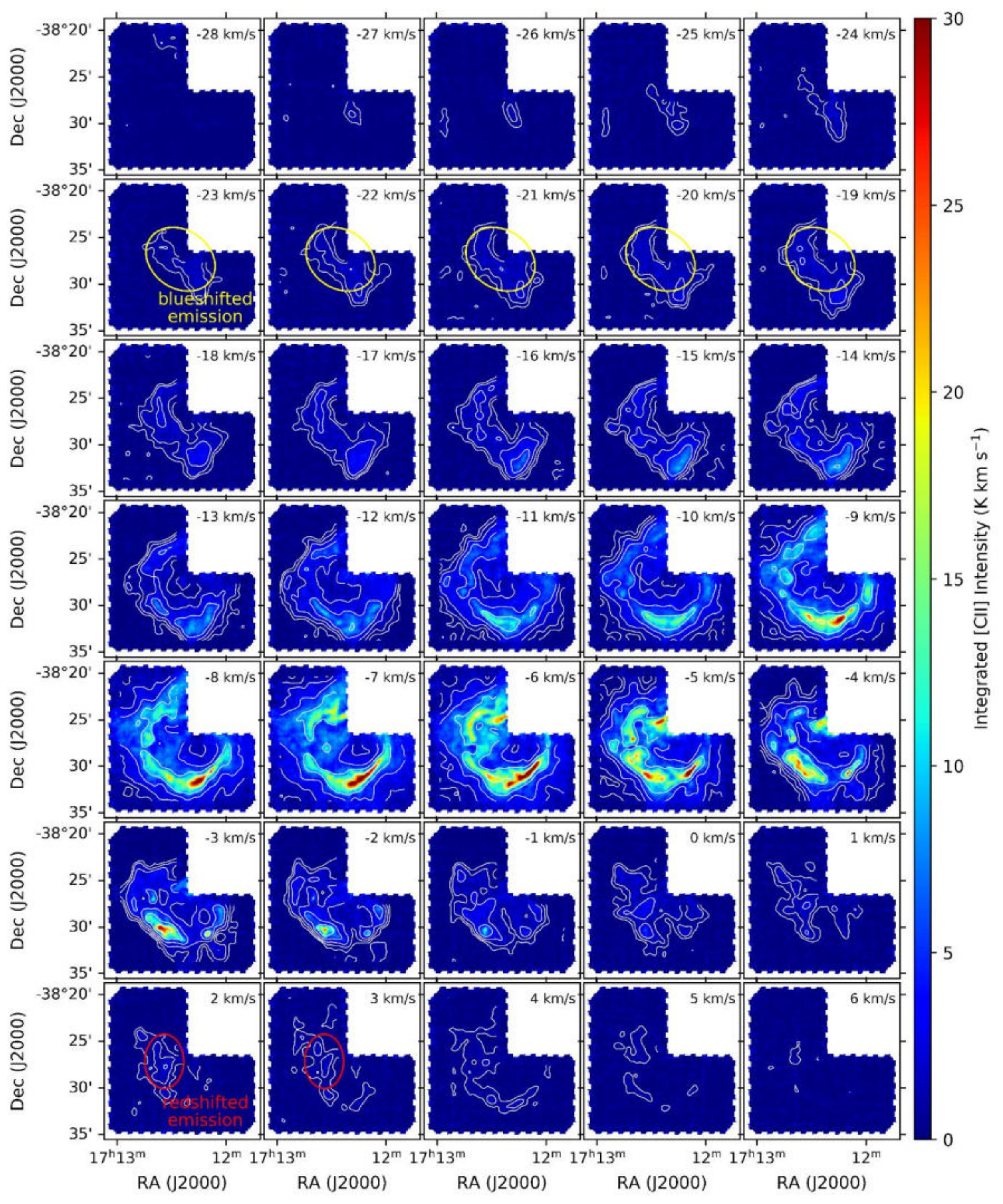


- The blue-shifted [CII] emission is consistent with that expected of an isotropically expanding half-shell



- Some red-shifted [CII] emission is also visible at an expansion velocity of ~ 10 km/s
- Red-shifted emission is fainter/more clumpy than the blue-shifted emission

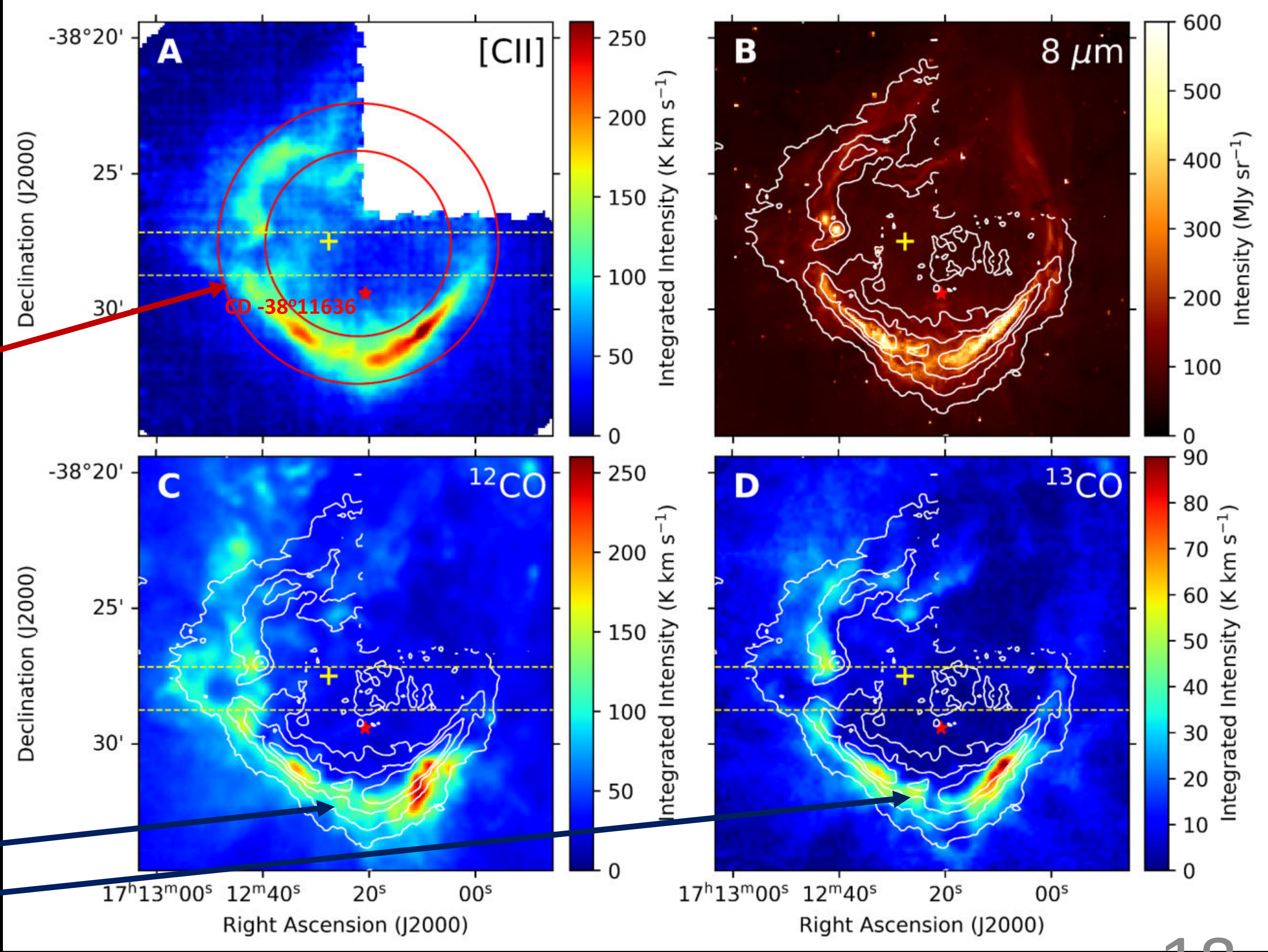




What about the molecular gas?

[CII] emission mostly found in limb-brightened ring tracing the PDR

CO emission ubiquitous, but strongest clumps detected near newly formed stars around the HII region



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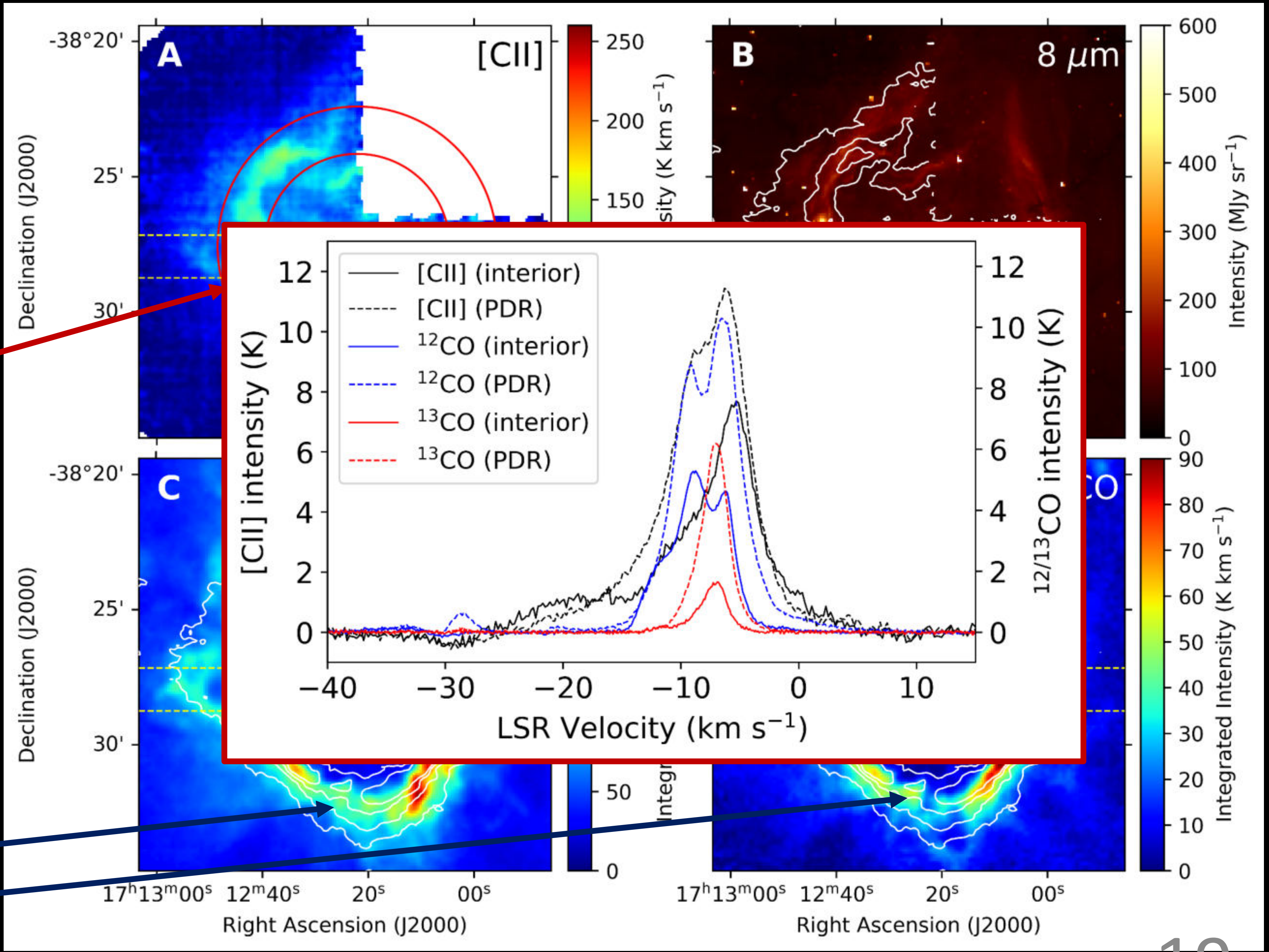
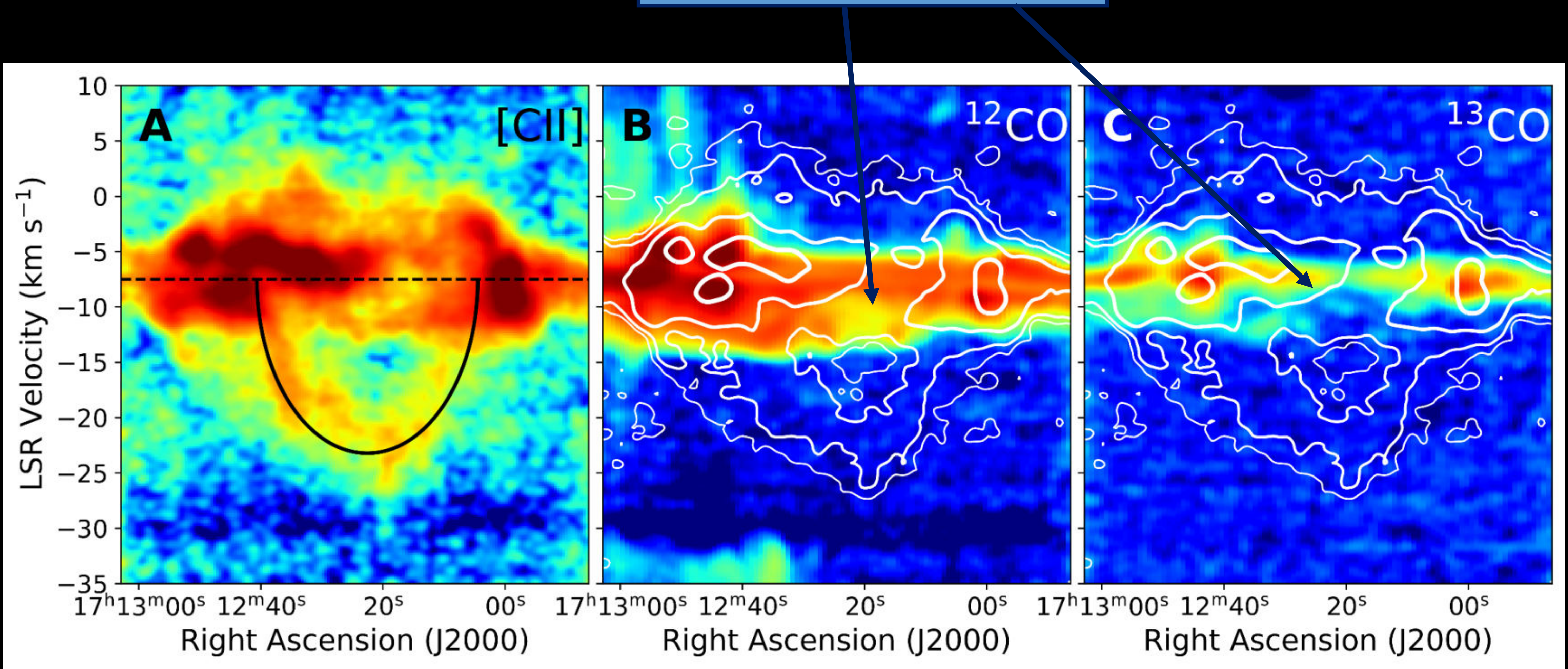
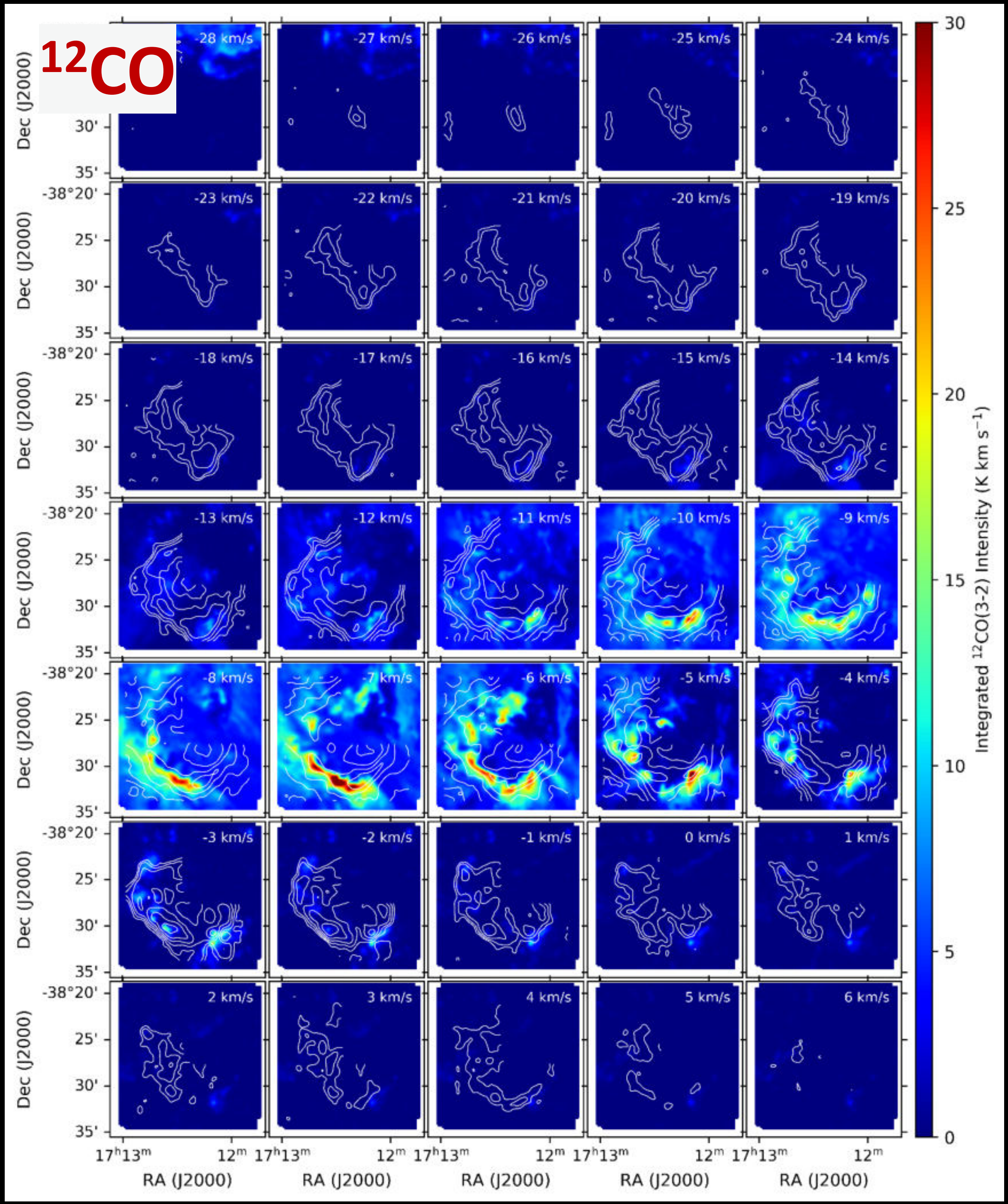
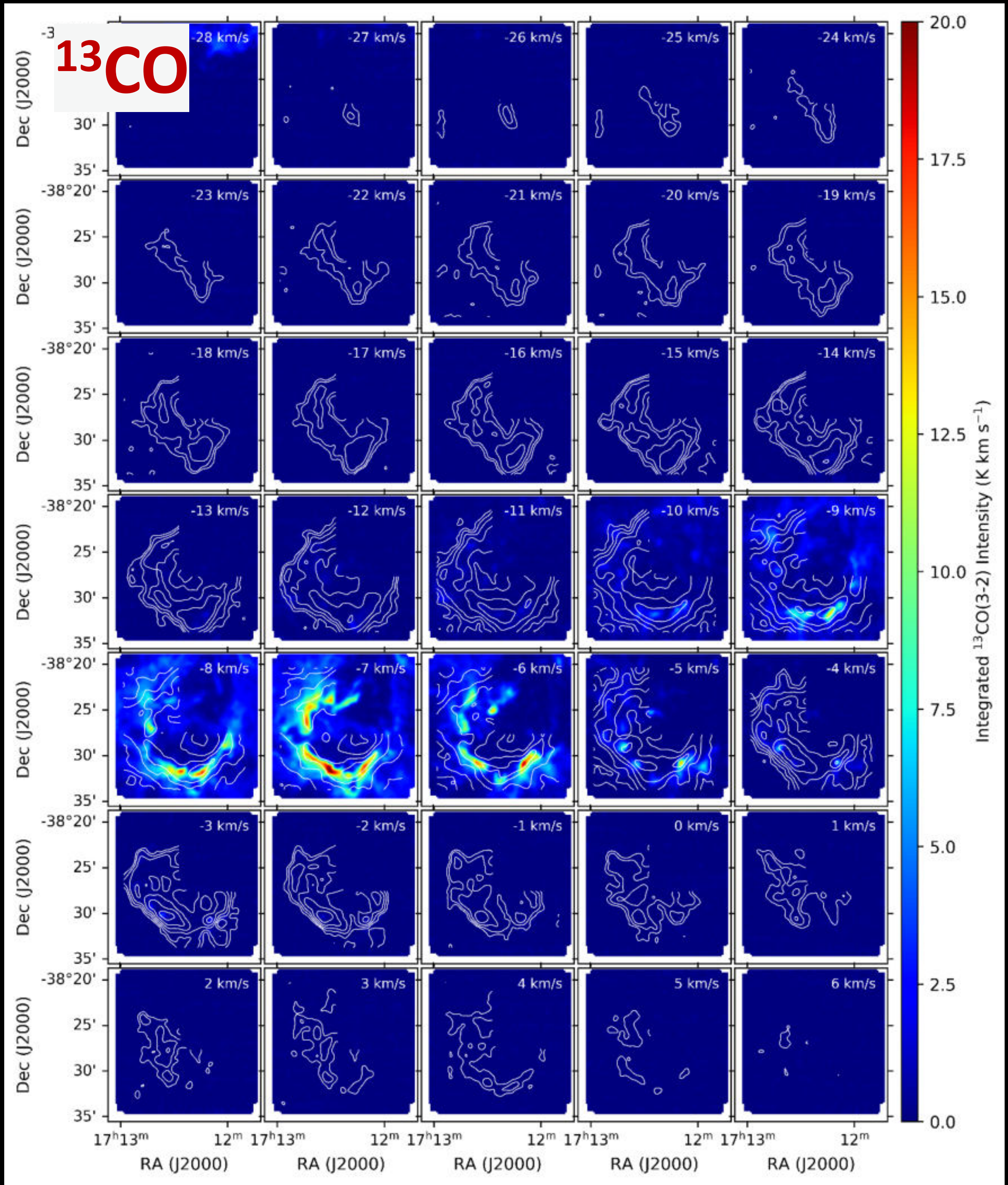


Expansion signal is absent in CO emission

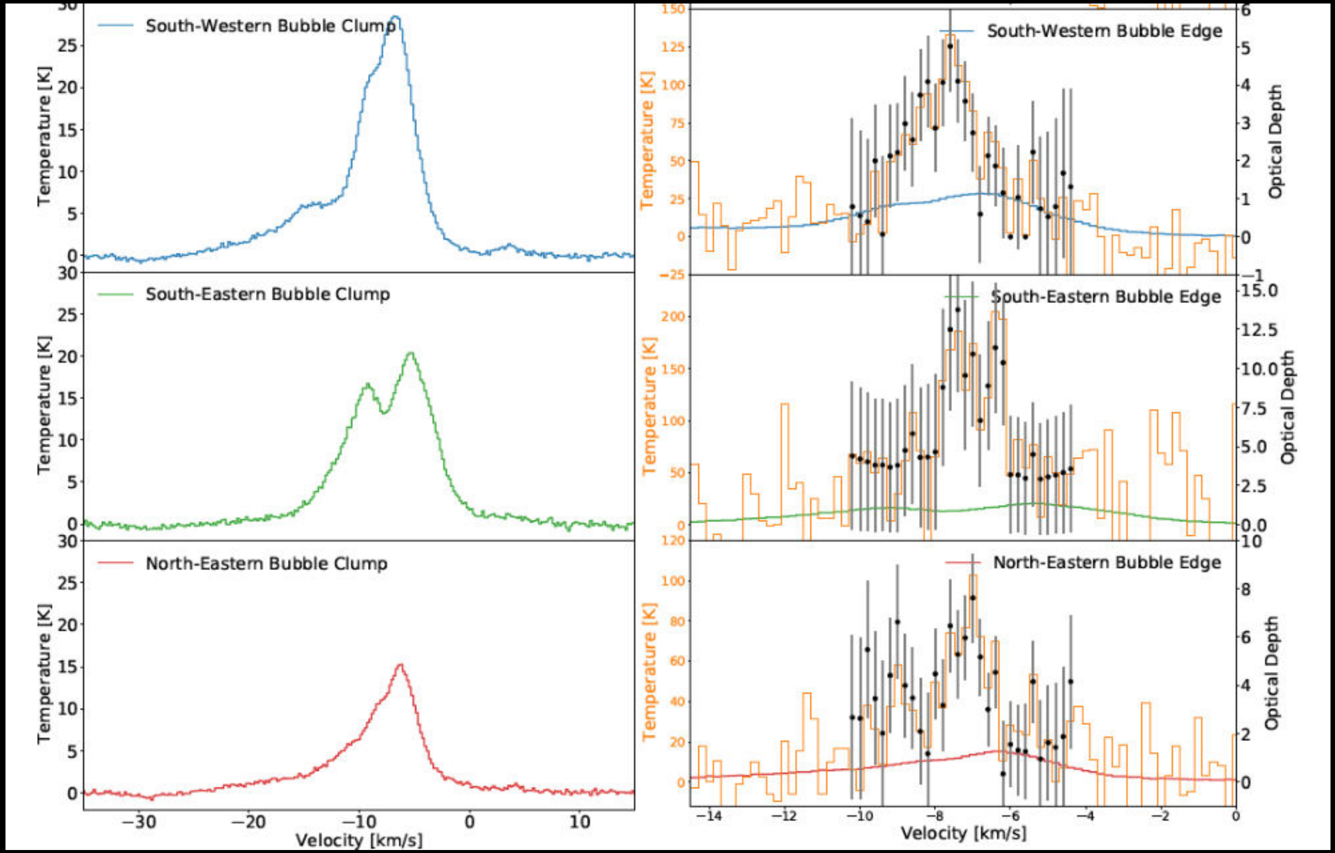



12CO
-28 km/s
-27 km/s
-26 km/s
-25 km/s
-24 km/s
-23 km/s
-22 km/s
-21 km/s
-20 km/s
-19 km/s
-18 km/s
-17 km/s
-16 km/s
-15 km/s
-14 km/s
-13 km/s
-12 km/s
-11 km/s
-10 km/s
-9 km/s
-8 km/s
-7 km/s
-6 km/s
-5 km/s
-4 km/s
-3 km/s
-2 km/s
-1 km/s
0 km/s
1 km/s
2 km/s
3 km/s
4 km/s
5 km/s
6 km/s
Dec (J2000)
-38°20'
25'
30'
35'
17h13m
12m
RA (J2000)
Integrated 12CO(3-2) Intensity (K km s-1)
0
5
10
15
20
25
30


13CO
-28 km/s
-27 km/s
-26 km/s
-25 km/s
-24 km/s
-23 km/s
-22 km/s
-21 km/s
-20 km/s
-19 km/s
-18 km/s
-17 km/s
-16 km/s
-15 km/s
-14 km/s
-13 km/s
-12 km/s
-11 km/s
-10 km/s
-9 km/s
-8 km/s
-7 km/s
-6 km/s
-5 km/s
-4 km/s
-3 km/s
-2 km/s
-1 km/s
0 km/s
1 km/s
2 km/s
3 km/s
4 km/s
5 km/s
6 km/s
Dec (J2000)
-38°20'
25'
30'
35'
17h13m
12m
RA (J2000)
Integrated 13CO(3-2) Intensity (K km s-1)
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0

Shell mass

- **The morphology of RCW 120 suggests that the entire shell traced by [CII] is expanding**
- Column density determination is complicated by [CII] self-absorption at some locations → need to use [^{13}CII] lines.



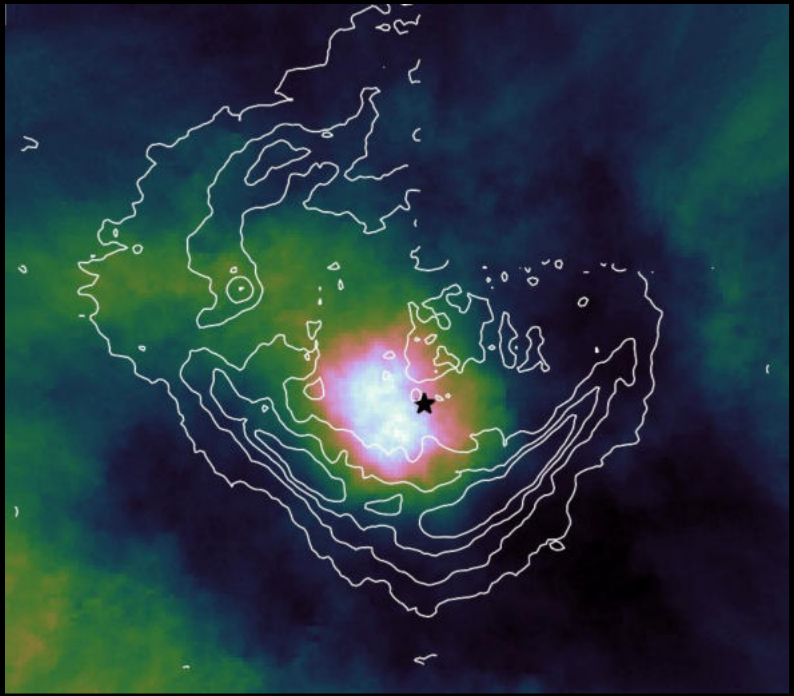
Transition line	Statistical weight g_u	g_l	Frequency ν [GHz]	Velocity offset $\Delta v_{F\to F'}$ [km/s]	Relative intensity $s_{F\to F'}$
[^{12}CII] $^2P_{3/2} \to ^2 P_{1/2}$	4	2	1900.5369	0	1
[^{13}CII] $F = 2 \to 1$	5	3	1900.4661	+ 11.2	0.625
[^{13}CII] $F = 1 \to 0$	3	1	1900.9500	- 65.2	0.250
[^{13}CII] $F = 1 \to 1$	3	3	1900.1360	+ 63.2	0.125

Shell mass

Slawa Kabanovic

- Total shell mass is 40-600 $M_{\odot}$ (depending on assumptions of 3D structure).
- Kinetic energy contained in the shell is 10^{47}-$10^{48.1}$ erg.
- Shell mass is significant fraction of total molecular gas mass (~4800 $M_{\odot}$).

Stellar wind drives expansion

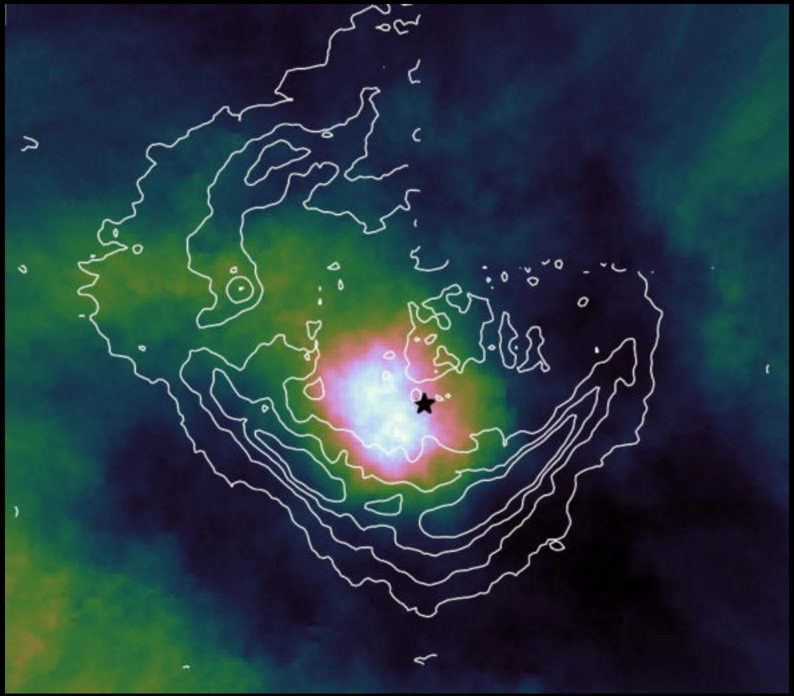


Chandra diffuse X-ray emission toward RCW 120. Contours are [CII] emission.

- **Big picture:** Stellar wind from CD -38°11636 creates hot, shocked plasma and drives the expansion of the region.
- Shocked plasma visible in *Chandra* X-ray data.
- Thermal energy of hot gas is 1.7×10^{47} erg (estimated by using a model of a lightly-absorbed soft plasma; kT = 0.35 keV).

Leisa Townsley

Stellar wind drives expansion



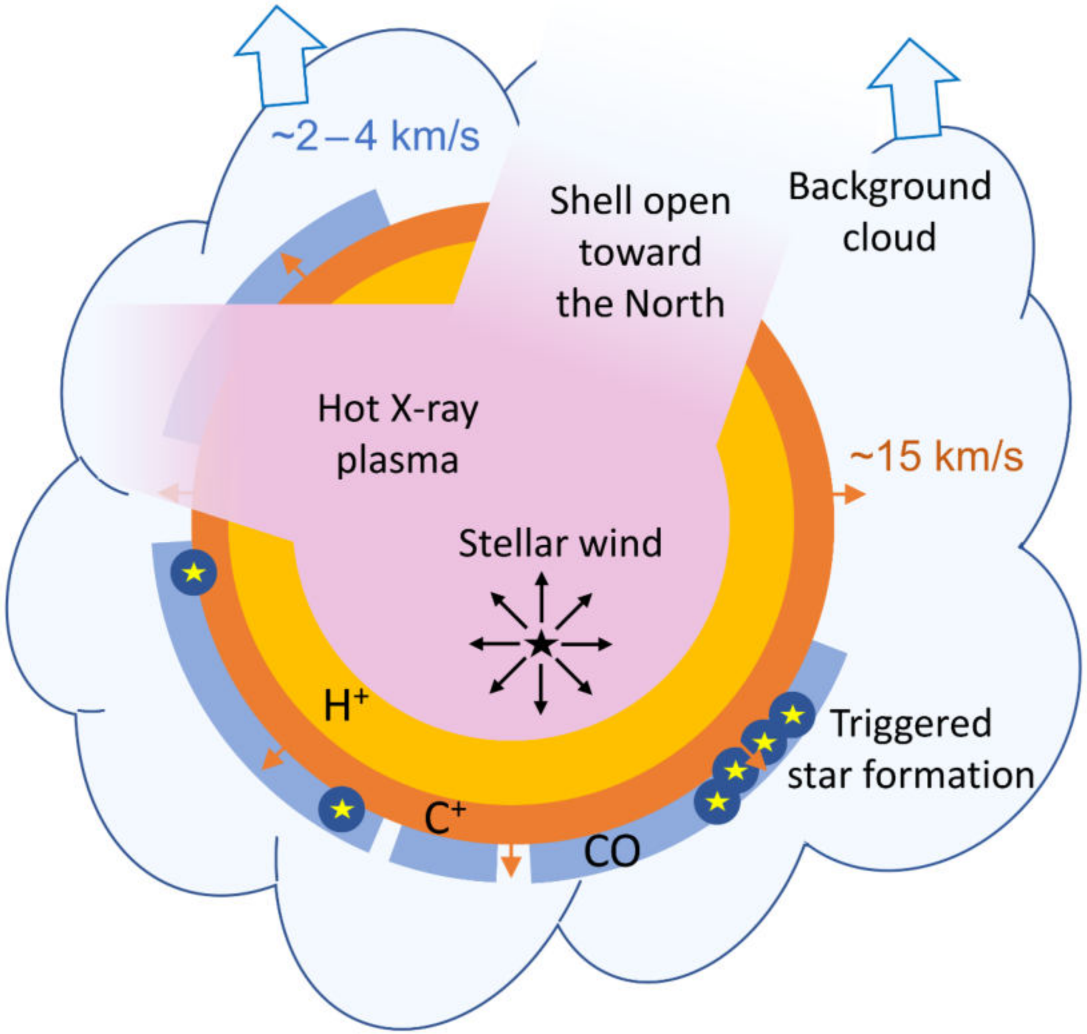
Chandra diffuse X-ray emission toward RCW 120. Contours are [CII] emission.

- Ratio of kinetic energy of shell to thermal energy of plasma is larger than predicted for adiabatic expansion of stellar wind bubbles.
  - Possibly because hot gas is escaping toward breaches in the east and north.
- Kinetic energy of expanding shell is considerable fraction (10-80%) of energy injected by stellar wind over bubble lifetime.
- Expansion speed of the shell of ~15 km/s implies bubble age of ~0.15 Myr.

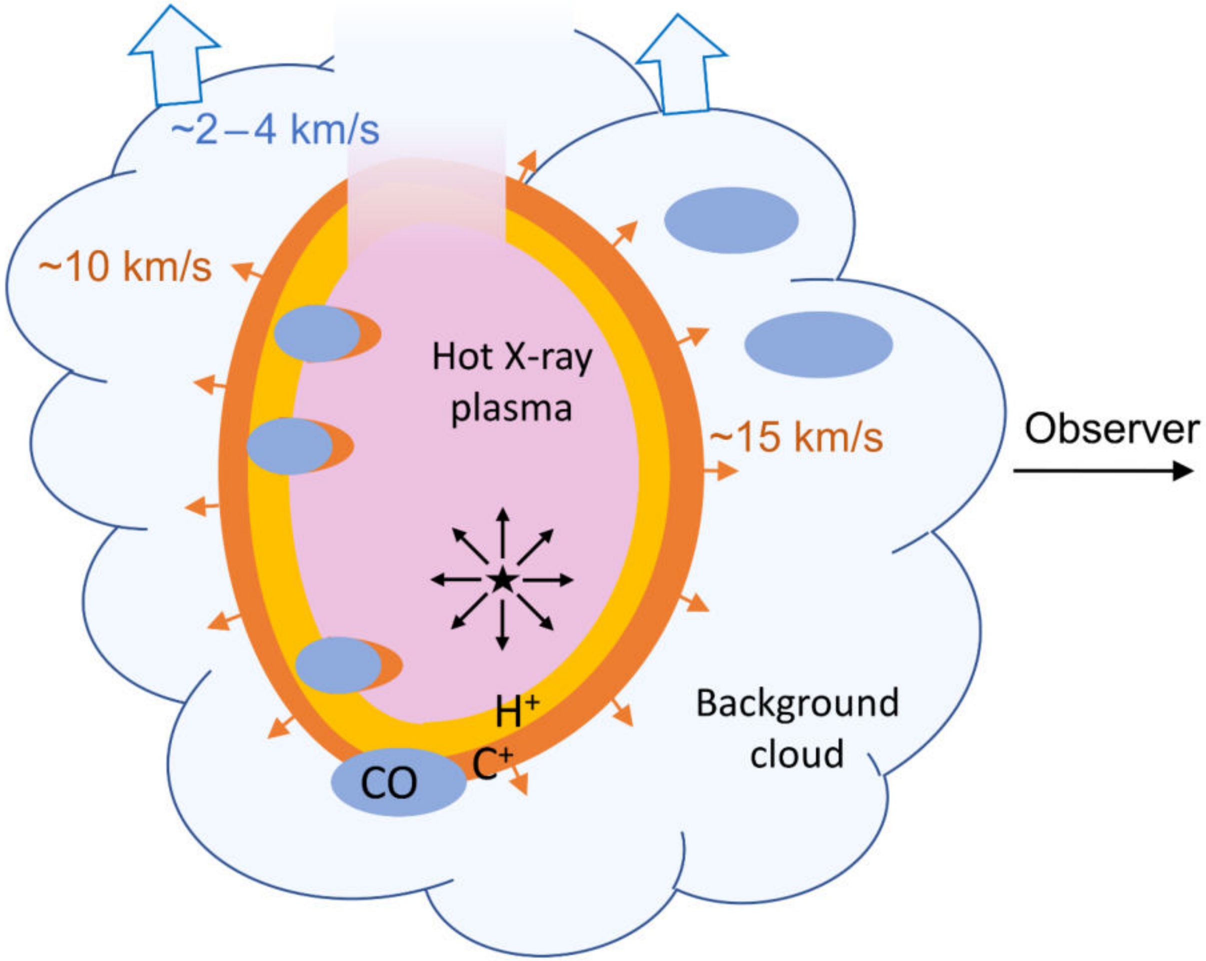
Table 1: Properties of the different components of RCW 120

Component	Mass ($M_\odot$)	Thermal Energy (10^{46} erg)	Kinetic Energy (10^{46} erg)	Luminosity ($L_\odot$)	Pressure (10^6 K cm^{-3})
Expanding [CII] shell	40-600[a]	0.1-1.5	10-130	-	1-10
Molecular gas	4800	3.9	-	-	0.03
Ionized gas	26[b]	5.1	-	-	8[c]
Stellar wind[d]	-	-	150	80[e]	0.8[f]
Hot X-ray plasma	0.05	17	-	0.10	0.7
CD -38°11636	-	-	-	9.1×10^4	-
[CII]	-	-	-	690	-
^{12}CO(3-2)	-	-	-	2.6	-
^{13}CO(3-2)	-	-	-	0.58	-

a: Total atomic mass
b: From [SII] observations *(33)*
c: From *(20)*
d: Over the lifetime of the bubble
e: Mechanical luminosity



Face-on view of RCW 120



Side view

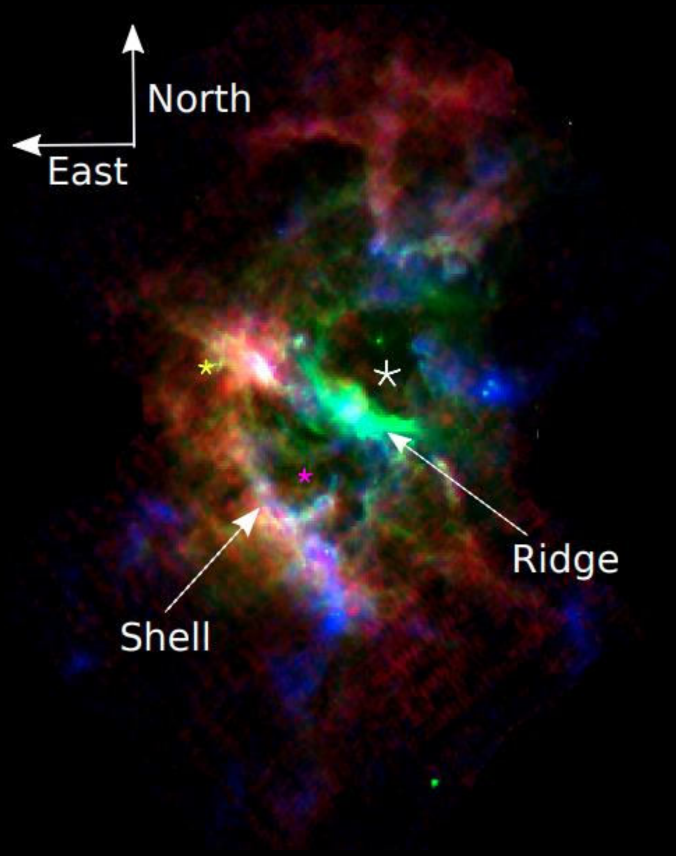
Triggered star formation

- Morphologically, the star-forming CO clumps are part of the shell and are formed by compression in situ.
- Star formation must have proceeded very rapidly after shell formation (<0.15 Myr), as the densest clumps have already formed stars.
- Suggests that positive feedback operates on short time periods.

Conclusions

- We observe an expansion signature in [CII] emission in RCW 120.
- The expansion signal is consistent with an isotropically expanding neutral shell with expansion speed ~15 km/s.
- The expansion is driven by stellar winds from a single ionizing source.
- The expansion speed sets an age limit for the region of ~0.15 Myr.
- There is recent and ongoing triggered star formation around RCW 120, suggesting that triggered star formation must operate on short time periods!

[CII] shells with similar expansion speeds were observed in the Orion Veil (Pabst et al., 2019) and in RCW 49 (Tiwari et al., 2021).



Expanding shells seem to be a relatively common feature among star-forming regions!

Outlook

- Clearly, a larger (statistical) sample of [CII] observations of star-forming regions is needed to investigate HII region dynamics and the impact of feedback on massive star formation.
- **With upGREAT, we are now in a position to do so!**
- FEEDBACK includes 11 sources and is ~35% complete (April 2021).

Thank you! Questions?

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