Radiative and Mechanical Feedback from Massive Stars

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Stuttgart – Germany

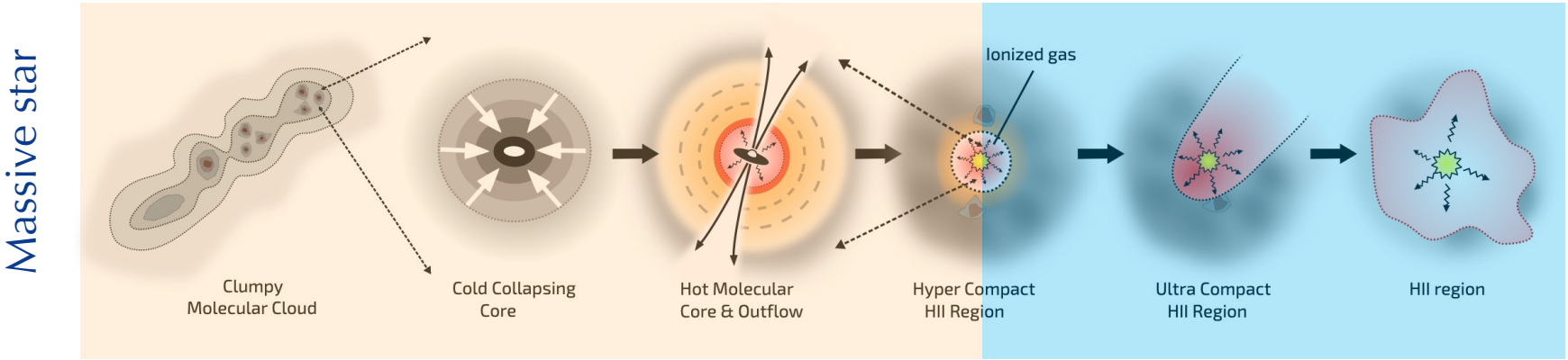
Wednesday / April 24, 2024 / 05:00 PM (CEST)

Science Questions

How does the "**FEEDBACK**" of a massive star affect the birth envoirenment?

What is **protostellar feedback**? Why it is important?

protostellar feedback vs. ***main sequence*** feedback?



Credit: C. Purcell & A. Ginsburg

Orion Nebula

Closest massive star-forming region (most detailed structures)

Orion Veil + a protruding structure (green solid lines) appear at the north-west of the Veil Shell.

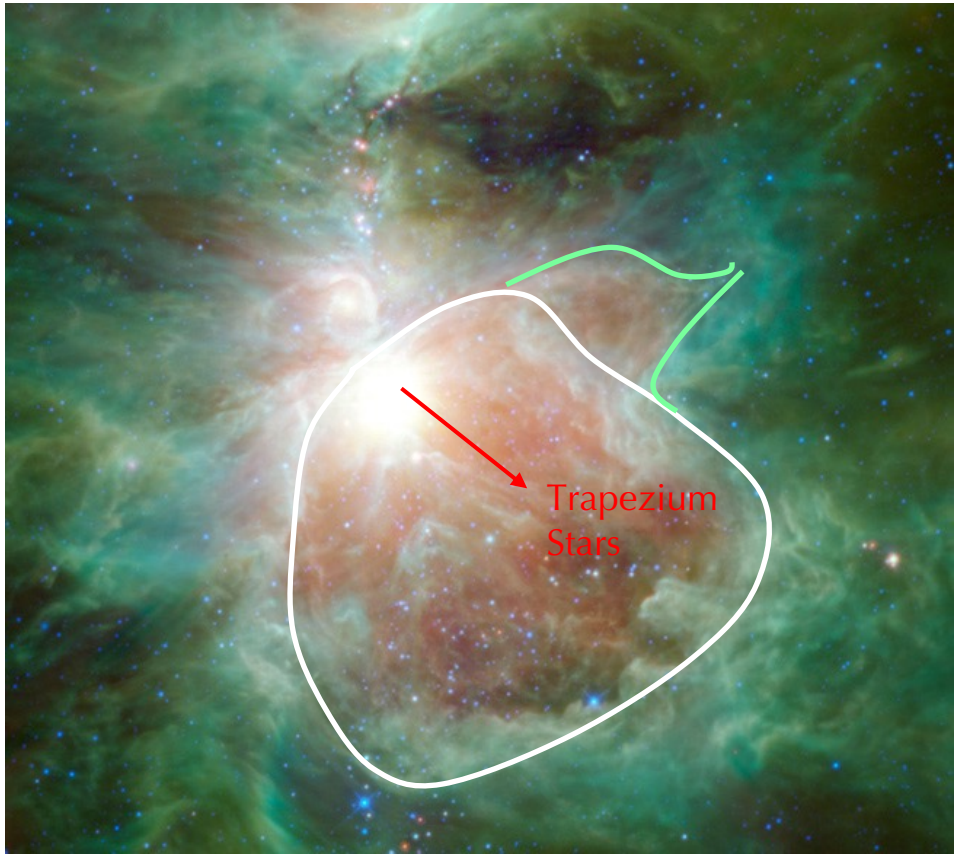
Orion Nebula – WISE image

Orion Veil

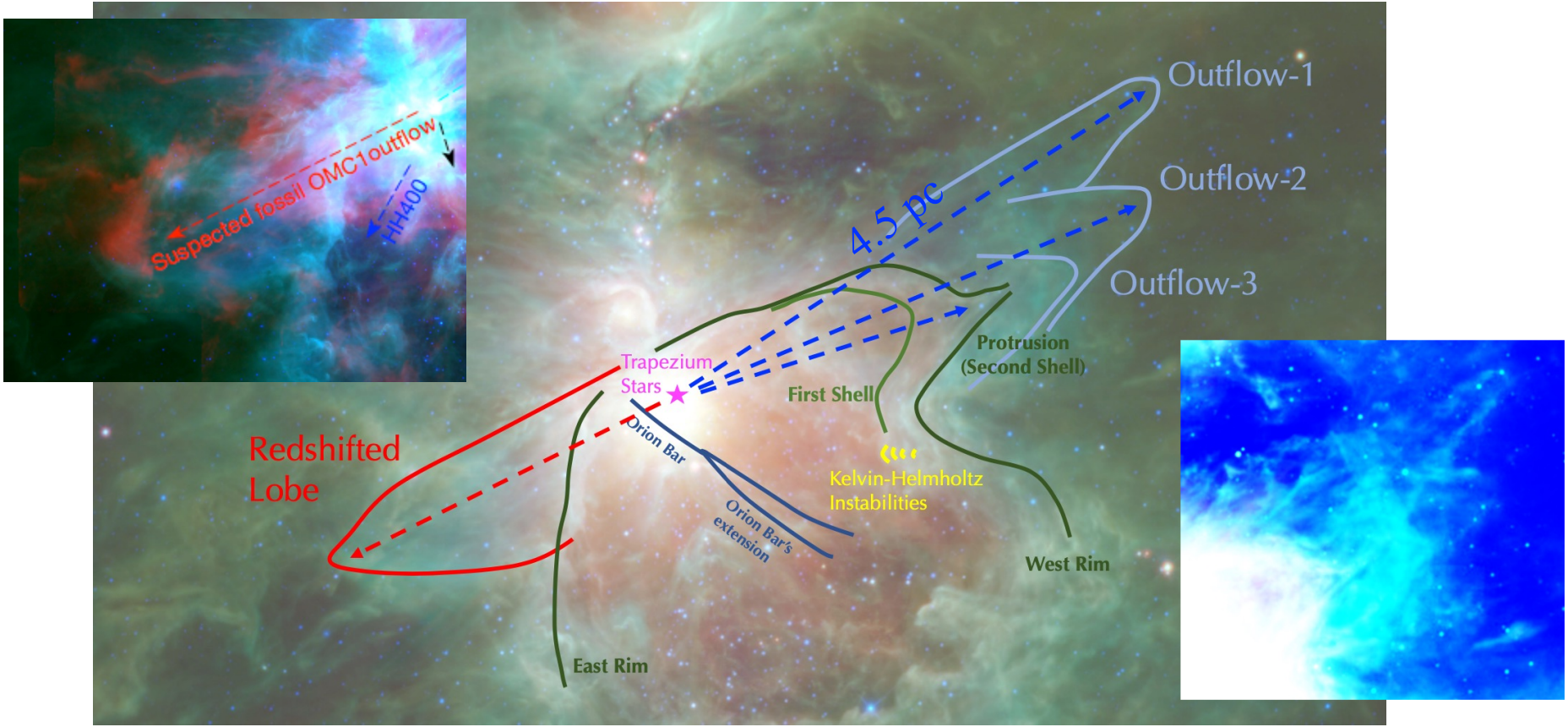
Veil shell is mainly driven by ***stellar winds*** from θ^1 Ori C (Pabst et al. 2019).

A protruding structure (green solid lines) appear at the north-west of the Veil Shell.

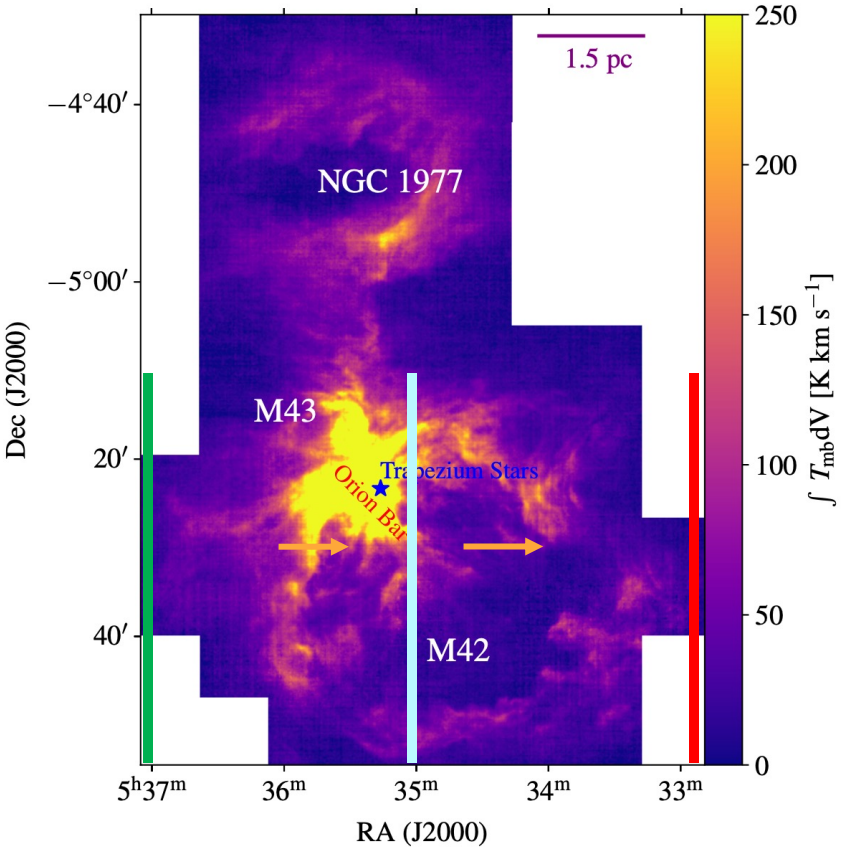
Orion Nebula – WISE image



Fossil Outflows from θ¹ Ori C (Kavak et al. 2022a)



[CII] 158 micron PV diagram movie

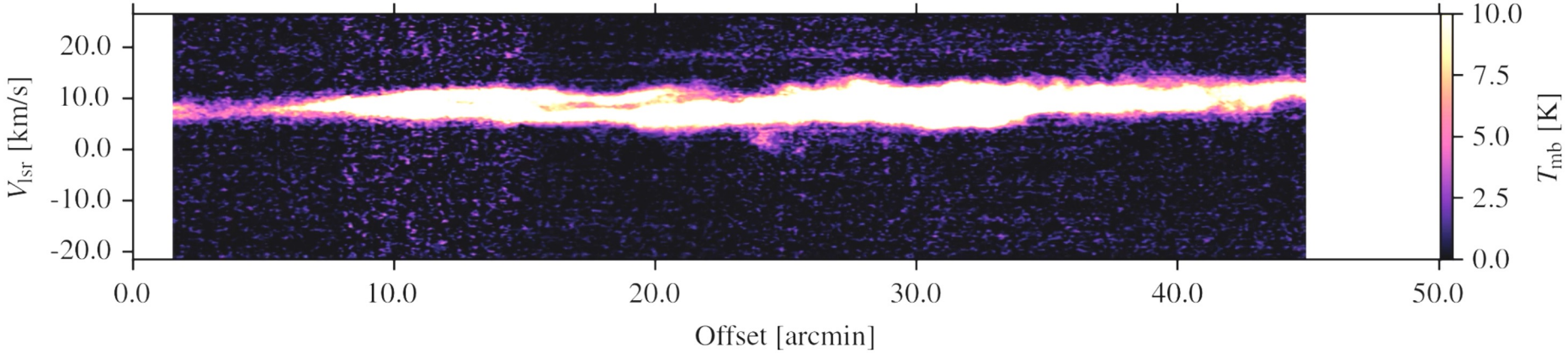


The velocity-resolved SOFIA [CII] observations

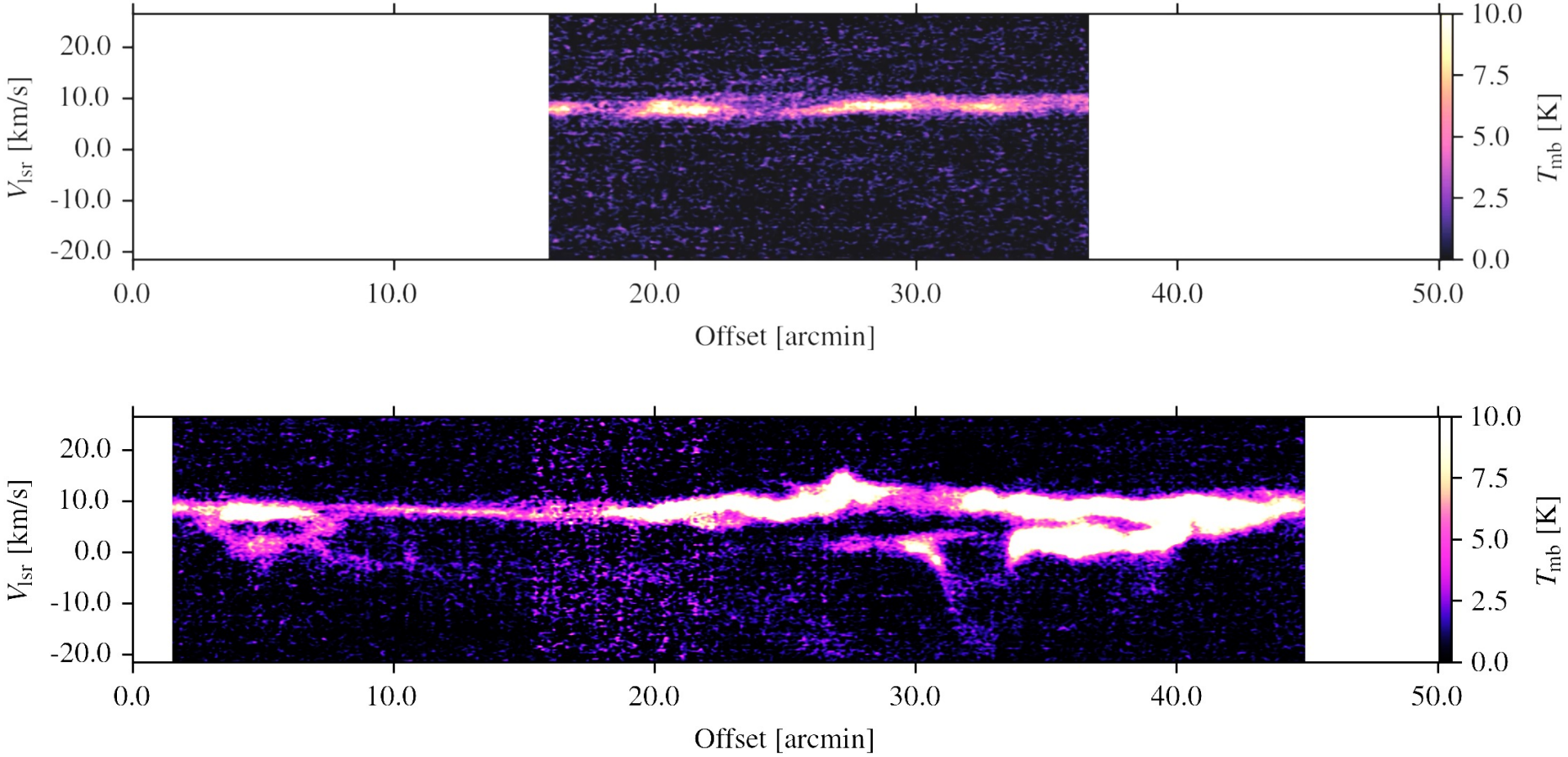
Cuts are 45 x 0.5 arcmin

120 [CII] PV diagrams

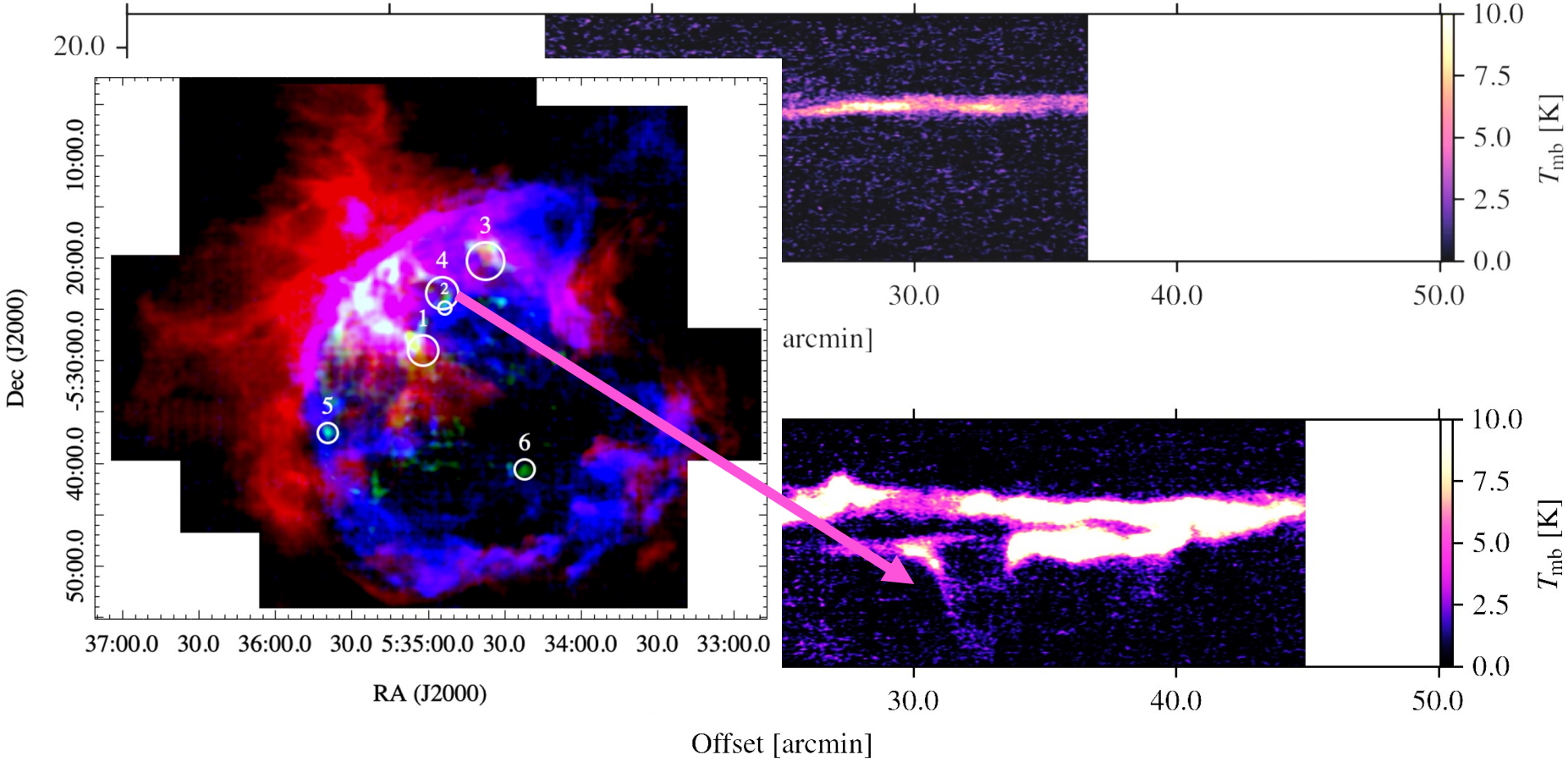
[CII] 158 micron PV diagram movie



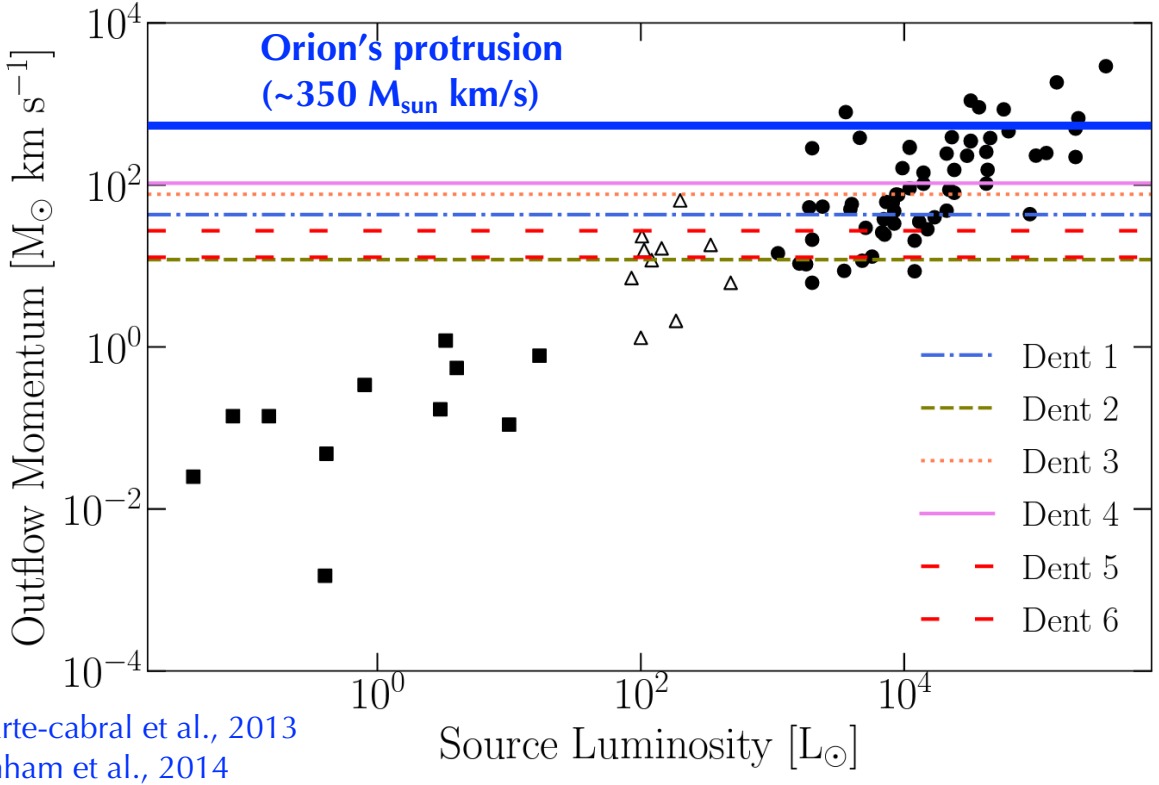
[CII] 158 micron PV diagram movie



[CII] 158 micron PV diagram movie

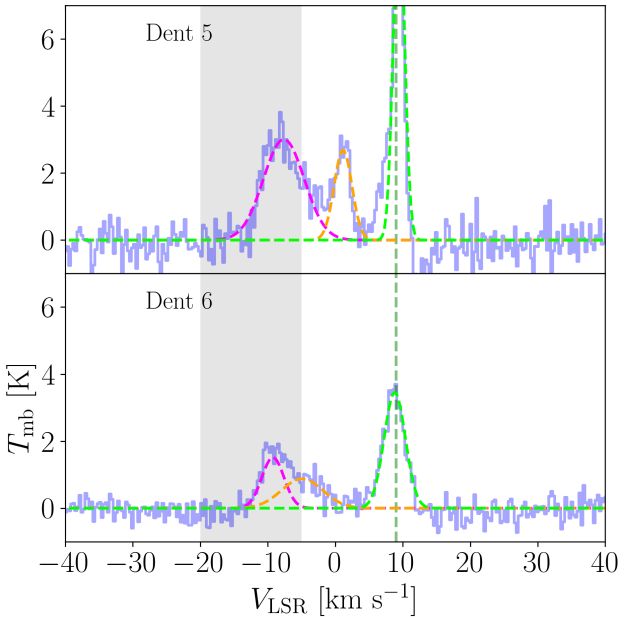


Active outflows from B and A-type stars (Kavak et al., 2022-b)



Duarte-cabral et al., 2013
Dunham et al., 2014
Maud et al., 2015
Kavak et al., 2022a
Kavak et al., 2022b

[CII] 158 micron spectra toward dents



Kavak et al., 2022b

- Orion Veil has a momentum of **20,000 M$_{sun}$ km/s** (Pabst et al., 2019)

SOFIA FEEDBACK Legacy Program

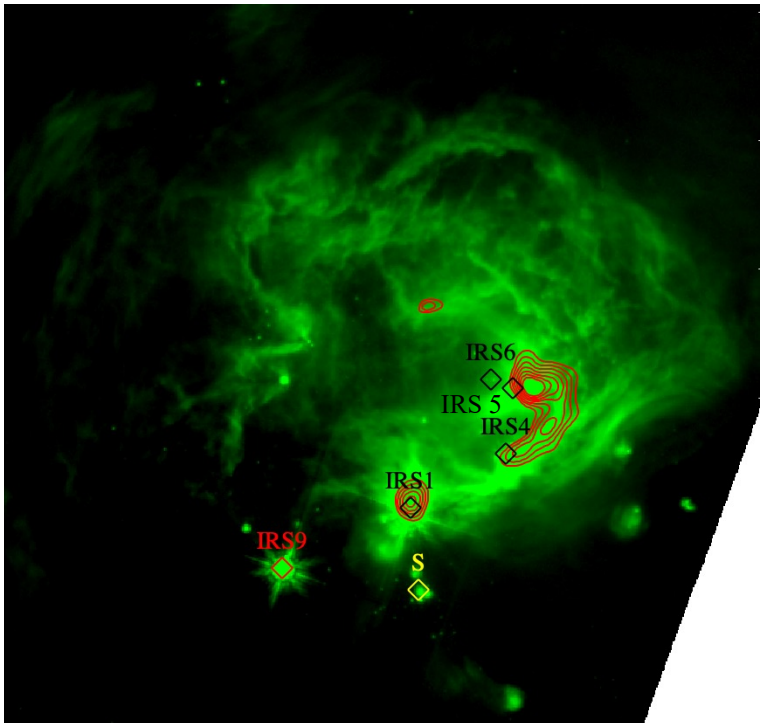
(PIs: A. G. G. M. Tielens N. Schneider)

Eleven Massive star-forming regions from SOFIA Observatory

Green Spitzer 8 micron

***Stellar winds* from IRS-6 created expanding bubble(s) in NGC 7538 (Beuther+22)**

NGC 7538



Red contours are SOFIA [OI] 63 micron

SOFIA FEEDBACK Legacy Program

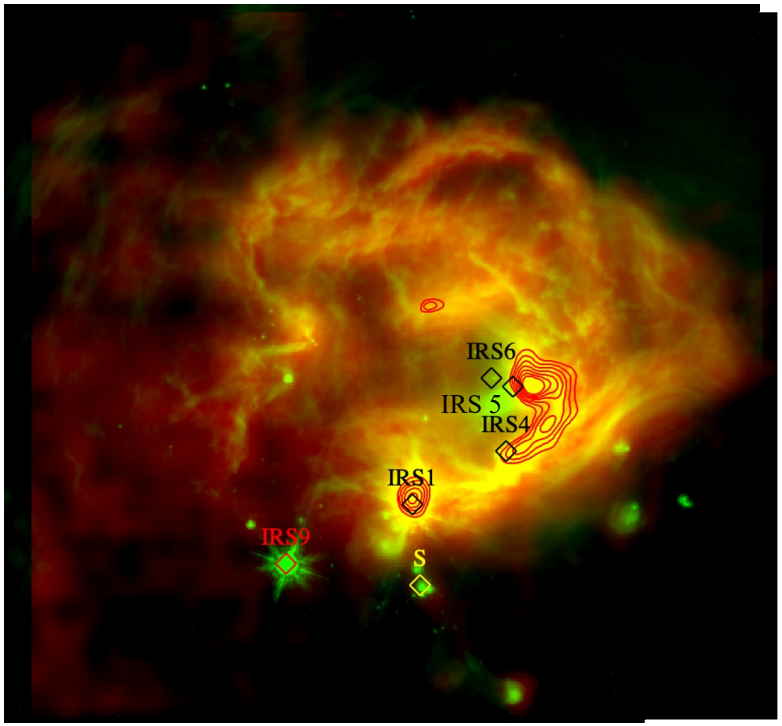
(PIs: A. G. G. M. Tielens N. Schneider)

Eleven Massive star-forming regions from SOFIA Observatory

Green Spitzer 8 micron

Red SOFIA [CII] 158 micron

NGC 7538



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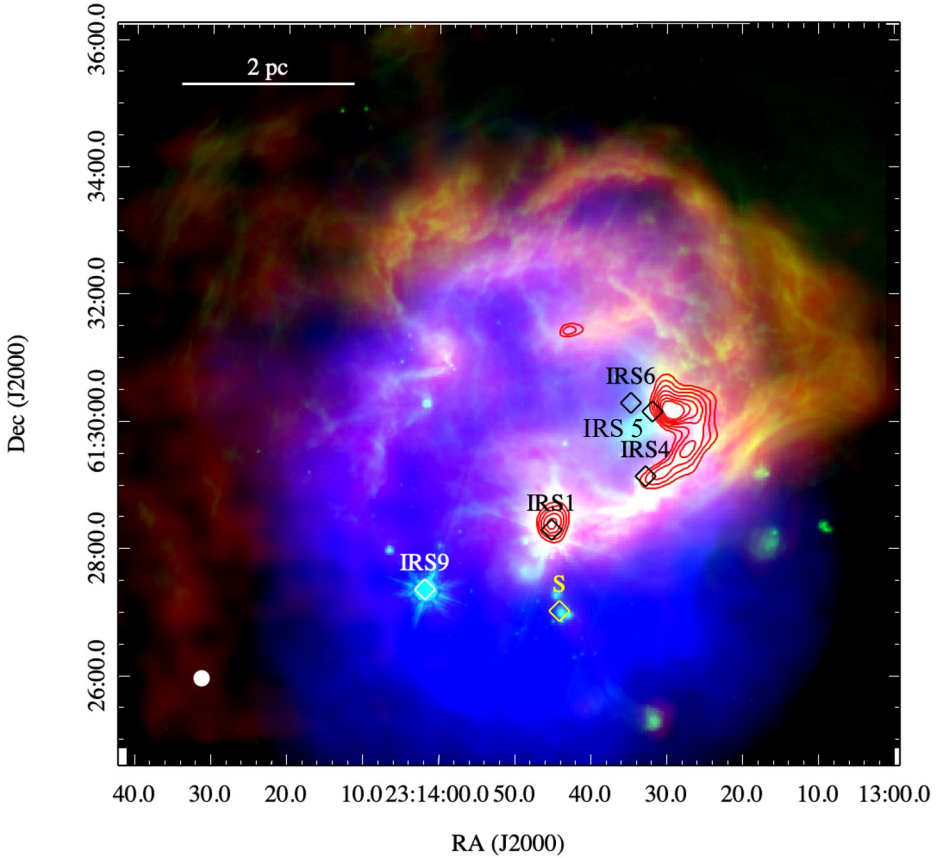
SOFIA FEEDBACK Legacy Program

(PIs: A. G. G. M. Tielens N. Schneider)

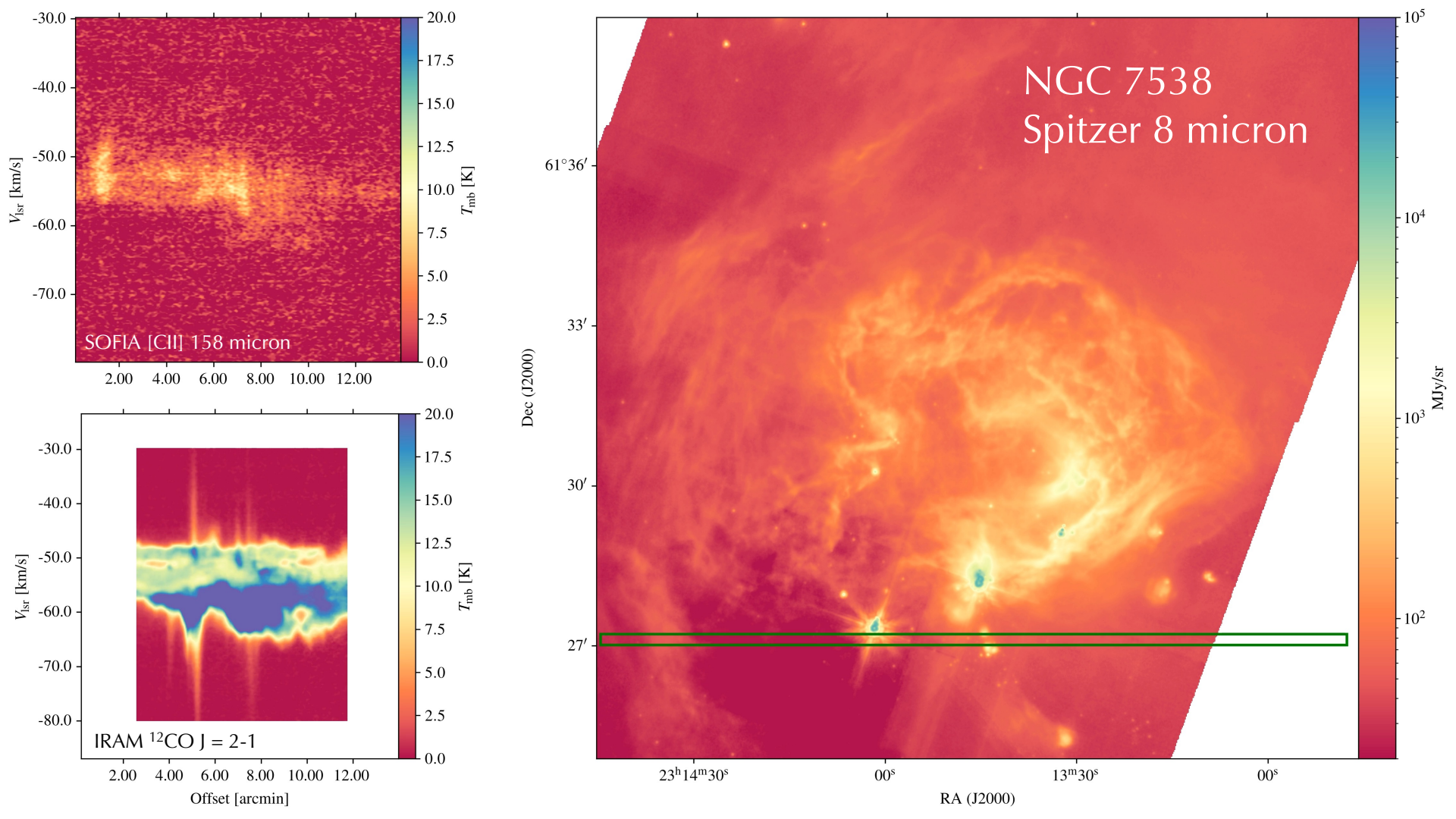
Eleven Massive star-forming regions from SOFIA Observatory

Green Spitzer 8 micron
Red SOFIA [CII] 158 micron
Blue Chandra X-ray

NGC 7538



Red contours are SOFIA [OI] 63 micron observations

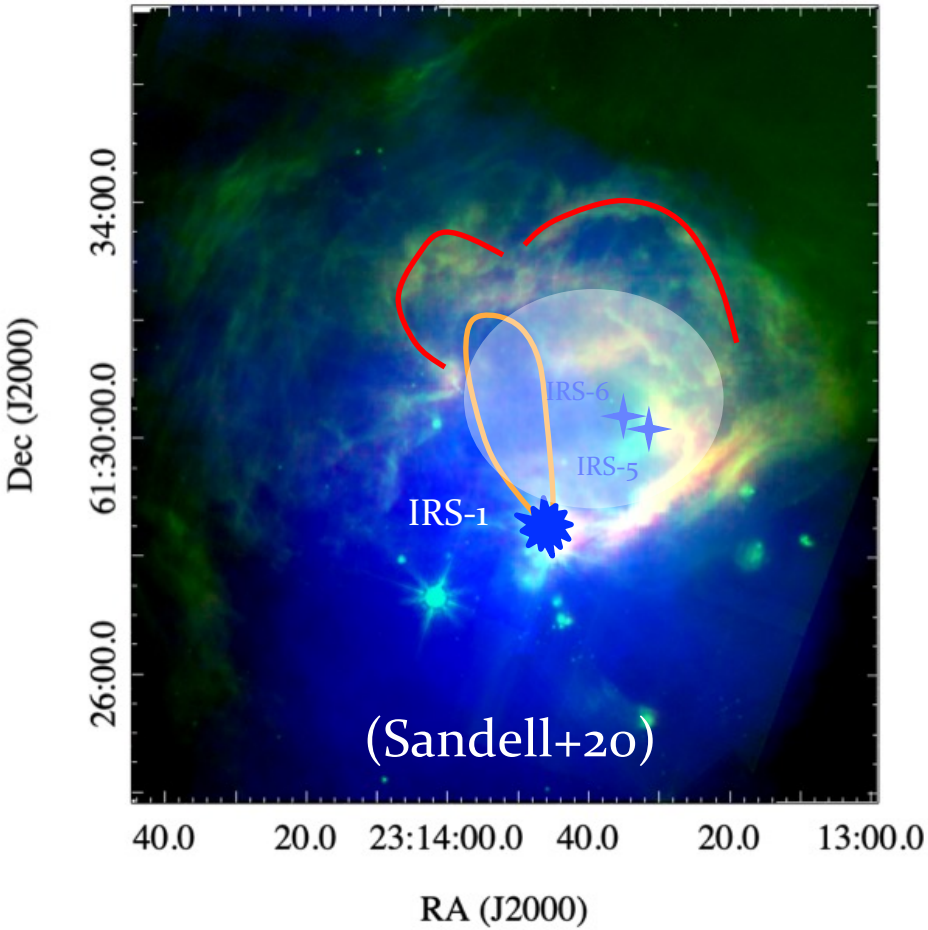

SOFIA [CII] 158 micron
IRAM ^{12}CO J = 2-1
NGC 7538
Spitzer 8 micron
V_{lsr} [km/s]
T_{mb} [K]
Offset [arcmin]
Dec (J2000)
RA (J2000)
MJy/sr

SOFIA FEEDBACK Legacy Program

(PIs: A. G. G. M. Tielens N. Schneider)

Eleven Massive star-forming regions from SOFIA Observatory

A dent inside NGC7538 created by *IRS-1's outflow* (3.6 pc proposed by Sandell+20)



SOFIA FEEDBACK Legacy Program

(PIs: A. G. G. M. Tielens N. Schneider)

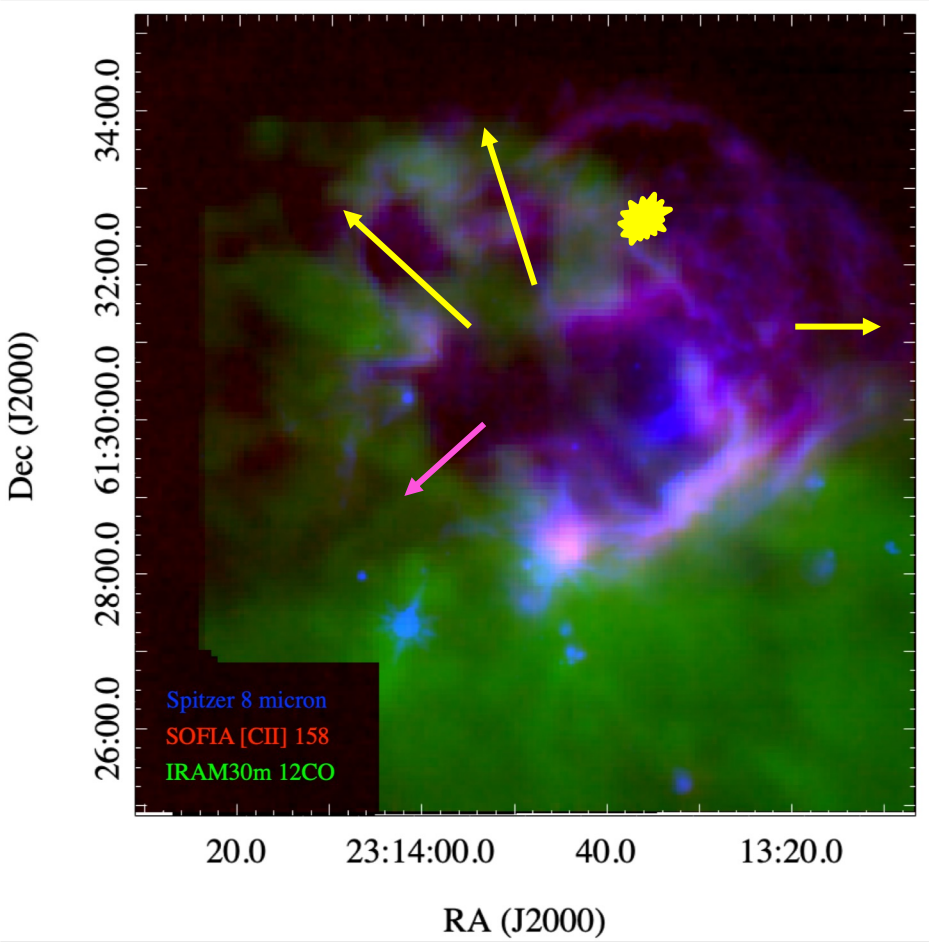
Eleven Massive star-forming regions from SOFIA Observatory

Breakage points in NGC 7538

Fallscheer et al. 2013

+

This work



Take home messages

Special thanks

- C+ SQUAD, FEEDBACK, and upGREAT Teams

- LOC/SOC for organizing this meeting

1. The momentum deposited into the Veil shell: ~15% ***through prestellar feedback*** + 85% ***through main-sequence feedback***.

2. During the prestellar phase, the ***outflow of θ¹ Ori C*** carved the northwestern portion of the Orion Nebula. After ***stellar winds from θ¹ Ori C*** began to drive the expansion of the Veil shell, less massive stars made the ***Veil shell porous*** with their outflows.

3. NGC 7538 has one large expanding shell as well as two additional cavities (one due to ***pre-existing conditions*** and one caused by ***stellar activity***). NGC 7538 leaks UV photons from ***multiple breakages***.

4. The ***velocity-resolved SOFIA [CII] line observations provide a unique view*** of the protostellar and main sequence feedback in the ISM. Waiting for ***GUSTO***!

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by Umit Kavak (Author)

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Take home messages

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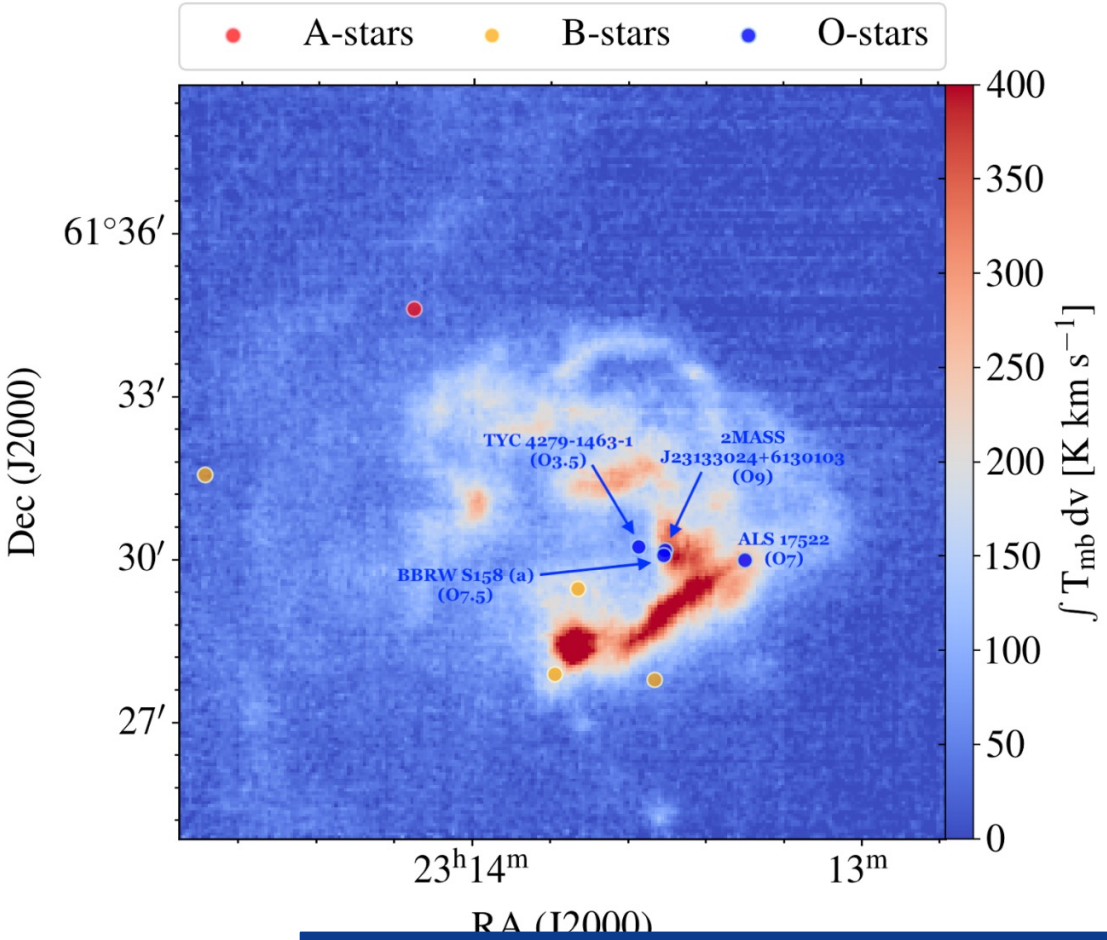
Back-up Slides

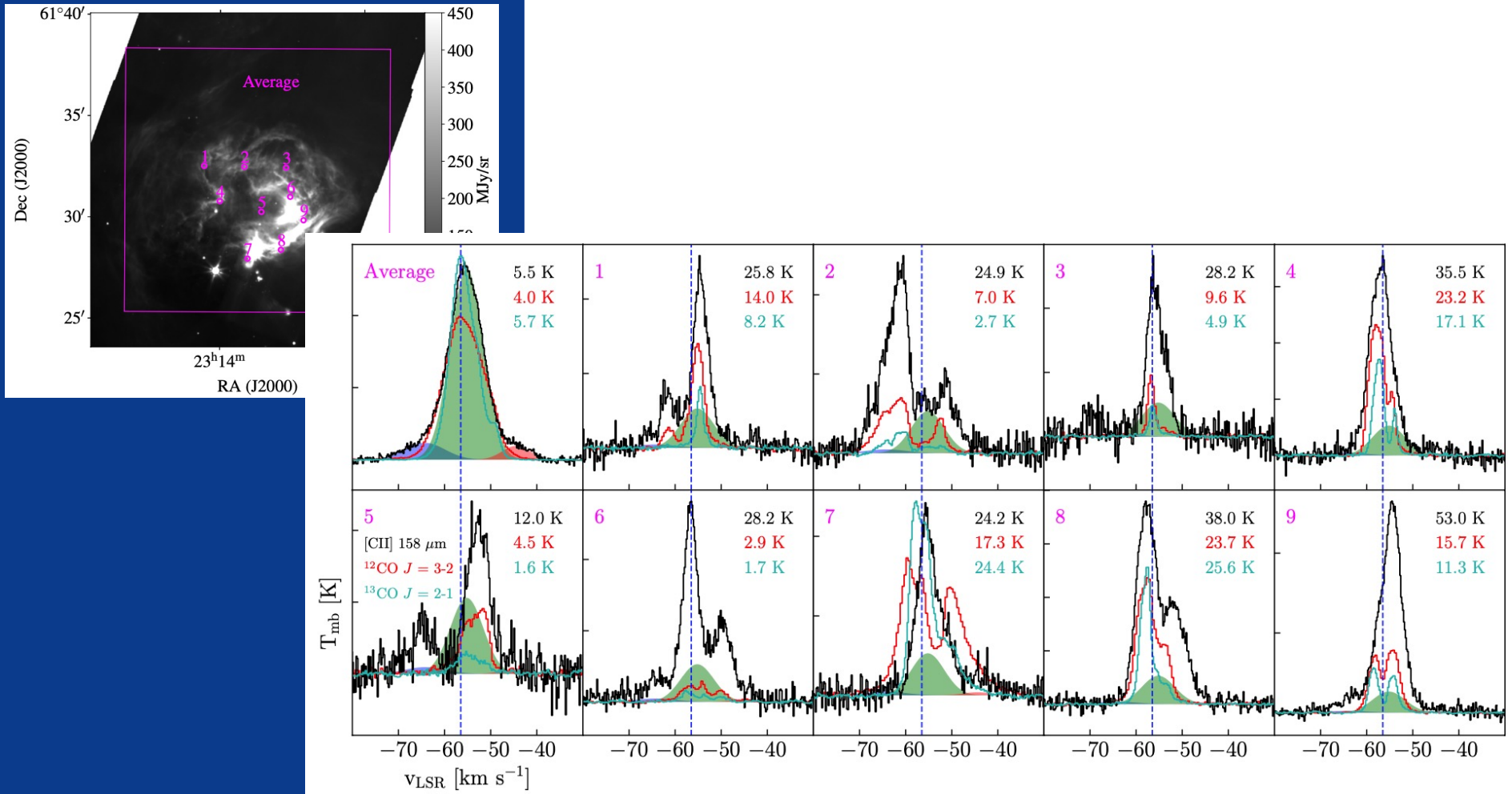

A-stars
B-stars
O-stars
61°36′
33′
30′
27′
Dec (J2000)
23h14m
13m
RA (J2000)
TYC 4279-1463-1
(O3.5)
2MASS
J23133024+6130103
(O9)
ALS 17522
(O7)
BBRW S158 (a)
(O7.5)
400
350
300
250
200
150
100
50
0
∫ Tmb dv [K km s−1]

The momentum deposited by fossil outflows is *5%* of the momentum that Veil shell has.

Table 1. Comparison of the masses and energetics of the protrusion with the Veil shell.

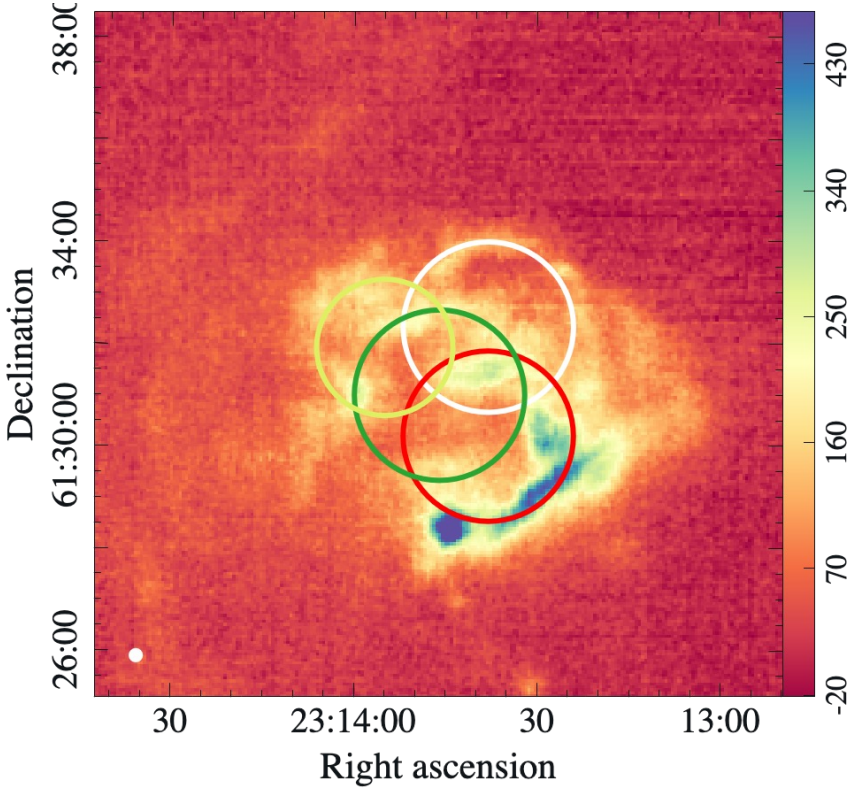
	Veil shell [a]	Protrusion
Size (pc)	2.7	1.3 [b]
Thickness (pc)	0.5	0.1
Density ($\times 10^3$ cm^{-3})	1–10	0.1–1
$E_{\rm kin}$ (10^{46} erg)	250	7
Momentum ($M_\odot$ km s^{-1})	20 000	360–540
Expansion velocity (km s^{-1})	13	12
Mass of neutral gas ($M_\odot$)	1500	30–45

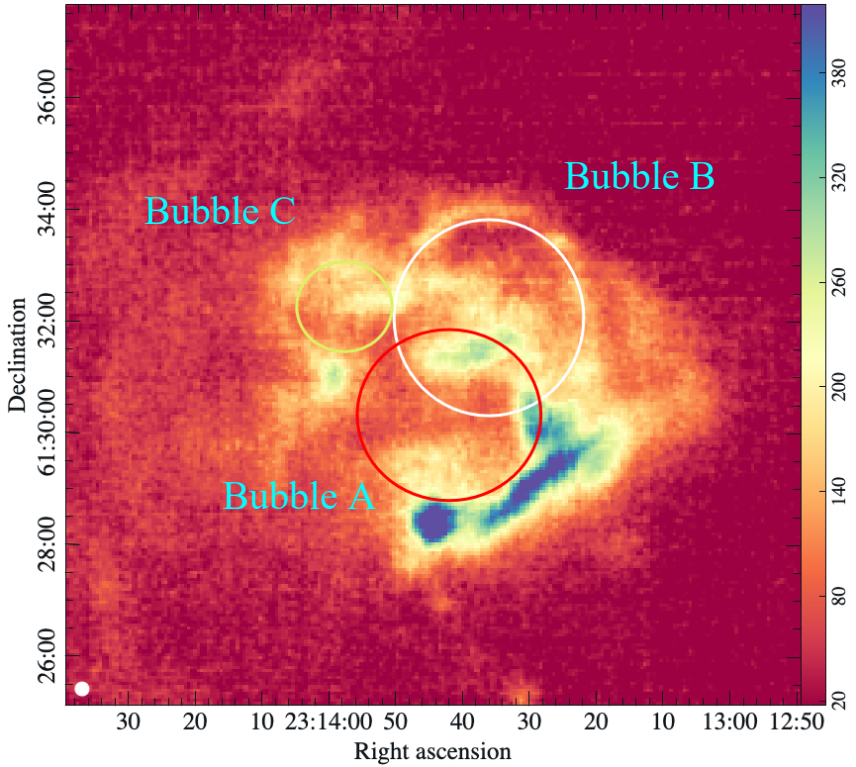
Notes. [a]From Pabst et al. (2020). [b]The protrusion size is measured from the wall of the Veil shell to the outer shell in the northwestern direction.

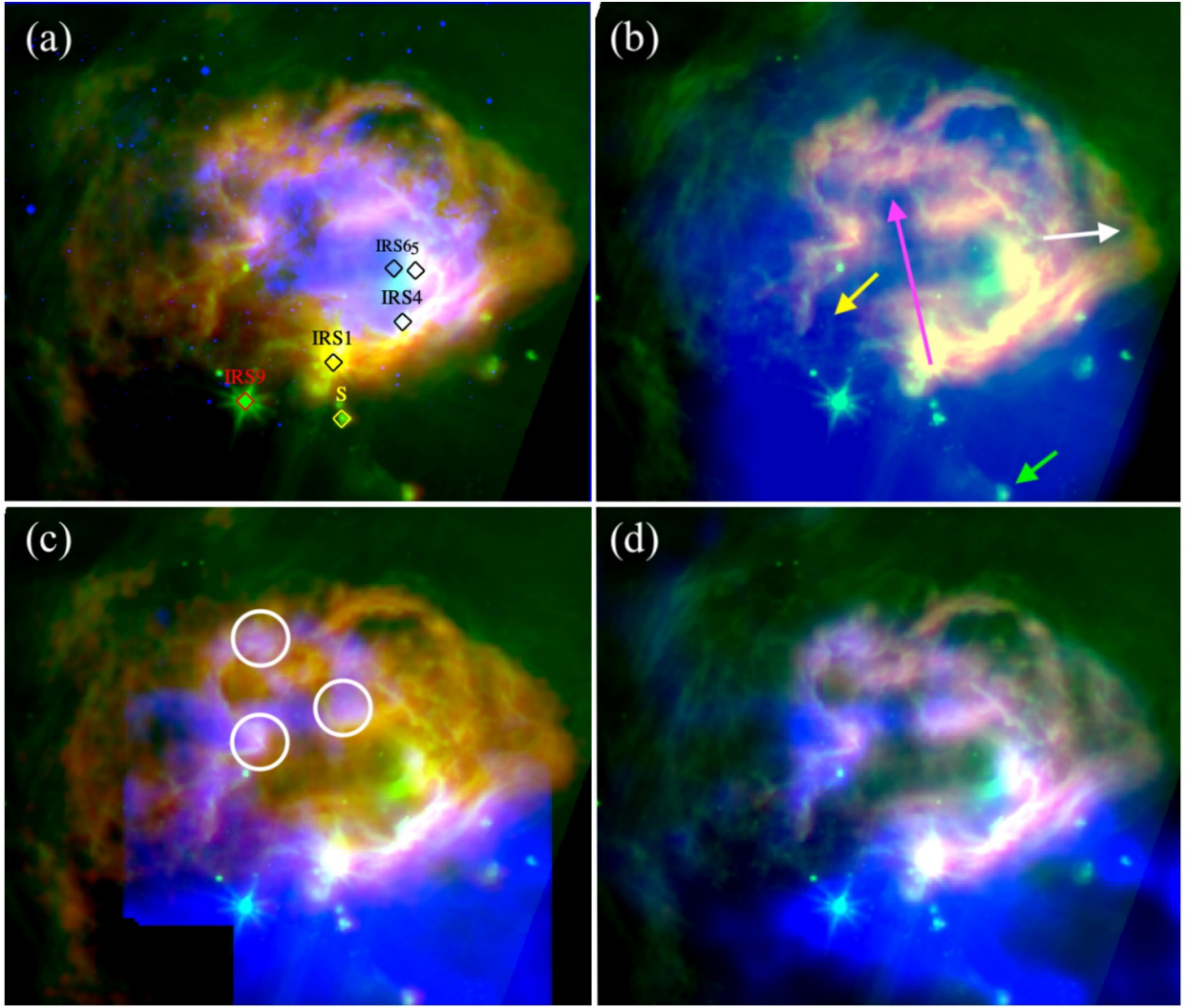

61°40′
35′
30′
25′
Dec (J2000)
23h14m
RA (J2000)
Average
1
2
3
4
5
6
7
8
9
450
400
350
300
250
200
MJy/sr
Average 5.5 K 4.0 K 5.7 K
1 25.8 K 14.0 K 8.2 K
2 24.9 K 7.0 K 2.7 K
3 28.2 K 9.6 K 4.9 K
4 35.5 K 23.2 K 17.1 K
5 12.0 K 4.5 K 1.6 K
6 28.2 K 2.9 K 1.7 K
7 24.2 K 17.3 K 24.4 K
8 38.0 K 23.7 K 25.6 K
9 53.0 K 15.7 K 11.3 K
[CII] 158 μm
12CO J = 3-2
13CO J = 2-1
Tmb [K]
−70 −60 −50 −40
vLSR [km s−1]

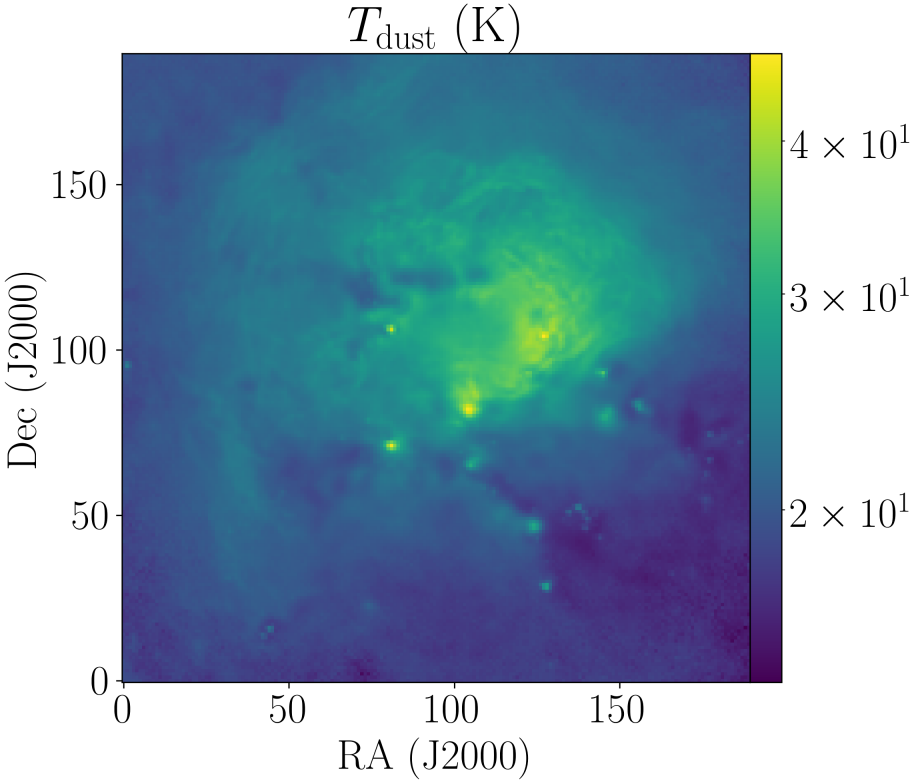
Bubbles in NGC 7538

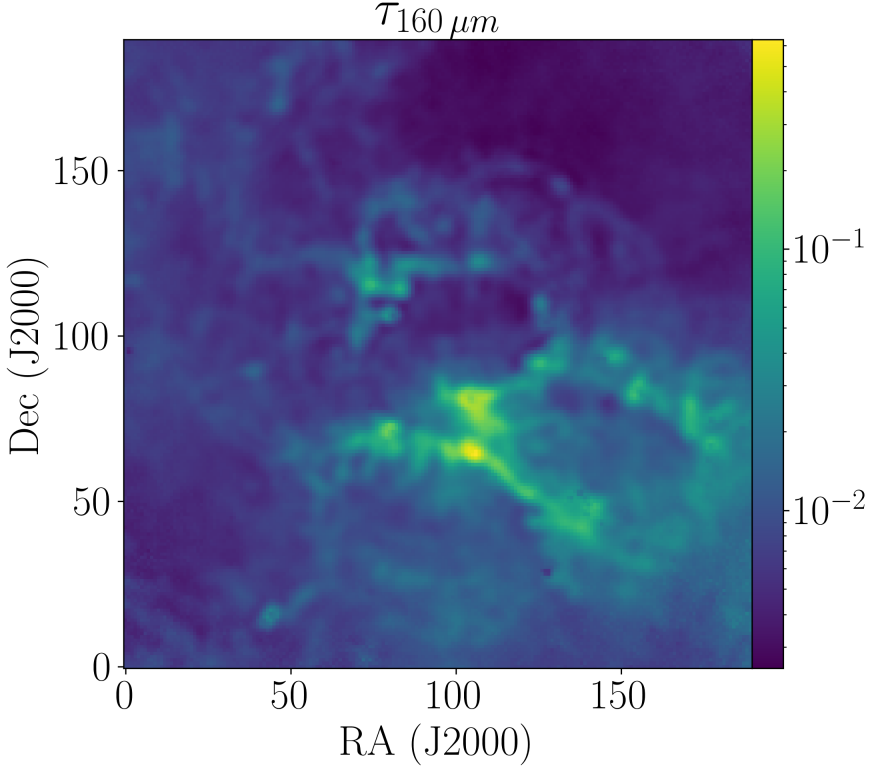
Bubbles from Beuther+22





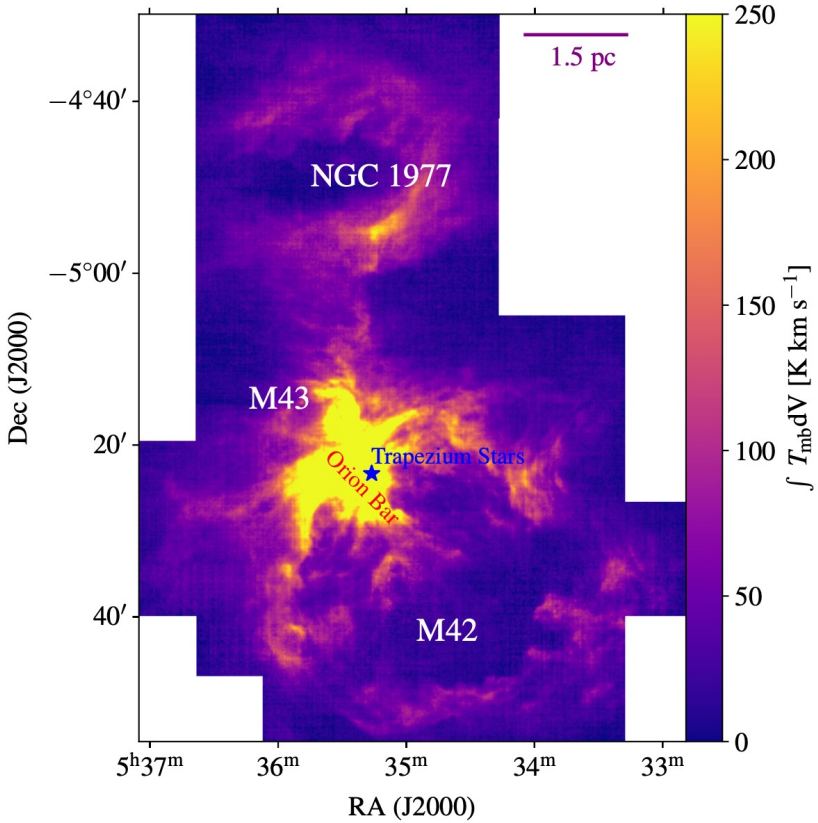

(a)
IRS65
IRS4
IRS1
IRS9
S
(b)
(c)
(d)

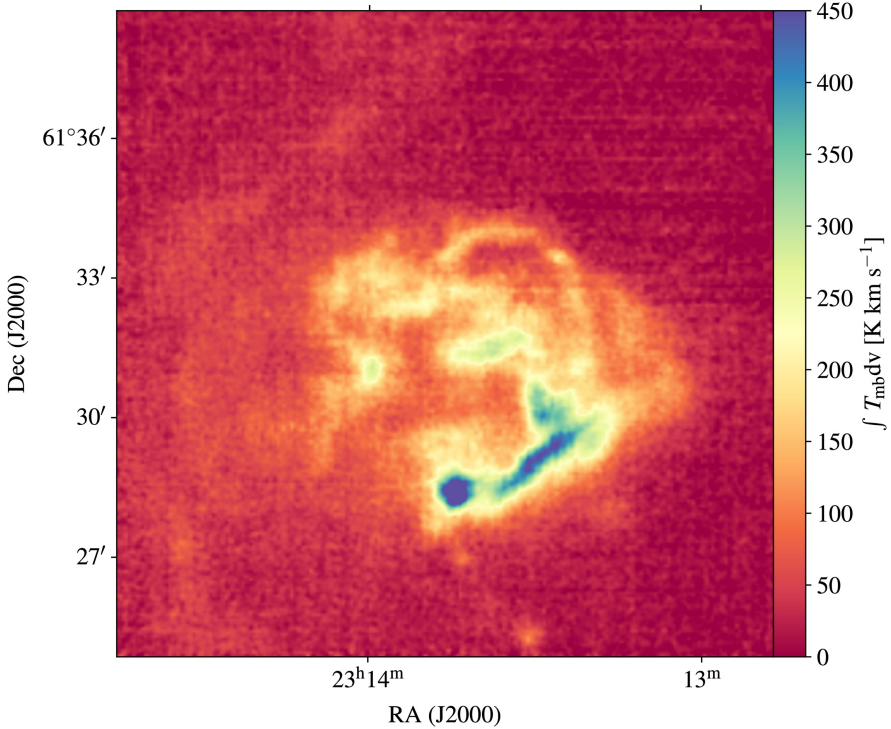




- See Kavak et al. 2022a, b for the method to produce the maps

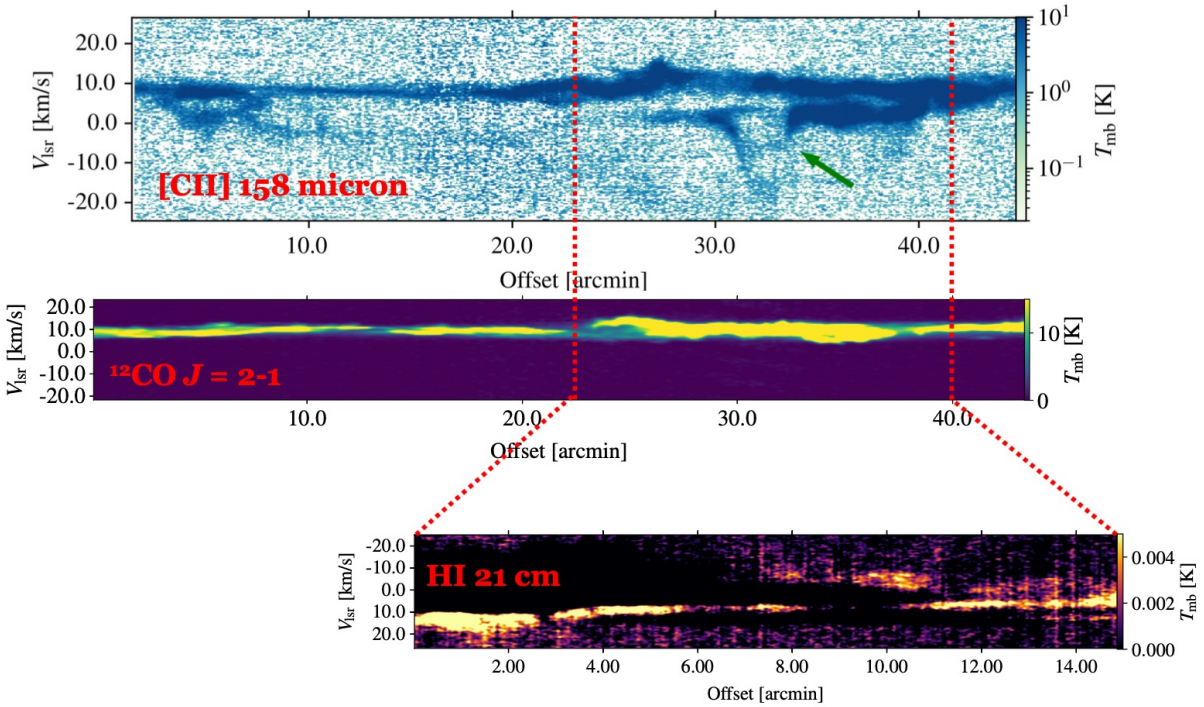
Comparison of the Orion Nebula and NGC 7538





- The Orion Nebula is much younger than NGC 7538.

Dents in the Veil shell

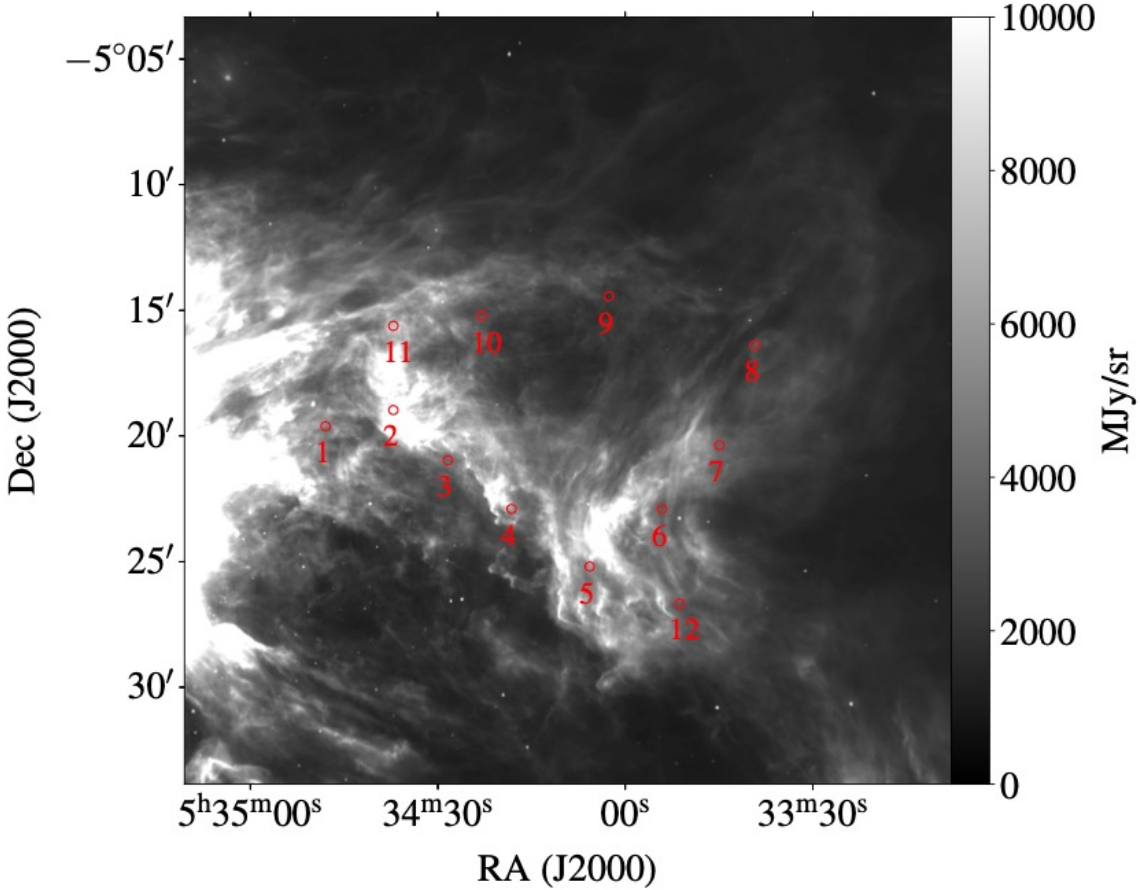


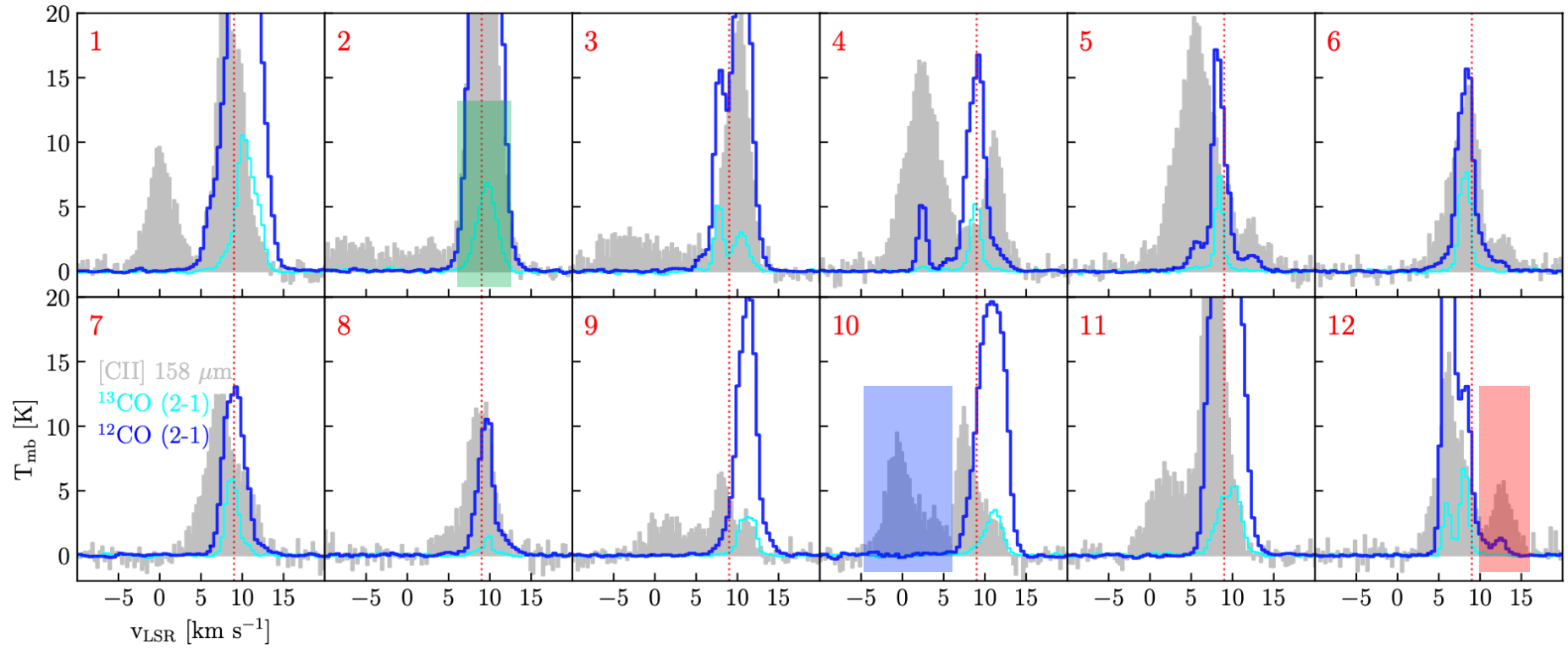
The velocity-resolved [CII] line observations from SOFIA provide unique view to study protostellar feedback.

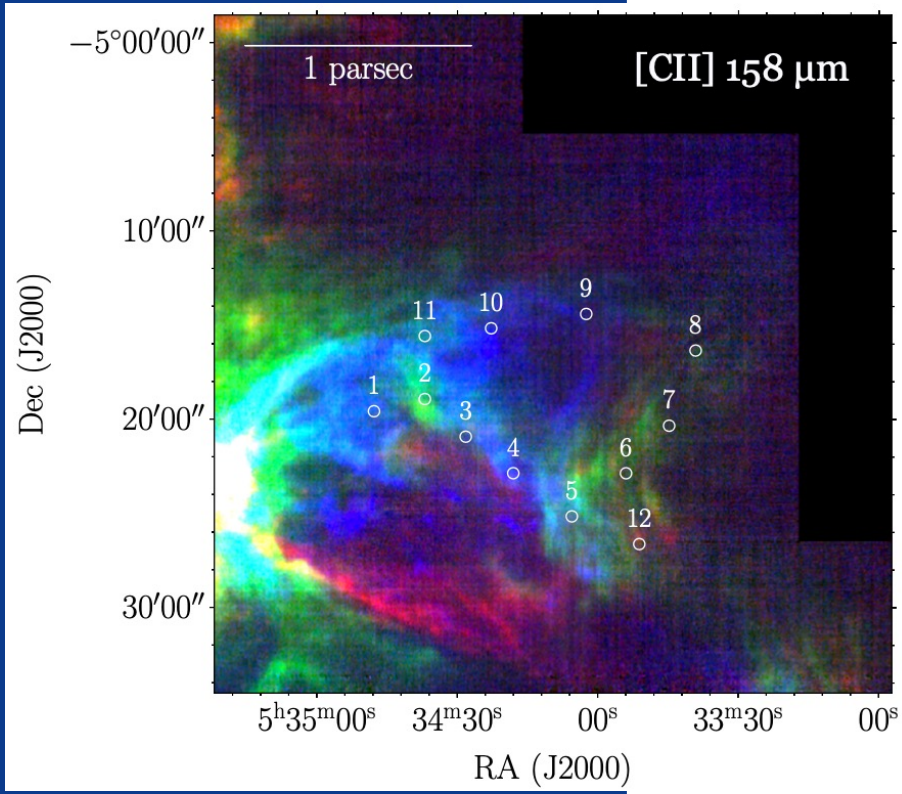
Comparison of [CII], ^{12}CO and ^{13}CO

Background image is *Spitzer* 8 micron map

Red circles are 18 arcseconds in diameter




1
2
3
4
5
6
7
8
9
10
11
12
[CII] 158 μm
13CO (2-1)
12CO (2-1)
Tmb [K]
vLSR [km s−1]


1 parsec
[CII] 158 μm
−5°00′00″
10′00″
20′00″
30′00″
Dec (J2000)
5h35m00s
34m30s
00s
33m30s
00s
RA (J2000)
1
2
3
4
5
6
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8
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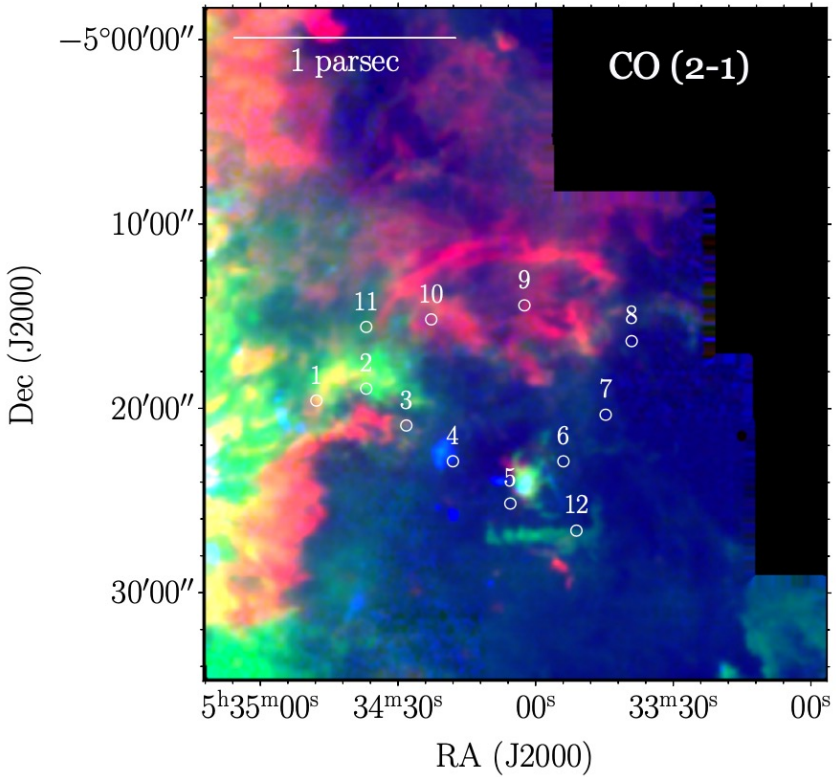
11
12


1 parsec
CO (2-1)
−5°00′00″
10′00″
20′00″
30′00″
Dec (J2000)
5h35m00s
34m30s
00s
33m30s
00s
RA (J2000)
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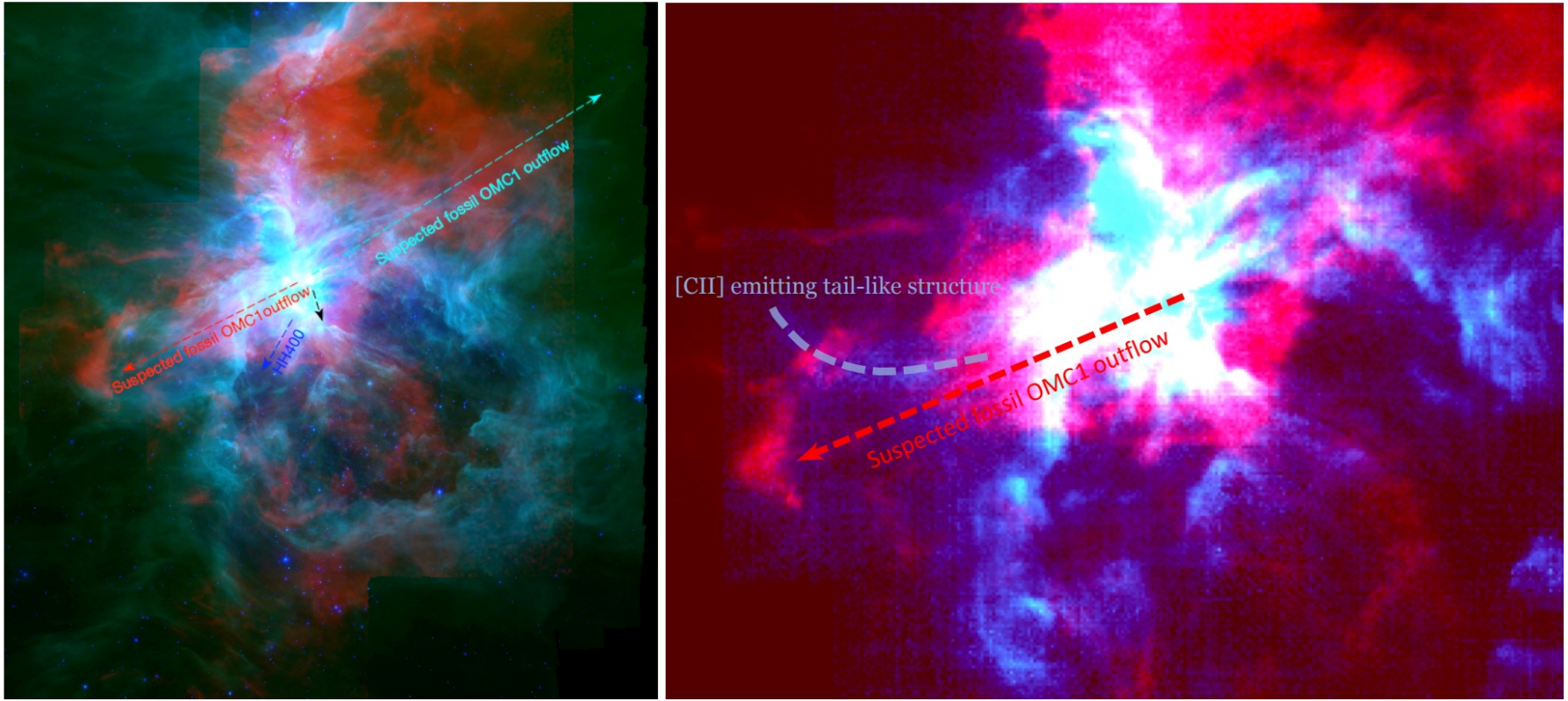
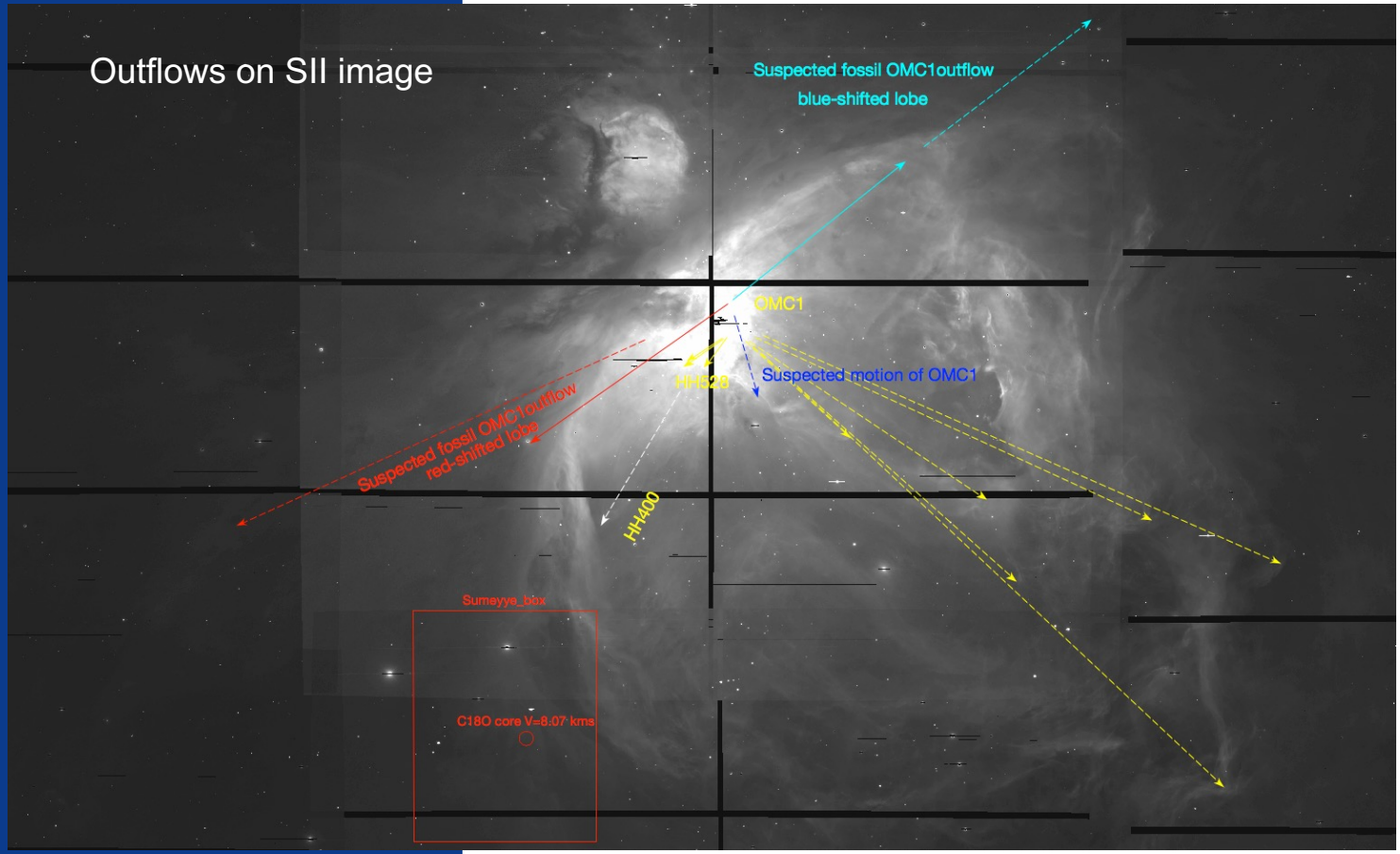
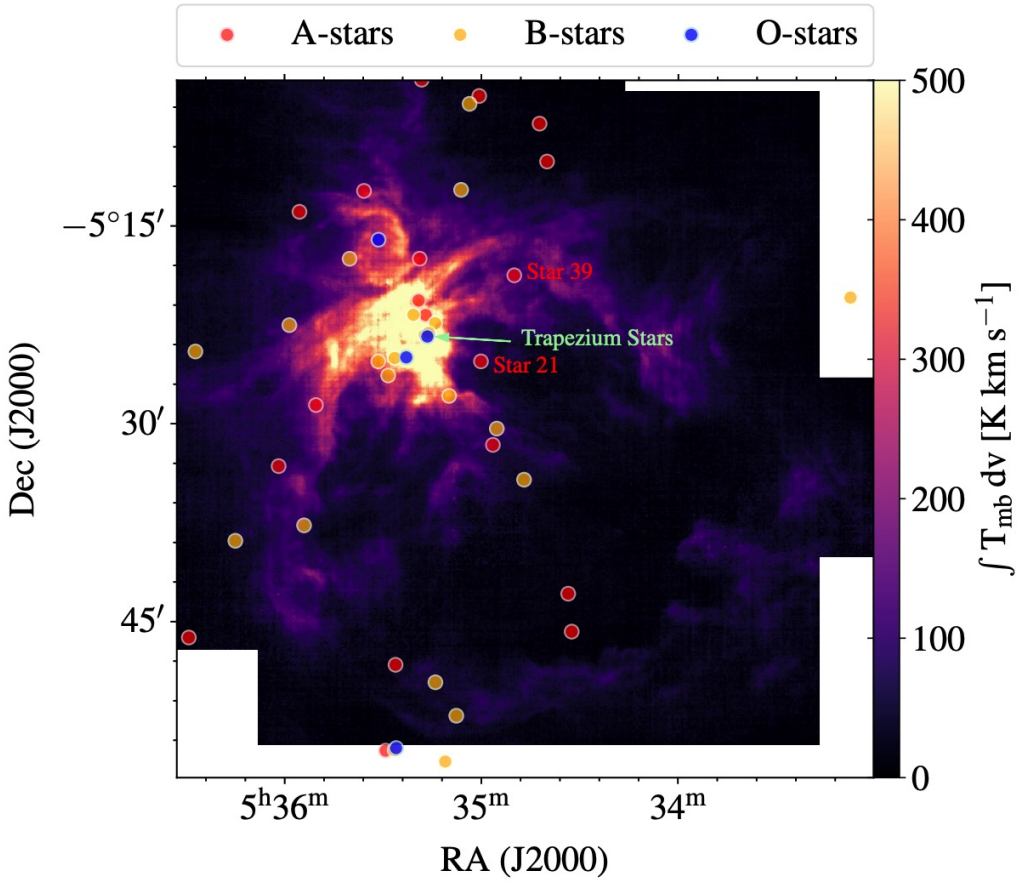


Fig. B.4. High-velocity CO emission. *Left:* Red- and blue-shifted lobes of suspected fossil OMC-1 outflow on a WISE image, including CO emission (red; Bally et al., in prep.). *Right:* Red-shifted lobe of suspected fossil OMC-1 outflow on [C II] (blue emission) and ^{12}CO emission (red emission). In both panels, CO emission is integrated between +10 and +13 km s^{-1}.

Outflows on SII image



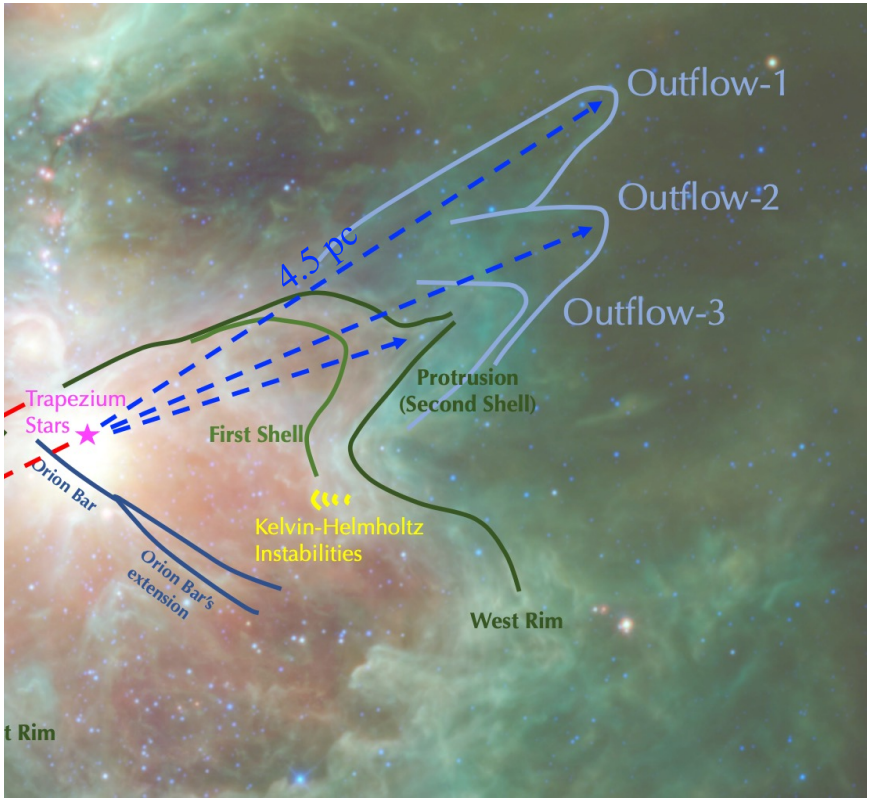

A-stars
B-stars
O-stars
Star 39
Trapezium Stars
Star 21
−5°15′
30′
45′
Dec (J2000)
5h36m
35m
34m
RA (J2000)
500
400
300
200
100
0
∫ Tmb dv [K km s−1]

Stellar winds?

If the protrusion is driven by ***stellar winds of θ¹ Ori C***, the protrusion itself should expand like the Veil shell

The protrusion has a lifetime of **1.6×10^5 years** due to photo-ablation from the inner surface of the protrusion.

Driving mechanism?

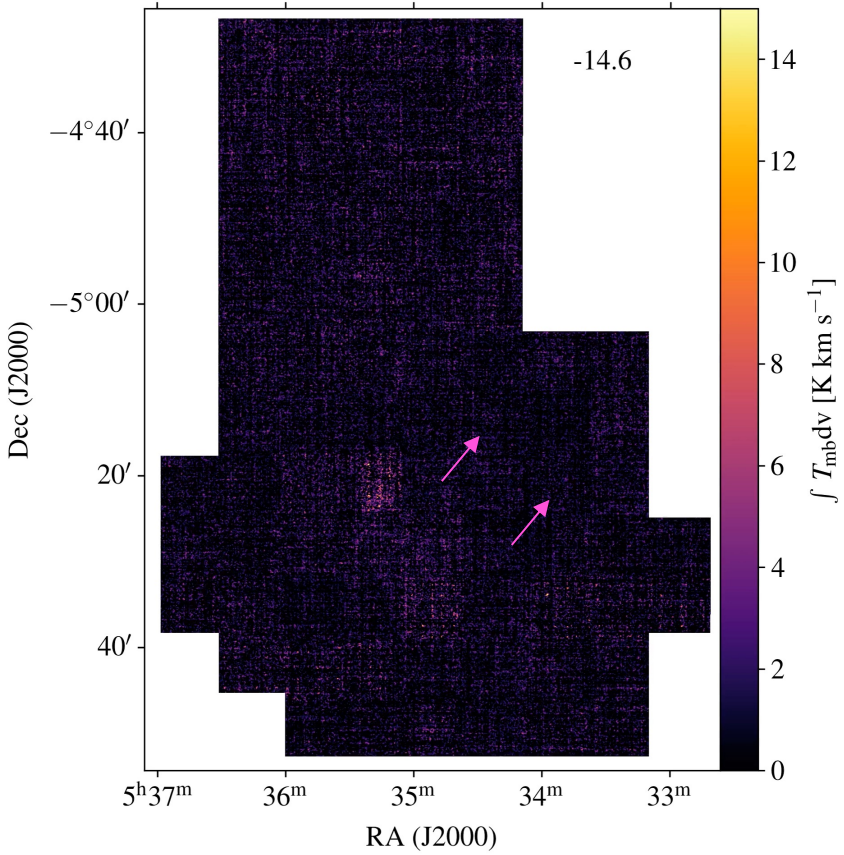


Obstacles and blow-out of the Veil shell?

Least resistance toward the northwest?

Both the expansion of the protrusion and the bipolar jet-like structures seen toward the Veil shell are difficult to reconcile with this scenario.

Driving mechanism?



Driving star?

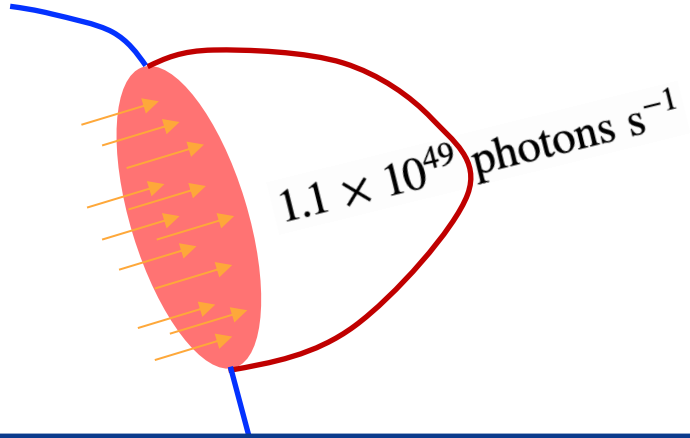
Ionizing source?

The number of ionizing indicates an ***O-type star.***

The honor goes to ***Trapezium cluster***, especially ***θ¹ Ori C.***

$$\left[\frac{EM}{\mathrm{pc\ cm^{-6}}}\right] = 4.197 \times 10^{17} \times I_{\mathrm{H}\alpha}$$

$$\mathbb{N}_{\mathrm{Lyc}} = A \times EM \times 2.6 \times 10^{-13}$$



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Mass of neutral gas ($M_\odot$)	1500	30–45

Notes. [a]From Pabst et al. (2020). [b]The protrusion size is measured from the wall of the Veil shell to the outer shell in the northwestern direction.

Orion Veil shell has been assumed to be a ***close, expending*** shell!

What are these ***structures*** in the Veil shell?