USRA Universities Space Research Association

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Prestellar Feedback in Massive Star-Forming Regions

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SOFIA Tele-Talk

Wednesday / 20 July 2022 / 9:00 AM (PDT)

Results from our recently *published* two papers

1. *Kavak et al., 2022* (Kavak+22a)

2. *Kavak et al., 2022* (Kavak+22b)

Astronomy & Astrophysics manuscript no. output
March 31, 2022
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Breaking Orion's Veil bubble with fossil outflows

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Dents in the Veil: Protostellar feedback in Orion

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Jets/Outflows have been proposed to *solve key questions* in star formation research

1. Explain the low-mass **star-formation rate** (SFR) and low-mass star formation efficiency (Krumholz+14, Guszejnov+21, Verliat+22)

2. Remove **angular momentum** from the star-forming regions (Pudritz+07, Frank+14)

3. Explain observed **initial mass function** (IMF; Kroupa+13, Kroupa+14, Grudic+21)

4. Explain the observed level of **turbulence** at various scales (Frank+14, Guszejnov+21)

5. Sustain and enhance **pre-existing** and **recent molecular cloud turbulence** (Cunningham+09; Stanke+22, Kavak+22 (a, b))

Science Questions

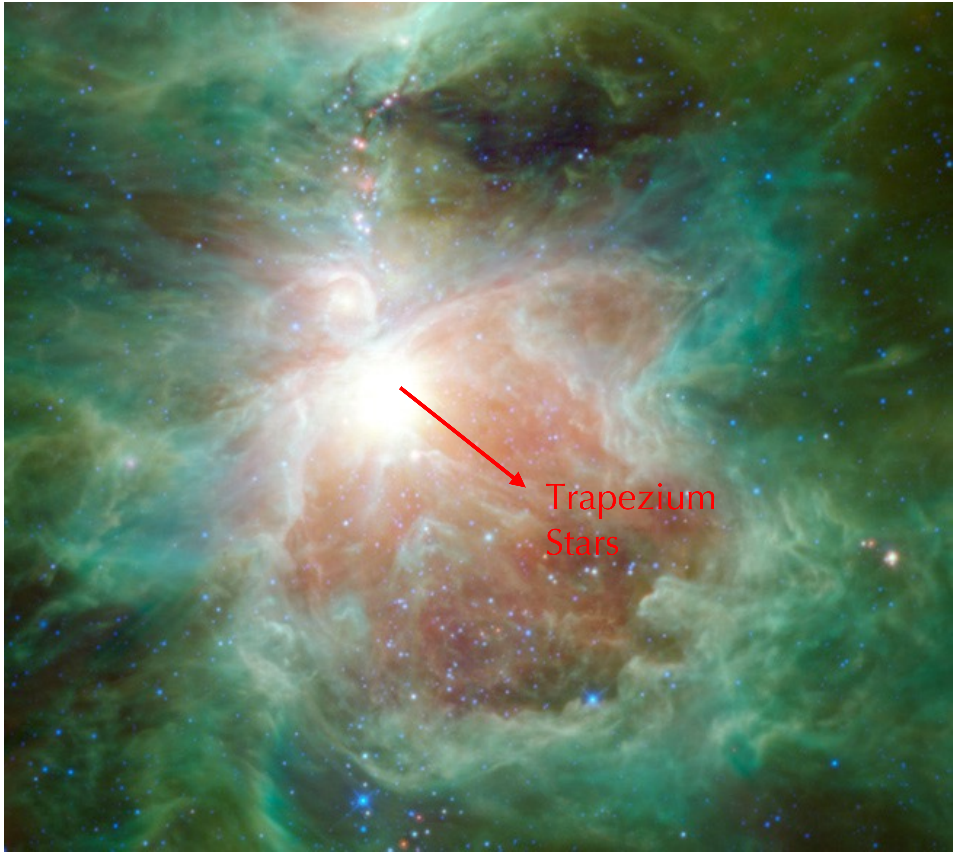
How does the "**FEEDBACK**" of a massive star affect the birth envoirenment?

Pre-stellar feedback vs.
Main sequence feedback?

Orion Nebula

Orion Nebula is a ***unique laboratory*** for these types of feedback studies.

Orion Veil is a shell which lies in front of the Trapezium Cluster

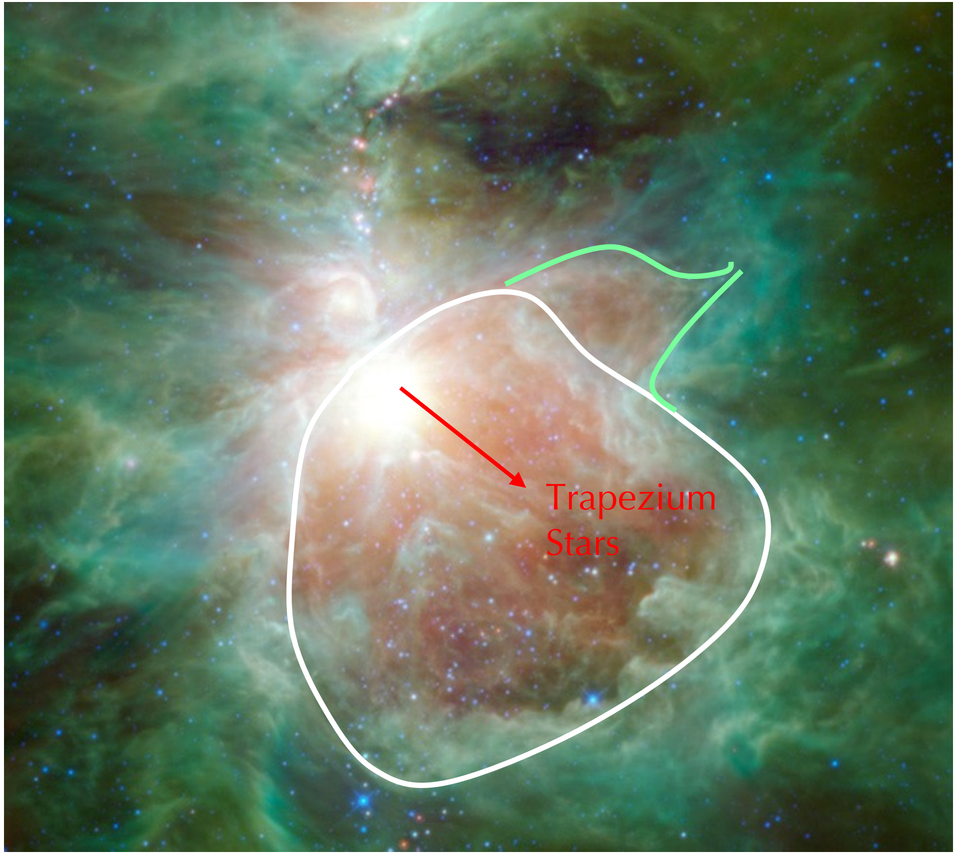


Orion Nebula – WISE

Orion Nebula

Veil shell is mainly driven by ***stellar winds*** from θ^1 Ori C (Pabst+19).

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

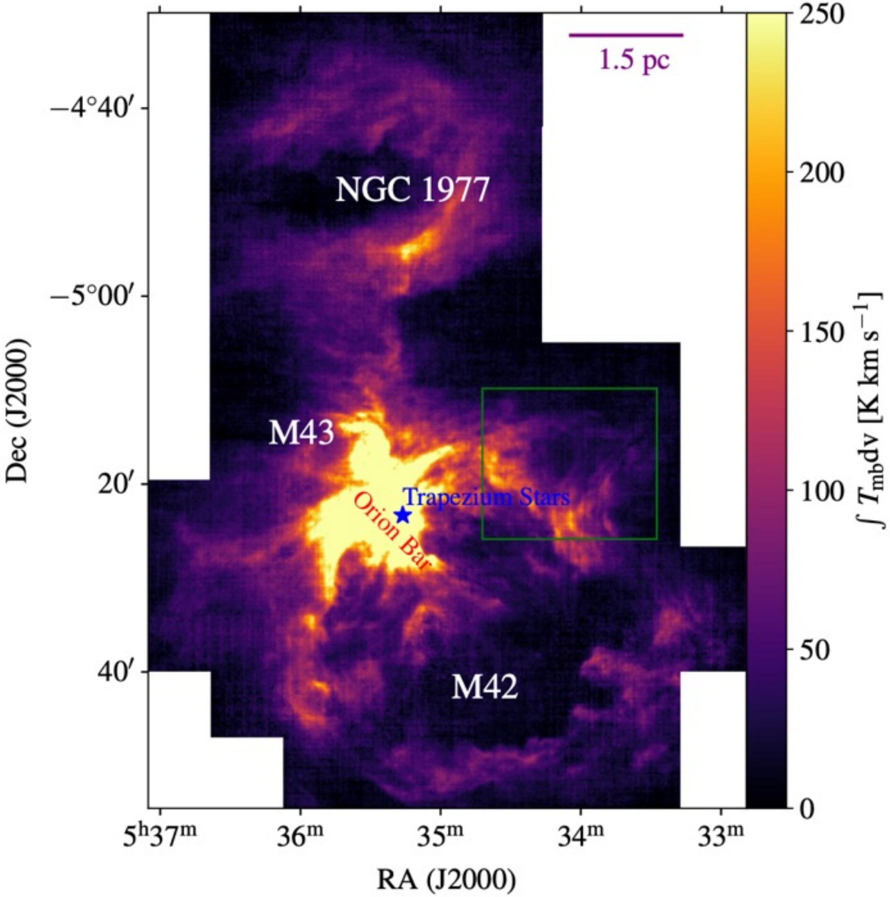


Orion Nebula – WISE

Orion Veil and Its protrusion
(Kavak+22a)

SOFIA/upGREAT C+ SQUAD Large Program (PI: Xander Tielens; 16 arcsec and 0.3 km/s; rms noise of T_{mb} = 1.14 K (78 square tiles)

Integrated intensity [-5, +15 km/s] map of the Orion Nebula



Orion Veil and its protrusion (Kavak+22a)

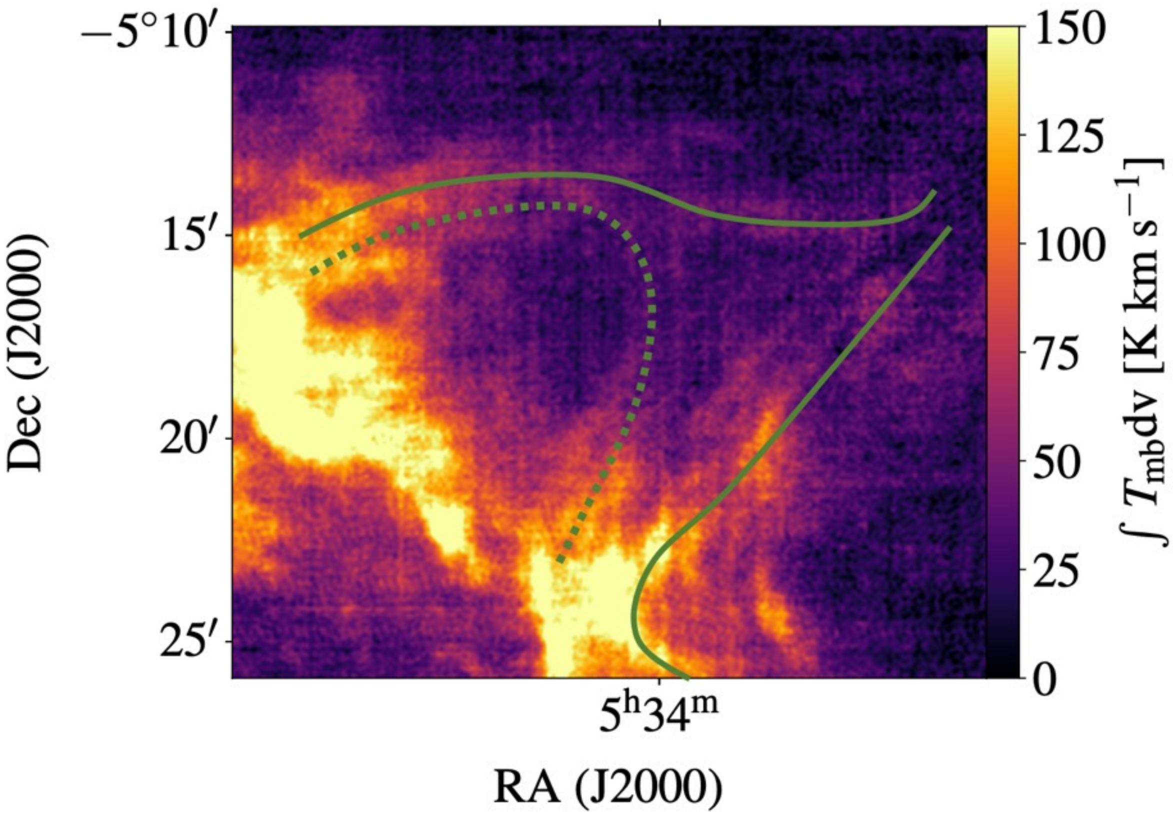
Our Questions

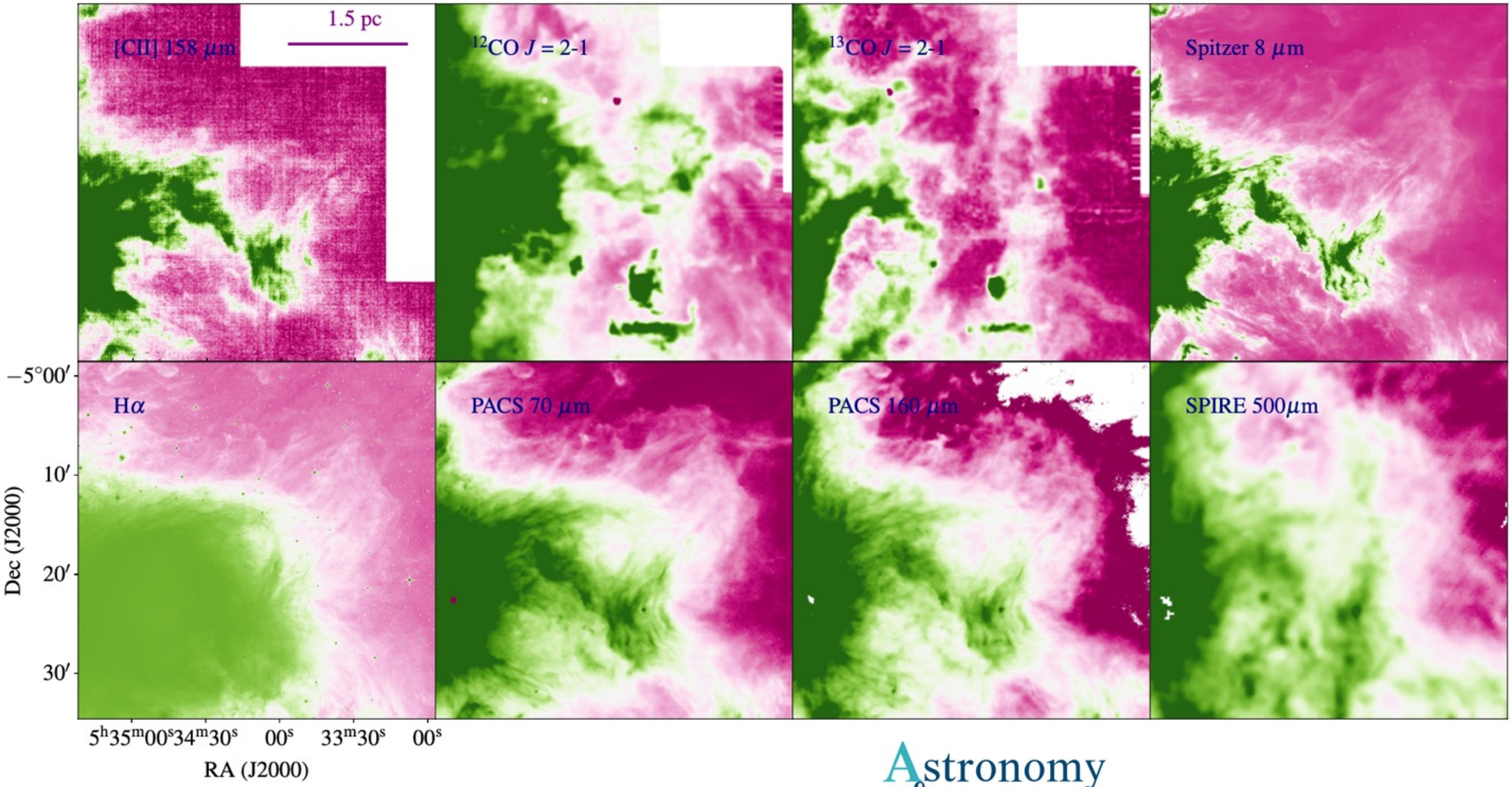
1. Is it also due to the stellar winds as found by Pabst+19?

2. Is it a different feedback mechanism?

3. If so, what is the feedback mechanism?

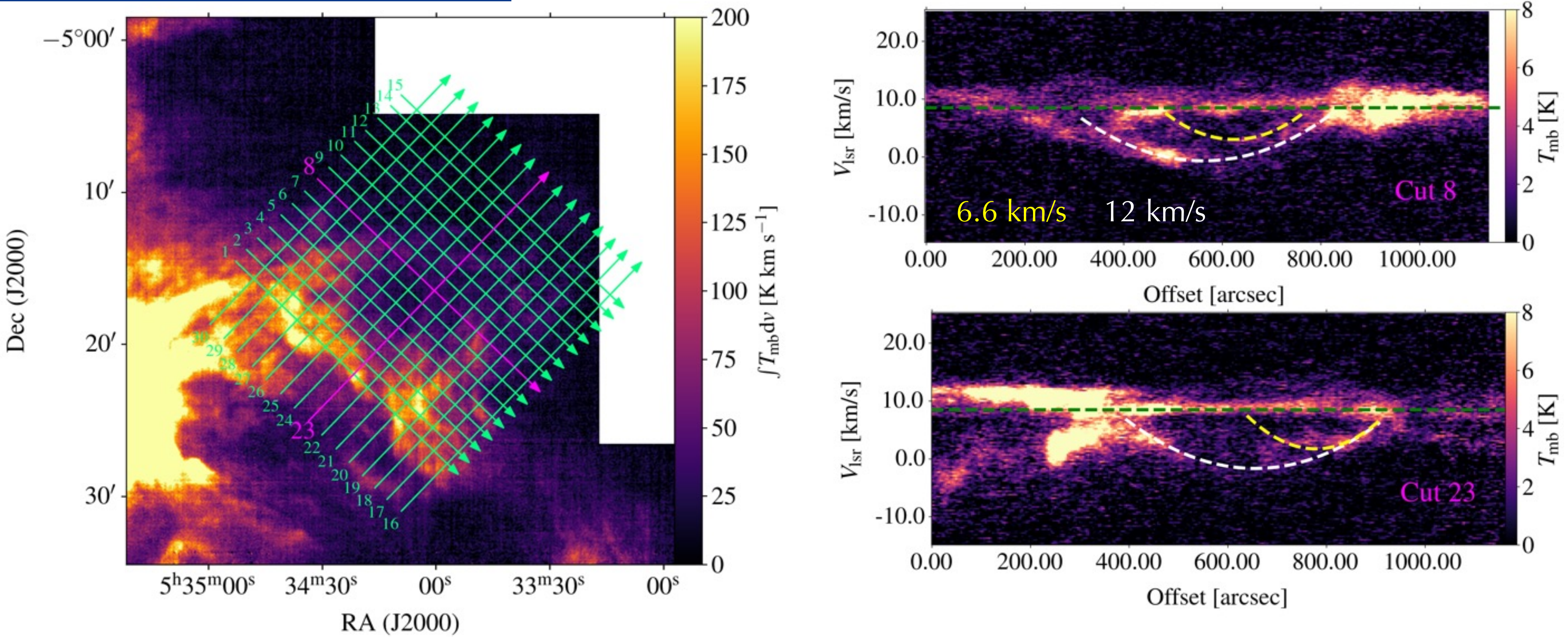
Integrated intensity [-5, +15 km/s] map of the protrusion





Astronomy & Astrophysics

Expanding shells and PV Diagrams

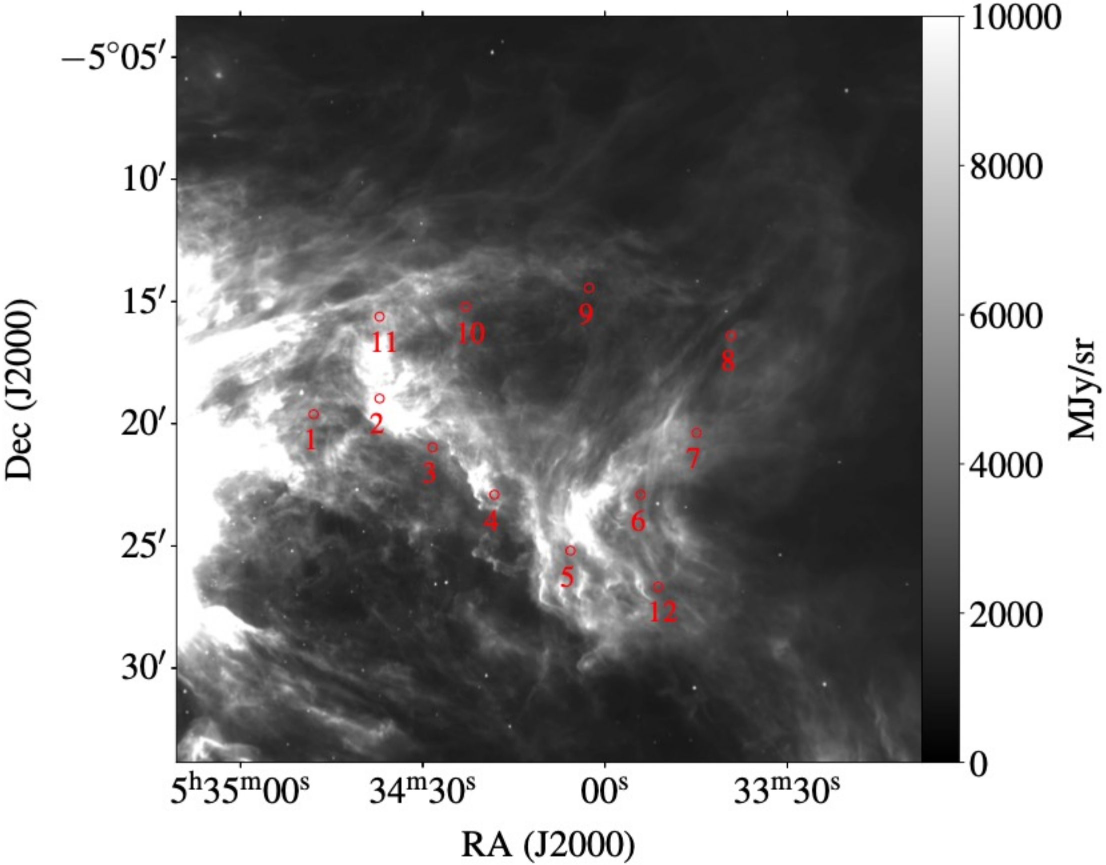


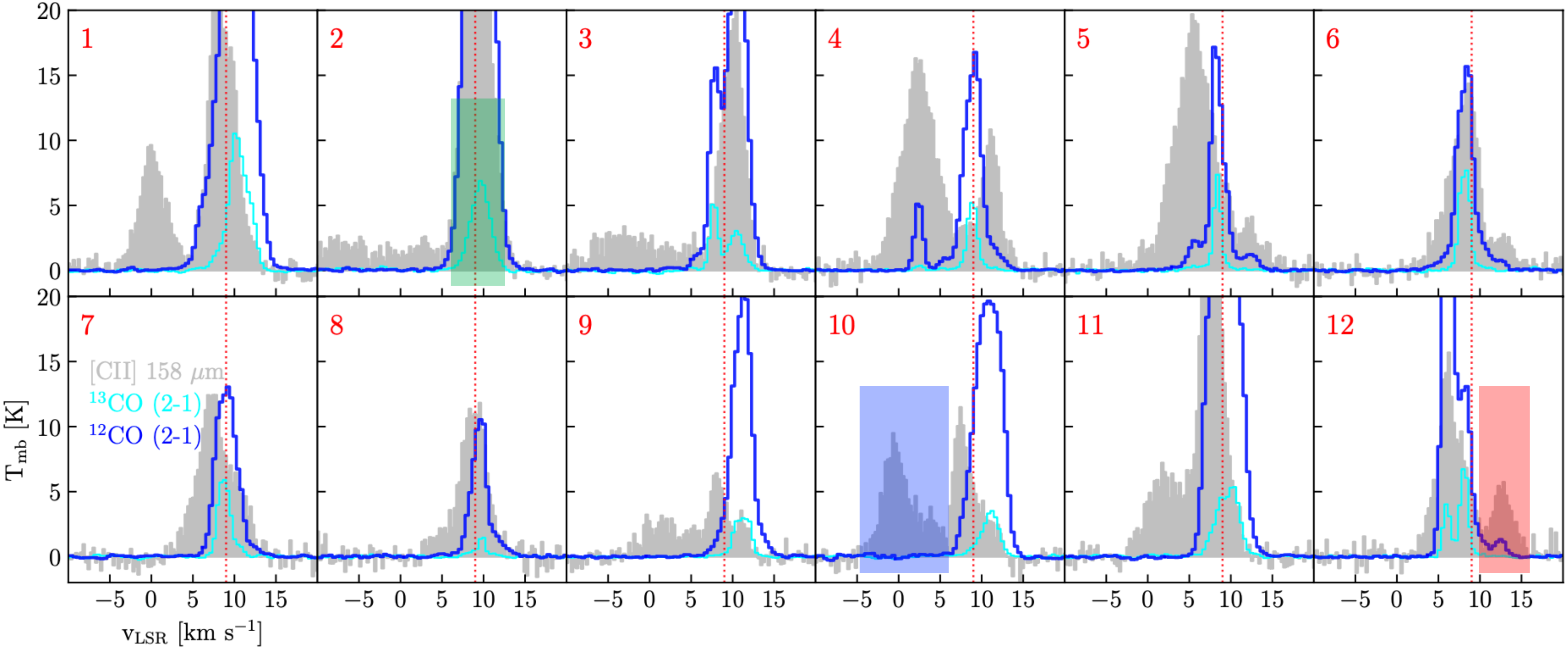
The size (**1.3 pc**) to maximum expansion velocity (**12 km/s**) gives us the expansion timescale of 1.06×10^5 yr

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

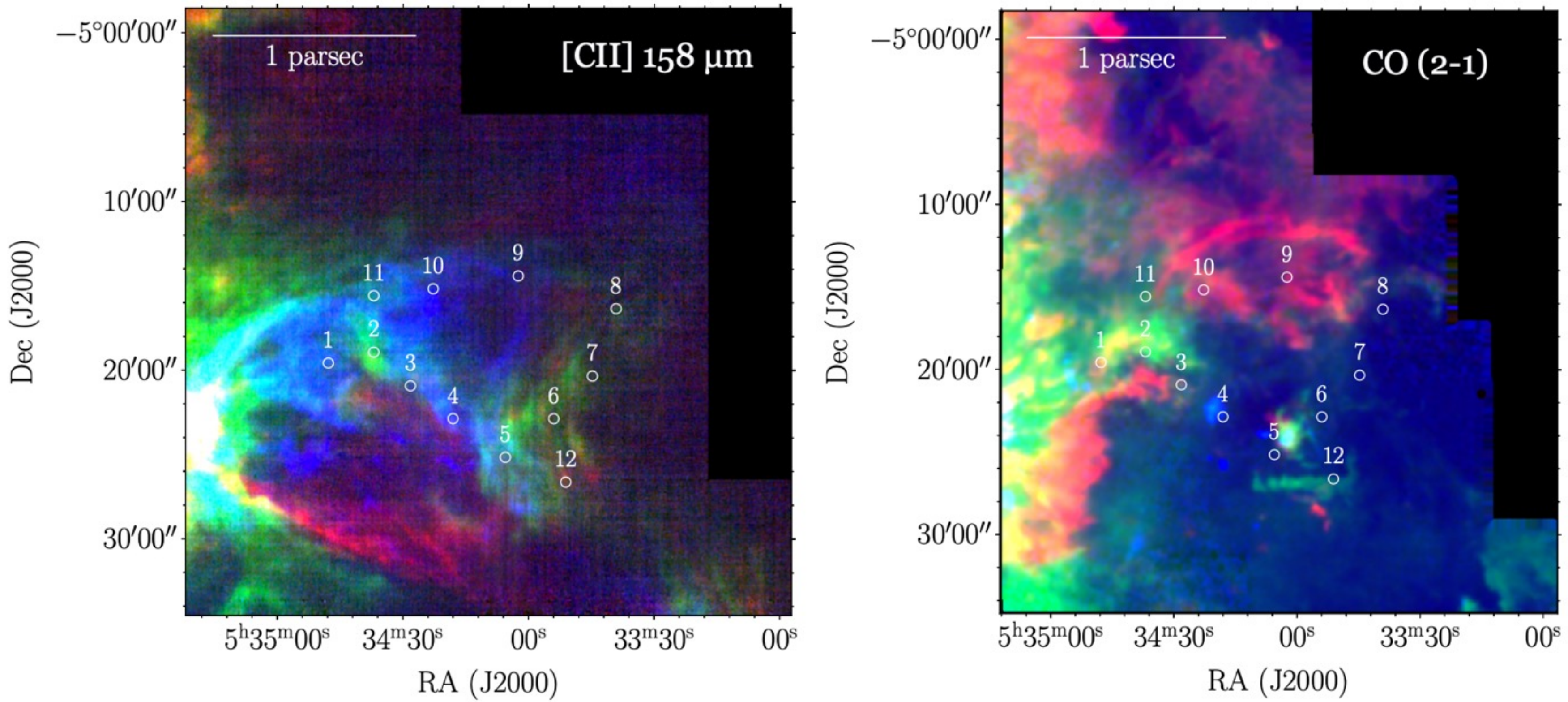
Background image is *Spitzer* 8 micron map

Red circles are 18 arcseconds





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



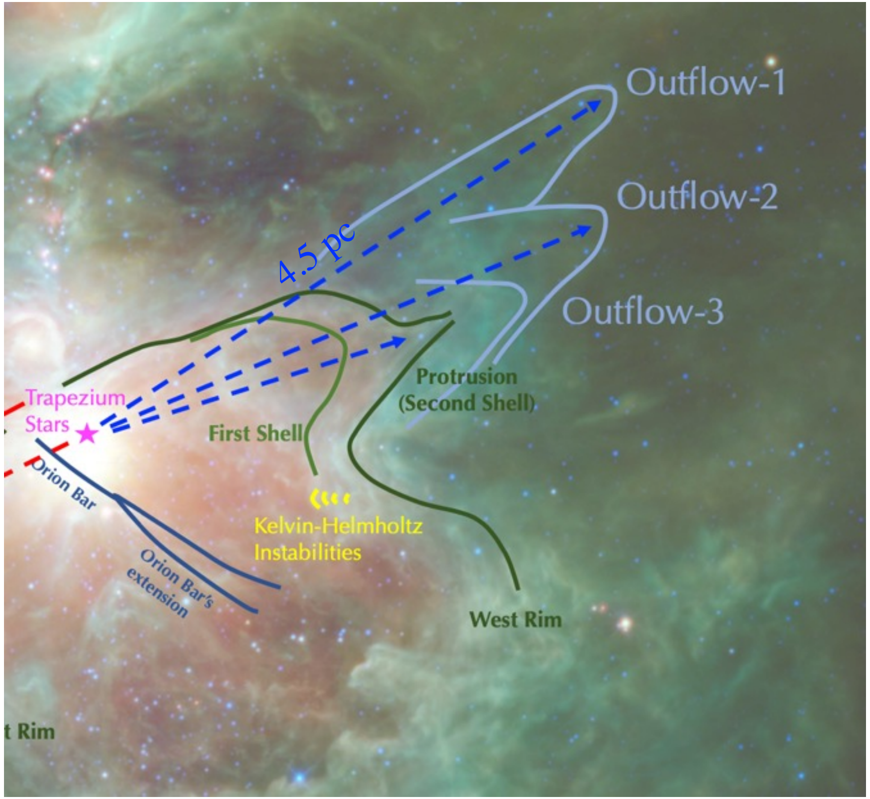
1 parsec
[CII] 158 μm
−5°00′00″
10′00″
20′00″
30′00″
Dec (J2000)
5h35m00s
34m30s
00s
33m30s
00s
RA (J2000)
1 parsec
CO (2-1)

Stellar winds?

If the protrusion is driven by ***stellar winds of*** $\boldsymbol{\theta^1}$ ***Ori C***, the protrusion itself should expand like the Veil shell

The protrusion has a lifetime of $\mathbf{1.6 \times 10^5}$ **years** due to photo-ablation from the inner surface of the protrusion.

Driving mechanism?

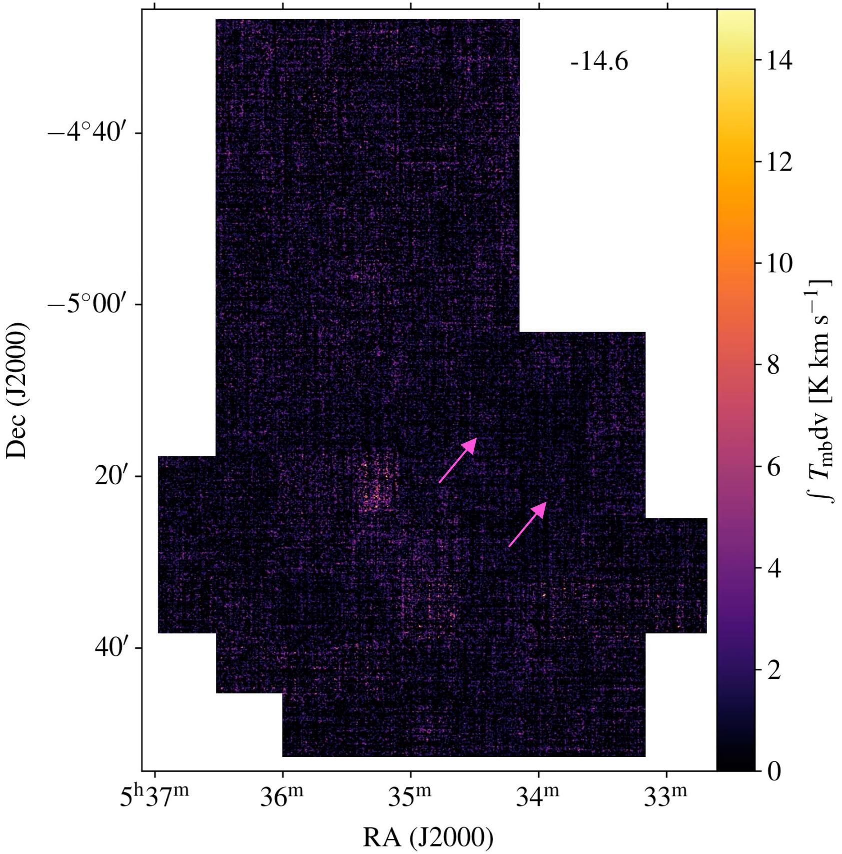


Obstacles and blow-out of the Veil shell?

Least resistance toward the northwest?

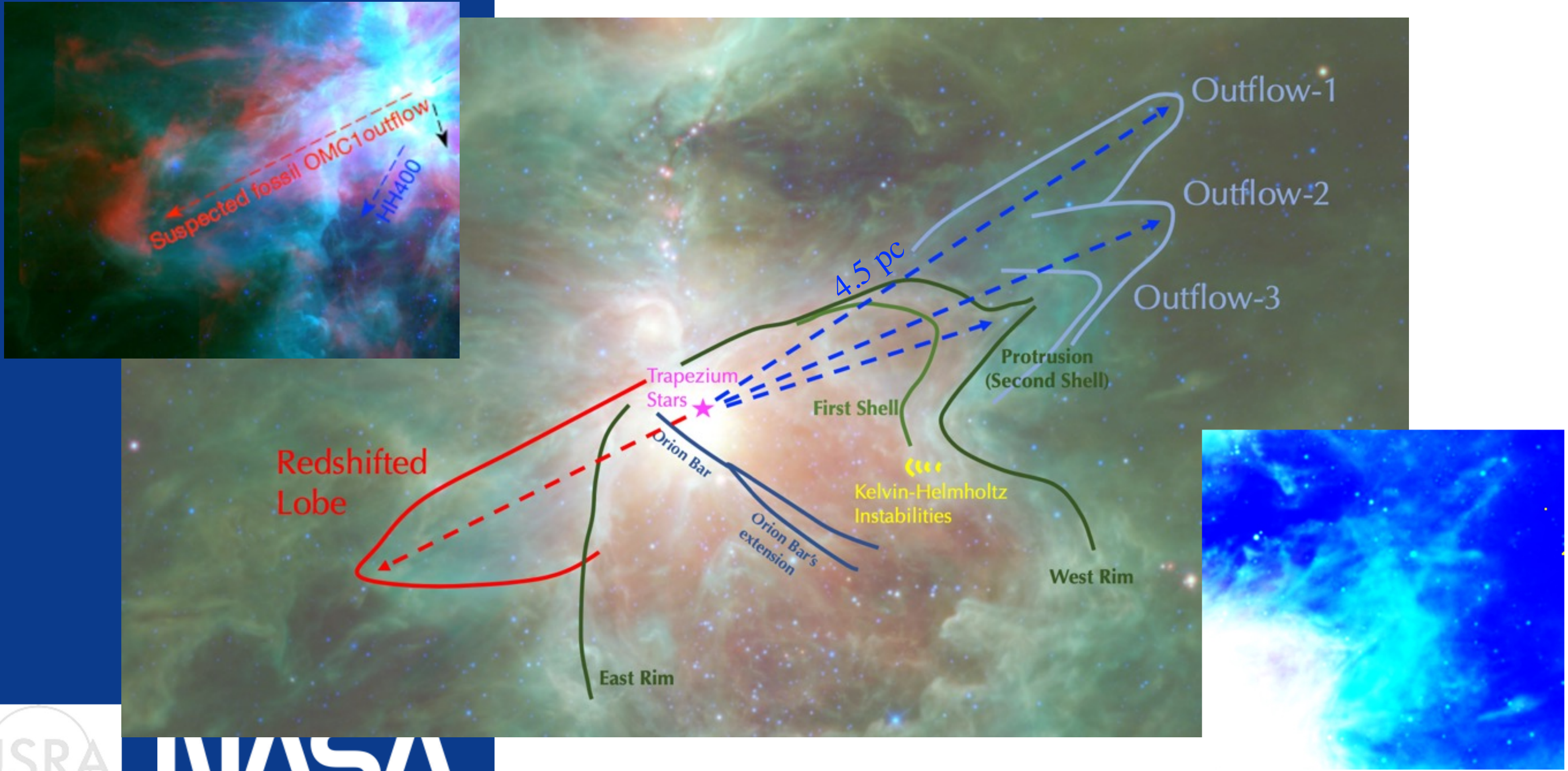
Both the expansion of the protrusion and the bipolar jet-like structures seen toward the Veil shell are difficult to reconcile with this scenario.

Driving mechanism?



Outflows?

Driving mechanism?



Ionizing source?

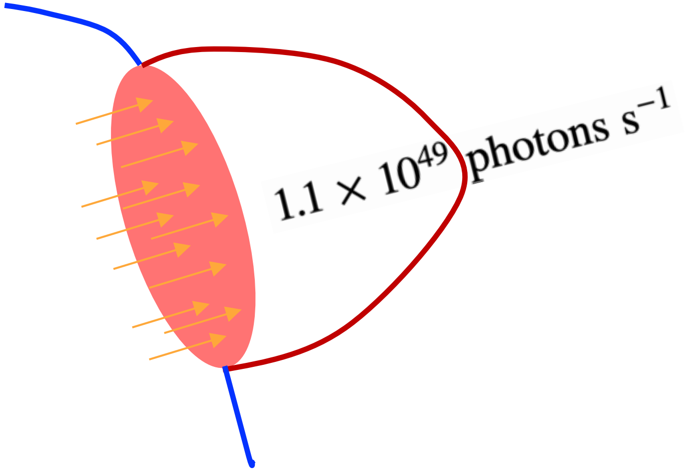
The number of ionizing indicates an ***O-type star.***

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

Driving star?

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

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

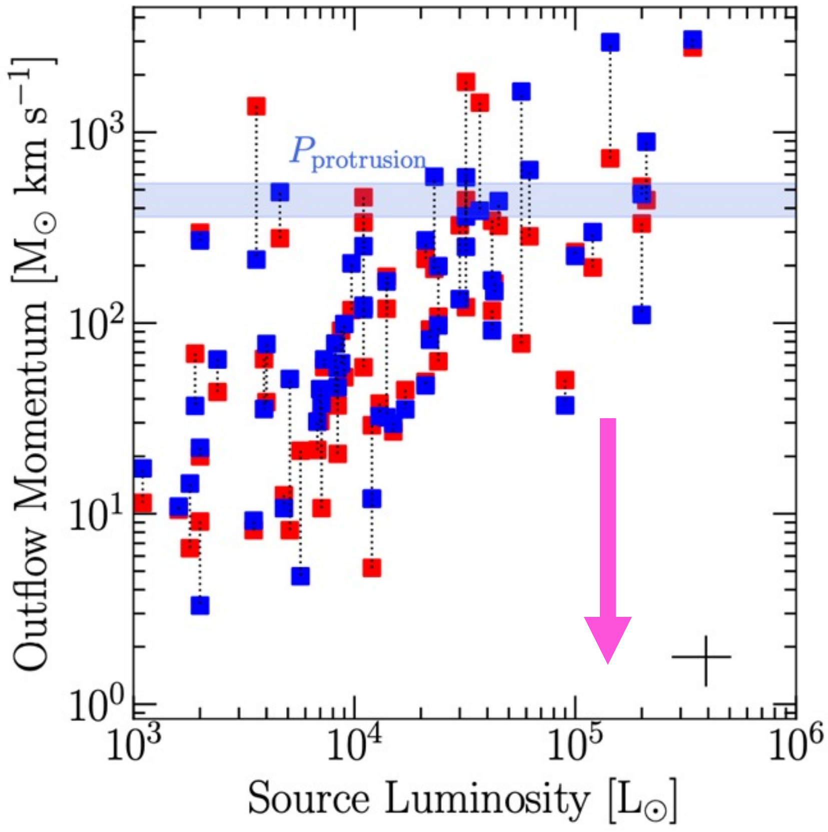


Outflows?

The protrusion is a ***pre-existing*** structure in OMC-1

It is the result of ***fossil outflow*** activity in the OMC-1 core

Driving star?



(Data points from Maud+15)

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_{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.

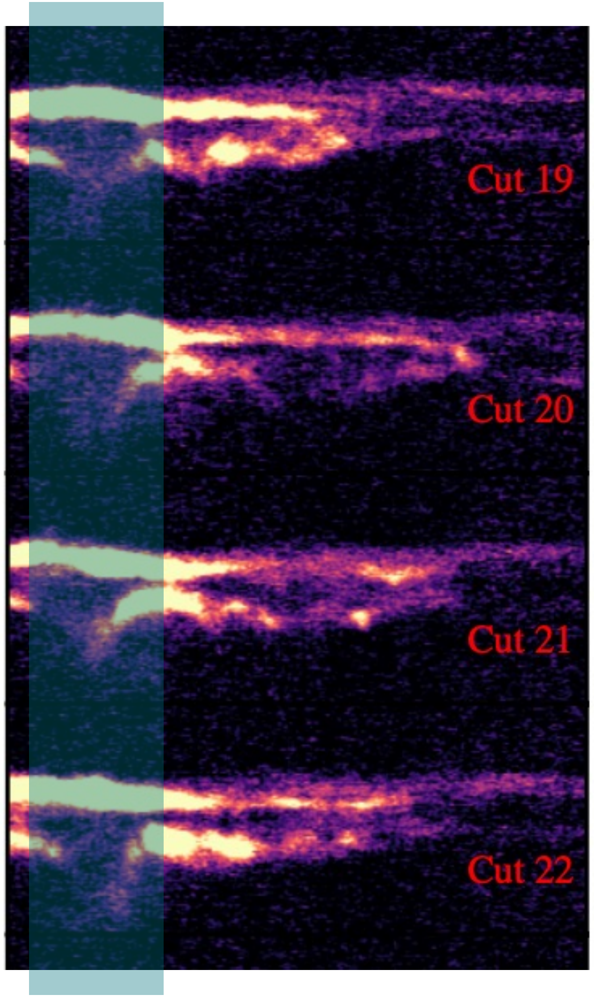
Conclusion

The cavity to the north-west of the Veil shell is a ***pre-existing cavity*** formed by fossil outflow activity which could ***break*** the bubble.

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

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

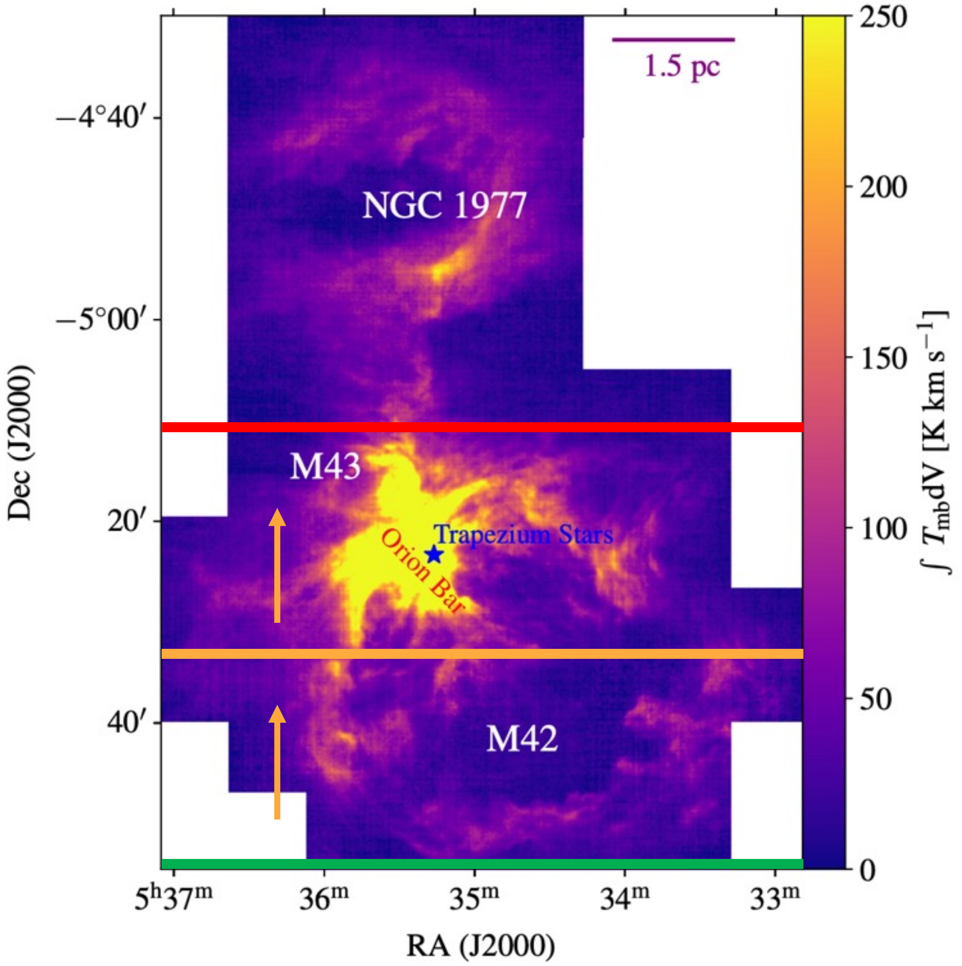
What are these ***structures*** in the Veil shell?



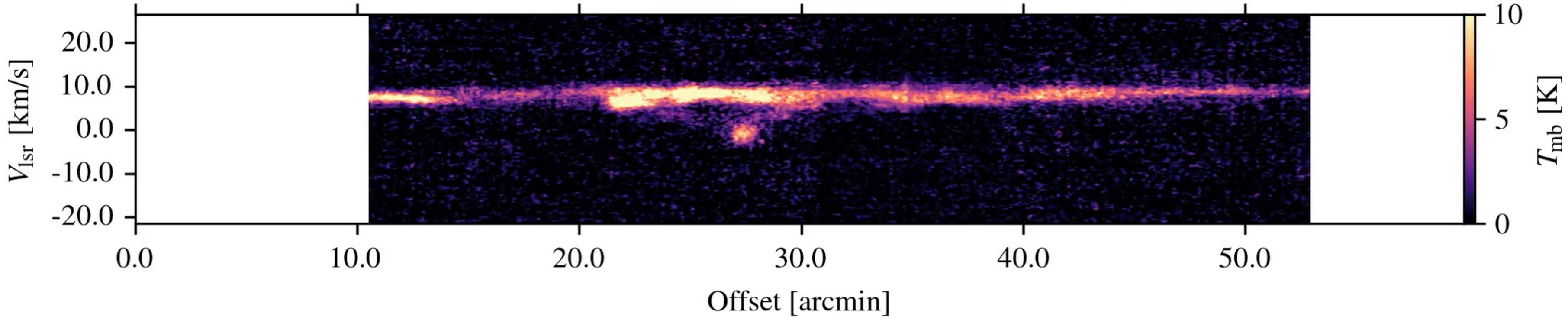
PV diagrams

cuts are 14 x 0.5 arcmin

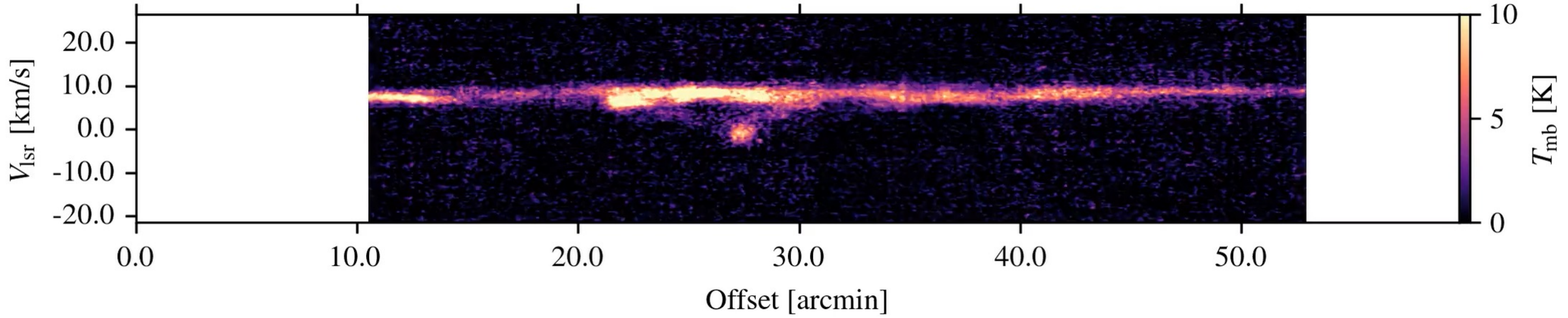
70 PV diagrams

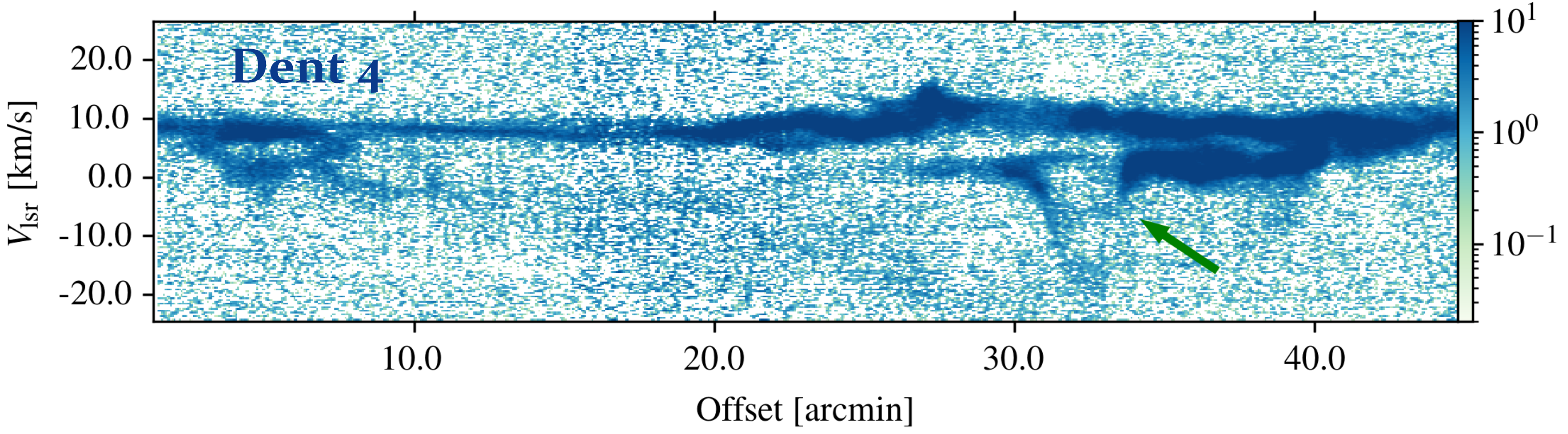


PV Diagram Movie

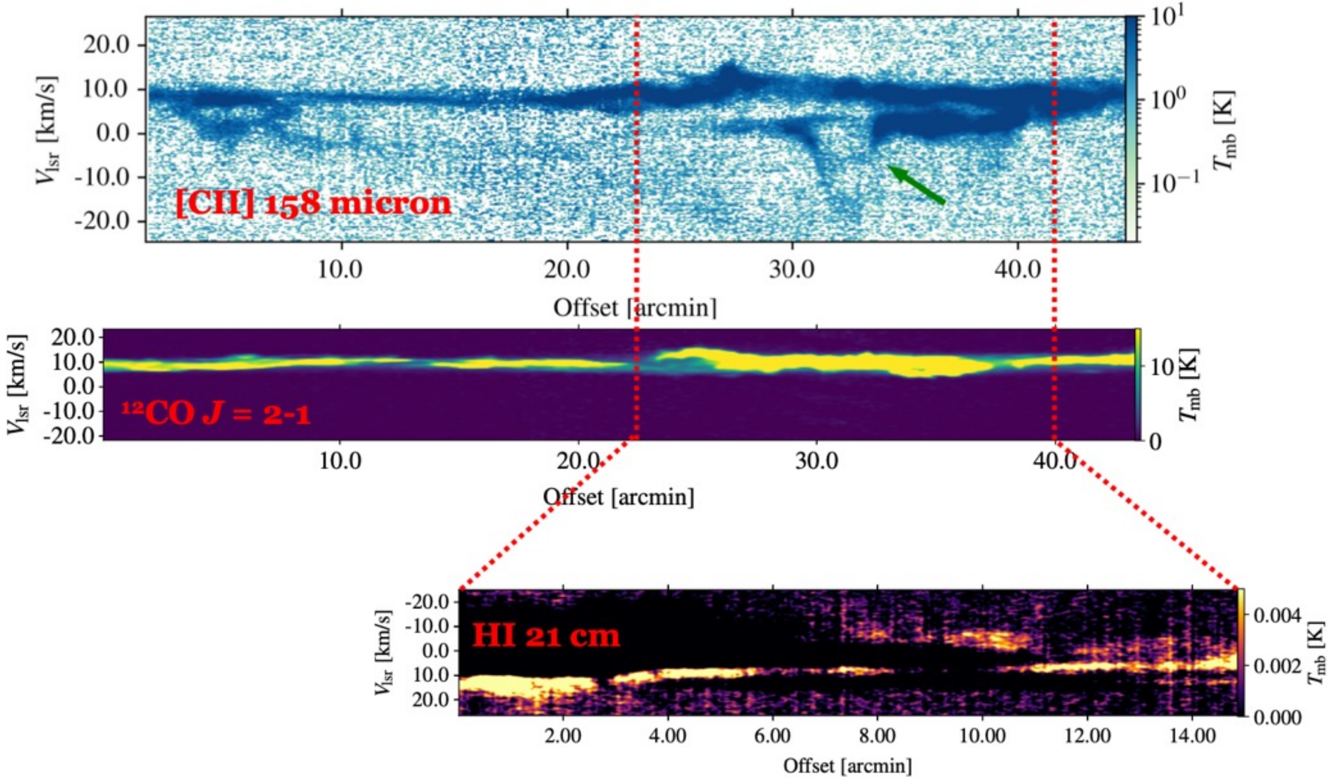


PV Diagram Movie



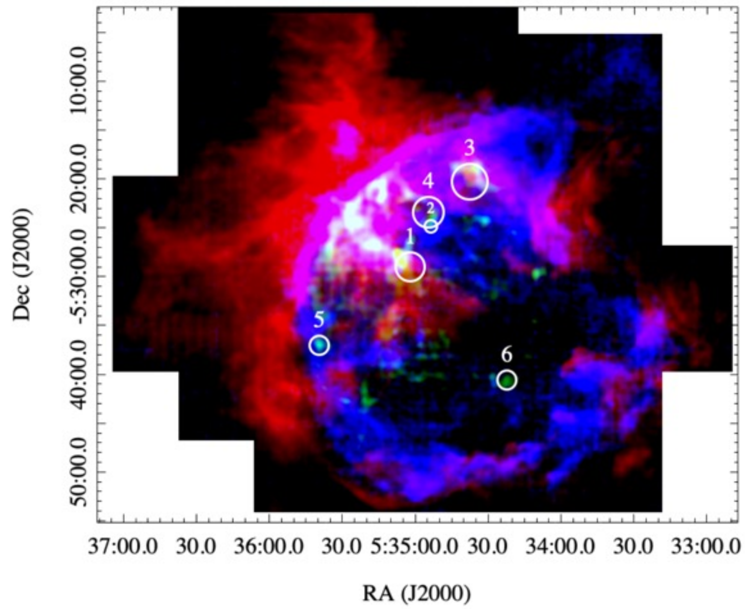


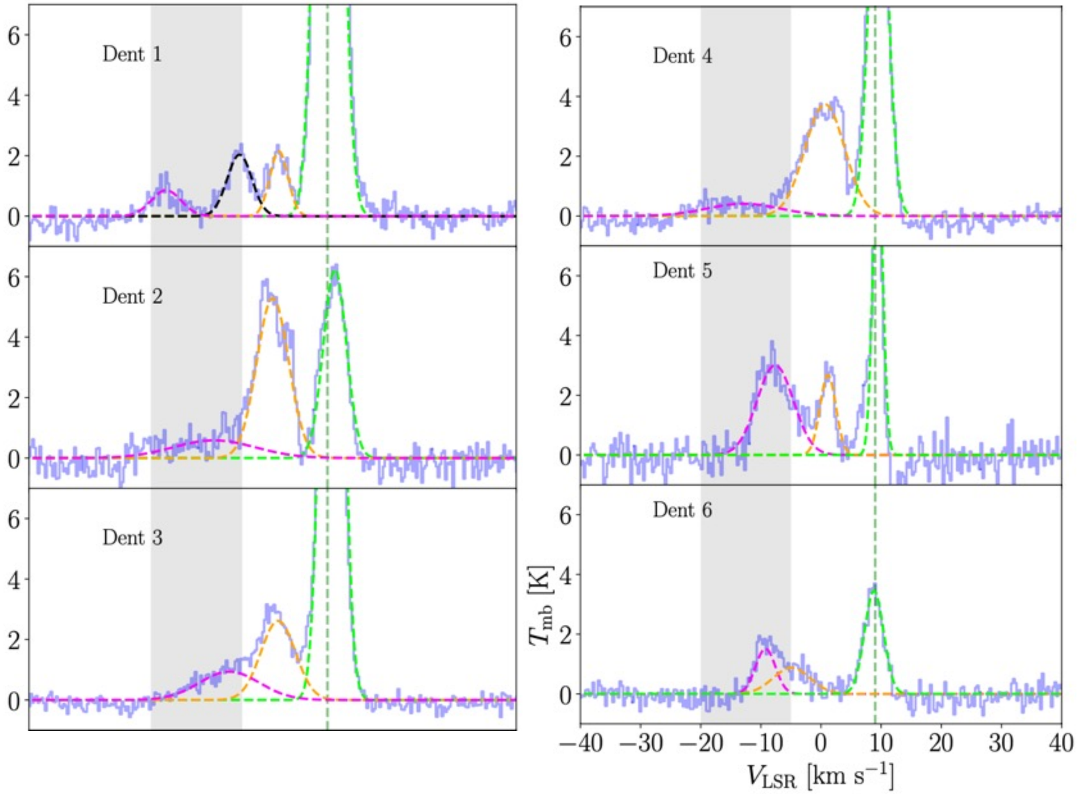
Dents in the Veil shell



The velocity-resolved [CII] line observations from SOFIA are crucial to study protostellar feedback.

[CII] spectrum toward dents

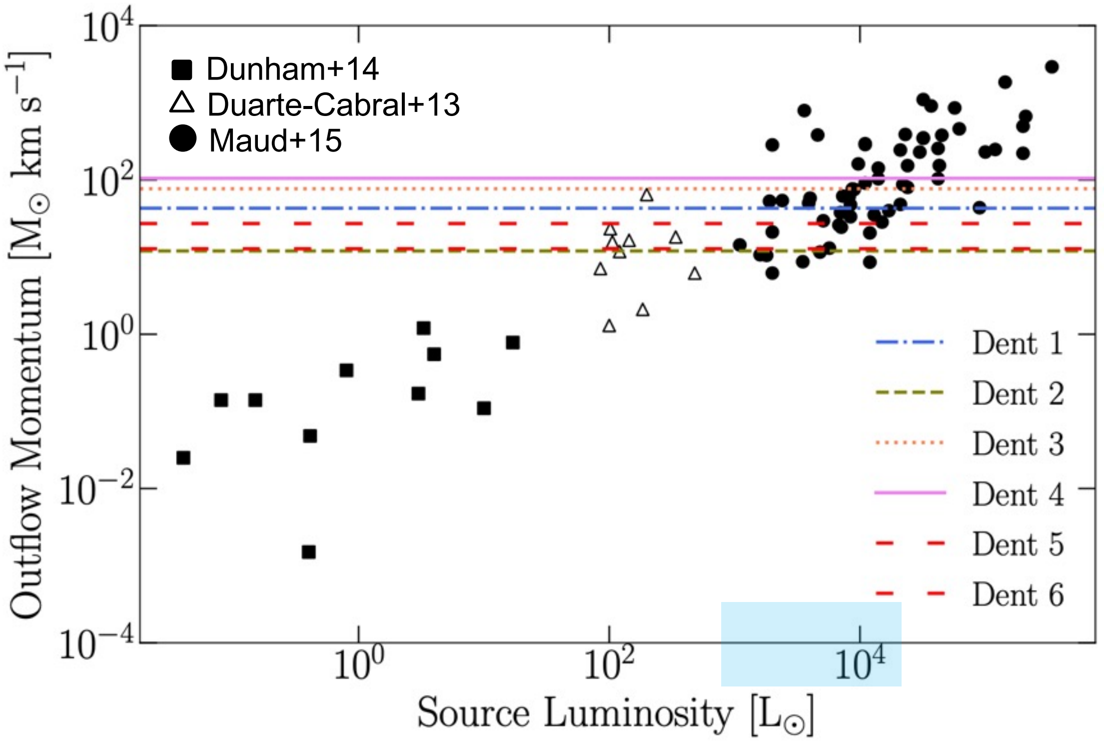




Orion Veil shell

The active outflows from ***B-type stars in Orion*** Nebula.

It is ***challenging*** to pinpoint the driving stars as they may have ***moved*** from the original ejection points of the jets/outflows.



1. Active outflows from B-type stars
2. The linewidths indicate turbulence motions
3. ~3% of the momentum that Veil has

Main Conclusions

1. The Orion Veil may have already been pierced by the **fossil outflows of θ^1 Ori C**. Other less massive stars, especially ***B-type***, made the Veil shell porous.

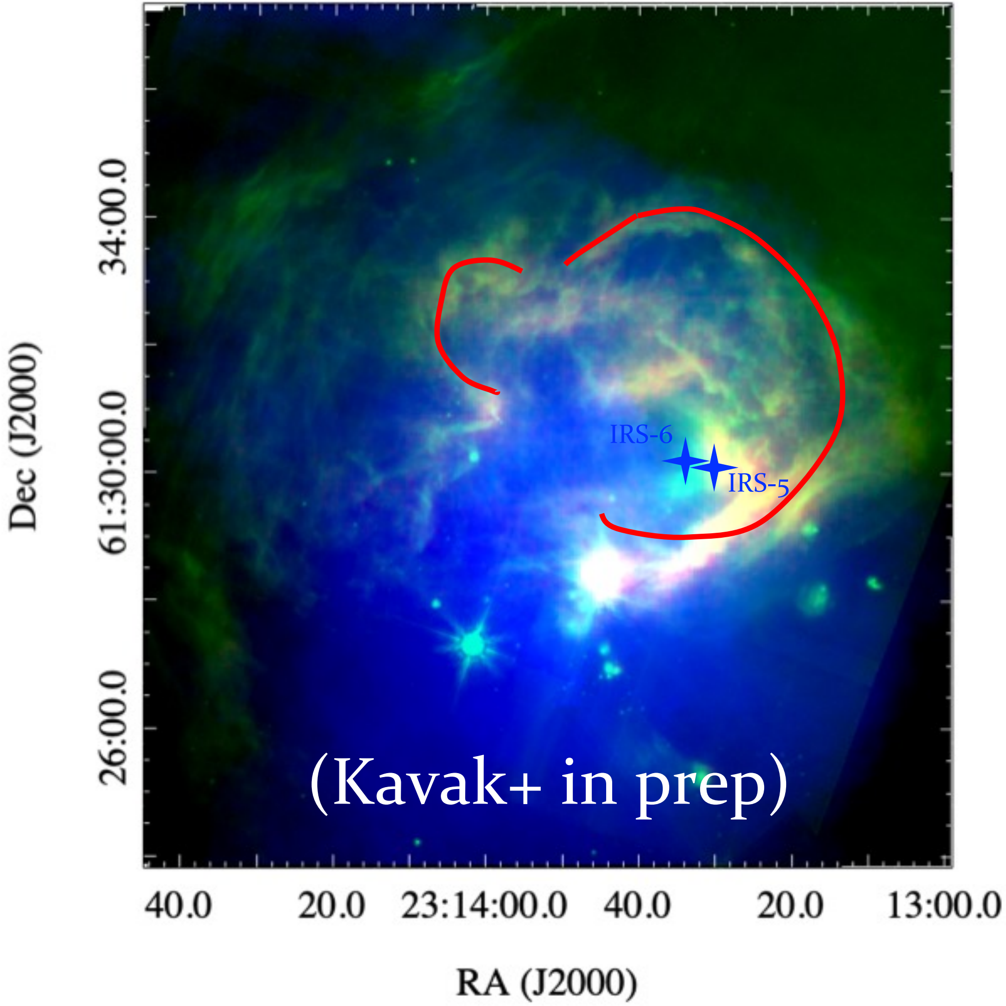
2. The momentum deposited ***through protostellar feedback*** in Orion is **~10%** ***of the momentum*** that Veil shell has.

3. The fossil outflows of massive protostars can influence the ***morphology of the future HII region*** and even ***cause punches*** through the bubble and will release the hot plasma.

4. Mechanical feedback from protostars, or ***pre-stellar feedback***, with a range of masses appears to play an important role injecting turbulence into the interstellar medium.

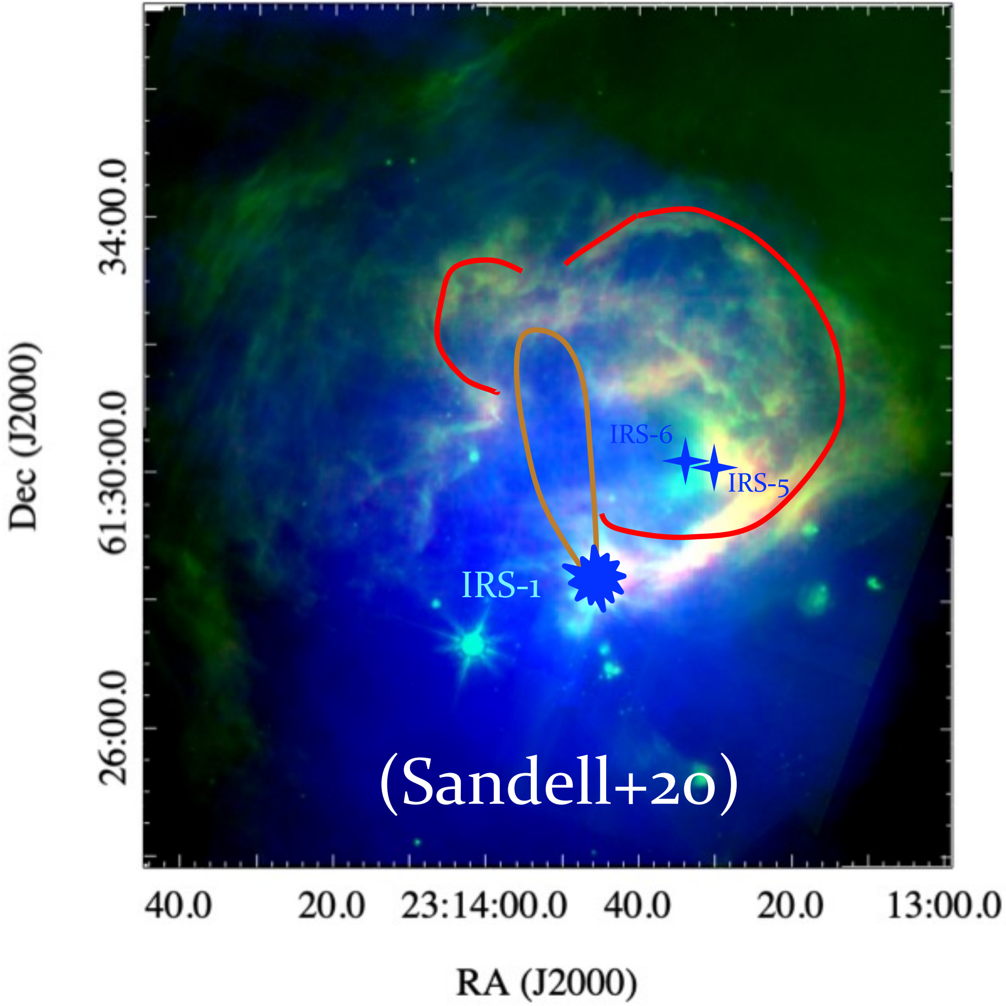
5. The ***velocity-resolved SOFIA [CII] line observations*** are ***crucial*** for investigating the protostellar and main sequence feedback in the ISM.

***Stellar winds* from IRS-6 created expanding bubble(s) in NGC7538 (Beuther+22)**



A dent inside NGC7538 created by *IRS-1's outflow*

(proposed by Sandell+20)

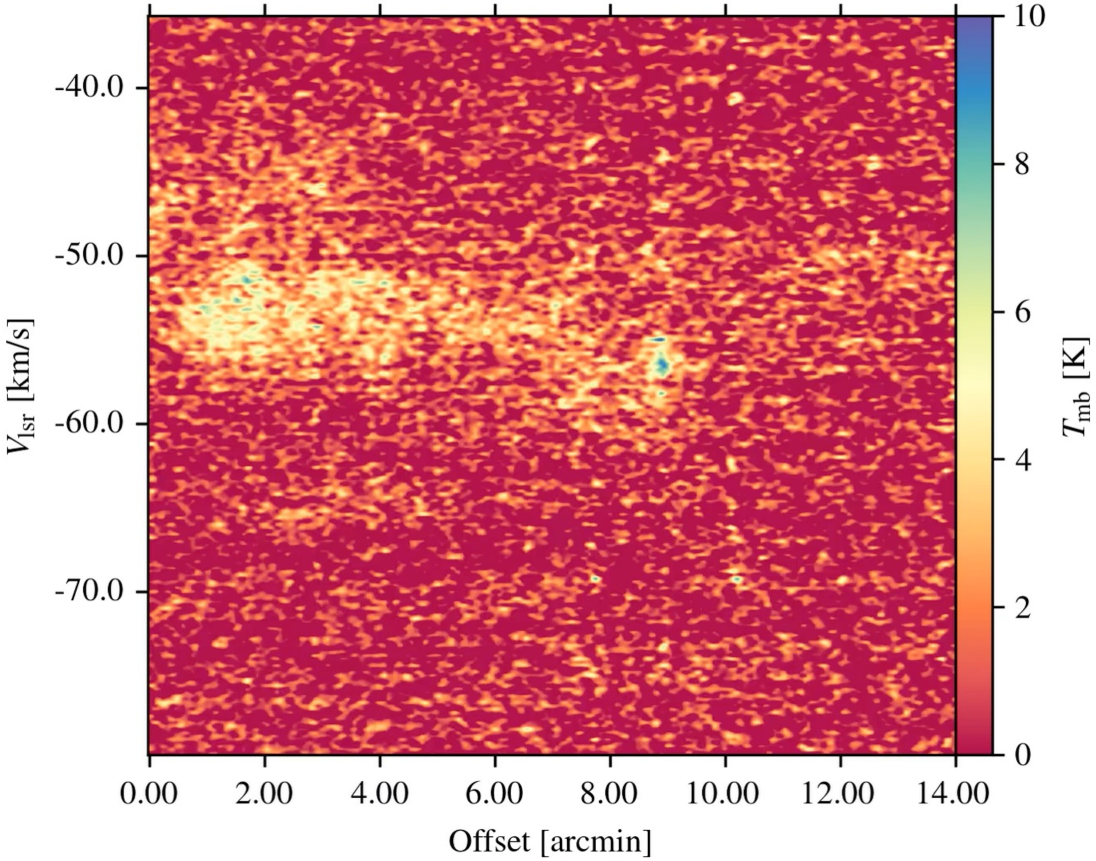


Back-up Slides

Stellar feedback **is a matter of** ***timescales*** **and** ***energy*****.**

Which mechanism is the most effective and how long does it take?

NGC 7538 - [CII] 158 micron PV movie



NGC 7538
RGB map - 1

12CO21 emission is associated with north-east portion of NGC 7538.

PV diagrams show that north-east portion is fragmented.