MAX-PLANCK-INSTITUT
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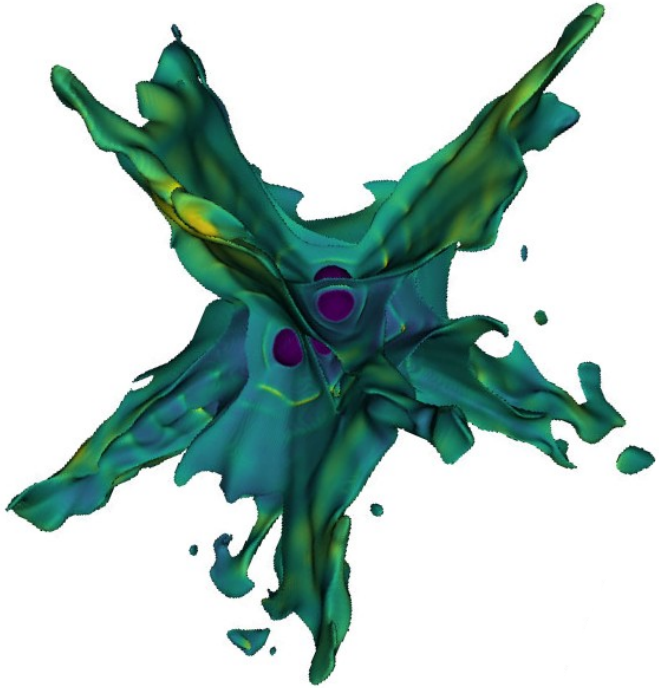
Termination shocks in massive star clusters



Thibault Vieu

w/ L. Härer, B. Reville

MPIK, Heidelberg

Intro: star clusters in gamma-rays

Hot topic nowadays, many observations from GeV to PeV

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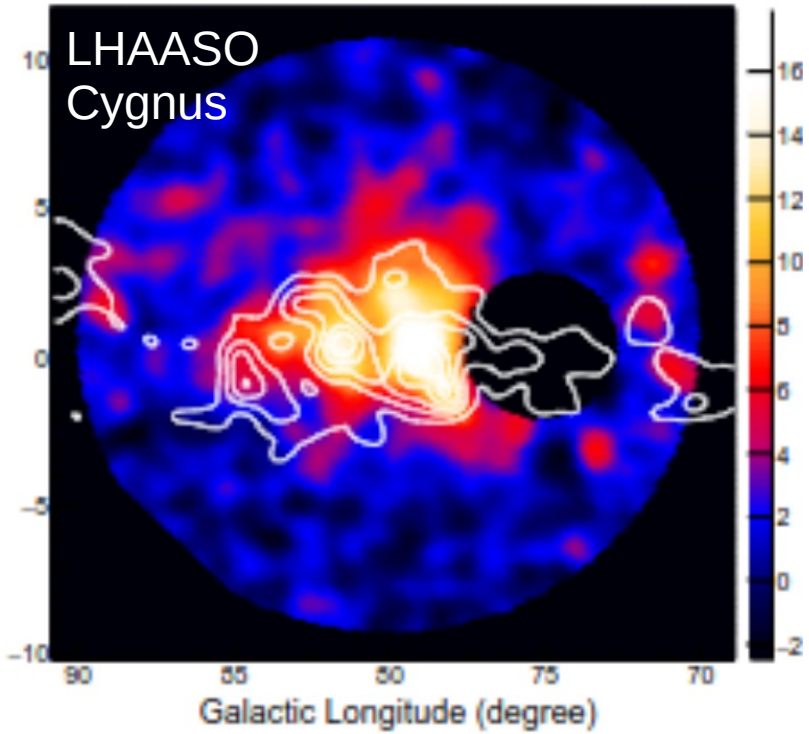
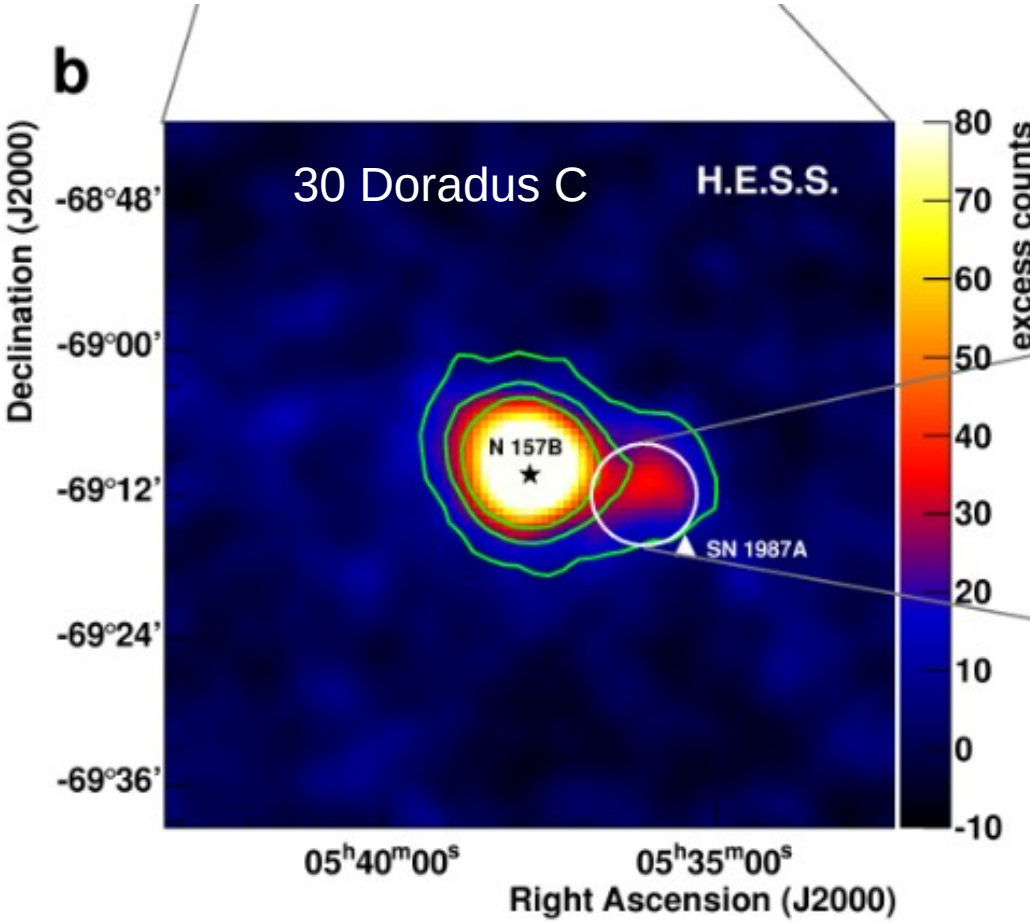




Intro: star clusters in gamma-rays

Hot topic nowadays, many observations from GeV to PeV

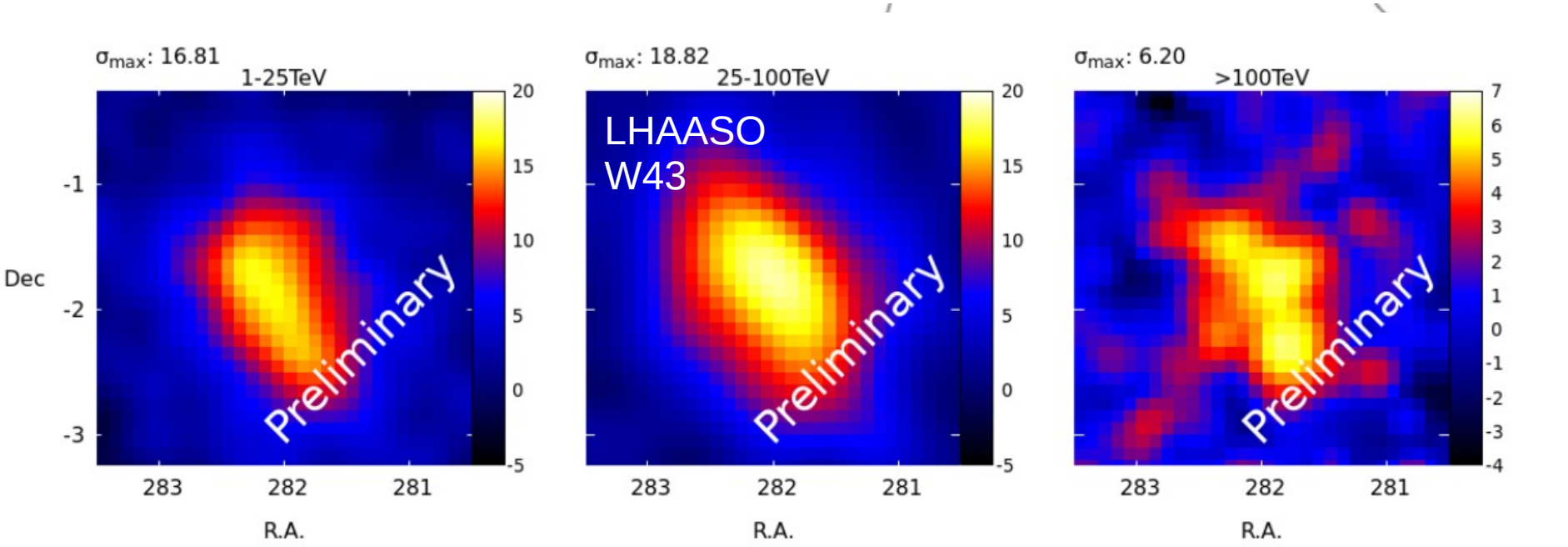
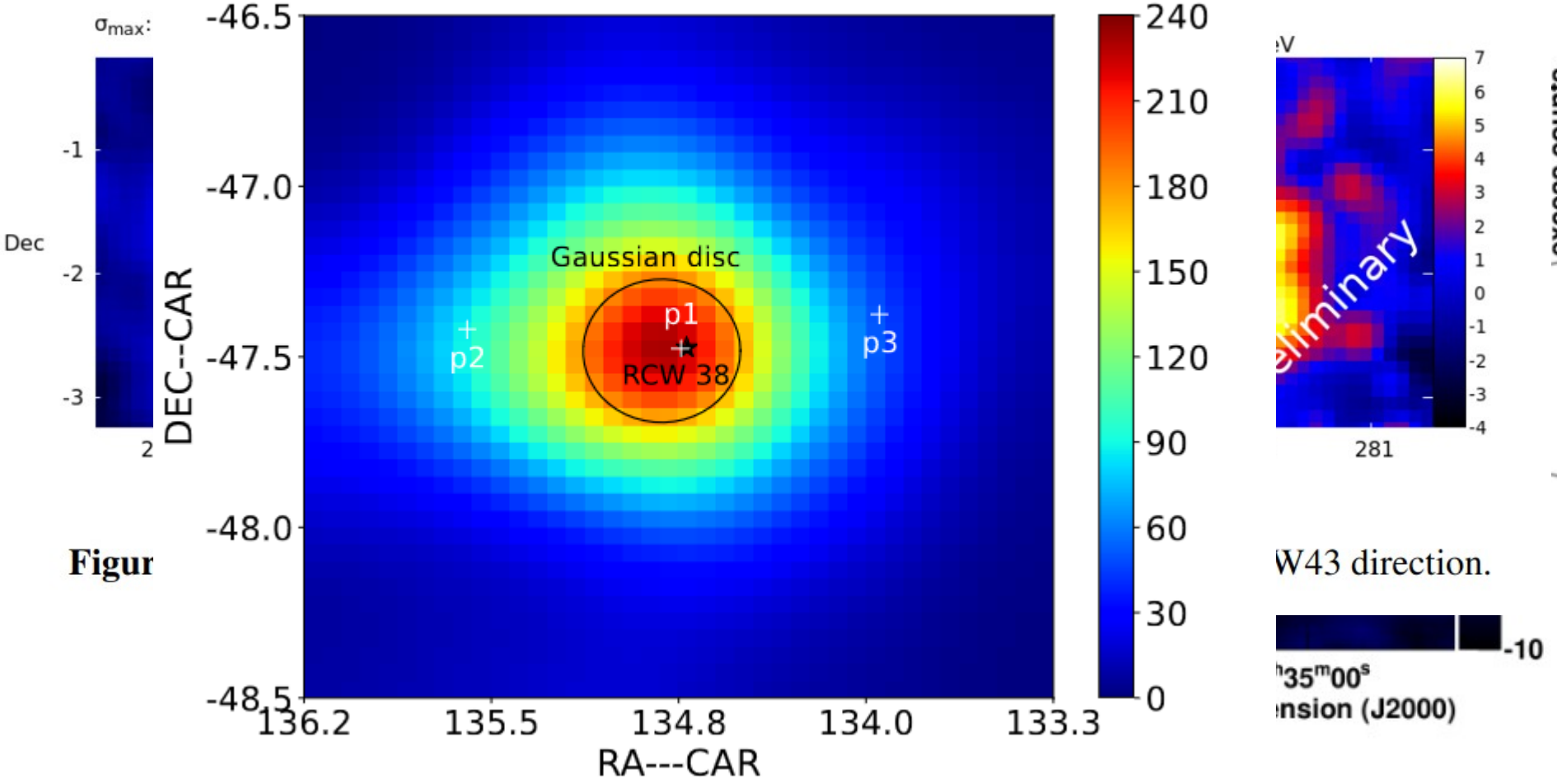


Figure 1: The significance maps of excess emission around the direction toward W43 direction.

Intro: star clusters in gamma-rays

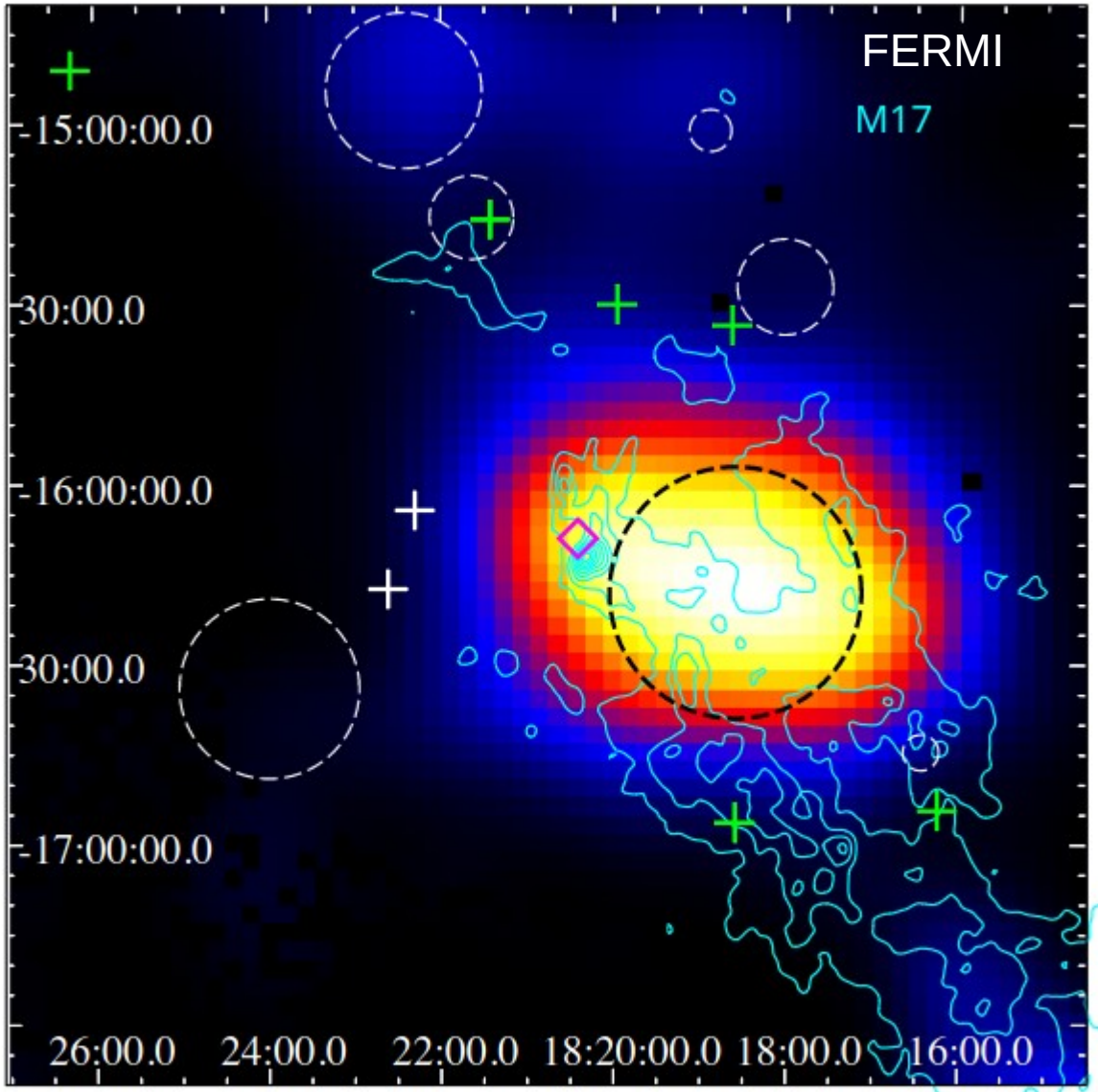
Ho

Fermi-LAT *detection around RCW38* 3

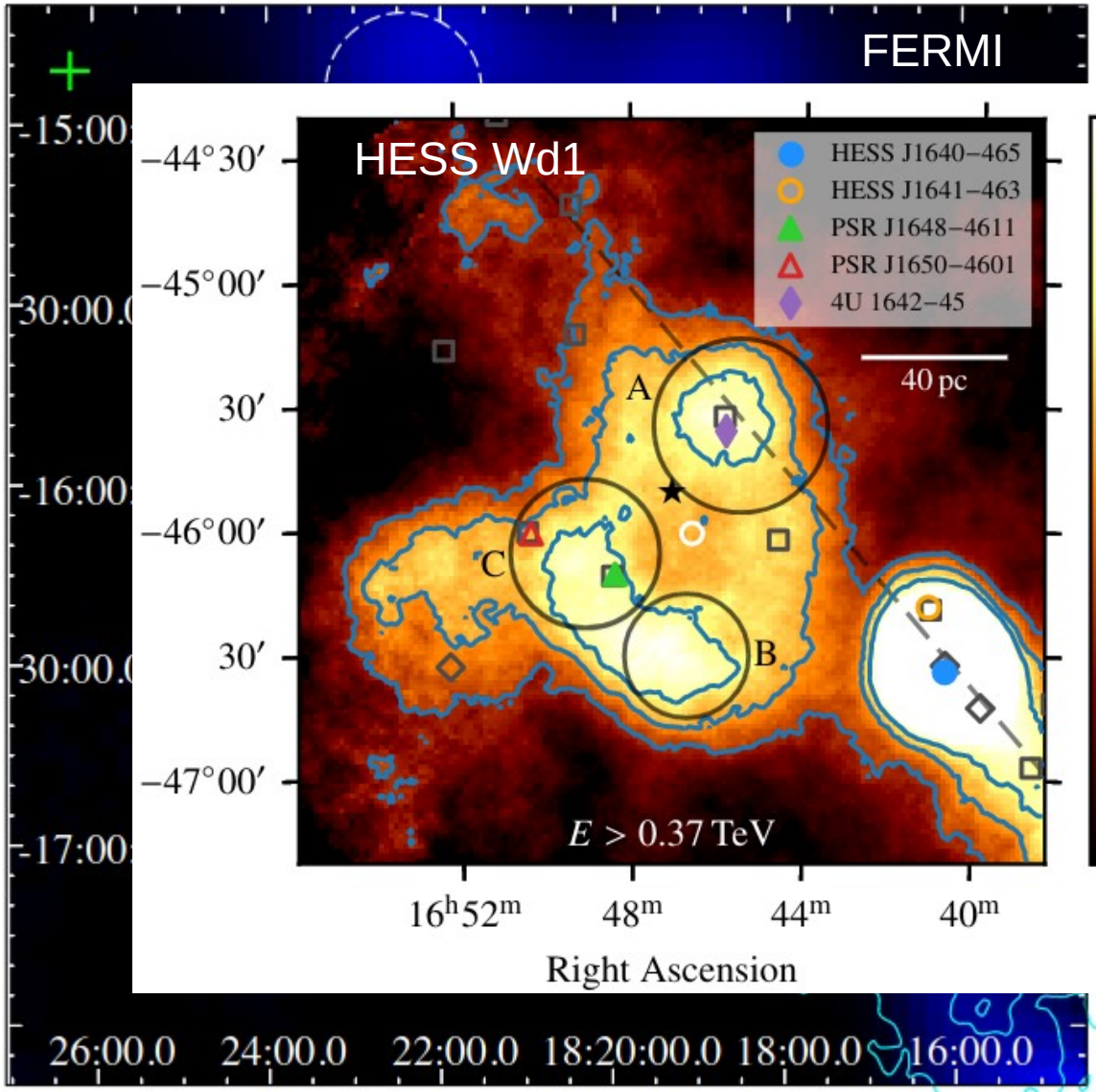


Figur W43 direction.

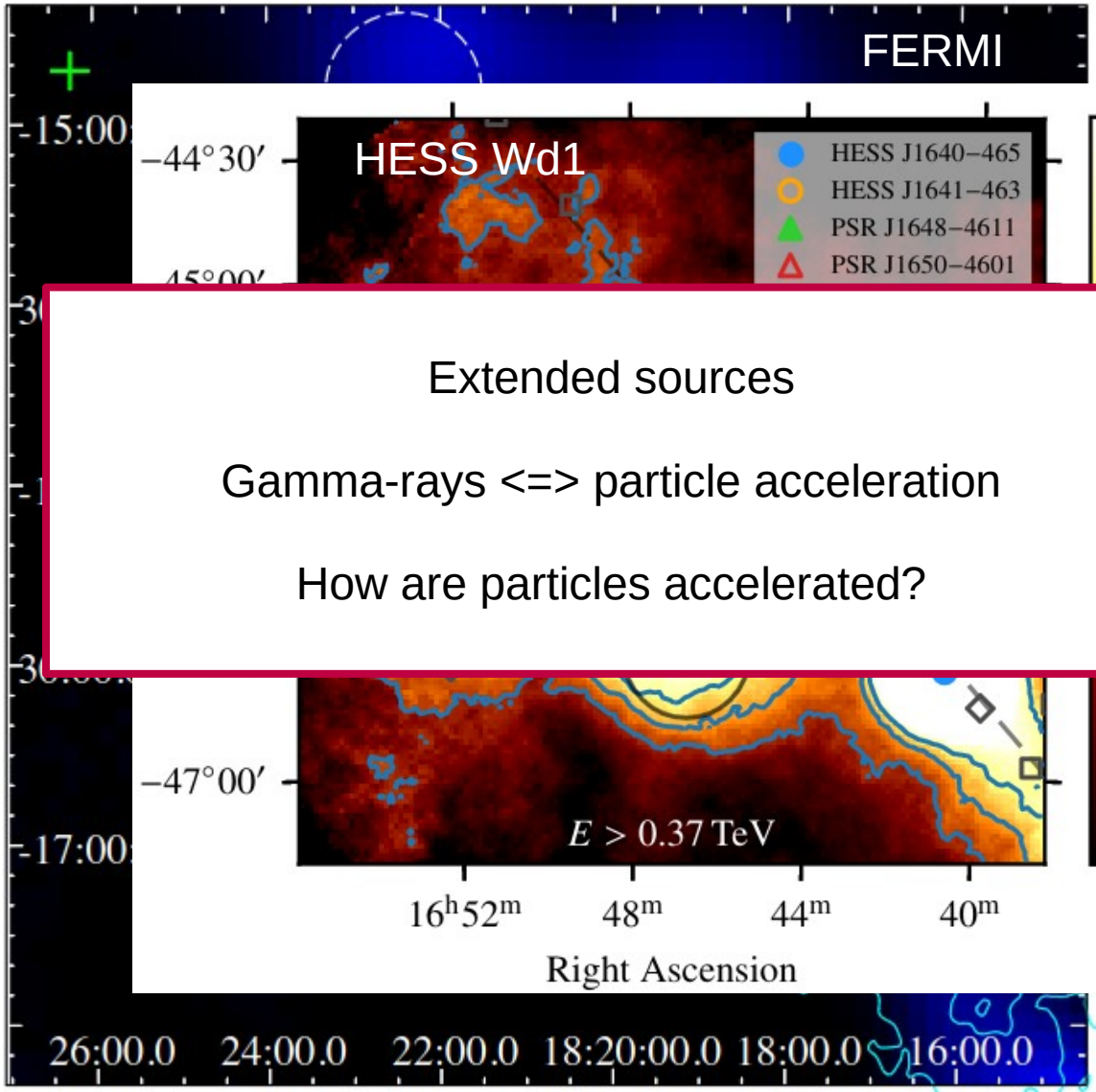
Intro: star clusters in gamma-rays



Intro: star clusters in gamma-rays



Intro: star clusters in gamma-rays

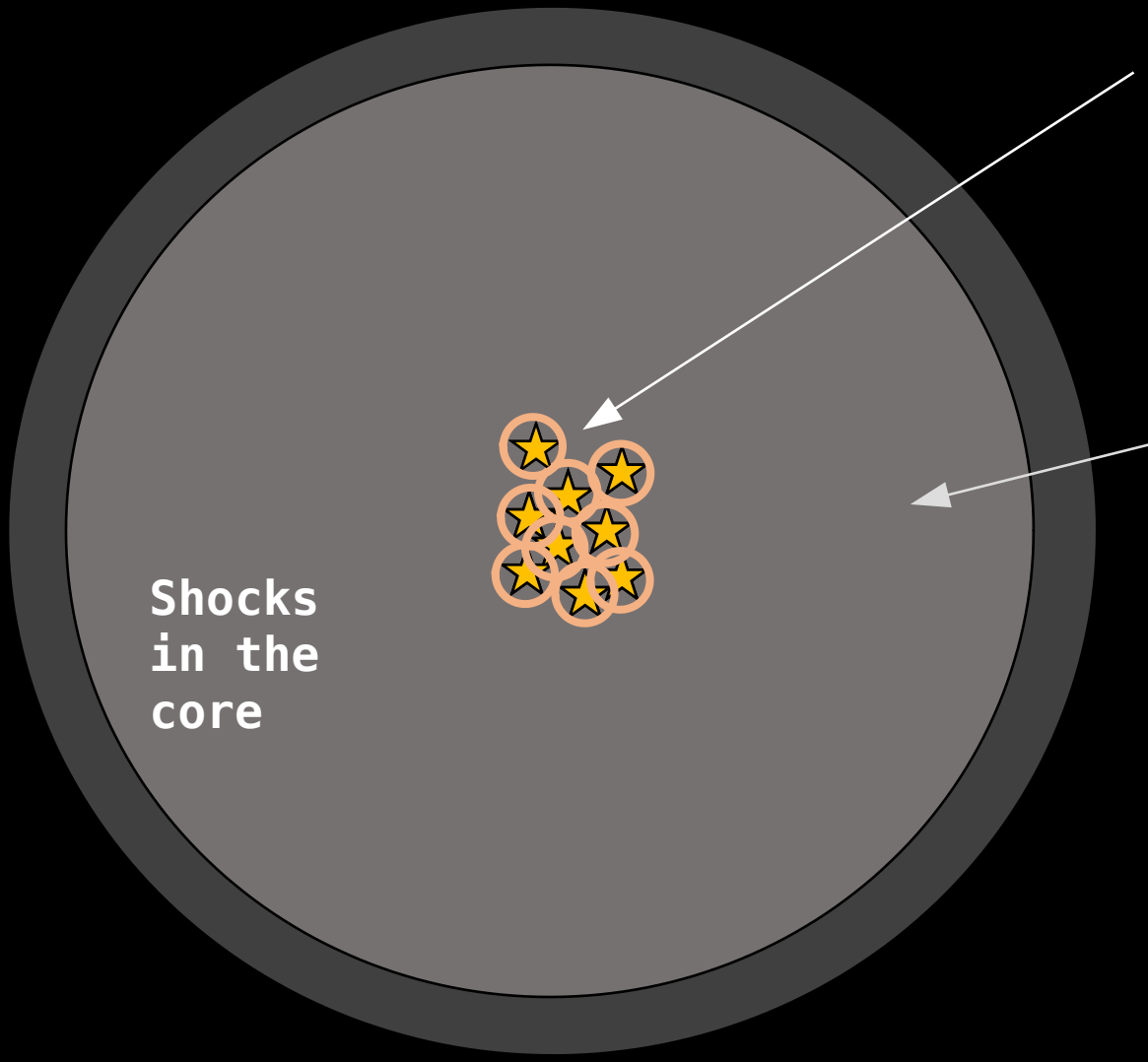


Extended sources

Gamma-rays <=> particle acceleration

How are particles accelerated?

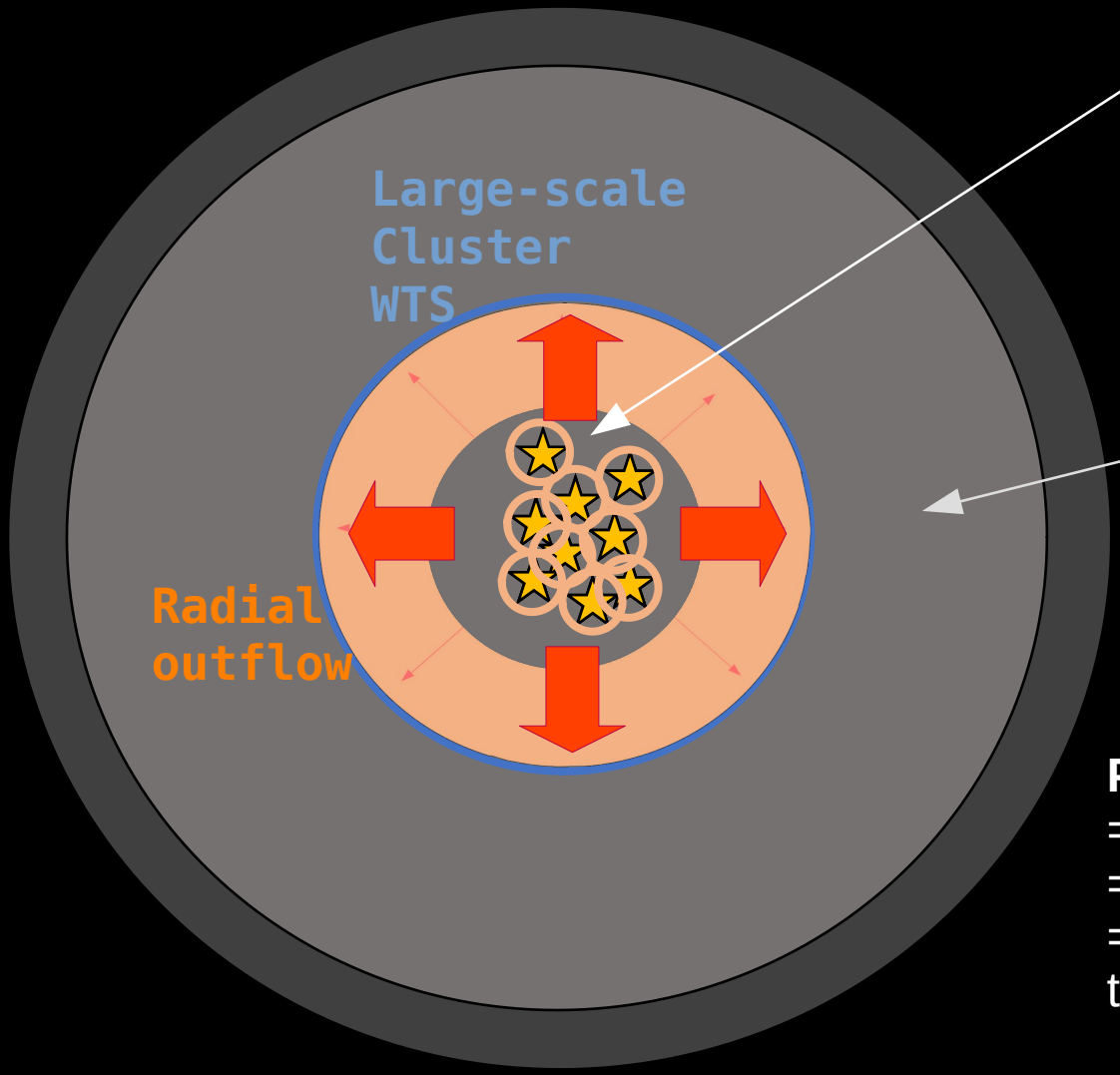
Superbubble and wind termination shock: textbook



Stellar wind interactions
=> pressure builds up in the core
=> heating of the ISM and superbubble expansion

Superbubble expansion
=> pressure drops outside of the core

Superbubble and wind termination shock: textbook



Stellar wind interactions
=> pressure builds up in the core
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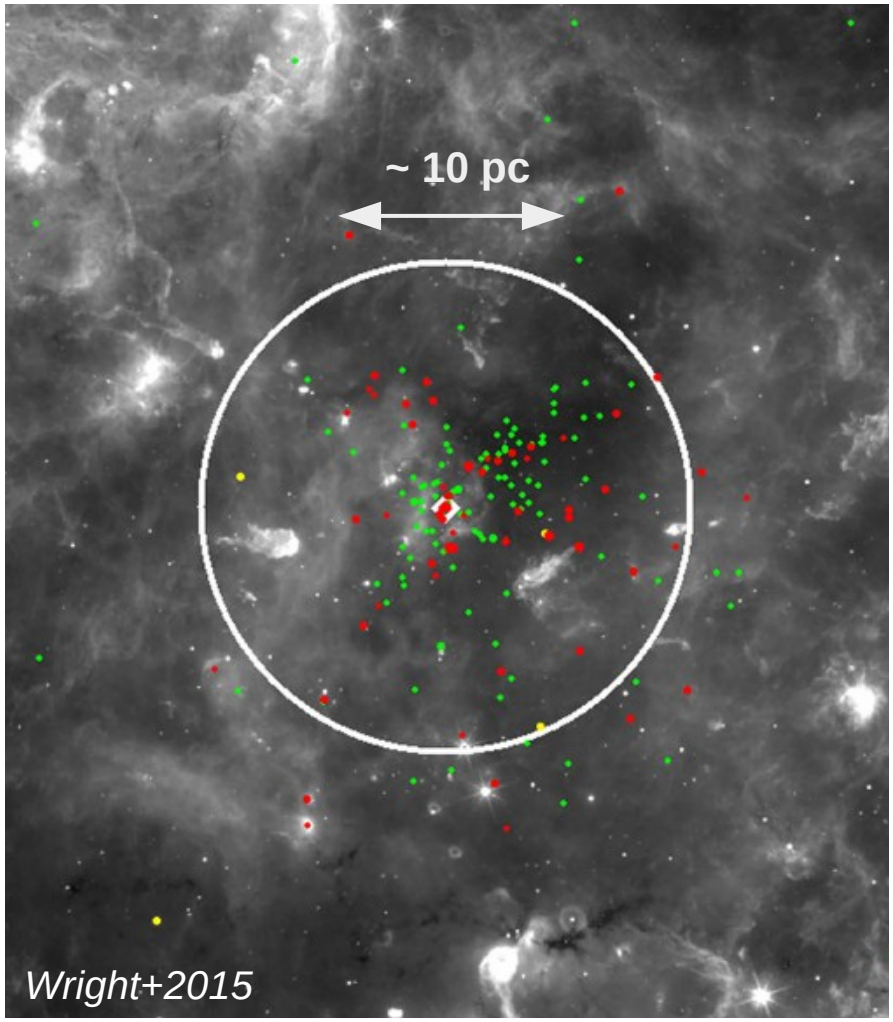
Superbubble expansion
=> pressure drops outside of the core

Pressure gradient
=> the flow accelerates outward
=> becomes supersonic
=> terminates at the “wind termination shock”

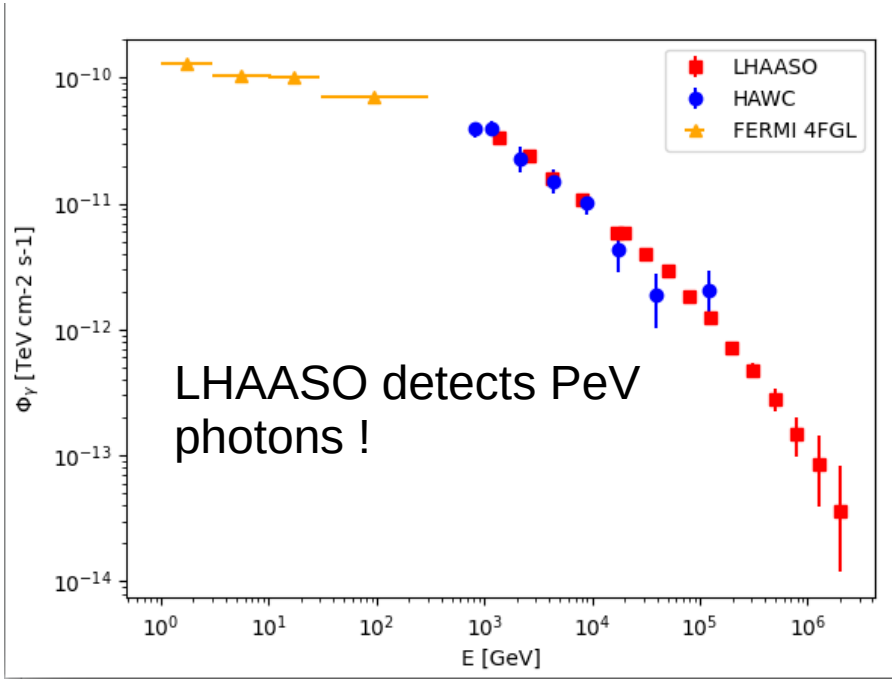
A “realistic” simulation: Cygnus OB2



Distance ~ 1.6 kpc
Age ~ 3-5 Myr

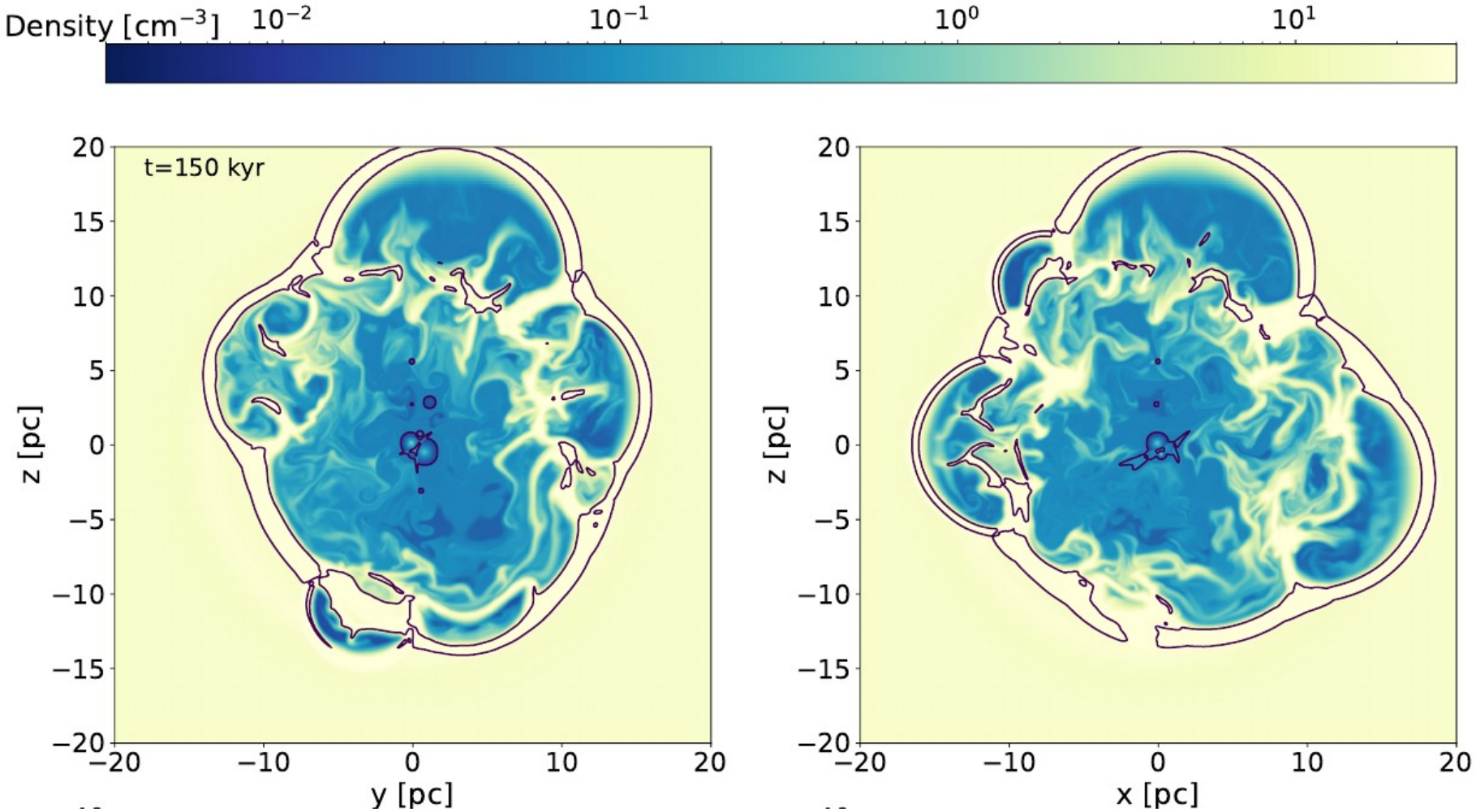
100s OB stars
3 off-centred WR stars

Lw ~ 10^{38} erg/s



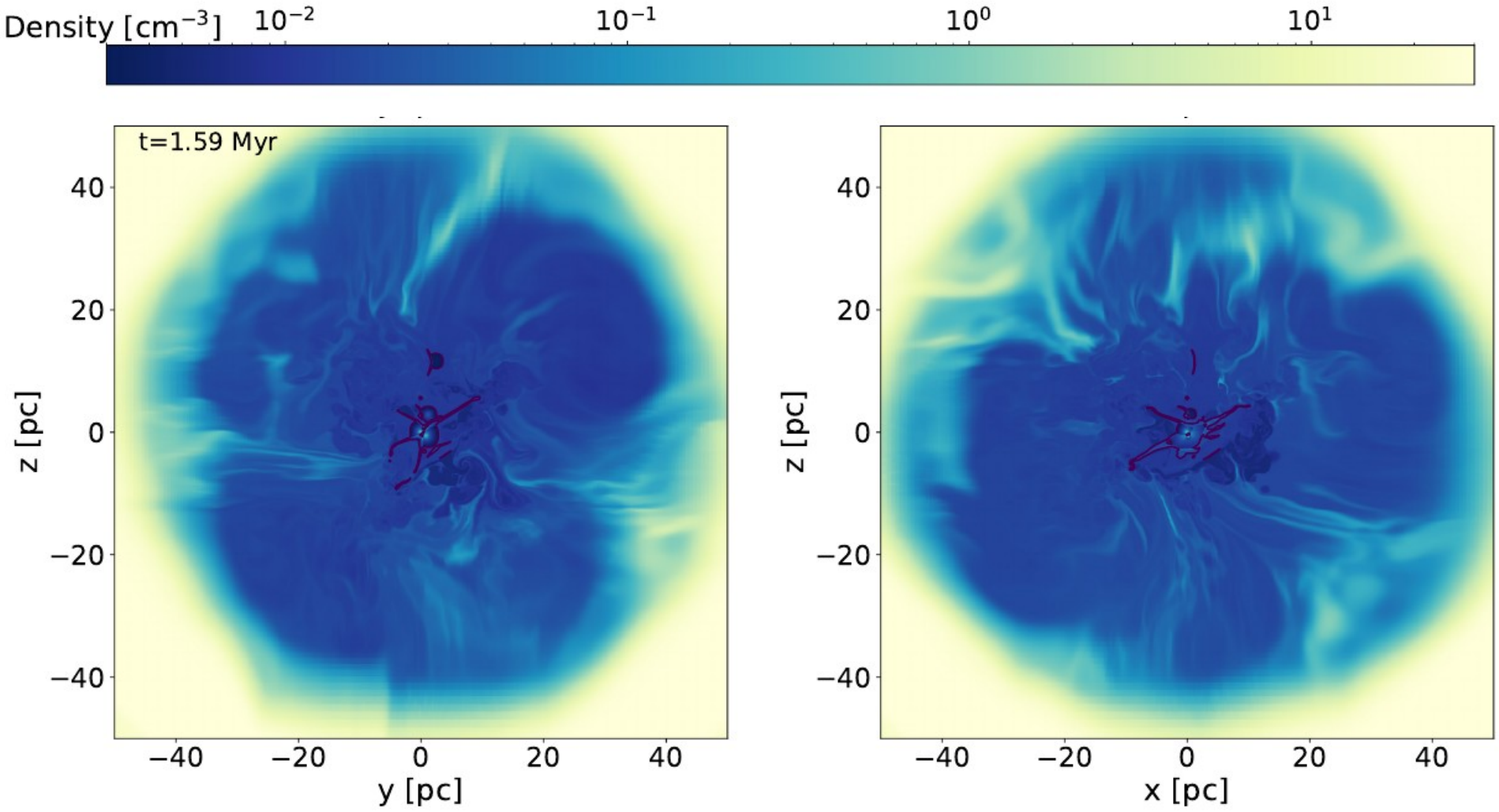
A “realistic” simulation: Cygnus OB2

150 kyr: the superbubble forms with an (already weak) forward shock



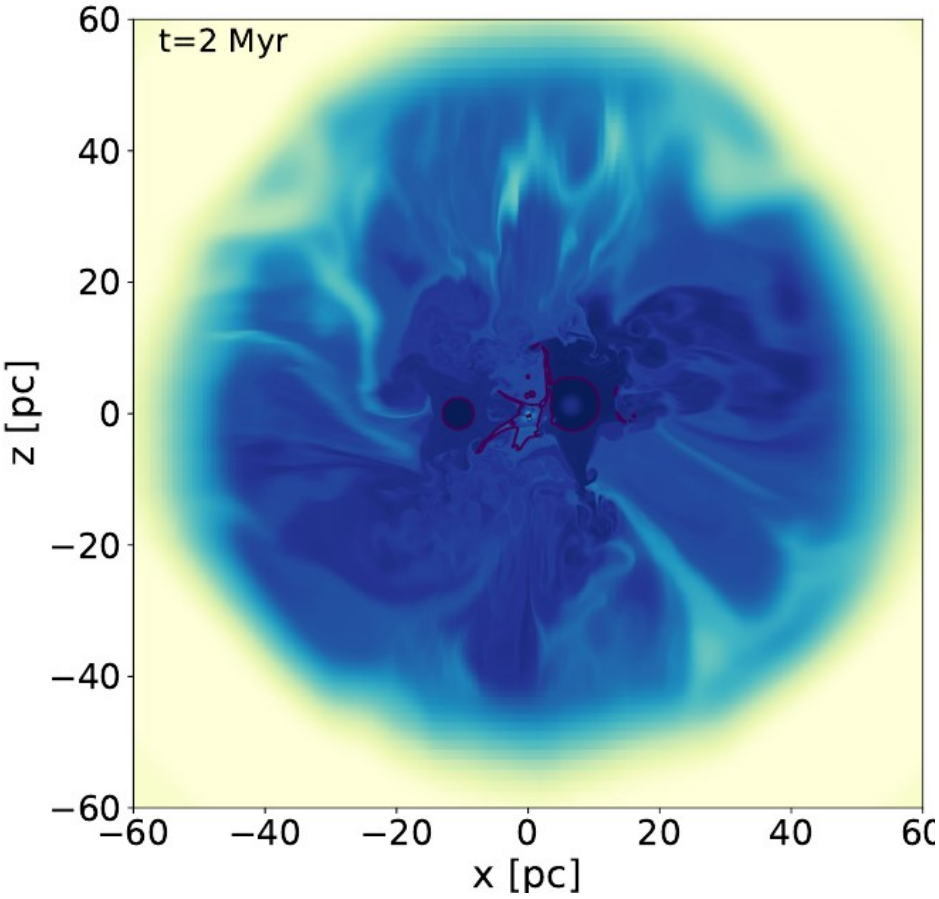
A “realistic” simulation: Cygnus OB2

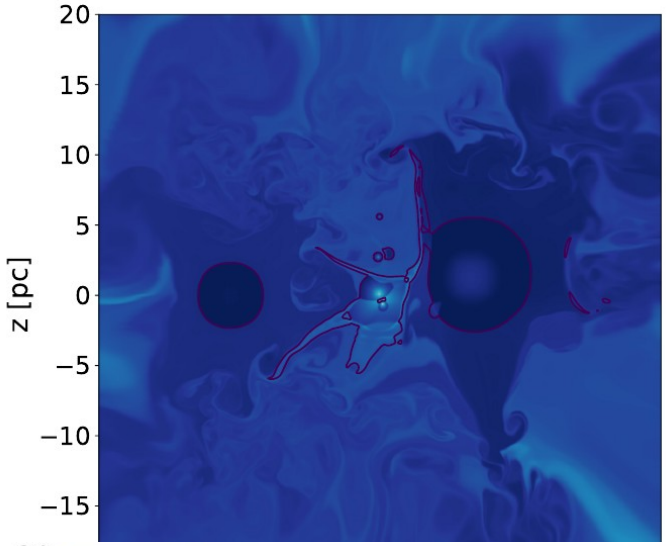
1.6 Myr: quasi-stationary state, forward shock became subsonic
NO CLUSTER WIND TERMINATION SHOCK!

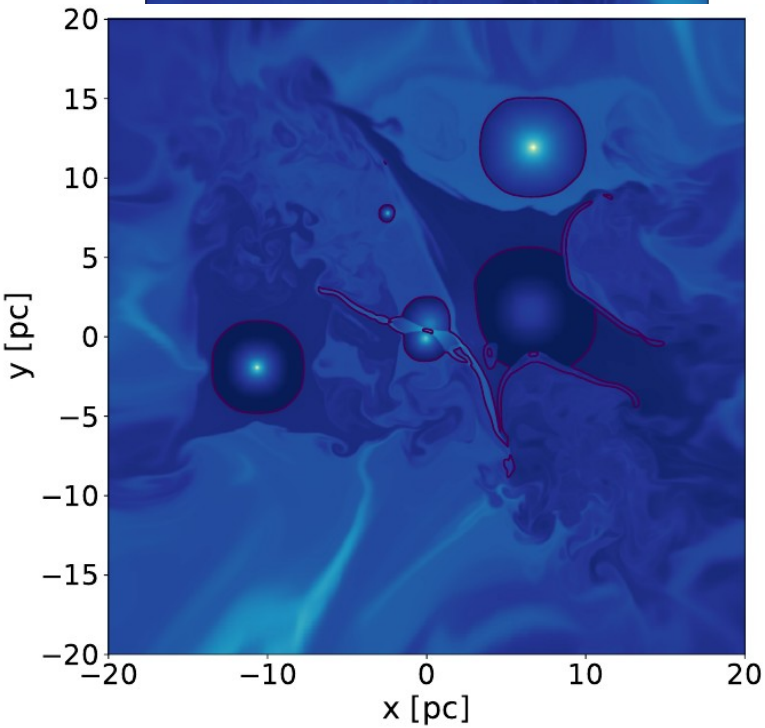


A “realistic” simulation: Cygnus OB2

Let’s switch on WR stars during 400 kyr







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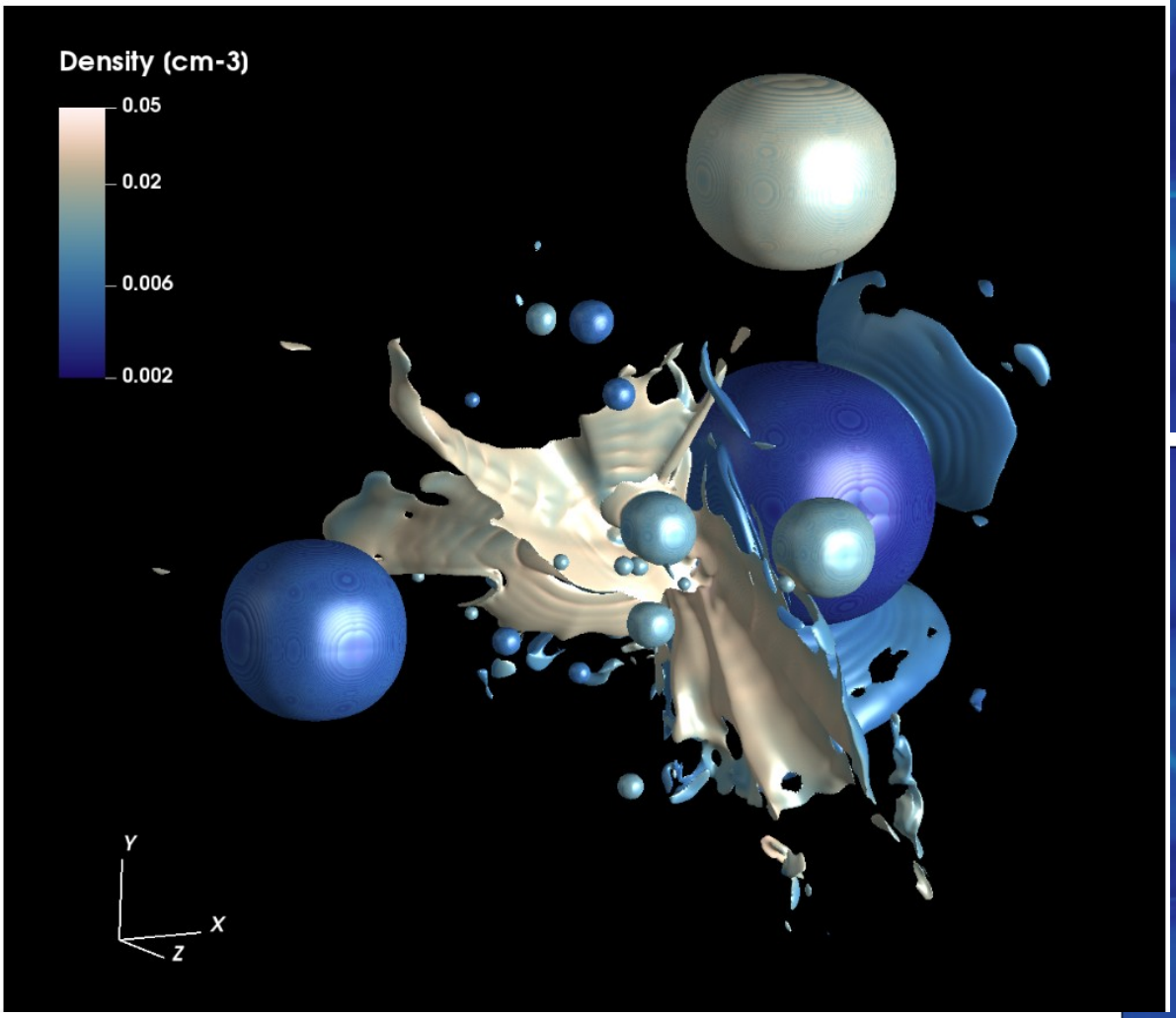
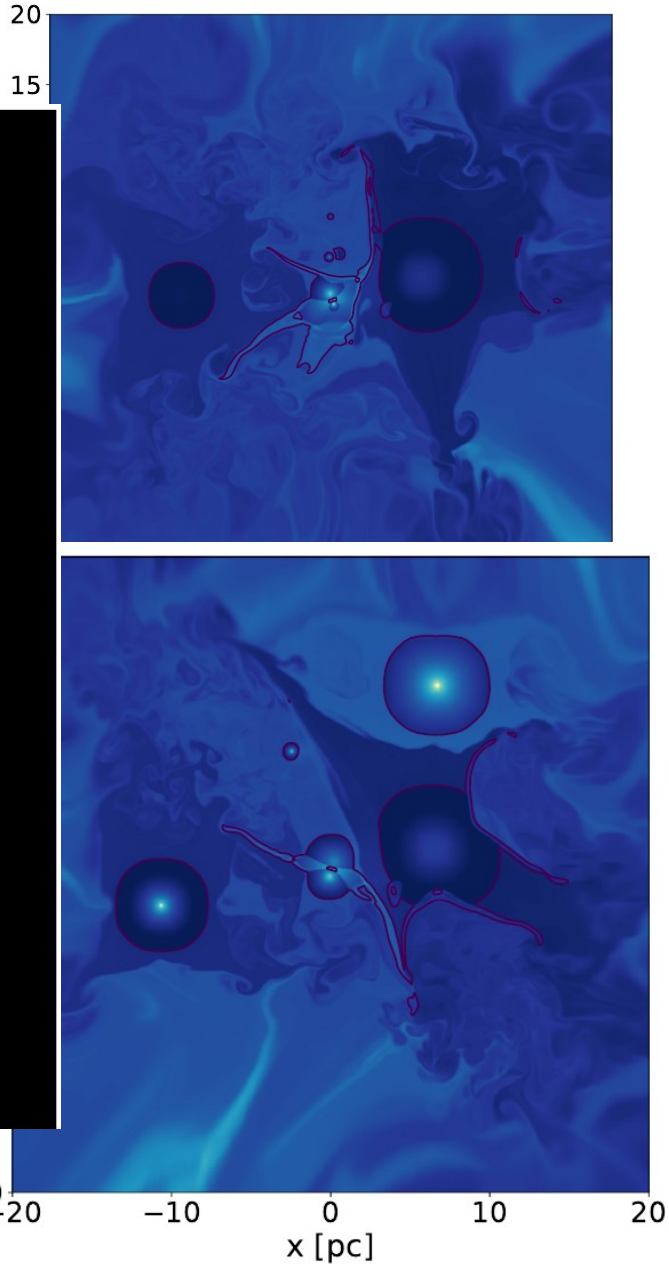
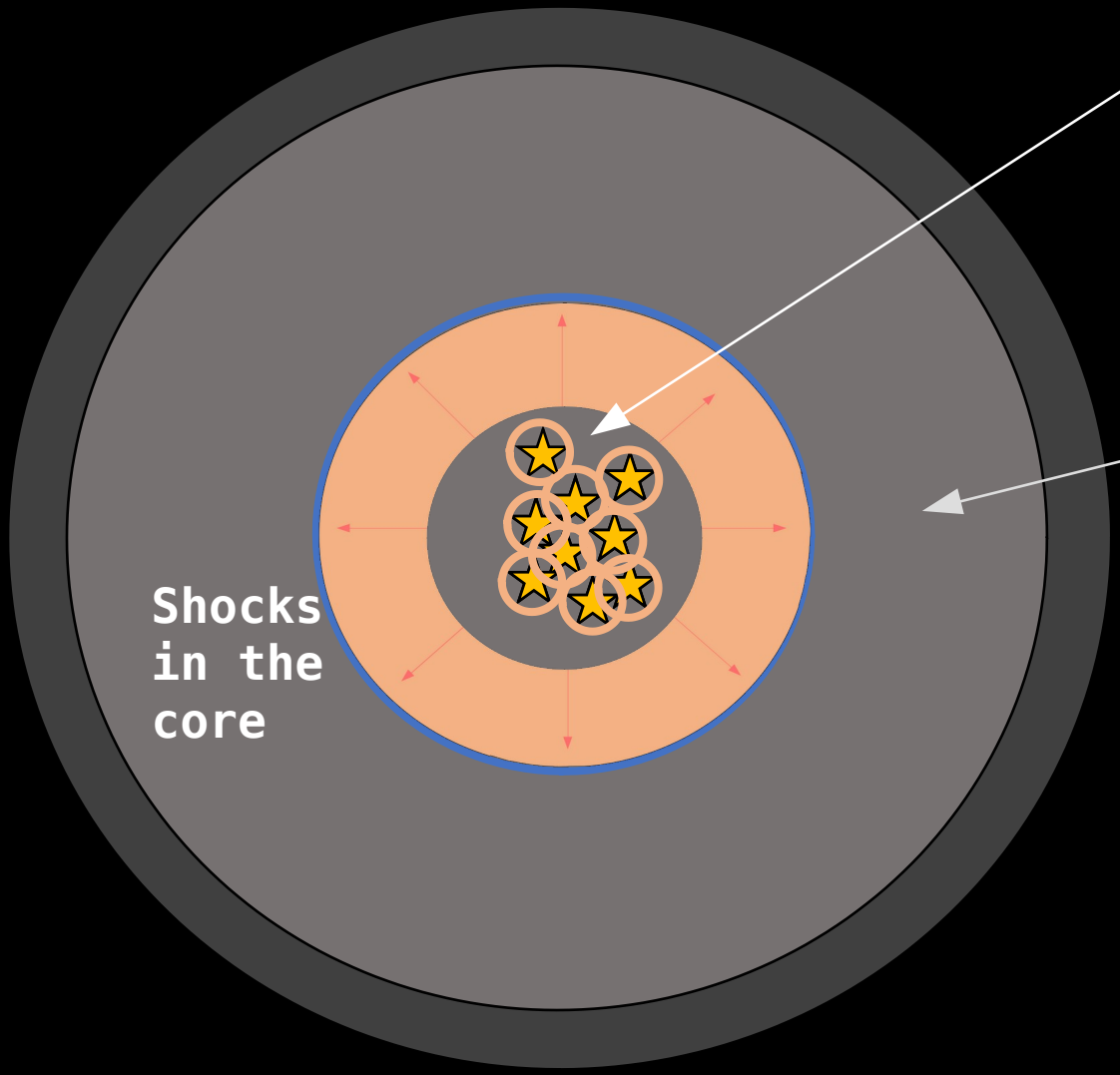




NO CLUSTER WIND TERMINATION SHOCK!

Why Cygnus OB2 cannot expand a cluster WTS?



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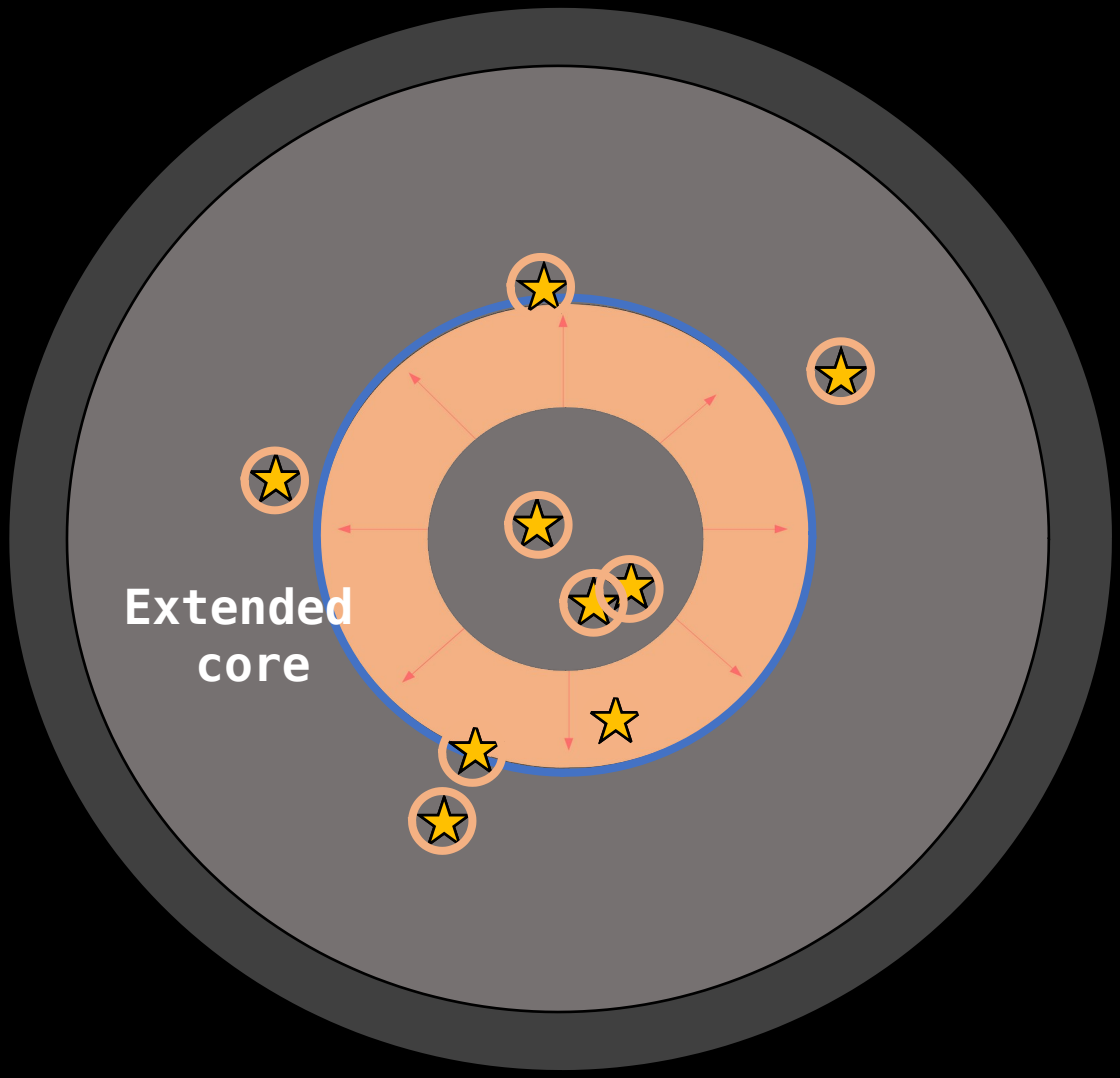


The stellar winds don't work together but against each other.

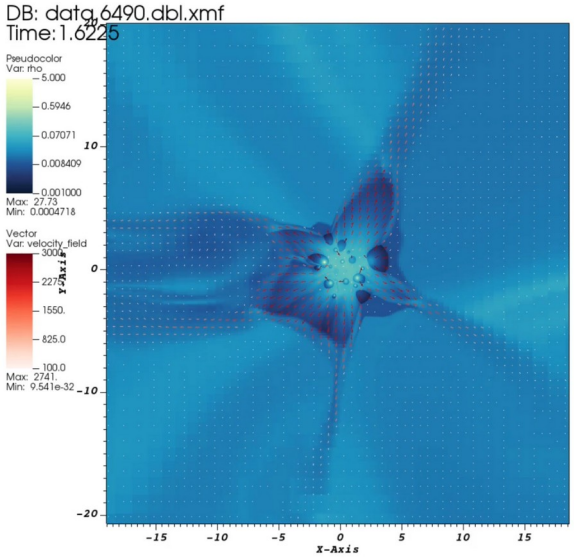
Low level of collective interactions

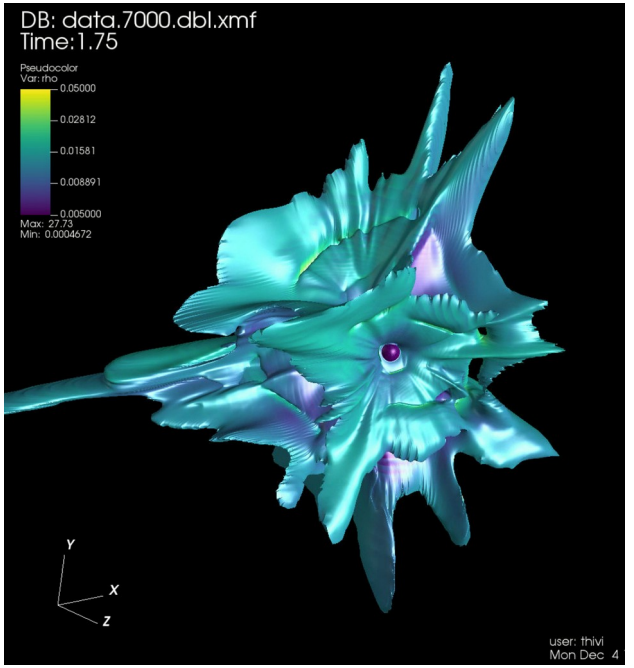
=> A collection of small individual stellar wind termination shocks

Can we obtain a sphericalish cluster WTS?

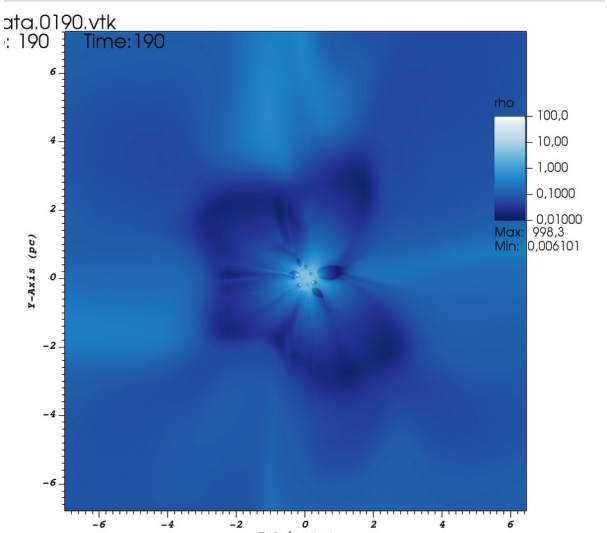
- Let's compactify CygOB2 within 3 pc

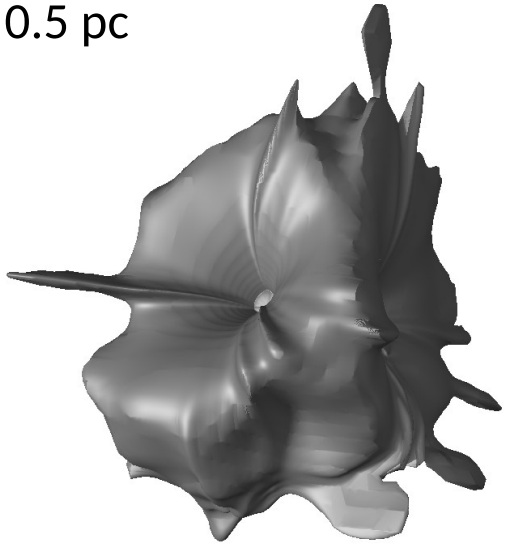
We get much more interactions, but still far from spherical symmetry!





- Let's compactify CygOB2 within 0.5 pc





Take-home:

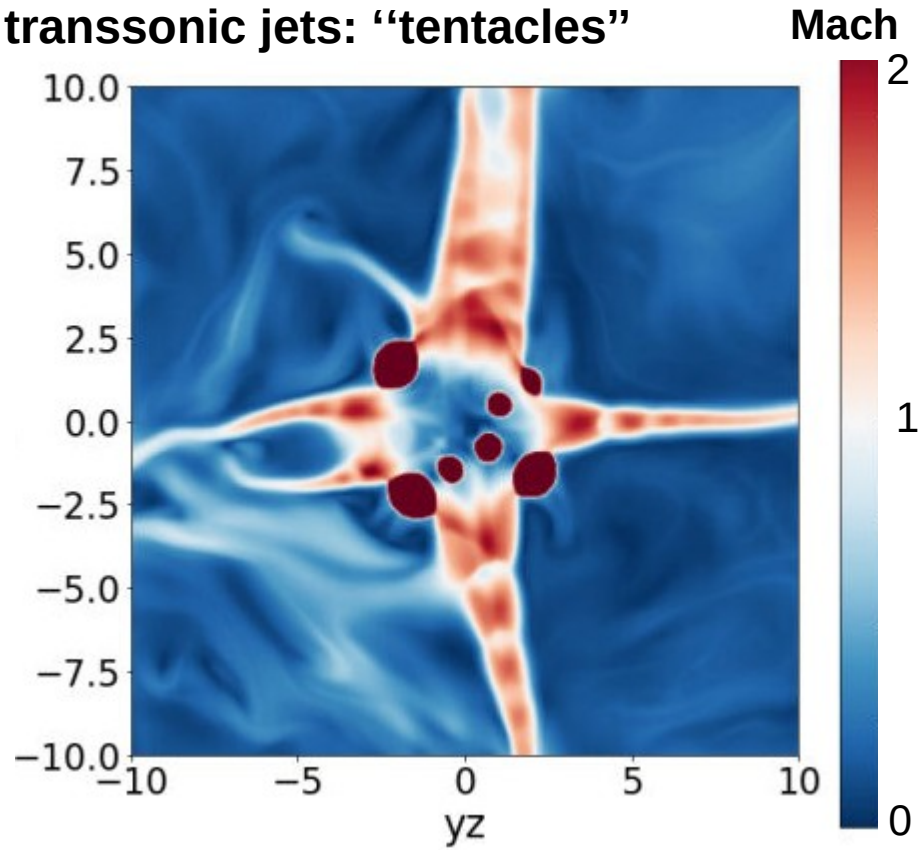
Only a very powerful and very compact cluster can generate a *spherical* WTS

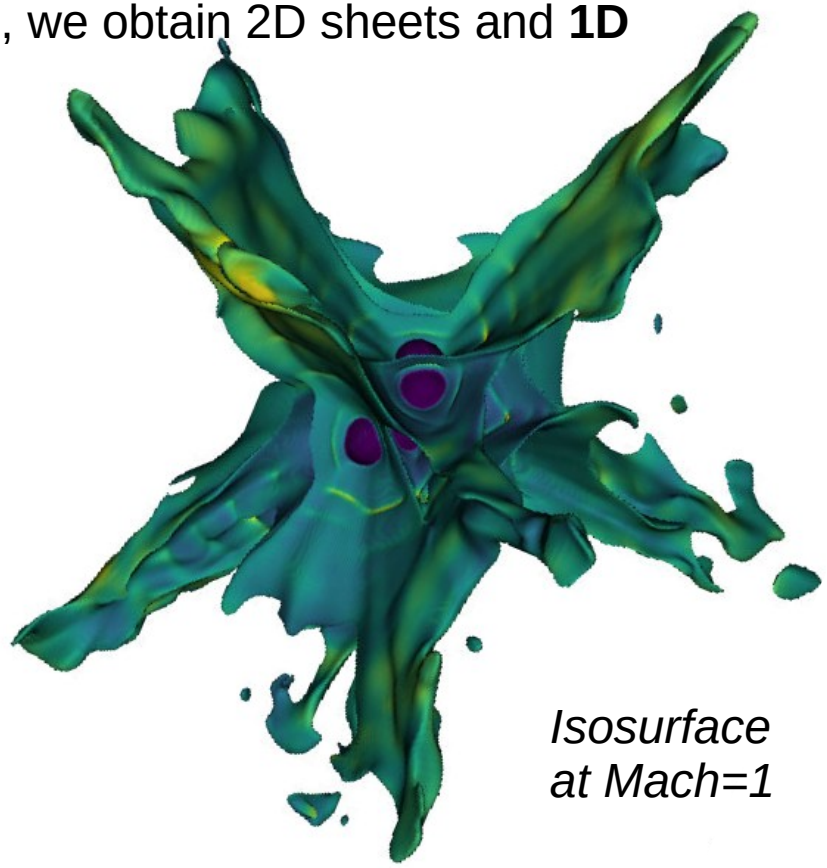
Can we obtain a sphericalish WTS?

Pressure gradient between the core and the superbubble
=> the flow accelerates outward

But the flow is blocked by the individual winds at the edge of the core
=> **asymmetric launching**

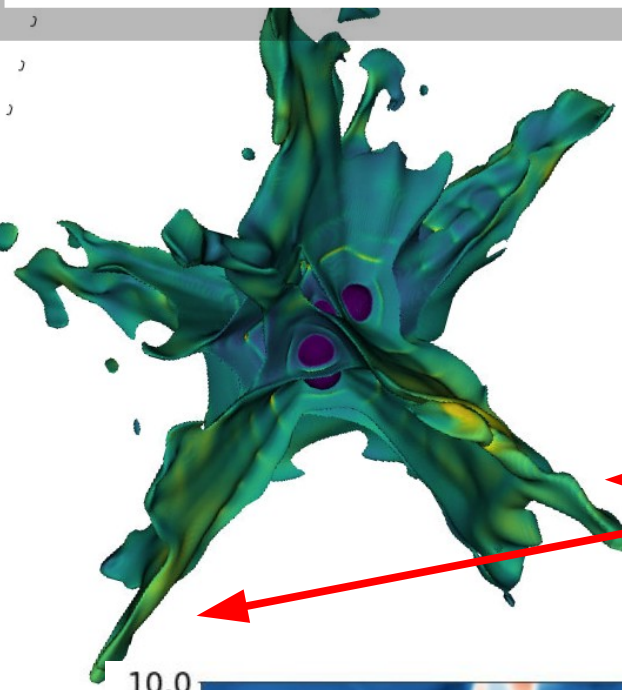
Instead of a spherical strongly supersonic wind, we obtain 2D sheets and **1D transsonic jets: ‘‘tentacles’’**





Isosurface at Mach=1

Tentacles: shock diamonds in star clusters



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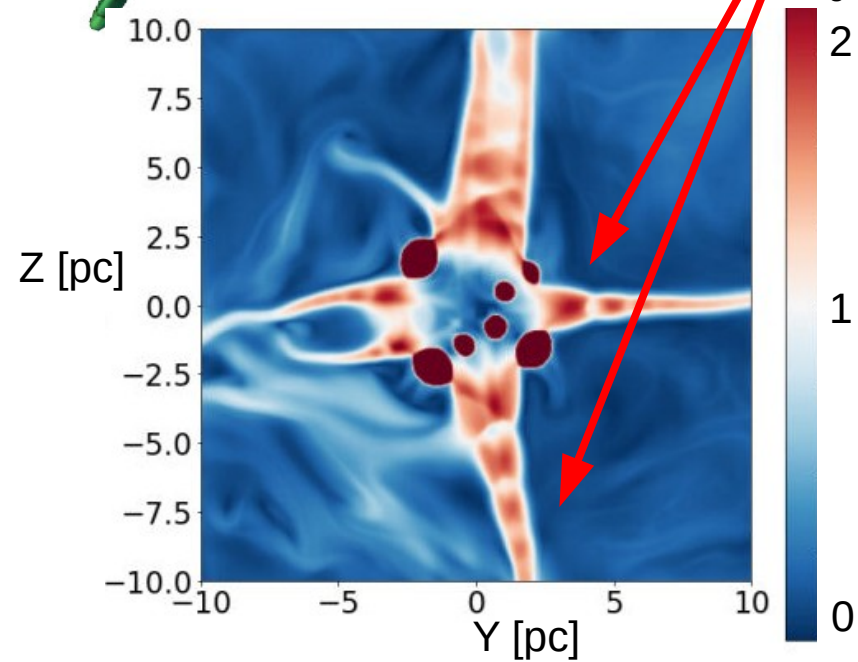
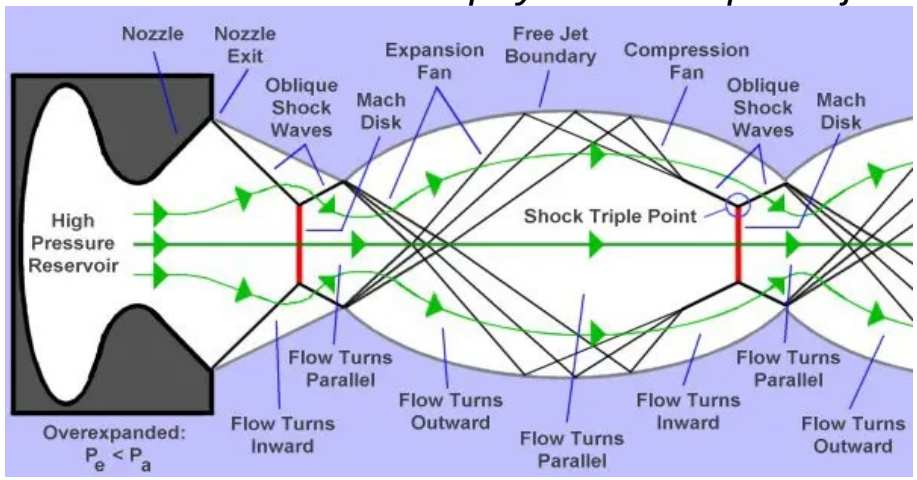


$$\left(\frac{t_{int}}{64\ \mathrm{kyr}}\right) \approx \left(\frac{d}{\mathrm{pc}}\right)^{5/2} \left(\frac{L_c}{10^{38}\mathrm{erg/s}}\right)^{1/2} \left(\frac{\rho_0}{10 m_p\ \mathrm{cm}^{-3}}\right)^{3/4}$$

$$\times \left(\frac{\dot{M}}{10^{-6} M_\odot/\mathrm{yr}}\right)^{-5/4} \left(\frac{v_\infty}{2500\ \mathrm{km/s}}\right)^{-5/4}$$

Tentacles formation time

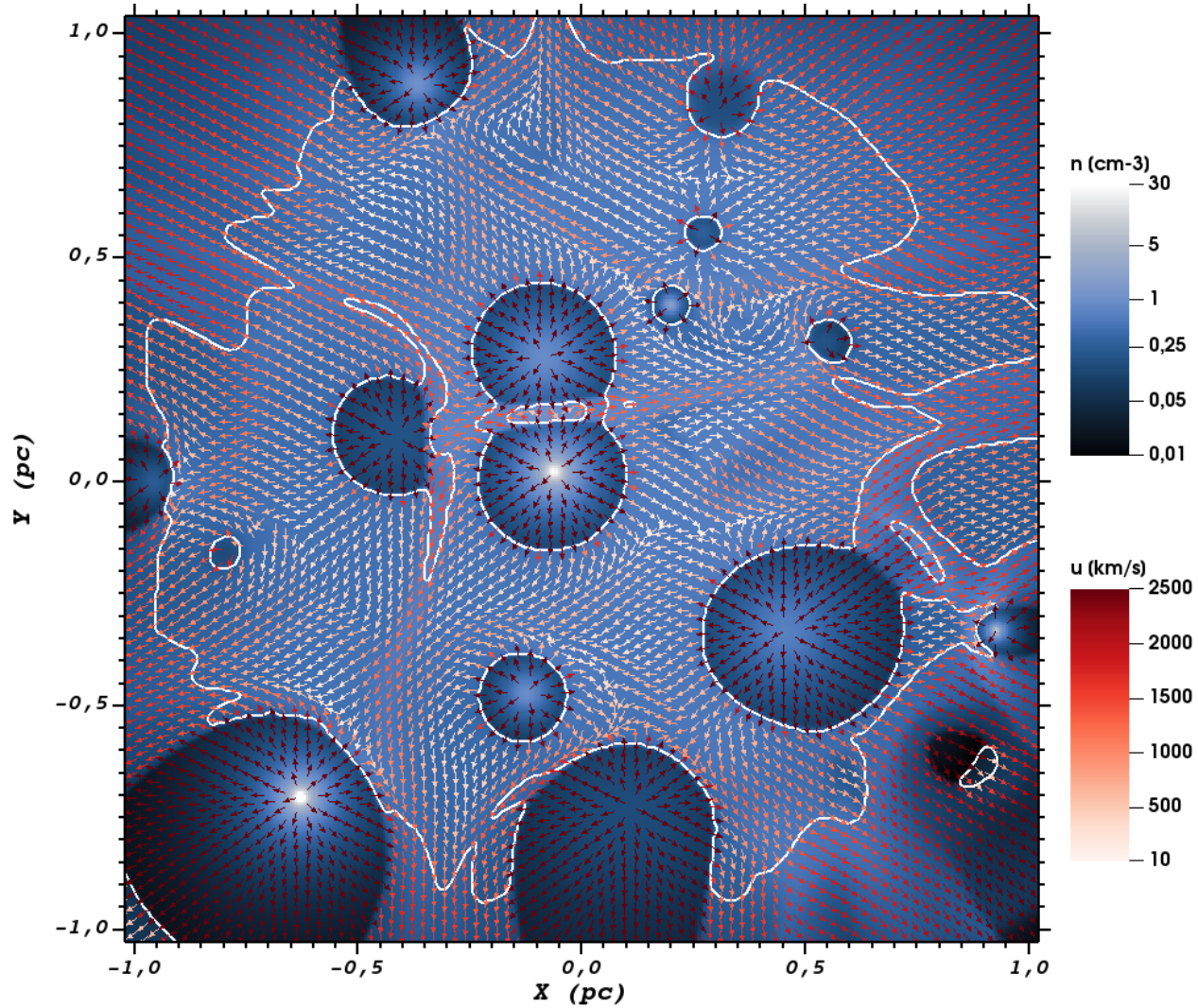
Same physics as airplane jets!



Summary

- A cluster cannot be modelled as a continuous region of deposition of thermal energy: kinetics of individual wind-wind interactions is key!
- These interactions generically produce highly asymmetric shocks, closer to jets!
- Important consequences for particle acceleration: reduced efficiency & maximum energy. Non spherical => morphology of extended gamma-ray emission is key!

Toy simulation resolving wind-wind interactions in a compact core



The energy is inhomogeneously injected through a collection of kinetic winds

In the bulk downstream, conversion to thermal energy.

Outward acceleration of the flow => back to kinetic energy beyond the core

On the inefficiency of particle re-acceleration mechanisms in the cores of massive stellar clusters

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