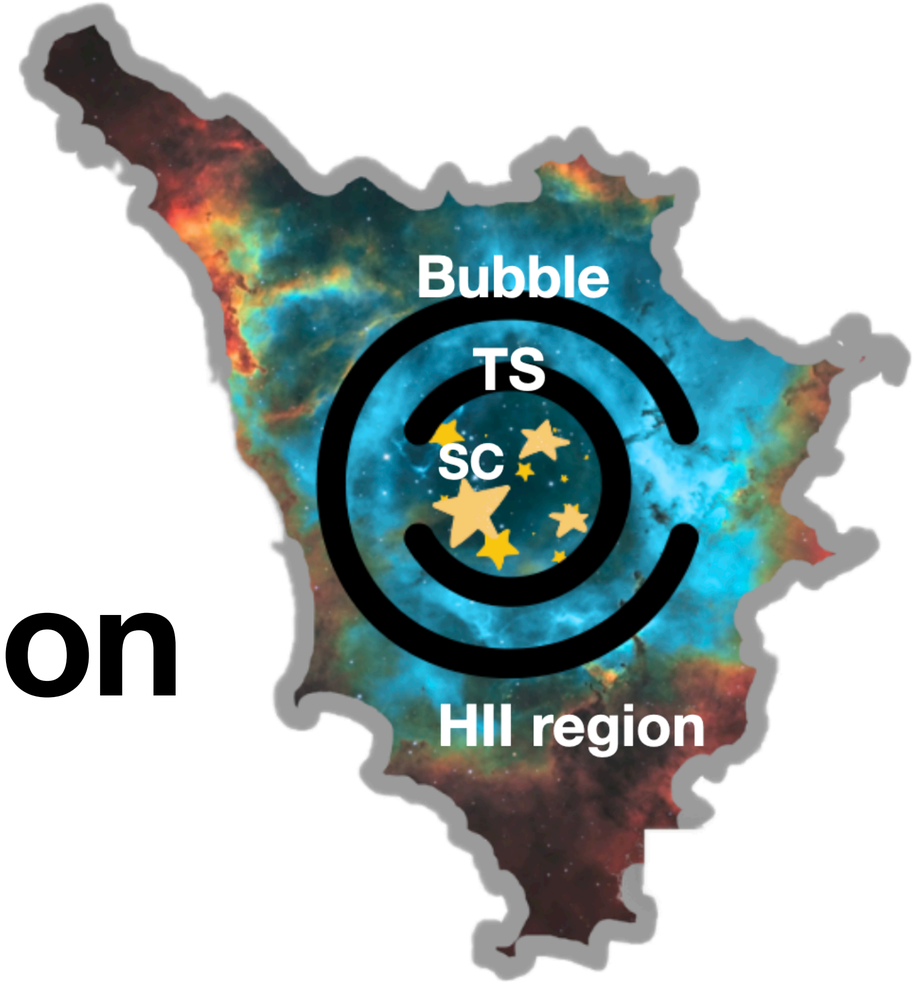
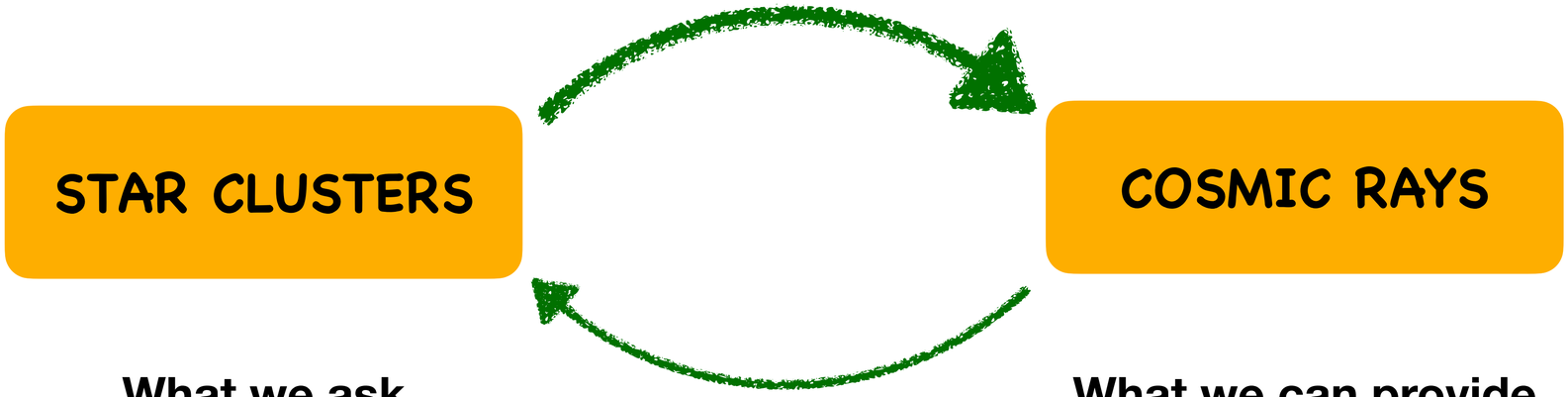
TOSCA final discussion

A *naive* summary



A positive interaction between different communities



What we ask

Help modelling the SC environment to understand whether efficient CR acceleration can be achieved

What we can provide

CR feedback:

- Mechanical feedback on
  - SC bubbles
  - ISM
  - Galaxy (galactic winds)
- Molecular cloud ionization

} Impact on star formation rate

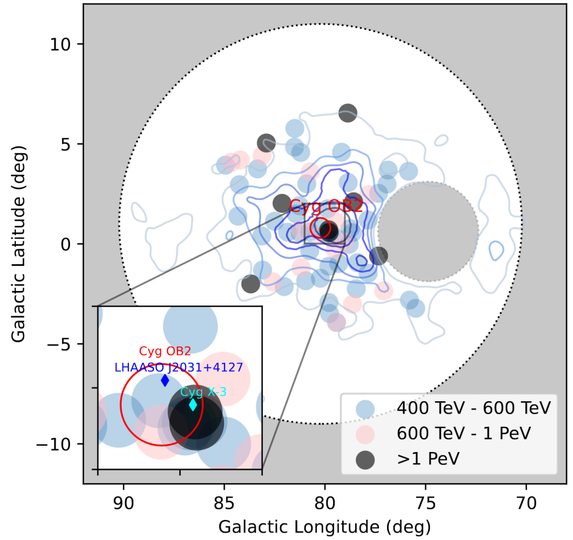
Do we need Star Clusters?

YES!

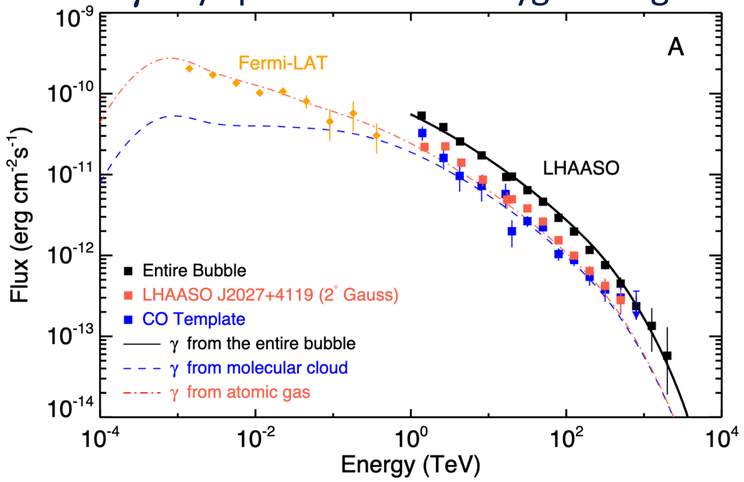
The γ-ray prospective

- Some SCs are detected in γ-rays ⇒ need to explain the emission
- The Cygnus region is among the most interesting ones showing PeV photons [talk by R. Yang], but is also very confusing, containing several sources and a complex gas distribution [see T. Vieu talk]
- Ideally, SCs may be divided into young and old according to the lack of SNs explosions. They can be used to discriminate between the role of stellar winds and SNRs in accelerating particles.
- **R136** is young enough that SN should have not occurred. It is detected in gamma-rays by HESS [talk by L. Mohrmann]
- **Westerlund 1**: old enough that many SNe may have exploded already?

LHAASO coll. (2023)



γ-ray spectrum of the Cygnus region



Do we need Star Clusters? UNCLEAR!

The cosmic ray prospective

- S. Gabici: acceleration of stellar winds + SNe explains well the chemical composition
- P. Blasi: problem: if a SC shine in γ-rays $\rightarrow$the grammage accumulated by CRs is too large. This remains true independently from the acceleration site (WTS; W-W collisions; SNRs; turbulence)
- Possible solutions:
    1. The γ-ray emission is mainly leptonic $\Rightarrow$ the grammage could be negligible but why?
        - Required a correct description of gas around SCs.
        - Need of more refined models to discriminate between leptonic and hadronic emission.
        - Leptonic scenario strongly disfavoured for very young MSC (see Peron's talk)

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  2. Only a small number of SCs emit γ-rays?: the majority are not visible because the grammage is small.

     Possible way to answer:
     - Using present and future observations of promising SCs (see talks by Peron and Mitchel)
     - Estimate the contribution of unresolved clusters to the diffuse Galactic γ-ray emission (see talk by Celli)

Do we need Star Clusters?

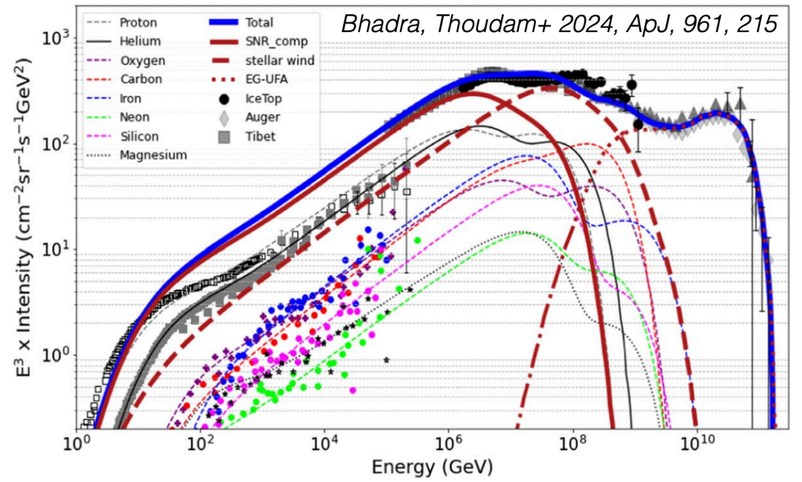
UNCLEAR!

The cosmic ray prospective

3. The bulk of CRs is produced by isolated SNR, not in SCs.
   - How many CC-SNe originate from runaway massive stars?
   - How many SNe explode in SCs?

} → Number of isolated/runaway massive stars?

   - Is a composite scenario realistic? (see Thoudam talk)
     - Bulk of CRs from isolated SNR + highest energy CR from SCs or SNR inside SCs
   - Is SNR rate high enough?
     - Alexis Quintana's talk: Galactic SN rate ~ 0.5 /century (2-6 times smaller than values adopted in literature)



Star Cluster modeling

SC population

- How well we know the local population?
- Especially the young one? Gaia is not especially helpful to discriminate the very young SCs (embedded)
- Which is the best way to estimate the SC mass?

Star Cluster modeling

Stellar population inside SCs

- IMF well know above ~1-2 $M_\odot$. Is the Salpeter distribution valid inside SCs?

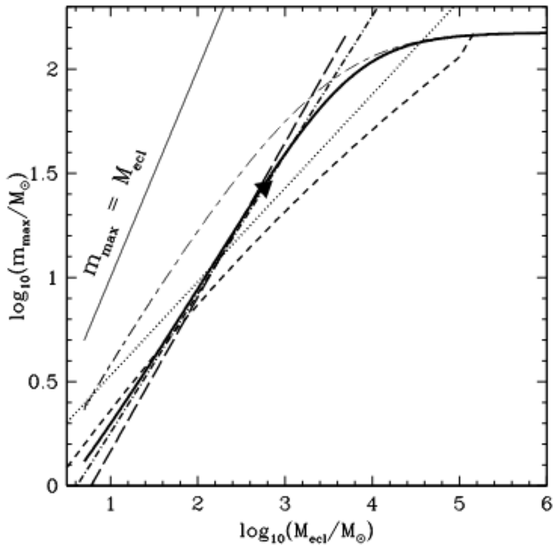
$$\frac{dN_{\rm sc}}{dM_{sc}} \propto M_{\rm sc}^{-(1.5\div2)} \; ; \; \frac{dN_\star}{dm_\star}|_{\rm sc} \propto m_\star^{-\beta} \Rightarrow \frac{dN_\star}{dm_\star} = \int \frac{dN_{\rm sc}}{dM_{sc}} \int \frac{dN_\star}{dm_\star}|_{\rm sc} \propto m_\star^{-2.3}$$?

Born top-heave Kroupa after runaway massive stars (valid for all clusters?) [J. Apellàniz]

- Which is the maximum stellar mass we find in SCs?

$M_{\rm max} \simeq 250\, M_\odot$ in 30 Dor (talk by Goutham Sabhaith)

Is there a dependency on the SC mass?
(Like the Kroupa relation?)



Maximum stellar mas as a function of the cluster mass for different models [Fig. 1 from Weidner & Kroupa, 2004]

Star Cluster modeling

Stellar winds

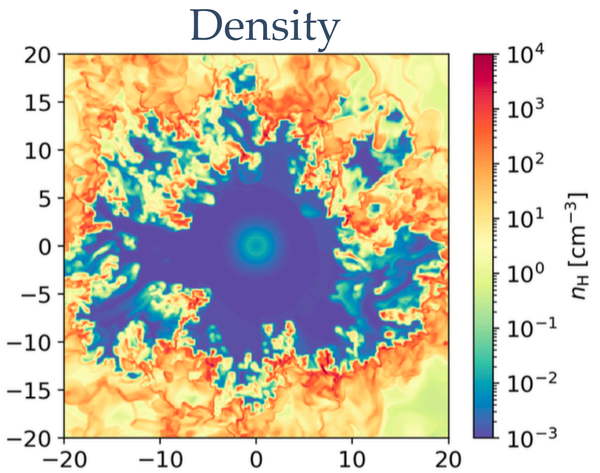
- Main sequence stars: reasonably well known (within a factor ~3)
- VMS and WR: relevant uncertainties on $\dot{M}$, less on v_∞: can we quantify those uncertainty?
  - Wind magnetisation?
  - Clumpiness? Relevant for turbulence generation → Magnetic field amplification
- WR phase last only ~0.3 Myr ⇒ stationary acceleration models may be insufficient

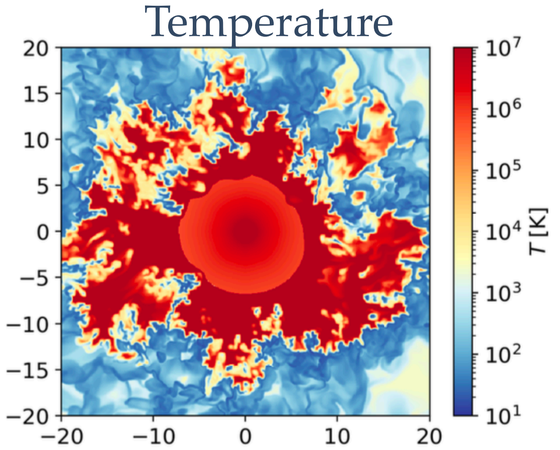
Star Cluster modeling

Wind-bubbles

- The Weaver model is insufficient
- Cooling relevant
  - Enhanced by ISM shell fragmentation
  - Fragmentation reduced by magnetic field (requires MHD simulations)
  - How different is the final shape wrt the Weaver model?
- How relevant is the radiative feedback on the bubble evolution?
- Thermal X-ray detected from some bubble: temperature typically lower than the adiabatic model. Models including cooling can explain the X-ray emission?
- Only simulations:
  - Can we compare different simulations? Do they provide similar results?
  - Can we develop a theory to describe a fractal bubble?
  - Observational handles?

[from L. Lancaster et al. (2021)]



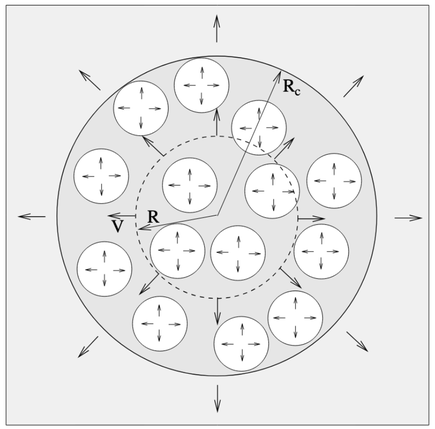


WHICH OBSERVATION CAN CONSTRAINT THE MODELS?

Star Cluster modeling

Super-bubbles (onset of SN explosions)

- Does the WTS survive after the SN explosions? The elapsed time between subsequent SNe can be larger than the wind dynamical time
- Can subsequent SNe sustain a “new” large scale shock similar to the wind termination shock?



THE HOT, DIFFUSE GAS IN A DENSE CLUSTER OF MASSIVE STARS

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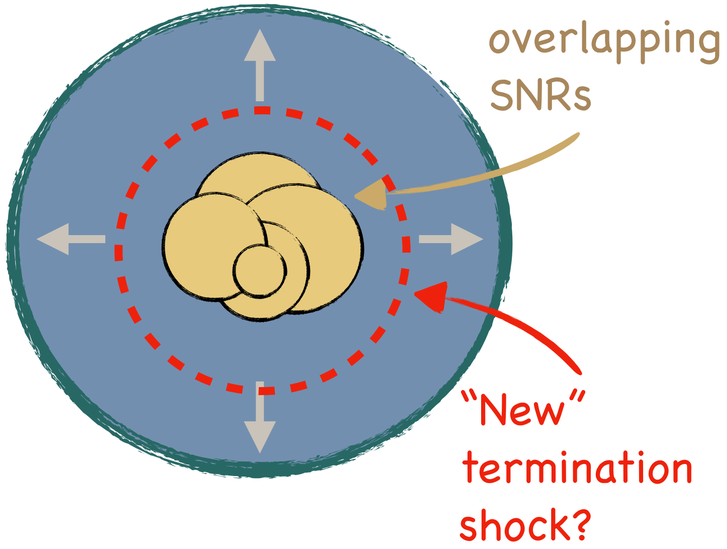
Received 1999 November 23; accepted 2000 January 28

ABSTRACT

We present an analytic model describing the “cluster wind” flow that results from the multiple interaction of the stellar winds produced by the stars of a dense cluster of massive stars. The analytic solution (obtained by matching an inner and an outer solution at the radius of the stellar cluster) can have asymptotically subsonic or supersonic behavior, the latter possibility being appropriate for the case of a cluster surrounded by a low-pressure environment. We also present a three-dimensional numerical simulation of such a cluster wind. We find that the behavior of the mean flow computed from the numerical simulation quite closely follows the flow properties deduced from the analytic model. Finally, we discuss the observational properties of the cluster wind produced by dense clusters such as the “Arches” cluster close to the center of our Galaxy. In particular, we predict that the X-ray emission from the intracluster gas in this stellar cluster could be detectable.

Subject headings: hydrodynamics — shock waves — stars: winds, outflows

[from Cantò, Raga & Rodriguez (2000)]



Star Cluster modeling

Chemical composition

- Is there a specific chemical signature that could allow us to discriminate the origin of CRs between SC and isolated SNRs?
  - ^{22}Ne excess suggest that some fraction of CRs comes from acceleration at the WTS
  - What about ^{26}Al?

Star Cluster modeling

Acceleration mechanisms

Possible acceleration mechanisms:

- Wind termination shock: spectrum $\approx E^{-2.3}$; $E_{\rm max} < (\ll) \, {\rm PeV}$) → Can be tested in very young SCs < 3Myr
- Wind-wind collisions: hard spectrum ; $E_{\rm max} \approx 10 \, {\rm TeV}$
- Turbulent acceleration: spectrum?; $E_{\rm max} > {\rm GeV}$ (maybe much larger, see Jacco Vink's talk)

All mechanisms strongly depend on the magnetic field strength and configuration.

Possible magnetic field sources:

- Magnetic field from stars: are they relevant in the bubble? (See Hearer's talk)
- Magnetic field generated by MHD instabilities
- Self-generation by CRs

Conclusion

Acknowledgements:

- INAF grant (S. Menchiari) for the economical support
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- L. Tibaldo, M. Guarcello & E. Sabbi for the outreach activity

If some of the above questions will be answered in the near future we will see at TOSCA 202?