Super Hot Cores in NGC 253:
Witnessing the formation and early evolution of super star clusters

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Using 0.2” ALMA images of HC_3N vibrational emission (HC_3N^*) we reveal the presence of 8 unresolved Super Hot Cores (SHCs) in the inner 160 pc of NGC 253. Our LTE and non-LTE modelling indicate that SHCs have high dust temperatures of 230-350 K and high IR luminosities of $(0.2-2)\times10^8\ \mathrm{L}_\odot$, all associated with young super star clusters. We use the ratio of luminsoties derived from HC_3N^* (proto-star phase) and from free-free emission (ZAMS phase) to establish the evolutionary stage of the forming SSCs. The estimated evolutionary stages are also supported by the observed HNCO/CS ratio. We find that the most evolved SSCs are located, in projection, closer to the center of the Galaxy than the younger proto-SSCs, indicating an inside-out SSC formation scenario.

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Context of the research

Super Star Clusters

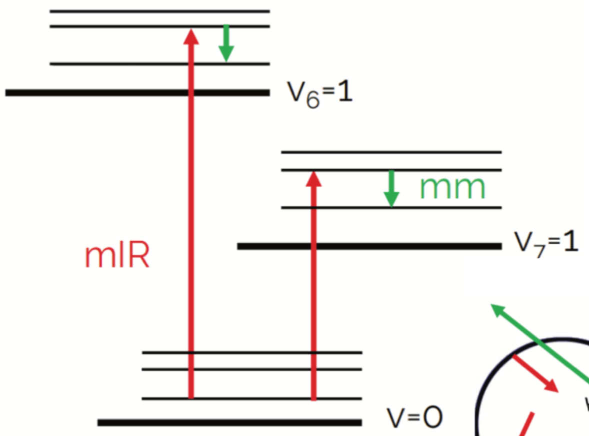
- A large fraction of the star formation in starburst galaxies is believed to be concentrated in relatively small regions in their nuclei, known as Super Star Clusters (SSCs)

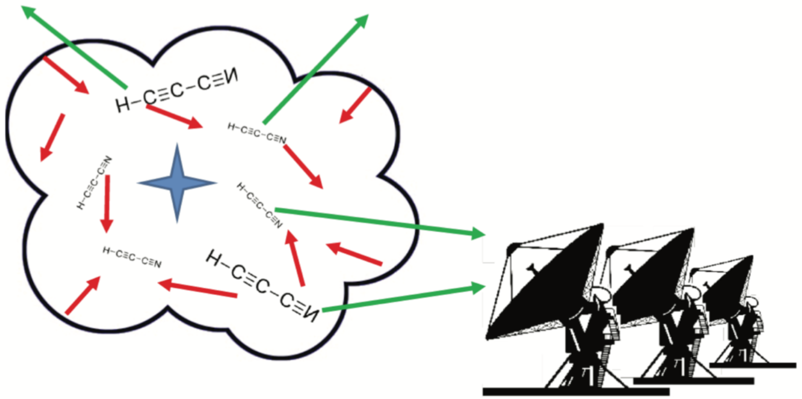
- Unfortunately the earliest phases of SSC are poorly known since they are still deeply embedded in the parental cloud.

Hot Cores

- The earliest phase (few 10^4 yr) of massive star formation (SF) in clusters is commonly recognized by very compact (0.02-0.1pc), hot (200-300 K) and dense condensation (nH2~10^6-10^7 cm^{-3}) known as Hot Cores (HCs).

- With luminosities 10^{5-7} $L_\odot$, HCs are heated by massive protostars deeply embedded in molecular clouds (de Vicente et al. 2000, 2002).





HC_3N

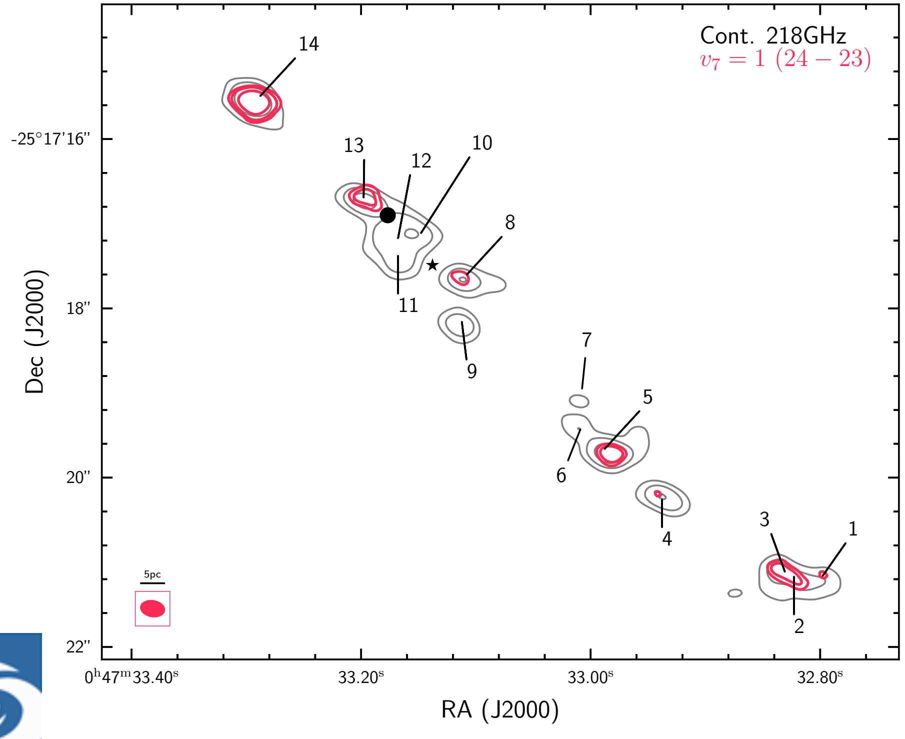
- Emission from its rotational transitions inside the vibrationally excited states (HC3N*) lay in the mm.

- Used to probe the high density and hot material surrounding the protostars since HC_3N v_7, v_6, v_5 … vibrational levels are excited by mIR radiation (Martín-Pintado et al. 2005).

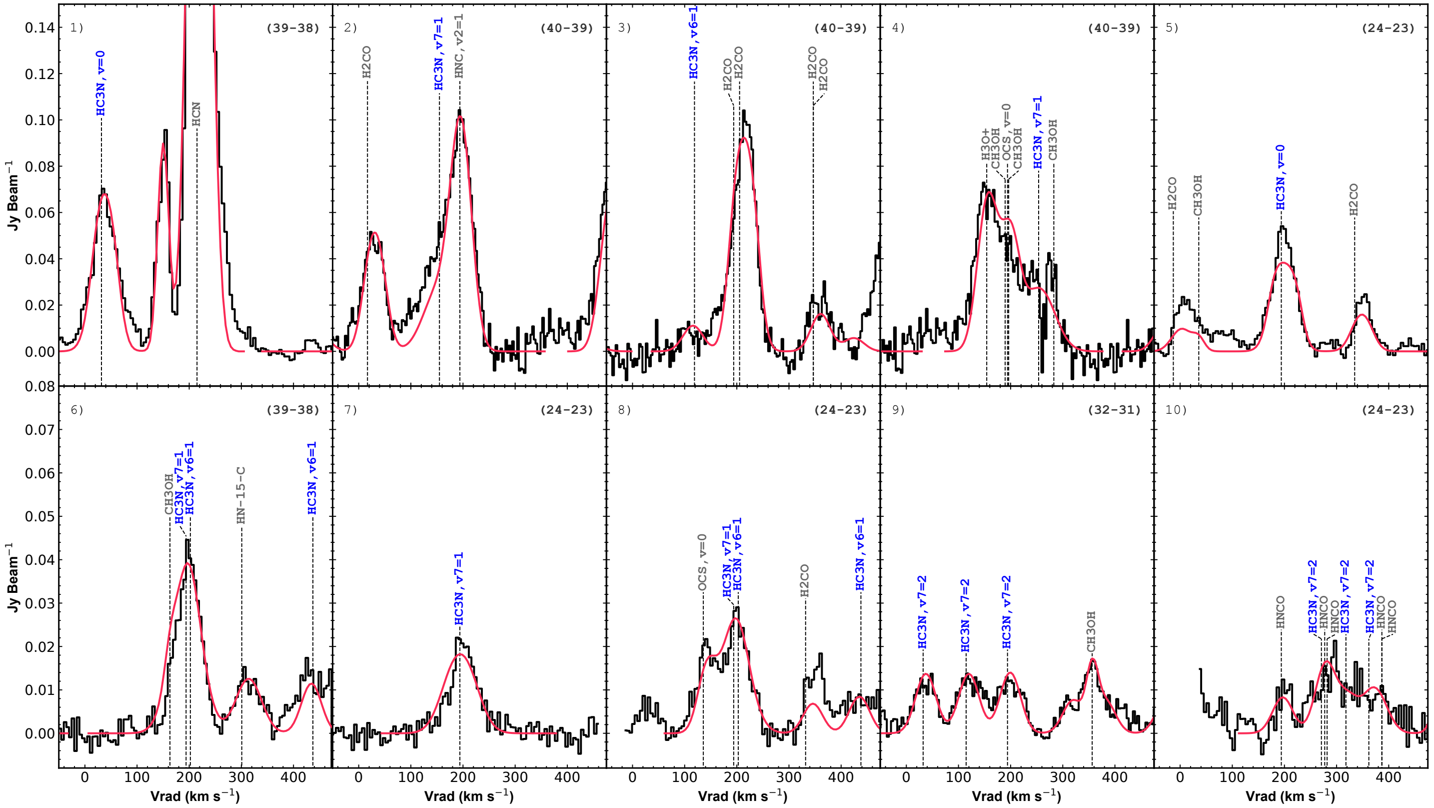
Description of the work

Continuum and HC_3N emission

- Using ALMA observations of NGC 253 we have studied the continuum and HC_3N emission inside 14 SSCs precursors (Leroy et al. 2018).
- 8 SSCs are detected in HC_3N^*



SSC 14



- From LTE and non-LTE modelling of HC_3N^* emission we derive
    - Dust temperatures 200-375 K
    - Densities $(1-6)\times10^6$ cm^{-3}
    - Protostar luminosites $L_{p*} = (0.2-1)\times10^8\ L_\odot$ → Super Hot Cores
- From continuum emission:
    - ZAMS luminosites $L_* = (0.2-10)\times10^8\ L_\odot$

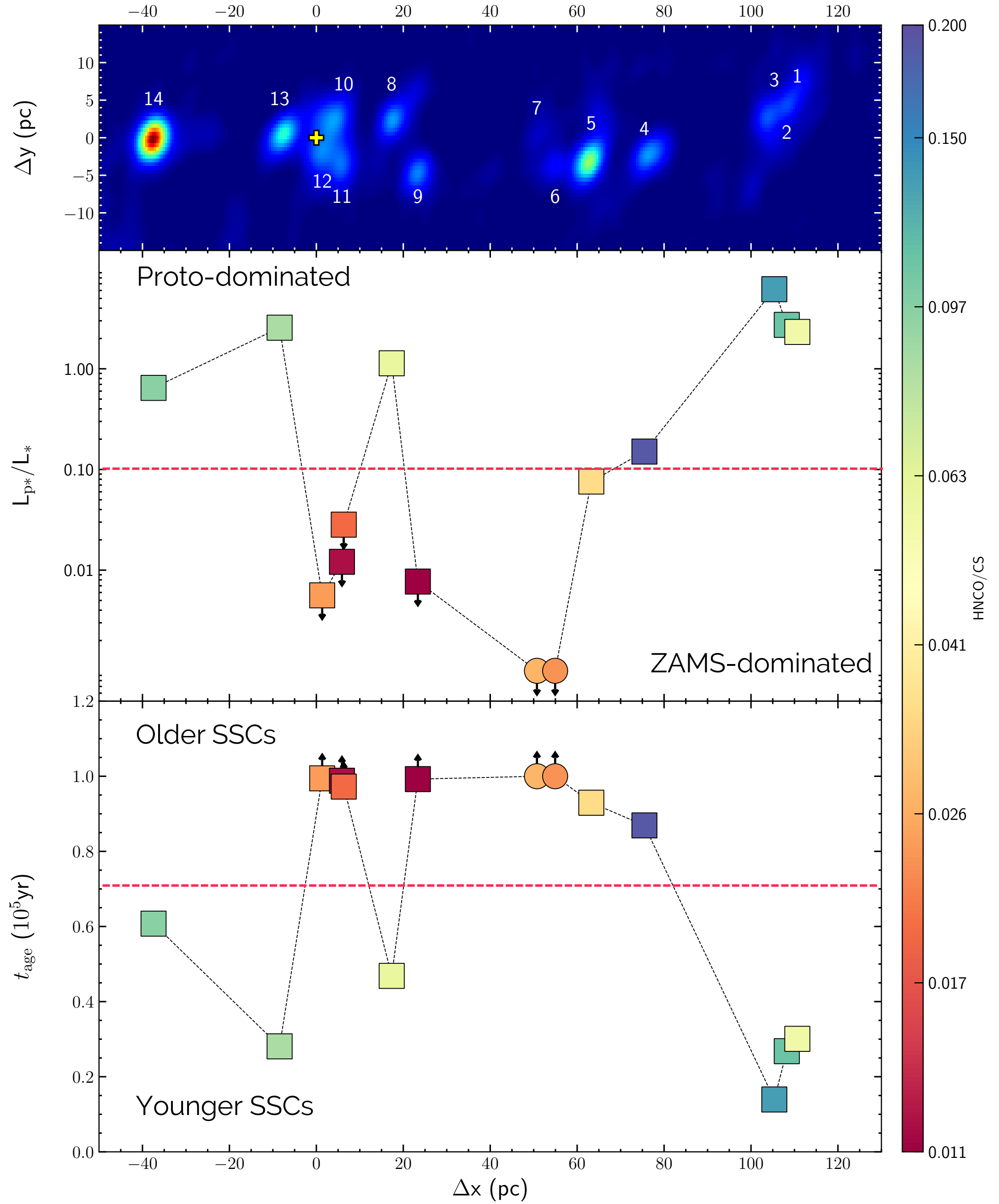
Results

Evolutionary trend of SSC formation

- **Inside-out formation scenario**
  - Trend in their evolutionary stage as a function of their position. $t_{age} \sim \frac{M_*}{M_* + M_{p*}} \times 10^5$ yr

- **Proto-dominated** $\mathbf{t_{age} \lesssim 6\times10^4 yr}$
  - Younger
  - HNCO/CS$\gtrsim 0.05$ - No radiation feedback
  - High L_{p*}
  - Mid. SFE – Still forming stars, can grow higher
  - SFR $\left(\sim 1-2\ M_{\odot}\ yr^{-1}\right)$
  - $M_{VIR} < M_{SHC}$ → No mechanical feedback

- **ZAMS-dominated** $\mathbf{t_{age} \gtrsim 8\times10^4 yr}$
  - Older
  - HNCO/CS$\lesssim 0.05$ - Radiation feedback
  - High L_* (low L_{p*})
  - High SFE – Converted most gas (gas expulsion?)
  - SFR $\left(\sim 2-4\ M_{\odot}\ yr^{-1}\right)$
  - $M_{VIR} \sim 1-5 \times M_{SHC}$ → Low mechanical feedback



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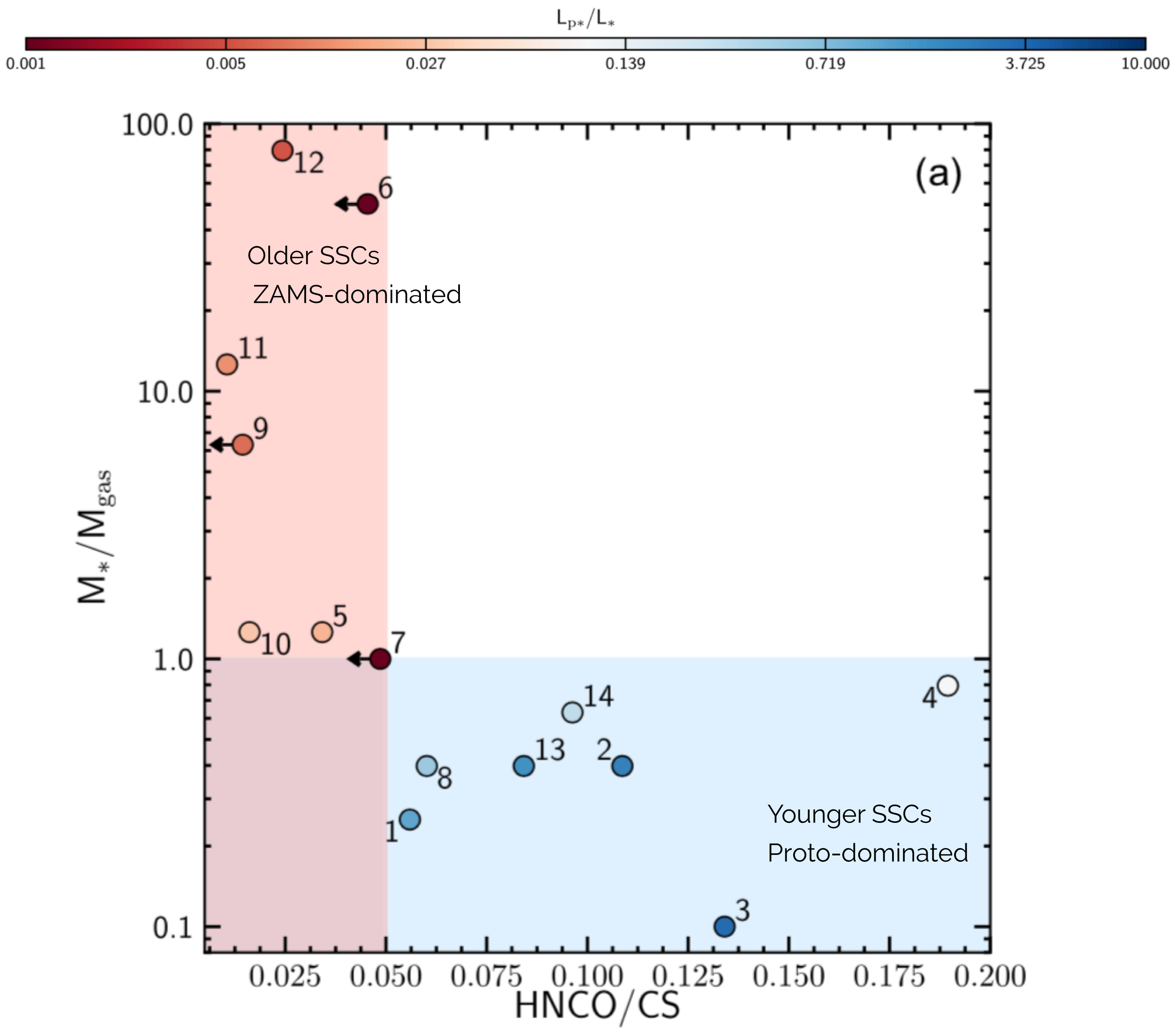

Conclusions

- From the 14 forming SSCs with strong free-free and dust emission, 8 of them show HC_3N^* emission (SHC phase).
- LTE and non-LTE analysis gives dust temperatures 200-375 K for sources with HC_3N^*.
- We have used the proto/ZAMS luminosity ratio ($L_{p*}/\ L_*$) to measure the evolutionary stage of the SSCs. The estimated ages are also supported by the radiative feedback as traced by HNCO/CS.
- We find a systematic trend between SSCs age and their projected location, with the older ZAMS-SSCs located in center and the younger proto-SSCs in the outer regions.
- This suggests an inside-out SSCs formation scenary likely triggered by external events.

Prospects for the future

- New observations with better resolution are needed to resolve the SSCs and constrain the temperatures and luminosities and discern between SSC formation mechanisms.