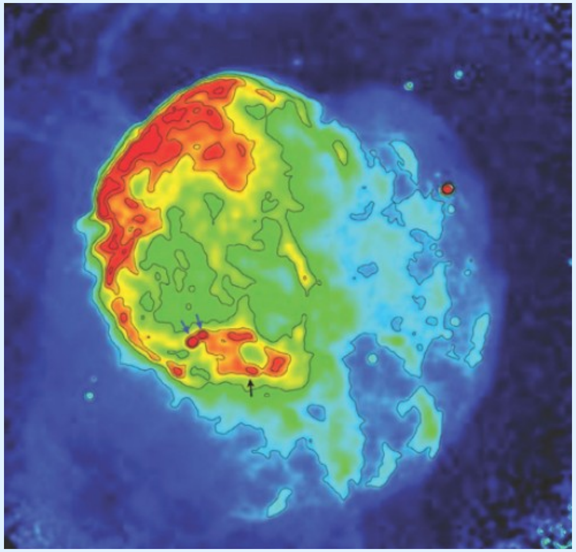
Kinematics of the shocked molecular clumps of SNR IC 443



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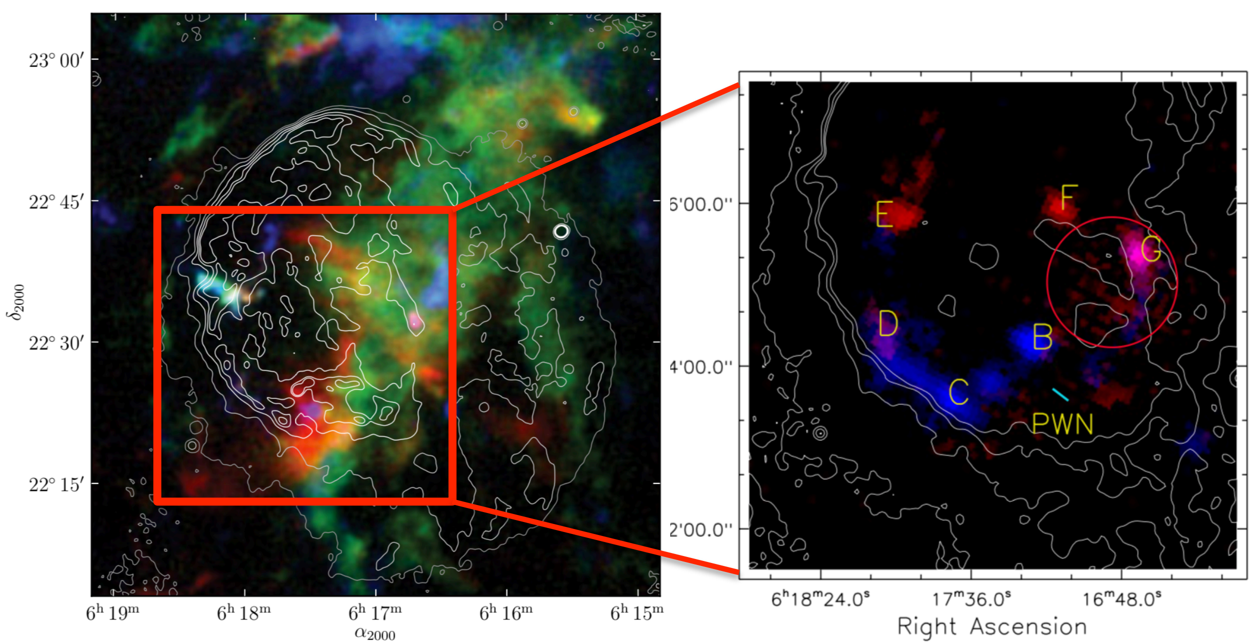
2019 EAO sub-mm future meeting, Nanjing

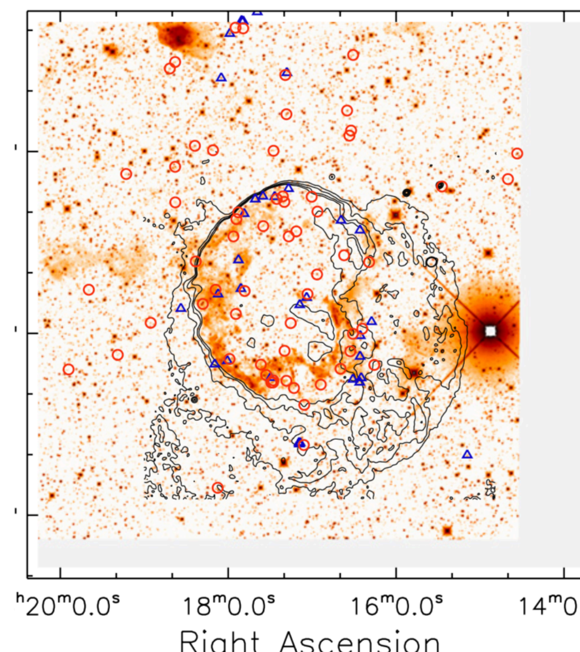
21cm image: Lee et al. (2012)

Background: SNRs interacting with MCs

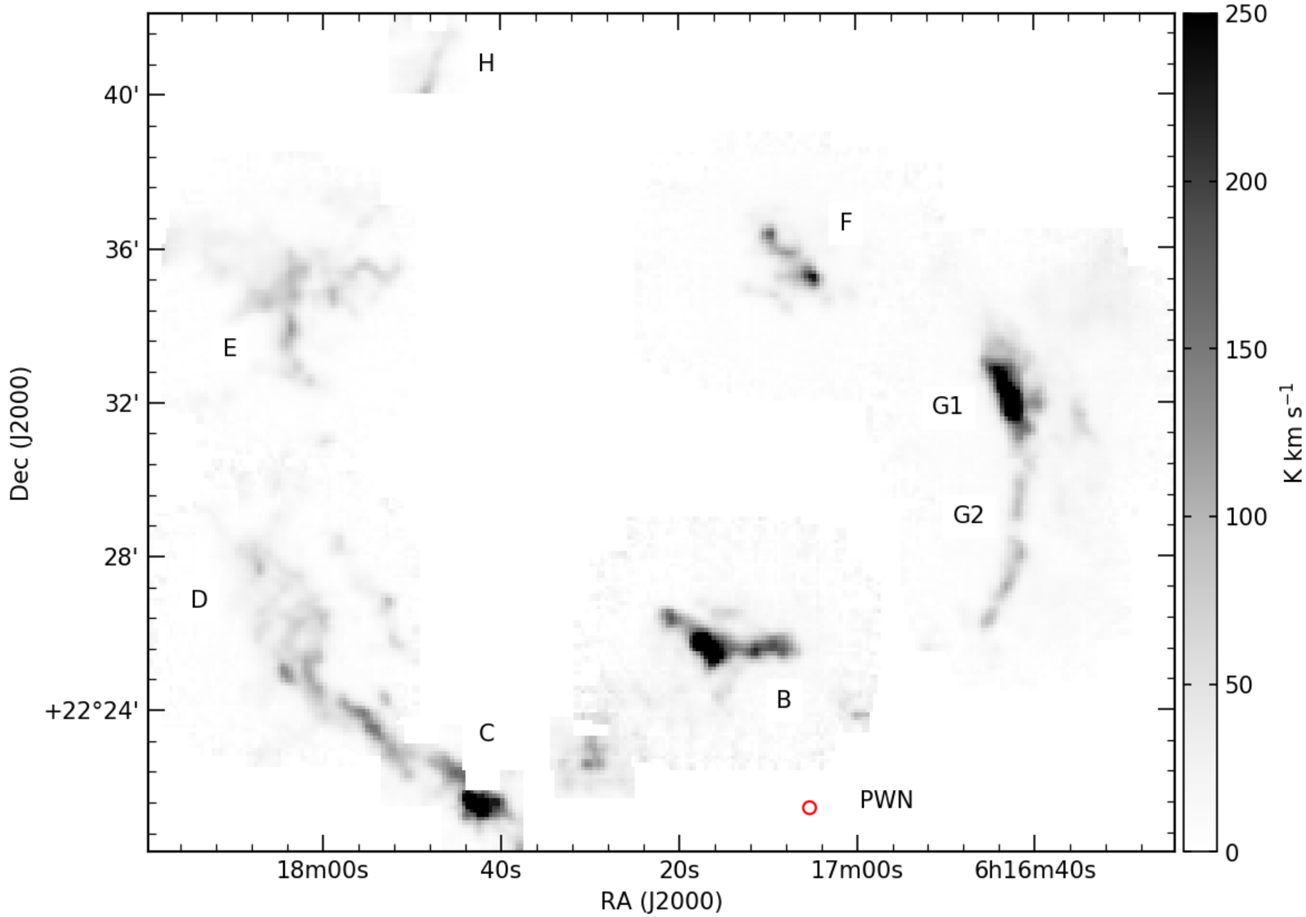
- Broad molecular line profiles
- Large line ratio ($R_{21/10}$>1)
- 1720MHz OH maser ($n \sim 10^5$ cm^{-3},T=50 -125 K)
- IR emission lines [FeII] and H_2
- Analogue shock conditions in ULIRGs

Su et al. (2014)
Lee et al. (2012)





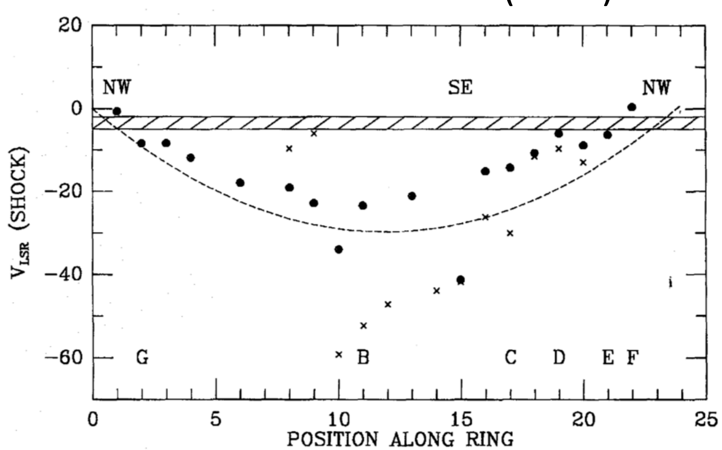
JCMT HARP CO (3-2) observations

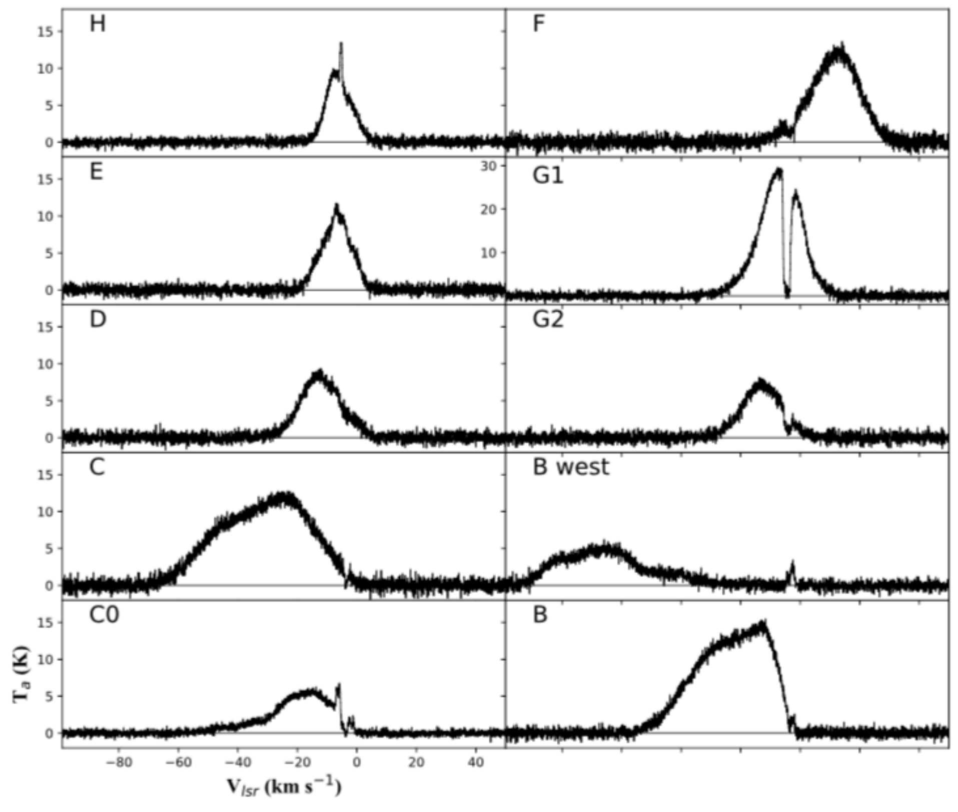


Large-scale kinematics

- A global collective expansion velocity of 25 km s^{-1} within the hot, fully ionized SNR interior.

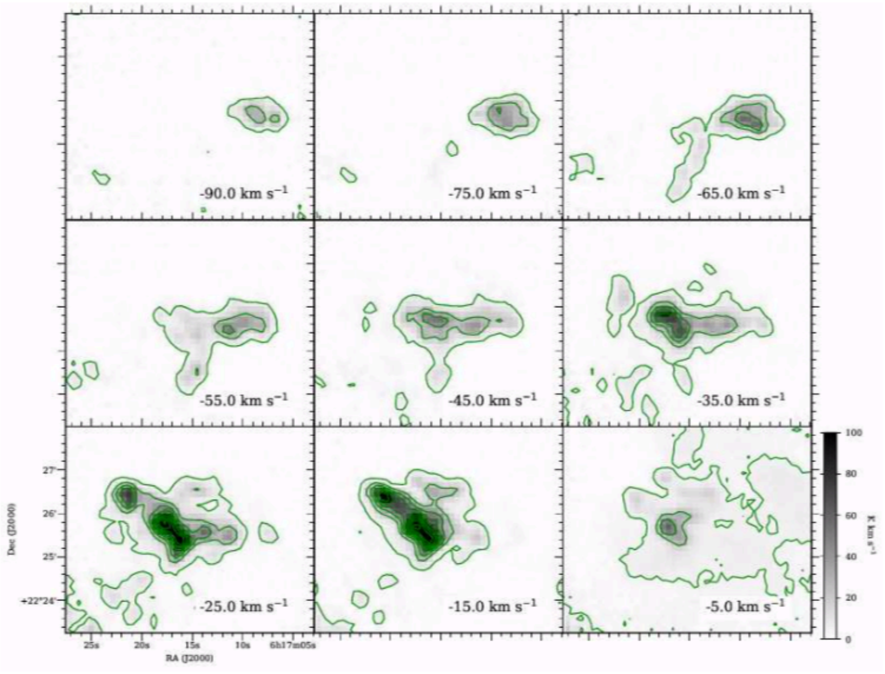
Van Dishoeck et al. (1993)

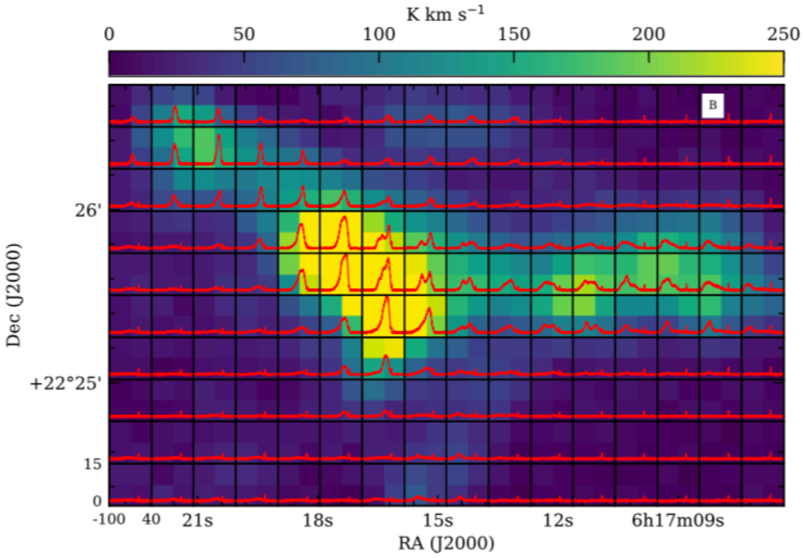




Clump B

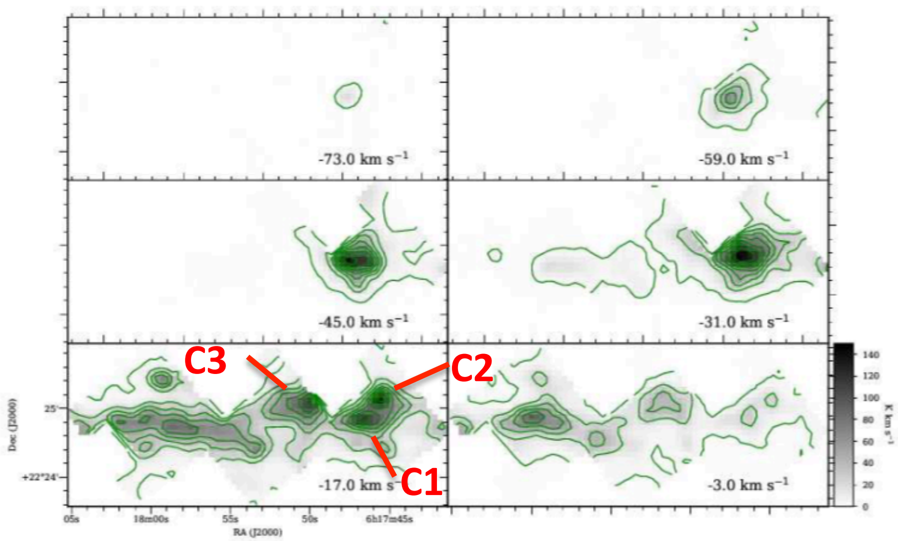
- 3 sub-clumps resolved
- High velocity up to -95 km s^{-1} in the western region

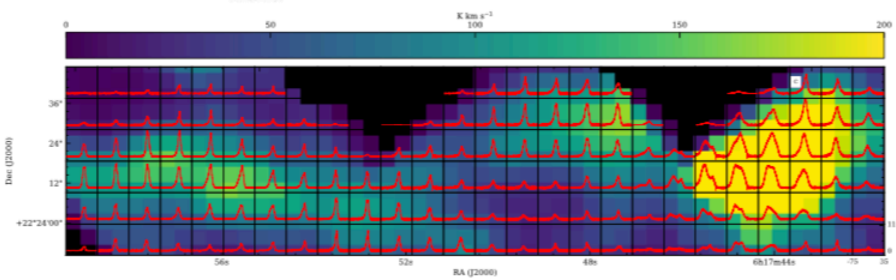


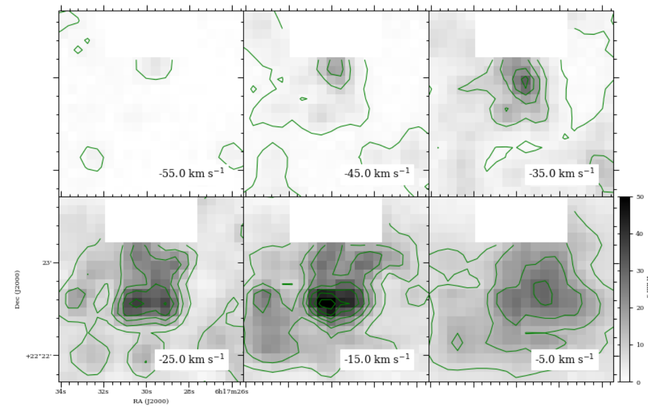


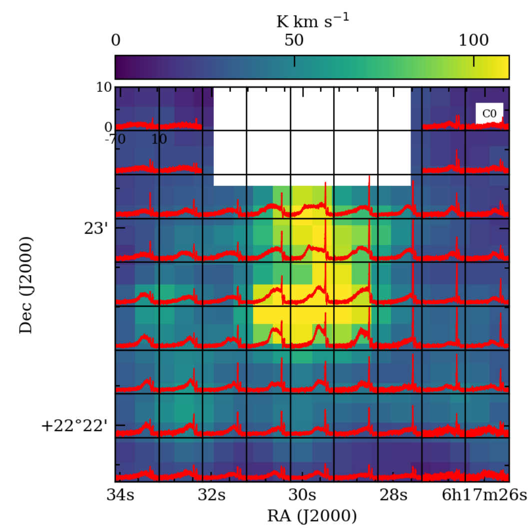
Clump C and C0

- gas patches C1, C2, C3 discriminated at -17 km s^{-1}
  shock layers at inner and outer side of the clump (Wang & Scoville 1992)
- 4 knots resolved in the flow ablating from the small cloud SC 05



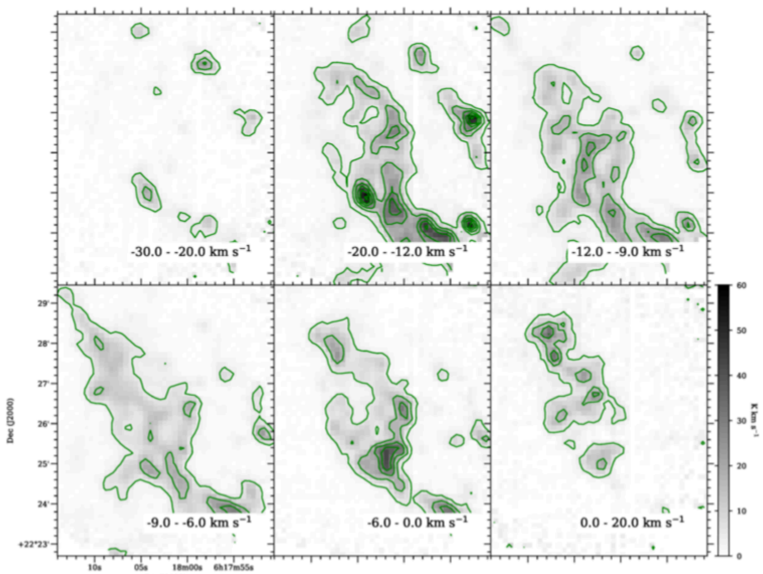


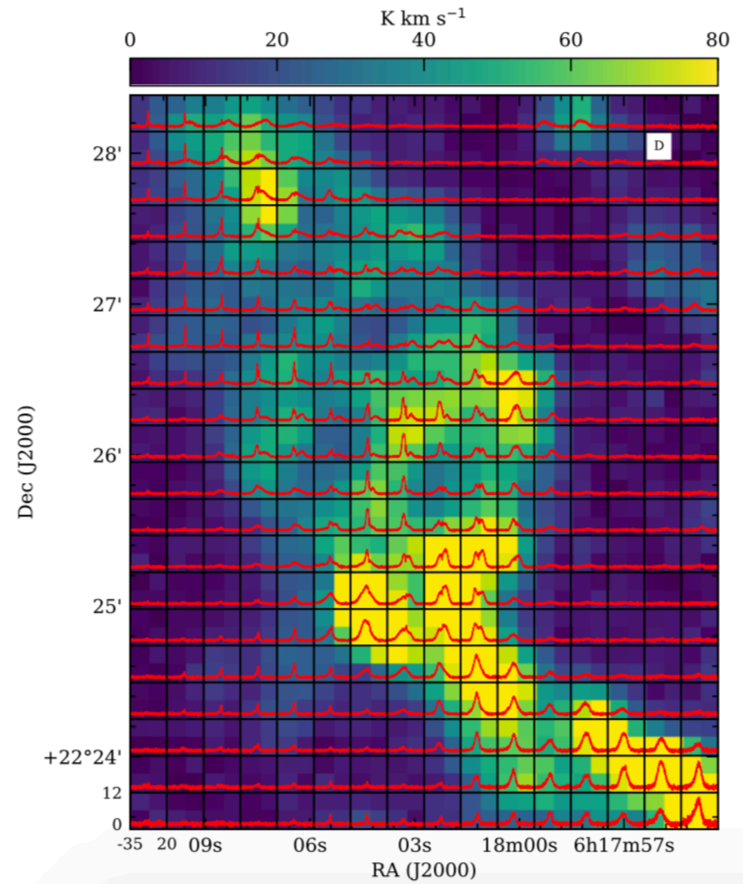




Clump D

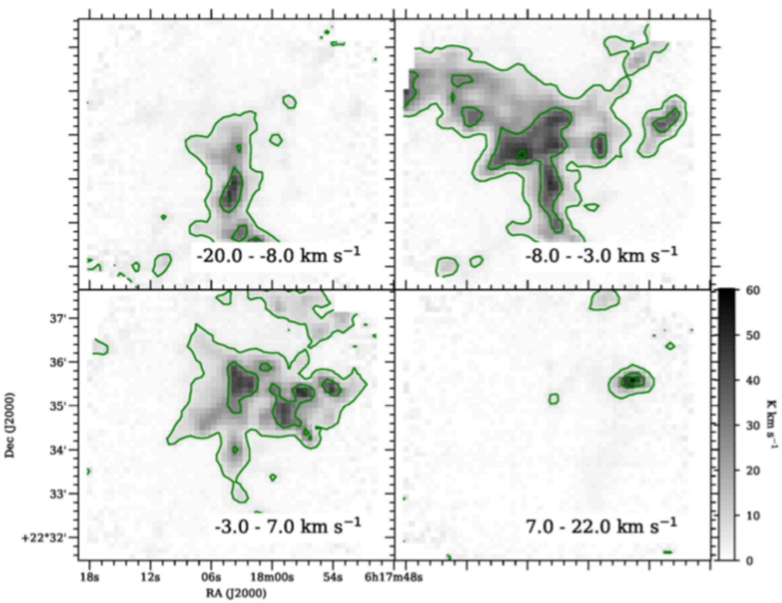
- Clumpy gas patches and filaments show that the fragmentation is happening
- The shock has propagated towards the outer rim at SC 06

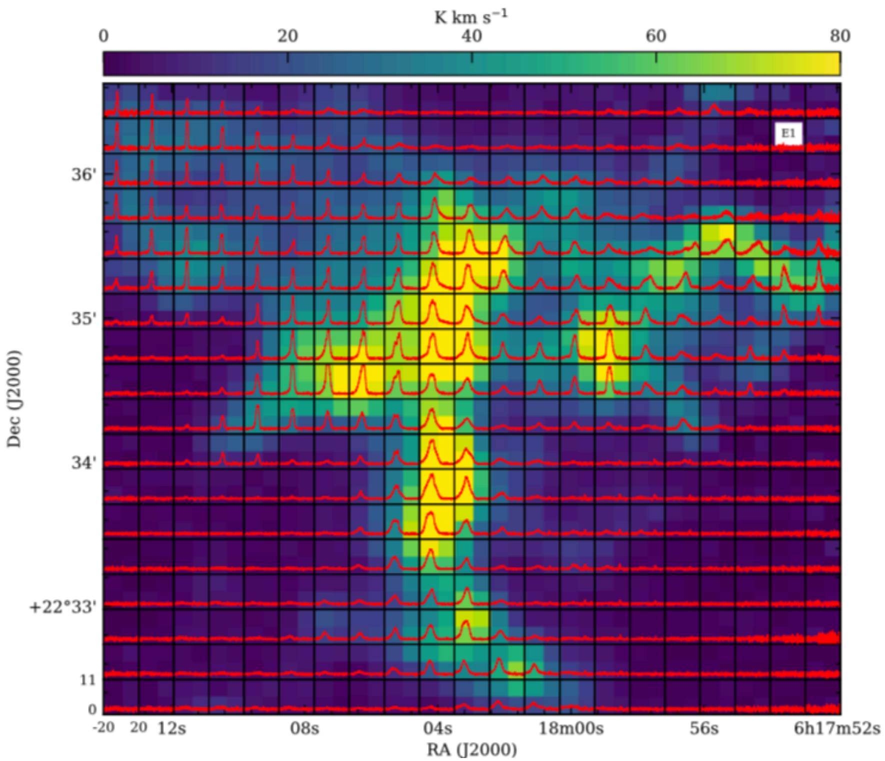




Clump E

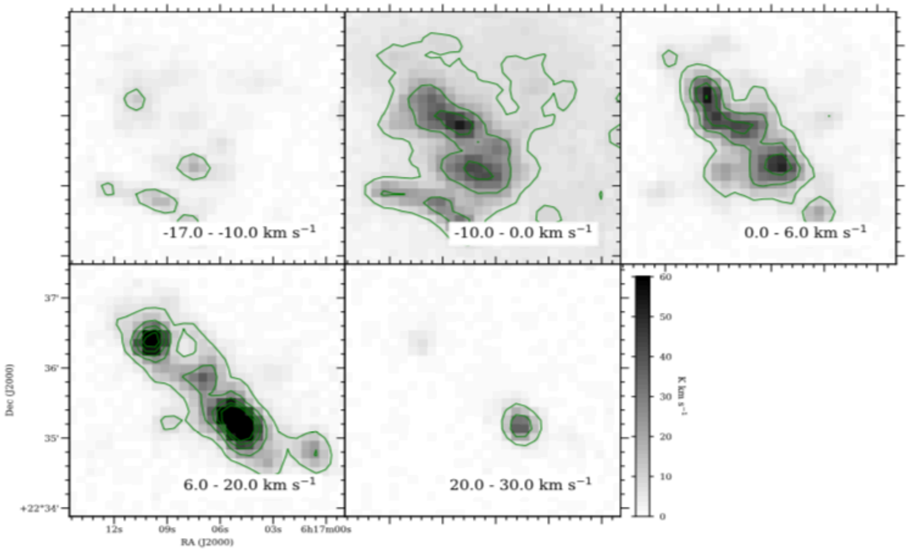
- 3 main velocity components:
  - More negative gas patch concentrated in the south at -7 km s^{-1}
  - Central patches, with SC 07 & 08 being impacted by the SNR shock
  - Knots with redshift velocity in the west

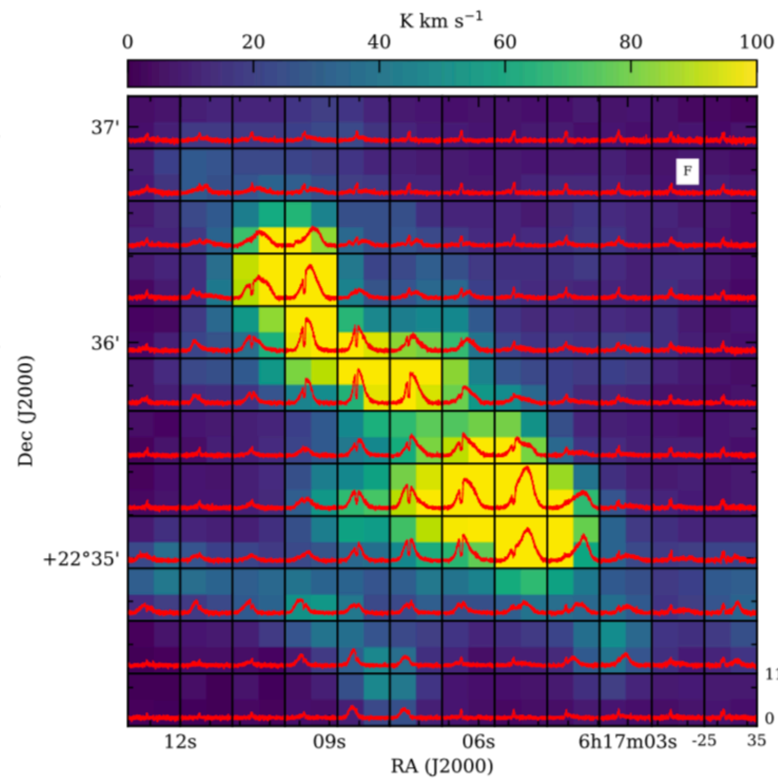




Clump F

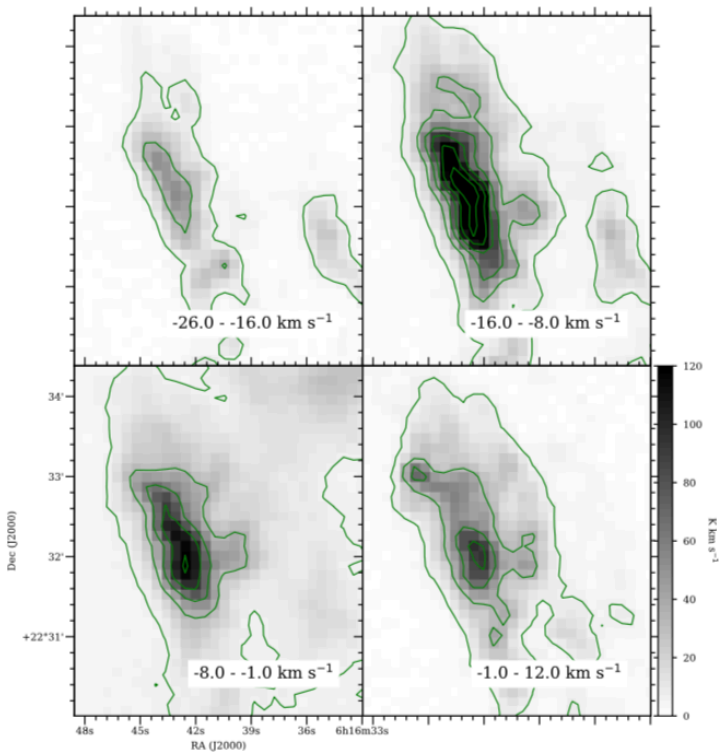
- At least 3 sub-clumps resolved, $R_{32/21}$ ~1
- A weak arc structure, collecting effect of the progenitor's stellar wind

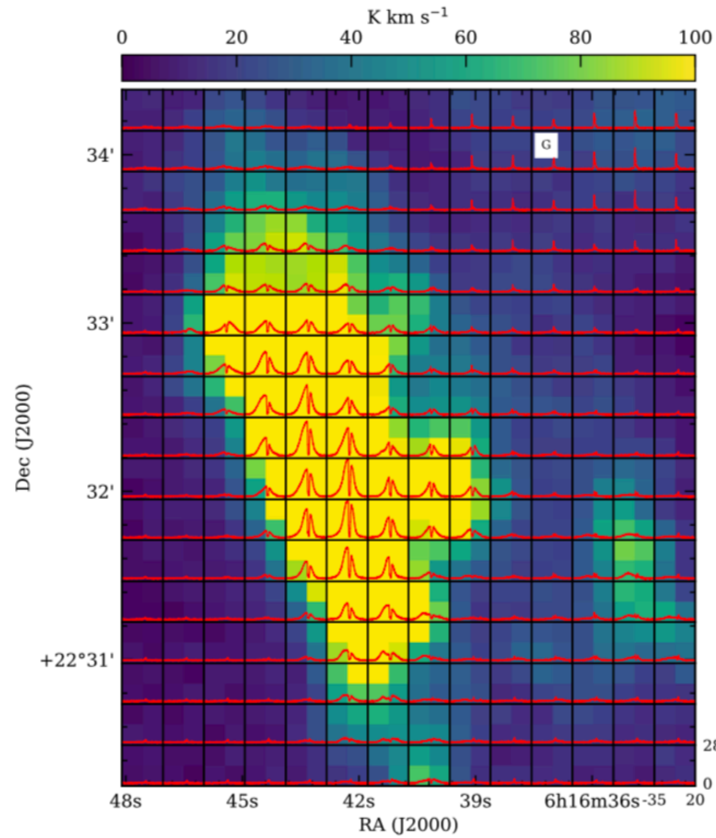




Clump G1

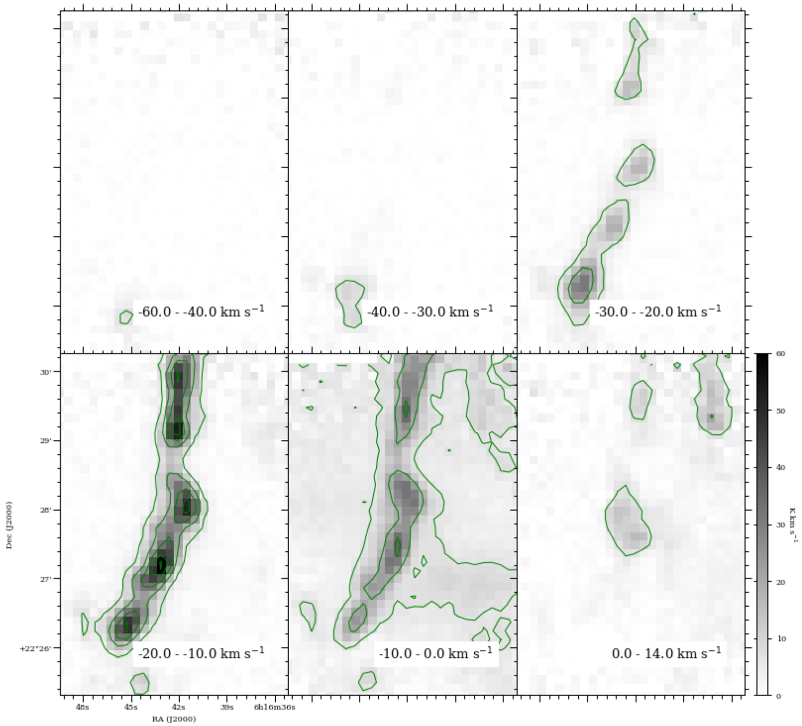
- Almost totally self-absorption by the foreground preshocked gas
- Composed of 2 sub-structures

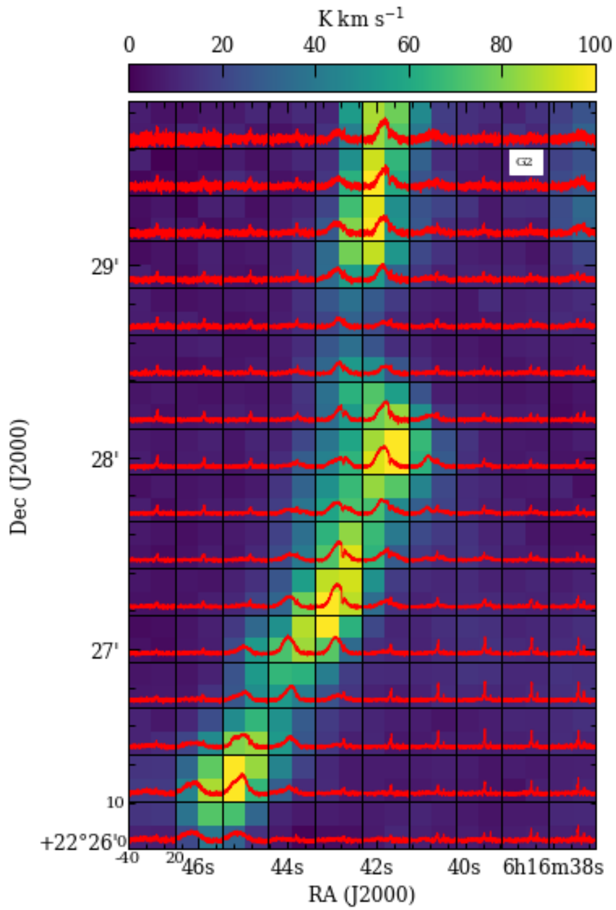




Clump G2

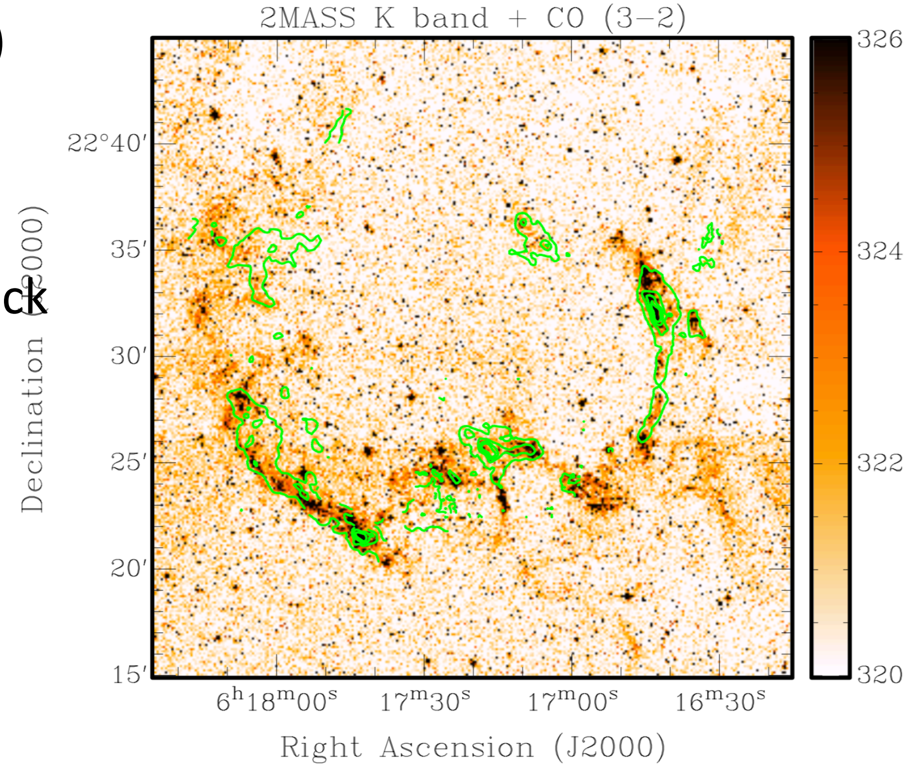
- Five sub-clumps, quasi-regular spacing of 0.31-0.47 pc
- the progenitor's stellar wind sweeping by the foreground molecular gas, and self-collapsed





Comparison with the 2MASS K band Emission

- Hot H_2 gas v = 1 − 0 S(1) (T>2000 K)
- good morphology correlation
- A combination of J- and C- type shock
  (Snell et al. 2005, Neufeld et al. 2007)
- Clump B & F:
  - weak in central cores , lower T
    - -> slow C-type shock with low fractional ionization
  - peak in western diffuse clump
    - -> J-type shock

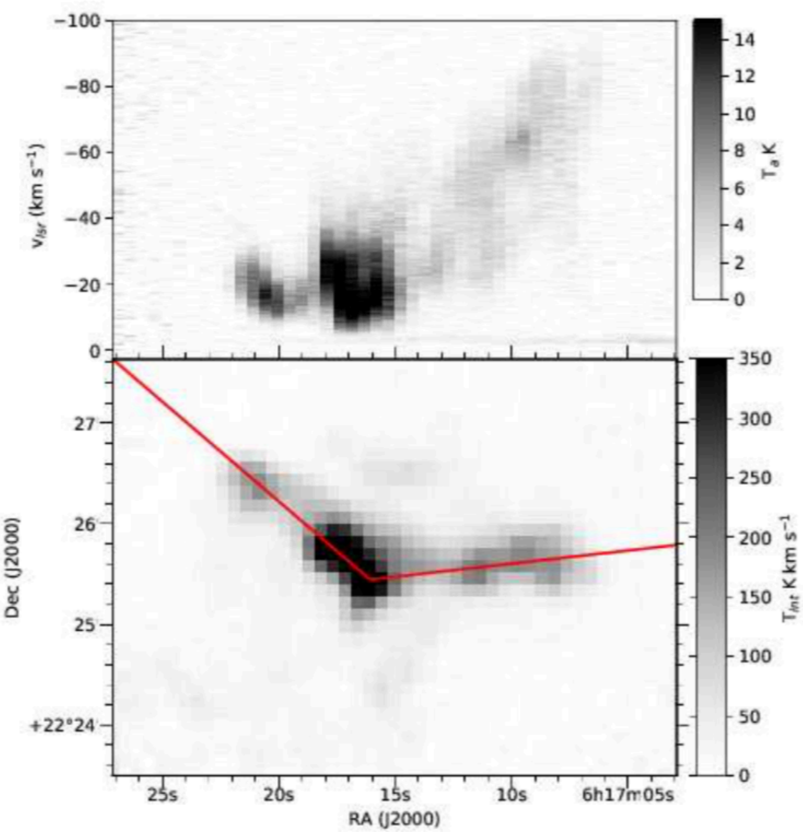


Turbulence in the subclumps

- Diffuse component at -40 km s^{-1}
  -> shook propagates into a low-density interclump media

- Turbulence with a velocity gradient of dV/dR~30 km s^{-1} pc^{-1}
  Similar order as in distant ULIRGs (Arp 220), power injection via SNRs dominated, decoupling of gas and dust ($T_{kin} > T_d$)

- Dissipated at a crossing timescale of t_{cr}~(l/δv)~10^5 yr



Fragmentation of Molecular Clumps

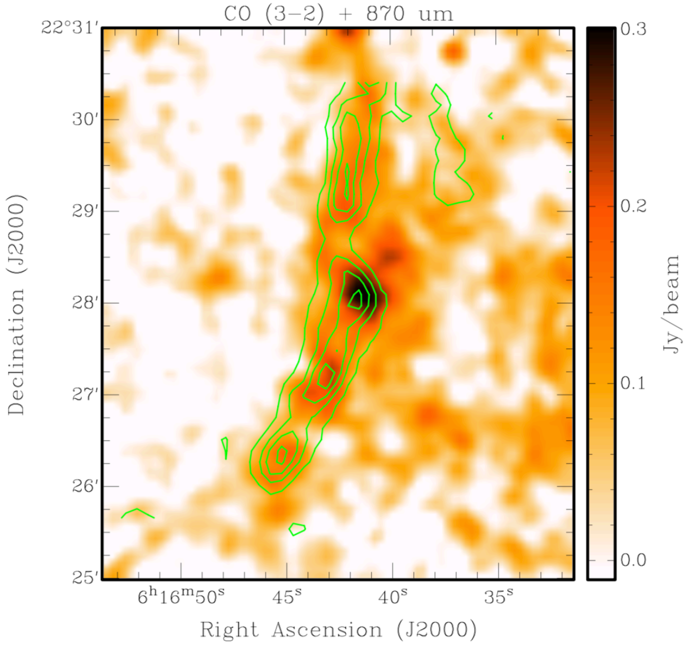
- crushing time of shocked dense cloud:

$$t_{cc} = \chi^{1/2} r_0 / v_i \sim 1 \times 10^5 / (v_i / 100\ km\ s^{-1})\ \text{yr}$$

- Assume Isothermal and thermally supported
  - Critical mass per unit length

  $M/R = 16\text{-}48\ M_\odot\ pc^{-1}$ (T=10-20 K)

- Fastest-growing unstable mode of the fluid instability
  - characteristic spacing of 0.6pc



Summary

- Rich substructure and the kinematics at smaller scales of the shocked molecular gas are resolved in CO (3-2).
- The sub-clumps in B and F clumps are likely fragmented dense cores under a slow C-type shock, having a turbulent with dV/dR of 30 km s^{-1} pc^{-1}.
- The weak diffuse gas at -40 km s^{-1} traces a relatively low-density interclump media associated with B sub-clumps.
- The fibrous G2 clump show five fragmented sub-clumps. It's probably formed by the progenitor's stellar wind sweeping by the preshock gas and then self-collapsed by cylinder collapse.

Thank you!