Stellar and interstellar content of the region interacting with cosmic rays in IC443

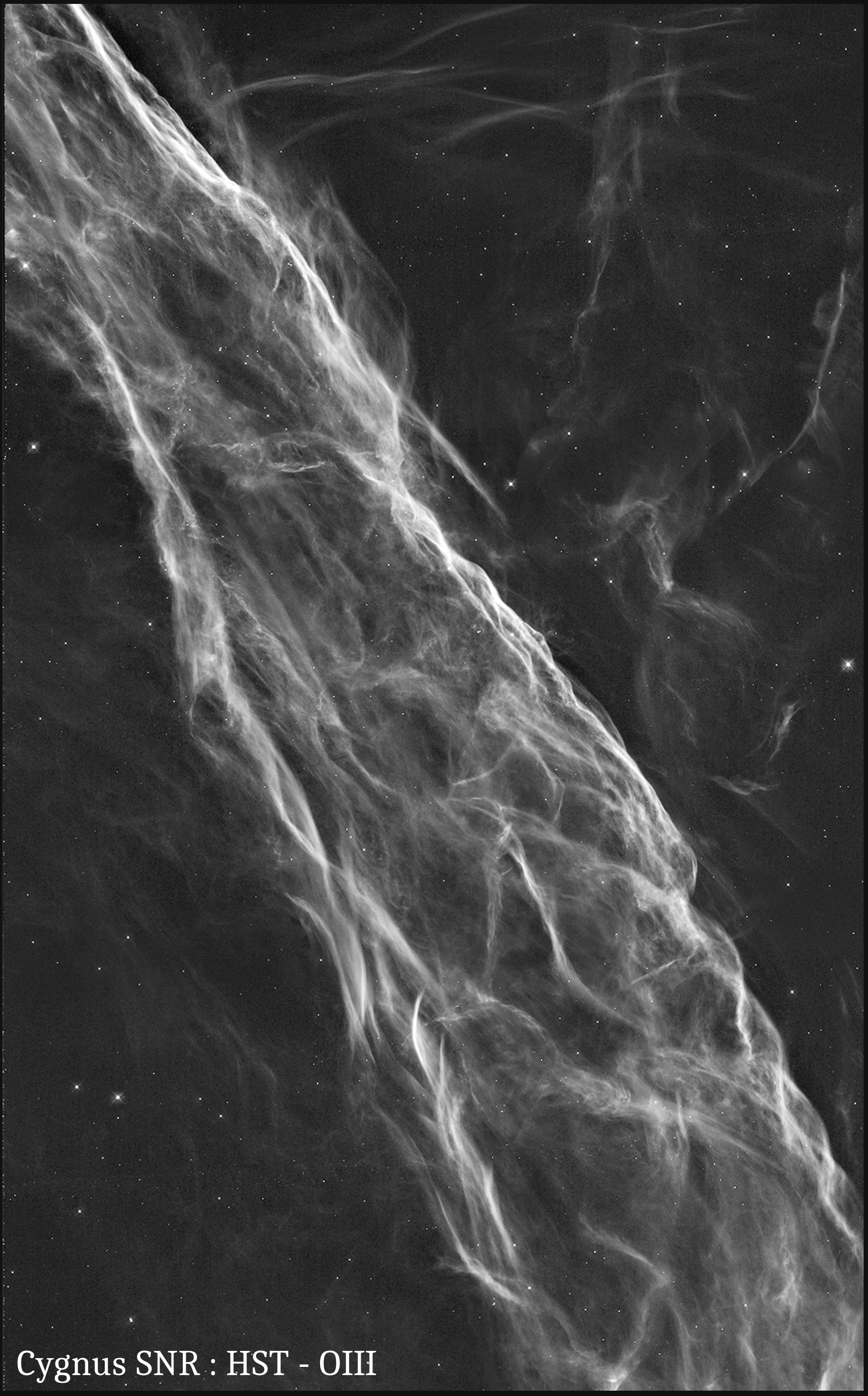
Pierre Dell'Ova[1,2], Antoine Gusdorf[1,2], Maryvonne Gerin[2]

[1]LPENS, École Normale Supérieure
[2]LERMA, Observatoire de Paris

Introduction : Supernova Remnants, Shocks, and the Interstellar Medium

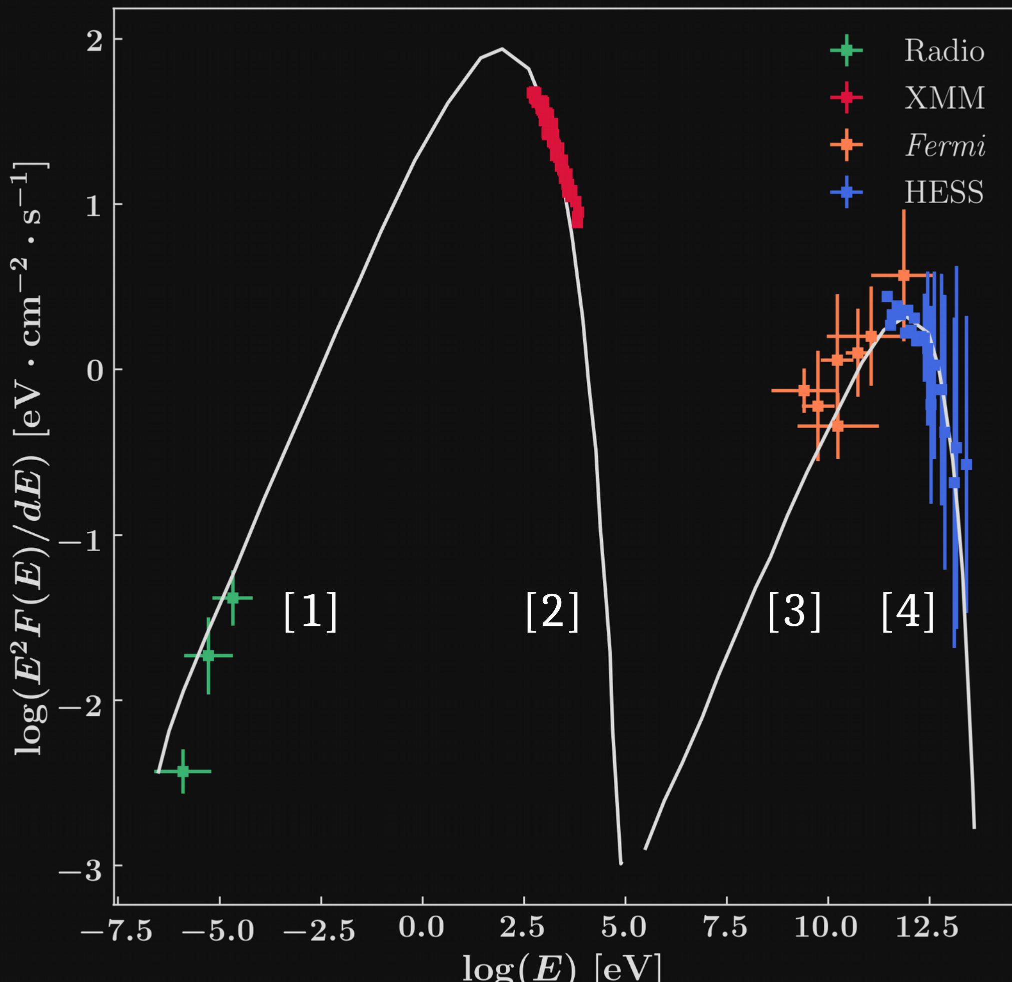
SNR Shocks :

- Inject kinetic energy
- Trigger specific chemistry
- Alter star formation



Cygnus SNR : HST - OIII

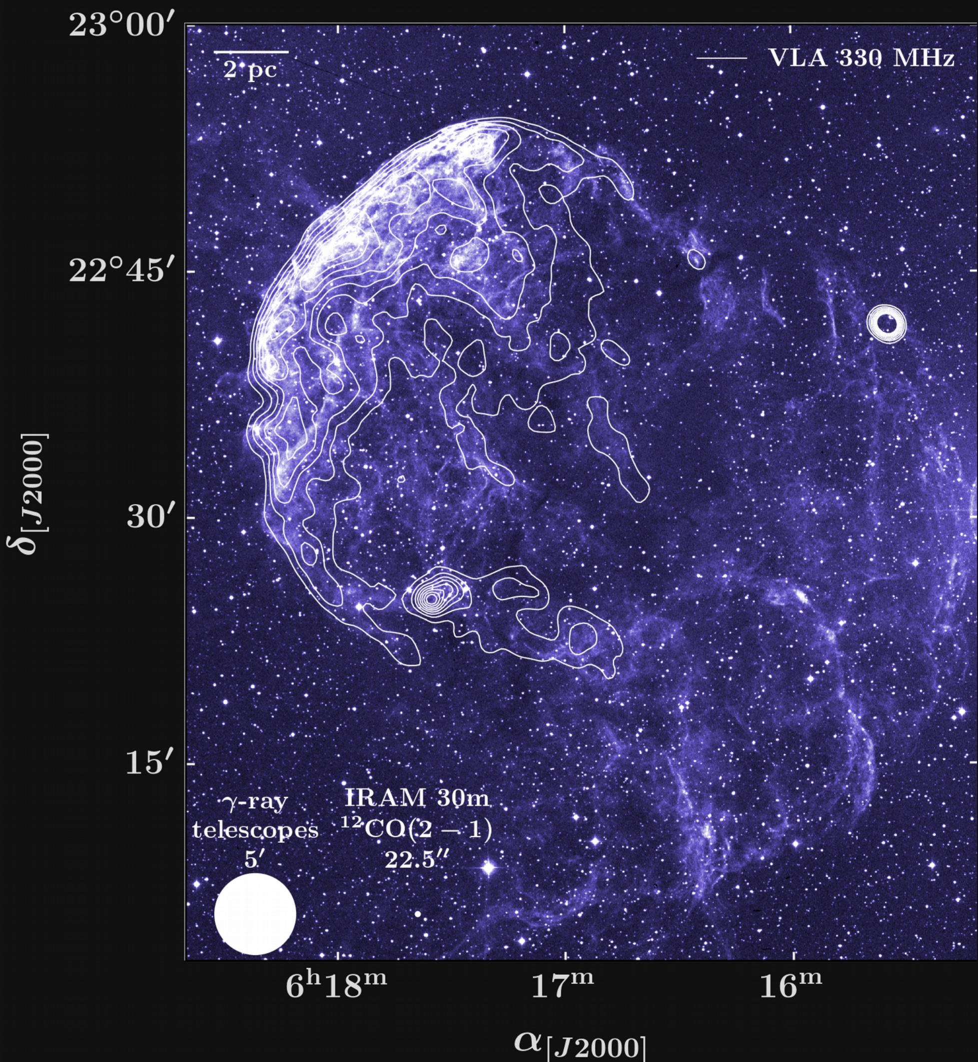
Supernova remnants : efficient engines for cosmic ray acceleration up to TeV



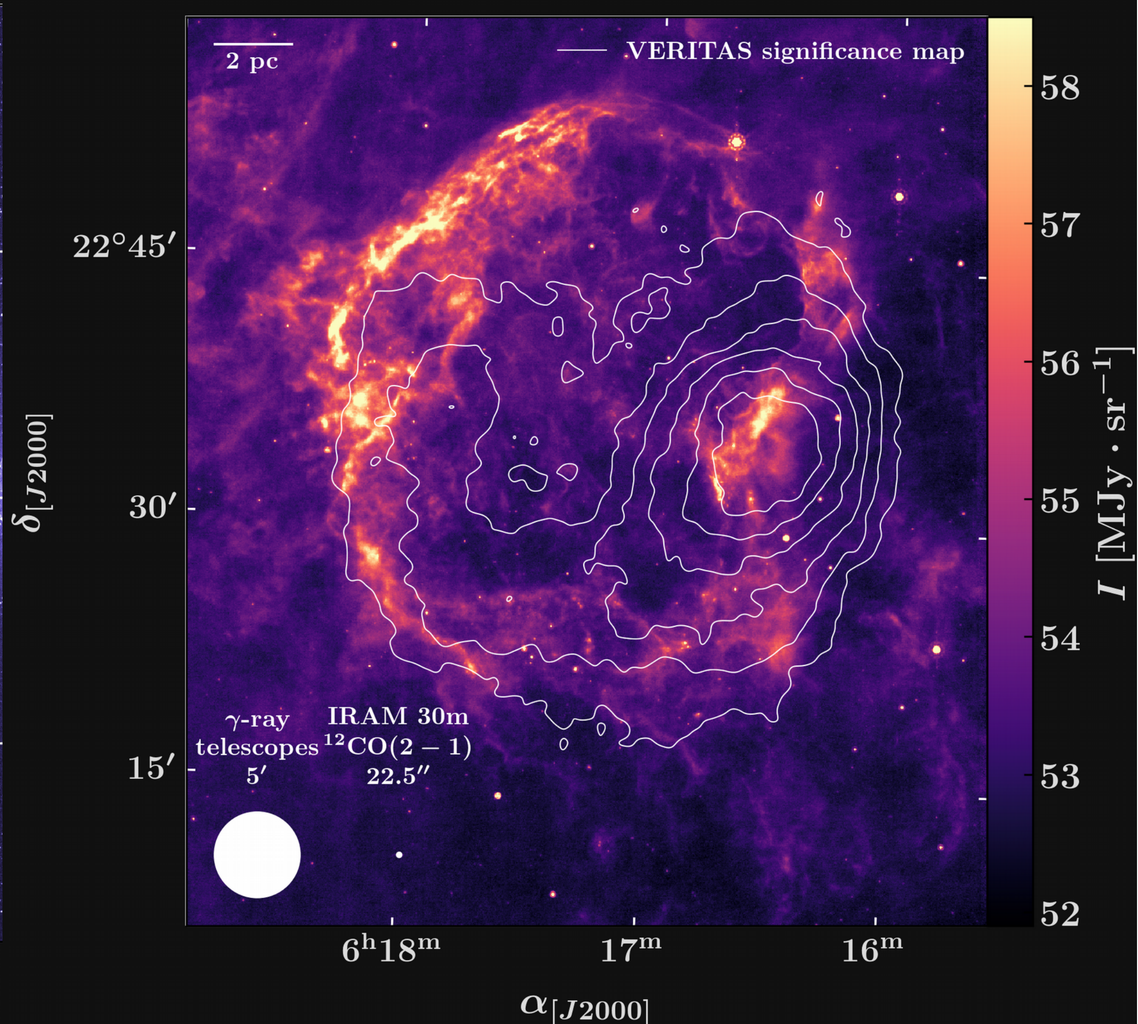
SNR HESS J1731-347
Cui et al. (2019)

- Synchrotron emission [1]
- Bremsstrahlung [2]
- Inverse compton scattering [3]
- Pion decay [4]

The Supernova Remnant IC443



DSS (optical)
VLA 330 MHz in contours



Spitzer - MIPS (24 micron)
VERITAS TeV(preliminary) in contours

Questions

- What is the star formation status ?
- Can we characterize shocks and their energetic & chemical impact ?
- Can we disentangle the large scale dynamics (shocks) from the outflows ?
- Can we better understand Cosmic Rays acceleration, composition and diffusion ?

Sub-mm observations of IC443G : presentation

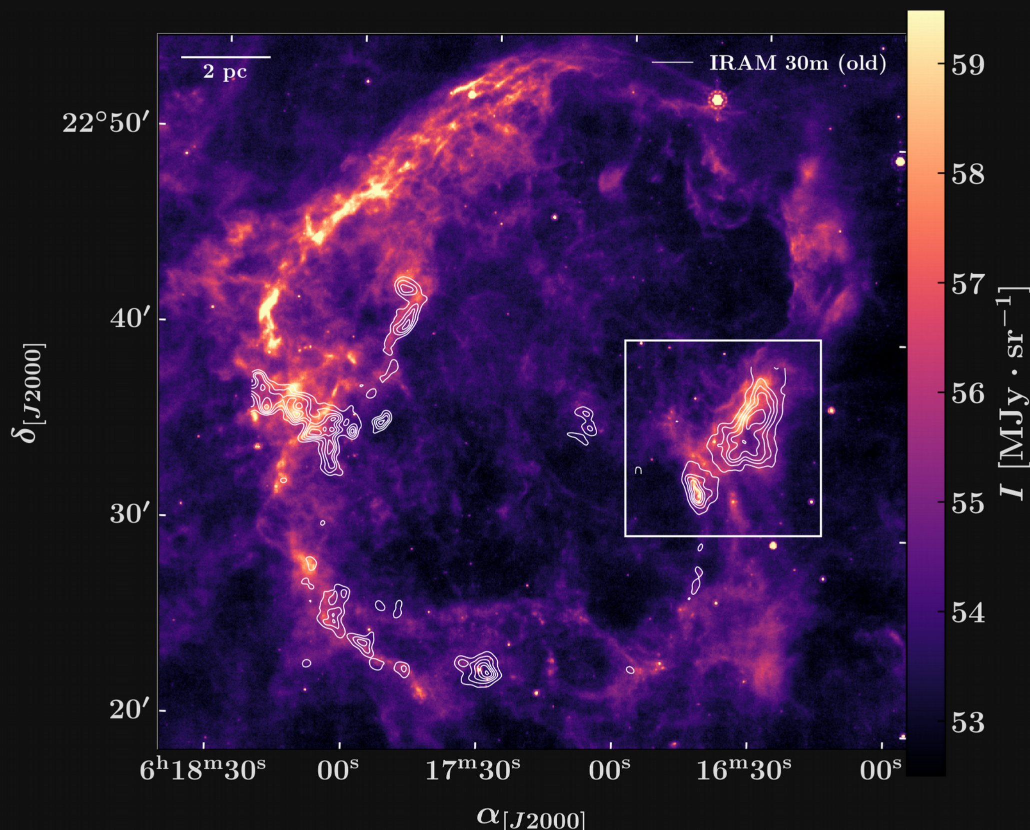
- IRAM 30m : $^{12}CO(1\text{-}0)$, $^{13}CO(1\text{-}0)$ — 20 hrs in feb. 2019
  $^{12}CO(2\text{-}1)$, $^{13}CO(2\text{-}1)$

  10'×10' maps with
  11.2'' - 23.5'' resolution

- APEX : $^{12}CO(2\text{-}1)$ — 12 hrs in sept. 2018
- $^{12}CO(3\text{-}2)$, $^{13}CO(3\text{-}2)$

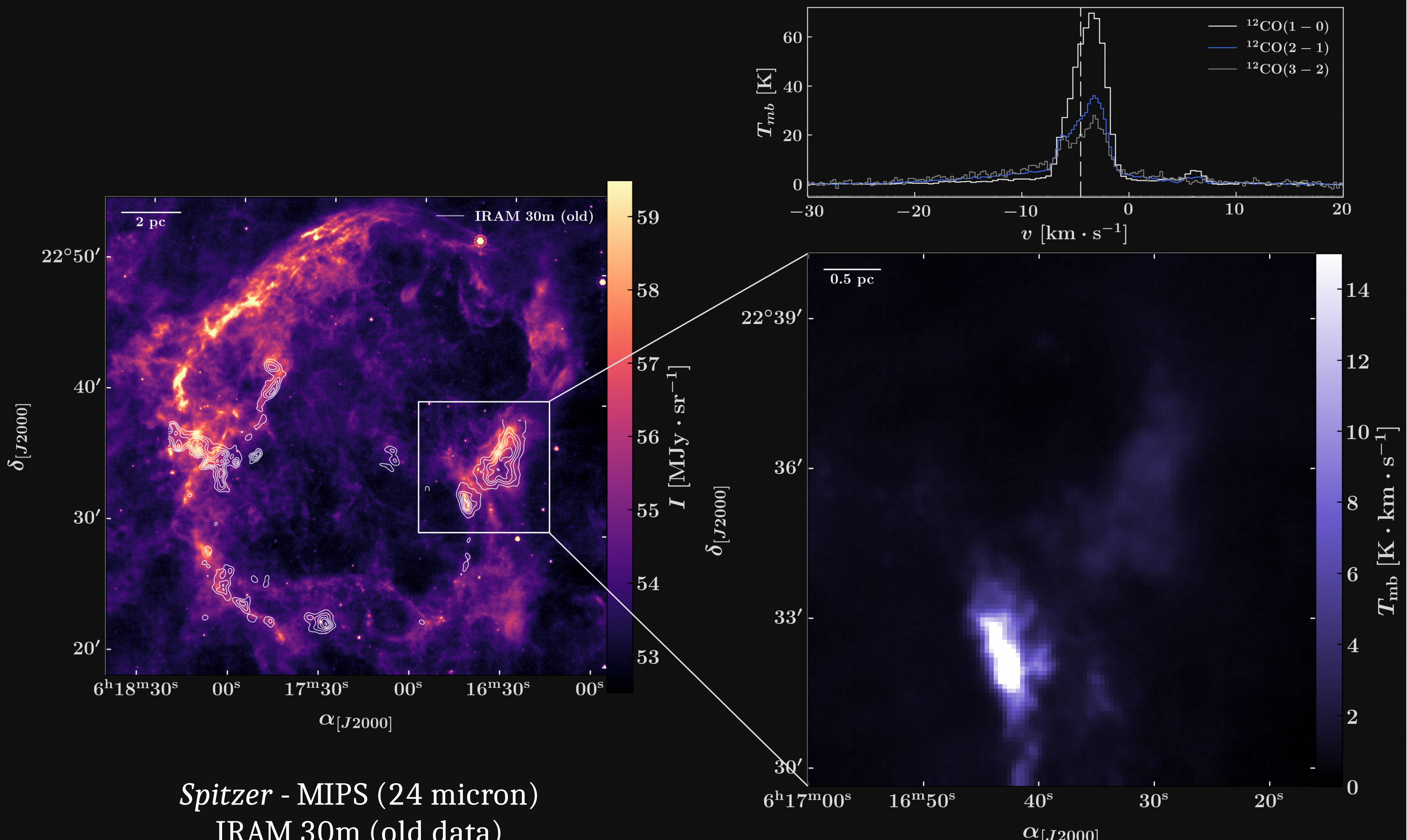
  10'×10' maps with
  19.2'' - 30.1'' resolution

Sub-mm observations of IC443G : integrated map



Spitzer - MIPS (24 micron)
IRAM 30m (old data)
in contours

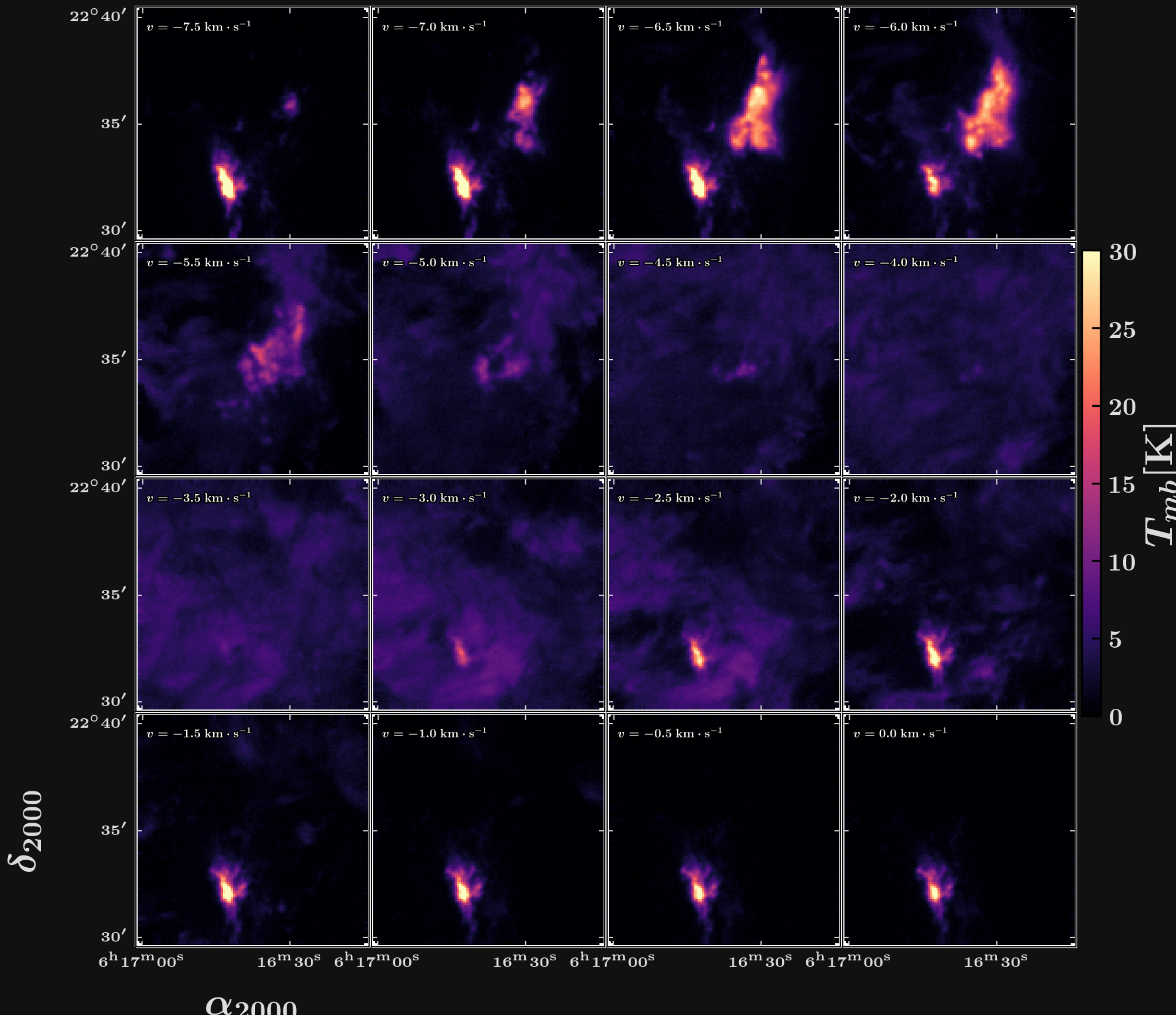
Sub-mm observations of IC443G : integrated map



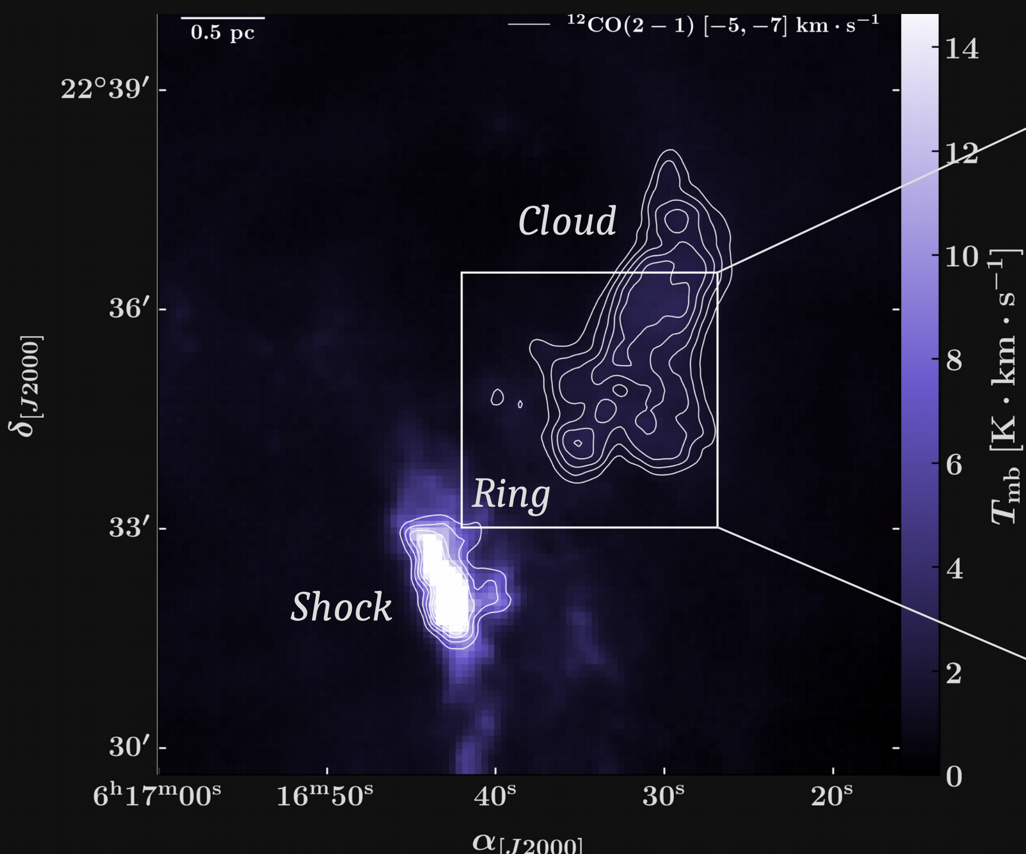
Spitzer - MIPS (24 micron)
IRAM 30m (old data)
in contours

Zoom :
^{12}CO(2-1) – IRAM 30m

Sub-mm observations of IC443G : $^{12}CO(2\text{-}1)$ channel map

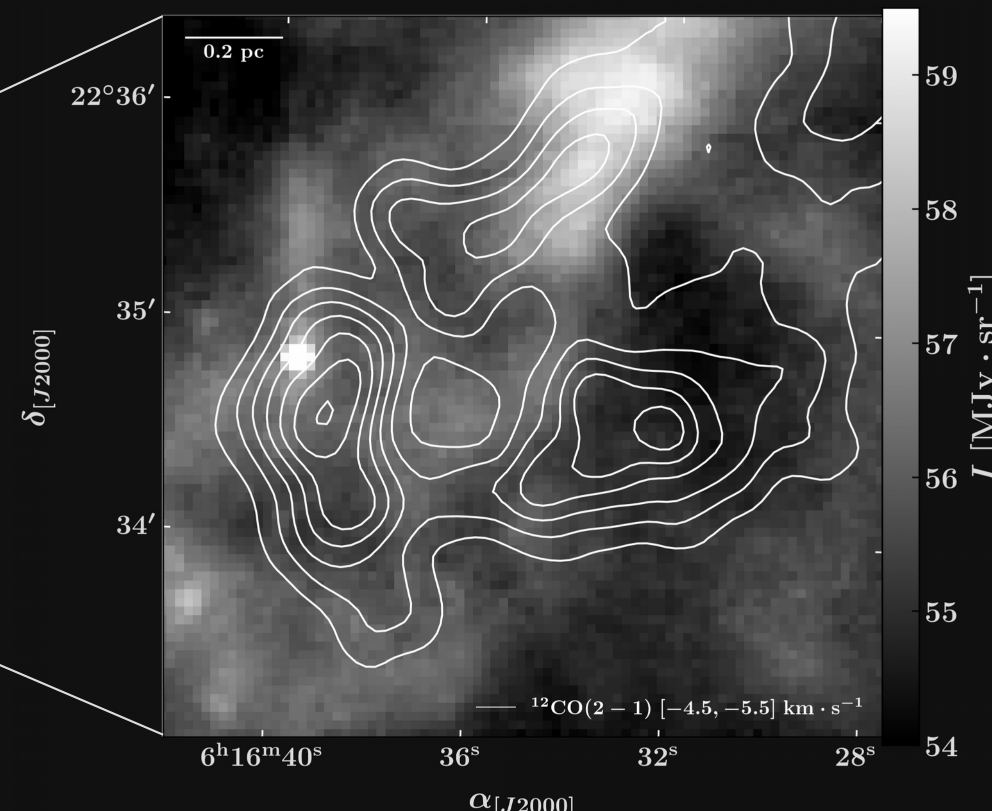


Sub-mm observations of IC443G : integrated map



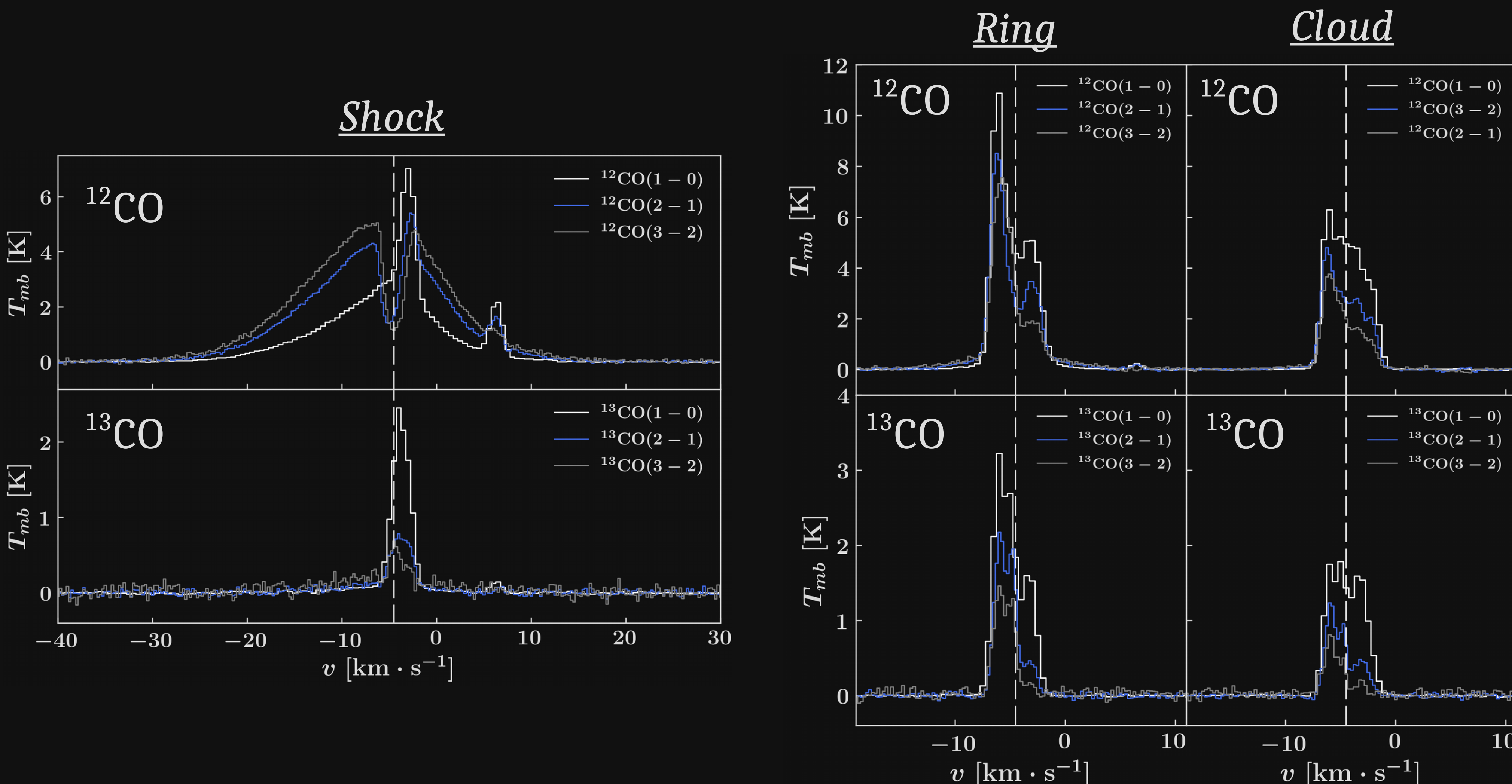
^{12}CO(2-1) IRAM 30m

Ring

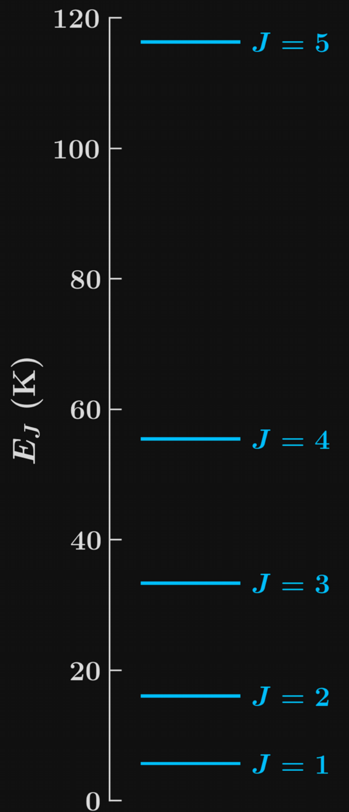


Zoom :
Spitzer - MIPS (24 micron)
^{12}CO(2-1) in contours

Sub-mm observations of IC443G : spectra



Method : option n.1 - Population diagrams



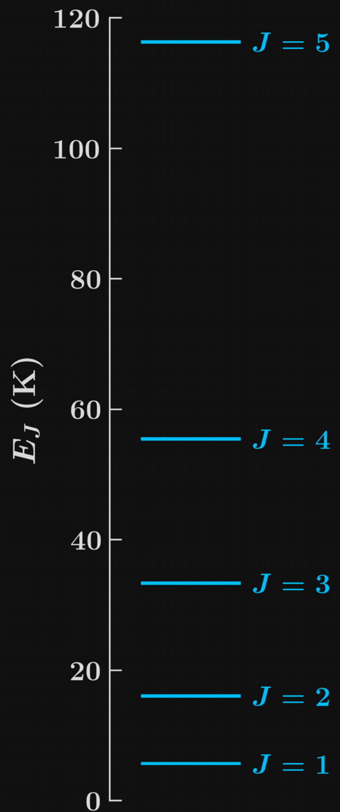
Assumptions:

1. LTE (Local Thermodynamic Equilibrium)

2. Optically thin

$$\log\left(\frac{N_{\mathrm{up}}}{g_{\mathrm{up}}}\right) = \log\left(\frac{N_{\mathrm{tot}}}{Q(T_{\mathrm{ex}})}\right) - \frac{E_{\mathrm{up}}}{kT_{\mathrm{ex}}}$$

Method : option n.1 - Population diagrams

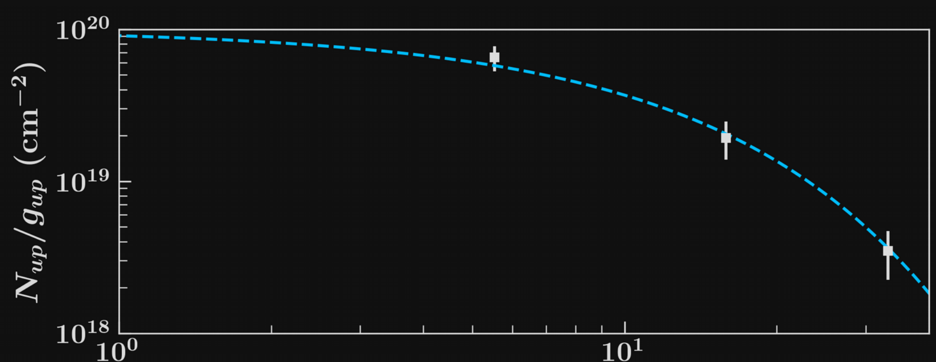


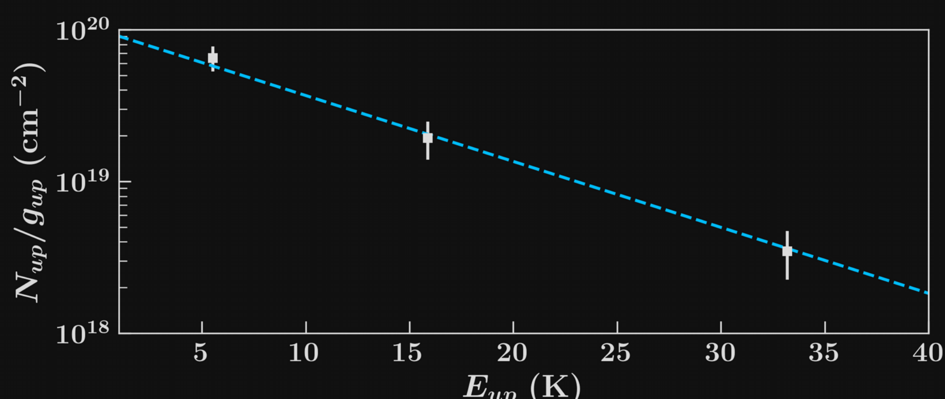
Assumptions:

1. LTE (Local Thermodynamic Equilibrium)

2. Optically thin

$$\log\left(\frac{N_{\rm up}}{g_{\rm up}}\right) = \underbrace{\log\left(\frac{N_{\rm tot}}{Q(T_{\rm ex})}\right)}_{\textit{offset}} - \underbrace{\frac{E_{\rm up}}{kT_{\rm ex}}}_{\textit{slope}}$$





1. Correction of the optical depth
2. Measure of N_{up}
3. Linear fit of the population diagram
4. Derive N (column density) and T (kinetic temperature)

Method : option n.2 – Radiative transfer code : RADEX

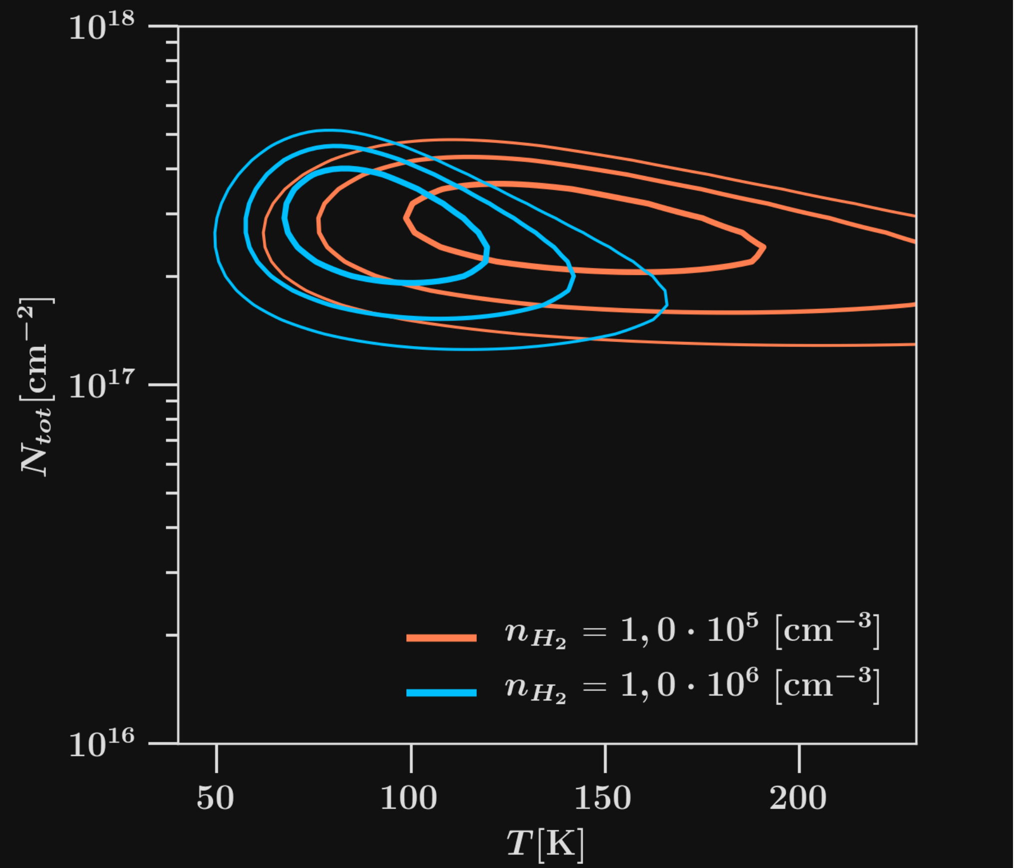
LVG assumptions:

1. Significant velocity gradient along the line of sight

1. Produce a grid of models with varying parameters (n, N, T)

2. Chi-square minimization of the modelled intensities v.s. observed intensities

3. Derive n (local density), N (column density) and T (kinetic temperature)



Results

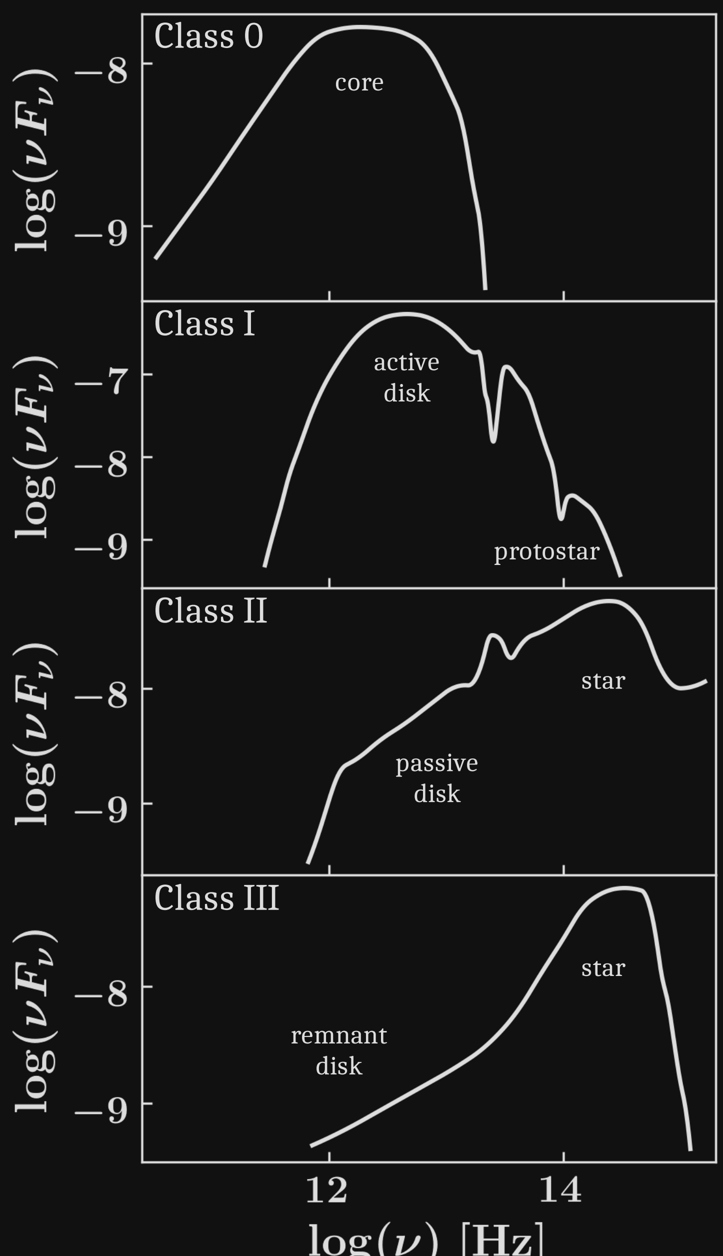
1. CO column densities : $[10^{17} – 10^{18}]\ cm^{-2}$

2. Total mass is [370 – 540] solar masses.

3. The shocked clump account only for [100 – 150] solar masses.

4. Kinetic temperatures : from [5 – 15] K in the quiescent cloud to 30K within the shocked clump

The stars in IC443G

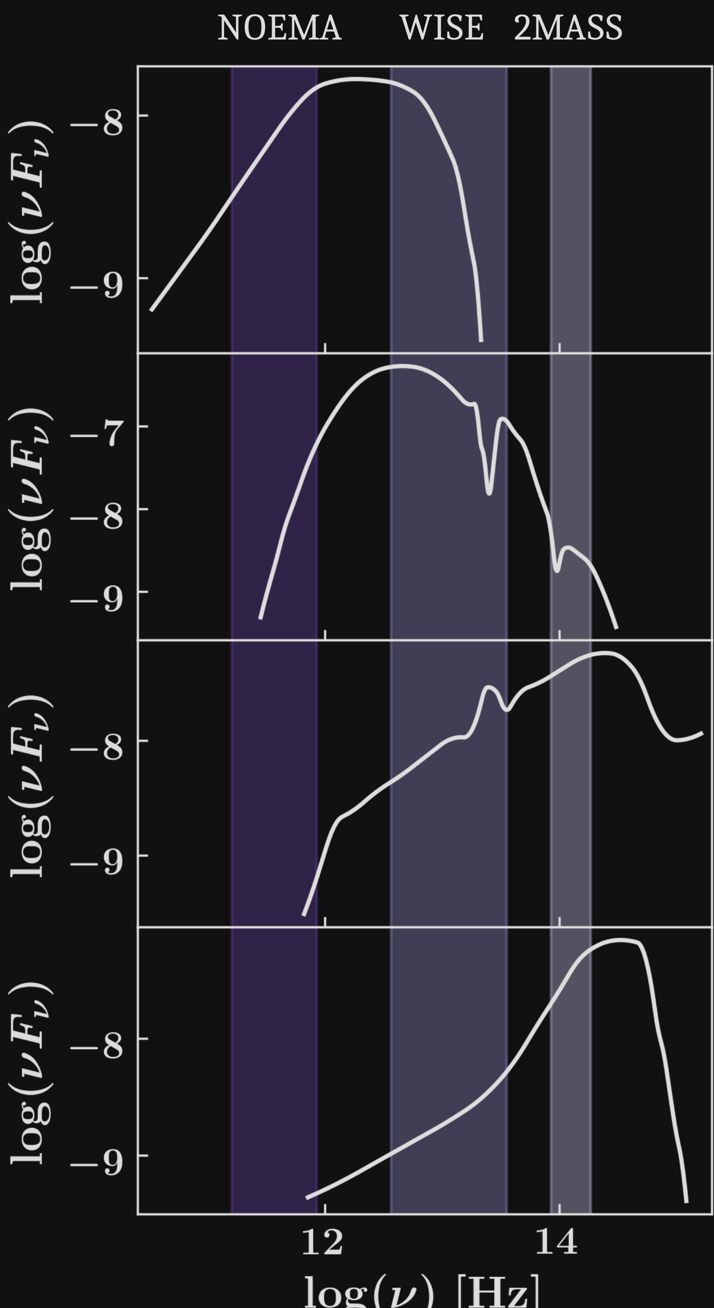


Available point source catalogues :

- 2MASS (near-infrared)
- WISE (infrared)
  - ✓ Infer properties from $\frac{d[\nu S_\nu]}{d\nu}$

Lada & Wilking (1984)

The stars in IC443G



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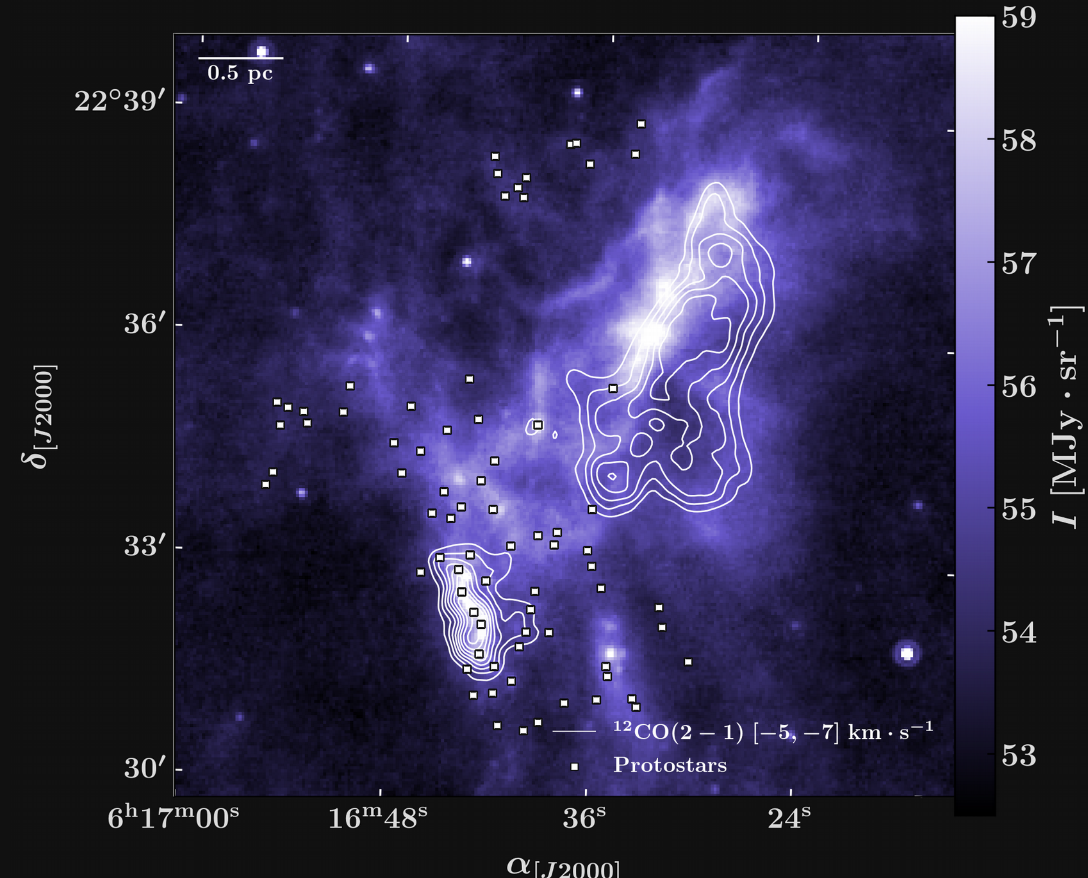
    Lada & Wilking (1984)



Concluding remarks

- **3 <u>massive</u> molecular structures are found.**
- **We cannot discard the quiescent clumps to understand the gamma-ray peak !**
- **Protostars might be injecting cosmic rays too.**
- ⚠ Estimation of the masses from the dust continuum might be much larger.
- ⚠ We will need interferometry to understand the nature of the ring-like structure and probe young stellar objects.