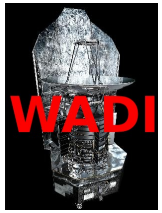
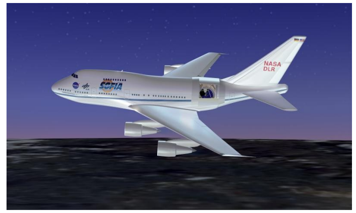




The role of radiative triggering for star-formation

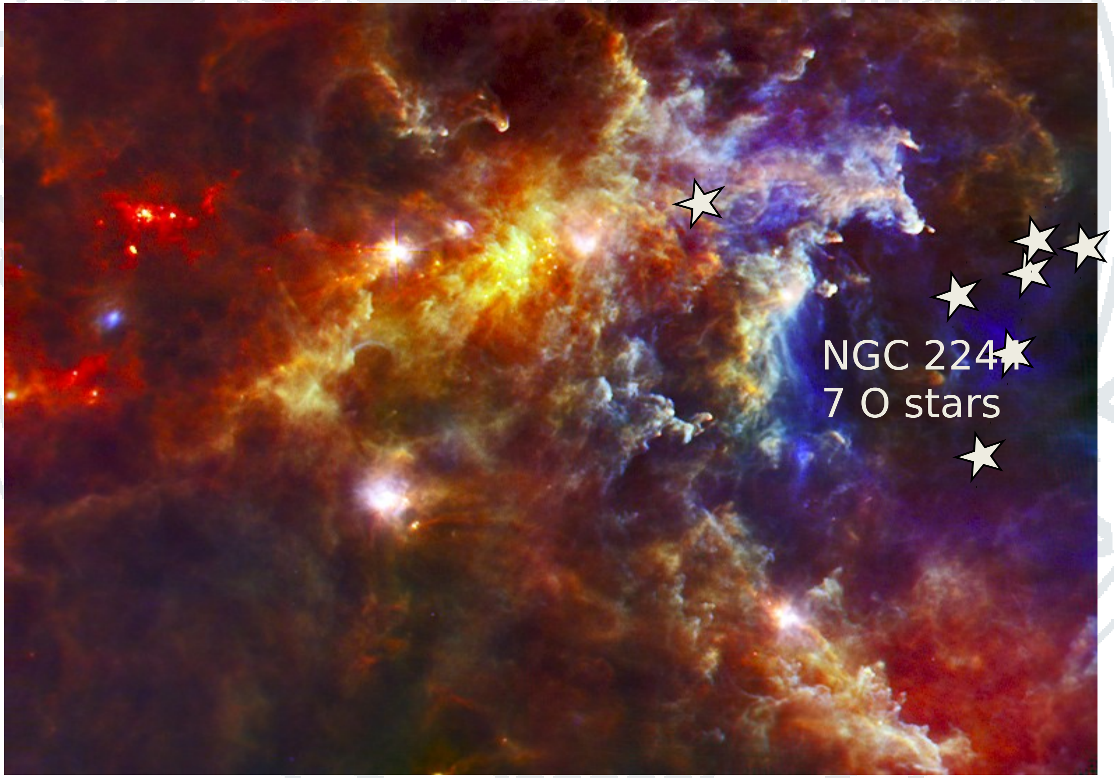
V. Ossenkopf, *M. Röllig, N. Schneider, P. Pilleri, B. Mookerjea, Z. Makai, Y. Okada*

Is star-formation significantly triggered?

- dynamic impact from winds and outflows
  - → dispersion → prevents SF
  - → compression → triggers SF

- UV radiation heats the gas
  - → temperature/pressure increase → prevents SF

- UV radiation dissociates the gas
  - → change of chemical structure
  - → remove cooling agents → prevents SF
  - → create cooling agents → triggers SF



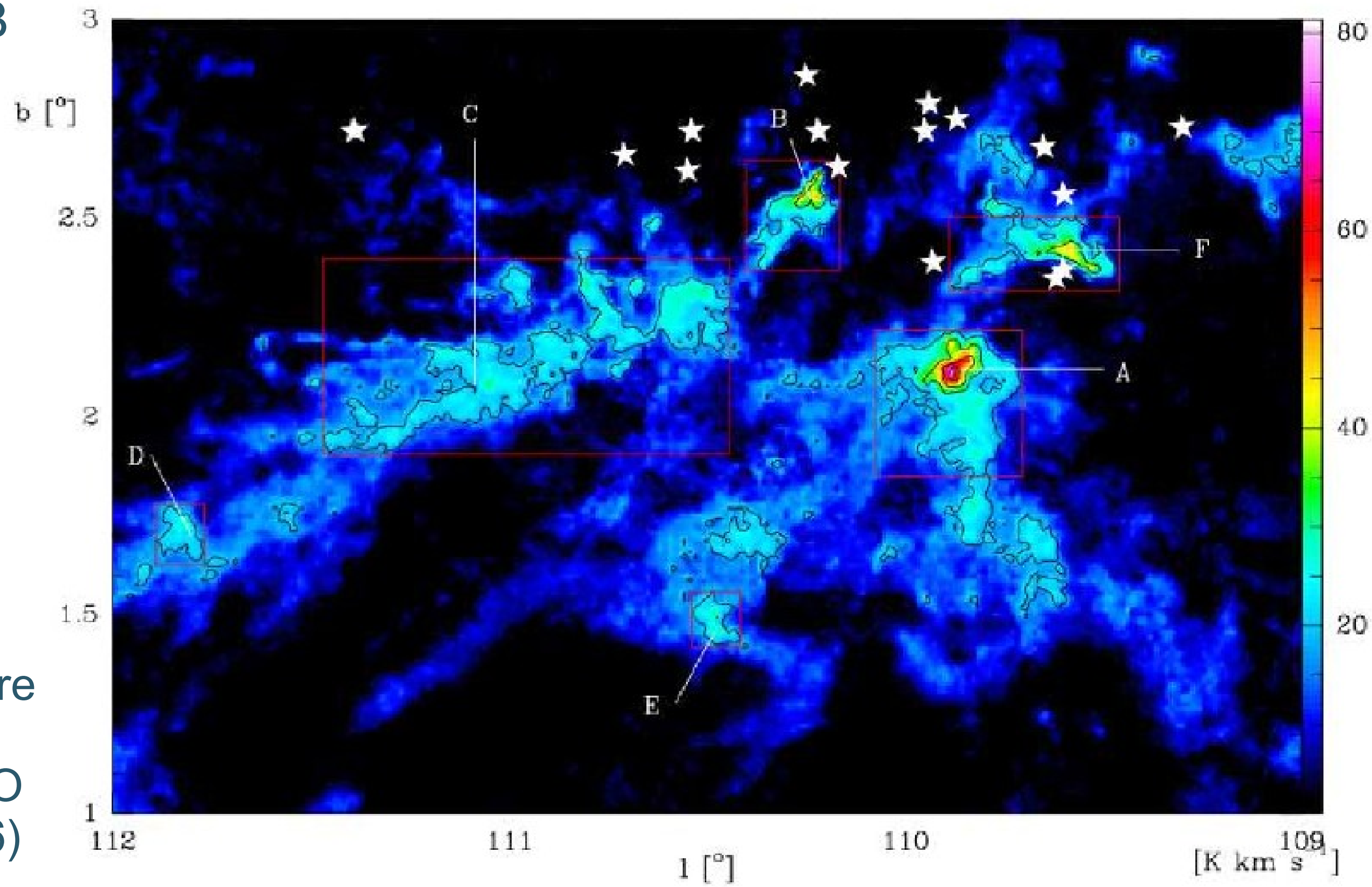
Pillars in Rosette (HOBYS team: Motte et al. 2010)

Total net effect ?

Observational evidence

Clear indication of sequential star formation:

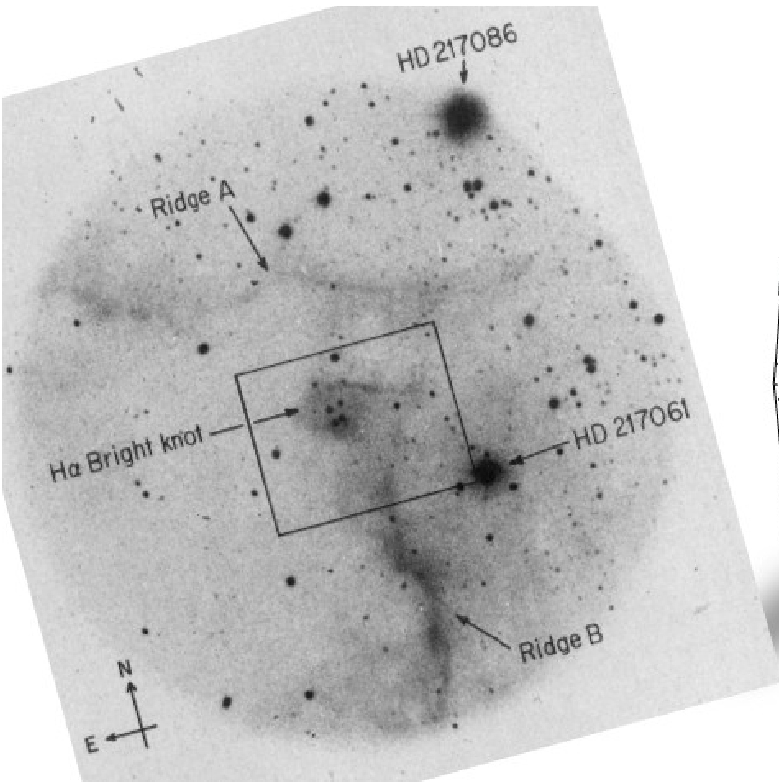
- Example: Cep B
- Age gradient of stars towards Cep B

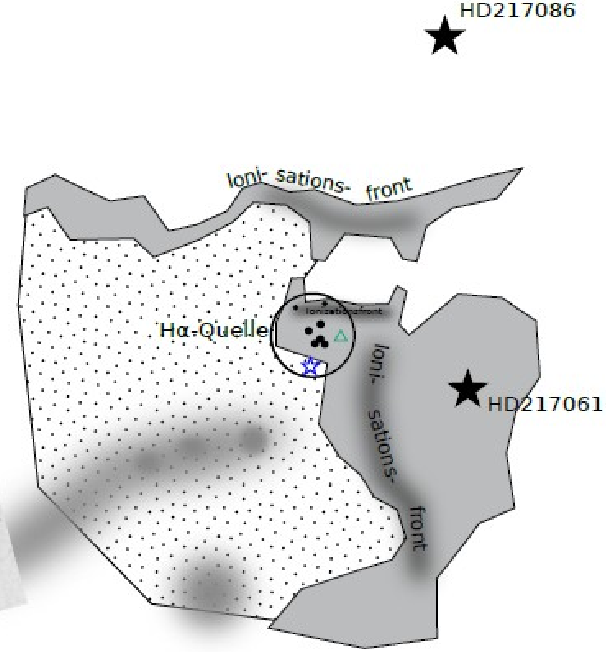


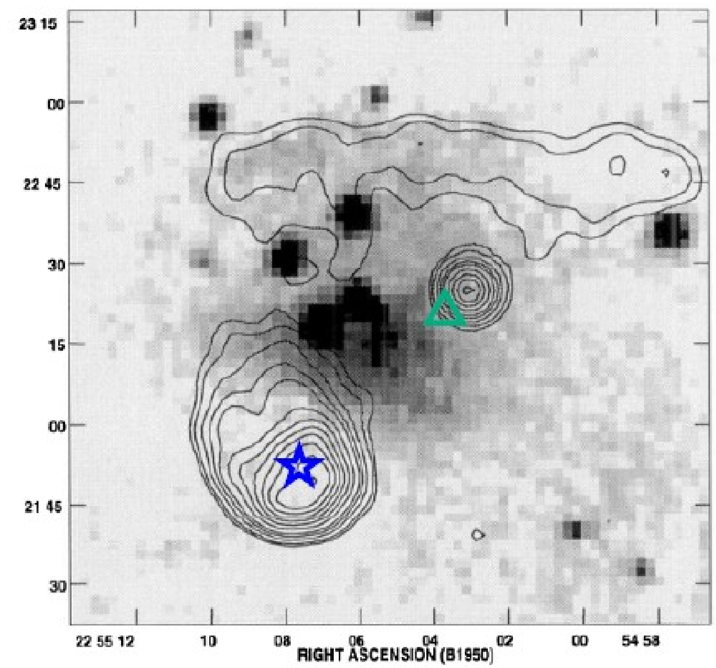
Large-scale structure of the Cepheus molecular cloud (CO 1-0, Sun et al. 2006)

Observational evidence

Sequential star-formation in Cep B:







Cep B structure (Moreno-Corral et al. 1993)

2 embedded HII regions (Testi et al. 1995)

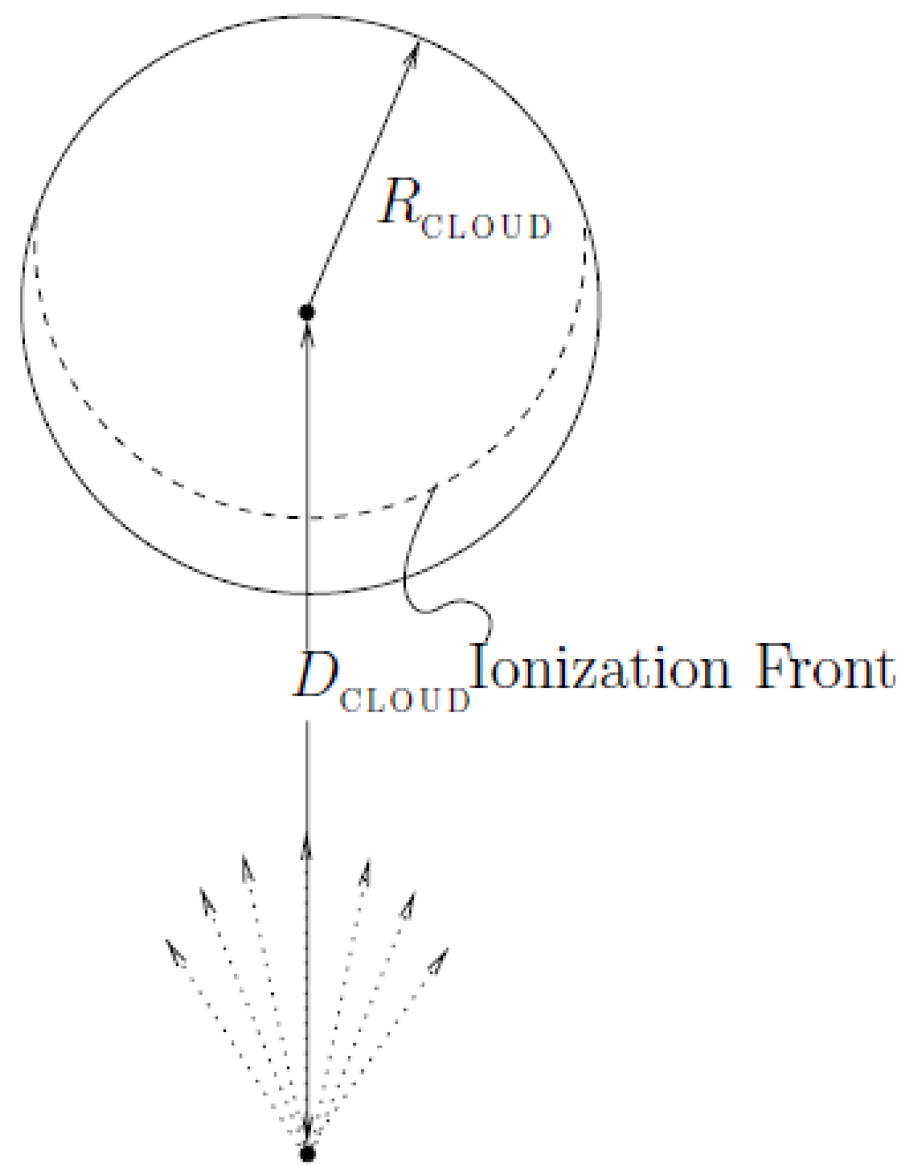
Radiative impact: what do we expect?

Theory:

- Radiation pressure
- Thermal pressure of heated gas

  →

  - Ionization and photo-chemistry
    → Photon-dominated regions (PDRs)
  - Compression of clouds
  - Dispersion



Schematic picture of pillar formation (Bisbas et al. 2011)

Radiative impact: what do we expect?

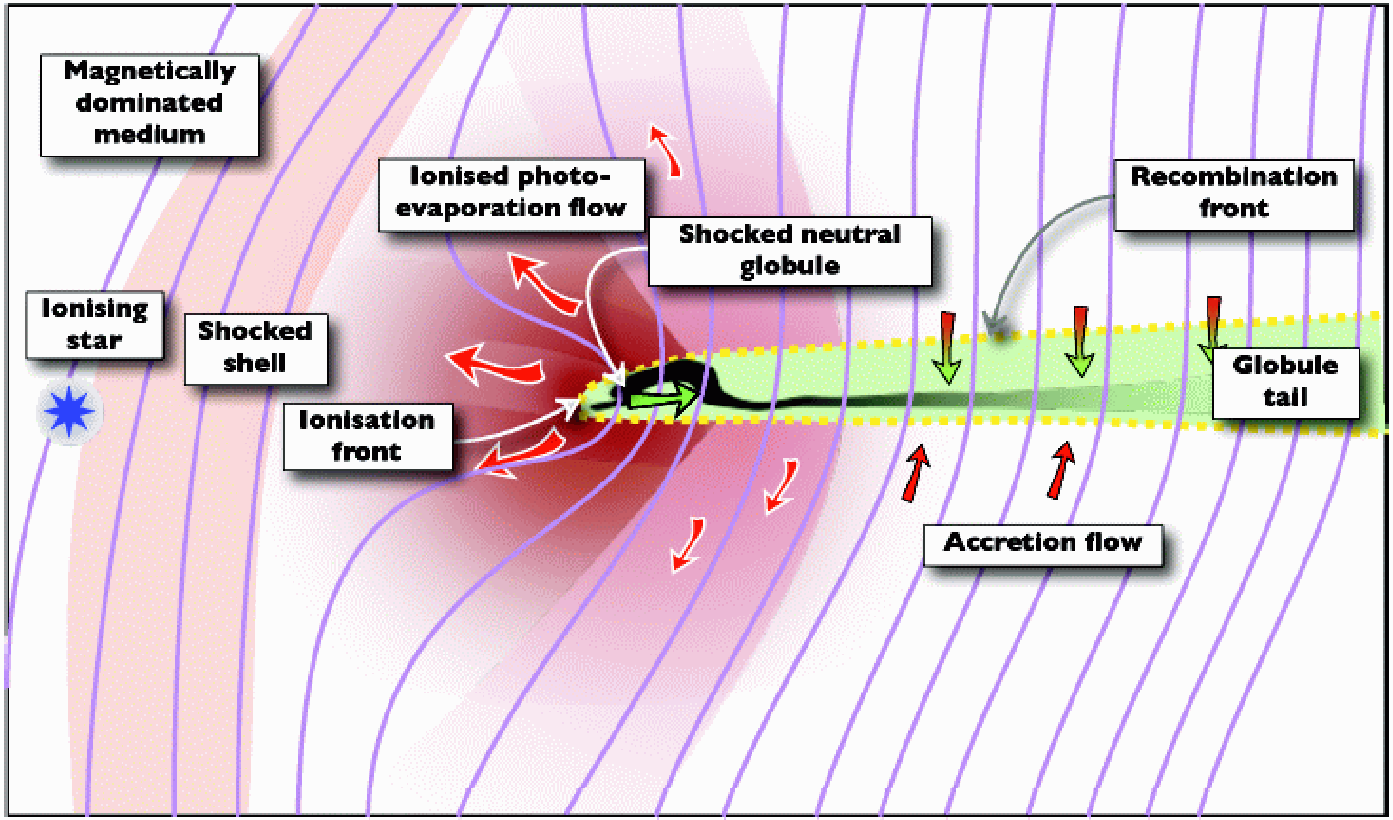
Dynamics:

- Photo-evaporation of PDRs → flow of ionized material
- High pressure zone at PDR surface → cloud compression
  → shock fronts
- Ionization front "eats" into molecular cloud

→ **pillar formation**

Unknowns:

- *Advection flows*
- *Impact of turbulence*

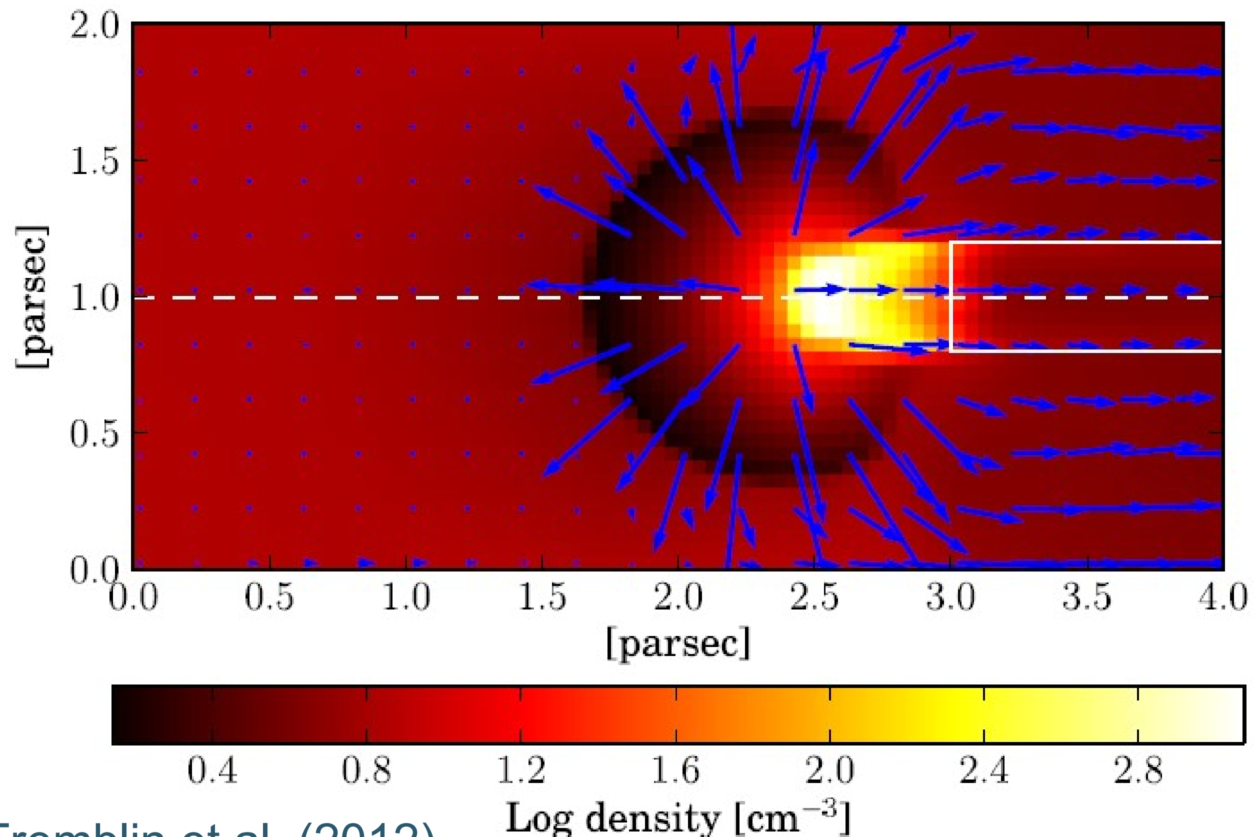


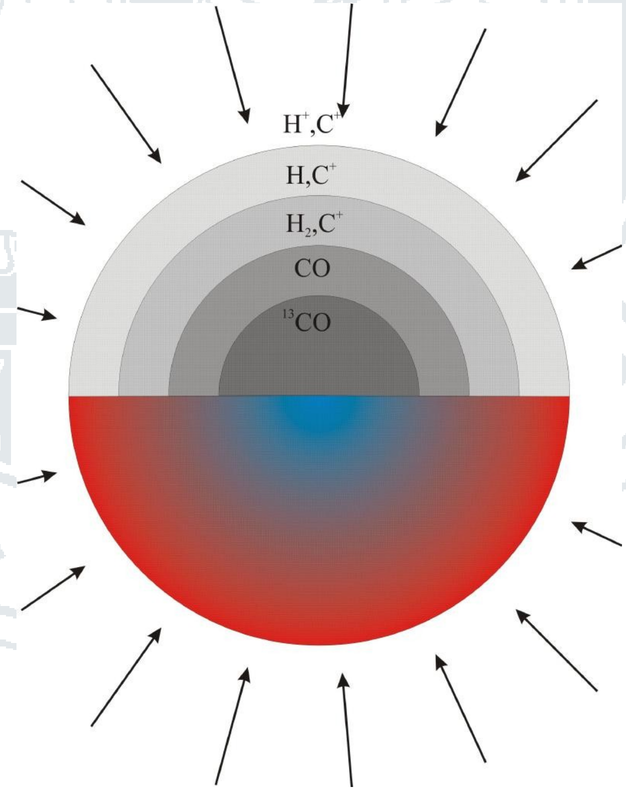
3-D MHD model by Henney et al. (2009)

Observational verification

Look for characteristic velocity flow patterns of triggered collapse

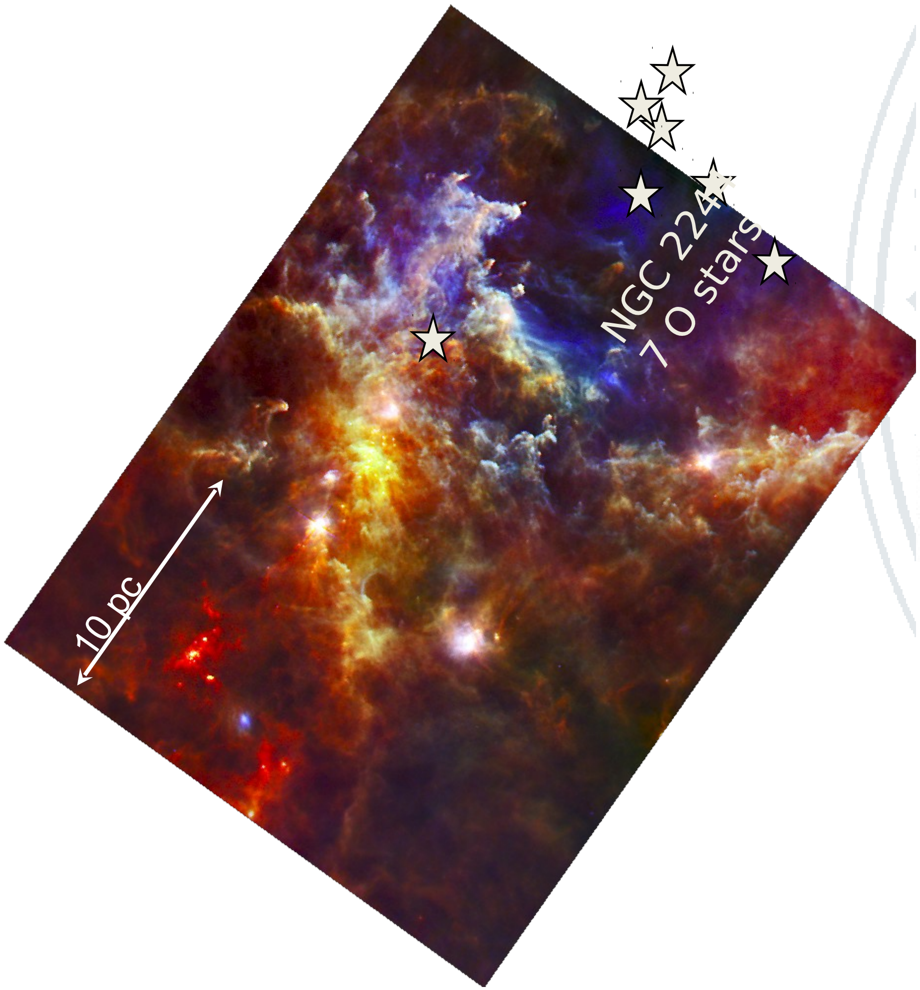
- Chemical structure has to be taken into account, but can be exploited

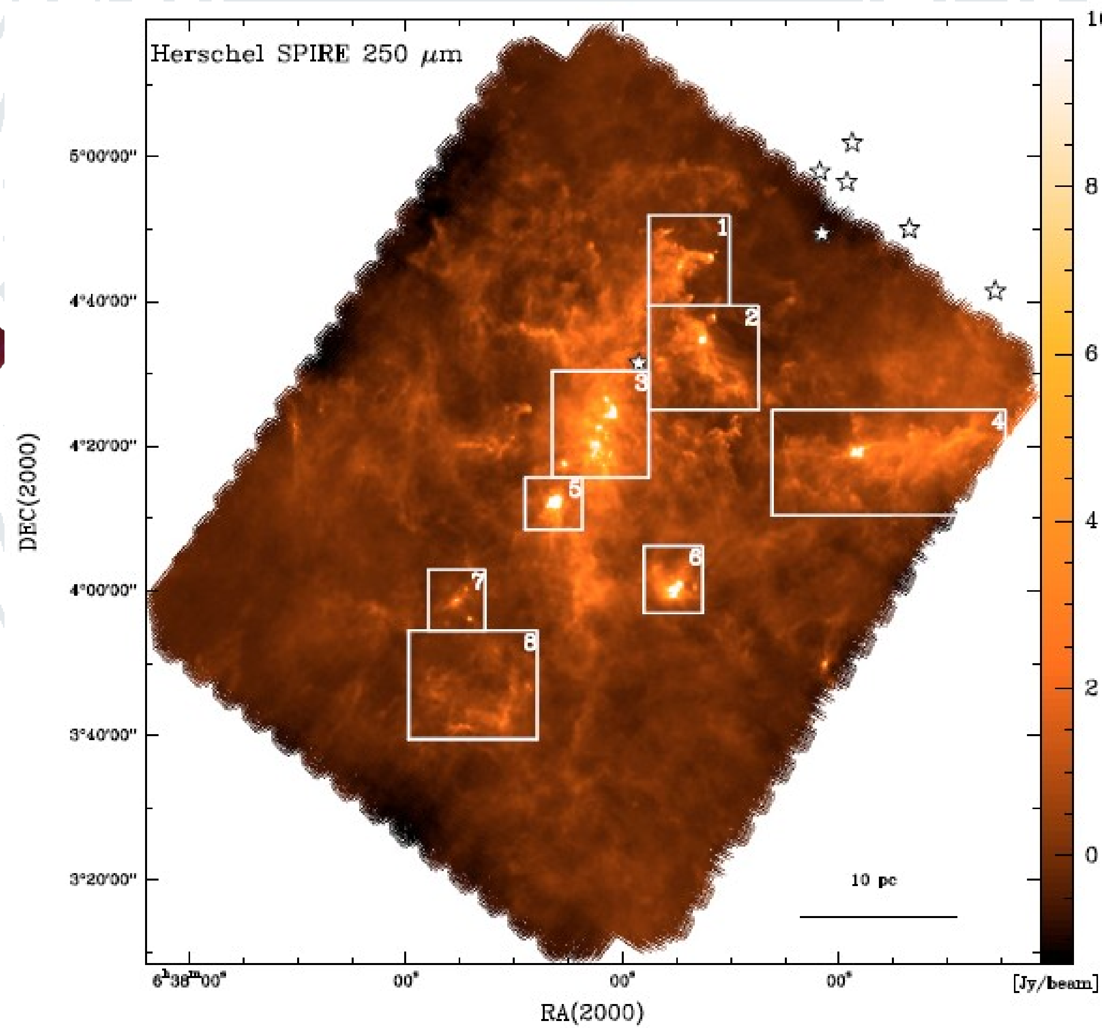




Tremblin et al. (2012)

Example 1: Rosette

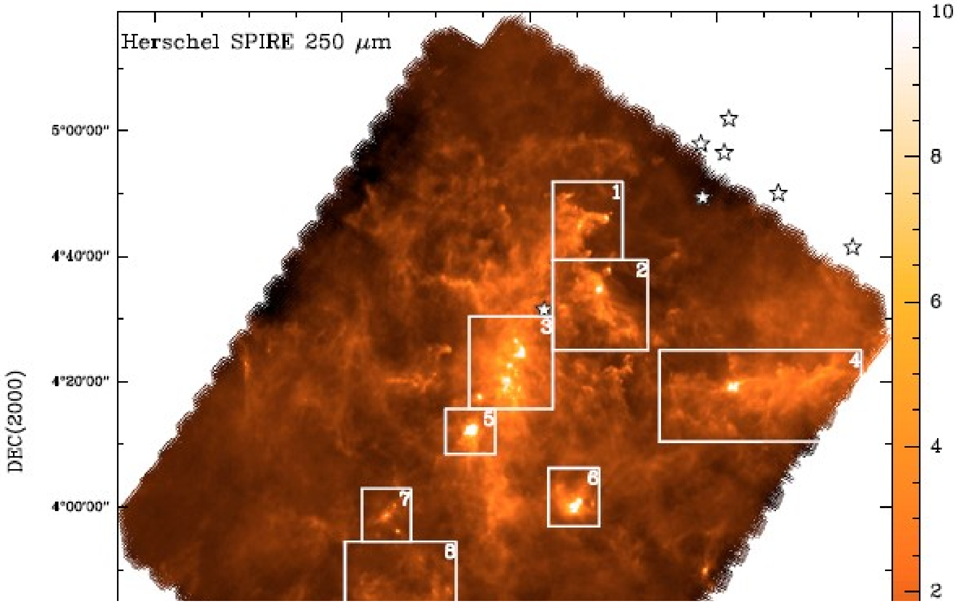




PACS/SPIRE map of Rosette
(Motte et al. 2010, Schneider et al. 2010)

Investigation of individual pillars: Region 1+2

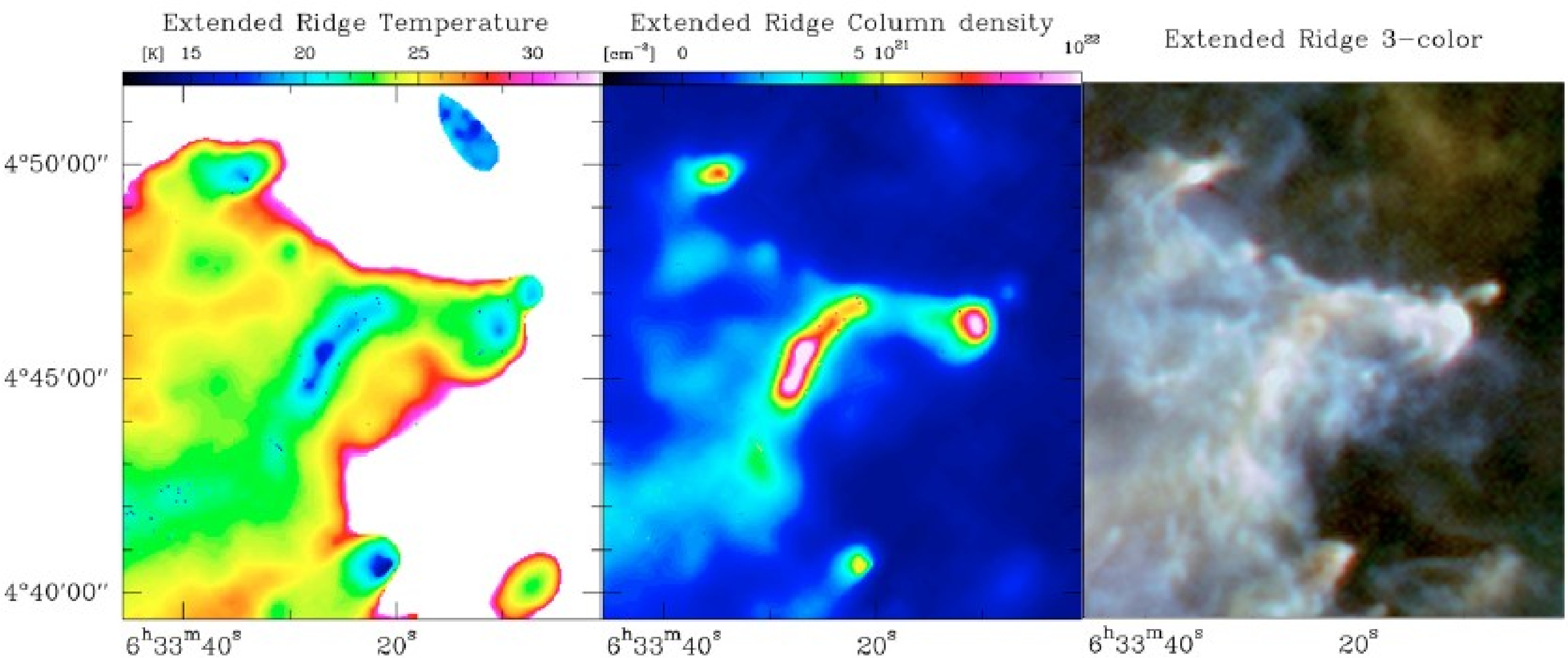
Rosette



Region 1 - high resolution:

- High density pillars
    - Temperature low from better cooling, heating only at surface
    - No SF in pillars

(Schneider et al. 2010)

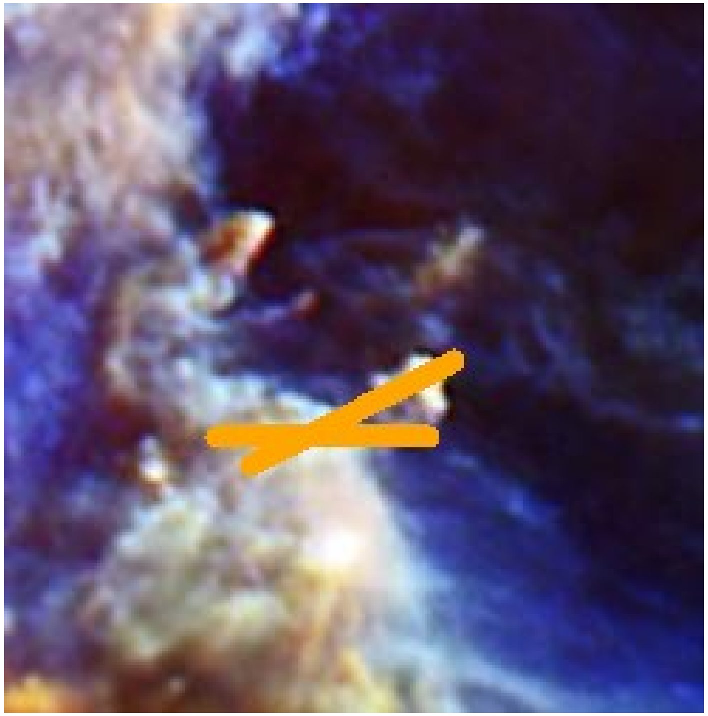


Rosette

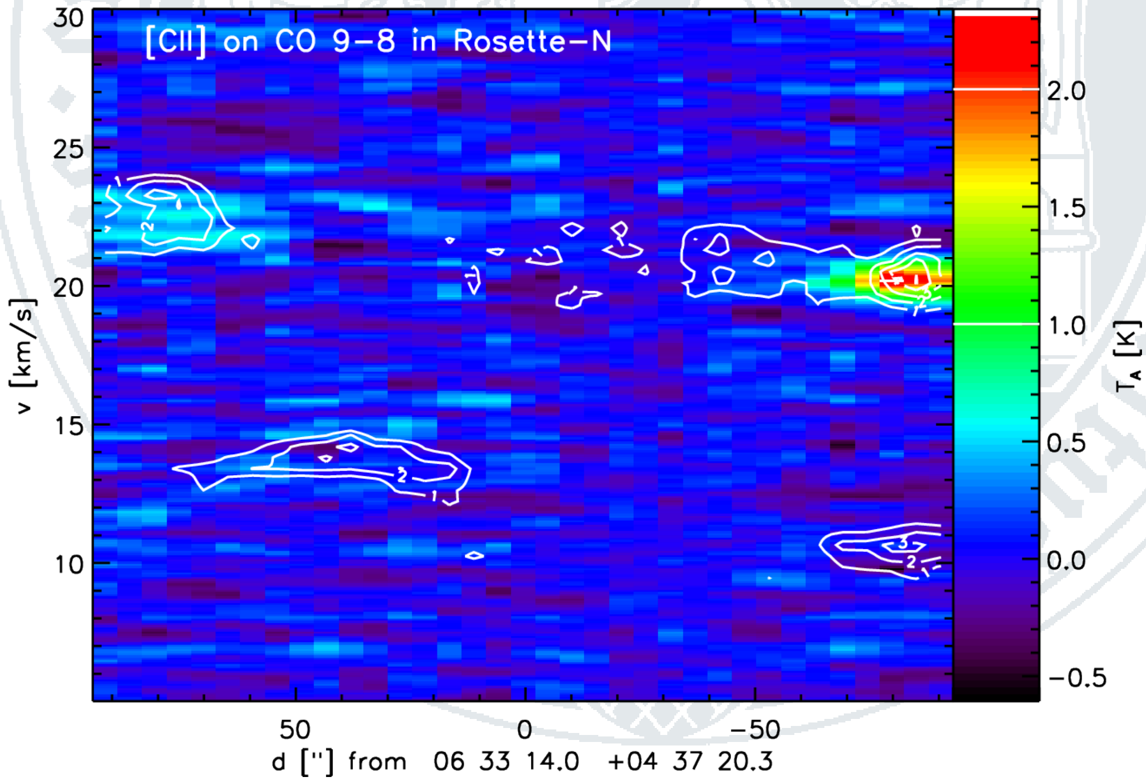
Region 1+2 - cuts through pillars to trace velocity structure:

- **Position-velocity diagrams**

2 interfaces:



[CII] (contour) on CO 9-8 (color)

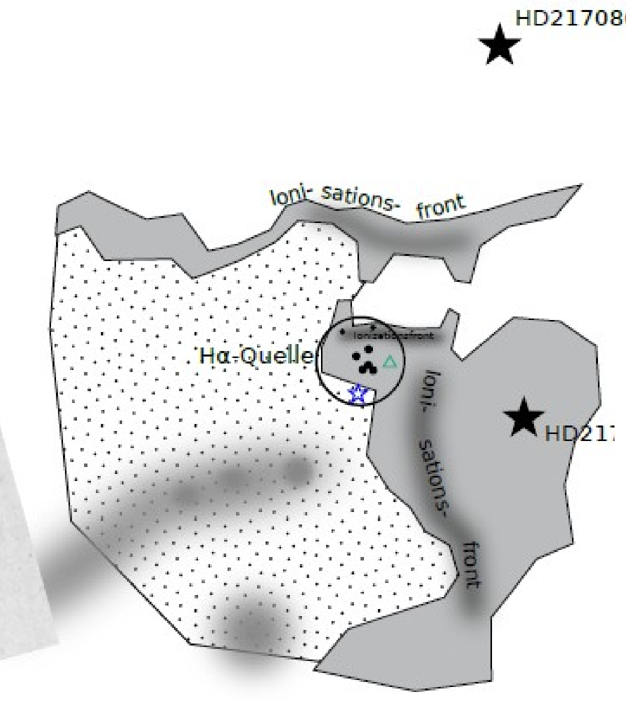


2 separate velocity components, i.e. 4 instead of 2 surfaces

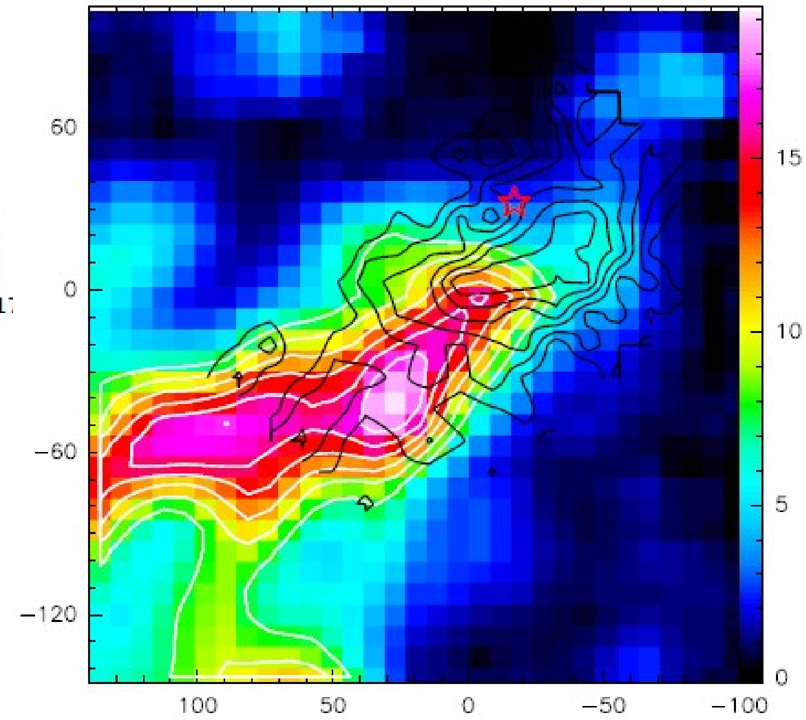
- CO only from dense gas
- No detection of a systematic flow

Example 2: Cep B

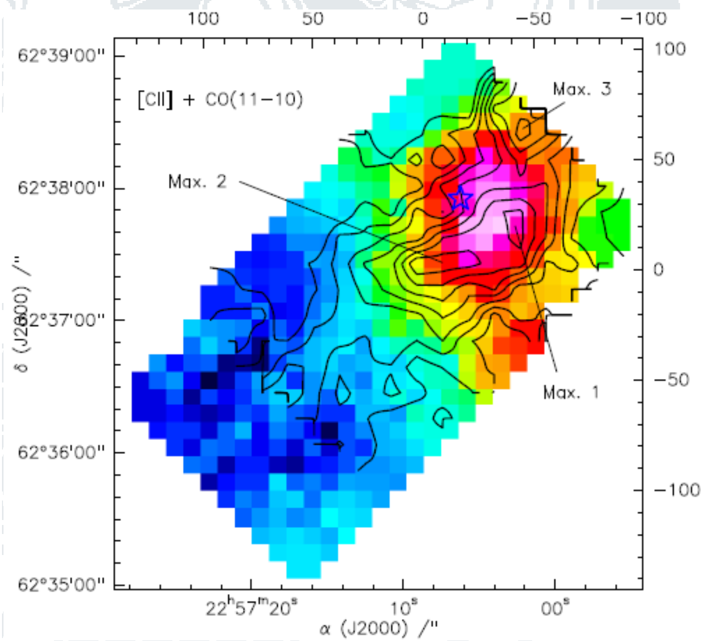
SOFIA observations:



(Moreno-Corral et al. 1993)



CO 11-10 (black contours) over ^{13}CO 1-0 (colors) (Mookerjea et al. 2012)



CO 11-10 (black contours) over [CII] (colors)

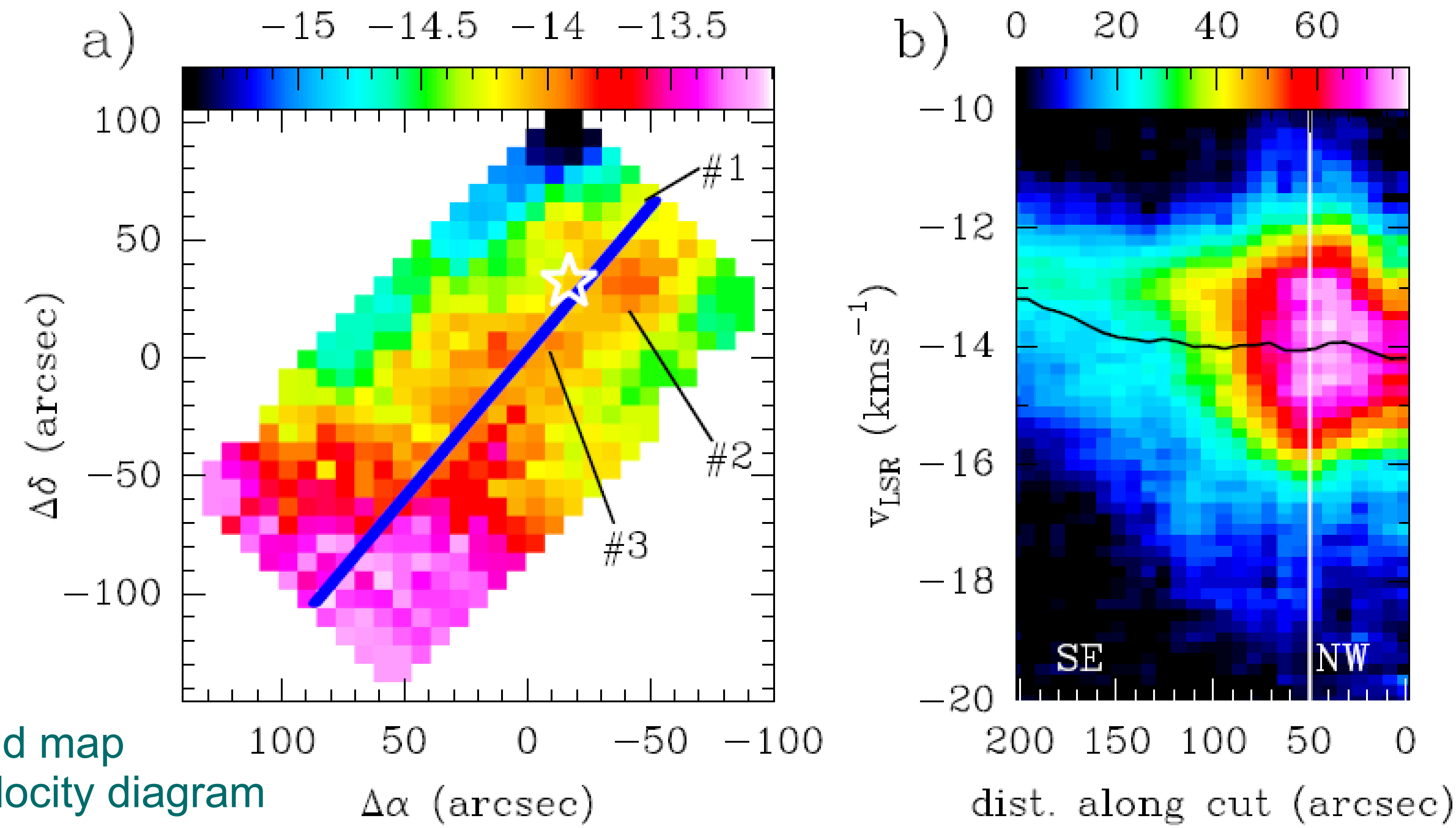
Embedded UC-HII-region • heats surrounding gas

• induces photon-dominated chemistry → trigger of SF?

Example: Cep B

Does the embedded HII-region compress/disperse the surrounding gas?

→ Study velocity structure

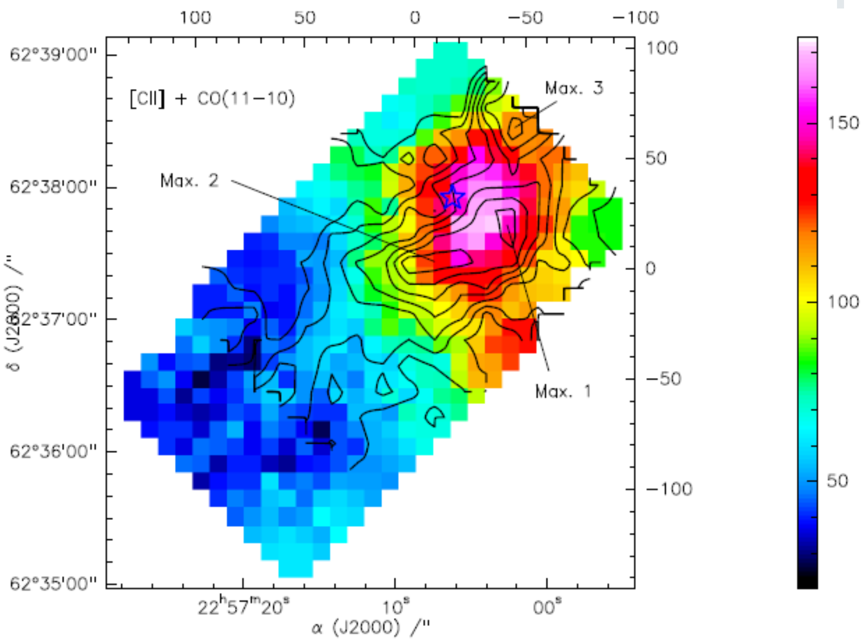


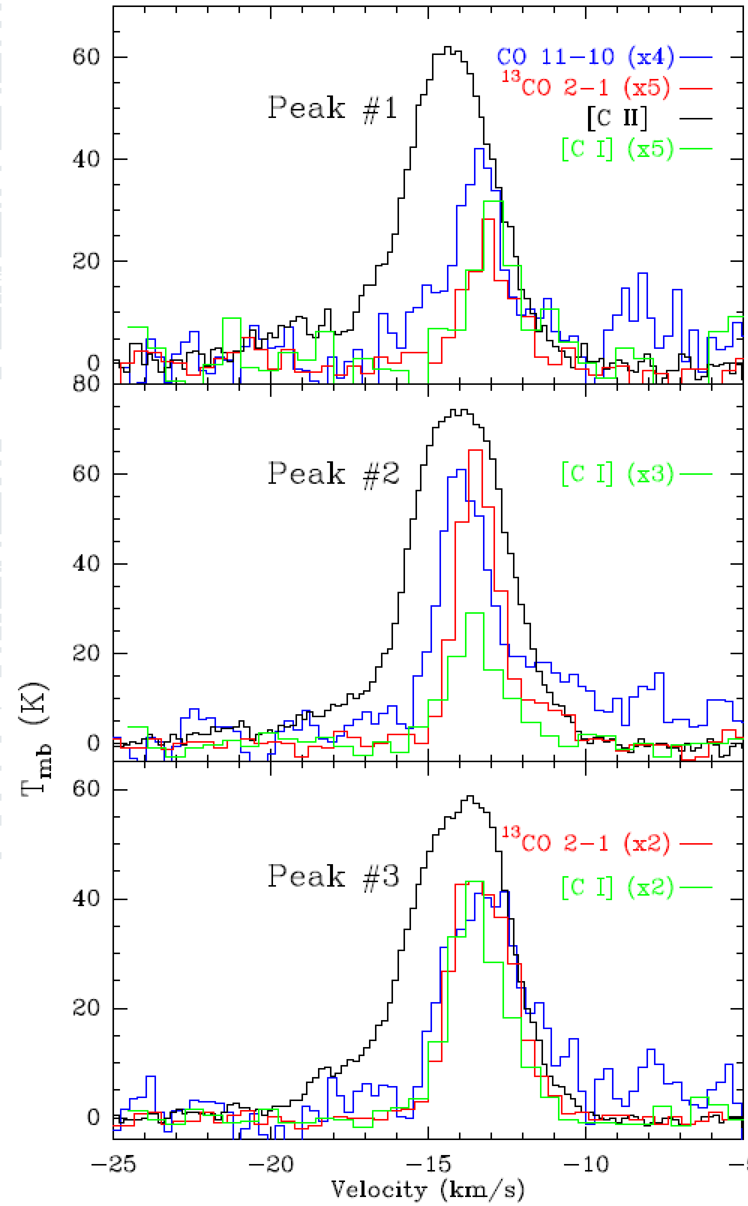
[CII] line centroid map and position-velocity diagram

- Global velocity gradient changed around HII region
- No large-scale impact

Example: Cep B

Velocity structure:



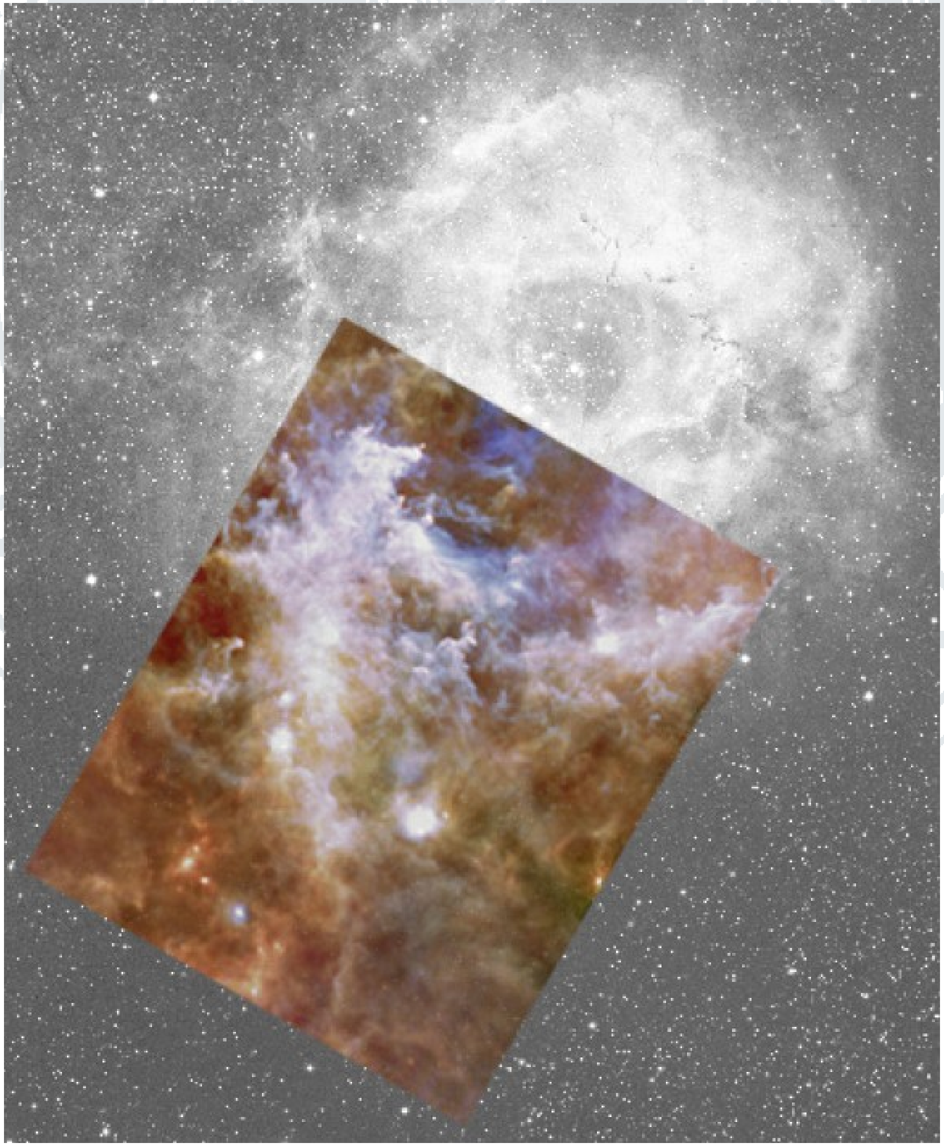


- Blue wing only in [CII]
- Ablating wind from S155 external HII region
- Dense gas **not** affected by radiation

Statistical approach

Is there more star-formation at high radiation fields?

- How to trace the spatial distribution of star-formation?
  - Look for high densities
    - Column density PDFs
  - Look for small structures
    - Δ-variance
  - Infall/outflow signatures
    - Velocity structure analysis

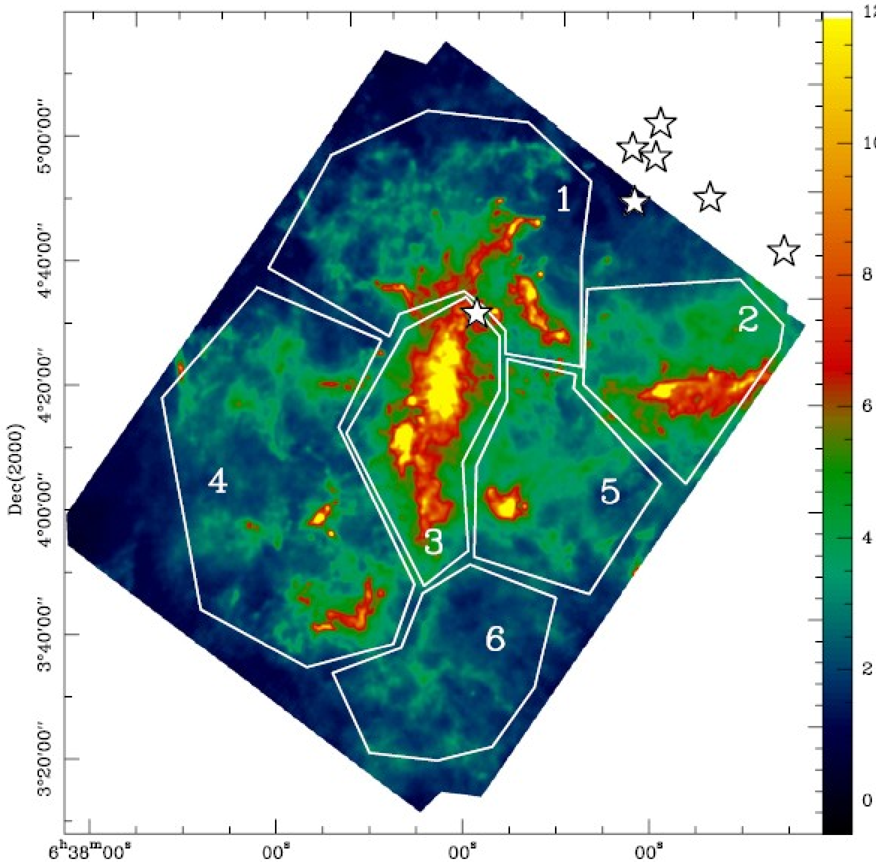


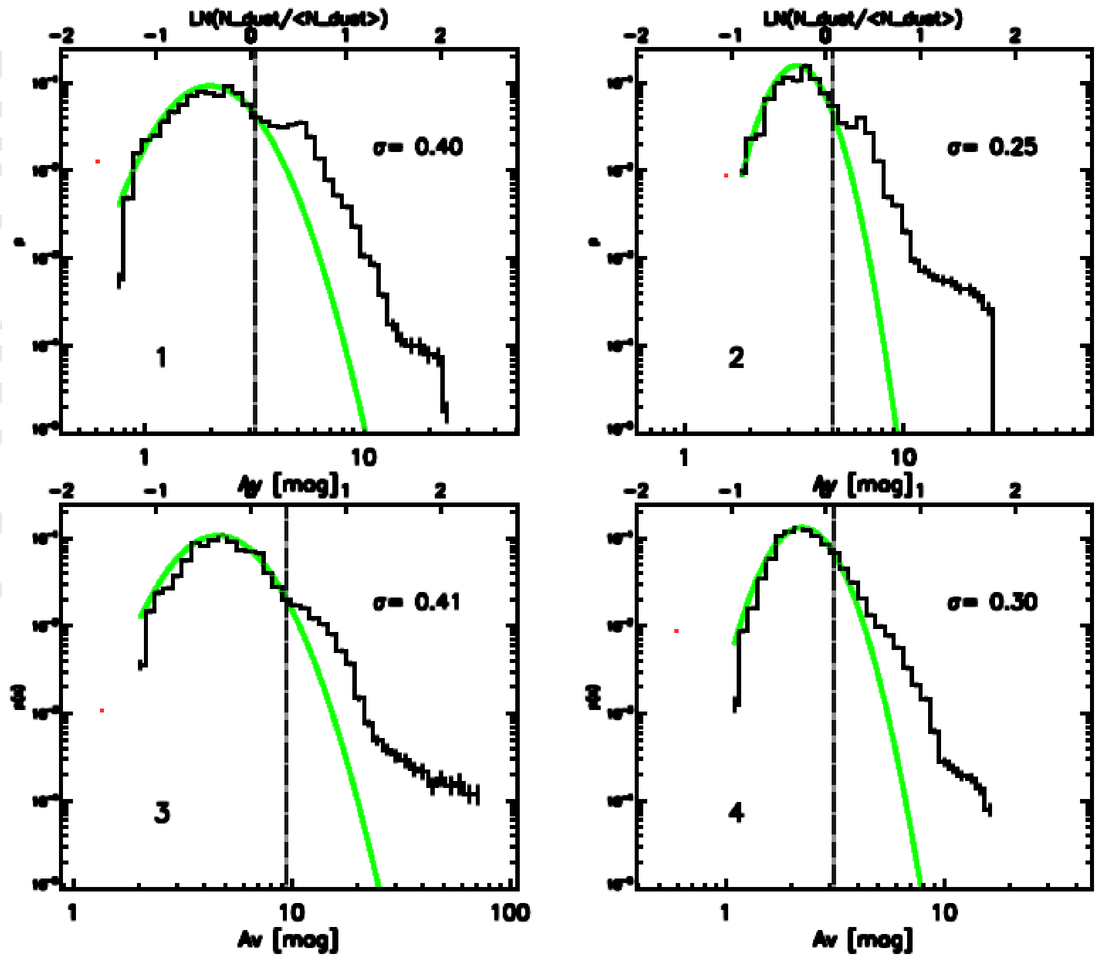
Rosette:

Extinction map from Herschel observations (Motte et al. 2010, Schneider et al. 2011)

Column density PDFs

Rosette:





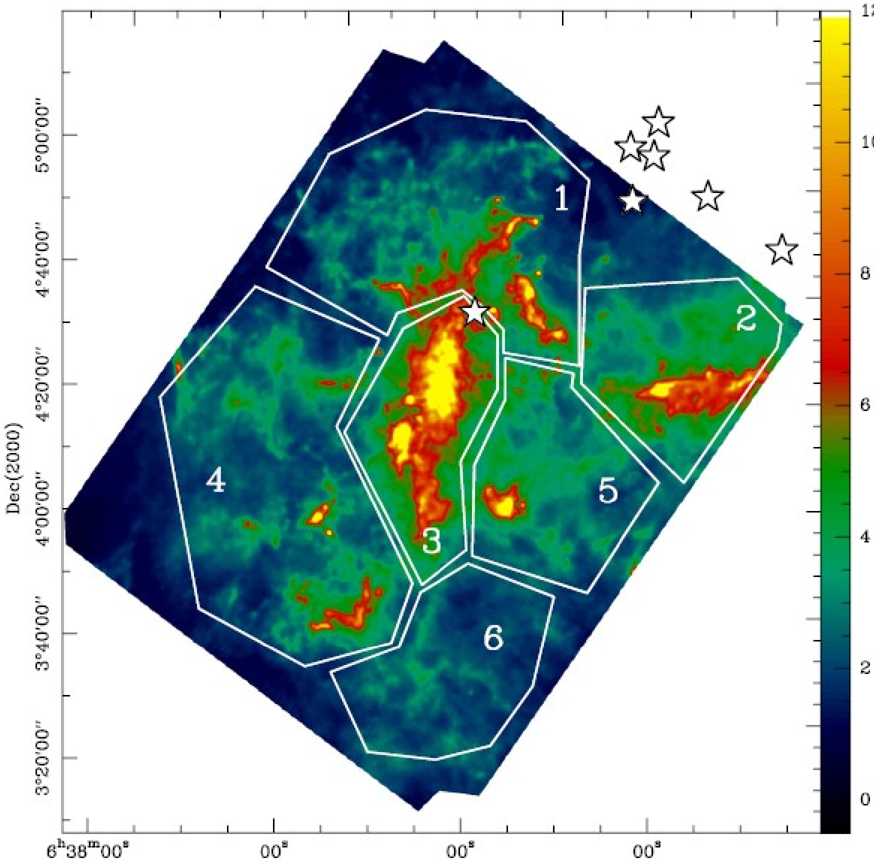
(Schneider et al. 2011)

High column density excess from gravitational collapse

- strongest in center region (3),
- weaker in PDR regions (1) and (2)

Analysis of significant scales

Column densities in Rosette:

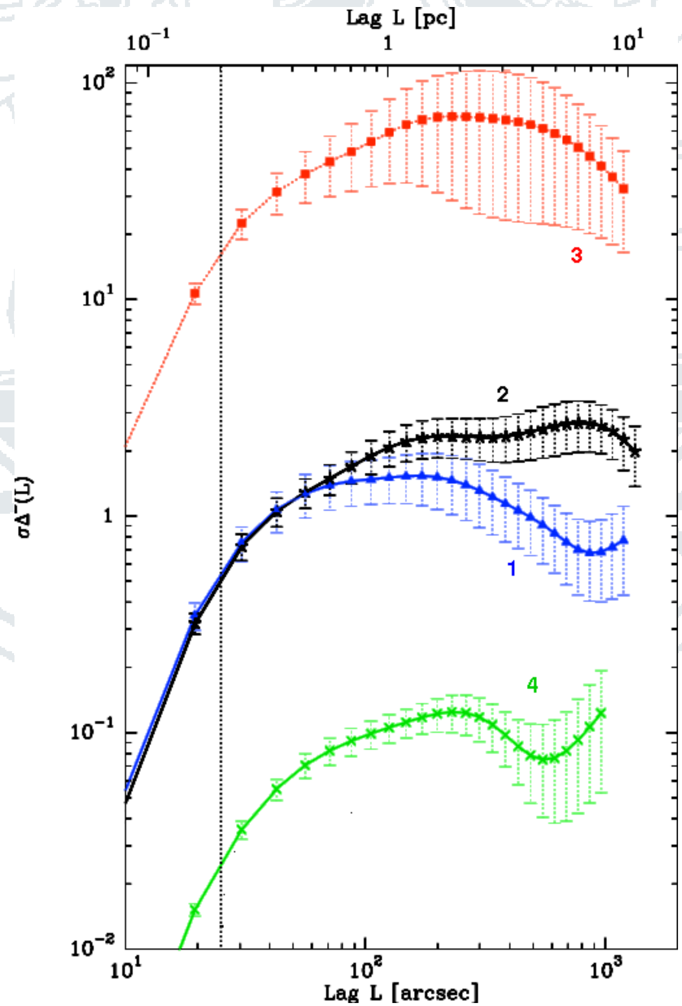


(Schneider et al. 2011)

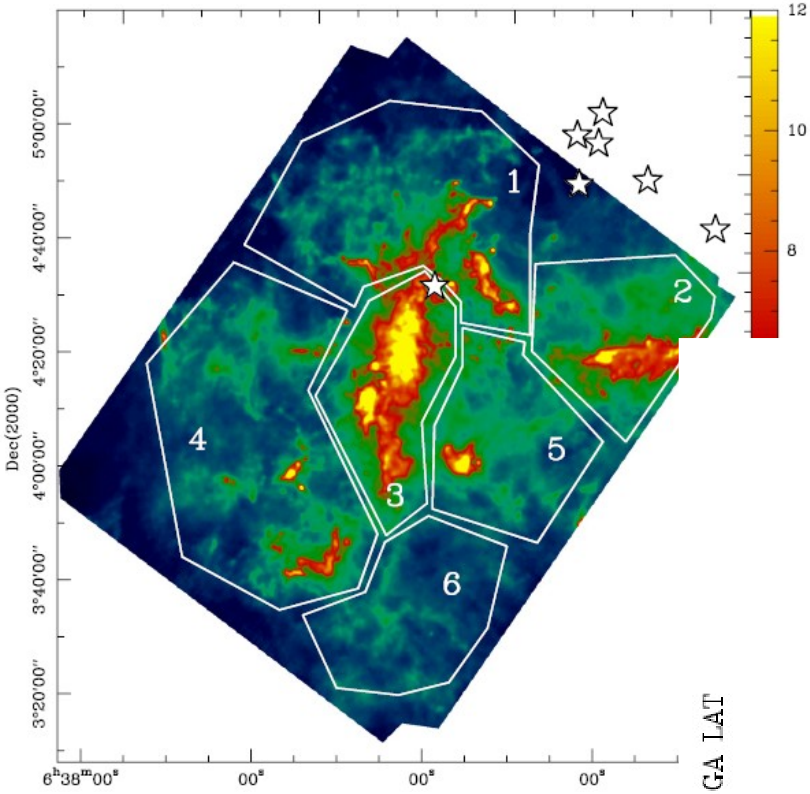
- Main ridge in center forms dominant structure
- No small-scale enhancement at PDR interfaces

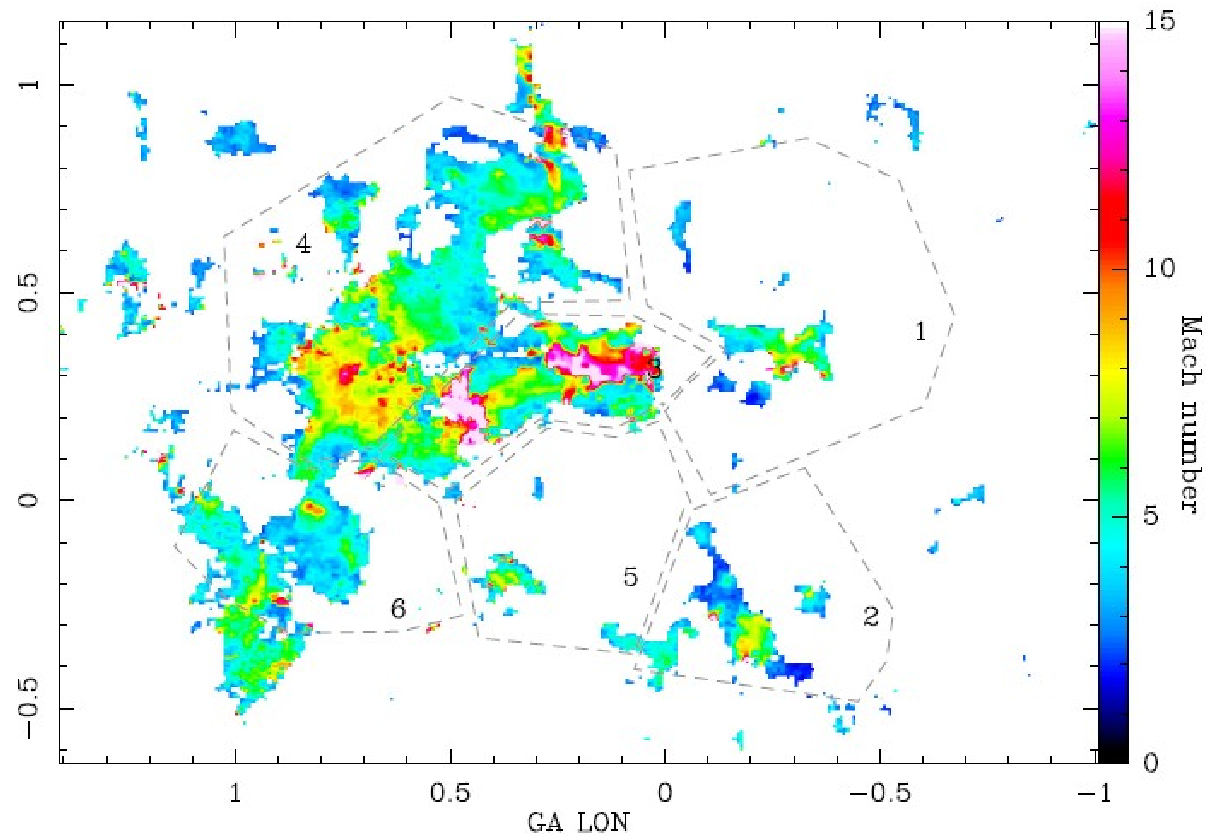
Δ-variance spectra:

- Gravitational collapse enhances small-scale structures



The velocity structure





Mach number derived from local velocity dispersion (Csengeri et al. 2013)

- Very localized line broadening at PDR surface
  - Affects little gas volume
- Main line broadening from ongoing SF activity in center region

Summary

- The layering of species in PDRs is quantitatively understood
- Pressure jump at the surface confirmed
  - But no detection of radiative core compression
- UV creates local heating and streams
  - Low-density gas is dynamically affected by UV radiation
  - But no large-scale collapse
  - Significant dispersion of gas
- Triggered SF around HII regions only in favourable conditions
  - Pillar formation rarely means star-formation triggering

- **Statistically, we find no significant radiative triggering of star-formation on global scales.**

- In contrast, sequential star formation is common.
  - Natural outcome of filament formation in titled colliding flows