The physics and chemistry of PDRs from HIFI observations

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What happens here?

How do winds and radiation from young stars affect the gas in their environment?

- density
- temperature
- velocity field

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

WADI science goals

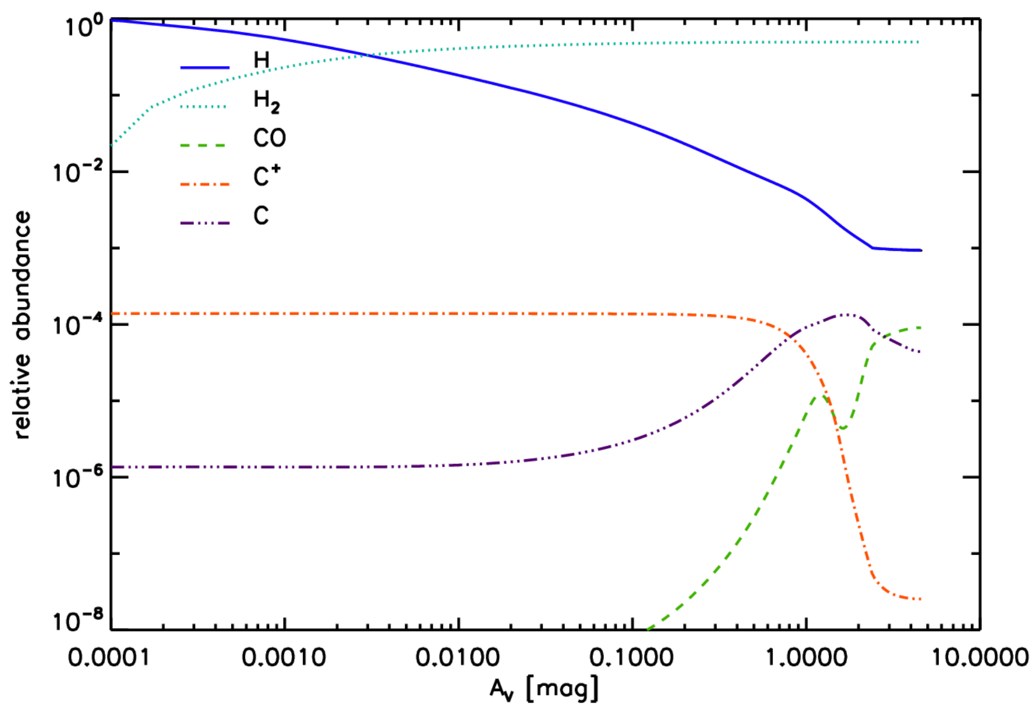
- Cloud evolution is critically determined by gas temperature
- Requires understanding of heating/cooling agents
  → Chemistry
- WADI science:
  - chemistry,
  - energy balance,
  - dynamics.

of the interaction regions.

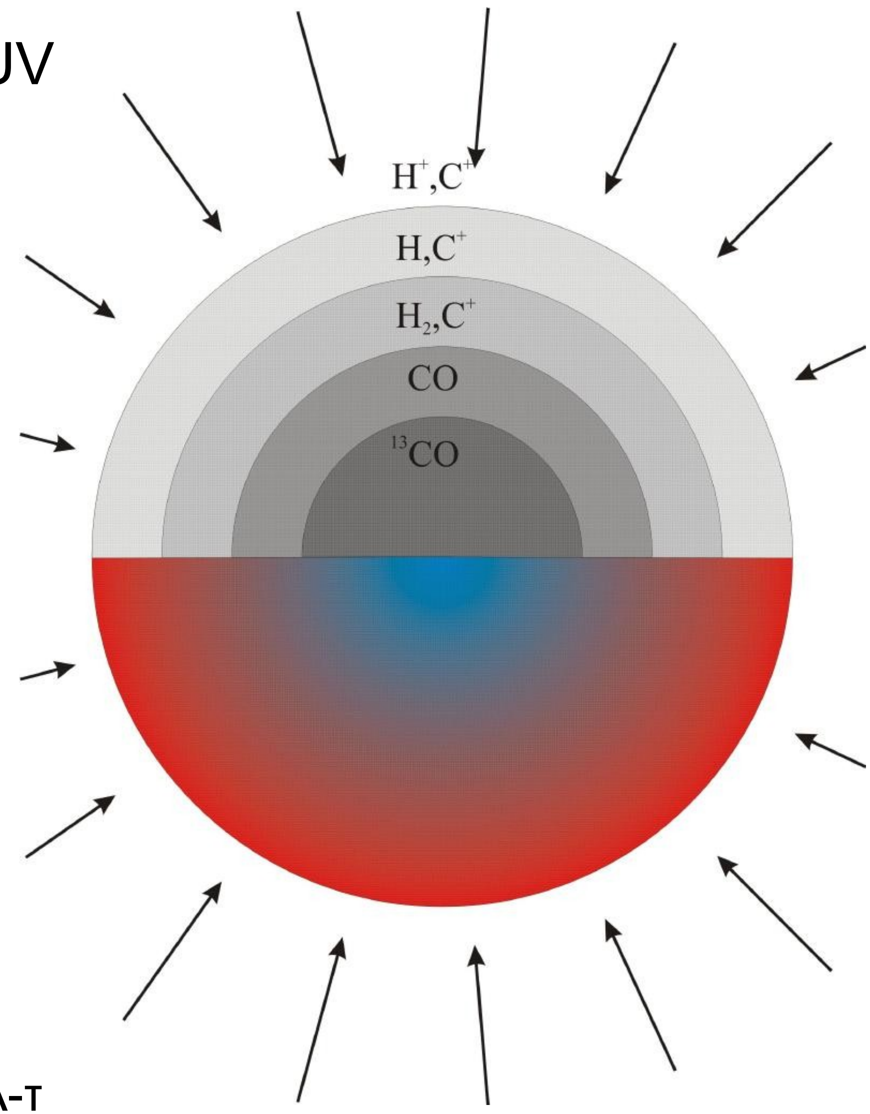
Pre-requisite to understand triggered star-formation.

Chemical structure

- Layering of species as a function of UV field



Abundance of selected species as a function of optical depth from the cloud surface (KOSMA-τ model with $\chi = 1$, $M_{tot} = 100M_{O}$, $n = 500 cm^{-3}$)

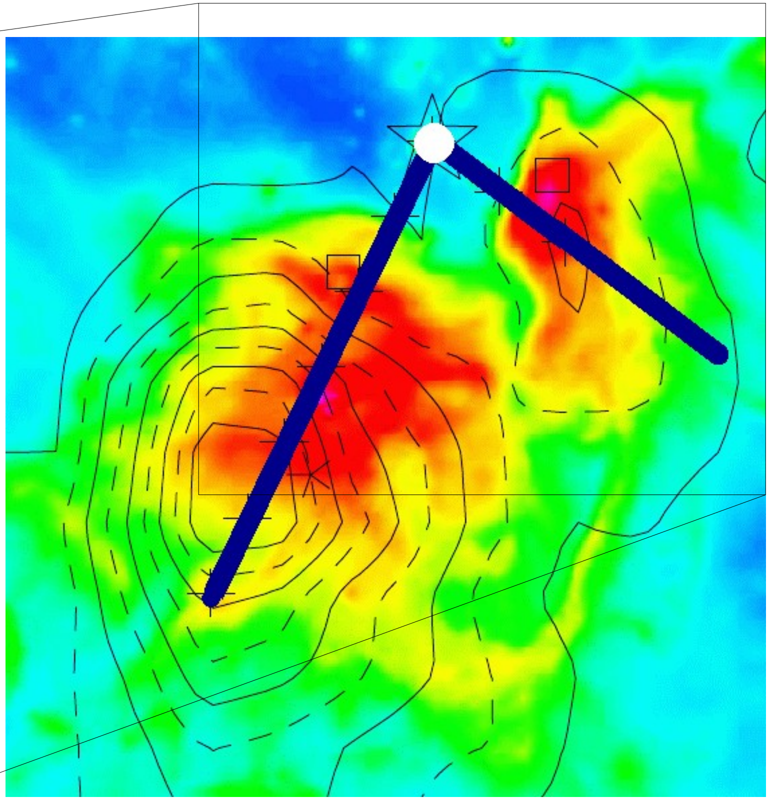


HIFI Observations

Measure layering structure - example: NGC3603

- cuts across the interfaces of PDRs and shock regions
- deep integrations at selected positions for rare species

Pillars at PDR fronts (HST, Brandner et al. 2000)



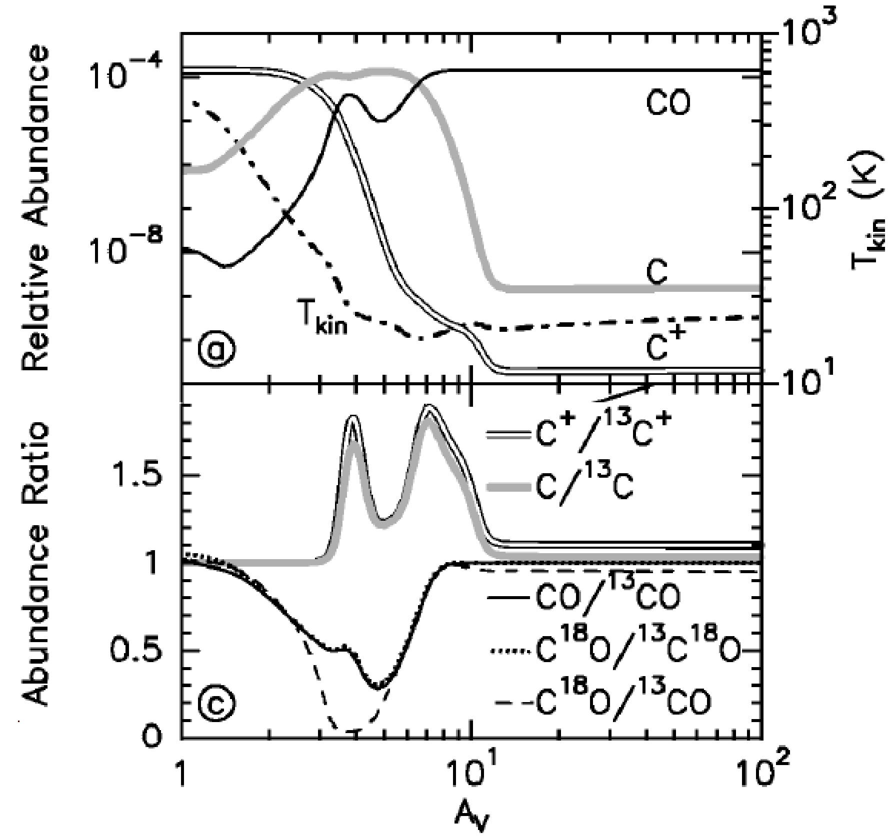
Observed cuts overlaid on Spitzer 8µm (color) and CO 4-3 (contours)

Carbon fractionation

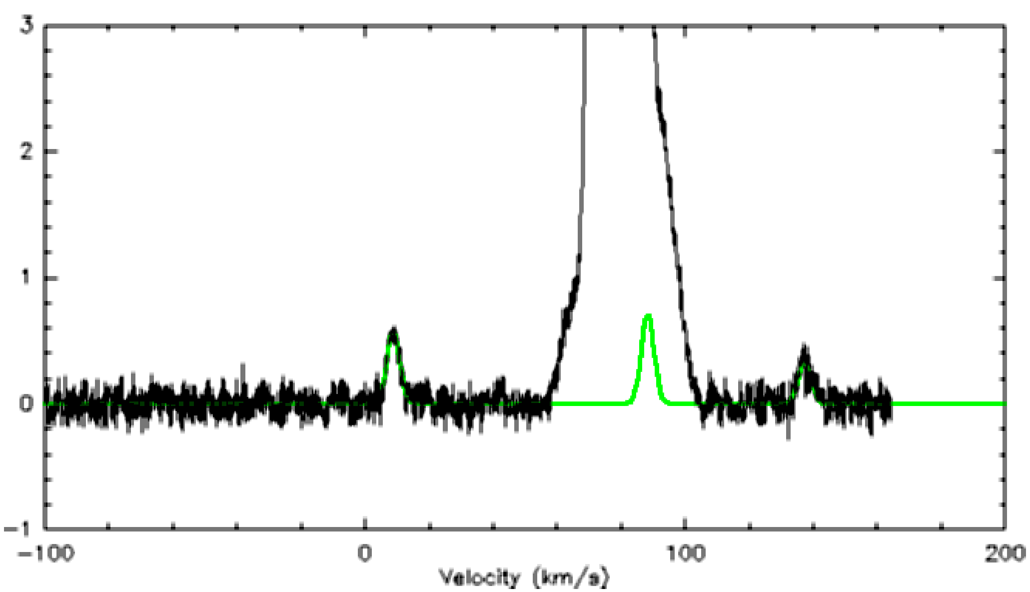
- ^{13}C fractionation driven by

  $^{13}C^{+} + CO \leftrightarrow {}^{13}CO + C^{+} + 35\ K$

- Enriches ^{13}CO, depletes $^{13}C^{+}$
- [^{13}CII] detection non-trivial:
  - 3 HF components, blended with [CII]
  - self-chopping in extended [CII]



Keene et al (1998)

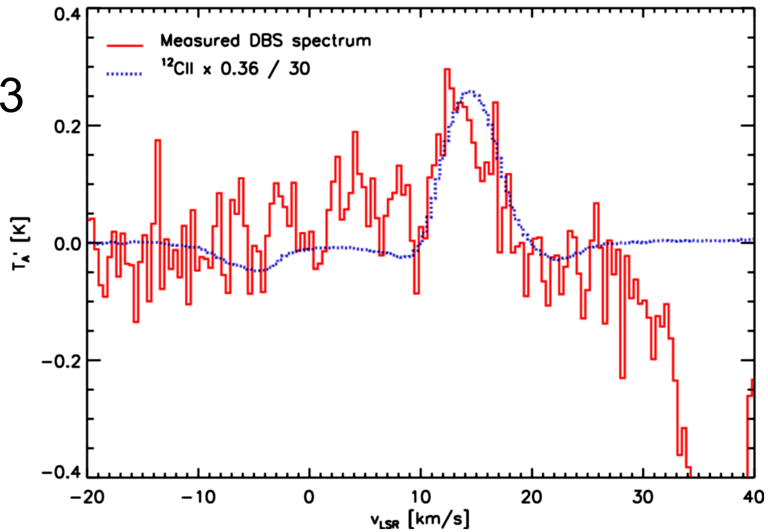


2 HF components clearly detected in Mon R2

^{13}CII detections

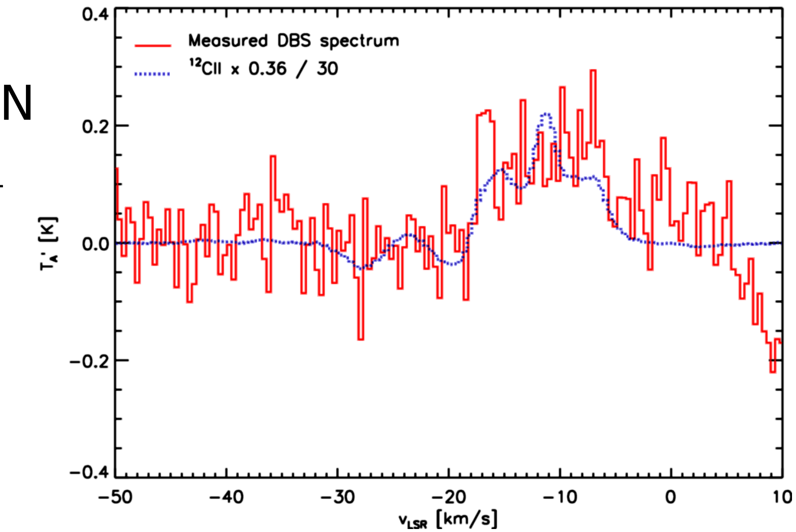
NGC3603

$^{12}C^+/^{13}C^+$ = 30



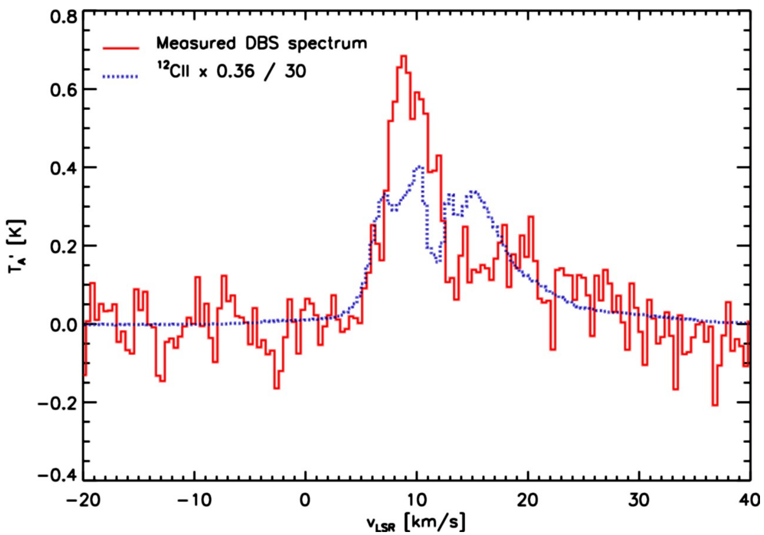
Carina N

$^{12}C^+/^{13}C^+$ = 30



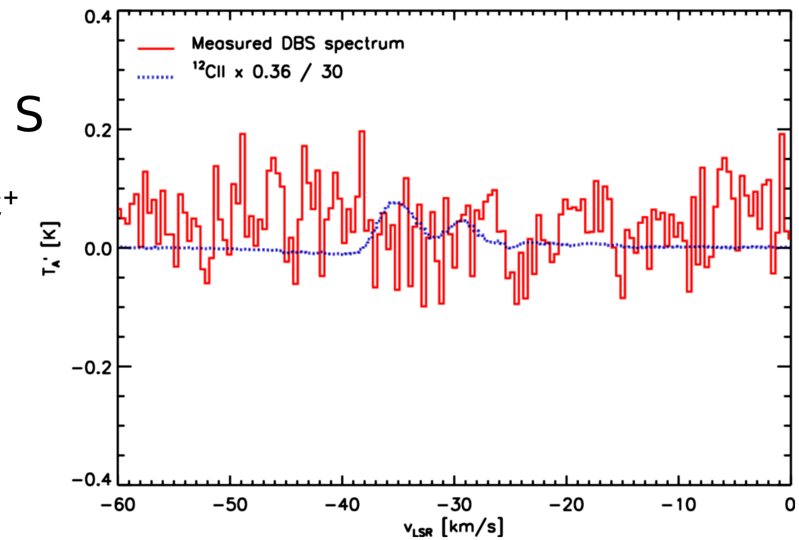
Mon R2

$^{12}C^+/^{13}C^+$ = 15-50



Carina S

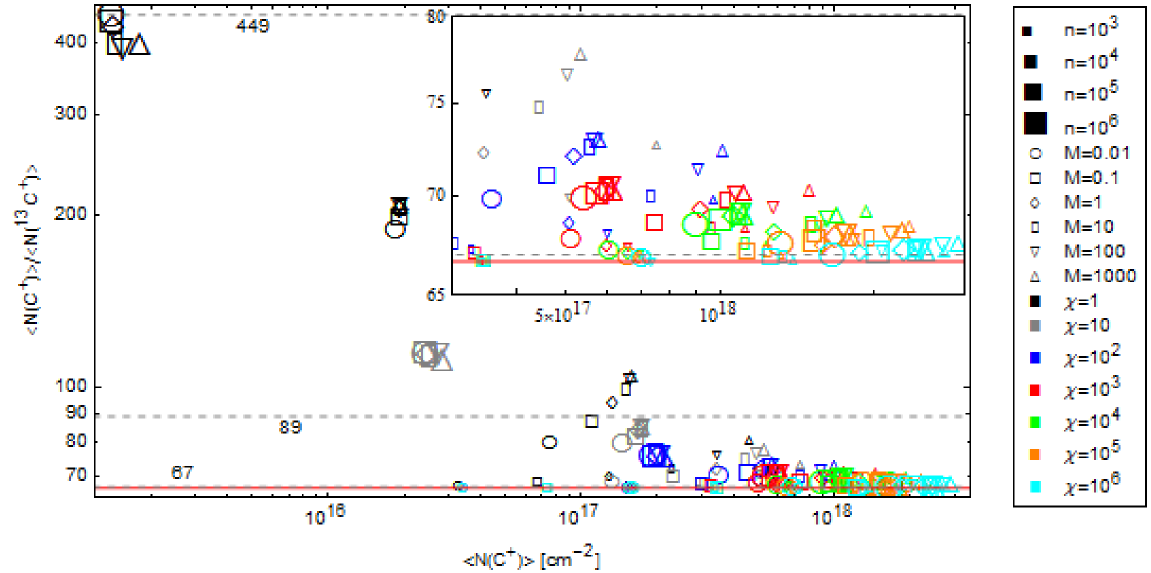
$^{12}C^+/^{13}C^+$ > 30



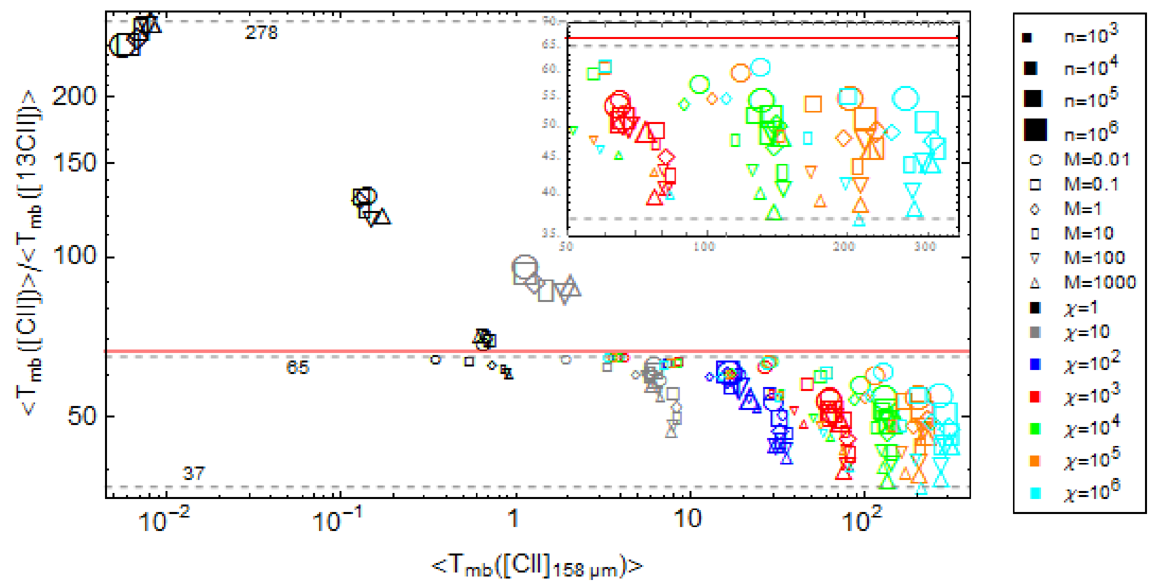
- Reduction of observed $^{12}C^+/^{13}C^+$ ratio compared to standard isotopic ratio
- In contrast to fractionation → optical depth effects

Model predictions

$N(C^+)/N(^{13}C^+)$:



$T_{mb}([CII])/T_{mb}([^{13}CII])$:

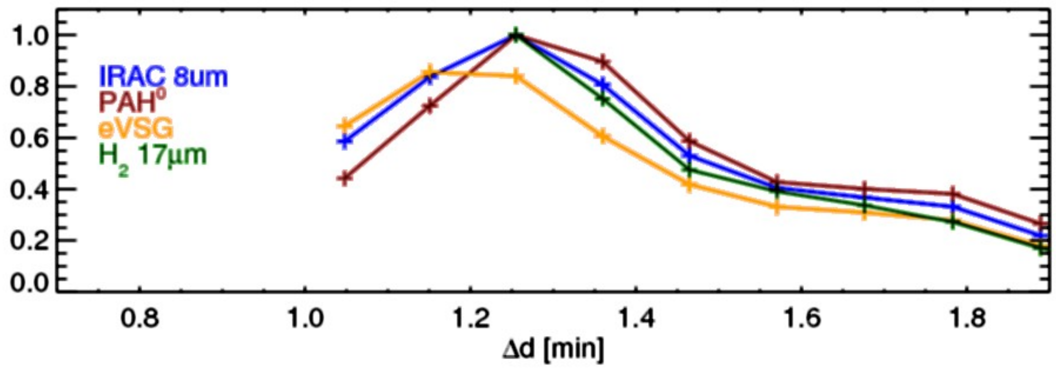


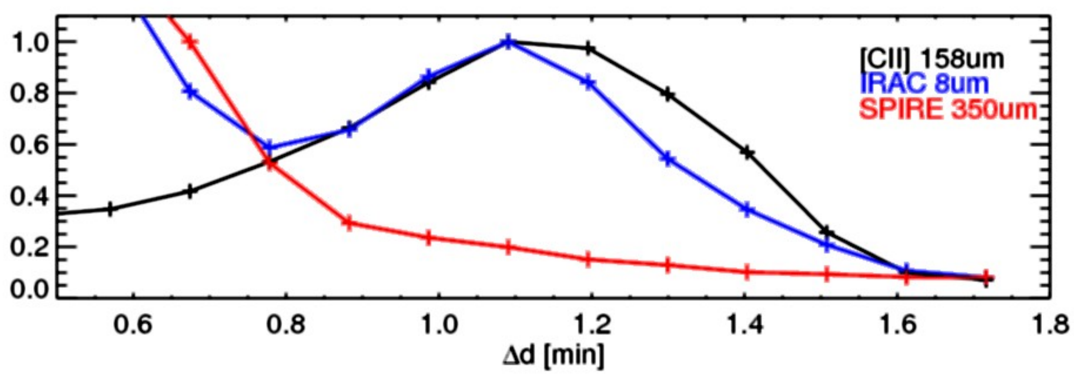
Observed abundance ratio consistent with τ([CII]) ~ 2-3, characteristic for large clumps, but in contradiction to results from SED fitting

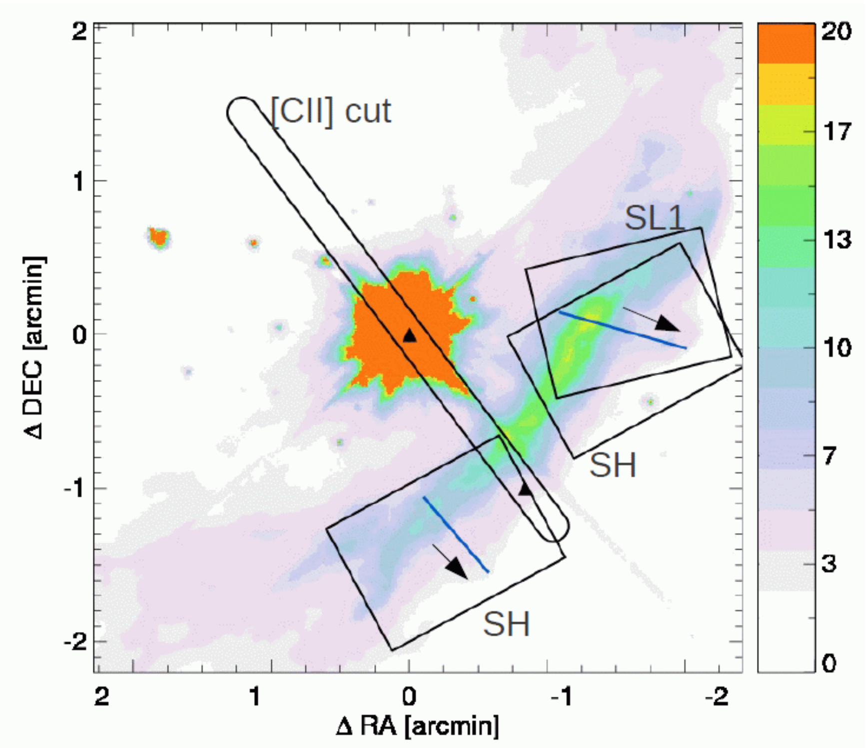
Energy balance

Physics of photoelectric heating:

- [CII] traces gas temperature
- Correlation with PAHs reveals their heating contribution







Cut across S140 PDR

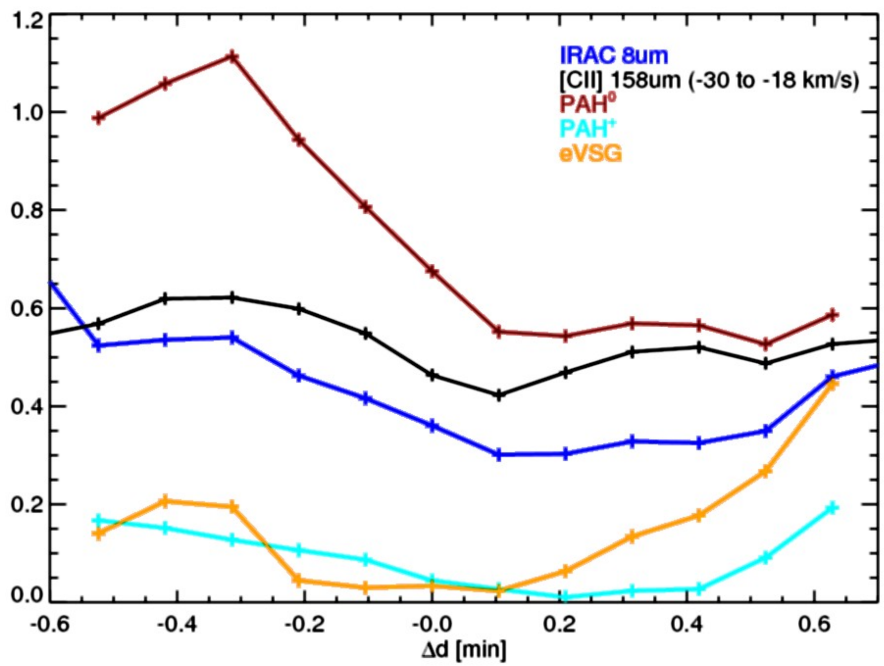
Photoelectric heating dominated by neutral PAHs.

- VSGs less important

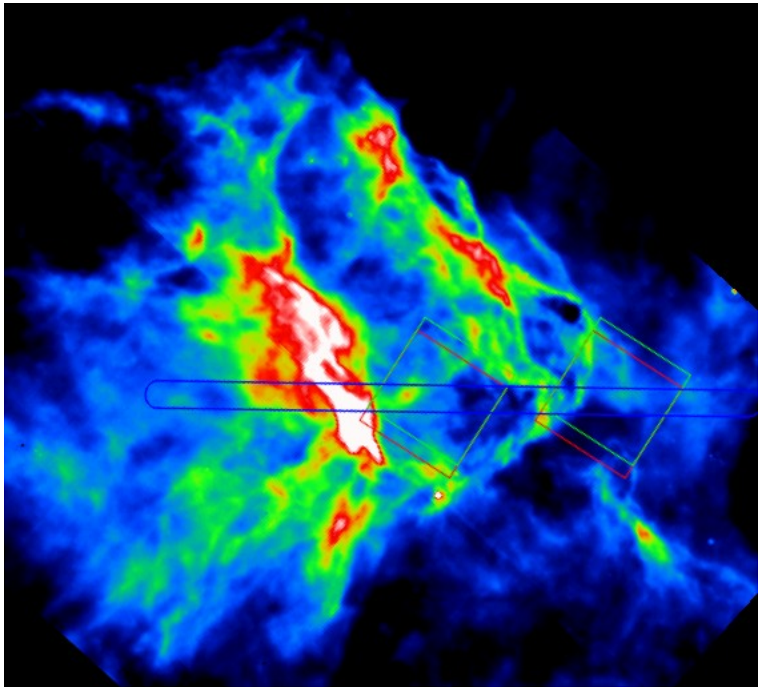
PE heating

Carina North PDR: two similar [CII] clumps

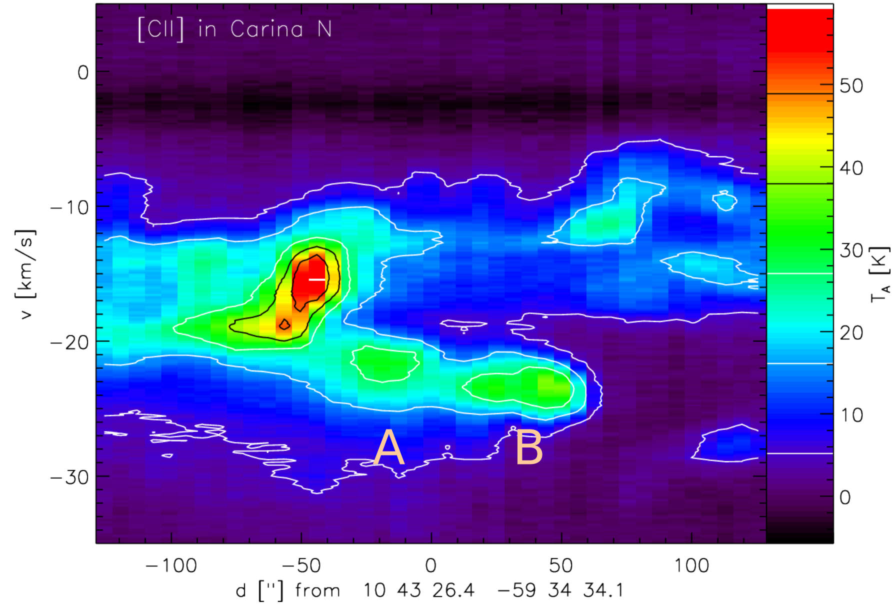
- A: strong in PAH^0 and ionized tracers (Ne II, Ne III, Fe II)
- B: strong in VSGs and PAH^+



Decomposition of IRS spectra in central part covering the two clumps



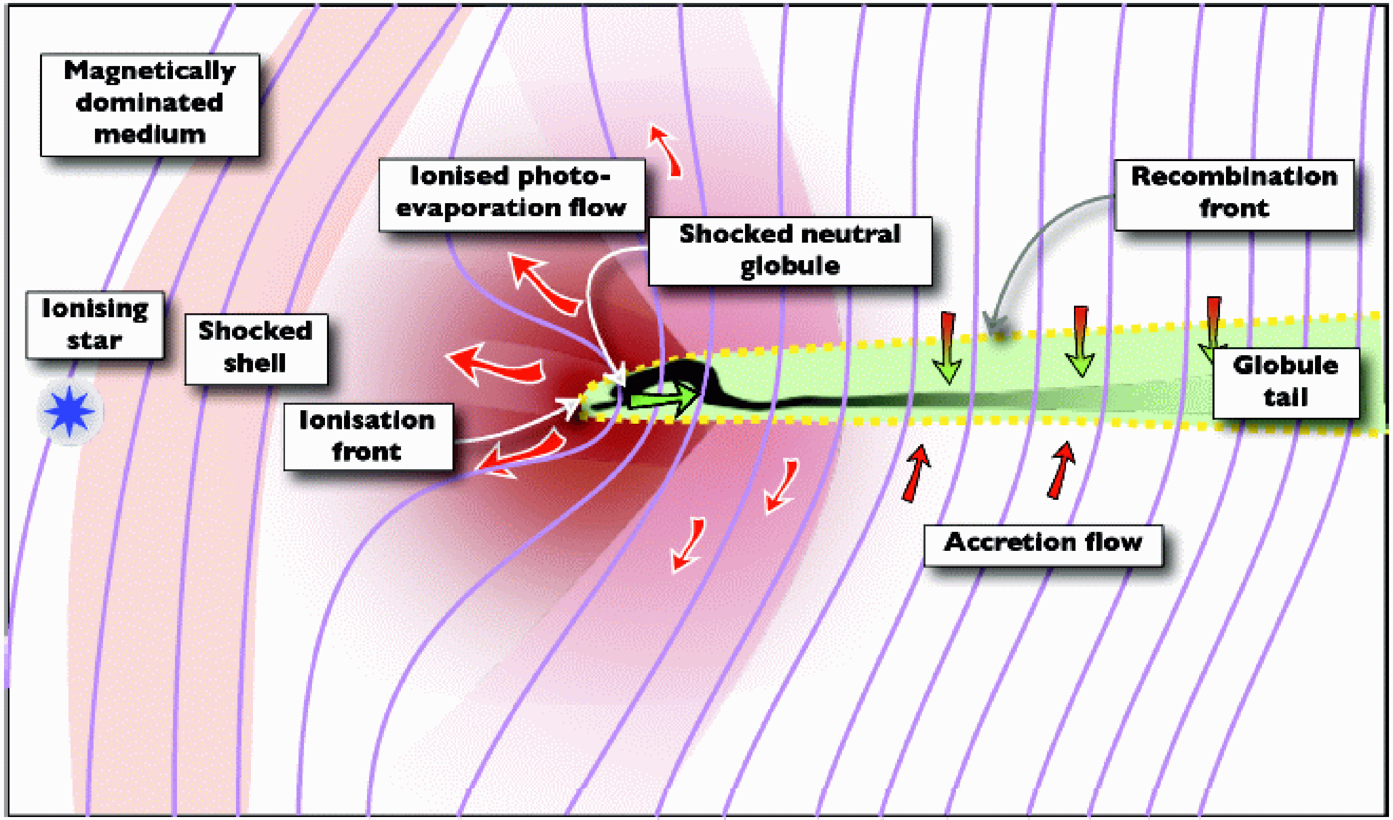
Cut through Carina North PDR



Resulting [CII] pv-diagram

Dynamics and kinematics

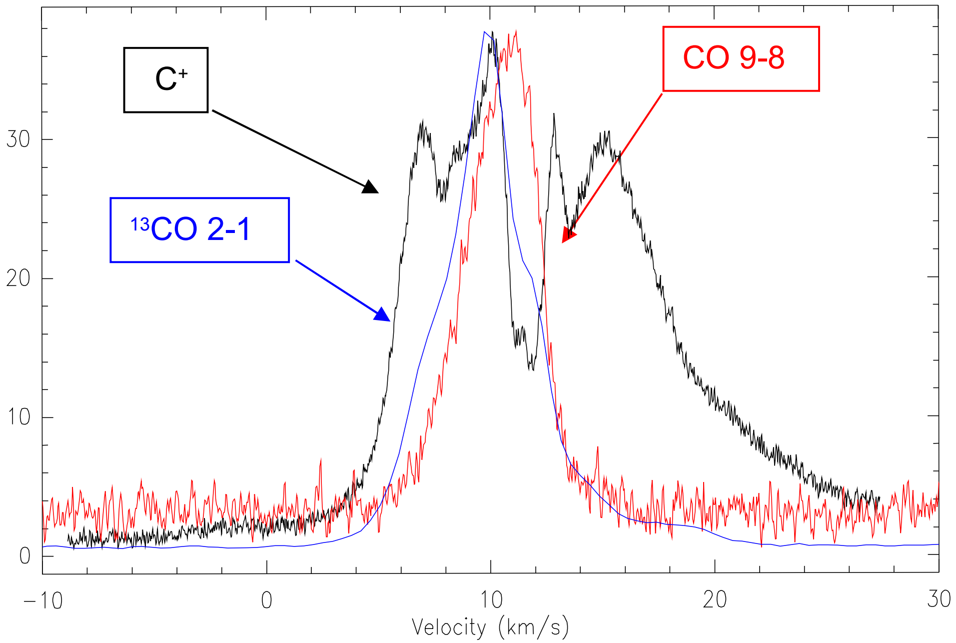
- High pressure zone at PDR surface
- Photo-evaporation of PDRs dominates flow of ionized material
- Cloud compression / shock fronts
- Advection flows
- Unknown impact of turbulence
- Magnetic fields

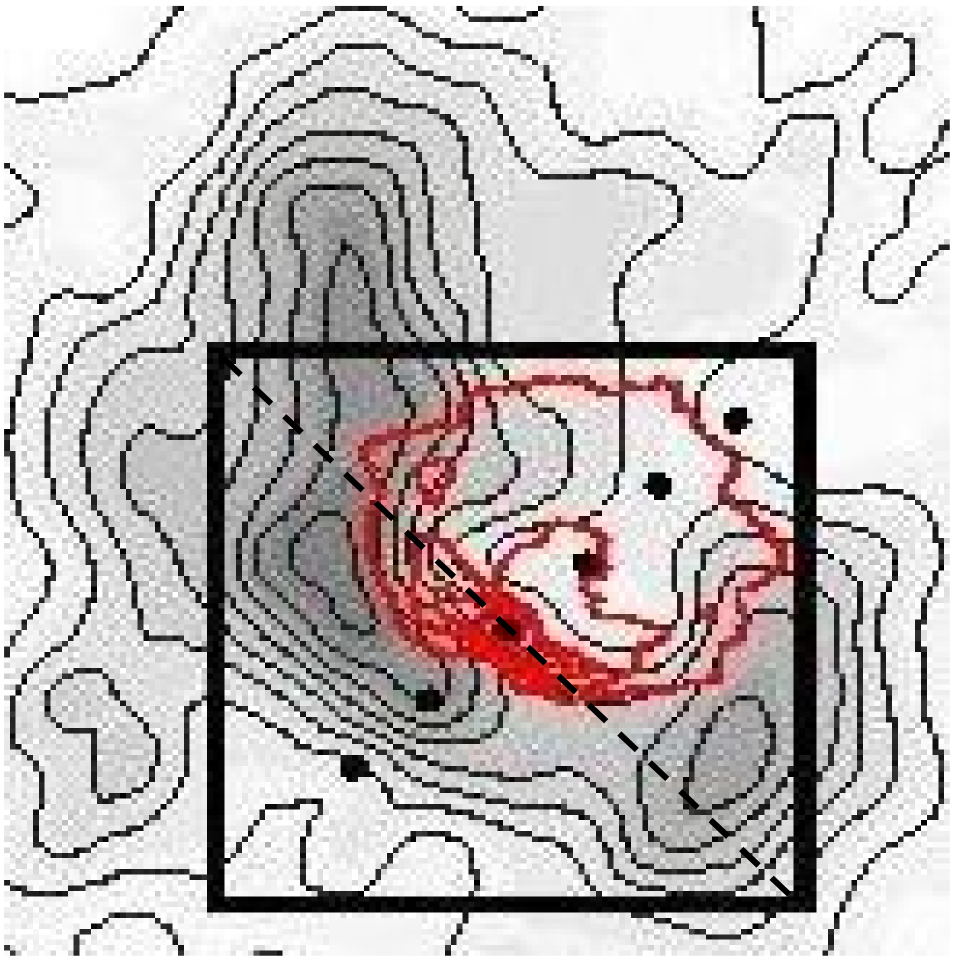


3-D MHD model by Henney et al. (2009)

Dynamics from line profiles

Example: Mon R2

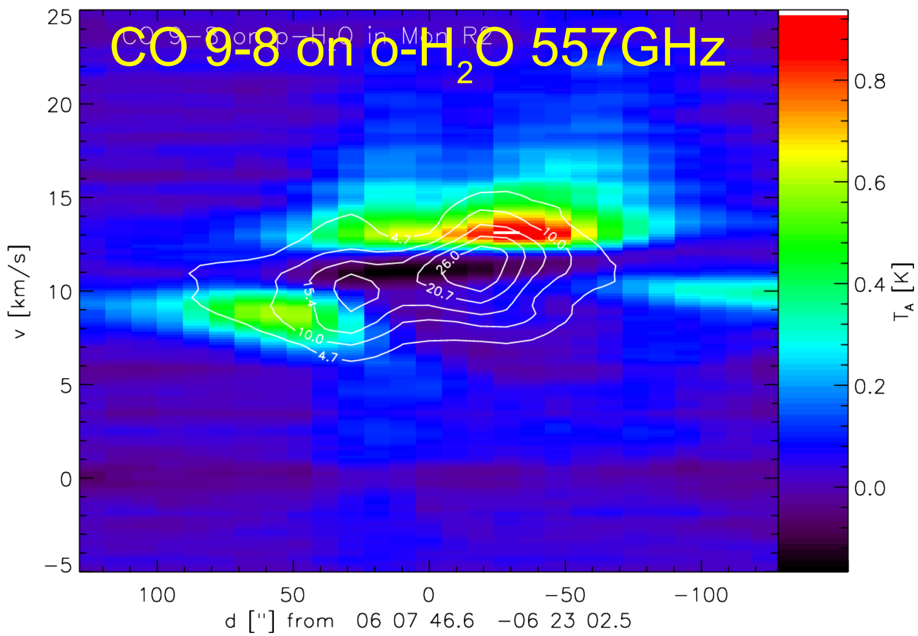


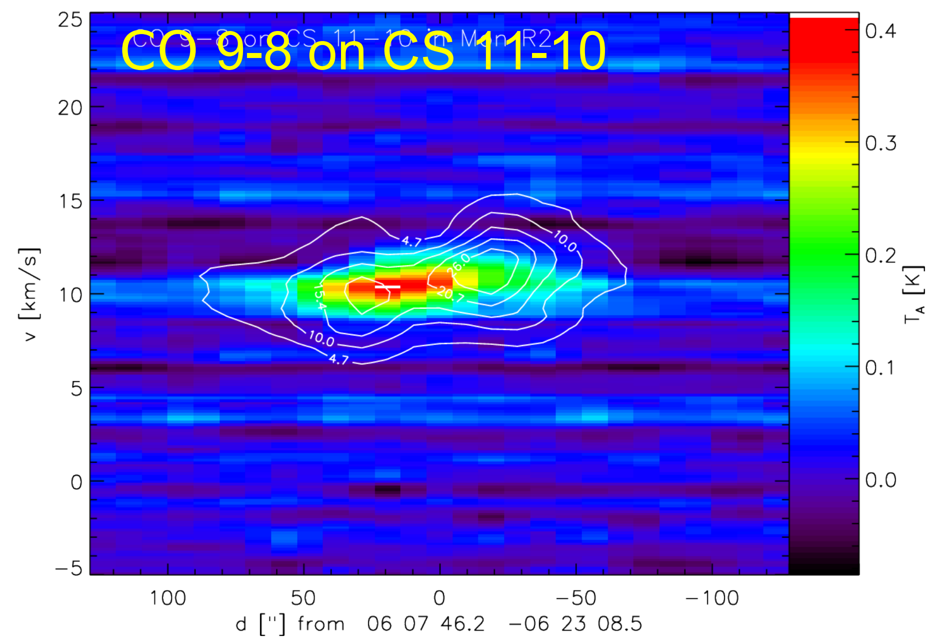


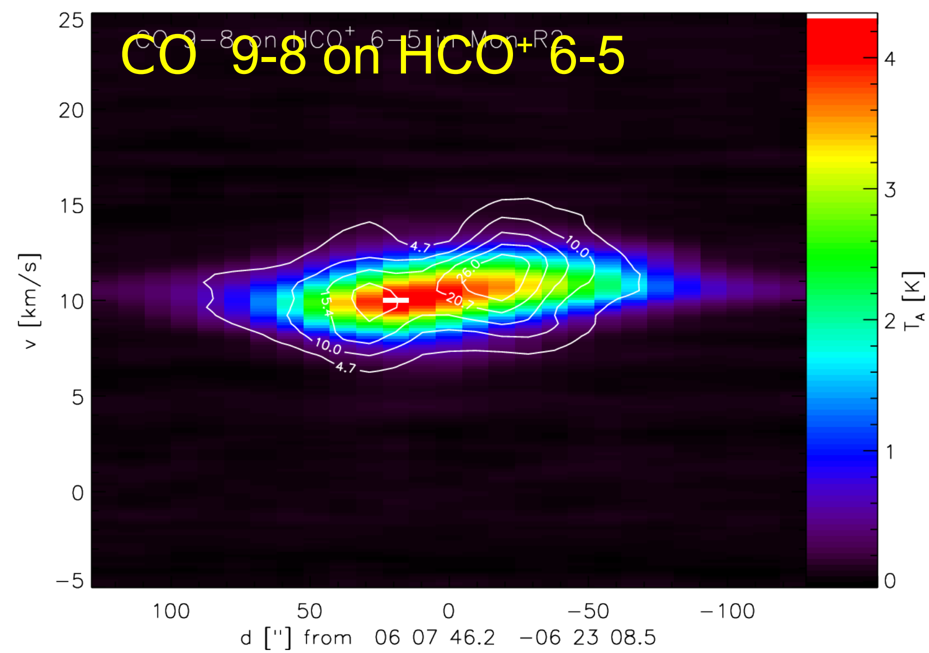
- Complex [CII] profile
  - similar to that of ^{12}CO 3-2
  - but very different from CO 9-8
  - [CII] partially from gas in the rear of the HII region
  - Ionized flow traced by wings (?)
  - PDR absorbs [CII]

Comparison of p-v diagrams

Example: Mon R2



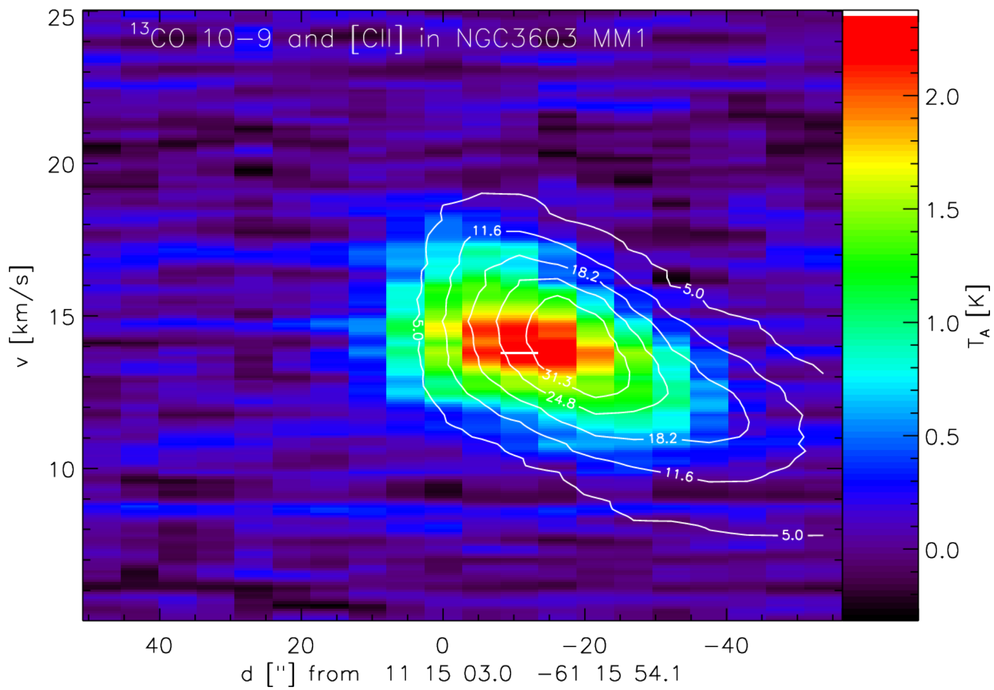




- PDR seen in CO 9-8 corresponds to the molecular cloud.
- Western part hotter in spite of similar distance from cluster
- Strong water self-absorption at molecular cloud velocity
- Puzzleing outflow (?) wings in H_2O not seen in any CO line

Dynamics from p-v diagrams

NGC3603 MM1



Position-velocity diagram for NGC3603 MM1:
^{13}CO 10-9 (colors) + [CII] (contours).
The cluster is to the left.

Exposed to brightest UV field:

- Clear broadening of the [CII] line at the PDR surface
- Long [CII] tail of material "behind" the core
  → clumpy medium
- [CII] peaks deeper in the core than ^{13}CO
- [CII] is red-shifted relative to molecular tracers

C^+ is blown from the surface into the clumpy medium

- ➔ Redshifted profiles → affected material sits behind the cluster
- ➔ The 4km/s gradient along the core measures compression!

Summary

- Chemistry:
  - Big step ahead towards complete chemical inventory including all major gas coolants
    - Carbon chemistry, including CH, HCO^+, … well understood
  - Major puzzles due to low intensity of NH, NH^+, NII, H_3O^+
- Energy balance:
  - Clumpy medium explains complex measured temperature structure
  - Dependence of photo-electric heating on PAH structure still unclear
- Dynamics:
  - No indications of photoevaporation flows, but wide C^+ in clumpy material
  - Possibly indications for pressure driven star-formation triggering

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