Dynamical properties of warm and dense photodissociation regions : from the interstellar medium to protoplanetary disks

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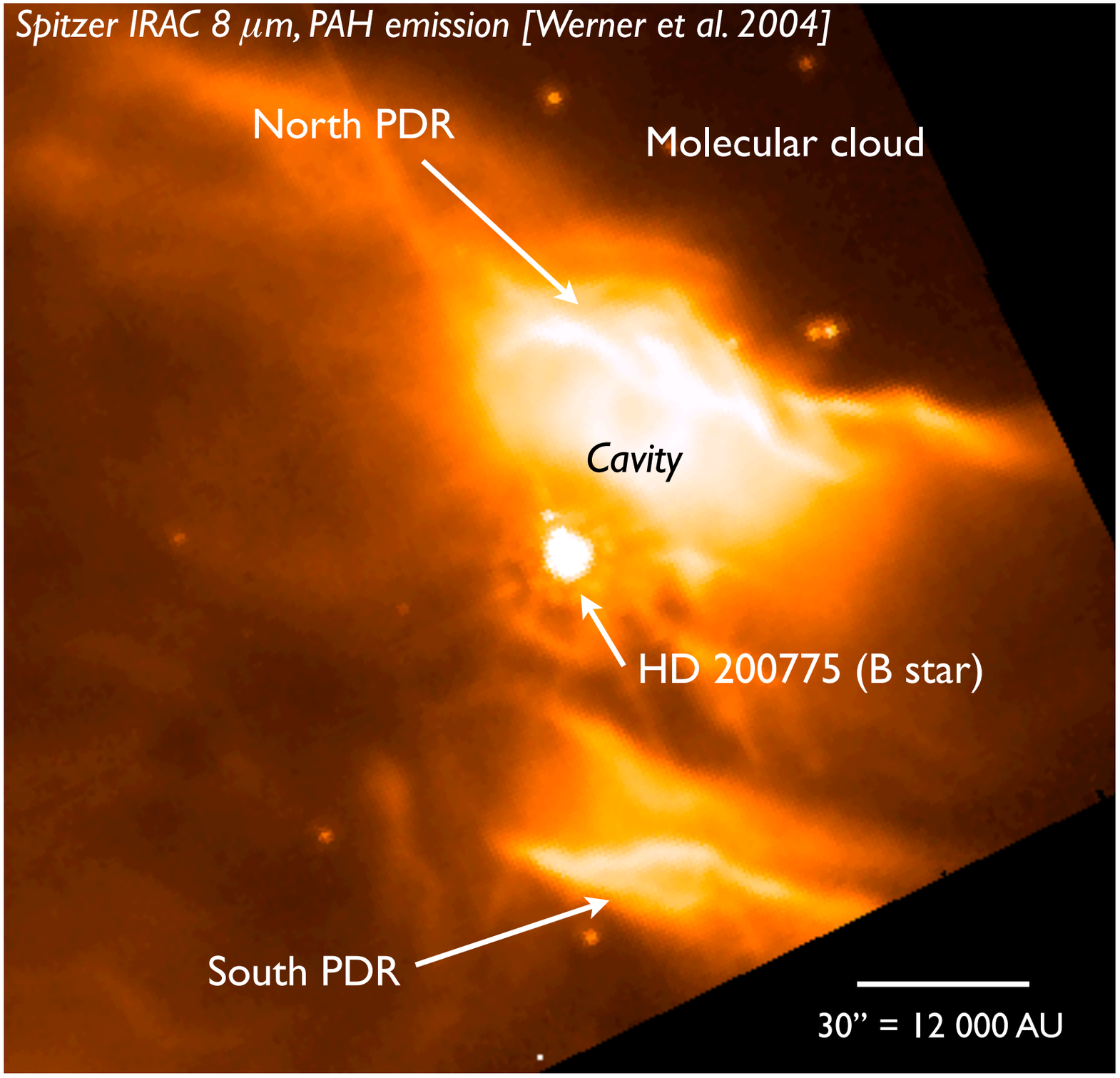
Herschel OT1 program, PI C. Joblin, «Physics of gas evaporation at PDR edges»
A. Boulais, J. Pety, M. Gerin, J. R. Goicoechea, P. Gratier, V. Guzman, E. Habart, ,D. Teyssier, F. Le Petit, J. Le Bourlot, J. Montillaud, P. Pilleri, A. Fuente, K. Sellgren, A. Abergel

Herschel OT2 program, PI O. Berné «A Herschel survey of PDRs in proplyds»
J. Champion, S. Vicente, I. Kamp, C. Joblin, F. Le Petit, P. Pilleri, X. Tielens, L. Podio, B. Merin, M. Avruch

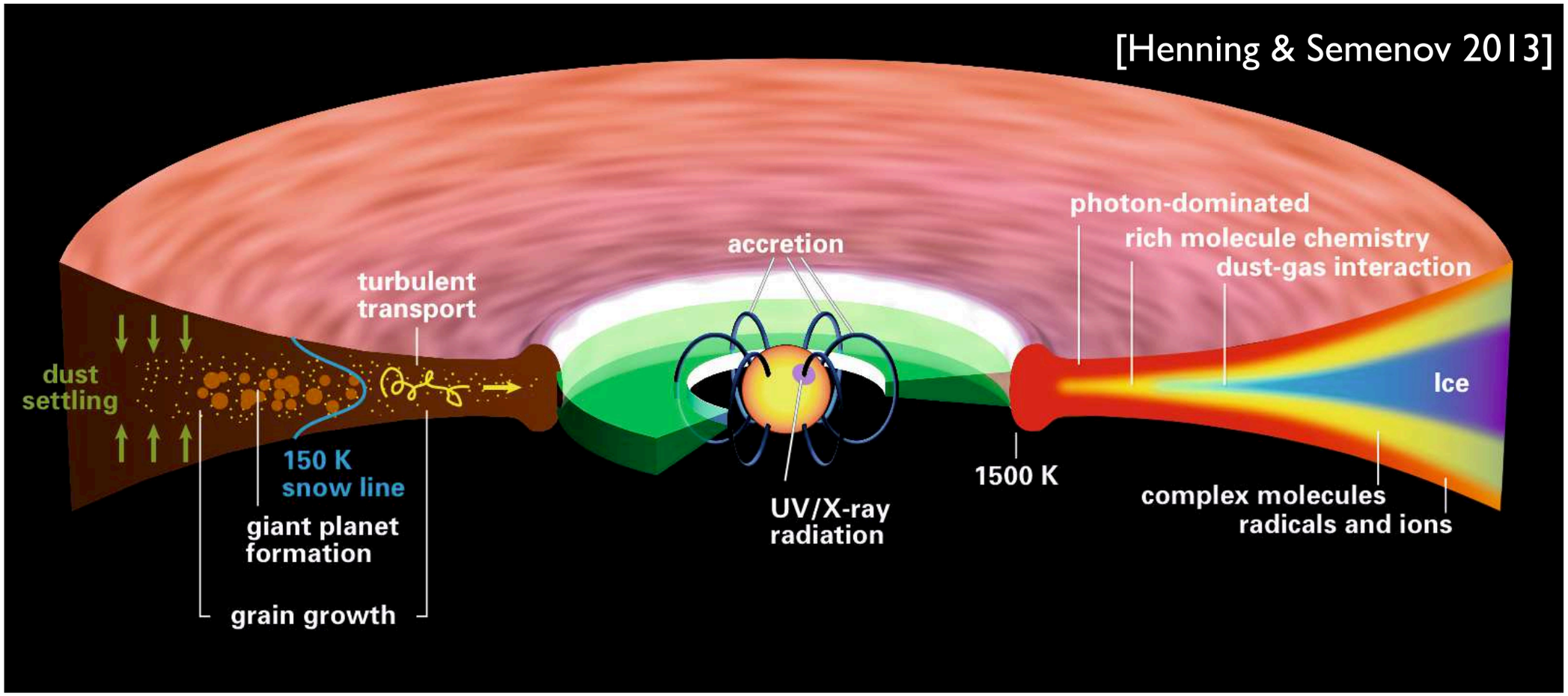
pcmi

PDRs in the NGC 7023 massive star forming region



PDRs in protoplanetary disk

- Disks around pre-main sequences stars are the sites of planet formation

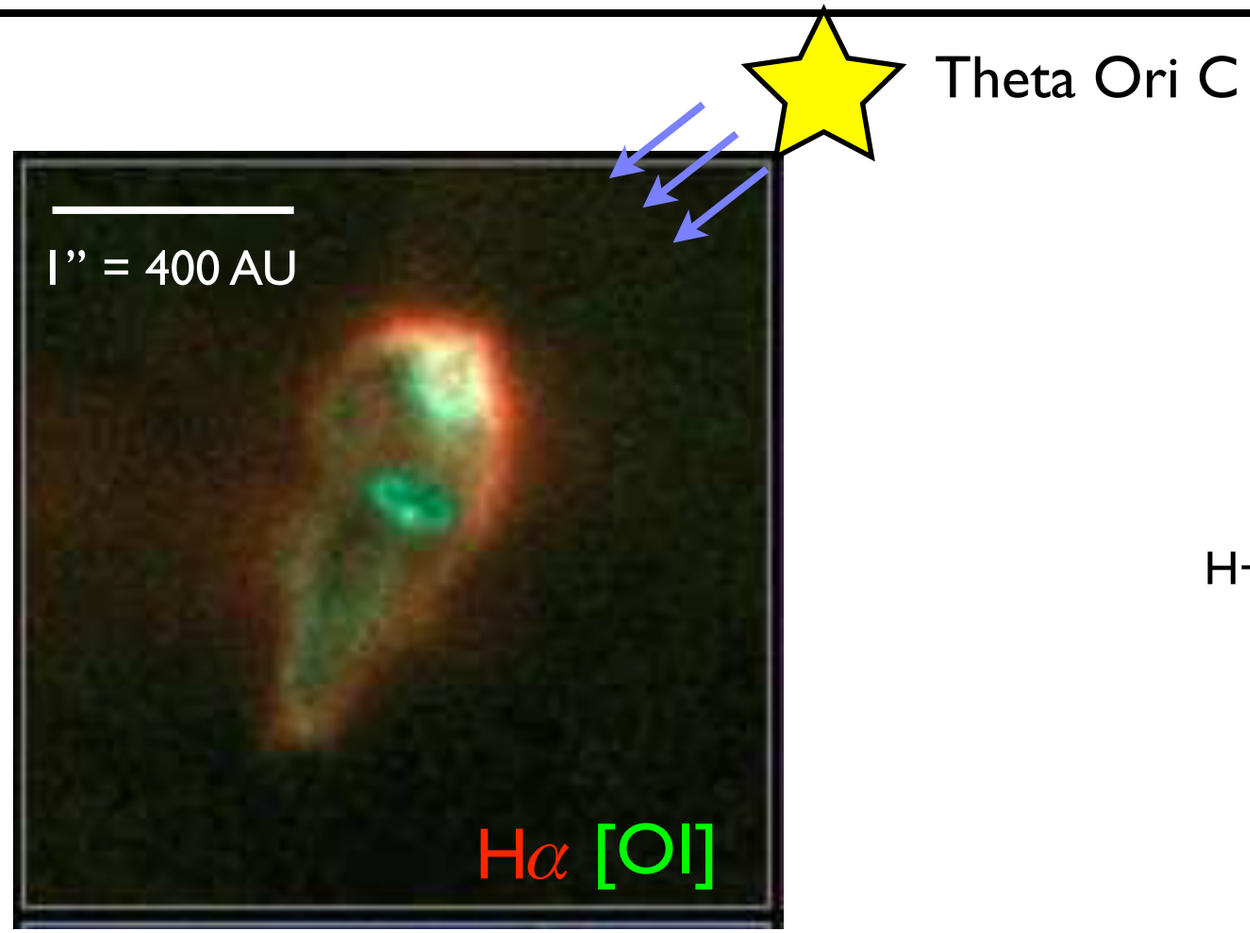


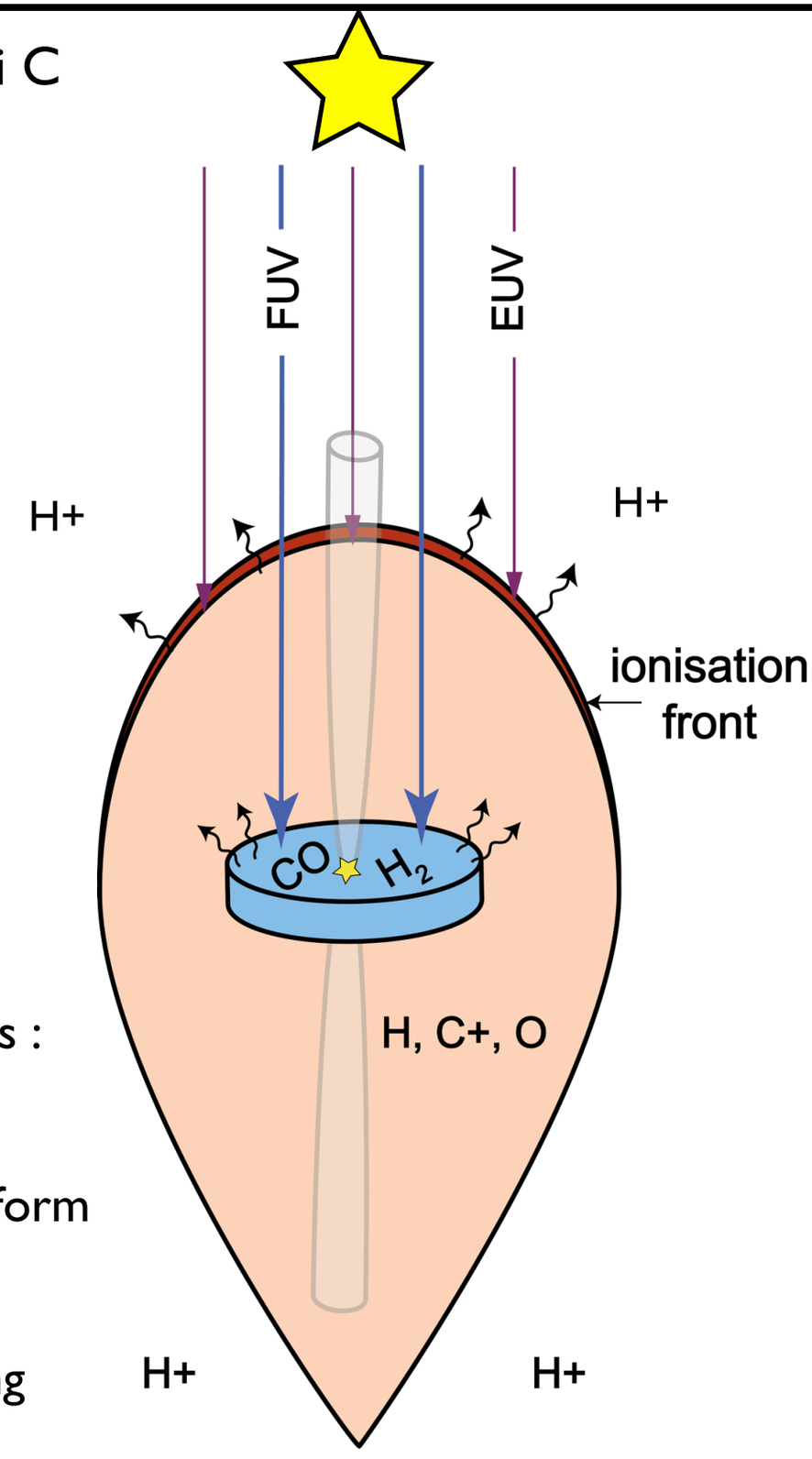
- Most low/intermediate mass stars form near massive stars (including the Sun)

- What is the effect of the presence of a massive star on protoplanetary disk ?

[Henney et al. 1996]
[Bally et al. 1998]

Externally illuminated protoplanetary disks





- UV exposition heats the disk, pressure increases and gas flows outwards : photoevaporation

- How fast does the disk looses all its gas ? Does it have enough time to form planets ? Can the flow trigger planet formation ?

- The physical structure of these systems has been studied in the 90s using PDR models (e.g. Johnstone et al. 1990, Storzer & Hollenbach 1999)

Objectives

Goal: understand the dynamical properties of photodissociation regions

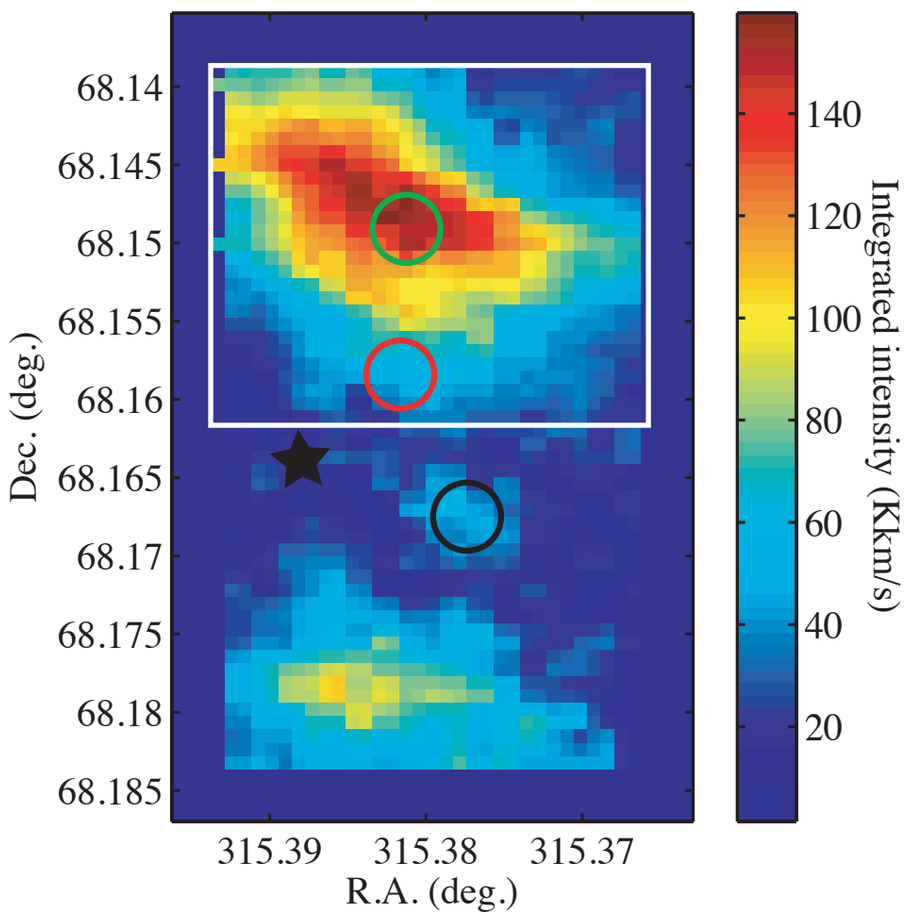
1) In extended photodissociation regions in star forming regions, where the spatial distribution of the main cooling lines in the far infrared can be resolved with Herschel

2) In unresolved externally illuminated protoplanetary disks, which we can for the first time detect with Herschel in the far-infrared where the key cooling lines of PDRs are found ([OI], [CII], CO)

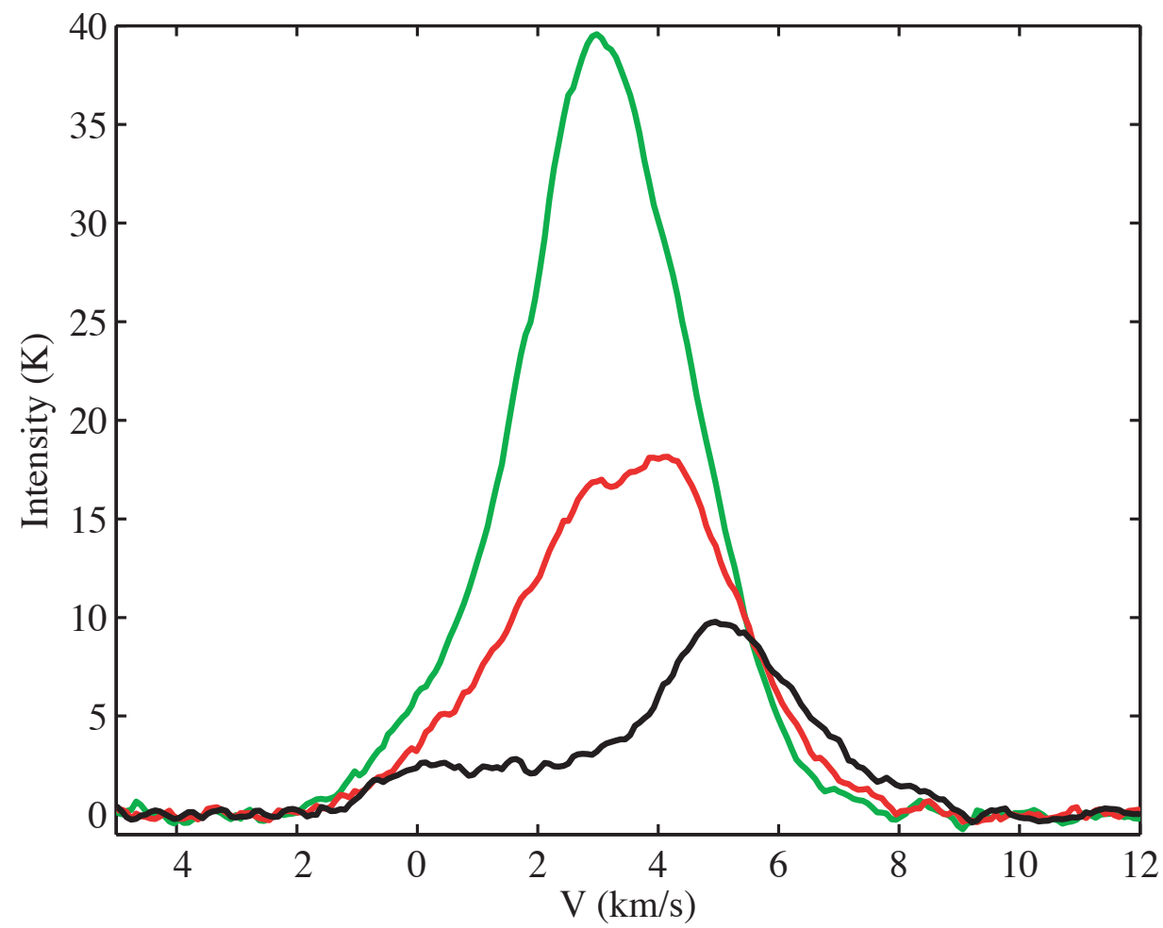
HIFI [CII] cube of NGC 7023

data reduction J. Pety & D. Teyssier

Integrated [CII] map



Selected [CII] spectra



Hypothesis

- Each observed spectrum is a linear combination of elementary spectra
- We observe different mixtures of the same elementary spectra

An hybrid blind signal separation method to decompose spectral cubes

[Boulais, Berné & Deville in prep.]

The problem

$$X = A \times S$$

Approach:

$$X \approx W \times H$$

Goal calculating W *and* H, from X, this is obviously an ill-posed problem

Additional constraints

- The number of rows of **H** is stet by the number of eigenvalues of the covariance matrix of **X**, needed to capture the data up to the noise level (equivalent to the number of orthogonal «principal components»)

- **W** and **H** are forced to be positive

- Initialization of **H** is done using «almost pure» spectra (i.e. where only one elementary spectrum dominates) in the data : over 5x5 pixel windows, we compute the correlation matrix of the spectra and where the average correlation is high the spectrum is «almost pure»

- Initialization of **W** is random

Optimization

[Lee & Seung, Nat. 2001]

Criterion

$$\|X - WH\|^2 = \sum_{ij} (X_{ij} - (WH)_{ij})^2$$

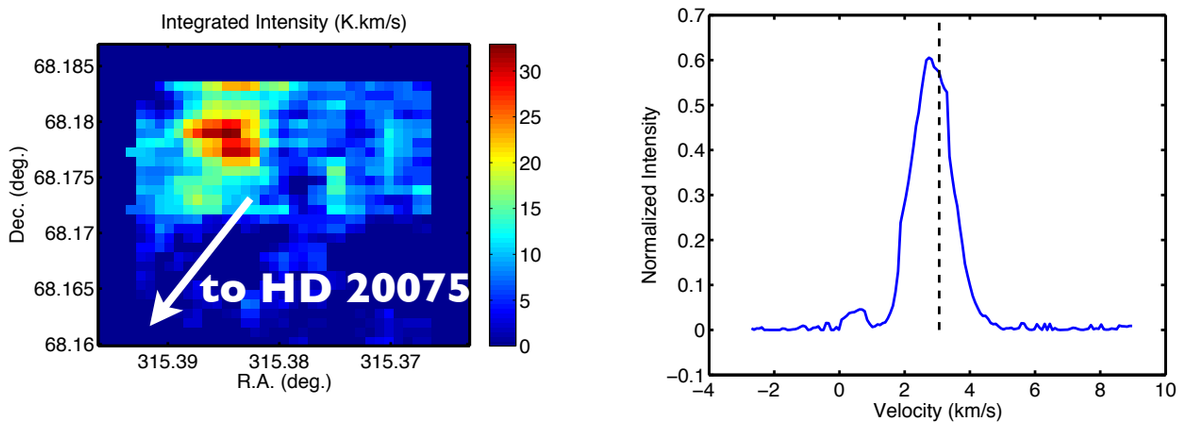
Algorithm

$$H_{a\mu} \leftarrow H_{a\mu} \frac{\sum_i W_{ia} X_{i\mu} / (WH)_{i\mu}}{\sum_k W_{ka}}, W_{ia} \leftarrow W_{ia} \frac{\sum_\mu H_{a\mu} X_{i\mu} / (WH)_{i\mu}}{\sum_\nu H_{a\nu}}$$

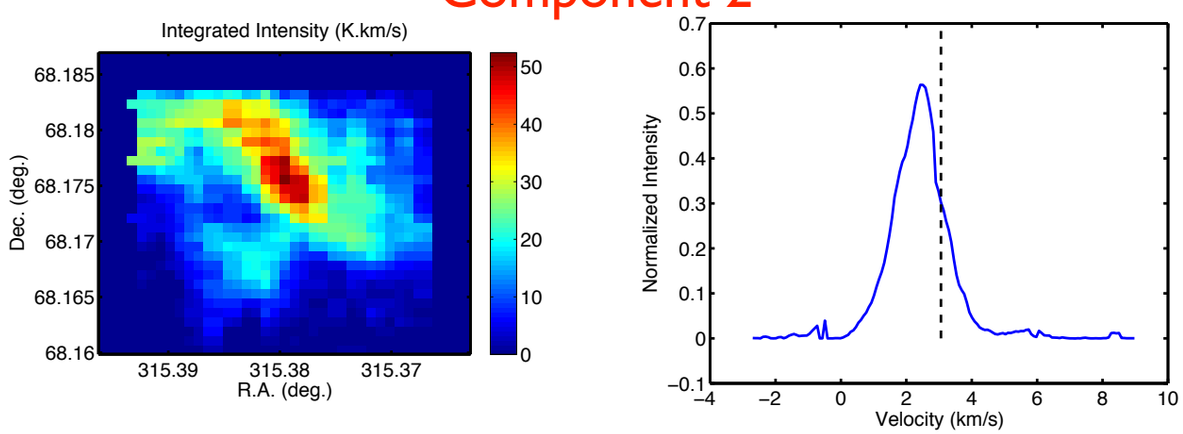
+ Monte-Carlo runs to check independence to random W initialization

Decomposition results for NGC 7023

Component 1



Component 2



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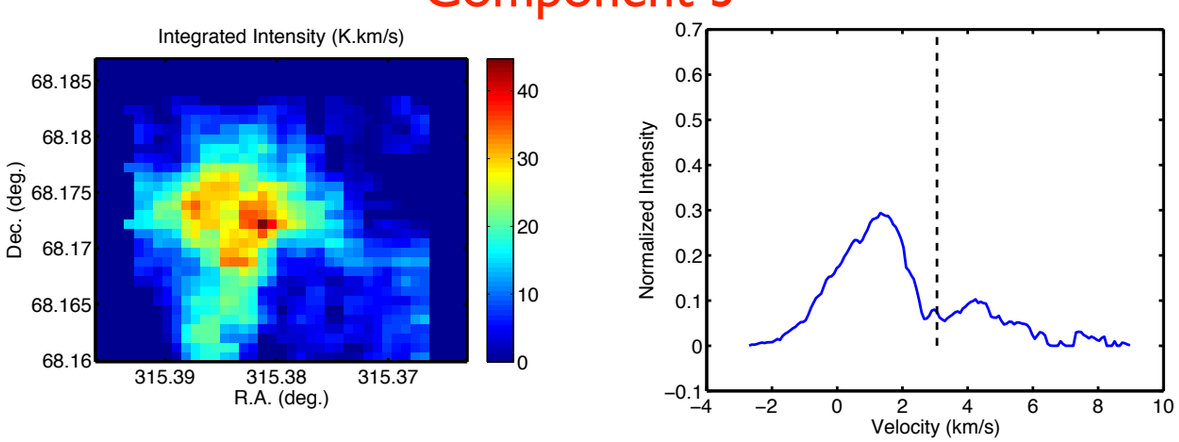

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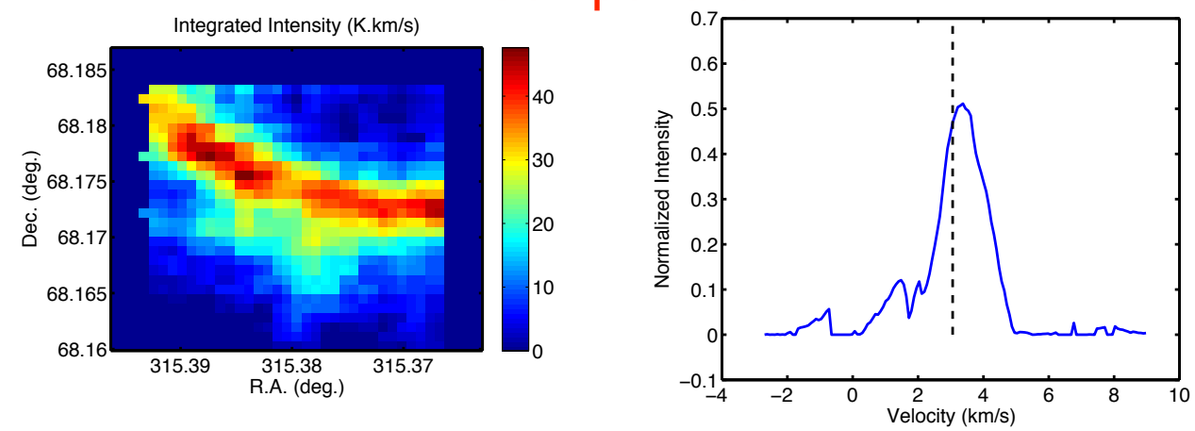

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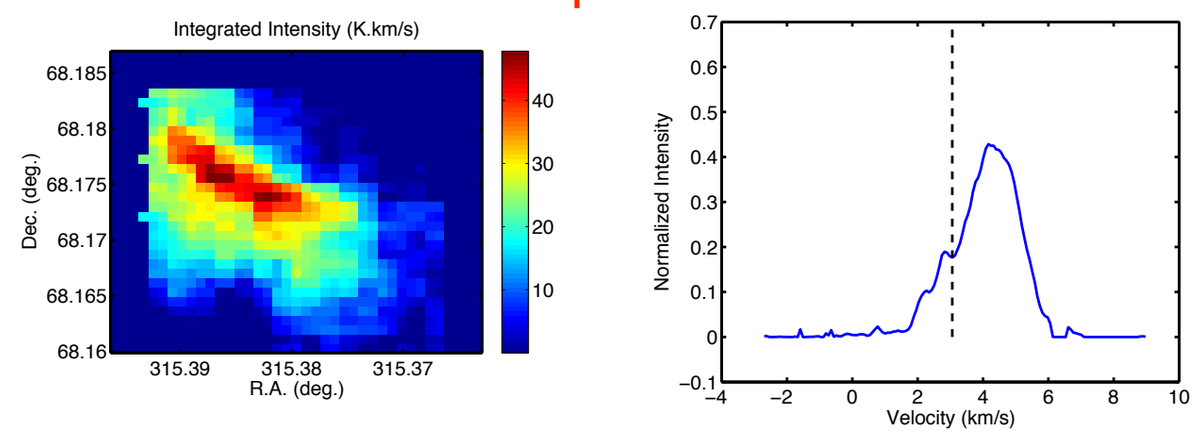
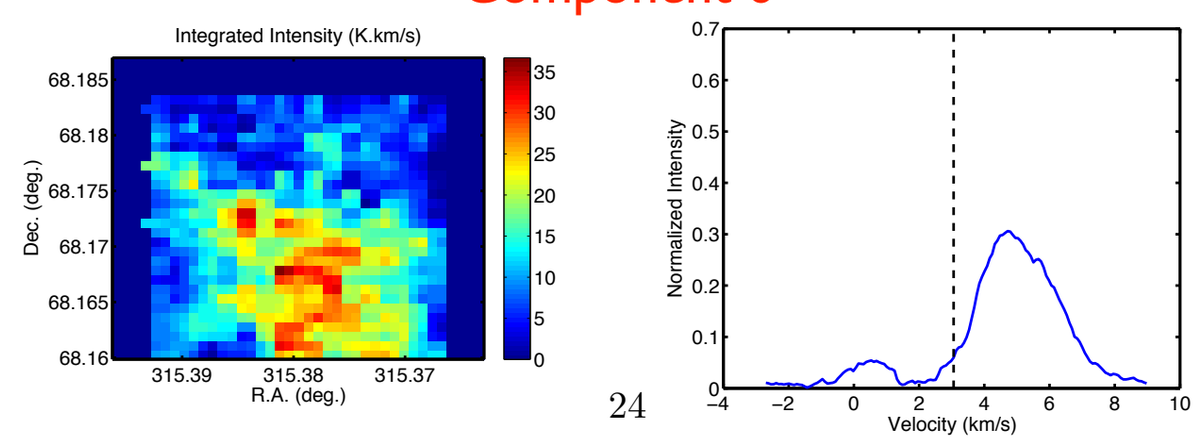


Component 6



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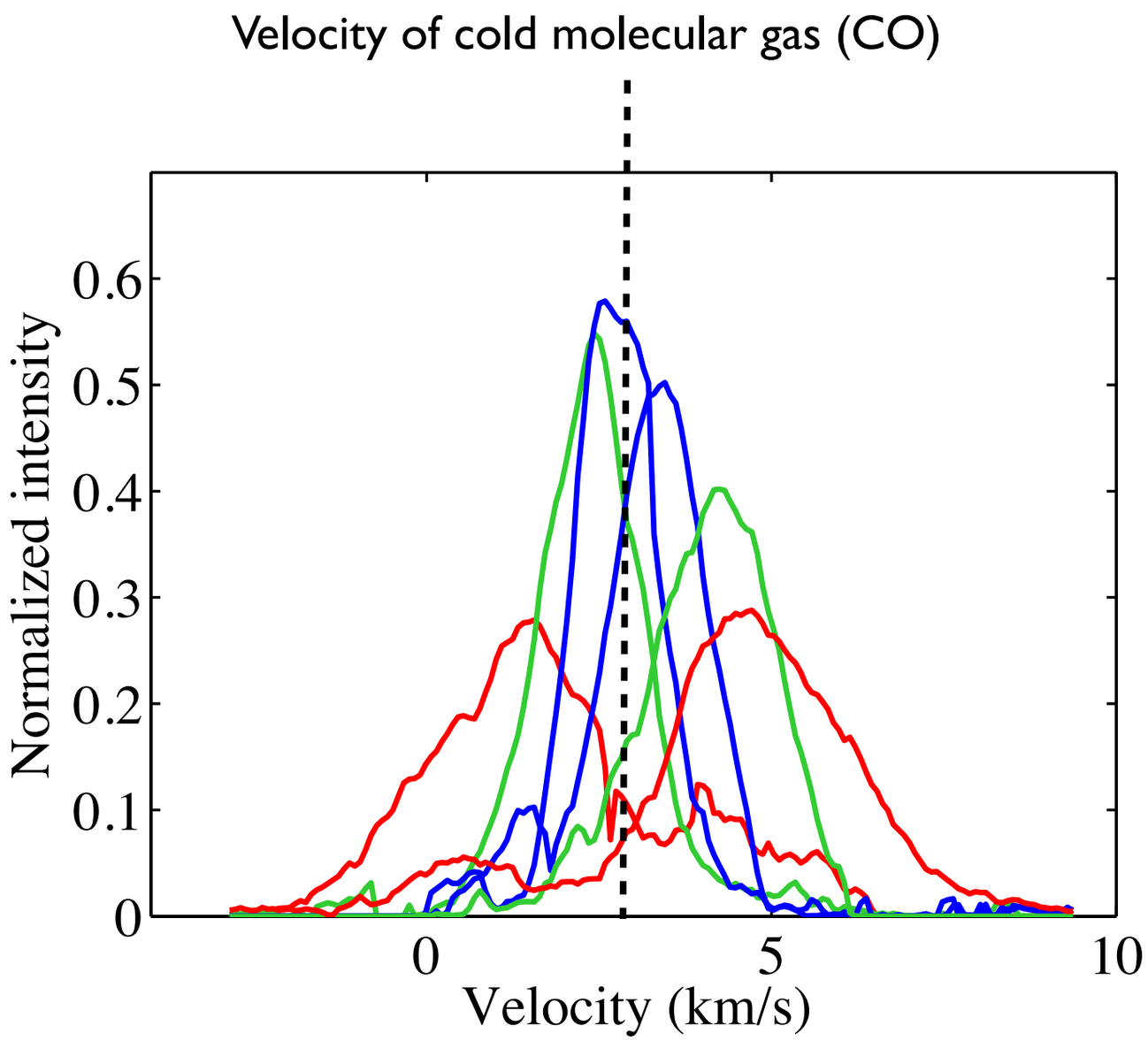
Proposed kinematic structure



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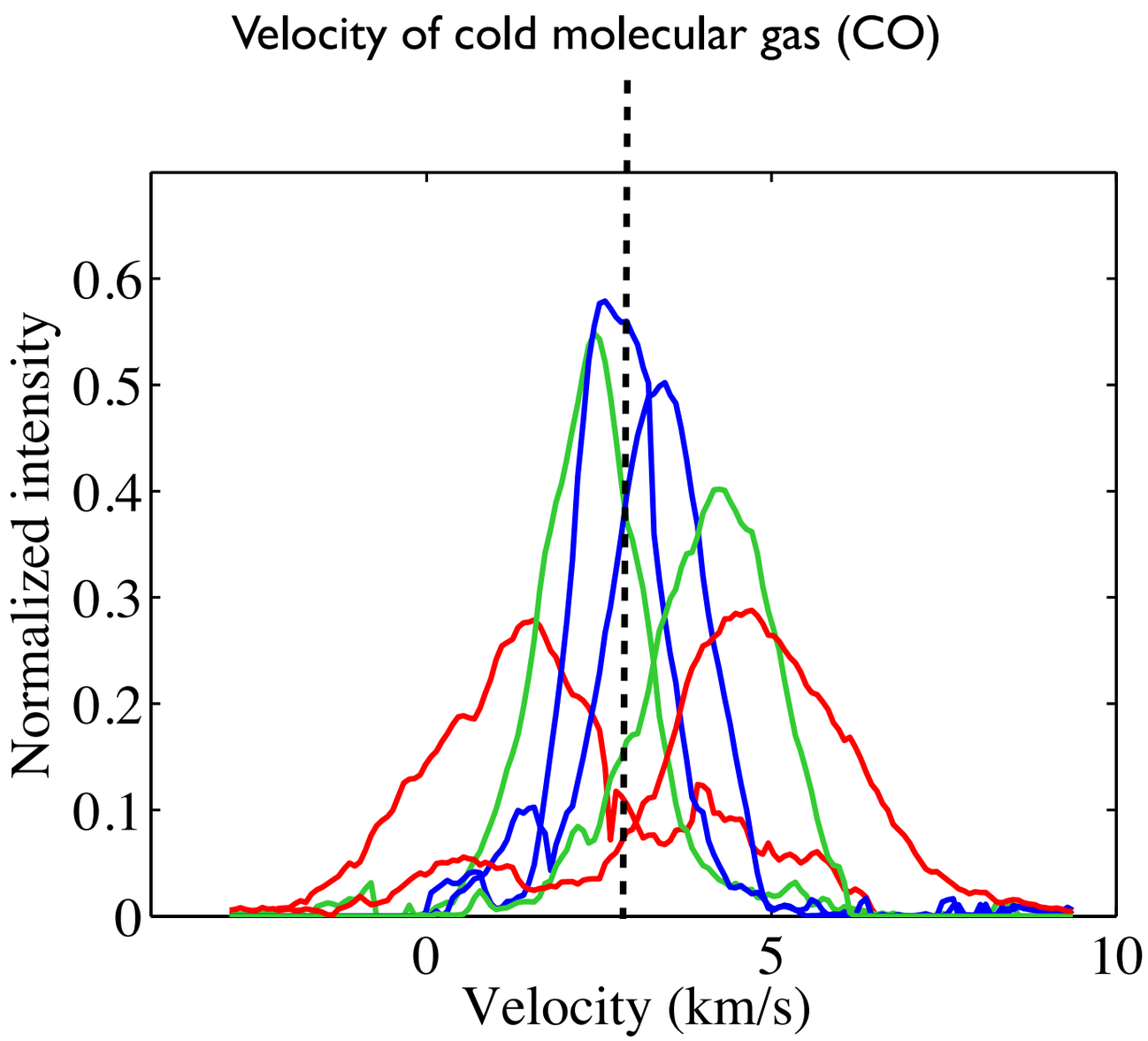
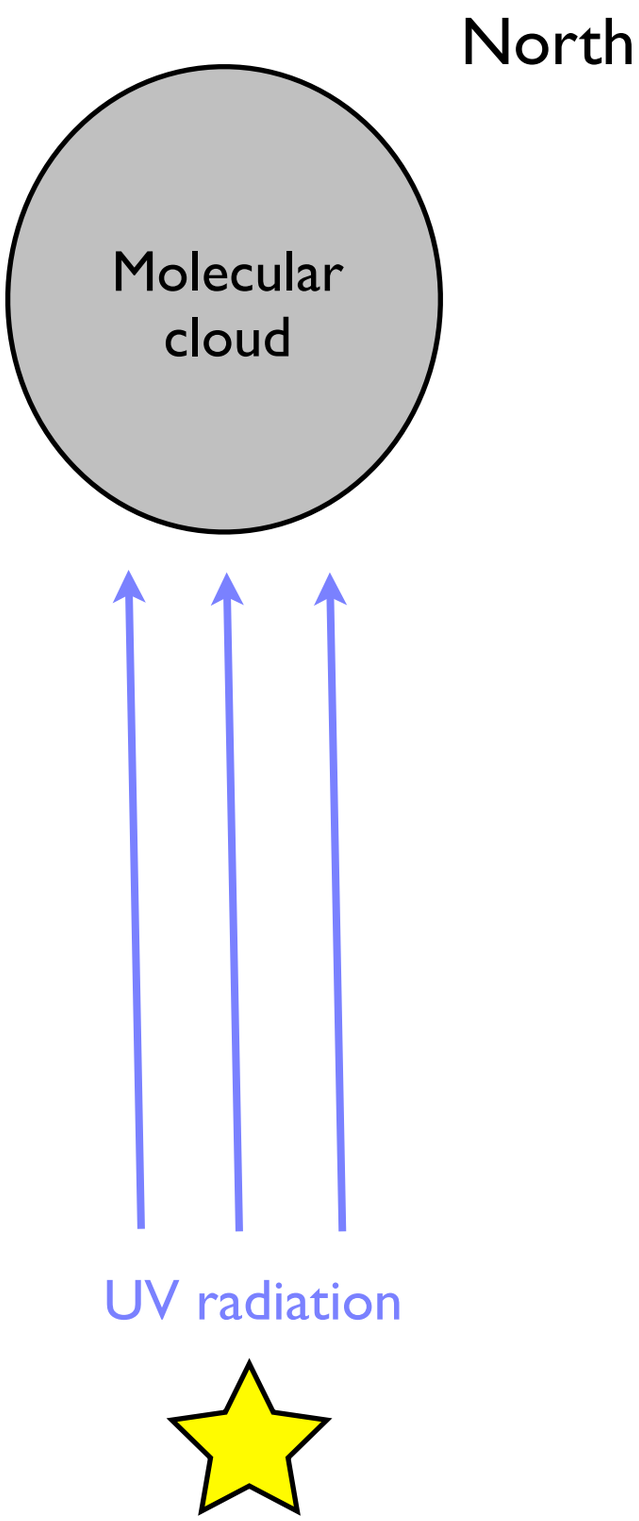
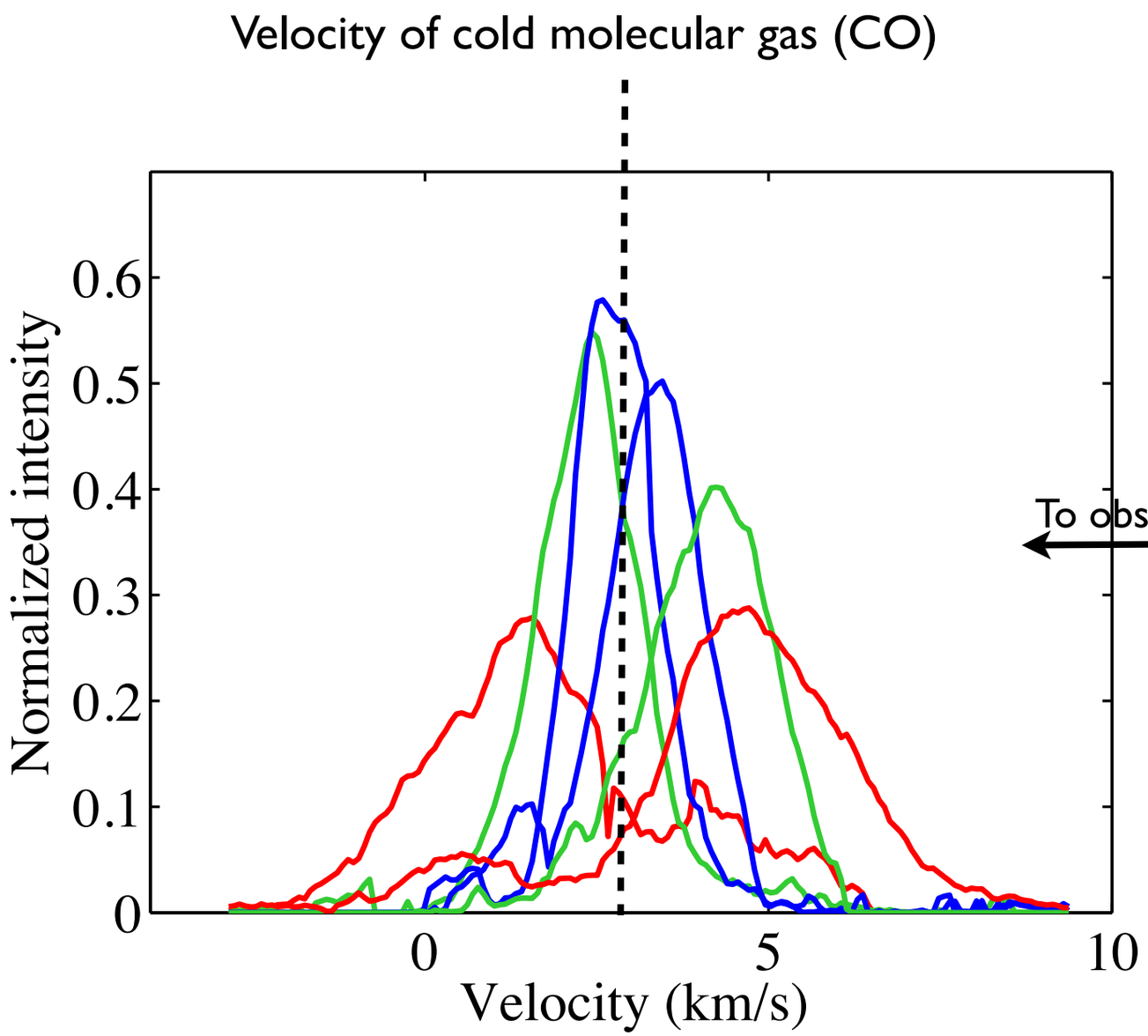
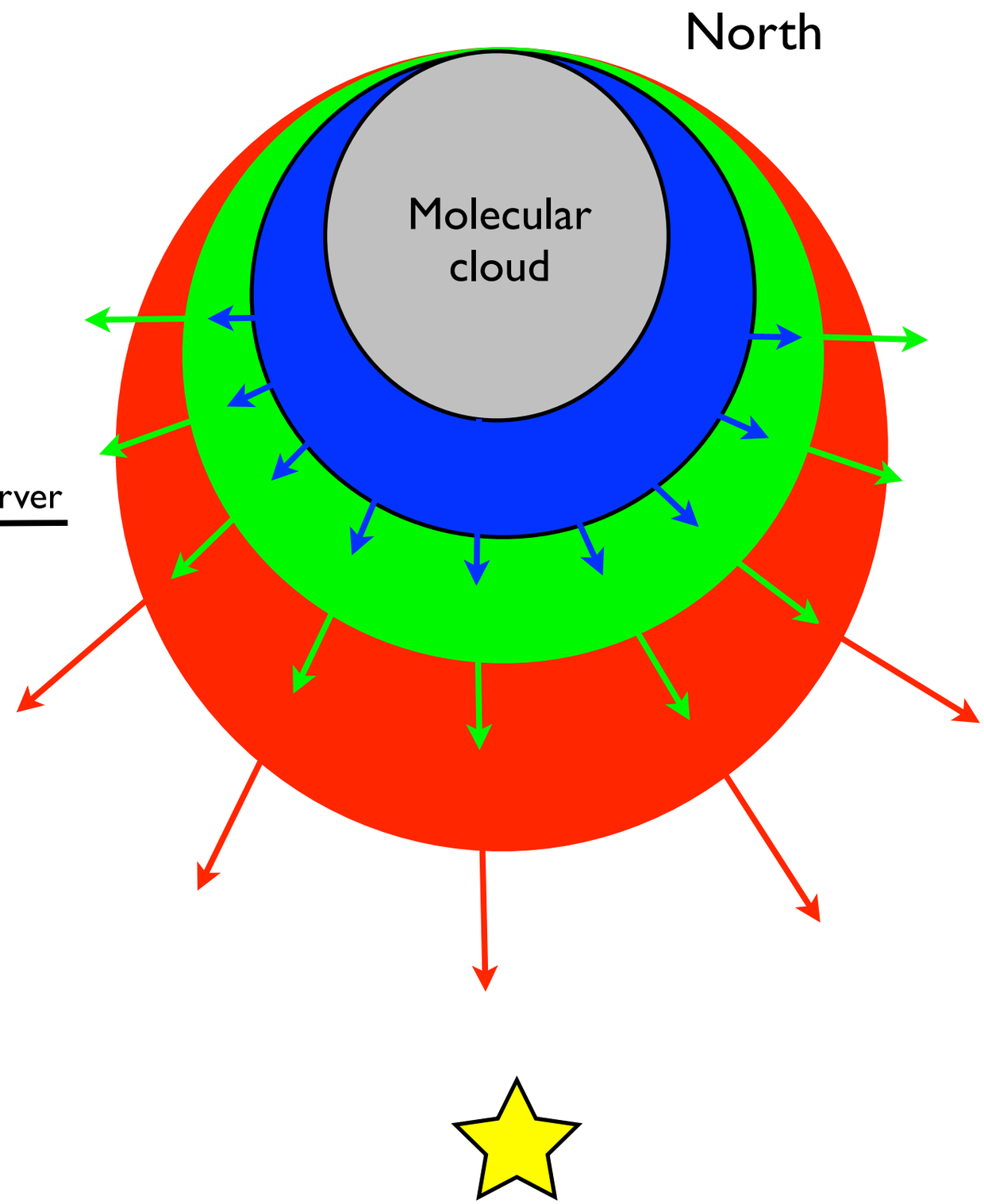




Photoevaporation flow





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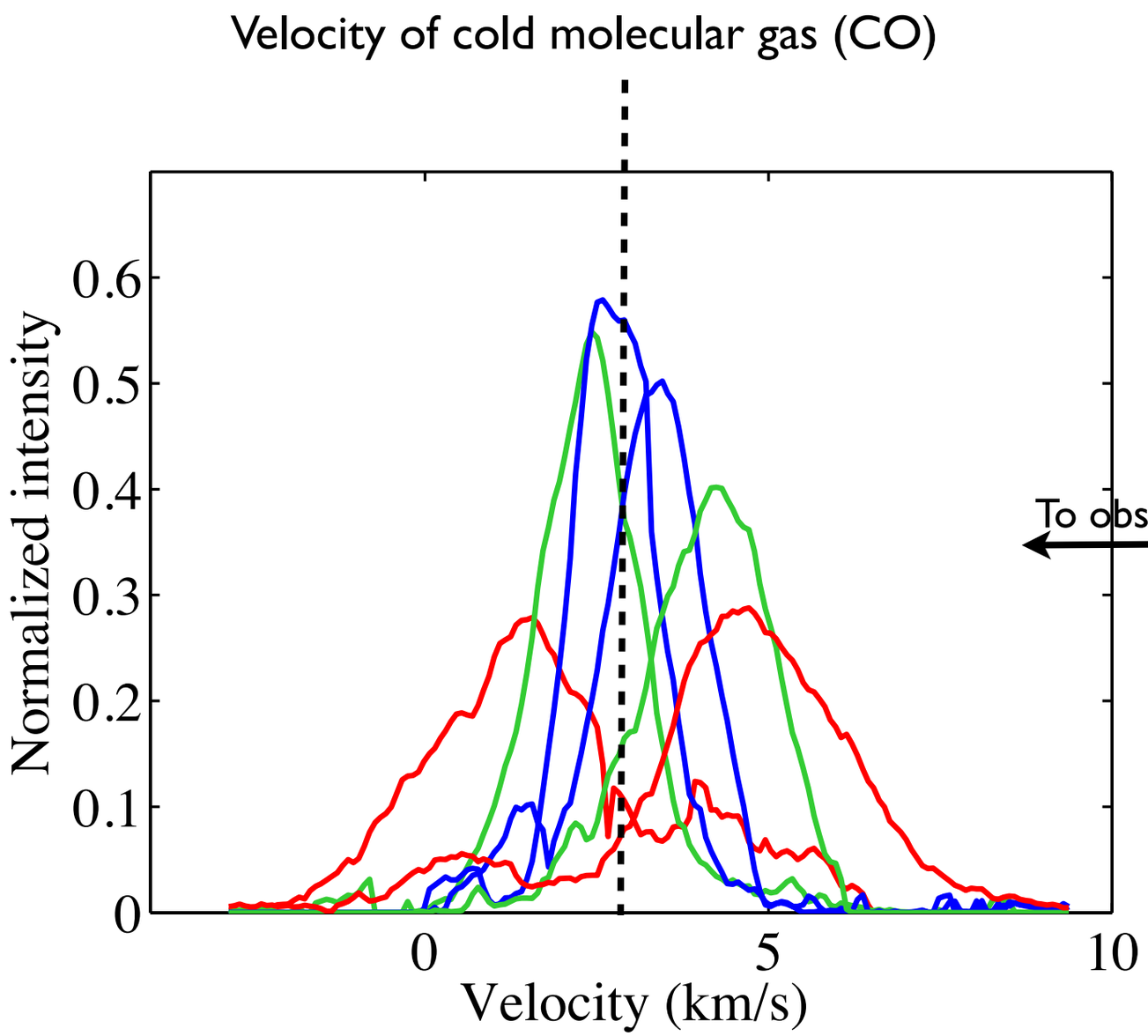
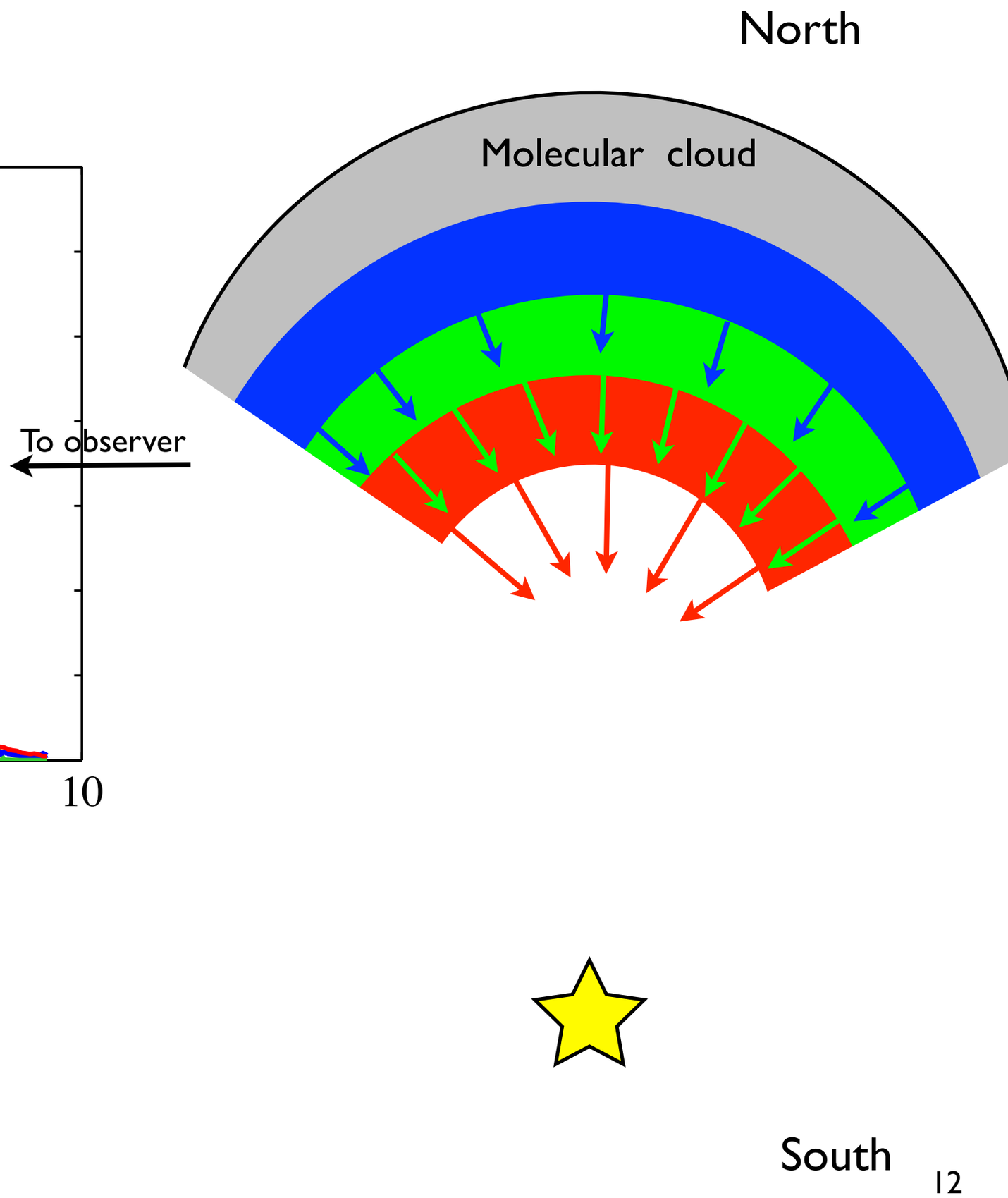


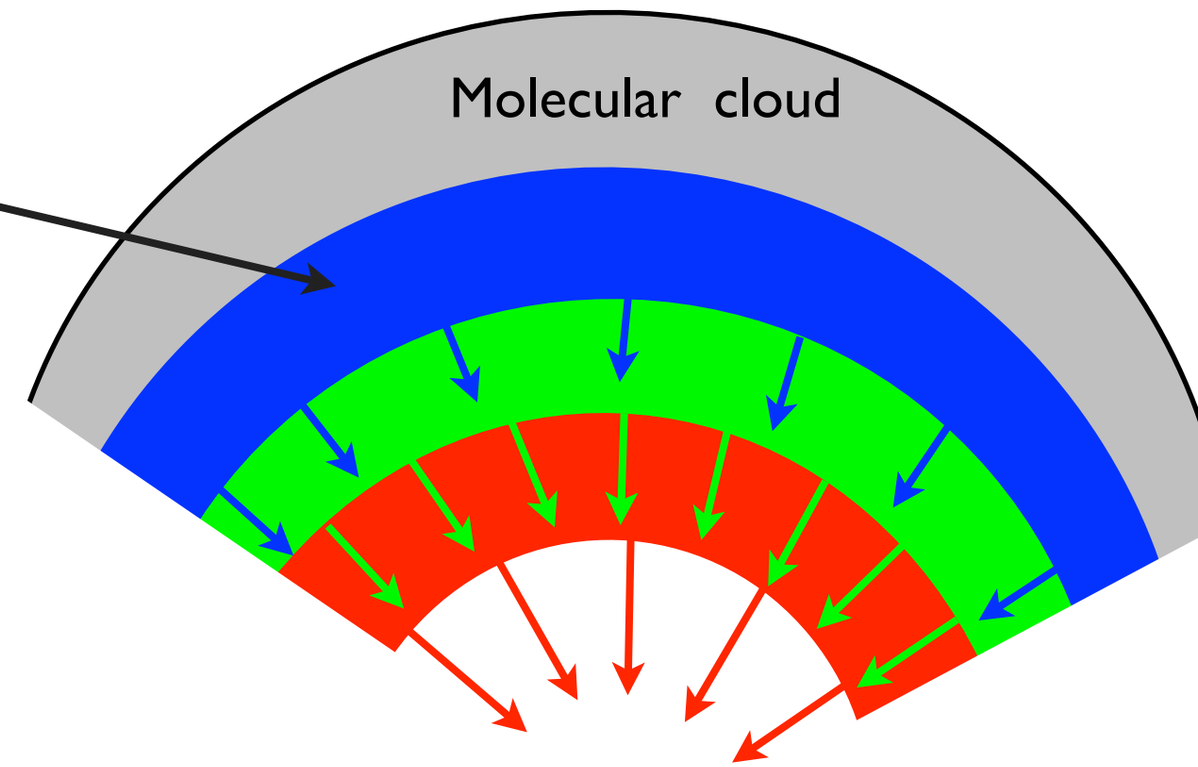


Photoevaporation flow

North

$P \sim 10^8$ K.cm^{-3}

To reproduce High-J CO lines (Joblin et al. in prep, Koehler et al. A&A 2014)



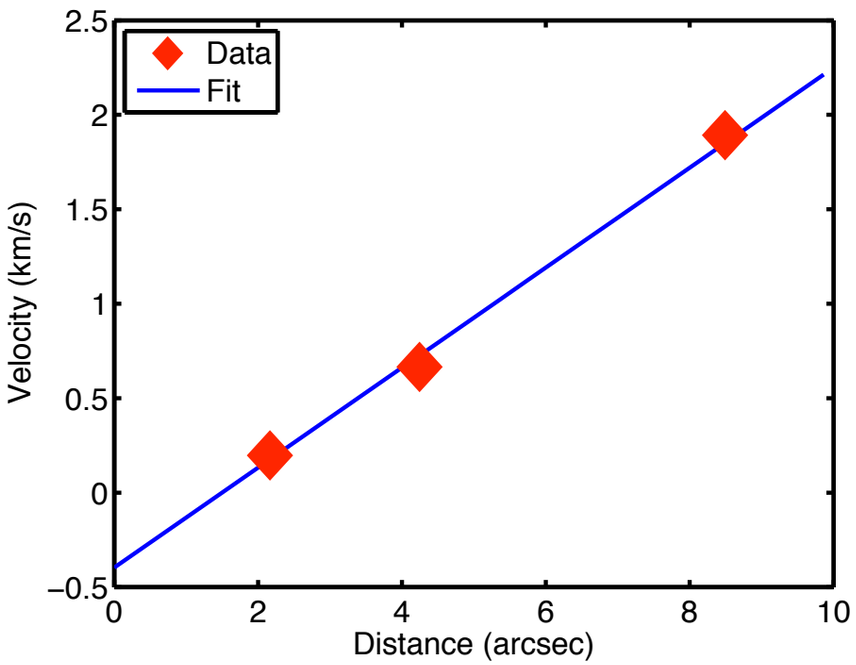
$P < 10^7$ K.cm^{-3}

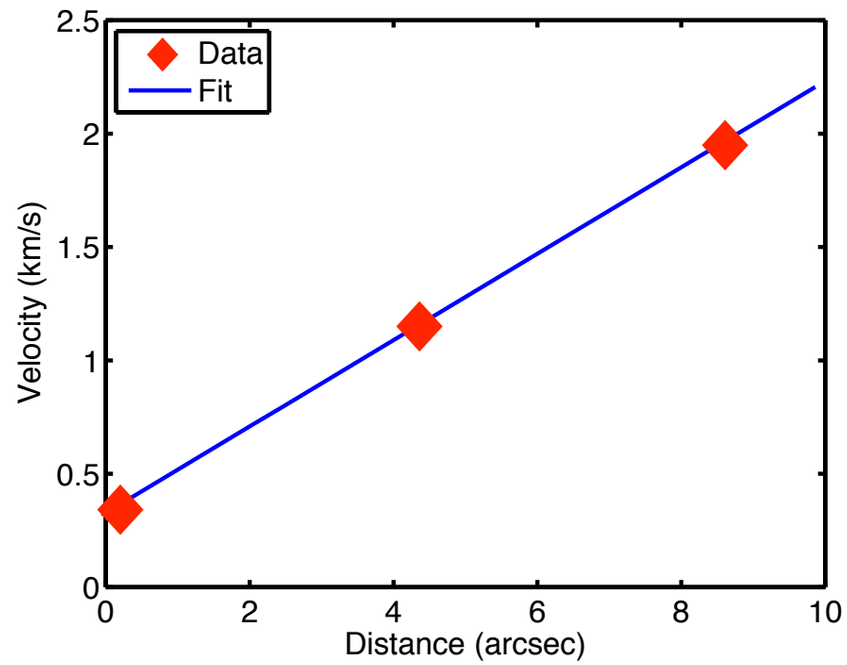
According to several tracers:
$n_H < 10^4$ cm^{-3}, $T < 10^3$ K

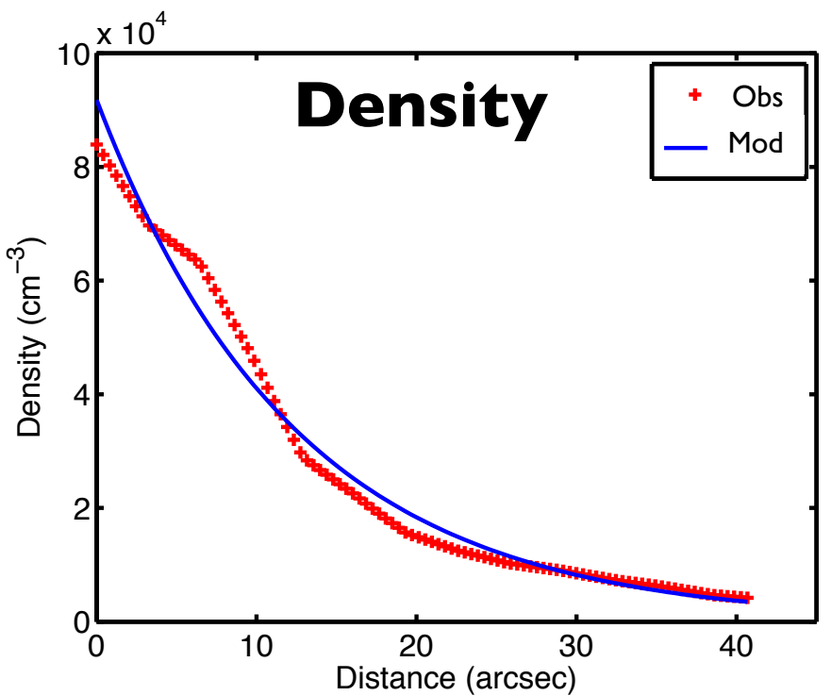
South

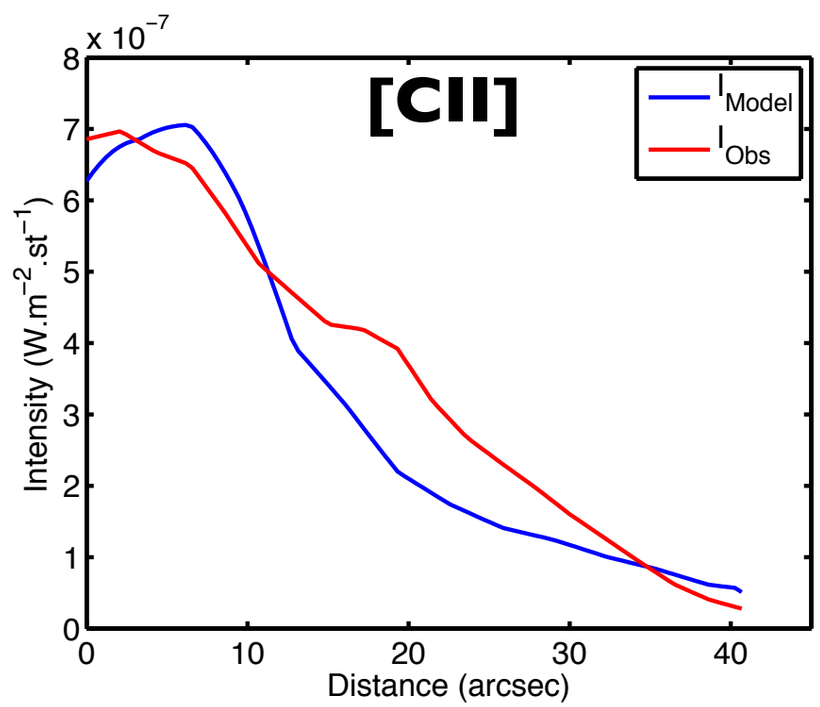
Isothermal flow toy model

Velocity gradients









$T = 530$ K
$C = 1.6$ km s^{-1}
$t = 2 \times 10^4$ years
$P_{min} = 7 \times 10^6$ K cm^{-3}

Model constrained by observed velocity gradient, intensity of [CII] and column density as derived by Herschel observations of dust emission

Conclusions

- Photodissociation regions are dynamically active : photoevaporation

- Studies of extended regions allow to resolve the photoevaporation flow, and to characterize its density profile, velocity gradient and age (?)

- In externally illuminated protoplanetary disks, modeling of Herschel observation with the Meudon code indicates the presence of a pressure gradient: they are also subject to photoevaporation, but there are issues with the found mass loss rates.

- Do we need a PDR model with dynamics ?

The end