Diffusion-advection effects in Photo-dissociation regions

B. Aleena[1], V. Ossenkopf-Okada[1], and M. Röllig[1]
[1] Institute of Physics I, University of Cologne, Germany, baby@ph1.uni-koeln.de

Problem

Molecular clouds are not static but species are transported through them by random motions. Quantifying this transport is essential for understanding the underlying physical conditions in a molecular cloud.

? How to evaluate the diffusion coefficient?

? What are the diffusion coefficient and coherence length of turbulent flows?

? Are there any observable effects?

Basic Concepts

Molecular diffusion($\phi_{\rm mol}$): diffusion due to abundance gradients of different molecules, atoms, and ions in the molecular cloud
Turbulent diffusion($\phi_{\rm tu}$): diffusion due to the turbulent eddies.
Thermal diffusion($\phi_{\rm th}$): diffusion due to the non-uniform temperature of the cloud.
Advection($\phi_{\rm adv}$): flow of material due to a pressure gradient.

Model

1. We investigated the diffusion-advection effects in the **multi-fluid gas** of photon-dissociation regions (PDRs).
2. A turbulent mixing-length theory along with molecular and thermal diffusion is included in the **KOSMA-τ PDR model**.
   * 61 different species, 816 reactions
   * tested with multiple temperature, density distributions, and radiation fields
3. The KOSMA-τ PDR model solves the chemistry, level populations, and energy balance simultaneously in a spherical geometry.

Math box

Diffusion-advection rates,

$$\frac{\partial n}{\partial t} = -\frac{\partial \phi}{\partial x} = -\frac{\partial \phi_{\rm tu}}{\partial x} - \frac{\partial \phi_{\rm mol}}{\partial x} + \frac{\partial \phi_{\rm th}}{\partial x} + \frac{\partial \phi_{adv}}{\partial x} \quad (1)$$

$\phi_{\rm tu} = K_{\rm tu}\frac{\partial n}{\partial x}$ $\quad K_{\rm tu} = V_{\rm turb}{\rm L}$ (shown in fig[3])

$$\phi_{\rm mol} = K_{\rm mol}\frac{\partial n}{\partial x} \qquad K_{\rm mol} = \sqrt{\frac{5kT_{\rm i}}{3\mu}}\frac{1}{\sigma N}$$

$$\phi_{\rm th} = \frac{K_{\rm th}}{T}\frac{\partial T}{\partial x} \qquad K_{\rm th} = K_{\rm mol}k_T$$

where, μ: average molecular weight, σ: cross-section, N: total number density, k_T: thermal diffusion factor

This research is carried out within the Collaborative Research Centre 956, sub-project C01, funded by the Deutsche Forschungsgemeinschaft (DFG) – project ID 184018867.

Dynamic effects in the chemistry

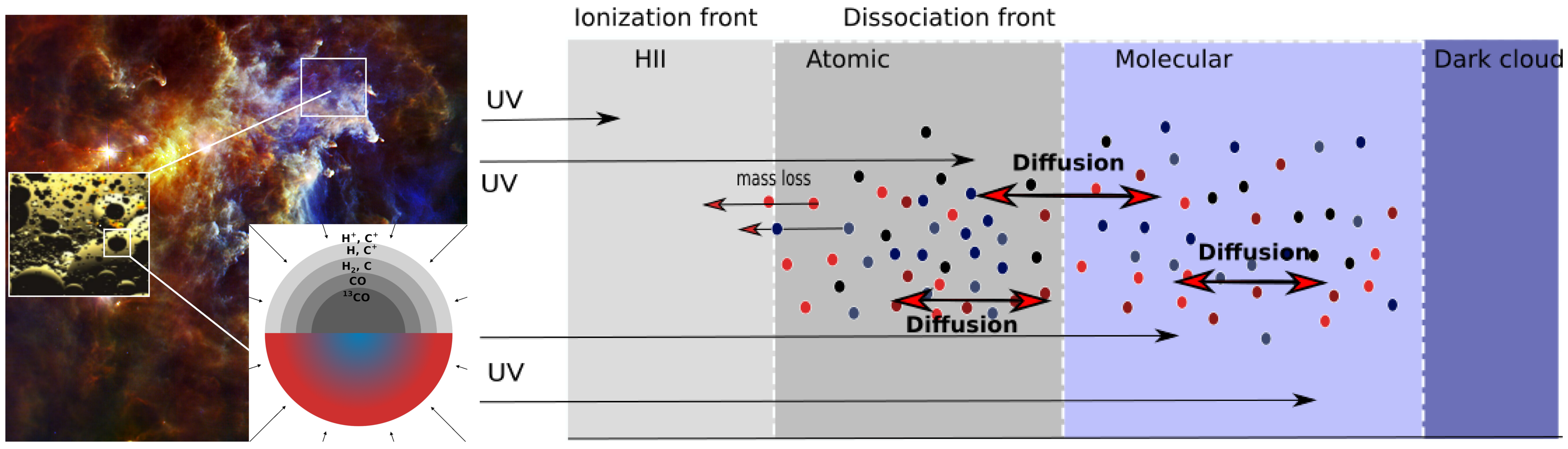

Fig.2: Spherical PDR model(left) and a simplified model depicting the diffusion and mass loss from the cloud(right).

* **limits of the total diffusion coefficient**: $10^{15} - 10^{22}$ cm^2 s^{-1}
* **coherence length of turbulent flows, L:** 5 – 10% of the radius of the cloud.
* Diffusion increases the surface temperature compared to the non-diffusive case.
* **For more results scan** $\Longrightarrow$

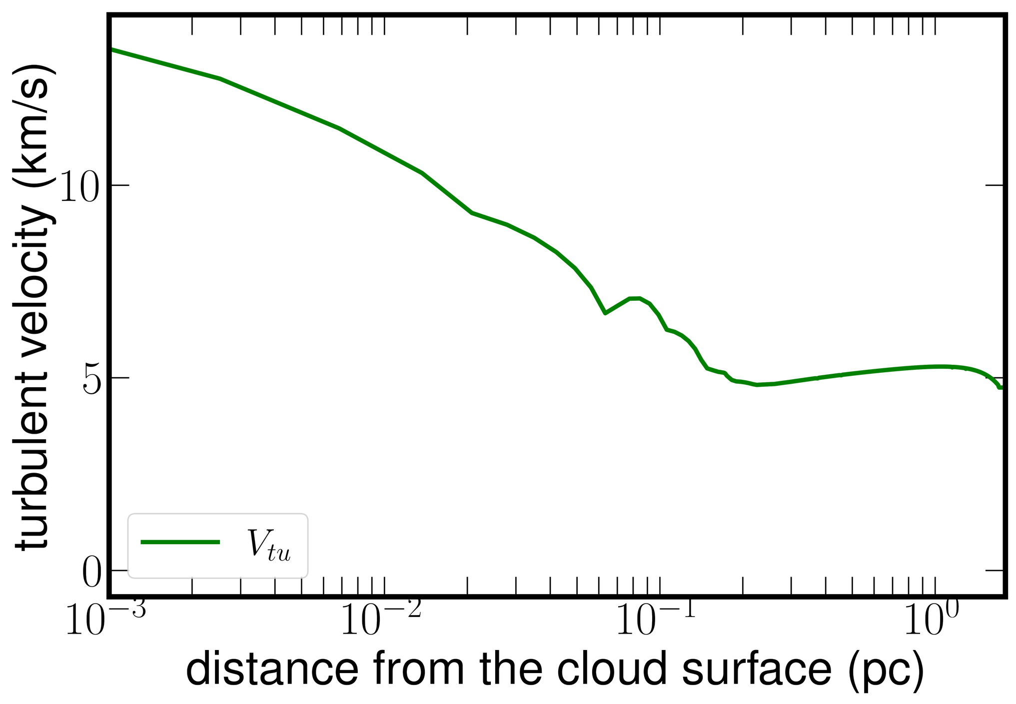

Fig.3: Turbulent velocity as a function of distance from the surface of the cloud.

Chemistry is no longer a local problem!

* The H/H_2 ratio is changing as a function of the diffusion velocity, with knock-on effects for the whole PDR chemistry.
* Diffusion increases the abundance of H^+, He^+, OH^+, CH^+, and decreases that of He, CH, CO in the warm gas at intermediate optical depths.
* The density profiles of C, C^+, HCO, and HCO^+ are shifted towards the cloud center.

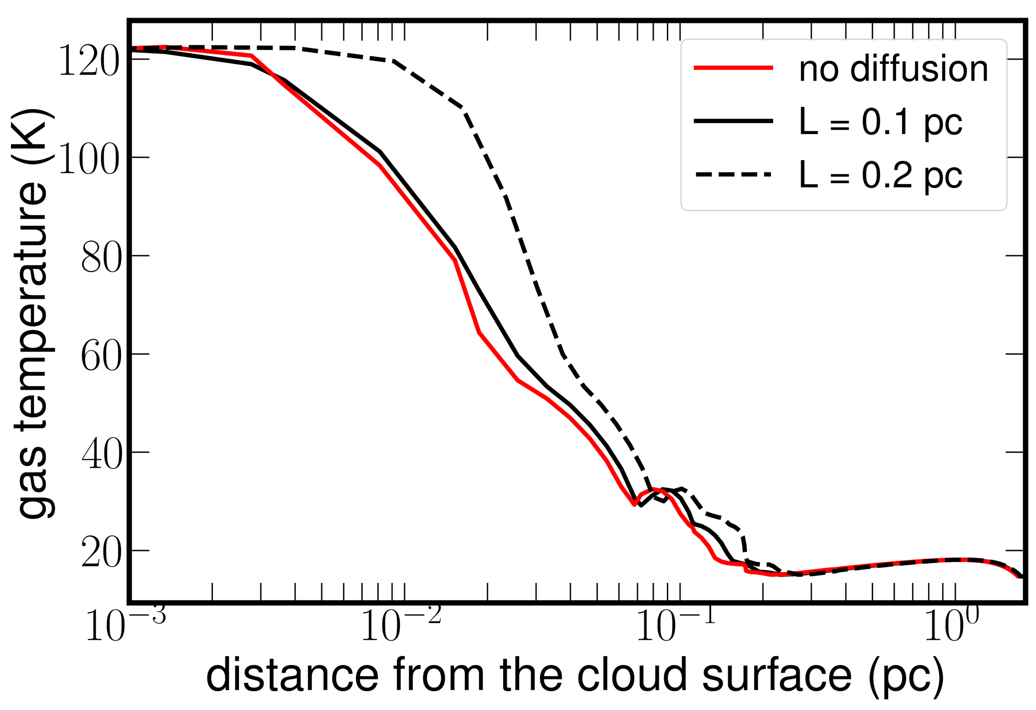

Fig.4: Gas temperature at different diffusion cases

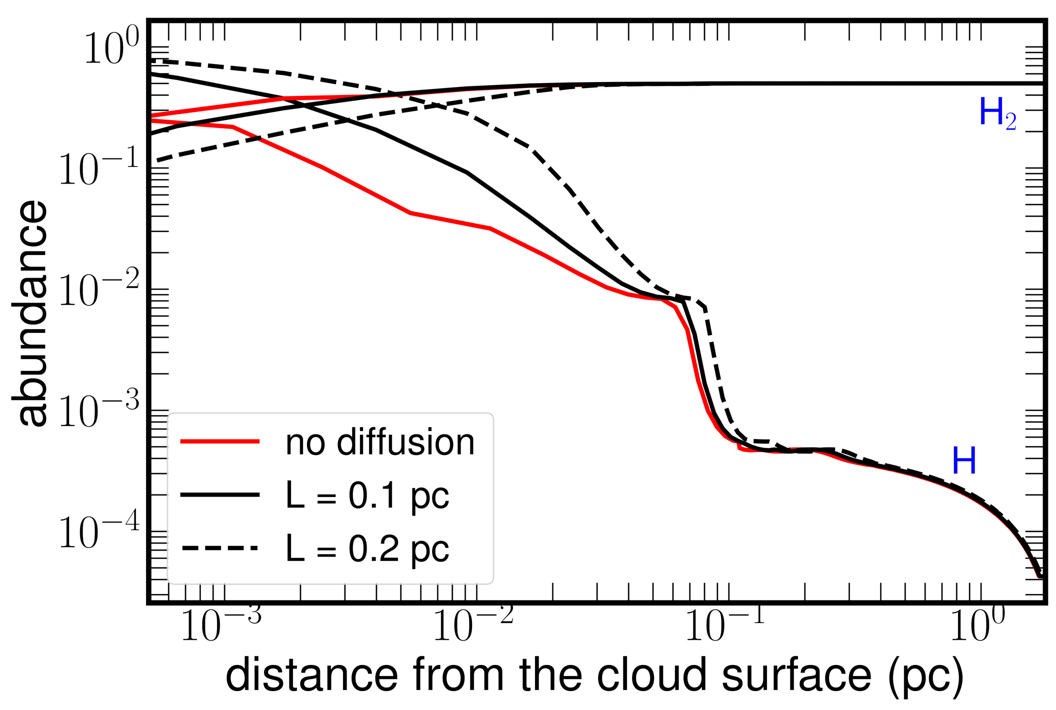

Fig.5: Abundance of H and H_2 at different diffusion cases

Effects are visible in C, C^+, $C^{18}O$, CH^+, CO, and HCO^+

Conclusion

* The limits of the total diffusion coefficients vary between $10^{15} - 10^{22}$ cm^2 s^{-1}
* Coherence length of turbulent flows should vary between 5 – 10% of the radius of the cloud to have an observable effect.
* The line intensities from C, C^+, CH^+, CO, and HCO^+ show significant differences for different diffusion-advection scenarios.
* C, CO, and other organic molecules can be used as a probe to understand non-stationary chemistry effects measuring changes in the PDR stratification from the diffusion and advection of gas.