Diffusion-advection effects in Photo-dissociation regions

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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(ϕ_{mol}): diffusion due to abundance gradients of different molecules, atoms, and ions in the molecular cloud
Turbulent diffusion(ϕ_{tu}): diffusion due to the turbulent eddies.
Thermal diffusion(ϕ_{th}): diffusion due to the non-uniform temperature of the cloud.
Advection(ϕ_{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,

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

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

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

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

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

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Dynamic effects in the chemistry

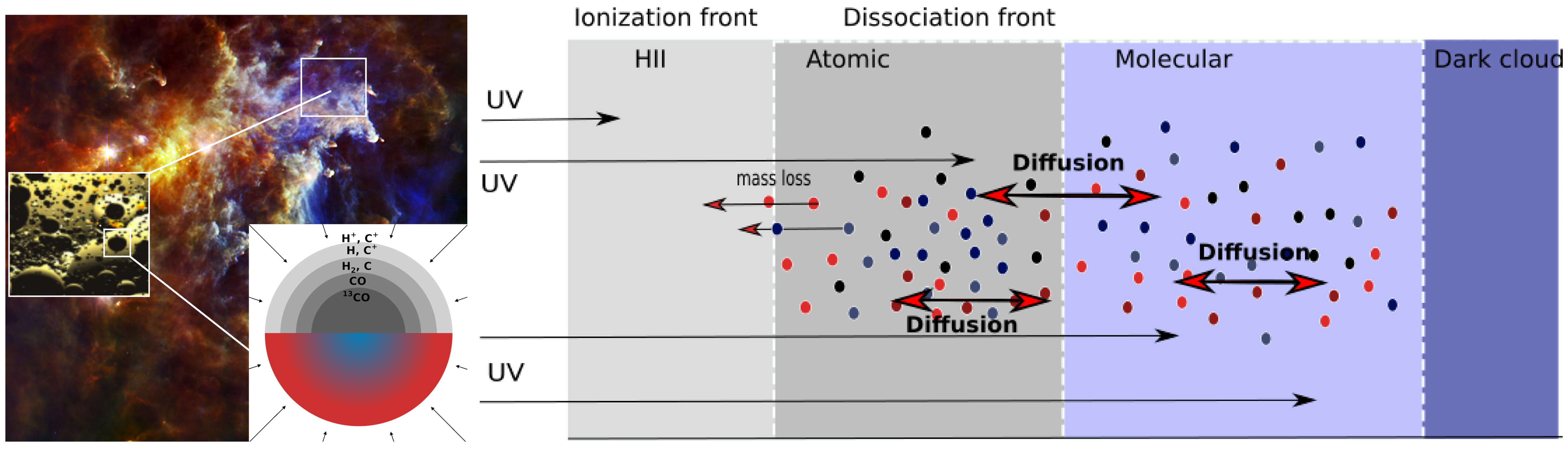

Fig.2: Spherical PDR model(left) and a simplified model depicting the diffusion and mass loss from the cloud(right).

* **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** ⟹

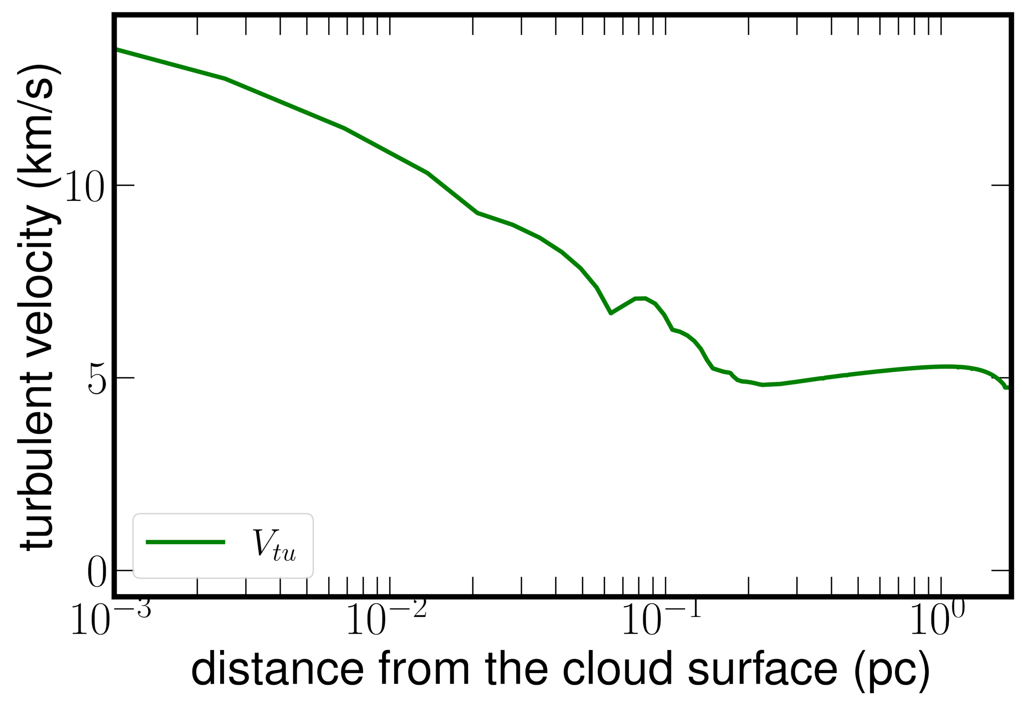

Fig.3: Turbulent velocity as a function of distance from the surface of the cloud.

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.

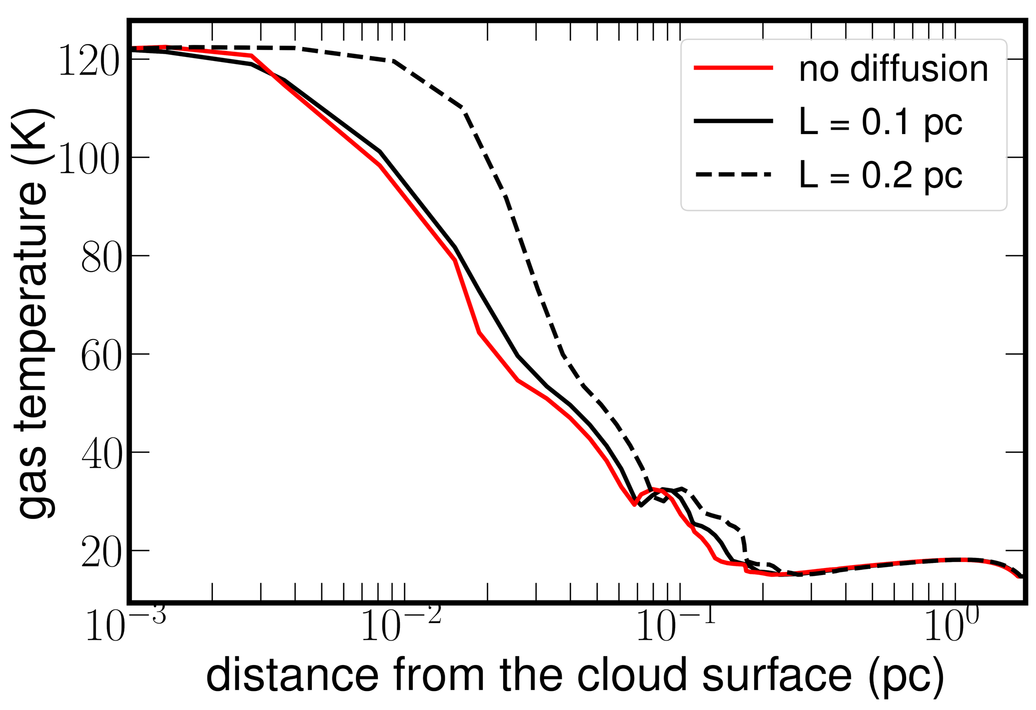

Fig.4: Gas temperature at different diffusion cases

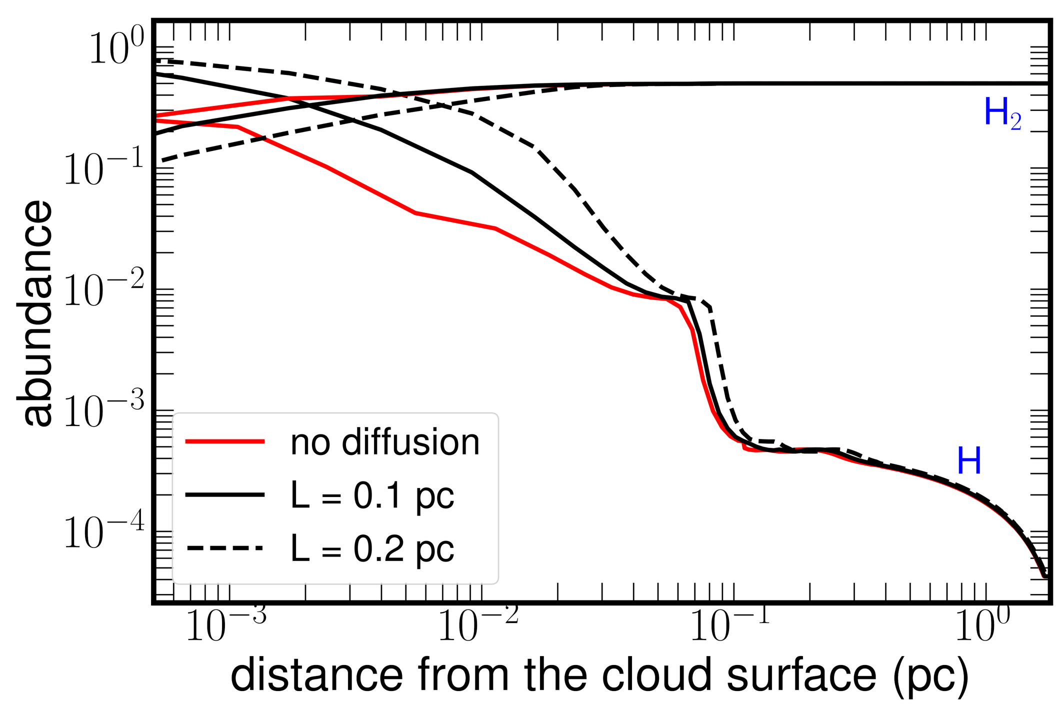

Fig.5: Abundance of H and H_2 at different diffusion cases

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.