H_2CO in the Horsehead nebula: Photo-desorption of dust grain ice mantles

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Motivation

PDR: Photo Dissociation Region

Regions where the chemistry and physics of the gas and dust is dominated by FUV photons (< 13.6 eV).

- Most of the mass in the ISM is found in PDRs.
- They are everywhere.

BUT **their chemical richness and physics is poorly known.**

(Complex) organic molecules have been observed in PDRs with high abundances. HCO, H_2CO, HCOOH, CH_3OH, ...

- How can these molecules form in such harsh environments?

Complex PDR models and chemical networks need well-defined observations to serve as basic references.

Horsehead nebula

A dark nebula: one of the most famous (photographed) objects in the sky.

ESO

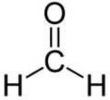
Template PDR:

- Viewed nearly edge-on (Habart et al. 2005).
- Nearby ($\sim$400 pc, $10" \leftrightarrow 0.02$ pc).
- Illuminated by the O9.5 star σ Ori ~ 3.5 pc away (Radiation field: $G_0 = 60$ in Draine units).
- Gas density is well constrained ($n_H \simeq 10^4 - 10^5$ cm^{-1}).

$\Rightarrow$ Reference to chemical models.

H_2CO - Formaldehyde

Guzmán et al. accepted for publication A&A



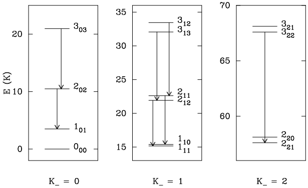
- First organic molecule discovered in the ISM (Snyder et al. 1969)
- Triggers formation of more complex molecules (Charnley et al. 1992).
- Accurate probe of the kinetic temperature and density (Mangum & Wootten 1993).
- Rotational lines are easy to detect from ground-base observations.
- It has been observed in HII regions, hot cores, YSO, molecular clouds, comets, PDRs..
  - Diffuse clouds: $\sim 10^{-9}$ (e.g., Liszt & Lucas 1995; Liszt et al. 2006)
  - W33A protostar: $\sim 10^{-7}$ (Roueff et al. 2006)
  - ρ Ophiuchi A cloud core: $\sim 5 \times 10^{-9}$ (Bergman et al. 2011)
  - Orion Bar PDR: $\sim 10^{-9} - 10^{-7}$ (Leurini et al. 2010)
- H_2CO can be formed both in the gas-phase and on grains surfaces.

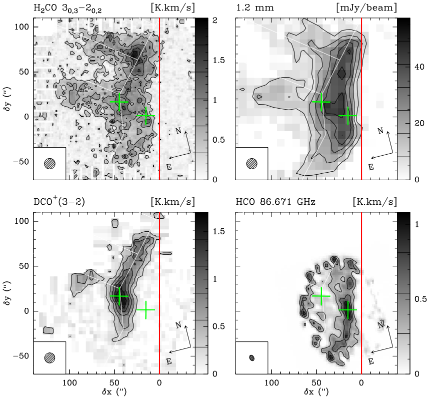
Observations

IRAM-30m

- Map of the p-$H_2CO\,3_{03} - 2_{02}$ line at 218.2 GHz (12" angular resolution).
- Deep integrations of o-H_2CO and p-H_2CO lines towards the PDR and Core positions.

"PDR": HCO peak (Gerin et al. 2009)
$n_H \simeq 10^4$ cm^{-3}, $T_{kin} \simeq 60$ K
"Core": DCO^+ peak (Pety et al. 2007)
$n_H \simeq 10^5$ cm^{-3}, $T_{kin} \simeq 23$ K





H_2CO column density

Radiative transfer models
Montecarlo code,
non-LTE, non-local
Goicoechea et al. (2006)

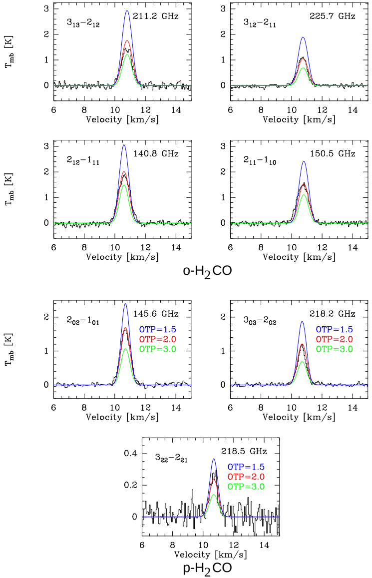
PDR

- $T_{\rm kin} = 60$ K
- $n_{\rm H} = 6 \times 10^4$ cm^{-3}

Best fits:

N(o-H_2CO) $= 7.2 \times 10^{12}$ cm^{-2}
N(p-H_2CO) $= 3.6 \times 10^{12}$ cm^{-2}

[H_2CO] $= 2.8 \times 10^{-10}$
o/p ~ 2



H_2CO column density

Radiative transfer models
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Goicoechea et al. (2006)

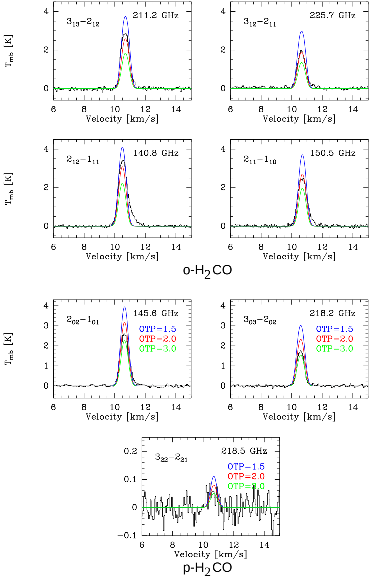
Cold Core

- $T_{\rm kin} = 20$ K
- $n_{\rm H}$ = 1 $\times 10^5$ cm^{-3}

Best fits:

N(o-H_2CO) $= 9.6 \times 10^{12}$ cm^{-2}
N(p-H_2CO) $= 3.2 \times 10^{12}$ cm^{-2}

[H_2CO] $= 2 \times 10^{-10}$
o/p ~ 3



H_2CO chemistry

Meudon PDR model

Le Bourlot et al. (1993), Le Petit et al. (2006)

Pure gas-phase models

- $G_0 = 60$ (Draine units)
- $n_H \sim \delta x^4$
- $T \rightarrow$ thermal balance

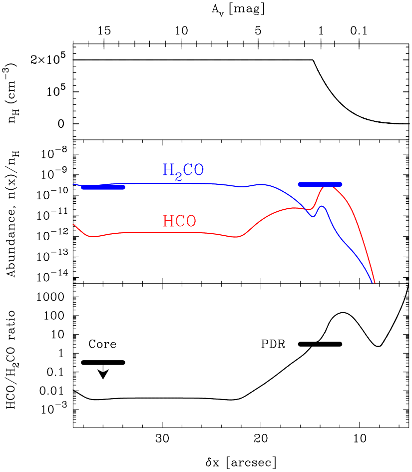
Formation: $CH_3 \underset{O}{\longrightarrow}$ H_2CO (PDR and Core)

Destruction: Photo-dissociation (PDR)
Reactions with ions (Core)

Observations v/s model

$[H_2CO]_{model} \approx [H_2CO]_{obs}$ core ✓

$[H_2CO]_{model} \ll [H_2CO]_{obs}$ PDR ***X***



H_2CO chemistry

Meudon PDR model

Le Bourlot et al., to be submitted

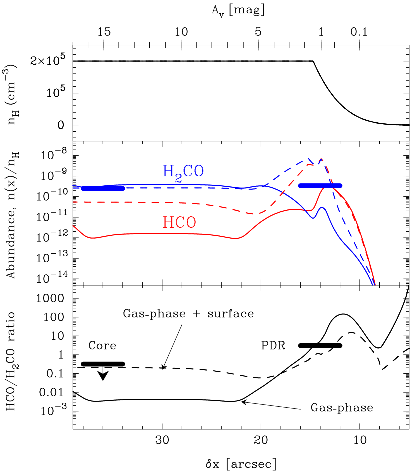
Grain surface chemistry

- Adsorption, desorption and diffusive reactions
  $CO \rightarrow HCO \rightarrow H_2CO \rightarrow CH_3O \rightarrow CH_3OH$
- Thermal and non-thermal desorption
- Grains are strongly coupled to the gas ($T_{dust} \lesssim 20$ K)

Gas-phase vs. grain chemistry

$[H_2CO]_{grain\text{-}chem} \sim 10^3 [H_2CO]_{gas\text{-}phase}$ (PDR)

$\Rightarrow$ Photo-desorption is needed to explain the observed H_2CO abundance in the PDR.



Summary

For the first time we investigate the role of grain surface chemistry in the Horsehead PDR.

- Formaldehyde is found in both the edge of the nebula and in the shielded core with a similar abundance ($\simeq 2 - 3 \times 10^{-10}$).
- Both gas-phase only and grain surface chemistry models reproduce the observed H_2CO abundance in the dense core.
  Main formation route in the core: gas-phase chemistry.
- In the PDR gas-phase chemistry alone does produce enough H_2CO.
  H_2CO forms on the surface of dust grains. Then, it is photo-desorbed into the gas-phase.
- These different formation routes are straightened by the different measured ortho-to-para ratio of H_2CO: $\sim$3 in the core and $\sim$2 in the PDR

Photo-desorption of ices is an efficient mechanism to produce gas-phase H_2CO in the Horsehead PDR.

Next: CH_3OH