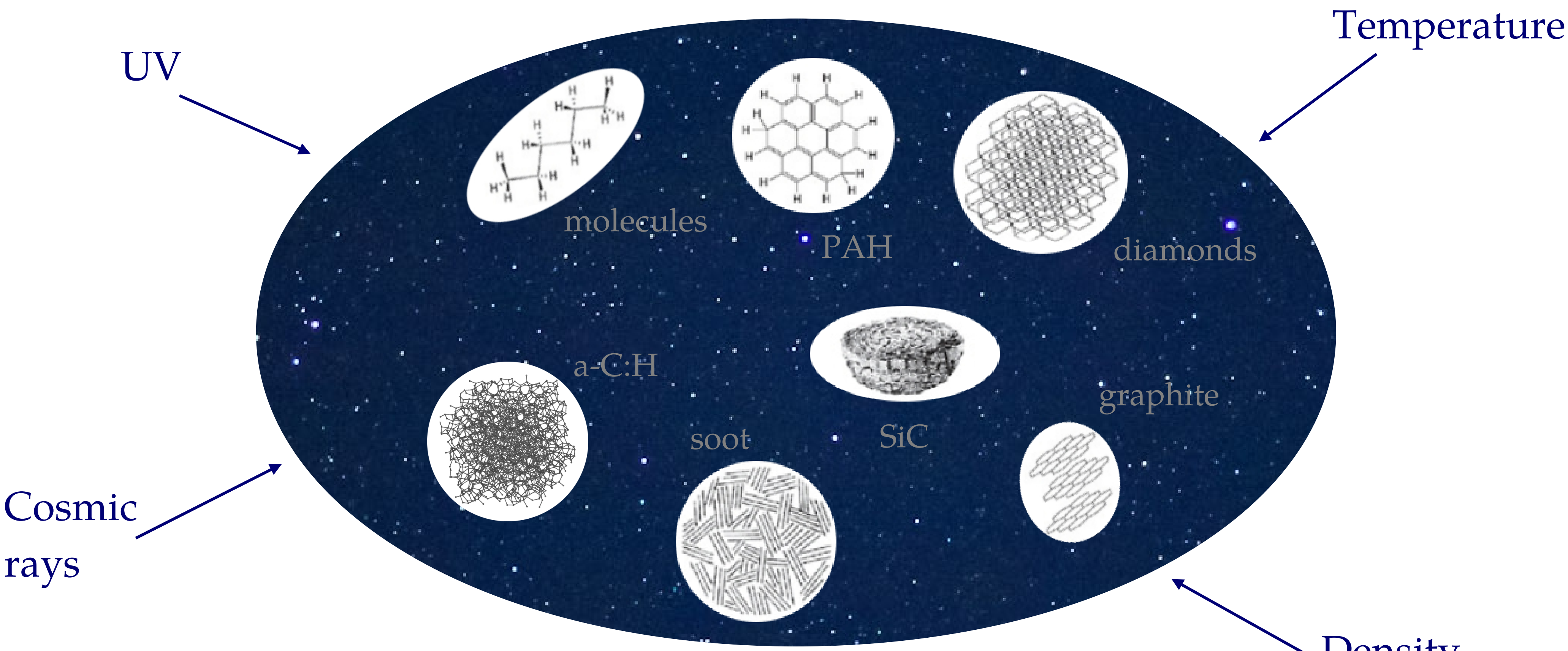
VUV photolysis of Hydrogenated amorphous carbons
Small hydrocarbons production in Photon Dominated Regions*

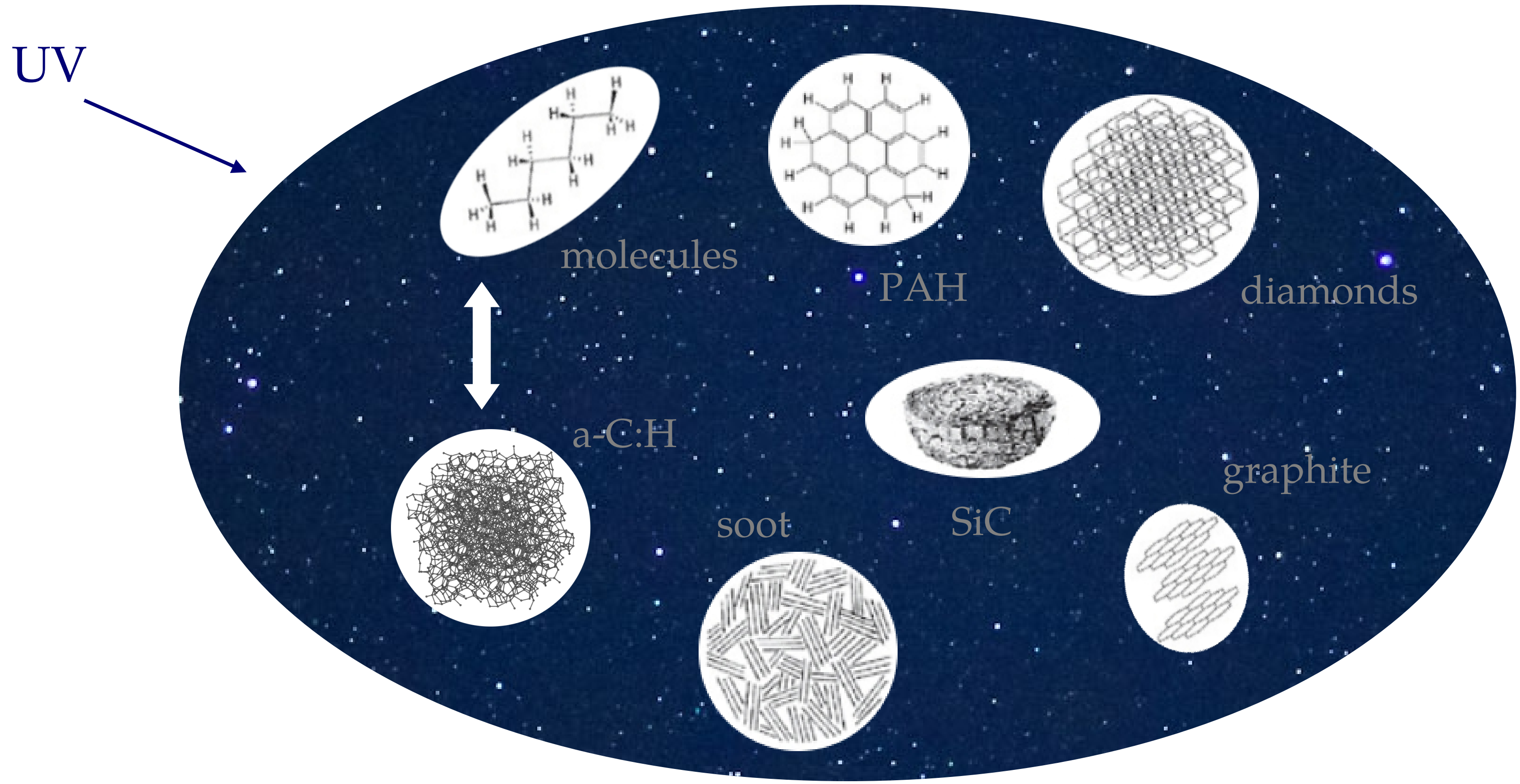
**submitted to A&A*

<u>A. Jallat</u>[3,4], I. Alata[1,2], L. Gavilan[1,2], G. A. Cruz-Diaz[4], M. Chabot[3,4], G. M. Munoz Caro[5], K. Béroff[6,7] and E. Dartois[1,2]

[1] *CNRS-INSU, Institut d'Astrophysique Spatiale, UMR 8617, 91405 Orsay, France*
[2] *Université Paris Sud, Institut d'Astrophysique Spatiale, UMR 8617, 91405 Orsay, France*
[3] *CNRS-IN2P3, Institut de Physique Nucléaire d'Orsay, UMR8608, 91406 Orsay, France*
[4] *Université Paris Sud, Institut de Physique Nucléaire d'Orsay, UMR8608, IN2P3-CNRS, 91406 Orsay, France*
[5] *Centro de Astrobiología, INTA-CSIC, Carretera de Ajalvir, km 4, Torrejón de Ardoz, 28850 Madrid, Spain*
[6] *CNRS-INP, Institut des Sciences Moléculaires d'Orsay, UMR8214, 91405 Orsay, France*
[7] *Université Paris Sud, Institut des Sciences Moléculaires d'Orsay, UMR8214, 91405 Orsay, France*



How are these different reservoirs related?

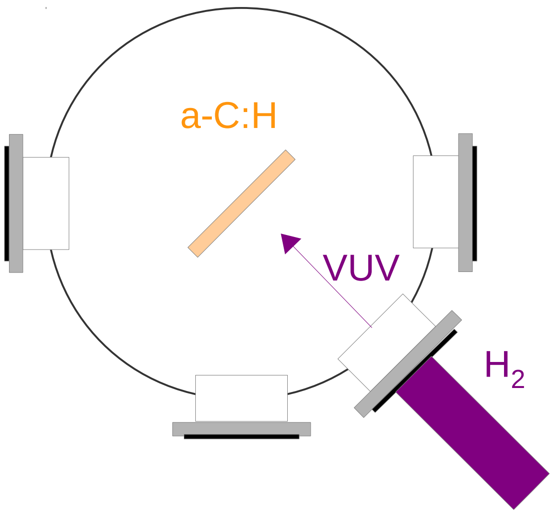


How are these different reservoirs related?

We explore the link between the a-C:H and the gaseous phase hydrocarbons in a photo-dissociation region.

Measuring photo-desorption rates

E. Dartois experiment at IAS[1] and Guillermo Munoz Caro in Spain[2]



1 Alata, I., Cruz-Diaz, G. A., Munóz Caro, G. M., & Dartois, E. 2014, A&A, 569,A119
2 Munóz Caro, G. M., Jiménez-Escobar, A., Martín-Gago, J. Á., et al. 2010, A&A,522, A108

Measuring photo-desorption rates

E. Dartois experiment at IAS[1] and Guillermo Munoz Caro in Spain[2]

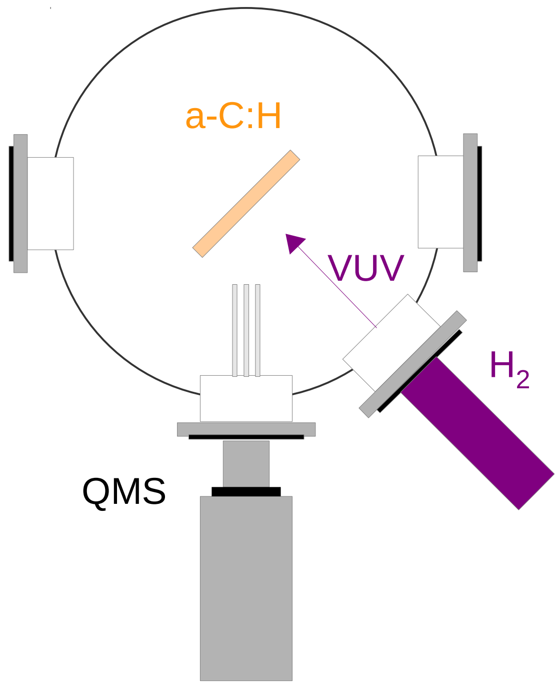


	Photo-production yield (%)
H_2	96.5 (±3.0)
CH_4	3.0 (±1.0)
C_2H_2	0.5 (±0.2)

1 Alata, I., Cruz-Diaz, G. A., Muńoz Caro, G. M., & Dartois, E. 2014, A&A, 569,A119
2 Muńoz Caro, G. M., Jiménez-Escobar, A., Martín-Gago, J. Á., et al. 2010, A&A,522, A108

E. Dartois experiment at IAS[1] and Guillermo Munoz Caro in Spain[2]

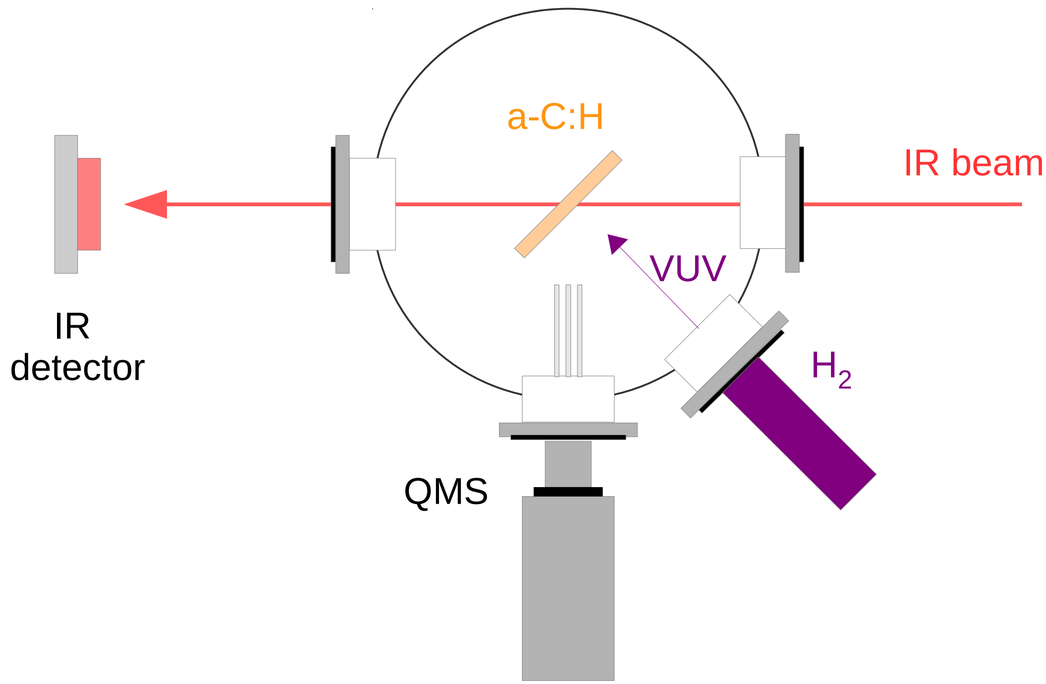


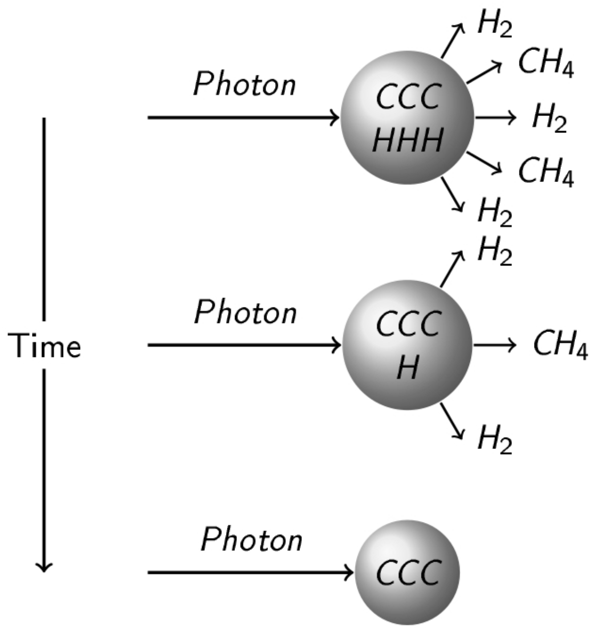
	Photo-production yield (%)	Photo-desorption rate (s^{-1})
H_2	96.5 (±3.0)	2.79×10^{-11}
CH_4	3.0 (±1.0)	8.6×10^{-13}
C_2H_2	0.5 (±0.2)	1.5×10^{-13}

a-C:H photo-destruction cross section : $3.0\pm0.9\times10^{-19}$ cm^2

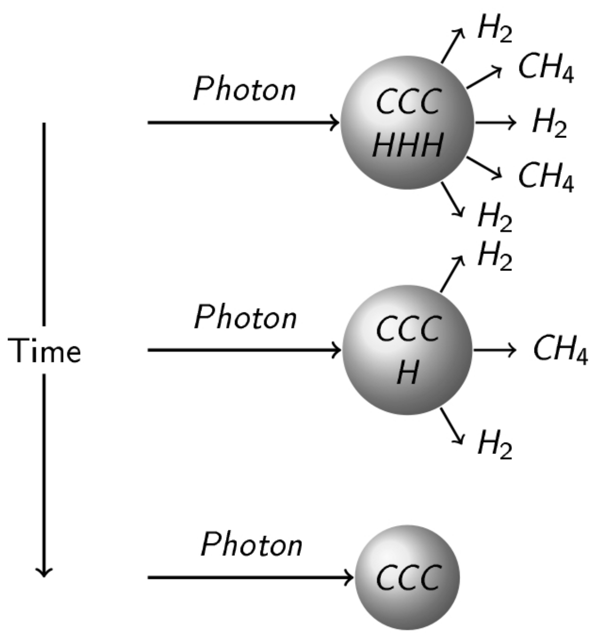
Standard FUV interstellar radiation field : 1.94×10^8 photons.$cm^{-2}.s^{-1}$

1 Alata, I., Cruz-Diaz, G. A., Muńz Caro, G. M., & Dartois, E. 2014, A&A, 569,A119
2 Muńz Caro, G. M., Jiménez-Escobar, A., Martín-Gago, J. Á., et al. 2010, A&A,522, A108

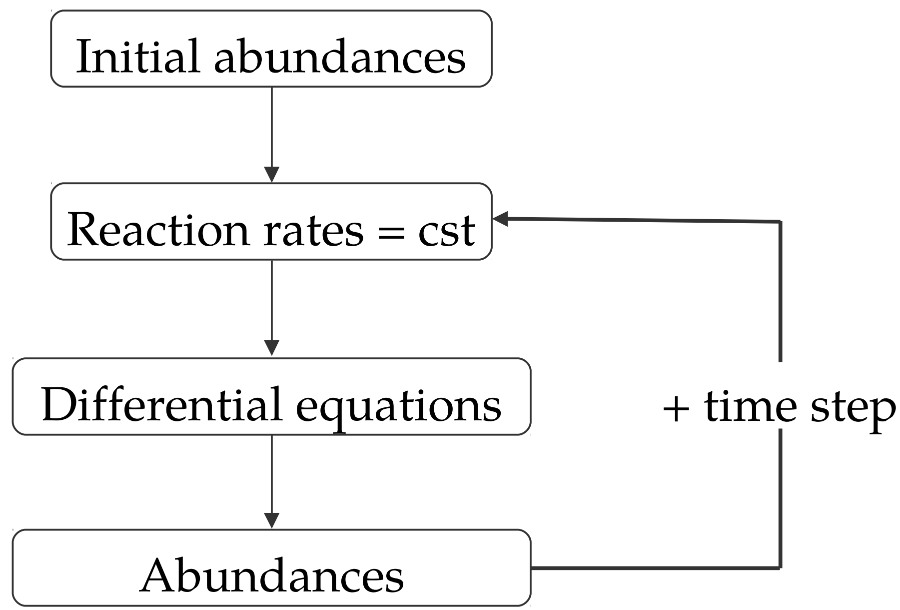
Incorporation of a-C:H photo-desorption rates in the calculations
I] Time dependant aspect



Incorporation of a-C:H photo-desorption rates in the calculations
I] Time dependant aspect

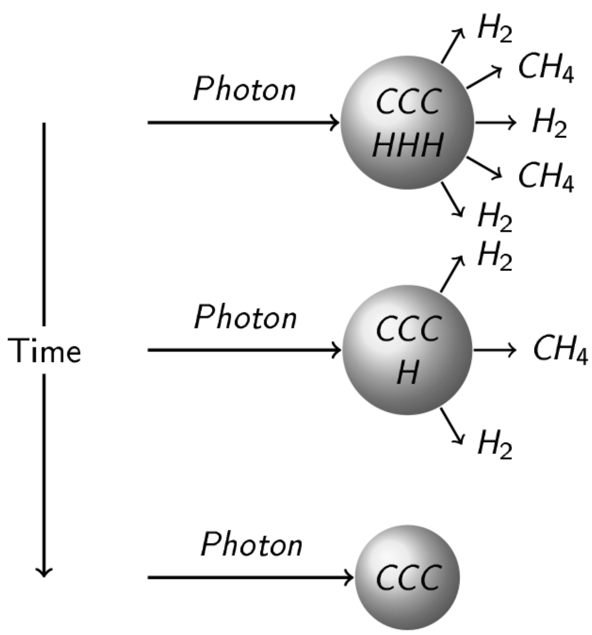


Nahoon[3] code:

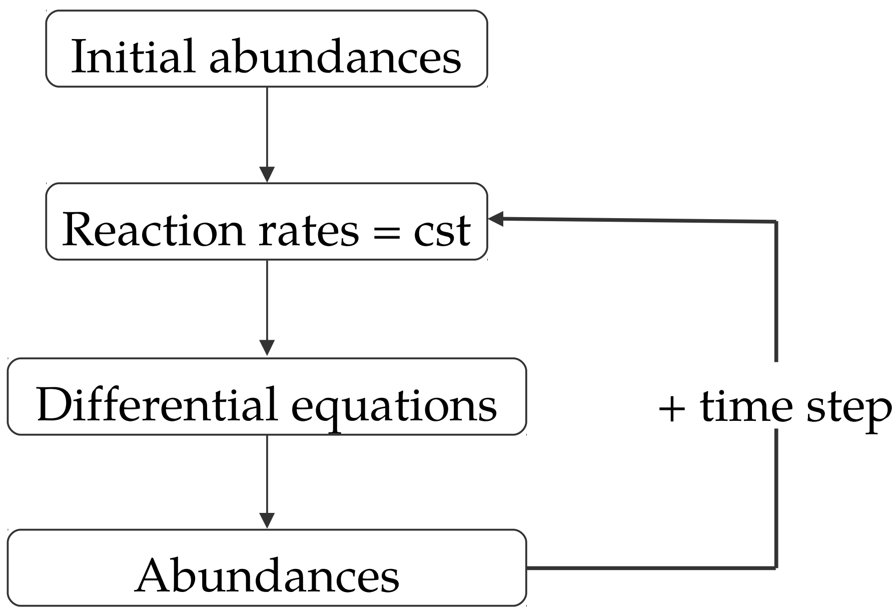


3 Wakelam, V. 2006, Astrophysics Software Database, 28

Incorporation of a-C:H photo-desorption rates in the calculations
I] Time dependant aspect



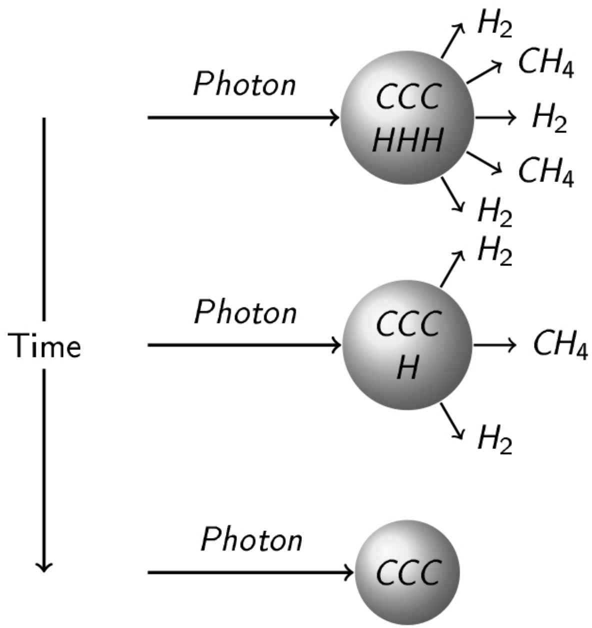
Nahoon[3] code:



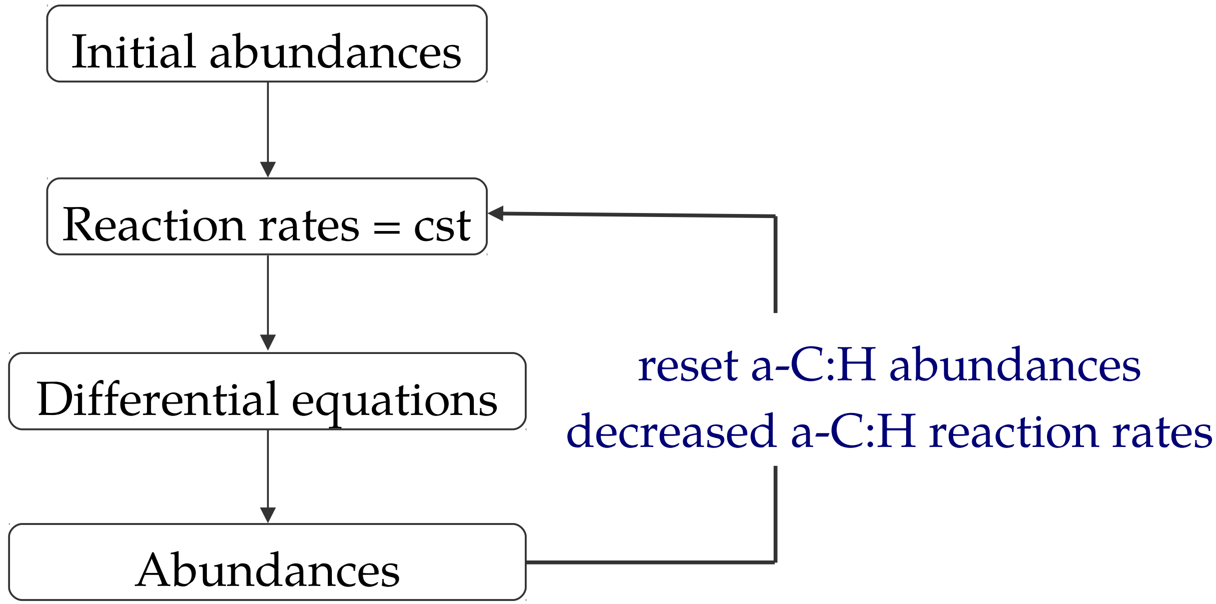
Impossible to compute all the reactions taking into account the composition of a-C:H (millions of chemical species)

3 Wakelam, V. 2006, Astrophysics Software Database, 28

Incorporation of a-C:H photo-desorption rates in the calculations
I] Time dependant aspect



Nahoon[3] code modified for a-C:H:



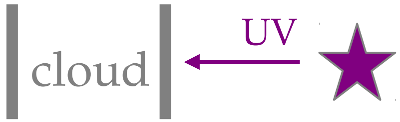
Impossible to compute all the reactions taking into account the composition of a-C:H (millions of chemical species)

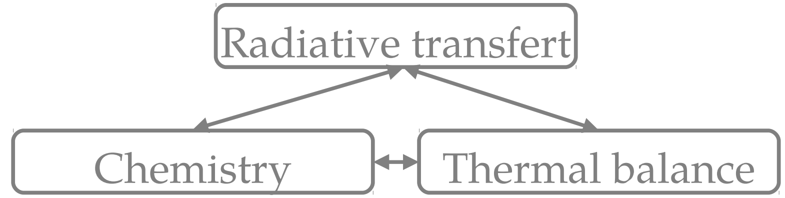
→ Trick

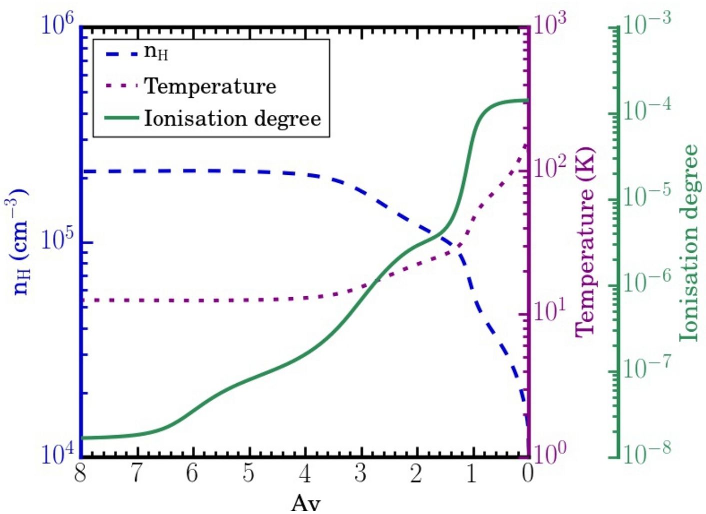
3 Wakelam, V. 2006, Astrophysics Software Database, 28

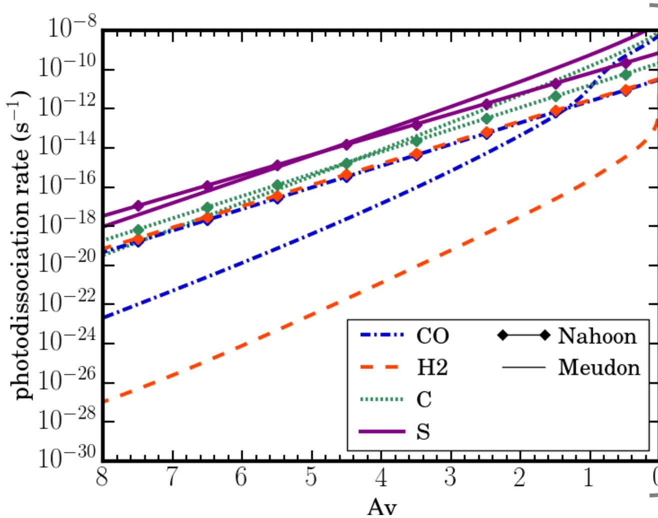
Incorporation of a-C:H photo-desorption rates in the calculations
II] Coupling with a PDR model

Meudon[4] code:









Meudon's output as fonction of Av:
- density
- température
- photo-dissociation rates

Av=1 → a-C:H Nahoon code → Results as a fonction of time

Av=2 → a-C:H Nahoon code → Results as a fonction of time

Av=3 → a-C:H Nahoon code → Results as a fonction of time

. . .

. . .

. . .

Results in fonction of Av at a given time

4 Le Petit, F., Nehmé, C., Le Bourlot, J., & Roueff, E. 2006, ApJS, 164, 506

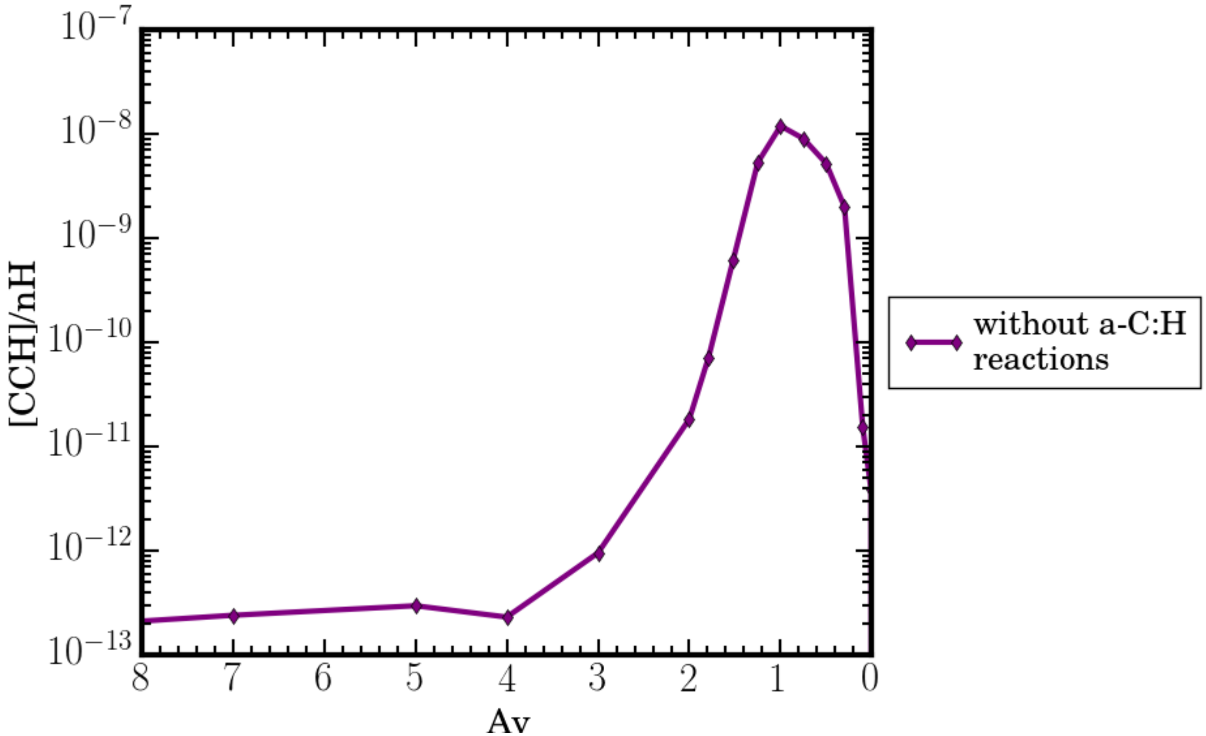
Case study: the Horsehead nebula following the recommandations of Pety 2005[5]

The horsehead nebula:

- T ≈ 100 K
- n_H ≈ 2.10^5 cm^3
- χ ≈ 60 Draine units
- ζ = 5.10^{-17} s^{-1}
- [S]/nH = 3.5x10^{-6}

Observed molecules:

CCH, C_4H, c-C_3H_2, l-C_3H_2, c-C_3H, l-C_3H, C_6H, CS, HCO, HOC^+, HCS^+, CO^+, …



5 Pety, J., Teyssier, D., Fossé, D., et al. 2005, A&A, 435, 885

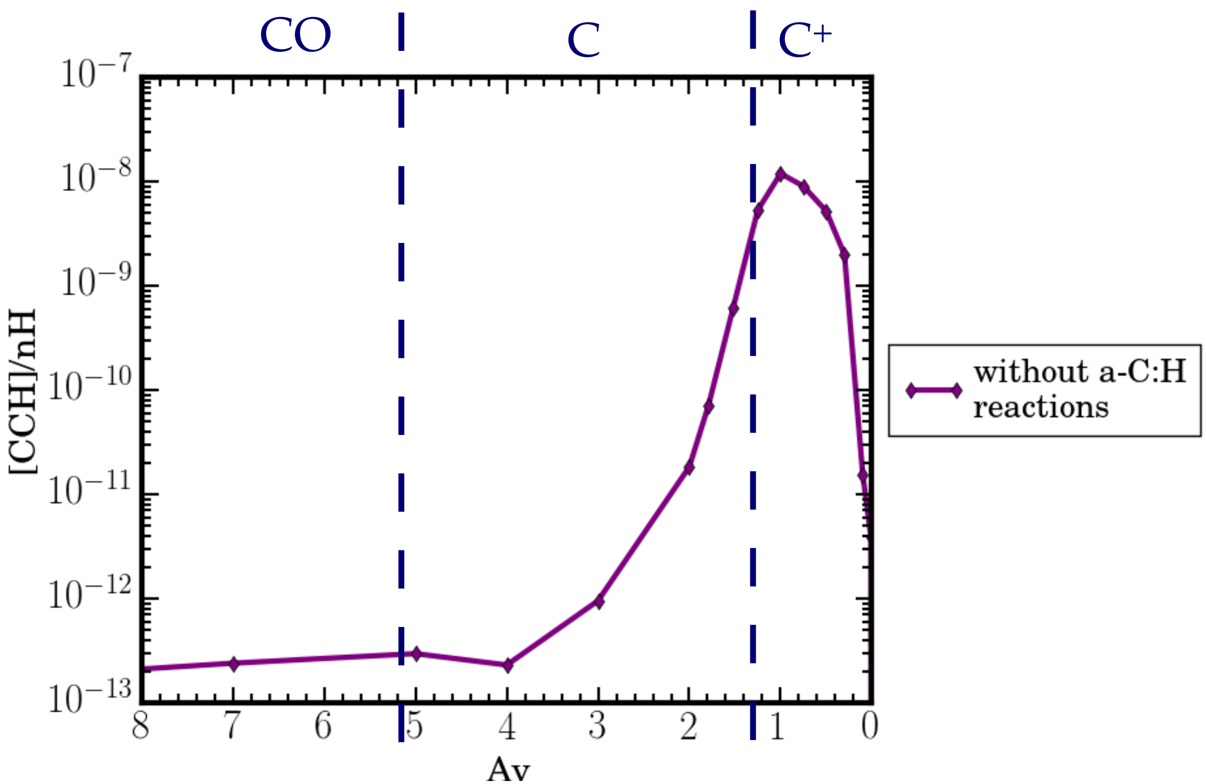
Case study: the Horsehead nebula following the recommandations of Pety 2005[5]

The horsehead nebula:

- $T \approx 100$ K
- $n_H \approx 2.10^5$ cm^3
- $\chi \approx 60$ Draine units
- $\zeta = 5.10^{-17}$ s^{-1}
- $[S]/nH = 3.5 \times 10^{-6}$

Observed molecules:

CCH, C_4H, $c\text{-}C_3H_2$, $l\text{-}C_3H_2$, $c\text{-}C_3H$, $l\text{-}C_3H$, C_6H, CS, HCO, HOC^+, HCS^+, CO^+, …



5 Pety, J., Teyssier, D., Fossé, D., et al. 2005, A&A, 435, 885

Results for the Horsehead nebula

Case study: the Horsehead nebula following the recommandations of Pety 2005[5]

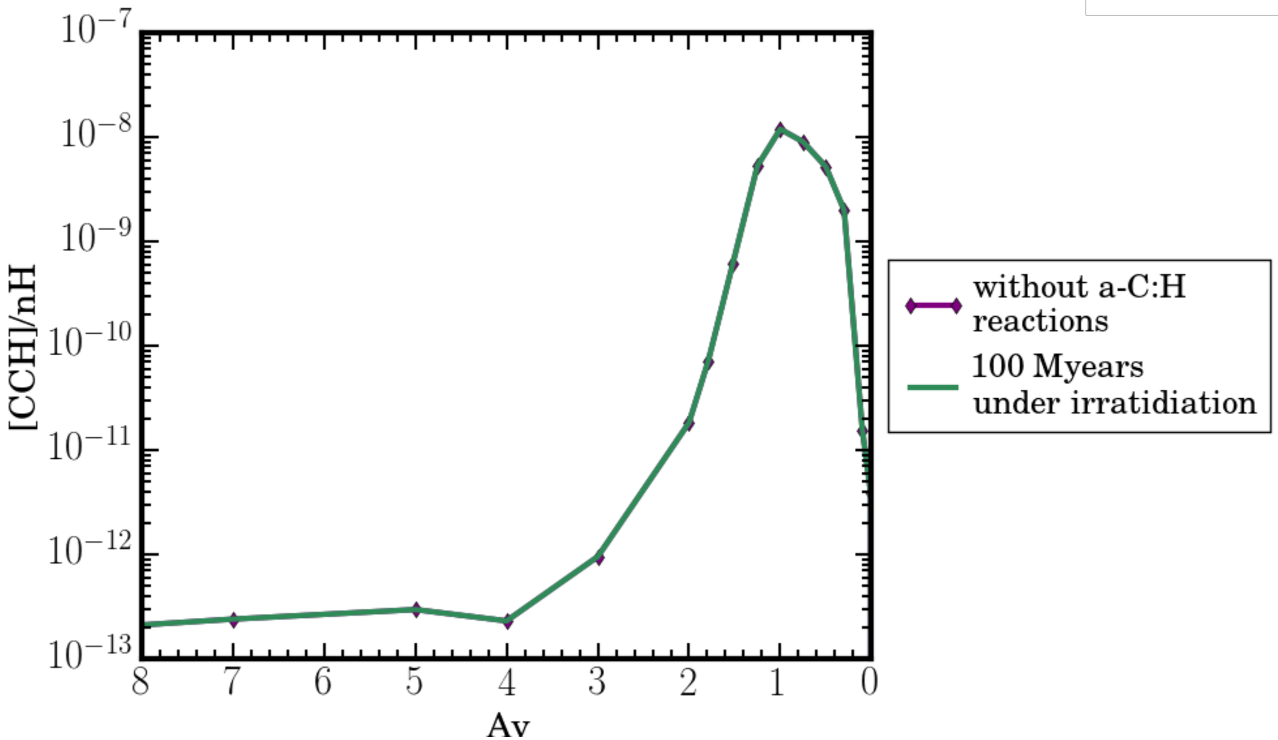
The horsehead nebula:

- $T \approx 100$ K
- $n_H \approx 2.10^5$ cm^3
- $\chi \approx 60$ Draine units
- $\zeta = 5.10^{-17}$ s^{-1}
- $[S]/nH = 3.5x10^{-6}$

Observed molecules:

CCH, C_4H, c-C_3H_2, l-C_3H_2, c-C_3H, l-C_3H, C_6H, CS, HCO, HOC^+, HCS^+, CO^+, …

5% of carbon is in the a-C:H



5 Pety, J., Teyssier, D., Fossé, D., et al. 2005, A&A, 435, 885

Results for the Horsehead nebula

Case study: the Horsehead nebula following the recommandations of Pety 2005[5]

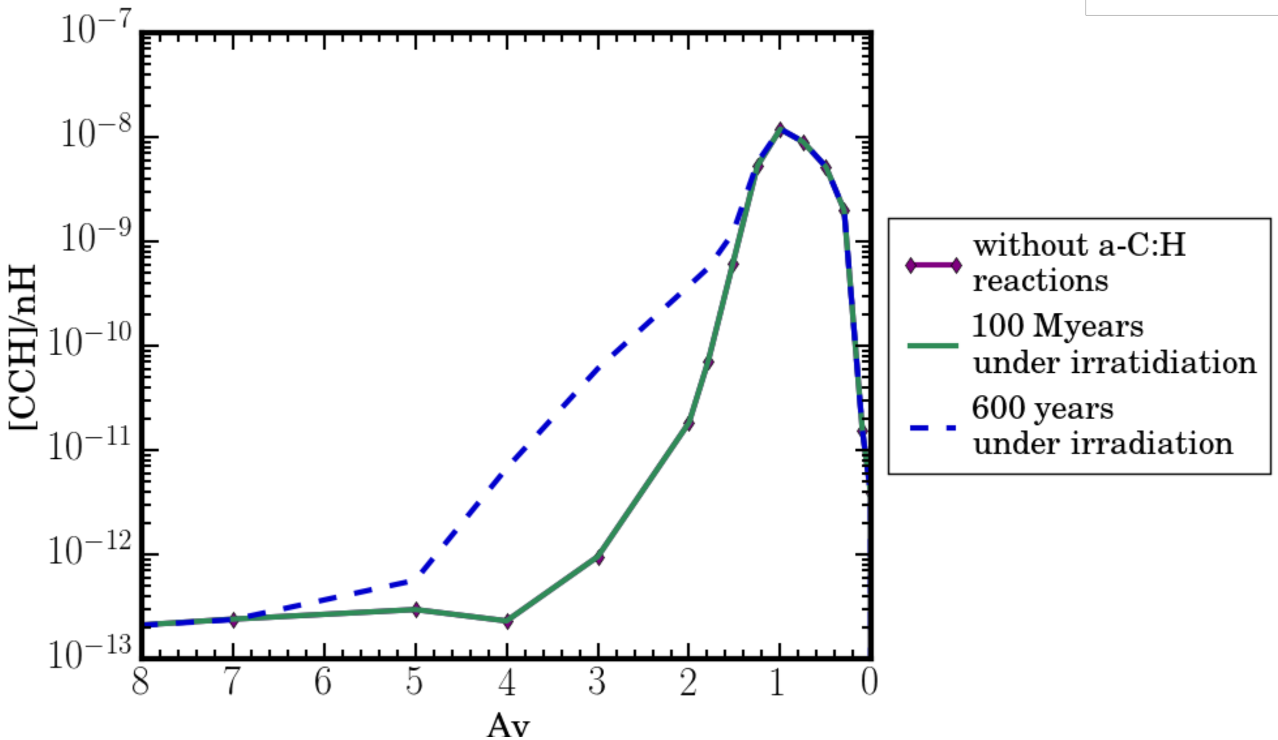
The horsehead nebula:

- $T \approx 100$ K
- $n_H \approx 2.10^5$ cm^3
- $\chi \approx 60$ Draine units
- $\zeta = 5.10^{-17}$ s^{-1}
- $[S]/nH = 3.5 \times 10^{-6}$

Observed molecules:

CCH, C_4H, c-C_3H_2, l-C_3H_2, c-C_3H, l-C_3H, C_6H, CS, HCO, HOC^+, HCS^+, CO^+, …

5% of carbon is in the a-C:H



5 Pety, J., Teyssier, D., Fossé, D., et al. 2005, A&A, 435, 885

Results for the Horsehead nebula

Case study: the Horsehead nebula following the recommandations of Pety 2005[4]

The horsehead nebula:

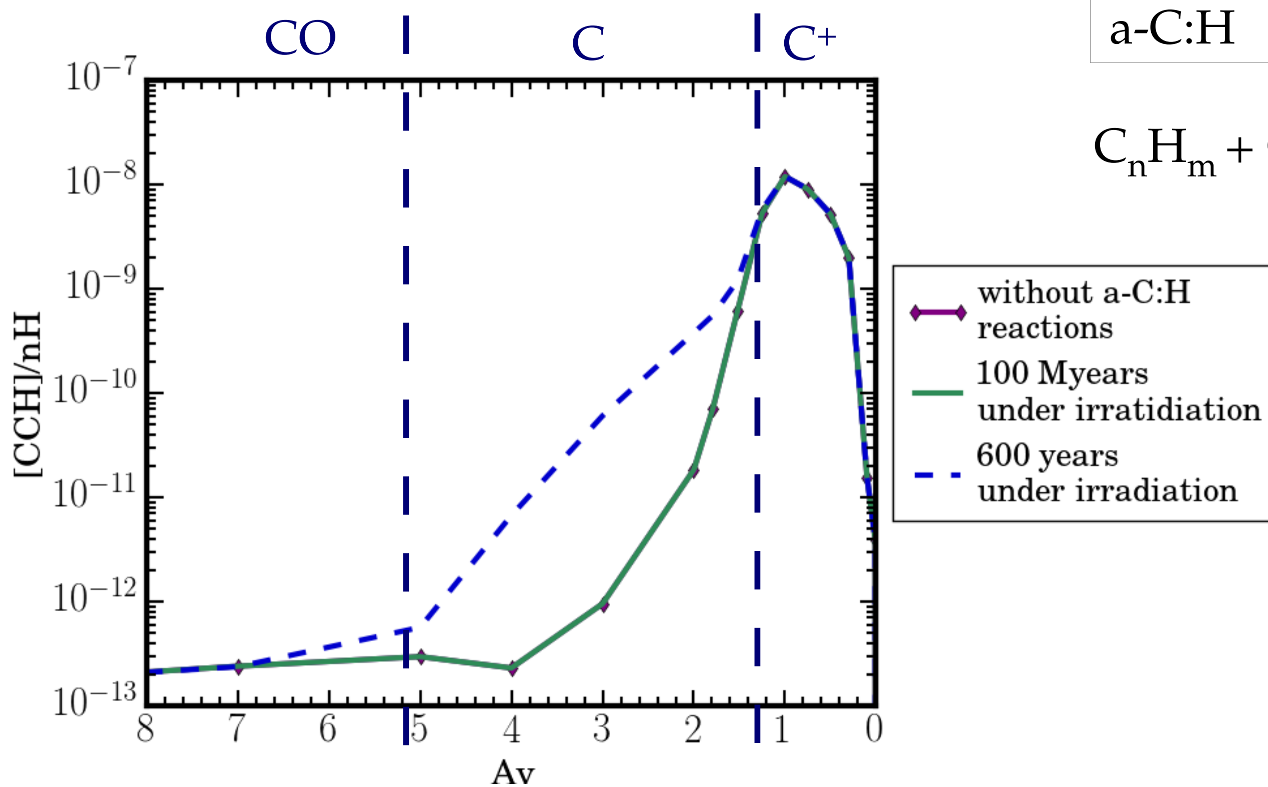
- $T \approx 100$ K
- $n_H \approx 2.10^5$ cm^3
- $\chi \approx 60$ Draine units
- $\zeta = 5.10^{-17}$ s^{-1}
- $[S]/nH = 3.5\times10^{-6}$

Observed molecules:

CCH, C_4H, c-C_3H_2, l-C_3H_2, c-C_3H, l-C_3H, C_6H, CS, HCO, HOC^+, HCS^+, CO^+, …

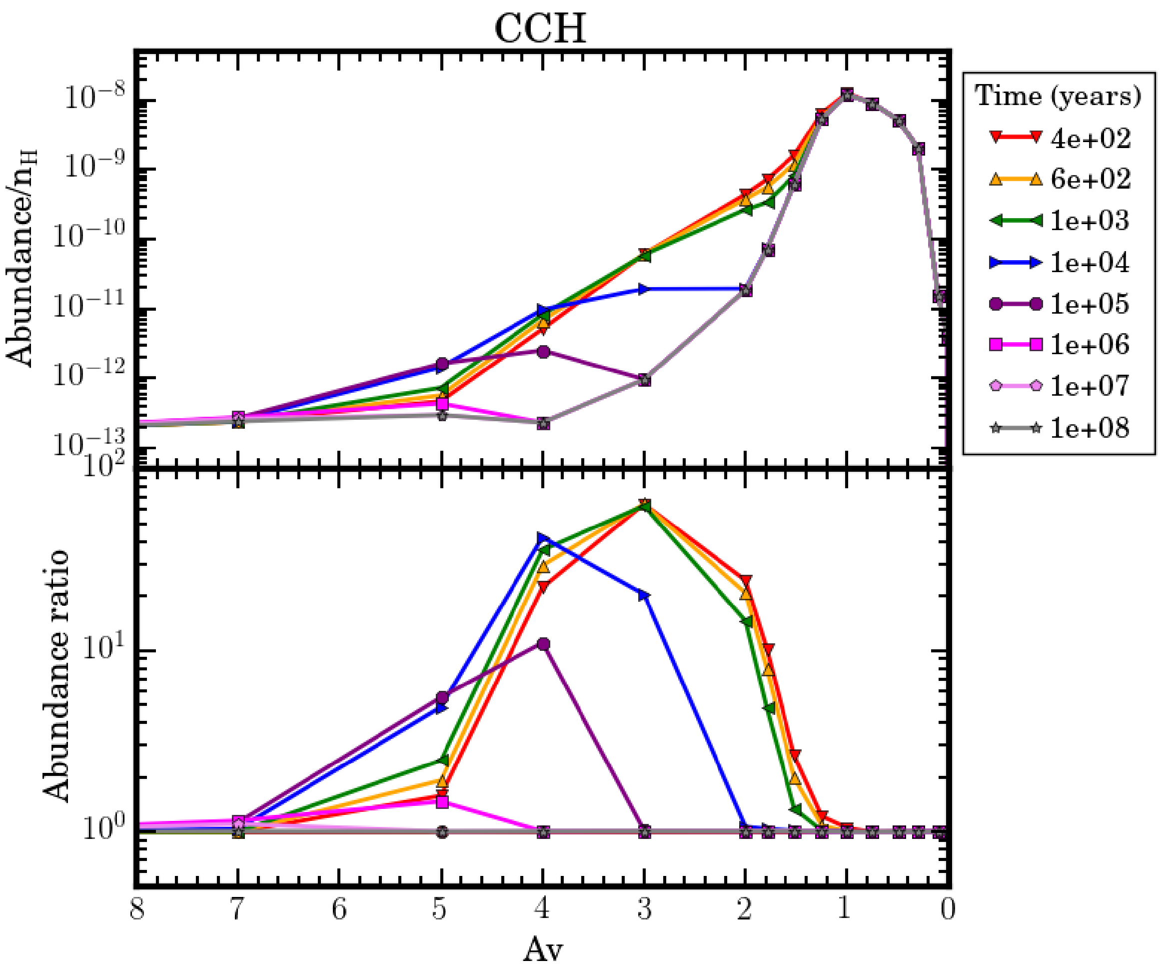
5% of carbon is in the a-C:H

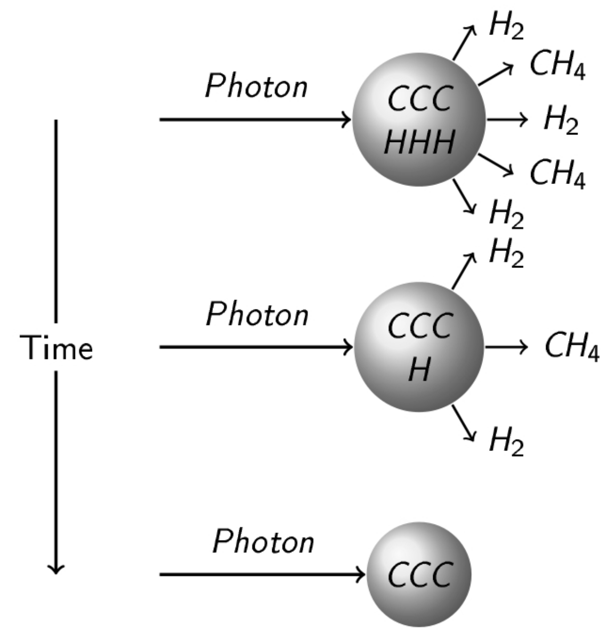
$$C_nH_m + C \rightarrow C_{n+1}H_{m-1} + H$$



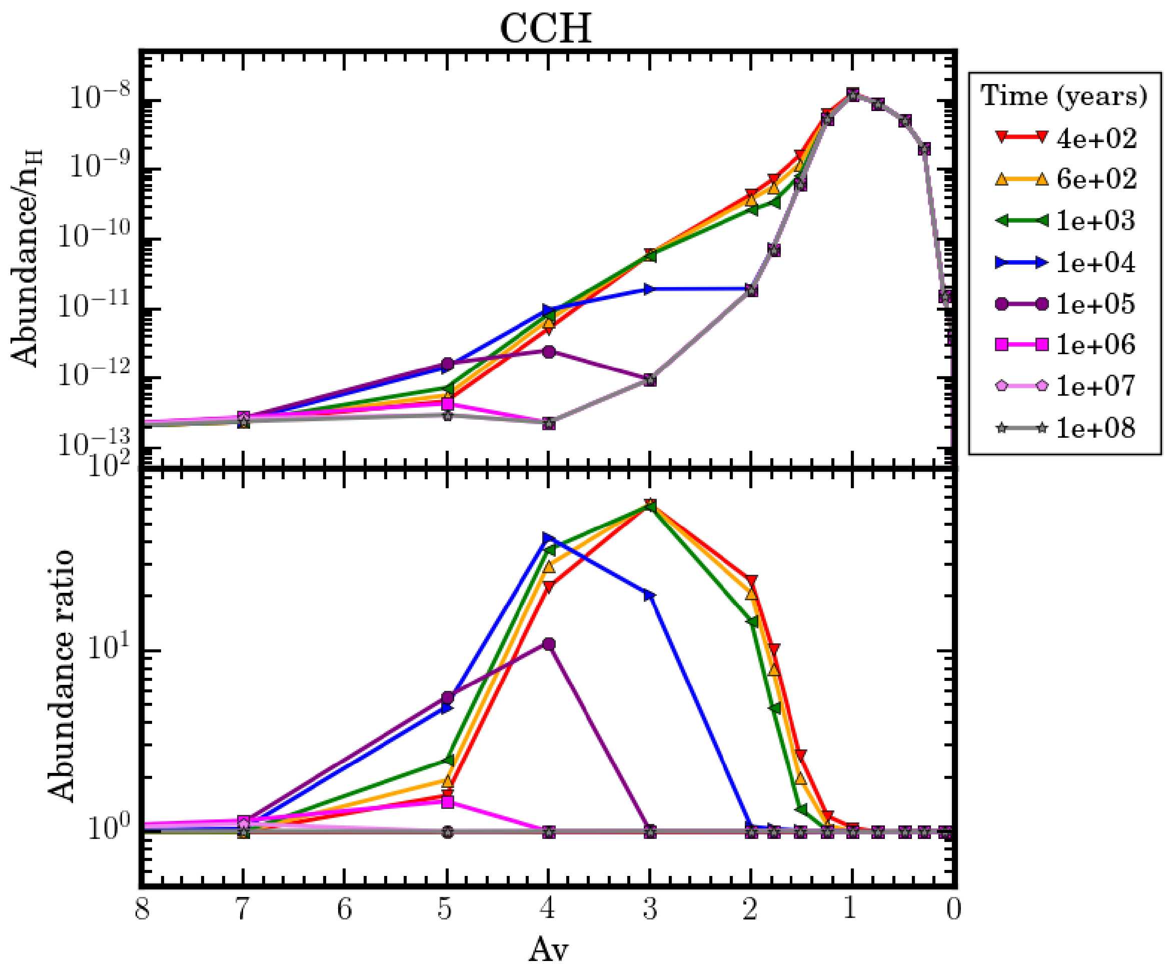
4 Pety, J., Teyssier, D., Fossé, D., et al. 2005, A&A, 435, 885

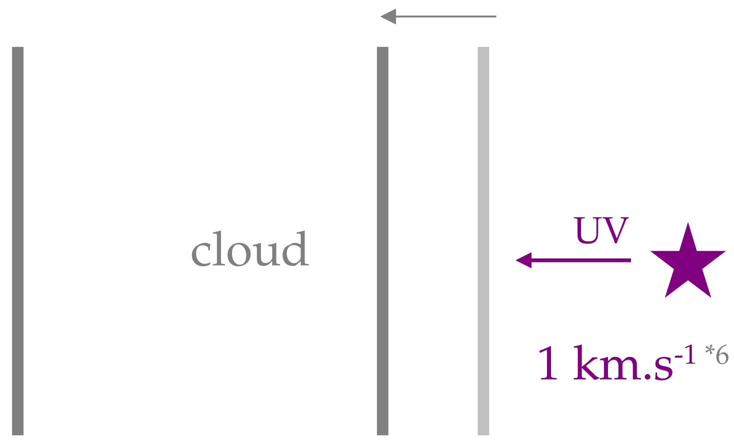
The time evolution





The time evolution





1 arcsec in 2,000 years

5,000 years from Av=0.5 to Av=1

The medium is constantly refilled with unprocessed, freshly exposed a-C:H with a time between 1,000 and 10,000 years.

6 Hollenbach, D. J., & Tielens, A. G. G. M. 1997, ARA&A, 35, 179

Outcomes and outlooks

Outcomes:

By incorporating three photolytic reactions of a-C:H, the gap between the observed abundances and those calculated is reduced by several orders of magnitude, supporting the hypothesis of Pety2005.

These results are obtained with a minimalist model since we put only 5% of carbon in a-C:H.

The medium is constantly refilled with freshly exposed a-C:H with a time scale between 1,000 and 10,000 years.

Outlooks:

It remains to incorporate a-C:H rehydrogenation.