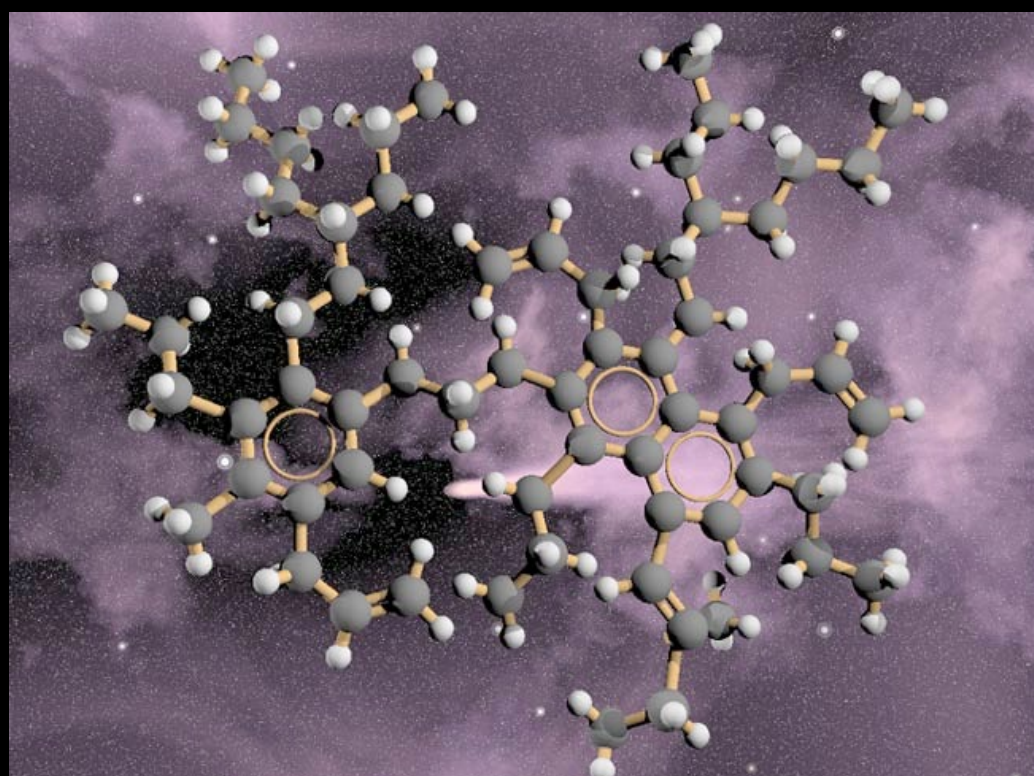
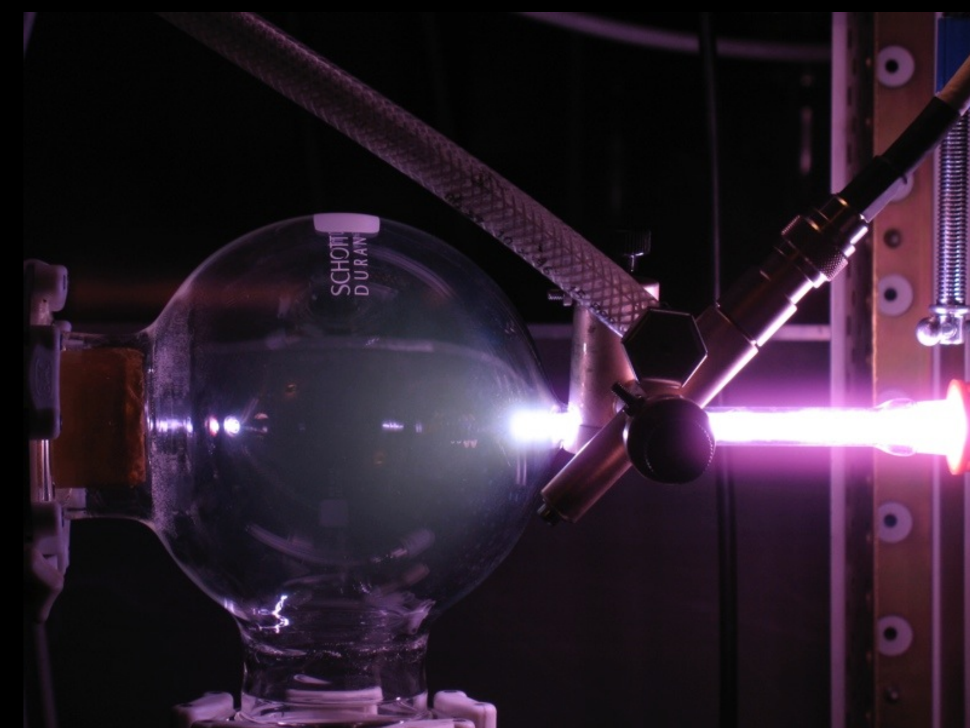
30 Octobre 2014

Hydrogenated Amorphous Carbons

evolution of interstellar carbon dust



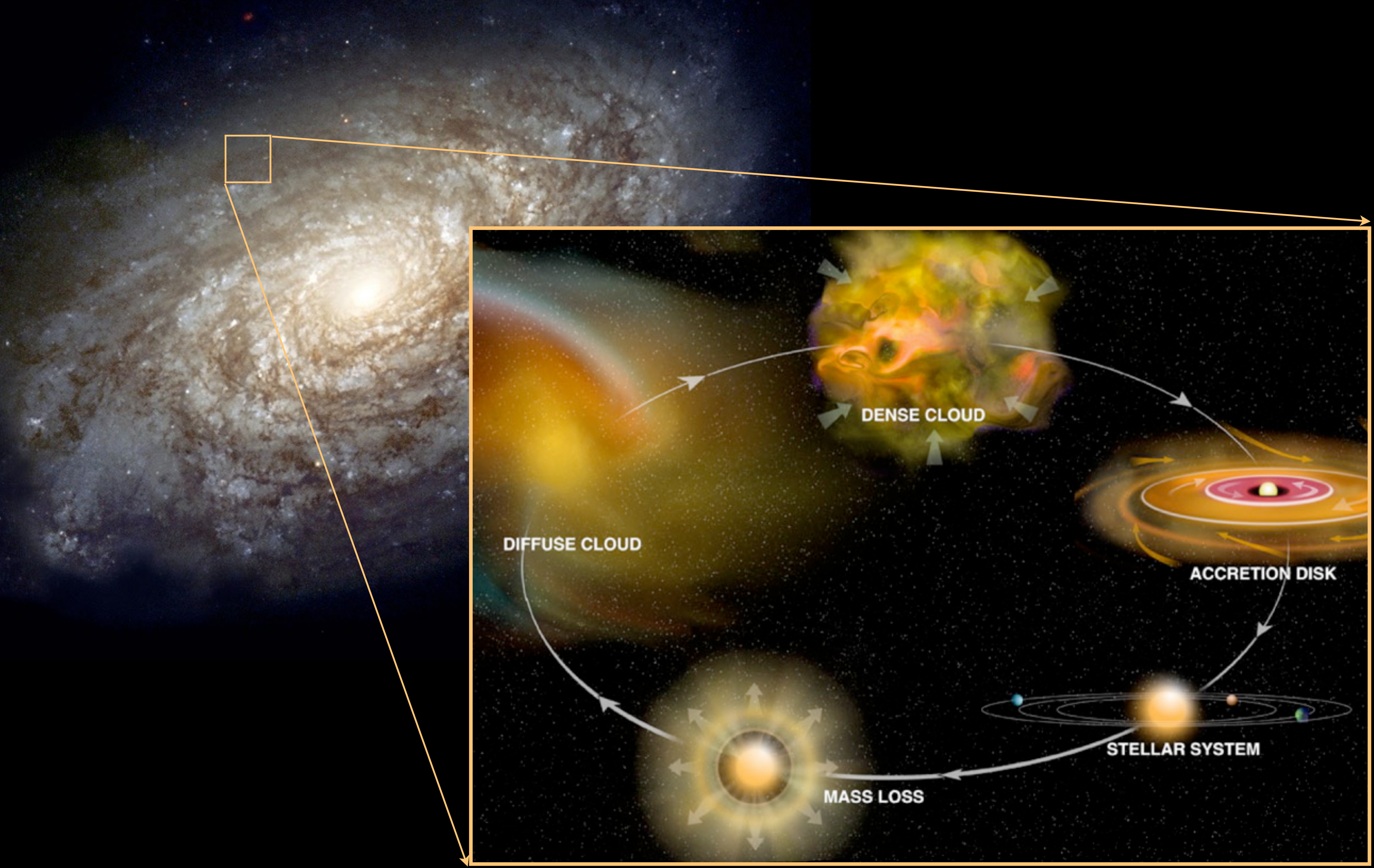


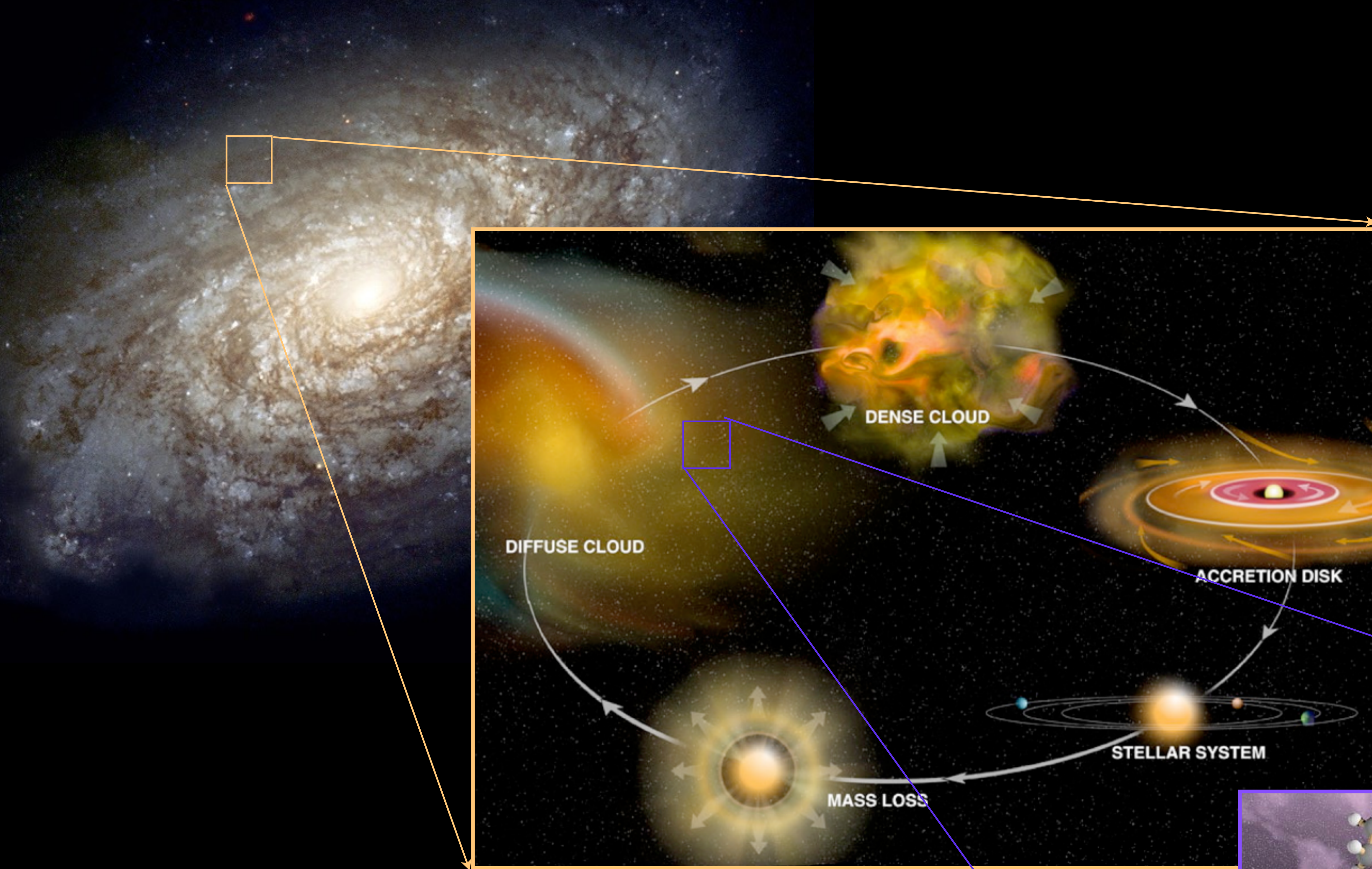
Marie Godard

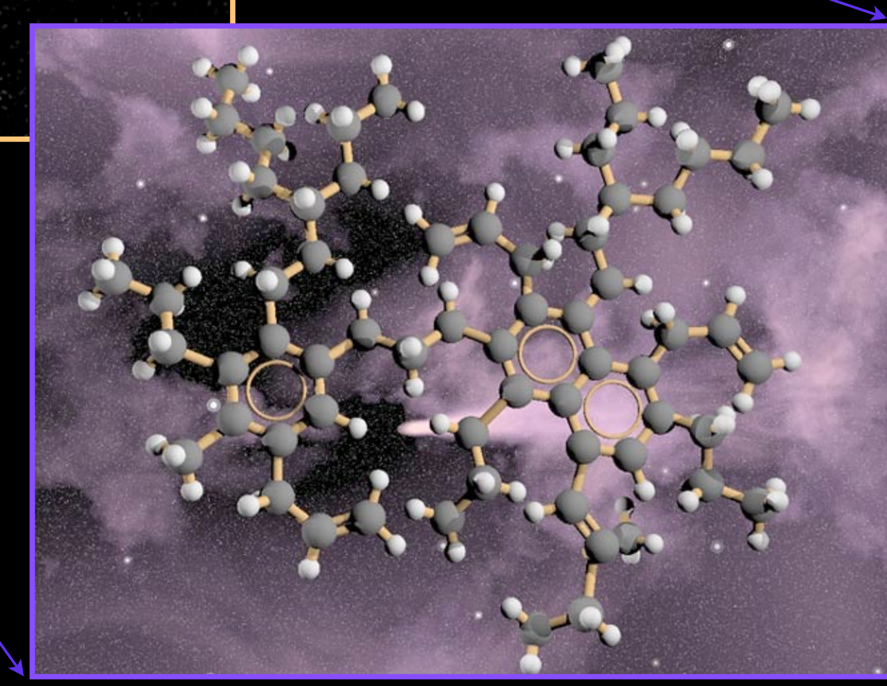
UNIVERSITÉ PARIS SUD

Centre de Sciences Nucléaires et de Sciences de la Matière
(CSNSM, Université Paris-Sud, Orsay)

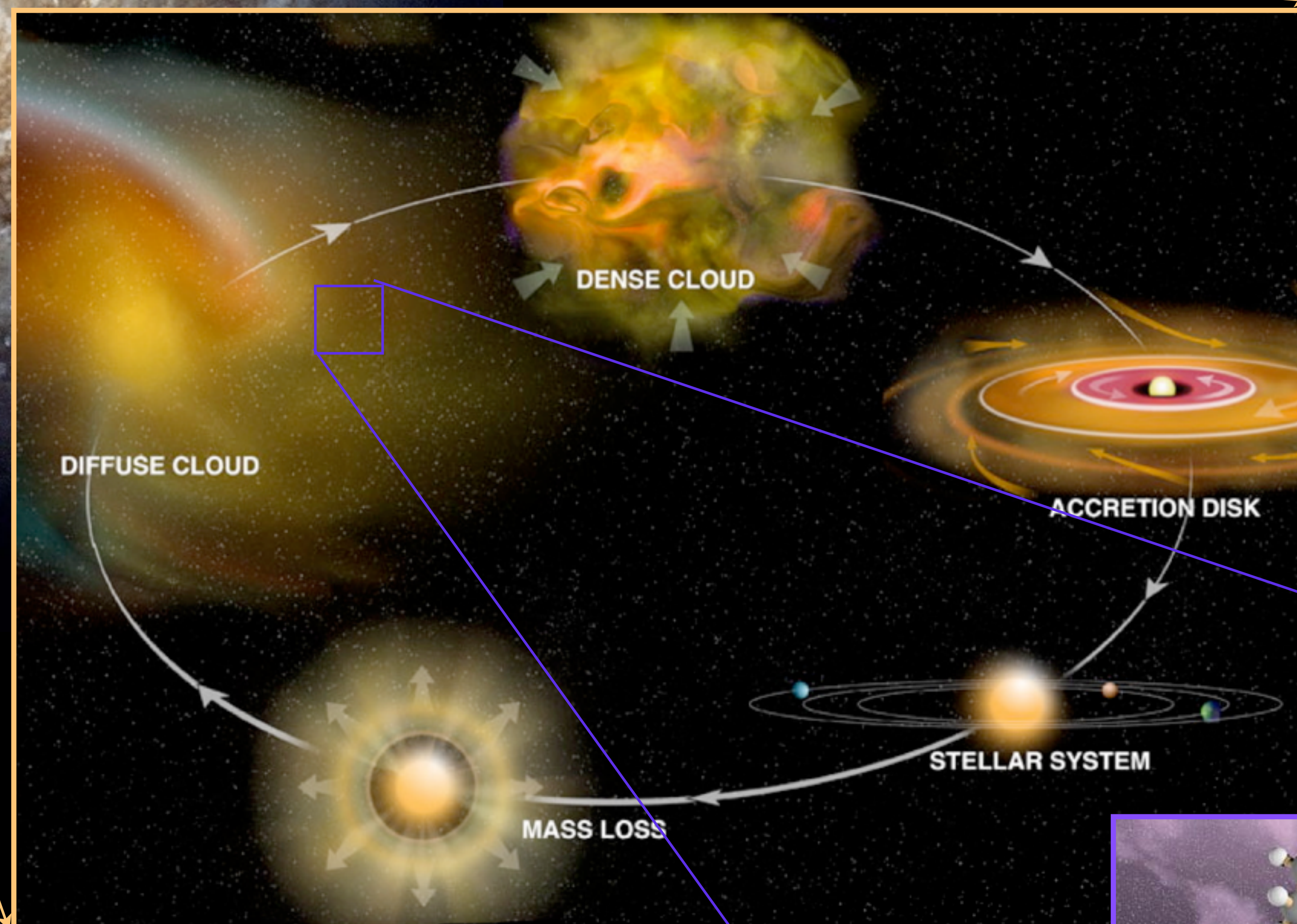
CSNSM
CENTRE DE SCIENCES NUCLÉAIRES ET DE SCIENCES DE LA MATIÈRE

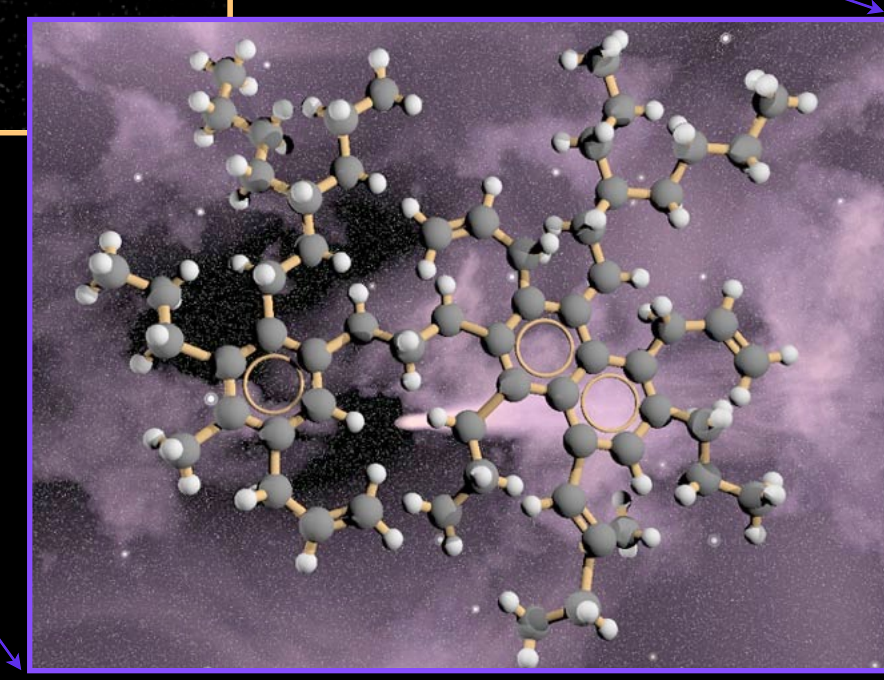

DENSE CLOUD
DIFFUSE CLOUD
ACCRETION DISK
STELLAR SYSTEM
MASS LOSS





Hydrogenated amorphous carbons
(**a-C:H** or **HAC**)
➩ Important component of carbonaceous interstellar dust
➩ Observed in **diffuse interstellar medium**



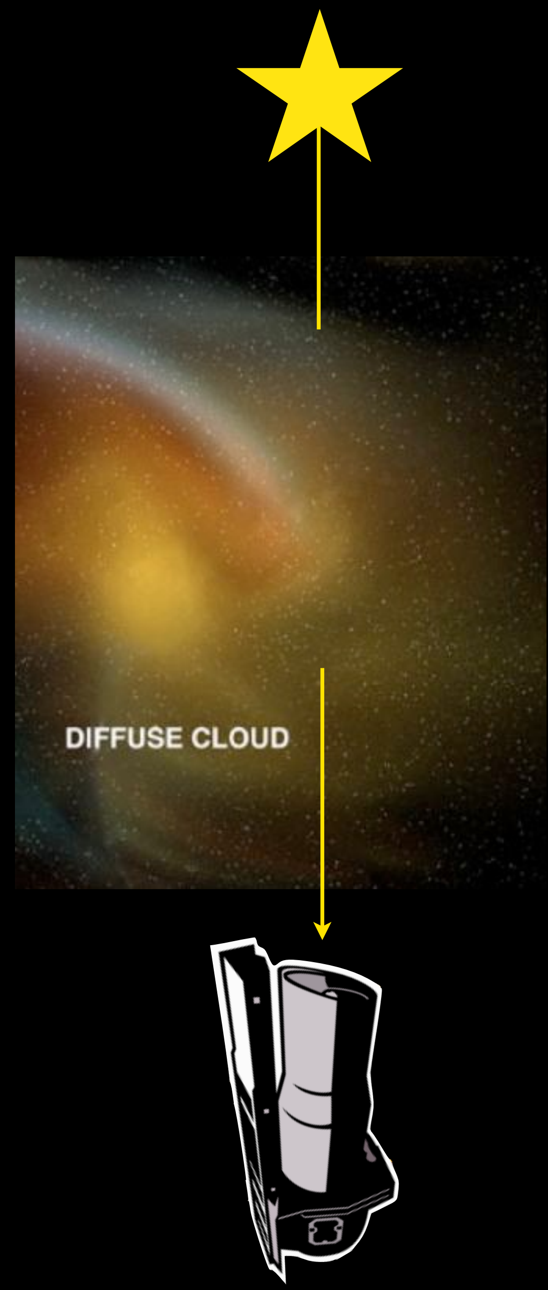


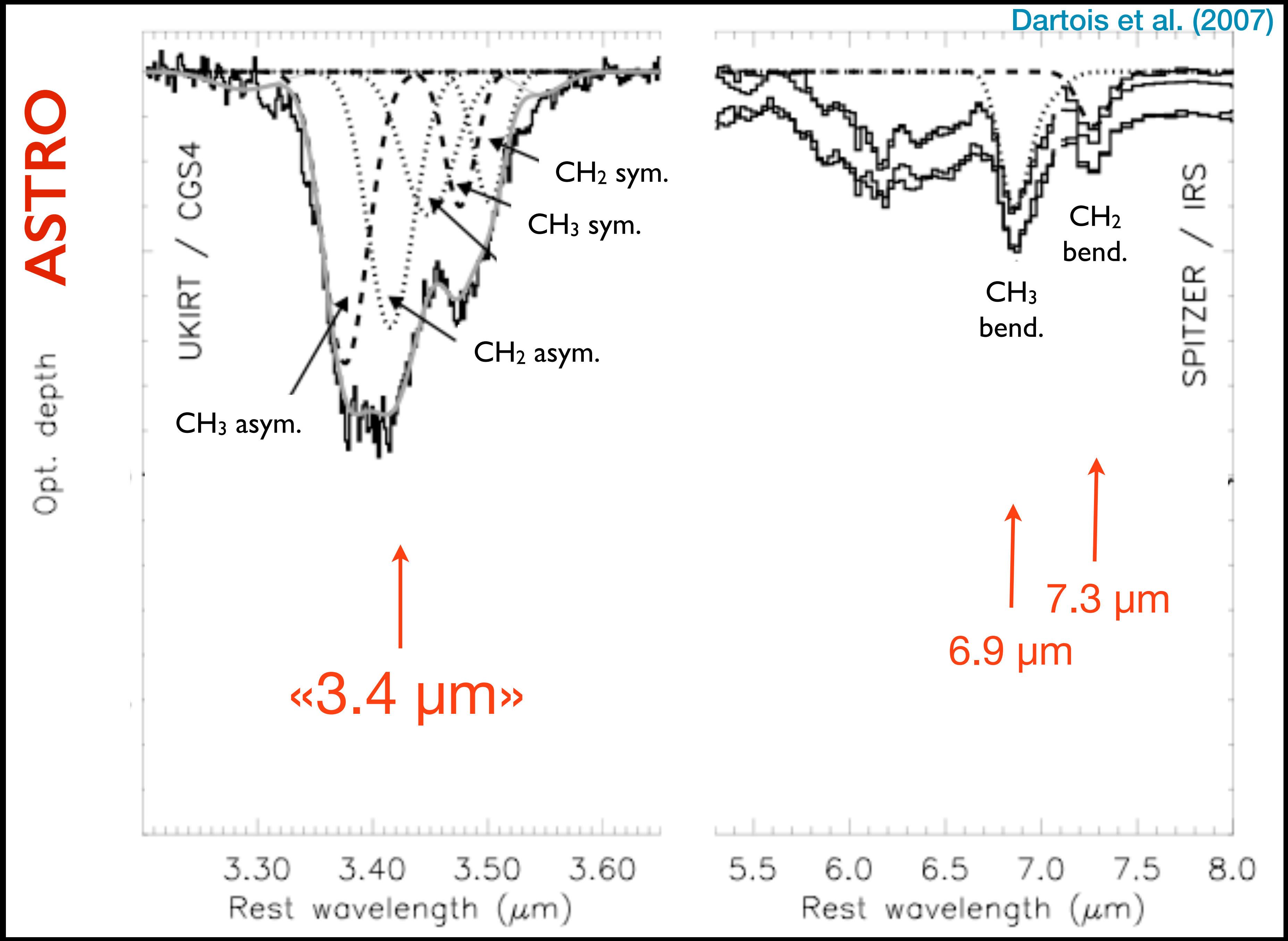
Hydrogenated amorphous carbons
(**a-C:H** or **HAC**)
➩ Important component of carbonaceous interstellar dust
➩ Observed in **diffuse interstellar medium**

Observables Properties Evolution
Focus on experimental studies

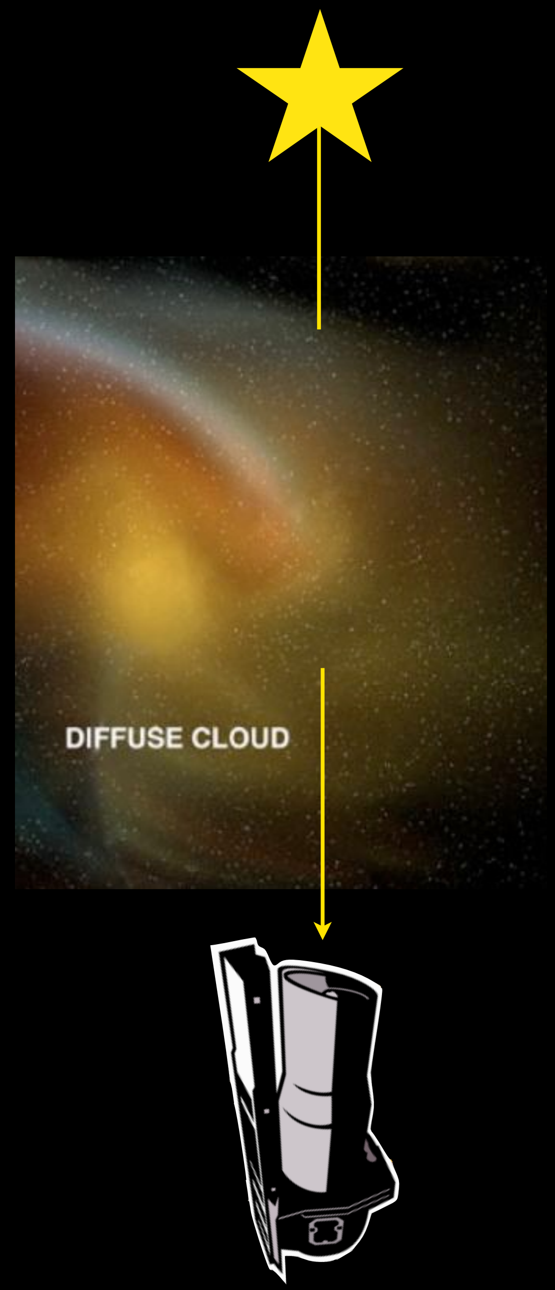
How are observed interstellar a-C:H ?

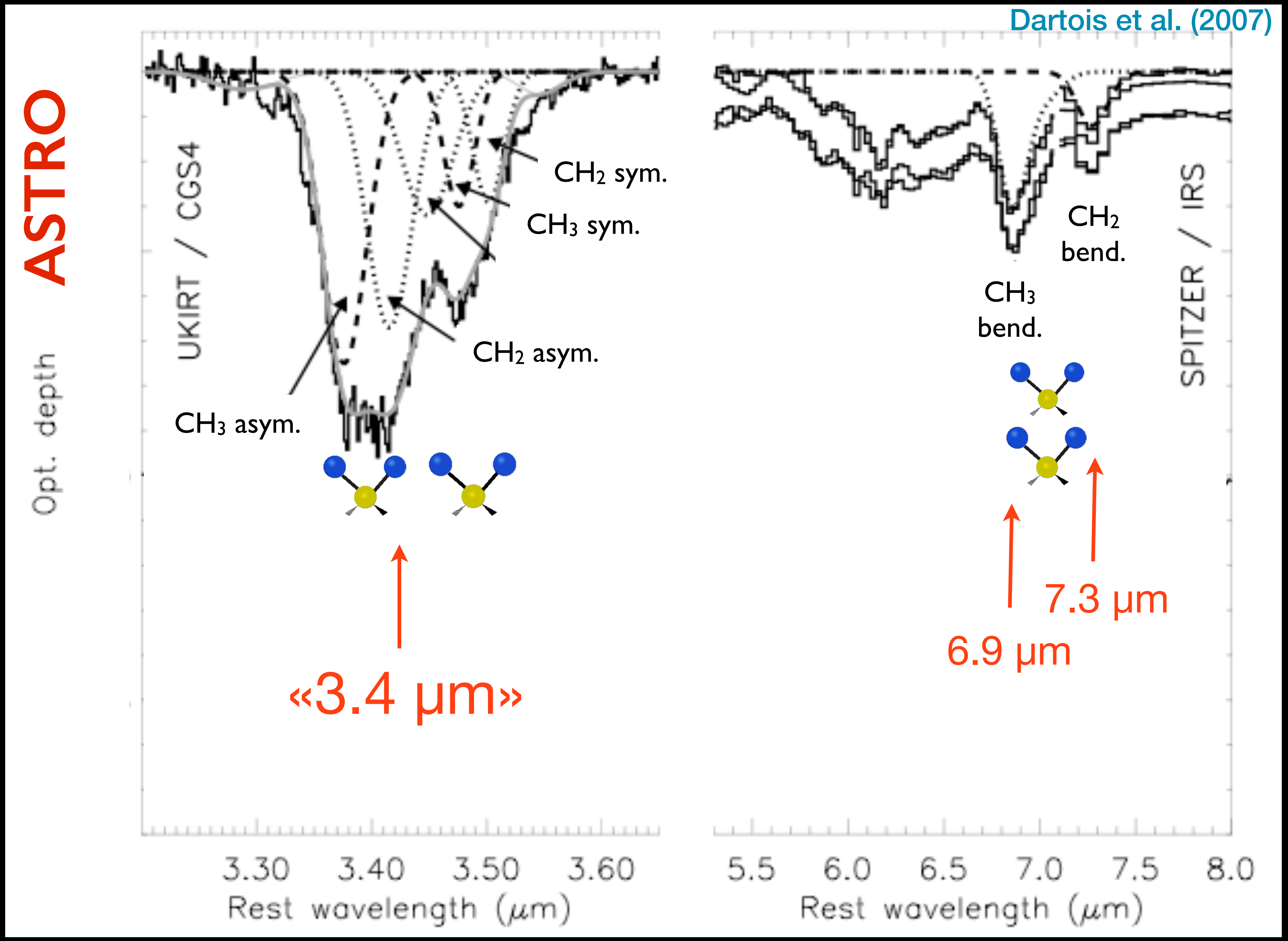
How are observed interstellar a-C:H ?





How are observed interstellar a-C:H ?



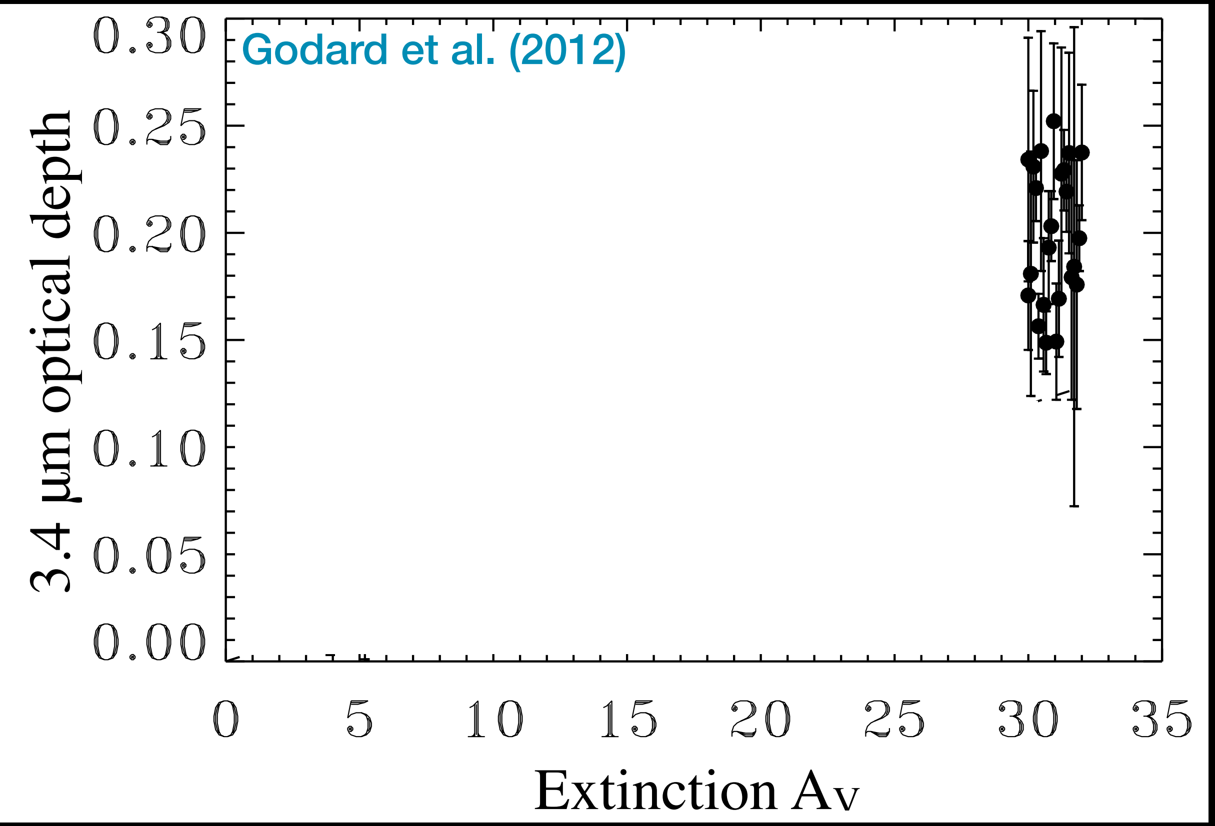


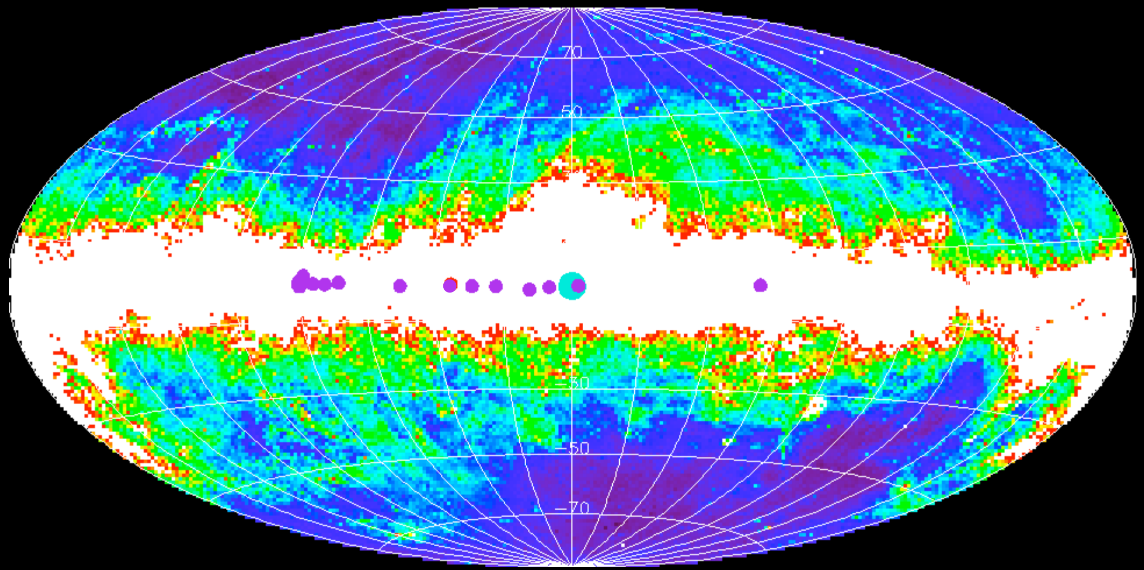
Spectral signatures of **aliphatic C-H vibrations**

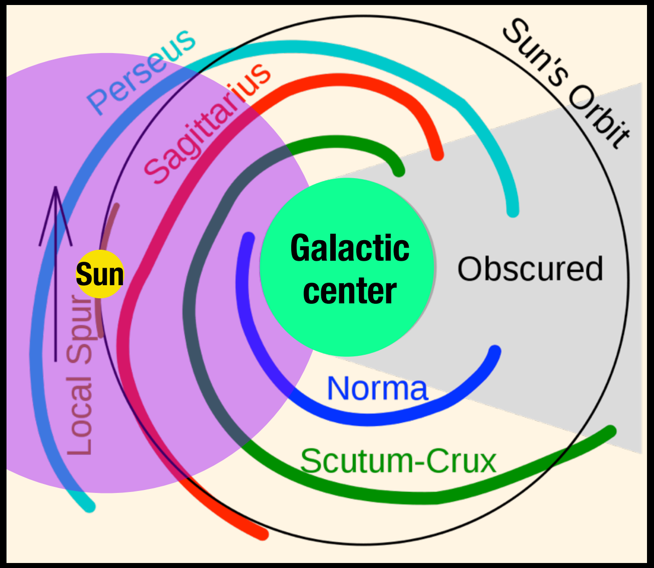
Detection of the 3.4 μm band in the diffuse ISM

To detect interstellar a-C:H

- ➯ high quantities of diffuse ISM
- ➯ lines of sight with **high visual extinction (A_V)**

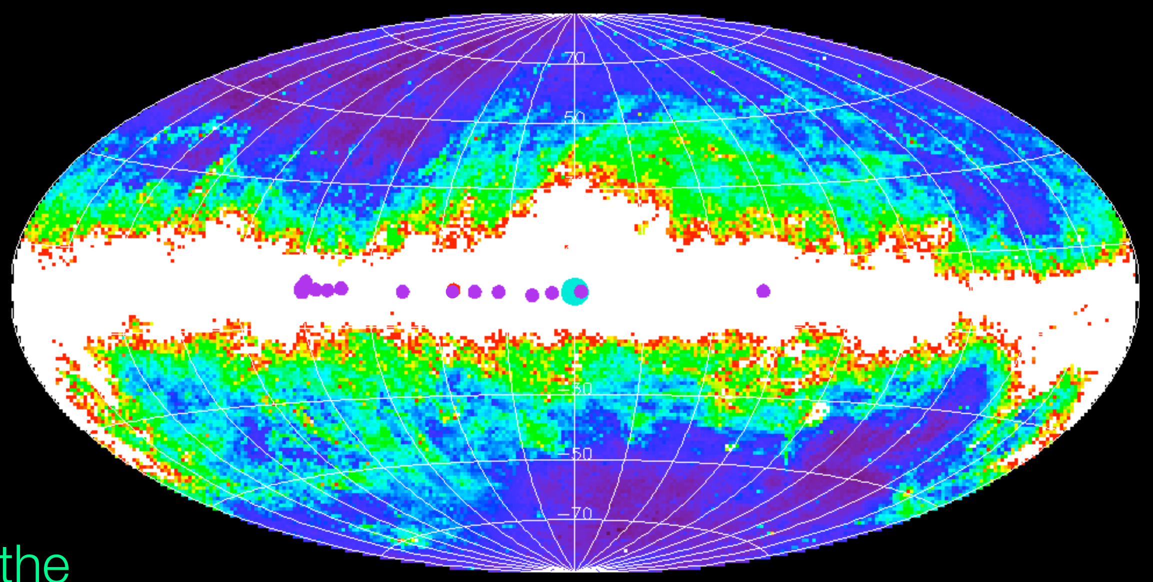


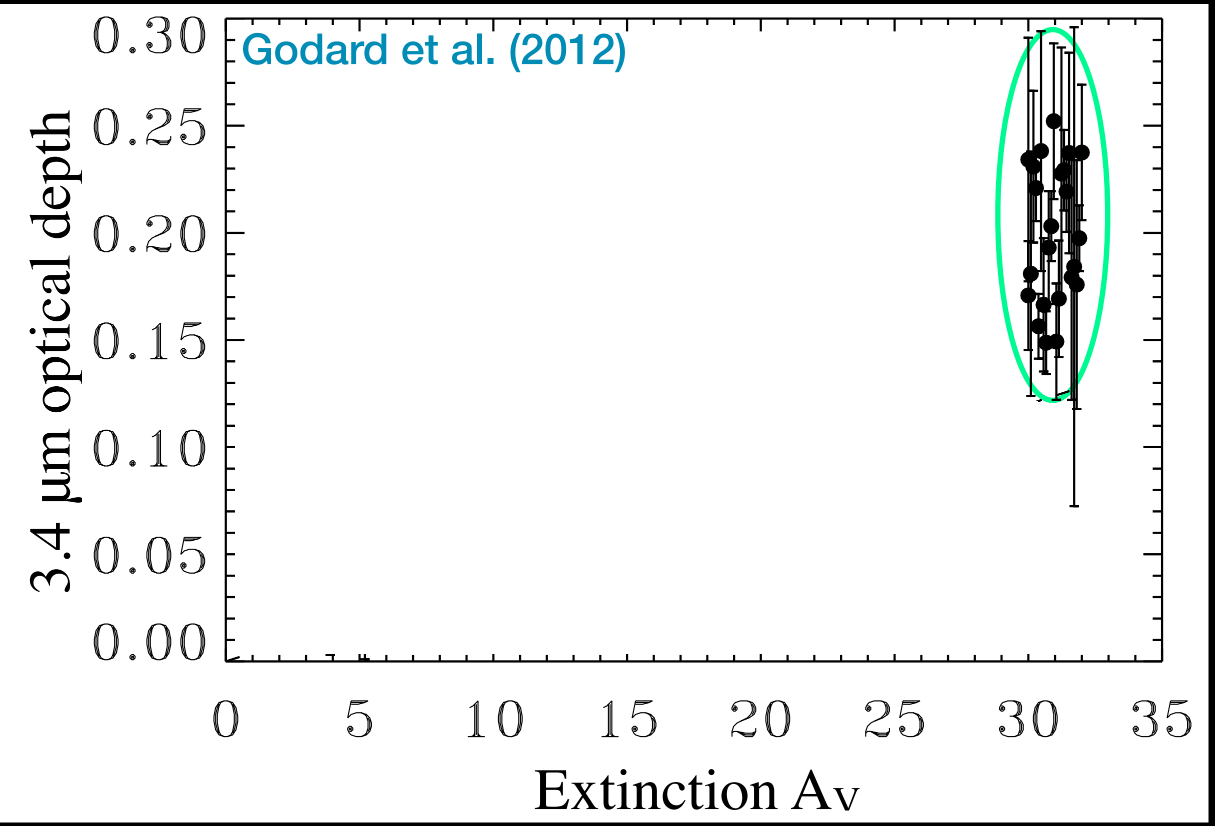




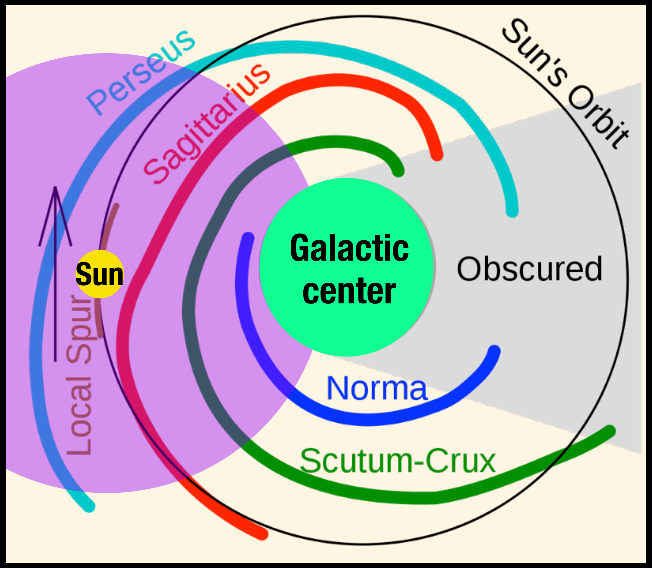
Detection of the 3.4 μm band in the diffuse ISM

To detect interstellar a-C:H
- ➯ high quantities of diffuse ISM
- ➯ lines of sight with **high visual extinction (A_V)**





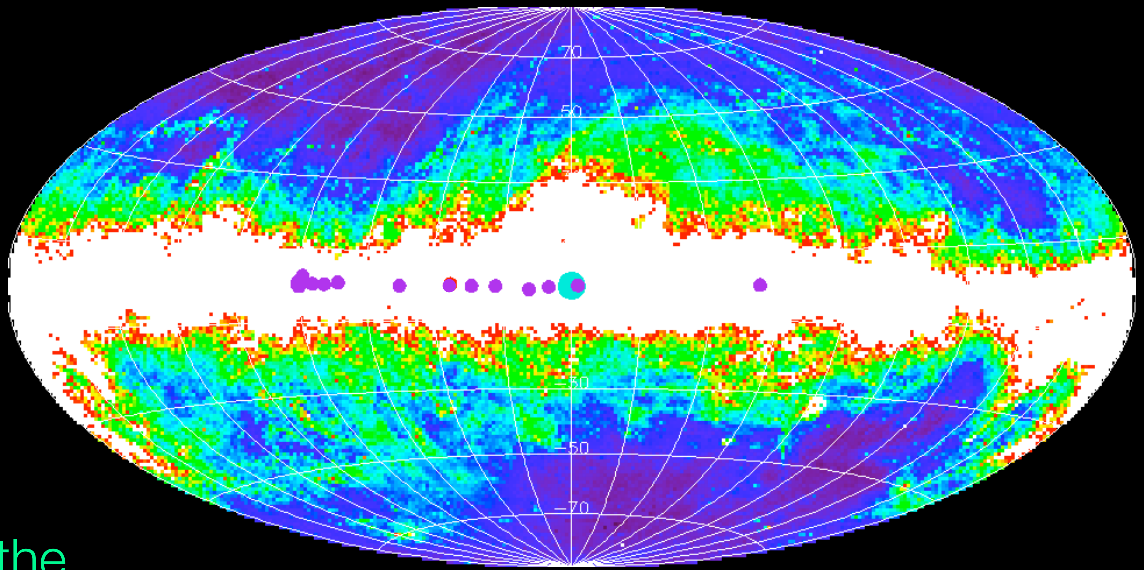
Toward the **Galactic centre**:
$A_V \approx 30 - 35$
➯ $A_V / \tau_{3.4} = 150$

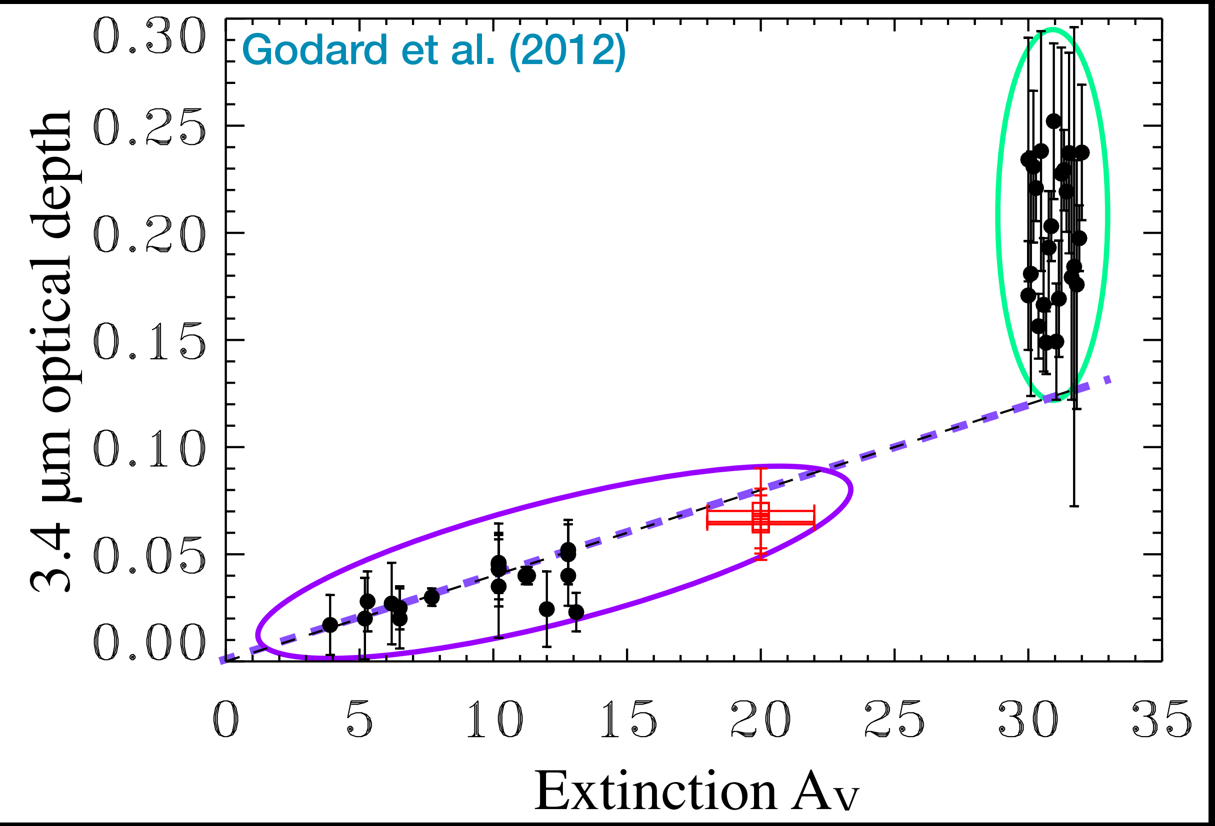


	1980's	1990's	2000's
Toward **Galactic centre**	Allen & Wickramasinghe (1981) McFadzean et al (1989)	Sandford et al. (1991) Pendleton et al. (1994)	Dartois et al. (2004) Chiar et al. (2000, 2002, 2006, 2013)

Detection of the 3.4 μm band in the diffuse ISM

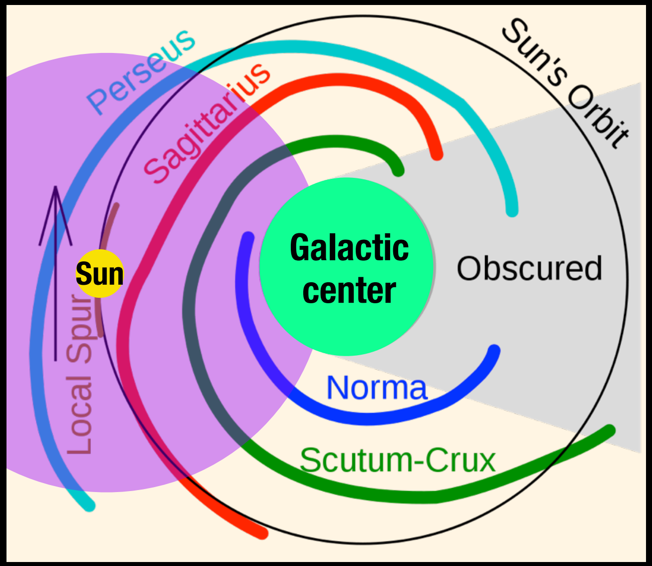
To detect interstellar a-C:H
- ➯ high quantities of diffuse ISM
- ➯ lines of sight with **high visual extinction (A_V)**





Toward the **Galactic centre**:
$A_V \approx 30 - 35$
➯ $A_V / \tau_{3.4} = 150$

In the **local diffuse ISM**:
$A_V \lesssim 15$
➯ $A_V / \tau_{3.4} = 250$

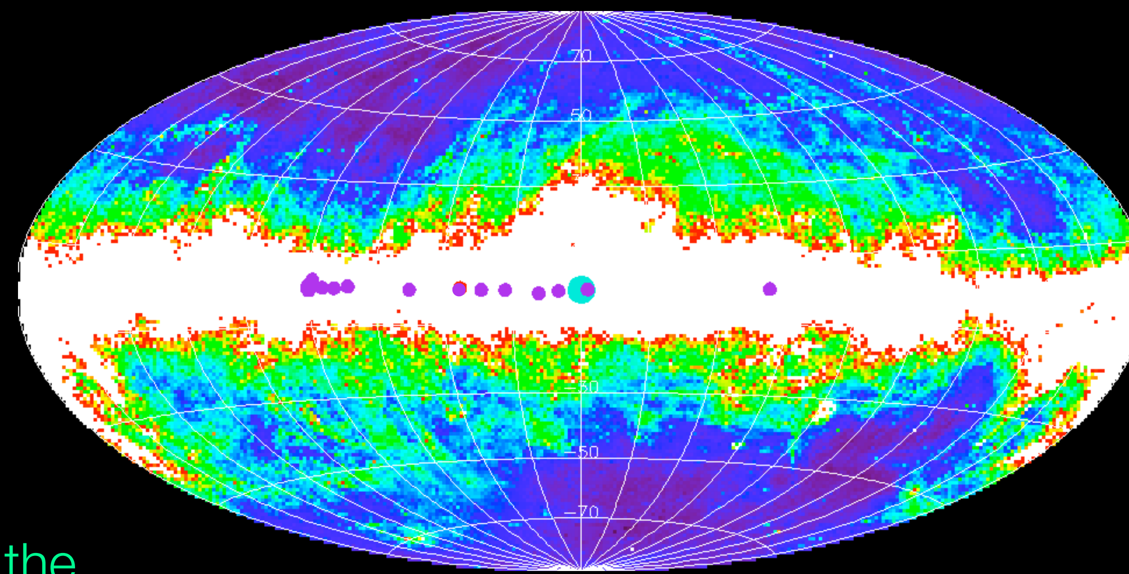


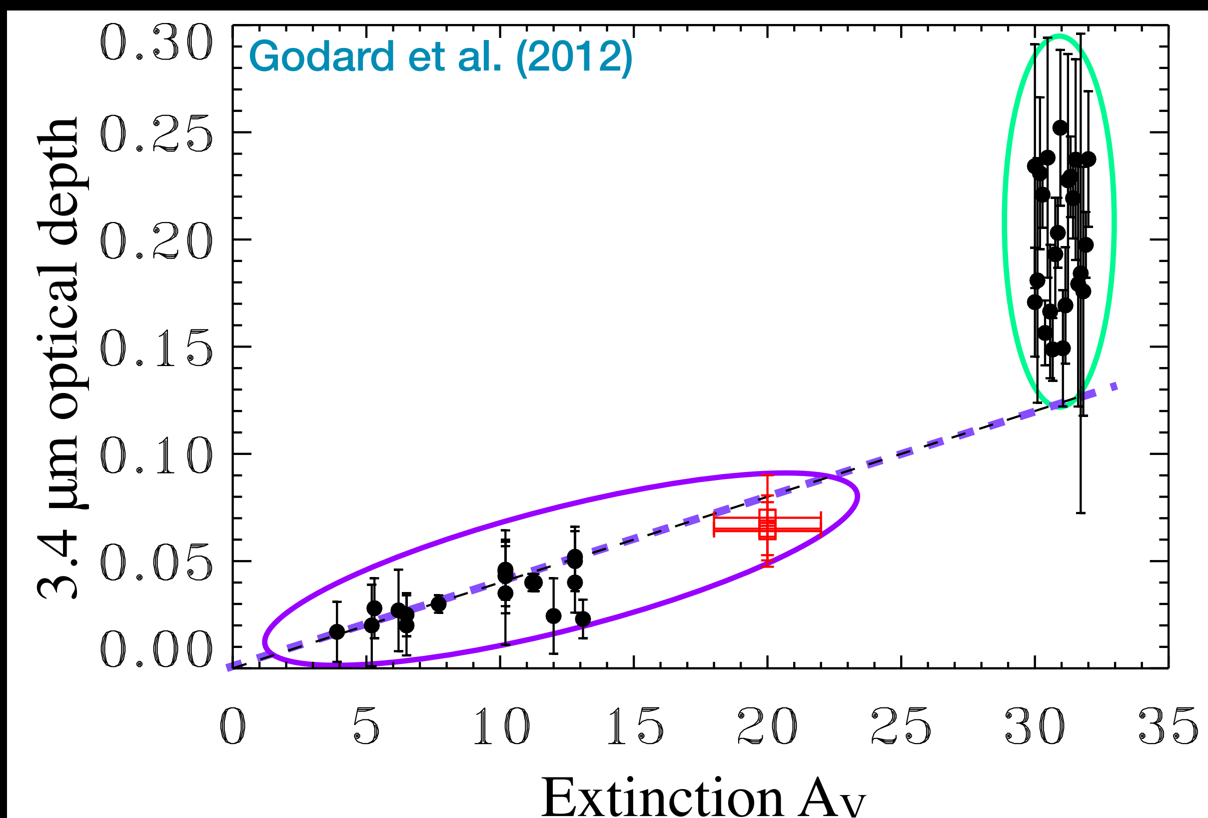
1980's — 1990's — 2000's — t

	1980's	1990's	2000's
Toward **Galactic centre**	Allen & Wickramasinghe (1981) McFadzean et al (1989)	Sandford et al. (1991) Pendleton et al. (1994)	Dartois et al. (2004) Chiar et al. (2000, 2002, 2006, 2013)
In the **local diffuse ISM**		Adamson et al (1990) Sandford et al. (1991) Pendleton et al. (1994)	Chiar et al. (2001) Rawlings et al. (2003) Godard et al. (2012)

Detection of the 3.4 μm band in the diffuse ISM

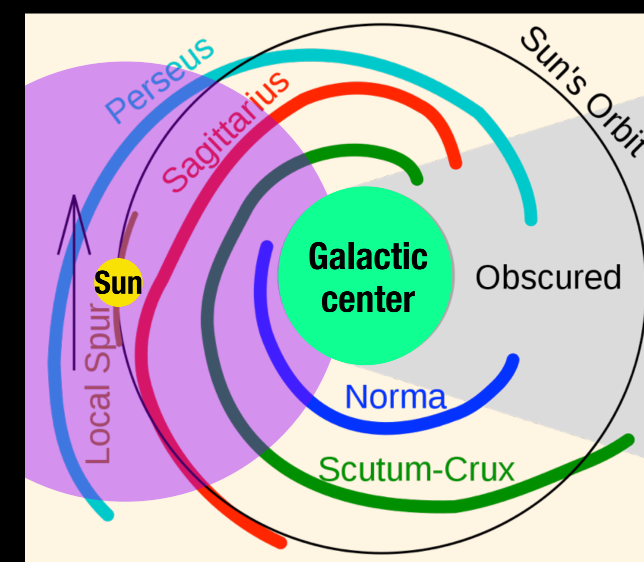
To detect interstellar a-C:H
- ➯ high quantities of diffuse ISM
- ➯ lines of sight with **high visual extinction (A_V)**





Toward the **Galactic centre**:
$A_V \approx 30 - 35$
➯ $A_V / \tau_{3.4} = 150$

In the **local diffuse ISM**:
$A_V \lesssim 15$
➯ $A_V / \tau_{3.4} = 250$



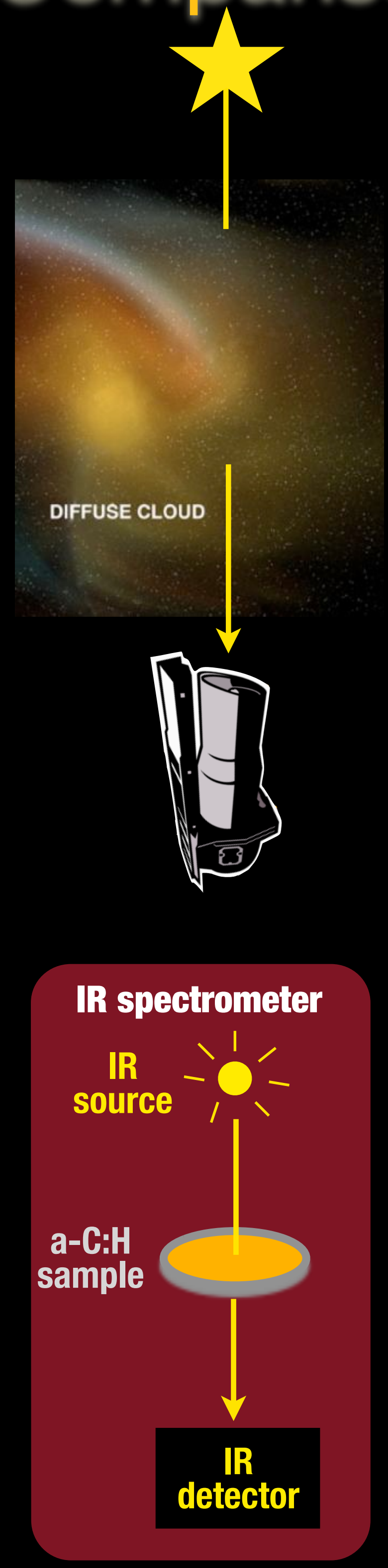
1980's — 1990's — 2000's — t

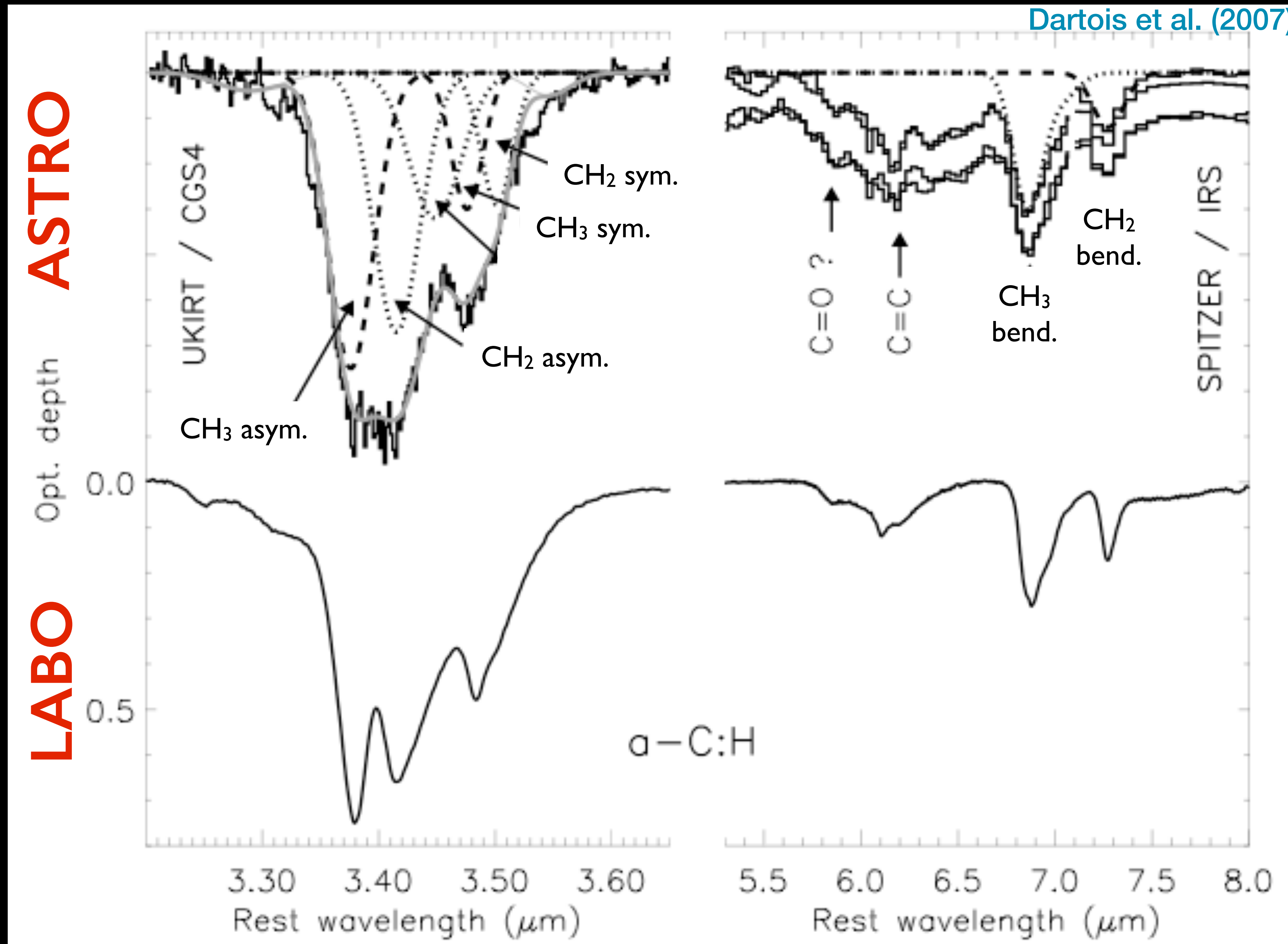
Toward Galactic centre
Allen & Wickramasinghe (1981)
McFadzean et al (1989)
Sandford et al. (1991)
Pendleton et al. (1994)
Dartois et al. (2004)
Chiar et al. (2000, 2002, 2006, 2013)

In the local diffuse ISM
Adamson et al (1990)
Sandford et al. (1991)
Pendleton et al. (1994)
Chiar et al. (2001)
Rawlings et al. (2003)
Godard et al. (2012)

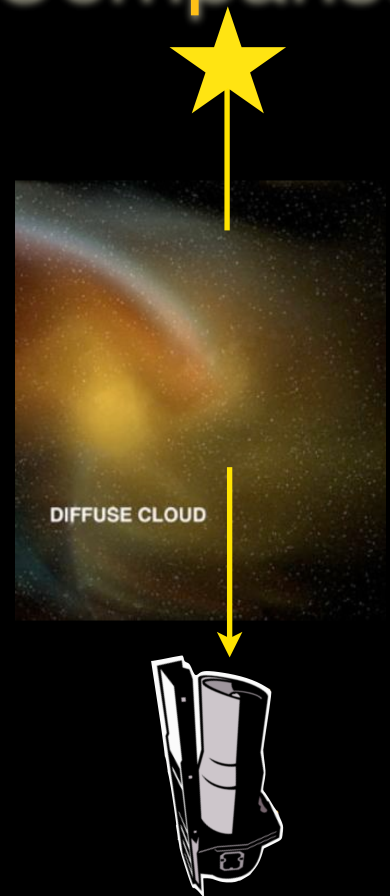
In external galaxies
Bridger et al (1994)
Wright et al. (1996)
Imanishi et al. (2000,2006, 2008)
Spoon et al. (2002,2004)
Dartois et al. (2004, 2007)

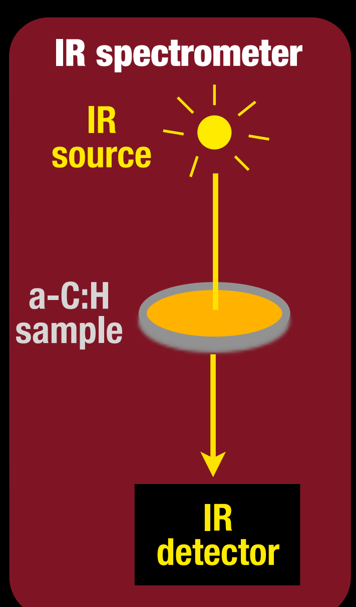
Comparison of observations with laboratory analogs spectra

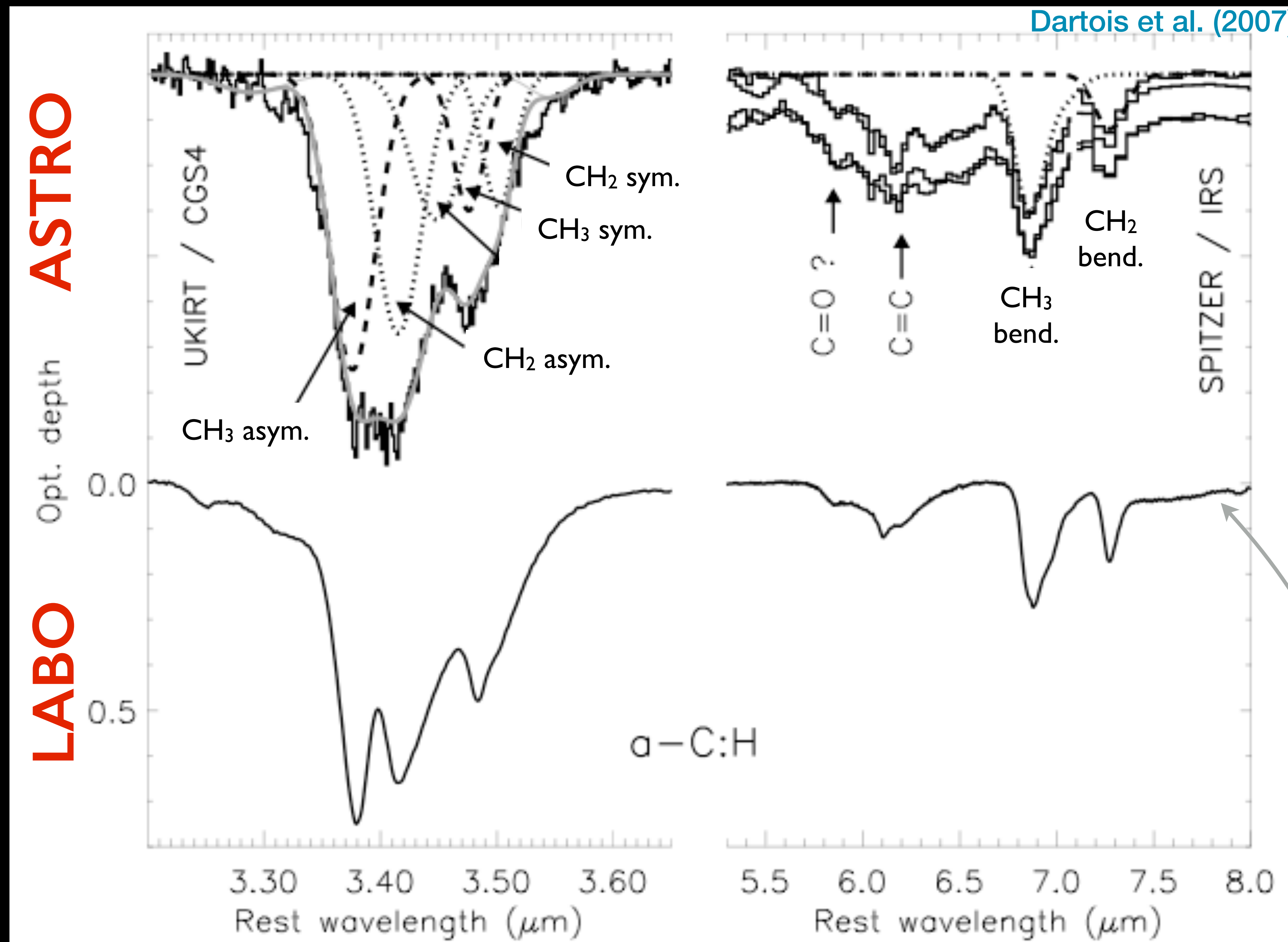




Comparison of observations with laboratory analogs spectra







Interstellar a-C:H analogs:

From carbon rods:

Mennella et al. (1999, 2003)
Scott & Duley (1994, 1996, 1997)
Schnaiter et al. (1998)
Gadallah et al. (2011)

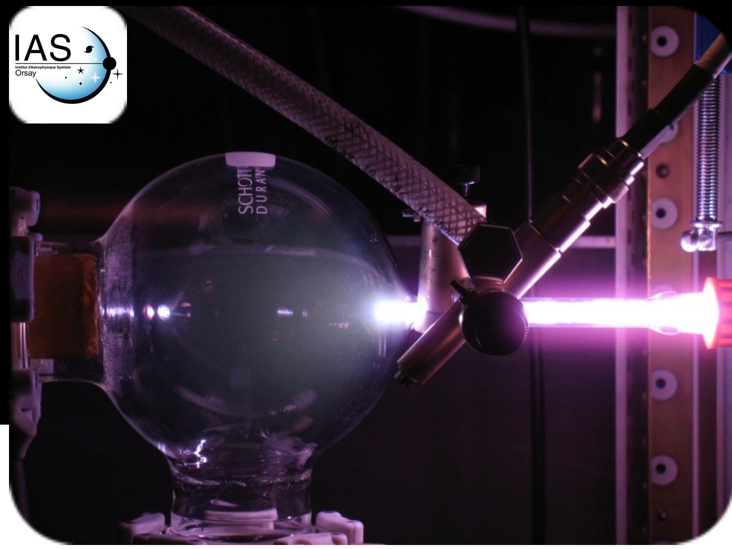
From plasma:

Sakata & Wada (1992, 2009)
Lee & Wdowiak (1993)
Furton et al. (1999)
Godard et al (2010, 2011)
Alata et al (2014)

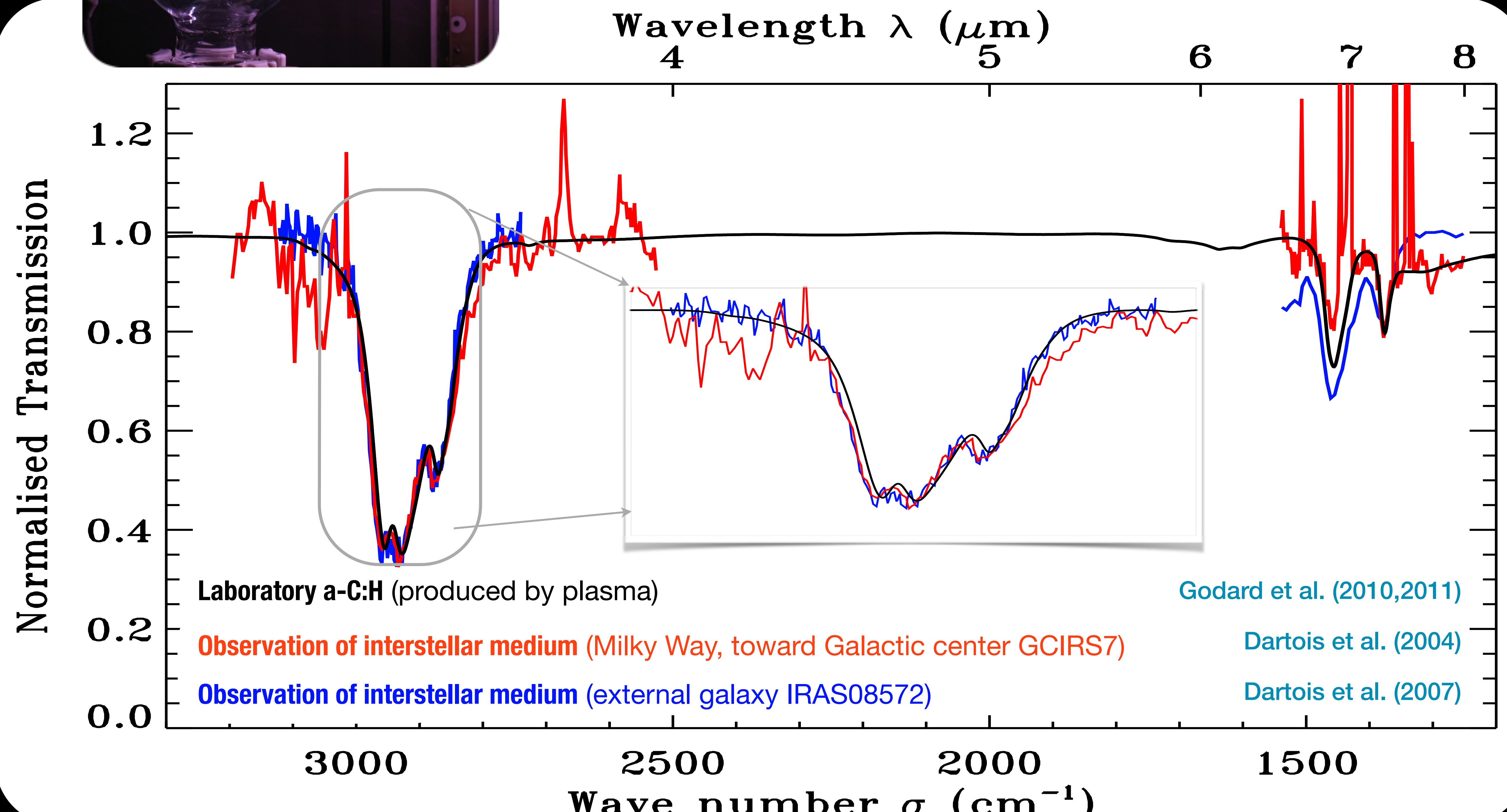
Photolysis at low temperature from C_nH_m ices :

Dartois et al. (2004,2005)

Comparison of observations with laboratory analogs spectra



➯ a-C:H are excellent analogs



Structure & Abundance of interstellar a-C:H

O content : very low

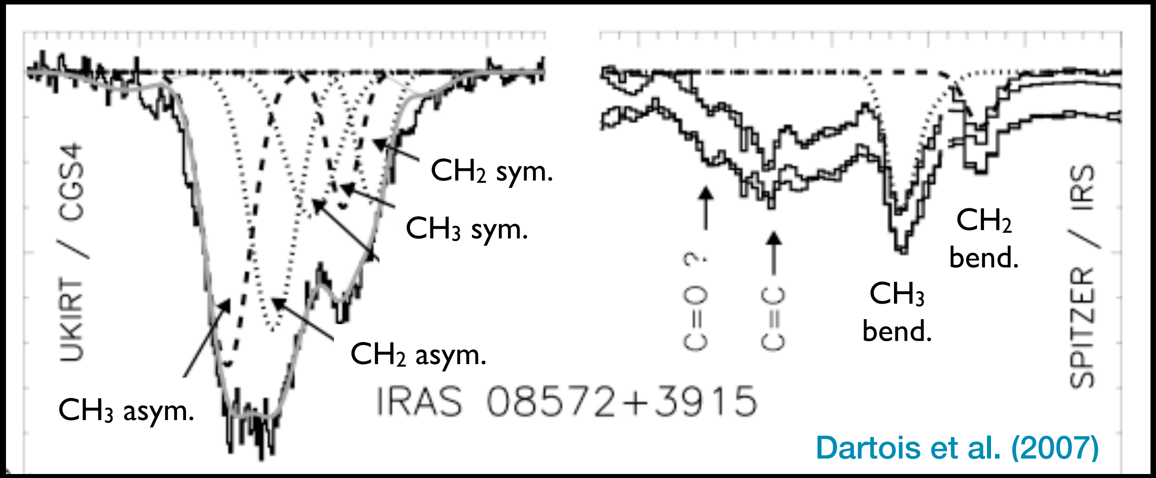
Pendleton & Allamandola (2002)
Dartois et al. (2007)

CH_2/CH_3 ~ 2 - 2,5

Sandford et al. (1991)
Pendleton et al. (1994)
Duley et al. (2005)

H content : X_H > 20%

Dartois et al. (2007)



Dartois et al. (2007)

Structure & Abundance of interstellar a-C:H

O content : very low

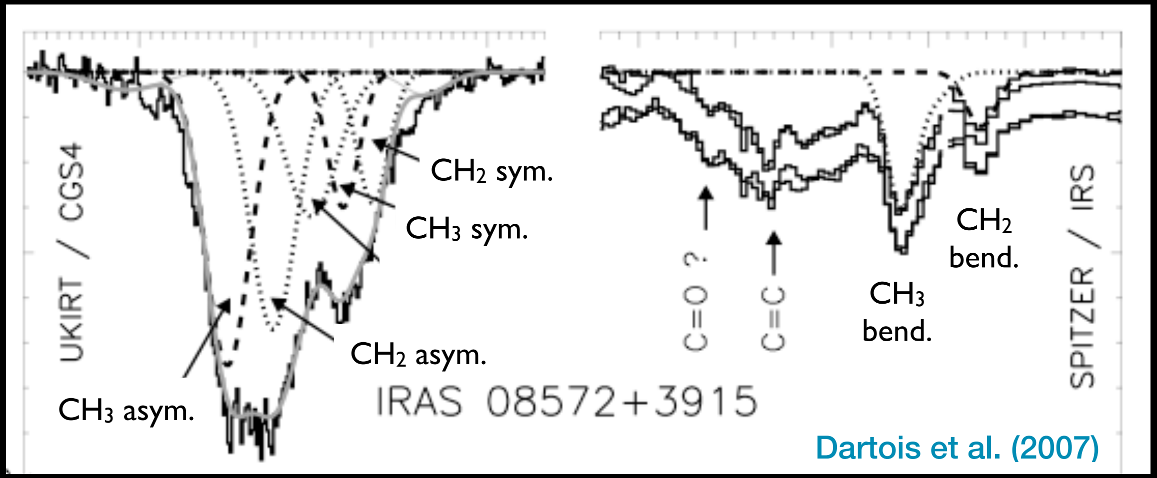
$CH_2/CH_3 \sim 2 - 2{,}5$

H content : $X_H > 20\%$

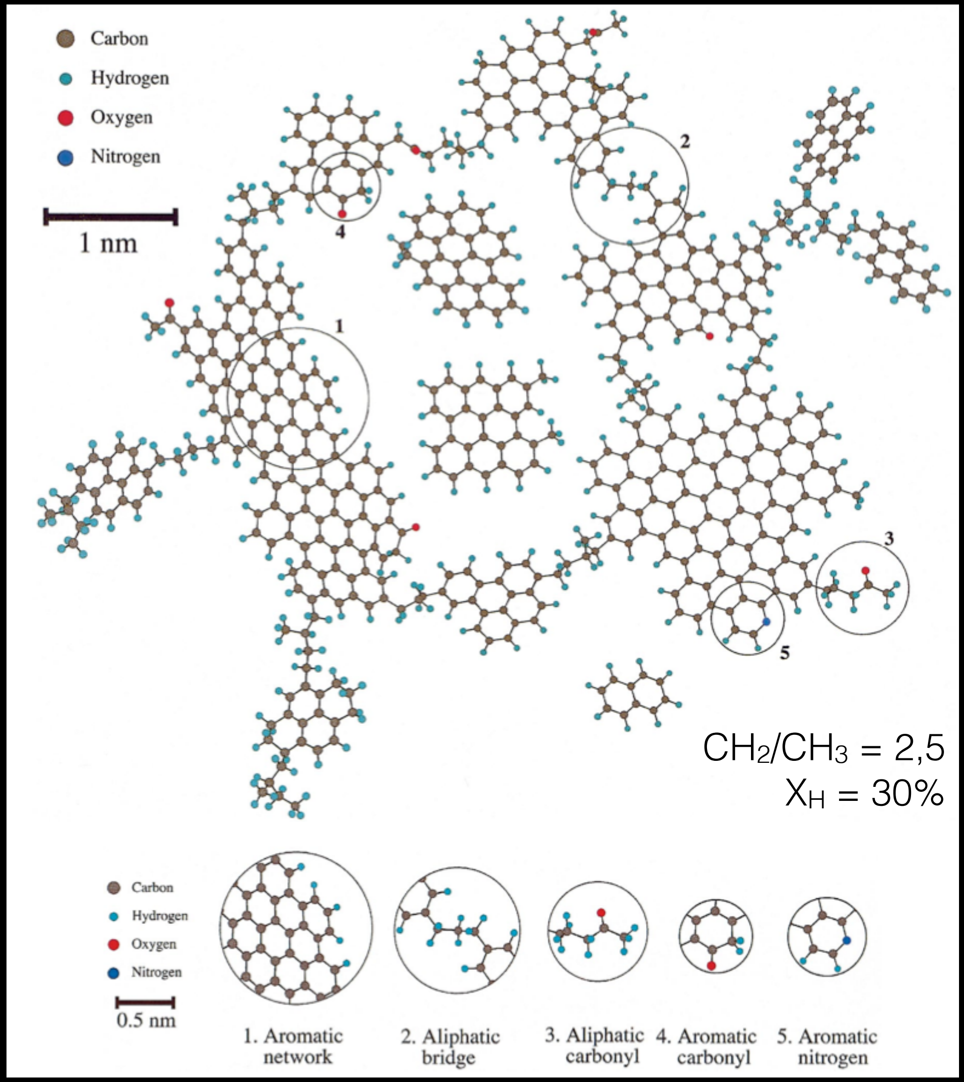
Pendleton & Allamandola (2002)
Dartois et al. (2007)

Sandford et al. (1991)
Pendleton et al. (1994)
Duley et al. (2005)

Dartois et al. (2007)



Dartois et al. (2007)



Pendleton & Allamandola (2002)

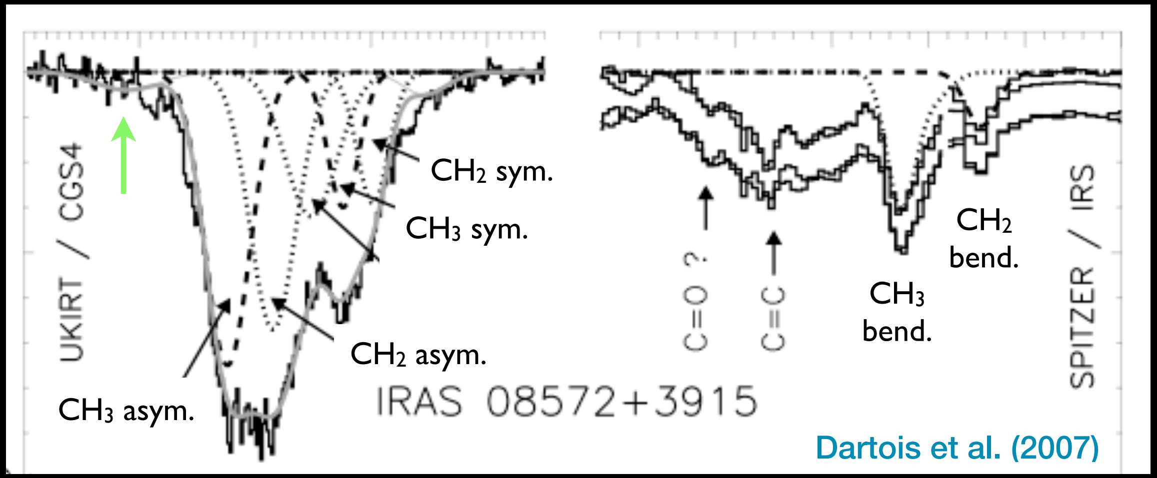
Structure & Abundance of interstellar a-C:H

O content : very low — Pendleton & Allamandola (2002), Dartois et al. (2007)

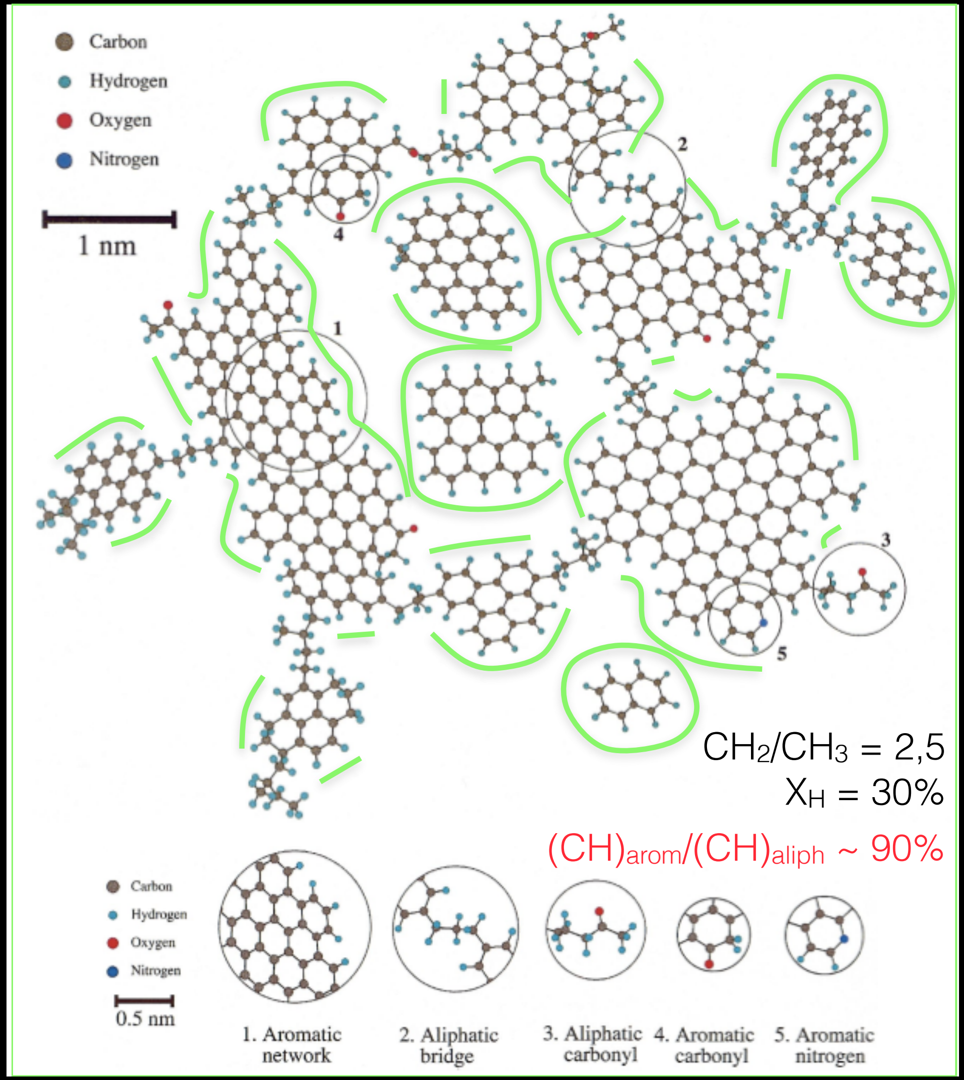
CH_2/CH_3 ~ 2 - 2,5 — Sandford et al. (1991), Pendleton et al. (1994), Duley et al. (2005)

H content : X_H > 20% — Dartois et al. (2007)

Aromatic : $(CH)_{arom}/(CH)_{aliph}$ < 8% — Dartois et al. (2007)



Dartois et al. (2007)



Pendleton & Allamandola (2002)

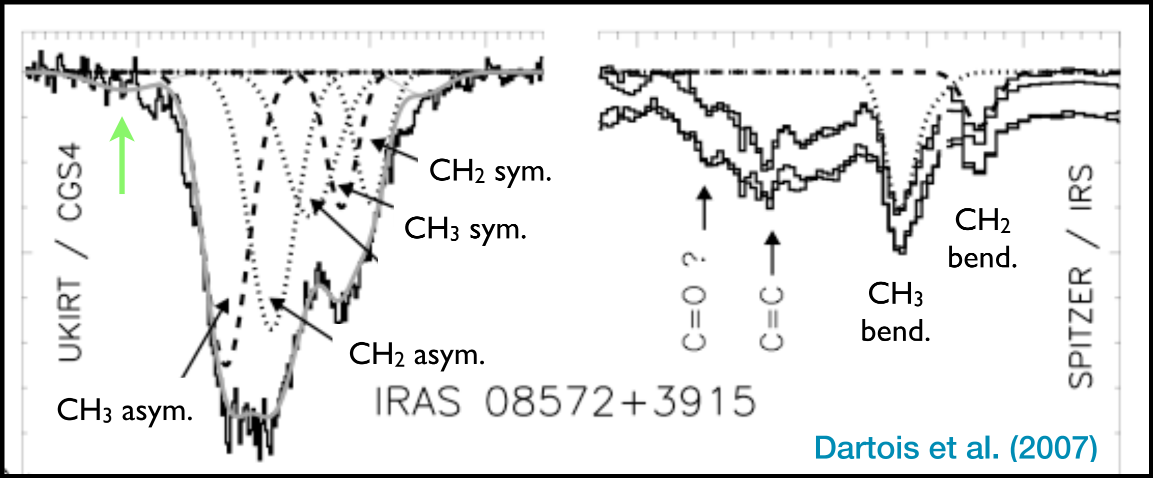
Structure & Abundance of interstellar a-C:H

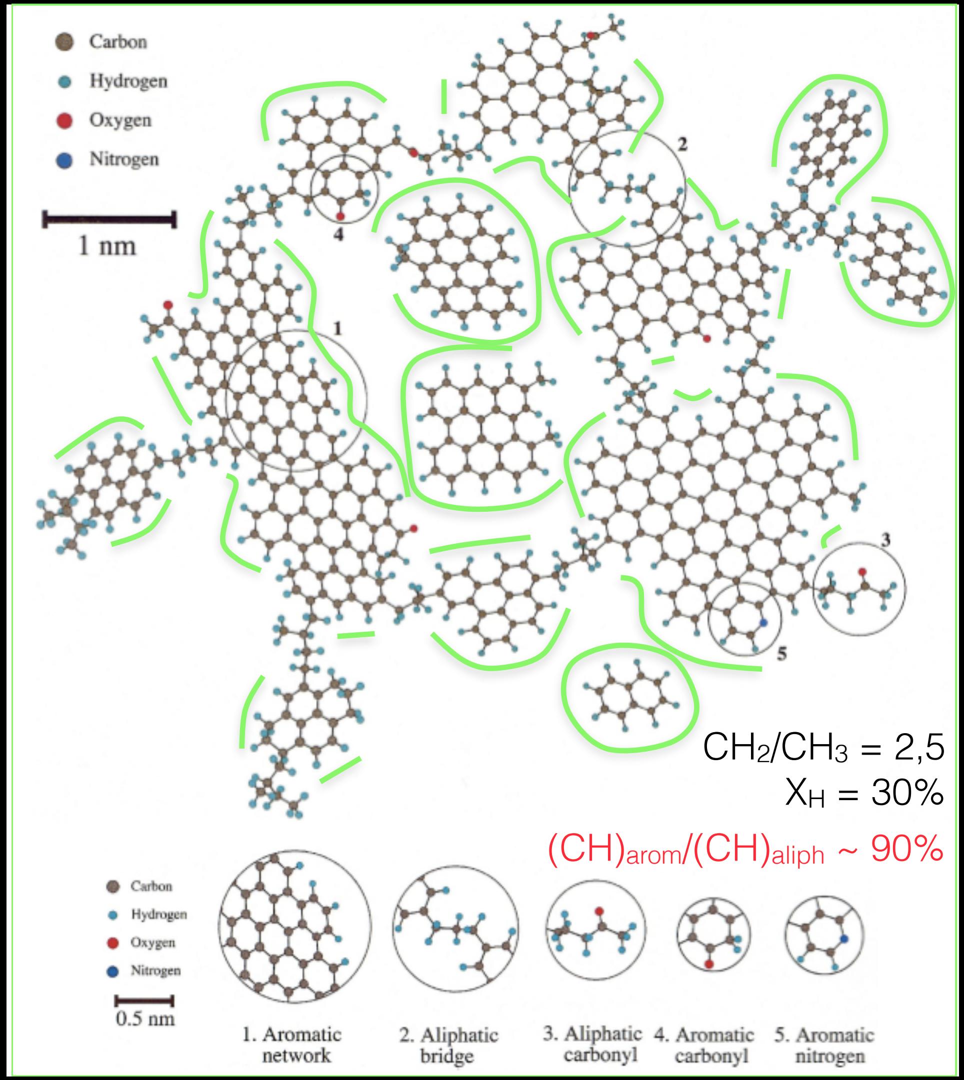
O content : very low — Pendleton & Allamandola (2002), Dartois et al. (2007)

CH_2/CH_3 ~ 2 - 2,5 — Sandford et al. (1991), Pendleton et al. (1994), Duley et al. (2005)

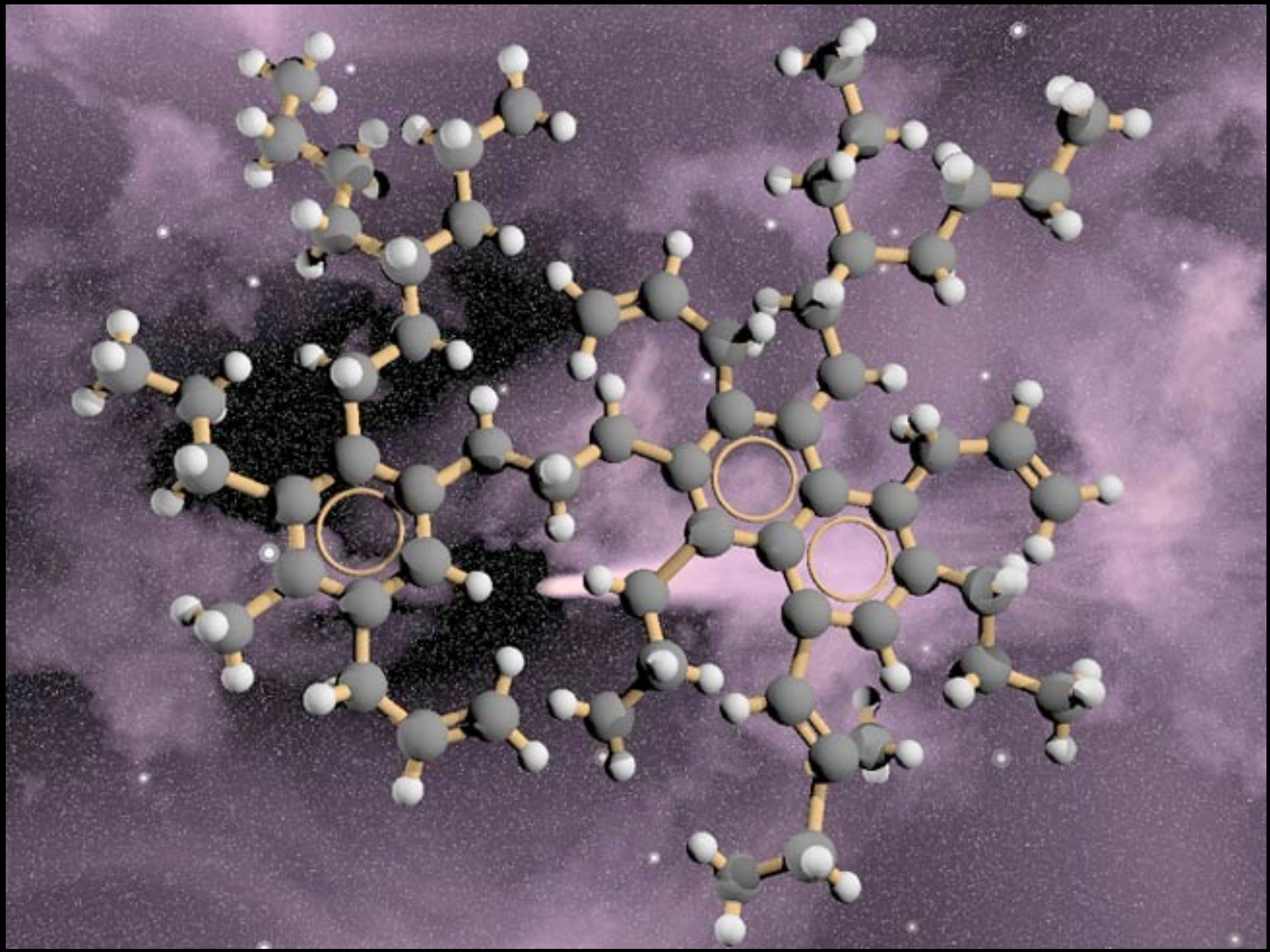
H content : $X_H > 20\%$ — Dartois et al. (2007)

Aromatic : $(CH)_{arom}/(CH)_{aliph} < 8\%$ — Dartois et al. (2007)





Pendleton & Allamandola (2002)



Dartois et al. (2007)

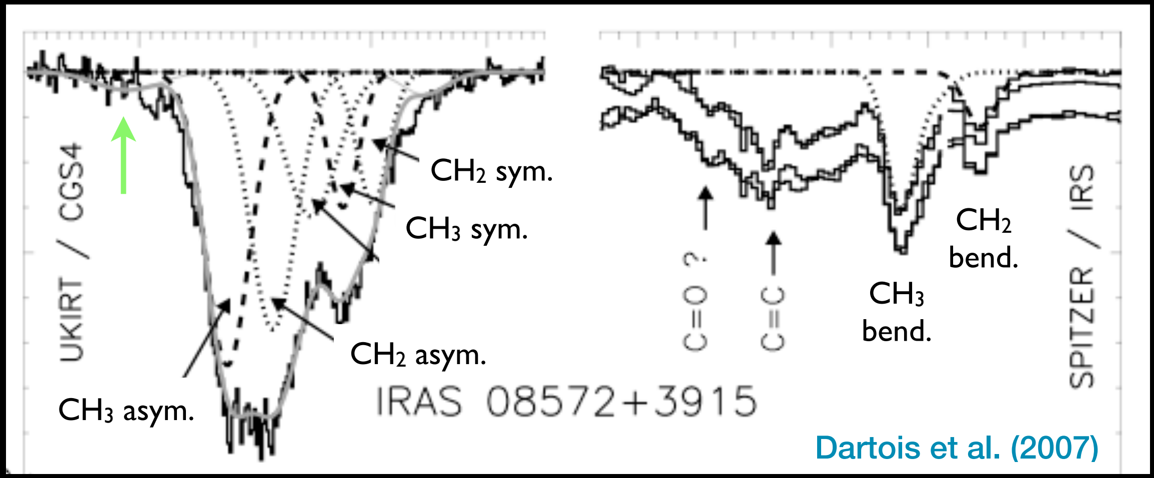
Structure & Abundance of interstellar a-C:H

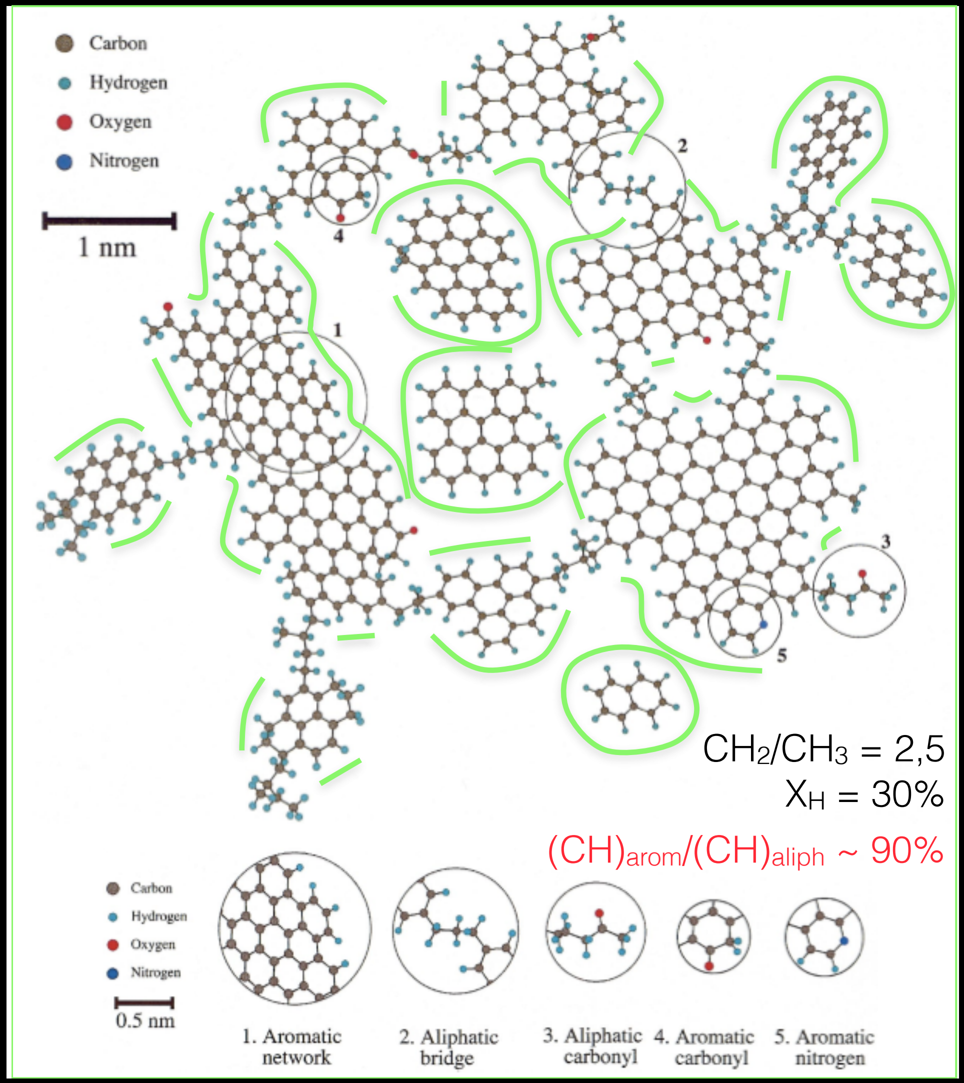
O content : very low — Pendleton & Allamandola (2002), Dartois et al. (2007)

CH_2/CH_3 ~ 2 - 2,5 — Sandford et al. (1991), Pendleton et al. (1994), Duley et al. (2005)

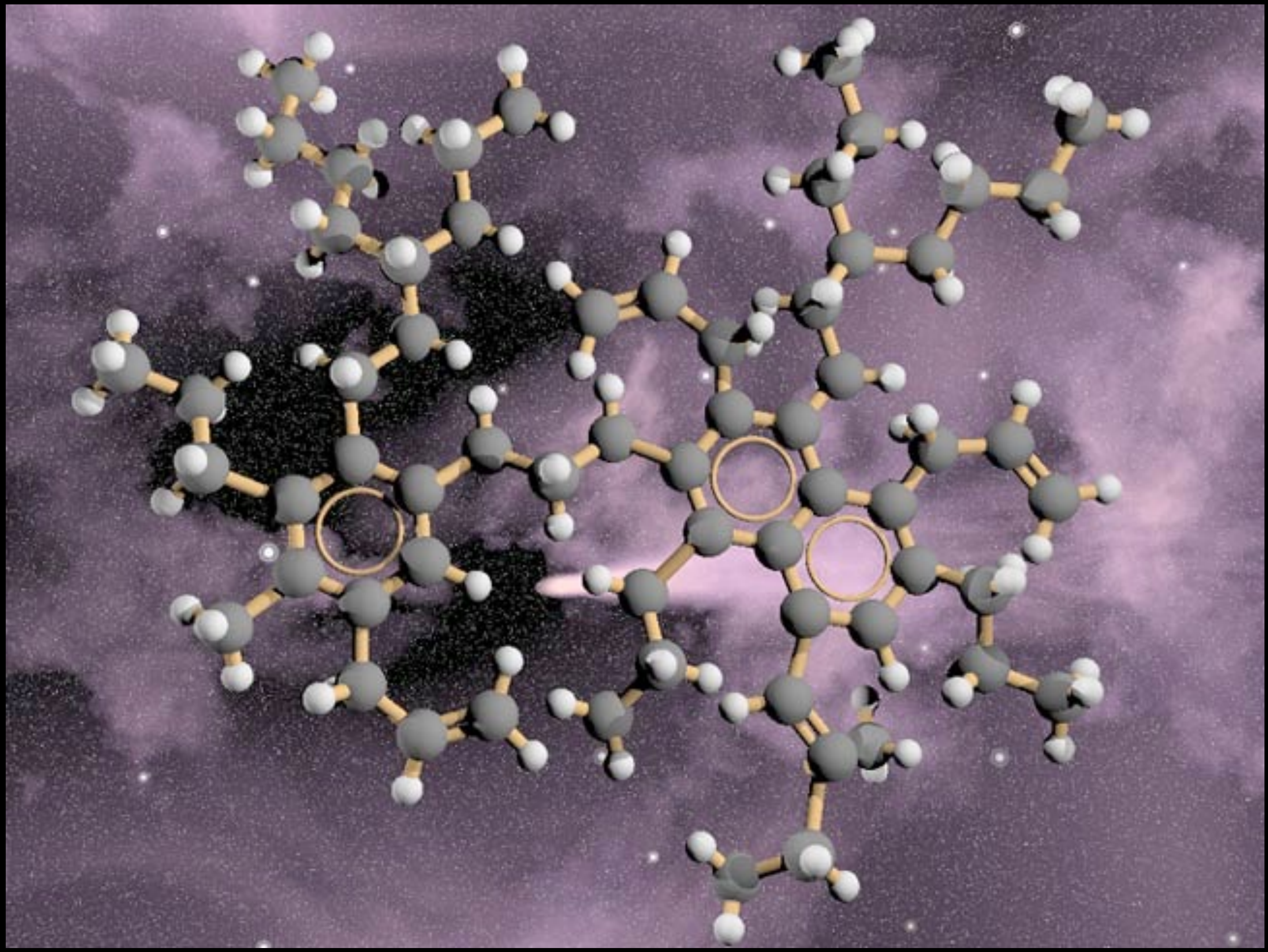
H content : X_H > 20% — Dartois et al. (2007)

Aromatic : $(CH)_{arom}/(CH)_{aliph}$ < 8% — Dartois et al. (2007)





Pendleton & Allamandola (2002)



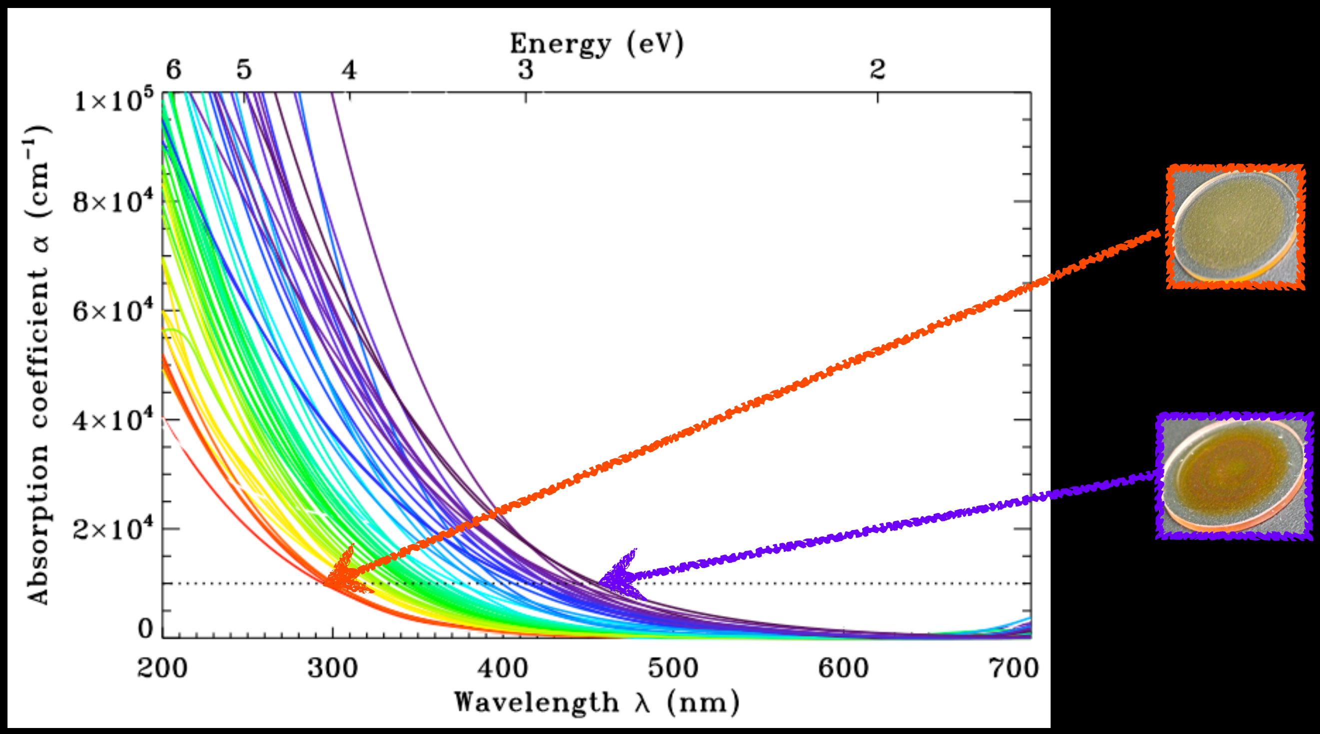
Dartois et al. (2007)

Abundance of interstellar a-C:H : $(CH)_{aliph}/C_{cosmic}$ ~ 10 to 35 %

Optical properties of a-C:H

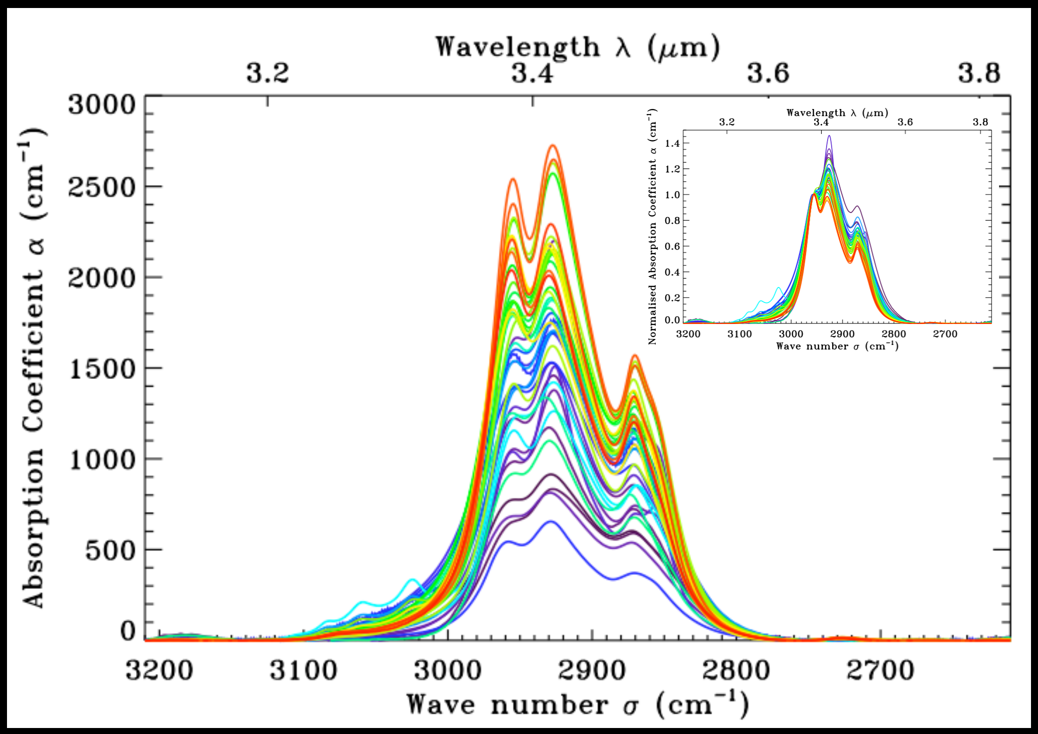
➫ Absorption

UV-Visible



Band gap energy

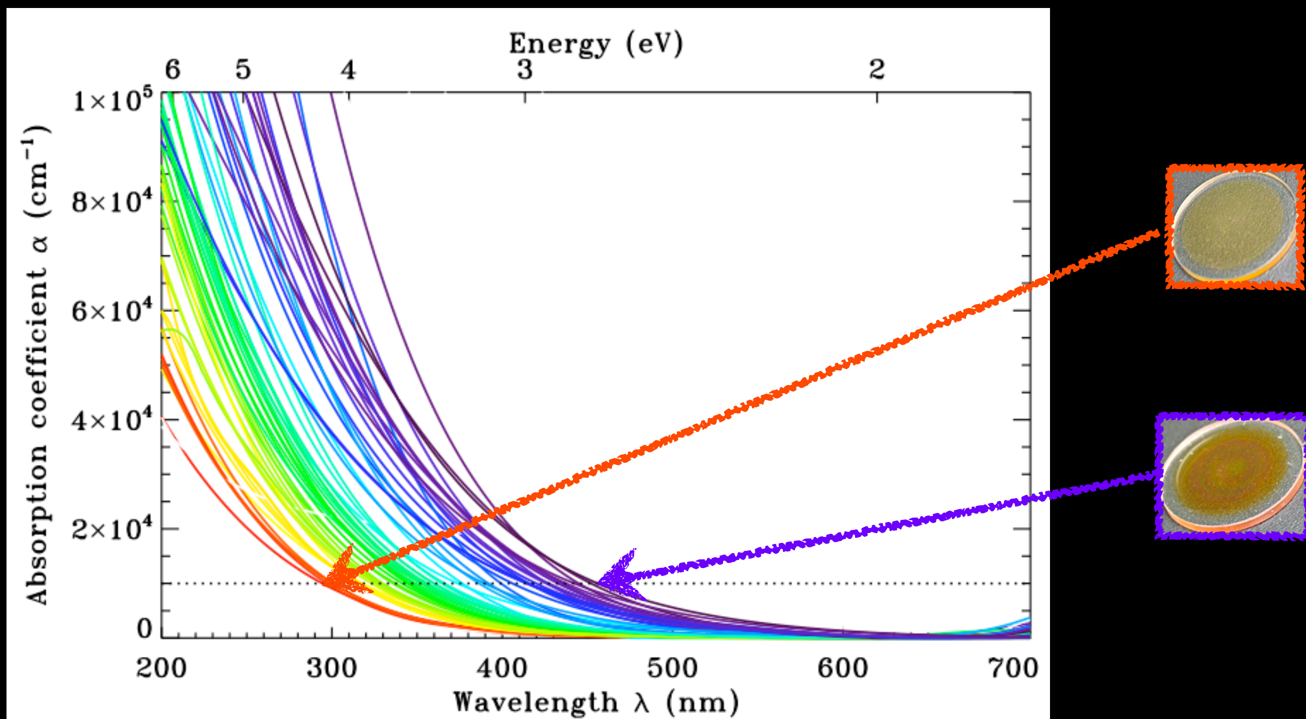
Infrared



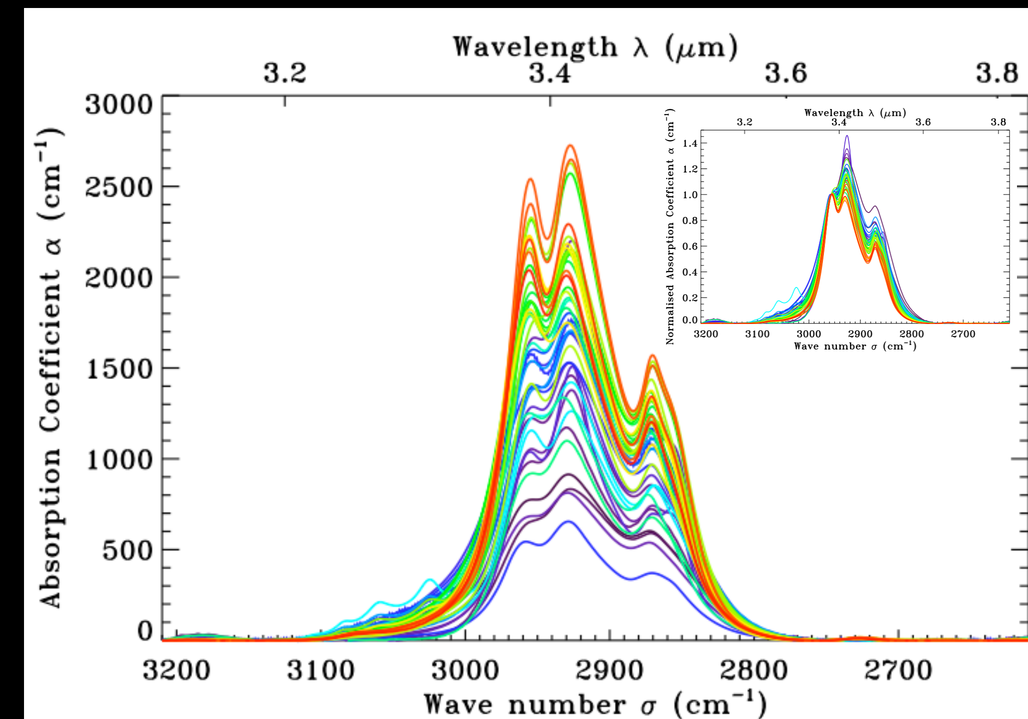
Optical properties of a-C:H

➫ Absorption

UV-Visible



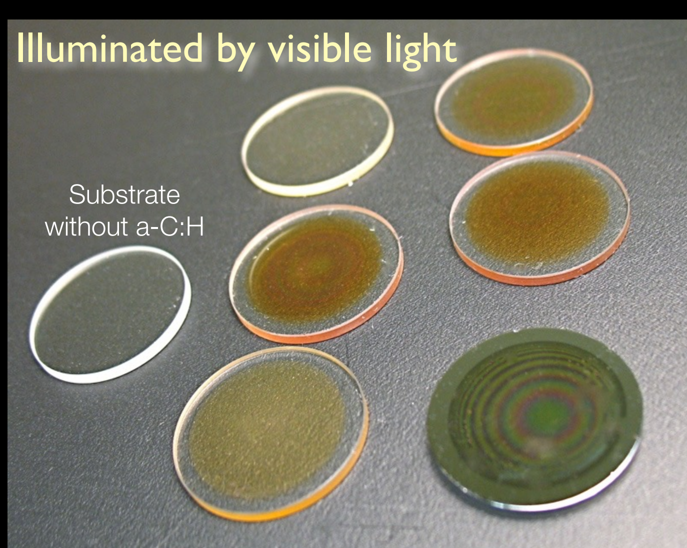
Infrared



← Band gap energy

➫ Emission

Visible photoluminescence (induced by UV-visible absorption)

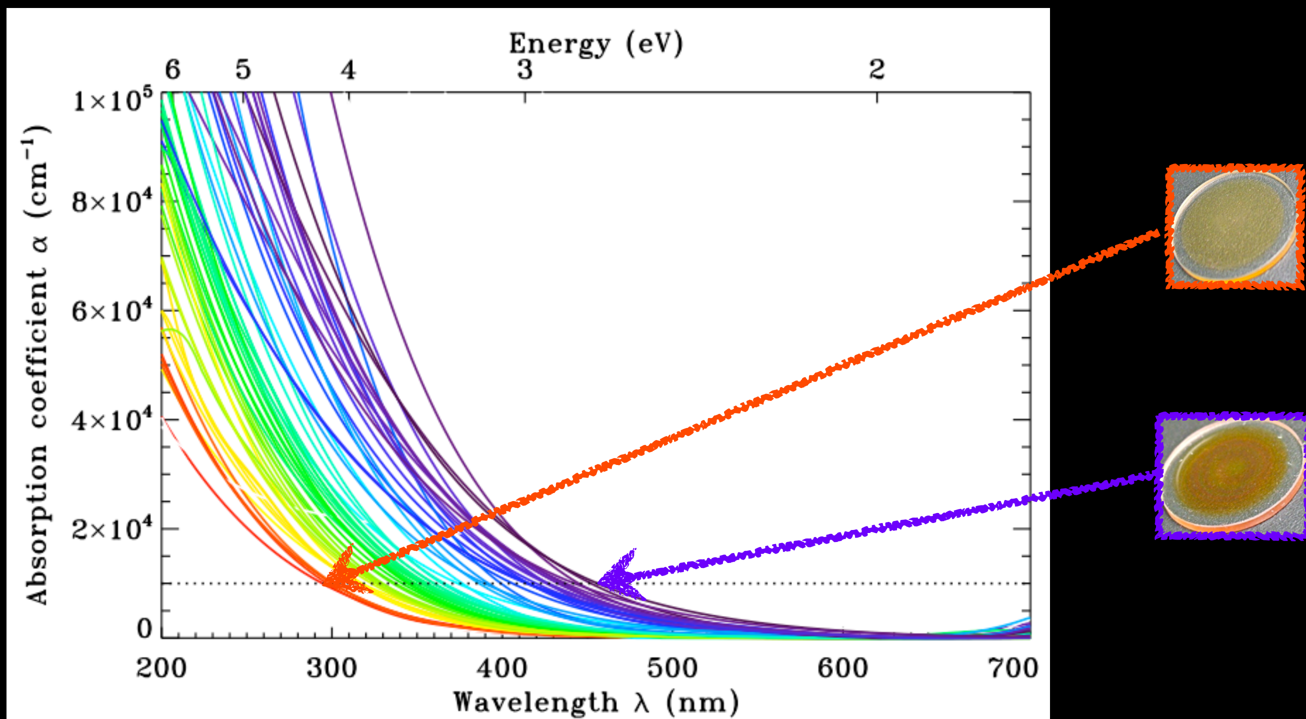


Godard & Dartois (2010)

Optical properties of a-C:H

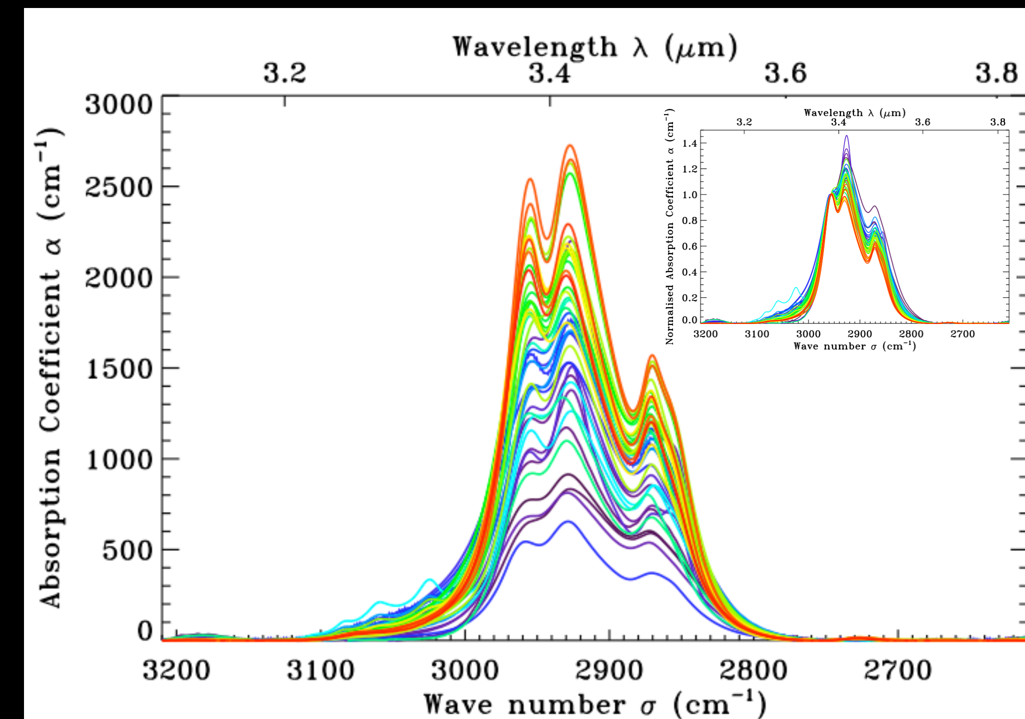
➯ Absorption

UV-Visible



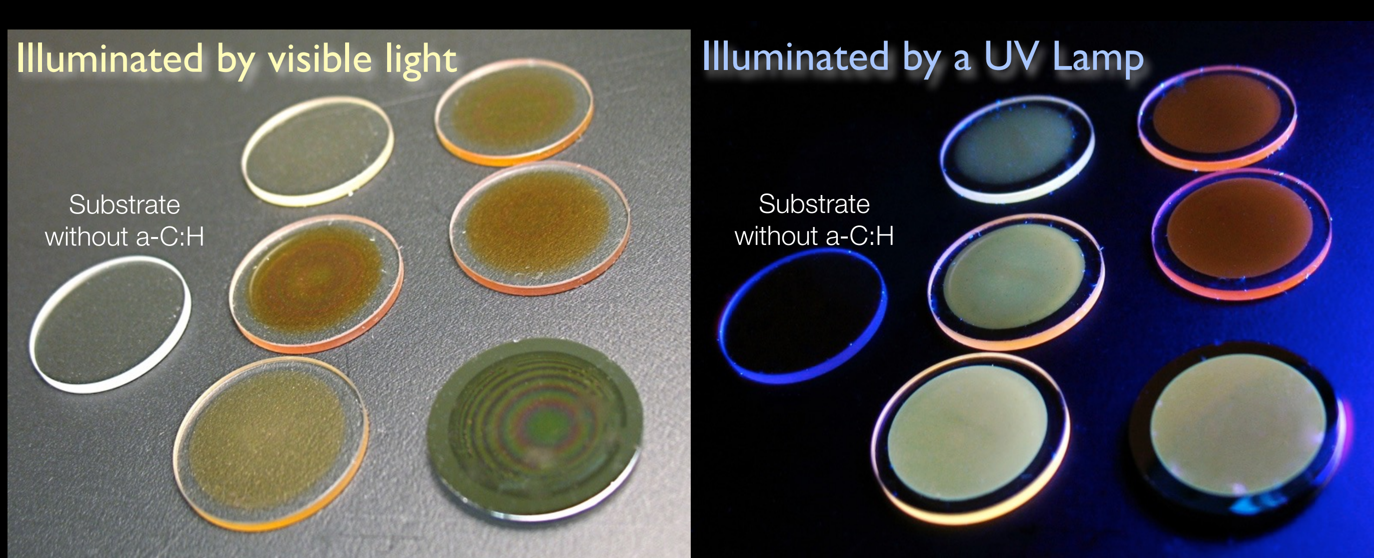
Band gap energy

Infrared



➯ Emission

Visible photoluminescence (induced by UV-visible absorption)



Godard & Dartois (2010)

Models of a-C(:H)

optEC$_{(s)}$(a) Jones, A&A (2012, a-c)
➯ model of the optical constants
➯ function of the band gap
➯ size-dependent properties

Model : Jones et al, A&A (2013)
evolution of interstellar a-C(:H)

Evolution of the 3.4 μm band carriers in the interstellar medium

3.4 μm band
observed

<u>Evolution of dust due to:</u>

Hydrogen atoms exposition
UV irradiation
Cosmic rays irradiation
...

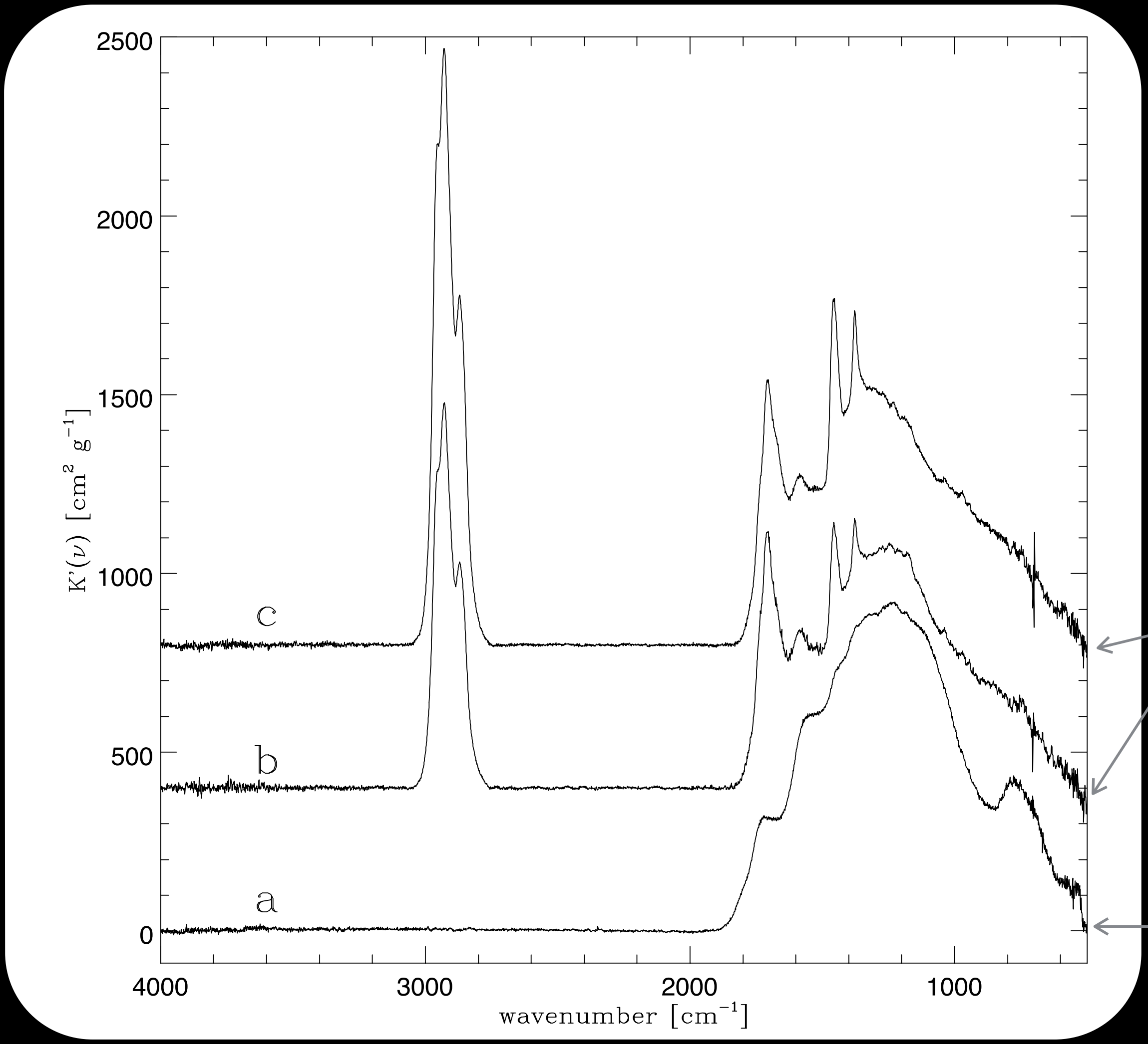
3.4 μm band
not observed

Very low upper limit :
Muñoz Caro et al. (2001)

➫ Evolution/processing of a-C:H in interstellar medium

Exposition to H atoms

Mennella et al, ApJ (1999, 2002, 2006)



a-C:H grains obtained by H atoms exposure

a-C grains before H exposure

- ➯ 3.4, 6.9 & 7.3 μm absorption band ↗
- ➯ Formation of aliphatic C—H bond by exposure to H atoms flux
- ➯ C—H formation cross section : $\sigma_{f,H} = 1.7\ 10^{-18}\ cm^2/H$ atom for T = 100 K
- ➯ $\sigma_{f,H}$ ↘ when T ↘

Formation of aliphatic C-H dust component occurs in diffuse ISM

Exposition to UV photons

Mennella et al, A&A (2001)

- ➫ Dehydrogenation (3.4 µm absorption band ↘)
- ➫ C-H destruction cross section : $\sigma_{d,UV} = 10^{-19}$ cm^2/photon

Destruction of aliphatic C-H dust by interstellar radiation field in diffuse ISM, but this effect is **counteracted** by H exposure.

Exposition to UV photons

Mennella et al, A&A (2001)

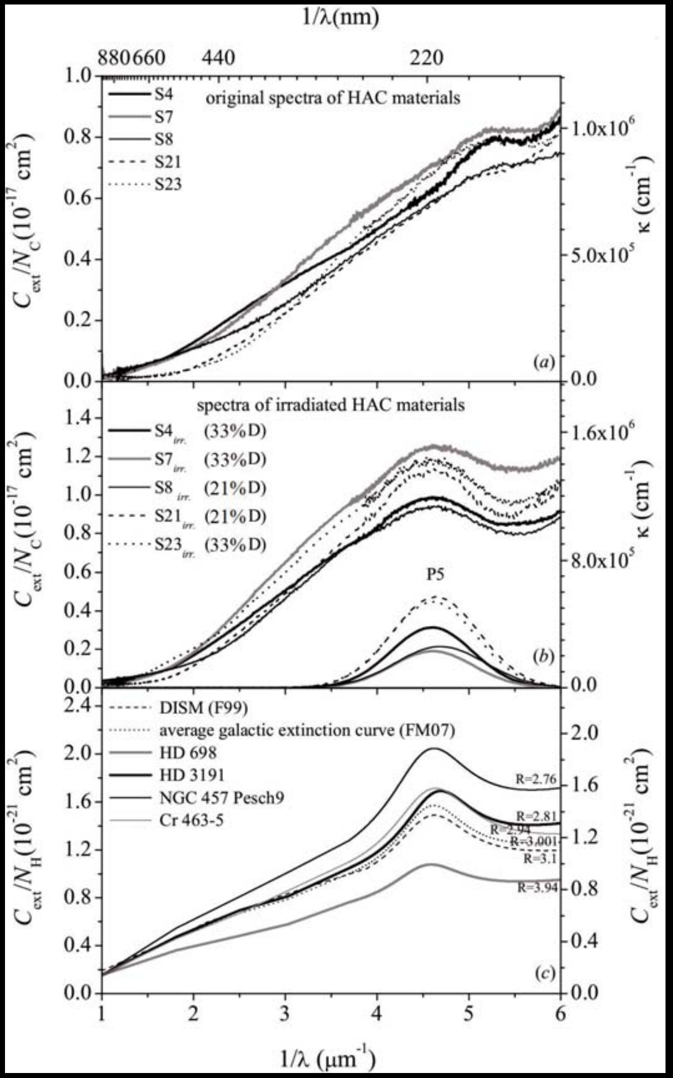
- ➯ Dehydrogenation (3.4 µm absorption band ↘)
- ➯ C-H destruction cross section : $\sigma_{d,UV} = 10^{-19}$ cm^2/photon

Destruction of aliphatic C-H dust by interstellar radiation field in diffuse ISM, but this effect is **counteracted** by H exposure.

Gadallah, Mutschke & Jäger, A&A (2011)

- ➯ Dehydrogenation (3.4 µm absorption band ↘)
- ➯ Graphitization
- ➯ Production of a new absorption band at 217,5 nm

UV-irradiated a-C:H involved in the **UV bump** at 217,5 nm ?
(C abundance problem)

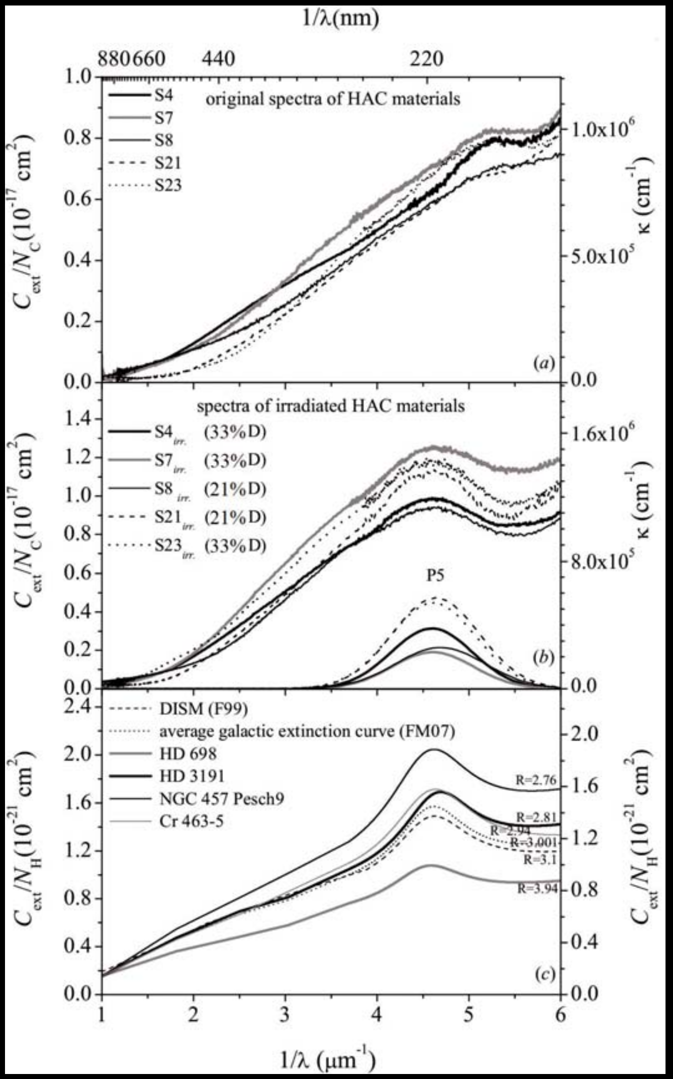


Exposition to UV photons

Mennella et al, A&A (2001)

- Dehydrogenation (3.4 µm absorption band ↘)
- C-H destruction cross section : $\sigma_{d,UV} = 10^{-19}$ cm^2/photon

Destruction of aliphatic C-H dust by interstellar radiation field in diffuse ISM, but this effect is **counteracted** by H exposure.



Gadallah, Mutschke & Jäger, A&A (2011)

- Dehydrogenation (3.4 µm absorption band ↘)
- Graphitization
- Production of a new absorption band at 217,5 nm

UV-irradiated a-C:H involved in the **UV bump** at 217,5 nm ?
(C abundance problem)

Alata, Cruz-Diaz, Muñoz Caro & Dartois, A&A (2014)

- Dehydrogenation (3.4 µm absorption band ↘) $\sigma_{d,UV} = 3\ 10^{-19}$ cm^2/photon
- Efficient production of H_2 molecules 96% of broken C—H => H_2
- within the bulk of a-C:H
- Production of small hydrocarbons (CH_4)

Photo-processed a-C:H is a **efficient source of H_2 and small hydrocarbons**, at **low to high T**

H atoms

a-C:H in diffuse ISM:
Hydrogenation by H
Dehydrogenation by UV

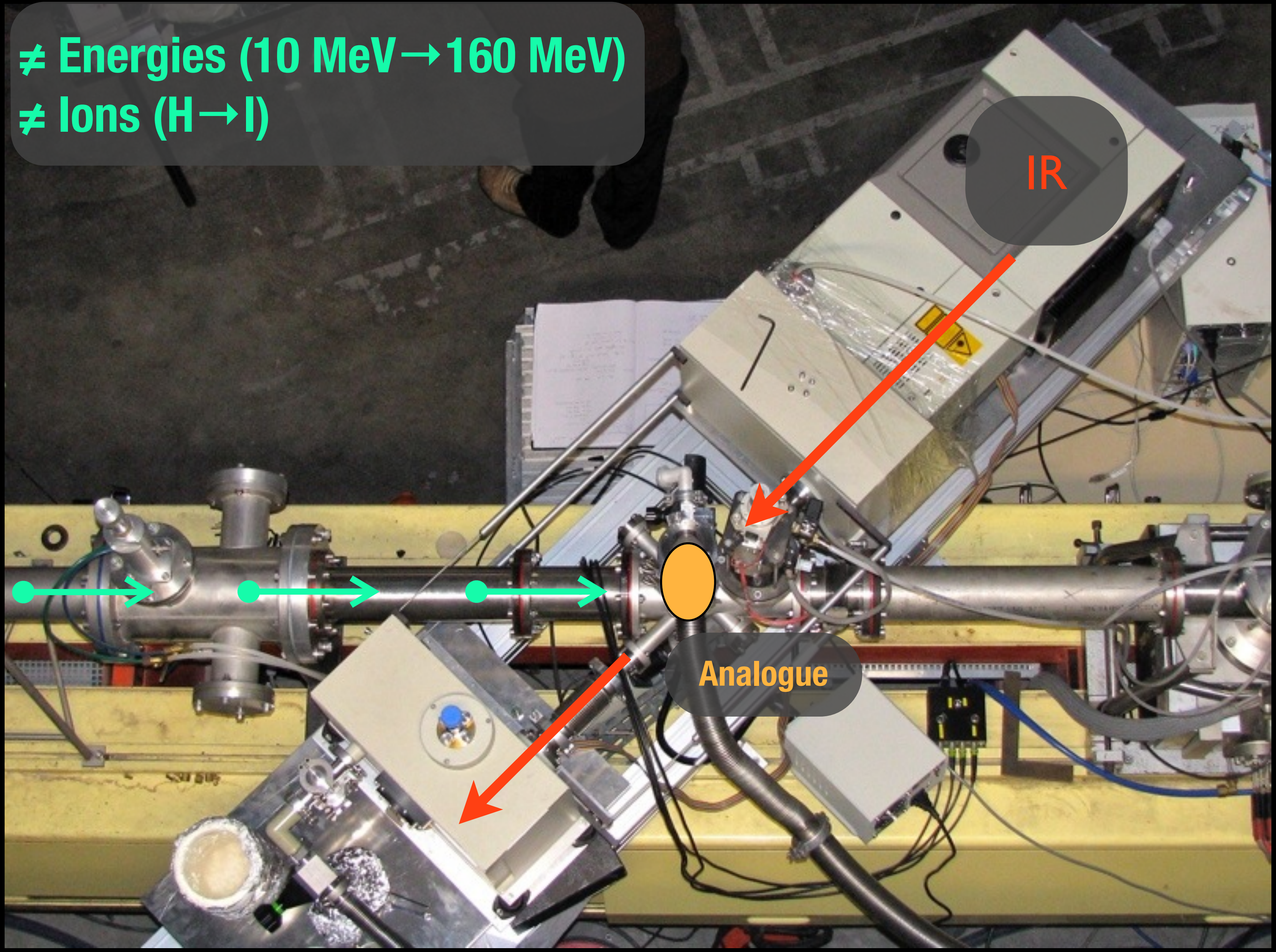
H_2 molecules

Exposition to energetic ions

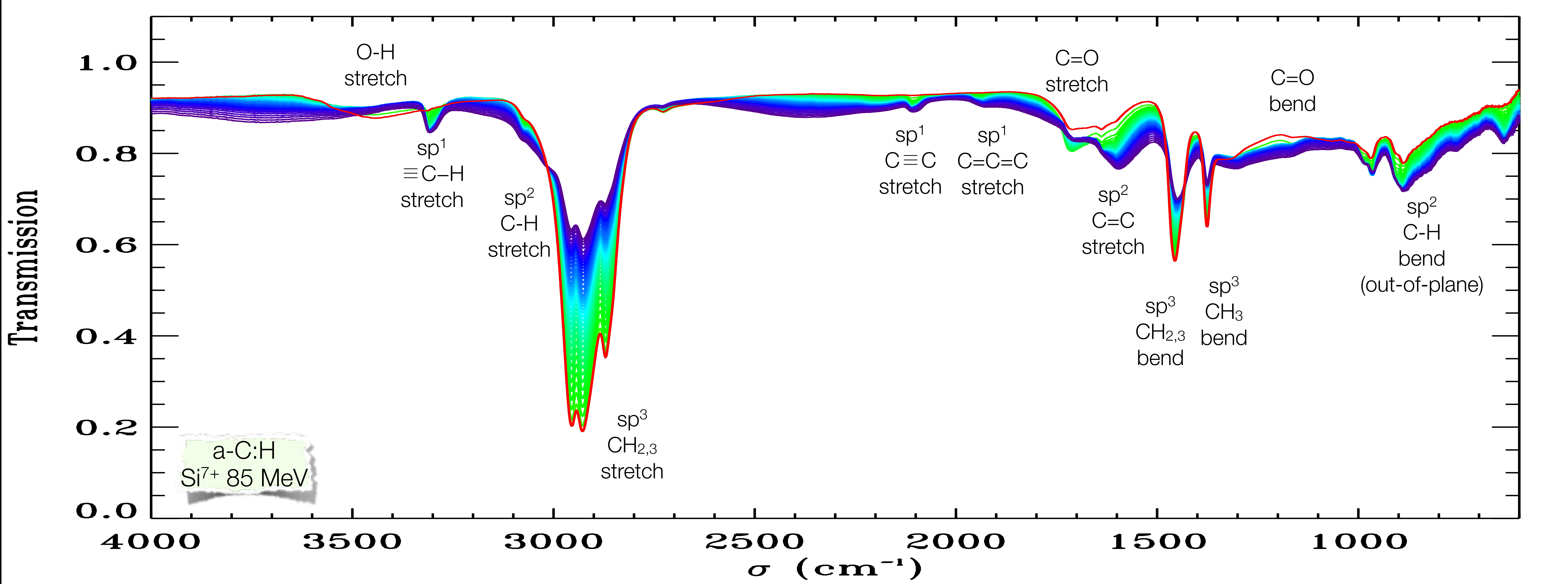
A large range of ≠ **ions and energies** were used to **simulate cosmic rays** :

TANDEM accelerator
(IPN Orsay)

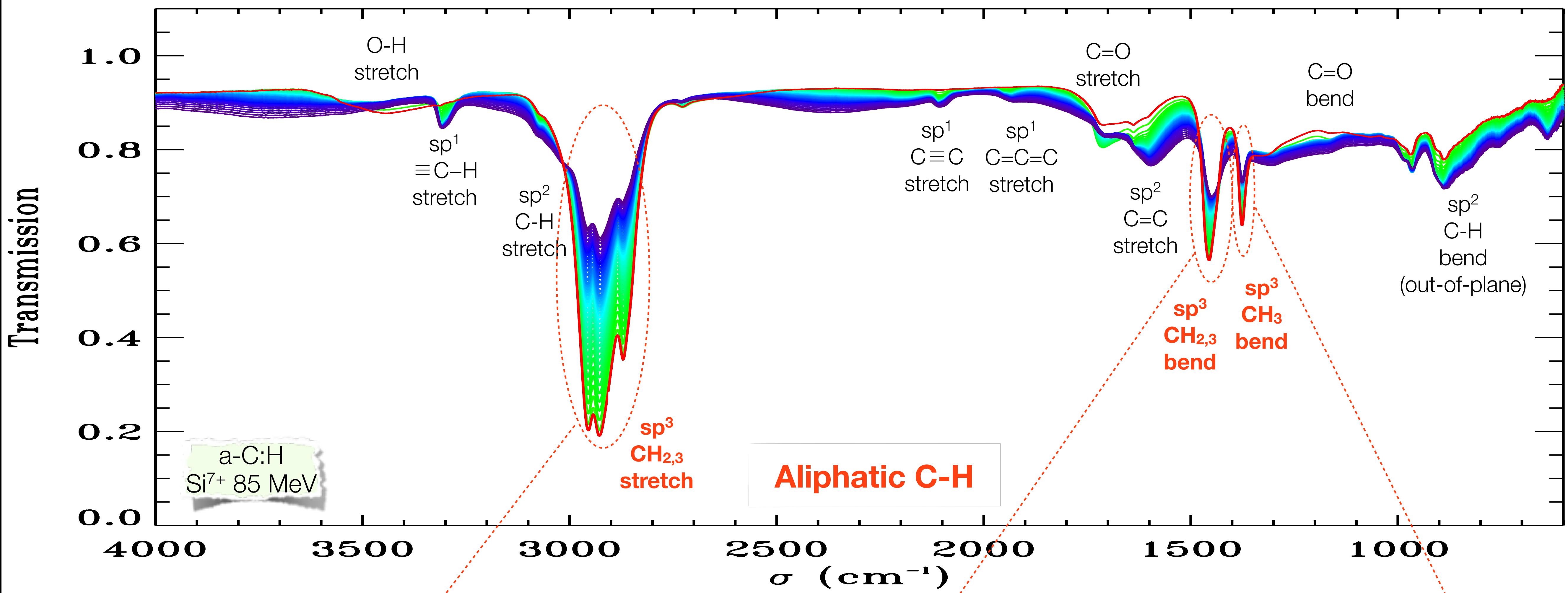
TANDEM
Ions

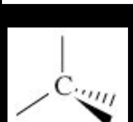


Godard et al, A&A (2011)



Godard et al, A&A (2011)

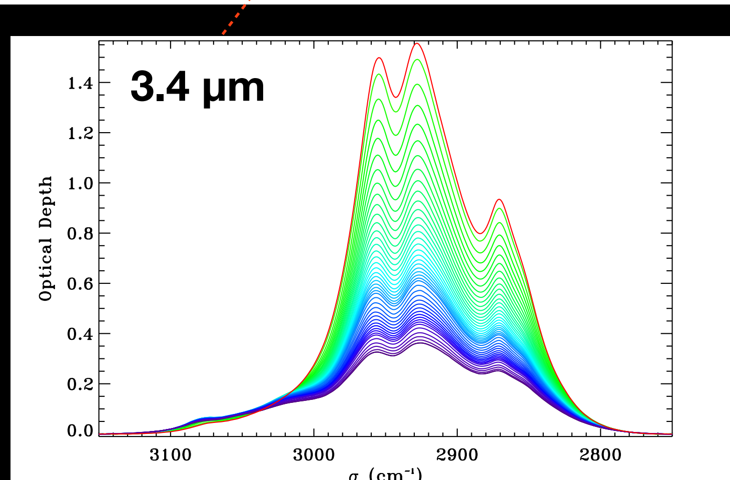


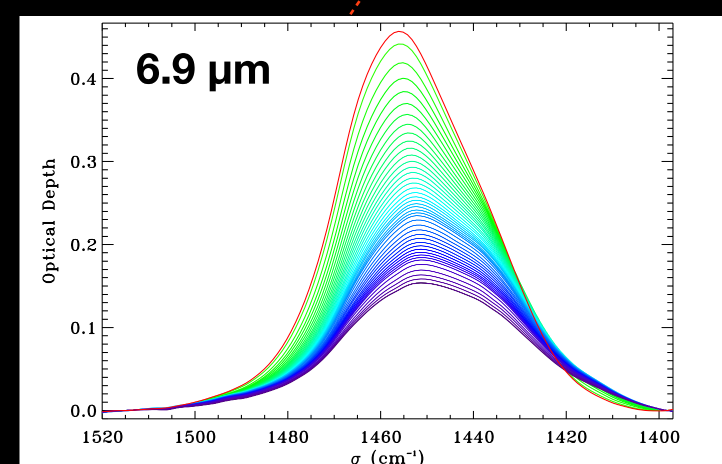


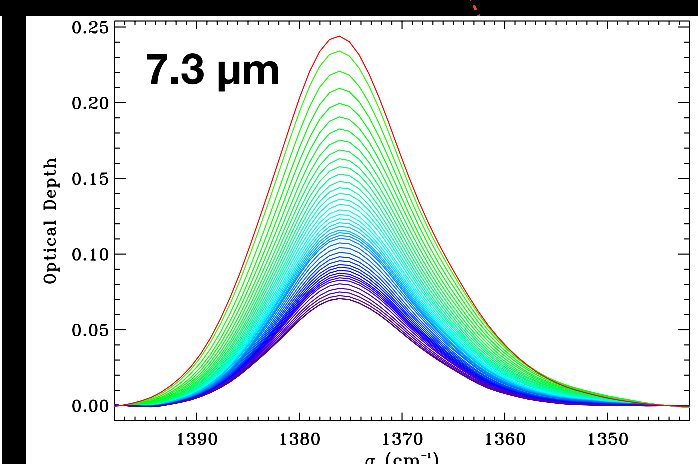
sp^3 carbon (aliphatic) :

Aliphatic C-H ↘

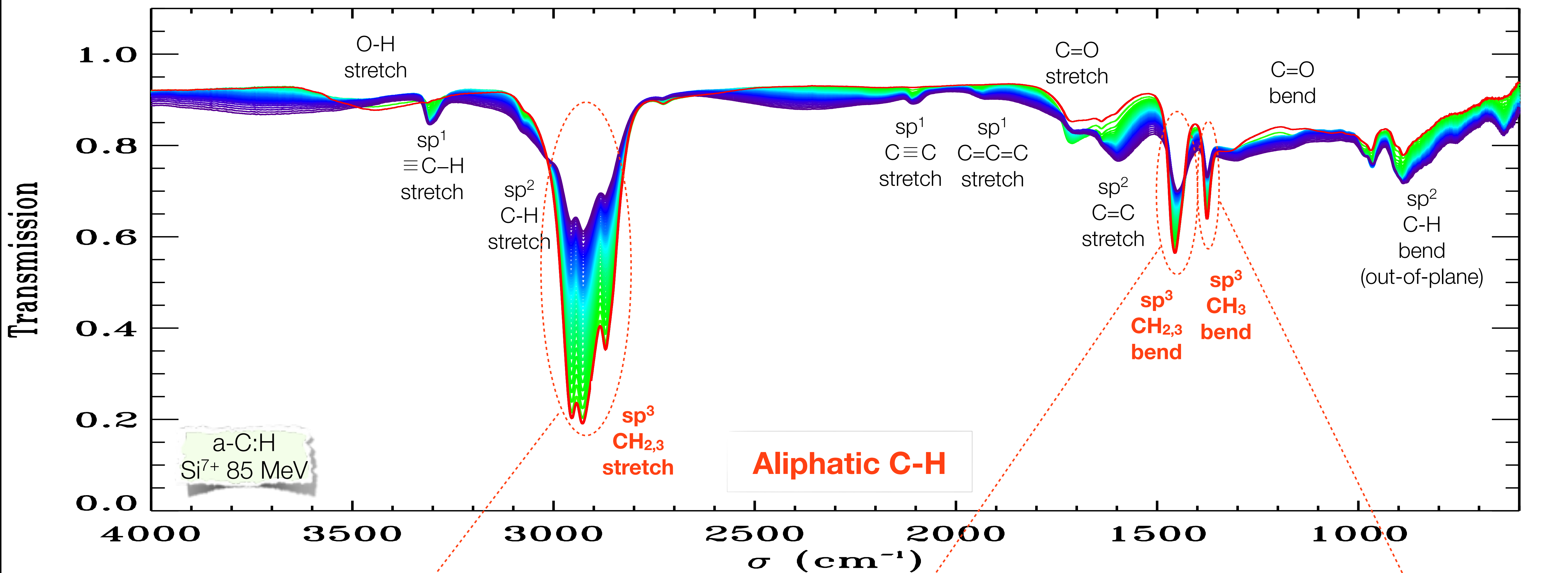
➾ Dehydrogenation

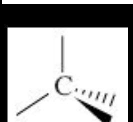






Godard et al, A&A (2011)

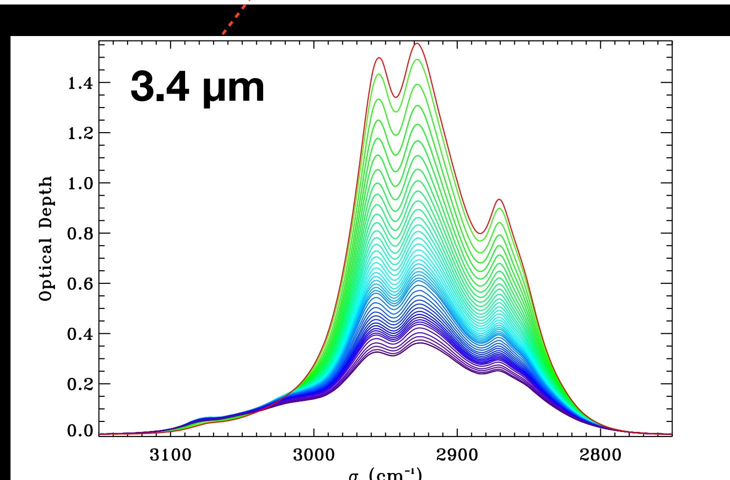


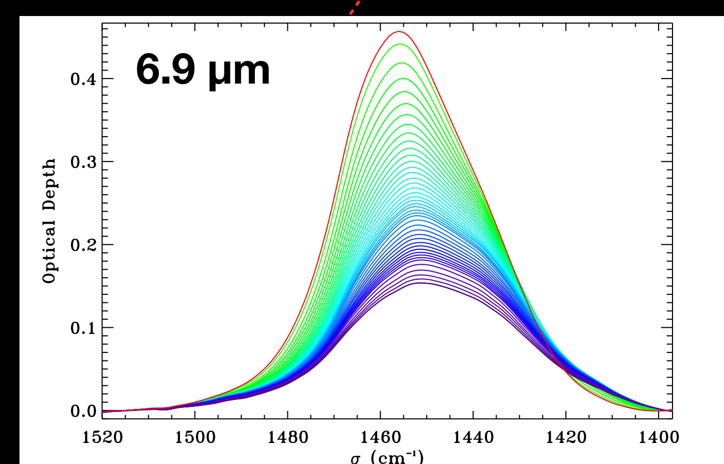


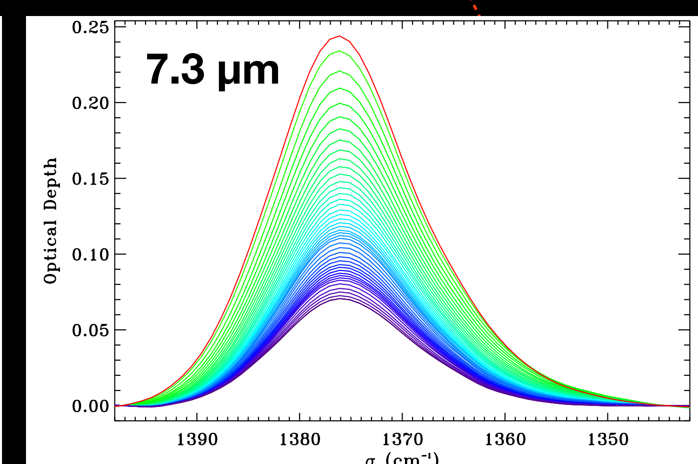
sp^3 carbon (aliphatic) :

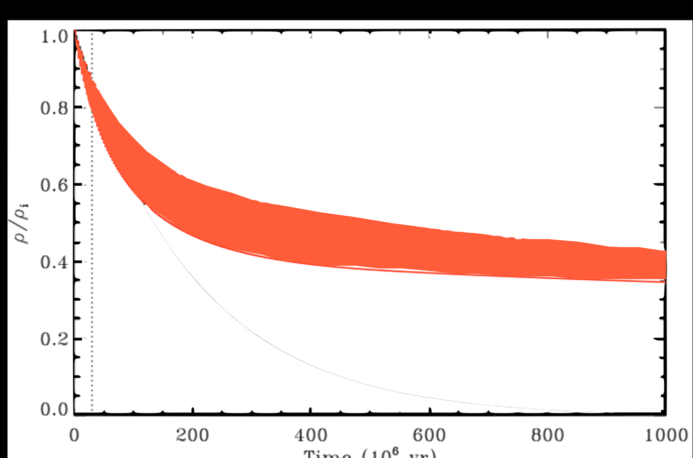
Aliphatic C-H ↘

➪ Dehydrogenation







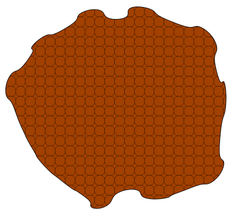
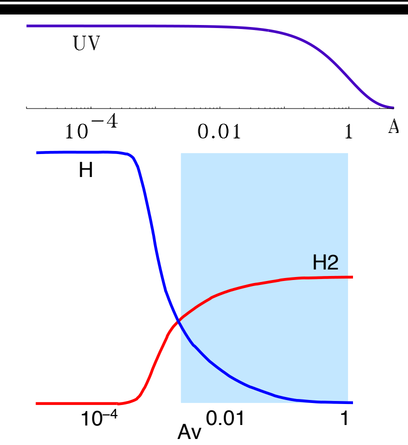
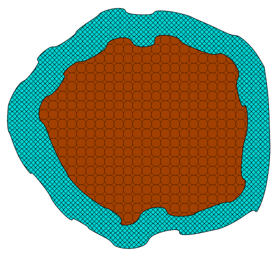


➪ **characteristic destruction time** of aliphatic C-H by cosmic rays:
~ a few **10^8 years**

>> 10^7 years : lifetime of an interstellar cloud

Godard et al, A&A (2011)

Evolution of the 3.4 µm band in interstellar medium

Interstellar Medium	Diffuse 	Interface	Dense 
			
3.4 µm band	observed		Not observed
Destruction time by **cosmic ray**	10^8 years	10^8 years	10^8 years
Destruction time by **UV photons**	$4\ 10^3$ years		$\gtrsim\ 10^7$ years
Formation time by **H atoms**	$2\ 10^3$ years		inefficient
Destruction/Formation of aliphatic C-H	Efficient formation	**Efficient destruction ?**	Slow destruction

Godard et al, A&A (2011)

Conclusion

a-C:H are a major component of interstellar carbonaceous dust in the diffuse ISM

a-C:H dust constantly **evolve** in response to their interstellar environments

a-C:H evolution could lead to formation of other interstellar components
(H2, small hydrocarbon molecules, link with PAHs, …)

Collaborators

CSNSM (Orsay)
J. Duprat
C. Engrand

IPN (Orsay)
M. Chabot

CAB (Madrid)
G. Muñoz Caro

IAS (Orsay)
E. Dartois
R. Brunetto
L. d'Hendecourt

ISMO (Orsay)
T. Pino
P. Bréchignac
G. Féraud
Y. Carpentier

Gemini Obs. (Hawaï)
T. Geballe