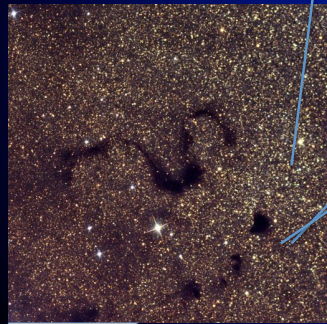
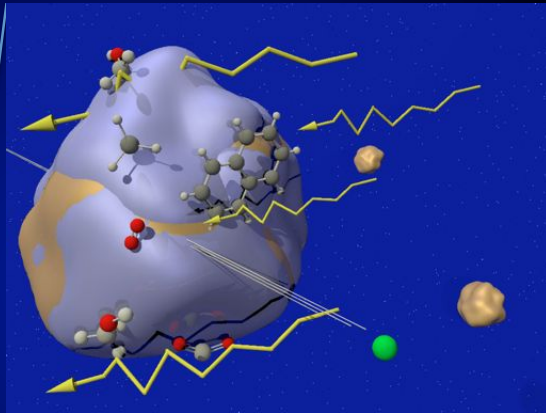


EL5 : Atomes, Molécules, Solides



J. Belushi 2008



E. Dartois, ISMO, Orsay, France
emmanuel.dartois@u-psud.fr

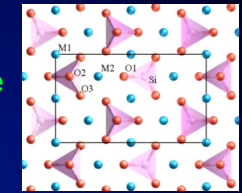


“Minéralogie” des Silicates

Olivines ($Mg_{2x}Fe_{2-2x}SiO_4$)

Mg_2SiO_4 **Forsterite**

Fe_2SiO_4 **Fayalite**



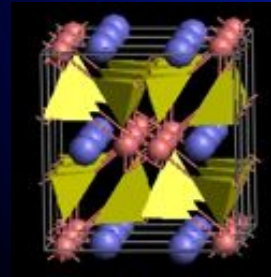
Pyroxenes ($Mg_xFe_{1-x}SiO_3$)

$Mg_2Si_2O_6$ **Enstatite**

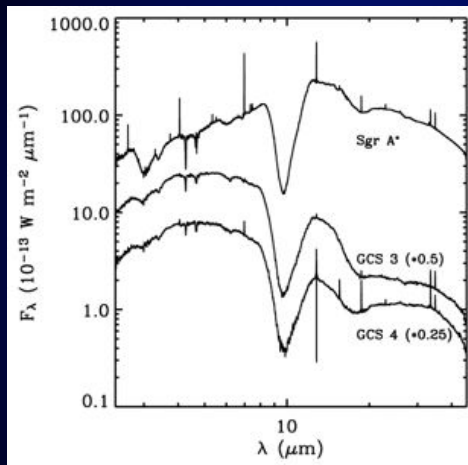
$Fe_2Si_2O_6$ **Ferrosilite (hypersthène)**

$CaMgSi_2O_6$ **Diopside**

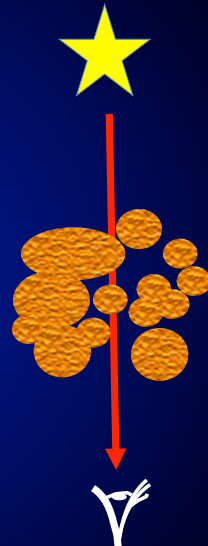
$CaFeSi_2O_6$ **Hedenbergite**



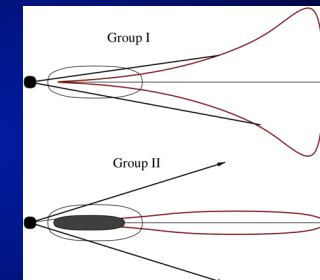
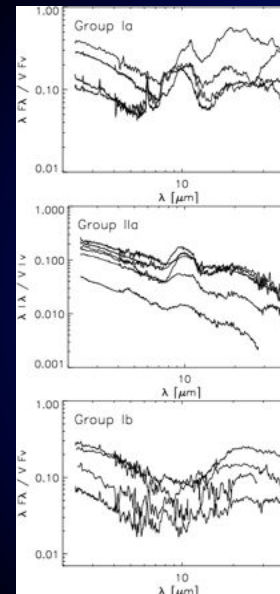
Silicates dans le MIS



Kemper et al. 2004

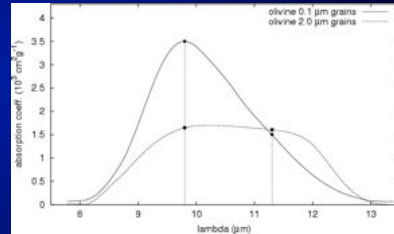
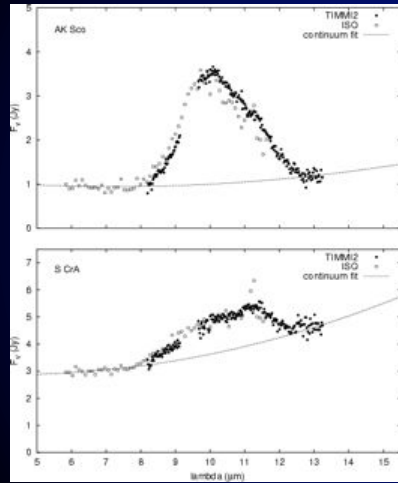


Silicates dans les disques



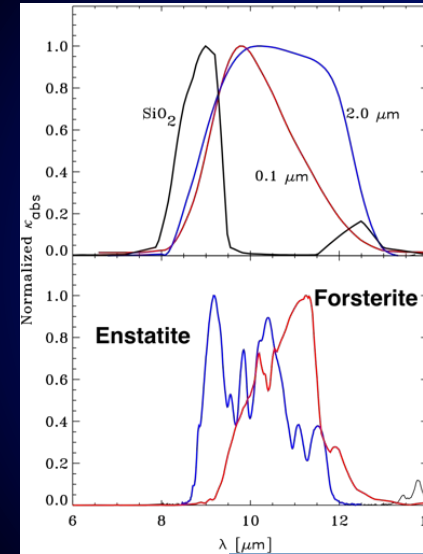
Meeus et al. 2001

Evidence spectrale du grossissement des grains

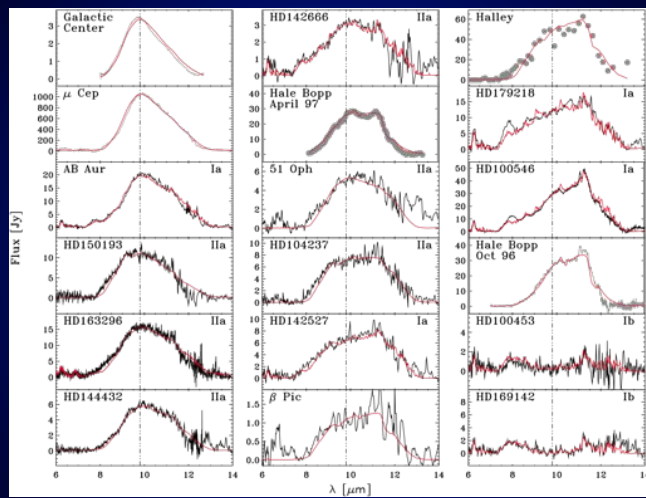


Przygoda et al. 2003

Minéralogie : La poussière dans les Herbig Ae Be

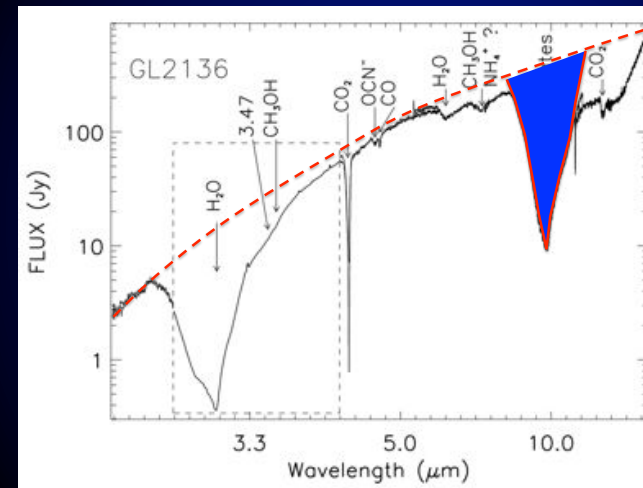


Bouwman et al. 2001



Bouwman et al. 2001

Absorption : calcul de la colonne densité

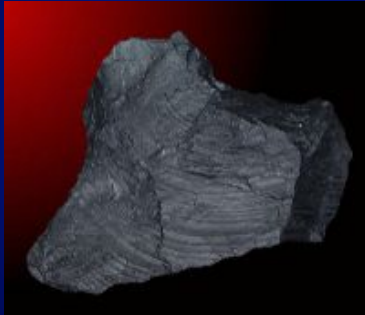


Dartois et al. 2002

$$N [\text{cm}^{-2}] = \int_{\text{raie}} \tau_{\nu} d\nu / A$$

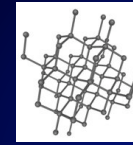
$$A = 1.6 \cdot 10^{-16} \text{ cm}^2/\text{Si}$$

Poussière « carbonée »

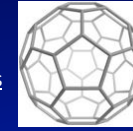


Quels sont les solides carbonés/grosses molécules observées dans le MIS ?

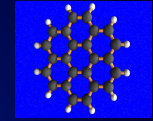
Diamant



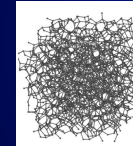
Fullerenes



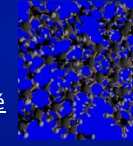
AIBs-PAHs :
Class A à C



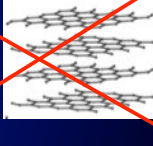
Carbone
amorphe



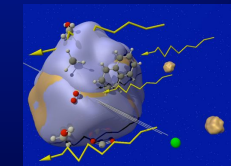
Carbone
amorphe
hydrogéné



~~Graphite~~

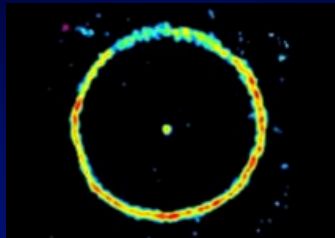


+ matière organique

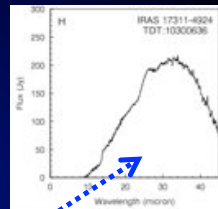


Résidus des
manteaux de
glace

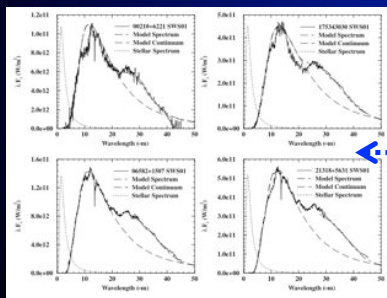
Etoiles carbonées (-phase)



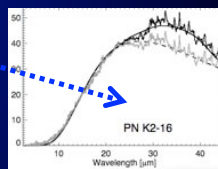
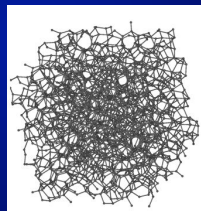
Etoile carbonée
TTCygni / IRAM



Chen et al.2010
Gaubia 2004

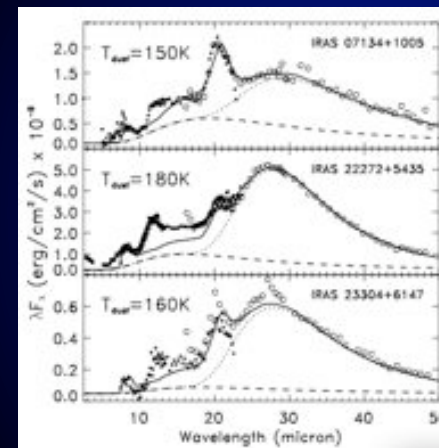
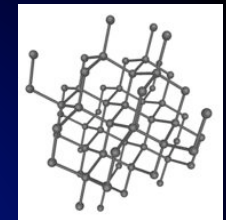


Volk et al.2001



Hony et al.2002

(nano-)diamants

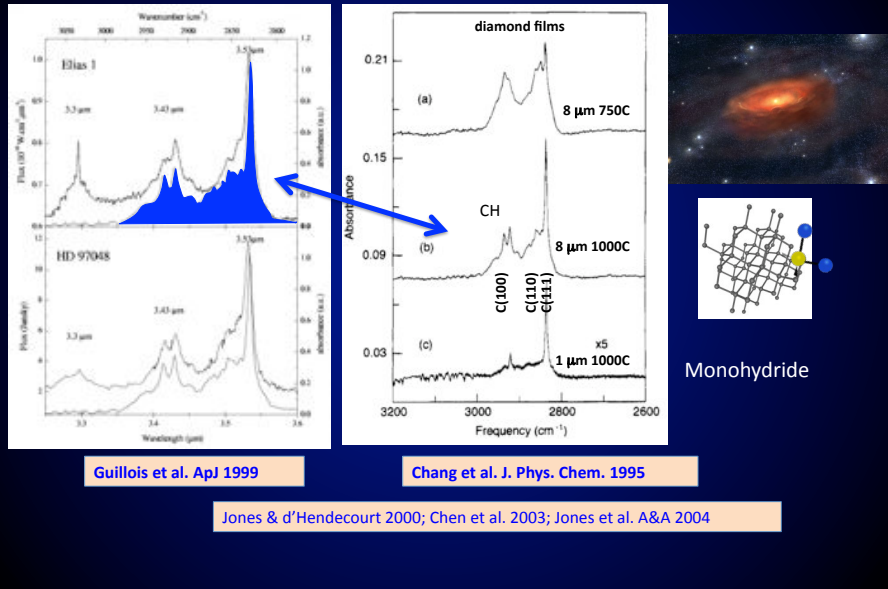


Candidat à une raie à 21 cm

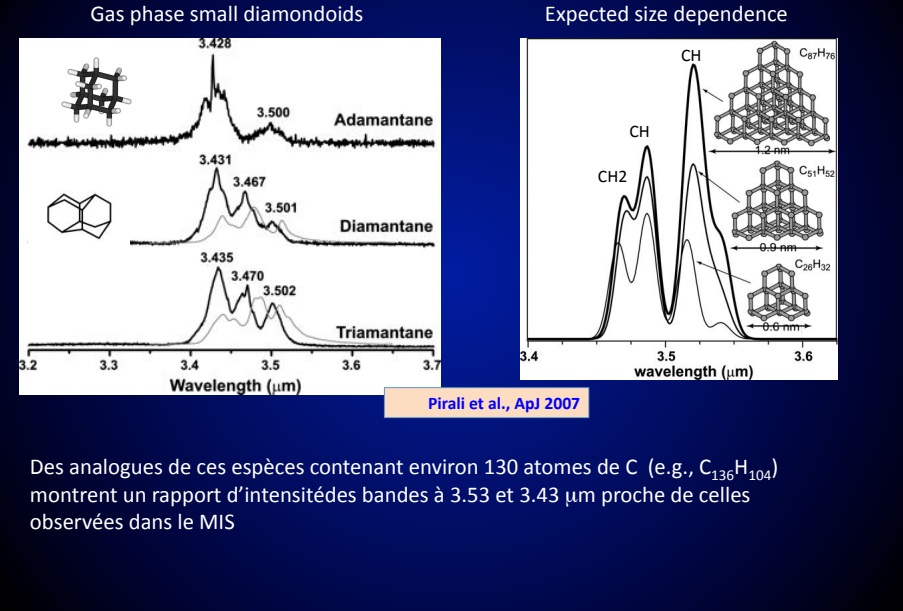
Selon spectro FTIR nanodiamants
meteorite « Orgueil »

Hill, Jones & d'Hendecourt, A&A 1998

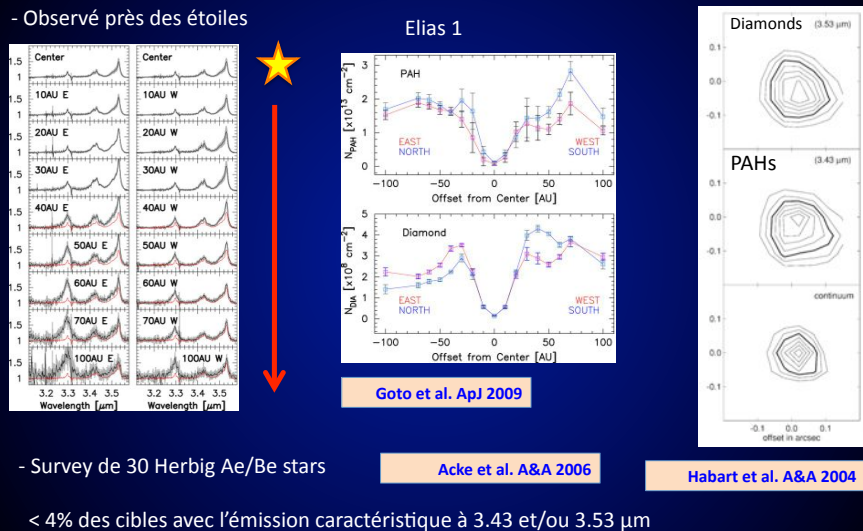
Observations des (nano-)diamants



Expériences diamantoïdes

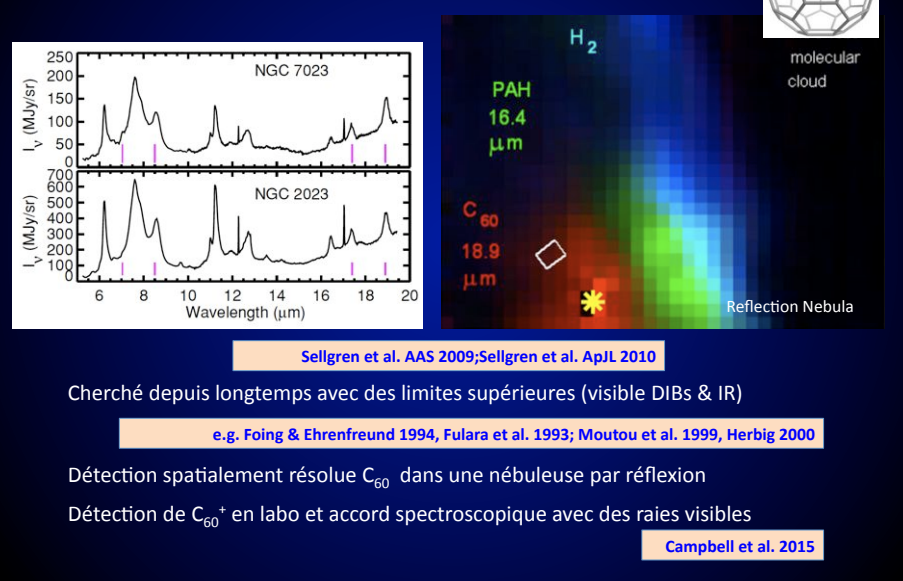


Diamants : observations résolues



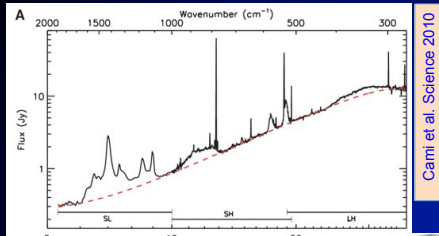
Fullerenes

(detection la plus récente)

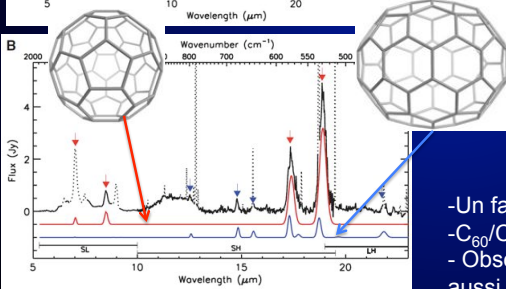


Fullerenes : observations

Pne (naine blanche) avec peu d'H

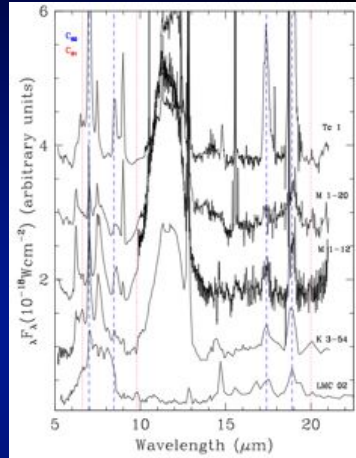


Cami et al. Science 2010



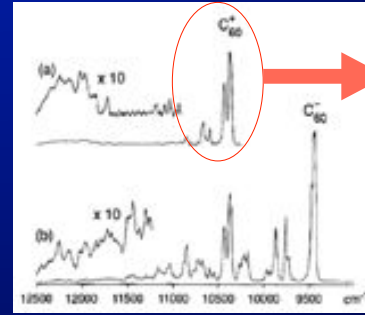
Roberts et al 2012

- Un faible % du C cosmique impliqué
- $C_{60}/C < 0.1\%$
- Observé principalement dans PnE mais aussi d'autres objets (AGB, Post-AGB, PPN, Herbig Ae/Be)

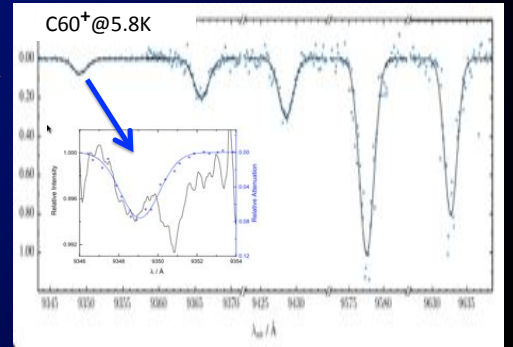


Garcia-Hernandez et al 2012

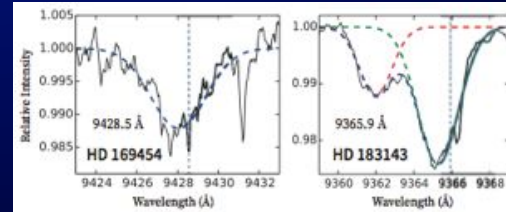
Fullerenes dans le MISD



C60+ in Neon@5K Fulara+1993



Campbell+2015, Campbell+2016



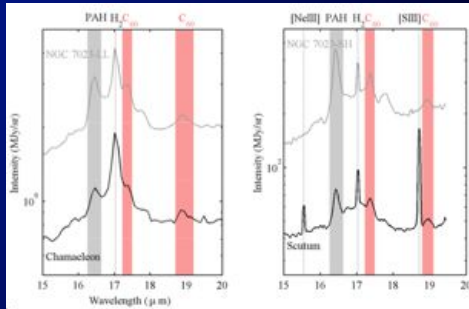
Walker+2015

C60+ : f mesurée dans Ne

Strel'nikov+2015

$< X_C(C60+) > \approx 0.04\%$

Fullerenes dans le MISD



Fraction de C « bloquée » dans les fullerenes $X_C \sim 10^{-4}-10^{-5}$

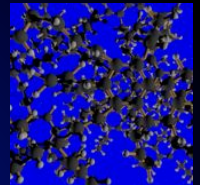
	Star-forming regions		Diffuse/translucent ISM	
	Em.	Abs.	Em.	Abs.
C^+	$1 \times 10^{-4**}$	-	$3 \times 10^{-5}*†$	$1-1.8 \times 10^{-5}*$
C_{60}	$0.4 - 5.6 \times 10^{-4**}$	-	$0.5-6.4 \times 10^{-5}*$	-

* From Berné et al. (2013); ** From Castellanos et al. (2014);

Berné+2017

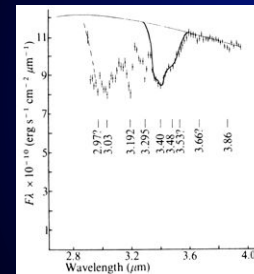
$N_{C60}/N_H \sim 10^{-9}-10^{-11}$

Carbones amorphes hydrogénés a-C:H / HAC



- Observés initialement à 3.4 microns en abs de source du GC

Allen & Wickramasinghe, Nature 294, 239, 1981



- Associés aux modes d'élongation sp^3 CH3 and CH2
« *Interstellar amorphous carbon dust with chemisorbed CH2 and CH3 groups may be a significant component of interstellar dust in diffuse clouds.* »

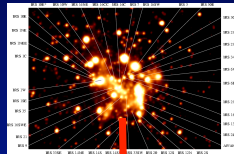
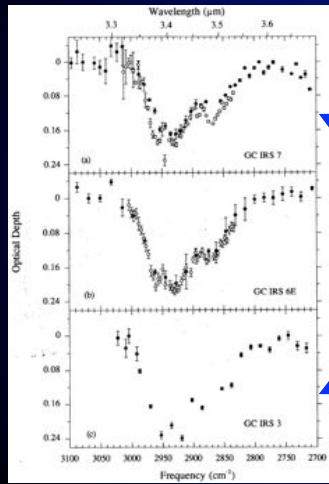
Duley & Williams, MNRAS 205, 67, 1983

- De nombreuses expériences/observations pour contraindre leur origine

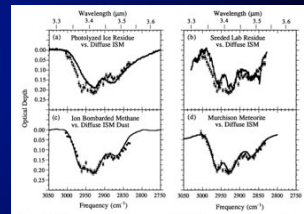
Mennella et al. 2002, Pendleton & Allamandola 2002, Chiar et al. 2002, Geballe et al. 1998, Tielens et al. 1996, Sandford et al. 1995, Pendleton et al. 1994, Sandford et al. 1991, Ehrenfreund et al. 1991, McFadzean et al. 1989, Butchart et al. 1986, Jones et al. 1983

a-C:H observations Galactiques

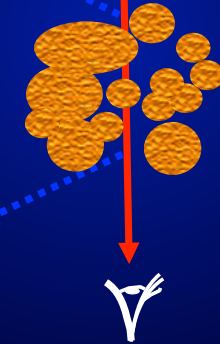
Absorptions NIR elongations CH
Sur des sources de fond du GC



Viehmann et al. A&A 2004



Pendleton et al. ApJ 1994



Abondance d'après les élongations CH

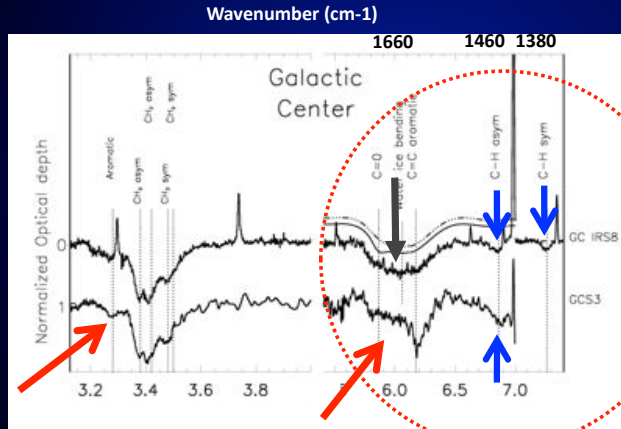


e.g. Sandford et al. ApJ 1991, Pendleton et al. ApJ 1994, Sandford et al. ApJ 1995

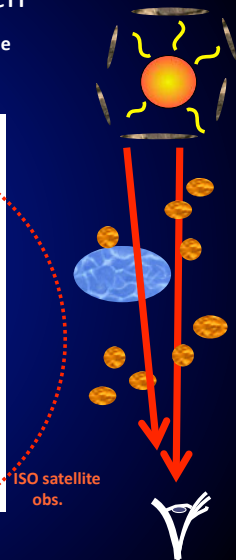
- 2.6% to 35% du carbone cosmique pour Sandford 1991
- >2.5% et >4% GC Pendleton 1994 basé sur des alcanes
- Duley (1994 & 1998) 72-97ppm basé sur des HAC exp. (avec H/C < alcanes) impliquant 20-30% du carbone disponible

Les contraintes observationnelles : empreintes dans l'IR moyen

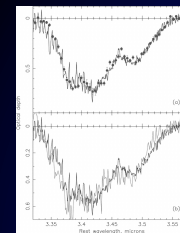
- mais confusion avec glaces dans les lignes de visée du centre galactique
- et confusion avec matériel circumstellaire



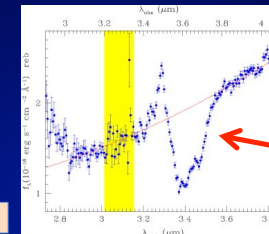
e.g. Chiar & Tielens 2001; Chiar et al. 2002; Dartois et al. 2004



Sources extragalactiques observée avec a-C:H

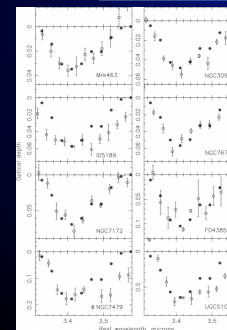


Pendleton et al. ApJ 1994

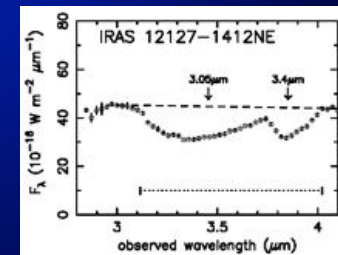


CH stretch

Risaliti et al. MNRAS 2006

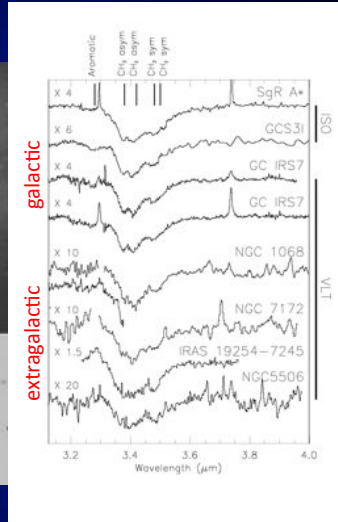
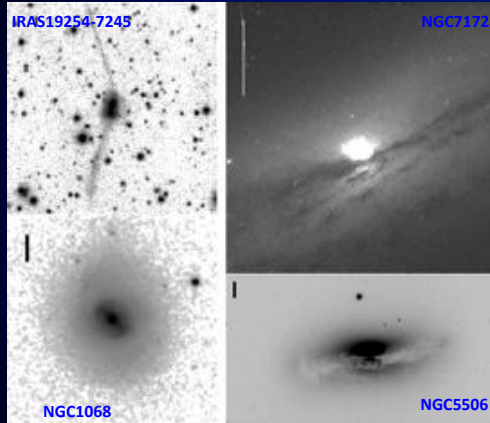


Mason et al. ApJ 2004



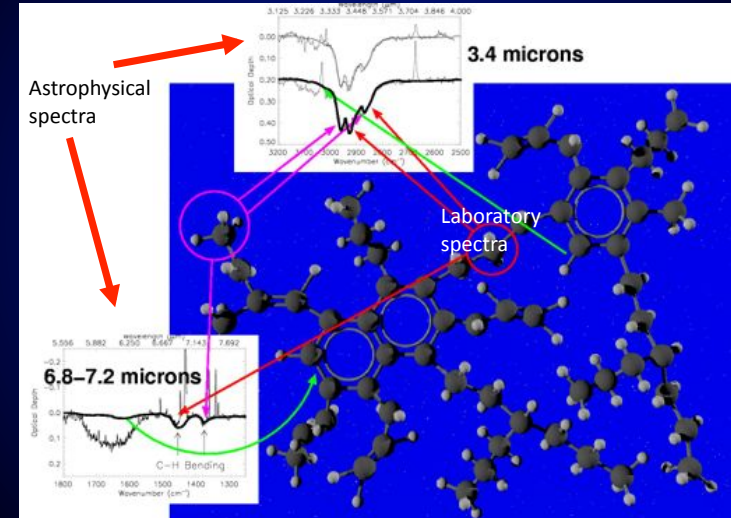
Imanishi et al. AJ 2006

... AGNs avec des a-C:H



Dartois et al. A&A 2004

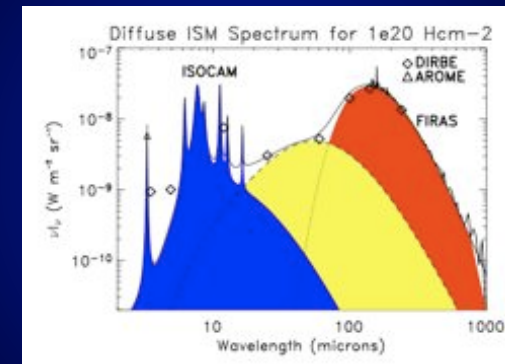
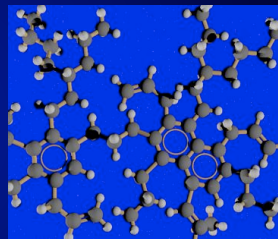
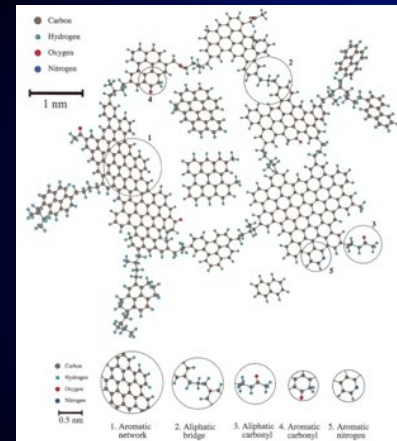
Ajustement des signatures d'absorption de l'ISM



Dartois et al. A&A 2005

Emission : milieu diffus et interfaces

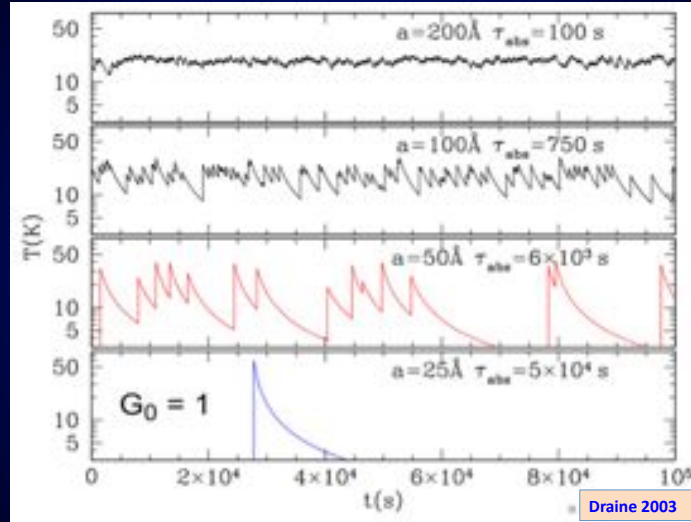
Aromatic Infrared Bands (AIB), Very Small Grains (VSG), Big Grains (BG)



Boulanger 2000

Émission après absorption d'un photon stellaire visible-UV ($h\nu$) par un grain

Emission en fct de la taille

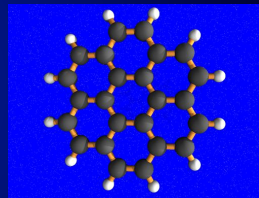
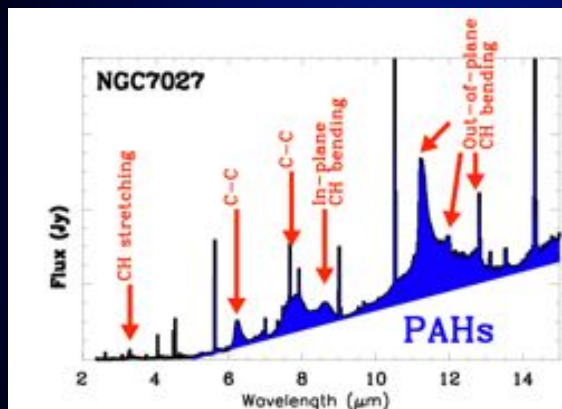


Émission après absorption d'un photon stellaire visible-UV ($h\nu$) par un grain

Cet ensemble reprocesse la moitié de l'énergie émise par les étoiles

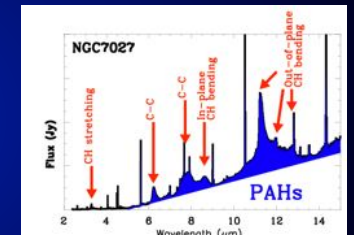
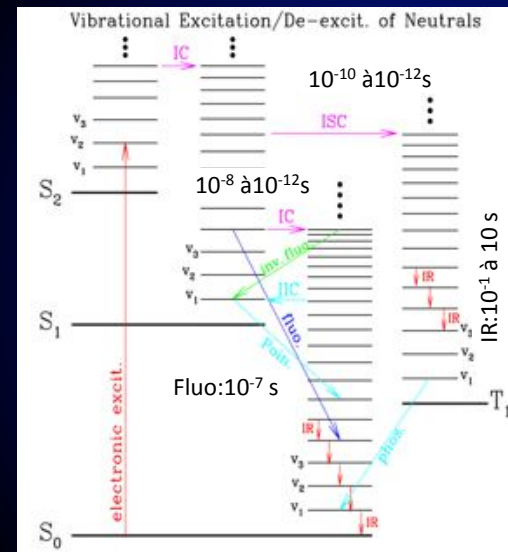
- **BG** :
FIR associé aux silicates/grains carbonés de relative grande taille : $10 \text{ nm} < a < 100 \text{ nm}$
- **VSG** :
Mid-IR emission requière grains $1 \text{ nm} < a < 10 \text{ nm}$
- **AIB** :
Caractère aromatique en spectroscopie, mais pas d'identification.
Emet par chauffage transitoire après absorption d'un photon VUV.

Emission des AIBs (l'hypothèse PAHs)



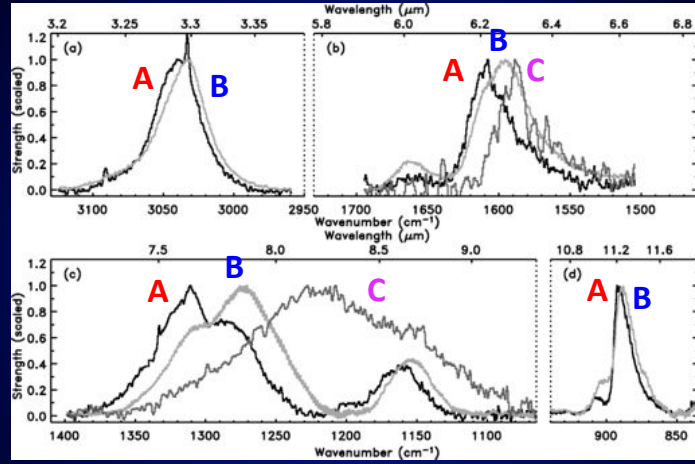
ISO database

Emission des HAPs (PAHs)



Li 2003

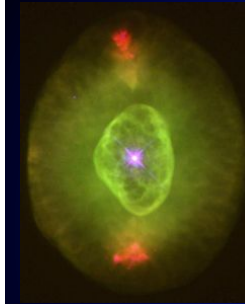
AIBs : Classes A, B and C



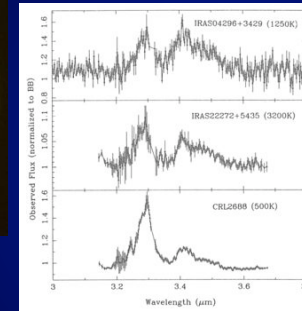
Van Dienenhoven et al. ApJ 2004

En nombre : class A >> class B > class C

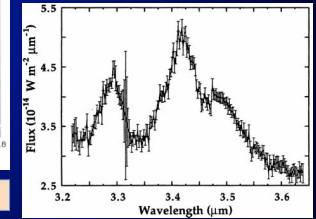
aliphatiques/aromatiques mélangés et la transition classe A vers C



HST



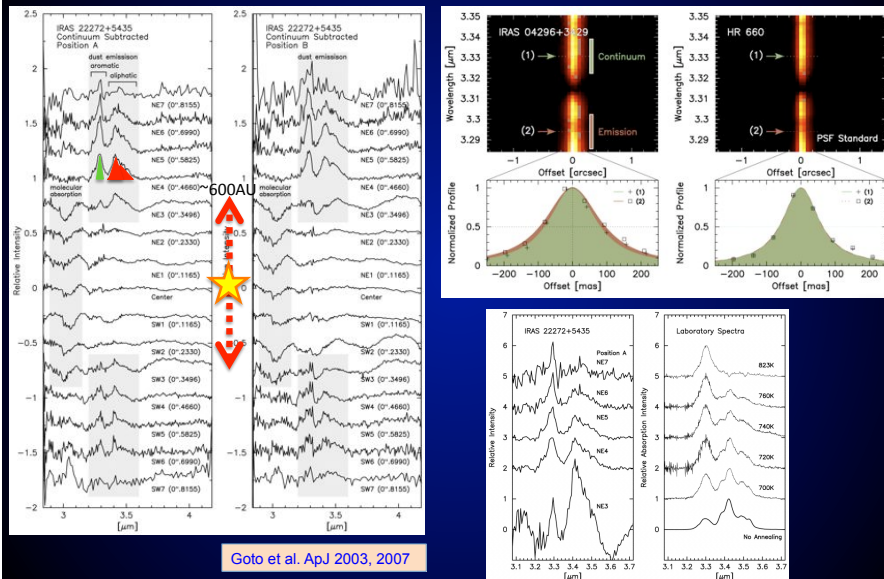
Geballe et al. ApJ 1992



Joblin et al. ApJ 1996

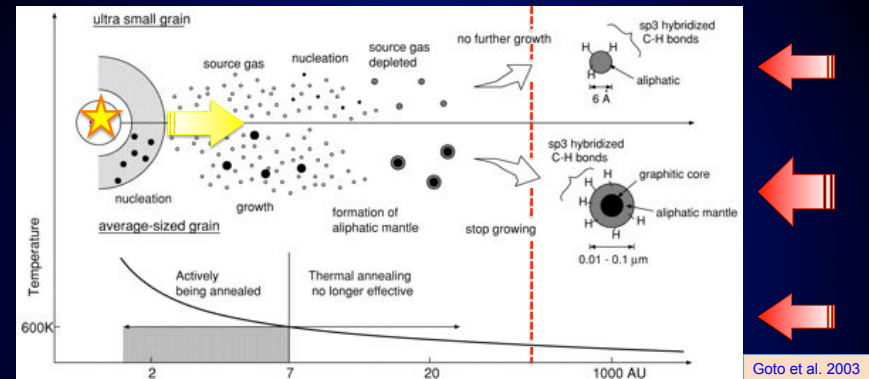
Existe-t-il un lien entre 'hydrocarbures' en absorption et emission ?

Elongation CH résolue en emission IR par A.O.



Goto et al. ApJ 2003, 2007

Comprendre la nucleation de la poussière carbonée

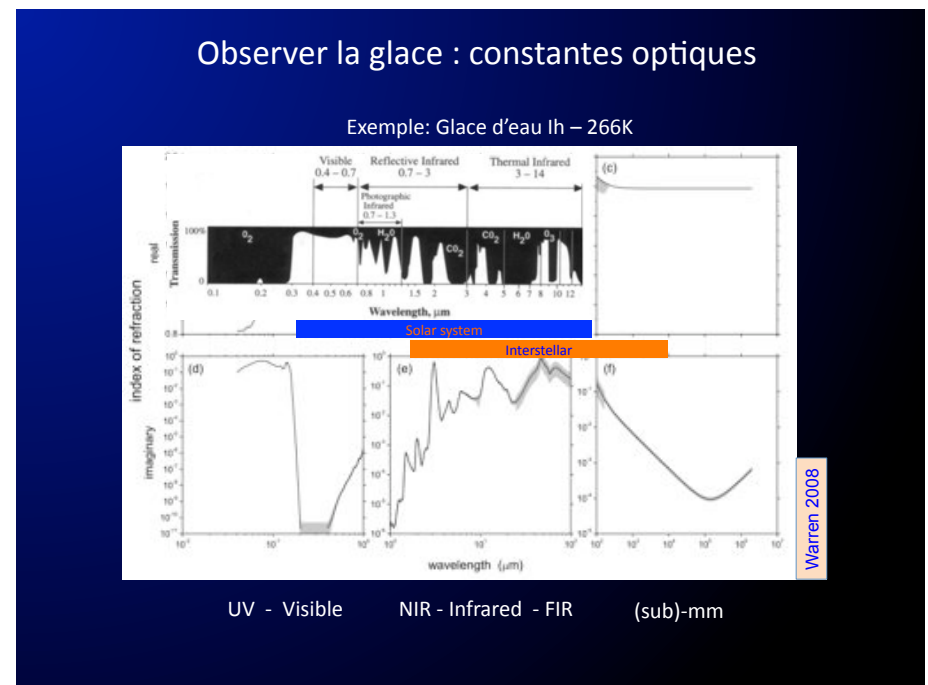
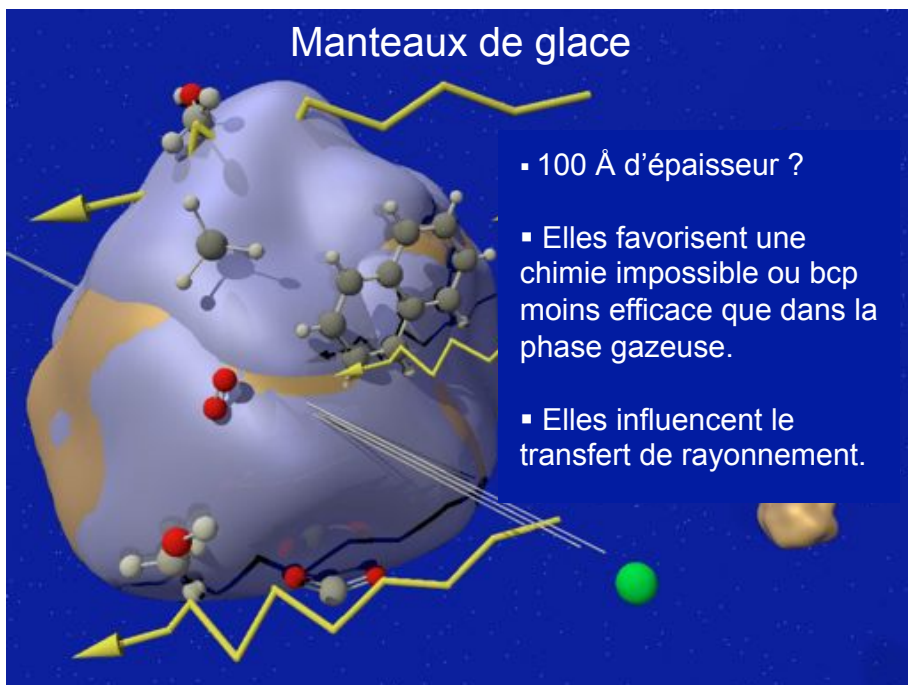
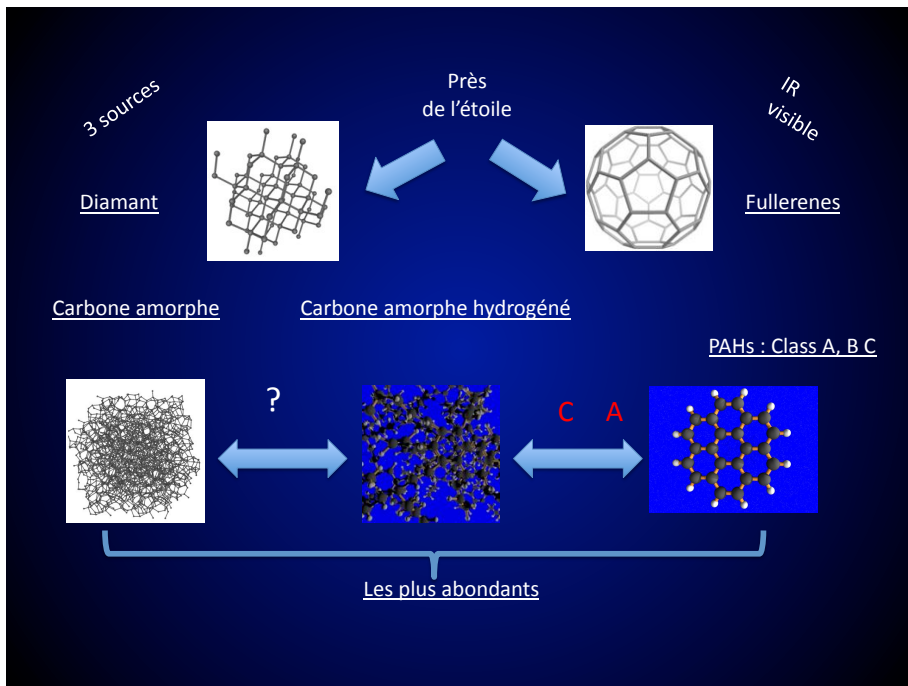


Goto et al. 2003

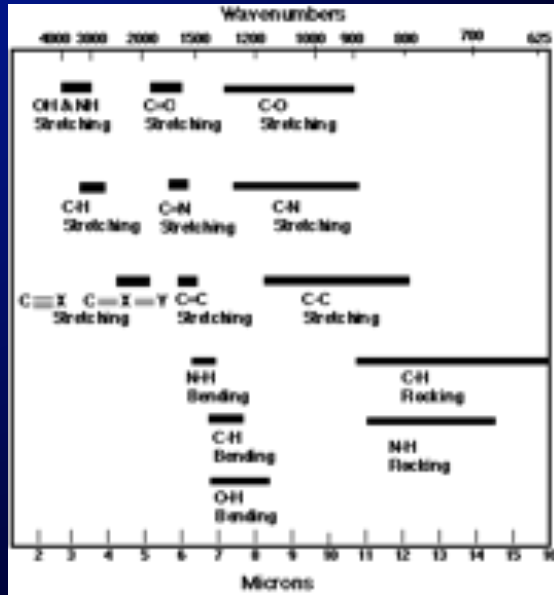
Accord avec des analogues de laboratoire chauffés thermiquement à différentes températures

Compétition entre différents mécanismes d'émission, dépendants de la taille ?

Mécanismes concomitants (modification, emission, Stellaire/ISRF) encore à contraindre.



Observer la glace : modes infrarouge



<http://www.wag.caltech.edu>

M 82 (NGC 3034)
FOCAS (B, V, H α)

Les glaces dans les galaxies

Copyright © 2000 National Astronomical Observatory of Japan, all rights reserved.
Subaru Telescope, National Astronomical Observatory of Japan March 24, 2000

Flux (μ Jy)

H₂O ice (OH stretch)

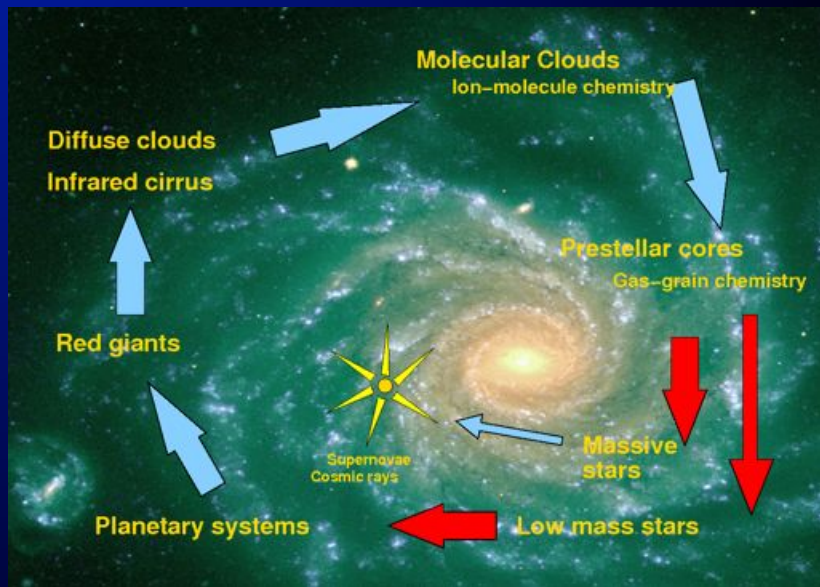
PAHs (CH stretch)

Galaxy

Wavelength (μ m)

Infrared Space Observatory database

Les glaces dans le cycle de la poussière Galactique



OH-IR

Flux (μ Jy)

Wavelength (μ m)

OH127.8+0.0

Water ice optical depth

AFGL5379

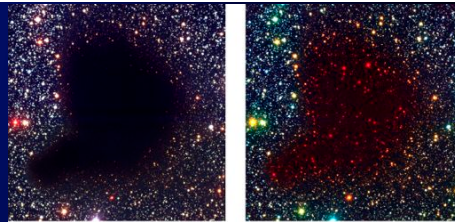
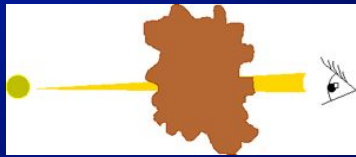
Silicates

OH-IR

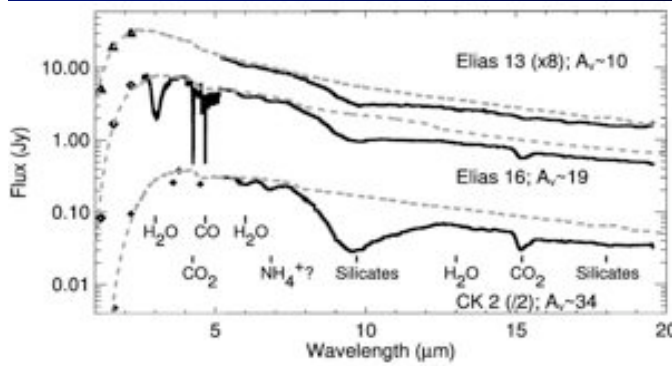
Infrared Space Observatory database

e.g. Maldoni et al. 2004, MNRAS 349, 665

Etoiles de champ

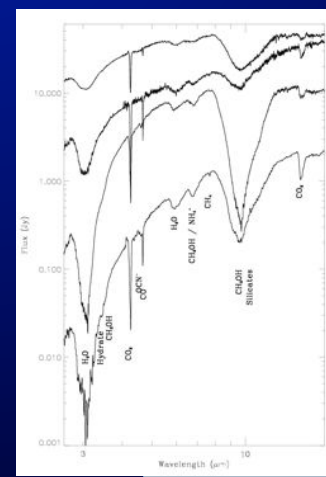
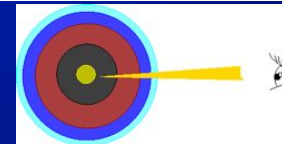


Pre-Collapse Black Cloud B68 (comparison)
(VLT ANTU + FORS 1 - NTT + SOFI)
B, V, I B, I, K
© European Southern Observatory

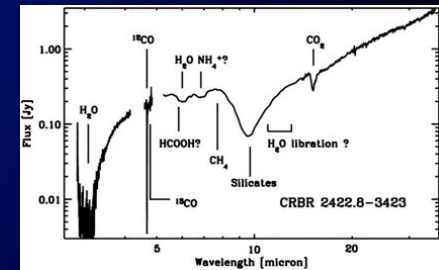


e.g.
Knez et al. 2005, ApJ 635, L145.
Bergin et al. 2005, ApJ 627, L33.

Protoétoiles/Disques



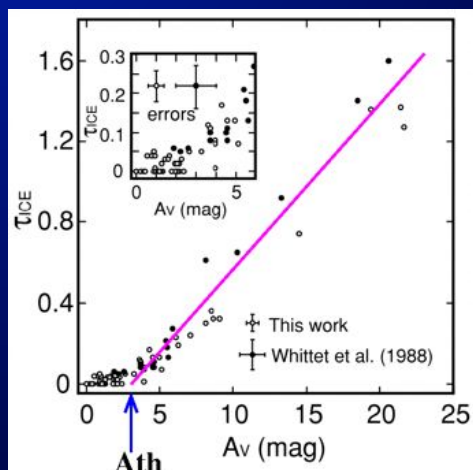
ISO database extract



Spitzer/VLT, Pontoppidan et al. 2005, ApJ 622, 453

- Les plus riches en glaces
- Les massives observées en premier
- Interaction source/enveloppe à l'interface

Réactions de surface – naissance et distribution des glaces



e.g. Murakawa et al. 2000, ApJS 128, 603, Whittet et al 1998, MNRAS 233, 321

- $\tau(\text{H}_2\text{O}) = \alpha(A_v - A_{v,\text{threshold}})$
- Abondance $10^{-5} - 10^{-4} N_H$
- Bien au dessus de la formation en gaz suivie par accretion
- réactions de surface impliquant l'oxygène
- besoin de solides pour la formation de H_2 aussi !

Réactions de surface – naissance et distribution des glaces

Epaisseur des manteaux de glace:

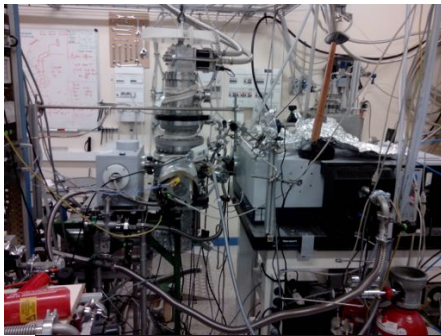
Taux de croissance en masse: $dm/dt = S \cdot \pi \cdot a^2 \cdot n \cdot \langle v \rangle \cdot \langle m \rangle$

$$\langle v \rangle = (8kT / \pi m)^{1/2}$$

Taux de croissance en rayon: $da/dt = (dm/dt) / (4 \cdot \pi \cdot a^2 \cdot \rho)$

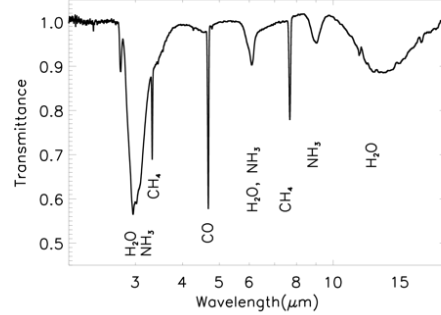
$$da/dt = S \cdot n \cdot \langle v \rangle \cdot \langle m \rangle / (4 \cdot \rho)$$

Croissance des manteaux indépendante du rayon du grain

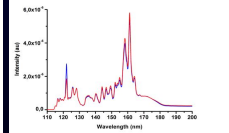
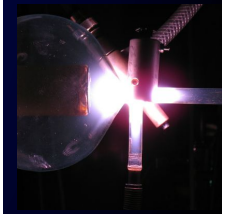
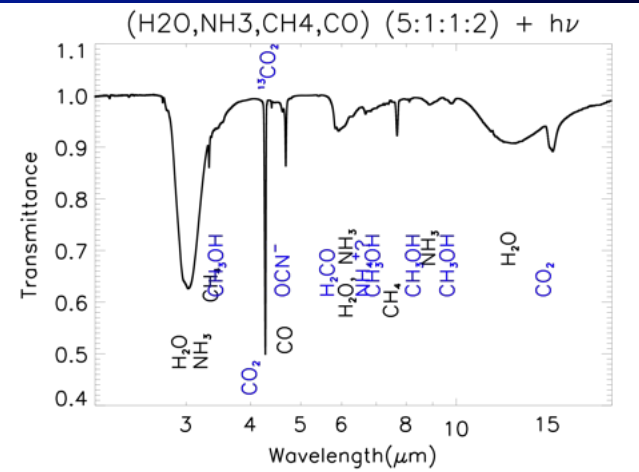


Bandes des glaces mesurées expérimentalement

(H₂O, NH₃, CH₄, CO) (5:1:1:2)

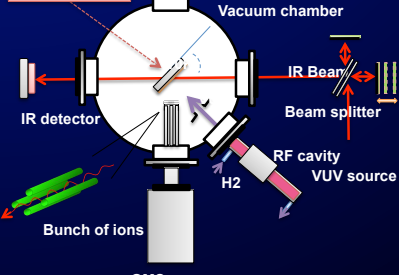


Glaces mesurées par simulations de laboratoire



Cruz Diaz et al. 2013

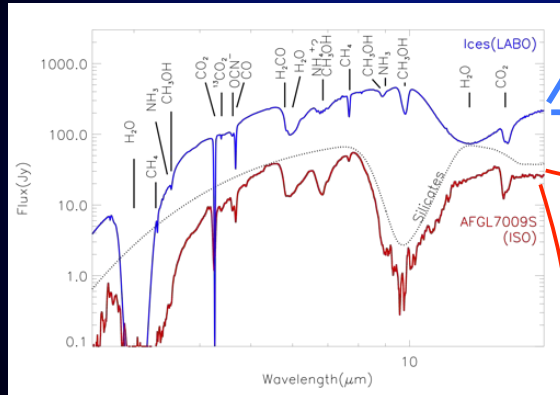
Echantillon de glace



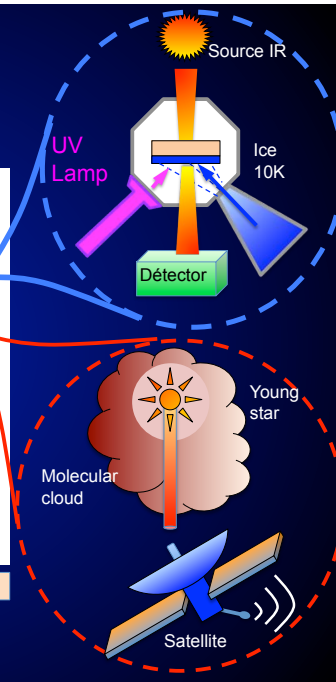
Incluant des sources de rayonnement pour reproduire la formation d'espèces radicalaires.

Simulations en laboratoire & comparaison avec les spectres astro

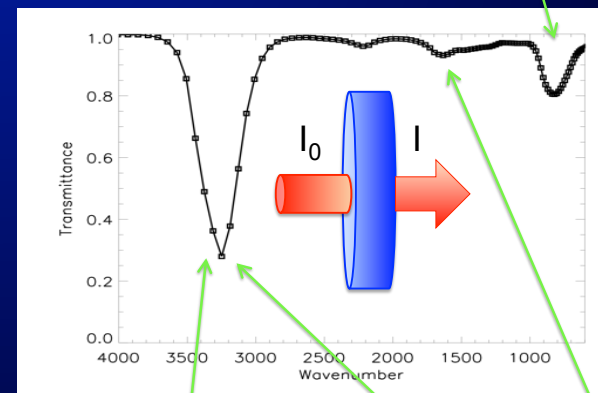
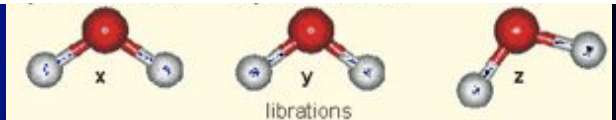
film H₂O/CO/CH₄/NH₃ @ 10 K + photolyse UV



Gerin et al. 2015; Dartois 1998



Identification IR film de glace pure (~ 500 nm)

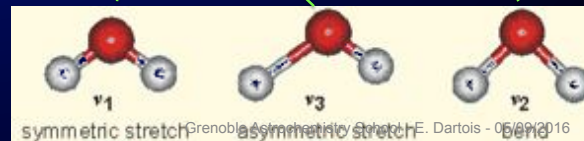


$$I = I_0 e^{-\sigma(\bar{\nu})N}$$

$$= I_0 e^{-\tau(\bar{\nu})}$$

$\sigma(\bar{\nu})$ section efficace d'absorption (cm²)

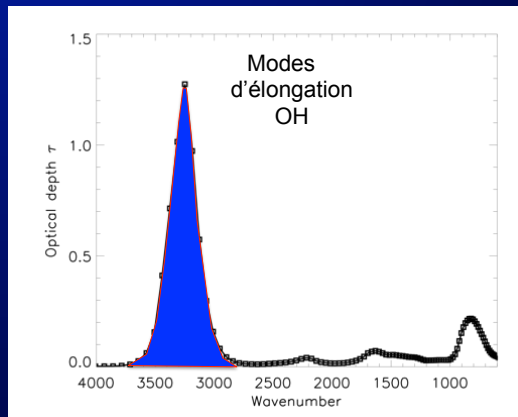
N Densité de colonne (molecules cm⁻²)



Grenoble Astrophysics Institute, E. Dartois - 06/09/2016

Martin Chaplin

Section efficace d'absorption intégrée A (analyse pratique du premier ordre)



$$N = e \rho N_A / M$$

cm^{-2} (for N)
 cm (for e)
 g.cm^{-3} (for ρ)
 g/mol (for M)

$$A = \int_{\text{band}} \tau(\bar{\nu}) d\bar{\nu} / N$$

cm/molecule (for A)

$$A_{\text{OH}} \sim 2 \cdot 10^{-16} \text{ cm/H}_2\text{O}$$

Section efficace d'absorption intégrée A

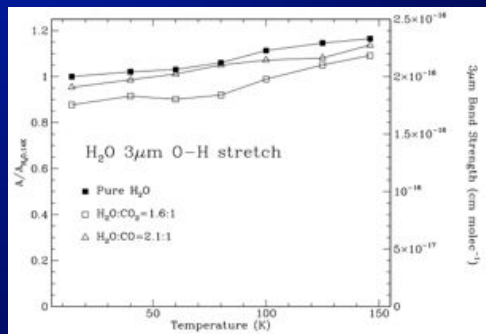
Table 3. Assignments and band strengths of H₂O ice.

Label	Mode	Position cm ⁻¹	Wavelength μm	T K	n	ρ g cm ⁻³	A cm molec ⁻¹	Corrected A cm molec ⁻¹ considering ρ = 0.87 g cm ⁻³	Reference
ν ₃	Libration	760	13.2	10	1.32	1	2.8 × 10 ⁻¹⁷	3.2 × 10 ⁻¹⁷	Hudgins et al. 1993
		750 ^a	13.3	10	*	*	2.6 × 10 ⁻¹⁷	2.8 × 10 ⁻¹⁷	d'Hendecourt & Allamandola 1986
ν ₂	Bend.	760 ^a	13.2	14	*	*	3.10 × 10 ⁻¹⁷	3.30 × 10 ⁻¹⁷	Gerakines et al. 1995
		763	13.1	25	1.29	1.10	2.5 × 10 ⁻¹⁷	3.2 × 10 ⁻¹⁷	Mastrapa et al. 2009
		1657	6.035	10	1.32	1	1.0 × 10 ⁻¹⁷	1.1 × 10 ⁻¹⁷	Hudgins et al. 1993
		1670 ^a	5.988	10	*	*	8.40 × 10 ⁻¹⁸	9.1 × 10 ⁻¹⁸	d'Hendecourt & Allamandola 1986
ν ₂ + ν ₃		1660 ^a	6.024	14	*	*	1.20 × 10 ⁻¹⁷	1.30 × 10 ⁻¹⁷	Gerakines et al. 1995
		1666	6.002	25	1.29	1.10	9.5 × 10 ⁻¹⁸	1.2 × 10 ⁻¹⁷	Mastrapa et al. 2009
		1659	6.028	25	1.27 ± 0.02	0.87 ± 0.03	9.0 × 10 ⁻¹⁸	9.0 × 10 ⁻¹⁸	This work
		2202	4.541	10	1.32	1	3.3 × 10 ⁻¹⁸	3.8 × 10 ⁻¹⁸	Hudgins et al. 1993
		2209	4.527	25	1.29	1.10	4.3 × 10 ⁻¹⁸	5.4 × 10 ⁻¹⁸	Mastrapa et al. 2009
		ν ₁	s-st.	3298	3.032	10	1.32	1	1.7 × 10 ⁻¹⁶
ν ₃	a-st.	3257	3.070	10	1.26	0.94	2.0 × 10 ⁻¹⁶	2.2 × 10 ⁻¹⁶	Hagen et al. 1981
		3275 ^a	3.053	10	*	*	2.0 × 10 ⁻¹⁶	2.2 × 10 ⁻¹⁶	d'Hendecourt & Allamandola 1986
		3280 ^a	3.049	14	*	*	2.0 × 10 ⁻¹⁶	2.2 × 10 ⁻¹⁶	Gerakines et al. 1995
		3285	3.044	25	1.29	1.1	1.9 × 10 ⁻¹⁶	2.4 × 10 ⁻¹⁶	Mastrapa et al. 2009
		3297	3.033	25	1.27 ± 0.02	0.87 ± 0.03	1.5 × 10 ⁻¹⁶	1.5 × 10 ⁻¹⁶	This work

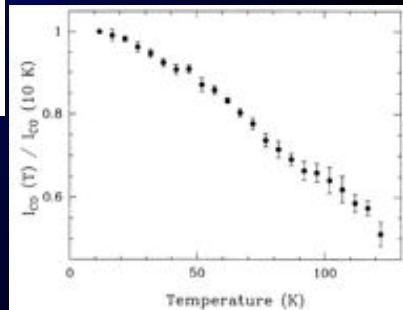
^ad'Hendecourt & Allamandola (1986) and Gerakines et al. (1995) performed measurements using the band strength of the OH-stretching mode of 2 × 10⁻¹⁶ cm molecule⁻¹ determined by Hagen et al. (1981) as a reference. So, we consider a density of ρ = 0.94 g cm⁻³ used by Hagen et al. (1981) to scale the band strengths found by d'Hendecourt & Allamandola (1986) and Gerakines et al. (1995) using the formula (6).

Bouilloud et al. 2015

Variations des bandes d'absorption



Gerakines et al. 1998



Schmitt et al. 1985