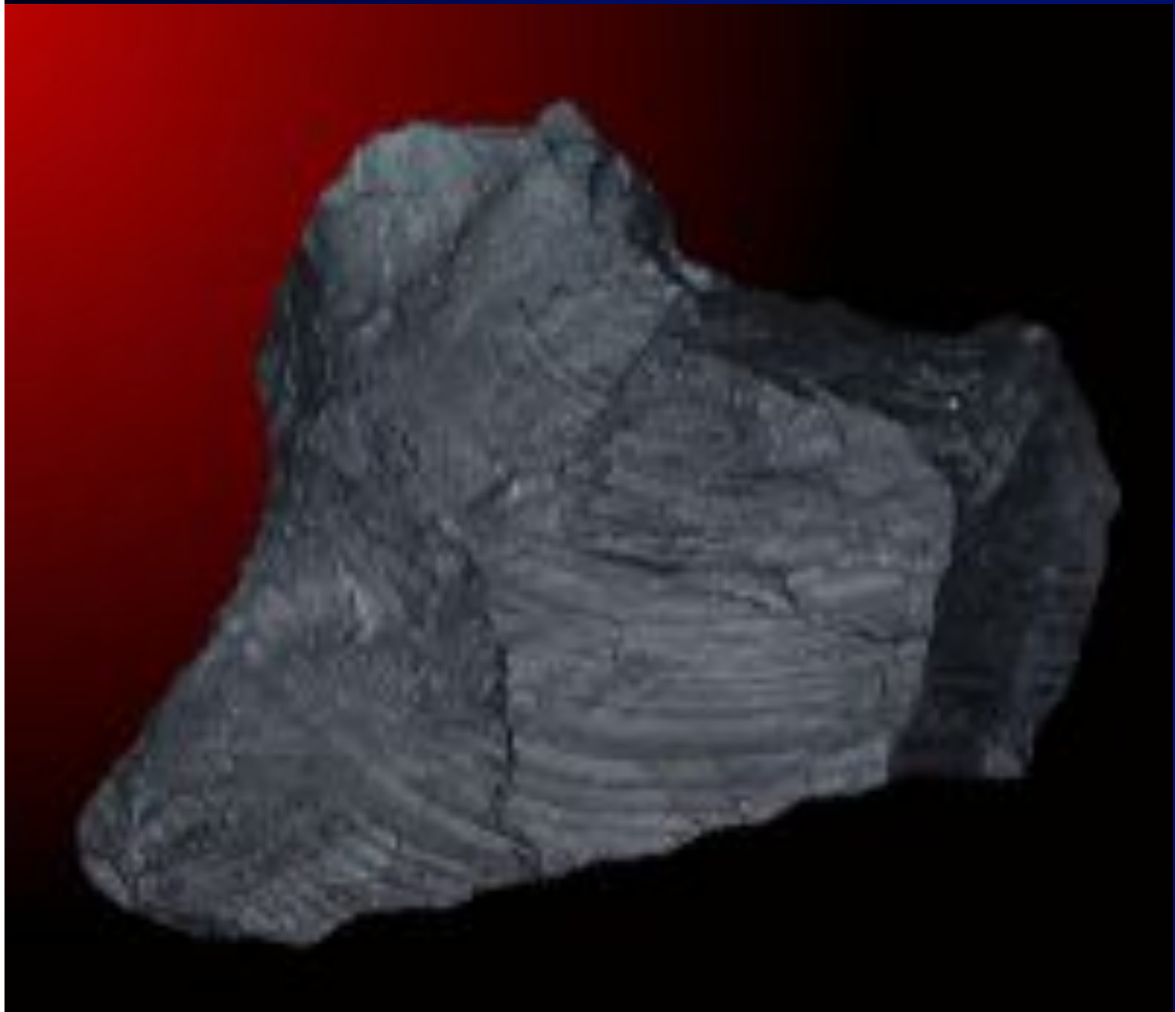
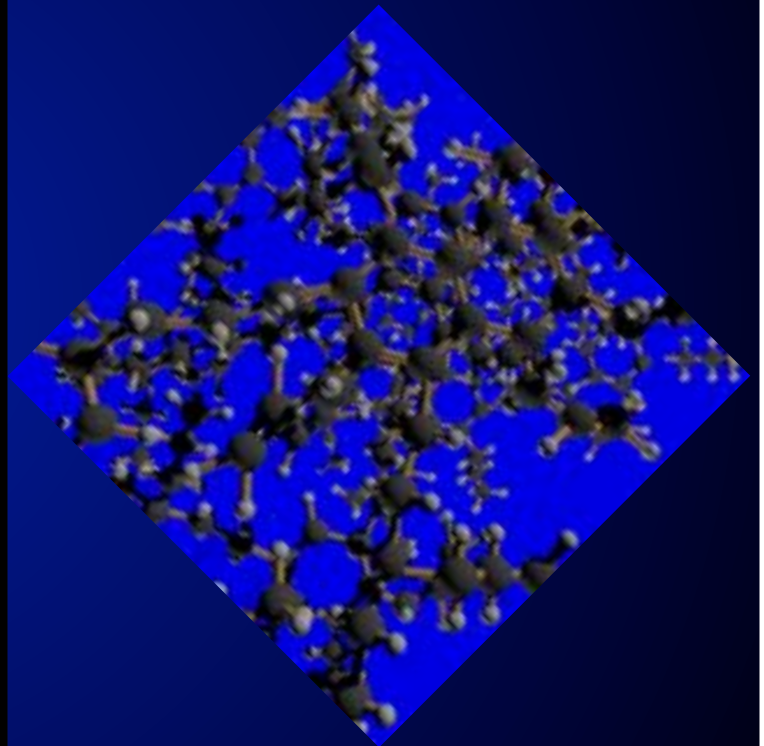
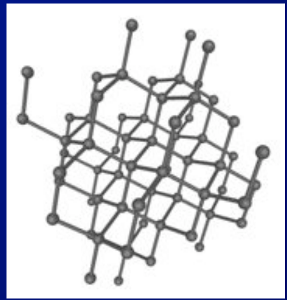
ISM « Carbonaceous » dust



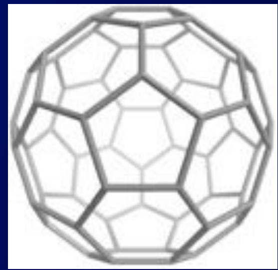


What are the main carbonacous solids / large molecules observed in the ISM?

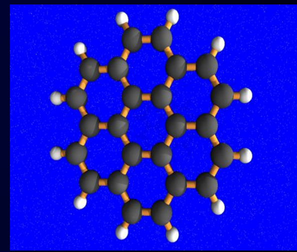
Diamond



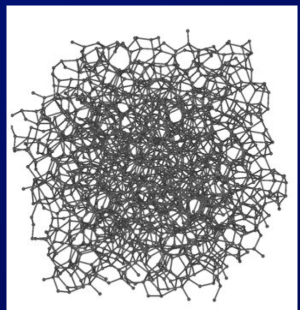
Fullerenes



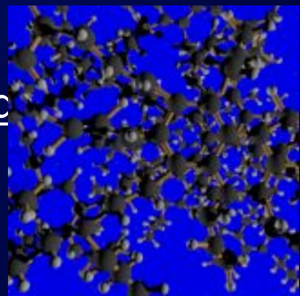
AIBs-PAHs : Class A à C



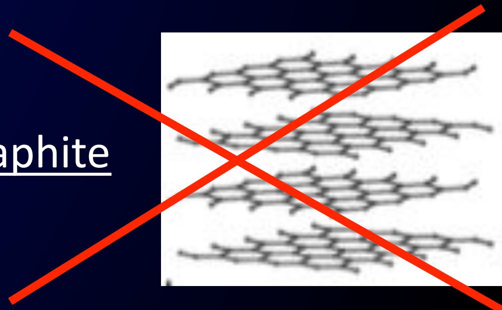
Amorphous carbon



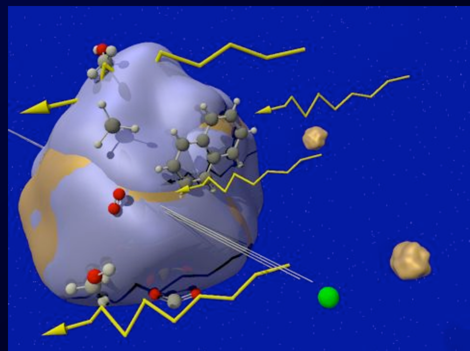
Hydrogenated Amorphous Carbon



Graphite

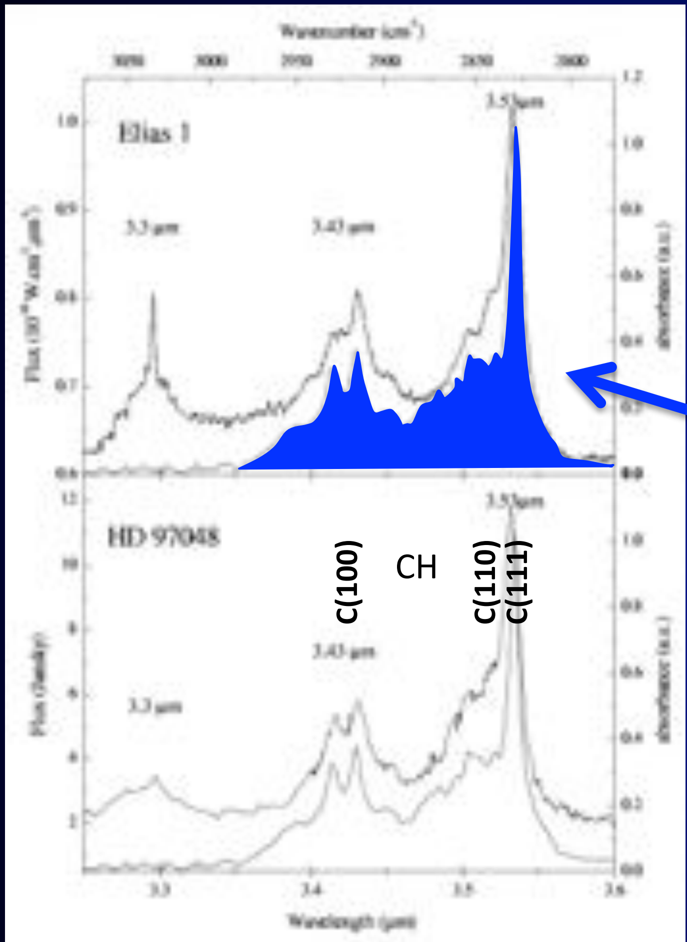


+ organic matter



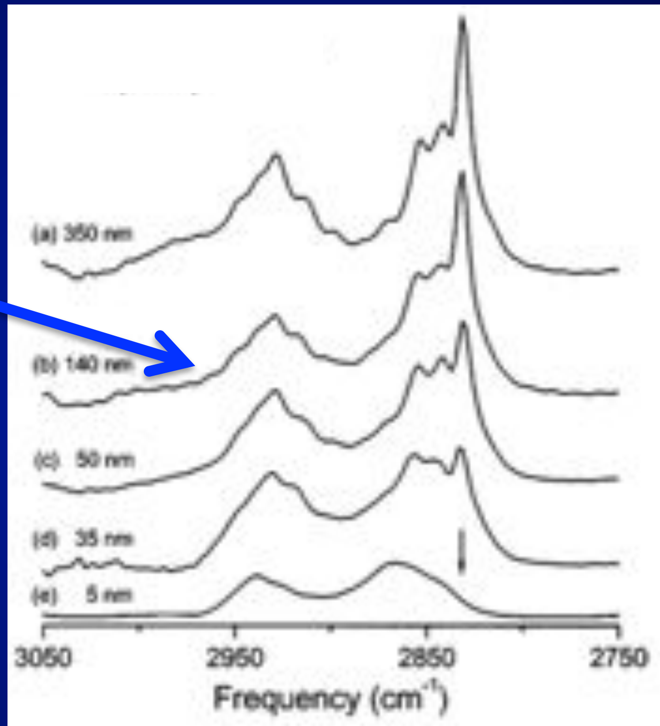
Ice mantles residues

ISM carbonaceous allotropes: *Nanodiamonds*

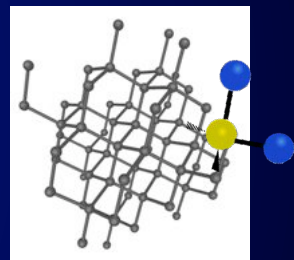


Guillois+1999; Chang+1995

Lab Top down approach > 35nm



Chen+2003



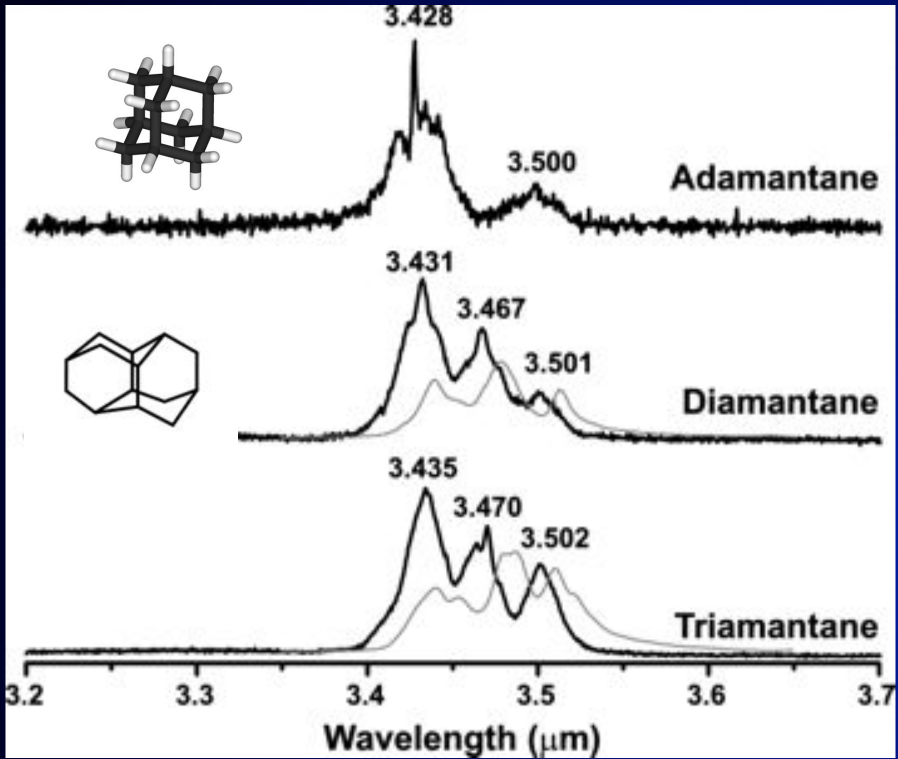
Monohydride

Nanodiamond approach :
Nonrelaxed surface for nanodiamonds < 35nm

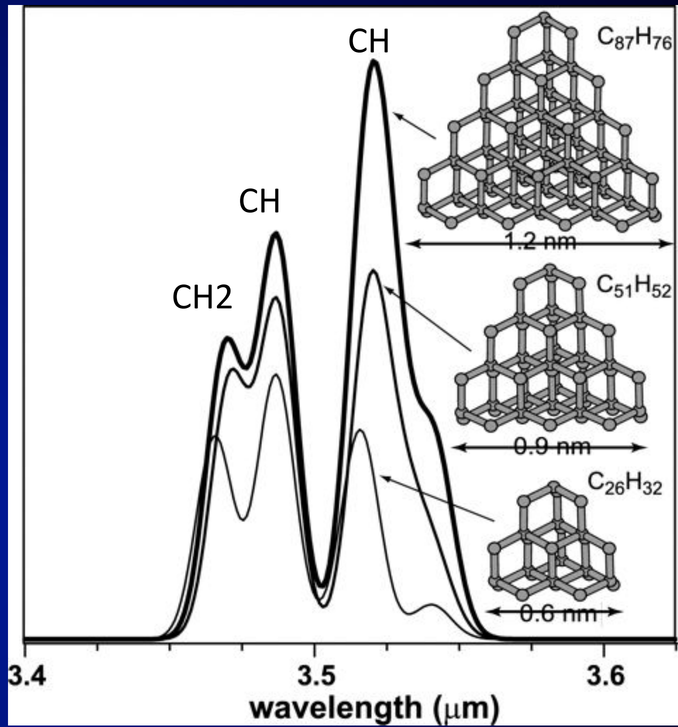
Jones & d'Hendecourt 2000; Chen+2003; Jones+2004

Experiments on diamondoïds

Gas phase small diamondoids



Expected size dependence



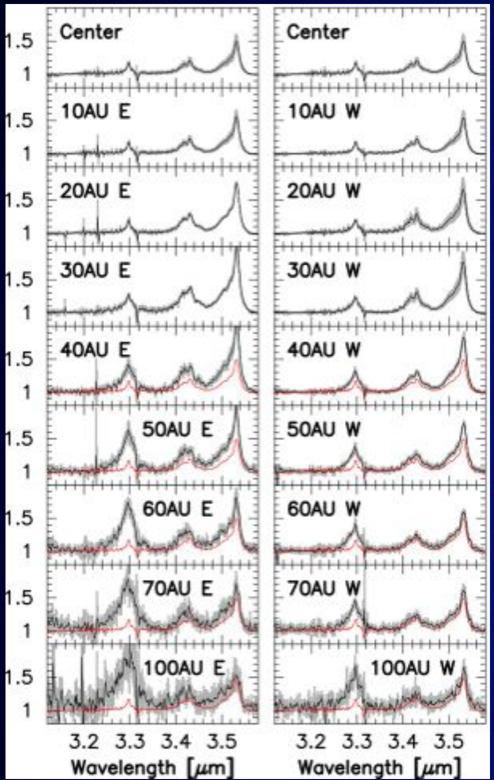
Lab Bottom up approach

Pirali et al., ApJ 2007

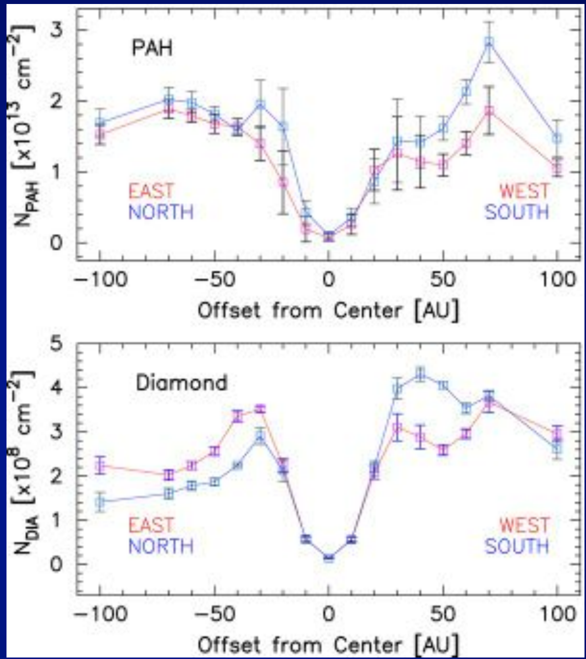
Analog species containing about 130 C atoms (e.g., $C_{136}H_{104}$) with a 3.53/3.43 μm intensity ratio close to observed in the ISM.

Diamond : resolved observations

- Observed close to stars

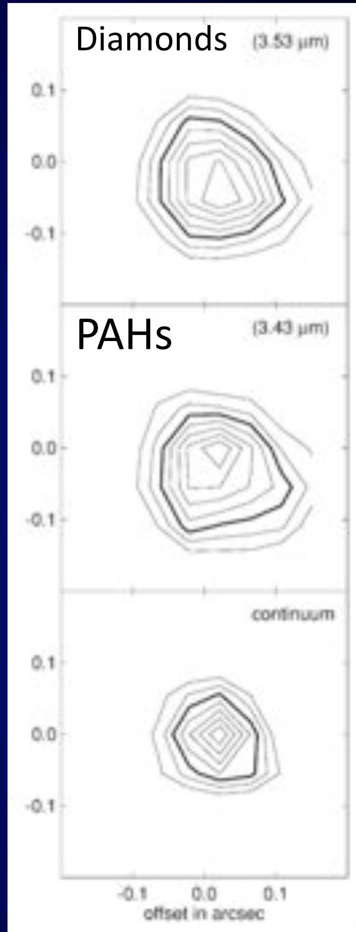


Elias 1



Goto et al. ApJ 2009

HD 97048



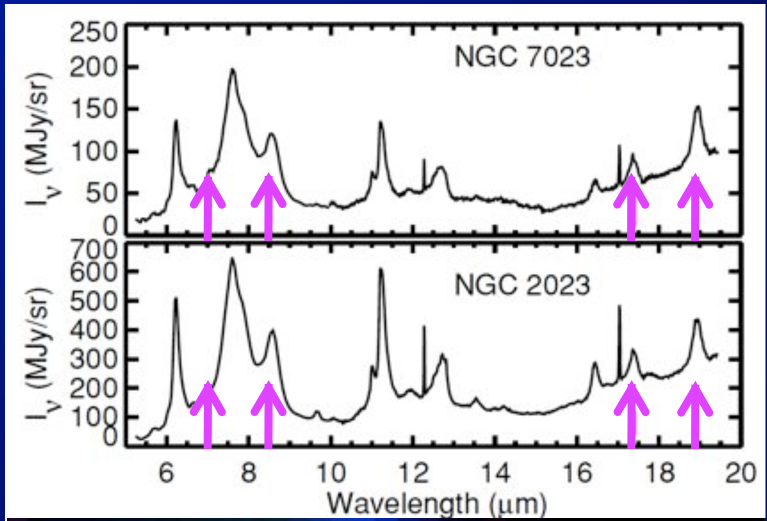
- Survey of 30 Herbig Ae/Be stars

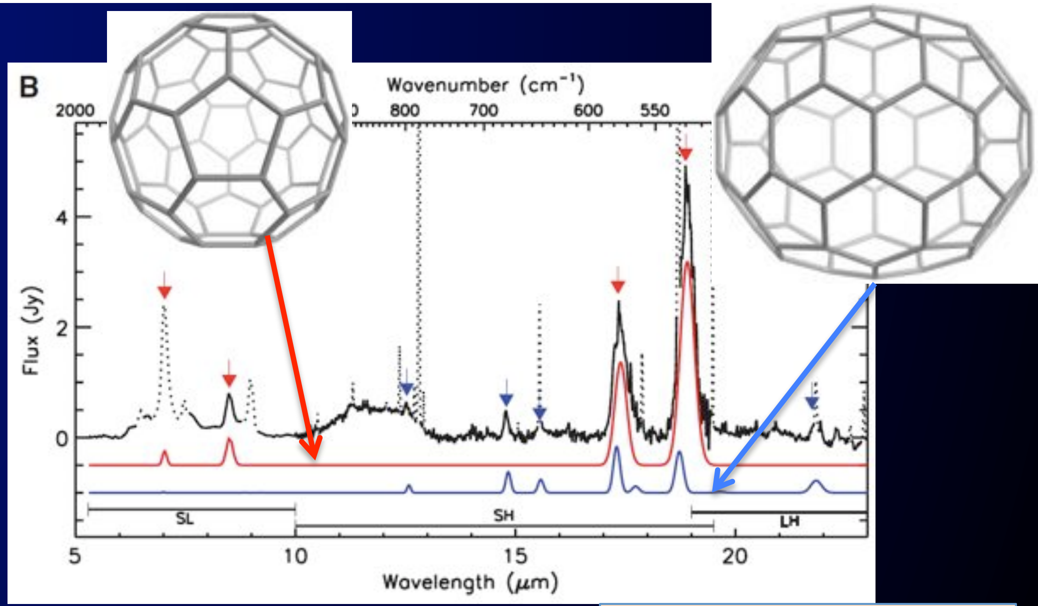
Acke et al. A&A 2006

Habart et al. A&A 2004

< 4% of targets with characteristic emissions at 3.43 and 3.53 µm

Space Fullerenes



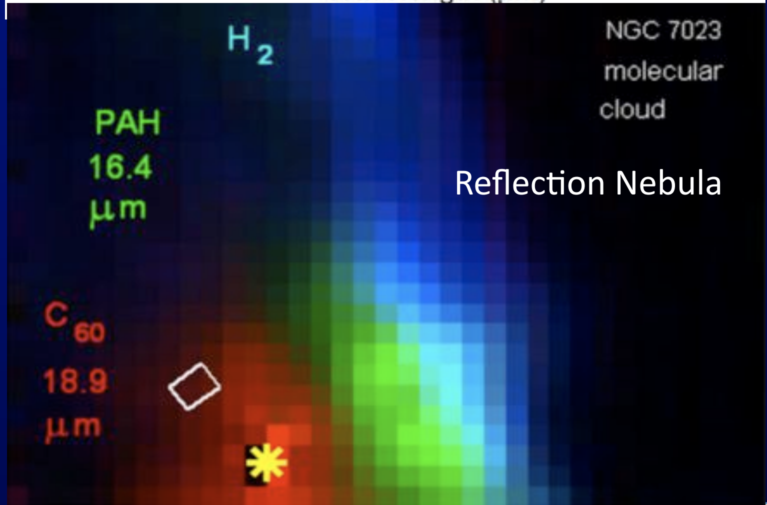


PN (white dwarf) with low H

Cami et al. Science 2010

A long search with upper limits: visible DIBs & IR

e.g. Foing & Ehrenfreund1994, Fulara+1993; Moutou+1999, Herbig 2000



Sellgren+2009, 2010

Spatially resolved C_{60} in Reflection Nebulae

Sellgren et al. AAS 2009, Sellgren et al. ApJL 2010

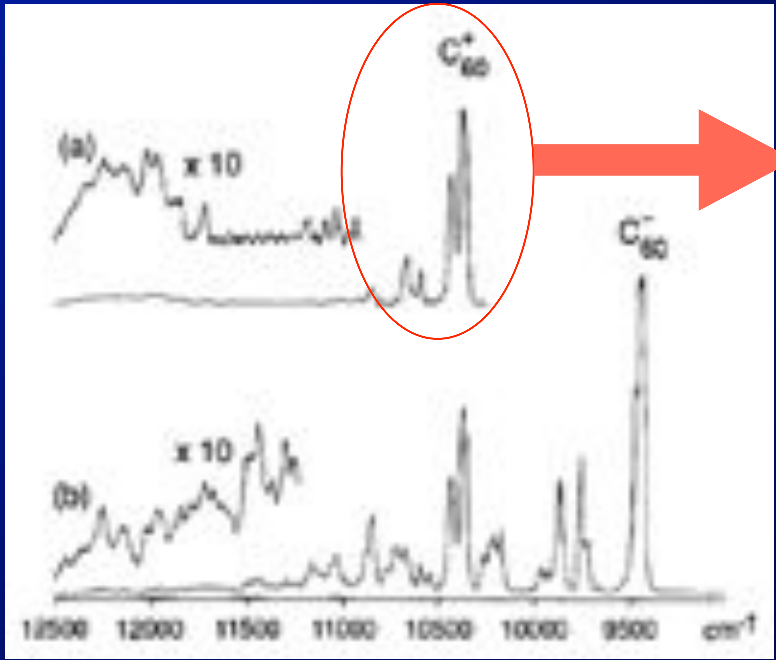
Observed mainly in PN (<5% C-rich) & many other objects (RN, AGB, Post-AGB, PPN, Herbig Ae/Be)

Cami+2010, García-Hernández+2010,2011,2012, Gielen+2011, Otsuka+2013, Zhang & Kwok 2011, Rubin+2011, Peeters+2012, Boersma+2012, Berné & Tielens 2012, Roberts+2012, Omont 2016

Low % of the cosmic C implied (~0.001-0.05 % of C)   Formation route ?

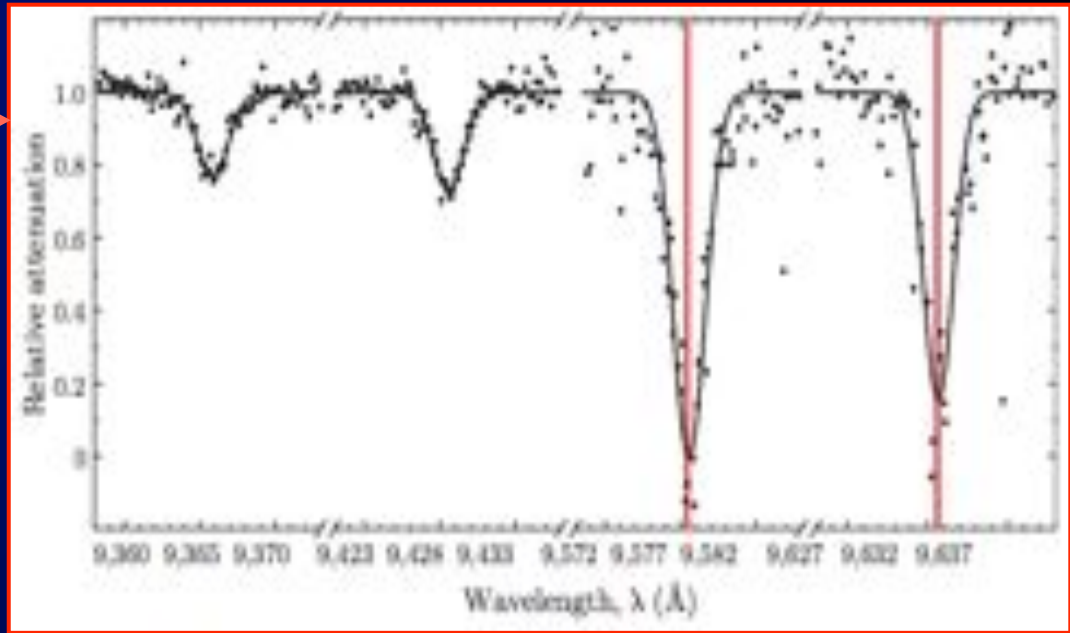
only ~ 3% of all PNe observed in the Milky Way with Spitzer show evidence of the C60 mid-IR bands Otsuka+2014

Fullerenes



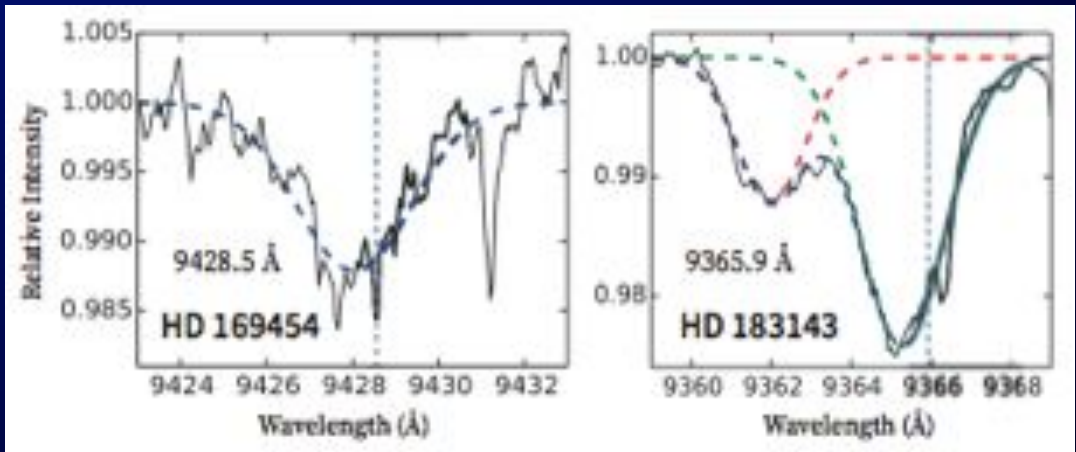
C60+ in Neon@5K

Fulara+1993



C60+@5.8K

Campbell+2015



Walker+2015

C60+ f value measured in Ne

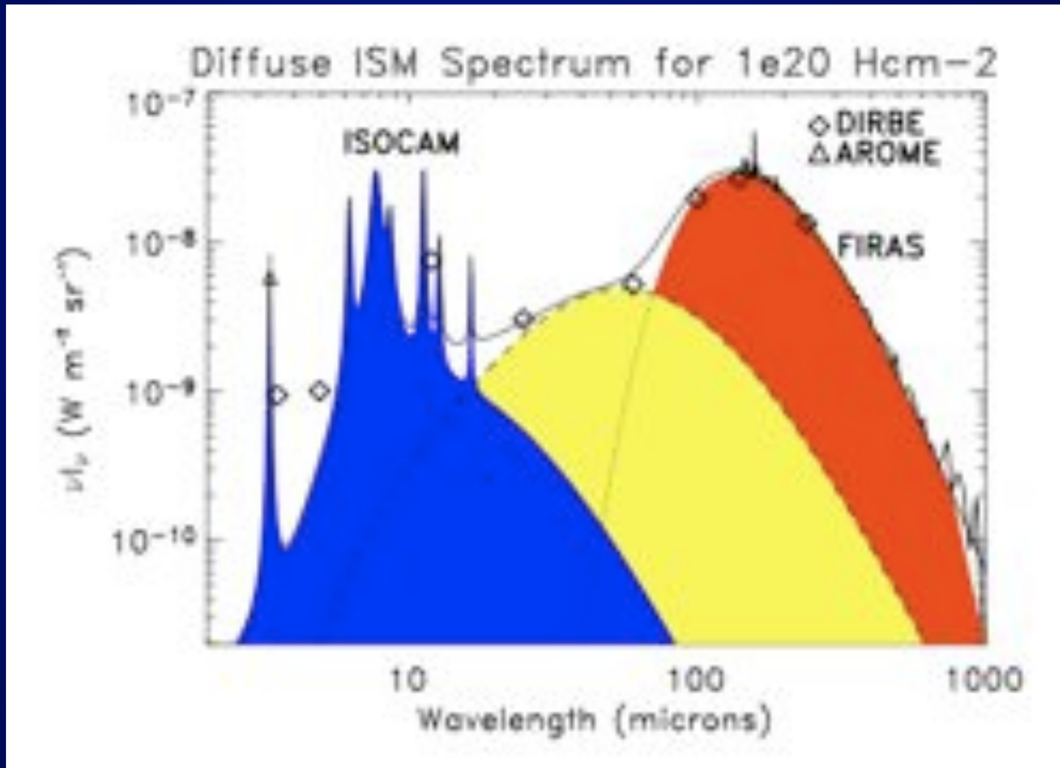
Strelnikov+2015

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

"Polycyclic Aromatic Hydrocarbons" hypothesis (AIBs)

Emission : diffuse medium & interfaces

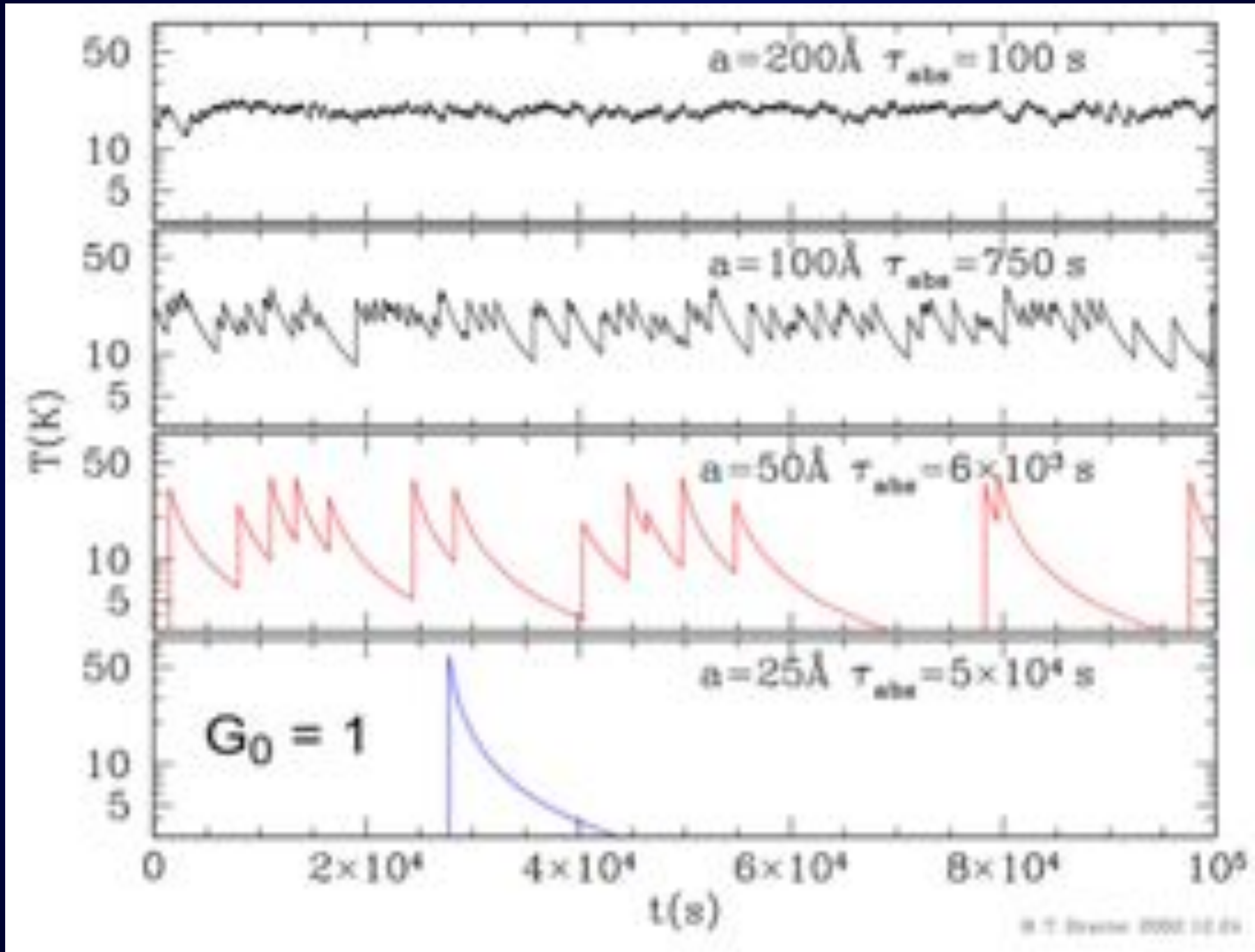
Aromatic Infrared Bands (AIB), Very Small Grains (VSG), Big Grains (BG)



Boulanger 2000

Emission after visible-UV stellar photon absorption (hv) by a grain

Size dependent emission



Draine 2003

Reprocesses half of the stellar energy

- BG :

FIR associated with large size silicates/ carbonaceous grains : 10 nm < a < 100 nm

- VSG :

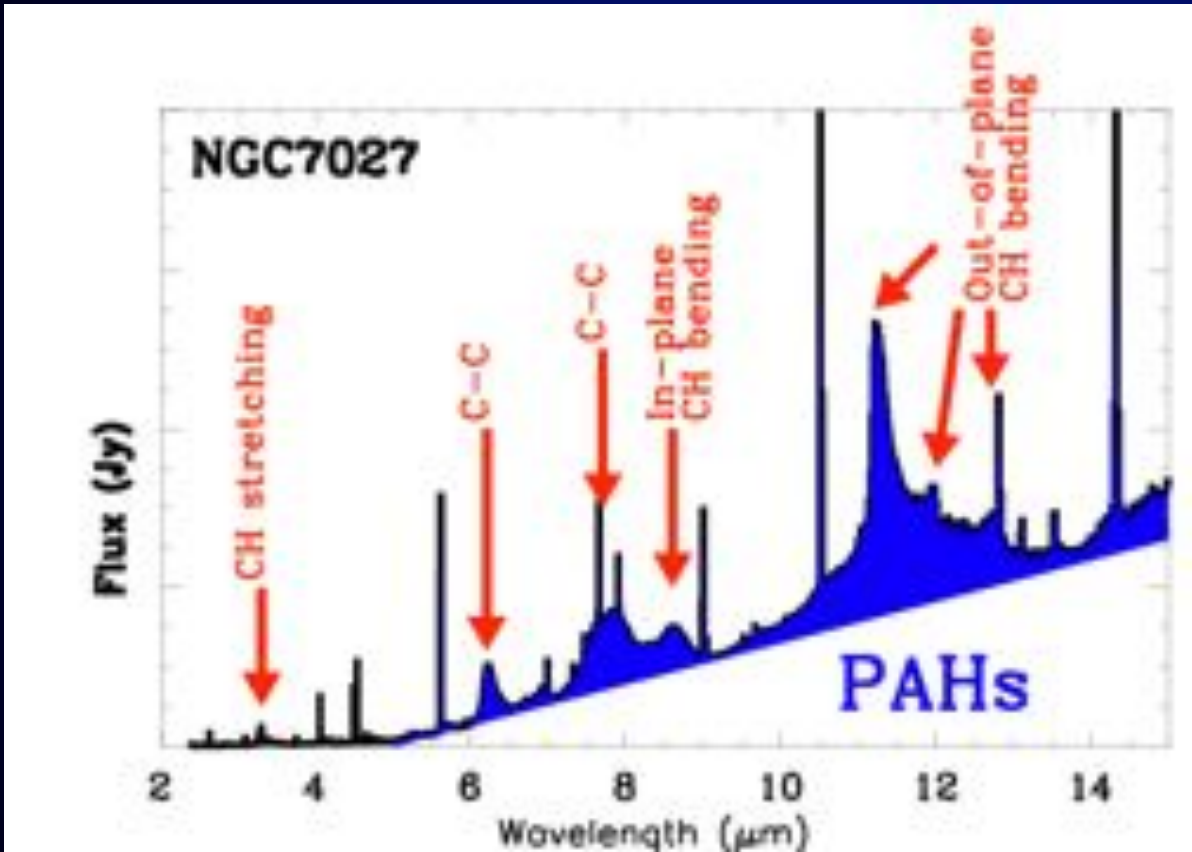
Mid-IR emission requires grains 1nm < a < 10nm

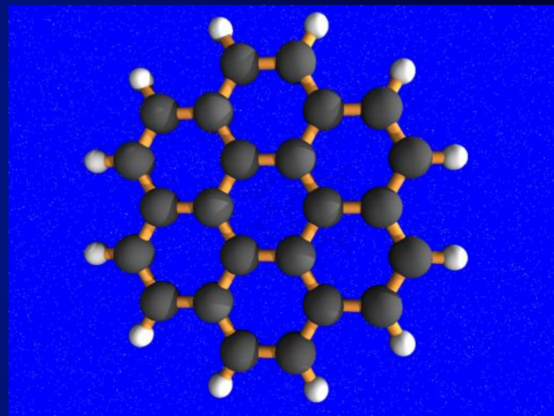
- AIB :

Aromatic character but still no single carrier identification.

Transient emission after VUV photon absorption.

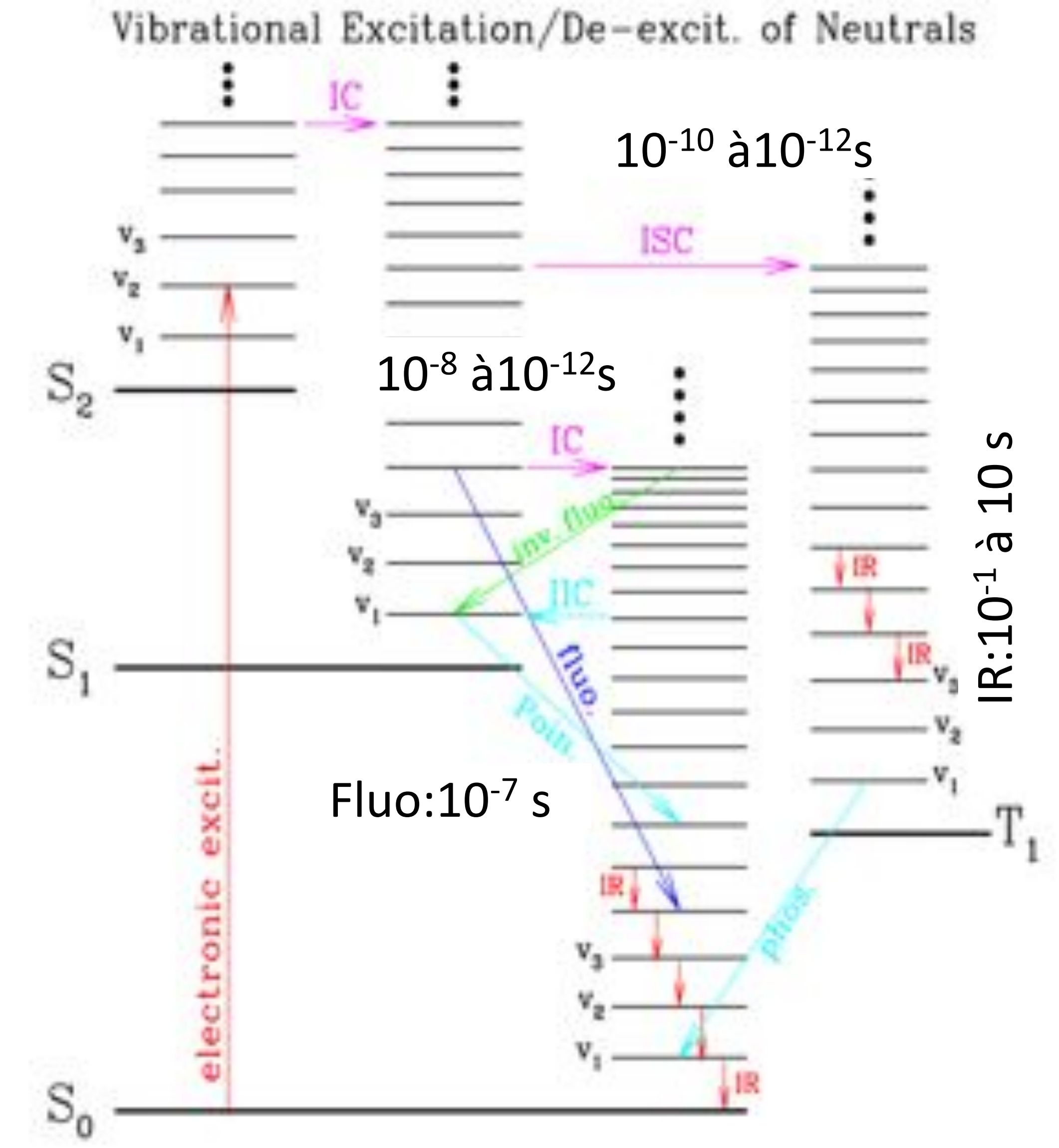
"Polycyclic Aromatic Hydrocarbons" hypothesis (AIBs)

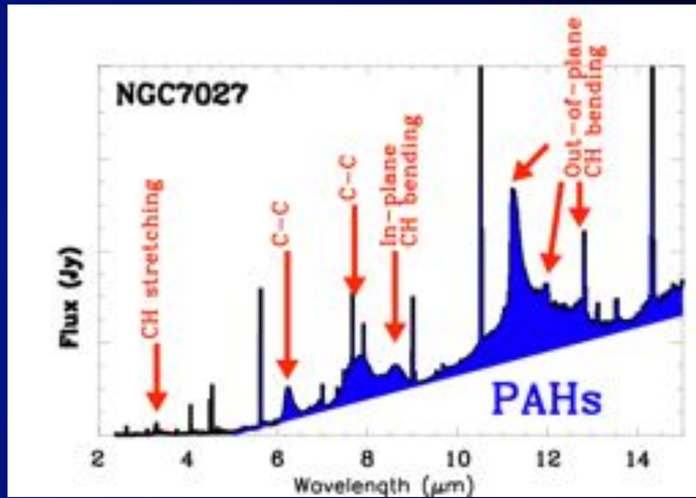




ISO database

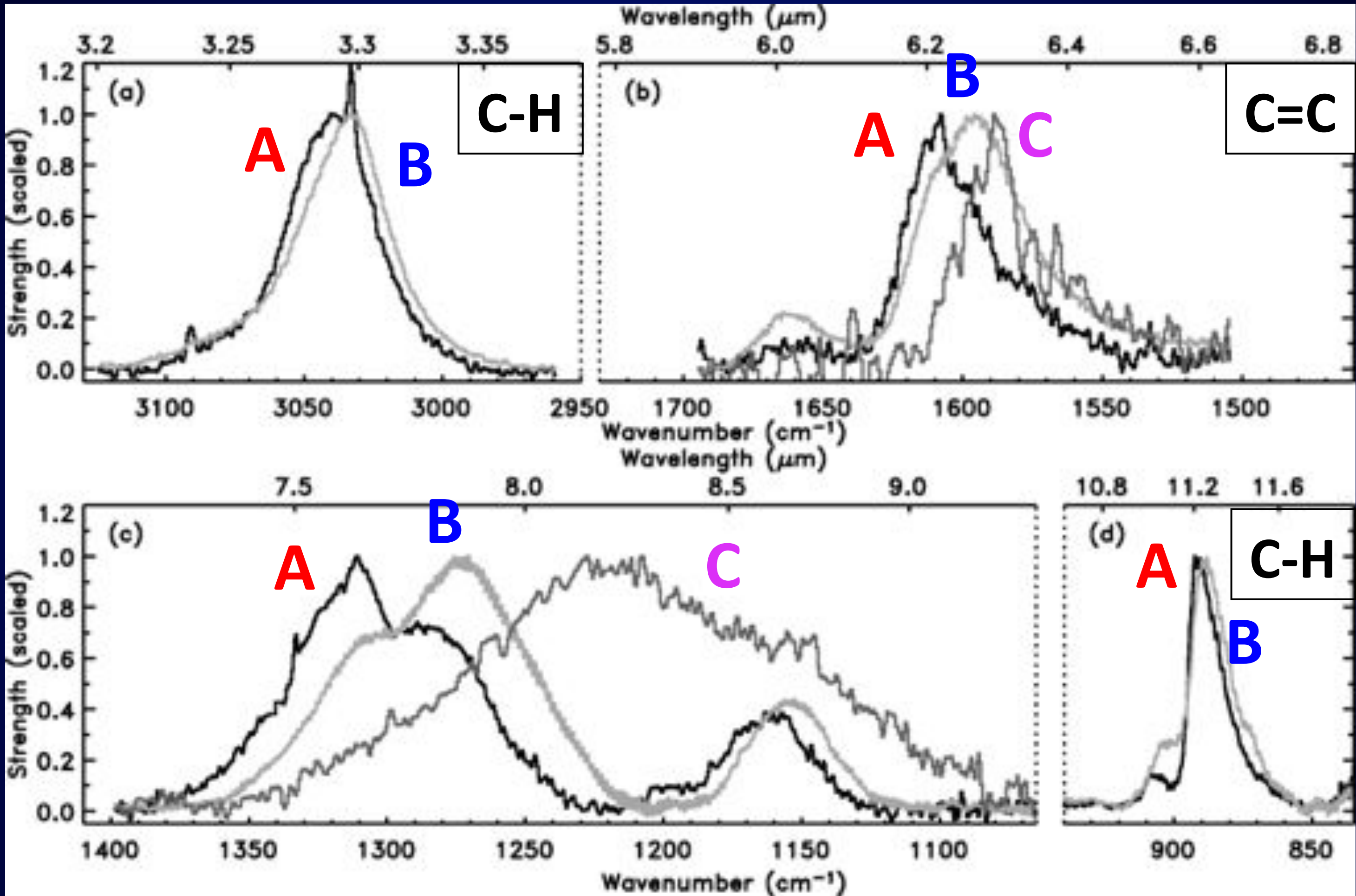
PAH emission mechanisms





Li 2003

PAHs : Classes A, B and C



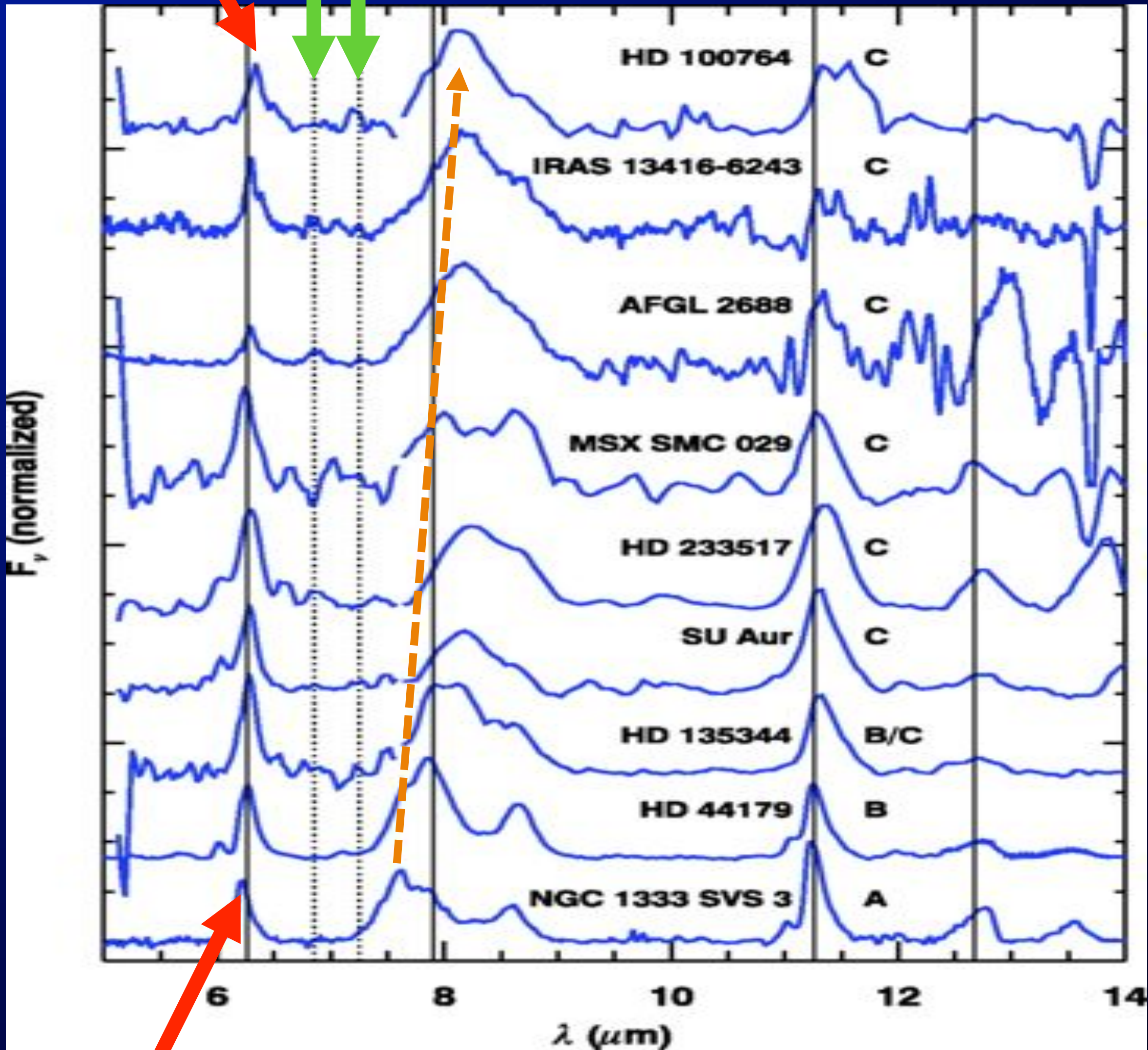
Van Diedenhoven et al. ApJ 2004

By number : class A >> class B > class C

6.3 µm

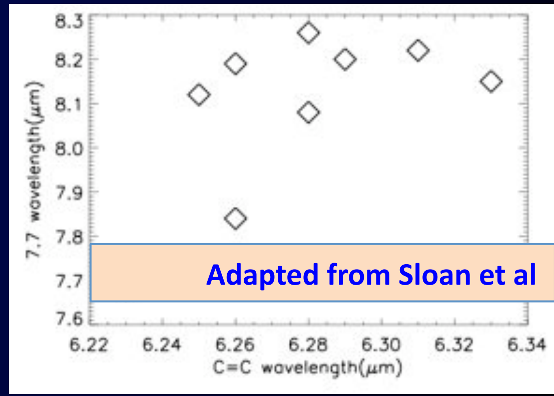
sp³ deformation modes

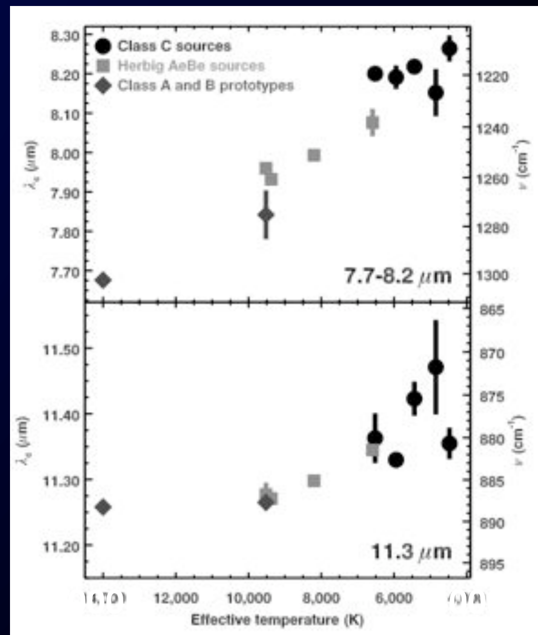
6.85/7.25 µm



6.2 µm

Sloan+2007, Keller+2008, Acke+2010





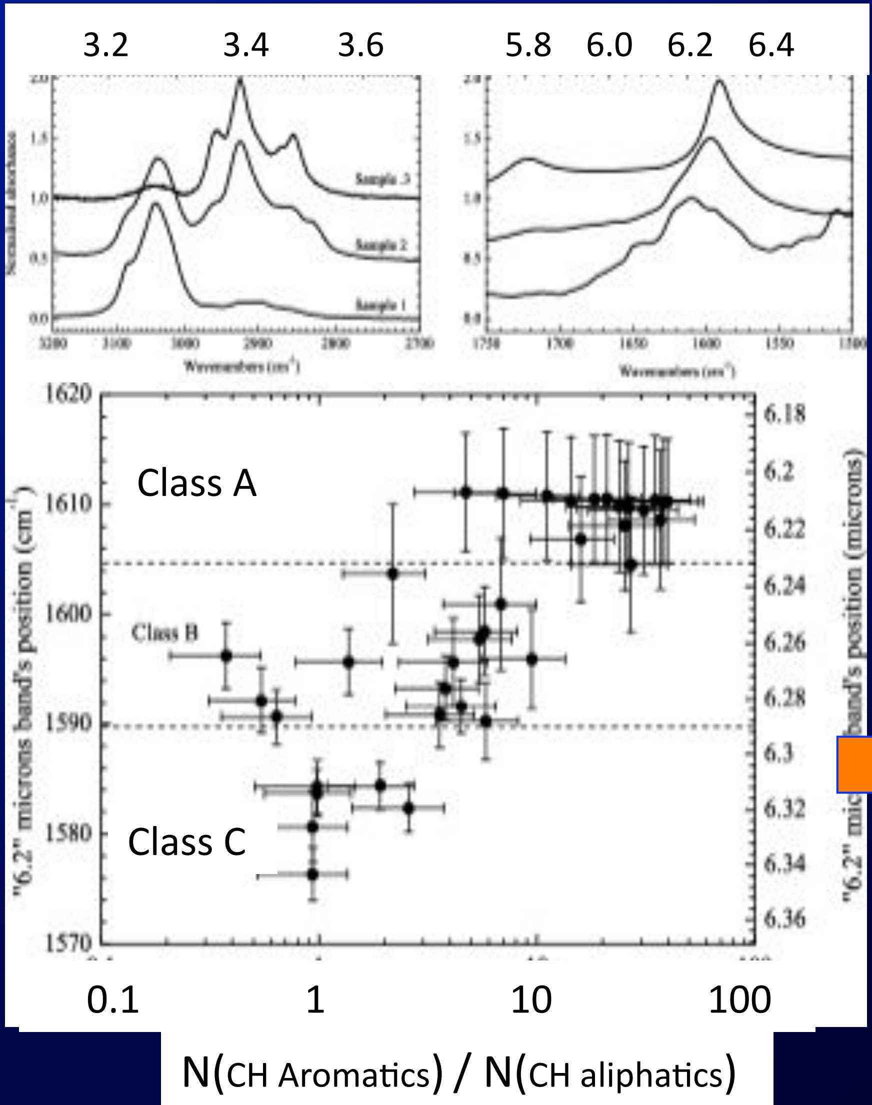
Teff

Planet. Ne and RNe not aligned

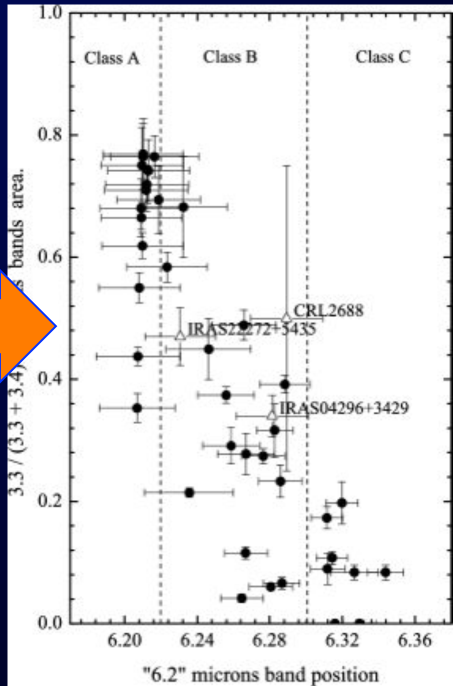
Xstry + UV

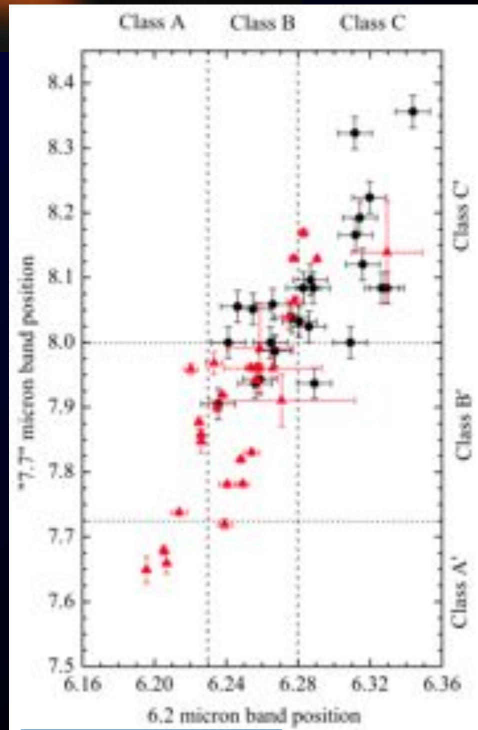
Aromatic C=C shift induced by aliphatics *sp3 CH bonds ?*

Premixed low pressure flame
Laboratory soot analogues spectra
(~50 samples)



Pino+2008



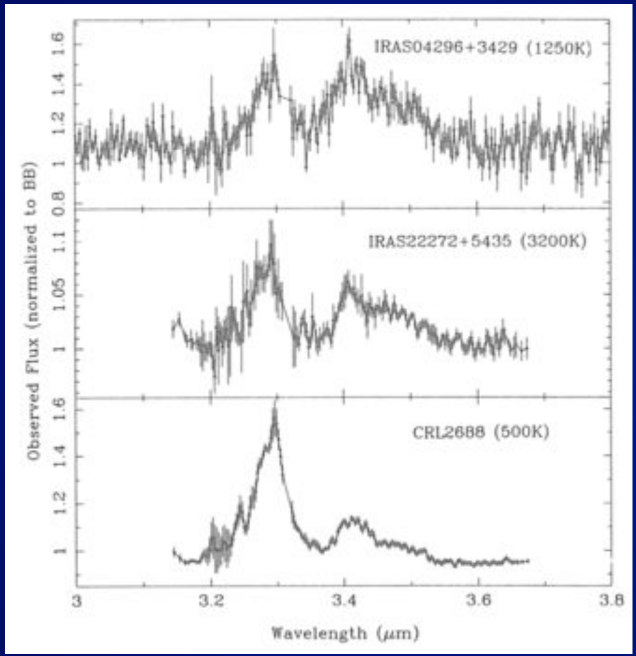


Carpentier+2012

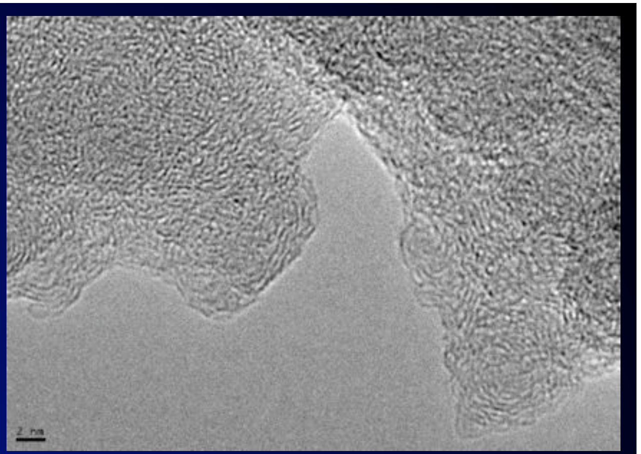
Kwok&Zhang2013

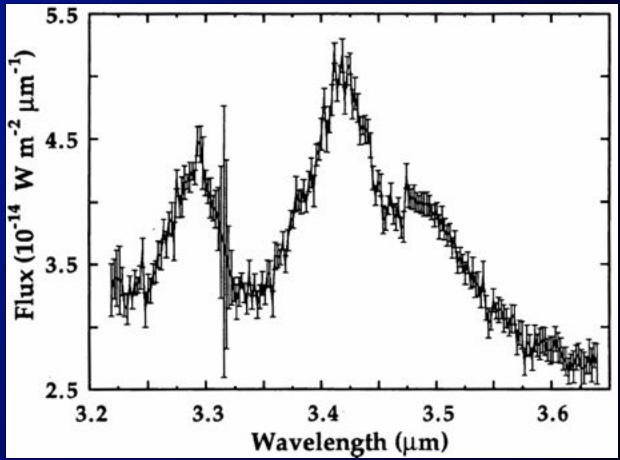
Mixed aliphatics/aromatics and transition from class A to C

HST



Geballe et al. ApJ 1992

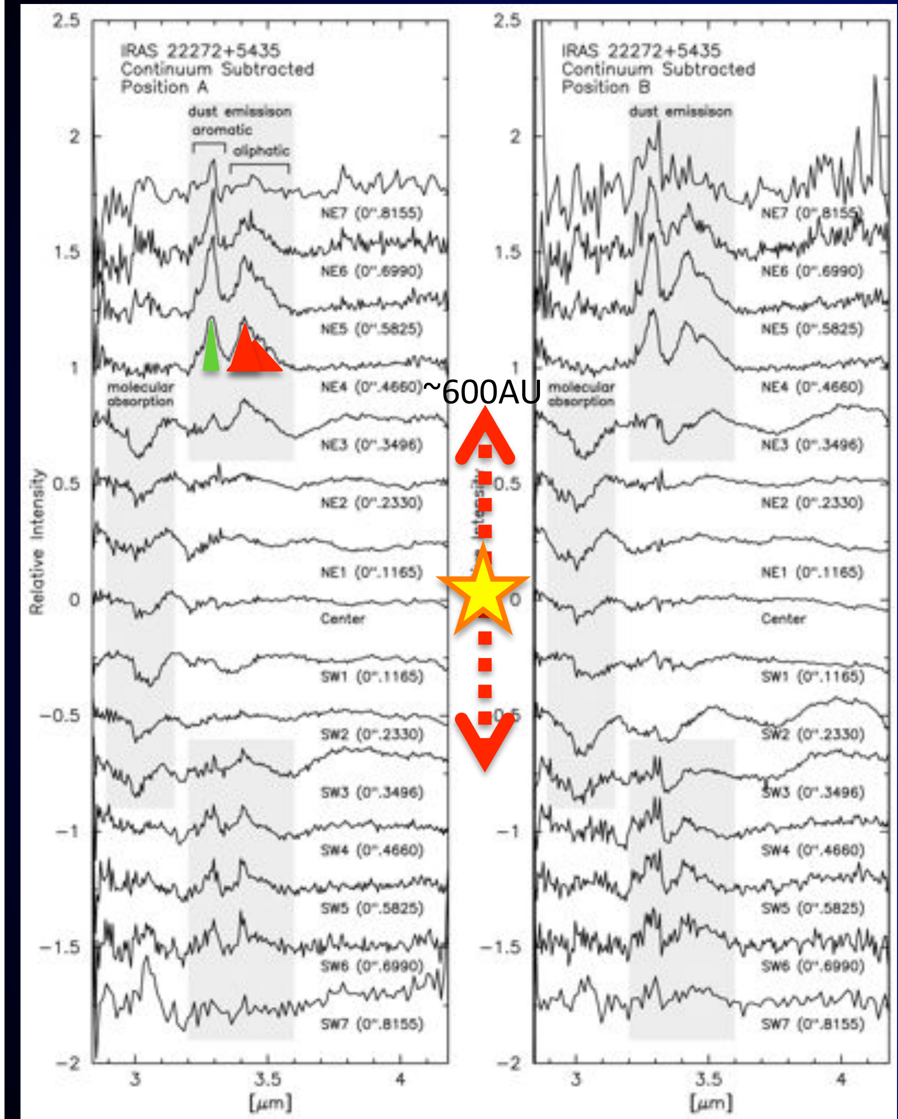


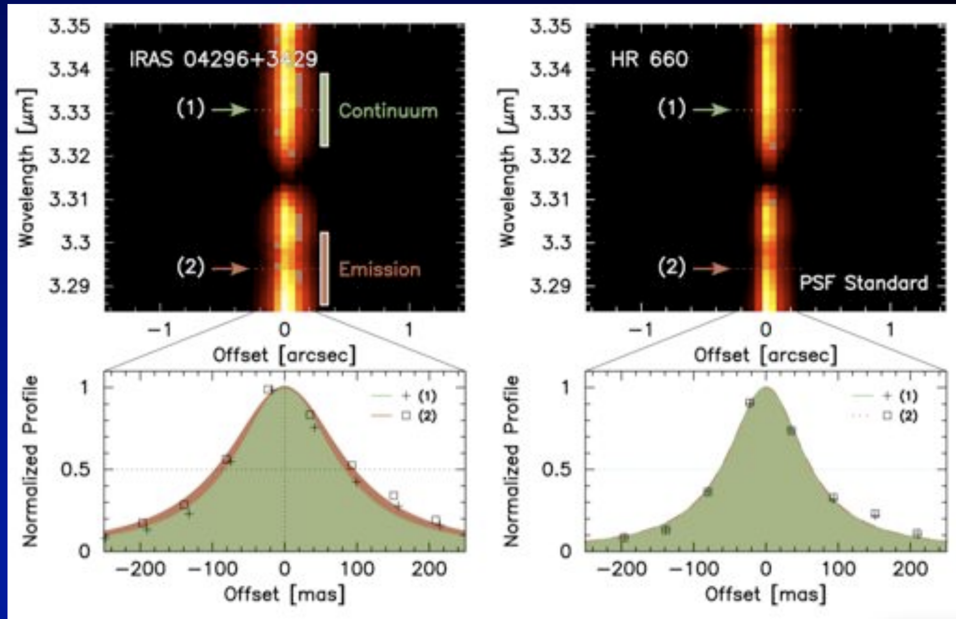


Joblin et al. ApJ 1996

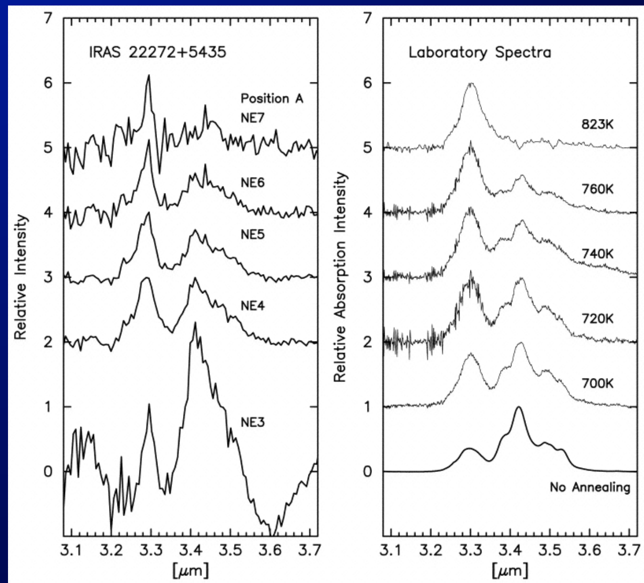
Does a link between hydrocarbons in absorption and emission ?

CH stretching resolved in IR emission by A.O.

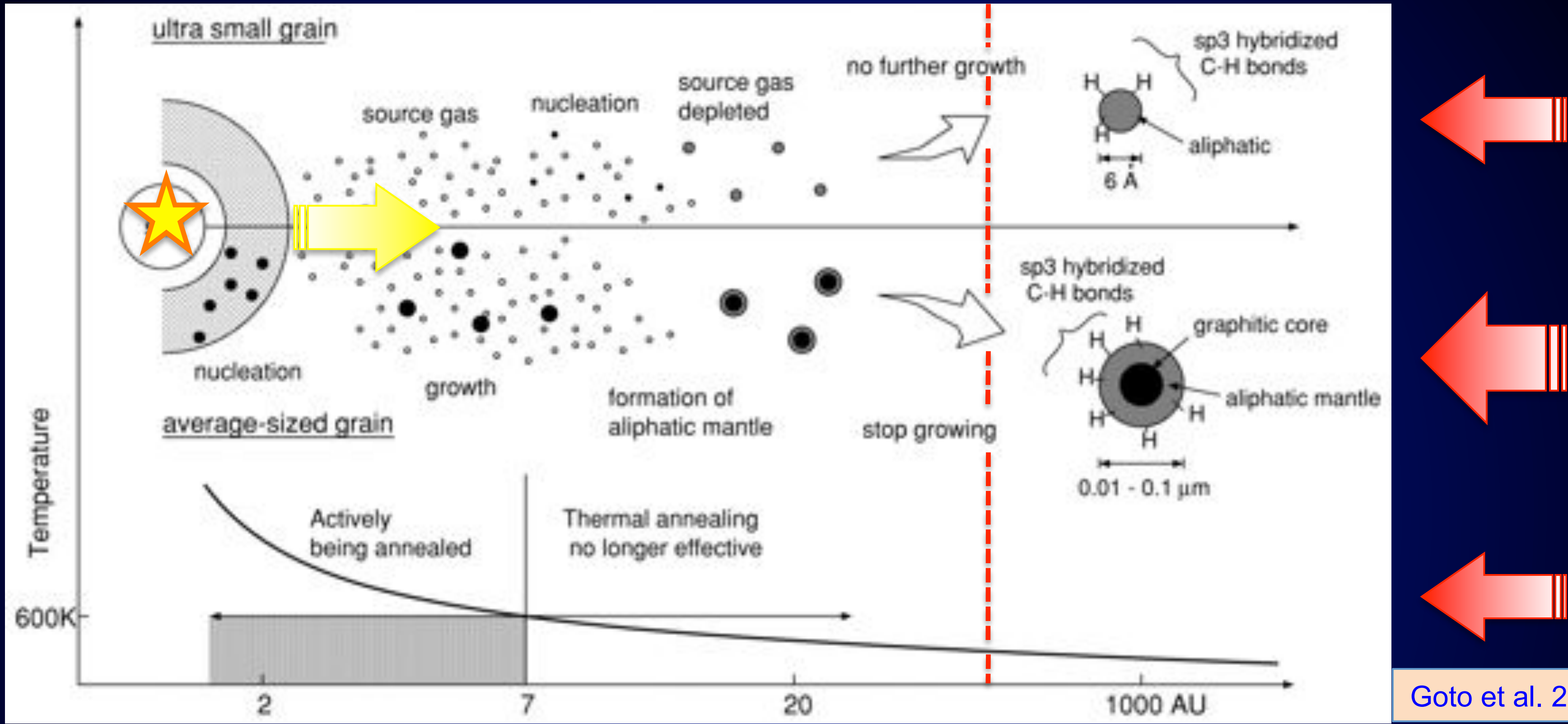




Goto et al. ApJ 2003, 2007



Understanding carbonaceous dust nucleation



Goto et al. 2003

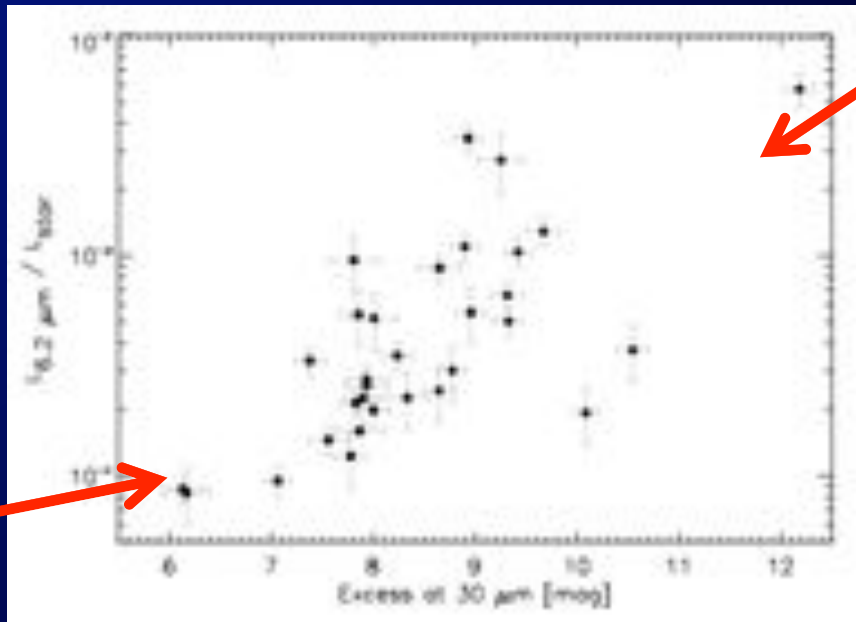
Competition between different emission mechanisms, size dependent?

Coexisting mechanisms (modification, emission, Stellar/ISRF) to be constrained

AIBs – PAHs in circumstellar disks

detection rate of IR PAH emission features PAH molecules:
low for T Tauri stars (~10%) / Herbig Be stars (<35%)
2/3 intermediate-mass Herbig Ae stars detected PAH emission

Flared dust disks



Flattened dust disks

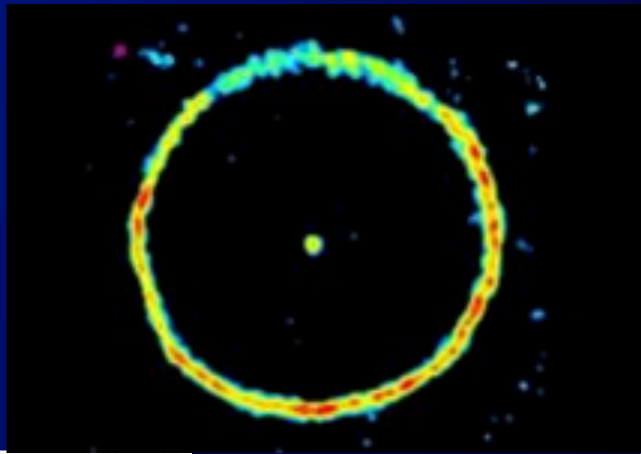
Acke+2011; Meeus+2001; Acke & van den Ancker 2004; Habart+2004; Keller +2008; Acke+2010

Flared dust disk stronger PAH features than flattened disks
Disk surface PAHs -> gas thermal balance -> shaping disk morphology

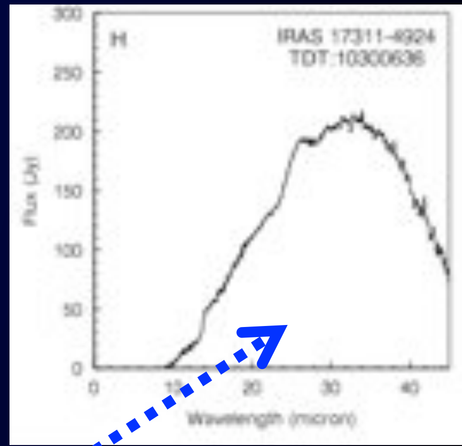
Interplay between disk struct. & strength of hydrocarbon emission

Amorphous carbon (a-C)

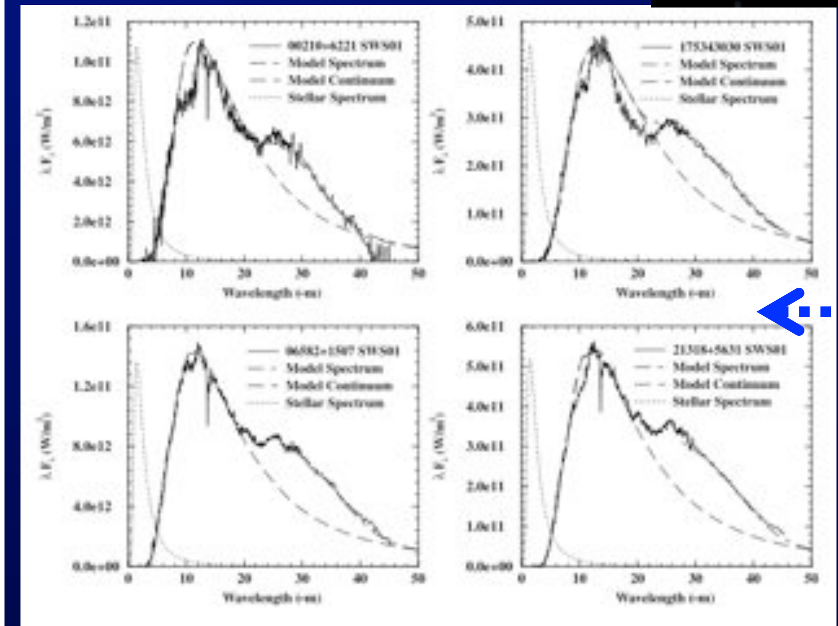
Carbon(-phase) stars

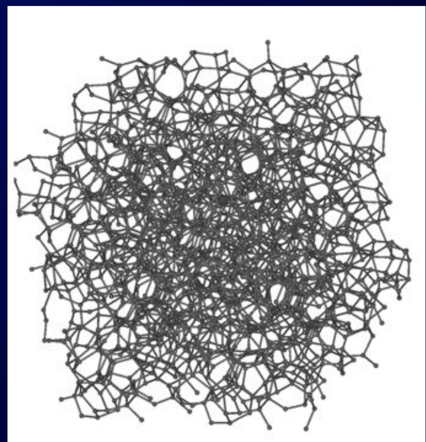


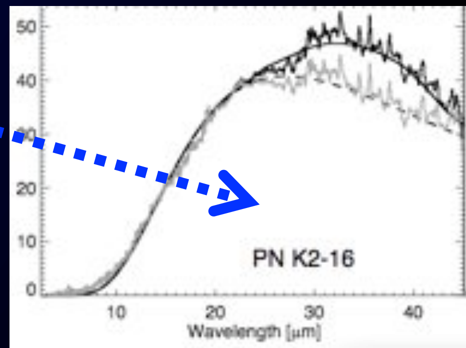
Etoile carbonée TTCygni / IRAM



Chen et al.2010
Gauba 2004







Hony et al.2002

Volk et al.2001

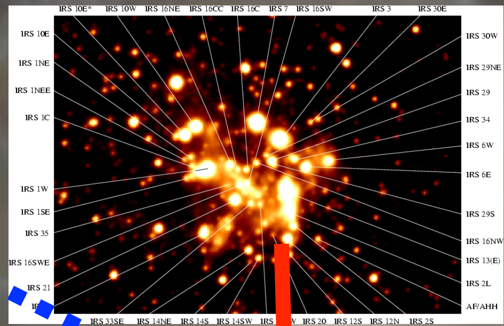
C rich PPNs progenitors like AFGL 2688 (class C) & PNs like NGC 7027

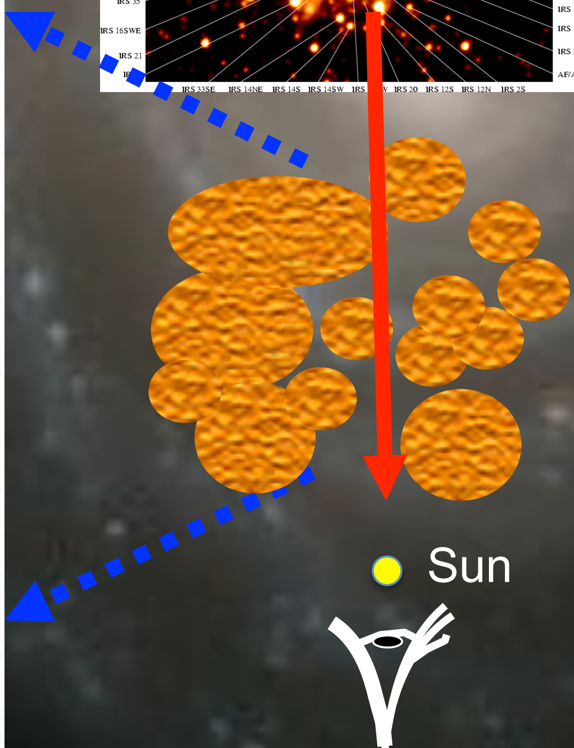
Hydrogenated amorphous carbons (a-C:H or HAC)

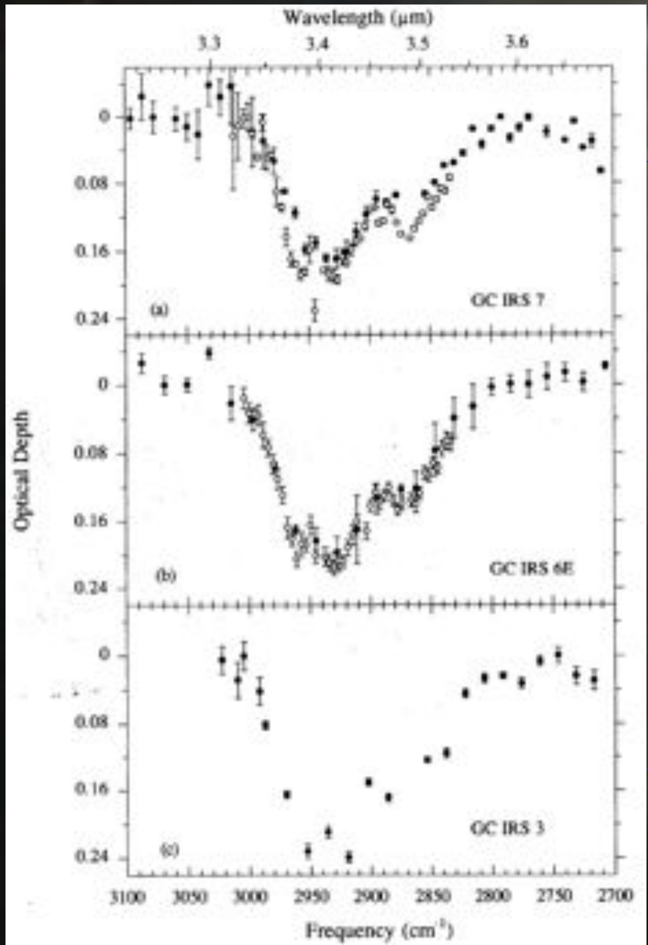
DISM

CH stretch abs. observed against
IR bkgd sources

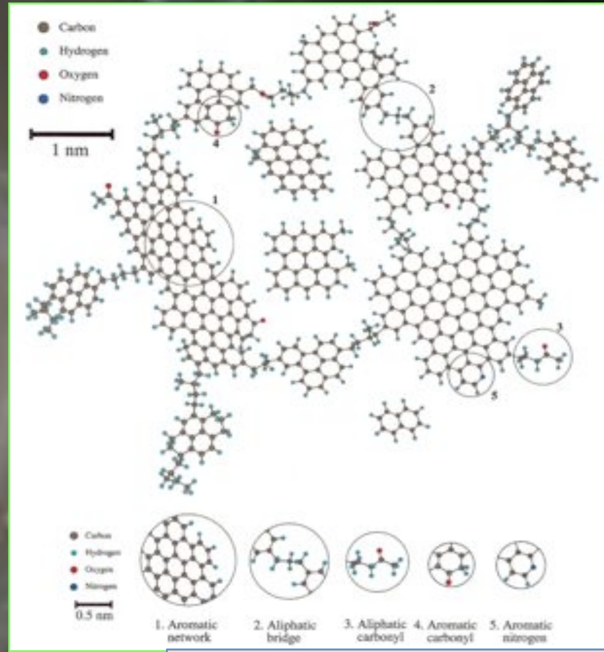
Viehmann+2004



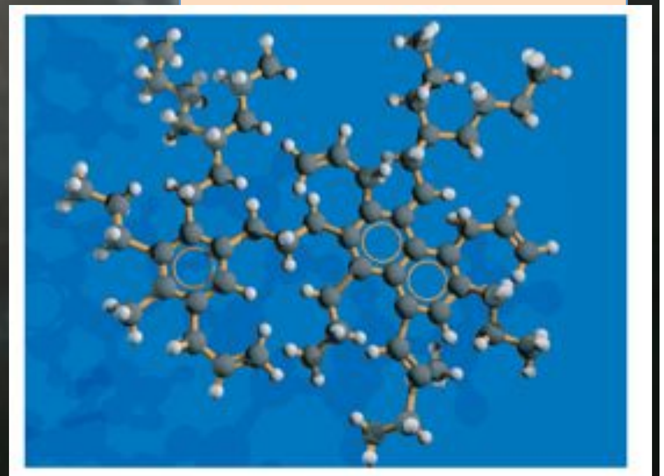




Pendleton+1994



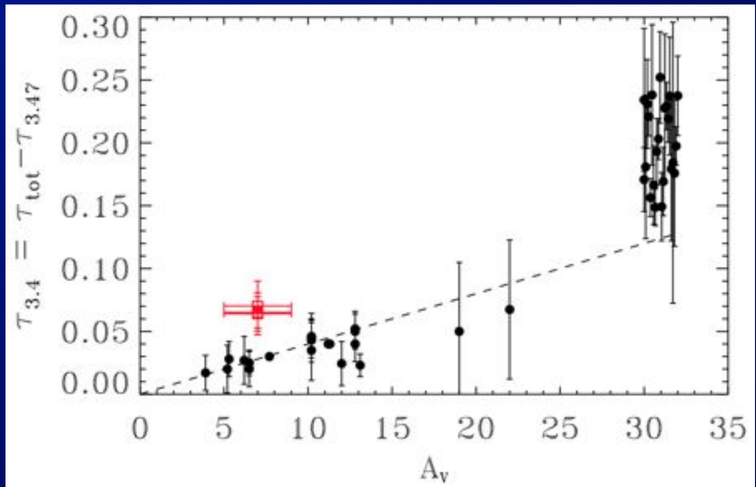
Pendleton & Allamandola2002



Dartois+2007

Hydrogenated amorphous carbons (a-C:H or HAC)

CH stretch abs. Galactic ISM



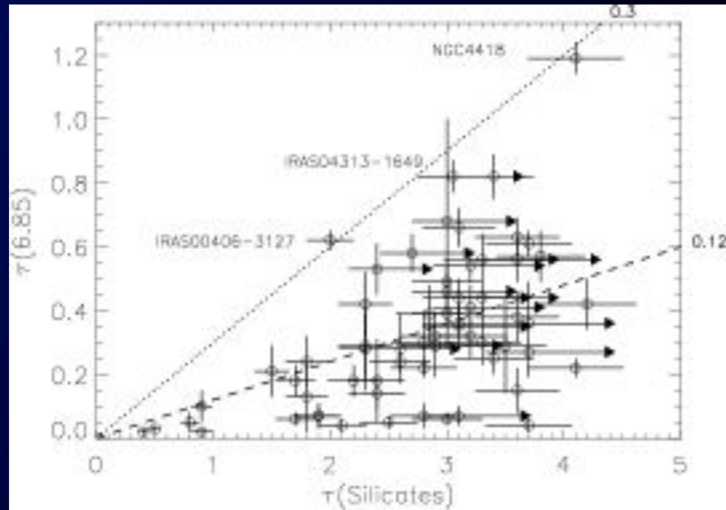
Godard+2011, Sandford+1991

e.g. Sandford+1995, Pendleton+1994, Duley+1994, 1998, Dartois+1997

τ (3.4) :

2.6% to 35% (lab HAC) of cosmic C

CH bendings abs. extragalactic DISM

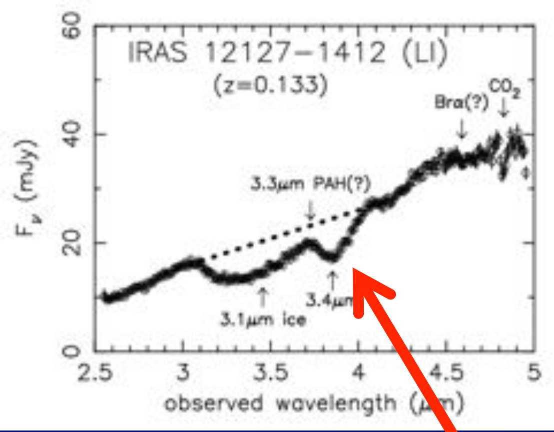


Dartois & Munoz Caro 2007

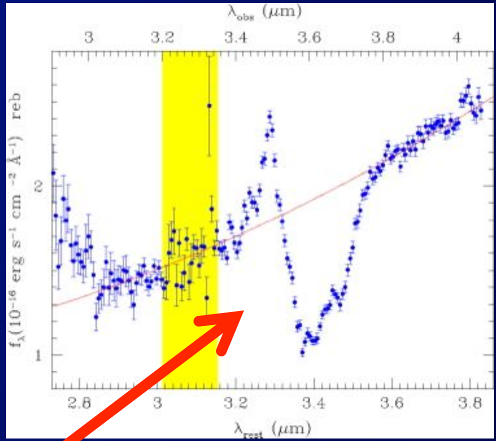
e.g. Risaliti+2006, Imanishi+2006; Mason +2004, 1998; Pendelton+1994

- τ(6.85) ~ 0.12 τ(Silicates)
- 15% +-7% of the cosmic carbon
- Up to 40% in extreme cases ?

Extragalactic sources ISM observed with a-C:H

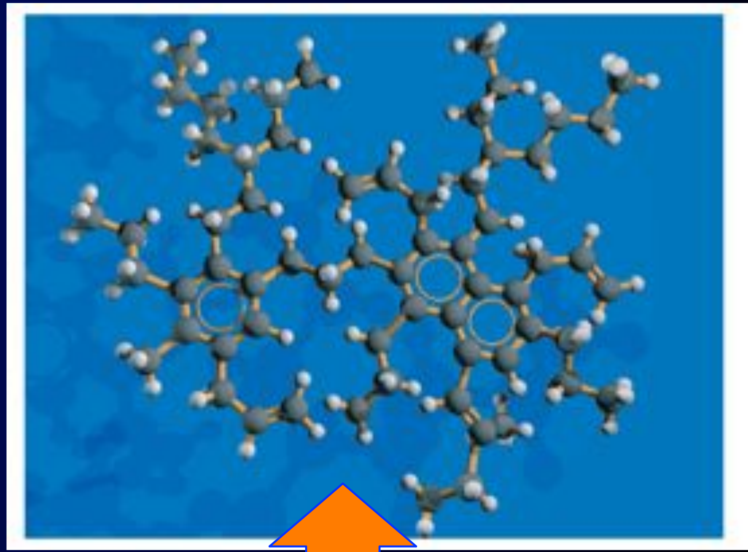


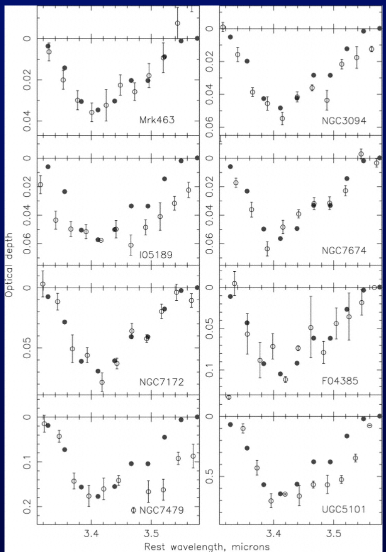
Imanishi et al. AJ 2010



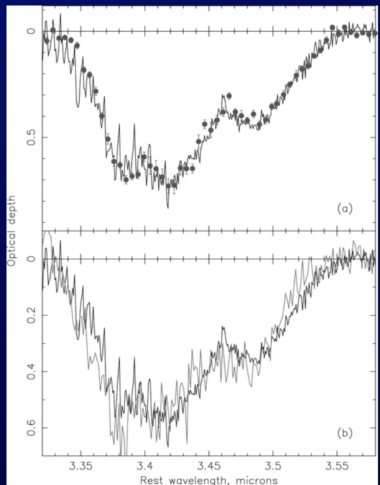
Risaliti et al. MNRAS 2006

CH stretch



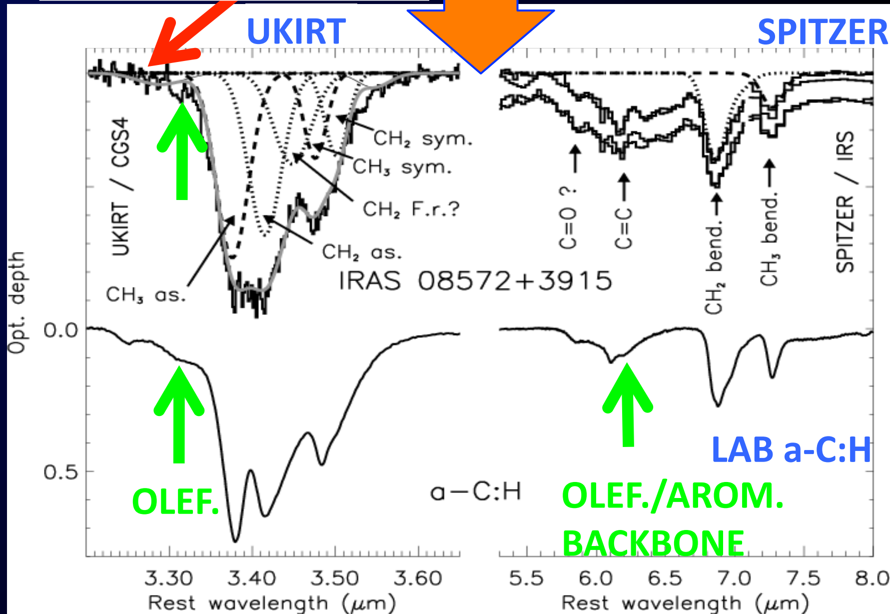


Mason et al. ApJ 2004



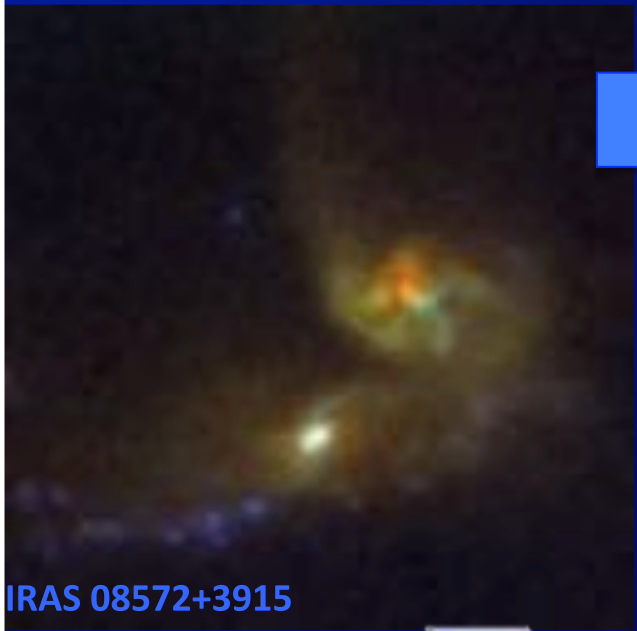
Pendleton et al. ApJ 1994

Arom. CH UPPER LIMIT



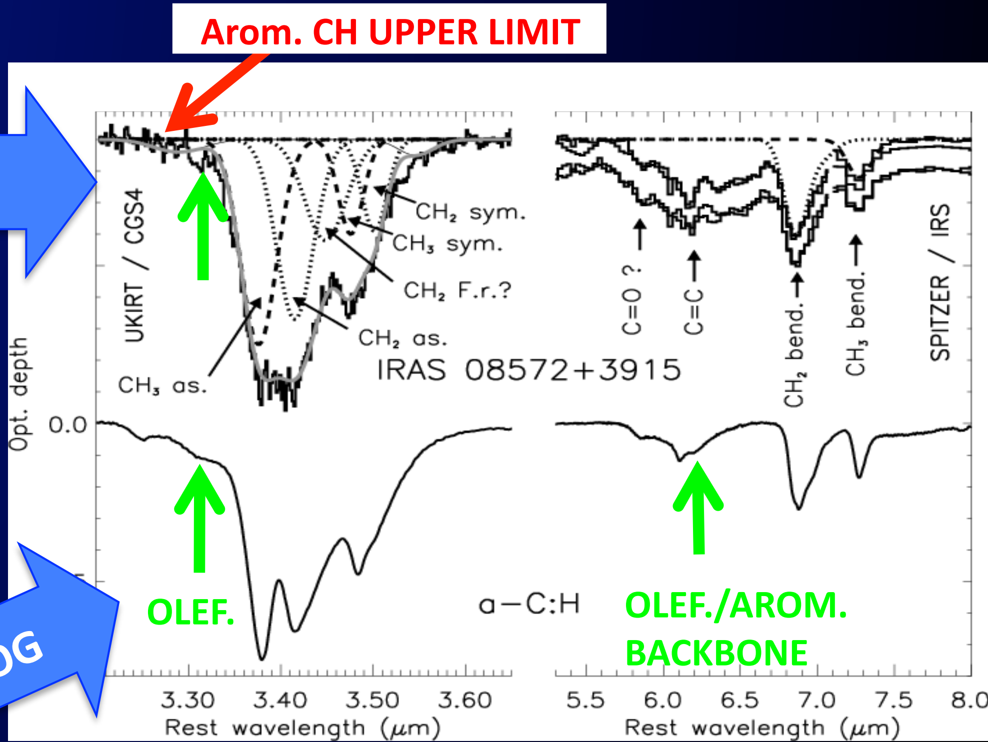
Godard et al. 2011; Dartois, Geballe, Pino et al. 2007

ISM (ext. galaxies)

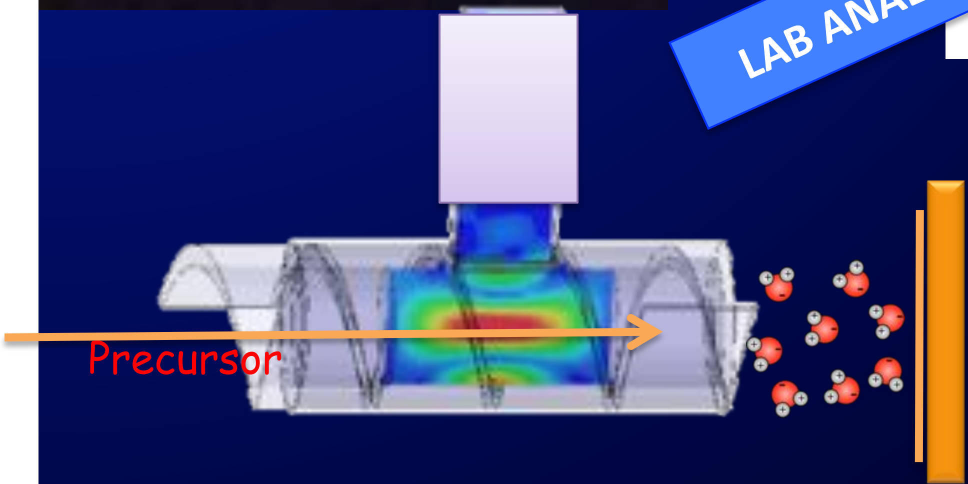


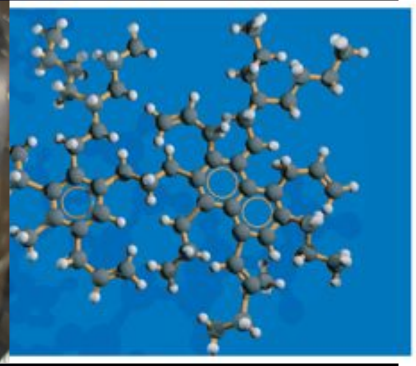
OBSERVED

LAB ANALOG



Dartois+2007



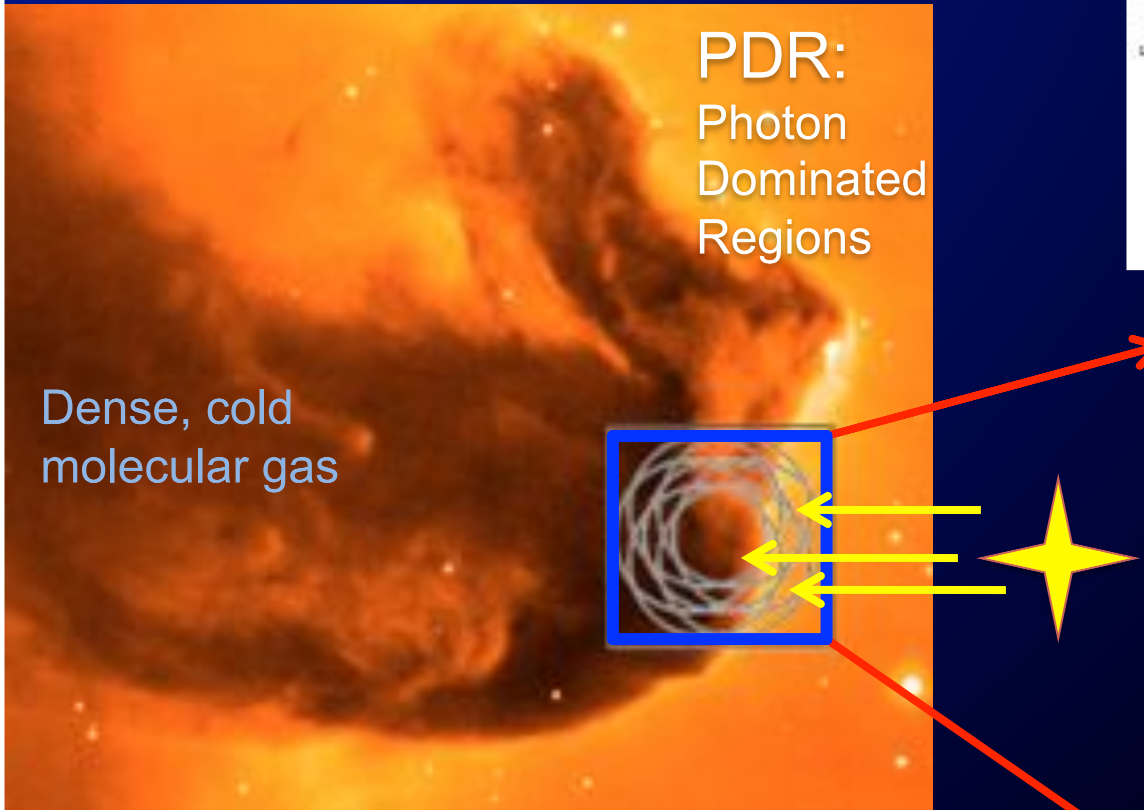


Evolution at the ISM interfaces & radiative env.

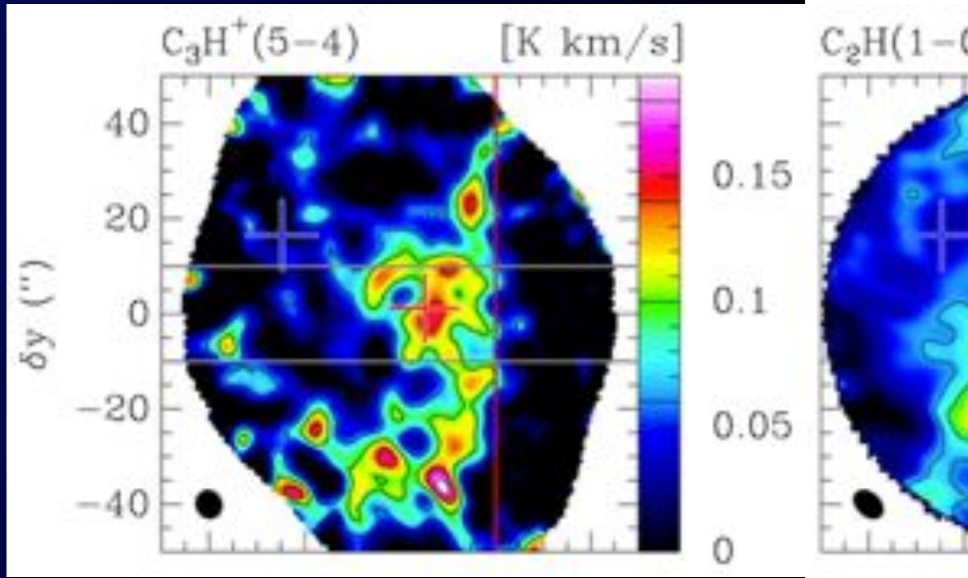
VUV

Hydrocarbons molecules detections

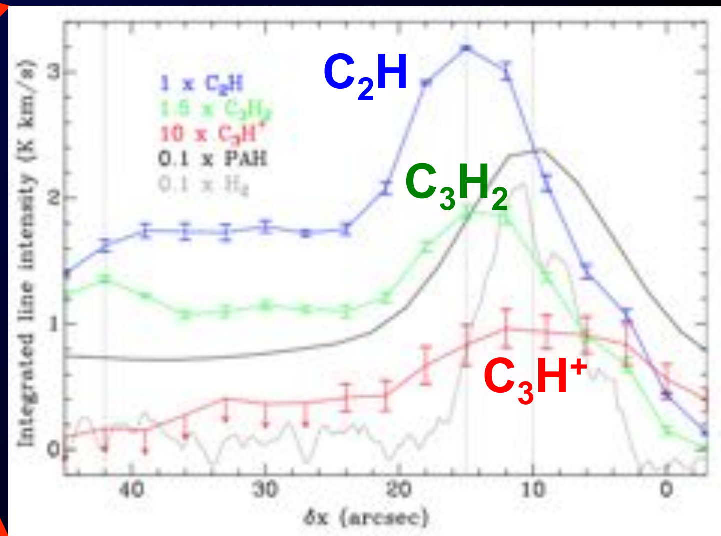
C_2, C_3, C_2H_2, CCH, c-C_3H_2, C_4H ....



Pety et al. 2005



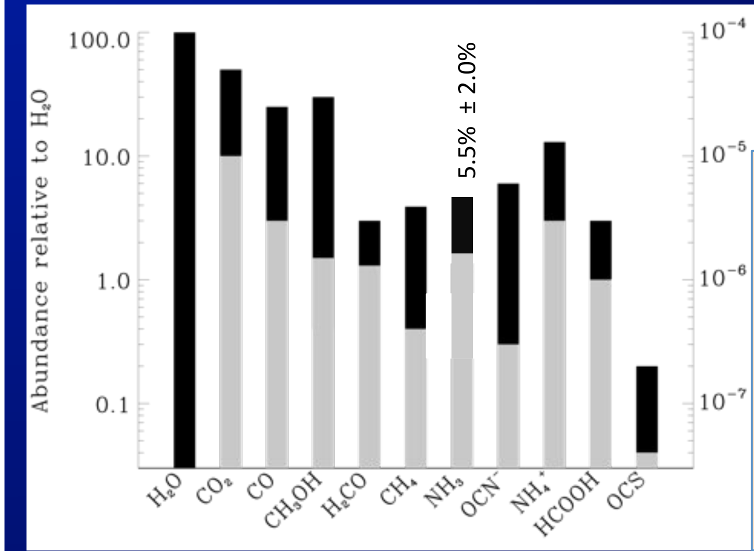
Top-down chemistry ?



Guzman et al. 2015

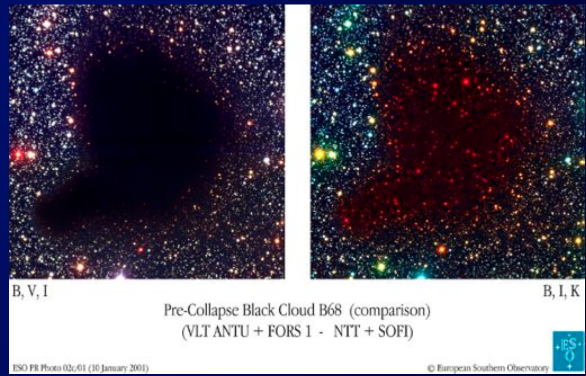
One-dimensional Photo-Dissociation Region,
The Horsehead (PDR)

Processes evolving ice mantles -> organic residues

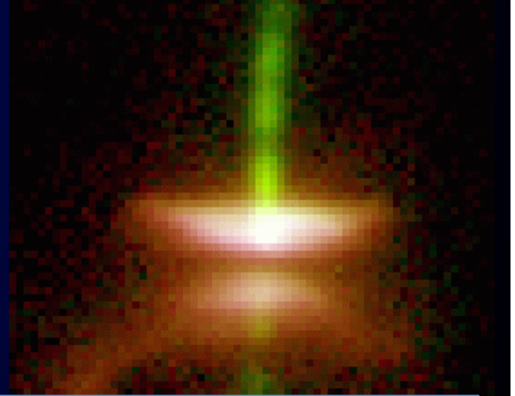


Dartois 2005, SSRv 119, 293

Field stars

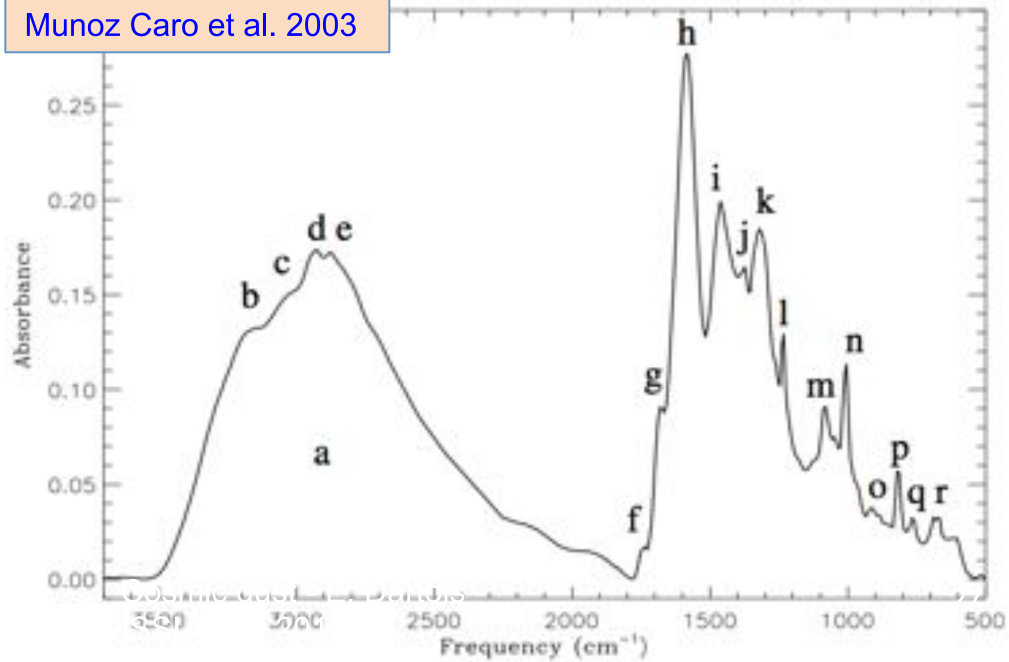


Protostars/Disks

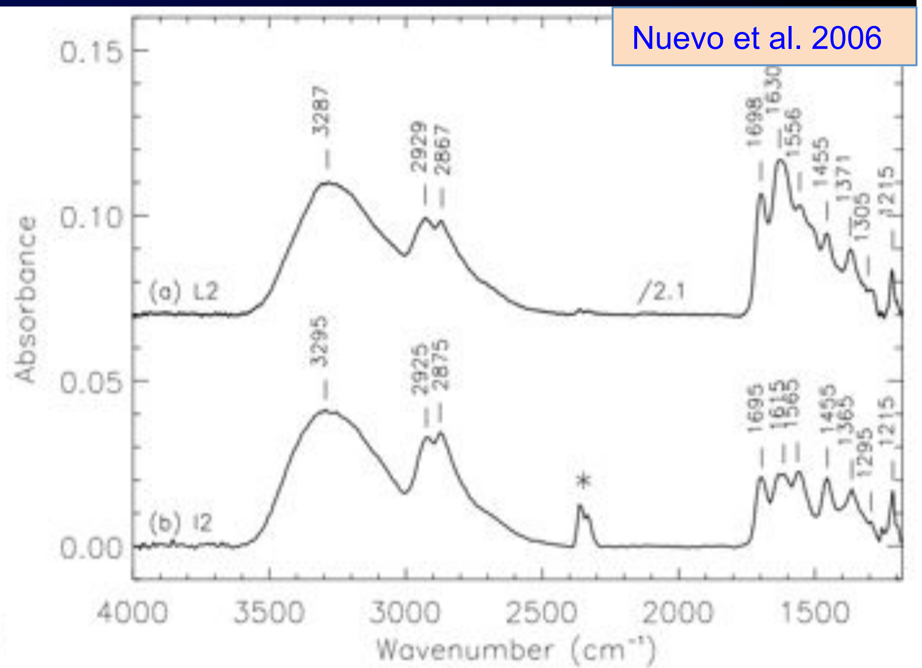


e.g. Bottinelli et al. 2010, Boogert et al. 2008; Pontoppidan et al. 2008; Oberg et al. 2008; Bergin et al 2005; Dartois et al. 2005; Van Dishoeck 2004; Boogert & Ehrenfreund 2004; Gibb et al. 2000.

Munoz Caro et al. 2003

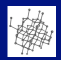


Nuevo et al. 2006



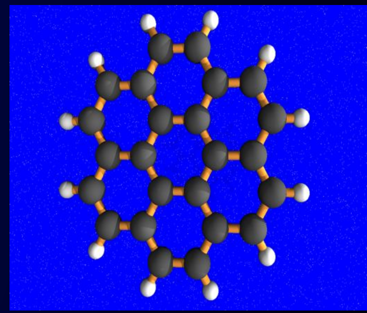
Carbonaceous solids abundances ?

(Nano-)
Diamond



Fullerenes

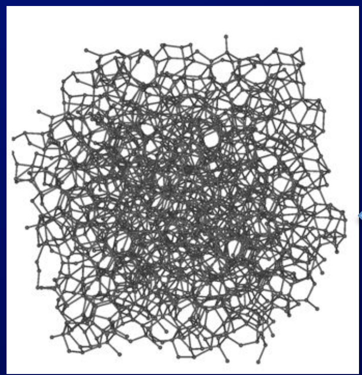
AIBs-PAHs :
Class A to C



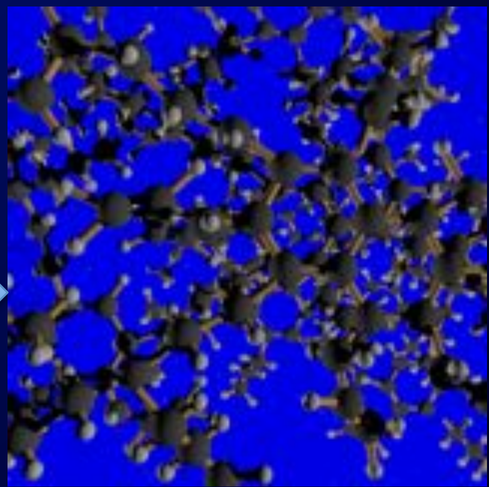
A

C

Amorphous
carbon



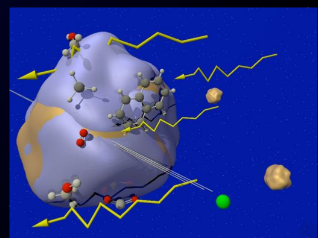
?



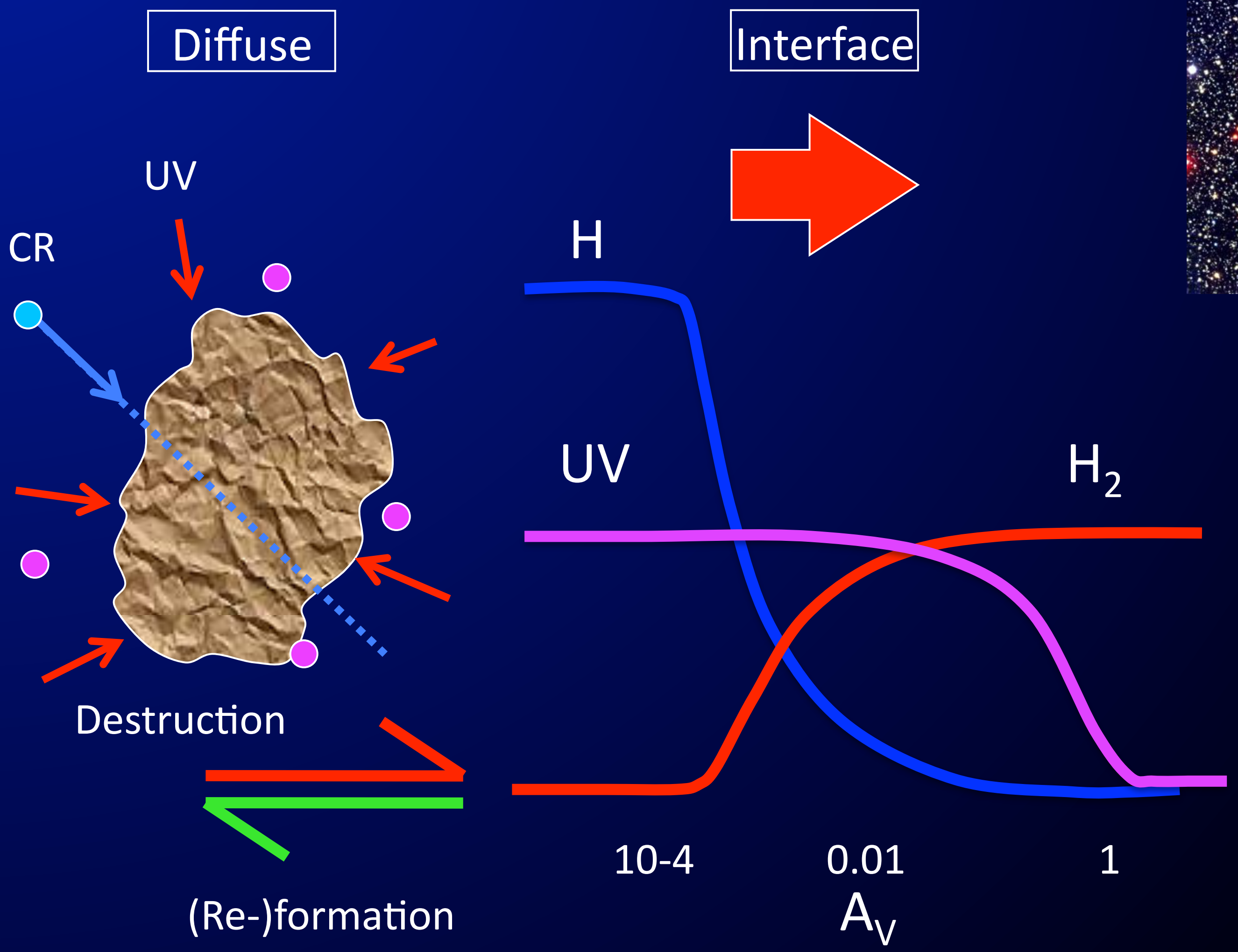
Hydrogenated
amorphous carbon

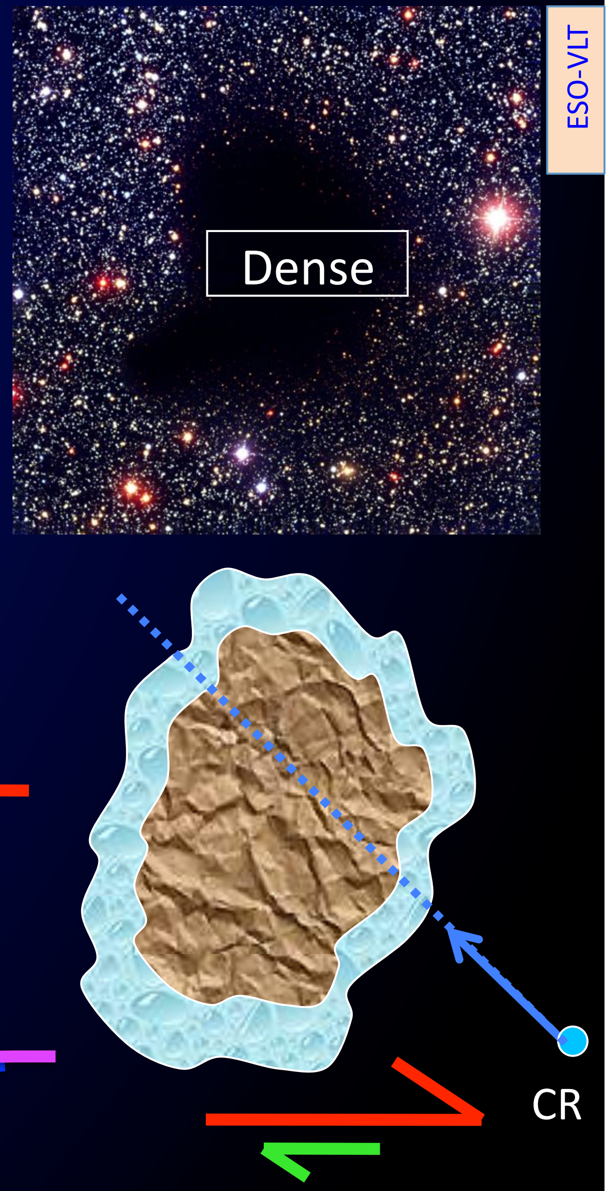
+ organic matter

Ice mantles
residues



Diffuse to dense ISM transition





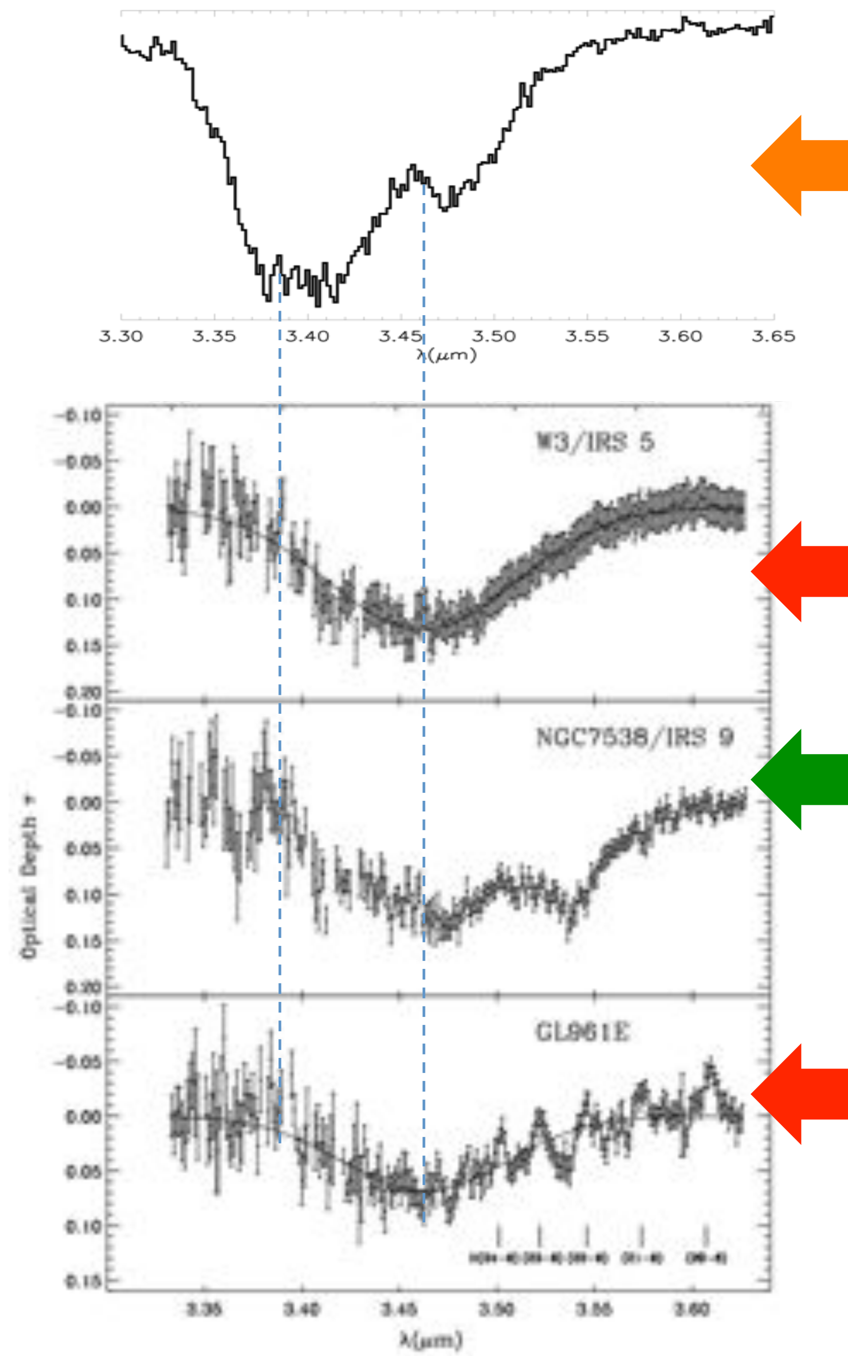
Transition from
ISM obs/labo a-C:H to solar system matter ?

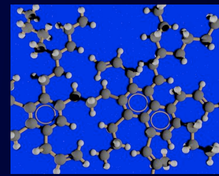
Diffuse to dense ISM transition

Carbonaceous dust signatures disappear to the benefit of ice mantles ones

Destruction or transformation ?

Complex chemistry by interaction with hv & CR

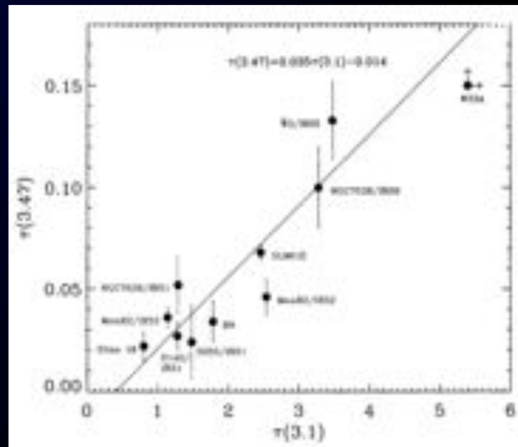




$NH_3 \ldots H_2O$ ammonia hydrate

e.g.Bottinelli+2010, Dartois+2001

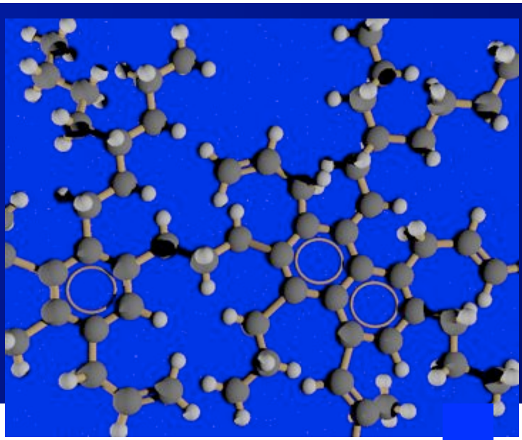
CH_3OH stretching

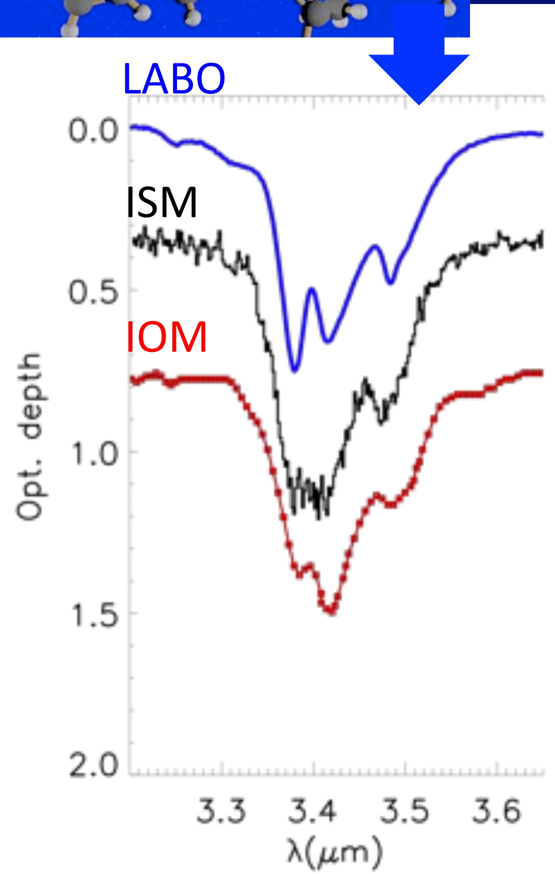


Brooke+1996, Oberg+2011, Boogert+2015

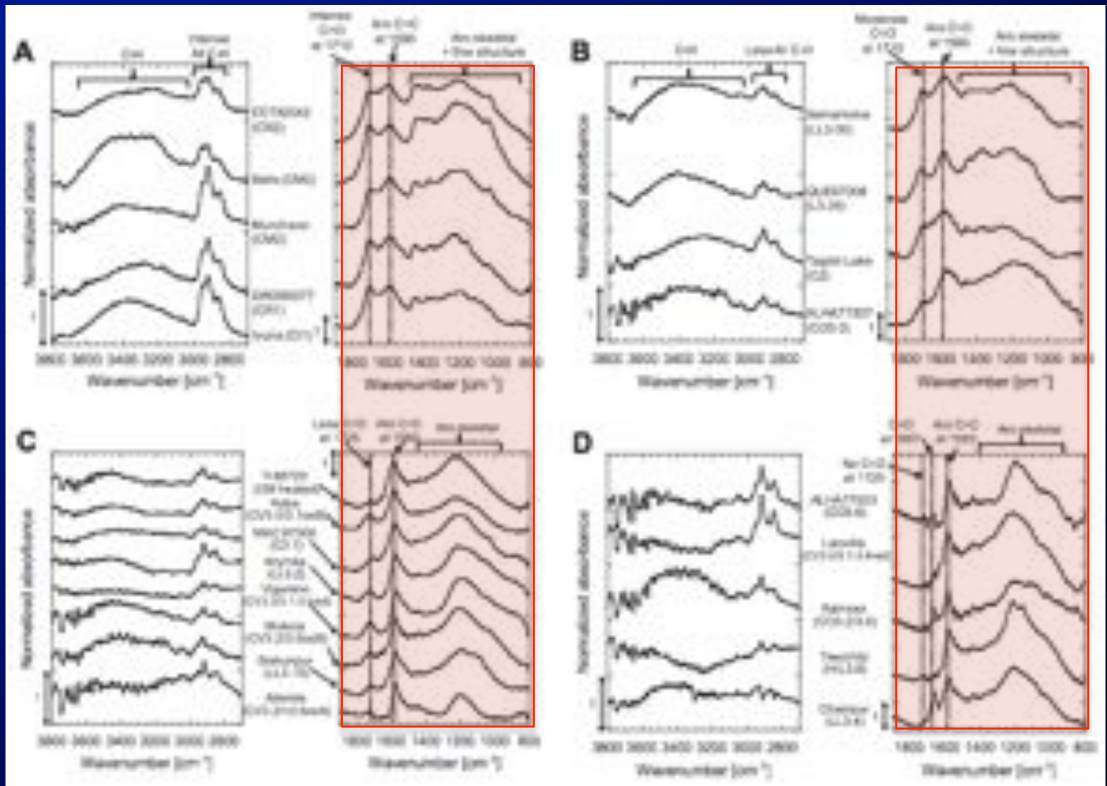
Incorporation of ISM obs/labo a-C:H within solar system matter ?

Comparison between IOM & ISM a-C:H

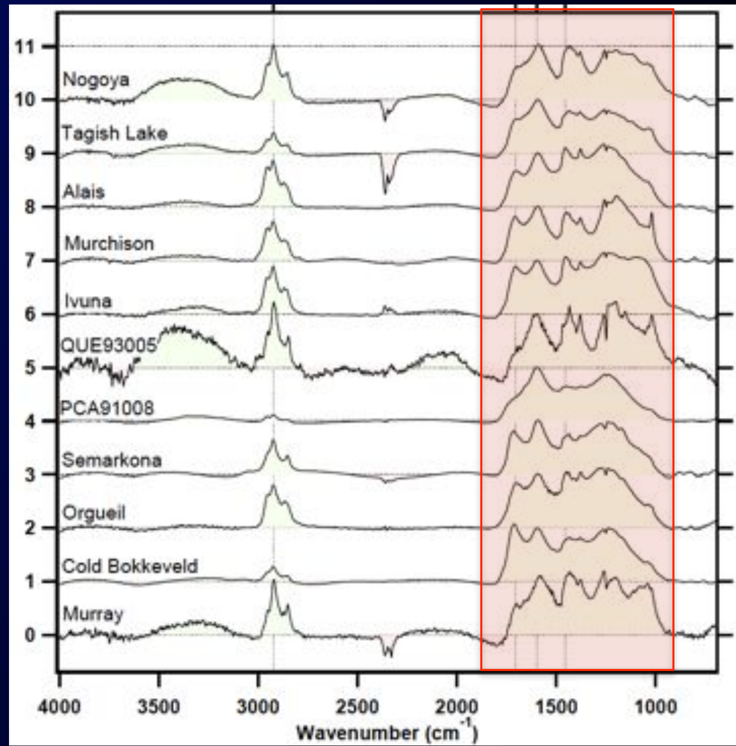




Comparison between ≠ IOMs & ISM a-C:H



Kebukawa et al. 2011

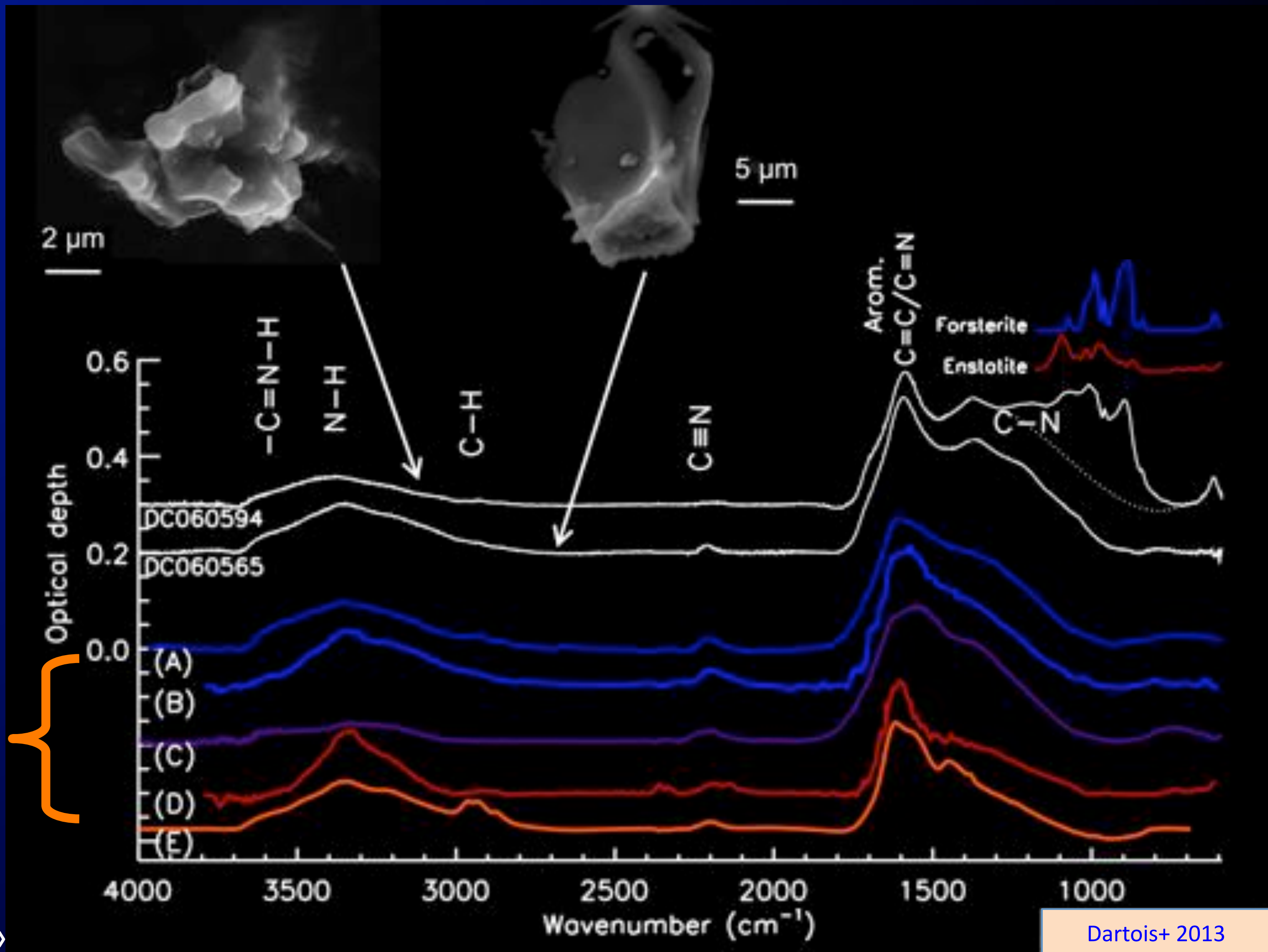


Orthous Daunay 2011

Too many absorptions in the mid-IR

UCAMMs : « natural » N-rich organic micrometeorites

Nakamura+ 2005, Duprat+ 2010



Dartois+ 2013

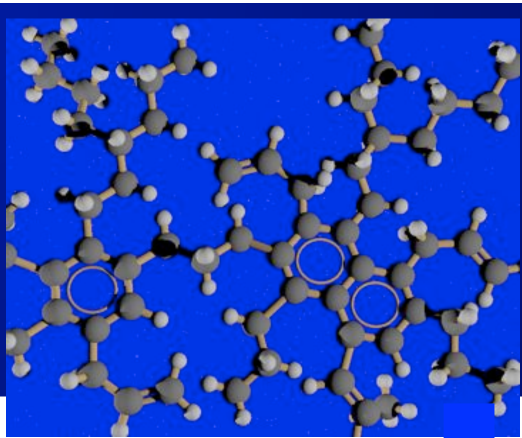
Laboratory Analogs

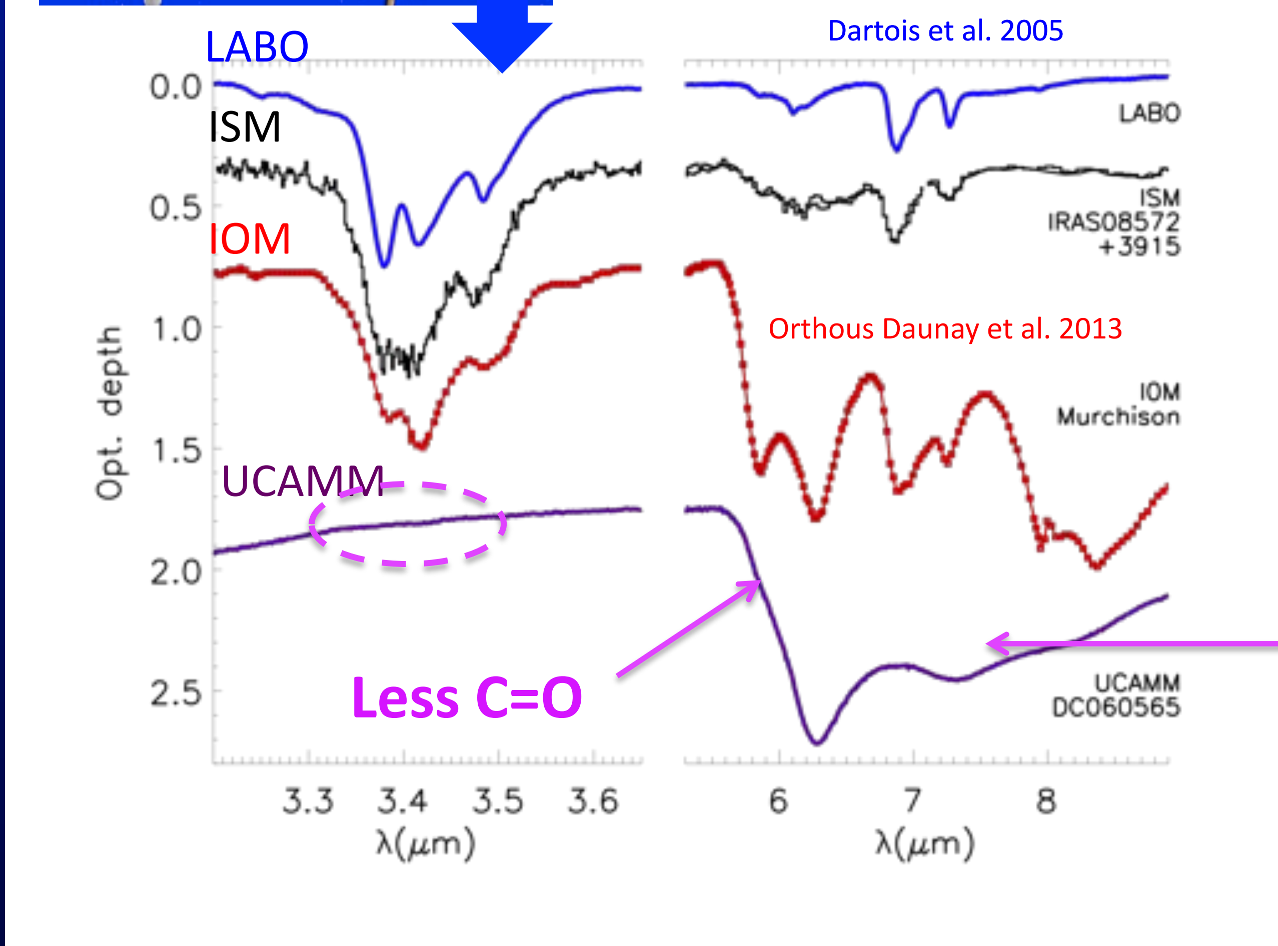
« polyaromatic hydrogenated carbon nitride »

Ong+ 1996, Hammer+ 2000, Fanchini+ 2002, Rodil+ 2001, Quirico+ 2008

Incorporation of ISM obs/labo a-C:H within solar system matter ?

Comparison between IOM, UCAMMs & ISM a-C:H





Low amount of inorganics (silicates)

>C-N<

& >C=N, -C≡N

UCAMMs formation scenarios:

1 – Heritage from the protoplanetary disk ?

small icy particles
CR, solar particles and UV

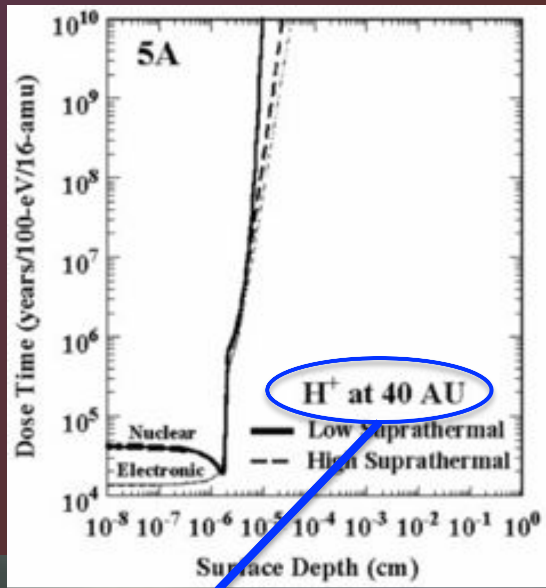
higher O in the organic matter, more IOM-like

larger proportion of minerals to organic matter compared to what is observed in UCAMMs.

2 – Fragment from a Kuiper Belt Object?

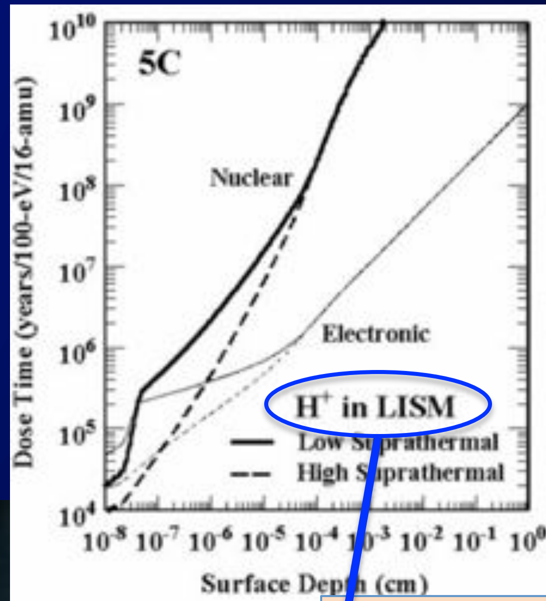
Objects N-rich compositions are @ large heliocentric distances (Pluto)

low amount produced

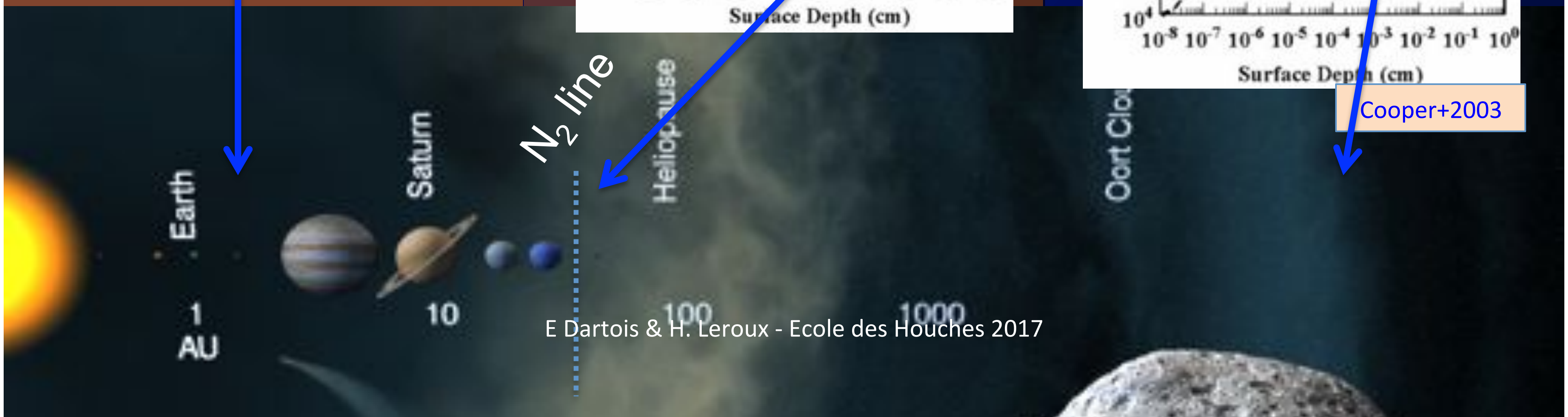


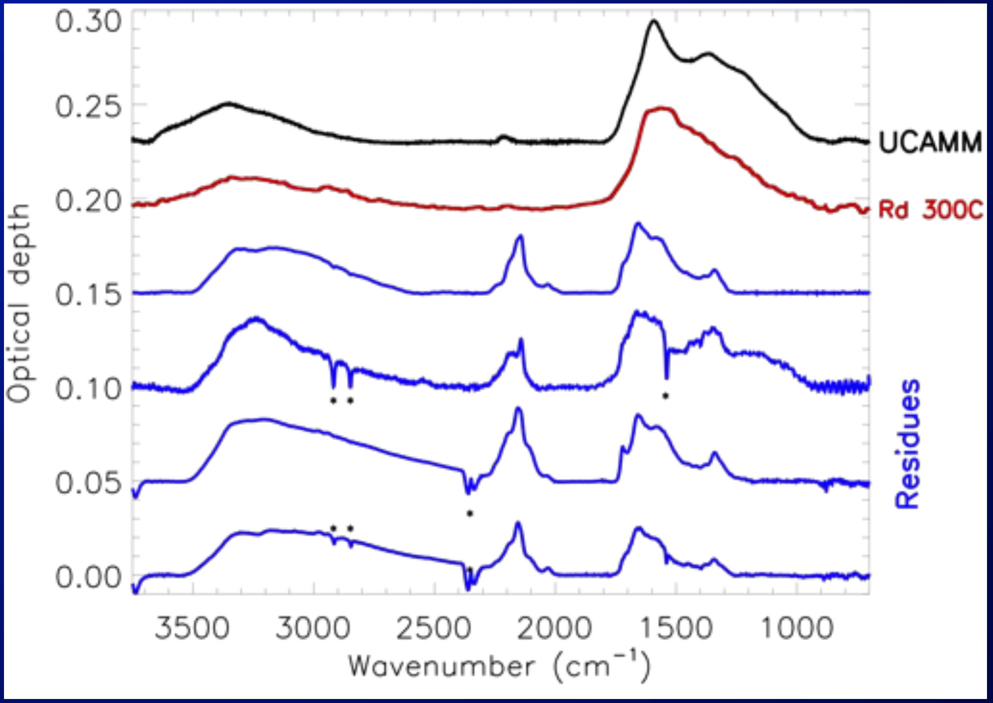
3 – Residue of irradiated ices on a comet-parent body in the Oort Cloud ?

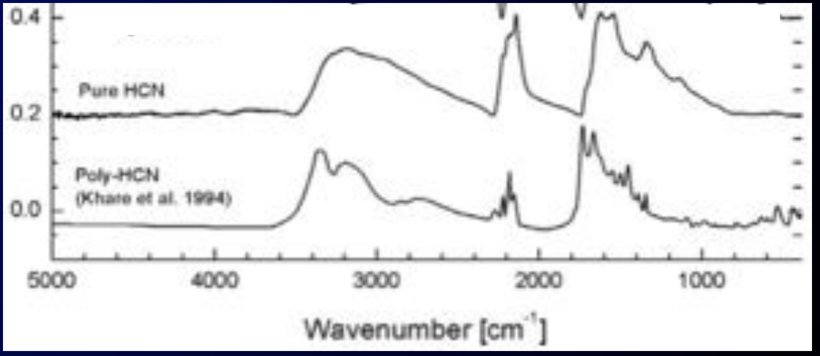
Dust from OCCs expected important contribution to population of meteoroids.



Cooper+2003







Gerakines+ 2004

Augé+ 2016

Moore+ 2003; Hudson+ 2001; Barrata+ 2015

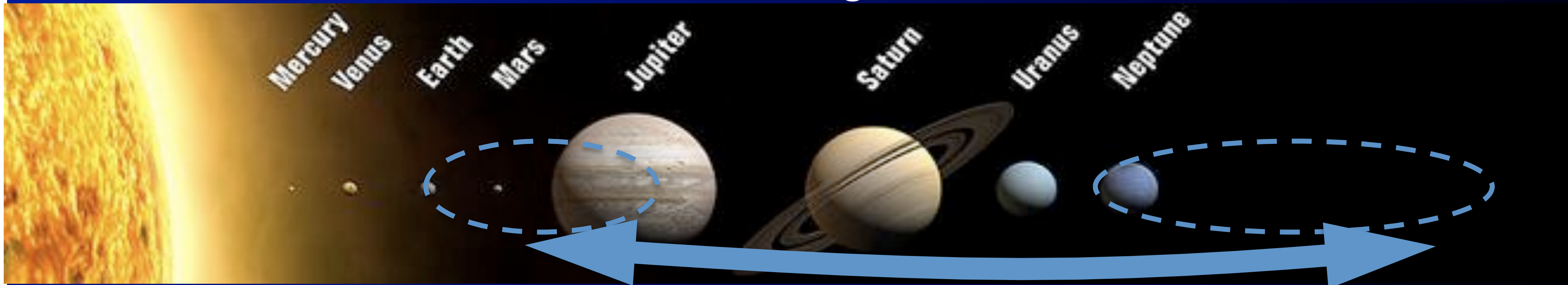
Formation of such residue precursor requires about 50 million years
(10eV.molecule^{-1})

Points toward a radial organic to silicates abundance ratio ?

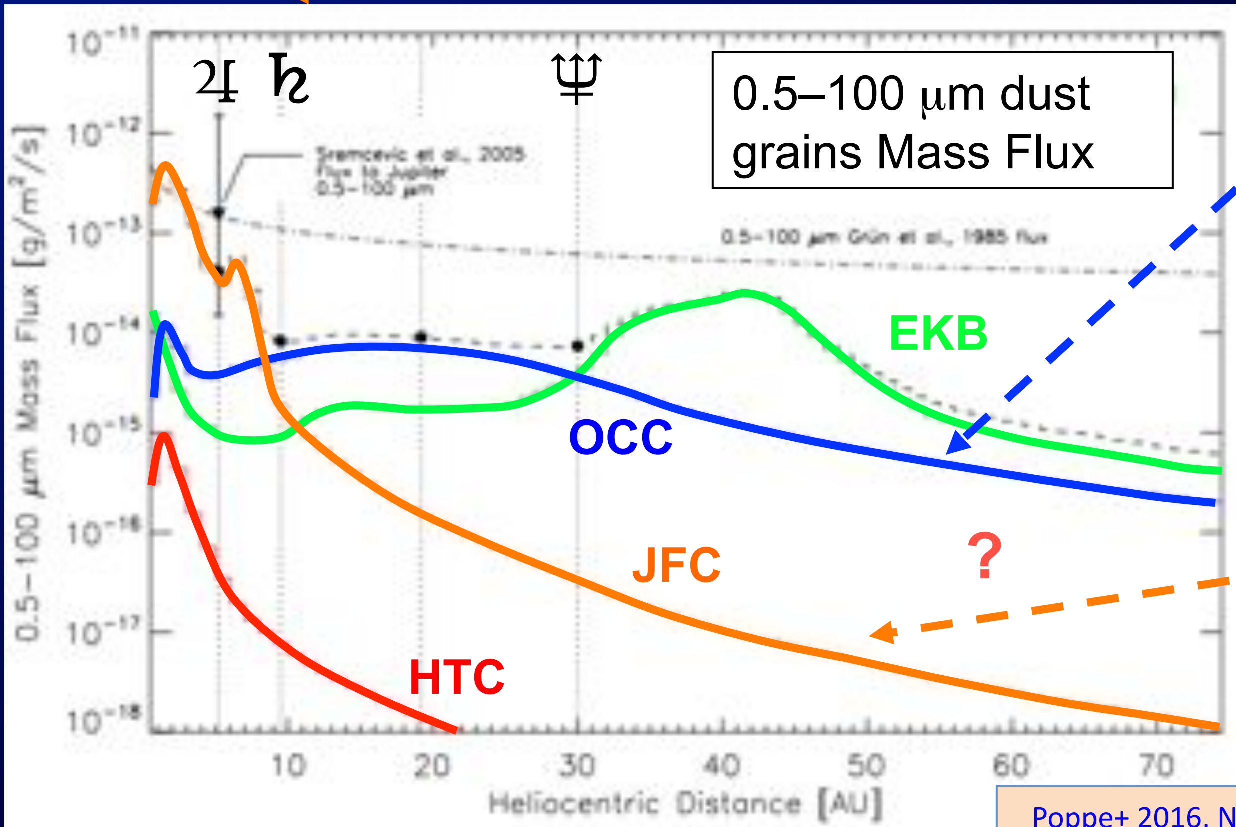
In addition to a lower IR contrast than silicates
contribute to why these carbonaceous dust remains elusive in ppdisks observations

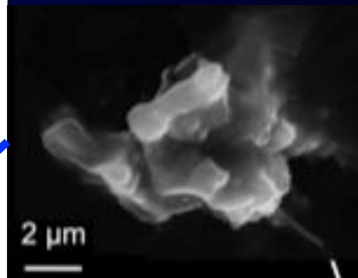
Sampling question:

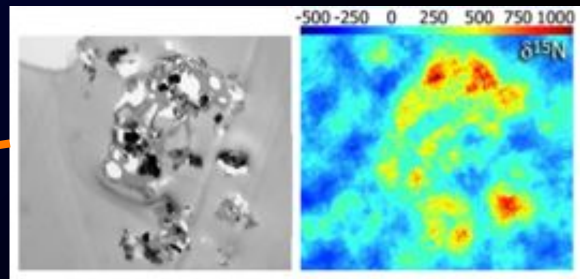
IDPs & micrometeorites from larger distances than AB ?



CAI IOM IDPs UCAMMs Presolar refractory grains







Poppe+ 2016, Nesvorny+ 2011

Messenger+ 2015

Probing ϕ- χ Mecanisms occuring in the solar protoplanetary disk