Inventory of dust features in Galactic Bulge PNe

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- There are 3 different classes of stars: O-rich; C-rich, and S-type.

- Russell (1934) showed that high binding energy of CO molecule (11.09 eV) leads to:

    - M-type spectra when O > C (all newly formed stars)
    - C-type spectra when C > O
    - S-type spectra when C ~ O

- According to the standard model:

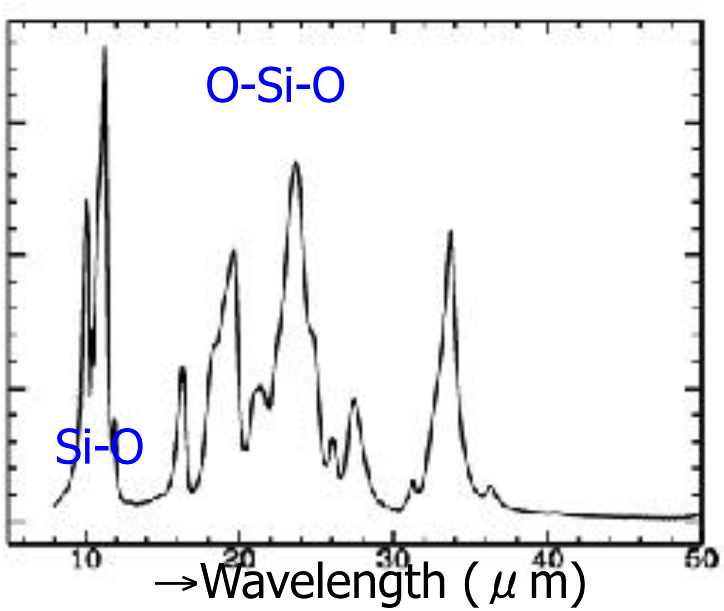
O > C => CO + O-based molecules: SiO, H_2O, …
& O-based dust: amorphous silicates, crystalline silicates, …

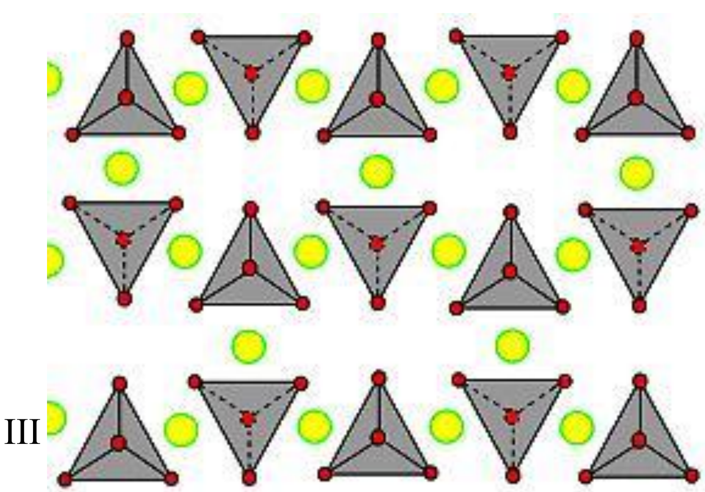
C > O => CO + C-based molecules: HCN, C_2H_2, PAHs, C_{60}, … &
C-based dust: amorphous carbon, HAC, SiC, …

O-rich dust

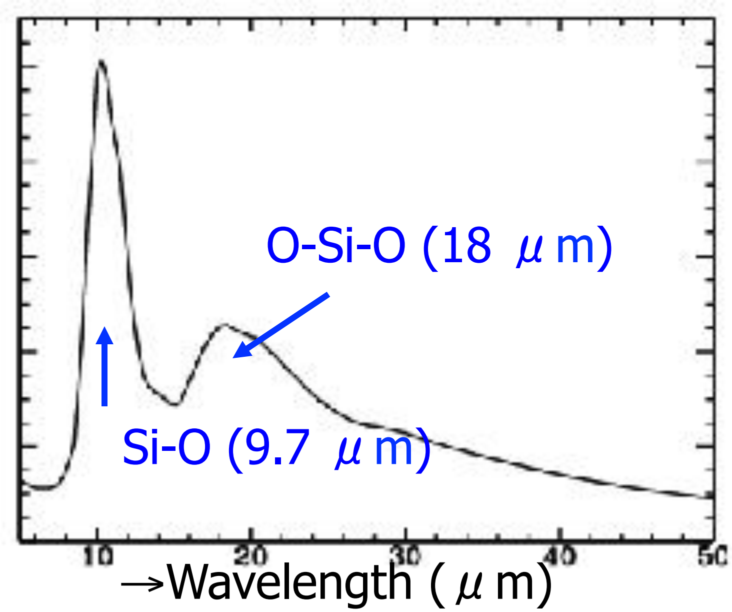
e.g. **Forsterite: Mg_2SiO_4**

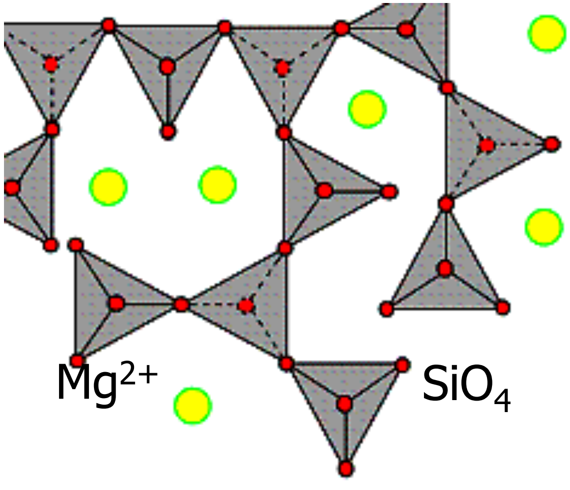
Crystalline





Amorphous





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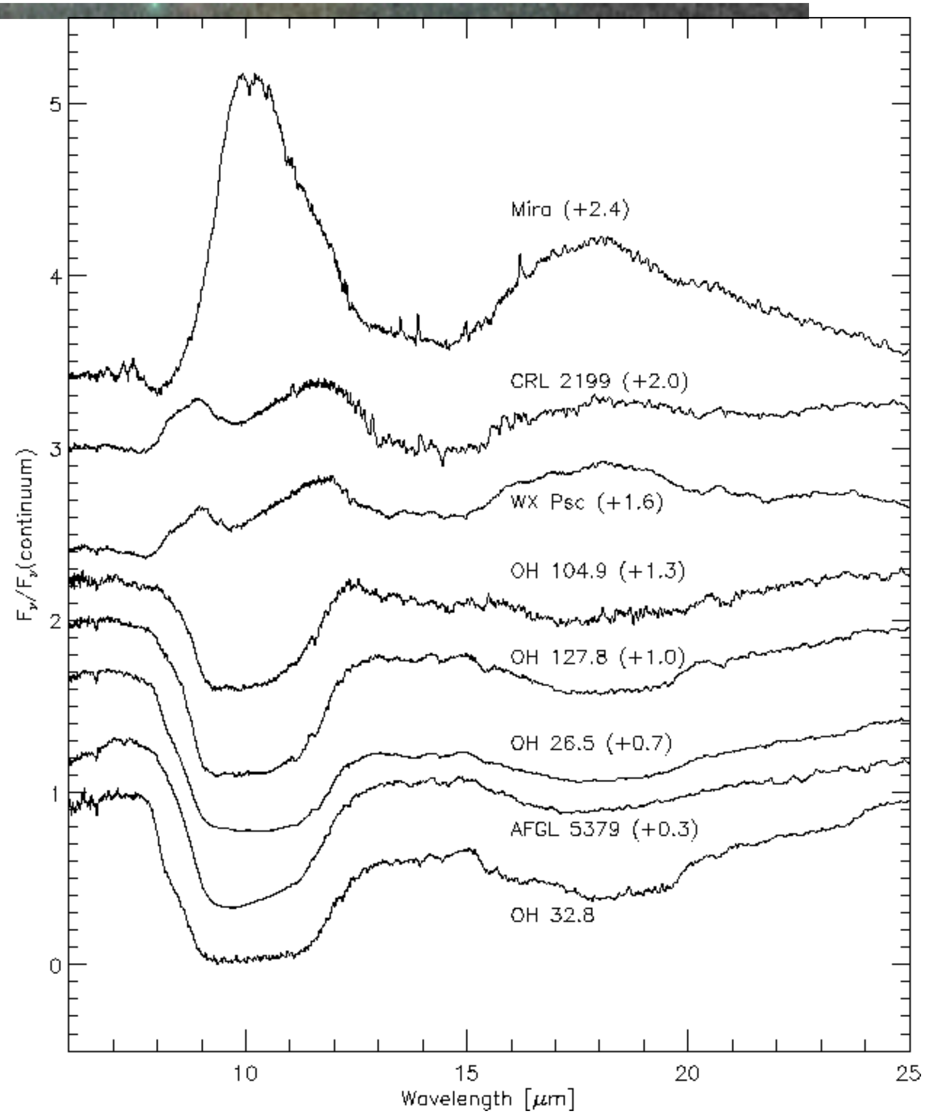
amorphous silicate features

9.7 μm Si-O stretching mode

18 μm O-Si-O bending mode



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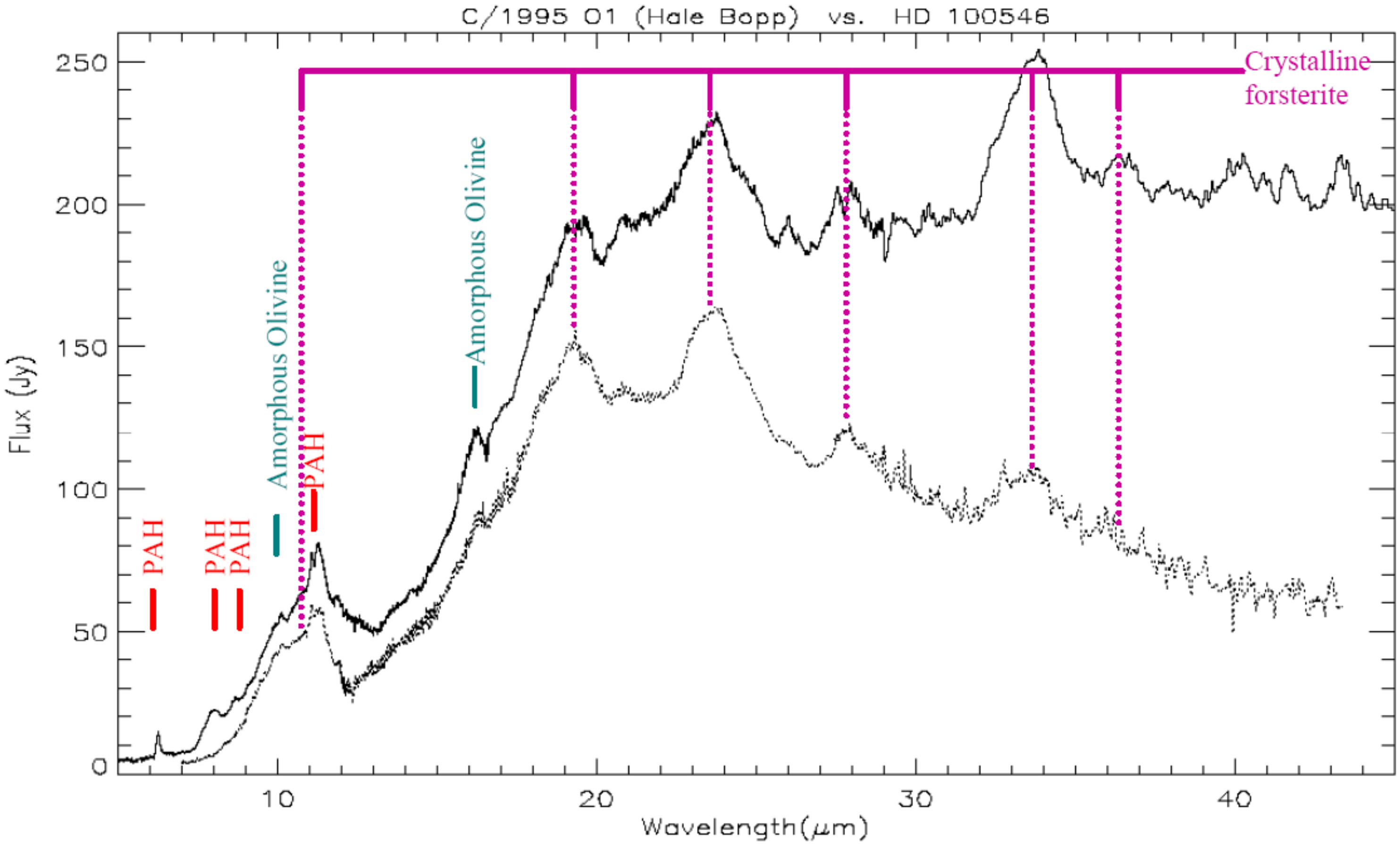
crystalline silicate features

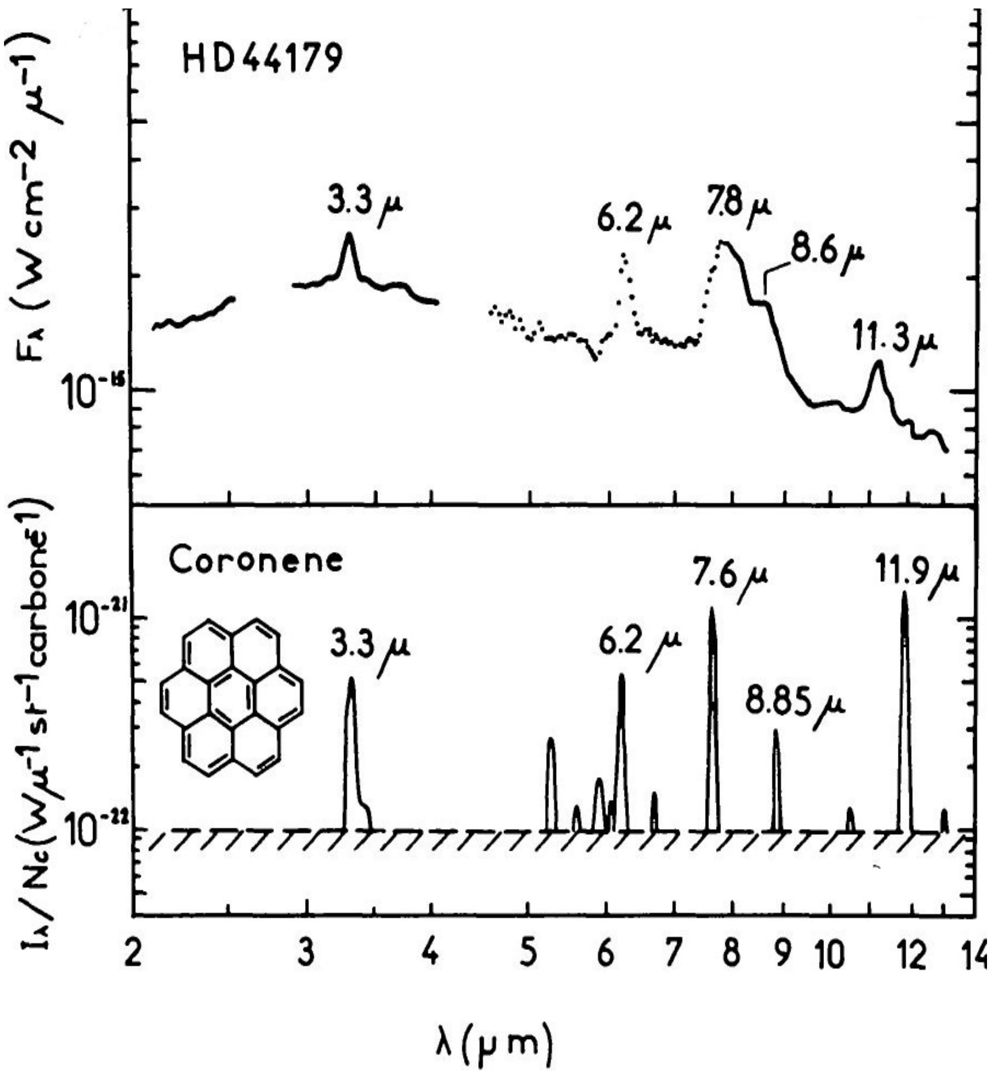


Hale-Bopp & star with proto-planetary disk:

ISO detected for the first time emission from crystalline silicates out of our solar system

C-rich dust

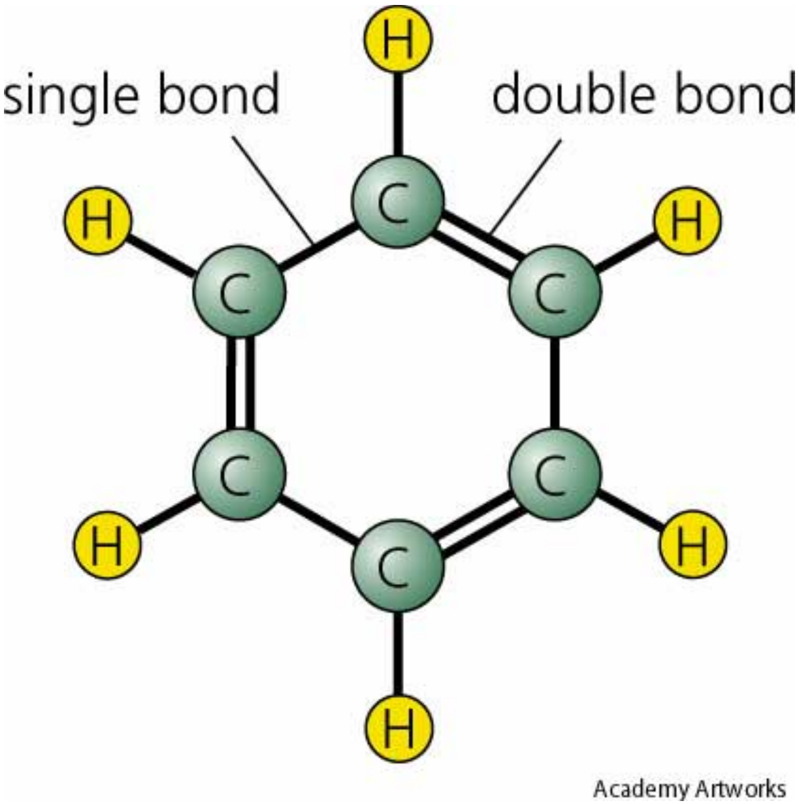
The ubiquitous distinctive set of „UIR" emission bands @ 3.3, 6.2, 7.7, 8.6 and 11.3 μm
(UIR bands were discoverd first by Gillet et al. (1973) in planetary nebulae).



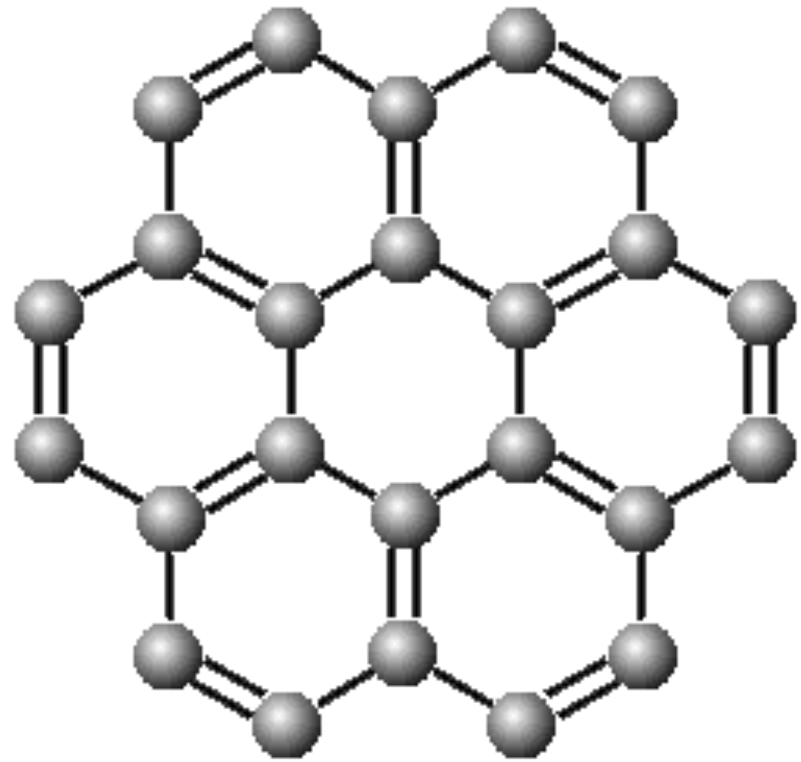
Léger & Puget (1984); Allamandola et al. (1985) – Policyclic Aromatic Hydrocarbons are responsible for „UIB's" =>

Aromatic Infrared Bands;

Polycyclic Aromatic Hydrocarbons (PAHs)



C_6H_6 - benzene



$C_{24}H_{12}$ - coronene

(H atoms not shown)

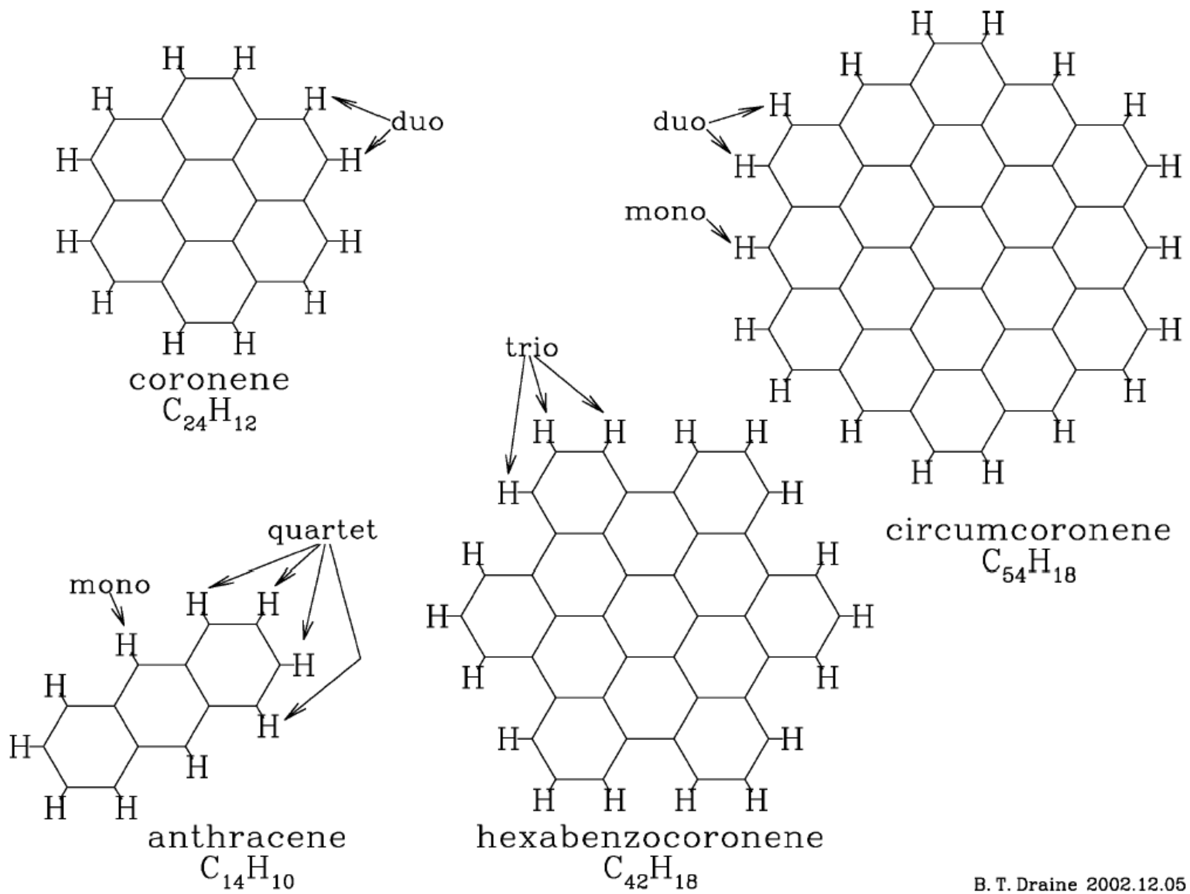
PAHs: aromatic rings + H

Leger & Puget (1984)
Allamandola et al. (1989)

- C-H „stretch" @ 3.3 µm
- C-C „stretch" @ 6.2 µm
- C-C „stretch" @ 7.7 µm
- C-H in-plane „bend" @ 8.6 µm
- C-H out of plane „bend"
@ 11.3 µm for mono H
@ 12.0 µm for duo H
@ 12.7 µm for trio H
@ 13.6 µm for quartet H

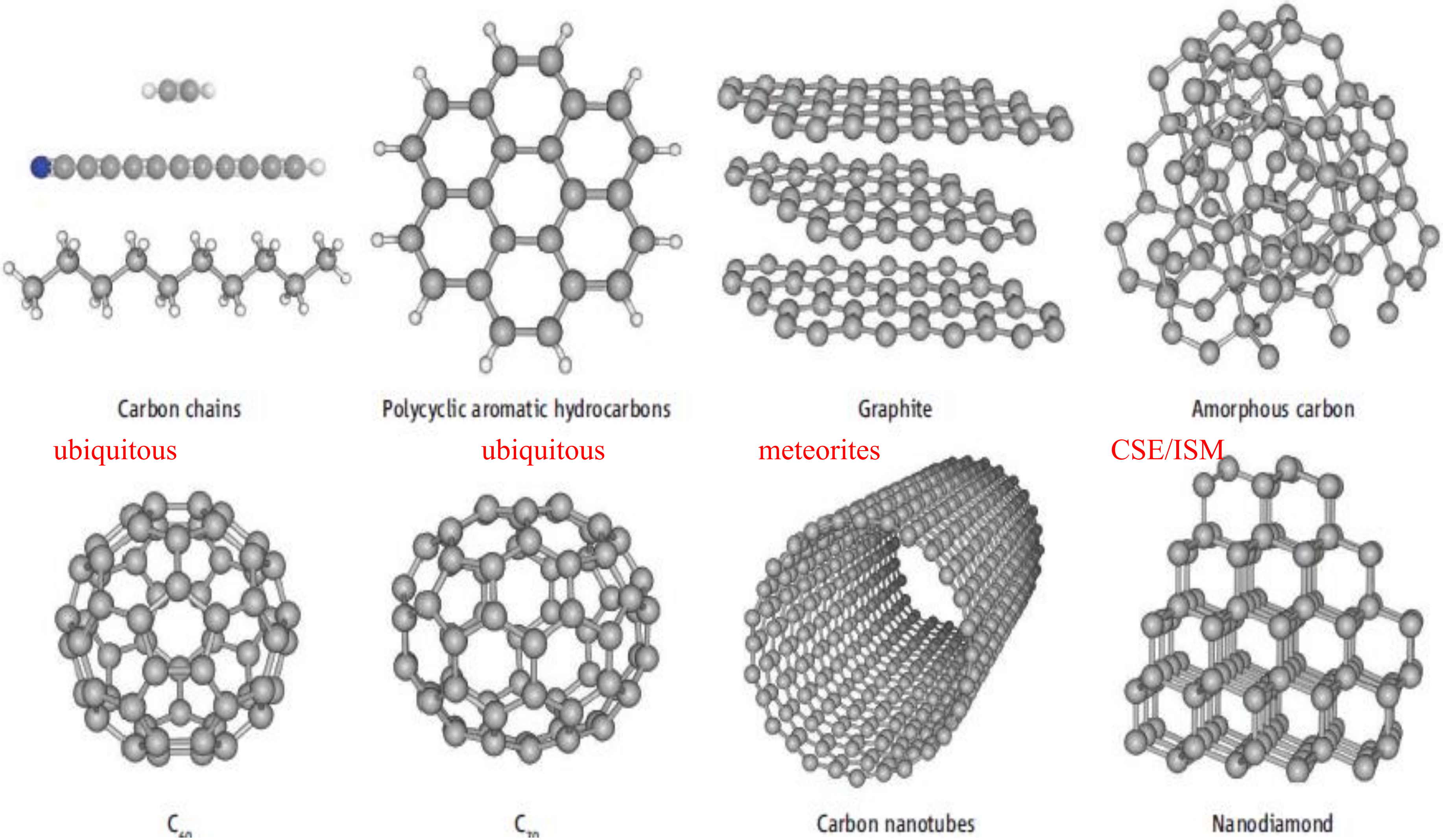
- aliphatic (chain-like) C-H „strech" @ 3.4 µm
- 6.9 µm

….



Allotropes of carbon.

HAC !



ubiquitous | ubiquitous | meteorites | CSE/ISM

PNe/ISM | PNe/ISM | laboratory | meteorites

P Ehrenfreund, B H Foing Science 2010;329:1159-1160

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A „standard" model

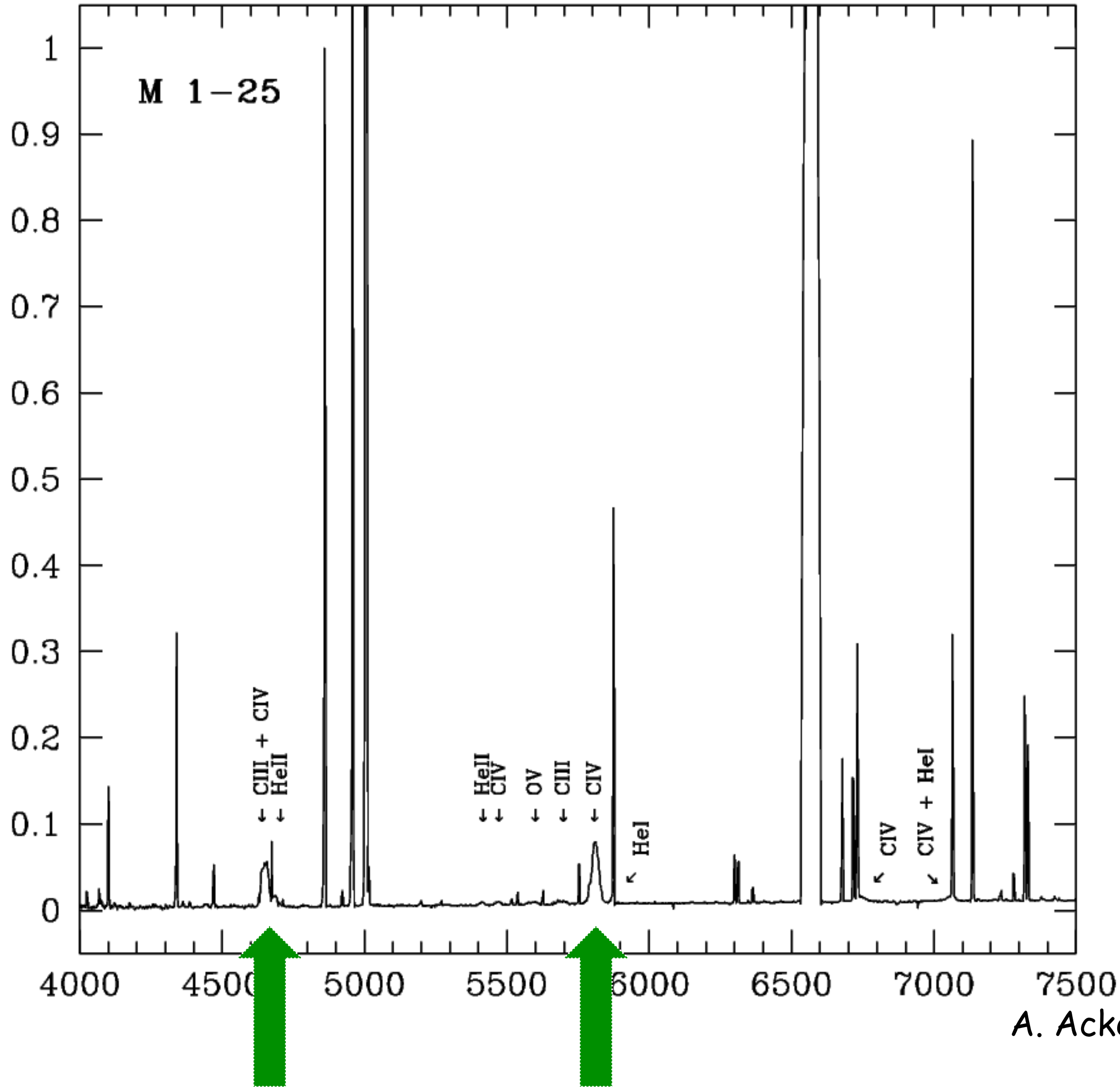
- **Equillibrium chemical models predict that:**
  - **in O-rich stars (O/C>1) => CO, H_2O, ...**
  - **in C-rich stars (C/O>1) => CO, HCN, C_2H_2, ...**

- **Therefore it was (and still is, in some cases) surprising to observe O-based dust (silicates) and O-rich molecules (like SiO, H_2O or OH) from envelopes around C-stars.**

- **One example of „mixed" or „double" chemistry were/are crystalline silicates in [WR] PNe**

Central stars of [WR] PNe

are H-poor & C-rich

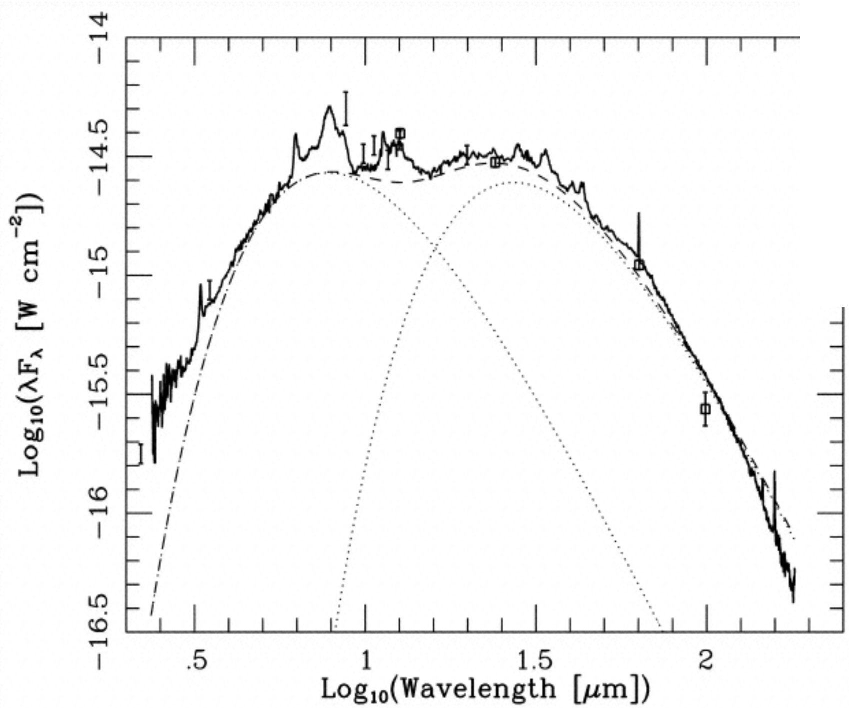


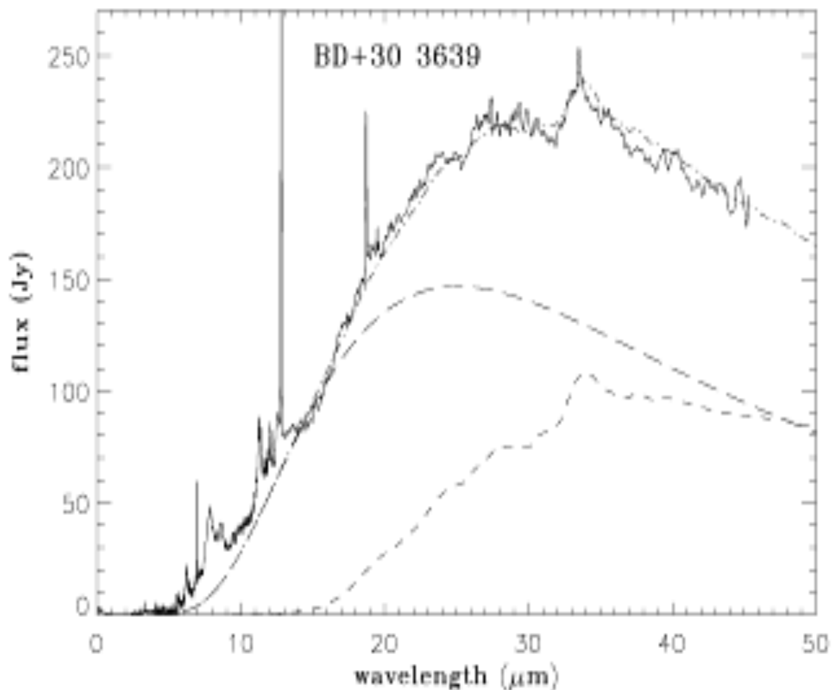
A. Acker

PAHs & Crystalline silicates in [WR] Pne

MIXED CHEMISTRY

Cohen et al. 1999





Waters et al. 1998

Inventory of mixed chemistry in [WR]PNe – after ISO

PN name	spectral type	UIBs	crystalline silicates	other features
He 3–1333	[WC 11]	+	+	
He 2–113	[WC 11]	+	+	
Vo 1	[WC 11]	+	+	
M 4–18	[WC 11]	+	?	
K 2–16	[WC 11]	–	–?	
SwSt 1	[WC 10]	+	–	33 μm?
BD+30°3639	[WC 9]	+	+	
He 2–142	[WC 9]	+	+?	
He 2–459	[WC 9]	+	+?	
NGC 40	[WC 8]	+	–?	
M 2–43	[WC 7]	+	–	33 μm
Cn 1–5	[WC 7]	?	?	
NGC 6369	[WC 4]	+	–?	33 μm?
NGC 5315	[WC 4]	+	+	
PM 1–89	[WC 4]	+	?	
NGC 5189	[WC 2]	?	?	

Mixed chemistry seen only in [WR] Pne

15/80 => ~ 20%

Szczerba+ (2001)

Spitzer Space Telescope observations of Galactic Bulge PNe

Gutenkunst et al. (2008): 5 O-rich dust

6 mixed chemistry (55%)

1 [WC] 1 WELS 2 “none” 2 unknown

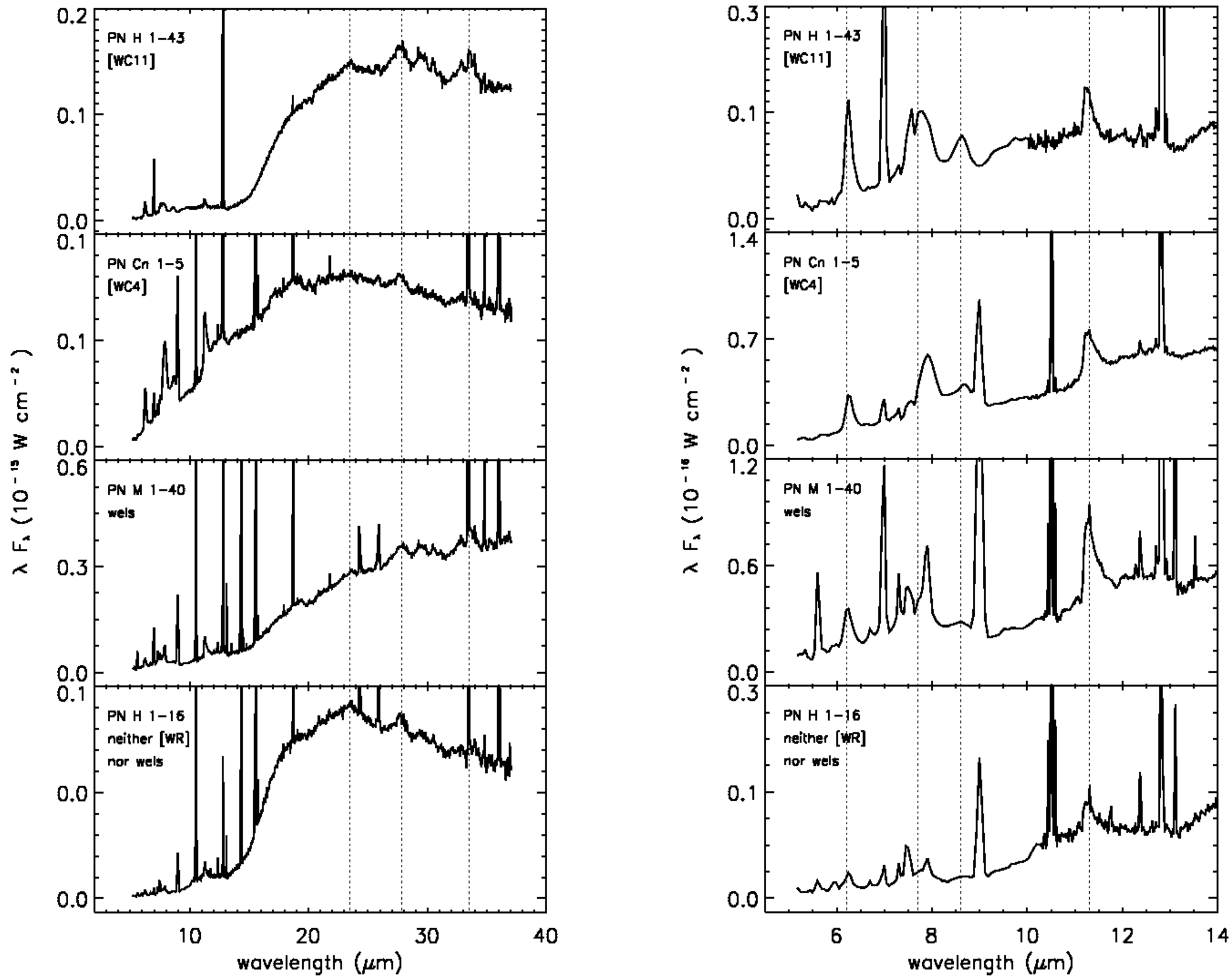
Perea-Calderón et al. (2009): 5 O-rich dust

21 mixed chemistry (81%)

5 [WC] 3 VL 5 WELS 7 “none” 1 unknown

Stanghellini et al. (2012): 26 O-rich or C-rich dust or „F“

25 mixed chemistry (48%)



Perea-Calderón et al. 2009

Galactic Bulge

- Is composed (mostly) of old stellar population (older than 10 Gyr) => low mass stars (~1.5 Mo)

- Metallicity is (rather) larger (or comparable) than (to) the solar

- In such environment (low mass & large metallicity) theory predicts:
no efficient dredge-up (of carbon) to the stellar surface during AGB

Gutenkunst et al. (2008) + Perea-Calderón et al. (2009)

Dust type	GB [# (%)]	non-GB [# (%)]
C-rich	0	2 (14%)
O-rich	3 (9%)	7 (50%)
Double Chemistry	26 (82%)	5 (36%)
Other/featureless	3 (9%)	0

Stanghellini et al. (2012)

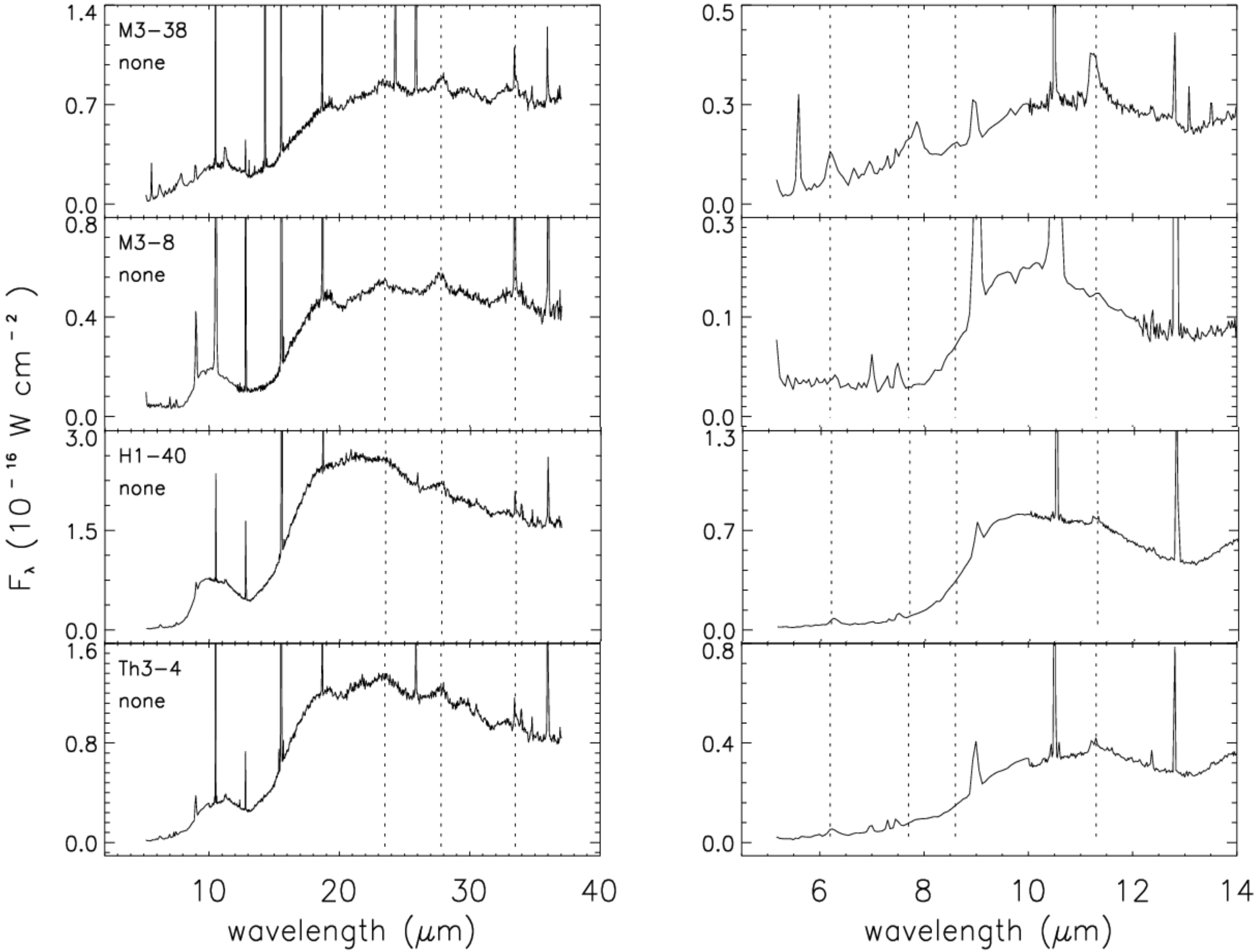
Dust type	GB [# (%)]	Non-GB [# (%)]
C-rich	5 (10%)	32 (32%)
O-rich	14 (27%)	31 (31%)
Double Chemistry	25 (48 %)	17 (18%)
Other/featureless	7 (13%)	18 (19%)

Gutenkunst et al. (2008) + Perea-Calderón et al. (2009)

Tabela 1.1: Statistics of PNe in the sample.

Group	#	GB [# (%)]	non-GB [# %]
C	2	- (0)	2 (14)
DC_{cr}	26	22 (69)	4 (29)
DC_{a+cr}	5	4 (13)	1 (7)
$\mathbf{OC_{cr}}$	2	- (0)	2 (14)
OC_{a+cr}	8	3 (9)	5 (36)
other	3	3 (9)	- (0)
total	46	32 (100)	14 (100)

AMORPHOUS SILICATES & CRYSTALLINE SILICATES & PAH's (mixed chemistry) – DC_{a+cr}



Górny+ (2010)

Gutenkunst et al. (2008) + Perea-Calderón et al. (2009)

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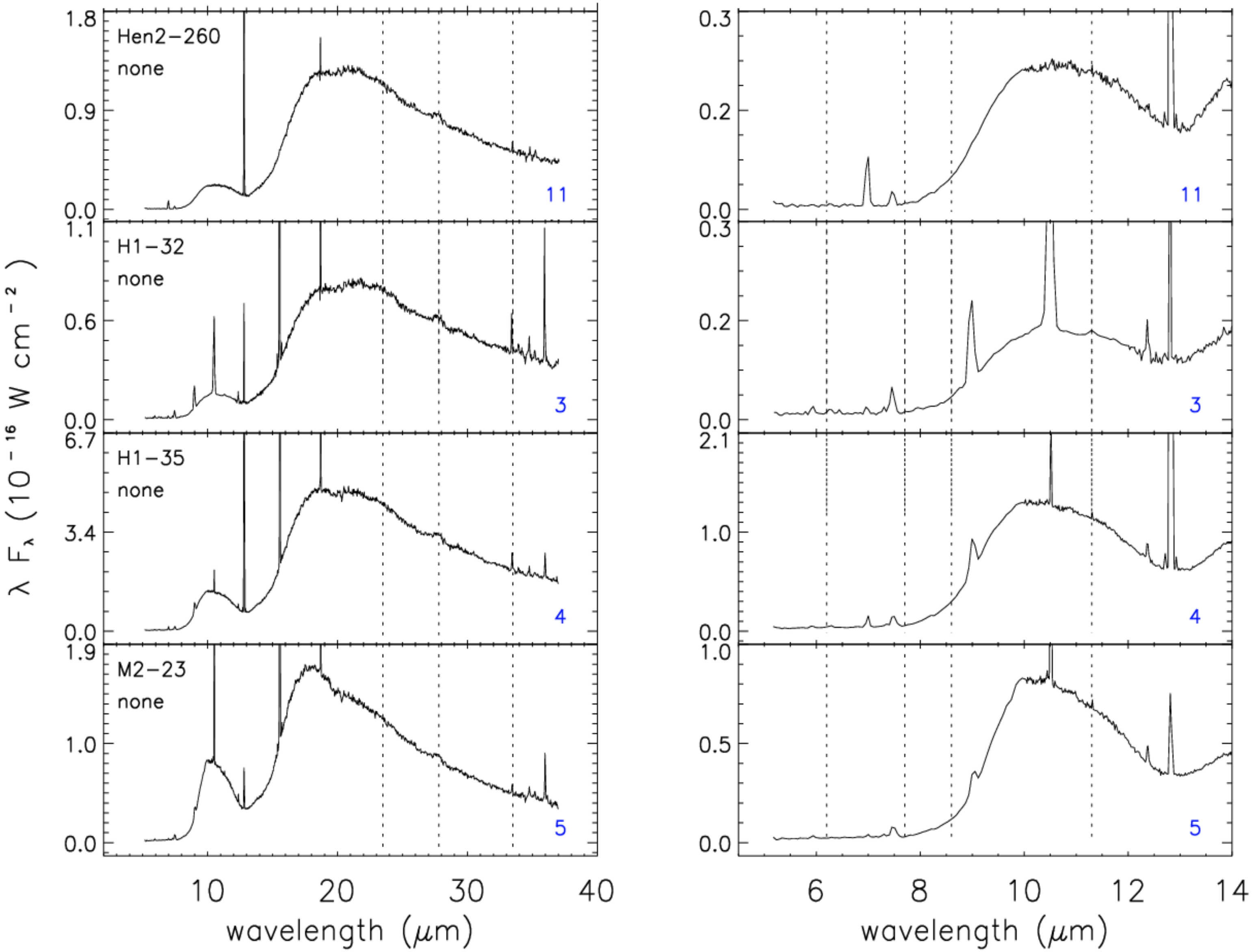
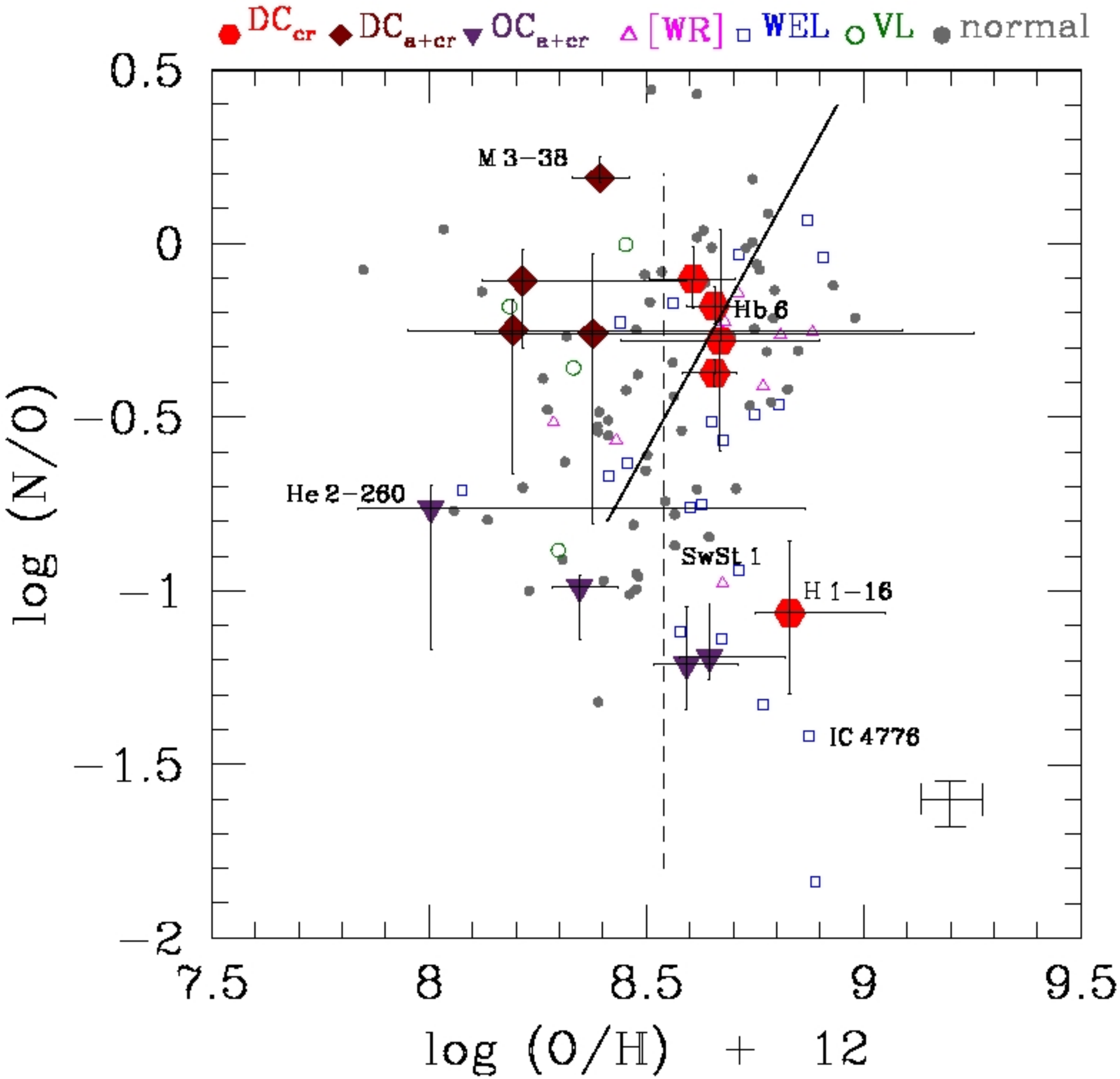
AMORPHOUS SILICATES weak CRYSTALLINE SILICATES, NO PAH's – **OC$_{a+cr}$**





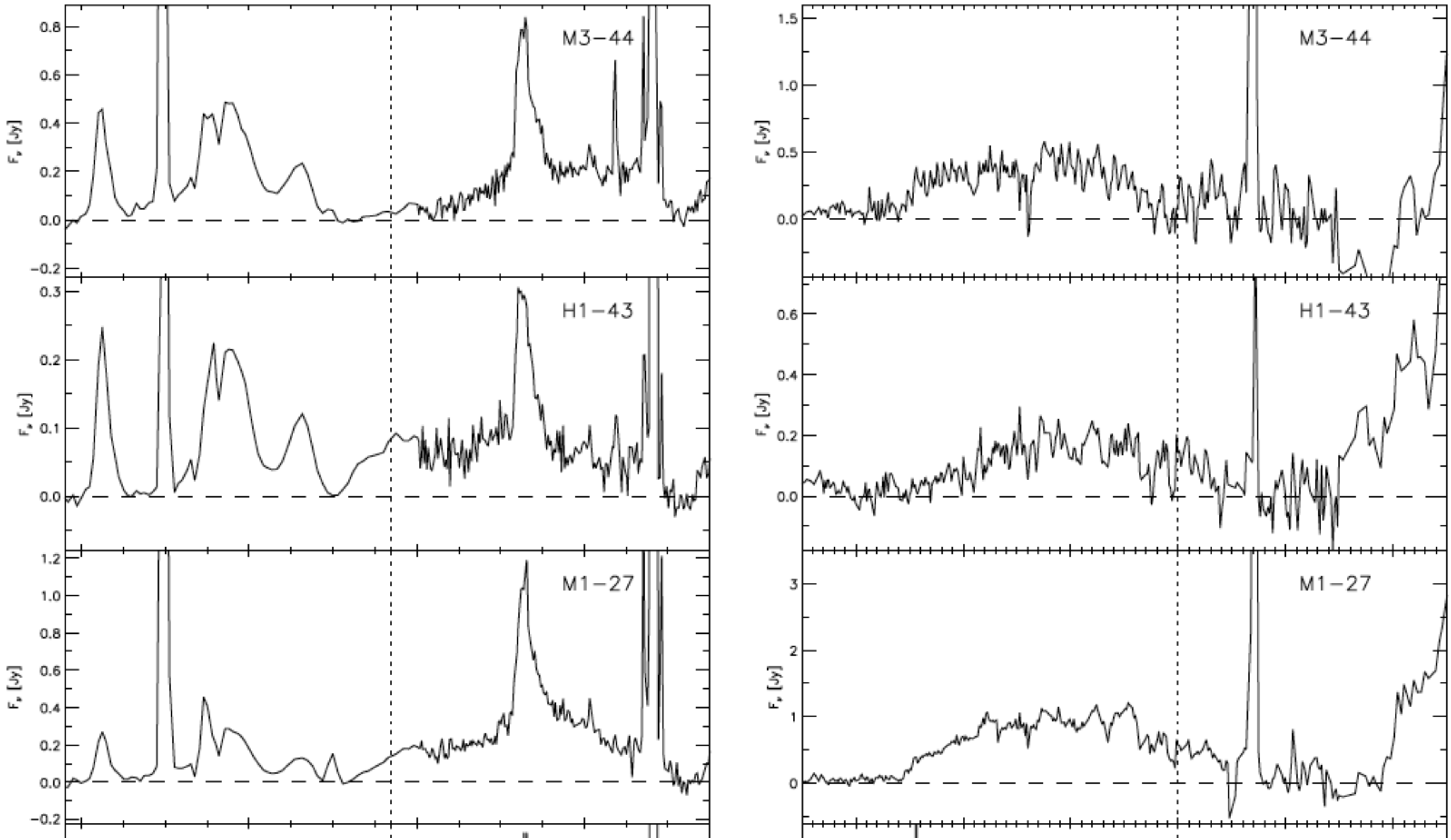
DCcr
DCa+cr
OCa+cr
[WR]
WEL
VL
normal
M 3−38
Hb 6
He 2−260
SwSt 1
H 1−16
IC 4776
log (N/O)
log (O/H) + 12
0.5
0
−0.5
−1
−1.5
−2
7.5
8
8.5
9
9.5

Górny+ (2010)

Name	Pop.	Sp. Type	Ref.	PAH	SiO cr.	SiO am.	Sławek	Marcin
M 3-44	GB	[WC11]	P-C	+	+	-		DC_{cr}
H 1-43	GB	[WC11]	P-C	+	+	-		DC_{cr}
M 1-27	GB	[WC11]	P-C	+	+	-		DC_{cr}
MaC 1-10	GB	[WC8]	P-C	11.3(+)	+	-		DC_{cr}
M 1-25	GB	[WC6]	P-C	+	+	-		DC_{cr}
M 3-15	GB	[WC5]	P-C	+	+	-		DC_{cr}
Hb 4	GB	[WC4]	P-C	+	+	-		DC_{cr}
Cn 1-5	GB	[WC4]	P-C	+	+	-		DC_{cr}
M 2-14	GB	wels	P-C	+	+	-		DC_{cr}
M 1-31	GB	wels	P-C	+	+	-		DC_{cr}
M 2-27	GB	wels	P-C	+	+	-		DC_{cr}
M 1-40	GB	wels	P-C	+	+	-		DC_{cr}
H 1-61	GB	wels	P-C	+	+	-		DC_{cr}
GLMP 698	non-GB	[WC8]	P-C	-	+	-		$\mathbf{OC_{cr}}$
M 1-51	non-GB	[WC4-6]	P-C	+	+	-		DC_{cr}
M 1-32	non-GB	[WC4]	P-C	+	+	-		DC_{cr}
M 1-60	non-GB	[WC4]	P-C	+	+	-		DC_{cr}
M 1-20	non-GB	wels	P-C	+	-	-		**C**
NGC 6644	non-GB	wels	P-C	+	-???	-		**C**
IC 4776	non-GB	wels	P-C	+	+	+		DC_{a+cr}
Th 3-4	GB	none	P-C	+	+	+	DC_{a+cr}	DC_{a+cr}
M 3-38	GB	none	P-C	+	+	+	DC_{a+cr}	DC_{a+cr}
M 3-8	GB	none	P-C	+	+	+	DC_{a+cr}	DC_{a+cr}

PAH's +CRYSTALLINE SILICATES – „classical" **DC_{cr}**

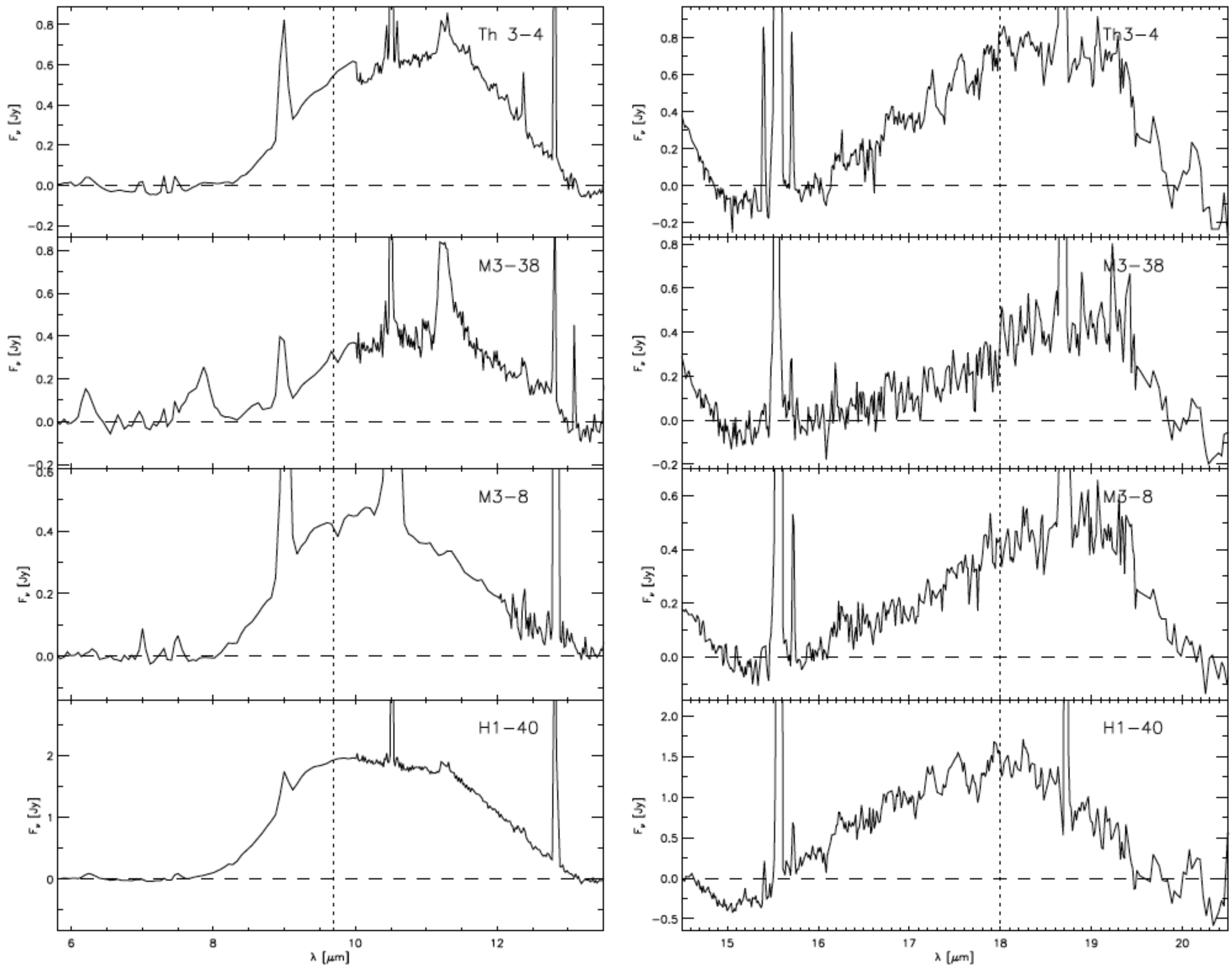
Gładkowski+ (2014)



9.7 um

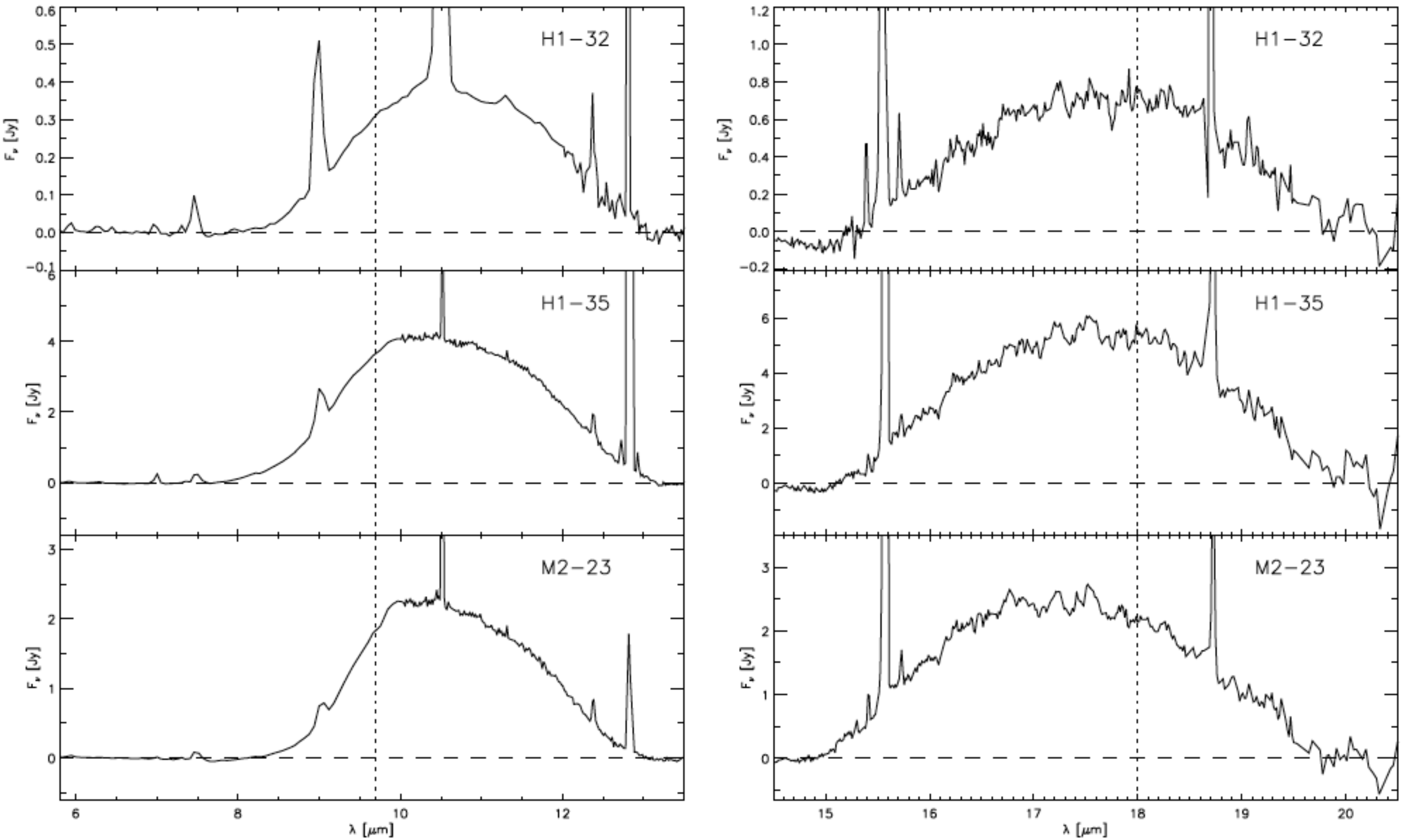
18 um

AMORPHOUS SILICATES & CRYSTALLINE SILICATES & PAH's (mixed chemistry) – DC_{a+cr} Gładkowski+ (2014)

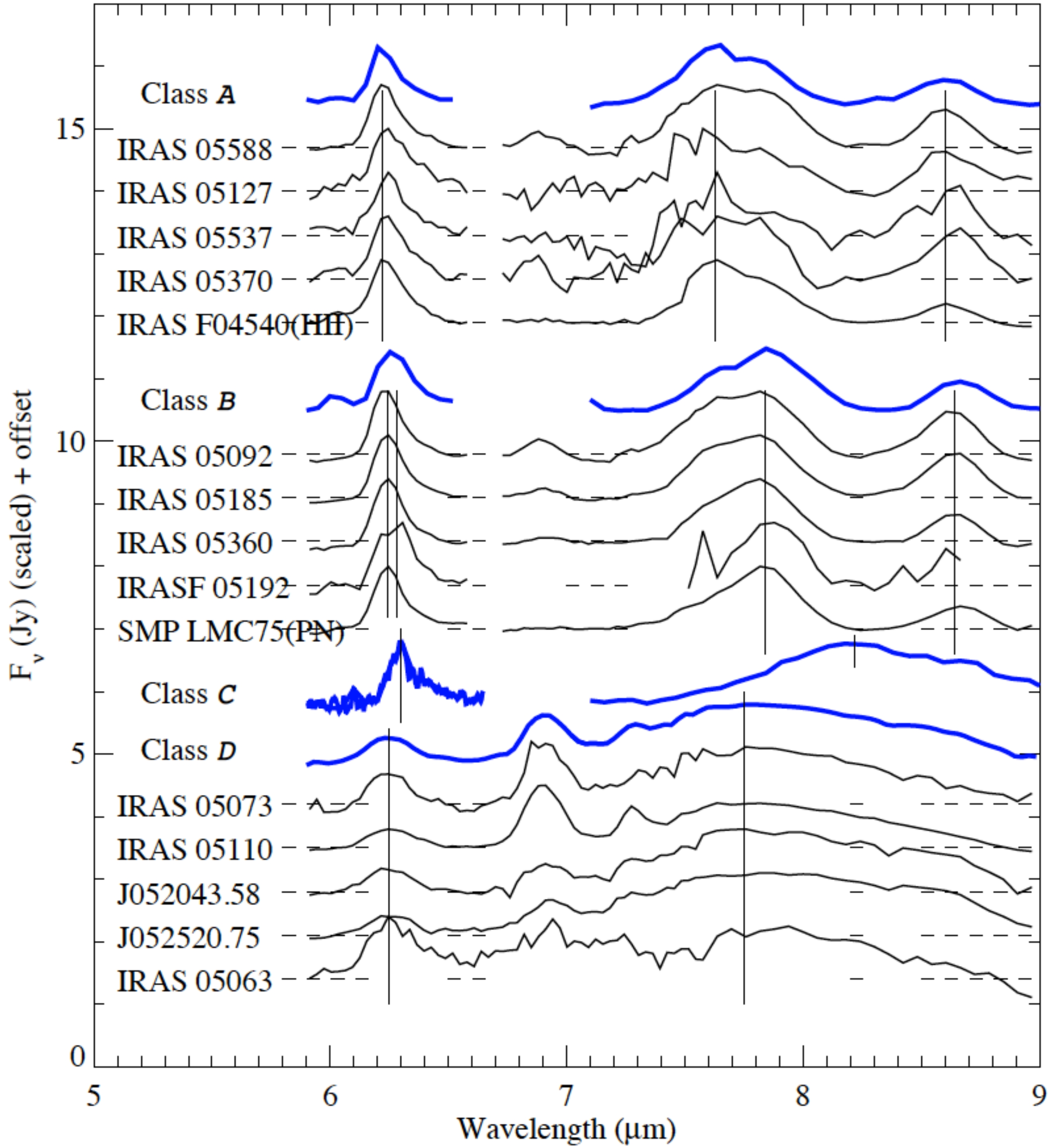


AMORPHOUS SILICATES & CRYSTALLINE SILICATES – OC_{a+cr}

Gładkowski+ (2014)



Classes of PAH's



Matsuura + (2013)

PAH classification

Gładkowski+ (2014)

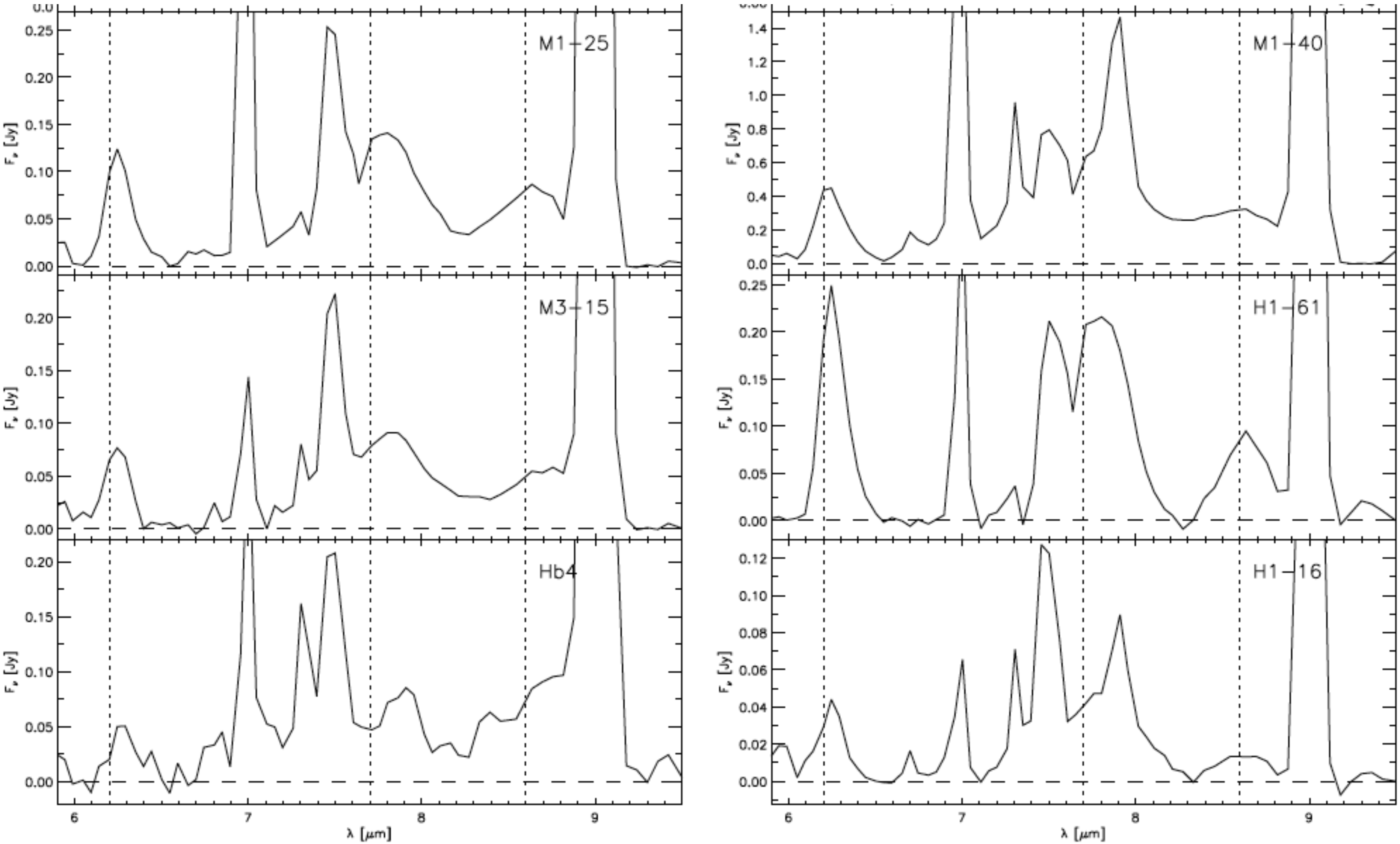


Tabela 1.6: Atomic lines detected in the PNe sample - part I.

Name	[Mg V] 5.61 [μm]	[Ar II] 6.99 [μm]	HI 7.27? [μm]	HI 7.46 [μm]	HI 7.50 [μm]	HI 7.78 [μm]	[Ar V] 7.90 [μm]	[Ar III] 8.99 [μm]
M 3-44	0	X	X	X	X	weak	0	weak
H 1-43	0	X	X	0?	0?	0	0	0
M 1-27	0	X	X	X	0?	X?	0	weak
MaC 1-10								
M 1-25	0	X	X	X	X?	0	0	X
M 3-15	0	X	X	X	X	0	0	X
Hb 4	0	X	0	X	X	0	0	X

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Concluding remarks

Concluding remarks

More work to do!!!

Especially:

Make sample of GB PNe as large as possible by including all PNe observed by SST ~80 (~30 analysed)