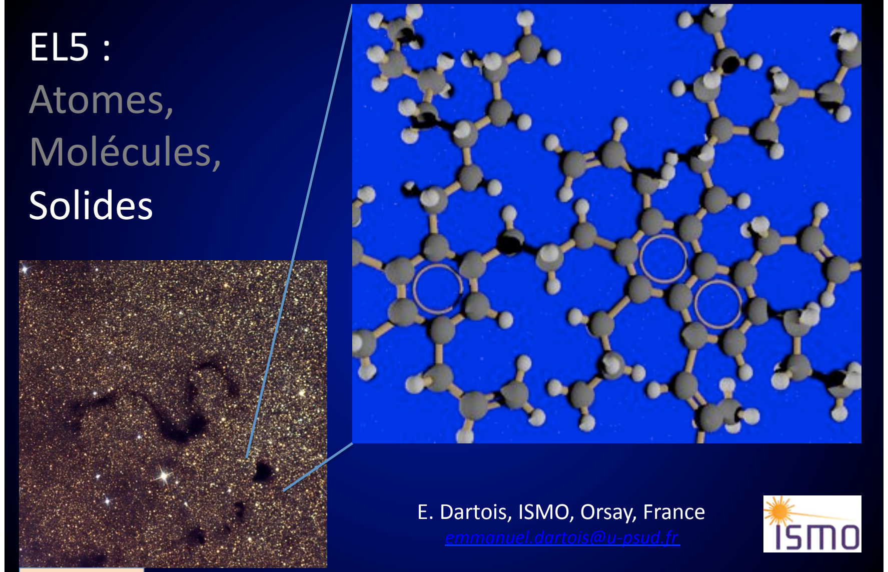
EL5 :
Atomes,
Molécules,
Solides

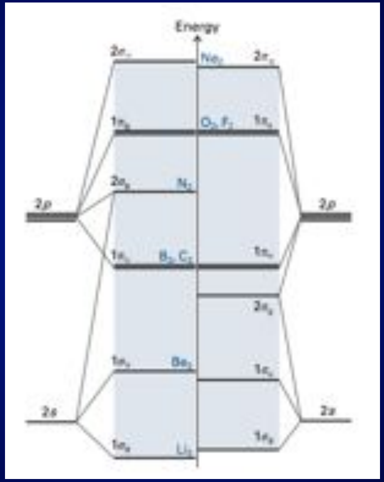


J. Belushi 2008

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

http://hebergement.u-psud.fr/edartois/Teaching.html

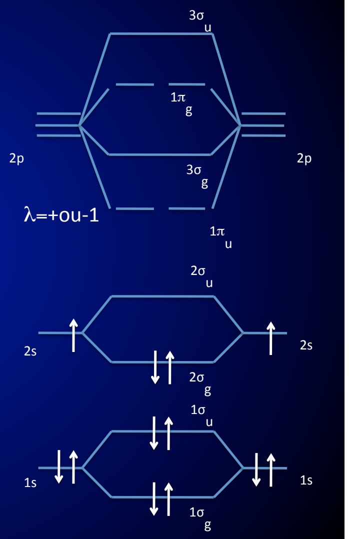
Niveau fondamentaux Li_2, B_2 et C_2



Niveau fondamentaux Li_2, B_2 et C_2

$Li_2 : (1\sigma_g)^2\ (1\sigma_u)^2\ (2\sigma_g)^2$

$1\,\Sigma^{+}_{g}$

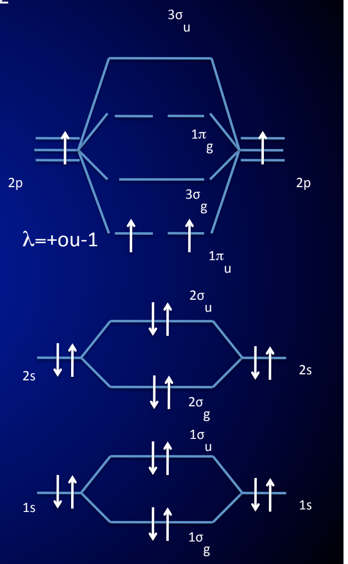


Niveau fondamentaux Li_2, B_2 et C_2

$B_2 : (1\sigma_g)^2\ (1\sigma_u)^2\ (2\sigma_g)^2\ (2\sigma_u)^2\ (1\pi_u)^2$

$3\,\Sigma^{-}_{g}$

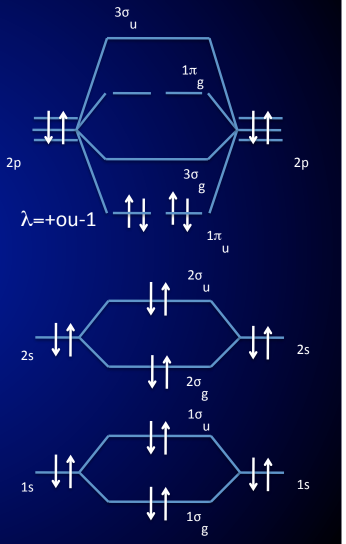
$1\Sigma^{+}_{g}$ $1\Delta_g$



Niveau fondamentaux Li_2, B_2 et C_2

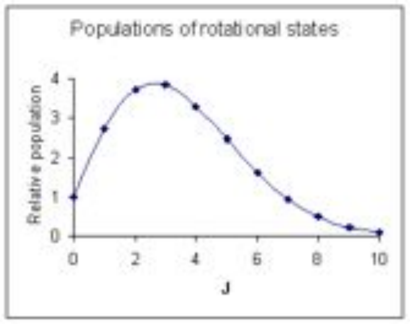
$C_2 : (1\sigma_g)^2\ (1\sigma_u)^2\ (2\sigma_g)^2\ (2\sigma_u)^2\ (1\pi_u)^4$

$1\Sigma^{+}_{g}$



Population des niveaux rotationnels

$N_J = N_{TOTAL} .(2J+1).\ e^{-BJ(J+1)/kT} / Q_{rot}$

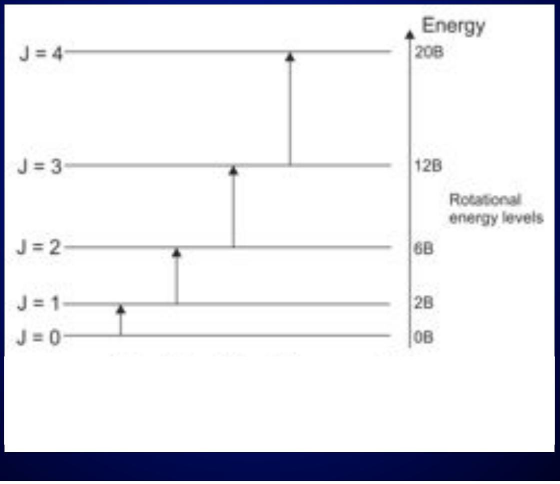


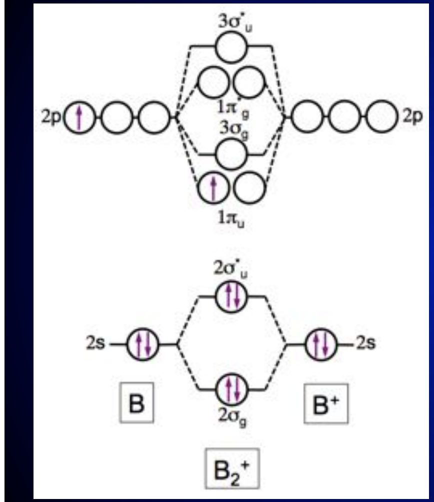
$Q_{rot} = \Sigma_J\ (2J+1).\ e^{-BJ(J+1)/kT}$

Déterminer le niveau le plus peuplé en fct de la température

Niveaux rotationnels & transitions

$\Delta E\ (J+1 \longleftarrow J)\ = B\ (J+1)(J+2) - B\ J(J+1) = 2B\ (J+1)$



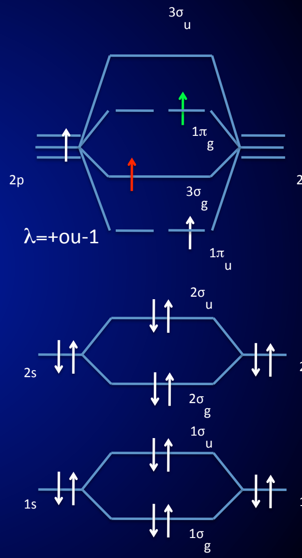


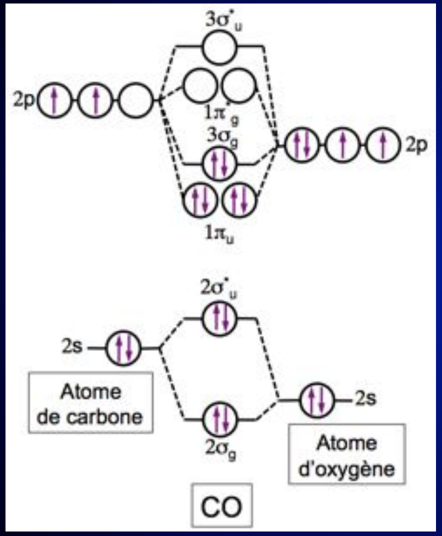
Niveaux B_2^+

$(B_2^+)^*$: $(1\sigma_g)^2\ (1\sigma_u)^2\ (2\sigma_g)^2\ (2\sigma_u)^2\ (3\sigma_g)^1$

$(B_2^+)^*$: $(1\sigma_g)^2\ (1\sigma_u)^2\ (2\sigma_g)^2\ (2\sigma_u)^2\ (1\pi_g)^1$

(B_2^+) : $(1\sigma_g)^2\ (1\sigma_u)^2\ (2\sigma_g)^2\ (2\sigma_u)^2\ (1\pi_u)^1$





Solides

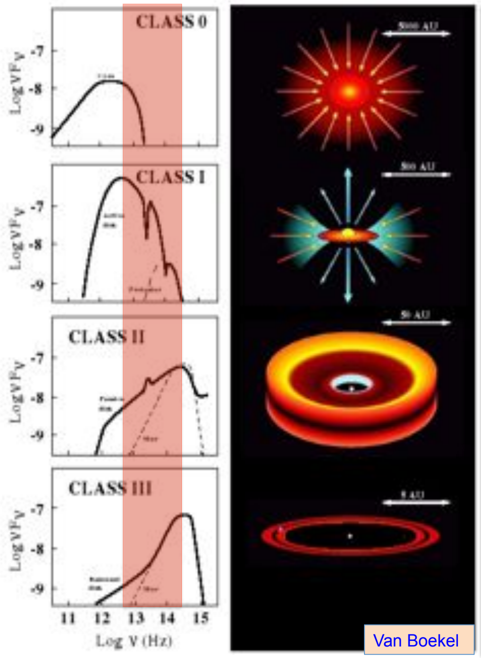
Introduction

Solides réfractaires (et très grosses molécules...)

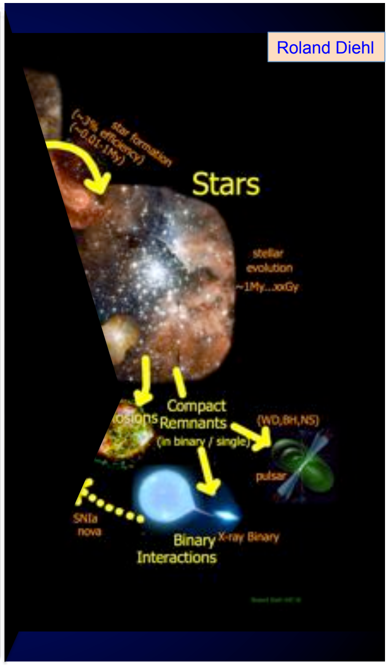
Observations

Minéraux (compositions et phases)

≠ formes de matière carbonée et leur mode d'émission/absorption (PAHs, fullérènes, HAC)



Van Boekel



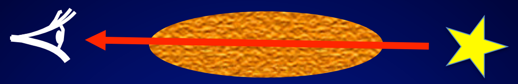
Roland Diehl

Phases neutres du MIS

Phase	nH (cm−3)	T (K)	x	Mass (%)
WNM	0.1–1	$10^4 - 10^3$	~0.01	25
CNM	10–100	500-100	$\sim 10^{-4}$	25
MC	$>10^3$	<50	$<10^{-5}$	30

Verstraete 2011, Wolfire 2003

La loi d'extinction



cm²

$$S = S_0 \exp[-\tau_\nu] = S_0 \exp[-\textstyle\int_0^D \kappa_\nu\, dx];\quad \tau_\nu = \kappa_\nu D = N\sigma_{ext} D$$

cm⁻³

Flux versus magnitude

$$-2.5\log_{10} S = -2.5\log_{10} S_0 - 2.5\log_{10} (\exp\text{-}[\tau])$$

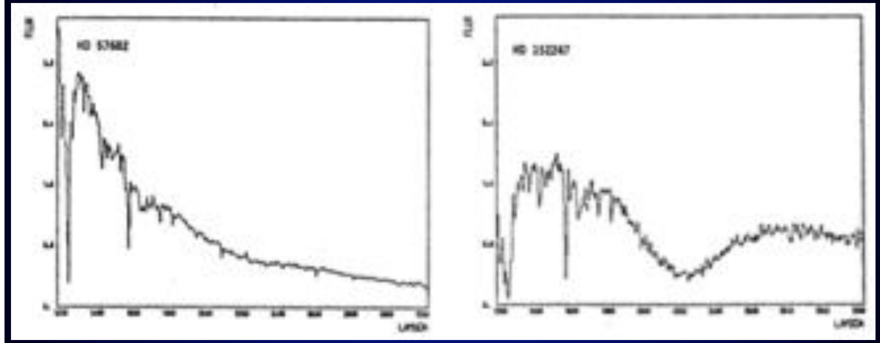
$$m = m_0 + 2.5\tau/\ln(10) = m_0 + A = m_0 + 1.086\tau$$

"A" est l'extinction en magnitude

Rappel : $m = -2.5 \log_{10}(F/F_0)$ magnitude apparente

F_0 représente le flux d'une étoile de référence

Extinction dans l'UV



IUE, Egret 1985

Excès de couleur (rougissement)

$$E(B\text{-}V) = (B\text{-}V) - (B\text{-}V)_0 = A_B - A_V$$

= [indice de couleur observé] - [intrinsèque]
indépendant de la distance

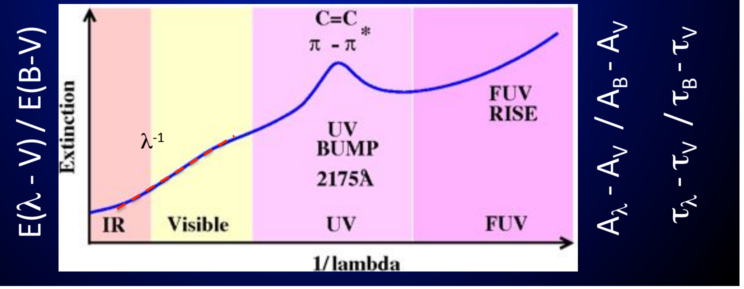
Magnitude apparente

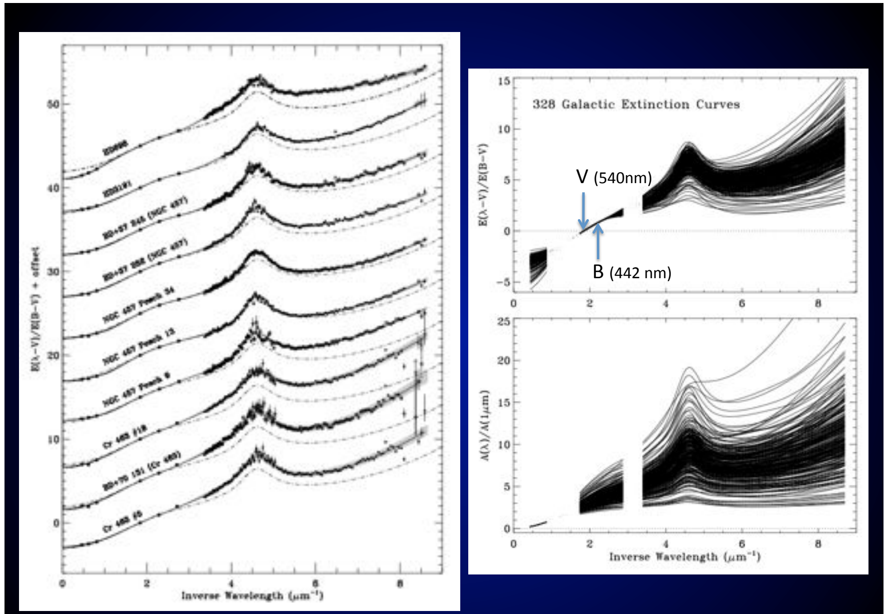
Rapport de l'extinction totale sur l'extinction sélective

$$R = A_V / E(B\text{-}V) \approx 3.1$$

$A_V = 1.086\tau$

Corrélé avec la taille moyenne des grains responsable de l'extinction





Fitzpatrick & Massa 2007

A_λ varie en λ^{-1}

Molécules Particules $a \ll \lambda$	λ^{-4}
Particules $a \gg \lambda$	λ^{0}
Particules $a \sim \lambda$	λ^{-1}

Quantité de poussière ?

Extinction galactique moyenne visible ≈ 1.8 mag/kpc

$\tau_V = N\sigma_{ext}D$ $\quad$ $A_V = 1.086\tau$

pc : 3.08×10^{16} m

$N\sigma_{ext}$?

Rapport gaz/grain

Si on prend a ≈ 0.1 μm

N_{grain} ?

Si on prend a ≈ 0.1 μm et ρ ≈ 2-3 g/cm^3

m_{grain} ?

ρ poussières / ρ gaz ≈

$M_{grain} \times N_{grain} / M_H \times N_H$

ρ poussières / ρ gaz ≈ ?

Abondances interstellaires des éléments
(DISM, N_H~ 100 cm^{-3})

Élément	[X/H]IS (ppm)	δX (%)
He	$7.8\ 10^4$	0
C	288.4	38.7
N	79.4	22.2
O	575.4	41.9
Mg	41.7	94.6
Si	40.7	95.6
S	18.2	80.7
Fe	34.7	99.4

Lodders 2003, Jenkins 2009, Verstraete 2011

Les trois grandes phases

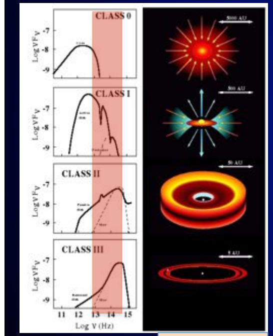
Mineraux / (Hydro-)carbures / Glaces



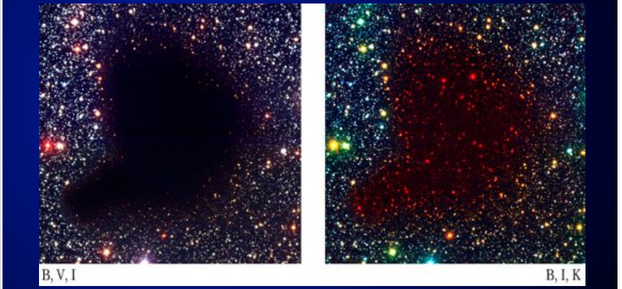

ICE house

Longueurs d'ondes d'intérêt :

Compromis longueur d'onde / signatures

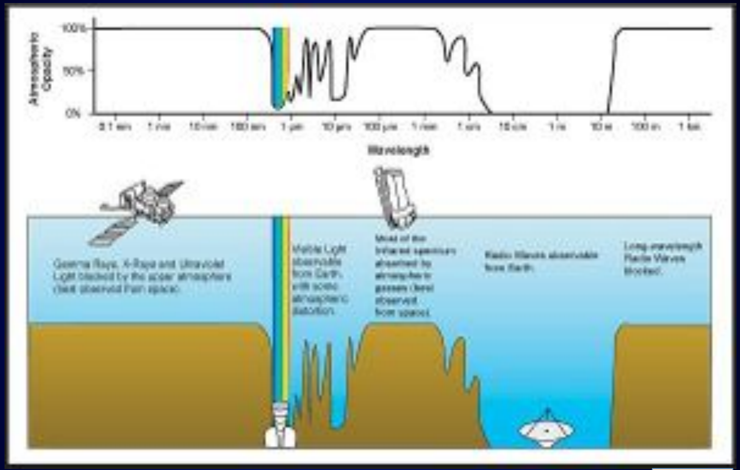


Van Boekel



ESO

Transmission atmosphérique



Gamma Rays, X-Rays and Ultraviolet Light blocked by the upper atmosphere (best observed from space).

Visible Light observable from Earth, with some atmospheric distortion.

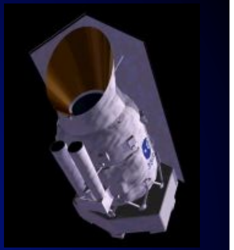
Most of the Infrared spectrum absorbed by atmospheric gases (best observed from space).

Radio Waves observable from Earth.

Long-wavelength Radio Waves blocked.

Caltech

Astronomie infrarouge spatiale



Beginning with the Infrared Astronomical Satellite (IRAS) in 1983. (the Netherlands, UK, USA/ 10 months / first maps of entire sky at 4 IR wavelengths.)

ESA's Infrared Space Observatory (ISO), 1995-1998, world's first general-purpose IR space observatory.

Japanese mission Akari. 2006-2007, it mapped more than 94% of the sky at infrared wavelengths in greater detail than IRAS.

NASA's Spitzer Space Telescope is a general-purpose infrared observatory with a slightly bigger telescope than ISO.

Herschel telescope, more than four times larger than any previous IR space telescope bridging the gap between infrared satellites and radio telescopes on ground.

IR astronomy become increasingly important to astronomers. ESA/NASA James Webb Space Telescope, IR space telescope designed to look into the very furthest reaches of space

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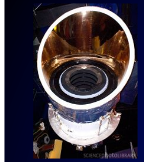
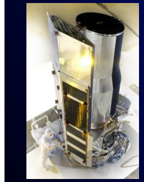


IRAS

ISO

Akari

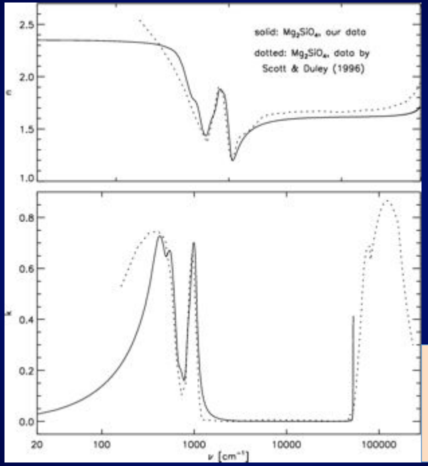


Spitzer

Herschel

JWST

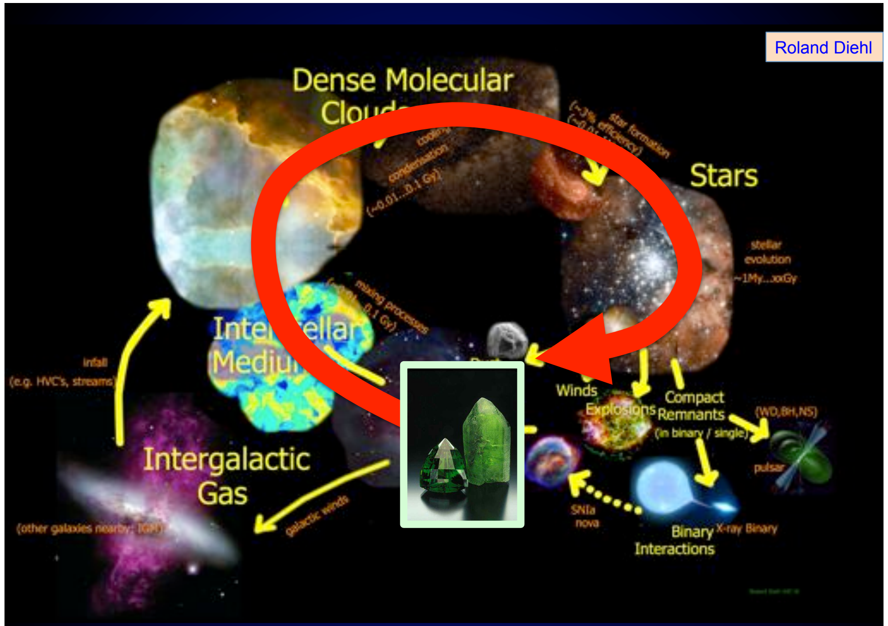
Observer : les constantes optiques



Jaeger 2003

(sub)-mm FIR - Infrared - NIR Visible - UV

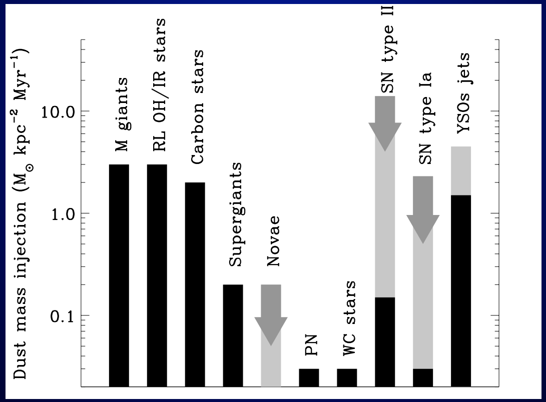
Poussières carbonées et inorganiques



Roland Diehl

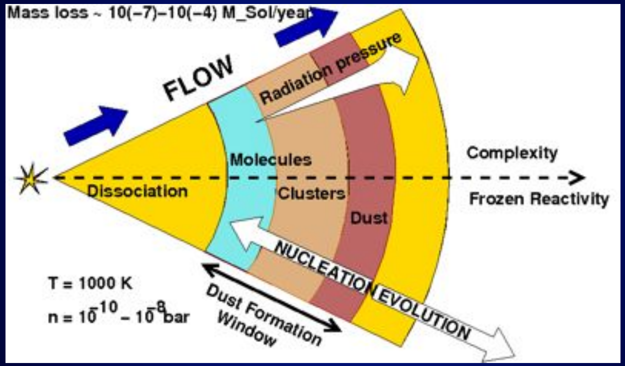
Les étoiles à perte de masse contribuent significativement à enrichir le milieu interstellaire en poussières.

La poussière est observée à des stades d'évolution ultérieurs



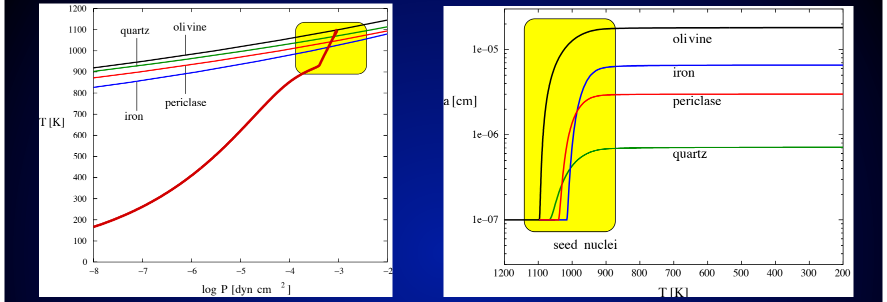
Jones 2001, Tielens 2005, Robitaille 2010, Matsuura 2011

Vue schématique d'un flot stellaire/refroidissement



Adapté de Patzer 2004

Exemple de modèle de vent



Gail & Sedlmayr 1999

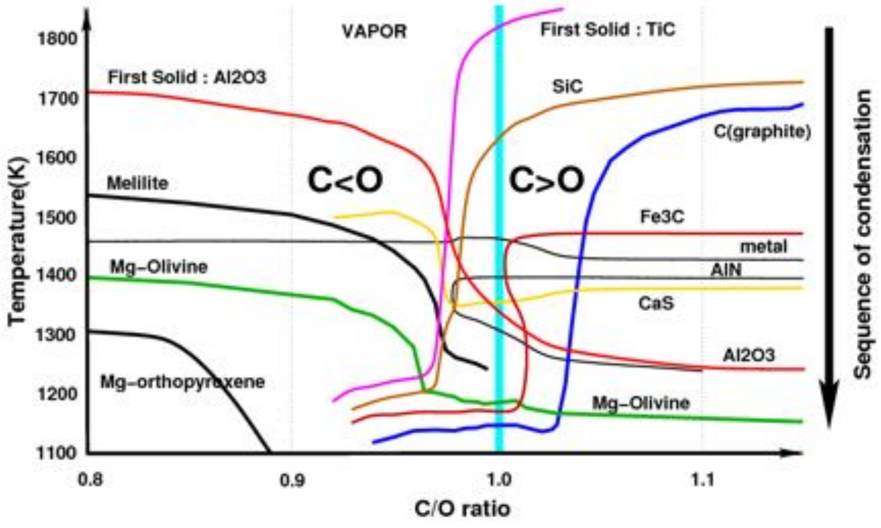
Condensation loin de l'ETL T~1000K, P~10(-10)atm

Phase critique : agrégat de molécules pour former des particules de 10-100 atomes

Ces noyaux de condensation sont moins stables que les gros et requièrent une sursaturation / solide

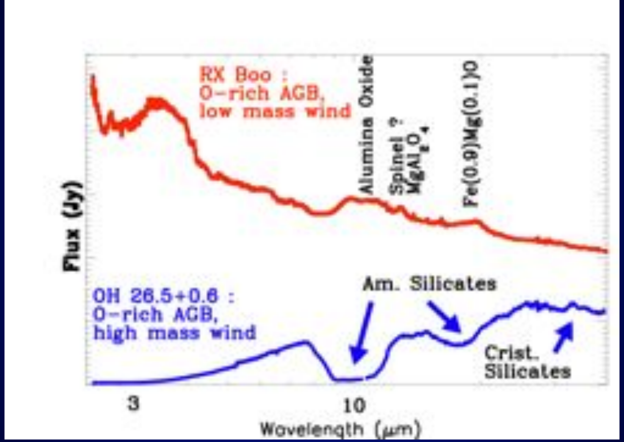
Compétition temps caractéristique de formation et éjection (réactions « gelées »)

χ



Ebel 2000

ϕ



Molster et al. 2002, Posch et al. 2002, Cami 2002 ...

“Minéralogie” des Silicates

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

Mg_2SiO_4 Forsterite

Fe_2SiO_4 Fayalite

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

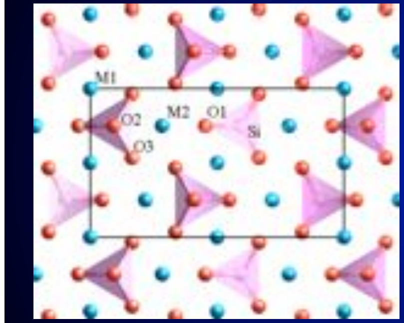
$Mg_2Si_2O_6$ Enstatite

$Fe_2Si_2O_6$ Ferrosilite (hypersthene)

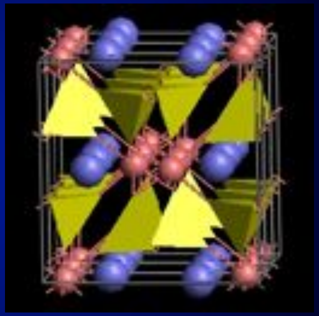
$CaMgSi_2O_6$ Diopside

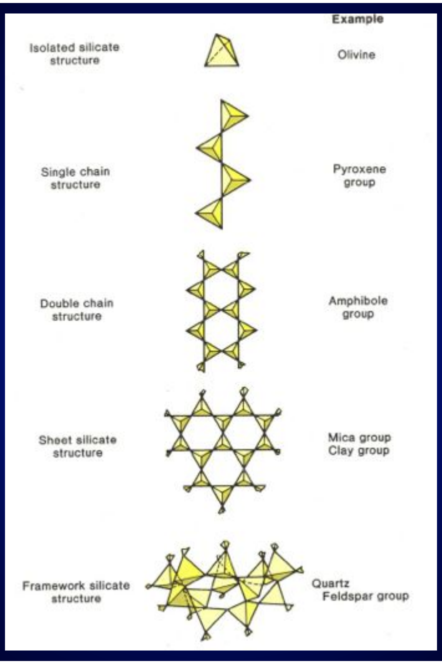
$CaFeSi_2O_6$ Hedenbergite

Olivine

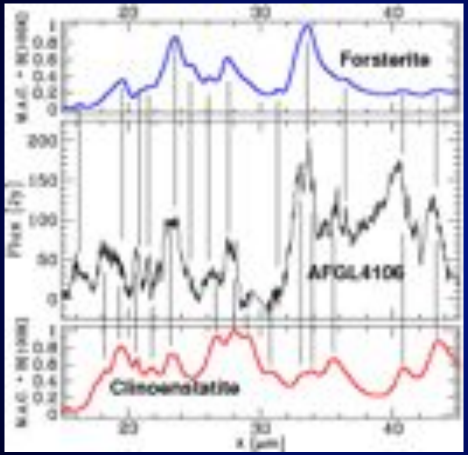


Pyroxène



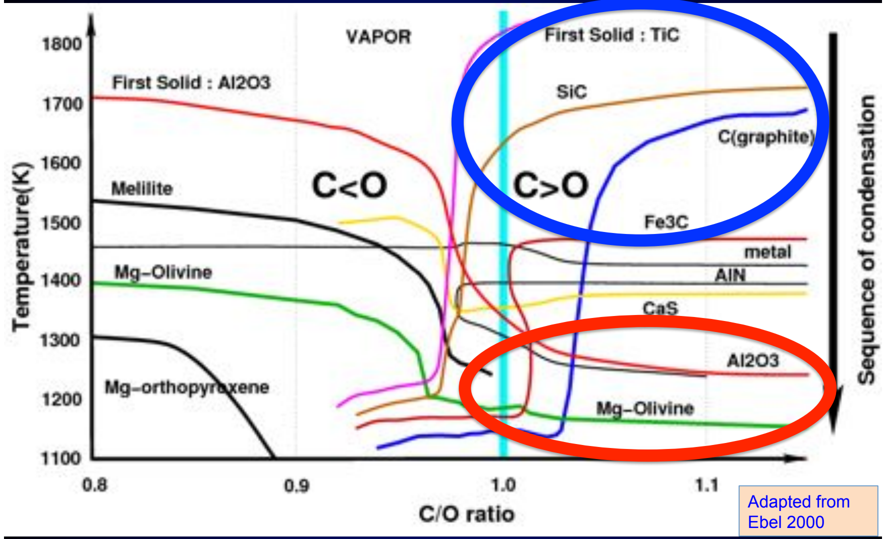


La révolution cristalline



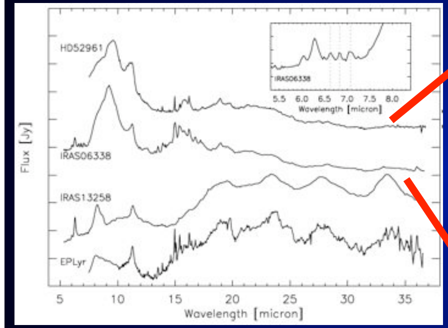
Jaeger et al. 1998

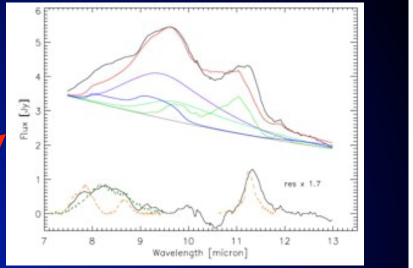
Sequence

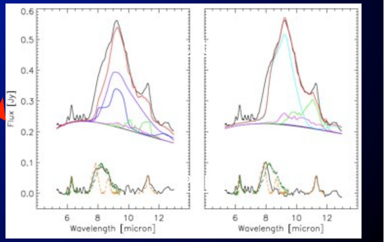


Adapted from Ebel 2000

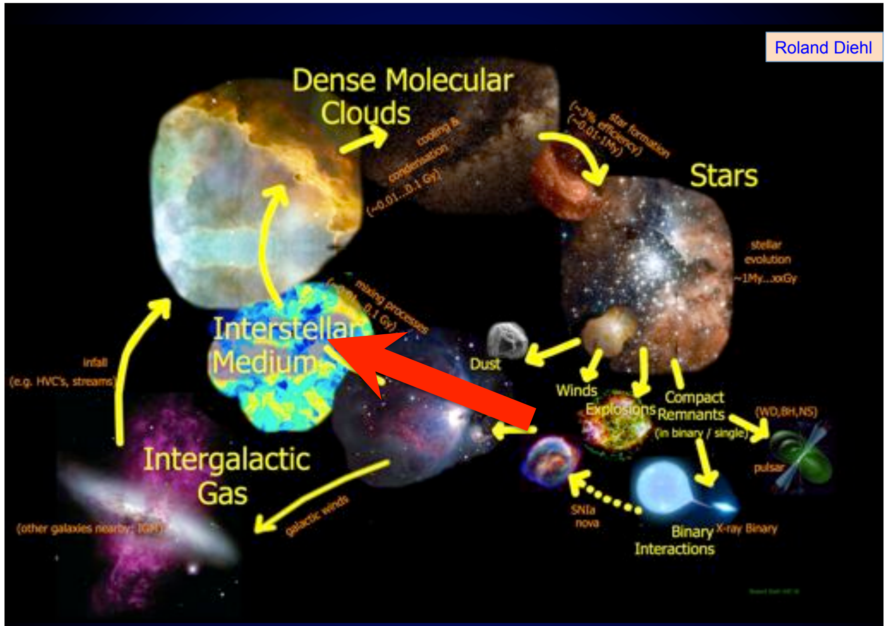
Exemple de sequences mélangées





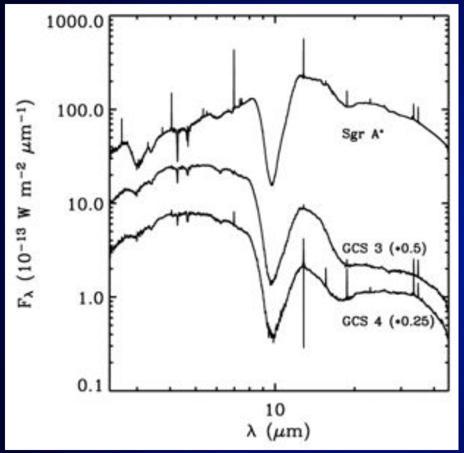


Gielen et al. 2011

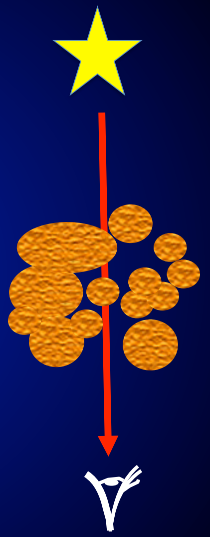


Roland Diehl

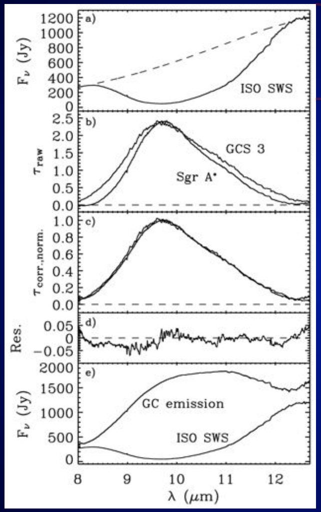
Silicates dans le MIS

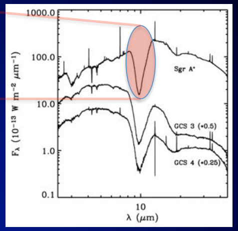


Kemper et al. 2004



Silicates dans le MIS





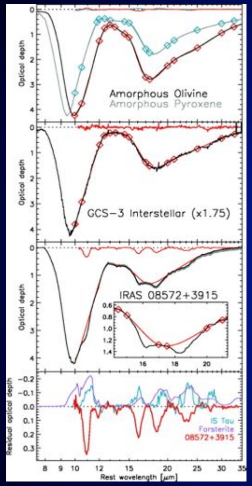
Kemper et al. 2004

Silicates dans l'ISM sont presque entièrement « amorphes »

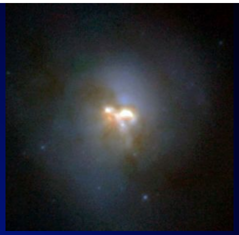
(<2.2% cristallins
Kemper et al. 2004 + erratum)

Et dans la limite de Rayleigh (petits)

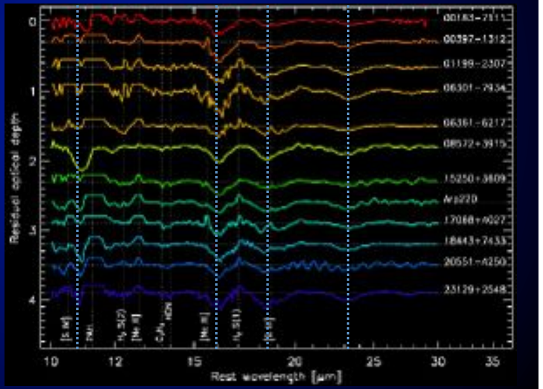
Exception : l'ISM des ULIRGs



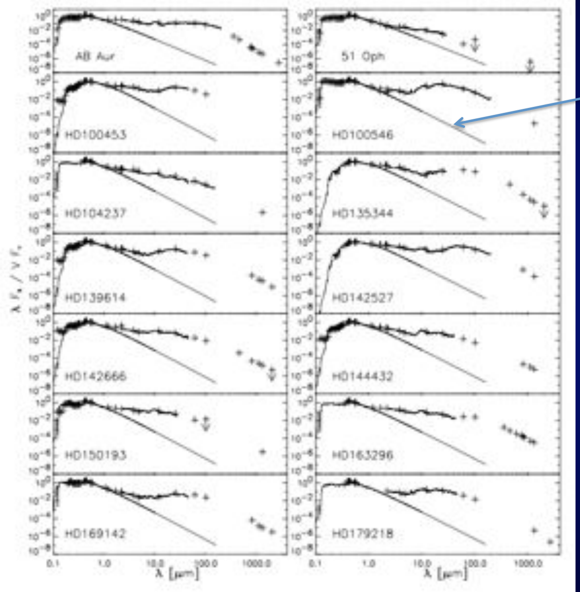
Spoon et al. 2006



Arp220, Hubble



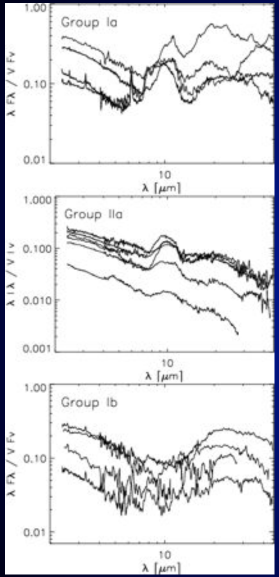
Silicates dans les disques

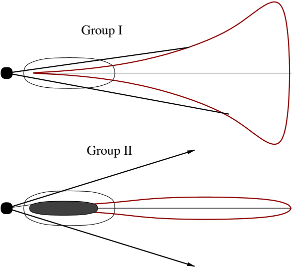


Modèle de Kurucz

Meeus et al. 2001

Silicates dans les disques





Meeus et al. 2001