Composition and evolution of grains

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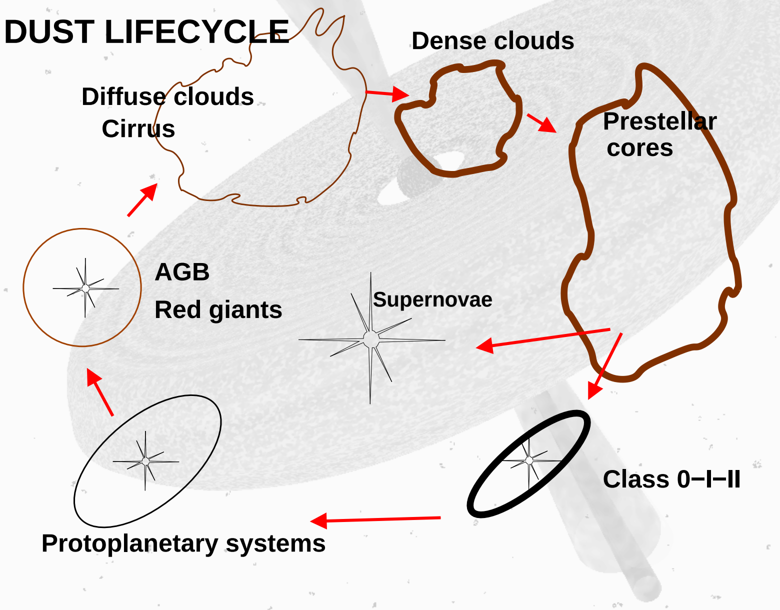
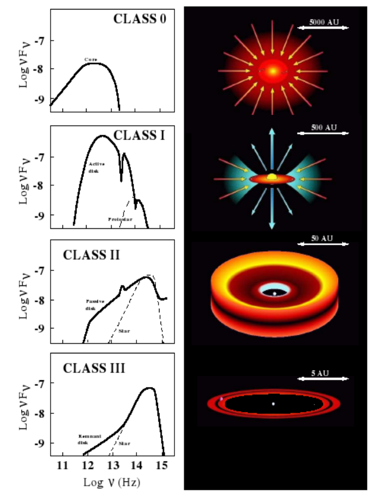
Aussois, March 2006

Galactic dust cycle



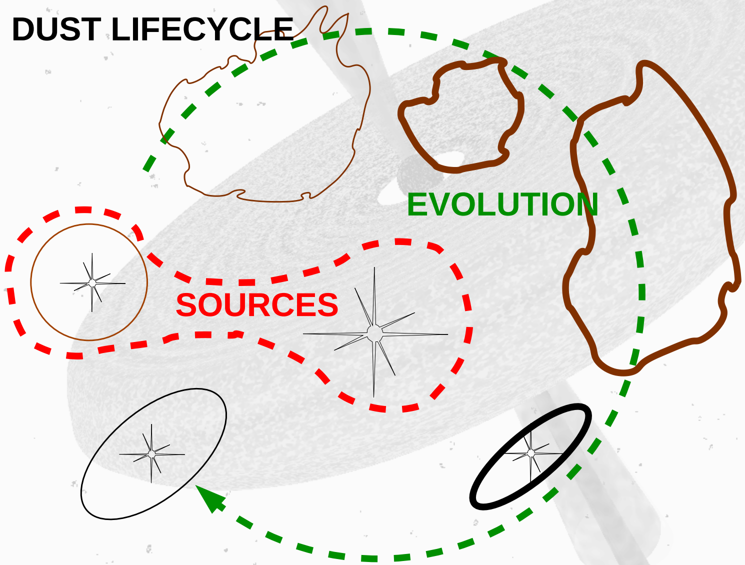
Class 0-III



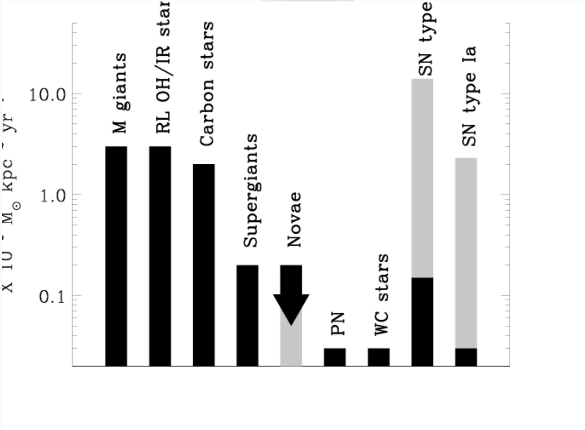
extract from Bam Acke thesis 2005, see ref. cited

- In terms of observability of dust composition, outside the solar system, limited to IR and MM.
- will lead to observational biases

Dust sources : from production to evolution



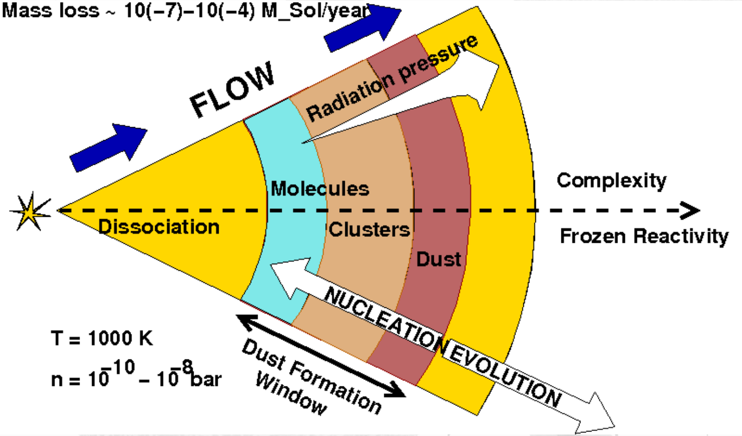
Contributions of Stardust Sources in the ISM



after Jones et al., 2001, Phil. Trans. R. Soc. Lond. A, 359, 1961

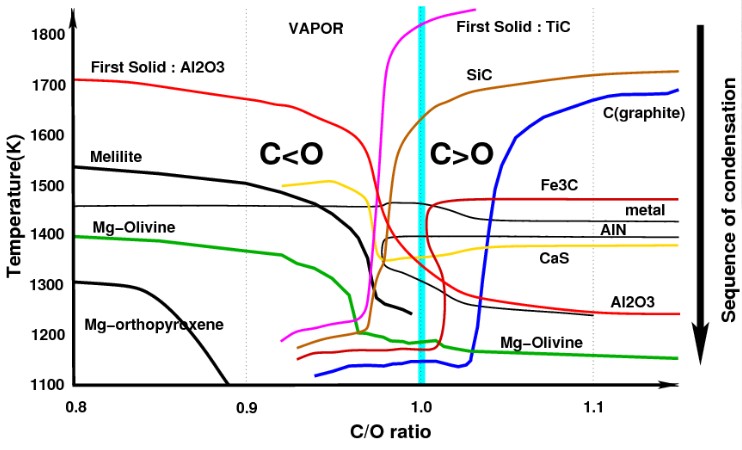
- Mass loss rates inject a large fraction of dust

Schematic view of a cooling/expanding flow



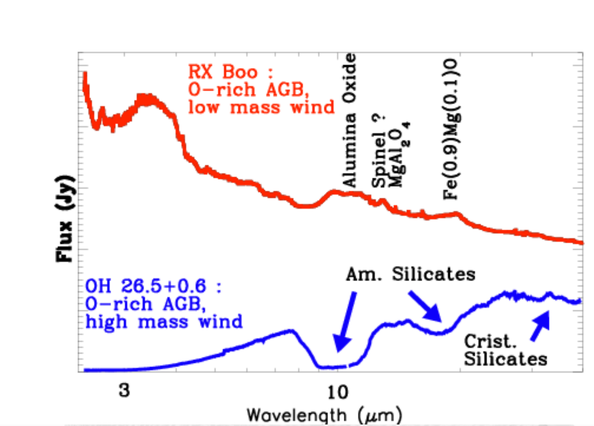
after Patzer 2004, ASP conference

Chemical effect : composition driven by the C/O ratio



Ebel, 2000, JGR 105, 10365.

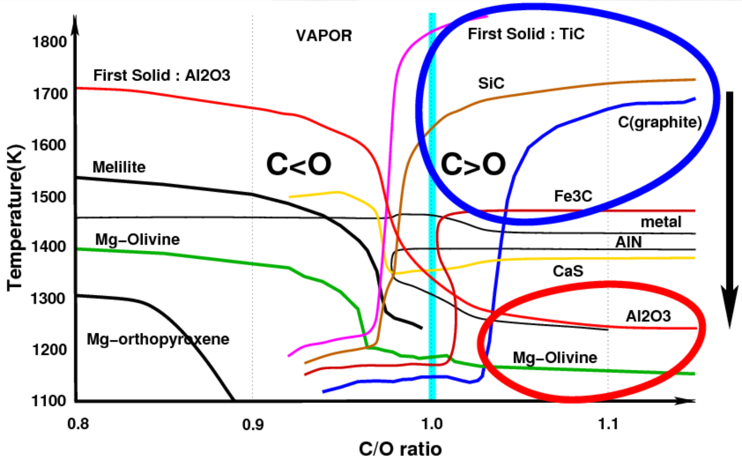
Physical effect : evolution of the flow rates



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

- Correlation between wind density and condensates
  - Low loss mass : Simple oxides (quenching)
  - High loss mass : Amorphous silicates like ISM ones
  - Even higher : Cristalline silicates

Reality : condensation sequences



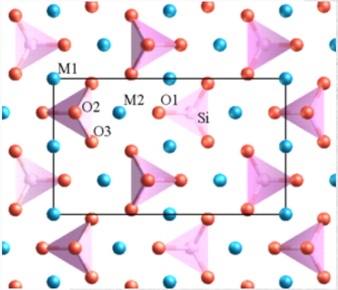
+ binarity

Silicates "astromineralogy"

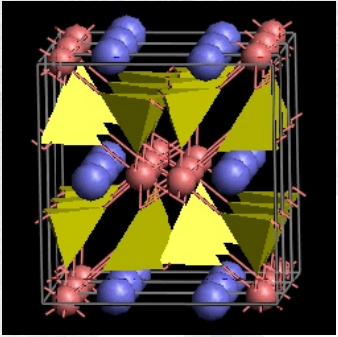
Olivines ($Mg_{2x}Fe_{2-2x}SiO_4$)	Formula	Name
	Mg_2SiO_4	Forsterite
	Fe_2SiO_4	Fayalite
Pyroxenes ($Mg_xFe_{1-x}SiO_3$)	**Formula**	**Name**
	$Mg_2Si_2O_6$	Enstatite
	$Fe_2Si_2O_6$	Ferrosilite (hypersthene)
	$CaMgSi_2O_6$	Diopside
	$CaFeSi_2O_6$	Hedenbergite

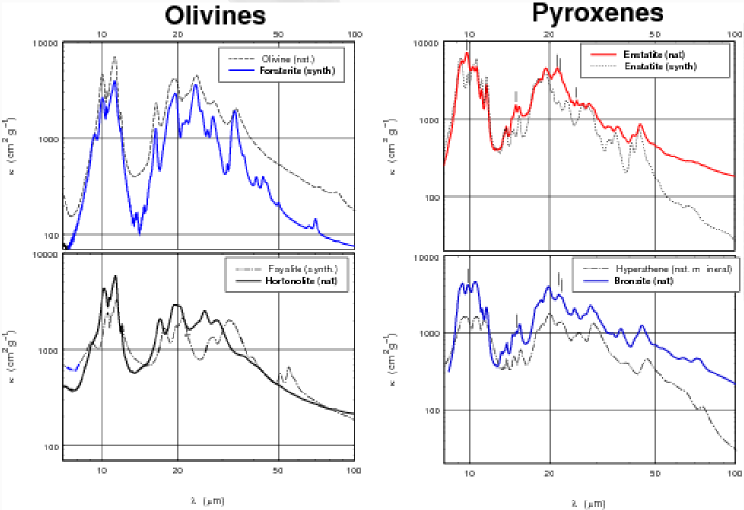
Silicates

Olivine

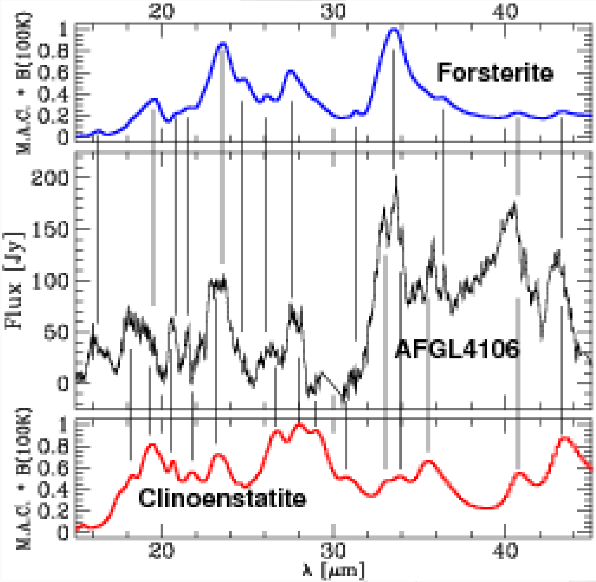


Pyroxene



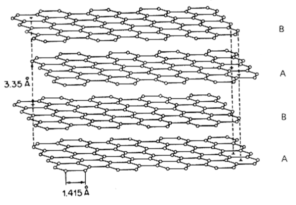


Jaeger et al. 1998

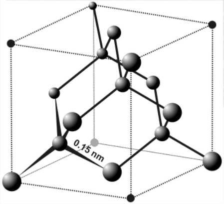

20
30
40
1
0.8
0.6
0.4
0.2
0
M.A.C. * B(100K)
Forsterite
200
150
100
50
0
Flux [Jy]
AFGL4106
Clinoenstatite
λ [μm]

Carbonaceous material : versatile bondings

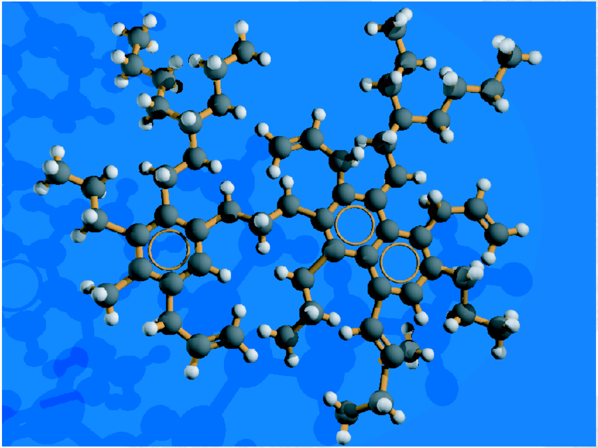
- sp (alkanes, carbon chains)
- sp^2 (graphite, fullerene, nanotubes, Polycyclic Aromatic Hydrocarbons (PAHs))



- sp^3 (diamond)



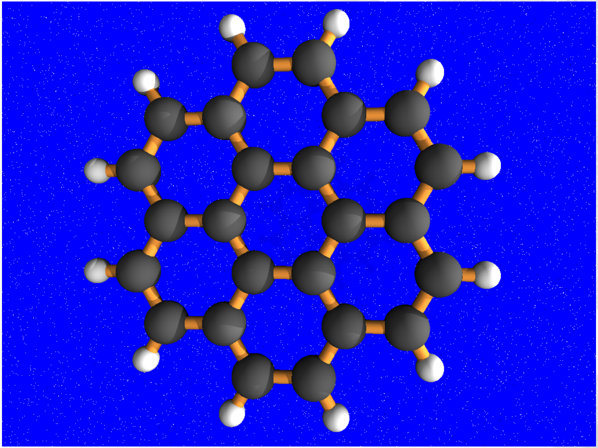
mixed bondings: (Hydrogenated) Amorphous Carbons (HAC)



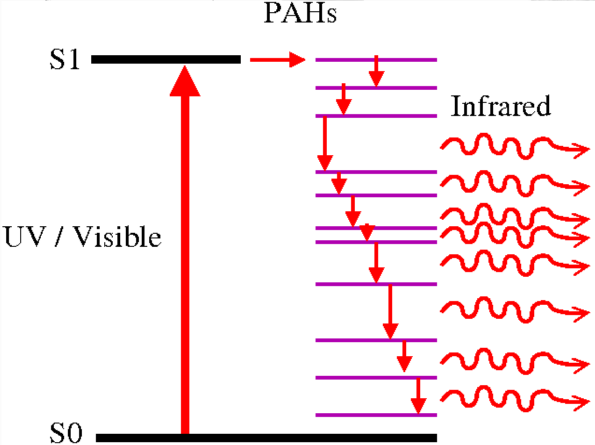
Dartois et al. 2005

■ Large number of phases

PAHs (coronene)

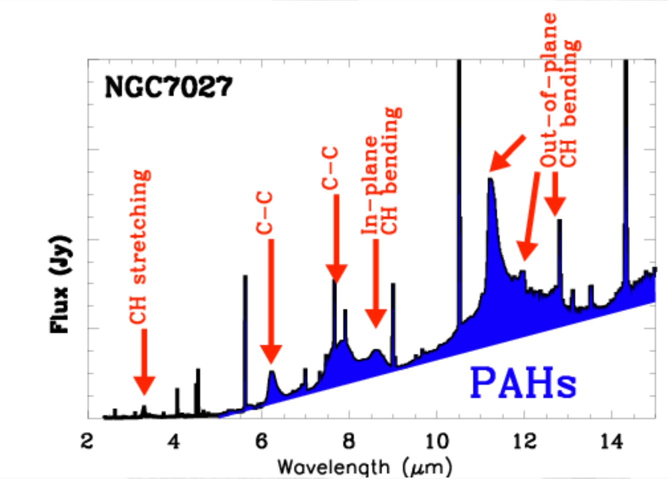


PAHs emission is not thermal



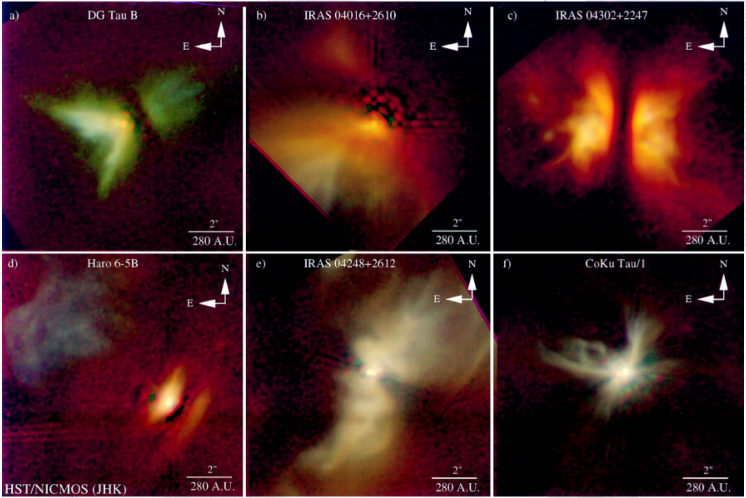
Léger (in this room !) Puget 1984

PAHs emission



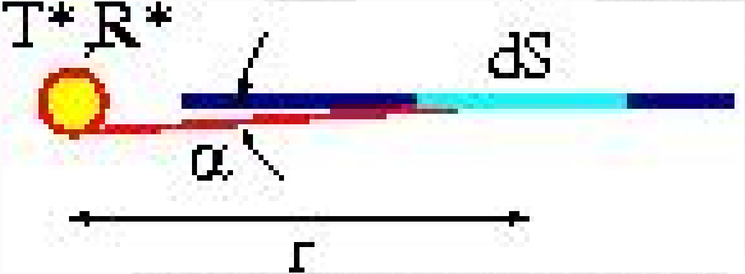
Extracted from ISO database

Observations



Padgett et al. 1999

Disks models : the simplest flat passive case



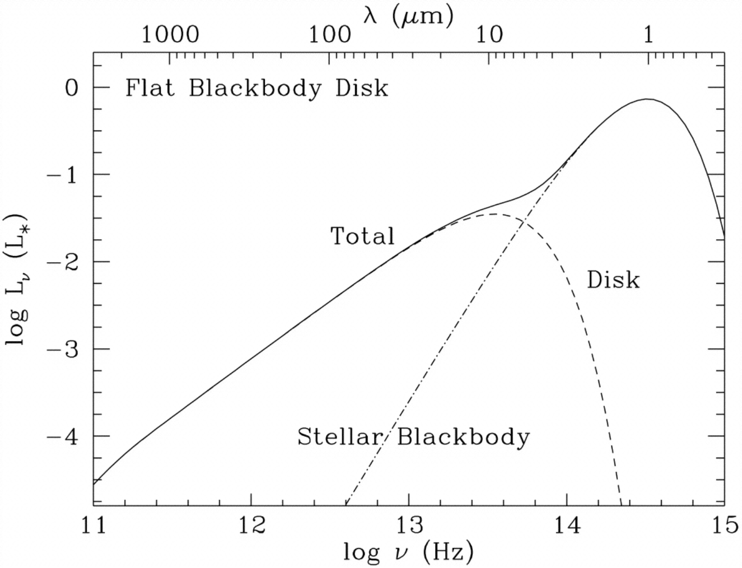
e.g. Lynden-Bell & Pringle 1974; Adams, Lada, Shu 1988

- Power absorbed by dS $\approx \frac{\sigma T_*^4 R_*^2}{r^2} sin(\alpha) dS$
- $\approx \frac{\sigma T_*^4 R_*^2}{r^2} dS \frac{R_*}{r}$
- Power radiated by dS $\approx \sigma T^4(r) dS$
- $T(r) \approx T_* \left(\frac{r}{R_*}\right)^{-3/4}$

Passive disks : integration

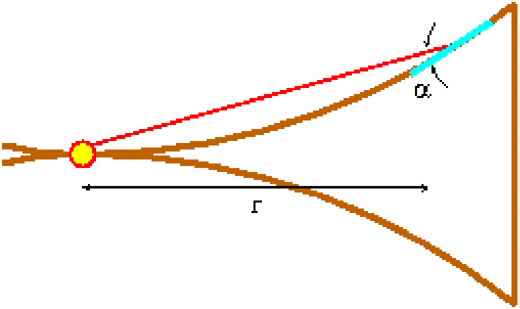
- Flux emitted
- $L_\nu / 4\pi d^2 = \nu F_\nu$
- $= \nu \int_{Rint}^{Rext} 2\pi r \, B_\nu(T(r)) \, dr$

Flat disk SED



Chiang & Goldreich, 1997

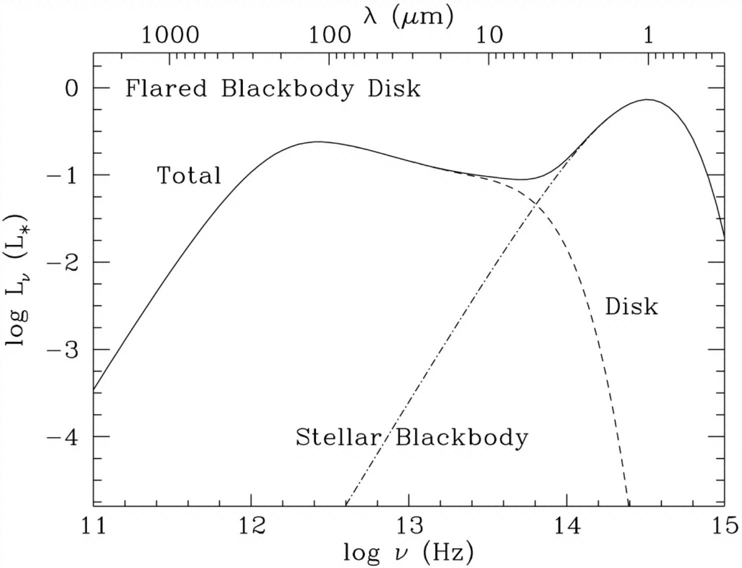
Passive disks : flared disk



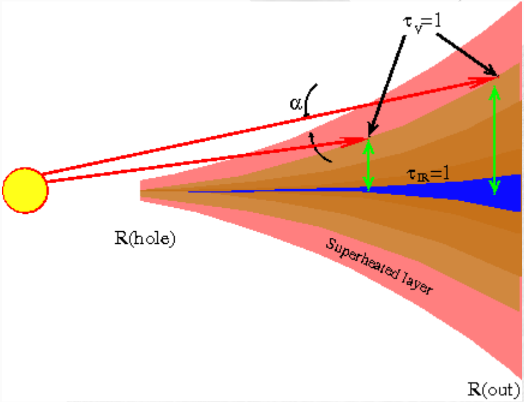
e.g. Kenyon & Hartmann 1987

- Expected due to hydrostatic equilibrium that gas/dust scale height and therefore α increase with radius.
- $\alpha_{flared} > \alpha_{flat}$, intercept more stellar flux
- $T(r) \propto r^{-2/5}$

Flared disk SED



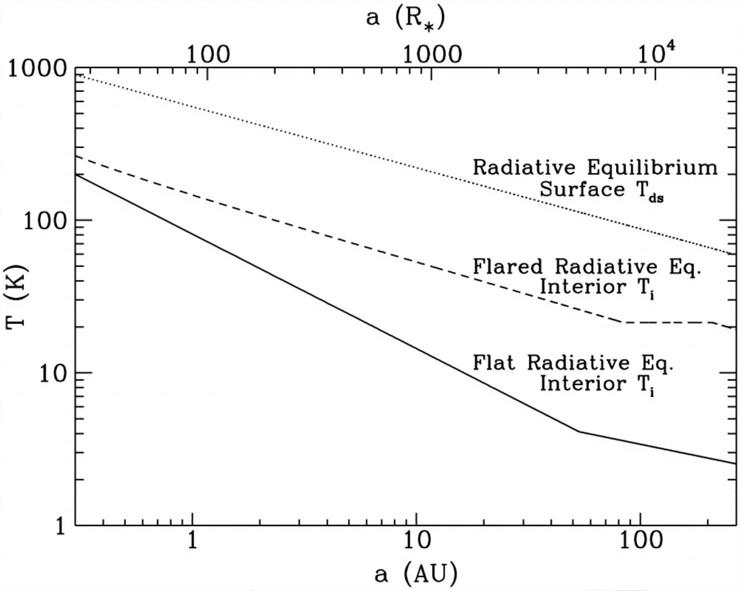
Flared disk radiative equilibrium



Chiang & Goldreich 1997

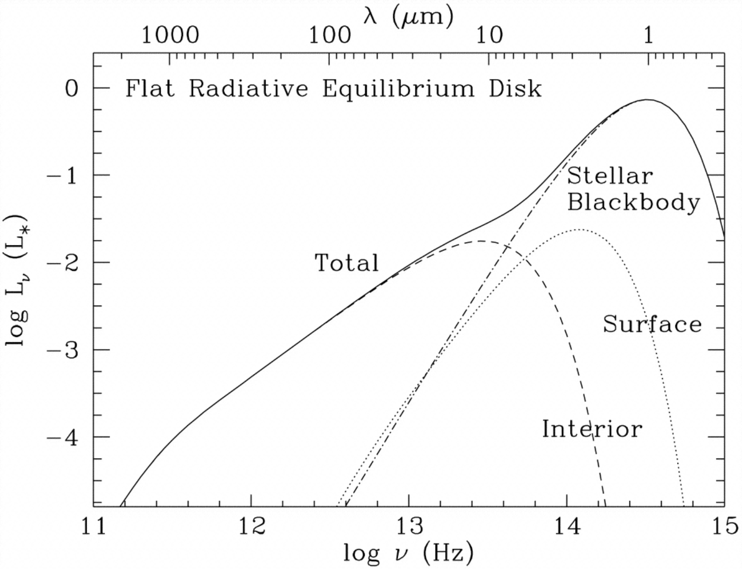
- Stellar light absorbed in the upper layer where $\tau_V \approx 1$
- T(surface) > T(blackbody) (flaring + $\kappa(\nu)$V>> $\kappa(\nu)$IR)
- IR emitted by surface outward detected ($\tau_{IR} << \tau_V$)
- IR emitted inward absorbed if $\tau_{IR} \approx 1$ (still related to α !!!).

Temperature profiles : 3 regimes (ee,ef,ff)



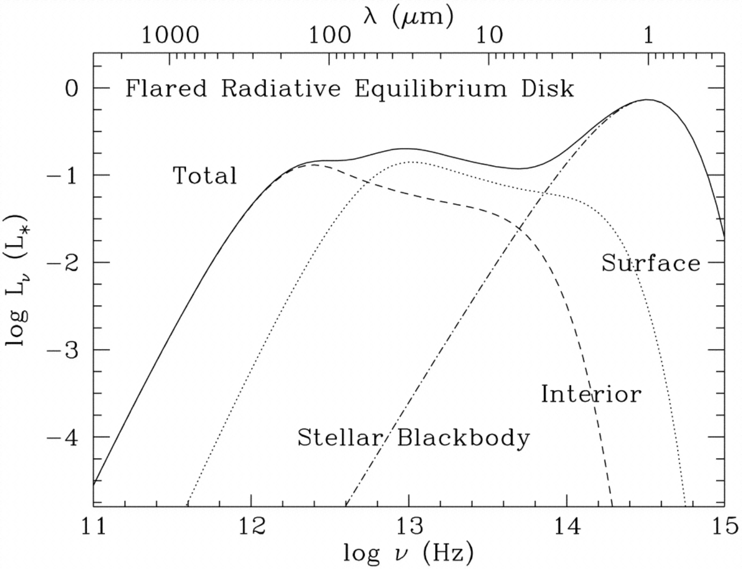
Chiang & Goldreich 1997

SED flat disk + transfer



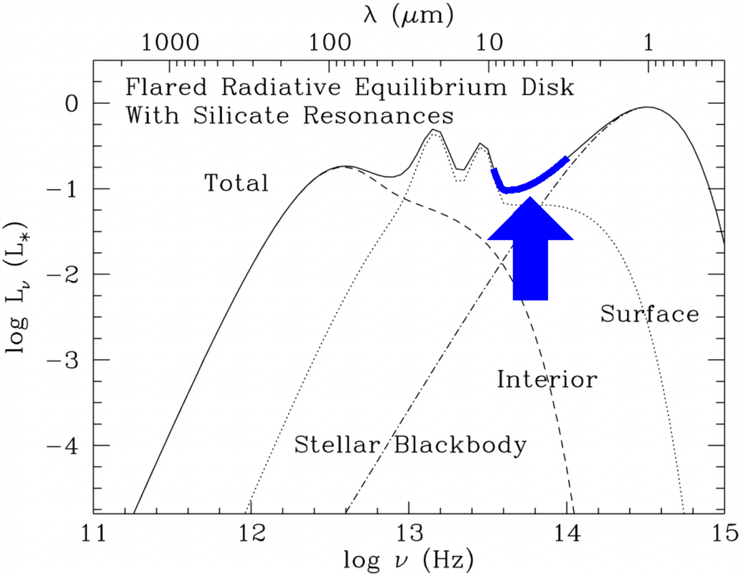
Chiang & Goldreich 1997

SED flared disk + transfer



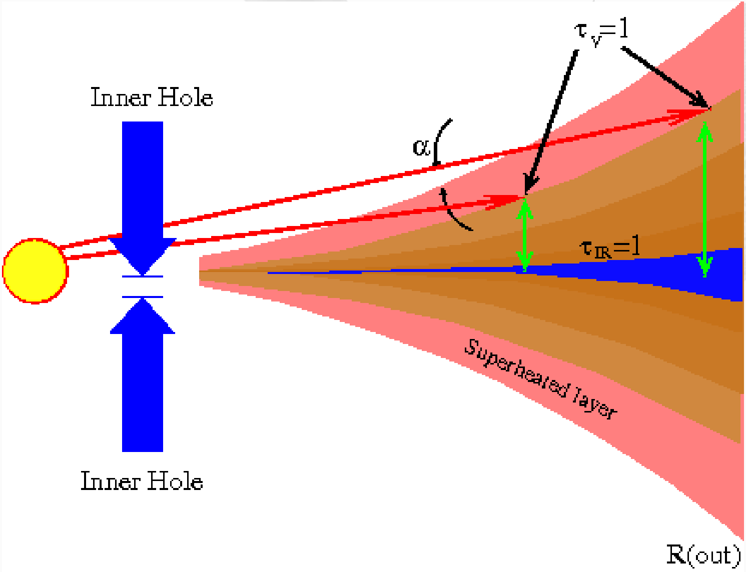
Chiang & Goldreich 1997

With features ...!!!...



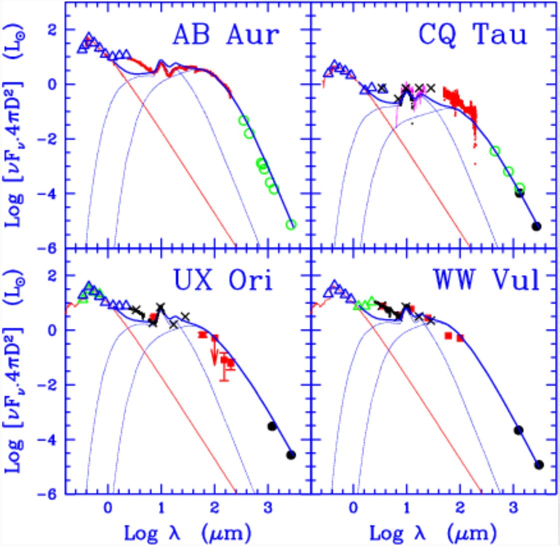
Chiang & Goldreich 1997

A hole in the SED



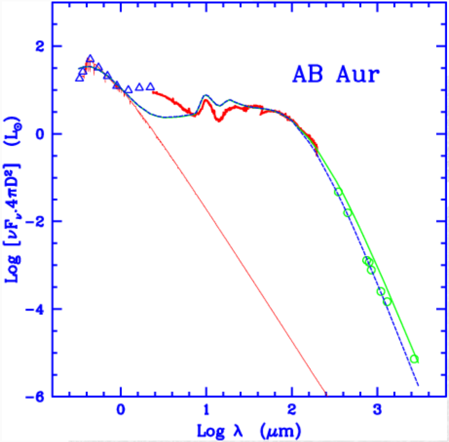
- Will produce fluxes deficits in the NIR-MIR range

Observations show near infrared excess



Natta et al. 2001

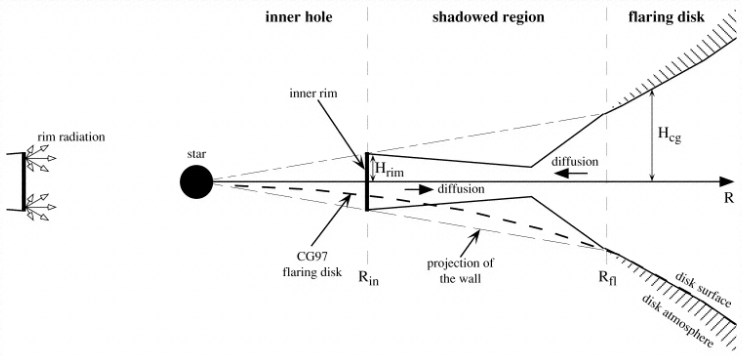
Quantify NIR excess



Natta et al. 2001

- up to ∼25% of total stellar flux
- poorly compatible with disks reaching stellar surface

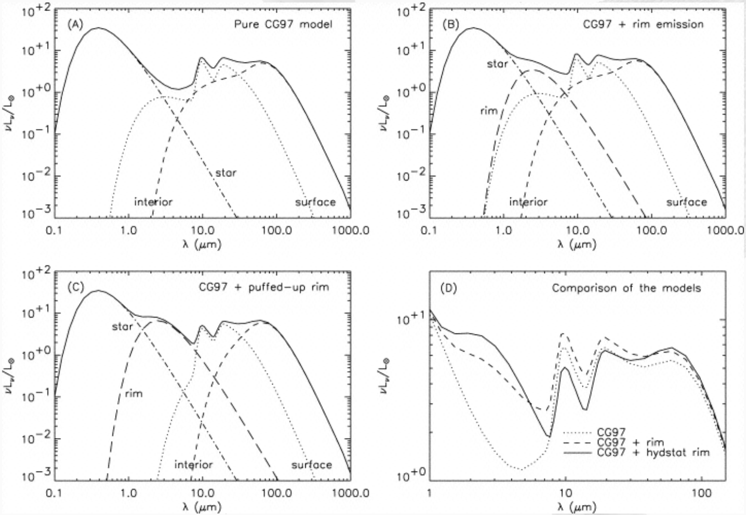
An geometry change near the dust sublimation ?



Dullemond, Dominik & Natta 2001

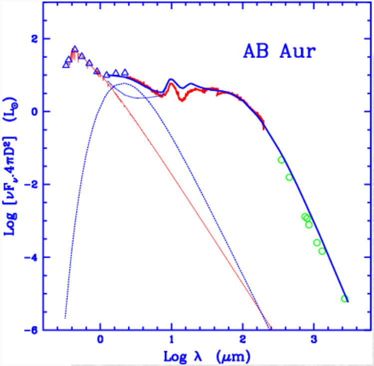
- Interface cavity/dust sublimation zone.
- Puffed-up and hotter rim (directly exposed to stellar flux).
- Will affect the shadowed region just behind (Mid-ir suppression).

Effect on the SED



Dullemond et al. 2001

SED need for this inner disk wall

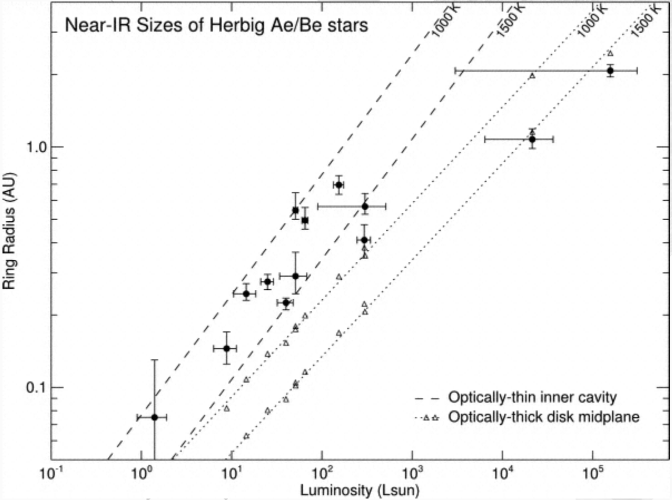


Natta et al. 2001

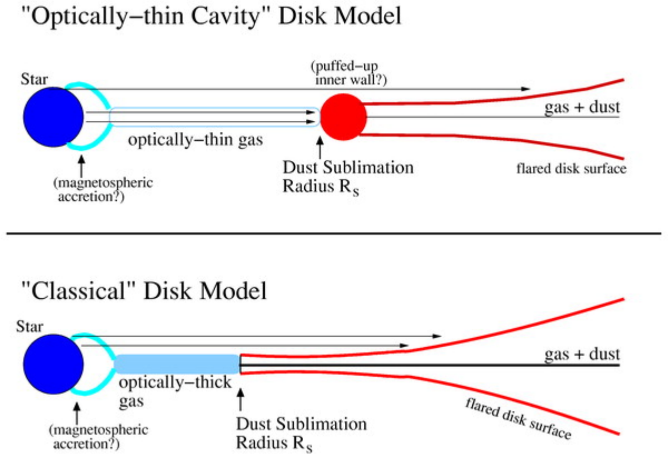
- Some SED show infrared deficit “Clearing” (DM Tau, GM Aur, Calvet et al. 2005)
- SED evidence of gaps in the first 10’s AU ?

Interferometry in the IR

Disk IR luminosity scales with size e.g. Monnier et al. 2005



Interferometry in the IR

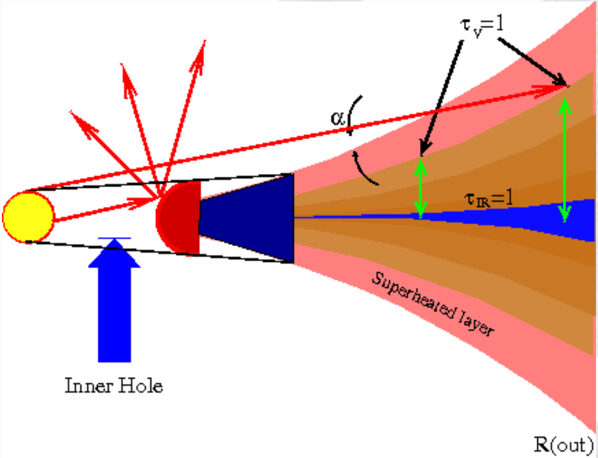


- Lower luminosities compatible with the puffed-up inner wall.

e.g. Monnier et al. 2005, see also Eisner et al. 2004, Millan-Gabet et al. 2001 and co-workers for more details on IRI.

NIR Excess observed at all disk angles

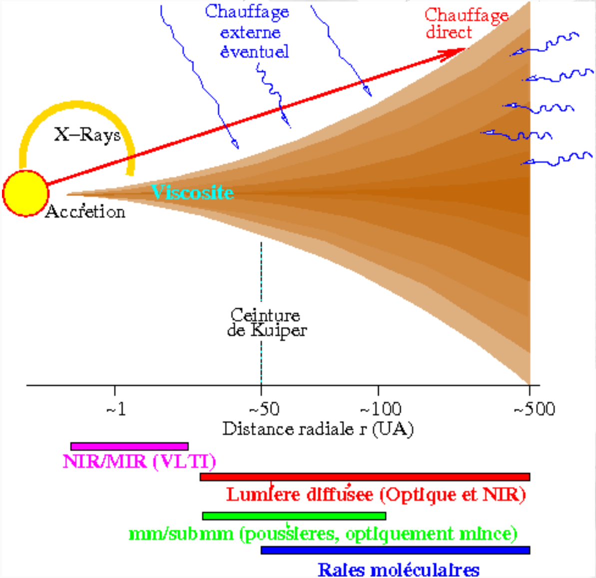
Not a wall !



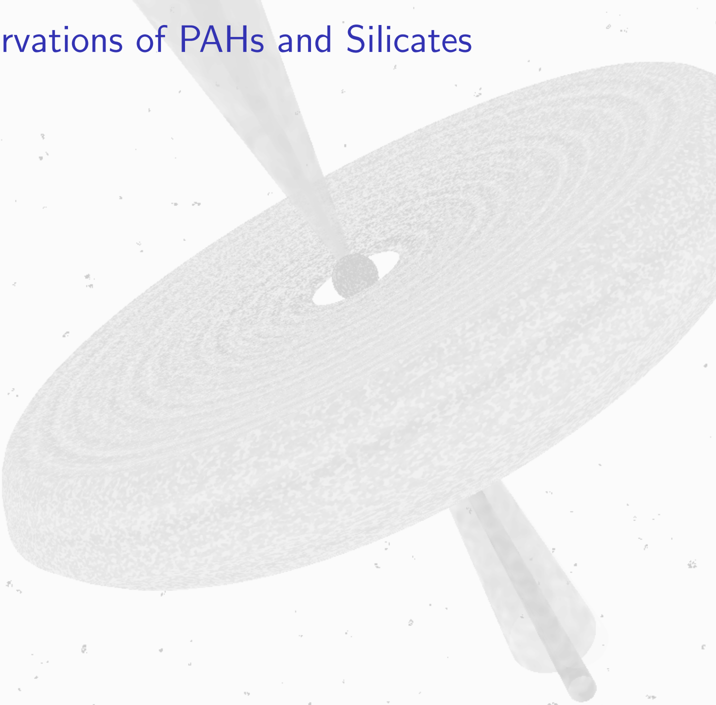
Isela & Natta 2005

- smoother inner puffed-up rim.
- Less sensitive to disk orientation as observed.

Other mecanisms to take into account for SED



Observations of PAHs and Silicates



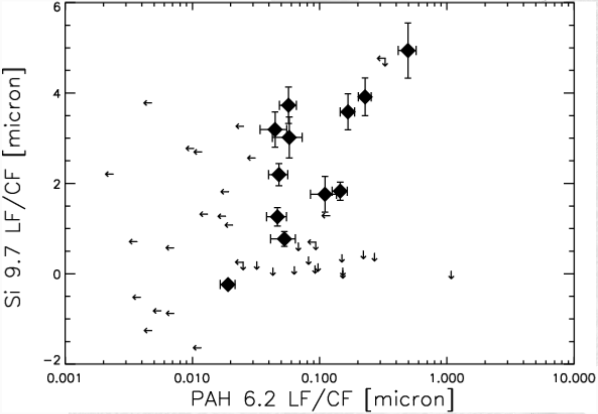
Emmanuel DARTOIS

Observations:
PAHs and Herbig-Ae/Be with ISO

Acke & van den Ancker 2004

- PAHs detected in 26 over 46 Herbig-Ae/Be (57%)
- 6.6μm in 25/46
- 7.7μm in 19/46
- 8.6μm in 16/46
- 3.3μm in 12/46

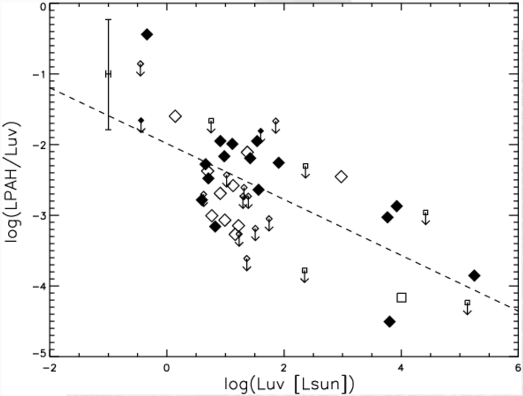
Correlation with Silicates



Acke & van den Ancker 2004

- PAHs poorly or uncorrelated with 10μm silicates

Luminosity emitted/absorbed



Acke & van den Ancker 2004

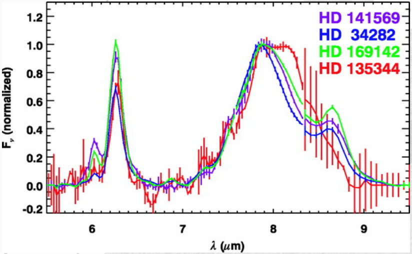
- absorption/emission decreases with increasing UV flux
- efficiency of PAH abs/em decreases ?
- Hardness play a role ?

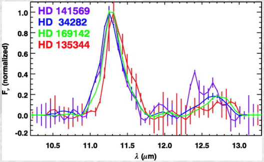
Insights ?

- No correlation between 850 or 1300 μm excess and PAHs features
- Not correlated with the disk mass but the surface ?
- No correlation between relative PAHs features strength and UV
- 3.3/6.6μm flux ratio varies from 9% to 94%
- and is apparently independent of stellar UV field
- Sources with faintest 60μm means faintest PAHs
- No correlation disk mass with PAHs emission $\Rightarrow$ surface layers excitation ?

Acke & van den Ancker 2004

Spitzer's spectra of Herbig Ae/Be

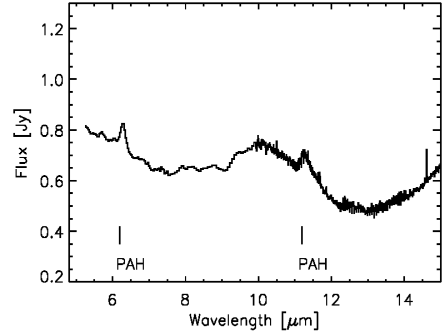




Sloan et al. 2005

- 6.2μm and 7.7μm shifted to higher wavelengths
- 2 out of 4 sources display aliphatic emission
- Variation in the 7.9μm/11.3μm ratio : ionisation state ?

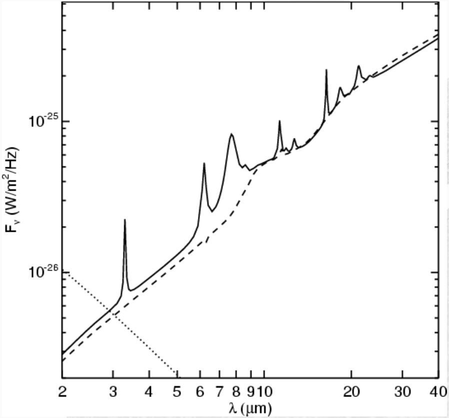
Spitzer's spectra of T Tauri



LkHα330, C2D program, Geers et al. 2005, Protostars and Planets V

- Confirmed detection of PAHS in about 15% of observed sources.
- ... but may be up to 45%
- Difficulty to observe the 7.7 and 8.6μm features, blended with silicates.

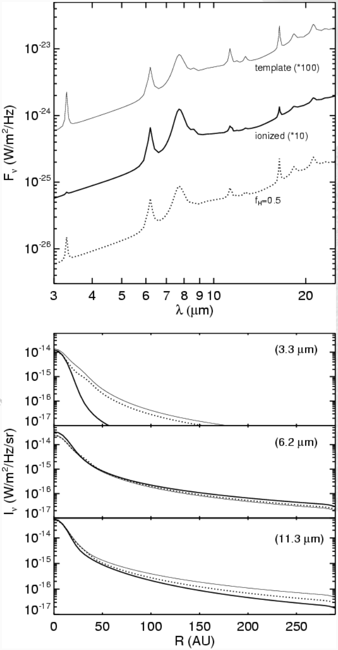
Modele de PAHs dans les disques



Habart et al. 2004

- Model "standard" idem au modele ISM
- $Nc = 100$, $Teff = 10500K$, $L = 32L\odot$, $M* = 2.4M\odot$, $Mdisk = 0.1M\odot$, $Rin = 0.3AU$, $Rext = 300AU$, Flared

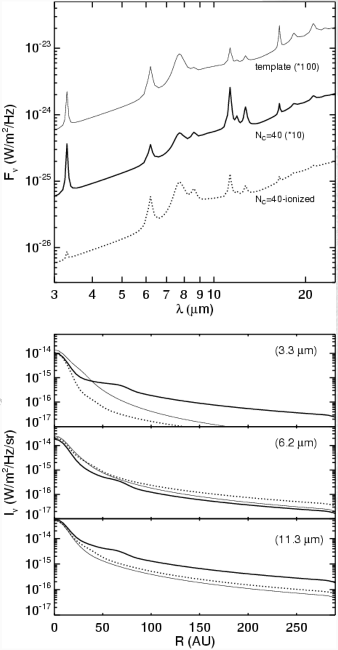
Modele de PAHs dans les disques



- Other parameters :
- ionized PAHs (lower CH modes)
- dehydrogenated PAHs (lower CH modes, enhance CC modes)

Habart et al. 2004

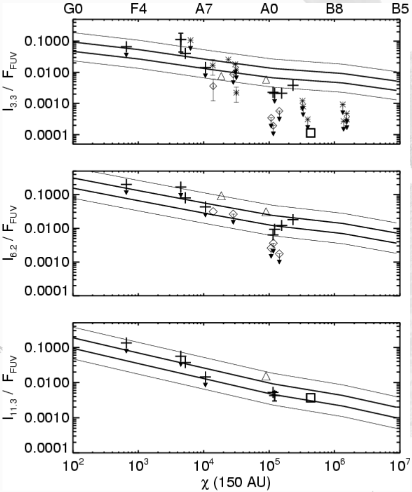
Modele de PAHs dans les disques



- Other parameters :
- lower sizes (Nc=40 instead of Nc=100)

Habart et al. 2004

Comparison with some obs



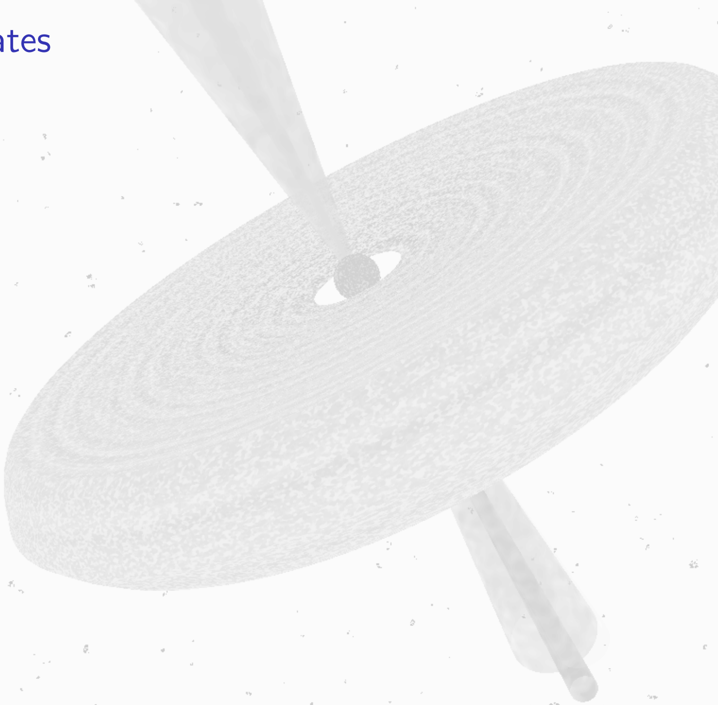
Habart et al. 2004

- Objects with strong UV have weak 3.3μm!
- The authors propose PAHs are destroyed or disk dissipated.
- integrated spectra are not good (need spatial resolution)
- compatible with large neutral or small ionized
- If present, provide an additional source of opacity and chemical reactant, should expect differences wrt silicates disks

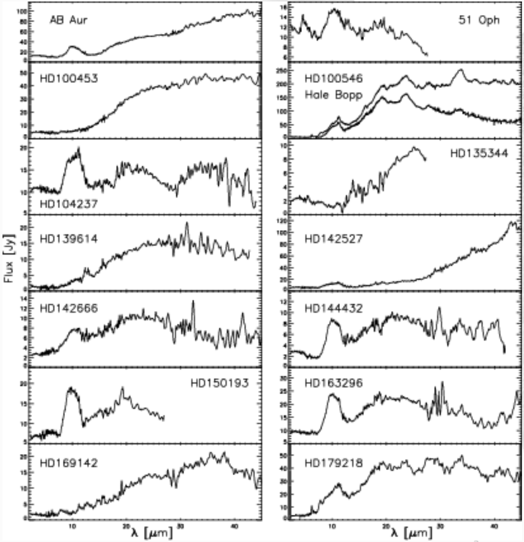
Spitzer's spectra of T Tauri

- Ground based obs start to resolve the PAH emission.
- Emission originate at (up to ?) 100-150 AU
- Geers et al. 2004; van Boekel et al. 2004; Habart et al. 2004
- If coming from 1AU would produce much higher fluxes
- Line flux for T Tauri 1-2 orders of magnitude higher than expected disk + ZAMS models (without taking into account UV form accretion shocks)
- Inner disk PAH abundance lower because destroyed (multi-photon process)

Silicates

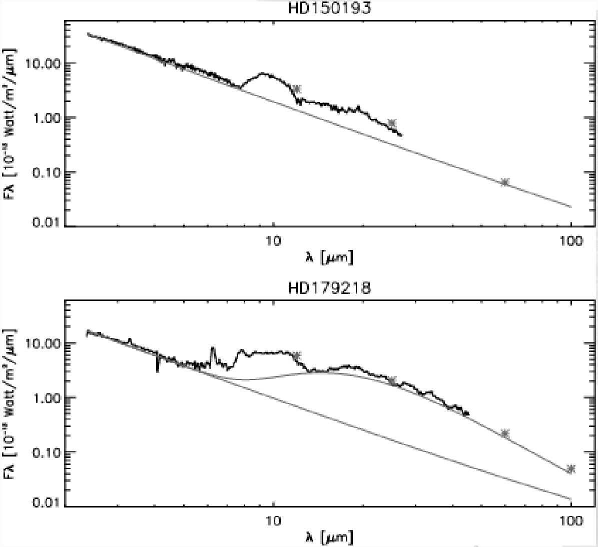


Silicates in Herbig Ae/Be and T Tauri



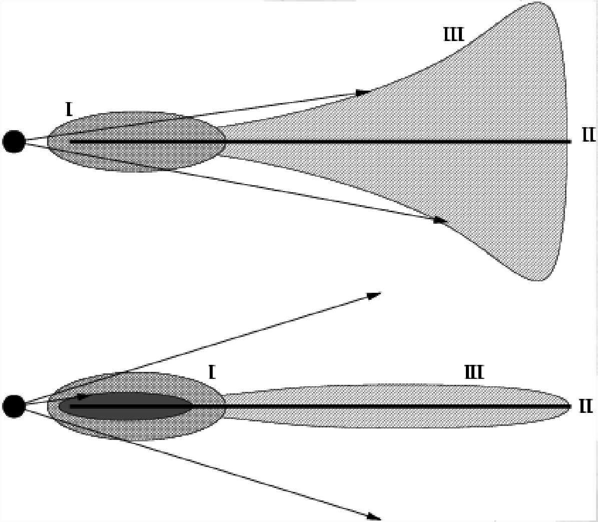
Meeus et al. 2001

Spectra of group I and II



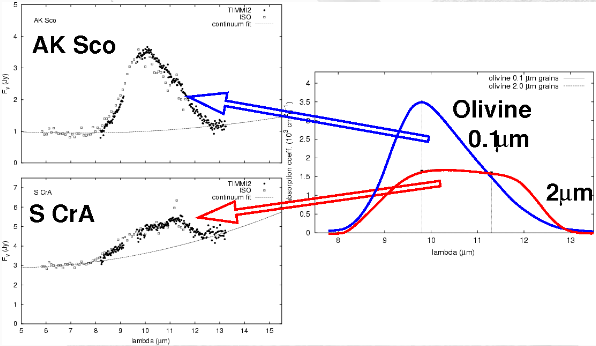
Meeus et al. 2001

Models of group I and II



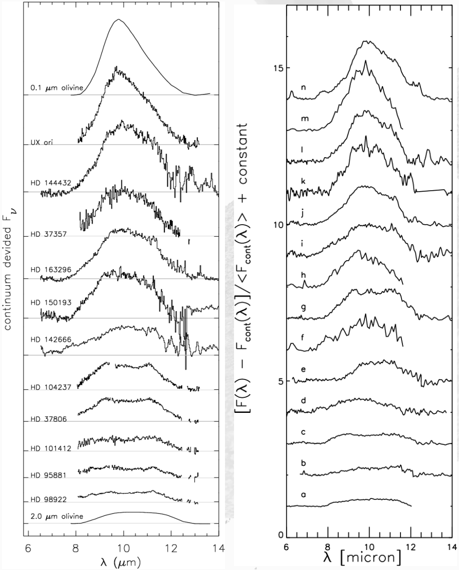
Dullemond and Dominik 2004

Grain growth : infrared evidence in T Tauri



Ground based, ISO; Przygodda et al. 2003, Bouwman et al. 2001

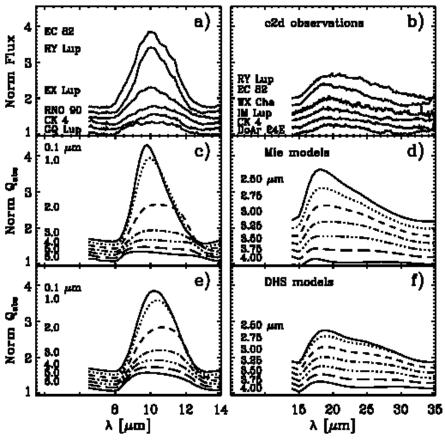
Grain growth : infrared evidence in Ae/Be



van Boekel et al. 2003

Acke & van den Ancker 2004

Spitzer's evidence in T Tauri

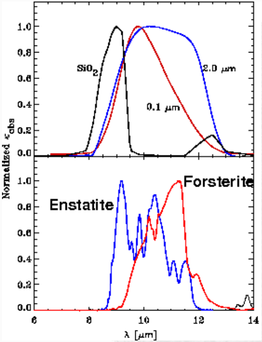


Kessler-Silacci 2006

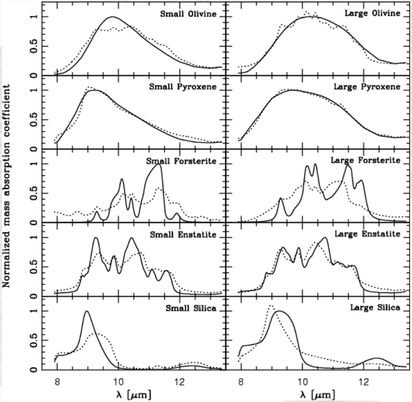
- Fast grain growth in the surface
- Not correlation strength/shape with age.
- Correlation strength/shape with spectral type ?

Compositional fits for Ae/Be

Must take simultaneously into account mineralogy AND grain growth

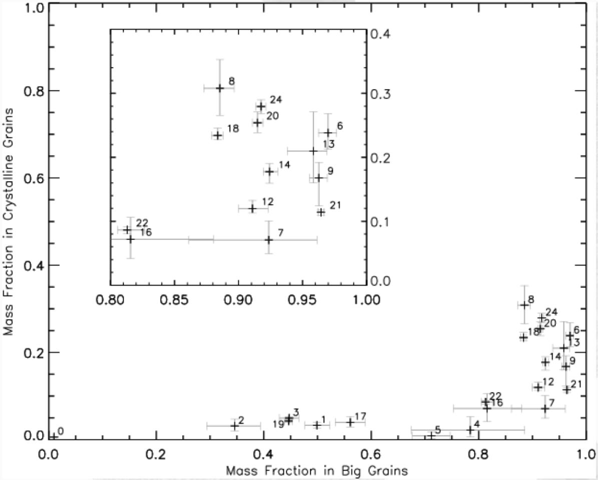


Bouwman et al. 2001



Van Boekel et al. 2005

Some correlations



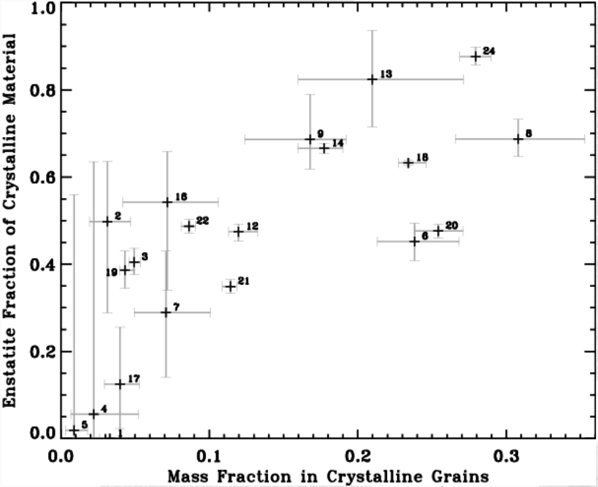
Grain size versus Crystallinity

Van Boekel et al. 2005 and ref therein

Implications ?

- Silicates in the ISM are almost 100% "amorphous"
- ($<$0.4% Kemper et al. 2004)
- and in the Rayleigh limit (small)
- all sources display at least 30% of big grains
- In disks observed, there is removal of small grains (otherwise we would see them !)
- grains are bigger than ISM (sensitivity bias, maybe even bigger)

Some correlations



Mass fraction in Enstatite versus total crystal

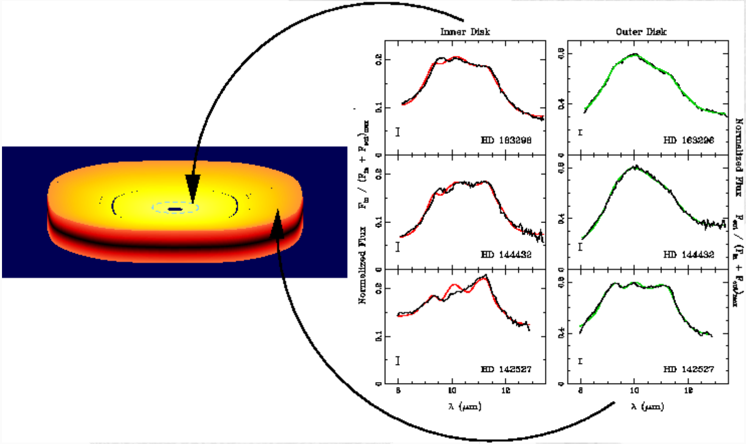
Van Boekel et al. 2005 and ref therein

Implications ?

- crystal/amorph. $\lesssim \approx$ 35%
- higher stellar mass $\rightarrow$ more crystal
- sources with crystal. sil. have more large grains
- Forsterite (Mg_2SiO_4) / Enstatite ($MgSiO_3$)
  Low crystallinities/ High cristallinities
- All sources with more than $2.5M_\odot$ have a high fraction of big grains.

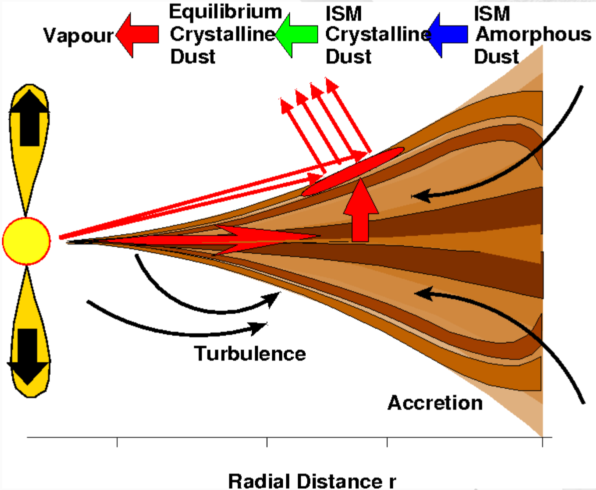
Van Boekel et al. 2005 and ref therein

Radial processing ?

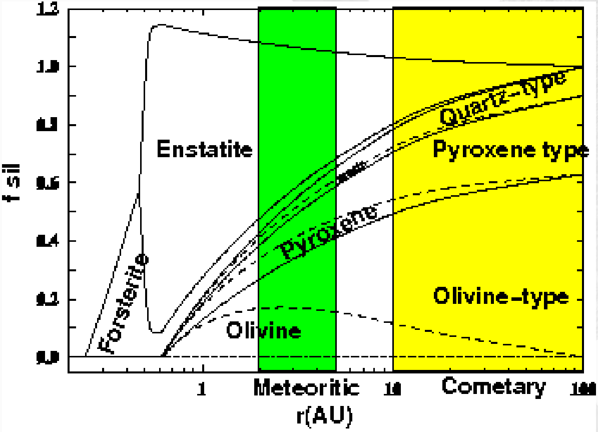


Van Bokel et al. 2004

Suggest differential processing :

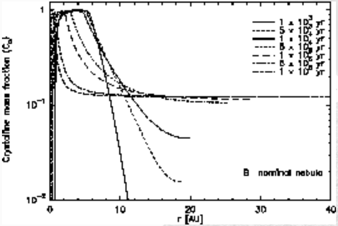


Differential processing : Enstatite/Forsterite

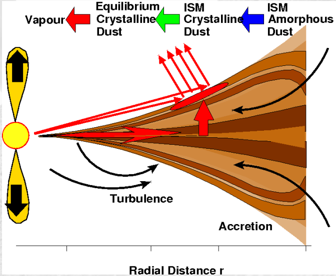


Gail & Seldmayr 2004

crystal to amorphous ratio



Bockelée-Morvan et al. 2002

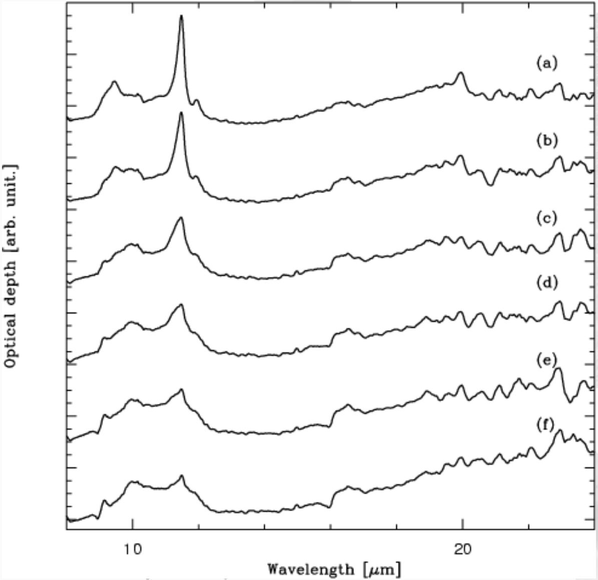


- If the radial mixing is efficient on timescale << disks life ...
- ... and the vertical mixing also
- then [cryst]/[amorph] might represent the global dust processing
- Forsterite band at 33.5μm Vandenbussche et al. 2004 with ISO $\rightarrow$ crystal at distance $>$ 10 AU.

A few processes affecting grains

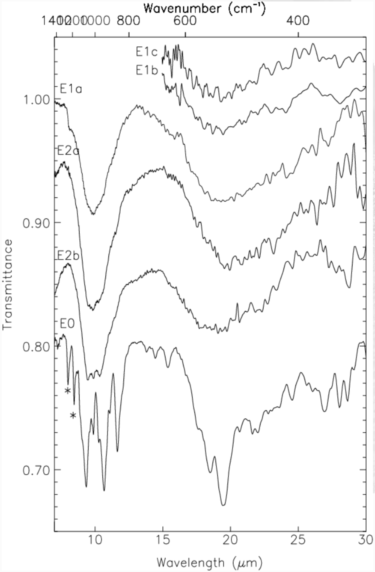
- Cosmic rays
- Thermal evolution (e.g. radial mixing)
- UV photolysis (stellar, ambient field, cosmic rays induced), X-Rays
- Surface reactions, accretion

30keV He+ irradiation of Forsterite (Mg_2SiO_4)



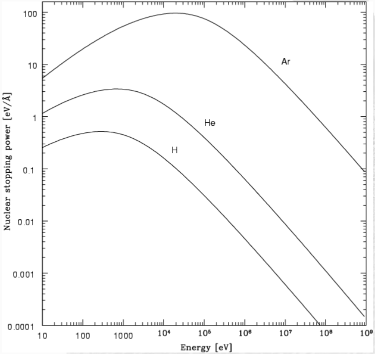
Brucato et al. 2004

20-50keV He+ irradiation of Enstatite ($MgSiO_3$)



Demyk et al. 2004, Carrez et al. 2002

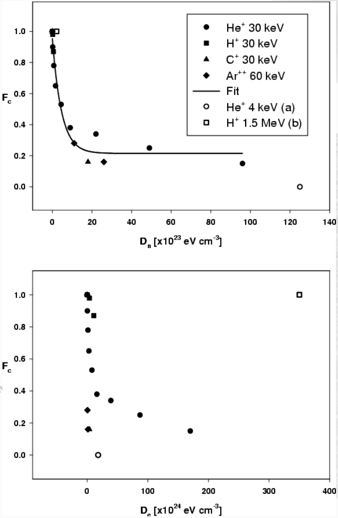
Energy dependence



Stopping power Forsterite, Brucato et al. 2004

- high-energetic cr (E $>$ 10MeV) pass through

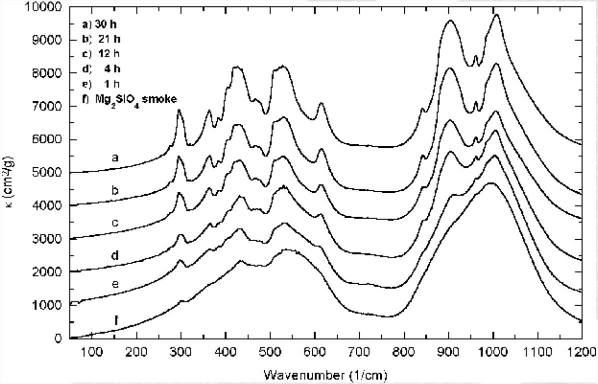
Astrophysical timescales



Irradiation doses, Brucato et al. 2004, Jager et al 2003

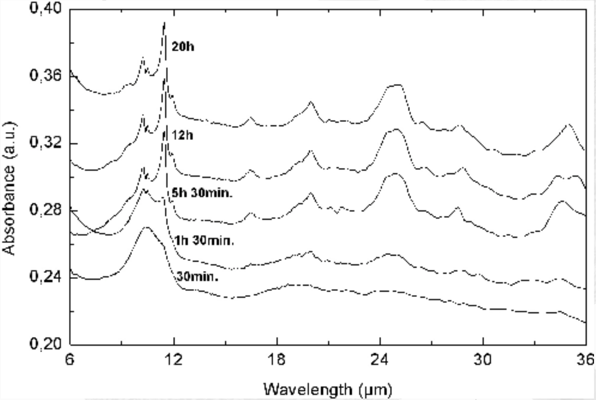
- low energy ions dose is about 10 ions $cm^{-2}.s^{-1}$ during a few 10^8 years Jones et al. 1996
- Grains receive therefore the equivalent of 10^{25-26} eV.cm−1 from SN ejecta
- Can fully amorphize 40 Angstrœ m grains, can explain ISM amorphous feature.

Thermal annealing of Mg_2SiO_4 smokes at 1000 K



Fabian et al. 2000

Thermal annealing keV amorphised Mg_2SiO_4 at 1030 K



Djouadi et al. 2005

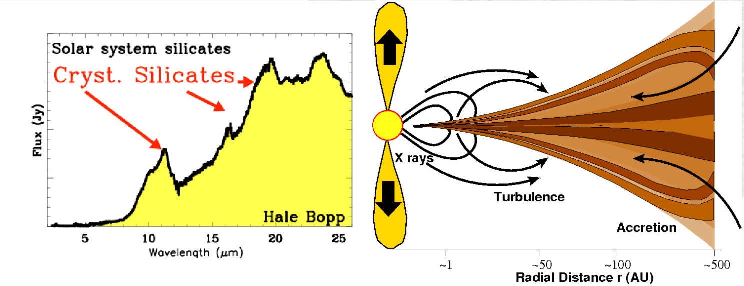
Activation energies for Mg_2SiO_4

$$\frac{1}{\tau} = \nu_0 \; exp(-\frac{E_a}{kT})$$

- Ea/k = 45500 K vapor phase + vacuum annealing (Hallenbeck et al. 1988)
- Ea/k = 39100 K laser smoke silicates + vacuum annealing (Fabian et al. 2000)
- Ea/k = 40400 K Laser vaporization + vacuum annealing (Brucato et al. 2002)
- Ea/k = 41700 K vapor phase + vacuum annealing + keV amorphization + vacuum annealing. (Djouadi et al. 2005)

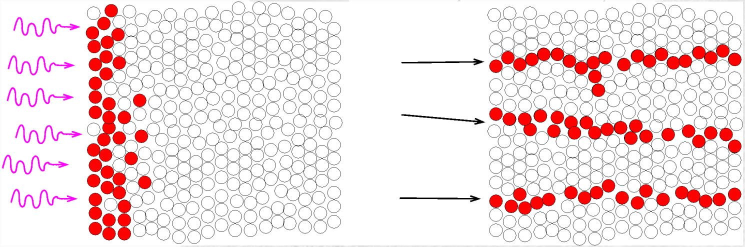
- Activation energies not much altered by irradiation
- No "metastable" state as suggested by e.g. Molster et al. 1998

Implication: radial mixing in disks !



- Cristalline silicates (Tform.≈1000K) mixed with ices (Tsubl.≈100K)
- Radial mixing, reprocessing, X ray

UV photons versus cosmic rays



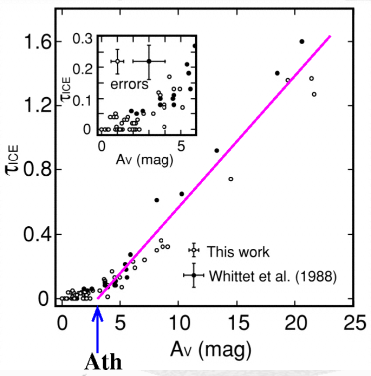
Adapted from Gerakines et al. 2001

- UV photons
- Photochemistry (break specific bonds)
- Penetration depth mixture dependant
- Stopped by a few molecular layers
- Ionise species

- Cosmic Rays
- Break bonds
- Penetration depth depends on stopping power
- Goes through the grain
- Ionise and generate secondary electrons

The existence of some surface reactions

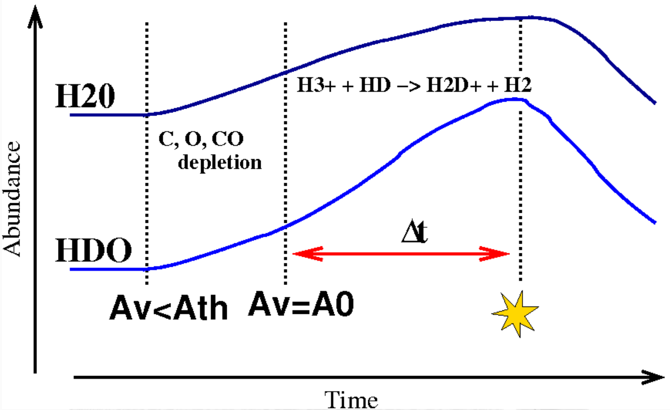
Much before class II, Field stars probe the onset and distribution of ices



Murakawa et al. 2000

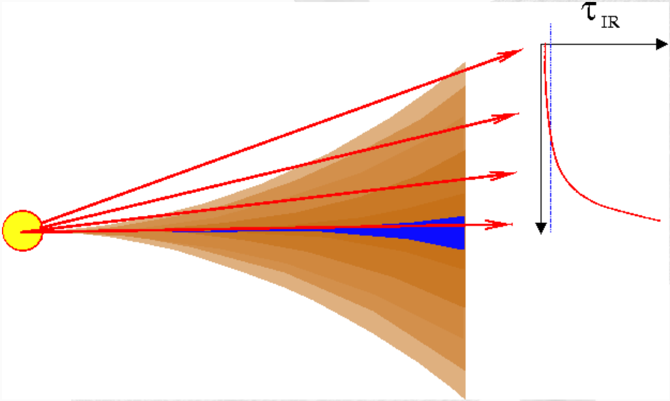
- τ H_20 $(\nu_1, \nu_3) = \alpha(Av - Ath)$
- Abundance 10^{-4}-$10^{-5}N_H$ $\neq$ Gas phase timescales
- surface reactions involving atomic oxygen needed
- well known for the formation of H_2 that surfaces required

Grain surfaces indirect influence



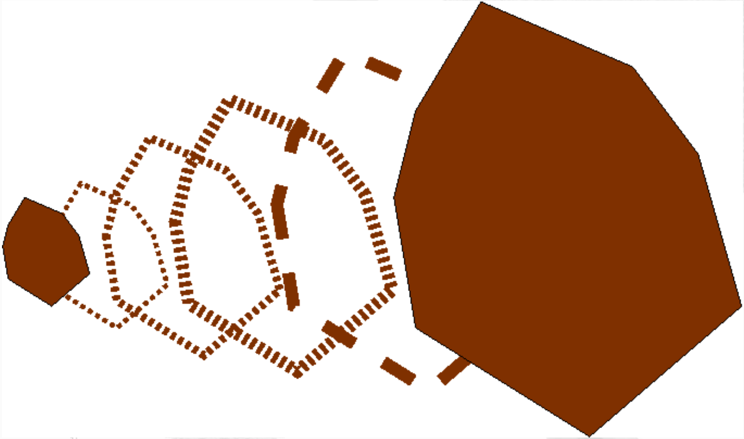
- Ices : inhibitors/promotors for gas phase chemistry.
- Coupling of gas and dust chemistry (need for grains to reform H_2 efficiently at the surface layer)

Grain surfaces indirect influence

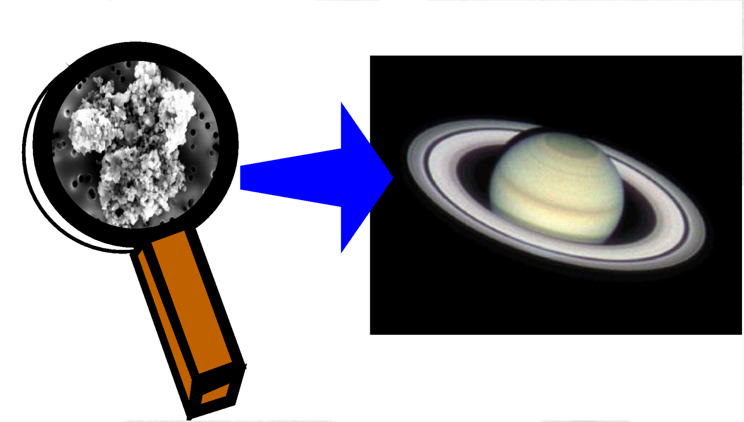


- Difficult to assess sometimes for geometrical reasons (τIR increases abruptly)

Size modification

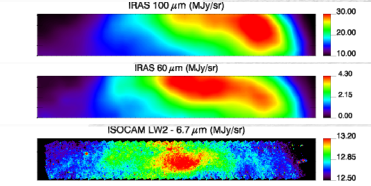


It exists !

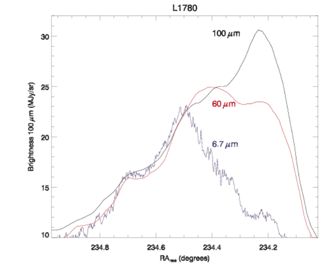


From diffuse to dense media: structuration of the ISM, intermediate phases

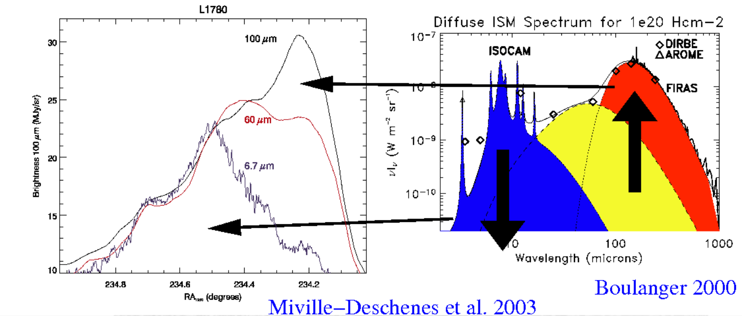
e.g. Cirrus cloud L1780



Miville-Deschênes et al. 2003

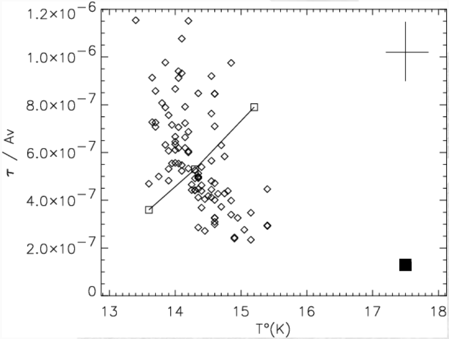


- Spectacular decrease of $6.7\mu m/100\mu m$ intensities
- ... but not due to extinction as the cloud is thin



- variations attributed to PAHs decrease versus VSG increase.
- No spectral info on silicates.
- Signs of dust processing, coagulation, but also protection

Gas accretion and coagulation

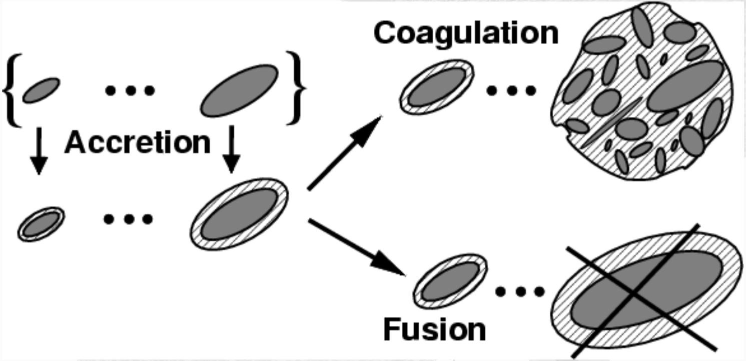


Cambresy et al. 2001

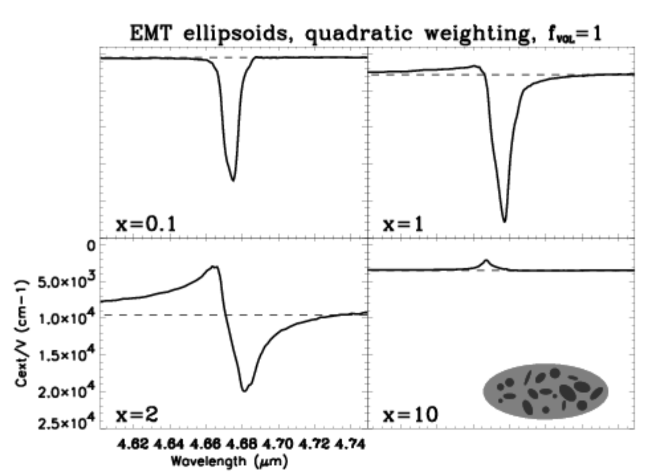
- $\tau(200\mu\mathrm{m})/\mathrm{A_V}$ for $\mathrm{A_V} \lesssim 6 \; > \; \tau(200\mu\mathrm{m})/\mathrm{A_V}$ diffuse

e.g. Boulanger et al. 1996, Bernard et al. 1999, Stepnik et al. 1999, del Burgo et al. 2003

Grain growth in class 0-I ?



Grain growth in class 0-I

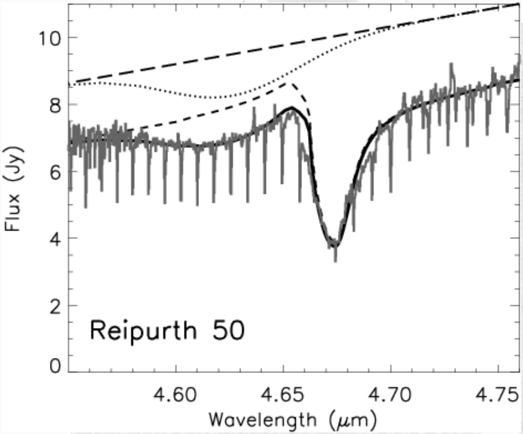


$$x = \frac{2\pi a}{\lambda}$$

Dartois 2006

- size effects on line profiles

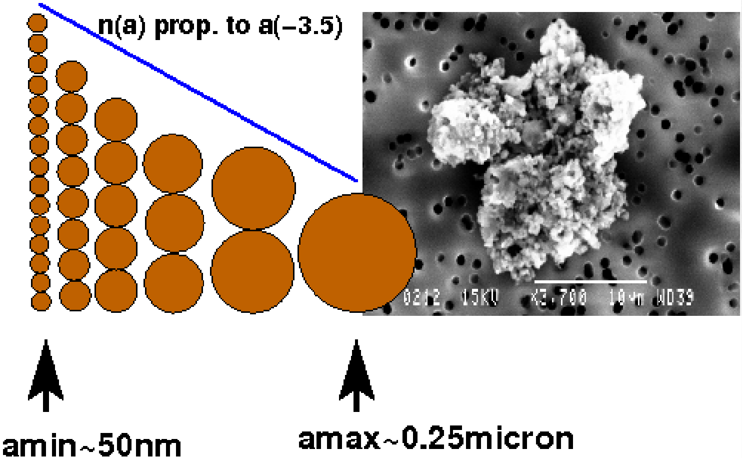
Observed with line ice mantles profiles ?



Dartois 2006

- influence on a weighted size distribution may be present.

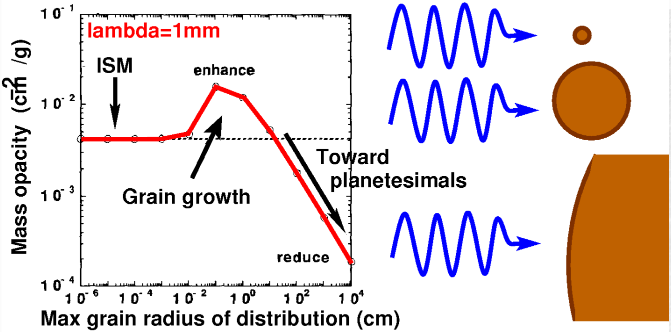
Global effect on a distribution



Mathis Rumpl Nordsieck 1977; Draine & Lee 1984

- ... slope changed wrt the dense clouds observed.

Mass absorption change with size

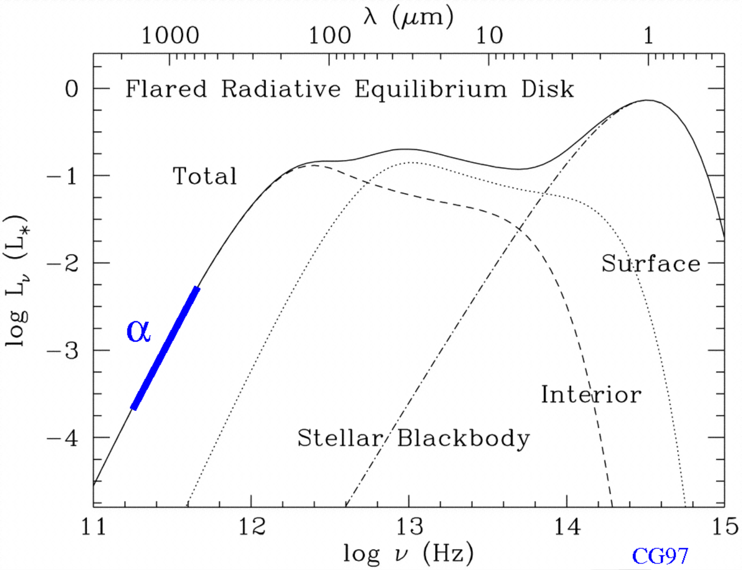


For an absorbing material:

e.g. Miyake & Nakagawa 1993, Kruegel & Siebenmorgen 1994

- ... but still size above about 50nm (otherwise nanoparticles effects and then molecular)
- low size parameter ($2\pi a/\lambda << 1$) $\kappa \propto$ volume
- intermediate size parameter ($2\pi a/\lambda \approx 1$) κ highest (best coupling of wave vector to grain size)
- low size parameter ($2\pi a/\lambda >> 1$) $\kappa \propto$ surface

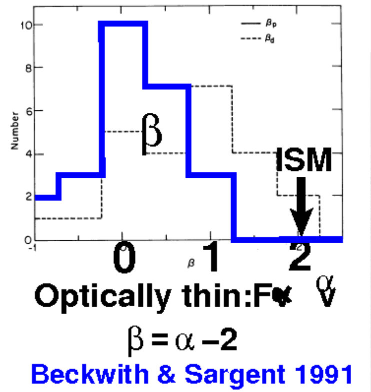
A jump into disks in the mm : spectral index β



A jump into disks in the mm : spectral index β

- Flux received from a disk in the mm:
- Optically thin:
  $F(\nu) \propto \kappa(\nu)[cm^2.g^{-1}]\ B_\nu(T_{dust})\ M_{dust}\ /\ d^2$
- Rayleigh-Jeans limit:
  $F(\nu) \propto \nu^2\ \kappa(\nu)[cm^2.g^{-1}]\ T_{dust}\ M_{dust}\ /\ d^2$
- Outside the solid material strong absorption bands
  If $\kappa(\nu) \propto \nu^\beta$ then $F(\nu) \propto \nu^{\beta+2}$
  The β of dust can be infered from the observed flux slope minus 2.

mm dust index change in disks wrt ISM



Consequences:

- Some grain properties have changed.
- With β, Mass determination and slope changes.
- The Dynamical masses requires this change in mass abs coeff (e.g. Hogerheijde et al. 2003; ref in talk by A.D., S.G.), otherwise unstable disks

$\beta \approx 1$ in the mm for circumstellar disks, Why ?

- Large fluffy grain ?
- Grain with sizes of the order of the wavelength ?
- Chemical composition ?
- Optical thickness effect ?
- Temperature effects ?

Optical thickness

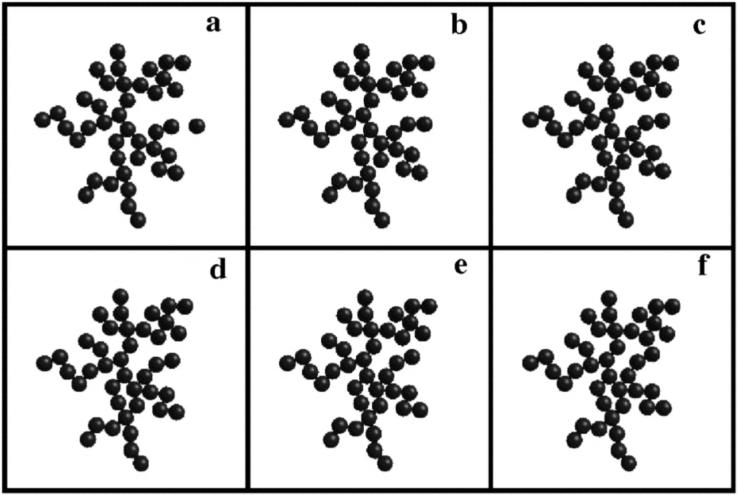
- If the disk is not fully optically thin at mm wavelengths
- $\beta \approx (1 + \Delta)(\alpha - 2)$
- with Δ ratio of thick to thin (Beckwith & Sargent 1991)
- it makes β higher

Composition

- Various components tested by e.g. (Pollack et al. 1994)
- authors say silicates and organics are dominant sources of grain opacities
- H_2O ice (also present in spherical cores and beta almost the same)
- Low k and n at long wavelength, a moderate effect if pure
- but may be important if allow to stick together high n,k material (H_2O matrix effect).

Fluffyness ?

Investigated theoretically and experimentally, e.g;



e.g. Dominik & Tielens 1997, Wurm & Blum 2004

Shape and Fluffyness ?

- κ ten times higher in the geom. regime.
- κ same in the Rayleigh regime (volume)
- κ smoother in the intermediate regime
- Increases the size parameter and coupling of the grains.
- Make an antenna if one dim. large for the same volume.

Compact

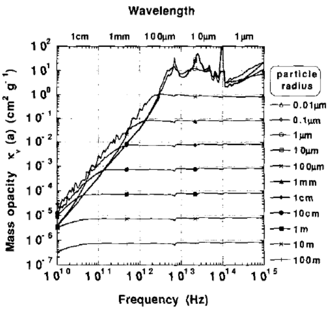


FIG. 4. Mass opacities (in cgs units) of single-sized compact dust particles ($f = 1$) for various radius a (0.01 μm to 100 m) composed of the intimate mixture of silicate and H_2O–ice, where the abundances of dust particles with respect to the H_2 gas are assumed to be solar. Curves for $a \lesssim 10$ μm are almost identical at $\nu \lesssim 10^{12.5}$ Hz.

Fluffy

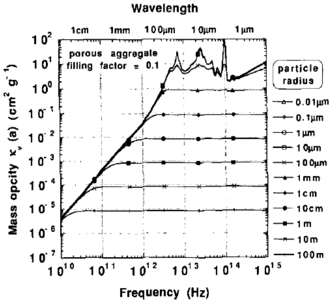
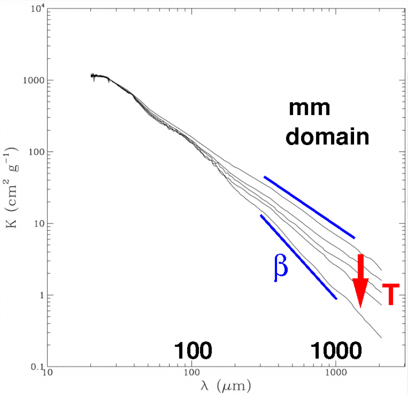


FIG. 8. Mass opacities of porous single-sized dust particles. The filling factor of dust materials f is taken to be 0.1. Except for the porosity of dust particles, the same as Fig. 4. Curves for $a \lesssim 100$ μm are almost identical at $\nu \lesssim 10^{12.5}$ Hz.

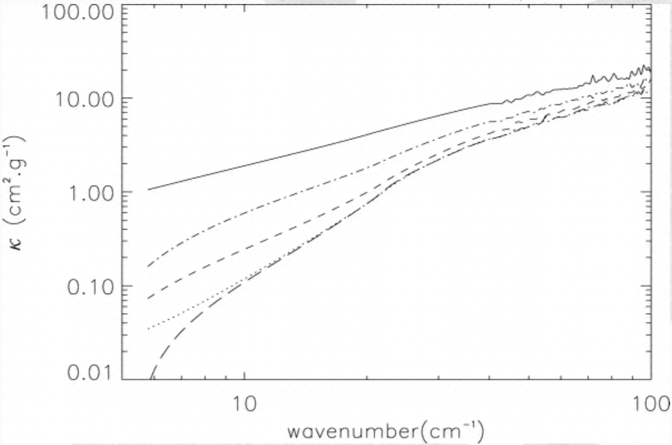
Temperature variation of β ?



Fayalite 295,200,160,100,24K e.g. Mennella et al 1998

- Dust index change for the same material, then T,M vary.

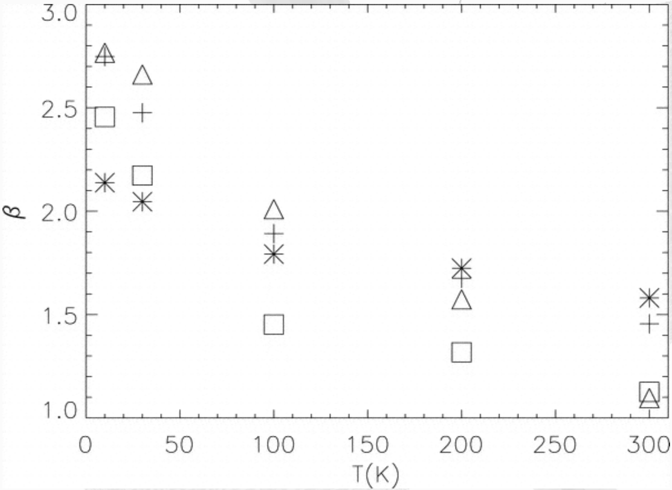
T variation of β



e.g. Boudet et al 2005

- MAC for 1.5μm silica spheres

T variation of β



e.g. Boudet et al 2005

- Temperature dependence of β MAC for various silicates in the $10 - 20\text{cm}^{-1}$ range.

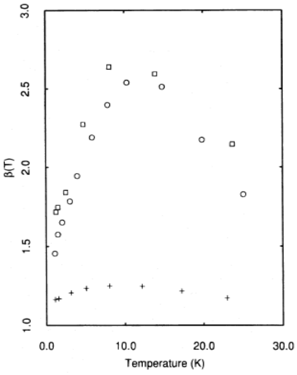
T variation of MAC

Temperature (K)	10	30	100	200	300
Silica spheres (1.5 μm)	0.33	0.36	0.73	1.79	5.66
Fumed silica	0.45	0.51	1.26	2.18	3.75
$MgSiO_3$ glass	0.22	0.25	0.37	0.53	0.75
$MgSiO_3$ sol-gel	0.12	0.15	0.32	0.59	0.98

Table: Mass absorption coefficient at $10cm^{-1}$ ($cm^2.g^{-1}$)

e.g. Boudet et al 2005

At very low temperatures

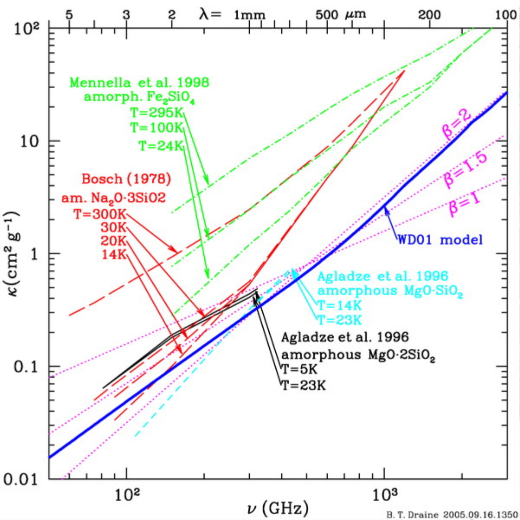


Silicates

e.g. Agladze et al. 1996

- Turnover in the MAC between 10 and 20K.
- Two Level Systems.

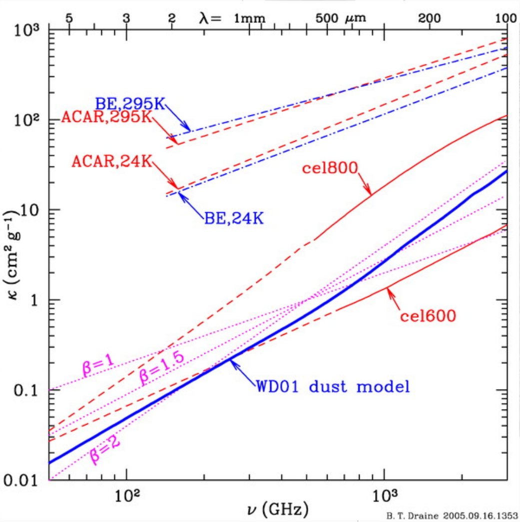
A summary of abs. coeff.



Silicates

Draine 2006

A summary of abs. coeff.



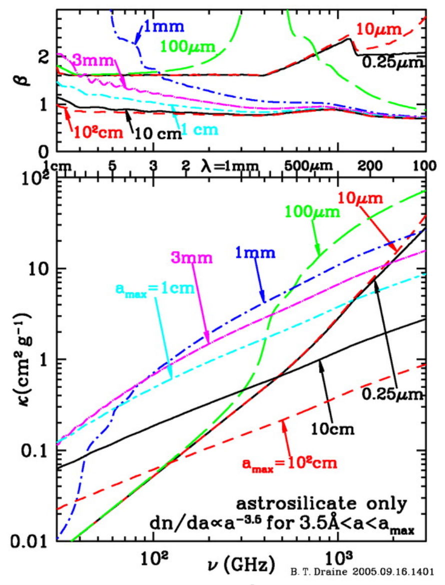
Carbonaceous material

Draine 2006

Effect of the size distribution

- $\kappa_\nu = \frac{\int_{amin}^{amax}(dn/da)Cabs(a,\nu)da}{\int_{amin}^{amax}(dn/da)\ V(grain)\rho da}$
- $dn/da \propto a^{-3.5}$
- $amin = 3.5Å$

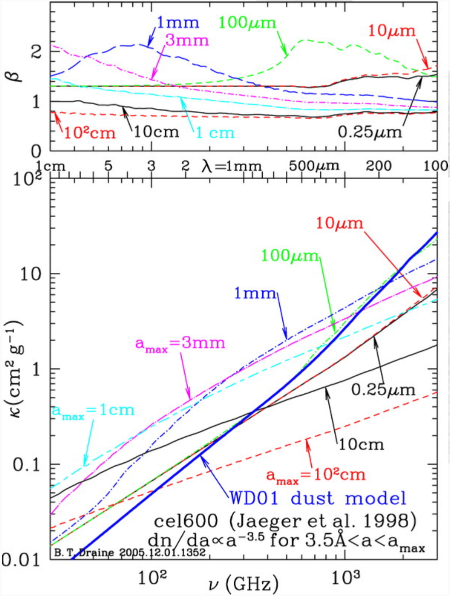
MRN size distribution effect on β



Silicates

Draine 2006

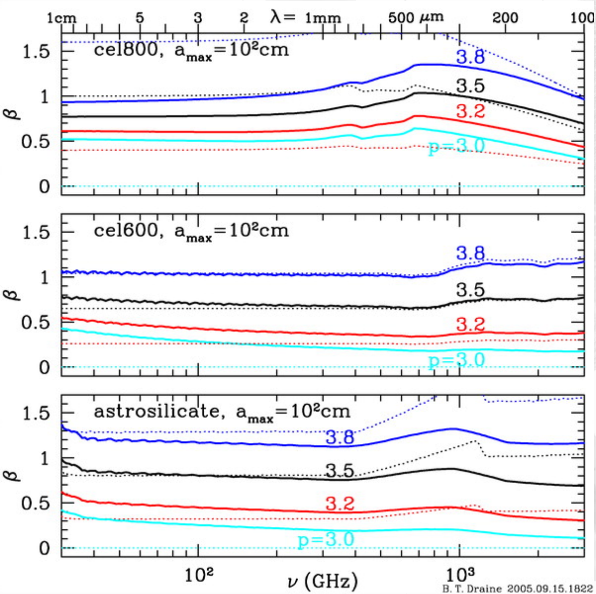
MRN size distribution effect on β



Carbonaceous material

Draine 2006

other large size distributions



Draine 2006

Modification of some grain size distribution

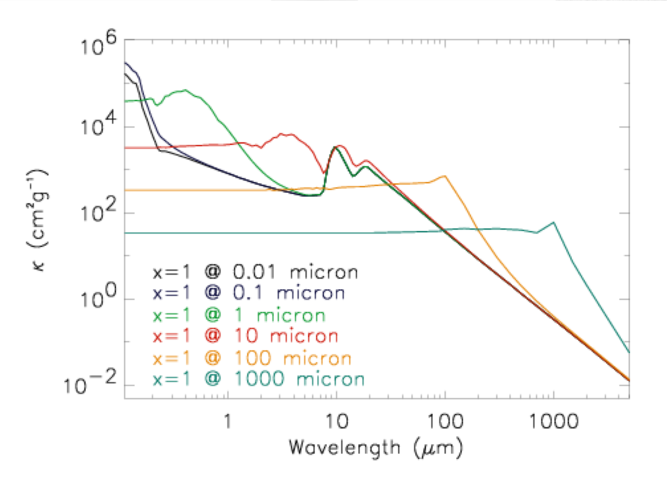
Somme insight with the hands for discussion

- Once defined a power law size distribution with $n(a)da \propto a^{\alpha}da$ between $a-$ and $a+$
- and with fixed total mass (Mgas+Mdust=Cte)
- case a : gaz phase accretion
- case b : coagulation
- case c : sedimentation

Size increase by gaz phase accretion

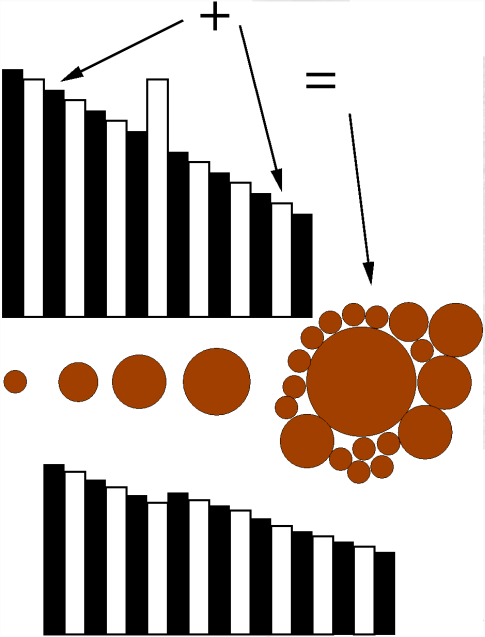
- $\rho_{gas}/\rho_{dust} \lessapprox 100$
- but only a few 10^{-3} to 10^{-2} in mass is accretable (i.e. not in H, H_2, He ...)
- increase almost independent of initial grain size (i.e. each grain acquire the same small thickness)
- small (tiny) increase of large size
- ... large increase of small sizes

Size increase by gaz phase accretion

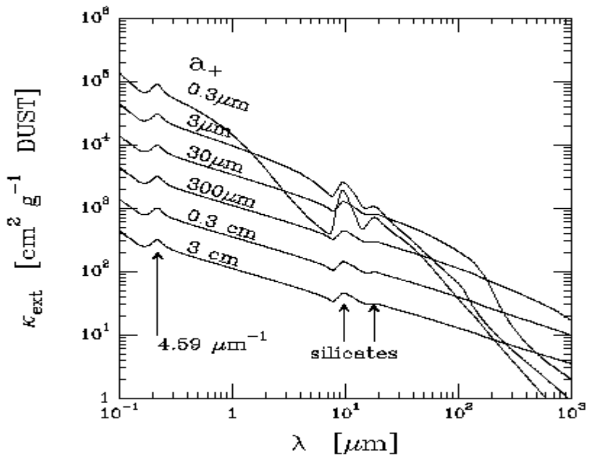


- moderate influence on lowering UV extinction.
- cannot account for mm emissivities.

Size distribution modification : coagulation



Some effects of coagulation



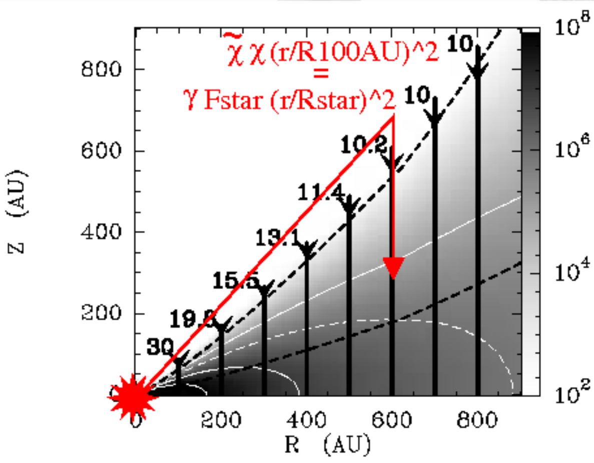
Hily-Blant et al. 2006

- Increase of the upper size cut-off @ fixed mass

Size distribution modification : coagulation

- large disappearance of the small grains.
- strong influence on UV properties.
- possibility to grow to mm sizes without cosmic abundance limit.
- Counterbalancing mechanism ?
- If grains in disks have grown bigger than $\sim$1cm, one need for a change in size distribution slope @ large grain radius, otherwise inconsistent

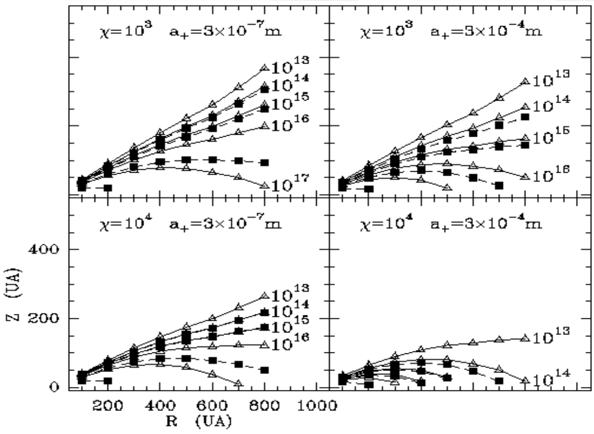
Some effects of coagulation on gas chemistry



Hily-Blant et al. 2006, see also ref therein

- Coupled to a PDR code Le bourlot et al. 1993

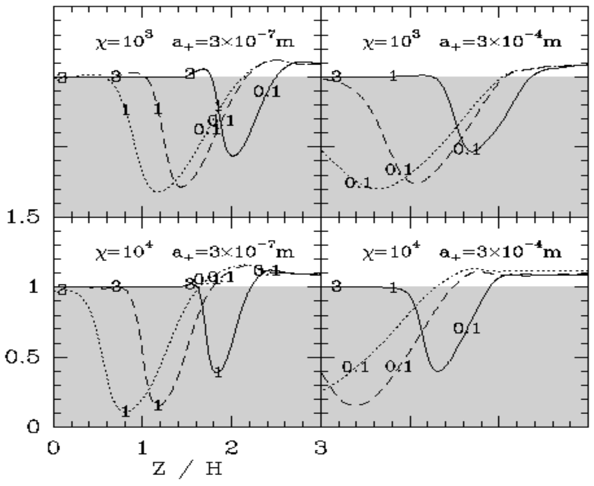
Some effects of coagulation



Hily-Blant et al. 2006

- Increasing a+ affects more than increasing UV flux.
- The CO photodissociation occurs deeper in the disk.

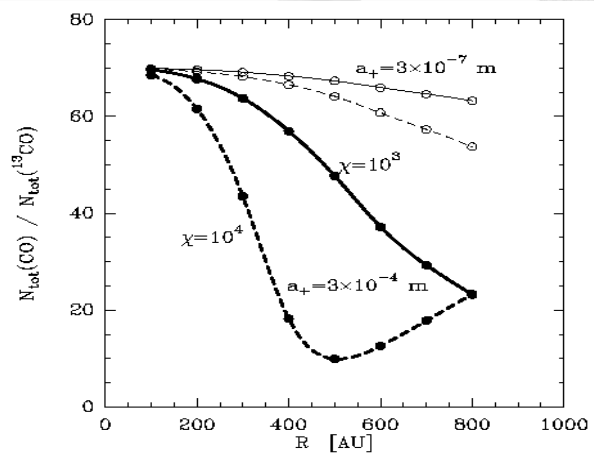
Some effects of coagulation



Hily-Blant et al. 2006

- $^{12}CO/^{13}CO$/initial($^{12}C/^{13}C$) @ 100,400,800 AU
- Affects also vertically the $^{12}CO/^{13}CO$ ratio

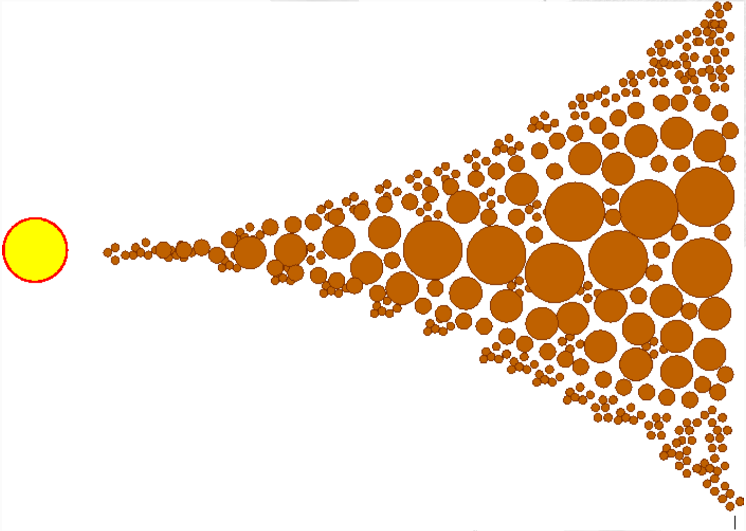
Some effects of coagulation



Hily-Blant et al. 2006

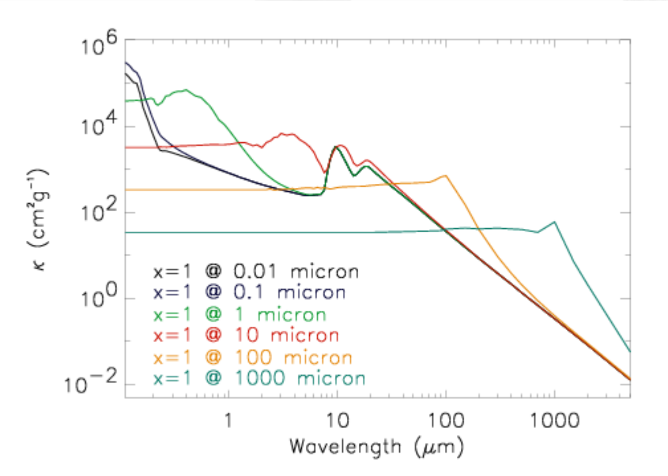
- then the integrated $^{12}CO/^{13}CO$ ratio

Sedimentation

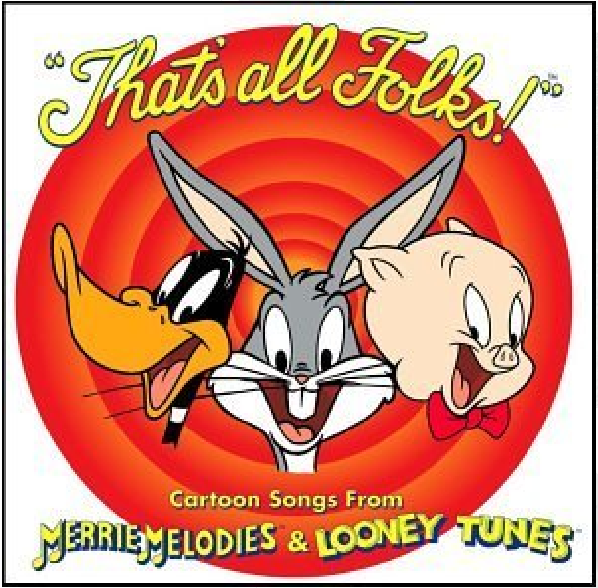


e.g. Barrière-Fouchet et al. 2005

Sedimentation



- Phase separation
- Affects largest grains in a distribution
- Therefore affect much less the transfer in the UV !


"That's all Folks!"
Cartoon Songs From
MERRIE MELODIES & LOONEY TUNES