Composition and evolution of grains

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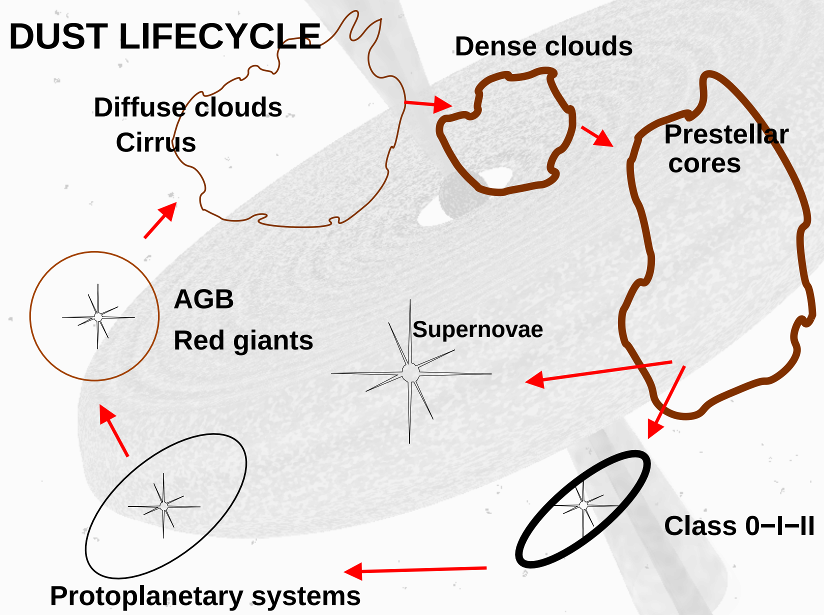
Galactic dust cycle



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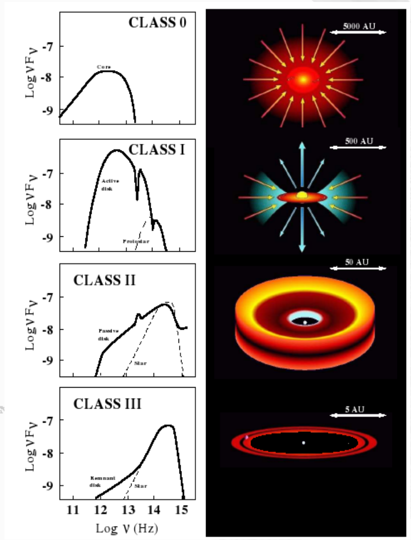
Class 0-III



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

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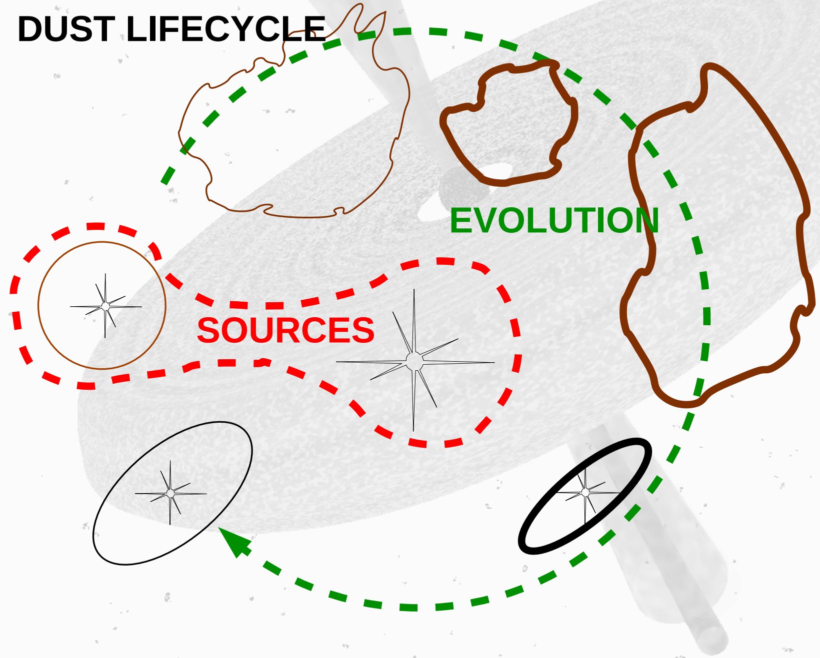
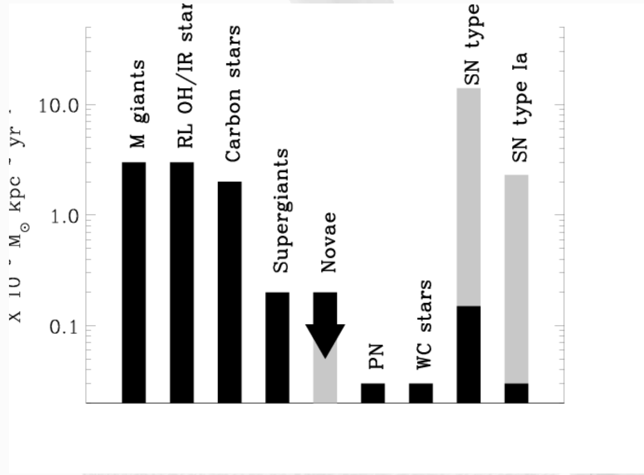
Dust sources : from production to evolution



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

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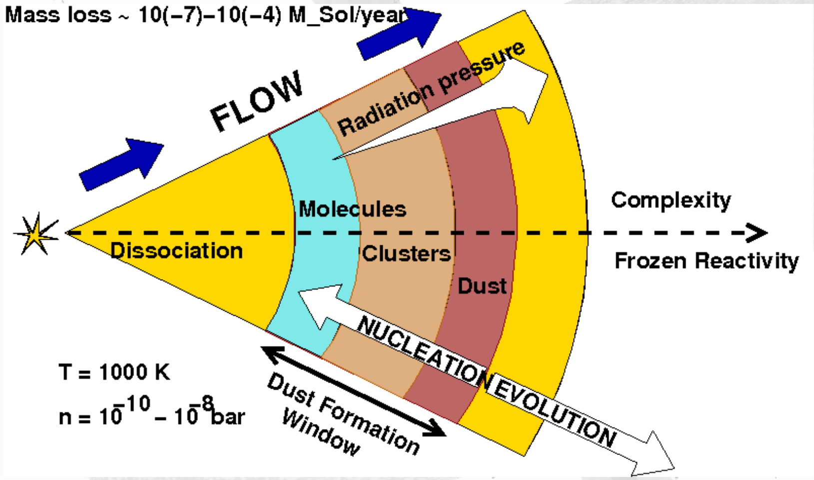
Schematic view of a cooling/expanding flow



after Patzer 2004, ASP conference

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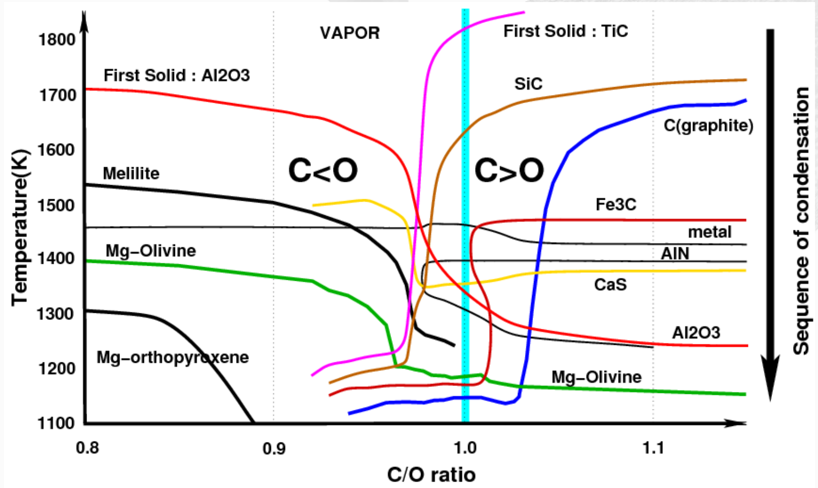
Chemical effect : composition driven by the C/O ratio



Ebel, 2000, JGR 105, 10365.

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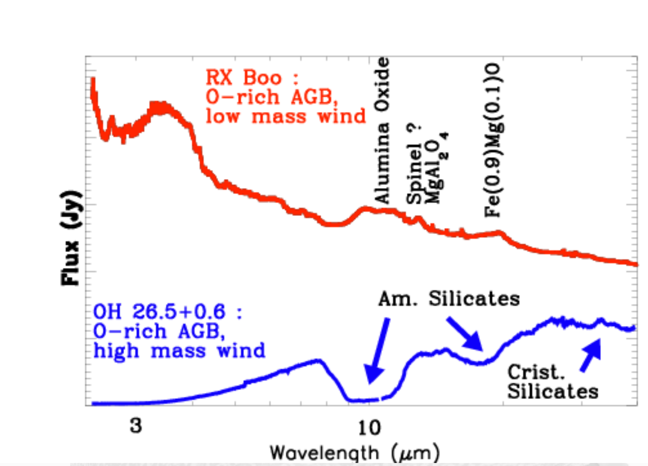
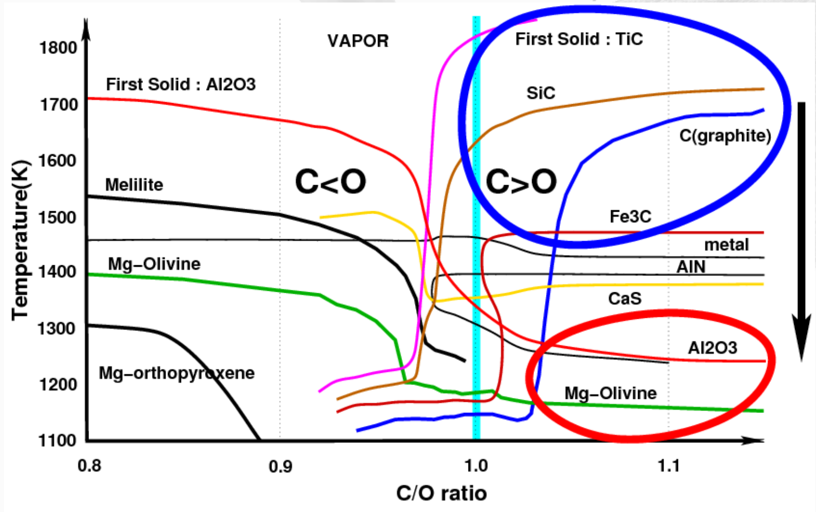
Physical effect : evolution of the flow rates



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

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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

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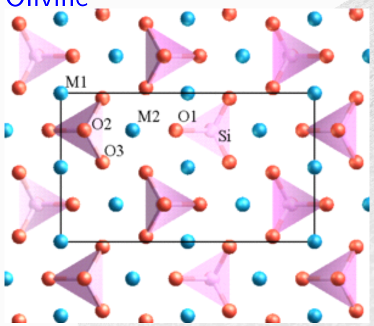
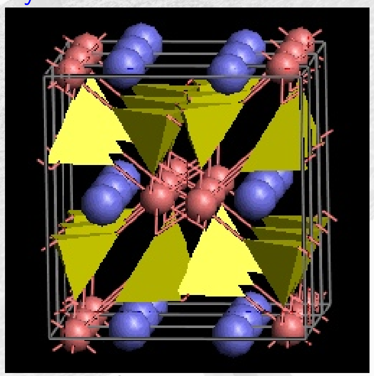
Silicates

Olivine



Pyroxene



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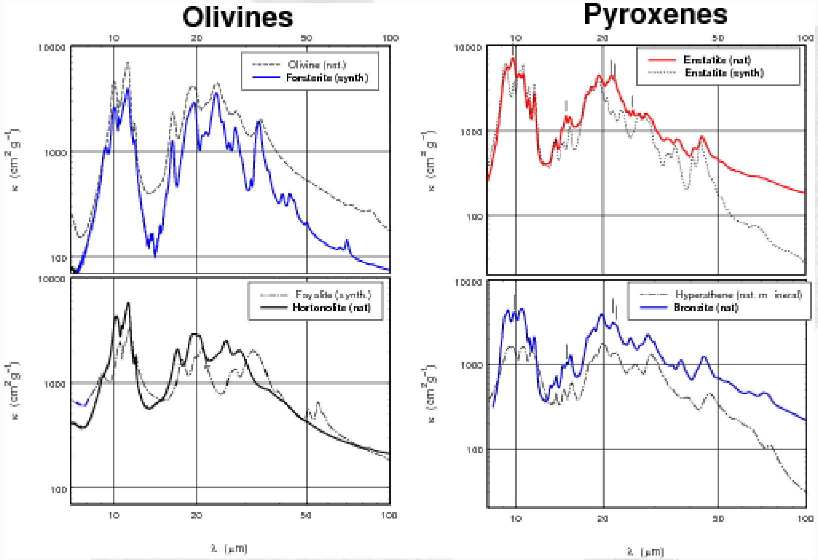
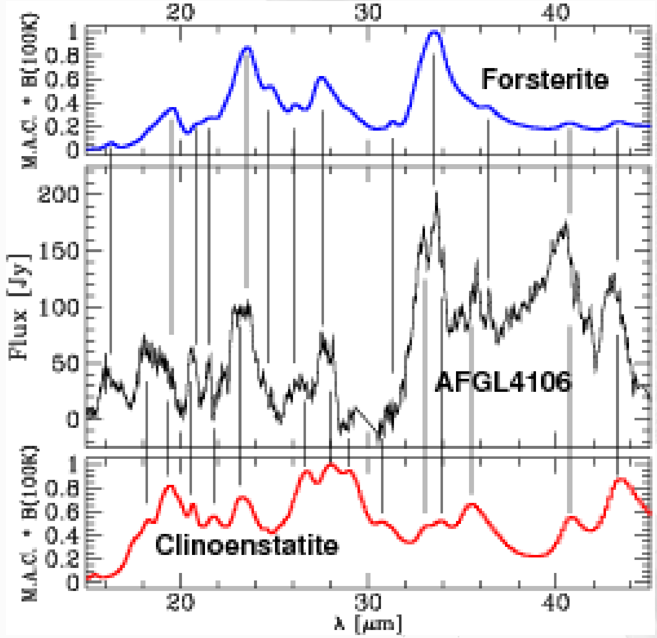


Jaeger et al. 1998



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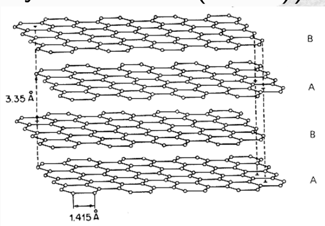
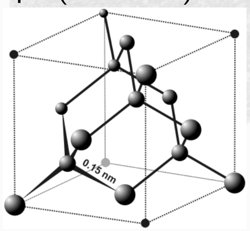
Carbonaceous material : versatile bondings

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



- sp^3 (diamond)



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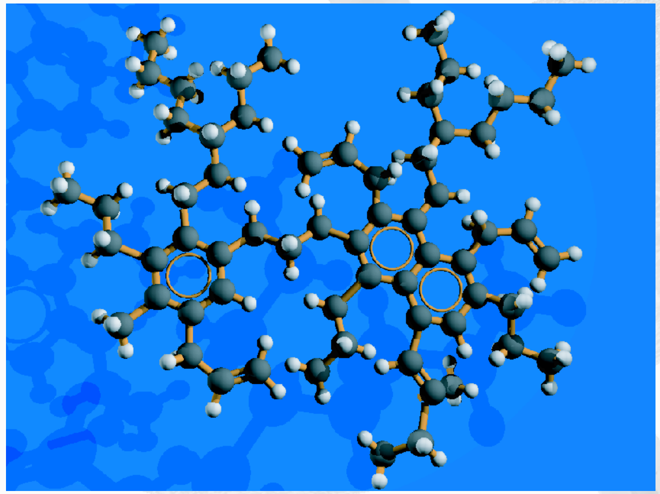
mixed bondings: (Hydrogenated) Amorphous Carbons (HAC)



Dartois et al. 2005

- Large number of phases

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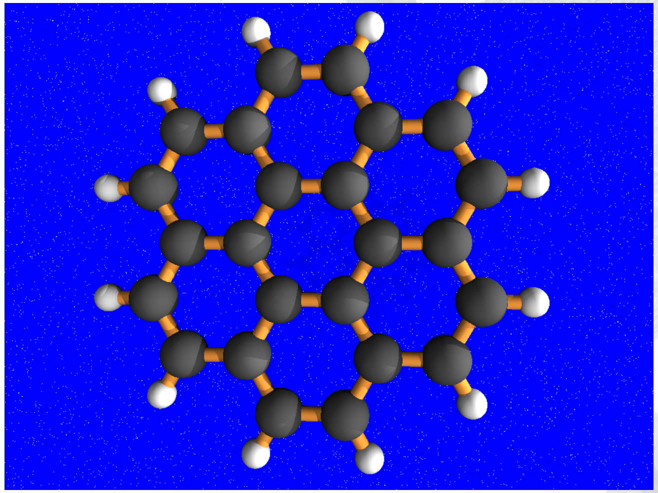
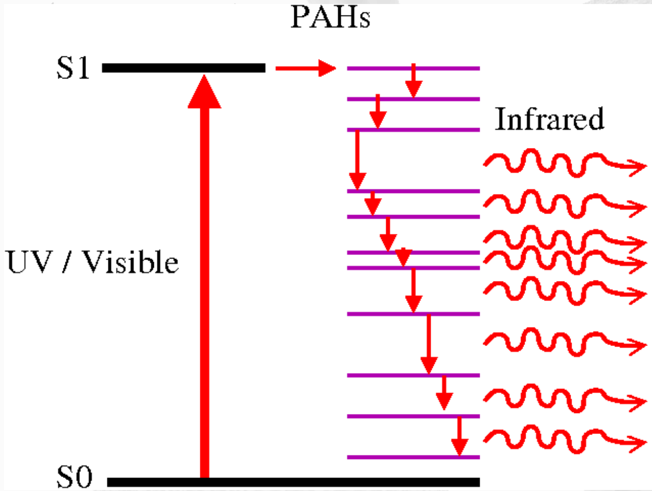
PAHs (coronene)



PAHs emission is not thermal



Léger (in this room !) Puget 1984

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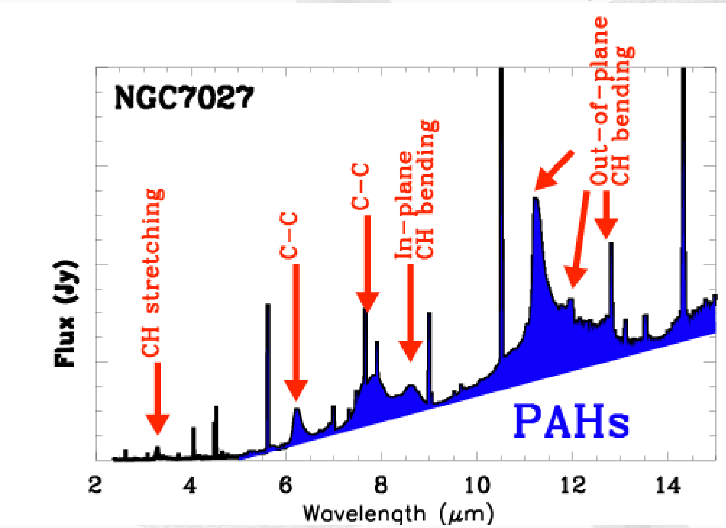
PAHs emission



Extracted from ISO database

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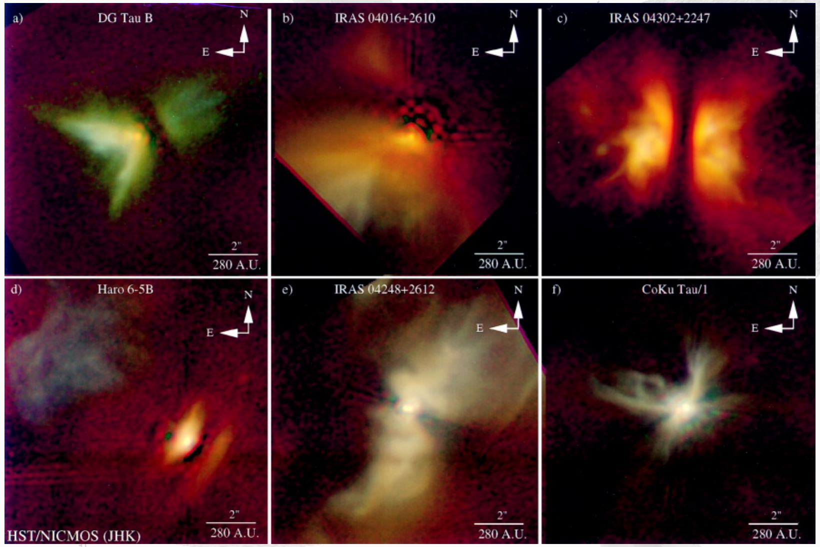

Padgett et al. 1999

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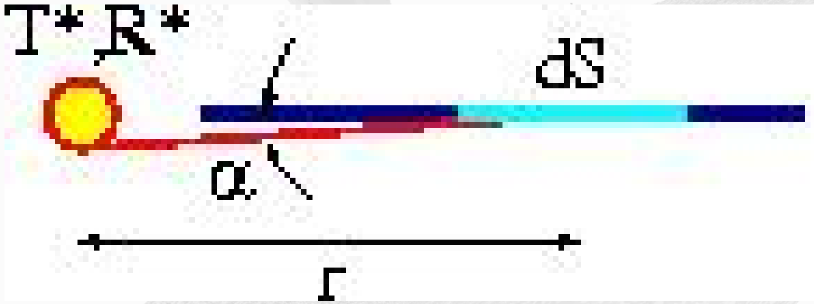
Disks models : the simplest flat passive case



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

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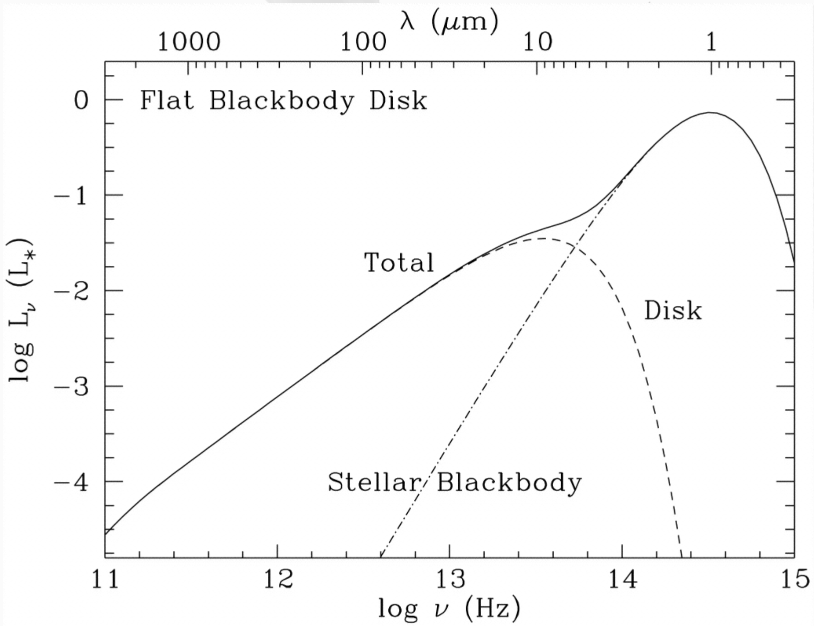
Flat disk SED



Chiang & Goldreich, 1997

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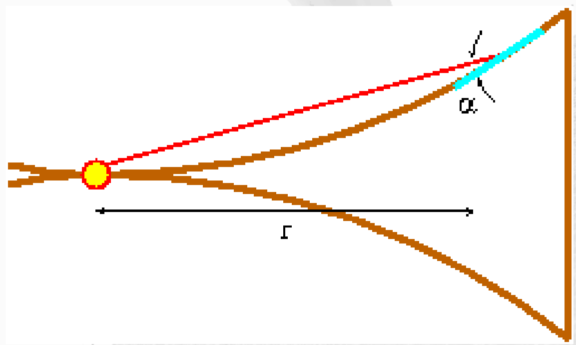
Passive disks : flared disk



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
- $T(r) \propto r^{-2/5}$

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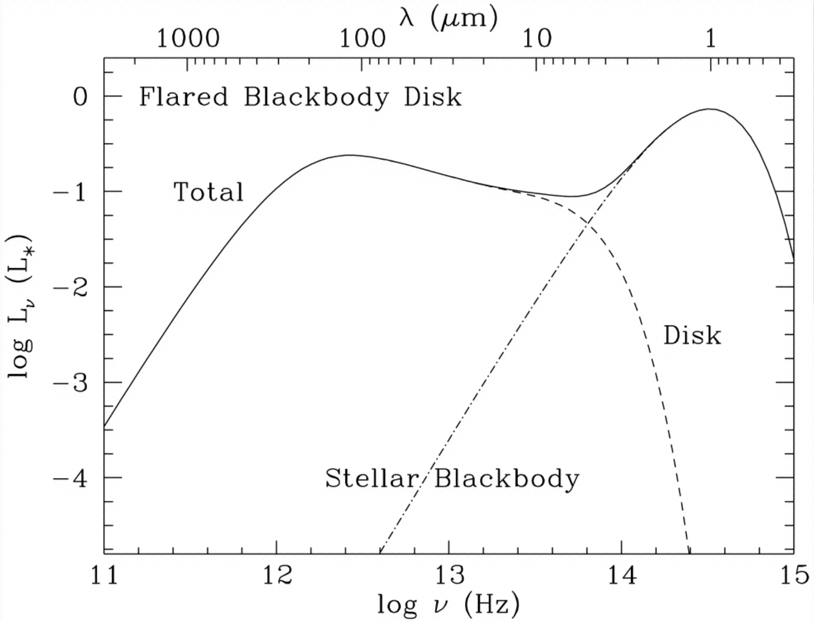
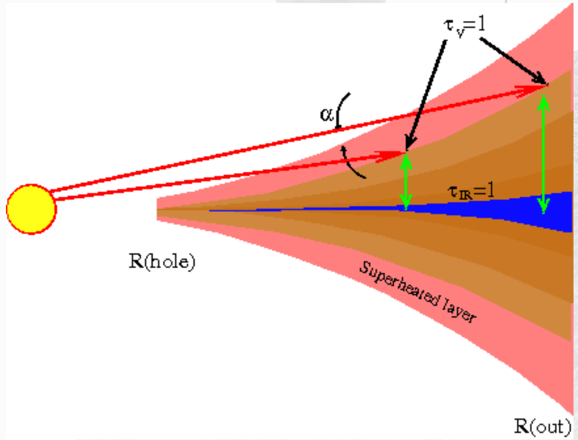
Flared disk SED



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 !!!).

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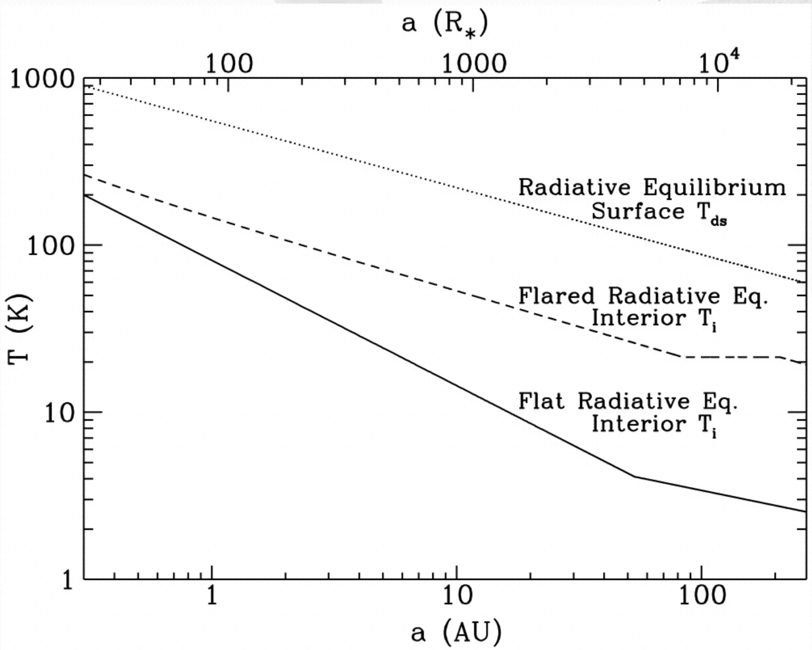
Temperature profiles : 3 regimes (ee,ef,ff)



Chiang & Goldreich 1997

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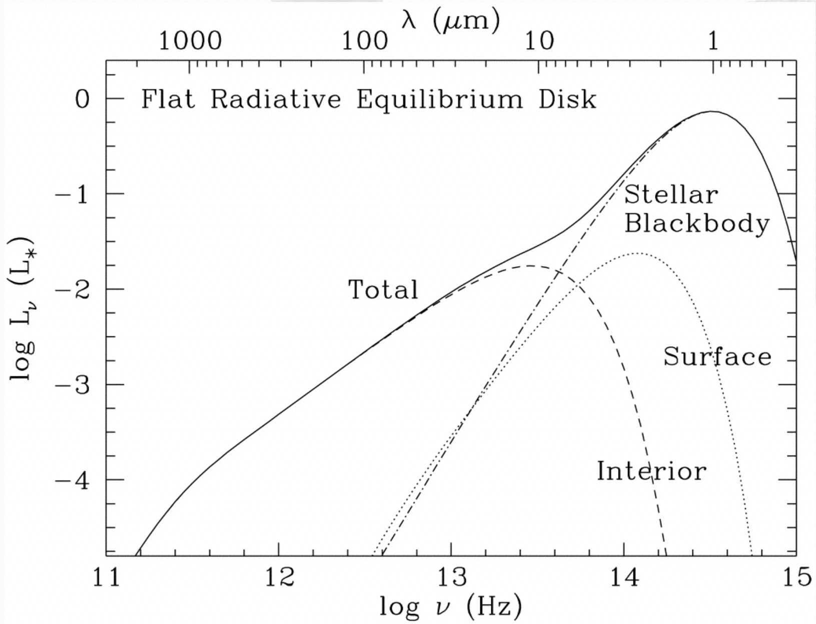
SED flat disk + transfer



Chiang & Goldreich 1997

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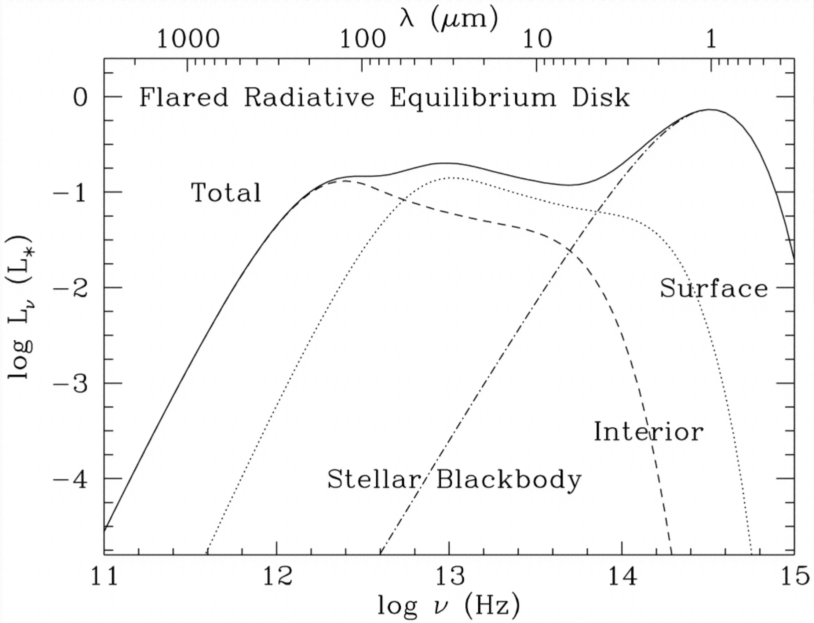
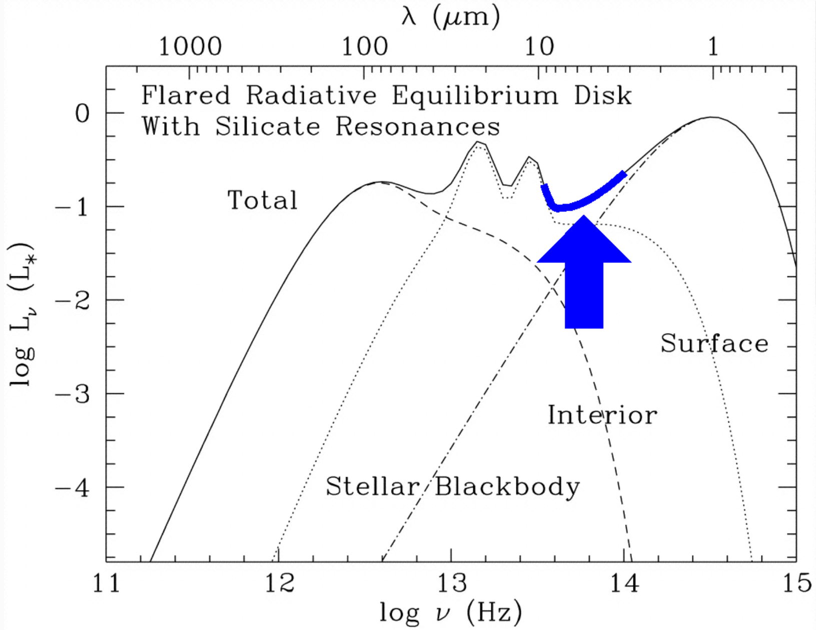
SED flared disk + transfer



Chiang & Goldreich 1997

With features ...!!!...



Chiang & Goldreich 1997

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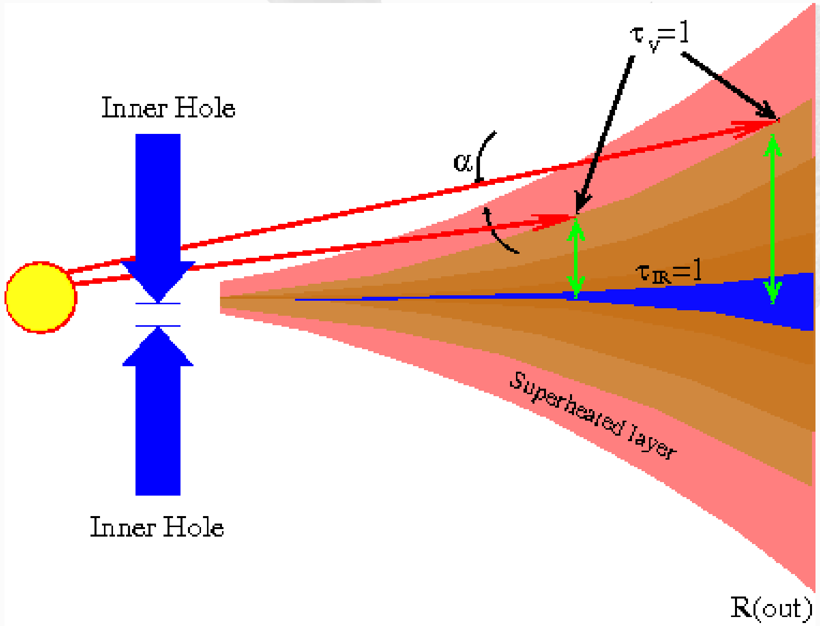
A hole in the SED



- Will produce fluxes deficits in the NIR-MIR range

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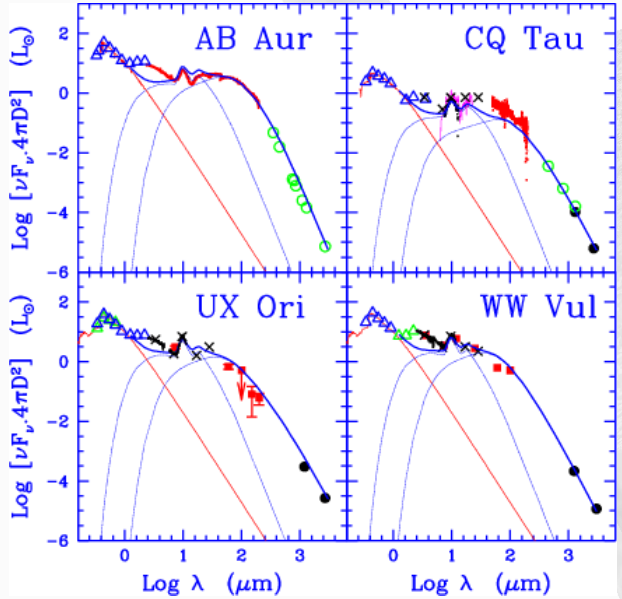
Observations show near infrared excess



Natta et al. 2001

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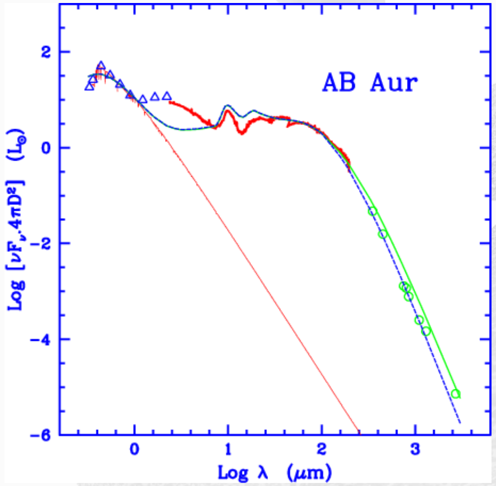
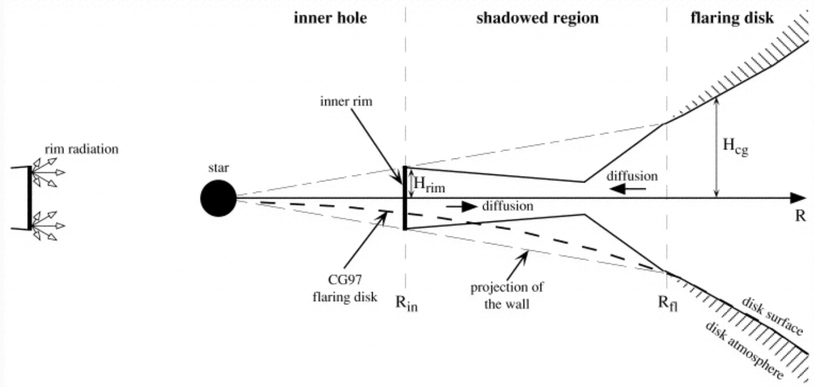
Quantify NIR excess



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).

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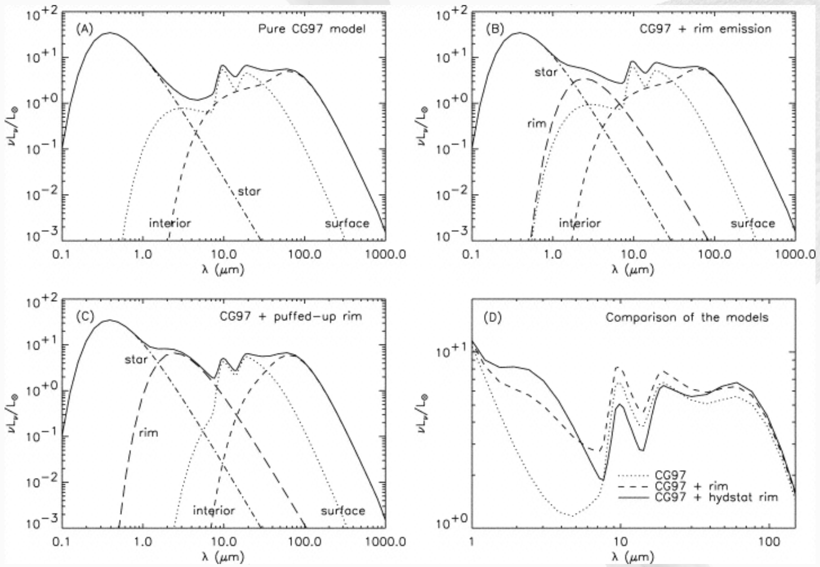
Effect on the SED



Dullemond et al. 2001

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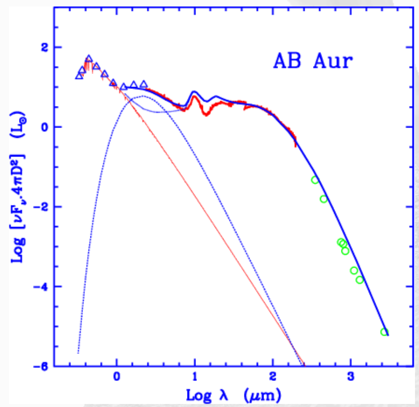
SED need for this inner disk wall



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 ?

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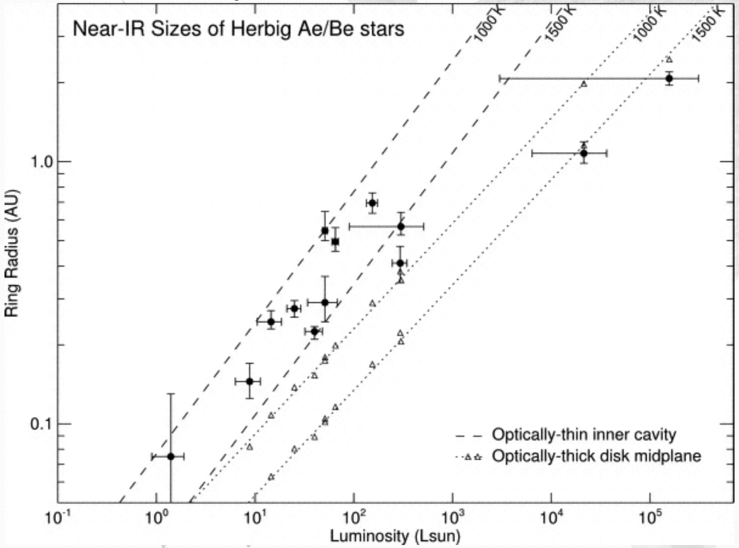
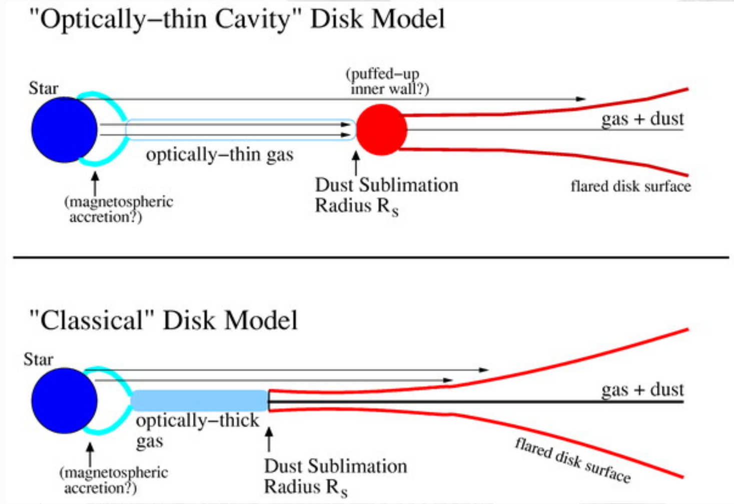
Interferometry in the IR

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.

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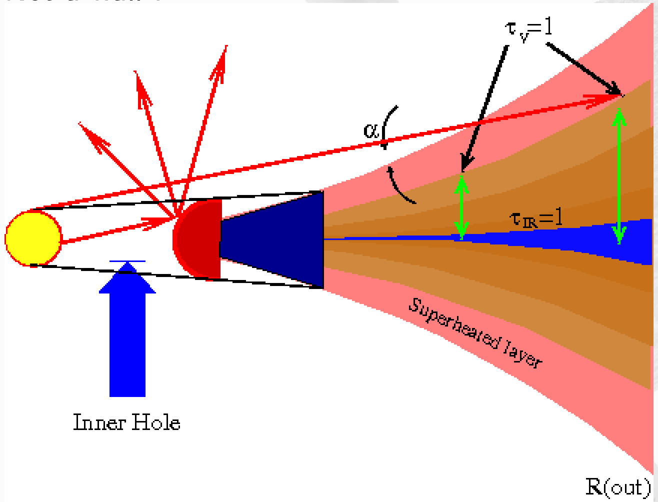
NIR Excess observed at all disk angles

Not a wall !



Isela & Natta 2005

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

Composition and evolution of grains

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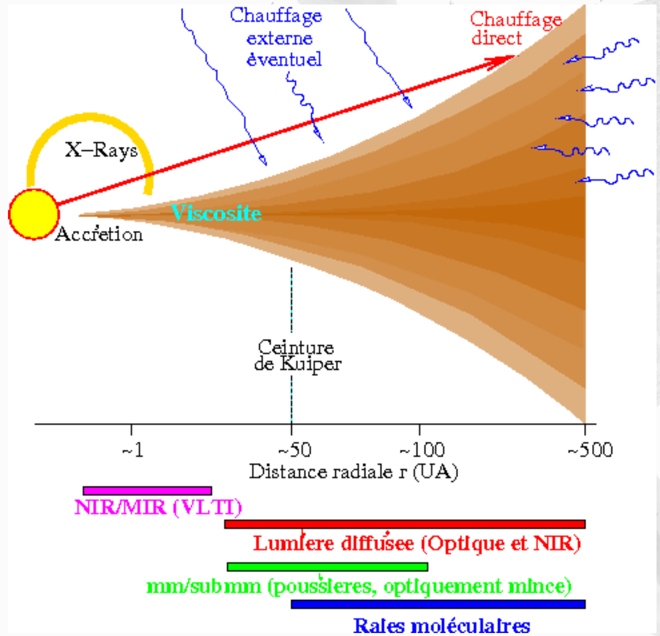
Other mecanisms to take into account for SED



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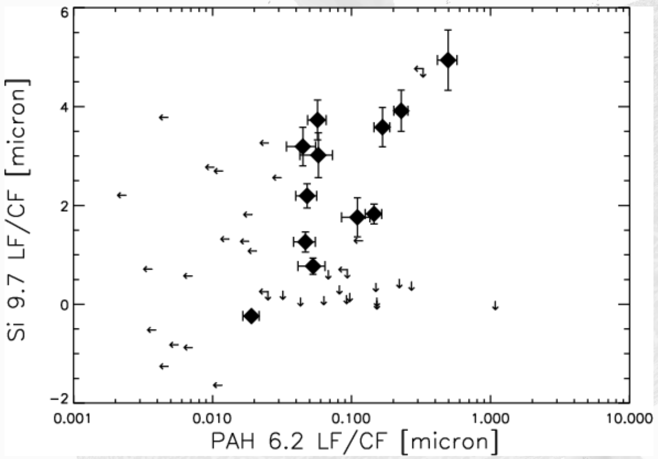
Observations of PAHs and Silicates

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

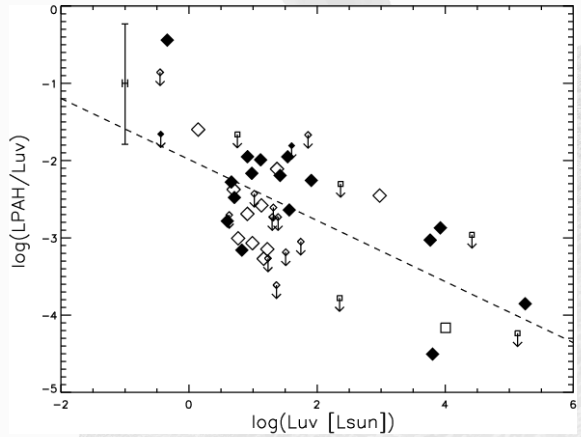
Correlation with Silicates



Acke & van den Ancker 2004

- PAHs poorly or uncorrelated with 10μm silicates

Luminosity emitted/absorbed



Acke & van den Ancker 2004

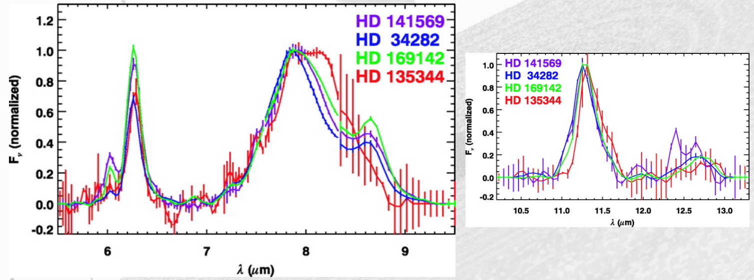
- absorption/emission decreases with increasing UV flux
- efficiency of PAH abs/em decreases ?
- Hardness play a role ?

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 ?

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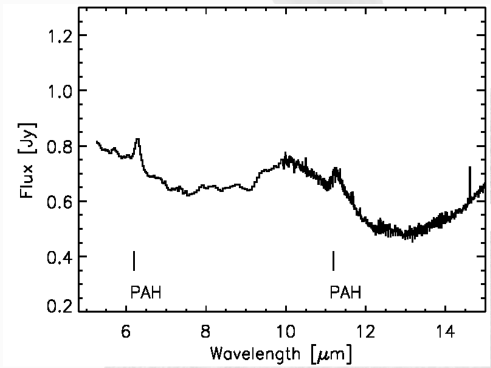
Spitzer's spectra of T Tauri



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.

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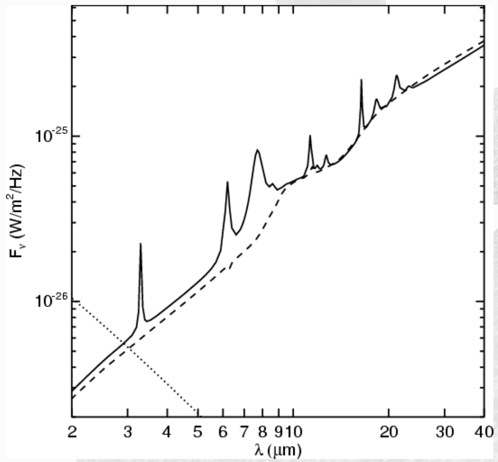
Modele de PAHs dans les disques



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

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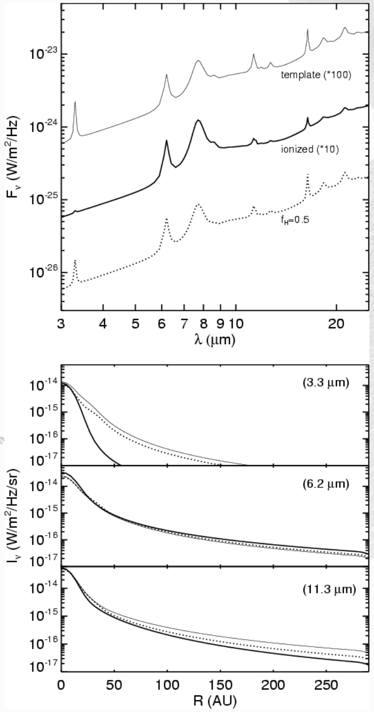
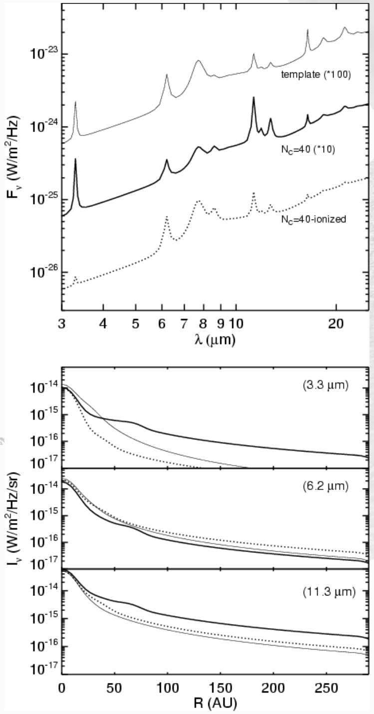
Modele de PAHs dans les disques



- 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

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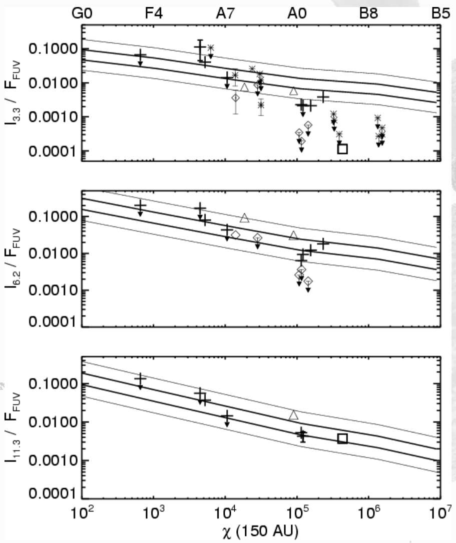
Comparison with some obs



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

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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)

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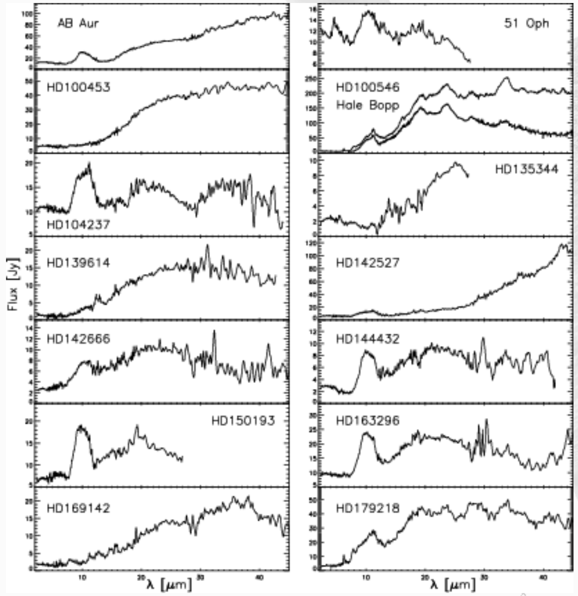
Silicates

Silicates in Herbig Ae/Be and T Tauri



Meeus et al. 2001

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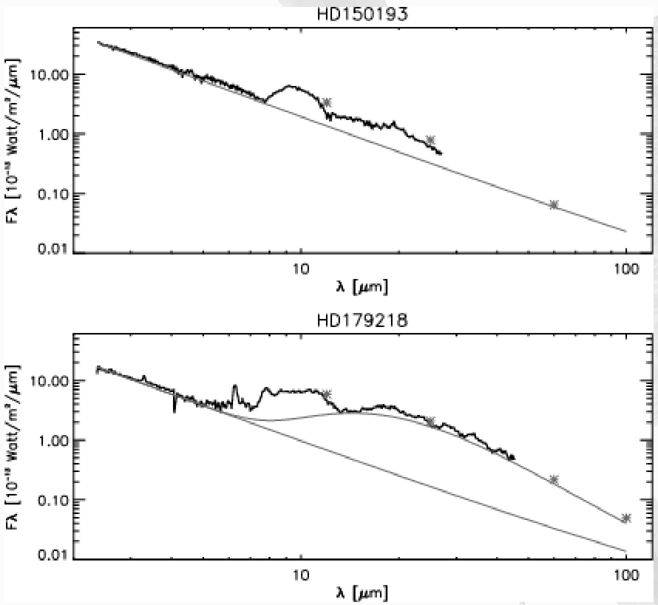
Spectra of group I and II



Meeus et al. 2001

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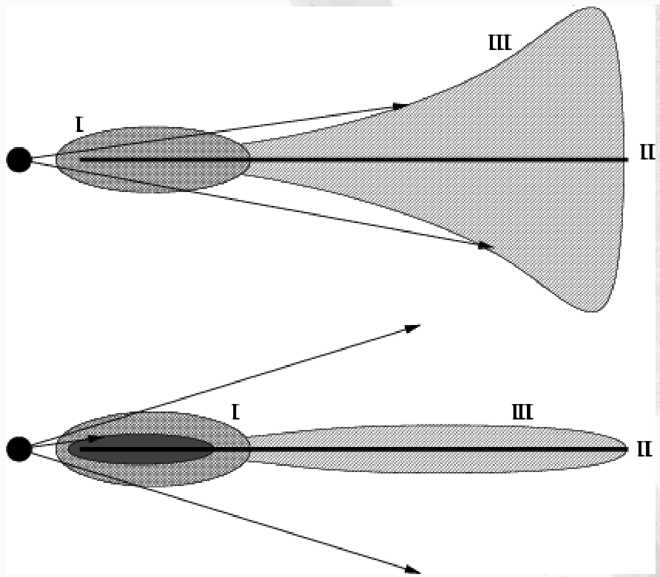
Models of group I and II



Dullemond and Dominik 2004

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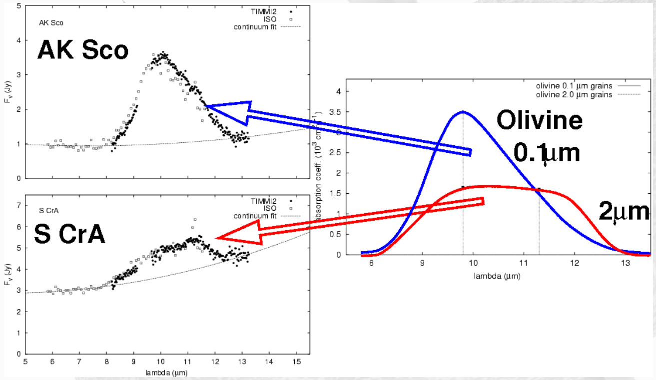
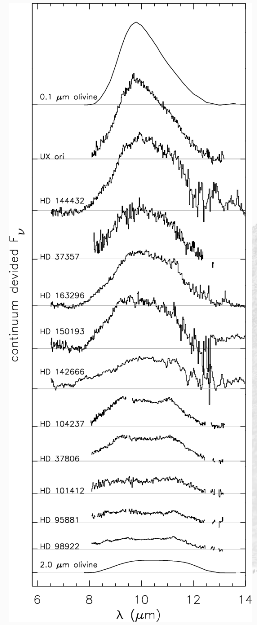
Grain growth : infrared evidence in T Tauri

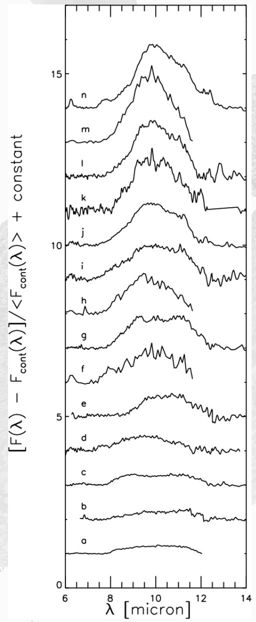


Ground based, ISO; Przygodda et al. 2003, Bouwman et al. 2001

Grain growth : infrared evidence in Ae/Be



van Boekel et al. 2003



Acke & van den Ancker 2004

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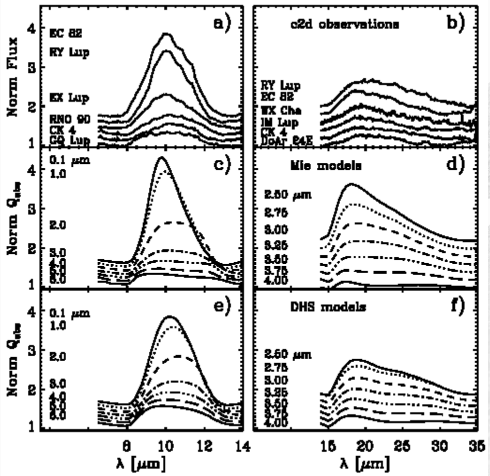
Spitzer's evidence in T Tauri



Kessler-Silacci 2006

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

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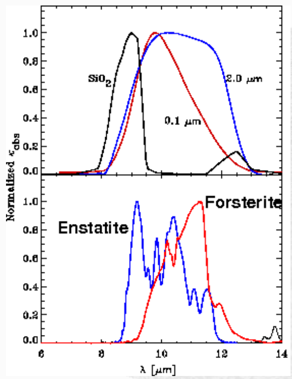
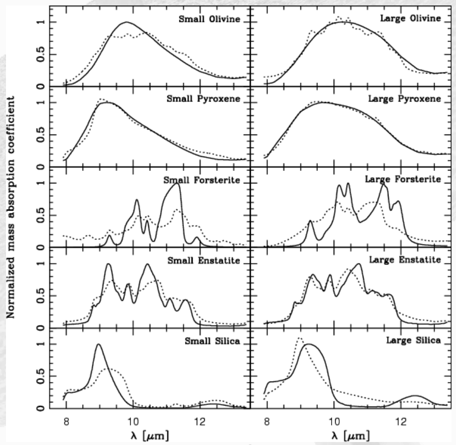
Compositional fits for Ae/Be

Must take simultaneously into account mineralogy AND grain growth



Bouwman et al. 2001



Van Boekel et al. 2005

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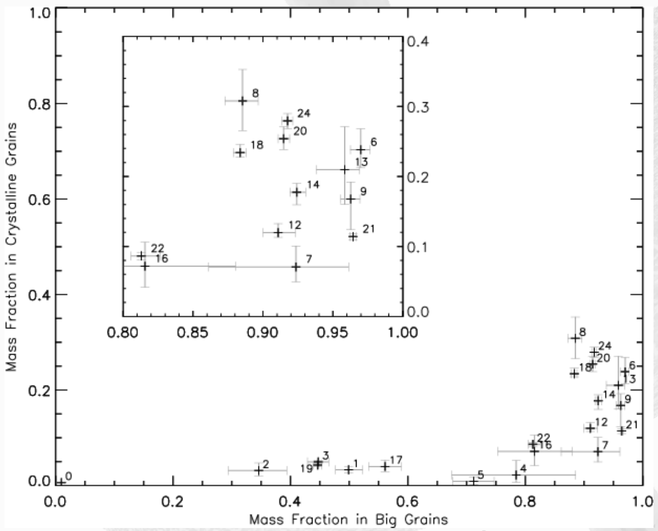
Some correlations



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)

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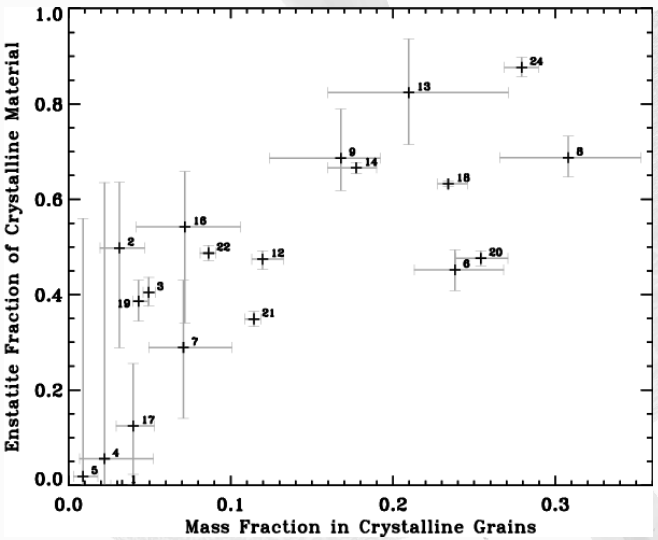
Some correlations



Mass fraction in Enstatite versus total crystal

Van Boekel et al. 2005 and ref therein

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Implications ?

- crystal/amorph. $\lesssim$ 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 $2.5 M_\odot$ have a high fraction of big grains.

Van Boekel et al. 2005 and ref therein

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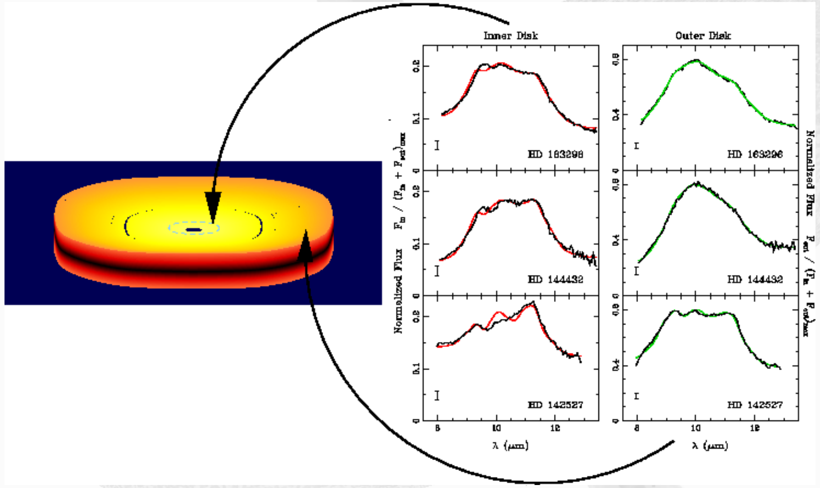
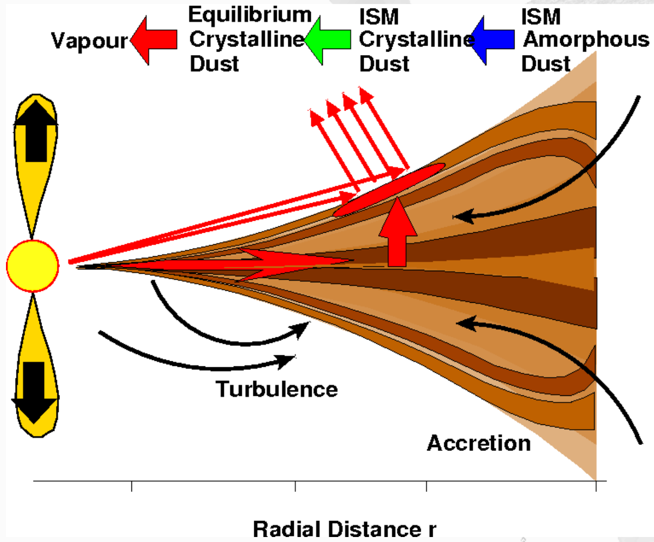
Radial processing ?

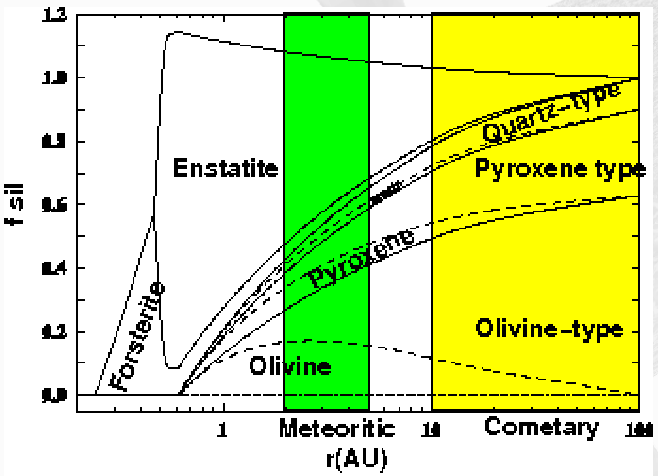


Van Bokel et al. 2004

Suggest differential processing :

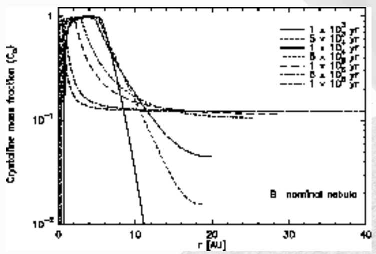


Differential processing : Enstatite/Forsterite

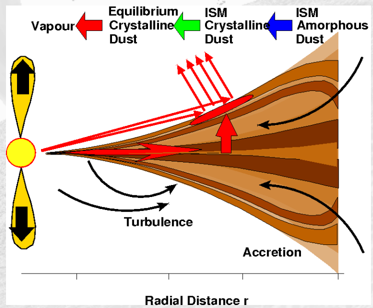


Gail & Seldmayr 2004

crystal to amorphous ratio



Bockelée-Morvan et al. 2002

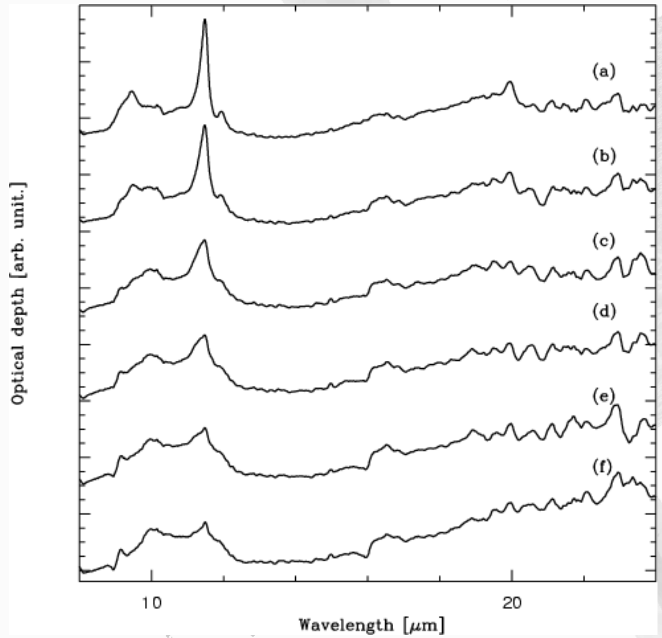


- If the radial mixing is efficient on timescale << disks life ...
- ... and the vertical mixing also
- then [cryst]/[amorph] might represent the global dust processing
- Forsterite band at 33.5μm Vandenbussche et al. 2004 with ISO → crystal at distance > 10 AU.

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

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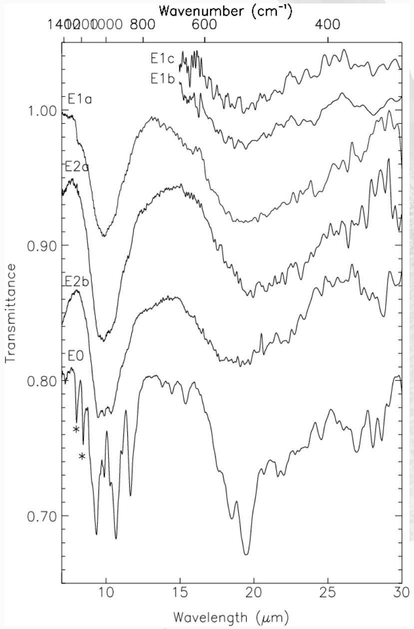
20-50keV He+ irradiation of Enstatite ($MgSiO_3$)



Demyk et al. 2004, Carrez et al. 2002

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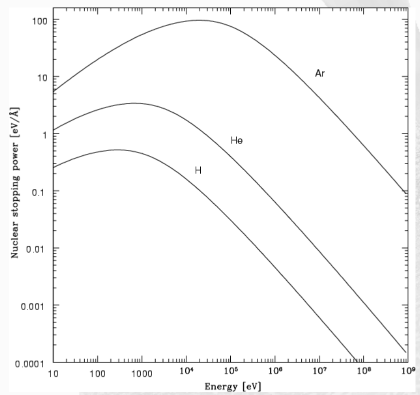
Energy dependence



Stopping power Forsterite, Brucato et al. 2004

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

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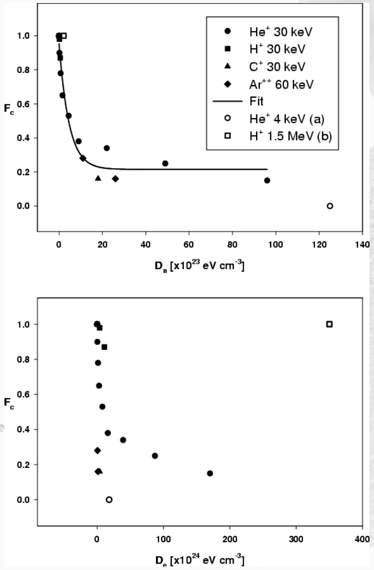
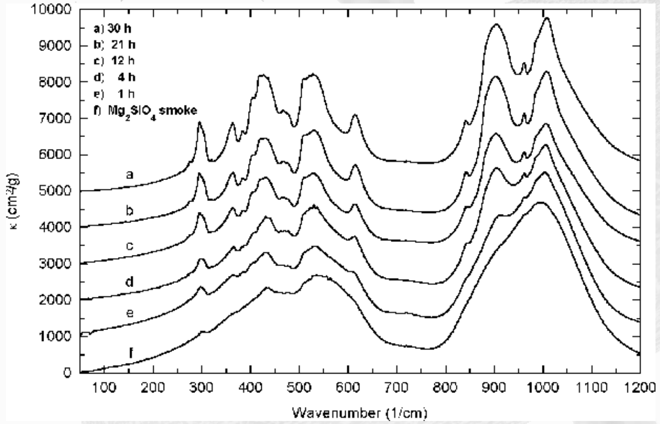
Astrophysical timescales



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

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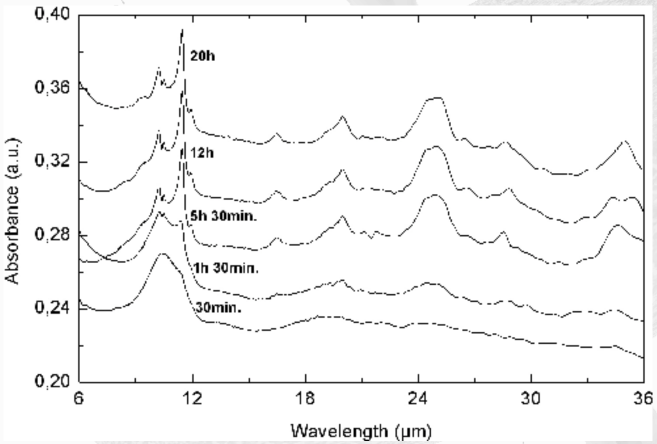
Thermal annealing keV amorphised Mg_2SiO_4 at 1030 K



Djouadi et al. 2005

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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

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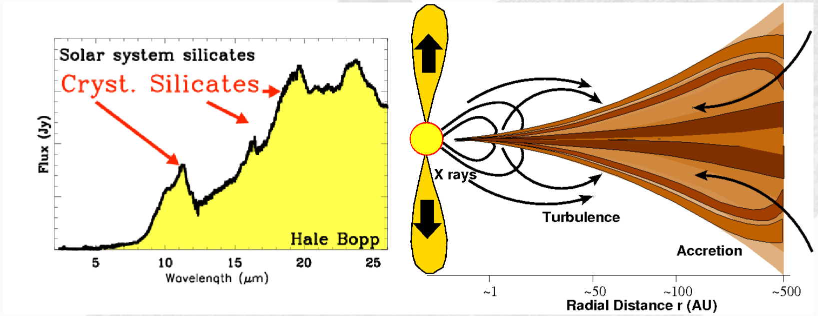
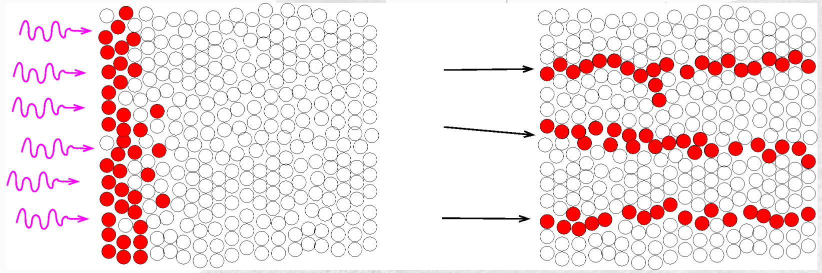
Implication: radial mixing in disks !



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

UV photons versus cosmic rays



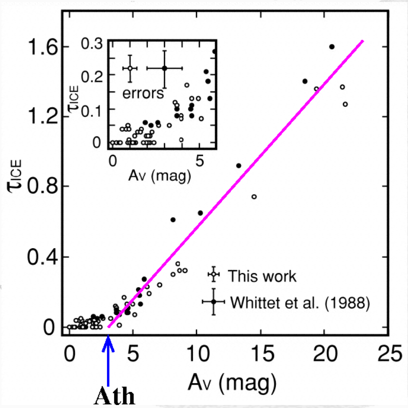
Adapted from Gerakines et al. 2001

- 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

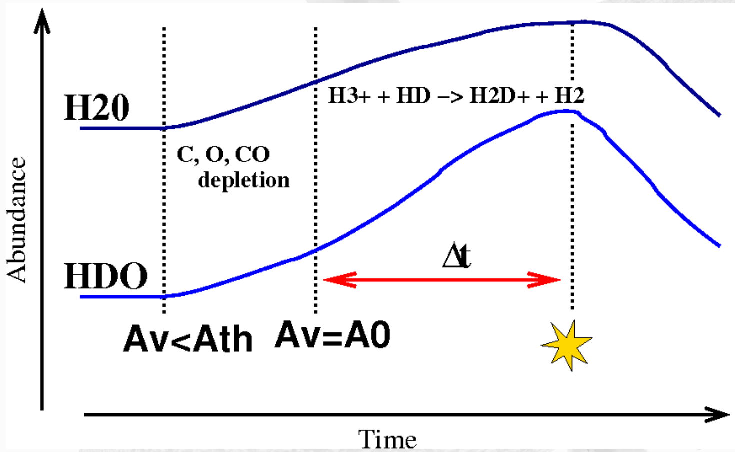
Much before class II, Field stars probe the onset and distribution of ices



Murakawa et al. 2000

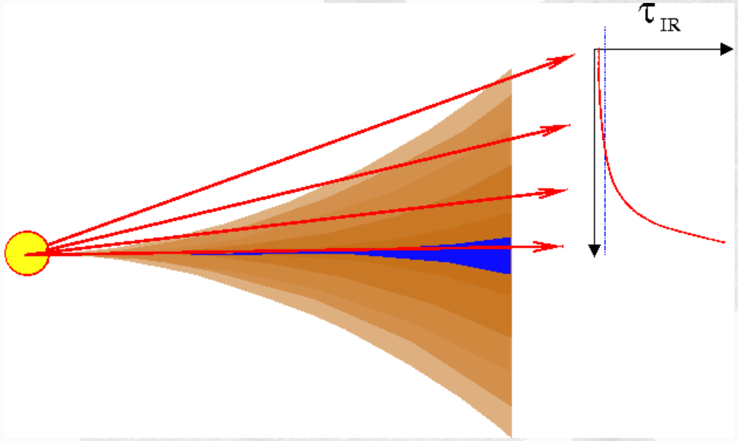
- τ H_20 $(\nu_1, \nu_3) = \alpha(\mathrm{Av} - \mathrm{Ath})$
- Abundance 10^{-4}-$10^{-5}N_H$ $\neq$ Gas phase timescales
- surface reactions involving atomic oxygen needed
- well known for the formation of H_2 that surfaces required

Grain surfaces indirect influence



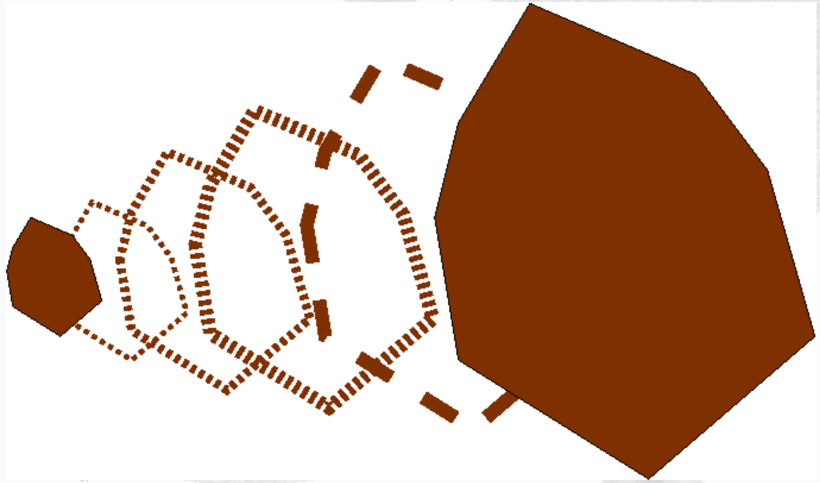
- Ices : inhibitors/promotors for gas phase chemistry.
- Coupling of gas and dust chemistry (need for grains to reform H_2 efficiently at the surface layer)

Grain surfaces indirect influence

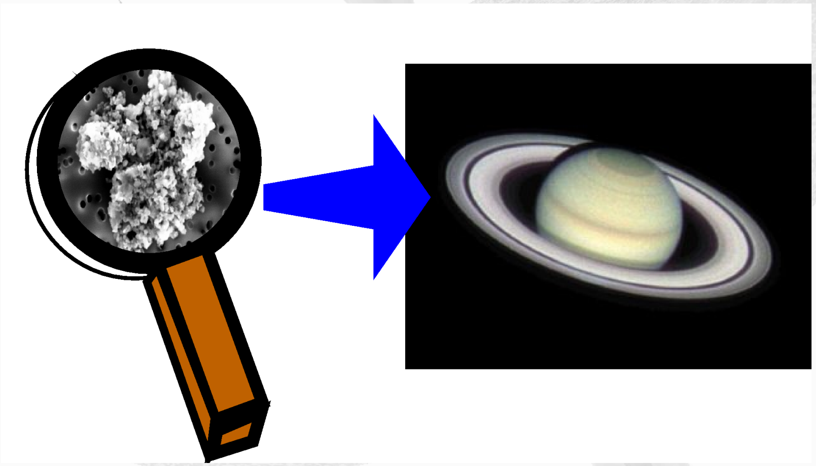


- Difficult to assess sometimes for geometrical reasons (τIR increases abruptly)

Size modification

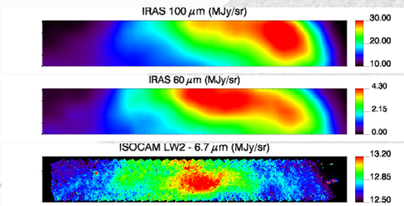


It exists !

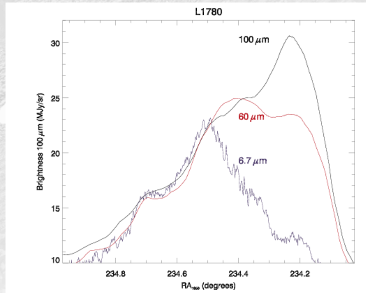


From diffuse to dense media: structuration of the ISM, intermediate phases

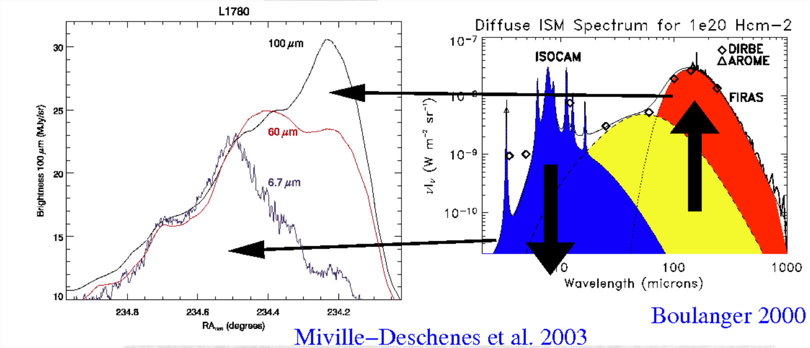
e.g. Cirrus cloud L1780



Miville-Deschênes et al. 2003

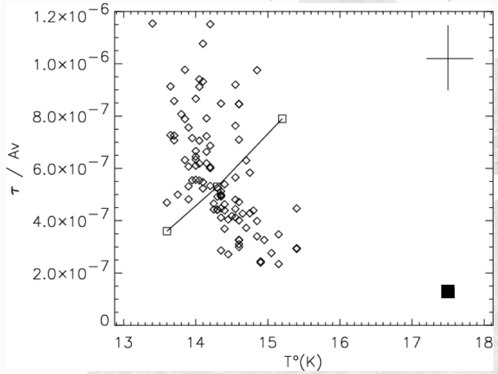


- Spectacular decrease of 6.7μm/100μm intensities
- ... but not due to extinction as the cloud is thin



- 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

■ $\tau(200\mu m)/A_V$ for $A_V \lesssim 6$ $>$ $\tau(200\mu m)/A_V$ diffuse

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

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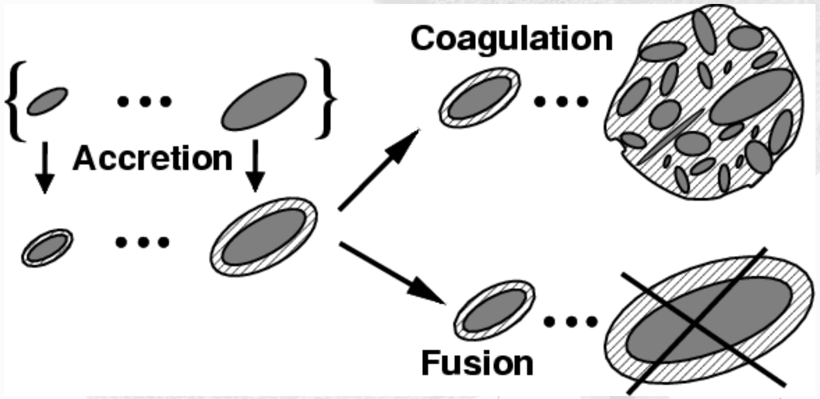
Grain growth in class 0-I ?



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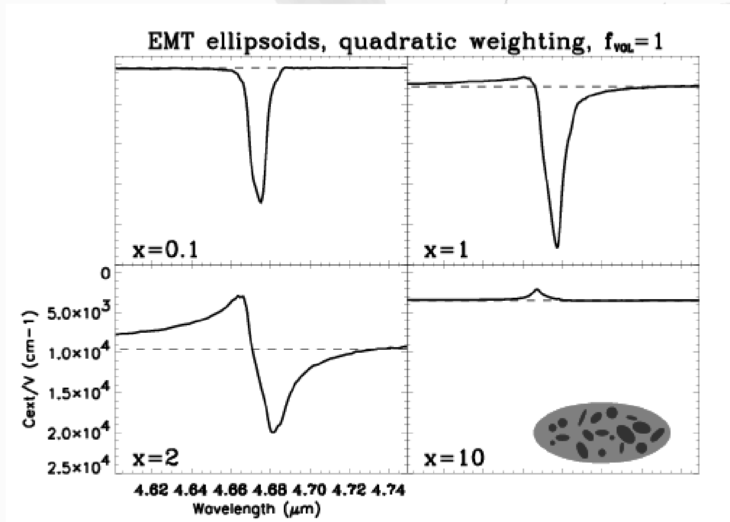

$$x = \frac{2\pi a}{\lambda}$$

Dartois 2006

- size effects on line profiles

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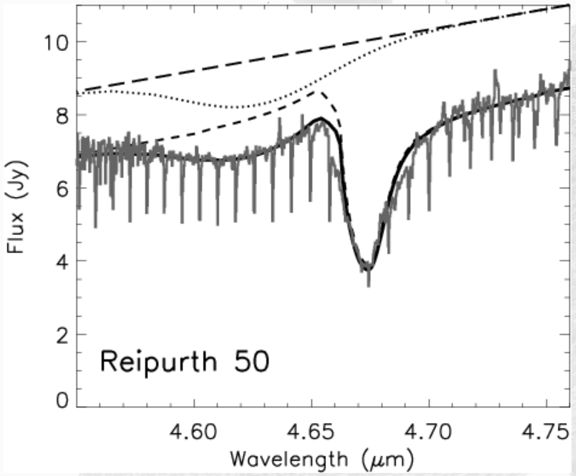
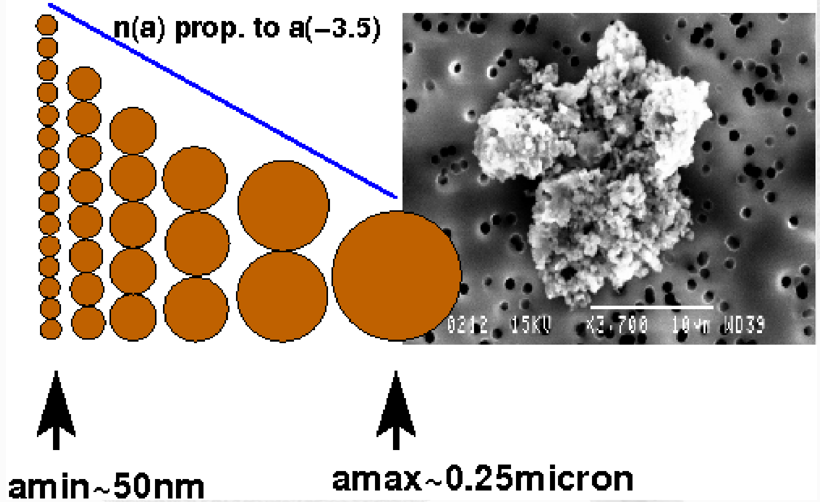
Observed with line ice mantles profiles ?



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.

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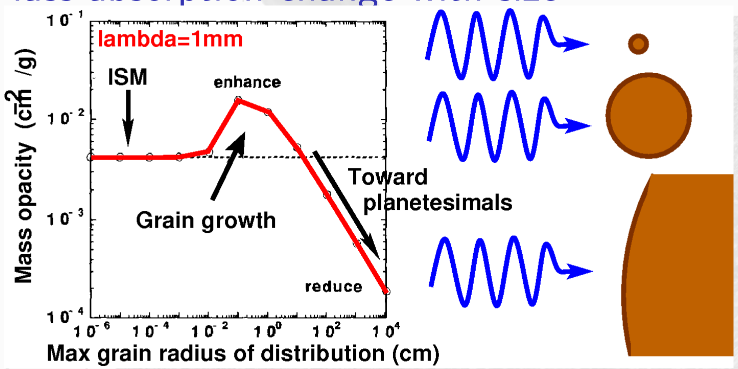
Mass absorption change with size



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

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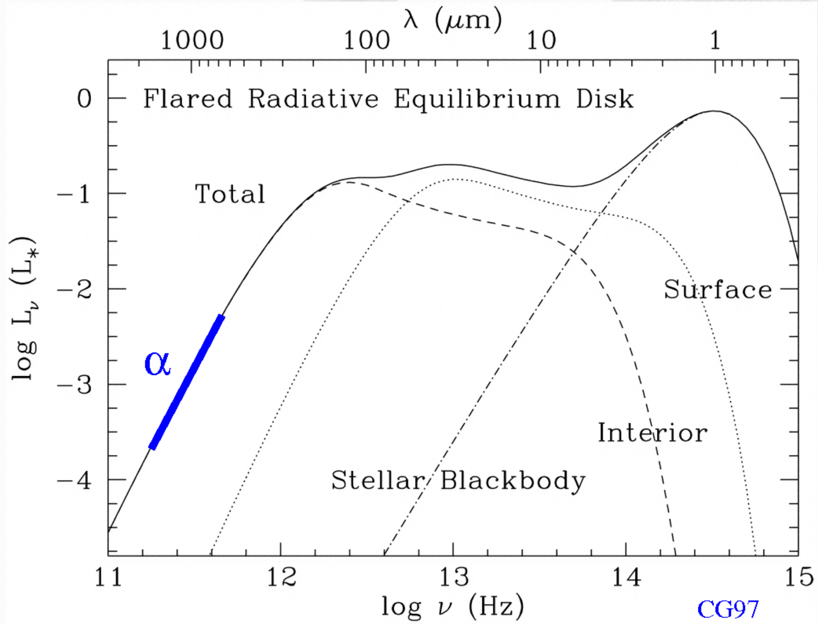
A jump into disks in the mm : spectral index β



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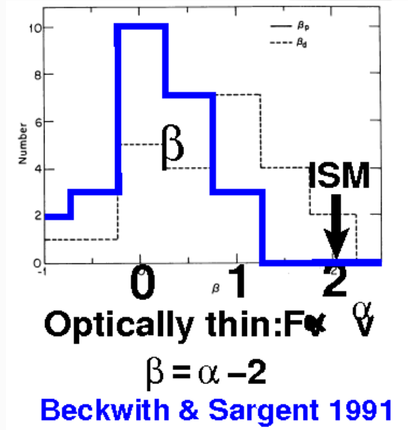
A jump into disks in the mm : spectral index β

- 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

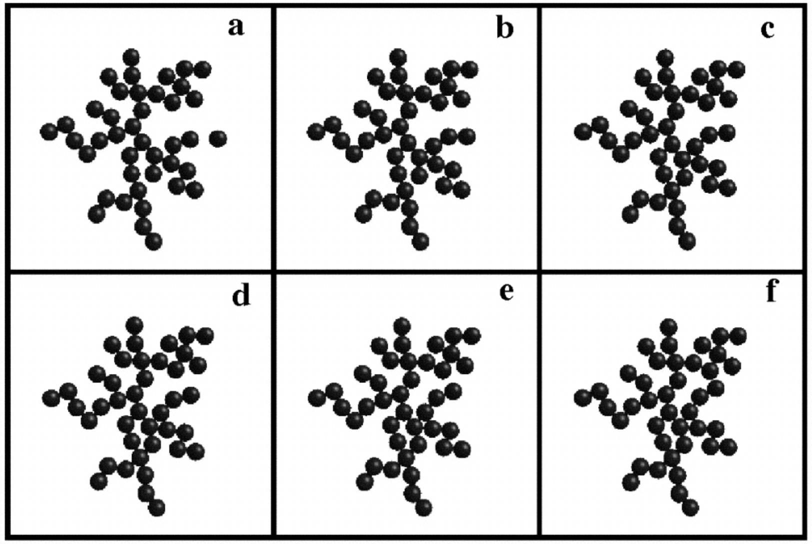
- If the disk is not fully optically thin at mm wavelengths
- $\beta \approx (1+\Delta)(\alpha-2)$
- with Δ ratio of thick to thin (Beckwith & Sargent 1991)
- it makes β higher

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

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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

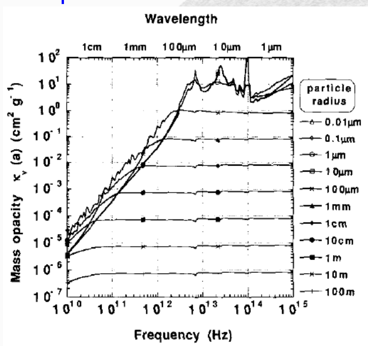

FIG. 4. Mass opacities (in cgs units) of single-sized compact dust particles ($f = 1$) for various radius a (0.01 μm to 100 m) composed of the intimate mixture of silicate and H_2O–ice, where the abundances of dust particles with respect to the H_2 gas are assumed to be solar. Curves for $a \leq 10$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

Fluffy

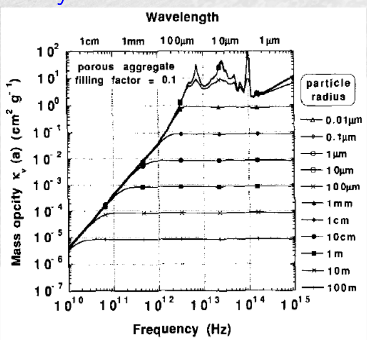

FIG. 8. Mass opacities of porous single-sized dust particles. The filling factor of dust materials f is taken to be 0.1. Except for the porosity of dust particles, the same as Fig. 4. Curves for $a \leq 100$ μm are almost identical at $\nu \leq 10^{12.5}$ Hz.

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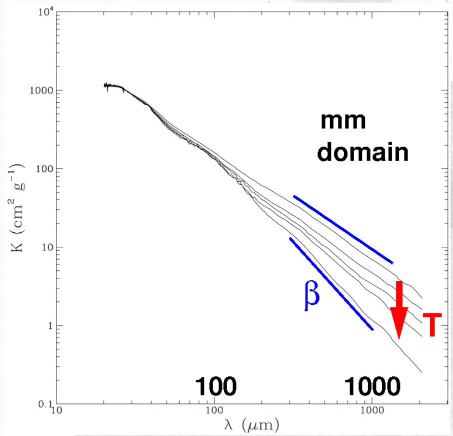
Temperature variation of β ?



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

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

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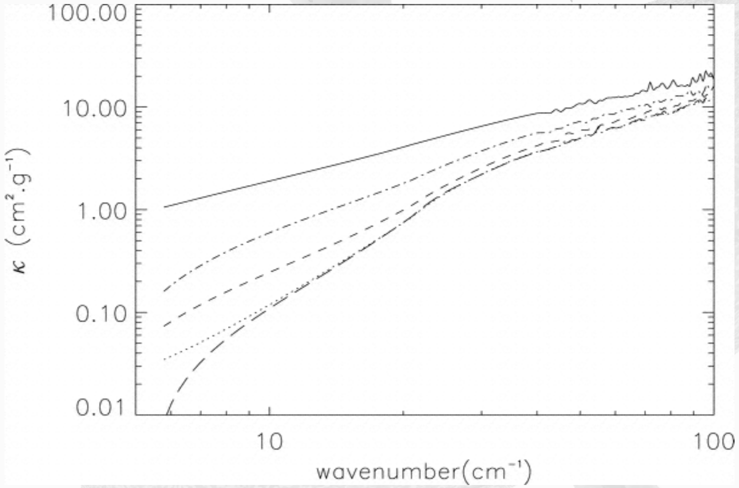
T variation of β



e.g. Boudet et al 2005

- MAC for 1.5μm silica spheres

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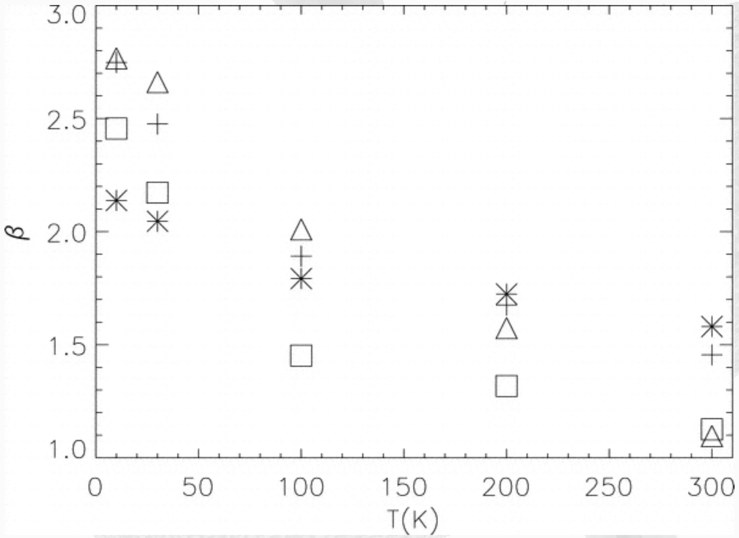
T variation of β



e.g. Boudet et al 2005

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

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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} ($\text{cm}^2.\text{g}^{-1}$)

e.g. Boudet et al 2005

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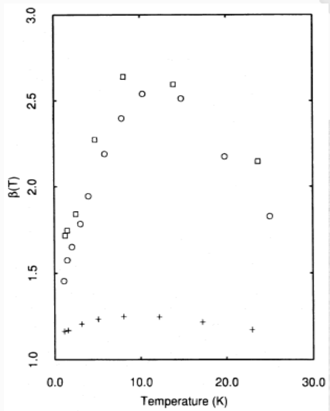
At very low temperatures

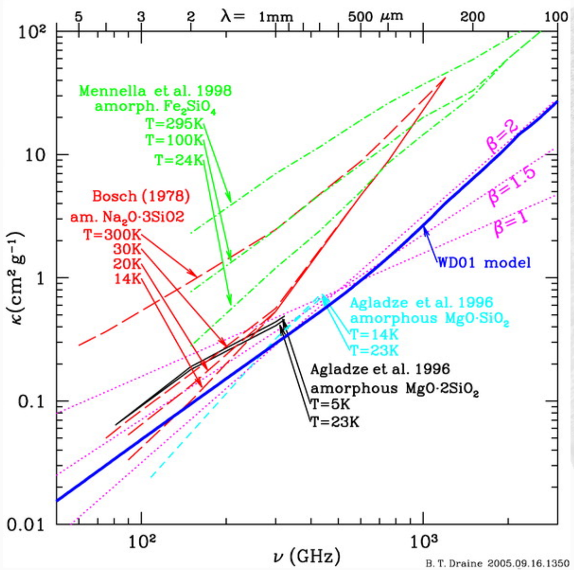


Silicates

e.g. Agladze et al. 1996

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

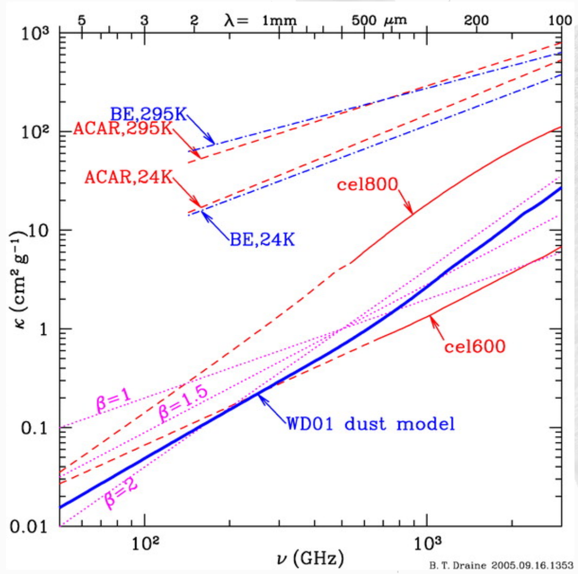
A summary of abs. coeff.



Silicates

Draine 2006

A summary of abs. coeff.



Carbonaceous material

Draine 2006

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Effect of the size distribution

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

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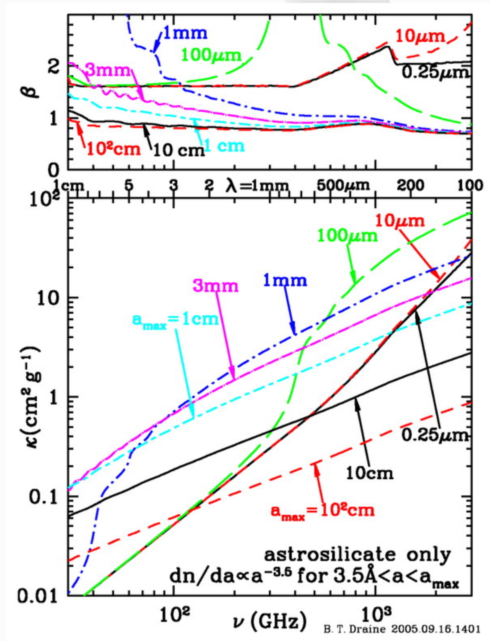
MRN size distribution effect on β



Silicates

Draine 2006

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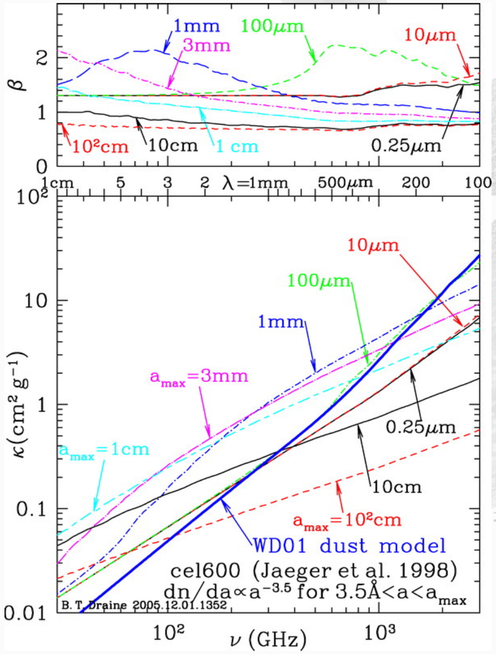
MRN size distribution effect on β



Carbonaceous material

Draine 2006

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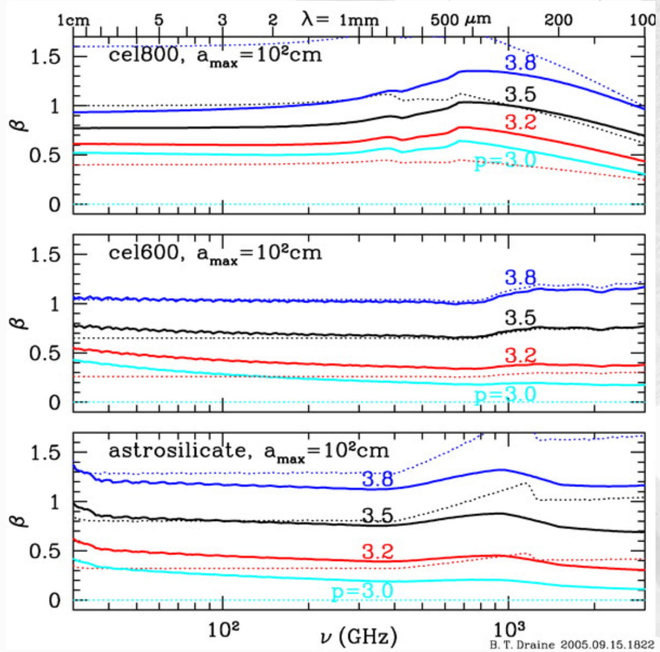
other large size distributions



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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

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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

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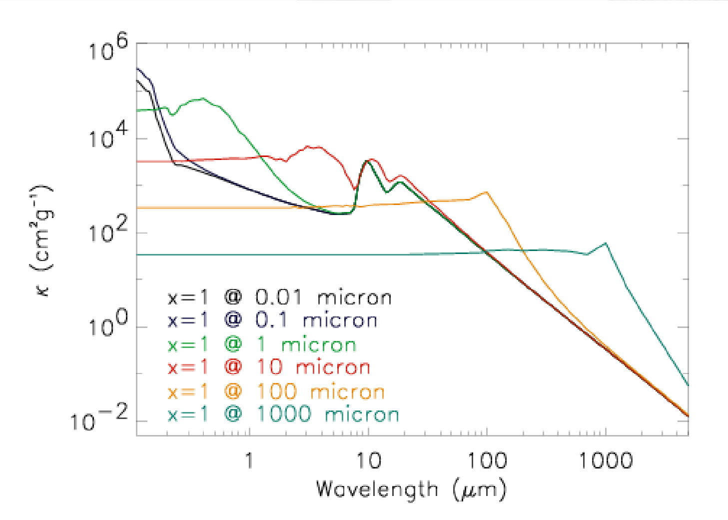
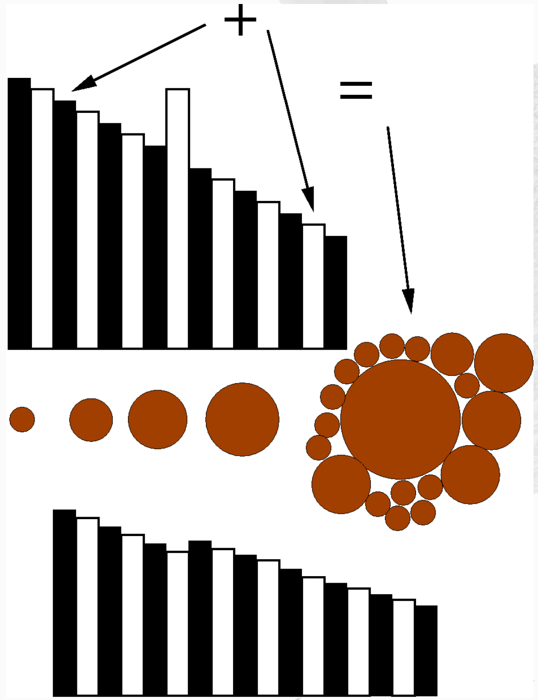
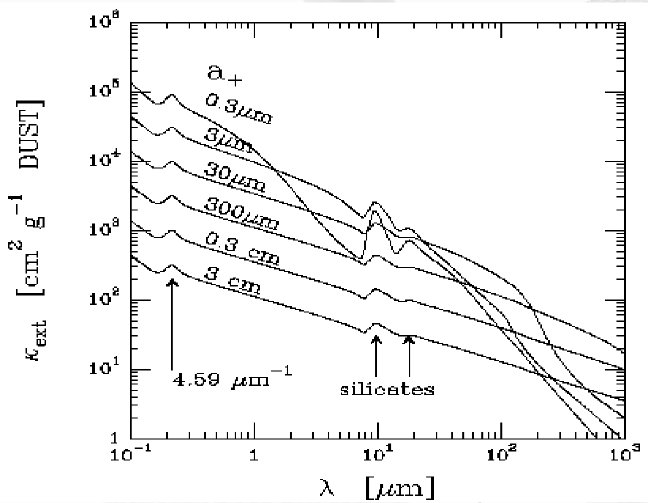


- moderate influence on lowering UV extinction.
- cannot account for mm emissivities.

Size distribution modification : coagulation



Some effects of coagulation



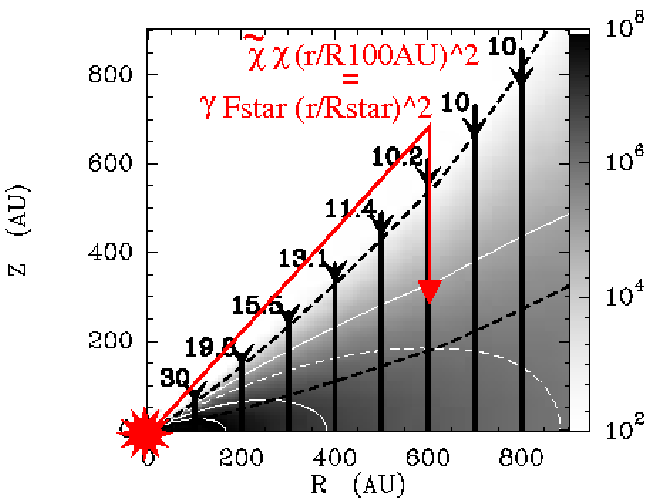
Hily-Blant et al. 2006

- 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 ~1cm, one need for a change in size distribution slope @ large grain radius, otherwise inconsistent

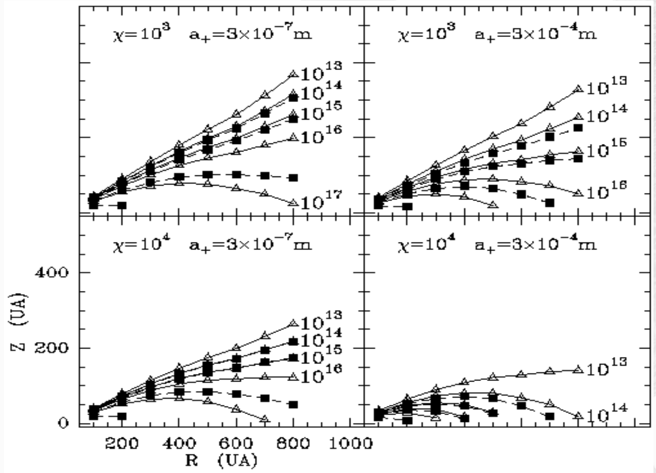
Some effects of coagulation on gas chemistry



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.

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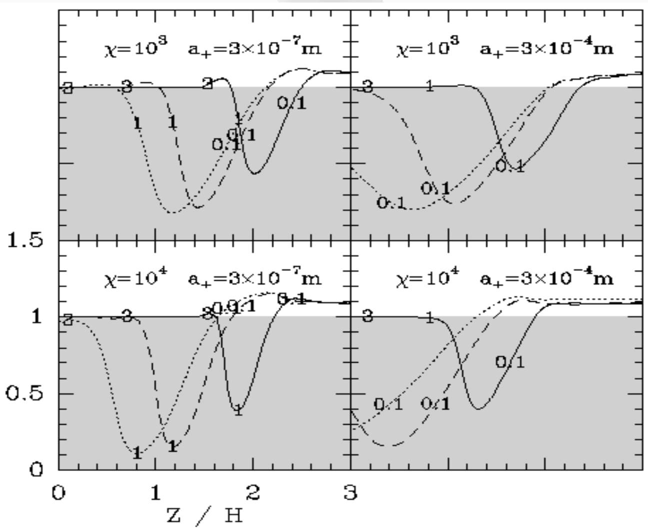

Hily-Blant et al. 2006

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

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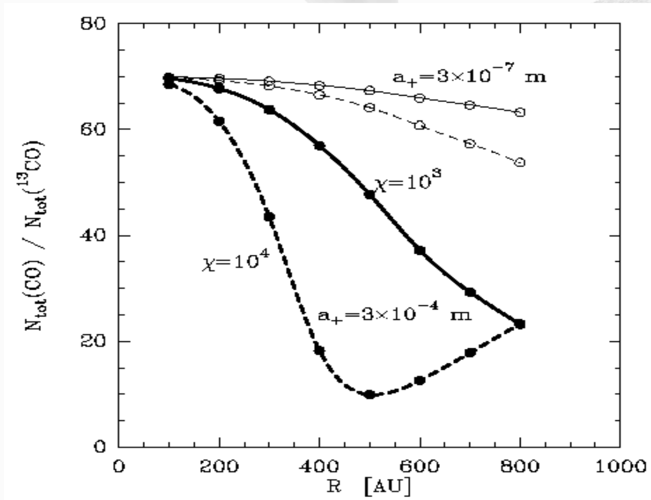
Some effects of coagulation



Hily-Blant et al. 2006

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

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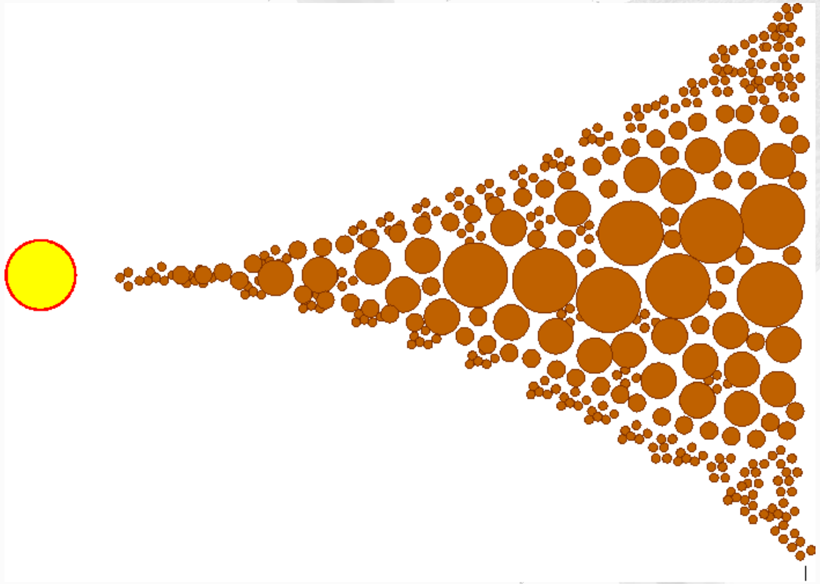
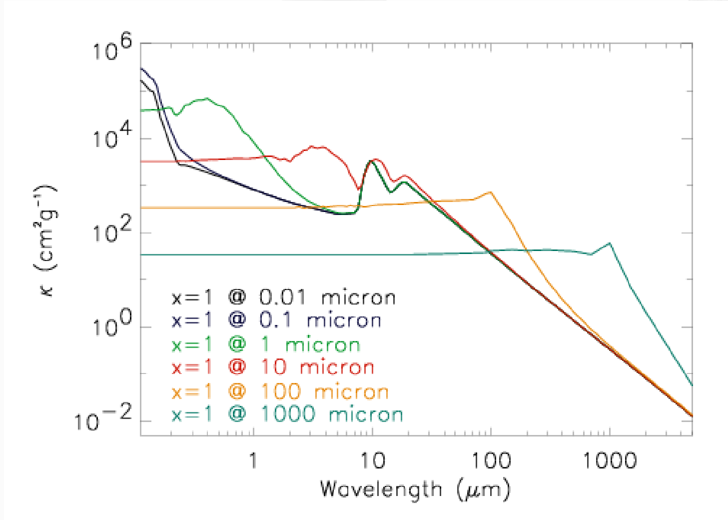
Sedimentation



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 !

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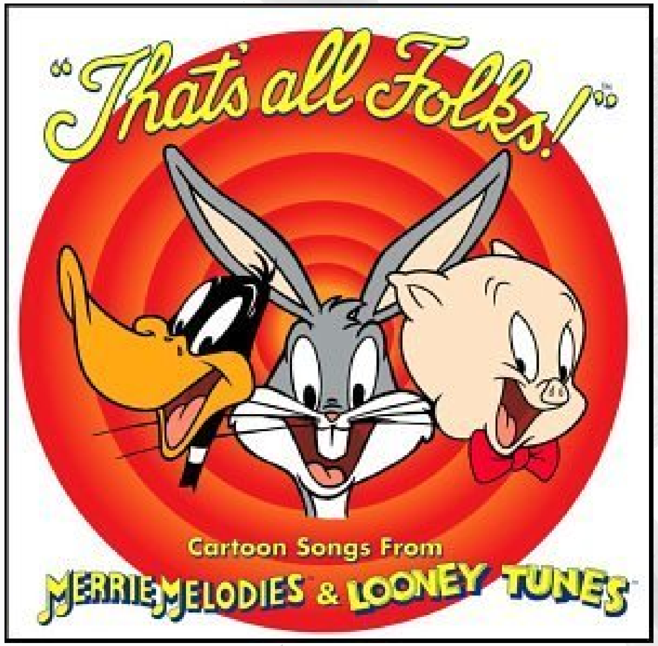

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