Dust & exoplanets & brown dwarfs
L1: introduction

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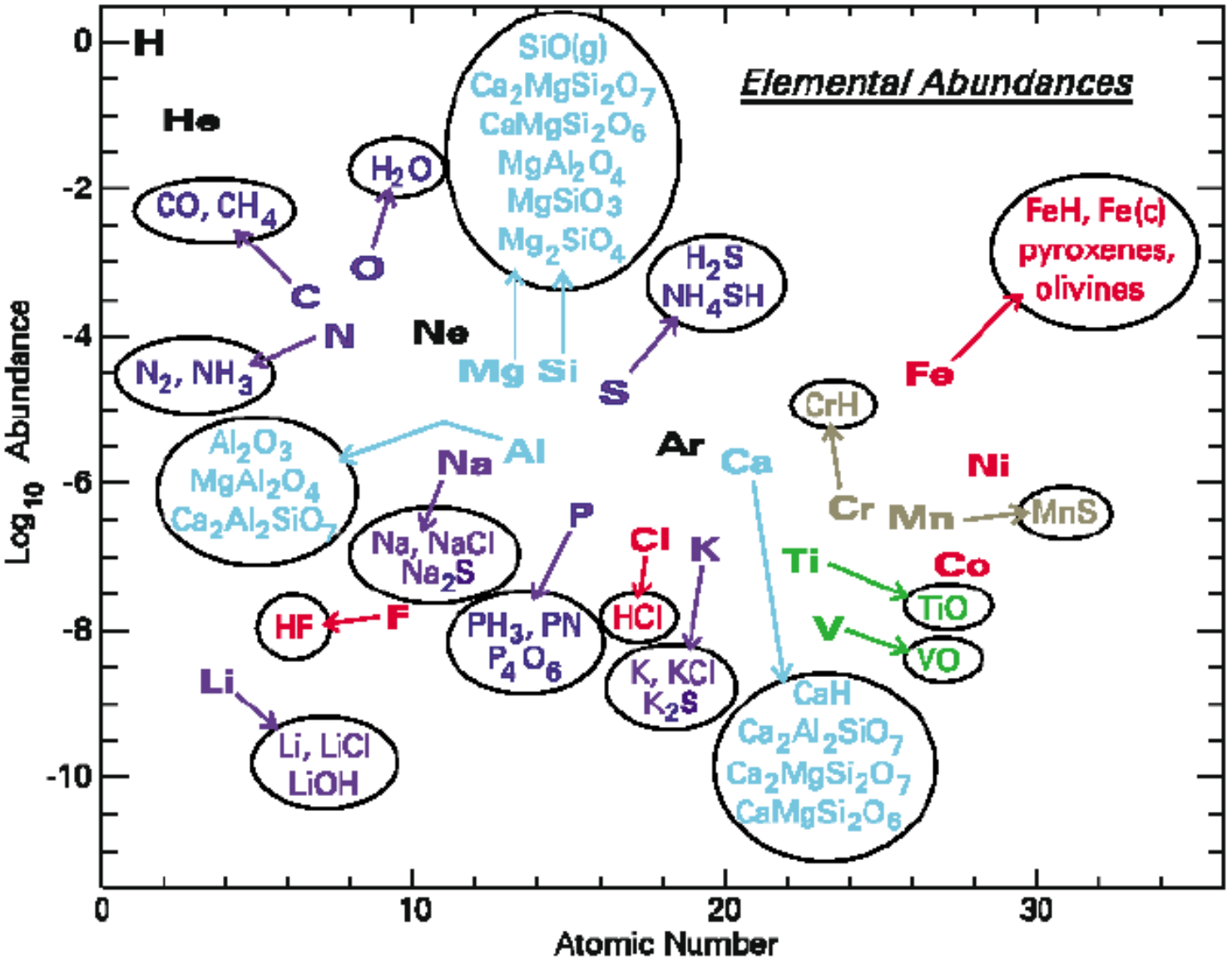
Content

- L1: Dust in BDs & exoplanets, introduction.
  - What is dust, condensate, grain, cloud?
  - Chemistry at low temperatures.
  - Dust formation, clouds, rain-out.
  - Dust clouds beyond the atmospheres.
- L2: Optical + other properties of dust.
  - Absorption, scattering, phase function.
  - Albedo, radiative acceleration, equilibrium grain temperature.
  - Our tables of dust properties.

Chemistry at low temperatures

Burrows et al. (2001)



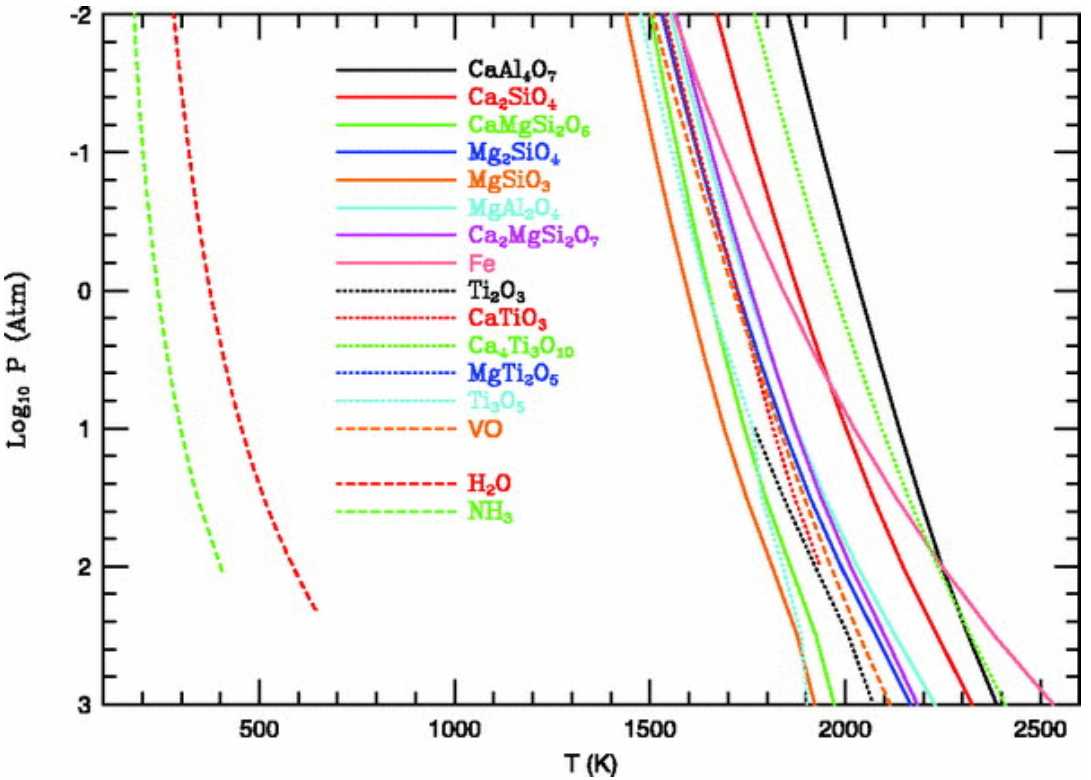
Dust, Clouds, Rain-out

What is dust, condensate, grain, cloud?

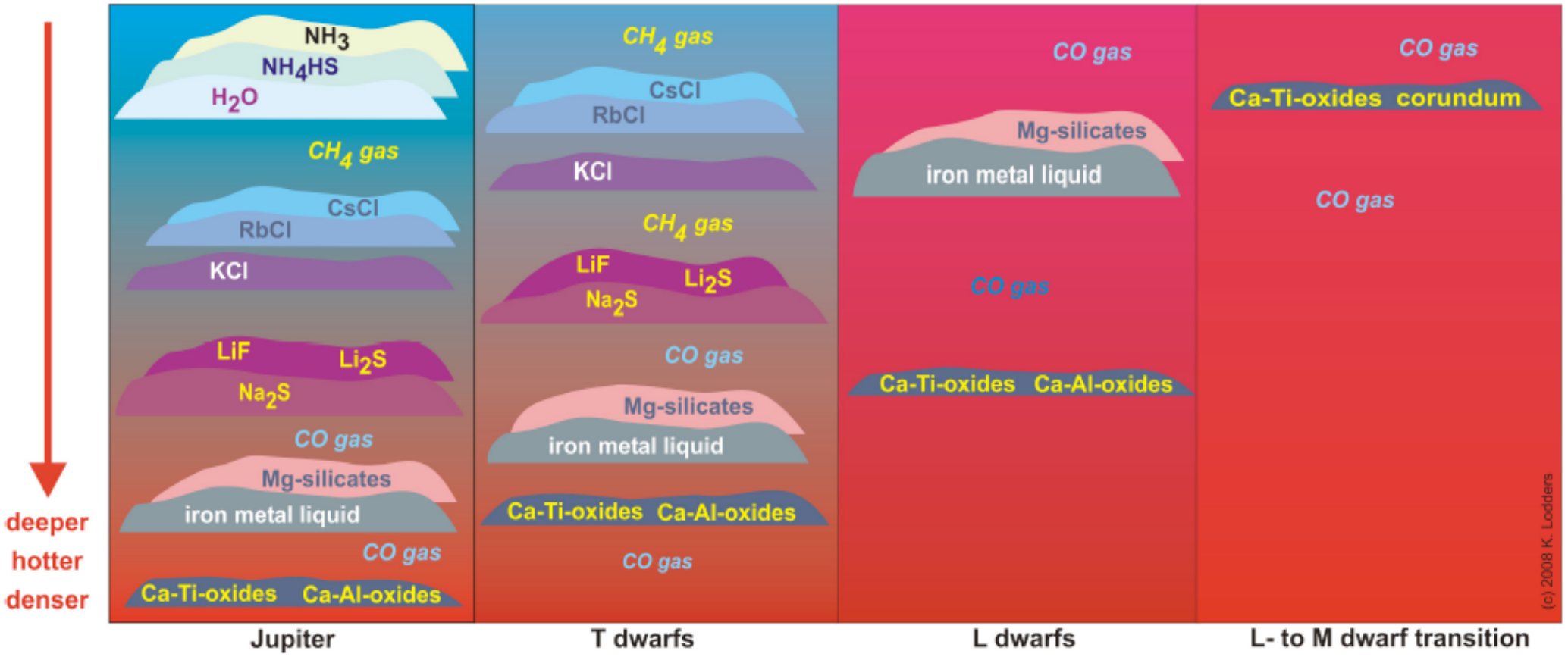
Most refractory species are composed of Ca, Al, Ti, Mg, Si. Then alkali metals, then H2O and NH3. CaAl4O7-grossite, Al2O3-corundum, Mg2SiO4-forsterite, MgSiO3 enstatite, ...

Proof of rain-out: the detection of H2S in Jupiter. Sulfur is not refractory. It should have been in the form of FeS. However, Fe is refractory, it rained out, FeS could not form hence H2S is observed.

Solar metallicity condensation curves taken from Burrows et al. 2006, ApJ, 640, 1063



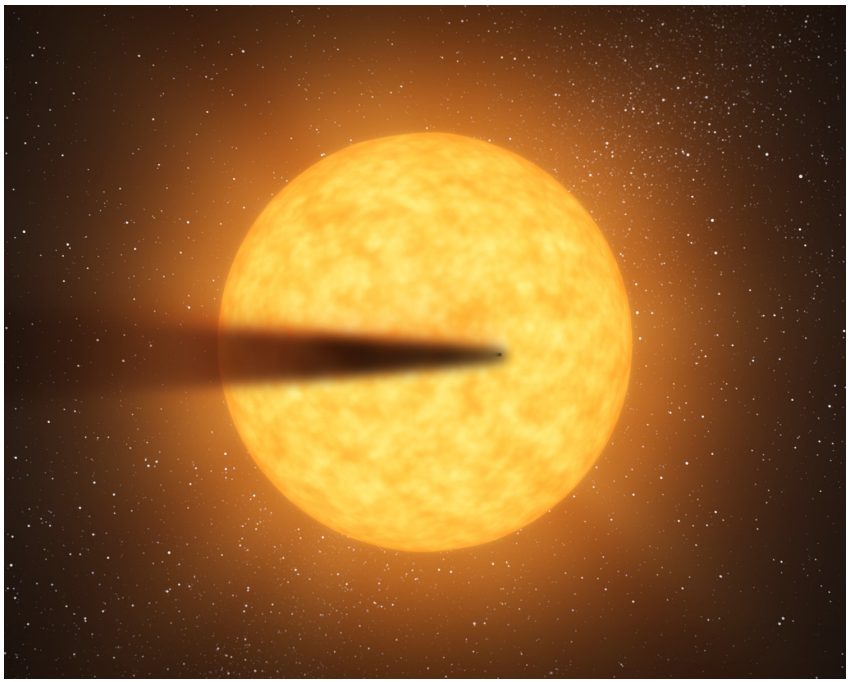
Cloud structure



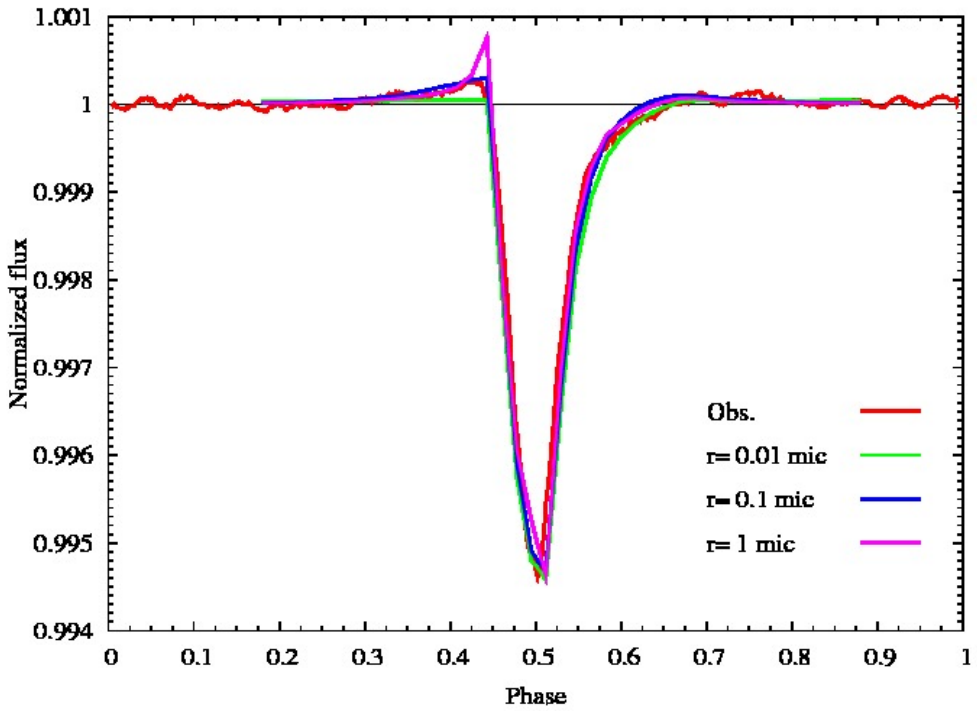
Lodders & Fegley (2006)

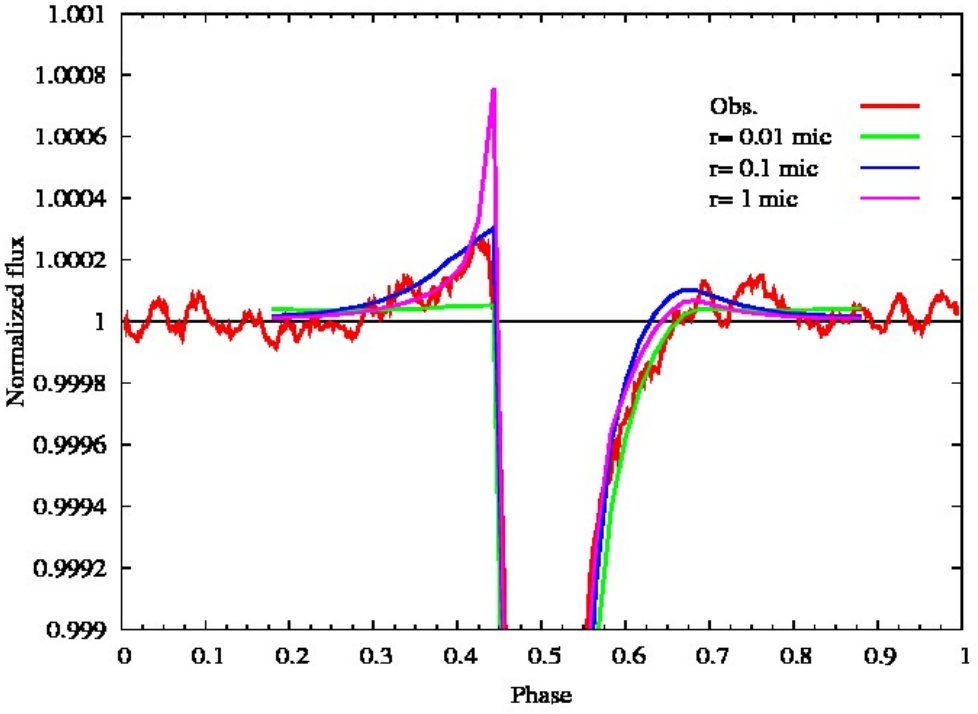
Exo-planet or exo-comet?

Discovered in Kepler data by Rappaport et al. (2012)



Budaj (2013)





Thank you!

L2: Optical & other dust properties

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Optical properties of dust grains

N,k,medium+Mie theory (hom. spheres)=>Absorption, Scattering, Phase Fun.
They depend on the wavelength, grain size, phase angle.
Mie scattering, Rayleigh scattering.

C-cross-sections, Q-efficiency factors:

$$C_{abs} = Q_{abs}\,\pi a^2 \qquad C_{sca} = Q_{sca}\,\pi a^2 \qquad Q_{ext} = Q_{sca} + Q_{abs}$$

$$Q_{sca} \sim (a/\lambda)^4 \qquad a \ll \lambda \qquad Q_{\lambda} \approx const. \qquad a \gg \lambda$$

$$Q_{abs} \sim a/\lambda \qquad a \ll \lambda$$

Single scattering albedo:

Opacities: $\kappa_\nu = C_{abs}\,n \qquad \sigma_\nu = C_{sca}\,n$

$$\varpi_\nu = \frac{\sigma_\nu}{\kappa_\nu + \sigma_\nu}$$

Radiative acceleration:

$$a_R = \frac{\omega}{Mc}\int [C_a + (1-g)C_s]\,B_\nu(T_{star})\,d\nu \qquad \beta = \frac{a_R}{a_G}$$

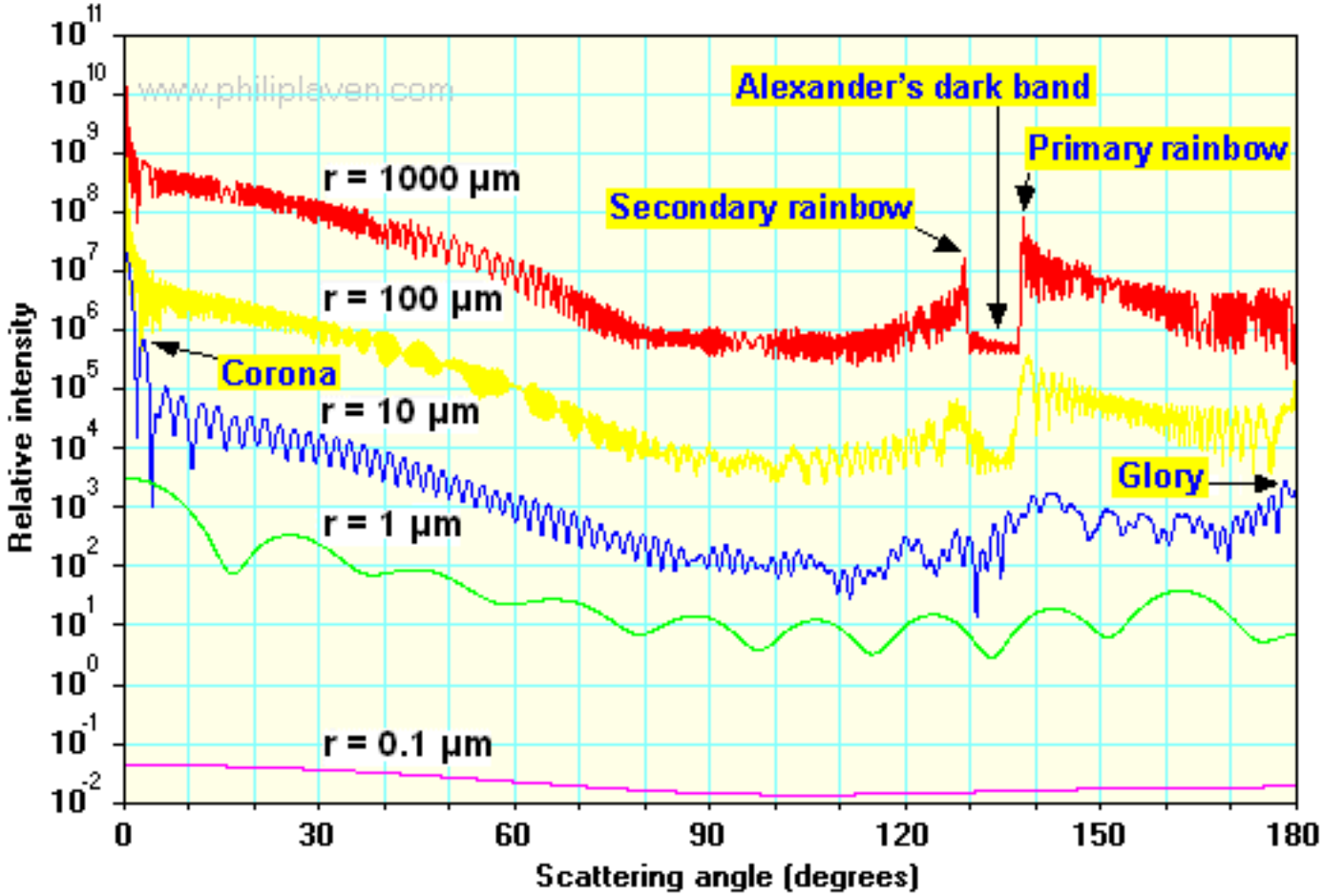
Radiative equilibrium, equilibrium temperature:

$$\int \kappa_\nu J_\nu\, d\nu = \int \kappa_\nu B_\nu(T)\, d\nu$$

Optical properties of dust grains

Phase function: function of phase angle (deflection from the original direction). Forward/backward scattering, glory, corona, rainbow.

$$\int p(\alpha) d\omega = 4\pi$$



MiePlot calculation of intensity for unpolarised red light (wavelength = 0.65 µm, refractive index = 1.33257) for water drops of radius 0.1, 1, 10, 100 and 1000 µm

Tables of phase functions, opacities, albedos, equilibrium temperatures, and radiative accelerations of dust grains in exoplanets

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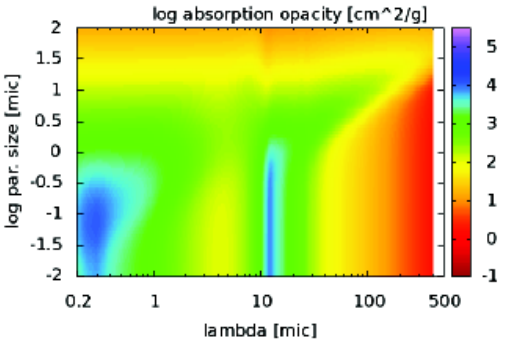
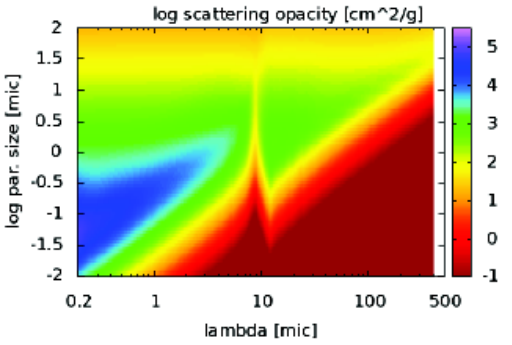
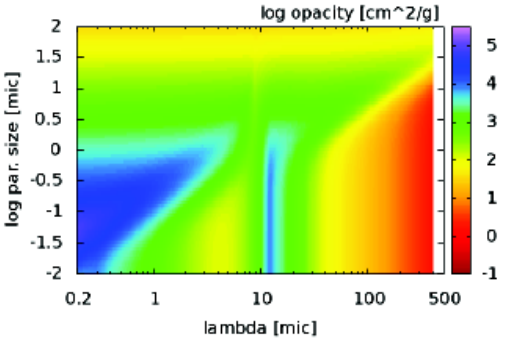
Assumptions:
homogeneous spherical grains, Deirmenjian particle size distribution, Mie theory, BHMIE subroutine (Bohren & Huffman, 1983)
14 species:alumina/corundum, perovskite, olivines (0,50%Fe), pyroxenes (0,20,60%Fe), Carbon(400,1000C), water ice&liquid, ammonia, modal particle size 0.01-100micron, wavelength 0.2-500micron, temperatures & accelerations for non-blackbody objects with T=7000-700K, solid angles: 2pi-1e-6sr, are publicly available

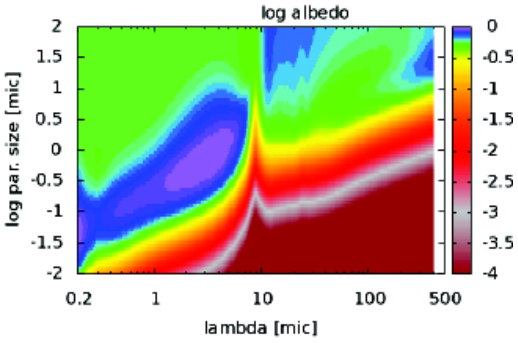
Alumina, Corundum

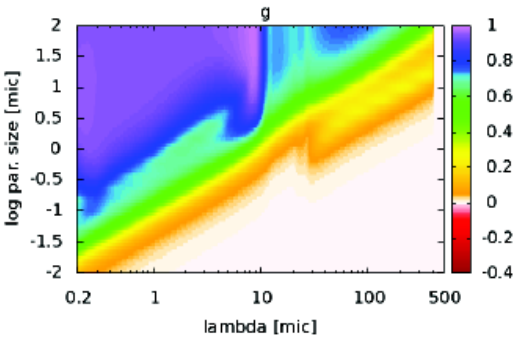
Al_2O_3

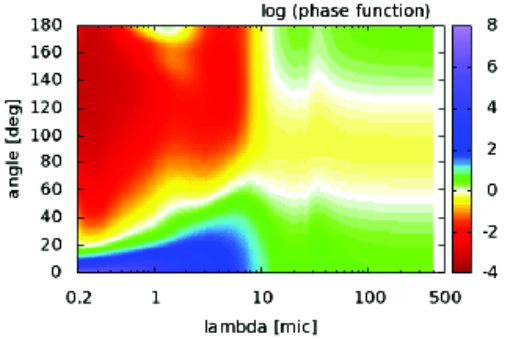


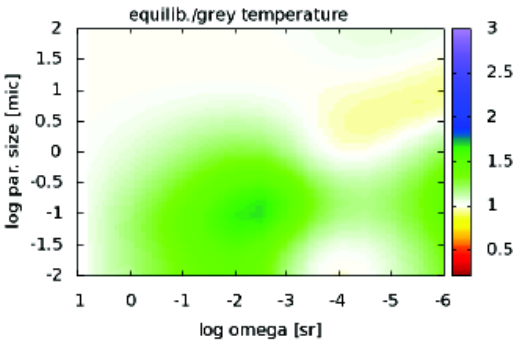


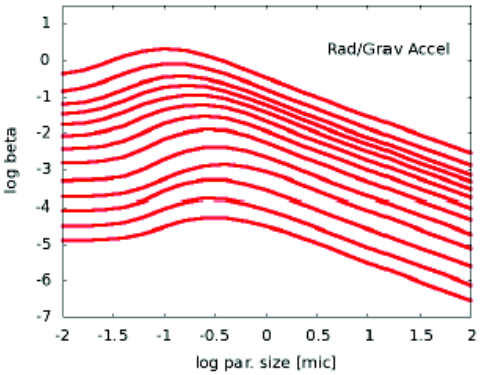






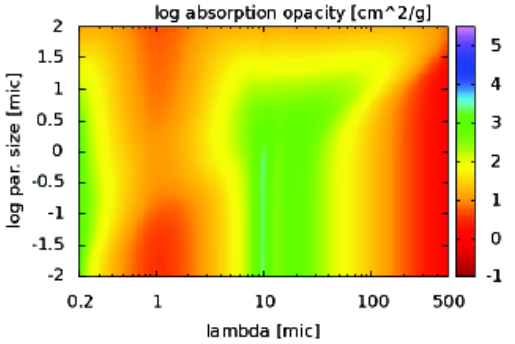


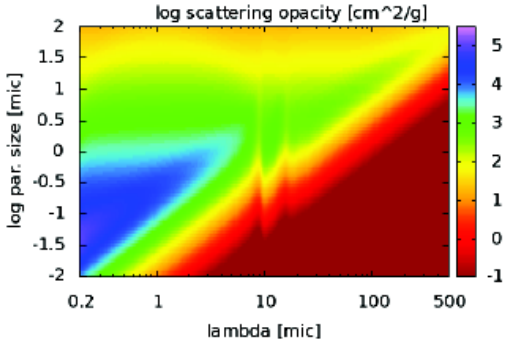


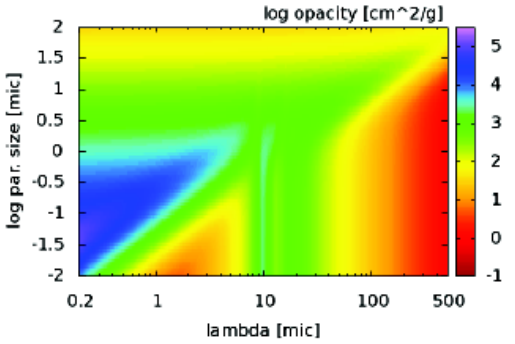


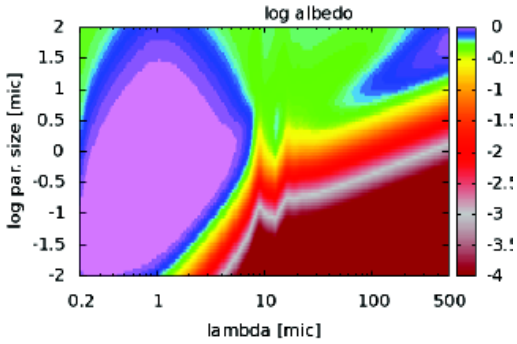
Forsterite, olivine

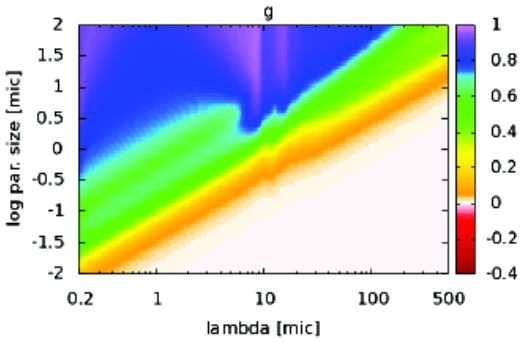
Mg_2SiO_4

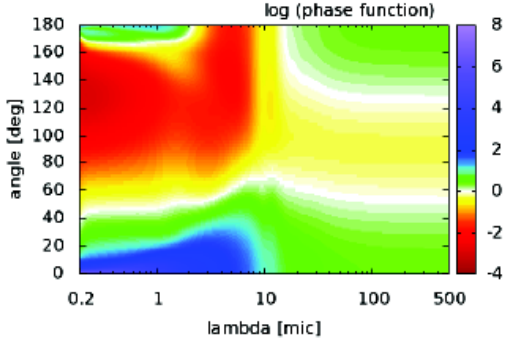


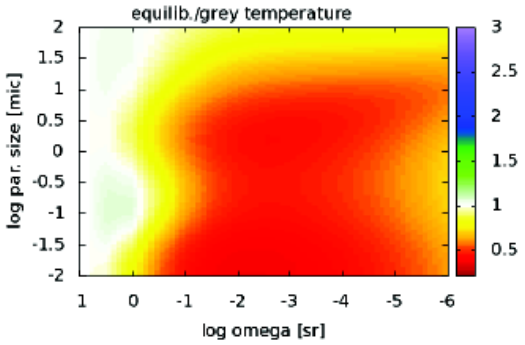


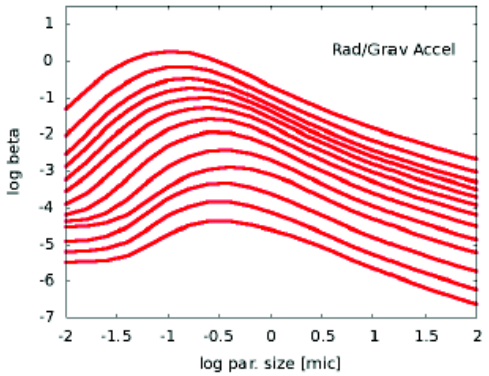




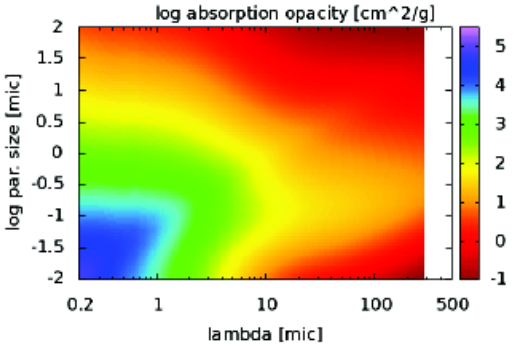


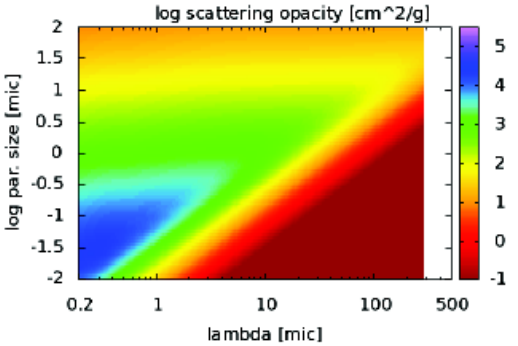


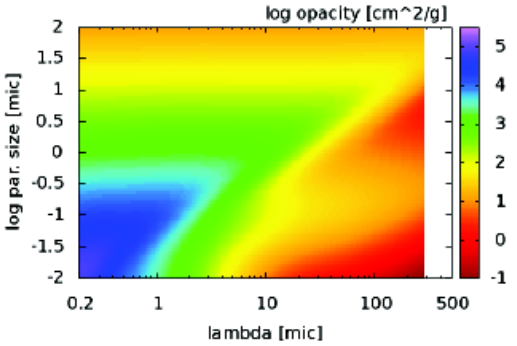


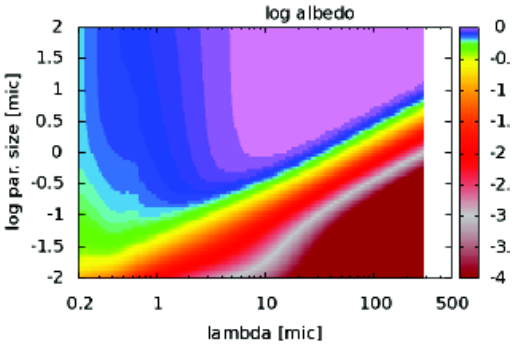


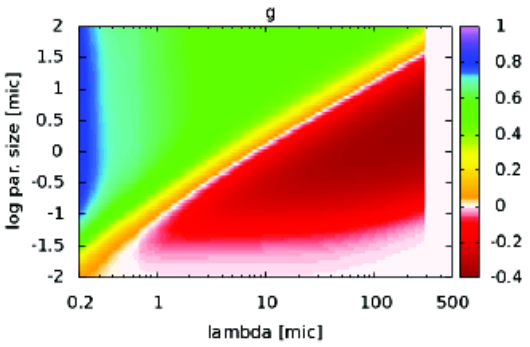
Iron, Fe

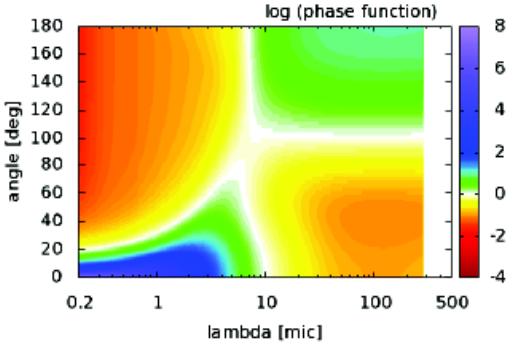

log absorption opacity [cm^2/g]
log par. size [mic]
lambda [mic]

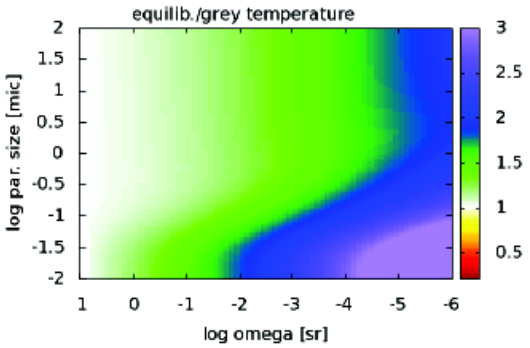

log scattering opacity [cm^2/g]
log par. size [mic]
lambda [mic]

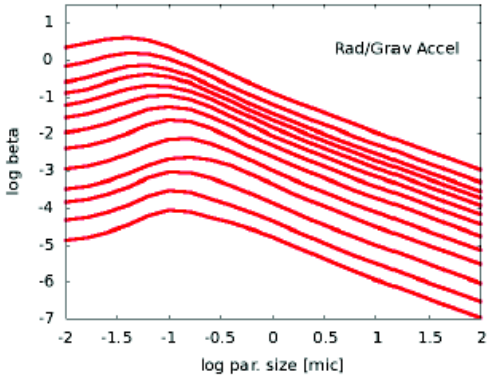

log opacity [cm^2/g]
log par. size [mic]
lambda [mic]


log albedo
log par. size [mic]
lambda [mic]

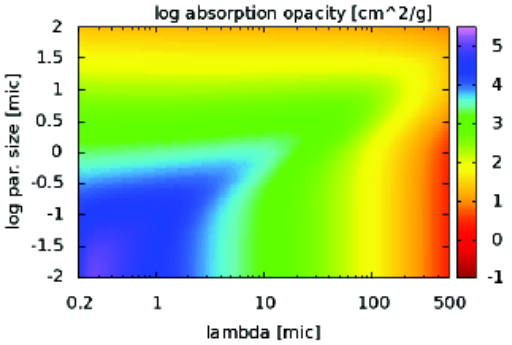

g
log par. size [mic]
lambda [mic]

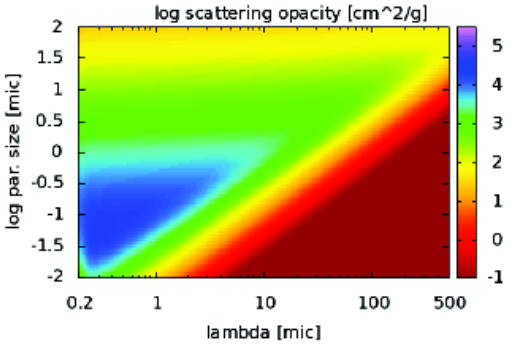

log (phase function)
angle [deg]
lambda [mic]

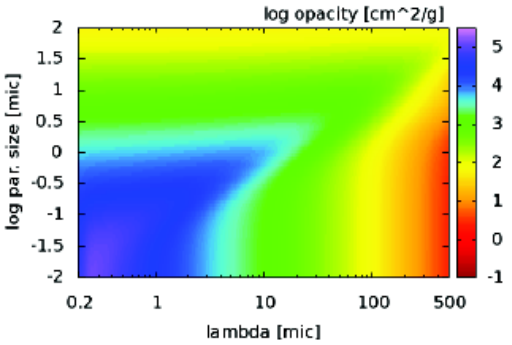

equilib./grey temperature
log par. size [mic]
log omega [sr]

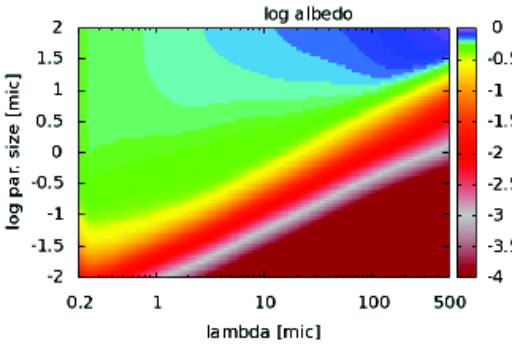

Rad/Grav Accel
log beta
log par. size [mic]

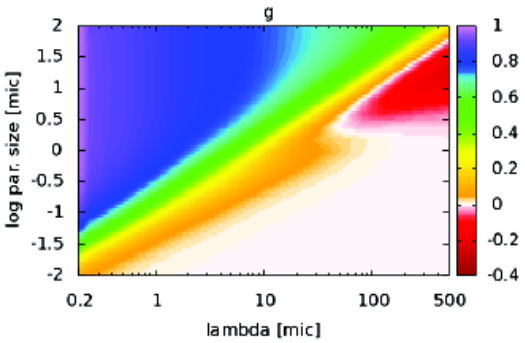
Carbon, C, 1000C

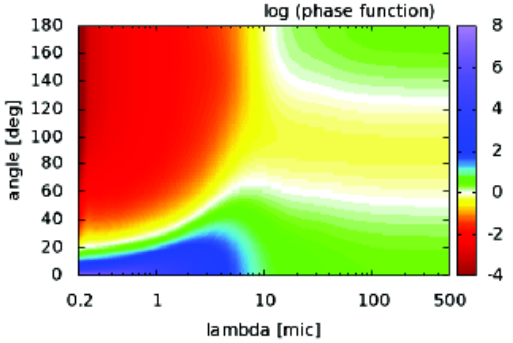


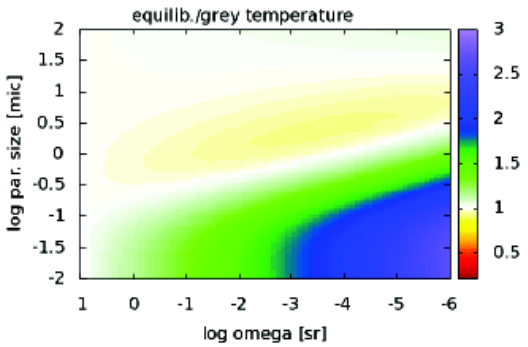


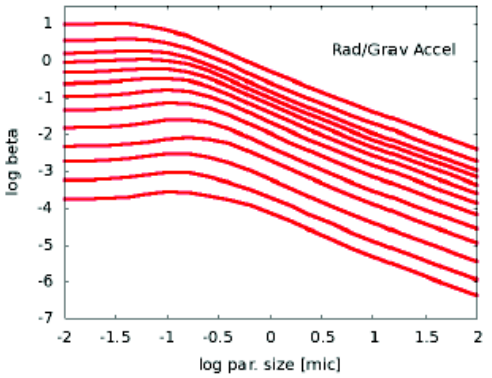






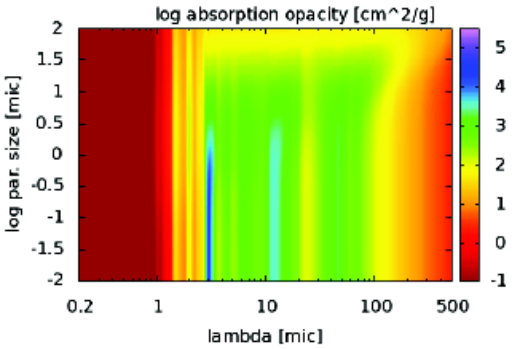


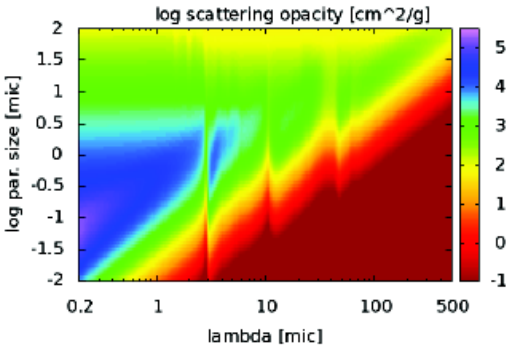


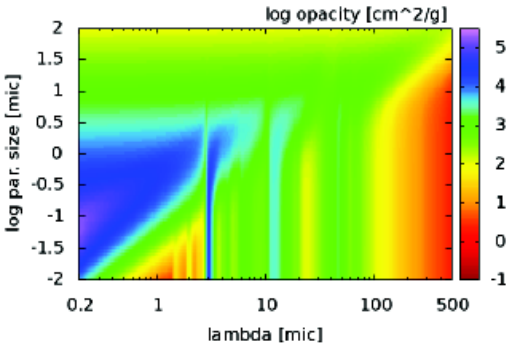


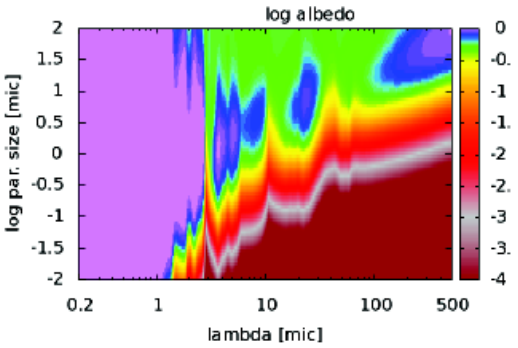
Water-Ice

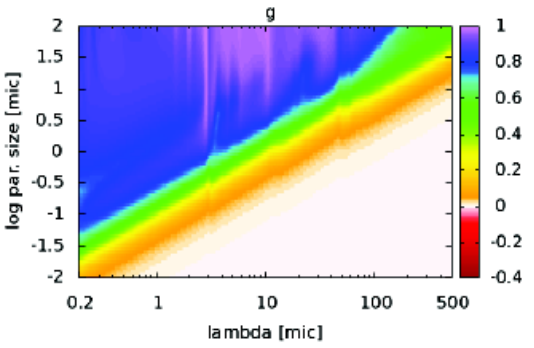
H_2O

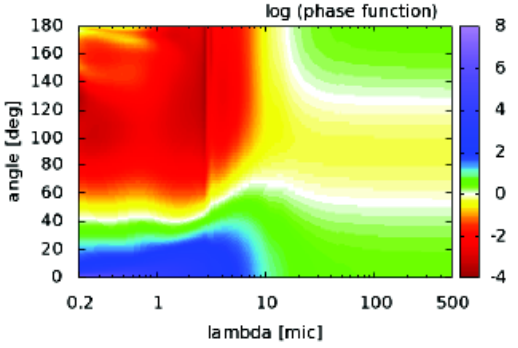


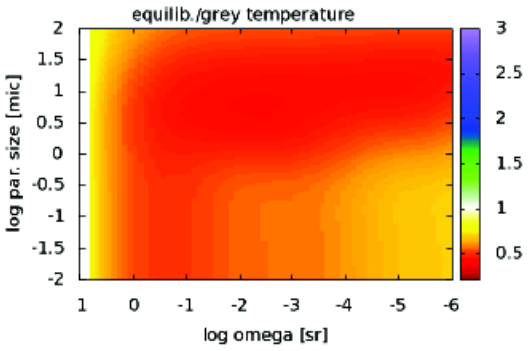


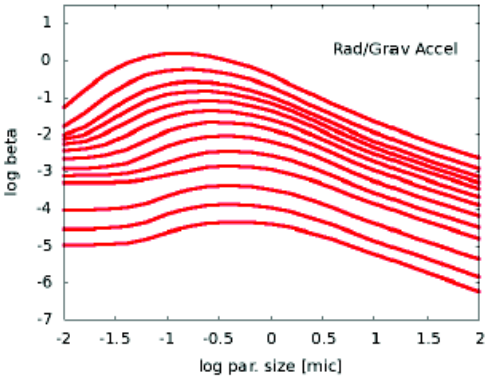












Thank you!