Constraints on the nature of dust particles by infrared observations

Cs. Kiss, P. Ábrahám, R.J. Laureijs, S.M. Birkmann

Konkoly Infrared & Space Astronomy Group,
Konkoly Observatory

email: pkisscs@konkoly.hu
web: http://kisag.konkoly.hu

Konkoly Infrared & Space Astronomy Group

Introduction: extinction and emission

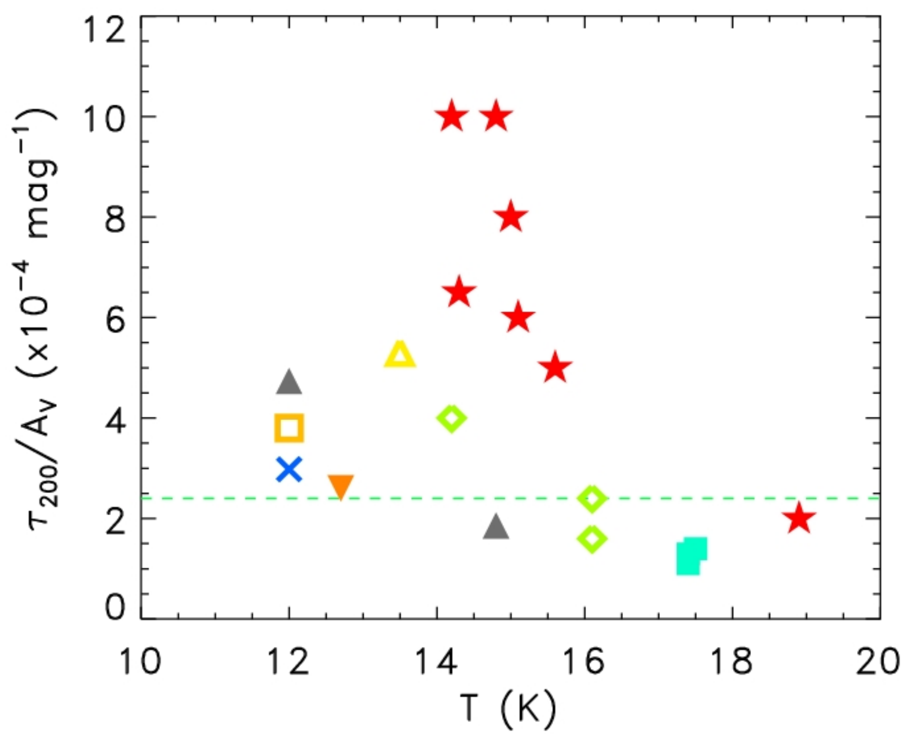
- **Dust seen in extinction:**
  - Interstellar dust scatters and absorbs starlight: the net effect is called *extinction*
  - $Q_a = -4 \cdot x \cdot \Im\left(\frac{n^2-1}{n^2+2}\right) \qquad Q_s = -\frac{8}{3} \cdot x^4 \cdot \Re\left(\frac{n^2-1}{n^2+2}\right)^2$
  - The optical depth: $\tau_\nu^{ex} = \int Q_e(a,\nu) \cdot \pi \cdot a^2 \cdot N(a) \cdot da$
  - We usually use the extinction measured in magnitudes instead of optical depth: $A_\lambda = 1.086 \cdot \tau_\lambda$
  - Extinction is wavelength dependent (the effect is smaller at longer wavelengths); this is usually characterized by the extinction curve $A_\lambda/E(B-V)$ where $E(\lambda_1-\lambda_2) = A_{\lambda_1} - A_{\lambda_2}$
  - Extinction curves measured at different line of sights can be well characterized by a single parameter, $R_V = A_V/E(B-V)$; R_V is ~3.1 in the diffuse interstellar medium, but can be ~6 in some directions (Orion molecular cloud).
- **Dust seen in emission:**
  - Thermal emission of dust particles: $Q(\nu) = Q_0 \left(\frac{\nu}{\nu_0}\right)^\beta \frac{a}{a_0} \qquad I_\nu = \tau_\nu B_\nu(T) \qquad \tau_\nu^{em} = \int 4\pi a^2 Q(\nu) N(a)\, da$

Introduction: grain growth

- **Radiative effect of grain growth**
  - For large particles (big grains) $Q_{ext} \simeq 2$, independent of the actual grain size
  - Since $\tau_\nu^{ex} \propto a^2$ and $\tau_\nu^{em} \propto a^3$, $\epsilon_\nu = (\tau_\nu^{em}/\tau_\nu^{ex})/(\tau_\nu^{em}/\tau_\nu^{ex})_0 \propto a/a_0$, i.e. for larger particles the emissivity is higher
  - Grain growth can be tested by measuring far-infrared emissivity
  - R_V should have a similar behavior (high values are usually interpreted by grain growth)
- **How can dust particles grow?**
  - Formation of ice mantles (H_2O, NH_3, etc.) or layers of 'organic' materials on the surface of silicate/carbon grains
  - Loose cluster of small particles (aggregates): PCA (Particle-Cluster Aggregates) or CCA (Cluster-Cluster Aggregates)
  - Grain growth can only happen in regions which are sufficiently dense to shadow the particles from UV photons

Observations of grain growth in dark clouds

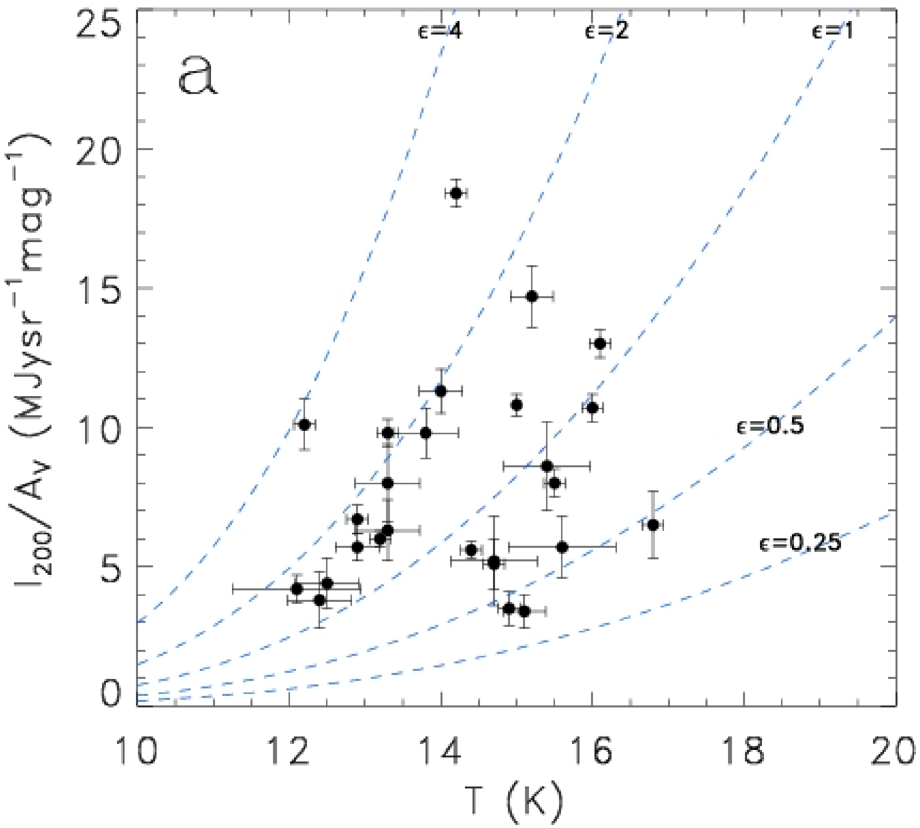
- **Recent observations:**
  - Several papers reported on the enhanced emissivity at $100\mu m \leqslant \lambda \leqslant 200\mu m$ wavelengths compared to that of the DISM ($\tau_{200}/A_V = 2.4 \times 10^{-4} mag^{-1}$), associated with HI (Bernard et al., 1999; Cambrésy et al., 2001, Juvela et al., 2002; Stepnik et al., 2003; del Burgo et al., 2003; Lehtinen et al., 2004; Rawlings et al., 2005, del Burgo & Laureijs, 2005)
  - In some cases low emissivities (below the DISM value) have also been found
  - All data point were derived in a different way, and often at different wavelengths



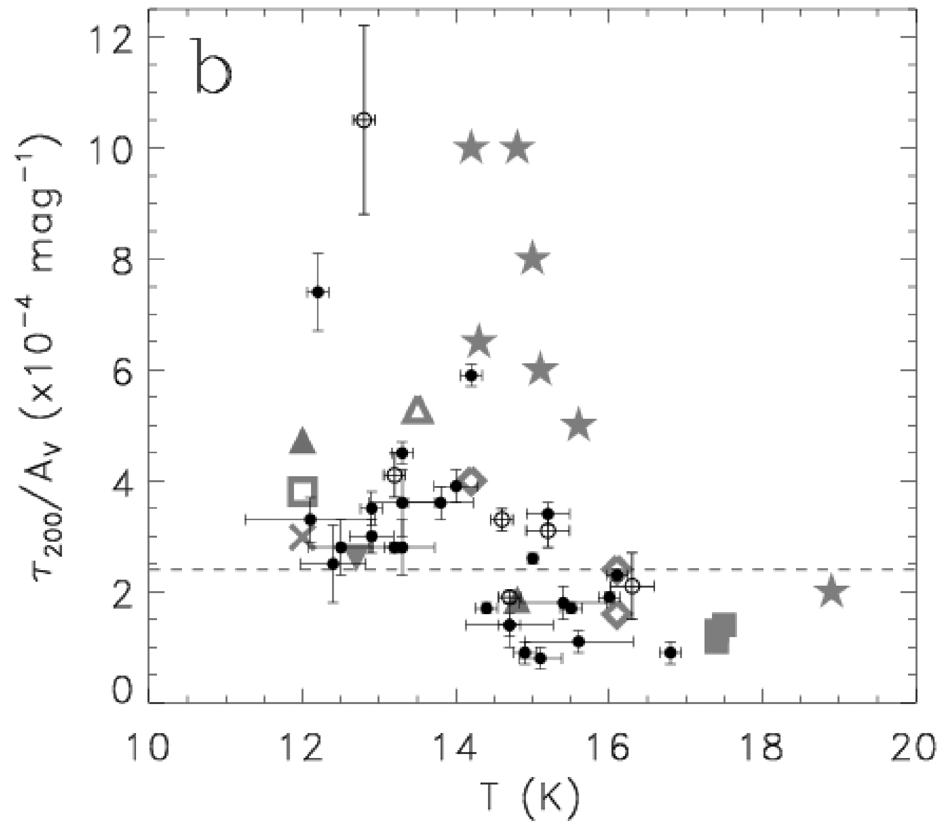
Observations of grain growth in dark clouds

- **Our dataset:**
  - All suitable P22 maps have been collected from the ISO archive, where a long (200μm) and a short (90, 100 or 120μm) map covered the same region, and the maps were suitable for further analysis (size, dinamic range, etc.).
  - Extinction maps were created using 2MASS J, H and K reddening data and the NICER method (Lombardi & Alves, 2001), after checking the reliability in a deep test field
  - We derived dust temperatures from short vs. long wavelenth surface birhtness scatter plots assuming a β=2 emissivity law
  - I_{200}/A_V ratios were derived for all fields as the slope of the A_V vs. I_{200} scatter plots
  - Emissivities were calculated as $\tau_{200}/A_V = (I_{200}/A_V) x B_{200}(T_d)^{-1}$,
  - This is the largest, homogeneously reduced dataset, analysed for this purpose (28 points)
  - Special care was taken on possible systematical errors and observational biases (see later)

Results

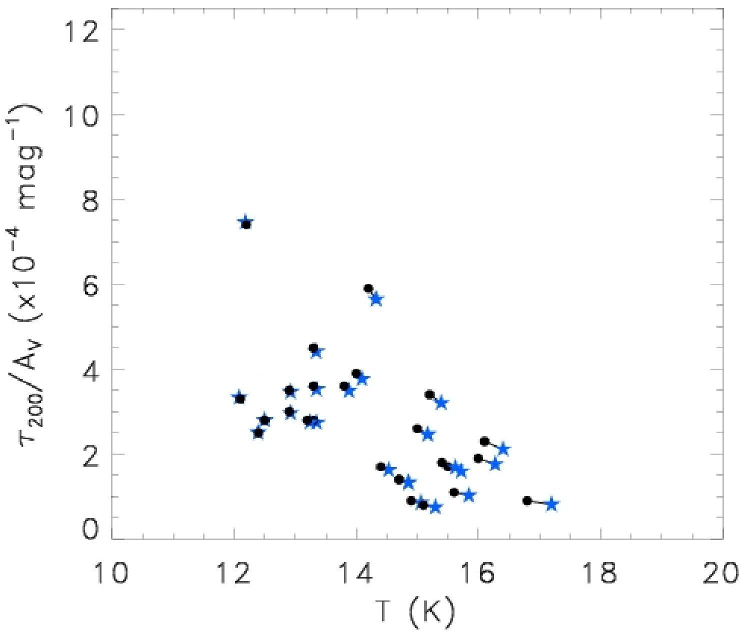


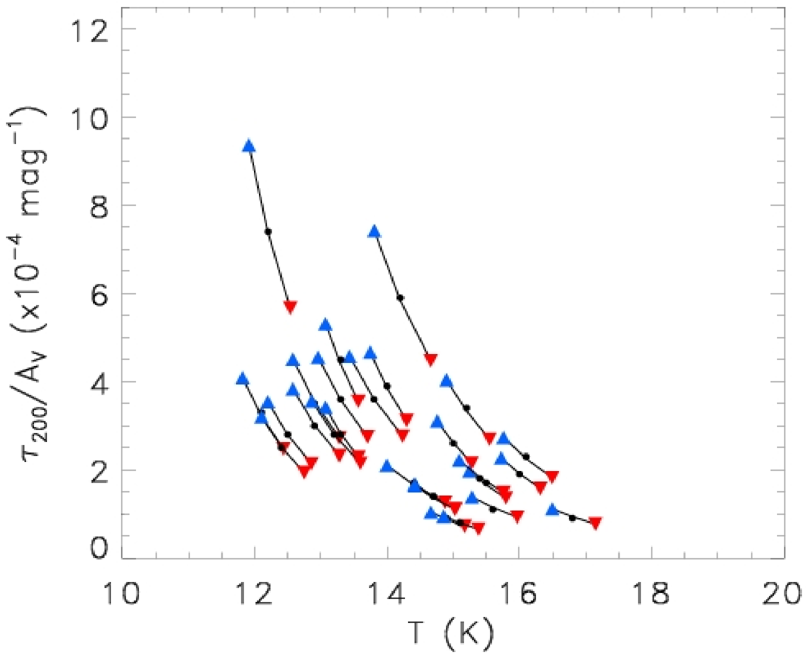
a
ε=4
ε=2
ε=1
ε=0.5
ε=0.25
I_{200}/A_V (MJysr^{-1}mag^{-1})
T (K)



b
τ_{200}/A_V (x10^{-4} mag^{-1})
T (K)

Systematic errors and observational biases

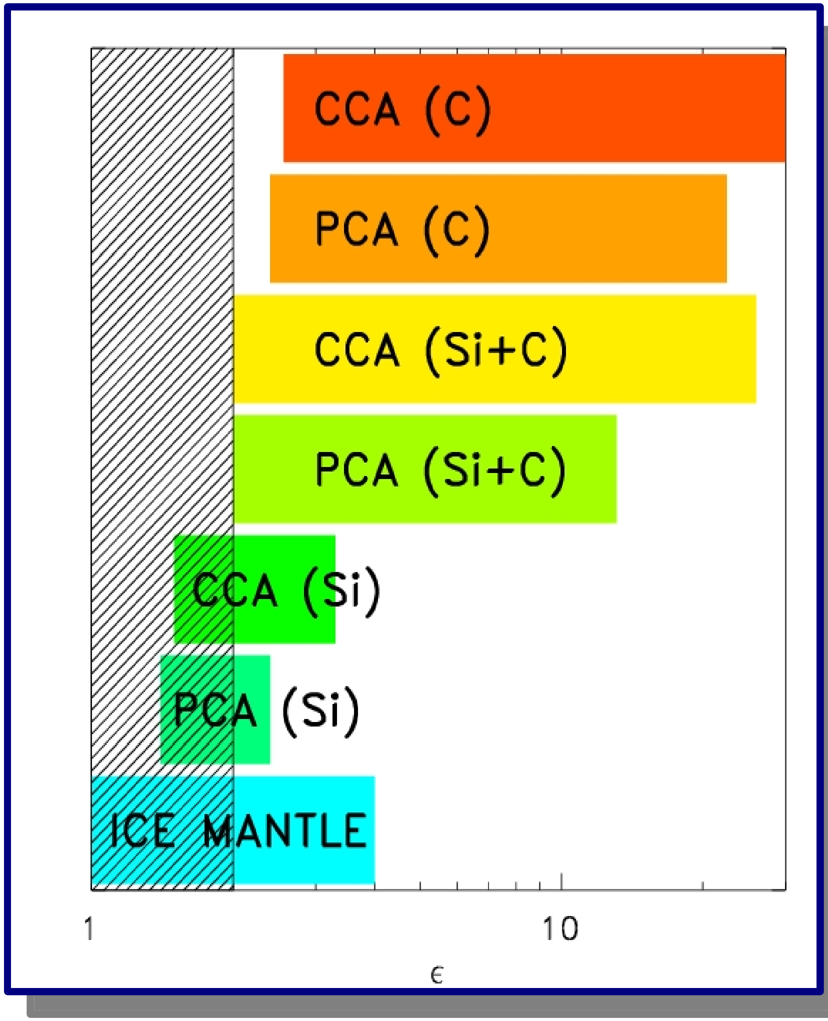




- **Effect of a different emissivity law**: Applying Dupac et al. (2003) β values (based on submm data, $\beta=1/[0.4+0.008\cdot T]$) instead of $\beta=2$ will not significantly modify the final emissivities
- **Different R_V**: $R_V \simeq 6$ would increase the final emissivities at most 19% (we assumed $R_V=3.1$)
- **Systematic uncertainties in the surface brightness calibration**: can be a serious effect, but large scaling factors (>50%) are not very likely
- **Presence of warm dust**: The presence of a warm (~18K) envelope around the cold clouds may increase the emissivities by ~30%

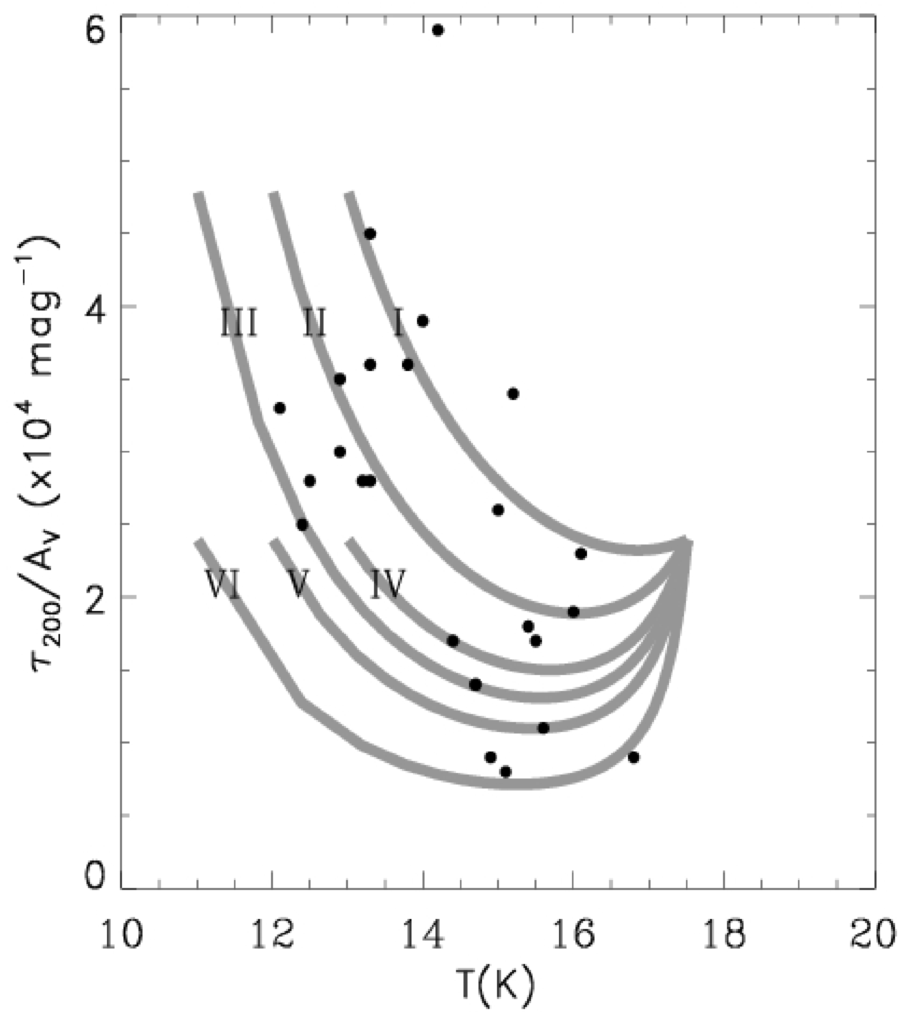
Change of dust properties at low temperature

- Below 14K all emissivity values are higher than that of the DISM (15 regions)
- The enhancement is moderate and the very high values seen in previous papers are not present
- The moderate emissivity increase restrict the possible grain growth scenarios to ice mantle formation and aggregates of silicate particles
- Our values are 'average' values of regions of ~100arcmin^2, i.e. regions with very high emissivity must be restricted to small regions, preferably below the scale of the ISOPHOT beam (carbonaceous aggregates).



Emissivities lower than in the DISM

- **Multiple dust temperatures:**
  - $I_\nu = \tau_{\nu,c} B_\nu(T_c) + \tau_{\nu,w} B_\nu(T_w)$
  - $\tau_{\nu,c} = \epsilon X \tau_{\nu,tot}$ $\tau_{\nu,w} = (1-X)\tau_{\nu,tot}$
  - Mixing, rather than temperature effect
  - It is necessary that the cold component is well mixed and not resolved by ISOPHOT (scatter diagrams would be highly non-linear)



- **Smaller grains**
  - If the relative contribution of the small grain component was enhanced, the observed emissivity would be higher, due to the additional emission from these grains
  - These clouds are relatively bright at shorter wavelengths (12, 25 and 60μm), as expected in this case

Summary

- We have compiled the so far largest database to study the variation of dust emissivity in the far-infrared (based on ISOPHOT C100 and C200 maps).
- According to our results, dust emissivity increases in cold ($T_d<14K$) clouds, but the increase is less significant than previously claimed;
- Observed emissivities are the best explained by the formation of ice-mantles or silicate aggregates
- Carbonaceous aggregates should be restricted to the densest cores, which are much smaller than the spatial extension of our observed clouds
- Low emissivities observed in regions with $14K<T_d<16K$ can be explained (i) by the presence of multiple temperatures in the line of sight, or (ii) by a bias towards smaller grain sizes
- A detailed analysis of possible systematic and/or observational error has shown, that it is plausible that our results are not due to artifacts in the data or to incorrect initial assumptions in the calculations
- A suspected close relationship between R_V and ϵ is going to be tested by deep, high resolution extinction maps of some selected clouds (observing run May 29/30, Isaac Newton Telescope, La Palma)