Describing the optical properties of astronomical dust analogs through numerical techniques

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From Dust to Galaxies, Paris, 06/30/2011







- Introduction
 - The interstellar medium in the infrared
 - The quest for the optical constants
- - Previous work
 - Methodology
- - . Experimental data and appelland
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- - 🚤 Conclusions
 - Future perspectives



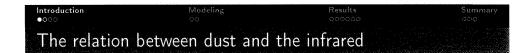
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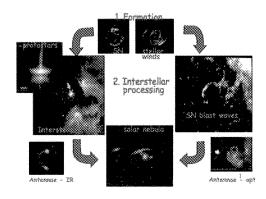


Figure: Formation, processing, and evolution of interstellar dust (Rinehart et al., 2008)

Interstellar dust:

- plays a role in the birth of stars
- precursor material for the formation of planets
- hides astronomical objects from our view

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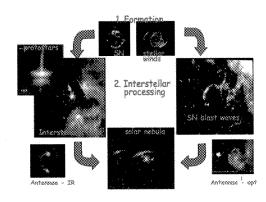


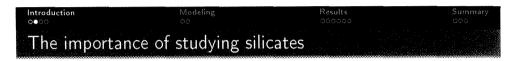
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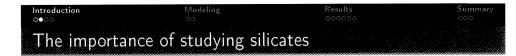
Spectral features attributed to:

- silicates
- carbonaceous grains
- PAHs

To receive the on observical and obvious structure.

Their spectra need be available through senormones experiments reproducing astrophysical enterinments. (See Hearing & Marschke, 2010)

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Constraints on chemical and physical structure

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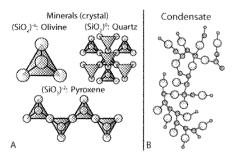


Figure: A) Silicates on Earth are ordered solids. B) In space their structure is chaotic. (Adapted from Rinehart et al., 2008)

The optical constants as primary parameters

Definition

Complex refractive index m = n + ik

- The refractive index *n* determines the velocity of constant-phase waves.
- \bullet The extinction index k determines the attenuation of the wave as it propagates through the medium.

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Problem: the optical constants are not directly measurable.

• Experimental apparatus and measurements

- Development of the model of the computation of the optical constants as a function of wavelength and temperature
- Validation through application to societies as a
- a Analysis and interpretation of post-processed data
- a Population of a line of optical properties to the far intraced regime.



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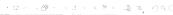
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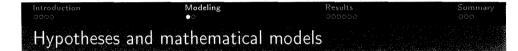


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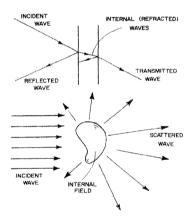


Figure: Analogy between scattering by a particle and transmission-reflection-absorption by a slab (Bohren and Huffman, 1983)

Transmission-line approximation

- One-laver slab modes
 (Botteen and Hilliman
 1963)
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Figure: Analogy between scattering by a particle and transmission-reflection-absorption by a slab (Bohren and Huffman, 1983)

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- One-layer slab model (Bohren and Huffman, 1983)
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Transition modes

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Hypotheses and mathematical models

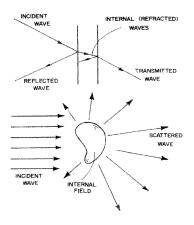


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Transition modes

Lorentz model

Adoption

 Mulliwell-Garden formets (Markett Garden), 1994).

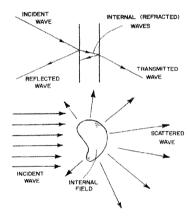


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Mixtures

 Maxwell-Garnett formula (Maxwell Garnett, 1904)

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Results 000000 Summary 000

Constrained minimization as main working tool

Definition (Least-Squares Nonlinear Fit)

$$\min_{DOFs} \chi_m^2 = \min_{DOFs} \frac{1}{N} \sum_{j=1}^{N} \left[T \left(DOFs, \lambda_j \right) - T_{measured} \right]^2$$

$$DOF_{min} \leq DOF \leq DOF_{max}$$

N = number of data points

 λ = wavelength

Initial condition \rightarrow Fig. $> DOS_2 \rightarrow \emptyset$ $\begin{cases}
-1, R, A \\
-6, k,
\end{cases}$ (2)



Constrained minimization as main working tool

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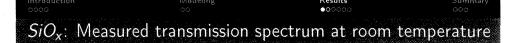
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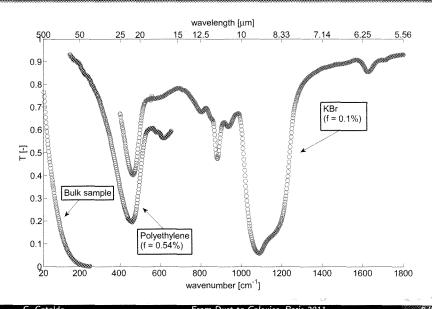
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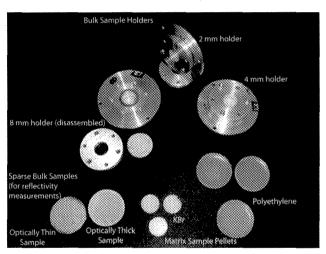


Figure: Various sample preparations are needed to cover the wide frequency range (Rinehart, Cataldo, et al., *Applied Optics*, in press).

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Each sample preparation has a different optical depth, which allows us to obtain transmission values in the range of 0.2-0.8 as needed to determine the optical constants to high accuracy.

Sample type	Spectral coverage $[\mu m]$
8-mm	300 — 1000
4-mm	100 - 500
2-mm	100 - 350
Polyethylene	15 - 100
KBr	1 - 25

SiO_x : How to extract the optical constants (bulk samples)

Beer's law

$$T = (1 - R)^2 \exp\left(-\alpha h\right)$$

$$R = \frac{(n+1)^2 + k^2}{(n+1)^2 + k^2}$$

$$T = T(a, a, b)$$

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$$k = \frac{\alpha}{2\omega} = \frac{\partial}{2\omega} \left(\frac{\omega}{2\pi}\right)^{b-1}$$

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$$T=T\left(n,a,b\right)$$

SiO_x : How to extract the optical constants (mixtures)

Maxwell-Garnett formula

$$\varepsilon_{\it eff} = \varepsilon_{\it eff} \left(f, \varepsilon_{\it b}, \varepsilon_{\it i} \right)$$

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Results ○○●○○ Summary

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Lorentz model

$$\varepsilon_{i} = (n + ik)^{2} = \varepsilon_{i,\infty} + \sum_{j=1}^{M} b_{m} \frac{\omega_{p,j}^{2}}{\omega_{0,j}^{2} - \omega^{2} - i\omega\nu_{j}} = \varepsilon_{i}(\text{OOFs}, \omega)$$

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Modified Lorentz model (Sihvola, 1999)

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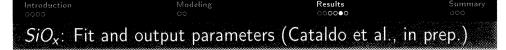
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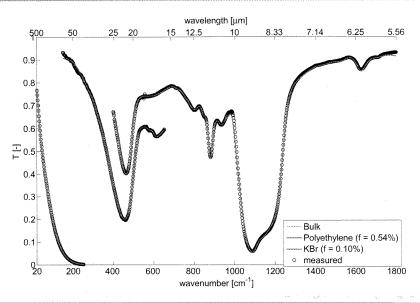
Modified Lorentz model (Sihvola, 1999)

$$\varepsilon_{\text{eff}} = \varepsilon_{\text{eff}} (f, \varepsilon_{b}, DOFs_{i}, \omega)$$

One-layer slab model (averaged)

$$T = T[f, \varepsilon_b, (4M+1)DOFs_i, \omega]$$





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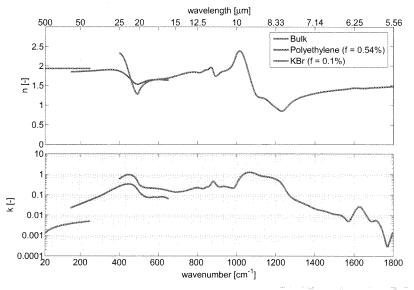
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 SiO_{x} : Fit and output parameters

		Bulk (4-mm)	Polyethylene	KBr
DOFs		3	53 (13 LOs)	153 (38 LOs)
Residual	average	0.32	0.62	0.25
ΔT [%]	maximum	2.68	3.93	1.47
χ_m^2	-	$2.55 \cdot 10^{-5}$	$11.12 \cdot 10^{-5}$	$1.29 \cdot 10^{-5}$
σ		0.005	0.012	0.008
χ^2		109.89	239.81	146.26
χ^2_{ν}		0.93	1.15	0.25



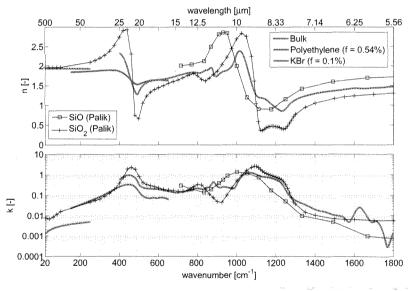
SiO_x : The optical constants in the FIR and MIR



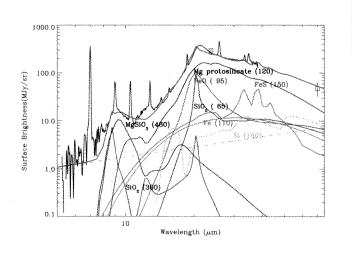
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SiO_x : The optical constants in the FIR and MIR



SiO_x : The optical constants in the FIR and MIR



(Adapted from Rho et al., 2008)

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Our sample description

	Advantages	Disadvantages	
Bulk sample	n consistent with other measurements	n not well constrained	
Bull sumple	a = 0.003, b = 1.552 (Agladze et al., 95;)	Need for data at longer wavelengths	
	n-k independent from filling fraction	n-k dependent on matrix	
Mixture	$x \approx 1.5$	Fine-tuning	
	DOFs well constrained	of starting guess	
	Outputs for mix and particles	Uncertainty in measurements	

• Measured reflectance data (TOP PRIORITY)

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- Development of more sophisticated models.
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- a Application to the appearing laboratory data and observation

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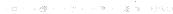
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 - Scattering
 - Multiple-layered structures
 - Unparalleled faces and roughness

Application to the opening aboretory data and designation





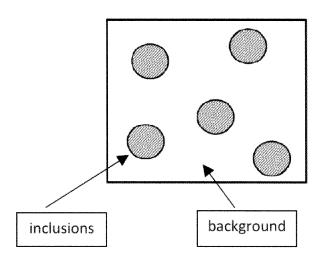
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Thanks! Questions?



The effective medium structure





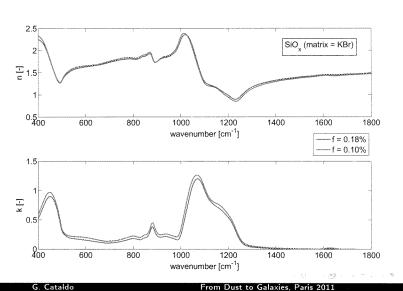
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Appendix

The optical constants as a function of filling fraction

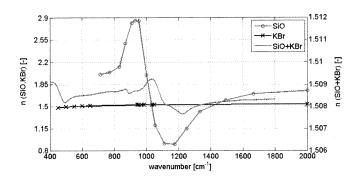




Appendi

The optical constants for the $SiO_x - KBr$ mixture





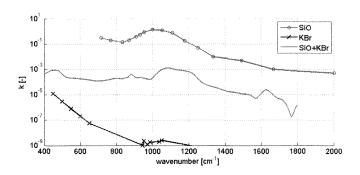
(Rinehart, Cataldo, et al., Applied Optics, in press)

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Appendi:

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