Modeling Long-Wavelength Amorphous Dust Emission Based on the Physically Motivated Soft-Potential Model

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Abstract

Motivation: constructing a new amorphous dust emission model beyond the TLS model

Goal: formulating long-wavelength amorphous dust emissions

Originality: applying the Soft-potential model in dust physics

Results: our model comparison test with obs. data is reasonable

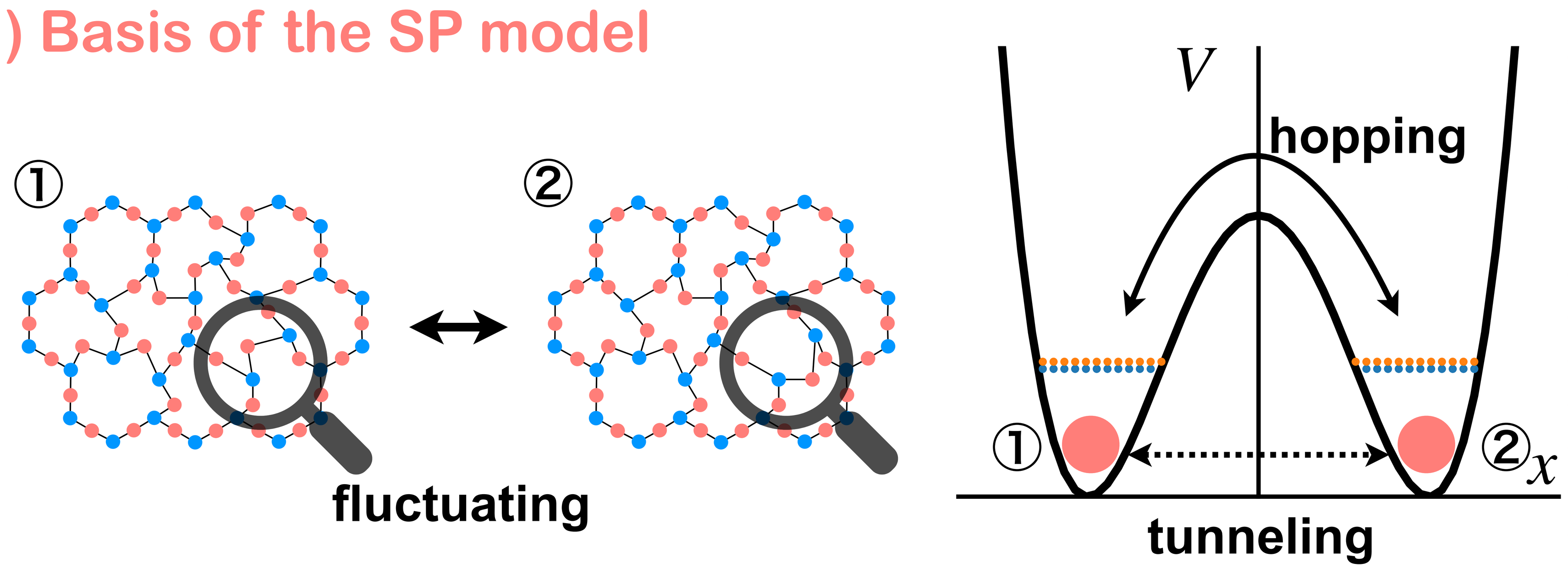
Background: Necessity for Models Beyond the TLS Model

- interstellar large dust grains are primarily composed of amorphous materials
  - optical properties of amorphous dust particles can be described by a physically-motivated model such as **Two-Level Systems** model (i, ii)
- the TLS model has some problems
  - cannot self-consistently solve each absorption process
  - although the TLS model can account for the amorphous properties of materials below approximately 1 K, it fails to reproduce the behavior measured around 10 K

Soft-Potential (SP) model (iii, iv) can revise the amorphous dust emission model!

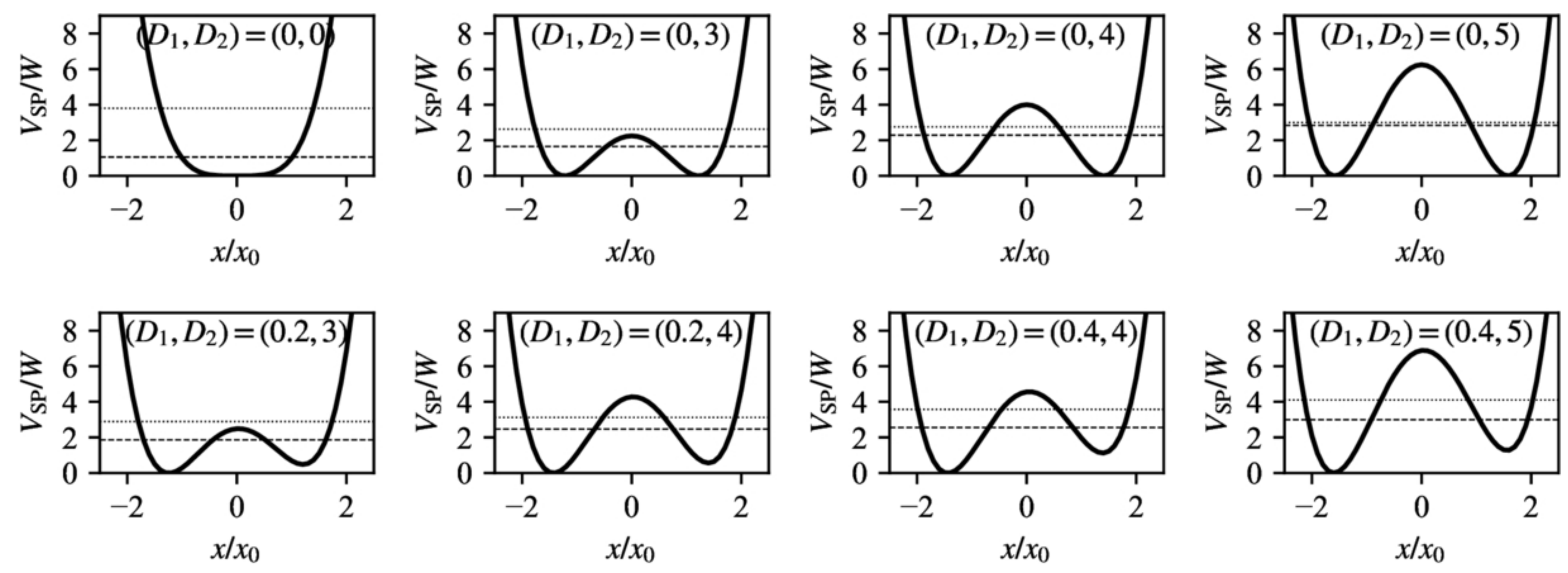
Methods: How to derive amorphous dust emission in the SP model

(1) Basis of the SP model



1) considering a situation in which some atoms constituting amorphous dust are trapped in a double-well potential described by a quartic function
2) solving the interaction of the atomic two-level system caused by the double-well potential and the electric field to determine the electric polarization

(2) Calculation

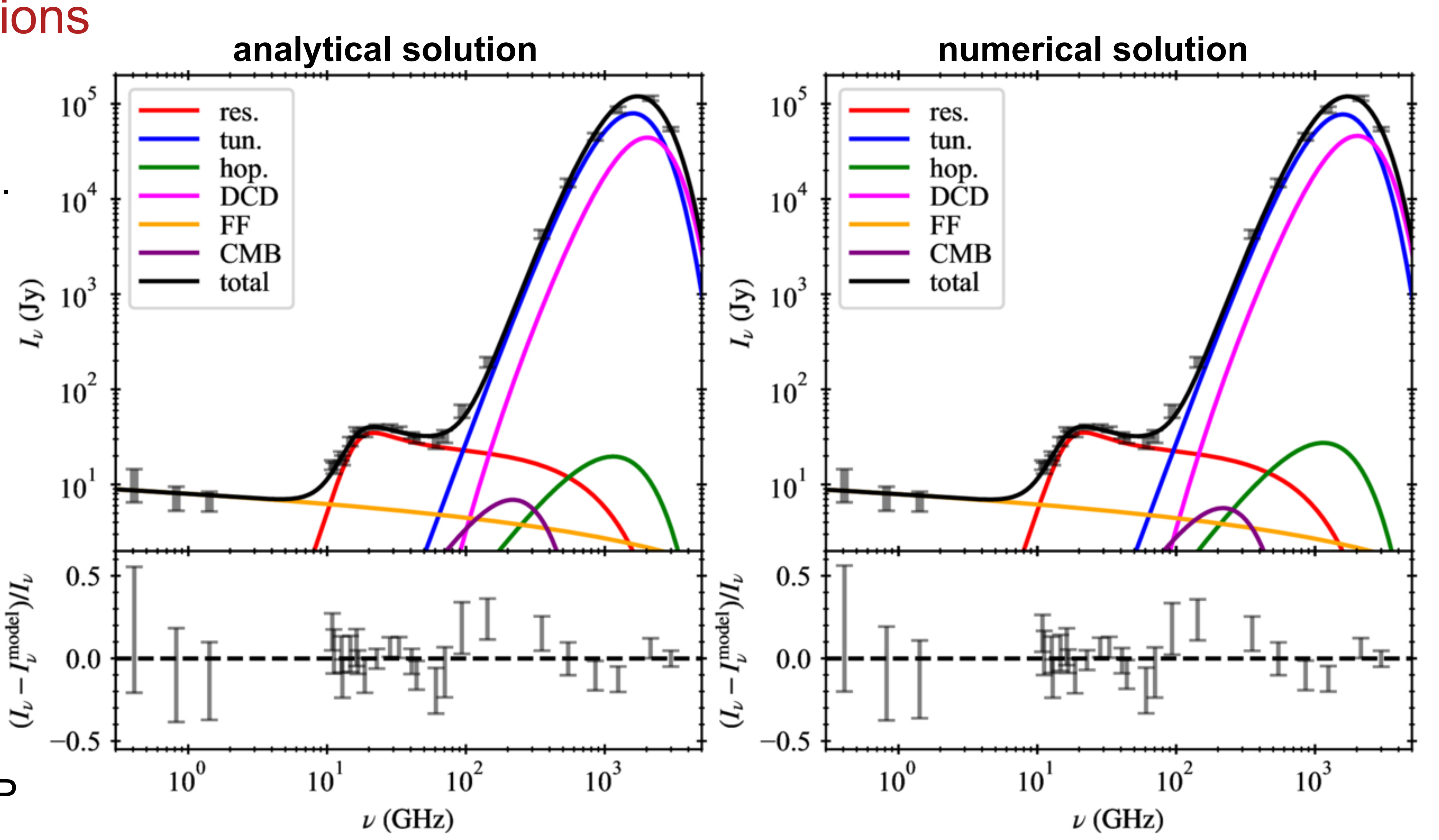


1) describing the DWP as $V_{SP}/W = D_1\left(\frac{x}{x_0}\right) - D_2\left(\frac{x}{x_0}\right)^2 + \left(\frac{x}{x_0}\right)^4$
2) assuming the atomic potential parameters, D_1 and D_2, are uniformly distributed in amorphous dust

Results: Comparison with observations

Setup

- object: Perseus Molecular Cloud
- data: Planck, WMAP, DIRBE, QUIJOTE, etc.
- dust type: amorphous silicate
- dust size: 0.1 micron
- dust emission mechanism
  - resonance transition
  - tunneling relaxation
  - hopping relaxation
  - lattice vibration (DCD)
- fitting parameters related to the SP model
  - W : energy scale of the potential
  - D_2^{max} : upper cutoff of D_2
  - γ : phase relaxation rate
  - T : dust temperature
  - f_{SP} : number ratio of atoms trapped in DWP



Discussion: Toward comparison with obs. & lab. features

Comparison pf physical quantities of amorphous dust in the best-fit model

	W $(K \times k_B)$	Δ_0^{max} $(K \times k_B)$	Δ_0^{min} $(K \times k_B)$	γ $(10^{10} s^{-1})$	$N_{SP}/(\rho V)$ (g^{-1})
Best-fit	0.329	0.698	0.646	4.72	1.45E+22
Ref.	1-5	20.6	< 2E-3	0.3	1E+16-1E+17

large differences

(Δ_0 : splitting energy between the two-level)

The reference values indicate typical properties of amorphous materials under various compositions and conditions, not those of interstellar dust.

Next Step: Comparison of our models with lab dust analogues and molecular dynamics simulations.

Conclusion

We have proposed a new amorphous dust emission model based on the SP model, which is applicable in the long-wavelength range and can more effectively explain various dust emission features.

References

This work is based on our recent publication in M. Nashimoto 2025 ApJ, 992, 195.

(i) C. Meny, et al. 2007, A&A, 468, 171.
(ii) M. Nashimoto, et al. 2020, ApJL, 900, L40.
(iii) Karpov, V. G., et al. 1982, Solid State Commun., 44, 333
(iv) Ramos. M. A., et al. 1983, Phys. Stat. Sol. (A)135, 477

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