Dynamical evolution of dust around the planet host star HD 69830

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Abstract

With the discovery of infrared dust emission and three Neptune-mass planets, the system HD 69830 provides one of the first possibilities to investigate the properties of a mature planetary system with its interactions between the different components: planets, dust-producing planetesimals, and a dust disk. We used our collisional code to model possible planetesimal belts in the system, the resulting distributions of dust, and its thermal emission. We confirm that the detected dust is more likely located in the outer stability zone at about 1 AU and that its production must have started only recently. We also show that a better agreement between the resulting spectral energy distribution and the observations is achieved if cratering collisional events are taken into account.

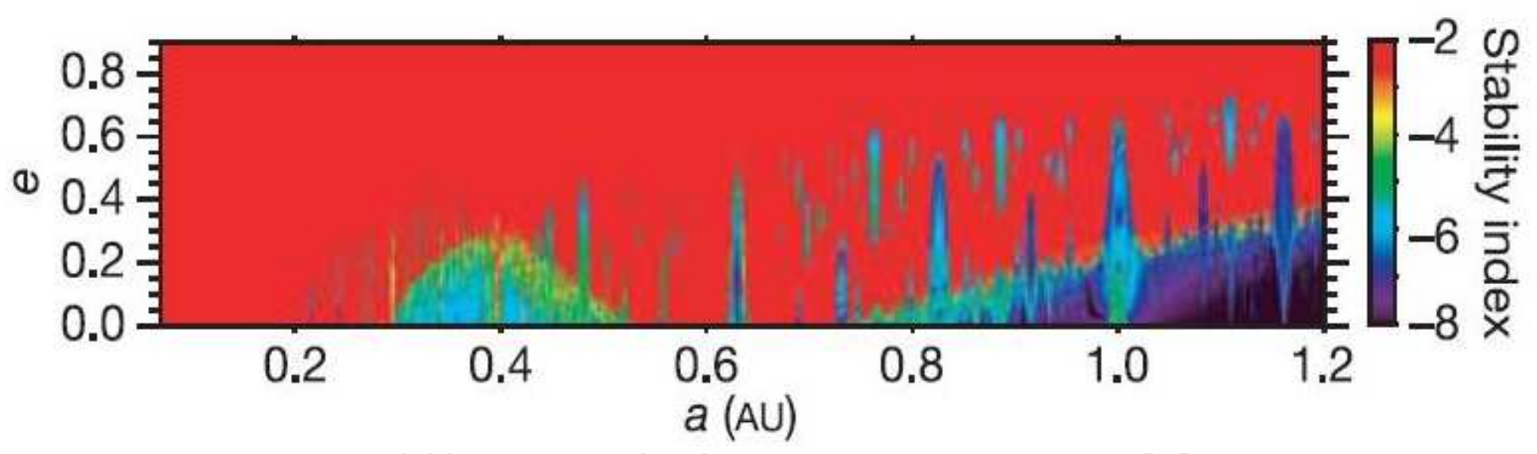
Some References

[1] Beichman et al.: ApJ, 626, 1061–1069 (2005)
[2] Lovis et al.: Nature, 441, 305–309 (2006)
[3] Lisse et al.: ApJ, 658, 584–592 (2007)
[4] Krivov et al.: A&A, 455, 509–519 (2006)

The System of HD 69830

Three Neptune-sized planets (their properties are listed in the table on the right) have been discovered in close-in orbits about the K0 V star HD 69830a. As shown by [2], the gravitational disturbance of the planets restricts the possible location of planetesimals in the system to two regions (see figure below). One is located between the second and the third planet, the other beyond the third planet.

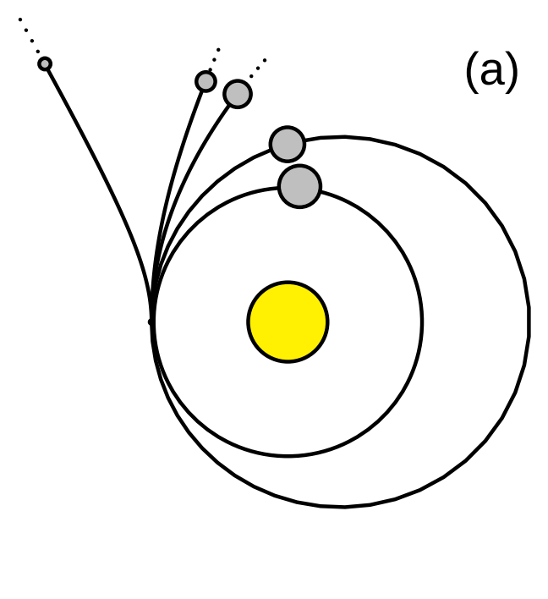
properties	HD 69830b	HD 69830c	HD 69830d
mass	$10.2\ M_\oplus$	$11.8\ M_\oplus$	$18,1\ M_\oplus$
semi–major axis	0.0785 AU	0.186 AU	0.63 AU
eccentricity	0.10 ± 0.04	0.13 ± 0.06	0.07 ± 0.07
period	8.667 ± 0.003 d	31.56 ± 0.04 d	197 ± 3 d



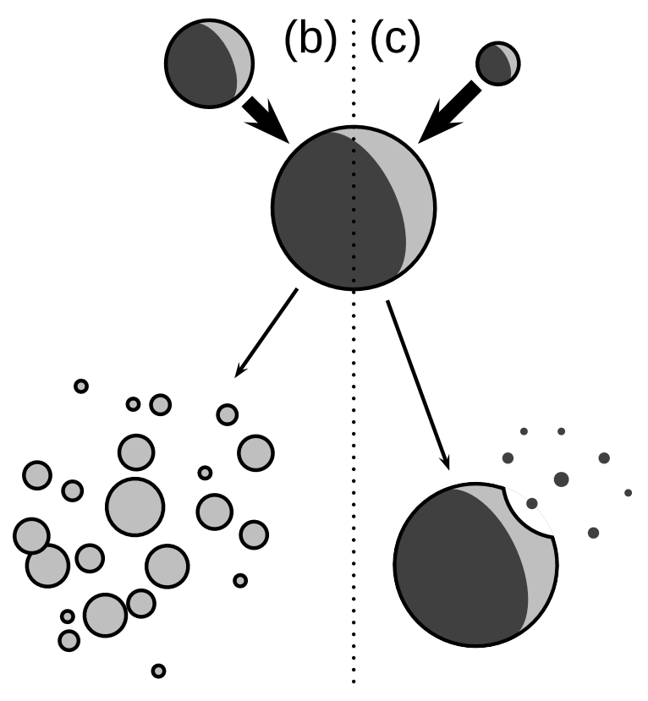
Stability zones in the HD 69830 system [2].

According to the stability zones we chose the initial conditions of our kinetic model and the distribution of dust and parent bodies. The disk as been assumed to be axisymmetric, gas-poor and optically thin. The resulting spectral energy distributions are then compared to photometric and spectroscopic observations.

The Dynamical Model



Based on the method and code (“Analysis of Collisional Evolution”, ACE) introduced in [4], we follow the evolution of the circumstellar matter from dust sizes up to planetesimals. Continuous collisional grinding and (a) radiation pressure shape the distribution of sizes and radial distances. We investigate narrow belts of parent bodies at 0.4 and 1.0 AU and check, in addition to (b) disruptive collisions, the influence of (c) purely erosive ones, that do not destroy the bigger object but only excavate a crater and remove some material.



Conclusions

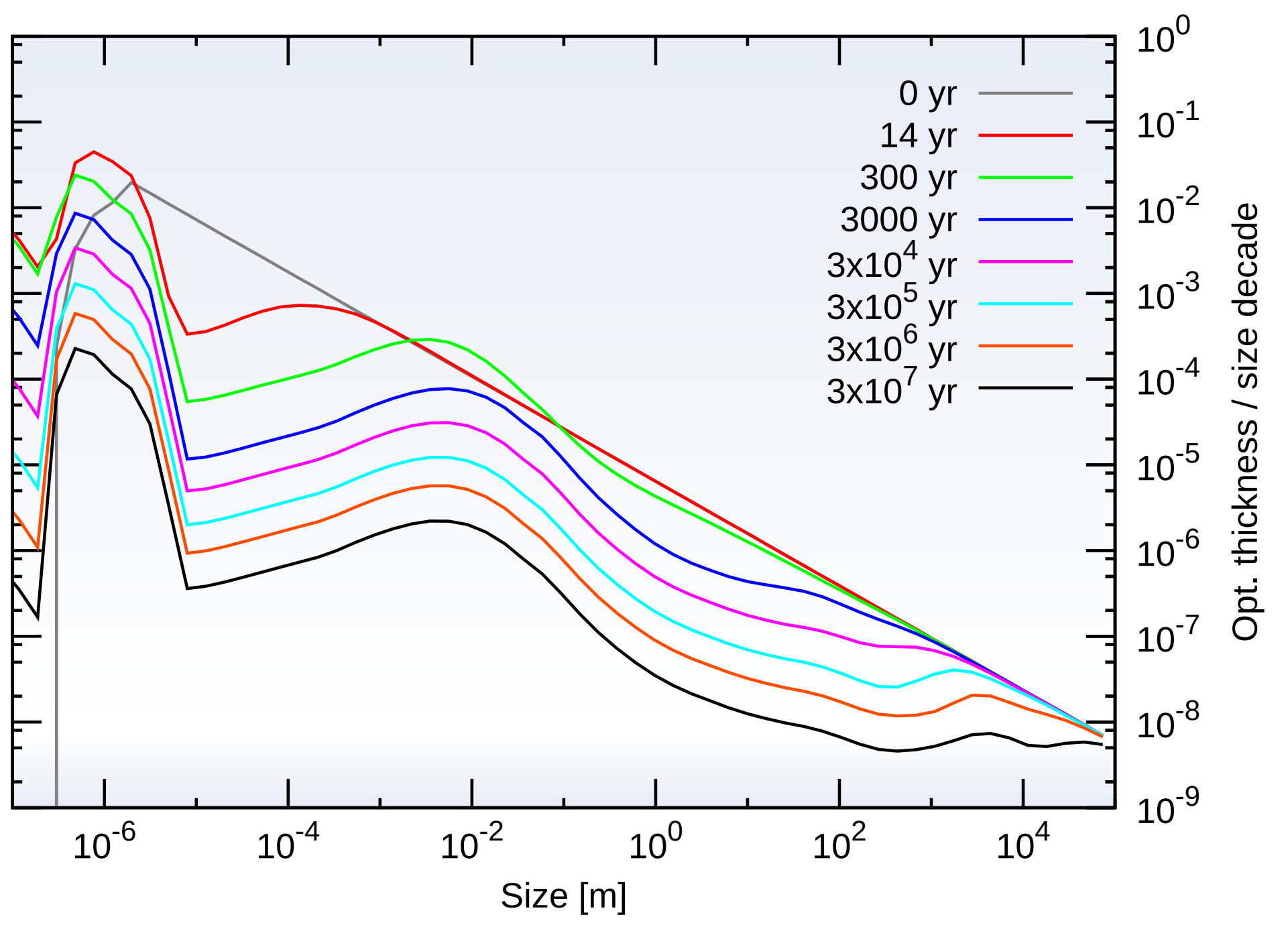
Due to high densities and relative velocities the particles’ collisional lifetimes are very short so that the observed IR excess must have been caused by a recent event.

Cratering is required for the description of collisions in order to reproduce the spectral energy distribution as it results in a larger amount of smaller particles being responsible for the IR excess at short wavelength.

Our kinetic model is capable of producing a spectral energy distribution that is in broad agreement with the observations and prevoius studies assuming simple power laws for the distribution of dust.

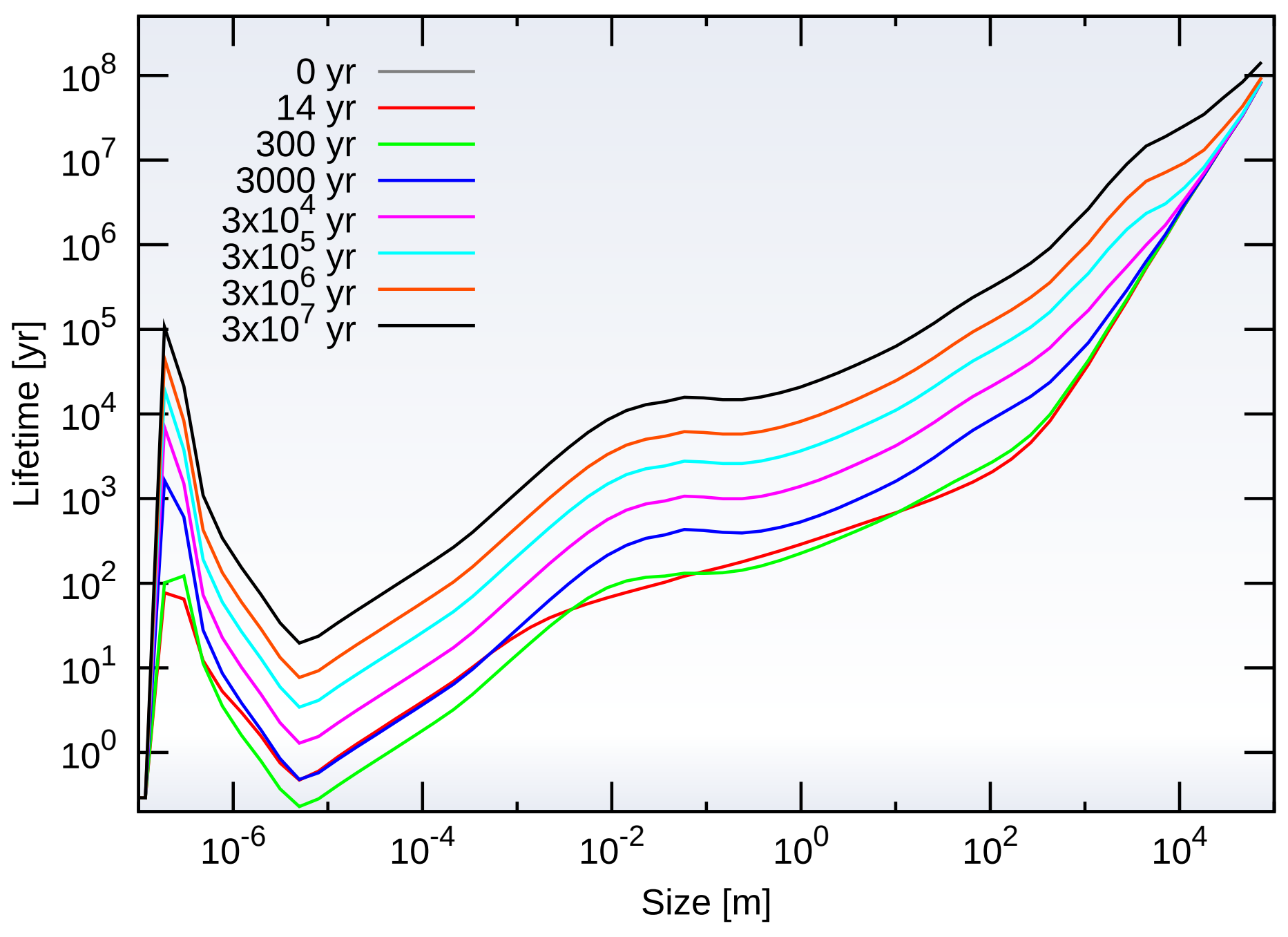
Dust in the inner stable region would produce too much flux at short wavelength as it is very hot. It seems more likely that the outer stability zone is the origin of excess producing dust.

Long–term Evolution

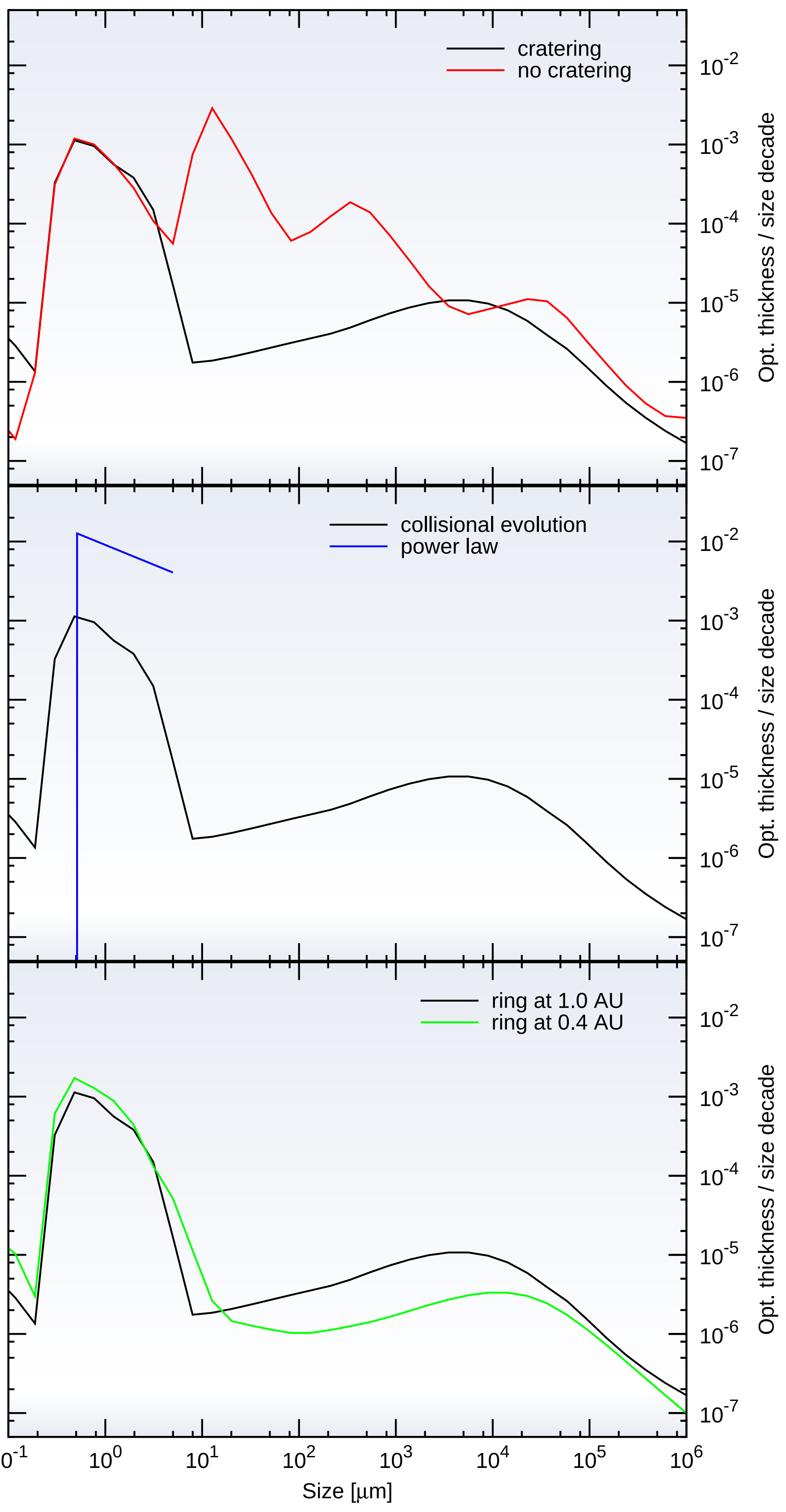


Since particles smaller than around 0.5 µm are quickly blown out of the system by the stellar radiation, they cannot efficiently participate in the collisional cascade. Particles of 1–5 µm are, therefore, relatively longlived and overabundant. Again bigger particles feel that overabundance of possibly disruptive or erosive projectiles and are themselves underabundant. The result is a well-understood wavy shape which evolves as soon as the simulation is left to itself.

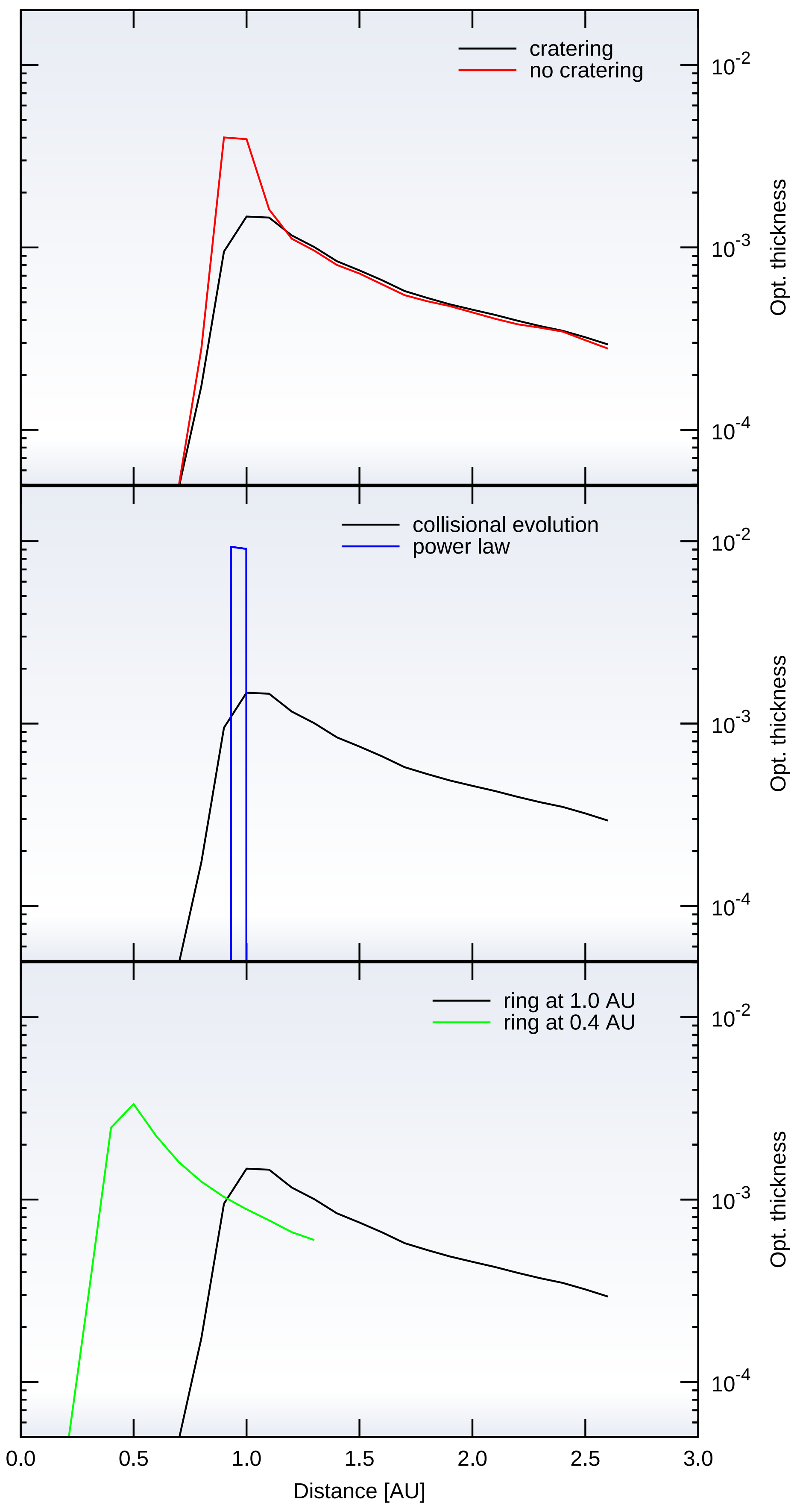
The biggest problem with having significantly abundant hot dust is the inavoidable high density and the high relative velocities, which together result in short collisional lifetimes. Even the biggest objects with a radius of 74 km survive only for 10^8 years, in average. Since the system is much older than that, namely at least 2 Gyr, a continuous depletion of material from the beginning until today can be ruled out. The collisional grinding must have started recently and might have been evoked by, e.g., the break-up of an asteroid/comet. [3]



Size Distribution



Radial Distribution



We compared two approaches. First, we considered only the disruptive collisions, and second, we additionally took cratering collisions into account. Erosive cratering provides a steep cut off in the size distribution at about 5 µm. As a consequence the spectral energy distribution drops much faster. Despite the discrepancies from the observations at about 30 µm, a sufficient description of collisions in the dust ring of HD 69830 seems to require cratering. However, some modifications will be necessary.

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All previous attempts of fitting the observed spectral energy distribution made use of the assumption that the dust distribution follows a power law in grain size and distance to the star. Narrow rings result in a high optical thickness. In contrast our kinetic model naturally creates a much broader distribution of dust from the ring of parent bodies and it is able to reproduce the observations with approximately the same accuracy as the power-law results. In-depth studies of the composition (as in [3]) are to follow.

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As a consequence of the existence of the three planets in the system, stable orbits of dust-generating parent bodies are restricted to two regions. We probed possible rings in both regions and found that dust in the inner stability zone is too hot to match the observed spectral energy distribution. Thus, the planetesimal belt is most likely located outside the third planet’s orbit.

Spectral Energy Distribution