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Dust production by planetesimal collisions in circumstellar disks hosting young giant planets: the case of HD 163296

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Abstract

The formation of giant planets in circumstellar disks triggers a phase of dynamical excitation of the surrounding planetesimal disk. This phase of dynamical excitation results in high-velocity impacts among the planetesimals and in the collisional production of second-generation dust. In this work we use HD 163296's circumstellar disk, recently suggested to host multiple young giant planets and whose abundant dust population shows an anomalous distribution, as a case study to investigate this process and verify whether it can be intense enough to alter the amount and distribution of the dust in this circumstellar disk.

1. Introduction

Recent ALMA's observations of circumstellar disks allowed for characterizing their gas and dust properties and distributions with a level of details previous unachievable. These observations revealed that disks can possess a number of small-scale features like gaps, ring and spirals, in most cases believed to arise from the presence of newly formed giant planets. One of the best studied cases to this regard is that of the circumstellar disk surrounding HD 163296, a 5 Myr old star of about 2 $M_{\odot}$. HD 163296's disk has been suggested to be home to at least three giant planets [1, 2, 3, 4, 5]. Notwithstanding its age, alongside its giant planets HD 163296's disk still possesses a high dust-to-gas ratio [1], with the dust distribution diverging from what would be expected from hydrodynamic simulations in the region inside the innermost giant planet [1]. Mature disks like HD 163296 are expected to contain invisible yet massive populations of planetesimals whose dynamical and collisional evolution will be sculpted by the growing gravitational perturbations of the forming giant planets [6, 7]. We investigated [8] the dynamical and collisional excitation of HD 163296's planetesimal disk resulting from the formation of its giant planets and showed that it results in a significant collisional production of second-generation dust that could explain the observed deviations from the theoretical expectations.

2. Numerical Methods

We performed N-body simulations of the dynamical evolution of HD 163296's planetesimal disk in response to the formation of the giant planets using *Mercury-Arχes* [8], a parallel implementation of the hybrid symplectic algorithm of the MERCURY software [9] that accounts for gas drag, orbital migration and planetary mass growth. We processed the output of the simulations with statistical methods [10] to estimate the impact fluxes and impact velocities among the planetesimals. Finally, to estimate the effects of collisions over the resulting wide range of impact conditions we used the scaling law from [11], valid both for cratering erosion and catastrophic disruption.

3. Results

Our results [8] indicate that the formation of HD 163296's giant planets can raise the dust-to-gas ratio in the circumstellar disk by triggering a phase of dynamical excitation of its planetesimal population and causing frequent high-velocity collisions (see Fig. 1). Our collisional model indicates that, depending on the characteristics of the planetesimals, the dynamical excitation process and the associated collisional dust production can be responsible for a large fraction, if not the entirety, of the current dust in HD 163296's circumstellar disk. Based on the gas and dust density profiles reconstructed by [1] about 70 $M_{\oplus}$ should be injected into the orbital region inside the innermost planet to explain the observations. According to our collisional model, the dynamical excitation process can produce the required amount of second-generation dust in 1-3 Myr depending on the specific planetary masses and size-frequency distribution of the planetesimals (see Fig. 1). Our results suggest that these processes can represent a common evolutionary phase for circumstellar disks hosting forming giant planets within a planetesimal disk [8].

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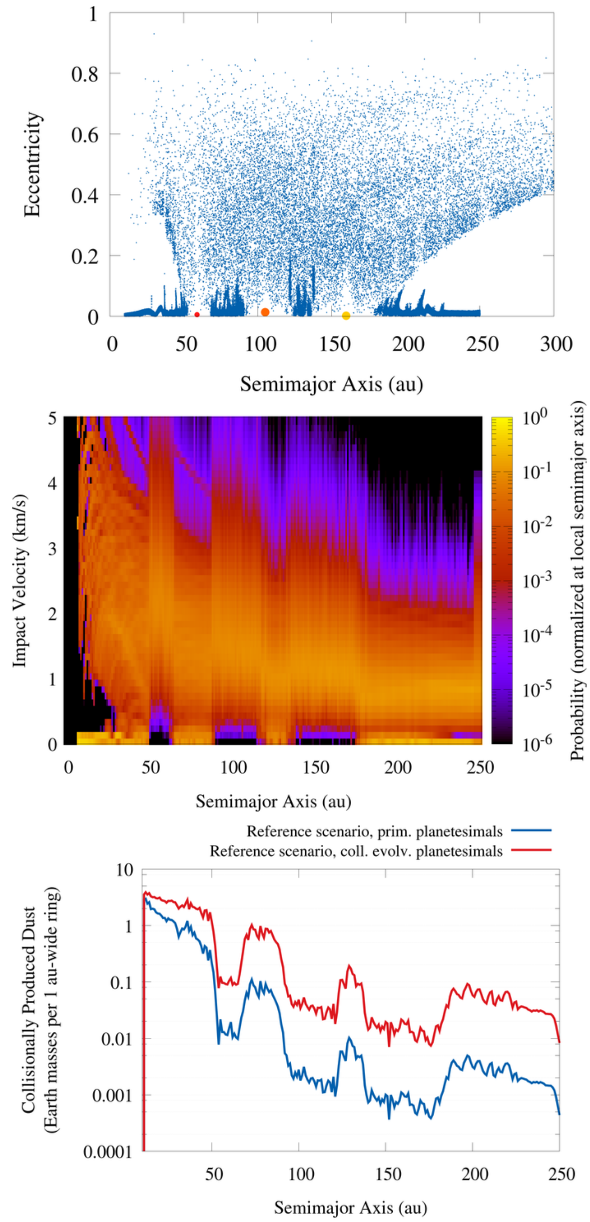

Figure 1: Dynamical and collisional state of the planetesimal disk of HD 163296 after 5 My in the reference simulation from [8]. From top to bottom: semimajor axis–eccentricity distribution of the planetesimals, radial distribution of the impact velocities among the planetesimals, and radial collisional dust production over the last 1 Myr of life of the circumstellar disk for two different populations of planetesimals.