A Comet Shower at the Pliocene-Pleistocene Transition Triggered by the Close Approach of HD7977

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Abstract

The Oort Cloud's dynamical evolution is significantly influenced by both the galactic tide and stellar flybys. We investigate the particular case of HD7977's close encounter 2.47 Myr ago, which likely repopulated the Inner Oort Cloud and potentially triggered a significant comet shower on Earth. Our results demonstrate that the shower's intensity strongly depends on HD7977's impact parameter (*b*), with possible flyby distances ranging from 2,300 AU to ~13,000 AU. For the closest approach (b ~2,300 AU), the terrestrial impact probability of 1 km comets increases by an order of magnitude compared to the steady state, slightly exceeding the asteroid impact probability at this size scale. The size-frequency distributions ($N_{asteroid} \propto D^{-0.97}$ vs. $N_{Oort} \propto D^{-2}$) imply that Oort Cloud comets dominate the impact flux for D < 1 km. We identify a threshold diameter $D_0 = 2.25$ km for guaranteed impacts ($P = 1$), with D_0 following a logarithmic dependence on *b*. These findings suggest that HD7977's flyby likely caused a significant comet shower during the Pliocene-Pleistocene transition, potentially contributing to the environmental changes at this era.

Background

The Oort Cloud, a vast reservoir of icy bodies surrounding the Solar System, comprises an inner (IOC) and outer (OOC) region. Gravitational perturbations from passing stars inject comets into the inner Solar System. While the OOC provides a steady comet flux, close stellar encounters can trigger intense comet showers primarily sourced from the more massive IOC. The recent Gaia DR3 data suggest the star HD 7977 passed exceptionally close (~2300 AU) to the Sun ~2.47 Myr ago. This study models the global dynamical response of the entire Oort Cloud (especially the IOC) to this flyby, quantifying changes in perihelion distances and the resulting enhanced terrestrial impact risk. This event potentially triggered a significant comet shower coinciding with the Pliocene-Pleistocene transition.

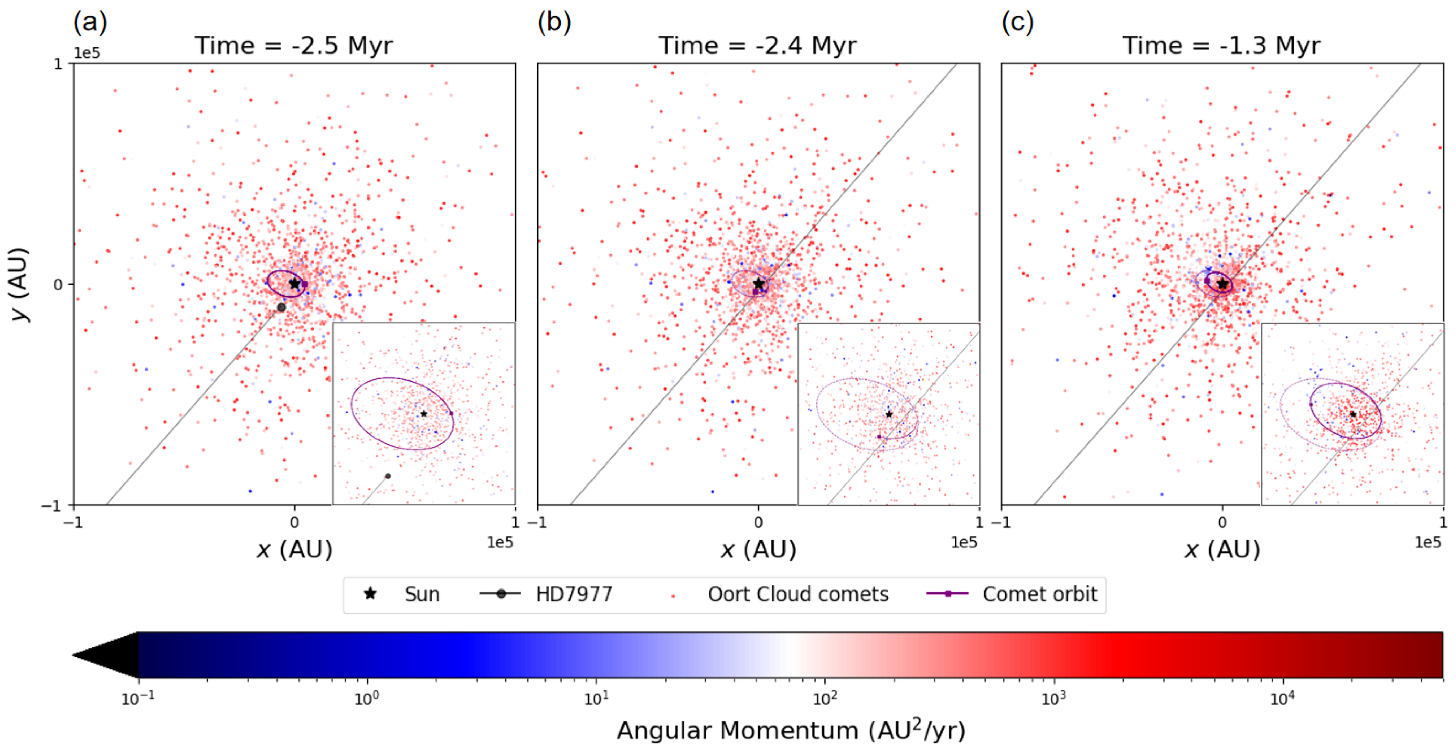

Fig.1 Snapshots of the REBOUND simulation

Method

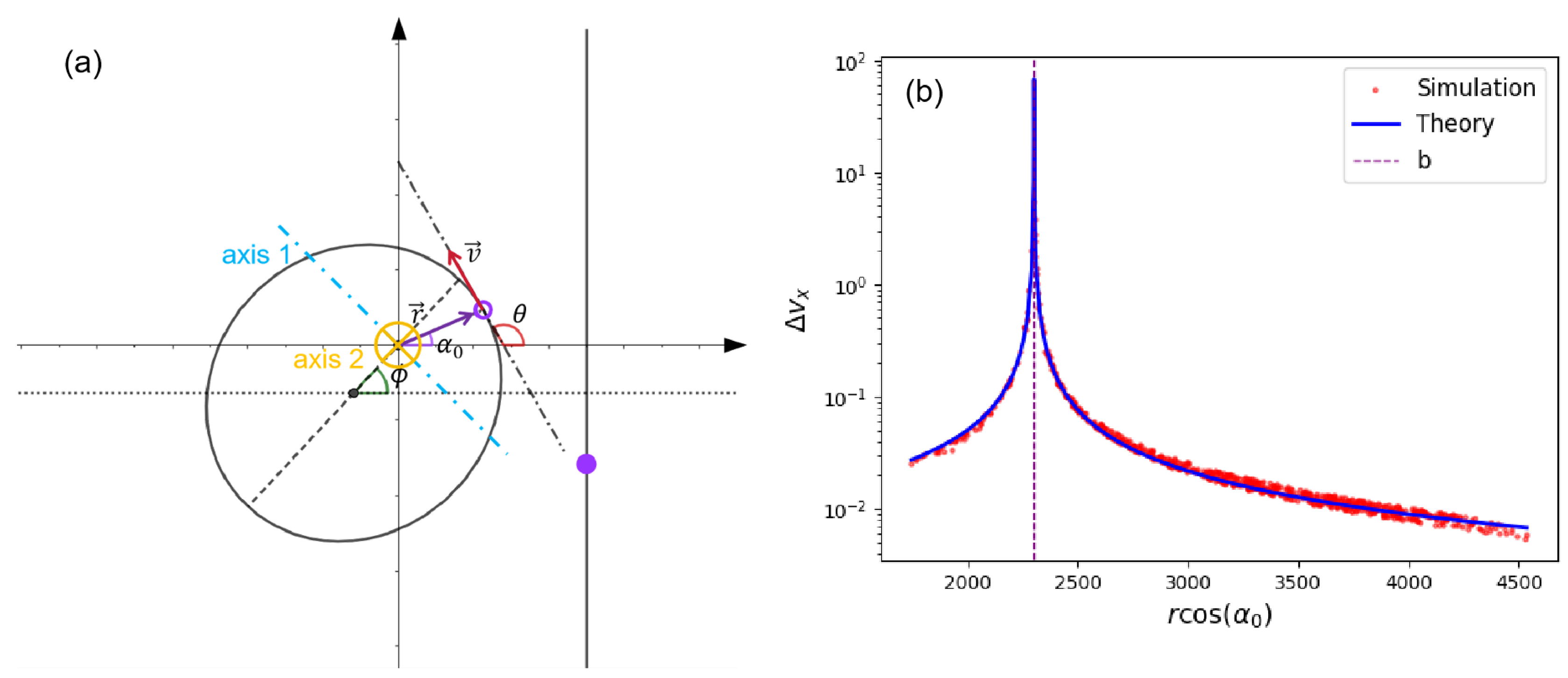

Fig.2 (a) Schematic of orbital parameters
(b) Comparison between impulse approximation theory and simulation

Impulse approximation:

$$\dot{\vec{v}} = GM_p \frac{(b - r\cos\alpha_0, y_{p0} + v_p t - r\sin\alpha_0)}{((b - r\cos\alpha_0)^2 + (y_{p0} + v_p t - r\sin\alpha_0)^2)^{3/2}}$$

$$\Delta\vec{v} = \int_{-\infty}^{+\infty} \dot{\vec{v}}\,dt = \left(\frac{2GM_p}{v_p}\frac{1}{b - r\cos\alpha_0}, 0\right),$$

Collide condition:

$$\vec{L} = \vec{r} \times (\vec{v} + \Delta\vec{v}) \le \left(\frac{GM_\odot}{1\,\mathrm{AU}}\right)^{1/2} \cdot (1\,\mathrm{AU}) = \sqrt{GM_\odot 1\,\mathrm{AU}}.$$

Results

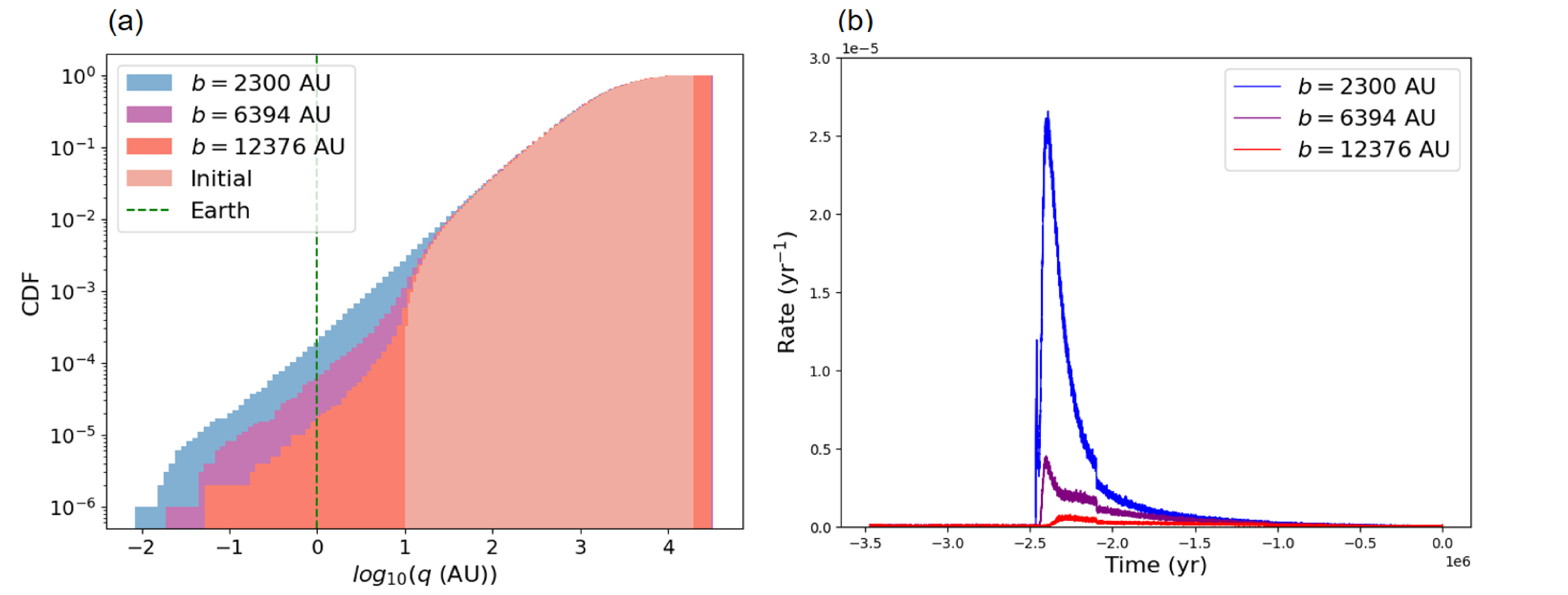

Fig.3 (a) Distribution of $\log_{10}(q)$ before and after the passage of HD7977
(b) Rate of comets with diameter ≥ 1 km colliding the Earth

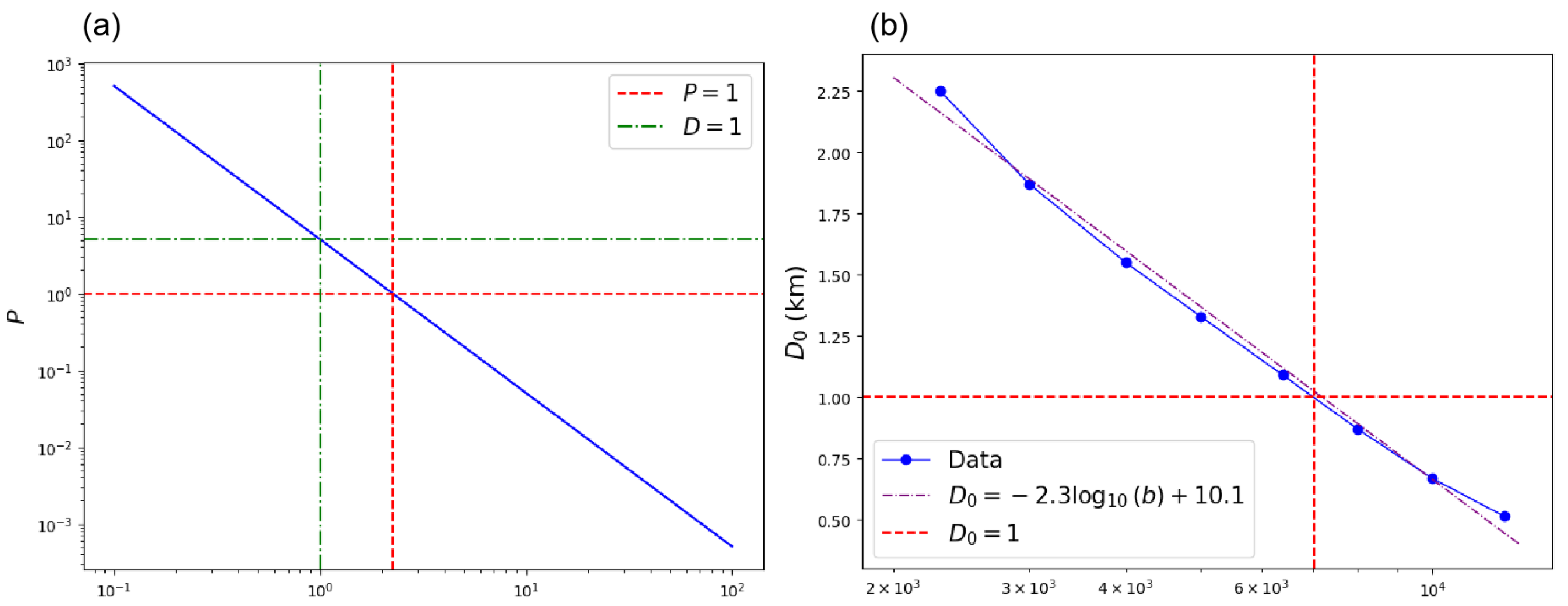

Fig.4 (a) Collision probability as a function of comet diameter
(b) Threshold diameter D_0 versus impact parameter b