A full-lifetime planetary simulation: from stellar birth cluster evolution to planetary destruction around white dwarfs

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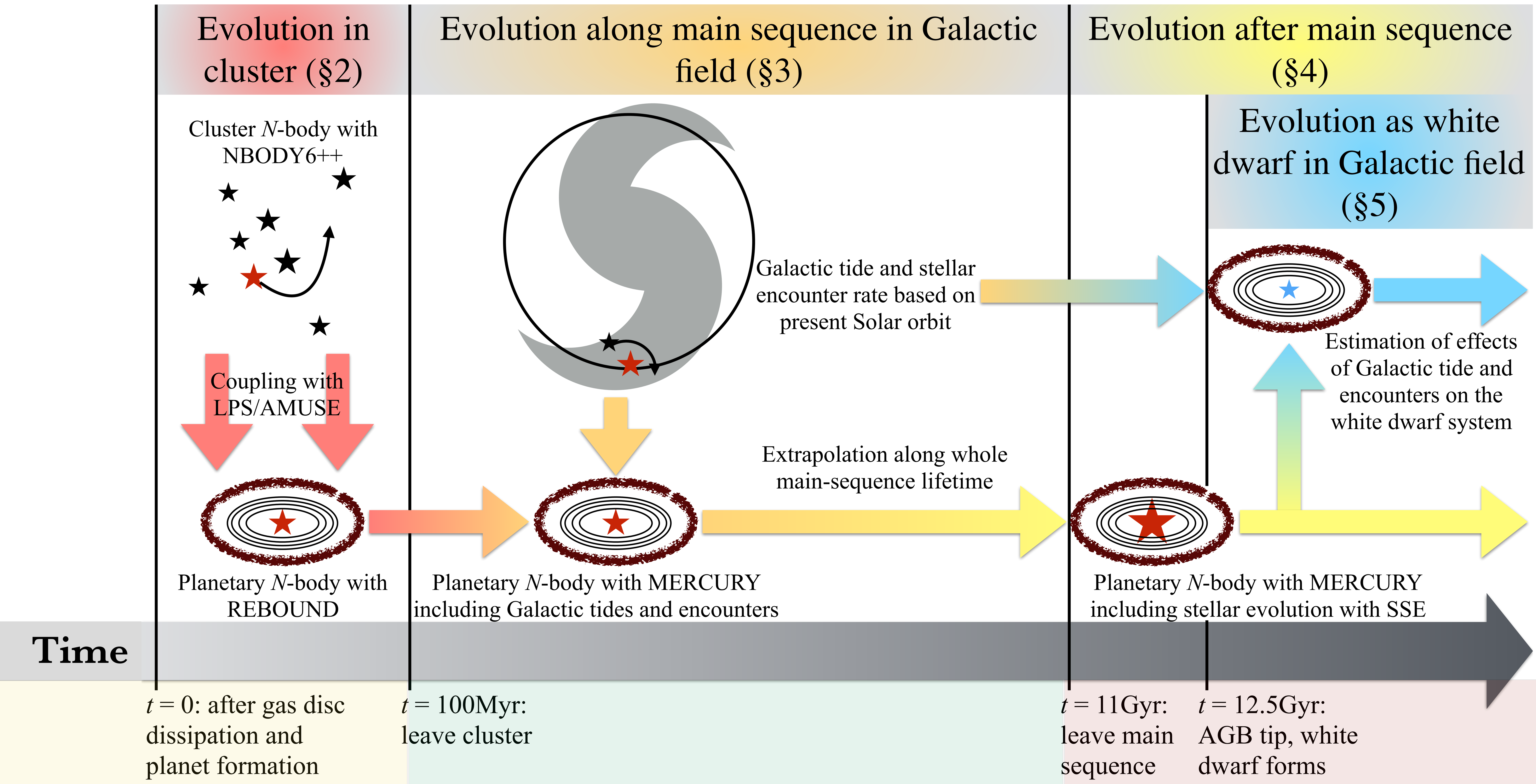
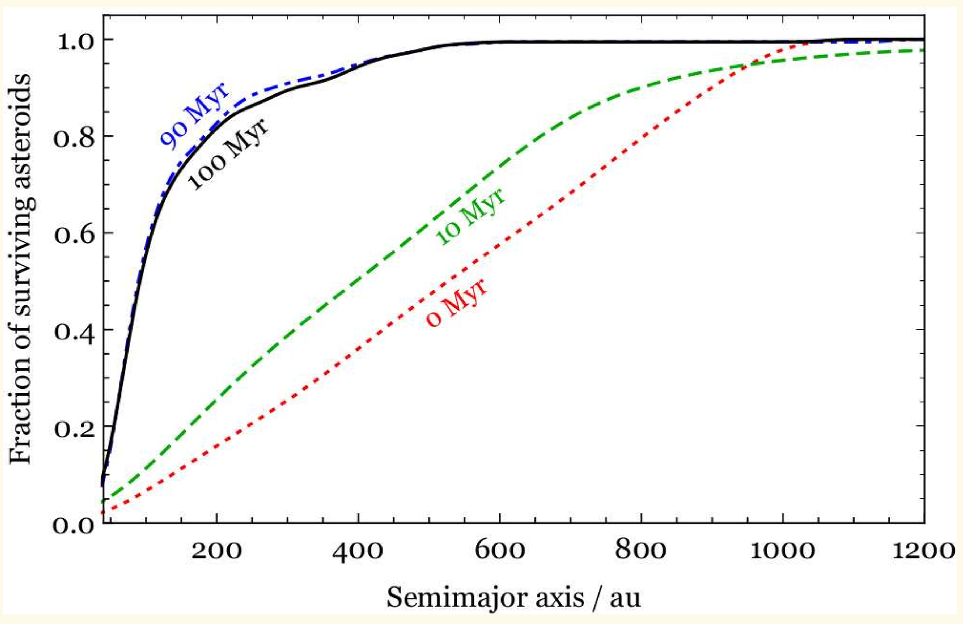
Objective:

To simulate the structure of a 40–1000 au annulus of asteroids/comets/planetesimals larger than 100 km orbiting inside of a Solar system analogue that is itself initially embedded within a stellar cluster environment throughout all phases of the parent star's evolution.

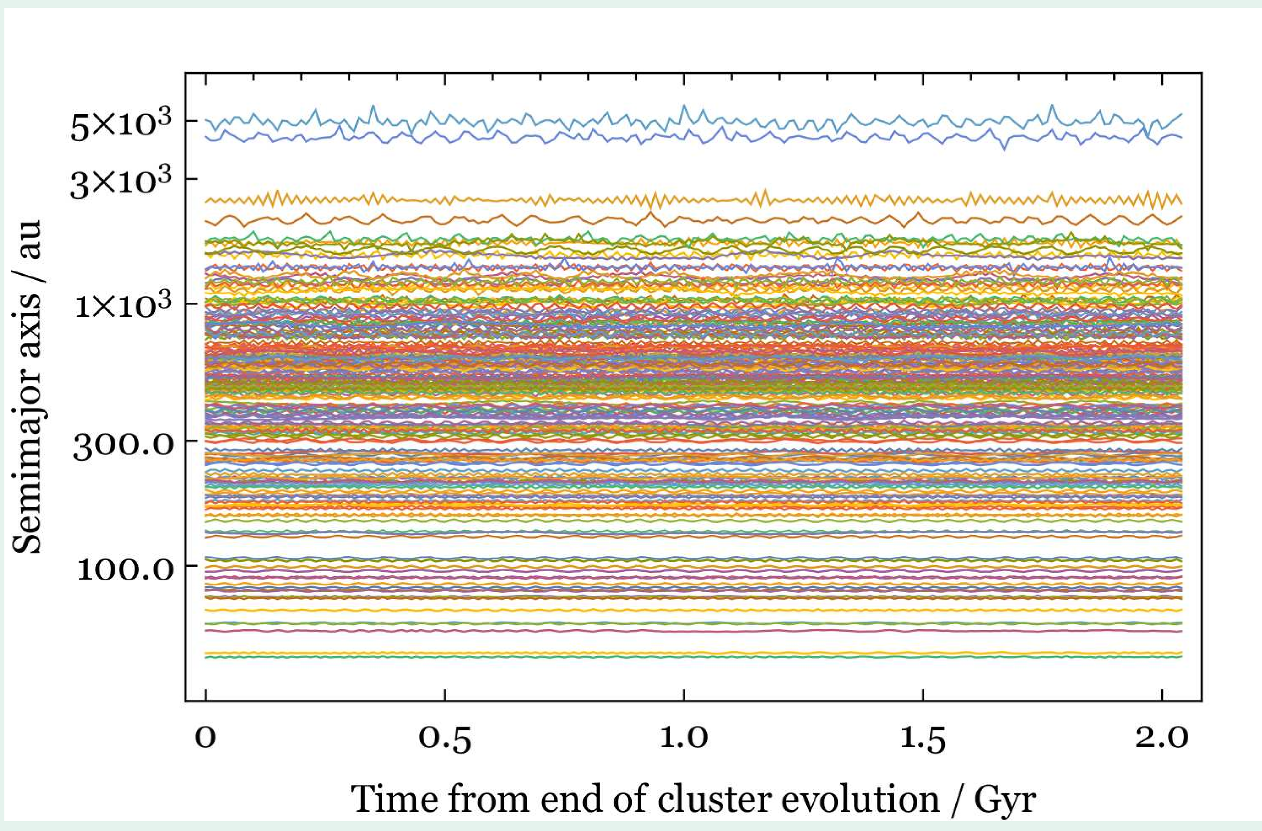


Cluster phase



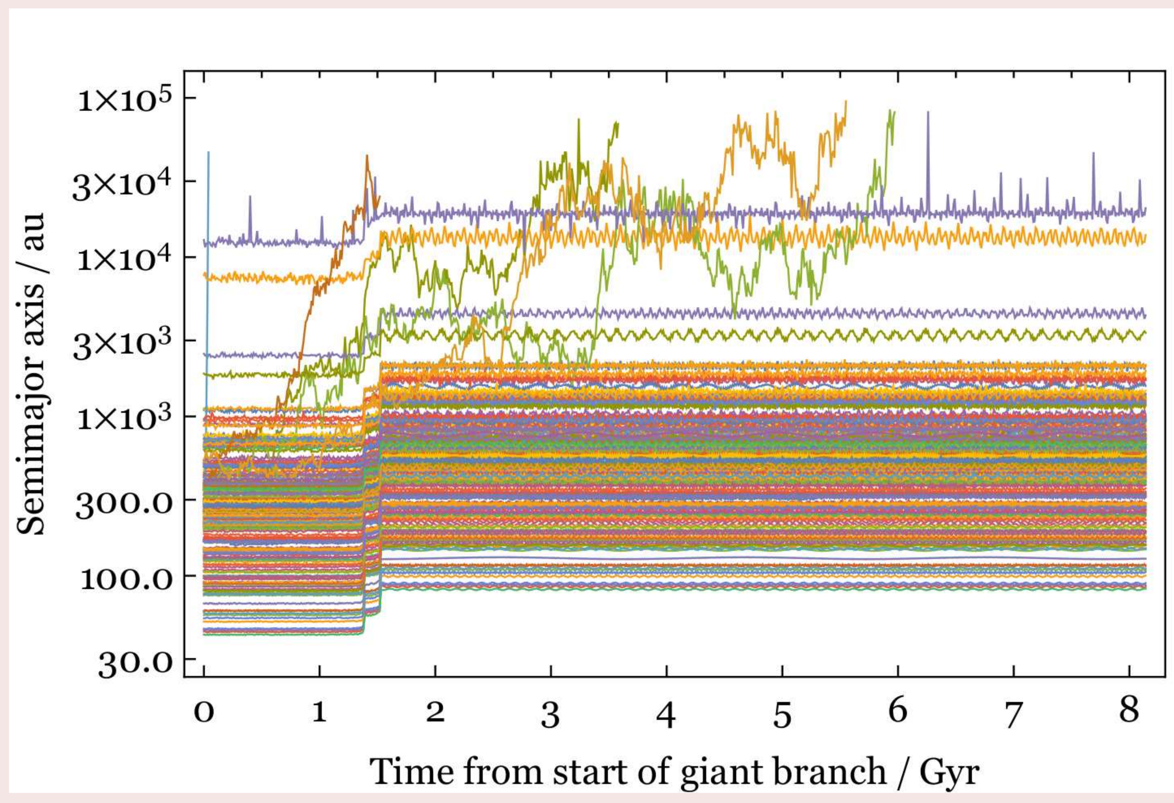
Cumulative distribution functions of semimajor axes for the time evolution of 2000 exo-planetesimals larger than about 100 km in initially 40–1000 au orbits subject to perturbations from a stellar birth cluster and four interior giant planets. The 90 and 100 Myr curves almost entirely overlap (the 90 Myr curves are dot–dashed blue curves while the 100 Myr curves are solid black), suggesting that by 100 Myr the systems have dynamically settled.

Main-sequence phase



Main-sequence evolution (for 2 Gyr only) of 200 exo-planetesimals subsequent to cluster evolution. The effects of stellar flybys and Galactic tides and an exo-Jupiter, exo-Saturn, exo-Uranus, and exo-Neptune are all included. None of these perturbations are strong. Collisional grinding and radiative effects for these large planetesimals, at such large distances from the host star, are negligible. Two events which could have disturbed this quiet picture are (i) a major gravitational instability amongst the planets, or (ii) a particularly close stellar flyby.

GB+WD phases



Post-main-sequence evolution for surviving planetesimals. Despite a few instabilities, 97.5 per cent of the post-cluster planetesimal disc remains intact, with an eccentricity variation of typically no more than a few hundredths, and an expected doubling of its semimajor axis due to stellar mass loss from the giant branch phases. Evolution along the white dwarf is quiescent, and does not represent a polluting reservoir nor an abundant source for interstellar asteroids.

Findings:

The orbital distribution of 100 km exo-Kuiper belt objects at the end of stellar cluster dissipation is just a scaled-down version of the evolved form of this distribution during the white dwarf phase unless a strong gravitational instability (amongst major planets or with a passing star) occurred in-between. These asteroids/comets/planetesimals effectively retain their primordial post-cluster eccentricity and inclination profiles while inflating their semimajor axes by an amount that is inversely proportional to the stellar mass lost. The 40–1000 au range represents a 'sweet spot' where other forces are ineffectual at producing significant changes, with implications for the free-floating planetesimal population and metal-polluted white dwarfs.

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