The GENGA Code: Gravitational Encounters in N-body simulations with GPU Acceleration

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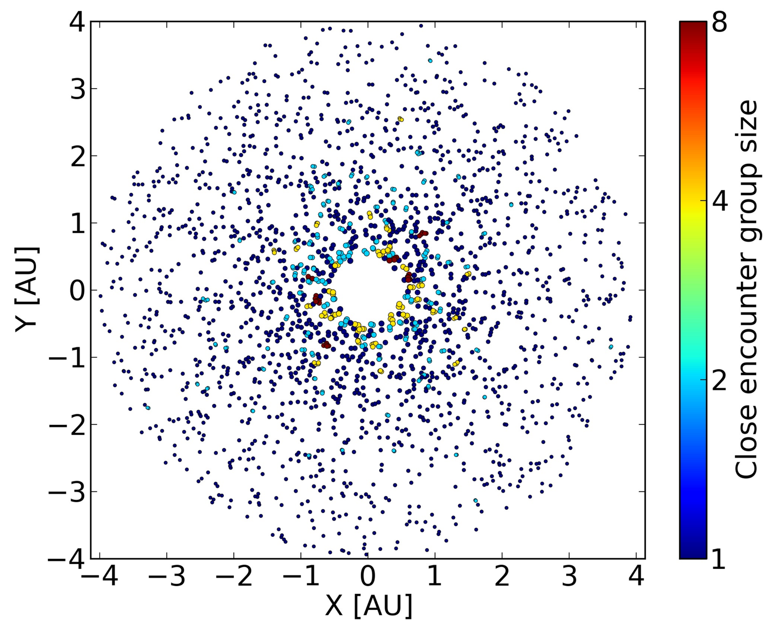
We present a GPU (Graphics Processing Unit) implementation of a hybrid symplectic N-body integrator based on the Mercury Code (Chambers 1999), which handles close encounters with very good energy conservation. It uses a combination of a mixed variable integration (Wisdom & Holman 1991) and a direct N-body Bulirsch-Stoer method. GENGA is written in CUDA C and runs on NVidia GPU's.

To achieve the best performance, GENGA runs completely on the GPU, where it can take advantage of the very fast, but limited, memory that exists there. All operations are performed in parallel, including the close encounter detection and grouping of independent close encounter pairs.
Compared to Mercury, GENGA runs up to 30 times faster.

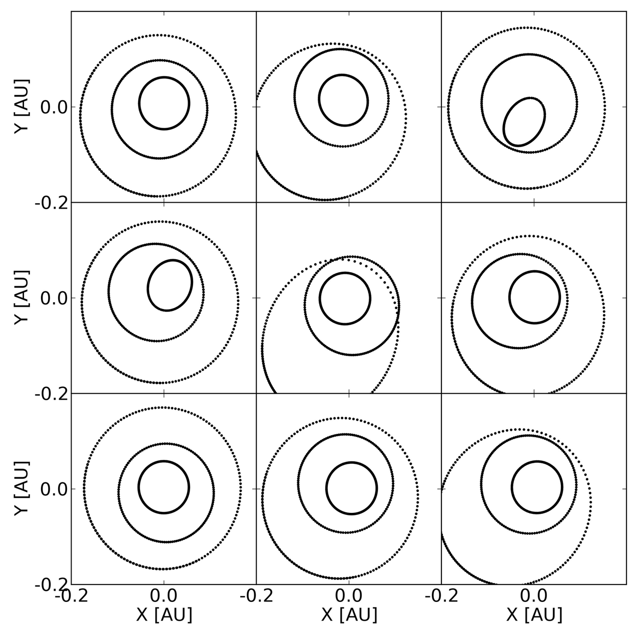
3 Simulation Modes

Integration up to 2048 massive bodies



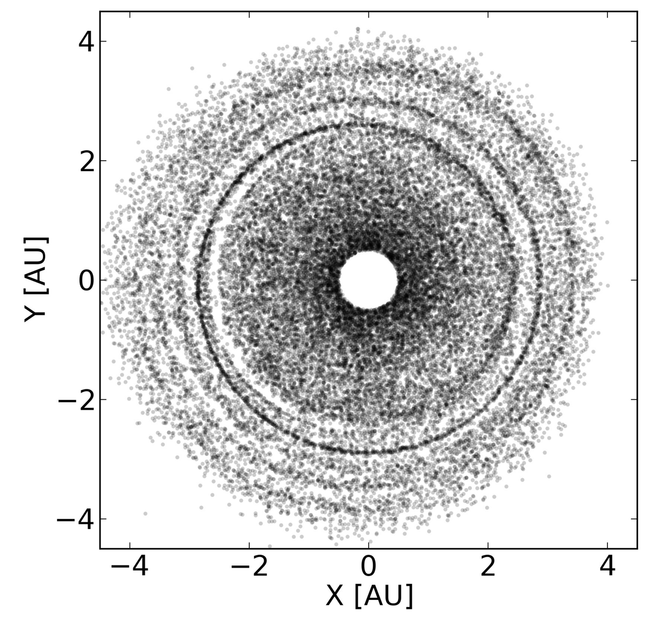
Independent close encounter groups are integrated in parallel with the Bulirsch-Stoer integrator. The close encounter radius depends on the Hill radius and the velocity of the body. Having close encounter groups with too many bodies slows the code down significantly.

Parallel integration of thousands of individual planetary systems



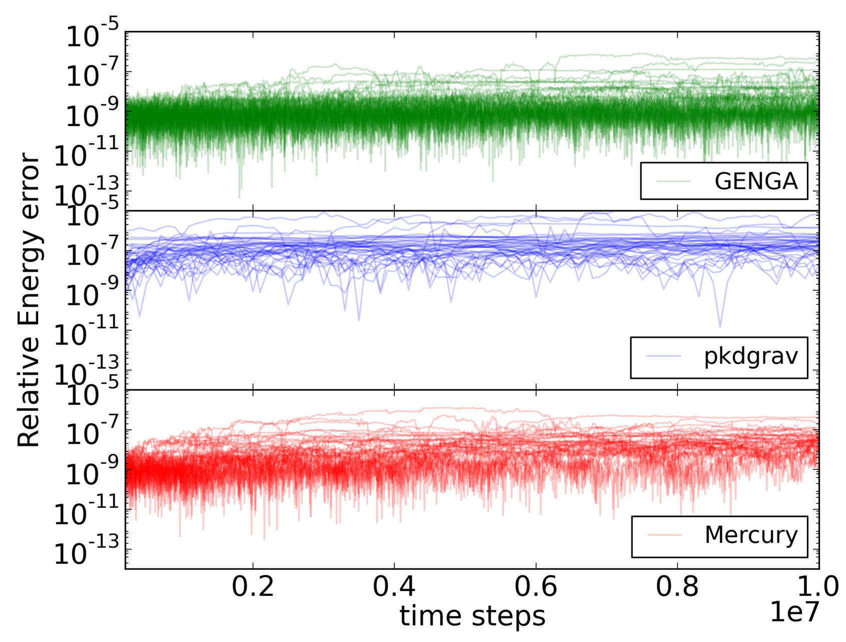
A subset of initial conditions, used for a stability analysis for a range of orbital parameters. Individual systems can have a different numbers of bodies but need to run synchronously on the GPU. It is possible to stop individual simulations after a collision or an ejection.

Integration of up to 1 million test particles

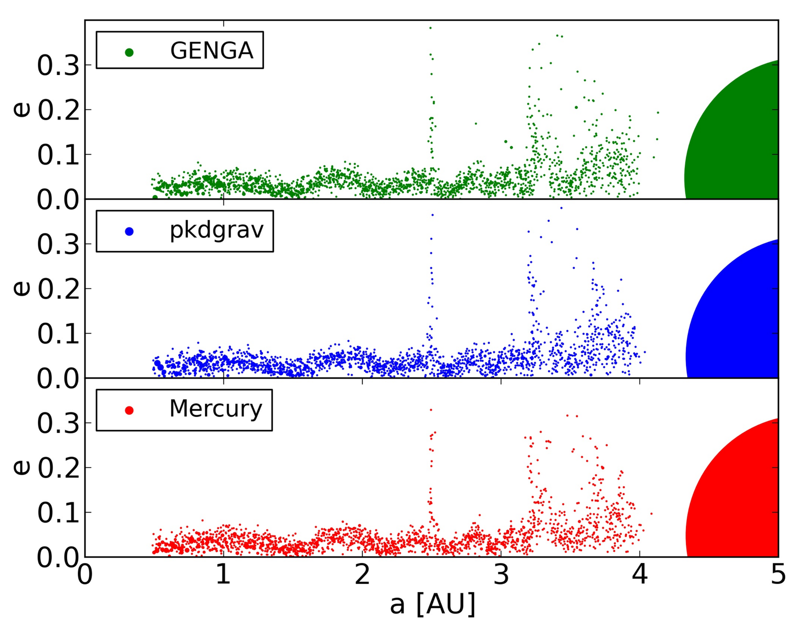


Shown are 32'000 massless test particles in the presence of Jupiter. A spiral density wave is wandering towards the center. The test particles don't interact with each other, which reduces the number of operations a lot. Test particles can collide with massive bodies.

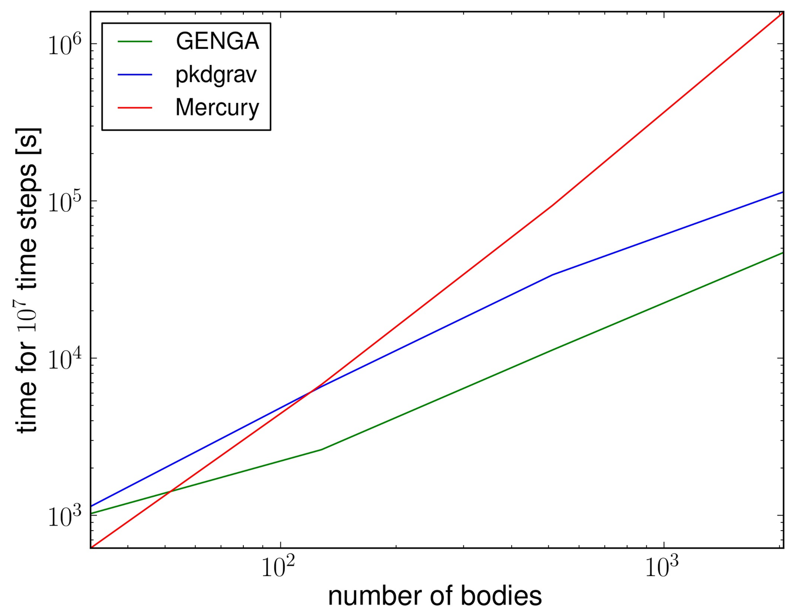
Code Comparison



The quality of the energy conservation can vary with different initial conditions and mass distributions. Over a set of 40 simulations with 16 planetesimals and a total mass of 5 earth masses, the energy conservation of GENGA is comparable with Mercury and better than pkdgrav.



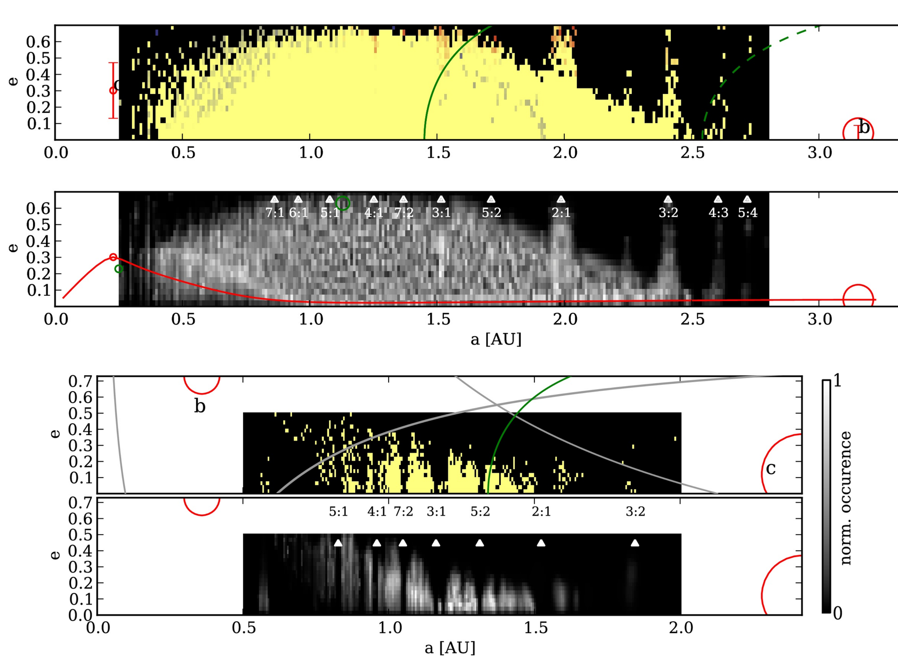
A comparison between GENGA, pkdgrav and Mercury for 2000 planetesimals and Jupiter. All three codes are in good agreement and show the same resonances in the eccentricity. Positions of individual bodies can vary. In the inner part of the disc, collisions are more frequent.



The execution time of GENGA and Mercury scale both with N^2, but GENGA is up to 30 times faster. Compared to the tree code pkdgrav which scales with Nlog(N), GENGA is up to 4 times faster, but reaches much higher precision in the force computation and energy conservation.

Applications

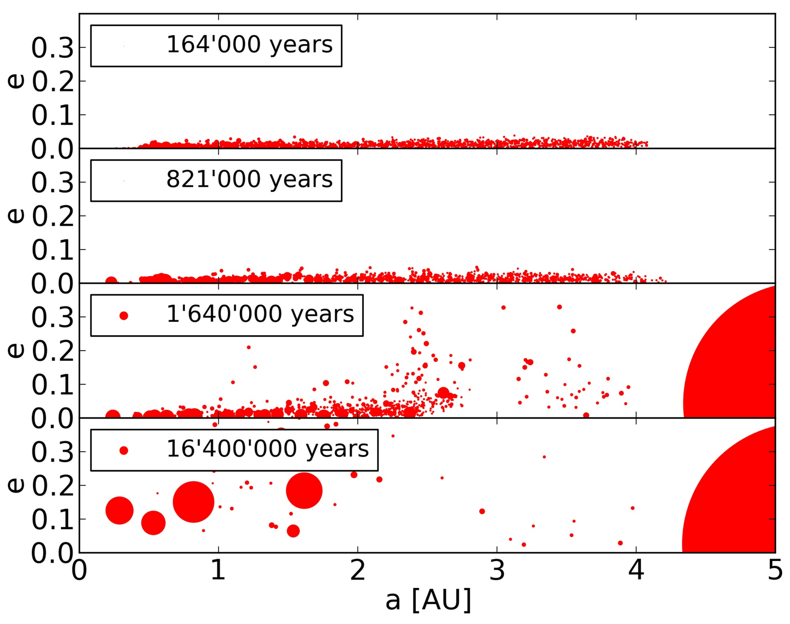
Analysing the dynamical stability of planetary systems



A stability analysis for the systems HD11964 (top) and HD163607 (bottom) with an additional hypothetical super earth placed in the habitable zone. 20000 simulations show the stable zone where an additional super earth can survive for over 10 million years. All simulations were performed with NVidia GTX 590 GPU's. Figures are from Elser et al. 2013.

Simulating the late stage of terrestrial planet formation

Terrestrial planet formation starting with 2048 planetesimals with a total mass of 5 earth masses. For the gas disc, an analytic gas model is taken from Morishima et al. (2010). After 1 million years, Jupiter is added to the system, which accelerates the formation of bigger objects in the inner part of the system. After 16 million years only 4 planets and a small number of planetesimals remain.



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References:
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Wisdom J., Holman M., 1991, AJ, 102, 1528
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Background images:
3D view of 32'000 test particles in the presence of Jupiter (top).
3D view of planet formation with 1800 planetesimals (bottom).