From Newton to Einstein

Relativistic Dynamics in Galactic Nuclei using special hardware and GRID

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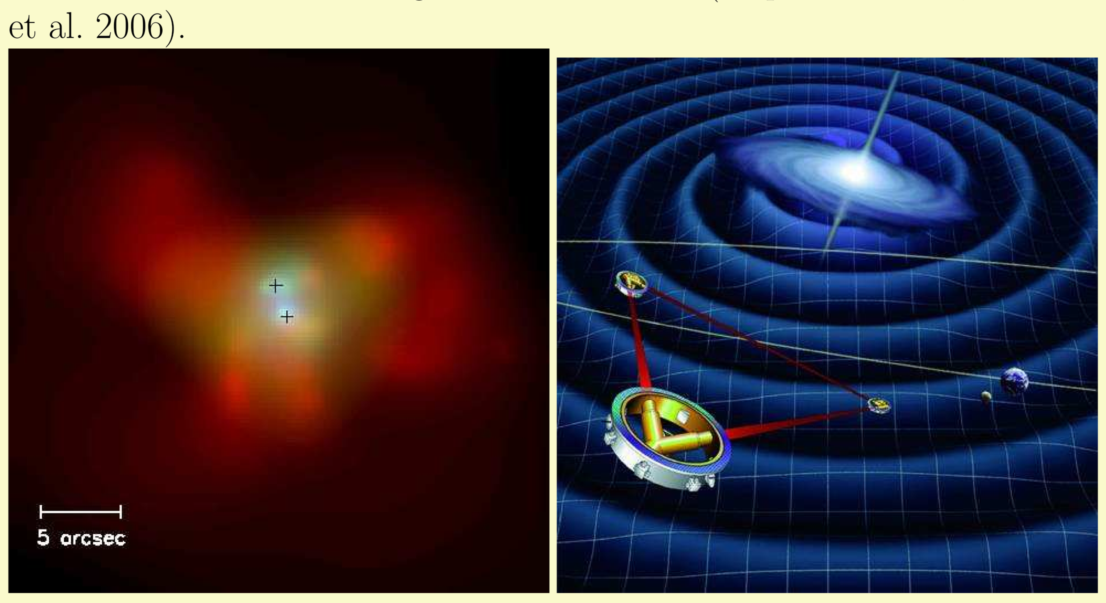
Abstract: The dynamics of galactic nuclei containing multiple supermassive black holes is modelled including relativistic dynamics. It is shown that for certain initial conditions there is no stalling problem for the relativistic coalescence of supermassive black hole binaries. We use a new computer architecture, based on special and reconfigurable accelerator cards developed in the GRACE project. Our present architecture still relies on the GRAPE special purpose hardware (not reconfigurable), but next generations will focus on new architectural approaches including custom network and computing architectures. The new hardware is embedded into national and international grid infrastructures.

Astrophysics - Galactic Nuclei

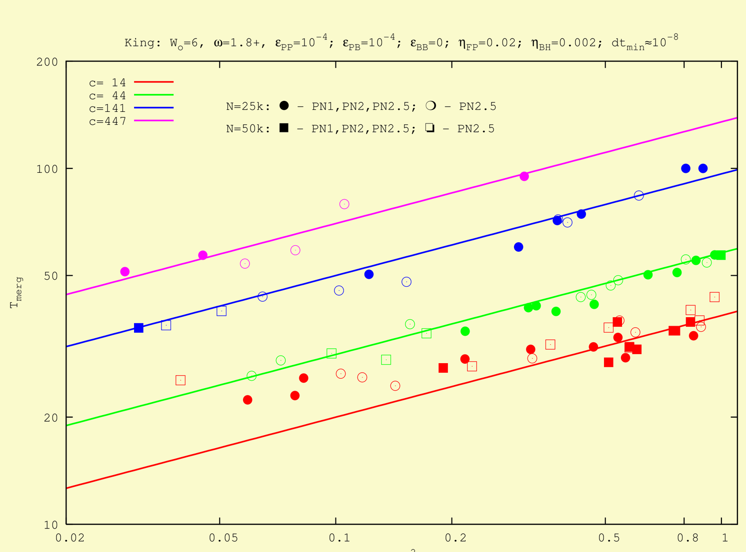
Many, if not all galaxies harbour supermassive black holes. If galaxies merge, which is quite common in the process of hierarchical structure formation in the universe, their black holes sink to the centre of the merger remnant and form a tight binary. Depending on initial conditions and time supermassive black hole binaries are prominent gravitational wave sources, if they ultimately come close together and coalesce. We model such systems as gravitating N-body systems (stars) with two or more massive bodies (black holes), including if necessary relativistic corrections to the classical Newtonian gravitational forces (Kupi et al. 2006, Berczik et al. 2006).



Figures: Left: X-Ray observation of two nuclei of a galaxy after merging, both bright spots are interpreted as hot gas around a supermassive black hole, which cannot be directly resolved. The distance between both black holes is 3000 light years (Picture from S. Komossa, MPE). Right: Artist's Impression of the space-based LISA laser interferometer satellites, designed to detect gravitational waves from massive black hole coalescences in the entire universe (Picture: ESA). The ARI-ZAH group is a member of the German LISA consortium for the research on astrophysical gravity wave sources for LISA.

Astrophysics - From Newton to Einstein

Accurate direct N-body integrations follow the evolution of supermassive binary black holes in galactic nuclei after mergers. First dynamical friction and superelastic scattering bring the black holes together to form a bound binary. The eccentricity of the binary strongly depends on initial conditions. Post-Newtonian corrections to the gravitational force (implemented similarly to Kupi et al. 2006) cause further shrinking and precession of the orbit, under gravitational wave emission. The figure shows final coalescence times as a function of initial eccentricity e (plotted is $1-e^2$). Straight lines depict theoretical expectation. 100 time units correspond to 100 million years. We conclude that the stalling problem of supermassive binary black holes can be overcome by highly eccentric orbits. (Berentzen, Berczik, Merritt, Spurzem, 2007, in prep.).

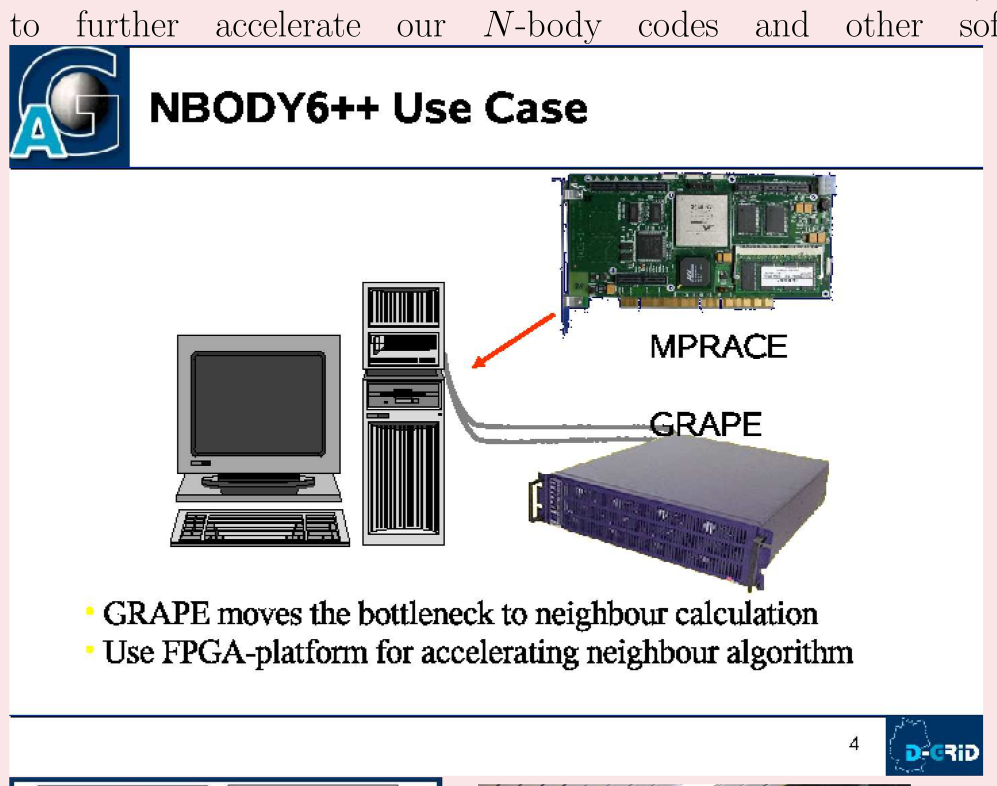


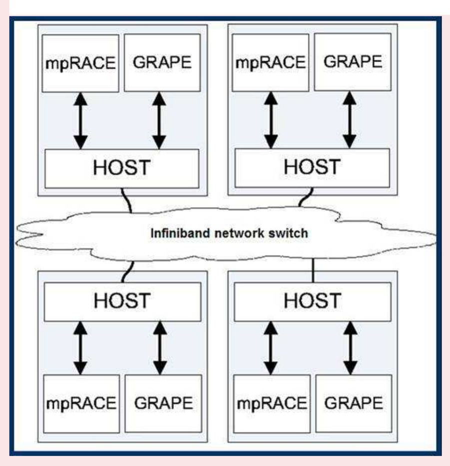
Direct N-Body Code

NBODY6++ is the latest child of a family of high (4th) order accurate many body integrators initiated by Aarseth (2003). It contains a regularization of close subsystems, an Ahmad-Cohen neighbour scheme and is fully parallelized (Spurzem 1999). Special hardware GRAPE (developed at the Univ. of Tokyo, Japan) and MPRACE (see below) can be used to accelerate its gravitational force calculations (Harfst et al. 2006).

GRAPE and MPRACE – special hardware

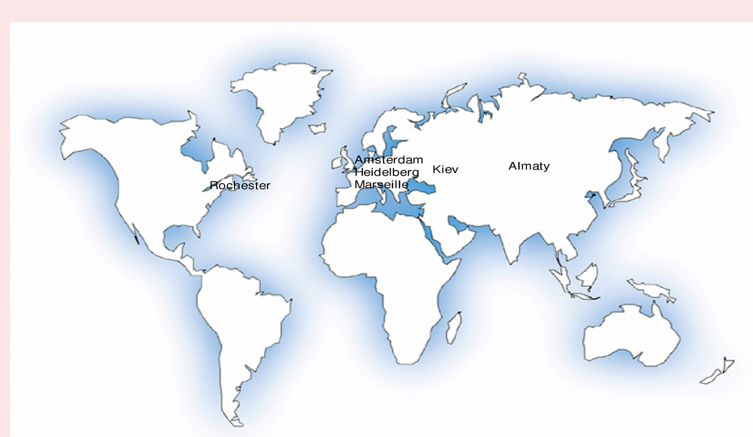
In an interdisciplinary project with computer engineering (Univ. of Mannheim) we use MPRACE, a new kind of hardware accelerator card using reconfigurable logical chips (FPGA) to further accelerate our N-body codes and other software.





The upper picture displays schematically one node, with GRAPE and the reconfigurable MPRACE card. The lower left picture shows the architecture, and right one can see the entire 4 Tflop/s cluster with 32 nodes and GRAPEs and (in the final expansion phase) 32 MPRACE cards. Performance tests can be found in Harfst et al. (2006).

Special Hardware - A Grid of GRAPE clusters

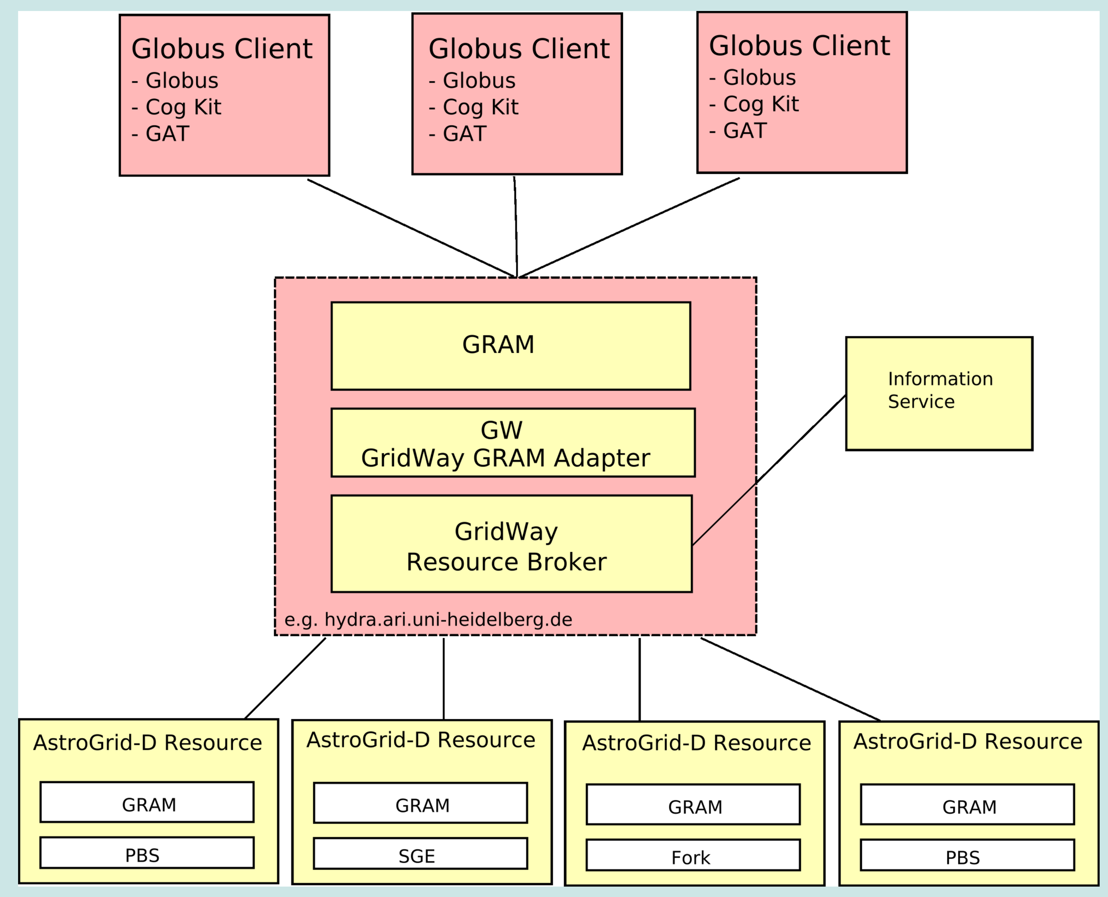


Sites of GRAPE clusters to cooperate in the deployment of an international grid for special hardware N-body applications, together with Astrogrid-D.

Acknowledgements

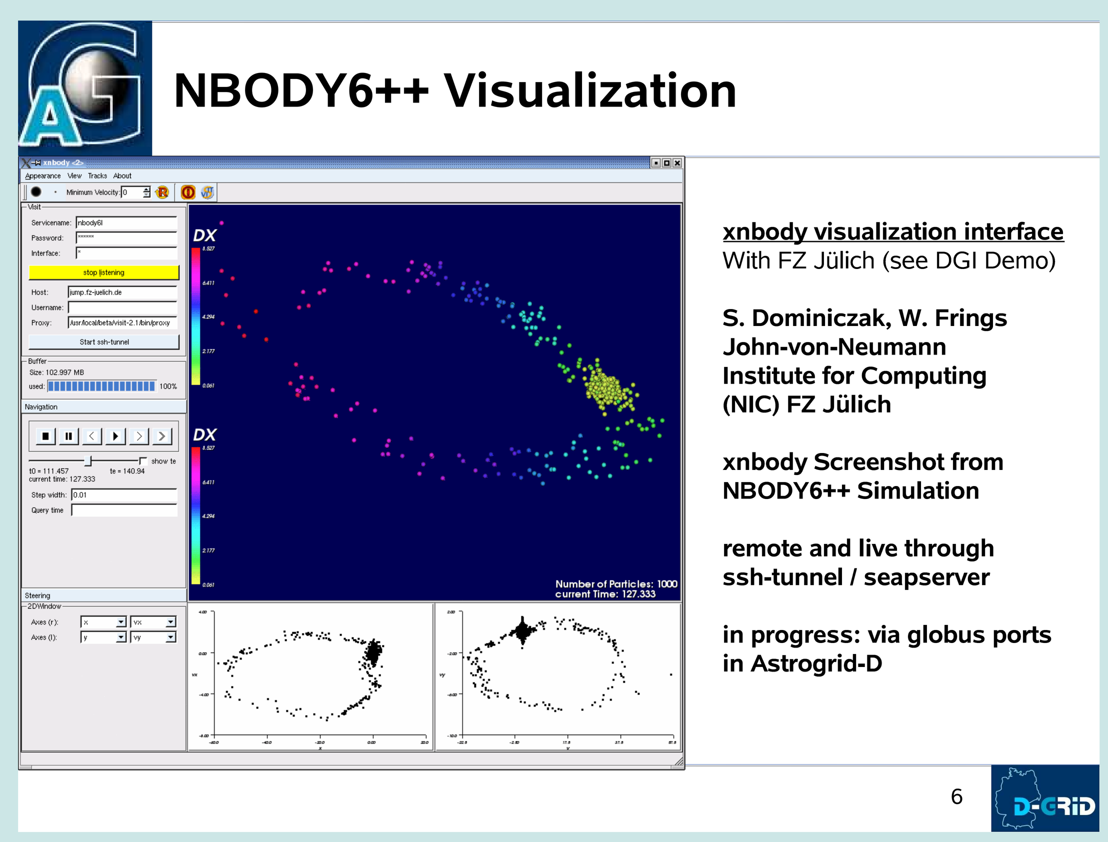
Volkswagen Foundation
Min. f. Wissenschaft, Forschung, Kunst in Baden-Württemberg
Sonderforschungsbereich 439 der DFG, Univ. Heidelberg
Astrogrid-D, D-Grid Initiative sponsored by Bundesministerium für Bildung und Forschung

Job Management and NBODY6++ in Astrogrid-D



Job submission in AstroGrid-D using the GridGateWay software. The GridWay resource broker acts as a gateway between one or more Globus Toolkit 4 (GT4) clients, and several GT4 compute elements. A GT4 client submits a job to a GT4 instance whose Globus Resource Allocation Manager (GRAM) component is configured such that it passes an incoming job on to the GridWay resource broker. By consulting the information service, GridWay finds matching (hardware and software) resources, and transfers the job to the execution host (Huedo et al. 2004, Kertész & Kacsuk 2007). Astrogrid-D will support through its information service also NBODY6++ jobs using special purpose hardware like GRAPE or MPRACE.

NBODY6++ visualization by xnbody



A Live-Demo will be provided at the Astrogrid-D Booth, with the support of the Visit/xnbody group of FZ Jülich in the D-Grid.

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