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Nuclear and Globular Star Clusters on the path to Exascale

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Nuclear and globular star clusters (NSC and GC) are spectacular self-gravitating stellar systems in our Galaxy and across the Universe - in many respects. They populate disks and spheroids of galaxies as well as almost every galactic center. In massive elliptical galaxies NSCs harbor supermassive black holes, which influence the evolution of their host galaxies as a whole. The evolution of star clusters is not only governed by the aging of their stellar populations and simple Newtonian dynamics. For increasing particle number, gravitational effects of collisional many-body systems, described by methods borrowed from plasma physics, determine the cluster evolution. Direct N-body simulations are the most computationally expensive but also the most astrophysically advanced method to simulate GC and NSC evolution, using massively parallel supercomputers with GPU acceleration. The current legacy code Nbody6++GPU has seen many algorithmic and astrophysical improvements in recent years. A timing model shown and confirmed by benchmarks with up to 16 million bodies is presented (a record number in this domain), which approach the Exaflop regime. Current and projected astrophysical results will be shown, for example on intermediate mass black hole formation in star clusters, on clusters as gravitational wave sources, and on powerful tools to predict and analyze properties of TDEs (tidal disruption events in nuclear star clusters, where stars are disrupted by tidal forces of a supermassive black hole). Such events will be observable by large numbers through next generation astrophysical instruments. Compared to molecular and biological computer modelling we are still not able to produce digital twins of astrophysical systems, it is currently more like multi-scale modelling. Future perspectives will be discussed - a fruitful exchange with other fields on the computational methods may be possible and useful.

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