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# Modeling dense stellar systems: background

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**Abstract.** I provide some background about recent efforts made in modeling dense stellar systems, within the context of the MODEST initiative. During the last four years, we have seen more than fifteen MODEST workshops, with an attendance between twenty and a hundred participants, and topics ranging from very specialized discussions to rather general overviews.

## 1. Dense stellar systems

The study of star clusters, and of dense stellar systems in general, has recently seen great progress, through observations as well as simulations, as is evident from the papers in the proceedings of this meeting, JD14. The label 'dense' is given when stars are close enough that significant interactions between them occur on a time scale short compared to the age of the stellar system.

A star forming region is dense in this sense, because the contracting protostellar clouds have a high probability to interact with each other during star formation. Old open clusters are called dense when their age exceeds their half-mass relaxation time. Most globular clusters in our galaxy are dense for that reason, and in addition, many globulars have a central density high enough for physical collisions between stars to occur frequently.

The most spectacular type of dense stellar system is that found in the nucleus of most galaxies. Our own Milky Way galaxy is no exception: in the central parsec around the central supermassive black hole, there are frequent collisions between the stars, which have a total mass of a few million solar masses.

## 2. Multi-scale simulations

Twenty-five years ago, stellar dynamics was split up in a number of different subfields that could be studied independently. Planetary dynamics, simulations of star forming regions, star cluster dynamics, modeling of galactic nuclei, the study of interacting galaxies, and cosmological simulations formed six different areas of research that had rather little in common.

In contrast, all six areas are now firmly integrated. In many cases, it makes little sense to study only of these in isolation. Starting at the smallest scales, a detailed simulation of planet formation may have to take into account the influence of neighboring stars within the same star forming region. Or looking from the largest scales, that of cosmological simulations, the most detailed modeling efforts resolve the encounters between individual galaxies; and in turn, a detailed simulation of such an encounter shows how new dense star clusters are formed in the process.

As a result, detailed simulations now routinely span multiple scales, on which the same physical laws show rather different emerging properties. In stellar dynamics, relaxation effects between stars can be ignored on galactic scales, yet are essential in the more dense areas of star clusters and galactic nuclei. And in star forming regions, hydrodynamics shows quite different behaviors on different scales.

## 3. Multi-physics simulations

The steady increase in computer power (Makino 2006) has made it possible to simulate multiple aspects of the physics of a single system. In a dense star cluster, we now can model the stellar dynamical history of a modest cluster, as well as the stellar evolution of each star. In addition, we can also model the hydrodynamical interactions that play a role when two or more stars have a close encounter, possibly resulting in a collision. Given that computer speed has increased by a factor of a million in the last thirty years, we can now follow the evolution of a million stars as quickly as we could calculate the track of a single star in the mid seventies.

As a consequence, the main bottlenecks in performing multi-scale, multi-physics simulations are no longer related to hardware, but rather to software limitations. For example, none of the existing legacy codes for stellar evolution can pass through all stages of stellar evolution in a robust way, without human intervention. One priority is to develop simpler and more robust versions of all three types of codes needed in the study of dense stellar systems, modeling the stellar dynamics, evolution, and hydrodynamics. Another priority is to find ways to combine these codes in easy and realible ways.

## 4. MODEST

These two priorities have been the main aims of the MODEST initiative, short for MOdeling DEnse STellar systems (`<http://www.manybody.org/modest.html>`). Starting four years ago with the first workshop in the American Museum for Natural History in New York city (Hut *et al.* 2002), we now hold a main workshop each year, as well as a number of satellite meetings, typically once every few months. Most meetings have a few dozen participants, though some of the yearly meetings have attracted a hundred participants or more. The topics of the workshops range from very specialized discussions to rather general overviews.

## 5. Frameworks

Having robust versions of stellar dynamics, stellar evolution, and hydrodynamics codes is not enough, if they cannot be coupled in modular and flexible ways. What is really needed is an umbrella software environment, a *framework* that contains the 'glue' to connect different codes with each other. In addition, such a framework should contain user-friendly tools for visualization, archiving, and comparisons with observations.

During the MODEST-6d workshop in Amsterdam in March 2006, we started a first prototype framework for dense stellar systems, MUSE. More information can be found on the 'projects' page of the MODEST home page, mentioned above. On the 'workshops' page, you can find the schedule of future frameworks-related workshops. We plan to hold several such workshops each year, to coordinate the ongoing development efforts.

### References

Hut, P., Shara, M. M., Aarseth, S. J., Klessen, R. S., Lombardi, J. C., Makino, J., McMillan, S., Pols, O. R., Teuben, P. J., & Webbink, R. F. 2003, *New Astronomy*, 8, 337

Makino, J. 2006, these proceedings p. 424

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