Highlights of Astronomy, Volume 14
IAU XXVI General Assembly, 14-25 August 2006
Karel A. van der Hucht, ed.

doi:10.1017/S1743921307011313

A summary of Joint Discussion 14

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Abstract. Modelling rich star clusters is at an exciting time, now that detailed star-by-star modelling of all open star clusters has become possible. We should renew attention to the modelling of globular star clusters, to enable us to exploit the flood of excellent observational data now available. At the same time, new ideas in star cluster astrophysics require us to broaden the realism of our modelling in various directions.

Keywords. methods: n-body simulations, binaries: general, stars: evolution, pulsars: general, globular clusters: general, open clusters and associations: general.

N-body modelling has reached a major landmark with the modelling of the open cluster M 67 (Hurley†). It is the hardest of all, because it is so old, and must have started life with far more stars than it has now. I hope that the modelling of open star clusters will now become a major industry, as there is lots to be done, even on M 67 (Latham; Verbunt).

Beyond the realm of the open star clusters, N-body techniques are pushing to larger N through both software and hardware advances (Aarseth; Makino), and their application to the study of tidal tails (Lee *et al.*), mass segregation (Vesperini *et al.*) and rotation (Vesperini & Zepf) is constantly being developed. And yet, *there is no star-by-star N-body model of any globular cluster*. This JD 14, as well as JD 6, has exposed several exciting problems which cry out for such modelling, including the constraints provided by the newly discovered abundance of pulsars in Ter 5 (Ransome), the many open dynamical questions on the binary populations in globular clusters (Richer; Piotto), the dynamical estimation of the white dwarf population in globulars (Fahlman), and so on. The very existence of exquisite observational data on increasing numbers of clusters (Piotto & Bedin; Dieball et al.; Ferraro *et al.*) demands a complementary effort in modelling.

Unfortunately, N-body techniques are still too slow. Furthermore, the pessimistic view is often expressed that there are just too many uncertainties in star-by-star modelling to make the effort worth while, such as in the evolution of collision remnants‡, stellar rotation/magnetism, tidal effects, etc. But we do not need to know everything about the physics of a problem to start modelling it. After all Kepler, who published his theory of the motion of Mars in Prague about 400 years ago, thought that the planets were pushed around by magnetic forces; but he managed to produce an excellent model which has stood the test of time, thanks to the wonderful observations of Tycho. Surely, we can do the same, given our better understanding of stellar dynamics and evolution, thanks to the wonderful and abundant observations of globular clusters.

JD 6 was better in giving appropriate weight to a viable alternative to N-body modelling: the Monte Carlo technique (Fregeau). Even the gas model can be used to understand many processes quantitatively (Boily), and in fact much can be understood by

† Where an author's name appears without a year, the reference is to a speaker or poster or panel contribution at either this Joint Discussion or JD6.

‡ Nevertheless, Glebbeek & Pols reported ongoing progress at this JD 14.

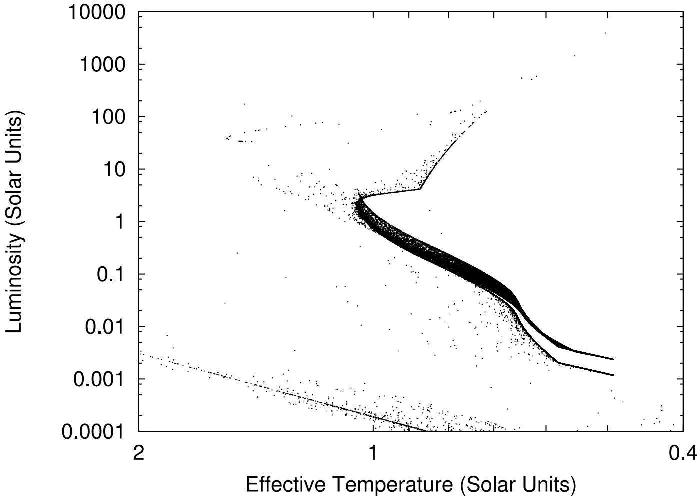

Figure 1. Preliminary Monte Carlo model of the globular cluster M4. The figure is a scatter plot of luminosity and effective temperature. The initial model has initially 75000 single stars and the same number of binaries. The curious bifurcation in the lower main sequence is an artefact of the way in which the initial masses of binary components are chosen, which had a lower limit of $0.1\,M_\odot$. Other choices for initial binary parameters and initial mass function were similar to those of Hurley *et al.*(2005). The initial model is a King model with $W_0 = 7$ and a tidal radius of 60 pc. At 12 Gyr the mass is close to that of M 4 but the radius is too large. The simulation uses a Monte Carlo code (Giersz 2006) combined with stellar evolution packages (Hurley *et al.* 2000, 2002) by means of the McScatter interface (Heggie *et al.* 2006).

modelling the dynamics in even simpler ways (Ivanova; Orlov et al). All that is needed is a concerted effort to bring the realism of some of these techniques up to the level of N-body methods. Indeed the author demonstrated ongoing work in collaboration with M. Giersz to do just this for the Warsaw Monte Carlo code (Fig. 1). In a general way, modelling of globular clusters has been undertaken for decades, but the modelling of *individual* clusters, with all the sophistication required by both the observations and the present state of knowledge of how populations evolve, needs fresh impetus from within the community.

This JD 14 has been very interesting for exposing the kind of issues which are usually neglected in modelling but which are perfectly feasible for inclusion now: multiple generations of stars (D'Antona; Piotto; Sills), spiral arms (Gieles et al), 'live' stellar evolution (Justham et al), planetary systems (Fregeau et al), massive black holes (Gebhardt), primordial triples (Eggleton) and rotation (Spurzem). These are themes which constantly arise in the regular meetings of the MODEST consortium, of which these two Joint Discussions have been one. With this momentum, our subject is in a rapid state of development.

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https://doi.org/10.1017/S1743921307011313 Published online by Cambridge University Press