

## Nbody Lecture 2023 - Rainer Spurzem

Note: more references will come into this file during or after the lecture

(see lecture slides p. 44 for some)

### References-Books

- Hut, P.; McMillan, S.L.W. (eds.): The Use of Supercomputers in Stellar Dynamics, Proceedings of a Workshop Held at the Institute for Advanced Study, Princeton, USA, June 2-4, 1986, VI, 240 pp.. Springer-Verlag Berlin Heidelberg New York. Also Lecture Notes in Physics, volume 267 (Earliest reference for Hermite scheme and hierarchical block steps)
- Aarseth, S.J.: Gravitational N-Body Simulations, by Sverre J. Aarseth, pp. 430. ISBN 0521432723. Cambridge, UK: Cambridge University Press, November 2003. New Edition January 2010.
- Binney, J., Tremaine, S.: Galactic Dynamics, Princeton, N.J. : Princeton University Press, 1987. 2nd edition 2008.
- Fridman, A. M.; Polyachenko, V. L.; (Translators: Aries, A. B.; Poliakoff, I. N.): Physics of gravitating systems. Vol. I: Equilibrium and stability. Vol. II. Nonlinear collective processes: nonlinear waves, solitons, collisionless shocks, turbulence. Astrophysical applications. Springer-Verlag, New York - Berlin - Heidelberg - Tokyo.
- Goodman, J., Hut, P. (eds.): Dynamics of Star Clusters, Proceedings of the 113th International Astronomical Union (IAU) Symposium, held in Princeton, USA, May 29 - June 1, 1984, Dordrecht: Reidel, 1985. With seminal articles by Heggie, Cohn, Bettwieser, Hénon, Stodołkiewicz, Aarseth, Antonov, Shapiro, Spitzer, Ambartsumian, Ostriker, King, Wielen, Bahcall, Mikkola, McMillan, ...
- Heggie, D.C., Hut, P.: The Gravitational Million-Body Problem: A Multidisciplinary Approach to Star Cluster Dynamics, by Douglas Heggie and Piet Hut. Cambridge University Press, 2003, 372 pp.
- Ogorodnikov, K.F.: Dynamics of Stellar Systems, Oxford: Pergamon, 1965, edited by Beer, Arthur
- Spitzer, L.: Dynamical Evolution of Globular Clusters Princeton, N.J. : Princeton University Press, 1987.

### References-Papers

Aarseth, S.J. [1972], ‘Direct integration methods for the  $N$ -body problem’, in *Gravitational N-Body Problem* ed. M. Lecar (D. Reidel), 373–87.

Aarseth, S.J. [1985], ‘Direct methods for  $N$ -body simulations’, in *Multiple Time Scales* ed. J.U. Brackbill & B.I. Cohen (Academic Press), 377–418.

Aarseth, S.J. [1999a], ‘From NBODY1 to NBODY6: the growth of an industry’, *Publ. Astron. Soc. Pac.* , **111**, 1333–46.

- Aarseth, S.J. [1999b], ‘Star Cluster Simulations: the State of the Art’, *Cel. Mech. Dyn. Ast.* **73**, 127.
- Aarseth, S.J. [2001a], ‘NBODY2: a direct  $N$ -body integration code’, *New Astron.* **6**, 277–91.
- Aarseth, S.J. [2001b], ‘Regularization methods for the  $N$ -body problem’, in *The Restless Universe*, ed. B.A. Steves & A.J. Maciejewski (Inst. Phys. Publ.), 93–108.
- Aarseth, S.J. [2003], *Gravitational N-Body Simulations* (Cambridge University Press).
- Aarseth, S.J., Tout, C.A. & Mardling, R.A. [2008], ‘The Cambridge N-Body Lectures’, <http://ads.bao.ac.cn/abs/2008LNP...760.....A>, with 17 lectures by many authors, all around N-Body.
- Aarseth, S.J. & Zare, K. [1974], ‘A regularization of the three-body problem’, *Celes. Mech.* **10**, 185–205.
- Ahmad, A. & Cohen, L. [1973], ‘A numerical integration scheme for the  $N$ -body gravitational problem’, *J. Comput. Phys.* **12**, 389–402.
- Glaschke, P., Amaro-Seoane, P. & Spurzem, R. [2011], ‘Hybrid methods in planetesimal dynamics (I) : Description of a new composite algorithm’, subm. to MNRAS, eprint <http://cn.arxiv.org/pdf/1105.6094v1>
- Bulirsch, R. & Stoer, J. [1966], ‘Numerical treatment of ordinary differential equations by extrapolation methods’, *Num. Math.* **8**, 1–13.
- Chin, S. A., Chen, C. R. [2005], ‘Forward Symplectic Integrators for Solving Gravitational Few-Body Problems’, *Celestial Mechanics and Dynamical Astronomy*, **91**, 301
- Cohn, H. and Kulsrud, R.M. [1978], ‘The stellar distribution around a black hole: numerical integration of the Fokker-Planck equation.’, *The Astrophysical Journal*, **226**, 1087-1108.
- Cohn, H. [1979], ‘Numerical integration of the Fokker-Planck equation and the evolution of star clusters’, *The Astrophysical Journal*, **234**, 1036-1053.
- Cohn, H. [1980], ‘Late core collapse in star clusters and the gravothermal instability’, *The Astrophysical Journal*, **242**, 765-771.
- Dorband, E.N., Hemsendorf, M., Merritt, D. [2003], ‘Systolic and hyper-systolic algorithms for the gravitational  $N$ -body problem, with an application to Brownian motion’, *J. Comput. Phys.* **185**, 484–511.
- Einsel, C. and Spurzem, R. [1999], ‘Dynamical evolution of rotating stellar systems - I. Pre-collapse, equal-mass system’, *Monthly Notices of the Royal Astronomical Society*, **302**, 81-95.
- Eggleton, P.P., Fitchett, M.J. & Tout, C.A. [1989], ‘The distribution of visual binaries with two bright components’, *Astrophys. J.* **347**, 998-1012. (Also see Errata in *Astrophys. J.* **354**, 387.)
- Glaschke, P. [2006], ‘Studying the Formation of Protoplanets : A new Hybrid Code for Planetesimal Dynamics’, Promotion Univ. Heidelberg, <http://www.ub.uni-heidelberg.de/archiv/6553>.

- Hansen, B.M.S. & Phinney, E.S. [1997], ‘The pulsar kick velocity distribution’, *Mon. Not. R. Astron. Soc.* **291**, 569–77.
- Harfst, S., Gualandris, A., Merritt, D., Spurzem, R., Portegies Zwart, S., Berczik, P. [2006], ‘Performance Analysis of Direct N-body Algorithms on Special-Purpose Supercomputers’, *New Astron.* , **12**, 357.
- Heggie, D.C. [1974], ‘A global regularisation of the gravitational N-body problem’, *Celes. Mech.* **10**, 217–41.
- Heggie, D.C. & Ramamani, N. [1995], ‘Approximate self-consistent models for tidally truncated star clusters’, *Mon. Not. R. Astron. Soc.* **272**, 317–22.
- von Hoerner, S. [1960], ‘Die numerische Integration des n-Körper-Problemes für Sternhaufen’, *Zs. f. Astroph.*, **50**, 184–214.
- von Hoerner, S. [1963], ‘Die numerische Integration des n-Körper-Problemes für Sternhaufen II’, *Zs. f. Astroph.*, **57**, 47–82.
- von Hoerner, S. [2001], ‘How it all started’. In: Dynamics of Star Clusters and the Milky Way, ASP Conference Series, Vol. 228. Edited by S. Deiters, B. Fuchs, R. Spurzem, A. Just, and R. Wielen. San Francisco: Astronomical Society of the Pacific. p.11.
- Hurley, J.R., Pols, O.R. & Tout, C.A. [2000], ‘Comprehensive analytical formulae for stellar evolution as a function of mass and metallicity’, *Mon. Not. R. Astron. Soc.* **315**, 543–69.
- Khalisi, E., Spurzem, R.. [2006] ‘NBODY6++ - Features of the computer code’, <ftp://ftp.ari.uni-heidelberg.de/pub/staff/spurzem/nb6mpi/nb6++manual-new.pdf>
- Khalisi, E., Omarov, C., Spurzem, R., Giersz, M., Lin, D., [2003] ‘Collisional dynamics of black holes, star clusters and galactic nuclei’. In: Krause, E., Jaeger, W., Resch, M. (Eds.), High Performance Computing in Science and Engineering’03. Springer Verlag, pp. 71-87.
- Kokubo, E., Makino, J. [2004], ‘A Modified Hermite Integrator for Planetary Dynamics’, *Publ. Astron. Soc. Japan* **56**, 861.
- Kustaanheimo, P. & Stiefel, E. [1965], ‘Perturbation theory of Kepler motion based on spinor regularization’, *J. Reine Angew. Math.* **218**, 204–19.
- Kroupa, P., Tout, C.A. & Gilmore, G. [1993], ‘The distribution of low-mass stars in the Galactic disc’, *Mon. Not. R. Astron. Soc.* **262**, 545–87.
- Kroupa, P., Aarseth, S.J. & Hurley, J. [2001], ‘The formation of a bound star cluster: from the Orion Cluster to the Pleiades’, *Mon. Not. R. Astron. Soc.* **321**, 699–712.
- Makino, J. [1991], ‘Optimal order and time-step criterion for Aarseth-type N-body integrators’, *Astrophys. J.* **369**, 200–12.
- Makino, J. [1991], ‘A Modified Aarseth Code for GRAPE and Vector Processors’, *Publ. Astron. Soc. Japan* , **43**, 859.
- Makino, J. & Aarseth, S.J. [1992], ‘On a Hermite integrator with Ahmad–Cohen scheme for gravitational many-body problems’, *Publ. Astron. Soc. Japan* **44**, 141–51.

- Makino, J. & Hut, P. [1988], 'Performance Analysis of direct N-body calculations', *Astrophys. J. Suppl.*, **68**, 833.
- Makino, J. & Hut, P., Kaplan, M., Saygin, H. [2006], 'A time-symmetric block time-step algorithm for N-body simulations', *New Astron.* **12**, 124–133.
- Makino, J. & Taiji, M. [1998], 'Scientific Simulations with Special Purpose Computers', Wiley, Chichester.
- Mardling, R.A. [2003], 'A new three-body formalism', in preparation.
- Mardling, R.A. & Aarseth, S.J. [1999], 'Dynamics and stability of three-body systems', in *The Dynamics of Small Bodies in the Solar System*, ed. B.A. Steves & A. Roy (Kluwer), 385–92.
- Mardling, R.A. & Aarseth, S.J. [2001], 'Tidal interactions in star cluster simulations', *Mon. Not. R. Astron. Soc.* **321**, 398–420.
- Mikkola, S. [1985], 'A practical and regular formulation of the  $N$ -body equations', *Mon. Not. R. Astron. Soc.* **215**, 171–7.
- Mikkola, S. and Aarseth, S.J. [1990], 'A chain regularization method for the few-body problem', *Celes. Mech. Dyn. Ast.* **47**, 375–90.
- Mikkola, S. & Aarseth, S.J. [1993], 'An implementation of  $N$ -body chain regularization', *Celes. Mech. Dyn. Ast.* **57**, 439–59.
- Mikkola, S. & Aarseth, S.J. [1996], 'A slow-down treatment for close binaries', *Celes. Mech. Dyn. Ast.* **64**, 197–208.
- Mikkola, S. & Aarseth, S.J. [1998], 'An efficient integration method for binaries in  $N$ -body simulations', *New Astron.* **3**, 309–20.
- Mikkola, S. & Aarseth, S.J. [2001], 'A time transformed leap-frog scheme', *Cel. Mech. Dyn. Ast.* **84**, 343–354.
- Miller, R.H. [1964], 'Irreversibility in Small Stellar Dynamical Systems.', *The Astrophysical Journal*, **140**, 250.
- Miyamoto, M. & Nagai, R. [1975], 'Three-dimensional models for the distribution of mass in galaxies', *Publ. Astron. Soc. Japan* **27**, 533–43.
- Nitadori, K., Makino, J., Hut, P. [2006], 'Performance Tuning of N-Body Codes on Modern Microprocessors: I. Direct Integration with a Hermite Scheme on x86\_64 architecture', *New Astron.*, **12**, 169.
- Nitadori, K., Aarseth, S. J. [2012], 'Accelerating NBODY6 with graphics processing units', *Monthly Notices of the Royal Astronomical Society*, **424**, 545
- Quinlan, G.D. and Tremaine, S. [1992], 'On the reliability of gravitational N-body integrations', *Monthly Notices of the Royal Astronomical Society*, **259**, 505–518.
- Rantala, A., Naab, T., Springel, V. [2021], 'frost: a momentum-conserving CUDA implementation of a hierarchical fourth-order forward symplectic integrator', *Monthly Notices of the Royal Astronomical Society*, **502**, 5546
- Rantala, A., Pihajoki, P., Mannerkoski, M., Johansson, P. H., Naab, T. [2020], 'MSTAR - a fast parallelized algorithmically regularized integrator with minimum spanning tree coordinates', *Monthly Notices of the Royal Astronomical Society*, **492**, 4131

- Spurzem, R. [1999], 'Direct N-body simulations', *Journ. Comp. Appl. Math.*, **109**, 407–432.
- Spurzem, R., Baumgardt, H. & Ibold, N. [2001], 'A parallel implementation of an  $N$ -body integrator on general and special-purpose computers', unfinished preprint at <ftp.ari.uni-heidelberg.de/pub/staff/spurzem/edinpaper.ps.gz>
- Spurzem, R., Berczik, P., Berentzen, I., Ge, W., Wang, X., Schive, H., Nitadori, K., Hamada, T., & Fiestas, J. 2011, Large-Scale Computing Techniques for Complex System Simulations (Wiley Series on Parallel and Distributed Computing), eds. Werner Dubitzky, Krzysztof Kurowski, Bernard Schott, Wiley-IEEE Computer Society Pr; 1 edition (November 22, 2011)
- Takahashi, K. and Lee, H.M. [2000], 'Evolution of multimass globular clusters in the Galactic tidal field with the effects of velocity anisotropy', *Monthly Notices of the Royal Astronomical Society*, **316**, 671–683.
- Tout, C.A., Aarseth, S.J., Pols, O. & Eggleton, P. [1997], 'Rapid binary star evolution for  $N$ -body simulations and population synthesis', *Mon. Not. R. Astron. Soc.* **291**, 732–48.
- Wang, L., Spurzem, R., Aarseth, S., Giersz, M., Askar, A., Berczik, P., Naab, T., Schadow, R., Kouwenhoven, M. B. N. [2016], 'The DRAGON simulations: globular cluster evolution with a million stars', *Monthly Notices of the Royal Astronomical Society*, **458**, 1450
- Wang, L., Spurzem, R., Aarseth, S., Nitadori, K., Berczik, P., Kouwenhoven, M. B. N., Naab, T. [2015], 'NBODY6++GPU: ready for the gravitational million-body problem', *Monthly Notices of the Royal Astronomical Society*, **450**, 4070
- Wang, L., Iwasawa, M., Nitadori, K., Makino, J. [2020], 'PETAR: a high-performance  $N$ -body code for modelling massive collisional stellar systems', *Monthly Notices of the Royal Astronomical Society*, **497**, 536