the SILK ROAD PROJECT at NAOC

丝绸之路 计划

Deutsche Forschungsgemeinschaft DFG

ZAH ZENTRUM FÜR ASTRONOMIE

ARI ITA LSW Univ. Heidelberg

How it all started

Rainer Spurzem, and Silk Road Team

(M. Arca Sedda, F. Flammini Dotti, J. Hurley, Shuo Li, P. Berczik, P. Cho, Kai Wu,….)

Kavli Institute for Astronomy and Astrophysics (KIAA), Peking University

National Astronomical Observatories (NAOC), Univ. of Chinese Academy of Sciences

Astronomisches Rechen-Inst., ZAH, Univ. of Heidelberg, Germany

Picture:

Xi Shuang Banna, Yunnan, SW China (R.Sp.)

MODEST24

Warsaw, Aug. 2024

spurzem@ari.uni-heidelberg.de

spurzem@nao.cas.cn

https://silkroad.zah.uni-heidelberg.de

VolkswagenStiftung

Kavli Institute for Astronomy and Astrophysics, Peking Univ..

北京大學
PEKING UNIVERSITY

Founded 2008

Astronomisches Rechen-Institut (ARI)
Univ. of Heidelberg, Germany

Founded May 10, 1700

How it all started

Dynamics of Star Clusters and the Milky Way
ASP Conference Series, Vol. 228, 2001
S. Deiters, B. Fuchs, A. Just, R. Spurzem, and R. Wielen, eds.

How it All Started

Sebastian von Hoerner

Krummenackerstraße 186, 73733 Esslingen, Germany

After having worked for turbulence and shock fronts, I changed 1956 to the structure and dynamics of star clusters, but soon I found this somewhat frustrating. Before starting a theoretical treatment, one had to make so many assumptions and approximations, that I did not know how much of the final results one really could believe. I would have loved to try it a completely different way, by "Experimental Mathematics", so to say. Just make a little cluster of stars, with random locations and random velocities, put it on a computer, integrate Newton's gravity in small time steps, and just look and see what the little thing really does. Without any assumptions or approximations to start with. Well, one assumption: that treating a small number will already make sense.

Star2000 Conference Heidelberg: 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.

How it all started

Erich Bettwieser

Daiiichiro Sugimoto, Jun Makino

Douglas Heggie, Sverre Aarseth

Mirek Giersz, Peter Berczik

Gerhard Hensler, Roland Wielen

Doug Lin, Suijian Xue

Mon. Not. R. astr. Soc. (1980) 191, 483–498

1980

On the consequences of the gravothermal catastrophe

D. Lynden-Bell and P. P. Eggleton *Institute of Astronomy, The Observatories, Cambridge CB3 0HA*

Received 1979 October 9; in original form 1979 July 11

between encounters. In such a stellar system a typical star at any radius moves in and out by about a local Jeans length $\lambda = 1/k_J$ where $k_J^2 v^2 = 4\pi G\rho$. This gives a typical radial distance between encounters. However, the time between those encounters is not λ/v but rather a relaxation time T_r. Hence the energy flux is given by equation (3.5) with $\lambda = k_J^{-1}$ and with τ replaced by T_r

$$\frac{L}{4\pi r^2} = -\frac{C\rho}{k_J^2 T_r}\frac{\partial}{\partial r}\left(\frac{3}{2}v^2\right) \quad (3.7)$$

$$= -3GmC(\log N)\frac{\rho}{v}\frac{\partial v^2}{\partial r} \quad (3.8)$$

- Conductivity ∝ ρ/v
- Based on Jeans Length
- Anisotropic generalization

(Louis & Spurzem 1991)

where C is a dimensionless constant of order unity. As Lecar pointed out, this implies a conductivity K proportional to $\rho T^{-1/2}$ or an opacity κ proportional to $T^{3.5}\rho^{-2}$. Notice that the details of the argument are unimportant, for the use of dimensions, coupled with the fact that the heat flux must be proportional to the relaxation rate (T_r^{-1}) gives the same dependence of conductivity on ρ, v. The detailed computation of Hachisu *et al.* (1978) was

GRAPE
Daiichiro
Sugimoto
Visiting
Gauss
Professor
Göttingen

Gravothermal Oscillations (“Catastrophe”)

Bettwieser & Sugimoto 1984, later confirmed by Heggie, Cohn, Hut (watch the time step!)

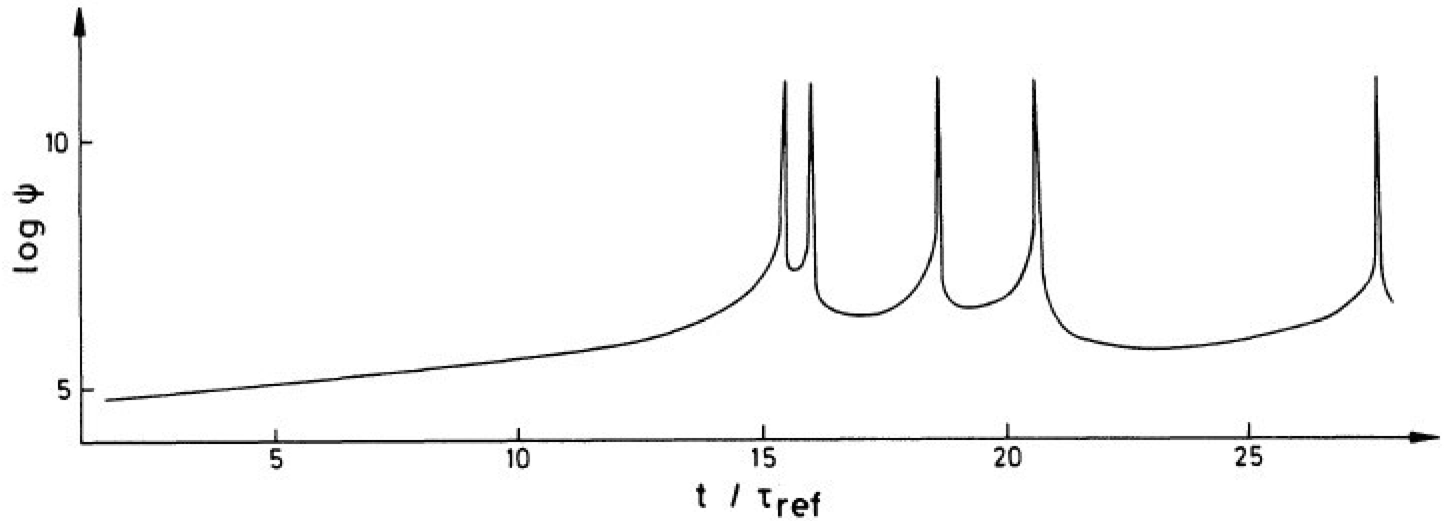
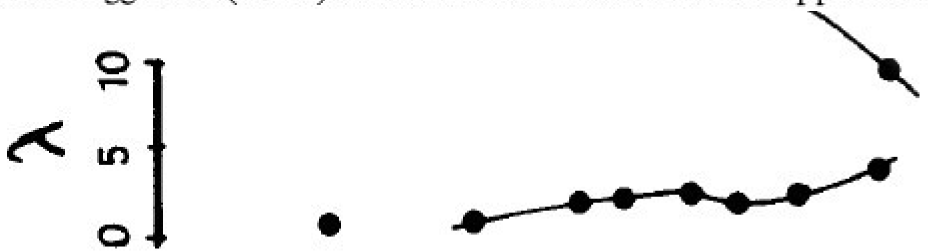


Figure 1. Gravothermal oscillation. The central density ψ in units of $M/(4\pi R^3)$ is plotted against time in units of the initial half-mass relaxation time. The case plotted has $C = 10^4$ erg s^{-1} and $k = 2$.

boundary conditions (equations 35 and 36) and for the corrected heat conductivity, as employed by Lynden-Bell & Eggleton (1980). Details are described in the Appendix.



Conductivity tested versus N-body (N=1000)! Bettwieser & Sugimoto 1985

-7/4 cusp in nuclei found: Amaro-Seoane, Freitag, Spurzem (2004)

Gravothermal Oscillations - Attractor in Phase Space
Spurzem 1994, in “Ergodic Concepts in Stellar Dynamics”, Springer
Giersz & Spurzem 1994, Amaro-Seoane, Freitag & Sp. 2004

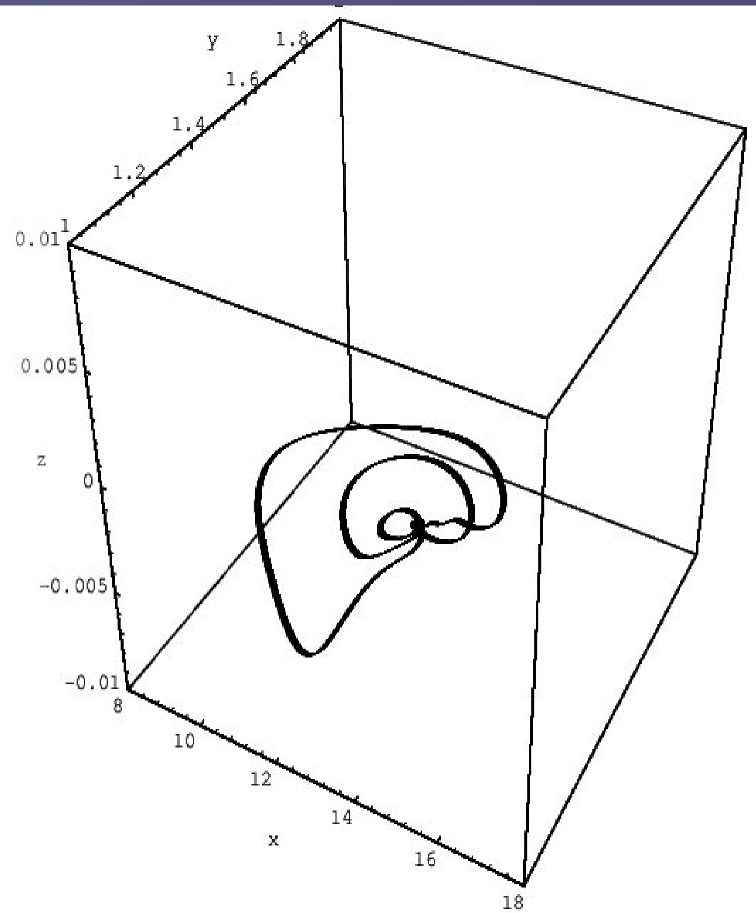


Fig. 3:
Projected three-dimensional attractor for $N = 100.000$ system, $x = \log \rho'_c$, $y = \log \sigma'_c$, $z = \xi$.

Erich Bettwieser:

$A \propto d_r(u/r), d_r(F/r)$

(gaseous model)

Douglas Heggie:

(analytic, kind of

Gaseous model)

Mirek Giersz:

(N-Body, gaseous model,

1D Fokker-Pl.)

Sverre Aarseth:

(N-Body)

Anisotropy in stellar dynamics

Astron. Astrophys. 161, 102–112 (1986)

E. Bettwieser and R. Spurzem

Universitätssternwarte Göttingen, Geismarlandstrasse 11, D-3400 Göttingen, Federal Republic of Germany

Mon. Not. R. astr. Soc. (1991) **252,** 177–189

Gravothermal instability of anisotropic self-gravitating gas spheres: singular equilibrium solution

R. Spurzem[1,2,3]

[1] *Institut für Theoretische Physik und Sternwarte, University of Kiel, Olshausenstraße 40, D-2300 Kiel, Germany*
[2] *Institut für Astronomie und Astrophysik, University of Würzburg, Am Hubland, D-8700 Würzburg, Germany*
[3] *Universitätssternwarte Göttingen, Geismarlandstraße 11, D-3400 Göttingen, Germany*

A comparison of direct *N*-body integration with anisotropic gaseous models of star clusters

Mirek Giersz★ and Rainer Spurzem†

Department of Mathematics and Statistics, University of Edinburgh, King's Buildings, Edinburgh EH9 3JZ

Mon. Not. R. Astron. Soc. **282,** 19–39 (1996)

Direct collisional simulation of 10 000 particles past core collapse

R. Spurzem[1] and S. J. Aarseth[2]

[1] *Institut für Astronomie und Astrophysik, Universität Kiel, Olshausenstraße 40, 24098 Kiel, Germany*
[2] *Institute of Astronomy, Madingley Road, Cambridge CB3 0HA*

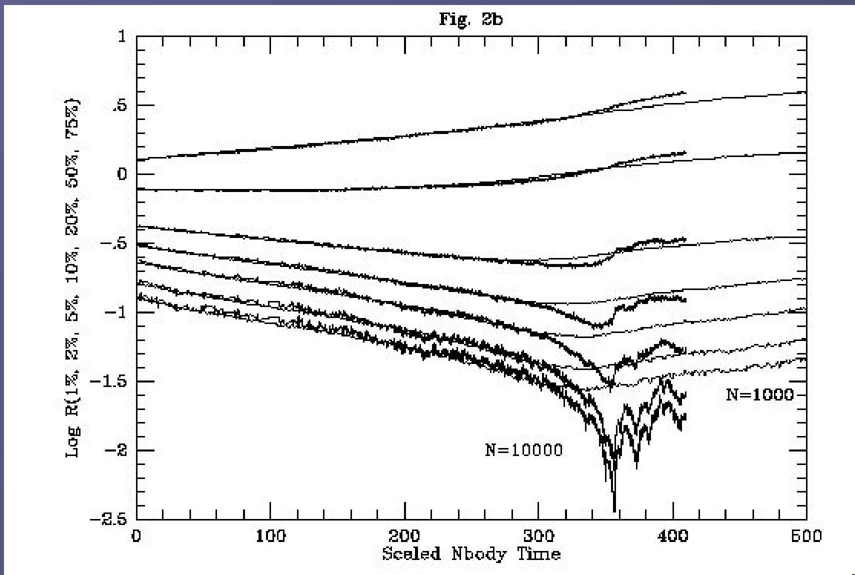
Jun Makino: 64k with GRAPE, 1996

Gerhard Hensler, Christian Theis: GRAPE-3/HARP-2 to Kiel!

Star Clusters: Modelling the Dynamics

(compare gaseous model with direct N-body integration)

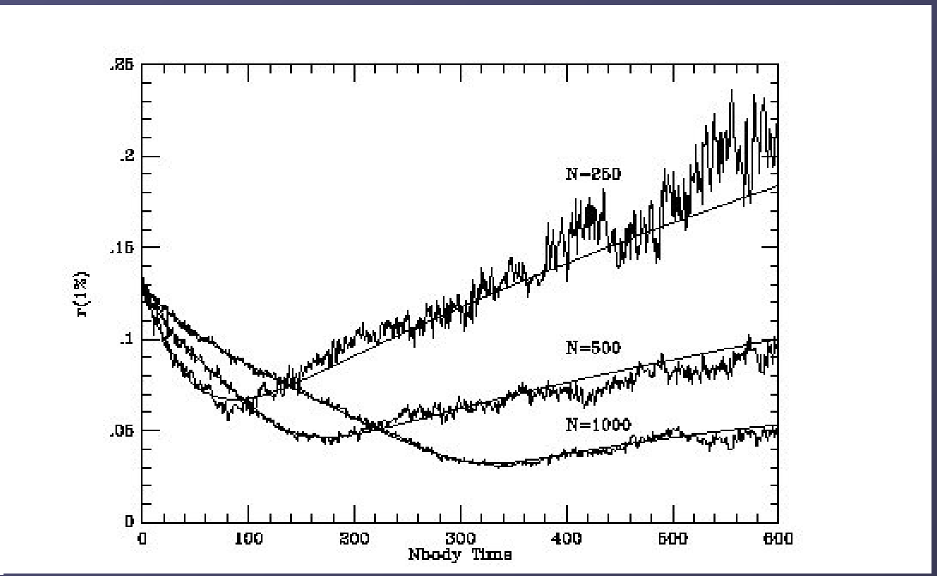
(Spurzem & Aarseth 1996)



N-Body / N-Body

(Giersz & Spurzem 1994)

(now in Binney/Tremaine)



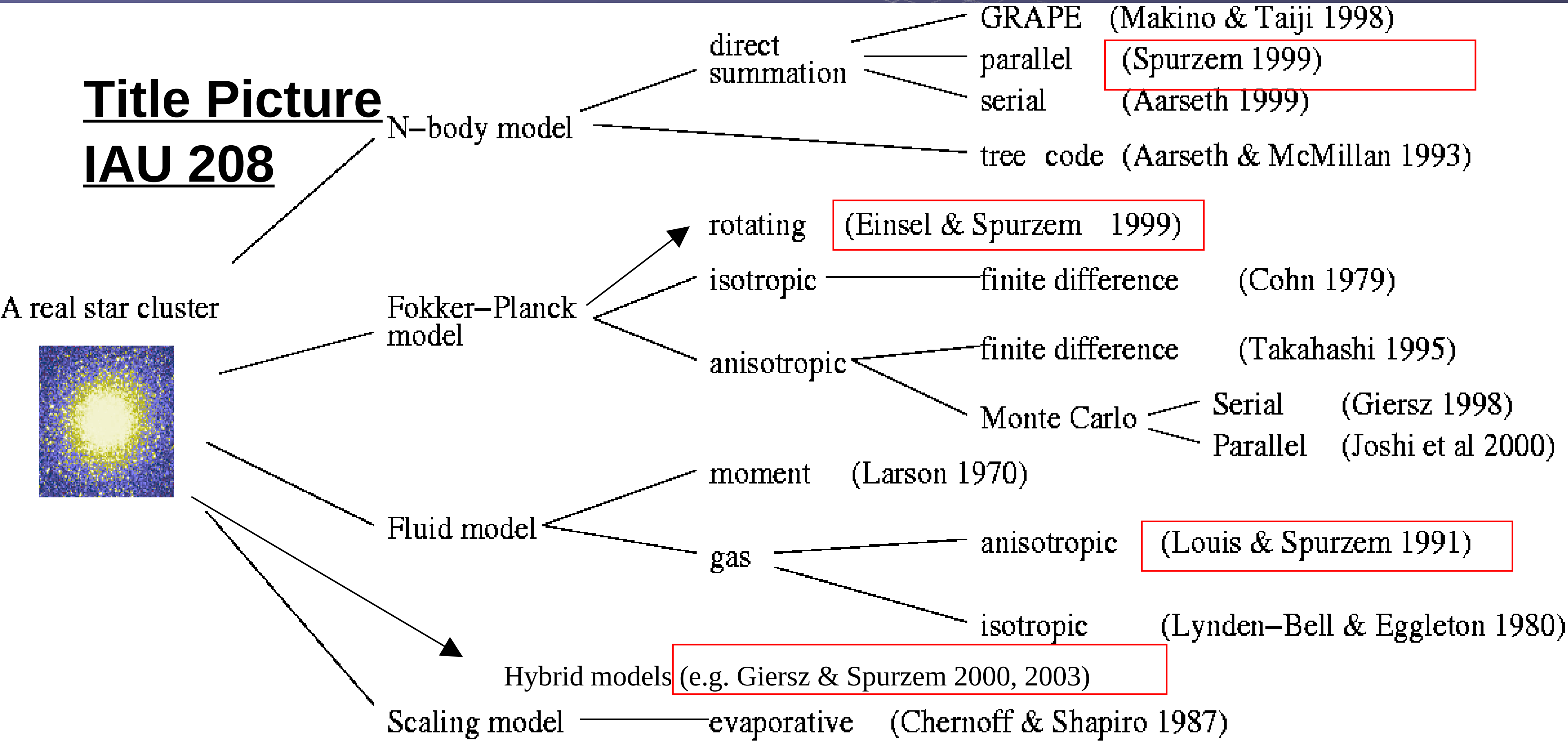
N-Body / Gas Model

→

- central supermassive black hole
- Anisotropic heat transport, aniso TOV generalization
- Ultracold plasma and self-interacting dark matter

Numerical Stellar Dynamics

Some methods for studying the evolution of globular clusters (by D.C.Heggie)



(citations are not complete for 2006)

Gerhard Hensler, call to Kiel, 1990-1996 ; Roland Wielen, to Heidelberg, since 1996

Doug Lin, Suijian Xue: Beijing, since 2009

Christian Einsel:

(2D Fokker-Pl.)

Mon. Not. R. Astron. Soc. **302,** 81–95 (1999)

Dynamical evolution of rotating stellar systems – I. Pre-collapse, equal-mass system

Christian Einsel[1,2] and Rainer Spurzem[2]★

[1] *Institut für Theoretische Physik und Astrophysik der Christian-Albrechts-Universität, Olshausenstraße 40, D-24098 Kiel, Germany*

[2] *Astronomisches Rechen-Institut, Mönchhofstraße 12–14, D-69115 Heidelberg, Germany*

Koji Takahashi:

(gaseous model,

1D Fokker-Pl.)

Mon. Not. R. Astron. Soc. **272**, 772–784 (1995)

Comparison between Fokker-Planck and gaseous models of star clusters in the multi-mass case revisited

R. Spurzem[1] and K. Takahashi[2]

[1] *Inst. für Astronomie und Astrophysik, Univ. Kiel, Olshausenstraße 40, 24098 Kiel, Germany*

[2] *Dept. of Earth and Space Science, Faculty of Science, Osaka Univ., Toyonaka, Osaka 560, Japan*

Pau Amaro-Seoane:

(gaseous model)

Mon. Not. R. Astron. Soc. **352,** 655–672 (2004) doi:10.1111/j.1365-2966.2004.07956.x

Accretion of stars on to a massive black hole: a realistic diffusion model and numerical studies

P. Amaro-Seoane,★ M. Freitag★ and R. Spurzem★

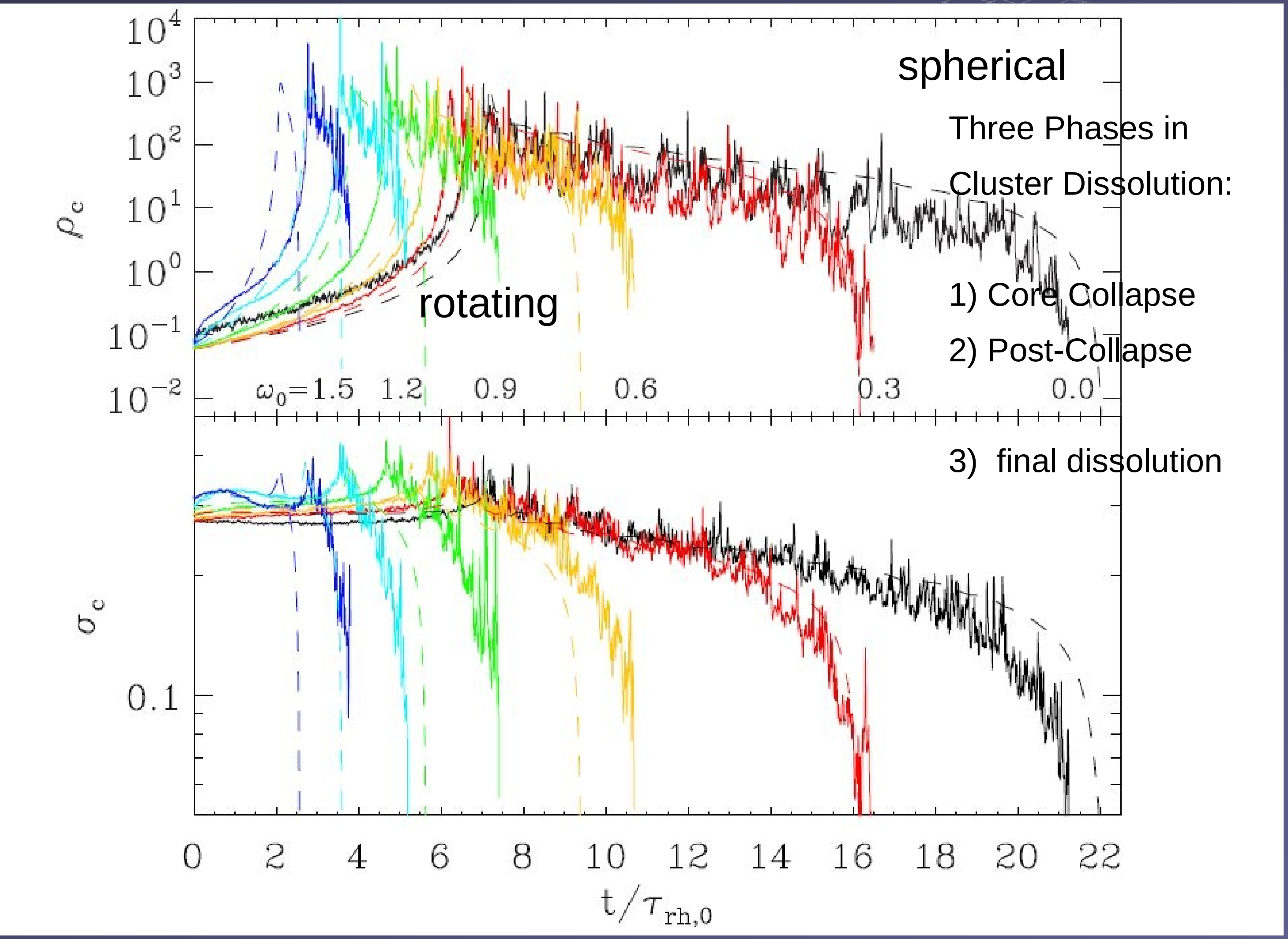
Astronomisches Rechen-Institut, Mönchhofstraße 12-14, Heidelberg, D-69120, Germany

Could be used for (self) interacting dark matter, cf. Shapiro & Heggie (2022)

Rotating Star Clusters

(compare Fokker-Planck model with direct N-body integration)

Dissolution of Star Cluster in Tidal Field



Three Phases in Cluster Dissolution:

1) Core Collapse
2) Post-Collapse
3) final dissolution

Kim, Einsel, Lee, Spurzem, Lee, 2002

Kim, Lee, Spurzem, 2004

Fiestas, Spurzem, Kim, 2006

Kim, Yoon, Lee, Spurzem, 2008

Hong, Kim, Lee, Spurzem, 2013

See also models with central star-accreting supermassive black hole and 2D loss cone:

Fiestas, Spurzem, 2010

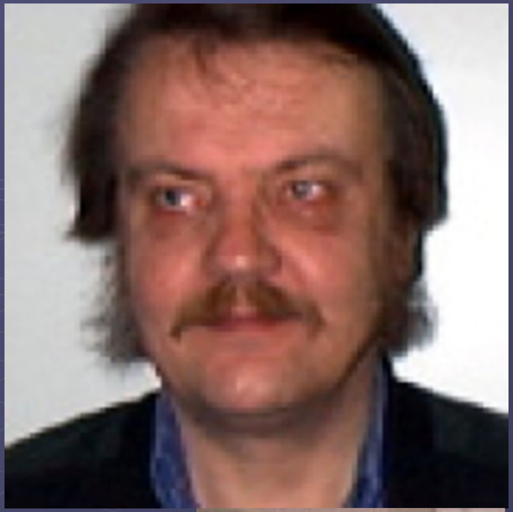
Fiestas, Porth, Berczik, Spurzem, 2012

GRAPE and GPU N-Body

Nbody-X History

After Holmberg and von Hoerner:

Sverre Aarseth, Roland Wielen, Seppo Mikkola



Jarrod Hurley, Steve McMillan, Jun Makino

Later see: Keigo Nitadori, Long Wang, Peter Berczik…

and more: Sambaran Banerjee, Albrecht Kamlah,

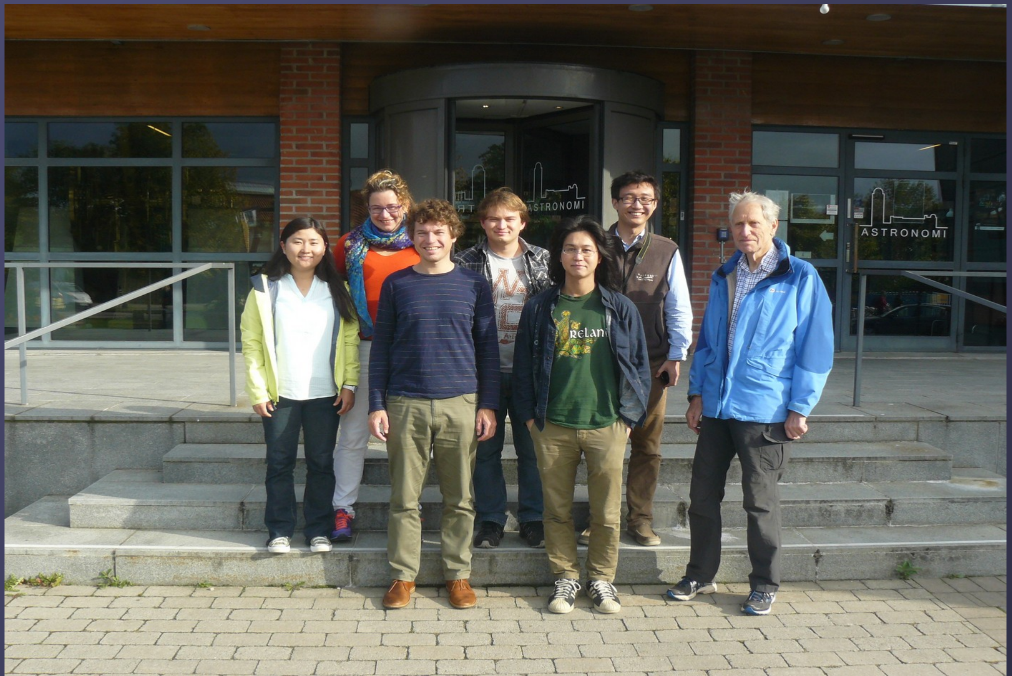
Manuel Arca Sedda, ...

Direct N-Body Simulations

So we need (among others):

- 2-body Regularization (Kustaanheimo & Stiefel 1965)
- 3-body Regularization (Aarseth & Zare 1974)
- Hierarchical Subsystems (Chain, Aarseth & Mikkola)
- Our GPU implementation: Keigo (Nitadori & Aarseth 2012)

Quaternions....



18 September 2015: some participants at the N-body workshop in Lund

From the left: Seungkyung Oh, Anna Sippel, Mark Gieles, ***Taras Panamarev, Keigo Nitadori, Long Wang, Sverre Aarseth***

Keigo: RIKEN Inst. Japan (→ Fugaku)

Kupi, G., Amaro-Seoane, P., Spurzem, R., Dynamics of compact object clusters: a post-Newtonian study, 2006, MNRAS 371, L45

Berentzen, I., Preto, M., Berczik, P., Merritt, D., Spurzem, R., Binary Black Hole Merger in Galactic Nuclei: Post-Newtonian Simulations, 2009, ApJ 695, 455

Seite 5 HEIDELBERGER NACHRICHTEN Mittwoch, 8. Februar 2006

Super-Rechner spürt Schwarzen Löchern nach

Astronomisches Rechen-Institut stellte mit „Grace“ einen der schnellsten Rechnern der Welt vor – 3200 Milliarden Rechenoperationen pro Sekunde

Von Harald Berlinghof

Schon ein ganz durchschnittliches dieser gefräßigen, schwarzen Ungeheuer des Universums, die oft in den Zentren der Galaxien hausen, wäre ein furchteinflößendes Etwas, könnten wir ihm je begegnen. Sie sind zwar dunkle Mysterien des Kosmos, doch unnahbar sind sie nicht. Vielmehr zerren sie sogar gerne alles an sich, um es sich einzuverleiben. Schwarze Löcher sind ausgepowerte, kollabierte Sterne, deren Brennstoff nicht mehr ausreicht, um sie strahlen zu lassen. Unter ihrem eigenen Gewicht brechen sie in sich zusammen und bilden eine gewaltige Masse, die solche Gravitationskräfte ausübt, dass nichts, was einmal den sogenannten Ereignishorizont überschritten hat, je wieder zurück kehren kann – noch nicht einmal Licht.

Wie gesagt, dies gilt für ganz normale Schwarze Löcher. Im Astronomischen Rechen-Institut (ARI) der Universität Heidelberg wagt man sich aber inzwischen sogar an sogenannte „supermassive Schwarze Löcher“ heran – rein rechnerisch natürlich. „Das sind Schwarze Löcher mit einer Masse vom mindestens einer Million Sonnenmassen und der Größe unseres gesamten Sonnensystems“, erklärt Professor Rainer Spurzem vom ARI.

In Computersimulationen wird berechnet, was passiert, wenn zwei Galaxien, die solche supermassiven Schwarzen Löcher in sich tragen, miteinander kollidieren. Millionen von Sonnen und Planetensystemen kommen sich dann so nahe, dass die gegenseitigen Anziehungskräfte die jeweiligen Bahnen der Sonnen verändern und beide Galaxien in starke Drehbewegungen und rotierende Verwirbelungen versetzen. Aus den beiden kollidierten Spiralgalaxien entstehen kurzzeitig – für wenige Millionen Jahre – sogenannte Antennengalaxien – so bezeichnet wegen ihrer Form.

Berechnen muss man solche hochkomplexen Ereignisse freilich mit einem Superrechner. Und im Astronomischen Rechen-Institut hat man mit der finanziellen Hilfe der Volkswagenstiftung, der Deutschen Forschungsgemeinschaft und dem Land Baden-Württemberg sowie des Hardware-Know-Hows der Informatik der Mannheimer Universität am Lehrstuhl von Professor Reinhard Männer aus 32 Hochleistungs-PCs einen Top-50-Rechner namens „Grace“ konstruiert, der zu den schnellsten Rechnern der Welt zählt.

So richtig schnell machen ihn spezielle Grafikkarten namens „Grape“ aus Japan und solche aus Mannheim mit Namen „MPRace“. 3200 Milliarden Rechenoperationen in der Sekunde sind die Folge. „Ein Rechner für 20 Millionen Euro bringt auch nicht mehr“, so Spurzem. Allerdings schafft es Grace nicht in die Weltrangliste der schnellsten Rechner, weil er ein Spezialist ist, der nur auf dem Problem der Gravitationsberechnung funktioniert. In anderen Bereichen würde er kläglich versagen.

Im Jahr 1937, also bevor Computersimulationen möglich waren, weil Konrad Zuse den Computer erst später erdachte, hatte der Forscher Erk Holmberg die Entstehung der „Antennengalaxien“ beim Zusammenstoß zweier Spiralgalaxien bereits aufgezeigt. Seine mechanische Methode brachte ein ähnliches Ergebnis hervor wie der Rechner „Grace“. Doch „Grace“ hat noch etwas anderes berechnet. Der Zusammenschluss zweier supermassiver Schwarzer Löcher erfolgt viel schneller als bisher vermutet – sie benötigen nur rund 100 Millionen Jahre, um zu verschmelzen und dabei starke Gravitationswellen auszusenden. Könnte man die Gravitationswellen nachweisen, wäre der letzte große Lückenschluss in Einsteins Relativitätstheorie gelungen.

Am Astronomischen Recheninstitut stellten Mitarbeiter ihren neuen schnellen Rechner vor, der auf der Suche nach den Gravitationswellen helfen soll. Von der Rechenkraft gehört er in die Top 50 der schnellsten Rechner auf der Welt, obwohl er nur aus einfachen PCs zusammengebaut ist. Foto: Kresin

Miro „schnappt“ zwei Einbrecher

Der Polizeihund erschnüffelte in Wieblingen die Männer, die sich im Keller versteckt hatten

POLIZEIBERICHT

Zwei verletzt

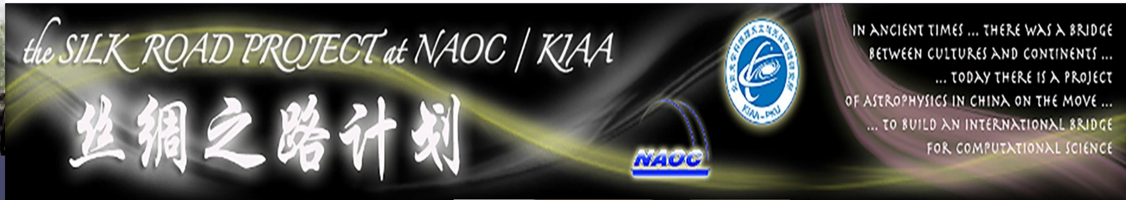
Maybe he detects gravitational waves with this?

VolkswagenStiftung

Kavli Institute for Astronomy and Astrophysics, Peking Univ..

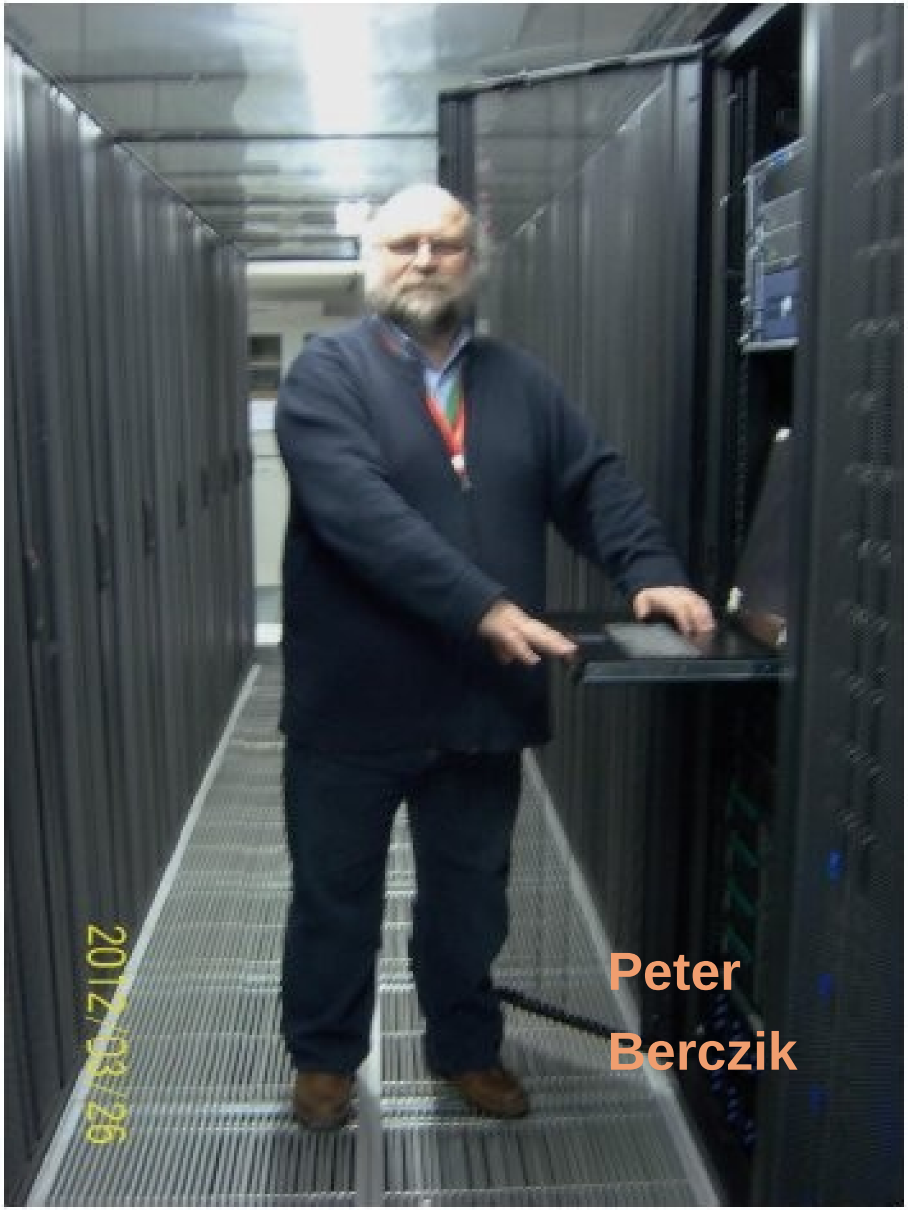
北京大学
PEKING UNIVERSITY

中国科学院国家天文台
NATIONAL ASTRONOMICAL OBSERVATORIES ,CHINESE ACADEMY OF SCIENCES



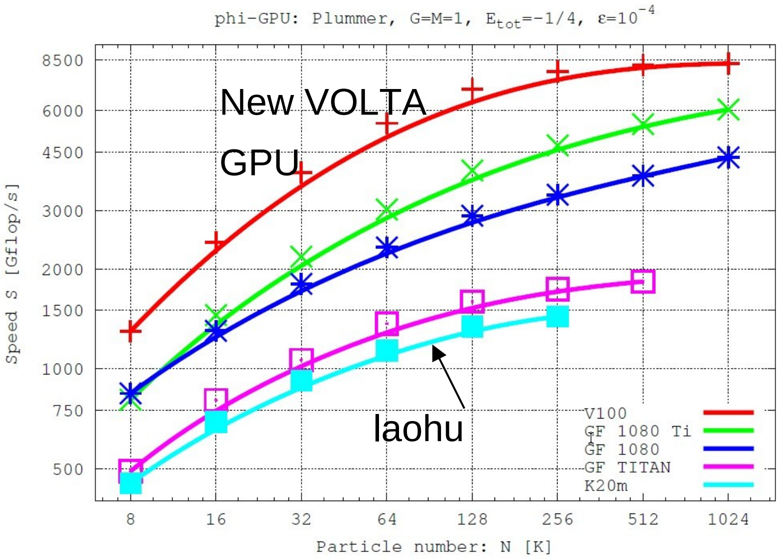
Douglas N.C. Lin,
Founding Director of
KIAA, Peking Univ.

2010 Beijing: NAOC laohu cluster 2015: 64 Kepler K20



Laohu: 2009/2015
(Kepler GPU)
100 Tflop/s 150k cores

New GPUs 5-6 times faster… (see below)



Top 10 List November 2010

From www.top500.org - list of fastest supercomputers in the world... ... last year Nov. 2010:

Rank	Site	System	
1	National Supercomputing Center in Tianjin China	**Tianhe-1A** - NUDT TH MPP, X5670 2.93Ghz 6C, NVIDIA GPU, FT-1000 8C NUDT	**GPU**
2	DOE/SC/Oak Ridge National Laboratory United States	**Jaguar** - Cray XT5-HE Opteron 6-core 2.6 GHz Cray Inc.	
3	National Supercomputing Centre in Shenzhen (NSCS) China	**Nebulae** - Dawning TC3600 Blade, Intel X5650, NVidia Tesla C2050 GPU Dawning	**GPU**
4	GSIC Center, Tokyo Institute of Technology Japan	**TSUBAME 2.0** - HP ProLiant SL390s G7 Xeon 6C X5670, Nvidia GPU, Linux/Windows NEC/HP	**GPU**
5	DOE/SC/LBNL/NERSC United States	**Hopper** - Cray XE6 12-core 2.1 GHz Cray Inc.	
6	Commissariat a l'Energie Atomique (CEA) France	**Tera-100** - Bull bullx super-node S6010/S6030 Bull SA	
7	DOE/NNSA/LANL United States	**Roadrunner** - BladeCenter QS22/LS21 Cluster, PowerXCell 8i 3.2 Ghz / Opteron DC 1.8 GHz, Voltaire Infiniband IBM	
8	National Institute for ... Sciences/University ... United States	**Kraken XT5** - Cray XT5-HE Opteron 6-core 2.6 GHz Cray Inc.	
9	Forschungszentrum Juelich (FZJ) Germany	**JUGENE** - Blue Gene/P Solution IBM	
10	DOE/NNSA/LANL/SNL United States	**Cielo** - Cray XE6 8-core 2.4 GHz Cray Inc.	

China Grabs Supercomputing Leadership Spot in Latest Ranking of World's Top 500 Supercomputers

Thu, 2010-11-11 22:42

MANNHEIM, Germany; BERKELEY, Calif.; and KNOXVILLE, Tenn.—The 36th edition of the closely watched TOP500 list of the world's most powerful supercomputers confirms the rumored takeover of the top spot by the Chinese Tianhe-1A system at the National Supercomputer Center in Tianjin, achieving a performance level of 2.57 petaflop/s (quadrillions of calculations per second).

NCSA director: GPU is future of supercomputing

by Brooke Crothers

A A Font size   Print   E-mail   Share   6 comments

Tweet 99   Share 25   2 Digg

The director of the National Center for Supercomputing Applications has seen the future of supercomputing and it can be summed up in three letters: GPU.

Thom Dunning, who directs the NCSA and the Institute for Advanced Computing Applications and Technologies at the famed supercomputing facilities on the campus of University of Illinois at Urbana-Champaign, says high-performance computing will begin to move toward graphics processing units or GPUs. Not coincidentally, **this is exactly what China has done to achieve the world's fastest speeds with its "Tianhe-1A"** supercomputer. That computer combines about 7,000 Nvidia GPUs with 14,000 Intel CPUs: the only hybrid CPU-GPU system in the world of that scale.

Thom Dunning directs the Institute for Advanced Computing Applications and Technologies and the NCSA.

"What we're really seeing in the efforts in China as well as the ones we have in the U.S. is that GPUs are what the future will look like," said Dunning in a phone interview Thursday. "What we're seeing is the beginning of something that's going to be happening all over the world."

NCSA already has a small CPU-GPU hybrid system. "It's something we have been working on for a number of years. We have a CPU-GPU cluster for the NCSA academic community. Made up of Intel CPUs and Nvidia GPUs. A 50 teraflop machine," he said. (Note that **Oak Ridge National Laboratories is also installing a hybrid system now**.)

LUMI

Supercomputer, Kajaani, Finland

Using only

Hydroelectric

Power and its

Heat used for heating buildings.

No. 3 in top500

No. 7 in green500

2.2 million cores

10.000 AMD GPUs

EuroHPC and LUMI consortium:

Finland, Belgium, Czech Republic, Denmark, Estonia, Iceland, Norway, Poland, Sweden, and Switzerland.

NBODY6++GPU with up to 16M particles

(Benchmarks on raven at MPCDF)

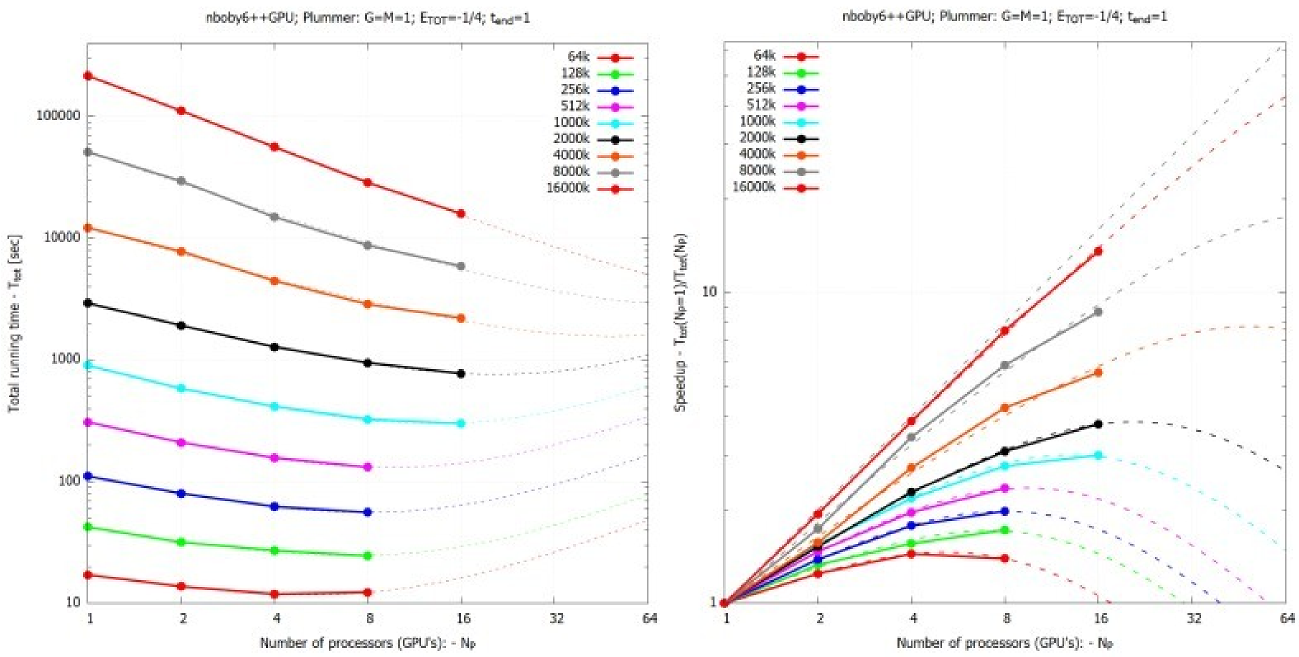


Figure 6: Benchmark results and extrapolated scaling for NBODY6++GPU, initial Plummer model, on the raven cluster at MPCDF, see main text. **Left:** Total time for one NBODY model unit in secs; **Right:** Speed-Up compared to using one GPU only. In both cases different curves for particle numbers from 64k to 16m. Ideal Speedup is the diagonal dashed lines, other dashed lines extrapolations from the timing model.

DRAGON I Simulation

Wang, Spurzem, Aarseth, et al. 2015, 2016

DRAGON II Simulation

Arca Sedda, Kamlah, Spurzem, et al. 2023, 2024ab

http://silkroad.zah.uni-heidelberg.de/dragon/

https://github.com/nbody6ppgpu

Also in: https://www.punch4nfdi.de/

MNRAS, 2015

The Future - DRAGON III 1m – 8m (16m?)

Only few models, 6-12 months

Request for Comments, Feedback, Initial Conditions: Call will go out, or contact

spurzem@ari.uni-heidelberg.de spurzem@nao.cas.cn

- Globular Cluster (GC) Simulations: Init. Density, IMF, Binaries (wide?), Rotation, Populations, Tides, GC orbit, specific clusters, …
- Nuclear Star Cluster (NSC) Simulations: add TDE, EMRI, direct capture, partial TDE, partial accretion to SMBH.

Silk Road Meeting at Xi’an Jiaotong Liverpool University (XJTLU) Suzhou November 2023

Instead of Summary:

Ongoing work ...

Silk Road Impressions

International Meeting on Black Holes and Grav. Waves
Beijing

M. Giersz/R.Spurzem/S.Aarseth

Heidelberg: Work Meeting with team of Kazakhstan