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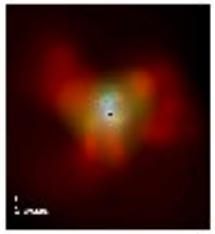
ACCELERATION OF NBODY6++ AND LARGE N-BODY SIMULATION OF GLOBULAR CLUSTERS

Our Main Research Projects are:

- Binary Supermassive Black Holes and Gravitational Waves in Quiet and Active Galactic Nuclei


- Dynamical Evolution of Stars and Gas in Galactic Nuclei and Dense Star Clusters
- How are planetary systems forming and evolving (in star clusters)?
- How can we design supercomputers which are faster and consume less energy?


- Education and Workshops in Computational and Theoretical Astrophysics, Parallel Programming and Accelerated Computing

China Funding (Government and Chinese Academy of Sciences):
6 m.Y hardware
2 m.Y 2009-12
5 m.Y 2013-15
13 m. Y =
1.5 m. €

the SILK ROAD PROJECT at NAOC

中国科学院国家天文台

National Astronomical Observatories, CAS

丝绸之路 计划

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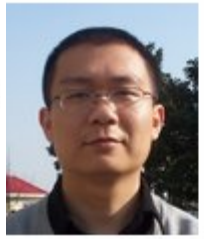

Lei Liu

Graduate student at:

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Senior Silk Road Project Postdoc

Thijs Kouwenhoven

Bairen research professor at KIAA

千人計畫

RECRUITMENT PROGRAM OF GLOBAL EXPERTS

北京大学

PEKING UNIVERSITY

Simulation of globular clusters

- Globular cluster (GC)
  - Age >10Gyr
  - $T_{rh} \geq 1$Gyr
  - $M \geq 10^5 M_{\odot}$
- Close encounters & binaries
- Monte-Carlo simulation (MOCCA)
  - Very fast
- Direct N-body simulation (Nbody6(++))
  - Less assumption, full information

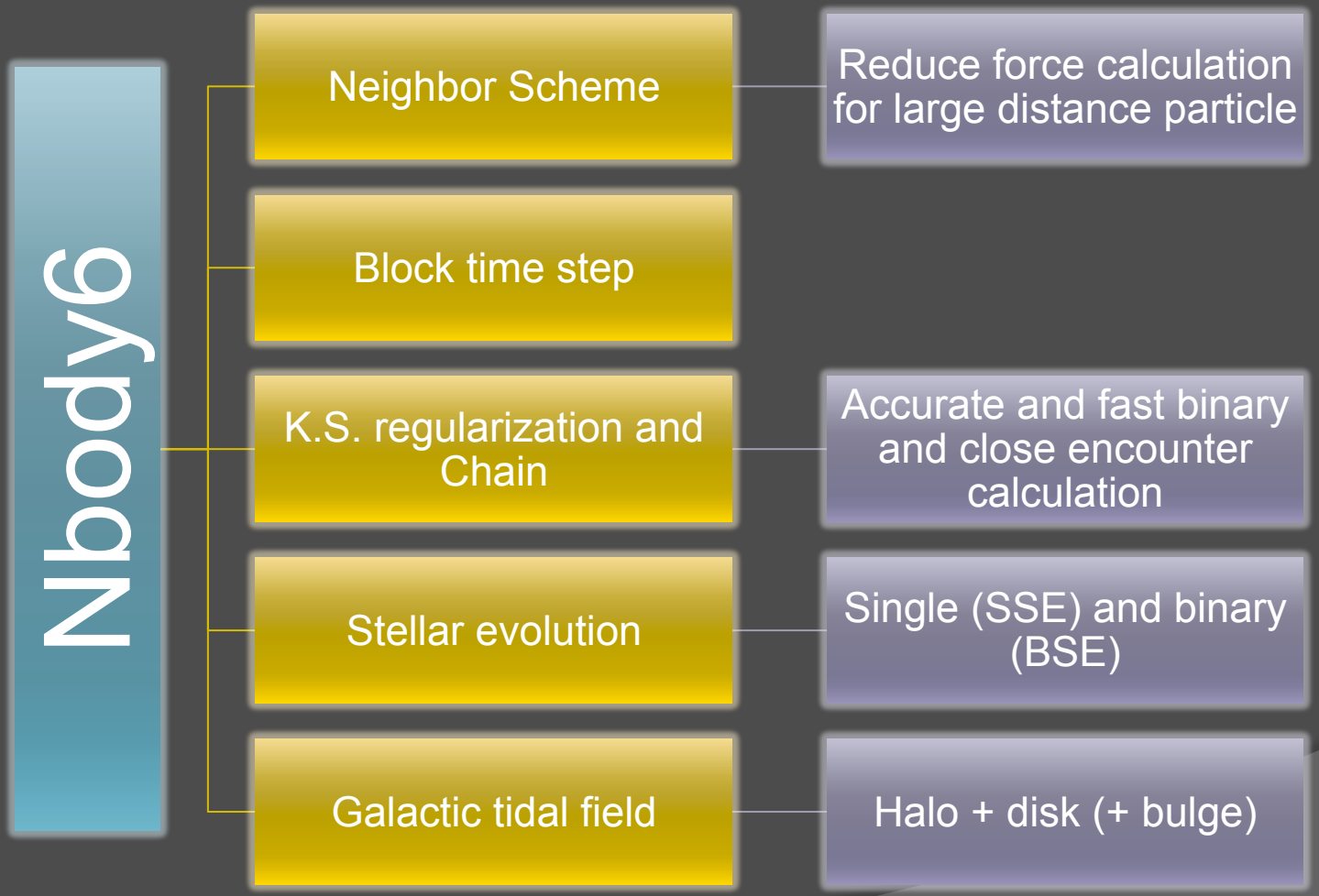
Direct N-body GC simulation

- $N \geq 10^6$
  - Not large N for parallel
  - 32~64 Nodes with GPU
- R_h~2-6pc
  - Short relaxation, binaries, close encounters
  - Challenge computing accuracy and speed
- Age~12Gyr
  - Small time scaling: ~0.1Myr/1NB time unit (NBT)
  - Very long time simulation

Direct N-body GC simulation

- Previous largest N:
  - 200k (195k single stars + 5k binaries) (Hurley, 2012)
    - Nbody4 with GRAPE-6
  - 500k (Douglas C)
- We want to reach N = 10^6
  - Initial mass ~ 5×10^5 $M_\odot$ (Kroupa 3-components IMF)

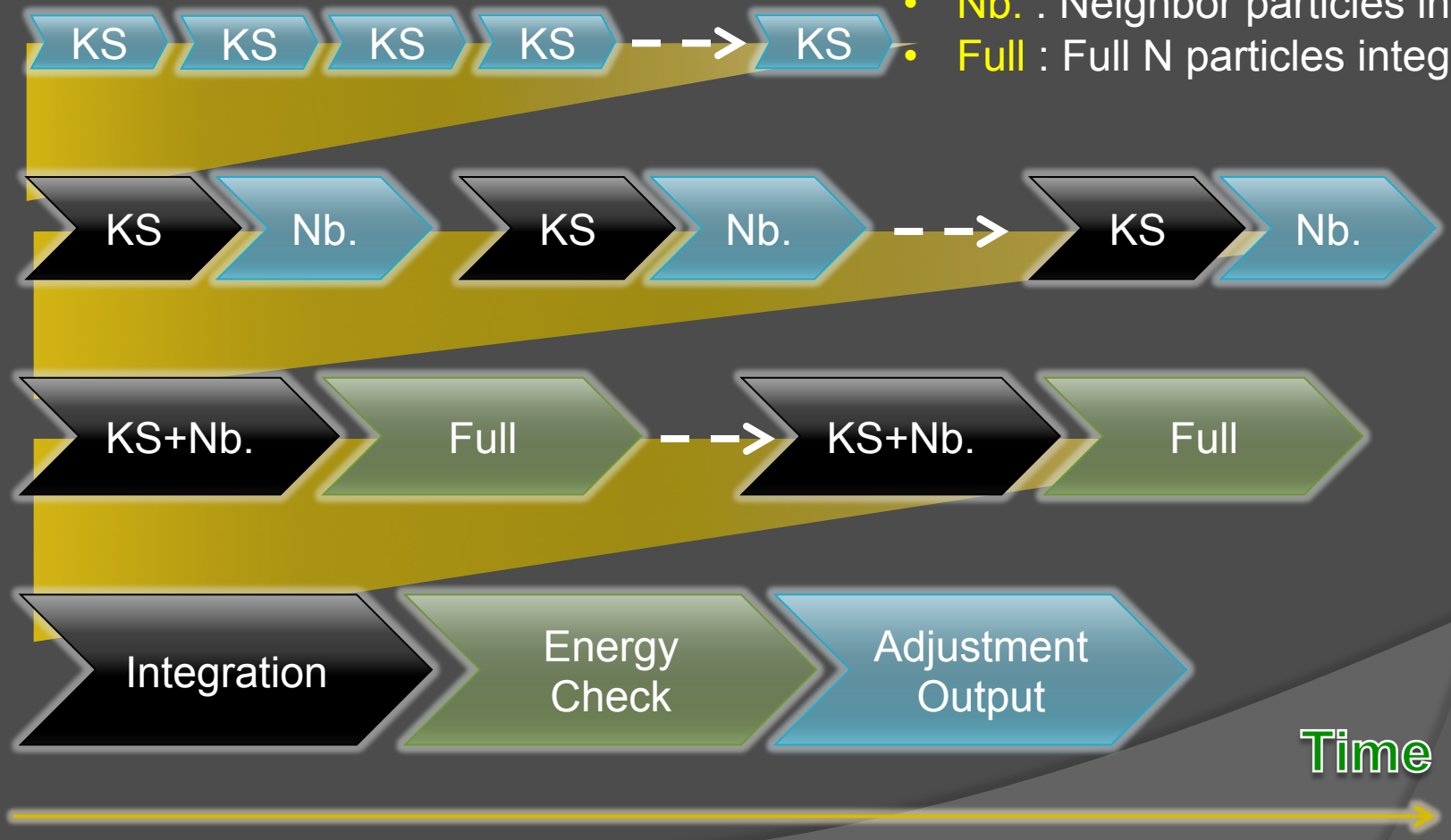
Direct N-body code – Nbody6(++)



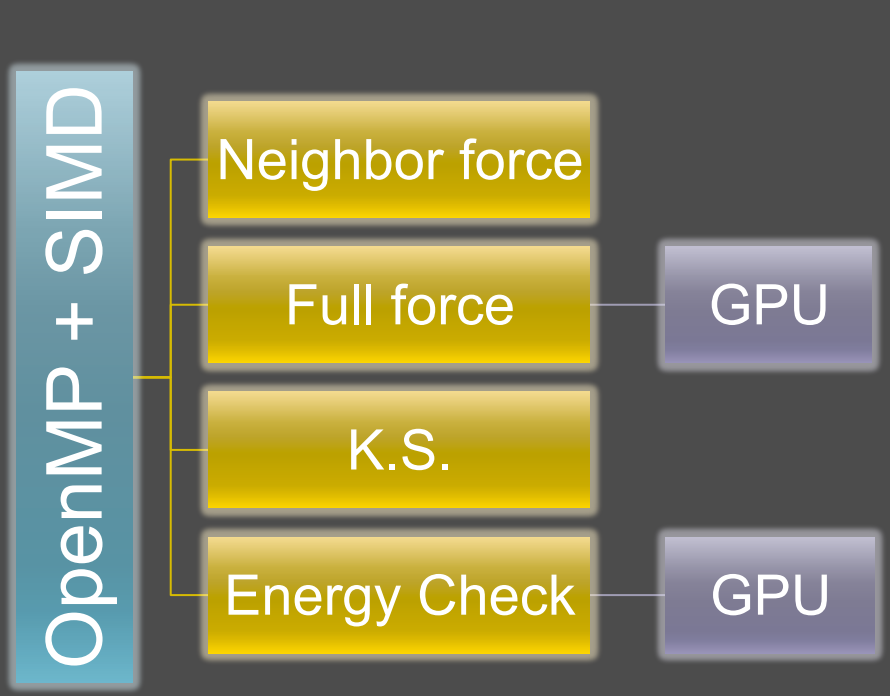
Nbody6(++) Structure

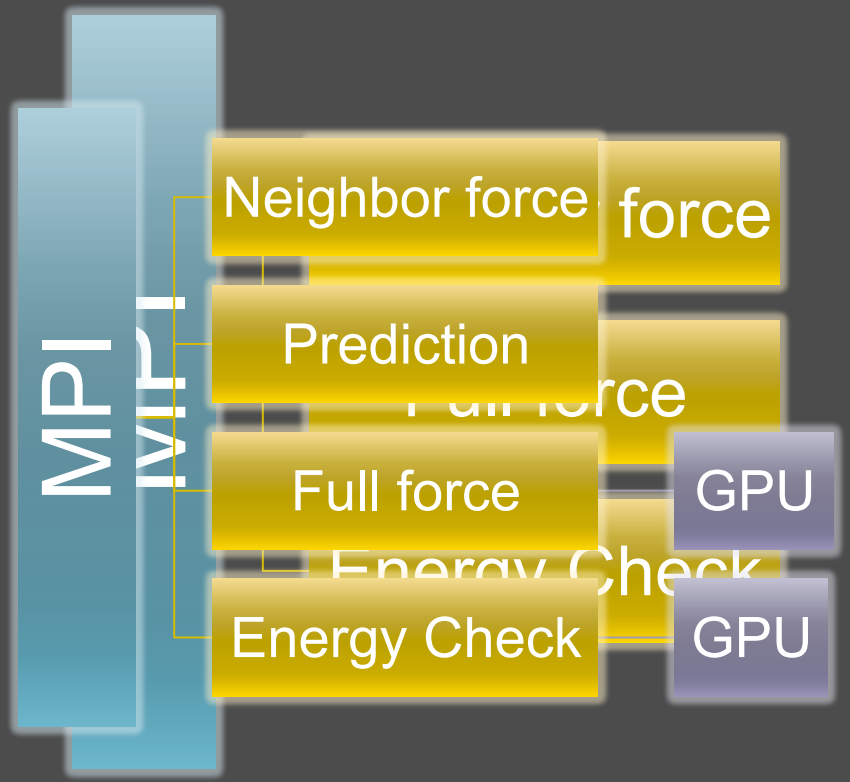
- Hierarchical Block steps

- KS : Binary & Close encounters
- Nb. : Neighbor particles integration
- Full : Full N particles integration



Nbody6.GPU and Nbody6++

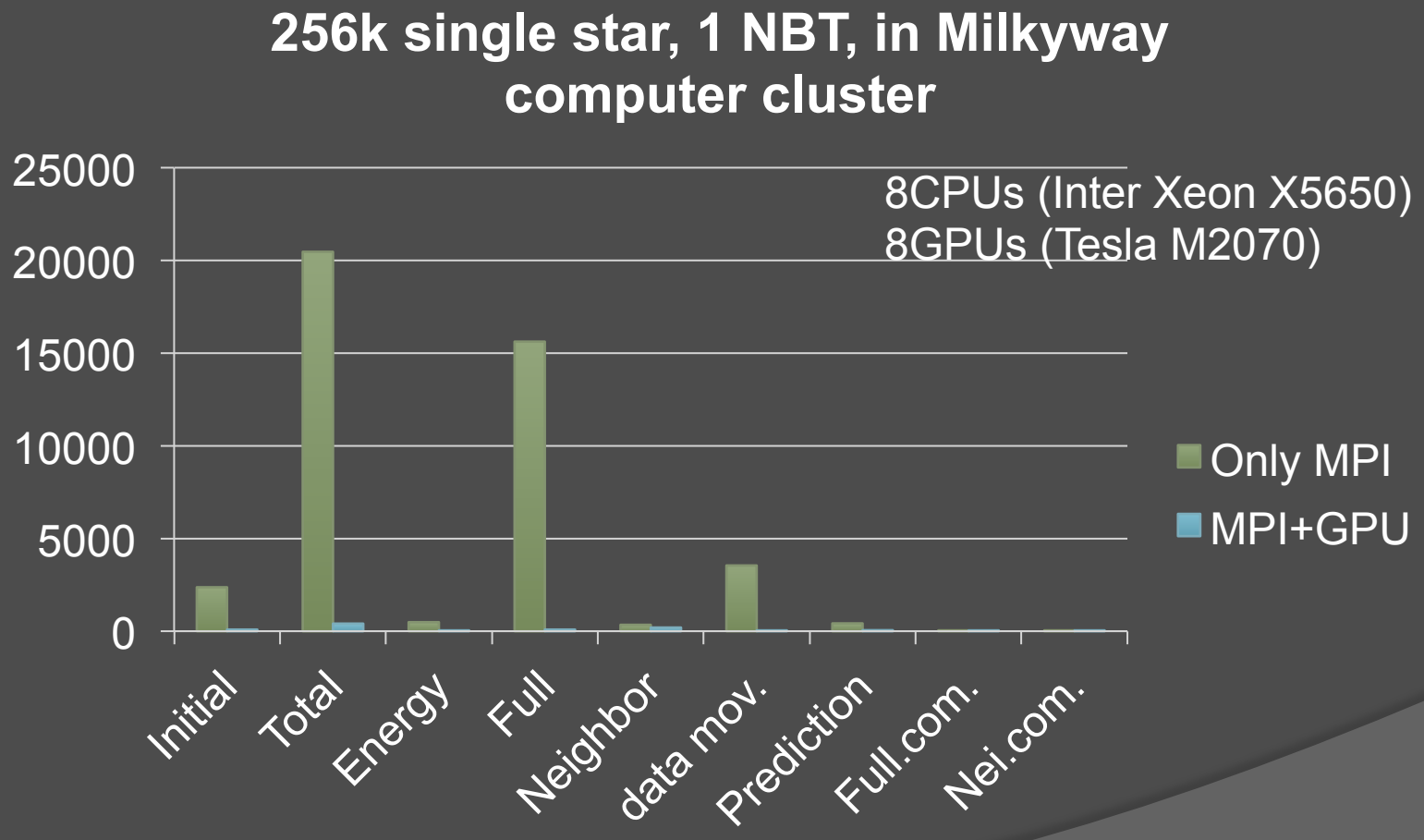




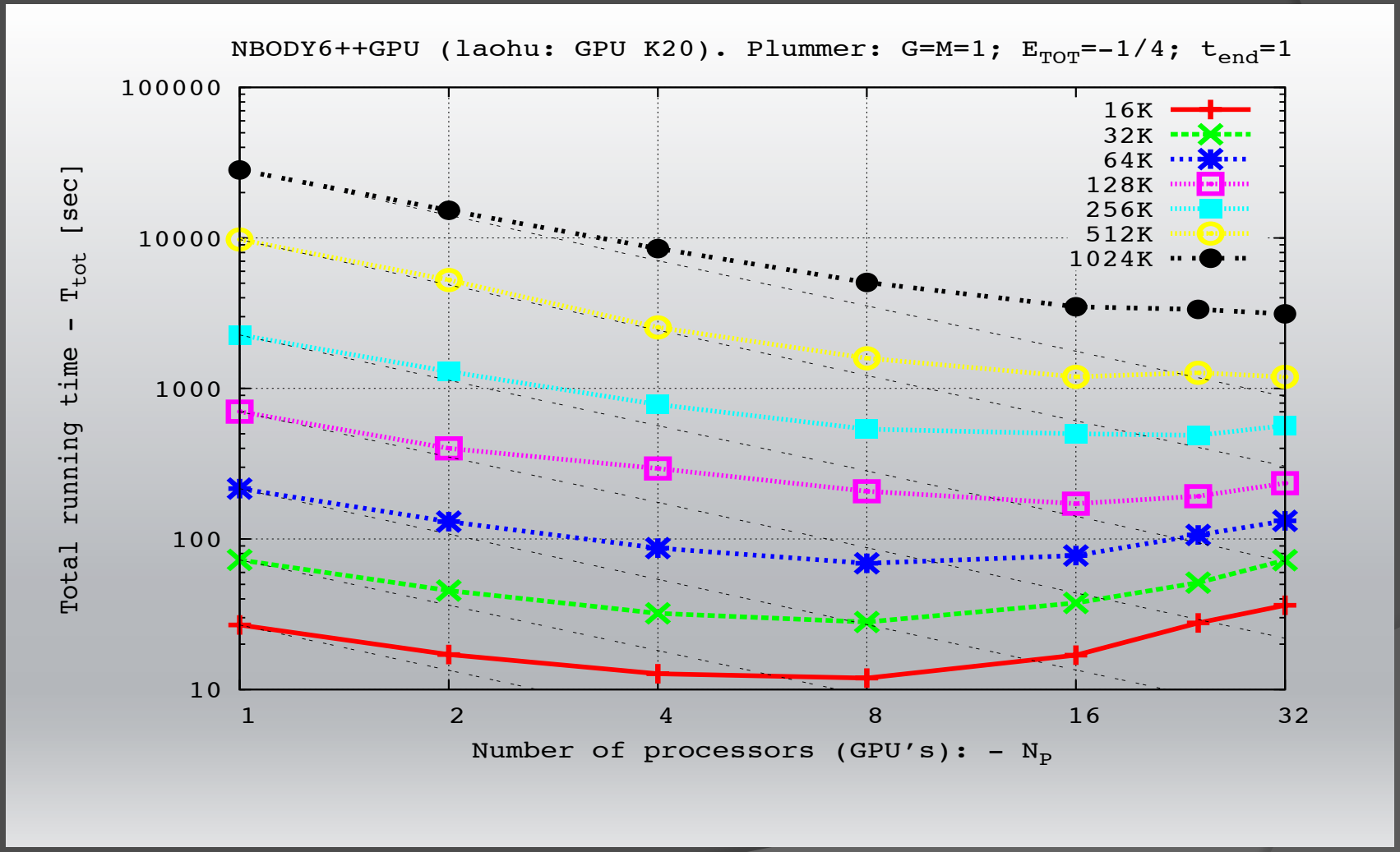
Nbody6.GPU (Nitadori & Aarseth, 2012)
For Desktop or Warkstation (~10^2 x speed up, N~10^5)

Nbody6++ (Spurzem)
For Computer Cluster
($N_{proc.}$ x speed up, N~10^4)

GPU acceleration is dramatic

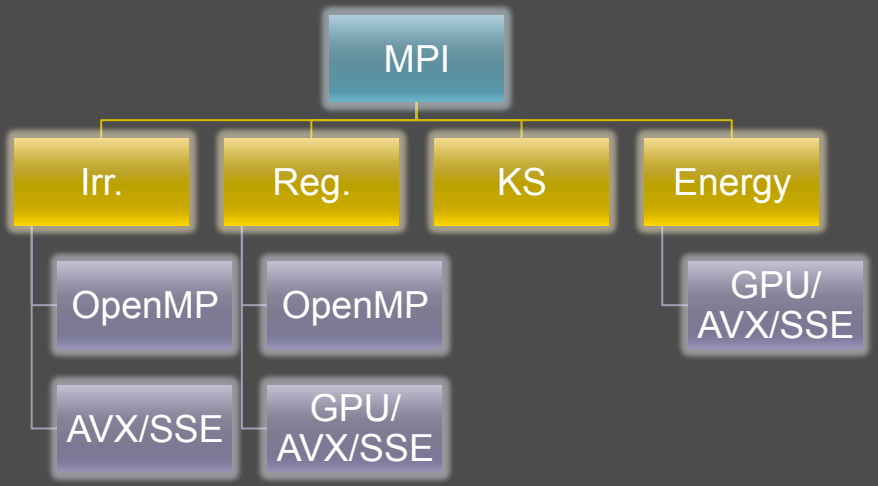


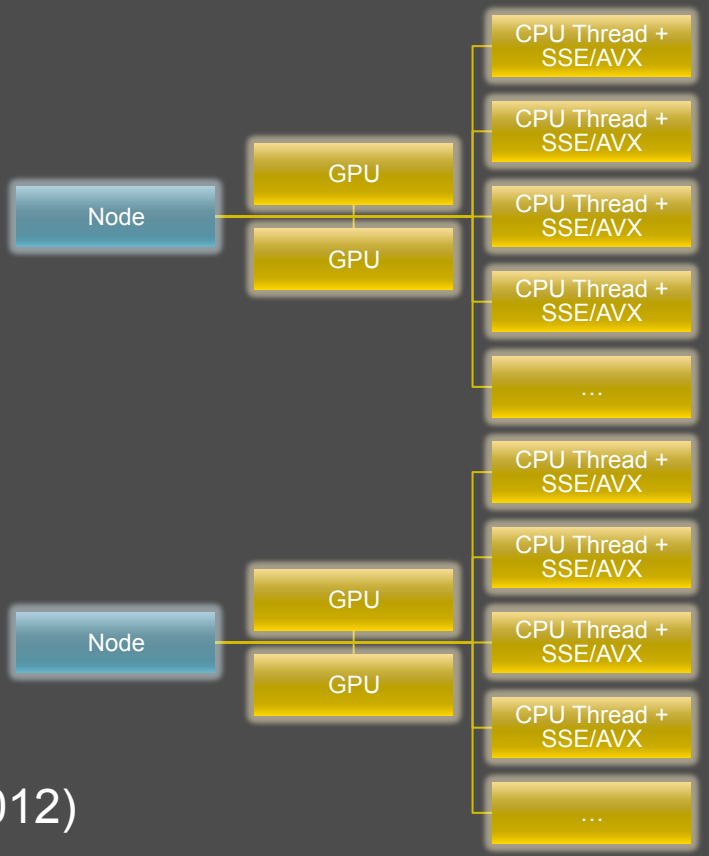
Benchmark of MPI+GPU



Nbody6++ Hybrid MPI + GPU + SIMD

Hybrid MPI (MPI + OpenMP)



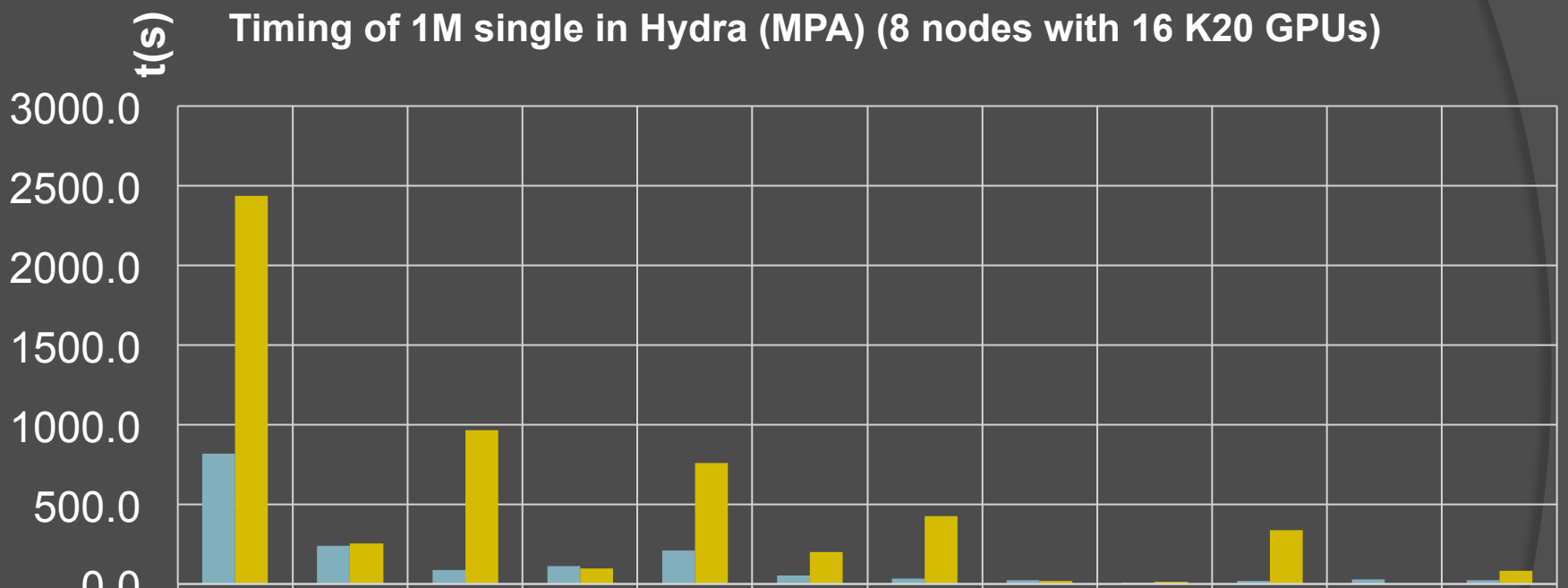


GPU, AVX/SSE Library (Nitadori & Aarseth, 2012)

Code parallelization structure

Assignment

14min/NBT for N = 1M with Hybrid MPI +GPU+ SIMD

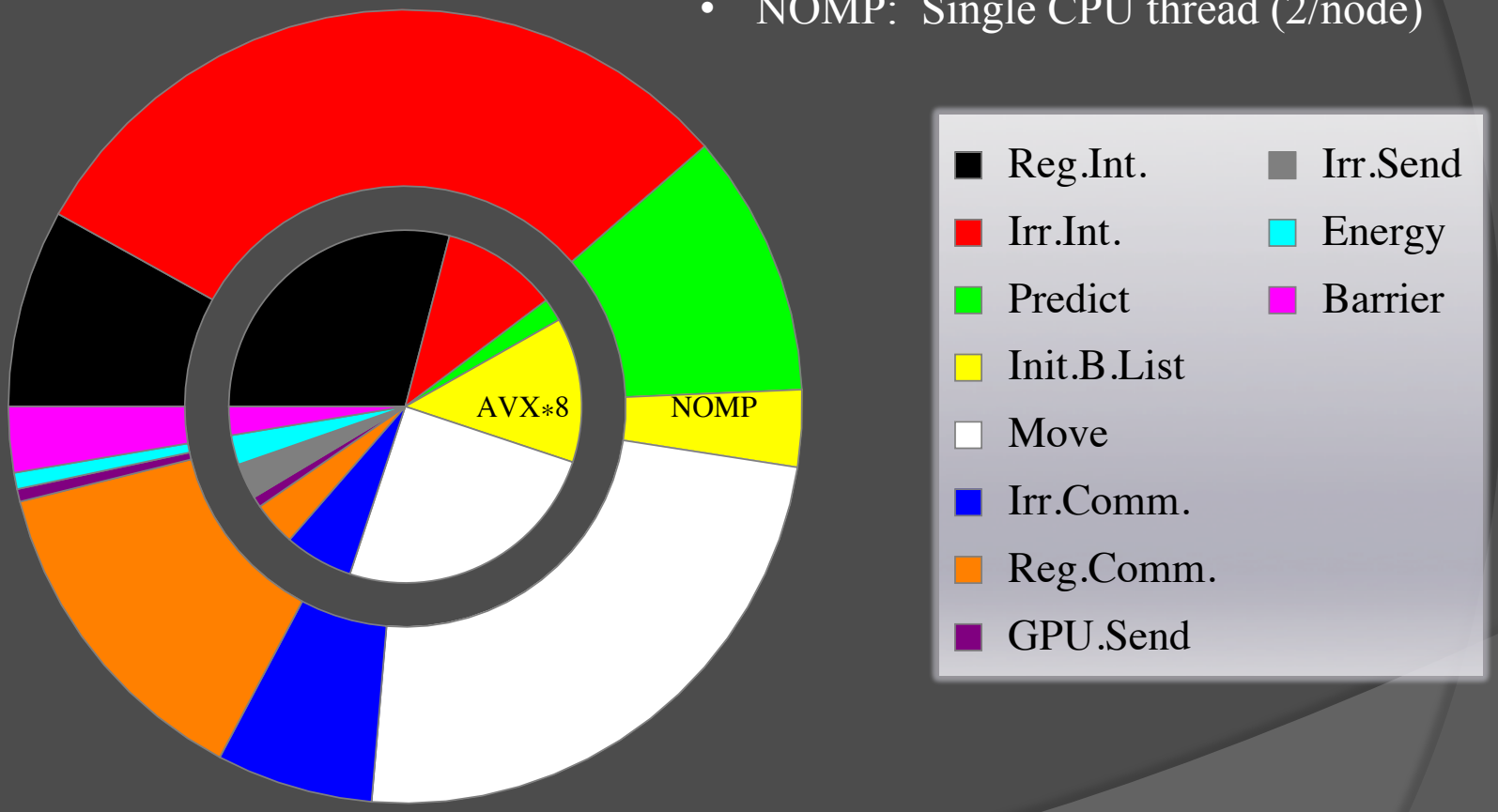


	Total	Full	Nb.	Init.B. List	Move	Nb.Comm.	Full.Comm.	Energy	GPU.Send	Predict	Nb.Send	Barrier
AVX*8	819.5	242.1	89.0	110.8	208.2	52.5	33.6	22.7	8.2	17.5	27.3	21.8
NOMP	2437.2	255.6	967.7	99.2	757.3	202.3	424.7	21.1	16.3	339.3	0.0	84.8

Timing fraction

1M single star
8 nodes (16 K20 GPUs) in Hydra

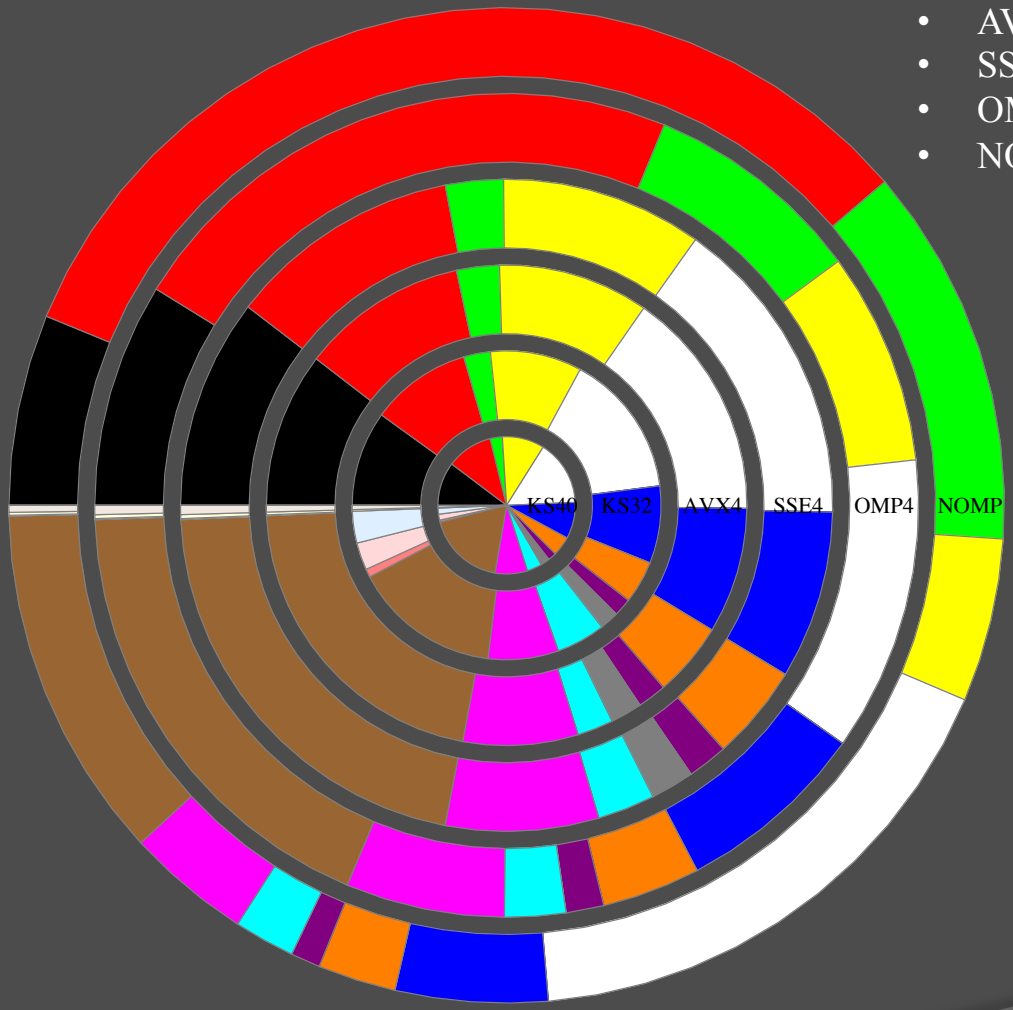
- AVX*8: 16 CPU Threads/node + AVX
- NOMP: Single CPU thread (2/node)

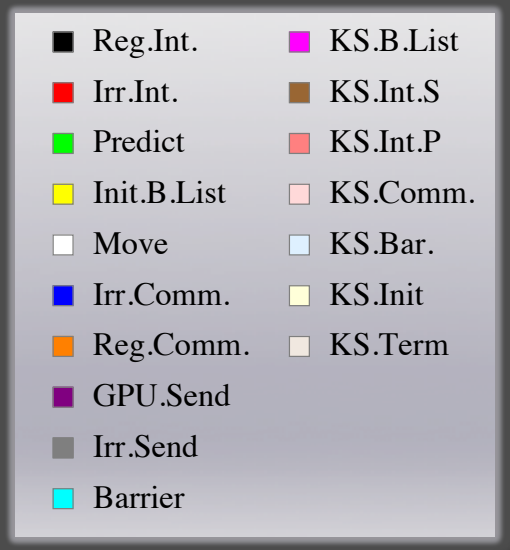


Timing fraction

231k single + 25k binaries
8 nodes (8 K20 GPUs) in Kepler

- KS40: Parallel KS (>40)
- KS32: Parallel KS (>32)
- AVX4: 4 CPU Threads/node + AVX
- SSE4: 4 CPU Threads/node + SSE
- OMP4: 4 CPU Threads/node
- NOMP: Single CPU thread/node

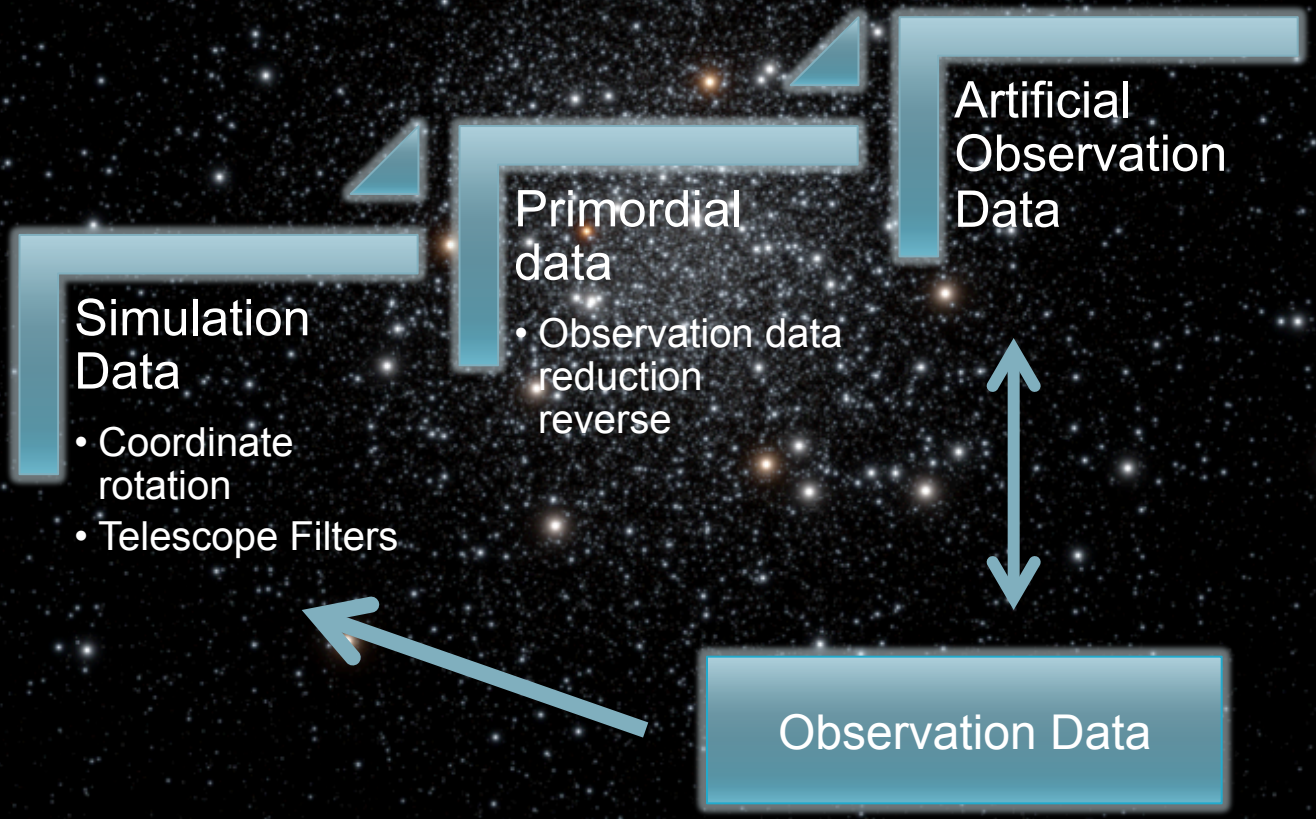




IM-body GC simulation

- NGC 4372 (Wang, Spurzem, Giersz, Berczik & Aarseth …)
  - Current mass ~ 2.5E5 $M_\odot$
  - R_h ~ 6 pc
- Initial model:
  - N=10^6 (950k single stars with 50k binaries)
  - Binary:
    - Log uniform distribution of binary semi-major axis
      - 5E-3 ~ 5E1 AU
    - Thermal distribution of eccentricity
  - Kroupa 3-component IMF (0.08 $M_\odot$ – 100 $M_\odot$)
  - Test with MOCCA (Giersz)

Transformation script (Askar, Giersz, Pych & Wang)



Simulation ≈ Observation

N = 1 M
T ~ 6 Myr
Filter:
- B -> Blue
- V -> Green
- I -> Red

PSF: Moffat
Generated by Ds9

Summary

- New Nbody6++ with parallel Hybrid MPI (MPI+OpenMP) + GPU +SIMD (AVX/SSE)
  - 14 min/NBT for N = 1M single star with 8*16 CPUs + 16 GPUs
- Prepare 1M GC simulation
  - NGC 4372
- Transformation from simulation data to observation data