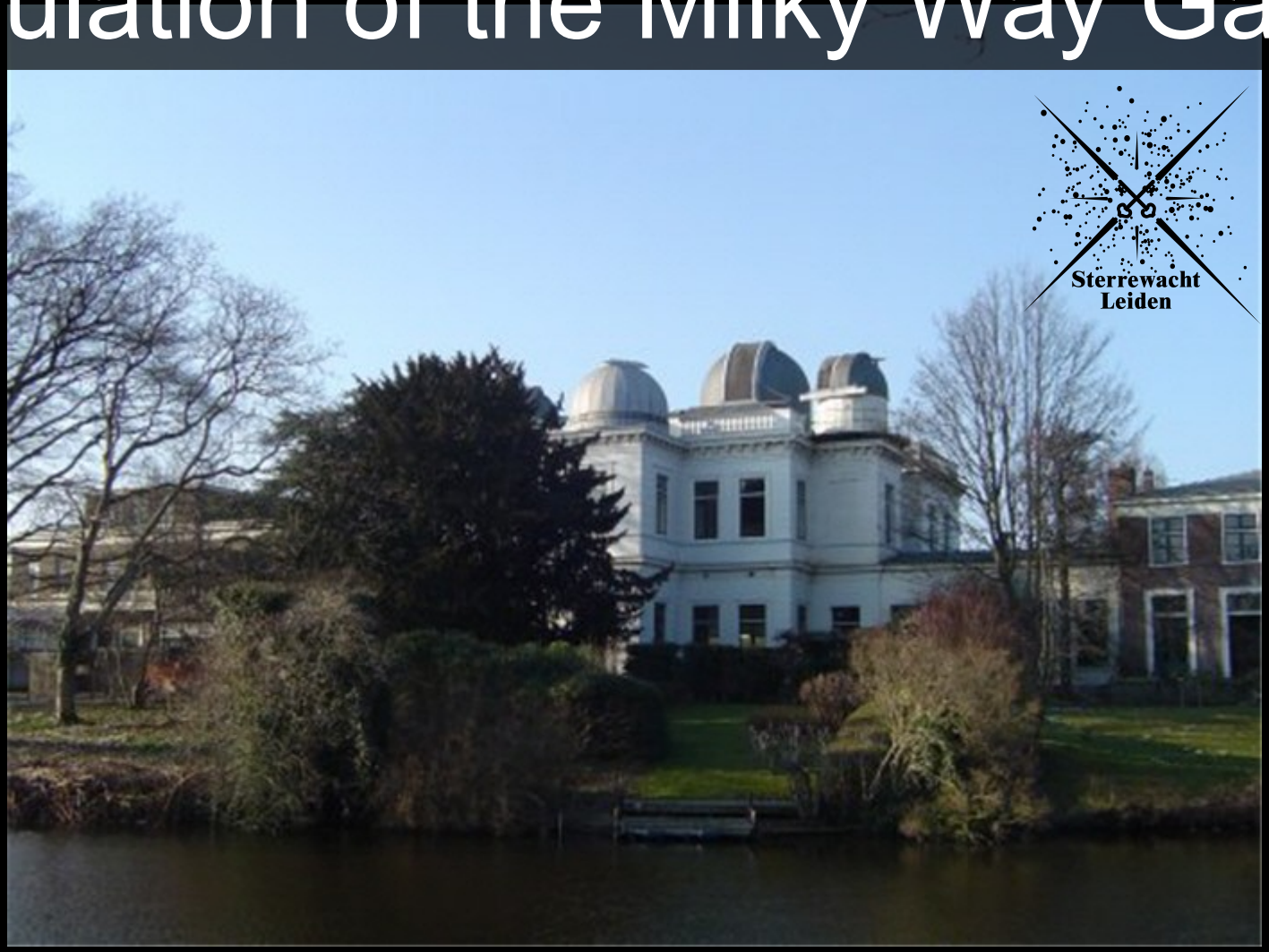
Massive Parallel GPU-accelerated Simulation of the Milky Way Galaxy

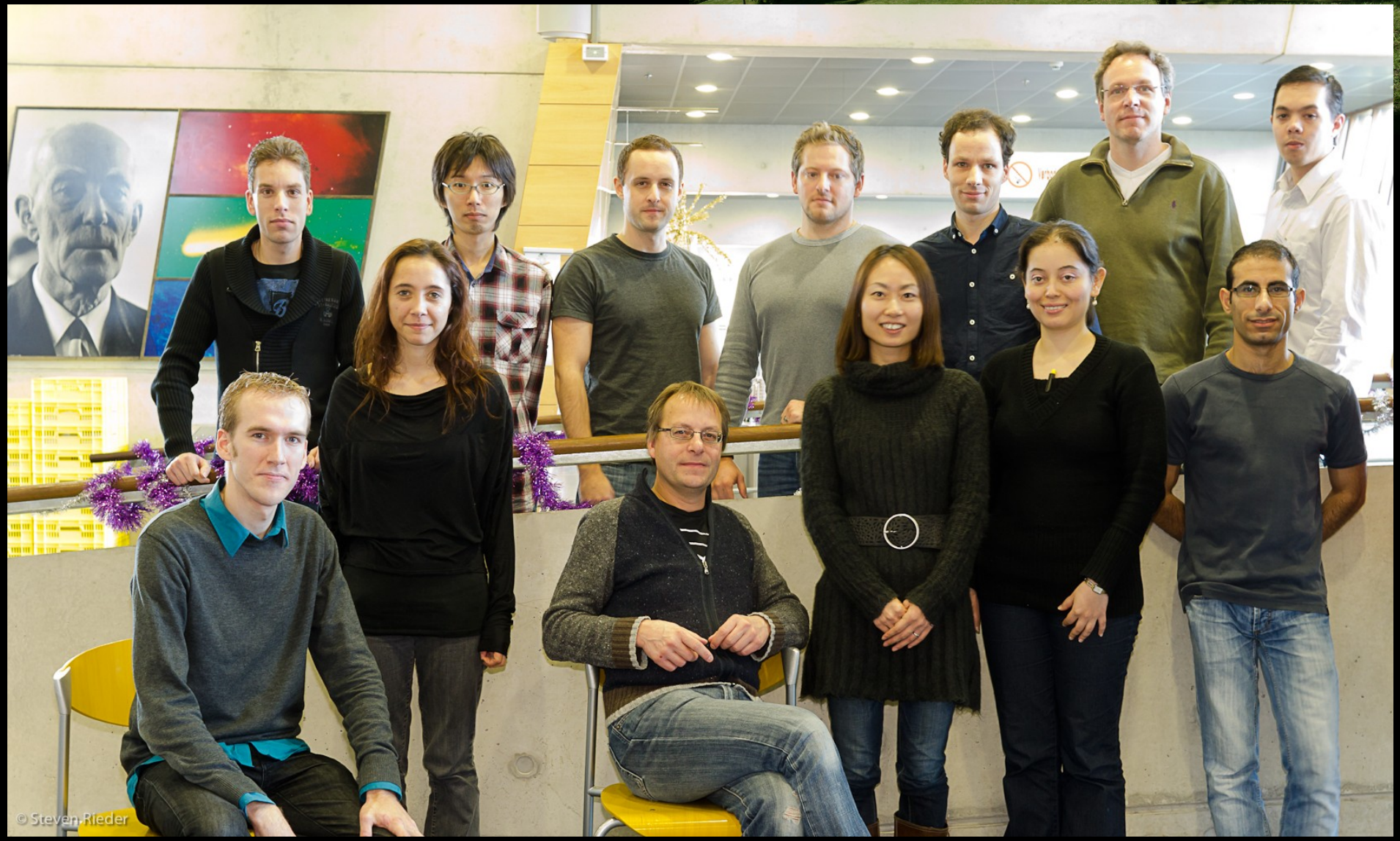


Simon Portegies Zwart

1608 Lippershey

For the last 400 years
telescopes became larger

CAStLe group



Computational Astrophysics and Cosmology

Open Access Springer Journal

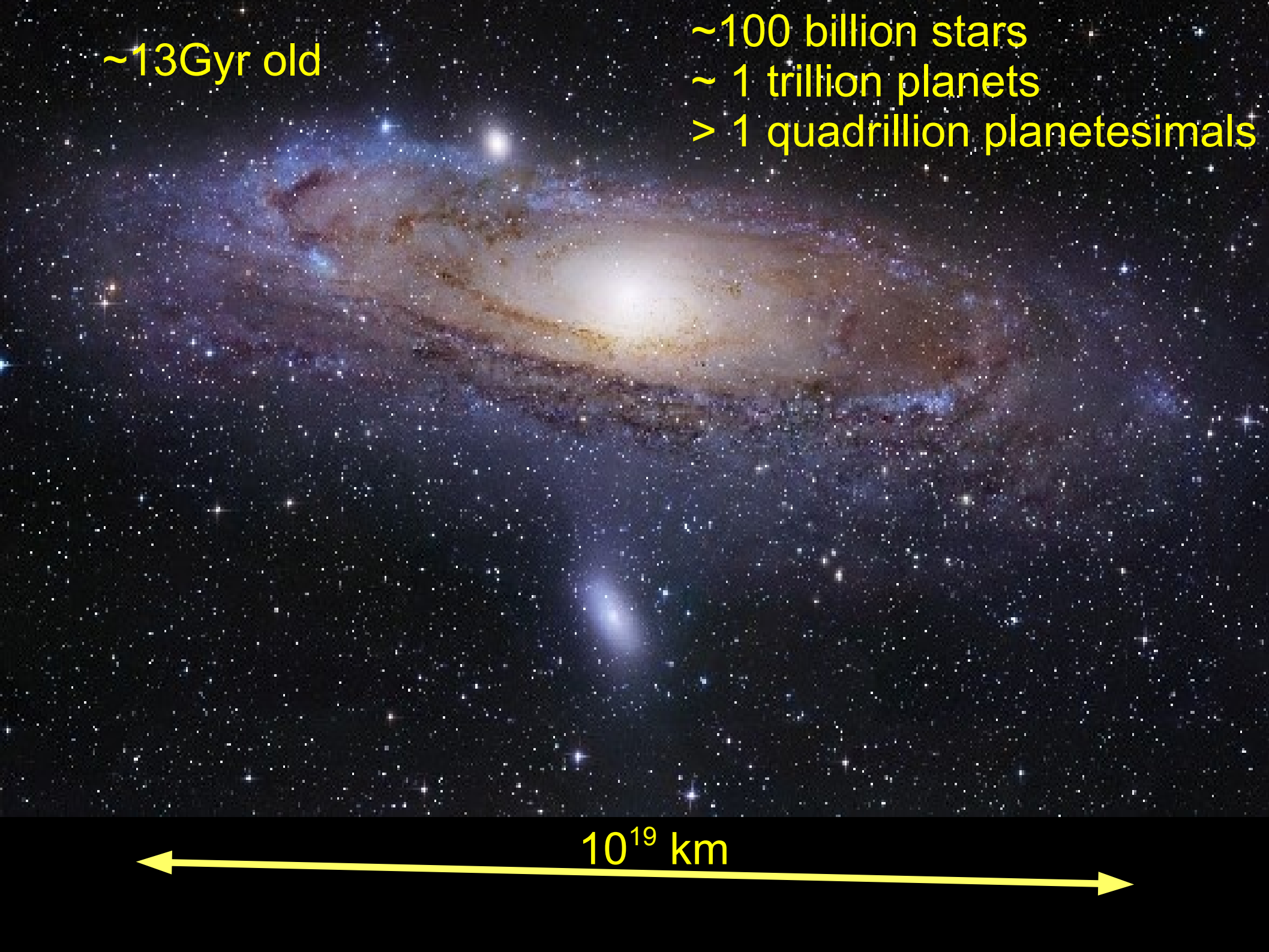
CompAC publishes paper on

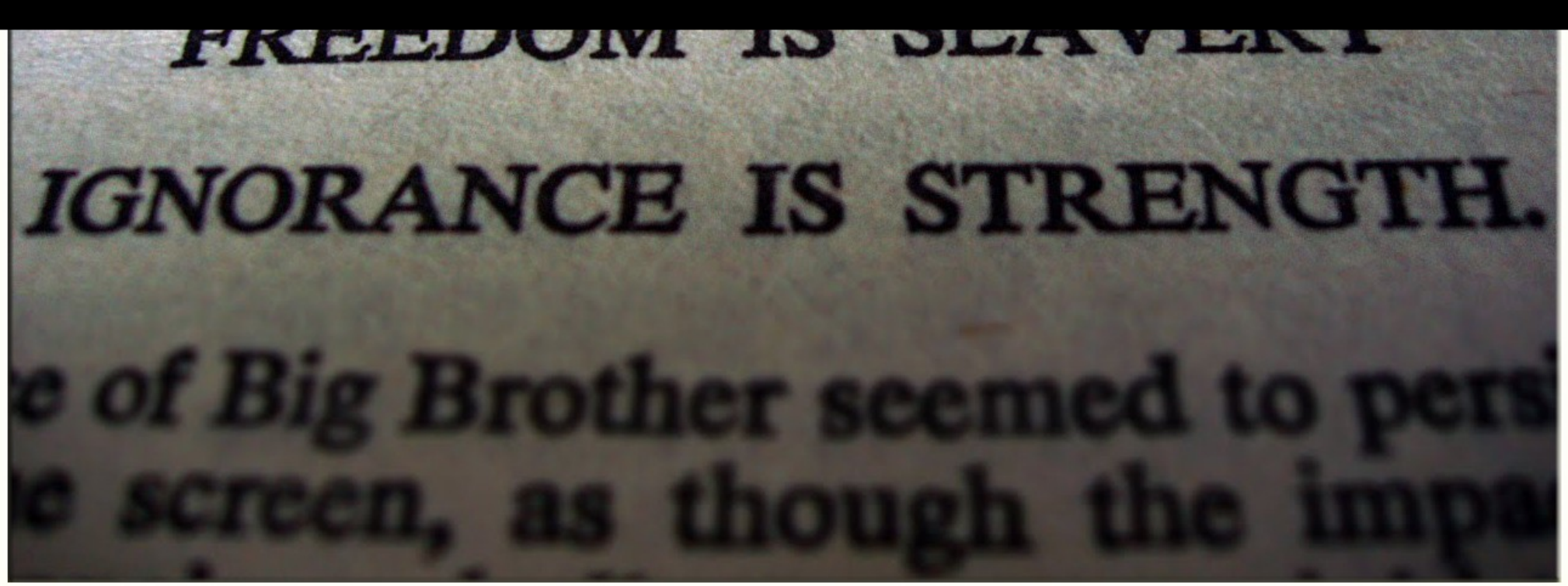
- **Astronomy, physics and cosmology**
- **Computational and information science**

The combination of these two disciplines leads to a wide range of topics which, from an astronomical point of view covers all scales and a rich palette of statistics, physics and chemistry. Computing is interpreted in the broadest sense and may include hardware, algorithms, software, networking, data management, visualization, modeling, simulation, visualization, high-performance computing and data intensive computing.

The Pillars of Science


~4.5Gyr old
13,000km
360,000km away

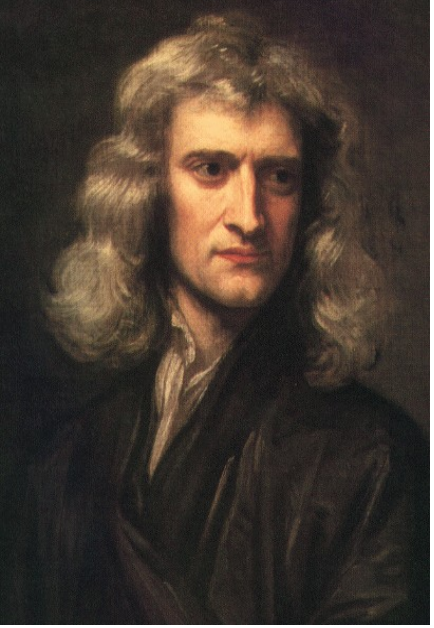

~13Gyr old
~100 billion stars
~ 1 trillion planets
> 1 quadrillion planetesimals
10^{19} km



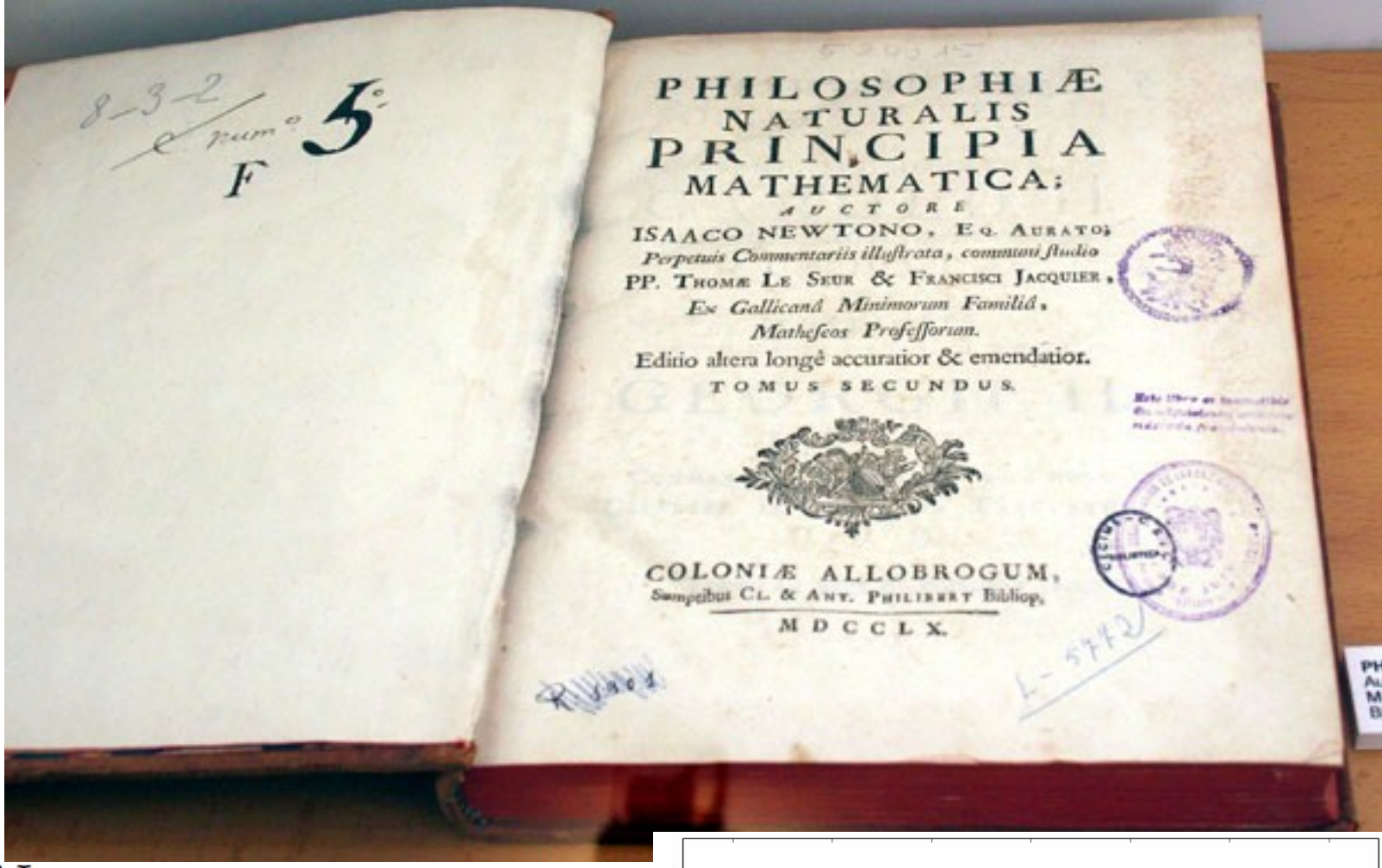
we ignore:

- The rest of the universe (our galaxy is isolated)
- The interstellar gas (~15% of the Galactic mass)
- Magnetic fields
- The evolution of the stars
- The prescence of planets and planetesimals
- The Human population (and any other form of life)

We ignore everything, except...



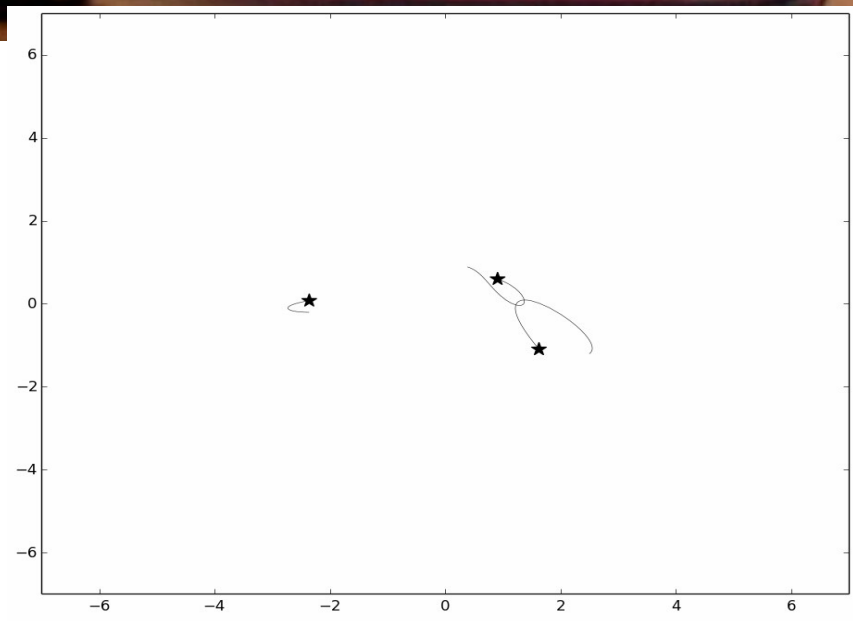
1642-1727



$$\vec{F}_i = -\sum_{j=1, j\neq i}^{N} \frac{m_i m_j}{|\vec{r}_i - \vec{r}_j|^2} \vec{e}_{ij}$$

"These equations have an appealing--if deceptive--simplicity"

Lyman Spitzer, Jr



Gravity's complexities

- Gravity has a negative heat capacity. As a consequence, our daily experience is not trained to appreciate the complexities of gravity.

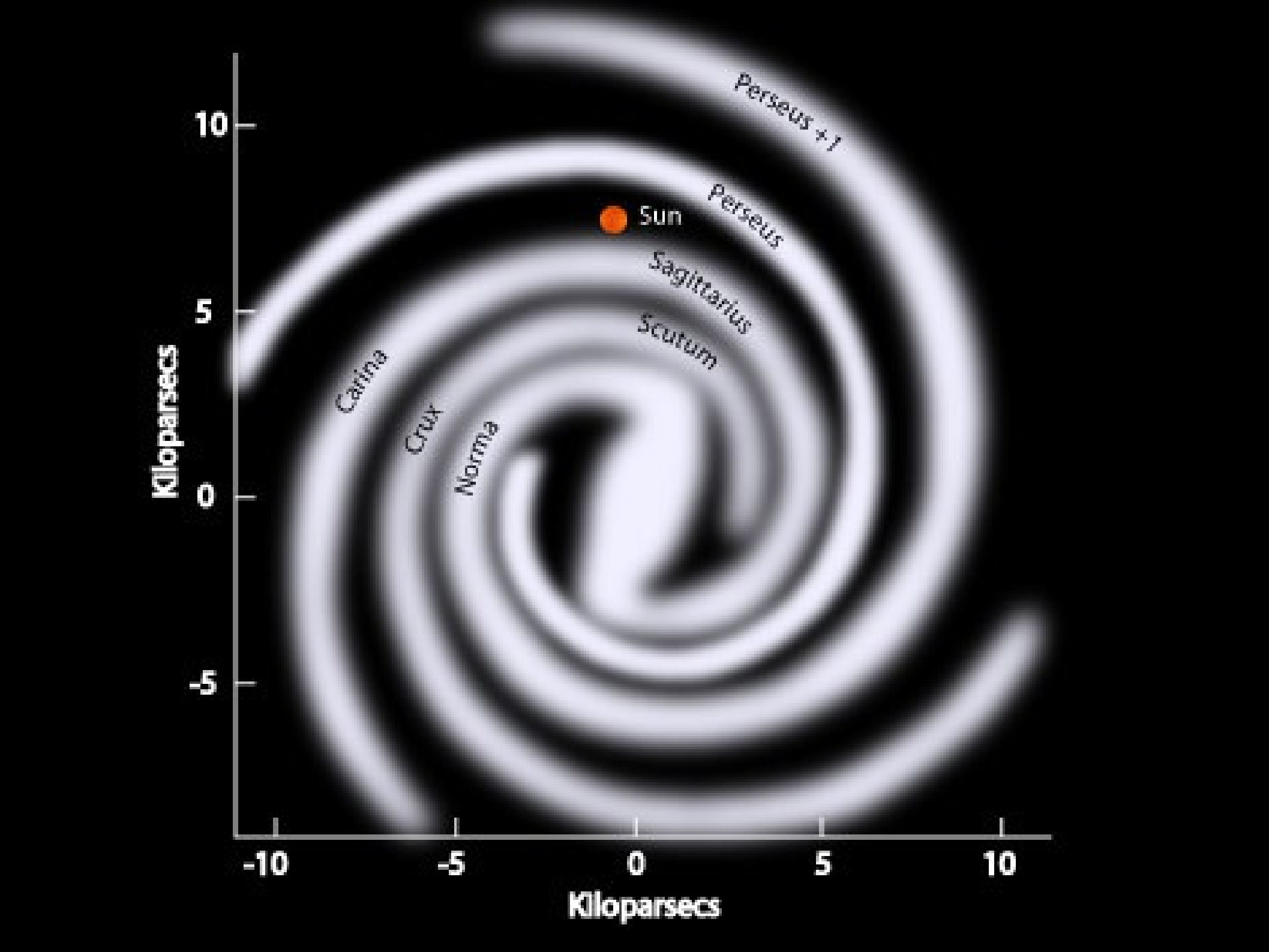
- The force calculation is an N*N operation.

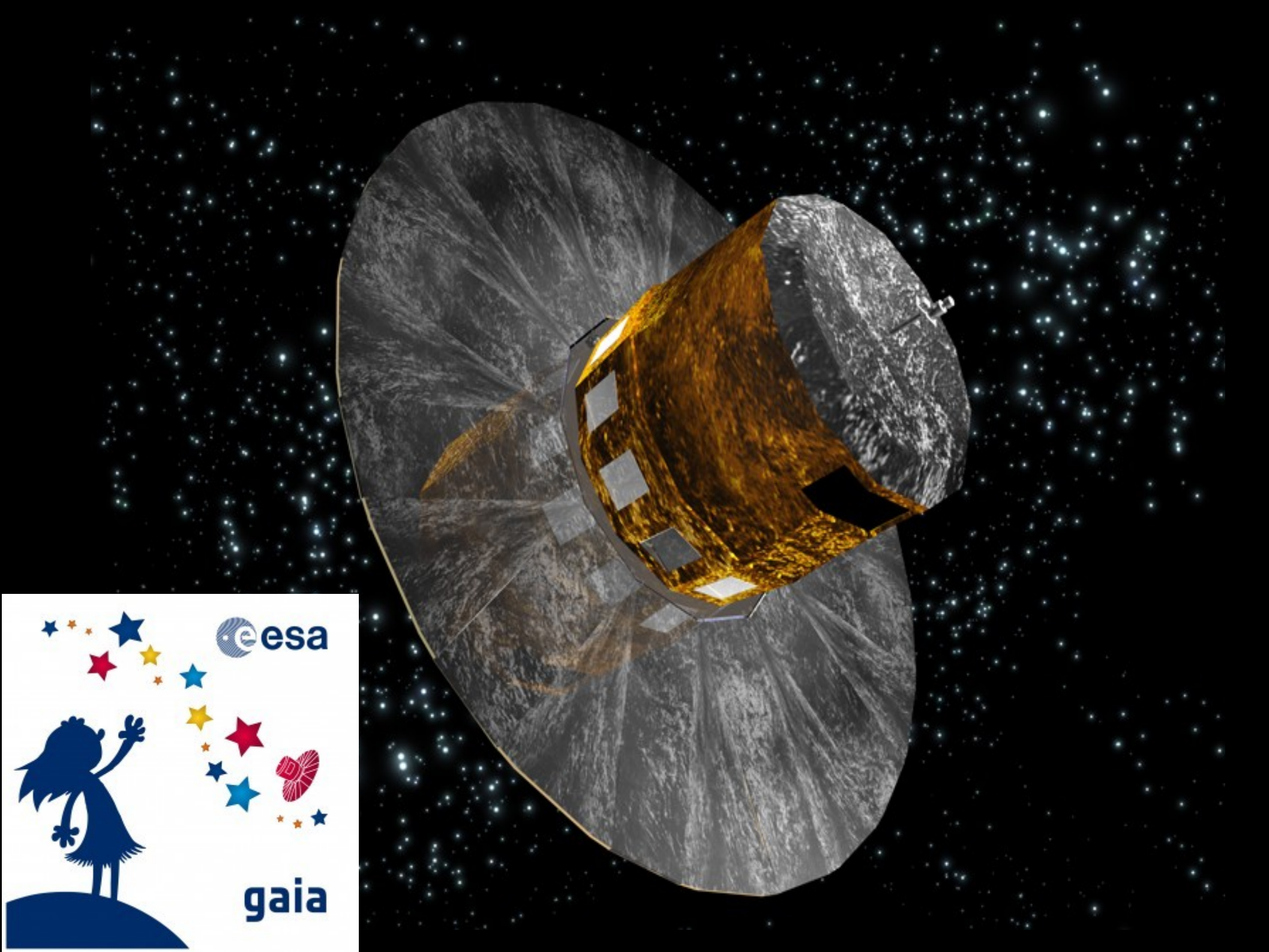
- There is no shielding in gravity, such as in molecular dynamics: the system is global-aware.

- At small distances the main driving force (gravity) grows limitless.

- The equations of motion are intrinsically chaotic.


N_{stars} ~ 100,000,000,000
$N_{interactions}$ ~ 10,000,000,000,000,000,000,000
N_{steps} ~ 100,000
N_{flops} ~ 10,000,000,000,000,000,000,000,000,000
yotta
zetta


Perseus +1
Perseus
Sun
Sagittarius
Scutum
Carina
Crux
Norma
10
5
0
-5
Kiloparsecs
-10
-5
0
5
10
Kiloparsecs


esa
gaia

THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME 94 NOVEMBER 1941 NUMBER 3

1908-200

ON THE CLUSTERING TENDENCIES AMONG THE NEBULAE

II. A STUDY OF ENCOUNTERS BETWEEN LABORATORY MODELS OF STELLAR SYSTEMS BY A NEW INTEGRATION PROCEDURE

ERIK HOLMBERG

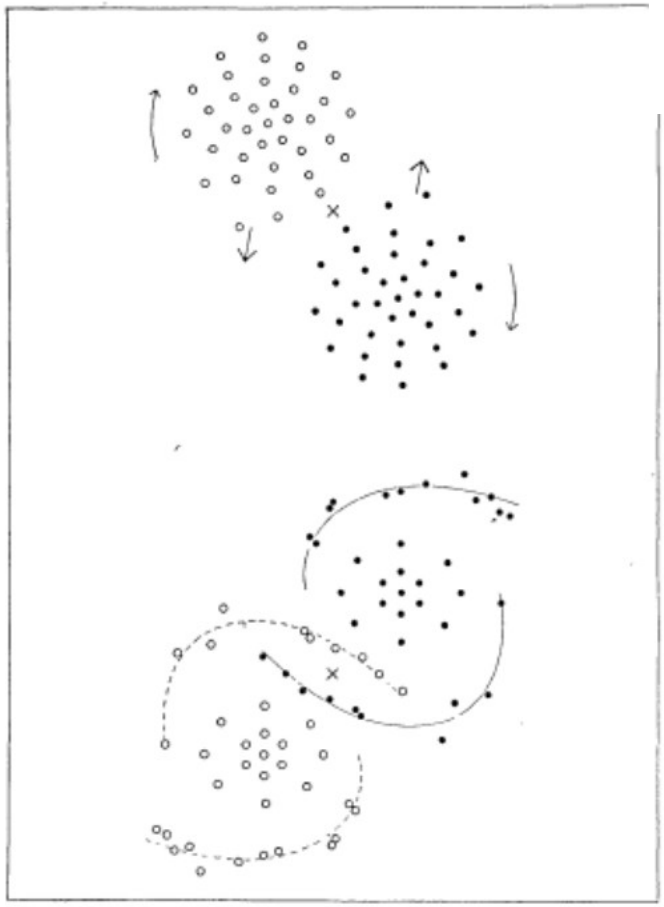


FIG. 4a

FIG. 4a.—Tidal deformations corresponding to parabolic moti
the diameters of the nebulae. The spiral arms point in the direc

FIG. 4b.—Same as above, with the exception of counterclock
the rotation.

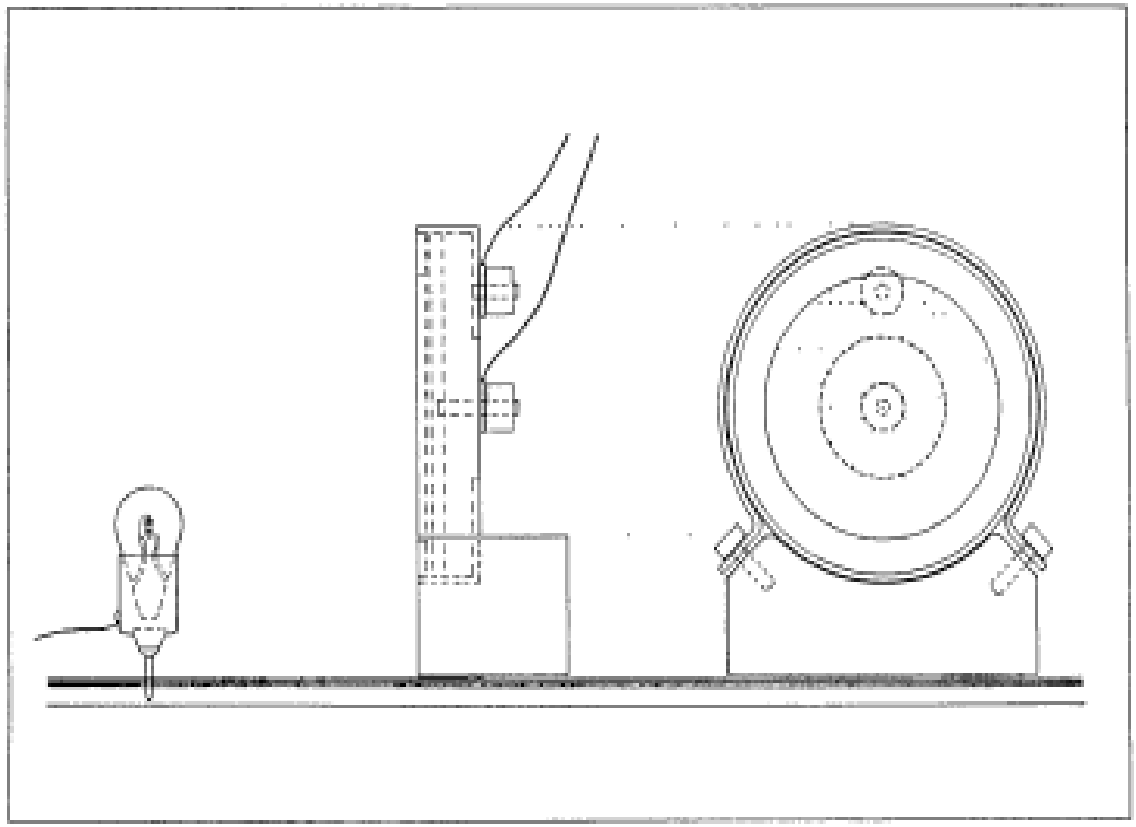
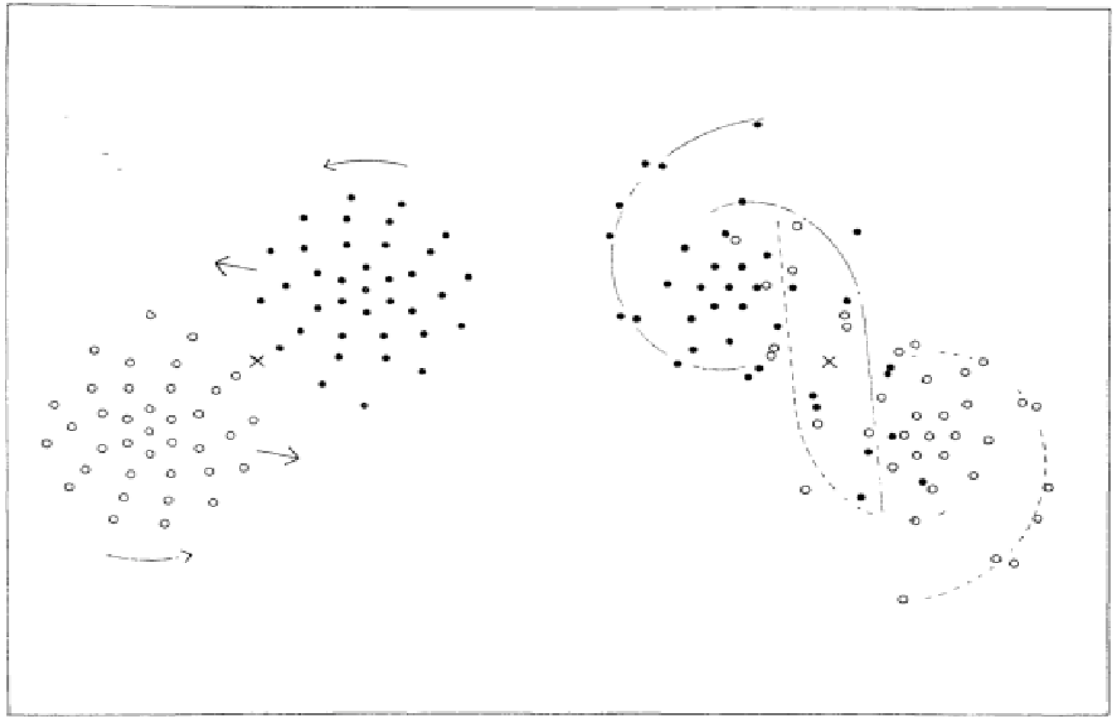
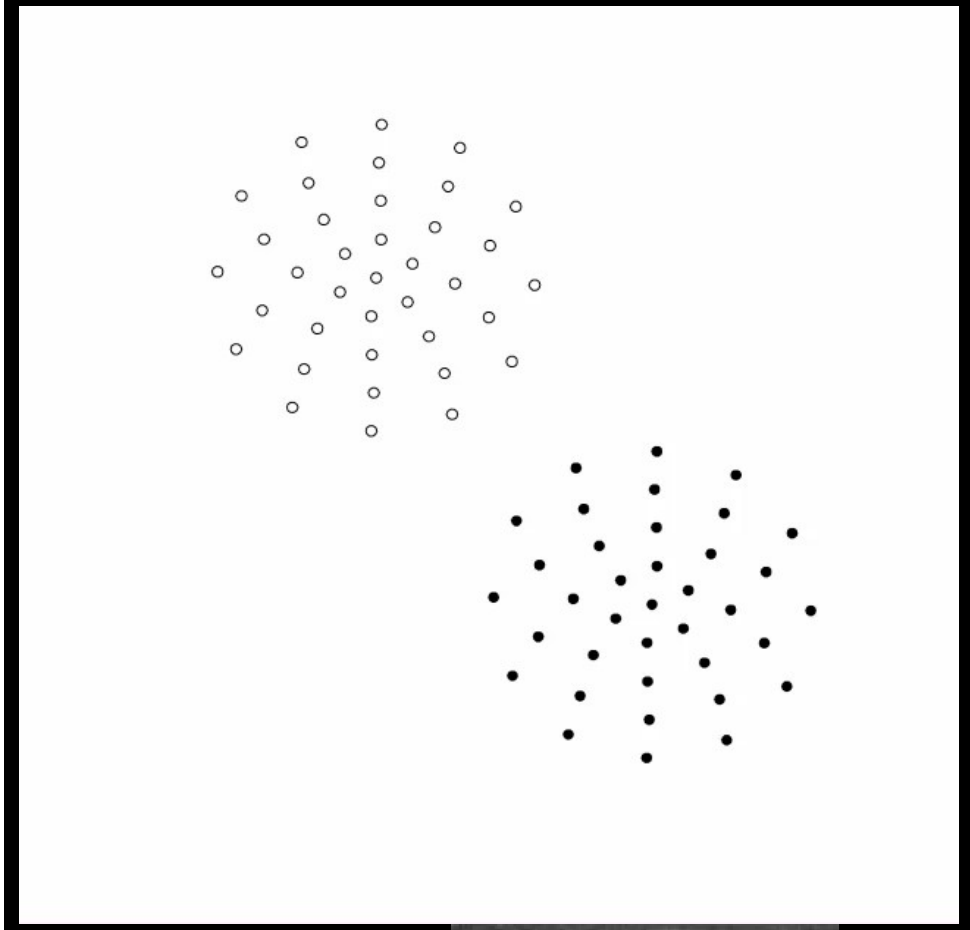
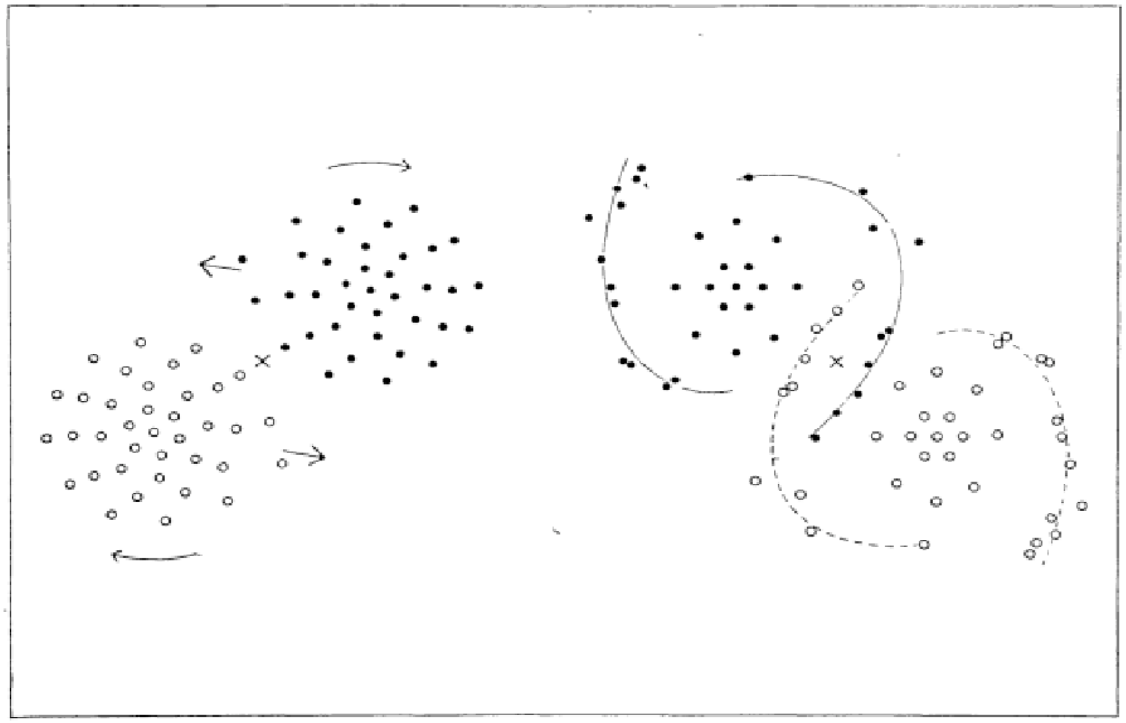


FIG. 1.—Cross-section of light-bulb and photocell (half-size)

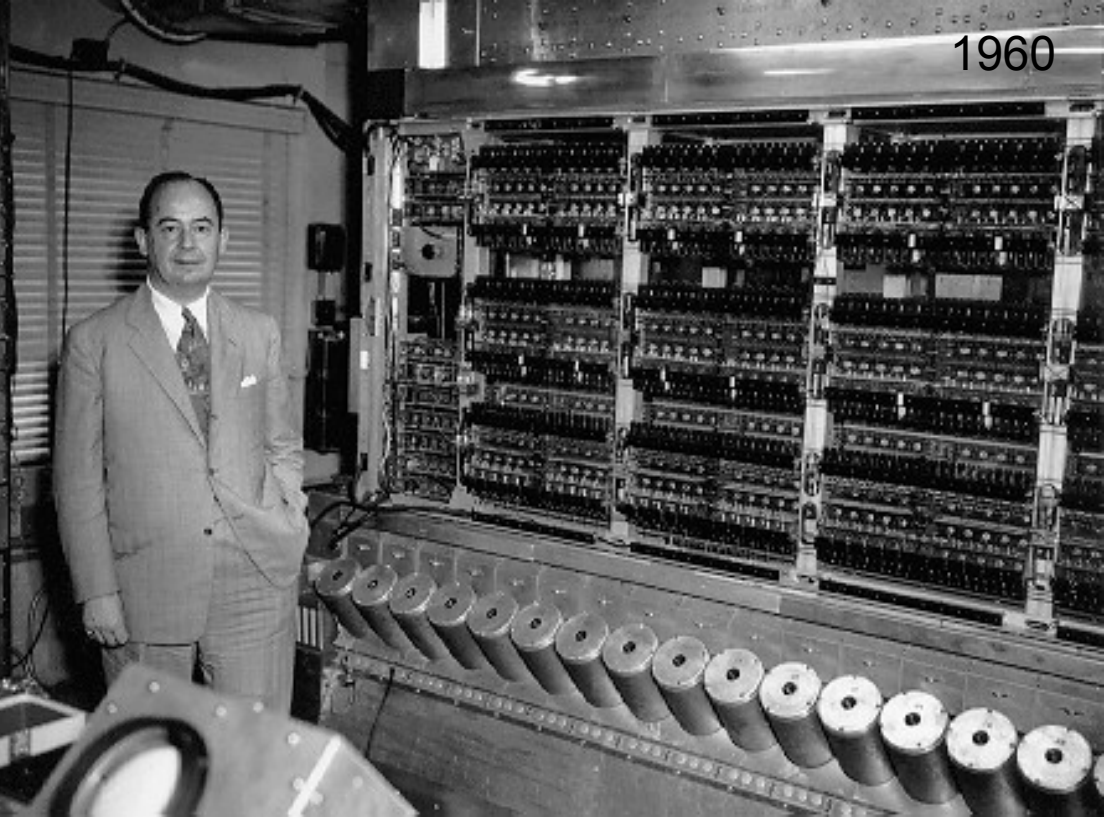
10mFlop



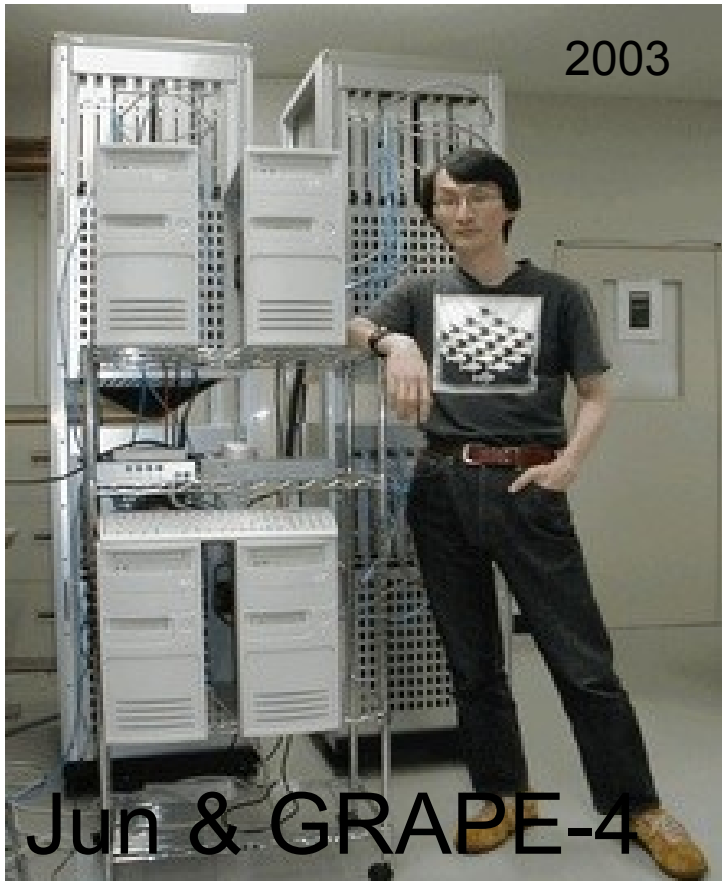




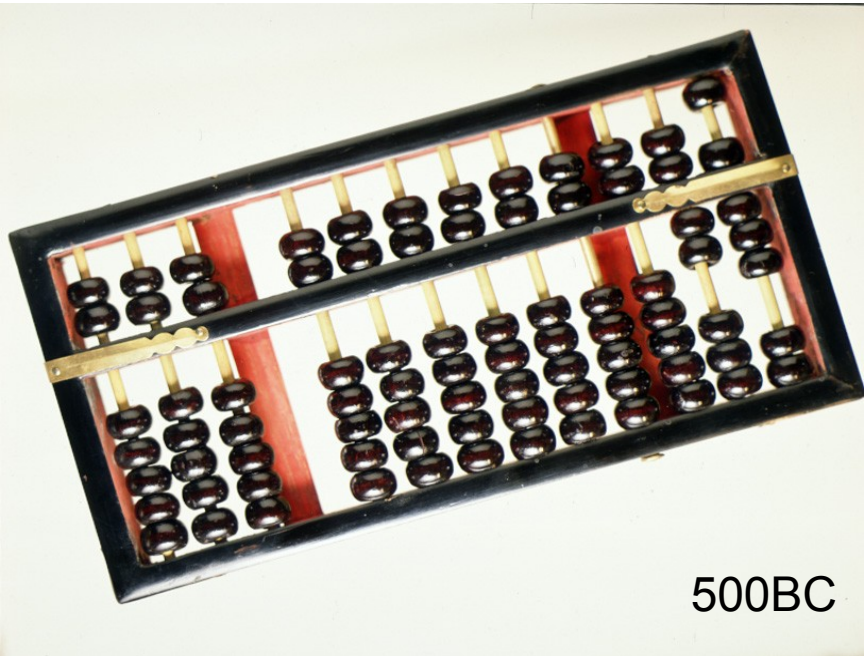
Erik Holmberg
1908-2000

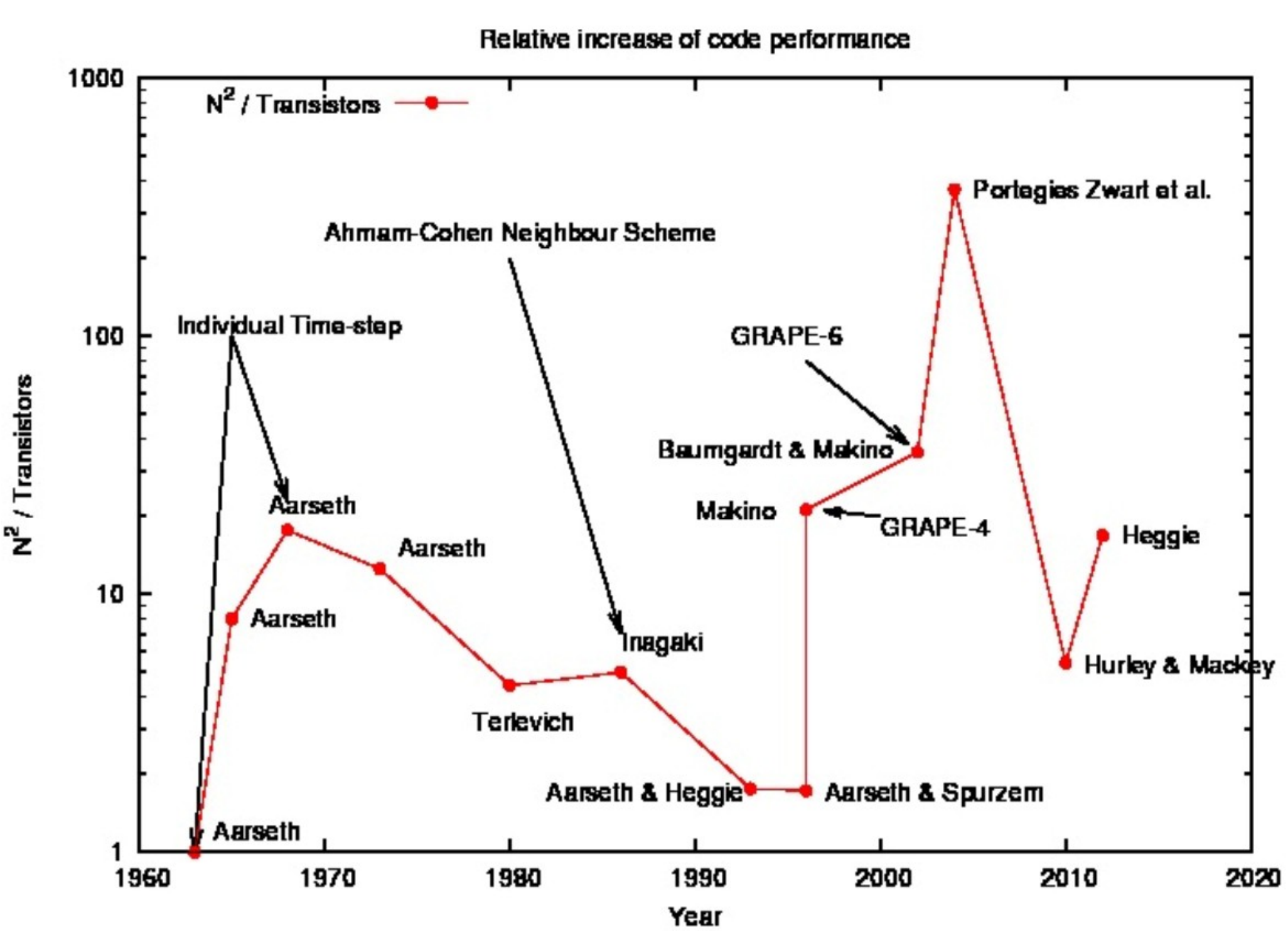


von Neuman & IAS



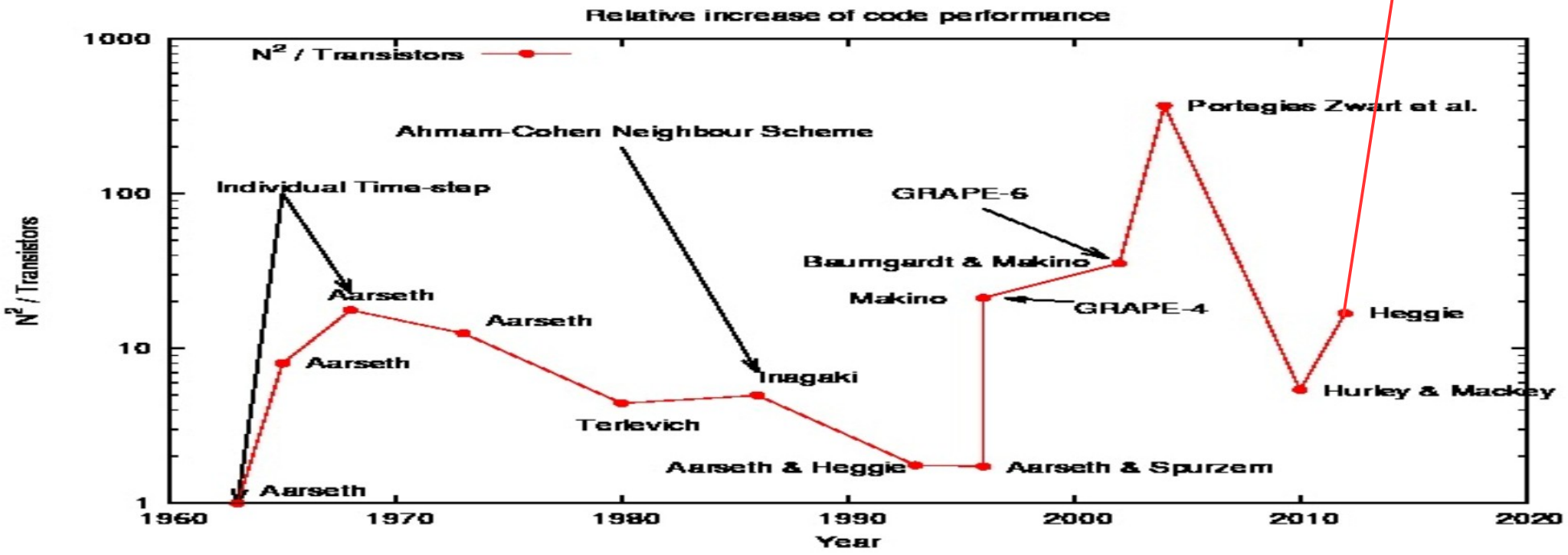
~30 000 000 times faster





Bedorf & PZ, 2012

This talk



Bedorf & PZ, 2012

Bonsai

Small,
but strong in the force

Available as part of the
AMUSE framework
at amusecode.org

Bedorf et al 2014

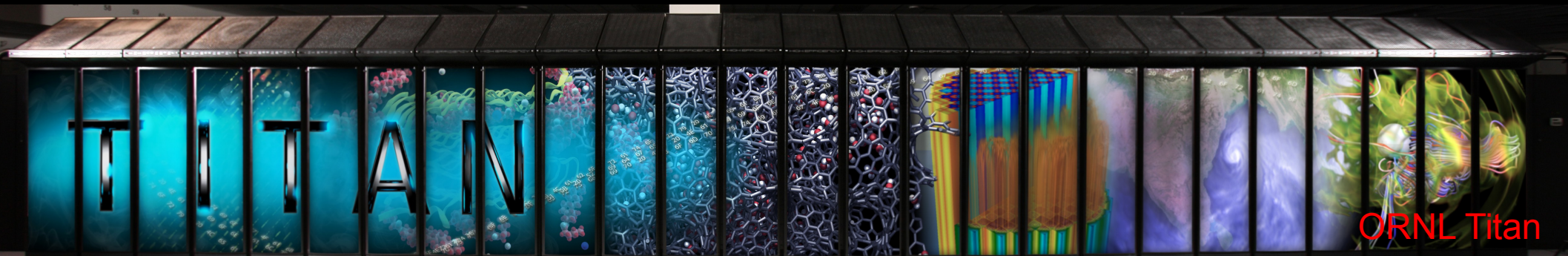
4GPUs = 0.005PFlops

40 GPUs=0.05PFlops

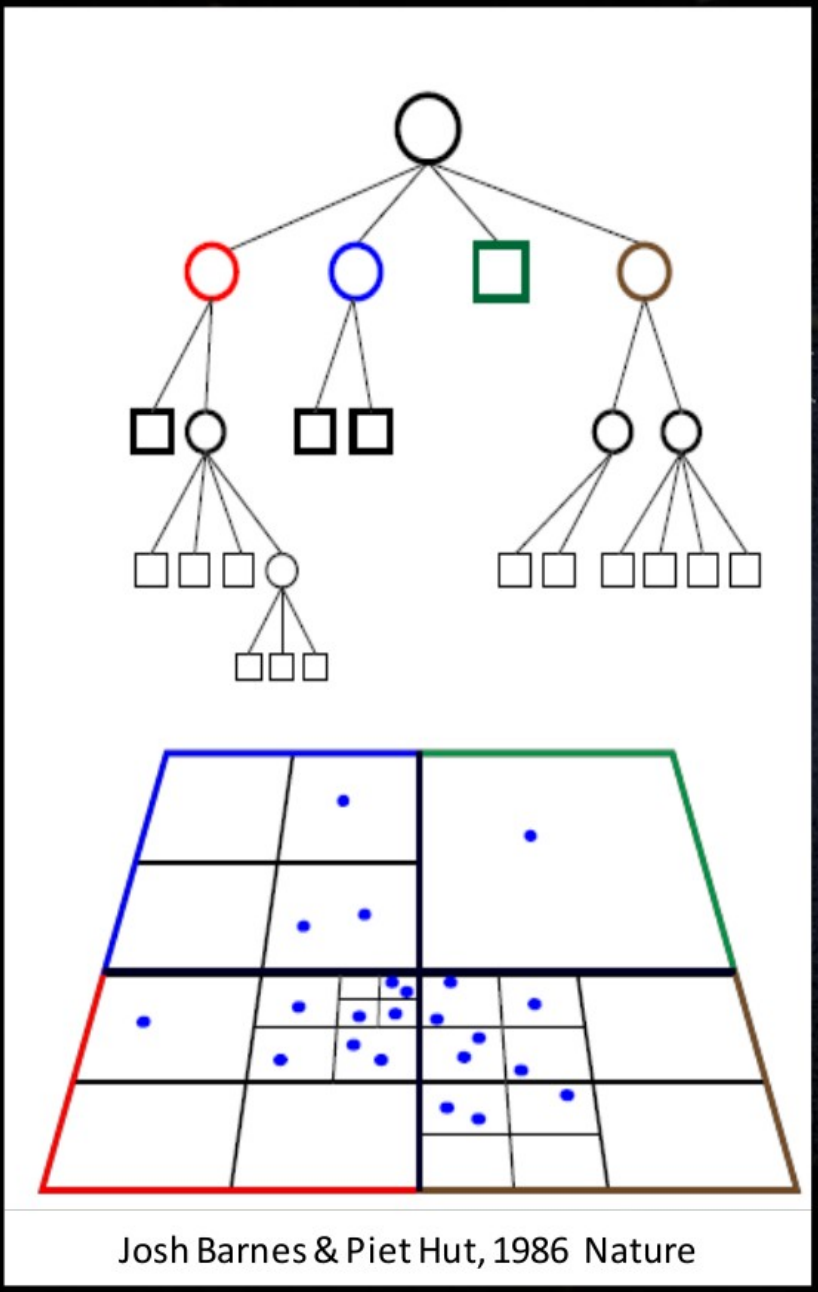
400GPUs=0.5PFflops

4000GPUs=5PFflops

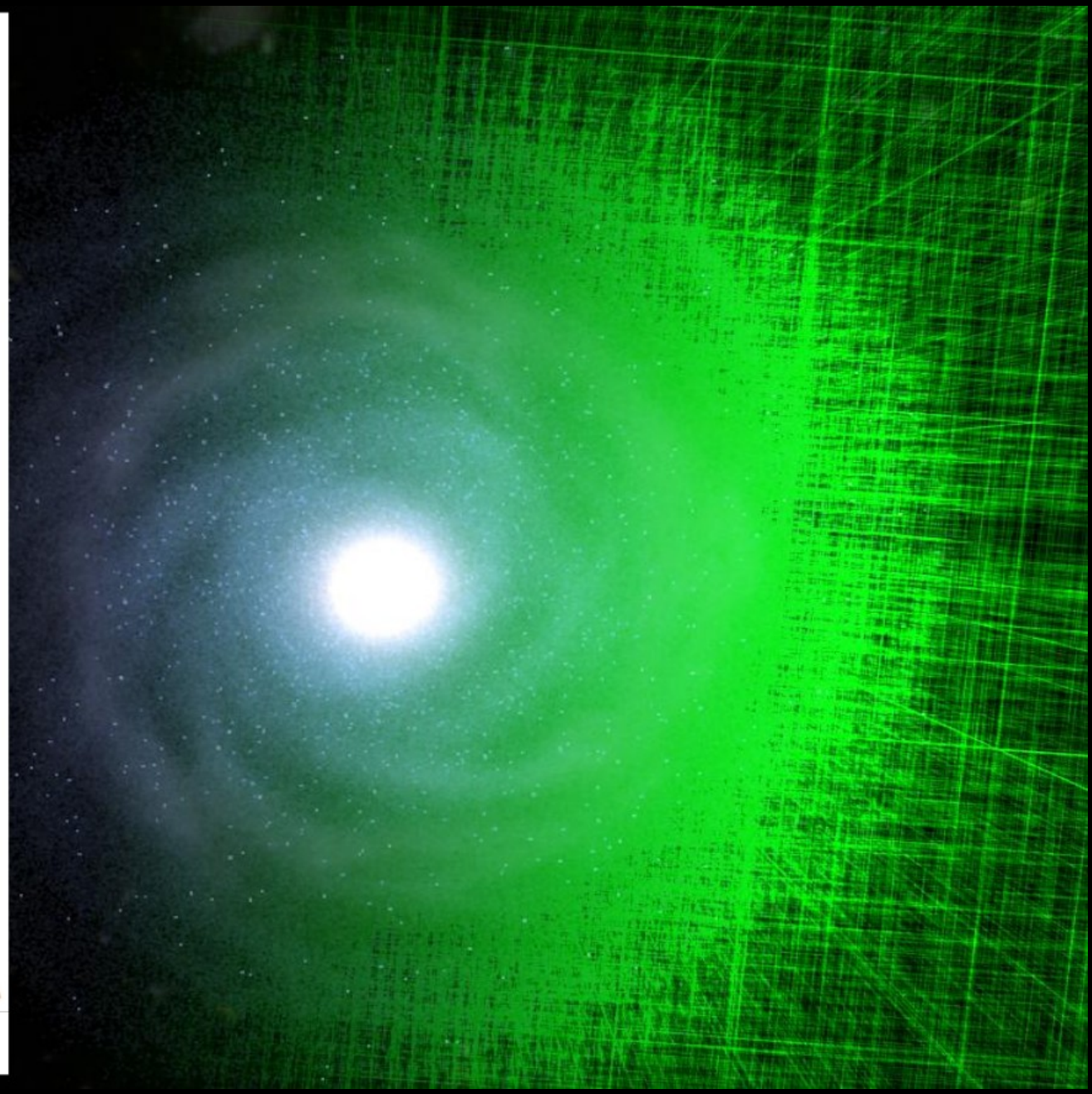
~20000GPUs= 25PFflops



Bonsai gravitationalTreecode



Josh Barnes & Piet Hut, 1986 Nature

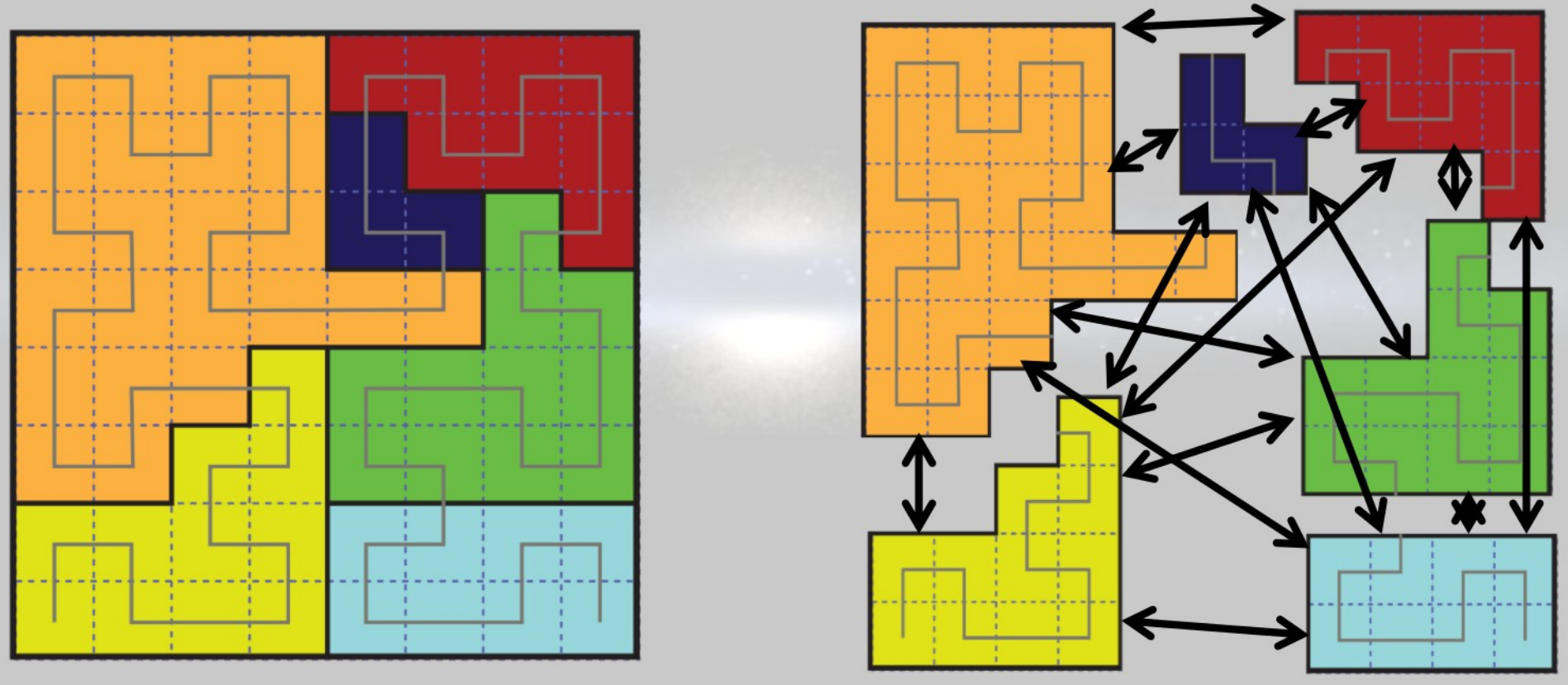


Novelties

- All force calculations on the GPU
- 2D space filling curve for the domain decomposition
  (allows higher degree of parallelism)
- Flactal-shaped domains combined with Tree structure
  (Allows asynchronicity: no communication during tree traversal)
- Use the fractal domain edges to minimize communication
  (Allows bulk data transport with exactly the right amount of data: saves latency and bandtwidth)

Peano-Hilbert Space Filling Curve

Beyond single GPU systems



Sort full data set along a Peano-Hilbert Space Filling Curve and chop this up in separate domains

Titan Node usage

GPU & CPU work | GPU work | CPU work

Domain decomposition

Data selection | Sort/exchange

Tree-construction

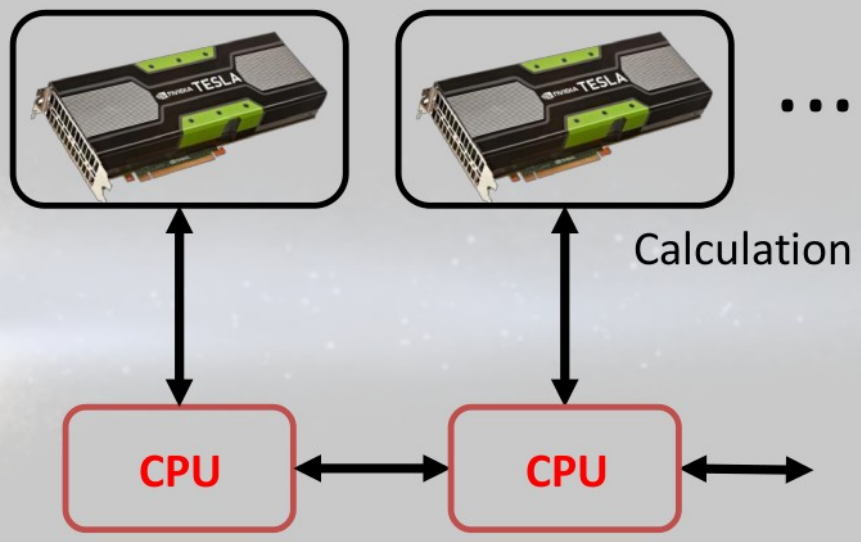
Gravity computation

Compute gravity on local and remote data | Select, send, receive & upload remote data to GPU

Update of position and velocity

Async I/O, post proces, in-situ viz

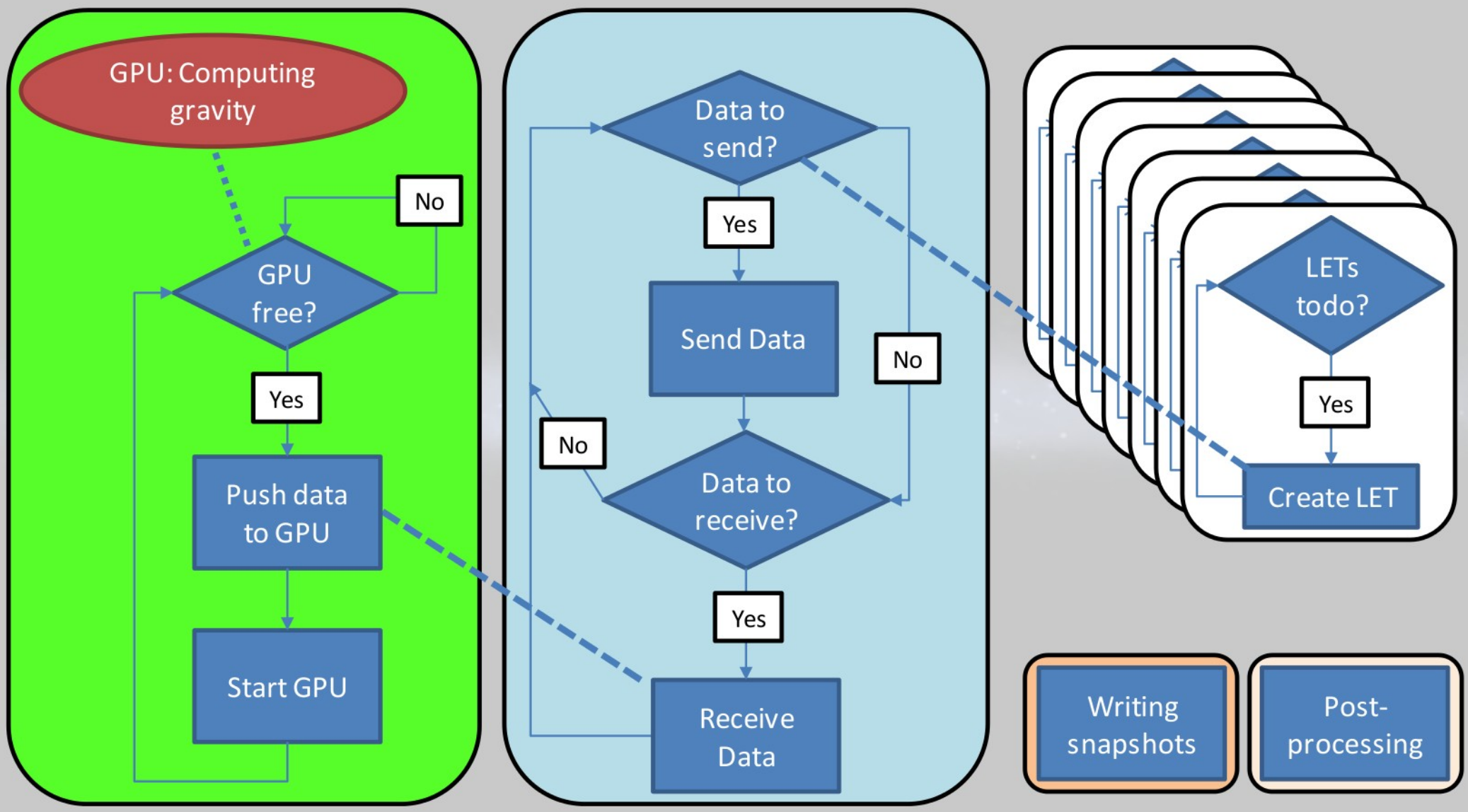
Making use of all the available massive parallelism inside a node (ready for future systems)



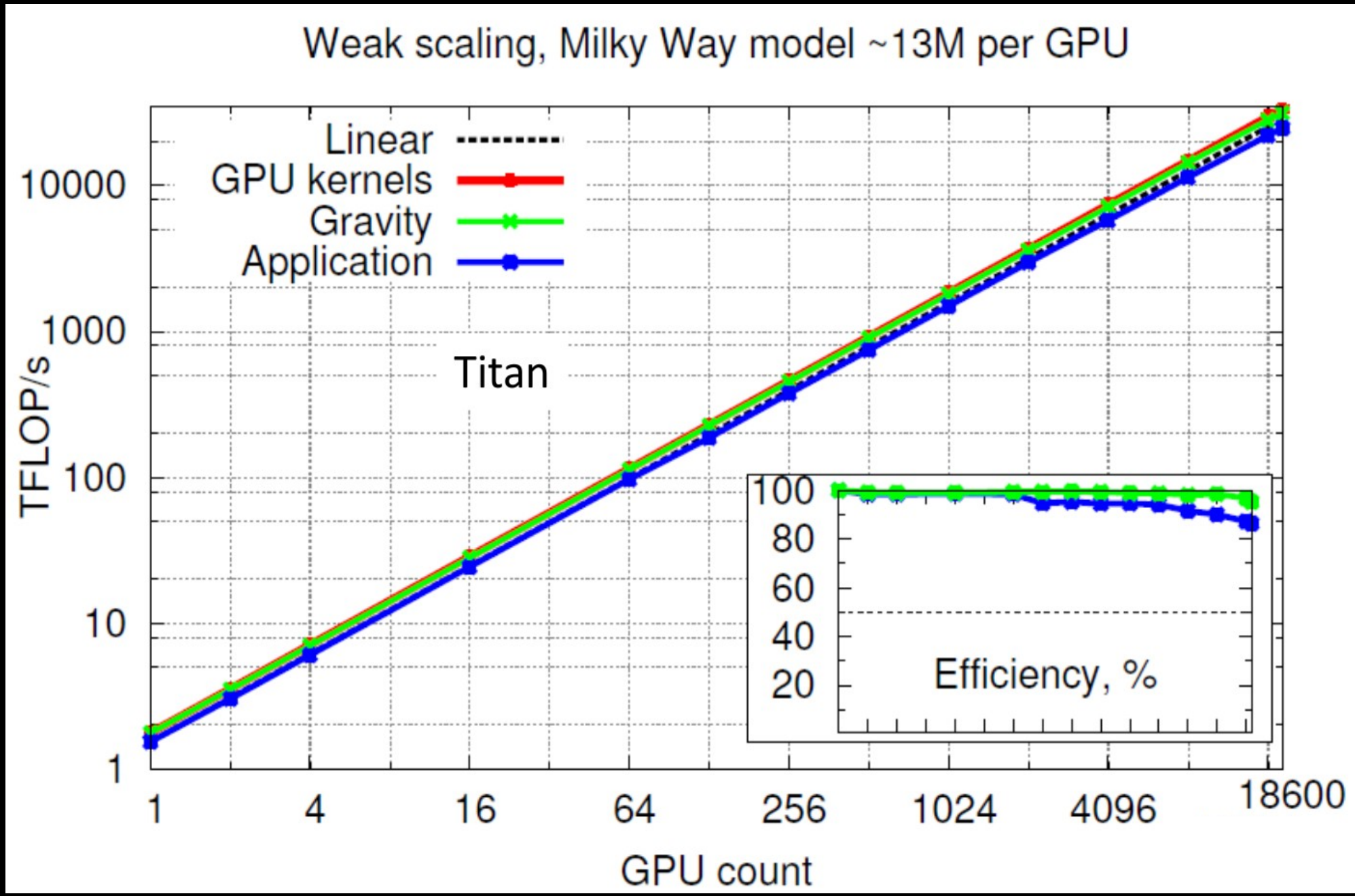
GPU: Compute and data-intensive operations → **performance**

CPU: Communication and control operations → **efficiency**

Titan Node Usage

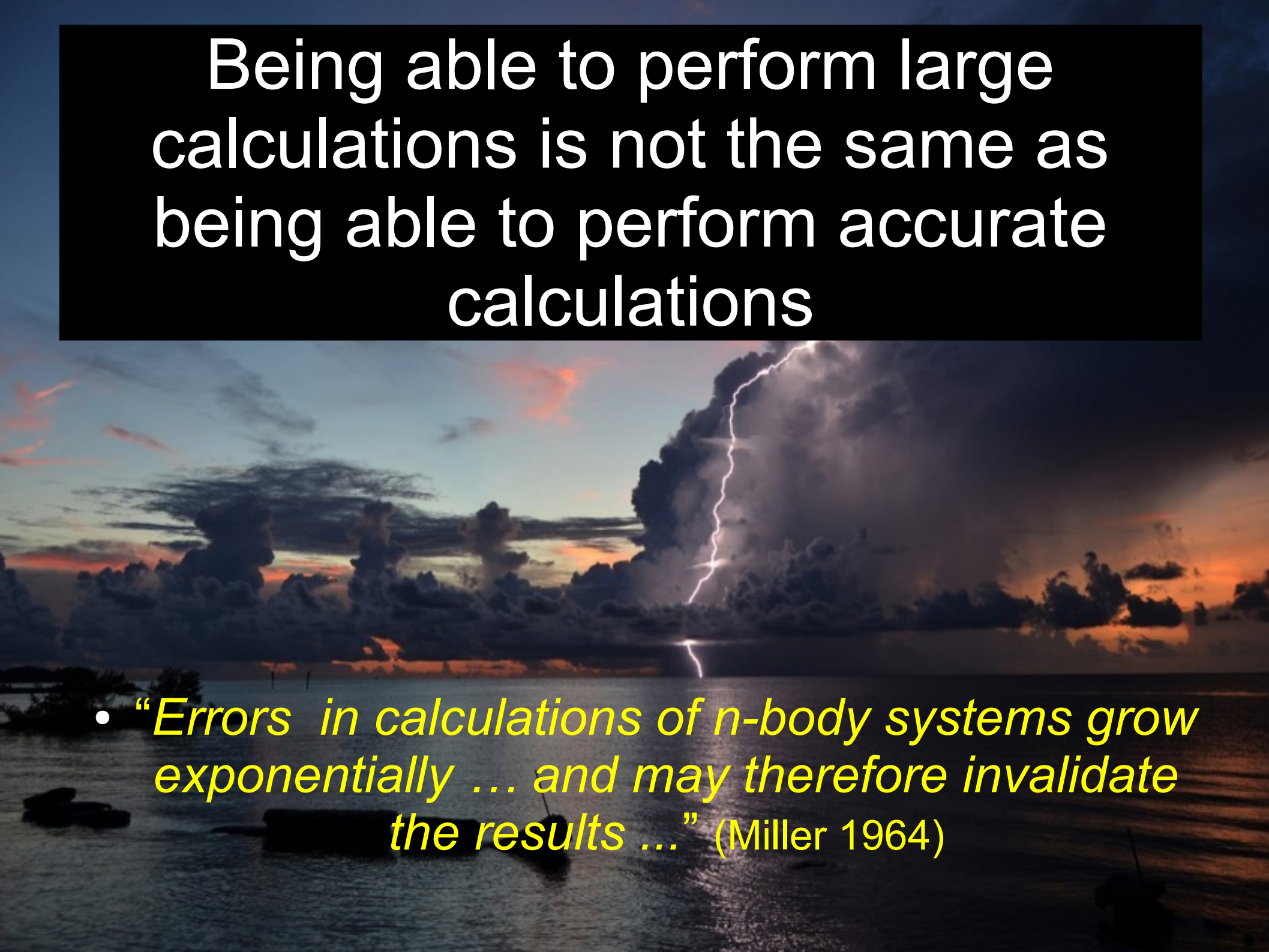


HPC on Titan's GPU-farm



Jeroen Bédorf etal: simulation of Andromeda/Milky Way encounter on Titan

Being able to perform large calculations is not the same as being able to perform accurate calculations



- "*Errors in calculations of n-body systems grow exponentially … and may therefore invalidate the results …*" (Miller 1964)

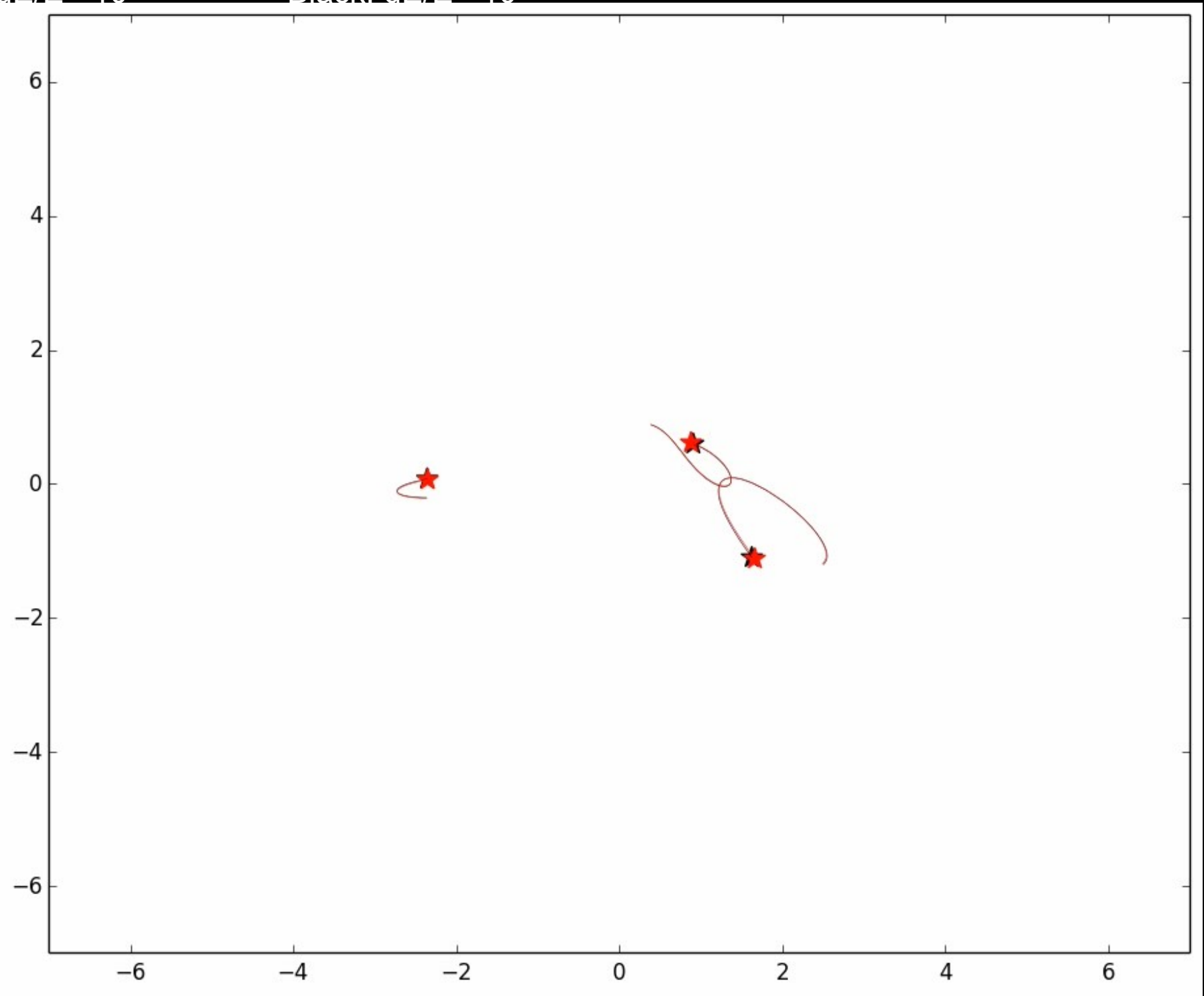
BRUTUS

a brute force arbitrary-precision N-body code

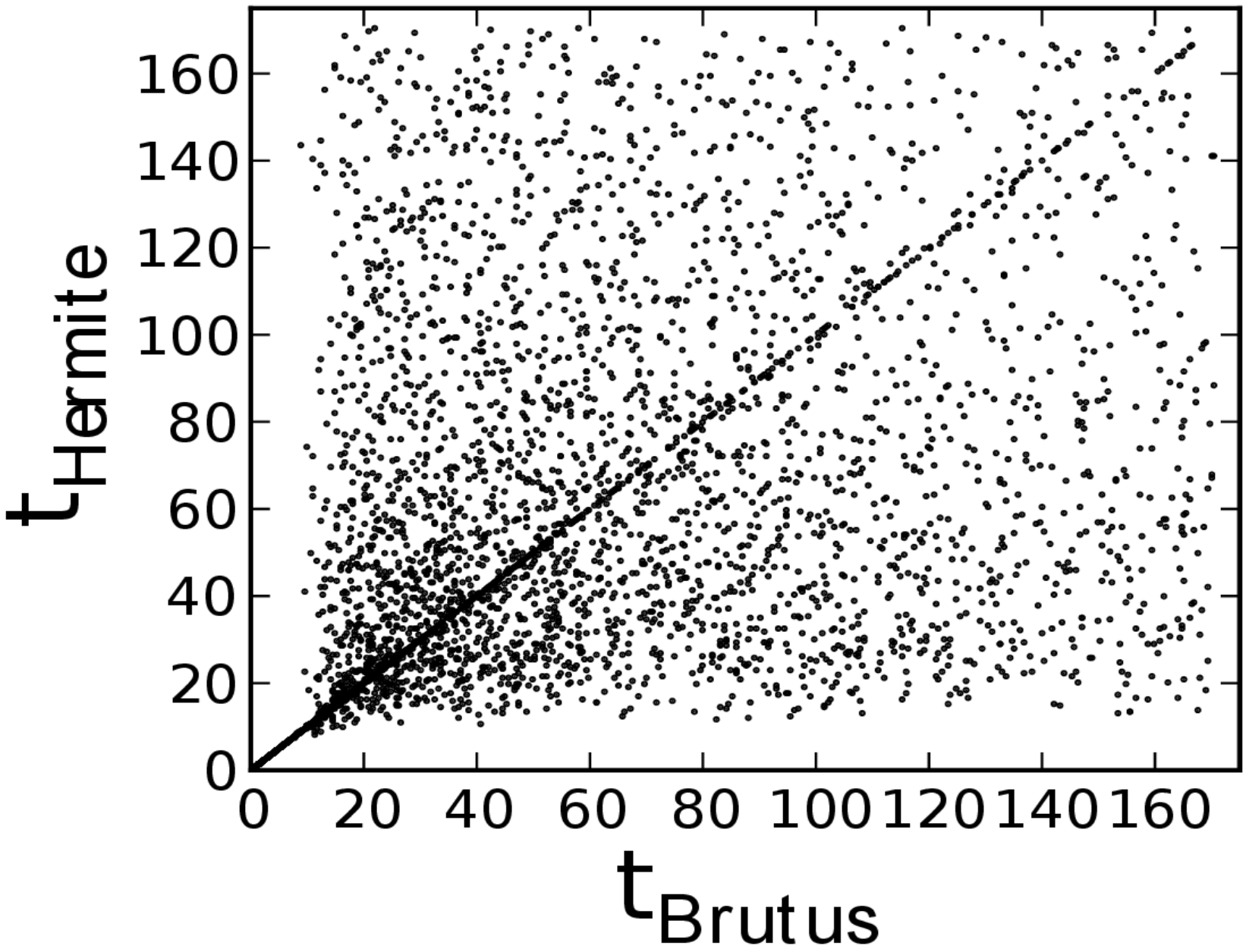
- Two ingredients:
  - Gragg-Bulirsch-Stoer method
    - Modified midpoint method
    - Richardson extrapolation
    - Tolerance parameter
  - Arbitrary-Precision arithmetic
    - Number of significant digits

Tjarda Boekholt

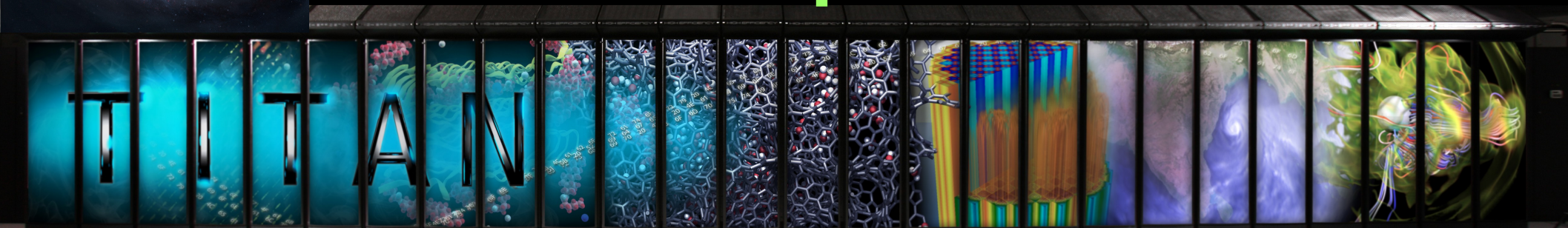
Red: dE/E <10^{-74} Black: dE/E <10^{-11}



10,000 realizations of N=3 give no systematic bias



Next step



Conclusions

- 24.773 PetaFlop/s on Titan (18600 nodes): about 90% efficiency
- Simulate 1Gyr of the Milky Way in about 1 day.
- All calculations on the GPUs
- Load-balance/communication/a-sync I/O on the CPU