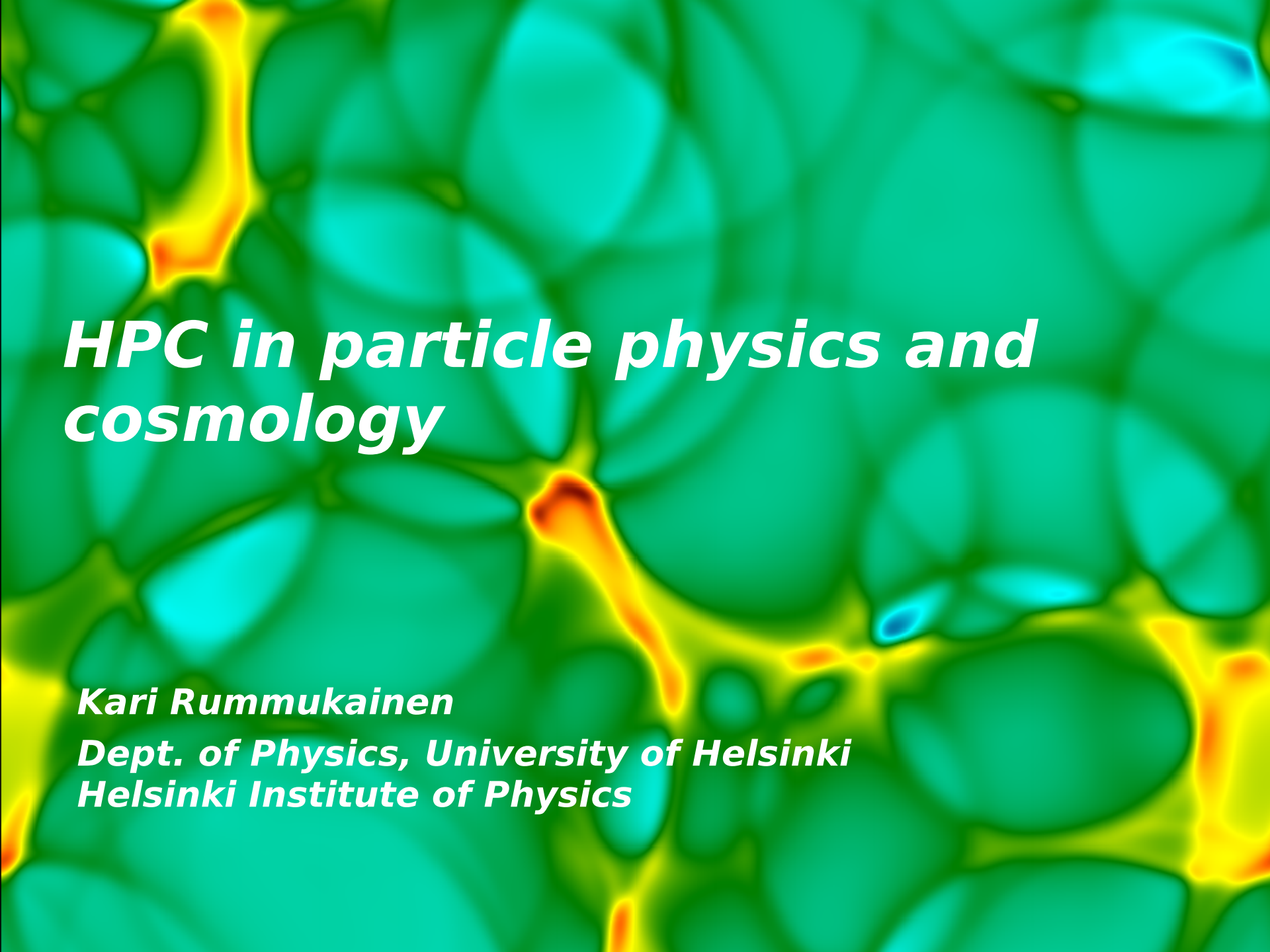
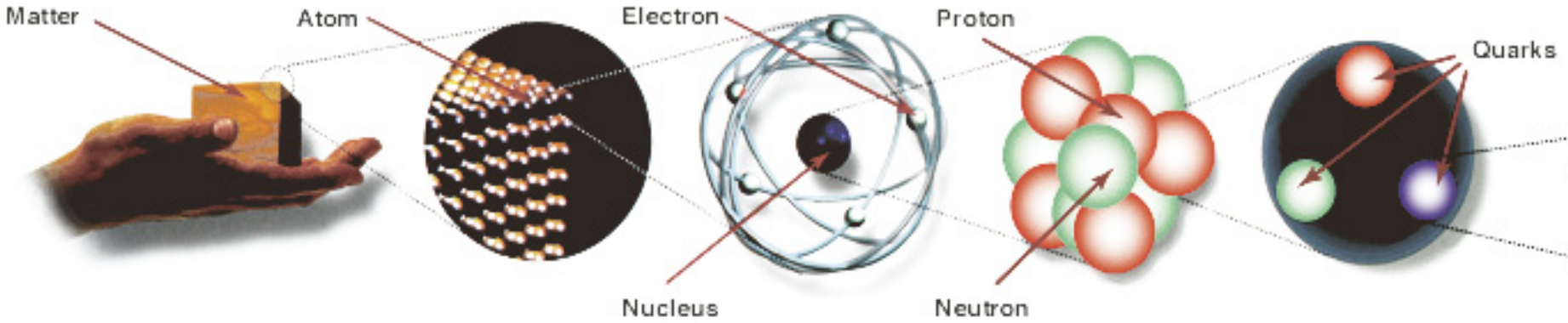


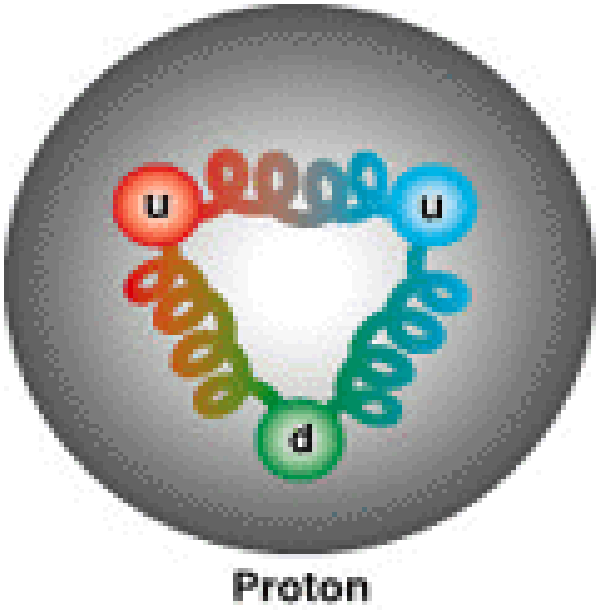
HPC in particle physics and cosmology

Kari Rummukainen

Dept. of Physics, University of Helsinki
Helsinki Institute of Physics

Matter consists of elementary particles:





Proton or neutron consists of 3 *quarks* bound together by *gluons*

How to calculate properties of a proton?

Lattice simulations of QCD:

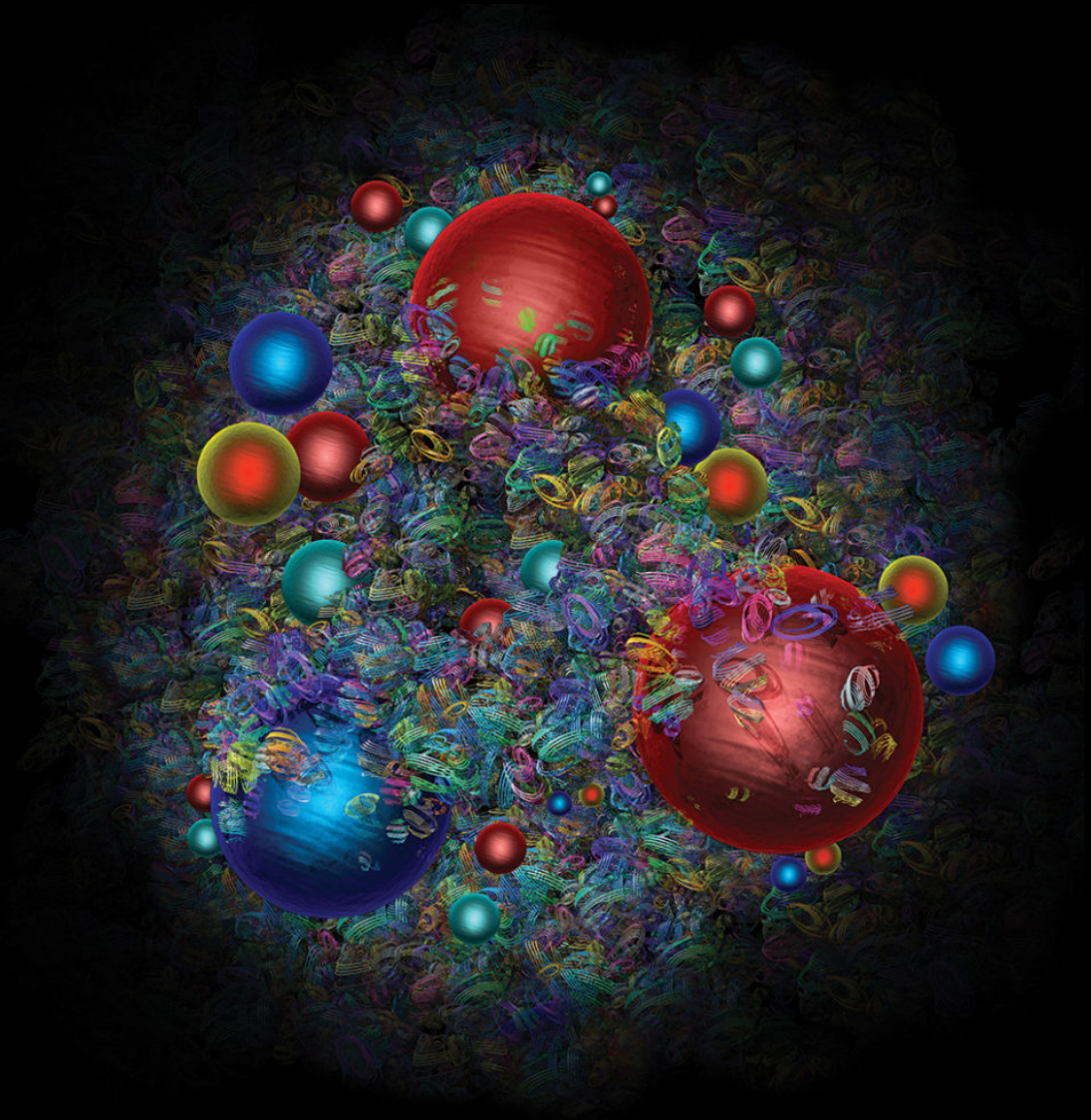


Figure: CERN

QCD (Quantum chromodynamics) tells us how quarks and gluons interact

Solution requires large-scale numerical simulations: **lattice QCD**

Helsinki is one of the pioneers in the field:
Kajantie, Montonen, Pietarinen, Z. Phys. C9 1981

Research still continues in Helsinki

Very large scale computing!

LISA

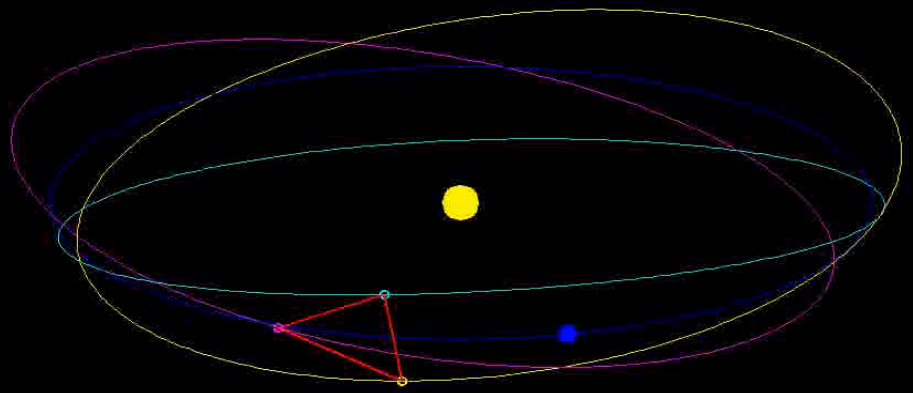
Gravitational wave observatory in space

ESA ”L3” science mission
Launch 2034

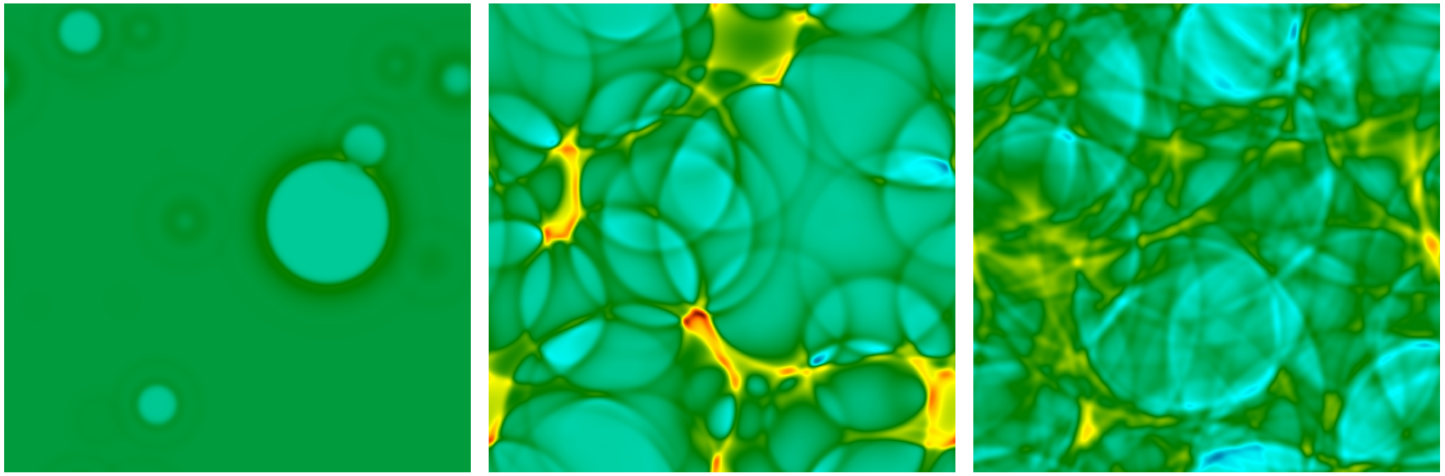
- Astronomy: galactic black holes, compact binaries
- cosmology

Helsinki has ~ 9 LISA consortium members in cosmology and astrophysics

Helsinki PROFI TT professorship in gravitational waves: David Weir



Gravitational waves from cosmological phase transitions



Hindmarsh, Huber, Rummukainen, Weir 2014

Phase transition in the very early Universe (t ~ 0.1 ns)?
Bubble nucleation → growth → collisions → **gravitational waves**

Observation in **Lisa** → revolutionary for:
→ *understanding the very early Universe*
→ *understanding physics at very high energy scales*

Large-scale computing effort in Helsinki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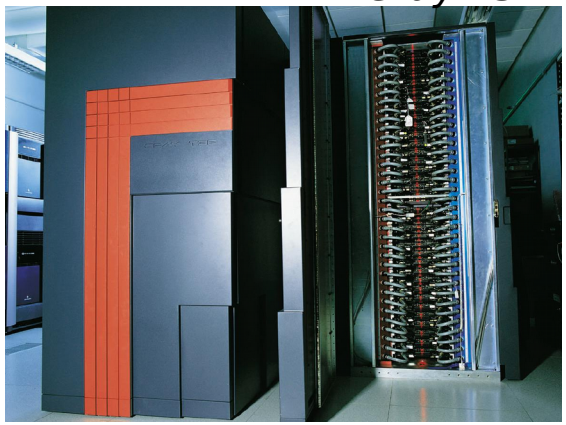
APS physics
Volume 112, Number 4


HIGGS THUNDER
Listening in on the birth pangs of the universe
NewScientist
WEEKLY 22 February 2014
THIS WEEK
The big bubble bang
Baby universe rumbled with Higgs thunder
BUBBLES popping in the hot particle soup that filled the early universe may have created a rumble like thunder, and it is possible that we can detect the echoes today. Finding them could help solve some mysteries of the Higgs boson and maybe lead to new physics.
go beyond the standard model, the transition would have happened more like water beginning to boil. Bubbles of the Higgs field would have grown in the hot dense matter that existed just after the big bang. When a bubble swept over an area, the particles in it suddenly gained the
calculation was about treating them properly, treating them like grown-up bubbles rather than toy bubbles like people had done in the past," Weir says.
The shock waves were essentially sonic booms that would have created a low rumble. The reverberations would have made gravitational waves, even after all the bubbles had popped. If we're lucky, Weir says, the next generation of sensitive detectors

CSC supercomputers 1989 → (10-15 machines)

Cray X-MP

Cray T3E



XT4/5

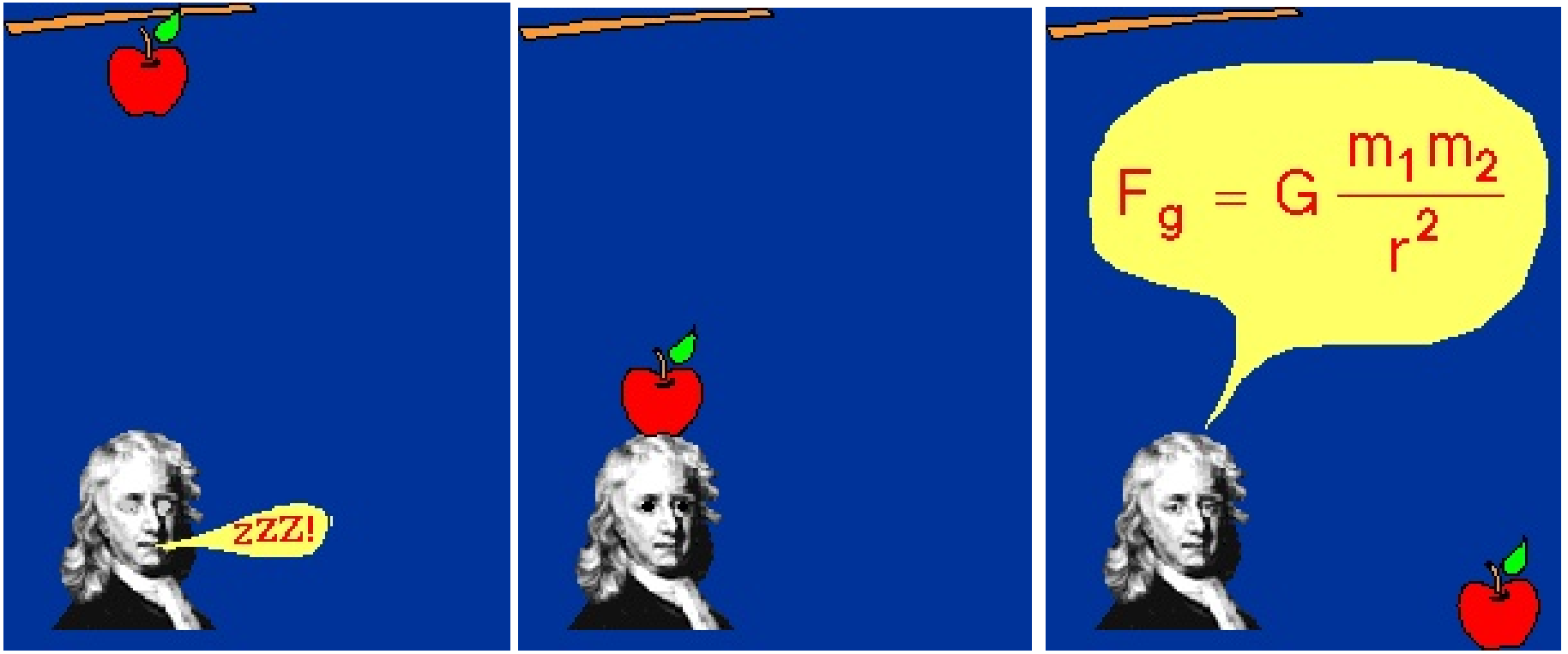
Cray XC40 “Sisu”

New super, “Puhti” →

Eagerly awaiting “Mahti” and “Lumi” (2020)

Physics:

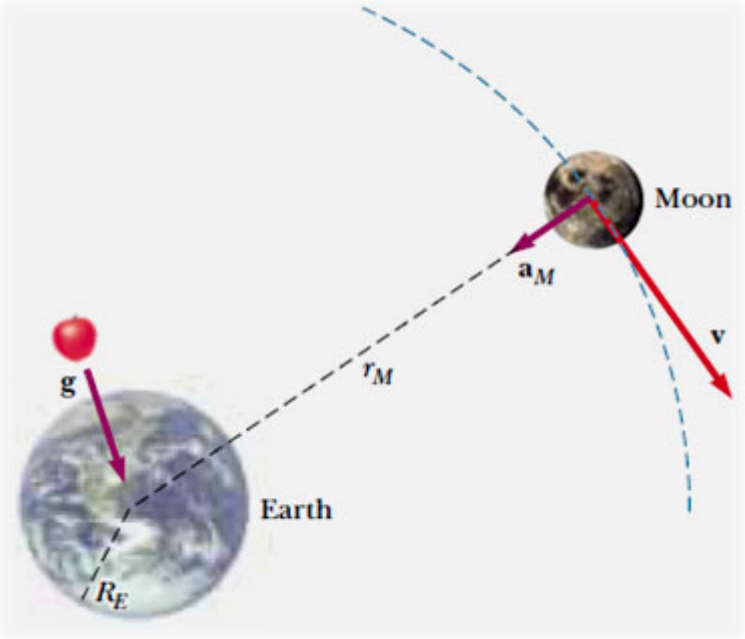
Explain observation with ... a theory

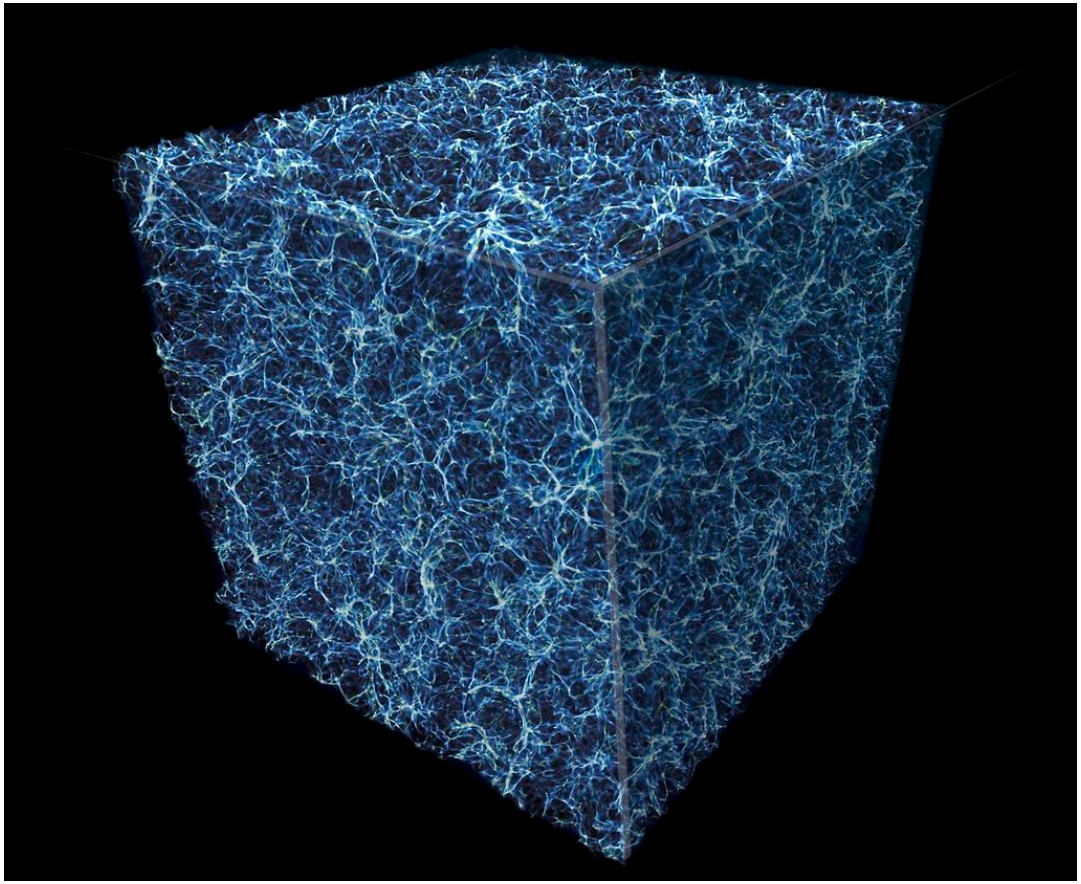


University of Rochester

Physics: model + predictions

Use the theory to make predictions:

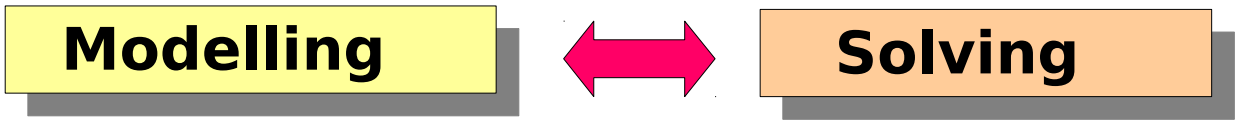




Matter distribution in the universe
NASA, University of Colorado

Physics + HPC skills

- Problem solving in science and **outside of it:**



Applicable to many areas:

  - Technology, design, acoustics, optics, scheduling, inversion problems, economy, game desgin, big data, ...

- **PhDs have gone to (outside of academia):**
  - Nokia, Ericsson, CSC, Silver Planet (founder), Leiki (founder), Ab Initio, Supercell, Eigenor, Unity Technologies, Planmeca, Zen Robotics, Finnair, Reaktor, Osuuspankki, WHO, ...

And many to academic positions:

Helsinki, Jyväskylä, CERN, Bern, Stavanger, Bielefeld, ...

Group members in Helsinki and Sussex:

Reuben Ares
Daniel Cutting
Jani Dahl
Oliver Gould
Chloe Gowling
Mark Hindmarsh
Stephan Huber
Venus Keus
Anna Kormu
Viljami Leino
Asier Lopez-Eiguren
Eelis Mielonen
Lauri Niemi
Tobias Rindlisbacher
Jarno Rantaharju
Kari Rummukainen
Ahmed Salami
Satumaaria Sukuvaara
Joni Suorsa
Tuomas Tenkanen
Kimmo Tuominen
Essi Vilhonen
David Weir