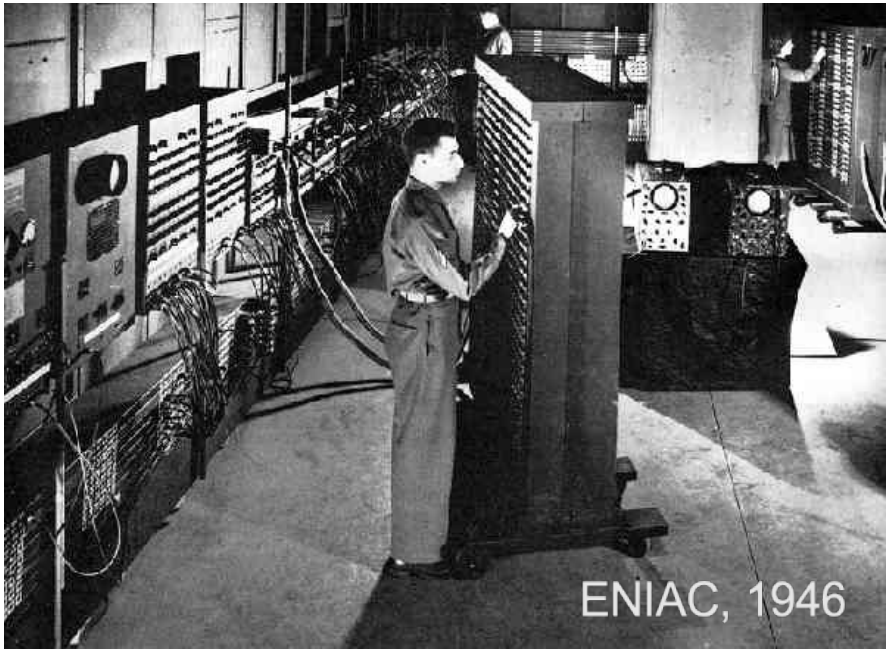
Simulation challenges

1) **Small-scale physics:**
   Multi-phase ISM, galactic winds, SN/AGN feedback
   (Christoph's discussion part)

2) **Large-scale physics:**
   Connecting galaxy formation to cosmology

3) **Technical challenges:**
   accuracy and scalability of codes, future of supercomputing



Simulation challenges in large-scale* cosmological simulations

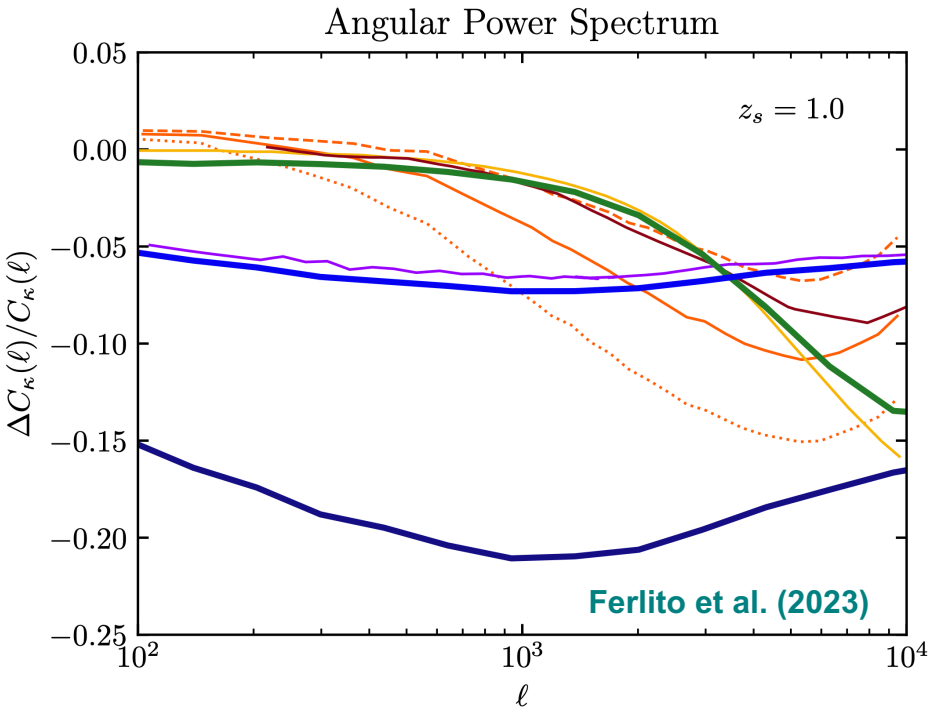
WHAT IS NEEDED FOR ONGOING MEGA GALAXY SURVEYS ?

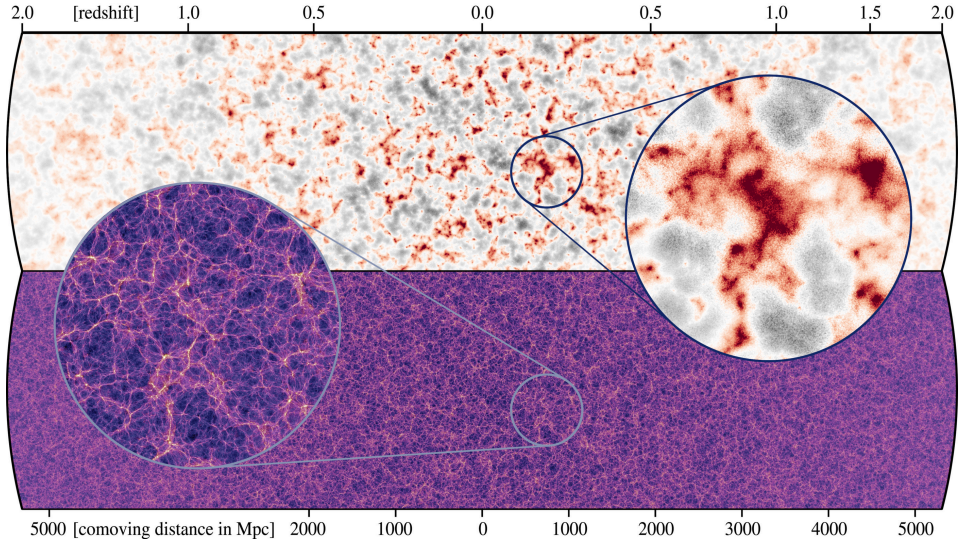
- How do arrive at **reliable predictions for baryonic impact** on LSS?
- Can we repeat the **star-by-star simulations** of the **formation of dwarf galaxies** for a **full galaxy cluster**?
- Do we need **full hydrodynamical simulations in ~3 Gpc volumes?**
- Should all our simulations contain **neutrinos**? What about **dynamical dark energy** simulations? Which **non-standard dark matter scenarios** need more detailed simulations? (e.g. primordial black holes, fuzzy dark matter, etc.) Do we need to focus more on **modified gravity** simulations?

* Not the “large-scale” of Max Gronke…

Massive neutrinos impact weak lensing similarly or more than AGN feedback

COMPARISON OF BARYONIC AND NEUTRINO IMPACT ON THE WEAK LENSING CONVERGENCE POWER SPECTRUM





Color	Simulation	Code
	MTNG740-1	AREPO
	MTNG630-DM-0.1	GADGET-4
	MTNG630-DM-0.3	GADGET-4
	TNG300-1	AREPO
	BAHAMAS	GADGET-3
	Horizon AGN	RAMSES
	MassiveNuS	GADGET-2

Accuracy challenges in simulations

HOW TO VALIDATE OUR RESULTS?

- Do different MHD codes agree sufficiently well on **magnetic field amplification**?
- RAMSES is **bug free** – but what about the other codes?
  How do we prevent them from becoming a **black box**?
- Are their any residual worries with respect to **accuracy of different hydro methods**?
- Is there any need to go to **high order methods**?
- What are the most important roadblocks in more commonly doing **radiation hydrodynamics** simulations?

Technical challenges in future simulations

NAVIGATING THE CURRENT TECHNOLOGICAL TRENDS AND EXPLOITING THEM FOR OUR FIELD

- Do we **still need full physics simulations** for cosmology, **or can they be replaced by AI** methods?
- **Will AI modify** the way we do **simulations in the future?**
  Do we still need to code ourselves?
- How do we cope with **increasingly complex physics** codes and keep them manageable, in particular for young people? **How to assure correctness?**
- How to we **cope with GPU computing**?
- What types of **simulations are most urgently needed** but aren't done yet?

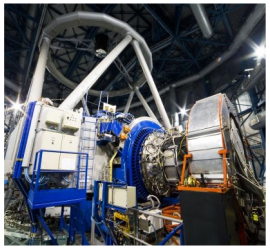

HELLO,
HOW CAN I HELP YOU TODAY?
WRITE ME AN APP IN PYTHON...
LOREM IPSUM
DOLOR SIT AMET, ["CONSECTETUR"
ADIPISCING ELIT (SED DO) F:
EIUSMOD = T.EMPOR ( )
INCIDIDUNT = UT . LABORE ET ( )
DOLORE MAGNA :
ALIQUA . QUIS IPSUM ("# ")
:
SUSPENDISSE
ULTRICES GRAVIDA . RISUS
GUESS WE DON'T NEED TO
LEARN TO CODE ANYMORE

Cosmological hydrodynamical simulations rely on ever more complex codes

HARDWARE WITHOUT SOFTWARE IS LIKE BUILDING TELESCOPES WITHOUT INSTRUMENTS

telescope

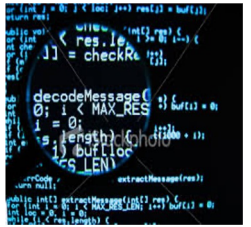
instrument



analogy

supercomputer

code

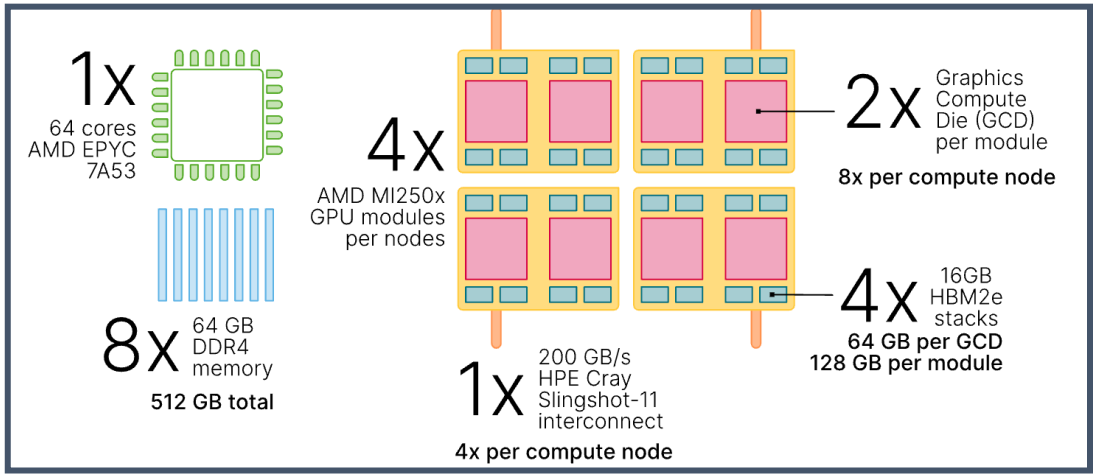


2001	2005	2010	2018	2024
GADGET-1	GADGET-2	GADGET → AREPO	AREPO	AREPO-2
8.000 lines	18.000 lines	160.000 lines	332.000 lines	480.000 lines

From the most recent call by the Gauss Centre for Supercomputing (GCS)…

Please note that SuperMUC-NG Phase 1 is currently the last large CPU-only deployment within GCS and will be operated at most for two more years. ***The compute power of forthcoming machines will be largely provided by accelerators in the foreseeable future****.* ***Accordingly, code porting to GPUs will be required to use these machines****. Please check out training offers and contact the local application support teams of the centres.*

Architecture overview of one FRONTIER / LUMI-G compute node



CPU side

- 64 cores
- 512 GB total

GPU side

- 8 GCDs (Graphics Compute Die)
- Each has 110 CUs (Compute Units)
- Each CU has 64 SIMD lanes (and 4 matrix cores), 64 threads are executed as a “wavefront” in parallel – think of this as a vector thread (similar to warps of 32 threads for Nvidia)
- 512 GB total
- 880 CUs, **56320 vector threads per node** in total

“There are 3 rules to follow when parallelizing large codes. Unfortunately, no one knows what these rules are.”

W. Somerset Maugham, Gary Montry

Total number of nodes

- 9472 on Frontier (USA)
- 2928 on LUMI-G (Europe)