First steps towards cosmological simulations with full EAGLE physics

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with

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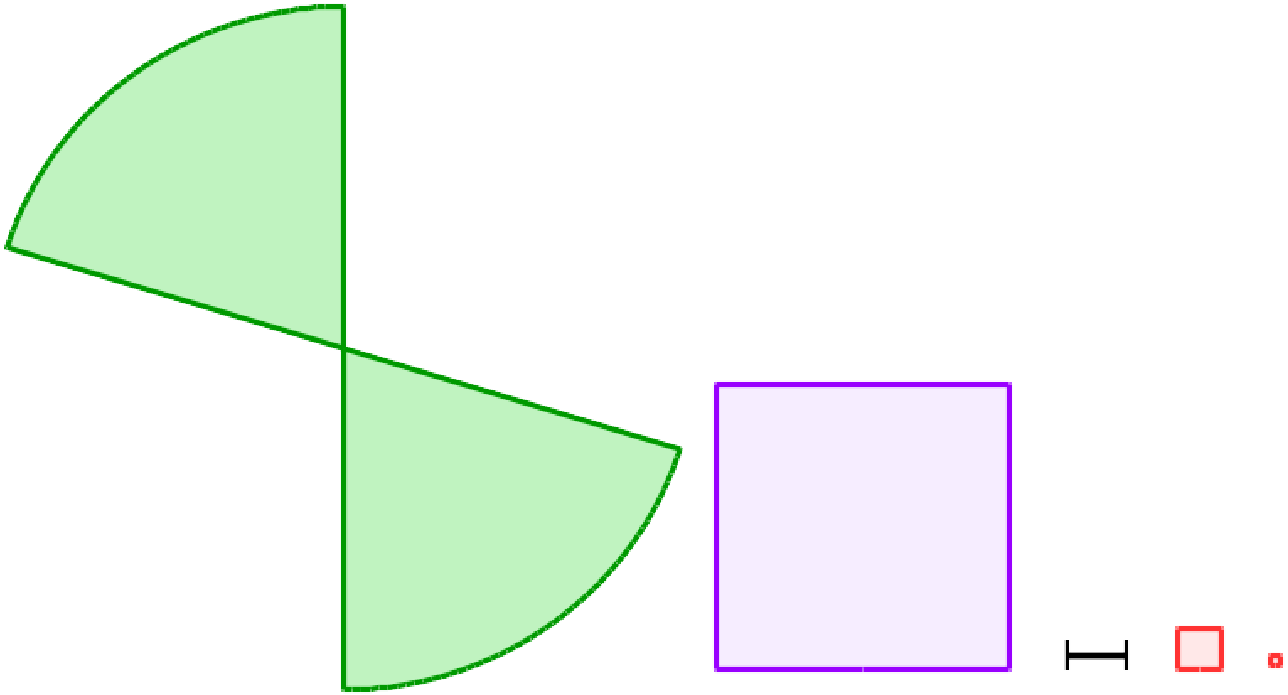
Cosmological scales?



Any needs for more?

- Thinking of future weak-lensing surveys:
  - Measure some cosmological information on scales down to ~ 1-30 Mpc. Clearly “baryon effects” seen on these scales.
  - “Common wisdom” asks for volume in excess of 300 Mpc.
  - That asks for particles counts in excess of 4500^3 ~ 100 billion.
  - With EAGLE code that would be >300M CPU hours and 1.3PB of RAM

SWIFT 101

- Aimed at replacing Gadget for EAGLE-like runs.
- Use task-based parallelism, modern algorithms, better parallelisation and domain decomposition.
- Leaner memory footprint, faster i/o, more modular, multiple hydro schemes.
- Collaboration with computer scientists and industry.

SWIFT 101

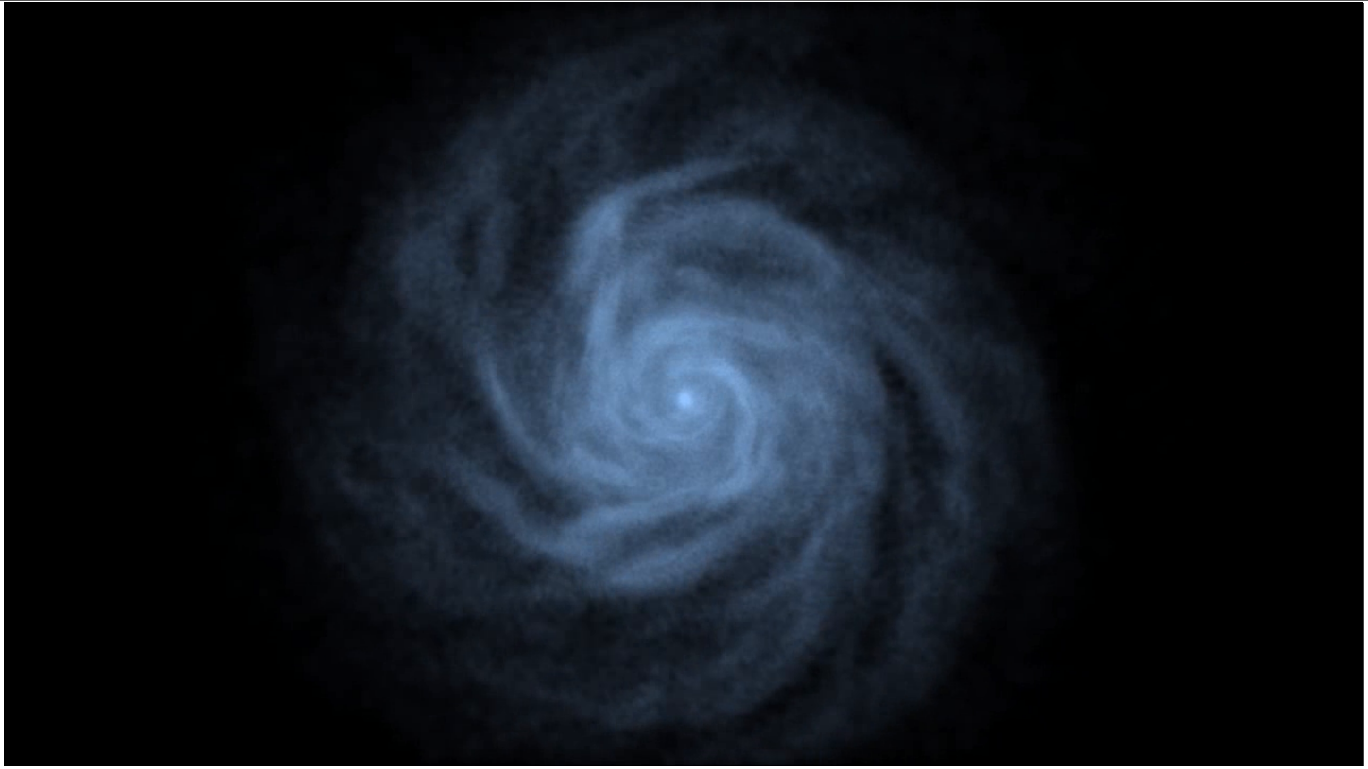
- Hydro neighbour finding based on regular AMR cell structure. Many flavours of SPH + “GIZMO”.

- FMM for gravity with a multipole-mesh method for periodic gravity.

- Particles sorted to enhance the vectorization of the code.

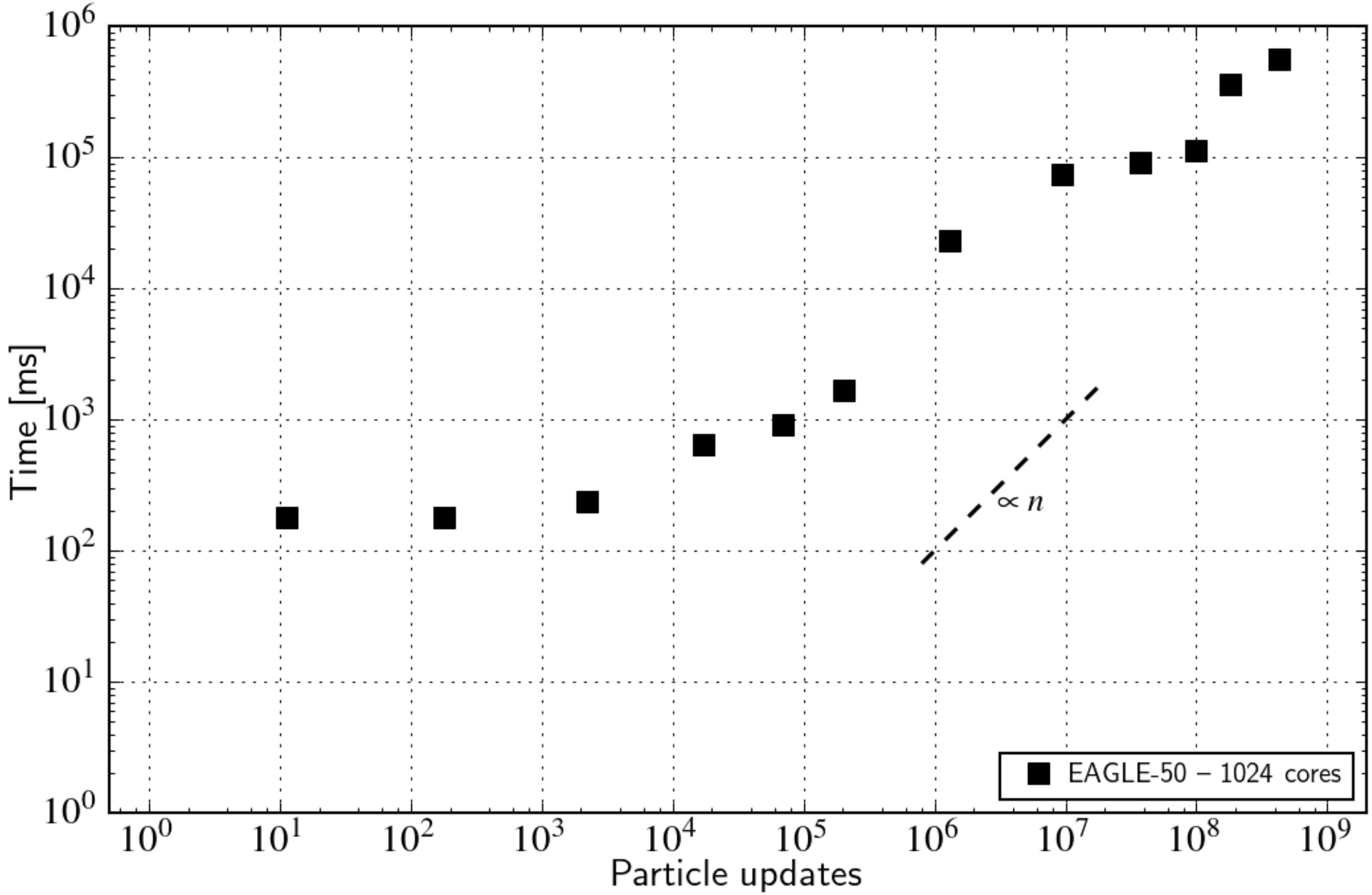
- Activation of work only in the “active” parts of the tree.

SWIFT interlude - AGORA galaxy

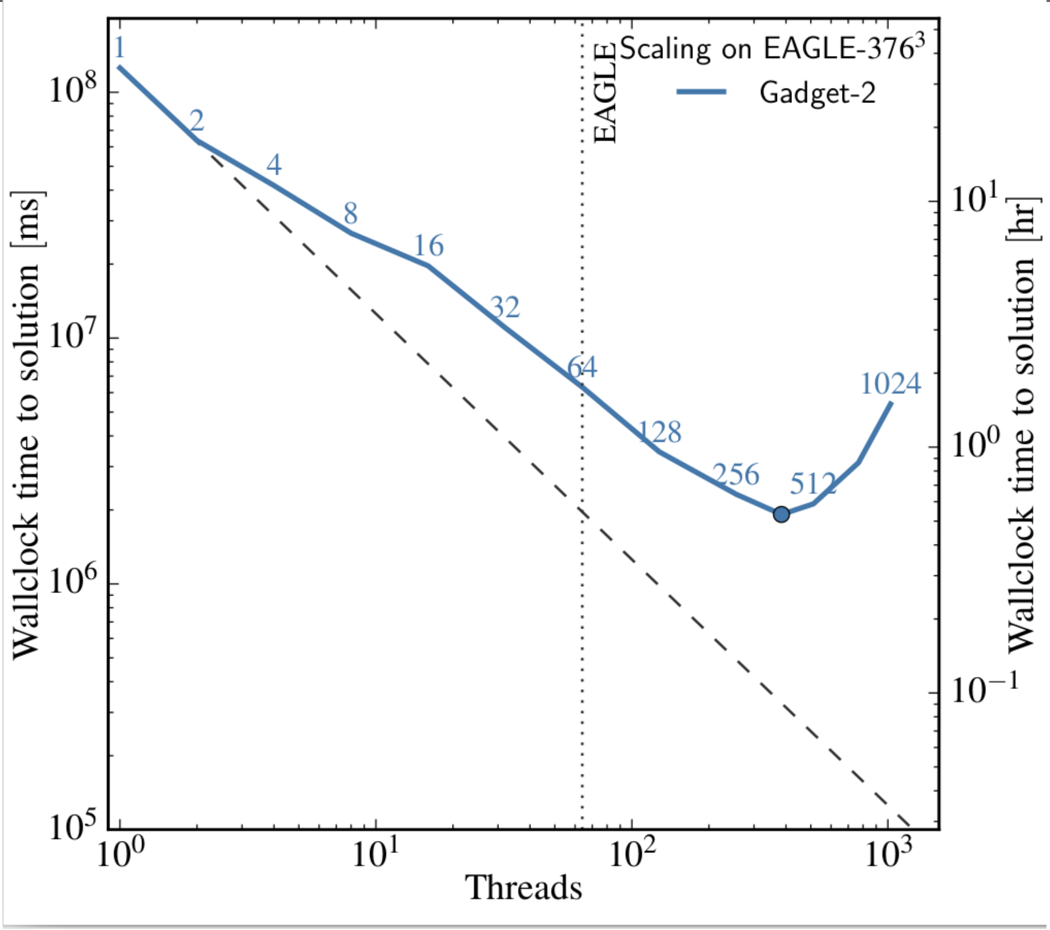


L. Hausammann, Y. Revaz, MS

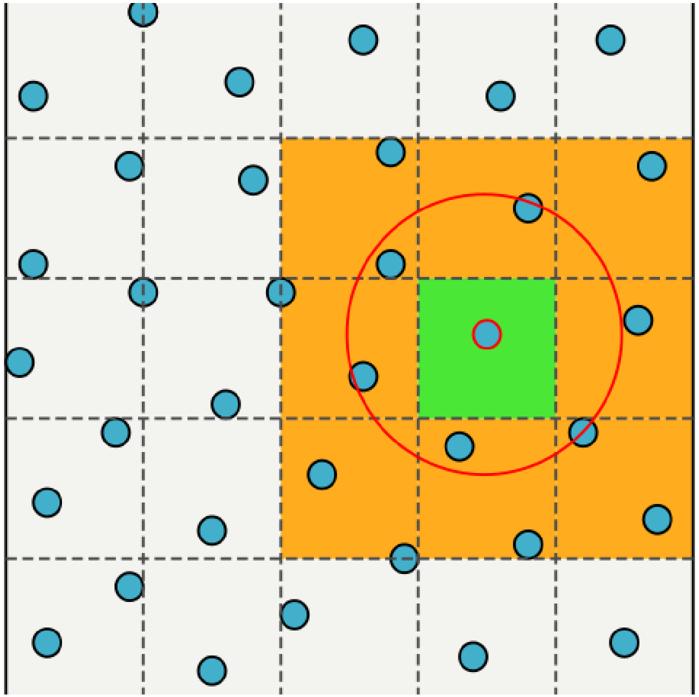
EAGLE code performance



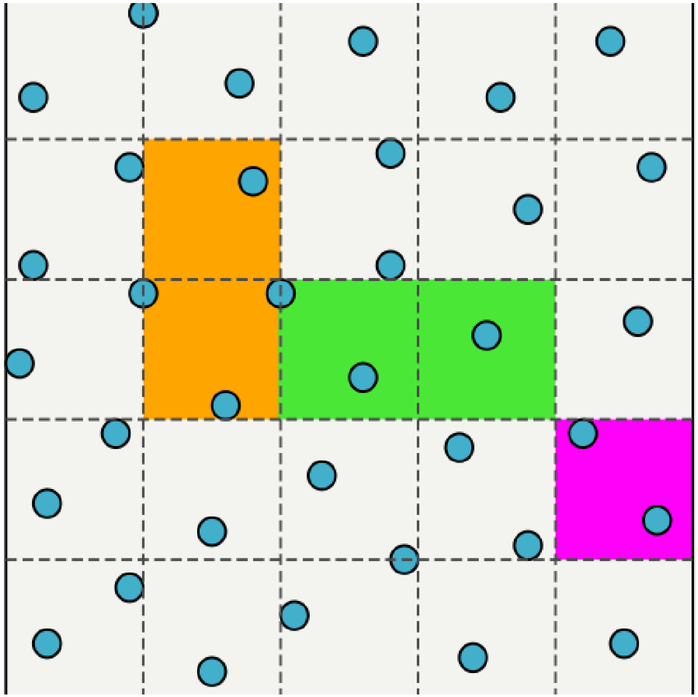
Strong scaling behaviour



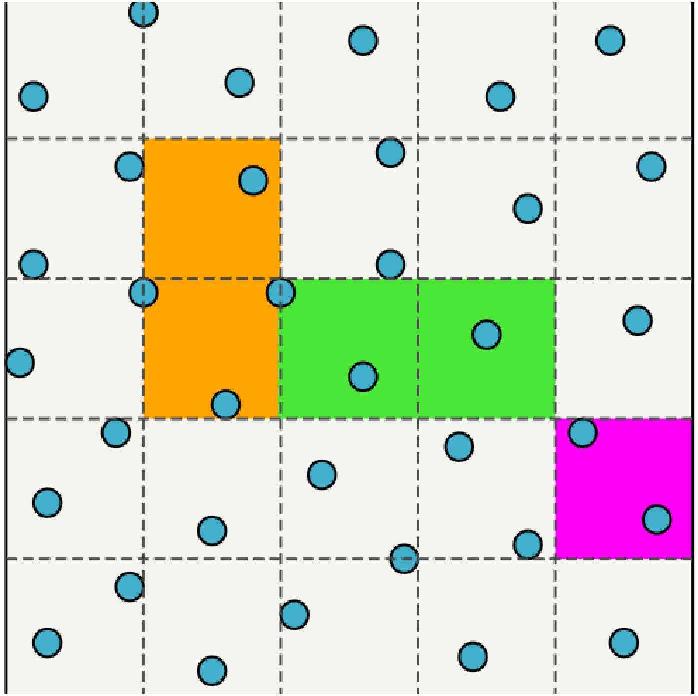
AMR Verlet-list neighbour search



- Target ~500 particles per cell via adaptive mesh refinement.
- Cell size naturally matches particle neighbour search radius.
- Particles only interact with particles in the same cell or any direct neighbouring cell.



- Cells pairs do not need to be processed in any pre-defined order.
- Only need to make sure two threads do not work on the same cell.
- Cell pairs can have vastly different work-loads.



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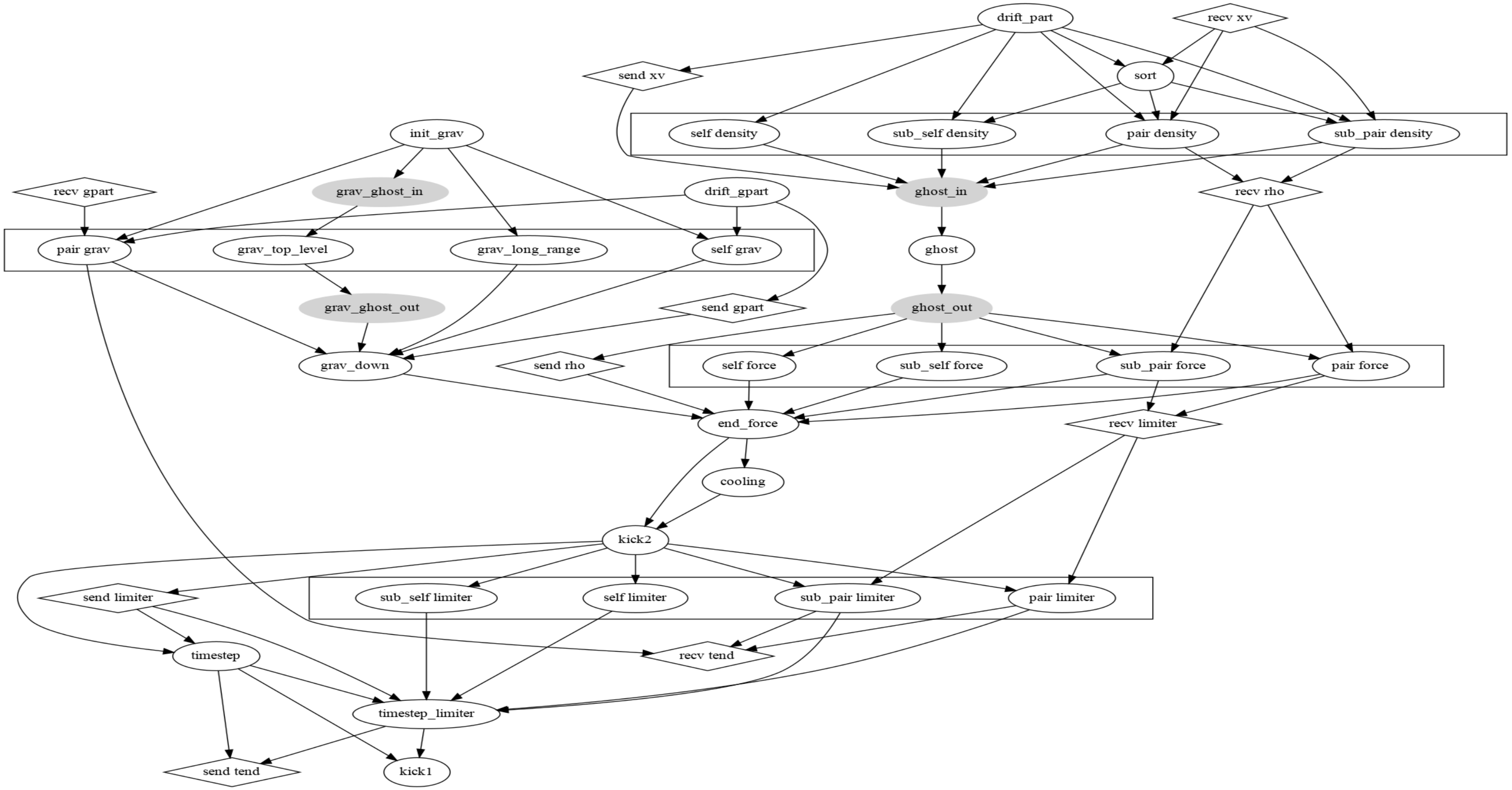
→ Need runtime dynamic scheduling

Task-based parallelism for science case



Task dependencies for SWIFT v0.6.0-1090-ga8e380a5-dirty

Task-based parallelism in action

Task-graph for one time-step. Colours correspond to different task types.
Almost perfect load-balance achieved on 16 cores.

Local time-stepping

Our particle methods for gravity and hydro-dynamics have a linear cost.

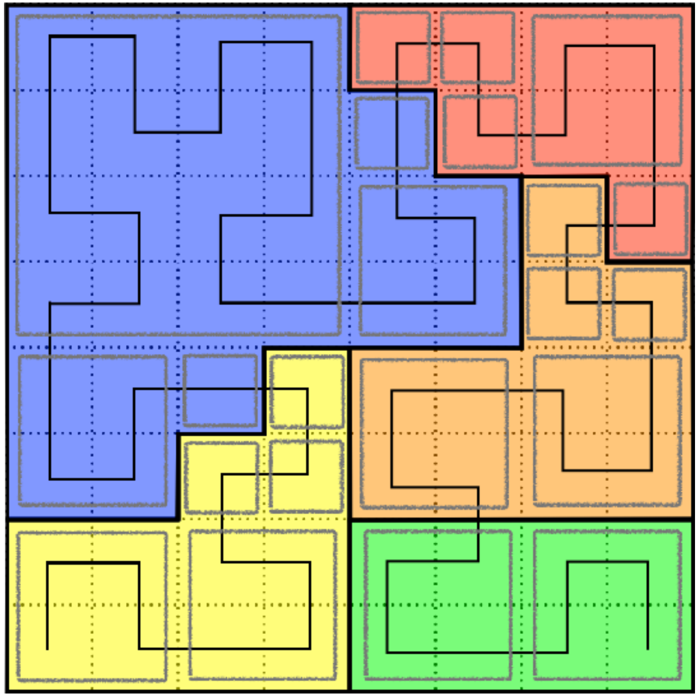
→ By only updating the particles on a short time-step we can gain orders of magnitude in run time.

→ You also kill your scaling.

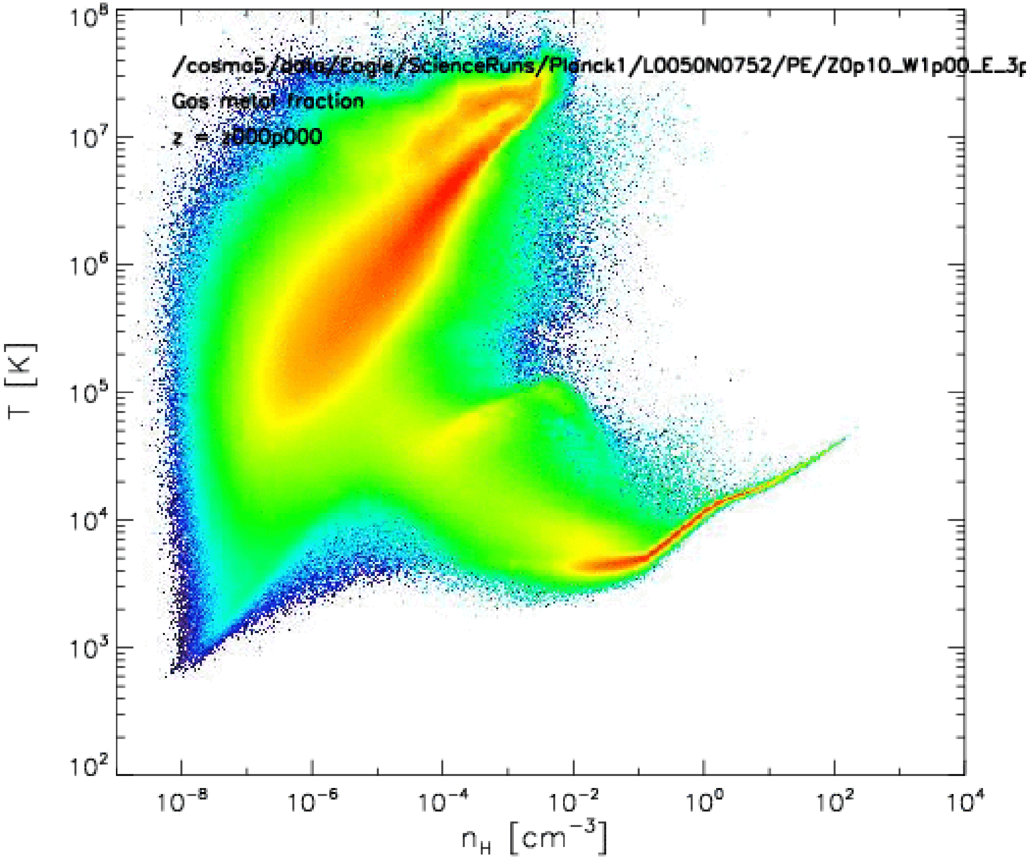
The question is then how to load-balance and parallelize this.
How do you update ~10 particles efficiently on 1000+ nodes?

Domain Decomposition

1. Sort the data along a space-filling curve.
2. Split the curve such that each node gets the same number of particles.
3. Do this at the top-level or close to the top.



Smallest time-steps?



A hand-written solution

- Avoid MPI for small updates.
- The particles with the smallest time-steps should be at the centre of their domains and not require any “halo” particles.
- Small time-steps are at the centre of galaxies.

- Identify galaxies → Grow domains organically around them
→ Get efficient code.

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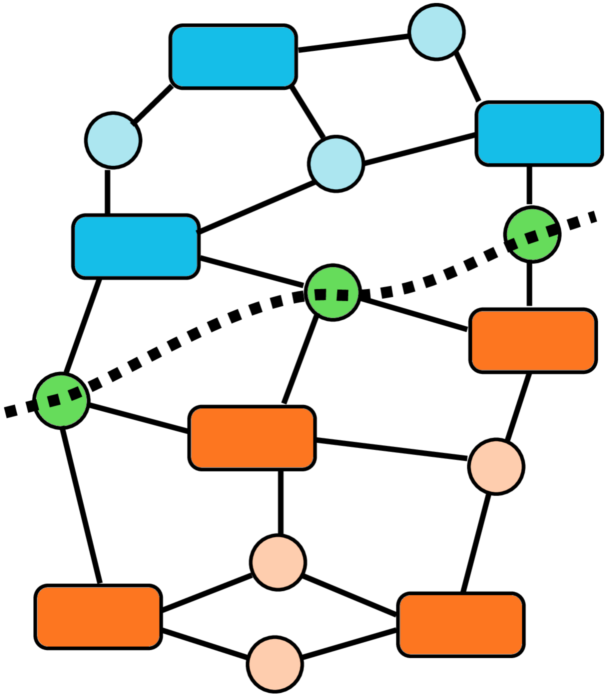
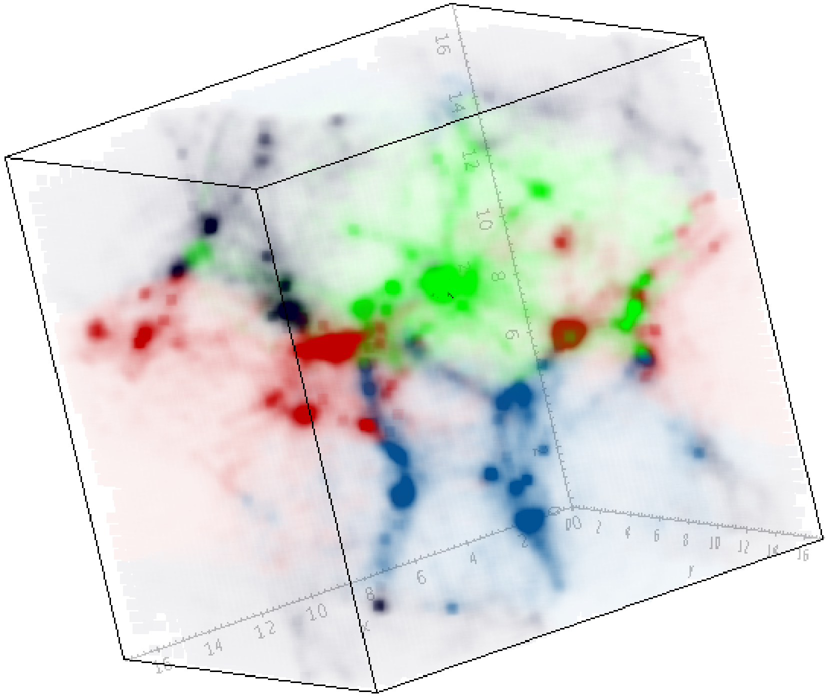
Drawbacks: Not generic. Identifying galaxies is not trivial.

A Graph-based strategy



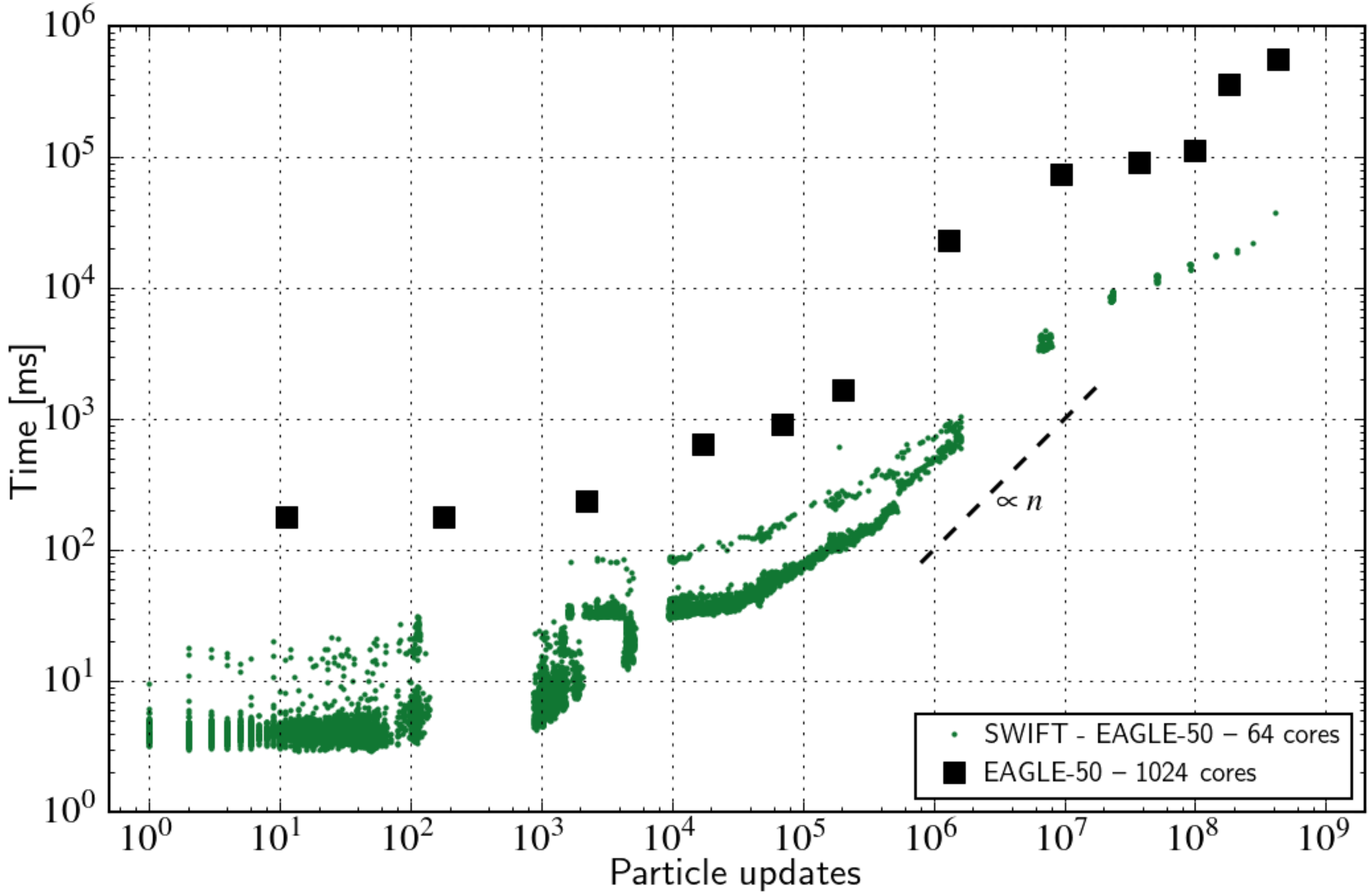
- For each task, we compute the amount of work (=runtime) required.
- We build a graph where the data are nodes and tasks are hyper-edges.
- METIS is used to split the graph such that the work (not the data!) is balanced.
- Extra cost added for communication tasks to minimise them.

What does it look like?

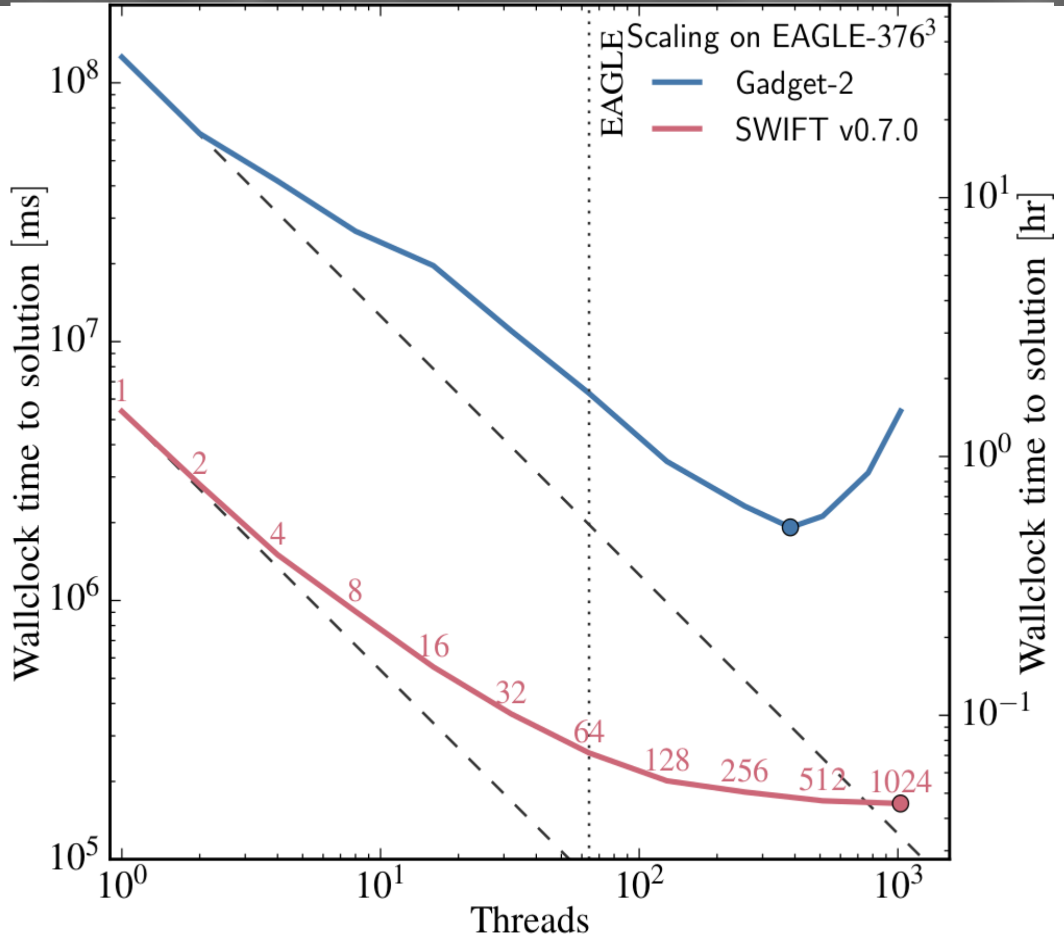


- No regular grid pattern.
- No space-filling curve pattern.
- Good (work) load-balancing by construction.
- The most dense regions are at the centre of their respective domains.

SWIFT code performance



Strong scaling behaviour



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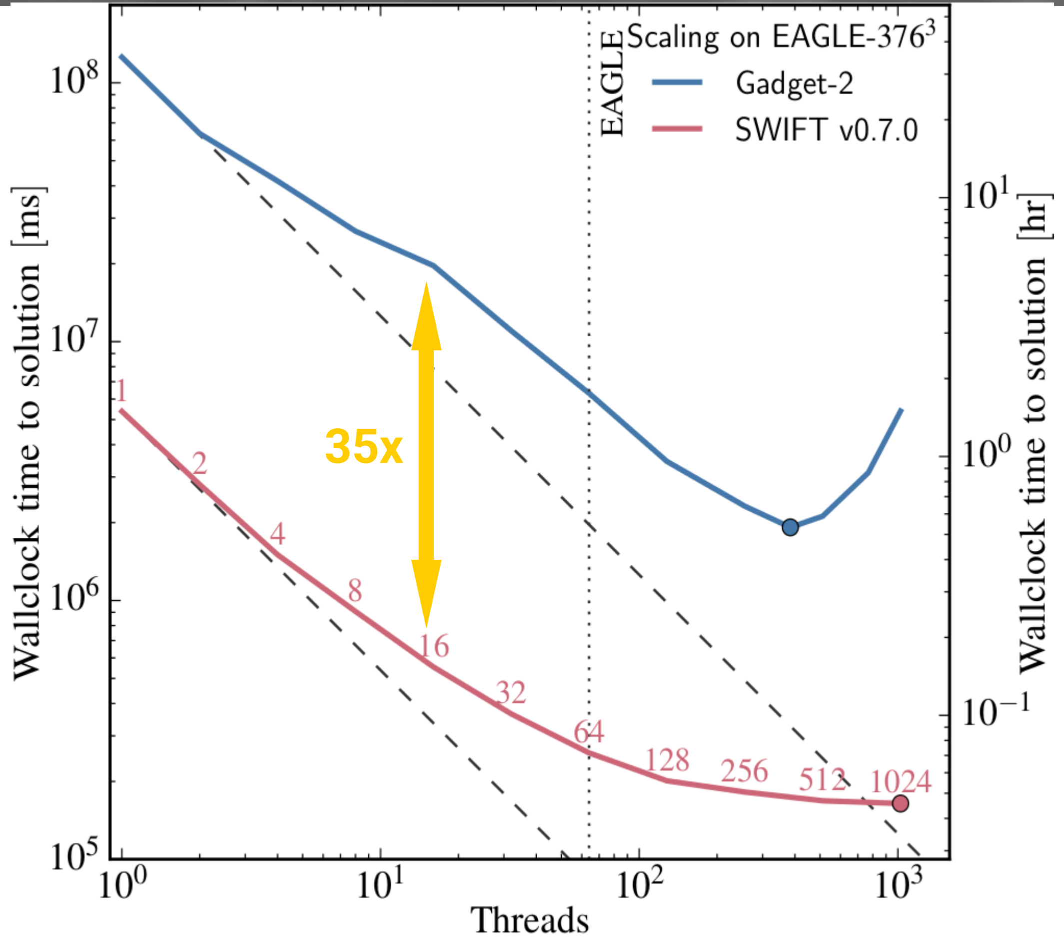
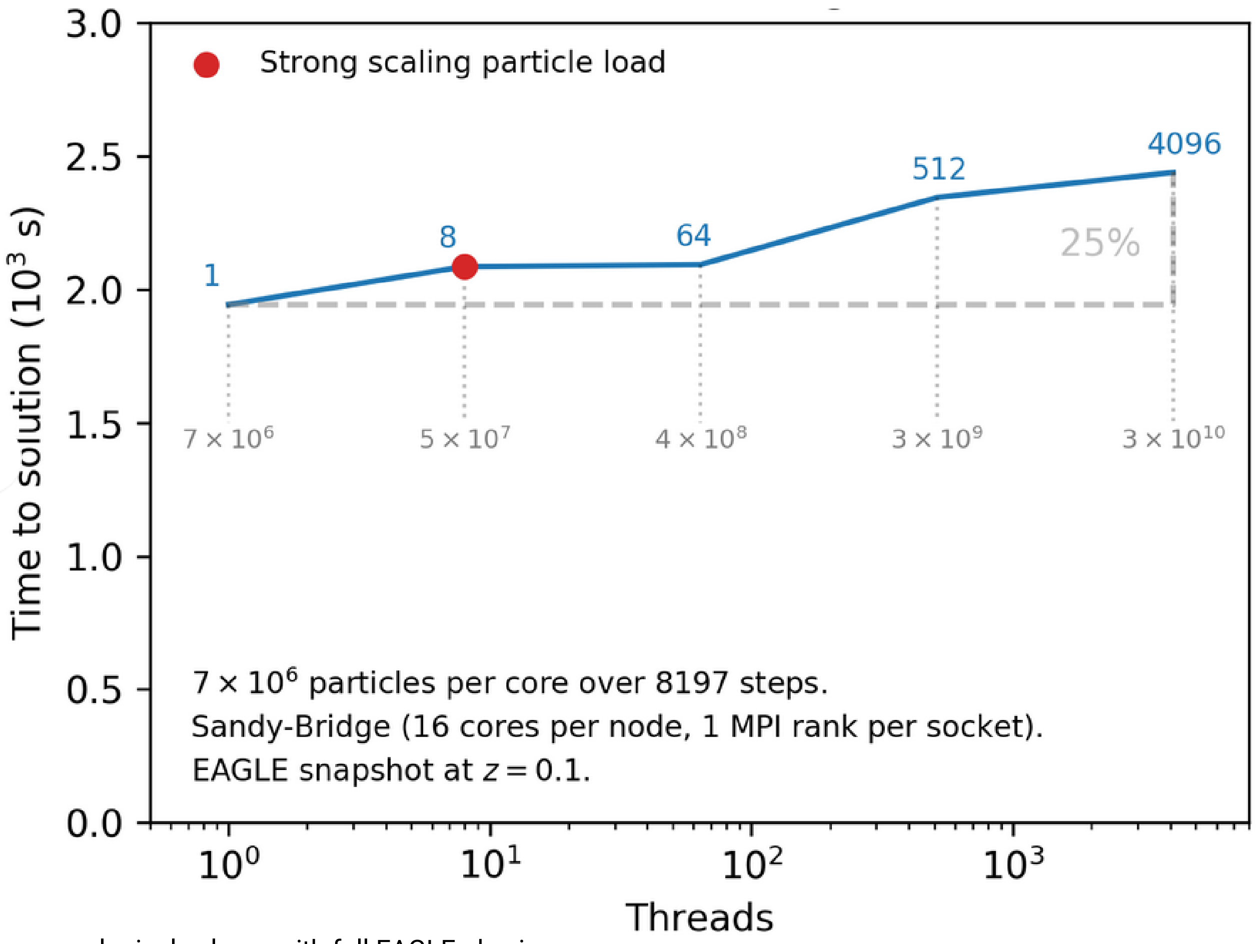


Sustained performance in weak-scaling



Conclusions

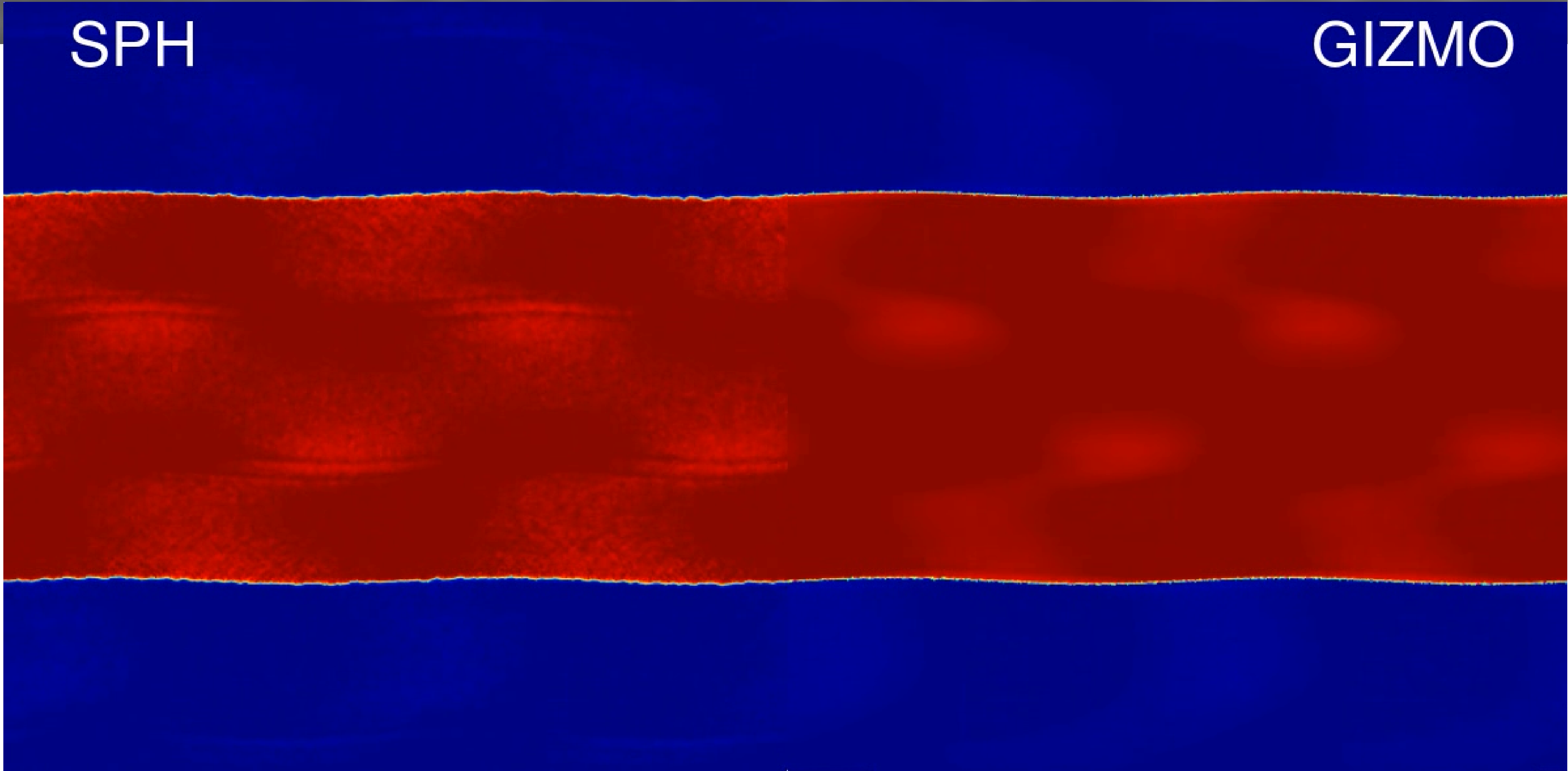
- New algorithms can lead to significant speed-ups over more conventional established methods.

  >30x over Gadget → "half way from peta-scale to exa-scale via algorithms"

- Task-based parallelism as a viable model for actual scientific applications.

  → Not just a research concept.

- The challenge of deep time-step hierarchies requires a rethinking of the domain decomposition algorithms.


SPH
GIZMO