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# Scaling the Plasma Simulation while Conserving the Mass

## A Massively-Parallel Semi-Lagrangian Solver with the Sparse Grid Combination Technique

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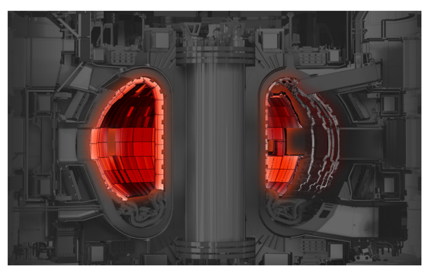


screenshot from http://www.iter.org/mach

Solve a higher-dimensional **6(+1)-d** system for the simulation of fusion plasma micro-turbulence

$$\frac{\partial F}{\partial t} + \nabla_{\vec{x}} F \cdot \frac{\partial \vec{x}}{\partial t} + \nabla_{\vec{v}} F \cdot \frac{\partial \vec{v}}{\partial t} = 0$$

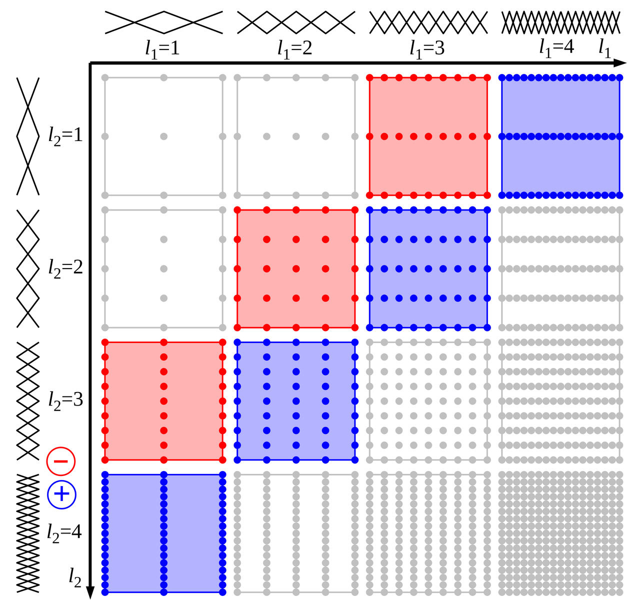
w.r.t. the distribution function $F(x_1, x_2, x_3, v_1, v_2, v_3, t)$

**SeLaLib**

Semi-Lagrangian solver: **conserves** mass, suffers **curse of dimensionality**

$N = \frac{1}{h}$

$\#DOF \sim \mathcal{O}(N^d)$



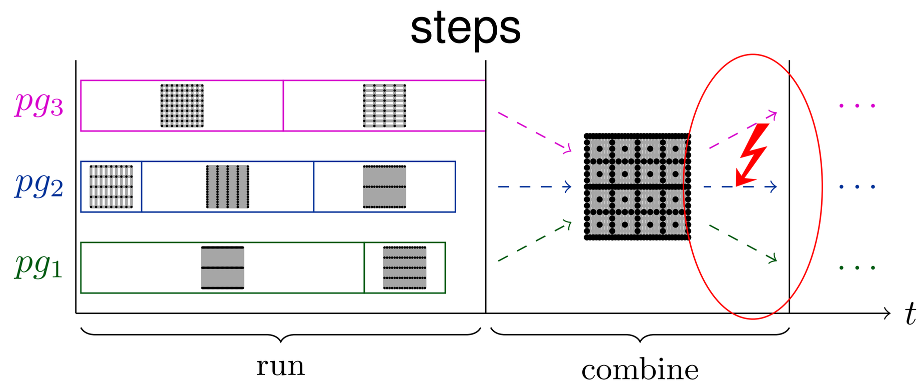

**Sparse Grid Combination Technique**

**mitigates** curse of dimensionality

$\#DOF \sim \mathcal{O}(d(\log N)^{d-1})$

Numerics: loosely-coupled extra level of parallelism

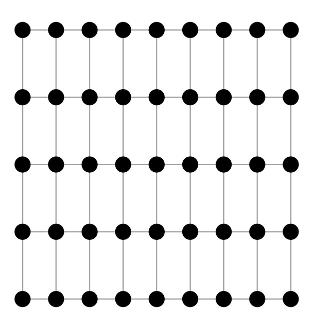
HPC: synchronization only every few time steps



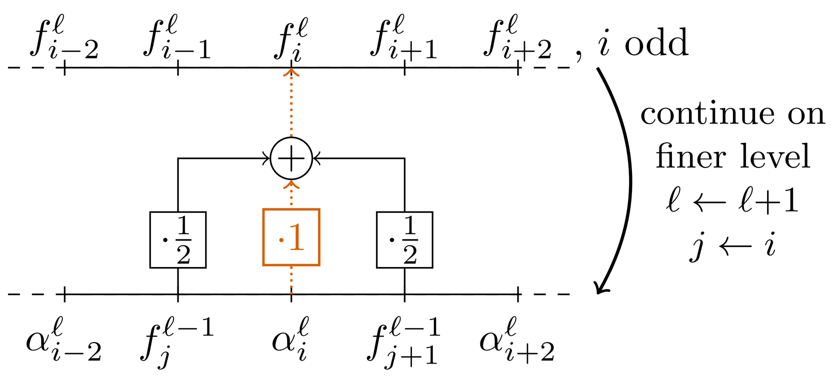

combine step: efficient basis transforms – only first one conserves mass

## Problems: No Conservation of Mass, Numerical Instabilites

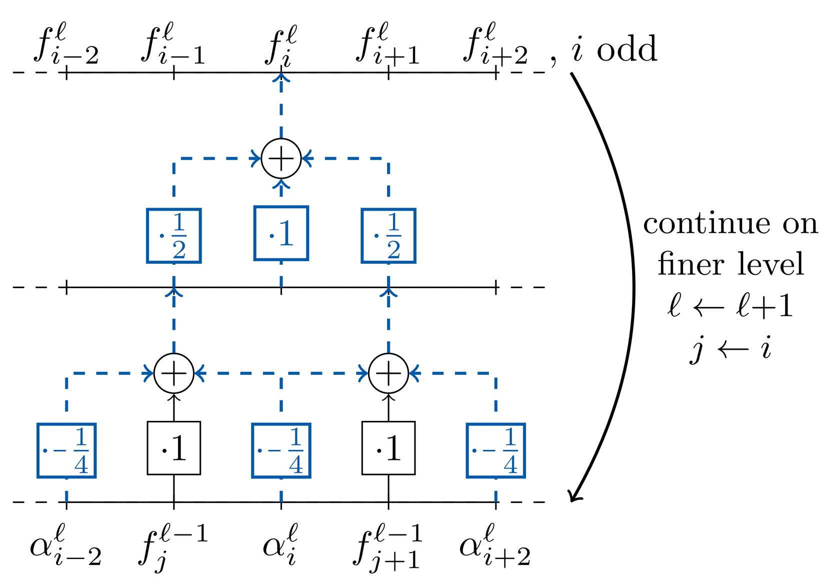
on each component grid, in each of the *d* dimensions



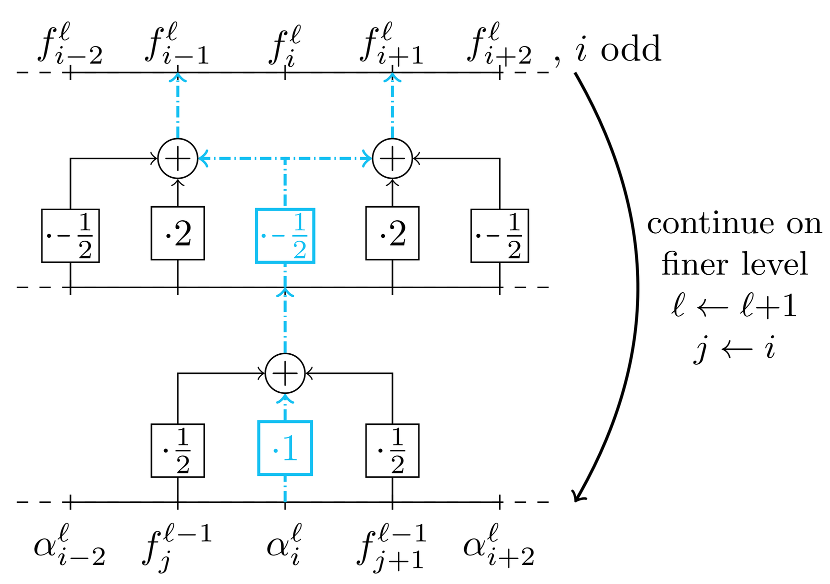
Standard stencil




New: **Mass-conserving** recombination stencils




biorthogonal




full weighting

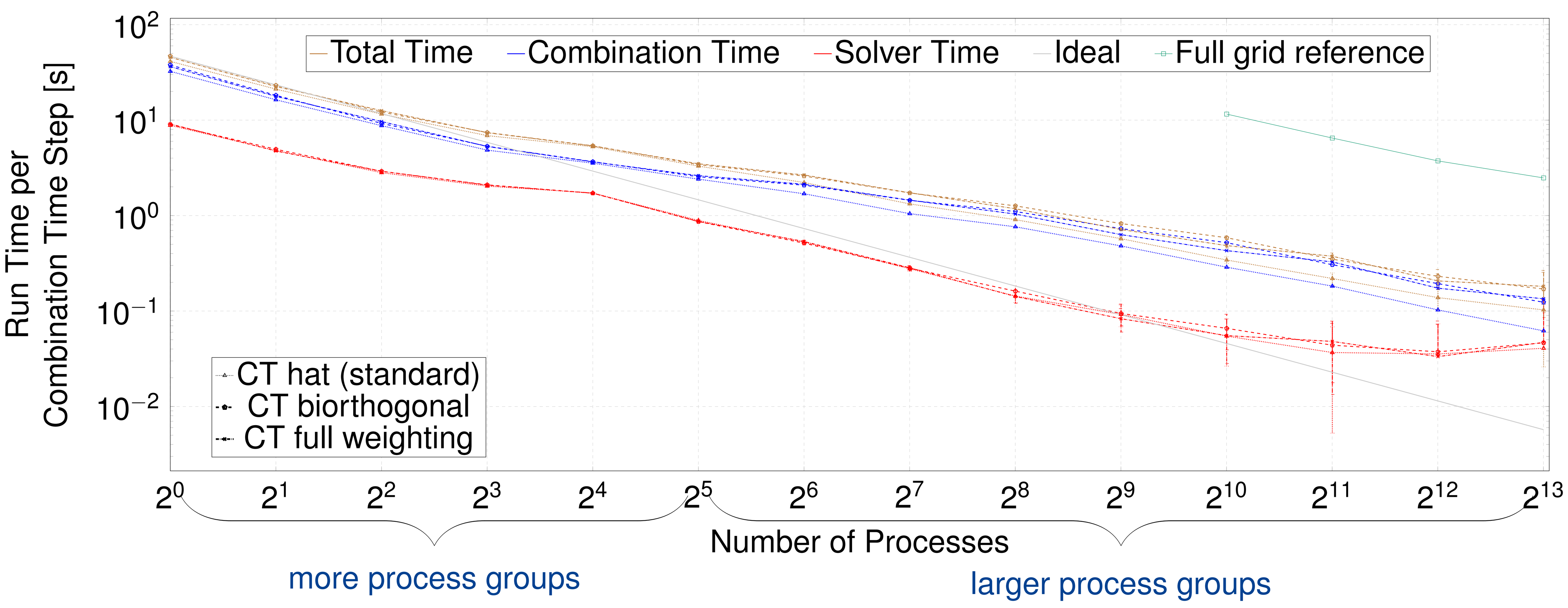
## More Data Dependencies – Problem for HPC?

### Plasma Instability scenario

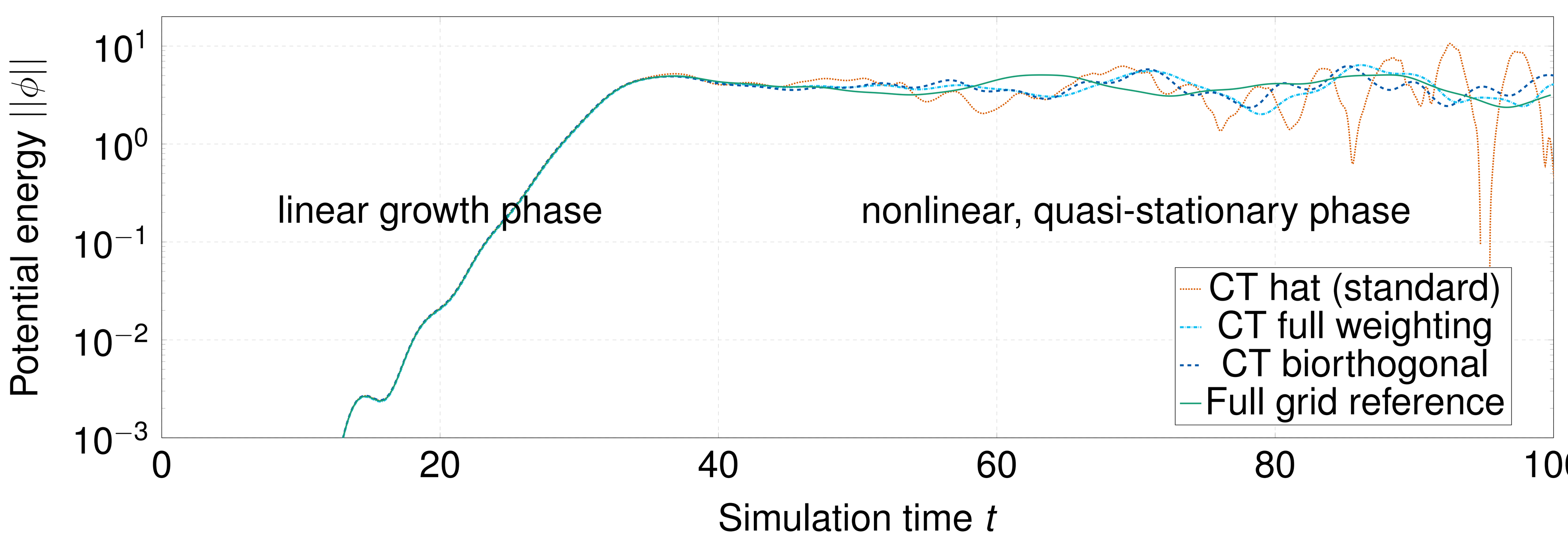
- $\vec{\ell}^{min} = [3, 3, 3, 3, 3, 3]$
- $\vec{\ell}^{max} = [6, 6, 6, 6, 6, 6] = \vec{\ell}^{fg}$
  $\Rightarrow$ 84 grids, 1.14GB total
- recombination every time step (0.01)

### On Hawk

- Hawk: AMD Epyc, 128 cores/node, use up to 64 nodes
- DisCoTec+SeLaLib ; MPI only
- Manager-Worker scheme: Workers' process groups share grids
  $\Rightarrow$ combination volume between process groups: 0.12GB




## Moderate Increase in Compute Time




### Benefits

- mass is conserved
- more accurate solutions (analytical advection scenario: factor $\approx$ 3!)
- Combination Technique's extra parallelism has negligible runtime overhead
- adaptivity possible
- stable solutions

## Accurate Solutions without Curse of Dimensionality!

## References

The simulations were performed on the national supercomputer HPE Apollo Hawk at the High Performance Computing Center Stuttgart (HLRS) under the grant number 12985.

[1] Katharina Kormann, Klaus Reuter, and Markus Rampp. "A massively parallel semi-Lagrangian solver for the six-dimensional Vlasov–Poisson equation". (2019).
[2] Frank Koster. "Multiskalen-basierte Finite-Differenzen-Verfahren auf adaptiven dünnen Gittern". Thesis. Universitäts- und Landesbibliothek Bonn, 2002.
[3] Rafael Lago et al. "EXAHD: A Massively Parallel Fault Tolerant Sparse Grid Approach for High-Dimensional Turbulent Plasma Simulations". 2020.

**Replication data at** `https://doi.org/10.18419/darus-2784`