Stockholm University

Numerical non-LTE 3D radiative transfer using a multigrid method

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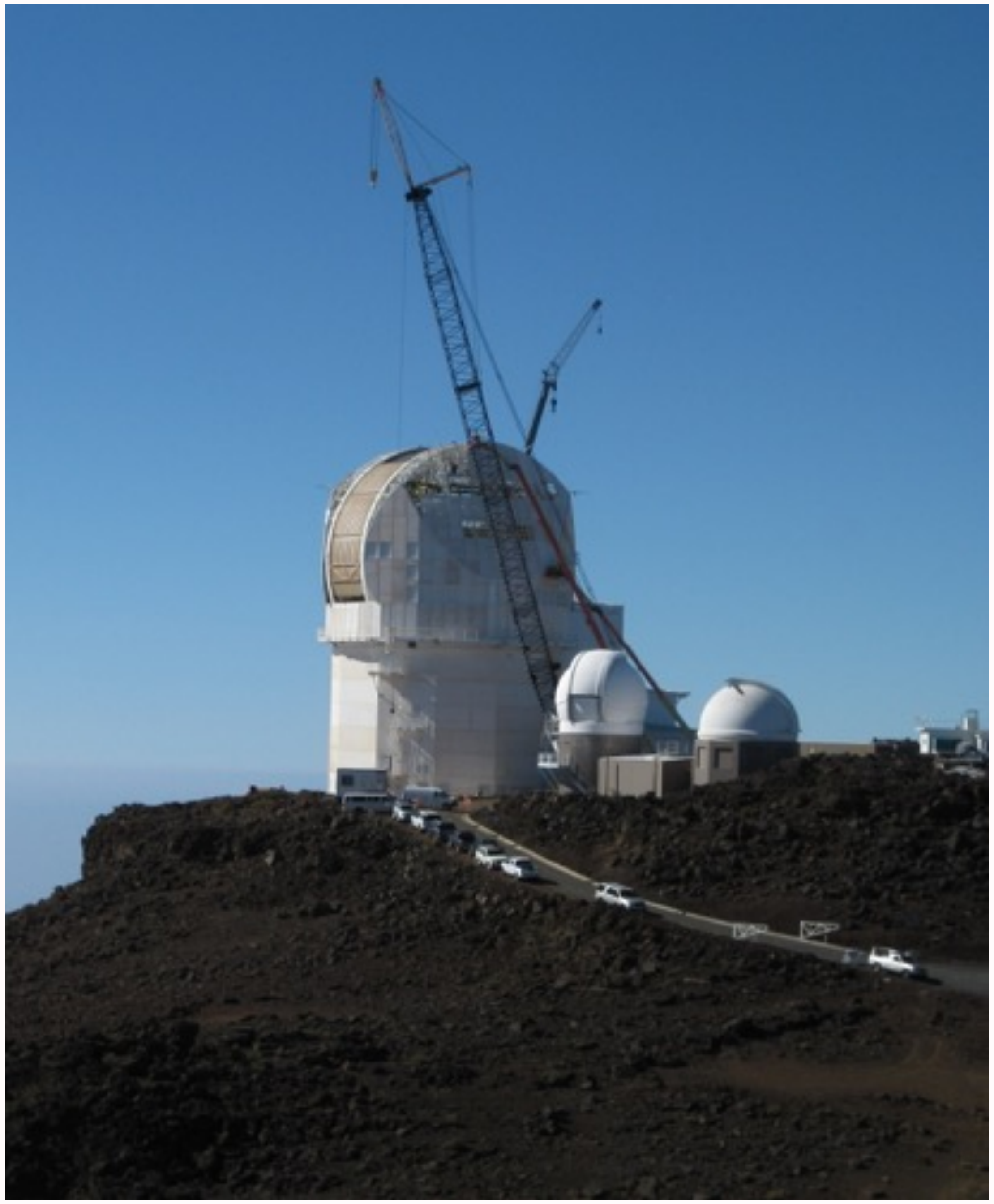
Next generation instruments

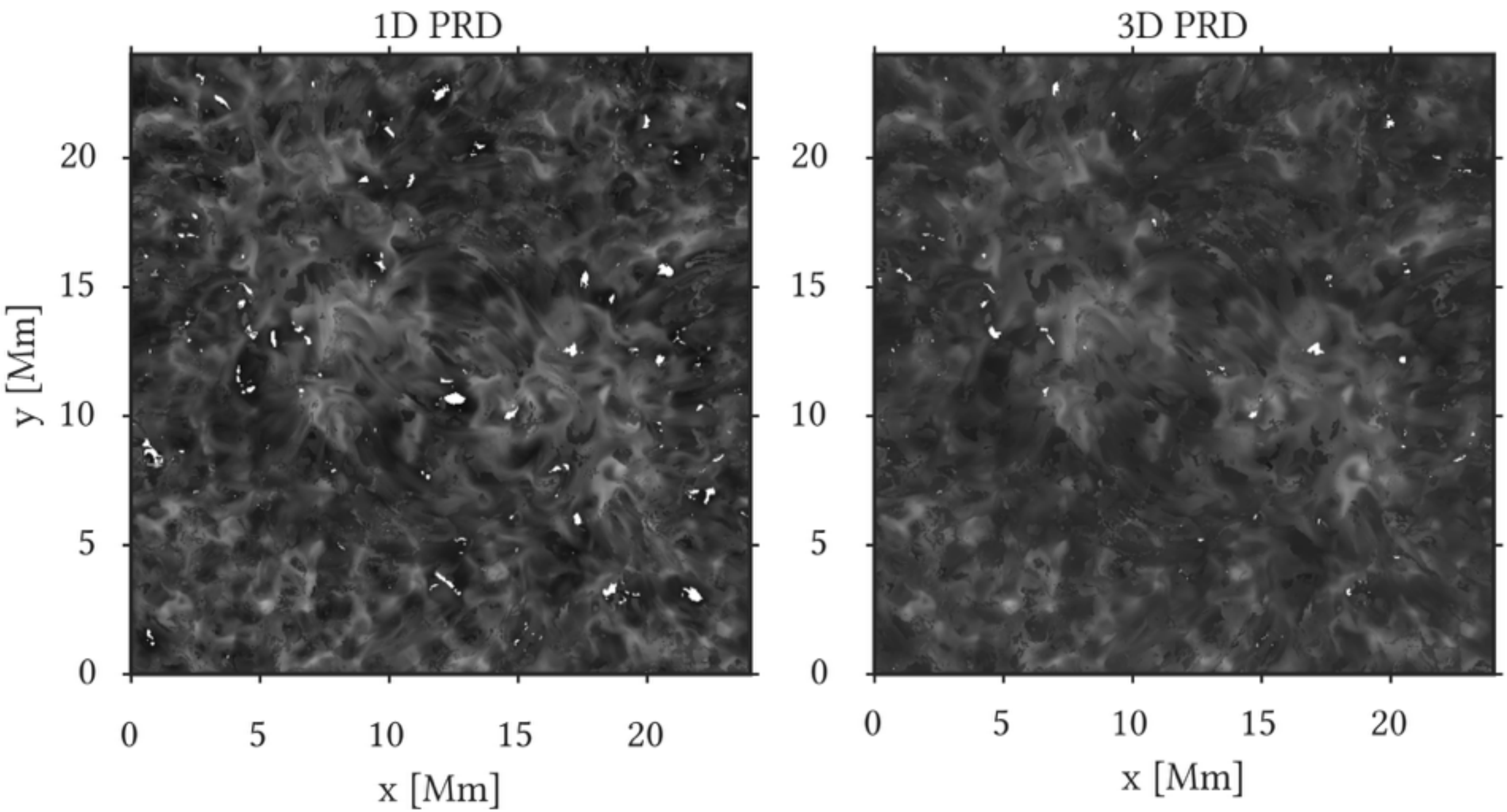
SST/CHROMIS

DKIST 4-meter



National Solar Observatory/AURA/NSF
January 12, 2016. Photo by Heather Marshall.

Partial redistribution: Ca II K_{2v}



PRD increases computational work with a **factor 10** compared to CRD

Sukhorukov & Leenaarts (2016)

Non-LTE radiative transfer

- Intensity depends on 6D parameter space
- Intensity is non-local
- The problem is non-linear
- MALI scales as $\mathcal{O}\left(n_{points}^2\right)$ *(Rybicki & Hummer, 1991)*

SE equilibrium equation

$$n_i \sum_{i \neq j}^{n_l} P_{ij}(I_\nu) - \sum_{i \neq j}^{n_l} n_j P_{ji}(I_\nu) = 0$$

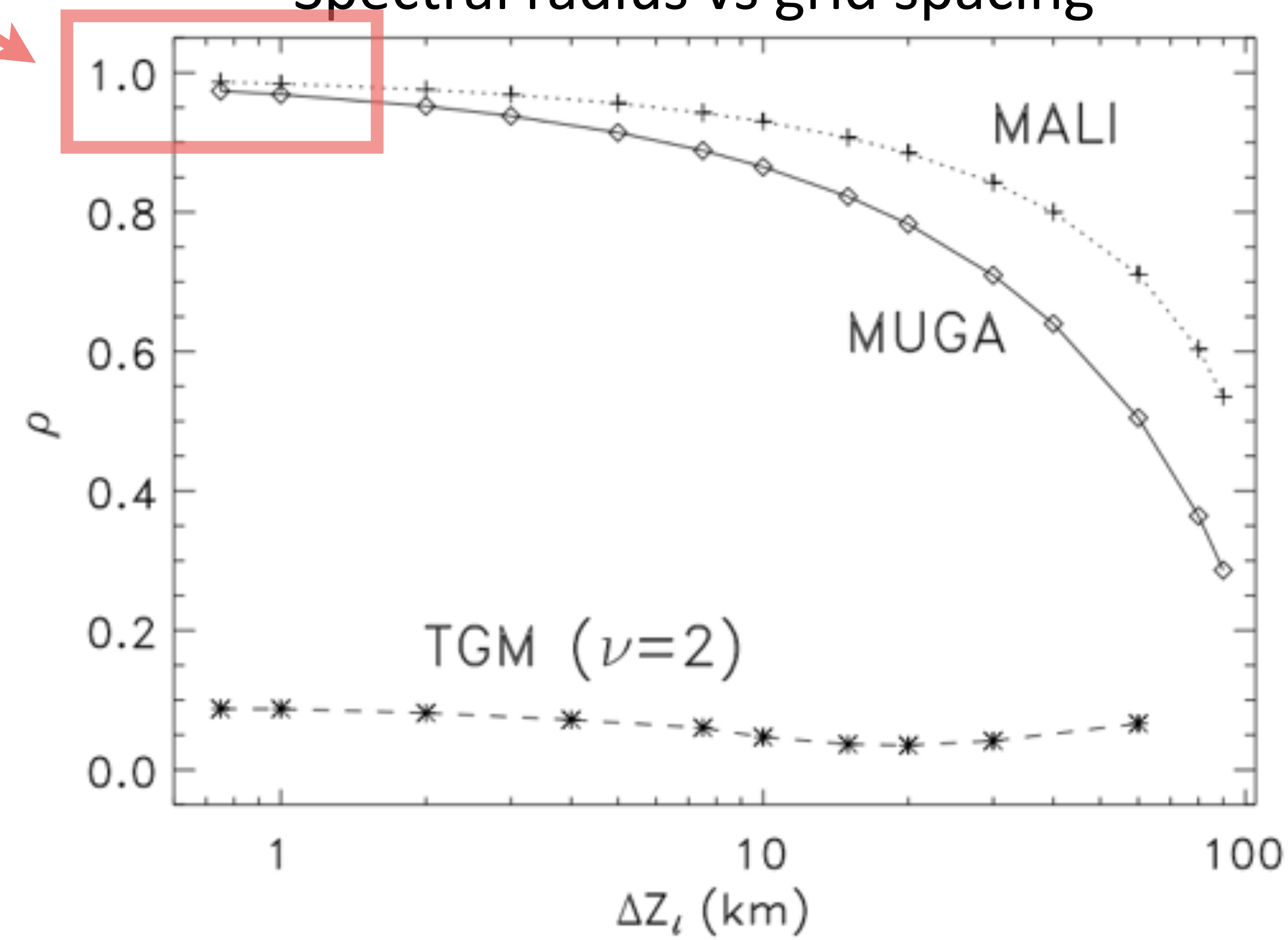
Transport equation

$$\frac{dI}{d\tau_\nu(n_i)} = S_\nu(n_i) - I_\nu$$

Radiative transfer with Multigrid

«*False convergence*» will occur (similar to Lambda iteration)

Spectral radius vs grid spacing

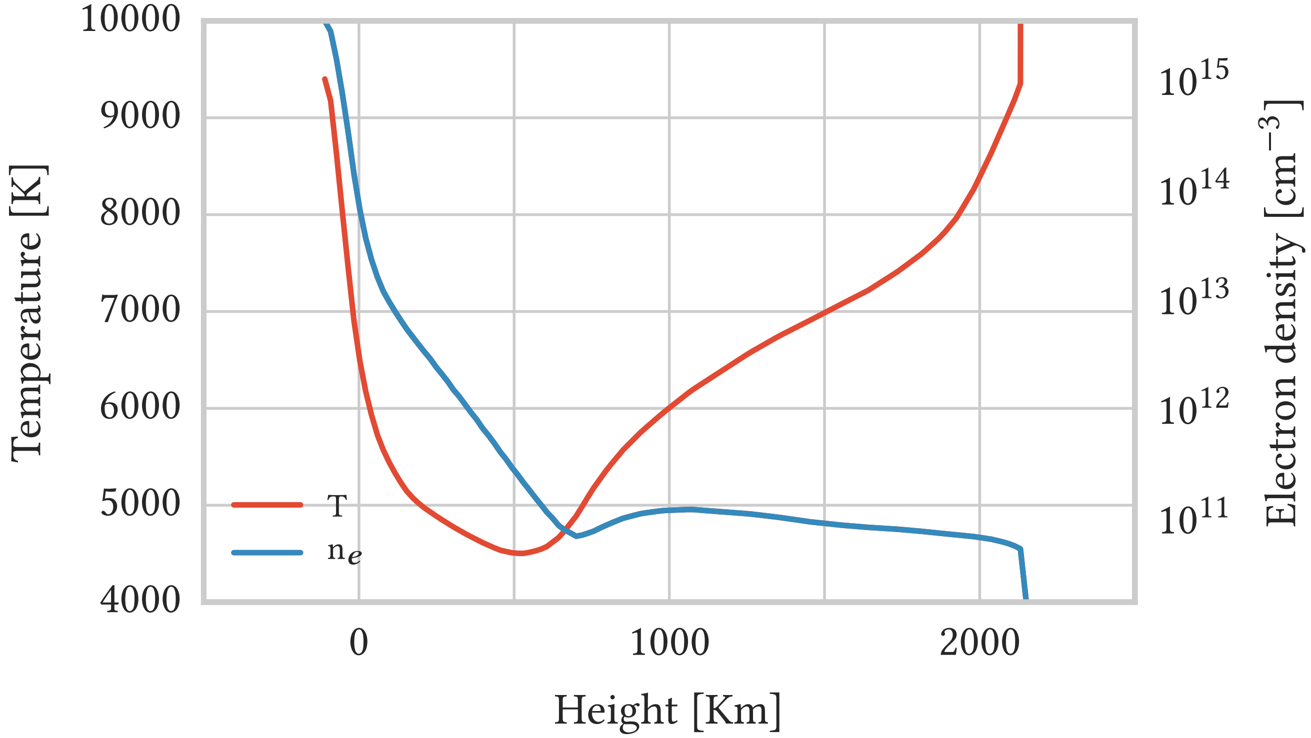


P. Fabiani Bendicho et al (1997)

- *O. Steiner (1990)* proved that multigrid works with RT problem
- *Väth (1994)* multigrid requires large model atmospheres in 3D
- *P. Fabiani Bendicho et al (1997)* MUGA with non-linear multigrid in 1D and 2D
- *J. Stepan & J. Trujillo Bueno (2013)* implemented in 3D with MALI

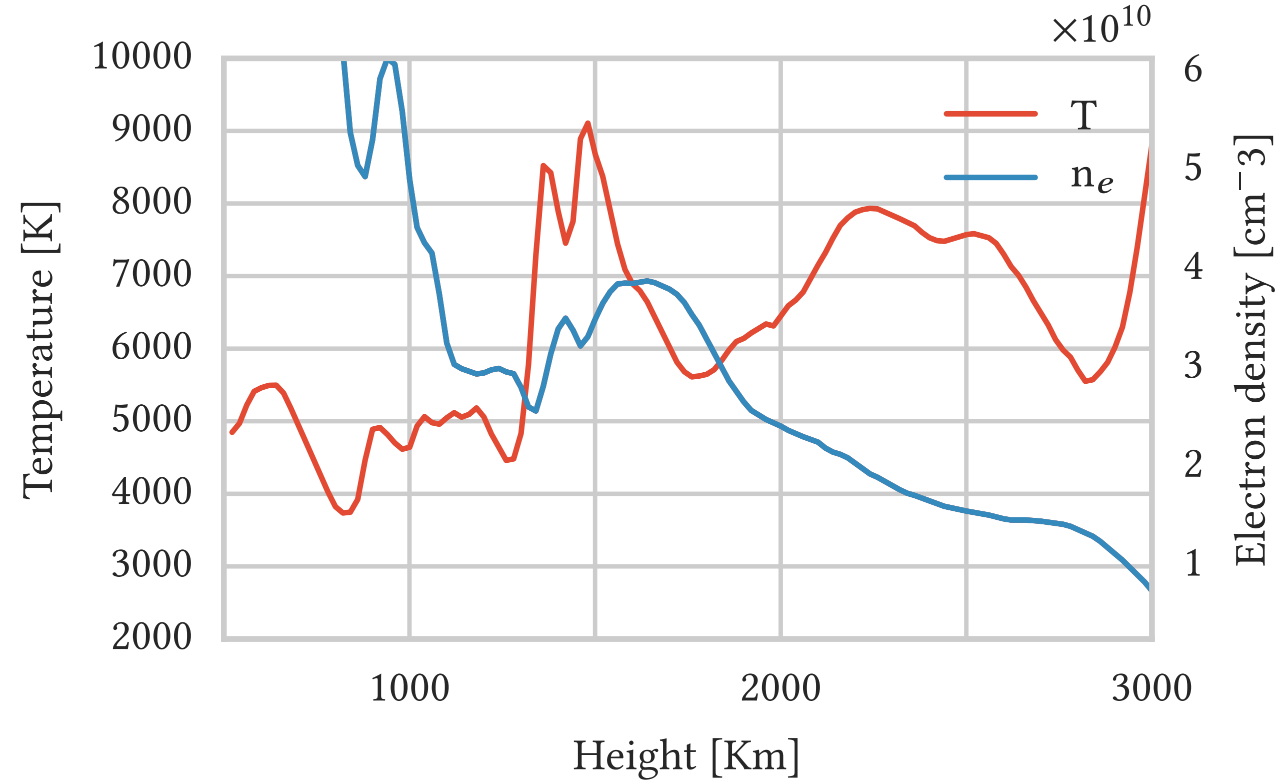
Model atmosphere

FAL-C



(Fontenla et al. 1993)

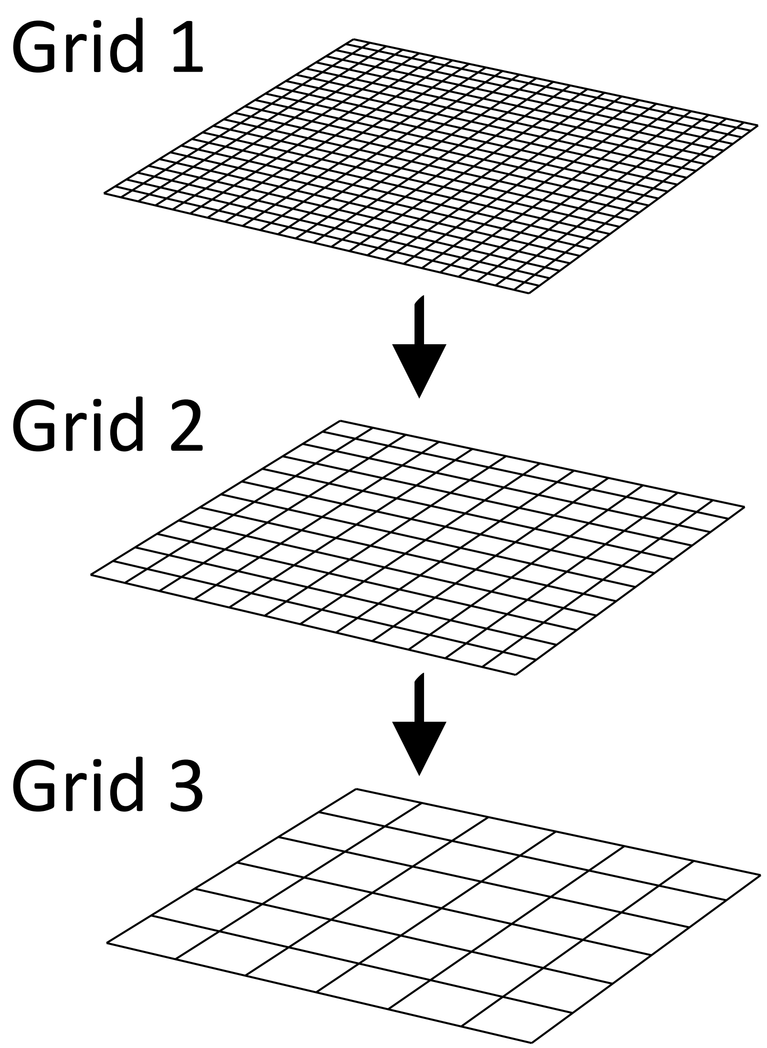
Extracted column from Bifrost 504x504x497



(Carlsson et al. 2016)

Idea of multigrid

Atmosphere



SE equilibrium equation

$$n_i \sum_{i \neq j}^{n_l} P_{ij}(I_\nu) - \sum_{i \neq j}^{n_l} n_j P_{ji}(I_\nu) = 0$$

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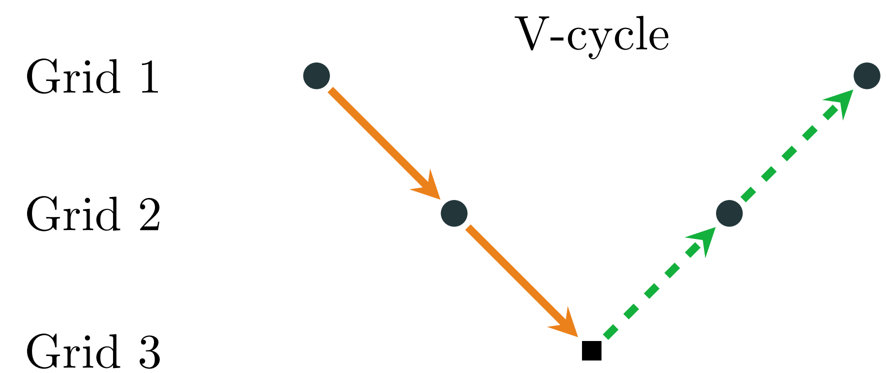
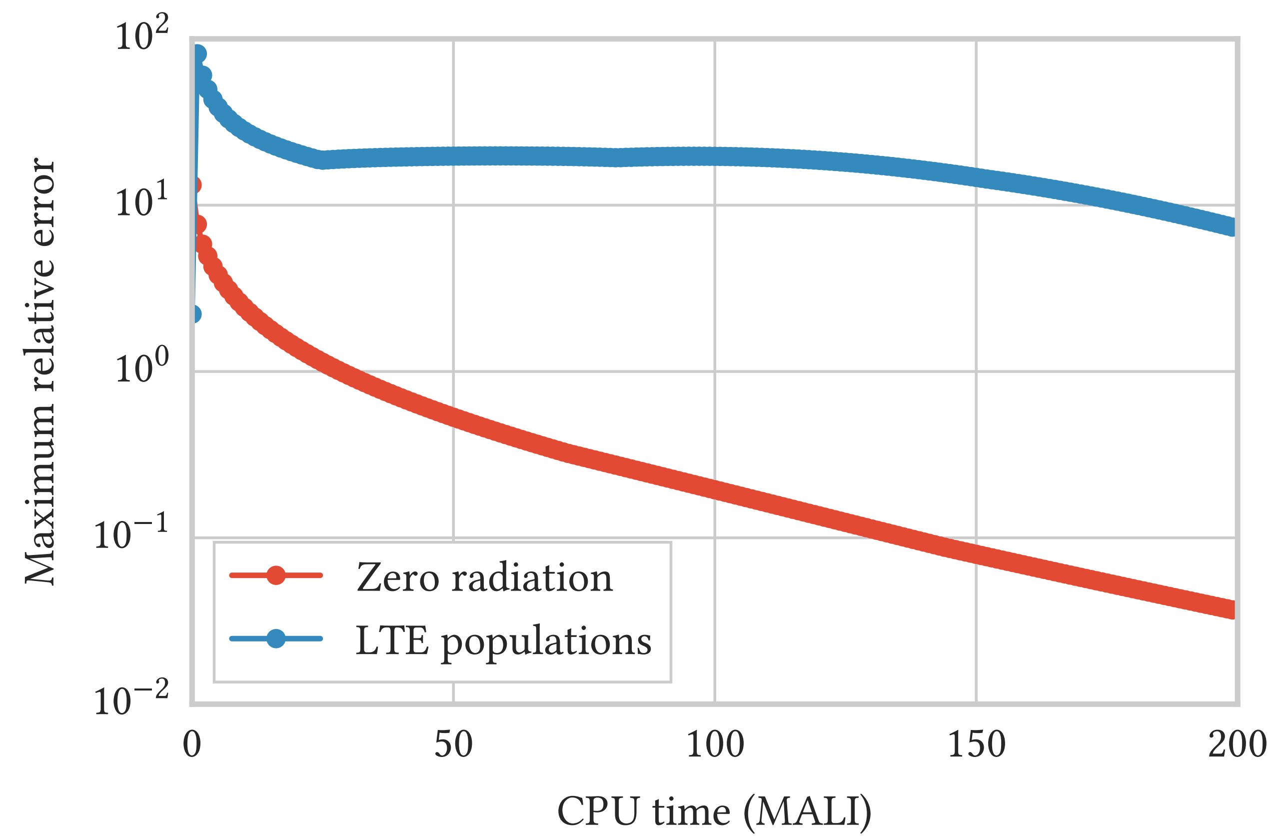


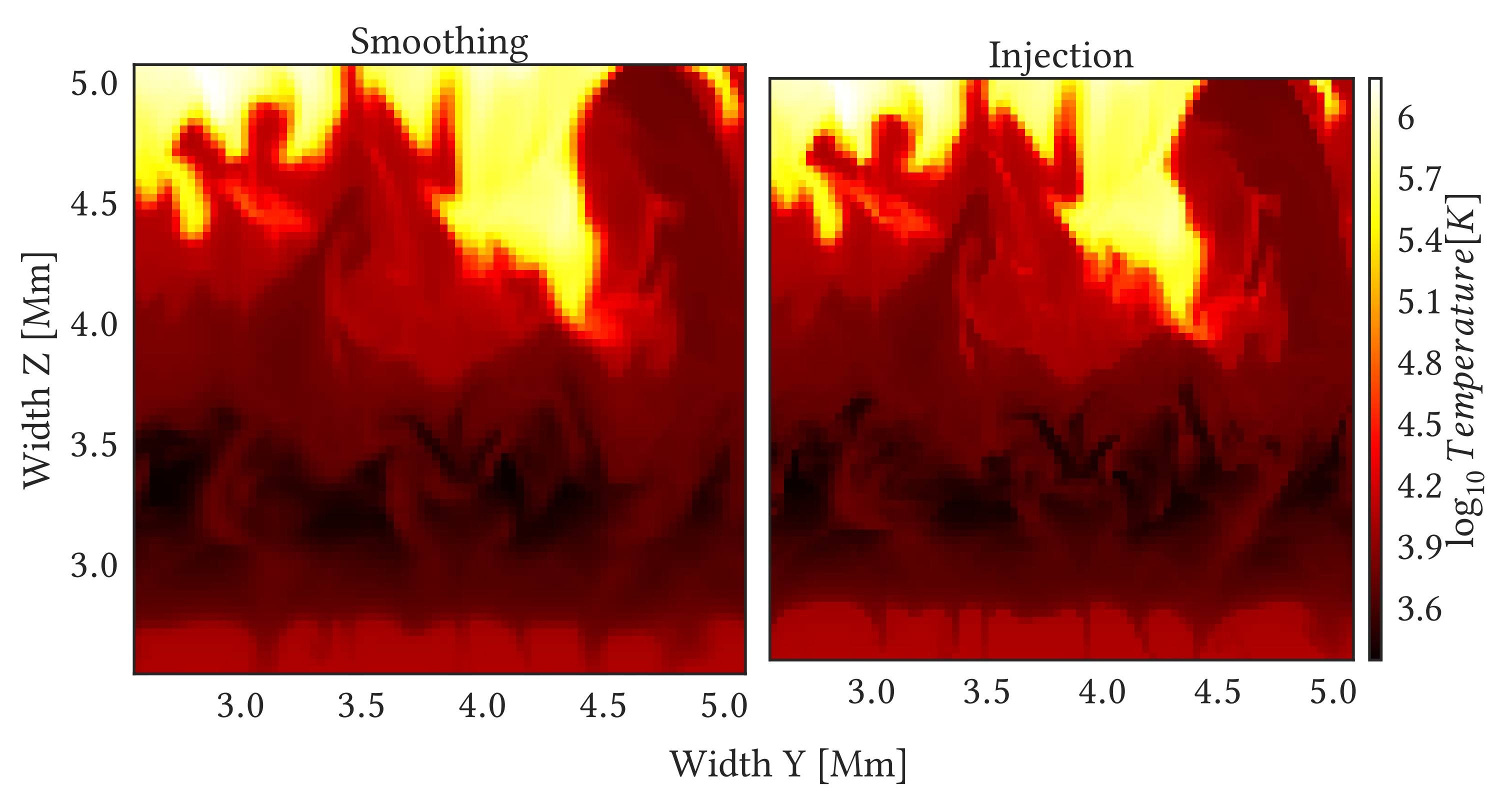
Negative populations allowed at the coarse grid!

Solutions for negative population

Initialize the population with zero-radiation field



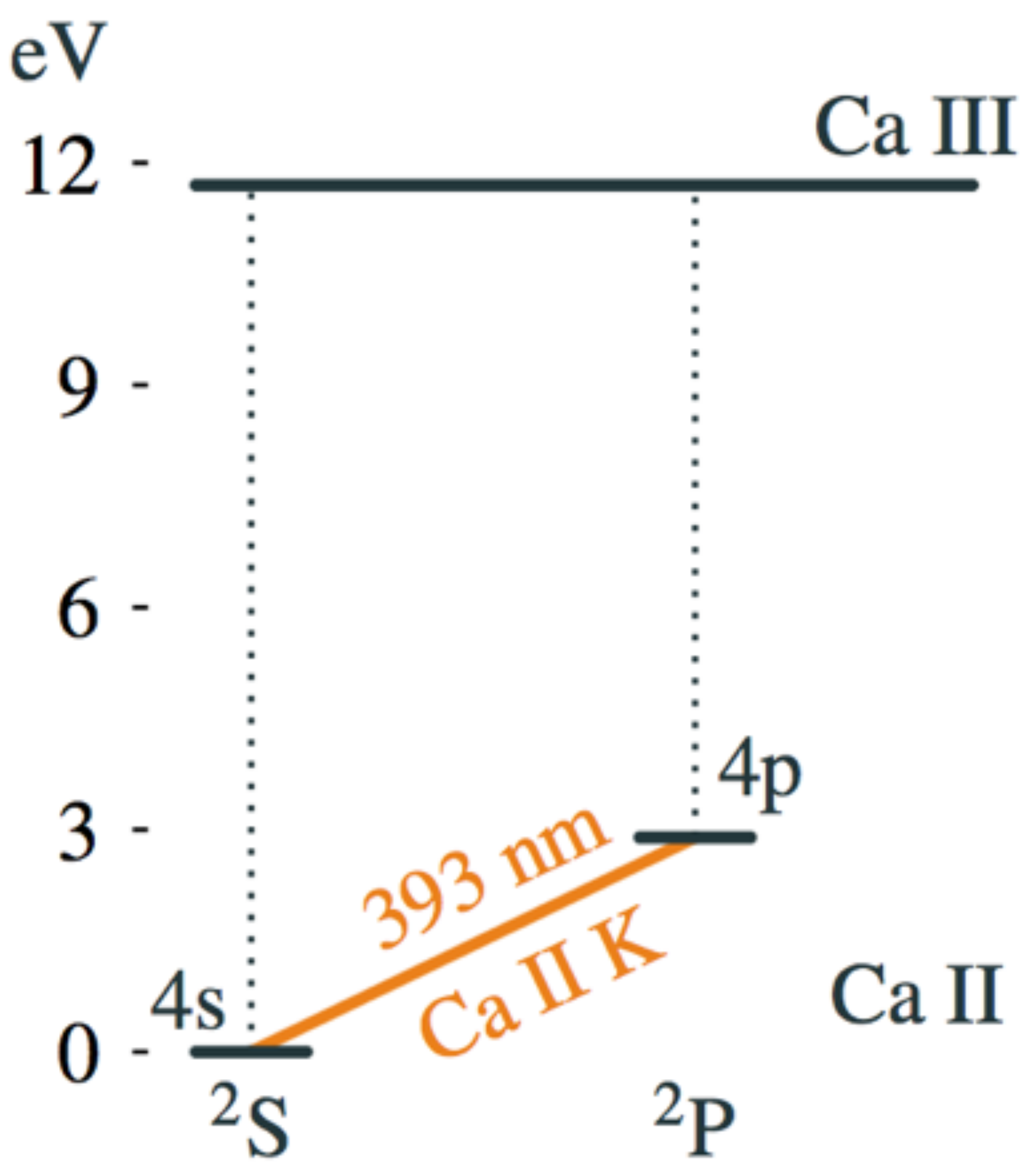
Resolve the problem on the coarse grid



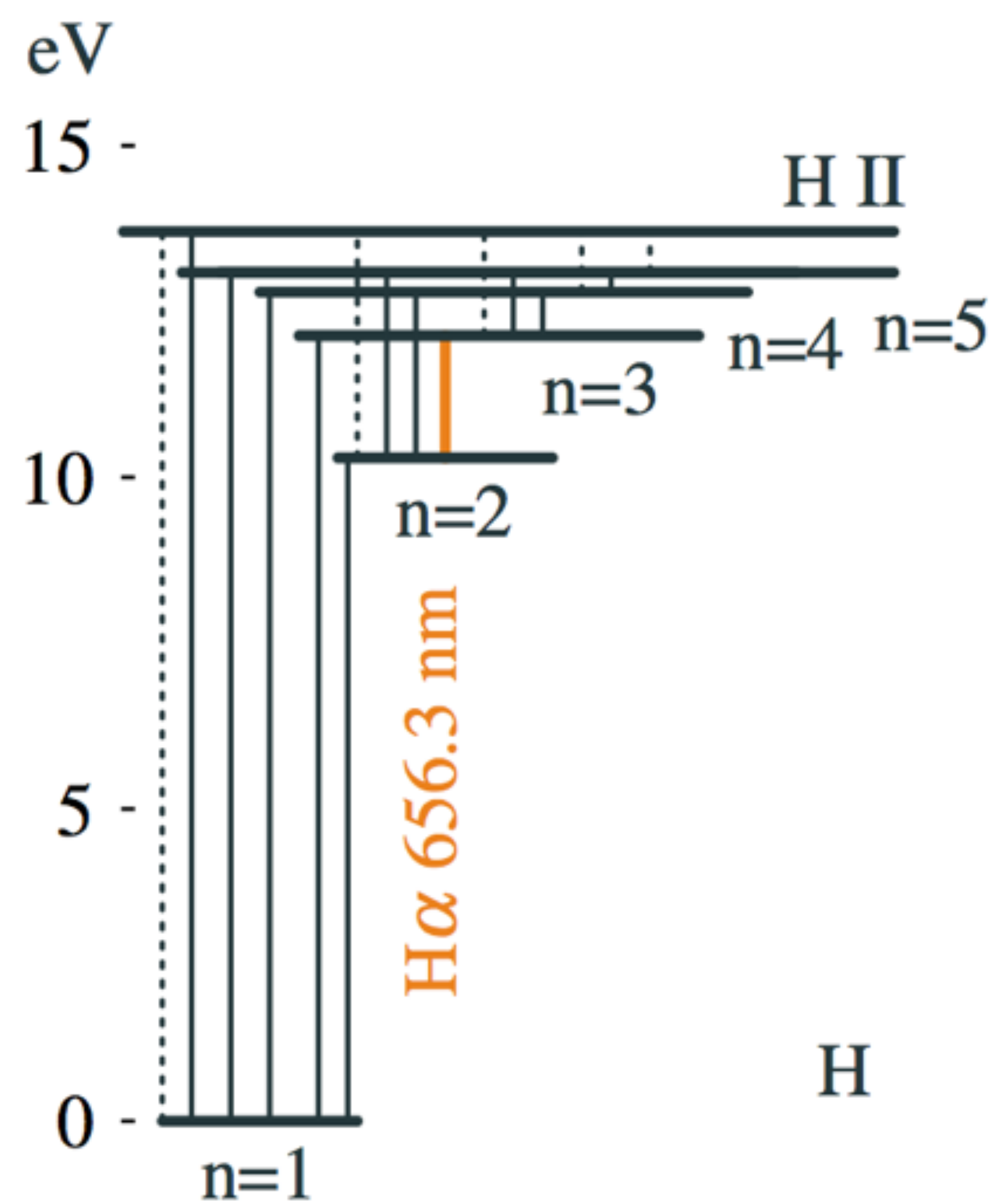
Setup: Multi3D

- Non-linear multigrid in Multi3D *(Leenaarts & Carlsson 2009)*
- Multilevel accelerated lambda iteration (MALI)
- 3D short characteristic solver
- Domain decomposition

Setup: Model atoms

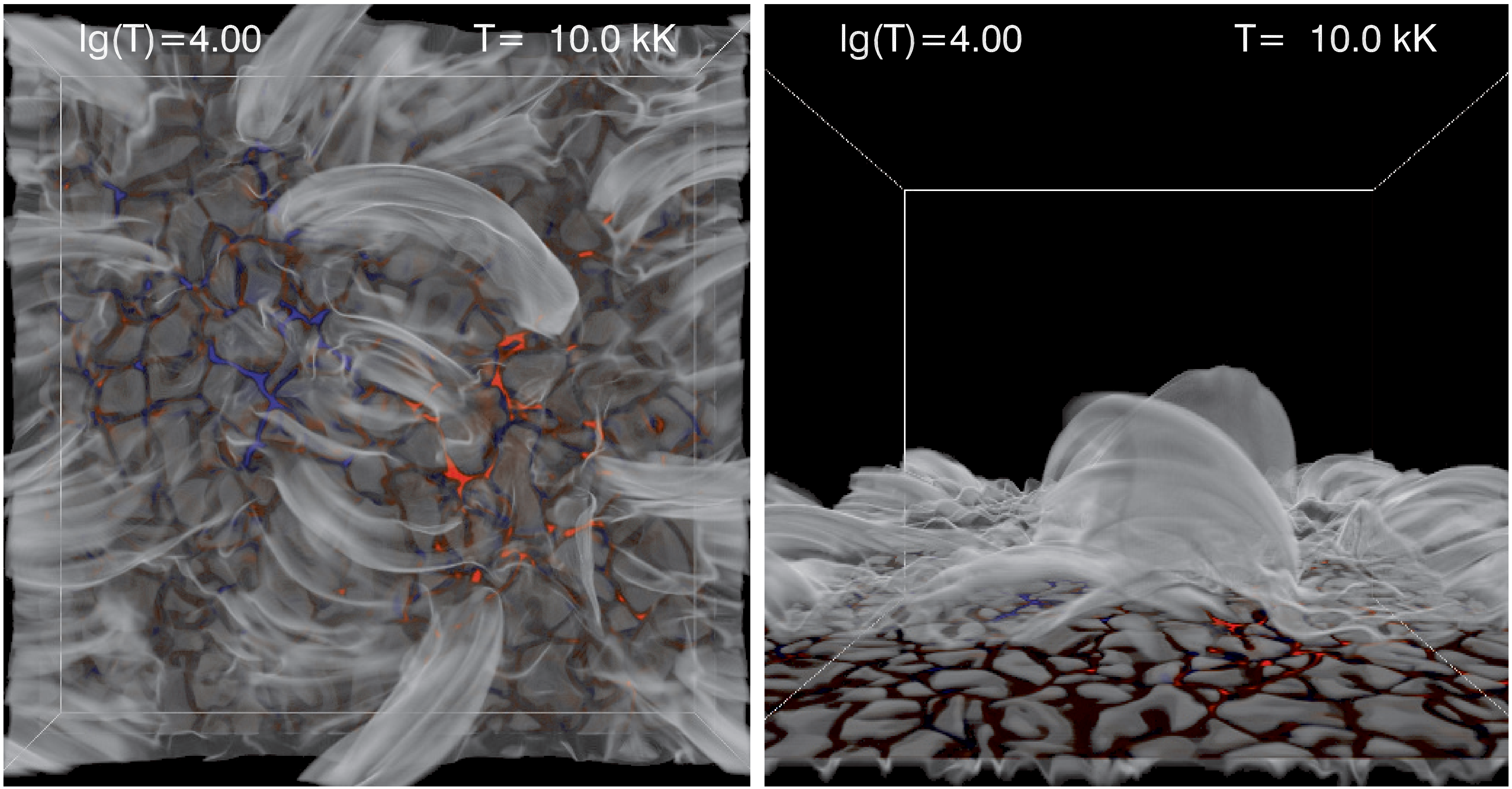


three-level Ca II atom
$\epsilon = 10^{-4}$



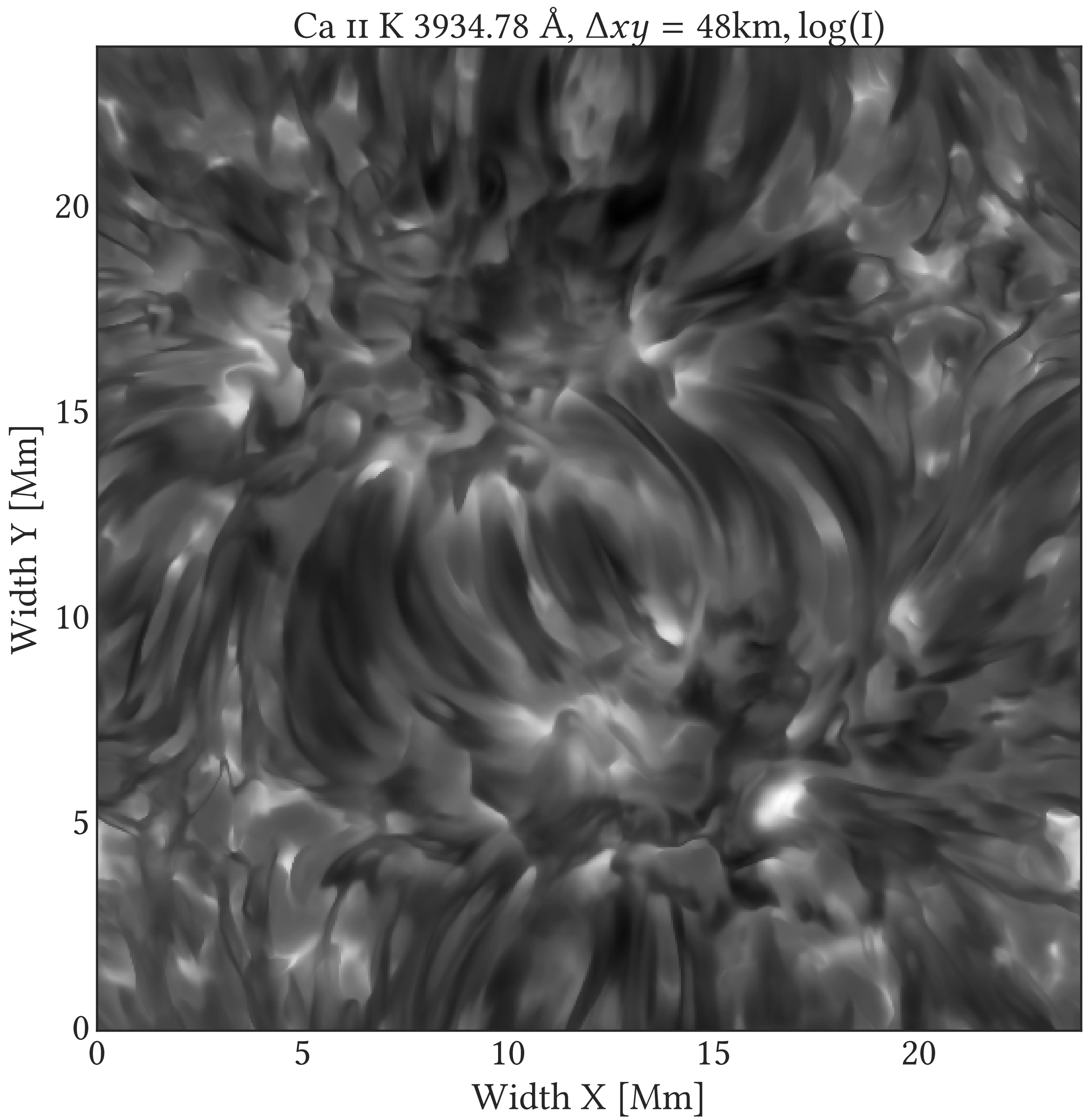
six-level hydrogen atom
$\epsilon = 10^{-8}$

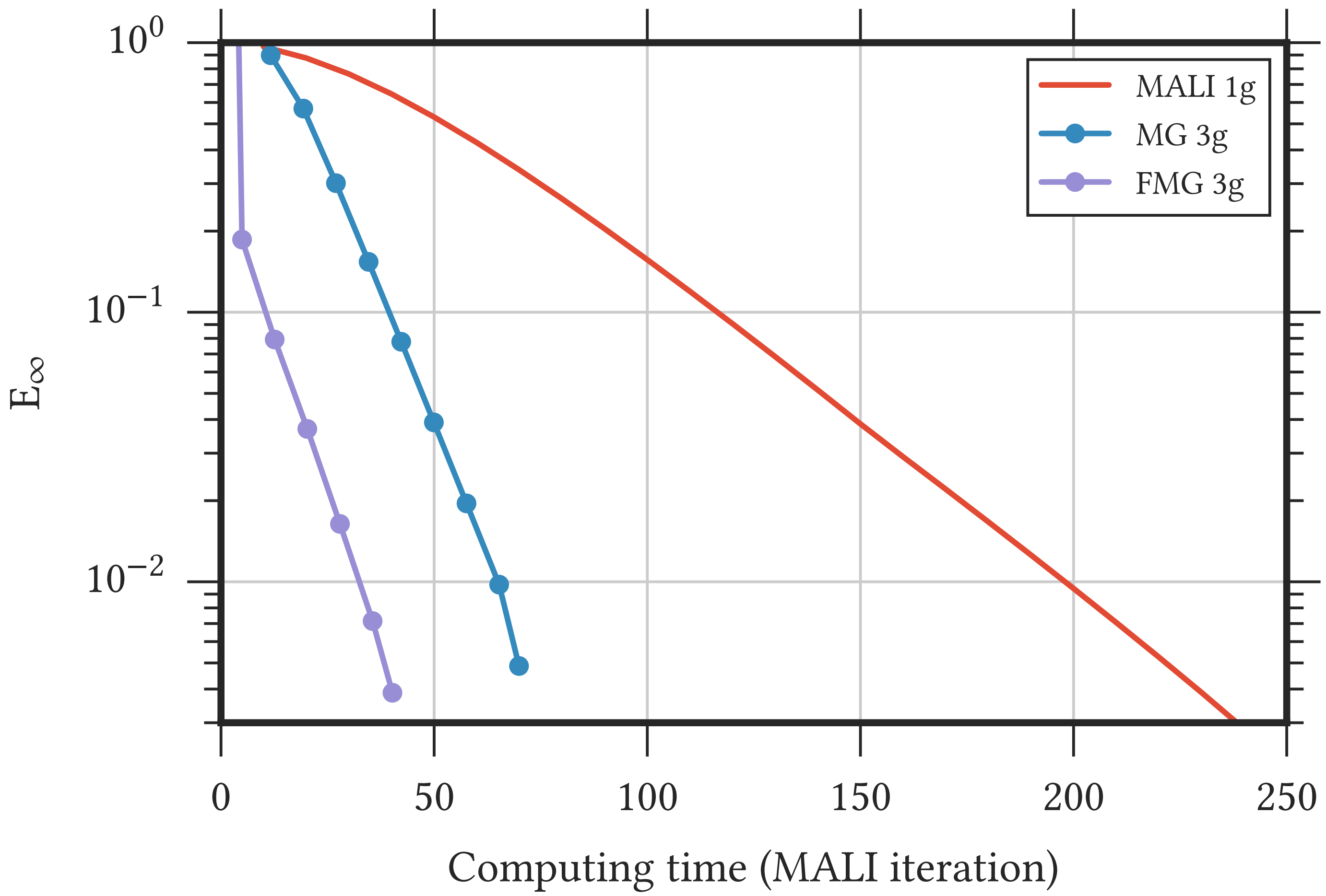
Setup: Model atmosphere



3D Bifrost snapshot for t= 3850 se, 504 x 504 x 496 points
(Carlsson et al. 2016)

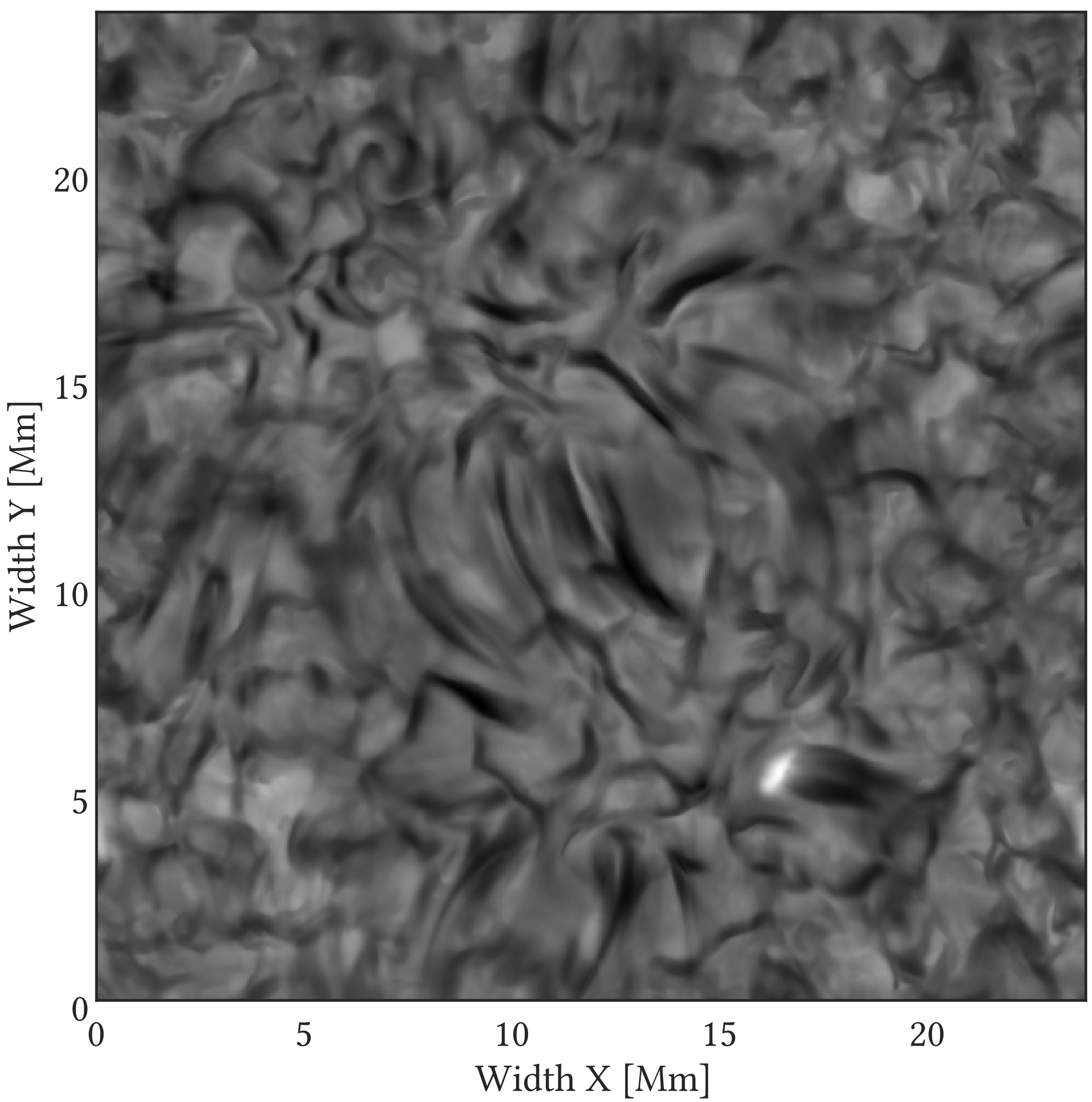
Result: three-level Ca II atom



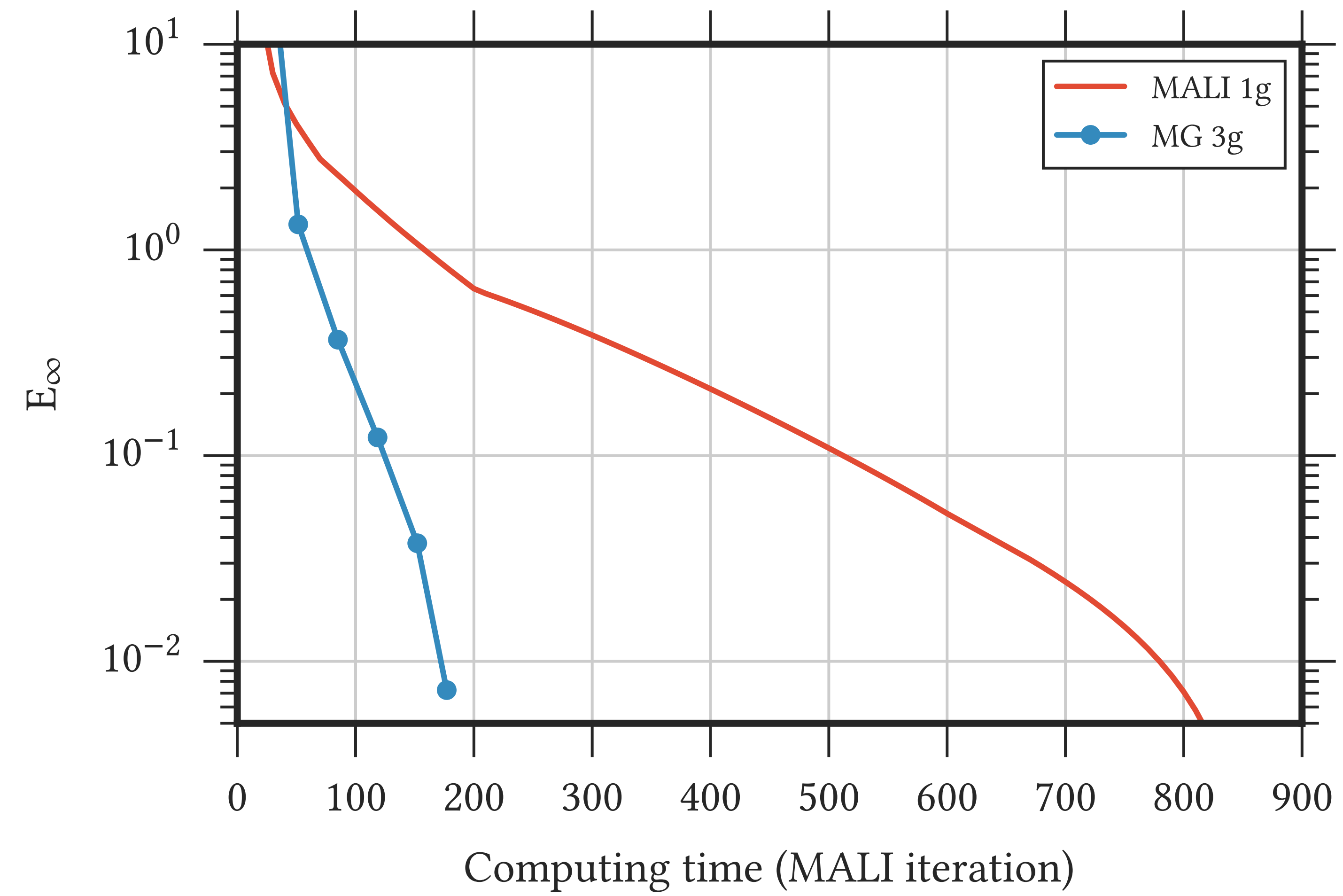


Method	Speed-up
Multigrid 3-grid	3.3x
Full multigrid 3-grid	6x

Result: Six-level hydrogen atom



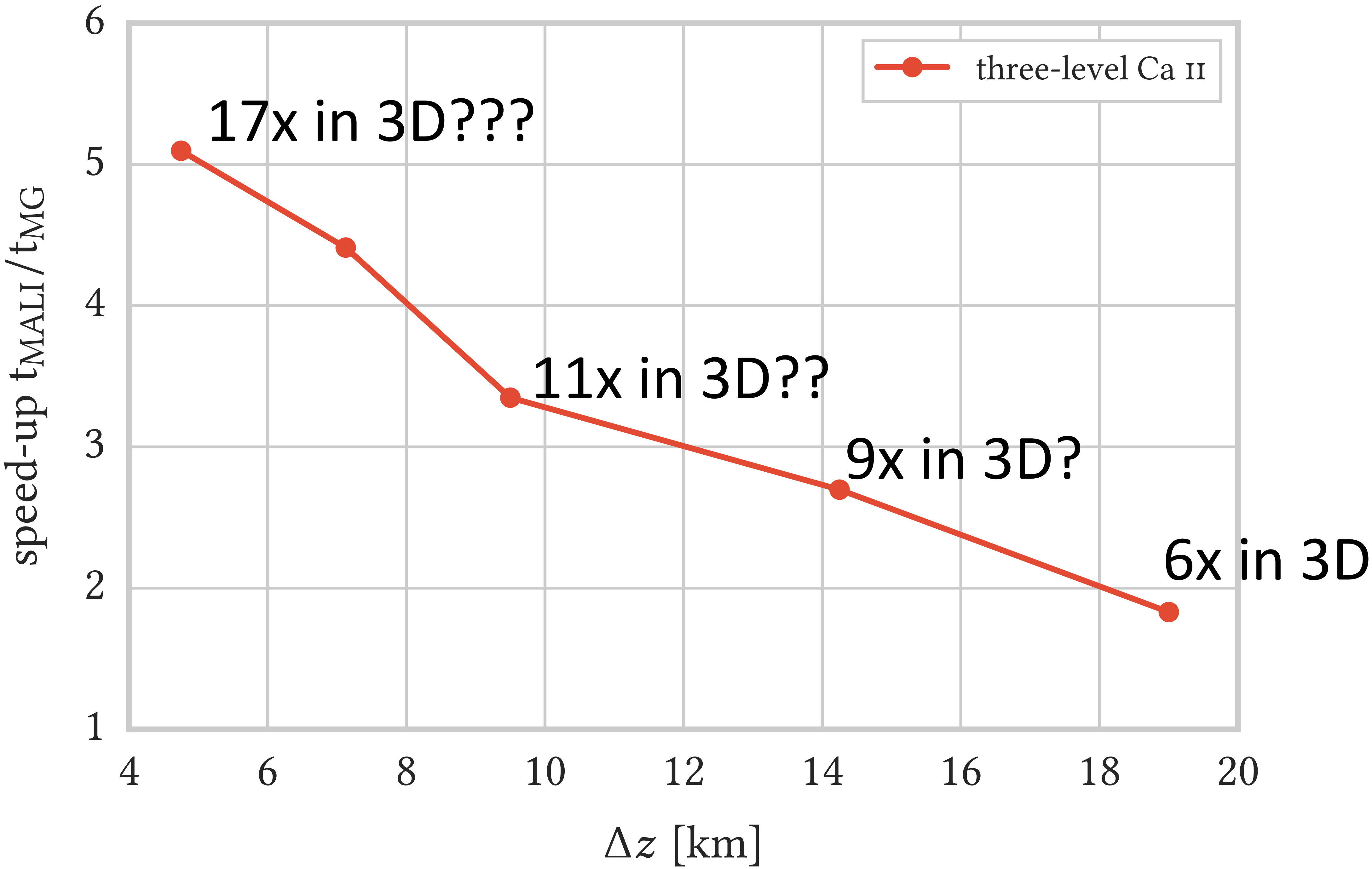
Speed-up 4.5x



Method	**CPU hours**
MALI 1-grid	300 000
Multigrid 3-grid	68 000
Full-multigrid 3-grid	38 000 (?)

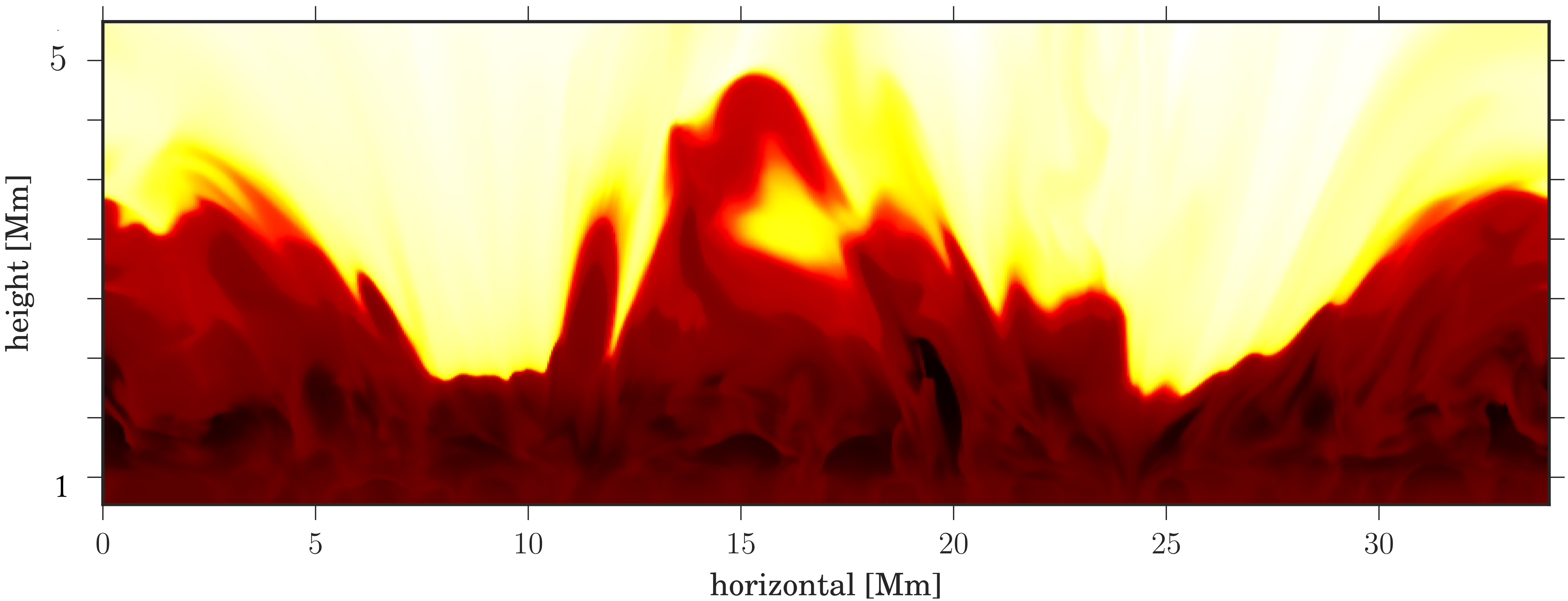
Used 4096 cores

Result: Speed-up in 1D and 3D



High-resolution atmosphere: Bifrost 768^3

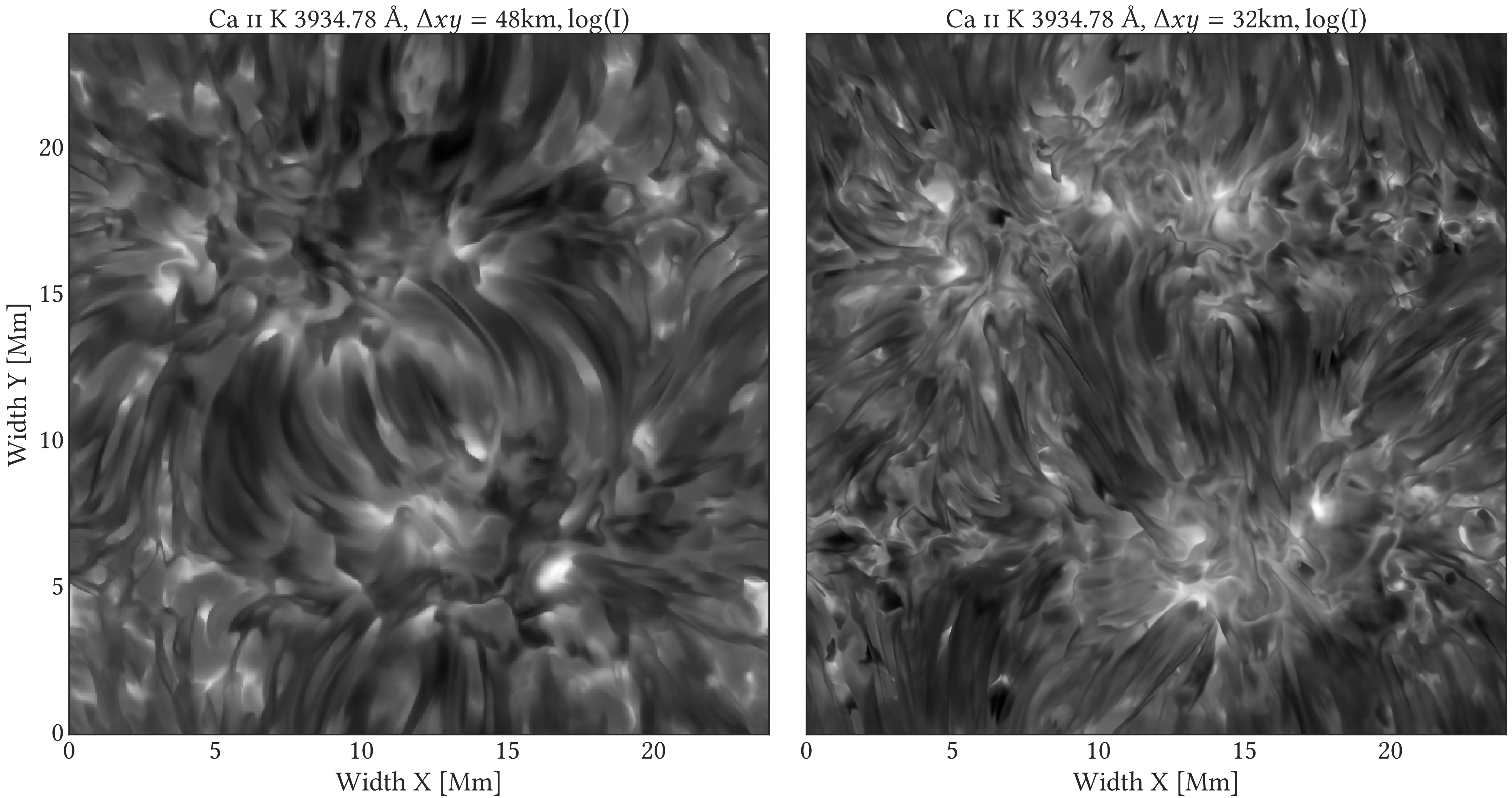
Diagonal temperature slice



courtesy of M. Carlsson & V. Hansteen

- 32 km horizontal grid spacing
- 13-100 km vertical grid spacing
- Enhanced network
- LTE Hydrogen population

Ca II K: line core



Study of formation properties of Ca II H&K with 3D PRD is undergoing

Conclusions

- Multigrid with MALI works for MHD snapshots
- Handle strongly scattering lines
- Factor **4-6x** speed-up for a 504x504x496 MHD snapshot
- Higher speed-up expected for future MHD simulations

Accepted for A&A: arxiv.org/abs/1701.01607