Rosseland
Centre
for Solar
Physics

3D NLTE radiative transfer in stellar atmospheres

Tiago M. D. Pereira

Non-LTE vs LTE

(LTE = Local Thermodynamical Equilibrium)

$$\frac{\mathrm{d}I_\nu}{\mathrm{d}\tau_\nu} = I_\nu - S_\nu$$

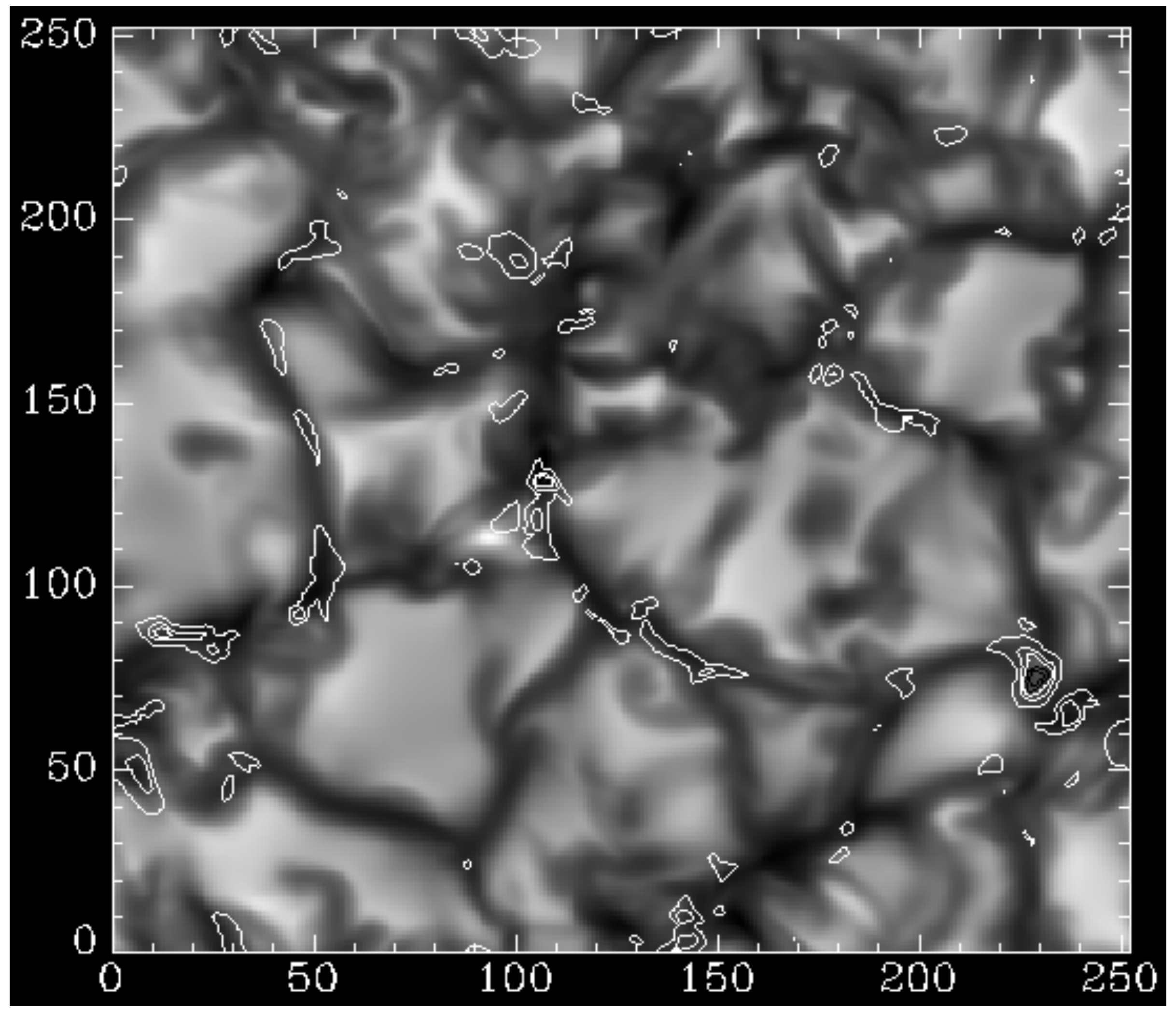
LTE: set by collisions, depends only on local conditions

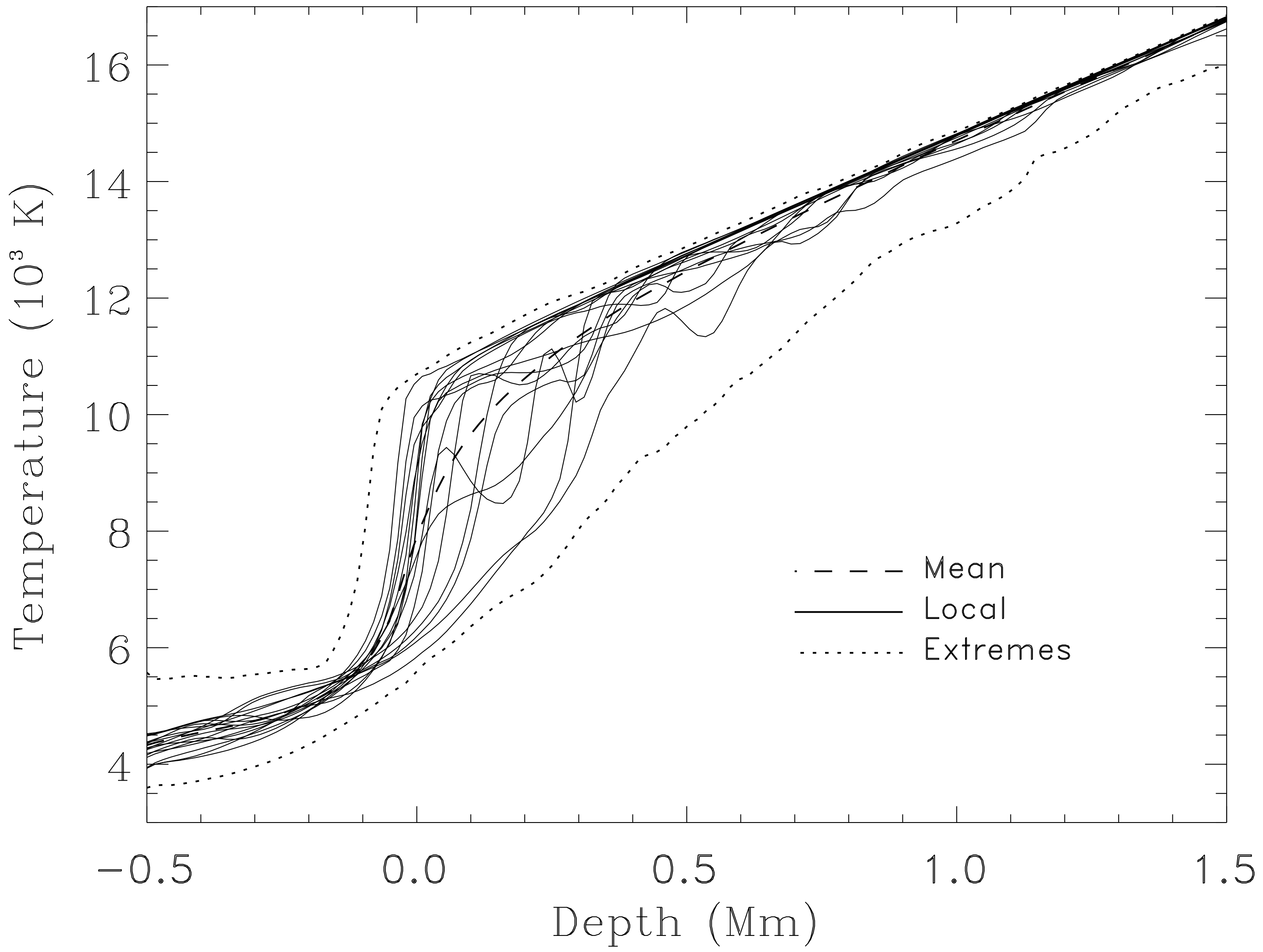
NLTE: set by collisions **and radiation**, depends on radiation everywhere!

Non-LTE: need large amounts of atomic data

Osorio et al. (2019), A&A 623, A103

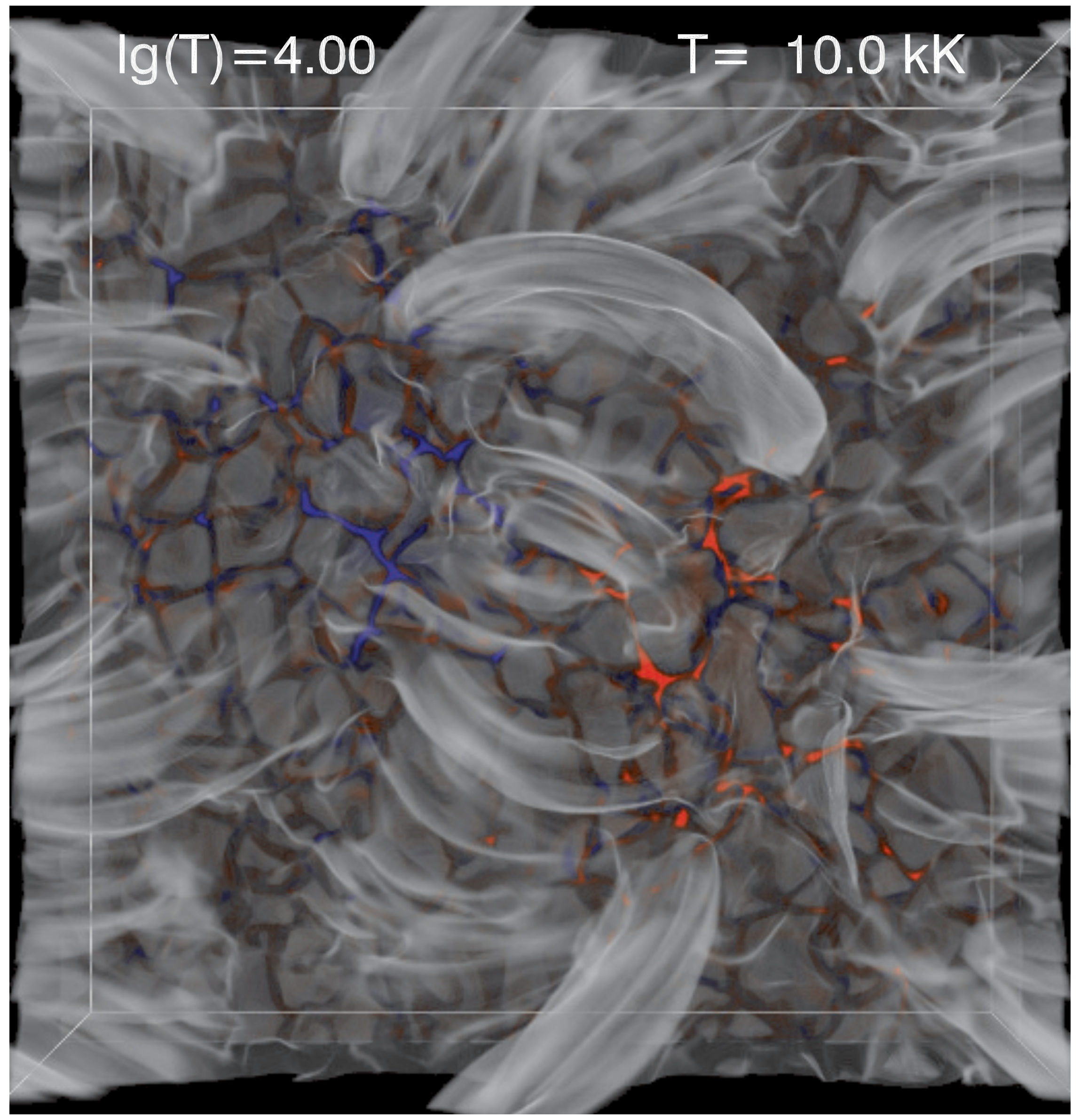
3D: convection simulations to coronal atmospheres

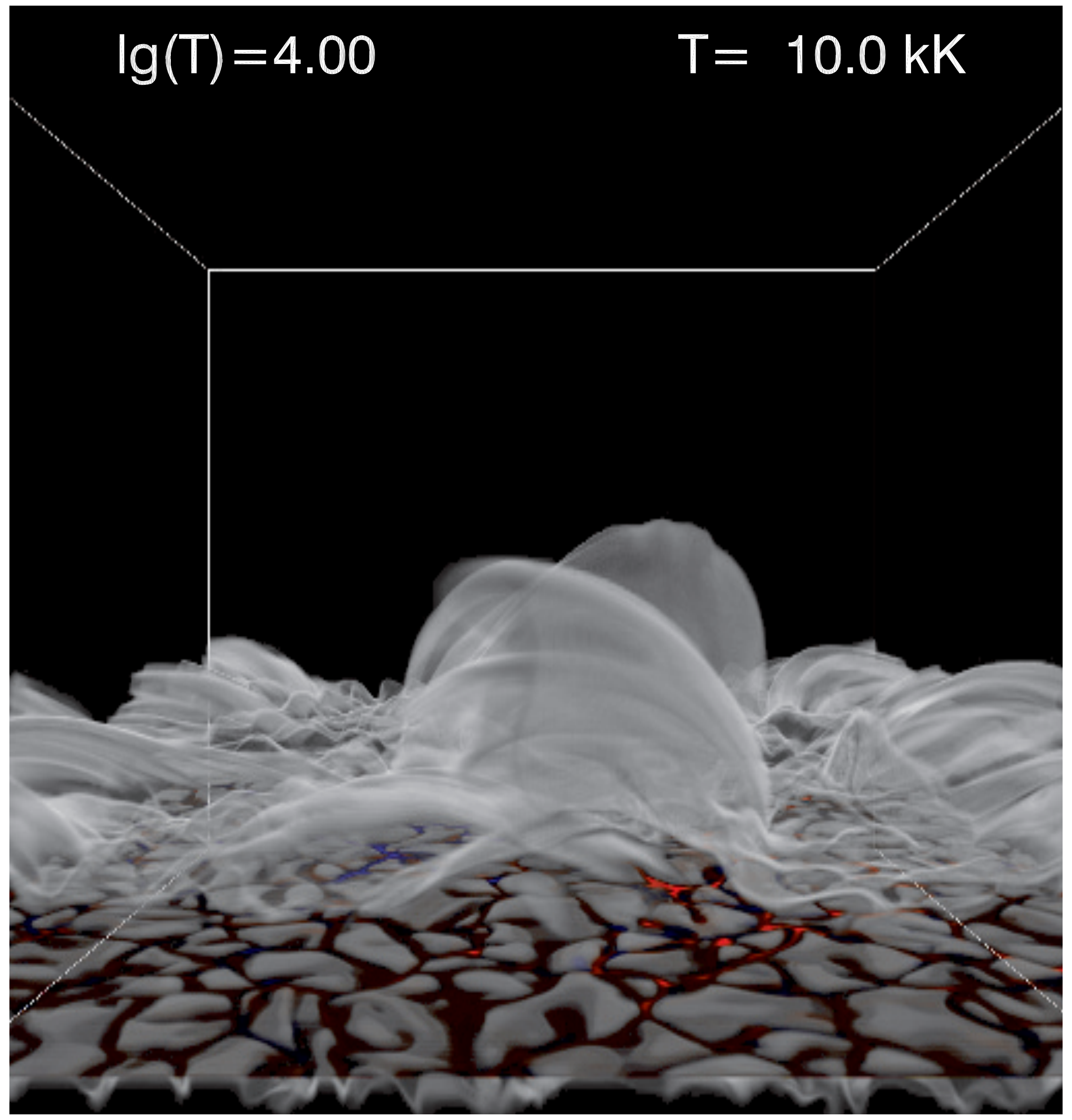


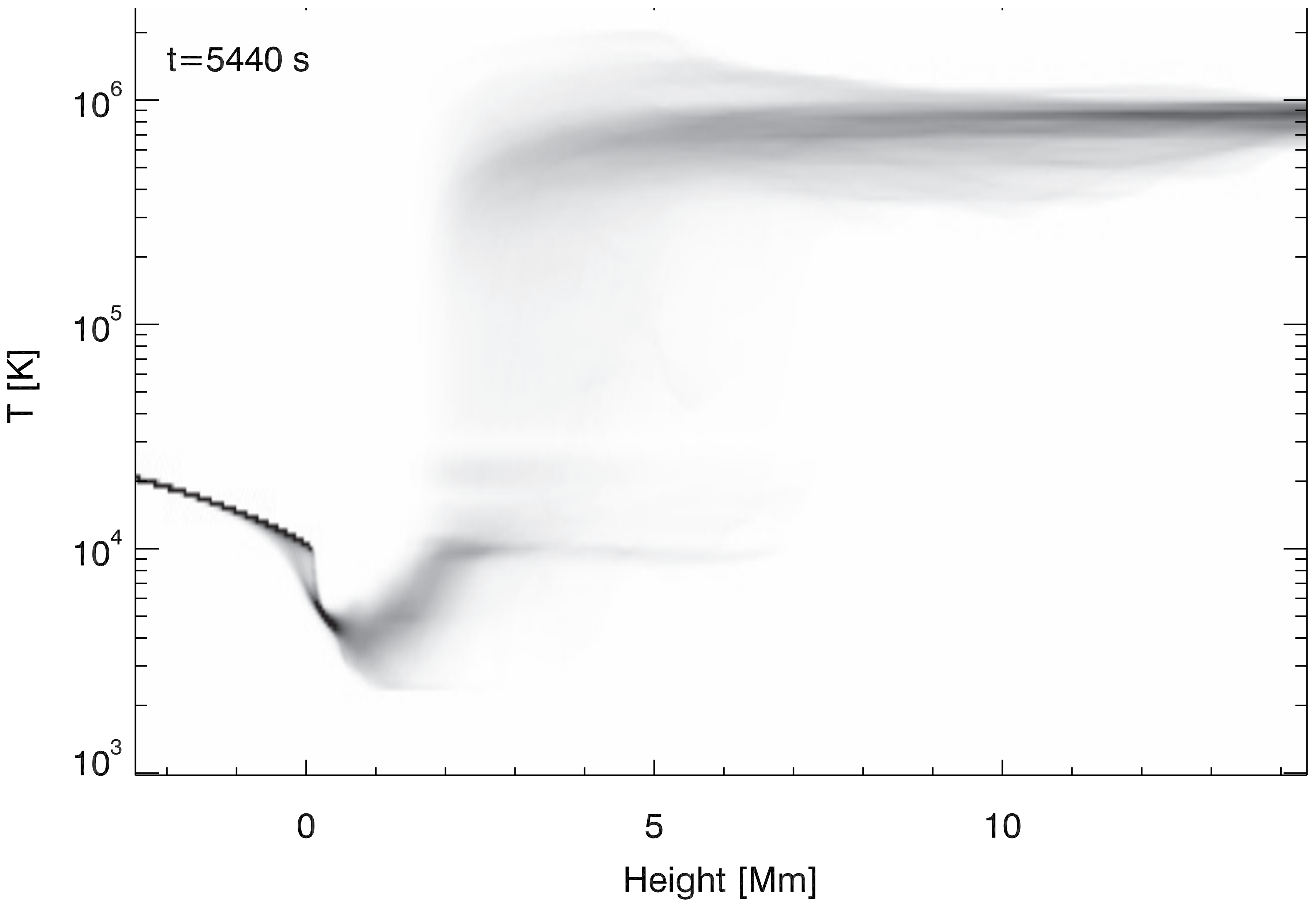


Stein & Nordlund (1998), ApJ 499, 914

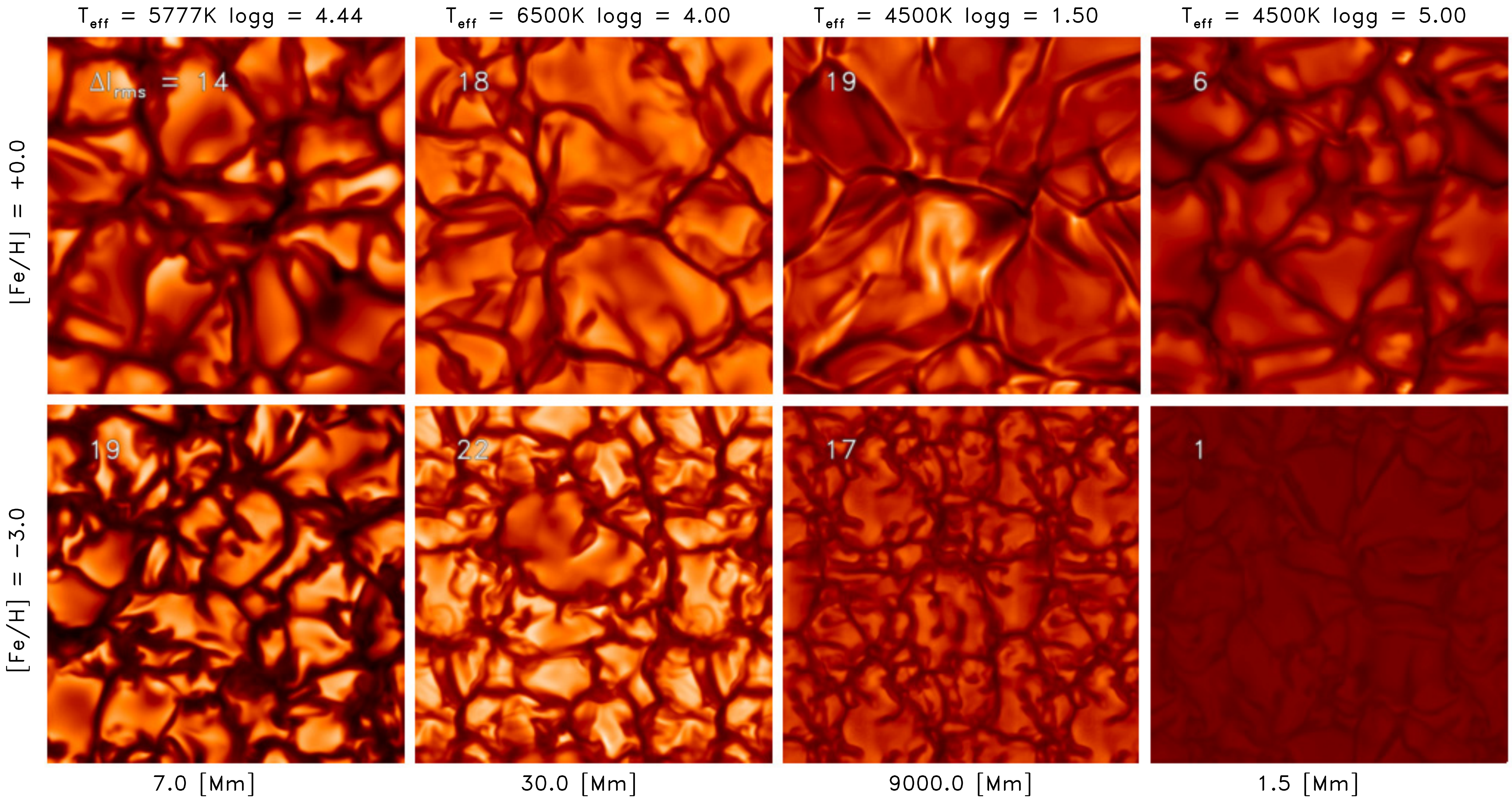
Carlsson et al. (2016), A&A 585, A4





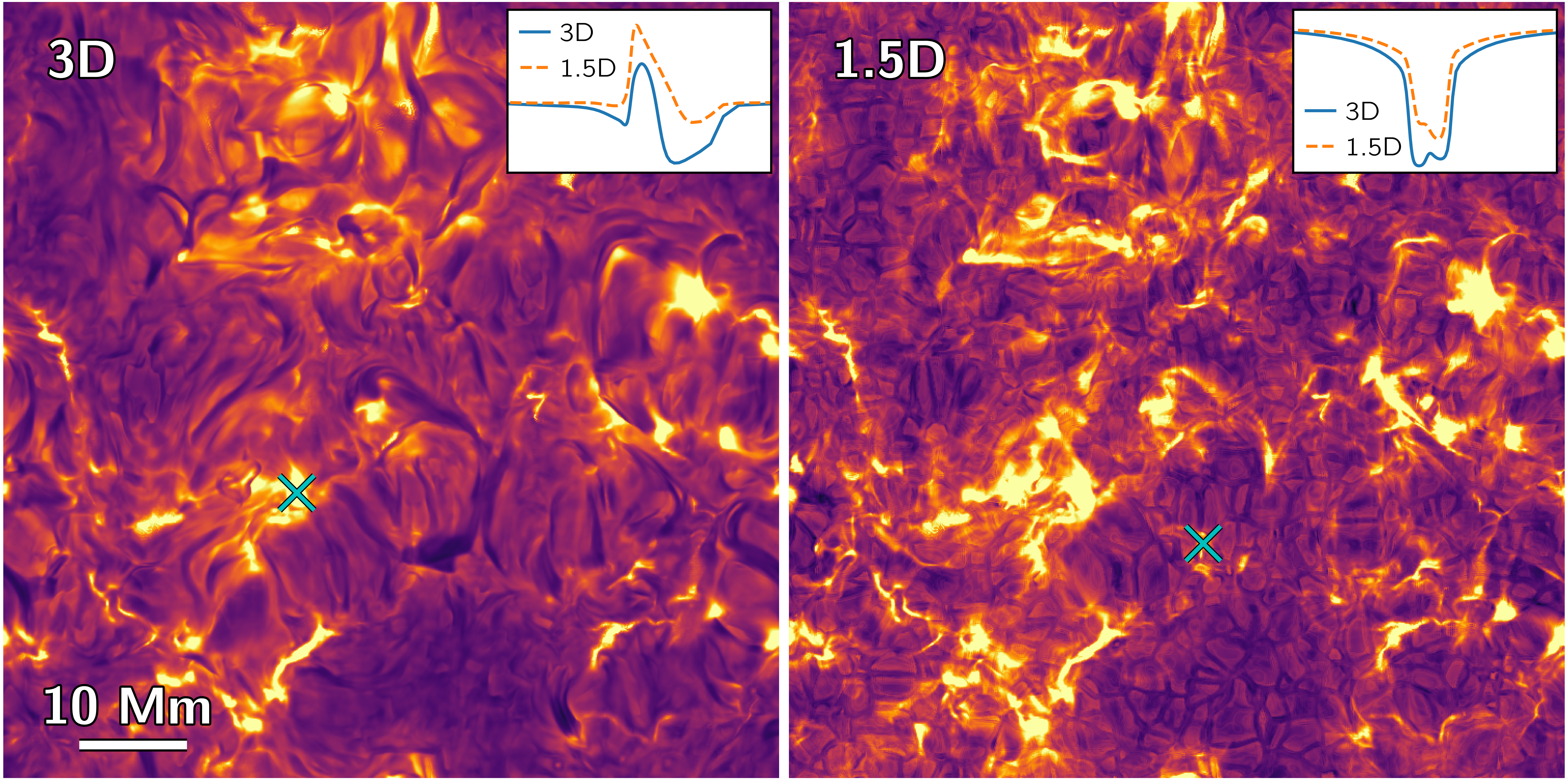


3D: solar to stellar models



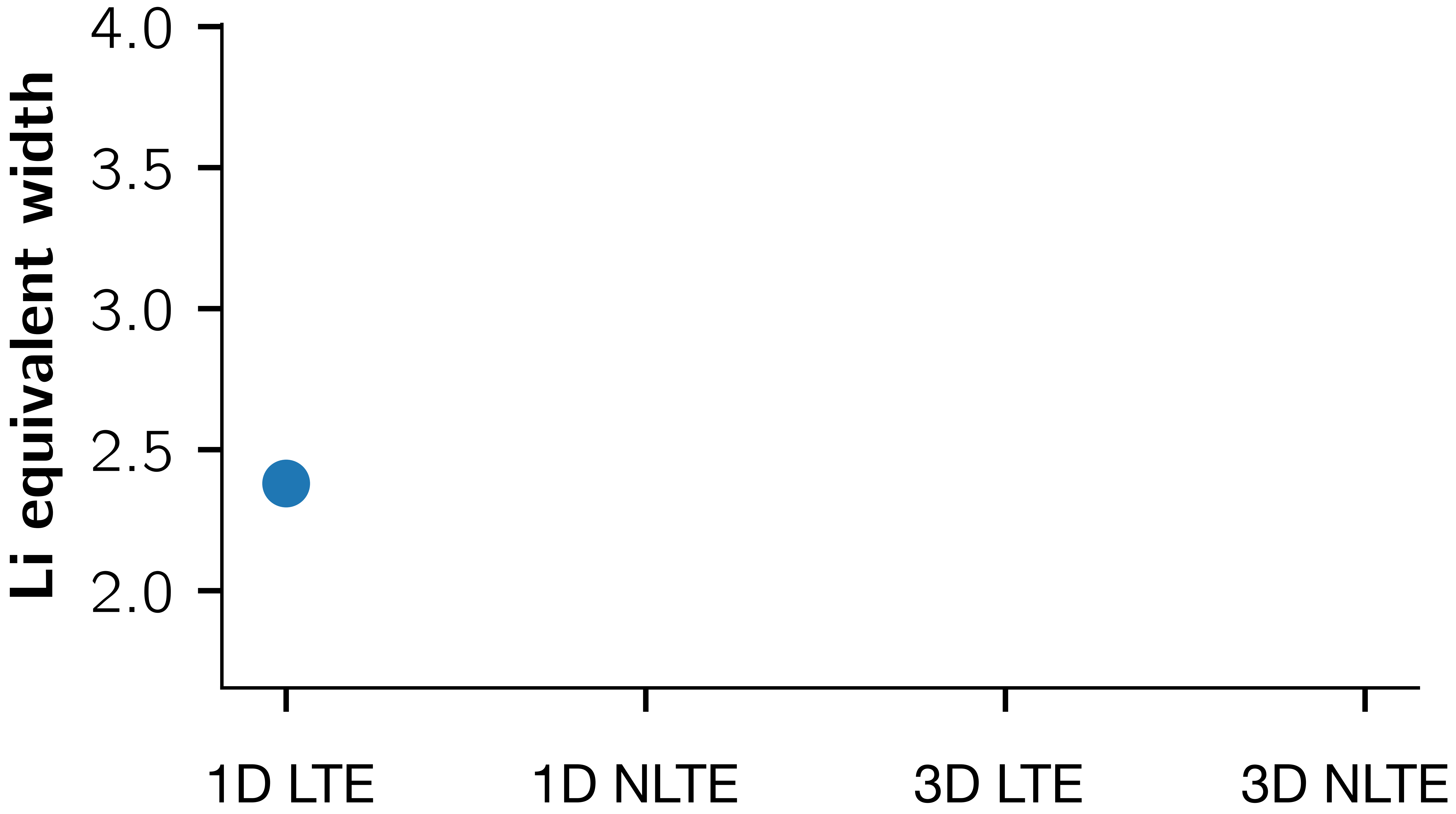
Magic et al. (2013), A&A, 557, A26

3D + Non-LTE: expensive to calculate radiation



Hα spectra: full 3D vs 1D column-by-column

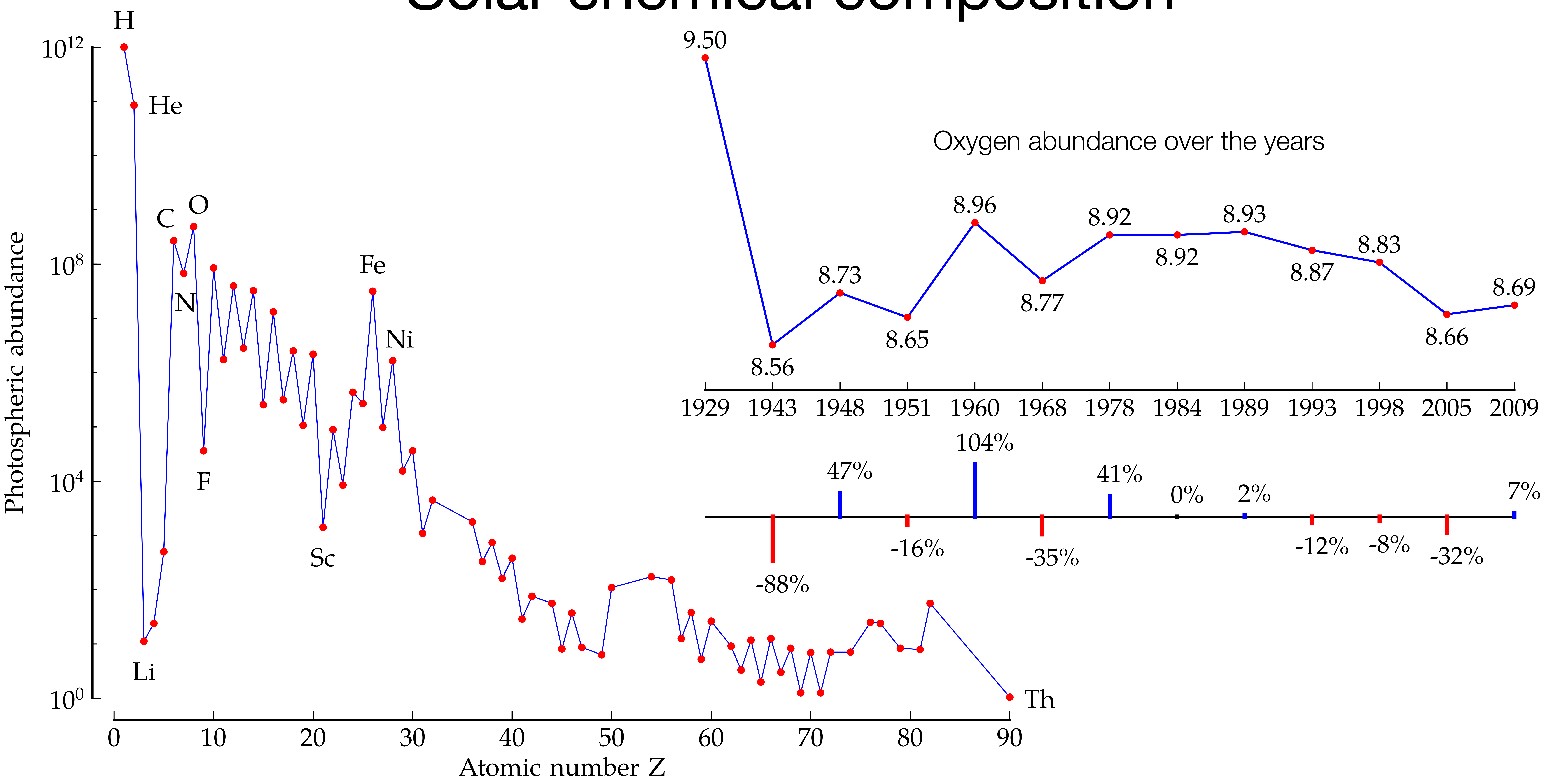
Primordial lithium abundance



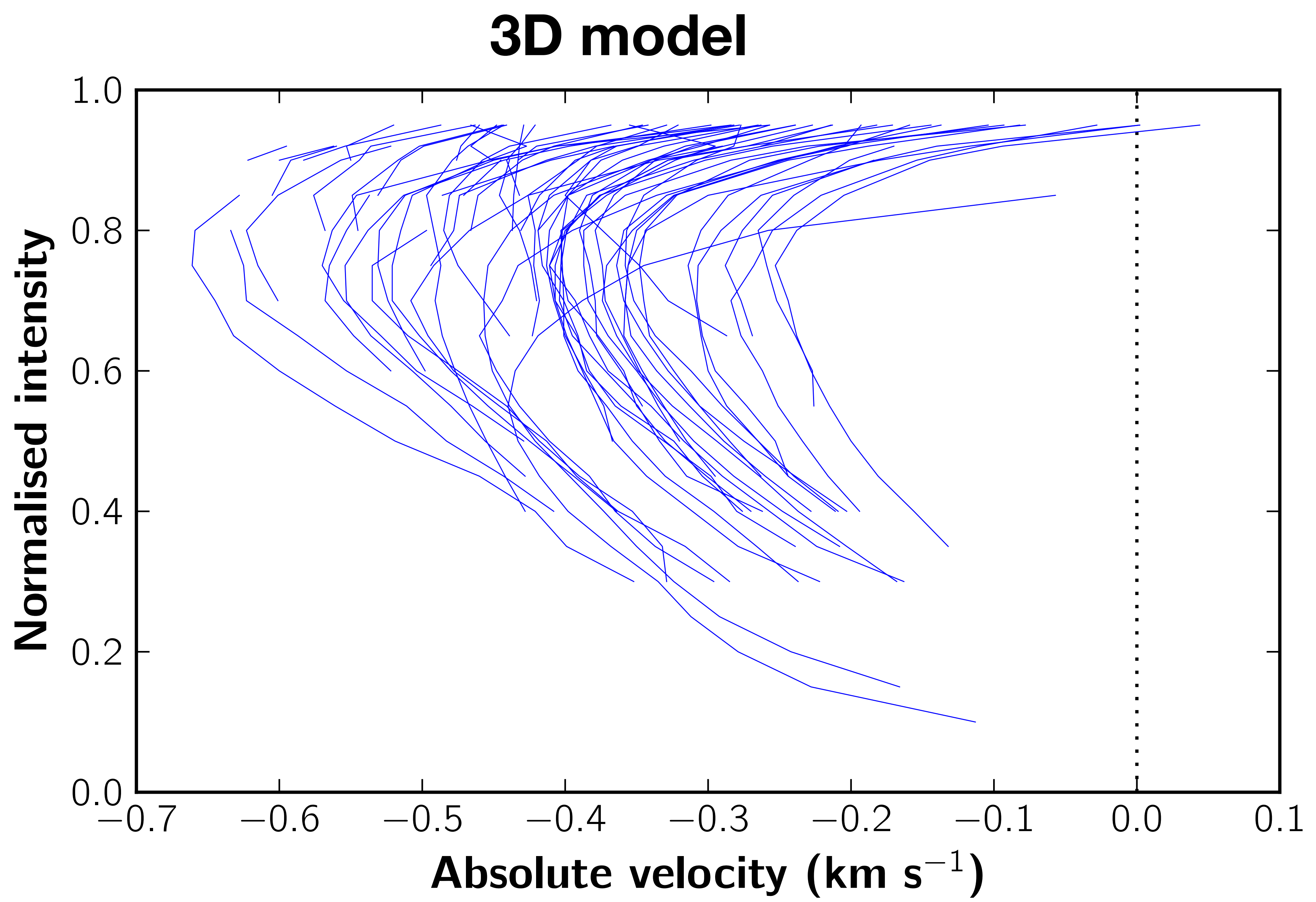
HD 140283, [Fe/H] = −2.5, T_{eff} = 5690 K, logg = 1.67

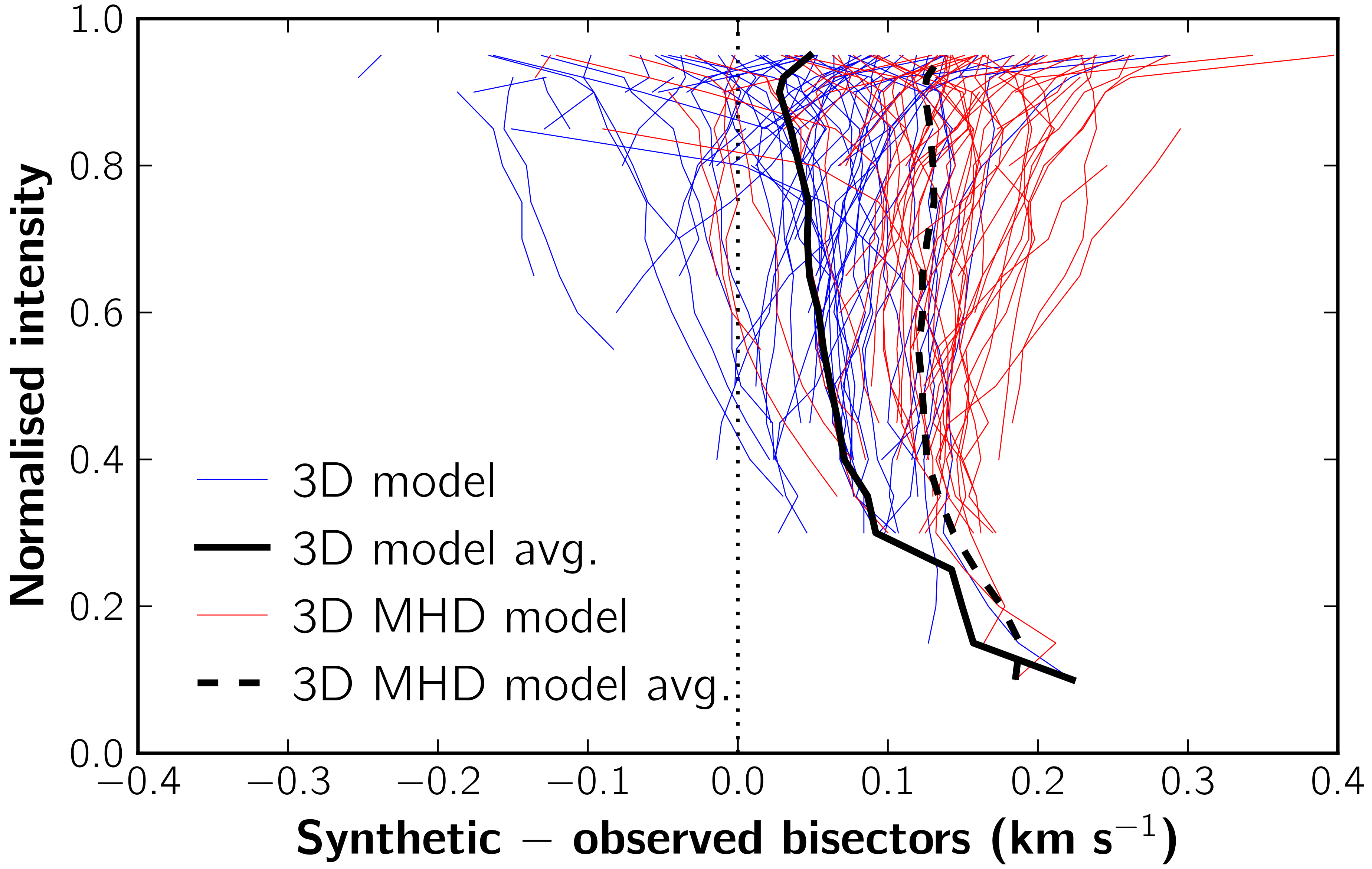
Asplund et al. (2003), A&A, 399, L31

Solar chemical composition



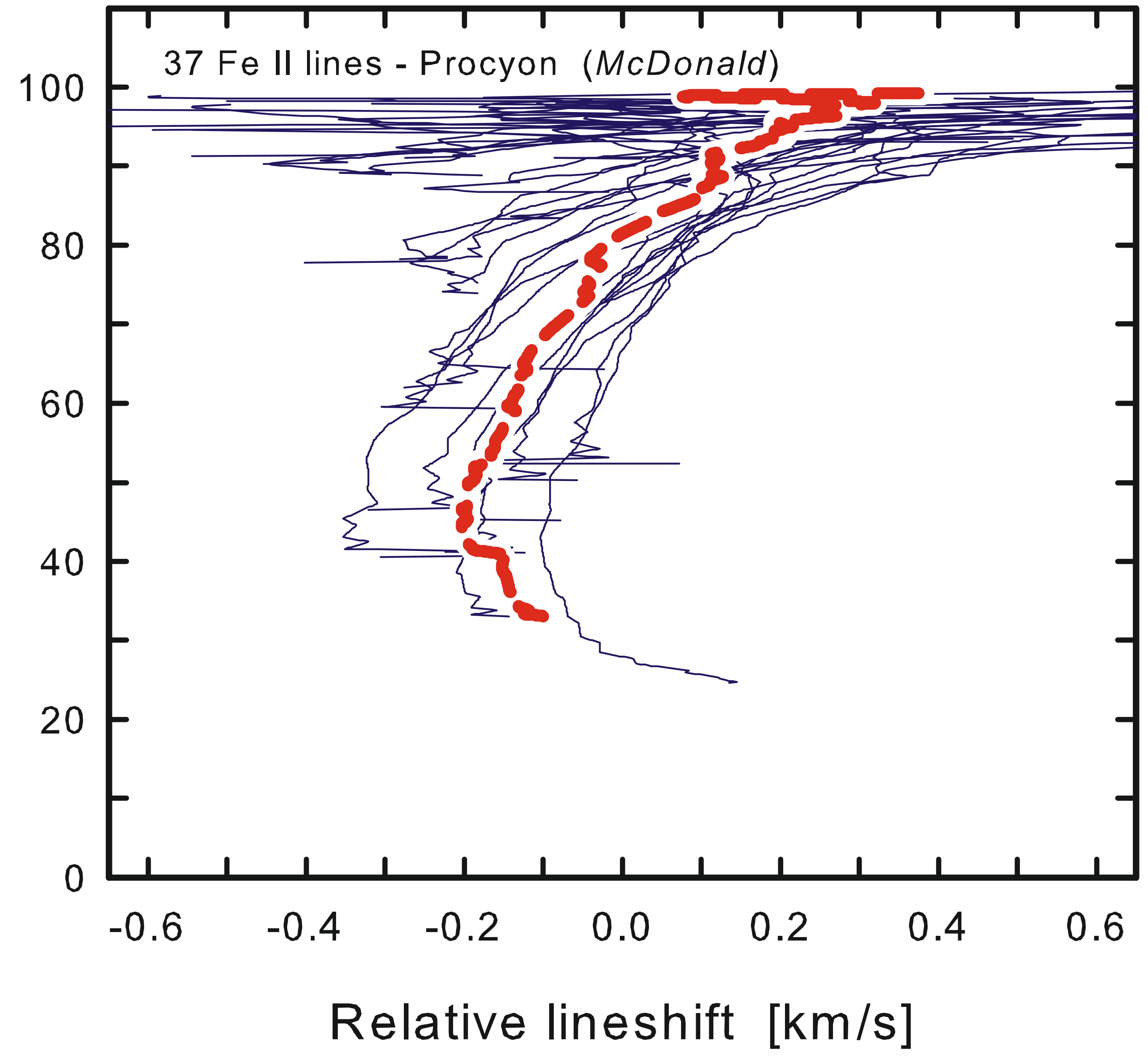
3D essential for imprint of convection in line shapes



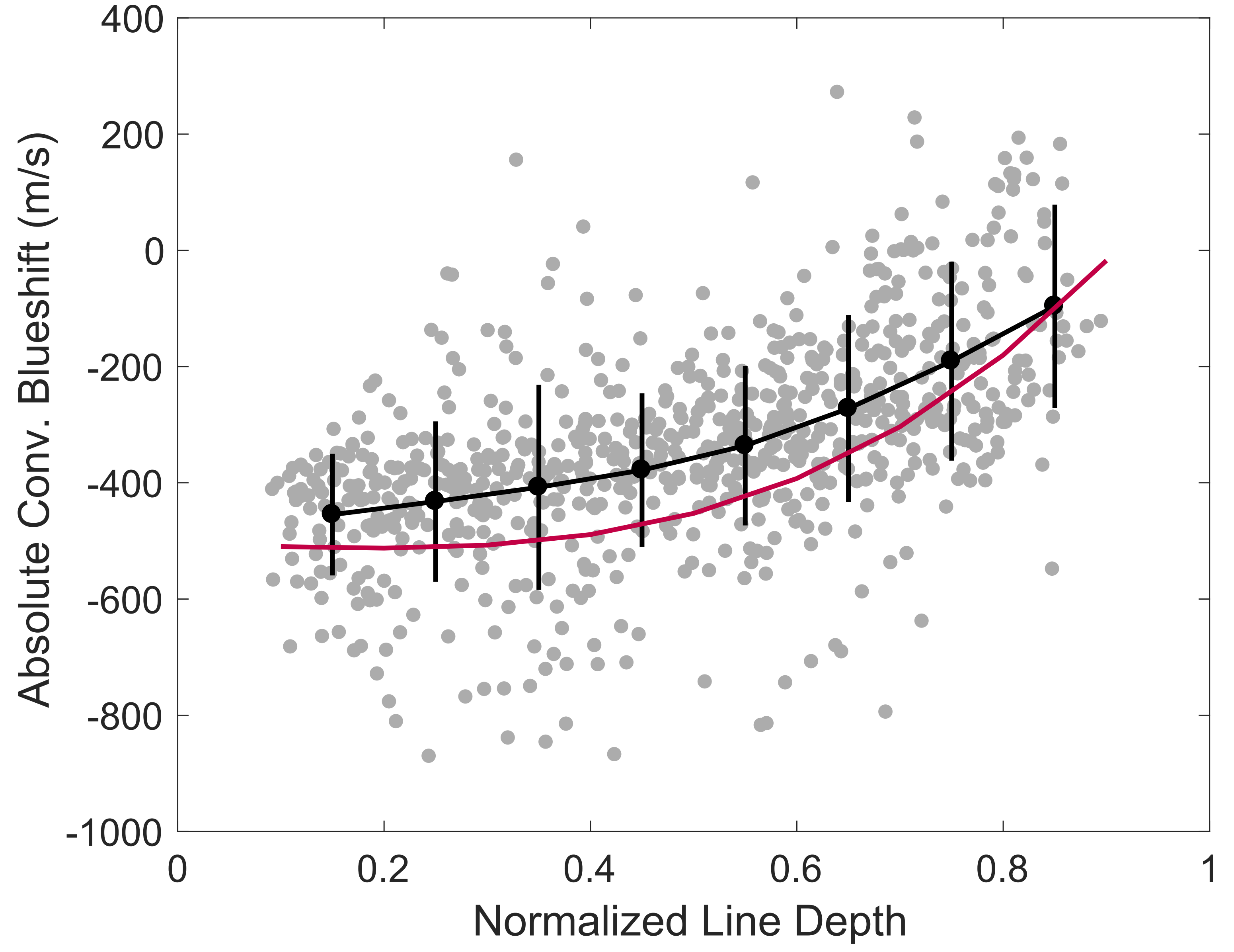


TMDP et al. (2013), A&A 554, A118

Observations

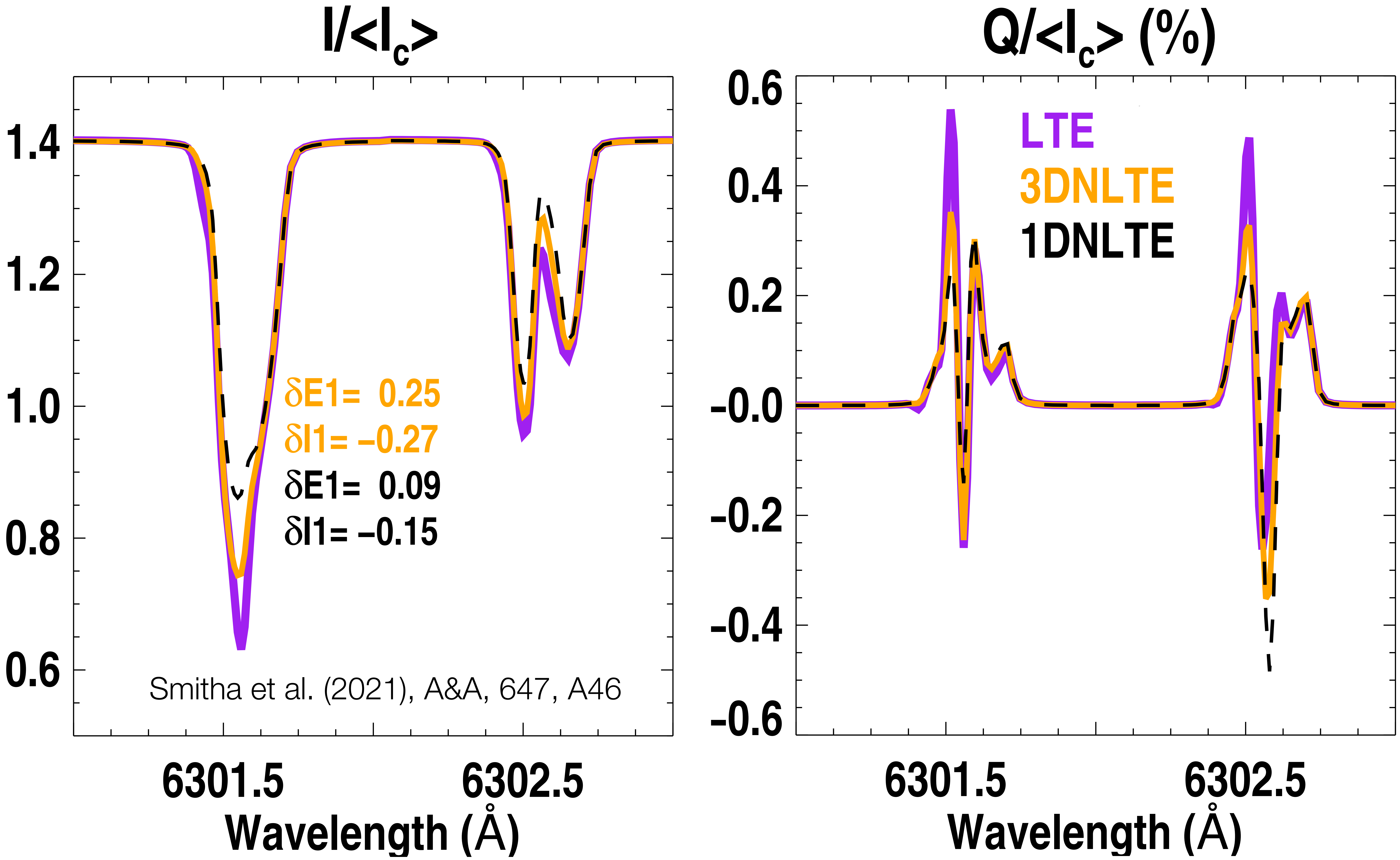


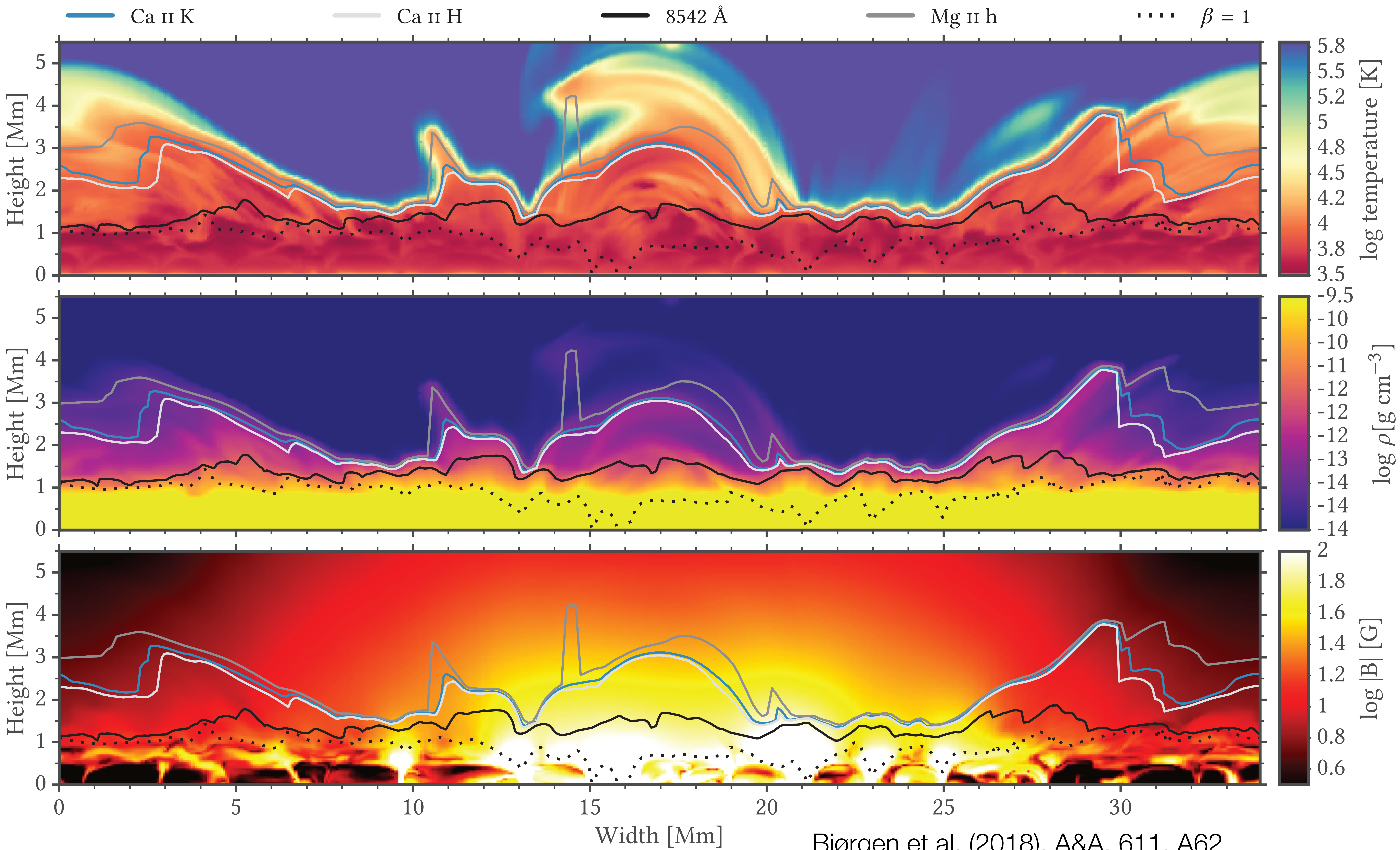
Dravins (2008), A&A, 492, 199



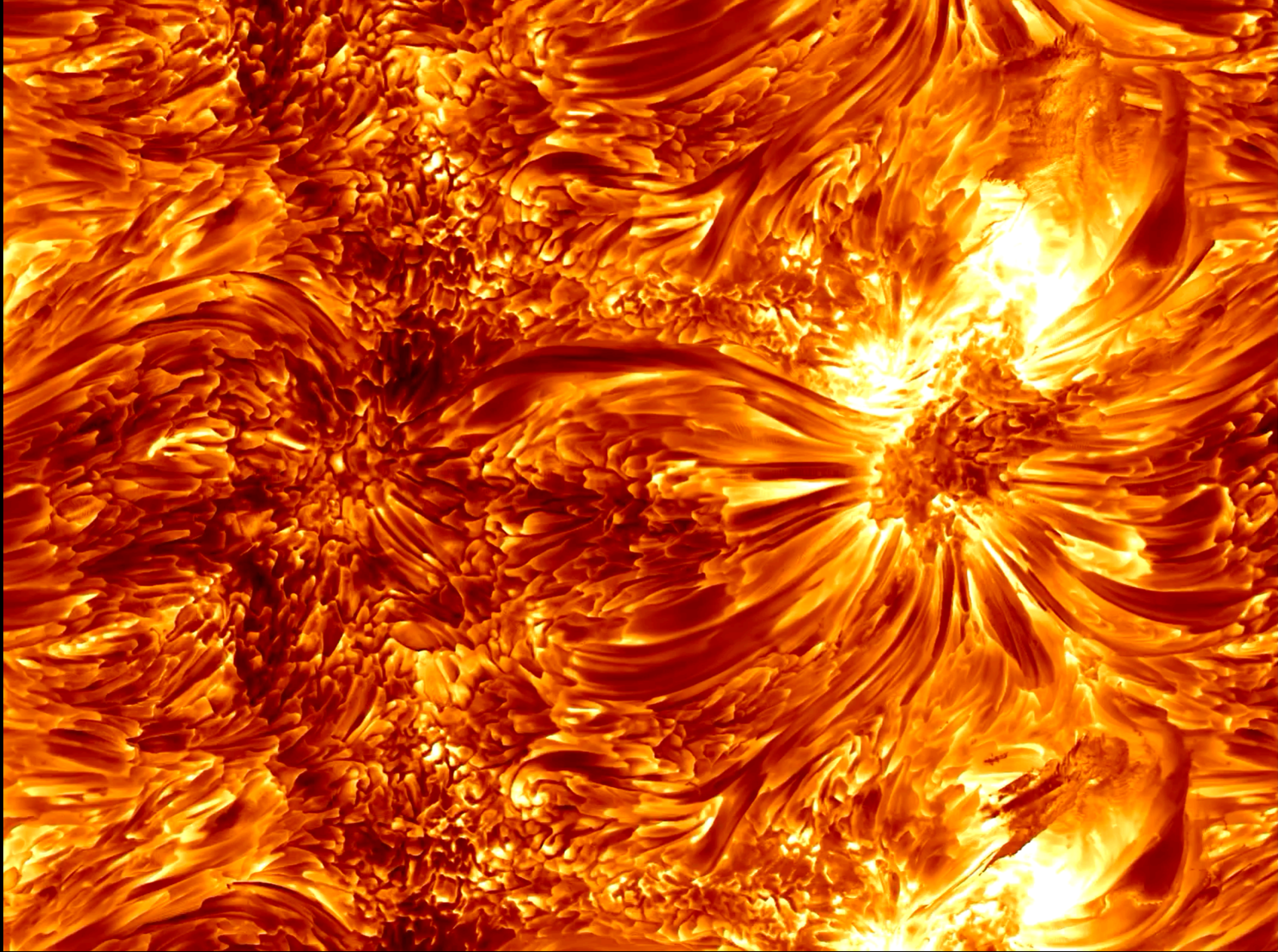
Miklos et al. (2020), ApJ, 888, 117

3D NLTE for precise Fe I lines in a solar model





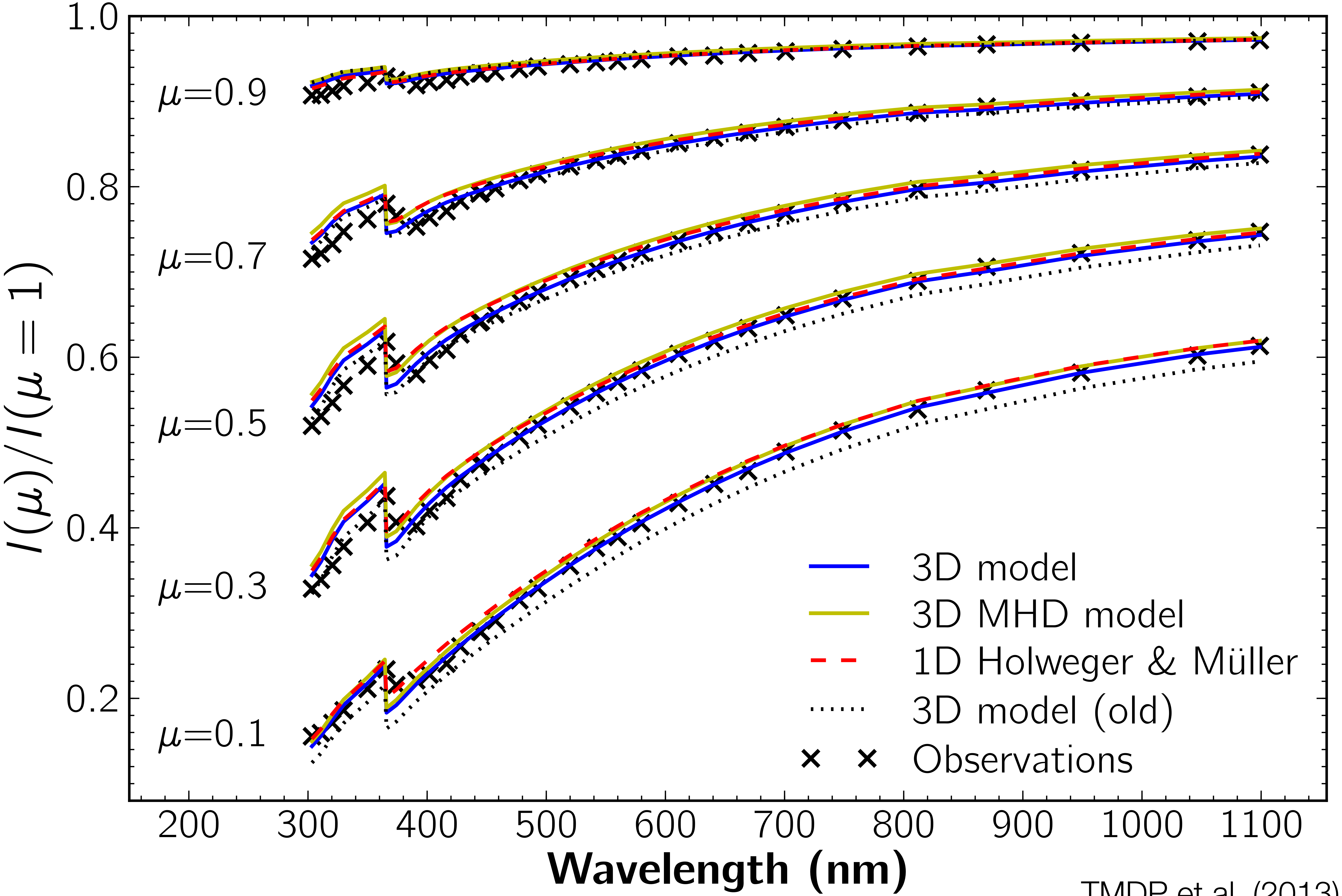
Bjørgen et al. (2018), A&A, 611, A62



Courtesy Johan Bjørgen

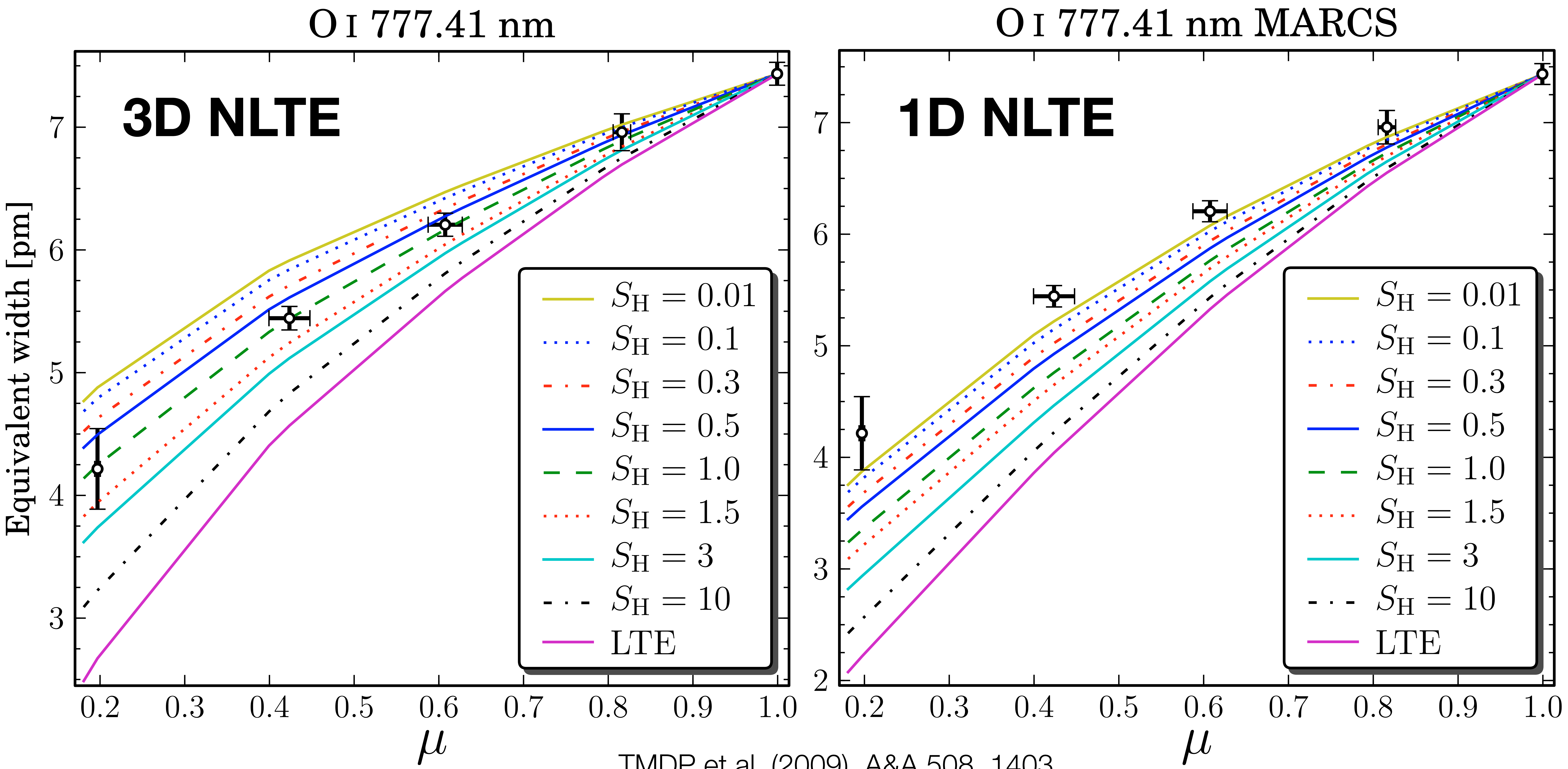
MURaM simulation, Ca II K

Solar observations as tests of model atmospheres



TMDP et al. (2013), A&A 554, A118

Solar observations as tests of NLTE calculations



TMDP et al. (2009), A&A 508, 1403

A COMPUTER PROGRAM FOR SOLVING MULTI-LEVEL NON-LTE RADIATIVE TRANSFER PROBLEMS IN MOVING OR STATIC ATMOSPHERES

by

Mats Carlsson

MULTILEVEL RADIATIVE TRANSFER WITH PARTIAL FREQUENCY REDISTRIBUTION

H. Uitenbroek

MULTI3D: A Domain-Decomposed 3D Radiative Transfer Code

Jorrit Leenaarts and Mats Carlsson

PORTA: A three-dimensional multilevel radiative transfer code for modeling the intensity and polarization of spectral lines with massively parallel computers

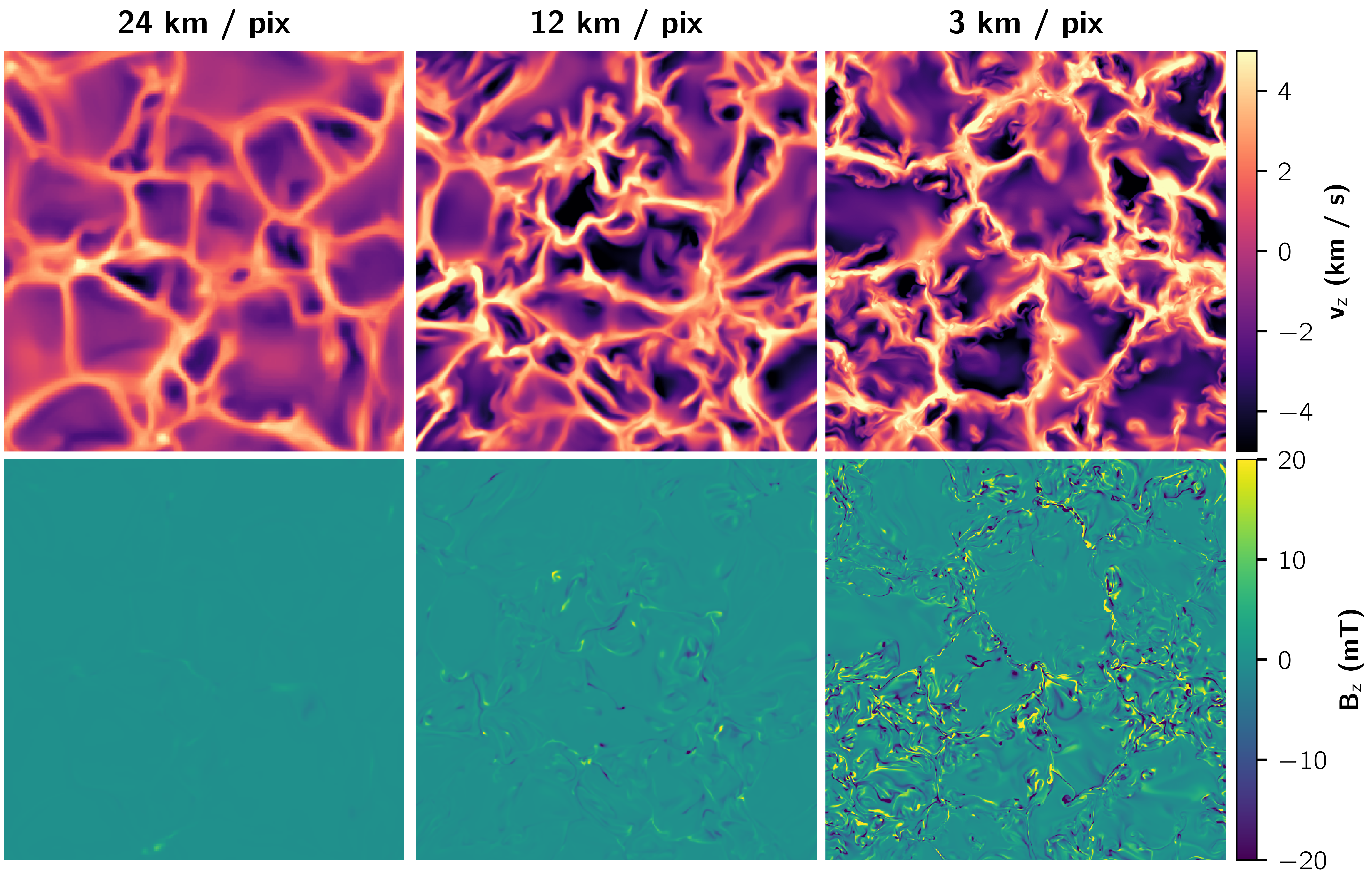
Jiří Štěpán[1] and Javier Trujillo Bueno[2,3,4]

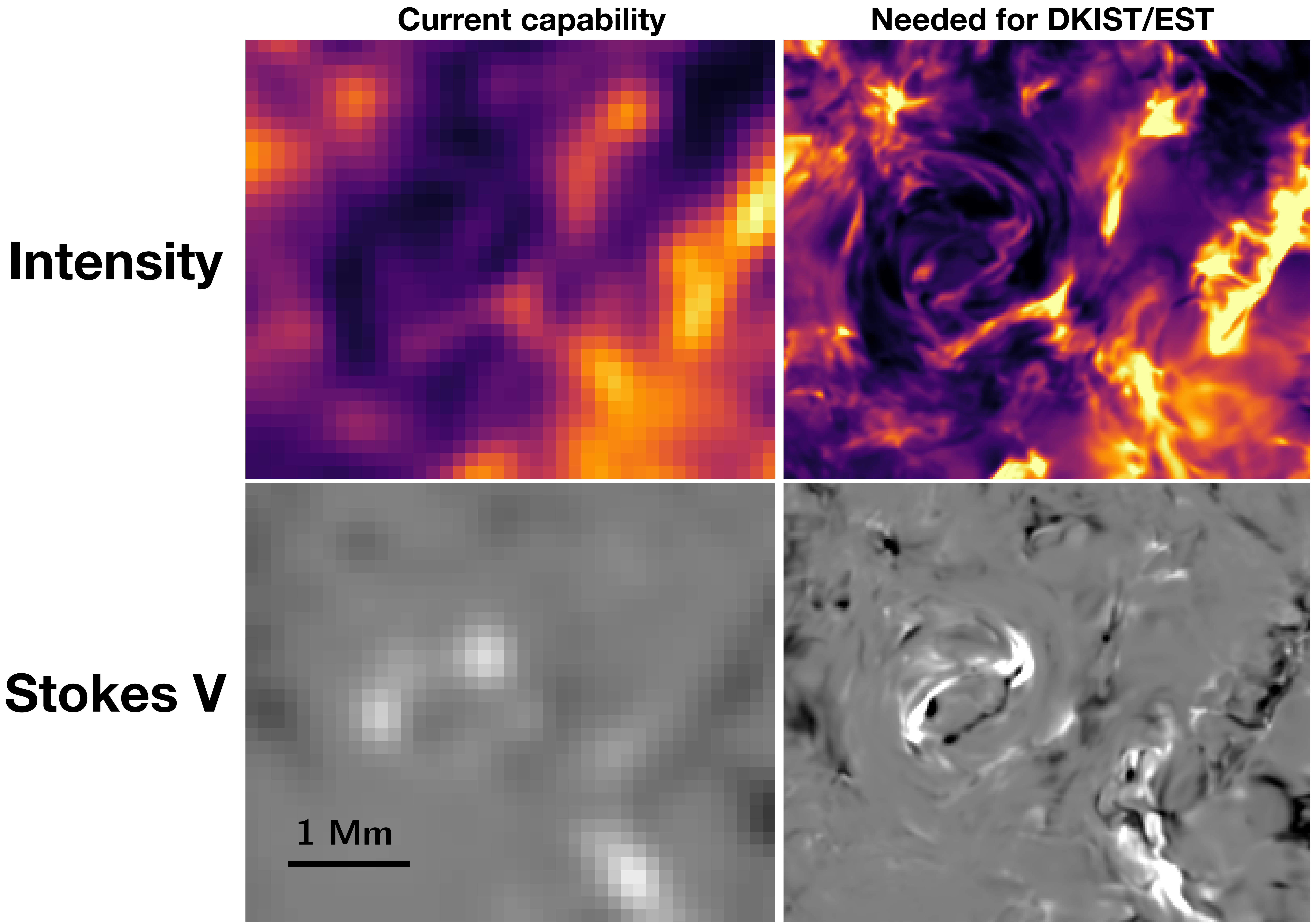
RH 1.5D: a massively parallel code for multi-level radiative transfer with partial frequency redistribution and Zeeman polarisation

Tiago M. D. Pereira[1,2,3] and Han Uitenbroek[4]

The *Lightweaver* Framework for Nonlocal Thermal Equilibrium Radiative Transfer in Python

Christopher M. J. Osborne[1] and Ivan Milić[2,3,4]

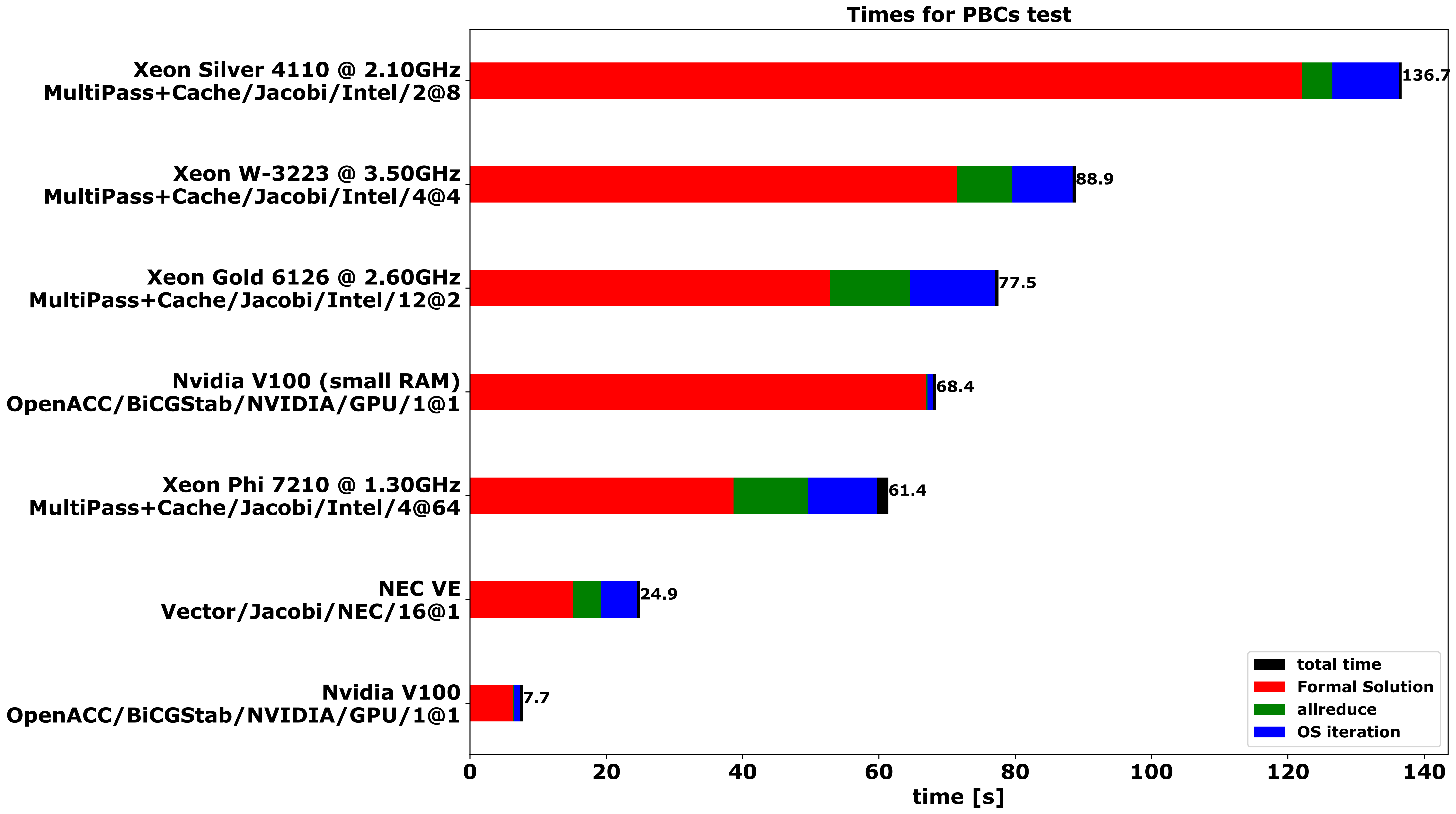

24 km / pix
12 km / pix
3 km / pix
v_z (km / s)
4
2
0
−2
−4
B_z (mT)
20
10
0
−10
−20

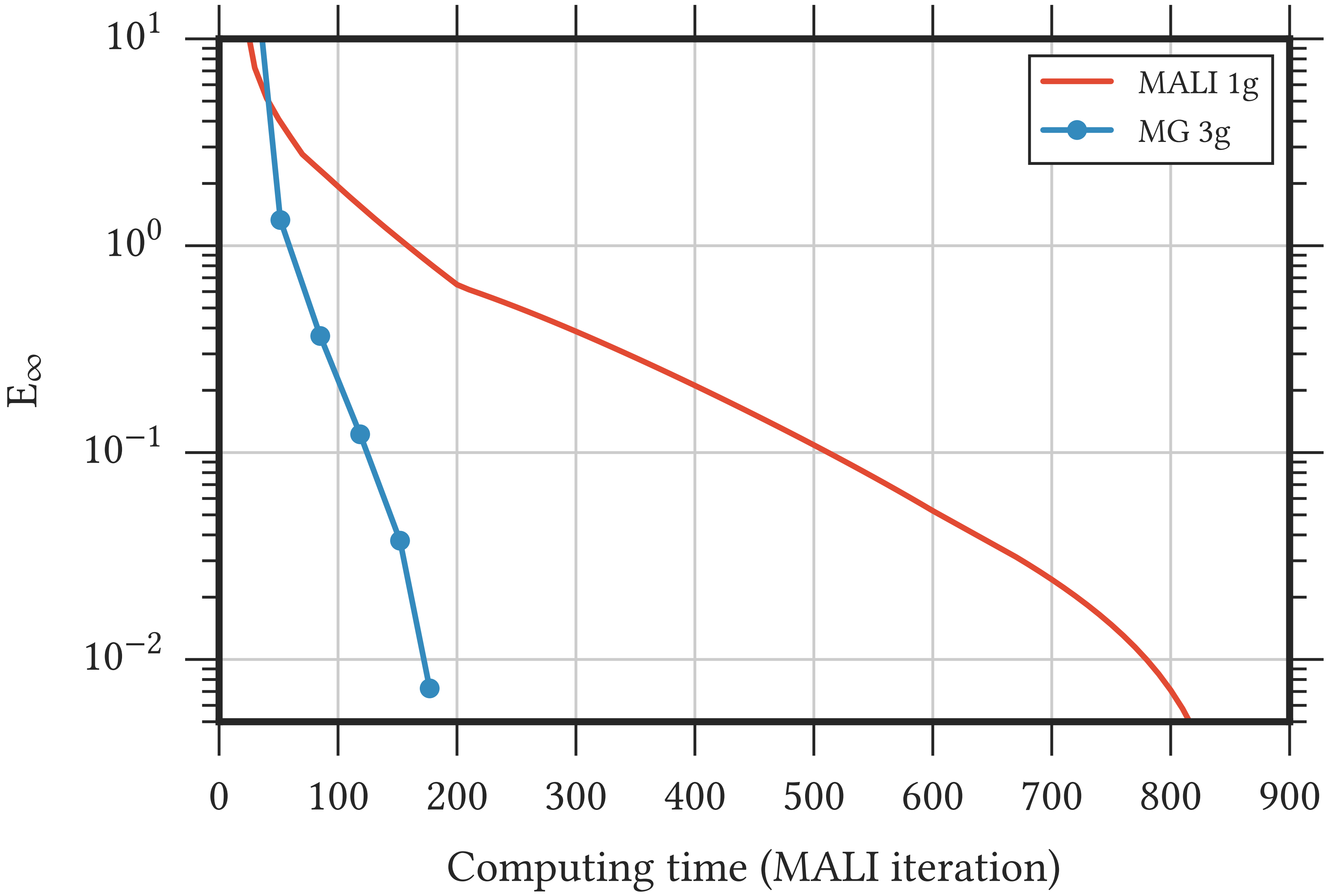

Current capability
Needed for DKIST/EST
Intensity
Stokes V
1 Mm

A 3D radiative transfer framework: XII. Many-core, vector and GPU methods

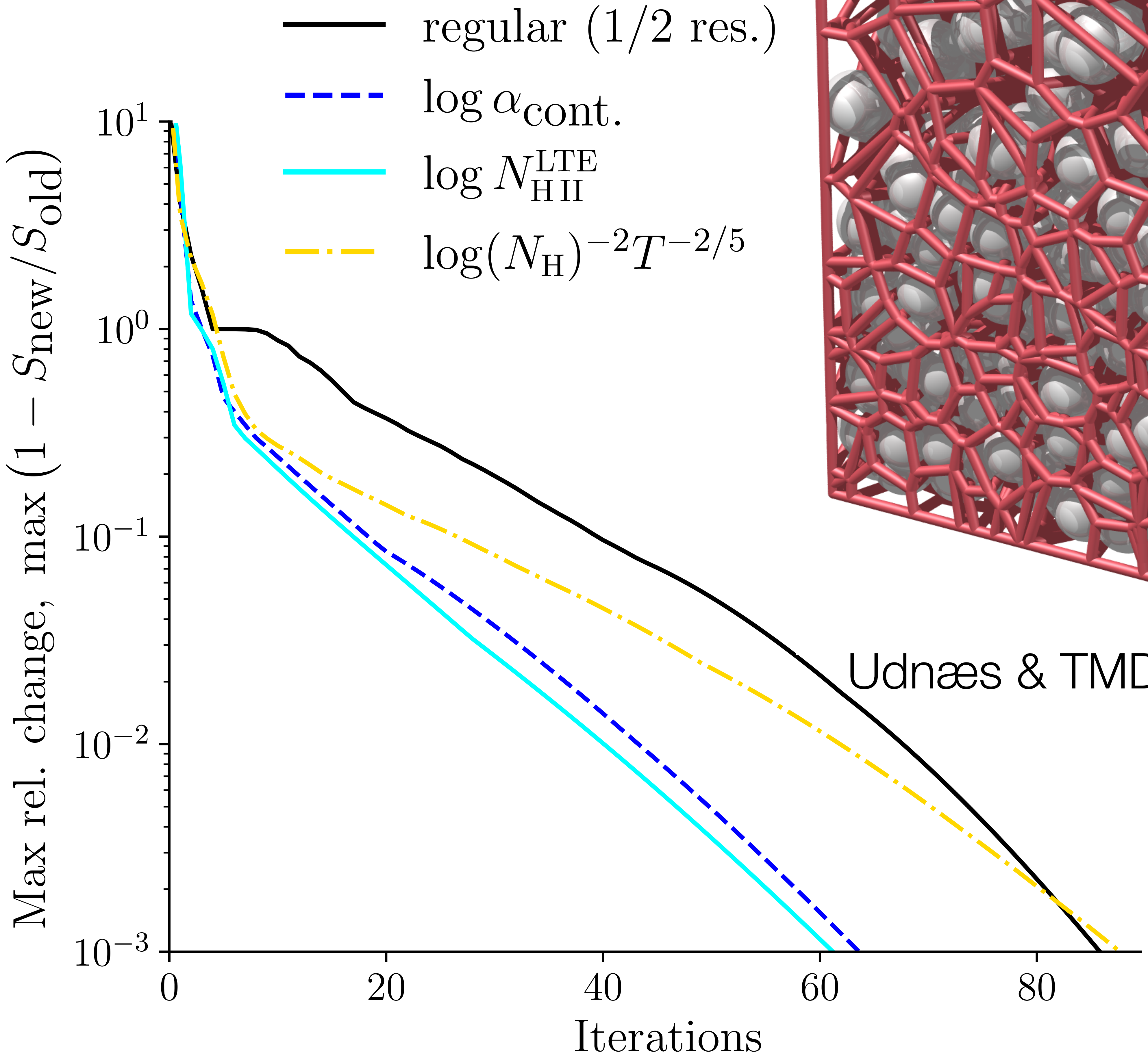
P.H. Hauschildt [a,*], E. Baron [b,c]

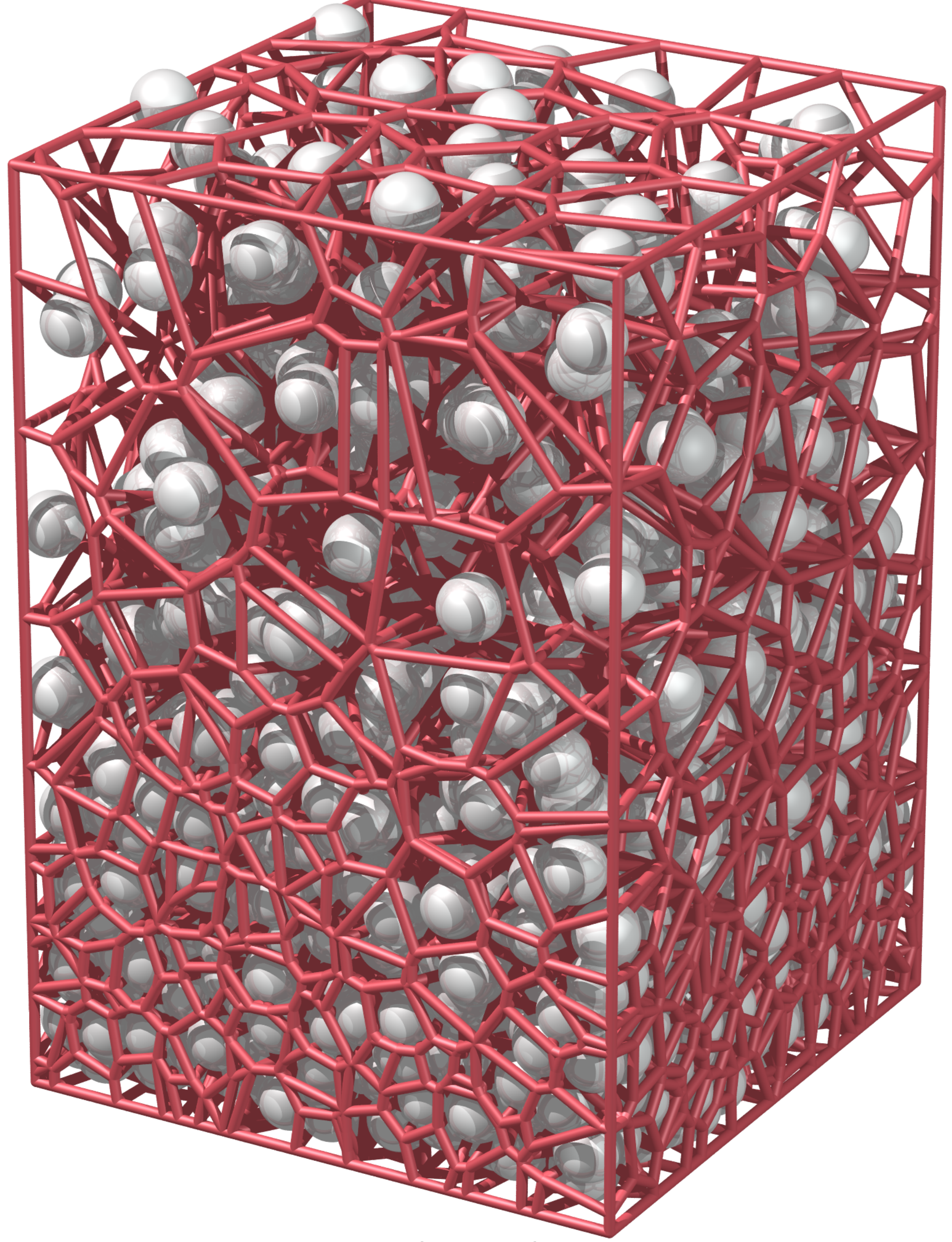
[a] Hamburger Sternwarte, Gojenbergsweg 112, 21029 Hamburg, Germany
[b] Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, 440 W. Brooks, Rm 100, Norman, OK 73019, USA
[c] Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK-8000 Aarhus C, Denmark





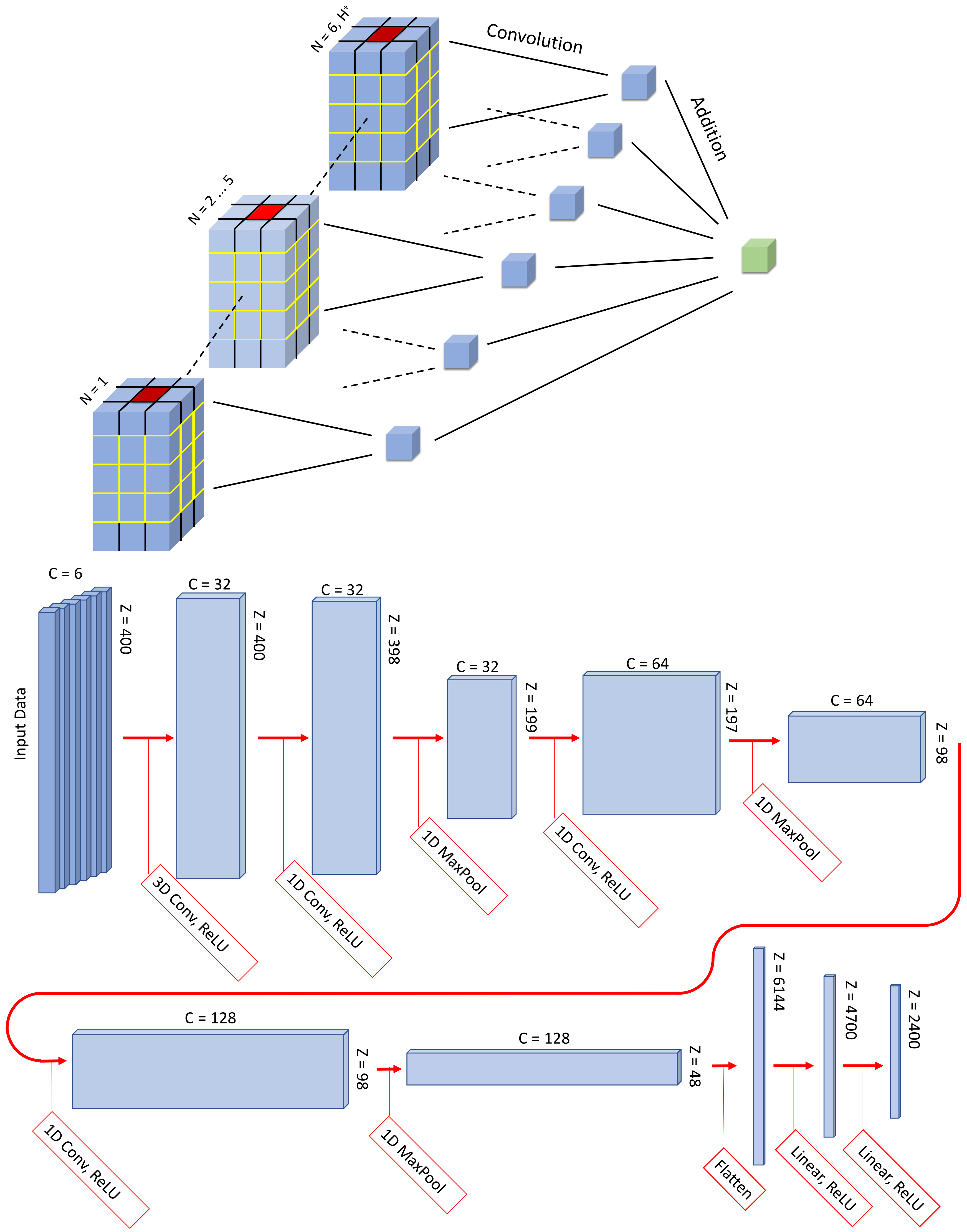
Bjørgen & Leenaarts (2017), A&A, 599, A118



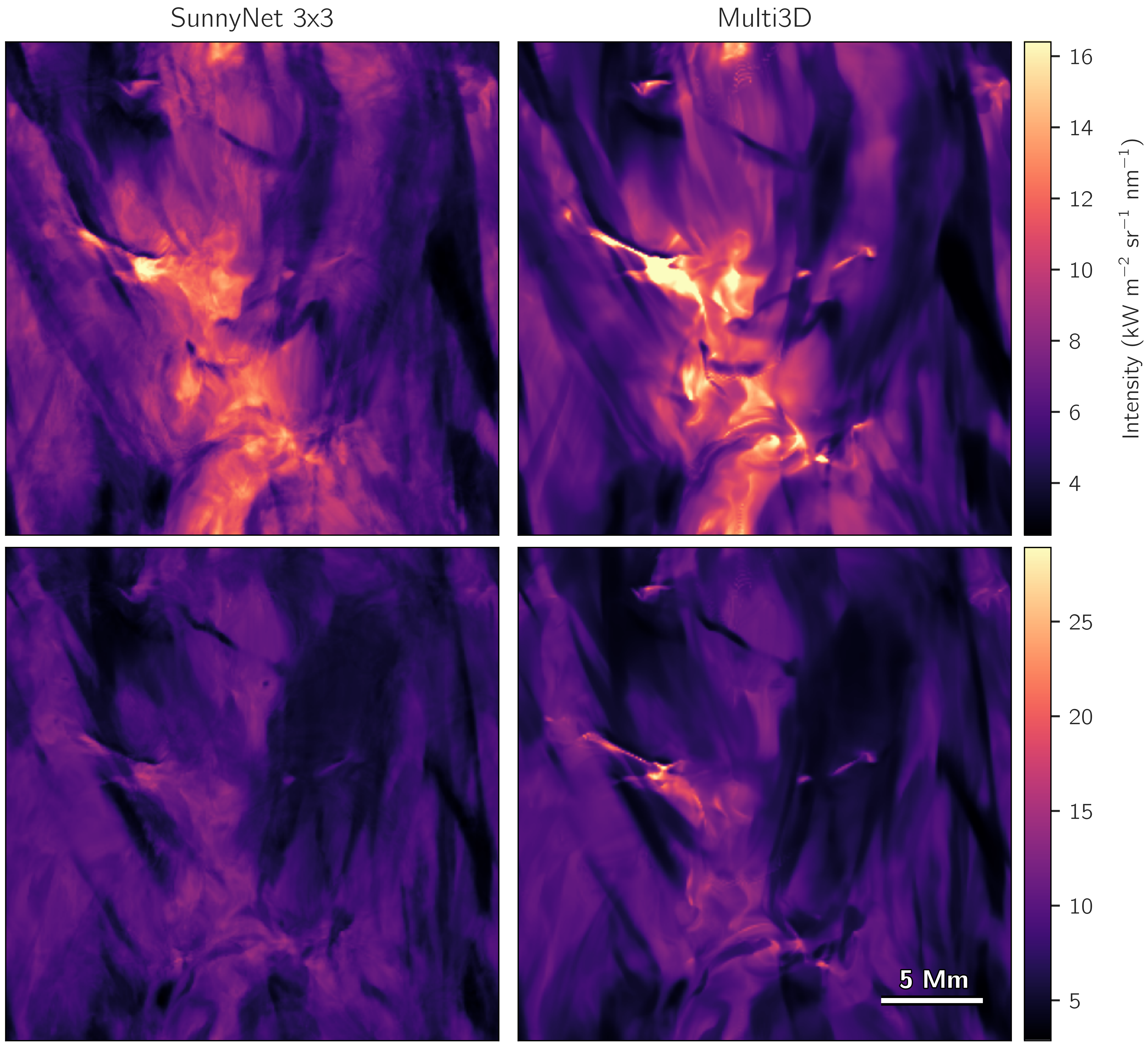


Udnæs & TMDP (2023), A&A, 675, A127

Speeding up 3D NLTE with neural networks



Chappell & TMDP (2022), A&A 658, A182




Hα −16 km/s
00:00:00
Hα core
5 Mm

Summary

- 3D NLTE essential for precision spectroscopy
- 3D NLTE essential to understand solar chromospheric radiation
- Challenges ahead: large surveys, exoplanets, new solar telescopes
- Need faster 3D NLTE: synergies for solar and stellar astrophysics