Stellar abundance and parameter determinations with 3D model atmospheres

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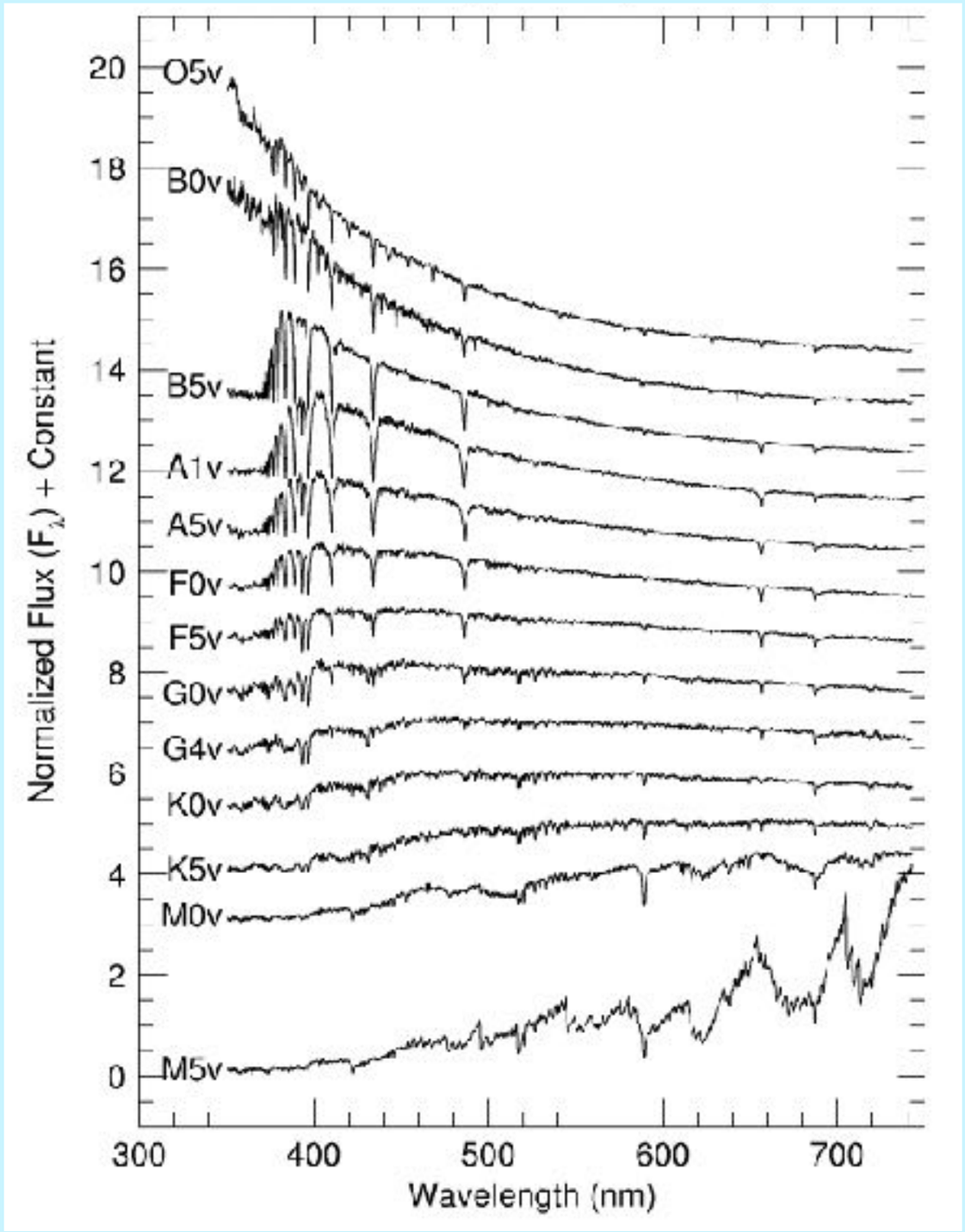
Stellar characterisation

- Stellar spectra carry the information about the physical properties and compositions of stars

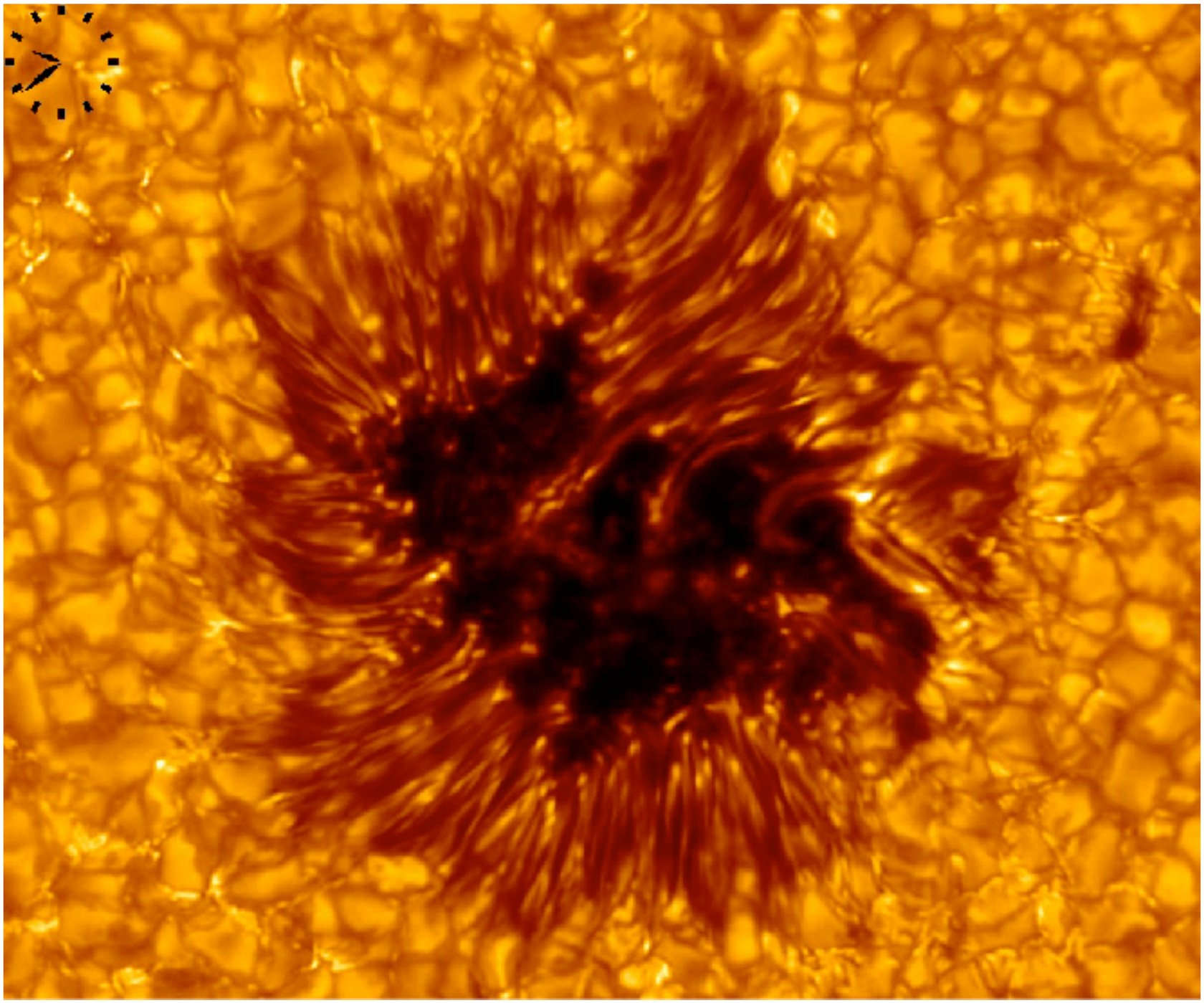
- Quantifying this information requires models of the atmospheres of stars



1D model atmospheres

- 1D Homogeneous stratification
- Hydrostatic
- Stationary
- Radiative transfer: 100,000 - 1,000,000 wavelengths
- Convection: simplified treatment (Mixing Length Theory)
- Free tuneable parameters

Real stellar atmospheres

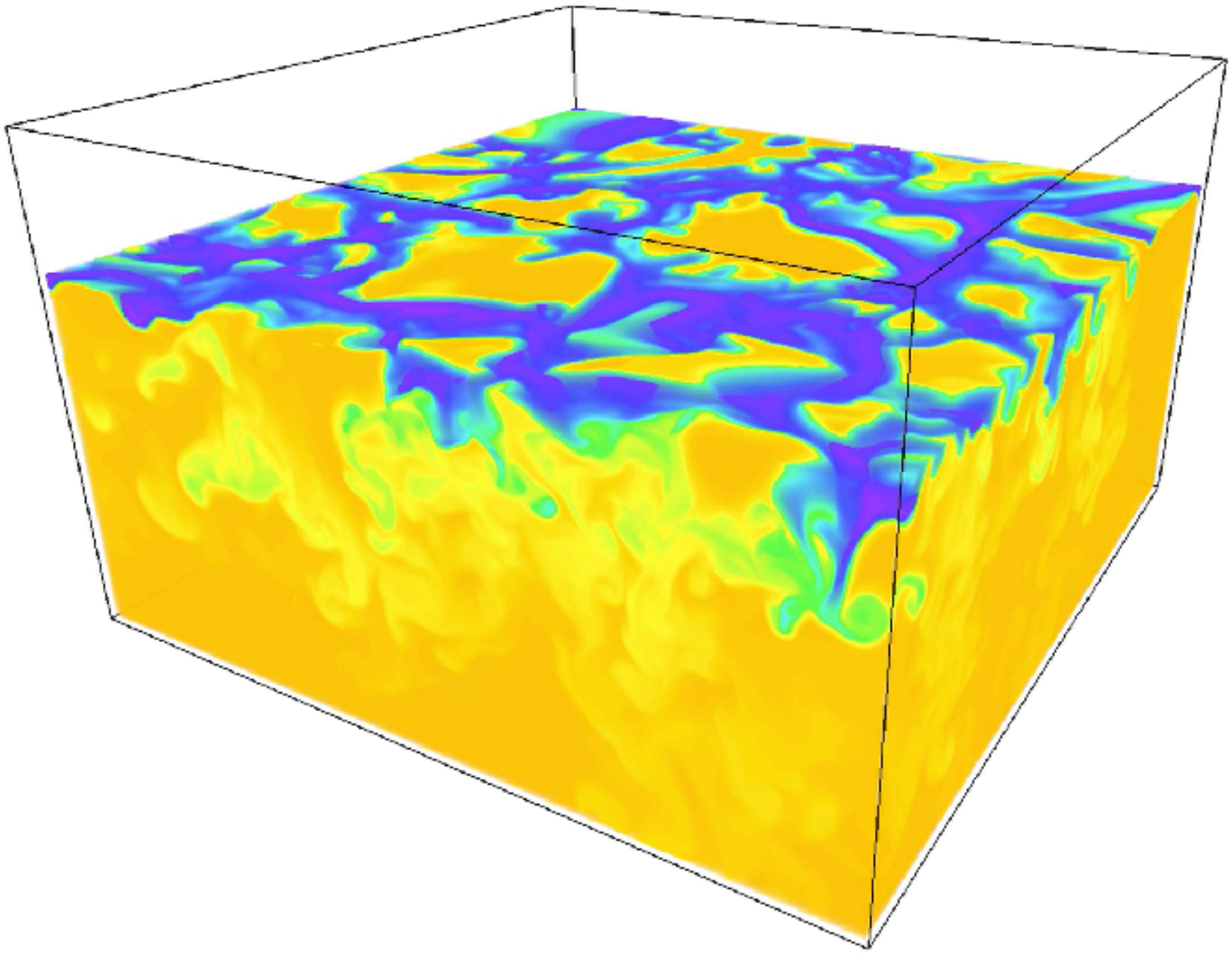


Credit: L. R. van der Voort (Swedish Solar Telescope)

3D models

- Solution of mass, momentum, and energy conservation equations
- 3D geometry
- Time-dependent
- 3D non-grey radiative transfer (with multi-group opacities)
- Convection: no need for dedicated free parameters

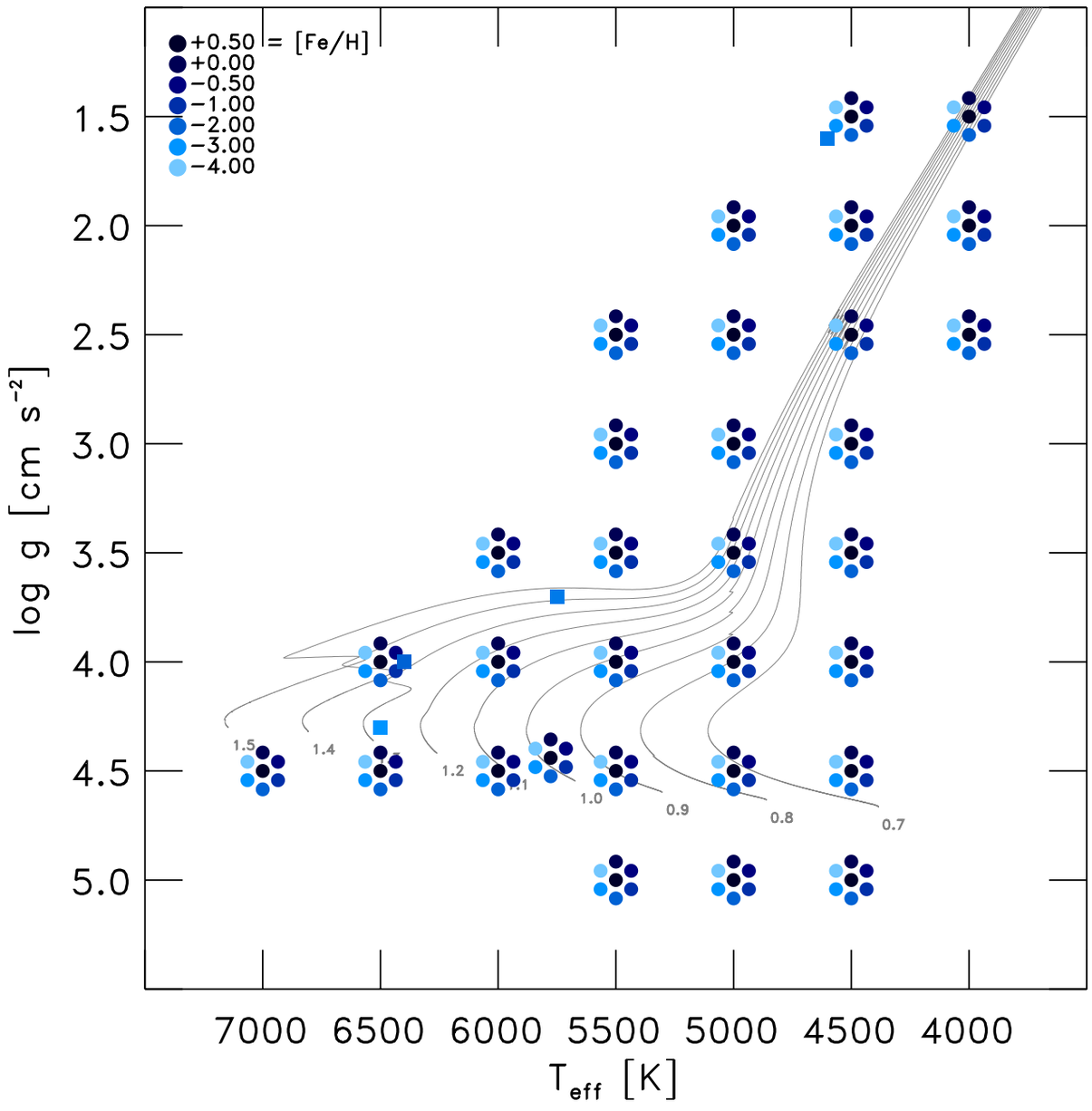
3D simulations: surface convection



Stagger-code solar surface convection simulation (R. Collet)

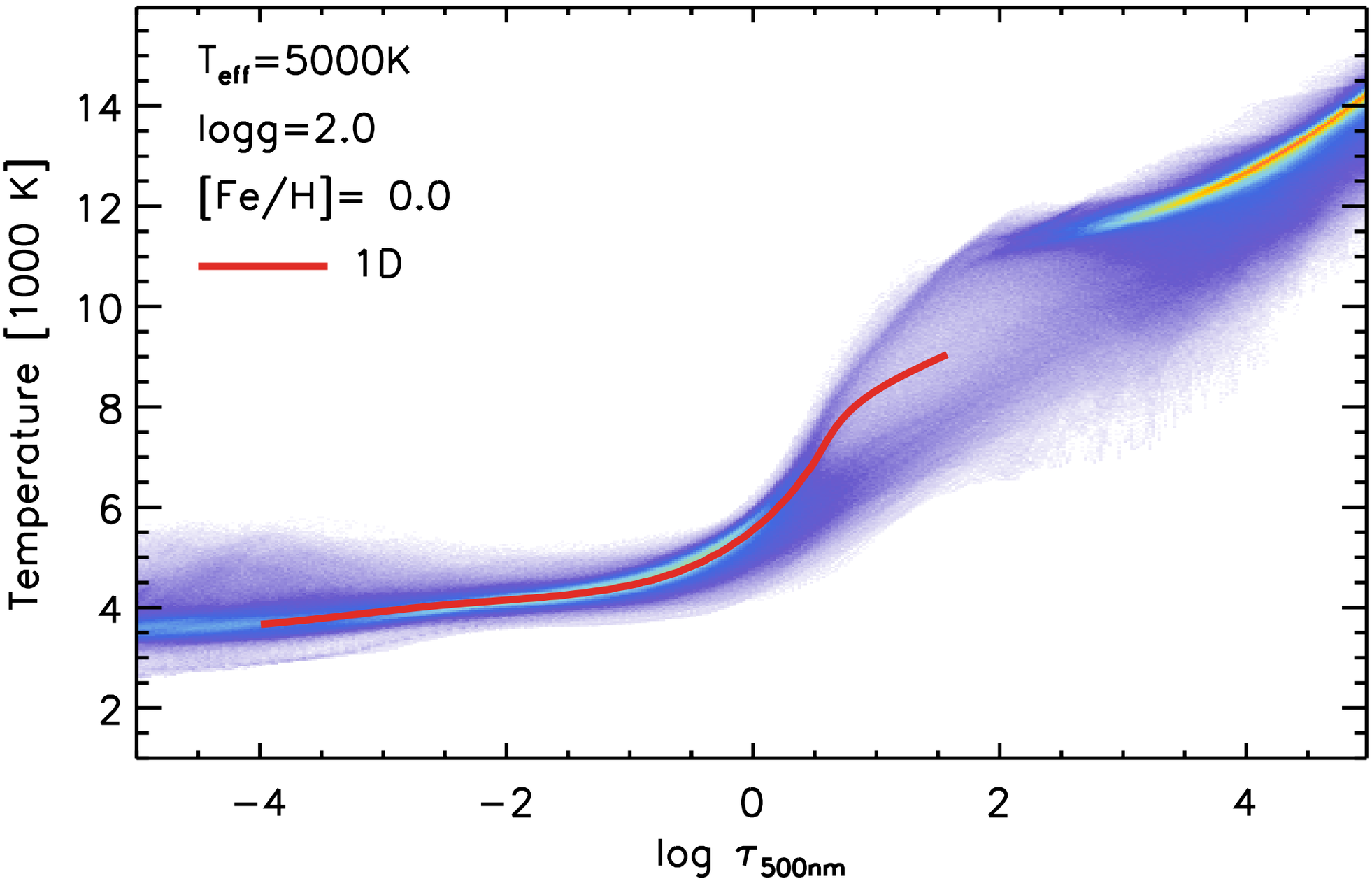
Stagger grid of 3D simulations

- Magic et al. (2013); Collet et al. (2011); Trampedach et al. 2013
- Over 200 3D surface convection simulations of FGK stars
- Systematic study of 3D-1D differences (spectroscopy and photometry)
- Calibration of MLT and improved boundary conditions for 1D stellar structure models

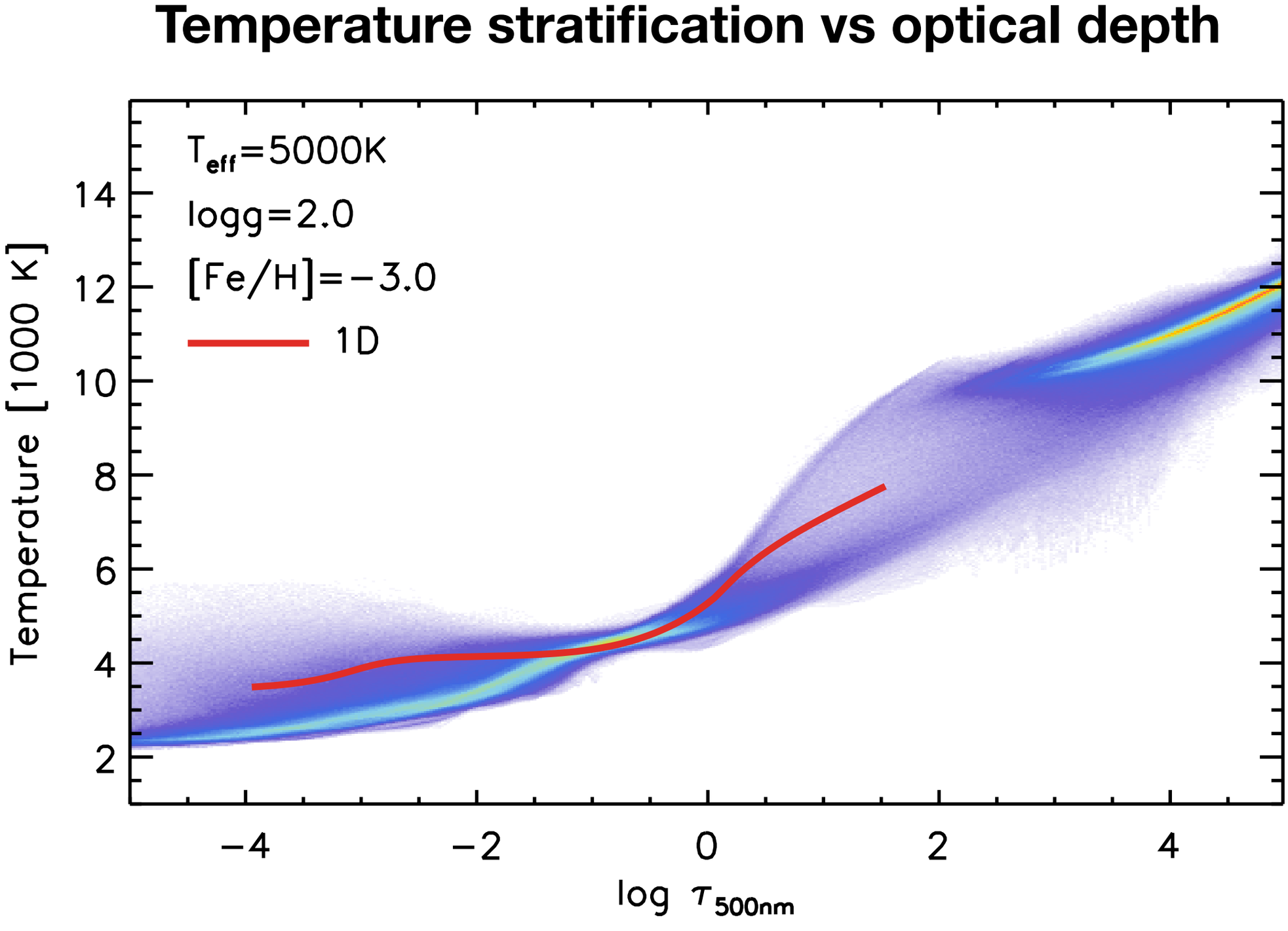


Solar metallicity

Temperature stratification vs optical depth

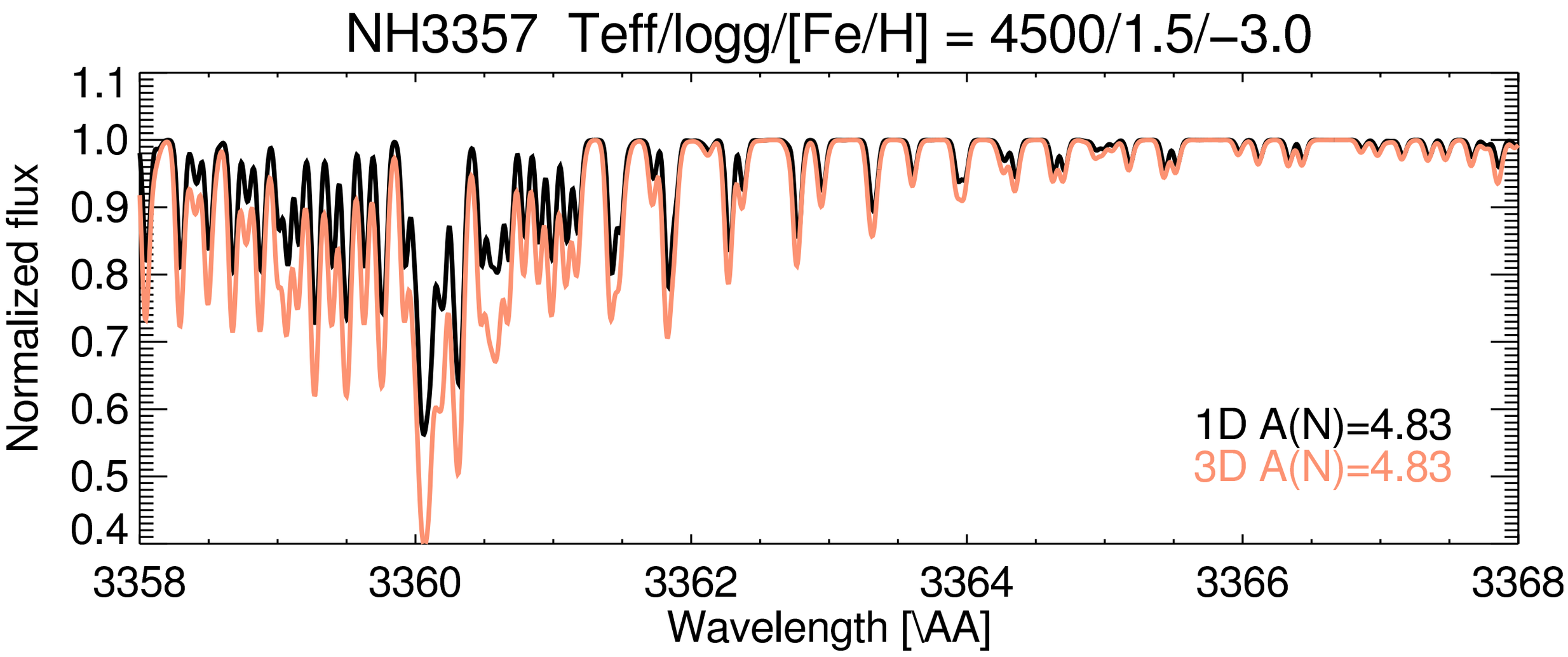


Low metallicity



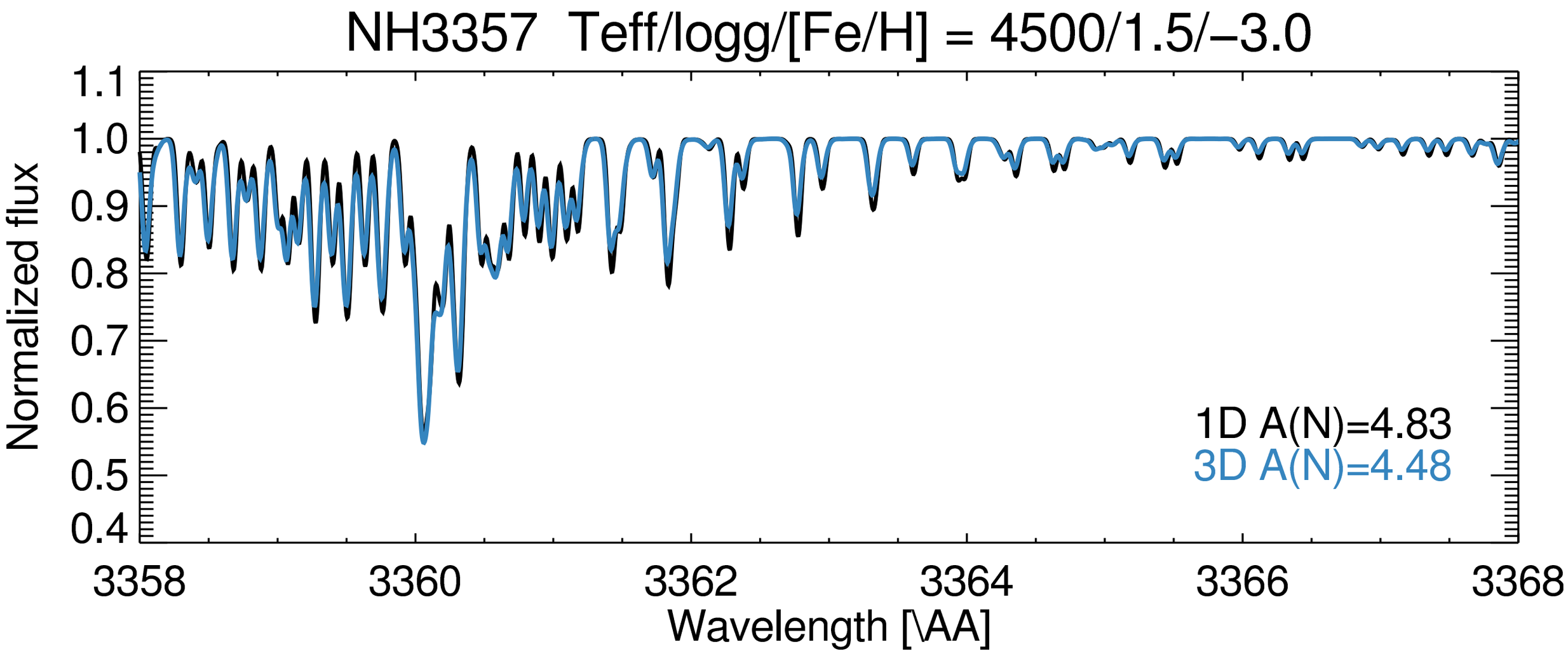
Molecular bands: 3D vs 1D

3D and 1D: same nitrogen abundance

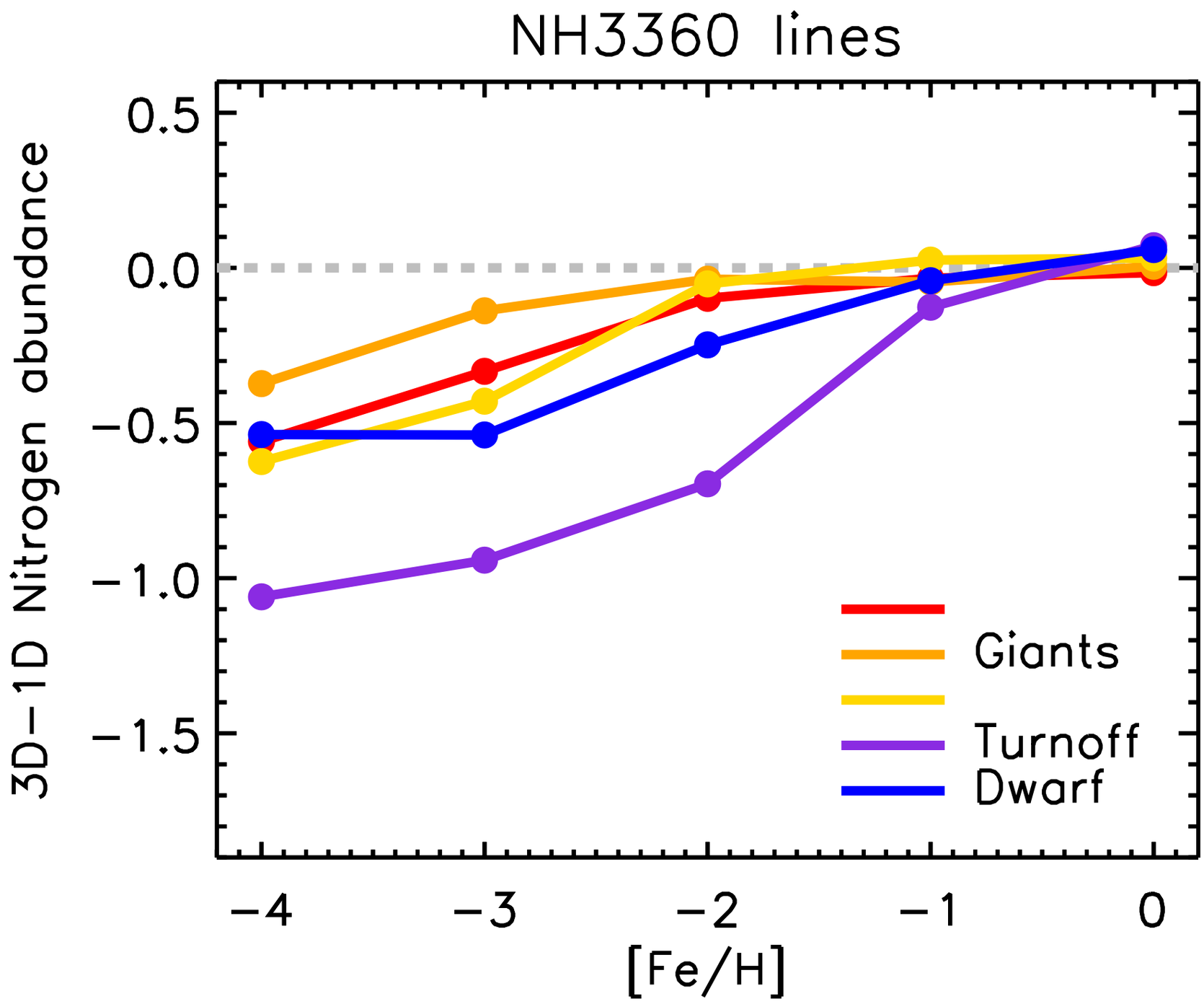


Molecular bands: 3D vs 1D

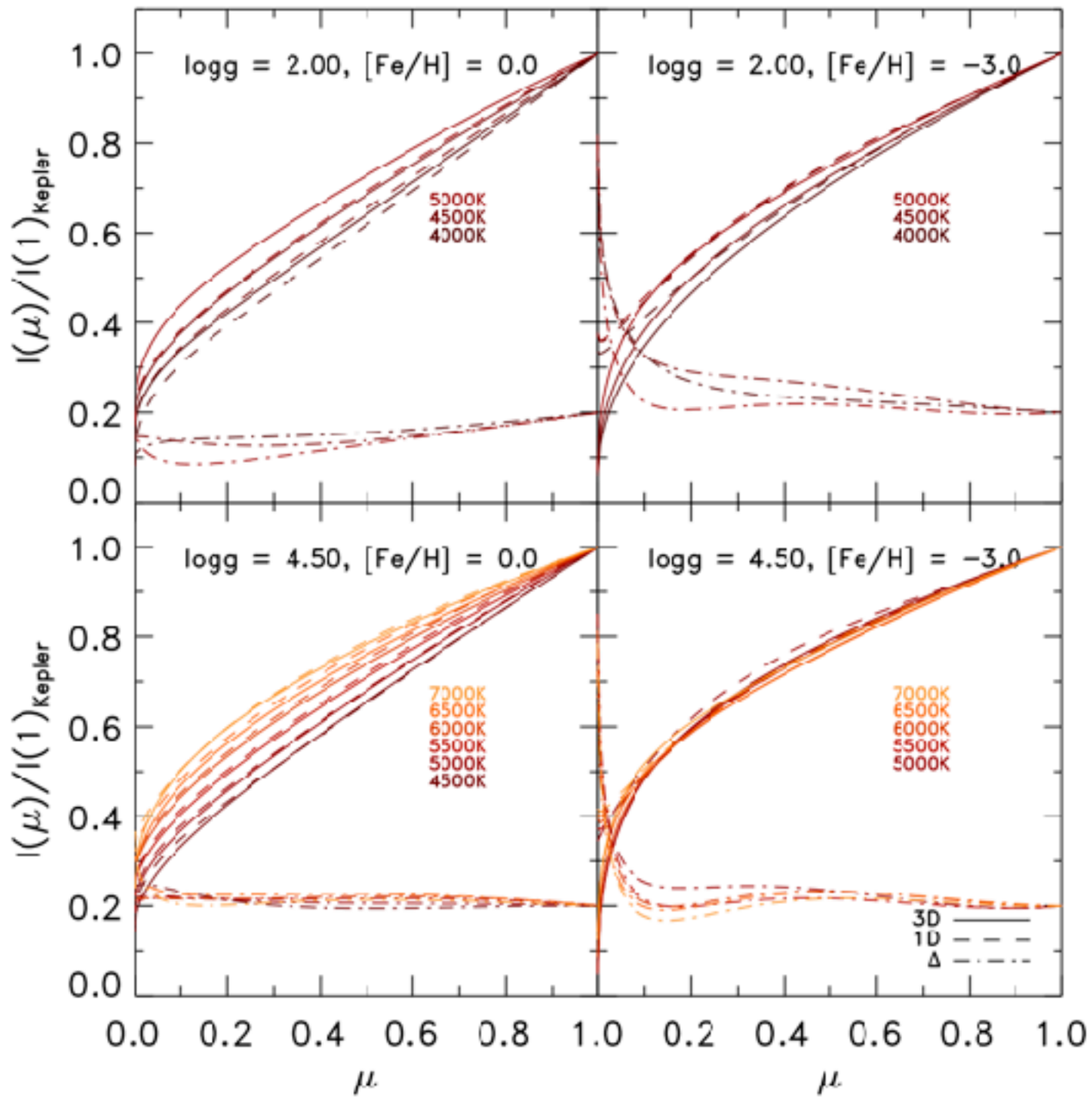
3D: low nitrogen abundance



Stellar abundances: 3D vs 1D



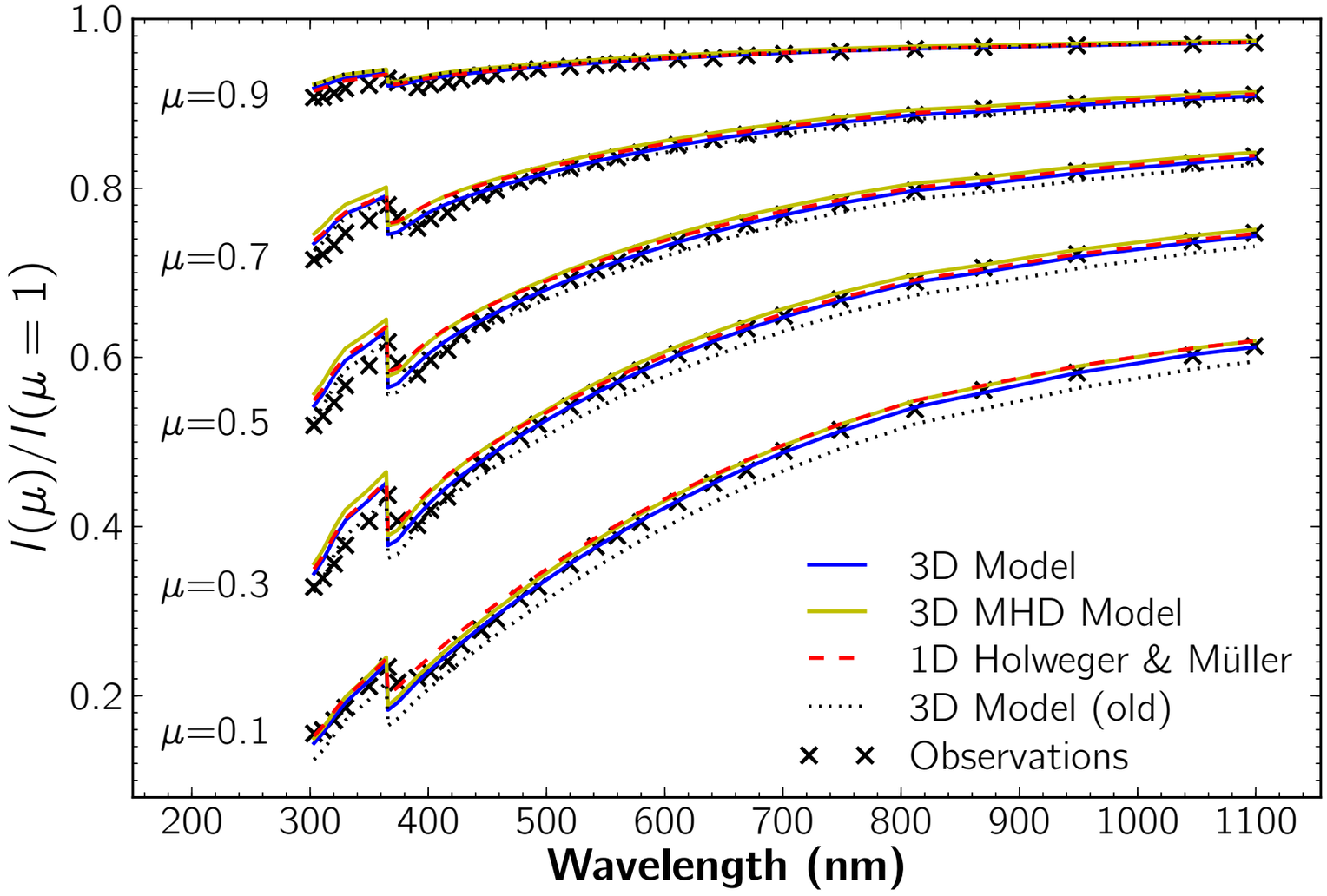
Limb darkening



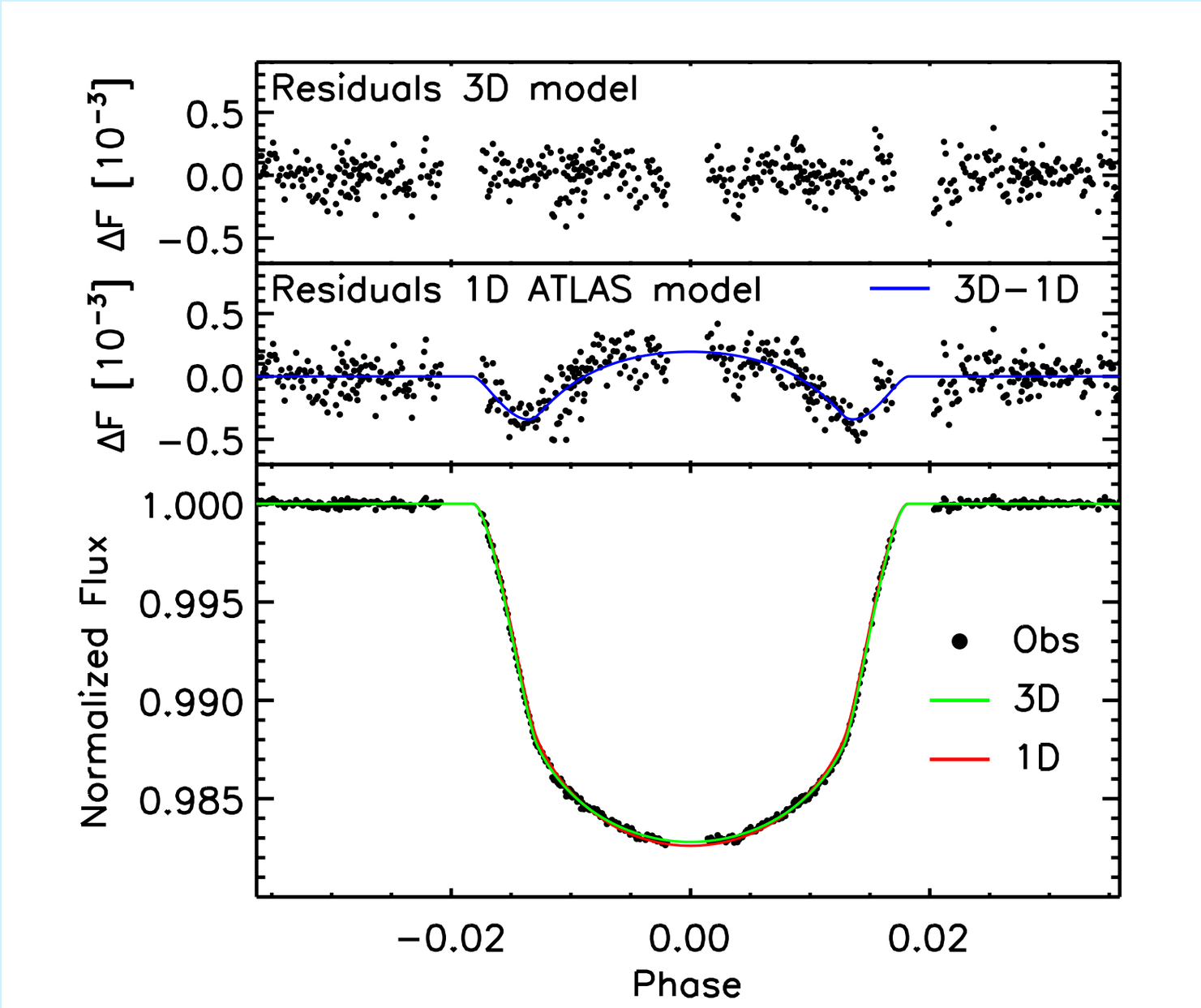
Centre-to-limb variations, 3D vs 1D (Magic et al. 2015)

Limb darkening: Sun

- Calculations based on 3D models give very good agreement with observations in UV and visible (Pereira, Asplund, Collet et al. 2013)



Exoplanet transits

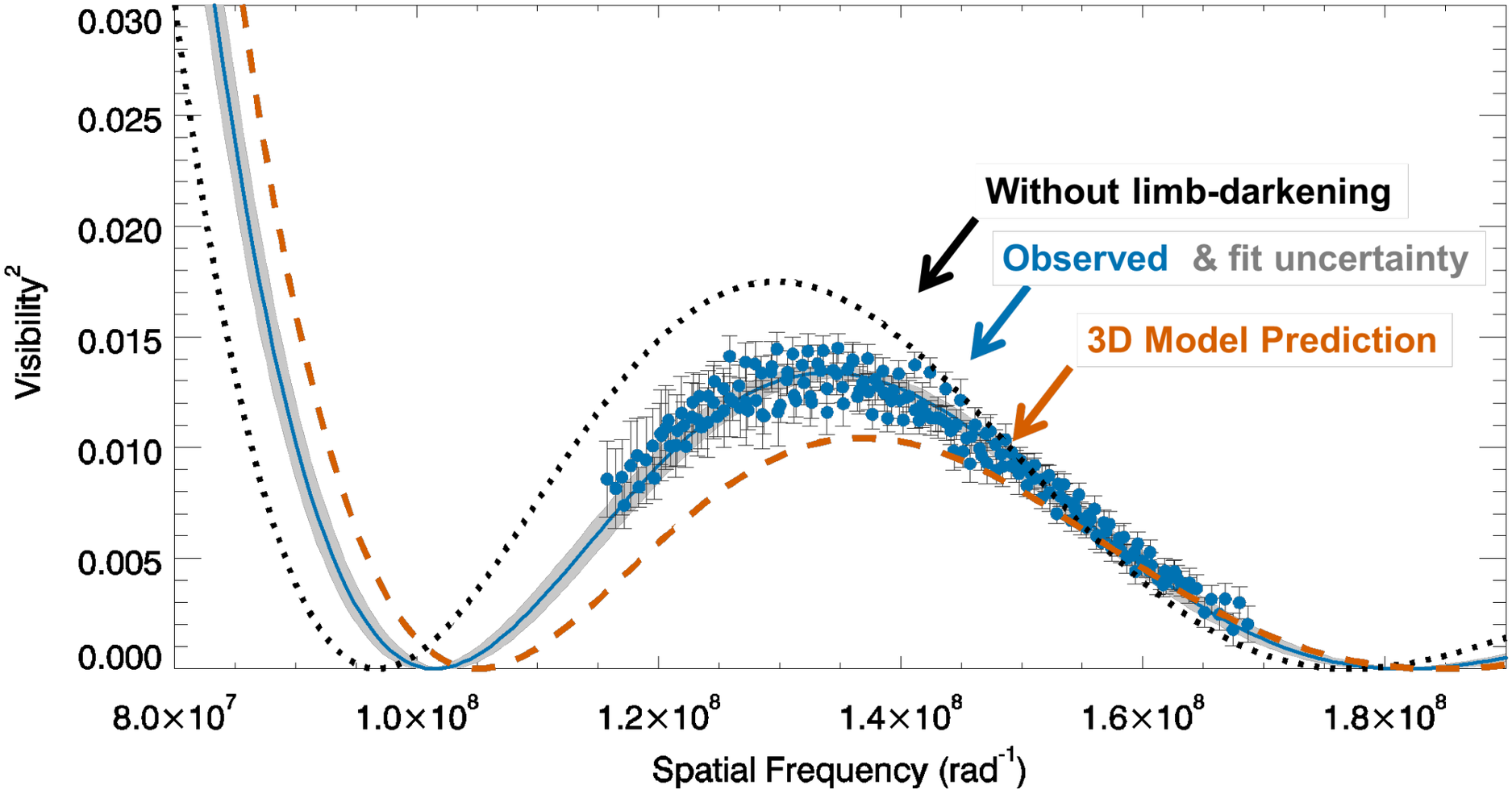


HD209458b transit (Hayek et al. 2012)

Interferometric tests

- Limb darkening from 3D/1D models: weaker than observed with CHARA/PAVO at visible wavelengths for evolved stars (T. White et al.)

- Similar result for α Cen A & B at IR wavelengths with VLTI/PIONIER (Kervella, Bigot et al. 2017)



Summary

- Systematic differences between 3D and 1D models: inhomogeneities, velocity fields, temperature gradients

- 3D models at low metallicity: steeper and cooler upper atmospheres

- Significant 3D-1D differences from molecular lines

- Limb darkening: in general, very good agreement with observations but some open issues at long wavelengths with predictions for interferometry