Spectroscopy with 3D Model Stellar Atmospheres of Late-Type Stars

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Stellar spectra

- Stellar spectra carry the information about the physical properties and compositions of stars
- Quantifying this information requires models of the atmospheres of stars
Classical 1D models vs Real Stellar Atmospheres

Emergent radiation

1D stationary hydrostatic model atmosphere

Observations (L. R. van der Voort, SST)
3D Simulations

STAGGER-CODE
Solar Surface Convection Simulation (R. Collet)
Solar Metallicity

Temperature vs Optical Depth

$T_{\text{eff}} = 5000 \text{K}$

$\log g = 2.0$

$[\text{Fe/H}] = 0.0$

1D
Low Metallicity

Temperature vs Optical Depth

$T_{\text{eff}} = 5000 \text{K}$

$\log g = 2.0$

$[\text{Fe/H}] = -3.0$

1D
Molecules: 3D vs 1D

Example: 3D and 1D, Same Nitrogen Abundance

NH3357  Teff/logg/[Fe/H] = 4500/1.5/–3.0

1D A(N)=4.83
3D A(N)=4.83
Molecules: 3D vs 1D

3D model: Lower Nitrogen Abundance

NH3357  Teff/logg/[Fe/H] = 4500/1.5/−3.0

1D A(N)=4.83
3D A(N)=4.48
Oxygen, 3D-1D LTE

OH3100 lines

3D-1D Oxygen abundance vs. [Fe/H]

- Red: Giants
- Orange: Turnoff
- Purple: Dwarf

[Graph showing abundance vs. metallicity]
Carbon, 3D-1D LTE

CH4300 lines

3D−1D Carbon abundance

[Fe/H]

Giants

Turnoff

Dwarf
CEMP Stars

3D-1D carbon abundance corrections depend on C/O ratio

![Graph showing CH4300 lines with different abundances and their dependence on C/O ratio. The graph includes lines for different stellar types: Giants, Turnoff, and Dwarf, with specific [C/Fe] and [Fe/H] values.]
Summary

- 3D vs 1D, **systematic differences**: inhomogeneities, velocity fields, temperature gradients

- 3D **metal-poor** model stellar atmospheres: *steeper* and *cooler* temperature stratification

- **Large, negative** 3D-1D CNO abundance **corrections** from molecular lines

- **Corrections** for CEMP stars depend on C/O ratio
Outtakes
Nitrogen, 3D-1D LTE

NH3360 lines

3D-1D Nitrogen abundance

[Fe/H]
Energy balance

- Competition between **adiabatic cooling** and **radiative heating**:

\[
\frac{de}{dt} = - \nabla \cdot (eu) - P \nabla \cdot u + Q_{\text{rad}} + Q_{\text{visc}}
\]

- Lower metallicity = lower line opacity = less radiative heating
The S\textsc{TAGGER-GRID} (Collet et al. 2011, Magic et al. 2013)