Investigation of velocity fields in 3D RHD M-Star simulations

$T_{\text{eff}}$ and $\log g$ dependence of FeH in M-stars

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Overview

▶ Methods
▶ Kinematic motion
▶ Influence of kinematic motion on FeH lines
▶ Summary & Outlook
Introduction

- M-stars are cool, they range from $T_{\text{eff}} \sim 4200$ K to $\sim 2000$ K
- pressure broadening is strong in these stars and atomic lines become very broad
- molecular FeH lines provide a good mean to measure slow rotation or magnetic fields because they are still narrow in cool stars
- convective motion have to be known to measure rotational or Zeeman broadening
CO$^5$BOLD

- used to model solar and stellar surface convection
- solves the coupled non-linear equations of compressible hydrodynamics in an external gravity field (mass-conservation, momentum, and energy) [Freytag et al., 2008]
- non-local frequency-dependent radiative transfer (opacity binning method see e.g. Ludwig et al. [2002] or Ludwig et al. [2006])
Model Overview

- models range in $T_{\text{eff}}$ from 2600 K to 4000 K for $\log g \sim 5 \, \text{[cgs]}$
- and in $\log g$ from 5.0 to 3.0 [cgs] for $T_{\text{eff}} \sim 3275$ K
Velocity Fields in CO\(^5\)BOLD Models

method: binning the radial velocities of the voxels in the CO\(^5\)BOLD models gives a histogram

- a histogram of the whole 3D cube gives a mean FWHM velocity
- a histogram of one layer gives a height dependent FWHM velocity
Velocity fields in $\text{CO}^5\text{BOLD}$ models

- upper panel: FWHM-velocity structure in three exemplary $\text{CO}^5\text{BOLD}$ models
- bottom panel: contribution function (depression) for an FeH line
Velocity fields in CO$^5$BOLD Models ($\log g$)

![Graph showing velocity fields in CO$^5$BOLD Models. The graph plots velocity [m/s] against $\log(g)$ with different markers representing mean FWHM-velocity (dots), weighted FWHM-velocity (triangles), and maximum FWHM-velocity (squares).]
Velocity fields in CO$^5$BOLD Models ($T_{\text{eff}}$)

![Graph showing velocity fields as a function of $T_{\text{eff}}$]

- • mean FWHM-velocity (dots)
- △ weighted FWHM-velocity (triangles)
- □ maximum FWHM-velocity (squares)
Linfor3D and FeH lines

Linfor3D (3D line formation code) can use 3D CO$^5$BOLD model atmospheres as input

- full 3D lines and mean $\langle 3D \rangle$ (1D) lines
- for FeH, we use Dulick et al. [2003] for line-strength, -position, and partition function (dissociative equilibrium)
Line asymmetries due to velocity fields

- $T_{\text{eff}}$ 3375 K, $\log g=3.5$
  - we use the micro- and macro-turbulence description to broaden $\langle 3D \rangle$ FeH lines
  - broadening from 3D velocity fields do not deviate strongly from pure Gaussian broadening
  - slightly asymmetries due to small line shifts

- $T_{\text{eff}}$ 3820 K, $\log g=4.9$
express RHD velocities in terms of micro- and macro-turbulence velocities

determination of micro-velocities with the curve of growth-method

determination of macro-velocities with Gaussian convolution
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Comparison of Micro- and Macro-turbulence Velocities with Hydrodynamical Velocities

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3D- and $<3D>$- FeH Lines (log $g$)

- investigation of ten FeH lines with different quantum numbers (chosen from Reiners and Basri [2006])
- determination of eq. width, FWHM, line depth
- $<3D>$-models (basically 1D) without velocity fields and 3D-models including velocity fields
3D- and \(< 3D >\)- FeH Lines (\(T_{\text{eff}}\))

- investigation of ten FeH lines with different quantum numbers (chosen from Reiners and Basri [2006])
- determination of eq. width, FWHM, line depth
- \(< 3D >\)-models (basically 1D) without velocity fields and 3D-models including velocity fields

\[
\begin{align*}
T_{\text{eff}} &= 3820K \\
T_{\text{eff}} &= 3380K \\
T_{\text{eff}} &= 3275K \\
T_{\text{eff}} &= 2800K \\
T_{\text{eff}} &= 2575K
\end{align*}
\]
Line Shapes (log $g$)

- Difference between 3D- and <3D>-models almost constant in eq. width
- Strong influence due to velocity fields on FWHM at small log $g$
- Line depth reflects eq. width and effects of velocity broadening
- Lines with different $gf$-values show differences due to different heights of formation
Line Shapes ($T_{\text{eff}}$)

- Difference between 3D- and $<3D>$-models almost constant in eq. width.
- Velocity broadening covered by thermal broadening at low $T_{\text{eff}}$.
- Line depth shows effects of velocity broadening (high $T_{\text{eff}}$) and saturation (low $T_{\text{eff}}$).
- Lines with different $gf$-values show differences due to different heights of formation.
Summary and Conclusion

- we have investigated a set of M-star models which range in $T_{\text{eff}} \sim 2600$ K $- 4000$ K and in $\log g \sim 3.0 - 5.0$ [cgs]
- the convective velocities vary from $\sim 100$ m/s (for cool models with high $\log g$) to $\sim 2000$ m/s (for hot models or small $\log g$)
- the influence of hydrodynamical velocity fields results in small asymmetries in FeH lines and the related broadening is almost Gaussian
- expression in micro- and macro-turbulent velocities gives values of the same order as in 3D RHD models
- investigation of ten FeH lines reflects the influence of dynamical velocity fields
- no significant differences between lines with different quantum numbers
- next step, face theory with observations (CRIRES data) and determine $T_{\text{eff}}$, $\log g$, and velocities in M-stars
Thank you for your attention


