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

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

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Overview

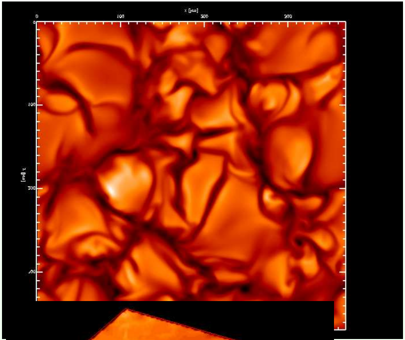
- Methods
- Kinematic motion
- Influence of kinematic motion on FeH lines
- Summary & Outlook

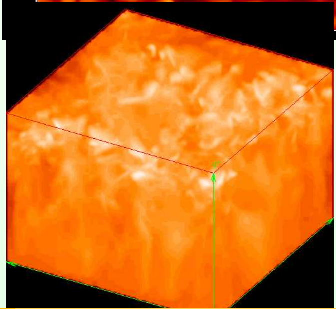
Introduction

- M-stars are cool, they range from $T_{\mathrm{eff}} \sim$ 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

CO⁵BOLD

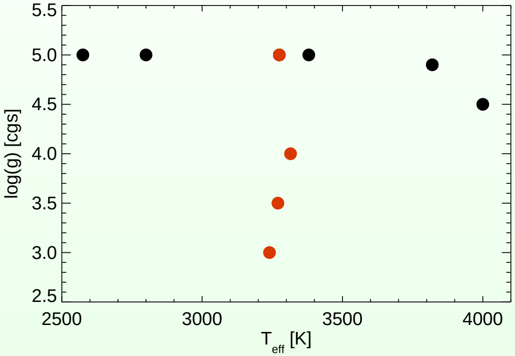
- used to model solar and stellar surface convection
- solves the coupled non-linear equations of compressible hydrodynamics in an external gravity field (mass-conservation, momentum, and energy) [Freytag et al., 2008]
- non-local frequency-dependent radiative transfer (opacity binning method see e.g.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



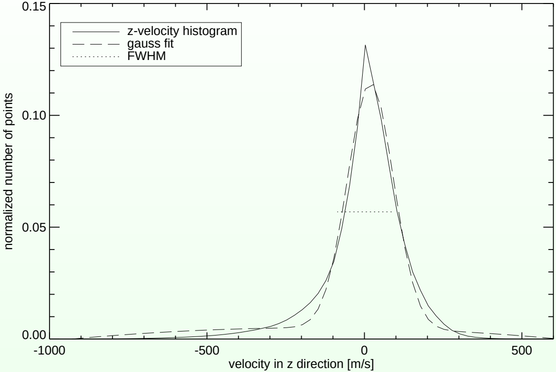


Model Overview

- models range in T_{eff} from 2600 K to 4000 K for $\log g \sim 5$ [cgs]
- and in $\log g$ from 5.0 to 3.0 [cgs] for $T_{\mathrm{eff}} \sim 3275$ K



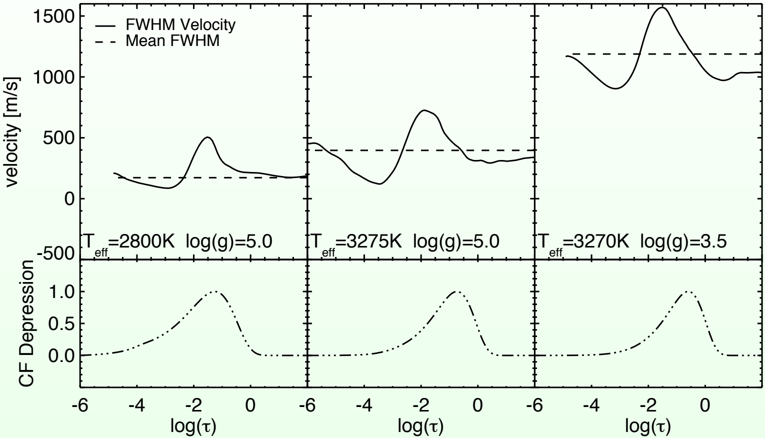
Velocity Fields in CO^{5}BOLD Models



method: binning the radial velocities of the voxels in the CO^{5}BOLD models gives a histogram

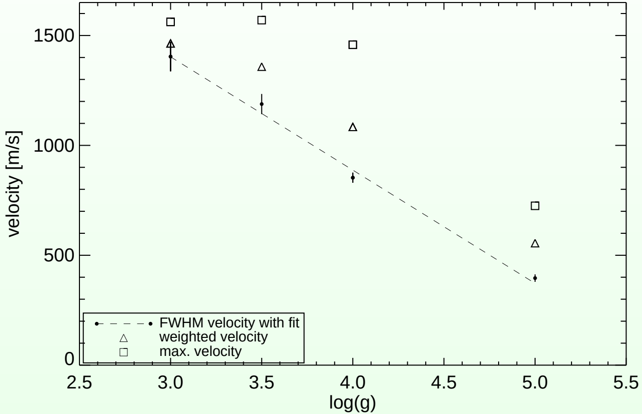
- a histogram of the whole 3D cube gives a mean FWHM velocity
- a histogram of one layer gives a height dependent FWHM velocity

Velocity fields in CO^5BOLD models



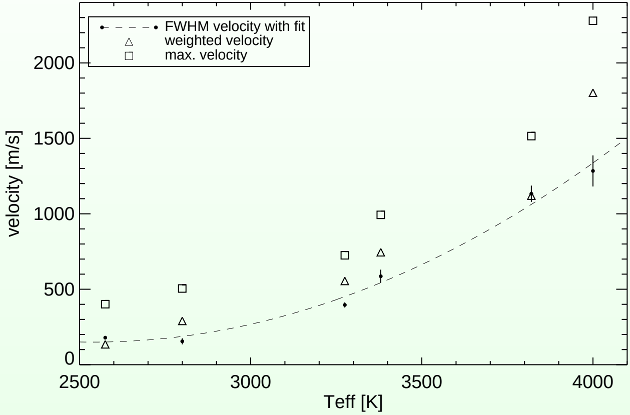
- upper panel: FWHM-velocity structure in three exemplary CO^5BOLD models
- bottom panel: contribution function (depression) for an FeH line

Velocity fields in CO^5BOLD Models ($\log g$)



- ● mean FWHM-velocity (dots)
- △ weighted FWHM-velocity (triangles)
- □ maximum FWHM-velocity (squares)

Velocity fields in CO^{5}BOLD Models (T_{eff})



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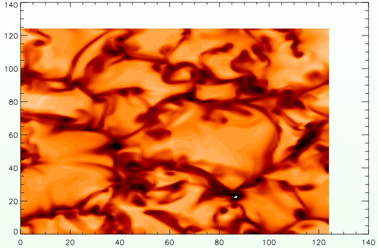
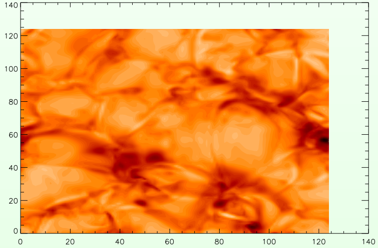
Linfor3D and FeH lines



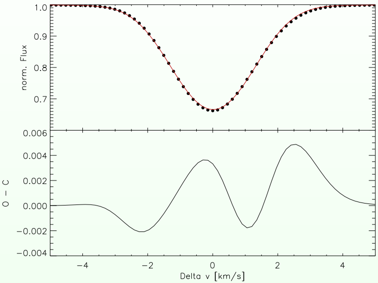
⟵ continuum intensity map

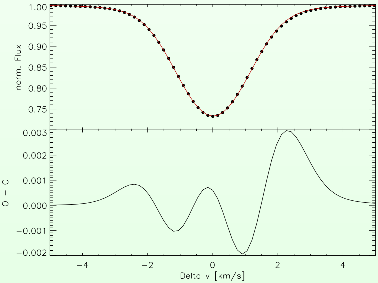
- Linfor3D (3D line formation code) can use 3D CO^{5}BOLD model atmospheres as input
- full 3D lines and mean $< 3D >$ (1D) lines
- for FeH, we use Dulick et al. [2003] for line-strength, -position, and partition function (dissociative equilibrium)



⟵ line intensity map

Line asymmetries due to velocity fields





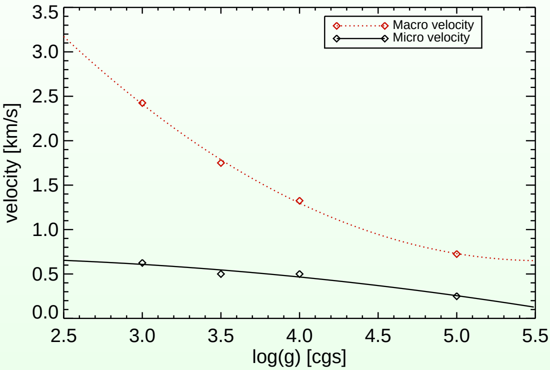
$\longleftarrow$ $T_{\rm eff}$ 3375 K, *logg*=3.5

- we use the micro- and macro-turbulence description to broaden <3D> FeH lines
- broadening from 3D velocity fields do not deviate strongly from pure Gaussian broadening
- slightly asymmetries due to small line shifts

$\longleftarrow$ $T_{\rm eff}$ 3820 K, *logg*=4.9

Micro- and Macro-turbulence Velocities (log g)

- 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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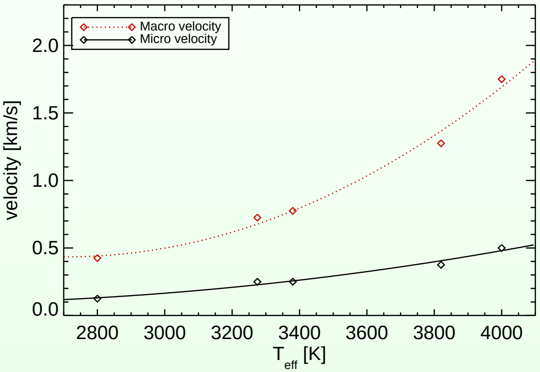
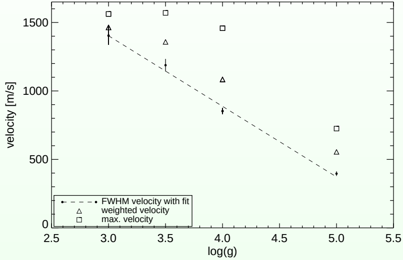
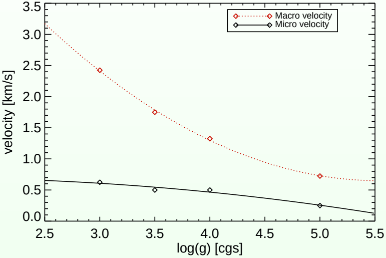
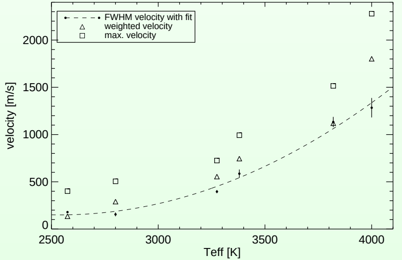
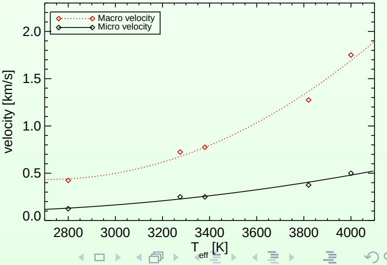


Comparison of Micro- and Macro-turbulence Velocities with Hydrodynamical Velocities



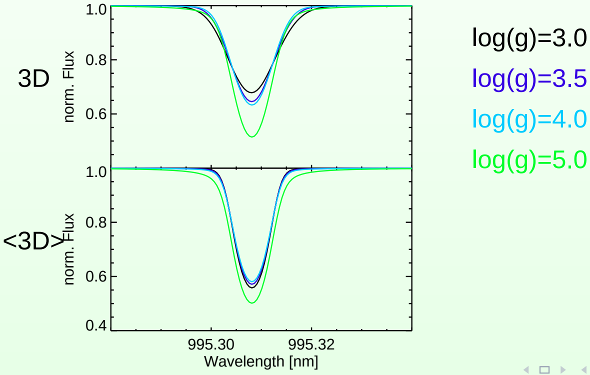






3D- and $< 3D >$- FeH Lines ($\log g$)

- 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 ($T_{\rm eff}$)

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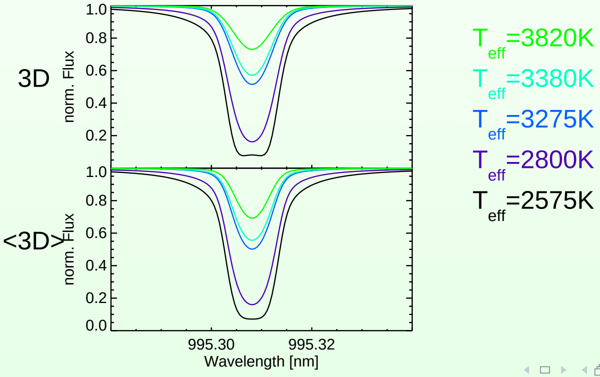
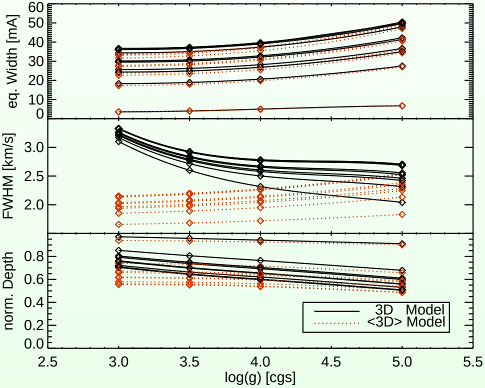
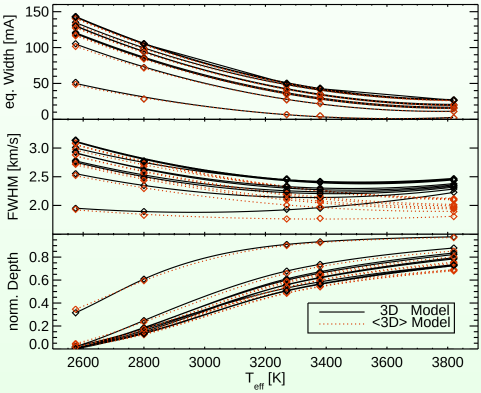


Line Shapes ($\log g$)



- 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 ($T_{\rm eff}$)



- difference between 3D- and $< 3D >$-models almost constant in eq. width
- velocity broadening covered by thermal broadening at low $T_{\rm eff}$
- line depth shows effects of velocity broadening (high $T_{\rm eff}$) and saturation (low $T_{\rm eff}$)
- 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 $T_{\mathrm{eff}} \sim 2600$ K $-$ 4000 K and in $\log g \sim 3.0 - 5.0$ [cgs]
- the convective velocities vary from ~ 100 m/s (for cool models with high $\log g$) to ~ 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_{eff}, $\log g$, and velocities in M-stars

Thank you for your attention

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