

# Pre-Main Sequence models with convection described by 2D-RHD numerical simulations

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## INTRODUCTION

The efficiency of convection in the superadiabatic region at the top of the convective stellar envelope determines the asymptotic value of the entropy in the deep and adiabatically stratified layers and, therefore, the star radius and  $T_{\text{eff}}$ . Any treatment of convection adjusted to obtain the correct adiabat will provide similar global structures.

This is the base of the MLT solar calibration.

The Sun yields only one calibration  $\alpha_{\text{MLT}}$  value, and no physical principle guarantees this value to be appropriate for the whole HRD, or the whole stellar structure.

During PMS evol.,  $T_{\text{eff}}$  and  $\log g$  are such that convection extend in the stellar atmosphere. The current procedure of mixing different convection treatments in the atmosphere and stellar interior modeling introduce an uncertainty of  $\sim 200\text{K}$  in the 1M PMS track without changing the  $T_{\text{eff}}$  of the MS. (Fig. 1)

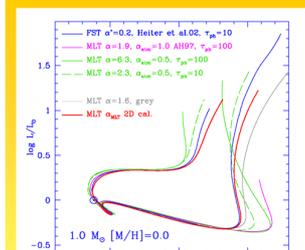


Fig. 1

**Non-grey models: FST interior and atmosphere.** MLT  $\alpha=1.5$  in the interior, up to  $\tau_{\text{ph}}=100$ , and MLT with  $\alpha=1$  in the atmosphere. MLT with  $\alpha=0.5$  in the atmosphere, and  $\alpha=2.3$  until  $\tau_{\text{ph}}=10$ , or  $\alpha=6.3$  until  $\tau_{\text{ph}}=100$ .  
**Grey models:** MLT  $\alpha=1.6$  until  $\tau_{\text{ph}}=2/3$   
**2D-MLT  $\alpha$  calibrated until  $\tau_{\text{ph}}=2/3$**

To overcoming the problem Ludwig et al. (1999, L99) suggest to compute grey MLT models the with the  $\alpha_{\text{MLT}}$  parameter given by a function  $\alpha_{\text{MLT}}(T_{\text{eff}}, \log g)$  derived from the 2D radiative-hydrodynamics (RHD) simulations of stellar surface convection.

Stellar models computed in this way provide the same adiabat as a complete 2D RHD computation  $\rightarrow$  same  $R^*$  and  $T_{\text{eff}}$

This procedure does not give information on the overadiabatic layers, but for a given  $M$ ,  $R^*$  and  $T_{\text{eff}}$  the overall structure does not depends on the details of the treatment of overadiabatic regions.

Therefore, HRD location and Lithium depletion of PMS stellar models computed with this approach will correspond to the results we could obtain by solving the hydrodynamic equations coupled to the equation of radiative transfer such as 2D-RHD numerical simulations do.

## MODELS

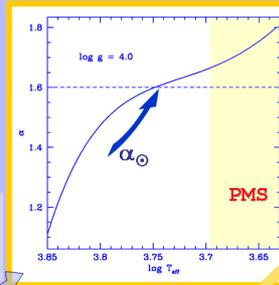
**2D-MLT** stellar models were computed by using ATON2.0 code (Ventura et al. 1998) with gray boundary condition option and MLT treatment of convection with  $\alpha_{\text{MLT}}(T_{\text{eff}}, \log g)$  by L99 (scaled to fit the Sun) for the domain:

- $T_{\text{eff}}$ : 4300 - 7100 K
- $\log g$ : 2.54 - 4.74

2D-RHD atmosphere models by L99 indicate that:

- Convection is, on average, efficient in the atmosphere and envelope  $\rightarrow$  large  $\alpha_{\text{MLT}}$  value.
- $\alpha_{\text{MLT}}$  increases as  $T_{\text{eff}}$  decreases.

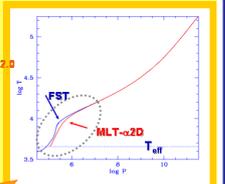
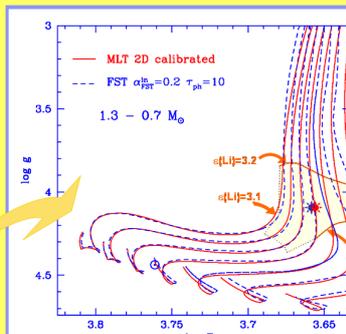
For PMS domain,  $\alpha_{\text{MLT}}$  is larger than the solar calibration value  $\alpha_{\odot} \rightarrow$  2D-MLT PMS tracks will be hotter than those obtained by using the  $\alpha$  value from solar calibration.



## PMS EVOLUTION AND STRUCTURE

We plot for comparison FST non-grey models. 2D-MLT and FST PMS tracks are very close.

\* and \* have the same radius, this one being determined by the entropy jump between the photosphere and the deep adiabatic regions.



## PMS Li DEPLETION

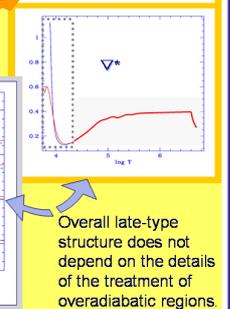
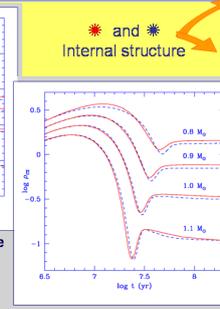
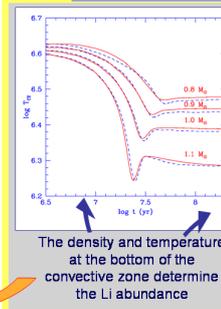
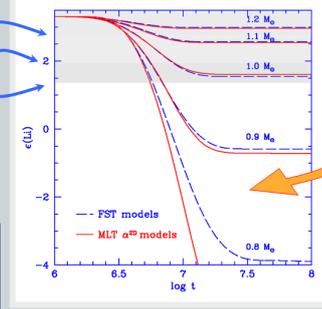
PMS Li burning starts when  $T$  reaches ed by the nuclear reaction:  $7\text{Li}(p, ^4\text{He})^4\text{He}$

Solar type stars in young clusters: Pleiades and  $\alpha$  Per (e.g. Soderblom 93) do not deplete a significant fraction of Li during their PMS evolution

Minimum Li abundance measured in Pleiades for:

- 1.0  $M_{\odot}$
- 0.9  $M_{\odot}$
- 0.8  $M_{\odot}$

Li abundance in young clusters suggest that PMS tracks should be cooler than 2D-RHD convection models predict.



## CONCLUSIONS

While some observations:

- Stellar parameters of binaries
- Lithium abundance in young clusters

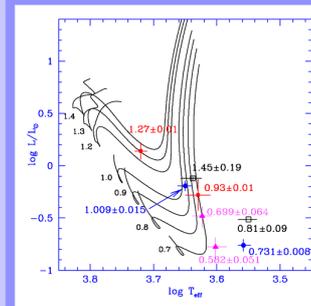
requires a low efficiency of convection in late-type domain of the HR diagram,

2D and 3D numerical simulations of convection predict the opposite: an equivalent value of  $\alpha_{\text{MLT}}$  that increase as  $T_{\text{eff}}$  decreases.

The high stellar activity level that PMS stars can show support the suggestion that other physical processes (such as rotation and magnetic fields) affect the efficiency of convection in late-type stars.

## PMS BINARIES

The location of PMS binaries in the HR diagram is a powerful way of constraining stellar models.



We compare the FST tracks (equivalent to 2D-MLT ones) with the parameters derived from observations of four binary systems:

**RXJ 0529.4+0041** A & B ~ Ok (Covino et al. 2004)

**V1174 Ori** A (1.009  $M_{\odot}$ ) Ok (Stassun et al. 2004) B (0.731  $M_{\odot}$ ) too cold

**NTT045251+3016** A (1.45  $M_{\odot}$ ) & B (0.81  $M_{\odot}$ ) too cold (Steffen et al. 2001)

**HD 98300 B** A (2.888  $M_{\odot}$ ) Ok (Boden et al. 2005) B (2.592  $M_{\odot}$ ) too cold

The same disagreement has been revealed in binaries with late-type low mass MS components (e.g. Ribas 2006). An accepted, but non proved, explanation is that the magnetic fields associated with the stellar activity can decrease the efficiency of convection  $\rightarrow R^*$  and  $T_{\text{eff}}$  due to the spots on stellar surface.

The agreement is reasonably good for most of the primaries but much less satisfactory for the less massive components.

## REFERENCES

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