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EFFECTS OF ROTATION ON INTERNAL STRUCTURE AND DYNAMICS OF MAIN-SEQUENCE STARS

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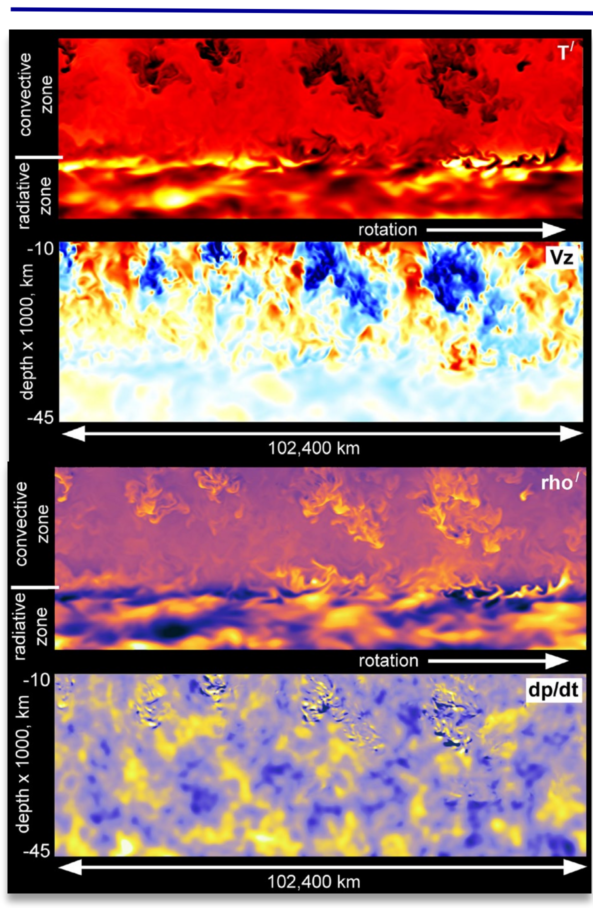
Current state-of-the-art computer simulations allow us to build 3D dynamical and radiative models of stars from physical first principles with a high degree of realism. The radiative 3D dynamical stellar models obtained with the StellarBox code take into account the effects of turbulence, stellar abundances, a realistic equation of state, and radiative energy transport. In this talk, I will discuss the effects of rotation on the turbulent dynamics and surface structure for a 1.47M_{sun} star for rotational periods of 1 and 14 days. The simulations are performed with the computational domain at various latitudes. The models reproduce stellar granulation, the subsurface shear layer, structural changes in convection, and the tachocline, which is the interface between the inner radiative zone and the outer convection zone and plays a crucial role in stellar variability. In particular, the model results reveal the formation of differential rotation and meridional circulation.

'StellarBox' code (Wray et al., 2018)

- 3D rectangular geometry
- Fully conservative, Fully compressible
- Fully coupled radiation solver:
- LTE using 4 opacity-distribution-function bins
- Ray-tracing transport by Feautrier method
- 18 ray angular quadrature
- Non-ideal (tabular) EOS
- 4th order Padé spatial discretization
- 4th order Runge-Kutta time integration
- Turbulence models:

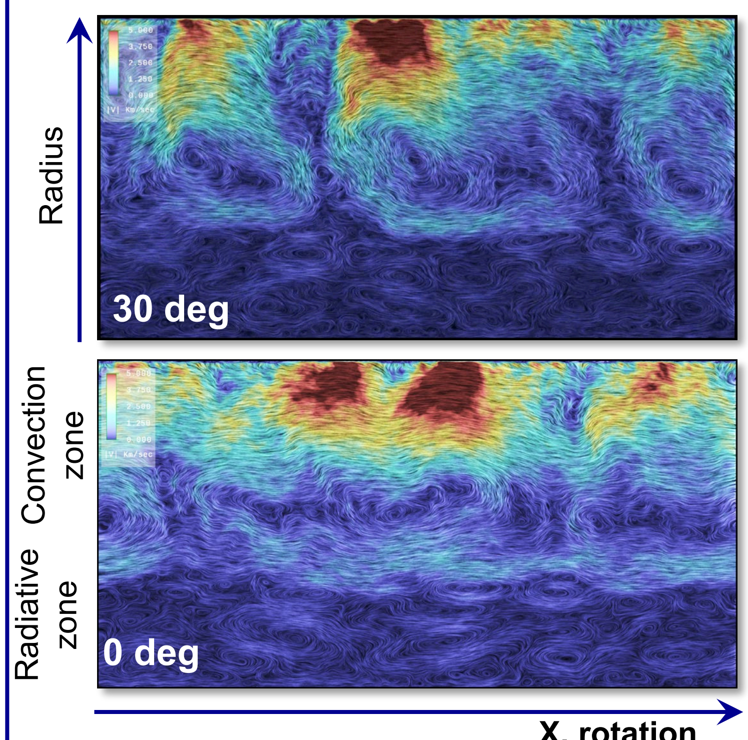
- Compressible Smagorinsky model
- Compressible Dynamic Smagorinsky model (Germano et al., 1991; Moin et al., 1991)
- MHD subgrid models (Theobald et al., 1994; Balarac et al., 2010)

- Effect of rotation
- Metallicity effects
- MPI parallelization

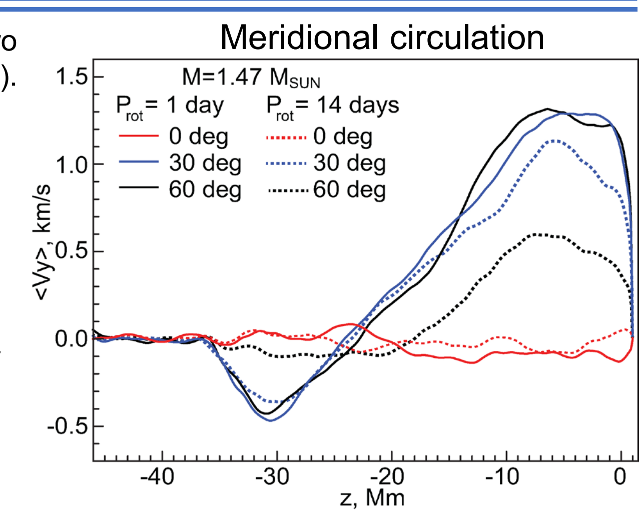


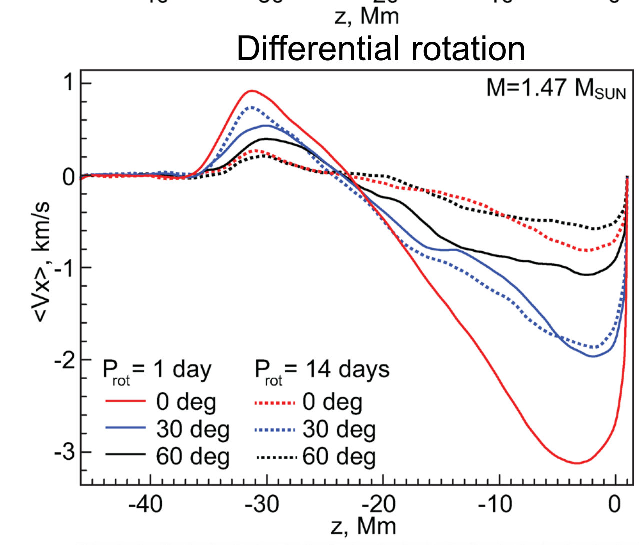
Vertical snapshots of bottom part of a computational domain shows (from top to bottom) distribution of the temperature fluctuations, radial velocity, density perturbations, and time-derivative of the gas pressure.

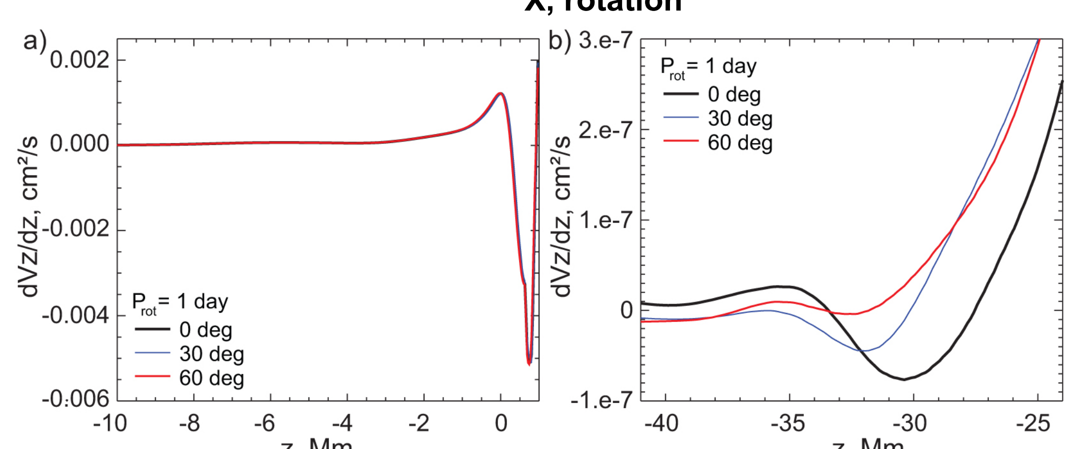
Comparison of the rotating convection zone with period of rotation of 1 day at two different latitudes: 30 degrees (upper panel), and 0 degrees (equator, bottom panel). The dynamical structure of the convective patterns is visualized by a particle tracing method.

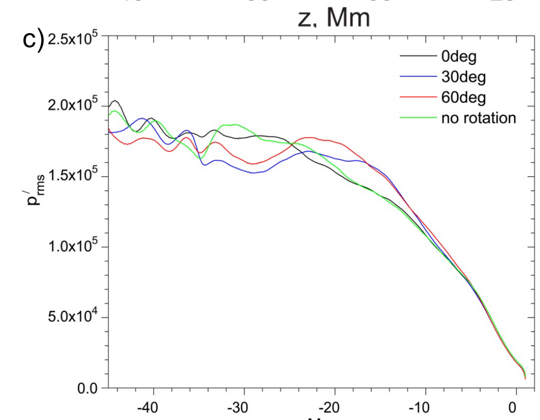


Effect of stellar rotation on the mean velocity profiles for rotation periods of 1 day (solid curves) and 14 days (dotted curves) at three latitudes: 0 deg (red curves), 30 deg (blue curves), and 60 deg (black curves). Top panel shows radial profiles of the azimuthal velocity, showing differential rotation. Bottom panel shows radial profiles of the mean velocity field corresponding to the meridional circulation at different latitudes.

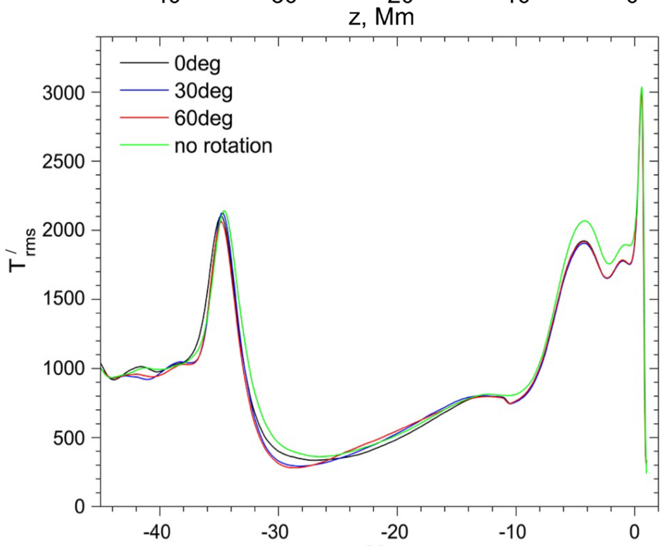






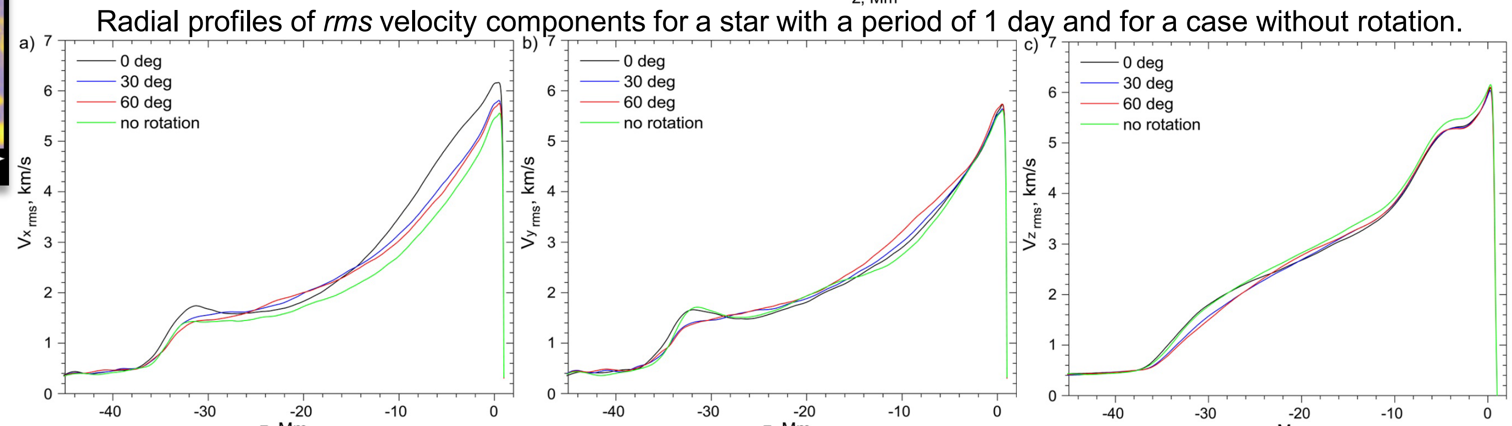


Radial profiles of the time-derivative of the mean vertical velocity, dV_z/dz, for the whole computational domain (panel a) and near the tachocline layer (b); gas pressure fluctuations (panel c).



Radial profiles of rms temperature fluctuations for rotating and non-rotating stars.

Radial profiles of *rms* velocity components for a star with a period of 1 day and for a case without rotation.



References

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Conclusions

- Despite the availability of advanced observational data from modern space and ground instruments, investigation of the dynamics and structure of the surface and subsurface layers of stars is quite challenging. We performed a series 3D radiative hydrodynamic simulations of an F-type star with mass 1.47M_{sun}, in which the whole convection zone and upper layers of the radiative zone were included in the computational domain.
- The simulation results reveal the formation of an overshoot layer and also multi-scale populations and clustering of the surface granulation. High-speed convective downdrafts of 20 - 25km/s penetrate through the convection zone, form an overshoot layer, and contribute to excitation of internal gravity waves (*g*-modes). These waves are identified near the overshoot layer. At the stellar photosphere, these modes are hidden among strong turbulent convective flows, and only *f*- and *p*-modes are clearly displayed in the simulated power spectra.
- Simulating of effects of stellar rotation, for rotational periods of 1 and 14 days at different latitudes, allowed us to identify the formation of a subsurface shear flow and roll-like convective patterns in the deep layers of the convection zone. The radial profiles of the differential rotation indicate that it is of anti-solar type. The subsurface shear flow velocity peaks closer to the photosphere at higher latitudes. The meridional circulation profiles do not show a significant difference at 30deg and 60deg latitudes. The simulation results show that the tachocline layer is located deeper and is less prominent at higher latitudes.