Investigation of the Impact of Rotation on Intermediate Stars

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Introduction

- Convection plays a dominant role in the dynamics of stellar interiors, while rotation profoundly impacts the structure and energy transfer of convective processes. However, the specifics of this interaction are not yet fully understood.
- Solar rotation is often considered too slow to significantly impact the dominant convective flow. Nevertheless, the inhibitory effect of rotation on convection is one potential mechanism that could explain the discrepancies between observed data and theoretical models concerning the convective amplitudes.
- A-type and F-type stars exhibit fast rotation and possess shallower convection zones, leading to a greater impact from rotational effects.

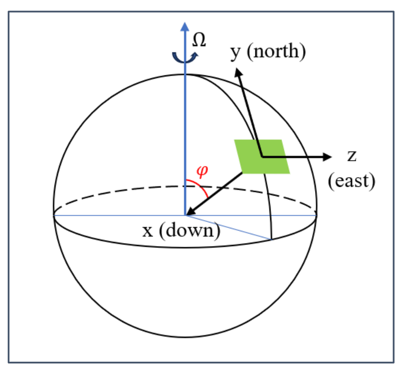
Questions

- Does rotation impact convection structures?
- Is this effect related to the latitude?
- Is this effect related to the type of stars?

ANTARES: Governing Equations

Without Rotation

$$\underbrace{\partial_t \begin{pmatrix}\rho\\ \rho c\\ \rho \boldsymbol{u}\\ e\end{pmatrix}}_{\partial_t y(t)} = \underbrace{-\nabla\cdot\left(\left(\begin{pmatrix}\rho \boldsymbol{u}\\ \rho c \boldsymbol{u}\\ \rho \boldsymbol{u}\otimes \boldsymbol{u}\\ e \boldsymbol{u}\end{pmatrix} + \begin{pmatrix}0\\0\\P\\P\boldsymbol{u}\end{pmatrix} - \begin{pmatrix}0\\0\\ \sigma\\ \boldsymbol{u}\cdot\sigma\end{pmatrix}\right)\right) + \begin{pmatrix}0\\0\\ \rho \boldsymbol{g}\\ \rho \boldsymbol{g}\cdot \boldsymbol{u}\end{pmatrix}}_{A(y(t))=(A_1+A_2+A_3+A_4)(y(t))} + \underbrace{\nabla\cdot\begin{pmatrix}0\\ \rho\kappa_c\nabla c\\ 0\\ K\nabla T\end{pmatrix}}_{B(y(t))}$$



With Rotation

The Coriolis Force

The Coordinates

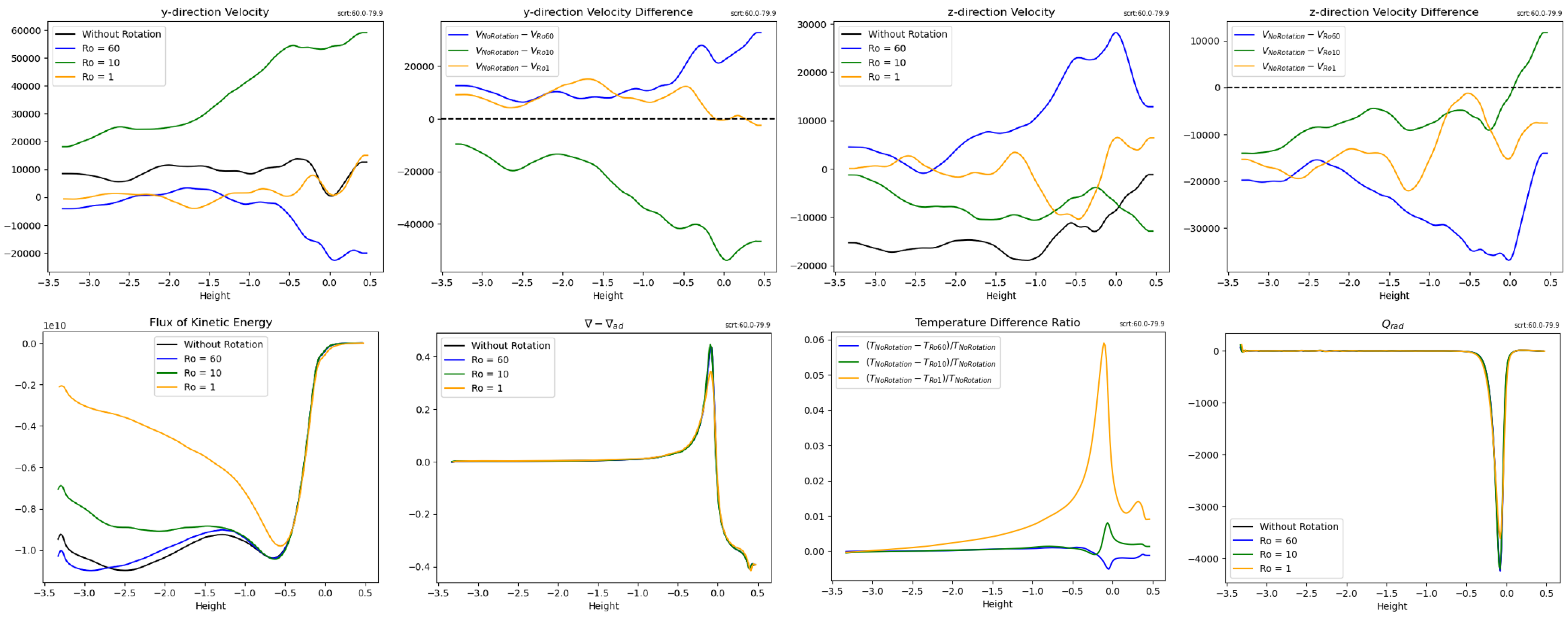
$$\underbrace{\partial_t \begin{pmatrix}\rho\\ \rho c\\ \rho \boldsymbol{u}\\ e\end{pmatrix}}_{\partial_t y(t)} = \underbrace{-\nabla\cdot\left(\left(\begin{pmatrix}\rho \boldsymbol{u}\\ \rho c \boldsymbol{u}\\ \rho \boldsymbol{u}\otimes \boldsymbol{u}\\ e \boldsymbol{u}\end{pmatrix} + \begin{pmatrix}0\\0\\P\\P\boldsymbol{u}\end{pmatrix} - \begin{pmatrix}0\\0\\ \sigma\\ \boldsymbol{u}\cdot\sigma\end{pmatrix}\right)\right) + \begin{pmatrix}0\\0\\ \rho \boldsymbol{g}\\ \rho \boldsymbol{g}\cdot \boldsymbol{u}\end{pmatrix} + \begin{pmatrix}0\\0\\ -\vec{f}\times\rho\boldsymbol{u}\\ 0\end{pmatrix}}_{A(y(t))=(A_1+A_2+A_3+A_4+A_5)(y(t))} + \underbrace{\nabla\cdot\begin{pmatrix}0\\ \rho\kappa_c\nabla c\\ 0\\ K\nabla T\end{pmatrix}}_{B(y(t))}$$

F-Plane Approximation

- The rotation frequency: $\vec{f} = (-2\Omega_0\cos\varphi, 2\Omega_0\sin\varphi, 0)$
- The f-plane: set $\varphi = constant$ and ignore the variation of $\vec{f}$ with latitude
- Rossby number: $Ro = \frac{U}{2\Omega_0 L}$ *When rotation increases, Ro decreases.*

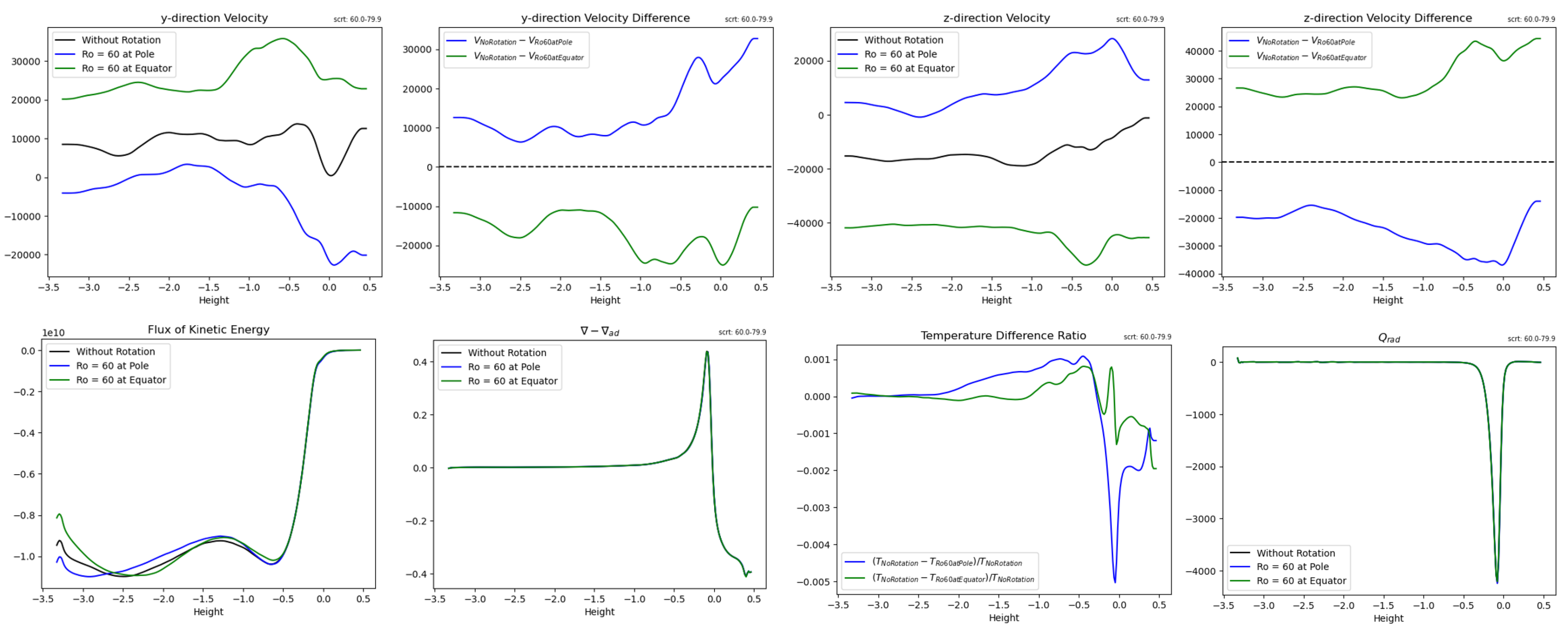
Results and Analyses: Solar Simulations

1 Polar Simulations with Different Rotation Rates



- Rotation can affect horizontal velocity, even at the solar rotation rate (Ro = 60), but the highest rotation rate (Ro = 1) shows less effect.
- Convection is damped in the interior of the convective zone due to rotation.
- At high enough rotation rates, the temperature structure changes significantly, and hence the cooling rates are altered.

2 Polar and Equatorial Simulations with Solar Rotation Rate



- At different latitudes, the direction of the Coriolis force changes, leading to varying effects on horizontal velocity.
- There is very little difference in kinetic energy, $\nabla - \nabla_{ad}$, temperature, and Q_{rad} between the solar rotation cases at the pole and the equator.

Summary

- The effect of rotation on horizontal velocity is significant, and different latitudes need to be taken into account.
- **Rotation constrains kinetic energy.**

Future Plans

- Solar simulations at other latitudes.
- Simulations of A- and F-type stars.

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