Small-scale dynamo in an F-star: effects on near-surface stratification, convection and intensity

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Introduction

In cool main-sequence stars, the near-surface convection has an impact on the center-to-limb variation (CLV) of photospheric emission, with implications for lightcurves of stars during planetary transits. In the Sun, there is strong evidence for a small-scale dynamo (SSD) maintaining the small-scale magnetic flux. This field could affect the near-surface convection in other cool main-sequence stars. We aim to investigate these effects. F-stars are interesting to explore in particular because of near-equipartition in internal and kinetic energy.

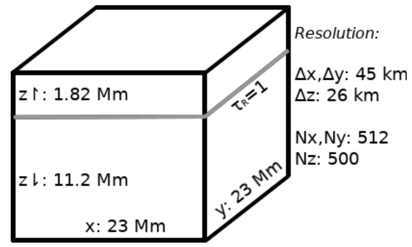
Methods & Setup

Simulation code `MURaM`: Conservative radiative-MHD, 3D cartesian box - sub-surface to lower atmosphere covered - Surface gravity and entropy influx determine stellar type - **F3V**

One hydro case, two SSD cases with differing bottom BCs

- SSD_{weak}: vertical (for testing) $B_{x,y} = 0$, $\partial_z B_z = 0$
- SSD_{strong}: symmetric (mimics deeper convection better) $\partial_z \vec{B} = 0$

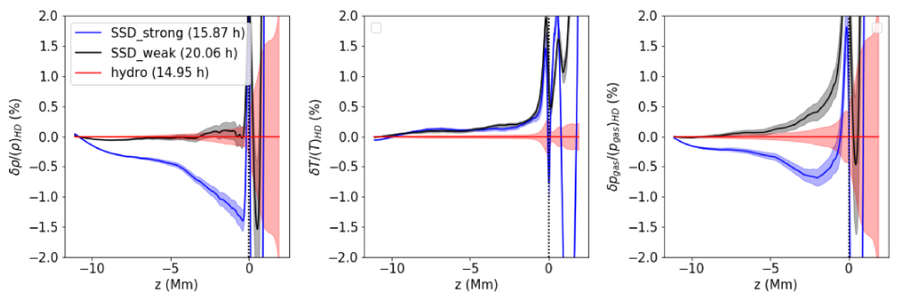
Hydro run seeded with negligible zero-flux field (10^{-5} G) and run till saturation



Simulation setup

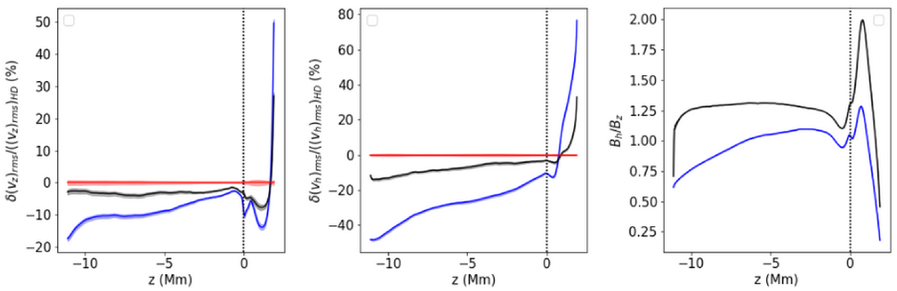
Results*

Thermodynamic stratification



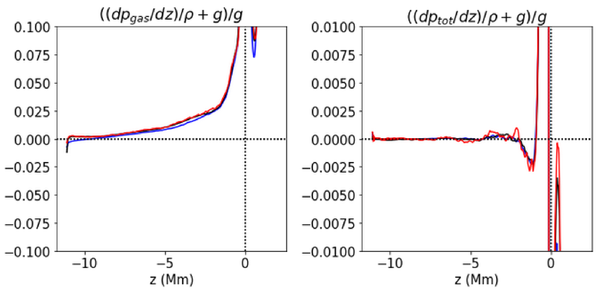
Decrease (increase) in density and gas pressure for SSD_{strong} (SSD_{weak}). Slight increase in temperature for both cases.

Velocities and magnetic field



Marked decrease in v_h for both cases - *strong B_z reduces v_h*. Decrease in v_z for SSD_{strong} - *not only strong B_z, but also strong B_h*.

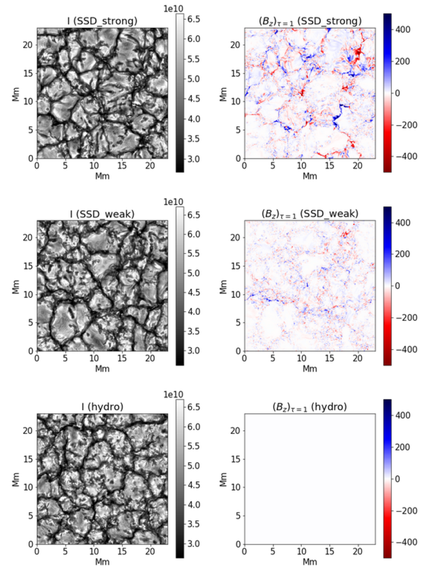
Turbulent pressure



Total pressure from Reynolds and Maxwell stress

$$p_{tot} = p_{gas} + \rho v_z^2 + (B_h^2 - B_z^2)/(8\pi)$$

- Hydrostatic balance maintained by p_{tot}, not just p_{gas}
- Related to density changes as $\delta \nabla p_{tot} \sim \delta \rho$
- B_h/B_z ratio determines if magnetic contribution is positive (SSD_{weak}) or negative (SSD_{strong})



Snapshot of bolometric intensity and B_z at $\tau = 1$

**Note: plots are horizontal averages, with 0 on x-axis corresponding to $\tau = 1$ surface, shaded regions correspond to 1-σ standard error ($\sigma/\sqrt{N}$), and deviations are calculated as $(q - q_{hydro})/q_{hydro}$*

A **small-scale dynamo** in near-surface convection zone can result in changes of 1-2% in ρ, p_{gas} and T stratification, shown here for an F-star.

This is primarily due to **MHD turbulence**, emphasizing the importance of quiescent magnetic fields.

BBB link for poster discussion
`https://meet.gwdg.de/b/tan-jpw-lrp-4qw`
Available during coffee break and from 17:00-18:00 CET