Simulations of the small-scale surface dynamo of cool main-sequence stars

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Motivation

We aim to investigate the origin and nature of small-scale magnetic fields and their interaction with plasma flows in the near-surface layers of four cool main-sequence stars of spectral type K8V, K2V, G2V, and F5V.

The interplay of small-scale magnetic fields with plasma flows affects the photometric and spectral variability of a star. This has far-reaching consequences, also in the context of exoplanet detection. Consequently, a detailed modeling of the magnetic fields and of the turbulent plasma flows present in the proximity of stellar surfaces is required.

Numerical setup

Star in a box simulations using the CO^5BOLD radiative MHD code (HLL solver, grey radiative transfer).

	K8V	K2V	G2V	F5V
T_{eff} [K]	4005	5000	5766	6506
log(g)	4.66	4.59	4.44	4.24
$L_x=L_y$ [km]	2200	3500	6000	15000
Vertical size [km]	[-748,220]	[-1190,350]	[-2412,660]	[-6150,1650]
L_{gran} [km]	356	615	1006	2501
$\ln[P(\langle\tau\rangle=1)/P]$	[-5.1,4.9]	[-5.2,4.9]	[-5.8,5.8]	[-6.4,8.0]
$n_x=n_y$	750	750	750	750
n_z	330	330	384	390
$\Delta x=\Delta y=\Delta z$ [km]	2.93	4.67	8.00	20.00
$v_{rms}(\langle\tau\rangle=1)$ [km/s]	1.75	2.95	4.3	6.4

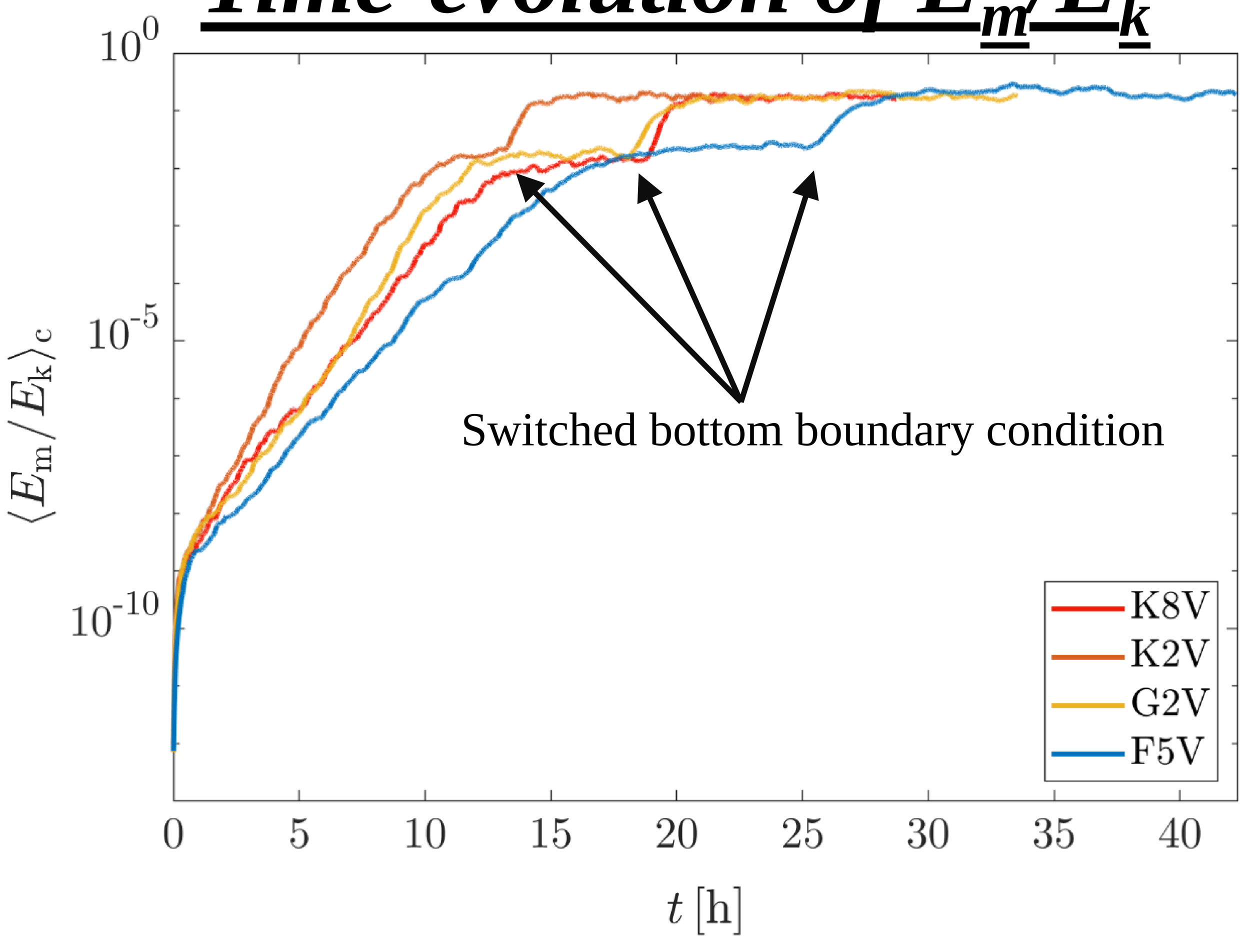
Similar number of granules and of grid cells per granule.

Small-scale dynamo (SSD) simulations started from HD runs with 1 mG vertical seed magnetic field. Two bottom boundary conditions for magnetic fields:

Bc. 1: $\partial_z \mathbf{B}=0$ in outflows and $\mathbf{B}_h=0$ in inflows (zero Poynting flux into box, net loss of Poynting flux);

Bc. 2: $\partial_z \mathbf{B}=0$ in outflows and $B_x=0.08B_{eq}$ in inflows (finite Poyinting flux into box, but still net loss of Poynting flux; $B_h=0.08B_{eq}$ is a typical value for the deep convection zone).

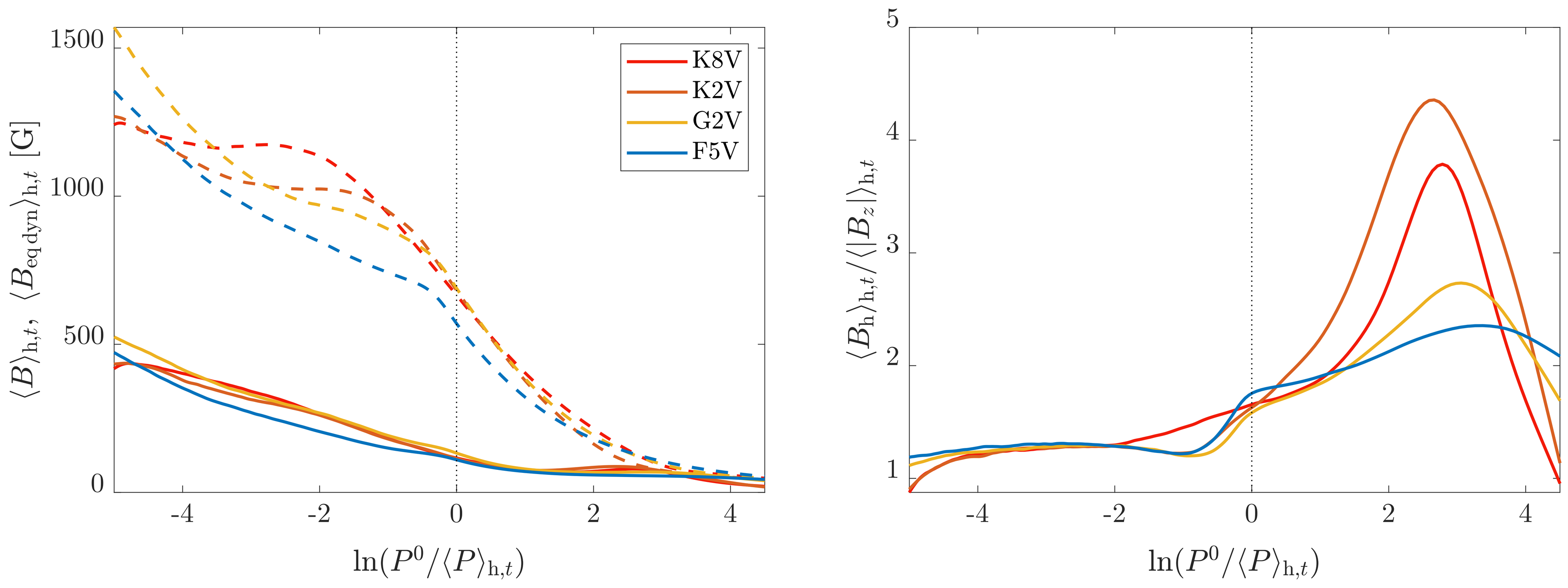
Time-evolution of E_m/E_k



- The growth rate is largest for K2V and smallest for F5V;
- No kG concentrations with Bc. 1. ⇒ no magnetic bright points;
- kG concentrations and magnetic bright points with Bc. 2.

Reference: Riva et al., submitted

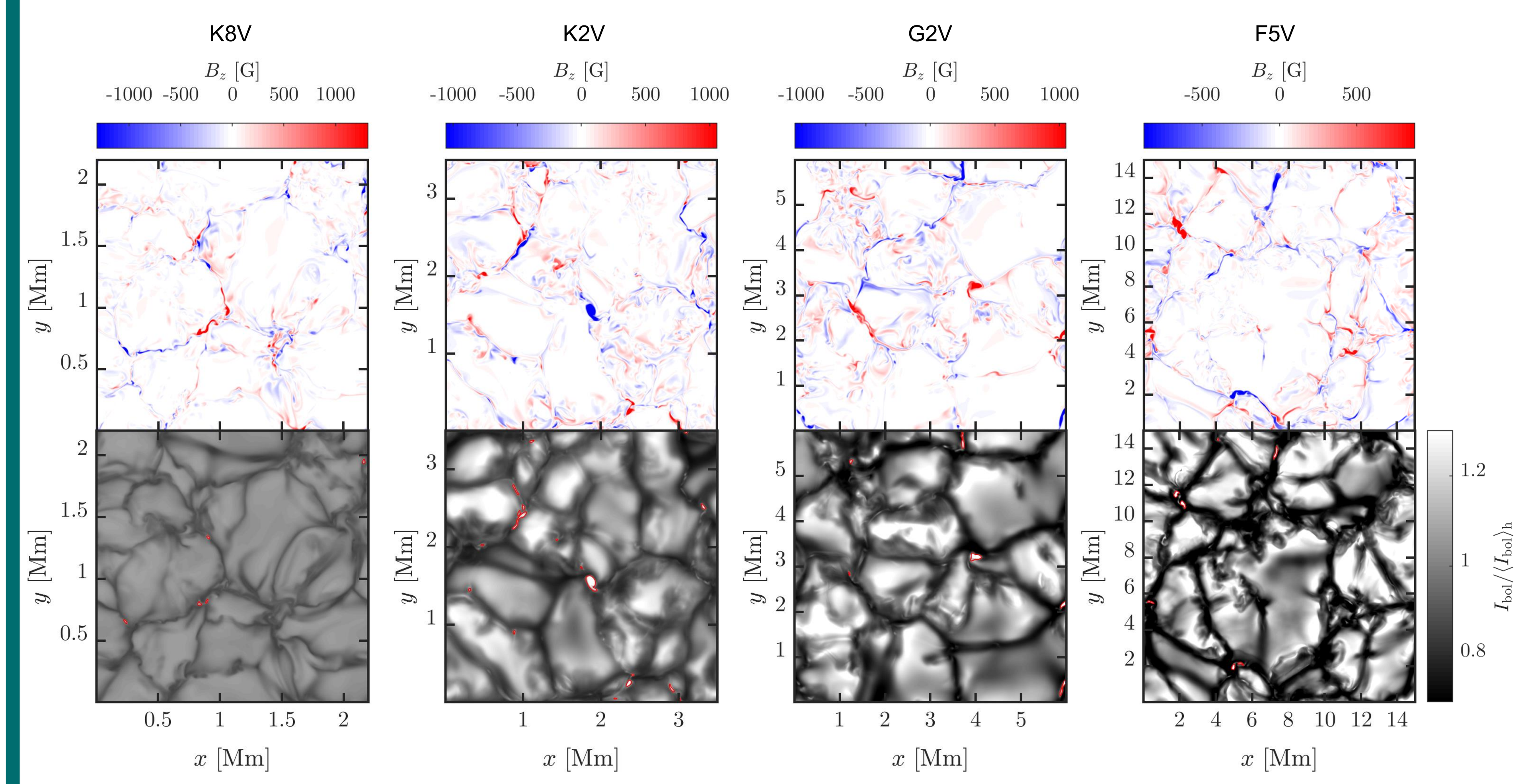
Magnetic field structure (with Bc. 2)



- Similar SSD field strengths reached in all models, irrespectively of the kinematic SSD growth rate;
- Similar fraction of kinetic energy converted into magnetic energy in all models (about 10-25%);
- Magnetic fields are slightly more vertical than horizontal in the convection zone, whereas they become more horizontal in the photosphere, in particular for the coolest models..

Spectral type	$\lvert B_z\rvert_{\tau_R=1}$ [G] saturation	$B_{\tau_R=1}$ [G] saturation	$B_{eq\,dyn,\tau_R=1}$ [G] kinematic	saturation
K8V	54	120	670	630
K2V	55	110	690	640
G2V	70	140	720	680
F5V	67	140	710	660

Magnetic bright features (with Bc. 2)



- With Bc. 2, strong magnetic flux concentrations and corresponding magnetic bright points form in all models;
- Magnetic flux concentrations are more numerous for the K2V and G2V than for the K8V and F5V models. This because of two competing effects: an increasing opacity with increasing effective temperature, and thus smaller thermal equipartition fields for larger T_{eff}, and an increasing evacuation efficiency with increasing T_{eff}.

Conclusions

- We simulated SSD action in the atmosphere of four cool main-sequence stars of different spectral type;
- The growth rate of the dynamo scales as $\sim v/L$;
- Stars of different spectral types display similar mean magnetic fields and mean magnetic to equipartition field ratios;
- With Bc. 2, strong magnetic flux concentrations form at the surface of all models, resulting in magnetic bright features.