The STARS project aims at modelling in a self-consistent and three-dimensional way the complex, time dependent and nonlinear dynamics present in the Sun and stars. In particular we wish to understand stellar magnetic activity, that depending on the spectral type of the star considered can be cyclic (solar type stars) irregular (very low mass stars, with spectral type later than M3), or even for stars with stellar mass greater than 2 solar mass, without any activity or simply possessing a modulated signal (probably due to the presence of a fossil field in their stably stratified, radiative envelope). The mecanism thought to be at the origin of the magnetism seen in solar type stars or in low mass stars is likely to be linked to dynamo action in the upper convective layers of such stars. The simultaneous existence of convective turbulent motions (that could even possess helicity), of rotation and its associated differential rotation and shear layers in stars, favour the emergence of a small and/or large scale magnetic field through induction. For more massive stars, possessing a convective core, understanding the interaction between the dynamo generated magnetic field and the probable fossil magnetic field of their radiative envelope constitute a major challenge in stellar fluid dynamics.

To study in great details the interaction between convection, rotation and magnetic field in stars IS the main scientific goal of this project.

Main Results:

This DEISA-DECI project has been extremely fruitful in terms of understanding the complex interplay between turbulent convection and magnetism and to appreciate how difficult it is to compute a highly nonlinear and turbulent 3-D MHD solar dynamo model at low magnetic Prandtl number. It is the first time that dynamo action in a turbulent convective sphere at low magnetic Prandtl number is achieved in the solar context.
We can already say that the level at which dynamo action is successful against Ohmic decay is higher than in the corresponding case with high Pm number published in Brun et al. 2004. We have computed several models in order to reach the dynamo threshold
while keeping a solar-like differential rotation profile. The first model had a magnetic Reynolds number around 300 (resolution Nr=256, Ntheta=512 and Nphi=1024), the threshold determined by our previous study (see Brun et al. 2004). This model did not succeed and the seed magnetic finally decayed away. We then progressively increased the level of turbulence while keeping Pm=0.8 and we had to reach about Rm=400 (and a resolution of 256x784x1568) to get a successful dynamo. This seems to indicate an increase of about 30% of the dynamo threshold with respect to the high Pm cases, and confirms that turbulence is actually making it harder to get a successful dynamo rather than easier (see for example Ponty et al. 2005).
We display on figure 1 the temporal evolution of the total (solid line) and mean (dashed line) magnetic energies of our latest successful DEISA DECI run. We can notice the linear phase (exponential growth) of the magnetic energy and then its nonlinear saturation via the feed back of the Lorentz forces on the flow in particular in region of high vorticity through Maxwell stresses. The mean (axisymmetric) magnetic energy is found to be small (~ 1%) confirming that turbulent magnetized convection generates mostly non axisymmetric and highly intermittent fields, characteristic of a small scale dynamo process. To illustrate the richness of the simulations, we show on figure 2 a snapshot of the convective radial velocity , of the log10

of the enstrophy (square of the vorticity) and the associated dynamo toroidal magnetic field in the bulk of the modelled convection zone. We see how turbulent the convective patterns are and how small scale and intricate the magnetic field can be. This indicates that the magnetic fields generated by dynamo processes in stellar plasma are likely to be disorganized (independently of the magnetic Prandtl number considered or possible inverse cascade processes), and that in order to get a large-scale organized field (mostly toroidal in nature), one needs to include an omega effect not only in the convection zone (as it is already the case in this simulation) but also in a sheared stable layer like the tachocline. A preliminary low resolution study seems to indicate that it is indeed the case, i.e a tachocline of shear is efficient at making stronger axisymmetric fields (Browning, Miesch, Brun et al. 2006)

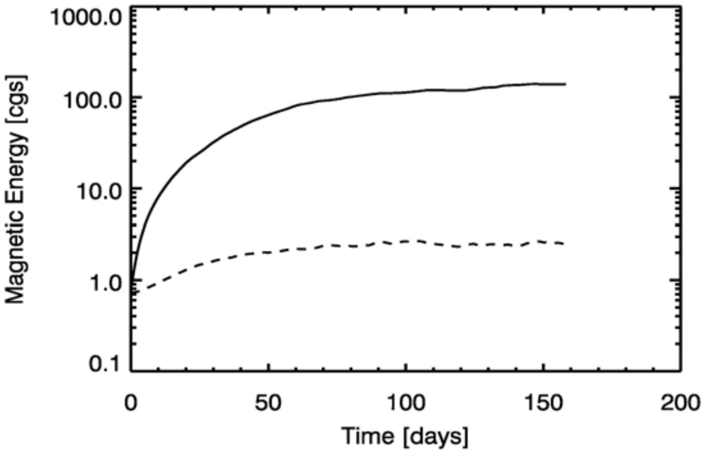

Figure 1: Temporal evolution over the 160 days of simulated time of the total and mean (dashed line) magnetic energy in a turbulent DEISA-DECI simulation of the solar convection at a Prandtl number Pm of 0.8.

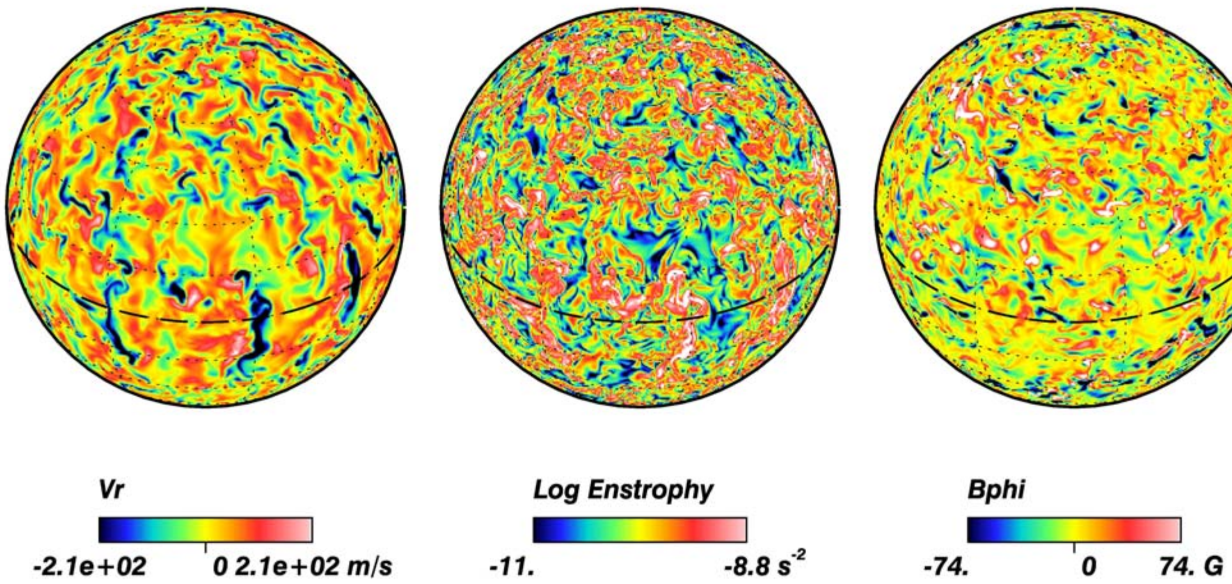

Figure 2: Snapshot of the radial velocity, log of enstrophy and toroidal magnetic field in the bulk of the highly turbulent convection zone of the DEISA DECI run. Highly intermittent

convection and magnetic fields are observed in this first low Pm simulation of the solar convective envelope. We note the high degree of vorticity present in the downflows.