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# MAGNETIC FIELD AMPLIFICATION BY SN-DRIVEN INTERSTELLAR TURBULENCE

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**Abstract.** Within the interstellar medium, supernovae are thought to be the prevailing agents in driving turbulence. Until recently, their effects on magnetic field amplification in disk galaxies remained uncertain. Analytical models based on the uncorrelated-ensemble approach predicted that any created field would be expelled from the disk before it could be amplified significantly. By means of direct simulations of supernova-driven turbulence, we demonstrate that this is not the case. Accounting for galactic differential rotation and vertical stratification, we find an exponential amplification of the mean field on timescales of several hundred million years. We especially highlight the importance of rotation in the generation of helicity by showing that a similar mechanism based on Cartesian shear does not lead to a sustained amplification of the mean magnetic field.

## 1 Introduction

In the framework of the so-called turbulent $\alpha$ effect, rotation has always been considered the pivot point in the generation of "cyclonic turbulence". Recently, by means of shearing box simulations with peculiarly elongated aspect ratios, Yousef et al. (2008) have claimed that a turbulent dynamo can already be excited in the presence of shear alone, i.e., in the absence of rotation. This finding notably disagrees with quasi-linear theory (Rüdiger & Kitchatinov, 2006) – at least for order of unity magnetic Prandtl numbers.

With this controversy in mind, we want to turn to the question whether the galactic dynamo indeed depends on rotation as a source of helicity. Rüdiger & Kitchatinov (2006) derive a non-vanishing shear $\alpha$ effect for the case where there exist gradients in the turbulence. This is certainly the case for the stratified galactic disk.

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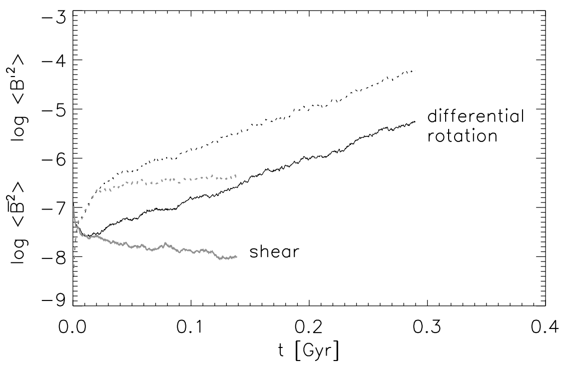


**Fig. 1.** Evolution of the regular (solid) and fluctuating (dashed line) magnetic field strength. We compare the cases of differential rotation (dark) and shear (light colour).

## 2 Simulations results

In Fig. 1 we see that the irregular field is indeed amplified by the combined action of turbulence and shear. This means that already the small-scale dynamo benefits from the local field-line stretching induced by the shear gradient. The growth, however, happens at a much lower rate compared to the case of differential rotation. Moreover, under the effect of the Coriolis force, the mean field grows at a similar rate compared to the irregular component. In the contrary, we observe a decaying mean magnetic field in the case of shear alone. As we will see from a detailed analysis of the inferred dynamo coefficients, this is not because there is no $\alpha$ effect but because the shear-induced effect has the wrong sign – for which the turbulent pumping is too weak to support the dynamo against the strong galactic wind. Note that the only difference between the models lies in the Coriolis force; because curvature terms are neglected in the shearing box approximation, both runs assume the same linear profile of the background velocity.

## 3 Mean-field modelling

Our simulations are based on first principles and their outcome has to be regarded as rather fundamental. Since, however, the current setup only represents a narrow region in parameter space, our findings have to be backed up by the underlying theory. Consequently, by means of the so-called test-field method (Schrinner et al., 2005), we derive closure parameters in the framework of mean-field MHD – for details see Gressel et al. (2008a), and references therein.

The relevant coefficients of the $\alpha$ tensor in the case of Cartesian shear are presented in Fig. 2. The diagonal elements (left panel) clearly show a negative (positive) sign in the top (bottom) half of the simulation box. While this is opposite to the case of differential rotation (see Fig. 1 in Gressel et al., 2008b), the vertical transport via the mean flow $\bar{u}_z$ and the off-diagonal elements (right panel) are comparable in both cases.

Based on the inferred $\alpha$ and $\tilde{\eta}$ coefficients, we study the dependence on the net vertical transport with the help of a 1D dynamo model. Because the shear

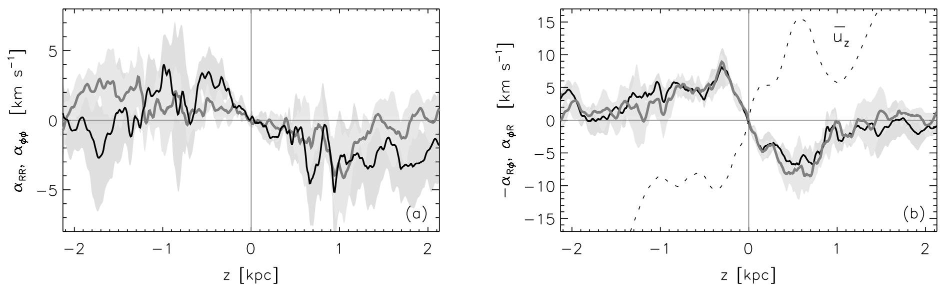


**Fig. 2.** Components of the $\alpha$ tensor for the case of Cartesian shear. The quantities are plotted in dark ($\alpha_{RR}, -\alpha_{R\phi}$) and light ($\alpha_{\phi\phi}, \alpha_{\phi R}$) colours, respectively.

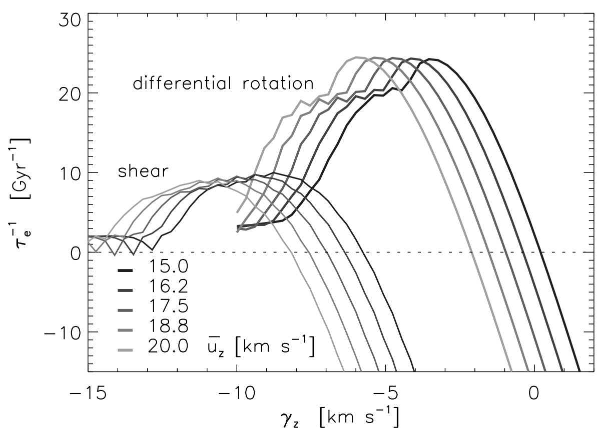


**Fig. 3.** Dynamo growth-rates as a function of the diamagnetic velocity $\gamma_z$ for different peak values $\bar{u}_z$ of the galactic wind. Negative $\tau_{\rm e}$ correspond to decaying solutions.

gradient defines a distinct sense of orientation, the overall sign in the $\alpha$ effect is indeed significant. It is well known from solar dynamo models that the sign of $\alpha\Omega$ determines the direction of the travelling dynamo wave. In the absence of net vertical transport, this is reflected in dynamo patterns travelling towards the midplane for differential rotation, and away from it for shear alone. As we will see shortly, the different behaviour affects the overall growth rate when the effects of the diamagnetism and mean flow are included.

In Fig. 3, we plot growth rates of dynamo solutions obtained by varying the amount of the diamagnetic transport $\gamma_z = \frac{1}{2}\,\langle \alpha_{\phi R} - \alpha_{R\phi} \rangle$ and the amplitude of the mean flow $\bar{u}_z$ while keeping the parameters $\alpha_{RR}$, $\alpha_{\phi\phi}$, and $\eta_{\rm t}$ fixed. For differential rotation, the fastest growing solutions are obtained at an outward residual velocity[1] of $\simeq 7\,{\rm km\,s^{-1}}$, which agrees well with the findings of Schultz, Elstner, & Rüdiger (1994) and Bardou et al. (2001). For stronger inward pumping, the field is more and more squeezed into the midplane and the effective turbulent dissipation is

[1]Due to the different shape of the contributing profiles (cf. Fig. 2), the definition of a "residual" is not quite straightforward. As a rule of thumb, one can double the value for $\gamma_z$.

enhanced. If, on the other hand, we reduce the amount of pumping, the wind can efficiently remove the created field and the dynamo mechanism is quenched as well. Independent of $\bar{u}_z$, we find a limit of $\simeq 15\,\mathrm{km\,s^{-1}}$ for the residual velocity, which implies that a weak inward pumping will already lead to growing dynamo solutions.

In the case of Cartesian shear, the situation is drastically changed. Because of the opposite sign of the $\alpha$ effect, the dependence on the diamagnetic pumping is found to be much more critical. Because the basic solution already constitutes outward travelling dynamo waves, a much stronger inward pumping is needed to balance the galactic wind. In accordance with the results from our direct simulations, we consequently do not observe growing dynamo modes (cf. Fig. 3) at a realistic level of turbulent pumping.

## 4 Conclusions

By means of combined direct numerical simulations and 1D dynamo models, we have demonstrated that the $\alpha$ effect arising from the combined action of stratification and Cartesian shear does not lead to a growing mean magnetic field in the context of the galactic disk. While the one-dimensional model closely resembles the elongated simulation box, it has to be checked carefully to what extent this approach puts constraints on the admissible dynamo solutions. This means that global mean-field models are required to further support the current results. With respect to the direct simulations, there remains the possibility that the relevant effects also depend on the magnetic Prandtl number Pm, which needs to be checked via quasi-linear theory.

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