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Tachocline, dynamo and the meridional flow connection

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Abstract. Our model for global circulations in the solar convective zone leads to an equatorial drift at its base with an amplitude of about 7 m/s. Its penetration into the solar tachocline is too weak to play any role in the solar dynamo. It confines, however, the internal magnetic decay modes to the radiative core so that the tachocline can be explained as a magnetic Hartmann layer. In the tachocline for the toroidal fields the magnetic Tayler instability exists. We found stability limits for toroidal fields of only 100 G.

Keywords. MHD, turbulence, Sun: rotation, Sun: magnetic fields

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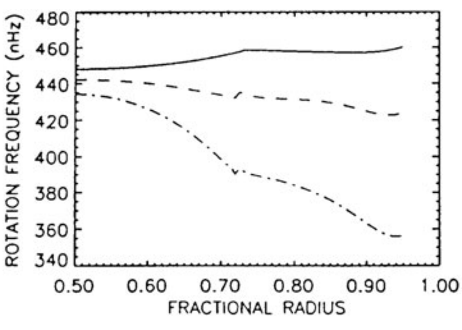
The transition region between the differential rotation in the solar convection zone and the rigid rotation of the solar interior is called the 'tachocline' which is known from helioseismology as thinner than 5% of the solar radius. Sofar such a thin tachocline could not be explained without magnetic fields but the inclusion of a weak poloidal magnetic field of order 10^{-4} G, which is basically confined to the radiative solar interior easily produces a thin enough transition zone between outer differential rotation and inner rigid rotation (Fig. 1, see Kitchatinov & Rüdiger 2005).

The meridional circulation associated with such a rotation law flows at the base of the convection zone towards the equator with an amplitude of about 7 m/s. This flow is fast enough to realize an advection-dominated α-Ω dynamo within the convection zone if the turbulent magnetic diffusivity there is low enough ($\sim 10^{11}\,\mathrm{cm^2 s^{-1}}$, see Küker *et al.* 2001; Bonanno *et al.* 2005).

The penetration of the meridional flow into the solar tachocline strongly depends on the viscosity values beneath the convection zone . For viscosity values of (say) $\sim 10^{11}\,\mathrm{cm^2 s^{-1}}$ the penetration depth is about 4,000 km. This is much too weak to play any role in the solar dynamo mechanism.



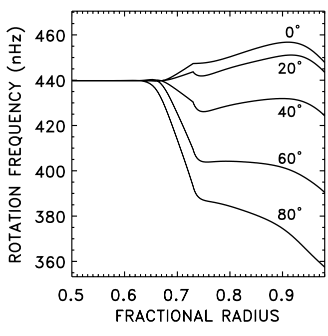


Figure 1. *Left:* Hydrodynamical model of the inner solar rotation law using turbulent values within the convection zone and microscopic viscosity values beneath. *Right:* In the radiative zone a fossil magnetic field is confined inducing a toroidal magnetic field which effectively destroys the latitudinal rotational shear.

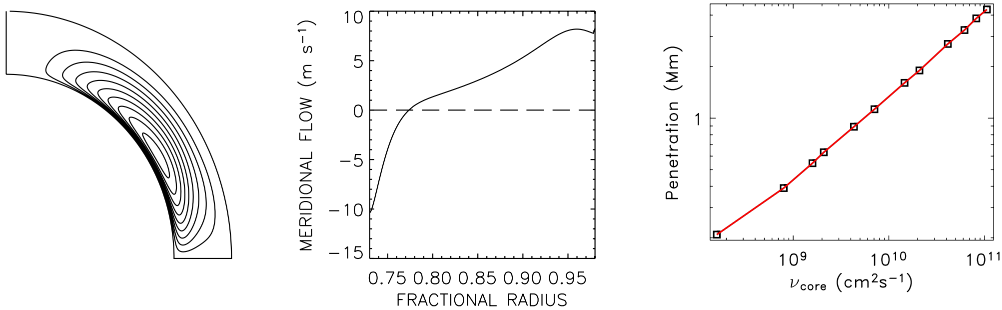


Figure 2. *Left:* The flow pattern of the meridional circulation which belongs to rotation law given in Fig. 1 (*right*). *Middle:* The flow amplitude over radius; at the base of the convection zone the flow drifts equatorwards. *Right:* The penetration of the meridional flow into the radiative solar core for the viscosity, $\nu_{\rm core}$ (Rüdiger *et al.* 2005).

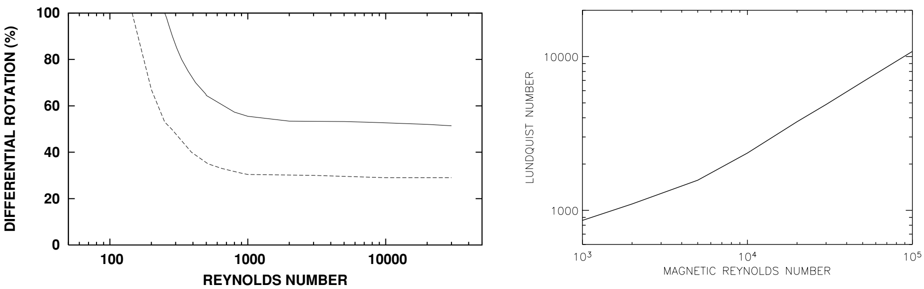


Figure 3. *Left:* the hydrodynamical stability of the solar tachocline (*dashed:* no radial shear; *solid:* real solar rotation law. Note the stabilizing action of the radial rotation shear. *Right:* the critical toroidal magnetic field measured by its Lundquist number for given magnetic Reynolds number (for the observed rotation law).

The flow is sufficiently fast, however, to induce strong latitudinal magnetic fields so that finally the internal magnetic field has a strong latitudinal field component. Only by this effect of (slight) penetration of the meridional flow into the solar core the tachocline can be explained as a magnetic Hartmann layer (Kitchatinov & Rüdiger 2006).

Also the *stability* of toroidal magnetic fields in the differentially rotating solar tachocline is important for our tachocline concept. The tachocline is the location where both the hydrodynamic Rayleigh instability and the magnetic Tayler instability can interact. If the magnetic field is strong enough then the hydrodynamically stable tachocline becomes unstable against nonaxisymmetric perturbations. We found stability limits for toroidal fields of only 100 G for a stably stratified sphere (Fig. 3, see Arlt *et al.* 2007). The tachocline is thus *not* a suitable site for the storage of strong magnetic fields.

References

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