Stars and Planets in computers

Spherical Couette dynamos

A. Barik, J. Wicht, U.R. Christensen, A. Tilgner, Max-Planck Institut für Sonnensystemforschung, Georg-August-Universität Göttingen

In Short

- Interiors of geo- and astrophysical objects can be modelled as spherical shells filled with fluid. Our goal is to study the effect of differential rotation on fluid interiors using the spherical Couette set-up two concentric rotating spheres with fluid filled in the gap.
- We compare our simulations with experiments performed at BTU Cottbus-Senftenberg [1], reproducing their observations while providing further insight, in terms of observed inertial modes as well as turbulence in the system.
- We scale regime boundaries of different hydrodynamic states to understand interiors of astrophysical objects better.
- We also explore the effect of introducing a density stratification, something never been done before. This yielded surprising results.
- We intend to study hydrodynamics and dynamo action with convection and shear flow which has never been done before for spherical shells and would be directly applicable to interiors of astrophysical objects.

The interiors of geo- and astrophysical objects can be thought of as rotating spherical shells with fluid filling the gap. This motivates the study of the spherical Couette system (figure 1) to study the hydroand magnetohydrodynamic (MHD) instabilities that are caused and modified by differential rotation. The system has been studied analytically (e.g. [2]), experimentally (e.g. [1],[3],[4],[5]) as well as using simulations (e.g. [6]). This is also the set-up used by the new generation of MHD experiments (e.g. 3-meter experiment by D. Lathrop, USA and DTS experiment, France).

Despite all the past studies, several open questions remain to be solved. Our aim is to simulate this set-up using our code **MagIC**^{1,2}. We solve MHD equations (Navier-Stokes, continuity, Maxwell's equations, induction equation) in a spherical shell using pseudo-spectral methods. Thus, we expand



Figure 1: The numerical set-up. Two concentric rotating spheres driving a fluid in between by differential viscous drag.



Figure 2: Zonal flow for laminar (left) and turbulent (right) regimes.

the unknowns in terms of orthogonal functions, solve for the coefficients, but solve the non-linear terms on a spherical grid, numerically. Details can be found in [7] and in the manual [8]. It is parallelised in a hybrid manner using MPI between different nodes of a cluster and OpenMP inside each node. The efficiency of the code scales ideally with the number of cores. The spherical harmonic transform library SHTns [9] has made our code a lot faster than before.

We have found that the equatorially antisymmetric wave-like instabilities observed by [1] are possibly due to the instability of the background flow. This and other related exciting results have been published in [10]. Right now we are investigating the transition to turbulence in the system. As an illustration, the zonal flow for the laminar and turbulent regimes are shown in figure 2. We scale the various hydrodynamic regimes we observe to astrophysical parameters, as shown in figure 3 which could possibly tell us something about the instabilities inside these objects driven by differential rotation. Our predictions work well for the observations in the 3-metre experiment in Maryland, USA [11].

¹https://github.com/magic-sph/magic

²https://magic-sph.github.io/



Figure 3: Scaling to astrophysical parameters

We are also trying to understand dynamo action driven by pure differential rotation as well as by both differential rotation and convection. In the latter case, we impose a super-adiabatic temperature gradient to obtain onset of convection while at the same time we differentially rotate the two boundaries. We have already found several dynamo solutions for the case of an incompressible fluid (examples shown in figures 4 and 5). These could be the next steps towards understanding alternative dynamo mechanisms in astrophysical bodies.



Figure 4: An example of a dynamo driven by spherical Couette flow. The left panel shows instability in the zonal low, while the right panel shows a nice dipolar dynamo.



Figure 5: Same as figure 4 but for convection and shear flow together

Lastly, we are collaborating closely with the group of Dan Lathrop at the University of Maryland, USA to investigate the effects of magnetic fields on global wave-like oscillations called inertial modes. The 3metre experiment in Maryland as well as the simulations use a current loop as the source of external magnetic field. This is illustrated in figure 6.

WWW

http://www.geo.physik.uni-goettingen.de/ ~atilgner/homepage.html



Figure 6: Illustration of the spherical Couette system under the influence of an external magnetic field generated by a current carrying coil.

More Information

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