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Numerical studies for GeoFlow: dynamics of thermal convection in rotating spherical shells

B. Futterer (1), M. Gellert (2), V. Travnikov(3), Th. von Larcher (1), C. Egbers (1)

(1) Brandenburg University of Technology Cottbus (futterer@tu-cottbus.de), (2) Astrophysical Institute of Potsdam (mgellert@aip.de), (3) Helmut Schmidt University Hamburg (travnik@hsu-hh.de)

Research on thermal convection in spherical shells is a fundamental model in geophysical fluid dynamics. Instabilities provide details for understanding large scale geophysical motions as convective transport phenomena in the Earth's liquid outer core.

We want to face this hydrodynamical problem within an experiment on thermal convection in rotating spherical shells influenced by a central force field. This experiment will take place at International Space Station in European Columbus Modul inside Fluid Science Laboratory (FSL). The special experiment container is called 'GeoFlow'. Central force field is produced using the effect of an dielectrophoretic force field by impressing a high voltage on the inner sphere. Optical measurement methods as Wollaston shearing interferometry will be used to determine the temperature fields and flow patterns.

Here we present extensive numerical preliminary studies of this spherical Rayleigh-Bénard problem under a central dielectrophoretic force in microgravity environment. Numerical simulation is accomplished for a wide range of radius ratio, Prandtl, Rayleigh and Taylor number. On the one hand it is used for design of the experiment, on the other hand it is expected to predict the experimental scenario and to support interpretation of flow states with interferometry, shadowgraphy and schlieren technique.

2D linear stability analysis and 3D numerical simulation is done with a pseudospectral method. Linear stability analysis for evaluation of the basic state shows a unique spherical mode to be unstable with steady bifurcation. Supercritical flow bifurcates

from basic via periodic and quasi-periodic state into chaos. In the non-rotating case of basic state mode interaction takes place. Further direct 3D simulation of parameters of detailed experiment flow plan show influences of initial conditions.

The Wollaston shearing interferometry detects the temperature dependency of refraction index producing an interferogram. A temperature gradient and thus a gradient of refraction index results into an optical path length difference for adjacent rays beaming through the spherical gap. The analysis of interferograms then gives an approximation of the temperature gradient of the flow field integrated in radial direction. To overcome difficulties in image processing of measured interferogram images, interferograms using numerical simulation data are constructed and compared to the experimentally obtained images.