On bifurcations of convection driven dynamos in a rotating spherical shell

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ABSTRACT

The classical problem of magnetic-field generation by the motion of an electrically conducting fluid in a rotating spherical shell, driven by the buoyancy force that results from thermal density variations and a radial gravity field, is revisited numerically. Starting from one of the benchmark tests posed by Christensen et al. [1], convective and dynamo solution branches are traced by means of a time-stepping spectral solver [2]. Bifurcation scenarios with the Ekman and Rayleigh numbers as the relevant control parameters are studied by changing the Ekman number in small steps and varying the Rayleigh number to trace solution branches with the Ekman number kept fixed. Convection sets in as a rotating wave in the form of a spiral pattern drifting in prograde direction with respect to the rotating frame of reference. The azimuthal mode number increases with the rotation rate (i.e., is larger for smaller Ekman numbers). On tracing these branches to higher Rayleigh numbers, a reversal of the drift direction from prograde to retrograde is observed. In the vicinity of the reversal points dynamo solutions are found. These appear to result from saddle-node bifurcations and have the form of retrogradely rotating waves that share many properties, like the mode numbers of the excited modes and the typical banana-shaped spatial structures, with the the purely convective waves. It has been conjectured previously that the dynamo bifurcation is subcritical, but a direct link to the convective state has not been found explicitly yet. Both branches coexist and are stable over nearly identical intervals of the Rayleigh number and become unstable in Hopf bifurcations. Due to the axial symmetry of the problem, these bifurcations generically generate modulated traveling waves. In conclusion, each convective rotating wave branch is associated with a separate dynamo branch, at least for situations where the parameters are chosen from the benchmark test [1], while the Ekman number can be varied by one order of magnitude.

A further type of multistability arises from the fact that a convective rotating wave branch belonging to the second instability of the conductive state, which is unstable when it bifurcates, becomes stable for higher Rayleigh numbers, leading to the coexistence of stable convective rotating wave branches whose azimuthal wave numbers belong to the first and second instability, respectively, of the conductive state. In addition, in the vicinity of Ekman numbers where the two modes becomes unstable simultaneously a quite complex dynamics is governed by mode interactions.

REFERENCES

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