Scientific session of the Division of General Physics and Astronomy and the Division of Nuclear Physics, Academy of Sciences of the USSR (23–24 April 1980)

Usp. Fiz. Nauk 132, 691–693 (December 1980)

PACS numbers: 01.10.Fv

A joint scientific session of the Division of General Physics and Astronomy and the Division of Nuclear Physics of the Academy of Sciences of the USSR was held on April 23 and 24, 1980, at the Academy's P. N. Lebedev Physics Institute. The following papers were delivered:

April 23

1. *V. A. Dogel'*, Physical models of the long-period variations of solar activity.
2. *I. D. Novikov*, SS 433, An object of a new class: observations and theory.

April 24

3. *A. N. Skrinskiĭ*, The electron-positron program of the Institute of Nuclear Physics of the USSR Academy of Sciences Siberian Division and colliding linear electron-positron beams (VLEPP).
4. *A. M. Baldin*, Relativistic nuclear physics.

We present below the content of one of the papers.

V. A. Dogel'. *Physical models of the long-period variations of solar activity.* The paper discusses a qualitative model that explains the nature of the prolonged solar-activity minima. The largest body of data available concerns the last Maunder minimum.[1] It lasted from 1645 through 1715. The Maunder minimum was characterized by a sharp decrease in the number of spots on the sun's surface. Fewer spots were observed during the entire seventy years of the Maunder minimum than during a single normal 11-year solar cycle. There are indications that the magnetic fields of both the solar corona and interplanetary space vanished during this period. The most convincing evidence supporting the reality of this effect has been obtained in studies of the amount of the isotope C^{14} in tree rings.[2] These data indicate not only the Maunder minimum, but also a number of other, earlier solar-activity minima.

The question as to the mechanism of this phenomenon remains open. For example, it has been suggested that the decrease in activity on the sun reflects superposition of the minima of the hypothetical 80- and 170-year solar cycles.[3] However, analysis of the statistical properties of solar activity fails to confirm any such hypothesis.[4]

As we noted above, the Maunder minimum was characterized by the disappearance of the magnetic fields on the photosphere. The process that generates the magnetic fields on the sun is related primarily to the structure of the convective-zone motions. Presumably, the convection structure during the activity minima was such that the heat flux toward the sun's surface remained nearly constant, while the efficiency of magnetic-field generation was significantly lowered.[5]

Study of convection structure presupposes, first of all, a hypothesis as to the scales of convective motions in the subphotospheric region. It is assumed in the model under consideration that the convection-cell diameters are comparable to the thickness of the convection zone. The influence of rotation then becomes significant. The result is a longitudinal structure of the convection cells,[6] which extended from pole to pole (Fig. 1a). Observation of longitudinal structure of the motions on the photosphere,[7] longitudinal magnetic-field structure[8] (see also the review of Ref. 9), and the direction of the meridional circulation observed on the surface of the sun,[10] which is consistent with the presence of a gigantic longitudinal convection-cell structure in the convection zone, may confirm that such a convection structure actually does exist on the sun.

Analysis of the convection equations indicates that in the presence of rotation, the convective motions in the longitudinal cells redistribute angular momentum, with the result that secondary flows arise: differential rotation (the angular velocity depends on the coordinates) and a meridional circulation.[6] The reciprocal effects of secondary flows (differential rotation) on convection structure were studied in Refs. 11 and 12. The convection in a thin, rotating spherical shell was

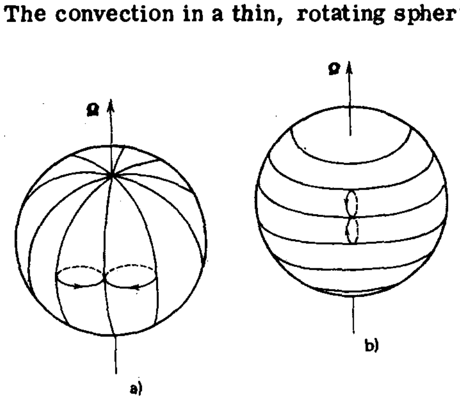

FIG. 1. Structure of convection cells in a differentially rotating spherical shell.

analyzed in the Boussinesq approximation in the presence of shear flow. The problem was solved at the stability limit, i.e., the convection mode that was excited at the smallest temperature difference between the inner and outer spheres was determined. It was shown that if the angular velocity gradients $\nabla\Omega$ are smaller than a certain critical value $\nabla\Omega_{cr}$ ($\nabla\Omega < \nabla\Omega_{cr}$), a longitudinal convection-cell structure appears (Fig. 1a), as in the case of uniform rotation. Otherwise ($\nabla\Omega > \nabla\Omega_{cr}$), the convection cells show an axially symmetric latitudinal structure in the form of toroids the axis of which coincides with the axis of rotation (Fig. 1b).

The development of convection in the shell with the passage of time may be envisaged as follows. The convection is longitudinal as long as the angular velocity gradients remain small. By redistributing angular momentum in the shell, the convection currents set up angular-velocity gradients. These gradients can increase until the transfer of angular momentum of convection is offset by transfer of angular momentum in the reverse direction due to viscosity, which tends to equalize the angular velocities. The result is a state in which a longitudinal convection structure exists against a background of steady differential rotation. It is characterized by the steady-state angular-velocity gradients $\nabla\Omega_{st}$. This state is possible if $\nabla\Omega < \nabla\Omega_{cr}$.

In the case $\nabla\Omega_{st} > \nabla\Omega_{cr}$, the gradients continue increasing only until $\nabla\Omega_{cr}$ has been reached, whereupon the convection structure changes from longitudinal to latitudinal. Since the latitudinal convection structure is incapable of sustaining the angular-velocity gradients responsible for its appearance, the gradients are lowered by viscosity and the system transfers back to the state with longitudinal convection structure, i.e., we have a self-excited oscillatory convection regime with changes from one convection structure to the other and back. The lifetime of the longitudinal convection structure is the rise time of the angular-velocity gradients, and the lifetime of the latitudinal structure is the dissipation time of these gradients.

If we assume that a self-oscillatory convection regime exists on the sun, periods of lowered activity (the Maunder minimum) can be associated with periods in which the latitudinal structure exists, since according to Cowling's theorem it is impossible for the magnetic-field-generating mechanism (the dynamo mechanism) to operate when the structure of the motions is axially symmetric. Periods of high solar activity correspond to those in which the longitudinal convection structure exists.

It should be observed that the process that set up differential rotation and the process of transition from one convection regime to the other are essentially related to nonlinear interaction of various modes of the motions generated in the convective shell. Under these conditions we may expect the transitions between states to occur in stochastic fashion (see Refs. 14 and 15 for examples of stochastization in hydrodynamic systems).

An alternative model that describes the possible nature and irregularity of appearance of long solar-activity minima was presented in Ref. 16, in which the reciprocal effect of the magnetic field on convective motions is taken into account.

It is interesting to note that the observed angular-velocity distribution in the period preceding the Maunder minimum is consistent with anomalously large latitudinal gradients on the photosphere;[17] according to the model presented here, this may have been the cause of the solar-activity decrease.

[1]J. A. Eddy, Science **192**, 1189 (1976); Scientific American **236**, (5), 80 (May 1977) [Russ. Transl. Usp. Fiz. Nauk **125**, 315 (1978)].
[2]G. E. Kocharov, V. A. Vasiliev, V. A. Dergachev, and N. G. Mikhalchenko, in: Proc. XVI Intern. Cosmic Ray Conference, Japan, 1979, Vol. 2, p. 256.
[3]F. Link, Solar Phys. **59**, 175 (1978).
[4]D. M. Willis and Y. K. Tulunay, *ibid.* **64**, 237 (1979).
[5]E. N. Parker, IAU Symp. No. 71, 3 (1976).
[6]F. H. Busse, Astron. Astrophys. **28**, 27 (1972).
[7]R. Howard, Solar Phys. **16**, 21 (1971).
[8]W. J. Wagner and L. B. Gilliam, *ibid*. **50**, 265 (1976).
[9]V. A. Dogel' and S. I. Syrovatskiĭ, in: Trudy IX Leningradskogo seminara po kosmofizike (Proc. Ninth Leningrad Space Physics Seminar), Leningrad Inst. Nucl. Phys., Acad. Sci. USSR, Leningrad 1978, p. 16.
[10]T. L. Duvall, Solar Phys. **63**, 3 (1979).
[11]V. A. Dogel' and S. I. Syrovatskiĭ, in: Trudy VIII Konsul'tativnogo soveshchaniya KAPG "Vneatmosfernye issledovaniya aktivnykh oblasteĭ" (Proc. Eighth Consultative Conference of the Committee on Aeronomy and Applied Geophysics on "Extraatmospheric Studies of the Active Regions"), Nauka, Moscow, 1976, p. 97.
[12]V. A. Dogel' and S. I. Syrovatskiĭ, Izv. Akad. Nauk SSSR, Ser. Fiz. **43**, 716 (1979).
[13]V. A. Dogel' and S. I. Syrovatskiĭ, in: Trudy XI Leningradskogo seminara po kosmofizike (Proc. Eleventh Leningrad Space Physics Seminar), Leningrad Inst. Nucl. Phys., Acad. Sci. USSR, Leningrad, 1980.
[14]A. S. Monin, Usp. Fiz. Nauk **125**, 97 (1978) [Sov. Phys. Usp. **21**, 429 (1978)].
[15]M. I. Rabinovich, *ibid.* p. 123 [443].
[16]Ya. B. Zel'dovich and A. A. Ruzmaĭkin, Problemy dinamo v astrofizike (Dynamo Problems in Astrophysics), Inst. Appl. Math. Acad. Sci. USSR Preprint No. 52, Moscow, 1980.
[17]J. A. Eddy, P. A. Gilman, and D. E. Troffer, Solar Phys. **46**, 3 (1976).

Translated by R. W. Bowers