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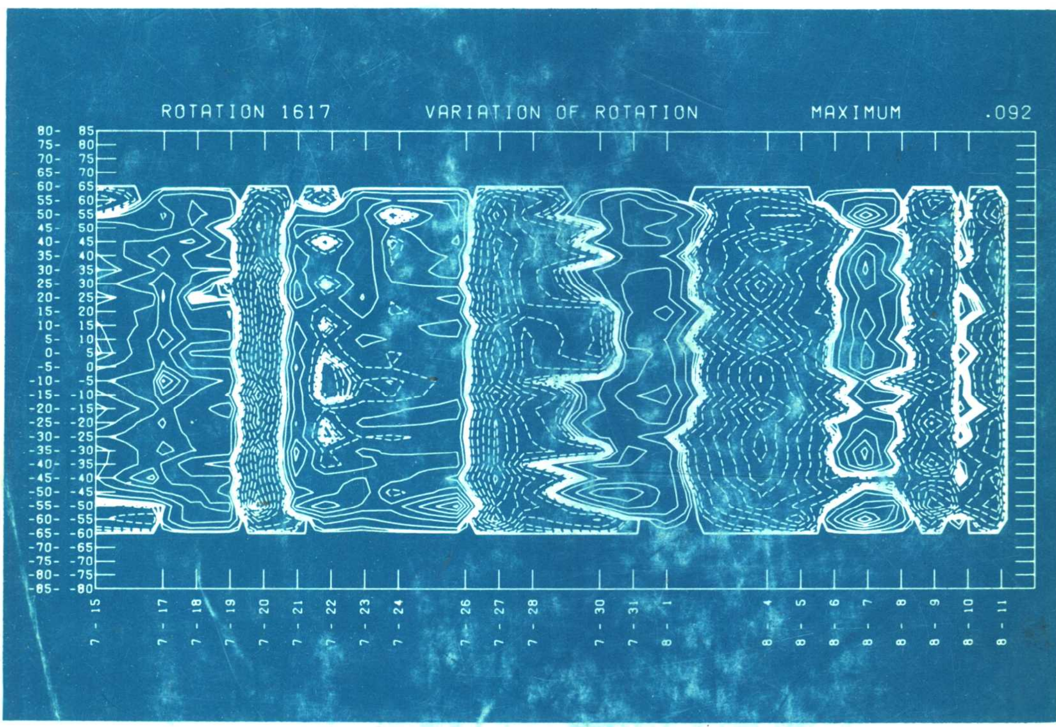
BASIC MECHANISMS OF SOLAR ACTIVITY

Edited by V. BUMBA and J. KLECZEK



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V. BUMBA AND J. KLECZEK

Astronomical Institute of the Czechoslovak Academy of Sciences, Ondřejov

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PREFACE

Our first attempt to organize a Symposium on solar activity was made at the IAU General Assembly in Brighton 1970. There, at the session of Commission 10, we proposed to organize a Symposium which would stress the observational aspects of solar activity. It was our hope that such a Symposium might stimulate studies of those important problems in solar physics which for a long time had been neglected in overall scientific discussion. Although a provisional date for the Symposium was then decided, it did not take place to avoid overlapping with other IAU activities.

At the session of Commission 10 in Sydney – on the occasion of the XVth IAU General Assembly in 1973 – we repeated our proposal and forwarded the invitation of the Czechoslovak Academy of Sciences to organize the Symposium in Prague. Both were accepted. During the discussions about the programme of the Symposium – enthusiastically promoted by the late president of Commission 10, Prof. K. O. Kiepenheuer – it was decided to change slightly its subject. The theoretical problems were stressed and the majority of the Scientific Organizing Committee agreed not to deal with short-lived phenomena of the solar activity or with individual active regions.

Symposium No. 71 was held in Prague from August 25 to August 29, 1975. Its Organizing Committee consisted of V. Bumba (Chairman), W. Deinzer, R. G. Giovanelli, R. Howard, K. O. Kiepenheuer, M. Kopecký, T. Krause, M. Kuperus, G. Newkirk and J. Vitinsky. The Local Organizing Committee of the Symposium was represented by M. Kopecký (Chairman), V. Rajský (Secretary), V. Bumba, J. Kleczek and J. Sýkora.

We wish to express our gratitude to all members of the Scientific Organizing Committee for their advice and assistance. It is our pleasure to thank J. O. Stenflo, V. E. Stepanov, M. Kopecký, L. Mestel, W. Deinzer, N. O. Weiss and B. R. Durney, who helped to organize the individual sessions and kindly served as their chairmen. Our special thanks are due to Dr Gordon Newkirk for organizing and presiding over the Concluding Summarizing Discussion. We are also obliged to P. Kotrč and his assistants, who kindly recorded all the discussions and persistently chased the discussion participants to get their questions and remarks in a definitive form. In most cases they succeeded.

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INAUGURAL ADDRESS*

JAROSLAV KOŽEŠNÍK
President of the Czechoslovak Academy of Sciences

Ladies and gentlemen, allow me to welcome you most sincerely on behalf of the Czechoslovak Academy of Sciences at the 71st Symposium of the International Astronomical Union whose subject matter is the basic mechanisms of solar activity.

The Czechoslovak Academy of Sciences esteems it an honour that the International Astronomical Union has accepted its invitation to organize this symposium in the Czechoslovak Socialist Republic. The presidium of the Czechoslovak Academy of Sciences has commissioned the Astronomical Institute to organize such an important international event. The Astronomical Institute in deciding to organize this symposium in Prague – a city with a rich astronomical tradition – certainly made a correct decision.

After all, astronomy took root in the Czech lands more than 600 years ago. Astronomy helped to establish a university in Prague as early as the turn of the 13th and the 14th centuries. In the Middle Ages, the Prague Astronomical School was a source of astronomical knowledge for the whole of Central Europe. The Polish research workers have recently proved that the Prague Astronomical School gave birth to the Cracovian School which, at the end of the 15th century, gave the world its greatest pupil Nicolas Copernicus. It was Prague again that played an important role in disseminating the teaching of Copernicus. The Copernicus teaching found its supporters especially in a Czech family of Tadeáš Hájek of Hájek, known under the name of Hagecius. Four hundred years ago, in 1574, the Hagecius book *Dialexis de novae et prius incognitae stellae apparitione* was published. This book sharply criticised the very base of the medieval and Aristotelian interpretation of the Universe. It became the most famous of all 16th-century writings. Thanks to Hagecius, born 450 years ago, Tycho Brahé and Johannes Kepler, the best astronomers in the world, came to Prague at the turn of the 16th and the 17th centuries and Prague became the most important centre of astronomical research all over the world.

The institutes in the Czechoslovak Socialist Republic follow in their work this glorious tradition. The Astronomical Institute of the Czechoslovak Academy of Sciences, the oldest and the largest of all our institutes, celebrated last year its 250 years of existence. It is one of the oldest scientific astronomical institutions in our country.

Therefore, we are glad that astronomers from the whole world meet again in Prague, after the International Astronomical Union General Assembly in 1967 and the COSPAR congress in 1969. A close international cooperation has a long tradition in the field of astronomy. As you probably know, a meeting of solar astronomers became the predecessor of the IAU General Assemblies. This close

* The Inaugural Address was presented by corresponding member of the Czechoslovak Academy of Sciences Vl. Guth.

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cooperation between scientists from the whole world is important not only for scientific progress itself but it also is an important element in the present day detente, in the struggle to strengthen peaceful cooperation in the spirit of the recent Helsinki Conference results.

We appreciate also the fact that the subject of our symposium is the basic mechanisms of solar activity in the first place. The study of these questions concerns not only solar activity itself but it also is of great importance for other scientific branches as well. The Sun is nothing but the nearest star and the knowledge of the Sun is of great importance for stellar astrophysics and cosmogony taken as a whole. Knowledge of basic mechanisms of solar activity is closely connected with plasma physics, with problems of plasma and magnetic-field interaction, with problems of nuclear reactions and energy release in general. For this reason solar physics can bring a lot of new stimuli in this field and thus can contribute to the solution of important technical and economic problems of mankind. Knowledge of basic mechanisms of solar activity plays an important role in the prognosis of solar activity, physically justified and thus reliable. These prognoses are ever more necessary since the importance of the solar activity influence upon the Earth is ever more evident in the sphere of geophysics, technology and of the biosphere. The actual trend shows that the importance of solar activity research for everyday life is steadily increasing.

Ladies and gentlemen, I am convinced that this symposium will represent another step in our efforts to know better the laws of nature and at the same time will enhance further cooperation between scientists all over the world. I wish you a lot of success in your work and a pleasant stay in Prague – the capital of the Czechoslovak Socialist Republic.

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INTRODUCTION

THE ENIGMA OF SOLAR ACTIVITY

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1. Introduction

The review lectures that make up the basic program of this symposium will cover the most recent observational results, and the present state of theoretical knowledge, of solar activity. It seems, therefore, that the most useful role for the introductory lecture would be to review the outstanding puzzles presented to us by the activity of the Sun so that we may have those numerous dilemmas clearly in mind as the speakers review the accumulated facts and theories.

It has become clear in the last ten years that the cause of all the many different forms of solar activity can be traced to the convection and circulation within the Sun. The convective zone of the Sun is a giant heat engine which converts a small fraction of the outward flowing heat into convective motions, and from there into magnetic fields and hydrodynamic and hydromagnetic waves. From these basic ingredients (of low entropy) there then arises the sunspot, the prominence, the flare, the corona and solar wind, etc.

The most obvious circulation within the Sun is the differential rotation of the visible surface, in which the equator rotates nearly 50% faster than the poles. This nonuniform rotation cannot be an artifact of the formation of the Sun, some 5×10^9 yr ago, for the eddy viscosity of the convective zone would long since have destroyed any initial nonuniform rotation. The present nonuniform rotation is an integral part of the present convection and circulation within the Sun, maintained today by the contemporary thermal gradients and heat fluxes.

The theory of convection, circulation, and nonuniform rotation is fundamental to the understanding of solar activity. Unfortunately, the enormous density variation across the convective zone, from 2×10^{-1} gm cm^{-3} at the bottom (at a depth of 2×10^5 km) to 5×10^{-7} gm cm^{-3} at the top, makes the theoretical treatment of the problem exceedingly difficult. What is difficult but possible in the Boussinesq approximation (uniform density) becomes a formidable task in the real stratified convective zone of the Sun. Some of the review speakers in this symposium will go into the problem in detail. I want to emphasize that the convection and circulation problem is fundamental to our understanding of any, and all, solar activity.

Let me begin, then, with the statement that we now know so much about the Sun that nearly every aspect of the Sun presents a dilemma. There is no other star about which we know enough to be so puzzled.

The most fundamental dilemma with the Sun is the failure to detect the expected neutrinos from the core (Davis and Evans, 1973). That problem, although not obviously central in questions of solar activity, is nonetheless so fundamental that we cannot ignore it. The neutrino dilemma involves the theory of weak interactions, opacity, radiative transfer, circulation and convection and, indeed, the whole

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physical basis for the theory of stellar structure (Bahcall *et al.*, 1973; Ulrich, 1974). We must not forget that our understanding of the convective zone – particularly its depth – is based in large measure on models of the solar interior. What would be the implications for solar activity if the Sun were convective all the way to its center? The explanation of the dilemma may, or may not, prove to be superficial, so far as the Sun is concerned. For instance, the luminosity of the Sun may vary by 5% over 10^4–10^6 yr (Fowler, 1972, 1973). Or it may be only that neutrinos are unstable (i.e., have nonvanishing rest mass) decaying before reaching Earth. This would have tremendous impact on the physics of elementary particles, but might well affect the theory of the solar interior very little. Or there may be some exotic effect that reduces opacity slightly, such as an absence of metals in the core of the Sun, or a convective core. But until the neutrino question is resolved, we cannot be sure of our knowledge of the interior structure of the Sun, and hence cannot be sure that we understand the convective origin of solar activity.

There are some curious questions of climatology that suggest that our knowledge of the solar interior, and the general evolution of a star on the main sequence, is less than complete. For instance, the conventional theory of evolution of the solar interior predicts that 10^9 yr ago the Sun was some 10% less luminous than we find it today; 4×10^9 yr ago it was 30% less luminous. Now the most sophisticated numerical atmospheric models of Earth predict that if the Sun were 6% less luminous, the surface of Earth would freeze over completely, increasing the albedo and further reducing the heating effect of the Sun, etc. But paleoclimatological studies are emphatic in the conclusion that Earth was not cooler 10^9 yr ago. Indeed, the indications are that it was, if anything, a few degrees warmer. Clearly we must keep an open mind when confronted with this problem. We know so little of the Sun and terrestrial climatology that the resolution could lie anywhere, and perhaps everywhere. But clearly something is out of line.

The historical sunspot record shows another gap in our understanding of the convective zone. Sunspots were first discovered and studied in the western world in 1610 with Galileo's application of the telescope to astronomy. Sunspots were considered at the time to be of no intrinsic interest in themselves (after the first trauma of their appearing as a blemish on the face of the 'perfect' sphere of the Sun) and so were not studied systematically. But there were enough records kept to show that the number of sunspots went through two distinct maxima after 1611, and then fell to a minimum at about 1645. The records go on to show that the Sun remained in a state of extreme minimum activity for about 70 yr thereafter, until approximately 1715, after which time activity resumed in the form of the familiar 11-yr cycle that we know so well today (Maunder, 1894, 1922). During the 70 yr of inactivity there was occasionally a sunspot or two, but long years with none at all; there was no white light corona visible during total eclipse by the Moon, whereas the corona is usually so conspicuous then; there were only a few significant auroral events, which are normally so common in clear skies over Scandinavia and Northern England. In view of the absence of a white light corona, we may conjecture whether the Sun was entirely shrouded in a coronal hole, yielding a fast, steady solar wind, or whether there was simply no solar wind at all. I would guess the former, but I know of no way to prove the answer.