INTRODUCTION

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ABSTRACT

1. Evolution of the modelling of the inside of the Sun, from "standard models" to the more empirical approach used now, and based on neutrino astronomy, solar sismology, and the interpretation of active phenomena. 2. New concepts introduced in the set of physical equations valid inside the Sun, under the pressure of new observations. 3. Similar trends seeming to affect in a comparable way the modelling of the solar cycle. 4. Other stars, and the improved knowledge of solar evolution may help to understand many observed features of rotation, magnetism, etc...Conclusion : the Sun is "one", - and it cannot safely be studied piecemeal.

1. For a very long time, and until only quite recently, it was customary to consider that the only informations one had about the physical conditions inside the Sun were the global informations concerning our star, namely its mass, its radius, its luminosity. The spectrum was also, in a way, a set of information : but the chemical composition of the atmosphere was not necessarily representative of the evolved composition of the core, unless completed by the age of the Sun (as inferred from solar system studies) and a theory of its evolution, in particular an history of how mixing has been operating since the start of nuclear reactions.

From this limited amount of data, "models" were built of an evolved Sun. A given initial composition of the gaseous sphere, the game of thermonuclear reactions, the use of radiative equilibrium (where allowed), of hydrostatic equilibrium, of thermodynamic equilibrium, and wherever necessary, a proper account of convective instabilities (using then, in convective layers, the mixing-length theory, with a somewhat arbitrary ratio l/H) - this set of equations being completed by oversimplified boundary conditions at the "solar surface" - this was in essence enough to be happy with, once one has succeeded, the computation finished, in matching the values of mass, radius, luminosity, and in insuring that initial composition, age, and actual atmospheric composition were at least compatible.

One of the greatest challenges in solar modelling was therefore not getting the necessary observations, but performing with accuracy the solution of very difficult systems of equations. As the

G. Berthomieu and M. Cribier (eds.), Inside the Sun, 1–4.

author of an introduction is, I presume, free to express his own idiosyncrasies, I would define this period as dominated by numerical acrobatics, and regrettably far from physical insight or accurate data.

But it was clear, however, for almost any one in the field, that many phenomena, although well-known by the observers, were unduly ignored by the modelists. Rotation, and its latitudinal differential behaviour, convection, and the complex imbrication of convective cells and turbulent motions, magnetic active phenomena, and their obviously deep-rooted origin, cycles of activity and the general magnetic field of the Sun, - all these phenomena, and most of their interplays were known; but none was properly taken into account in modelling the inside of the Sun, and many were not even completely understood.

2. Fast progress came a few decades ago, from various new advances in techniques and in observations.

First of all, the quick development of high-speed performant computers allowed theoreticians to tackle more ambitious programs. But often, very gratuitous style exercises were performed, without enough attention being paid to the physical value of the game. At least, everything seemed to become possible...

Then the accuracy with which physical constants were known (cross sections of nuclear reactions, opacity tables, ionic and atomic processes), even improvements in such things as the equation of state, allowed the astrophysicists to work on safer grounds.

Finally, new phenomena were discovered. Not only was the explored electromagnetic spectral range considerably extended, allowing the discovery of such coronal features as coronal holes, bright X-ray points, etc..., but other messages from the Sun began to be deciphered ; the neutrino flux gives direct information concerning what happens in the Sun's core; and the oscillation frequencies spectrum can be inverted (as for sismic waves on Earth) and provides us with values of the sound velocity as a function of depth; even, in principle, it can also provide the solar physicist with the rotational velocity as a function of depth. But one can also state that abundances of ^{3}He in cosmic rays, or of ^{7}Li in the solar atmosphere may reveal much about the physical conditions at the bottom of the convective zone, and can be very useful clues.

Active phenomena, although still far from being understood in many of their more important aspects, give also clues during the various phases of the solar cycle, concerning the general behaviour of convective cells which act in dragging out magnetic tubes of force before they actually can emerge, and concerning the properties of the solar magnetic field embedded in the deep Sun. These clues request certainly much effort towards a real understanding of their meaning. But no theory can avoid to match these data, even if some of them are still ambiguous and perhaps compatible with quite different types of theories.

Thus, in a few decades, "modelling the Sun" became a completely different concept. From a very "abstract" approach, essentially a study a priori of gaseous spheres, based upon the solutions of the equations of internal structure, one has progressively been led to an almost "empirical" approach, where the ideal (standard) model serves only as a starting block, improved in its details on the basis of successive observational refinements.

3. In this new approach, a close cooperation is necessary with the physicists, as contradictions appear between the refinements derived from different observational sources : as an example, we must note that the apparent depletion in the observed flux of neutrinos (compared with the expectations of standard models) has led to a stimulating interchange between physicists and solar physicists : has the solar structure to be modified ? or are the neutrinos behaving differently from what was previously thought ?

Improvements in the physics of the internal regions of the Sun are thus a by-product of this approach. Not only do they concern some basic physics (such as the neutrino physics), but also they imply the introduction of some concepts already known, but now thought to be relevant, in the equations of solar structure. For example, it is clear that diffusive processes have to play a part either by reintroducing in the core unprocessed matter, or by allowing some atoms, produced in the core, to reach the convective layers and to be observable in the spectra. But we have not yet reached a state of affairs where it is safe to assert quantitatively the effects of diffusion ... Clearly also, the phenomenological mixing-length theory has to be refined, to justify "the" good choice of the ratio l /H, and even to be replaced by some exact hydrodynamical theory. Above and below the convective layers, one has also to take into account overshooting : in itself, this process leads us to think that one cannot treat the transition layer between radiative inner or outer zones and convective zone as spherically symmetric. And departures from spherically-symmetric geometry yields to local instabilities which may well affect the transport of magnetic fields. Similarly, granulation affects the geometry of the photosphere, and abundance determinations may be sensitive to departures from spherically-symmetric geometry, - as they were already known to be sensitive to departures from local thermodynamic equilibrium. These sensitivities may, in their turn, affect the opacities.

4. Modelling the cycle of activity is developing more slowly than modelling the averaged Sun. Still the progress follows similar lines. A few years ago, one computed with great accuracy dynamo models of the Sun, which were assumed to be linear, and, even under their non-magnetic aspects, grossly oversimplified. Nowadays, the highly non-linear character of the solar dynamo has been widely recognized. Assuming the observed characteristics of the emergence of active regions to be strongly coupled with the general features of the magnetic field, and with the hydrodynamical properties of the Sun, one can think of some partly theoretical, partly empirical description of the solar cyclic behaviour. There is a little doubt that much progress will come from that kind of approach in the years to come.

5. For years, in the "old days" as well as more recently, much emphasis have been given, in an almost purely literary or philosophical perspective, to statements such as "the Sun is a star", or even "the active Sun is a star". True of course! ... But the present state of our knowledge of active phenomena in stellar atmospheres, as well, on another side, as the theory of stellar evolution which affects all stellar layers, allow us to consider that the Sun is a body on its way from birth to the normal stellar life, and finally to its death as a main-sequence star. One has to understand not only how is the Sun behaving the way it does, but why. Conservation of energy, of momentum ... allow to reconstruct pre-stellar conditions, or to account for the distribution of magnetism and rotation in the Sun, or even in the solar system.

CONCLUSION

Therefore, one cannot escape the conclusion, obvious and trivial, but important, that the Sun is one object, in which the different layers are coupled with each other, in which the past conditions commands the future. One cannot treat a given solar region - say the convective layer - without taking into consideration the boundary conditions linked with what happens in the surrounding (radiative, in the chosen example) regions. One cannot understand one aspect of solar physics without some idea on the history of the involved matter and of its behaviour. In other terms, solar and stellar physicists cannot divide in overspecialized groups without risking to loose the very essence of their problem. We are well beyond the first approximation, well beyond the linearizations, in front of a highly coupled, highly non-linear set of physical equations. Solar physics cannot be reduced to a simple-minded modelling, according the "standard" line, whatever its merits as a good starting point.

AKNOWLEDGMENTS

This meeting has been co-organized, under the auspices of the I.A.U., by physicists and by astronomers, which, in itself, happily symbolizes the spirit of the new solar astrophysics. In particular, I would like to acknowledge the important work, behind or in front of the scene, of J. Boratav and of the Saclay physicists, M. Cribier, T. Montmerle and D. Vignaud. The chairman of the Scientific Organizing Committee has been Evry Schatzman. One should outline the fact that almost all aspects of the solar physics have been successfully tackled by Schatzman; he has been a novator in many of them. I want to thank him personally, for all what I have learnt from him, over more than four decades.