

Preface

It is the stars, The stars above us, govern our conditions.

William Shakespeare, King Lear

A Few Words about What, Why and How

The structure of the stars in general, and the Sun in particular, has been the subject of extensive scientific research and debate for over a century. The discovery of quantum theory during the first half of the nineteenth century provided much of the theoretical background needed to understand the making of the stars and how they live off their energy source. Progress in the theory of stellar structure was made through extensive discussions and controversies between the giants of the fields, as well as brilliant discoveries by astronomers. In this book, we shall carefully expose the building of the theory of stellar structure and evolution, and explain how our understanding of the stars has emerged from this background of incessant debate.

About hundred years were required for astrophysics to answer the crucial questions: What is the energy source of the stars? How are the stars made? How do they evolve and eventually die? The answers to these questions have profound implications for astrophysics, physics, and biology, and the question of how we ourselves come to be here. While we already possess many of the answers, the theory of stellar structure is far from being complete, and there are many open questions, for example, concerning the mechanisms which trigger giant supernova explosions. Many internal hydrodynamic processes remain a mystery. Yet some global pictures can indeed be outlined, and this is what we shall attempt to do here.

Astrophysical systems, like the Sun, the solar system, the stars, and the galaxies are very complex, and they cannot be brought into the laboratory for extensive investigation, taken apart for examination, or perturbed to learn how they respond. Consequently, progress is far from trivial, and we shall witness much controversy and debate before a consistent picture and theory eventually emerge.

It is not unusual to hear non-scientific arguments along the following lines: the famous rabbi says ‘so must it be’, and then his statement is quoted as the authoritative answer and the reason. One may suppose that the origin of this kind of reasoning goes back to the Talmud, The Chapter of the Fathers, Pirkei Avot: *Rabban Gamaliel*

said: *Provide yourself with a teacher and remove yourself from doubt . . .*¹ In other words, follow the doctrine of some clever fellow. The continuation of this frequently cited phrase is: *. . . and do not accustom yourself to give tithes by estimate*. So when you have difficulty estimating what is the suitable donation to the poor, ask the wise man. It does not mean that one should always, and on all matters, blindly adopt the pronouncements of some ‘authority’. The quotations given in the present book are not meant to convince you that this or that great scientist believed such and such and for this reason you must also believe it. On the contrary, think for yourself and find your own reason to be convinced. Let us not forget that great scientists can make great errors. In the Eddington versus Jeans controversy about the energy source of the stars, Jeans was wrong and Eddington was right, but in the Chandrasekhar versus Eddington controversy about the structure of cooling, dying stars, Eddington was wrong and Chandrasekhar was right. And nobody in the history of astrophysics knew the stars better than Eddington!

Too frequently we witness something rather opposite, namely, a lack of proper credit. It is for scientists that we quote the following: *Rabban Yochanan ben Zakkai received the Torah from Hillel and from Shamai. He used to say: If you have learnt much Torah do not claim for yourself moral excellence, for to this end you were created*.²

The non-existence of a scientific answer or an explanation for a phenomenon, or indeed some controversy among scientists, are often held against science. This is a misconception. Our purpose in depicting the history of the theory of stellar structure and evolution is to show that heated debate and argument among scientists are a fundamental feature of the scientific arena. The discussions lead to sharper views and tests to validate or disprove the theory. Science progresses via discussion and argument. Scientists strive at objectivity. Yet science is not objective on the short timescale, but only in the long term. Human feelings, even hatred, play a significant role on this short timescale, but science is a long term self-correcting process.

The age of the Earth and the age of the Sun fix a timescale over which most of the important elements for life were formed. It is therefore pivotal to understand how the long life of the Sun gives rise to a long age for the Earth, which in turn provides ample time for the evolution of biology. The evolution of biology on the Earth and the age of the Sun are intimately bound together! So what determines the age of the Sun?

It is remarkable how fashion can dictate scientific thinking or bias. This is probably due to the way physicists are trained, which ignores alternative explanations raised in the past. As a consequence, the average physics student accepts the preaching and indoctrination of the day without questioning its validity. While the history of failed ideas is no substitute for what we may believe today to be the ‘last word’, there is much to be gained from an adequate exposition of how the ‘final answer’ was reached. We agree on this point with Bogdan Paczinski who said: *If less than half of your ideas are wrong, you are not trying hard enough*. Consequently, quota-

¹ Pirkei Avot, Chap. A, Mishna 16.

² Pirkei Avot, Chap. B, Mishna 9.

tions or excerpts, even from the greatest scientists, need not always reflect the truth, or be taken as ‘God’s will’.

With regard to methodology, we shall refer to papers published in the professional literature (even when the ideas were completely irrational), and refrain from quoting personal letters, notes, or rumors, as these can seldom be assured to be the final word, and they cannot be expected to commit their writers. For this reason, detailed references are given. Quotations from papers are given in italics. The problem of giving proper citations and credit is thousands of years old, as we find in the Talmud: *Says Rabi Elazar in the name of Rabi Hanina: He who repeats something said by another, in that person’s name, brings salvation to the world.*³

Many of the contributors to the theory have been immortalized by having their names attributed to craters or mountain peaks and ridges on the moon. The letter m after the year of death of a scientist indicates that some feature on the moon has been named after him.

Some Scientific Remarks

Physical systems comprising several components are said to be bound if the separation of the components requires energy. This energy is called the binding energy. The system is stable as long as there is no state with lower energy into which it can descend. A nucleus is stable only to the extent that there is no state with lower energy into which it can decay. A nucleus is radioactive whenever there exists a lower energy state.

Stars are large bound macroscopic systems which lose energy continuously. Hence, stars gradually evolve into lower energy states. The evolution of stars is an incessant decrease in the (negative) binding energy. Periods in which the star has a particular energy source, like nuclear energy, are nothing but temporary halts in this incredible pumping of energy from the stellar gravitational field into the surrounding space. Biology develops during one of these temporary stops. The process continues until the state of lowest energy is reached. At this moment, the star stops evolving and can be pronounced dead.

Different stars reach different ‘last stops’. What we describe in this book is an outline of this extraordinary life of the stars, and how it was discovered and debated.

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³ Talmud Bavli, Tractate Megillah, Chap. I.

of the libraries in the Department of Physics at Stanford University, at the Institute for Theoretical Physics, Heidelberg University, and at the Max Planck Institute for Medicine, Heidelberg. The library of the physics department helped me find some old papers. The library in the Hebrew University allowed me to maintain connections with various archives. The library at Toronto University was extremely helpful in finding and extracting old articles and books.

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