# Preface

This book deals with the chemical evolution of galaxies. The term *chemical evolution* is immediately associated with Beatrice Tinsley, who greatly contributed to this important astrophysical field. Simultaneously with R.J.Jr. Talbot and D.W. Arnett, she developed a formalism that allowed us to explore galaxy evolution from the point of view of element production and distribution inside and outside galaxies. During the Big Bang, only light elements (H, D, He, and Li) were produced and all the heavier ones (from carbon to the heaviest) originated in stars. The history of star formation is one of the main drivers of chemical evolution since the number of stars formed (the star formation rate) and the distribution of stars as a function of their mass (the initial mass function) are regulating the rate of chemical enrichment at any cosmic time. Then, the stellar evolution and nucleosynthesis provides us with fundamental information about element production and their restoration into the interstellar medium. As time passes, more and more stellar generations succeed one another and the new ones form out of gas enriched in heavy elements by the previous generations. This is the process we call chemical evolution. Bernard Pagel also greatly contributed to the study of galactic chemical evolution, first of all as a careful and experienced observer and also by modeling chemical evolution, with a preference for analytical models, whose results are easier to understand than those of numerical models. However, numerical models became necessary to follow the evolution of single chemical elements produced by stars in different mass ranges and by different nucleosynthetic processes. The hypothesis of instantaneous recycling, which allows us to solve analytically the chemical evolution equations, assumes that the stellar lifetimes are negligible and that all stars restore their processed and unprocessed material instantaneously. While this hypothesis can still be acceptable for those chemical elements which are produced on very short timescales compared to the age of the Universe (massive stars), it is a very poor assumption for those elements restored into the interstellar medium on timescales ranging from several hundred million to billion years. One such element is iron, which is used as the main tracer of the "metallicity" (i.e., the sum of the abundances of all the elements from carbon and heavier) in stars. We believe now that most of the iron is produced in longer living stars such as those which end their lives as carbon–oxygen white dwarfs. Adopting the instantaneous recycling approximation implies that the ratio of every two chemical elements, such as oxygen and iron, would be constant across the life of the Universe. As we will see, this is not the case for many pairs of elements, in particular for oxygen and iron.

The topic of galactic chemical evolution is a highly challenging one since it involves many physical processes that we have not yet fully understood. One of the most common criticisms of the chemical evolution models is that they contain too many free parameters. This is true, but my answer to this criticism has always been that what matters is the number of observational constraints that we can reproduce: in fact, this number should be much larger than the number of free parameters. Besides the star formation history and stellar nucleosynthesis, the important processes regulating the chemical evolution of galaxies are the feedback between supernovae and the interstellar medium, namely, the transfer of energy from stars to the interstellar gas, and the gas flows which can be entering or leaving galaxies. The balance between all of these processes will eventually determine the metal content and the abundance patterns we observe in stars and gas. The interpretation of the behavior of abundance ratios in galaxies is one of the main topics of this book and it is based on the different roles played in the chemical enrichment by stars with different lifetimes which produce different elements. For example, oxygen is produced mainly in core-collapse supernovae emanating from short-lived massive stars, whereas iron is mainly produced in thermonuclear supernovae (Type Ia), which are believed to originate from white dwarfs in binary systems which can evolve over long timescales. The difference in the timescales for element production produces the observed abundance patterns; this interpretation is known as "time-delay model." On the basis of the time-delay model we can try to estimate the nature and the ages of high redshift objects of unknown morphology, just by analysing their observed abundances and abundance ratios. In general, models of galactic chemical evolution can be helpful in constraining both stellar nucleosynthesis and galaxy formation mechanisms. For example, the study of the abundance gradients along the thin disk of the Milky Way leads us to suggest the disk formed inside-out, a mechanism which should be shared also by other spiral disks.

Many researchers have contributed in the last 30 years to the understanding of galactic chemical evolution. Many of them are quoted in this book. I apologize to those researchers who have not been mentioned, but the number of references in a book should be smaller than in research articles and, therefore, I have made an effort of constrain the number of citations.

The organization of this book is as follows.

In Introduction, I discuss the concept and definition of chemical abundances starting from the abundances derived for the Sun. Then, I describe the main stellar populations in our Galaxy, characterized by their chemical and kinematical properties. The Hubble sequence of galaxies is presented and a possible interpretation of this sequence in terms of different star formation histories is attempted. Some of the main observables in galaxies are reviewed and, finally, different methodological approaches to modeling galaxy evolution, are described.

Chapter 2 deals with the basic ingredients for constructing models of chemical evolution. They are: (1) the initial conditions, (2) the star formation history, (3) the stellar evolution and nucleosynthesis, the so-called stellar yields, and (4) the gas flows.

In Chap. 3, I present several analytical solutions to models assuming instantaneous recycling approximation and refer to these models as "simple models." The various solutions are critically discussed.

Chapter 4 contains the complete equations of chemical evolution which can be solved only numerically. Recipes for the various ingredients are given. I show how to compute the supernova and nova rates in galaxies. Finally, I describe possible methods of solution for the basic equations.

Within Chap. 5, the chemical evolution of the Milky Way is studied in detail. The comparison between model results and observations is used to impose constraints on the mechanisms of formation of the different components: halo, thick disk, thin disk, and bulge. At the end of this chapter, some considerations on the chemical evolution of other spirals of the Local Group are presented.

I describe in Chap. 6 the chemical evolution of spheroids, in particular, ellipticals, bulges, and dwarf spheroidals. The connection between ellipticals and quasars is also discussed.

In Chap. 7, I present the chemical evolution of irregular galaxies, including the Magellanic Clouds and the blue compact galaxies, and their connection to damped Lyman-$\alpha$ systems.

Finally, in Chap. 8, I introduce the so-called *cosmic chemical evolution*, namely, the evolution of a comoving unitary volume of the Universe, where galaxies of all types are present. The methods and the results obtained so far are discussed. The subject of the cosmic star formation rate as well as the cosmic gamma-ray burst rate is touched upon.

This book is aimed at graduate students and young researchers who want to enter in the field of modeling galactic chemical evolution and try to understand the complex processes governing galaxies through comparing observations and model results. Other similar books already exists, they are "Nucleosynthesis and Chemical Evolution of Galaxies" by Bernard Pagel (1997) and "The Chemical Evolution of the Galaxy" by myself (2001).

*I want to warmly thank many people who have helped me in producing this book. In particular, I would like to mention my collaborators who have greatly contributed to the material presented in this book: Francesco Calura, Gabriele Cescutti, Cristina Chiappini, Annibale D'Ercole, Brad Gibson, Gustavo Lanfranchi, Monica Marcon-Uchida, Antonio Pipino, Simone Recchi, Donatella Romano, Emanuele Spitoni, Monica Tosi, and Jun Yin. I am also indebted to some of my students who read extremely carefully the manuscript finding typos and repetitions that I would never have found, they are: Valentina Grieco, Shaji Vattakunnel, and Luca Vincoletto. A special thanks go to my husband John Danziger, who patiently improved the English of some Chapters.*

Trieste, Italy *Francesca Matteucci*

Springer

http://www.springer.com/978-3-642-22490-4

Chemical Evolution of Galaxies
Matteucci, F.
2012, XIV, 226 p., Hardcover
ISBN: 978-3-642-22490-4