On the chemical and spectro-photometric evolution of nearby galaxies

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General introduction and thesis outline

If you stare at the deeply lined face of an old, grey man and you have a close look at his eyes, expression, eyebrows, cheeks, skin, mouth, chin, beard, and pose, you may get a tiny impression of the kind of person he is and/or used to be. If you watch his movements, gestures, pliancy, the way he walks, eats, breaths, turns, and holds his walking-stick, you may deduce some of his character and way of life. If you see his hands, fingers, muscles, and knees, you may infer details about his occupations, habits, and daily pursuits. For instance, you may find out that the old man smokes (or did smoke), plays the guitar, is patient, does not sport frequently, works with his hands, reads a lot, and is a gentleman. If you compare the characteristics and behaviour of the old man with that of other aged persons, you may find that the old man is rather tall and active for people of his profession. You may deduce where the old man comes from and what is his age, provided that you can determine the other persons' ages and birthplaces in an independent way. Then, from striking similarities, you may be able to conclude that old men who don't smoke are more patient than people who do smoke with an age of 25 years and above, if they were born in western Europe. If you take a closer look at the interaction of the old man with that of other persons in his neighbourhood, you may observe that the old man predominantly interacts with men and women born in Japan so that he probably speaks Japanese. If the old man was born in Helsinki then he probably travelled a lot around the world. Combined with his habits, oversized hands, and strong muscles, this may indicate that he used to be a constructional engineer. In turn, you may conclude that most people in Japan become interested in architecture during their lives and that there must be a connection with their cultural education when they are approximately 18 years old. Thus, from the characteristics of many different people observed — at the same instant in time — you may be able to deduce what the old man among these people has experienced — during his life — as well as to forecast what he — will be doing — in the next twenty-five years. This principle essentially forms the basis of the research on the chemical and spectro-photometric evolution of nearby galaxies presented in this thesis.

In this thesis, we focus on the star formation history and chemical evolution of the Galactic disk. Using a wide range of observational constraints, most of which have become available during the last few years, we aim to reconstruct the Galactic star formation history by modelling simultaneously various aspects of Galactic chemical evolution. In the second part of this thesis, we investigate the spectro-photometric and chemical evolution of nearby galaxies by means of a photometric evolution model. This model is applied to the stellar populations of Low Surface Brightness galaxies, a class of very faint galaxies for which a wealth of observational data have recently become available.

The chemical enrichment of the interstellar medium (ISM) by successive generations of stars is a key issue in understanding the chemical evolution of galaxies in general, and the formation history and abundance distributions of the stellar populations in our Galaxy in particular. The goal of galactic chemical evolution modelling is to predict reliable abundances in our Galaxy as well as in other galaxies both as a function of time and location. From such modelling, we can learn what processes essentially determine the chemical enrichment history of different galactic regions (e.g. disk, bulge, halo) and deduce how the formation and evolution of galaxies in general may have proceeded according to their chemical properties.
Both the chemical and spectro-photometric properties of galaxies are directed by the complex interplay between stars and interstellar matter. In order to unravel the underlying physics that can explain adequately the integrated properties of stellar populations observed in galaxies, detailed knowledge is required of how these populations formed, evolved, and interacted with the ambient ISM. In this thesis, we will test several basic concepts of galactic evolution and examine the ability of these concepts to reproduce various observational constraints simultaneously. From a comparison of such predictions for many individual galaxies, we hope to converge to a consistent and uniform description of how galaxies evolve and to understand the processes that can explain the origin of both the diversity and the striking similarities of the galaxies in our neighbourhood.

This thesis is organized as follows:

In Chapter 2, we deal with several observational and theoretical aspects of local and global star formation processes in galaxies. The chapter is meant as a brief introduction to the subject and highlights some of the basic assumptions and ingredients involved in the theoretical description of the process of star formation in galaxies.

In Chapter 3, we describe a general model for the chemical evolution of a galactic region such as the Galactic disk and discuss the basic equations, assumptions, and stellar input data used. The region is considered as an open, non closed-box system and is allowed to experience inflow and outflow of both gas and stars. In particular, we assume that the region is homogeneous at any time in its evolution. Up-to-date metallicity dependent stellar lifetimes, remnant masses, and nucleosynthesis yields are taken into account. We present the complete set of stellar yields of elements up to Zn used, both for Asymptotic Giant Branch (AGB) stars, Supernovae Type Ia (SNIa), SN Ib/c, and SN II and discuss the uncertainties involved. An overall comparison of the yields of intermediate and massive stars is made by means of the cumulative initial mass function (IMF) weighed yields and the net yield function. These quantities are well suited for comparison with other galactic chemical evolution studies and may have direct implications for the chemical evolution of the Galactic disk.

The ultimate goal of modelling various observational characteristics of the chemical evolution of the local disk ISM is to obtain information about the principal processes that have directed the star formation history and chemical enrichment of the Galactic disk. In particular, the abundances of stars observed in the local Galactic disk and halo probably provide the most stringent test for Galactic chemical evolution models.

In Chapter 4, we concentrate on the star formation history and chemical evolution of the local Galactic disk. We consider several basic issues concerning the dynamical and chemical evolution of the Galaxy as a whole. We investigate the sensitivity of the age-metallicity relation (AMR) to specific model assumptions, and we select a set of models which can explain adequately the mean [Fe/H] vs. age relation observed in the local Galactic disk. The models selected are confronted with a wide range of observational constraints related to the chemical enrichment and stellar content of the disk. Our study has several important improvements over previous investigations which include: 1) simultaneous modelling of various independent observational constraints which were not available until recently (e.g. the stellar abundance-abundance variations for disk and halo stars, present-day element abundances in the disk ISM, the luminosity functions of white dwarfs and AGB stars, the age- and metallicity distributions of main-sequence F, G, and K dwarfs, the abundances in planetary nebulae, the gas consumption rate and gas ejection rate by evolved stars, the present-day mass function, the remnant mass distribution) using one and the same galactic chemical evolution model, and 2) the application of a uniform, up-to-date, and comprehensive metallicity dependent set of stellar evolution data. In particular, we investigate what kind of models are able to explain adequately the chemical evolution of the Galaxy as traced by the abundance-abundance variations observed among long-living stars and we discuss our results with respect to the validity of the various assumptions made.

While exploiting numerous improvements, both in theoretical and observational fields of Galactic evolution, we aim to reconstruct the star formation history of the Galactic disk and to derive essential quantities such as the current gas infall and star formation rate, the typical enrichment time scale for different elements, and the upper mass limit for SNII. Apart from studies that concern the evolution of our Galaxy, knowledge of these quantities are of particular interest for research on the evolution of nearby systems such as the Magellanic Clouds and M31. In turn, these Local Group galaxies provide an important reference frame of
observations to which the evolution of more distant galaxies in the universe can be compared. We summarize the type of chemical evolution models that are in best overall agreement with the observations and we discuss what our results may imply for the chemical evolution of the Galaxy as a whole.

Observational studies related to the heavy element enrichment of the local Galactic disk have long shown that stars of similar age exhibit large abundance variations (e.g. Mayor 1976; Twarog 1980a; Twarog & Wheeler 1982; Carlberg et al. 1985; Gilmore 1989; Kloczkova et al. 1989; Schuster & Nissen 1989; Meusinger et al. 1991). Recently, Edvardsson et al. (1993) presented accurate abundance data for nearly 200 F and G main-sequence dwarfs in the solar neighbourhood (SNBH). Their spectroscopic data, analysed with up-to-date input physics, confirms abundance variations as large as ∼0.6 dex in e.g. Δ[Fe/H] among similarly aged stars. In contrast to previous understanding, these variations are much in excess of experimental uncertainties and seem to suggest that the abundance spread for stars born at roughly the same galactocentric distance is similar in magnitude to the overall increase in metallicity during the lifetime of the disk.

In Chapter 5, we investigate the origin of the abundance variations observed among similarly aged F and G dwarfs in the local Galactic disk. We briefly review recent observations related to the inhomogeneous heavy element enrichment of the local disk ISM and we present arguments in support of combined infall of metal-deficient gas and sequential enrichment in the SNBH. A model for the inhomogeneous chemical evolution of a star forming gas cloud is presented which incorporates sequential stellar enrichment and mixing processes (including infall) and which allows for temporal and/or spatial inhomogeneities in the ISM. With this model, we investigate in detail the combined effect of metal-deficient gas infall and sequential stellar enrichment by successive stellar generations on the chemical evolution of multiple gas clouds in the Galactic disk. We show that Galactic chemical evolution models which take into account these processes simultaneously are consistent with the observed abundance variations among similarly aged F and G dwarfs in the SNBH as well as with the abundances observed nowadays in the local disk ISM. We discuss these results in the more general context of the chemical evolution of the Galactic disk and adduce observational arguments in support of both sequential star formation and metal-deficient gas infall in the local ISM.

In Chapter 6, we investigate the star formation history and chemical evolution of low surface brightness (LSB) disk galaxies by means of their observed spectro-photometric and chemical properties. The goal of this investigation is to address several plausible scenarios for the evolution of LSB galaxies by detailed modelling of their spectro-photometric and chemical properties. To this end, we developed a galactic spectro-photometric evolution model incorporating a detailed metallicity dependent set of up-to-date stellar input data covering all relevant stages of stellar evolution. We compare and calibrate the model and describe the basic set of star formation histories studied. Model results are compared directly with the observed colors, gas phase abundances, gas contents, and current star formation rates of LSB galaxies to constrain the global star formation history and chemical evolution of these systems. In particular, the impact of small amplitude star formation bursts in LSB galaxies is investigated and the star formation rates predicted are compared with the observations. We discuss our results in the context of the star formation history and dynamical evolution of LSB galaxies and we address the important question whether LSB spirals do have an evolutionary history fundamentally different from that of HSB spirals (such as the Galaxy) and dwarf galaxies.

We like to note that the research of galactic chemical and spectro-photometric evolution comprises many different areas which by far cannot be dealt with in one single thesis. In particular, the kinematical and hydrodynamical aspects of galactic evolution are not taken into account here. Other possibly important aspects include the influence on galactic chemical and spectro-photometric evolution of: the compact galaxy nucleus and spiral arms, the merging and interaction of galaxies in clusters, a distinction between molecular and atomic gas components, dust grains, galactic chimney and superbubble blowouts, primordial nucleosynthesis, the early evolution of galaxies after the big bang, and dark matter. Certainly, these aspects will be considered in future studies of galactic evolution.
Naarmate het getij verloopt worden de bakens verzet