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Current problems of stellar astrophysics in optical spectroscopy

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Abstract. We present the highlights of current programs in stellar optical spectroscopy carried out with 8-10m class telescopes as well as with smaller telescopes. Topics briefly discussed here include: 1. light element abundances and their cosmological implications; 2. search for Population III stars and spectroscopy of extremely metal deficient stars; 3. abundances of different stellar populations in the Galaxy; 4. spectroscopy of resolved stars in Local Group galaxies; 5. Li and Be abundances and internal mixing in stars; 6. spectroscopy of very-low mass stars and brown dwarfs; 7. radial velocity search of extrasolar planets; 8. stellar oscillations and asteroseismology; 9. stellar magnetic activity and Doppler imaging of stellar surface features.

Key words. spectroscopy – stars – light elements – stellar populations – abundances – brown dwarfs – exoplanets – stellar activity.

1. Introduction

The advent of large 8-10m class telescopes equipped with high-efficiency echelle spectrographs and sensitive detectors has given a tremendous boost in the last several years to optical spectroscopy. It is now possible to observe at medium to high-resolution (R $\approx$ $20,000 - 100,000$) fainter sources than previously possible with 4m-class and smaller telescopes. This has opened new avenues to the investigation of many astrophysical problems, from the physics of very faint stars in the Galaxy to resolved stars in Local Group galaxies, to QSO absorption systems. In this paper we will review current researches in observational spectroscopy, focusing on stars in the Galaxy and in Local Group galaxies. Only a summary will be presented here. The full text with associated figures and references is available in Pallavicini, & Randich, 2004, Astronomische Nachrichten, 325, 462 (full text available at http://www3.interscience.wiley.com/cgi-bin/jissue/109703533). Additional material and references related to the topics discussed in this paper can be found in Proceedings of the ESO-Arcetri Workshop "Chemical Abundances and Mixing in Stars in the Milky Way and its Satellites", 2005, L. Pasquini and S. Randich (eds), ESO Astrophysics symposia, Springer-Verlag, in press.

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2. From Pop. III stars to brown dwarfs

We present below a list of topics that are best addressed with high resolution spectroscopy. We will not make any attempt to be comprehensive, but we will present only a very subjective selection of some of the most important issues, in the hope that the limited number of topics will be enough to give the flavour of what optical echelle spectroscopy can do for our understanding of stars.

Light elements – Spectroscopic determinations of the abundances of light elements (D, ^{3}He, ^{4}He, Li) produced by primordial nucleosynthesis in the first few minutes after the Big Bang allow constraining the amount of baryonic matter in the Universe. Standard Big Bang Nucleosynthesis (BBN) makes definite predictions for the abundance of ^{4}He, ^{3}He, D and Li as a function of the baryon-to-photon ratio (η). Consistency requires that measured abundances would all agree for a single value of η and that this value should be consistent with that derived independently from the observed fluctuations of the Cosmic Microwave Background (CMB). Whereas a good consistency is found for D, ^{3}He, and ^{4}He, the primordial abundance of ^{7}Li determined spectroscopically from the 6708 Å Li I line is still matter of controversy casting doubts on the use of Pop II Li determinations as indicative of the genuine Li primordial abundance.

The first stars – According to standard BBN no metals were produced in the early Universe and thus the first stellar population should have formed from gas of zero metallicity. The outstanding question thus is: can we find remnants of that early population of stars? Extensive photometric, proper motion and spectroscopic surveys have been carried out over the past several years to find true zero-metallicity (Pop. III) stars. So far, none has been detected, but more than 100 stars have already been identified with [Fe/H] < -3.0 and a few with [Fe/H] close to -4.0. Recently the detection of two objects with metallicities [Fe/H]$= -5.3$ and -5.6 has been reported.

Stellar populations in the Milky Way – The study of the Milky Way and its components plays an important role to address the issue of galaxy formation and evolution. The last few years have witnessed enormous progress in the study of the properties of stars belonging to different galactic populations (thin and thick disks, bulge and halo) and many more investigations are expected to be carried out thanks to the multiplex facilities now available on 8-10m class telescopes such as FLAMES (Fibre Large Array Multi-Element Spectrograph) at the VLT. More specifically, several spectroscopic surveys of *old open clusters* have been carried out in order to derive the galactocentric radial abundance gradient in the disk and the age-metallicity relationship, which, in turn, provide feed-back to models of disk formation and evolution. Current results suggest a rather shallow radial gradient and the absence of any age–metallicity trend. Several new high resolution spectroscopic study are now being carried out. *Globular Clusters (GCs)* are among the oldest objects in our Galaxy and in the whole Universe; a precise determination of their ages appears thus crucial to constrain the early epochs of formation of the Milky Way, as well as for cosmology. Accurate ages for different GCs have recently been derived in the context of an ESO Large Programme carried out with UVES on VLT. Also, a precise determination of the chemical composition of GC stars provides a tool to put constraints on their formation. In particular, we mention the O-Na anticorrelation which is currently interpreted as due to pollution from a previous generation of intermediate mass AGB stars. A variety of questions related to the formation and evolution of the *Galactic bulge* can be addressed by deriving abundances of stars in the bulge. Different spectroscopic surveys of the bulge are now under way. Preliminary results on α elements suggest a top-heavy initial mass function.

Local Group Galaxies – High spectral resolution abundance studies of resolved stars dwarf spheroidal (dSph) and dwarf irregular (dIrr) satellite galaxies represent a fairly new field of investigation which has become possible with the advent of echelle spectrographs on 8-10m class telescopes. Several studies have already been carried out on the abundance patterns in different galaxies with the primary goal of investigating their chemical evolution, their star formation history, their connection with the Milky Way, the relative importance of different gas enrichment sources and the effects of metal infall and outflow. Among the most important results, we mention the fact that the comparison of [α/Fe] patterns in dSph's with those of different galactic populations suggests that no population in the Galaxy is in general representative of dSph's.

Mixing in stellar interiors – Because of their low burning temperatures Li and Be are powerful tracers of the physics of stellar interiors. In the last 20 years a large observational effort has been devoted to Li and, to a much lower extent, to Be surveys in field and cluster stars. These studies have evidenced the failures of standard stellar models, showing that convection is not the main mixing process at work in solar–type stars during the main sequence phases. However, in spite of the large body of observations, the models are so far still rather poorly constrained; understanding the non-standard mixing processes remains a challenging task which requires additional observations of large sample of stars in open clusters well sampling the age-metallicity space. FLAMES at the VLT appears to be the ideal instrument to carry out such observations in a very efficient way.

Very low mass stars and brown dwarfs – Spectroscopy at medium to high resolution is playing an increasing role in the study of very-low mass stars and brown dwarfs (BDs) in our Galaxy. In particular, the best way to discriminate between BDs and very-low mass stars is indeed based on spectroscopy through what is known as the "Li-test". Spectroscopy is also a tool to determine the spectral-types of these objects. Also, the atmospheric properties of the coolest BDs, intermediate between stars and planets, are fascinating: this is a field in which spectroscopic observations can provide crucial information.

Radial velocity search of exoplanets – The detection of planets orbiting nearby stars has been one of the major discoveries in recent years. There are at present about 120 such objects detected and all are giant Jupiter-like bodies orbiting late-type stars. The technique that has been used up to now to detect most of them is the accurate measurement of radial velocity variations induced in the light of the parent star by the motion of the surrounding planet. The new HARPS (High Accuracy Radial velocity Planetary Search) spectrograph at the ESO 3.6m telescope, capable of reaching a precision of 1 m/s, has been designed specifically for this type of research and is expected to provide many new detections in the new future.

Asteroseismology – Stellar oscillations are important since they probe the interior structure of stars and thus provide the only means of directly testing the results of stellar structure theory. The extension of helioseismology to other stars, can provide similar constraints as those that have been put on the depth of the solar convective zone and internal rotation. So far, only a handful of bright stars like α Cen, Procyon, η Boo β Hyi and a few others have been monitored in search of oscillations and detection of p-mode oscillations have been reported for a few of them. As for planet searches, HARPS is ideal for asteroseismology observations.

Stellar activity – Magnetic activity in late-type stars results from a dynamo mechanism involving rotation and subphotospheric convection. The emergence of magnetic fields at the stellar surface gives rise to a variety of phenomena similar to those that we observe directly on the Sun. High-resolution spectroscopy is crucial to infer the properties of magnetic activity in stars. Large apertures telescopes (>4m) are usually not required (unless very high resolution and S/N are needed): field stars, in fact, can be easily studied with moderate size (1 – 2m) telescopes, while 4m-class telescopes are usually required to investigate magnetic activity of stars in open clusters and star forming regions. As an example, we mention the technique of Doppler imaging that has been developed to allow the reconstruction of the spatial structure and distribution of surface features. Doppler images of evolved RS CVn stars and of young, main-sequence stars have revealed interesting differences in the types of activity seen in these two classes of objects and in our Sun.