HIGH-RESOLUTION OPTICAL SPECTROSCOPY OF COOL STARS

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1. Introduction

High-resolution spectroscopy at resolving powers \( R \geq 30,000 \) is an essential tool for investigating the properties of late-type stars. Information on physical quantities such as chemical abundances, rotation rates, velocity fields, chromospheric radiative losses, surface inhomogeneities and photospheric magnetic fields can be extracted from spectra of sufficiently high resolution and S/N ratio (see general discussions of these topics in Gray 1988, Cayrel de Strobel and Spite 1988, Pallavicini 1990).

Over the past decade the spectroscopic facilities that are available at present at ESO-La Silla have allowed many new results to be obtained for relatively bright stars (see Pasquini and Pallavicini 1990 for a summary). However, the small aperture (\( \approx 1.5 \text{ m} \)) of the telescopes commonly used for high-resolution stellar work, and the small amount of observing time that has been allocated to such studies on larger telescopes, have severely limited the progress in this research area.

Larger apertures and/or higher efficiency of the spectrograph/detector combination not only allow the same studies to be extended to more distant stars, but, more importantly, lead to the investigation of new classes of objects and of physical processes that otherwise would remain largely unexplored. In this short contribution, we will try to demonstrate this statement by using a few examples from our current programs in high-resolution spectroscopy of cool stars at ESO.

2. Increasing the efficiency of the spectrograph/detector combination

Until a few years ago, the ESO CAT telescope was used mainly in combination with a Long Camera and a Reticon detector. In practice, this limited the study of cool stars to objects in the Bright Star Catalogue (i.e. \( V \leq 6.5 \)). With the use of a more efficient CCD detector and a Short Camera the limiting magnitude has been extended by \( \approx 3 \) magnitudes, making objects
in the range $V \approx 7 - 9$ easily accessible. With the new system, useful spectroscopic data can now be obtained for stars as faint as $V \approx 10$. Many new programs have thus become possible even with the relatively small aperture (1.4m) of the CAT telescope. As an example we will discuss the study of active late-type stars.

A program that was not possible to carry out with the CES + Long Camera + Reticon, but which is easily accessible to the CAT + Short Camera + CCD is high-resolution spectroscopy of active chromosphere stars from the list of Bidelman and MacConnell (1973). This list is expected to contain a variety of active stars including RS CVn binaries, FK Comae stars, PMS objects, and possibly others. In order to identify the nature of the various objects in the Bidelman and MacConnell list, we have carried out extensive high resolution spectroscopic observations of these stars using the CAT + CES + Short Camera + CCD. Spectra were obtained in the Li I 6708 Å line, in Hα and in the Ca II H and K lines.


- A few PMS stars, possibly Post-T Tauri stars, have been identified.
- Most active stars in the sample, including several evolved RS CVn binaries and FK Comae stars, appear to have an anomalously high Li abundance.
- There is no evidence of rotational modulation of the Li line as could be expected if the Li I line were significantly strengthened by the presence of cool spots.
- There is little correlation between Li abundance and chromospheric activity as measured in Hα and in the Ca II H and K lines.
- There are phase-dependent variations in the Hα emission of some of these stars, indicating the presence of plage-like features. In one case (AB Dor), the variations of Hα emission were in phase (and not in antiphase as expected) with the photometric variations.

3. Need for larger aperture telescopes

In spite of the significant improvement obtained by using the CAT + CES + Short Camera + CCD, there are still many studies that require necessarily a larger telescope. An example is the study of the pre-main sequence evolution of low-mass stars, for instance of those objects such as Post-T Tauri and Naked T-Tauri stars that do not possess dense circumstellar envelopes and hence are better studied at optical rather than infrared wavelengths.

Post T-Tauri (PTT) stars are low-mass PMS objects that are intermediate between classical T-Tauri (CTT) and ZAMS stars. Since they lack the extreme properties of CTT’s (e.g. strong Hα emission and infrared excess) they are difficult to detect by conventional optical methods. Probably the best way to find PTT’s is through X-ray surveys (e.g. Walter et al. 1988).

Gahm, Ahlin and Lindroos (1983) suggested an alternative method for finding PTT stars. This consists in searching for visual binaries with early-type primaries and late-type secondaries. If the binaries are physical and not just optical pairs, their late-type secondaries should
still be contracting towards the ZAMS or should have recently arrived upon it. In this way, Lindroos (1986) was able to identify 78 systems with likely PTT secondaries.

We have carried out an extensive spectroscopic survey of the Lindroos stars using the CES + Short Camera + CCD detector as well as both the ESO 1.5m and MPI 2.2m telescopes with B&C spectrographs and CCD detectors. However, since most of the late-type secondaries in Lindroos list are of magnitude $V = 10 - 13$, they are out of reach with the CAT + CES and the B&C spectrographs can only observe them at moderate resolution. Large aperture telescopes are definitely needed in this case.

Our moderate resolution survey in the Li I 6708 Å region, in Hα and in the Ca II H and K lines (Pallavicini, Pasquini and Randich 1992) has shown that only a small fraction ($\leq 40\%$) of the PTT candidates proposed by Lindroos present spectroscopic evidence of youth, the other being more likely optical pairs. All stars that appear to be young are located in the HR diagram very close to the ZAMS. They could be either genuine PTT’s or stars that have recently arrived on the main sequence.

The stars in Lindroos list that do show evidence for youth are ideal candidates for studying the late phases of evolution toward the ZAMS. Their physical properties, however, can be determined only by using high-resolution spectrographs on larger telescopes (either CASPEC with the 3.6m telescope or EMMI with the NTT). These observations are currently carried on by our group and are expected to provide important information on the rotation rates, chromospheric emission and chemical abundances of these stars.

Larger aperture telescopes are also needed to study many other cool stars that have magnitudes comparable to or fainter than those of the objects discussed above. These include M dwarf flare stars, late-type stars in galactic clusters, T-Tauri stars and other young objects in star forming regions, and Pop II stars. Moreover, the need of very high S/N ratios for many purposes (e.g. Doppler imaging, magnetic field measurements, line bisector studies, etc.), and/or of short integration times for rapidly varying phenomena (e.g. stellar flares), means that in practice large aperture telescopes are often required even for relatively bright objects.

4. Conclusion

We have shown by example that high-resolution, high-efficiency spectroscopic facilities on large aperture telescopes are required to address many of the fundamental problems of cool star research. With the next generation of high-resolution facilities on larger telescopes, which will allow $R \approx 100,000$ and $S/N \approx 100 - 1000$, it should be possible to tackle fundamental problems of stellar physics such as:

- the physical properties (rotation, chemical abundances, magnetic activity) of faint low-mass stars like dMe and PMS objects.
- the chromospheric activity and rotation of stars in galactic clusters (to calibrate the dependence of surface activity and rotation upon age).
- the mapping of surface inhomogeneities in a large variety of spotted stars, using Doppler
imaging techniques.

- the velocity fields (rotation, turbulence, circumstellar flows) in different types of stars.
- the presence and dynamics of cool prominence-like material of the type recently found in some active cool stars (e.g. in AB Dor).
- the time-resolved spectroscopy (on time scales as low as \( \approx 1 \) sec) of flares and other transient phenomena in dMe, RS CVn and PMS stars.
- the chemical abundance and activity of stars in globular clusters and in the halo.
- the atmospheric properties of giants and supergiants in the Magellanic Clouds.

These and other questions can be addressed only partially, and imperfectly, with the spectroscopic facilities available at present. The VLT will have the capabilities for studying all of them in the proper way.

References