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HIPPARCOS, IUE, AND THE STELLAR CONTENT OF THE SOLAR NEIGHBOURHOOD

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RESUMEN

La combinación de flujos absolutos estelares medidos en la Tierra con las paralajes espectroscópicas del catálogo de *Hipparcos*, permite determinar con precisión los flujos emergentes de las superficies de estrellas cercanas. Comparando estos flujos con las predicciones de modelos teóricos de atmósferas, es posible determinar la temperatura efectiva y la metalicidad de las estrellas. Se plantea la posibilidad de estudiar el contenido estelar de la vecindad solar haciendo uso del gran número de espectros ultravioletas disponibles en el archivo del satélite IUE.

ABSTRACT

The spectroscopic parallaxes in the *Hipparcos* catalogue can be used to translate absolute stellar fluxes observed at Earth to the fluxes emerging at the stellar surface for nearby stars. The comparison of these fluxes with the predictions of theoretical model atmospheres allows us to determine the effective temperature and the metallicity of the stars. It is suggested that it is possible to study the stellar content of the solar neighbourhood making use of the large number of ultraviolet spectra in the archive of the IUE satellite.

Key Words: **STARS: ATMOSPHERES — STARS: FUNDAMENTAL PARAMETERS — STARS: LATE-TYPE — SOLAR NEIGHBOURHOOD — ULTRAVIOLET: STARS**

1. INTRODUCTION

Understanding how the complex near–UV region of the spectra of stars is shaped within the stellar atmospheres can provide a homogeneous source of information on several of the fundamental stellar parameters, the chemical composition, magnetic activity, rotational velocity, atmospheric velocities, and ages. Many neutron capture elements, whose abundance in metal–deficient stars keeps a record of the supernovae rates during galactic evolution, produce undetectable (or subject to large measurement errors) features in the optical spectrum, but strong lines in the near–UV (see e.g. Sneden et al. 1998). Interesting absorption lines in the spectrum of light atoms, such as boron and beryllium (see e.g. García López et al. 1998), are only present in the near–UV. Furthermore, F–type main sequence stars dominate this region of the spectrum for intermediate–age stellar populations, and therefore constitute a powerful prospective tool for dating galaxies (Heap et al. 1999).

A lack of proper understanding has prevented full use of the data gathered by the space observatory IUE to study the stellar population in the proximity to the Sun. Indeed all the available determinations of the metallicity distribution in the solar neighbourhood, except for the polemical work by Favata, Micela & Sciortino (1997), are based on photometric calibrations (Twarog 1980; Wyse & Gilmore 1995; Rocha–Pinto & Maciel 1998; Flynn & Morell 1997). The star counts do not fit, and the so–called G–dwarf problem, the deficiency in relative numbers of metal–poor stars in the main sequence, seems to extend to other spectral types as well, to the more metal–rich end of the metallicity distribution (Rocha–Pinto & Maciel 1998). Ideally, to extract the available information from the near–UV spectrum, the model atmospheres and other spectral synthesis ingredients should be carefully tuned for each of the stars: the abundances and abundance anomalies of all relevant elements, microturbulence, effective temperature, gravity, interstellar extinction, etc. However, as a first step I am neglecting here the abundance anomalies, variations in microturbulence, and the effect

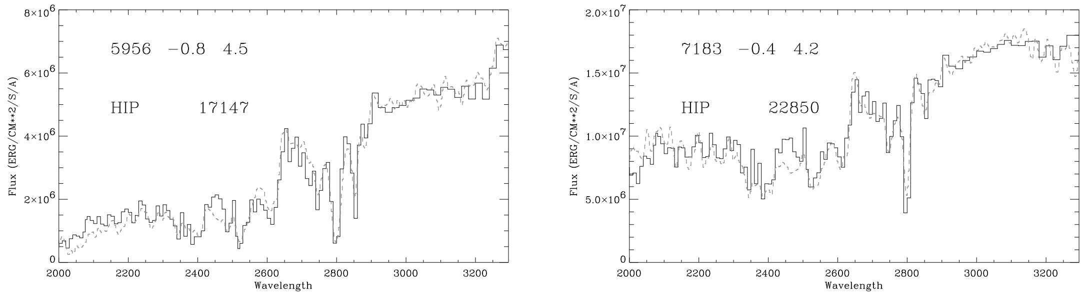

Fig. 1. Two examples of the match between observed (dashed lines) and theoretical (solid lines) absolute fluxes at the stellar surface in the region between 2000 and 3000 Å. Within the panels, $T_{\rm eff}$ ($^{\rm o}$K), [Fe/H] (dex) and $\log g$ (g in cgs) have been printed, as well as the star's identification in the *Hipparcos* catalogue.

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of interstellar extinction, to derive only the effective temperatures ($T_{\rm eff}$s) and overall metallicities ([Fe/H]s). Selecting a sample limited in volume to 100 pc makes the availability of *Hipparcos* (ESA 1997) parallaxes very likely for the stars observed by IUE, and places a safe limit on the role of the interstellar extinction.

2. OBSERVATIONS AND ANALYSIS

The *Hipparcos* Catalogue includes data for 22982 stars within 100 pc of the Sun. Making use of the MAST Cross Correlation Search Tool, I have identified 3421 low–resolution LW ($\sim$ 1800 − 3500 Å) spectra of 992 such stars. The IUE (NEWSIPS) observations have been retrieved from the Villafranca node of the IUE Final Archive in Spain. A newer version of the archive has been released recently (INES; Rodríguez–Pascual et al. 1999). When more than a single spectrum was available for a given star, they were combined and cleaned using the IUEDAC IDL Software libraries to produce a single spectrum per star.

I have made use of the flux distributions calculated by Kurucz, and available at CCP7 since 1993. The grid includes models for different gravities ($\log g$), effective temperatures ($T_{\rm eff}$) and metallicities ([Fe/H]), while the parameters in the mixing–length treatment of the convection are fixed, as well as is the microturbulence (2 km/s), and the abundance ratio between different metals (solar proportions). For a given set of ($T_{\rm eff}$, $\log g$, [Fe/H]), I obtain the theoretical flux from linear interpolation, therefore using the information of the eight nearest models available in the grid, which is divided in steps of 200$^{\rm o}$ K in $T_{\rm eff}$, 0.5 dex in $\log g$, and 0.5 dex in [Fe/H].

Making use of an accurate stellar parallax (p), BV photometry and state–of–the–art evolutionary isochrones (Bertelli et al. 1994), one can estimate the stellar radius (R) with an accuracy of roughly 6% (Allende Prieto & Lambert 1999; Lambert & Allende Prieto 2000), and get a small error in the determination of the ratio (pR)^2, which allows to transform the absolute flux measured at Earth to flux emerging from the stellar atmosphere. It is as well possible to constrain the mass to within 8% (in the range of metallicities we are interested in) and, therefore, the gravity within 0.07 dex. Once the gravity and the dilution factor for the flux are fixed, it is possible to compare the absolute near–UV fluxes measured by IUE with theoretical fluxes, and determine $T_{\rm eff}$ and [Fe/H]. As showed by Allende Prieto & Lambert (1999), knowing the absolute visual magnitude and the $B-V$ color index, comparison with evolutionary isochrones provides an independent estimate of the effective temperature $T_{\rm eff}$, accurate to roughly 2% for stars with $4500 < T_{\rm eff} < 8500^{\rm o}$ K, which can be used to check for systematic errors (see below).

For each of the analyzed stars I first derive its gravity and the flux dilution factor, then the values of [Fe/H] and $T_{\rm eff}$ are obtained by finding the minimum of the square of the difference between the observed and the synthetic spectrum. Previously, the observed spectrum, which has a resolution between 5.2 and 8.0 Å is degraded to that of the synthetic spectra, roughly twice poorer. The search for the optimum ($T_{\rm eff}$,[Fe/H]) pair

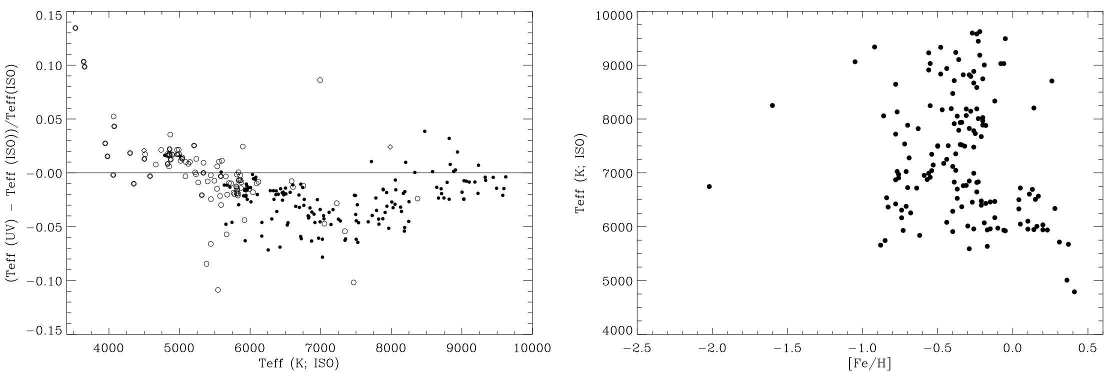

Fig. 2. *Left panel*: Differences between the effective temperatures derived from the comparison of the star's position in the colour–magnitude diagram with evolutionary isochrones (labeled ISO) and those from fitting the near–ultraviolet continuum (labeled UV). Stars with strong Mg II 2852 Å emission are identified with rhombi, those with a continuum in the region 2000–2400 Å much stronger than predicted by the models with open circles, and the rest with filled circles. Right panel: Position of the *normal* stars (whose spectra do not show evidence for a chromosphere), on the [Fe/H]–$T_{\rm eff}$ plane. Two stars stand out from the rest, one is the halo star HD 84937 (HIP 48152; [Fe/H] $\simeq -2.0$) and the other is HD 192640, a well–known λ Bootis star. The two hot stars with [Fe/H] $\simeq -1.0$ are both peculiar too – HD 161868 is a spectroscopic binary and HD 177724 has been assigned a spectral type A0Vpnn by Abt & Morrell (1995).

is performed using the Nelder–Mead simplex method, as implemented by Press et al. (1988). Figure 1 shows two examples of the typical goodness–of–fit achieved.

3. DISCUSSION

The sample was restricted to stars with $3500 < T_{\rm eff} < 10000^{\rm o}$ K. The employed models are known to be inappropriate close to and below the cooler limit, as the plentiful molecules are not properly taken into account, and the number of nearby stars beyond the upper limit is very small.

A first look at the comparison between the 'evolutionary' and near–UV effective temperatures $T_{\rm eff}$, reveals systematic differences. The left panel of Figure 2 shows the comparison for the 253 stars whose IUE spectra have perfect quality flags in the considered spectral range (2000-3000 Å). Stars with strong Mg II 2852 Å emission are identified with rhombi, those with a continuum in the region 2000–2400 Å much stronger than the model predictions with open circles, and the rest with filled circles. Disregarding the stars for which there is indication of a chromospheric component in the spectrum (open symbols), the spectroscopic $T_{\rm eff}$s of 'normal' stars exhibit a systematic difference from the evolutionary $T_{\rm eff}$s. Similar–although smaller–effects could be present in other $T_{\rm eff}$ scales that make use of the same type of model atmospheres, such as that derived from the InfraRed Flux Method (IRFM; e.g. Blackwell & Lynas-Gray 1994). di Benedeto (1998) showed that indeed the IRFM $T_{\rm eff}$s of A stars are about 2.3% lower than his empirical scale. The 150 stars whose spectra do not show evidence for a chromosphere are spread out in the [Fe/H]–$T_{\rm eff}$ plane as shown in the right panel of Figure 2.

It is obviously very difficult to determine the selection effects of the sample, as the stars are required to have been observed by IUE. It is likely that peculiar objects were favoured: multiple systems, stars with abundance anomalies, pulsating/variable stars, metal–poor stars, etc. That explains the excess of stars with $-1.0 <$ [Fe/H] < -0.5 found here, in comparison with every other photometric study in the literature. Many of theses stars would indeed be chemically peculiar stars (not being deficient in all metals, but having a low abundance of some of the species relevant to the atmospheric structure and the near–UV opacities) or spatially unresolved binary (multiple) systems. In both cases the stars would tend to be erroneously shifted towards hotter $T_{\rm eff}$s and lower metallicities, in order to compensate for the excess flux. The same argument could provide an explanation for the lack of stars with $T_{\rm eff} > 7000^{\rm o}$ K at near/super–solar metallicities: the peculiar

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stars, preferred by IUE observers, would tend to have lower metallicities. Further study is clearly needed to shed light on this issue.

4. CONCLUSION

Several issues have been raised in this preliminary analysis, and are fundamental. The first of all is that it is necessary to identify ALL the basic elements (chemical and non-chemical) that affect the shape of the near–UV spectrum. They may be quite different for different types of stars. Once those elements are identified, we should attempt the fit of the spectrum allowing for ALL to vary. The parameters determined should be compared with other scales, of empirical or independent nature, to asses the real possibilities of this kind of analysis and the performance of the model atmospheres, opacities, and other modeling ingredients. That procedure will likely help to improve the modelling. It will very likely shed light on another basic problem that is still far from being solved: the effective temperature scale.

At that stage, we should look back to the application of near–UV spectroscopic analysis to other affairs, such as the stellar content of the local neighbourhood, and then review the apparent scarcity of solar and super–solar metallicity A–F stars.

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