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S^4N: A Spectroscopic Survey of Stars in the Solar Neighborhood

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Abstract.

We are using the McDonald 2.7m and ESO 1.52m telescopes to obtain spectra of nearby stars at high-resolution, high S/N, and with complete optical coverage. The sample includes all stars in the *Hipparcos* catalog brighter than $M_V = 6.5$ ($\sim$ K2 V) within a 12770 pc^3 sphere centered at the Sun. The survey is 78 % complete. The database will be publicly released in approximately 1 year. We plan to: 1) Provide homogeneous radial velocities with the accuracy required to exploiting in full the accurate proper motions and parallaxes determined by *Hipparcos* ($0.1 < \sigma(v) < 1.0$ km s^{-1}); 2) Provide homogeneous chemical abundances for a large (> 30) number of elements with an accuracy of 0.04 dex; 3) Determine the fundamental stellar parameters for the sample using an array of different methods. We discuss potential applications.

1. Introduction

The stellar population of the solar neighborhood is obviously of special interest for an observer at Earth. Nearby stars afford the best opportunity to study the physics of stellar interiors and atmospheres of late-type main-sequence stars. Nearby stars are the only stars for which we can obtain crucial measurements, such as parallaxes or angular diameters, and they provide the best arena for addressing a number of astrophysical issues. Searches for companions to stars (stellar, brown dwarf, or planetary), circumstellar disks, or solar-like cycles select their targets from this pool, attempting to shed light on how stars, brown dwarfs, or planets form and whether the Sun is somehow special or not.

On a wider perspective, the stellar population of the solar neighborhood is expected to be representative of the local Galactic disk. Early studies of Galactic chemical evolution revealed that the simplest models could not match the observed metallicity distribution – the so-called G-dwarf problem (van den Bergh 1962). More recent investigations have shown that more complex scenarios, such as those including an inhomogeneous evolution (Malinie et al. 1993) or infall (Chiappini et al. 1997), get closer to the observations. However, almost all the derived metallicity distributions of volume-limited samples have been obtained from photometry (Rocha-Pinto & Maciel 1996, 1998a, Flynn & Morell 1997).

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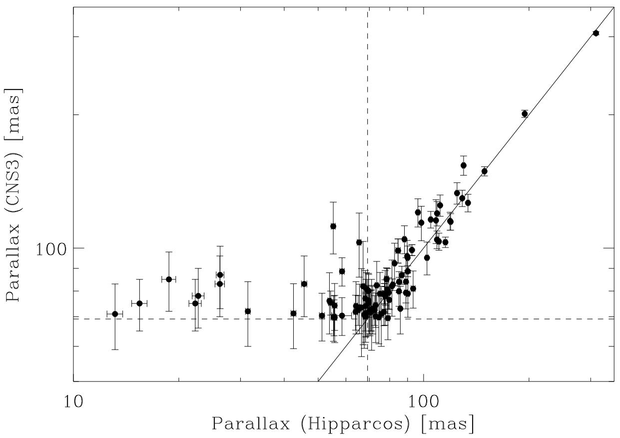

Figure 1. Comparison of the parallaxes for nearby stars in CNS3 and the *Hipparcos* catalog.

This is worrying, as it has been recognized that some of the employed photometric indices are seriously affected by chromospheric activity (Rocha-Pinto & Maciel 1998b; Favata et al. 1997).

In addition to the *Catalogue of Nearby Stars* (Gliese & Jahreiß1991; hereafter CNS3) – employed by most of previous studies– a relatively new resource has been used to pick our sample: the *Hipparcos* catalog (ESA 1997). *Hipparcos* is complete down to V = 7.3. Restricting the study to stars earlier than K2V ($M_V \sim 6.5$), *Hipparcos*' completeness reaches out to 14.5 pc. Figure 1 shows that nearly 25 % of the stars included in CNS3 within 14.5 pc from the Sun (parallaxes larger than 69.18 mas) are in fact further away according to the very accurate parallaxes determined by *Hipparcos*. All previous spectroscopic and photometric studies are obviously affected by these findings.

2. Sample and Observations

Our program will supply high-dispersion high signal-to-noise optical spectra for 118 stars: all the objects with spectral types earlier than K2V within 14.5 pc from the Sun. The sample's distribution of absolute and visual magnitudes, M_V (solid line) and V (dashed line), is shown in Figure 2. As a reference, approximate main-sequence spectral types are assigned to different ranges in M_V. The stars are accessible to high signal-to-noise ratio at high dispersion from medium-sized telescopes.

The high-dispersion data are being gathered with the Harlan J. Smith 2.7m telescope coupled to the *2dcoudé* spectrograph at McDonald Observatory (Texas), and the ESO 1.52m telescope coupled to the FEROS spectrograph at La Silla Observatory (Chile). Both instruments provide a resolving power of about 60,000 and complete spectral coverage in the optical. Low-dispersion spectrophotometric observations with the Hubble Space Telescope (HST) are

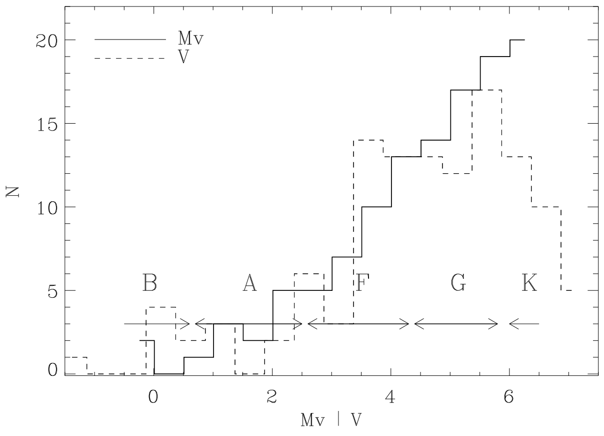

Figure 2. M_V and V distributions for the sample.

also planned. Onboard HST, STIS (with grating G750L) delivers a resolving power of about 1,000 and full spectral coverage between 5240 and 10,270 .

As of August 2001, 78 % of the sample has been observed. A few examples in the region of the Na D lines are shown in Figure 3. The project has a web page[1] for the most up-to-date information on its status.

3. Analysis

3.1. Radial Velocities

The determined radial velocities will complete the position and proper motion vectors available from *Hipparcos*. There are already published radial velocities for most of the stars in our sample, but their precision does not match that of the astrometric data. Use of the available radial velocities would degrade the potentially high accuracy of the kinematic solution obtained with the combination of parallaxes and proper motions measured by *Hipparcos*. To match *Hipparcos*' quality, radial velocities precise to $0.1 - 1.0$ km s^{-1} are required.

The large spectral coverage of the data provides a large number of photospheric Fe I lines and telluric features whose central wavelengths will be measured and compared with available accurate values at rest. This procedure should be able to provide accuracies ~ 1.0 km s^{-1} for the radial velocities of most of the stars in our sample. Careful consideration of the following sources of systematic effects will further improve the accuracy down to the $0.1-0.3$ km s^{-1} level: gravitational redshift, transverse Doppler effect, and surface convection.

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[1] http://hebe.as.utexas.edu/s4n

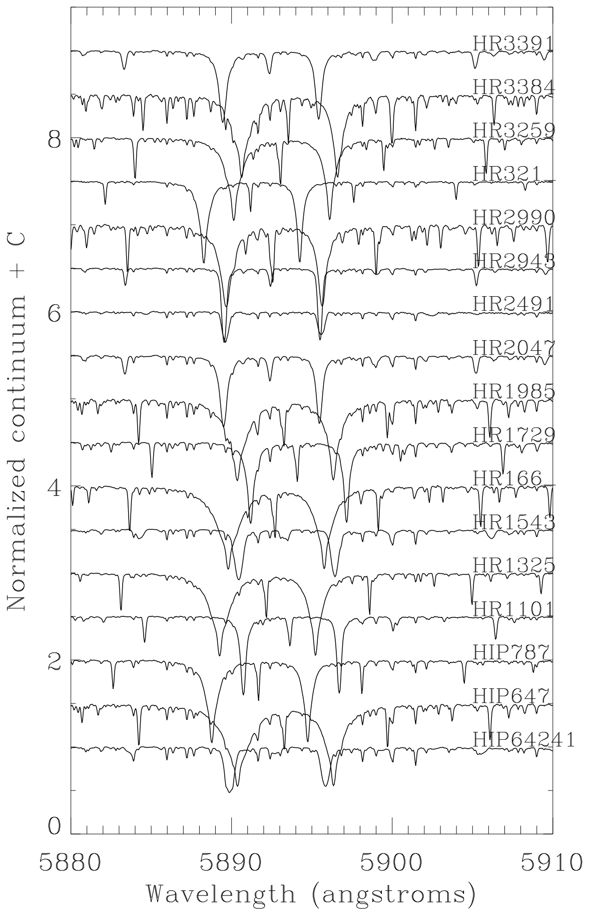

Figure 3. McDonald spectra around the Na D lines for a few of the observed stars.

3.2. Chemical Abundances

From the study of line profiles originated in a 3D time-dependent hydrodynamical model of the solar surface, Allende Prieto et al. (2001) have recently shown that semi-empirical static 1D model atmospheres can be constructed providing estimates of metal abundances that are typically within 0.04 dex of the real composition. The semi-empirical models are obtained from inversion of high-resolution spectra normalized to the local continuum, such as the database we are building for the solar neighborhood. Spectral line profiles, rather than equivalent widths, are involved. The availability of low-dispersion optical-near IR fluxes from HST observations will tightly constrain the effective temperature of the stars, and the temperature structure in the continuum-forming region of the atmosphere. The gravities of the stars are precisely defined by their trigonometric parallaxes. Departures from LTE can be minimized by selecting low-excitation weak lines, wings of strong lines, and dominant species. At the same time we are performing NLTE line formation calculations to support our selection of spectral features.

The selection of the spectral lines is still in progress, but the emphasis is on spectral lines with gf-values from laboratory measurements and theoretical calculations. Model atmospheres with several components to simulate the effect of granulation, are also being explored, in view of the promising success of a recent study of alpha Cen A and B (Frutiger & Solanki 2001).

3.3. Stellar Parameters

Comparison of accurate optical spectrophotometry against surface fluxes predicted by model atmospheres allows for a simultaneous solution for the $T_{\rm eff}$ and the stellar angular diameter. As an example, Fitzpatrick & Massa (1999) matched spectrophotometric data of Vega with Kurucz's model atmospheres, with no a-priori assumption about the star's fundamental parameters. They determined the angular diameter of the star 3.26 ± 0.01 mas and $T_{\rm eff} = 9600 \pm 10$ K, in excellent agreement with the interferometric determination by Code et al. (1976): 3.24 ± 0.07 mas, and the empirical surface brightness technique $T_{\rm eff} = 9660 \pm 140$ K, as applied by Di Benedetto (1998).

The high-dispersion data will constrain tightly the chemical abundances that play a direct (on the spectrum) or indirect (on the atmospheric structure) role. Therefore, the final solution matching both the low and high resolution observed spectra should provide extremely reliable stellar parameters and trustable chemical abundances. Reddening will not be a factor, as our sample is limited to stars at a distance of 14.5 pc or less from the Sun. HST is unique for this purpose in that the absolute accuracy obtainable is remarkably better than that of ground-based observations: 3 % is expected for the L modes of STIS (Instrument Handbook). The quoted accuracy takes into account the severe fringing that affects STIS CCD observations at wavelengths longer than about 7500 A, which can be corrected to better than 1 % when contemporaneous flatfields are acquired (see, e.g., Kimble et al. 1998). The ideal spectral range is in the red and near-infrared, as metal absorption, which is difficult to model, does not interfere as it would happen in the ultraviolet.

Most of our stars have errors in their trigonometric parallaxes under 1.5 % (Fig. 1). Fitting their absolute fluxes at Earth, constrains the angular diameter to about 1 %, making it possible to determine the stellar radius within $1 - 2$ %. This accuracy has been possible before only for stars in eclipsing binary systems. The roughly 100 binaries studied so far have proven insufficient to build useful multiparametric calibrations of radii vs., e.g., color and metallicity (Andersen 1991), but the measurements here proposed will significantly enlarge the available data. It will be possible as well to compare evolutionary surface gravities (Allende Prieto et al. 1999) against the spectroscopic determinations.

4. Summary. Potential Applications

The final product will consist of a database of high-resolution high signal-to-noise spectra and low-dispersion high-accuracy spectrophotometry for 118 stars – all the stars brighter than $M_V = 6.5$ ($\sim$ K2V) within 14.5 pc from the Sun. In addition, we shall provide a catalog for these stars including their position and velocity vectors, fundamental parameters ($T_{\rm eff}$, $\log g$, radius, mass), and detailed chemical composition, including the abundances of more than 30 elements.

Our limited imagination can hardly predict a small fraction of the possible applications of a survey of this kind. It will provide a reference to compare with models of the chemical evolution of the Galactic disk. Several age indicators will be then available for the sample in a homogeneous manner and their comparison would be very valuable to constrain the time scales for stellar and Galactic evolution. The data could also be useful to map the interstellar gas in the local interstellar medium.

We will make the data available to the astronomical community through the internet. A simple but efficient web interface is under development to allow fast access to any wavelength window for parts or the entire sample.

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