The Stellar Content of the Hamburg/ESO Survey

We report on the exploitation of the stellar content of the Hamburg/ESO objective-prism survey (HES), which covers the total southern extragalactic sky down to $B \approx 17.5$. Quantitative criteria have been developed for selecting interesting stars in the digital HES database, containing almost 5 million spectra. We give an overview of ongoing projects directed at finding extremely metal-poor stars, field-horizontal branch A-type stars, carbon stars, and white dwarfs. Highlights of these efforts are the discovery of more than 200 new extremely metal-poor ([Fe/H] < –3.0) stars, including the most metal-poor star known so far, HE0107-5240 ([Fe/H] = –5.3), and the discovery of many new magnetic DA and DB white dwarfs and other peculiar white dwarfs.

N. Christlieb[1], D. Reimers[1], L. Wisotzki[2]

[1]Hamburger Sternwarte, University of Hamburg; [2]Astrophysikalisches Institut Potsdam

The Hamburg/ESO objective-prism survey (HES) was carried out with the ESO-Schmidt telescope from 1990 to 1998 in the course of a Key Programme (No. 145.B-0009; P.I.: Reimers). The final survey area consists of 380 fields covering a nominal area of 9500 square degrees, i.e., the total southern extragalactic sky. The plates have been digitized at Hamburger Sternwarte, yielding a data base of almost 5 million spectra of objects in the magnitude range $10 \lesssim B \lesssim 17.5$. The driving aim of the HES during its constitution was the pursuit of a wide angle survey for the brightest quasars in the southern hemisphere (see Reimers 1990; Reimers & Wisotzki 1997). The digital database enabled us to efficiently select quasar candidates using various colour criteria supplemented by spectral feature detection (Wisotzki et al. 2000). Quasar candidates were followed up mostly by ESO telescopes, which resulted in the measurement of over 2000 quasar redshifts, providing by far the largest existing homogeneous set of bright quasars in the south. Besides constraining the bright end of the QSO luminosity function, the survey yielded highlights such as the discovery of several gravitationally lensed quasars, and the first detection of the epoch of He II reionization.

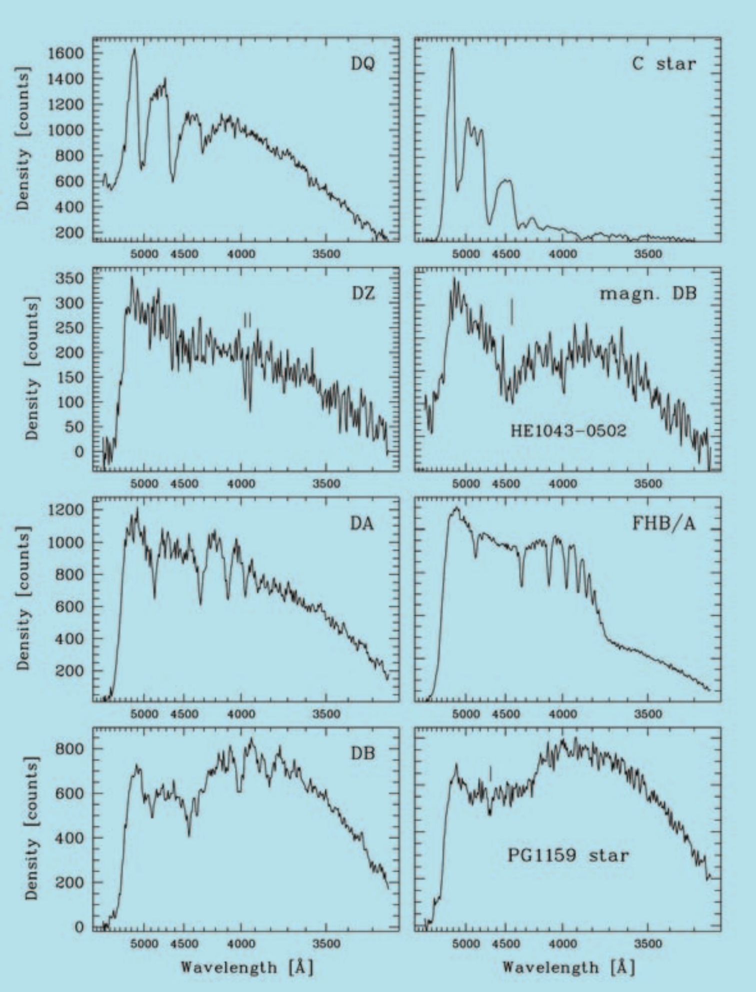

Figure 1: Sample spectra of various stellar objects detected in the Hamburg/ESO survey. Note that wavelength is decreasing from left to right. The sharp drop at about 5400 Å is due to the sensitivity cutoff of the photographic emulsion (IIIa-J) of the HES objective-prism plates.

It was realized right from the start that the spectral resolution of the objective-prism spectra would be sufficient for stellar survey work as well. The spectral resolution is typically 1 nm at Ca II K, depending on the seeing conditions during the observations of the plates. The resolution of the spectra proved quite useful, at first, mainly to *eliminate* the stellar contamination of quasar candidate samples. Notice that already a pure UV excess selected sample in the magnitude range of the HES has more than 90% stars and less than 10% quasars. This ratio increases further if the selection includes also non-UV-excess objects. Yet, the strong Balmer lines of DA white dwarfs and Field Horizontal-Branch A-type (FHB/A) stars are easily detected already in the digital prism spectra, but also e.g. the much weaker He I lines of DB white dwarfs and hot subdwarfs, or the Ca II H and K lines of cool stars (see Figs. 1 and 3). Recognizing these features helped enormously to achieve a hitherto unparalleled (for an optical quasar survey) follow-up efficiency of ~70%, without any compromises in completeness (Wisotzki et al. 2000). However, one person's leftovers may become another person's wealth, in this case a wealth of interesting stars. It was decided that there was so much potential information in this survey for studies of the stellar populations of the Milky Way that a dedicated effort was certainly desirable, and we developed quantitative methods for the selection of interesting stellar objects in the HES. We started by exploring techniques of automatic spectral classification applied to the entire digital HES data base (Christlieb et al. 2002). Our work subsequently focused on searching for specific types of rare stars with efficient selection techniques.

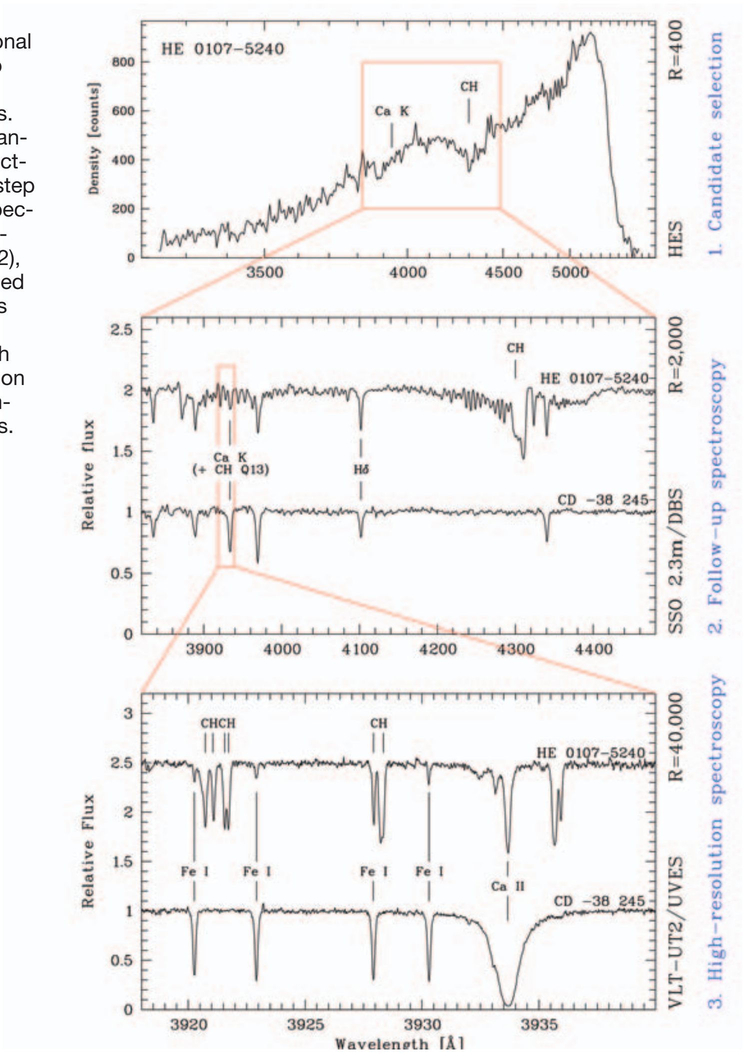

Figure 2: The three observational steps leading to abundances of metal-poor stars. About 10,000 candidates are selected in the HES (step 1). These are spectroscopically followed up (step 2), yielding confirmed metal-poor stars which are then observed at high spectral resolution (step 3) with 8m-class telescopes.

Here we describe some of the most successful projects that emerged: selection of metal-poor stars, carbon stars, FHB/A stars, and white dwarfs. Other projects which we do not discuss here are searches for T Tauri stars, subdwarf B and O stars, and cataclysmic variable stars.

STELLAR ARCHAEOLOGY AND NEAR-FIELD COSMOLOGY WITH METAL-POOR STARS

Metal-poor stars preserve in their atmospheres, to a large extent, the chemical composition of the gas clouds from which they formed. They can hence be used for "stellar archaeology": their abundance patterns provide information on the first, now extinct generation of massive stars which ended their lives in supernova type-II (SN II) explosions. In particular, the most metal-poor stars constrain the yields of these SN II of Population III stars (i.e., stars with the chemical composition of Big Bang material), and the mass-distribution of the first generation of stars. They also allow one to determine the nature and constrain the sites of nucleosynthesis processes such as the slow (s) and rapid (r) neutron-capture processes in the early Universe. There are also cosmological applications of metal-poor stars. Their ages provide an independent lower limit for the age of the Universe. Metal-poor stars with strong enrichment of elements produced in the r-process provide the opportunity to determine individual stellar ages using long-lived radioactive isotopes, such as ^{232}Th (half-life 14.05Gyr) or ^{238}U (4.468Gyr). By comparing the abundance ratio of one of these elements relative to a stable r-process element (e.g., Th/Eu or U/Eu) to the production ratio expected from theoretical r-process yields, the time elapsed since the nucleosynthesis event that produced these elements took place can be derived. Alternatively, U/Th can also be used as a "cosmo-chronometer" (Cayrel et al. 2001).

The convection zones of unevolved stars near the main-sequence turnoff are shallow enough to prevent lithium from being destroyed in deeper, hotter layers of the star. Therefore, it is thought that the Li abundances in the atmospheres of old, metal-poor turnoff stars reflect the Li abundance produced in Big Bang nucleosynthesis (BBN). Using BBN models, the baryon density of the Universe can be derived from the "Spite plateau" value of the Li abundance. However, a recent investigation based on 23 metal-poor stars in the range[1] $-3.6 < [\mathrm{Fe/H}] < -2.3$ has shown that the Spite plateau is actually not a plateau but exhibits a trend with [Fe/H]. The scatter around this trend is very small (i.e., $\sigma < 0.031$ dex) and fully accountable by measurement errors, not an intrinsic scatter (Ryan et al. 1999). The Li trend can be explained by galactic chemical evolution (i.e., Li might have been produced e.g. by Galactic cosmic-ray spallation). A larger sample of metal-poor turnoff stars extending to lower [Fe/H] would help to pin down the steepness of the Li trend more accurately and reduce the extrapolation to the primordial Li abundance.

The above reasons justify the investment of considerable amounts of telescope time (in addition to the survey itself) in finding more metal-poor stars and studying large samples of them in detail. In the HES, only *candidates* for metal-poor stars can be selected. These have to be confirmed by moderate-resolution follow-up spectroscopy before they can enter target lists for high-resolution spectroscopy (see Fig. 2 for sample spectra from these observational steps).

SELECTION OF METAL-POOR CANDIDATES

A total of ~10,000 metal-poor candidates has been selected in the HES. Stars with a Ca II K line which is weaker than expected for a star with $[\mathrm{Fe/H}] = -2.5$ at a given $B-V$ colour are selected as candidates. $B-V$ can be measured with an accuracy of 0.1mag from the HES objective-prism spectra (Christlieb et al. 2001a) and is therefore available for all HES stars. Figure 3 illustrates the selection procedure with three bright stars of similar temperature from the HK survey of Beers and collaborators (Beers et al. 1992) which have been rediscovered in the HES. One can clearly see the decreasing strength of Ca II K with decreasing [Fe/H].

---

[1] $[\mathrm{X/H}] = \log_{10}[\mathrm{N(X)/N(H)}]_* - \log_{10}[\mathrm{N(X)/N(H)}]_\odot$, and analogously for [X/Fe].

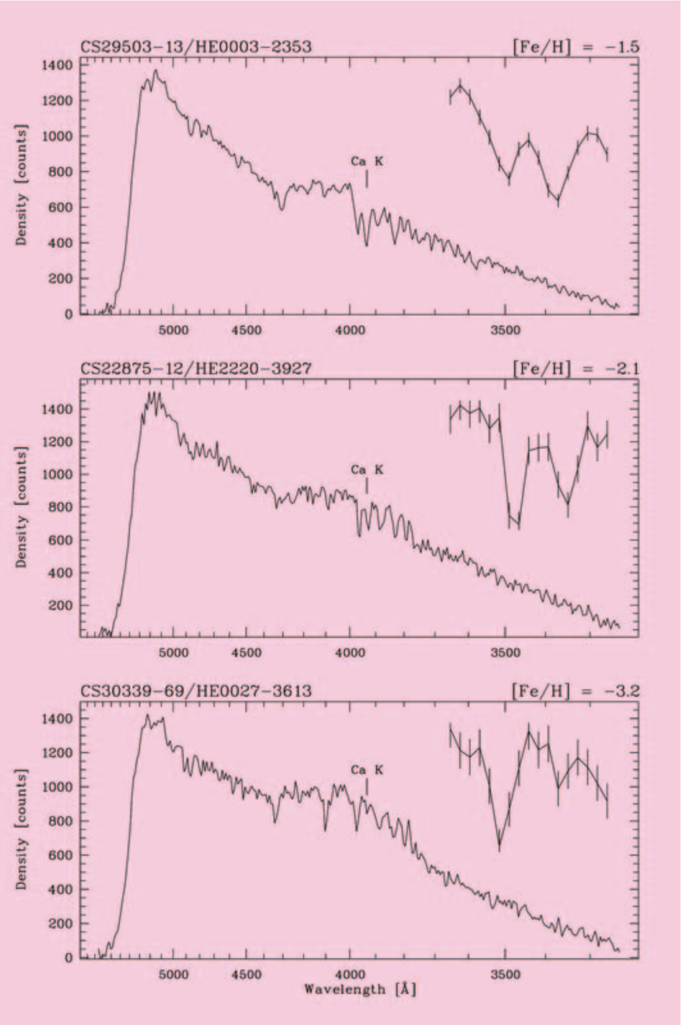

Figure 3: HES sample spectra of metal-poor stars. An enlargement of the spectral region covering Ca II H + Hε and Ca II K is shown in the upper right corner of each panel. The 1-σ noise level of each pixel of the digital objective-prism spectra is overplotted. In the spectrum of the bright (*B* = 14.9) star CS30339-69 = HE0027-3613, the Ca K line is barely detected even though the star has a metallicity as low as [Fe/H] = –3.2.

It is impossible to follow-up thousands of metal-poor candidates in single-slit mode at a single observatory, because typically only 20–40 stars can be observed in a clear night. Therefore we employ a variety of facilities in both hemispheres for this task.[2]

About half of the metal-poor candidates have been observed so far, and more than 200 stars have been confirmed to have [Fe/H] < –3.0. This trebles the total number of known stars in this metallicity regime from previously ~100 to now more than 300. In Fig. 4 we compare the metallicity distribution function (MDF) of a representative subset of the observed HES candidates with the MDF of the HK survey candidates. It can be seen that the fraction of stars at [Fe/H] > –2.0 is considerably lower in the HES, i.e., the candidate selection efficiency is much higher. While in the HK survey only 11% and 1% of the candidates are genuinely below [Fe/H] = –2.0 and [Fe/H] = –3.0, respectively, the efficiency for stars having unsaturated spectra in the HES is about a factor of five higher (Christlieb 2003). For the 1767 (partly) saturated HES stars in the magnitude range 10 ≲ B ≲ 14, the efficiency is still a factor of two higher than in the HK survey (Frebel et al., in preparation). The reasons are the higher quality of the HES spectra and the employment of an automated and quantitative selection as opposed to visual inspection of objective-prism plates using a binocular microscope.

High-resolution spectra of the confirmed metal-poor stars are being obtained with VLT/UVES, Keck/HIRES, Subaru/HDS and Magellan/MIKE. In the next two sections we present selected highlights from these efforts.

HE0107-5240

For more than 20 years, it has been assumed that there is a low-metallicity "cutoff" in the metallicity distribution function of the galactic halo, at [Fe/H] ~ –4.0, i.e., 1/10,000 of the metallicity of the Sun (see Fig. 4). Two of the physical reasons that have been suggested to explain the absence of stars with [Fe/H] < –4.0 are pre-enrichment of the interstellar medium by supernovae of type II to [Fe/H] > –4.0, or suppression of low-mass star formation due to the absence of cooling mechanisms in ultra metal-poor gas clouds (see e.g. Bond 1981).

Hence it was rather surprising to discover HE0107-5240, a giant with [Fe/H] = –5.3 (Christlieb et al. 2002; see also ESO Press Release 19/02). This star was found during spectroscopic follow-up observations at the Siding Spring Observatory 2.3m. High-resolution spectra were obtained with VLT/UVES in 2001 and 2002. The elements

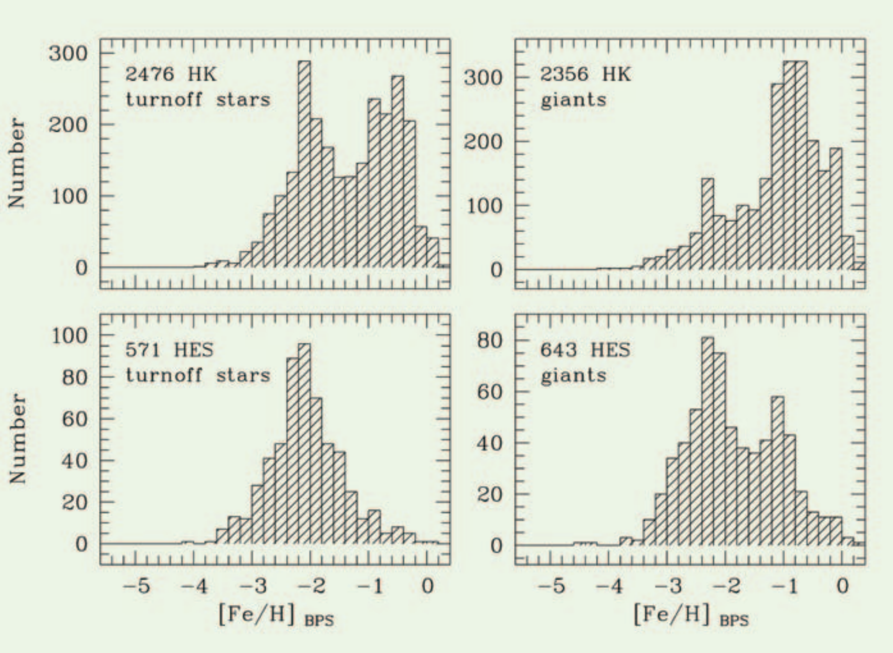

Figure 4: Metallicity distribution function of metal-poor candidates selected in the HK (upper panels) and HE (lower panels) surveys. Note the much smaller fraction of stars with [Fe/H] > –2.0 in the HES.

---

[2] This includes the ESO 3.6m/EFOSC2, SSO 2.3m/DBS, UK 1m-Schmidt/6dF, Magellan 6.5m/B&C, Palomar 200″/DS, CTIO and KPNO 4m/RCSPEC, and the 4m Anglo-Australian Telescope/RGO.

heavier than Na are depleted by amounts similar to that seen for Fe, while carbon and nitrogen are strongly enhanced with respect to iron and the Sun, by 3.7–4.0 and 2.3–2.6 dex, respectively. Na is also strongly enhanced ([Na/Fe] = +0.8 dex).

A lot of the discussion in the recent literature has focused on explaining the origin of the abundance pattern of HE0107-5240. Particularly interesting is the supernova model of Umeda & Nomoto (2003) of a Population III star of about 25 solar masses that explodes with low explosion energy ($E_{exp} = 3 \cdot 10^{50}$ erg) followed by mixing and fallback. It produces elemental yields that fit the overall abundance pattern of HE0107-5240 rather well, in particular the high C to N and light to heavy element ratios. However, the oxygen abundance predicted for HE0107-5240 is [O/Fe] = 3.0 dex, while Bessell et al. (2004) measure [O/Fe] = $2.3^{+0.2}_{-0.4}$ dex. It remains to be studied whether this disagreement can be reduced by modifying one of the free parameters of the Umeda & Nomoto model, e.g., the progenitor mass, and/or the mass coordinate range in which mixing occurs. One advantage of the Umeda & Nomoto pre-enrichment scenario is that it might solve the "star formation problem". While it is difficult to form a 0.8 solar mass star from a gas cloud with [Fe/H] = –5.3, the presence of a lot of carbon and oxygen would provide efficient cooling channels (Umeda & Nomoto 2003; Bromm & Loeb 2003).

It has also been argued that HE0107-5240 might even be a Population III star, i.e., a star originally consisting only of material produced in the Big Bang. The abundances of most heavy elements observed in HE0107-5240 are so low, and the age of the star presumably so large (on the order of the age of the Universe), that its abundances might have been severely changed by accretion from the interstellar medium (Christlieb et al. 2002; Shigeyama et al. 2003). The large amount of carbon, nitrogen and oxygen might have been accreted from a formerly more massive companion which is now a white dwarf (Christlieb et al. 2002; Suda et al. 2004). However, if it is assumed that there was no pre-enrichment of the gas cloud from which HE0107-5240 formed, it is unclear how the star could have formed.

Based on new calculations of the evolution of and nucleosynthesis in ultra metal-poor low-mass stars, two groups argued independently that self-enrichment of HE0107-5240 with CNO can be excluded (see Weiss et al. 2004, and references therein), because the predicted abundances of C and N are too large by several orders of magnitude; the predicted C/N ratio is close to 1, while 50 is observed; and the predicted $^{12}C/^{13}C$ isotopic ratios are about a factor of ten lower than the lower limit of 50 observed in HE0107-5240.

In summary, HE0107-5240 gives us the opportunity to learn about star formation processes in the early Universe, the first generation of stars exploding as supernovae, and stellar evolution at extremely-low metallicities. Therefore, its discovery has sparked a lot of new research. Some of the elements that we see in HE0107-5240 might be associated with the very first nucleosynthesis events in the Universe, occurring in the stars that formed only about 200 Myr after the Big Bang, according to recent results obtained with the Wilkinson Microwave Anisotropy Probe.

R-PROCESS ENHANCED STARS

We have started a dedicated effort to find more stars with strong enhancements (i.e., by more than a factor of 10) of neutron-capture elements associated with the r-process. In the course of a Large Programme (No. 170.D-0010; P.I.: Christlieb), "snapshot" spectra of 373 confirmed metal-poor giants brighter than $B \sim 16.5$ mag, including 4 comparison stars, are scheduled to be obtained with VLT/UVES. Most of the targets are from the HES. The snapshot spectra typically have R = 20,000 and S/N = 30, which is sufficient for measuring the abundances of some 20 elements and recognizing r-process enhanced and other interesting stars. The snapshot spectra are being secured when the seeing at Paranal is > 1.2″, and the constraints on the other observing conditions are very low. This "filler program" philosophy has already been employed successfully in the SPY project (Napiwotzki et al. 2003) aiming at finding supernova type Ia (SN Ia) progenitors (see also below).

So far we have received and analyzed snapshot spectra of 350 stars. We have found 10 new stars with enhancements of r-process elements by more than a factor of 10, as traced by Eu (i.e., [Eu/Fe] > 1 dex). That is, we have increased the number of known stars of this kind by more than a factor of 4, from previously 3 (CS22892-052, CS31082-001, and CS22183-031) to now 13. High-quality spectra of at least 5 of the new stars will be obtained in the course of the Large Programme.

The first new strongly r-process enhanced star that we discovered, CS29497-004, shows an enhancement of Ba to Dy by on average 1.5 dex with respect to iron and the Sun (Christlieb et al. 2004). The abundances of the elements with $Z \geq 56$ match a scaled solar r-process pattern well, while Th is underabundant relative to that pattern by 0.3 dex, which we attribute to radioactive decay. The CH features in the spectrum of this star are much weaker than in CS22892-052 and about as weak as in CS31082-001, making it a good candidate for an attempt to detect uranium. VLT/UVES spectra of sufficient quality for this enterprise have already been obtained and are currently being analyzed. As a by-product of the Christlieb et al. Large Programme, we have almost doubled the number of stars confirmed by high-resolution spectroscopy to have [Fe/H] < –3.5, from 8 to 15. Furthermore, we have assembled by far the largest homogeneously analyzed sample of extremely metal-poor stars to date. This allows us to examine the abundance trends and scatter around these trends for this large sample, which is of unprecedented value for investigations of galactic chemical evolution.

The homogeneous analysis of 350 stars was feasible because an automated abundance analysis technique (Barklem et al. 2004) has been used. It has been specifically developed for our Large Programme, but it is general in the sense that it can be applied to high-resolution spectra of other stars as well (e.g., more metal-rich stars) if appropriate line lists are compiled.

CARBON STARS

Christlieb et al. (2001b) identified 403 faint high latitude carbon (FHLC) stars in the HES by means of their strong C_2 and CN features (see upper right panel of Figure 1 for an HES example spectrum). Spectroscopic follow-up observations have revealed that this sample consists of a mixture of intermediate-mass asymptotic giant branch (AGB) stars and earlier type, metal-poor, but carbon-rich stars. Already from the HK survey it was apparent that about 20% of the metal-poor stars at [Fe/H] < –2.5 have strong overabundances of carbon, i.e., [C/Fe] > 1.0. This is confirmed by the HES, with the most extreme case found so far being HE0107-5240. A selection of stars with strong carbon features therefore provides an independent means for selecting the most metal-poor stars.

The carbon-enhanced metal-poor stars that show enrichment with s-process elements give us observational access to an extinct generation of extremely metal-poor AGB stars that via mass transfer left their "fingerprints" on their less massive companions, which we observe today. They provide strong observational constraints for simulations of the structure, evolution and nucleosynthesis of AGB stars, and allow us to investigate the s-process at very low metallicities. One extreme case which was found in the HES is HE0024-2523. Lucatello et al. (2003) analyzed high-resolution spectra obtained with Keck/HIRES as well as VLT/UVES, and find that it is a short-period (P = 3.4126 days) binary with a very large overabundance of the s-process elements; e.g., [Ba/Fe] = 1.5, and [Pb/Fe] = +3.3. The high overabundances of Pb in this and other "lead stars" are in concert with theoretical calculations, which predict that an efficient production of s-process elements takes place even in very low metallicity AGB stars despite the shortage of iron seeds, provided that protons are mixed into carbon-rich layers. Proton mixing results in formation of ^{13}C, which is a strong neutron source due to the reaction ^{13}C(α, n)^{16}O.

It is likely that there are more “lead stars” among the 403 HES FHLC stars of Christlieb et al. (2001b). High-resolution spectra of many good candidates and additional stars from the metal-poor star sample have already been obtained with VLT/UVES.

Among the original motivations for selecting FHLC stars in the HES was also to compile a large, homogeneously selected sample of dwarf carbon stars (dCs), i.e., main-sequence stars with strong overabundances of carbon – not to be confused with DQs, i.e., white dwarfs with strong carbon features in their spectra (see upper left panel of Figure 1 for an example). However, these efforts have now been superseded by the (much deeper) Sloan Digital Sky Survey (SDSS), in which so far more than 100 dCs have been found, and a total of 200-300 are expected to be detected in the full survey.

FIELD-HORIZONTAL BRANCH A-TYPE STARS

Field horizontal branch A-Type (FHB/A) stars are valuable tracers for the structure and kinematics of the halo of the Galaxy. In the HES, FHB/A stars with distances of up to ~ 30 kpc can be found. Another application of FHB/A stars is distance estimation of High Velocity Clouds (HVCs). HVCs are clouds of neutral hydrogen having radial velocities incompatible with Galactic differential rotation. There is an ongoing discussion as to whether HVCs are Galactic objects, or if they are extragalactic. Distances to HVCs can be determined by using stars of known distance in the line of sight of the clouds. Provided that the HVC under consideration has a detectable metal content, we see absorption lines of these metals at the velocity of the cloud in the spectra of stars located behind the cloud, but do not see these lines in spectra of stars located in front of the cloud. By using several stars at different distances in the line of sight of the cloud we can constrain its distance. FHB stars are particularly well-suited for this purpose, because they are numerous, distant, and their spectra are almost free of intrinsic absorption lines of metals.

Using the techniques of automatic spectral classification of Christlieb et al. (2002), we have identified 8321 FHB/A candidates in the HES. Representative follow-up observations of ~200 stars with the 3.6m/EFOSC2 as well as the CTIO and KPNO 4m telescopes have shown that the contamination of the sample with the less distant “blue metal-poor stars” of Preston et al. (the majority of which are likely halo blue stragglers) is less than 10%, while it would be as high as 1/3 in purely flux-limited sample of field A-type stars at high galactic latitudes. The contamination could be kept low by using the Strömgren c_1 index, which can be directly measured in the HES spectra with an accuracy of 0.15 mag (Christlieb et al. 2001a), as a gravity indicator. The stars are being used as HVC distance probes in ongoing observational programs at ESO and elsewhere.

Table 1: Remarkable “faint blue stars” from the HES

Name	Type
HE0015+0024	magn. DB with Zeeman triplets; B = 6MG (Figure 5)
HE1043-0502	magnetic DB, B ~ 800MG
HE1211-1707	variable magn. DB, B = 50MG, P = 110 minutes
HE0330-0002	non-DA magn. WD, unidentified lines
HE0236-2656	non-DA magn. WD, unidentified lines
HE0241-0155	magn. DA, B = 150-400 MG, Grw +70° 8247 type
HE1045-0908	magn. DA, P = 2-4 hours, B = 30 MG [20 MG?; Schmidt et al.]
HE0504-2408	DO with ultrahighly excited lines
HE1314+0018	DO with unexplained strong He II lines
HE1414-0848	double degenerate, $M_1 + M_2 = 1.26\ M_\odot$
HE2209-1444	double degenerate, $M_1 + M_2 = 1.15\ M_\odot$
HE0301-3039	first sdB + sdB binary
HE1146-0109	DQ with exceptionally strong C_2 and CI lines
HE0127-3110	variable He I spectrum, transient C_2 bands, variable high velocity components, AM CVn type?

WHITE DWARFS AND OTHER “FAINT BLUE STARS”

White dwarfs (WDs) are a common by-product of any QSO survey since blue colour selection will detect WDs with $T \gtrsim 10{,}000$ K. At the HE survey limit of $B \lesssim 17.5$ for the stellar work, typically two DA WDs per Schmidt plate can be selected unambiguously. The advantage of the HE compared to the PG survey, a UV excess QSO survey, is that blue subdwarfs, which dominate the population at 16 mag, can be reliably separated from QSOs and WDs spectroscopically at the spectral resolution of the HES. The DA search yielded 830 DA candidates, 737 of them are not listed in the catalogue of McCook & Sion (1999). Christlieb et al. (2001a) estimate that the contamination of this sample with non-WDs is less than 10%.

The high and uniform density of bright WDs over the whole southern sky provided by the HES was a pre-requisite of the SPY project, a search for SNIa progenitors among double degenerates (DDs) conducted as a Large Programme with UT2/UVES (Napiwotzki et al. 2003). In addition to the DA search, an automated DB search has been conducted for SPY as well (Christlieb et al., in preparation). Besides the dedicated search for WDs, the follow-up spectroscopy of QSO candidates yielded a number of more peculiar WDs not recognizable directly on the Schmidt plates, e.g., WDs with extremely high magnetic field strengths and extremely hot new types of WDs. In the following we highlight the most important new HE faint blue stars. Table 1 lists these highlights.

MAGNETIC WDS

The discovery of HE1211-1707 and HE1043-0502 (Reimers et al. 1996, 1998) together with dedicated calculation of the He I spectrum in fields up to 1000 MG (e.g. Becken 2001) which were motivated also by these discoveries, led to an improved (first) understanding of He I in strong magnetic fields. HE1211-1707 is an ideal test object since it is a highly spectrum variable DB white dwarf with a mean field of 50 MG (Wickramasinghe et al. 2002) and a period of 110 min (Jordan 2001). An even more exotic case is HE1043-0502: it shows an extremely strong feature near 445.0nm (Reimers & Wisotzki 1997; see also Fig. 1). According to Wickramasinghe et al. (2002) these features can be explained on the basis of Beckens and Schmelchers (2001) quantum mechanical calculation of He I in strong magnetic fields as 2^1S_0–3^1P_0 transition at 800 MG. Since the 445.0nm feature is a “stationary component” one would expect more objects of the HE1043-0502 type. However, our dedicated search in the HES data base, using the spectrum of HE1043-0502 as a template, and follow-up spec-

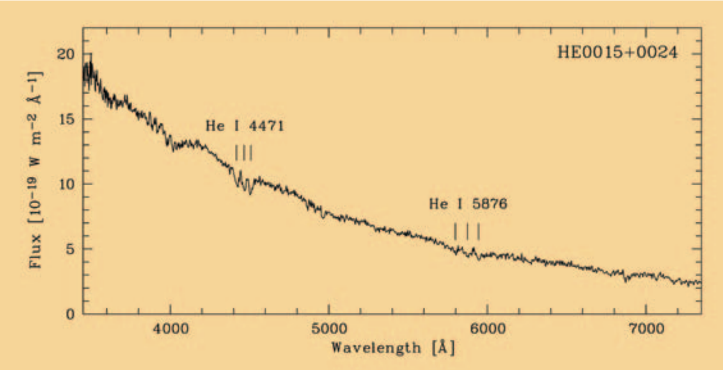

Figure 5: 3.6m/EFOSC2 spectrum of the magnetic DB white dwarf HE0015+0024, clearly showing Zeeman triplets of He I 4471 and He I 5876.

troscopy of candidates at the 3.6m telescope was not successful. Instead, a number of highly peculiar broad-absortpion line quasars with a feature at 445.0nm and many new DBs were discovered. In conclusion, DB white dwarfs with field strengths as high as 800 MG appear to be extremely rare.

Among the newly-discovered magnetic DAs, two are especially noteworthy: HE1045-0908 and HE0241-0155. The former shows a distinctive, rich Zeeman spectrum. Schmidt et al. (2001) discovered spectrum and circular polarization variability over one hour. The period is not yet precisely known, but should be in the range 2–4 hours. Observing and modeling this star might yield new information on departures from simple dipole configuration (see Schmidt et al. 2001).

HE0241-0155, with a magnetic field of 150–400 MG, is similar to the prototype of strong field DAs, Grw +70° 8247. On the other hand it shows features in the spectrum between 500 and 550nm which cannot be explained by the normal stationary components that require a large homogeneous field with 200 MG field strength, possibly due to a large spot. One might expect variability due to the spot. However, a new spectrum taken 5 years later (2003) does not reveal any variations.

New DO types

Werner et al. (1995, 2004) have discovered two new types of extremely hot WDs among the HE follow-up spectra. HE0504-2408 is one of the prototypes of DO white dwarfs with lines from ultra-high ionization states like Ne IX or O VIII. HE1314+0018 is a DO with exceptionally strong He II absorption lines. Both phenomena are not explainable within the concept of static non-local thermodynamic equilibrium stellar atmospheres. They possibly originate in expanding coronae/winds of hot WDs. The strong He II lines could also be due to an unusual composition of the atmospheres not detectable in the optical spectral range.

SPY – The search for SNIa progenitors

This ESO Large Program has been described in detail by Napiwotzki in the *Messenger* (Napiwotzki et al. 2003). In recent years SNIa have played an increasing role as distance indicators in cosmology up to redshifts of more than 1 and they have provided evidence for a non-vanishing cosmological constant, independent of other measurements like microwave background fluctuations. However, since the progenitors of SNIa are not known there remains room for speculations on intrinsic variations of SNIa peak luminosities with cosmic epoch. One of the progenitor scenarios is the double degenerate (DD) scenario where two WDs with total mass above the Chandrasekhar limit (1.4 solar masses) merge within a Hubble time due to angular momentum loss via gravitational radiation. SPY aimed at detecting DD systems by repeated spectroscopy of about 1000 WDs, including DAs as well as non-DAs. More than 100 DDs have been discovered, 16 with double lines. Two systems (HE1414-0848, HE2209-3039) qualify nearly for SNIa progenitors, a third one appears to make it (Napiwotzki et al., in preparation). SPY has demonstrated that the DD scenario is one of the possible evolutionary paths leading to a SNIa. The large population of newly discovered DDs will allow us to study more quantitatively the pre-SNIa stages, e.g. the common envelope phase which is difficult to model from first principles.

HE0127-3110

A never ending story?

Three spectra of HE0127-3110 taken in September and December 1994 show broad absorption features at 465.0nm and 505.0nm and a relatively narrow line at 587.0nm. These spectra have been reproduced successfully by a magnetic DA model with field strengths between 85 MG and 235 MG, in particular the 587.0nm feature appeared to be the well-known stationary $^2S_0 \rightarrow {}^3P_0$ Hα component (Reimers et al., 1996). It was also discussed in the discovery paper that the broad features might be the C_2 Swan bands, and that the 587.0nm is He I 587.6nm, while He I 447.1nm was missing. However, this possibility was dismissed because no single WD model can explain the simultaneous occurrence of strong C_2 and He I.

Later, we discovered that we had taken a spectrum of HE0127-3110 already in September 1992, which looked like a pure DB spectrum with both He I 447.1 and 587.6nm but without the "C_2 features" (Friedrich et al. 2000). The magnetic DA hypothesis was wrong. This conclusion was independently also reached by Schmidt et al. (2001), who found that HE0127-3110 does not show any circular polarization.

Was the C_2 band due to a cool spot on the DB which would re-appear one day by rotation? We have taken more than a dozen spectra between 1998 and 2003 with the hope to see again the C_2 bands, but without success (see Fig. 6). However, the He I 587.6nm and 447.1nm lines appear to vary on the timescale of days, in particular He I 447.1nm is weak or absent in several spec-

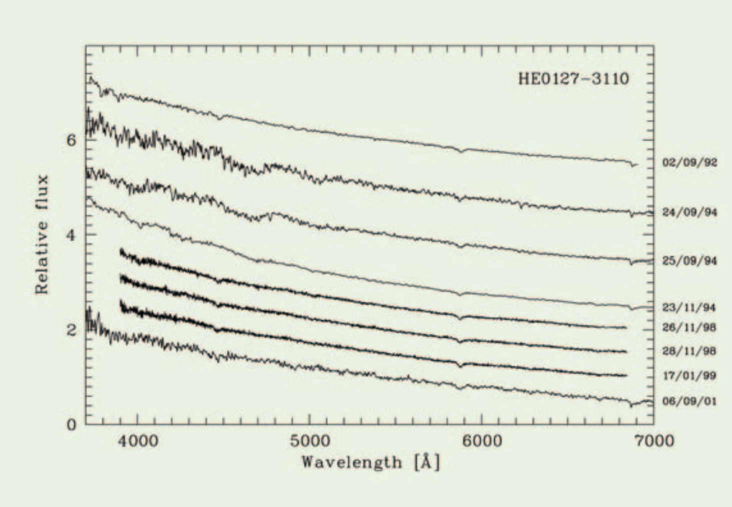

Figure 6: Slit spectra of the spectrum variable object HE0127-3110.

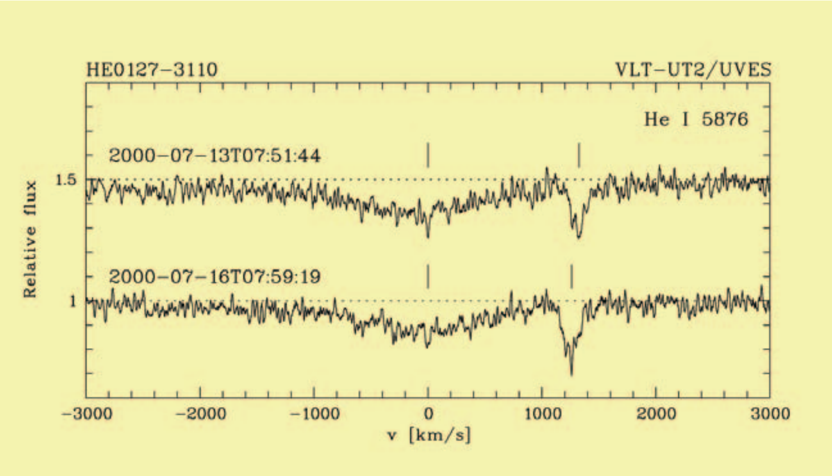

Figure 7: VLT/UVES spectra of He I 5876 in HE0127-3110. Note the sharp, moving component at a radial velocity of ~1300 km/s relative to He I 5876.

tra. Two UVES spectra of HE0127-3110 taken in the course of the SPY project within 3 days give a hint to a possible solution of the problem. The He I 587.6 nm line is very broad and shallow (line depth 20 %) and has a narrow, deeper satellite component at +1330 km/s relative to the broad He I 587.6 nm line (see Fig. 7). The narrow component moved to +1260 km/s within 3 days. Velocities that high and variable on short timescales in the context of an otherwise mostly "normal" DB spectrum hint to a close double degenerate (DD), possibly of the AM CVn type, i.e., binaries in contact, with periods as short as 15 minutes. And what about the C_2 features? Could they have been produced as transient features in an outburst which ejected carbon? We invite the interested CV community to take the next obvious steps: photometry and spectroscopy with high time resolution (minutes) and polarimetry – not easy for a $B = 16$ mag star.

OUTLOOK

Due to technical reasons, so far only 329 of the 380 HES plates have been used for the exploitation of the stellar content of the survey. Given the tremendous success of this effort, we are now in the process of extending it to the remaining 51 plates.

We also plan to continue with collecting medium-resolution follow-up spectroscopy for at least the most interesting of the remaining ~5000 HES candidates for metal-poor stars. The ESO 3.6m with its very efficient instrument EFOSC2 is the ideal telescope/instrument combination at ESO for such an effort, which emphasizes the continued need for "small" telescopes even in the era of 8-10m class telescopes.

In addition to the more than 200 new stars with [Fe/H] < –3.0, we have also found a few more stars which appear from the moderate-resolution spectra to have [Fe/H] < –4.0. Some of them might turn out to have metallicities even much lower, because the Ca II K line, which is used for estimating [Fe/H] from the follow-up spectra, might be contaminated by CH lines (which is the case in HE0107-5240), interstellar absorption, or the Fe abundance might be overestimated due to the presence of a strong over-abundance of the α-element Ca. This can only be clarified by high-resolution spectroscopy. HE0107-5240 was found in a set of ~2000 of the best metal-poor candidates (which in turn have been selected from about 1 million objects). Since the total number of HES candidates is about 10,000, it is not excluded that a few more stars with [Fe/H] < –5.0 might be found in the HES. For the determination of the primordial Li abundance it is most desirable to find a turnoff star at this metallicity.

For all stars estimated to have [Fe/H] < –3.5 from the follow-up spectra, high-resolution spectroscopy is being obtained in ongoing observing programs at 8-10m-class telescopes. We plan to use the VLT for this in the future as well. Very high S/N is needed because the lines of elements other than hydrogen are exceedingly weak at the lowest metallicities.

Finding more metal-poor stars with [Fe/H] < –5.0 and significant numbers of other interesting stellar objects would require us to extend the survey volume significantly with respect to the HES; that is, it has to be much deeper. Such a survey is only feasible if either the candidate selection efficiency is further improved, to reduce the number of candidates to be followed up in single-slit mode, or if a large amount of time at a suitable telescope with a multi-fiber spectrograph is available. Only in this way can one cope with the large number of metal-poor candidates which would result e.g. from a deeper colorimetric survey.

ACKNOWLEDGEMENTS

We thank T.C. Beers for helpful comments and careful proof-reading. N.C. is grateful to his numerous collaborators who have contributed over many years in various ways to make the exploitation of the stellar content of the HES a success. In the context of the results described here, he would especially like to thank P.S. Barklem, T.C. Beers, M.S. Bessell, J. Cohen, A. Frebel, B. Gustafsson, V. Hill, D. Koester, S. Lucatello, and C. Thom. This work is supported by Deutsche Forschungs-gemeinschaft, and a Henry Chretien International Research Grant administered by the American Astronomical Society. It has been supported by the European Commission through a Marie Curie Fellowship and by the Australian Research Council through a Linkage International Fellowship, both awarded to N.C.

REFERENCES

Barklem P.S., Christlieb N., Beers T.C. et al. 2004, A&A submitted
Becken, W., Schmelcher, P. 2001, J. Phys. A, 63, 053412
Beers T.C., Preston G.W., Shectman S.A. 1992, AJ 103, 1987
Bessell M.S., Christlieb N., Gustafsson B. 2004, ApJ 612, L61
Bond H. 1981, ApJ, 248, 606
Bromm, V., Loeb, A. 2003, Nature 425, 812
Cayrel R., Hill V., Beers T.C. et al. 2001, Nature 409, 691
Christlieb N. 2003, Rev. Mod. Astron. 16, 191 (astro-ph/0308016)
Christlieb N., Wisotzki L., Reimers D. et al. 2001a, A&A 366, 898
Christlieb N., Green P.J., Wisotzki L. et al. 2001b, A&A 375, 366
Christlieb N., Wisotzki L., Grahoff, G., 2002, A&A 391, 397
Christlieb N., Bessell M.S., Beers T.C., et al., 2002, Nature 419, 904
Christlieb N., Beers T.C., Barklem P.S. et al. 2004, A&A in press (astro-ph/0408389)
Friedrich S., Koester D., Christlieb N. et al. 2000, A&A 363, 1040
Jordan, S. 2001 in 12th European Conf. on White Darfs, ASP Conf. Ser. 226, p. 269
McCook G.P. & Sion E.M. 1999, ApJS 121, 1
Napiwotzki R., Christlieb, N., Drechsel H., et al., 2003, The Messenger 112, 25
Reimers D., 1990, The Messenger 60, 13
Reimers D., Wisotzki L, 1997, The Messenger 88, 14 12
Reimers D., Jordan S., Koester D. et al. 1996, A&A 311, 572
Reimers D., Jordan S., Beckmann V. et al. 1998, A&A 337, L13
Ryan S.G., Norris J.E., Beers T.C. 1999, ApJ 523, 654
Schmidt G.D., Vennes S., Wickramasinghe D.T. et al. 2001, MNRAS 328, 203
Shigeyama T., T. Tsujimoto, Yoshii Y. 2003, ApJ 586, L57
Suda T., Aikawa M., Machida M.N. et al. 2004, ApJ 611, 476
Umeda H., Nomoto K. 2003, Nature 422, 871
Weiss A., Schlattl H., Salaris M., Cassisi S. 2004, A&A 422, 217
Werner, K. et al. 1995, A&A 293, L75
Werner, K. et al. 2004, A&A 424, 657
Wisotzki L., Christlieb N., Bade N. et al. 2000, A&A 358, 77
Wickramasinghe et al. 2002, MNRAS 332, 29