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The Hamburg All-Sky Bright QSO Surveys

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Abstract. Over the past decade, our team has pursued a quest to search for the optically brightest quasars in the entire extragalactic sky, by means of automated quasar selection using digitised objective prism spectra. We give a brief overview over the observational database and selection strategies and present some of the major survey highlights.

1. Introduction

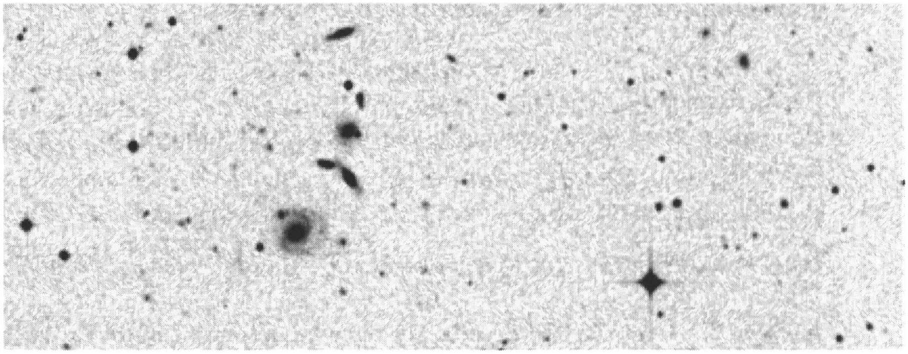
Bright quasars are important targets for a variety of astrophysical studies, interesting in their own but also valuable tools to probe the intervening matter by absorption-line spectroscopy and gravitational lensing. However, bright quasars are also very rare, and to sample the brightest part of the quasar population, substantial fractions of the extragalactic sky have to be covered with efficient surveying techniques. Both of our wide-angle surveys were conceived in this spirit: The Northern hemisphere 'Hamburg Quasar Survey' (HQS) and its Southern counterpart, the 'Hamburg/ESO Survey' (HES); both projects are now practically completed. The applications of such surveys can generally be numbered under two categories: (1) The discovery aspect, where statistical completeness is not important; and (2) the completeness aspect, where well-defined flux-limited samples are to be constructed. In the following we pay attention to both aspects.

2. Basic Survey Properties and Project Status

2.1. Common Properties

Both surveys are based on the same basic technical layout, using Schmidt telescopes equipped with objective prisms to produce deep unwidened and unfiltered spectral plates. The blue-sensitive Kodak IIIa-J photographic emulsion determines the spectral range to the red, while to the blue it is limited by the atmosphere; $3200 \lesssim \lambda \lesssim 5400$ Å. The magnitude range for processable spectra is roughly $13 \lesssim B \lesssim 18$, although strongly dependent on observing conditions, in particular on the seeing. The plates were digitised with the Hamburg PDS 1010G microdensitometer. An example of the result of the digitisation procedure is shown in Fig. 1. The total survey area is about $\sim 22\,000$ deg^2. By

Direct plate scan from UKST Schmidt telescope:
Slit 50 μm × 50 μm, step 25 μm × 25 μm (*The Digitized Sky Survey*)



PDS scan of ESO Schmidt objective prism plate:
Slit 30 μm × 30 μm, step 20 μm × 20 μm

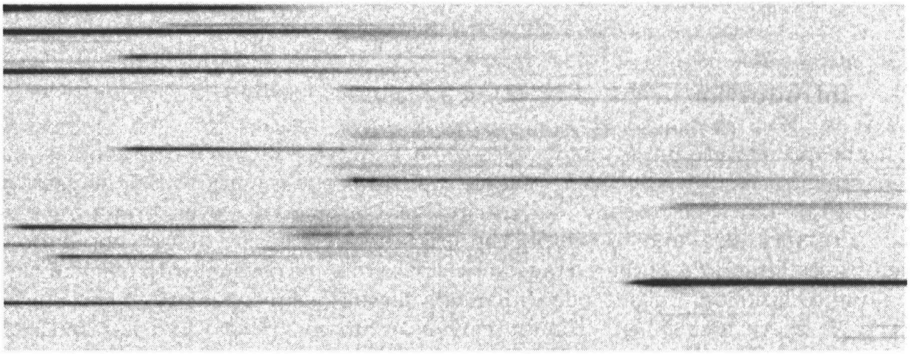


Figure 1. The top panel shows the direct data for a small survey area, taken from the DSS. Below is shown the corresponding area in the spectral data.

the end of 2001, the pixel data of fully digitised objective prism plates will be available over the web. Check the survey homepage[1] .

2.2. Hamburg Quasar Survey (HQS):

The HQS is based on the 80 cm former Hamburg Schmidt telescope on Calar Alto, Spain. Prism dispersion is 1390 Å/mm and yields a seeing-limited spectral resolution of typically 50 Å FWHM at Hγ. The HQS has reached full coverage of the Northern extragalactic sky, defined as $\delta > 0°$, $|b| > 20°$. The formally covered sky area is 13 600 deg^2, or 567 Schmidt fields. Quasar candidates are part of a search for objects with 'blue continuum shape' (Hagen et al., 1995). Follow-up spectroscopy was mainly conducted at Calar Alto observatory and

[1] `www.hs.uni-hamburg.de/english/arbgeb/extgalqso/surveys.html`

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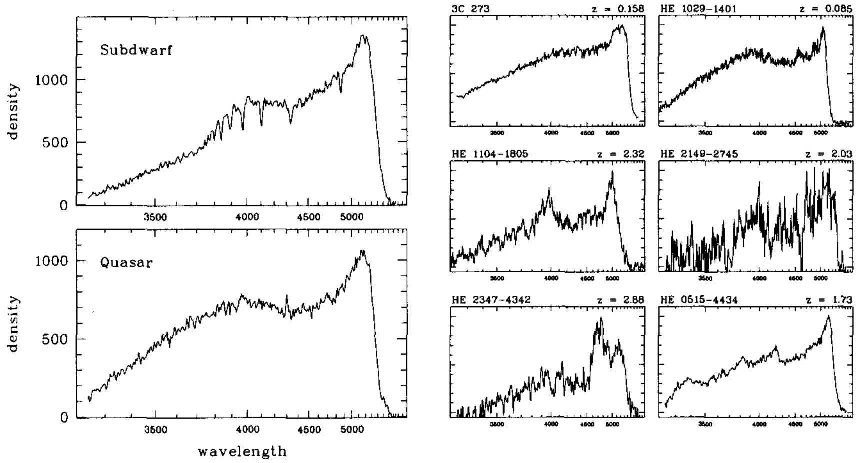

Figure 2. Example digitised objective prism spectra. Left: comparison of two UV excess objects. The top spectrum is a blue star with conspicuous Balmer absorption, the bottom is a low-redshift QSO ($z = 0.15$). Right: 'Mugshots' of several confirmed QSOs.

has yielded so far 720 confirmed new QSOs with $0 \lesssim z \lesssim 3.3$ (Engels et al. (1998); Hagen et al. (1999)). The HQS is a 'discovery survey', as no effort for completeness has been made. Besides quasars, a large variety of odd objects has been identified. Many additional AGN were found through the Hamburg/RASS identification project (Bade et al., 1998).

2.3. Hamburg / ESO survey (HES):

The HES was installed in 1990 as an ESO key programme. The ESO 1 m Schmidt telescope on La Silla, Chile, was used to take prism plates with a dispersion of 450 Å/mm, corresponding to a seeing-limited spectral resolution of ~ 15 Å FWHM at Hγ. The Southern extragalactic sky is fully covered, although more constrained to high Galactic latitudes than the HQS. The survey area is mainly defined by $\delta < 2^\circ\!.5$ and $E(B-V) < 0.15$, covering 380 Schmidt fields or ~ 9000 deg^2. QSO search was conducted with a multitude of selection criteria (Wisotzki et al., 2000). To date, 1220 QSOs were spectroscopically confirmed at ESO, with $0 \lesssim z \lesssim 3.3$ (Reimers et al. (1996b); Wisotzki et al. (2000), Reimers et al., in prep.). Flux-limited subsamples for statistical analyses have been constructed: 48 QSOs in 611 deg^2 (Köhler et al., 1997); 415 QSOs in 3700 deg^2 (Wisotzki et al., 2000); 862 QSOs in ~ 7500 deg^2 (Wisotzki et al., in prep.). The remaining ~ 4000 QSO candidates will be observed in 2002–2003 with the 6dF facility at the UK Schmidt telescope.

2.4. Quasar Selection

Quasars are known to have spectra that differ strongly from those of stars, most prominently by their ultraviolet excess. On the other hand, there has always

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been a suspicion that UV excess surveys might miss a substantial fraction of the QSO population, especially when the UV criterion is applied in a very restrictive way. In the HES, we have established a highly efficient two-step selection procedure allowing us to formulate the UV excess condition in an extremely relaxed way, effectively regarding everything bluer than $(U - B) = -0.17$ as a QSO candidate. The high quality of the spectra permits the estimation of colours with an accuracy of better than 0.1 mag rms, another important property to assure that QSOs with only a moderate UV excess will be included. Further selection criteria exploit additional colour information, in particular the presence of a superimposed host galaxy as in low-redshift Seyferts. We emphasise that contrary to popular belief, emission line detection plays a minor role – in fact, *all* our $z < 2.6$ QSOs are colour-selected. Only at the highest accessible redshifts it is that colour selection becomes inefficient because of Lyα moving out of the spectral range, plus additional Lyman forest blanketing. At $z > 2.6$, the selection has therefore to rely on feature detection algorithms.

The crucial second step in the selection procedure is the elimination of the unavoidable stellar contamination. Here the high spectral resolution of the HES prism spectra is an asset: As illustrated in Fig. 2, faint blue stars show conspicuous Balmer absorption lines readily visible in the prism spectra (and detectable by automated techniques); such objects do not enter the final QSO candidate lists. Recall that at $B \simeq 16$, more than 90 % of classical UV excess objects are stars, and this fraction is even higher for the relaxed UV excess criterion used in the HES. Nevertheless, the second stage of eliminating the stellar content is so efficient that the QSO success rate in follow-up spectroscopy is of the order of 70 %, without sacrifices in completeness.

3. Highlights

3.1. Observations of UV-bright QSOs

Bright high-redshift quasars are perfect background sources for absorption line studies of the Intergalactic Medium. They are also very rare. Véron-Cetty & Véron (2001) list 93 (17) QSOs with $z > 2$ ($z > 3$) and $B < 17$. Of these, ~ 40 % were discovered by HQS and HES. In order to facilitate far-UV spectroscopy with HST and FUSE, an additional requirement is an *unabsorbed line of sight*, which in turn eliminates the major fraction of available high-z quasars (Moller & Jakobsen, 1990). Our true all-sky approach opened the possibility to systematically search for new targets.

The first known high-redshift QSO with a clean UV line of sight was HS 1700+6416 ($z = 2.72$; Reimers et al. (1989)). Its rich absorption line spectrum was measured by HST and showed over 50 new EUV absorption lines (Reimers et al. (1992); see Fig. 3), yielding valuable information about the chemical evolution of the intergalactic medium.

The first QSO bright enough for detailed spectroscopy at $\lambda_{\rm rest} < 304$ (the wavelength of the He II Lyα emission line) was HE 2347−4342 at $z = 2.885$. The HST spectrum revealed a complex pattern of He II-Lyα absorption 'voids' and 'troughs' (see Fig. 4), in part much too strong to be explained by the normal hydrogen Lyman forest. Instead, we interpreted this as evidence for intergalactic Helium being not completely ionised, possibly as consequence of

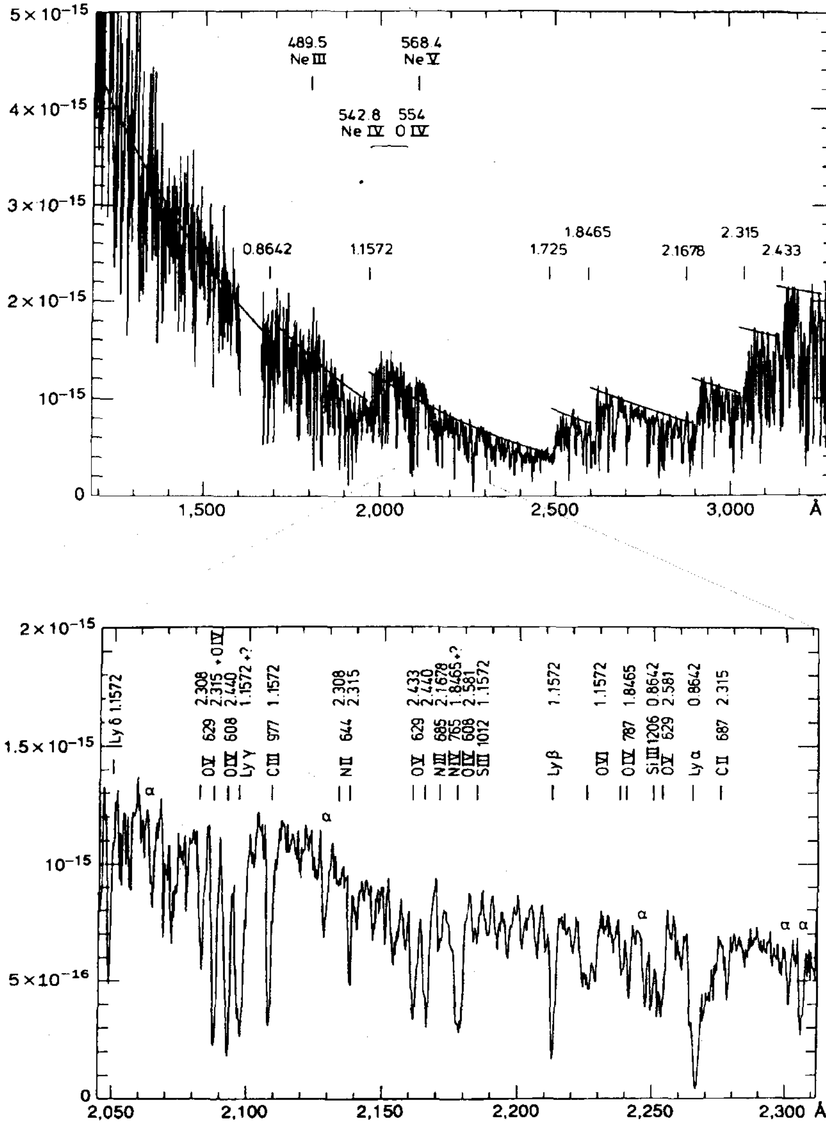

Figure 3. Spectrum of HS 1700+6416 ($z = 2.72$) taken with the Faint Object Spectrograph of the Hubble Space Telescope. Notice the 'Lyman Valley', 7 optically thin Lyman limit systems, and the wealth of intrinsic EUV high ionization metal absorption lines seen for the first time in this QSO (from Reimers et al. 1992).

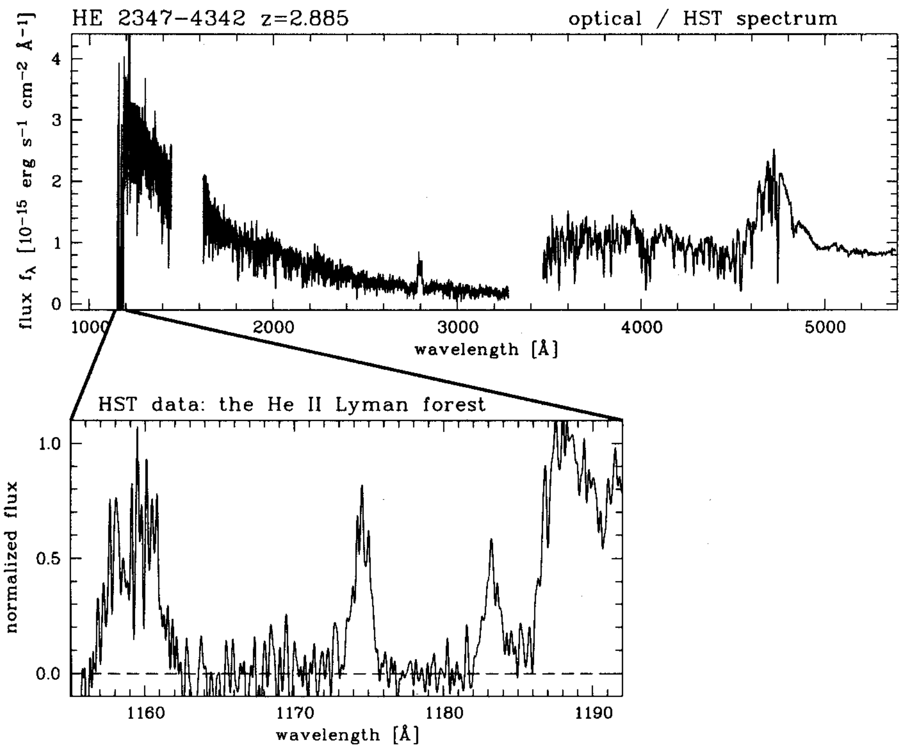

Figure 4. Optical and HST spectroscopy of the UV-bright QSO HE 2347−4342. The bottom panel shows the small section below the λ304 He II Lyα emission line.

only recently started cosmic reionisation of He II to He III (Reimers et al., 1997). The observation of the reionisation phase of the universe has been confirmed by FUSE observations of the He II 304 Å forest of this quasar (Kriss et al. (2001))

High-resolution spectroscopy of the extremely bright QSO HE 0515−4414 ($V = 14.9$, $z = 1.73$) has enabled us to detect the Warm-Hot-Intergalactic medium via O VI absorption lines (Reimers et al. (2001)). Two additional $z > 1.5$ QSOs from the HQS have been observed in 2001 with HST at high resolution for the same purpose.

Further UV-bright QSOs include HS 0747+4259 ($z = 1.90$), HS 1103+6416 ($z = 2.19$) and HS 1307+4716 ($z = 2.13$). A review of UV observations of high-redshift QSOs has been given by Reimers et al. (1998b). Together with the above, these objects constitute 100 % of known high-redshift QSOs bright enough for high-resolution UV spectroscopy. A useful byproduct of these observations are reliable (i.e. Lyα forest-corrected) EUV spectral energy distributions; it seems that most are highly incompatible with canonically assumed EUV SEDs (Reimers et al. (1998b)).

3.2. Gravitational Lenses in the Hamburg Surveys

The optical depth to QSO image splitting induced by gravitational lensing is of the order of $\sim 10^{-3}$ for high-redshift quasars. Because of the so-called magnification bias, the lens fraction is substantially enhanced in bright QSO samples, by up to a factor ~ 10 – this means that at least $\sim 1\,\%$ of the $z \gtrsim 1$ HQS and HES QSOs are probably lensed. Several interesting cases were already found.

Most prominent is HE 1104−1805, also known as the 'Double Hamburger'. This bright wide separation lens is an excellent target for monitoring, time delay determination, and microlensing studies (Wisotzki et al. (1993, 1998)); it furthermore offers two nearby lines of sight to study the spatial extent of intervening absorbers (Lopez et al. (1999); see also Fig. 4). Another four lensed QSOs (all doubles) were discovered serendipitously, and two recent small imaging follow-up studies found two further lensed QSOs out of only ~ 80 objects. This is a dramatic confirmation of the effect of magnification bias: With 6 newly discovered and several rediscovered lensed QSOs, HQS and HES form together already the second-largest existing single lens survey. Efforts to systematically exploit the lens content of HQS and HES are under way.

3.3. The Bright End of the QSO Luminosity Function

A flux-limited subsample, constructed from about 60 % of the HES, comprises 415 QSOs and Seyfert 1 nuclei with broad emission lines in an effective area of $3700\,\mathrm{deg}^2$ (Wisotzki et al. (2000)). Average limiting magnitude is $B_J \lesssim 17.2$, i.e. approx. 1 magnitude brighter than the survey detection limit. This constitutes by far the largest existing sample of very bright QSOs. It shows also a high degree of completeness: (1) The redshift distribution peaks at low z, and there is no evidence for z-dependent incompleteness. (2) A cross-comparison with other surveys showed that all known QSOs within the survey area and (B, z) limits were selected by the HES criteria. (3) The inferred surface density of QSOs is perfectly consistent with many other samples. It is, however, 1.5× higher than in the Palomar-Green survey, but the extreme degree of incompleteness of the PG that others suggested in the past could be ruled out. The statistical analysis of the sample yielded a luminosity function where the bright tail flattens considerably towards lower z, incompatible with Pure Luminosity Evolution (Wisotzki (2000)). Fig. 5 shows the nonparametrically constructed cumulative luminosity function in five redshift shells and compares these data to the prediction from 'standard' PLE. Especially at low redshifts there is a significant excess of high-luminosity QSOs over the predictions.

3.4. The Local AGN Population

Despite their proximity, the statistical properties of AGN with $z \approx 0$ are not well constrained. This has the main reason that most optical QSO surveys are limited to *point sources*, but another important effect is that host galaxies contribute to the photometry and make interpretations of number counts difficult. To overcome these problems, special strategies were developed in the HES surveying procedure: (1) No morphological discrimination against extended sources is exerted; all objects go through the same filters. (2) A specific 'colour' criterion for Seyfert-like spectra has been installed. (3) Magnitudes are measured

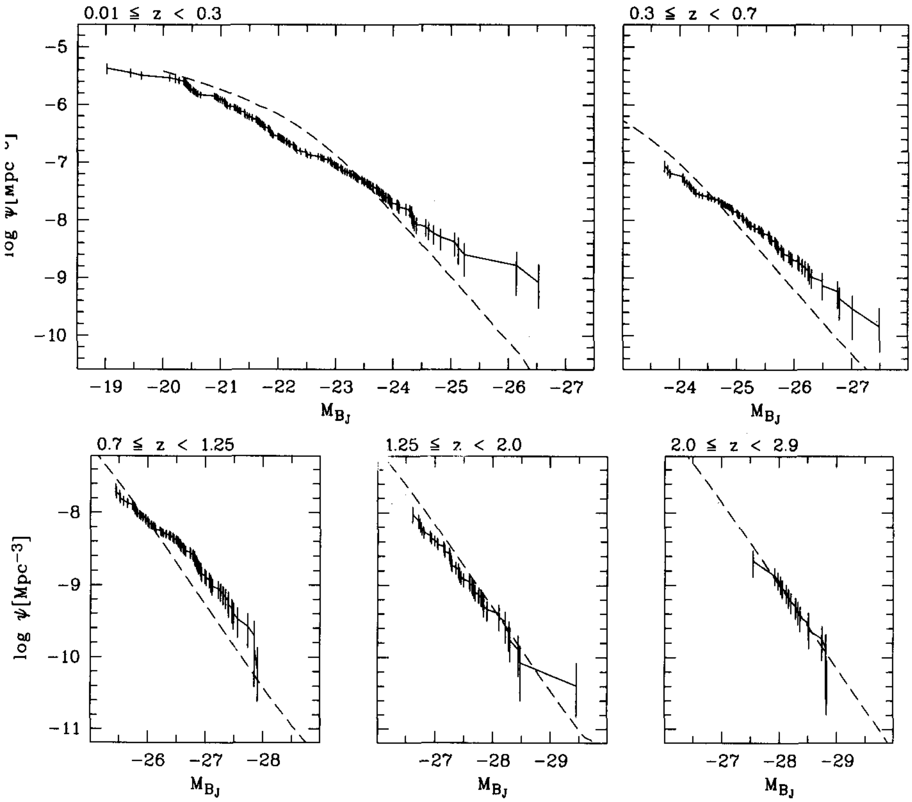

Figure 5. Segments of the cumulative QSO luminosity function, as constructed from the flux-limited HES subsample. Overplotted are the predictions from Pure Luminosity Evolution.

in an aperture of the size of the seeing disk – the sample is limited by *nuclear magnitude.*

These properties make the HES unique among optical AGN surveys, as it is unbiased to sample the local AGN population. Applications so far include the discovery that the local luminosity function of QSOs and Seyfert 1 nuclei is nearly a featureless power law (Köhler et al. (1997); cf. also the lowest redshift panel of Fig. 5) and the definition of complete samples for QSO host galaxy studies. Combining the statistical analyses performed on complete QSO samples with the measurement of QSO host galaxy parameters, we have recently been able to construct the luminosity function of QSO host galaxies (Wisotzki et al. (2001); Fig. 6). It is sufficiently similar to that of 'inactive' field galaxies to suggest that the parent population of QSOs are completely average galaxies.

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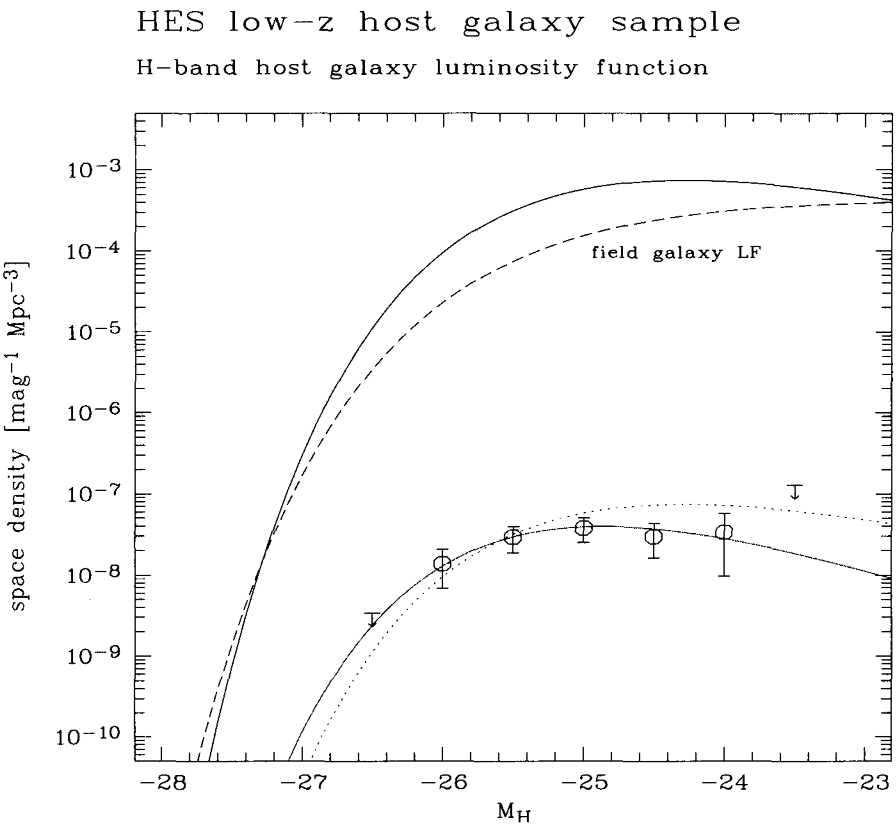

Figure 6. *H*-band luminosity function of QSO host galaxies (HGLF), in comparison to recent determinations of the NIR LF of field galaxies. The HGLF at $z = 0$ is nearly compatible with the field galaxy LF, downscaled by a factor $10^3 \ldots 10^4$.

3.5. Non-AGN Applications

Hamburg / SAO Survey for Emission Line Galaxies: A semi-automated search for BCD and starburst galaxies in an 1700 deg^2 HQS subarea, has so far generated 559 published objects (e.g., Ugryumov et al. (2001)).

Serendipitous search for magnetic white dwarfs: This is a byproduct of our QSO candidate search: White Dwarfs with strong magnetic fields are not recognised as stars in the prism spectra and therefore included as QSO candidates in the follow-up spectroscopy (Reimers et al. (1996a, 1998a)).

The stellar component of the Hamburg/ESO survey: Recently a systematic exploitation of the entire digital database of $\sim 10^7$ spectra was started, including a fully automated search for white dwarfs (Christlieb et al. (2001b)), carbon stars (Christlieb et al. (2001a)), cataclysmic variables etc.

A search for extremely metal-poor halo stars: This project makes full use of the spectral resolution provided by HES: Automated selection of stars with no detectable metal absorption lines (Christlieb et al. (2000)).

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