Southern African Large Telescope

Title: **Lick Index System with RSS at SALT**

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Doc. number: **2202AA0001**

Version: **1.1**

Date: *October 16, 2012*

Keywords: Lick index

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ABSTRACT

We present Lick absorption-line index measurements of standard stars from the list of Worthey. The spectra were taken with RSS spectrograph at SALT during PV phase. We describe in detail our method of analysis and explain the importance of using the Lick index system for studying extragalactic objects. Our results show that the calibration of RSS instrumental system to the standard Lick system can be performed with high level of confidence.

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1 Introduction

To derive stellar population properties from the integrated absorption-line spectra of a stellar system, in particular, of a galaxy or its part, one can use equivalent widths of the stellar absorption spectral lines. Lick indices (Faber et al. 1985, Worthey et al. 1994, Worthey & Ottaviani 1997) is a uniform, strictly established system of line set parameters measured partly as equivalent widths of the strong absorption lines in the spectral range of 4000–6200 Å. The system was named 'Lick' one because it was arranged by using the data of 20-yr spectral survey of nearby galaxies **and** stars with the 3-m Lick telescope equipped with the photon-counting detector IDS at the Cassegrain spectrograph. The line and continuum border definitions within the Lick system were hence adopted to the spectral resolution of the Lick spectrograph which was nearly 8 Å but was slightly varying with the wavelength: the aim was to include a full spectral line into the integrated spectral ranges. The necessity to apply just the Lick definitions of the absorption-line equivalent width measuring to the galactic spectra was strengthened by the fact that many evolutionary synthesis models of simple stellar populations, starting from the work of Worthey (1994) and later, used calibrations of the *stellar* Lick indices on the stellar effective temperatures and metallicities as the input data; these calibration relations were obtained by involving observations of more than 460 nearby stars fulfilled with the same Lick spectral setup.

2 Systems of the Lick indices with the RSS

2.1 The grating VPH1800

The grating VPH1800 of the SALT RSS used with the slit width of 1.25″ has shown a spectral resolution of about 2.5 Å – much higher than the standard Lick resolution. So we feel a necessity to calibrate the instrumental absorption-line indices obtained from the RSS spectra by integrating the spectral fluxes in the bands prescribed by the Lick system, to the standard Lick system by using the observations of the stars from the list of Worthey et al. (1994). To do so, a sample of Lick standard stars visible at the southern sky has been observed; a totality of 12 giant and dwarf bright stars, with the spectral types between F7 and M1, have been exposed with the grating VPH1800, the slit width of 1.25″, in the spectral range of 4500–5900 Å. Some stars were observed more than once, and the K0-giant HD 6203 was observed in 5 dates being used also as a velocity standard. For all the spectra obtained we have calculated the instrumental-system Lick indices Hβ, Mgb, Fe5270, and Fe5335, by integrating fluxes within the prescribed wavelength intervals recommended by Worthey et al. (1994) for the lines and for the blue and red continuum points for every line. The repeating measurements of the instrumental Lick indices in the spectra of the stars observed have shown that the intrinsic stability of the spectrograph setup is high, and the intrinsic rms scatters of the index measurements are very small: on average, 0.03 Å for Hβ, 0.05 Å for Mgb, and 0.07 Å for Fe5335. For some unclear reasons, the index Fe5270 measured on July 30, 2011, in the spectra of 7 Lick standard stars, has appeared to be overestimated by some 0.5–0.7 Å; in other dates the accuracy of this index measurements is also about 0.1 Å.

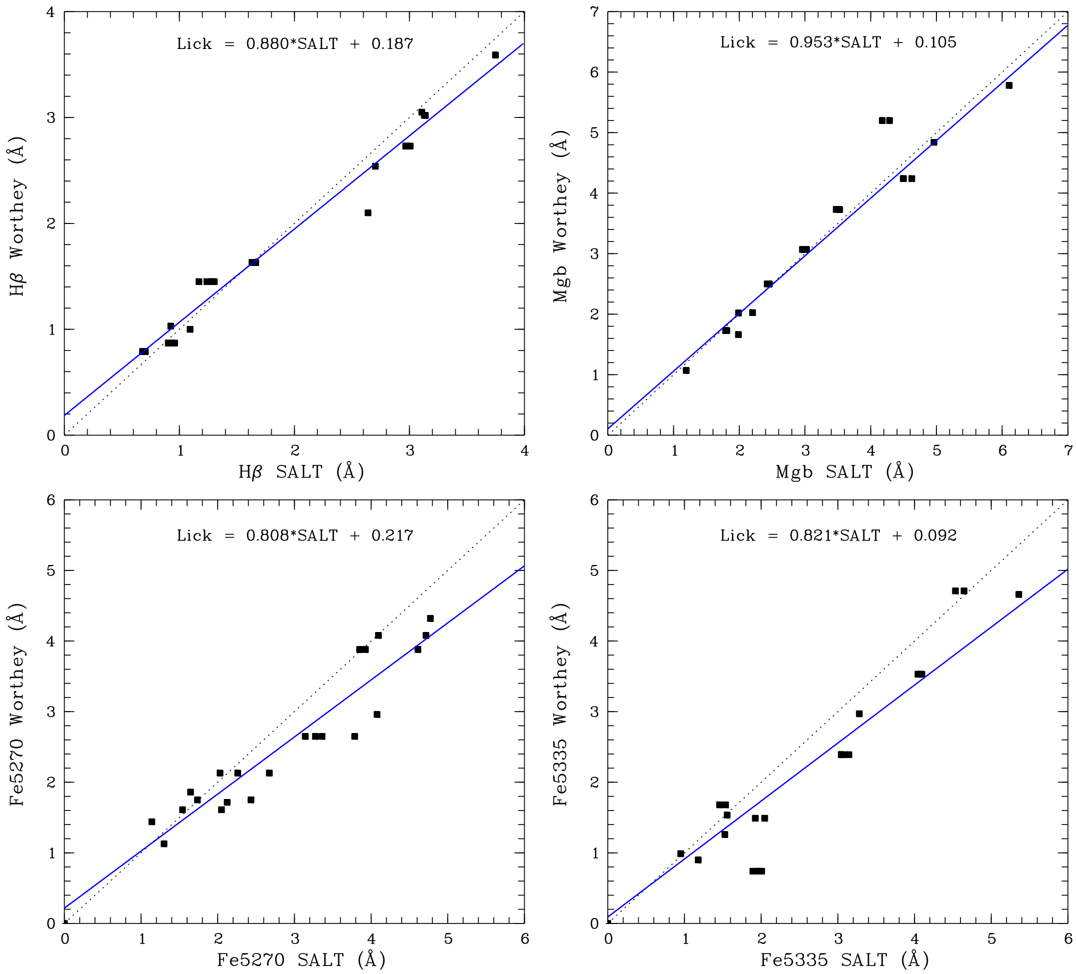

Figure 1: The correlation of the instrumental absorption-line indices obtained with the spectrograph RSS, the grating VPH1800, and the standard Lick indices for 12 stars from the list of Worthey et al. (1994). The blue lines are regressions obtained (with the formulae above the plots), the dotted lines are equality lines.

Then the instrumental-system Lick indices were compared to the tabular values provided by Worthey et al. (1994). The linear dependencies between two sets of data have been recovered, and the linear regressions have been calculated (Fig. 1):

$$\mathrm{H}\beta(\mathrm{Lick}) = (0.88 \pm 0.03) \times \mathrm{H}\beta(\mathrm{RSS1800}) + (0.187 \pm 0.065),$$

the rms scatter of the points around the straight line is 0.14 Å.

$$\mathrm{Mgb}(\mathrm{Lick}) = (0.953 \pm 0.034) \times \mathrm{Mgb}(\mathrm{RSS1800}) + (0.105 \pm 0.110),$$

without HD 4656, with the remaining 11 stars, the rms scatter of the points around the straight line is 0.19 Å.

$$\mathrm{Fe5270}(\mathrm{Lick}) = (0.808 \pm 0.065) \times \mathrm{Fe5270}(\mathrm{RSS1800}) + (0.217 \pm 0.20),$$

the rms scatter of the points around the straight line is 0.35 Å.

$$\mathrm{Fe5335}(\mathrm{Lick}) = (0.821 \pm 0.044) \times \mathrm{Fe5335}(\mathrm{RSS1800}) + (0.09 \pm 0.13),$$

without HD 4656 and HD 10700, with the remaining 10 stars, the rms scatter of the points around the straight line is 0.22 Å.

By comparing the derived rms scatters of the individual stars around the regression straight lines with the mean accuracy of the tabular Lick indices mentioned by Worthey et al. (1994), namely, 0.22 Å for Hβ, 0.23 Å for Mgb, 0.28 Å for Fe5270, and 0.26 Å for Fe5335, we have assured that the scatter of the points at the plots of Fig. 1 is produced mainly by the errors of the tabular indices.

The absorption lines in the spectra of galaxies are broadened by chaotic motions of the stars along the line of sight (so called stellar velocity dispersion). Due to the line broadening, the absorption-line edges can sometimes be beyond the wavelength range of integration prescribed by the Lick system definitions, and the calculated Lick indices may be underestimated. To study the index corrections for the stellar velocity dispersion, we have taken the spectrum of the K0III star HD 6203 (this spectral type is close to the typical integrated spectrum of an old stellar population) observed with the same RSS configuration (the grating VPH1800, the slit width of 1.25″), and have convolved it with a set of Gaussians with the dispersion parameter σ varying smoothly between 50 km/s and 200 km/s. The Lick indices Hβ, Mgb, Fe5270, and Fe5335 have been measured in the convolved spectra, and the dependencies of the relative index differences, $[Index(0) - Index(\sigma)]/Index(0)$, on the dispersion have been derived; they are presented in Fig. 2. To use these dependencies to correct the Lick indices in the galactic spectra with arbitrary line broadening, we approximate the points at Figs. 2 by polinomials of 4th order; the coefficients are in the Table 1.

2.2 The grating VPH900

We have also constructed the system of Lick indices for the grating VPH900, which is used now by us at the RSS to observe the lenticular galaxies with ring structures. We used the slit

Table 1: The polynomial coefficients to correct the Lick indices for the stellar velocity dispersion (the grating VPH1800, the spectral resolution of 2.5 Å)

Index	$\times\sigma$	$\times\sigma^2$	$\times\sigma^3$	$\times\sigma^4$
Hβ	-0.000204	-2.74E-7	7.39E-8	-3.23E-10
Mgb	-0.000587	1.54E-5	-1.9E-7	7.66E-10
Fe5270	0.000376	-4.91E-6	5.2E-8	0
Fe5335	0.00077	-1.31E-5	1.02E-7	0

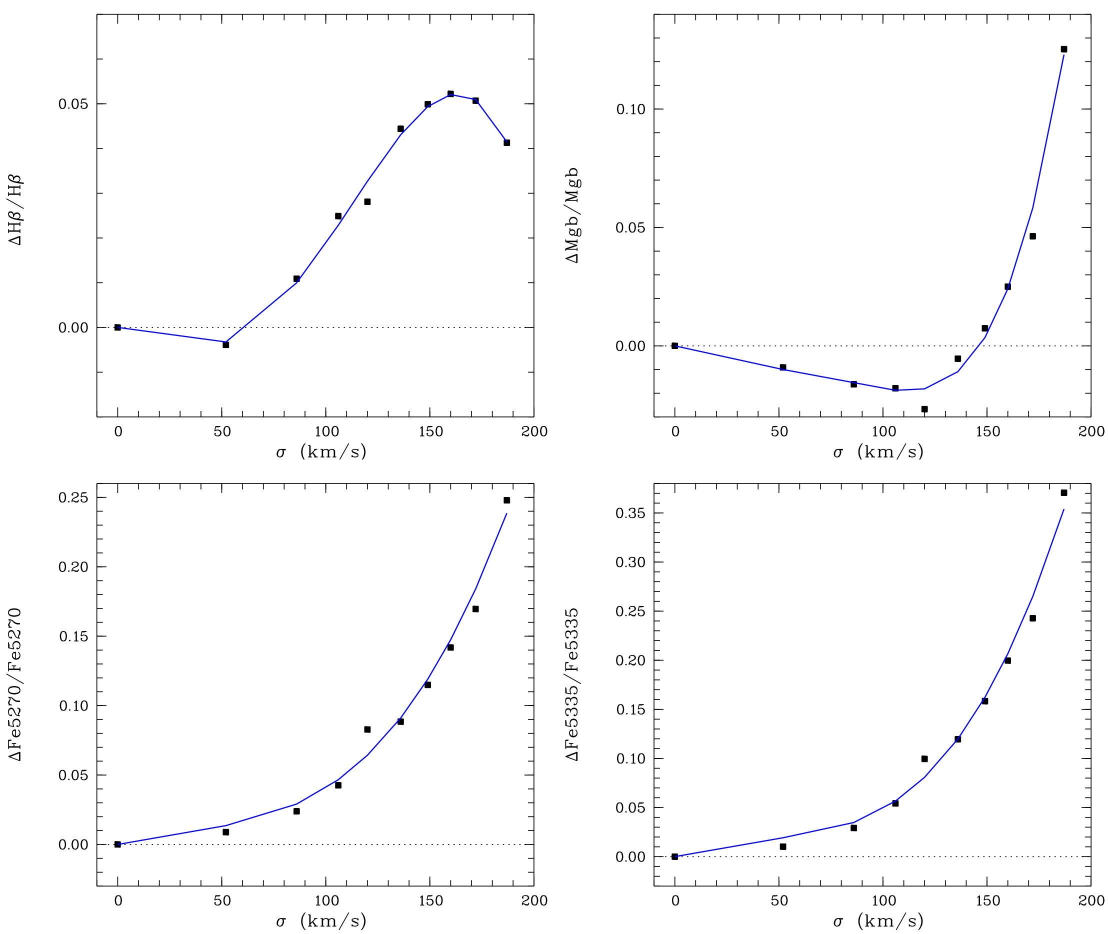

Figure 2: The corrections for the absorption-line broadening (due to stellar velocity dispersion in galaxies) for the Lick indices Hβ, Mgb, Fe5270, and Fe5335, when obtained from the observations with the grating VPH1800, slit of 1.25 arcsec. Blue curves show the polynomial approximations with the coefficients given in Table 1.

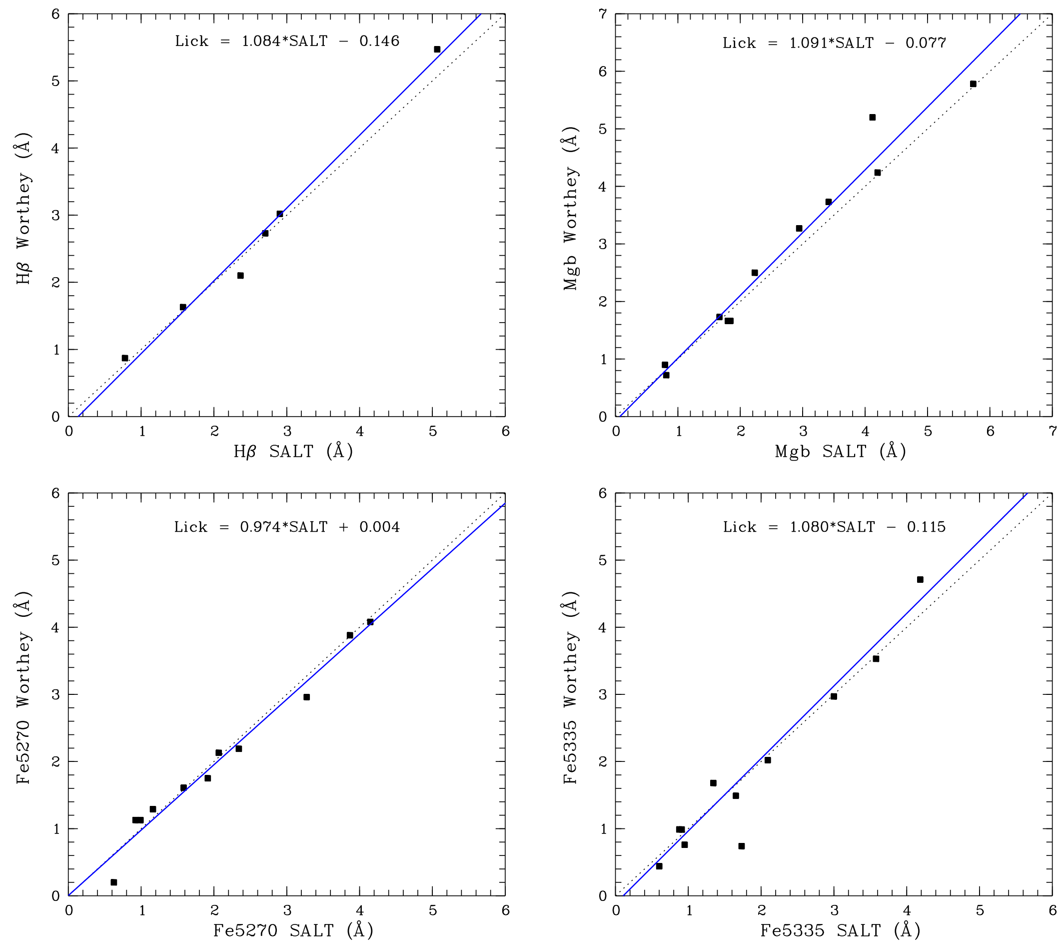

Figure 3: The correlation of the instrumental absorption-line indices obtained with the spectrograph RSS, the grating VPH900, and the standard Lick indices for 10 stars from the list of Worthey et al. (1994). The blue lines are regressions obtained (with the formulae above the plots), the dotted lines are equality lines.

width of 1.25″ providing the spectral resolution of 5.6 Å. This resolution is closer to the Lick standard one, and the spectral range is very large, so the instrumental index system for the grating VPH900 is rather close to the standard Lick system. In Fig. 3 we show the comparison of the instrumental and tabular indices for the Lick stars which have been observed; for 4 stars the grating angle was chosen unluckily, so that the Hβ index was lost. The regression formulae are the following:

$$\mathrm{H}\beta(\mathrm{Lick}) = (1.084 \pm 0.06) \times \mathrm{H}\beta(\mathrm{RSS900}) - (0.146 \pm 0.158),$$

6 points, the rms scatter of the points around the straight line is 0.20 Å.

$$\mathrm{Mgb}(\mathrm{Lick}) = (1.091 \pm 0.069) \times \mathrm{Mgb}(\mathrm{RSS900}) - (0.077 \pm 0.189),$$

10 points, the rms scatter of the points around the straight line is 0.34 Å.

$$\mathrm{Fe5270}(\mathrm{Lick}) = (0.974 \pm 0.053) \times \mathrm{Fe5270}(\mathrm{RSS900}) + (0.004 \pm 0.113),$$

the rms scatter of the points around the straight line is 0.20 Å.

$$\mathrm{Fe5335}(\mathrm{Lick}) = (1.080 \pm 0.059) \times \mathrm{Fe5335}(\mathrm{RSS900}) - (0.115 \pm 0.116),$$

without HD 10700, with the remaining 9 stars, the rms scatter of the points around the straight line is 0.22 Å.

By comparing the derived rms scatters of the individual stars around the regression straight lines with the mean accuracy of the tabular Lick indices mentioned by Worthey et al. (1994), namely, 0.22 Å for Hβ, 0.23 Å for Mgb, 0.28 Å for Fe5270, and 0.26 Å for Fe5335, we have concluded that the scatter of the points at the plots of Fig. 3 is produced mainly by the errors of the tabular indices.

To study the index corrections for the stellar velocity dispersion, we have taken the spectrum of the K3III star HD 10380 observed with the same RSS configuration (the grating VPH900, the slit width of 1.25″), and have convolved it with a set of Gaussians with the dispersion parameter σ varying smoothly between 50 km/s and 200 km/s. The Lick indices Hβ, Mgb, Fe5270, and Fe5335 have been measured in the convolved spectra, and the dependencies of the relative index differences, $[Index(0) - Index(\sigma)]/Index(0)$, on the dispersion have been derived; they are presented in Fig. 4. To use these dependencies to correct the Lick indices in the galactic spectra with arbitrary line broadening, we approximate the points at Figs. 4 by polinomials of 4th order; the coefficients are in the Table 2.

3 Comparison with previous results

To illustrate the validity of the Lick index system obtained by us for the spectral configuration of RSS+VPH1800 explored at the SALT, we have compared the results on the Lick index radial profiles obtained for the lenticular galaxy NGC 509 at the SALT in July-September 2011 to the Lick index profiles obtained earlier at the Russian 6m telescope with the integral-field spectrograph MPFS (Sil'chenko & Afanasiev 2012). The spectral resolution of the latter

Table 2: The polynomial coefficients to correct the Lick indices for the stellar velocity dispersion(the grating VPH900, the spectral resolution of 5.6 Å)

Index	$\times\sigma$	$\times\sigma^2$	$\times\sigma^3$	$\times\sigma^4$
Hβ	-0.000489	1.78E-5	-1.71E-7	3.84E-10
Mgb	0.000978	-2.82E-5	2.45E-7	-5.09E-10
Fe5270	0.000703	-1.53E-5	1.84E-7	-4.38E-10
Fe5335	0.00147	-3.64E-5	3.91E-7	-9.35E-10

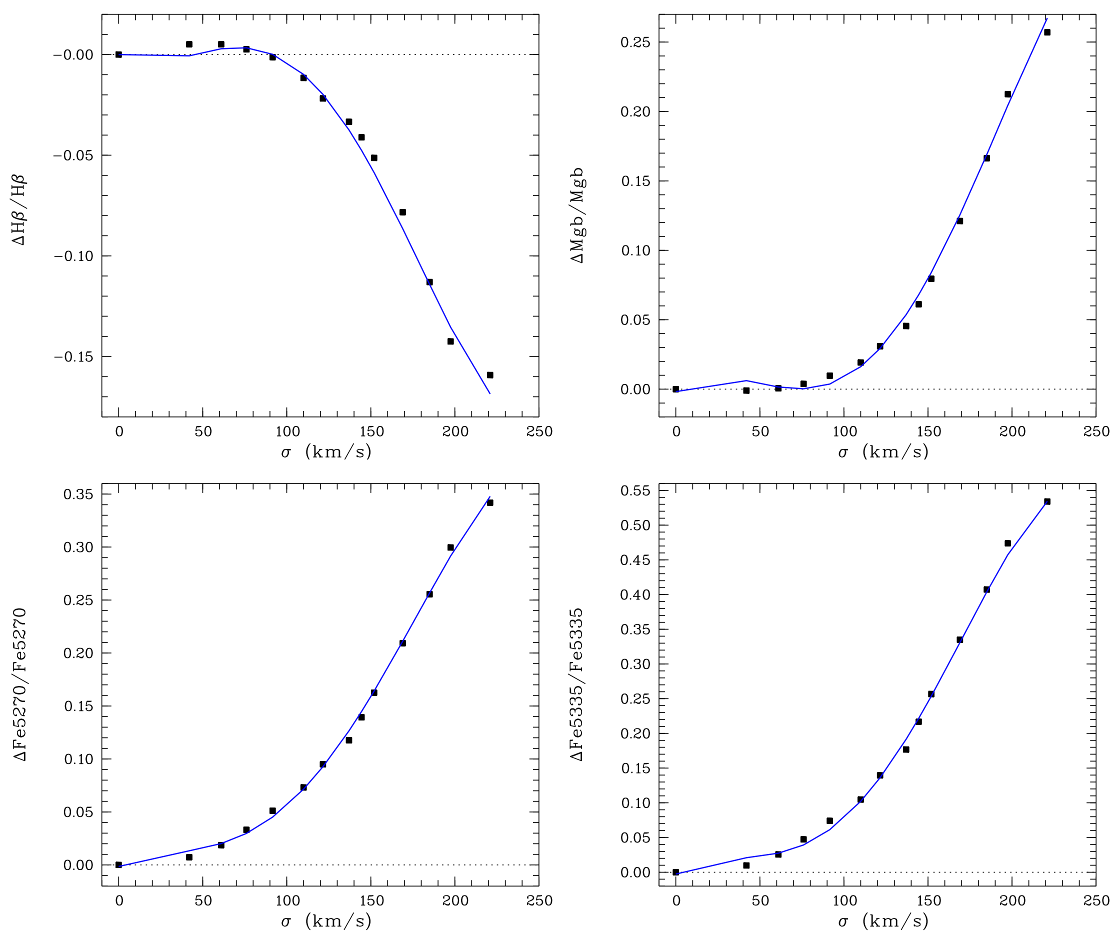

Figure 4: The corrections for the absorption-line broadening (due to stellar velocity dispersion in galaxies) for the Lick indices Hβ, Mgb, Fe5270, and Fe5335, when obtained from the observations with the grating VPH900, slit of 1.25 arcsec. Blue curves show the polynomial approximations with the coefficients given in the Table 2.

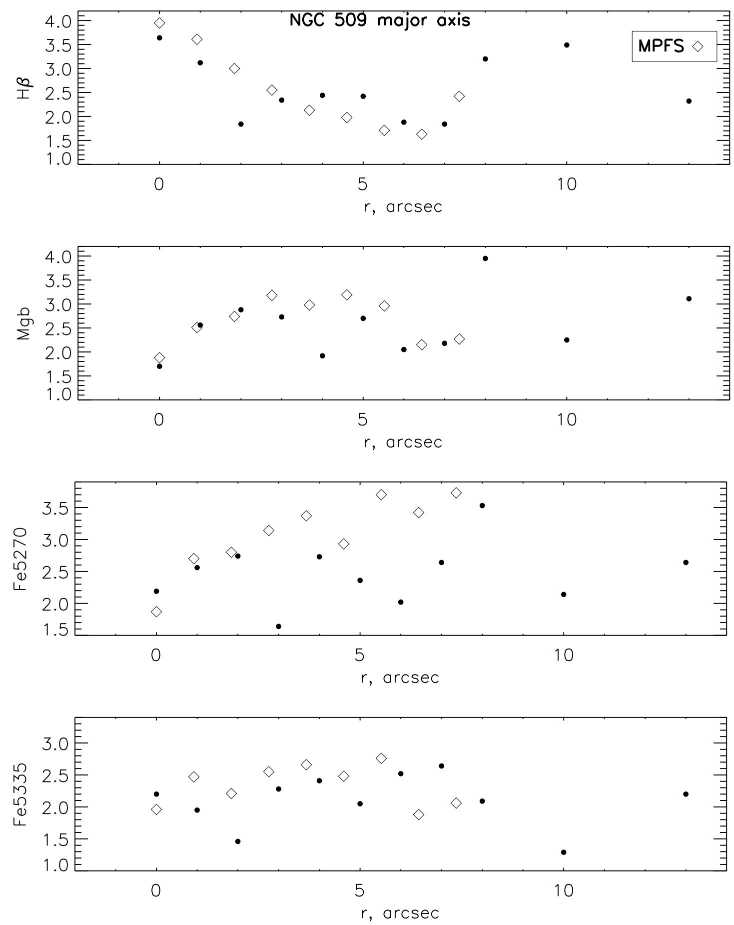

Figure 5: The comparison of the fully calibrated Lick index profiles for the lenticular galaxy NGC 509 observed in 2011 at the RSS/SALT, long-slit mode, the grating VPH1800, with the index profiles obtained earlier with the integral-field unit MPFS of the Russian 6m telescope (Sil'chenko & Afanasiev 2012).

observations was about 4 Å. The comparison is presented in Fig. 5. The direct comparison of the two data sets is not probably straightforward, because the observations with the RSS represent long-slit spectroscopy, with the slit of $1.25''$ aligned with the galactic disk major axis, while the MPFS data are azimuthally averaged in rings; the exact coincidence is certainly expectable only within the central bulge-dominated area. However, one can see in Fig. 5 that the Hβ and Mgb profiles agree in the center of NGC 509 almost perfectly and that of the iron indices – reasonably.

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