EUROPEAN SOUTHERN OBSERVATORY

INTERNAL MEMORANDUM

March 26, 2007

To: VIMOS IOT

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Subject: VIMOS total transmission profiles for broad-band filters

1 Introduction

The VIMOS consortium has provided the laboratory measurements of grism and filter transmission profiles. These are available from the consortium web page:
http://www.mi.astro.it/docM/OAB/oab.html
and they are also shown in figures in the VIMOS User Manual Appendix B.
For a number of scientific projects the measured total transmission curves including the detector and optics of the telescope are the most appropriate data. What is available to ESO now are the "average" efficiency curves for all four quadrants (available through the ETC), whereas some of our customers asked for the characteristics of the individual quadrants. Furthermore, a re-measurement of filter transmission is necessary to check the status of the filters after some years.

2 Observations and data reduction

The data necessary to derive the transmission and efficiency curves were collected between 21st March and 24th of August 2006, see also the Appendix. They consist of standard-star exposures with the LR red (for RIz filters inserted) and LR blue grism (for UBV filters inserted), plus corresponding bias, screen-flat and wave-lamp exposures. Note that the calibration data were taken as close as possible in time to the science data. The screen flats were taken with and without filters for both the blue and red grism. We took an entire UBVRIz set of spectra for the standard star Hiltner 600. In addition, we observed the standards LTT 1020 and LTT 7379 in B and LTT 7379 in U.
The data reduction was performed using the VIMOS pipeline recipes vmspflat, vmspcaldisp, vmmosstandard and the IRAF packages twodspec and onedspec.

We will use the following definitions:

- $T_t(\lambda)$ - transmission of the CCD + telescope optics

- $T_g(\lambda)$ - grism transmission profile (tabulated, see Fig. 1)
- $T_f(\lambda)$ - filter transmission profile
- $F(\lambda)$ - spectral energy distribution of the spectrophotometric standard star (tabulated)
- $L(\lambda)$ - spectral energy distribution of the continuum lamp used to create screen flats
- $k(\lambda)$ - atmospheric extinction coefficient (tabulated, taken from La Silla)
- $S(\lambda)$ - flux measured on the detector

3 Filter transmission curves

The filter transmissions are derived from spectroscopic continuum lamp flat-field spectra. One set of flats was measured with the filters inserted, another set without a filter inserted. For the two intensity curves measured without and with the filter it holds:

$$S_1(\lambda) = T_t(\lambda) \times T_g(\lambda) \times L(\lambda) \tag{1}$$

and

$$S_2(\lambda) = T_t(\lambda) \times T_g(\lambda) \times L(\lambda) \times T_f(\lambda) \tag{2}$$

The filter transmission is simply the ratio of the two curves:

$$T_f(\lambda) = \frac{S_2(\lambda)}{S_1(\lambda)} \tag{3}$$

The derived filter transmission curves are shown in Fig. 2, including for comparison the filter curves provided by the VIMOS consortium. We note that our measurements for U and B band are the mean of two sets of screen flat exposures obtained within 5 month separation. The difference in absolute transmission between these two sets were below 0.1% for both U and B. For the VRIz filters there is very good agreement between the consortium transmission estimate and our measurements derived from the screen flats. For the B filter, the screen-flat transmission is about 10-15% below that of the consortium for quadrants Q1 and Q2. For the U-band, the new estimates are below the consortium ones by about 25% for all 4 quadrants. Note that the consortium estimates for the U-band show a red leak at about 4200 Å. This is not detected in our data. Only Q4 shows a very minor red leak at about 4850 Å, see the next Section.

4 Total filter+CCD+telescope efficiency curves for UBVRIz filters

The scientifically most useful information is the product of the (unknown) CCD+telescope transmission $T_t(\lambda)$ and the filter sensitivity $T_f(\lambda)$, that is the "telescope+instrument efficiency". To derive this quantity, one only requires the flux $S_S(\lambda)$ of the standard star observed with the grims and the respective broad band filter inserted:

$$S_S(\lambda) = T_t(\lambda) \times T_f(\lambda) \times k(\lambda) \times T_g(\lambda) \times F(\lambda) \tag{4}$$

The instrument efficiency $T_t(\lambda)\times T_f(\lambda)$ it then derived with the following transformed equation

$$T_t(\lambda) \times T_f(\lambda) = \frac{S_S(\lambda)}{k(\lambda) \times T_g(\lambda) \times F(\lambda)} \tag{5}$$

Note that the three quantities in the denominator are known: $k(\lambda)$ is the La Silla extinction curve, $T_g(\lambda)$ is the grism transmission taken from the consortium web page (see also Fig. 1), and $F(\lambda)$ is the SED of the standard star.
The resulting efficiency curves derived for all six broad band filters UBVRIz in the four quadrants are shown in Fig. 3. For comparison, the efficiency curves presently used for the VIMOS ETC (using filter transmissions provided by the consortium) are also shown. Except for quadrant 3 in the U-band (see below), there is good agreement between our measurements and the ETC values. A general feature of these transmission curves is the overall lower transmission of quadrant 3 with respect to other quadrants.
The lines plotted in Fig. 3 are fits of the transmission efficiency that smooth out residual spectral features of standard stars. We took care that the fitted sensitivity integrated over all wavelengthes did not vary by more than 0.5 from that in the original, non-smoothed spectra. The efficiency curves for VRIz filters are derived from the standard star Hiltner 600. B-band curves are the mean of the measurements from Hiltner 600 and LTT 7379 for quadrants 2, 3 and 4. The difference between the two measurements is less than 2%. For quadrant 1, the fit for LTT 7379 still had notable residual features around the 4000 Å break, such that we used only Hiltner 600 for the quadrant 1 B-band efficiency curve. The observation of standard star LTT 1020 in B-band was not used, because it was affected by non-photometric/clear conditions yielding significantly lower total efficiency. For the U-band we used only LTT 7379, since the exposures with Hiltner 600 yielded systematically lower efficiency. This was traced to the flux losses beyond the slit borders due to imperfect centering of the star in the slit.
Three final notes on the U-band efficiency curves:
1. The U-band showed the strongest signs of instrument flexure. That is, the difference between the 0th order standard star position and 0th order arc lamp was non negligible and varied significantly between different quadrants. To correct for this effect, we shifted the efficiency curve by the displacement between standard star and arc lamp 0th order. The shifts ranged between 5 and 30 Å.
2. The substantial loss of efficiency in quadrant 3 equally occurs for the two different standard stars. Since the U-band photometric zeropoints for Q3 that are tabulated on the ESO-webpage (http://www.eso.org/observing/dfo/quality/VIMOS/qc/qc1.html) do not show such a strong drop, a systematic centering problem due to instrument flexure is a possible reason for this lack of measured flux. In addition, the consortium estimate of the grism tranmission in Q3 for l<3800 Å may be too high. Given the deviation in Q3, we advise that the efficiency estimates especially in the U-band be always re-scaled to the (integrated) photometric zero-points.
3. Unlike in the consortium filter transmission curves from Fig. 2, we do *not* detect a pronounced red leak of the U-band filter around 4200 Å. Only in quadrant 4, there is a very minor leak at about 4850 Å, which amounts to about 0.1% of the peak efficiency (see Fig. 4).

Appendix

In the following Tables 1 and 2 we give a list of raw images used for creating filter transmission curves (Fig. 2) and total instrument efficiency curves (Fig. 3).

Table 1: List of raw images used for creating the filter transmission curves in Fig. 2. The symbol "*" for the U-band screen flat No.2 corresponds to a set of 6 images, where "*" runs from 3 to 8. The image names given here are for quadrant 1.

Image name	Filter	grism	Image type
VIMOS_MOS_LAMP084_0061_B.1.fits	U	LR blue	screen flat No.1
VIMOS_MOS_LAMP236_000*_B.1_0001.fits	U	LR blue	screen flat No.2
VIMOS_MOS_LAMP084_0062_B.1.fits	B	LR blue	screen flat No.1
VIMOS_MOS_LAMP236_0009_B.1_0001.fits	B	LR blue	screen flat No.2
VIMOS_MOS_LAMP084_0063_B.1.fits	V	LR blue	screen flat
VIMOS_MOS_LAMP084_0060_B.1.fits	free	LR blue	screen flat without filter No.1
VIMOS_MOS_LAMP236_0001_B.1.fits	free	LR blue	screen flat without filter No.2
VIMOS_MOS_LAMP084_0057_B.1.fits	R	LR red	screen flat
VIMOS_MOS_LAMP084_0058_B.1.fits	I	LR red	screen flat
VIMOS_MOS_LAMP084_0059_B.1.fits	z	LR red	screen flat
VIMOS_MOS_LAMP084_0052_B.1.fits	free	LR red	screen flat without filter

Table 2: List of raw images used for creating the total instrument efficiency in Fig. 3. The image names given here are for quadrant 1.

Image name	Filter	grism	Image type
VIMOS_MOS_STD080_0005_B.1.fits	U	LR blue	Standard star spectrum Hiltner 600
VIMOS_MOS_STD235_0006_B.1.fits	U	LR blue	Standard star spectrum LTT 7379
VIMOS_MOS_STD081_0001_B.1.fits	B	LR blue	Standard star spectrum Hiltner 600
VIMOS_MOS_STD236_0002_B.1.fits	B	LR blue	Standard star spectrum LTT 7379
VIMOS_MOS_STD211_0012_B.1.fits	B	LR blue	Standard star spectrum LTT 1020
VIMOS_MOS_STD082_0001_B.1.fits	V	LR blue	Standard star spectrum Hiltner 600
VIMOS_MOS_STD082_0001_B.1.fits	R	LR red	Standard star spectrum Hiltner 600
VIMOS_MOS_STD083_0001_B.1.fits	I	LR red	Standard star spectrum Hiltner 600
VIMOS_MOS_STD083_0001_B.1.fits	z	LR red	Standard star spectrum Hiltner 600

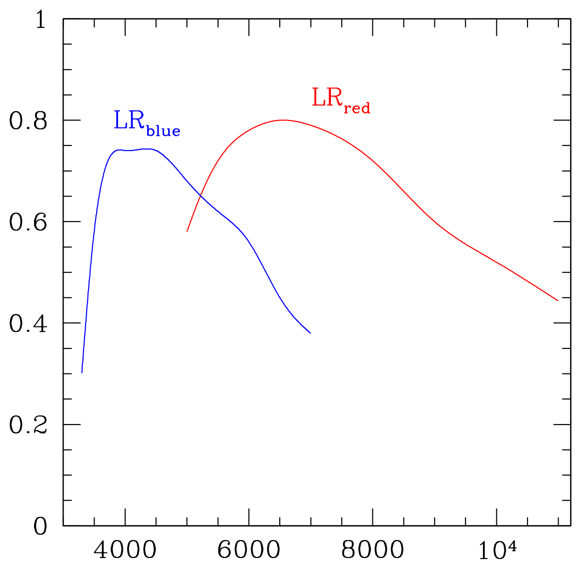

Figure 1: Consortium transmission profiles of the LR red and blue grism. X-axis is in units of Å.

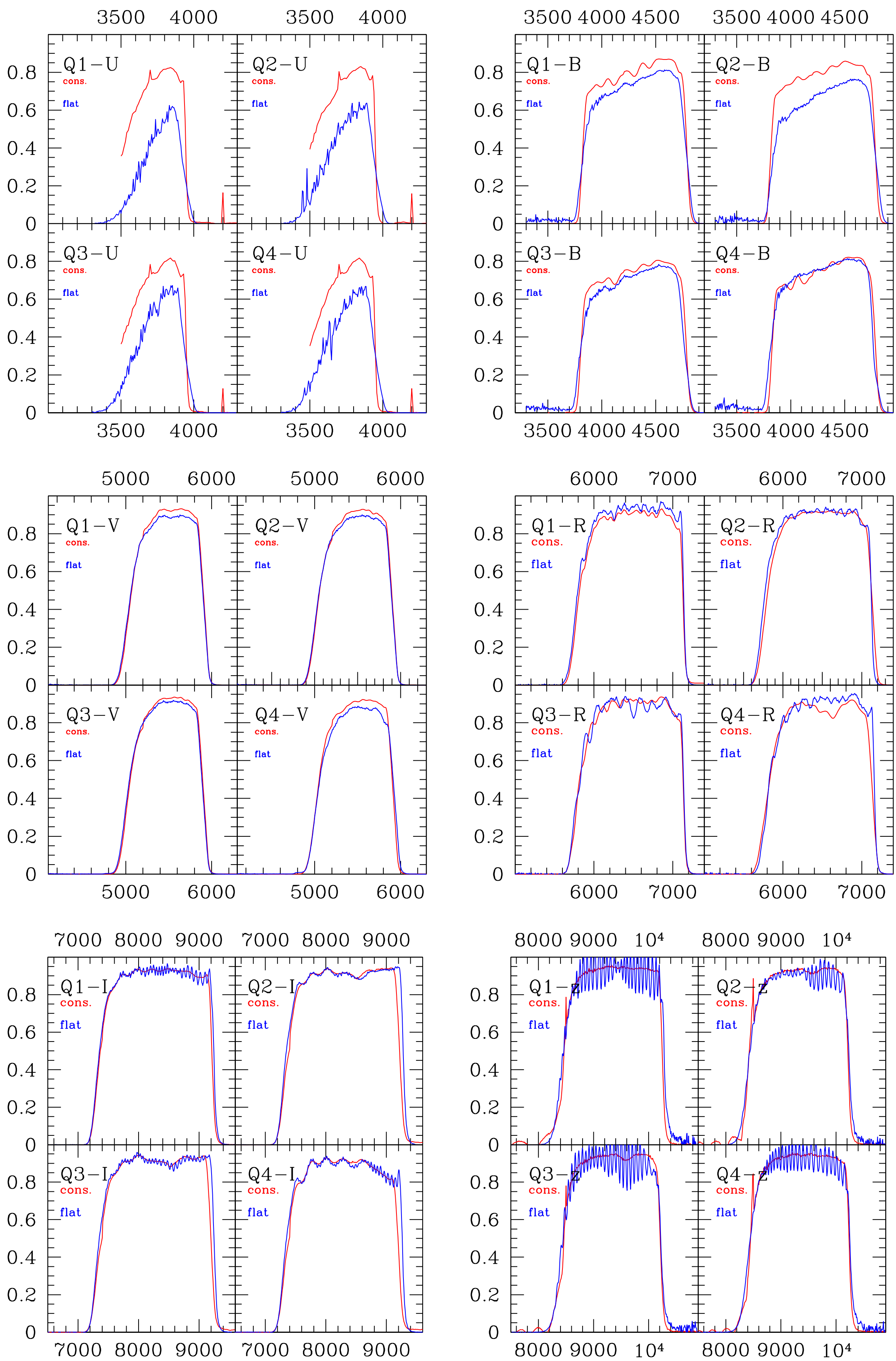

Figure 2: . Filter transmission profiles for VIMOS UBVRIz. X-axis is in units of Å.

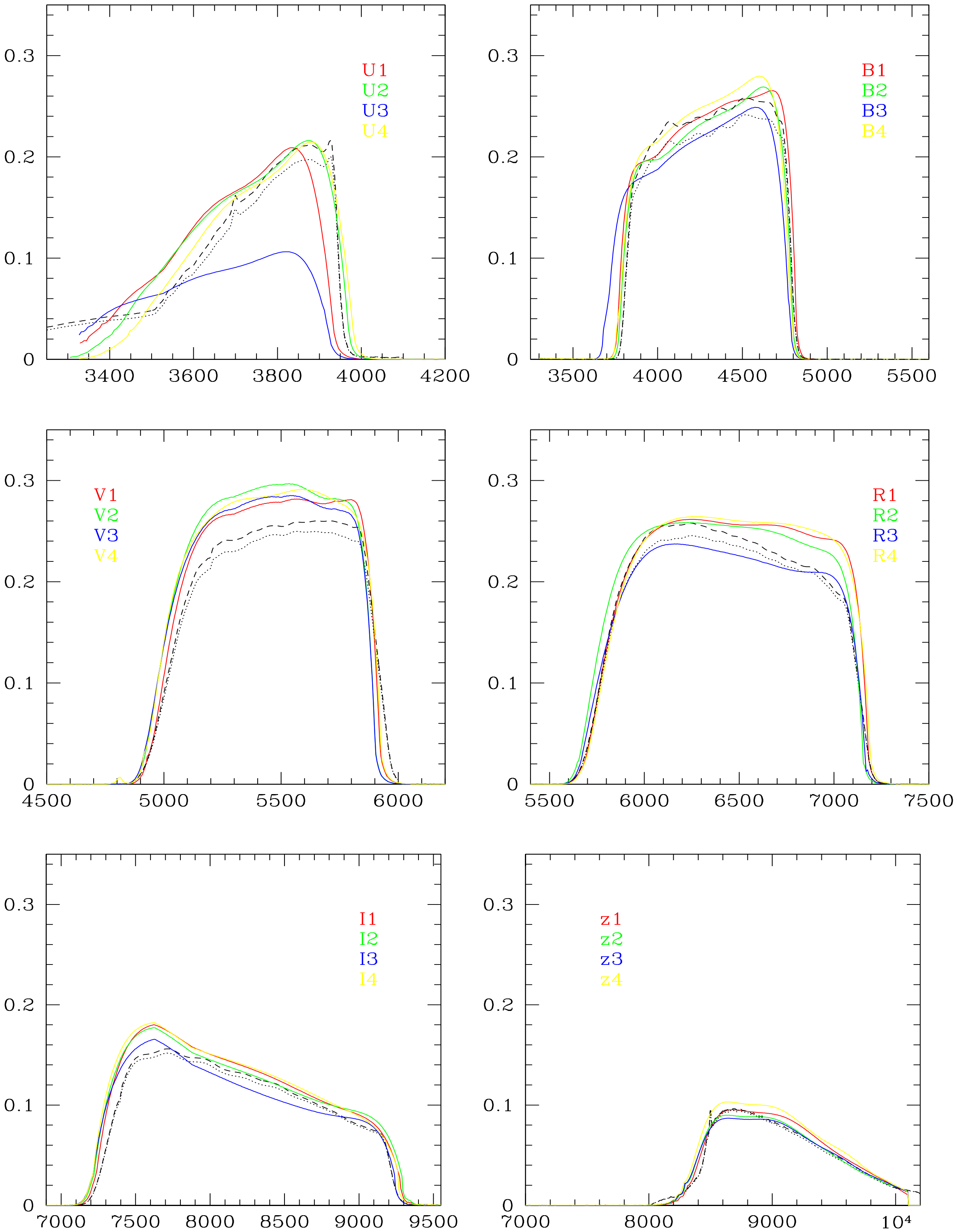

Figure 3: . Total VIMOS telescope+instrument efficiency curves for UBVRIz. X-axis is in units of Å. The dotted lines are the efficiency curves available from the VIMOS ETC on the web. Since the latter curves also include atmospheric extinction, we have divided them by the La Silla extinction curve $k(\lambda)$ that is also used to correct the efficiency measurements of the present data set. For comparison, the dashed line indicates the VIMOS ETC efficieny curves when using the CTIO extinction curve instead of the La Silla one.

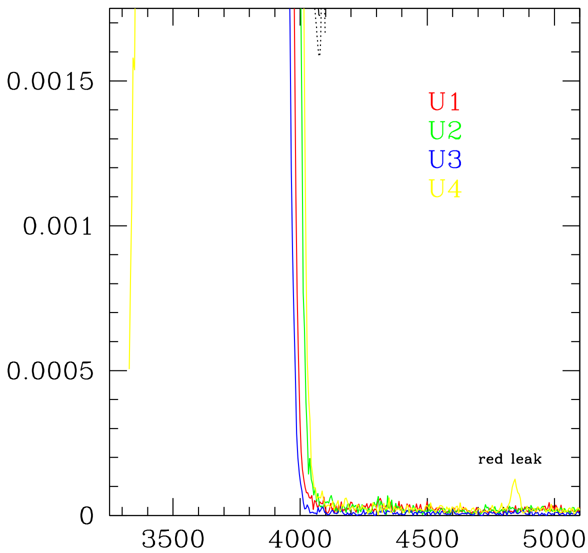

Figure 4: Detection of a very small "red leak" in the U-band efficiency curve of Q4. Note that the y-axis has been zoomed in by a factor of 200 compared to Fig. 3. The peak of the red leak is about 0.1% of the efficiency peak.