Determination of Quantum Efficiency of UVIT Flight Model Detectors

C. S. Stalin, S. Sriram & Amit Kumar

Indian Institute of Astrophysics

Bangalore 560 034

Version 0.2

26 July 2011

1. Introduction

UVIT has three FM detectors of same type for imaging in three wavelength regions FUV, NUV and VIS bands. During March 2010, some experiments were carried out at CREST, Hoskote, with an aim to calibrate the Quantum Efficiency (QE) of FM detectors of UVIT.

2. Calibration Tests on the Detectors:

Calibration tests were carried out to measure the following

1. QE of the FUV detector
2. QE of the NUV detector
3. QE of the VIS detector

The QE measurement for each detector involves two steps

1. Measurement of the number of photons detected by the detector
2. Measurement of the total number of photons falling on the detector surface

Both these tests need the same experimental conditions to be maintained

3.0 Calibration of 3X3 holemask:

To measure the total no. of photons falling on the detector input window, a NIST photo-diode was used. The sensitivity of NIST photo-diode is 1000 times lesser than that of the Flight Model Detector Modules (DM). Therefore, sufficient amount of light is to be made incident on the Photo-diode to get good results. However, if the same amount of light is allowed to incident on the FM DM it may damage the Detector. To avoid this damage a mask of hole size 500 microns and separation 5mm of 0.1% transmission was made to be placed in the collimated beam path for measuring the number of photons detected by the detector. However, before performing the experiment, the mask also needs to be well calibrated such that it is transmitting 0.1% of light incident on it.

3.1 Experimental Set-up:

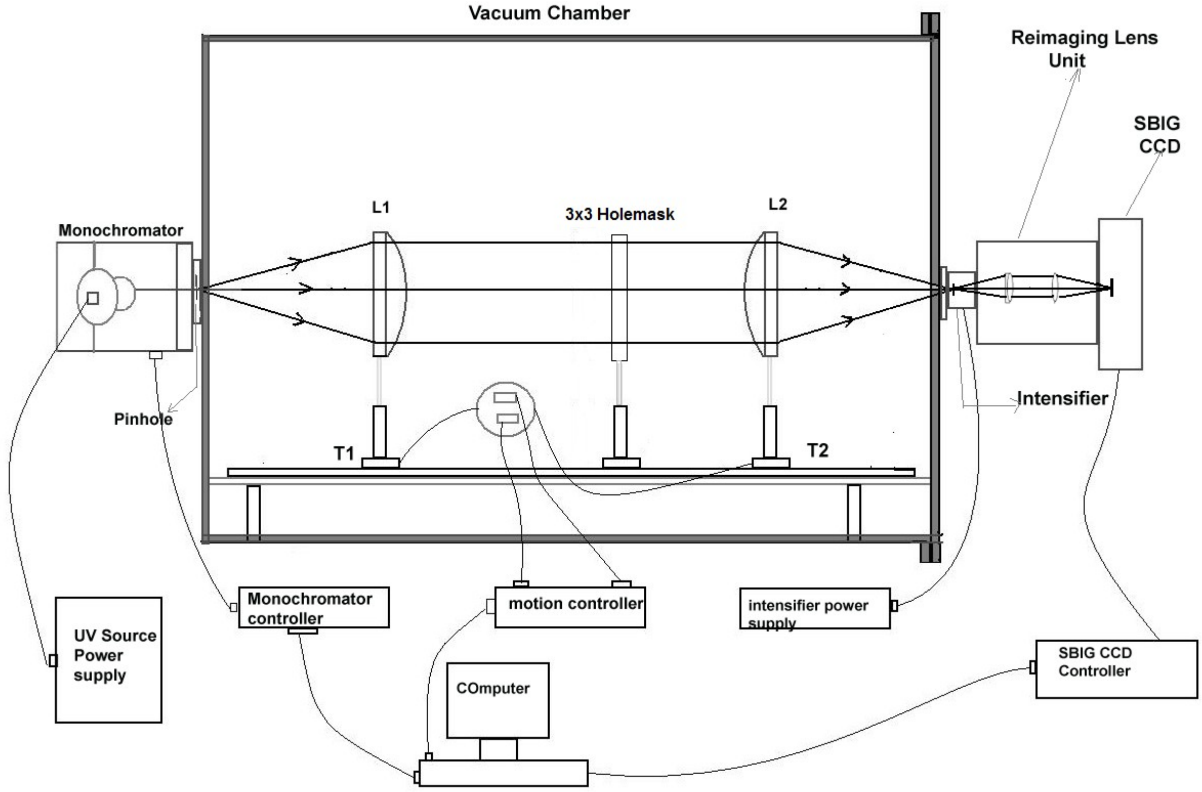

Fig. 1: Test set up for calibrating the mask

For calibrating the mask, the test set up as shown in Fig. 1 was used. Here, the input port of the vacuum chamber (evacuated to 10^{-4} mbar) hosts the monochromator. This monochromator helps in selecting the desired wavelength. The light beam of any selected wavelength from the monochromator with an input slit width of 5 micron enters the vacuum chamber through a pinhole with a size of 50 micron. Diverging beam from the pinhole was made into a well collimated beam with the help of lens L1 placed at a certain distance from the aperture and is equal to the focal length of the lens. This collimated beam was focused on to the image intensifier mounted at the output port of the vacuum chamber with the help of another lens L2. The output beam from the image intensifier was focused onto a SBIG CCD camera with the help of re-imaging lens system. The positions of lenses L1 and L2 are adjustable as required for the wavelength, by moving the stages T1 and T2 with the help of the motion controller in order to get a well focused beam at the focal plane.

3.2 Data Acquisition & Analysis:

In a effort to get rid of the light reflection noticed in an earlier data set obtained for mask calibration (a) the mask was coated with black (b) proper baffling was done to get rid of any external light and (c) the SBIG camera was covered with a black sheet. In addition to that, two more changes were made to the experimental set up described in Fig. 1 (a) the monochromator input slit was increased to 90 micron and (b) the monochromator output pin hole size was changed to 100 micron.

Data was acquired at the wavelengths 182.3nm, 187.9nm, 193.7nm, 200.3nm, 206.7nm, 213.8nm, 221.4nm, 229.6nm, 238.5nm and 253.7nm. At each wavelength image frames with and without mask were recorded. A sequence of 10 image frames of dark and light exposures were taken without mask in collimated beam path. The filter wheel was then rotated to select the 3x3 mask and again 10 image frames of light and dark were taken. This was repeated for the 10 wavelengths. The exposure time of image frames with and without mask are 30 secs and 5 secs respectively. Dark frames were median combined to form master dark frames. These master dark frames were then substracted from the corresponding light image frames. The dark substracted light frames were then median combined to form one light frame each with and without mask for a total of 10 wavelengths. The number of counts in each final image with and without mask was estimated for each wavelength. The background counts estimated from few light free regions in the frame were substracted from these counts. This was carried out with the CCD software which came along with the SBIG camera. An example image frame is shown in Fig. 2 . The results of this experiment is given in Table. 1.

Fig 2: Image of the hole mask onto the SBIG Camera for an exposure of 30 seconds

Table 1. Mask calibration measurements for the data taken on 20/01/2010 (?)

Wave length in nm	Without mask		With mask		Counts/sec		Transmit. (%)
	counts	Exp (s).	counts	Exp. (s)	Open	mask	
182.3	198655916	5	1137172	30	39731183.2	37905.7	0.095
187.9	186332392	5	1056791	30	37266478.4	35226.4	0.095
193.7	171047802	5	968313	30	34209560.4	32277.1	0.094
200.5	164227076	5	933155	30	32845415.2	31105.2	0.095
206.7	165950556	5	947778	30	33190111.2	31592.6	0.095
213.8	167148703	5	949283	30	33429740.6	31642.8	0.095
221.4	161786796	5	902520	30	32357359.2	30084.0	0.093
229.6	154522655	5	848075	30	30904531.0	28269.2	0.091
238.5	146760649	5	809054	30	29352129.8	26968.5	0.092
253.7	123947176	5	712422	30	24789435.2	23747.4	0.096

The average transmittance = 0.095%

3.3 Measurement of the numer of photons detected by the detector

Experimental setup:

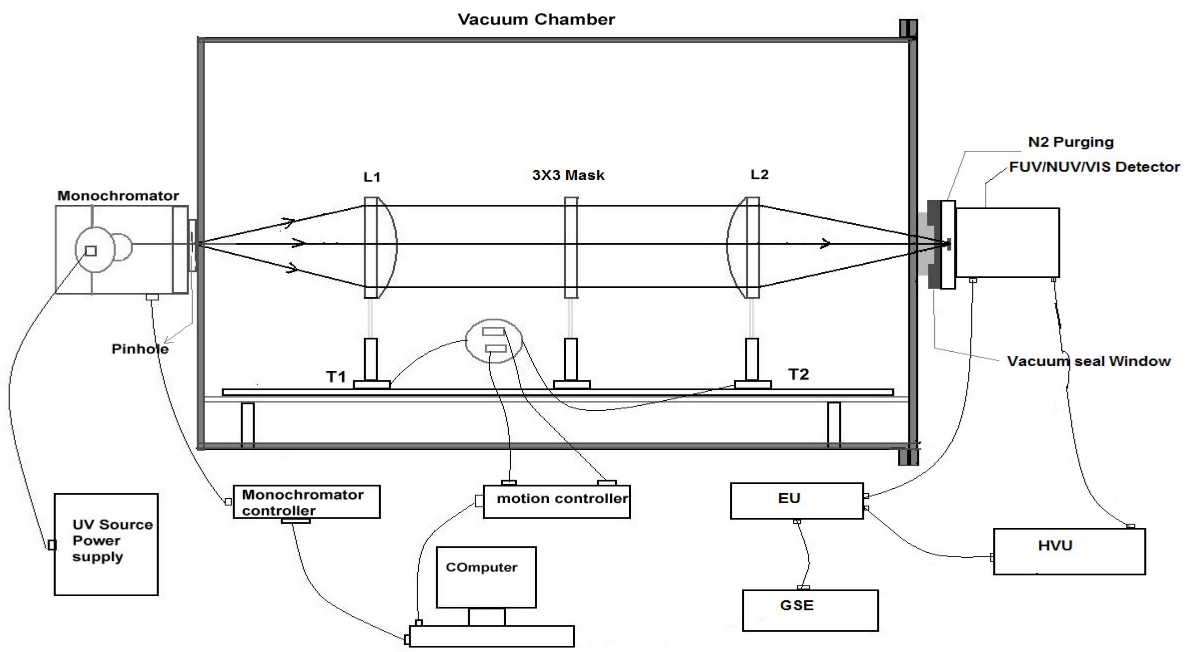

Fig. 3. Test set up for measuring the QE

The test setup for measuring the Q.E. is shown in Fig. 3. The input port of the vacuum chamber hosts the monochromator. Using the monochromator, the desired wavelength can be selected. The light beam of the selected wavelength from the monochromator with an input slit of 90 micron enters into the vacuum chamber through the monochromator output pinhole of size 100 microns. The diverging beam from the pinhole was made into a well collimated beam with the help of lens L1 placed at a certain distance from the pinhole, equal to the focal length of the lens. This collimated beam was then focused with the help of another lens L2 of same kind as L1 on to the photocathode inside the input window of FM detector module. The photocathode thus produces an electron for each incident photon. These photoelectrons were then accelerated through a gap of 100-200 mm towards the MCP stack resulting in an electron shower. At the rare end of the MCP stack ,the electron shower was fed through a fiber taper, the ends of which was fixed to the Star 250 CMOS image sensor. The positions of lenses L1 and L2 were adjustable as required for the wavelength, by moving the stages T1 and T2 with the help of the motion controller in order to get the well focused beam at the focal plane.

3.4 Data Acquisition:

Using the experimental setup in Fig. 3, the images were acquired using the FM detectors.

I. FUV DETECTOR:

With FUV detector, the wavelength region 125 nm-155 nm was scanned. The complete detector was exposed (512X512pixels); however only 200X200 pixel region of the detector was read. The exposures were taken in photon counting mode and the images read with a frame rate 172 frames/sec and the total exposure time in case of each wavelength was about 39 sec. While taking the exposures a 3x3 mask with 0.095% transmission was kept in the path of the light beam. The active area on the NIST photo-diode was 10 mm which corresponds to 3.3 mm area on the star250 CMOS sensor after fiber taper which is equivalent to 133x133 pixel area.

II. NUV DETECTOR:

With NUV detector, the wavelength region 170 nm-300 nm was scanned. The complete detector was exposed (512X512pixels); however only 200X200 pixel region of the detector was read. The exposures were taken in photon counting mode and the images read with a frame rate of 172 frames/sec and total exposure time in case of each wavelength was about 27 sec. While taking the exposures a 3x3 mask with 0.095% transmission was kept in the path of the light beam. The active area on the NIST photodiode is 10 mm which corresponds to 3.3 mm area on the star250 CMOS sensor after fiber taper and is equal to 133x133 pixel area.

III.VIS DETECTOR:

With VIS detector, the wavelength region 310 nm-550 nm was scanned. The complete detector was exposed (512X512pixels); however only 200X200 pixel region of the detector was read. The exposures were taken in photon counting mode and the images read with a frame rate of 172 frames/sec and total exposure time in case of each wavelength was about 32 sec. While taking the exposures a 3x3 mask with 0.095% transmission was kept in the path of the light beam. The active area on the NIST photodiode is 10 mm which corresponds to 3.3 mm area on the star250 CMOS sensor after fiber taper and is equal to 133x133 pixel area.

3.5 Data Analysis:

At each wavelength for the given exposure time the output data file was created in the .img format, which contains both science data and telemetry information. Each *.img file is of size 512MB and it consist of many *.raw (FITS) files. The conversion from *.img to *.raw was made by using the CCDLAB software developed at University of Calgary by Joe Postma.

i. FUV region:

Here the main objective was to determine total number of counts on the detector surface. In order to calculate the counts, photometry was done on an aperture with a box size of 50x50 pixels with help of POLYPHOT task in IRAF. To measure the background value a ring of 20 pixels width was fixed around the annulus of diameter 35.355 pixels. By running the POLYPHOT task, the total number of counts was obtained in the 50x50 pixels region. The measured counts after background substraction was then converted to counts/sec. The same procedure was repeated for all the wavelengths in the region.

ii. NUV region & VIS region:

The same procedure as detailed above for FUV was repeated in case of NUV and VIS regions as well and the counts per second was measured.

The above photometry resulted in the total number of photons detected by the FM detectors. To get the QE of the detectors, the total number of photons falling on the detector needs to be known. Therefore, to know the photons incident on the detector, another experiment was conducted using the NIST photo-diode.

3.6 Measurement of total number of photons incident on the detector

The experimental setup remains almost the same as in Fig. 3, except two changes (i) the light was allowed to fall on the Photodiode mask without any mask in the path of the beam and (ii) NIST photo-diode was mounted on the output port of the detector chamber instead of FM-detectors. This is shown in Fig. 4. The output voltage of the NIST photodiode due to the incident photons was measured with the help of a multimeter connected to the photo-diode.

Experimental Setup:

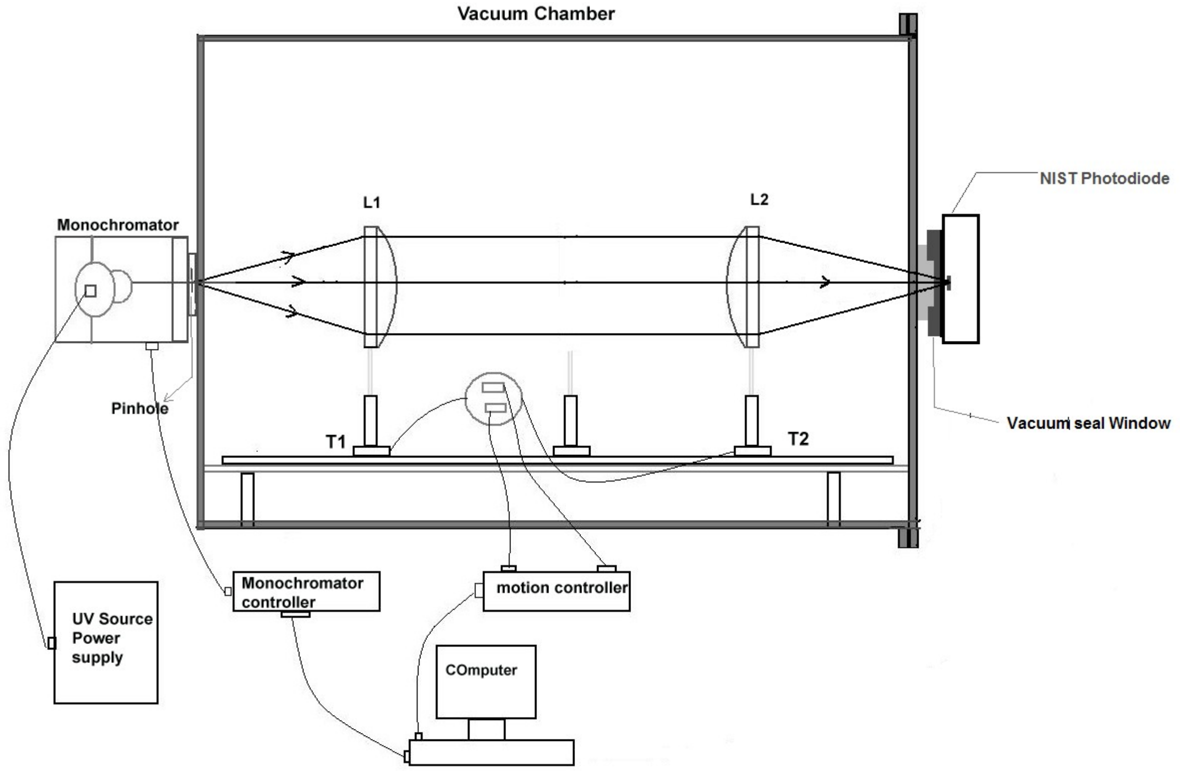

Fig. 4. Experimental set up for NIST photo-diode measurements

3.7. NIST Photo Diode:

International Radiation Detectors Silicon Photodiode AXUV 100G was used in the experiment for determining the absolute QE of the FM detectors. Using this test photo diode, the total number of photons falling on the detector window was measured (from the output voltage produced by the photo diode).

The test photo diode S/N 08-6 10, is a windowless International Radiation Detectors (IRD) AXUV 100G Silicon Photo diode supplied by the National Institute of Standards and Technology. The active area of the photo diode was approximately 1 cm^2. The spectral power responsivity for the region (200 nm-110 nm) was in the calibration report provided by the manufacturer and is used for further measurements with the detector.

3.8 Data Acquisition with NIST Photodiode:

The experimental set up shown in Fig. 4 was used to acquire data using the NIST photo-diode.

i. FUV Region:

In this region data was acquired in the wavelength region 125 nm-155 nm, (for the same wavelengths, which were used to acquire the exposures by the FUV detector).For each wavelength the photo-diode was exposed and the output current (voltage) of the photo-diode was fed to an amplifier circuit and the amplified output voltage of the diode was measured. For each wavelength, a set of 10 output voltages were measured with light exposure. For the same wavelength before exposing the diode to light, a set of ten output voltage values for dark exposure was also measured. The same procedure was repeated for all the remaining wavelengths in the region.

ii. NUV Region:

In this region data was acquired in the wavelength region 170 nm-300 nm, (for the same wavelengths, which were used to acquire the exposures by the NUV detector).For each wavelength the photo-diode was exposed and the output current (voltage) of the photo-diode was fed to an amplifier circuit and the amplified output voltage of the diode was measured. For each wavelength a set of 10 output voltages were measured with light exposure. For the same wavelength before exposing the diode to light, a set of ten output voltage values for dark exposure was also measured. The same procedure was repeated for all the remaining wavelengths in the region.

iii. VIS Region:

In this region data was acquired in the wavelength region 310 nm-550 nm, (for the same wavelengths, which were used to acquire the exposures by the VIS detector).For each wavelength the photo-diode was exposed and the output current (voltage) of the photo-diode was fed to an amplifier circuit and the amplified output voltage of the diode was measured. For each wavelength a set of 10 output voltages were measured with light exposure. For the same wavelength before exposing the diode to light, a set of ten output voltage values for dark exposure was also measured. The same procedure was repeated for all the remaining wavelengths in the region.

3.9. Data Analysis:

For each wavelength, a set of ten output voltages with light and dark exposures were obtained. From these ten output voltages the average was determined in case of both light as well as dark exposures. The difference between the voltage of light and dark exposures gives the resultant voltage due to the incident photons on the photo diode surface. This procedure was followed to measure the resultant voltage due to incident photons on the photo-diode surface for all wavelengths in the three regions (FUV, NUV, and VIS). From this measured resultant voltage, the number of photons incident on the surface of the photo diode was estimated by using the spectral responsivity of the photo-diode provided by the manufacturer.

The number of photons falling on the surface of the FM detector was obtained by multiplying the transmission of the mask (used in the path of the light while acquiring the images with FM detectors) and the photons falling on the photo-diode surface. Also we had a measure of the number of photons detected by the detector using the experimental set up shown in Fig. 4 using the procedures outlined in Section 3.3. The ratio between number of photons detected to the number of photons falling on the detector surface provides the QE of the detector. The same procedure was repeated for all wavelengths in FUV, NUV and VIS regions to measure the QE of all the three detectors.

4. Results:

The results of the QE measurements are given in Tables 4, 5 and 6 and in Figures 5, 6 and 7. The figures also show the QE values provided by the manufacturer of the detector.

Table 4.: FM-FUV Detector Module Quantum Efficiency

Wavelength (in nm)	QE(%)
135.4	4.84
140.3	4.53
144.1	4.00
148.7	3.67

154.5	3.45
160.8	2.73
164.8	2.77
170.0	2.44
175.0	1.67
182.3	0.42

Table 5.: FM-NUV Detector Module Quantum Efficiency

Wavelength (in nm)	QE(%)
170.0	6.18
175.0	7.62
182.3	8.24
187.9	8.73
193.7	9.17
200.0	9.20
206.7	9.51
213.8	9.81
221.4	10.25
229.6	10.57
238.5	10.18
253.7	9.41
255.0	9.33

260.0	8.92
265.0	8.00
270.0	7.37
275.0	5.99
280.0	5.15
285.0	3.99
290.0	2.89
295.0	1.94
300.0	1.22
305.0	0.86

Table 6: FM-Visual Detector Module Quantum Efficiency

Wavelength (in nm)	QE(%)
310.0	10.06
315.0	10.32
325.0	8.48
335.0	8.98
345.0	9.78
355.0	10.08
365.0	9.57
375.0	9.60
385.0	9.78
395.0	10.46
405.0	10.31

415.0	10.07
425.0	10.98
435.0	10.12
445.0	10.44
455.0	9.88
465.0	9.72
475.0	9.48
485.0	9.26
495.0	8.28
505.0	7.61
515.0	5.97
525.0	7.86
535.0	5.94
545.0	4.91
550.0	4.89

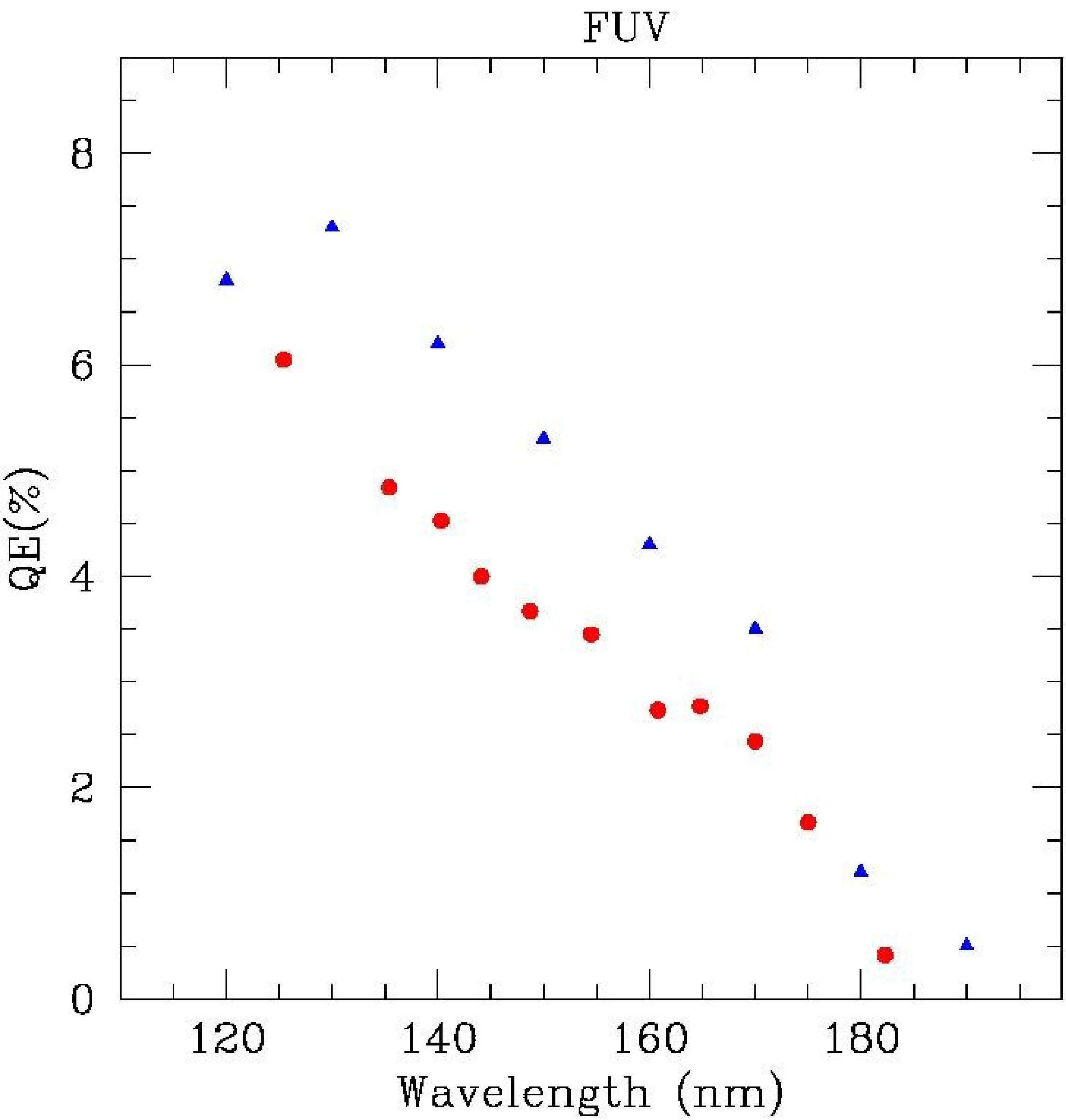

Fig. 5: QE of the FM FUV detector. Here red filled circles refer to our measured values, and the blue filled triangles refer to the values provided by Photek.

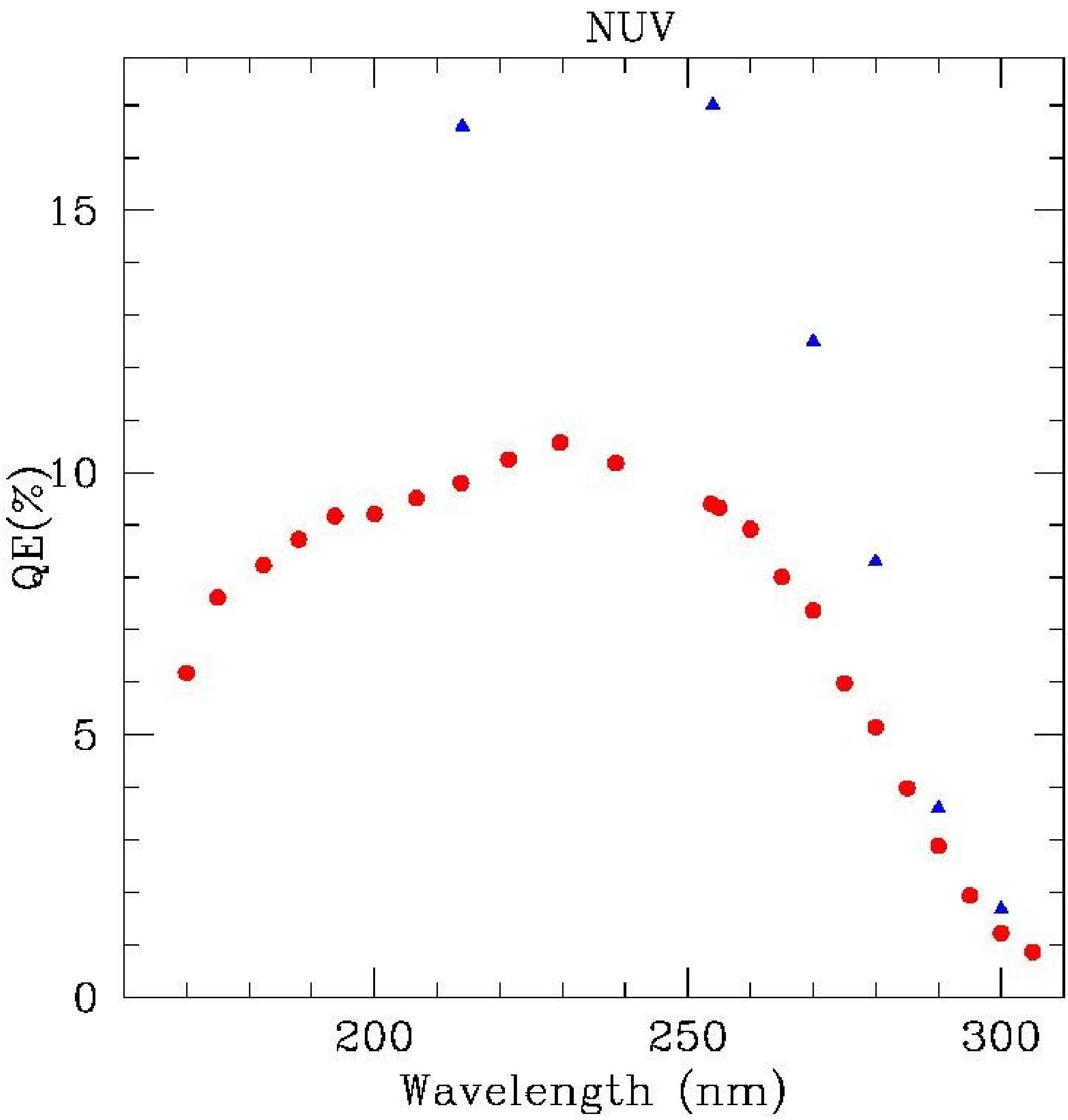

Fig. 6. QE of the FM NUV detector. Here red filled circles refer to our measured values, and the blue filled triangles refer to the values provided by Photek.

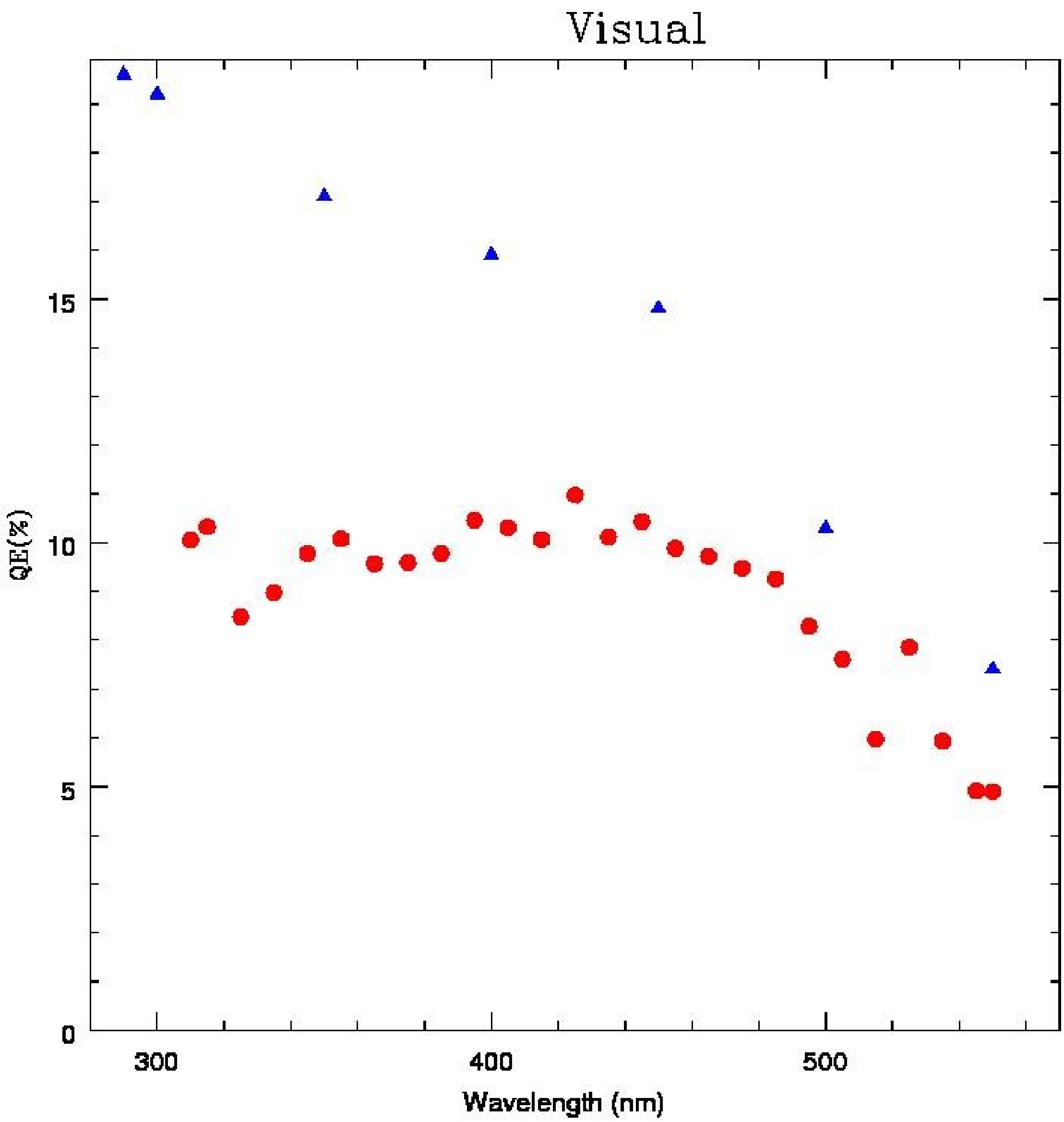

Fig. 7: QE of the FM Visual detector. Here red filled circles refer to our measured values, and the blue filled triangles refer to the values provided by Photek.