Precision UV-QE Measurements at Optical Detectors

with a special calibrated detector test bench

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ABSTRACT

In the detector laboratory of ESO a detector test bench was developed and recently improved in order to get high precision UV-QE measurements of optical CCD detectors. During the last years the calibration of the test bench was refined as well as the reliability of the resulting quantum efficiency results, especially in the critical ultra-violet range of the spectrum. The paper describes the principle, the methods and some tricks to get more precise and reliable UV quantum efficiency values with only small errors. This is currently needed for the new VLT CUBES instrument project, which is a spectrograph mainly in the UV spectral range. In addition this poster gives a comprehensive overview of the used test bench, which is now fully automated and controlled by a Windows PC using LabView, IDL and the very comfortable PRiSM image processing software.

1. INTRODUCTION

During the last years the UV-quantum efficiency (QE) of optical detectors could be improved, but it is still a challenge to have a good calibration of the detector in the UV spectral range. This paper describes how to proceed with a proposed test bench step by step in order to get reliable measurements / calibrations of the optical CCD detectors

2. STEP 1: CORRECT ABSOLUTE CALIBRATED PHOTO-DIODE

A 10x10mm UV sensitive photo-diode was selected from Hamamatsu with quartz window.

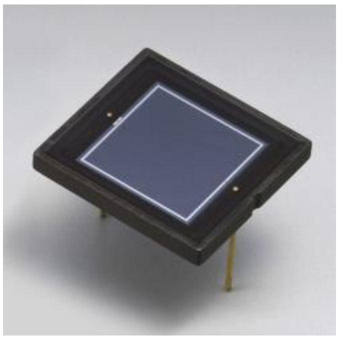

Figure 1: Hamamatsu Photo Diode S1337-1010BQ Package size 15 x 16.5 mm photosensitive area size 10 x 10 mm Window material Quartz

Hamamatsu supplies on request a calibration of this diode. One of these diodes was sent to the National Physical Laboratory (NPL) in UK for cross-calibration. NPL gives a calibration error of 1%. Comparing the curves and the measurement results in the critical UV range we then even preferred the Hamamatsu calibration which was anyway not far from the NPL calibration:

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Wav. [nm]	300	310	320	330	340	350	360	370	380	390	400
Diode sensitivity [mA/W]											
Hamamatsu	19	93	112	128	139	146	153	160	174	193	205
NPL (Error 1%)	28	72	116	132	138	143	148	158	170	186	201

Table 1: Photo-diode calibrated by Hamamatsu and by National Physical Laboratory (NPL) United Kingdom

Wav. [nm]	Diode 2006	Diode 2012	New Diode 2013
300	19	11	129
310	93	12	137
320	112	21	142
330	128	113	145
340	139	135	148
350	146	145	148

Table 2: Diode decay in the hard UV range after 6 years and new selected diode 2013 (all values in [mA/W])

3. Step 2: Correct calibrated electrometer for DIODE current measurements

ESO’s detector test bench has a halogen light source which gives a quite low output in the UV range. Therefore and for precise diode current measurements we selected the Keithley 6514 System Electrometer, which can be calibrated on request by the manufacturer.

Figure 2: Keithley 6514 System Electrometer

Three of these devices are used: one for the detector plane diode, one for the sphere diode and another one to as a spare. The red calibration curve in Figure 3 shows a jump in the UV range with its very low photo-currents if using the halogen lamp Osram HLX 64641. This jump results from a bad calibrated and/or defective range-switch in the electrometer. The green curve shows a perfect calibrated electrometer without problems especially in the range 1–100 picoampere. This is important for a successful test bench calibration and later for the correct detector QE measurement:

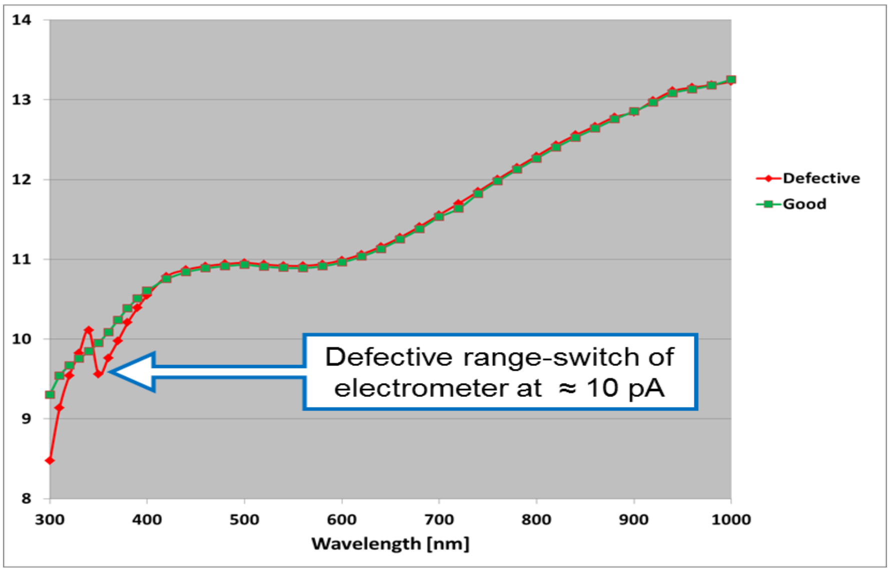


Table 3: Measurement curve with defective (red) and with correct calibrated (green) electrometer

4. STEP 3: DOUBLE MONOCHROMATOR CALIBRATION

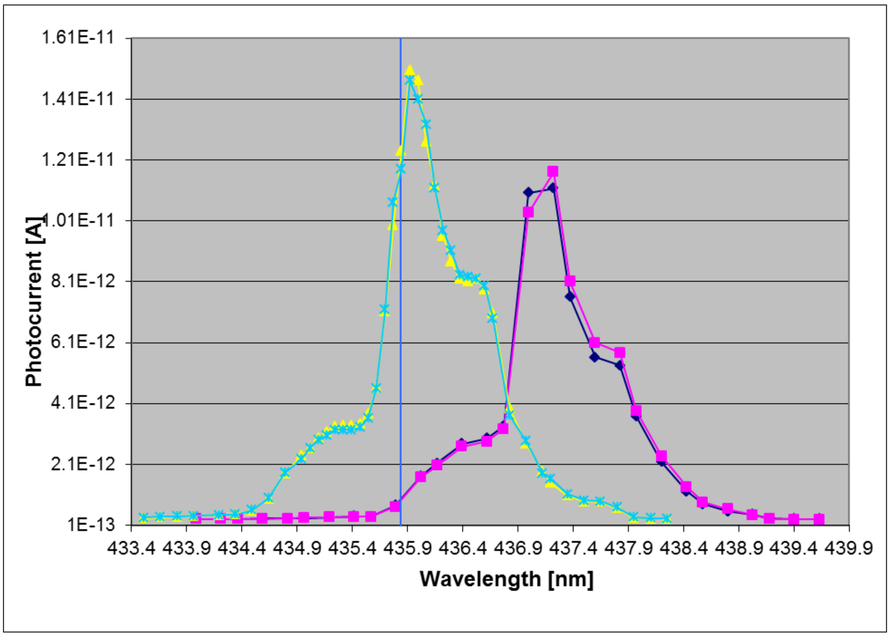


Table 1: Calibration at 435.8 nm (blue vertical line): The pink - dark blue lines show measurements before calibration and the turquois - yellow lines after the calibration.

The monochromator ORIEL MS257 (new order name: NEWPORT Cornerstone 260 1/4m) was calibrated with the spectral lamp ORIEL 6036 Hg(A) at three points of the used spectrum between 300 and 1100 nm. The monochromator ratio wavelength of interest for the UV-QE is 435.9 nm. The accuracy of calibration resulted in 0.086 nm and is therefore far better than needed!

5. STEP 4: TEST BENCH CROSS-CALIBRATION

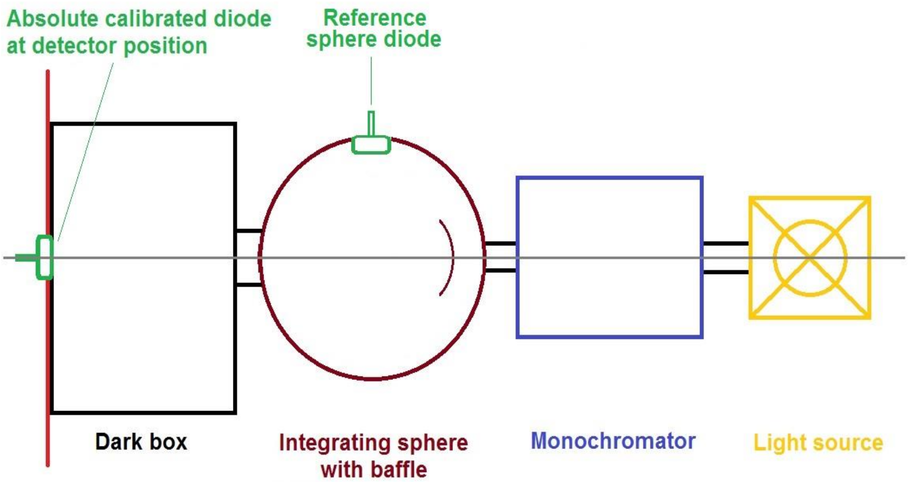


Figure 4: Schematic view of test bench cross-calibration

The absolute calibrated diode is placed at the position of the detector, which later has to be characterized and a reference diode is placed in the integrating sphere. Now the relation of these two diode is measured for each wavelength of interest by tuning the monochromator, using a current regulated halogen light source and a precision BONN-shutter.

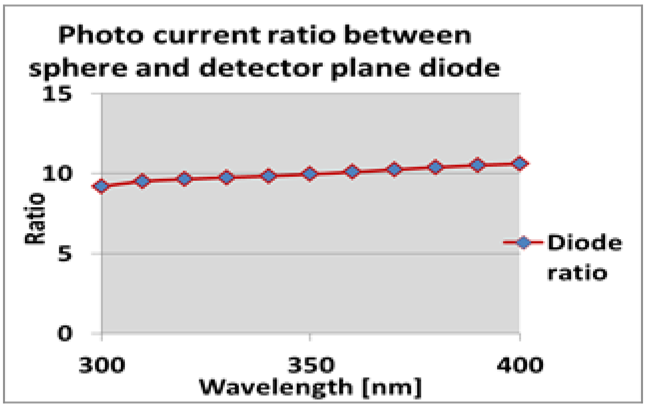


Table 5: Result(Ratio) of test bench cross-calibration in the UV

Later from these results and from the absolute calibration of the detector plane diode the number of photons at the detector position can be calculated with only current measurement at the integrating sphere diode for each illumination as a function of the wavelength. Therefore CCD characterizations for quantum efficiency are possible with different light levels at all wavelengths of interest.

Wav. [nm]	Flux@CCD [photons/s]	Diode@ sphere [A]	Flux error	Diode error
300	2.2362E+07	1.7542E-11	6.8371E+04	2.6435E-14
310	4.1222E+07	3.4392E-11	5.5955E+04	2.1193E-14
320	7.4772E+07	6.3520E-11	3.1517E+04	2.4202E-14
330	1.3530E+08	1.1507E-10	8.0879E+04	3.5189E-14
340	2.1401E+08	1.8197E-10	1.0187E+05	3.3314E-14
350	3.6574E+08	3.0551E-10	1.0859E+05	4.1744E-14
360	5.0010E+08	4.0345E-10	1.8175E+05	1.6076E-13
370	6.6013E+08	5.2974E-10	1.5346E+06	3.4030E-14
380	9.0075E+08	7.6790E-10	1.3439E+06	1.5937E-12
390	1.1722E+09	1.0731E-09	2.1636E+05	1.4432E-13
400	1.6215E+09	1.5459E-09	6.9065E+05	4.1629E-13

Table 6: Detailed results of test bench calibration in the UV

This operation only works if the light source of the test bench is stable. A light Source Stabilization is done with the NEWPORT Radiometric Power Supply 69931 in combination with an ORIEL Light Intensity Controller in order to compensate short term and long term oscillations and flickering of the used light source.

6. Step 5: Correct CCD gain calculation

Janesick's method [1] was used for determining the gain and read noise of the CCD detector from a pair of flat-field exposures and a pair of dark or bias exposures. For bias subtraction the average of many zero frames is used. Bad pixels have been avoided on the selected frame window. Relative short exposure times of approx. 10s have been used to avoid too much cosmic rays deteriorating the statistics. Then pairs of each type of comparison frame are used to reduce the effects of gain variations from pixel to pixel. The derivation follows from the definition of the gain (N(e) = gain * N(ADU)) and from simple error propagation. The measured variance (sigma**2) is related to the exposure level and read-noise variance (sigma(readout)**2) as follows:

variance(e) = N(e) + variance(readout)

Where N(e) is the number of electrons. Then the resulting gains are plotted against the different illumination levels:

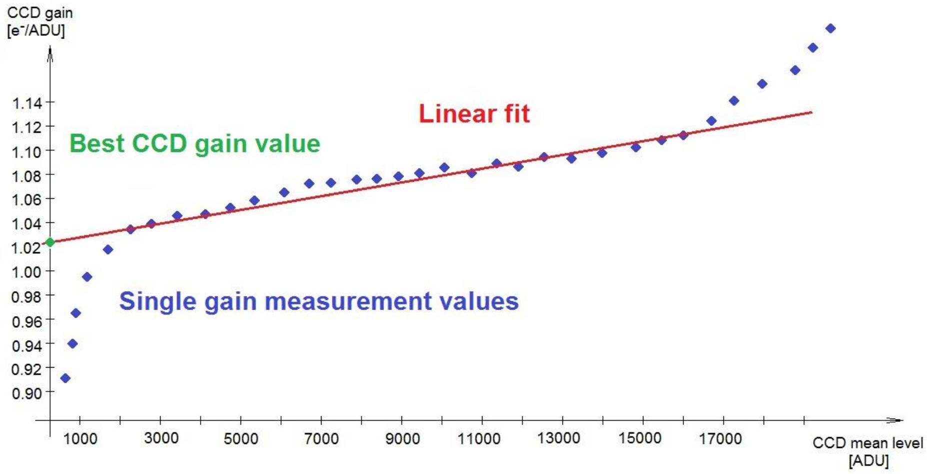


Figure 6: The CCD gain is calculated at different illumination levels using the statistical method and plotted as given. Then a fit is done from values above 1000 and below 15000 ADU and the intersection with the y-axis gives the best CCD gain value

In order not to get too high gain values a fit is done for values above approx. 1000 ADU and below approx. 15000 ADU with a gain of approx. 1 ADU/e-. The intersection of this fitted line with the y-axis gives the final gain value. Therefore most QE-values given in literature are too high, because the CCD gain is overestimated if not processed in the given way. Mark Downing also reports this problem in [4] as charge loss to neighbor pixels, which damages the needed statistics.

7. STEP 6: REPEATED AUTOMATED QE CCD MEASUREMENTS

The CCD detector has to be in stable operation conditions in its clean and baked cryostat with regenerated sorption pump and several days kept cold. In this way the processes on the detector surface have been stabilized, which could influence the UV QE values. Now several automated QE measurement runs are done to get reliable results.

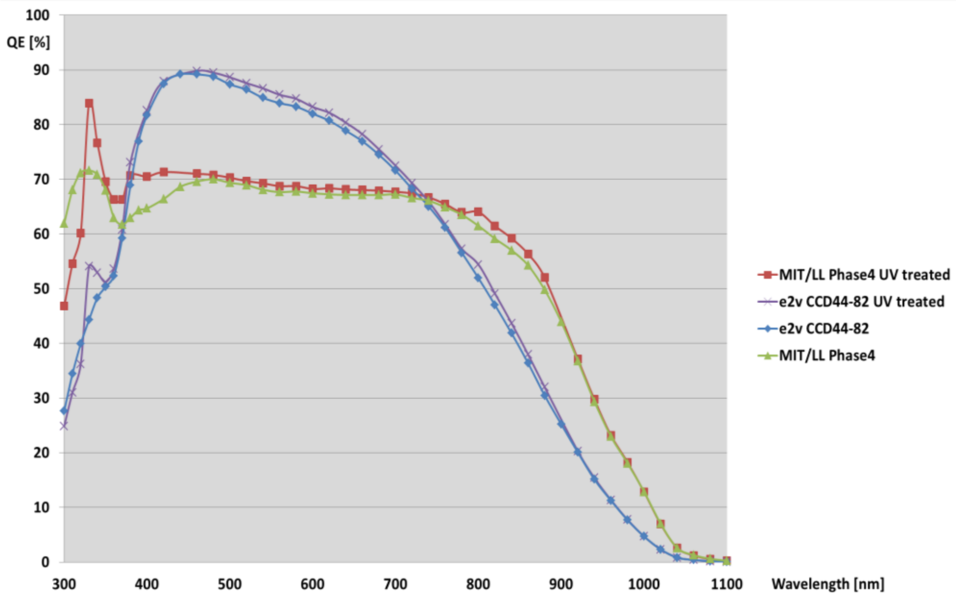


Figure 7: Precision UV-QE results of MIT/LL-phase 4 CCD and e2v CCD 44-82

The following errors are considered for the resulting absolute Qe values:

- Calibration error of the absolutely calibrated photodiode at Hamamatsu: 1% between 400 and 1000nm: estimated 2-3% below 400nm (the given 1% is maybe too optimistic)
- Error of Keithley electrometer measurements during calibration at CCD position: max. 1%
- Error of Keithley electrometer measurements during calibration at sphere position: max. 1%
- Error of Keithley electrometer measurements during CCD tests at sphere position: max. 1%
- Error of CCD conversion-factor calculation: 1%
- Statistical error of CCD Signal: 0.7%
- Variation of Qe over measured CCD area (1024 x 512 pixel in the centre): approx. 2%

All these errors have to be added with the square-root- law, which results in: 3% (relative error of absolute QE value).

UV-QE measurements of different CCDs at the wavelength of interest for CUBES:

CCD	MIT phase4 CCD	UVES blue e2v 44-82 CCD	X-Shooter blue e2v-44-82 CCD
QE @310 nm	68.1±2.0%	82.9±2.5 %	70.5±2.1 %

Table 2: Comparison: CUBES instrument candidate MIT/LL-CCD "Caruso" with e2v-CCD "Pisces Australis II" of X-Shooter blue arm and e2v-CCD "Pavarotti" of UVES blue

8. STEP 7: UV ENHANCEMENT OF THE DETECTOR

At some CCD detectors the UV QE can be improved by a treatment with temperature, UV light and oxygen gas. To make this improvement stable the detector has to be kept cool and/or in a perfect vacuum [3]

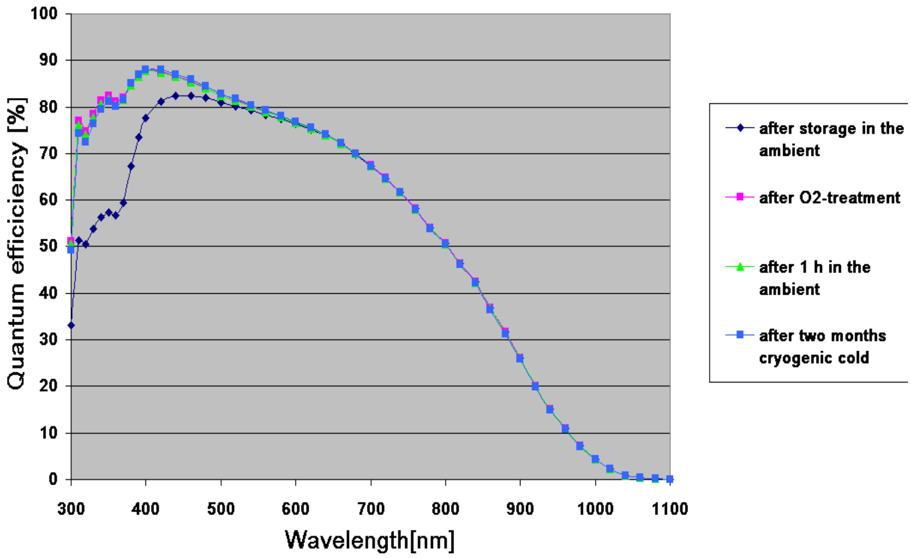


Figure 8: QE of UVES blue e2v CCD 44-82 UV AR coated before, directly after and two months after UV enhancement treatment

9. HARDWARE DESCRIPTION OF USED DETECTOR TEST BENCH

The following components have been used for the fully automated test bench:

- NEWPORT M-RT-310-8 (0.9 x 3.00) optical table
- ESO detector vessel [2] (ESO detector head with ESO CFC, ESO Bath or ESO Pt14 CryoTiger cryostat) pumped with Adixen Drytel 1025 pump and ESO Teepee JUMO temperature controller
- ESO Next generation CCD Controller (NGC)
- Hamamatsu S1337-1010BQ photo-diodes
- NEWPORT M-RT-310-8 (0.9 x 3.9m) optical table
- ESO dark box and ESO Door warning lamp with PCI controller card
- DLP-TH1 temperature and humidity sensor
- Photo diode room-light sensor with Keitley 2100/120 controller
- LabSphere CSTM-US-200-SF integrating sphere
- Keithley 6514 Electrometers
- ORIEL MS257 double monochromator with NEWPORT 74041 filter wheels and BONN 125mm shutter
- ORIEL 60000 Q lamp housing, LCS115 condenser and 60090 interface plate with OSRAM 64641 HLX Xenophot 24V/150W lamp
- NEWPORT 69931 radiometric power supply

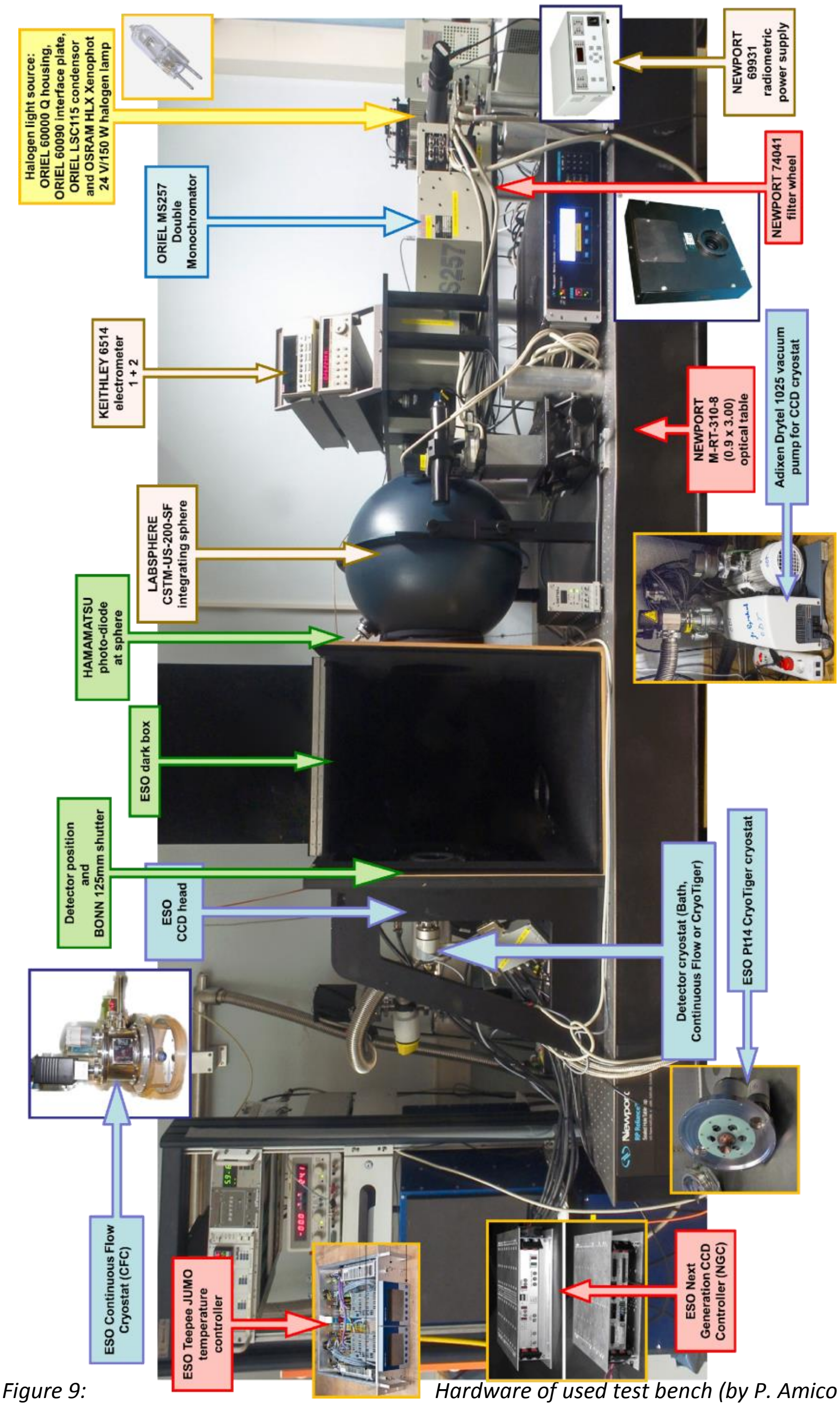
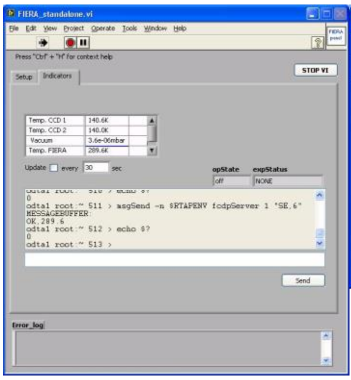
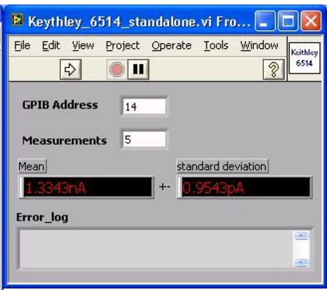


Figure 9: Hardware of used test bench (by P. Amico and J. Beletic in 1996)

10. Software used for detector test bench at Windows7 64-bit PC

Fully automated software with scripts doing all routine CCD characterizations including script to build up a test report from resulting raw data:





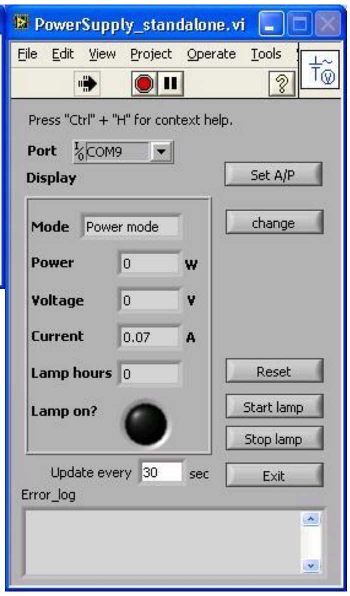


Figure 10: LabView panel examples: Test bench drivers

LabView as hardware driver and interface between systems like CCD controller, script software and user input.

PRiSM image processing software (or IDL) as script and master software for fully automated operation of test bench.

For data acquisition and producing result tables the very easy and comfortable PRiSM image processing software [5] is used:

In the evening we press the start button and next morning all results of the CCD characterizations are received, which can be easily converted into an Excel test report by pressing another button.

11. Acknowledgements

The authors would also like to thank Evi Hummel for the help in the laboratory and the layout of the poster.

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