# Precision UV-QE Measurements at Optical Detectors

## with a special calibrated test bench

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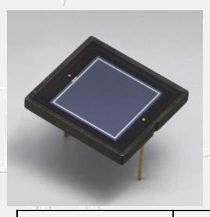
## Summary:

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 poster 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.

## Step 1: Absolute calibrated photo-diode



New (2013) Hamamatsu Photo Diode S1337-1010BQ
Package size 15 x 16.5 mm
Photosensitive area size 10 x 10 mm
Window material Quarz
This diode was selected because of very high hard-UV sensitivity.

| Wav. [nm] / Diode sensitivity [mA/W] | 300 | 310 | 320 | 330 | 340 | 350 | 360 | 370 | 380 | 390 | 400 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |

The diode is calibrated by Hamamatsu and the calibration was compared with a calibration of the same diode by National Physical Laboratory (NPL) United Kingdom.

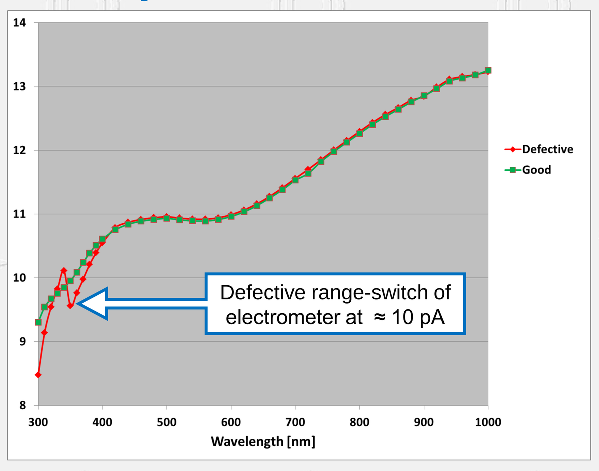
Diode decay in hard UV range after 6 years and newly selected diode (values in [mA/W]):

| 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 |

## Step 2: Electrometer for diode current measurements

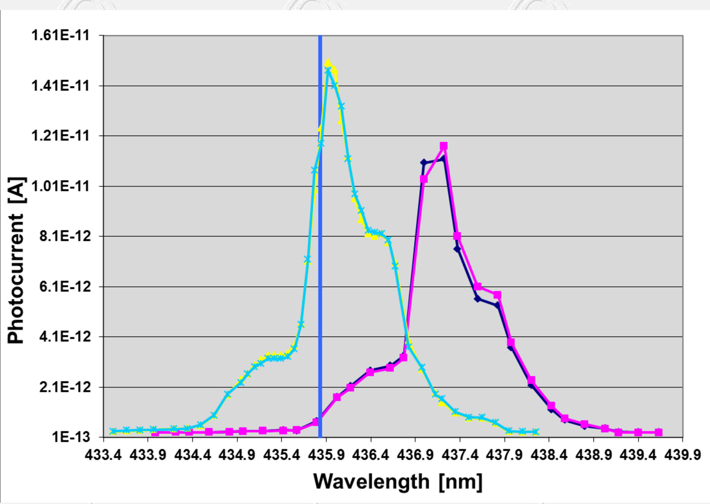
Keithley 6514 System Electrometer with accuracy of 0.01 pA

### Linearity calibration of the electrometer:




Measurement curve of defective (red) and correct calibrated (green) electrometer.

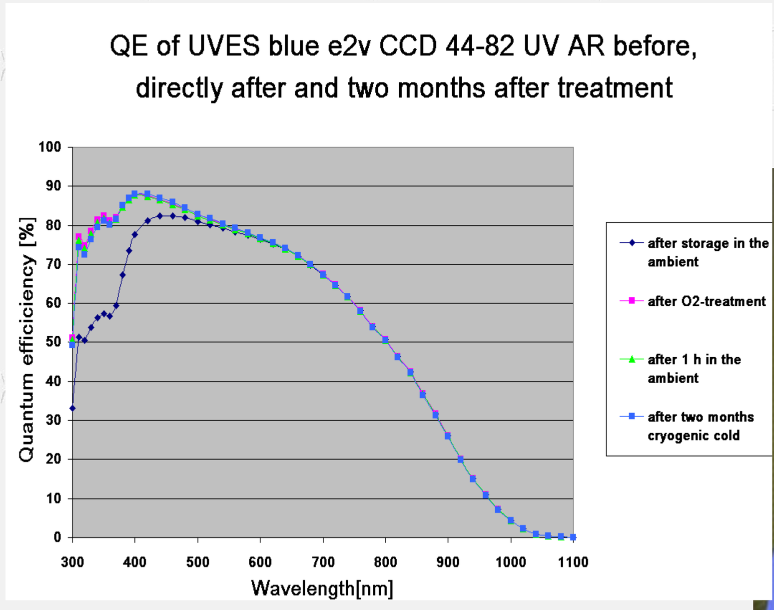
## Step 3: Calibration of mono-chromator with spectral Hg-lamp

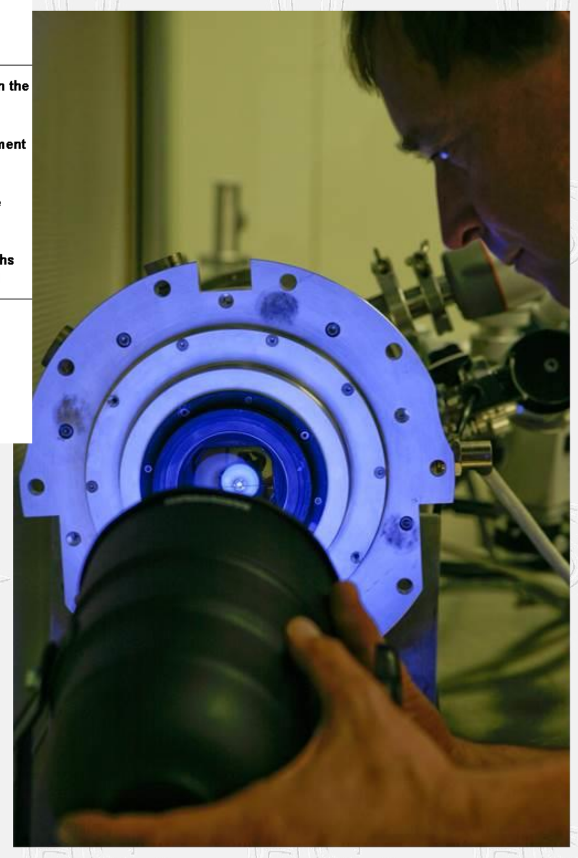



Calibration at 435.8 nm (blue vertical line):
The pink-darkblue lines show measurements before calibration and the turquois-yellow lines after the calibration.
The acurracy of calibration is 0.086 nm (far better than needed!)

Devices used:
ORIEL 6036 Hg (A) spectral lamp
ORIEL MS257 Double monochromator

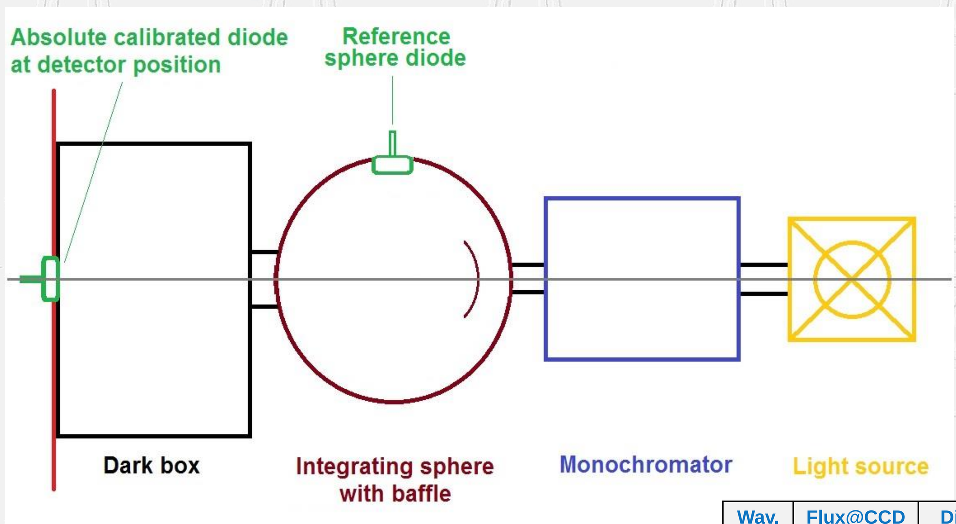
## Step 7: UV and gas sensitivation of CCDs to improve UV-QE



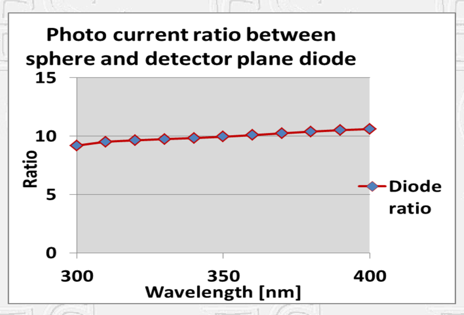



At some CCD detectors the UV-QE can be improved up to 50 % by a treatment with temperature, UV light and oxygen gas. To make this improvement stable the detector has to be kept cool and/or in a perfect vacuum.

## Step 4: Relative test bench calibration



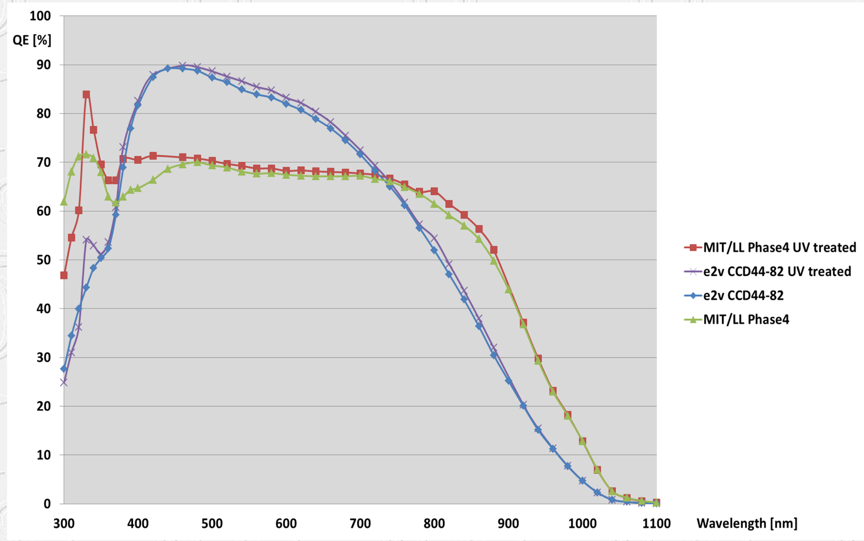

After the cross-calibration of the sphere diode with the detector position diode with a stabilized light source we get for each wavelength the ratio of photo current between sphere and detector position. Now we can use the sphere diode only during CCD QE measurements.




Results of test bench cross calibration

| Wav. [nm] | Flux@CCD [photons] | 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 |

## Step 6: Repeated QE CCD measurements




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

| Wav. [nm] | QE [%] | Statistical QE error |
|---|---|---|
| 300 | 61.92 | 0.27 |
| 310 | 68.09 | 0.13 |
| 320 | 71.17 | 0.05 |
| 330 | 71.60 | 0.06 |
| 340 | 70.85 | 0.04 |
| 350 | 67.98 | 0.03 |
| 360 | 62.98 | 0.04 |
| 370 | 61.70 | 0.14 |
| 380 | 62.98 | 0.21 |
| 390 | 64.36 | 0.02 |
| 400 | 64.68 | 0.04 |

Final precise result of CUBE candidate MIT/LL-phase 4-CCD

### High precision QE measurement error budget

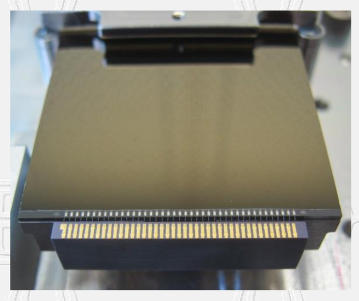
1. Calibration error of the absolutely calibrated photodiode at Hamamatsu: 1% between 400 and 1000 nm and estimated 2 – 3 % below 400 nm
2. Error of Keithley electrometer meaurements during calibration at CCD position: max. 1 %
3. Error of Keithley electrometer meaurements during calibration at sphere position: max. 1 %
4. Error of Keithley electrometer meaurements during CCD tests at sphere position: max. 1 %
5. Error of CCD conversion-factor calculation: 1 %
6. Statistical error of CCD signal: 0.7 %
7. Variation of QE over measured CCD area (1024 x 512 pixel in the centre): approx. 2 %

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

| CCD | MIT/LL phase 4 (CUBES candidate) | e2v 44-82 (UVES blue) | e2v 44-82 (X-Shooter blue arm) |
|---|---|---|---|
| QE @ 310 nm | 68.1 ± 2.0 % | 82.9 ± 2.5 % | 70.5 ± 2.1 % |

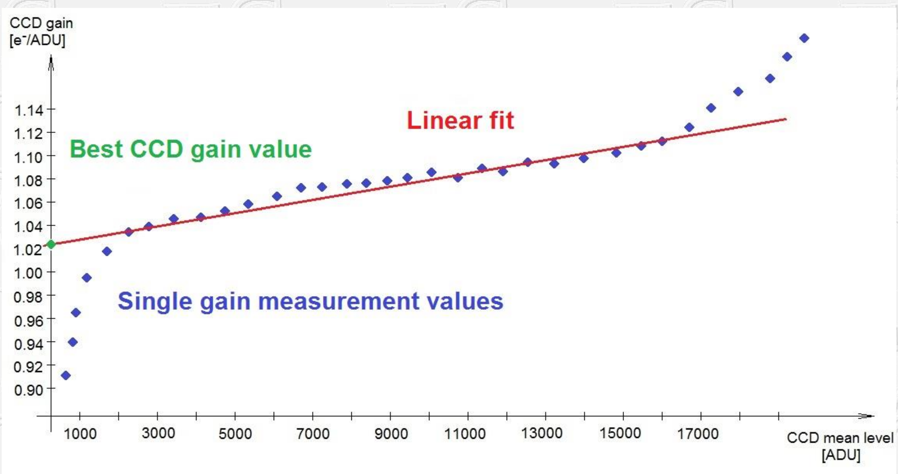
310 nm is the UV-wavelength of interest for the planned CUBES VLT instrument.

MIT/LL Phase 4 CCD



e2v CCD 44-82

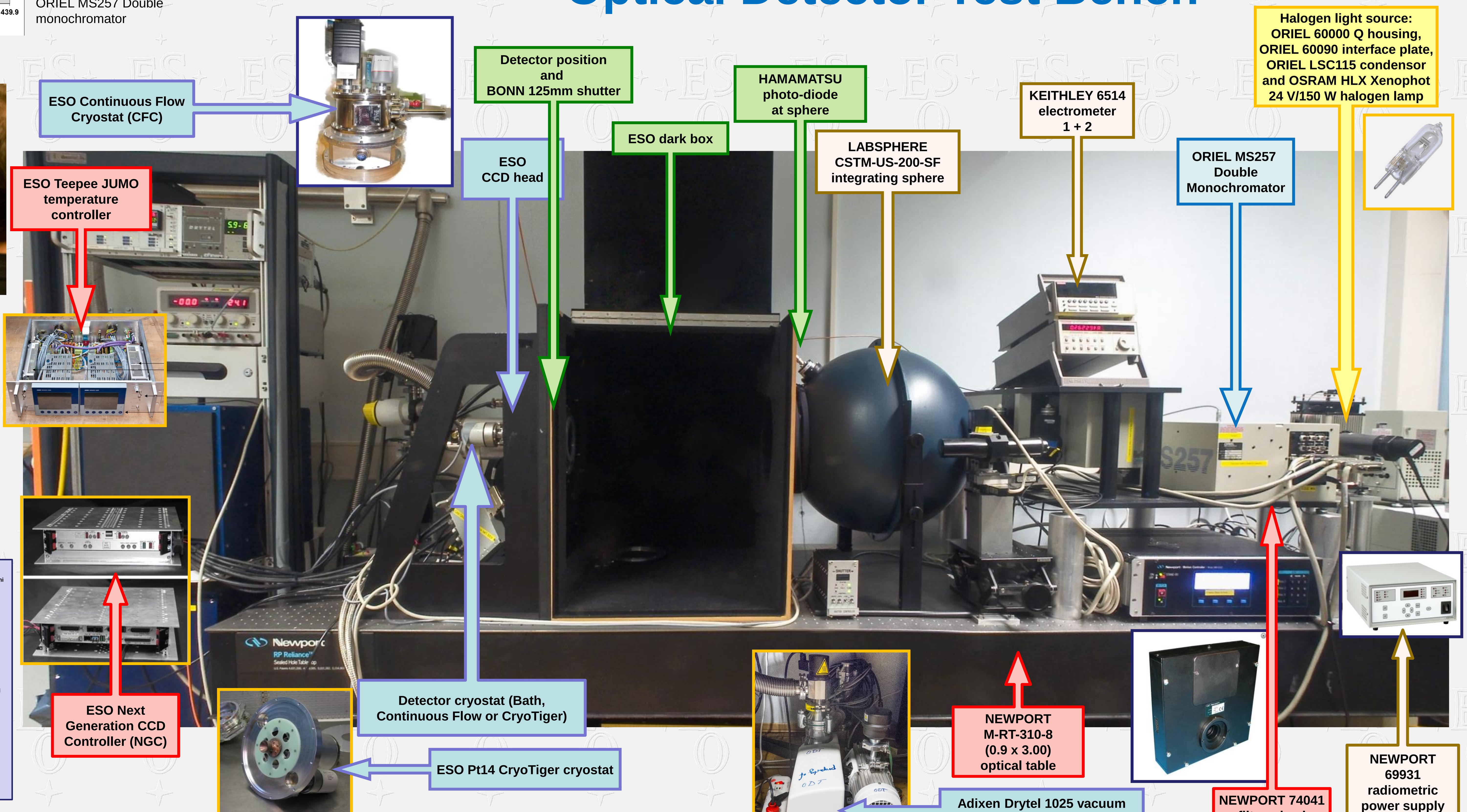
## Step 5: CCD gain calculation and calibration



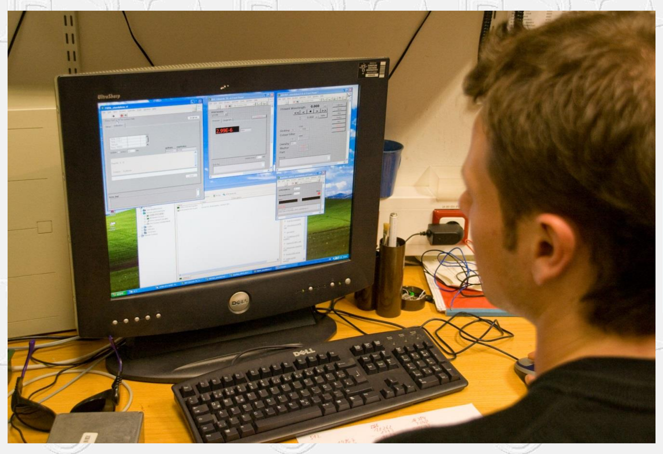

The CCD gain is calculated at different illumination levels using the statistical method and plotted as given. Then a fit is done from values above 1000 and below 15000 ADU and the intersection with the y-axis gives the best CCD gain value.

**Light Source Stabilization**
with NEWPORT Radiometric Power Supply 69931 and ORIEL Light Intensity Controller in order to compensate short term and long term oscillations and flickering of the light source.

# Optical Detector Test Bench

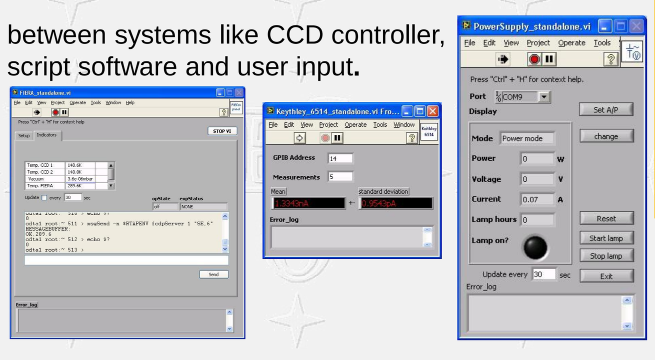



## Test Bench Software



### LabView as hardware driver and interface

between systems like CCD controller, script software and user input.



### PRiSM or IDL as script 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 is used:

Example for PRiSM testbench script:

```
//StartDetectorTestBench:
SetLoadFitsToFloating Integer
SetTransformRescaleFITsDynamic CutFits
QE$="not Running“
IF TBModus<3 THEN
SetFlagShutter
CloseS
ENDIF
Device$="LAMP“
Command$="ON“
GOSUB LabViewDevice:
Device$="CCDF“
Command$="CL“
STR
ClockModeCheckTemperature
Value$
GOSUB LabViewDevice:
IF CCDController$="NGC" THEN
  Device$="CCDF“
  Command$="BN“
  Value$="1“
  Value2$="1“
  GOSUB LabViewDevice:
ENDIF
ELSE
SetClockMode
ClockModeCheckTemperature
ENDIF
Exposure=0
CheckTemperature:
    Device$="CCDF“
...
```

In the evening we press the start button and the next morning all results of the CCD characterizations are received !

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**Scientific Detector Workshop, Oct 7–11, 2013**