How CCD Quantum efficiency is computed?

Definition:

This is the formula used in PRiSM software to compute the QE is the following :

$$QE(\lambda) = \frac{\dfrac{Median(I\lambda(X_1,Y_1,X_2,Y_2) - Bias(X_1,Y_1,X_2,Y_2)) * CVF}{Tex}}{Photons(\lambda) * \dfrac{DiodeFluxMeas(\lambda)}{DiodeFluxCalibration(\lambda)} * \dfrac{Pix^2}{100} * Window(\lambda)} * 100$$

$$QE(\lambda) = \frac{Electrons / pixel / \sec}{Photons / pixel / \sec} * 100$$

Name	Definition	Source	Type
λ	Wavelength expressed in nm	FITS file header	Double
Bias	Master bias file, made from a median stack of 5 single bias frames	User input	Image
X_1,X_2,Y_1,Y_2	Definition of the window where the computations are done, set such as $(X_1+X_2)/2$ = X CCD center and $(Y_1+Y_2)/2$ = Y CCD	User input	Set of Integers
$Bias(X_1,X_2,Y_1,Y_2)$	Bias image sub-window	Computed	Image
CVF	The conversion factor expressed in e^-/ADU	User input	Double
$I\lambda\ (X_1,X_2,Y_1,Y_2)$	Image sub-window, for a given wavelength that serves to compute the QE at a given wavelength	User input	Image
$I\lambda$	Image for a given wavelength that serves to compute the QE at a given wavelength	User input	Image
Median(I)	Provides the Median value of an image or sub window, expressed in ADUs	Computed	Double
Tex	Exposure time in sec	User Input	Double
Photons (λ)	Amount of photons for 1 cm^2 and per second at the CCD level for a given wavelength	Calibration file	Set of Double
DiodeFluxMeas(λ)	Current measured at the photodiode integrating Sphere level, in Amps for a	FITS file header	Double

	given wavelength		
DiodeFluxCalibration(λ)	Calibration current measured at the integrating Sphere level, in Amps for a given wavelength and a given amount of photons at the CCD level (see photodiode calibration procedures)	Calibration file	Set of Double
Pix	Pixel's size expressed in mm, divided by 100 mm^2 , which is the diode surface.	FITS file header	Double
Window(λ)	CCD Windows Transmission for a given wavelength	Calibration file	Set of Double

This is the software output for each files:

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Window area is : X1= 58 X2= 1068 Y1= 25 Y2= 508

Filename         Wavelength  Flux        Exposure  Mean        Stddev.Rms  Median     Mean-Median  Min@5%     Max@95% Enthropy
QE00320-4.fits   320         1.3918E-10  1200      89563       955         89578       -14.386       31425      32540  6.4
QE00340-4.fits   340         3.7269E-10  563.86    1.2818E5    1165.7      1.282E5     -19.339       45095      46449  6.3

Flux           :      in A
Exposure       :      in secs


Filename         Wavelength  PRNU%       QE%       FDio/FDio.cal    Ph/pix/sec  e-/pix/sec
QE0002.fits      320         2.262       61.065    0.83684          207.12      118.89
QE0034.fits      340         2.1125      69.312    0.87389          501.4       337.1
QE0004.fits      360         2.0669      73.139    0.91787          1069.8      766.77
QE0032.fits      380         1.3742      85.51     0.94499          1971        1651.7
QE0006.fits      400         0.95867     93.401    0.98385          3187.7      2947.5
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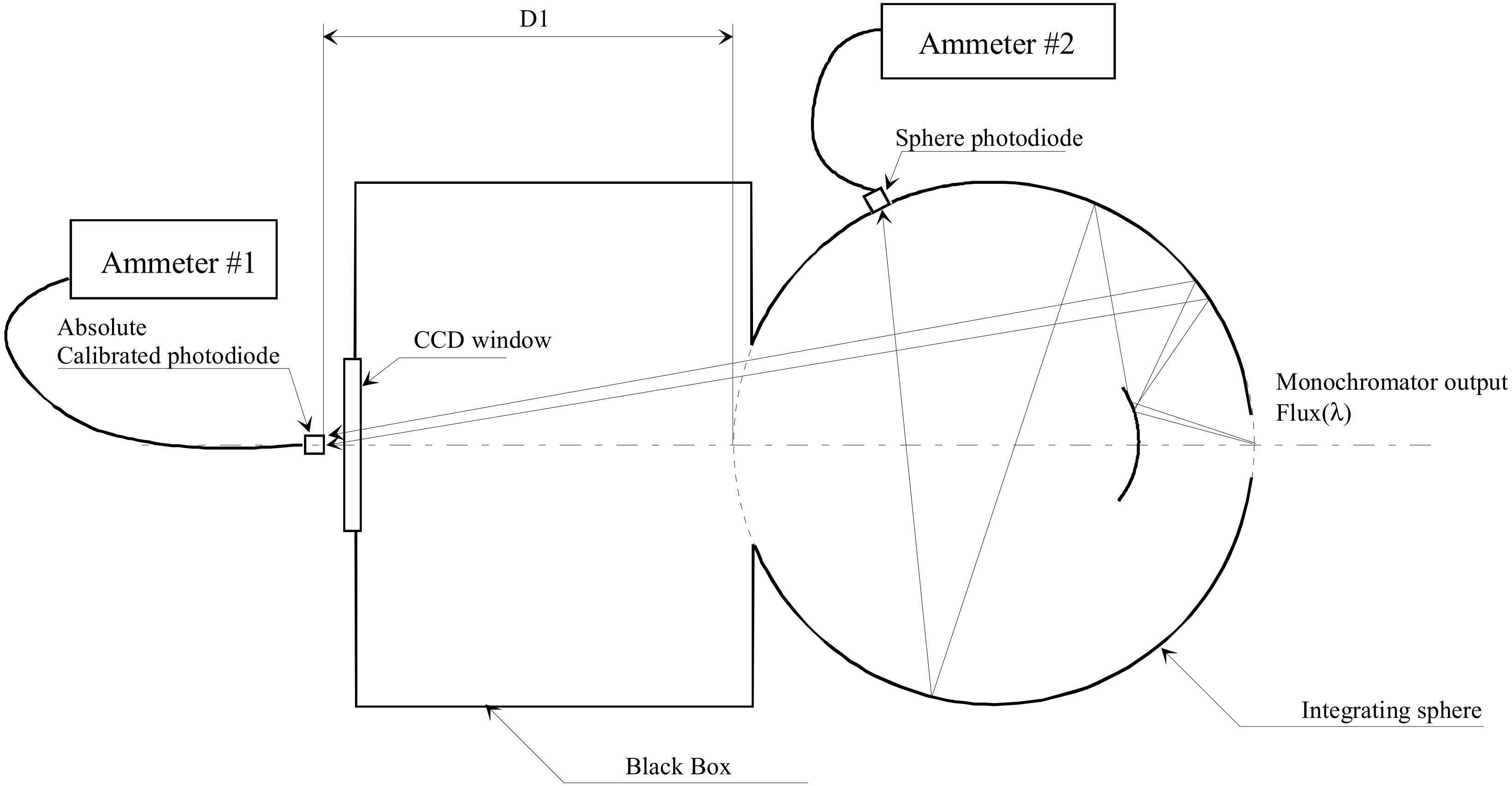
Photodiode Calibration:

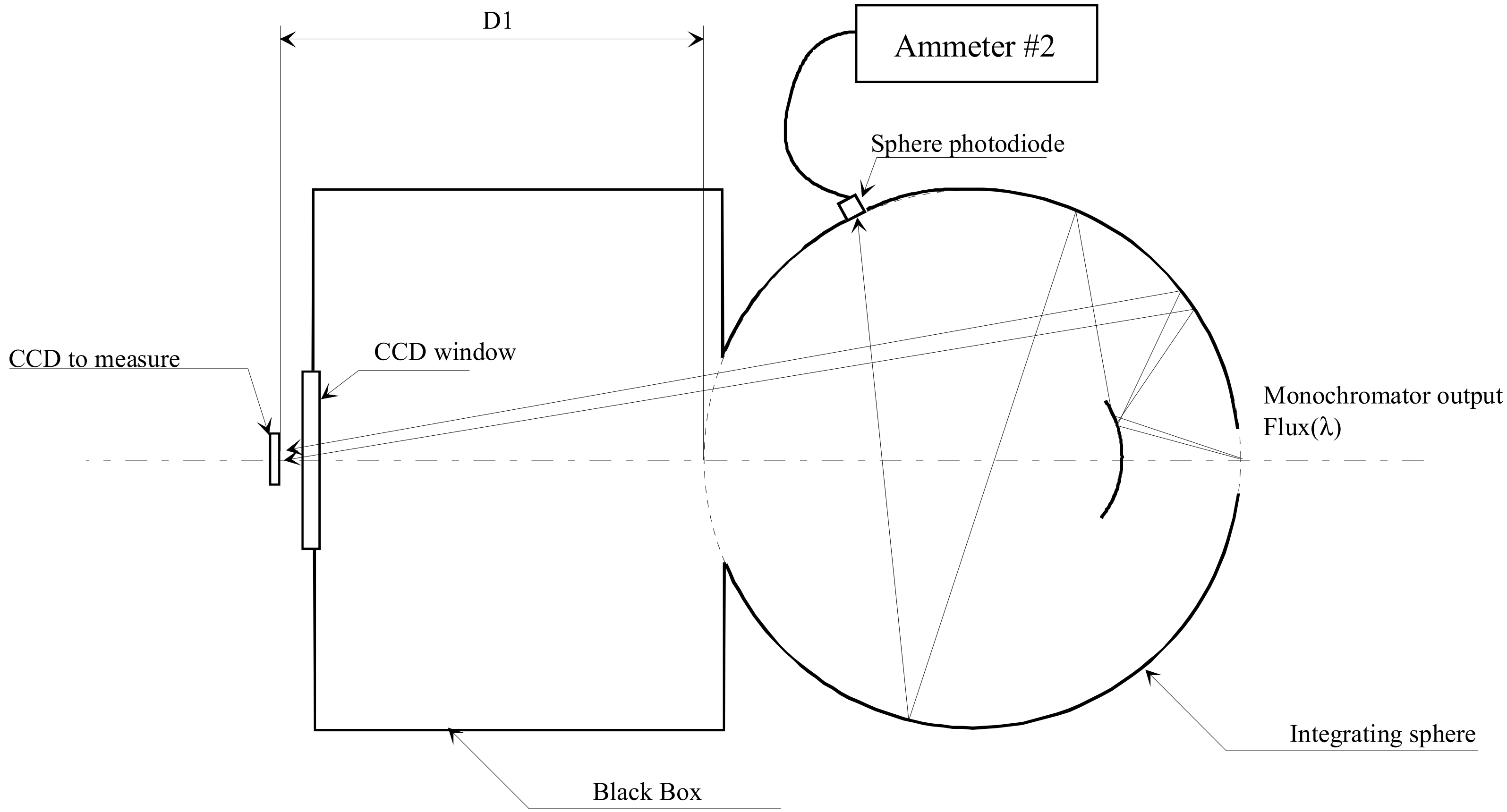
The QE measurements use calibration data which accuracy is critical to get a correct QE curve.

The 1cm^2 Hamamatsu SR2387-1010R absolute calibrated photodiode comes with a datasheet form the manufacturer that provides: the wavelength, the number of photons and the current expressed in Amps. The bandwidth used for measurements and calibration is so narrow (5nm) that a small change in bandwidth makes linear changes in amount of photons and current. Nevertheless, all the tests must be carried out with the same bandwidth that as been used for the photodiode calibration.

The absolute calibrated photodiode has been re-calibrated by the German "Physikalish-Technise Bundesanstalt" on April 2001. This absolute calibrated photodiode is installed at the level of the CCD surface (D1 distance) and calibrates the 1cm^2 photon ratio between the sphere photodiode and the CCD. As the absolute calibrated photodiode cannot be kept during actual CCD measurements, the photon ratio between the sphere photodiode and the CCD surface must be known very accurately and recalibrated on regular basis (6 months). This ratio is around 20-22 but varies according to the wavelength. The current of the absolute calibrated photodiode can be very low at the 300-400 nm domain: the way to overcome this problem is to raise the lamp level (150-200W) and tune perfectly the lamp with the entrance slit of the monochromator.

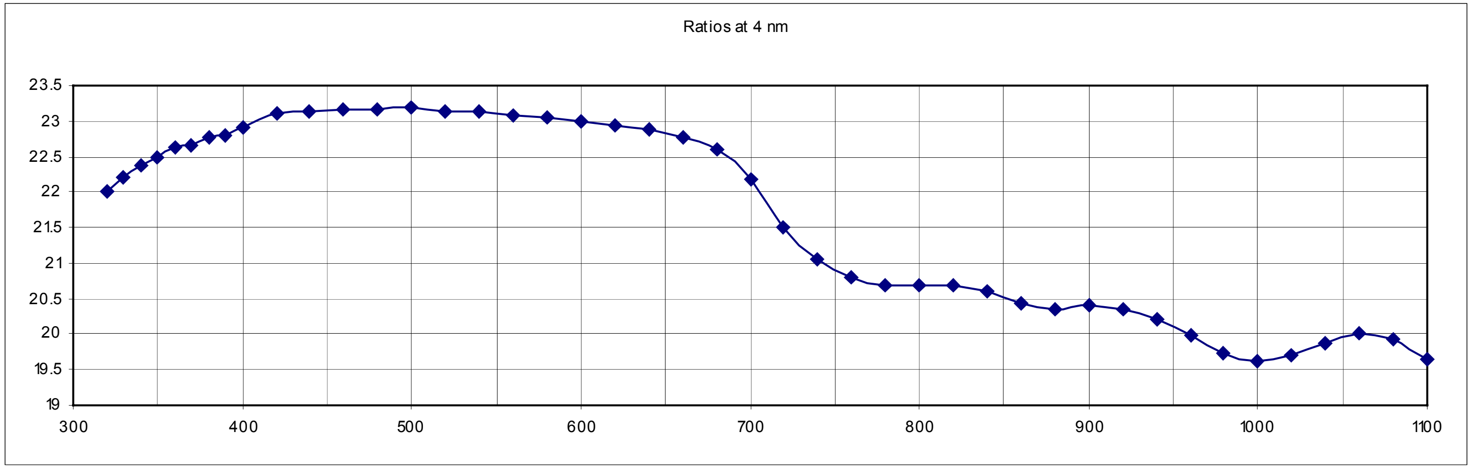


Setup used for sphere photodiode calibration

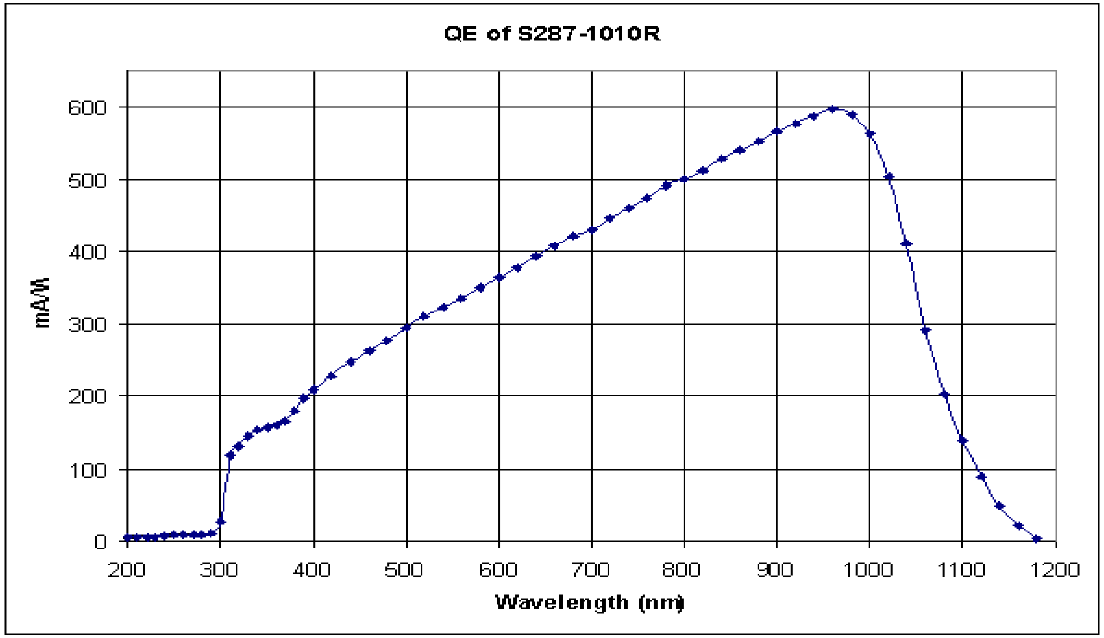


Setup used for QE measurements with a real CCD

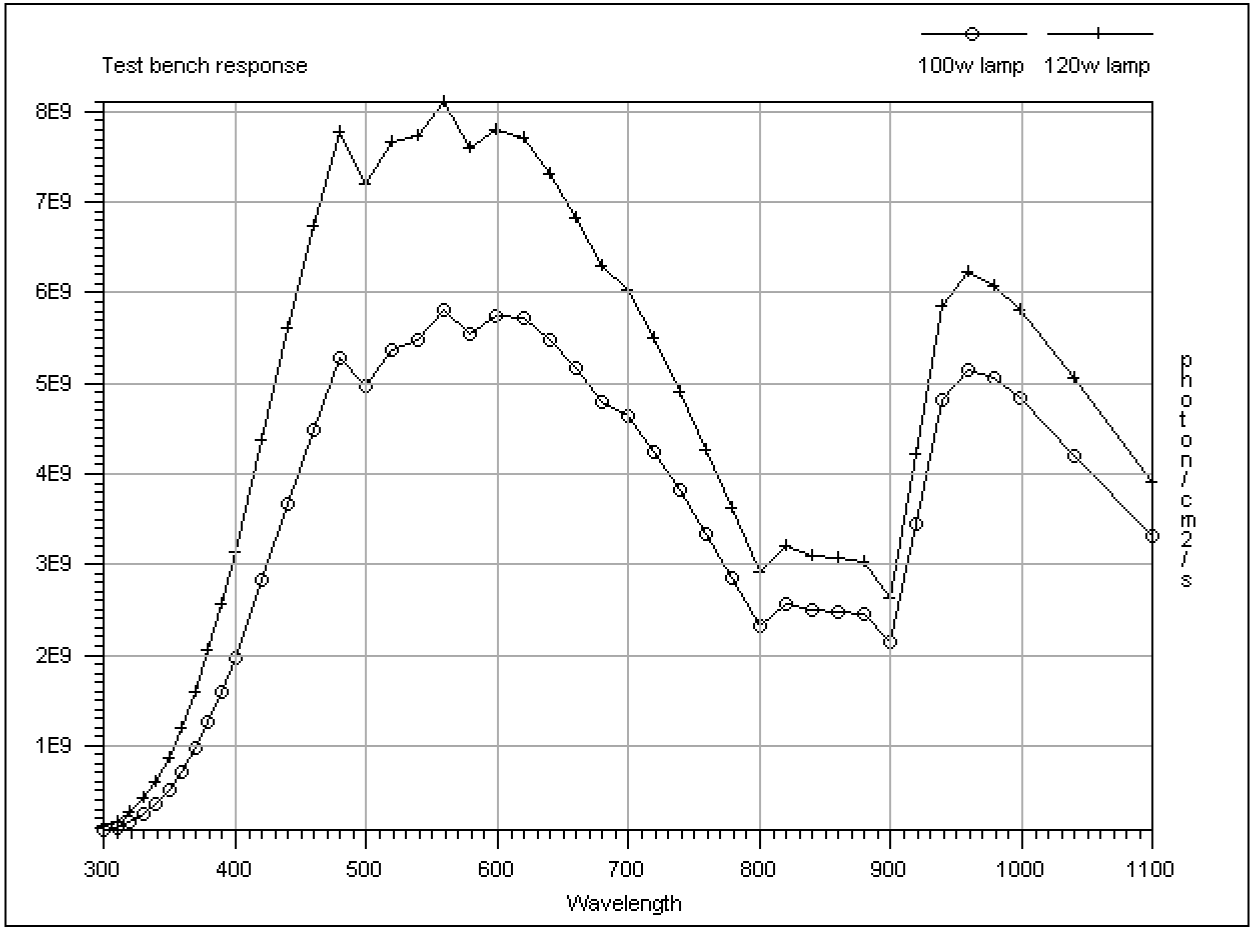
The CCD window transmission shall be measured the most accurately possible, or to avoid any problems, this transmission file data can be left to 1, and during calibration of the sphere photodiode, the window that will be used for the CCD cryostat can be installed in front of the CCD calibrated diode, like shown in the previous drawings.



Ratio of light/current between the absolute calibrated photodiode and the integrating sphere photodiode (Nov 99)



QE (in mA/W) of the 1cm^2 Hamamatsu SR2387-1010R



Efficiency of the overall testbench at the CCD surface, no window, for 2 power level applied to the Lamp

<u>Errors and source of errors:</u>

Name	Error source	Effect of error
λ	1. Error in the monochromator wavelength settings 2. Monochromator has lost its wavelength calibration 3. Bandwidth too far from the one used for the	1. The effect of the error could lead from: a non sense QE Curve, to errors very subtle to notice depending on λ

	calibration of the diode	2. Same as 1. 3. Same as 1
Bias	1. Bias taken with a different clock mode than the image data	1. Error mostly visible for low signal level of $I\lambda$, in the UV
X_1, X_2, Y_1, Y_2	1. Bad definition of the window, outside the center	1. Integrating sphere Flat field non-uniformity can lead to mismatches between the calibration diode located at the center of the field and the measurement.
CVF	1. Bad input or wrong computation	1. The whole QE curve is scaled accordingly
$I\lambda$	1. Bad image : signal too low 2. Contaminated CCD 3. Non linear CCD/controller 4. CCD not located is at D1 from the integrating sphere vertex	1.Inaccuracy in QE, especially in UV 2. False QE, effect depending on λ 3. The effect of the error could lead from a non-sense QE Curve to errors very subtle to notice depending on λ. 4. The whole QE curve is scaled accordingly
Tex	1. Wrong exposure time 2. Too short exposure time (less than 1s)	1. The effect of the error could lead from a non-sense QE Curve, to errors very subtle to notice depending on λ. 2. Shutter errors and non linearity may induce effects described in 1.
Photons (λ)	1. General calibration error	1. The effect of the error could lead from: a non sense QE Curve, to errors very subtle to notice depending on λ
DiodeFluxMeas(λ)	1. Current Measurement error	1. The effect of the error could lead from: a non sense QE Curve, to errors very subtle to notice depending on λ
DiodeFluxCalibration(λ)	1. Calibration Errors	1. The effect of the error could lead from: a non sense QE Curve, to errors very subtle to notice depending on λ
Pix	1. Wrong pixel size	1. The whole QE curve is scaled accordingly
Window(λ)	1. Wrong window transmission	1. The effect of the error could lead from a non sense QE Curve to errors very subtle to notice depending on λ

More analytical uncertainty computations:

Let's assume :

$$S(\lambda) = Median(I\lambda(X_1, Y_1, X_2, Y_2) - Bias(X_1, Y_1, X_2, Y_2))$$

If the CCD diode has been calibrated with the CCD window, the window transmission is embedded to $DiodeFluxCalibration(\lambda)$ data.

In that case :

$$Window(\lambda) = 1$$

Let's compute the partial derivative for each variable (errors contribution factors δ):

$$\delta DiodeFluxCalibration(\lambda) = \left| \frac{CVF * 100 * S(\lambda)}{Tex * Pix^2 * Photons(\lambda) * DiodeFluxMeas(\lambda)} \right|$$

$$\delta DiodeFluxMeas(\lambda) = \left| \frac{-100 * CVF * S(\lambda) * DiodeFluxMeas(\lambda)}{Tex * Pix^2 * Photons(\lambda) * DiodeFluxCalibration(\lambda)^2} \right|$$

$$\delta S(\lambda) = \left| \frac{CVF * 100 * DiodeFluxMeas(\lambda)}{Tex * Pix^2 * Photons(\lambda) * DiodeFluxCalibration(\lambda)} \right|$$

$$\delta Tex = \left| \frac{-100 * CVF * S(\lambda) * DiodeFluxMeas(\lambda)}{Tex^2 * Pix^2 * Photons(\lambda) * DiodeFluxCalibration(\lambda)} \right|$$

$$\delta Photons(\lambda) = \left| \frac{-100 * CVF * S(\lambda) * DiodeFluxMeas(\lambda)}{Tex * Pix^2 * Photons(\lambda)^2 * DiodeFluxCalibration(\lambda)} \right|$$

$$\delta CVF = \left| \frac{100 * S(\lambda) * DiodeFluxMeas(\lambda)}{Tex * Pix^2 * Photons(\lambda) * DiodeFluxCalibration(\lambda)} \right|$$

$$\delta Pix = \left| \frac{-200 * CVF * S(\lambda) * DiodeFluxMeas(\lambda)}{Tex * Pix^3 * Photons(\lambda) * DiodeFluxCalibration(\lambda)} \right|$$

If all the measurements errors from the parameters are expressed as Δ, The ΔQE error yields to :

$$\Delta QE(\lambda) = (\delta Tex * \Delta Tex + \delta S(\lambda) * \Delta S(\lambda) + \delta Photons(\lambda) * \Delta Photons(\lambda) + \delta DiodeFluxMeas(\lambda) * \Delta DiodeFluxMeas(\lambda)$$
$$+ \delta DiodeFluxCalibration(\lambda) * \Delta DiodeFluxCalibration(\lambda) + \delta Pix * \Delta Pix + \delta CVF * \Delta CVF) * 100$$

The dominant parameters are, the other are negligible:

- ΔPhotons(λ)
- ΔDiodeFluxCalibration (λ)

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