# Technical Evaluation Report
# Calibration Report For The Rascal
# CsTe Photo-Multiplier Tube

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| Date: | July 9, 2003 |
| Document Number: | COS-11-0042 |
| Revision: | Initial Release |
| Contract No.: | NAS5-98043 |
| CDRL No.: | |

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# REVISIONS

| Letter | ECO No. | Description | Check | Approved | Date |
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| Drawn: Dr. Erik Wilkinson | 7/9/03 | **THE UNIVERSITY OF COLORADO**<br>At Boulder<br>**The Center for Astrophysics and Space Astronomy** |
| Reviewed: | | **Technical Evaluation Report**<br>Calibration Report for the RASCAL<br>CsTe Photo-Multiplier Tube |
| Approved: | | |

| Size | Code Indent No. | Document No. | Rev |
|---|---|---|---|
| A | | COS-11-0042 | - |
| Scale: N/A | | | |

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## 1. INTRODUCTION

This document presents the calibration of the RASCAL CsTe PMT, the fundemental photometric standard used to evaluate the sensitivity of the Cosmic Origins Spectrograph. The calibration and subsequent report were conducted by personnel at the Laboratory for Atmospheric and Space Physics (LASP). The calibration report forms the body of this report and is attached.

## 2. LASP CALIBRATION REPORT

The calibration report provided by LASP is attached.

It is worth noting that on page of the LASP report there is some discussion regarding the differences in the LASP numbers compared to our 1996 values. Although it's possible that there has been a real change in the sensitivity, there is an alternate explanation. Both BATC and LASP used a small spot of light, roughly 2mm diameter, to illuminate the 'center' of the photocathode. Dennis Ebbets recalls that BATC did not try to center this spot with exquisite accuracy in 1996, nor was any attempt made to insure that the two measurements were made at exactly the same place. Looking at the contour maps, a difference of a few milliters could easily give results that differ by the amount observed. Therefore, caution should be used when interpreting the observed differences in efficiency.

## 3. ADJUSTMENTS TO THE LASP PMT CALIBRAITON

Also appended to this document is an analysis conducted by Steve Osterman and Dennis Ebbets that computes adjustments to the PMT calibration based on the variation in quantum efficiency with position. These adjustments were included in the computation of the efficiency of COS during initial alignment and final calibration.

Laboratory for Atmospheric and Space Physics
University of Colorado
Boulder, CO

April 29, 2003

# REPORT OF TEST

Revision 1

Spectral Response

Of

RAS/CAL Photomultiplier Tube

**Description of Detector**

The Photomultiplier tube to be calibrated has a CsTe photocathode, and is sensitive in the ultraviolet region from 120-300nm. This Hamamatsu detector has a $MgF_2$ window over an active area of approximately 1in diameter.

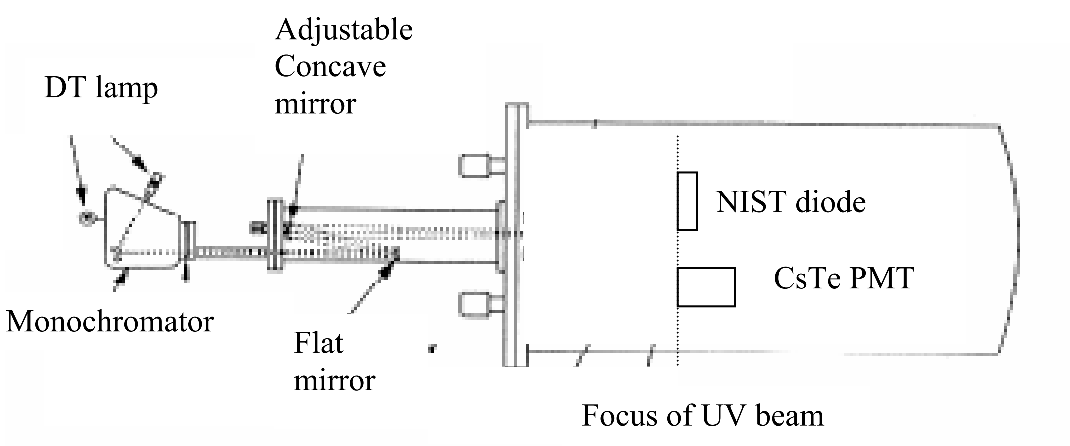
The Hamamatsu CsTe photomultiplier tube came prepackaged with an integrated high voltage power supply and pulse amplification. Positive 28 volts was applied using the provided CASA GSE test cable, in order to power both the HVPS and the pulse amplifier.

## Calibration set-up and facilities

The initial turn on and characterization was performed in the pulse height distribution box. This was done in order to check functionality of the PMT and to verify the shape of the analog output pulse. This is a clean environment with controllable UV light levels for stimulating the tube. PMT dark count rates are also measured in this facility.

The primary calibration was performed in the CTE2 vacuum tank. This UV system uses a deuterium lamp as a light source mounted on a monochromator with entrance and exit slits adjustable from 10-100 microns. The beam reflects off of a flat mirror onto a concave mirror. The focussing mirror's horizontal and vertical positions are adjustable to a resolution of about 0.5mm at the beam's focus. The NIST calibrated UV diode is located at the beam focal plane. During calibration the PMT was mounted next to the diode with its active window also in the focal plane. The current from the diode is connected to an electrometer whose output is linear and has been calibrated (–3.825 V= 1pA).

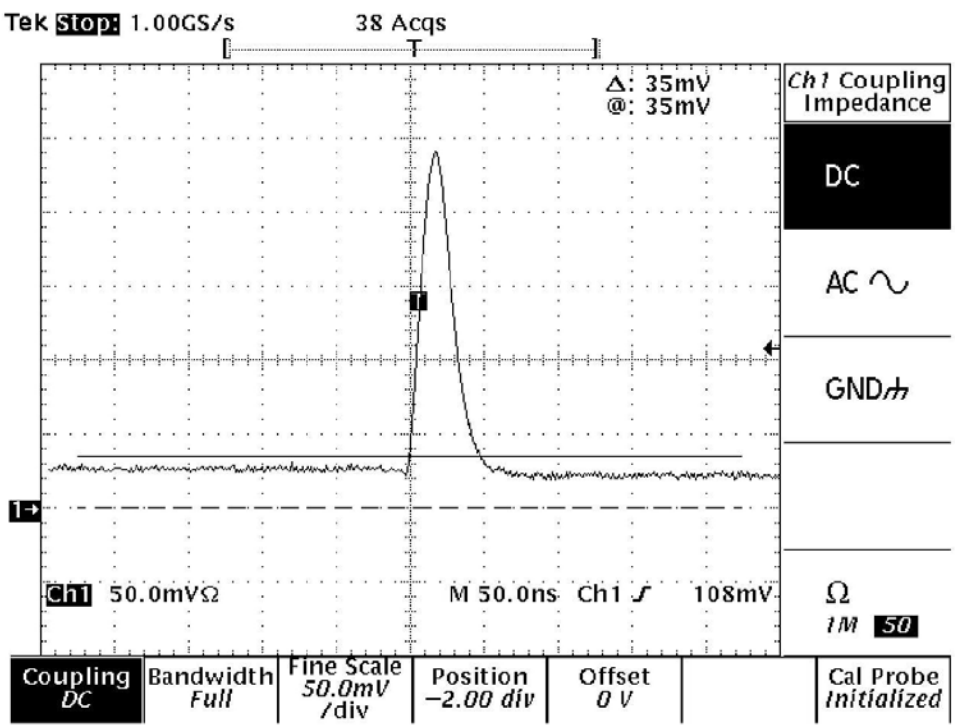
**Optical Layout of the Calibration and Test Equipment (CTE2)**



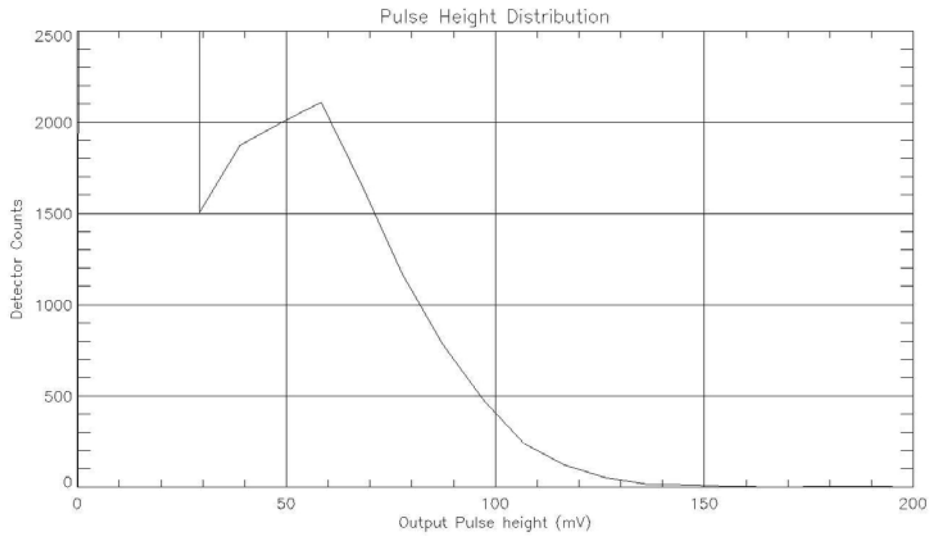

The output of the PMT was recorded using the calibrated SR400 gated counter, while the voltage difference of the diode was recorded using a Keithley 2010 Digital Multimeter. A Lab View program acquired data from both devices.

## Initial turn on and characterization

The output of the CsTe PMT was terminated at 50 ohms in order to simulate the impedance of the SR400 counter. The DC offset of the analog output signal with the 50 ohm termination was equal to 27mV with the noise on the ground being < 2mV. Thus, a threshold of 35mV for the provided counter is well above the noise on the ground of the output signal, as seen in the following scope picture.




The largest output pulse saturates at a value of 275mV. Stimulating the PMT with UV light results in a pulse height that is distributed from 30mV to 185mV centered on approximately 60 mV. The following is the Pulse Height Distribution for the analog output pulse.

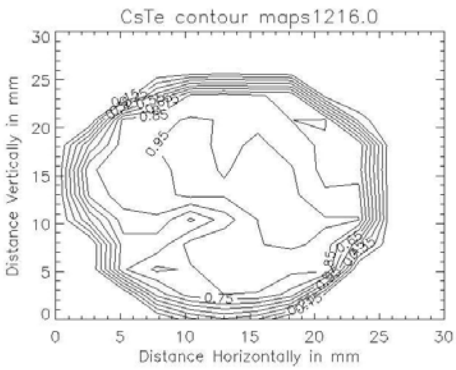


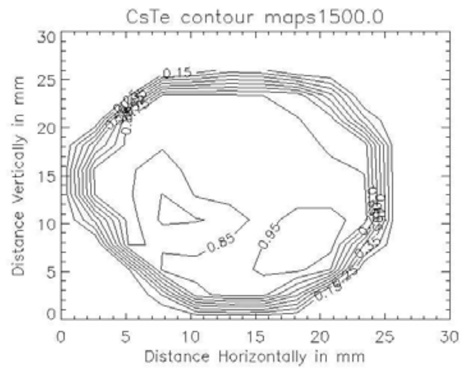

A dark test was performed using a ten-second integration period with a total of 12,168 counts over a time frame of 5120 seconds. The average dark count for the CsTe PMT was 2.38 Hz with a stdev=0.62.

## Results of UV Testing

### Photocathode Maps

Response maps of the photocathode were done at five different wavelengths (1216A, 1500, 1608, 2000, and 2800Å). These maps are 11x11 in dimension with 1.3 mm between each spatial reading. These contour plots illustrate the PMTs' surface, showing relative percentages of the maximum value.


CsTe contour maps1216.0
Distance Vertically in mm
Distance Horizontally in mm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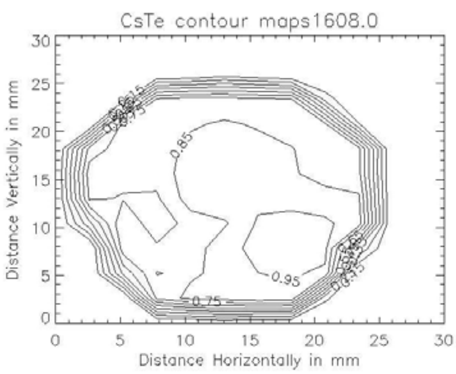
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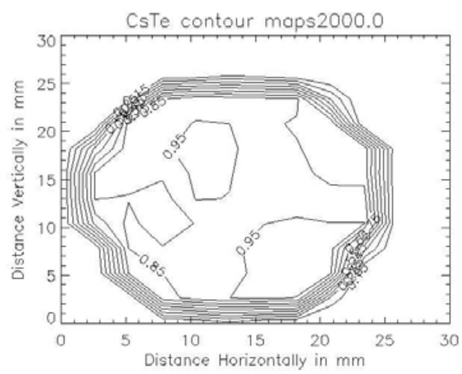
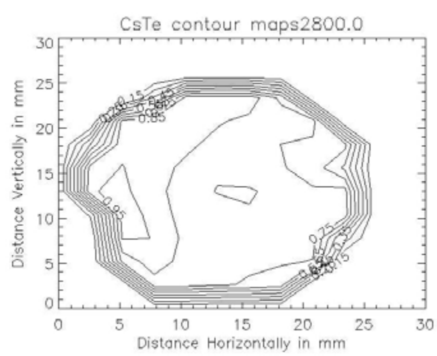
Distance Horizontally in mm


CsTe contour maps2000.0
Distance Vertically in mm
Distance Horizontally in mm

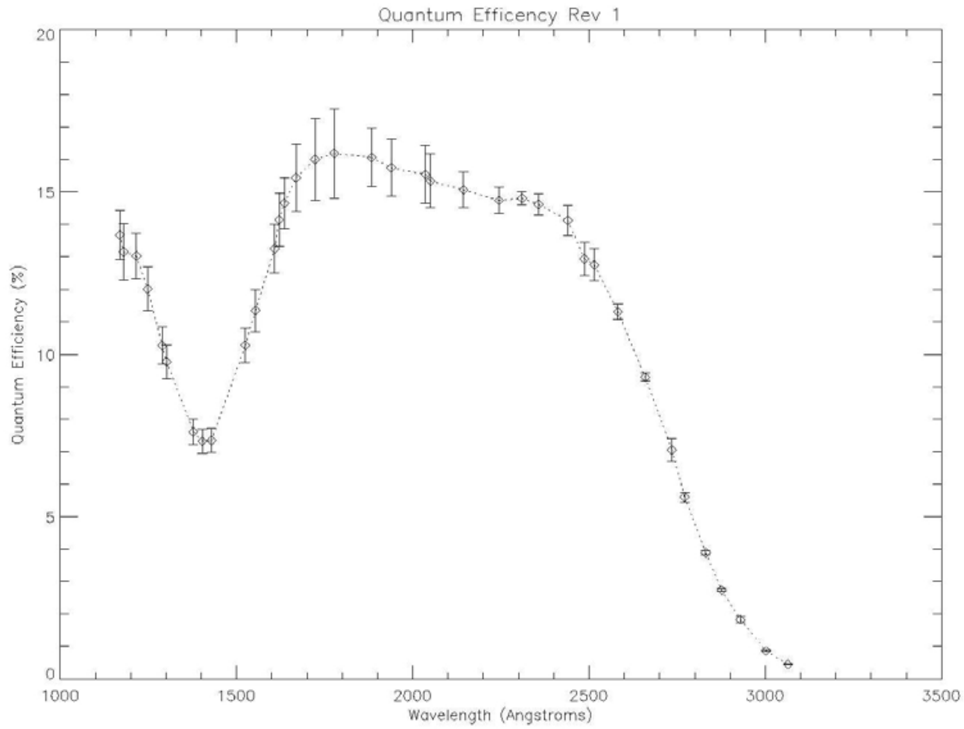

CsTe contour maps2800.0
Distance Vertically in mm
Distance Horizontally in mm

Below is a picture of the photocathode oriented such that the maps correspond directly to the window of the PMT.

## Quantum Efficiency

Quantum Efficiency measurements were performed in CTE2 from 1169-3064Å at 37 different spectral positions. The count rates for the PMT were in the range of 60-100kHz in order to get adequate signal from the photodiode. The pulse width of the PMT is 60ns, which has a dead time correction of < 0.1% for count rates below 100kHz. The QE measurement was done at the center position of the PMT window as well as the center of the calibrated diode. While the UV beam was being read by one detector, the other detector recorded a dark reading for that particular setting. Four separate runs were taken to account for systematic errors and then averaged to get the following quantum efficiency. The error bars on the QE measurement are found from the root sum squared combination of the reproducibility of the QE measurements and the propagated errors, including counting statistics as well as NIST diode uncertainties.

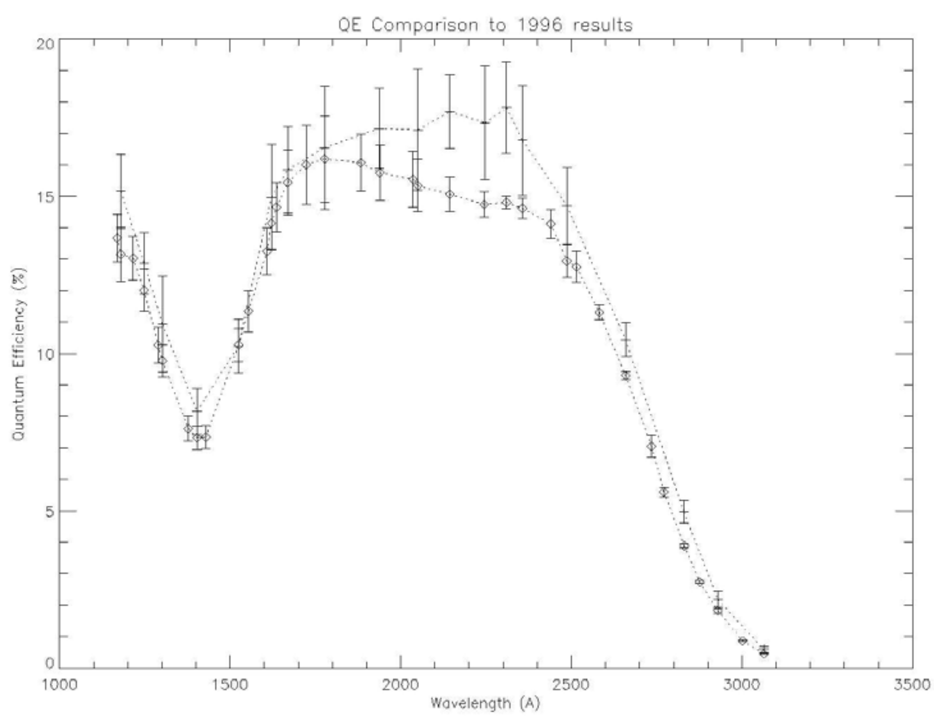
QE = PMT counts (Hz) / Diode (V) * 3.825(V/pA) * 1.602e-7(e-/pA) * NIST Diode QE



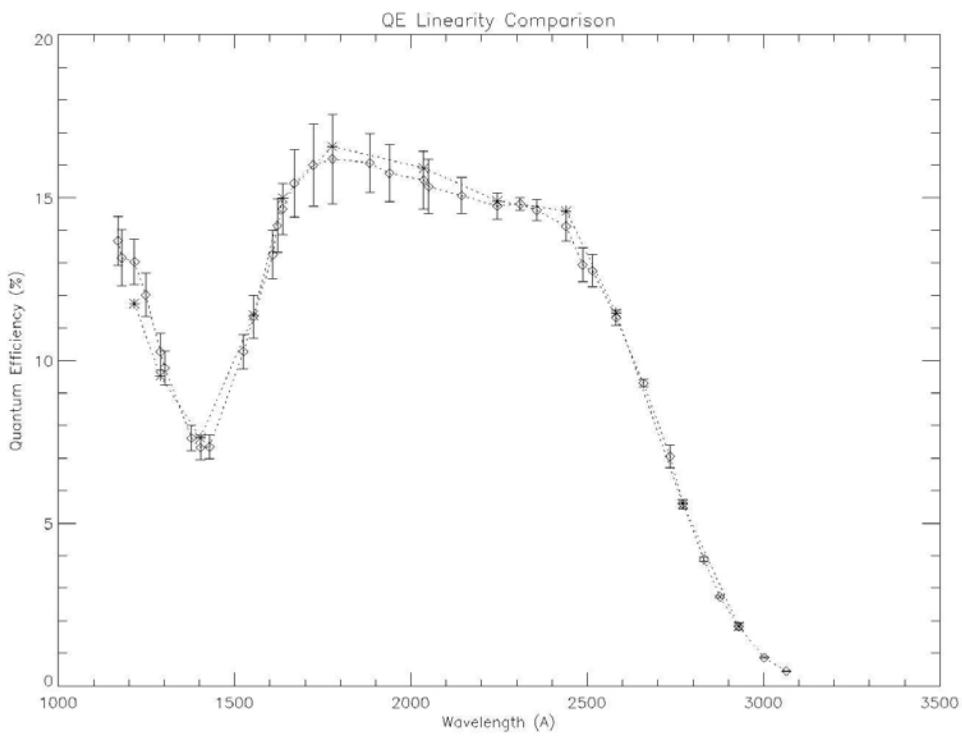

| Wavelength (Å) | QE (%) | Std Dev | Propagated Error | Uncertainty |
|---|---|---|---|---|
| 1169 | 13.67 | 0.338 | 0.684 | 0.763 |
| 1180 | 13.15 | 0.573 | 0.658 | 0.872 |
| 1216 | 13.02 | 0.379 | 0.587 | 0.699 |
| 1248 | 12.01 | 0.309 | 0.592 | 0.668 |
| 1289 | 10.26 | 0.253 | 0.514 | 0.573 |
| 1302 | 9.77 | 0.183 | 0.489 | 0.522 |
| 1378 | 7.61 | 0.155 | 0.362 | 0.394 |
| 1403 | 7.32 | 0.158 | 0.330 | 0.366 |
| 1429 | 7.34 | 0.156 | 0.331 | 0.366 |
| 1525 | 10.27 | 0.253 | 0.463 | 0.528 |
| 1554 | 11.34 | 0.407 | 0.511 | 0.653 |
| 1608 | 13.25 | 0.450 | 0.597 | 0.748 |
| 1621 | 14.14 | 0.482 | 0.660 | 0.817 |
| 1636 | 14.65 | 0.351 | 0.711 | 0.793 |
| 1669 | 15.43 | 0.699 | 0.772 | 1.04 |
| 1723 | 16.00 | 0.455 | 1.17 | 1.25 |
| 1777 | 16.19 | 0.372 | 1.32 | 1.37 |
| 1883 | 16.06 | 0.411 | 0.804 | 0.903 |
| 1939 | 15.74 | 0.392 | 0.788 | 0.880 |
| 2036 | 15.54 | 0.416 | 0.778 | 0.882 |
| 2050 | 15.34 | 0.318 | 0.768 | 0.831 |
| 2144 | 15.07 | 0.128 | 0.536 | 0.551 |
| 2245 | 14.74 | 0.348 | 0.207 | 0.405 |
| 2310 | 14.80 | 0.136 | 0.140 | 0.196 |
| 2357 | 14.62 | 0.203 | 0.247 | 0.320 |
| 2440 | 14.12 | 0.447 | 0.129 | 0.465 |

| Wavelength (Å) | QE (%) | Std Dev | Propagated Error | Uncertainty |
|---|---|---|---|---|
| 2487 | 12.94 | 0.498 | 0.115 | 0.511 |
| 2515 | 12.75 | 0.369 | 0.324 | 0.491 |
| 2582 | 11.30 | 0.213 | 0.095 | 0.234 |
| 2659 | 9.30 | 0.089 | 0.082 | 0.121 |
| 2735 | 7.05 | 0.336 | 0.070 | 0.343 |
| 2771 | 5.59 | 0.130 | 0.061 | 0.144 |
| 2831 | 3.88 | 0.043 | 0.050 | 0.066 |
| 2876 | 2.73 | 0.027 | 0.037 | 0.046 |
| 2929 | 1.82 | 0.094 | 0.029 | 0.098 |
| 3002 | 0.863 | 0.016 | 0.017 | 0.024 |
| 3064 | 0.452 | 0.010 | 0.010 | 0.014 |

If we compare the 1996 calibration results (+ in the plot below), to the current results, it can been seen that for the shorter wavelengths the results fall within the error range of the measurements. For the longer wavelengths the sensitivity has decreased, with the maximum discrepancy at 2310Å, changing QE from 17.82% to 14.80%.



Linearity was verified by measuring the quantum efficiency at lower count rates. In order to get a reliable reading from the diode, the count rates for the 11 different spectral lines were kept between 5-20kHz. The lower flux of photons resulted in sensitivity within the error range of the higher count rate results (* indicates the lower count rate measurements).

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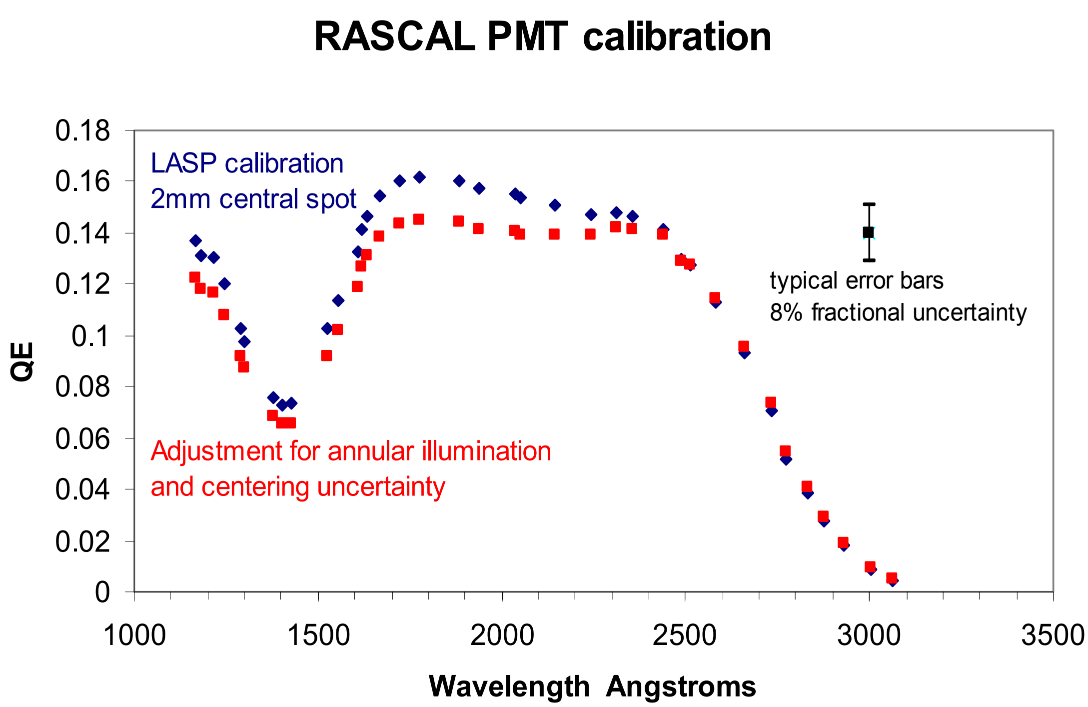
# RASCAL PMT calibration adjustment

D. Ebbets, S. Osterman
June 20, 2003


RASCAL PMT calibration
LASP calibration
2mm central spot
typical error bars
8% fractional uncertainty
Adjustment for annular illumination
and centering uncertainty
QE
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1000
1500
2000
2500
3000
3500
Wavelength Angstroms

| Wavelength (Angstroms) | adjusted QE | $1\sigma$ | fractional uncertainty |
|---|---|---|---|
| | | | |
| 1169 | 0.123 | 0.009 | 0.071 |
| 1180 | 0.118 | 0.009 | 0.079 |
| 1216 | 0.117 | 0.008 | 0.069 |
| 1248 | 0.108 | 0.008 | 0.071 |
| 1289 | 0.092 | 0.007 | 0.071 |
| 1302 | 0.088 | 0.006 | 0.069 |
| 1378 | 0.068 | 0.005 | 0.068 |
| 1403 | 0.066 | 0.004 | 0.066 |
| 1429 | 0.066 | 0.004 | 0.066 |
| 1525 | 0.092 | 0.006 | 0.067 |
| 1554 | 0.102 | 0.007 | 0.072 |
| 1608 | 0.119 | 0.008 | 0.071 |
| 1621 | 0.127 | 0.009 | 0.072 |
| 1636 | 0.131 | 0.009 | 0.070 |
| 1669 | 0.138 | 0.011 | 0.080 |
| 1723 | 0.144 | 0.013 | 0.090 |
| 1777 | 0.145 | 0.014 | 0.095 |
| 1883 | 0.144 | 0.010 | 0.071 |
| 1939 | 0.141 | 0.010 | 0.071 |
| 2036 | 0.141 | 0.011 | 0.081 |
| 2050 | 0.139 | 0.011 | 0.080 |
| 2144 | 0.140 | 0.010 | 0.069 |
| 2245 | 0.139 | 0.009 | 0.064 |
| 2310 | 0.142 | 0.008 | 0.060 |
| 2357 | 0.142 | 0.009 | 0.062 |
| 2440 | 0.139 | 0.009 | 0.067 |
| 2487 | 0.129 | 0.009 | 0.070 |
| 2515 | 0.128 | 0.009 | 0.070 |
| 2582 | 0.115 | 0.007 | 0.062 |
| 2659 | 0.096 | 0.006 | 0.060 |
| 2735 | 0.074 | 0.006 | 0.076 |
| 2771 | 0.055 | 0.009 | 0.165 |
| 2831 | 0.041 | 0.004 | 0.094 |
| 2876 | 0.029 | 0.003 | 0.090 |
| 2929 | 0.019 | 0.002 | 0.087 |
| 3002 | 0.009 | 0.001 | 0.086 |
| 3064 | 0.005 | 0.000 | 0.086 |

## PMT Effective QE and uncertainties to be used for reduction of COS sensitivity measurements

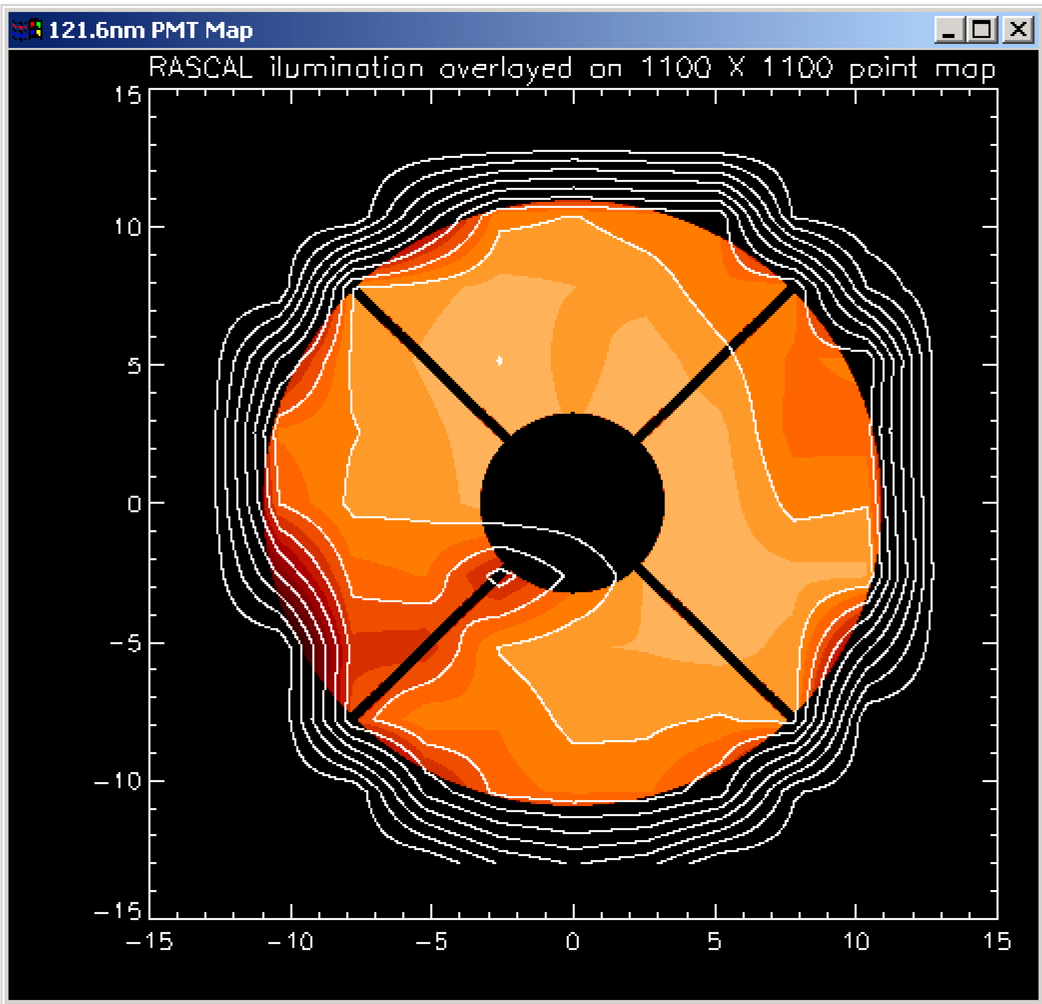
Values account for:

- LASP calibration
- Annular illumination
- Centering uncertainty
- Propagation of errors

# Rationale for adjustments

- LASP provided the basic calibration data
  - QE measured for a 2mm spot at center of pmt
  - Carefully propagated uncertainties
  - 2D maps of phototcathode at several wavelengths
- Steve O. estimated two effects that will be present when pmt is used for COS calibration
  - RASCAL illuminates an annular region of the photocathode. The size of the annulus is nearly as large as the entire photocathode. The very center not used. The pmt response is not spatially uniform.
  - The pmt may not be placed in the RASCAL beam with perfect centering

# Example of illumination and PMT response for λ = 1216 A




LASP calibration QE = 0.130 for 2mm spot at center

White contours = 10% intervals relative to maximum measured QE (not necessarily center value)

Colored contours = 5% intervals

Colored annulus = RASCAL illumination, with central obscuration and spiders shown

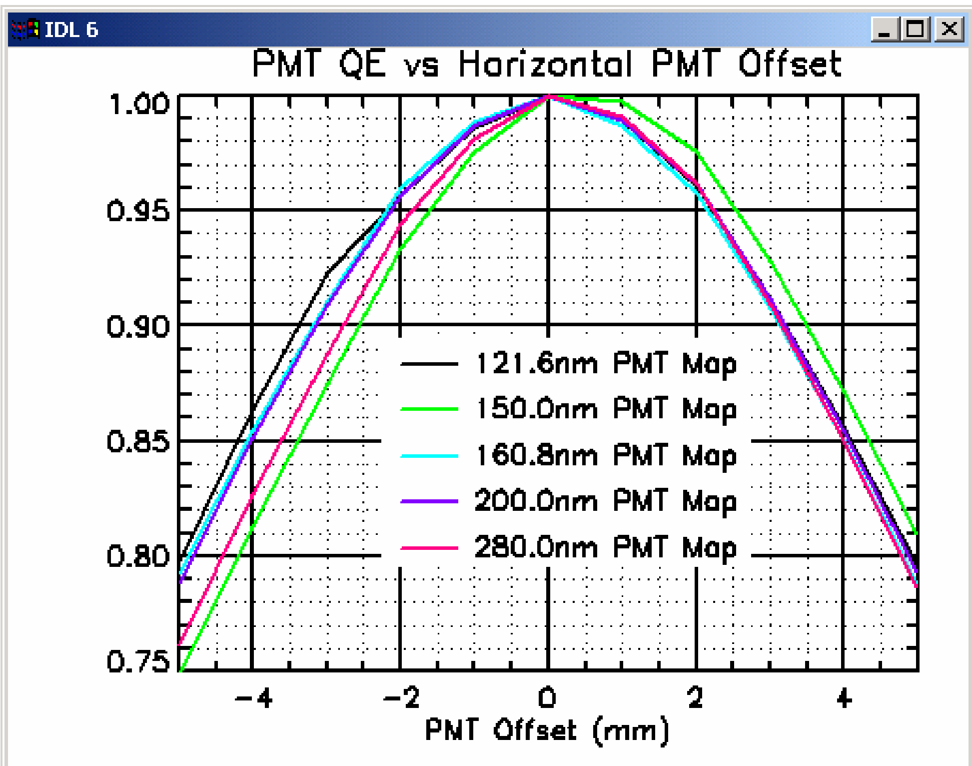
# Adjustments for annular illumination

| Wavelength (interpolated values in italic) | Nominal DQE (Center) | Effective DQE (over illum. Area) | QE Scale Factor |
|---|---|---|---|
| 1216 | 13.0251 | 11.7263 | 0.9002848 |
| *1500* | 9.51105 | 8.99354 | 0.9455886 |
| 1608 | 13.2551 | 11.697 | 0.8824528 |
| *2000* | 15.6171 | 14.5756 | 0.9333103 |
| *2800* | 4.56105 | 4.92282 | 1.0793173 |

"effective DQE" estimated by integrating 2D QE map over illumination pattern

- for l < 2000
  - Use average of 4 values   QE scale factor = 0.915
  - standard deviation = .03
- 2000 < l < 2800
  - linearly interpolate QE scale factor
  - relative uncertainty = 0.05 (only two data points)
- for l > 2800
  - use value for 2800 QE scale factor = 1.079
  - relative uncertainty = 0.08

# Adjustments for centering error




We assume PMT will be centered in the RASCAL beam to about +/- 1mm of the optimum value.

- Use adjustment factor = 0.98
- Add an additional 0.03 relative uncertainty in quadrature
- Adjust later if we have more information about accuracy of centering of pmt

# Application to data

- QE and uncertainties are used for reduction of data for COS sensitivity measurements
- LASP calibration was performed at wavelengths expected to be used. No interpolation should be necessary.
- Include pmt uncertainties in calculating total error bars for sensitivity measurements.