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

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**THE UNIVERSITY OF COLORADO**  
At Boulder  
The Center for Astrophysics and Space Astronomy  

**Technical Evaluation Report**  
Calibration Report for the RASCAL CsTe Photo-Multiplier Tube

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1. **INTRODUCTION**

This document presents the calibration of the RASCAL CsTe PMT, the fundamental 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 CALIBRATION**

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 MgF₂ 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 (1216Å, 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.
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.

\[ QE = \frac{\text{PMT counts (Hz)}}{\text{Diode (V)}} \times 3.825(V/pA) \times 1.602e-7(e-/pA) \times \text{NIST Diode QE} \]
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 | 0.309 | 0.592 | 0.668
1248 | 10.26 | 0.253 | 0.514 | 0.573
1289 | 9.77 | 0.183 | 0.489 | 0.522
1302 | 7.61 | 0.155 | 0.362 | 0.394
1378 | 7.32 | 0.158 | 0.330 | 0.366
1403 | 7.34 | 0.156 | 0.331 | 0.366
1429 | 10.27 | 0.253 | 0.463 | 0.528
1525 | 11.34 | 0.407 | 0.511 | 0.653
1554 | 13.25 | 0.450 | 0.597 | 0.748
1608 | 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
1863 | 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
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%.

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

D. Ebbets, S. Osterman
June 20, 2003
RASCAL PMT calibration

LASP calibration
2mm central spot

 Adjustment for annular illumination and centering uncertainty

typical error bars
8% fractional uncertainty

Wavelength Angstroms

QE

0 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18

1000 1500 2000 2500 3000 3500
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 photocathode 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 $\lambda = 1216$ Å

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

<table>
<thead>
<tr>
<th>Wavelength (interpolated values in italic)</th>
<th>Nominal DQE (Center)</th>
<th>Effective DQE (over illum. Area)</th>
<th>QE Scale Factor</th>
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<tbody>
<tr>
<td>1216</td>
<td>13.0251</td>
<td>11.7263</td>
<td>0.9002848</td>
</tr>
<tr>
<td>1500</td>
<td>9.51105</td>
<td>8.99354</td>
<td>0.9455886</td>
</tr>
<tr>
<td>1608</td>
<td>13.2551</td>
<td>11.697</td>
<td>0.8824528</td>
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<tr>
<td>2000</td>
<td>15.6171</td>
<td>14.5756</td>
<td>0.9333103</td>
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<tr>
<td>2800</td>
<td>4.56105</td>
<td>4.92282</td>
<td>1.0793173</td>
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</table>

“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.