Swift X-ray Telescope Operations

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XRT Lead

University Partners:
PSU  UL  OAB

Calibration Partners:
PSU / UL / OAB / MPE

7 September 2004, Swift Workshop @ HEAD 2004
The Swift Observatory

XRT Telescope
Tube

UVOT

XRT Electronics

7 September 2004, Swift Workshop @ HEAD 2004
The Swift Observatory

7 September 2004, Swift Workshop @ HEAD 2004
XRT Science Goals

1) Rapid determination of GRB position
   (accuracy < 5”, transmit to ground < 100 s after burst)

2) X-ray spectroscopy
   - Determine Redshift from Emission Lines or Absorption Features in X-ray Spectrum
   - Determine physical conditions of ISM in vicinity of burst
     (energy resolution < 140 eV @ 6 keV at launch)

3) Burst/Afterglow Lightcurve
   - Monitor blast wave evolution
     (time resolution: 0.14 ms or 2.2 ms)
# XRT Instrument Characteristics

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telescope</td>
<td>3.5m Wolter I</td>
</tr>
<tr>
<td>Telescope PSF</td>
<td>18 arcsec HPD @ 1.5 keV</td>
</tr>
<tr>
<td></td>
<td>22 arcsec HPD @ 8.1 keV</td>
</tr>
<tr>
<td>Detector</td>
<td>e2v CCD-22</td>
</tr>
<tr>
<td>Detector Format</td>
<td>600 x 602 pixels</td>
</tr>
<tr>
<td>Detector Readout Modes</td>
<td>Photon-counting, Imaging, &amp; Timing</td>
</tr>
<tr>
<td>Field of View</td>
<td>23.6 x 23.6 arcmin</td>
</tr>
<tr>
<td>Pixel Scale</td>
<td>2.36 arcsec / pixel</td>
</tr>
<tr>
<td>Energy Range</td>
<td>0.2 - 10 keV</td>
</tr>
<tr>
<td>Effective Area</td>
<td>135 cm$^2$ @ 1.5 keV</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>$2 \times 10^{-14}$ ergs/cm$^2$/s in $10^4$ s</td>
</tr>
<tr>
<td>Position Accuracy</td>
<td>2.5 arcseconds</td>
</tr>
<tr>
<td>Operation</td>
<td>Autonomous</td>
</tr>
</tbody>
</table>
Observing Scenario

1. Burst Alert Telescope triggers on GRB, calculates position on sky to < 4 arcmin
2. Spacecraft autonomously slews to GRB position in 20-75 s
3. X-ray Telescope determines position to ~3 arcseconds
4. UV/Optical Telescope images field, transmits finding chart to ground

\[ T < 10 \text{ sec} \]
\[ d_\theta \sim 4' \]
\[ T < 100 \text{ sec} \]
\[ d_\theta \sim 3 \text{ arcseconds} \]
\[ T < 300 \text{ sec} \]
XRT Readout Modes

XRT must autonomously select readout modes suited to observations of GRBs and afterglows:

<table>
<thead>
<tr>
<th>Mode</th>
<th>Flux (Crabs)</th>
<th>Imaging</th>
<th>Spectroscopy</th>
<th>Timing</th>
<th>Bias</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Gain Imaging</td>
<td>.025 - 37</td>
<td>2-D</td>
<td>None</td>
<td>0.1 / 2.5 s</td>
<td>No bias subtraction</td>
<td>Centroid, Postage-stamp, thresholded image</td>
</tr>
<tr>
<td>Imaging (centroid)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photodiode Timing</td>
<td>.05 – 60</td>
<td>None</td>
<td>Full</td>
<td>0.14 ms</td>
<td>Bias level subtraction</td>
<td>Events above threshold</td>
</tr>
<tr>
<td>Windowed Timing</td>
<td>.00005 - .15</td>
<td>1-D</td>
<td>Full</td>
<td>2.2 ms</td>
<td>Bias row subtraction</td>
<td>Events above threshold</td>
</tr>
<tr>
<td>Photon-Counting</td>
<td>&lt; 0.0001</td>
<td>2-D</td>
<td>Full</td>
<td>2.5 s</td>
<td>Bias map subtraction</td>
<td>3x3 neighborhoods above threshold</td>
</tr>
</tbody>
</table>
XRT Autonomous Observing Sequence

Take Bias Images → Start Slew

On Target? (N)

Image mode

Photodiode (no position)

Windowed Timing (1-D position)

Photon-Counting

Δt < 5 s

Position to TDRSS

Y

0.6 Crabs < \( F_X \) < 60 Crabs

1 mCrabs < \( F_X \) < 600 mCrabs

\( F_X < 1 \) milliCrabs
Swift GRB Monitoring

Sample GRB Monitoring Campaign

Trigger No 100001

Observation

Snapshot

Observation

Observation

Observation

Observation

Observation

Intensity (arbitrary units)

Time (d)

0

1

2

3

4

5

6

150

100

50

0
Day in the Life of Swift XRT

TDRSS messages:
- Centroid Position Message
- Postage-Stamp Image Message
- Raw Spectrum Message

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Typical XRT Observation Sequence

<table>
<thead>
<tr>
<th>Activity</th>
<th>Flux (mCrabs)</th>
<th>Time (s)</th>
<th>Science Data Products</th>
<th>TDRSS Data Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slew</td>
<td>5000</td>
<td>0</td>
<td>Bias map 600 x 602, (Raw Frame 635 x 602)</td>
<td>Centroid Position</td>
</tr>
<tr>
<td>Settle</td>
<td>5000</td>
<td>43</td>
<td>Photodiode events, 1 pixel 24’ x 24’</td>
<td>Postage-Stamp Image, 51 x 51 pixels, 2’ x 2’</td>
</tr>
<tr>
<td>Centroid</td>
<td>3000</td>
<td>50</td>
<td>Image pixels, 600 x 602 24’ x 24’</td>
<td>Raw Spectrum, 1024 channels, 0-10 keV</td>
</tr>
<tr>
<td>Automated Observation</td>
<td>800</td>
<td>55</td>
<td>Photodiode events, 1 pixel 24’ x 24’</td>
<td></td>
</tr>
<tr>
<td>Centroid</td>
<td>100</td>
<td>400</td>
<td>Windowed Timing mode, 0.8 s per ‘frame’</td>
<td></td>
</tr>
<tr>
<td>Automated Observation</td>
<td>100</td>
<td>1000</td>
<td>Windowed Timing mode, 8s per ‘frame’</td>
<td></td>
</tr>
<tr>
<td>Constraint Violation</td>
<td>100</td>
<td></td>
<td>Windowed Timing events, 200 columns 8’ x 24’</td>
<td></td>
</tr>
</tbody>
</table>

Flux (mCrabs) 5000, 3000, 800, 100

Centroid Position

Postage-Stamp Image, 51 x 51 pixels, 2’ x 2’

Raw Spectrum, 1024 channels, 0-10 keV

TDRSS Data Products

Centroid

Postage-Stamp Image, 51 x 51 pixels, 2’ x 2’

Raw Spectrum, 1024 channels, 0-10 keV

GCN
XRT Calibration – Munich, September/October 2002
XRT Angular Resolution

PSF is uniform over FOV
HPD = 18 arcsec @ 1.5 keV
= 22 arcsec @ 8.1 keV
XRT Position Determination Accuracy

Panter test results: Centroid Accuracy vs Flux

Switches from 2.5 s to 0.1 s exposure

Centroid Accuracy (arcseconds)

Flux (Crabs)
XRT Position Determination
Timing

Total time (exposure + readout + calculation) < 5.2 s

Switches from 2.5 s to 0.1 s
XRT Spectroscopy

$^{55}$Fe spectrum ($\text{Mn K}\alpha$ and $\text{K}\beta$ lines at 5.89 and 6.40 keV) measured during XRT thermal balance tests.

XRT monitors these lines in the corners of the CCD image continuously.

<table>
<thead>
<tr>
<th>Readout Mode</th>
<th>Energy Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imaging</td>
<td>N/A</td>
</tr>
<tr>
<td>Photodiode</td>
<td>140 eV</td>
</tr>
<tr>
<td>Windowed Timing</td>
<td>138 eV</td>
</tr>
<tr>
<td>Photon-Counting</td>
<td>133 eV</td>
</tr>
</tbody>
</table>

Preliminary Energy Resolution (5.9 keV, Panter) (requirement is < 150 eV at launch)
XRT Spectroscopy

- X-ray spectroscopy of GRBs and afterglows
  - Redshift determination, ISM measurements

**Energy resolution < 140 eV @ 5.9 keV**

Simulated 1 hr observation of a GRB afterglow, 1.5 hours after the burst. Based on Beppo-SAX observation of GRB000214.

XMM observation of 5 ks from the afterglow of GRB011211, beginning 11 hours after the burst.
XRT Calibration Spectrum

$^{55}\text{Fe}$ Calibration spectrum
E = 5.9 keV / 6.4 keV
Noise = 5.0 e$^{-}$ (rms)
Resolution = 130 eV (FWHM)
XRT Data Products

- Prompt GRB data transmitted through TDRSS and distributed via GCN
- Full data sets transmitted through Malindi ground-station
  - Converted to standard OGIP FITS formats by Swift Data Center at NASA/GSFC
  - Data products available on SDC Quick-Look site within 2 hours of ground pass
  - XRT Data Analysis Software (ASDC) performs high-level processing and analysis (see talk by Tagliaferri)
Summary

- XRT is a powerful, flexible instrument that will provide rapid, arcsecond GRB positions and spectroscopy
- Ground calibrations will be validated on-orbit using standard X-ray calibration sources
- GRB prompt data products converted to standard FITS formats and distributed in minutes via GCN
- Data products converted to standard FITS binary table formats and publicly available to community within hours