Computational Modeling of Photon Scattering In Gamma Ray Bursts Using Monte Carlo Methods

By: Bao Nguyen
Advisor: Dr. Davide Lazzati
Oregon State University
2015
Outline:

• Introduction and Motivation
• Methods
• Results
• Future Work
What Are Gamma Ray Bursts (GRBs)?

- High energy jets of photons usually above 0.1 MeV and peak in the gamma-spectrum.
- GRBs were first discovered in the late 1960s by military satellites.
- GRBs’ light curves are very diverse but can be categorized into short GRBs and long GRBs.
Fireball Model

- The process is modeled as discrete shells expanding at different velocities.
- Pressure and temperature fluctuation causing the shells in GRB to expand at different velocities.
- The collisions between fast expanding shell and slowly expanding shells release gamma-ray.
Motivation

• To exam the initial environment’s effects on the observed light curve of a GRB.
• To exam the expanding velocity’s effects on the observed light curve of a GRB.
Methods

• Using Monte Carlo methods (MCM) to mimic the photon scattering process in GRBs.

• Three models:
  - Model 1: Non-expanding centered photon model
  - Model 2: Non-expanding uniformly distributed photon model
  - Model 3: Expanding centered photon model
Photon Scattering

• Photons were generated at the center/ uniformly distributed inside with a known radius of a sphere, using MCM. The sphere also had an opacity, \( \tau = \sigma \times \rho_{\text{electron}} \).

• The photons were assigned a random initial velocity (using MCM) and were scattered until they escaped the sphere.

• The photons were assigned with a new normalized velocity after each scattering.
Scattering Time

- The stepsize for the scattering was determined using Beer’s law combined with Poisson probability distribution:

\[ \varepsilon = \exp(-\tau \Delta x) \]

\[ \Delta x = -\ln(\varepsilon)/\tau \]
Generating Emission and Observed Light Curves.

• The emission times of the photons were recorded to generate the observed light curve.

• The observed light curve was generated using the expression:

\[ T_{\text{observed}} = T_{\text{emission}} - T_{\text{emission}} \frac{V_{\text{sphere}}}{c} \]
Non-Expanding Photon Centered Photon Model and Uniformly Distributed Parameters

- The radius and the opacity were different for each case.

<table>
<thead>
<tr>
<th>Case</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{sphere}$</td>
<td>1.0</td>
<td>10.0</td>
<td>1.0</td>
<td>10.0</td>
<td>1.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Opacity ($\tau$)</td>
<td>10.0</td>
<td>10.0</td>
<td>100.0</td>
<td>100.0</td>
<td>1000.0</td>
<td>1000.0</td>
</tr>
</tbody>
</table>

Table 2: The cases for the non-expanding models. These parameters were used in both the uniformly distributed model and the centered model.
## Expanding Centered Photon Model Parameters

<table>
<thead>
<tr>
<th>Case</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>(R_{sphere})</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opacity ((\tau))</td>
<td>1000.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expanding speed (v_{sphere})</td>
<td>0.1c</td>
<td>0.2c</td>
<td>0.3c</td>
<td>0.4c</td>
<td>0.5c</td>
<td>0.6c</td>
<td>0.7c</td>
<td>0.8c</td>
<td>0.9c</td>
<td>0.99c</td>
</tr>
</tbody>
</table>

Table 3: The sphere were expanded at the relativistic speeds showing in the table with the same initial conditions. The radius rate of change depended on \(\Delta t\).
Results
Non-Expanding Centered Photon Cases

Case 1, Rsphere = 1, tau = 10

Case 2, Rsphere = 10, tau = 10

Case 3, Rsphere = 1, tau = 100

Case 4, Rsphere = 10, tau = 100

Case 5, Rsphere = 1, tau = 1000

Case 6, Rsphere = 10, tau = 1000
Kolmogorov-Smirnov Test (KS2)

Table 4: The results of KS tests of the cases. The first value in each cell corresponds to the D-value and the second value corresponds to the P-value.

- Level of significance was 0.1.
- Cases with $\tau > 100$, changing $\tau$ and keeping $R$ fixed produced the same observed light curve.
- Cases with the same $\tau$, changing $R$ did not alter the observed light curve.
Non-Expanding Uniformly Distributed Photon Cases

Case 1, Rsphere = 1, tau = 10

Case 2, Rsphere = 10, tau = 10

Case 3, Rsphere = 1, tau = 100

Case 4, Rsphere = 10, tau = 100

Case 5, Rsphere = 1, tau = 1000

Case 6, Rsphere = 10, tau = 1000
Kolmogorov-Smirnov Test (KS2)

<table>
<thead>
<tr>
<th>Case</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(D-value, P-value)</td>
<td>6.67E-03, 5.16E-01</td>
<td>9.86E-02, 1.99E-127</td>
<td>9.86E-02, 2.43E-127</td>
<td>1.12E-01, 4.39E-164</td>
<td>1.11E-01, 4.81E-162</td>
</tr>
<tr>
<td>2</td>
<td>(D-value, P-value)</td>
<td>9.77E-02, 5.98E-125</td>
<td>9.86E-02, 2.43E-127</td>
<td>1.12E-01, 8.59E-164</td>
<td>1.10E-01, 3.01E-159</td>
<td>1.97E-03, 8.52E-01</td>
</tr>
<tr>
<td>3</td>
<td>(D-value, P-value)</td>
<td></td>
<td>4.97E-03, 8.52E-01</td>
<td>1.89E-01, 4.34E-05</td>
<td>1.87E-02, 5.24E-05</td>
<td>1.71E-02, 3.05E-04</td>
</tr>
<tr>
<td>4</td>
<td>(D-value, P-value)</td>
<td></td>
<td></td>
<td>1.71E-02, 3.05E-04</td>
<td>1.69E-02, 3.61E-04</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>(D-value, P-value)</td>
<td></td>
<td></td>
<td></td>
<td>6.00E-03, 6.51E-01</td>
<td></td>
</tr>
</tbody>
</table>

Table 5: The results of KS tests of the cases. The first value in each cell corresponds to the D-value and the second value corresponds to the P-value.

- Level of significance was 0.1.
- Cases with different $\tau$, changing R did not produce the same observed light curve.
- Cases with the same $\tau$, changing R did not alter the observed light curve.
Expanding Centered Photon Cases
Expanding Centered Photon Cases

• The results were modified and compared with GRB 7475 from BATSE.

• $\chi^2$ tests were used to compare the data.
• Level of significance was 0.001.
• 1718 data points and 5 fitting parameters.
• Critical $\chi^2$ was 1900.

<table>
<thead>
<tr>
<th>Case</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td>21</td>
<td>18.4</td>
<td>14.4</td>
<td>11.4</td>
<td>9.2</td>
<td>7.3</td>
<td>6</td>
<td>4.9</td>
<td>4.5</td>
<td>1.7</td>
</tr>
<tr>
<td>$t_0$</td>
<td>-10</td>
<td>-7.2</td>
<td>-4.3</td>
<td>-2.1</td>
<td>-0.2</td>
<td>1.35</td>
<td>2.4</td>
<td>3.4</td>
<td>3.4</td>
<td>5.18</td>
</tr>
<tr>
<td>$\chi^2$</td>
<td>2543</td>
<td>1873</td>
<td>2096</td>
<td>3024</td>
<td>4484</td>
<td>6305</td>
<td>8075</td>
<td>10738</td>
<td>14105</td>
<td>15874</td>
</tr>
</tbody>
</table>

Table 6: The values of $a, t_0$, and $\chi^2$ for GRB 7475 fitting. The values of $a$ and $t_0$ were chosen so that the theoretical results closely resembled GRB 7475 data.

• Case 2 has $\chi^2$-value less than 1900.
Summary

• The photon scattering process in GRBs was simulated using Monte Carlo method for three different models:
  
  • 1) Non-expanding centered photon model.
  • 2) Non-expanding uniformly distributed model.
  • 3) Expanding centered photon model.

• Model 1:
  
  • Cases with the same $\tau$, changing $R$ did not alter the observed light curve.
  • Cases with $\tau > 100$, changing $\tau$ and keeping $R$ fixed produced the same observed light curve.

• Model 2:
  
  • Cases with the same $\tau$, changing $R$ did not alter the observed light curve.
  • Cases with different $\tau$ did not produce the same observed light curve.

• Model 3:
  
  • Only case 2 with $V_{sphere} = 0.2c$ had $\chi^2 < 1900$
Future Goals

• Obtain results for Model 4: Expanding uniformly distributed photon model.
• Compare Model 3 and Model 4 with other GRB data from BATSE.
References


Acknowledgements

• Professor Davide Lazzati

• Classmates:
  • Lisa Fletcher
  • David Konyndyk
  • Samuel Kowash
  • Daniel Lin
  • Blythe Nourie