Utilizing Fractionated Space Mission Design and Small Satellites for a Next Generation Gamma Ray Burst Observatory

Rashied B Amini
Outline

• Background
• Missions Objectives
• (Abridged) Satellite Overview
• Sortie Overview
• Conclusion
Background

- Most energetic event in the universe
- Discovered by Vela satellites during Cold War
- Recent GRB missions:
  - CGRO
  - SWIFT
  - Agile
  - HETE-II
- Many participated in the Interplanetary Network (IPN)
Background

• Why does this matter?

Early missions achieve all-sky coverage with limited precision. Current missions achieve high precision with limited coverage.

How can we get all-sky coverage with high precision for a next generation mission?
Mission Objectives

• Science Mission
  – To provide rapid detection and observation of GRBs as well as prompt relay of GRB coordinates

• Technology Mission
  – Utilize several small satellites as a demonstration of the viability of fractionated mission design for space science missions
Satellite Overview

• Formation of four satellites flying on a 10,000 km, equatorial, circular orbit
  – Position and direction provided to high precisions and accuracy by GPS and on-board gyroscopes
  – Right outside of Inner Van Allen Belt

• Each satellite has:
  – 5 Sodium Iodide (NaI) scintillating detectors
  – 2 Wide Field X-ray Cameras (WFXC)
  – Primary observation instrument
Satellite Overview

- Dry Mass: \(\approx 470\) kg
- Peak Power Consumption: \(\approx 515\) W
- Nominal Power Consumption: \(\approx 365\) W

- Subsystems Discussed:
  - ADC
  - Power
  - Propulsion
  - Comm
  - Payload
• Attitude Determination and Control (ADC)
  – Control Moment Gyros (CMGs) slew satellite quickly (3°/sec²)
  – Magnetorquers and hydrazine provide active control from CMG nulls
  – GPS provides position and timing information
    • Low MEO orbit utilization of GPS may lead to negligible errors
• Power
  – Solar panels with $A=1.17 \text{ m}^2$
  – Energy storage using NiMH batteries

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Power (W)</th>
<th>Power Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communications</td>
<td>89.</td>
<td>0.25</td>
</tr>
<tr>
<td>Power</td>
<td>123.</td>
<td>0.35</td>
</tr>
<tr>
<td>ADC</td>
<td>53.</td>
<td>0.15</td>
</tr>
<tr>
<td>Propulsion</td>
<td>0.</td>
<td>0.00</td>
</tr>
<tr>
<td>CDH</td>
<td>40.</td>
<td>0.11</td>
</tr>
<tr>
<td>Payload</td>
<td>49.</td>
<td>0.14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Power (W)</th>
<th>Power Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communications</td>
<td>159.</td>
<td>0.31</td>
</tr>
<tr>
<td>Power</td>
<td>123.</td>
<td>0.24</td>
</tr>
<tr>
<td>ADC</td>
<td>53.</td>
<td>0.10</td>
</tr>
<tr>
<td>Propulsion</td>
<td>50.</td>
<td>0.10</td>
</tr>
<tr>
<td>CDH</td>
<td>55.</td>
<td>0.11</td>
</tr>
<tr>
<td>Payload</td>
<td>74.</td>
<td>0.14</td>
</tr>
<tr>
<td>Remaining Power</td>
<td>1.</td>
<td>0</td>
</tr>
</tbody>
</table>
• Propulsion
  – Two orbit insertion options:
    • Launch formation direct to MEO
      – Will require extra hydrazine for maneuvering
      – Continued hydrazine use for stationkeeping
    • Launch formation from LEO
      – Solid kick stage used for MEO insertion
      – Hydrazine used for stationkeeping
Satellite Overview

- Communications
  - 100 MHz crosslink used to relay GRB data, position, and telemetry data between satellites
  - S-band used for ground and GCN via TDRSS communication
  - L-band for ground communication to GCN for telemetry

<table>
<thead>
<tr>
<th>Table 2: Mission Communications Data Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (km)</td>
</tr>
<tr>
<td>Frequency (GHz)</td>
</tr>
<tr>
<td>Data Rate (bps)</td>
</tr>
<tr>
<td>Output Power (W)</td>
</tr>
<tr>
<td>Tx Gain (dB)</td>
</tr>
<tr>
<td>Rx Gain (dB)</td>
</tr>
<tr>
<td>SNR</td>
</tr>
</tbody>
</table>
• Payload
  – NaI detectors
    • Area of 2,756 cm$^2$/detector, total 13,780 cm$^2$ for 5 detectors
    • Poor accuracy (on order of degrees, like BATSE)
    • All-sky coverage and high sensitivity

  – Wide Field X-ray Camera
    • Area of 175 cm$^2$/detector, total 350 cm$^2$ for 2 detectors
    • Good accuracy (~11’, like HETE’s WXN)
    • About 1.5 sr coverage for each instrument
Satellite Overview

• Arbitrary primary payload: Coded Cadmium Zinc Telluride (CZT) GRB detector
  – Lead-lined coded mask
  – 100 cm$^2$ SWIFT-life detector
  – 10° field of view

• Primary payload can vary
  – CCD detectors
  – Scintillating fiber detectors
  – UV/Optical instruments
Baseline Accuracy
- Uses time delay to triangulate GRBs
- $\theta_\sigma = 44'$, for 2-satellite, 10 ms burst
  - Useful for GRBs $t < 0.1$ s
- GRBs observed by all satellites become over-determined
  - All GRBs above $\pm 22^\circ$ declination are visible to all satellites

“Stereoscopic” observation
- $\theta_\sigma \propto \theta_0 / \sqrt{N}$
  - NaI: 2.5°
  - WFXC: 5.5’
- Follow up observations can be accomplished quickly with a small field of view primary instrument
• Three phases:
  – Detection:
    • Individual satellites use NaI and WFXC to observe and locally target burst
    • Begin slew
  – Communication:
    • Satellites communicate differential light curve data and timing to utilize baselines and multiple observations to reform GRB coordinates
    • Satellites all slew to reformed coordinates
    • Satellites downlink to GCN, or via TDRSS if required
  – Observation
    • Primary instrument slews to observe and provides final coordinates for GCN
    • Data is recorded and forwarded to ground for the duration of the burst

• From detection to observation should take approximately 10 seconds, (SWIFT generally takes greater than 40 seconds)
• By utilizing fractionation and small satellites for GRB observation, we can provide:
  – Redundant, all-sky coverage
  – Fast observation times
  – Comparable accuracies to current missions
  – More robust mission performance
  – Multiwavelength observations with primary instrumentation
  – Confidence in future multi-spacecraft missions, such as Darwin, New Worlds, and LISA
  – Potentially cheaper than current flagship GRB missions
• Thank you to:
  – Dr. Henric Krawczynski, Dr. James Buckley, Dr. Michael Swartwout, and Andrea Huegetter of Washington University in St. Louis
  – Dr. Kevin Hurley at UC Berekley (PI of IPN)
  – Dr. Scott Bartholemy at GSFC
  – Frank J. Redd Student Scholarship Competition and SmallSat
• By utilizing fractionation and small satellites for GRB observation, we can provide:
  – Redundant, all-sky coverage
  – Fast observation times
  – Comparable accuracies to current missions
  – More robust mission performance
  – Multiwavelength observations with primary instrumentation
  – Confidence in future multi-spacecraft missions, such as Darwin, New Worlds, and LISA
  – Potentially cheaper than current flagship GRB missions