GUVI Performance Assessment Review

Presented at
TIMED SWG MEETING
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Applied Physics Laboratory

Prepared by
GUVI SWG
GUVI

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Outline

• (1) Science Objectives
• (2) Measurement Objectives
• (3) Measurement requirements: parameters, and altitude range, measurement precision, measurement accuracy, measurement cadence for each of the parameters;
• (4) Instrument performance requirements: mechanism performance, optical throughput, signal to noise etc.
• (5) Instrument performance assessments: demonstrate performance versus specifications; All performance requirements met by GUVI
  – Precision of Radiance Measurements
  – Responsivity
  – Pointing Accuracy and Knowledge
  – Scattered Light and other Noise Sources
• (6) Measurement assessments: requirements versus performance of all essential parameters. All requirements met by GUVI
  – Density Comparisons with Champ
  – Composition
  – Temperature
  – Auroral Energy and Flux
  – Solar EUV < 40 nm
• (7) Data processing requirements and milestones. All requirements met by GUVI
• (8) Data processing status: Currently producing all products.
• (9) Any change of science objectives and focus. No change in focus – new activities (not funded by NASA TIMED) have been spawned
• (10) Science Utility Assessment.
• (11) Extended Mission Plans
Determine Major Species Composition in MLTI

Coverage
Accuracy
Spatial Scales
Mission Life

Horizontal Resolution
Altitude Resolution
Pointing Knowledge
Calibration accuracy

Spectral Resolution
Spectral Passband
Scan Mechanism Performance
Data System Requirements

Step size
Stray light
Integration period

Measure auroral energy inputs

Auroral Boundary Location
Accuracy of Q and E Spatial Scales

Data System Capability Requirements (C)

Command and Control Capability Requirements (C)

Science Objectives (A)

Measurement Objectives (B)

Measurement Requirements (C)

Instrument Functional Requirements (D)

Implementation Requirements (E)
(1) GUVI Science Objectives

Science drivers for instrument design and data processing plan.

There have been no changes since CDR.
A1. Determine seasonal and local solar time variation of the major species composition in the MLTI region in accordance to the TIMED science requirements for accuracy, temporal and spatial scales and coverage.

A1a. Provide a global determination of O, N$_2$, O$_2$ and temperature profiles through measurement of spectral radiance of principal atomic and molecular ultraviolet dayglow emission features.

A2. Measure energy inputs in the auroral region to understand the global MLTI energy balance in accordance with TIMED requirements.

A2a. Provide the precipitating auroral particle flux (Q), average energy (E), auroral boundaries and conductivity through measurement of spectral radiance of auroral ultraviolet emission features.
GUVI

GEOPHYSICAL REGIONS OF STUDY

• Dayside
  * Constituent Densities: N₂, O₂, O, H
  * Solar EUV Flux: Integral $\lambda \leq 40$ nm

• Auroral Regions
  * Particle Energy Input
  * Joule Heating
  * Auroral Boundaries

• Nightside (included in PDR, and de-emphasized at CDR)
  * F-Region Height, Peak Density
  * Total Electron Content
  * Meridional Winds
  * Ring Current Precipitation
(2) Measurement Objectives

Description of what we measure and why.
There have been no changes since CDR.
GUVI MEASUREMENTS APPROACH

- Ground state transitions for N$_2$, O, and H are located in the far ultraviolet (110-180 nm)
- Radiation is absorbed below ~100 km providing black background and no albedo
- Well developed models of excitation and radiation transport to extract geophysical quantities from the measured UV radiances
- Instrumental techniques mature
- Measure brightness on the disk and limb in five colors:
  - HI(121.6)
  - OI(130.4)
  - OI(135.6)
  - N$_2$LBH(140-150nm) - LBH(1)
  - N$_2$LBH(165-180nm) - LBH(2)
GUVI MEASUREMENTS APPROACH (CONT.)

The radiances are measured with sufficient accuracy and precision to infer changes in the

STATE VARIABLES:

• O₂, O, N₂, O/N₂ column, Temp, Density

AURORAL QUANTITIES:

• Q, <E>, goal is to provide Σp

SOLAR FLUX:

• Qₑᵥᵥ (λ < 40 nm)
GUVI - INSTRUMENT SCHEMATIC

Scan Mirror

520 km tangent altitude

Spatial Imaging Pixels (Limb Scan)

11.8° FOV

Spectral Elements Detector

Spatial Elements

140° Cross-track Scan

Spatial Imaging Pixels (Disk Scan)
GUVI LAYOUT DIAGRAM

- Primary detector
- 180nm
- 140nm
- 115nm
- Spacecraft outer surface
- Witness mirror
- Scan mirror motor
- Cross track scan range
- Telescope mirror
- Slit mechanism
- Toroidal grating
- Secondary detector
- Primary detector
LEVEL B

B.1 Provide Global coverage of HI(121.6), OI(130.4), OI(135.6), and N₂(LBH) Emission

B.1.a Maximize the extent of the local solar time and geographic coverage. √
B.1.b Provide limb profile capability from 110 to 300 km. √
B.1.c Accuracy for composition +_ 15% during solar maximum conditions. see below
B.1.d Spatial scales: 1/2 scale height (vertical); 100 km (horizontal). √

B.2 Auroral measurement must yield HI(121.6), OI(135.6) and N₂(LBH)

B.2.a Auroral oval and boundary detection for a 1 erg cm⁻²s⁻¹ electron aurora √
B.2.b Accuracy better than +_ 20% for energy input per spatial element see below
B.2.c Accuracy better than +_ 25% for average energy per spatial element “
B.2.d Locate boundary to +_ 10 km “
B.2.e Spatial scales: Energetic particles ~ 20 km; Conductivity ~ 100 km √
(3) Measurement Requirements

Investigation level Requirements

All Performance Requirements Satisfied
## INSTRUMENT CAPABILITY REQUIREMENTS

### LEVEL C

<table>
<thead>
<tr>
<th>Requirement</th>
<th>On-Orbit</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.1 Contiguous coverage of the Earth dayglow on the disk</td>
<td>√</td>
</tr>
<tr>
<td>C.2 Limb coverage from 60 to 500 tangent altitudes</td>
<td>100 - 500 km</td>
</tr>
<tr>
<td>C.3 Maximum intensity levels equivalent to solar max conditions at local noon</td>
<td>√</td>
</tr>
<tr>
<td>C.4 Contrast in signal brightness day to night 1000:1 in Rayleighs</td>
<td>√</td>
</tr>
<tr>
<td>C.5 Sampling interval on limb equivalent to 15 km at 250 km tangent altitude</td>
<td>√</td>
</tr>
<tr>
<td>C.6 Altitude resolution of an individual limb measurement &lt;= 6 km</td>
<td>√</td>
</tr>
<tr>
<td>C.7 Horizontal resolution dayglow measurements ~ 100 km</td>
<td>√</td>
</tr>
<tr>
<td>C.8 Horizontal resolution auroral ~ 20 km post-processing</td>
<td>√</td>
</tr>
<tr>
<td>C.9 Knowledge of S/C altitude &lt;= 1 km; latitude and long. &lt;= 3 km</td>
<td>√</td>
</tr>
<tr>
<td>C.10 Maintain error budgets to meet accuracy requirements</td>
<td>see below</td>
</tr>
</tbody>
</table>

### SYSTEM LEVEL REQUIREMENTS

<table>
<thead>
<tr>
<th>Requirement</th>
<th>On-Orbit</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.11.a Orbital altitude 600 &lt; 900 km</td>
<td>630 km</td>
</tr>
<tr>
<td>C.11.b Orbital inclination &gt; 70 degrees</td>
<td>74.1 degrees</td>
</tr>
</tbody>
</table>
(4) Instrument Performance Requirements

Specific Instrument Requirements

All Requirements Satisfied
D.1 IMAGING SPECTROGRAPH REQUIREMENTS

D.1.a Image spatial and spectral FUV airglow and aurora 115 to 180 nm

D.1.b Spectral Resolution 15 to 50 nm FWHM

D.1.c Spatial pixel size from 0.4 to 1.5 degrees

D.1.d Photon counting system with low dark rate and low stray light

D.1.e Responsivity, scan range, dwell time consistent with accuracy req.

D.2 SCAN MECHANISM REQUIREMENTS

D.2.a Spatial Resolution < 10 km nadir

D.2.b Scan rate and FOV to provide contiguous imaging of disk

D.2.c Uncertainties in pointing and stability to meet <6 km (Vert) knowledge

D.2.d Field of Regard: 140 degrees; -60 to + 80 degrees
### Data System Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Level D</th>
<th>On-Orbit</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.3.a Down link wavelength and pointing data</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>D.3.b Support 100% duty cycle</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>D.3.c Support command and control functions</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>D.3.d Support “color” definitions up to 5</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

### Detector Electronics

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Level D</th>
<th>On-Orbit</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.4.a Maximum count rates 117 kHz</td>
<td></td>
<td>120 kHz</td>
</tr>
<tr>
<td>D.4.b Control distortions and non-linearities</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>D.4.c Intrascene dynamic range 1000:1</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>D.4.d Control gain for 2 yr lifetime</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

### Error Budgets (Maximums)

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Level D</th>
<th>On-Orbit</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.5.a Brightness Measurement Uncertainty: 8%</td>
<td></td>
<td>see below</td>
</tr>
<tr>
<td>D.5.b Pointing Errors: 6%</td>
<td></td>
<td>“</td>
</tr>
<tr>
<td>D.5.c Calibration Errors: 8%</td>
<td></td>
<td>“</td>
</tr>
<tr>
<td>D.5.d Inversion/theory: 7%</td>
<td></td>
<td>“</td>
</tr>
</tbody>
</table>
IMPLEMENTATION REQUIREMENTS

LEVEL E

E.1 Scan mechanism repeatability better than 1/4 step

E.2 Integration period = 0.068 s

E.3 Total scan range: 140 degrees, -60 to + 80

E.4 Scan step size: 0.4 degrees

E.5 Instrument placement error +_ 0.1 degree all axes

E.6 BRIGHTNESS ERROR BUDGET
   E.6.a Counting Statistics: 6% see below
   E.6.b Dark Count: 1%
   E.6.c Stray Light: 2%
   E.6.d Non-linearities: 3%
   E.6.e Data Compression: 2%

E.7 Spectrograph internal straylight performance: <0.1% per spectral pixel see E.7-8a.

E.8 Off-axis rejection: 6x10(-2) @ 0.8 degrees

E.7a Noise in the background count rates must be substantially less than an equivalent source of ~ 0.1 R/A
## DERIVED PRODUCTS ACCURACY

### DAYSIDE SCIENCE

<table>
<thead>
<tr>
<th>QUANTITY</th>
<th>SPATIAL SCALE</th>
<th>ALTITUDE</th>
<th>ACCURACY RQMT.</th>
<th>ON-ORBIT PERFORMANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIMB</td>
<td></td>
<td></td>
<td></td>
<td>(CY2003 GUVI/MSIS)</td>
</tr>
<tr>
<td>N₂</td>
<td>±15%</td>
<td></td>
<td>0.99 ±15%</td>
<td></td>
</tr>
<tr>
<td>O₂</td>
<td>250 km Horizontal</td>
<td>130 - 300 km</td>
<td>±15%</td>
<td>Under Study</td>
</tr>
<tr>
<td>O</td>
<td>±15%</td>
<td></td>
<td>0.83 ±20%</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>±8%</td>
<td></td>
<td>0.995 ±6%</td>
<td>Under Study</td>
</tr>
</tbody>
</table>

*(also Density Satellite Comparisons)*

### DISK

<table>
<thead>
<tr>
<th>QUANTITY</th>
<th>SPATIAL SCALE</th>
<th>ALTITUDE</th>
<th>ACCURACY RQMT.</th>
<th>ON-ORBIT PERFORMANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>O/N₂</td>
<td>100 x 100 km²</td>
<td>Column</td>
<td>±5%</td>
<td>±5% (Cross Section Issues)</td>
</tr>
<tr>
<td>Solar EUV</td>
<td>λ&lt;40 nm</td>
<td>±10 - 15%</td>
<td>Under Study</td>
<td></td>
</tr>
</tbody>
</table>

### AURORAL SCIENCE - Class II Aurora (10 erg/cm²/s)

<table>
<thead>
<tr>
<th>QUANTITY</th>
<th>SPATIAL SCALE</th>
<th>ALTITUDE</th>
<th>ACCURACY RQMT.</th>
<th>ON-ORBIT PERFORMANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q, Energy Flux</td>
<td>20 x 20 km²</td>
<td>100 - 150 km</td>
<td>±25%</td>
<td>Under study test cases show agreement</td>
</tr>
<tr>
<td>&lt;E&gt;, Mean Particle Energy</td>
<td></td>
<td></td>
<td>±30%</td>
<td>Under study test cases show agreement</td>
</tr>
<tr>
<td>Conductivity</td>
<td></td>
<td></td>
<td>±30%</td>
<td>Under study test cases show EDP good</td>
</tr>
<tr>
<td>Boundary location</td>
<td></td>
<td>±10 km</td>
<td>Under Study</td>
<td>test cases show good agreement</td>
</tr>
</tbody>
</table>

Under study
(5) Instrument Performance Assessments

• Precision of Radiance Measurements
• Responsivity
• Pointing Accuracy and Knowledge
• Scattered Light and other Noise Sources
BRIGHTNESS PRECISION
(On-orbit radiance calibration error < 10%)

<table>
<thead>
<tr>
<th>LIMB</th>
<th>SPATIAL SCALE</th>
<th>ALTITUDE</th>
<th>PRECISION RQMT.</th>
<th>ON-ORBIT PERFORMANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>OI(135.6)</td>
<td>250 km Horizontal</td>
<td>300 km, ZA=75</td>
<td>±3%</td>
<td>±4%</td>
</tr>
<tr>
<td>LBH (1)</td>
<td>&quot;</td>
<td>&quot;</td>
<td>7%</td>
<td>±9%</td>
</tr>
<tr>
<td>LBH (2)</td>
<td>&quot;</td>
<td>&quot;</td>
<td>10%</td>
<td>±10%</td>
</tr>
<tr>
<td>HI(121.6)</td>
<td>100 x 100 km²</td>
<td>&quot;</td>
<td>1%</td>
<td>1%</td>
</tr>
</tbody>
</table>

DISK

| OI(135.6) | 100 x 100 km² | n/a            | 3%              | 2%                   |
| LBH (1)   | "             | "              | 5%              | 3%                   |
| HI(121.6) | "             | "              | 1%              | 1%                   |

AURORAL SCIENCE - Class II Aurora (10 erg/cm²/s)

| OI(135.6) | 20 x 20 km²  | n/a            | ±7%             | 7%                   |
| LBH (1)   | "            | "             | 9%              | 11%                  |
| LBH (2)   | "            | "             | 13%             | 13%                  |
| HI(121.6) | "            | (0.1 erg/cm²/s) | 9%            | 20%                  |
Calibration of the GUVI Detector #1
Responsivity

GUVI Detector 1 Responsivity

Responsivity (c/s/R)

Wavelength (Å)

Narrow Slit
Wide Slit
Medium Slit
Comparison of Stellar Observations Show that the Response has not Changed

• Stellar calibrations are difficult because:
  – There is significant airglow in the lines where the most current is pulled through the tube
  – The position of the star in slit (not known) affects the apparent wavelength of the emission.
  – Few stars are suitable.

• We are able to see stars throughout the year and we see the same stars from year to year.
  – Comparison of the same star a year apart follows.
  – The analysis shows that the response has changed by less than 10% over the mission.
GUVI’s View of a Star Moving Thru the Slit

- Two GUVI data frames
  - Vertical dimension is spatial direction of the detector
  - Horizontal dimension is wavelength
  - The horizontal lines are the stellar spectra (there are two stars during this event).
  - The slanted vertical lines are the Lyman alpha geocorona and the O 1356 nightglow.
GUVI Stellar Calibration
The responsivity from in-flight calibration at 135 nm
Pre-launch \( R=0.094 \pm 0.007 \)
Post-launch \( R=0.104 \pm 0.015 \) (initial stellar calibration)
No systematic changes have been noted in subsequent cals
Microchannel Plate Gain has not Changed Significantly For Detector 1

- GUVI tubes were carefully designed to reduce the effects of detector aging.

- Two detectors are available for use – we are currently holding one in reserve.

- Stellar calibrations show that the end-to-end response of the instrument has not changed.
Trend Analysis: Detector Aging and Pulse Height Distribution

• MCP based focal plane arrays are subject to aging at a rate that depends on the average illumination of a given region on the detector.

• Aging manifests itself as a lower responsivity in strongly illuminated regions as more charge is pulled through the MCP in these areas. In addition, the pulse height distribution generated in these areas will change over time.

• Pulse height distributions, as measured at different locations on the focal plane array, are being tracked.
  – Analysis shows less than a 10% decrease in gain: This does NOT result in a change in instrument response.
Gain Map: On-Orbit Results
Pointing Performance is Verified

• GUVI pointing is based on counting steps in the scan motor from a fiducial.
  – GUVI is not mounted on an optical bench.
  – GUVI is at the bottom of the spacecraft and spacecraft orientation is deduced from star cameras and IRUs.

• Validation using stellar locations on focal plane
  – There is a beta angle dependence on the pointing that we model.

• Validation through limb observations of the airglow
  – Very effective technique for tracking pointing offsets
Pointing validation performed with stellar observations. Shown are offsets in the GUVI pointing vector versus the motor step position.
Meier Pointing Analysis is based on Limb data and the L1B data base pointing values.
Scattered Light Correction is Applied During Processing Radiance Data

• The GUVI instrument uses a holographic grating to disperse the light in the spectral dimension.
• Careful tests on the ground allowed us to develop a model of the spatial and spectral cross talk due to this unavoidable scatter.
• On-orbit verification showed us that scattered light is as observed and characterized on the ground
  – No surprises
  – No science impact
Regular Spectroscopic Mode Operations provide a check on band locations and backgrounds rates.
Scattered Light Correction Applied to Spectrograph Data

Total signal
Data corrected for scattered light
AURIC model convolved with a 20Å Gaussian
Sum of all scattered light corrections

Nadir dayglow spectrum - near local noon.
GUVI SAA Sensitivity

Typical SAA detector noise is equivalent to a brightness of ~10 R (OI 1356)
(6) Measurement Assessment

• Density Comparisons with Champ & Starshine Satellites
• Composition
• Temperature
• Auroral Energy and Flux
• Solar EUV < 40 nm
Density Measurements from Accelerometers on CHAMP Satellite
STARSHINE Satellite Drag Measurements of Density

GUVI-Limb (points) & Starshine3 (red)  Max GUVI SZA = 40

Starshine Altitude

Beta Angle & F_{10.7}/10 (red) & Ap/10 (green)
Composition Changes Consistent With Temperature Changes

O/N2 Composition Ratio from GUVI

GUVI temperature along a western hemispheric orbit track through eastern US.