Solid State Telescope Instrument
End of Prime Mission Review

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The SST Principle of Operation

Sensor similar to Wind 3DP – Triplet detector stack in double ended telescope
- Foils filter out low energy ions
- Broom magnets sweep out low energy electrons
- Energetic particles will penetrate outer detectors and produce coincidence events.
- Attenuator paddles flip into place to lower geometric factor in inner magnetosphere.

Electron Side

Al/Polyamide/Al Foil
(4150 Ang thick – stops Protons < 350 keV)

Foil Collimator
Attenuator

Foil Detector
Thick Detector
Open Detector

Open Collimator

Sm-Co Magnet
~1kG reflect electrons <350 keV

THEMIS SWG

SST-2

UCB, December, 19 2009
Summary Performance

SST Prime mission requirements

• No major failures during prime mission
• Degradation of 3 out of 20 ion detectors was much greater than expected (possibly due to radiation damage but cause not known for certain)
• All data is valid for timing analysis
• SST met nearly all mission and science requirements
• SST met most performance requirements
• SST team has provided software and preliminary calibrated data
• Over 2 papers with SST data published

SST Current Status

• All sensors continue functioning
• All attenuator mechanisms are working well
• Final calibrations are still in progress
• No noticeable increase in background noise since launch
Applying Electron Scattering Correction

SST flux
Uncorrected

SST flux
Corrected

Model Maxwellian
Electron Efficiency correction for $E>300$ keV

Accounting for high energy efficiency.

We know there is a substantial difference in measured flux as compared with LANL! (~8)

Slightly higher flux at high energy
Solid state detectors only measure the energy deposited in the active (depleted) region of the silicon.

As the dead layer grows in time all energy channels shift to higher energy.

During the first 9 months after launch we noticed a gradual reduction in signal, primarily in 3 of 20 ion detectors (1 on Probe-B, 2 on Probe-C) Somewhat mitigated by increasing bias voltage.
Correcting for increase in Dead layer

Themis E is shown
Themis B&C have much more severe damage

Ion Distribution
Uncorrected

Ion Distribution
Corrected

All energies Shifted up
6 keV
Future Improvements

SST Data Work in Progress or planned work

- In flight calibration of ion sensors
- Placing new electron calibrations in public source
- Modeling of SST sensor head using GEANT4
- Removal of cross contamination between electron and ion channels in inner Magnetosphere
- Improved dead time corrections
- New software algorithms for more accurate moments (combining ESA and SST partial moments)
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End of Presentation
SST efforts to facilitate data analysis

• SST data is available within 24 hrs after collection on the THEMIS Website:

• Summary Plots with SST data at: http://themis.ssl.berkeley.edu/summary.shtml?autoload=1

• SST instrument paper (in preparation):

• Instrument description at: http://themis.ssl.berkeley.edu/instrument_sst.shtml
Bremsstrahlung Background

Energetic electrons measured by the SST detectors produce X-rays that contaminate the ion ESA measurement.

Moment calculations without removal of this background will overestimate ion density (green). Simple background removal algorithms (black) help, but still do not provide good agreement with electron density (red).
Caveats when using SST data

Saturation at high count rates (>20 kHz/channel)
- Sun Pulse
  - Once per spin
  - Affects all channels
  - Easily removed if FULL dists are used

Low energy electron geometric factor caused by scattering by foil

Ion detectors – Increasing Dead layer vs time.

Cross Species contamination
- Only important when flux of >400 keV particles becomes significant (inner magnetosphere)

Attenuator state (64x)
- Closed within inner magnetosphere (<10 Re)
- Controlled by count rate in outer MS

We know there is a substantial difference in measured flux as compared with LANL! (~10)
THEMIS Papers utilizing SST Data:

- List in formulation (Vassilis has this).

Data Analysis Software and Products

- SST raw and level 2 data available within ~24 hrs of collection.
- Data analysis tools available to all, regular improvements to software.
- Electron Level 2 data will be soon regenerated to account for foil efficiency.
- Ion Level 2 data will be regenerated to account for degradation of ion sensors.
- Data will continue to improve with age like a good bottle of wine.
SST Lessons Learned

- **TEST – TEST – TEST!** And then test some more. Consider all possible failure modes.
- Set up GSE that will record all instrument data as well as laboratory environmental data (i.e. vacuum pressure, temperature, input voltages and currents) so that if a problem occurs the experimenter can go back and find the cause.
- Automate test routines so that they can be repeated identically and quickly. Avoid human input.
- Be more selective when choosing detectors. Monitor many detectors over a long time interval (months) and then pick the best ones that show no change over time.
- Leave equipment running (and recording) throughout thermal-vac testing. Perform tests at all temperatures, not just the extremes. Ignore any concerns about instruments running while not “monitored” by a human.
- Conducting (aluminum) tape does not work well in vacuum.
- Don’t do initial instrument turn-on while in the radiation belts. (or if you do – at least know that the instrument is in the radiation belt)
- Check (and test) polarity of all polarized capacitors on all boards. Don’t assume the circuit board was printed correctly. (This is a very common problem!)
- Thoroughly test instrument for light sensitivity.
- Test for noise contamination early.
- Measure and/or account for in-rush current at instrument turn-on.
- Watch out for large preamp current draw during saturation events.
- Build at least two of every unit, even if you only need one unit.
- Built in **test electronics** simplifies in-flight instrument monitoring.
- **Two electron sensors** looking in opposite directions are essential for accurate Ve measurements when density fluctuations are present.
- **Combined plasma measurements** (ESA+SST) are required for correct plasma moment calculations.
Requirements and Specifications

Measurement

• The SST instrument measures 3-D electron and ion energy distribution functions over the Energy range 30 KeV to ~1 MeV.
• A full 4-pi distribution measurement is produced during each spin
• Raw measurements are compressed to selectable “reduced distributions” and moments

Implementation

• 2 Pairs of double ended Triplet Stack of electrostatic analyzers have 180 degree field of view
• Field of view is divided into 16 phi sectors and 4 elevation bins
• SST detectors have configurable energy, angle and time resolution. These functions are set by command.
• Higher level data formatting and computed products are carried out in the ETC board.
• Default Energy table is approximately logarithmic.

SST Instrument continues to operate and continues to produce data products. However there is some degradation of ion detectors. The ion sensor degradation primarily affects 2 probes (P1 and P2).
Block Diagram

- Electronics functional design is similar to Stereo STE
- Amptek 225FB used as preamplifier in sensor head.
- PHA circuitry on DAP board in the IDPU
## Mission Requirements

<table>
<thead>
<tr>
<th>REQUIREMENT</th>
<th>SST DESIGN</th>
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<tbody>
<tr>
<td><strong>IN-1.</strong> The Instrument Payload shall be designed for at least a two-year lifetime</td>
<td><strong>Compliance.</strong> All 10 Sensors functioning after 2.5 years.</td>
</tr>
<tr>
<td><strong>IN-2.</strong> The Instrument Payload shall be designed for a total dose environment of 33 krad/year (66 krad for 2 year mission, 5mm of Al, RDM 2)</td>
<td><strong>Compliance.</strong> No evidence of radiation degradation of the electronics. Some degradation of detectors possibly due to low energy (30-100 keV) ion implantations.</td>
</tr>
<tr>
<td><strong>IN-3.</strong> The Instrument Payload shall be Single Event Effect (SEE) tolerant and immune to destructive latch-up</td>
<td><strong>Compliance.</strong> No known SEEs or latch-ups of the SST sensors or electronics.</td>
</tr>
<tr>
<td><strong>IN-7.</strong> No component of the Instrument Payload shall exceed the allocated mass budget in THM-SYS-008 THEMIS System Mass Budget.xls</td>
<td><strong>Compliance.</strong> No mass budget problem. Sensor: 554 gm x2 (Measured) Harness: 141 gm x2 (1.73 meter) (DAP Board tracked with IDPU)</td>
</tr>
<tr>
<td><strong>IN-9.</strong> No component of the Instrument Payload shall exceed the power allocated in THM-SYS-009 THEMIS System Power Budget.xls</td>
<td><strong>Compliance.</strong> No power problems during 2.5 years. DFE + DAP: 1200 mW (Estimate @ 10 kHz count rate)</td>
</tr>
<tr>
<td><strong>IN-13.</strong> The Instrument Payload shall survive the temperature ranges provided in the ICDs</td>
<td><strong>Compliance.</strong> No observed anomalies during eclipse.</td>
</tr>
<tr>
<td><strong>IN-14.</strong> The Instrument Payload shall perform as designed within the temperature ranges provided in the ICDs</td>
<td><strong>Compliance.</strong> No SST temperature problems.</td>
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<td><strong>IN-16</strong> The Instrument Payload shall comply with the Magnetics Cleanliness standard described in the THEMIS Magnetics Control Plan</td>
<td><strong>Compliance.</strong> SST complied (with expanded budget) and experienced no magnetic problems. $&lt;2 \text{nT} @ 2.5 \text{ meters}$. 11 Hz FGM noise first attributed to SST was found to be due to aliasing of digital noise in the IDPU</td>
</tr>
<tr>
<td><strong>IN-17</strong> The Instrument Payload shall comply with the THEMIS Electrostatic Cleanliness Plan</td>
<td><strong>Compliance.</strong> SST complied and experienced no electrostatic cleanliness problems.</td>
</tr>
<tr>
<td><strong>IN-18</strong> The Instrument Payload shall comply with the THEMIS Contamination Control Plan</td>
<td><strong>Compliance.</strong> SST complied and experienced no contamination problems.</td>
</tr>
<tr>
<td><strong>IN-19</strong> All Instruments shall comply with all electrical specifications</td>
<td><strong>Compliance.</strong> SST complied and experienced no electrical problems.</td>
</tr>
<tr>
<td><strong>IN-20</strong> The Instrument Payload shall be compatible per IDPU-Instrument ICDs</td>
<td><strong>Compliance.</strong> SST was compatible and experienced no communication problems with the IDPU and ETC. ETC table loading problems were resolved during commissioning phase prior to first tail season.</td>
</tr>
<tr>
<td><strong>IN-21</strong> The Instrument Payload shall be compatible per the IDPU-Probe Bus ICD</td>
<td><strong>Compliance.</strong> SST was compatible.</td>
</tr>
<tr>
<td><strong>IN-23</strong> The Instrument Payload shall verify performance requirements are met per the THEMIS Verification Plan and Environmental Test Spec.</td>
<td><strong>Compliance.</strong> SST performance met the Verification Plan and Environmental Test Specification.</td>
</tr>
<tr>
<td><strong>IN-24</strong> The Instrument Payload shall survive and function prior, during and after exposure to the environments described in the THEMIS Verification Plan and Environmental Test Specification</td>
<td><strong>Compliance.</strong> SST survived all pre-launch testing and continues to function.</td>
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<td><strong>IN.SST-1.</strong> The SST shall perform measurements of the tailward-moving current disruption boundary speed using the finite gyroradius technique</td>
<td><strong>Compliance.</strong> Provided by Full Distribution Functions (FDFs). Technique used in paper by (provide reference)</td>
</tr>
<tr>
<td><strong>IN.SST-2.</strong> The SST shall measure the time-of-arrival of superthermal ions and electrons of different energies emanating from the reconnection region to determine RX onset time.</td>
<td><strong>Compliance.</strong> 3 second time resolution of FDFs</td>
</tr>
<tr>
<td><strong>IN.SST-3.</strong> The SST shall obtain partial moments of the plasma electron and ion distributions in the magnetotail plasma sheet</td>
<td><strong>Compliance.</strong> Partial moments produced by ETC board but are of limited quality for ions. Higher quality partial moments are computed on the ground.</td>
</tr>
<tr>
<td><strong>IN.SST-4.</strong> The SST shall obtain measurements of ion and electron distribution functions with one spin resolution (&lt;10sec required)</td>
<td><strong>Compliance.</strong> Full electron distribution functions at 1 spin resolution obtained in burst mode. Full ion distribution function at 1 spin res are produced in fast survey.</td>
</tr>
<tr>
<td><strong>IN.SST-5.</strong> The SST shall measure energetic electron fluxes as close to Earth as 6RE geocentric, at all local times.</td>
<td><strong>Compliance.</strong> Attenuator lowers flux sufficiently to avoid saturation at this distance. All Attenuators are functioning nominally after 2.5 years</td>
</tr>
<tr>
<td><strong>IN.SST-6.</strong> The SST shall measure energetic ions in the solar wind, at the magnetopause and in the magnetosheath.</td>
<td><strong>Compliance.</strong> As above when sensors are operating</td>
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**Science Requirements**

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| **IN.SST-7.** The SST shall measure energetic particles over an energy range of 30-300keV for ions and 30-100keV for electrons found in the magnetotail plasma sheet. | Compliance.  
Electrons: ~30 keV to ~800 keV  
Ions: ~30 keV to ~6 MeV |
| **IN.SST-8.** The SST energy sampling resolution, dE/E, shall be better than 30% for ions and electrons. | Compliance.  
Intrinsic energy resolution is ~6 keV with 1.5 keV binning. Measured full system resolution is 8 keV @ 30 keV |
| **IN.SST-9.** The SST shall be capable of measuring differential energy flux in the range from: 10^2 to 5x10^6 for ions; 10^3-10^7 for electrons (keV/cm^2-s -st- keV) whilst providing adequate counts within a 10 second interval. | Compliance. Max counting rate estimated at 50,000 cps (per detector). Two geometric factors:  
G1 ~ 0.1 cm^2-ster  
G2 = G1/64.  
Dead time correction required for R>20,000 cps |
| **IN.SST-10.** The SST shall measure over 90 deg. in elevation with a minimum resolution of 45 deg. | Compliance.  
Elevation: +/- 60 deg, Resolution:~37 deg. |
| **IN.SST-11.** The SST shall have an azimuthal resolution of 45 deg. | Compliance.  
Azimuthal resolution = 22.5 deg |
| **IN.SST-12.** The SST shall supply the high energy partial moments at one spin time resolution. | Compliance.  
Performed by ETC board |
| **IN.SST-13.** SST calibration shall ensure <20% relative flux uncertainty over the ranges defined above. | Partial Compliance. Measured pre-flight;  
In-flight calibration has shown changes in ion calibration, primarily caused by increased dead layers over time. |
Scientific assessment of data products:
• a. Are the products sufficient to meet L1 requirements? Yes
• b. How far do products go beyond L1 science requirements

Data maturity:
• a. Version history and release dates
  Level 1 has no version number (unless major architecture change is required)
  Level 2 (we don't have versions but > you can talk about how often we re-processed)
• b. Data accessibility, calibration and error estimates
• c. Community use and publication history [L1 versus non-L1] > > I will have presented the data analysis tools and concept of data > distribution. > I can find the community use and publication history and will add a chart > > for the ESA/SST, either in your presentation or in a top-level > presentation.
ESA and SST combined

Accurate density measurements

Errors in electron velocity measurements due to density fluctuations

THEMIS SWG SST-24 UCB, December, 19 2009
We estimate background using both the eSST and iESA data.

Cross fitting these two estimates allows corrections due to changes in response with time.

Using eSST rather than iESA estimate eliminates removal of real counts at low energy.