Finding the Sources of Irradiance Variation at Sunspot Minimum

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Outline

- Science Motivation
- Science Objectives
- Measurement Requirements
- Instrument
- Results From First Flight of SBI
- Mission Design
- Conclusions & Future Plans
Need to understand the *physical* mechanisms of TSI

Total Solar Irradiance (TSI) variations affect Earth’s climate

However! Magnitude of Sun’s intrinsic irradiance variation is still uncertain

- Over 11-yr solar cycle irradiance variation is ~ 0.1%
- Short term variation can be well explained by magnetic activity variation alone
- However! Long term variation not well known, due to instrument drifts and difficulty in absolute calibration of space radiometers

Study irradiance at solar minimum

- Local magnetic fields are weakest
- Observations can detect *other* possible sources of TSI variation
- Will allow physical understanding of long-term TSI variation
Science Objectives

- **Temperature structure of photosphere**
  - Limb-darkening 5250 ±1000 K
  - Spots, faculae, enhanced network ±150K

- **Acoustic oscillations:**
  - Torsional waves ~ ±0.3K

- **Convection physics:** ±30K → ±3K
  - Meridional flows
  - Giant cells

- **Comparison with SORCE/TIM & ACRIMSAT irradiance measurements**
<table>
<thead>
<tr>
<th>Measurement Requirement</th>
<th>Requirement</th>
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<tbody>
<tr>
<td>Bolometric accuracy limited by residual extinction at flight altitude</td>
<td>Sun intensity integrated over range including &gt; 90% of bolometric flux</td>
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<tr>
<td>Image precision limited by solar convection oscillation noise</td>
<td>Intensity response variation &lt; 10%</td>
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<tr>
<td>Resolve facular network &amp; spot penumbrae</td>
<td>Detector noise &lt; 1%</td>
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<tr>
<td>Resolve acoustic oscillations &amp; convection noise</td>
<td>Spatial resolution &lt; 3&quot;/pixel</td>
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<td>Stable image quality &amp; constant extinction</td>
<td>Full-disk images</td>
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<td>Ability to observe features during entire transit across solar disk</td>
<td>Image cadence 10-30 s</td>
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<td></td>
<td>Spatial resolution &lt; 3&quot;/pixel</td>
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<td>Space/near-space environment</td>
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<td>Uninterrupted observations for &gt; 14 days</td>
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SEC Rome 27 June – 1 July, 2005
SBI Detector

- Array of 320 × 240 Barium Strontium Titanate (BST) ferroelectric elements
  - Pixel size: 50 × 50 µm
  - Sensitive to thermal IR
  - Runs at ambient temperature (~ 30 °C)

- Detector array covered with a thin film of gold black
  - Spectral absorptance of gold black vary < 1% from 0.2 µm to beyond 3 µm
  - Energy of absorbed radiation is redistributed by the gold black in form of thermal emission and detected by the thermal IR BST imaging array
  - The thin coating retains ~ 70% of the original detector MTF

- Detector has uniform response from UV to beyond 10 µm

Spectral reflectance of gold black
**SBI Optical system**

- **Dall-Kirkham 30 cm ∅ F/12.** Design chosen to provide long focal length with a compact package, as required for a balloon flight
  - Resolution: 0.2" at 0.28 µm, 2.2" at 2.6 µm
  - Pixel size: 2.86 × 2.86 arcsec/pixel
  - Field of view: 917" × 687" (for 320 × 240 pixels detector)

- **Primary and secondary made of bare (un-coated) pyrex**
  - Pyrex reflectivity has desirable flatness across required spectral range
  - Average reflectivity ~ 4%

- **Filter wheel with 5 selectable filters**

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SEC Rome 27 June – 1 July, 2005
SBI telescope transmission calculated from measured values for individual components
SBI First Flight

- SBI had a first stratospheric flight on September 1, 2003
- Launched from Fort Sumner, NM
- ~ 10 hours flight
- Average altitude: 109 kf

SBI-1 during a pointing test session before September 1, 2003 flight.
Limb Darkening Measured by SBI-1

Full-disk wide-band image measured by SBI-1

Limb darkening profile measured by SBI and compared with other indirect methods (Foukal et al. 2004, ApJ. 611, L57)
Identification of faculae on contrast image

Center-to-limb variation of facular contrast
(Foukal et al. 2004, ApJ. 611, L57)
Result: reconstruction and radiometry not only correlate, but also agree in amplitude to approximately ± 5% rms

A: Determine faculae and spots areas on SFO CaK and red filter images.

C: Spot contrast: \( \left( \frac{\partial F}{F} \right)_S = 0.33 \cdot A_S \cdot \frac{(3\mu + 2)}{4} \)

B: Facular contrast:

\[ \left( \frac{\partial F}{F} \right)_F = A_f \cdot (C_{SBI}(\mu) - 1) \cdot \frac{(3\mu + 2)}{4} \]
SBI-2 Mission Design

- Balloon flight planned for Antarctic summer season 2006/2007
  - Launch from McMurdo station at 78° Latitude North
  - Average altitude: ~120 kft
  - Flight duration: 10-20 days
  - Minimum science data downloaded in-flight
  - On-board storage space: 600 GB
  - Recovery of all data (and payload) at end of mission

- 2 observing modes:
  - 1: SBI record series of bolometric mosaics, and at different narrow band wavelengths. One full mosaic in ~8 min, 10 tiles per mosaic.
  - 2: Pointing at fixed location & high cadence observations, both bolometric and narrow band
Conclusions

- In 2006-2007 SBI will operate for 10-20 days in polar stratosphere
- Instrument will provide bolometric & color temperature images of the Sun
- Investigate causes of long-term irradiance variation
- Study predicted causes of secular variability like torsional waves and meridional flows

For more information visit our web site at:

http://sd-www.jhuapl.edu/SBI
**Future Plans**

- **Develop a space-borne instrument**
  - Larger bolometric detector array
  - Validate technology for space

- **Solar Climate Explorer**
  - Possible SMEX mission dedicated to Solar Irradiance
  - Sun-synchronous orbit
  - 5 years life-time, 6 years extension
  - Core instruments suite:
    - SBI
    - MSI
    - Radiometer