Comparison and Validation for SIM

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Status of SIM Data and Analysis:

- **SIM A corrected for prism transmission degradation**
  - Correction for SIM B small, but necessary
  - Currently not included in processing

- **4/1/2003 to 4/21/2005 wavelength scale affected by instrument operations.**

- **Photodiode data affected by wavelength dependent sensitivity degradation. Currently only Vis2 for \( \lambda > 720 \) nm corrected.**

- **A refined temperature coefficient for Si photodiodes in the 800-950 nm region is needed.**
## Design Highlights

- Dual instrument configuration for duty cycling and redundancy
- Instrument coupled with periscope for direct prism calibration
- Electrical Substitution Radiometer (ESR) for primary detector
  - Uses phase sensitive detection: noise floor \( \sim 2 \text{ nW Hz}^{-\frac{1}{2}} \)
- Spectrum acquired with only one optical element (Fery Prism)
**SIM Detector Ranges**

- **Photodiode Composite**

  - Irradiance (W m\(^{-2}\) nm\(^{-1}\))
  - Brightness Temperature (K)

- Wavelength (nm):
  - UV
  - n-p silicon
  - VIS1
  - p-n silicon
  - VIS2
  - IR
  - InGaAs
  - ESR

- Range: 200 to 2000 nm

- Scale: 0.0 to 2.0
SIM Measurement Equations

**Wavelength Drive Shifts**

### Calibration Parameter | Derived From:
--- | ---
λ | Wavelength
S’ | Instrument function
W₁ | Entrance slit width
W₂ | Exit slit width
L₁ | Slit height
x,y,z | Component location
Tᵣ | Prism transmission
Φᵣ | Diffraction correction
V,R | Electrical components
αₚ | ESR absorption
G | ESR Servo Loop gain
Zₑ/Zₑ₁ | Equivalence ratio
Rₖ | Photodiode radiant responsivity

* = In-flight calibration or modification

#### Wavelength Calculation

Encoder Reading (C) \[ \rightarrow \] Wavelength (λₛ)

Rotation Angle (γ) \[ \rightarrow \] Refractive Index n(λₛ, T)

Focal Plane Dispersion (y, yₛ)

#### Instrument Profile

\[
S(yₛ) = \int_{\alpha_r} a_r \, T_p \, \Phi_p \, S’(y, yₛ) \, dy \quad \text{(ESR)}
\]

\[
L₁ \int \alpha_r \, T_p \, \Phi_p \, S’(y, yₛ) \, dy \quad \text{(Diode)}
\]

#### Measured Irradiance

\[
\mathcal{E}_s(\lambda) = \left. \frac{P(yₛ)}{S(yₛ)} \right|_{\lambda = yₛ}
\]

#### Slit Function Convolution

\[
\mathcal{E}_s(\lambda) = \int S(\lambda, \lambda₁) \, E_s \, d\lambda
\]

#### ESR Phase Sensitive Power Detection

\[
P_{\text{ESR}}\big|_{\lambda = yₛ} = \frac{1}{M} \left( \frac{V_r^2 \, R_{ii}}{R_i + R_{ii}} \right) \left( \frac{1 + G}{Z_R} \right) \frac{\tilde{P} \, \tilde{D}}{\tilde{p} \, \tilde{Q}}
\]

#### Photodiode Power Detection

\[
P_{\text{diode}}\big|_{\lambda = yₛ} = \left( \frac{D - D_{\text{dark}}}{M \, R_f} \right)
\]

**Instrument Profile S’(y, yₛ)**

- **Photodiodes**
  - 6 samples/slit width
- **ESR full scans**
  - 3 samples/slit width
- **Needed for:**
  - Spectral interpolation
  - Wavelength determination
  - Noise filtering
  - Instrument response characterization
  - Degradation corrections
### Current Estimates of the Calibration Parameters for the SIM Instrument

<table>
<thead>
<tr>
<th>Parameter (units)</th>
<th>Magnitude/Range</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Distance (ppm)</td>
<td>+33116 to -33764</td>
<td>1</td>
</tr>
<tr>
<td>Doppler (ppm)</td>
<td>43</td>
<td>1</td>
</tr>
<tr>
<td>Wavelength (nm)</td>
<td>200-1650</td>
<td>(\sim 0.02 \pm (150 \times 10^{-6}) \times \lambda) (worst case)</td>
</tr>
<tr>
<td>Instrument Function Area</td>
<td>0.58-34.5</td>
<td>~0.4%</td>
</tr>
<tr>
<td>Slit Parameters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width ((\mu m))</td>
<td>300.0</td>
<td>0.5 \pm 0.03</td>
</tr>
<tr>
<td>Area (mm(^2))</td>
<td>2.1</td>
<td>3\times10^{-5} \pm 2\times10^{-5}</td>
</tr>
<tr>
<td>Component Metrology (mm)</td>
<td>0-400 mm</td>
<td>0.01</td>
</tr>
<tr>
<td>Prism Transmission</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value (%)</td>
<td>0.55-0.77</td>
<td>0.1% 200-700 nm \sim 1% 1000-2700 nm ~ 0.1%</td>
</tr>
<tr>
<td>Degradation Correction</td>
<td>~0 to 0.65</td>
<td></td>
</tr>
<tr>
<td>Diffraction Correction (%)</td>
<td>0.3-2.2</td>
<td>~0.01</td>
</tr>
<tr>
<td>ESR Parameters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard Volt (V)</td>
<td>7.1615 V</td>
<td>10 (\mu) V</td>
</tr>
<tr>
<td>ESR Absorptance (%)</td>
<td>~99</td>
<td>+0 to -1 (200-700 nm) +0 to -10 (700-2700 nm)</td>
</tr>
<tr>
<td>Closed Loop Gain</td>
<td>15.086</td>
<td>1 \times10^{-4} (0.05 Hz)</td>
</tr>
<tr>
<td>Equivalence (ppm)</td>
<td>73.205</td>
<td>3\times10^{-5} (0.01 Hz)</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>60</td>
</tr>
</tbody>
</table>
SIM measures the irradiance weighted by the bandpass.

Low resolution instruments respond to the density of lines, not to individual lines.
Prism Degradation

\[
\frac{\mathcal{T}(\lambda, t)}{\mathcal{T}_0(\lambda)} = \exp\left(-\kappa(\lambda) \ C(t)\right)
\]

- \(\kappa(\lambda)\)
  - Function of wavelength alone
  - Derived from comparisons of ESR and UV diode spectra

- \(C(t)\)
  - Function of time alone
  - Derived from prism transmission experiments
Photodiode Degradation

- ESR table scans sample 60 discrete wavelengths from 250-2700 nm.
- The ESR detector does not experience degradation.
  - From SIM A / SIM B comparisons.
  - Photodiode radiant sensitivity found from diode comparisons with the ESR (accounting for differences in profile integral)
- Rate of change is found by matching the slope of the photodiode data to the ESR.
  - The correction is made to the radiant sensitivity, not to the time series.
Instrument Precision

![Graph showing spectral irradiance vs. wavelength with various SNR levels and expected solar cycle variability.]

- Measured Irradiance:
  - UV photodiode
  - ESR

- Expected Solar (J. Lean) Cycle Variability:
  - ESR DPower
  - UV DP Power

- Noise Equivalent Irradiance:
  - ESR (0.01 Hz)
  - ESR (0.05 Hz)
  - UV
  - Vis1
  - Vis2
  - IR
Absolute Accuracy ESR Principal

Combined Absorbance:

\[ \alpha = \frac{1 - \beta}{1 - \beta r} \]

Input from prism
Intensity = 1
Bolometer reflectivity = \( \beta \)
Hemisphere reflectivity = \( r \)

- Black surfaces measured and tested in visible
- Combined absorbance equations assume diffuse reflectivity and optical system re-images reflected light.
Measured ESR Absolute Accuracy

Preliminary Calibration at NIST SIRCUS
Tests done with flight spare ESR
Small amount of prism degradation in SIM B not corrected here.

Efficiency of ESR slightly different (~0.5%) in the infrared.
Self Comparisons 2 - ESR versus Vis1 Photodiode

- Independent detectors show the same trends
- Trends are not caused by prism degradation – corrected in all cases
Self Comparisons 3 - ESR versus IR Photodiode

964.80 nm

1213.80 nm

1356.60 nm

1591.07 nm

Irradiance (W m⁻² nm⁻¹)

SORCE Day
Self Comparisons 4 - Integrated SIM versus TSI

- ~53 Wm\(^{-2}\) contributed to the TSI for \(\lambda>2400\) nm.
- Character of the variability changes over the integrated bands
- Integrated SIM data shows 4.5 Wm\(^{-2}\) sag over 900 days of operation (~5 mW m\(^{-2}\)/day)
Instrument Intercomparisons – Near UV

![Graph showing irradiance relative to SOLSPEC Composite 3 against wavelength (nm).]
Conclusions & Plans

♦ Complete NIST SIRCUS calibration
  • Replace SOLSPEC-based response curve with the measured one
♦ Include refined prism degradation function for SIM B
♦ Revisit Diode degradation for Vis 1 and IR
♦ Evaluate possible ‘non-optical’ degradation mechanisms