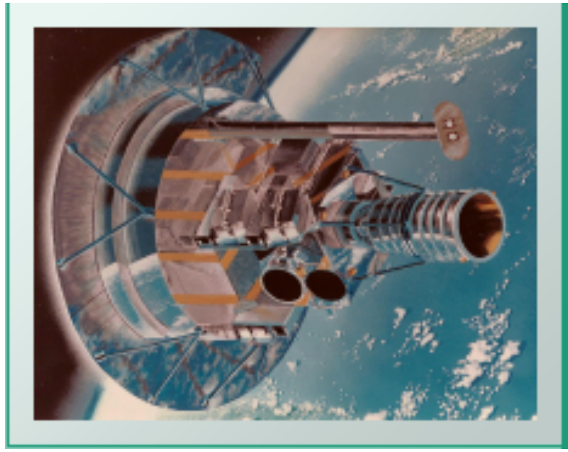


The Solar
Mesosphere
Explorer

# Update on the SME dataset reprocessing efforts

Odele Coddington, Gary Rottman

As part of a larger team effort with Judith Lean (PI),

“How does the Sun’s Spectrum Vary?”

# Outline

- Motivation: Proposed Tasks
- Brief mission and instrument description
- Year 2 Findings:
  - Measurement Uncertainty
    - photon noise, quantization error, Monte Carlo experiment, look-up table of measurement uncertainties
  - Processing Algorithm (Approach “A”)
    - Preliminary dataset of daily SSI as a function of grating position with associated uncertainties
  - Results of Approach “A”
    - Spectra, time series, Shifts in grating position(?)
  - Processing Algorithm (Approach “B”)
    - Preliminary dataset of daily Lyman alpha irradiance as a function of location of “peak” irradiance with associated uncertainties
  - Results of Approach “B”
    - Time Series
    - Correction for Temperature dependencies
    - Comparison to Approach “A”, measurement composites, and models
- Concluding Statements and Year 3 Plans
    - Necessary improvements on Approach “B”
    - Correction for Instrument Degradation
    - Investigate if Approach ”B” can be applied to additional spectral bands

# Motivation

- SME reanalysis will give an improved understanding of solar cycle variability.
- SME observations are potentially stable SSI database due to limited solar exposure and in-flight monitoring of degradation.
  - Re-analyzed SME observations may:
    - constrain UV variability, and – ***through a model and TSI observations*** – further constrain visible and infrared SSI variability.
    - This new knowledge would be used to improve solar variability models.

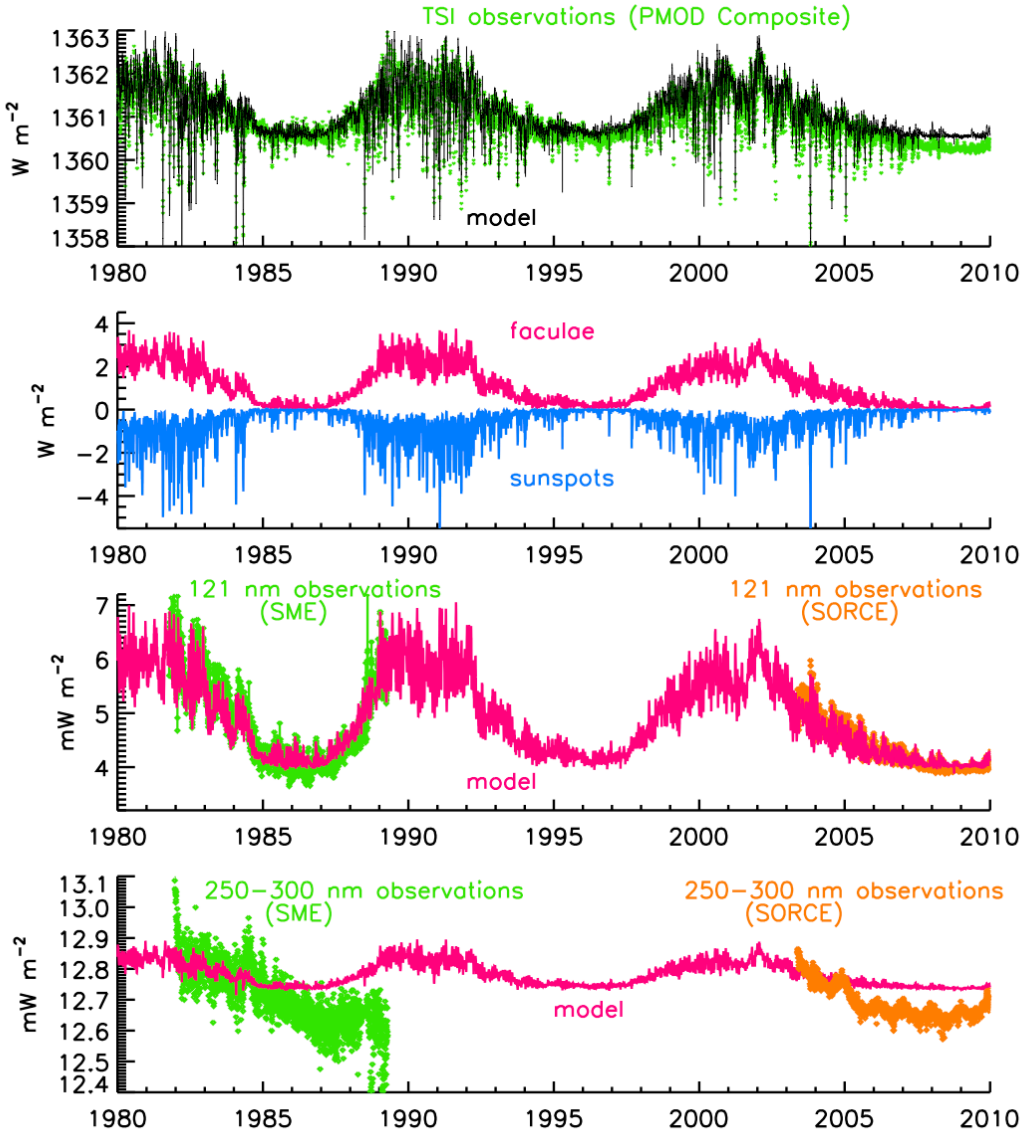


***Figure:*** *Comparisons of modeled and measured solar irradiance over solar cycle time scales along with components of sunspot and facular influence (Courtesy Judith Lean)*

# Mission and Instrument

- LASP proposed SME in October, 1974
- ***Primary Objective***: determine how the mesospheric ozone distribution varies with changes in incoming solar radiation.
- SME launched 6 October 1981
- SME had 5 instruments
  - Earth-viewing: Ozone, airglow, nitrogen dioxide, infrared radiometer
  - Sun-viewing: solar UV spectrometer
    - Monitors SSI scattered from a diffusing screen
    - Ebert-Fastie Spectrometer; 115-300 nm, $\Delta\lambda$=0.26 nm per grating step
    - G-channel: 115 to 210 nm (far-uv)
    - F-channel: 180 to 302 nm (mid-uv)

SME launched on a Delta rocket from Vandenburg AFB, California.

**SME launched 6 October 1981**
**Data transmission ceased 4 April 1989**

# Year 2 Findings: Measurement Uncertainty

- SME used 8-bit telemetry words -> photon counts, or DNs, from 0-255
- The instrument counter was larger (16 bits?)
- To fit the 16-bit data into an 8-bit telemetered word (reported at bin midpoint), the data was truncated to 5-bits, with the other 3-bits reporting the shift

| # of shifts | 5-bits of data (DN) | Data increments (DN) “quantization error” | Square root of data (DN) “photon noise” |
|---|---|---|---|
| **0** | 0 to 31 | 1 | 0 to 5.6 |
| **1** | 32 to 63 | 2 | 5.7 to 7.9 |
| **2** | 64 to 127 | 4 | 8 to 11.3 |
| **3** | 128 to 255 | 8 | 11.3 to 16 |
| **4** | 256 to 511 | 16 | 16 to 22.6 |
| **5** | 512 to 1023 | 32 | 22.6 to 32 |
| **6** | 1024 to 2047 | 64 | 32 to 45 |
| **7** | 2048 to 4095 | 128 | 45 to 64 |

Quantization error exceeds photon noise

**A histogram analysis of the entire SME mission record confirms these results (not shown).*

# Measurement Uncertainty (cont.)

Quantization Error and Photon Noise

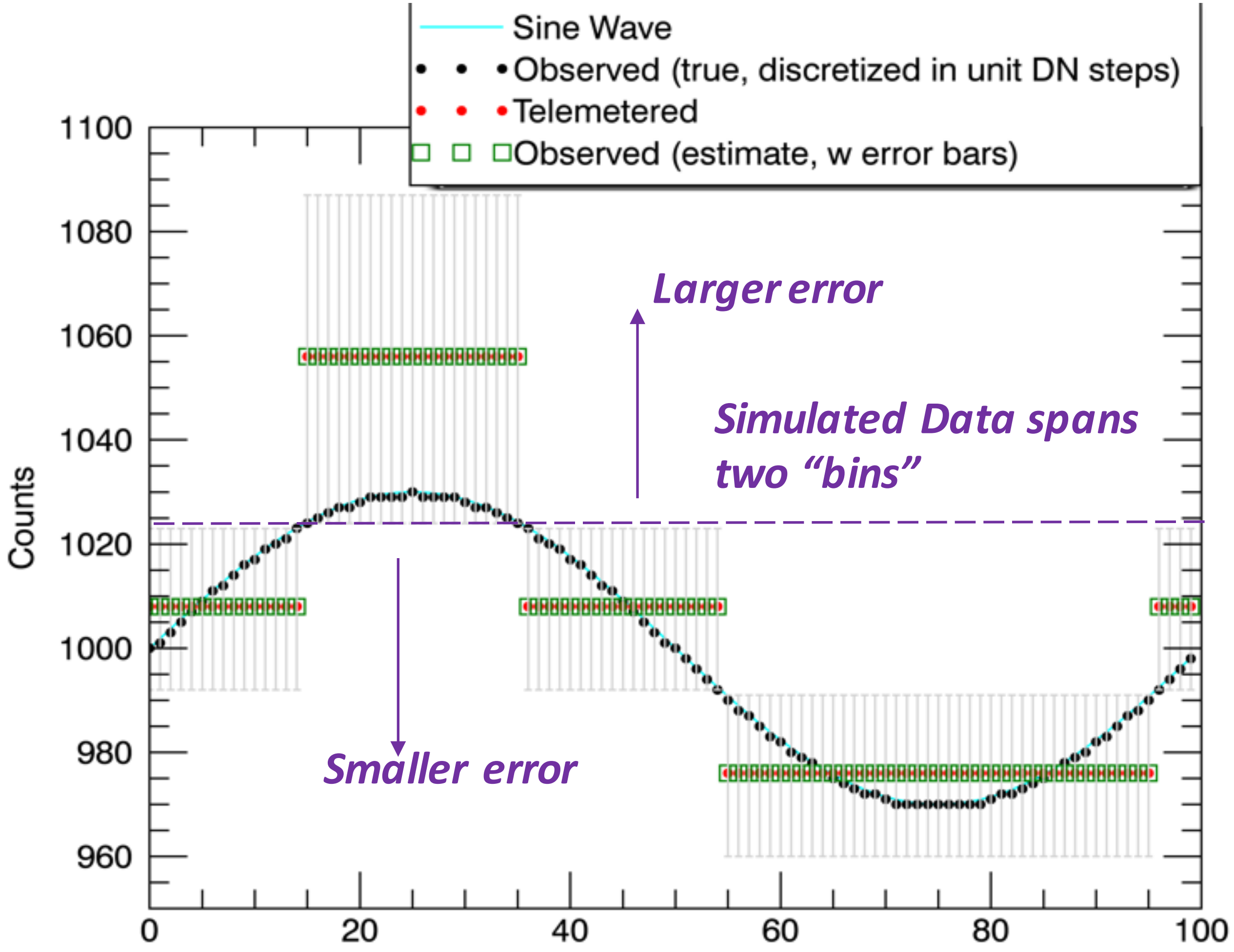
| # of shifts | 5-bits of data (DN) | Data increments (DN) "quantization error" | Square root of data (DN) "photon noise" |
|---|---|---|---|
| **0** | 0 to 31 | 1 | 0 to 5.6 |
| **1** | 32 to 63 | 2 | 5.7 to 7.9 |
| **2** | 64 to 127 | 4 | 8 to 11.3 |
| **3** | 128 to 255 | 8 | 11.3 to 16 |
| **4** | 256 to 511 | 16 | 16 to 22.6 |
| **5** | 512 to 1023 | 32 | 22.6 to 32 |
| **6** | 1024 to 2047 | 64 | 32 to 45 |
| **7** | 2048 to 4095 | 128 | 45 to 64 |

Percentage of data in each quantized bin for the entire mission

| # of shifts | 5-bits of data (DN) | Percentage of DN's (of total) |
|---|---|---|
| **0** | 0 to 31 | 18.63% |
| **1** | 32 to 63 | 8.74% |
| **2** | 64 to 127 | 6.94% |
| **3** | 128 to 255 | 14.79% |
| **4** | 256 to 511 | 33.53% |
| **5** | 512 to 1023 | 15.79% |
| **6** | 1024 to 2047 | 1.32% |
| **7** | 2048 to 4095 | 0.01% |

# Estimating “Truth” from the telemetered DN’s

- The quantization error findings allowed us to develop routines to ta a telemetered DN value and estimat the observed DN (and vice versa).



*Larger error*

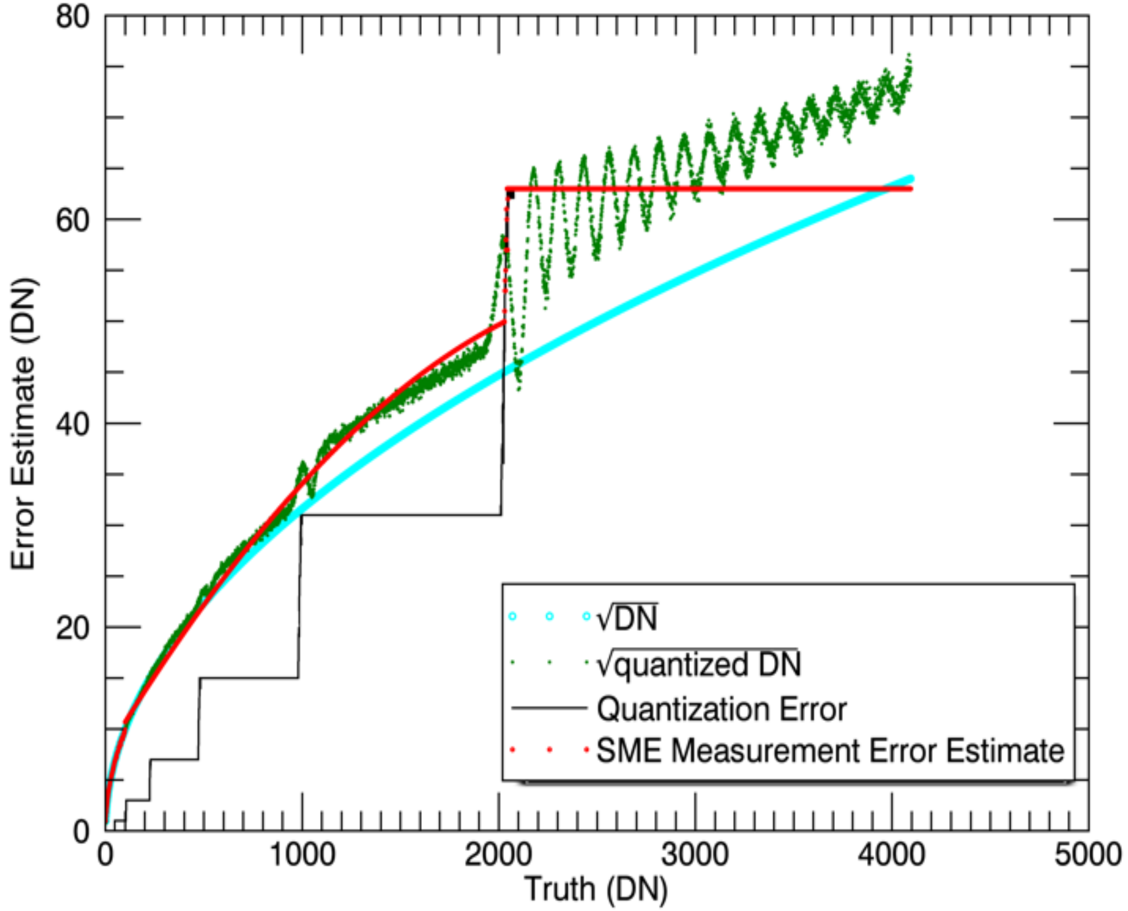
*Simulated Data spans two “bins”*

*Smaller error*

***Figure:*** *A sine-wave experiment of +/- 3% around a mean DN value = 1000 is used to demonstrate the impact of quantization error on deriving true solar variability from the SME observations. Estimates of variability could over- or under-estimate the “truth”.*

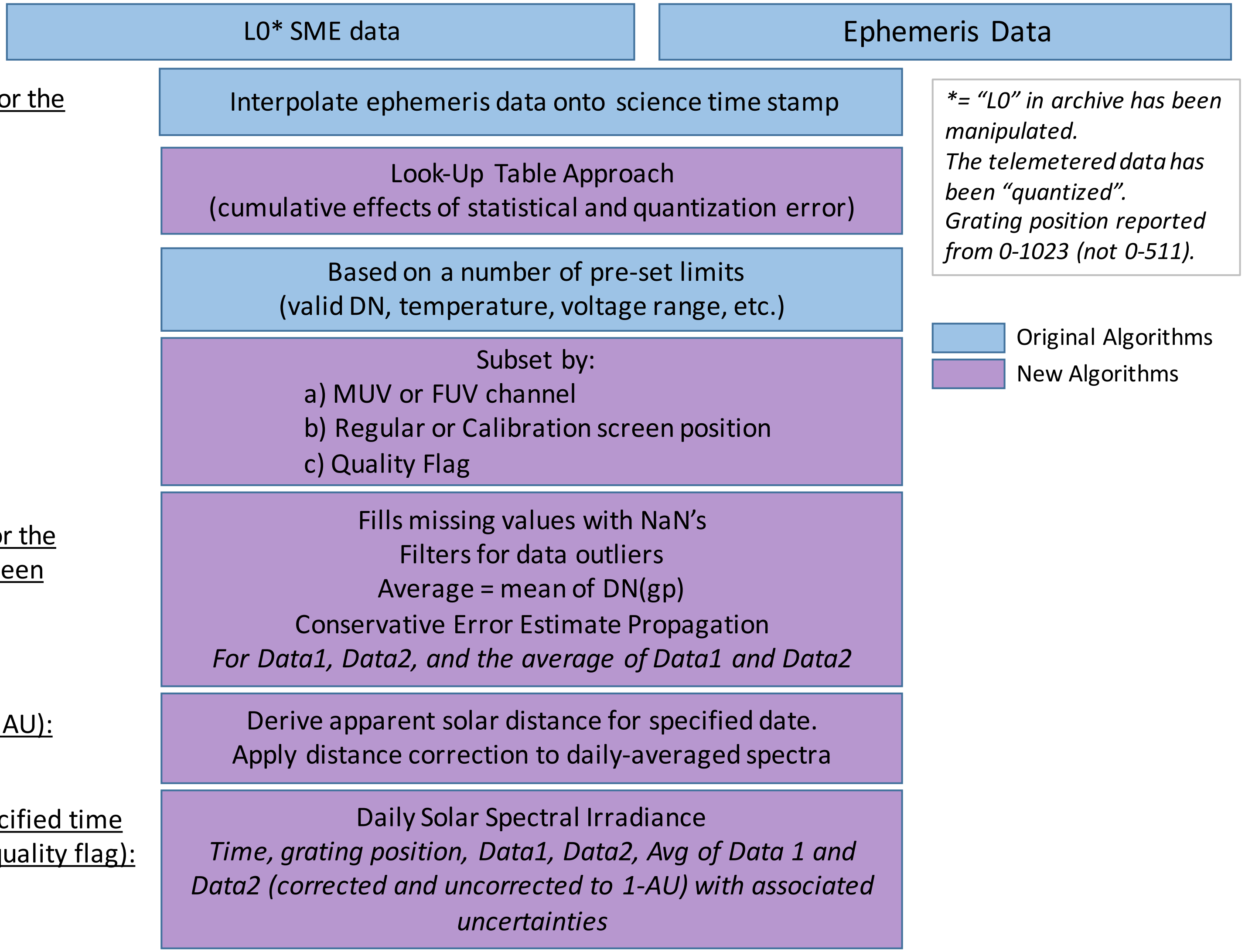
# Calculating “Look-Up-Table” of Uncertainty

- Monte Carlo Experiment
  - Random sampling of observed DNs
  - Assume observed DN “Truth” is affected by photon noise: Gaussian distributed with 1 std. dev. = √DN
  - Determine ”Telemetered” DN (i.e. according to quantize bins)
  - Determine error = difference between “Truth” and “Telemetered”
  - Repeat 5,000 times at each DN from 0 to 4096



***Prescribed SME uncertainty is the cumulative effect of photon noise and quantization error. The red curve provides a look-up-table of uncertainty for each “truth” DN.***

# Processing Algorithm: Approach "A"



| | |
|---|---|
| Acquire data from archive (for a specified time range): | 🟦 L0* SME data<br>🟦 Ephemeris Data |
| Create Combined Data Product (for the specified time range): | 🟦 Interpolate ephemeris data onto science time stamp |
| Assign Data Number Uncertainty: | 🟪 Look-Up Table Approach<br>(cumulative effects of statistical and quantization error) |
| Assign Data Quality Flags: | 🟦 Based on a number of pre-set limits<br>(valid DN, temperature, voltage range, etc.) |
| Subset Data (user specified) | 🟪 Subset by:<br>a) MUV or FUV channel<br>b) Regular or Calibration screen position<br>c) Quality Flag |
| Obtain Daily Averaged Spectra (for the specified time range, channel, screen position, quality flag): | 🟪 Fills missing values with NaN's<br>Filters for data outliers<br>Average = mean of DN(gp)<br>Conservative Error Estimate Propagation<br>*For Data1, Data2, and the average of Data1 and Data2* |
| Apply Sun-Distance Correction (1 AU): | 🟪 Derive apparent solar distance for specified date.<br>Apply distance correction to daily-averaged spectra |
| Generate Output File (for the specified time range, channel, screen position, quality flag): | 🟪 Daily Solar Spectral Irradiance<br>*Time, grating position, Data1, Data2, Avg of Data 1 and Data2 (corrected and uncorrected to 1-AU) with associated uncertainties* |

**= "L0" in archive has been manipulated.*
*The telemetered data has been "quantized".*
*Grating position reported from 0-1023 (not 0-511).*

🟦 Original Algorithms
🟪 New Algorithms

# Processing Approach “A” (cont.)

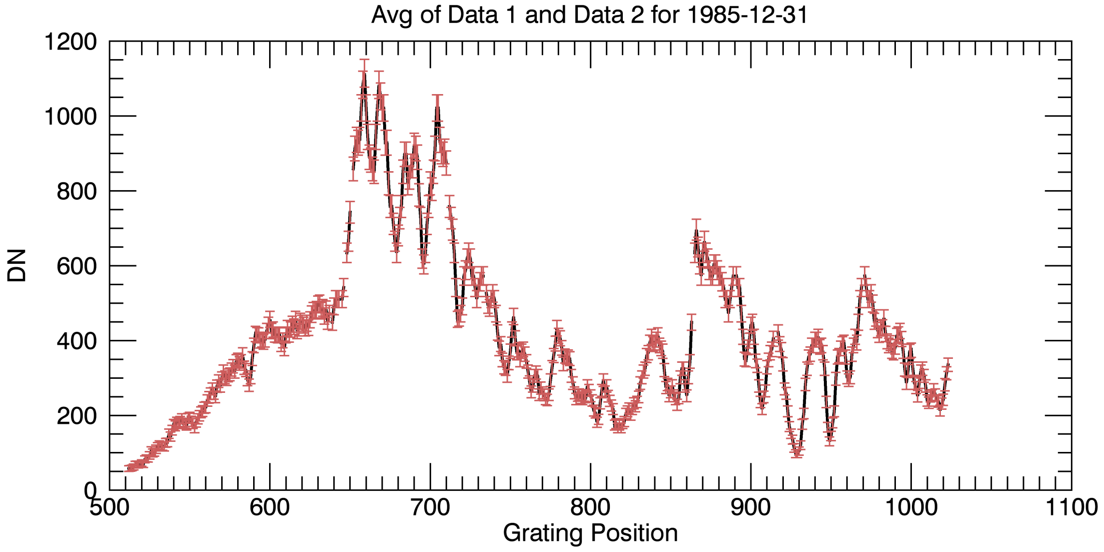
**Filtering for data outliers**

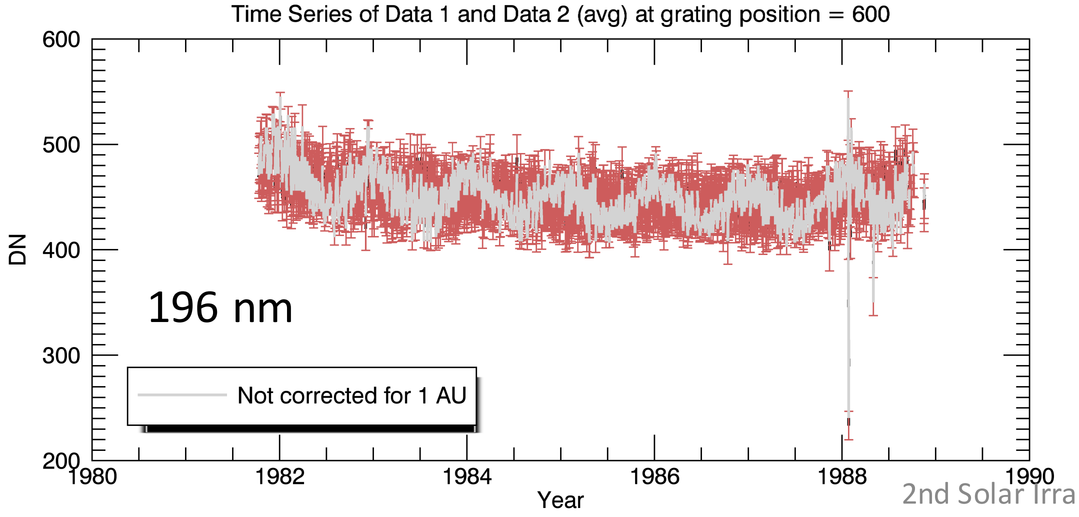
- When looping over time at a grating position, if a data value falls outside of the uncertainty range of a reference spectrum, it is discarded.
- To account for solar variability, the reference spectrum moves in time.

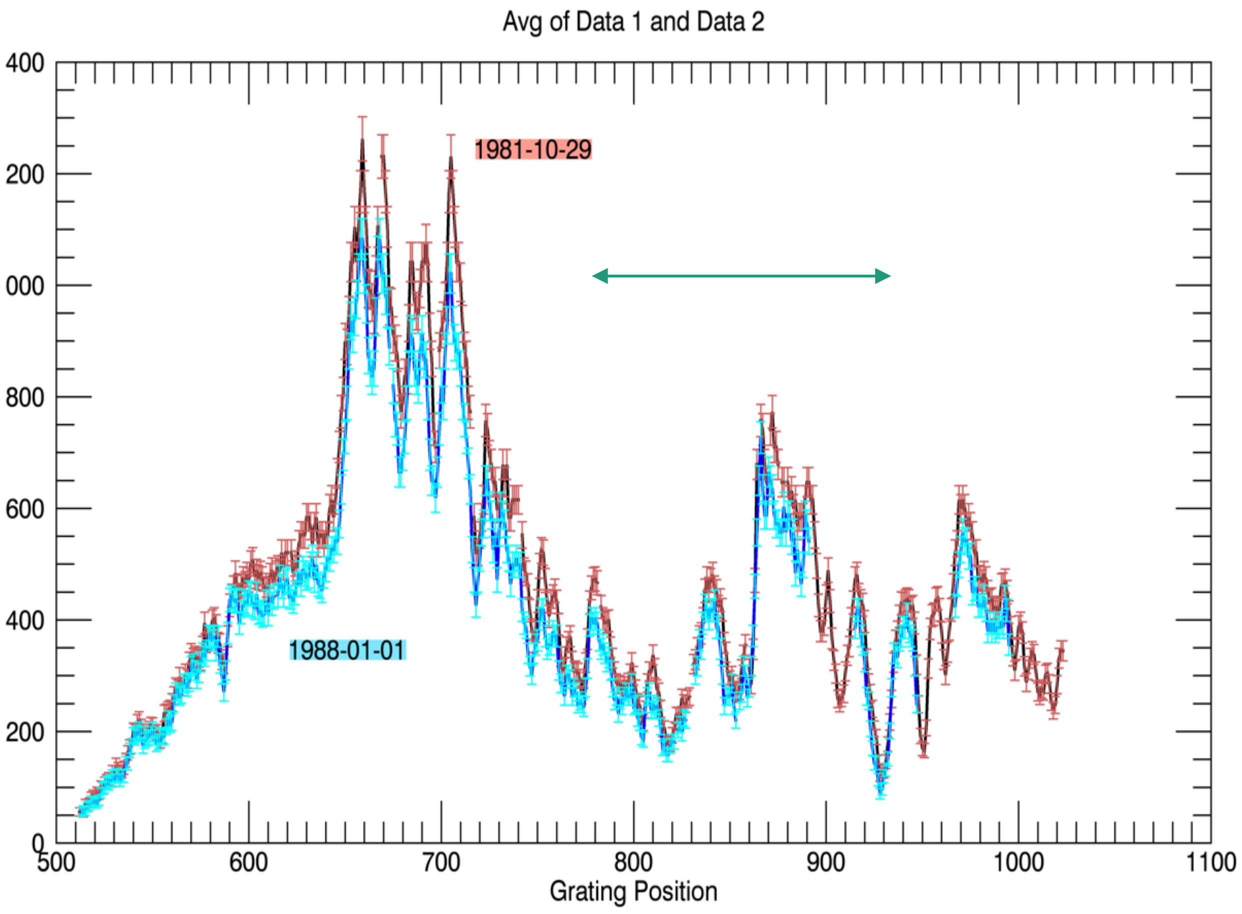
**Conservative Propagation of Uncertainties when averaging (data streams and in time)**

- For more than 1 “data1” or “data2” values:
    - $DN_{daily_{\downarrow}avg} = \frac{1}{N}\sum DN_i$
    - $\sigma_{daily_{\downarrow}avg} = \frac{1}{N}\sum \sigma_i$
- Averaging “data1” and “data2” streams together:
    - “Data12” = mean of the daily average Data1 and Data2 values
    - $\sigma_{Data12}$ = mean of the data1 and Data2 uncertainties

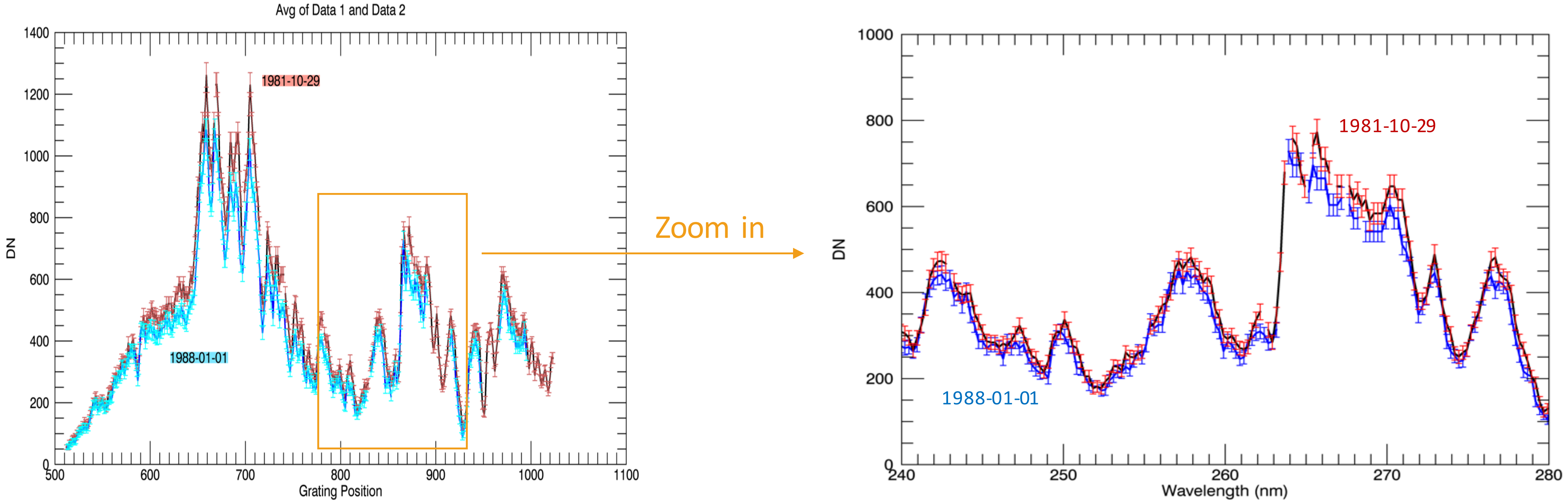
# MUV Results: Processing Approach “A"







# Shifts in grating position?



Offsets are sometimes apparent along wings of features.
Example shown here is within the combined uncertainties of the two spectra.
Separating potential effect from measurement uncertainty may depend on the Sun's variability, the magnitude of the signal and the spectral range.

# Processing Algorithm: Approach "B"

**Developed to focus on regions of large solar variability and pronounced spectral features*

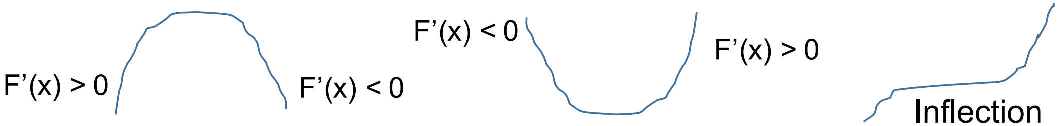
Acquire daily averaged data (for a specified time range, channel, screen position, quality flag):

Daily Solar Spectral Irradiance
*Time, grating position, Data1, Data2, Avg of Data 1 and Data2 (corrected and uncorrected to 1-AU) with associated uncertainties*

Compute Stationary Points of Spectrum:

Compute Derivative of the Daily Average Spectrum
(Stationary points: where derivative of spectrum vanishes)

For an assigned Δgp around central gp:



Inflection Point
(not sufficient)

Identify stationary points by peaks or valleys:

Peak = local maximum

Valley = local minimum

Obtain value of (floating) grating position for local maximum or local minimum

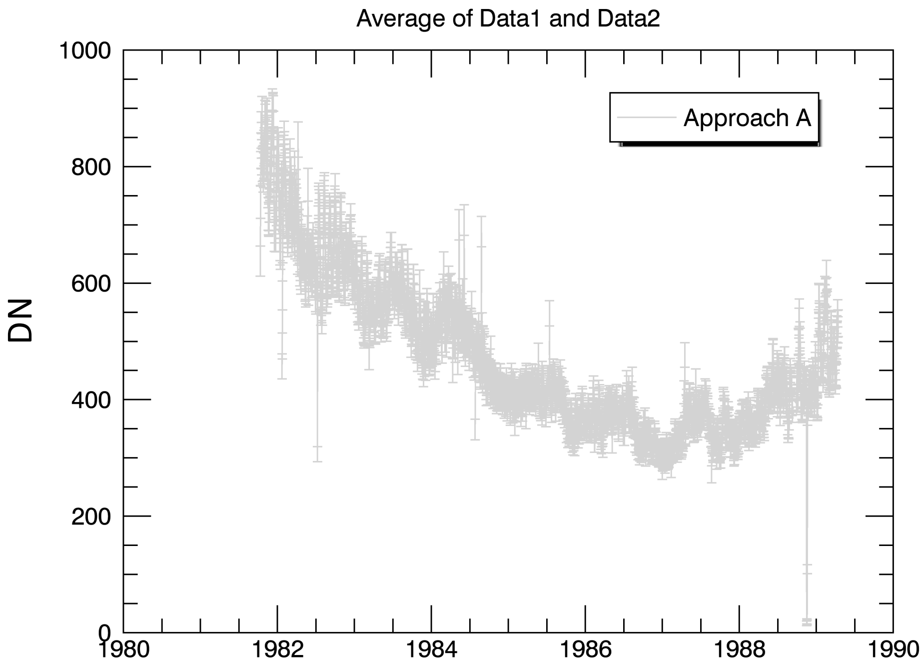
Identifies gp corresponding to max DN (or a peak)
Identifies gp corresponding to min DN (for a valley)
*For Data1, Data2, and the average of Data1 and Data2*

Generate Output File (for the specified time range, (floating) grating position, channel, screen position, quality flag):

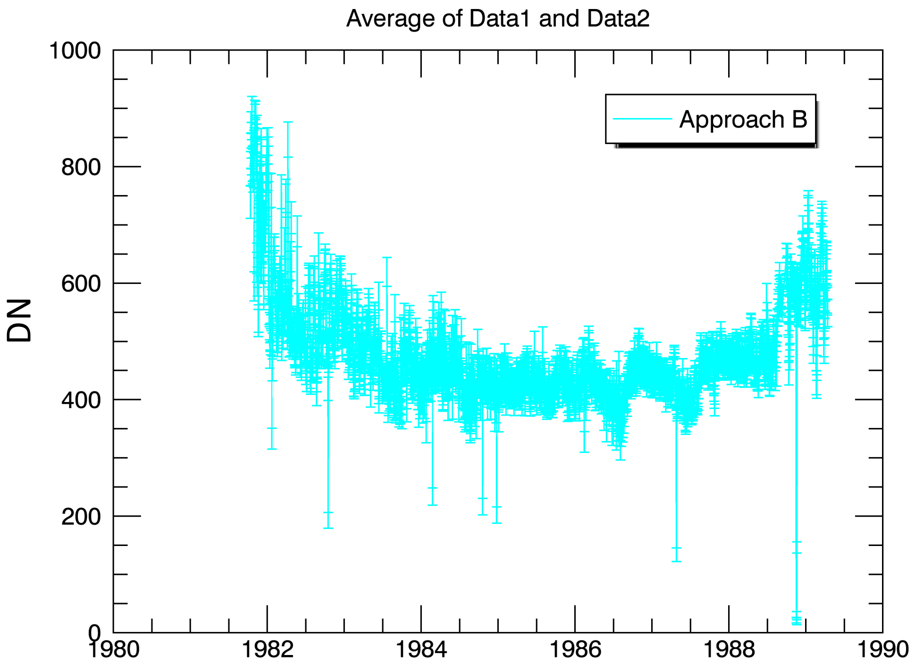
Revised Daily Solar Spectral Irradiance
*Time, Data1, Data2, Avg of Data 1 and Data2 (corrected and uncorrected to 1-AU) with associated uncertainties (floating) as a function of floating grating position.*

# Results: Lyman Alpha Example

**Approach "A"**

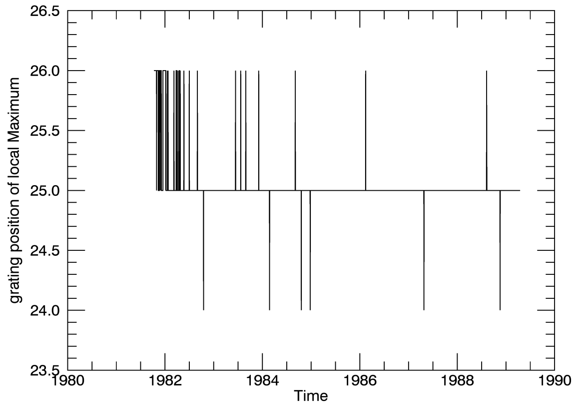


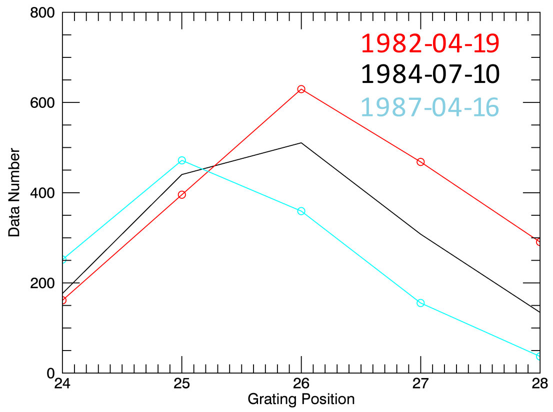
**Approach "B"**



# Results: Lyman Alpha Example

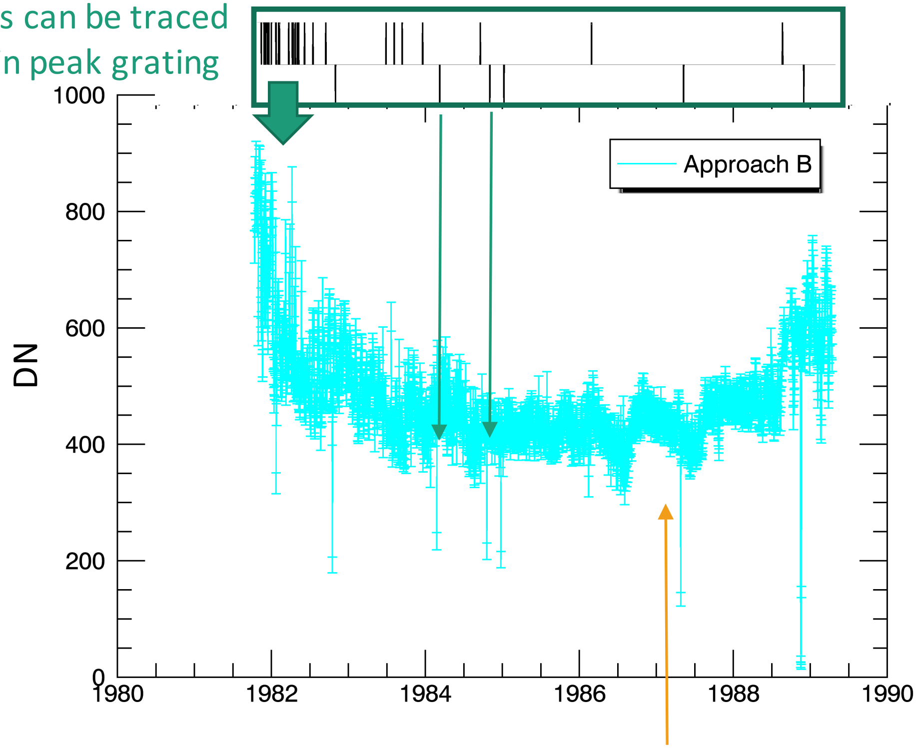
## How much does grating position of “peak” Lyman feature vary?





## Approach “B”

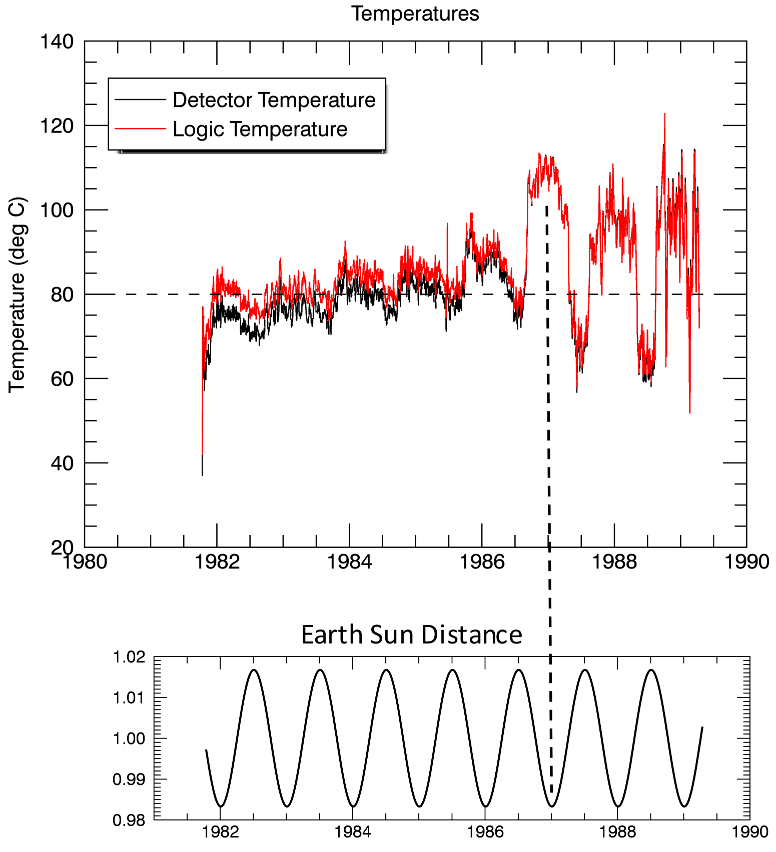
Data outliers can be traced to changes in peak grating position



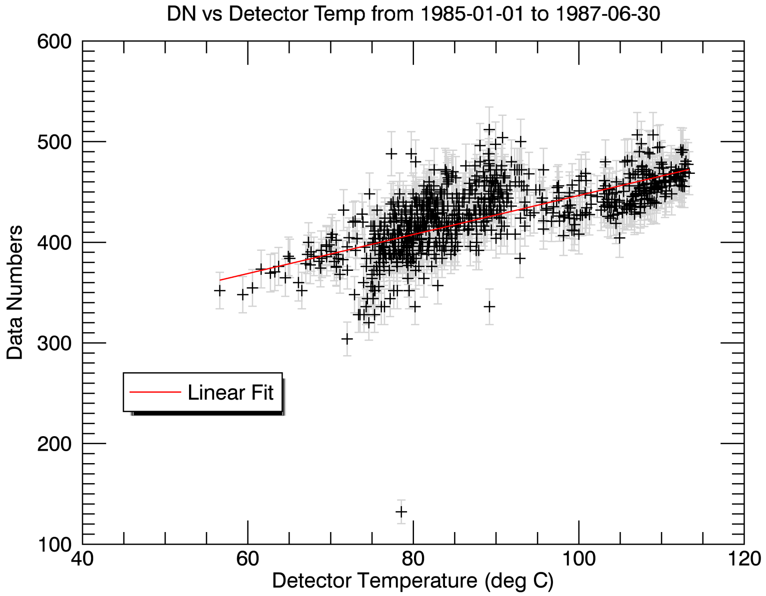
**We recall variability in detector temperature has similar features, so…*

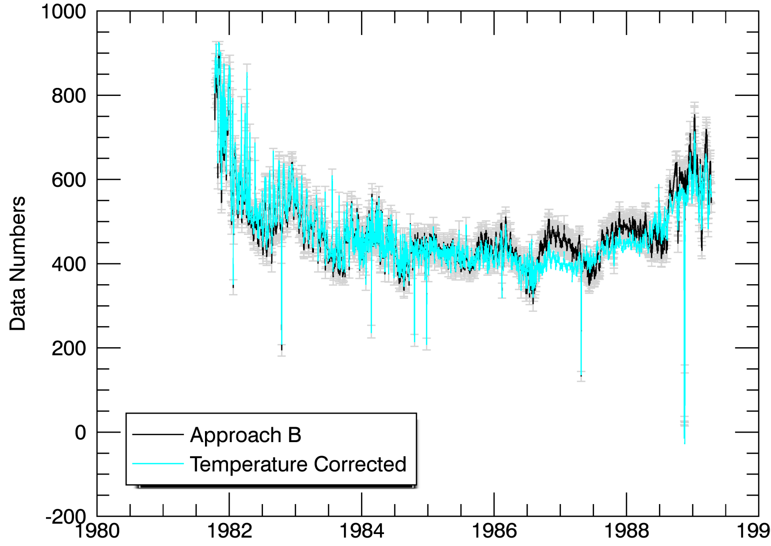
# Deriving a Temperature Correction:

**We correct for temperature affects by evaluating (and correcting) the non-zero slope of DN with temperature over solar minimum time period.*



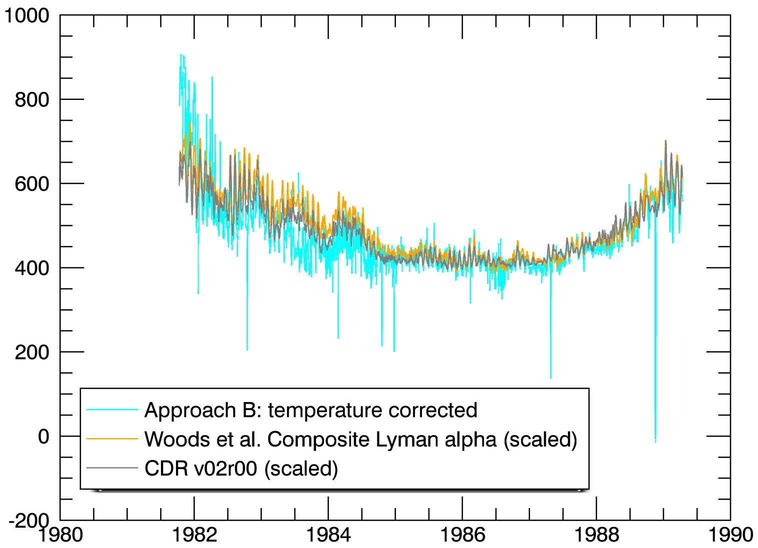
*Earth-viewing instruments turned off Dec 11, 1986*

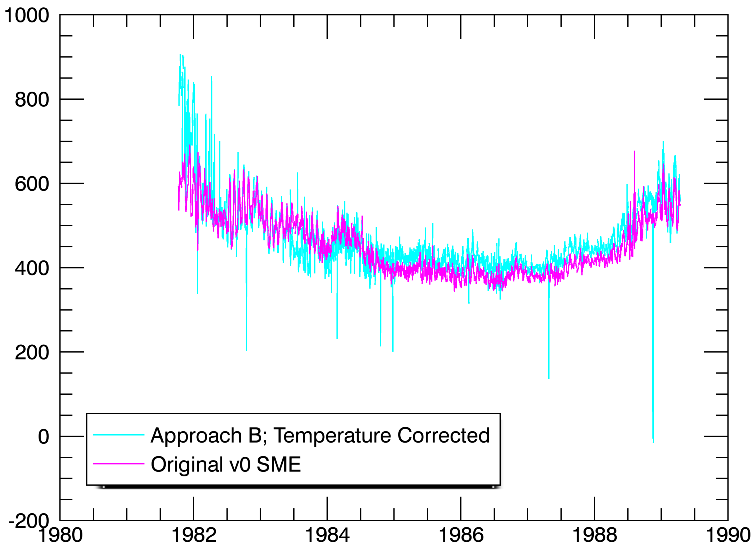




**Corrected to a constant Temperature (80 deg C).*

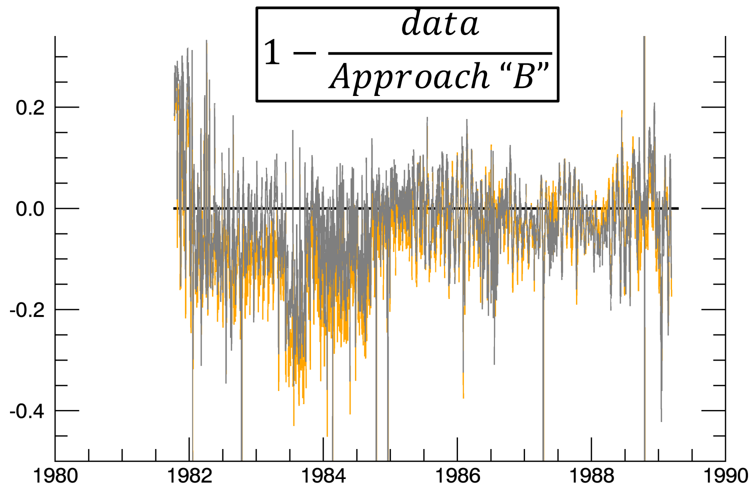
# Comparison to Measurements and Models





New Approach “B”:

- Shows more promise than Approach “A”.
- Lyman alpha time series has greater solar cycle variability than v0 data.
- Is reproducible (records of v0 data processing steps have not been kept).
- Can not be broadly applied to the spectrum (requires spectral “features”).



- *Neither our approach “A” or “B” Lyman alpha results match those in the v0 data in the LISIRD database (1 nm binned), which also had a form of degradation correction applied.*

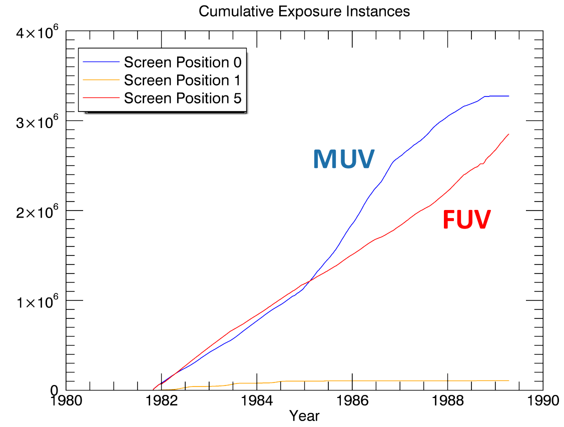
Necessary Approach “B” improvements:

- It begins (incorrectly) using daily averaged data output from Approach ”A” (averaging has already occurred for a given fixed grating position).
- We will develop an improved Approach “B” algorithm beginning from the L0 data.

# Summary and Year 3 Plans:

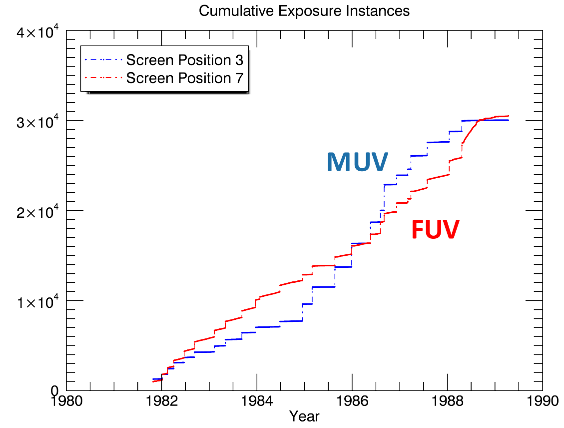
- Today, we can provide you with:
  - preliminary, daily averaged, SME SSI based on Approach "A" with associated uncertainties (corrected for 1AU, but not temperature).
  - preliminary, daily averaged, Lyman Alpha irradiance based on Approach "B" with associated uncertainties (corrected for 1AU and temperature).
- In Year 3, we will:
  - Develop an improved Approach "B", beginning from L0 data.
  - Apply improved approach "B" to Lyman alpha time series.
  - Evaluate if Approach "B" can be applied to other wavelengths.
  - Develop and apply an algorithm to correct for degradation of primary screen based on known understanding of cumulative exposure on primary and backup screen positions.

Cumulative Exposure "Instances" on Primary Channels



** Primary channels are exposed ~ 100 x more than calibration channels.*

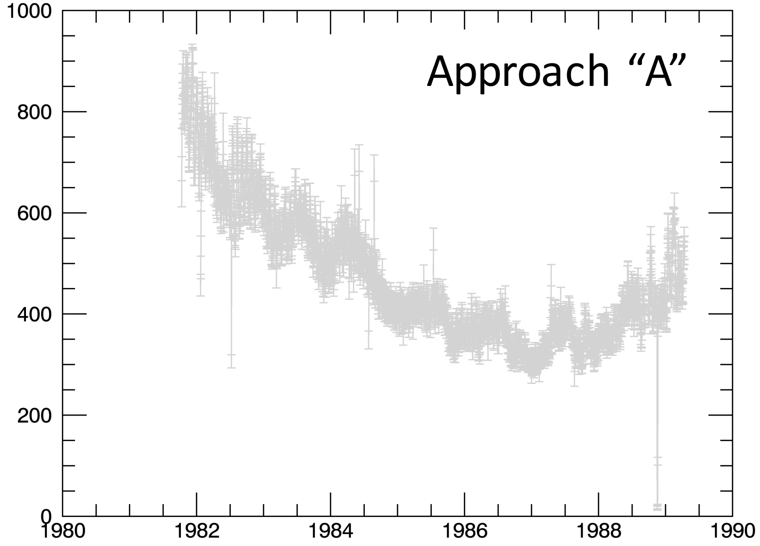
Cumulative Exposure "Instances" on Calibration Channels

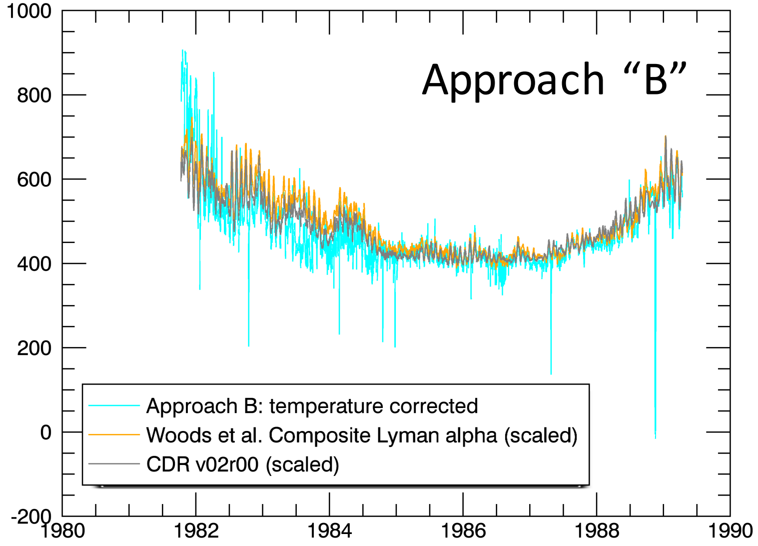


# Questions or Comments?

Is our uncertainty propagation approach correct? Too conservative?

SME Lyman Alpha Time Series



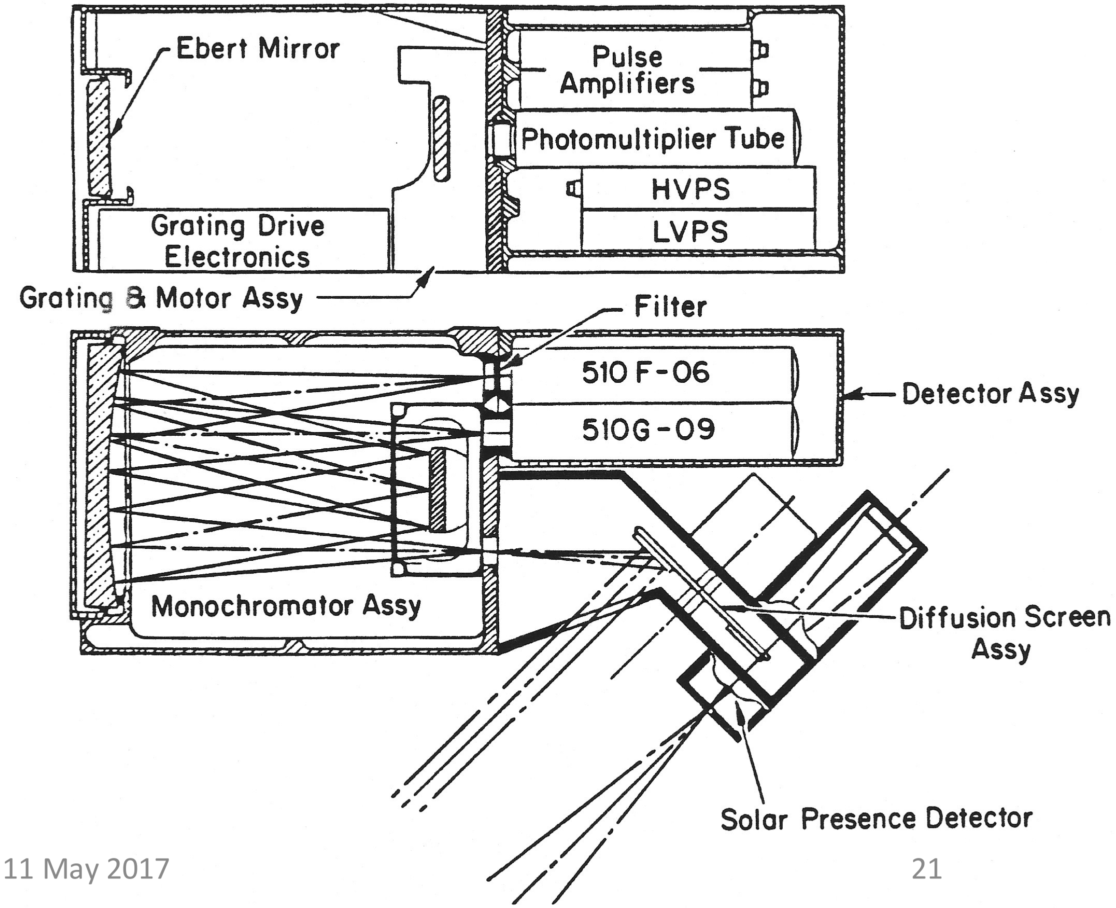


# Backups

# Solar Ultraviolet Spectrometer (UVS)

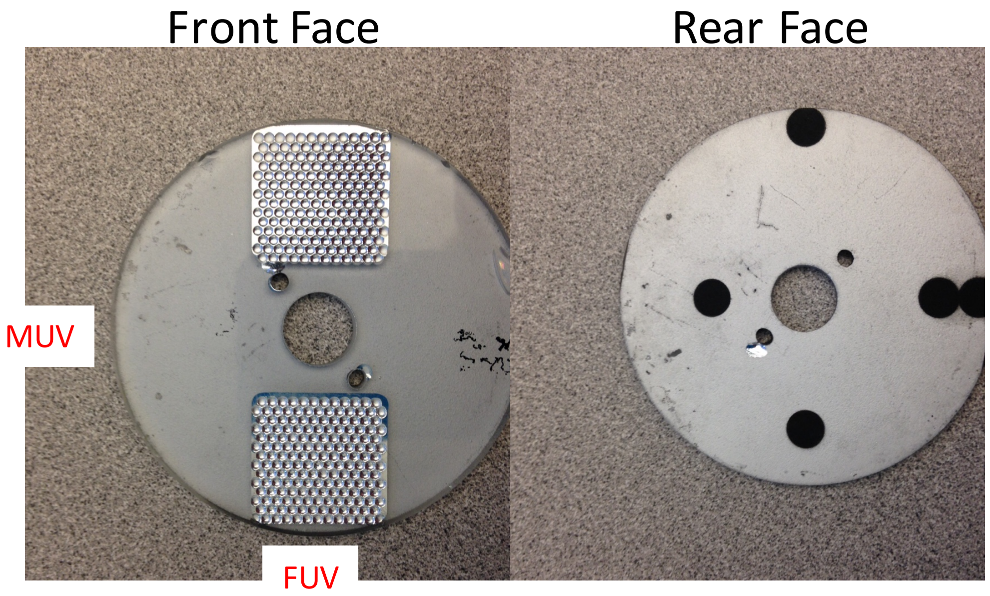
- Monitors solar spectral irradiance scattered from a diffusing screen.
- Detectors (photomultiplier tubes):
  - EMR 510-G-09 (FUV; 115 to 250 nm)
  - EMR 510-F-06 (MUV; 173 to 305 nm)
  - Switched between detectors (and screen) every 4 hr.
- Grating has Al + MgFl coating and 2400 grooves/mm; 1 step = 0.019° = 0.26 nm

**Ebert-Fastie Spectrometer**



# Screen Assembly & Grating Drive Assembly

- The grating and grating drive mechanism are common to both FUV and MUV channels
- The FUV channel ('G' screen) is a front surface mirror with "fly eyes". It is overcoated with Al+MgFl to scatter light to detector.
- The MUV channel ('F' screen) allows light to pass through the quartz and scatter off rear Al coating
- The screen position sensor is a bit flag reflected off rear face of screen to indicate which screen is in place.



FUV and MUV channels had a primary and backup screen position.
*This particular scattering screen lived a battered existence in a desk drawer for 20+years.

# Calculating "Look-Up-Table" of Uncertainty

- Shows results of look-up table of measurement uncertainty (red) versus DN (telemetered and truth).
- Shows that the maximum assigned SME measurement uncertainty is equivalent to the maximum quantized error at the largest bin.