Responsivity Calibration of the SUSIM UARS

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Solar Ultraviolet Spectral Irradiance Monitor (SUSIM)

experiment overview

Operated between 11 October 1991 (UARS day 30) and 1 August 2005 (UARS day 5072) aboard the Upper Atmosphere Research Satellite (UARS)

Dual-dispersion, dual-spectrometer wavelength scanning instrument calibrated by 4 onboard stable deuterium lamps

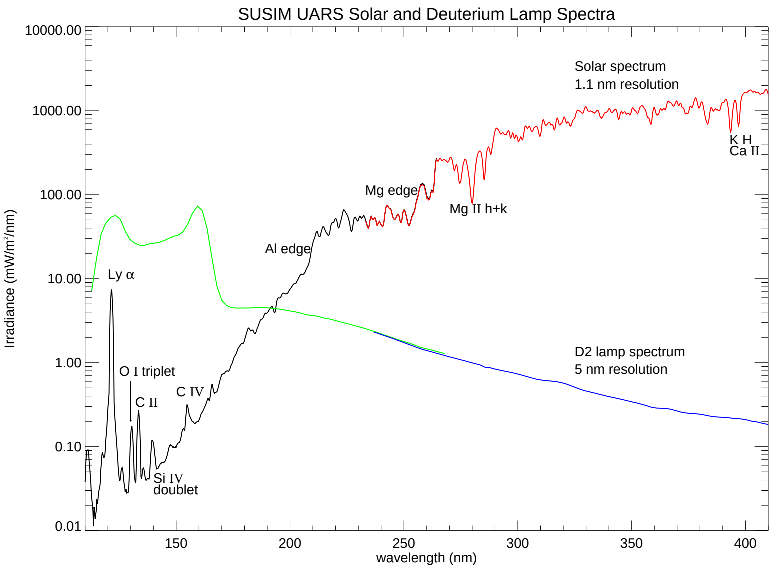
Full wavelength range: 108–412 nm

Three available wavelength resolutions: low (5 nm), mid (1.1 nm), and high (0.15 nm)

Selectable entrance filters (6), primary gratings (2), secondary gratings (2x4), exit filters (6), detectors (7).

SUSIM UARS Solar and Lamp Scans

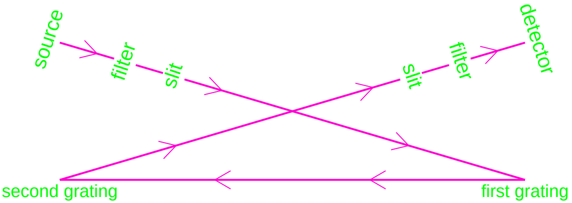
Solar and lamp UV spectra each measured using two separate scans



SUSIM UARS Optical Paths

a flexible instrument with interchangeable optical elements

SUSIM UARS OPTICAL ELEMENT DIAGRAM



source	entrance filter	entrance slit	first grating	second grating	exit slit	exit filter	detector
D_2 lamp 1	quartz	narrow (.15 nm)	UG1	UG	narrow (.15 nm)	MgF_2	PLE
D_2 lamp 2	MgF_2	mid (1.1 nm)	UG2		mid (1.1 nm)	ND 7%	PSE
D_2 lamp 3	MgF_2	wide (5 nm)	UG3		wide (5 nm)	ND 15%	PCS
D_2 lamp 4	quartz	wide (5 nm)	UG4		wide (5 nm)	glass	SLE
sun	MgF_2		LG1	LG		ND 7%	SSE
	MgF_2		LG2			ND 15%	SRE
	none		LG3			glass	PCL
			LG4			none	

Elements used to obtain SUSIM daily 1.1 nm spectral irradiance

SUSIM Terminology

definitions of specific terms

An **optical channel** comprises the set of optical elements in a single optical path used to observe UV radiation either from the Sun or lamps.

The **Working Channel** (aka Standard Channel) is the optical path used to gather the daily and weekly solar UV irradiances.

The **Reference Channels** are the set of channels scanned infrequently on **calibration days** whose purpose is to provide responsivity information.

Anomalous degradation is amount of additional responsivity degradation in a channel when it observes the sun over that observing a lamp.

A **self-similar** calibration determines the parameters in a calibration model through intercomparisons of two or more data sets.

SUSIM UARS UV Irradiance Measurements
summary of working channel solar measurements

Full wavelength range (108–412 nm) solar measurements:

- mid resolution (1.1 nm) scans, daily cadence (primary measurement)
- low resolution (5 nm) scans, daily cadence
- high resolution (0.15 nm) scans, weekly cadence

High resolution scans of selected solar features (aka continuous monitoring), daily cadence:

- Ly-α (121.6 nm)
- CII (134 nm)
- CIV (154 nm)
- MgII/MgI (280 nm/285 nm)
- CaII K (393 nm)

SUSIM UARS: Working Channel Evolution

Working channel was changed to maintain measurement quality.

Operational Philosophy: use working channel in to as near to a consistent day-to-day and week-to-week manner as possible

- so that the responsivity can be accurately interpolated between calibration days.

wavelength range (nm)	entrance filter	grating pair	detector	UARS day range
110–264	MgF_2-1	UG4	PSE	30–895
233–412	Quartz-1	UG4	PLE	30–2741
110–264	none	UG4	PSE	896–2740
110–264	MgF_2-2	UG1	PSE	2741–4318
233–412	Quartz-1	UG1	PLE	2741–5072
110–264	MgF_2-3	UG1	PSE	4319–5072

SUSIM UARS UV Irradiance Measurements
responsivity calibration overview

SUSIM working channel responsivity is established as follows:

- scans of NIST sources provide initial calibration of working and reference channels
- declining deuterium lamp output over time is calibrated through lamp intercomparisons
- degradation in infrequently used reference channels are calibrated by scans of the lamps
- intercomparison of reference channels establishes their anomalous (i.e., the difference between solar and lamp) degradation
- working channel responsivity on reference channel days is found through intercomparisons with reference channel scans
- working channel responsivity on all other days is established through interpolation

SUSIM UV Irradiance Measurements

measurements of deuterium lamps

Lamps are scanned by various channels on approximately, monthly, quarterly, biannual, and annual cadences.

Self-similar calibration of the output of each lamp consists of:

- assumption of a parameterized model of lamp output degradation that applies to all lamps
- determination of the parameter values through (nearly) coincident measurement of different lamps by the same optical channel.

Base measurement is the ratio of the degradation of one lamp to another as measured by the same optical channel:

$$\frac{L_2(d_1)}{L_2(d_2)} \times \frac{L_4(d_2)}{L_4(d_1)}$$

where L_2 and L_4 are the signals of lamps 2 & 4, respectively, and d_1 and d_2 are days where both lamps were measured.

SUSIM Calibration

summary overview

Initial calibration performed at NIST SURF and with FEL lamps.

In flight corrections applied for:

- dark current (D)
- detector gain/temperature (G)
- stray/scattered light (Y)
- wavelength (λ)
- solar pointing ($P(\theta, \lambda)$); θ represents off-pointing angles
- responsivity of optical path (R)

The spectral irradiance, I, is related to the measured signal, S, by:

$$I(\lambda) = \int \frac{G(T)\,[P(\theta,\lambda)\,(S(\lambda) - D)) - P(\theta,\lambda')\,Y(\lambda,\lambda')]}{R(\lambda)}\,d\lambda'$$

Responsivity Degradation in the SUSIM Instrument
characteristics and causes

Responsivity of all optical elements degrade in proportion to UV exposure.

Accordingly, entrance filters degrade most strongly followed by primary gratings.

Filters only degrade because they “darken”.

Gratings mostly degrade because of interference (!):

- negative degradation has been observed ($> 3\times$)
- near 180 nm gratings don’t degrade (for moderate exposures)

Responsivity Degradation in the SUSIM Instrument
characteristics and causes

Responsivity of channels with entrance filters (both MgF_2 and quartz types) follow the same general dependence (Floyd, 1999):

$$R(\lambda, x) = c_0(\lambda) + c_1(\lambda) * log(1 + x/c_2(\lambda))$$

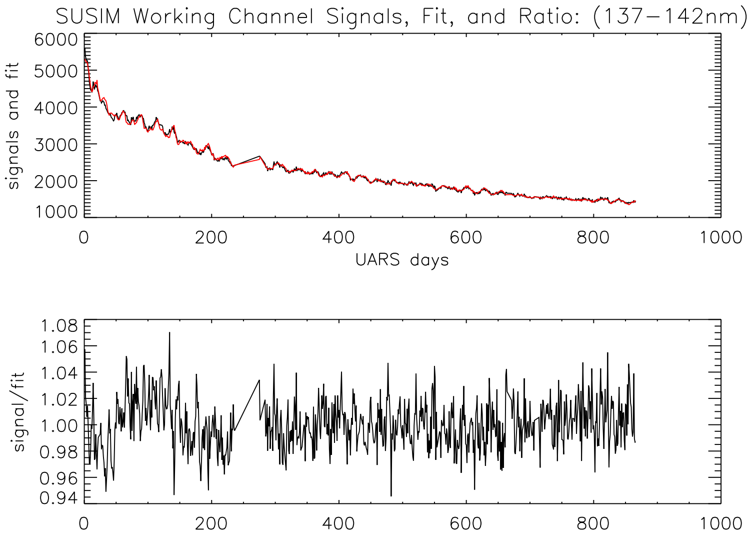
where:	x	–	exposure
	λ	–	wavelength
	c_n	–	wavelength-dependent constants

That the same general dependence is experienced by both types of filters indicates that the responsivity degradation is a surface phenomenon.

Likely candidate: UV-induced polymerization of contaminant hydrocarbons

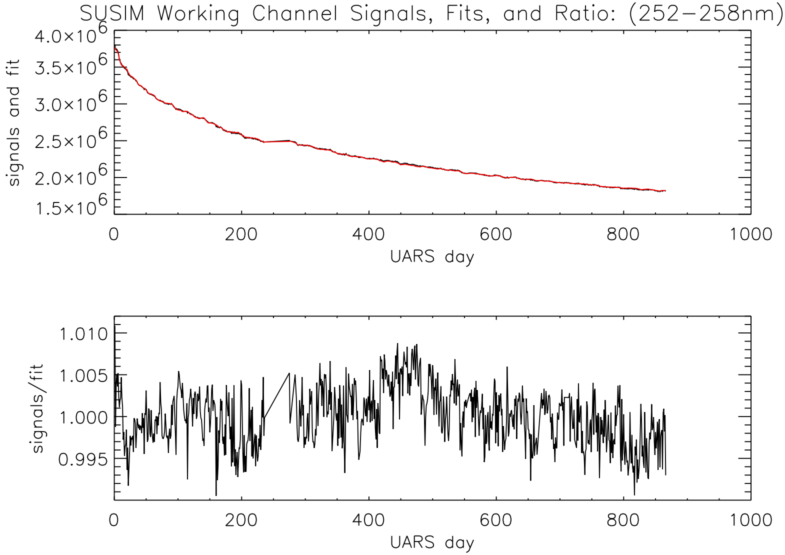
Responsivity Degradation in the SUSIM Working Channel

Example: MgF_2 entrance filter



Responsivity Degradation in the SUSIM Working Channel

Example: Quartz entrance filter



Calibration of the Output of the Deuterium Lamps

implementation

Although the lamp output is itself stable, the lamp's MgF_2 exit window degrades probably by the same (polymerization) mechanism as do the other optical elements

Accordingly, we assume the same form of the lamp (window) degradation as was found for the SUSIM entrance filters.

Although most and channels gave similar results, the least degrading lamps (biannual and annual) and channel (RC) were used to establish the output degradation for those lamps.

The degradations of the other (monthly and quarterly) lamps were established through direct intercomparisons with the other two lamps.

Anomalous Degradation

Responsivity degradation will be different for the lamps and sun if each has a different grating footprint.

Because the rays from the lamp are not parallel, the grating exposure footprint is larger for the lamp than for the sun.

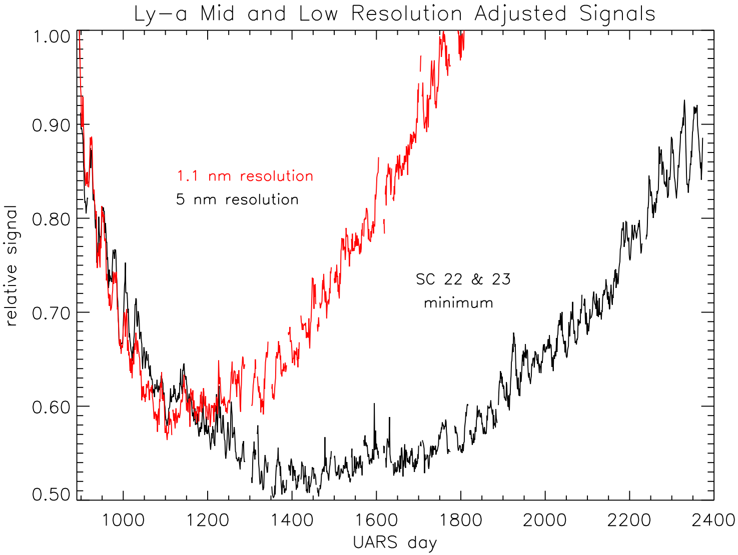
Because lamp measurements are made with, on average, less exposed and therefore less degraded grating surfaces, they will experience (at first) LESS degradation than solar measurements on the same channel.

Accordingly, the lamp's larger exposure footprint causes its measurements to underestimate the degradation experienced with solar measurements.

Anomalous degradation estimated through self-similar comparisons of the time series of measurements by different channels having different UV exposures.

Anomalous Degradation

Ly-α signals during period of no entrance filter



SUSIM UARS Reference Channels

Reference Channel	λ range (nm)	Entrance Filter	Grat. Pair	Det.	UARS days	cadence
RC	110–265	MgF_2-4	UG1	SSE	30–2741	2/year
RC	235–412	Quartz-2	UG1	SLE	30–2741	2/year
nRC	110–265	MgF_2-4	LG2	SSE	2741–5071	2/year
nRC	235–412	Quartz-2	LG2	SLE	2741–5071	2/year
MoRC	110–265	none	UG2	PSE	316–5071	12/year
MoRC	235–412	none	UG2	PLE	316–5071	12/year
MiRC	110–265	none	UG3	SSE	1369–5071	9/all
MiRC	235–412	none	UG3	SLE	1369–5071	9/all
LMiRC	110–265	none	LG3	SSE	2740–5071	4/all
LMiRC	235–412	none	LG3	SLE	2740–5071	4/all
StRC	110–265	none	UG4	PSE	2741–5071	4/year
StRC	235–412	Quartz-1	UG4	PLE	2741–5071	4/year

Solar Changes as Measured by Reference Channels

determine the change in responsivity over each time period

Ratios of solar scans from each reference channel, after correction for degradation (both lamp-measured and anomalous) measure the solar change over the corresponding period of time

By combining (e.g., averaging) the solar changes over the same time interval as measured by different reference channels, one may generate an estimate of solar change over than period.

These solar changes serve to determine the responsivity change in the working channel over that period.

The working channel was changed only on days when several reference channel scans were performed.

Solar Changes as Measured by Reference Channels

determine the change in responsivity over each time period