200 nm to 100 µm, with 0.25% Band-Integrated Uncertainty Requirements: Meeting the Challenges of the RBI Spectral Calibration

CALCON 2016

James Q Peterson (SDL), Harri Latvakoski (SDL), Greg Cantwell (SDL), James Champagne (SDL), Joel Cardon (SDL)

Abstract

The Radiation Budget Instrument (RBI) is a satellite payload being built by Harris Corporation, Fort Wayne, IN for NASA Langley for inclusion on the Joint Polar Satellite Systems 2 (JPSS-2) mission. Space Dynamics Laboratory (SDL) has contracted with Harris to provide calibration services for RBI.

RBI will measure earth-reflected solar and earth-emitted radiation using three broadband radiometric sensors, covering a spectral range from 200 nm to greater than 100 µm. A key RBI spectral calibration requirement is to provide a relative spectral responsivity (RSR) for each sensor, over the full spectral range, with an RSR band-integrated uncertainty budget of 0.25% for both a solar irradiance spectrum and a 300 K blackbody spectrum.

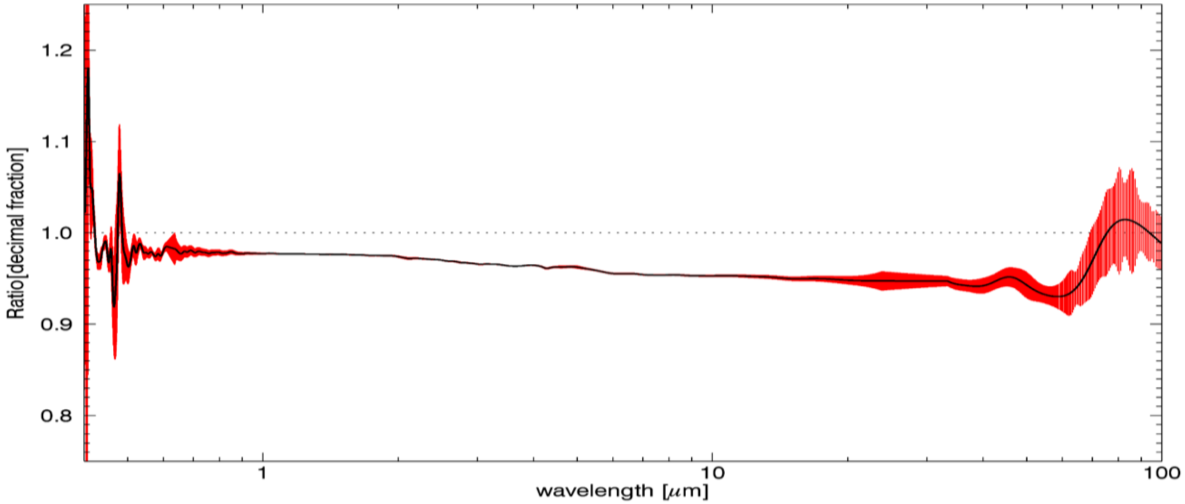
This paper shows how SDL will accomplish these demanding RBI RSR measurements. Included is an overview of measurement planning, testing configurations, and detailed modeling of the expected results.

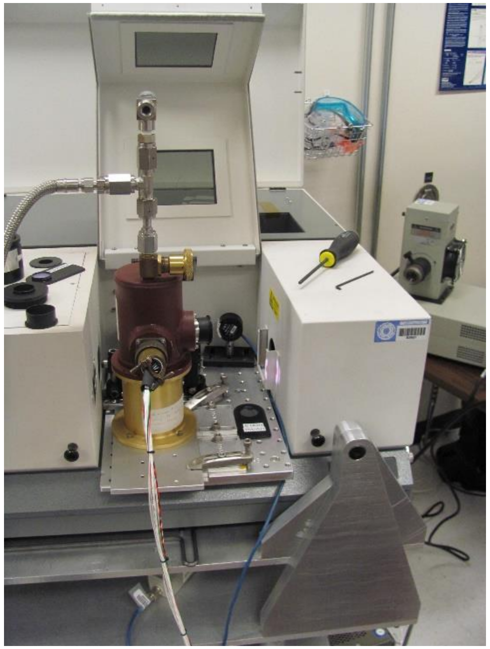
RBI Spectral Calibration Challenges

- RSR spectral range coverage from 200 nm to greater than 100 µm
- Band-integrated RSR uncertainty of 0.25% for two cases
  - Solar irradiance spectrum
  - 300 K blackbody spectrum

SDL Background and Experience

- Previous SDL spectral calibrations include:
  - CIRRIS 1A, SPIRIT-III/MSX, SOFIE, SABER, MSTI-III, WIRE, WISE, SBIRS-High HEO, NFIRE, CHIRP, MKV, AFT1, AFT2, MIGHTI
- FTS methodology and approach is available:
  - James Q Peterson, S. Hansen, A. Thurgood, “SDL Experiences with Interferometric Testing of Sensor Spectral Characteristics”, Proceedings of the 2010 Conference on Characterization and Radiometric Calibration for Remote Sensing, Logan, UT, Aug. 2010
- SDL spectral measurements of RBI detectors – fall 2015
  - An excellent training exercise for test planning and modeling





RBI Calibration Uses a Combination of RSR Derivation Methods

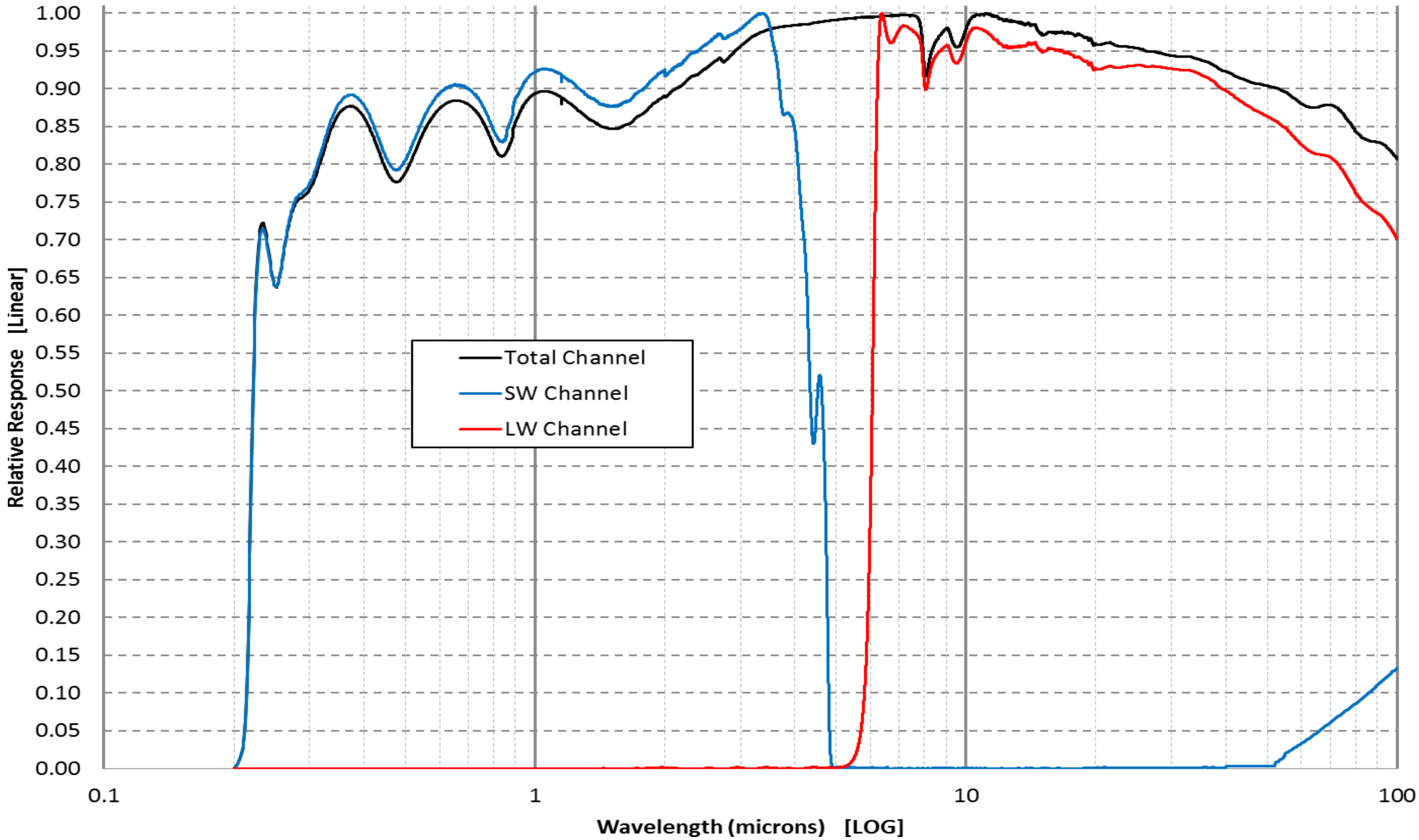
1. Model system-level RSR based on component-level measurements
   – Used for deep UV spectral coverage
2. Measure system-level RSR using band-pass filters
   – Direct link from ACR to RBI provides lowest uncertainty of all methods
   – Negligible systematic uncertainty
   – Measurements are limited to spectral locations of band-pass filters only
   – Provide Tie Points for the FTS measurements
3. Measure system-level RSR using FTS
   – Provides continuous spectral coverage, with sufficient spectral resolution
   – Measurements are subject to systematic (spectrally correlated) uncertainties: source temperature changes, detector non-linearity, etc.
      - Creates a need for Tie Point corrections

Combining these three derivation methods, SDL is confident the spectral range and uncertainty requirements will be met

Space Dynamics Laboratory
Utah State University Research Foundation

RBI Component-Level Measurements

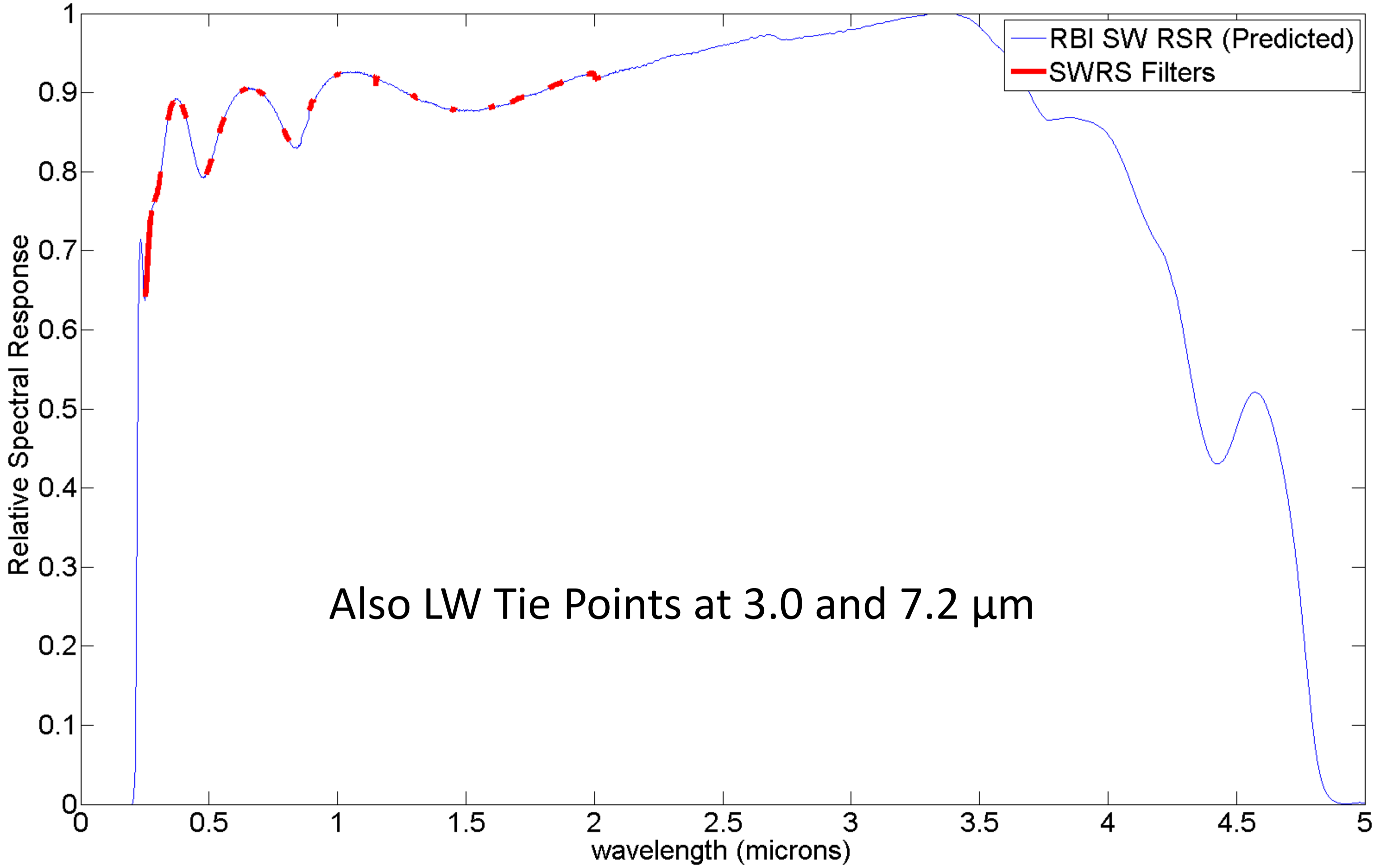
Modeled RSR Provided to SDL by Harris



Space Dynamics Laboratory
Utah State University Research Foundation

ACR Transfer Measurements using Band-Pass Filters Provide Accurate RSR Tie Points

Nominal Center Wavelength (nm)	Nominal Bandwidth (nm)
265	25
300	25
350	20
400	20
500	20
550	20
633	20
700	20
800	20
900	20
1000	20
1150	20
1300	20
1450	20
1600	20
1700	50
1850	50
2000	50



NIST traceable, highly accurate, measured in test-as-flown conditions and includes uncertainty, but lacks spectral resolution and spectral range coverage

Space Dynamics LABORATORY
Utah State University Research Foundation

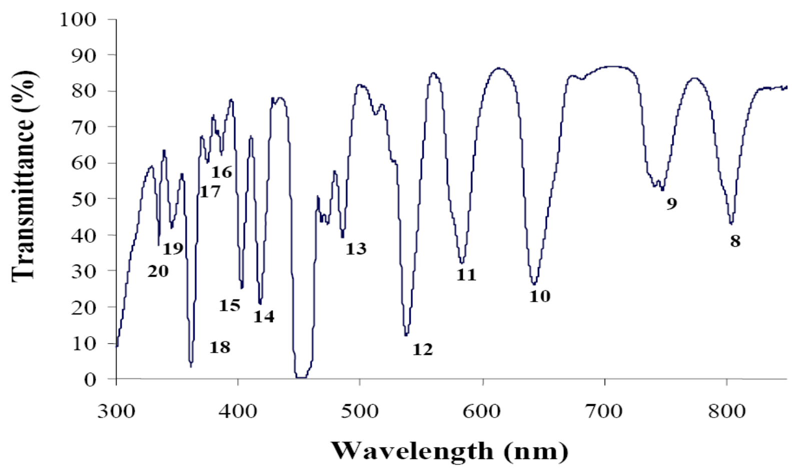
RBI RSR Calibration is NIST Traceable

RSR Standard ⟶ ACR Cavity Absorptance

ACR Trap-Cavity Detector Specifications		
Parameter	Requirement	Range
Cavity Absorptance	>0.9998 (at 632.8 nm)	0.3 - 35 µm
Cavity Spectral Absorptance (Primary)	>0.9995	35 - 100 µm
Cavity Spectral Absorptance (Extended)	>0.995	100 - 300 µm

- Spectral Position Standards
  - FTS HeNe sample laser
  - Absorption features in NIST spectral reference materials

NIST Spectral Reference Material 2065



Space Dynamics LABORATORY
Utah State University Research Foundation

SDL/16-1057

RBI RSR Calibration Requires Seven FTS Measurement Configuration Combinations

FTS Test Configuration →		1	2	3	4	5	6	7
Wavelength Coverage [µm] →		0.35 - 0.63	0.63 - 1.0	0.63 - 2.1	2.0 - 22.2	20.0 - 28.6	26.7 - 55.6	50.0 - 110
RBI Band	SW	In-band	In-band	In-band	In/OOB	OOB	OOB	OOB
	LW	OOB	OOB	OOB	OOB/In	In-band	In-band	In-band
	Total	In-band	In-band	In-band	In-band	In-band	In-band	In-band
FTS Hardware Configuration	FTS ID	6000	6000	6000	680	680	680	680
	Config	Al lightpipe	Al lightpipe	Al lightpipe	Internal	Internal	Internal	Internal
	Source	Xe	Xe	QTH lamp	MWIR	MWIR	MWIR	MWIR
	Ap	Open	Open	Open	Open	Open	Open	Open
	B/S	UV-Quartz	NIR-Quartz	NIR-Quartz	KBr	Mylar-6	Mylar-6	Mylar-12
	Filter	HeNe-Blue	HeNe-Red	HeNe-Red	None	None	None	None
FTS Software Controlled Parameter and Settings	Source	off	off	off	MWIR	MWIR	MWIR	MWIR
	Ap	Open	Open	Open	Open	Open	Open	Open
	Res	32	32	32	32	16	16	16
	Scans	10	10	10	10	10	10	10
	UDR	1	1	1	2	4	4	4
	Scan Rate	4Hz	4Hz	4Hz	4Hz	4Hz	4Hz	4Hz
	Step Delay	50 msec	50 msec	50 msec	50 msec	50 msec	50 msec	50 msec
	Sym	Asym	Asym	Asym	Asym	Asym	Asym	Asym
Coupling Optics	Path	SWRS	SWRS	SWRS	LWRS	LWDC	LWDC	LWDC
	Window	UV-Quartz	UV-Quartz	UV-Quartz	KBr	KBr	Silicon	Silicon

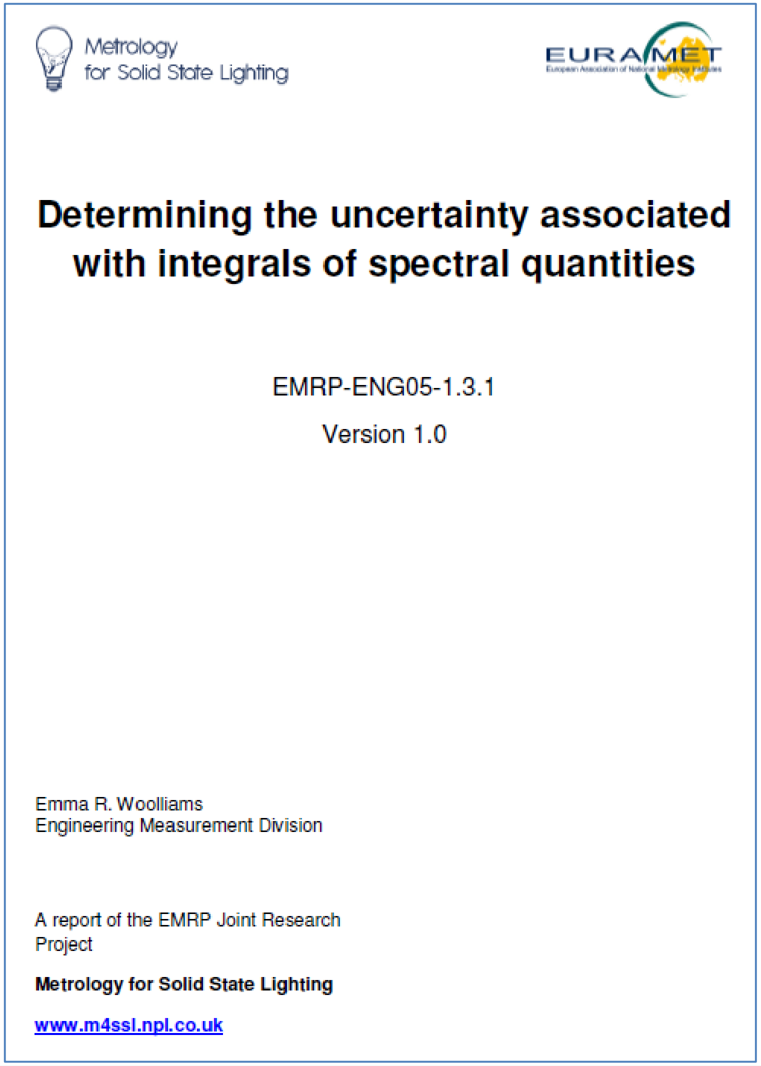
Seven FTS test configurations cover a spectral range of 0.35 to 110 µm

Space Dynamics LABORATORY
Utah State University Research Foundation

RSR Uncertainty Reference

RBI RSR Uncertainty Terms and Definitions

- RSR Random Uncertainty
  - Not spectrally (or otherwise) correlated
  - Combined spectrally using RSS
- RSR Systematic Uncertainty
  - Spectrally correlated uncertainty
  - Combined spectrally by integrating
- RSR Correlated Uncertainty
  - Highly correlated uncertainty terms appearing in both numerator and denominator of RSR derivation equation
  - Cancellation effects render these insignificant in the overall RSR uncertainty
- RSR Tie Points
  - RSR method #2 on previous slide
  - Discrete RSR values computed using ACR and RBI band-pass filter measurement ratios


Metrology for Solid State Lighting

EURAMET

Determining the uncertainty associated with integrals of spectral quantities

EMRP-ENG05-1.3.1

Version 1.0

Emma R. Woolliams
Engineering Measurement Division

A report of the EMRP Joint Research Project

Metrology for Solid State Lighting

www.m4ssl.npl.co.uk

RBI RSR Uncertainty Budget → Modeled

Level-0 Modeled Uncertainty Term List

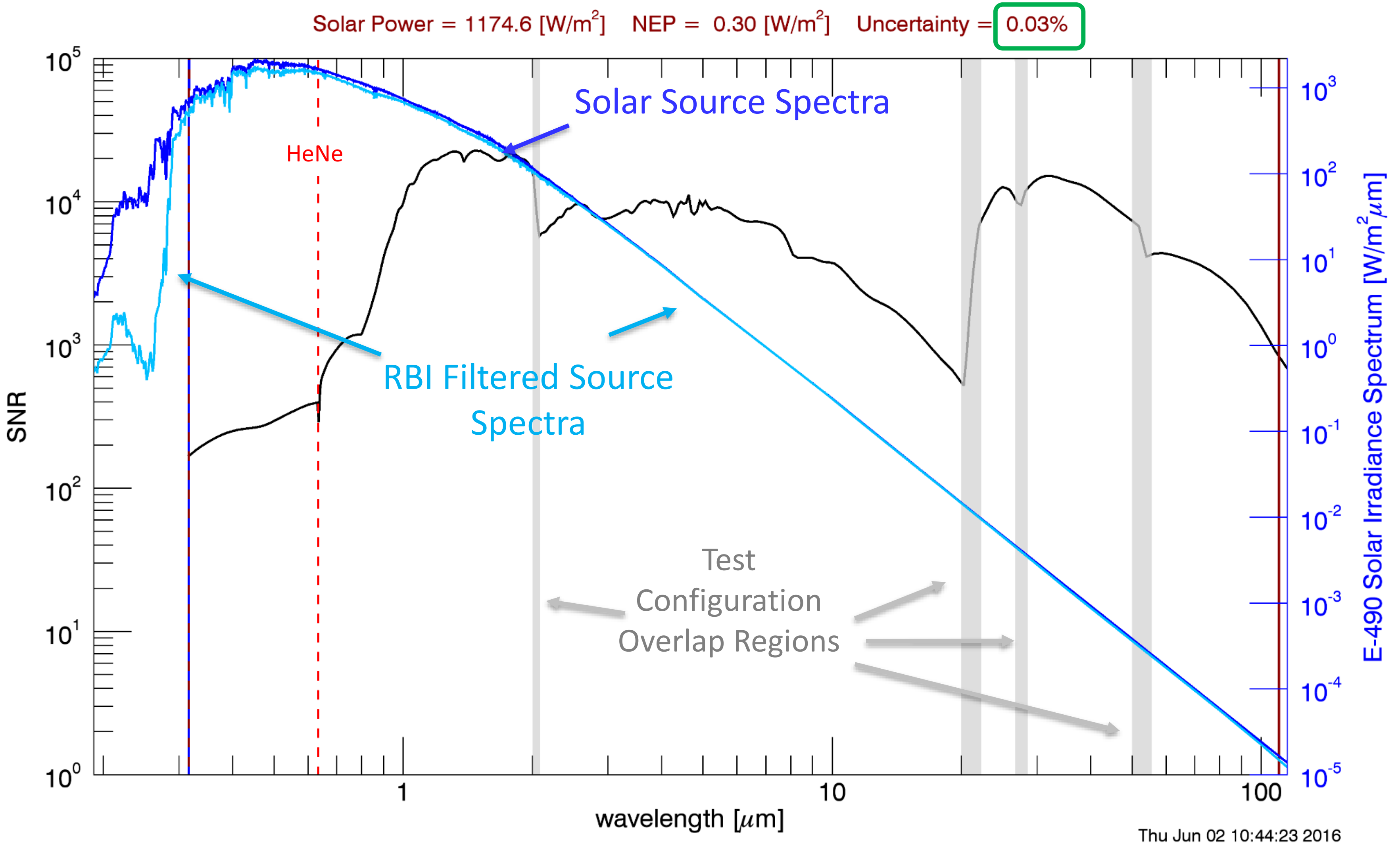
Uncertainty Basis	Level 0 Uncertainty ID	Level 0 Uncertainty Type	Independent Variables			Reflected Solar		300K Blackbody	
			RBI Band	FTS Config	ν (wn)	Total	SW	Total	LW
ACR RSR	u_{ACR_RSR}	Random*			x	-	-	-	-
	$u_{APC\_A\Omega}$	Systematic‡		x		-	-	-	-
	u_{ACR_freq}	Systematic‡		x	x	-	-	-	-
	u_{APC_diff}	Systematic‡			x	-	-	-	-
T_{RBI}	σ_{RBI}	Random*	x	x	x	0.03%	0.02%	0.00%	0.00%
	u_{RBI_Lin}	Systematic‡	x	x	x	0.02%	0.02%	0.06%	0.00%
	σ_{SRD}	Random*		x	x	0.05%	0.05%	0.00%	0.00%
	u_{SRD_Lin}	Correlated†		x	x	-	-	-	-
	u_{RBI_Scan}	Sys‡/Ran*		x	x	0.07%	0.07%	0.06%	0.06%
	u_{SRD_Scan}	Sys‡/Ran*		x	x	0.07%	0.07%	0.06%	0.06%
	u_{RBI_Proc}	Correlated†	x	x	x	-	-	-	-
	u_{SRD_Proc}	Correlated†		x	x	-	-	-	-
	u_{RBI_CO}	Systematic‡	x	x	x	-	-	0.10%	0.10%
	u_{SRD_CO}	Correlated†		x	x	-	-	-	-
$T_{APC} \longrightarrow T_{RBI}$	u_{SRD_T}	Systematic†		x	x	-	-	-	-
T_{APC}	σ_{APC}	Random*		x	x	0.18%	0.18%	0.02%	0.02%
	u_{APC_Lin}	Systematic‡		x	x	-	-	-	-
	σ_{SRD}	Random*		x	x	0.05%	0.05%	0.00%	0.00%
	u_{SRD_Lin}	Correlated†		x	x	-	-	-	-
	u_{APC_Scan}	Sys‡/Ran*		x	x	0.07%	0.07%	0.06%	0.06%
	u_{SRD_Scan}	Sys‡/Ran*		x	x	0.07%	0.07%	0.06%	0.06%
	u_{APC_Proc}	Correlated†		x	x	-	-	-	-
	u_{SRD_Proc}	Correlated†		x	x	-	-	-	-
	u_{APC_CO}	Systematic‡		x	x	-	-	0.10%	0.10%
	u_{SRD_CO}	Correlated†		x	x	-	-	-	-
K_{Norm}	u_K	Systematic‡	x	x		-	-	-	-
Tie Points	u_{TP_Val}	Random*	x		x	0.04%	0.04%	0.12%	0.12%
	u_{TP_Proc}	Random*	x		x	0.05%	0.04%	0.01%	0.02%
Combined Uncertainty						**0.24%**	**0.24%**	**0.23%**	**0.22%**

- An exhaustive list of potentially significant uncertainty terms have been identified and modeled
- The modeled uncertainty values are current best estimates (CBEs)
- Values are subject to change as updates and refinements are made
  - RSR uncertainty model
  - RSR measurement plan
  - Test configuration component performance requirements, predictions, assumptions and/or modeling
  - Data collection, handling and processing plans

Space Dynamics LABORATORY
Utah State University Research Foundation

SDL/16-1057

RSR Level-0 Uncertainty Modeling Predictions Random Example ⟶ RBI SNR Component



All Test Configurations Merged

Space Dynamics LABORATORY
Utah State University Research Foundation

SDL/16-1057

RBI RSR Uncertainty Budget → As-Run

- During RSR data collection, uncertainty budget level-0 values will be updated with as-run measurement values to assure the overall RSR uncertainty requirements are achieved
  - Update RSR level-0 model predictions based on new information
  - Adjust data collections as needed to ensure that level-0 uncertainties are within an acceptable range*
    - Example – if the SNR for TC3 ACR measurements are lower than predicted, collect more scans to increase the SNR by coadding scans
  - As-run data collection and adjustment periods include
    - Chamber cold test
    - EDU testing
    - Flight-sensor calibration

*An acceptable range is defined as when RSS'ed with other uncertainty terms, the overall results are within the overall RSR uncertainty budget allocation

RBI RSR Uncertainty Budget → Final

- Replace modeled level-0 RSR random uncertainty values with final RSR measurement values
  - All random uncertainties (σ-values in uncertainty budget table)
  - FTS repeatability – random component
  - Tie Point uncertainty
- Force RSR values through RSR Tie Points to reduce accumulative effects in systematic RSR uncertainties
  - ACR and RBI linearity
  - FTS repeatability – systematic component
  - Coupling optics repeatability
- Create a level-0 uncertainty contribution component for each level-0 uncertainty spectra by performing a product integral with the Harris-specified scene spectra (solar spectrum or 300 K BB)
- Combine all level-0 uncertainty components using RSS

Summary and Conclusions

- SDL has created an RSR plan that will meet the RBI system requirements
- RSR modeling is sufficiently mature to show that SDL will meet the RSR spectral coverage and low uncertainty requirements
- RSR uncertainty modeling will be maintained and updated going forward
  - As-run uncertainty values will be used during testing to update data collections as needed to ensure requirements are met
  - Final RSR uncertainty results will be created by replacing level-0 modeled uncertainty values with final uncertainty values derived from the as-run measurements