# Towards Evaluating the Performance of the J-2/CrIS Instrument During Thermal Vacuum Testing

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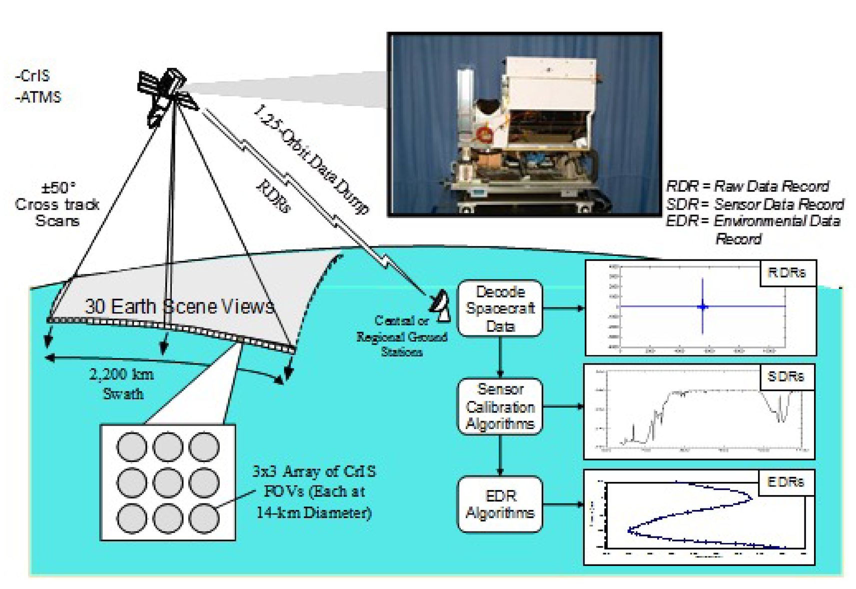
## Abstract

The Joint Polar Satellite System-2 (JPSS-2) is currently set to launch in 2022 and will join the weather satellites NOAA-20 and Suomi-NPP in their orbit. The instruments which are set to be onboard the JPSS-2 satellite are currently undergoing preparatory calibration activities before their installation. Among these instruments includes the third iteration of the Cross-track Infrared Sounder (CrIS), which is currently undergoing Thermal Vacuum Testing (TVAC). During these tests, the CrIS Sensor Data Record (SDR) team aims to independently evaluate the performance of the new CrIS instrument. This will be achieved by assessing the NEdN noise during vibration tests, processing the slit scan data to calculate the Field-of-View (FOV) crosstalk, processing the gas cell to verify the ILS parameters and to verify the spectral uncertainty of the CrIS sensor, and to measure the external calibration target (ECT) radiance during the incrementing of the ECT temperature to validate the radiometric calibration of CrIS. Additionally, the non-linearity $a_2$ parameters that will later be used during normal mission operations will also be derived from this ECT radiance data set. These tests should ensure that the CrIS sensor is capable of carrying out its mission up to specifications once it is in operation. In this presentation, an outline of these tests, and an overview of the instrument is provided.

## CrIS Sensor Overview




From Zavyalov et. al. 2011

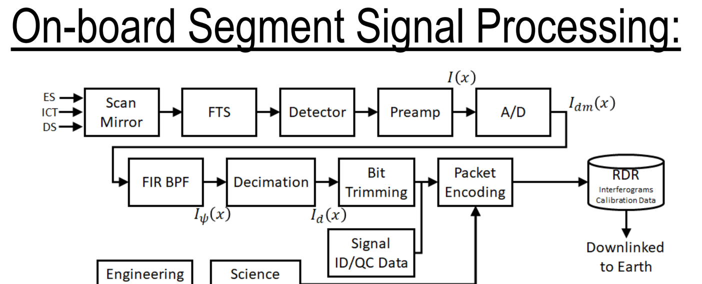
### Overview

The Cross-Track Infrared Sounder (CrIS) instrument is an infrared hyperspectral Fourier-transform spectrometer that provides atmospheric temperature, moisture, and trace gas measurements for climate and weather applications. It utilizes a Michelson interferometer imaging the earth scene to produce, through on-board segment signal processing, a Raw Data Record (RDR) which contains raw interferograms. Through ground segment signal processing, these interferograms are converted Sensor Data Record (SDR) products, which are converted into raw infrared spectra. This is then further processed to develop Environmental Data Record (EDR) products.

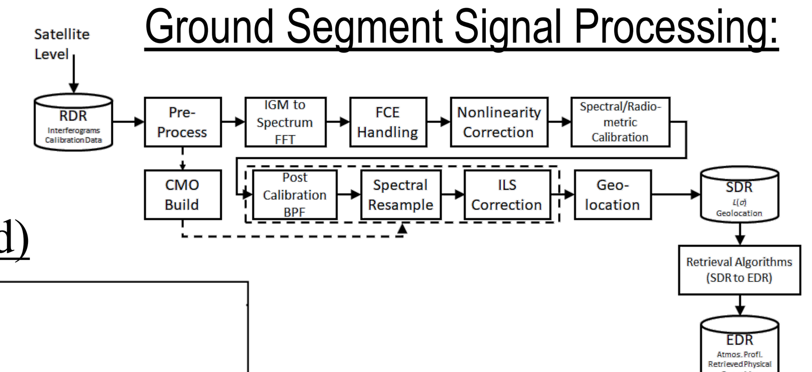
### Specifications

| Characteristic | CrIS |
|---|---|
| Instrument Type | Cross-Track Scanner |
| Interferometer Principle | Fourier Transform Spectrometer based on the Michelson Interferometer Configuration |
| Spectral Range | LWIR: 650-1095 $cm^{-1}$ or 9.13-15.40 μm<br>MWIR: 1210-1750 $cm^{-1}$ or 5.71-8.26 μm<br>SWIR: 2155-2550 $cm^{-1}$ or 3.92-4.64 μm |
| Swath | 96.6° |
| Instrument Field Of View | 3x3 pixels in a box of 48 $km^2$ x 48 $km^2$<br>Each 14 km diameter |
| Cycle Scan | 30 steps of 48 km Field of Regard (FOR) at nadir + 2 deep space + 2 internal calibration target ≈ 8 s |
| Spectral sampling | Laser metrology system |
| Radiometric Calibration | 2 ICT and 2 DS scenes |
| Spectral Calibration | Neon-calibration system |
| Detector Package | 3 Bands<br>PV HgCdTe |
| Cryocooling | Four-stage passive cooling from 205 K down to 81 K |
| On board metrologies | Metrology laser system |
| Data transmitted | Un-calibrated interferograms |

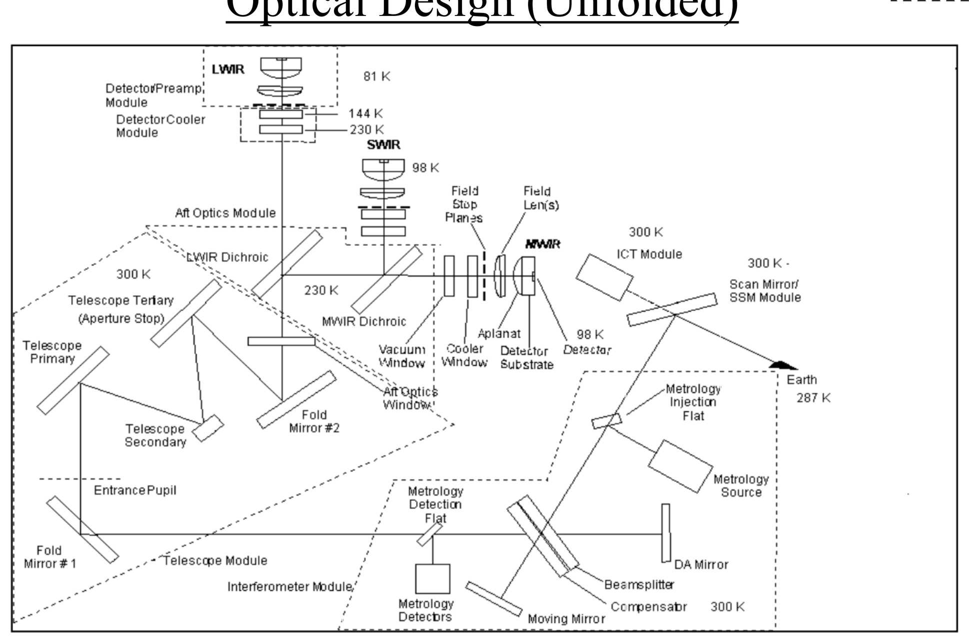
### On-board Segment Signal Processing:




### Ground Segment Signal Processing:




### Optical Design (Unfolded)



From Stumpf et. al. 2001

### Impact

The TVAC activities have a direct impact on the ground segment signal processing used to produce the raw spectra, As this procedure contains the nonlinearity correction and Instrument line shape correction, as well as spectral and radiometric calibration .

## Nonlinearity and ECT Stepped Temperature Test

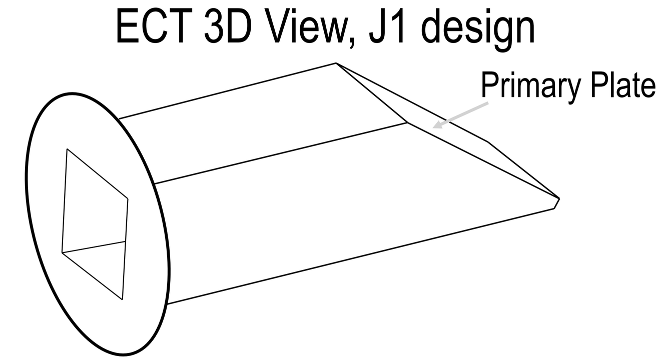
Along with ICT uncertainty, ICT temperature knowledge, and FOV-to-FOV crosstalk, nonlinearity is a dominant source of radiometric uncertainty during the CrIS instrument's mission operations. Nonlinearity is also large enough to require correction in the ground segment processing of the RDR-to-SDR data (for the MWIR and LWIR bands). The interferogram signal that has a nonlinear contribution manifests in equation form:

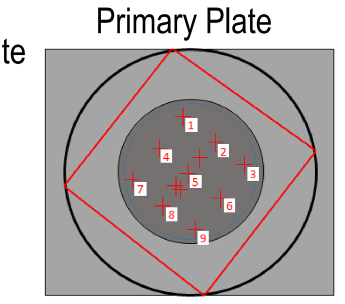
$$Interferogram_{ideal} + V_{ideal} = (Interferogram_m + V) + a_2(Interferogram_m + V)^2$$

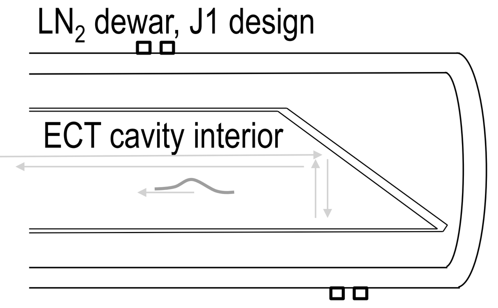
$Interferogram_{ideal}$: Ideal Interferogram (no nonlinearity)
$Interferogram_m$: measured Interferogram
$V$: DC voltage at the detector/preamp output which is produced from detector photo & dark currents
$a_2$: nonlinearity coefficient

In the spectral domain, solving for $a_2$ this looks like:

$$a_2 = \frac{a_2'}{(1 - 2Va_2')}; \quad a_2' = -\frac{Spectrum_m}{(Spectrum_m \otimes Spectrum_m)}$$



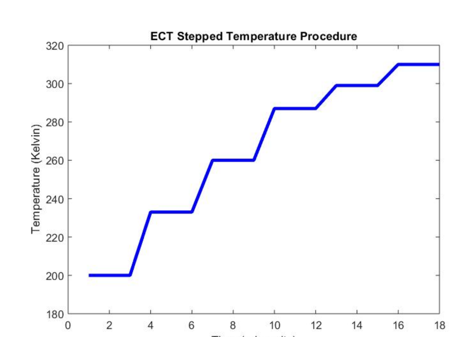



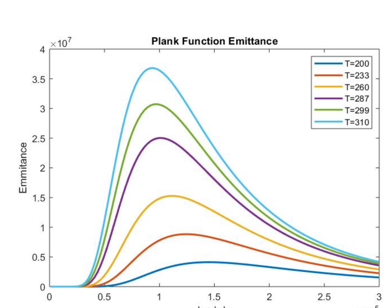




An ECT test is utilized to perform a radiometric uncertainty test as well as a test of detector nonlinearity.

The ECT test involves placing the CrIS instrument in a large chamber with an External Calibration Target (ECT). The ECT is a radiation source that is thermally controlled, with a primary plate used as a scene which the CrIS instrument images. It is slanted in such a way as to minimize external scattered light from appearing to be sourced from the primary plate. The primary plate has a heating element on the back of the plate which controls the temperature of the infrared source to be measured. Nine Platinum Resistance Thermometers (PRTs) are placed at the center of the FOV footprints which the CrIS instrument views. NIST-traceable sensors and additional PRTs are placed on the plate to monitor the plate's temperature.

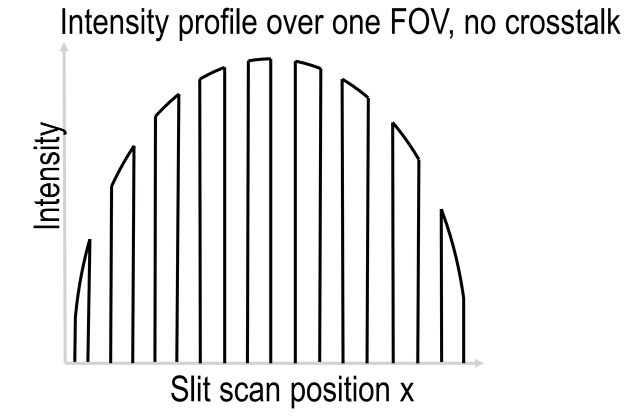
For six different ECT scene temperatures ranging from 200 K to 310 K, the output radiance of the ECT measured by the CrIS sensor will be compared to calculated output ECT radiances. At this point, the linearity of the measured radiance as a function of scene temperature can be characterized.

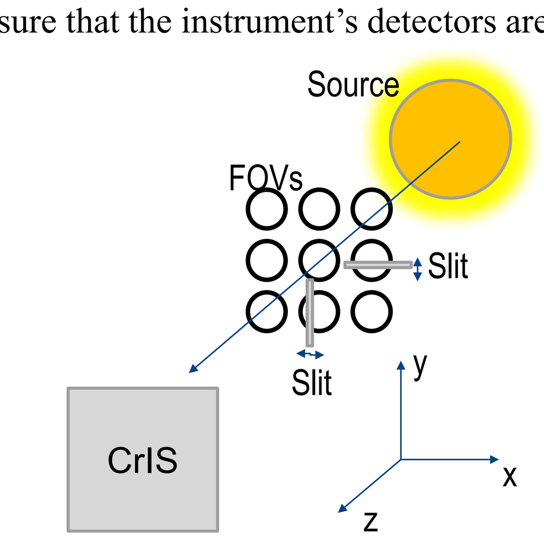



## Slit Scan Test (FOV Crosstalk)

The Slit Scan Test involves utilizing a blackbody source which illuminates a nearby slit, which is positioned at the location of the FOV footprint of the CrIS system. The slit's position is then translated as the intensity of the source is measured by the CrIS instrument using a step and stare method, producing a 2D map of the 9 FOV footprints. By scanning each FOV individually, the crosstalk, or overlap of the FOV, is measured to ensure that the instrument's detectors are well aligned with respect to their expected positions.

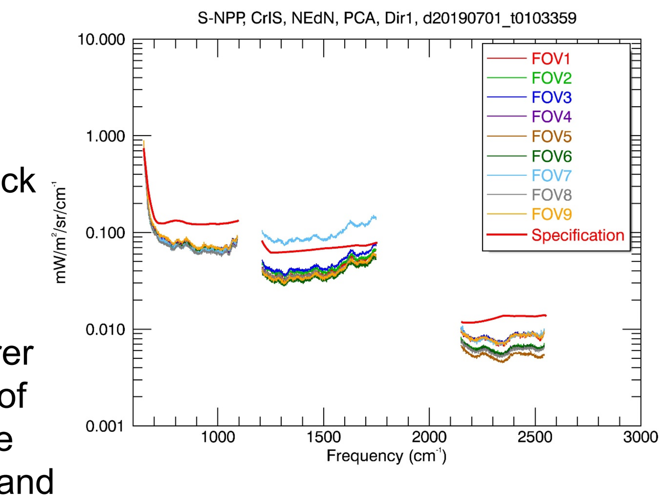



## NEdN Noise (Vibration Test)

The Noise performance requirements are defined at the aperture of the system by the noise-equivalent radiance difference (NEdN). The noise-equivalent temperature difference (NEdT) at a given wavenumber is defined by dividing the NEdN by the derivative w/ respect to the Planck function @ 250K[2].

Noise performance tests in the TVAC operations is a key metric that is evaluated. There are strict noise manufacturer specifications that are used as a reference for the quality of the noise (which has been met with past instruments). The noise will be measured and evaluated for all three bands and fields of views. Previous dominant sources of noise included detector diode material that changes parameters with warm-up/cool down cycles (such as MWIR FOV 7 for the case of SNPP-CrIS) and dominant random noise components other FOVs. Other sources of noise include scene shot, background shot, dark shot, Johnson noise, electronics, 1/f noise, A/D quantization, Metrology SNR and delay mismatch, delay quantization, delay slope, gain slope, and tilt[3]

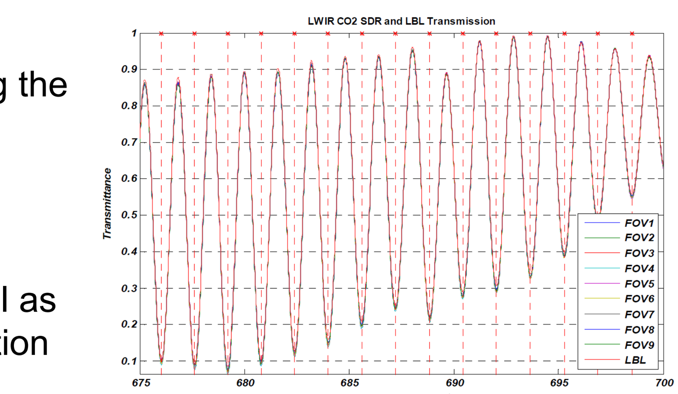



Typical NEdN noise characterization of the CrIS instrument. From S-NPP CrIS after the recent electronic side switch. Provided by D. Tremblay

## Gas Cell Test

A gas cell test will be used to verify the spectral uncertainty of the CrIS Instrument, as well as verifying the Instrument Line Shape (ILS) parameters.

The ILS is a mathematical function that describes the response of the spectrometer to a monochromatic spectral stimulus. It is wavenumber dependent as well as FOV (as the ILS depends on the relative off-axis position of the detector). Divergences in the infrared beam produce a complex ILS. Whereas the ideal response is the Sinc function, the ILS corresponds to the deviation from the Sinc function. The resolution of the instrument is defined as the FWHM of the ILS. For the unapodized spectra, this corresponds to FWHM= 1.2 /(2*MPD).[2]




From Zavyalov et al 2011. LWIR absorption lines with $CO_2$ gas cell for all 9 FOVs from previous SNPP TVAC test.

| Gas Content | Pressure in Cell[1] | Used For |
|---|---|---|
| $CO_2$ gas | 100 Torr | LWIR Band |
| $CH_4$ | 40 Torr | MWIR Band |
| HBr | 175 Torr | SWIR Band |

The Gas cell test involves sending infrared light from a blackbody source through the Gas cell and to the CrIS instrument. The CrIS instrument then measures the absorptions line. Because these absorption lines are well known by theory (line-by-line radiative transfer model), it serves as a useful reference for spectral uncertainty of the CrIS instrument

## Conclusion

TVAC activities are scheduled to conclude by February 2020. The CrIS SDR is prepared to provide for the first time independent scientific verification of these important tests, Including ECT tests of nonlinearity, NEdN noise tests, Gas Cell Tests, and Slit Scan tests. which have large impact on the radiometric and spectral performance of the CrIS instrument.

## References

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[2]CrIS SDR ATBD 2017
[3]Zavyalov et. al. "Noise performance of the CrIS instrument", J. Geophys Res. Atmospheres, V118,13 2013
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[5]Strow et al J. Geophys Res. Atmospheres, V118, 12, 2013
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