Expected Calibration Performance of the NPP Cross-track Infrared Sounder (CrIS)

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NASA Sounder Science Team Meeting
Aqua AIRS/ NPP CrIS
Beckman Institute, Caltech, Pasadena, CA
4-7 May 2009

Acknowledgements

Joe Predina, Ron Glumb, and others at ITT

Mark Esplin, Gail Bingham and others at SDL

Larrabee Strow at UMBC

Dan Mooney and Bill Blackwell at MIT

Bill Smith, Graeme Martin, and Ray Garcia at UW

Allen Larar at NASA LaRC

Farhang Sabet-Peyman and others at NGC

Karen St. Germain and others at the Integrated Program Office

This presentation includes independent analysis of CrIS Flight Model 1 thermal vacuum test data performed by the SSEC/UW-Madison under IPO support and summarizes our view of the expected radiometric performance and accuracy of the sensor

(More detail presented at Vancouver OSA, 27-30 April 2009 by Tobin et al., HMC1 and Taylor et al., FMA4)

Topics

1. **Introduction to CrIS**

2. **Flight Model Calibration Issues:**
   Identified early in 2008 and subsequently fixed
   - ***Unexpectedly low Internal Calibration Target (ICT) emissivity led to replacement with EDU ICT***
   - ***Correction developed for higher than expected non-linearity***

3. **Absolute Accuracy Expectations for CrIS:**
   Thermal Vacuum Test Results

   In-flight and testing uncertainty separately identified

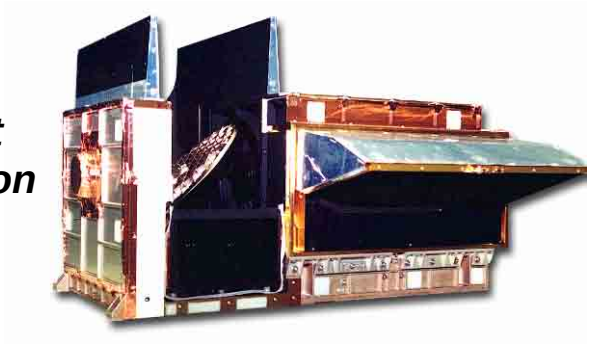
Preview: Uncertainty generally <0.2 K 3-sigma

1. Introduction to CrIS

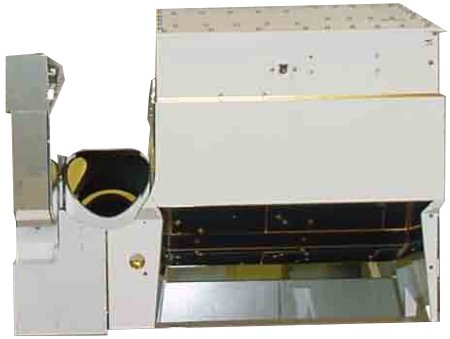
- The operational follow-on to AIRS PM Sounder
- IASI provides AM Soundings

Cross-track Infrared Sounder (CrIS) for NPP / NPOESS

Current Generation HIRS (20 ch)



Next Generation CrIS (1307 ch)

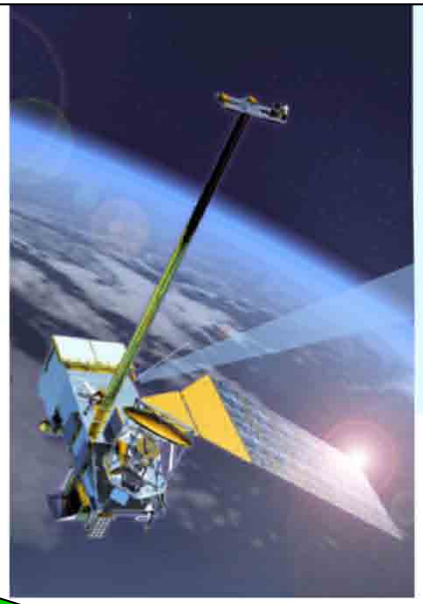


Volume: < 71 x 80 x 95 cm
Mass: < 152 kg
Power: < 124 W
Data Rate: <1.5 Mbps

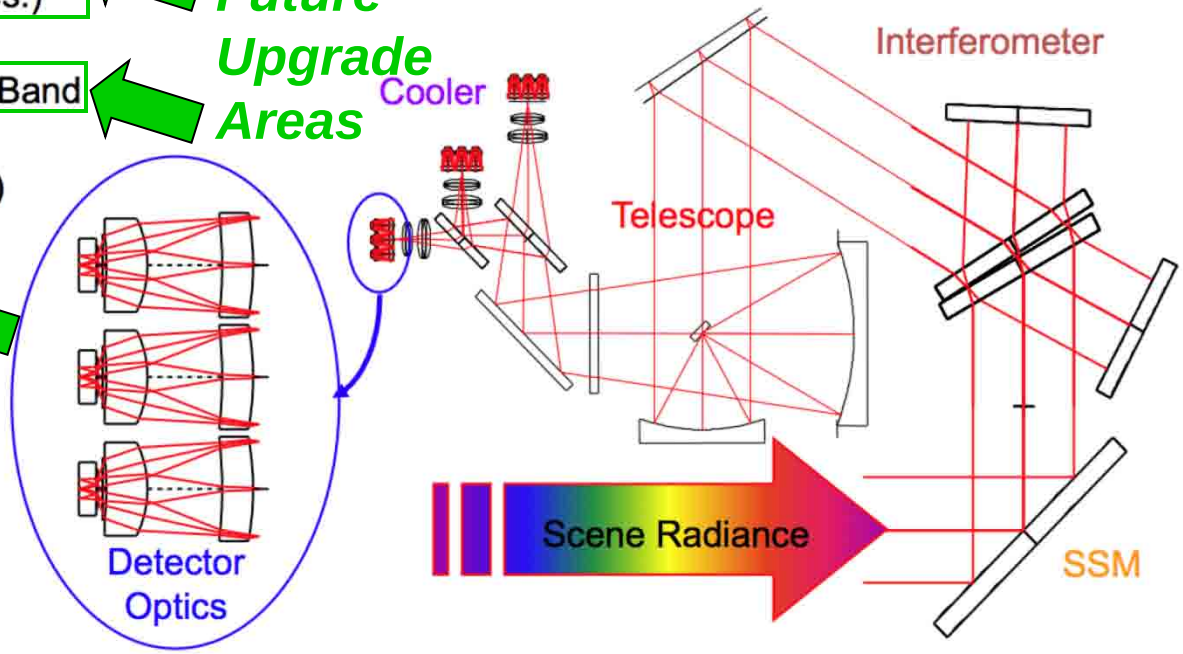
from Williams, Glumb and Predina, ITT, August 2005 SPIE

CrIS:

- Part of the Crosstrack Infrared and Microwave Sensor Suite (CrIMSS) on NPP and NPOESS to produce all-weather high vertical resolution vertical profiles of temperature, moisture, and pressure
- Plane-Mirror Interferometer With DAPS
- Large 8 cm Clear Aperture
- Three Spectral Bands
  - LWIR: 650-1095 cm^{-1} (0.625 cm^{-1} res.)
  - MWIR: 1210-1750 cm^{-1} (1.25 cm^{-1} res.)
  - SWIR: 2155-2550 cm^{-1} (2.5 cm^{-1} res.)
- 1305 Total Spectral Channels
- 3x3 FOVs at 14 km Diameter for each Band
- Photovoltaic Detectors in All 3 Bands
- 4-Stage Passive Detector Cooler (81K)
- Internal Laser Wavelength Calibration
- Deep-Cavity Internal Calibration Target
- Passive Vibration Isolation System Allows Robust Operation
- Modular Construction



Future Upgrade Areas



Partially unfolded CrIS optical system shows flow of signal radiance to detectors

Tobin et al., OSA FTS 2005

Flight Model 1 (FM1) Status

- **Primary Thermal Vacuum (TVAC) testing complete & in Pre-ship review process**
  - Vibration & EMI tests
  - FOV Shape / Co-registration
  - ILS / Spectral Accuracy
  - NEDN
  - Short Term Repeatability
  - Long Term Repeatability
  - Radiometric uncertainty and linearity testing
- **NIST post TVAC External Calibration Target validation being planned**
- **FM1 expected to ship to the spacecraft for integration testing later this year**
- **NPP launch in early 2011**

Calibration Accuracy Requirements

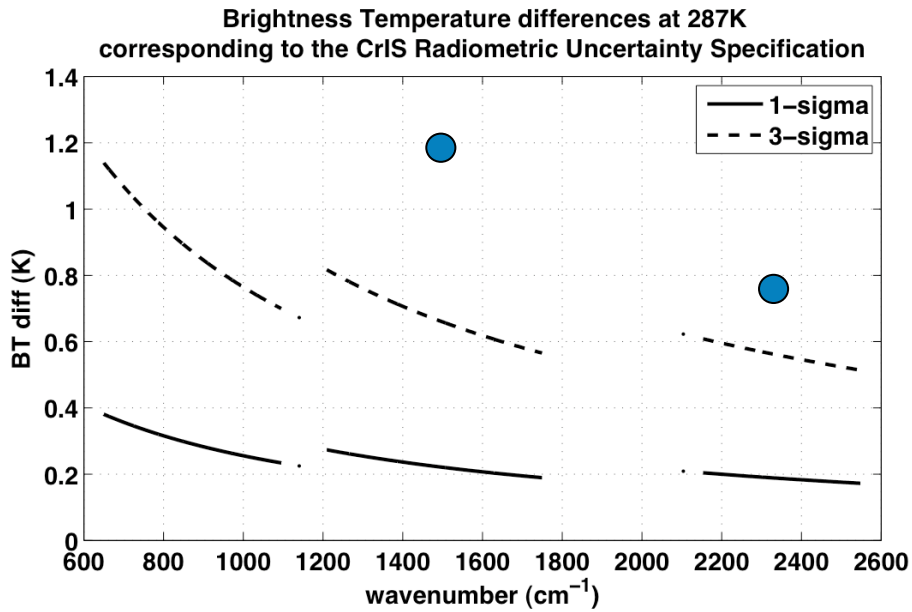
- **CrIS sensor Radiometric Specifications** are primarily driven by weather applications. Expressed as (1-sigma) percent radiance uncertainty with respect to Planck 287K radiance [i.e. 100•dR/B(287K)]:
  - Longwave: 0.45%
  - Midwave: 0.58%
  - Shortwave: 0.77%

  for B(233K) to B(287K)

- **Climate Applications** typically desire better accuracy

e.g. AIRS spec was 3% radiance, but cal/val has shown much lower uncertainty. Similarly for IASI.

AIRS Specification (3%)



Will show expected CrIS 3-sigma accuracy is less than the 1-sigma specification

Original Expectations

- **General Design:** Incorporates a high emissivity (>0.99), ambient temperature Internal Calibration Target (ICT), giving a high degree of insensitivity to the ICT emissivity ($e_{effective}$ very close to 1)
- **Linearity:** Photovoltaic detectors would be highly linear, requiring no correction
- **NIST:** Confirmation of ICT and External Calibration Target characteristics and radiance uncertainty budget prior to TVAC testing

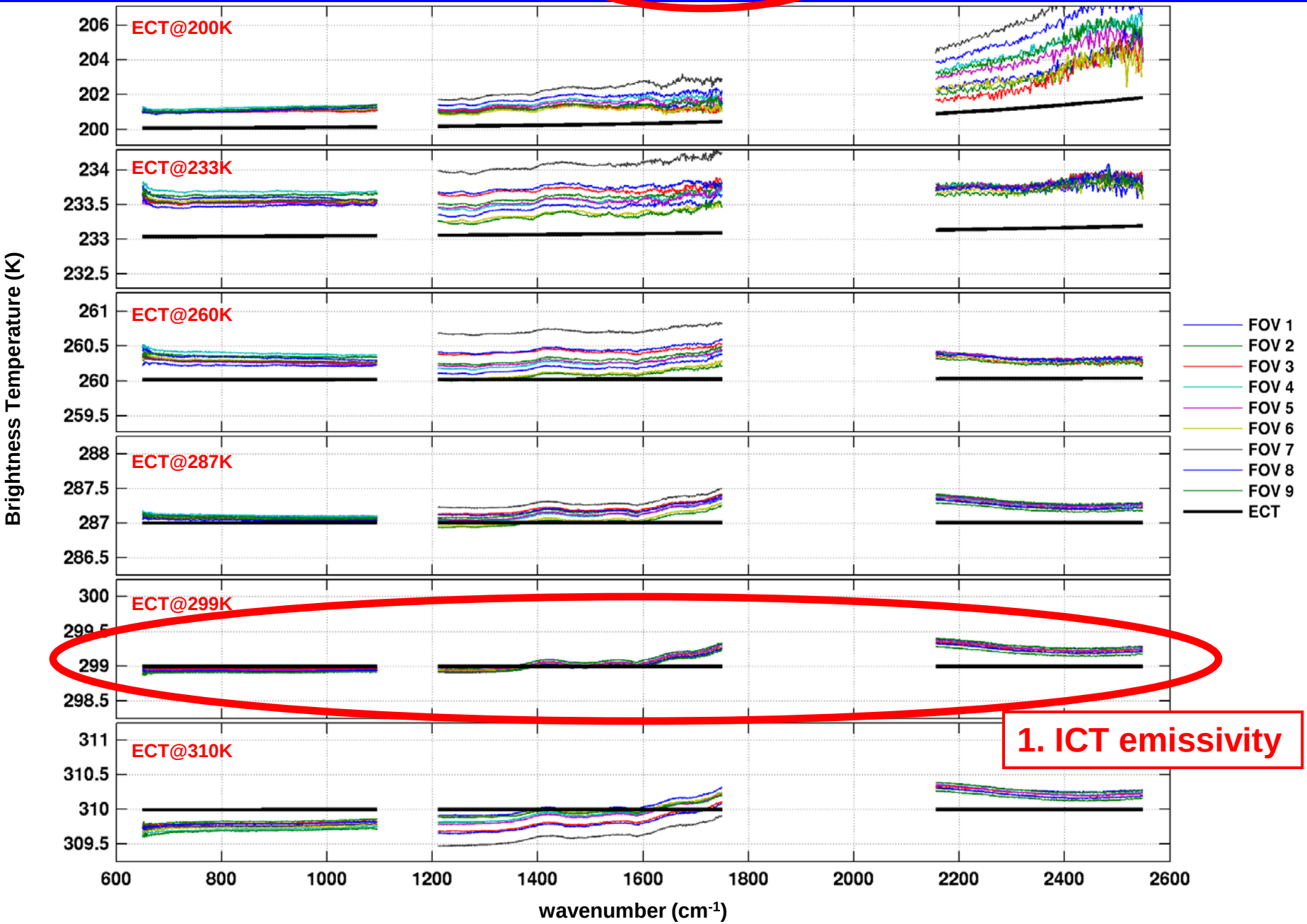
But, NIST Blackbody testing was not performed and early FM1 TVAC results (Jan-May 2008) showed major departures

2. Flight Model Calibration Issues:

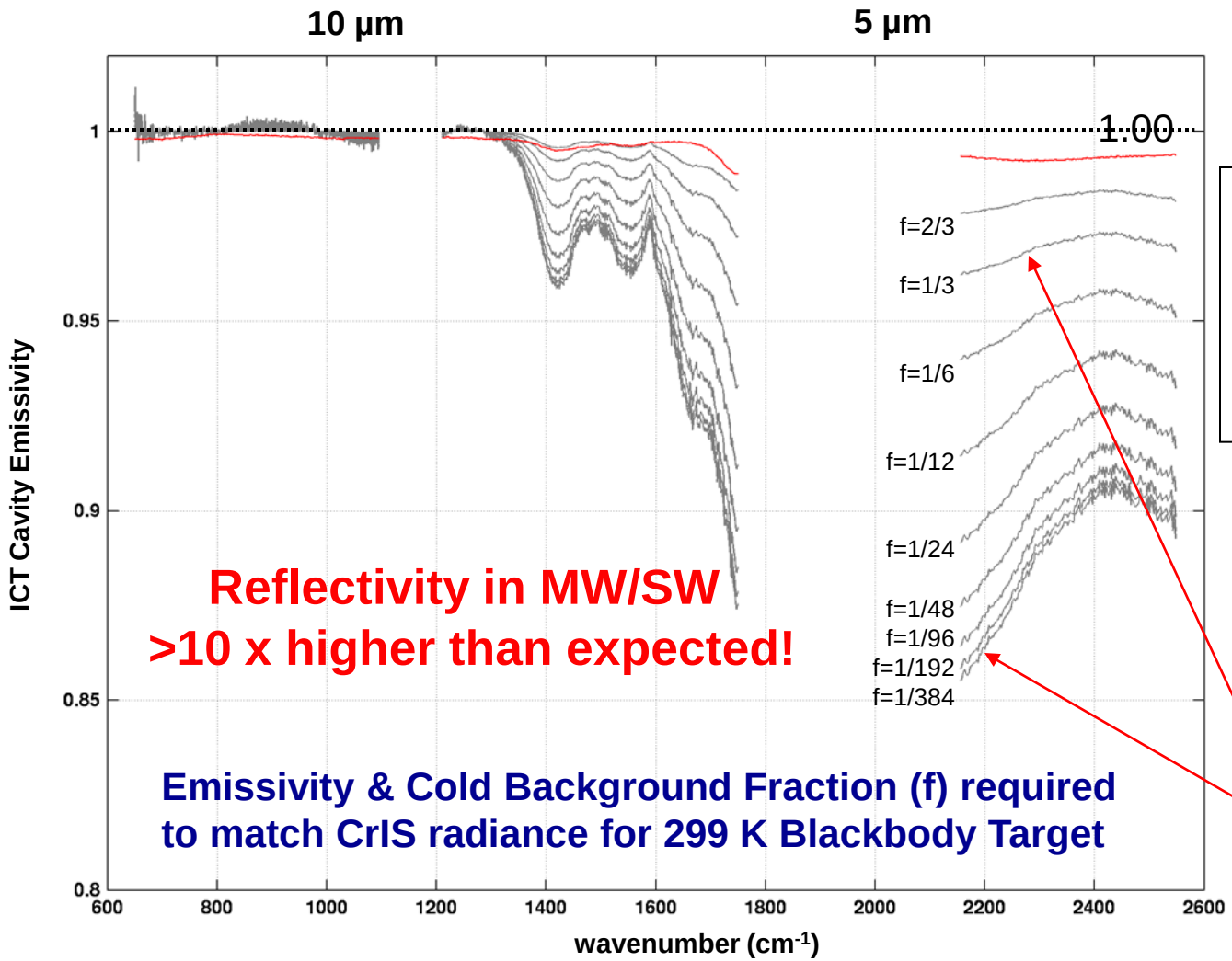
Identified early in 2008 and subsequently fixed

- **Unexpectedly low Internal Calibration Target (ICT) MW/SW emissivity led to replacement with EDU ICT**
- **Correction developed for higher than expected non-linearity**

TVAC MN results circa June 2008 (original ICT) using linear calibrations



Original FM1 ICT emissivity



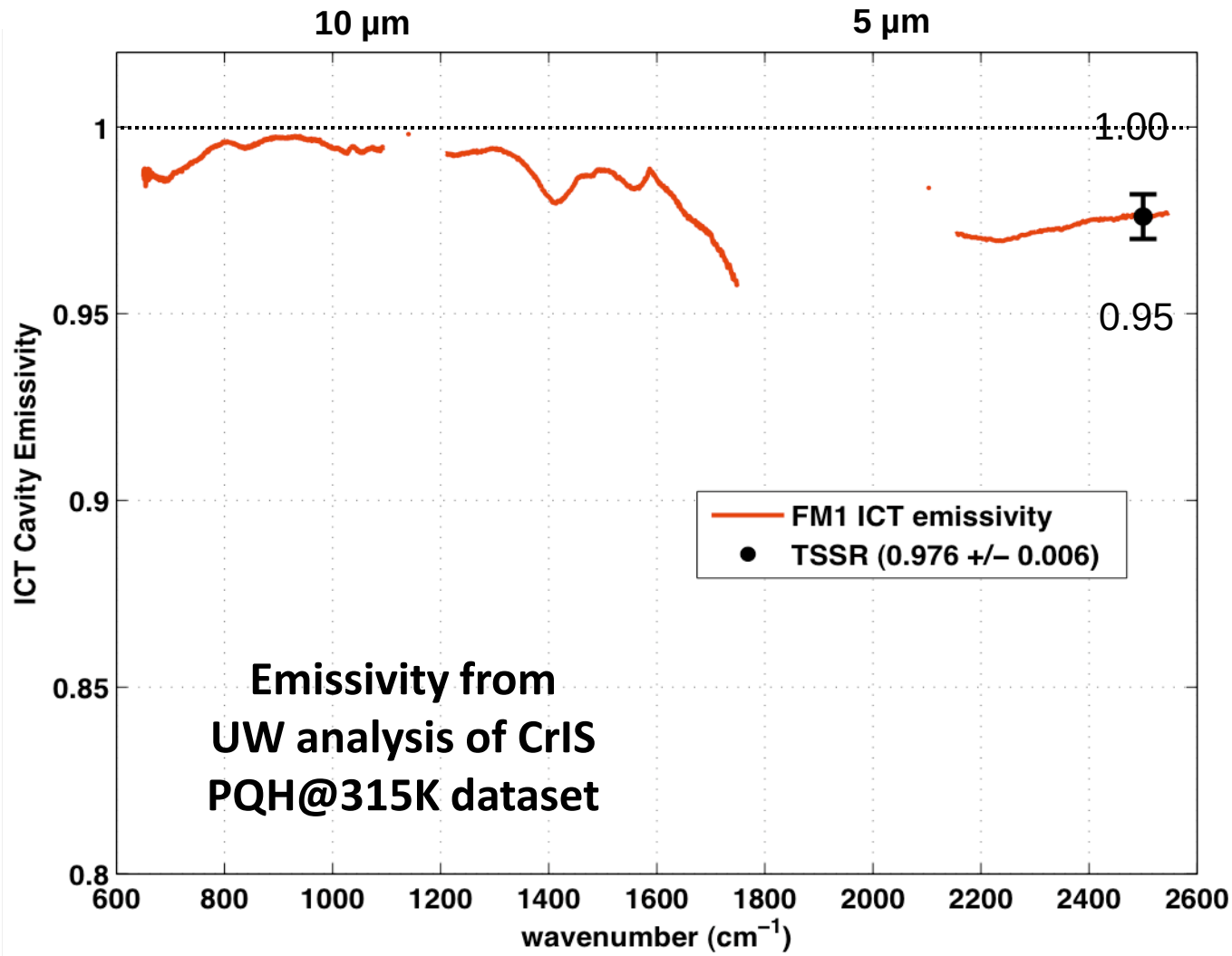
Expected ICT emissivity

Derived ε_{eff} assuming
$R_{ICT} = \varepsilon_{eff} B(T_{ICT}) + (1-f)(1-\varepsilon_{eff})B(295K) + f(1-\varepsilon_{eff})B(100K)$

Observed spectra explained by:
(a) implausibly large cold backround fraction, or
(b) very low cavity/surface emissivity

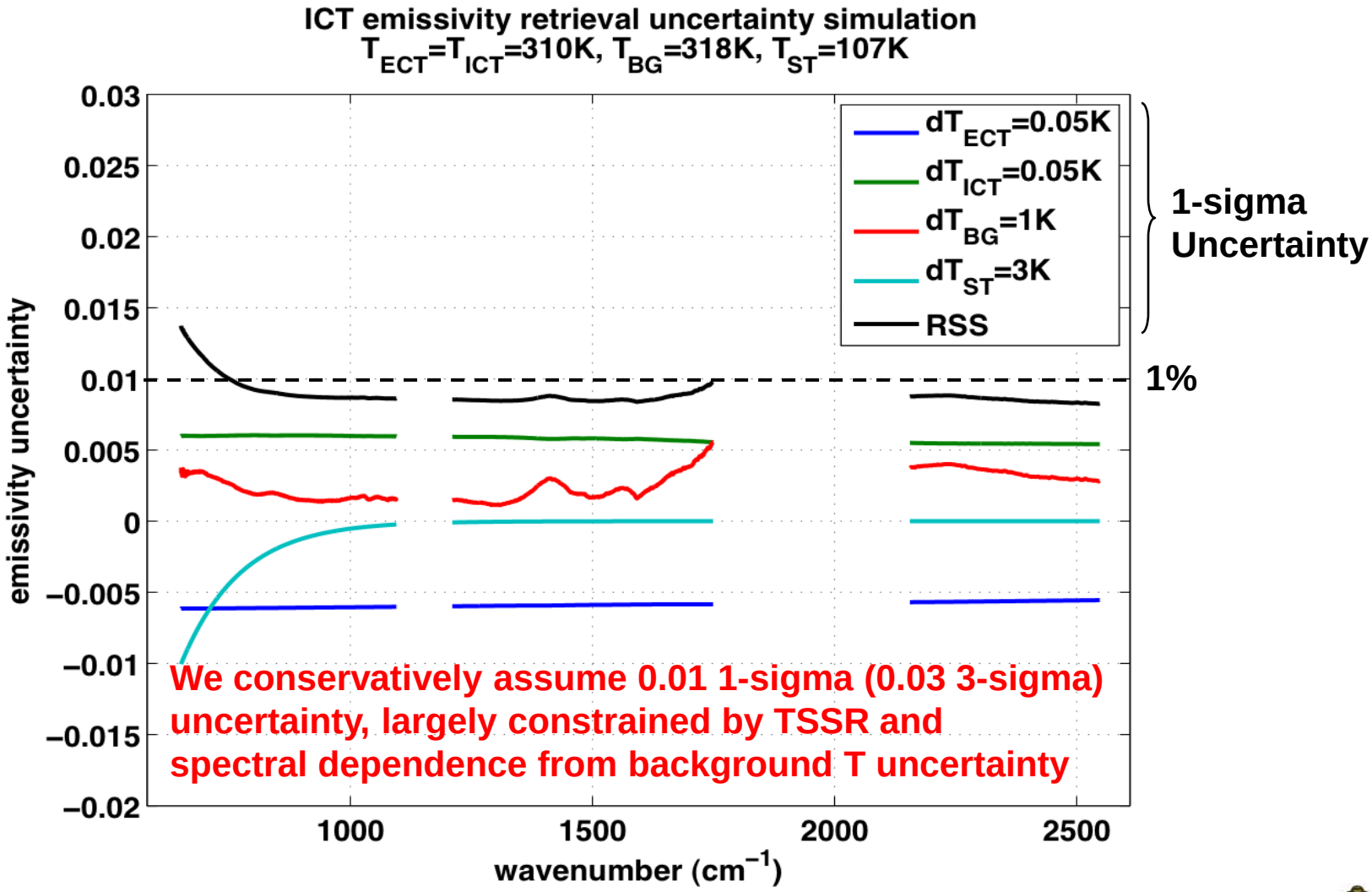
Proven answer

Current FM1 ICT emissivity



- Defective ICT replaced by EDU3 ICT
- ITT transfer radio-meter (TSSR) measured 4 µm emissivity
- Special TVAC test measured spectrum

Emissivity uncertainty dependencies



Reflected Component of Predicted ICT Radiance

View factors accurately determined by ITT, yielding the following simplified picture:

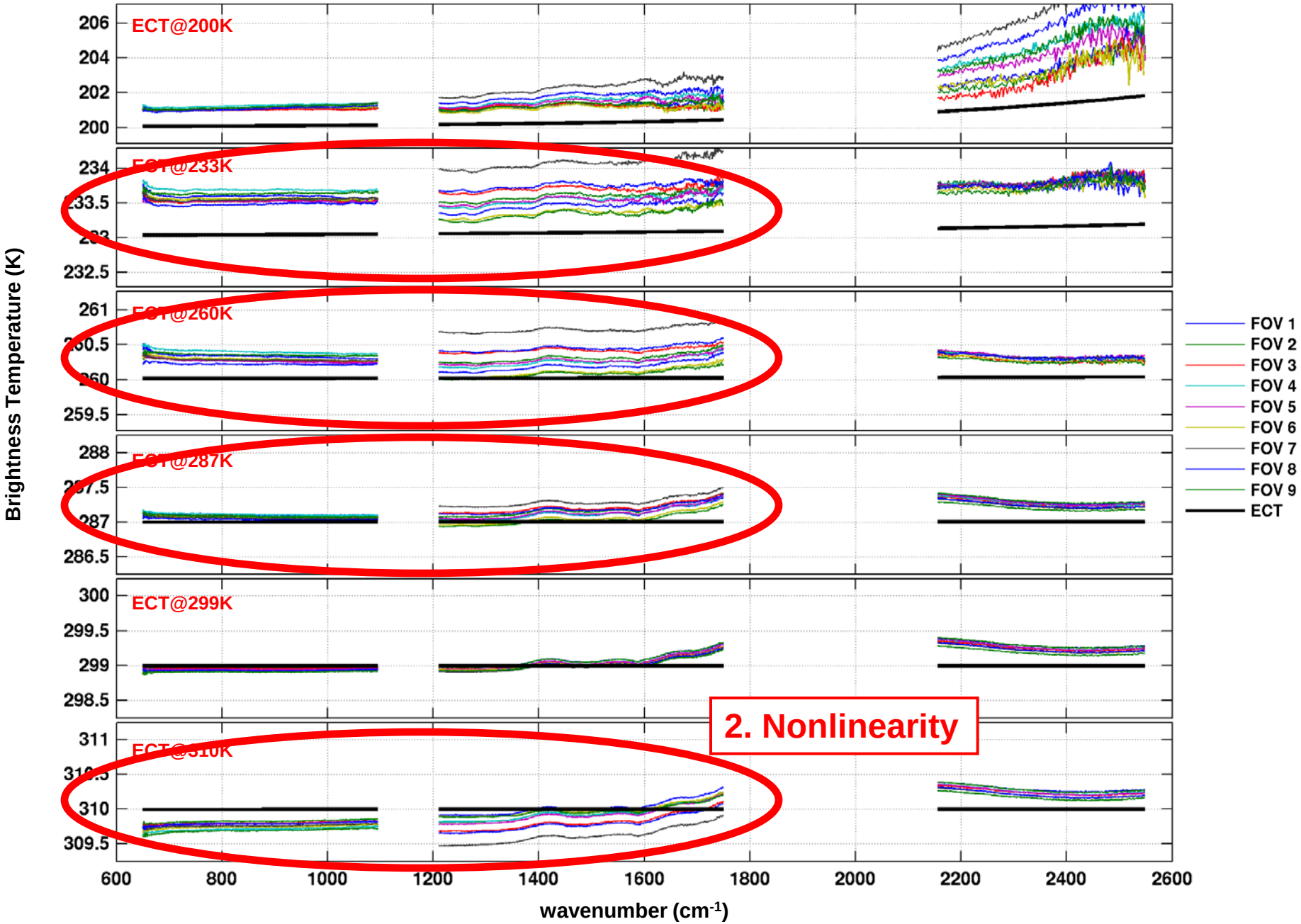
The predicted ICT Radiance, used in the calibration equation, is:

$$R_{ICT} = \varepsilon_{ICT}\, B(T_{ICT}) + (1-\varepsilon_{ICT})\, R_{ICT,Reflected}$$

where $(1-\varepsilon_{ICT})\, R_{ICT,Reflected}$ is the reflected term.
Contributions to $R_{ICT,Reflected}$ fall into three groups

1. Ambient temperature components with active temperature sensors, accounting for ~47.5% view factor.
2. Near ambient temperature components without representative temperature monitoring, accounting for ~50.8% view factor. Thermal modeling predicts orbital variation of ~5.5K peak-to-peak variation in these components.
3. Cold view components, accounting for ~1.8% view factor.

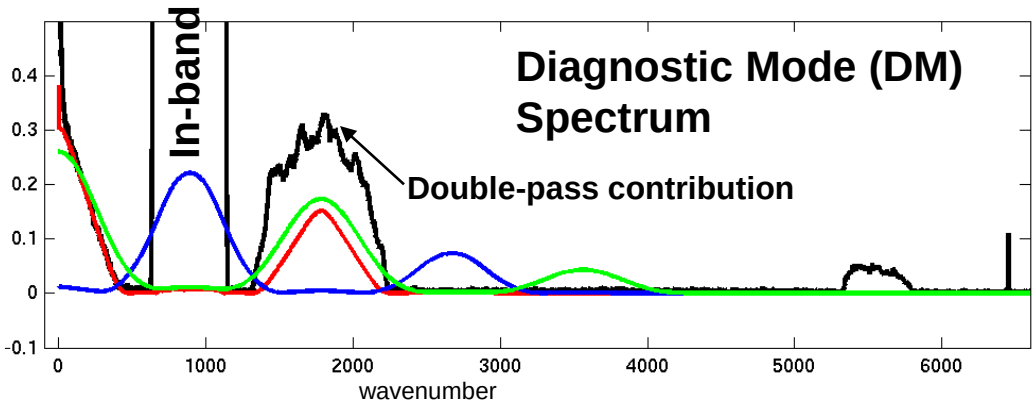
TVAC results circa June 2008 (original ICT) using linear calibrations



CrIS FM1 Non-linearity Summary

- The LW and MW ECT view residuals (calibrated minus predicted) using linear calibrations display spread among FOVs and mean residuals which are negative for $T_{ECT} > T_{ICT}$ and positive for $T_{ECT} < T_{ECT}$. Minimal spread and near zero mean residual for $T_{ECT} \sim = T_{ICT}$. SW linear.

- Out-of-band harmonic analyses utilizing Diagnostic Mode (DM) data collections show the nonlinearity to be purely quadratic for the LW and MW bands, and linear for the SW.



- UW Correction (developed for PC MCT detectors) applied to all CrIS LW & MW interferograms

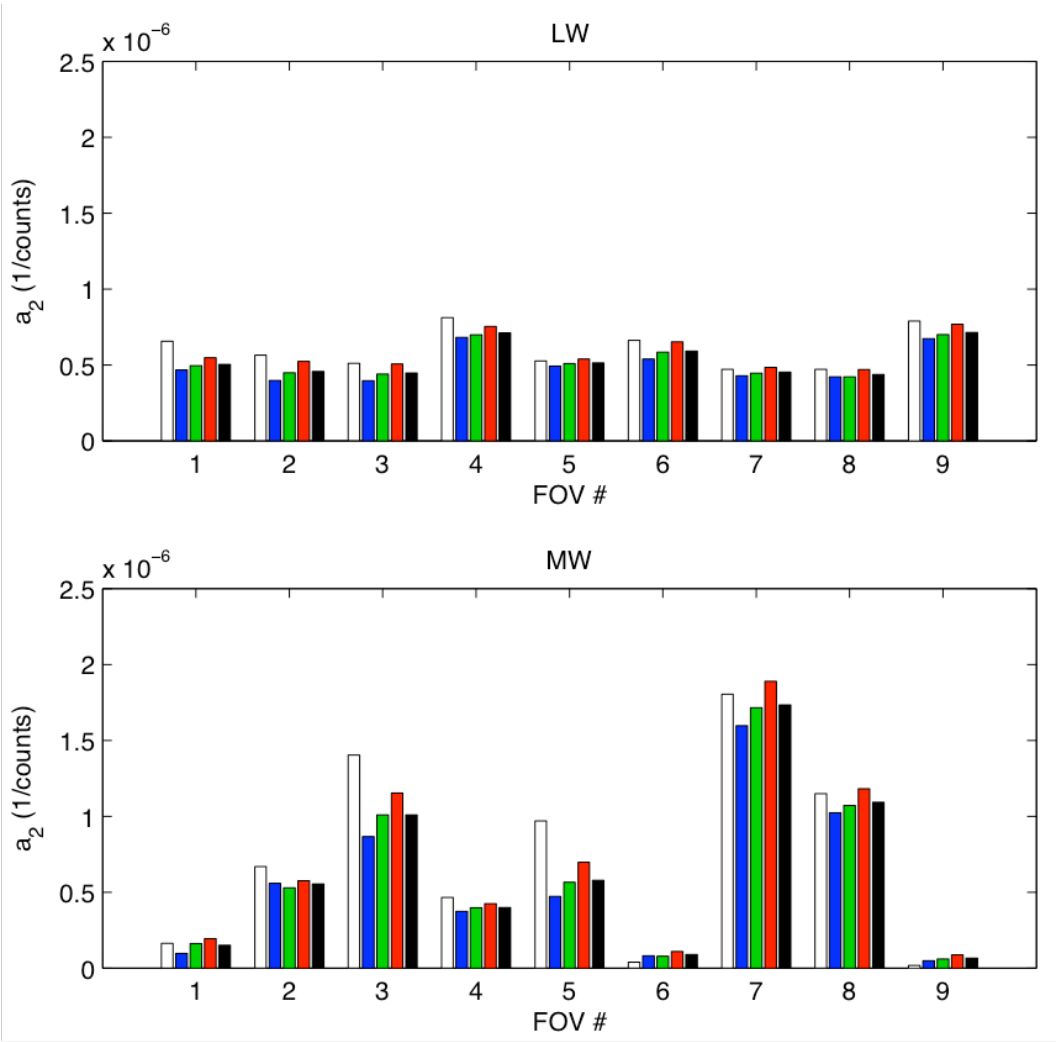
$$C_{LIN} = (1+2\, a_2 V_{DC})\, C_{MEAS}$$

where C_{MEAS} is the measured (nonlinear) complex spectrum, a_2 is the the quadratic nonlinearity coefficient, and V_{DC} is the DC level.

- V_{DC} is modeled based on measurements from CrIS
  a_2 is estimated for each LW and MW FOV using in-band ECT view data and out-of-band harmonic analysis.

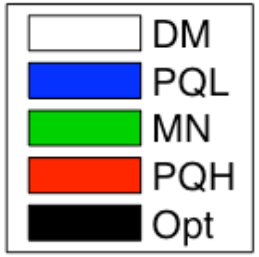
Non-linearity Parameters (a_2)

From DM data & TVAC (Low, Nominal, High)

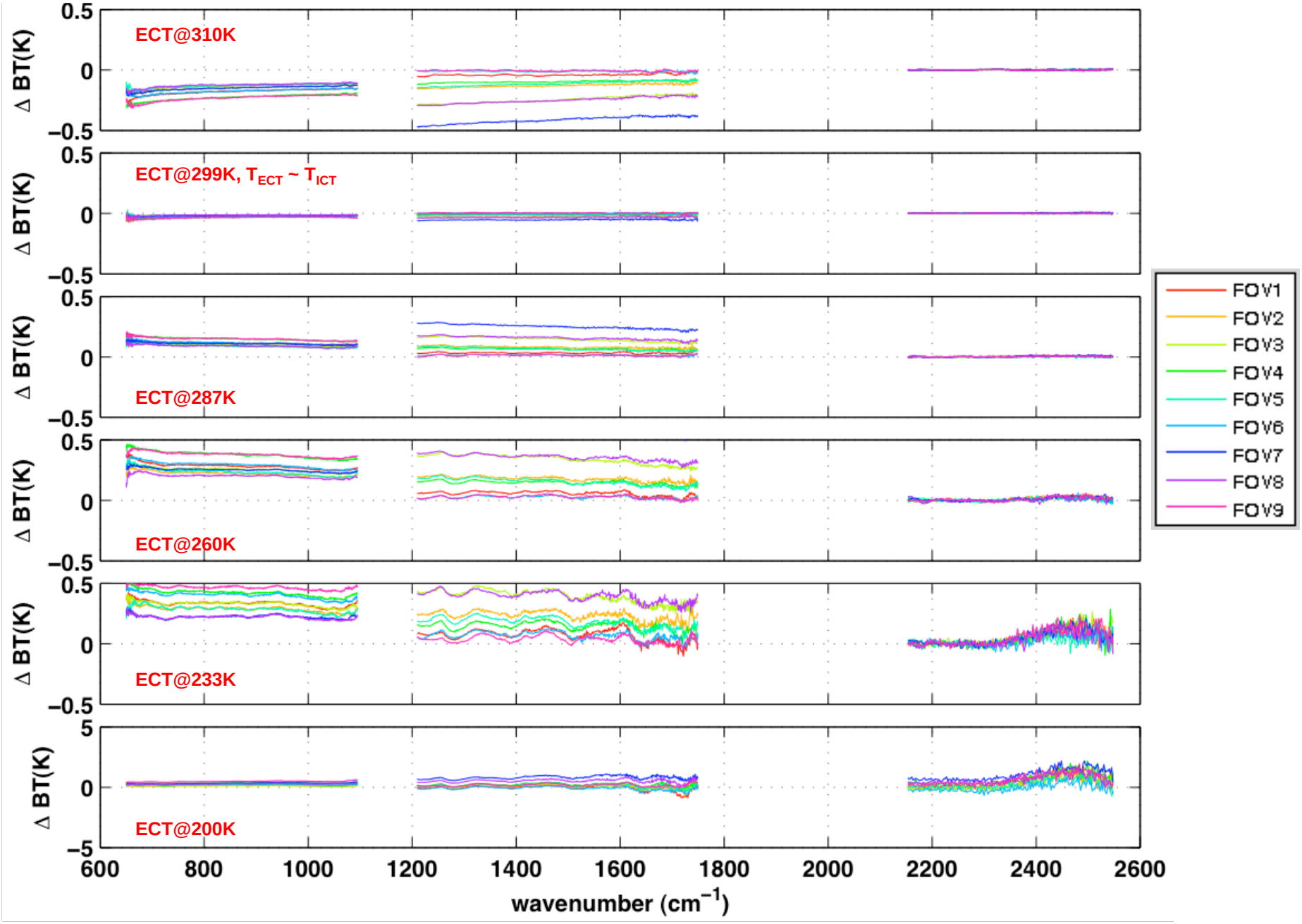


Final estimates ("Opt") are mean of estimates for each FOV

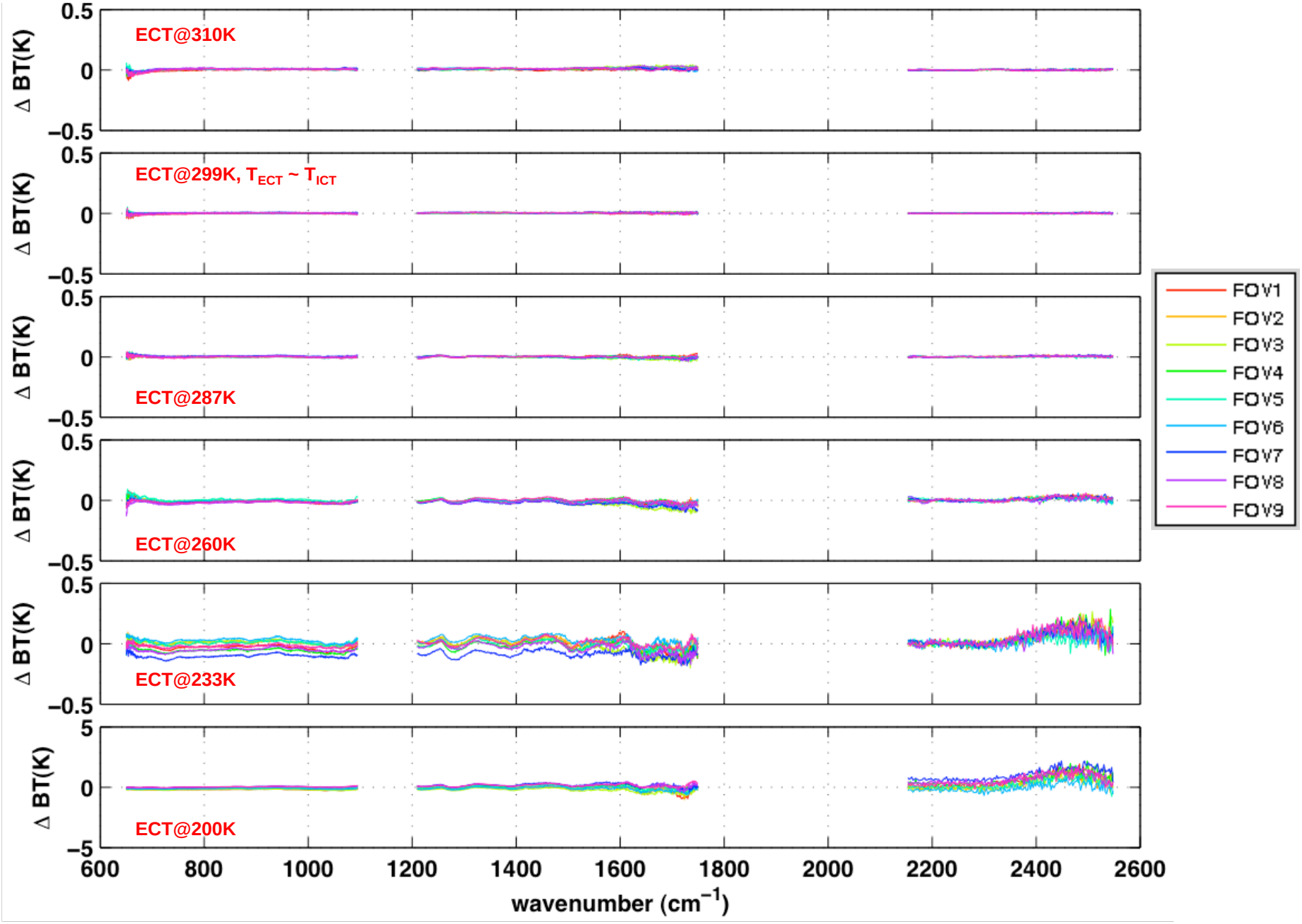
1-sigma uncertainty from estimate variability:
9.6% for LW
15.5% for MW
Yield very conservative 3-sigma estimates



MN (T~296K) Brightness Temperature residuals without NLC



MN: Brightness Temperature residuals w/ NLC and "Opt" a_2 values



3. Absolute Accuracy Expectations for CrIS:

Thermal Vacuum Test Results

- In-flight calibration uncertainty
- Thermal Vacuum Testing Uncertainty

CrIS FM1 In-flight Radiometric Uncertainty

On-orbit radiometric calibration equation:

$$R_{Earth} = \mathcal{R}e\{(C'_{Earth} - C'_{Space})/(C'_{ICT}-C'_{Space})\}(R_{ICT}-R_{Space}) + R_{Space}$$

with: $R_{ICT} = \varepsilon_{ICT}\, B(T_{ICT}) + (1-\varepsilon_{ICT})\, R_{ICT,Reflected}$

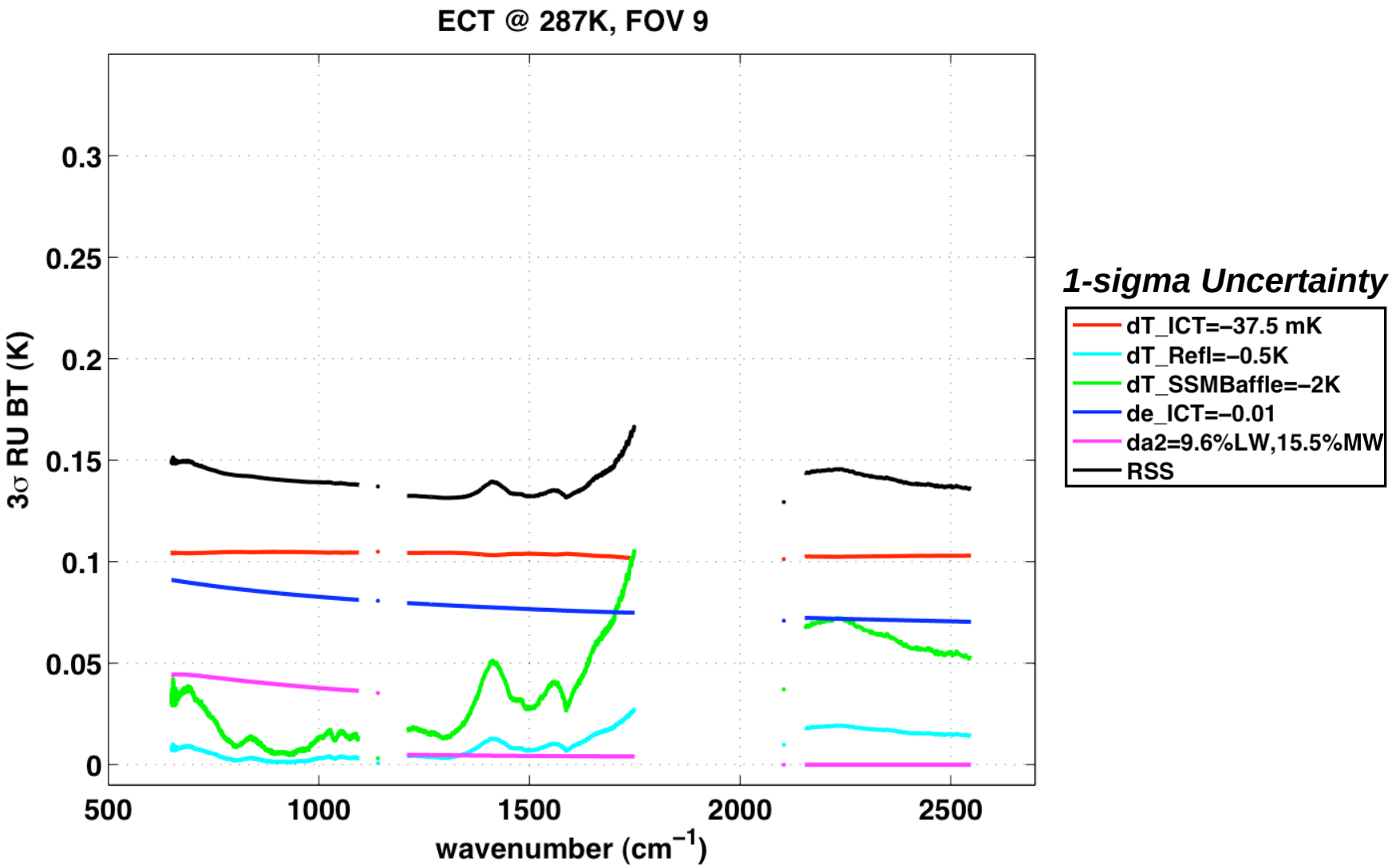
$R_{Space} = B(T_{Space})$

$C' = C\,(1+2\,a_2 V_{DC})$

Parameter	1-σ uncertainty	3-σ uncertainty	Source/Comment
T_{ICT} (K)	37.5 mK	112.5 mK	Bomem/ITT eng. estimate (w/o known readout issue)
ε_{ICT} ( )	0.01	0.03	Independent measurement (TSSR) at 2500 cm^{-1} plus Analysis
$T_{refl,measured}$ (K)	0.5 K	1.5 K	Temperature monitored components (Frame, OMA, BS, ICT Baffle)
$T_{refl,modelled}$ (K)	2 K	6 K	Worst case estimate of unmonitored SSM Baffle T variations
a_2 (1/counts)	9.6% Longwave 15.5% Midwave	28.8% Longwave 46.5% Midwave	DM and ECT view analysis

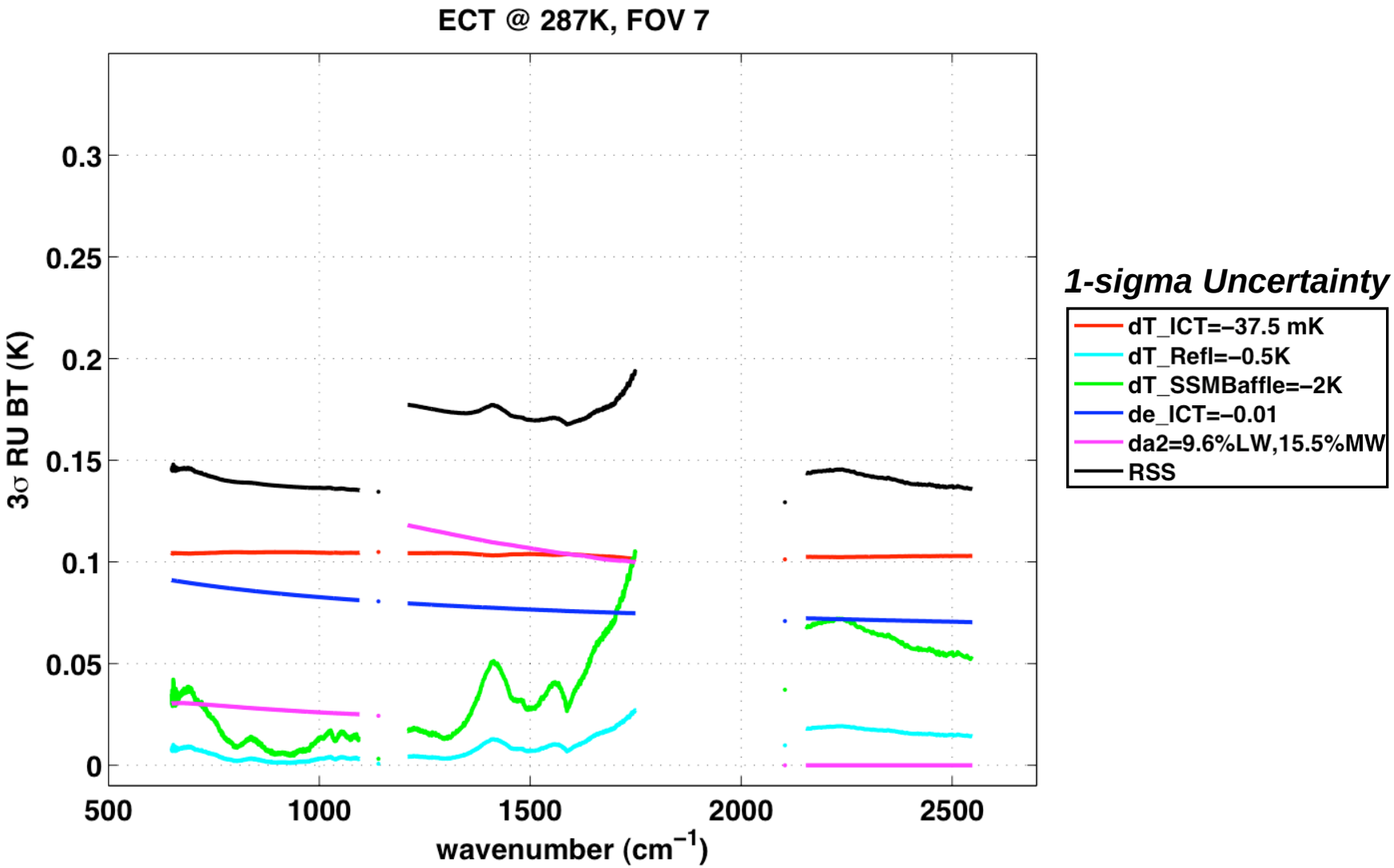
CrIS FM1 In-flight Radiometric Uncertainty (3-sigma Tb)

Example for Small MW non-linearity (FOV 9)



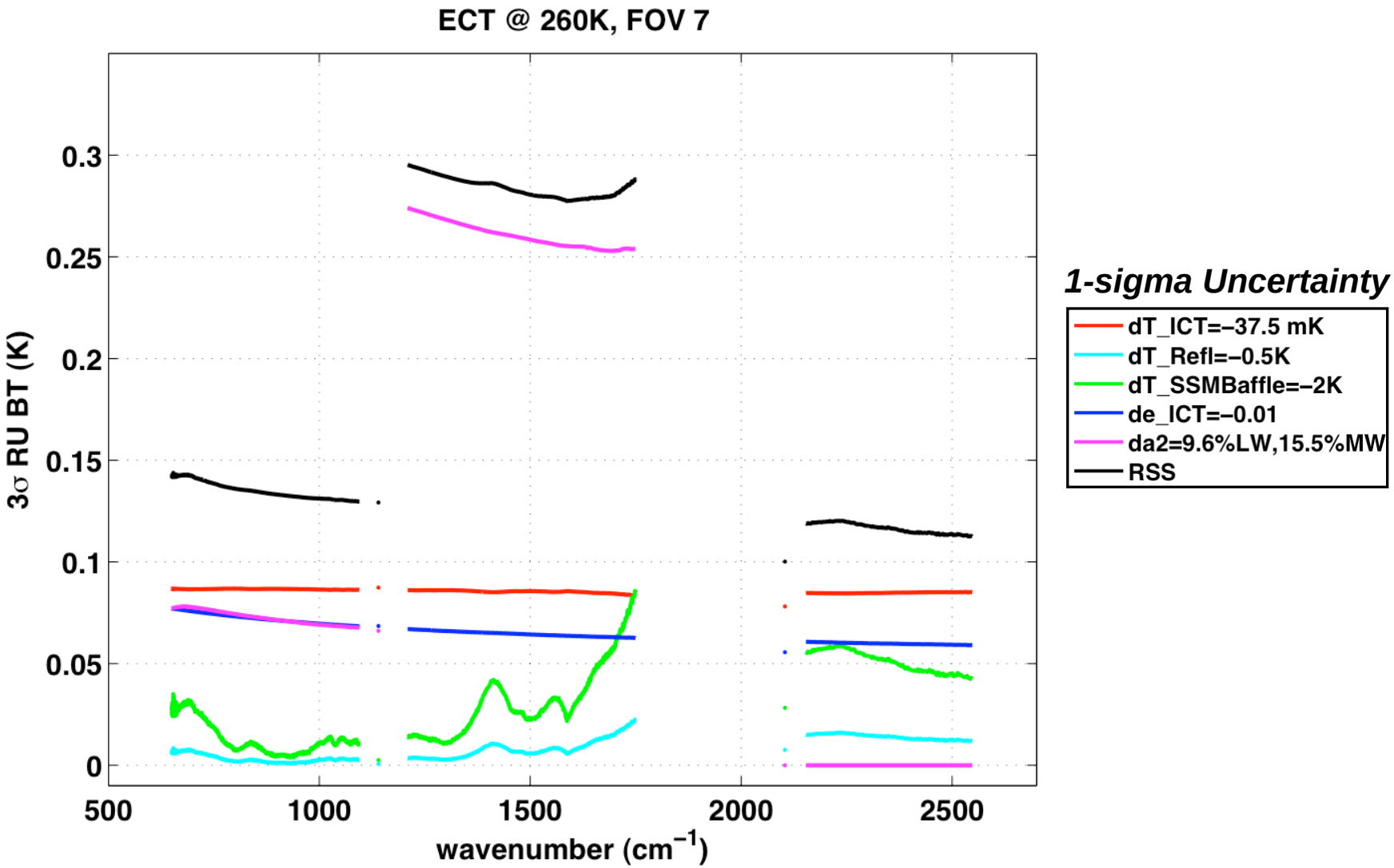
CrIS FM1 In-flight Radiometric Uncertainty (3-sigma Tb)

Example for Largest MW non-linearity (FOV 7)

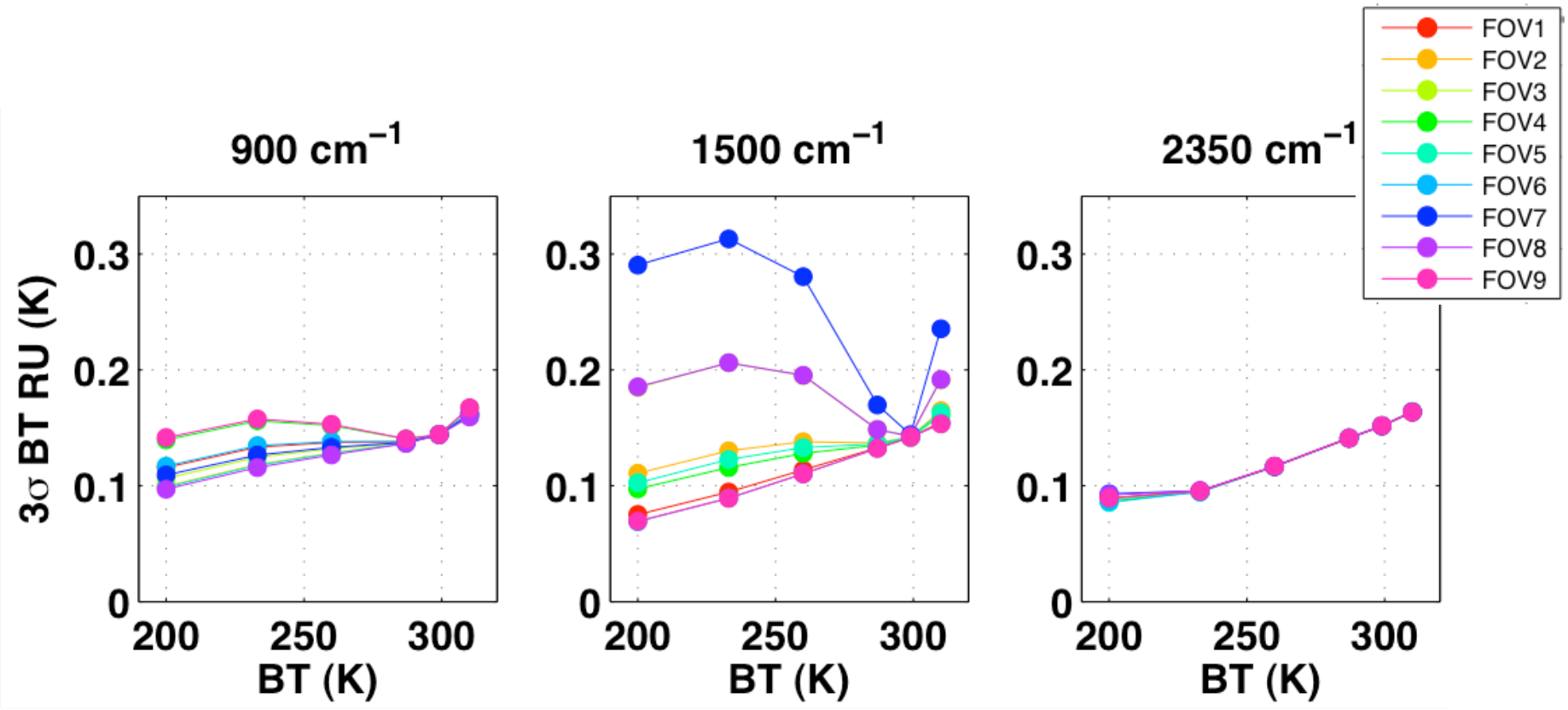


CrIS FM1 In-flight Radiometric Uncertainty (3-sigma Tb)

Example for Largest MW non-linearity (FOV 7)

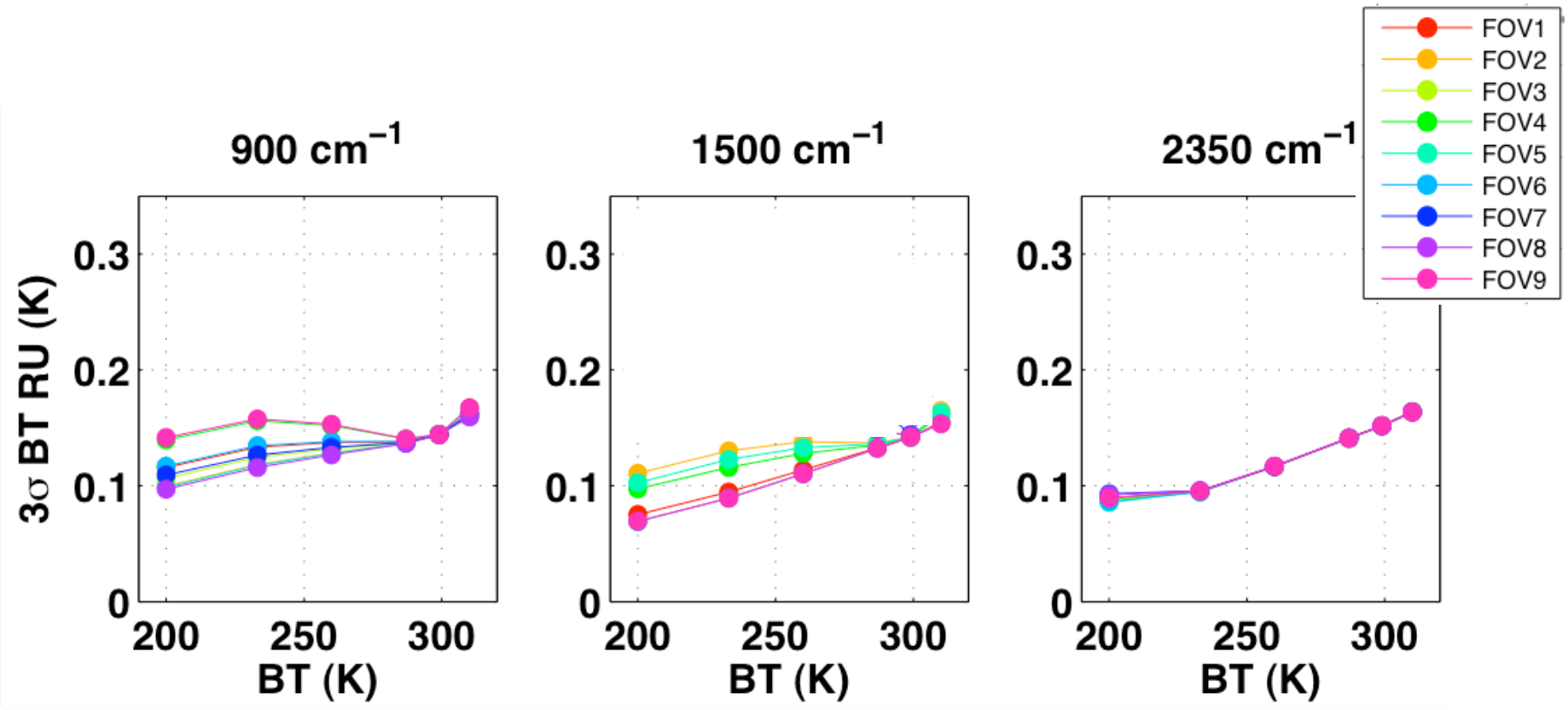


CrIS FM1 In-flight Radiometric Uncertainty (3-sigma Tb)
versus scene T for all FOVs at ~mid-band



Uncertainty generally <0.2 K 3-sigma

CrIS FM1 In-flight Radiometric Uncertainty (3-sigma Tb)
versus scene T for all FOVs at ~mid-band



Uncertainty for FOVs with larger non-linearity will be reduced from inflight data

CrIS TVAC Testing Radiometric Uncertainty

TVAC calibration equation for ECT view:

$$R_{ECT} = \mathcal{R}e\{(C'_{ECT} - C'_{ST})/(C'_{ICT}-C'_{ST})\}(R_{ICT}-R_{ST}) + R_{ST}$$

Calibrated

with:

$$R_{ST} = \varepsilon_{ST}\, B(T_{ST}) + (1-\varepsilon_{ST})\, B(T_{ST,Relected})$$

$$R_{ICT} = \varepsilon_{ICT}\, B(T_{ICT}) + (1-\varepsilon_{ICT})\, R_{ICT,Reflected}$$

$$C' = C\,(1+2\,a_2 V_{DC})$$

TVAC "truth": ECT view predicted:

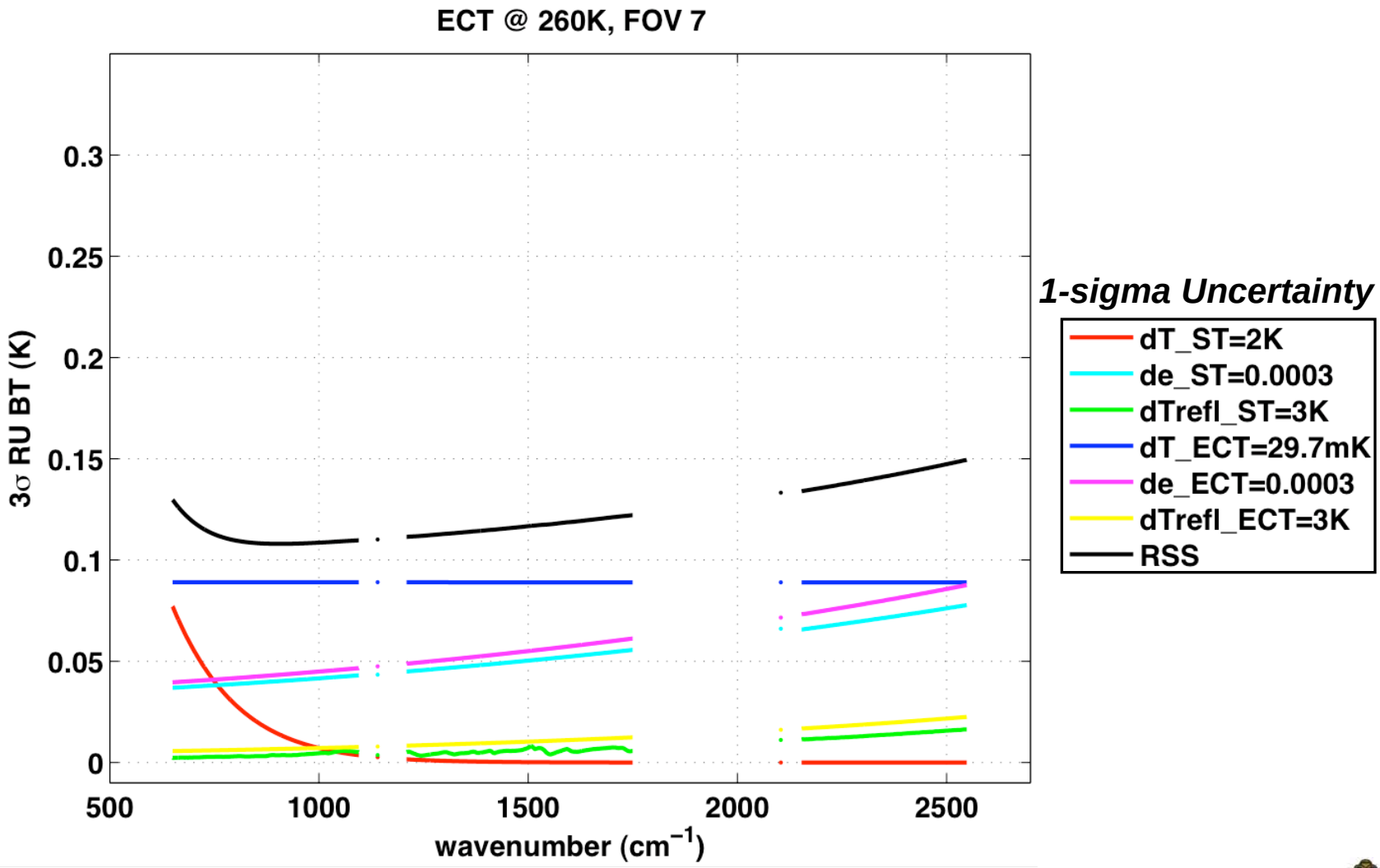
$$R_{ECT} = \varepsilon_{ECT}\, B(T_{ECT}) + (1-\varepsilon_{ECT})\, B(T_{ECT,Relected})$$

Predicted

Parameter	Value	1-σ uncertainty	3-σ uncertainty	Source/Comment
T_{ECT} (K)	200-310 K	29.7 mK	89.1 mK	Bomem/ITT estimate recent new Hart/UW absolute cal info, and without spatial gradients
ε_{ECT} ( )	0.9995	0.0003	0.0009	Bomem report
$T_{ECT,Reflected}$ (K)	T_{ICT}	3 K	9 K	Conservative estimate
T_{ST} (K)	105 K	2 K	6 K	Conservative estimate
ε_{ST} ( )	0.9995	0.0003	0.0009	Bomem report
$T_{ST,Reflected}$ (K)	T_{ICT}	3 K	9 K	Conservative estimate

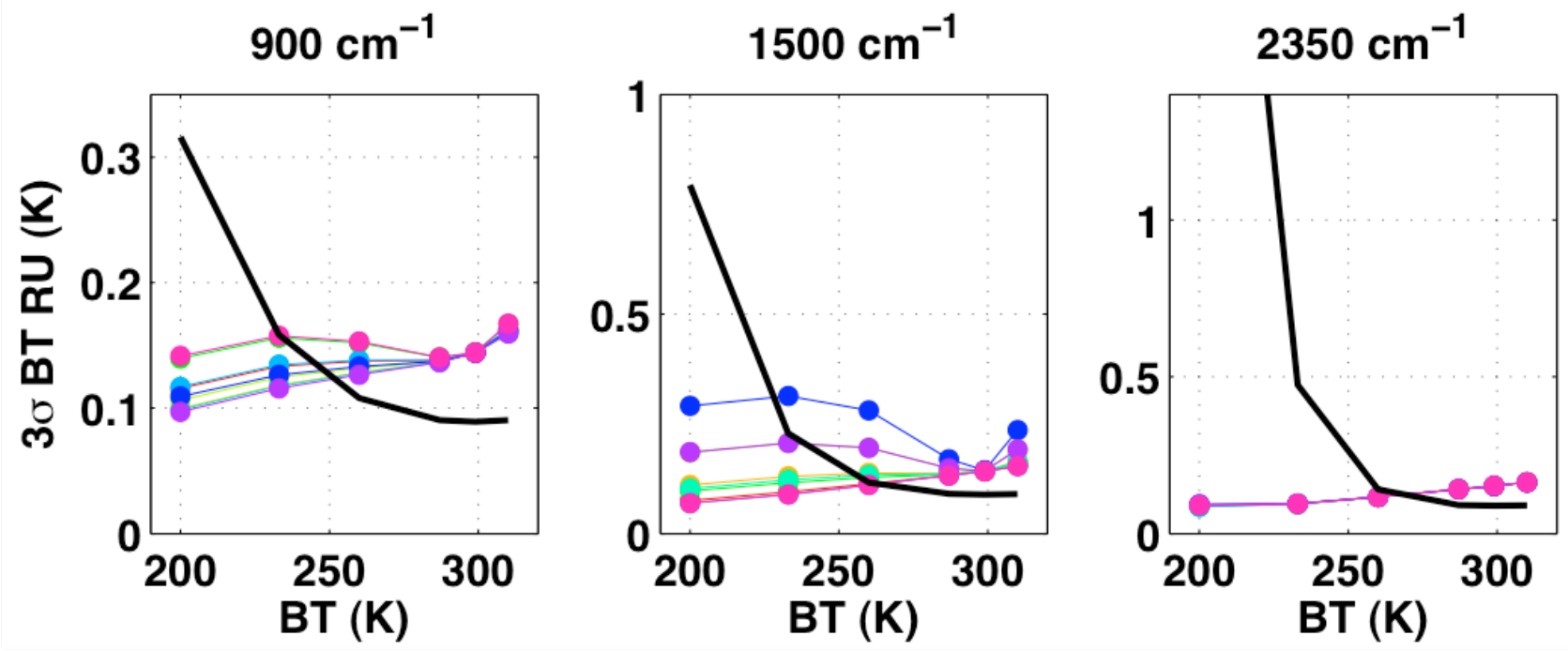
TVAC Testing 3-sigma Radiometric Uncertainty

Example for FOV 7 & 260 K



TVAC Testing 3-sigma Radiometric Uncertainty

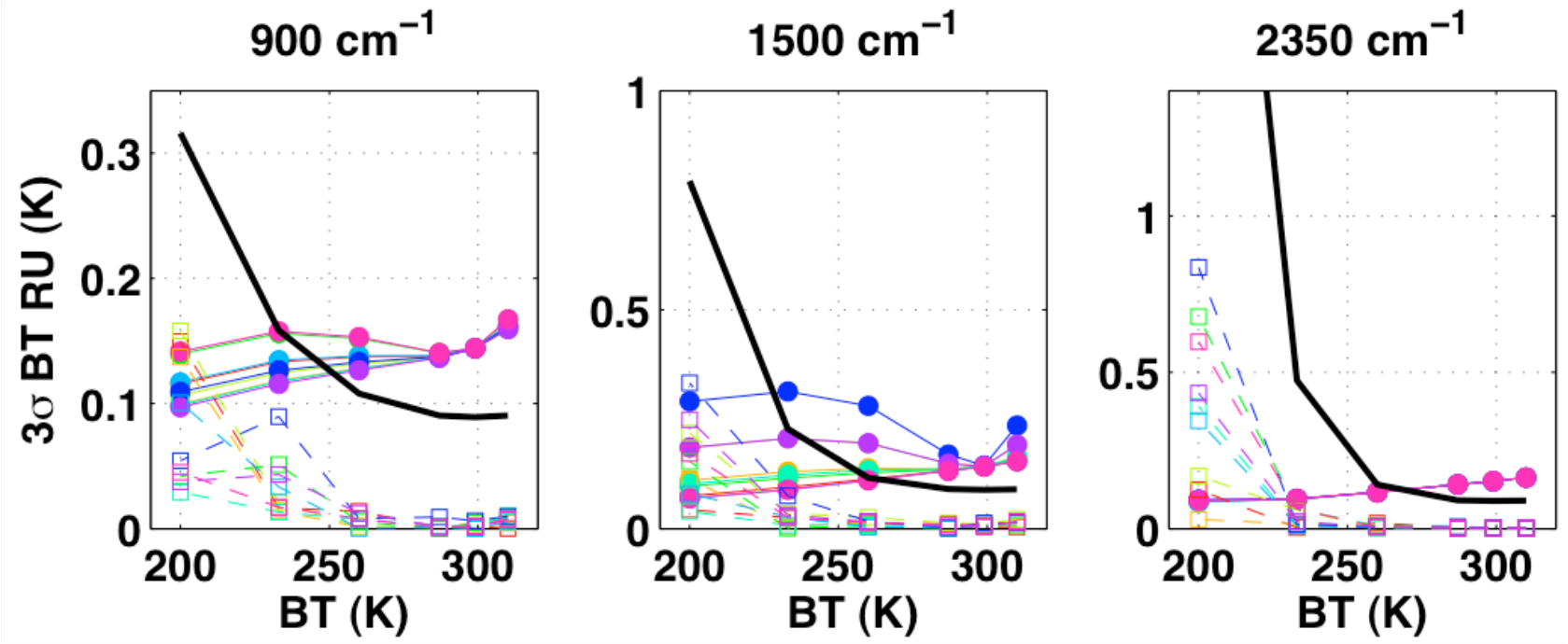
Compared to CrIS Calibration Uncertainty



- **Colored, Filled, Circles** = CrIS Inflight Uncertainty
- **Solid Black Line** = TVAC testing Uncertainty

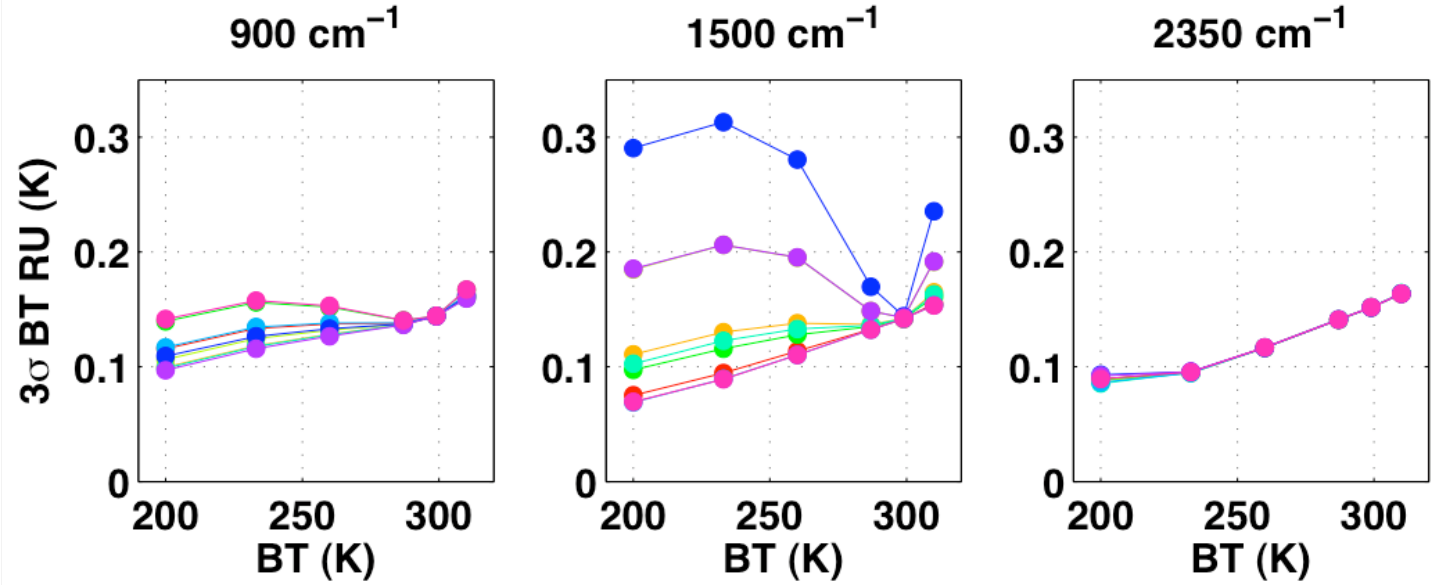
TVAC Testing 3-sigma Radiometric Uncertainty

Compared to CrIS Calibration Uncertainty



- ● **Colored, Filled, Circles** = CrIS Inflight Uncertainty
- □ **Colored, Open, Squares** = TVAC Residuals (absolute value)
- – **Solid Black Line** = TVAC testing Uncertainty

Summary/Conclusions

- **Two main issues encountered and addressed during the CrIS FM1 TVAC testing campaign were presented here:**
  - Low emissivity of the original FM1 ICT
  - Significant nonlinearity in the LW and MW FOVs

- **The In-flight Radiometric Uncertainty of CrIS FM1 is estimated to be very good, with 3-sigma BT RU estimates below ~0.2K for the large majority of FOVs and channels**