# S – NPP VIIRS On-orbit Uncertainty Estimate for Emissive Bands

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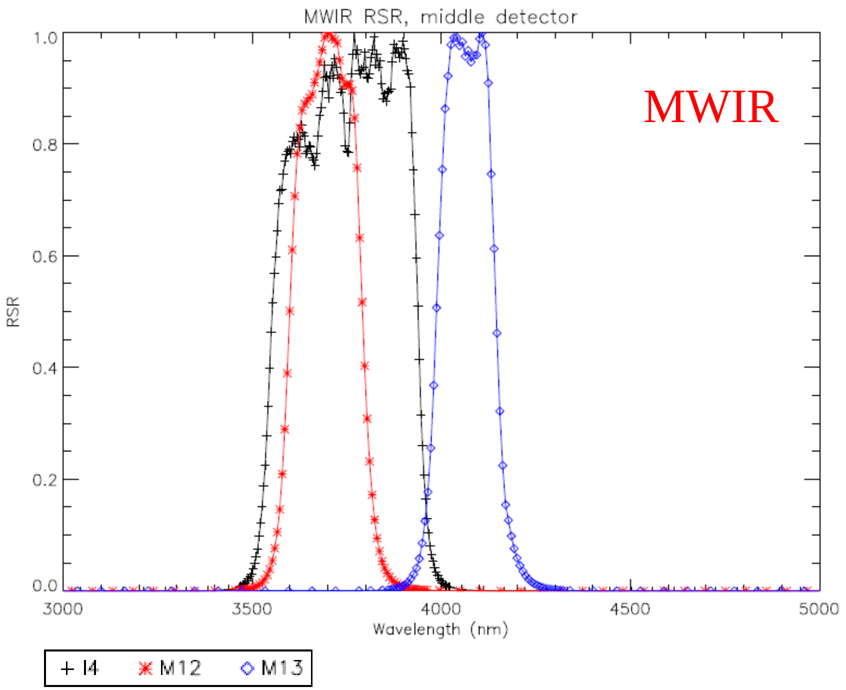
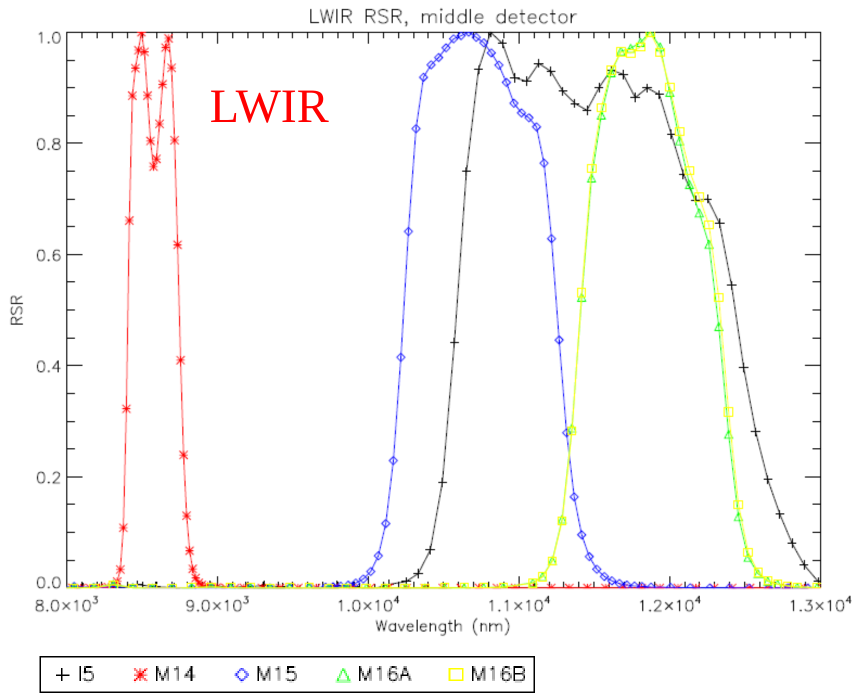
**CALCON Conference**
**Logan UT**
**August 21, 2013**

# S-NPP VIIRS Thermal Bands Overview




| Band | Center wavelength (nm) | Bandwidth (nm) | Resolution (m) | # of Detectors |
|---|---|---|---|---|
| I4 | 3743 | 386 | 375 | 32 |
| I5 | 11508 | 1882 | 375 | 32 |
| M12 | 3695 | 192 | 750 | 16 |
| M13 | 4066 | 158 | 750 | 16 |
| M14 | 8578 | 341 | 750 | 16 |
| M15 | 10744 | 1014 | 750 | 16 |
| M16A | 11861 | 919 | 750 | 16 |
| M16B | 11869 | 923 | 750 | 16 |

TDI

**On-board blackbody**

**Normally controlled at ~292 K**

**Can be cycled from ~267 K to ~315 K**

**Thermal bands are important in EDRs**

**Used by science teams (Ocean, Land, and Aerosol) for SST, LST, fire detection, cloud properties, etc.**

# Thermal Band Uncertainty

- Important to characterize thermal band uncertainty on-orbit at the SDR level for propagation into EDRs
- Propagated uncertainty to retrieved radiance using standard NIST formulation (k=1)
  - Propagated uncertainty into blackbody radiance estimate
  - Generated the radiometric coefficient uncertainties
    - Used data from blackbody WUCD (12/2012)
  - Estimated the uncertainty in the retrieved EV radiance
- Performed analysis on a series of signal (dn) levels for all bands:
  - Designed to cover the dynamic range for each band
  - (dn = 5, 20, 100, 250, 500, 750, 1000, 1500, 2000, 2500, 3000, and 3500)
- Evaluated results for an individual, unaggregated EV pixel
  - In terms of radiance uncertainty [%] and temperature uncertainty [K]
  - Evaluated results at different RVS angles / aggregation zones

# Thermal Band Uncertainty Requirement

**Thermal Band Uncertainty Requirements**

**Uncertainty requirements are listed in % of radiance at specific scene temperatures**

- **I bands specified at 267 K only**
- **M bands specified at 4 or 5 scene temperatures**

**Specified radiance uncertainty limits in %**

| Band | 190 K | 230 K | 267 K | 270 K | 310 K | 340 K |
|---|---|---|---|---|---|---|
| I4 | -- | -- | 5.0 | -- | -- | -- |
| I5 | -- | -- | 2.5 | -- | -- | -- |
| M12 | -- | 7.0 | -- | 0.7 | 0.7 | 0.7 |
| M13 | -- | 5.7 | -- | 0.7 | 0.7 | 0.7 |
| M14 | 12.3 | 2.4 | -- | 0.6 | 0.4 | 0.5 |
| M15 | 2.1 | 0.6 | -- | 0.4 | 0.4 | 0.4 |
| M16 | 1.6 | 0.6 | -- | 0.4 | 0.4 | 0.4 |

# Uncertainty in BB Radiance

**The at-detector BB radiance is described by the following model**

$$L_{BB-scene} = rvs_{BB}\varepsilon_{BB}L_{BB} + rvs_{BB}(1-\varepsilon_{BB})(F_{SH}L_{SH} + F_{CAV}L_{CAV} + F_{RTA}L_{RTA}) + \frac{(rvs_{SV} - rvs_{BB})}{\rho_{RTA}}[L_{HAM} - (1-\rho_{RTA})L_{RTA}]$$

**Detector response to input radiance model**

- **At-detector BB radiance is modeled as a quadratic polynomial in signal (dn)**
- **Derived coefficients from BB WUCD performed 12/2012**

$$L_{BB-scene} = c_0 + c_1 dn_{BB} + c_2 dn_{BB}^2$$

**Individual uncertainties in $\Delta L_{BB}$**

- **Uncertainty in RVS**
  - **combination of measurement and fitting uncertainties**
- **Uncertainty in $L_{BB}$, $L_{HAM}$, $L_{RTA}$, $L_{SH}$, and $L_{CAV}$**
  - **combination of temperature, spectral, statistical, and interpolation uncertainties**
- **Uncertainty in $F_{SH}$, $F_{CAV}$, and $F_{RTA}$ – uncertainty of 100 %**
- **Uncertainty in $\varepsilon_{BB}$ – uncertainty of 0.0007 %**
- **Uncertainty in $\rho_{RTA}$ – uncertainty of 0.5 %**

**See backup slides for more details (and references)**

# Uncertainty in EV Retrieved Radiance

**EV retrieval equation is listed below with the scan-by-scan F factor correction included**

$$L_{EV} = \frac{L_{BB-scene}}{rvs_{EV}} \frac{c_0 + c_1 dn_{EV} + c_2 dn_{EV}^2}{c_0 + c_1 dn_{BB} + c_2 dn_{BN}^2} - \frac{(rvs_{SV} - rvs_{EV})}{\rho_{RTA} rvs_{EV}} \left[L_{HAM} - (1 - \rho_{RTA}) L_{RTA}\right]$$

**Propagate the uncertainties to the retrieved radiance**

**Individual uncertainties in $L_{EV}$**

- **Uncertainty in $c_0$, $c_1$, and $c_2$**
  - **determined from the least squares fitting algorithm (using 12/2012 WUCD)**
- **Uncertainty in RVS**
  - **combination of measurement and fitting uncertainties**
- **Uncertainty in $dn_{EV}$ and $dn_{BB}$**
  - **random measurement uncertainty**
- **Uncertainty in $L_{BB}$, $L_{HAM}$, $L_{RTA}$, $L_{SH}$, and $L_{CAV}$**
  - **combination of temperature, spectral, statistical, and interpolation uncertainties**
- **Uncertainty in $F_{SH}$, $F_{CAV}$, and $F_{RTA}$ – uncertainty of 100 %**
- **Uncertainty in $\varepsilon_{BB}$ – uncertainty of 0.0007 %**
- **Uncertainty in $\rho_{RTA}$ – uncertainty of 0.5 %**

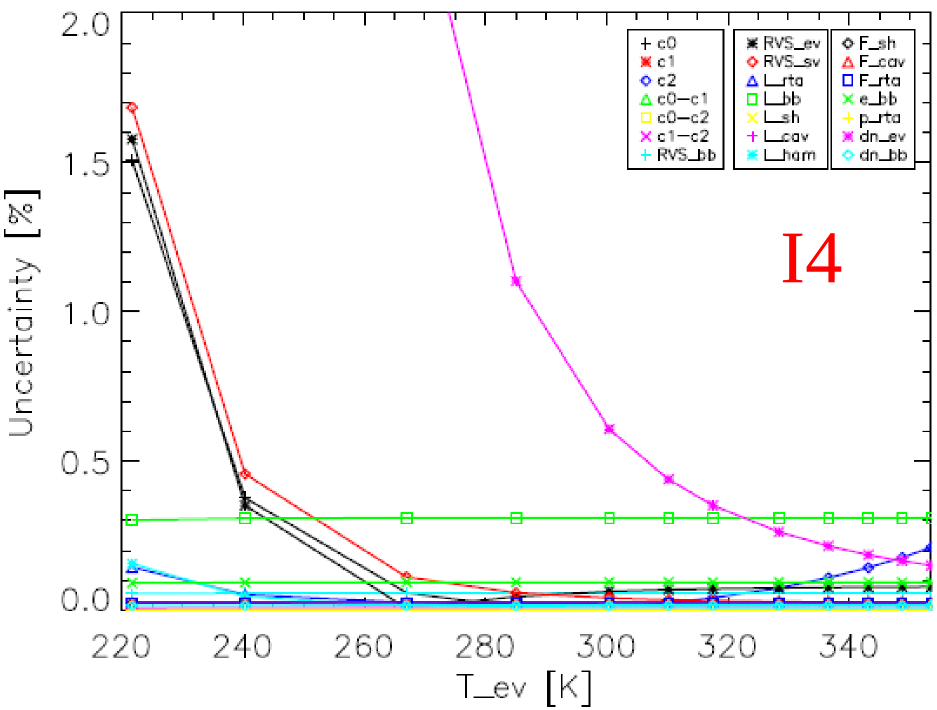
**See backup slides for more details (and references)**

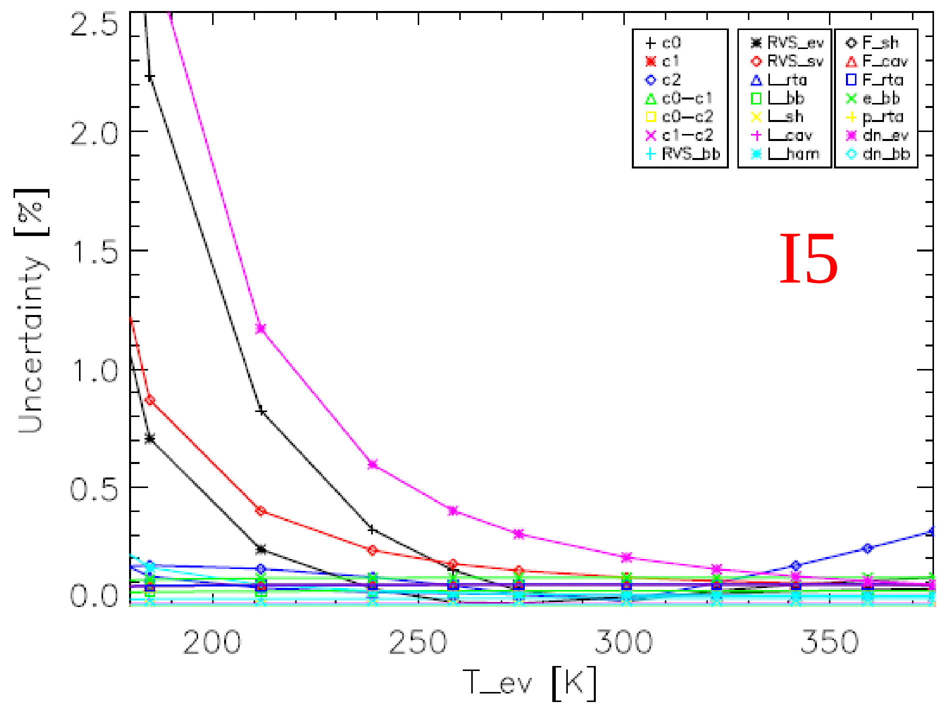
# Individual Contributors (I bands)

**Individual uncertainty contributors in the I bands**

**I4 (left) – the dominant terms are the BB L and EV dn uncertainties**

**I5 (right) – the most important terms are c2 and EV dn uncertainties**



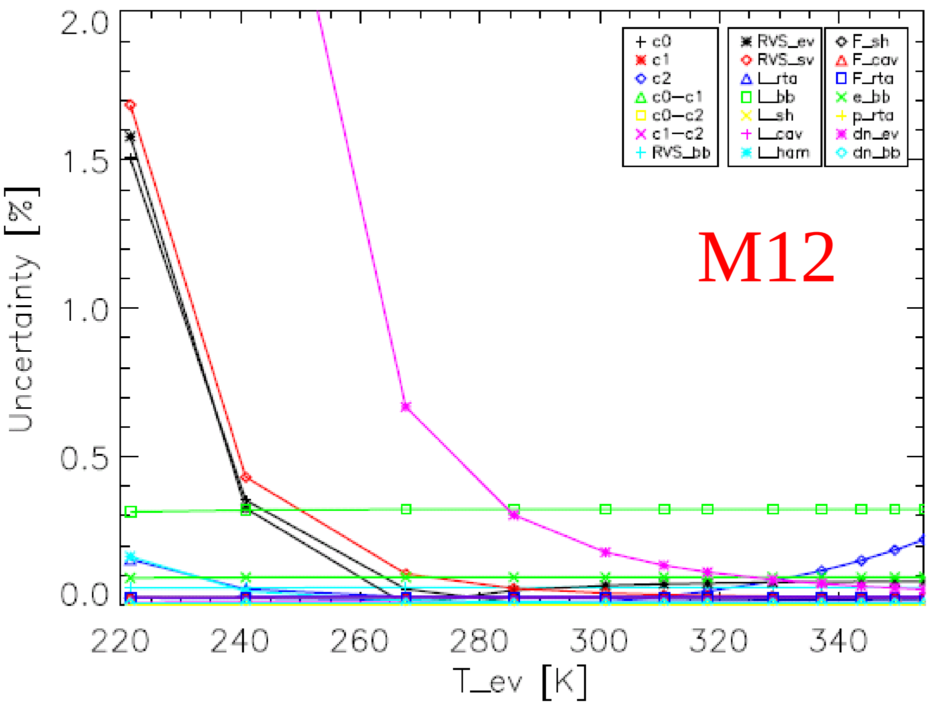



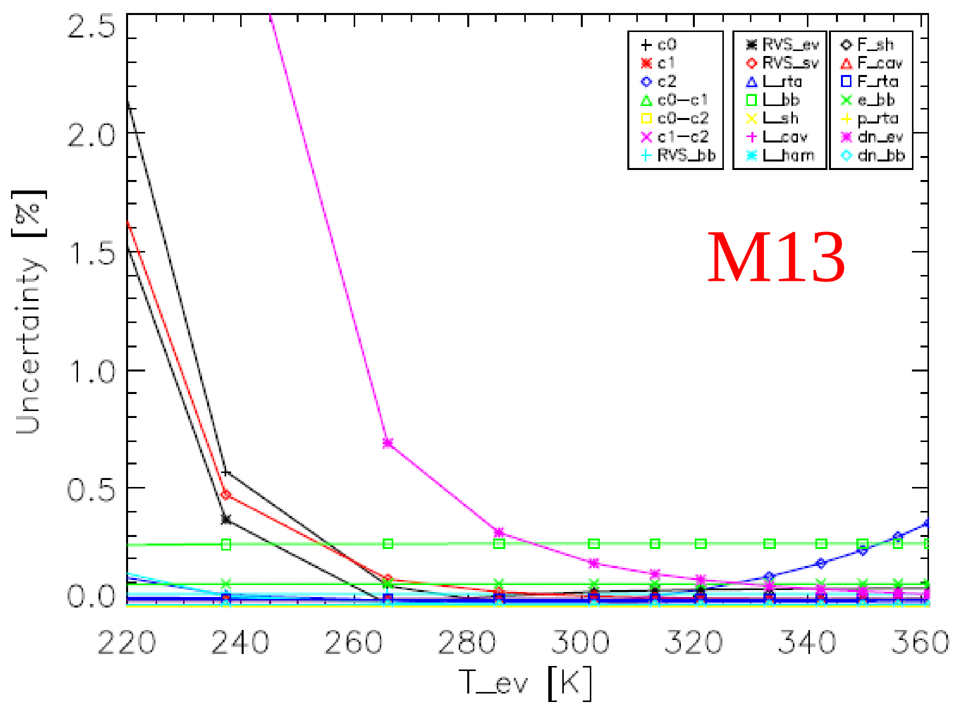
# Individual Contributors (M12 and M13)

**Individual uncertainty contributors in the M12 and M13**

**M12 (left) – the dominant terms are the BB L and EV dn uncertainties**

**M13 (right) – the dominant terms are BB L and EV dn uncertainties; c2 uncertainty also important at high scene temperatures**



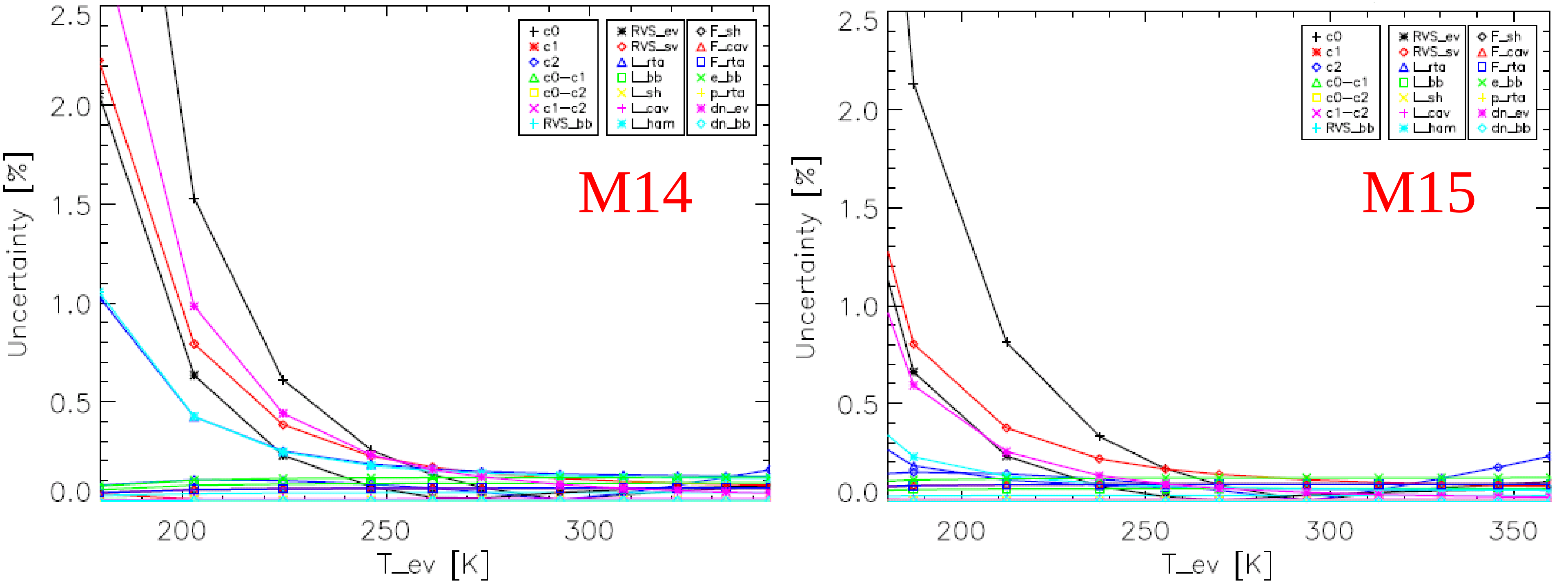



# Individual Contributors (M14 and M15)

**Individual uncertainty contributors in the M14 and M15**

**M14 (left) – the most important terms are the HAM and RTA L uncertainties**

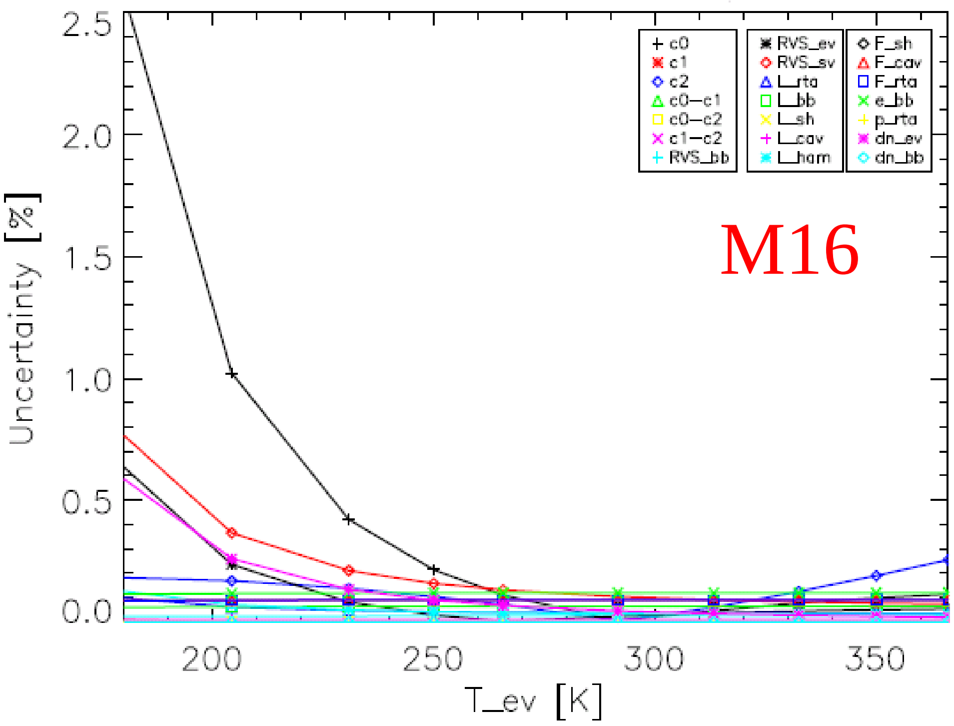
**M15 (right) – no terms clearly dominate except the c0 uncertainties at low scene temperatures and the c2 uncertainties at high scene temperatures**



# Individual Contributors M16

**Individual uncertainty contributors in the M16**

**M16 – no terms clearly dominate except the c0 uncertainties at low scene temperatures and the c2 uncertainties at high scene temperatures**



# Total Uncertainty

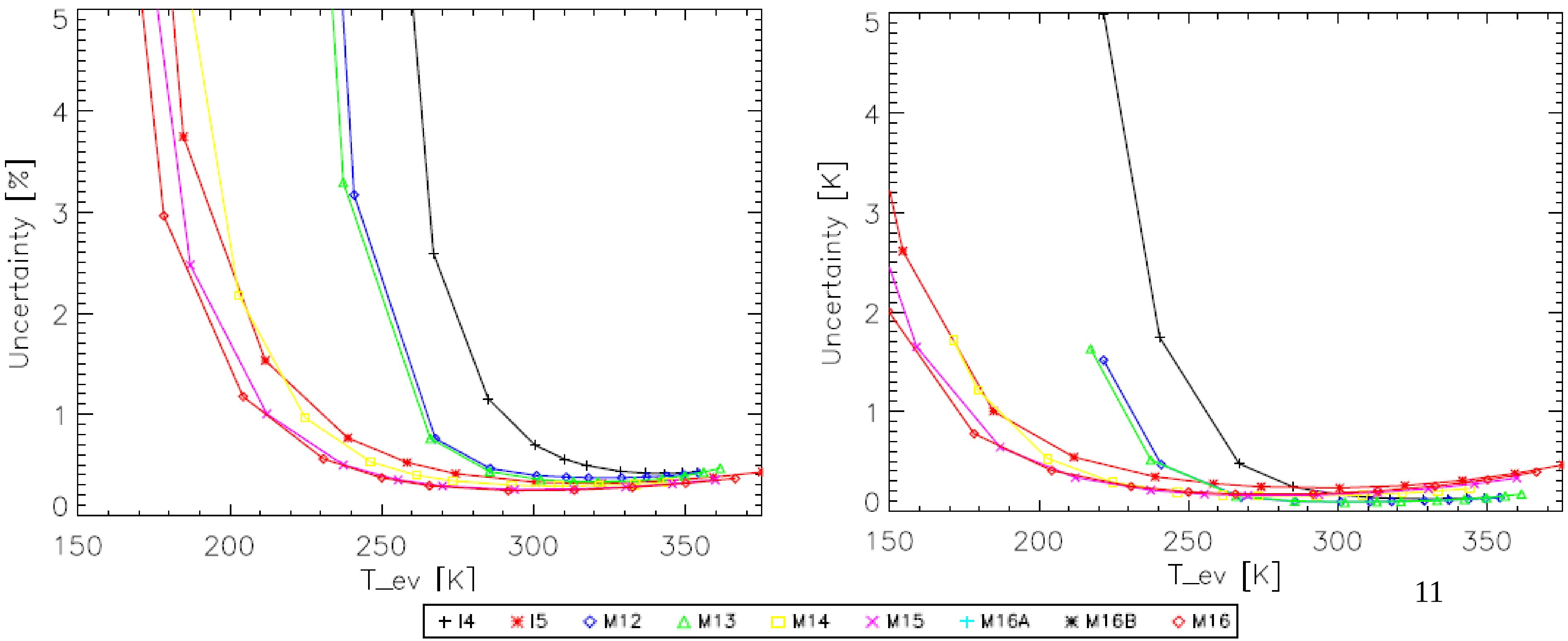
**Total uncertainty (single, unaggregated EV pixel, beginning of scan)**

**Left plot – uncertainty in radiance [%]**

- **Uncertainties increase at low scene temperatures, and are roughly constant elsewhere**
- **MWIR band uncertainties increase earlier than LWIR bands, particularly I4**

**Right plot – uncertainty in temperature [K]**

- **Uncertainties are below 1 K above ~190 K for the LWIR bands**
- **Uncertainties are below 1 K above ~230 K for M12 and M13, and above ~250 K for I4**



# Comparison to Requirement [%]

**Uncertainty specifications**

**Defined in terms of % of radiance, at particular uniform scene temperatures**

**Estimates exceed the specification at lower scene temperatures for bands M12, M13, M15, and M16**

| Band | 267 K |
|---|---|
| I4 spec | 5.0 |
| I4 estimate | 2.59 |
| I5 spec | 2.5 |
| I5 estimate | 0.464 |

| Band | 190 K | 230 K | 270 K | 310 K | 340 K |
|---|---|---|---|---|---|
| M12 spec | --- | 7.0 | 0.7 | 0.7 | 0.7 |
| M12 estimate | --- | 8.52 | 0.721 | 0.380 | 0.384 |
| M13 spec | --- | 5.7 | 0.7 | 0.7 | 0.7 |
| M13 estimate | --- | 6.82 | 0.694 | 0.340 | 0.356 |
| M14 spec | 12.3 | 2.4 | 0.6 | 0.4 | 0.5 |
| M14 estimate | 4.56 | 0.860 | 0.357 | 0.292 | 0.318 |
| M15 spec | 2.1 | 0.6 | 0.4 | 0.4 | 0.4 |
| M15 estimate | 2.30 | 0.647 | 0.291 | 0.259 | 0.301 |
| M16 spec | 1.6 | 0.6 | 0.4 | 0.4 | 0.4 |
| M16 estimate | 2.16 | 0.578 | 0.286 | 0.250 | 0.296 |

# Comparison to Requirement [K]

**Uncertainty specifications**

**Defined in terms of %, at particular uniform scene temperatures; converted to K**

**Estimates exceed the specification at lower scene temperatures for bands M12, M13, M15, and M16**

| Band | 267 K |
|---|---|
| I4 spec | 0.91 |
| I4 estimate | 0.475 |
| I5 spec | 1.4 |
| I5 estimate | 0.259 |

| Band | 190 K | 230 K | 270 K | 310 K | 340 K |
|---|---|---|---|---|---|
| M12 spec | --- | 0.92 | 0.13 | 0.17 | 0.21 |
| M12 estimate | --- | 1.06 | 0.134 | 0.094 | 0.114 |
| M13 spec | --- | 0.85 | 0.14 | 0.19 | 0.23 |
| M13 estimate | --- | 0.923 | 0.141 | 0.092 | 0.116 |
| M14 spec | 2.6 | 0.75 | 0.26 | 0.23 | 0.34 |
| M14 estimate | 0.907 | 0.265 | 0.154 | 0.166 | 0.217 |
| M15 spec | 0.56 | 0.24 | 0.22 | 0.28 | 0.34 |
| M15 estimate | 0.604 | 0.247 | 0.157 | 0.184 | 0.256 |
| M16 spec | 0.48 | 0.26 | 0.24 | 0.31 | 0.37 |
| M16 estimate | 0.610 | 0.252 | 0.171 | 0.197 | 0.278 |

# RVS / Aggregation Zone Dependence

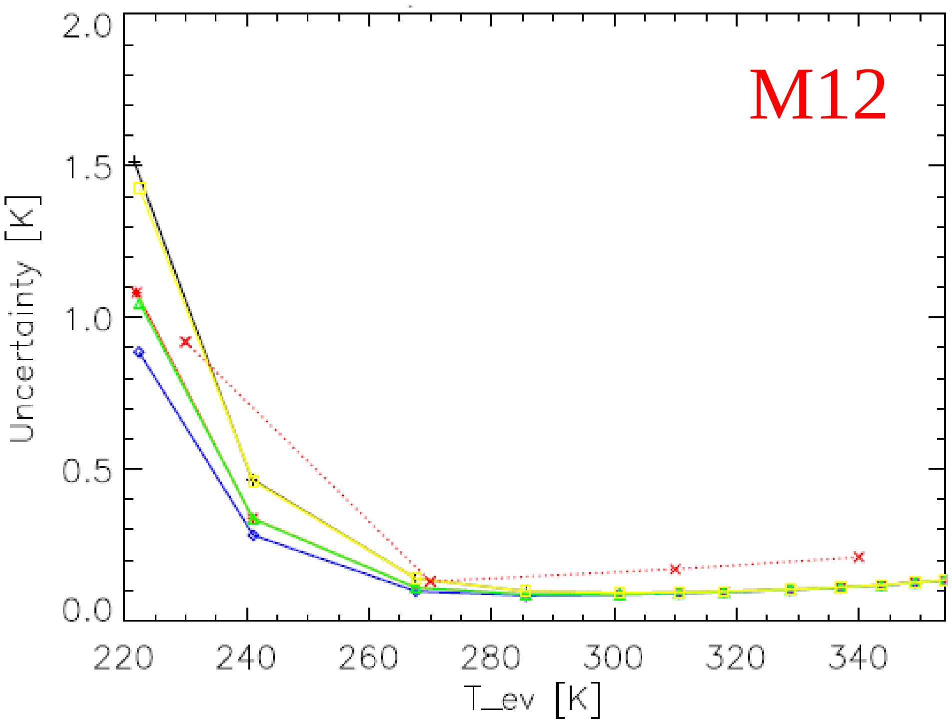
**Dependence of uncertainty on RVS angle / aggregation zone (uniform scene)**

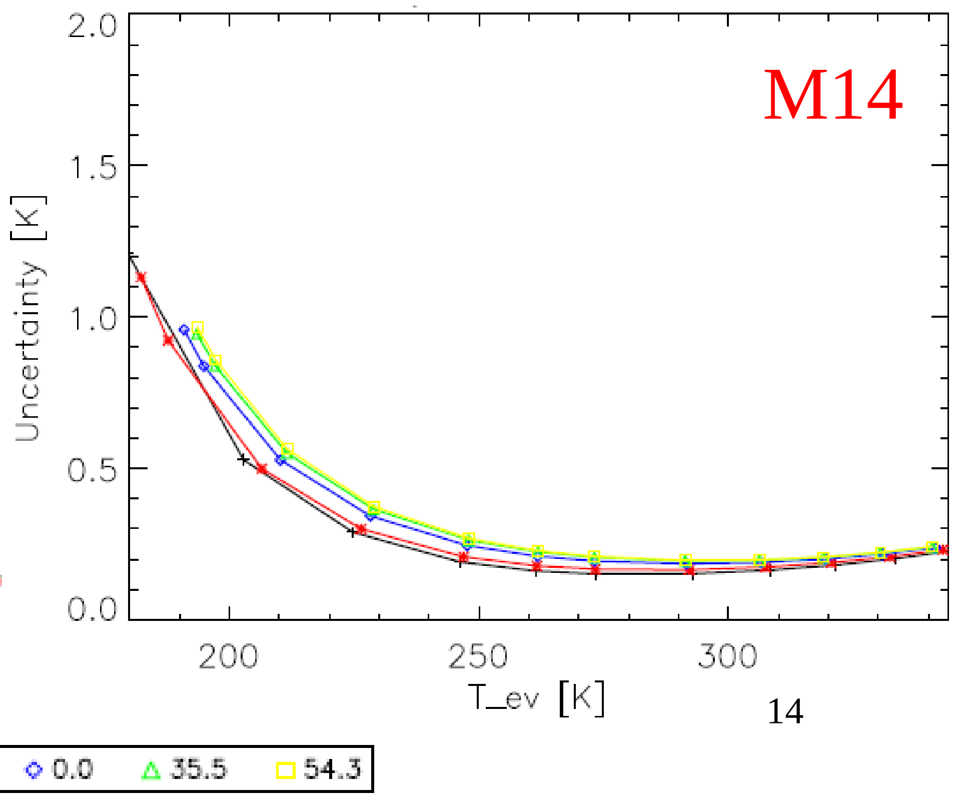
**Examples -- uncertainties shown at the five scan angles (-54.3, -35.4, 0.0, 35.5, and 54.3); specification also shown with a dashed red line**

**M12 (left) – increasing differences at lower scene temperatures (mainly due to reduced EV dn uncertainty)**

**M14 (right) – differences of up to 0.1 K observed at lower scene temperatures (mainly due to RVS)**

**Other bands – I4, I5, and M13 show similar behavior to M12; M15 and M16 show only minor differences**



# M13 Low Gain

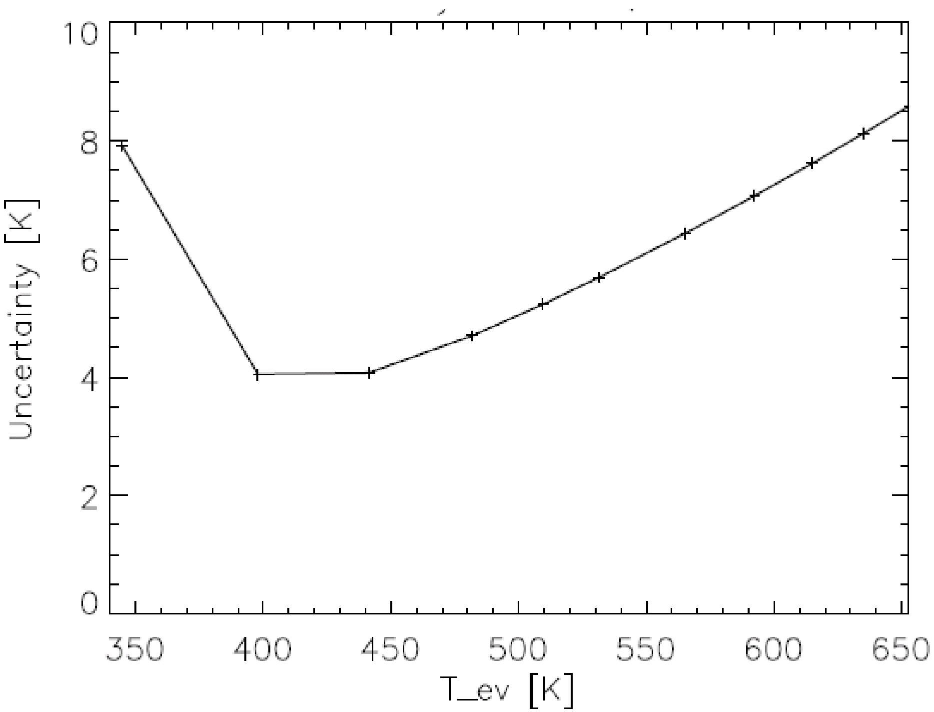
**Left plot – total uncertainty in temperature [K]**

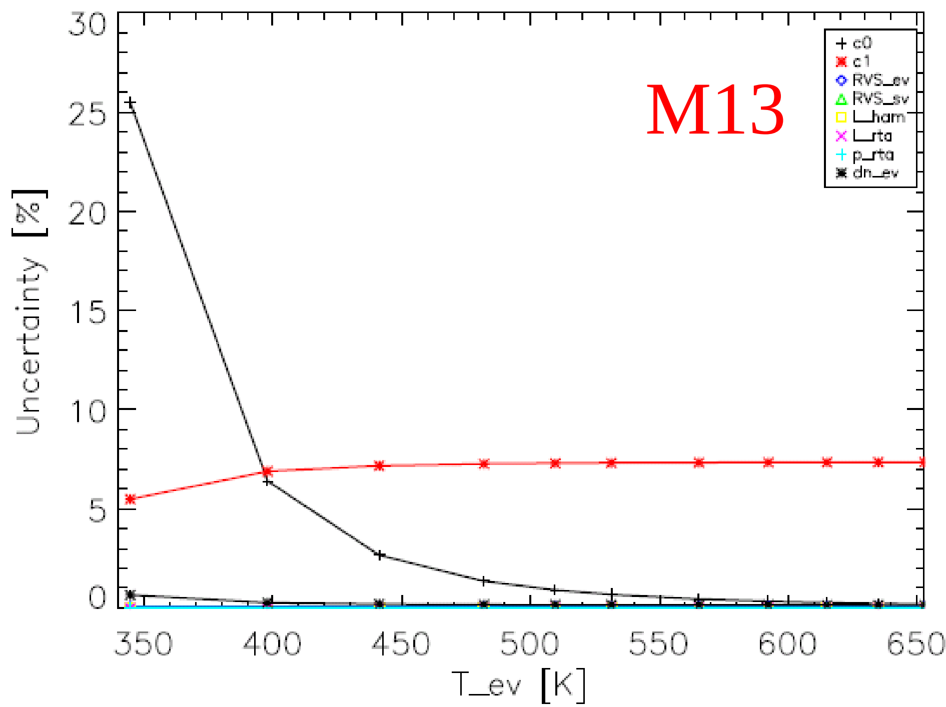
**Uncertainties increase at low scene temperatures, and increase gradually at high temperatures**

**Right plot – individual uncertainty contributors in [%]**

**Uncertainty dominated by offset coefficient at lower temperature**

**Uncertainty dominated by linear coefficient at high temperature**



# Conclusions

**Thermal Band Uncertainty**

**Important to characterize thermal band uncertainty on-orbit at the SDR level for propagation into EDRs**

**Propagated uncertainty to retrieved radiance using standard NIST formulation (k=1)**

**Performed analysis on a series of signal (dn) levels for all bands**

**Evaluated results for an individual, unaggregated EV pixel**

- **In terms of radiance uncertainty [%] and temperature uncertainty [K]**

**Evaluated results at different RVS angles / aggregation zones**

**Compared uncertainty estimates to requirements**

- **Thermal bands meet requirements for most scene temperatures**
- **M12, M13, M15, and M16 had slightly larger than specified uncertainties at low scene temperatures**
- **Larger uncertainties in M13 low gain (above 350 K)**

# Backup Slides

# Individual Uncertainty Contributors

**Radiance uncertainties**
RSS of the spectral, temperature, statistical, and interpolation uncertainties
* Raytheon PVR – temperature
* Presentation by J. Young – spectral

$$u(L_\lambda) = \max(|L(T,\lambda) - L(T,\lambda \pm \Delta\lambda)|)$$

$$u(L_T) = \max(|L(T,\lambda) - L(T \pm \Delta T,\lambda)|)$$

| Source | Temperature Uncertainty (K) |
|---|---|
| OBC | 0.04 |
| HAM | 1.0 |
| RTA | 9.0 |
| SH | 3.0 |
| CAV | 6.0 |

| Band | Spectral Uncertainty (nm) |
|---|---|
| I4 | 1.2 |
| I5 | 4.0 |
| M12 | 1.2 |
| M13 | 1.2 |
| M14 | 4.0 |
| M15 | 4.0 |
| M16A | 4.0 |
| M16B | 4.0 |

**RVS uncertainties**
RSS of the fitting and measurement uncertainties
One uncertainty for all RVS angles
* NICST analysis

| Band | RVS uncertainty |
|---|---|
| I4 | 0.000811 |
| I5 | 0.000986 |
| M12 | 0.000818 |
| M13 | 0.000798 |
| M14 | 0.001003 |
| M15 | 0.000875 |
| M16A | 0.000804 |
| M16B | 0.000759 |

**$\rho_{RTA}$ uncertainty**
Measured uncertainty at 270 K is 0.05 %
Error used for all scene temperatures
* Raytheon PVR

**$\varepsilon_{BB}$ uncertainty**
Measured uncertainty at 3.39 μm is 0.0007
* Raytheon PVR

**$F_{SH}$, $F_{CAV}$, and $F_{RTA}$ uncertainty**
Uncertainties taken to be the 100%

# Individual Uncertainty Contributors

**Radiance uncertainties**
The uncertainty in the BB path difference radiance was determined via the uncertainty propagation

**Coefficient uncertainties**
The coefficient uncertainties were output from the least squares fitting algorithm (both uncertainties and covariances)

These uncertainties were determined from inputting the radiance uncertainties into the least squares algorithm

For this work, coefficients were derived from 12/2012 BB WUCD

M13 low gain coefficient uncertainties derived from comparisons to lunar observations and pre-launch Government team analysis

**dn uncertainty**
The dn uncertainty was determined by the standard deviation of the mean for all scans and samples used (known bias between EV and SV has been removed in the processing)

This uncertainty calculation was performed separately for both $dn_{EV}$ and $dn_{BB}$

The $dn_{EV}$ uncertainty was estimated by fitting the 12/2012 WUCD data

Statistics were used to lower the $dn_{BB}$ uncertainty

A factor of the square root of 2 or 3 was used to decrease the $dn_{EV}$ uncertainty of the inner aggregation zones

Some known biases have not been included (M16 TDI, Aggregation, M13 A vs F)
Assumed not applicable to uniform scenes

# Uncertainty Propagation

**Uncertainty Propagation**
Use NIST standard approach

For a function $y=f(x_1,\ldots x_N)$
- $u(x_i)$ is the uncertainty in the parameter $x_i$
- $u(x_i,x_j)$ is the covariance of parameters $x_i$ and $x_j$
- N is the number of parameters

Uncertainties may include both random errors and biases

$$u^2(y)=\sum_{i=1}^{N}\left(\frac{\partial y}{\partial x_i}\right)^2 u^2(x_i)+2\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\left(\frac{\partial y}{\partial x_i}\right)\left(\frac{\partial y}{\partial x_j}\right)u(x_i,x_j)$$