Suomi NPP/JPSS Cross-track Infrared Sounder (CrIS): Radiometric and Spectral Performance

Hank Revercomb, Dave Tobin, Bob Knuteson, Fred, Best, Joe Taylor, Dan Deslover, Lori Borg, Graeme Martin, Greg Quinn, Ray Garcia, and the UW Atmosphere PEATE Team

University of Wisconsin - Madison
Space Science and Engineering Center (SSEC)

AMS Annual Meeting, 9th Symposium on Future Operational Environmental Satellite Systems
Suomi NPP/JPSS Cal/Val &Product Development
Austin, TX, 8 January 2013

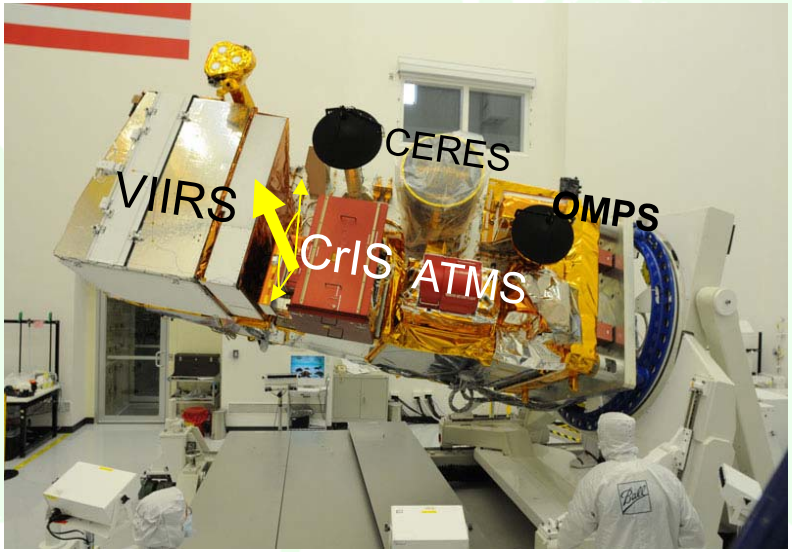
CrIS Sensor Data Record Team

PI Name	Organization	Funding Agency
Yong Han*	NOAA/STAR	NOAA JPSS Office (NJO)
Deron Scott	USU/SDL	NJO
Hank Revercomb	UWisconsin/SSEC	NJO
Larrabee Strow	UMBC	NJO
Dan Mooney	MIT/LL	NJO
Neal Baker	JPSS/Data Prod. & Anal.	NJO
Dave Johnson	NASA	NASA
Joe Predina	Exelis (ITT)	NASA / NJO
Degui Gu	NGAS	NASA
Wael Ibrahim	Raytheon	NASA

**** Team lead***

Topics

1) CrIS Background
2) Radiometric Calibration Accuracy
   1) Preflight assessment
   2) On-orbit refinement
3) Spectral Calibration Accuracy
   1) Preflight
   2) On-orbit refinement
4) On-orbit Inter-comparison to AIRS, IASI, S-HIS
5) Future

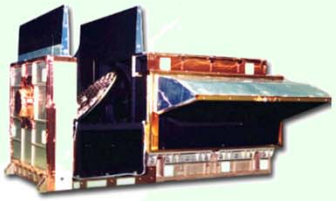


Suomi NPP Spacecraft

LEO (& Aircraft) Sounders

1978-

HIRS
(20 ch)

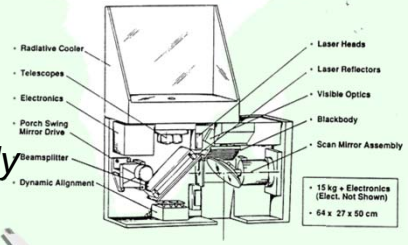


1986-

HIS, S-HIS, NAST-I

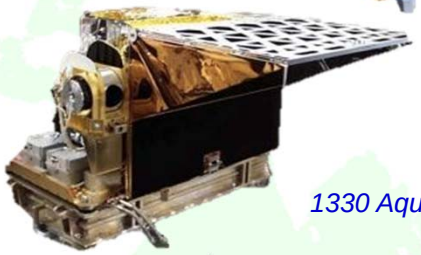
1990/91

ITS (~CrIS)
UW Design Study



2002-

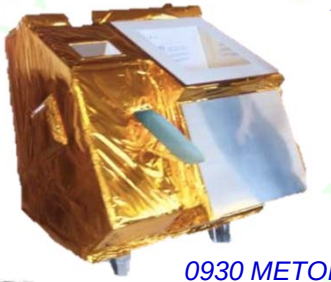
AIRS
(2378 ch)



1330 Aqua

2006-

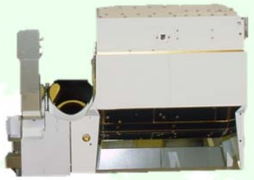
IASI
(8461 ch)



0930 METOP

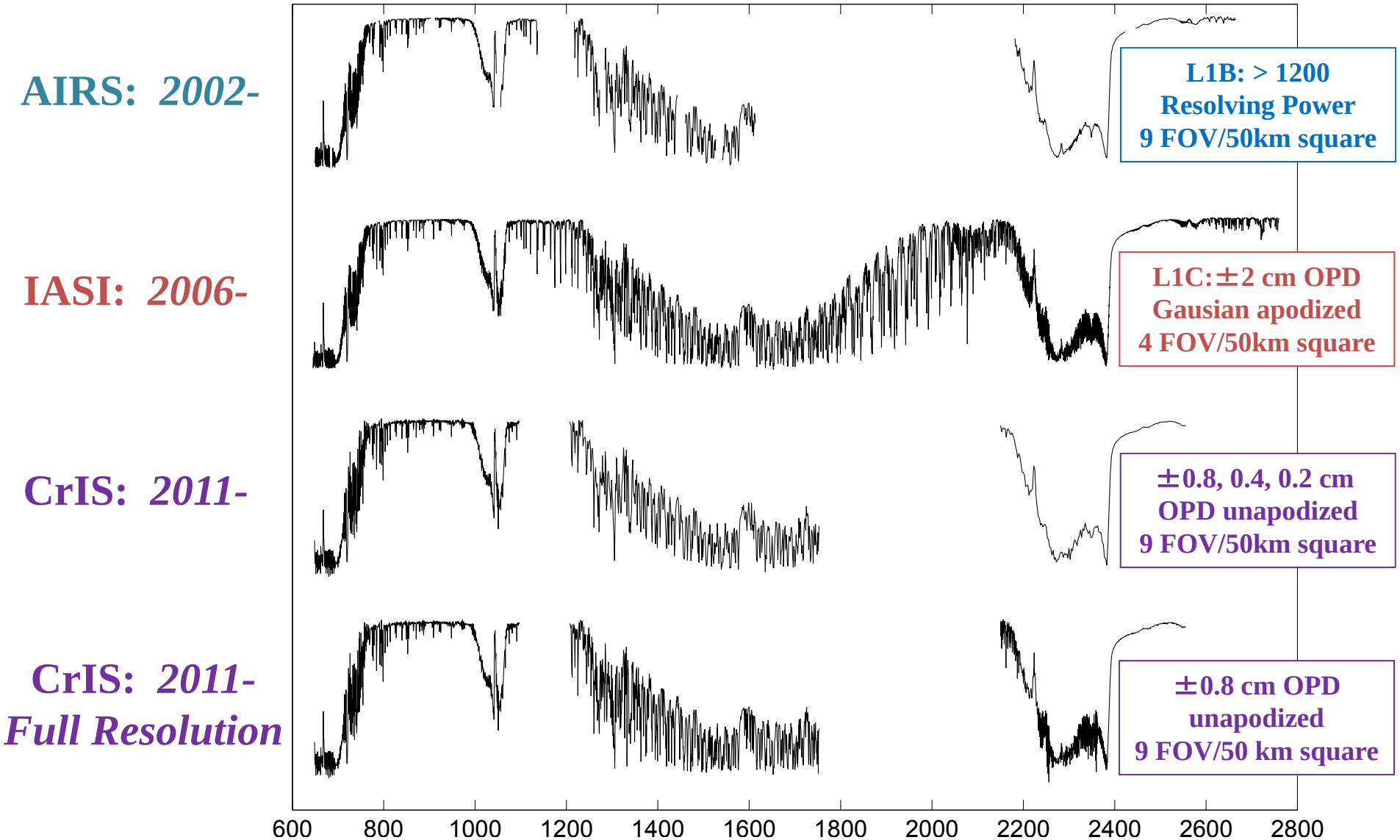
2011-

CrIS
(2211 ch)



1330 Suomi-NPP

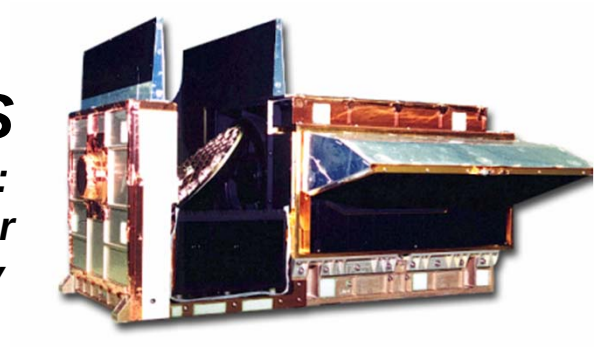
Spectral Coverage and Resolution Comparison



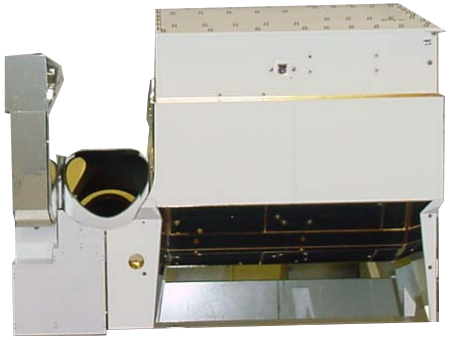
from LBLRTM for US Standard Atmosphere

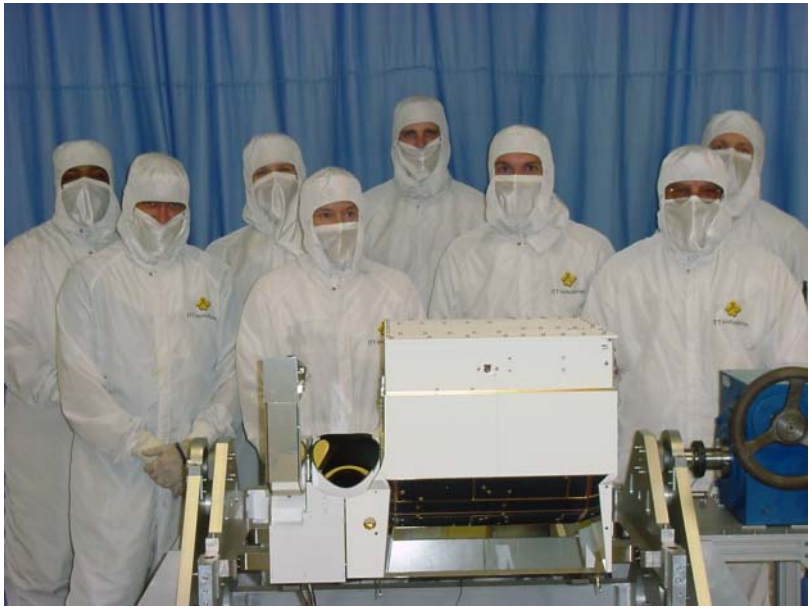
CrIS—about the size of HIRS

HIRS
(20 ch):
30+ year history



CrIS
(1307 ch):
NPP/JPSS

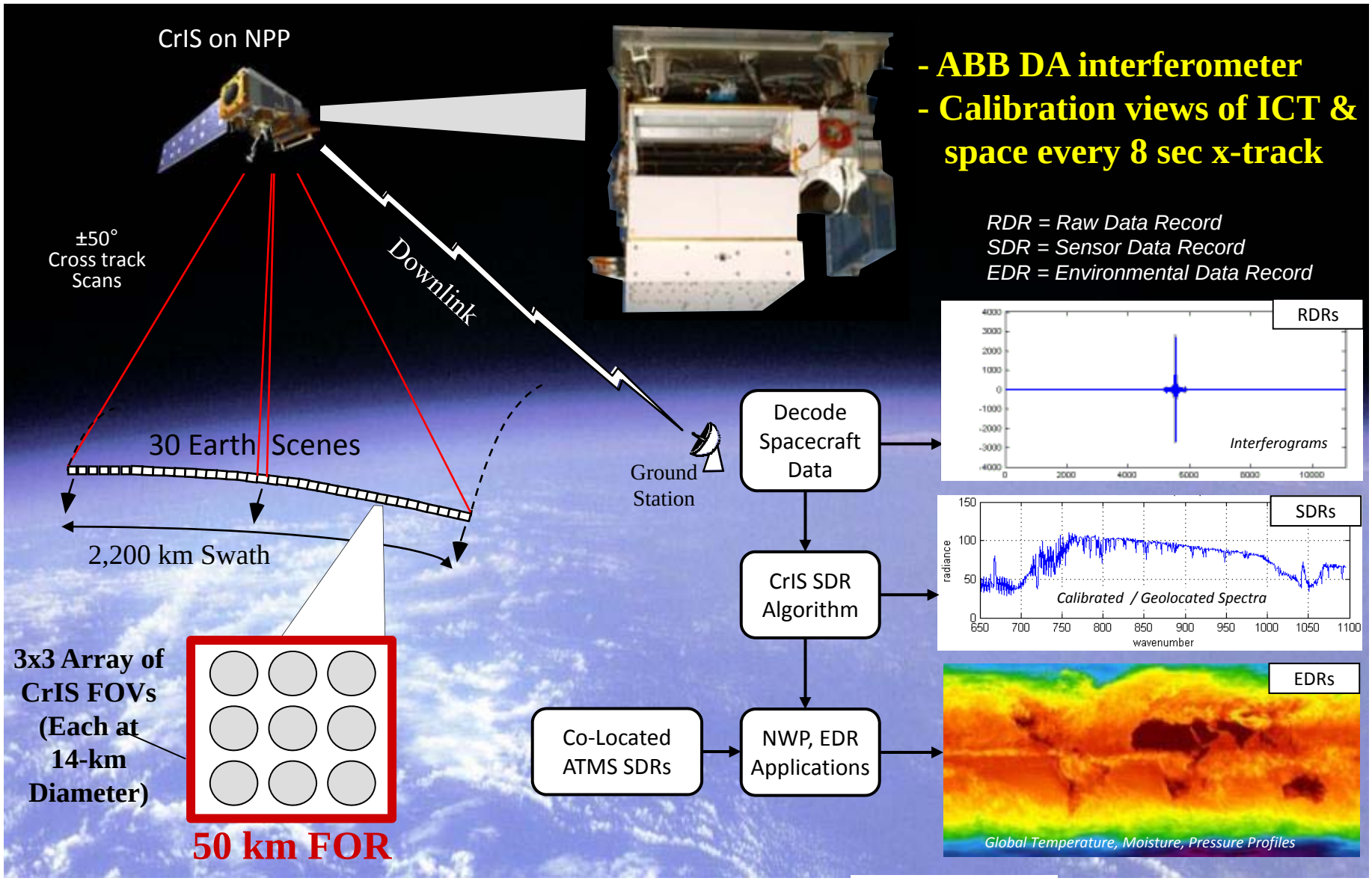




Volume: < 71 x 80 x 95 cm
Mass: 146 kg
Power: 110 W

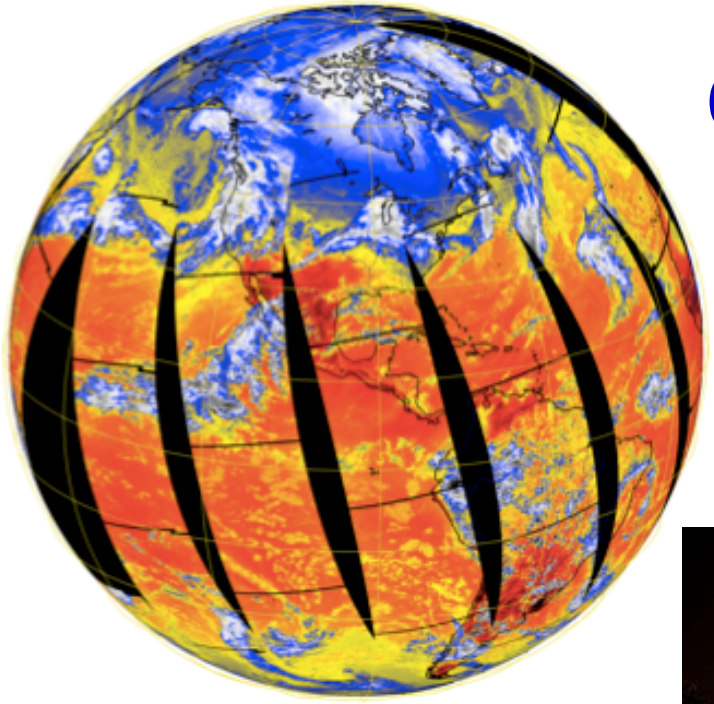
from Williams, Glumb and Predina, ITT, August 2005 SPIE

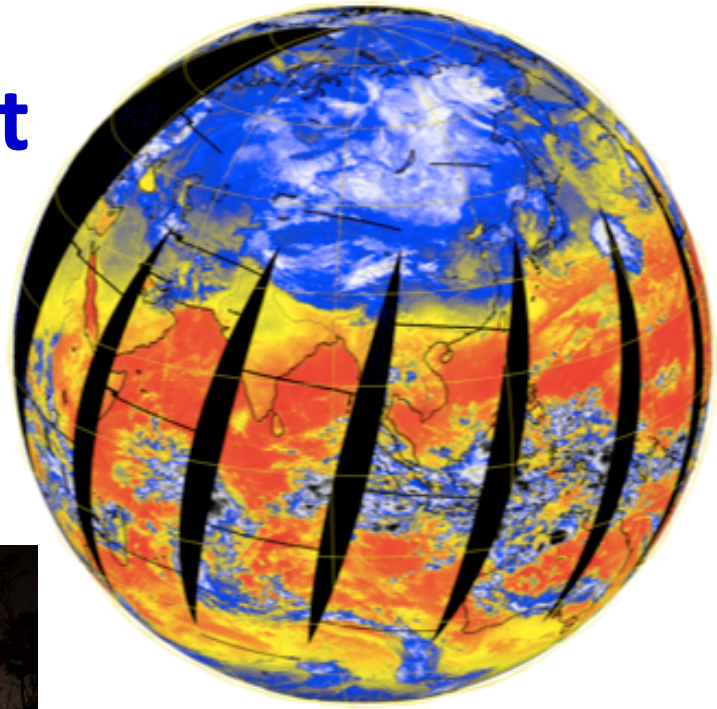
CrIS Operational Concept



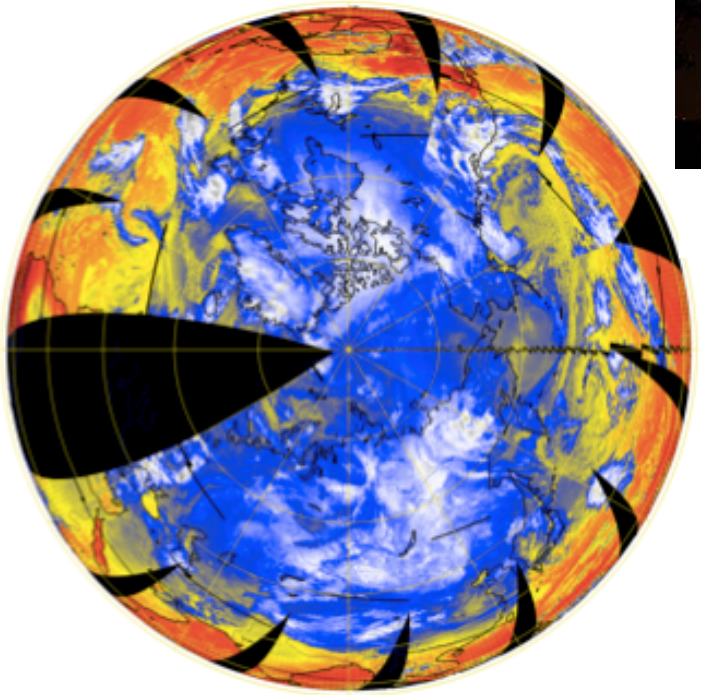
CrIS 1st Light

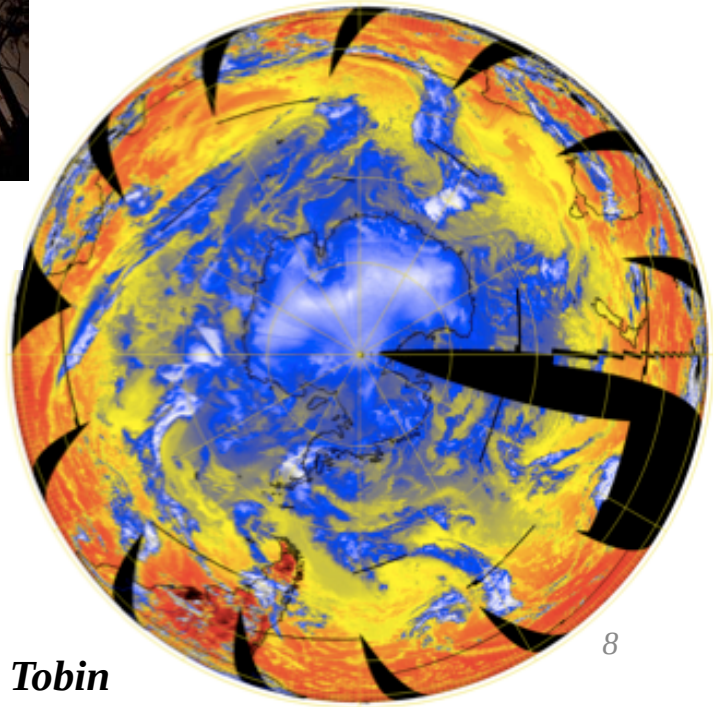
20-Jan-2012





Suomi-NPP launch



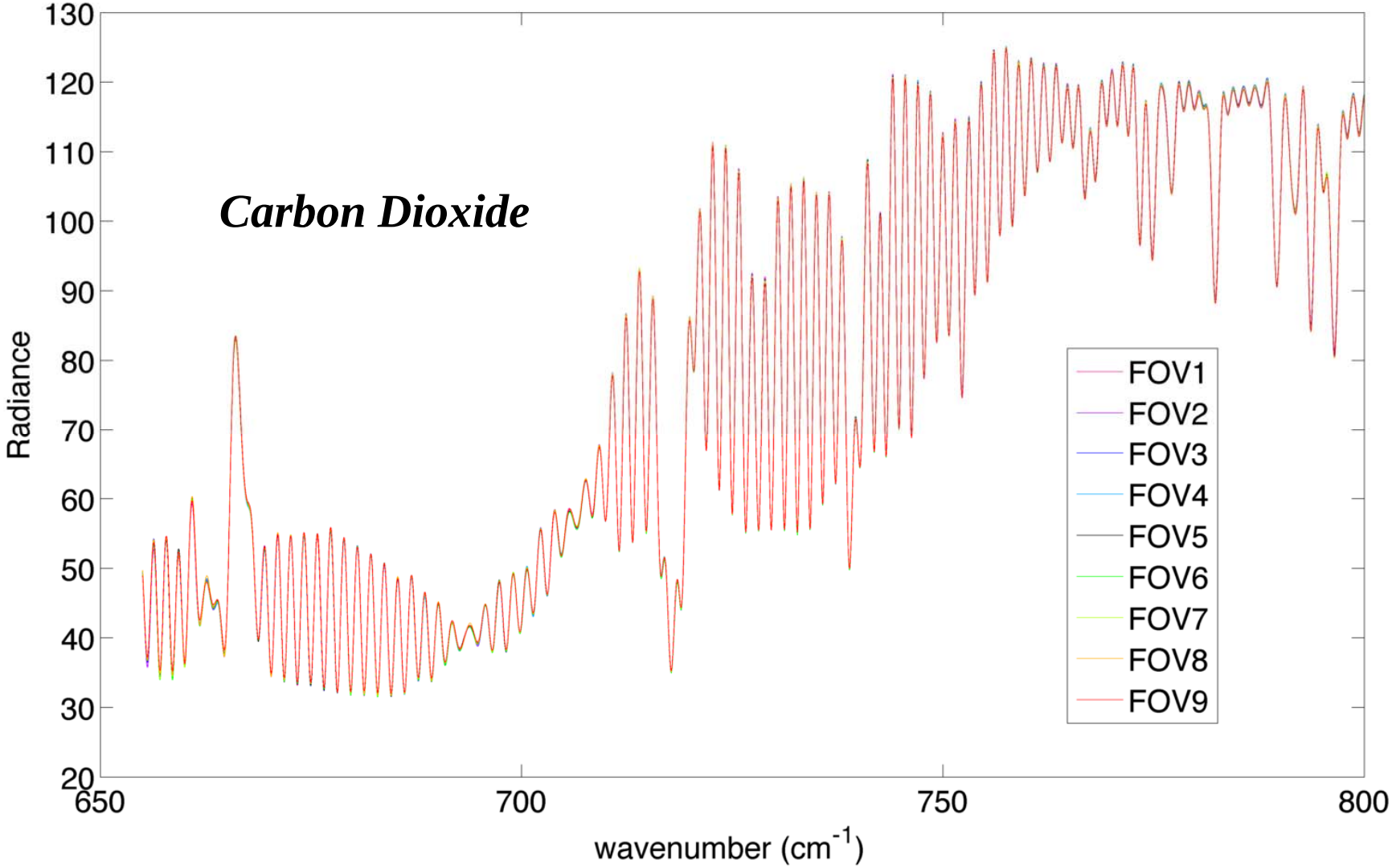


900 cm^{-1} BT (K) Window

Dave Tobin

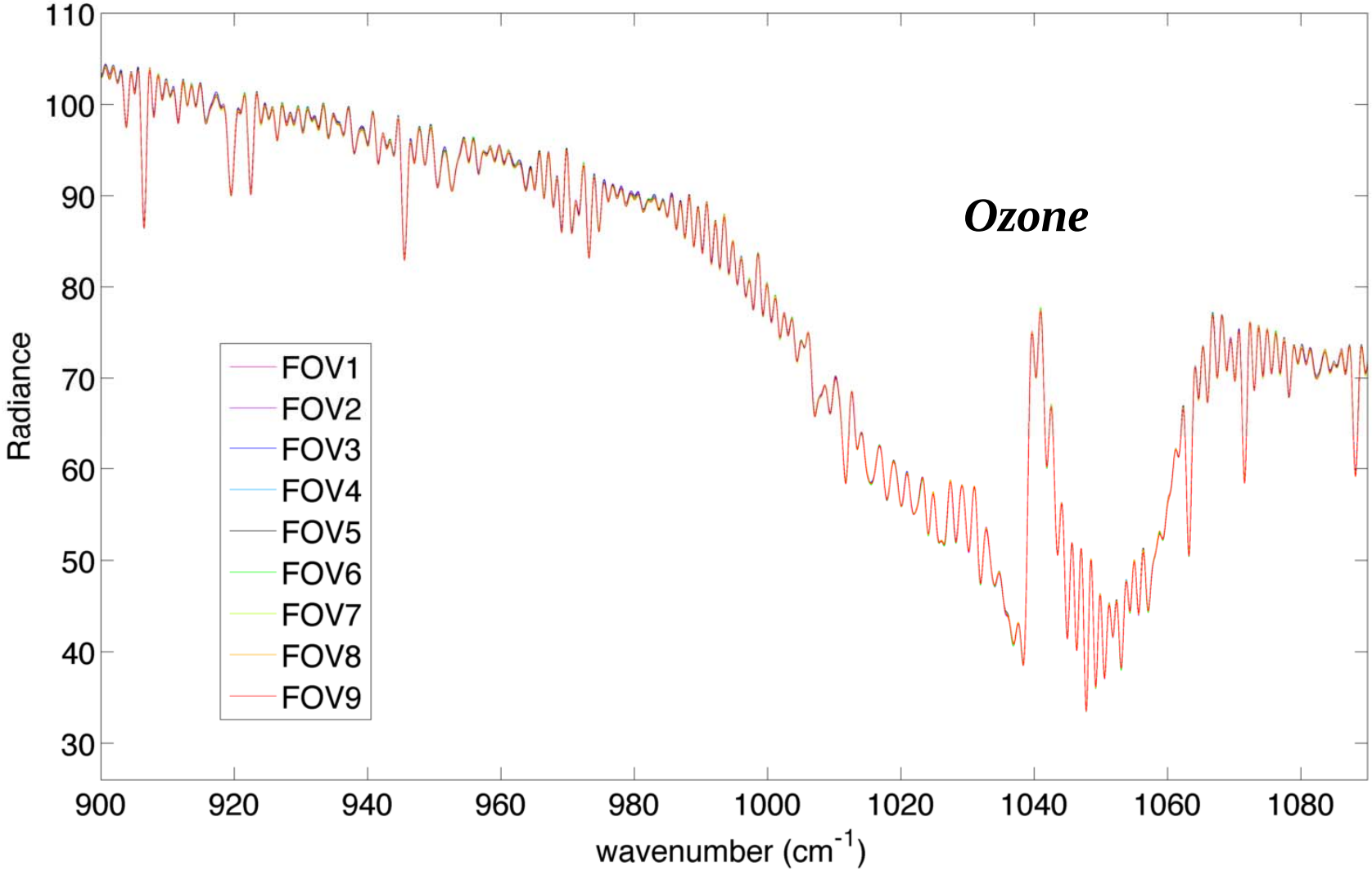
Sample "1st Light" spectra (20 January)

Overlays for a uniform 3x3 FOR



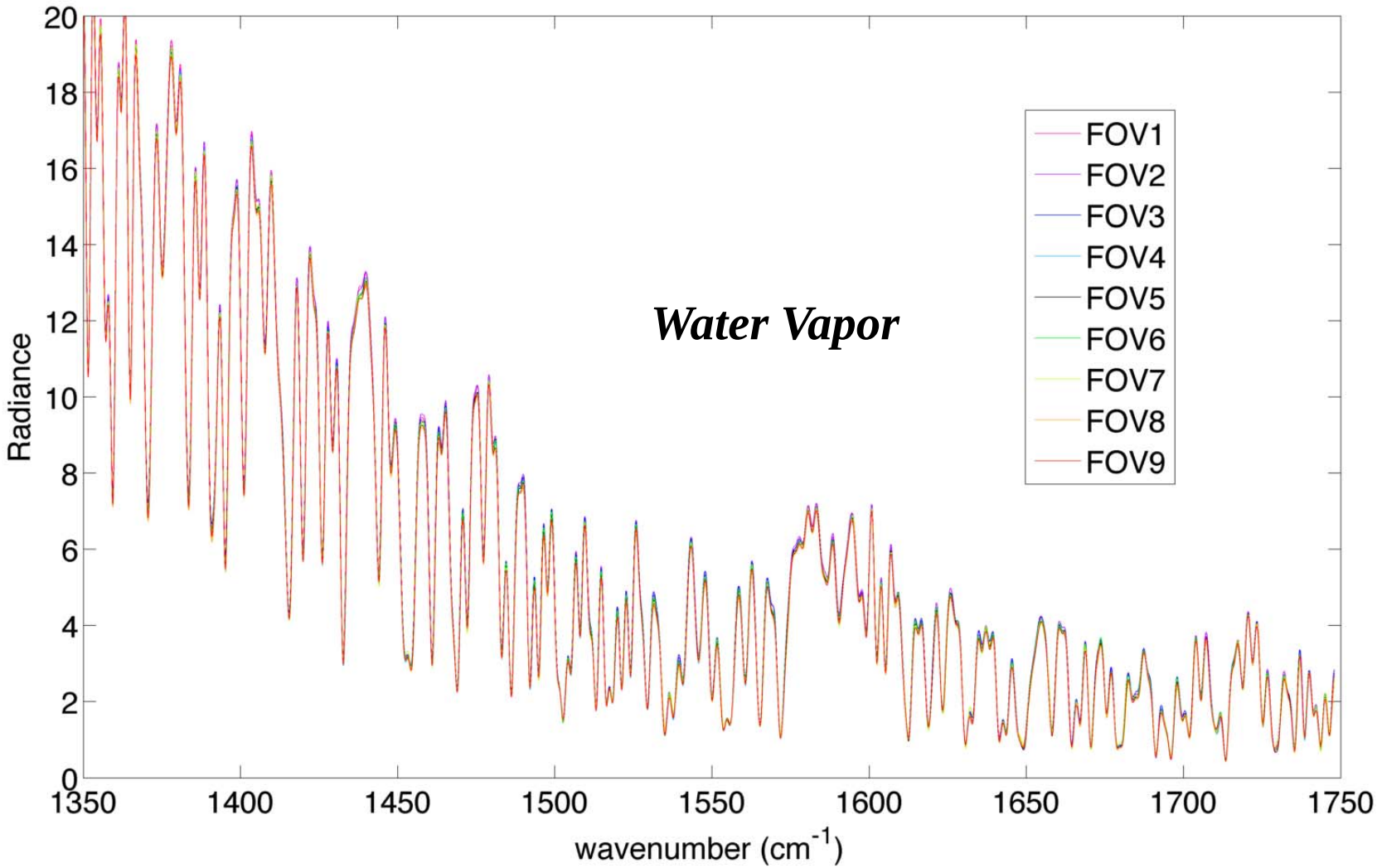
Sample "1st Light" spectra (20 January)

Overlays for a uniform 3x3 FOR



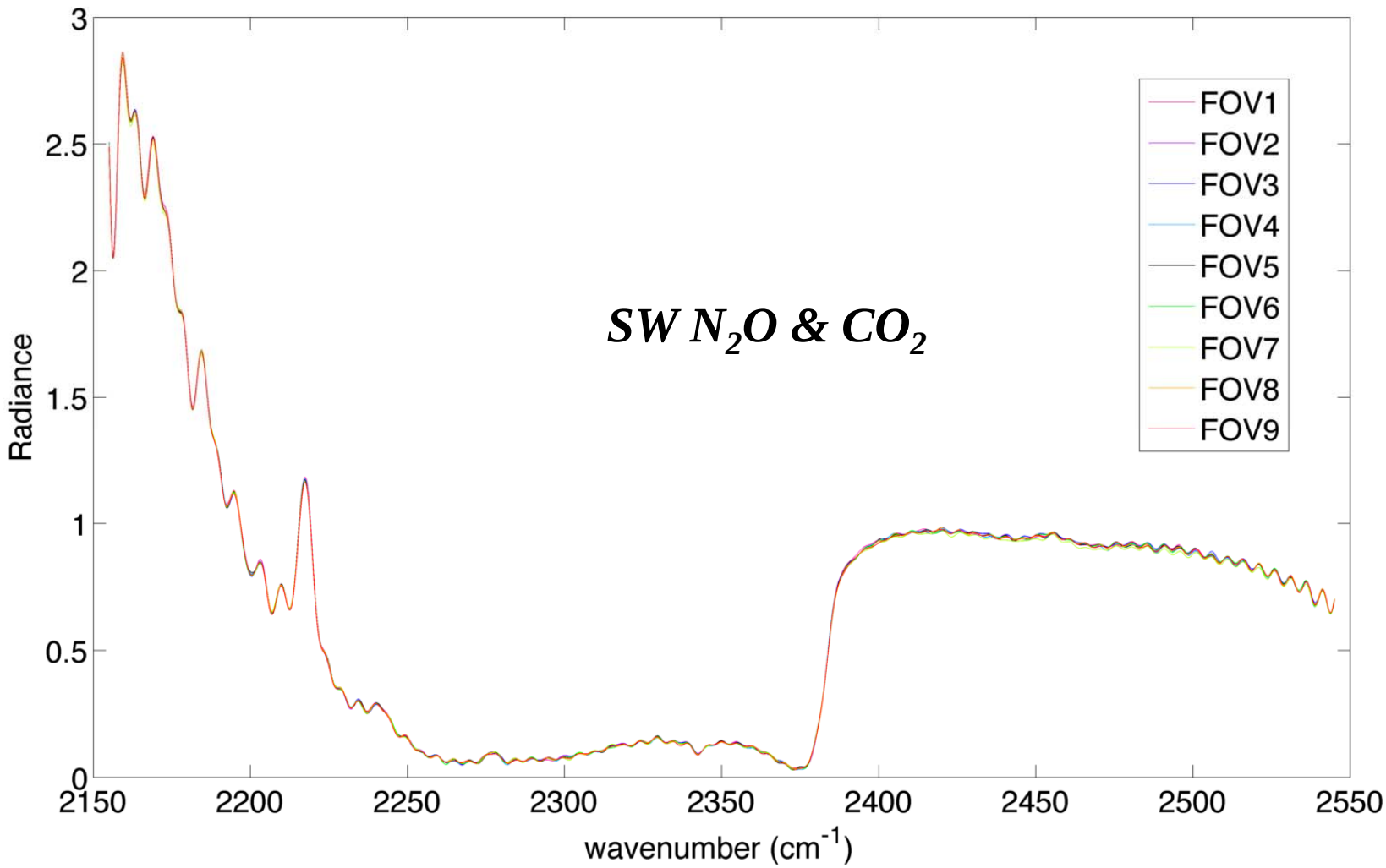
Sample "1st Light" spectra (20 January)

Overlays for a uniform 3x3 FOR



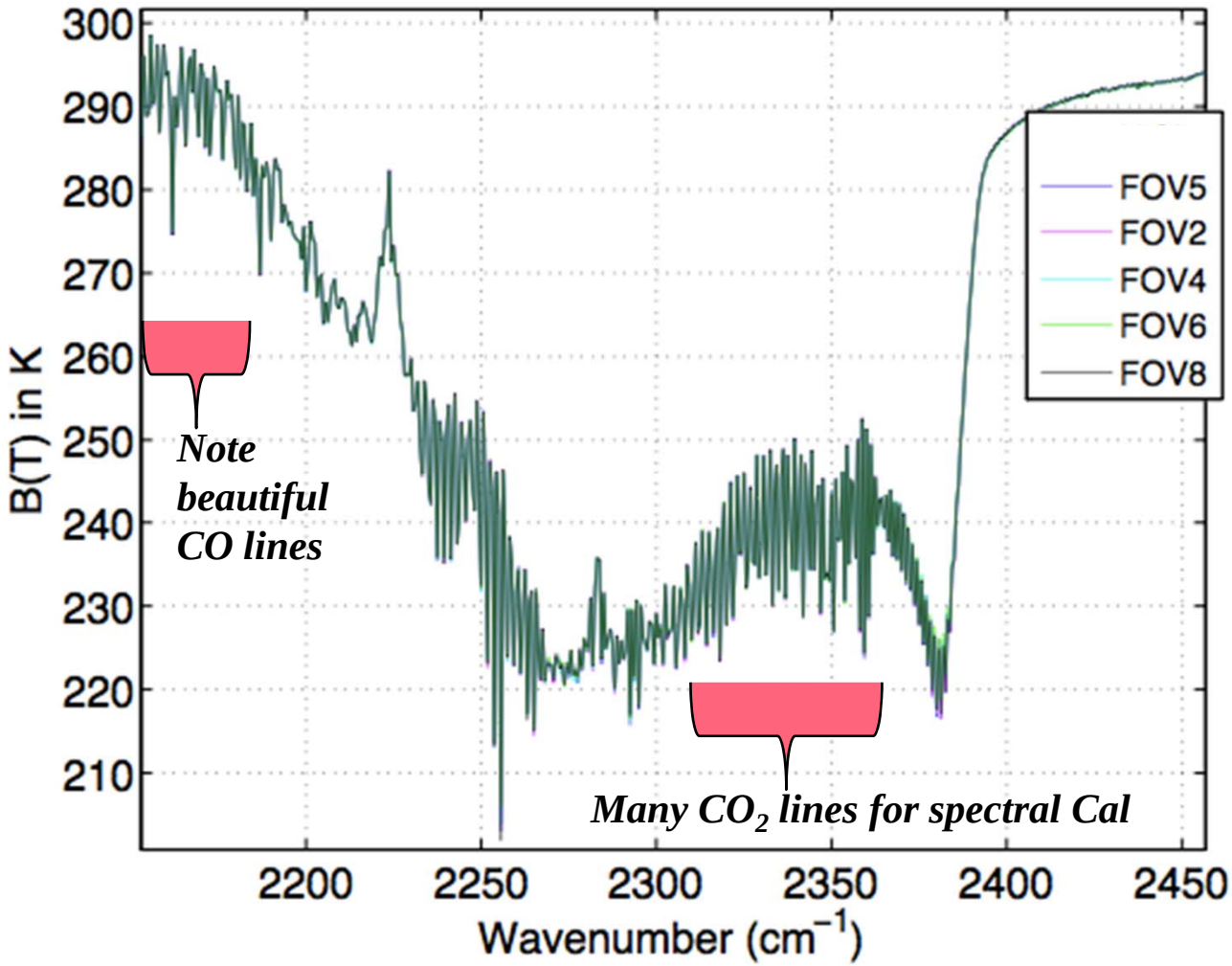
Sample "1st Light" spectra (20 January)

Overlays for a uniform 3x3 FOR



Full Resolution SW band from CrIS

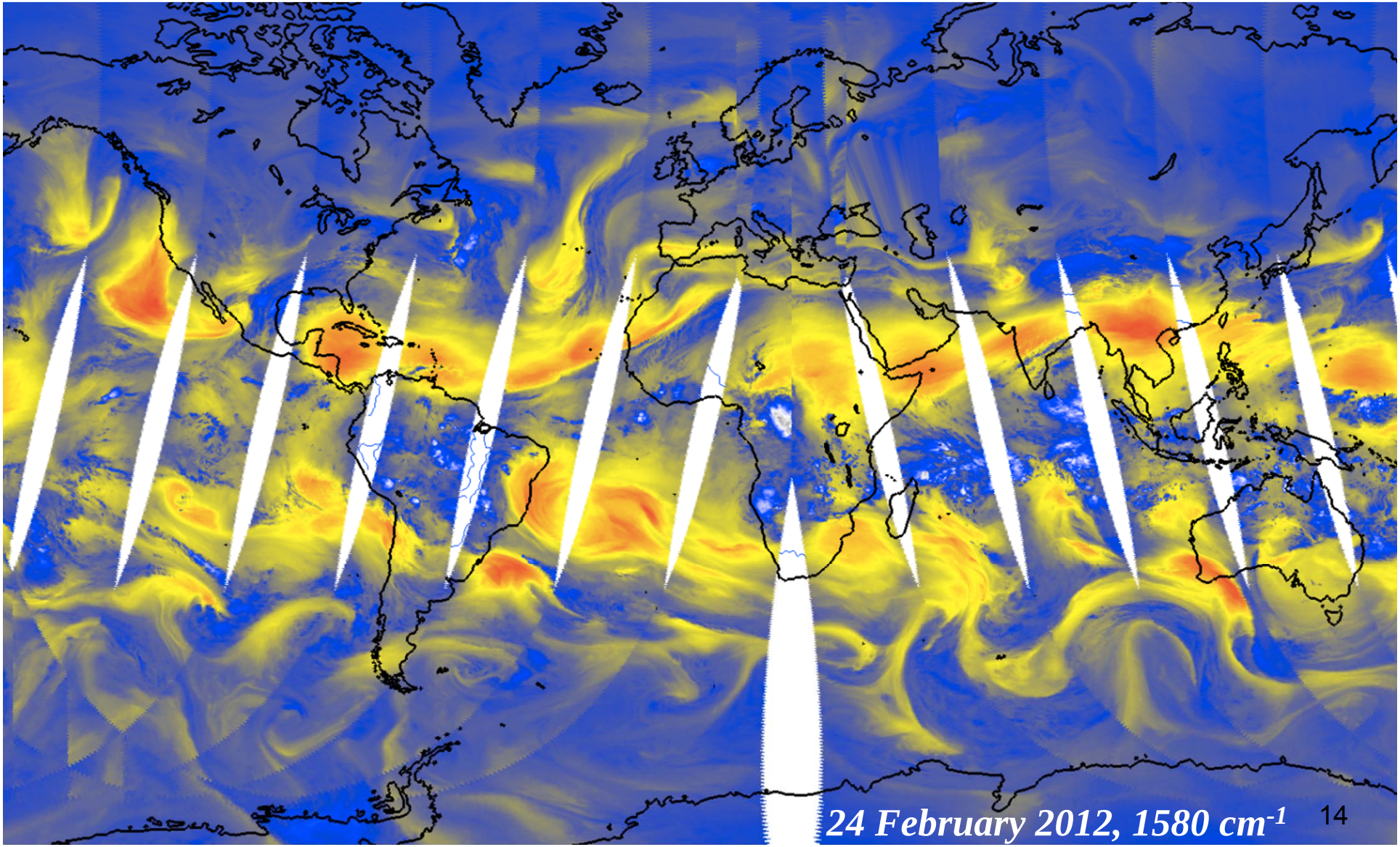
Routine downlink to start ~June 2013



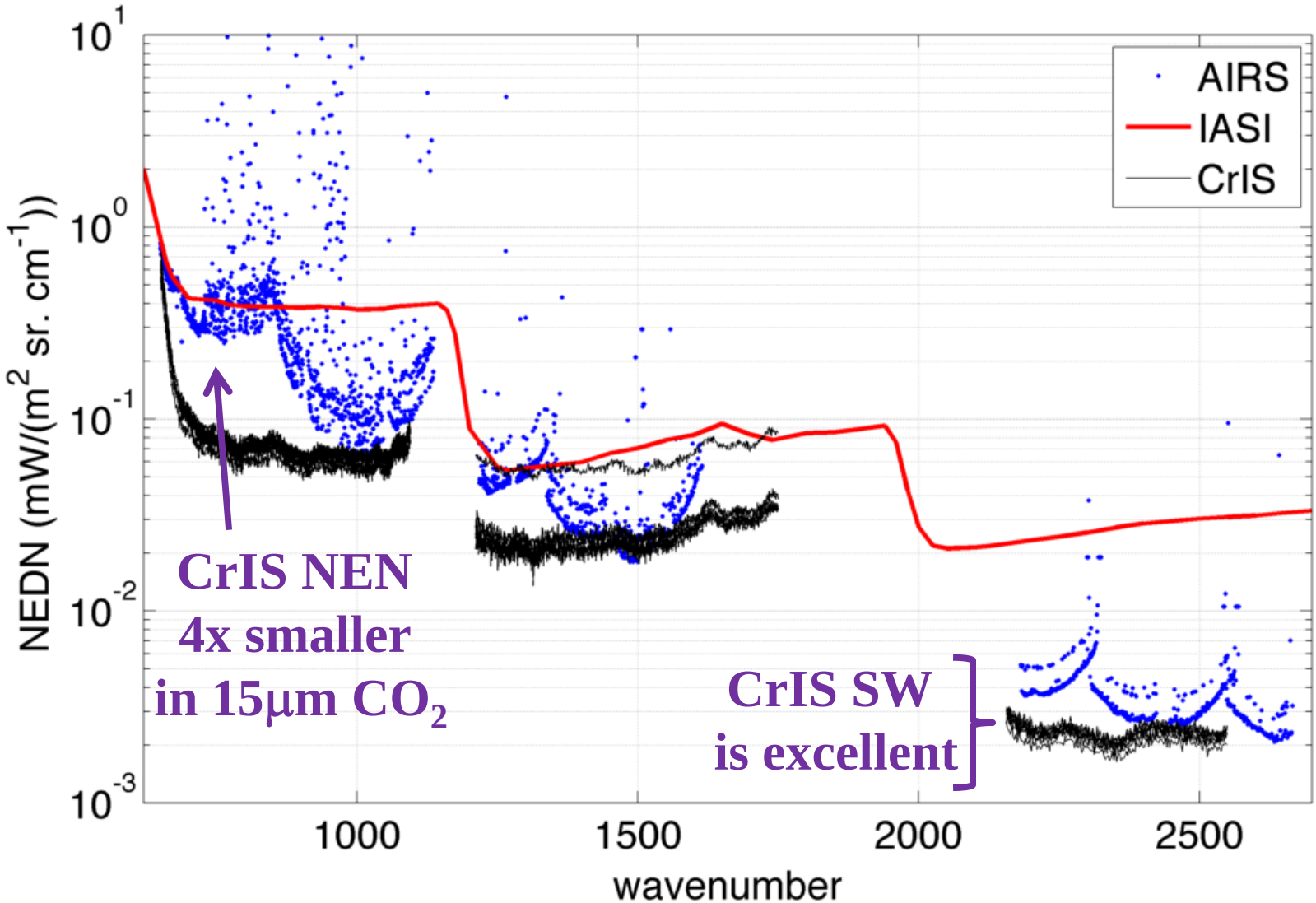
Calibrated with UW/UMBC CCAST

Water Vapor Map from CrIS

Especially important given lack of WV channels on VIIRS



Noise Comparison:
CrIS, AIRS L1B, IASI L1C

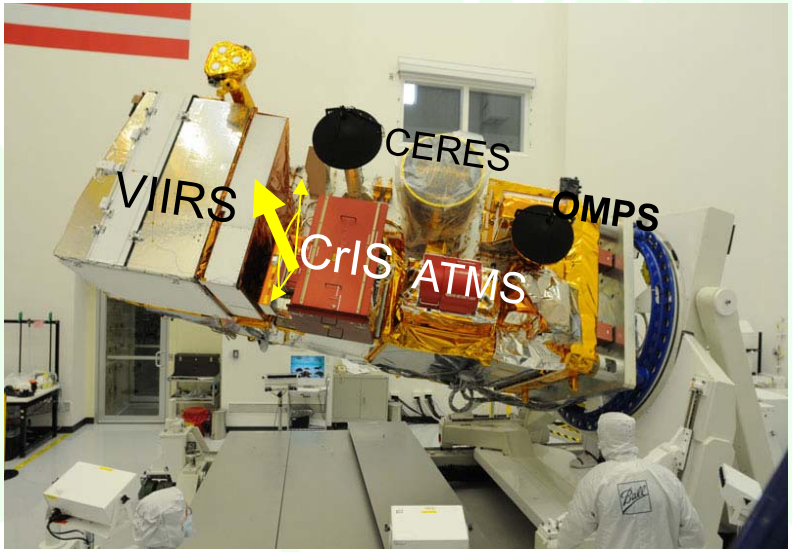


Performance Notes:
(what did **not** happen)

- Interferometric noise (spectrally correlated) is exceptionally small– therefore, the vibration isolation stage was not deployed
- No interferometer fringe count errors
- Radiation/particle induced Spikes are essentially non-existent – only 2 detected since launch!
- No signs of transmittance reduction from Ice buildup
- ILS effects on climate mean spectra from non-uniform scenes is very small (demonstrated by difference of corner and center FOV means)

Topics

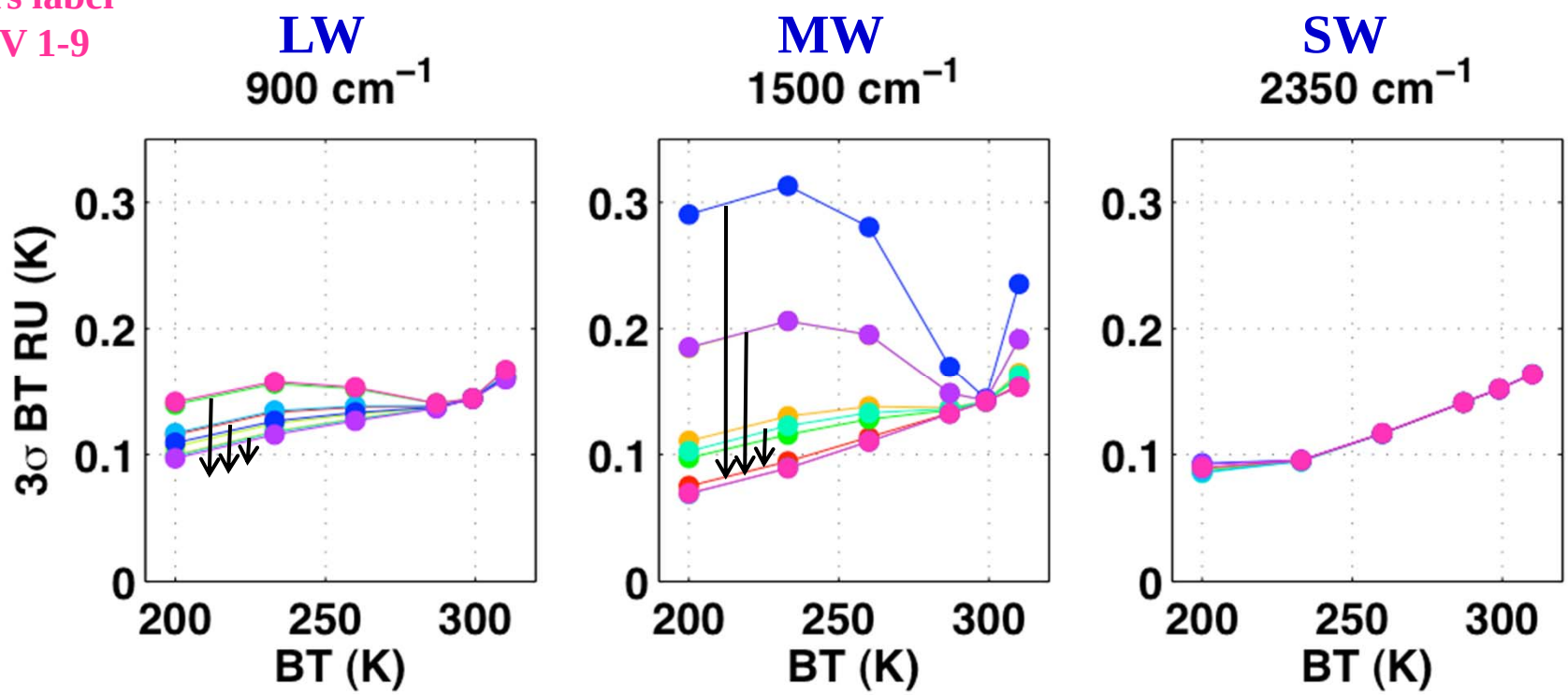
1) CrIS Background
2) Radiometric Calibration Accuracy
   1) Preflight assessment
   2) On-orbit refinement
3) Spectral Calibration Accuracy
   1) Preflight
   2) On-orbit refinement
4) On-orbit Inter-comparison to AIRS, IASI, S-HIS
5) Future



Suomi NPP Spacecraft

Expected Radiometric Uncertainty

Colors label
FOV 1-9



- *FOV to FOV spread in LW and especially MW is due to non-linearity*
- *SW is linear with uncertainty dominated by ICT temperature uncertainty*

Final on-orbit uncertainty < 0.2 K 3-sigma!

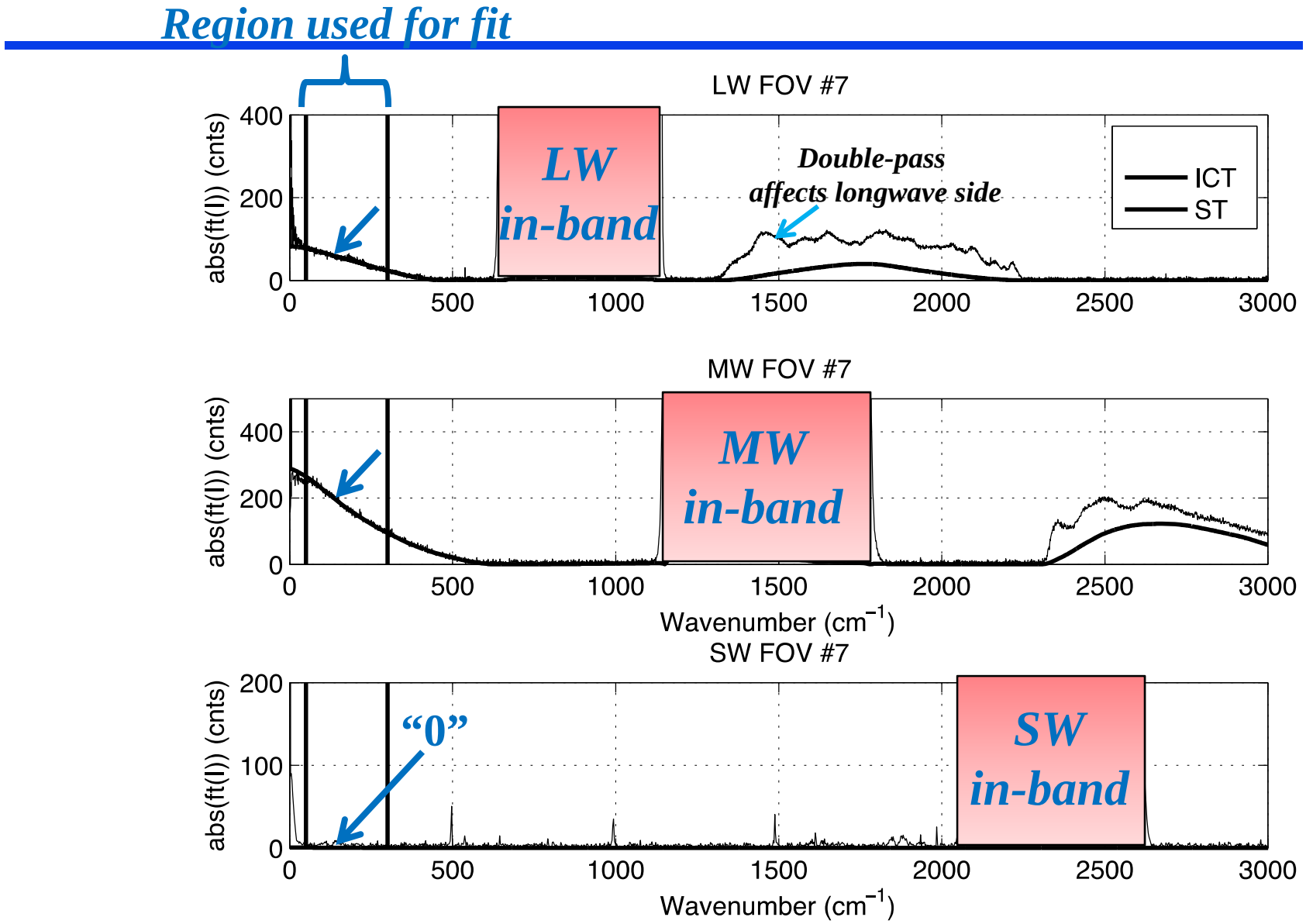
(after inflight non-linearity refinement)

Non-linearity Correction
2 Tools for On-orbit Refinement

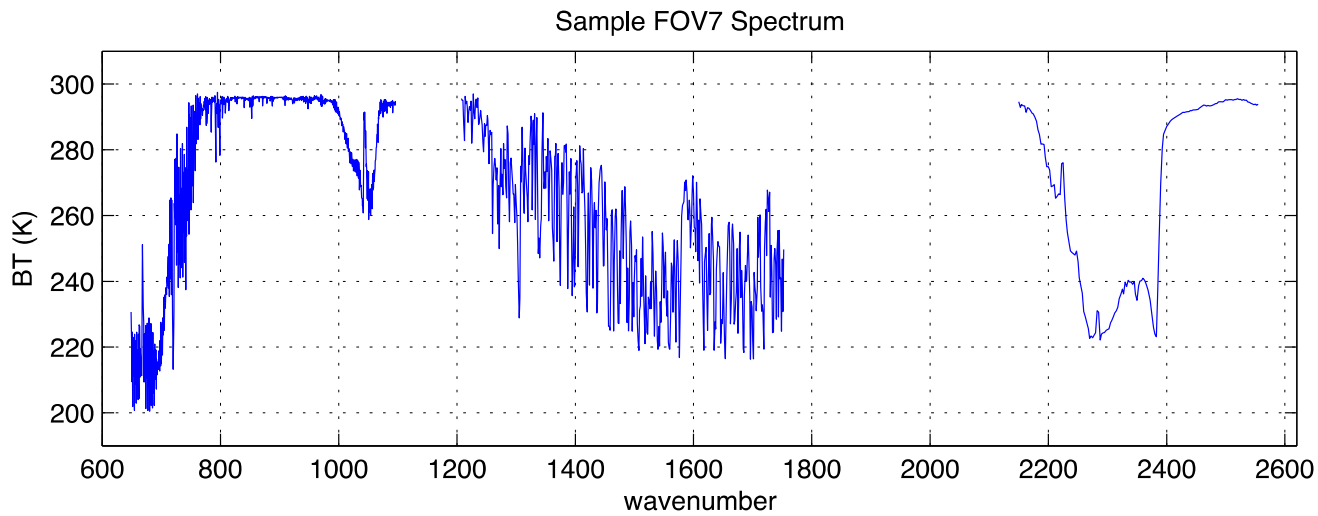
- **Out-of-Band Harmonic Monitoring**
  - Shape fits squared non-linearity
  - Low wavenumber signal fit to a_2, coefficient of squared term
- **Relative FOV-to-FOV adjustments with Earth data**
  - As reference, MW uses its one very linear detector (FOV9)
  - As reference, LW uses a_2 for FOV5 from Out-of-Band Harmonic analysis

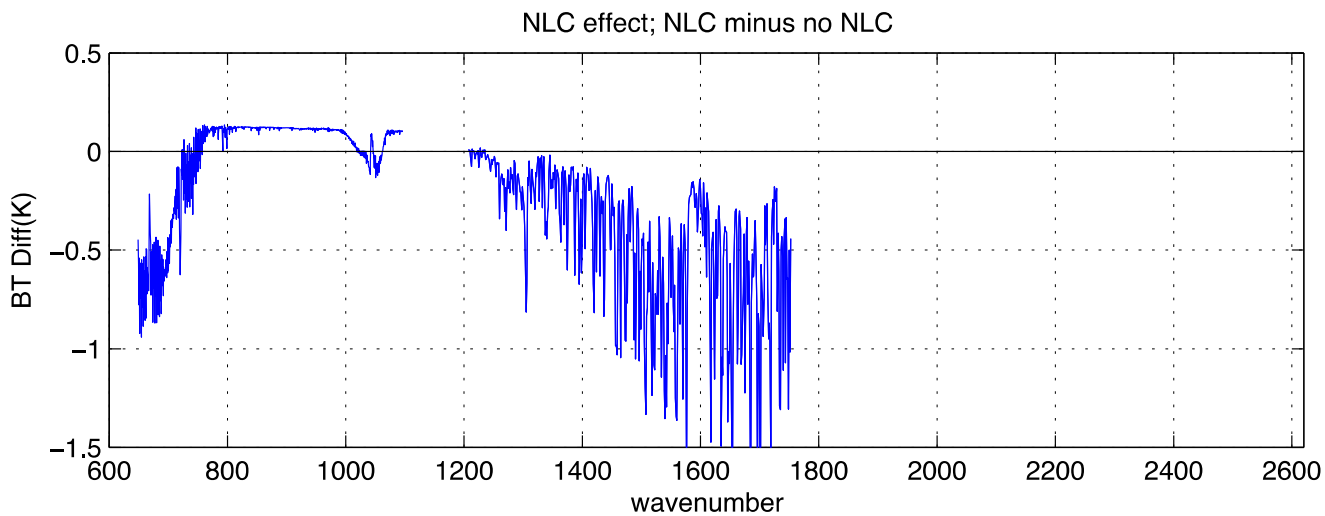
See Knuteson et al., GOES-R/JPSS Posters Part 1, #301

Fit for squared non-linearity coefficient a_2



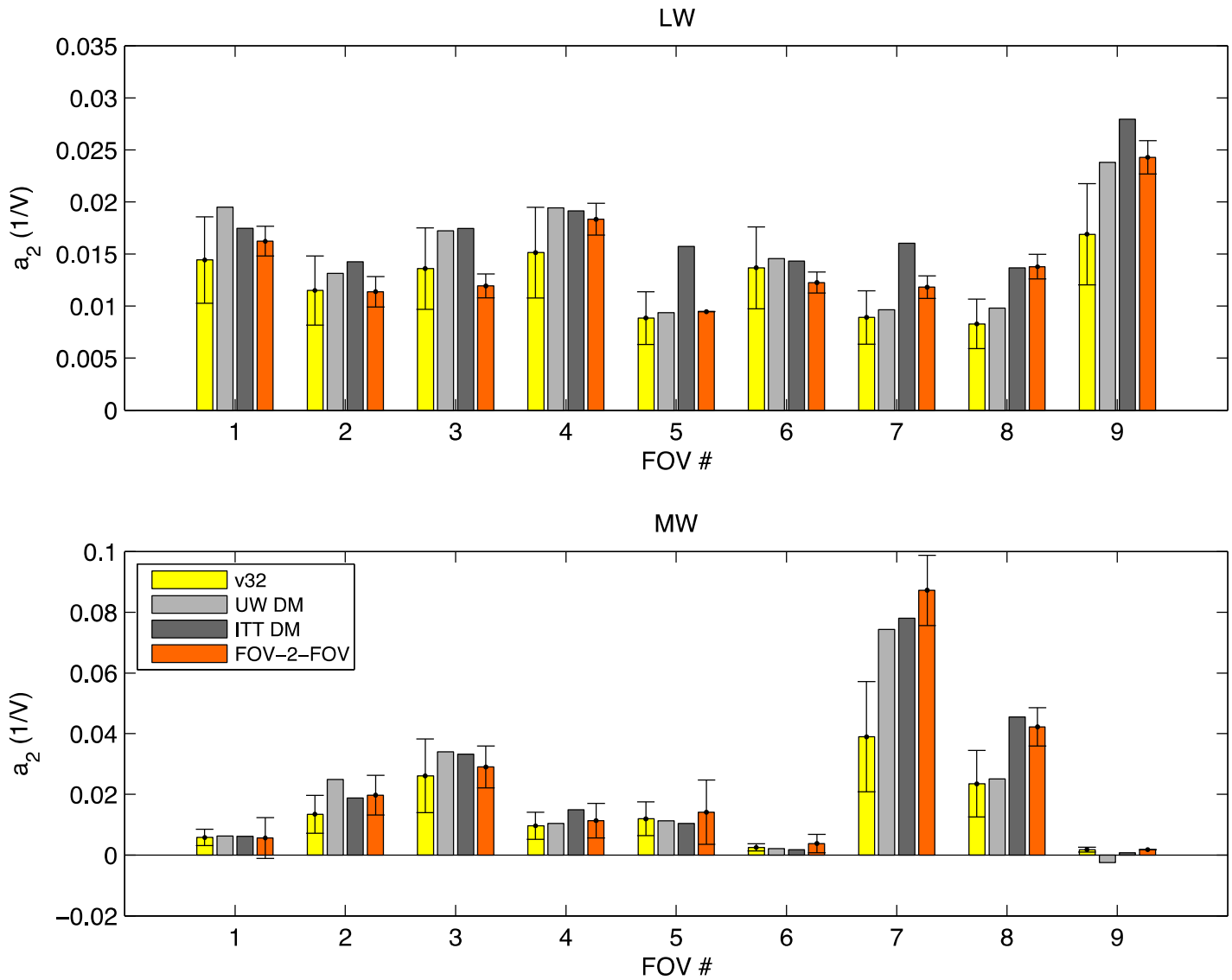
Example Non-linearity
(For FOV with Largest Non-linearity)





Largest correction can exceed 1.5 K

Non-Linearity Correction Coefficient, a_2



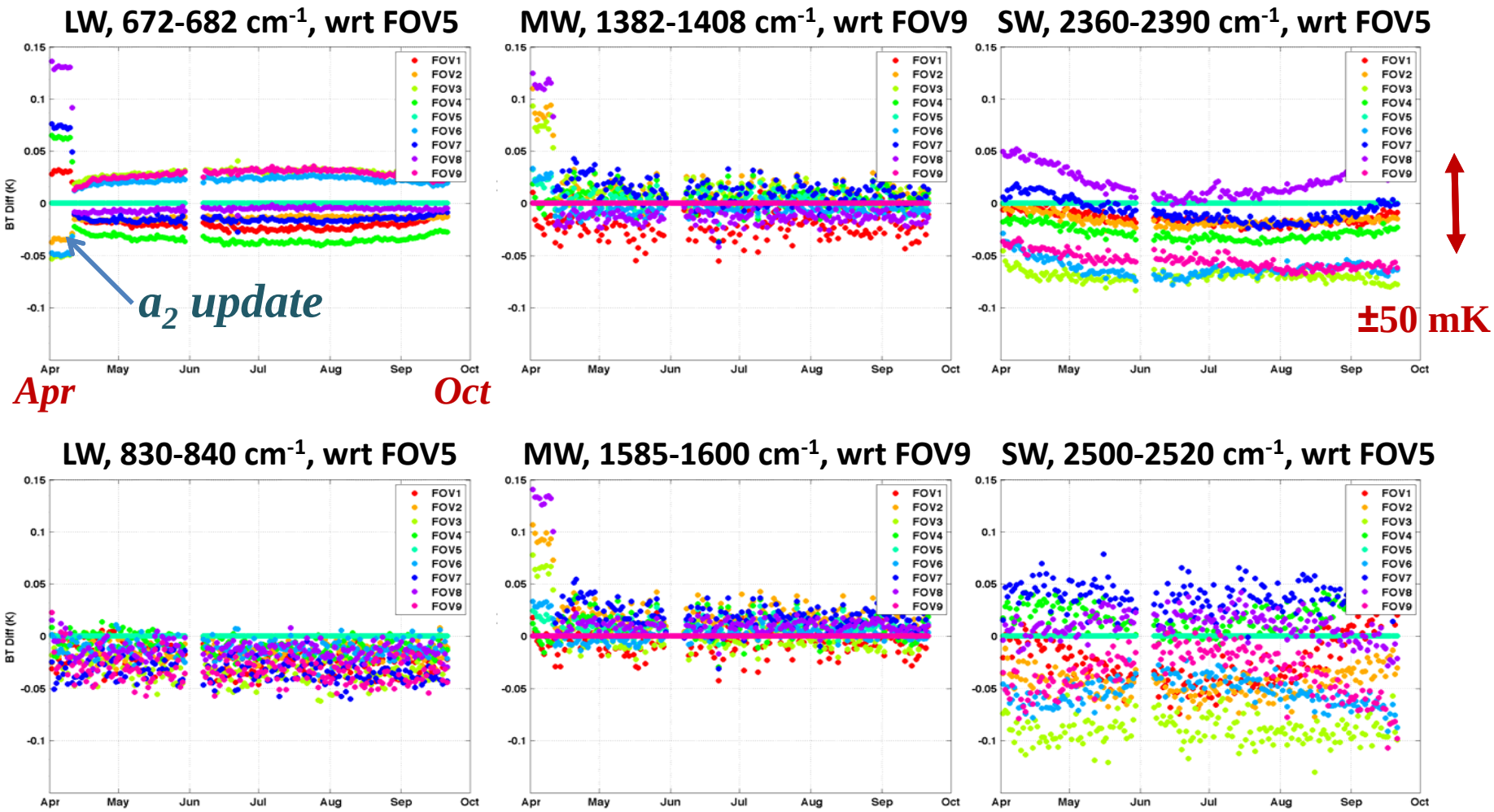
v32 based on TVAC3; "02" based on Earth view FOV-to-FOV analysis; Gray from Out-of-Band analyses

Corrected Raw Complex Spectrum = Raw Complex Spectrum $\times$ (1+ 2 a_2 V)

where V is DC level voltage at 1st stage of preamplifier

CrIS FOV-to-FOV Difference Stability

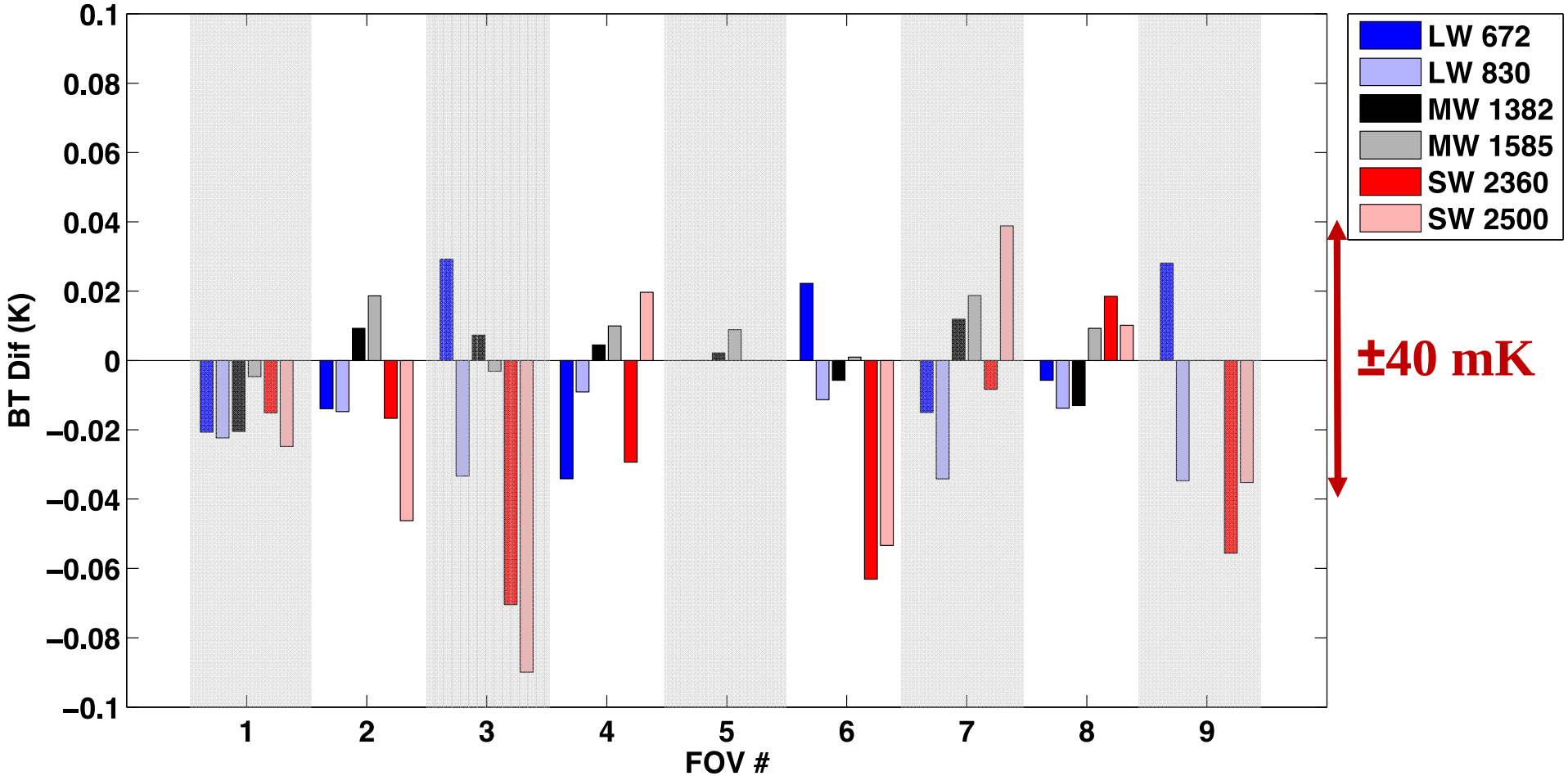
April – October 2012 Daily mean differences



- No conclusive evidence for a_2 change exceeding the 10% level
- Further refinements in progress

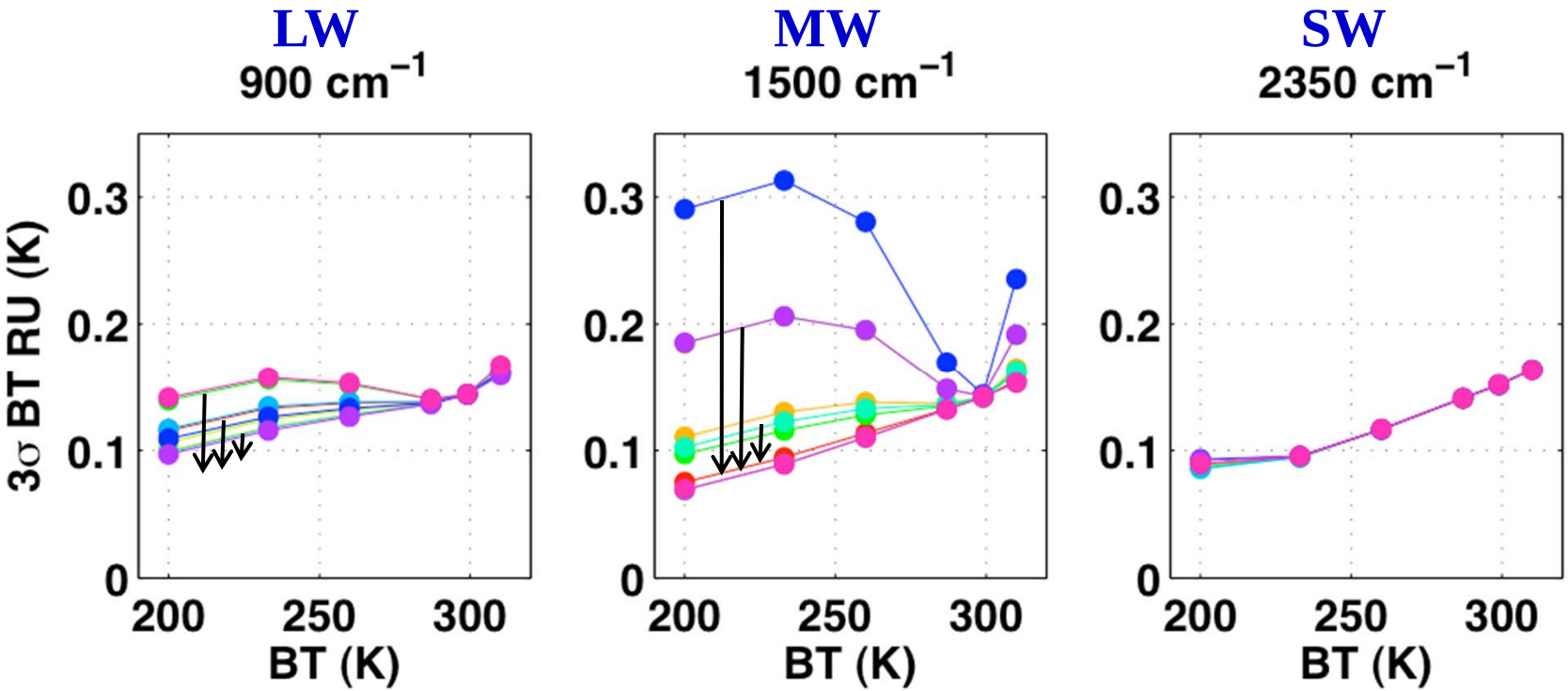
CrIS FOV-to-FOV Differences

Mean T_b Differences over last 6 months



- LW and MW values are less than ~30mK.
- SW values are larger, particularly for FOVs 3,6, and 9, for both opaque and window regions.

Expected Radiometric Uncertainty



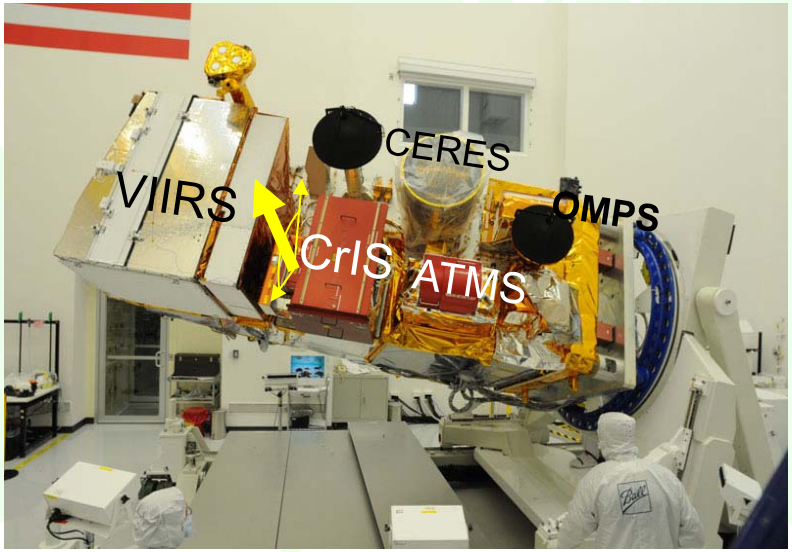
Current liens on achieving < 0.2 K 3-σ ∀ ν:

(1) Gibbs effect ringing at some LW & SW regions

(2) Possible small SW FOV-dependent bias

Topics

1) CrIS Background
2) Radiometric Calibration Accuracy
   1) Preflight assessment
   2) On-orbit refinement
3) Spectral Calibration Accuracy
   1) Preflight
   2) On-orbit refinement
4) On-orbit Inter-comparison to AIRS, IASI, S-HIS
5) Future



Suomi NPP Spacecraft

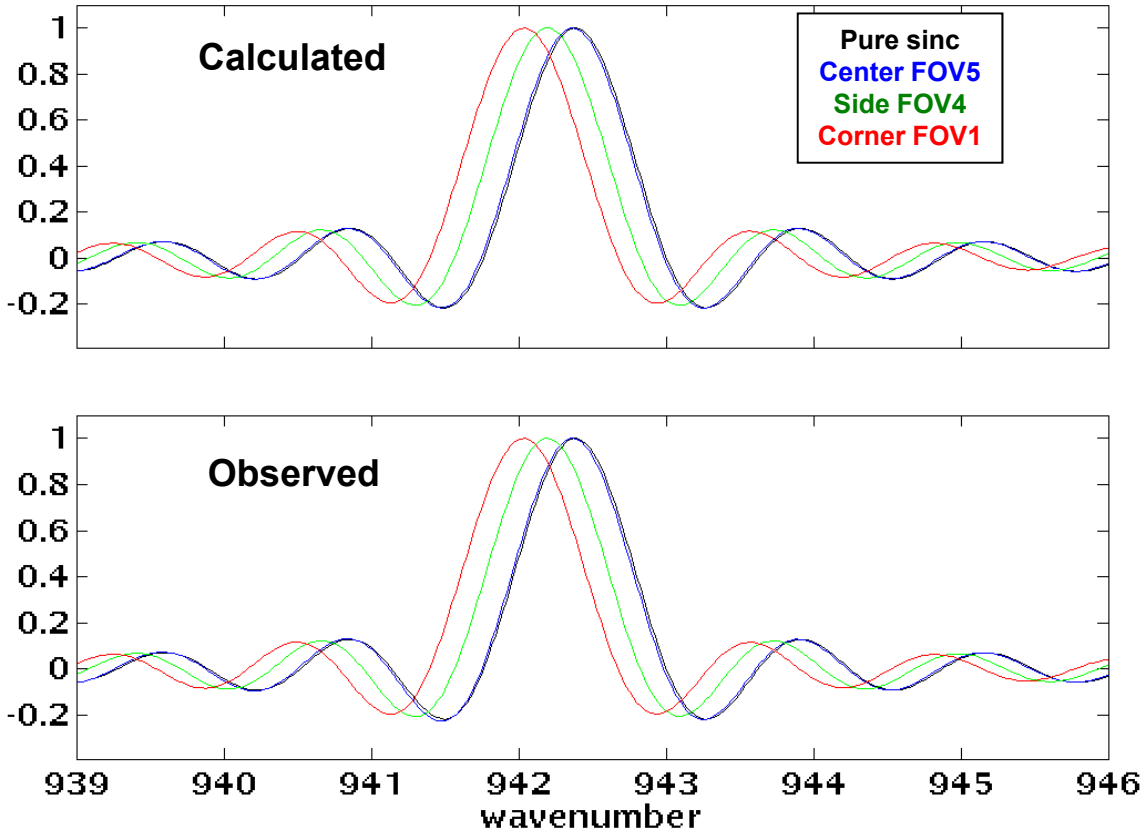
Pre-flight Spectral Characterization and Calibration

- Self Apodization Correction Proven Pre-flight
  - **Instrument Line Shape (ILS) for 3x3 array accurately understood**
  - **Matrix multiplication used for normalization to ideal sinc ILS**
- Gas cell tests used to verify Neon Source Calibration

CrIS Instrument Line Shapes (ILS)

Center, Side, Corner FOV

Processing needs to make ILS for all FOVs look like sinc (black)



		Center FOV	Side FOV	Corner FOV
centroid (cm^{-1})	Obs	942.367	942.195	942.034
	Calc	942.366	942.195	942.034
FWHM (cm^{-1})	Obs	0.747	0.757	0.767
	Calc	0.751	0.759	0.767
Lfoot	Obs	0.358	0.329	0.313
	Calc	0.347	0.328	0.313
Rfoot	Obs	0.347	0.326	0.311
	Calc	0.345	0.329	0.313

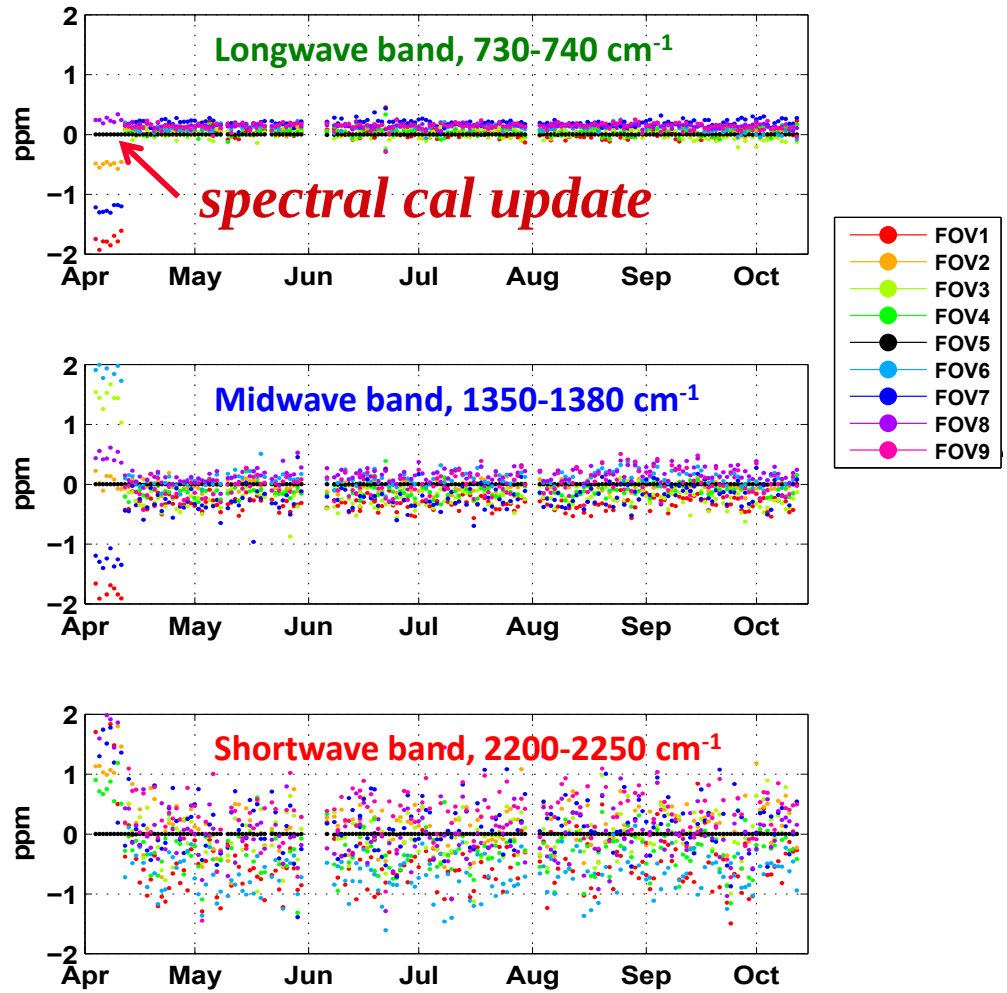
Example Center, Side, and Corner FOV ILSs, before Self-Apodization Corrections

On-orbit Spectral Calibration

- Relative FOV-to-FOV Adjustments
  - **No calculations needed**
  - **Highly accurate**
- Absolute Cal Verification performed by Larrabee Strow's group at UMBC
  - **Based on atmospheric calculations**
  - **Good agreement with onboard Neon source**

FOV-to-FOV Adjustments & Stability

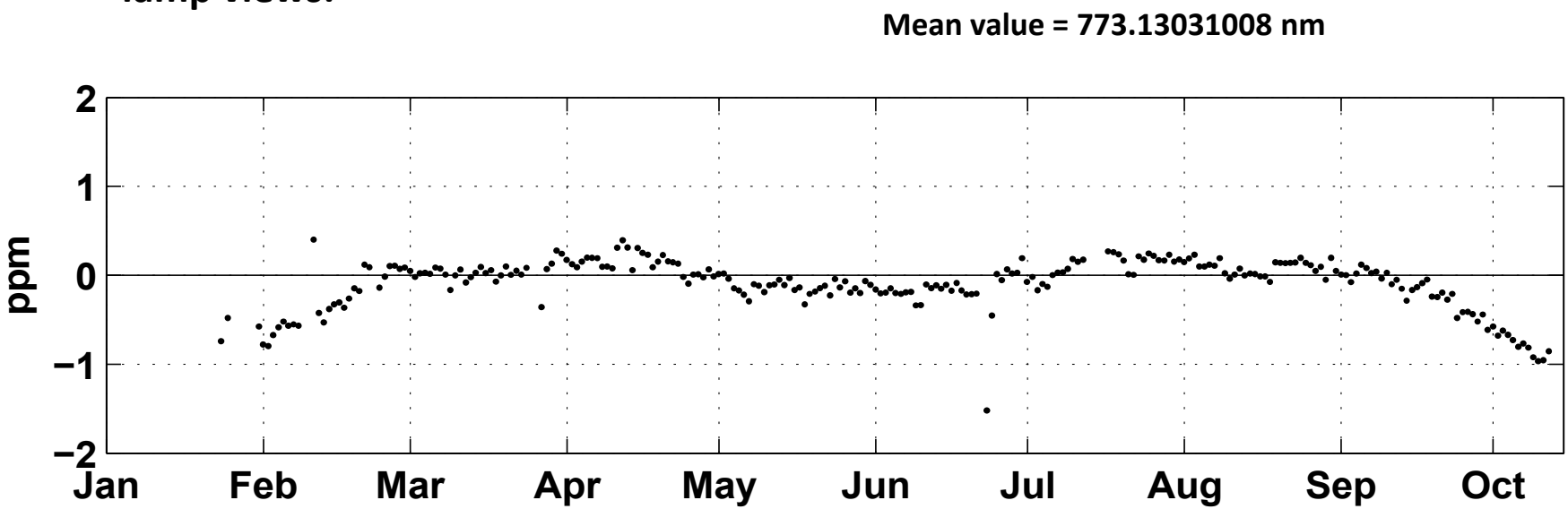
Inter-FOV spectral shifts wrt FOV5, derived from spectral correlation analysis:



All FOVs agree to better than 1 ppm!

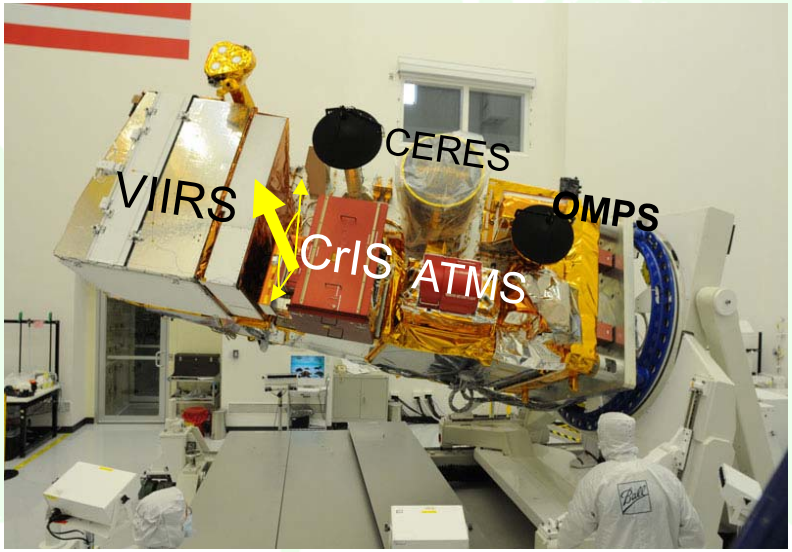
Neon Lamp views consistent with Metrology Laser Stability better than ~1 ppm for 8 months

Metrology laser wavelength deviations, derived from Neon lamp views:



Topics

1) CrIS Background
2) Radiometric Calibration Accuracy
   1) Preflight assessment
   2) On-orbit refinement
3) Spectral Calibration Accuracy
   1) Preflight
   2) On-orbit refinement
4) On-orbit Inter-comparison to AIRS, IASI, S-HIS
5) Future

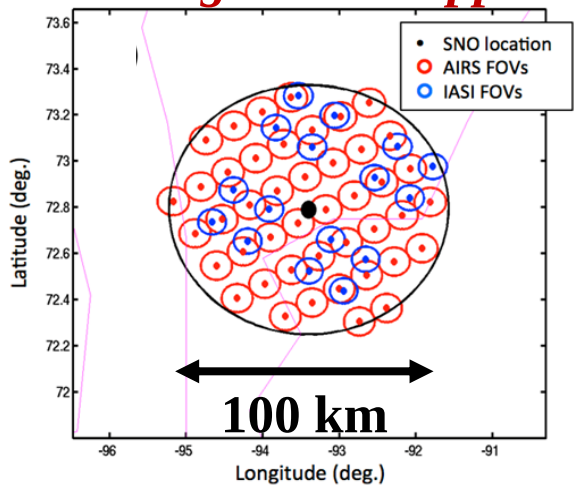


Suomi NPP Spacecraft

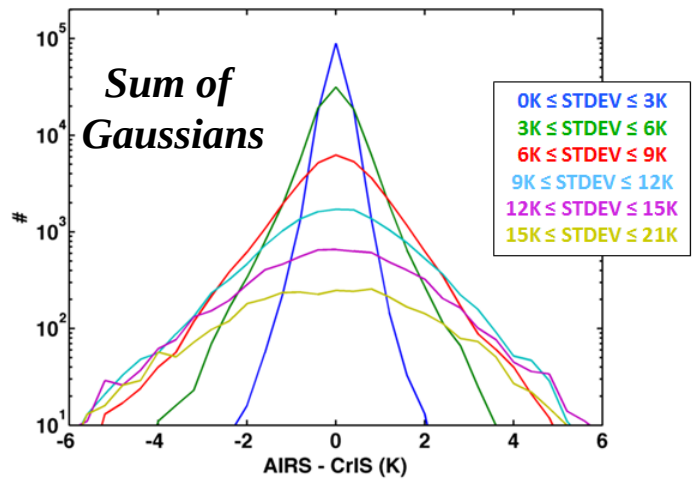
Simultaneous Overpass Comparisons: CrIS to AIRS & IASI

Tobin, et al., GOES-R/JPSS Posters Part 2, #700

Tobin "Big Circle" Approach

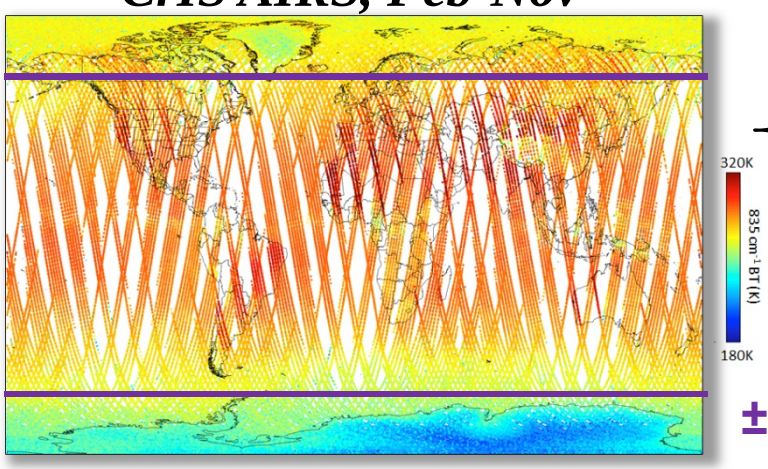


Well Understood Sampling Errors



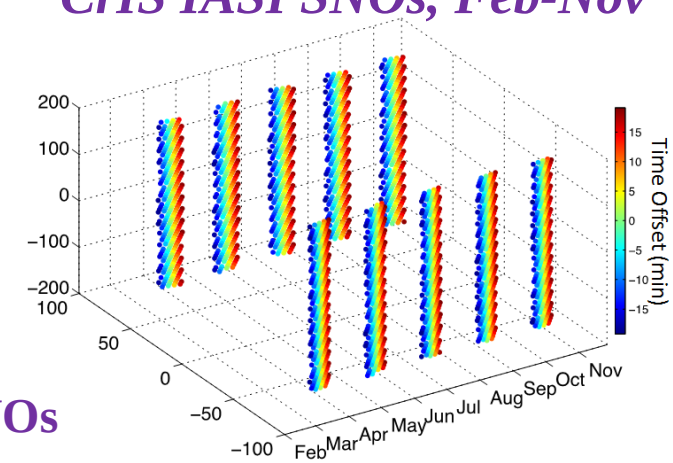
Selected Overpasses

CrIS AIRS, Feb-Nov



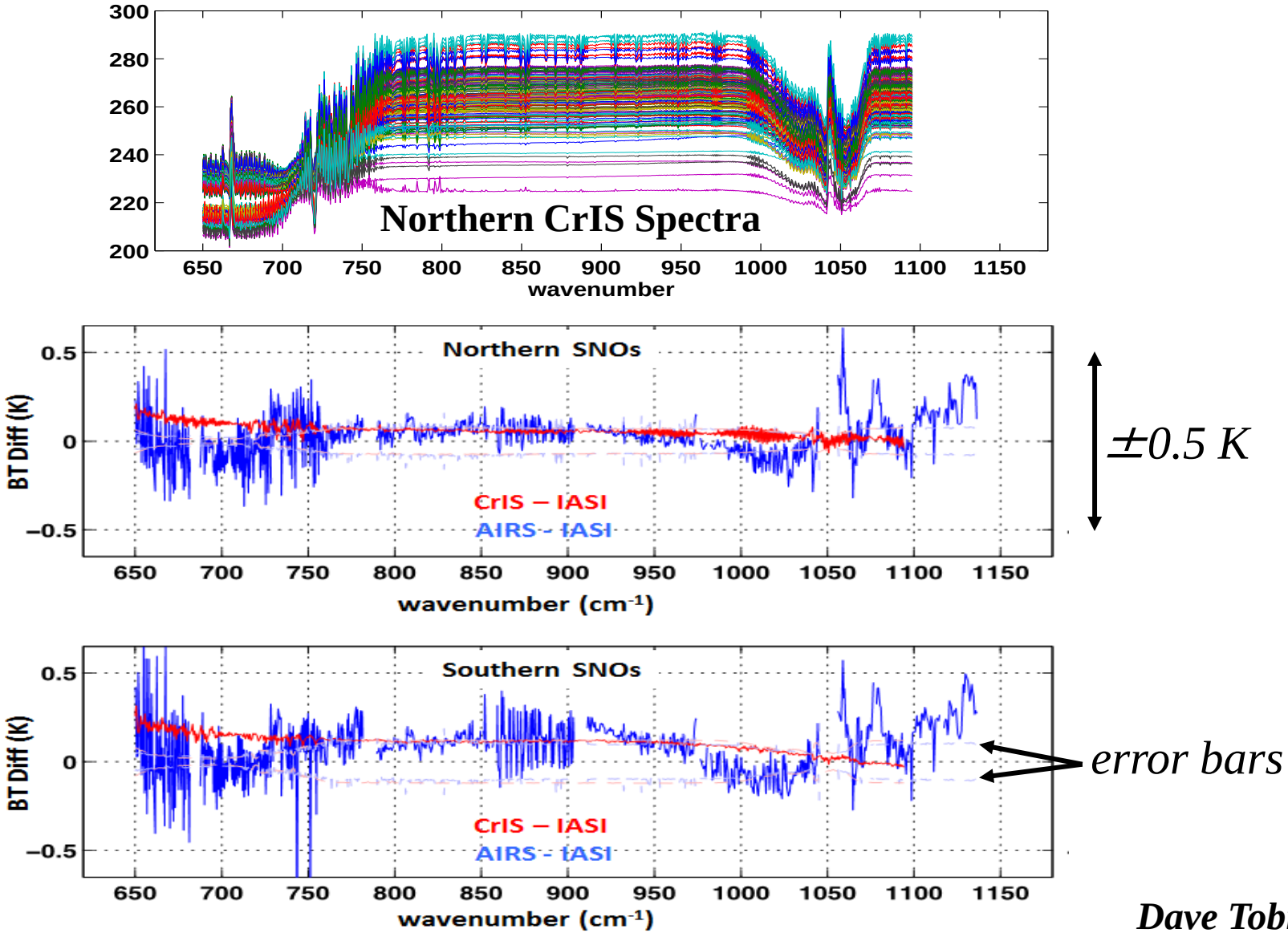
Δ t < 20 min
view θ < 30°
Δθ < 3°

CrIS IASI SNOs, Feb-Nov



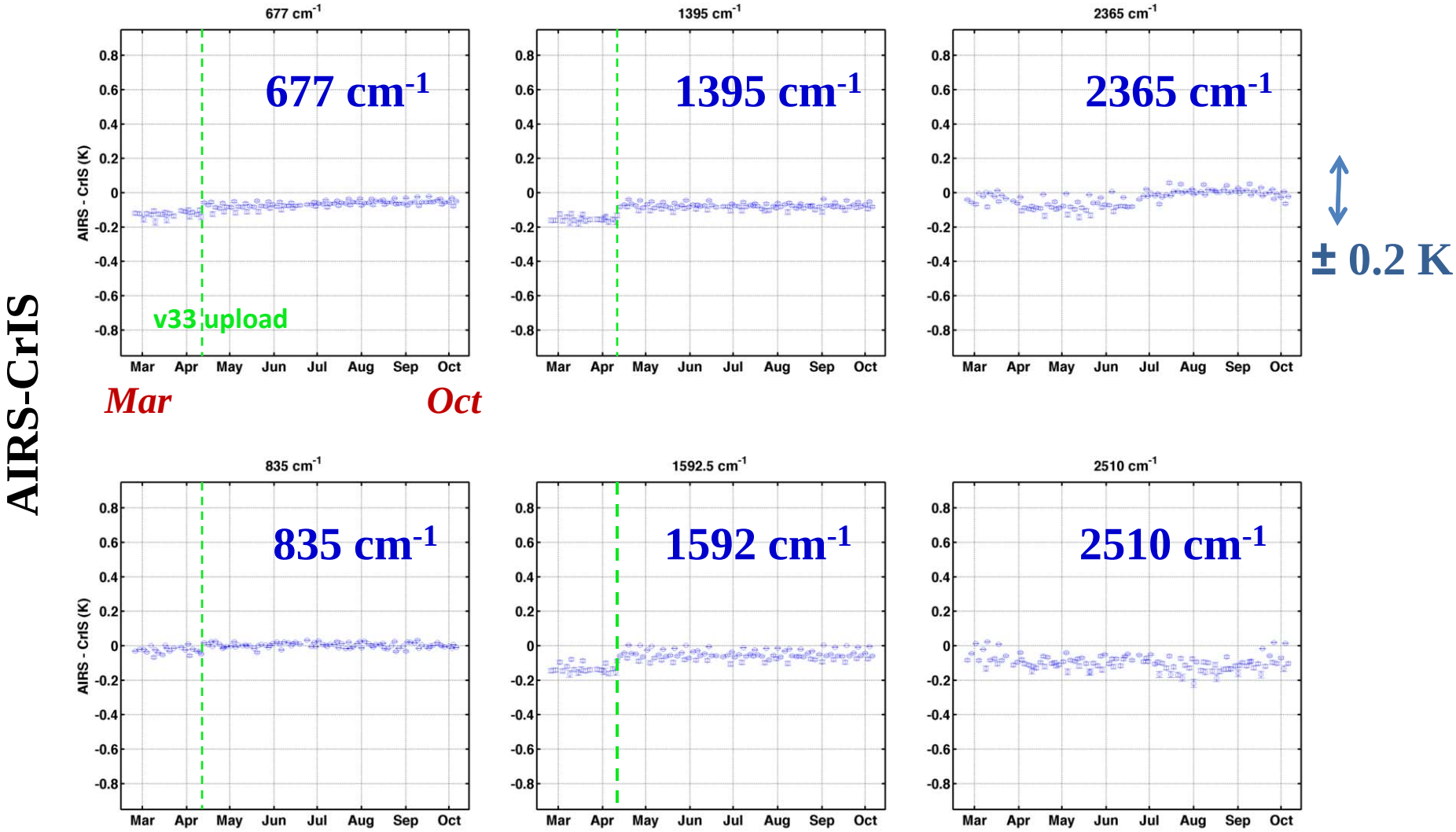
±73°: 9:30-13:30 SNOs

Example CrIS-IASI & CrIS-AIRS



Dave Tobin

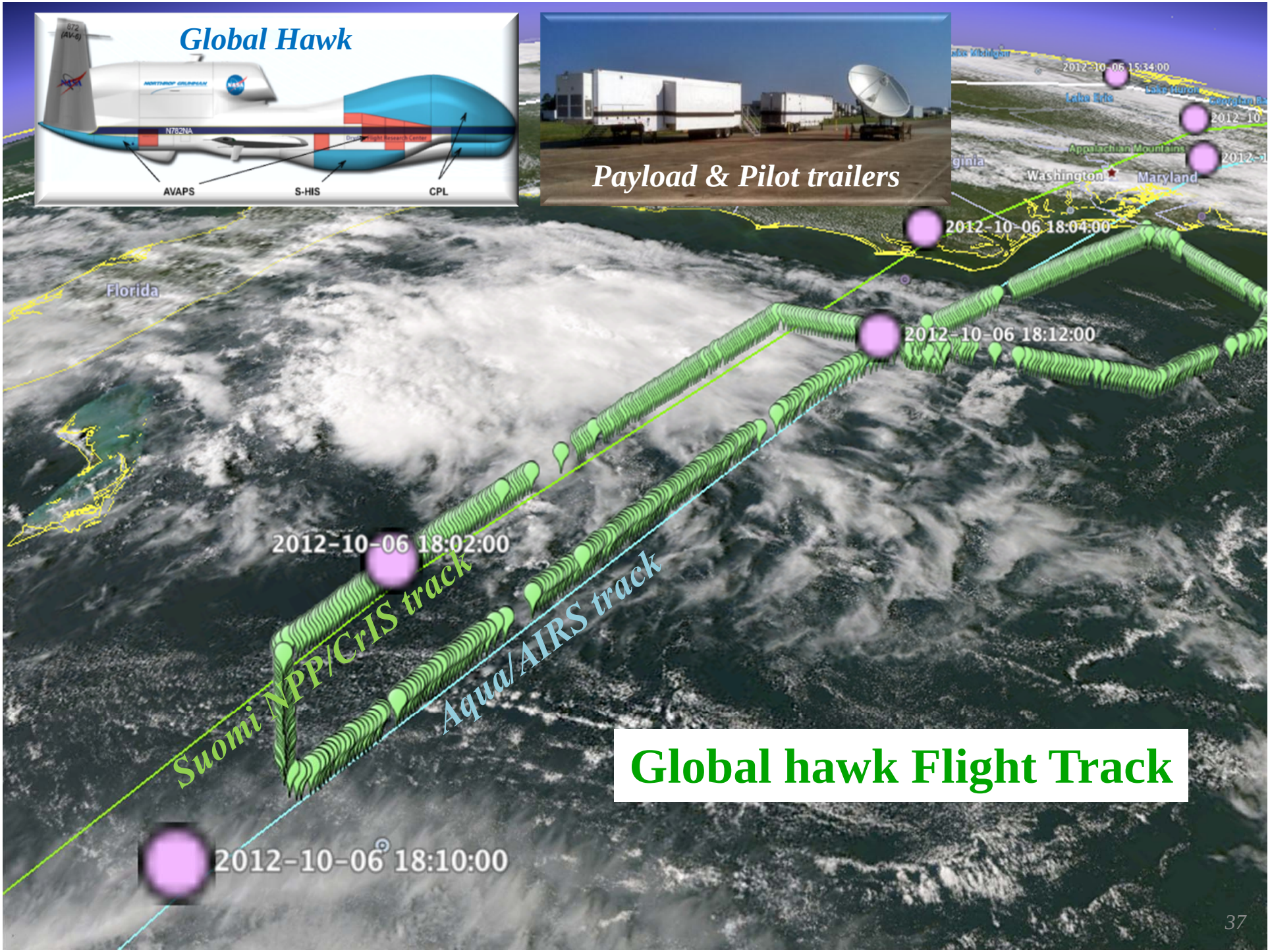
Daily Mean AIRS-CrIS Differences (Mar-Oct)



- V33 Engineering packet upload on April 11 (changes to NL a2 coefficients for LW and MW)
- Changes over time are very small.
- Largest are for LW 677 cm^{-1} region, ~30mK, under investigation.
- Interesting change in SW 2365 cm^{-1} behavior in late June.

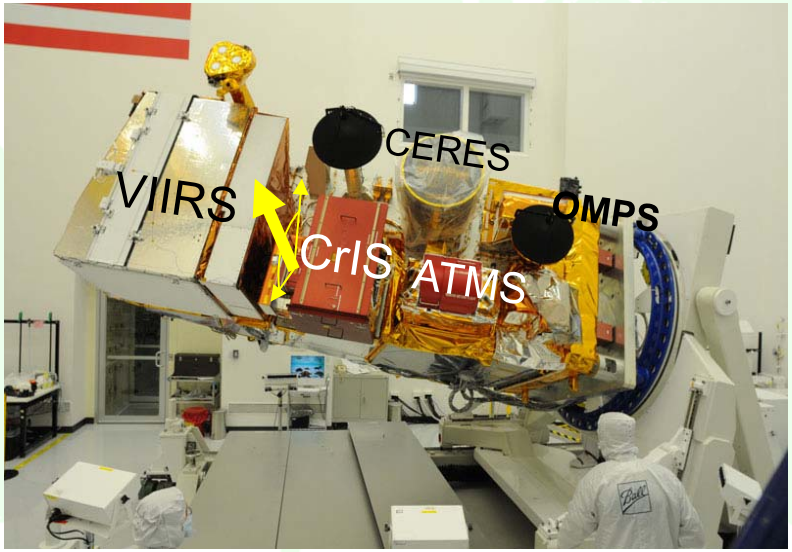
Scanning HIS/CrIS Intercomparison

- **1st Under-flight of Suomi NPP** was conducted by Global Hawk high altitude UAV carrying Scanning HIS, AVAPS dropsondes and Cloud Physics Lidar on 6 October, as part of the NASA HS3 campaign
  Taylor et al., GOES-R/JPSS Posters Part 2, #695
- **A dedicated Suomi-NPP aircraft campaign planned for May 2013** using the NASA ER2 and UK research aircraft in support of the "Validated" SDR review.


Global Hawk
AVAPS
S-HIS
CPL
Payload & Pilot trailers
2012-10-06 15:34:00
Washington
Maryland
Appalachian Mountains
2012-10-06 18:04:00
Florida
2012-10-06 18:12:00
2012-10-06 18:02:00
Suomi NPP/CrIS track
Aqua/AIRS track
2012-10-06 18:10:00
Global hawk Flight Track

Topics

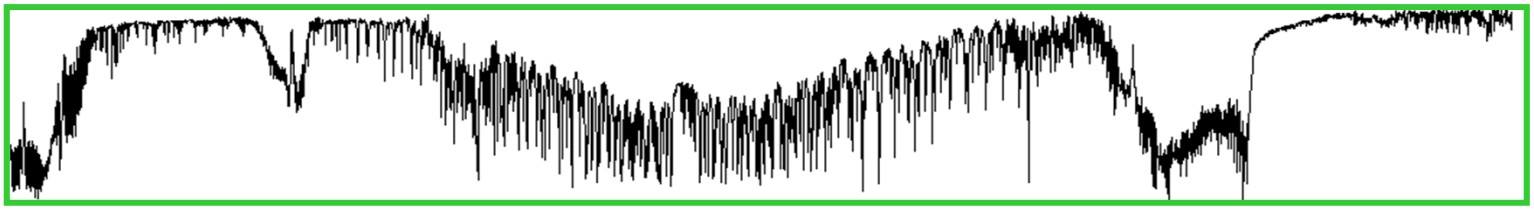
1) CrIS Background
2) Radiometric Calibration Accuracy
   1) Preflight assessment
   2) On-orbit refinement
3) Spectral Calibration Accuracy
   1) Preflight
   2) On-orbit refinement
4) On-orbit Inter-comparison to AIRS, IASI, S-HIS
5) Future



Suomi NPP Spacecraft

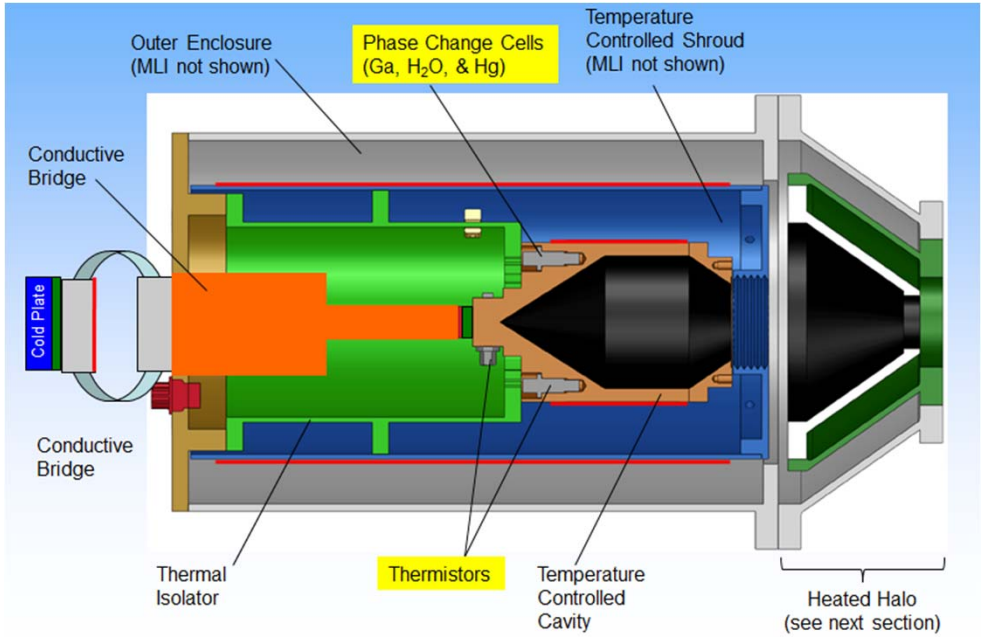
Looking Ahead: Future US Polar Sounding

- **CrIS provides a foundation well suited to the upgrades needed for Next Generation US Weather & Climate Monitoring**
- **Modular design allows achieving**
  (1) Contiguous spectral coverage
  (2) Higher spatial resolution with more complete coverage
  by just changing to a 2-D detector array with different optical bandpass filters



IR Climate Benchmark Mission (a la CLARREO) still urgently needed

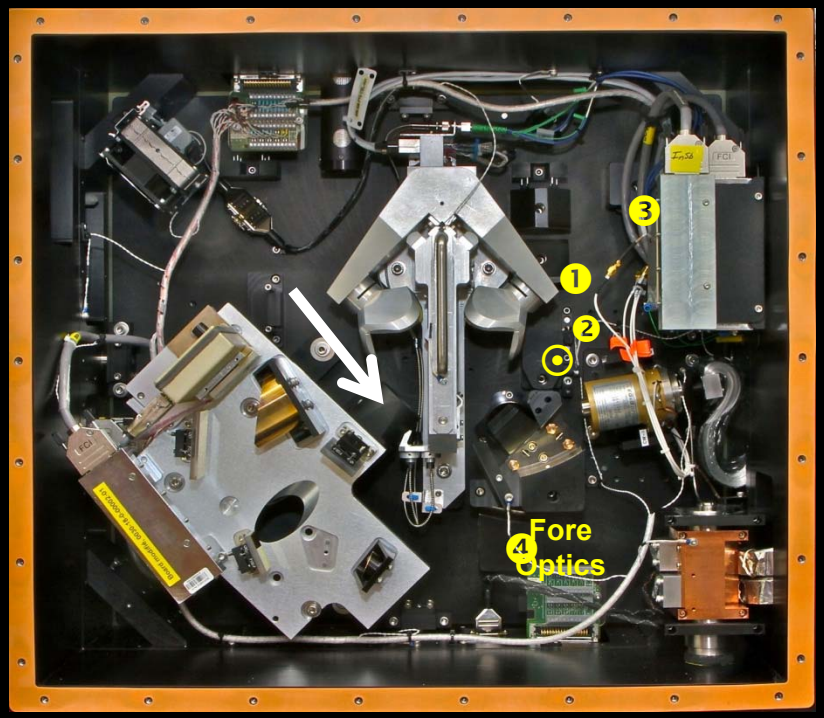
- On-orbit Absolute Radiance standard with
  (1) Phase-change based temperature scale
  (2) Wide range of blackbody temperatures
  (3) Emissivity measurement capability
  is essential
- < ± 0.1K 3σ proven on-orbit
- CrIS record would supplement global sampling after inter-calibration with a benchmark sensor

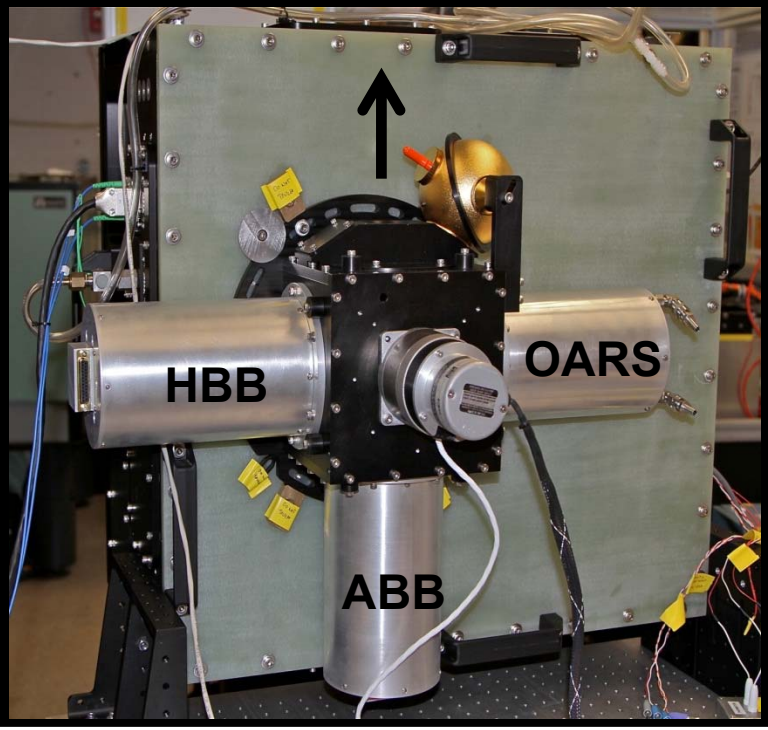


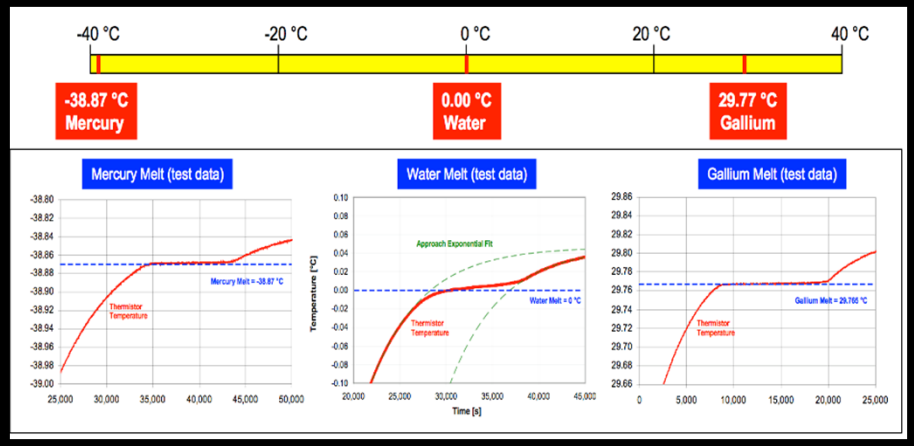
UW On-orbit Absolute Radiance Standard

We already have the Prototype

Absolute Radiance Interferometer

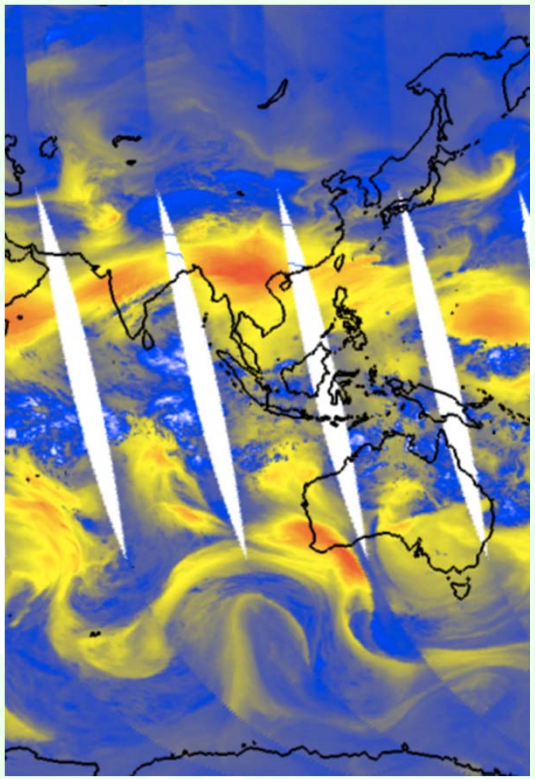






Absolute Temperature Calibration
Using Multiple Phase Change Materials,
plus Heated Halo emissivity
and Inst. Line Shape (ILS) measurement

Summary



- **CrIS instrument performance is exceptional**
  - **Very low noise**
  - **Very stable and accurate**
  - **Provisional SDRs adequate for many applications** ***(see Deslover, et al., GOES-R/JPSS Posters Part 1, #299)***
  - **Provides excellent baseline for future upgrades**
- **Recently declared Provisional Status**
  - **Further small refinements expected at a later date**
  - **Validated status expected 1st half 2013**
  - **ECMWF and UKMET Office have demonstrated positive impact on early assimilation tests**

CrIS on Suomi NPP is part of a fitting tribute to Verner Suomi