TESTING, VERIFICATION AND CALIBRATION OF THE THERMAL AND NEAR INFRARED SENSOR FOR CARBON OBSERVATION FOURIER TRANSFORM SPECTROMETER (TANSO-FTS-2) SENSOR

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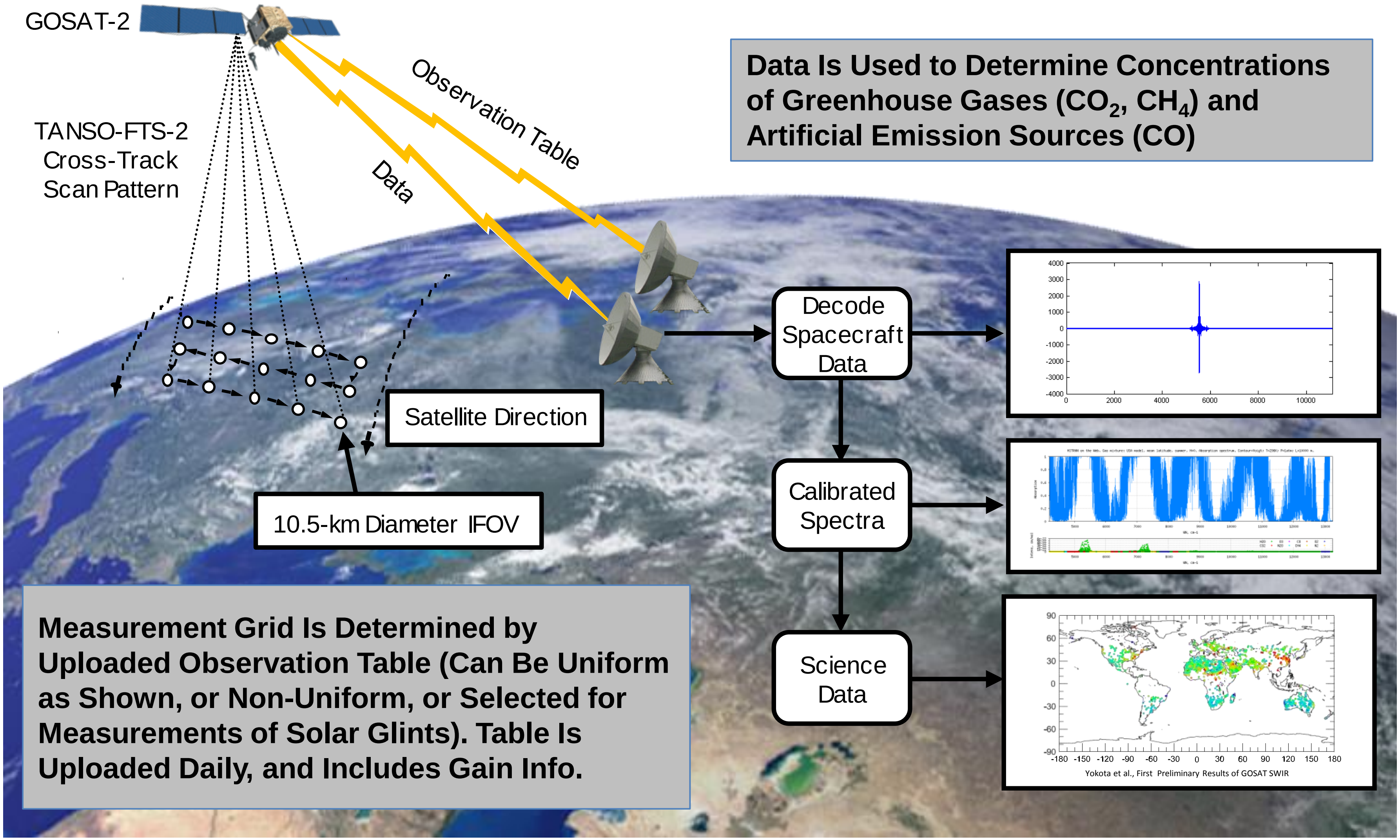
CALCON TECHNICAL MEETING, 6-20-2018

FTS-2 OVERVIEW

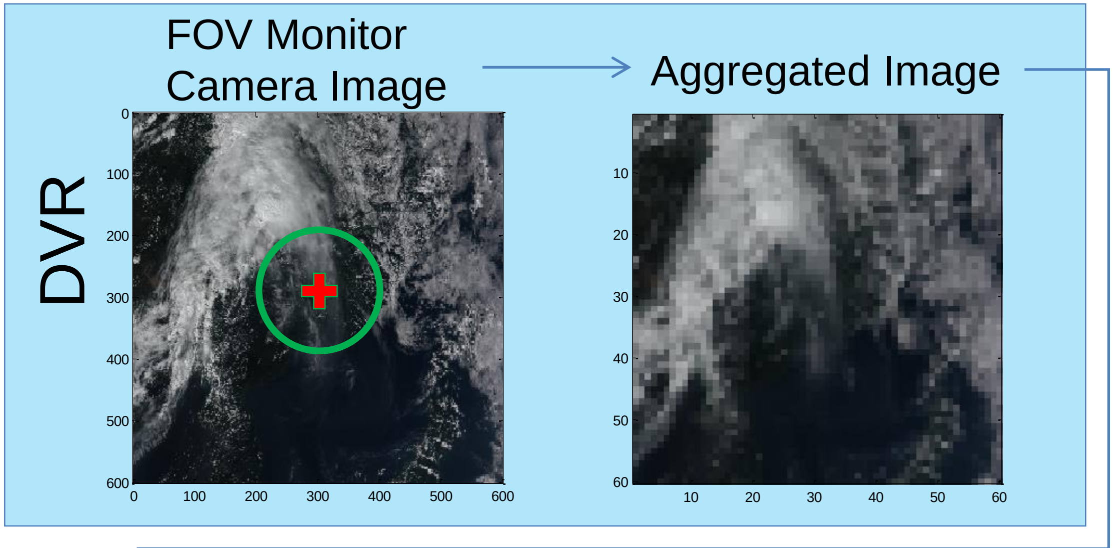
TANSO-FTS-2 Mission Overview



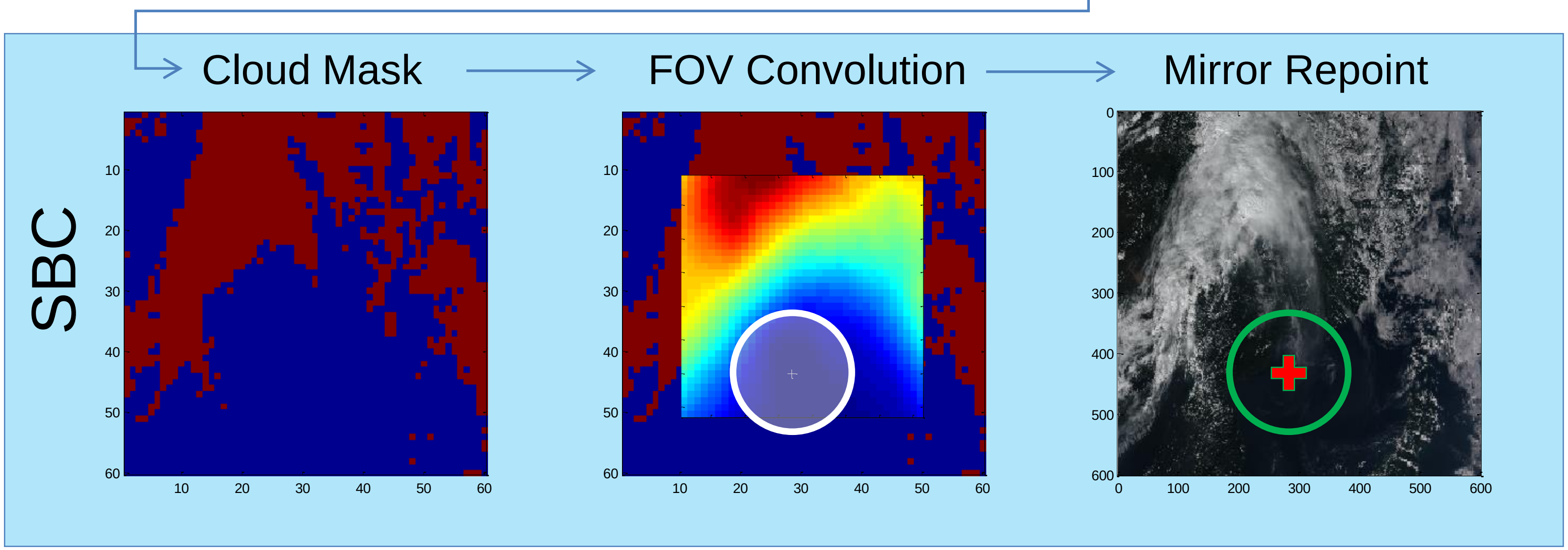
Data Is Used to Determine Concentrations of Greenhouse Gases (CO_2, CH_4) and Artificial Emission Sources (CO)

Measurement Grid Is Determined by Uploaded Observation Table (Can Be Uniform as Shown, or Non-Uniform, or Selected for Measurements of Solar Glints). Table Is Uploaded Daily, and Includes Gain Info.

Intelligent Pointing Increases the Number of Usable Cloud-Free Observations



- Scanner takes large step to nominal location per table
- FOV monitor camera takes a 50x30km image in 3 colors
- Image is aggregated, cloud mask determined, convolution finds best cloud-free region
- Scanner takes small step, 4-sec interferogram is collected



TANSO-FTS-2 Provides Five Hyperspectral Bands Optimized for Greenhouse Gas Measurement Mission

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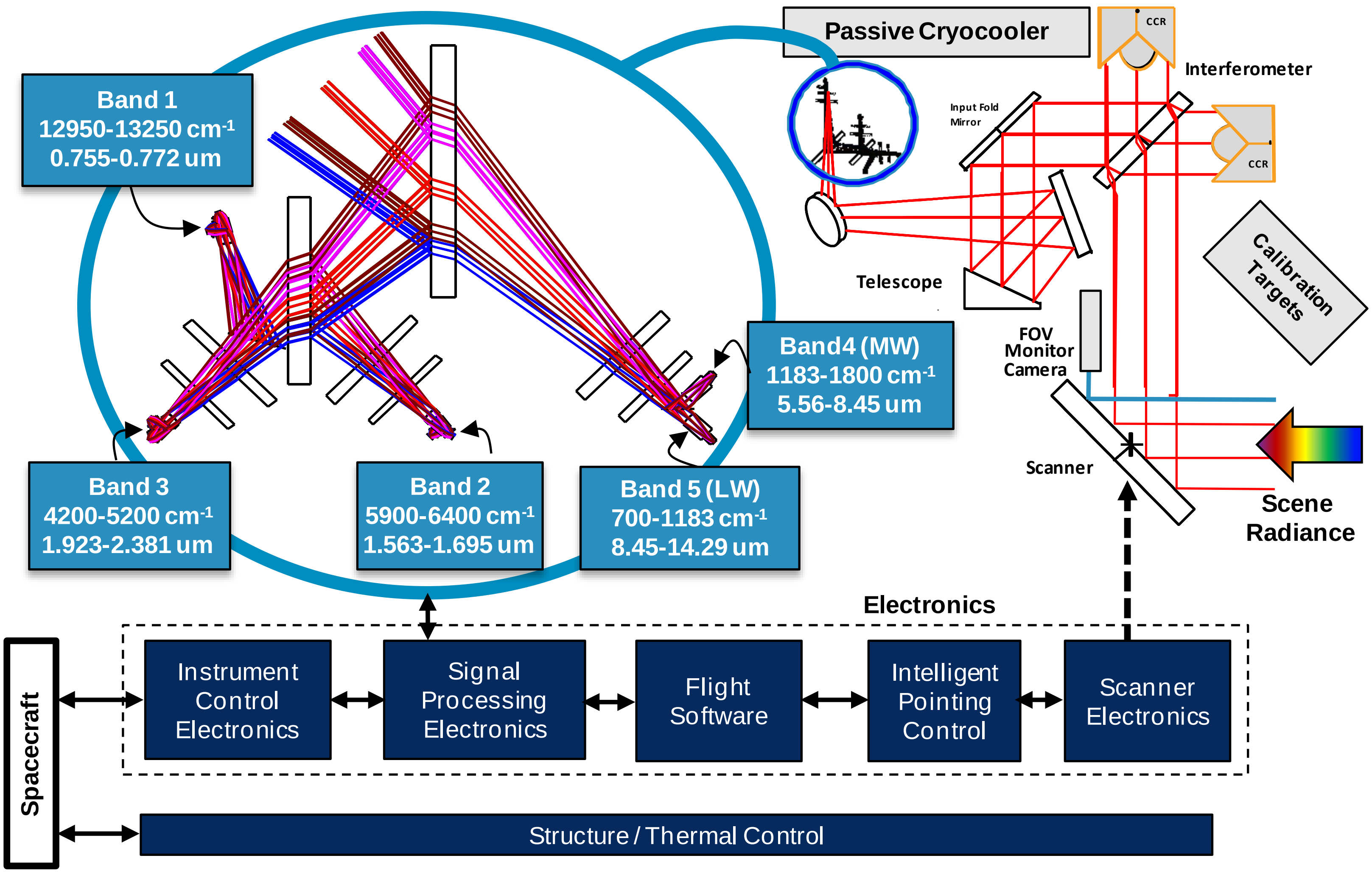

FTS-2 Design Consists of Two Main Modules

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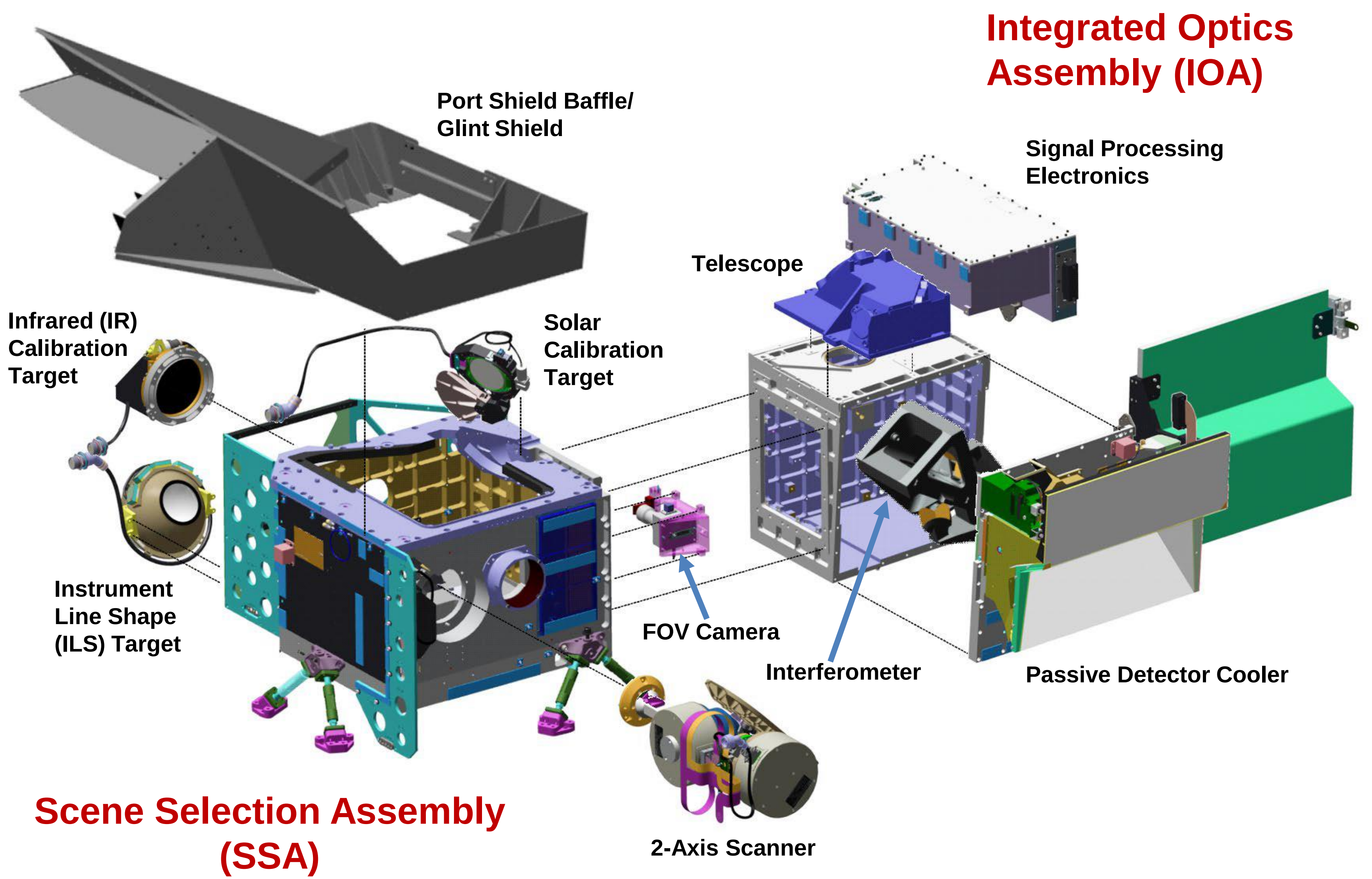
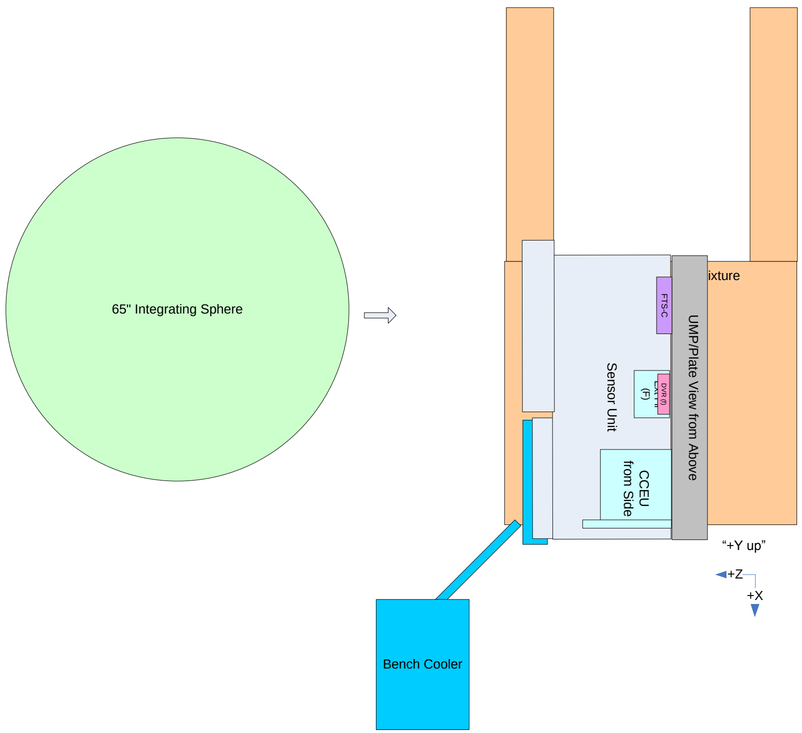


FTS-2 VERIFICATION AND CALIBRATION

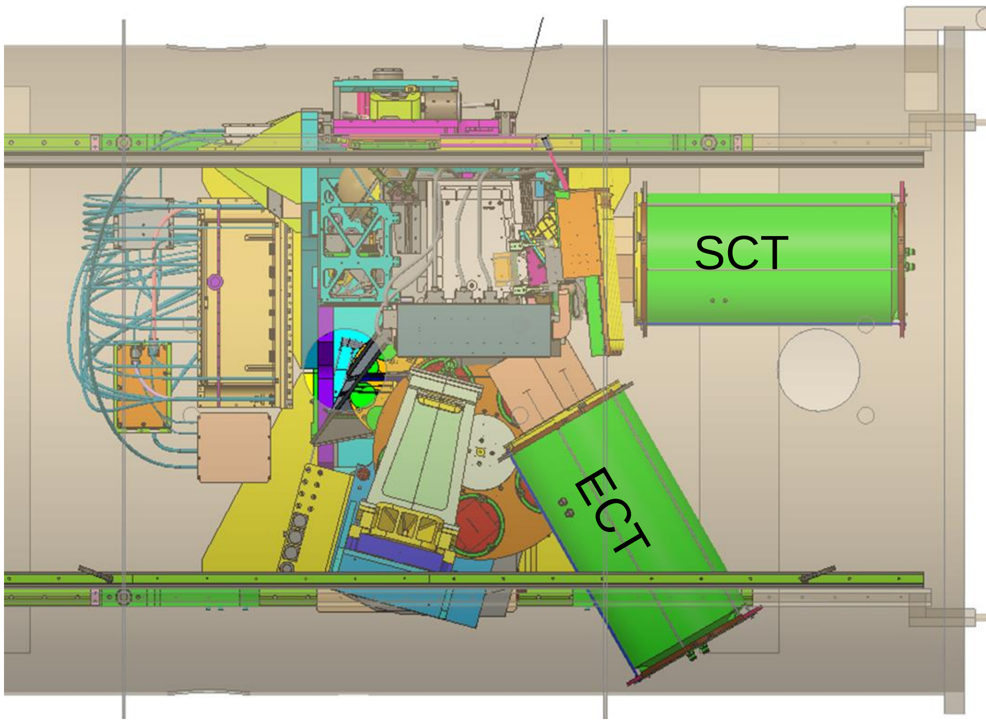
TECHNOLOGY TO CONNECT, INFORM AND PROTECT™

SWIR and TIR Band Radiometric Performance Assessed Independently

SWIR Bands (Bands 1-3) evaluated using integrating sphere at ambient conditions



TIR Bands (4/5) evaluated using blackbody targets in TVAC chamber



Further Details on Next Slide

Accurate Radiometric Calibration Highly Important to FTS-2 Mission

Bands 1-3: Radiometric performance assessed via NIST-traceable integrating sphere

- Sphere output at multiple levels used to assess nonlinearity, noise and polarization performance
- Sphere also used to characterize Spectralon solar diffusers
  - "Routine" (viewed every other orbit) and "Reference" (viewed monthly) Spectralon diffusers available to monitor instrument response on-orbit

Bands 4-5: Radiometric performance assessed via NIST-traceable blackbody targets

- Internal sensor ICT used as calibration reference
  - ICT PRT calibration is NIST-traceable
- External Calibration Target (ECT) blackbody used at multiple temperatures to assess nonlinearity and noise performance
  - Performance verified by NIST TXR in 2015
- Very similar to JPSS Cross-Track Infrared Sounder (CrIS) calibration and test methodology

Sensor SNR Performance Is Very Good

Band	Regulation Wavenumber [cm^{-1}]	Scene Radiance [mW/m^2/sr/cm^{-1}]			Spec			Measured Side 1			Measured Side 2		
		C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3
1S	13050	5.5	18	1.8	400	650	200	561	998	250	545	942	259
1P	13050	5.5	18	1.8	400	650	200	462	763	192	431	700	203
2S	6200	5.2	17	1.7	300	500	150	459	799	256	540	900	255
2P	6200	5.2	17	1.7	300	500	150	390	674	202	445	734	197
3S	5000	3.8	13	1.3	300	500	150	326	505	151	321	552	151
3P	5000	3.8	13	1.3	300	500	150	252	412	110	247	469	114
3S	4250	3	10	1	250	500	150	257	440	119	261	431	118
3P	4250	3	10	1	250	500	150	303	518	129	291	531	134

Band	Wavenumber	Side 1	Side 2	Spec
4	1300	1512	1534	300
5	700	941	961	300

FTS-2 Meets Mission Needs for Linear Radiometric Response

Channel	Requirement	Spec + Meas Uncertainty	Max Residual (%)
B1P	≤ 0.1% (TBR)	0.7	0.5
B1S	≤ 0.1% (TBR)	0.7	0.4
B2P	≤ 0.1% (TBR)	0.7	0.5
B2S	≤ 0.1% (TBR)	0.7	0.4
B3P(5000 cm^{-1})	≤ 0.1% (TBR)	0.7	0.5
B3S(5000 cm^{-1})	≤ 0.1% (TBR)	0.7	0.5
B3P(4250 cm^{-1})	≤ 0.1% (TBR)	0.7	0.6
B3S(4250 cm^{-1})	≤ 0.1% (TBR)	0.7	0.6
B4	≤ 0.1% (TBR)	N/A	0.07
B5	≤ 0.1% (TBR)	N/A	0.1

All Channels Except for Band 5 Meet Requirement Without Ground Processing Nonlinearity Correction

FTS-2 Polarization Performance Is Outstanding

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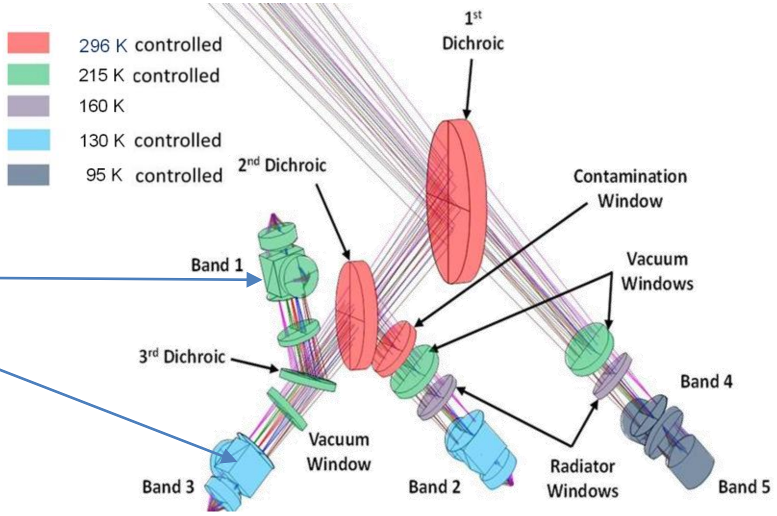
Instrument Induced Polarization is Low

Channel	Polarization Requirement	Polarization Measured (%)
B1P	≤ 34%	15
B1S	≤ 34%	15
B2P	≤ 38%	7
B2S	≤ 38%	7
B3P	≤ 38%	8
B3S	≤ 38%	8

Polarization Extinction Ratios Are High

Channel	Polarization Requirement	Polarization Measured
B1P	≥ 33	49
B1S	≥ 33	72
B2P	≥ 33	216
B2S	≥ 33	64
B3P	≥ 33	117
B3S	≥ 33	103

Bands 1-3 Contain Polarizing Beamsplitters to Separate S and P Components



Calibration Accuracy Assessed Via Component Measurements and Analysis Roll-Up

Calibration Error Sources, Bands 1-3

	Error Term	Basis
Random Errors	Signal Error	Determined by analysis
	Solar Irradiance Error	World Radiometric Reference uncertainty combined with instrument attitude uncertainty
	Diffuser Characterization Error	Determined by analysis
	Mirror Characterization Error	Determined by analysis using vendor measurements of the prescribed coating
	Earth Shield Characterization Error	Determined by analysis of baffle dimensions
Drift Errors	Solar Irradiance Change	RMS of ACRIM composite data
	Diffuser BRDF Drift Error	Estimated from GOSAT 1 data
	Solar Vector to Diffuser Error	Calculated from instrument alignment error allocation, expected spacecraft attitude uncertainty, and diameter of the solar disc
	Earth Irradiance Error	Determined by analysis using measured Antarctic snow BRDF
	Port Baffle Scatter	Engineering Estimate

Calibration Errors

			Case		
Band	cm^{-1}	Spec	1	2	3
1	13050	<3%	2.48	2.54	2.47
2	6200	<3%	2.21	2.26	2.21
3S	5000	<3%	2.21	2.27	2.22
3L	4250	<3%	2.24	2.34	2.23

Error Sources Rolled Up to Assess Compliance; Solar Irradiance Error is Dominant Term for Bands 1-3

Bands 4 and 5 Calibration Is Highly Accurate

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Calibration Error Sources

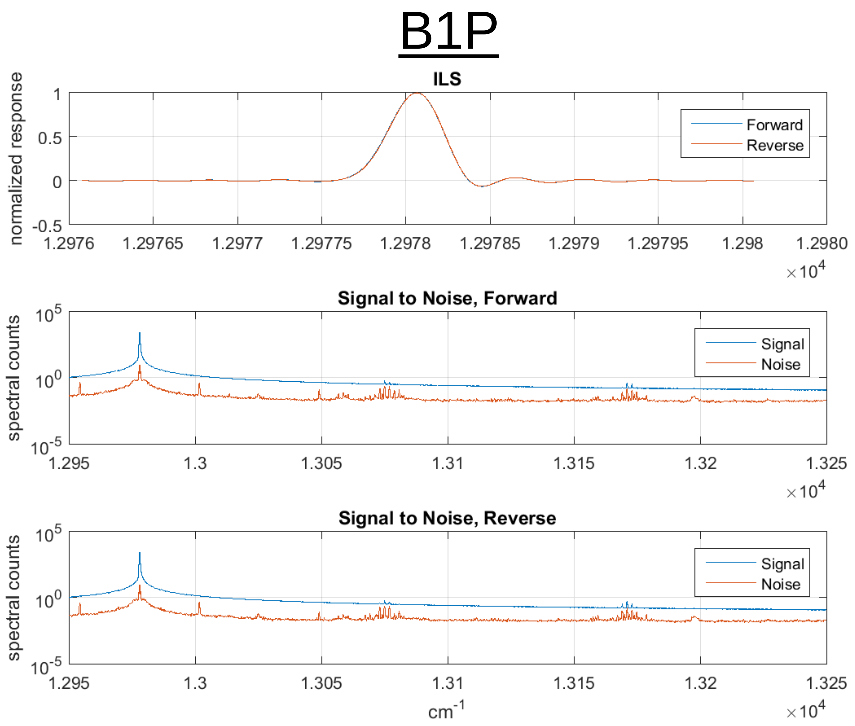
Error Term	Basis
Patch temperature drift	Determined by Thermal model analysis
Modulation Efficiency Drift	Determined by interferometer vendor
OMA temperature drift	Determined by Thermal model analysis
Scan Mirror Temperature Gradient	Determined by Thermal model analysis
Scan Mirror Temperature Drift	Determined by Thermal model analysis
Electronics Gain	Electronic design tolerance analysis
Polarization Sensitivity	Determined by analysis
Nonlinearity	Determined by analysis
Channel Spectra	Optical design analysis
ICT temperature	ICT temperature uncertainty analysis
ICT Paint reflectance	Reflectance measurements uncertainty
Signal Radiance Scan Angle Correction	Determined by analysis using vendor measurements of the prescribed coating
Background Radiance Scan Angle Correction	Determined by analysis using vendor measurements of the prescribed coating
ICT Signal Error	Analysis using system noise, from minimum of SNR spec and CBE from SNR model
Spacelook Signal Error	Analysis using system noise, from minimum of SNR spec and CBE from SNR model

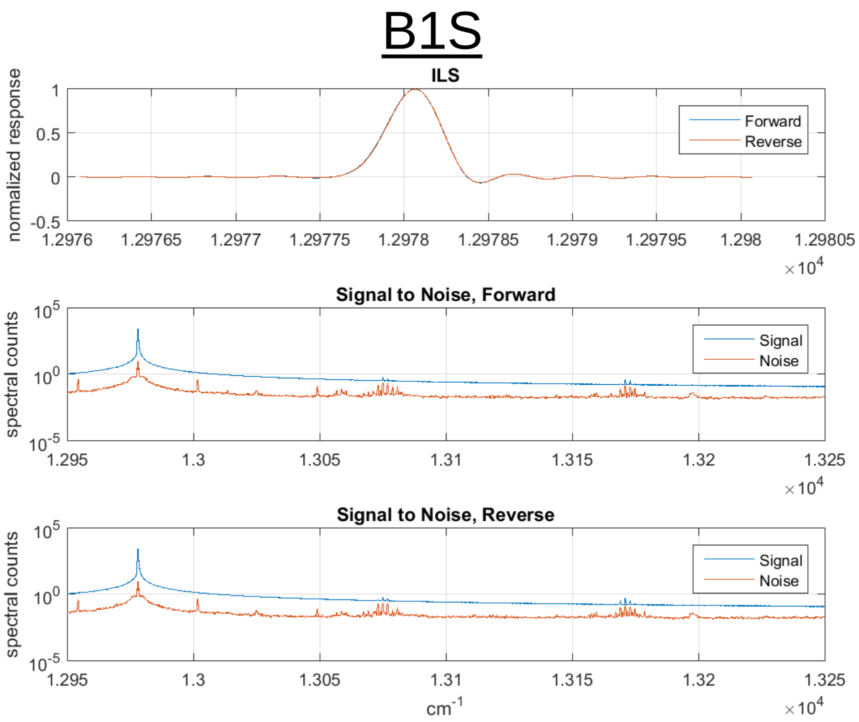
Calibration Errors

Band	cm^{-1}	Spec	Error
4	1300	<0.3K	0.161K
5	700	<0.3K	0.223K

ICT Temperature Uncertainty Is Driving Error Source for Bands 4-5

Band 1 and 2 Performance Using Internal ILS Laser Target Is Excellent





Band	FWHM	Spec FWHM	SNR	Spec SNR
1P	0.363	<0.4	38125	>300
1S	0.364	<0.4	41507	>300
2P	0.262	<0.27	45207	>300
2S	0.262	<0.27	51530	>300

FTS-2 ILS Target Contains Laser Diodes to Trend FWHM in Bands 1 and 2

Bands 3-5 FWHM Confirmed Through Gas Cell Testing

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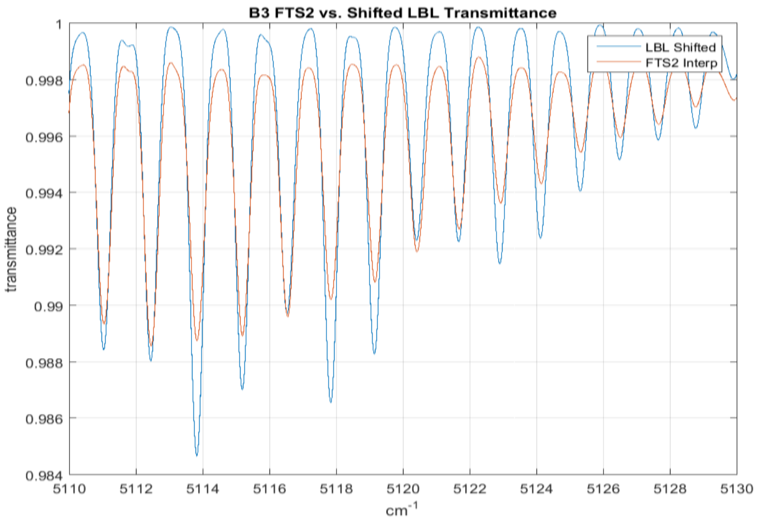
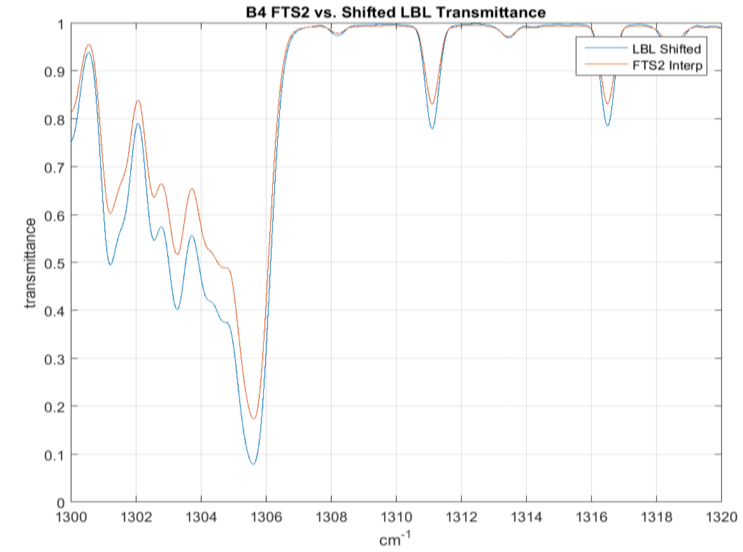
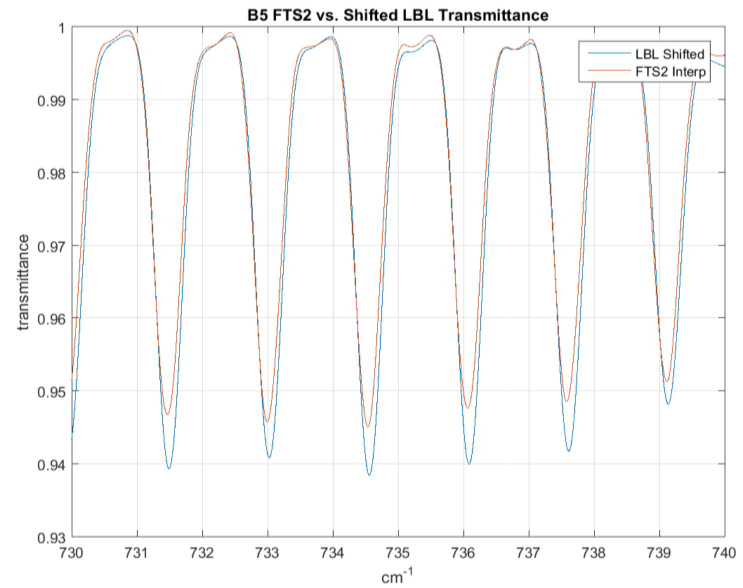
Band	FWHM	Specification
3	0.258	<0.27
4	0.244	<0.27
5	0.243	<0.27

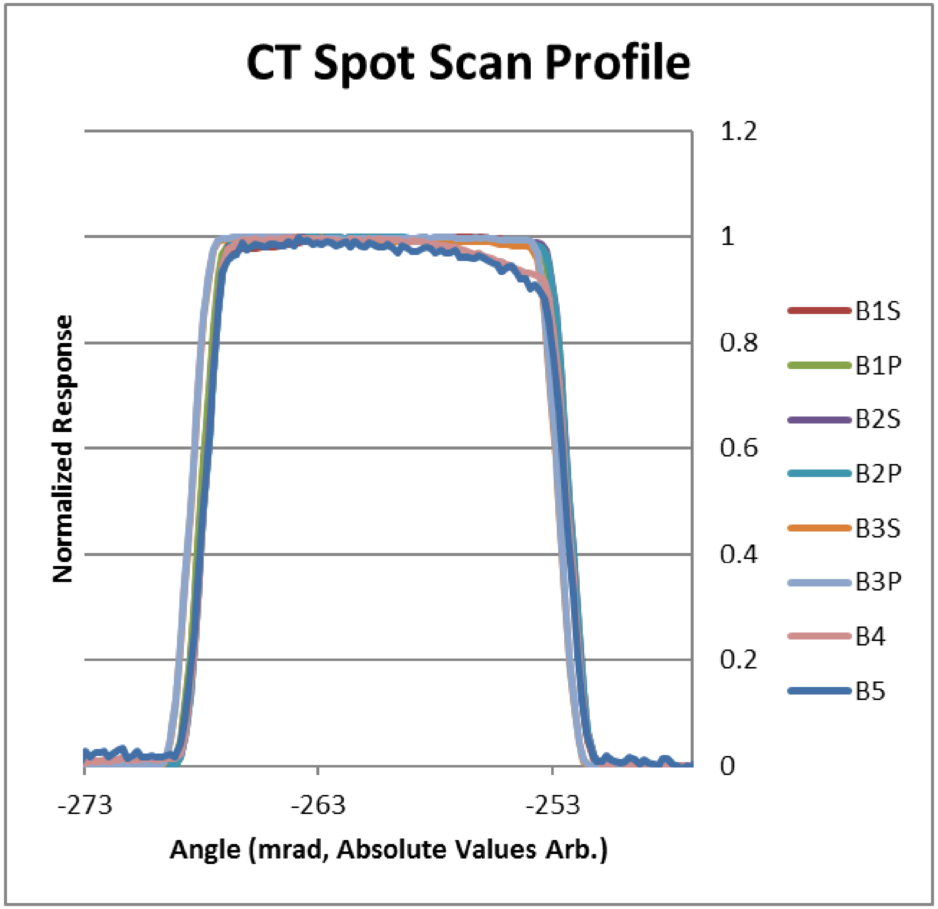


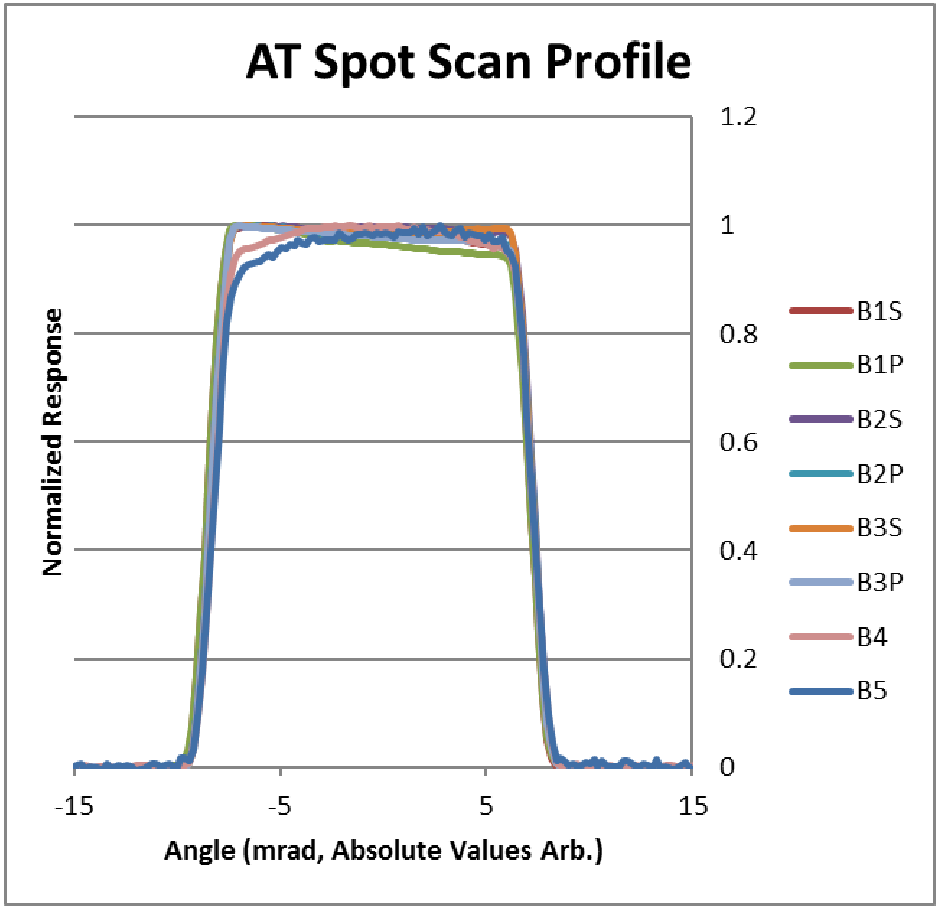




CO_2, CO and CH_4 Used to Assess FWHM Uncertainty for Bands 3-5

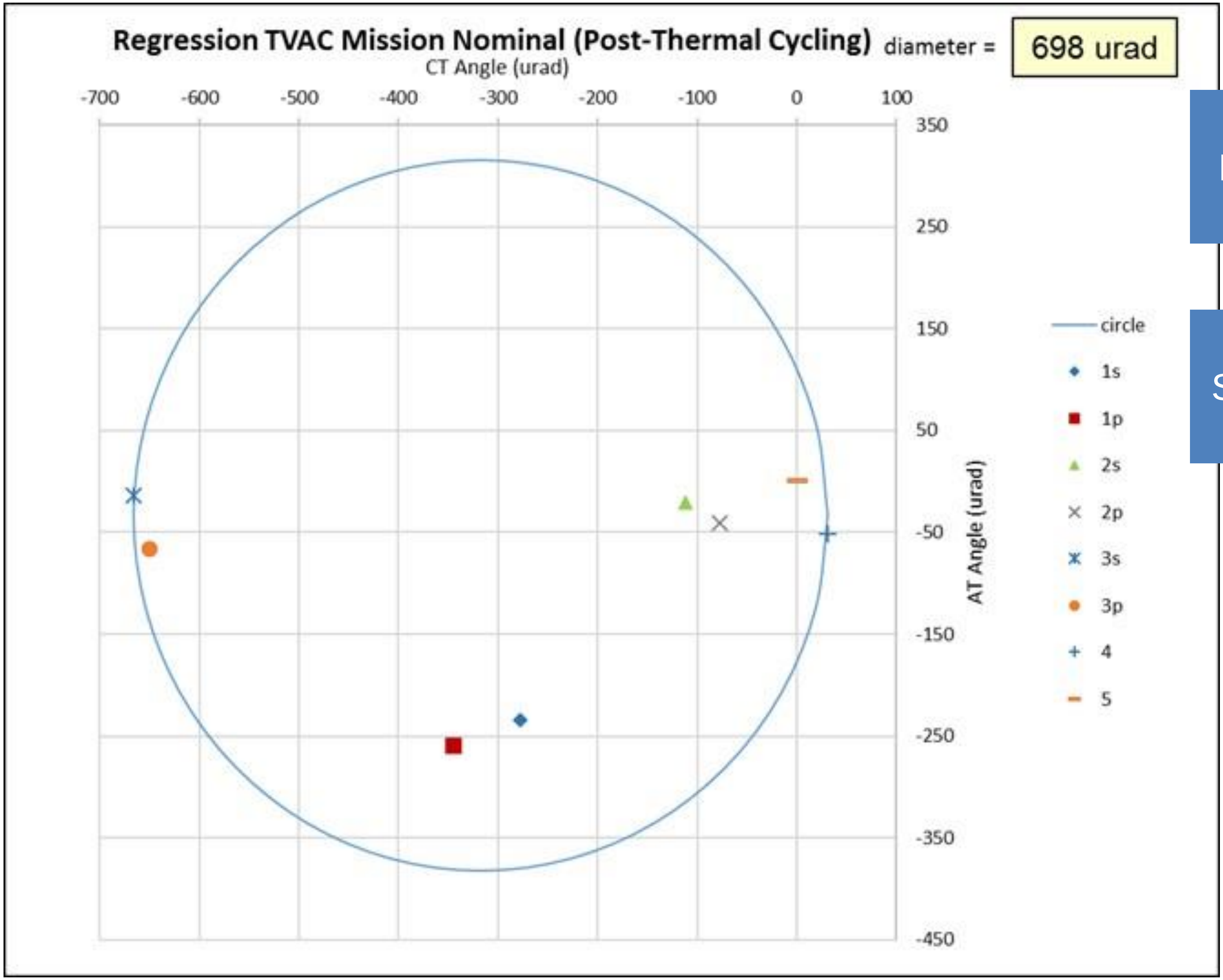
FTS-2 Spot Scans Confirm Expected FOV Shape





50%/80% Response Widths and Out of Field Responses Meet Specifications with Margin

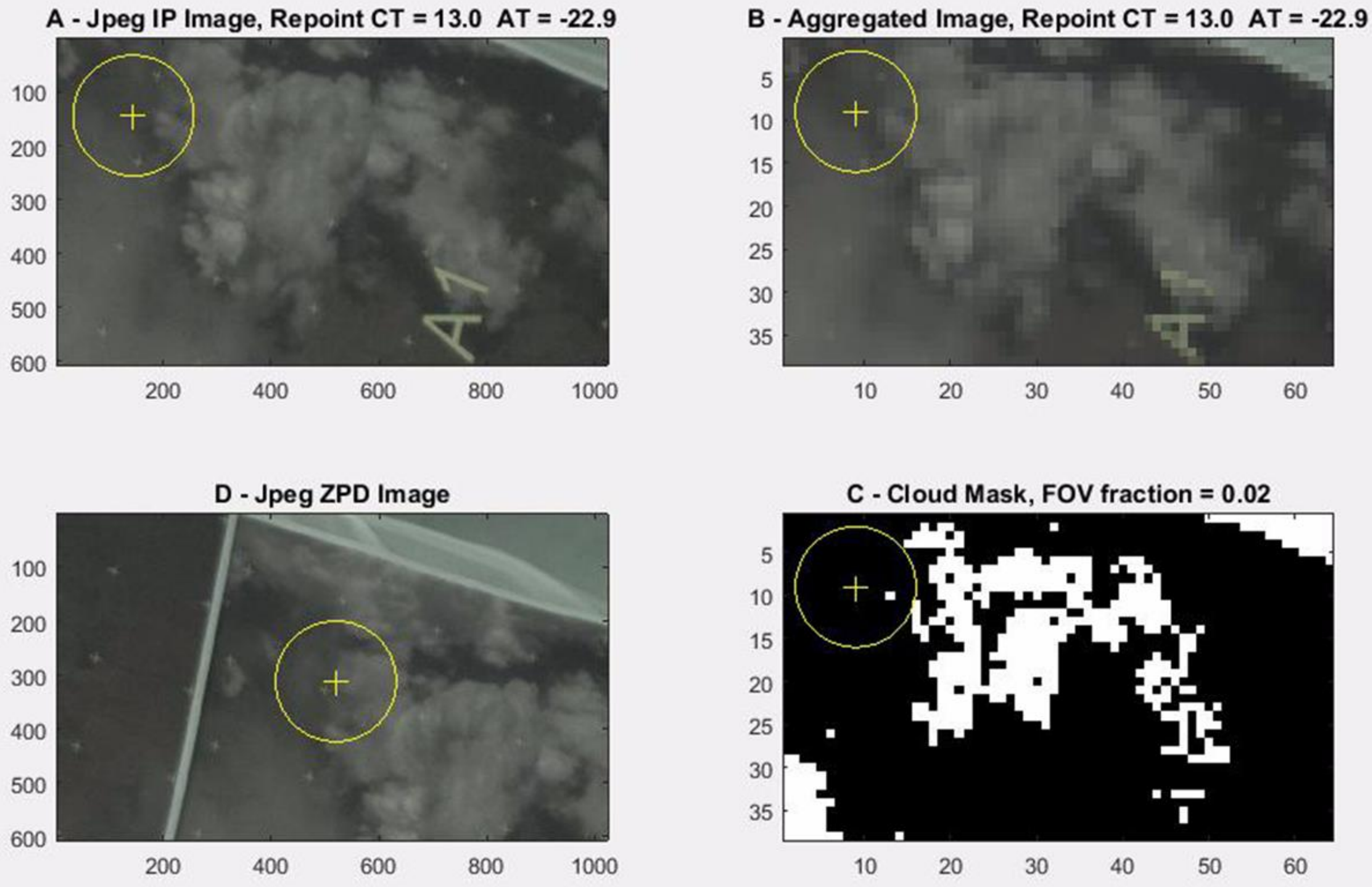
TVAC Slit Scan Tests Indicate Compliant and Stable Coregistration Performance



Coregistration Requirement of 791 μrad Met with Margin

<27 μrad Coregistration Shift Pre to Post Vibration and Thermal Cycling

Intelligent Pointing Testing was Successful; Re-Point Working as Expected



Intelligent Pointing Functionality Expected to Provide 2x Increase in Cloud-Free Data Yield On-Orbit

Overall FTS-2 Test Performance Is Excellent

GOSAT-2 Launch Planned for JFY 2018

SNR performance is very good

ILS FWHM is well within specification

Linearity performance meets mission needs

Calibration accuracy is very good

FOV shapes meet specification

Channel coregistration is compliant and stable following vibration and thermal cycling

Intelligent pointing verification successful