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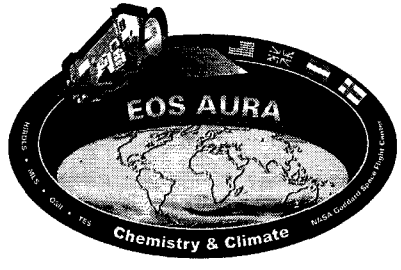
The EOS Aura Tropospheric Emission Spectrometer (TES)



Reinhard Beer & Helen M. Worden

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA

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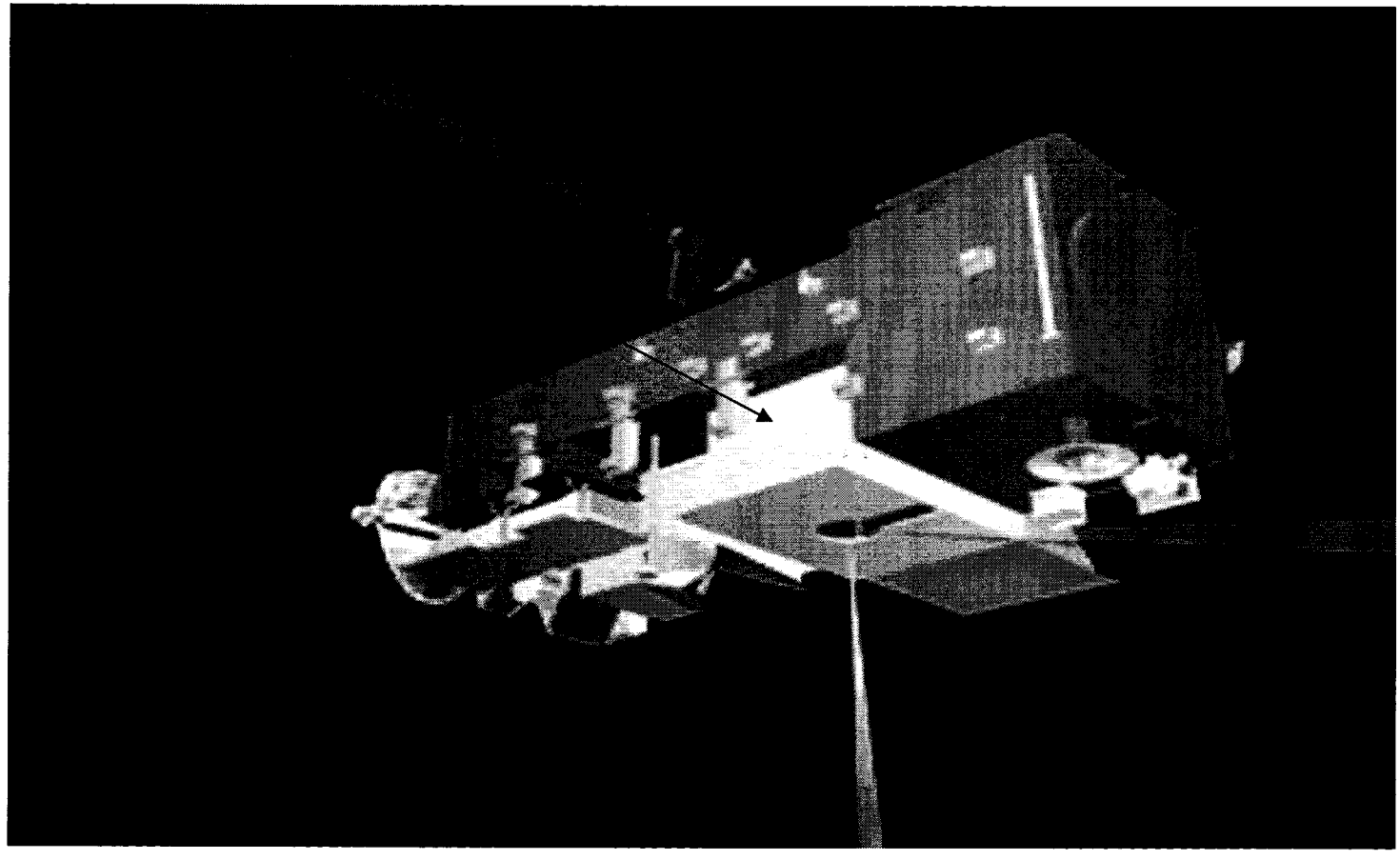
TES on the Aura Spacecraft



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Topics

Science Overview

Instrument status

Algorithm & Ground Data System status

Plans for launch and early operations

Data availability:
- for validation purposes
- for the community

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Science Overview

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Formal Co-Investigators

NAME	INSTITUTION	ROLE
Reinhard Beer	JPL	Principal Investigator
Shepard A. Clough	AER, Inc.	L2 Algorithms, Validation
Michael R. Gunson	JPL	Deputy PI
Daniel J. Jacob	Harvard University	Tropospheric Chem. Modeling
Jennifer A. Logan	Harvard University	Tropospheric Climatology
Frank J. Murcray	University of Denver	Correlative Measurements, Calibration
David M. Rider	JPL	Instrument Scientist, Calibration
Curtis P. Rinsland	NASA Langley RC	Spectroscopy, Validation
Clive D. Rodgers	Oxford University	L2 Algorithms, Validation
Stanley P. Sander	JPL	Tropospheric Chemistry, Validation
Fredric W. Taylor	Oxford University	Strat-Trop Exchange, Non-LTE
Helen M. Worden	JPL	Algorithm Team Leader, Calibration

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Associate Investigators

NAME	INSTITUTION	ROLE
Kevin W. Bowman	JPL	L1B Algorithms
Linda R. Brown	JPL	Spectroscopy
Annmarie Eldering	JPL	Clouds & Aerosols
Brendan M. Fisher	JPL	Calibration
Aaron Goldman	University of Denver	Spectroscopy
Mingzhao Luo	JPL	Calibration, L3 Products
Gregory B. Osterman	JPL	Operational Support Products
Mark Shepherd	AER, Inc.	L2 Algorithms
Susan Sund Kulawik	JPL	L2 Algorithms
John R. Worden	JPL	L2 Algorithms

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TES Level 1 Requirements[1]

PRODUCT	UNITS	ACCURACY REL::ABS[2]	HORIZONTAL RES::COV[3]	VERTICAL RES::COV[4]
L1B Radiances [@ 10 μm]	$W/m^2/sr/cm^{-1}$	1%::1%	5.3 x 8.5 km: GN 53 x 169 km: GL	NA::NA
Temperature Profile	K	2K::1K	5.3 x 8.5 km: GN 53 x 169 km: GL	2-6 km::0-34 km
H_2O mixing ratio	%v	3%::3%	5.3 x 8.5 km: GN 53 x 169 km: GL	2-6 km::0-34 km
O_3 mixing ratio	ppbv	3%::3-20 ppbv	5.3 x 8.5 km: GN 53 x 169 km: GL	2-6 km::0-34 km
CO mixing ratio	ppbv	3%::10 ppbv	5.3 x 8.5 km: GN 53 x 169 km: GL	2-6 km::0-34 km
CH_4 mixing ratio	ppbv	3%::14 ppbv	5.3 x 8.5 km: GN 53 x 169 km: GL	2-6 km::0-34 km
NO_2 mixing ratio	pptv	5%::500 pptv	53 x 169 km: GL	2-6 km::10-34 km
HNO_3 mixing ratio	pptv	5%::25 pptv	53 x 169 km: GL	2-6 km::5-34 km
Surface Temperature	K	1K::1K	5.3 x 8.5 km: GN	NA::NA

[1] Temporal resolution is "every other day"
[2] Values for clear skies, northern mid-latitudes & mid-troposphere
[3] GN represents global coverage (nadir view), GL represents global coverage (limb view)
[4] NA = not applicable

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Potential Special (Research) Products (1)

Chemical Group	Common Name	Formula	Product Source
H_xO_y	Hydrogen Peroxide	H_2O_2	L
	Monodeuterated Water Vapor	HDO	N & L
C-compounds	Ethane	C_2H_6	L
	Acetylene	C_2H_2	L
	Formic Acid	HCOOH	N & L
	Methyl Alcohol	CH_3OH	N & L
	Peroxyacetyl Nitrate	$CH_3C(O)OONO_2$	L
	Acetone	$CH_3C(O)CH_3$	L
	Ethylene	C_2H_4	L

N = nadir view, L = limb view

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Potential Special (Research) Products (2)

Chemical Group	Common Name	Formula	Product Source
N-compounds	Nitric Oxide	NO	L
	Peroxynitric Acid	HO_2NO_2	L
	Ammonia	NH_3	N* & L
	Hydrogen Cyanide	HCN	N & L
	Dinitrogen Pentoxide	N_2O_5	L
S-compounds	Sulfur Dioxide	SO_2	N & L
	Carbonyl Sulfide	OCS	N & L
	Hydrogen Sulfide	H_2S	N* & L
	Sulfur Hexafluoride	SF_6	L

N = nadir view, L = limb view, * = volcanic/industrial/biomass burning plume column densities only

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Potential Special (Research) Products (3)

Chemical Group	Common Name	Formula	Product Source
Halogen compounds	Hydrogen Chloride	HCl	N*
	Chlorine Nitrate	$ClONO_2$	L
	Carbon Tetrachloride	CCl4	L
	CFC-11	CCl_3F	N & L
	CFC-12	CCl_2F_2	N & L
	HCFC-21	$CHCl_2F$	L
	HCFC-22	$CHClF_2$	L

N = nadir view, L = limb view, * = volcanic/industrial/biomass burning plume column densities only

Instrument

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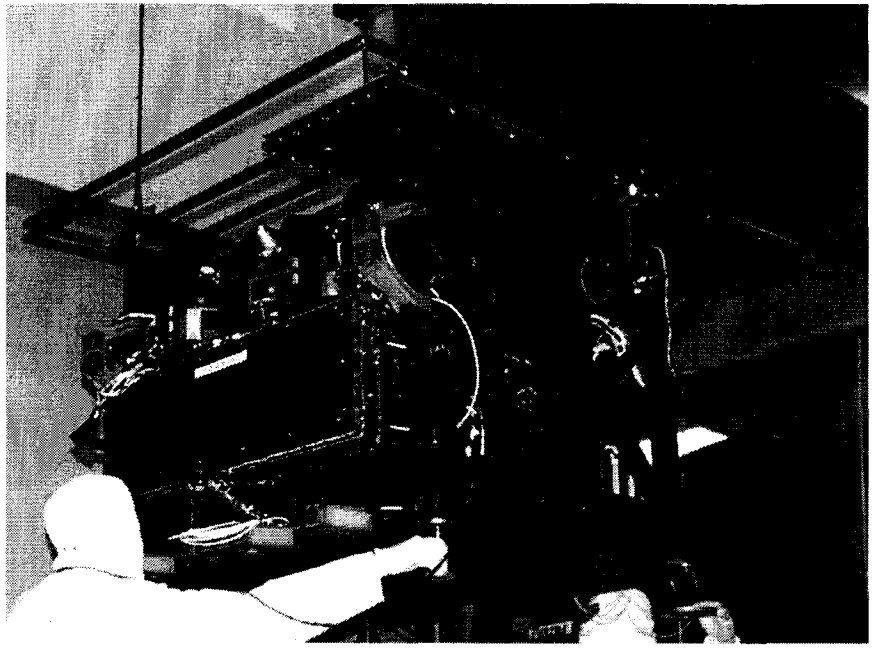
TES Interferometer and Detectors



TES (without thermal blankets or radiators)

Spectrometer Type	Connes'-type 4-port FTS
Max. Optical Path Difference	± 8.45 cm (nadir & calibration) ± 33.8 cm (limb)
Scan (integration) Time	4 sec (nadir & calibration) 16 sec (limb)
Sampling Metrology	Nd:YAG laser
Spectral Resolution (unap)	0.07 cm^{-1} (nadir) 0.018 cm^{-1} (limb)
Spectral Coverage	650 to 3050 cm^{-1} (3.2 to 15.4 ?m) in 200 – 300 cm^{-1} bands
Detector Arrays	4 (1 x 16) arrays, optically-conjugated, all MCT PV @65K
Signal-to-Noise Ratio (spectral)	Up to 200:1 Minimum requirement is 30:1
Radiometric Calibration	Internal, adjustable, cavity blackbody (340K) + cold space view
Spatial Calibration	Illuminated slit scanned across FOV
Radiometric Accuracy	< 1K 650 – 2500 cm^{-1} < 2K 2500 – 3050 cm^{-1}

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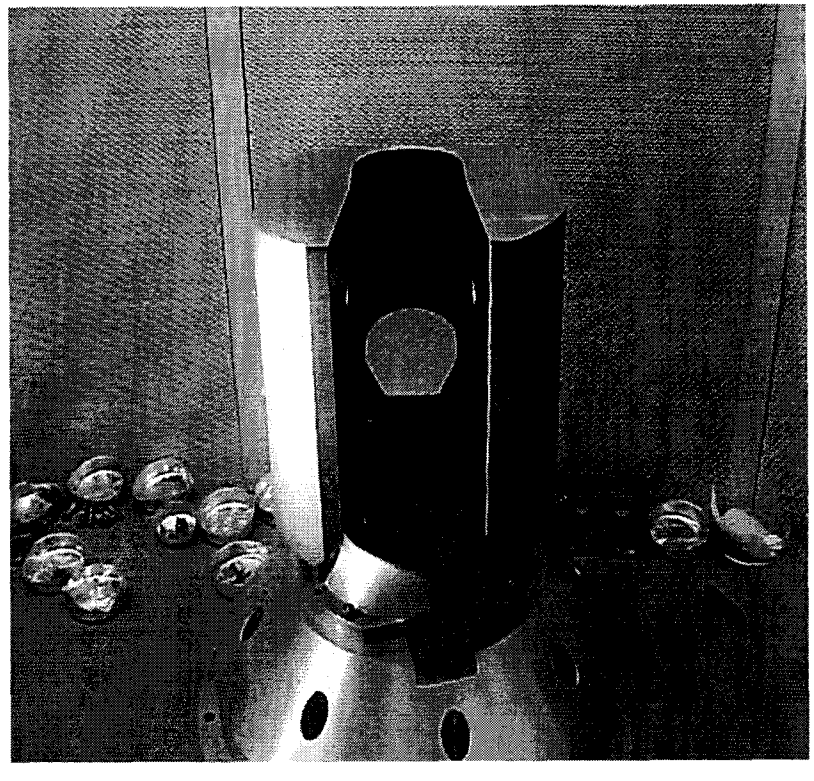
TES Pointing and Operating Modes

Field of Regard	45° cone about nadir; trailing limb 0 – 34 km; cold space; internal calibration sources
Pointing Accuracy	75 μrad pitch 750 μrad yaw 1100 μrad roll
Spatial Resolution	0.5 x 5 km (nadir) 2.3 x 23 km (limb)
Operating Modes	1) Global (spot) coverage in 16 orbits every other day 2) Continuous transects up to 800 km long 3) Stare at specific targets for up to 208 seconds



TES gimbal pointing mirror

Current Status

TES is mounted on the Aura spacecraft at Northrup Grumman Space Technology (NGST), Redondo Beach, California.

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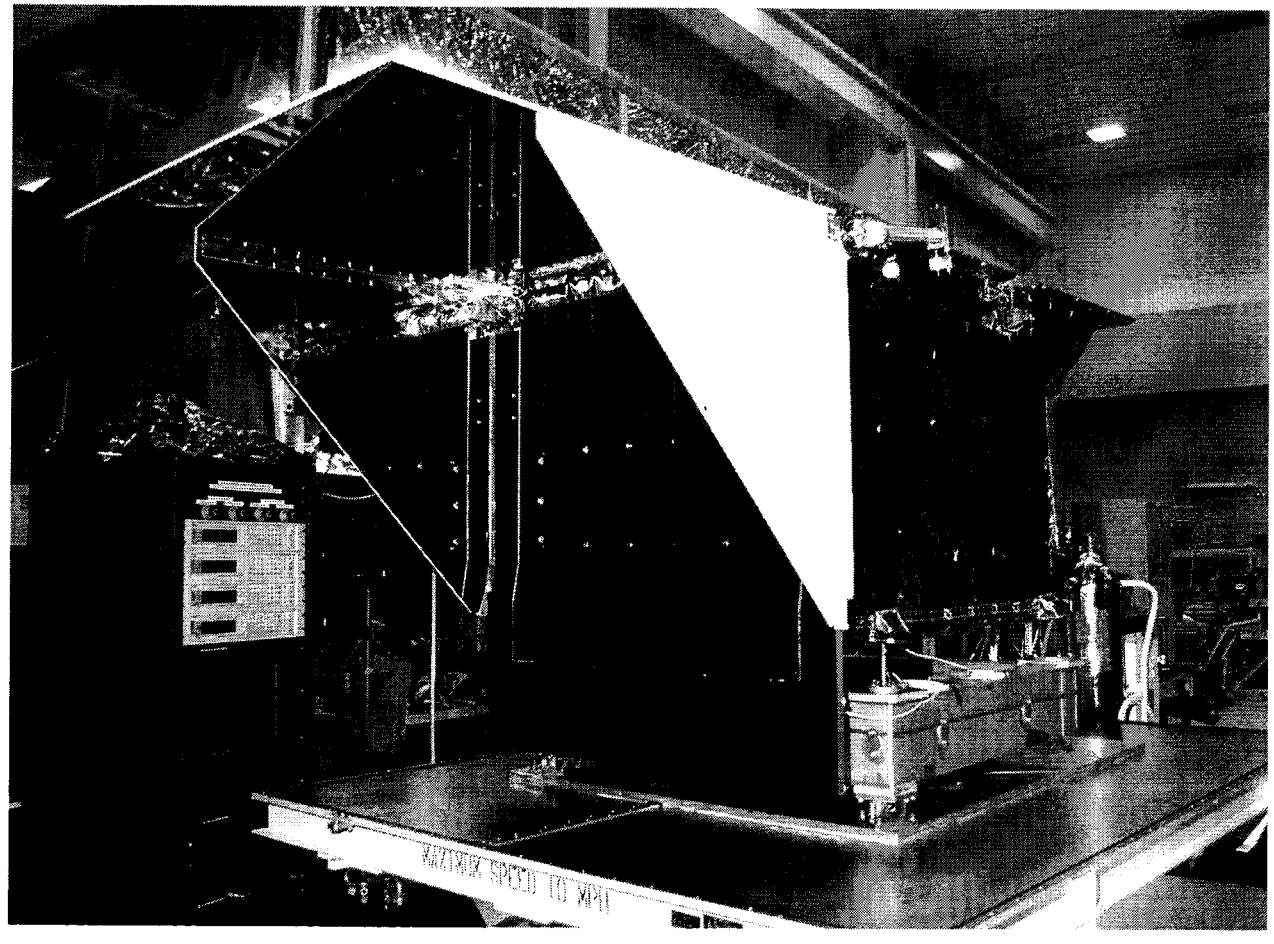
Space View Side



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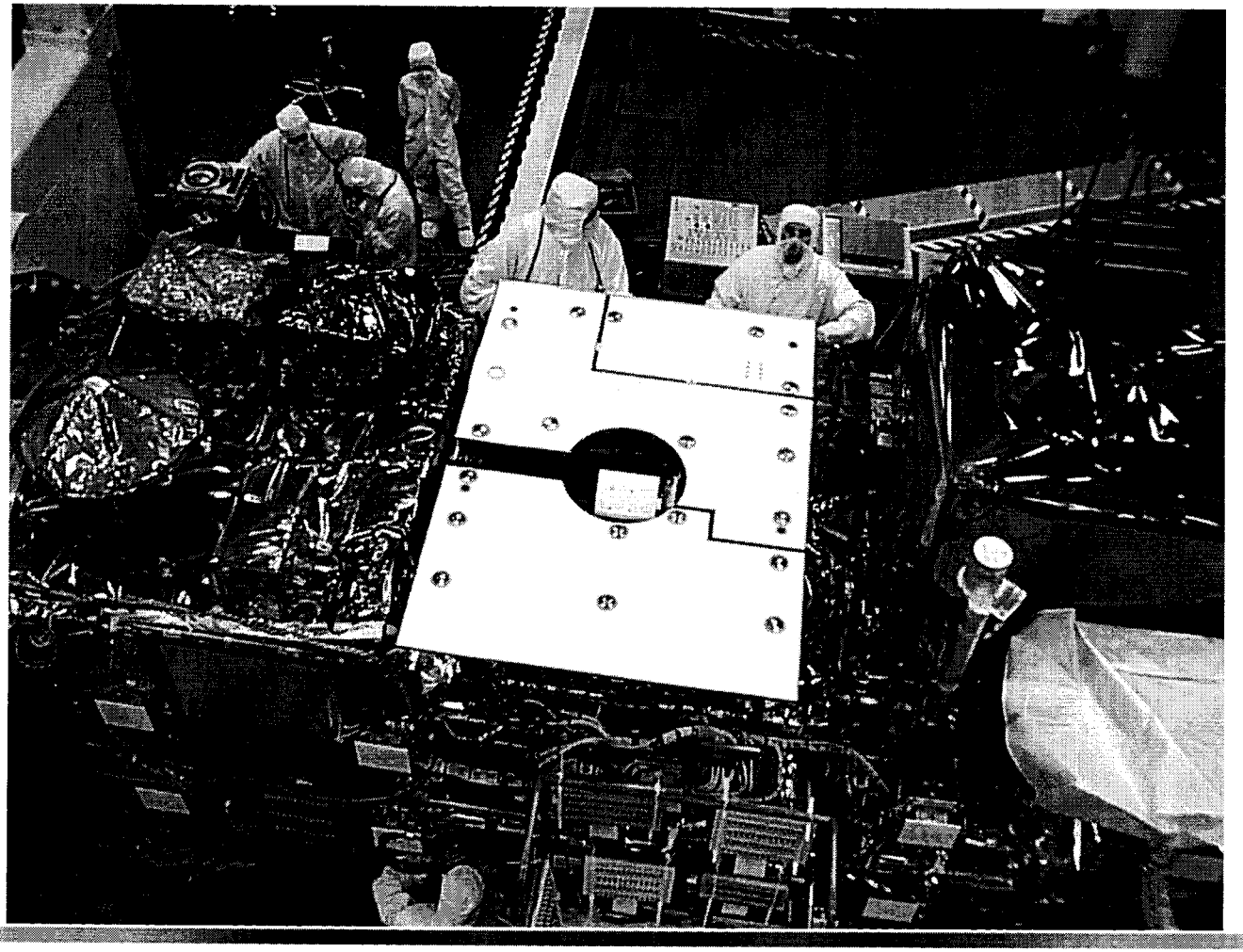
TES on Aura



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Instrument Test & Calibration

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Calibration Overview

Calibrations performed:

Radiometric

- for comparison to radiative transfer calculations, inc. NESR, gain, linearity, cal of on-board BB.

Spectral

- for frequency precision and Instrumental Line Shape extraction. Uses gas cells & CO2 laser.

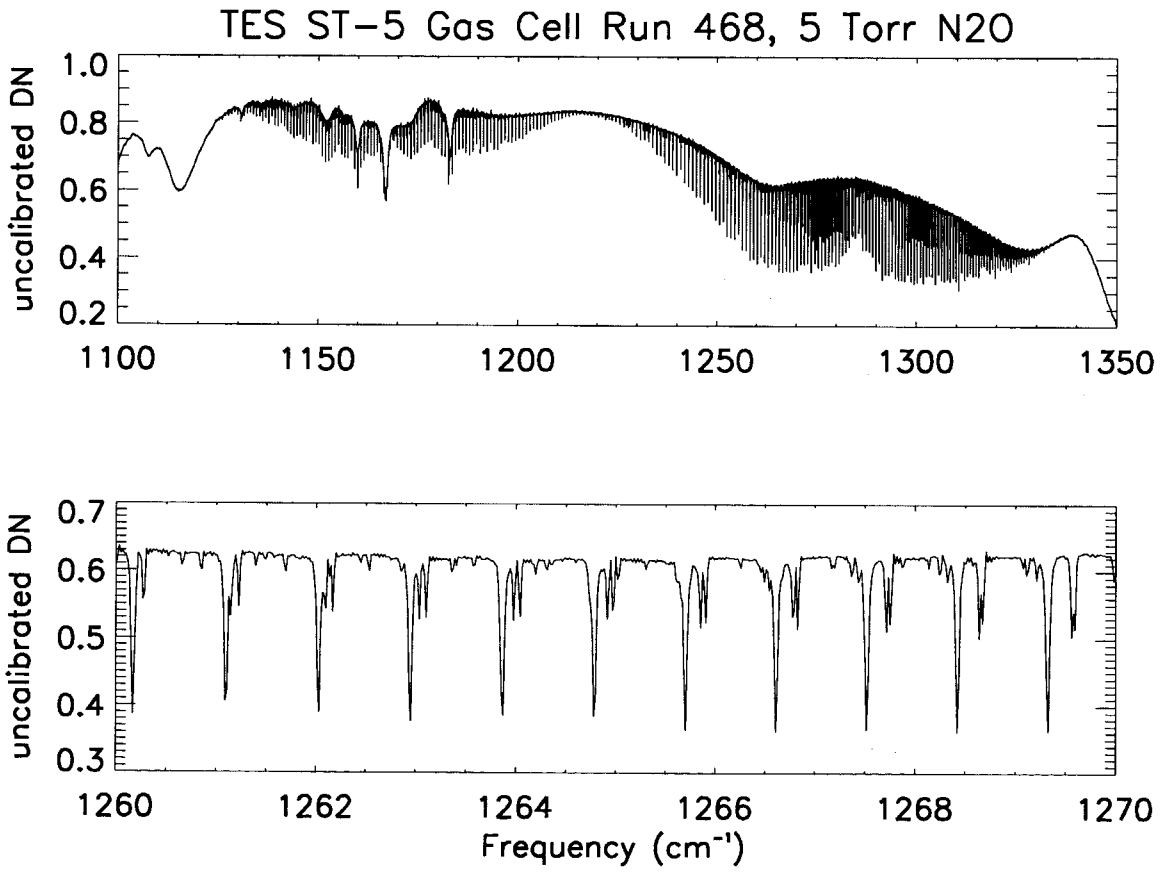
Spatial

- for Instantaneous Field of View extraction and co-boresight determination.

Calibration Accuracy (300K BB)

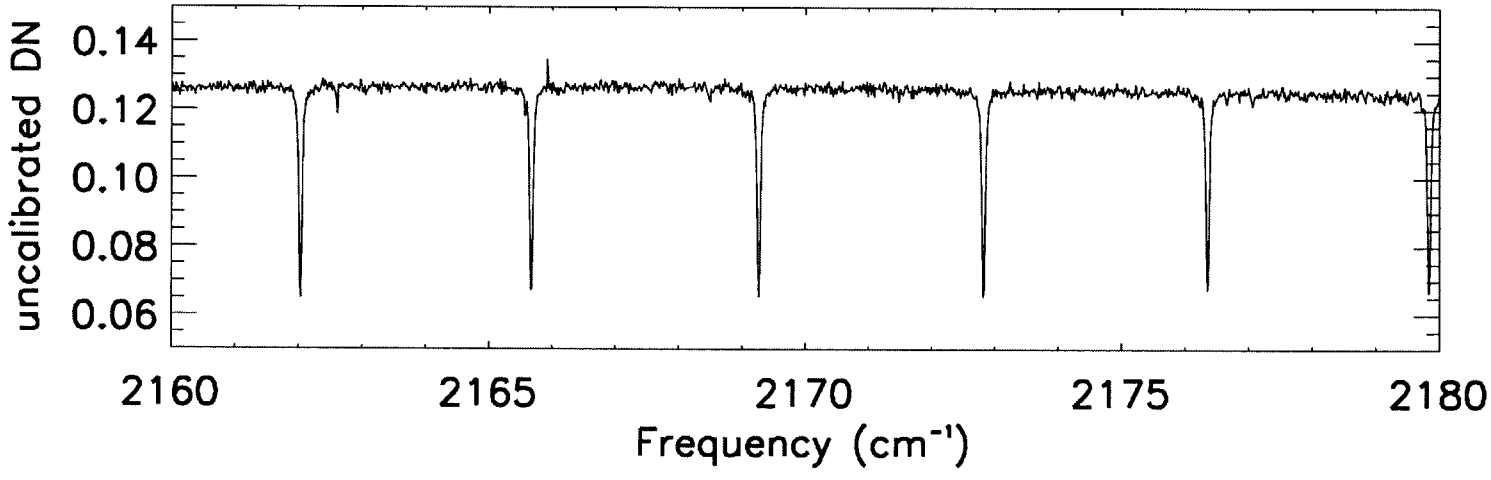
Filter	# scans averaged	NEDT (K)	Sys. Err. (K) T(extBB)-T(best fit)
2B1	40	0.58	0.30
1B1	20	0.23	0.19
1B2	20	0.24	0.23
2A1	10	0.46	-0.24
2A4	10	2.0	-0.63
1A1	20	2.6	-0.56

TES Gas Cell Spectra (1)



TES Gas Cell Spectra (2)

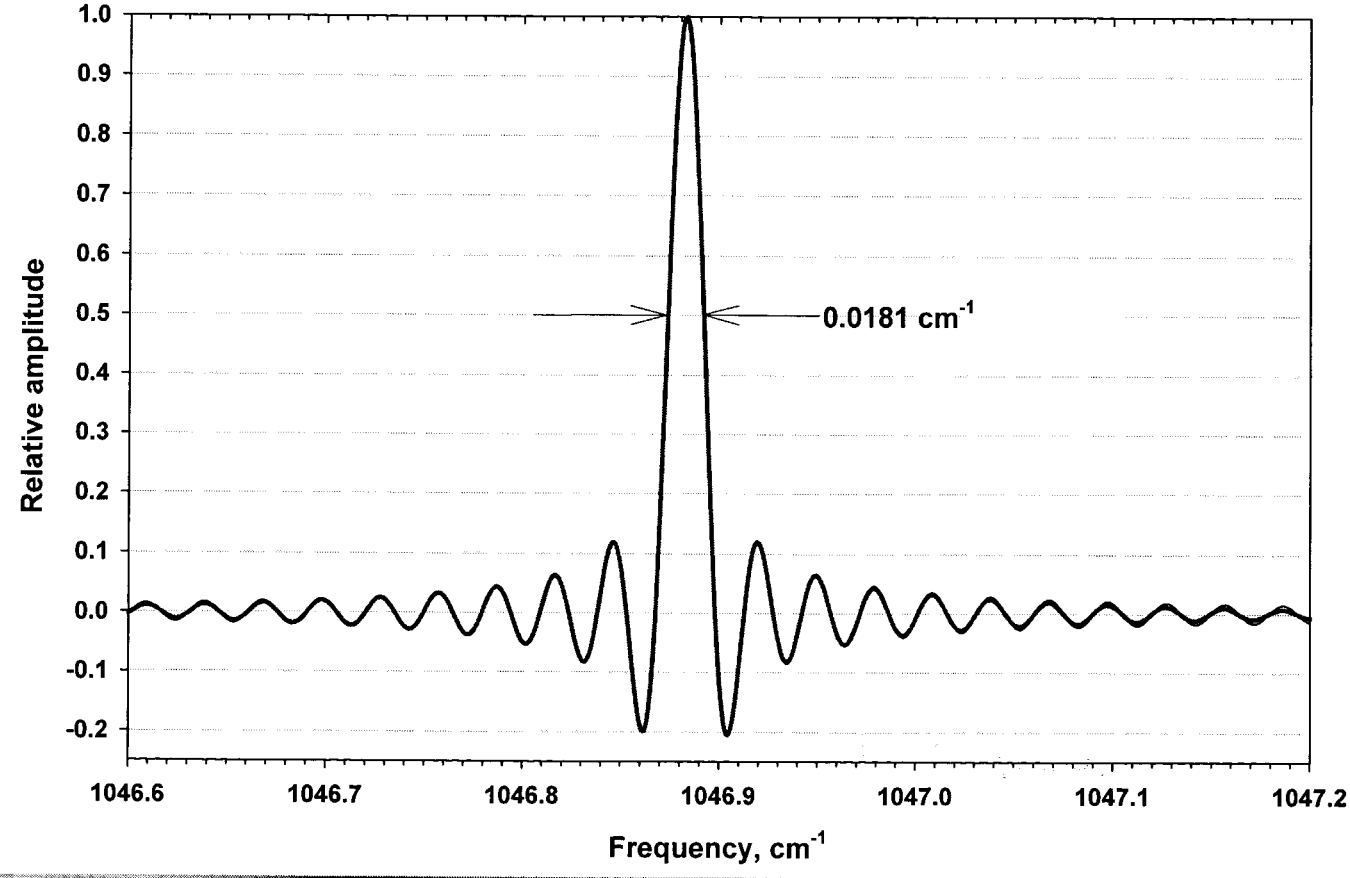
TES ST5 Gas Cell Run 473, 5 torr CO



TES Instrumental Line Shape (ILS)

CO_2 Laser 00^01 - 02^00 P(20) line (nominally @ 1046.8543 cm^{-1})

Model prediction



Contamination

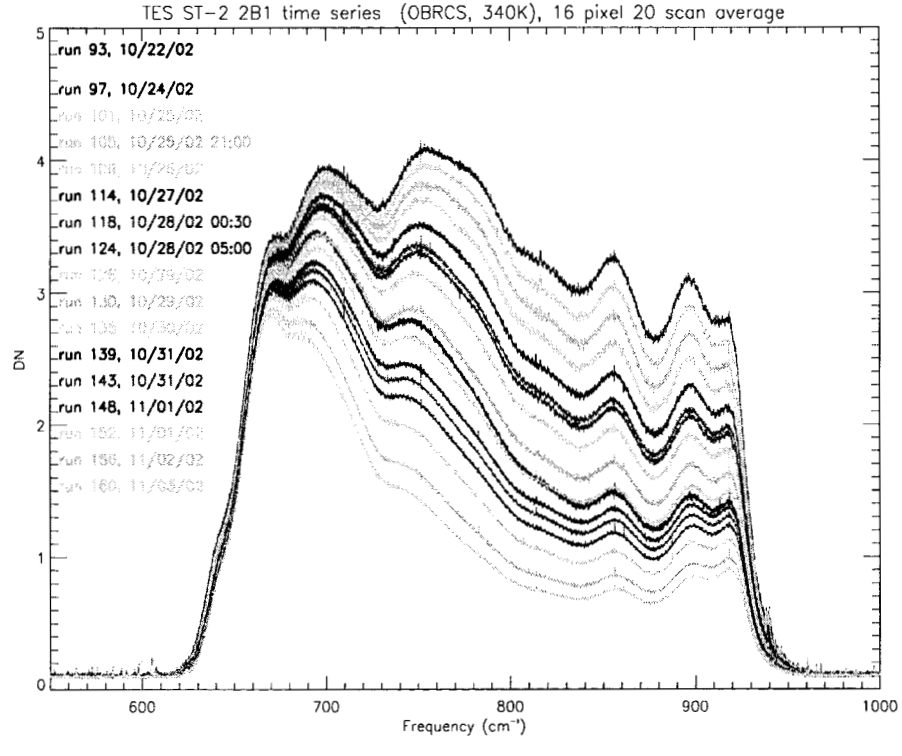
It was expected that the focal planes (at 65K) would experience a build-up of contamination (primarily water ice) while in the Thermal Vacuum chamber.

What was not expected was the speed at which this happens – in the region of the strongest ice band (around 800 cm^{-1}), the signal loss due to ice can be as much as 10% per day!

We also see CO_2 ice around 2340 cm^{-1} but this feature is comparatively narrow.

We believe (on the basis of other experiments [e.g., AIRS] with cold focal planes) that this rate of build-up will decrease with time once we are on orbit.

Ice Build-up
(2B array over 10 days)



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Algorithm & Ground Data System Status

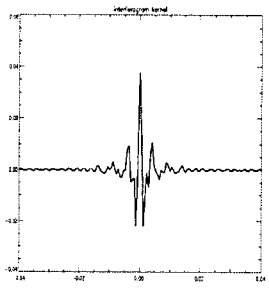
TES Algorithm Overview

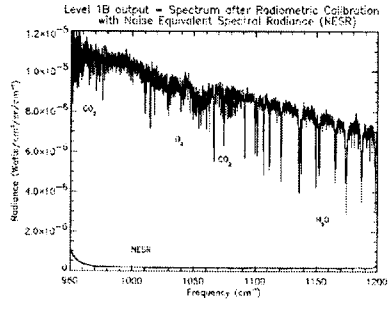
Level 1A: Produces geolocated interferograms.

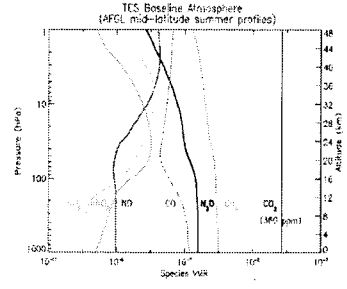
Level 1B: Produces radiometrically and frequency calibrated spectra with NESR.

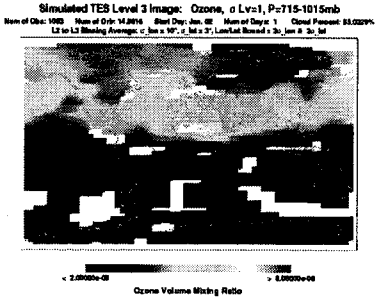
Level 2: Produces VMR and temperature profiles.

Level 3: Produces global maps.









Algorithm Status

All Mission Critical & Mission Essential algorithms are in place and tested.

L1 algorithms were *thoroughly* tested during several months of System Tests (5 vacuum cycles of 2-3 weeks each)

L2 algorithms are being tested using back-produced spectra from MOZART model fields for one day of 16 orbits (the "One Day Test")

L1 – L2 internal & external connectivity has been demonstrated in Software Release 4 and mission operations testing

Updated Algorithm Theoretical Basis Documents (ATBD) are in progress

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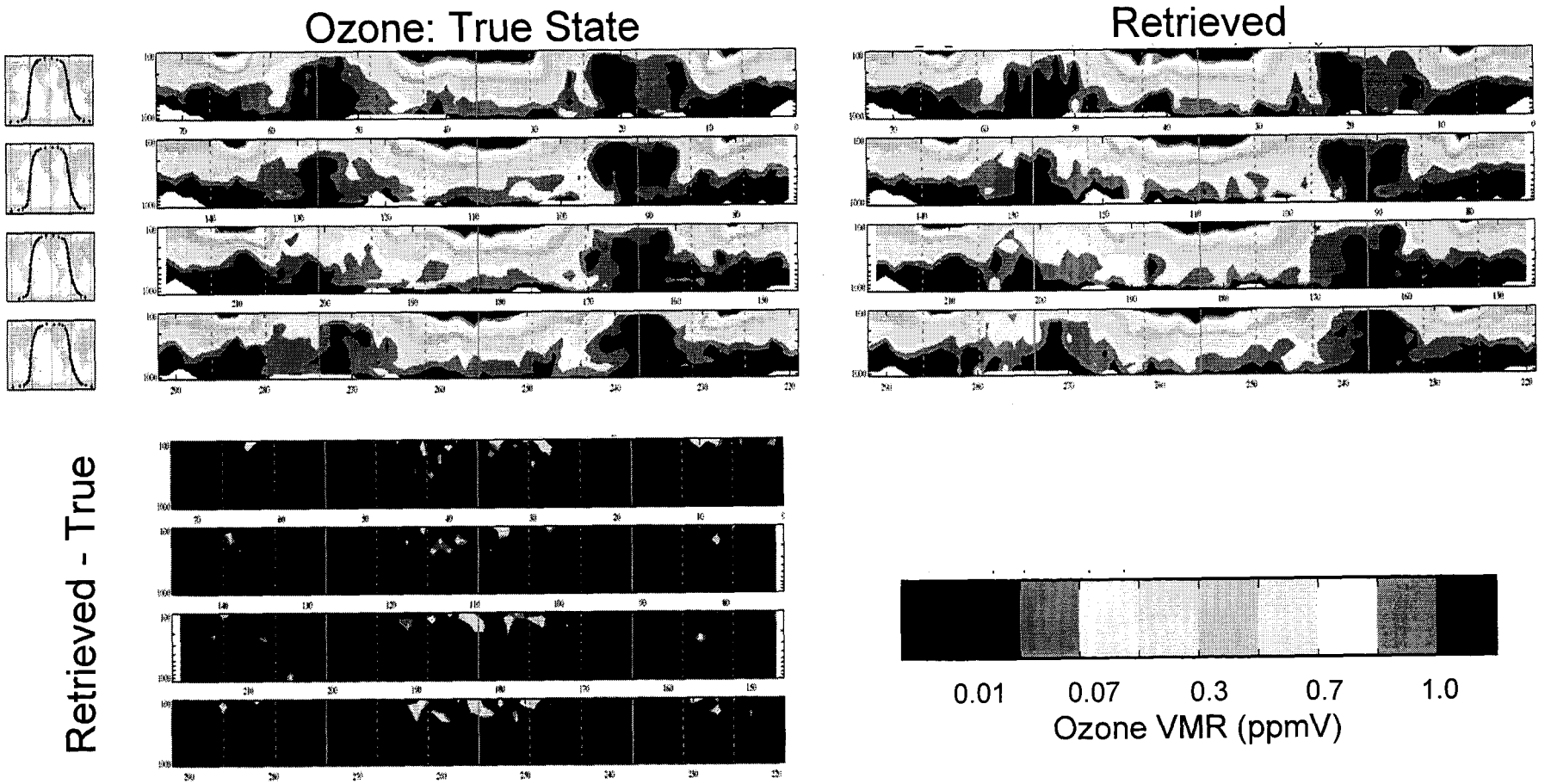
One Day Test Results

(1000 – 100 hPa; 4/16 orbits shown)



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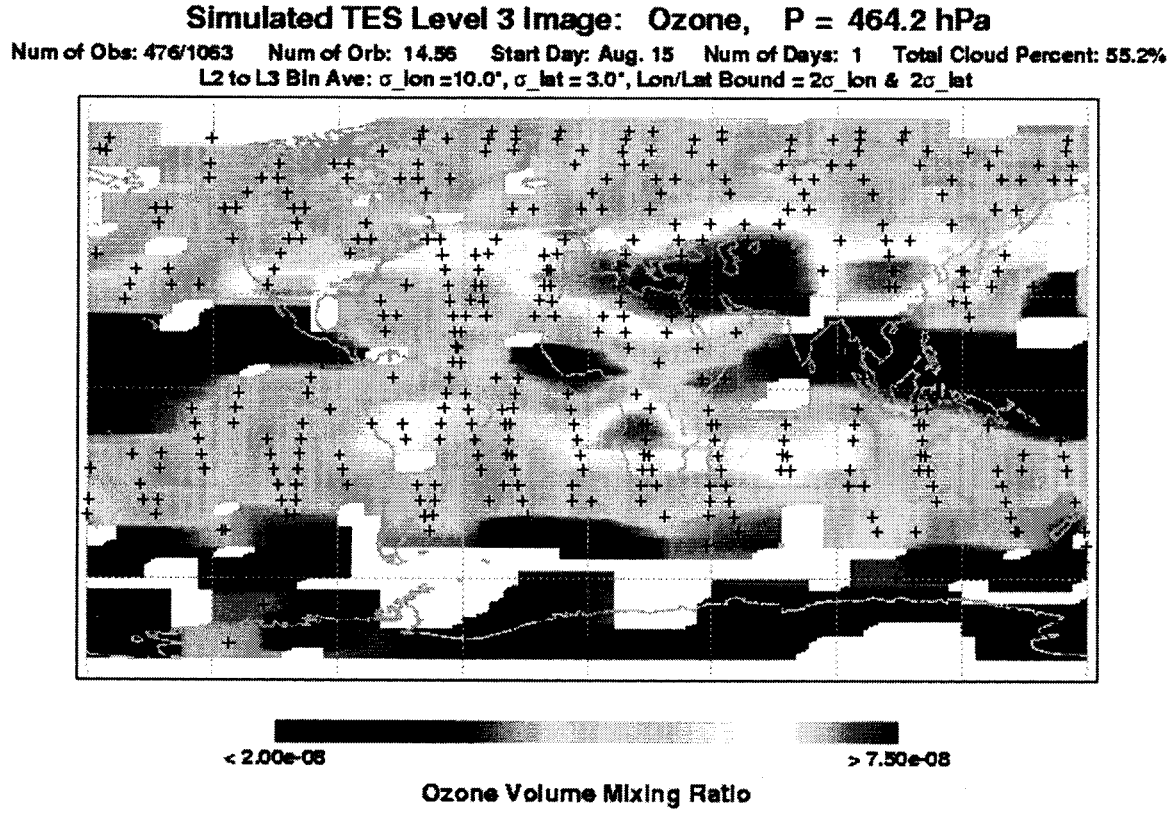
Browse Product with Observation Locations



SIPS / SCF / ASDC Facilities

The Science Investigator Processing System (SIPS) Production facility is hosted by Raytheon in Pasadena (152-node dual AMD Opteron cluster + RAIDs etc.).

The Science Computing Facility (SCF) for Research Products, algorithm and software development is at JPL (20-node dual AMD Opteron cluster + RAIDs etc.).

The Atmospheric Science Data Center (ASDC) is at the NASA Langley Research Center. There, all TES data will be archived.

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Plans for Launch & Early Operations

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First Year Activities

L→ L+30	Instrument Activation (power on, unlatch, outgas, open Earth shade, cool down, signal chain on)
L+30 → L+150	Post-launch Commissioning (initial calibration to assess instrument alignment & ice accumulation, defrost as necessary, first cold space views, Global Survey checkout)
L+150→ L+240	Initial Operations (transects & staring mode to support validation, defrost as necessary, trial Global Surveys & analysis)
L+240 →	Transition to routine operations

Data Availability

Data Plans

FOR VALIDATION

- L+5 – L+8 months

FOR THE COMMUNITY

- L+12 months for nadir products
- L+18 months for limb products

Summary

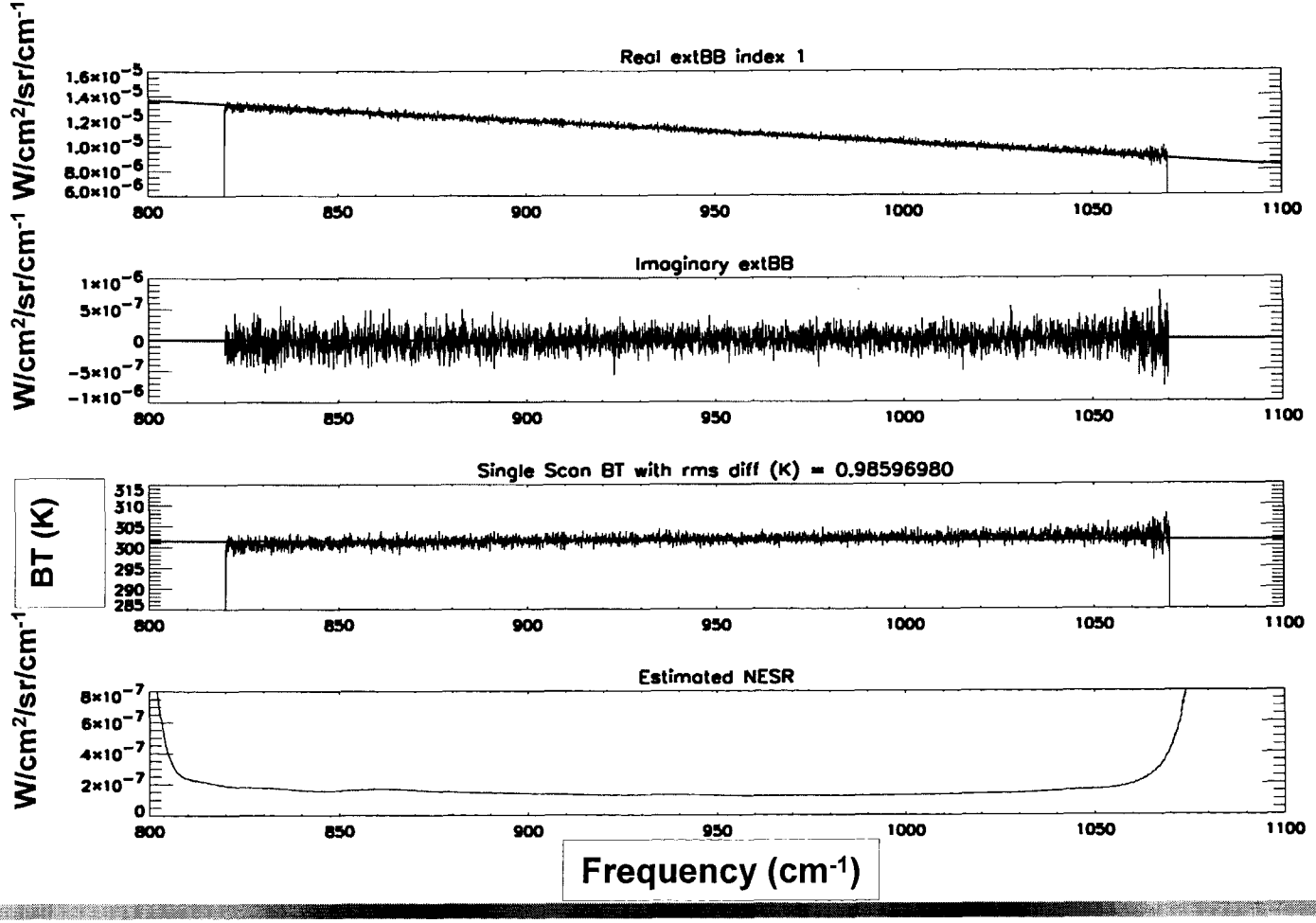
TES IS READY FOR LAUNCH

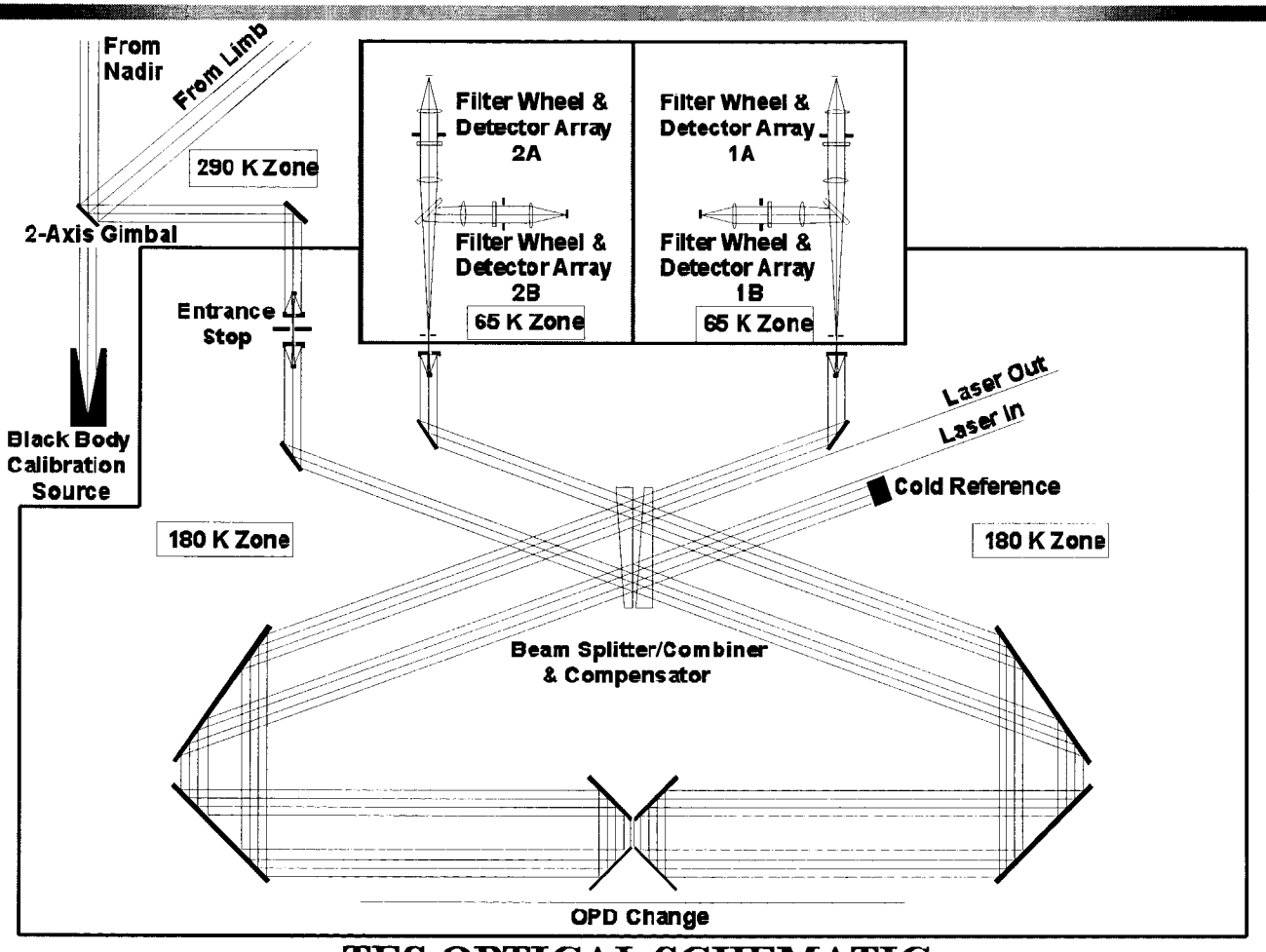
For more information:

http://tes.jpl.nasa.gov

Backup Slides

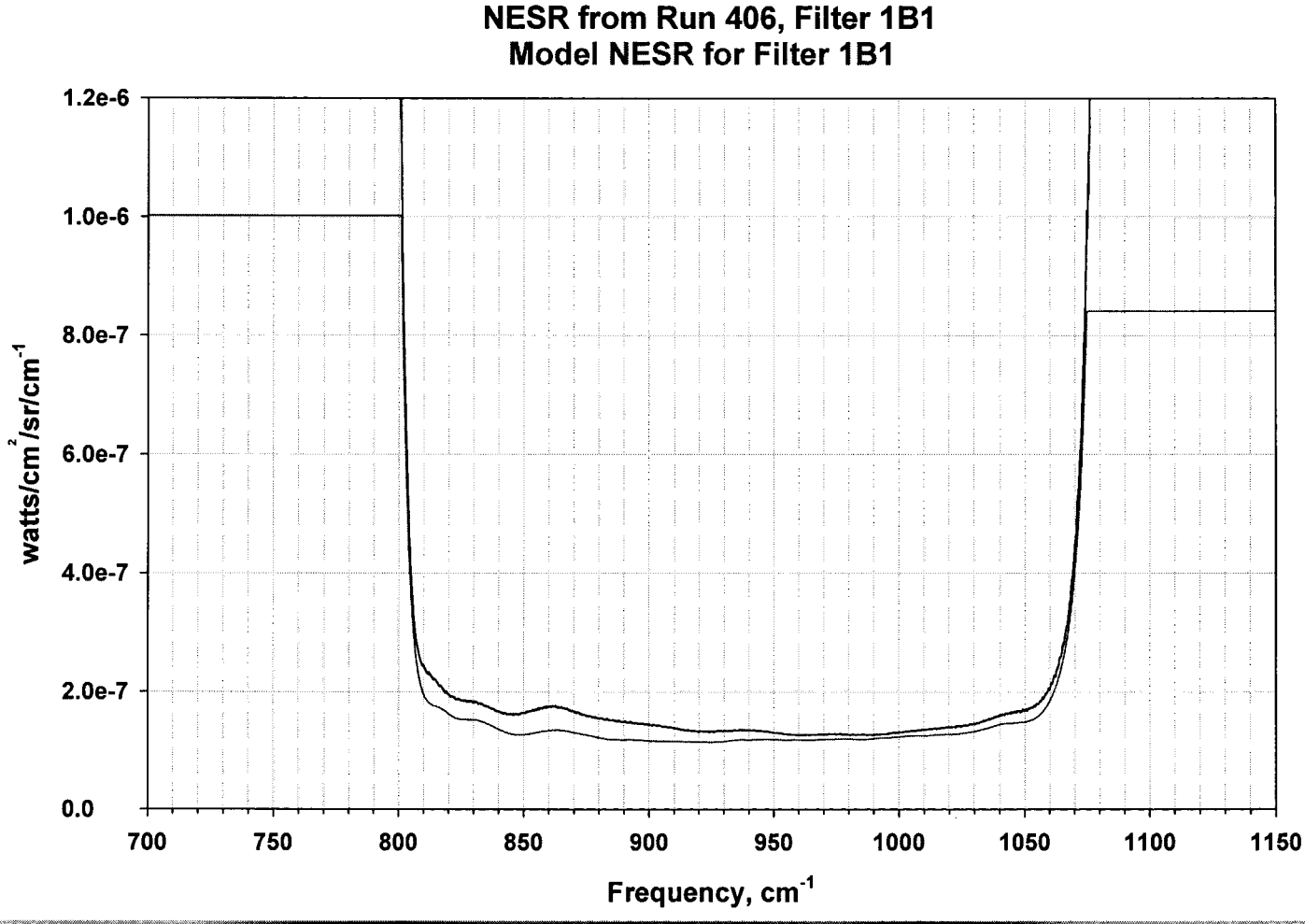
Radiometric Calibration - Result



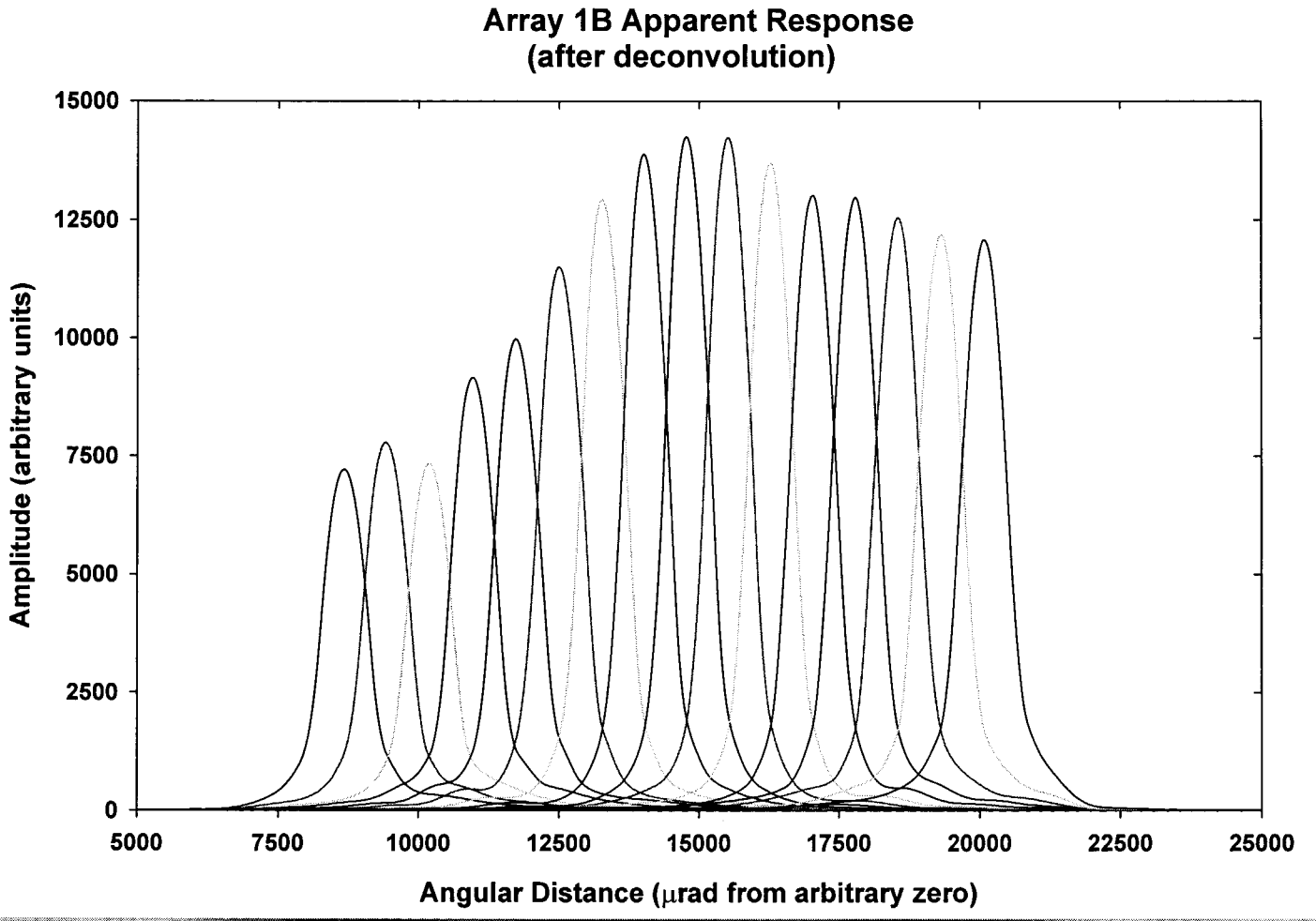


TES OPTICAL SCHEMATIC

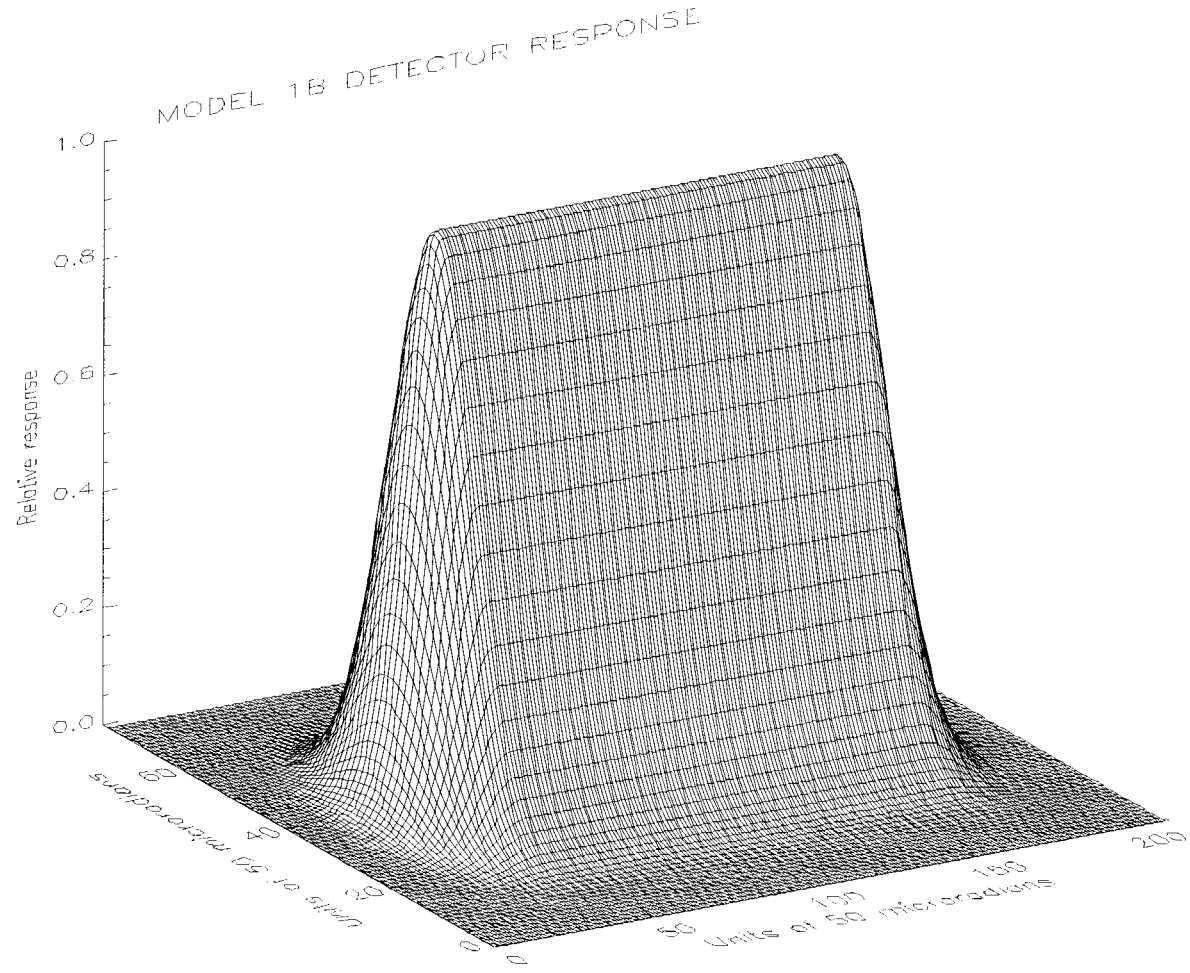
Measured & Modeled NESR's



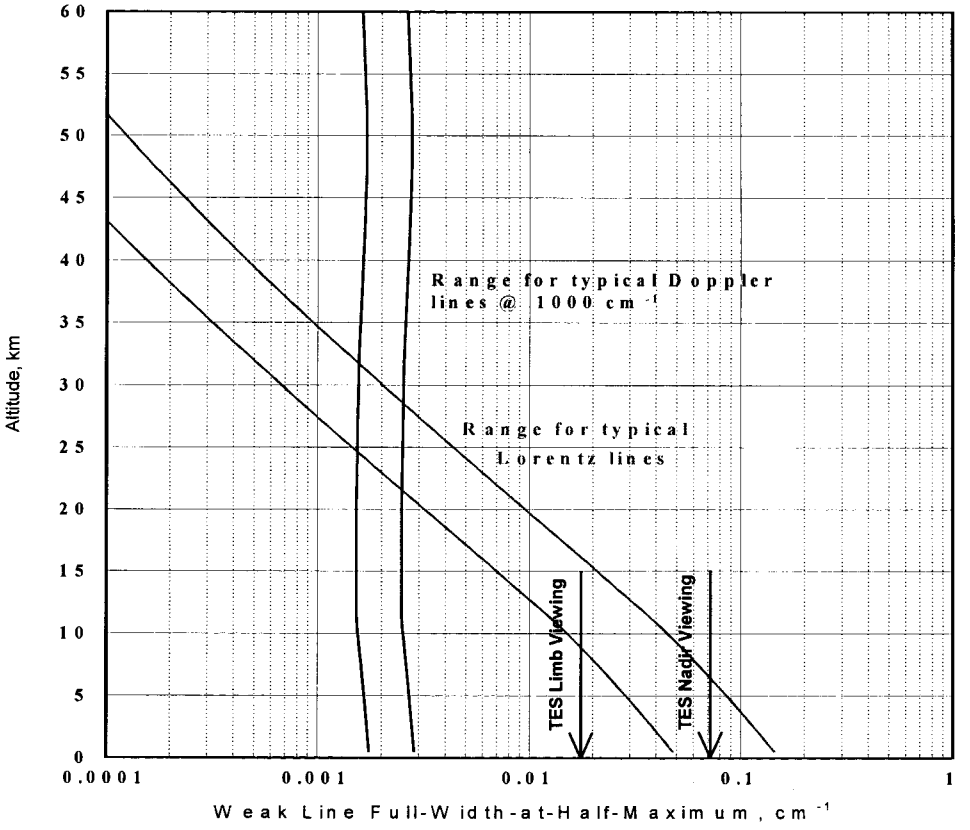
Instantaneous Field of View



1B Pixel Response Model



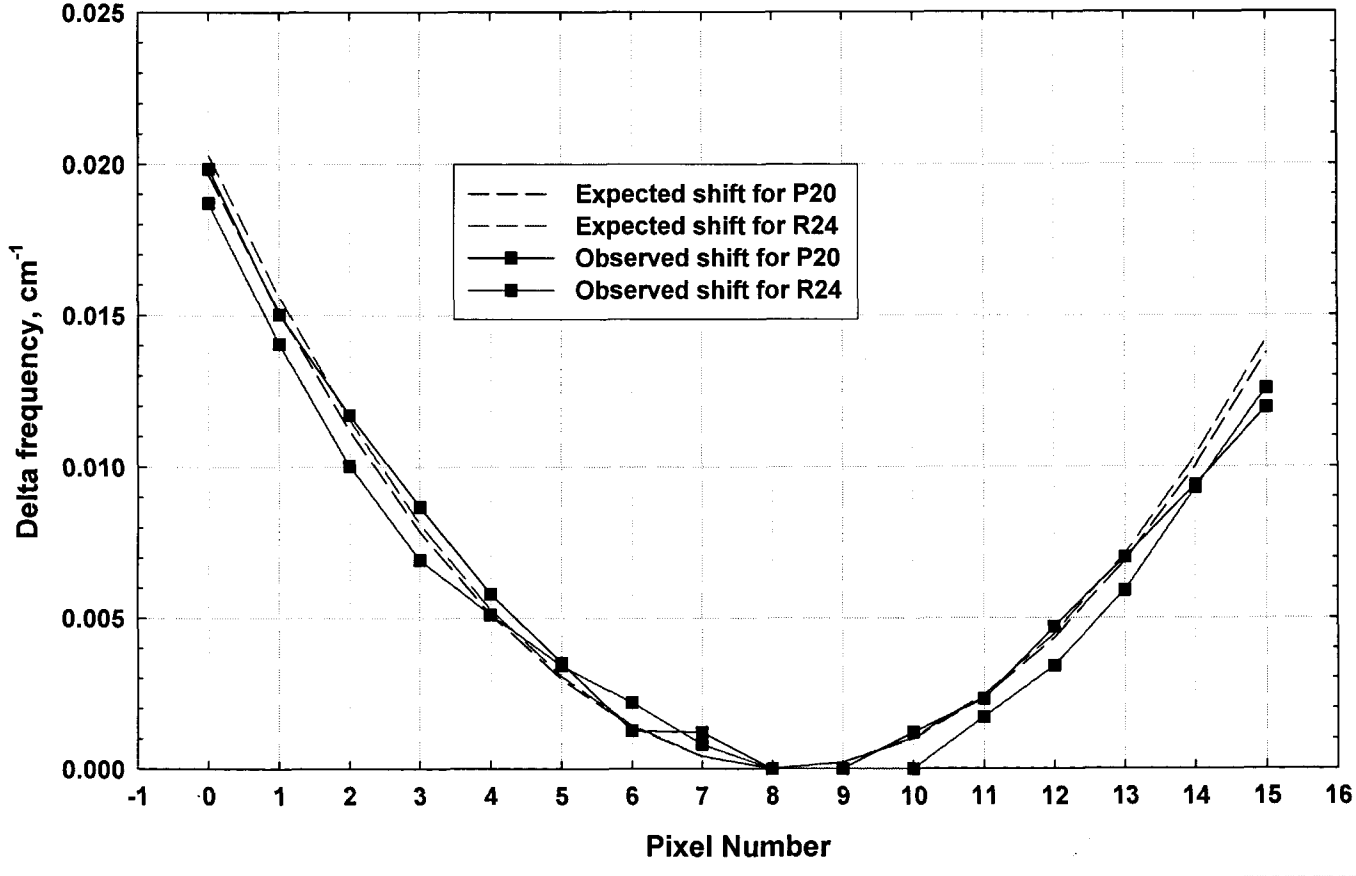
Variation of Typical Linewidths with Altitude



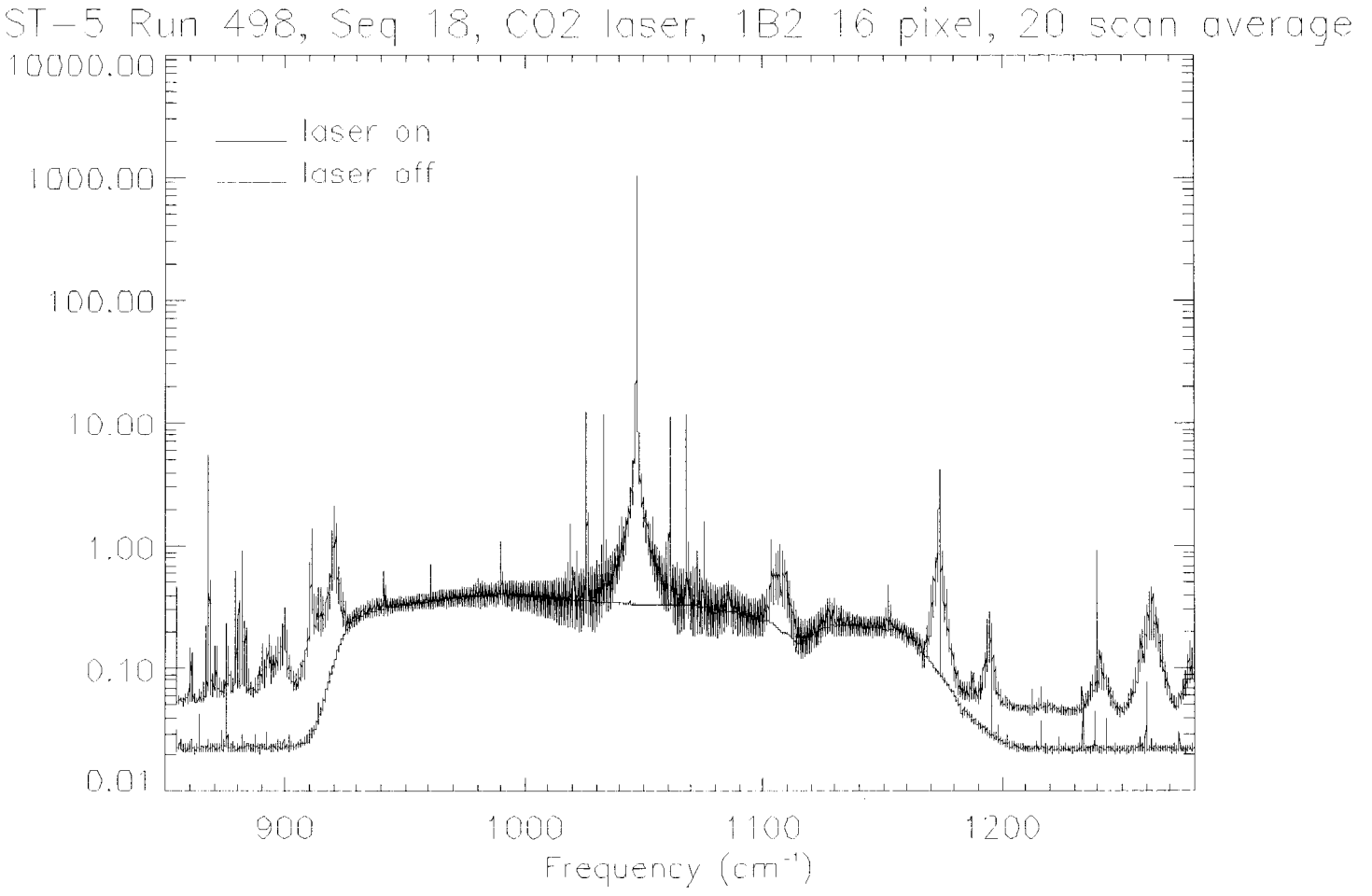
Relative Frequency Calibration (1B array)

Observed & expected frequency shifts for the CO_2 laser

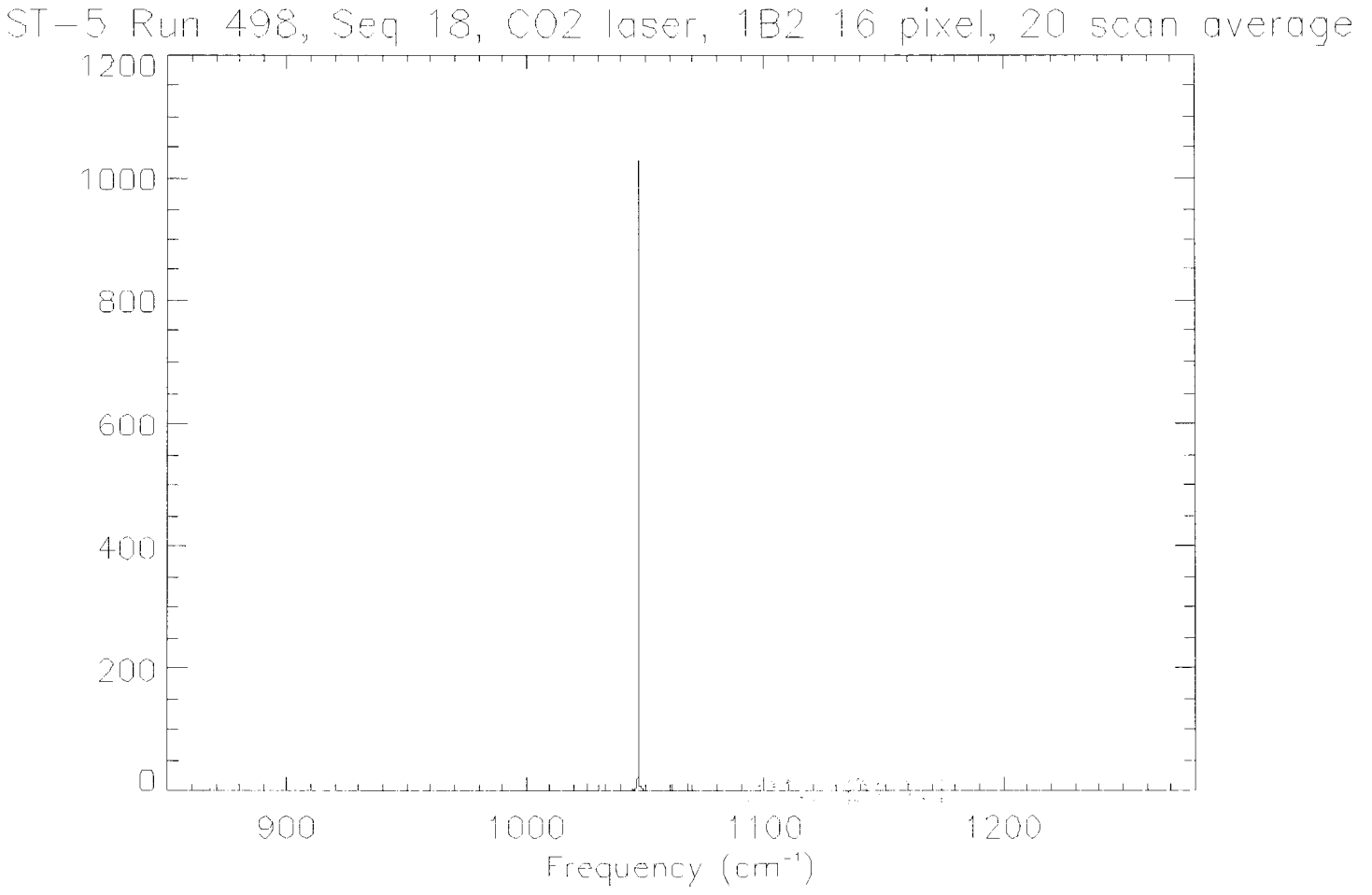
P20 (1046.8543 cm^{-1}); R24 (1081.0877 cm^{-1}); shift = +0.5 mrad



CO_2 Laser (log plot)

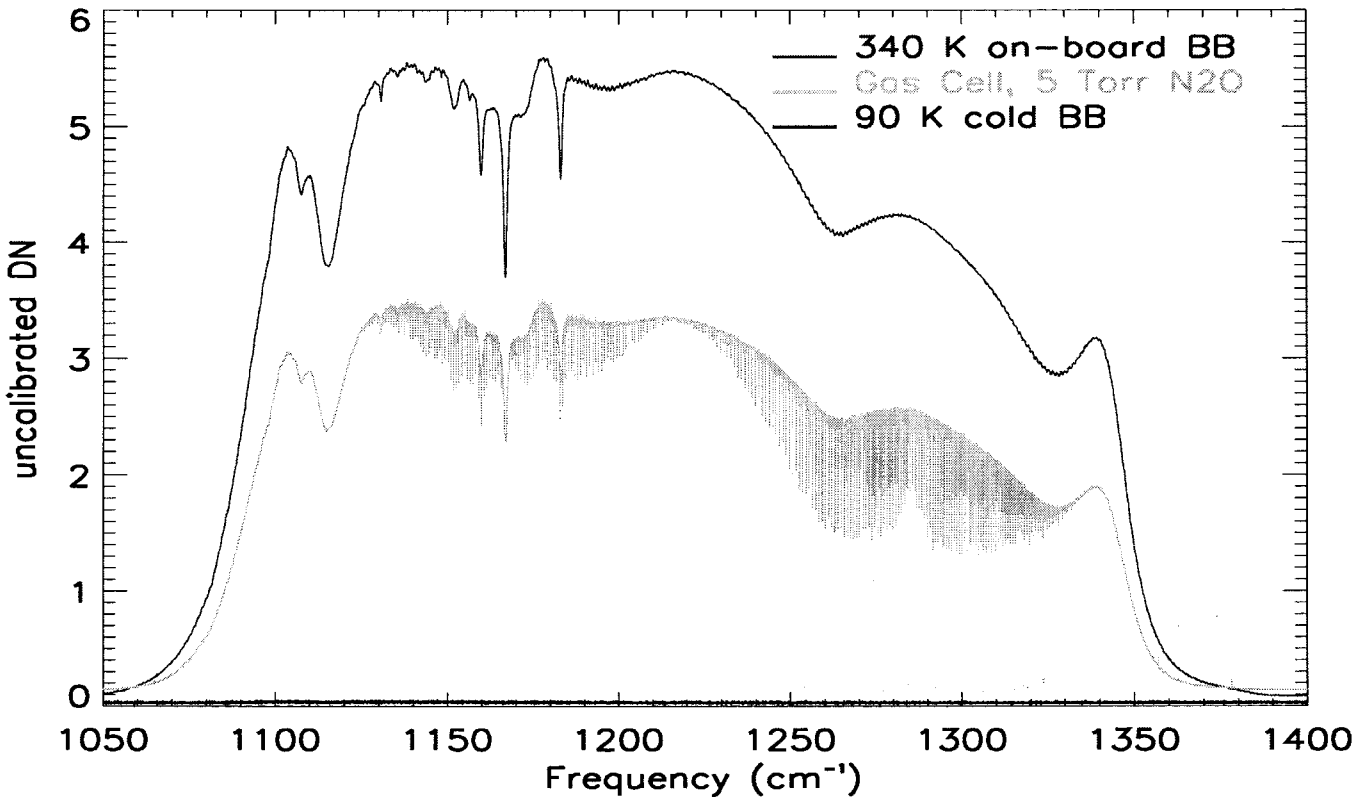


CO_2 Laser (linear plot)

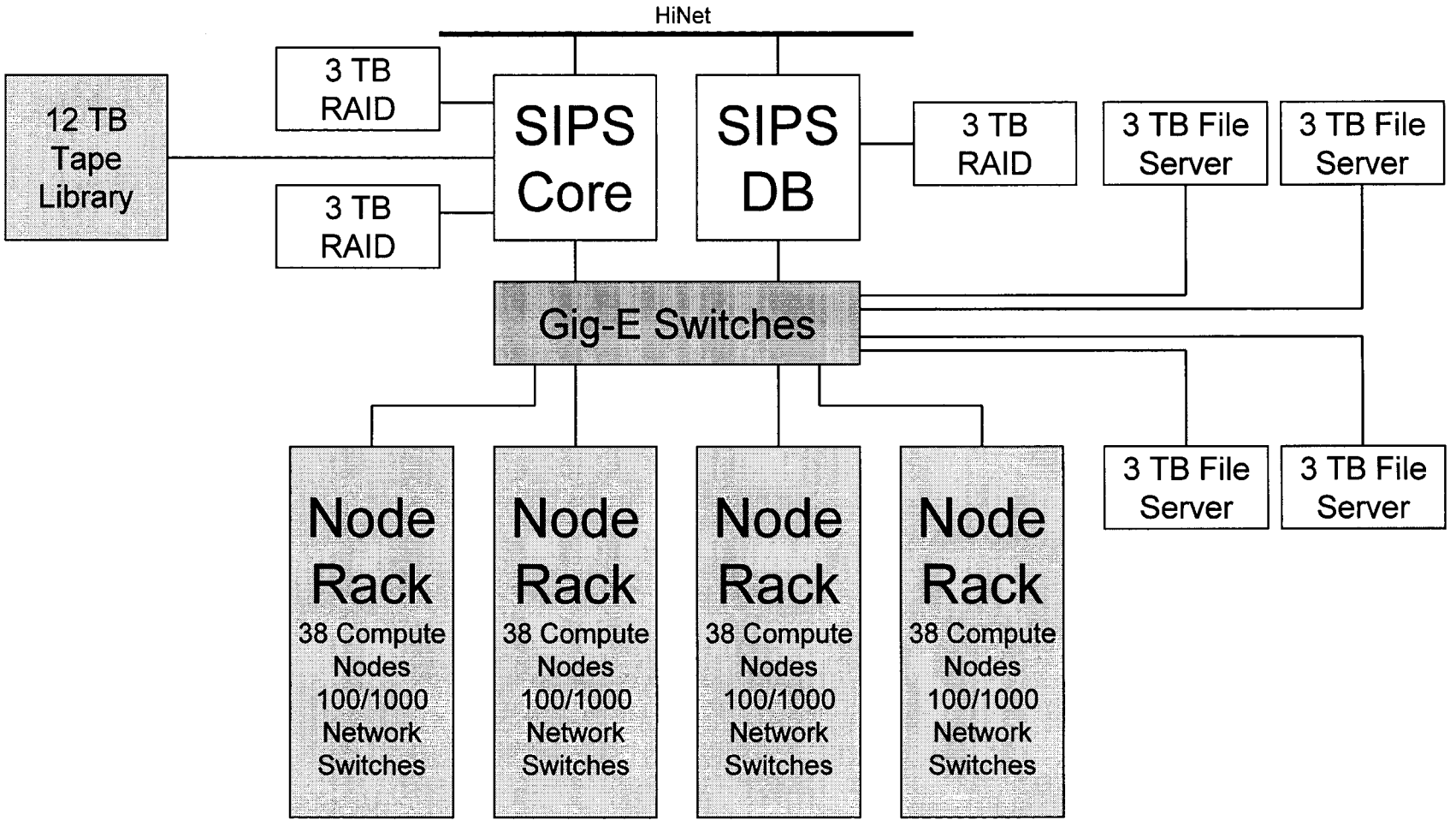


Radiometric Calibration - Principle

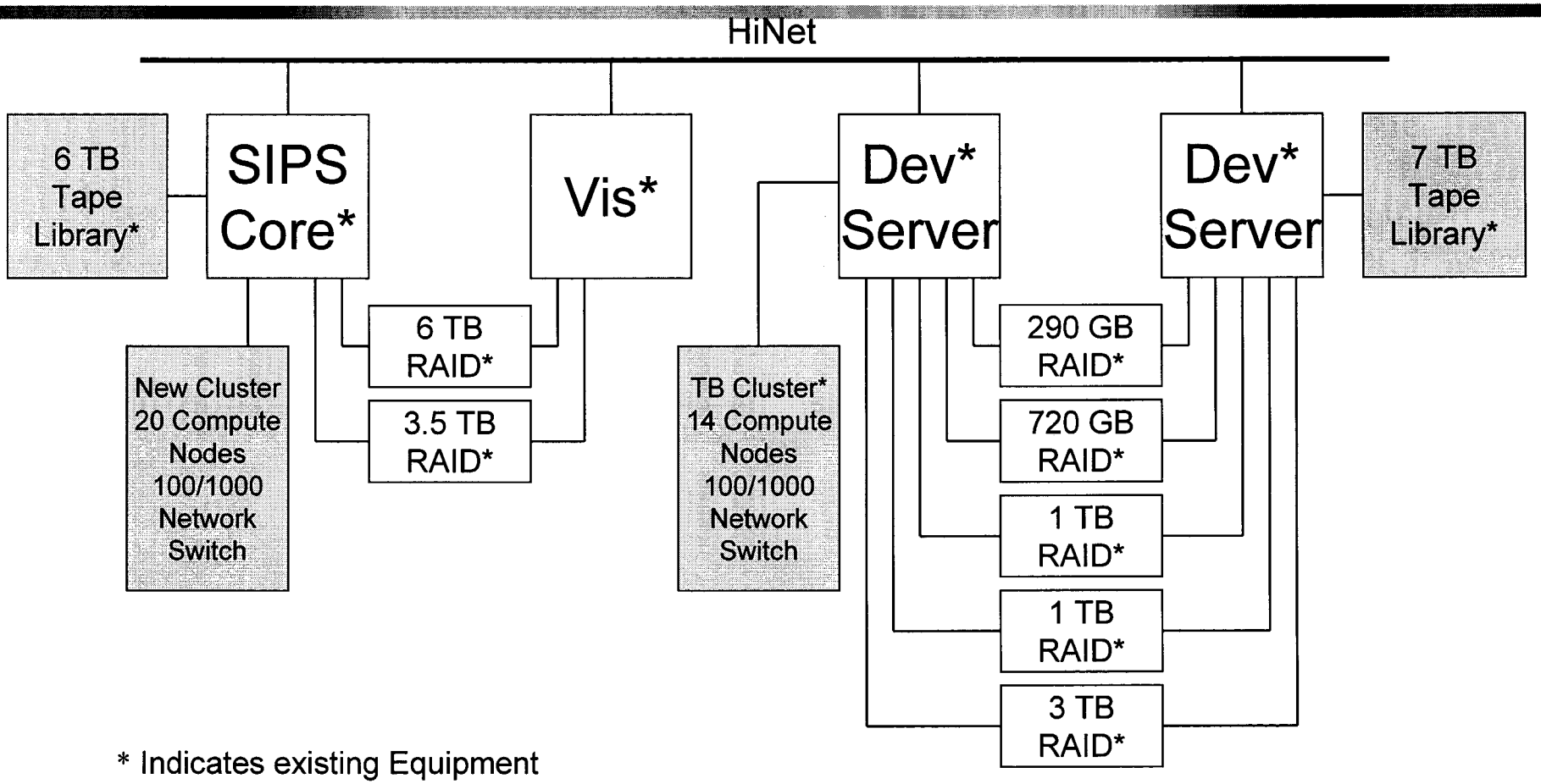
$$L_{target} = \frac{C_{target} - C_{CS}}{C_{BB} - C_{CS}} \varepsilon_{BB} B(T_{BB})$$



TES At-Launch
SIPS Hardware Diagram

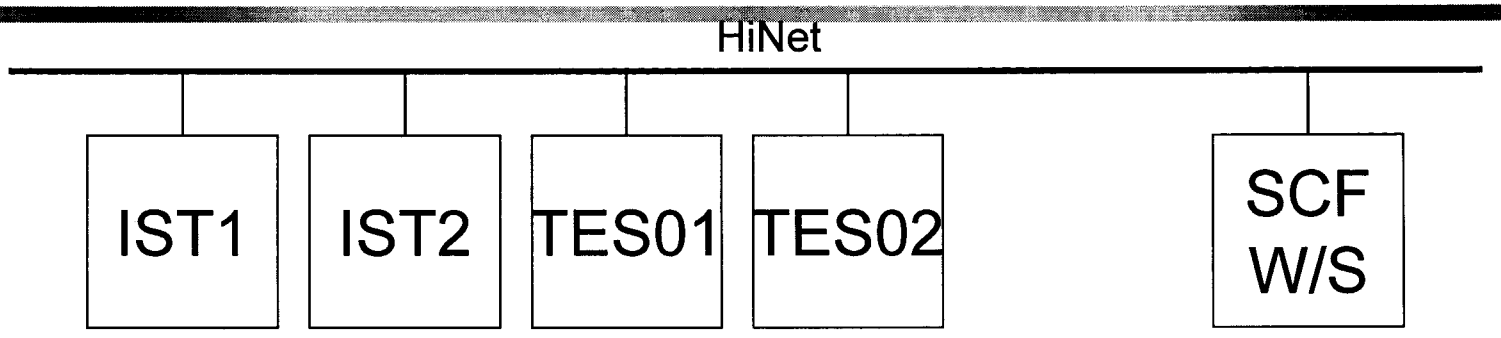


TES At-Launch
SCF Hardware Diagram



* Indicates existing Equipment

TES At-Launch
IST Hardware Diagram



* Indicates existing Equipment