Documentation For

SPECTRE/SIRIS

HIGH-SPECTRAL-RESOLUTION EMISSION DATA

Goddard Space Flight Center

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1. INTRODUCTION

This documentation describes the instrumentation, data reduction, calibration, and archiving of the SPECTRE /SIRIS high spectral resolution observations obtained at Coffeyville, Kansas in November-December, 1991. The data for Ch 1 WB was released on April 1, 1994. The data being released at this time is for Ch 1 NB and Ch 2 NB.

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2. THE SIRIS INSTRUMENT

The SIRIS instrument has been previously flown for balloon-borne studies of stratospheric chemistry relevant to the ozone cycles (Brasunas et al., 1988). It is a modified version of a Bomem continuously scanning Fourier transform spectrometer, operating in the emission mode (Fig. 1). The following instrument parameters were applicable for the Coffeyville SPECTRE campaign:

Field of View:	0.5 degrees, full width at half maximum
Spectral Resolution:	0.122 cm^{-1}
Integration Time:	82 sec for wide band mode
	68 sec for narrow band mode

The instrument was run at ambient temperature, with the Si:Ga detectors at liquid helium (LHe) temperature. Under these conditions, detector noise is not a factor, the data instead is limited by photon noise from the emission from the instrument and from the atmosphere itself. Therefore, data were recorded with two different width bandpasses: 1) narrow bandpass(NB) cooled filters in channels(ch's) 1-4, which reduces the background noise, yielding higher signal-to-noise; and, 2) wide band(WB) in channel 5 for more complete spectral coverage. These channels and their dominant radiative gases emitting

in their bandpass are:

Ch 1 - NB	0700 - 960 cm^{-1}	CO_2, H_2O, H_2O continuum
Ch 2 - NB	1235 - 1350 cm^{-1}	N_2O, CH_4, H_2O
Ch 3 - NB	1580 - 1620 cm^{-1}	NO_2, H_2O
Ch 4 - NB	1880 - 1920 cm^{-1}	NO, H_2O
Ch 5 - WB	0700 - 2000 cm^{-1}	All of the above.

The digital filtering in the narrow band mode was slightly more narrow than the optical band for Ch 1 NB, so an auxiliary observing mode was also used with the Ch 1 optical signal processed through the Ch 5 wide band(WB) signal handling chain. This extended the spectral coverage of Ch 1 NB region, this mode is labelled as:

Ch 1 - WB 0700 - 1100 cm^{-1} CO_2, H_2O, O_3, H_2O continuum.

As SIRIS was operated in an open shed near ambient temperature, it was important to stabilize its temperature to reduce changes in self-emission. Uncontrolled, SIRIS rises about 1K/hour during a typical, sunny afternoon; it falls about 1K/hour at night. A two-zone temperature stabilization system was employed. One zone was for the entrance window to the vacuum chamber (see Fig. 1). The other zone was for the rest of the instrument; here a 60W heater was used, which was capable of raising the temperature by 2K/hour. With the temperature stabilization circuits on, the temperature could be maintained steady to within better than 0.2K/hour (Fig. 2).

Intensity calibration of the SIRIS spectra is accomplished by looking at a blackbody calibrator above and external to the SIRIS vacuum (Fig. 3). The calibrator consists of a blackbody cavity capable of having its temperature set within a range of temperatures, custom-made by Electro Optics; and a surrounding enclosure of N2 purge gas. Some of the relevant parameters of the cavity are:

Temperature range:	100 to 300 Kelvin
Cavity opening:	2.5 inch diameter
Cavity emissivity:	0.99 ± 0.01
Calibration accuracy:	$\pm$ 1K

The blackbody cavity is normally intended for operation within a vacuum, or stable, dry nitrogen gas; and the 1K temperature and 0.01 emissivity accuracies are applicable only under these conditions. Since it was desirable to operate the cryogenic cavity without a window to have a well-characterized blackbody

emission, an outer shell enclosing the cryogenic blackbody was constructed. A combination of a long snout and a high flow rate of N2 purge gas was used to attempt to achieve frost-free operation. During actual field use, there was some frosting in the cavity during some of the calibration periods due to the extremely high relative humidities encountered, with the local atmosphere sometimes in supersaturation

3. THE SPECTRE/SIRIS OBSERVATIONS

SIRIS began taking spectra on November 17, and was operational every SPECTRE day until the end on December 6, 1991. It was the goal of SPECTRE to acquire clear-sky radiance spectra under a variety of temperature and water vapor conditions. The SPECTRE team chose the following days as being especially representative of different meteorological conditions:

WARM WET:	November 18, 19
MID-LATITUDE/INTERMEDIATE:	November 26
WARM DRY:	November 30
COLD DRY:	December 4
COLD WET:	December 5 (also some cirrus)
CIRRUS/SUB-TROPICAL:	December 6

These are UT days: in Coffeyville, 18:00 CST corresponded to the start of a new UT day. A large fraction of the data was taken at 0.122 cm-1 resolution to reduce the time duration of the measurements, and to allow more frequent calibration. High quality SIRIS data exist for most of the SPECTRE key days. The data for the WARM WET day(Nov 18,19) are not included in this release; due to a lack of cold calibration data.

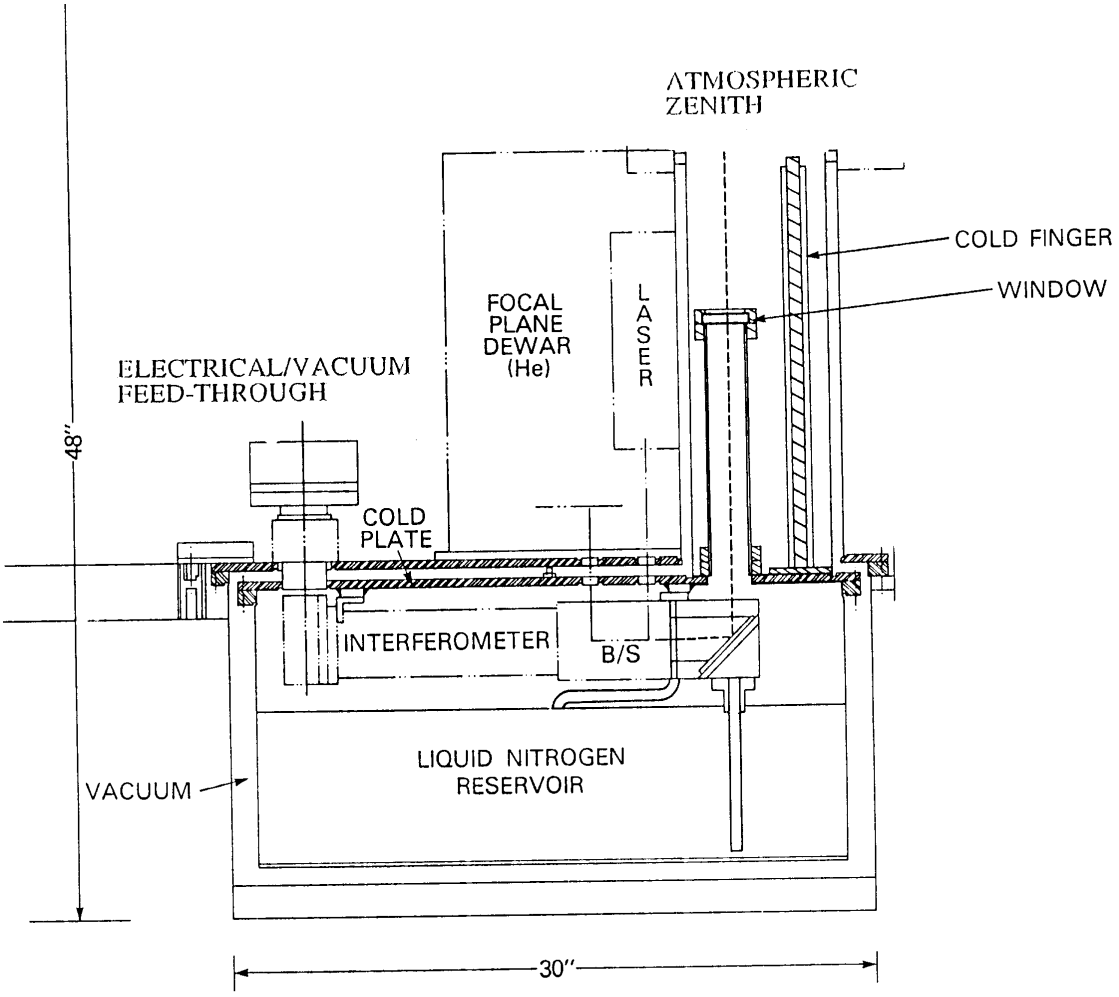

Fig. 1. SIRIS interferometer configuration for SPECTRE.

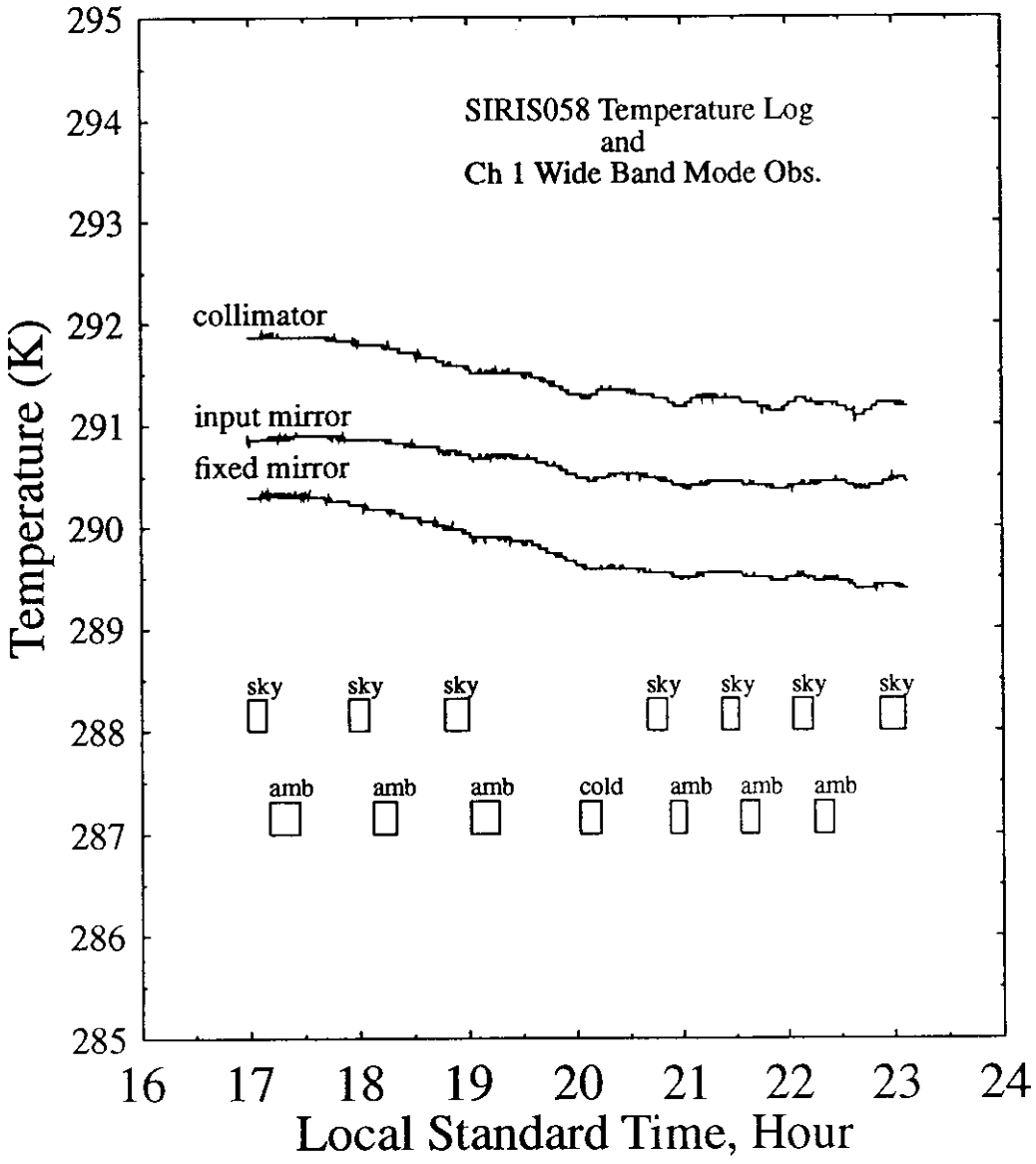

Fig. 2. Plot of temperature log for Nov 29, 1991 showing instrument temperture stability under active thermal control. The plot also shows the time of calibration and sky observations for the wide band mode.

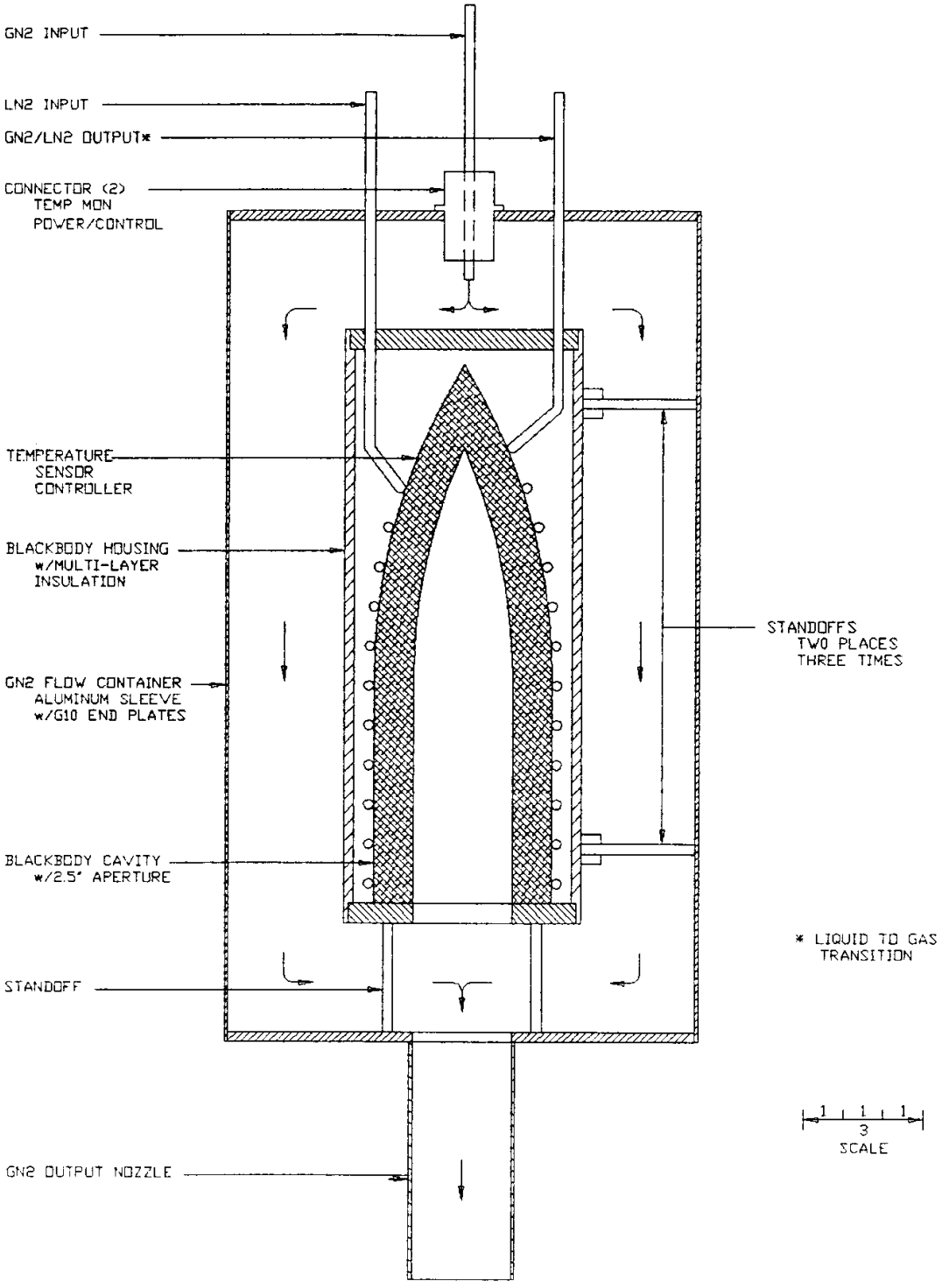

Fig 3. Schematic of cold blackbody calibrator.

4. CALIBRATION

Considerable attention was given to the calibration strategy and calibration facilities to insure a good self-calibration, as well as to inter-calibrate with the other infrared spectrometers in the field.

The measured output interferogram as a function of optical path displacement, x, may be expressed as

$$I(x) = \int_{-\infty}^{\infty} r(\nu)\,(B_T(\nu) - B_i(\nu)\exp(i\phi^\circ(\nu)))\exp(i\phi(\nu))\exp(2\pi i\nu x)\ d\nu \qquad (1)$$

where

$r(\nu)$ is the spectral response

$B_T(\nu)$ is the viewed target emission

$B_i(\nu)$ is the instrument self emission

$\phi(\nu)$ is the phase spectrum determined by the sampling postion and dispersion in the optical paths

$\phi^\circ(\nu)$ is a small phase difference unique to the instrument emission. The instrument emission is nominally 180 degrees out of phase with the target emission.

The interferogram has two components. One component comes from the target and the other comes from the instrument self emission which is nearly 180 degrees out of phase with the target. The resultant phase has a low signal to noise and is not well behaved in spectral areas where the instrument emission is nearly equal to the target emission. Also a typical sky spectrum will have some spectral regions warmer than the instrument emission and some regions colder. The proper phase spectrum is required for proper retrieval of the signal.

The basic approach for determining absolute radiances is to view a blackbody at two different temperatures (called warm and cold) in order to define the instrument response and instrument background radiance at each wavenumber. The following procedure is used to calibrate the data and obtain well behaved phase spectra. The interferogram can be represented as the sum of two interferogram signals.

$$I(x) = I_t(x) + I_i(x) \qquad (2)$$

where

$$I_t(x) = \int_{-\infty}^{\infty} r(\nu)\ B_t(\nu)\ \exp(i\phi(\nu))\ \exp(2\pi i\nu x)\ d\nu \qquad (3)$$

and

$$I_i(x) = \int_{-\infty}^{\infty} -r(\nu)(B_i(\nu)\ \exp(i\phi^{\circ}(\nu))\ \exp(i\phi(\nu))\ \exp(2\pi i\nu x)\ d\nu \qquad (4)$$

When we view a warm target we have

$$I_W(x) = I_{tW}(x) + I_i(x) \qquad (5)$$

and with a cold target we have

$$I_C(x) = I_{tC}(x) + I_i(x) \qquad (6)$$

If these interferograms are sampled identically we may difference them.

$$I_W(x) - I_C(x) = \int_{-\infty}^{\infty} r(\nu)\ (B_{tW}(\nu) - B_{tC}(\nu))\exp(i\phi(\nu))\ \exp(2\pi i\nu x)\ d\nu \qquad (7)$$

This interferogram has a well behaved phase spectrum with high signal to noise, and the instrument emission signal and phase has been removed. Since the calibration target radiances are known we can calculate the spectral radiance $r(\nu)$ from the above difference. The warm blackbody temperature was typically 292^{o} Kelvin, and the typical cold blackbody temperature was 203^{o} Kelvin. Further details and illustrated examples of this calibration scheme have been given by Revercomb, et al., 1988. When the cold target interferogram is subtracted from the sky interferogram we can use the spectral response to calculate the sky emission.

5. DATA PROCESSING AND INSTRUMENT PERFORMANCE

The first step in the data processing consisted of a process to insure that all of the interferograms were sampled identically. This step was necessary so we may difference interferograms to keep the proper phase relationship between target and instrument components as described in section 4. The interferometer does not sample all scans identically. They are sampled on different reference interferometer fringes. These differences are recorded with the data automatically

but the information is not reliable. In addition, small shifts in sampling from scan to scan occur due to velocity variations in the scan mechanism. If the reference interferogram signal is not delay matched to the infrared interferogram signal, the velocity variations will cause a sampling variation. The actual sampling shifts are determined graphically by viewing the phase spectra together and shifting the sampling until the phase spectra overlap. Each interferogram is then resampled by a convolution process.

Warm and cold calibration sets of data are averaged (interferograms are averaged) and the differences are used to isolate the instrument emission average interferogram and spectral response. The target sky interferograms are read and the instrument emission interferogram is removed leaving only the sky component.These interferograms are symmetrized, apodized, and Fourier transformed to power spectra. The spectral response is applied to convert the power spectrum to the proper radiometric sky emission.

The apodization applied is a Hamming apodization of

$$ap = .54 + .46 \cdot \cos(\pi \cdot x / L) \tag{8}$$

where

x = optical path difference

L = maximum optical path difference(For a resolution of .125 cm^{-1} L = 8 cm).

The wave number correction consisted of fine tuning the observed wavenumbers to match theoretical molecular lines in synthesized SIRIS spectra. A constant wavenumber offset was determined and applied for each channel.

In many cases good cold target calibration did not exist due to frost contamination of the blackbody but good warm blackbody data did exist. With only one target we cannot solve for both the instrument emission and the spectral response. In these cases we made the assumption that the spectral response was constant and the instrument emission has varied. For these calibrations we calculate the instrument emission and spectral response from a good set of calibration and update the instrument emission with the current warm blackbody data. The header of the data indicates when this technique was used by the presence of values in the “update etc.” fields near the end of the header.

The noise level is defined in terms of the Noise Equivalent Spectral Radiance (NESR) which is the signal level for unity signal-to-noise ratio. The NESR is calculated from the standard deviation of spectra looking at the same calibration target. The NESR is shown is Fig's 4-6 for Ch 1 WB, Ch 1 NB, and Ch 2 NB.

A varying interference from external vibrations or from other sources, such as heaters, has been identified in Ch 1 WB spectra. Vibrations can cause artificial modulations of the signal by beam movement, and cause sampling errors due to velocity variations.An increased NESR noise level, with several distinct peaks, is seen in Ch 1 WB in the 840 - 925 cm^{-1} region. An ambient calibration target case with little interference in shown in Fig. 4a. Stronger interference is shown in the example in Fig. 4b.

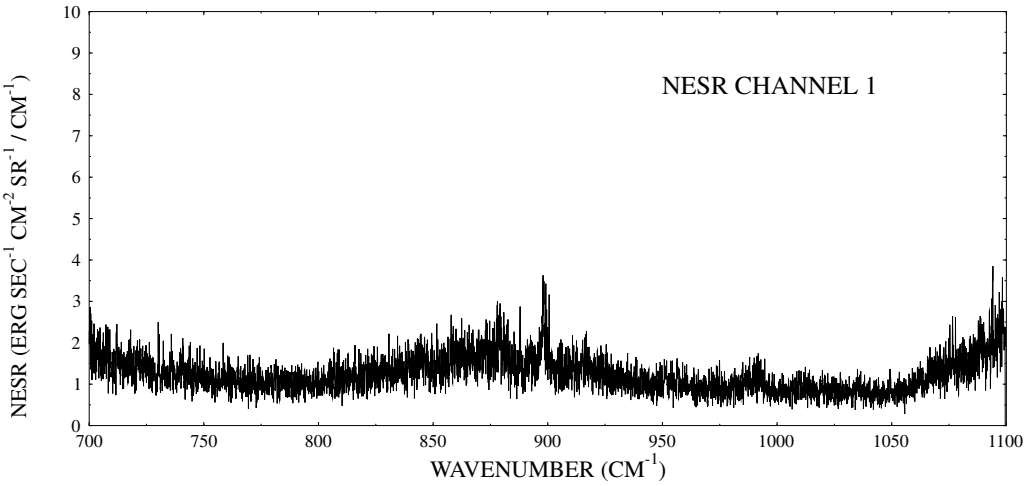

Figure 4a. NESR for Ch 1 WB; calculated from observations of the ambient calibration target.

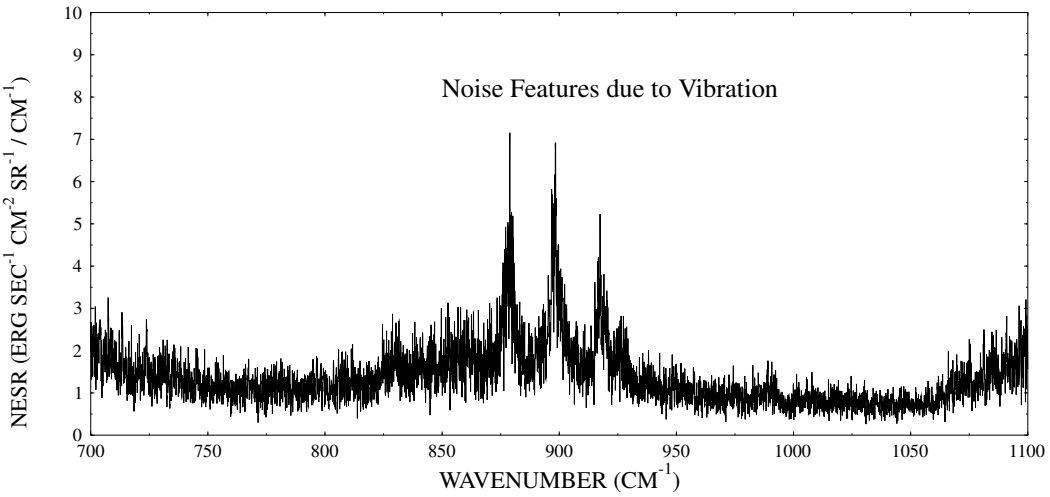

Figure 4b. NESR for Ch 1 WB; calculated from observations of the ambient calibration target.

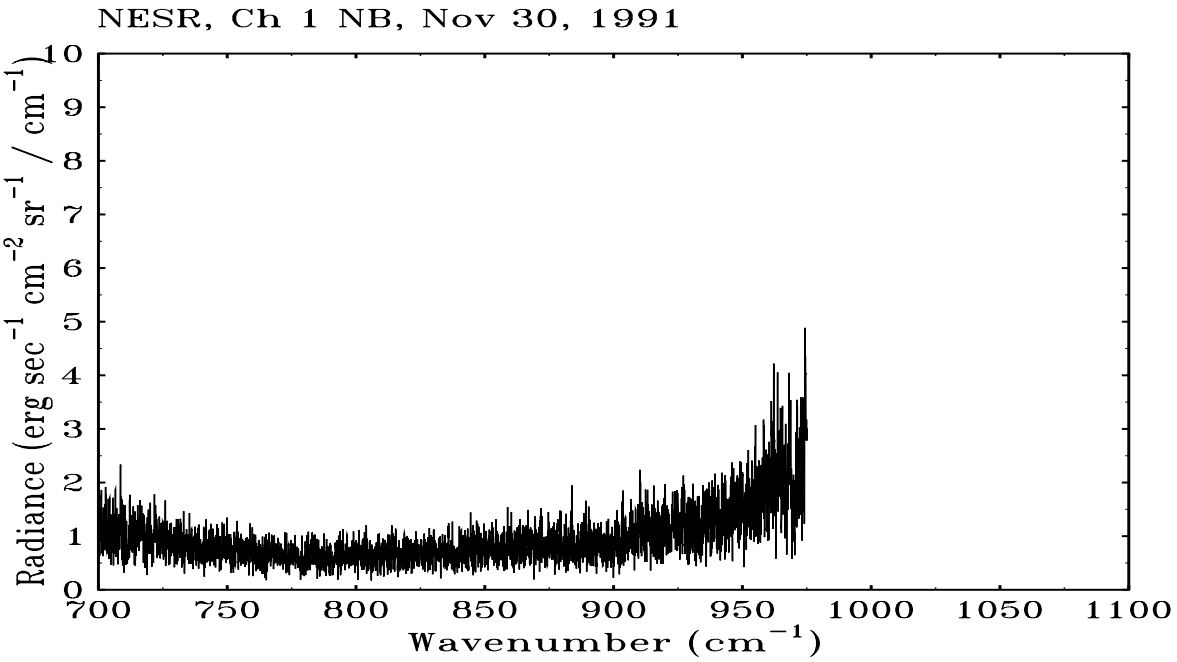

Fig. 5. NESR for Ch 1 NB, calculated from observations of the ambient calibration target.

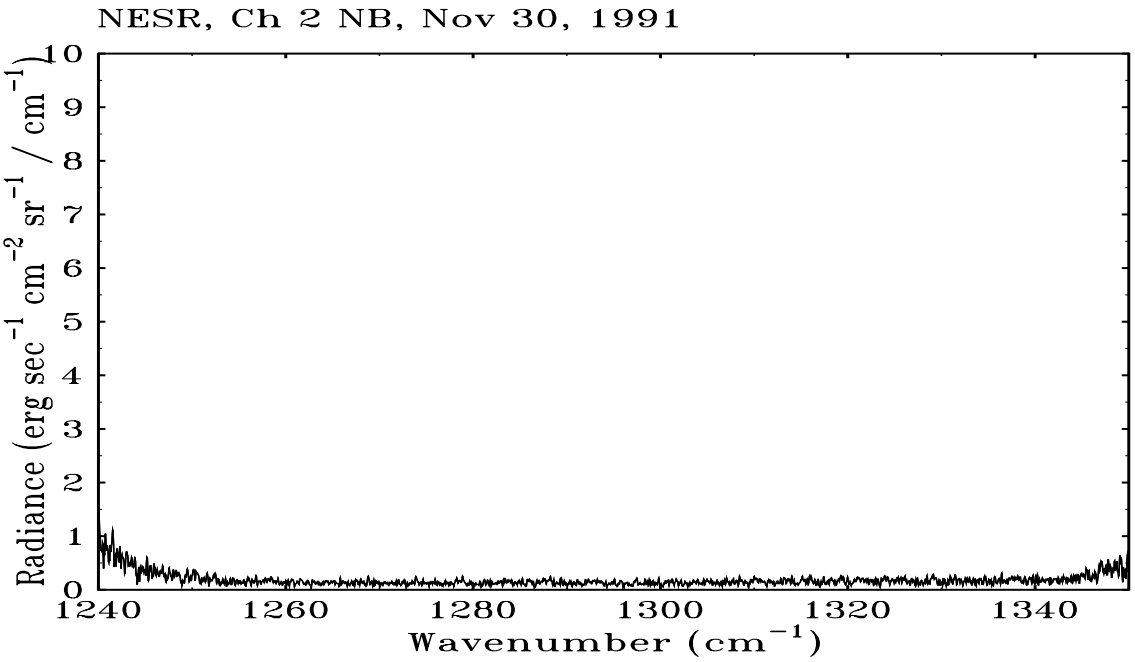

Fig. 6. NESR for Ch 2 NB, calculated from observations of the ambient calibration target.