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Radiometric error and re-calibration of the MGS TES spectra

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ABSTRACT

Several sources of systematic error were identified in the spectra of the Thermal Emission Spectrometer (TES) onboard the Mars Global Surveyor (MGS) spacecraft during its mission. Some of these errors were corrected, some still remain and contaminate spectra. One of the most significant remaining errors is a time-variable systematic radiometric error. This error significantly affects nighttime and polar spectra, and spectra of the Mars' limb. The existence of this error hampered analysis of roughly half of the data collected by TES spectrometer. The error arises due to a periodic sampling error of TES interferograms, which is a common problem in Fourier-transform interferometers. The error negatively affects calibrated TES spectra in two ways: it introduces an error into estimates of the Instrument Response Functions (IRF) and instrument's radiances that are used to calibrate TES spectra, and it introduces an error into TES spectra themselves.

This paper presents a new approach to calibrating TES spectra that enables removing the error from the calibration functions. The new approach utilizes long-term averages of uncalibrated TES spectra of deep space to estimate the true shape of the TES IRF and its dependence on instrument temperature. This, and parameterization of the radiometric error spectral shape, enables removing the error from calibration. Examples of re-calibrated spectra are presented. The largest improvement in the quality of the spectra is observed for nighttime and polar spectra, and spectra of the Mars' limb. Re-calibration would significantly improve retrievals of aerosol abundances and surface temperatures from these spectra.

1. Introduction

Almost a decade after the end of the Mars Global Surveyor (MGS) mission the data collected by the Thermal Emission Spectrometer (TES) onboard MGS still constitute an invaluable source for analysis of the Martian atmosphere and surface. TES provided first multi-year global view of the Martian dust and water vapor cycles, atmospheric and surface temperatures, and provided a window into surface mineralogy (Bandfield et al., 2000; Conrath et al., 2000; Christensen et al., 2001; Smith, 2004). The data collected by TES are widely used in the Mars community. The MGS TES operated in orbit around Mars from 1999 until 2004, or for almost 3 full Martian years. During this time TES collected ~200 million infrared spectra of the Martian surface and atmosphere, vastly improving understanding of the Martian geology and atmospheric processes.

The MGS TES spectrometer was a Michelson interferometer that measured thermal emission in the spectral range 200–1600 cm^{-1} with selectable sampling intervals of 5 and 10 cm^{-1}. The TES sensor consisted of a 3×2 array of physically identical detectors. The raw spectra collected by the TES were calibrated using simultaneous observations of deep space and of the reference blackbody surface. A pointing mirror capable of rotating 360° provided views to nadir, space, planet's limb, and to internal calibration targets (Christensen et al., 2001).

Already during the early part of the MGS mission it was noted that the TES spectra contain a small radiometric error that grew larger with time. Bandfield (2004) identified several factors that contributed to the radiometric error. The first one was the small misalignment of the secondary mirror that resulted in an error that depended on pointing mirror angle (PMA), but was independent of time. This error is informally called 'COBE', because it was incorrectly thought that this error was the main source of the significantly non-zero radiance in observations of deep space. However, the radiance seen in the calibrated spectra of deep space is mostly due to the second error, which is time and wavenumber dependent, and grew stronger as the mission progressed (Fig. 1). The source of this error was not identified by Bandfield (2004). This error is consistent with the periodic sampling error of the TES interferogram (Pankine, 2015). After OCK 12581 (OCK – Orbit Count Keeper, sequential count of the number of orbital revolutions since orbit insertion) when MGS was rotated by 16° degrees, a new error arose in the data. At this new so-called 'Relay 16′ spacecraft configuration a portion of the instrument shroud was in the field of view when observing deep space for calibration purposes. As a result, the deep space spectra were contaminated by the radiance

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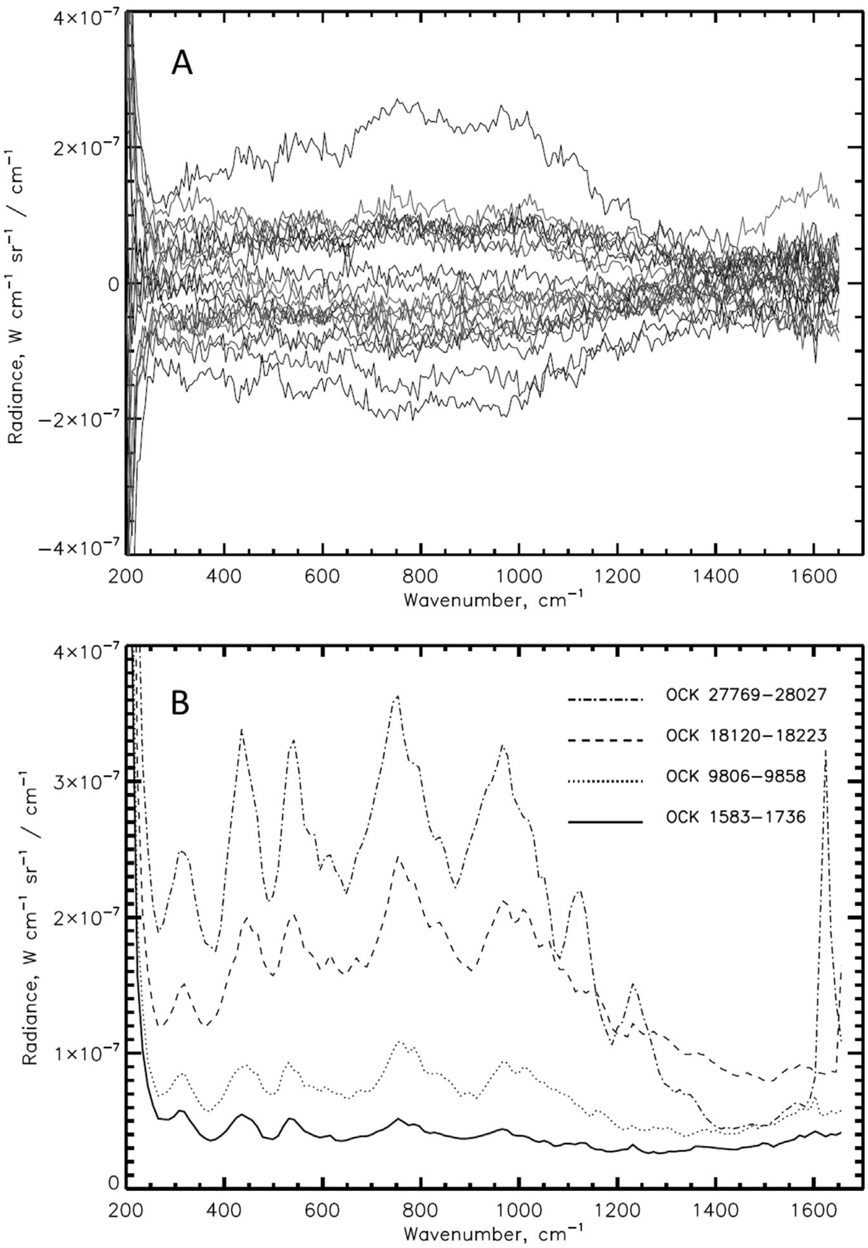

Fig. 1. (A) Example of radiometric error observed in MGS TES space views taken on OCK 9614 by detector 2. (B) Changes in the magnitude of the error (1–σ deviation) for four different epochs during the MGS mission.

emitted by the shroud, which contributed additional ~3×10^{-7} W cm^{-2} sr^{-1}/cm^{-1} respectively between 400 and 800 cm^{-1} (Bandfield, 2004). To remove this effect the TES calibration software (version 2E) was modified to change the value of the space radiance used in calibration calculations to a constant radiance calculated from averages of a large number of space view spectra.

The second radiometric error described above (the time and wavenumber dependent error) is larger than the 'COBE' error and was not corrected. Pankine (2015) identified periodic sampling error of the TES interferogram as the source of this radiometric error. The radiometric error is present in every observation and thus affects calibrated TES spectra in two ways: by introducing spurious radiance in the observations of Mars and also by introducing an error into the TES calibration functions that are used to convert measured voltages to radiances and use observations of space. The present paper uses results from Pankine (2015) to addresses the effects of the second radiometric error on the TES calibration functions. A new approach to remove the error from the calibration functions is presented below. This approach only corrects the calibration functions – it does not correct the radiometric error that is present in the spectra of Mars. Removal of the radiometric error from re-calibrated spectra will be addressed in a follow-up paper.

Periodic sampling error is common type of error in Fourier-transform interferometers. As the results of the error in sampling, a 'ghost' spectrum is superimposed on the true spectrum (e.g. Learner et al., 1996). Fig. 1 shows examples of the TES radiometric error that can be seen when instrument is observing deep space. Fig. 1A shows several individual space spectra observed by TES detector 2 during OCK=9614. The signal observed in spaceviews is much larger than the spectral radiance of space (black body radiance at ~3 K) or the instrumental noise (~4×10^{-8} W cm^{-1} sr^{-1}/cm^{-1}). The spaceview spectra also exhibit wavenumber dependent spectral shape and their magnitude varies seemingly randomly from observation to observation. Fig. 1B shows standard deviation of the error in detector 2 for several time periods during the MGS TES mission. Characteristic spectral features of the error spectral shape at ~300, 430, 530, 750 and 970 cm^{-1} can be