CORSAIR: Calibrated Observations of Radiance Spectra from the Atmosphere in the Far-Infrared

M. Mlynczak[1], R. Cageao[1], N. Abedin[1], H. Latvakoski[2], M. Gritz[3], D. Jordan[4], J. Walker[5], and I. Pang[5]
[1]NASA Langley Research Center, Hampton, VA 23681-2199 USA
[2]Space Dynamics Lab., Logan UT; [3]Raytheon Vision Systems, Goleta CA; [4]ITT, Fort Wayne IN;
[5]SSAI, Hampton VA

***Abstract*. The CORSAIR project is sponsored by the Instrument Incubator Program of the NASA Earth Science Technology Office. The objective of CORSAIR is to develop and demonstrate advanced technologies to facilitate the measurement of infrared radiance spectra at high absolute accuracy for the purposes of diagnosing climate change. The specific technologies under development by the CORSAIR project are antenna coupled detector devices specifically for measuring the far-infrared portion of the spectrum; high emissivity blackbodies for instrument calibration; and broad bandpass beamsplitters to enable measurement of the entire energetically significant portion of the infrared spectrum on a single detector with a Fourier transform spectrometer. Now in its third year, the CORSAIR project is moving towards completion in late 2011. This paper will present aspects of the individual technology development efforts and will discuss how these will be used in the design of instruments and systems to measure climate change on decadal time scales.**

I. Introduction

In 2007, the United States' National Academy of Science, at the request of NASA, NOAA, and the US Geological Survey, released a report entitled "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond" [http://www.nap.edu/catalog/11820.html; *National Academy Press*]. The first of its kind for Earth science, this "decadal survey" recommended a series of space missions for NASA and NOAA to undertake over the course of the next decade to further our knowledge of the Earth system. Along with the missions themselves, the decadal survey provided a notional schedule for implementation of these missions. Among the first set is a mission called the Climate Absolute Radiance and Refractivity Observatory or "CLARREO." A primary objective of the CLARREO mission is to measure climate change on decadal time scales through the measurement of the Earth's infrared emission spectrum at very high accuracy and traceable to the international system of units (Système International or SI) and radiometric standards. An additional objective of the CLARREO mission is to make measurements that can be used to cross-calibrate other orbiting sensors.

To measure climate change via measurements of the infrared emission spectrum will require a series of very accurate and stable interferometers (Fourier Transform Spectrometers, FTS) measuring the infrared spectrum at high accuracy and stability. The nominal measurement requirements from the Decadal Survey are:

Spectral Range: 5 to 50 μm (2000 to 200 cm^{-1}).
Spectral Resolution: 1 cm^{-1}
Instantaneous Field-of-View: < 100 km
Absolute accuracy: 0.1 Kelvin (3-sigma)
SI Traceability: Entire spectrum
Time to record 1 spectrum: < 8 seconds

The focus of our efforts is on technology demonstration necessary to achieve the accurate measurement of the far-infrared (far-IR) portion of the Earth's emission spectrum, those wavelengths longer than 15 μm. The far-IR spectrum has not been comprehensively observed from space for the purposes of climate science. The scientific need for measurement of the far-IR, beyond that contained in the decadal survey, is given by *Mlynczak et al.* [2001]. A major review paper on the importance of the far-IR [*Harries et al.*, 2008] has recently been published. The far-IR contains over half of the outgoing longwave radiation exiting the Earth and its atmosphere; it is fundamental to determining the radiative feedback from water vapor associated with climate change; it is responsible for approximately half of the greenhouse effect that keeps the Earth at temperatures habitable by humans; and it contains a large portion of the radiative effects of cirrus on climate. Far-infrared measurements will literally open a new window on the observation of

Earth's climate. An apt analogy is witnessed in the astrophysical sciences wherein major discoveries are obtained each time a new portion of the spectrum is comprehensively observed from space for the first time. It is expected that similar discoveries will be obtained when comprehensive far-IR observations commence from space in the future.

II. THE CORSAIR PROJECT

With the release of the Decadal Survey and the nominal high-level requirements for the mission given in the Introduction above, the Calibrated Observations of Radiance Spectra from the Atmosphere in the far-Infrared (CORSAIR) was proposed to and selected by the NASA Instrument Incubator (IIP) program. The CORSAIR project is to demonstrate sensitive uncooled detectors for the far-infrared, high emissivity blackbodies with the capability to monitor the emissivity; and broad bandpass beamsplitters. To address these needs Langley Research Center partnered with industry (Raytheon Vision Systems; Space Dynamics Laboratory; and ITT, Inc.) to develop the above technologies under the CORSAIR effort.

A. Warm detectors

To meet the anticipated measurement requirements on a small satellite will require detector technologies that do not need cryogenic cooling. Current far-IR detection technologies (e.g., silicon bolometers) typically require cooling to liquid helium temperatures (4 Kelvin or lower) and are not viable options for long-term spaceflight missions due to the absence of cryocoolers. The volume of liquid helium required for passive cooling to 4 Kelvin is prohibitive.

Raytheon Vision Systems (RVS) of Santa Barbara, CA has been developing antenna-coupled devices for detecting infrared radiation at terahertz (THz) frequencies (1 THz corresponds to a wavelength of 300 μm). The objective of this task for CORSAIR is to extend the technology to operate into the far-infrared at frequencies as high as 20 THz (15 μm). This is achieved by a combination of decreasing the length of the antenna arm and reducing the junction gap in the diode that forms the detector element in the device. The devices operate at room temperature.

As of this writing RVS has succeeded in fabricating a diode and coupling it to an antenna. Initial laboratory testing shows evidence of measured response in broad spectral intervals in the infrared. Detailed testing at moderate to high spectral resolution is about to commence to quantify the response of these antenna coupled terahertz devices (ATCD) in the infrared and far-infrared.

B. Blackbodies with emissivity monitoring capability

One of the main challenges in measuring climate change is to prove unequivocally that an observed change is due to a change in the climate system and not to an undetected change in the instrument. A host of instrument parameters must be monitored in order to meet the measurement accuracy required to detect decadal change (0.1 Kelvin, 3-σ). Foremost amongst these is the emissivity of the calibration blackbodies. Techniques to measure emissivity changes on the order of several parts in 10,000 are required.

The approach to measuring changes in the emissivity of a blackbody over the duration of a mission is to periodically have a source of radiation flood the blackbody and to measure the change in the amount of radiation leaving the cavity. That is, at intervals during the mission, measure the reflectivity (hence emissivity) of the flight blackbody calibration sources and monitor those changes over time.

To accomplish this objective requires a small, bright source capable of generating a sufficient number of photons so that the small fraction that reflect out of the blackbody constitute a signal sufficiently large to be measured with the required accuracy. This is necessary since the emissivity of blackbodies will be greater than 0.999 and so only 0.1% of all photons are actually reflected back out.

Quantum cascade lasers (QCL) provide sources that are bright (typically hundreds of milliwatts) but are small enough to be fitted into a blackbody assembly so as to inject their full fluence into the cavity. The Space Dynamics Laboratory in Logan, UT has built a high emissivity blackbody and has successfully tested the incorporation of a QCL into a high emissivity blackbody. Figure 1 shows the CORSAIR blackbody with an expanded view of the QCL mounting hardware.

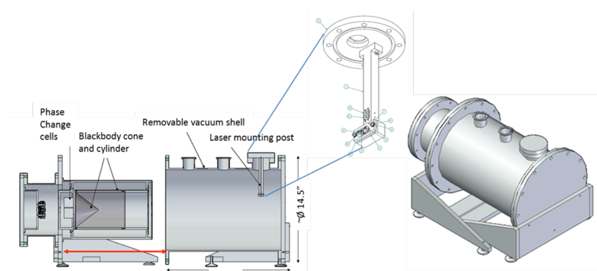

Figure 1. Schematic of the CORSAIR blackbody with the view of the QCL emphasized.

Testing of the operation and properties of the QCL is now complete. The entire blackbody with the QCL integrated into it is now undergoing testing at SDL with anticipated delivery to NASA Langley in the summer of 2011.

C. High efficiency beamsplitters

The Far-Infrared Spectroscopy of the Troposphere (FIRST) project [*Mlynczak et al*., 2006] demonstrated a thin film pellicle beamsplitter in and FTS for measuring the far-IR. Although the FIRST instrument demonstrated an ability to measure essentially the entire infrared spectrum, there are regions in the infrared spectrum where absorption features in the FIRST beamsplitter substrate are sufficiently large to substantially degrade the measurement. In addition, there are concerns about the ability of a thin film pellicle beamsplitter to survive launch. As defined in the Decadal Survey, the measurement of climate change requires the spectrum between 5 and 50 μm, or equivalently, between 2000 and 200 wavenumbers (cm^{-1}), to be measured. The CORSAIR project is pursuing advanced optical coating technology applied to conventional cesium iodide substrates to enable one beamsplitter to cover the entire 5 to 50 μm spectral region with minimal losses across the band.

Shown in Figure 2 are measured efficiency curves for different polarizations (E_s and E_p) and for the average or mean of the two polarizations (E_m). The curves corresponding to the label "ITT" represent optical modeling predictions of the beamsplitter efficiency, while the other curves correspond to measured efficiency for actual beamsplitters. The turquoise curve represents a measured efficiency curve for a cesium iodide substrate coated under the CORSAIR project, and represents good performance across the bulk of the 5 to 50 μm interval.

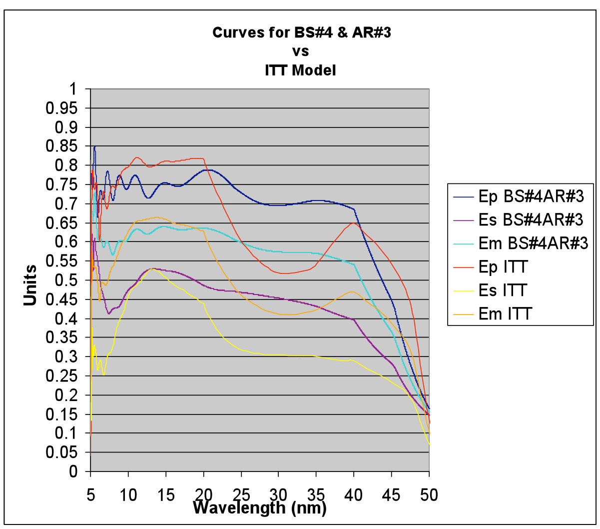

Figure 2. Modeled (Ep ITT, Es ITT, Em ITT) and measured efficiency curves for p, s, and mean polarizations for CORSAIR beamsplitters, between 5 and 50 micrometers (μm).

The beamsplitters for CORSAIR are currently being manufactured and will be tested and delivered to Langley Research Center in late 2011.

III. SUMMARY

The measurement from space of climate change on decadal scales through the observation of infrared spectra presents several technical challenges. The CORSAIR Instrument Incubator Project, in recognition of these challenges, is developing and demonstrating the technologies to measure the far-infrared spectrum. Particular emphasis is on uncooled detector technologies, high emissivity blackbodies, and broad bandpass beamsplitters. All of these technologies are in or nearing the final stages of testing after more than 2 years of development. It is anticipated that each of these technologies will be delivered to NASA Langley Research Center in the latter part of 2011.

ACKNOWLEDGEMENT

The authors would like to acknowledge the continued support from the NASA Earth Science Technology Office, the NASA Radiation Sciences Program, and the NASA Langley Research Center.

REFERENCES

Harries, J., B. Carli, R. Rizzi, C. Serio, M. G. Mlynczak, L. Palchetti, T. Maestri, H. E. Brindley, and G. Masiello (2008), The Far Infrared Earth, *Rev. Geophys*., doi:10.1029/2007RG000233.

Mlynczak, M. G., et al., (2001)The far-infrared: A frontier in remote sensing of Earth's climate and energy balance, in *Optical Spectroscopic Techniques, Remote Sensing, and Instrumentation for Atmospheric and Space Research IV*, Allen M. Larar and Martin G. Mlynczak, Editors, Proceedings of SPIE, Vol 4485, 150-158.

Mlynczak M. G., et al. (2006), First light from the Far-Infrared Spectroscopy of the Troposphere (FIRST) instrument, *Geophys. Res. Lett*., 33, L07704, doi:10.1029/2005GL025114.