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With this project's support, we have defined, designed, constructed, and successfully flown the hypervelocity shockwave experiment that has come to be known as "DEBI". The flight instrumentation originally proposed made some evolutionary changes as a result of new thoughts on the spectral regions to emphasize, detector developments, and background suppression techniques that greatly improved the infrared measurements. The flight was a complete success, with the launch vehicle and all instruments working perfectly.

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Infrared Spectroscopy of Hyper Velocity Shock

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Synopsis of Work:

Optical diagnostic instrumentation aboard high-speed, atmospheric, sounding rockets has proven to be a very successful way of investigating hyper-velocity shocks. The intensely heated air in the shock produces optical radiation from both atomic and molecular species over a wide spectrum. This radiation is characteristic of the shock conditions, and can be used to derive temperatures and species densities in the shock region. The Bowshock I and II experiments concentrated on the shorter wavelength regions of such emission, specifically the ultraviolet emission due mostly to nitric oxide and OH, and the vacuum ultraviolet emission due to atomic nitrogen, hydrogen and oxygen. Modeling of these emissions has proven to be a challenging task, and it is now clear that measurements in other portions of the spectrum would be important to validate the conclusions of these models. The number of data points is at present very small, and without such validation it is not yet clear what power of prediction exists for other, unmeasured conditions.

These experiments were characterized by a close collaboration between the experimental and modeling teams, which was essential for the objective--better understanding of the shock characteristics including temperatures, densities, and species composition. The net result was a data set and modeling evolution that has proven its usefulness in improving our understanding of this phenomenon. In order to continue this valuable process, new measurements must be made in order to test the models as they exist at their present state of evolution, and to provide insights into how they might be improved.

Moving our observations into the infrared, we can observe emission from ground state molecules that are part of the ambient atmosphere, in addition to those that are created in the shock chemistry. This becomes a powerful test of the models' ability to predict the shock "temperatures". For example, if the vibrational temperature of nitric oxide created in the shock was first fit by ultraviolet observations of the Gamma bands, then that same temperature should apply to ground state ro-vibrational emission observed in the infrared from the nitric oxide fundamental band or its overtones. Similarly, the carbon dioxide fundamental or its overtones could be observed and vibrational temperatures compared with those of nitric oxide. Hydroxyl excited state emission observed in the ultraviolet also has ground state ro-vibrational bands in the infrared as a further check on this process.

We have now defined, designed, constructed, and flown a suitable set of instruments on a sounding rocket that nearly duplicated the altitude and velocity regime of the Bowshock I experiment. These instruments included ultraviolet photometers, infrared radiometers, and a scanning IR spectrometer. As on the previous Bowshock experiments, we viewed not only in the forward direction, directly at the stagnation point, but also at an angle to the velocity vector.

All the instruments also had their input from fiber optics running between their respective entrance apertures and the appropriate windows. For the UV measurements on BSI & II, quartz fibers worked well, but do not transmit far enough into the IR. Fortunately, there does exist a new fluoride glass fiber material with excellent transmission out to nearly 5 microns. Hence the location of the instruments can be separated from their viewing geometry requirements, without which it would have been impossible to fit even this instrument set into the very small payload package.

It is impossible to fit all the desirable instrumentation into any payload with such limited resources, or even to use conventional designs for them. We believe that the instrument suite described below presented a good compromise of measurement coverage and practicality for this flight. An AIAA paper describing this payload and flight is being prepared.

Optical Instrumentation Overview:

UV filtered photometers – Two Channels

- One channel in each look direction
- ~0.24μ band center
- Photomultiplier detectors, pulse counting only

Micro Optic Multispectral Radiometer (MOMS) – Fourteen Channels

- Eight channels of MWIR (3—4.3μ wavelength)
- Six channels of SWIR (1.0—2.7μ wavelength)

Scanning IR Spectrometer (1.0 - 3.0μ) – Sixteen Channels

- Dual Look Direction
- Eight Detector Channels in each look direction

Look Directions:

- One spectrometer input and one UV photometer looking forward at stagnation point through recessed window in nose piece
- Second spectrometer input, second UV photometer, and all IR MOMS channels observing sideways through two recessed windows located as far forward on nose piece as practical

Instrument Specifics:

Two UV filtered photometers

Inputs coupled to windows with UV silica fibers.

Side-looking fiber area 10x that of forward-looking fiber for maximum dynamic range in signal levels
~240nm band center, ~50nm filter bandpass (FWHM)
Photomultiplier detectors, CsTe cathode—very low noise and "solar blind"
Detector pulse counting outputs integrated with 20 bit counters
"Legacy" data for overlap with BSI & II

Fourteen IR MOMS Radiometers

Eight channels of MWIR (3--4.3μ wavelength)
- Six channels monitoring 3-4μ region with 0.2μ spacing, ~0.2μ filter bandpass
- One channel ~4.3μ band center for CO_2 , ~0.2μ filter bandpass
- One channel ~0.8μ filter bandpass centered at ~3.5μ for maximum sensitivity.

Six channels of SWIR (1.0—2.7μ wavelength)
- Provide: spectrometer backup (as on BSI & II), high temporal resolution, high sensitivity
- Place filter bandcenters at emission peaks and predicted "holes"
- (2.7μ CO_2 , NO; 2.3μ "hole"; 2μ CO_2 ; 1.5μ OH ; 1.27μ O_2 ; 1.0μ)

All photodiode detectors cooled (below -120C) before flight, with sufficient
- heat capacity to maintain temperature for the next 40 seconds
- InGaAs, and HgCdTe photodiode detectors

Inputs coupled to windows with fibers:
- Wavelengths <2.5μ will use IR Silica
- Wavelengths >2.5μ will use IR Fluoride glass

Optics and filters 5mm diameter
Each detector output into individual gated integrator preamplifier, then digitized to 20 bits resolution

Scanning IR Spectrometer

Modified Fastie-Ebert optical design, 300mm focal length
Dual spectrometer input slits coupled to windows with IR Fluoride glass fibers
- Fast scan, ~0.5 second
- ~1.0 - 3.0μ wavelength coverage
- ~0.05μ resolution

Cooled (< -100C), photodiode detector array
- Eight elements in each of two detector arrays
- Photodiode types matched to specific wavelength region covered for best signal to noise
  - InGaAs for shortest wavelength region
  - Extended InGaAs (types 1-3) for intermediate regions
  - Photovoltaic, shortwavelength (1-3μ), HgCdTe for longest wavelength region

Fast (f/0.5) relay lens system at exit slit for minimum detector size
Each detector output into individual gated integrator preamplifier, then digitized to 20 bits resolution

Results:

The DEBI experiment was successfully flown on a NASA Terrier-Malemute two stage sounding rocket from Wallops Island, Virginia. The vehicle performed perfectly, following predicted parameters. The challenges of pre-flight cryogenic cooling of the payload were met, and the temperature at launch was ideal. Nose tip and radiometer detector temperatures were below –150C as desired in order to reduce thermal background, give a good zero reference at nose tip ejection, and reduce detector noise to a minimum.

Telemetry and tracking were good, and all instruments performed perfectly. An extensive data set was accumulated, continuing until loss of signal on the downleg portion of the flight. Analysis of this data set and comparison with models will be a significant task, but the preliminary "quick-look" shows substantial differences from the predicted model results. It is very clear that a great deal of work needs to be done in this area in order to develop our understanding of the chemistry and physics of such shocks, and to expand the experimental data available for study.