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A New Mass Spectrometer for Upper Atmospheric measurements in the Auroral Region

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Research Objectives

- Develop a mass spectrometer capable of measuring densities of ions and neutral particles in the mesosphere/thermosphere (MLT)
- Demonstrate instrument performance with a laboratory prototype instrument
- Obtain high sensitivity to allow for high resolution spatial profiling of atmospheric species using time-of-flight mass spectrometry (TOF-MS)

Introduction

Last year at the AGU fall meeting we presented a mass spectrometer instrument concept for making measurements in the MLT. Continued instrument design and research during the past year has resulted in a laboratory prototype initially sampling times-of-flight mass spectrometry (TOF-MS). The TOF-MS is inherently adaptable and can be configured to detect ions or neutral particles. The TOF-MS is intended for use on sounding rocket missions and we have submitted two proposals that plan to employ the TOF-MS to make ex-voto measurements of ambient ions and neutral particles in the polar MLT. Mass Spectrometry of the Therapause Region (MSTR) proposes four sounding rocket flights at different seasons of the year to measure the vertical distribution of several related species from 70 km to document the time-varying nature of the mass spectrometry measurement in the polar MLT, particularly in the thermosphere. ROCK(Ste)ad-sbus® Energetics of Auroral Dosing in the E-region (ROCK-STEAD) proposes one sounding rocket flight with a similar instrument suite to investigate the ionospheric-thermosphere energy transfer process during the aurora. ROCK-STEAD will use two TOF-MS instruments, one to measure ions and neutral particles from 70-110 km.

Mass spectrometry in the thermosphere is challenging, due to the high speeds and elevated pressures encountered on sounding rocket flights. Sampling the unembalmed atmosphere generally requires cryo-cryotron to eliminate the bow shock that forms on the ram side of the instrument. In addition, several methods of vacuum pumping are available to maintain suitable operating pressures inside the TOF-MS. These methods include barium loaded getter tubes, miniature turbo pumps, and basic cryo-cryotron pumping. Because it is necessary to make fast, accurate measurements the TOF-MS has the potential to greatly aid in enhancing our understanding of the MLT.

Electronics

Bradbury-Nielsen gate (BNG)

• Two sets of interlaced wires, used to modulate incoming ions
• For beam "on" both sets of wires are at the acceleration potential Vₐ
• For beam "off" every other wire is at Vₐ, Vᵦ = Vₐ/2
• Waves are 10.5 mm gold plated tungsten with average wire spacing of 75 µm
• Pulse rise time ~5 ns

Control board

• Makes select allows TOF-MS to operate in conventional TOF or mass spectrometer modes
• Multiplying Hadamard Transform (HT) TOF-MS, beam "on" or beam "off" mode
• Provides the TOF-MS with modulated drive voltages to pulse the ion beam, along with a start of pulse signal to beam current monitor, to the first pulse of each of the TOF or HT-TOF sequences to trigger data collection
• Due to design challenges due to required large drive amplitudes (~80 V differential, large negatives bias voltage (-200 V), and because fast risetime, selected PFPD (Altera Cyclone III EPFC15T200C) for the fast enough rise time and adequate memory to hold several Hadamard sequences of different lengths
• Pulse risetime times of ~5 ns with 20 V range

Spectra

• Laboratory prototype TOF-MS placed in ion optics test chamber (see figure below) Noz 28 2011, ions are obtained from the test data in conventional TOF mode
• Figure a) obtained from 122 V Ar, 222 seconds integration time, S/N = 5600, mass resolution x = 76 at DWIAM
• Figure b) obtained with ion gun velocity filter off. Ar SNR ~ 546, mass resolution x = 76 at DWIAM
• Figure c) obtained by chamber bucklack with various gases, with instrument oriented toward ion range. Peak shifting due to "lost" ions with large energy distribution. Peak "doubling" due to problems with modulation pulses, but spectra obtained nonetheless (ion mass for modulation voltages only)
• Pressure for data collection for figure c) was ~10^3 Torr, corresponding to a mean-free-path ~10 µm at the length of the instrument
• Figure d) obtained from 122 V Ar over 6.27 hrs. Signal after Ar peak is caused modulation pulse. Ions velocity distribution and broadening due to instrument contribute to a signal spread ~100 x
• After more than 24 hrs of simple pumdown, TOF-MS experienced only one problem related to the nozzle ~19 hours of continuous operation at pressures stepping into the 10^-3 Torr range

Figure at left shows the BNG modulation voltages that was used to collect the mass spectrum shown in Figure d)
• Magnified spectrum (not) shows oscillations due to beam modulation

Spectra simulations

• High-speed rocket flight through the MLT normally causes a region of reduced density and pressure, called a bow shock, on the ram side of the rocket (envelope)
• Bow shock can interfere with direct sampling of ambient atmosphere
• Beam ~25 K, nearly all ions collected on a copper surface (Brown et al.)
• Rock STrack and ROCK-STEAD will employ cryo-cooled front plates to enable direct atmospheric sampling by eliminating the bow shock
• Figure below shows simulated instrument pressure
• Mean-free-path requirement (~105 driff tube length) is met at 5x10^2 Torr
• Barium loaded getter tubes, can be used as an inexpensive pumping method
• Aperture size can be tailored for the specific mission and pressure requirement

Laboratory Prototype

• TOF-MS will consist of sounding rocket launch
• Several options include a Field-Widened interferometer, four photomultipliers, and two TOF-MS instruments
• One TOF-MS will be configured to measure neutral particles while the second TOF-MS will measure ions
• TOF-MS measurements will begin at about 70 km, and will measure neutral N₂, O₂, CO, NO, H₂O, and ions: Ne, N₂⁺, O₂⁺, O⁺, -0.4 V - 0.3 V

Mass Spectrometry of the Thermopause Region (MSTR)

Science Questions

• What is the altitude at which the atmosphericenuous with little to no diurnal equilibria? At what rate do the major species encounter the stratopause with altitude near the thermopause?
• Comparison of measured CO₂ profiles with those retrieved by IR instruments in synergistic experiments with profiles obtained by a developmental simultaneous Temperature-Cloud retrieval with SABER data
• Transport of NO across the thermopause. How strong is the diurnal over the polar night? How much NO is transported downward across the thermopause?

Evolutionary models to estimate volume mixing ratios of CO₂, NO, and NO as a function of altitude from 90 to 120 km

• MSTR will consist of four sounding rocket launches at different times of the year in order to make observations of summer and winter solstice conditions and near-polar night
• Each rocket will carry one TOF-MS instrument
• Overall goal is to measure volume mixing ratios of CO₂, NO, and NO as a function of altitude from 90 to 120 km

Conclusions and Future Work

• Good resolution is achieved with the linear TOF-MS instrument
• For situations with high UV flux, a reflection design can be incorporated to reduce background
• Testing of the TOF-MS will continue in the SDL ion optics facility
• Beam modulation improvements will enable collection of clearer spectra
• Several options are available for maintaining stable pressure inside the instrument, including cryo-pumping, barium loaded getter tubes combined with properly tailored orifice apertures, and miniature turbo pumps

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