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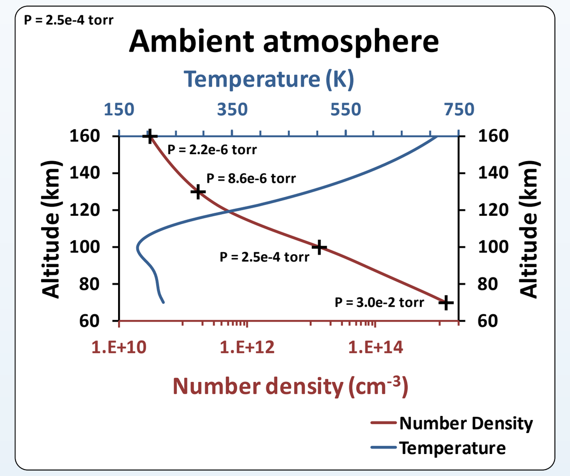
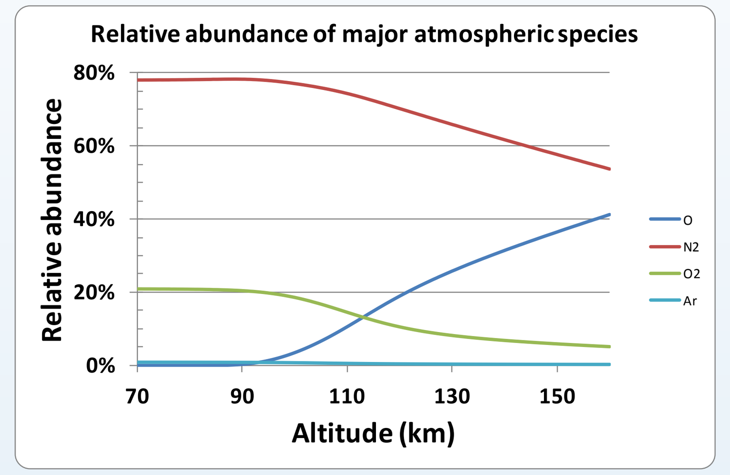
Research Objectives

- Develop a time-of-flight mass spectrometer (TOF-MS) for deployment aboard sounding rockets to make accurate *in-situ* measurements of charged and neutral species in the mesosphere/lower thermosphere (MLT) region of the earth's atmosphere
- Achieve unit mass resolution of atmospheric species of interest
- Characterize and demonstrate successful operation of a prototype TOF-MS instrument

Introduction



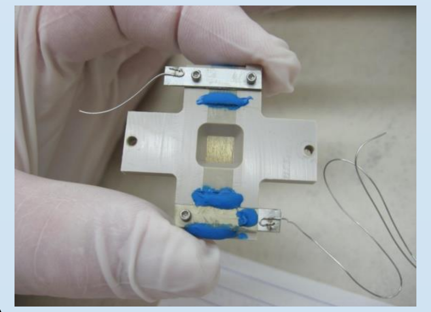


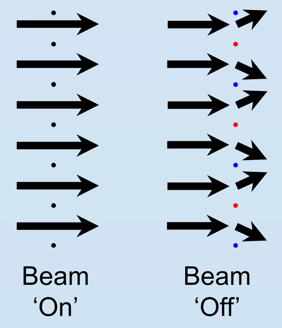
The mesosphere/lower thermosphere (MLT) lies between the turbulent mixing and diffusive layers of the earth's upper atmosphere. Temperatures in this region are varied and include the coldest region of the earth's atmosphere, the mesopause. Too high for aircraft and too low for satellites, the only method of direct access to the MLT is by sounding rocket for periods of at most a few minutes. Because of this, the MLT is the most difficult region of the earth's atmosphere to access and is therefore the least understood region of the earth's atmosphere. Accurate *in-situ* measurements of MLT species are important for the following reasons:

- CO_2 concentration profiles collected *in-situ* will be useful in validating and improving atmospheric temperature measurements made by satellite based instruments, for example, the Sounding of the Atmosphere using Broadband Emission Radiometry on the TIMED spacecraft.
- Study the transport of atmospheric species near the turbopause region. For example, NO, which is thought to be linked to ozone depletion in the stratosphere
- *In-situ* concentration data will help to improve atmospheric models, such as the MSIS model

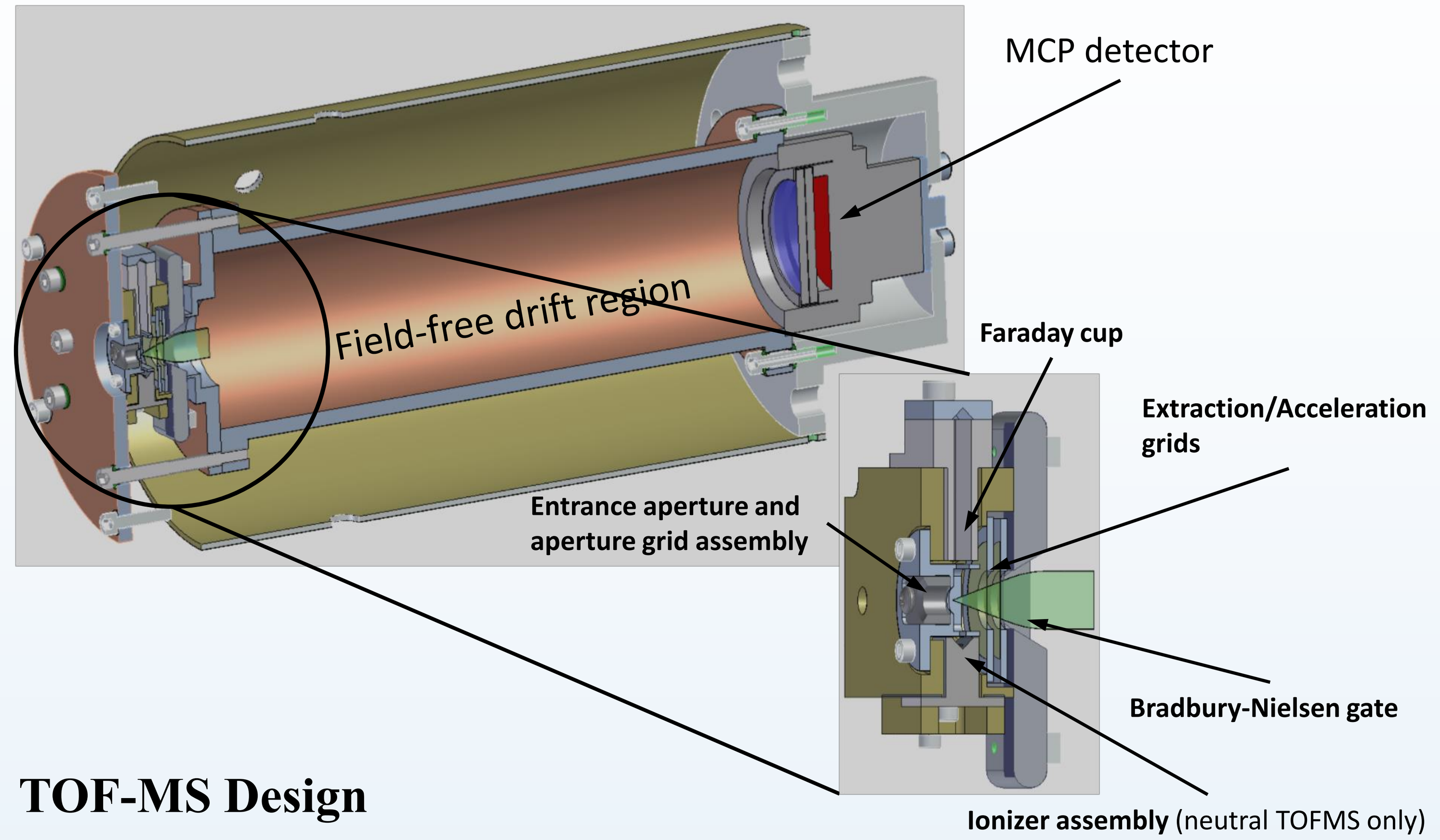
We present an axially-sampling time-of-flight mass spectrometer (TOF-MS) suitable for deployment aboard sounding rockets to make measurements in the MLT. Use of a Bradbury-Nielsen gate to modulate ions makes on-axis sampling possible. The TOF-MS also employs a pressure tolerant microchannel plate (MCP) detector capable of operating at pressures into the 10^{-4} torr range. We have built and are currently testing a prototype instrument in our ion optics facility. Experiments to date demonstrate the potential of the TOF-MS to successfully make measurements in the MLT and thereby improve our knowledge of this important region of the earth's atmosphere.

Bradbury-Nielsen Gate





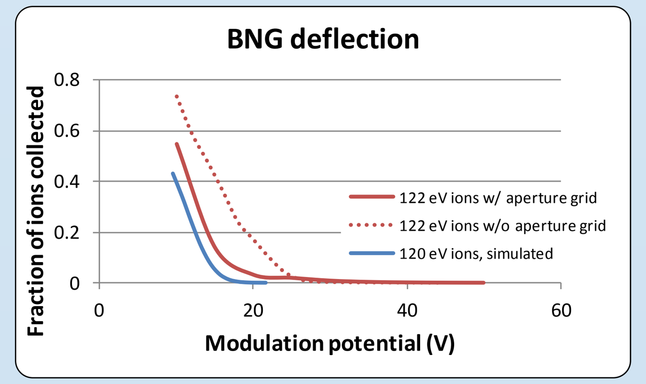
- Two sets of interleaved wires, used to modulate incoming ions
- For beam "on" both sets of wires are set at the acceleration potential, V_{acc}
- For beam "off" every other wire is at $V_{acc} \pm V_{mod}$
- Wires are 10 µm gold plated tungsten with average wire spacing of 75 µm

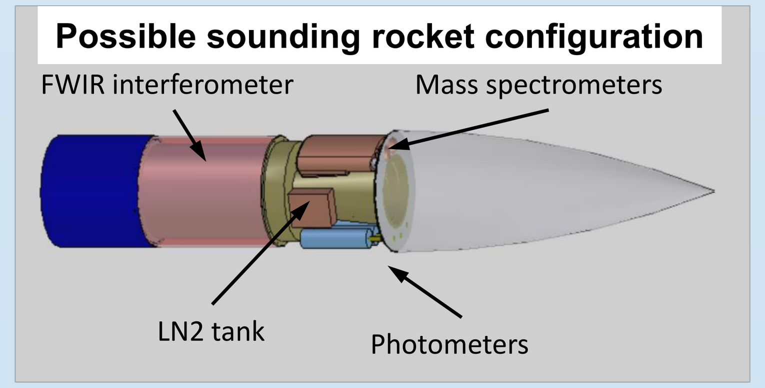


TOF-MS Design

The TOF-MS is a small instrument (~8 cm diameter, 20 cm length) intended for use on sounding rockets to study the upper atmosphere. The prototype instrument is a linear TOF design, solid model shown above. The TOF-MS is inherently adaptable and is capable of measuring both ions and neutrals. In addition, the TOF-MS may be operated in either traditional TOF mode or in a high duty cycle multiplexing mode. Key TOF-MS design features are:

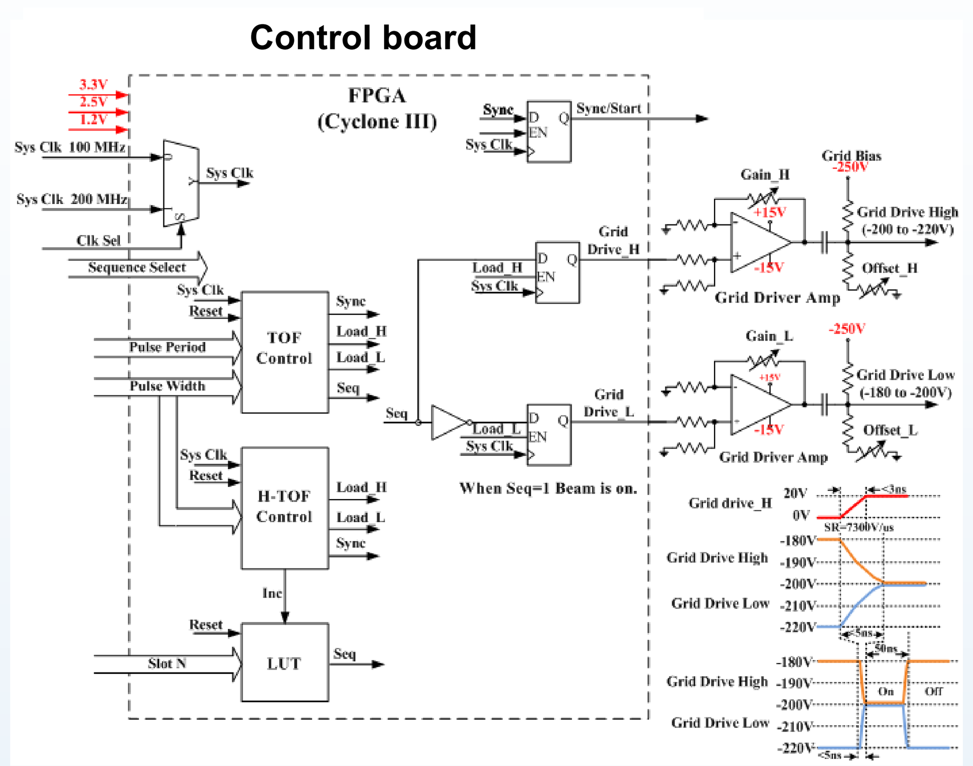
- **Sampling aperture:** Diameter is customizable to fit the specific application. Designed to maximize sensitivity while reducing gas load to interior of instrument. The prototype has a 2 mm diameter aperture.
- **Aperture grid:** Held at instrument exterior potential to eliminate stray fields outside the aperture. Aids in creating a more uniform acceleration field.
- **Ionizer** (neutral TOF-MS only): Electron sheet located behind aperture to convert neutrals to ions via electron impact.
- **Acceleration grids:** two grids located behind the ionizer that accelerate and focus ions. For ion mode both grids are set to the acceleration potential. For neutral mode, the first grid is biased slightly negative and becomes an "extraction" grid to pull ions from the ionization region and the second grid becomes the acceleration grid. Grid system results in ion beams with uniform KE, usually between 100-200 eV.
- **Bradbury-Nielsen gate:** located behind acceleration grid, provides on-axis ion beam modulation. Consists of two coplanar interleaved sets of wires (see figures below/left). Currently generates start pulses 70 ns wide with 40 ns rise times using low voltages (±22 V). Shorter pulses anticipated with improved electronics (20 ns pulse width, 5 ns rise time). Capable of generating pulses for traditional TOF mode or in a multiplexing mode.
- **Drift tube:** field free region where ions separate according to their m/z value, heavier ions traveling slower than light ions.
- **MCP detector (Photonis)**: pulse counting ion detection with high gain (10^7) and narrow pulses (350 ps FWHM). We routinely operate in the high 10^{-5} - low 10^{-4} torr range.
- **Pulse-processing electronics:** amplify, digitize and count pulses from MCP with high temporal precision (100 ps) and high count rates (up to 1 GHz)

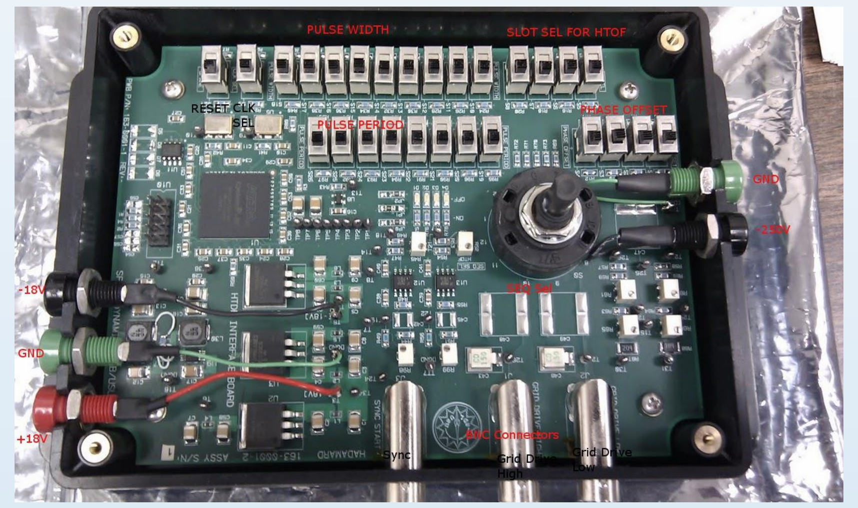




Electronics

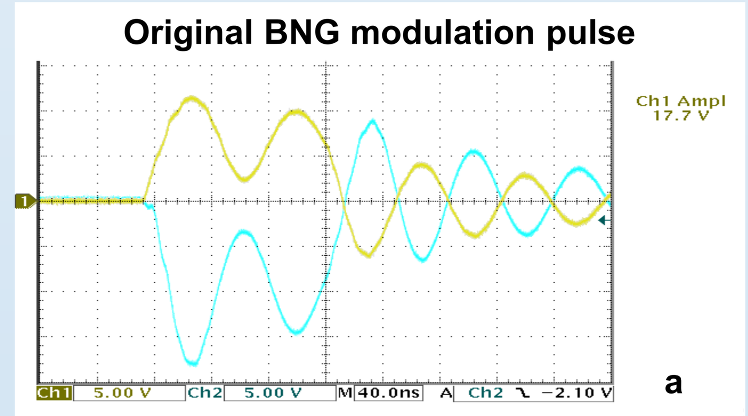
- Mode select allows TOF-MS to operate in conventional TOF-MS or multiplexing Hadamard Transform (HT) mode.
- Provides the TOF-MS with modulated drive voltages to pulse the ion beam, along with a start of sequence pulse coincident to the first pulse of each of the TOF or HT-TOF sequences to trigger data collection
- Because of design challenges due to required large drive amplitudes (~40 V differential), large negative bias voltage (-200 V), and fast rise/fall times, selected FPGA (Altera Cyclone III, EP3C5F256C6N) for its fast switching speed and adequate memory to hold several Hadamard sequences of different lengths.
- Pulse rise/fall times of ~40 ns with 20 V range

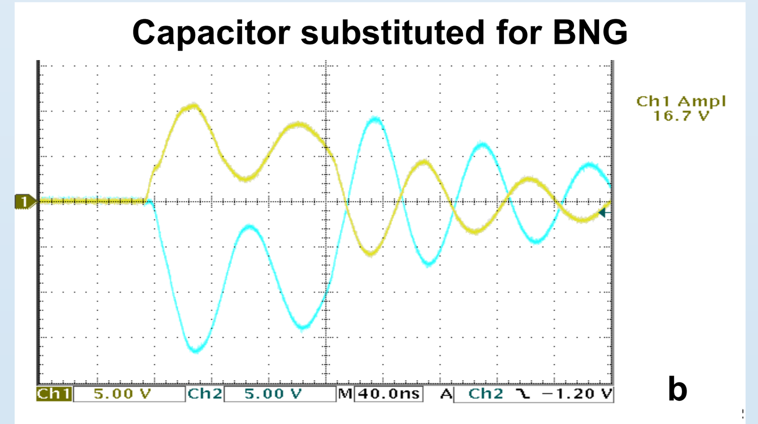


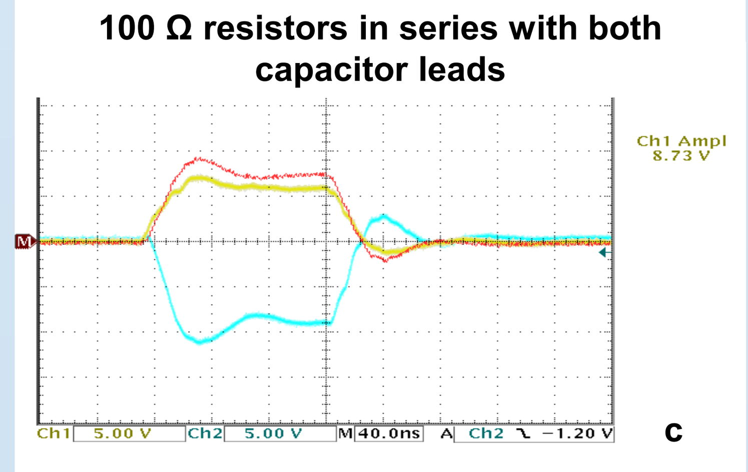


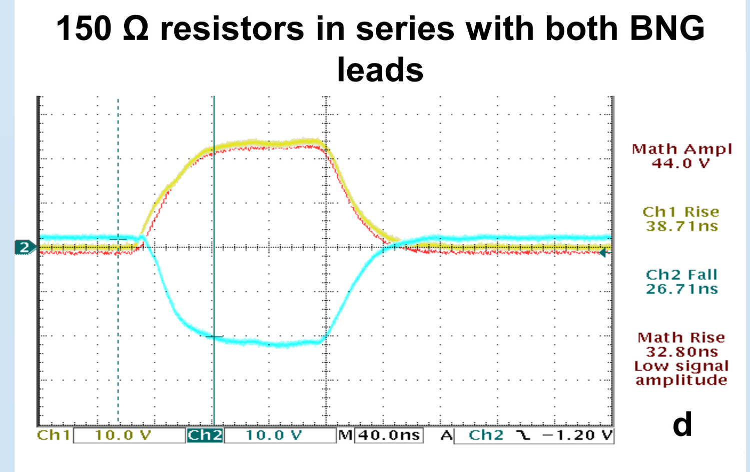
As originally configured, there were some problems with the BNG modulation pulses, see below.

- Initial spectra were taken with BNG modulation waveform similar to figure a) below. See also "Effects of Beam Modulation Improvements" section at right.
- It was found that a 70 pF capacitor behaved almost identically to the BNG.
- Bench testing made heavy use of the 70 pF capacitor to minimize BNG exposure (figs b and c).
- After an acceptable resistor combination was found using the capacitor, the setup was repeated and fine-tuned using the BNG (fig d).

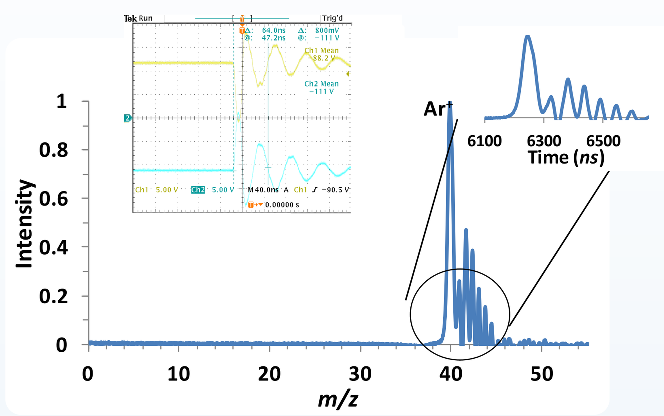




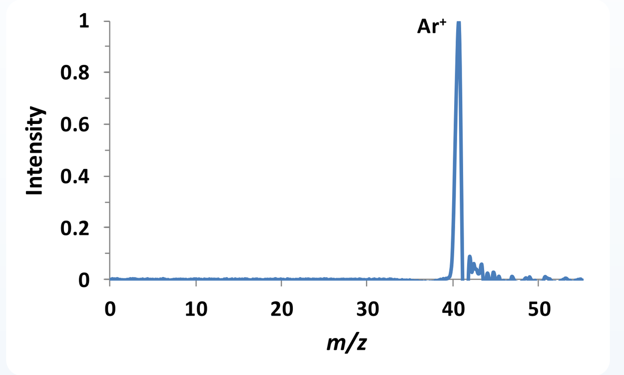




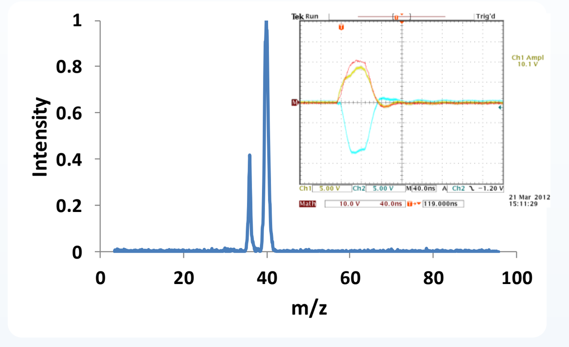
Effects of Beam Modulation Improvements



Ar^+ spectrum before improvements to BNG modulation waveform (see previous section). Initial spectra were affected by severe modulation defects, see insets.

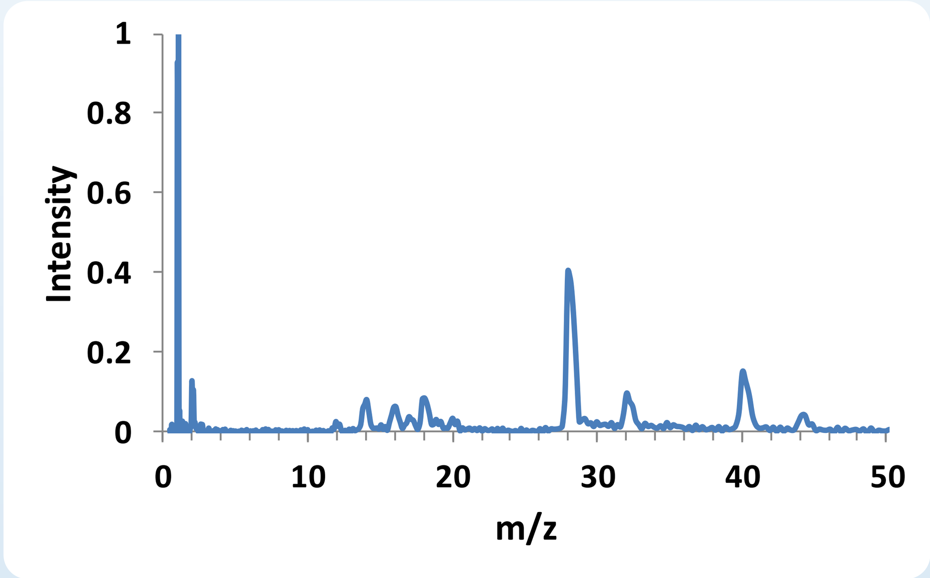


Mass spectrum obtained from 122 eV Ar^+ with a mass 40 resolution of 56 at FWHM before improved electronics. Previous to improvements, small signals could be easily lost due to modulation "ringing."

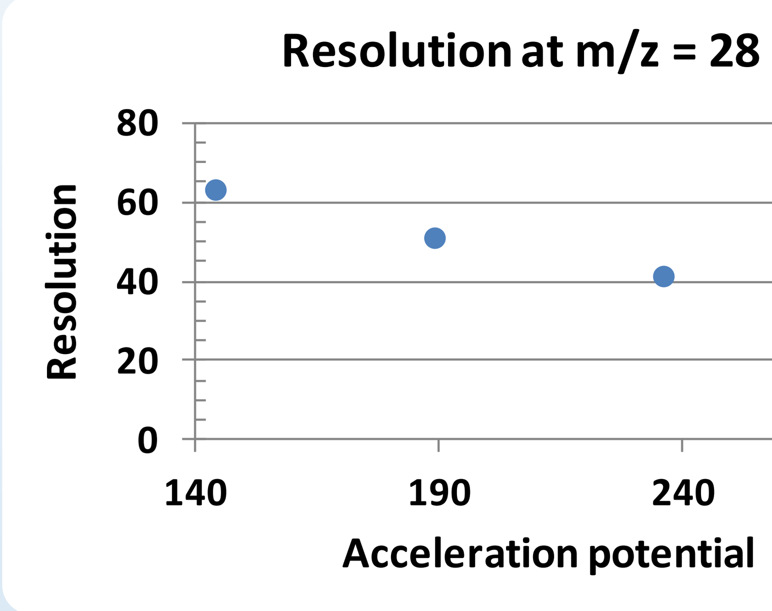


Improved BNG modulation (see inset) led to improved spectra. The above spectrum was collected using 122 eV Ar^+ ions. For the spectrum above, resolution is 25 at 10% peak height, and 40 at FWHM.

Neutral TOF-MS



Mass spectrum obtained by operating TOF-MS in neutral mode. Signals are from background gases present in chamber along with backfill using Ar and N_2.



Mass resolution at m/z = 28, TOF-MS operating in neutral mode. Higher resolution at lower acceleration potentials likely due to greater modulation efficiency at lower acceleration potentials.

Conclusions/Future Work

- The TOF-MS shows promise for contributing to our knowledge of the upper atmosphere by taking measurements in the MLT.
- Electronics improvements have led to "cleaner" spectra. Further improvements (increased deflection potential, decreased modulation pulse rise time, decreased pulse width) should further improve instrument performance.
- Further work needs to be performed to analyze instrument performance under conditions likely to be encountered on a sounding rocket mission. For example:
  - Low energy ions with a small energy distribution
  - Further measurement of neutral species to determine neutral TOF-MS performance
- Reflectron TOF-MS design for eventual deployment aboard sounding rockets, satellites, and/or planetary probes.
- Sounding rocket missions in the lower MLT will require liquid He cryogenic cooling to eliminate the bow shock and allow *in-situ* sampling of the un-disturbed ambient atmosphere.

Acknowledgment

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