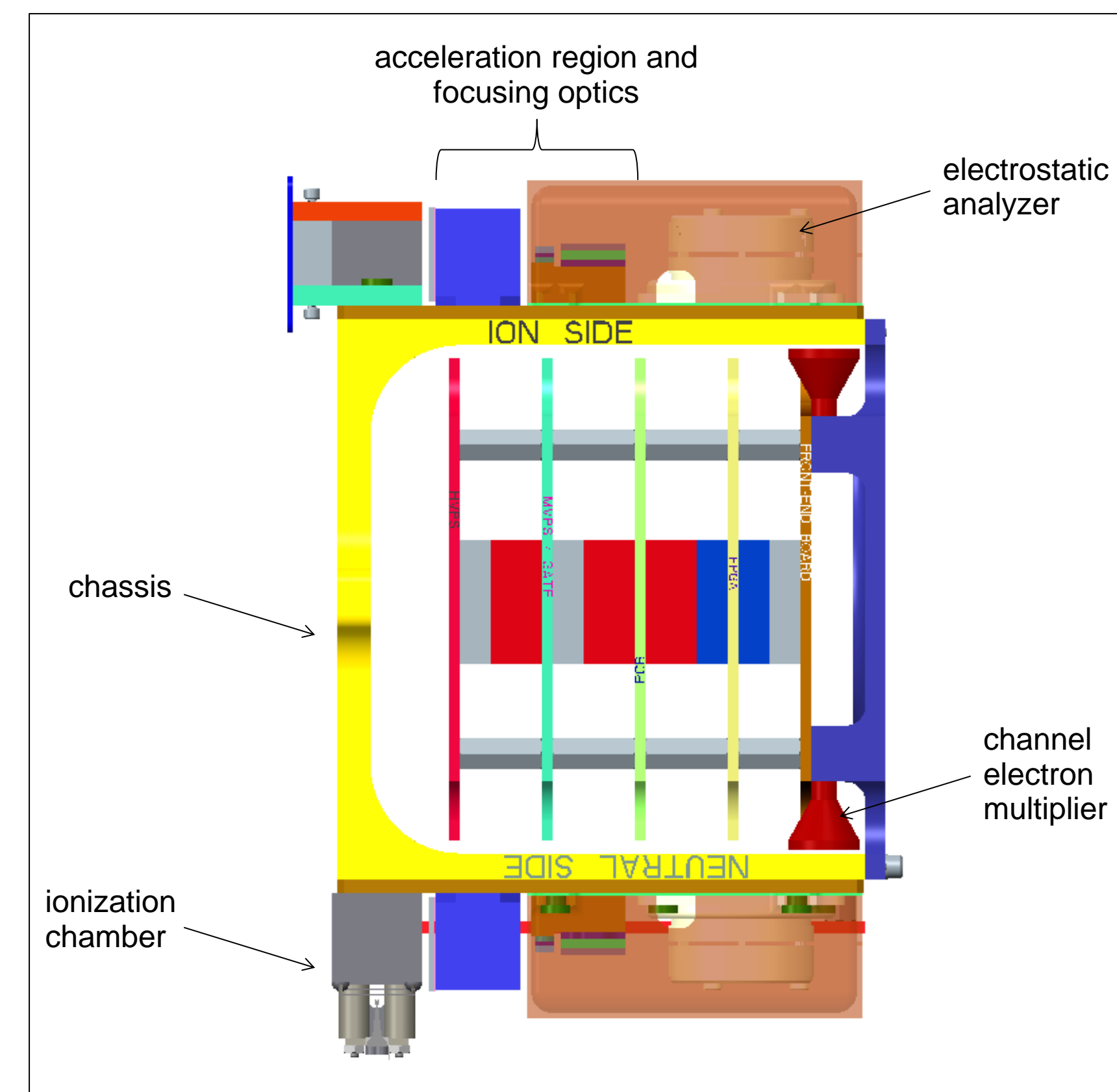


A Compact Ion and Neutral Mass Spectrometer for CubeSat/SmallSat Platforms

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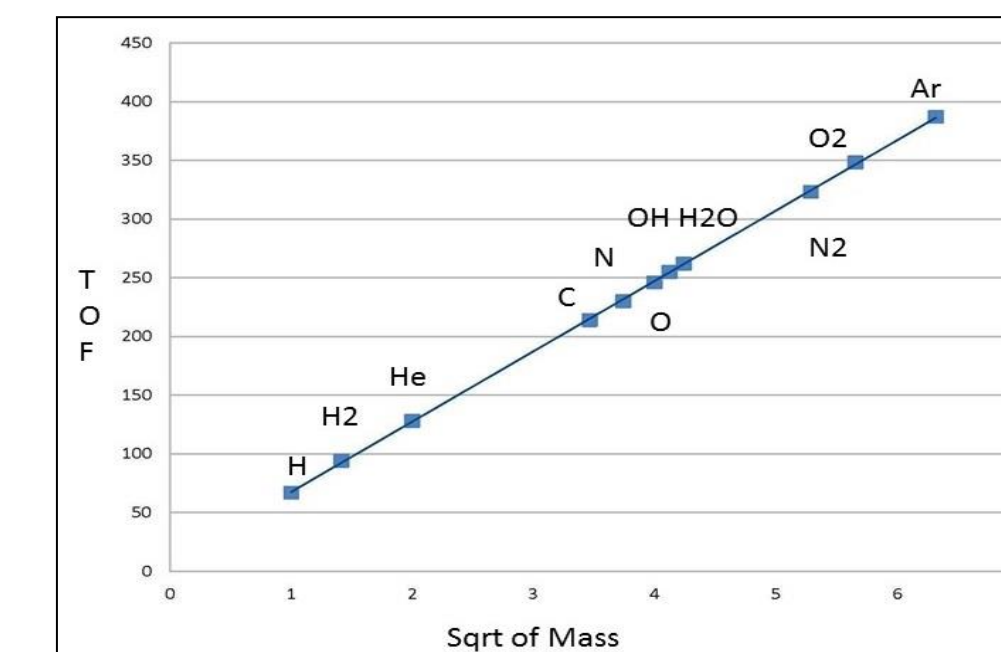
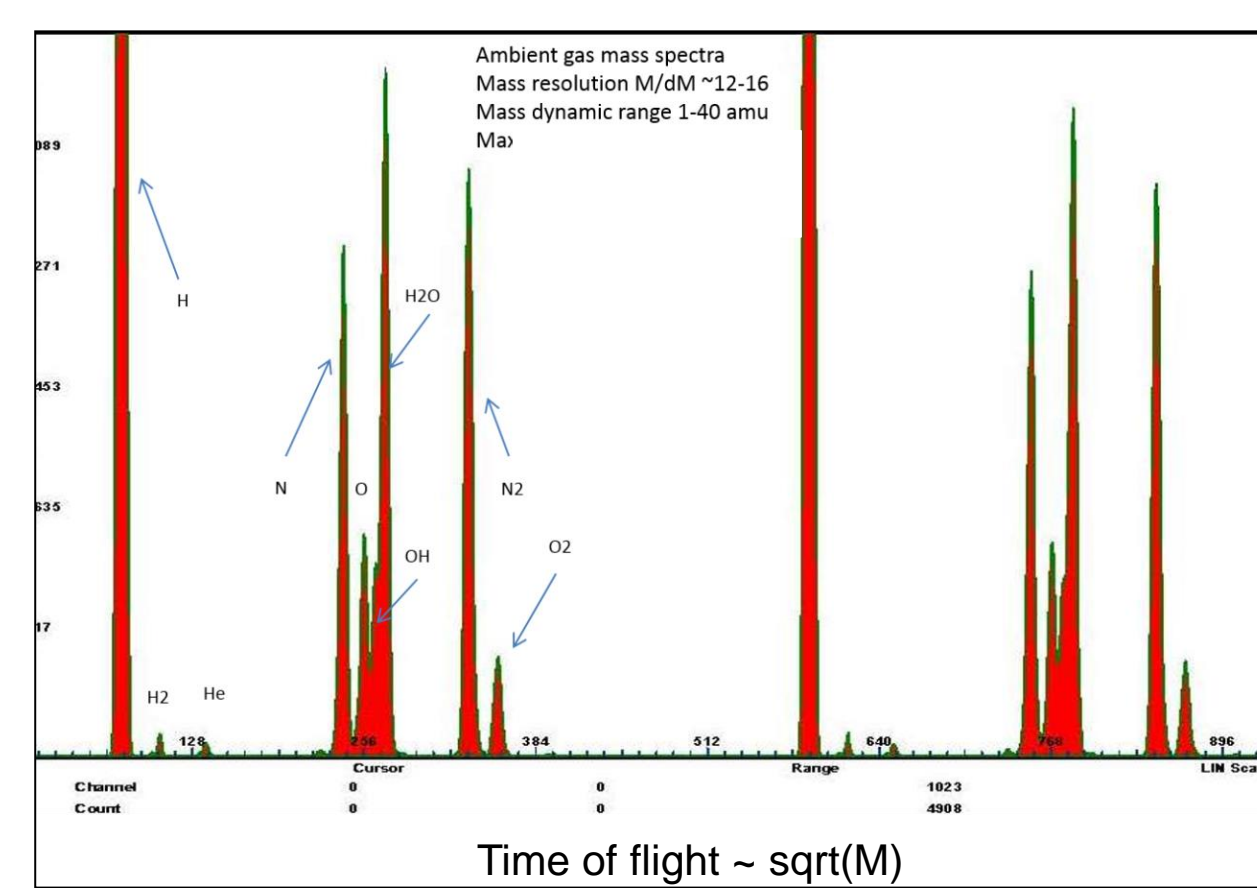
Summary

The Heliophysics Division of GSFC has developed a compact Ion and Neutral Mass Spectrometer (INMS) for in situ measurements of ions and neutrals H, He, N, O, N₂, O₂ with M/dM of approximately 12 at an incoming energy range of 0-50eV. The INMS is based on front end optics, post acceleration, gated time of flight, ESA and CEM or MCP detectors. The compact sensor has a dual symmetric configuration with the ion and neutral sensor heads on opposite sides and with full electronics in the middle. The neutral front end optics includes thermionic emission ionization and ion blocking grids, and the ion front end optics includes spacecraft potential compensation grids. The electronics include front end, fast gating, HVPS, ionizer, TOF binning and full bi directional C&DH digital electronics. The data package includes 400 mass bins each for ions and neutrals and key housekeeping data for instrument health and calibration. The data sampling can be commanded as fast as 10 msec per frame (corresponding to ~80 m spatial separation) in burst mode, and has significant onboard storage capability and data compression scheme. Experimental data from instrument testing with both ions and neutrals will be presented. INMS was recently launched on The ExoCube 3U CubeSat mission (SMAP launch) on January 31, 2015. A second upgraded INMS is scheduled to be delivered August 2015 to Dellingr 6U CubeSat mission to be launched in 2016. This miniaturized instrument fills a 1.5U volume, weighs only 560 g and requires nominal power of 1.6W.



Compact CubeSat – INMS Measurements

Measurements of atmospheric neutral and ion composition and density are needed not only for studies of the dynamic ionosphere-thermosphere-mesosphere system but simply to define the steady state background atmospheric conditions. Remote sensing measurements of atomic oxygen density at altitudes between 80-95 km have shown that the density can vary by over an order of magnitude. This causes deviations from the densities estimated by MSIS (a well known empirical model of Earth's atmosphere) by up to a factor of four. CubeSats provide an ideal platform for an ion/neutral mass spectrometer capable of obtaining the in situ measurements that are critical to understanding this complicated system.

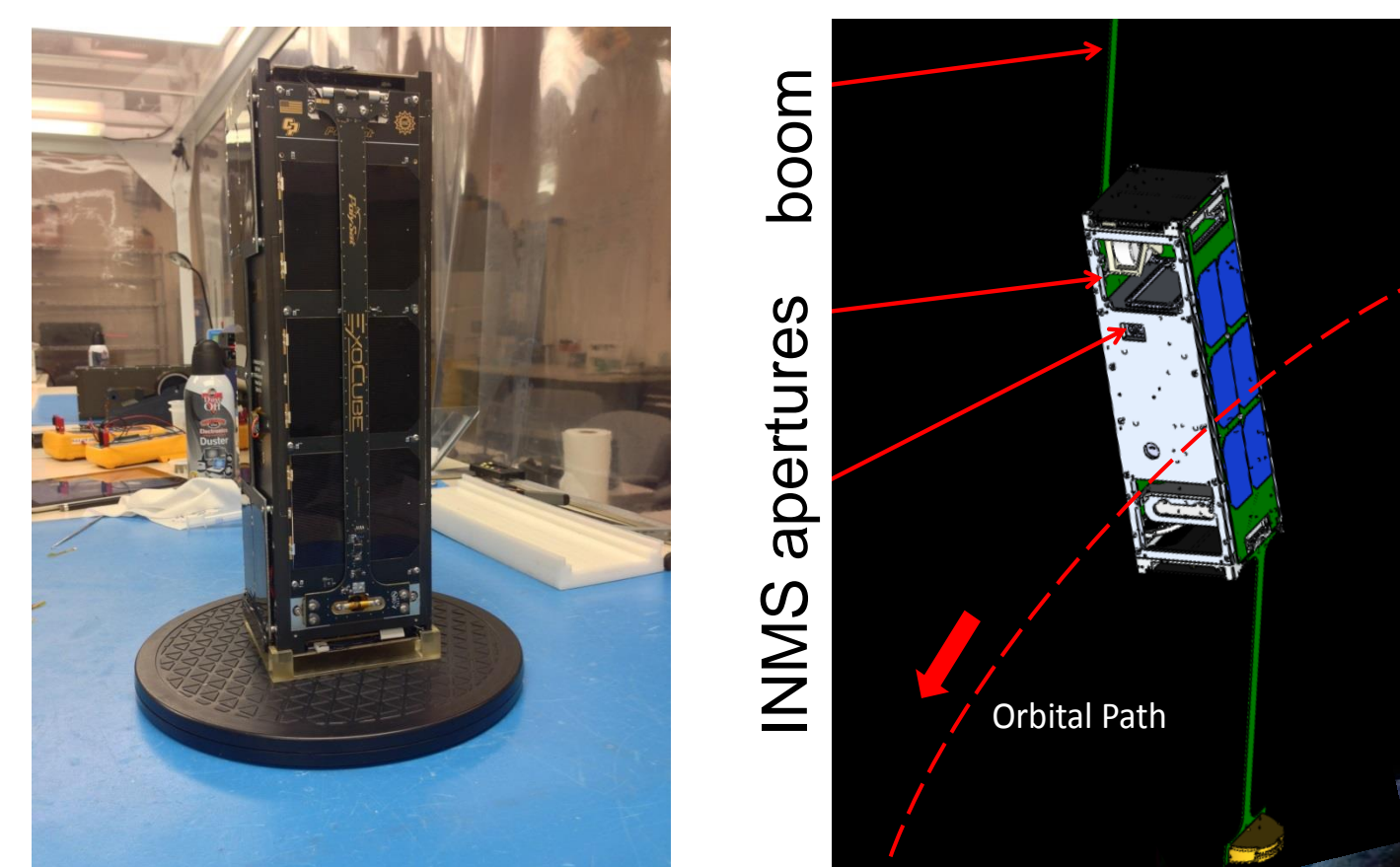


Measurement Objectives
high-resolution, *in-situ*
[H], [He], [N], [O], [N₂], [O₂]
[H⁺], [He⁺], [N⁺] [O⁺], [N₂⁺], [O₂⁺]

ExoCube and Dellingr Missions

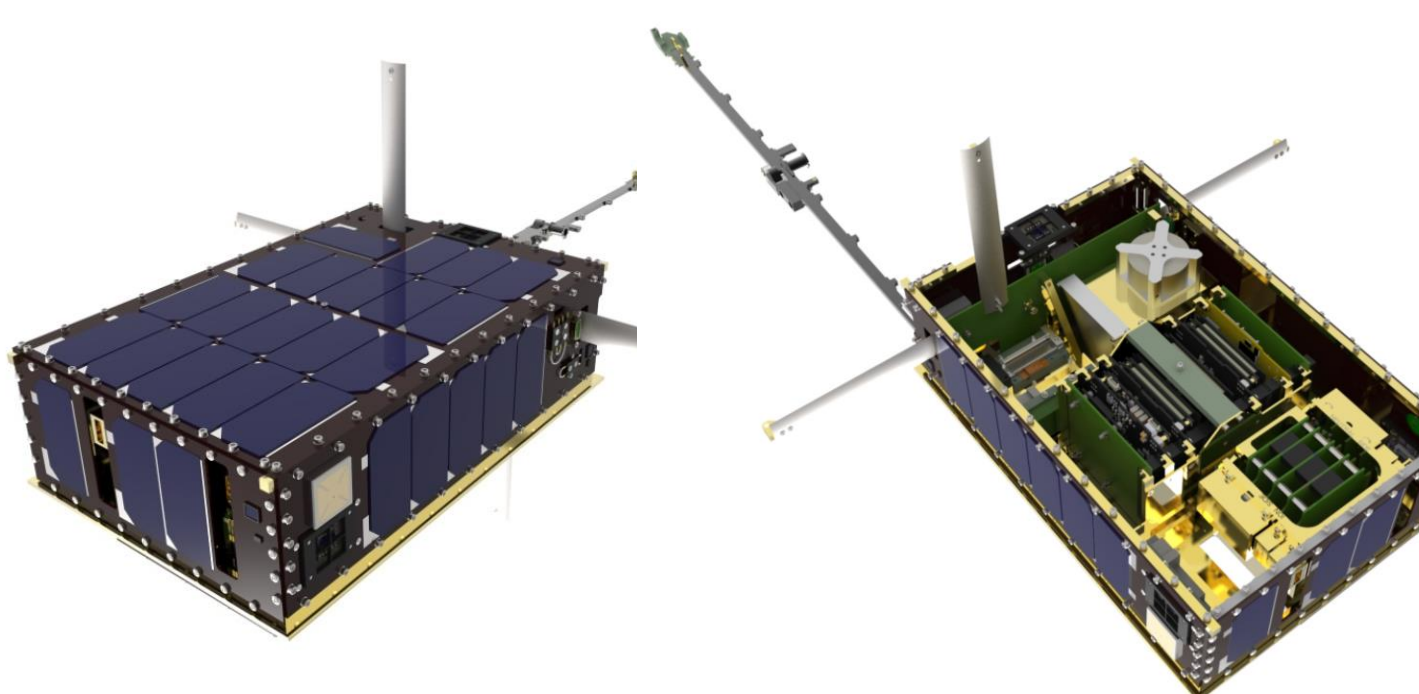
The ExoCube mission (PI John Noto, Scientific Solutions)

- Designed to acquire global knowledge of in-situ densities of [H], [He], [O] and [H⁺], [He⁺], [O⁺] in the upper ionosphere and lower exosphere in combination with incoherent scatter radar ground stations distributed in the north polar region.
- California Polytechnic State (Calpoly) University built 3U CubeSat bus
- ELaNa-X SMAP Delta II launch January 31, 2015
- 6-12 month operation
- 440x675km Orbit altitude, 98 degree inclination



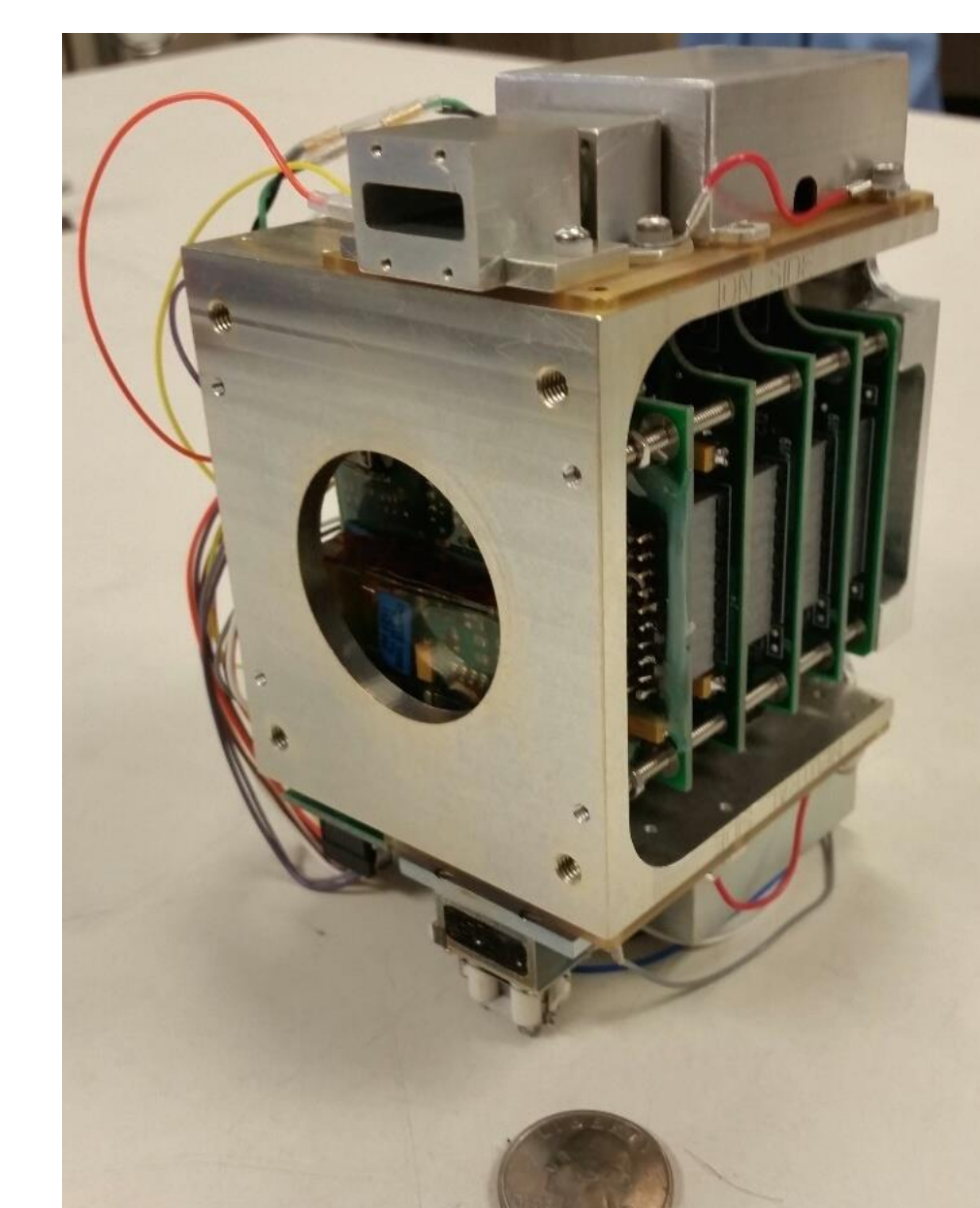
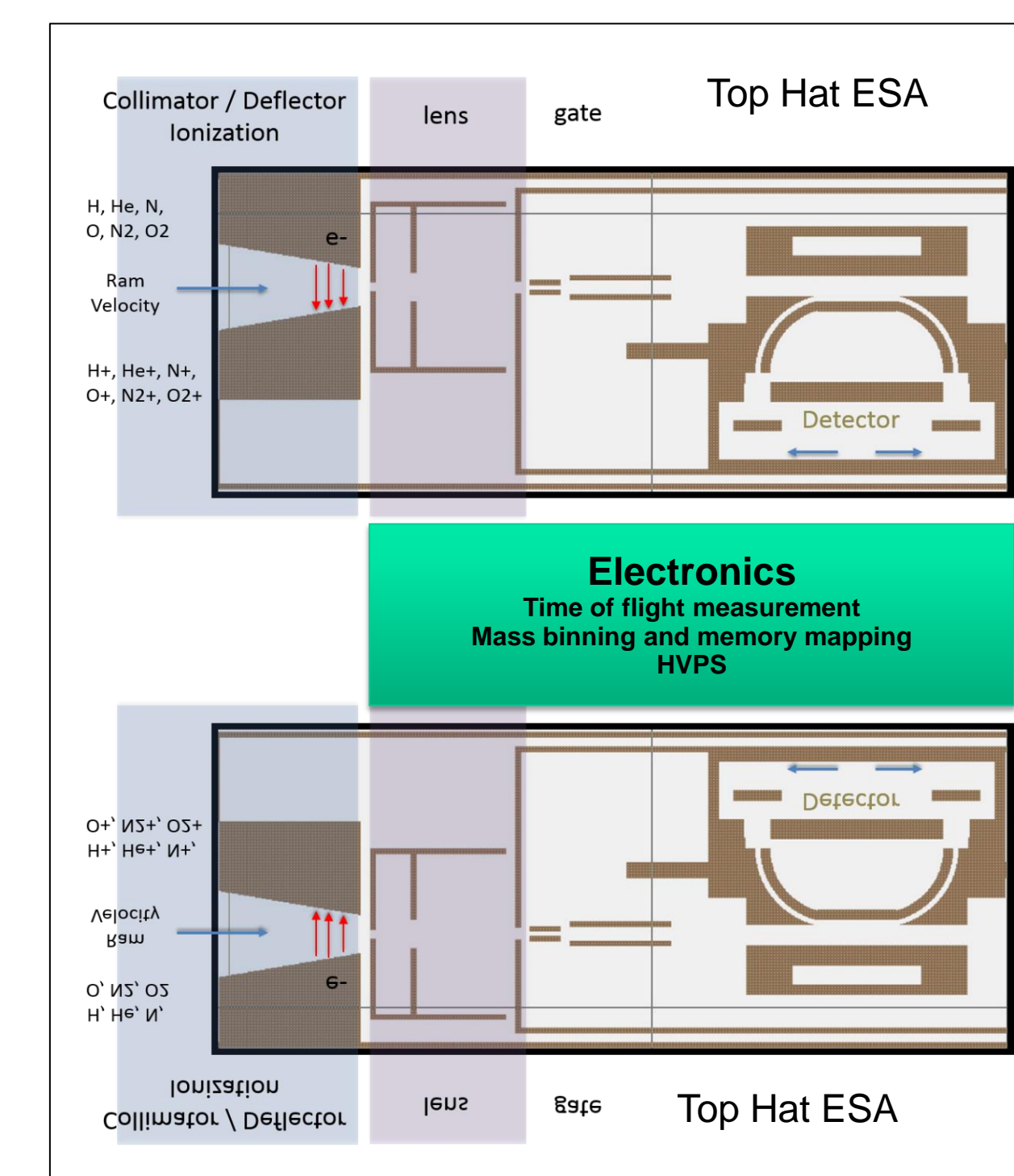
The Dellingr mission (NASA Goddard Space Flight Center)

- Goddard's internal development to design, build, test and fly a 6U CubeSat carrying 2 GSFC's science instruments (Science Magnetometer and Ion-Neutral Mass Spectrometer)
- 3-axis stabilized GNC system
- ISS Launch possibly 2016
- Thoroughly tested, high capability s/c bus

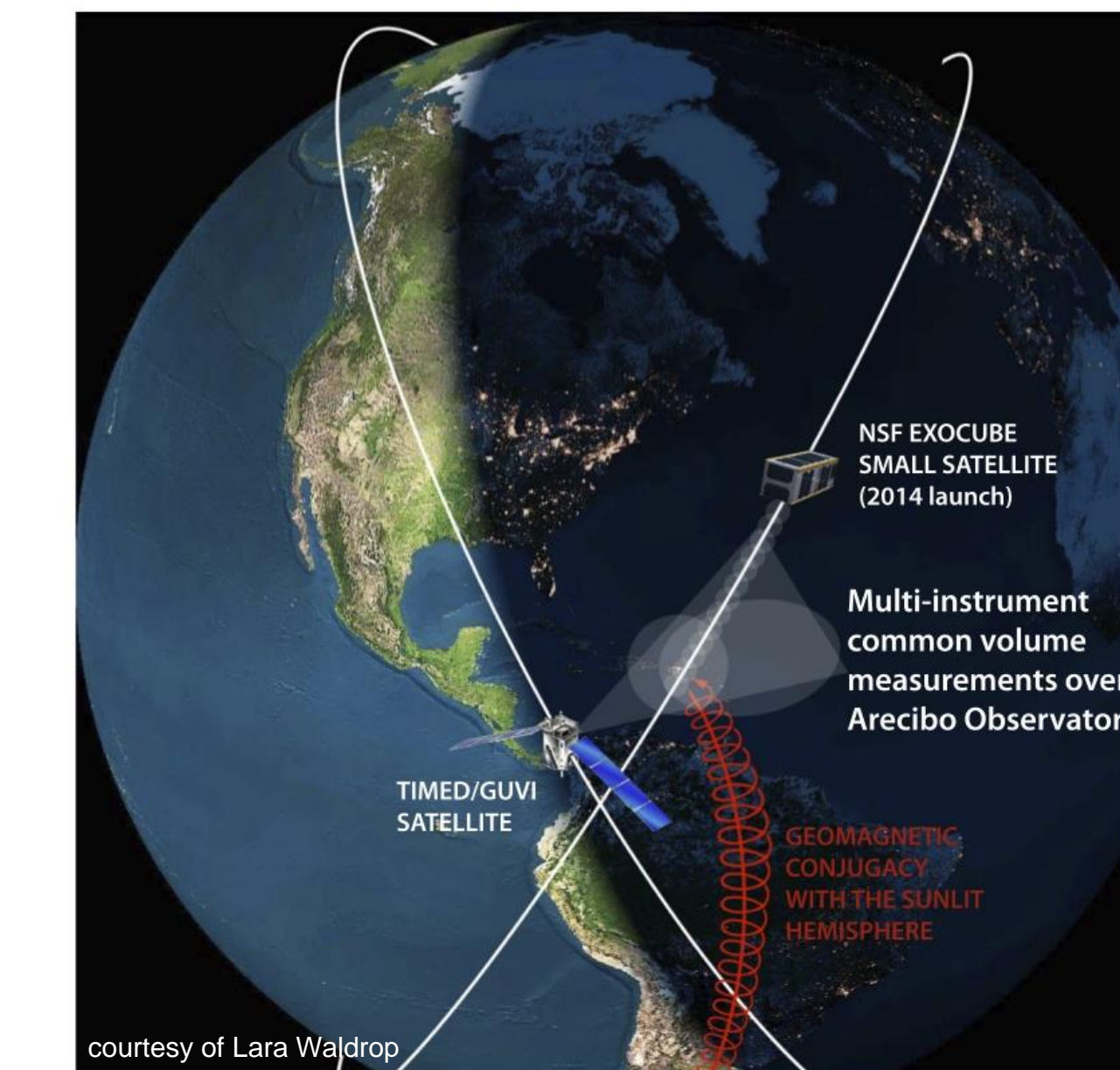


Principles of Operation

- Neutral particles are first ionized with a compact thermionic filament. Ions are blocked from the neutral aperture by a retarding potential grid
- The ions are directly focused into the gate from pre acceleration
- Pre acceleration by voltage V gives all ions same energy $E = qV$, much greater than initial energy dispersions dE .
- Ions are ordered in velocity according to their mass on the basis of the simple formula $E = \frac{1}{2} m v^2$
- Measuring the velocity of each ion - with time of flight over a distance d- gives the mass of the ion according to $M/q = 2 \times E/q \times TOF^2 / d$.
- Accelerated ions are focused through an electric gate into an electrostatic analyzer (ESA)
- Ions are normally blocked by the gate and can pass through only during a short pulse duration dt, marking a start in the time of flight measurement at the pulse edge
- Ions are detected at the output of the ESA by a CEM detector marking the stops for the time of flight measurements.
- The ESA is tuned to the proper energy pass band set by the pre acceleration voltage blocking out of band particles, as well as attenuating any UV.
- The mass resolution is limited by uncertainties in energy dispersion, time resolution and time of flight path.



Optimizing Science Performance for the Exosphere



The first-ever empirical estimation of global atomic hydrogen density [H] in the thermosphere and exosphere (from 90 km to 3 R_E) was enabled by TIMED/GUVI measurements of ultraviolet airglow emission (Waldrop and Paxton, JGR, 2013)

Specification of [H] over Arecibo Observatory in turn allows the first-ever empirical estimation of:

- atomic oxygen density [O]
- exospheric temperature
- photoelectron flux from the conjugate hemisphere
- key chemical reaction rates

via coincident measurements of optical airglow emissions and incoherent radar scatter.

← NSF Highlight from AMS Meeting

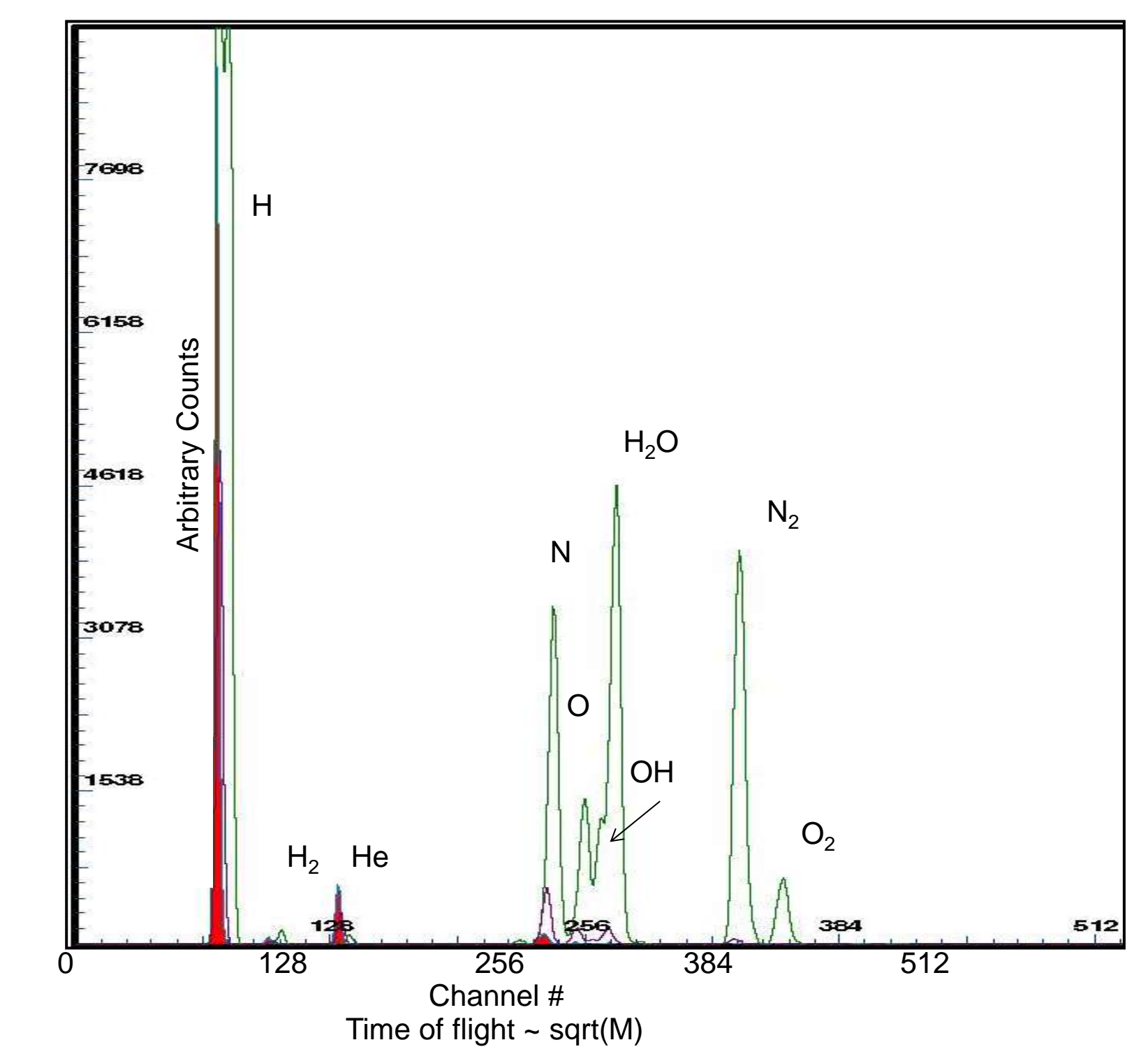
Exospheric ion density environment as modeled by the IRI-2007. (from Lara Waldrop, Univ. of Illinois)

	max [/cc]	min [/cc]	Ideal Dynamic Range
O ⁺	5.00E+08	1.00E+04	1.00E+04
H ⁺	1.00E+06	1.00E+03	1.00E+03
He ⁺	1.00E+06	1.00E+04	1.00E+03
combined	5.00E+08	1.00E+03	5.00E+05

- * First in situ measurement of H
- * No in situ O and He since 1983

Instrument Specifications

- Separate apertures for ions and neutrals +-20deg x +-10deg around ram
- Thermionic ionization of neutrals
- Mass resolution M/dM ~12, Mass dynamic range 1-40 amu
- Max counting rate: 1 Meg-cps
- Adjustable gate pulse width serves as crude mass filter to select full mass scale or exclude heavy elements with short pulses.
- Spectra sampling 100 ms to 10 sec programmable with 10 ms steps
- Onboard memory and processing capability
- Data product: Raw TOF spectra up to 400 bins for mass window of interest, and species counters
- Electrical interface: +5V, +3.3V, I2C and SPI serial communication
- Volume 8 cm x 13 cm (fits in 1.5U), mass 560 g
- Peak power at full filament 1.6W, ions only 0.6W



Spectral measurement of ambient gas composition using gate pulse width of 80 ns (green line) and 20 ns (red solid). A shorter gate pulse will attenuate the flux of heavier species through the gate.

ExoCube Instrument Operations

- ExoCube launched with SMAP on January 31, 2015. Functionality testing shows that the instrument is in good health.
- First flight spectra of INMS instrument on ExoCube. Ion data taken May 20th, 2015.
- Neutral data of background outgassing taken July 15th, 2015

