CubeSat Scale Ion and Neutral Mass Spectrometers for Exploration of Planetary Ionospheres - Initial Results from the Exocube 1 and Dellingr Missions

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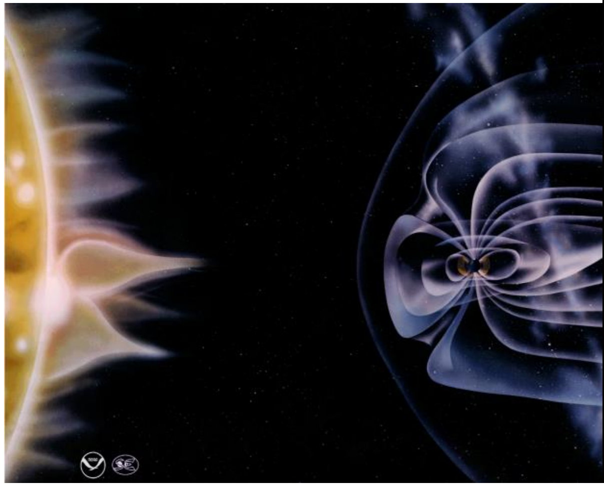
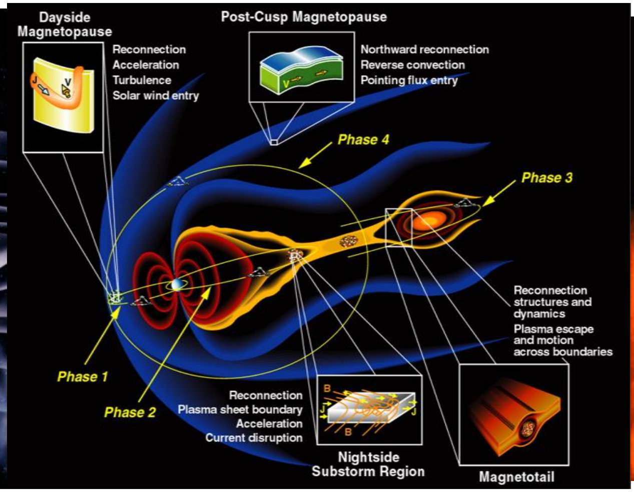
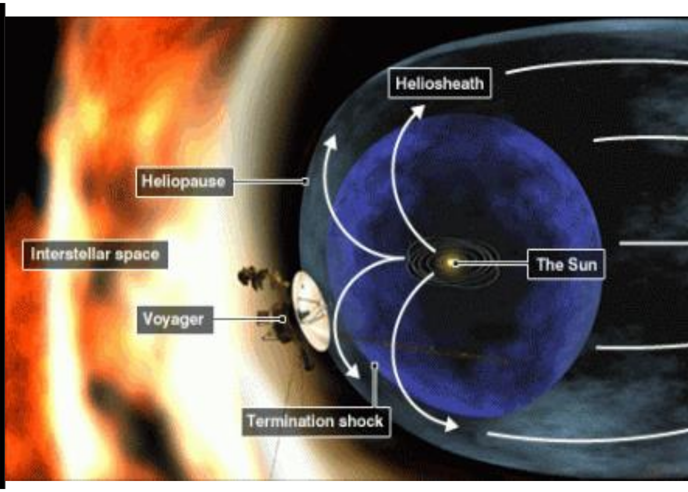
4th GSFC Planetary CubeSats Symposium

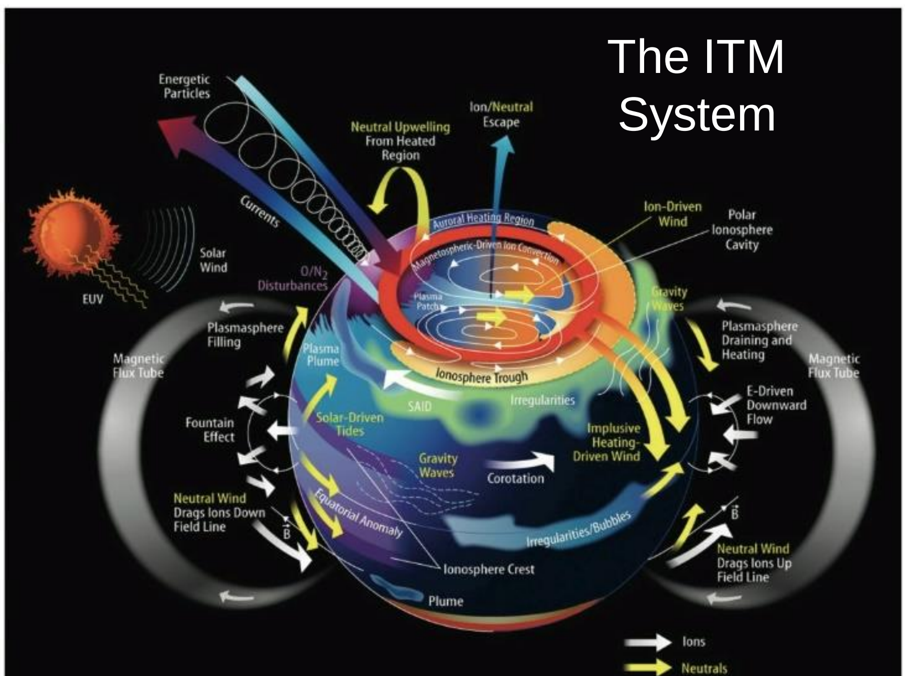
The Heliopshysics Environment

Ions and neutrals both coexists in equivalent densities at the low ionospheres and the LISM









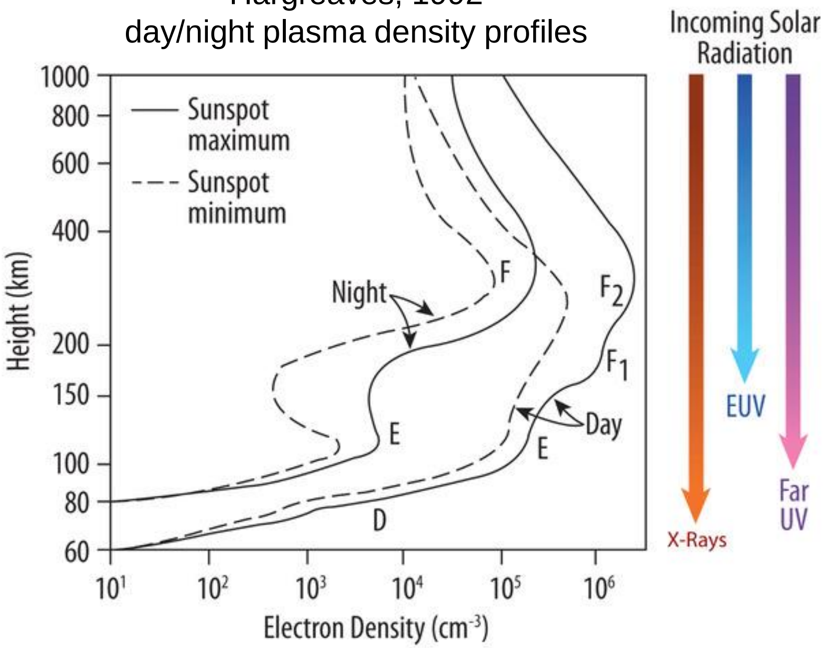
The solar wind flows radially outward from the sun in the interplanetary space, and slows down and heats up on encountering Earth / Planetary magnetospheres driving several current systems, waves and acceleration phenomena

Some of the solar wind kinetic energy is deposited in ionospheres, causing currents, heating and bulk flows of ions and neutrals

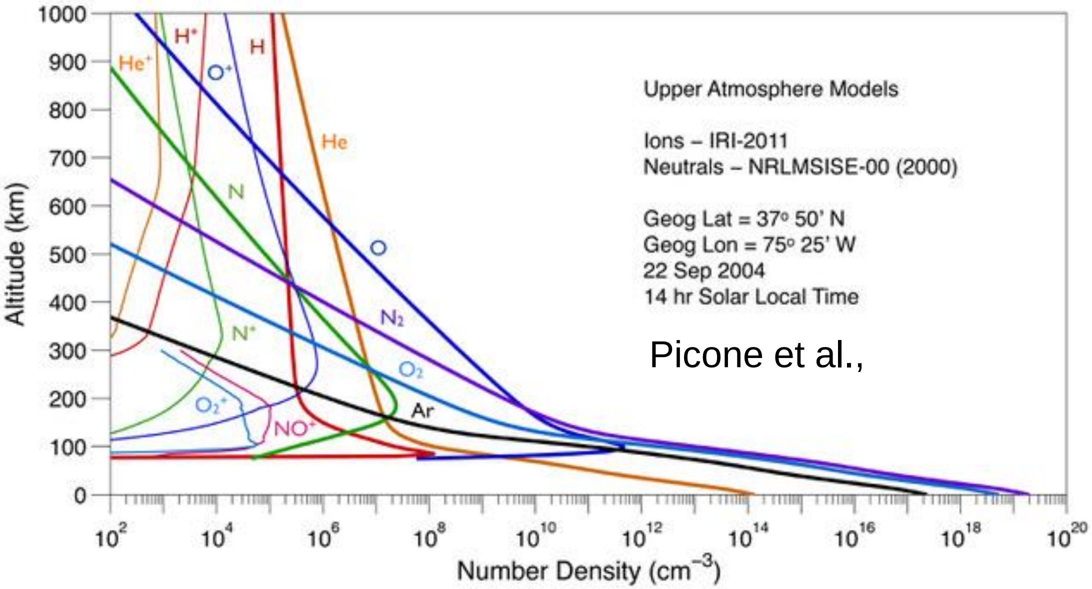
The relatively high densities at LEO allow for small apertures, therefore small instruments and constellation of SmallSat / CubeSats

Model ion / neural density profiles and day/night electron density profiles in the earth's ionosphere

Hargreaves, 1992
day/night plasma density profiles



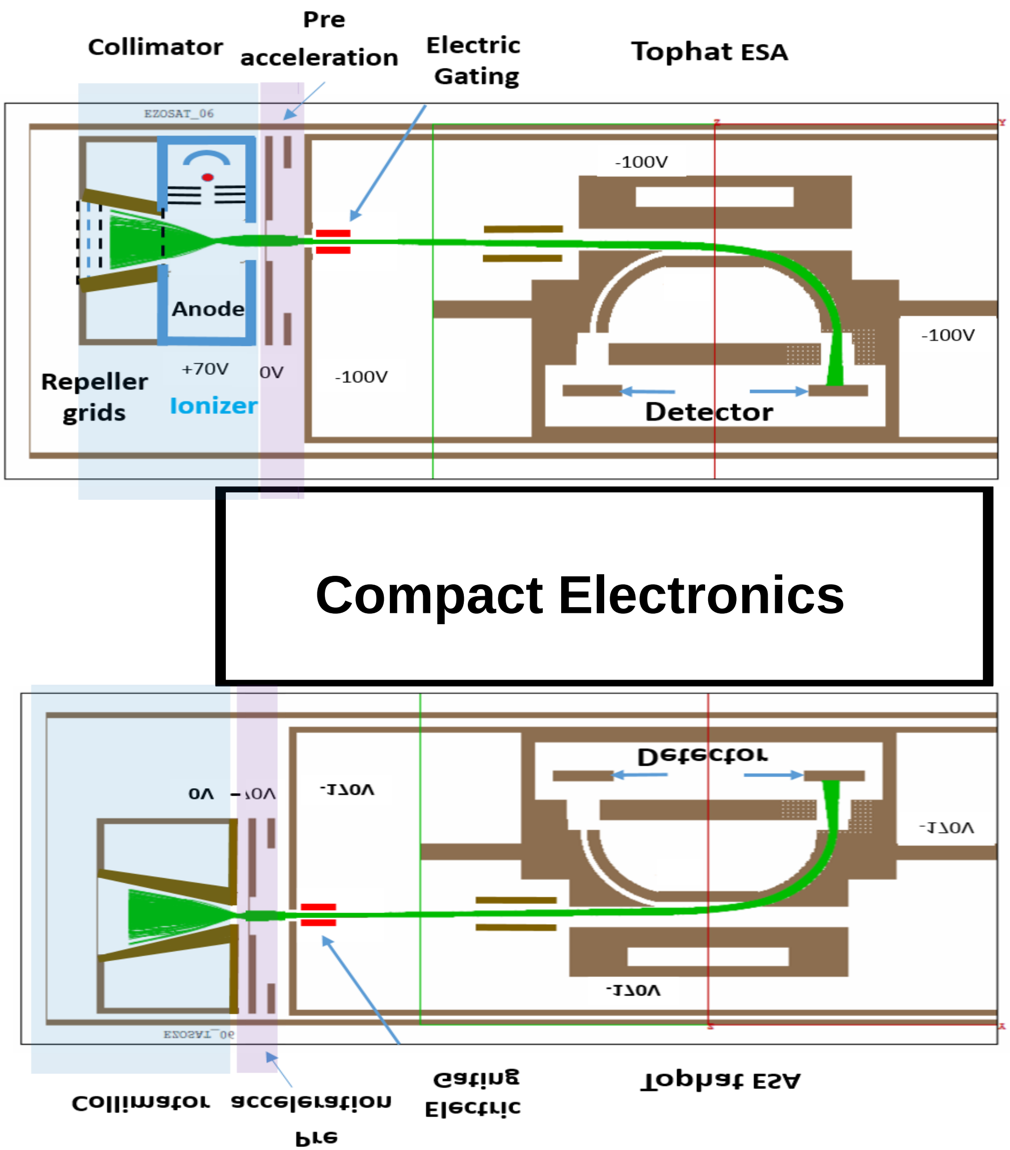
Simultaneous multi point measurements of ion and neutral composition along with temperatures, ion drifts, and neutral winds, are very important to understand the integral and global response of the ITM system to the solar drive from above, the atmospheric drive from below, and the coupling



Typical Earth's ionospheric parameters at 400-500km: Ion density 1e4 - 1e6 /cm^3 , neutral density 1e4-1e8/cm^3, T ~500K-3000K, ion drifts up to 2000m/sec, neutral winds up to 500m/sec.

The GSFC mini – Ion Neutral Mass Spectrometer (INMS) - Gated Time of Flight Technology

Missions NSF Exocube 1 (launched in 2015), NASA DELLINGR (launched Nov 2017), Exocube 2 to be launched in Aug 2019, PetitSat to be launched in 2020 and future missions



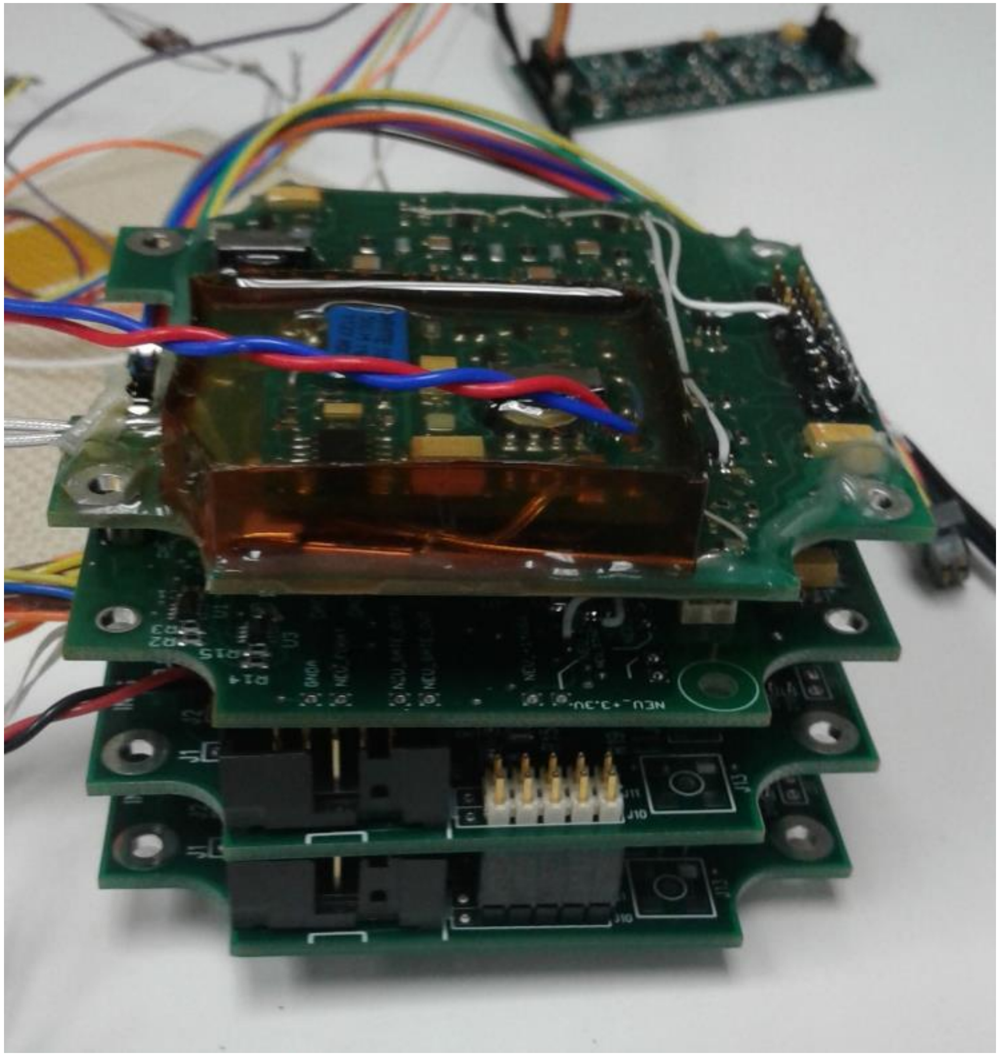
Pixel Aperture ~1mm^2, FOV ~10x10 deg M/dM ~10, Mass Range 1-40amu, sampling rate 1Hz, 0.56kgr, size 10cm x 10 cm x 13 cm, peak power 1.6W, Product 2 x 400 bin TOF spectra

INMS Principle of Operation

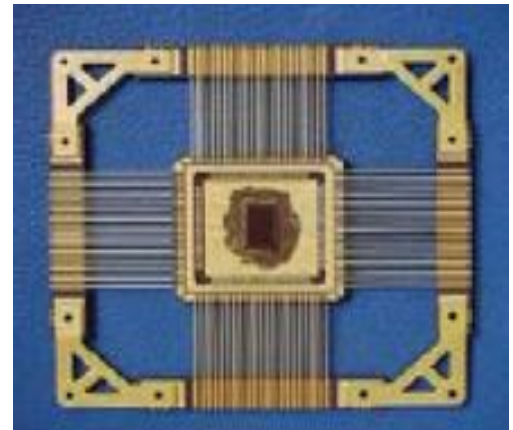
- Gated time of flight technology for simultaneous species measurements without scanning
- Separate ion and neutral apertures and sensors sharing common electronics
- In ion aperture ions are accelerated and focused towards an electric gate and into a field free area towards an ESA and the CEM detector
- In neutral aperture charged particles are blocked with entrance grids and neutrals are ionized with thermionic electron impact ionization
- The ESA blocks attenuates light and out of band
- The acceleration voltage orders particles in square root with their time of flight
- Separate TOF binning gives a 2 x 400 bin ion and neutral spectra sampled at 1Hz

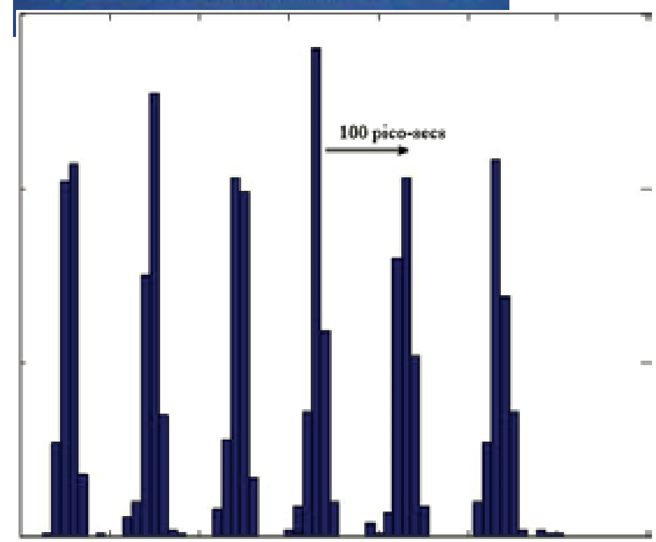
Compact Electronics: optics, 3KV HVPS, gate driver, electron gun, FEE, FPGA

TOF binning and CDH; stack size 8cm x 8cm x 8cm

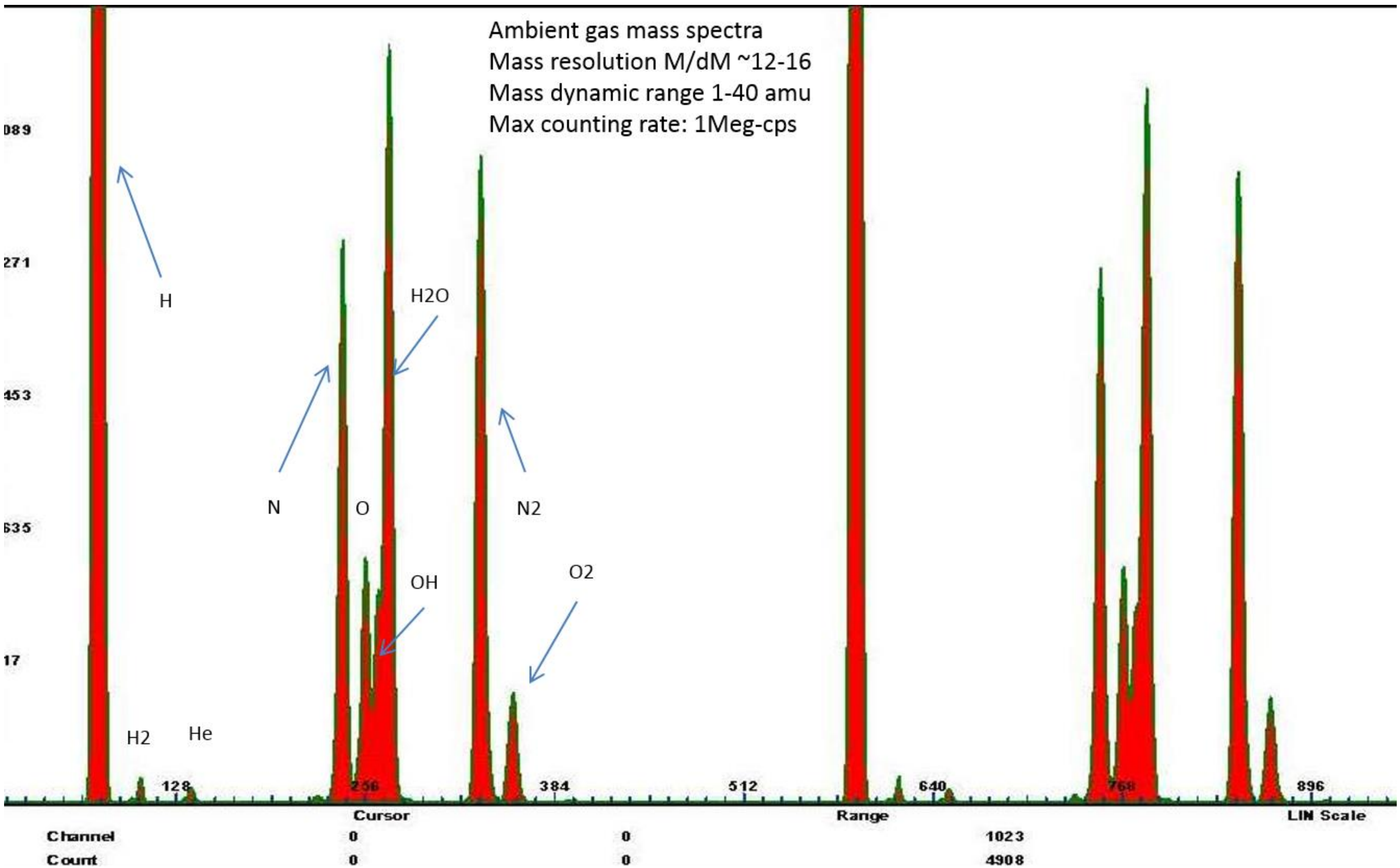


TOF-G chip nickP
Time resolution 10ps





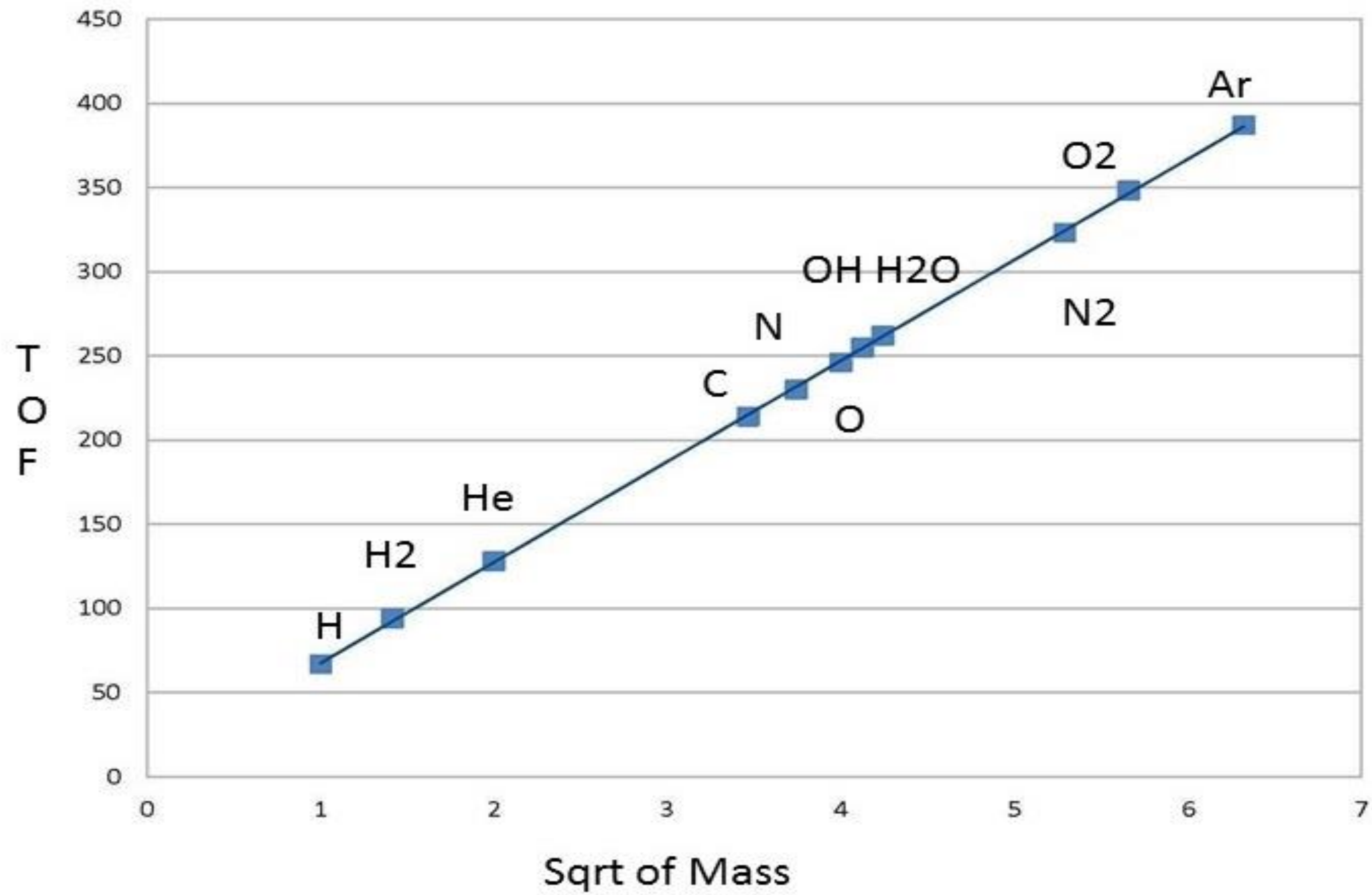
Laboratory neutral spectra



Time of flight ~ sqrt(M)

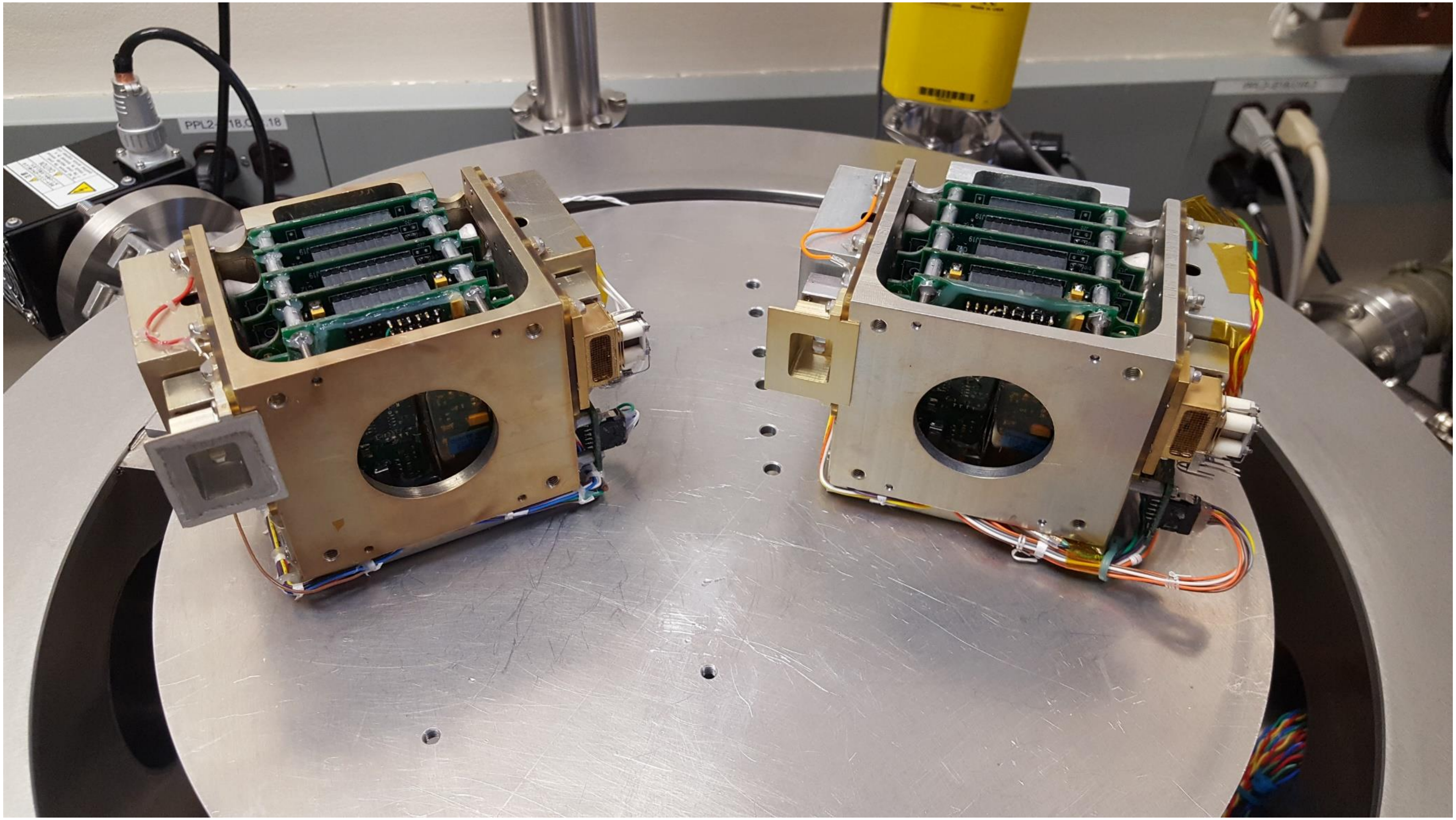
Mini-INMS Measurements H to Argon
TOF vs SQRT Plot

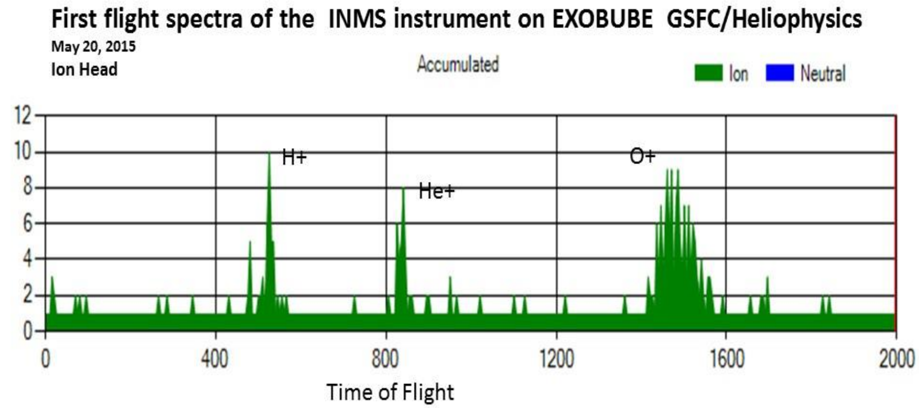
Excellent linearity

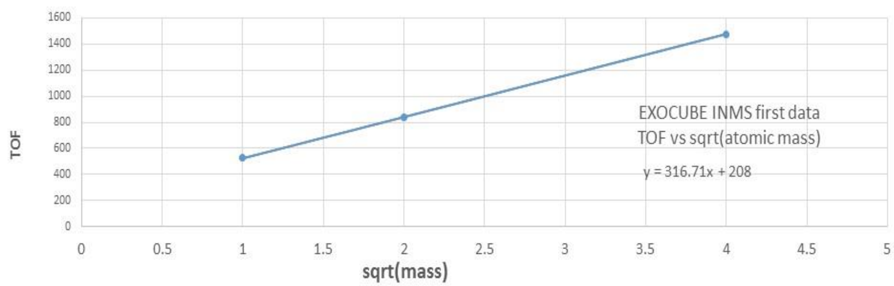


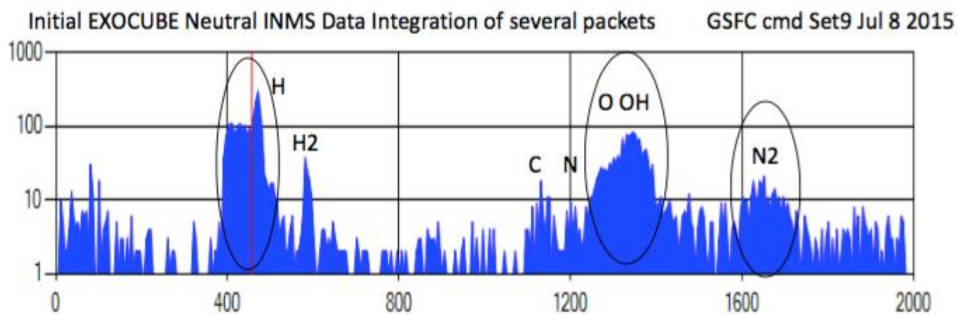
M = TOF^2 / (2E*L^2)

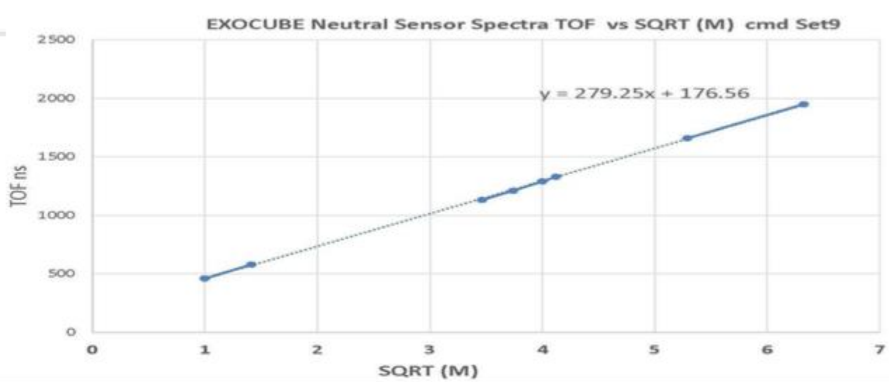
Two Flight INMS instruments for the GSFC Dillinger 6U (left) and the NSF Exocube 2 (right)





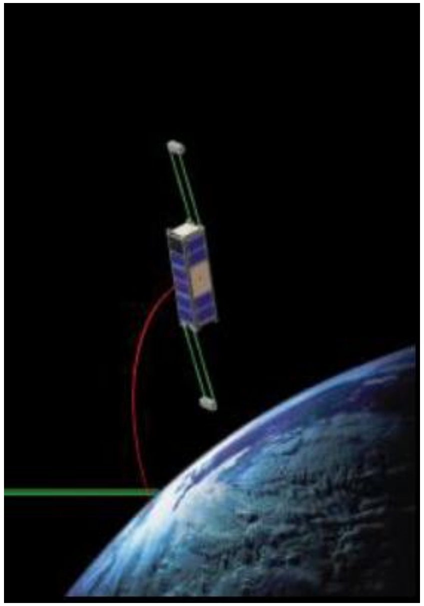


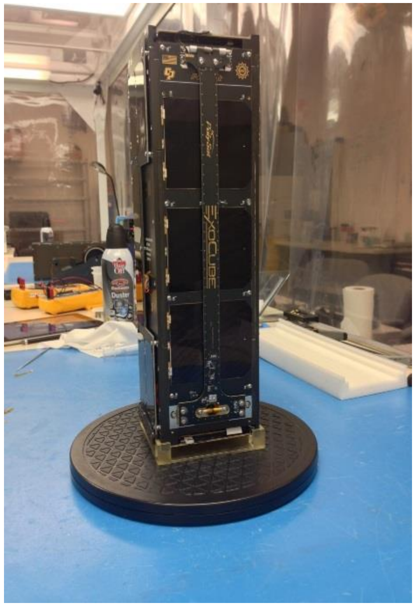




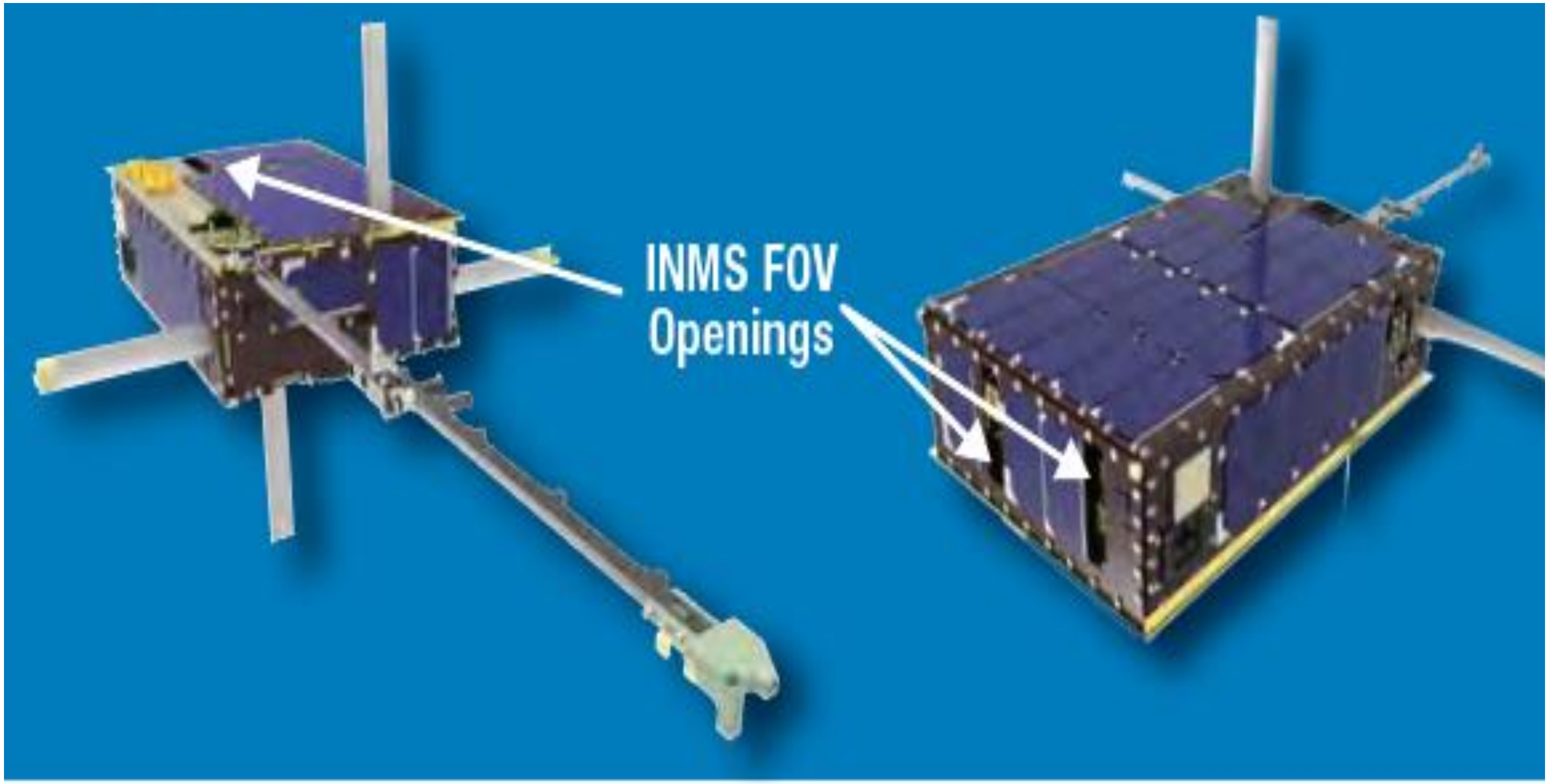
Very poor communications antenna did not deploy
Spacecraft tumbling
Lost SC after short operation

Mission PI	John Noto SSC
CubeSat Bus	California Polytechnic
	3U gravity stabilized
Compact INMS	GSFC / HSD
Launch Date	Jan 2015
Primary mission	NASA/SMAP
Orbit	450km x 680km, 98º inclination, sun-synchronous
INMS	Occupies the central 1.3U





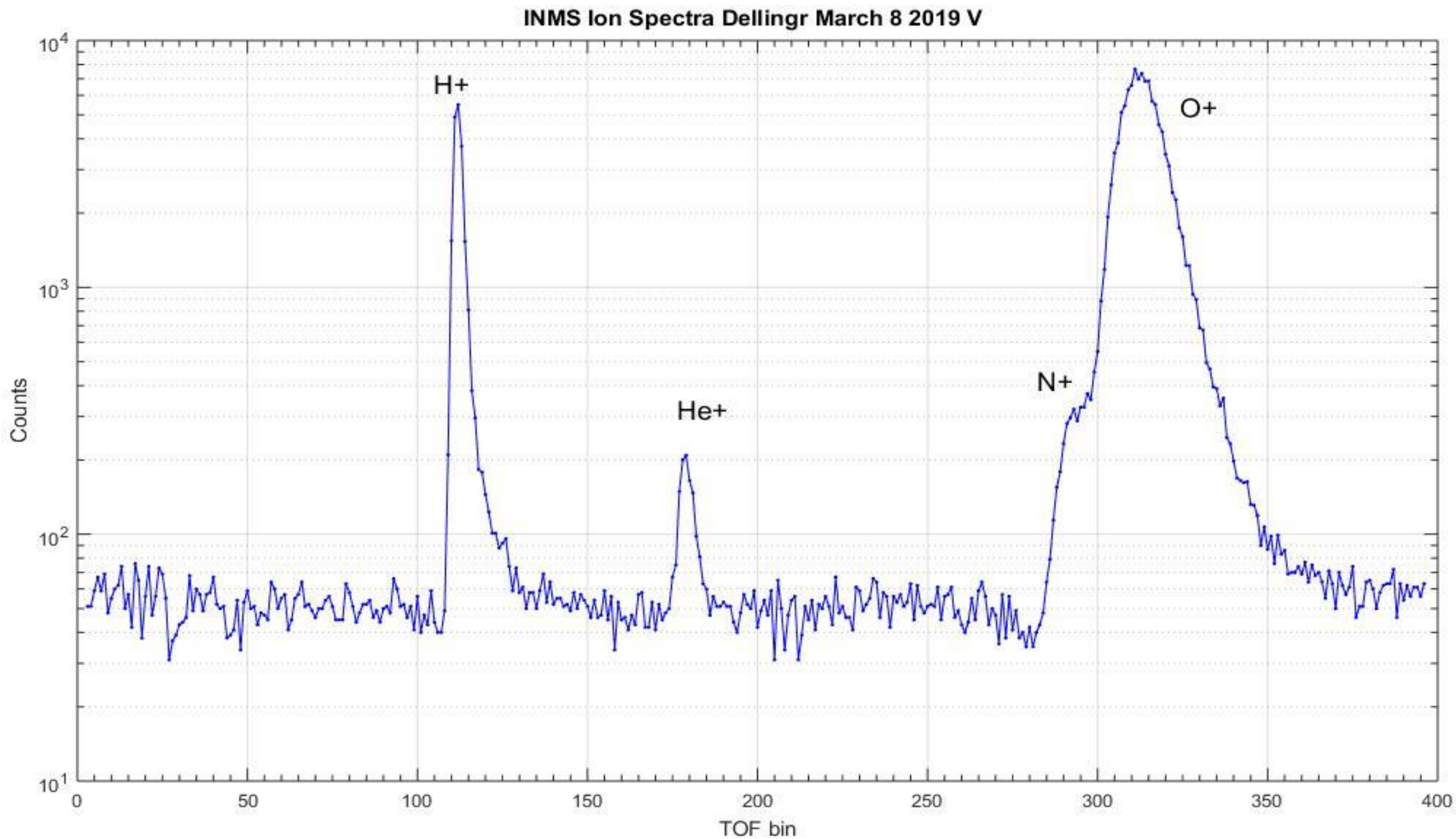
NASA GSFC Tech Demo DELLINGR 6U
Deployed in LEO Orbit ~450 km from the ISS on November 2017



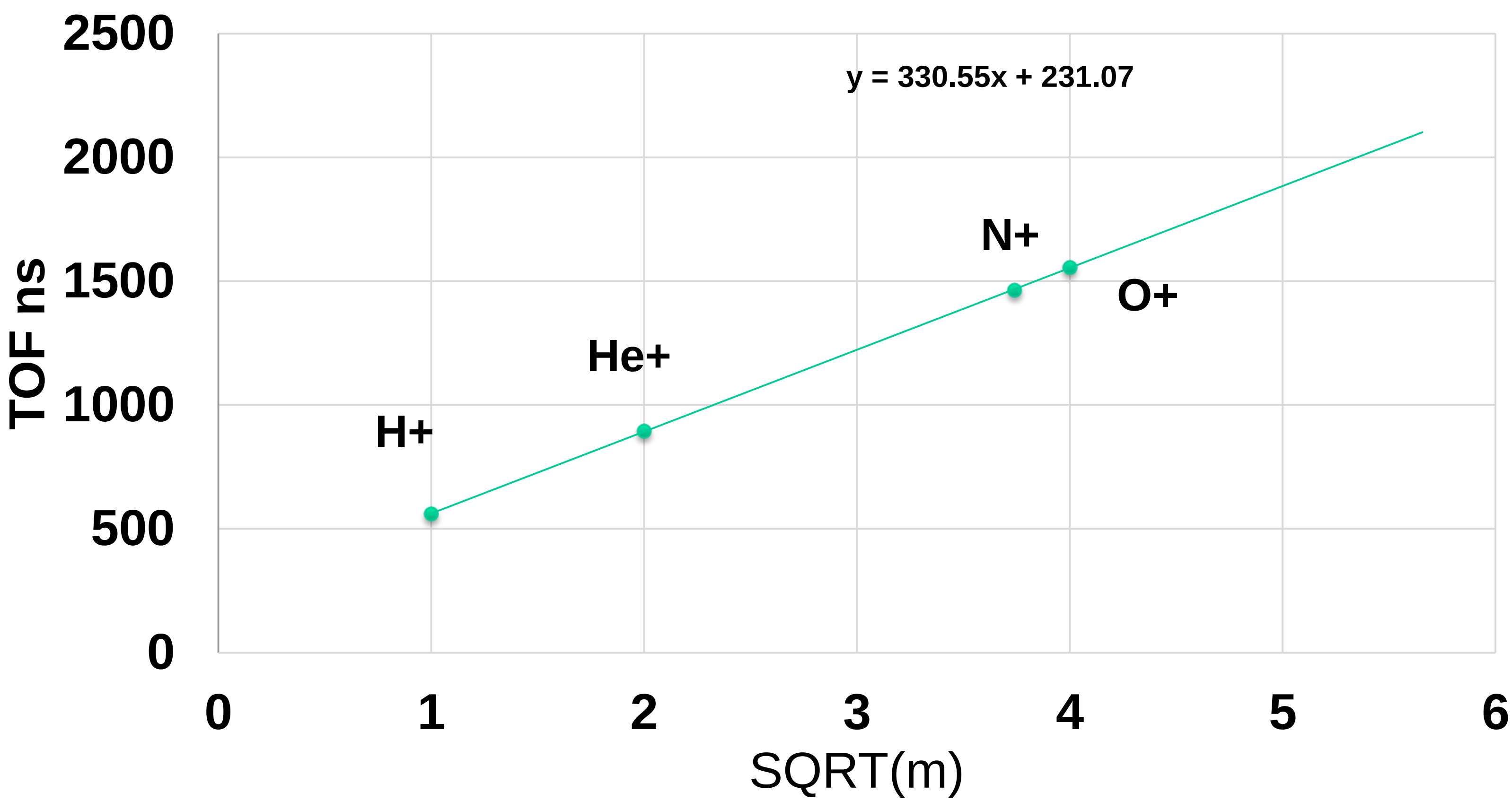
The Dellingr team: L. Kepko, M. Johnson, C. Clagget, L. Santos, B. Azimi, N. Paschalidis, S. Jones, E. Zesta, T. Bonalsky, J. Lucas, A. Cudmore, D. Chai, J. Marshall, D. Simpson, K. Bromund et al.

Due to attitude control failure the SC is tumbling with a period in the range 10-20 min

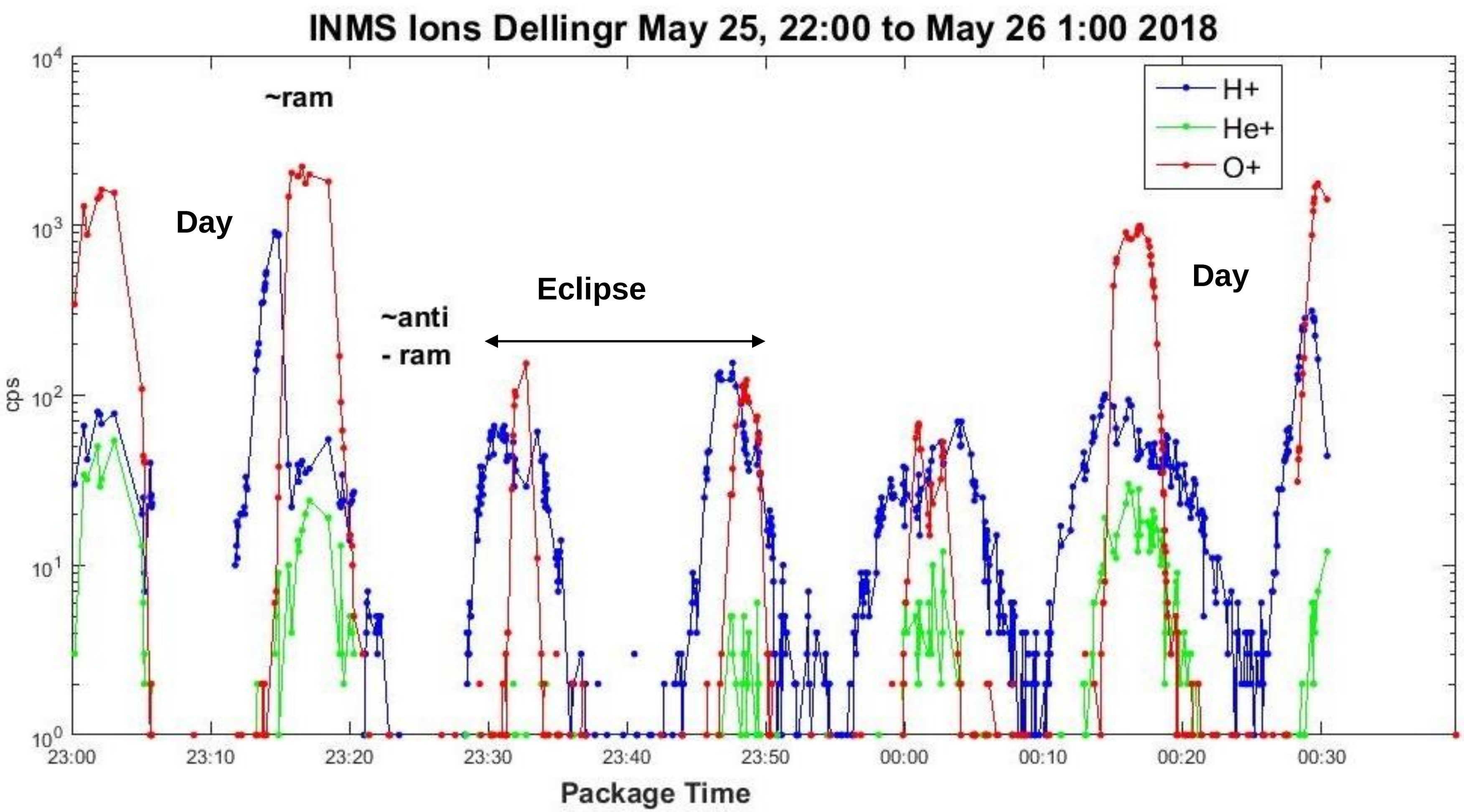
Typical flight Ion spectra of Dellingr INMS averaged in all look directions. Higher HV programming improves the massrsolution



Dellingr INMS Ions Spectra Fit March8, year 2019



Dellingr full orbit data, LEO ISS type ~450 km



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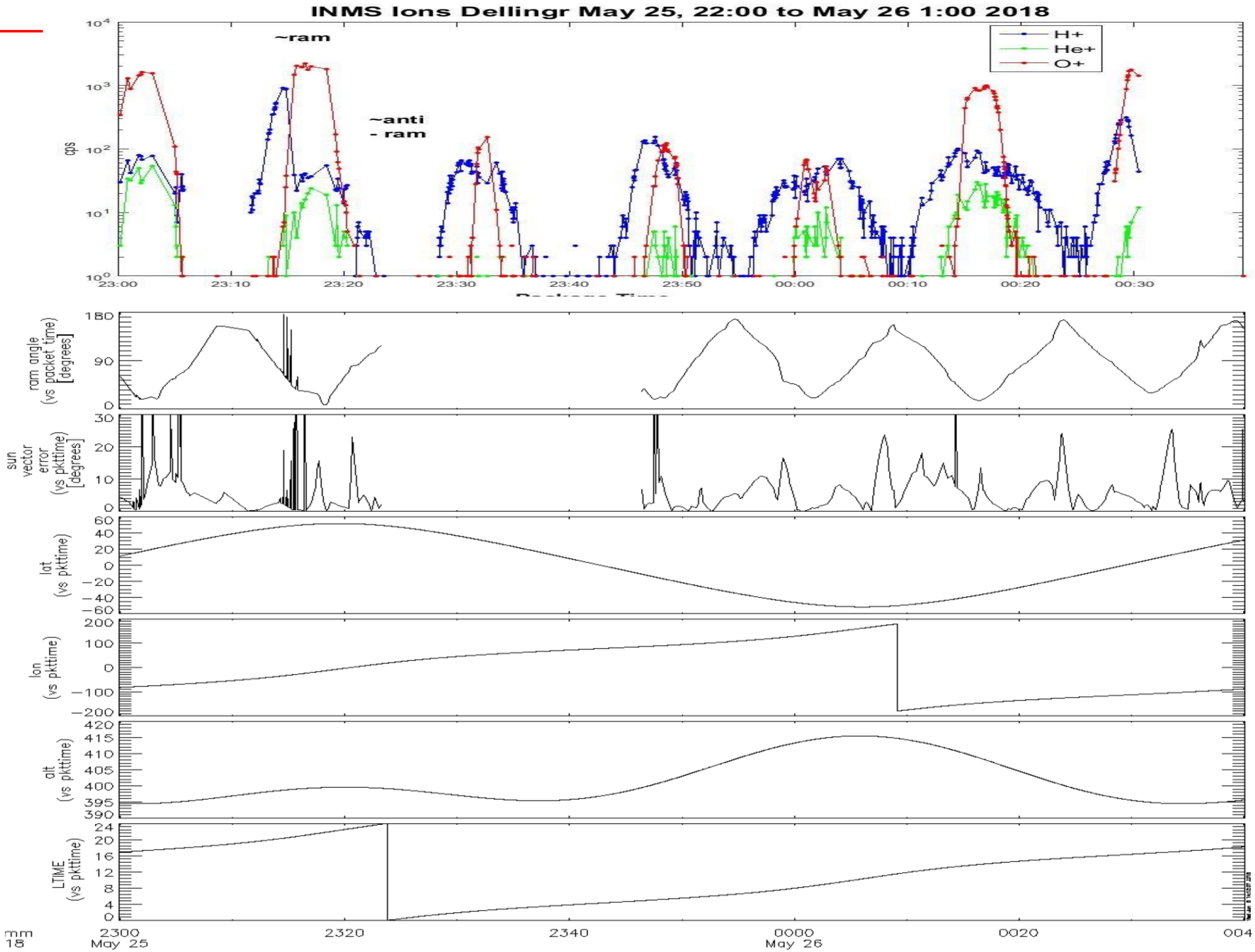
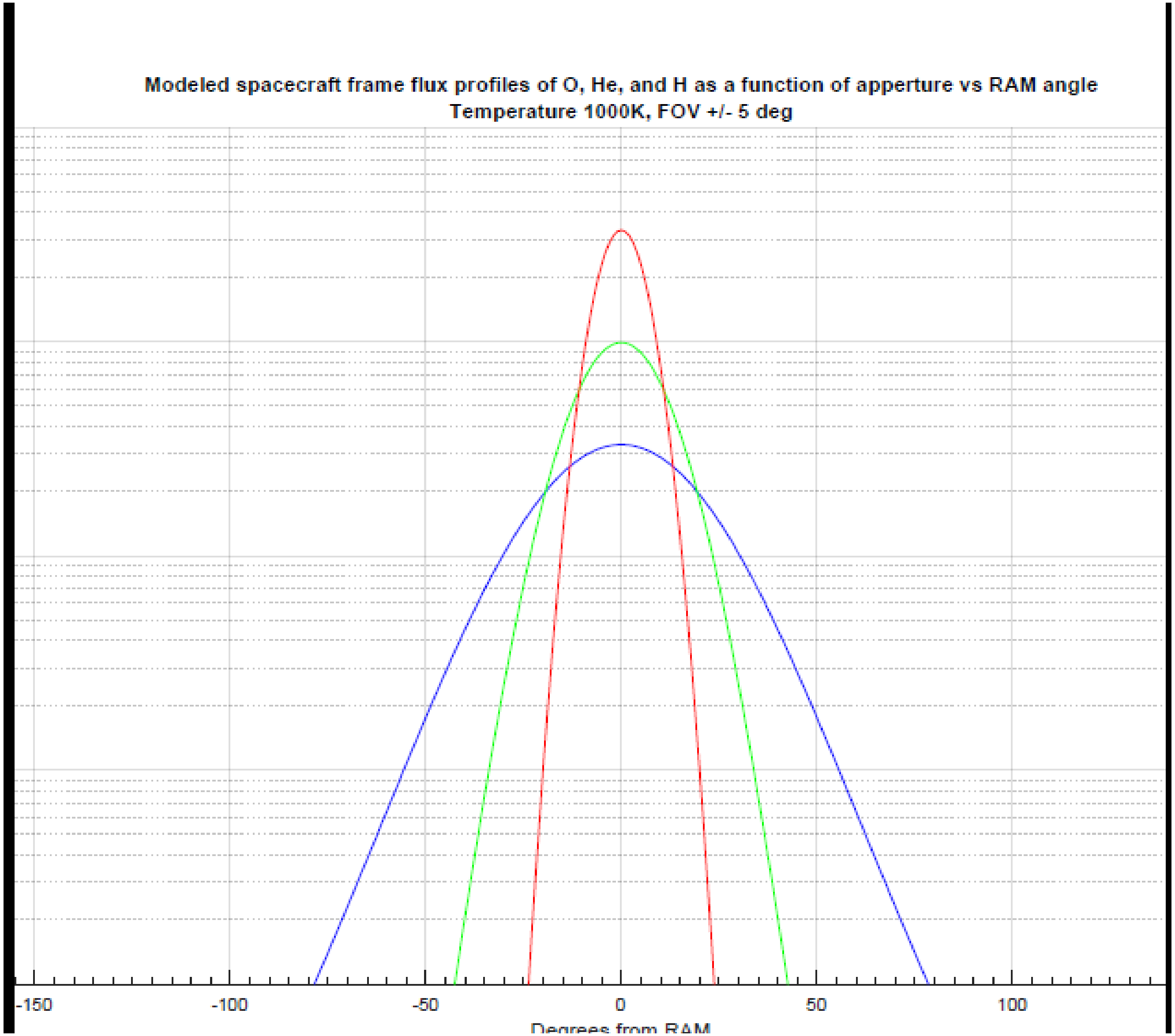


The measurements are consistent with the modeled flux profile of spinning spacecraft



Tech Demo Conclusion

- The INMs was demonstrated in flight with the Exocube 1 and Dellingr missions

- Exocube 1 antenna did not deploy – very poor communications – spacecraft tumbling
  - Non optimized instrument settings
  - Got sample ion specta
  - Activated neutrals and got sample neutral spectra

- Dellingr SC attitude control failed - spacecraft tumbling
  - Initial high spin spacecraft spin led to premature neutral activation in February 2018 and subsequent ionizer failure
  - Spacecarft spin recover to slow spin in May 2018

  - Sapcecraft and INMS work well until present

  - INMs optimization for ion measurements on both apertures
  - Science data is collected while still instrument is tech demoed in various modes.
  - Good ion data consistent with modeling

  - Lessons learned - Improved versions of he INMS on Exocube 2 and PetitSat