Overview of Advanced NASA/GSFC Instruments for Heliophysics Science including TOF x E x Delay Line Particle Technologies

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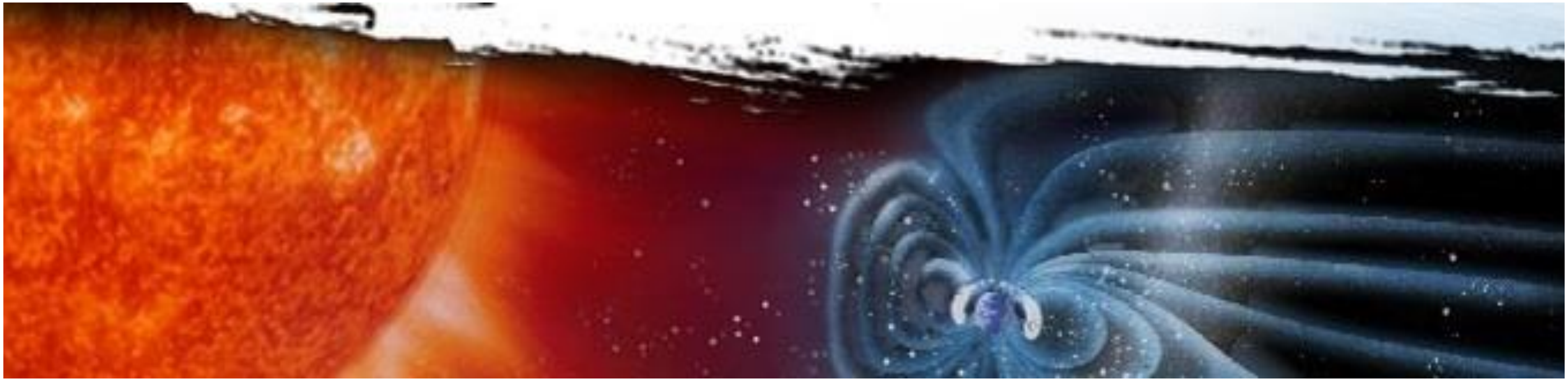
Goddard Space Flight Center

NASA HQ SMD talk Tuesday, February 28, 2017

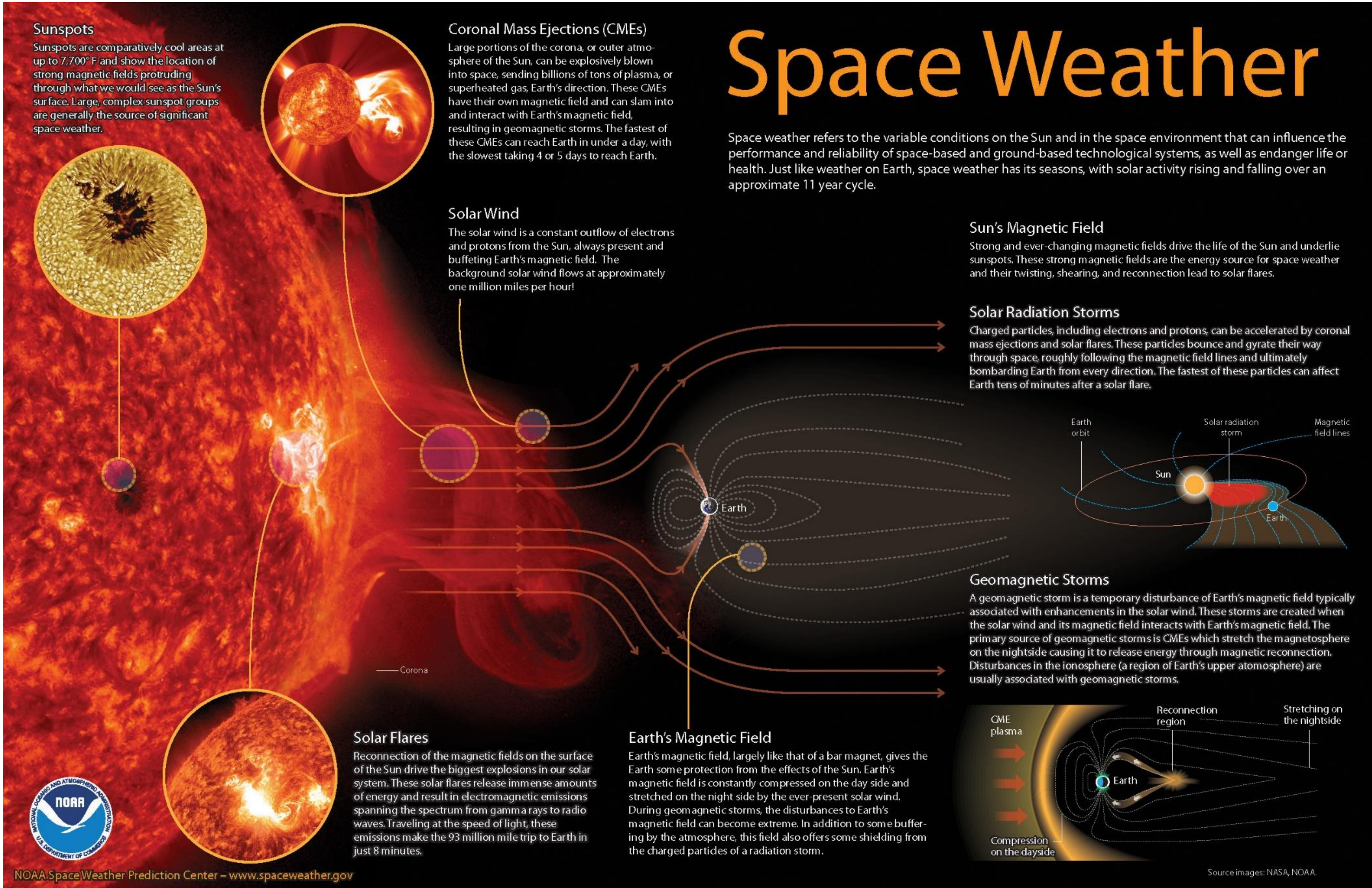
HSD

Advanced NASA/GSFC Instruments for Heliophysics Science including TOF x E x Delay Line Particle Technologies

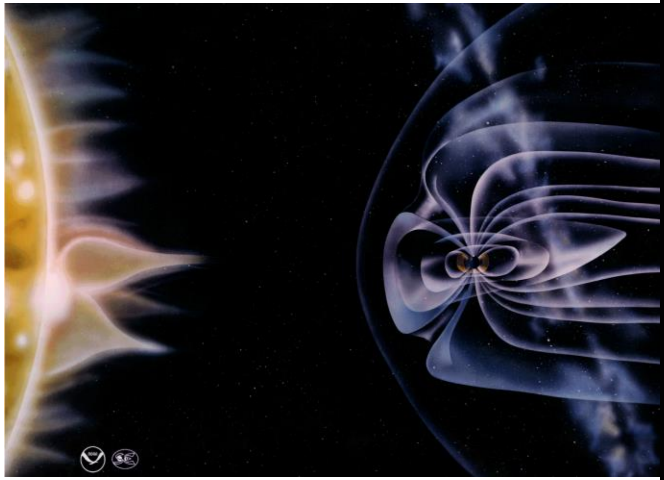


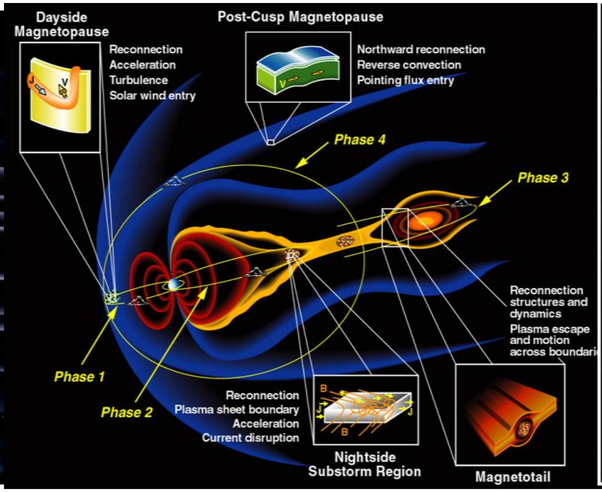
ABSTRACT: From the complex interactions on the sun's surface and within its corona out to the boundaries of the heliosphere, we are witnessing the development of ground breaking scientific discovery and technological innovation across all disciplines in Heliophysics science and research. Dr. Paschalidis will present information on time of flight (TOF) x Energy x angle particle analyzers, a family of rad hard application specific integrated circuits (ASICs, TOF, Energy, TRIO, CFD, PKD) and delay line imagers. The ASICs and delay imagers were created by Dr. Paschalidis himself and have been flown on missions across science mission directorate including IMAGE, CASSINI, MESSENGER, STEREO, IBEX, PLUTO, RBSP, MMS, JUNO, and will be flown on Bebi Colombo, Solar Orbiter, Solar Probe Plus, JUICE and also Cubesat missions CeREs and Cusp+. New innovations on neutral/charges particles will be discussed including a compact Ion and Neutral Mass Spec with temperature / drift/ wind capability for recent Cube/Small Satellite missions including NSF's ExoCube1 and ExoCube2, and GSFC Dellingr and PetitSat. The presentation will expand on a diverse portfolio of particles, fields and photon imaging instruments, including platform requirements for constellation and precision formation flying.

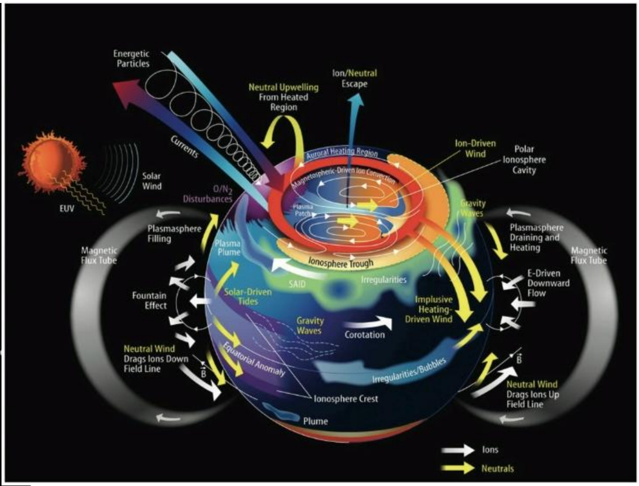
The Heliophysics Environment



Heliophysics Decadal Survey Themes

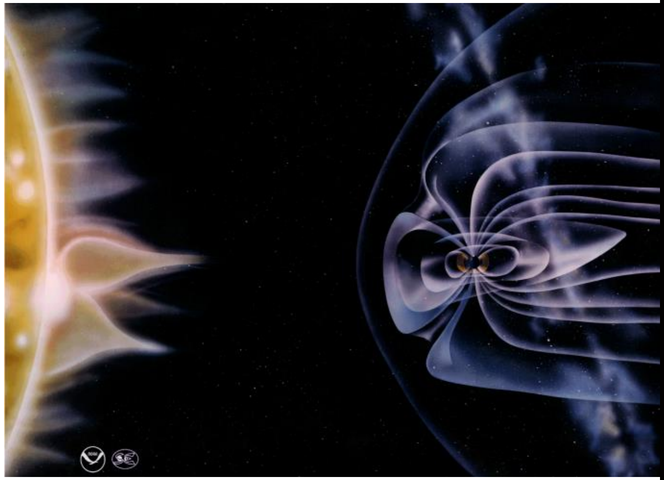


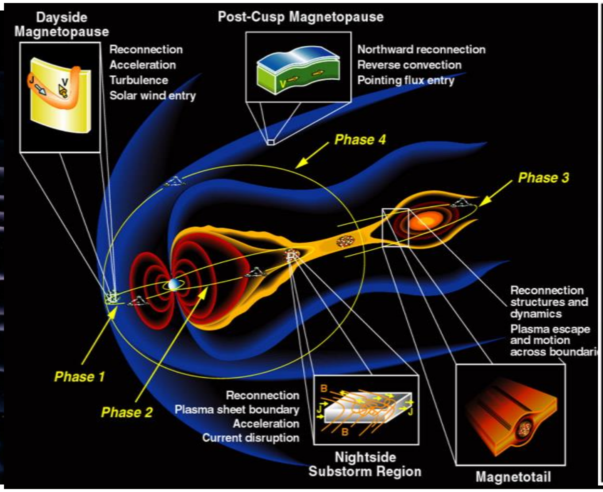


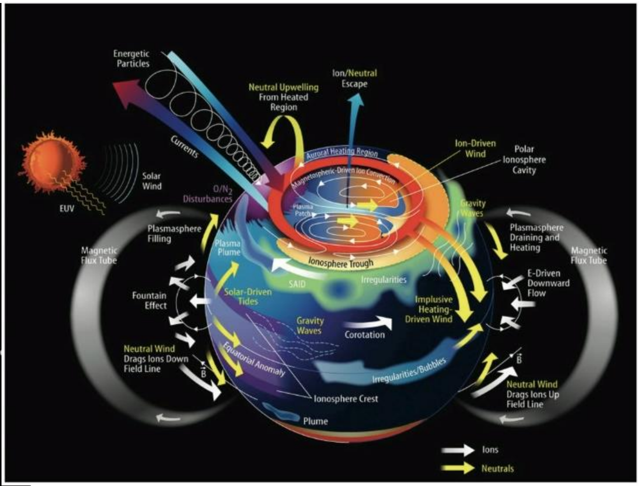


- Determine the origins of the Sun’s activity and predict the variations in the space environment.
- Determine the dynamics and coupling of Earth’s magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs.
- Determine the interaction of the Sun with the solar system and the interstellar medium.
- Discover and characterize fundamental processes that occur both within the heliosphere and throughout the universe.
- Enable and improve situational awareness and forecasting tools for the nation's Space Weather Needs

Solar Terrestrial Connection





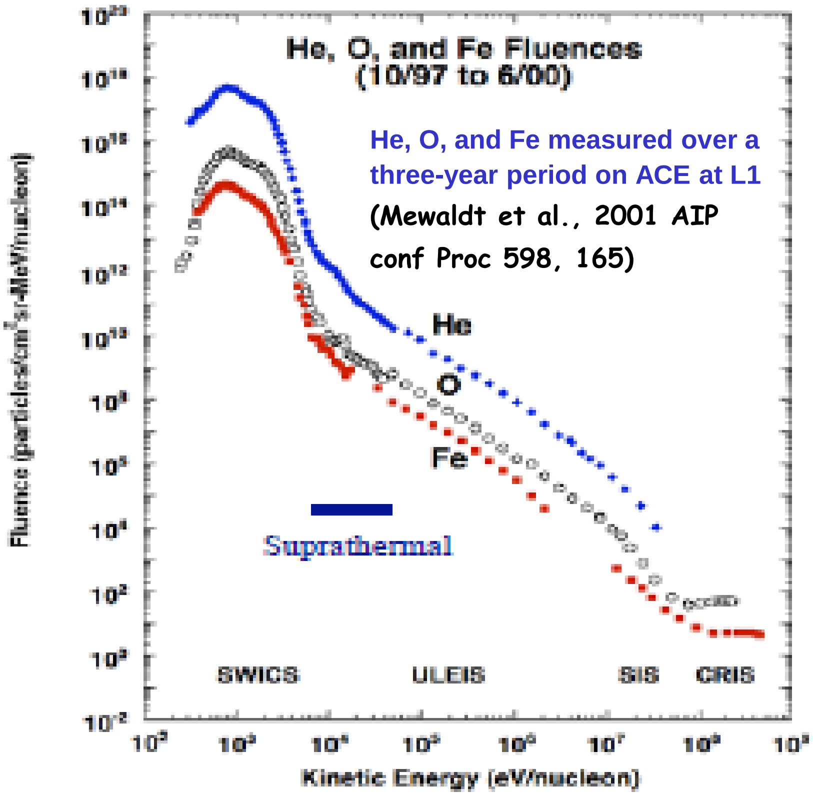


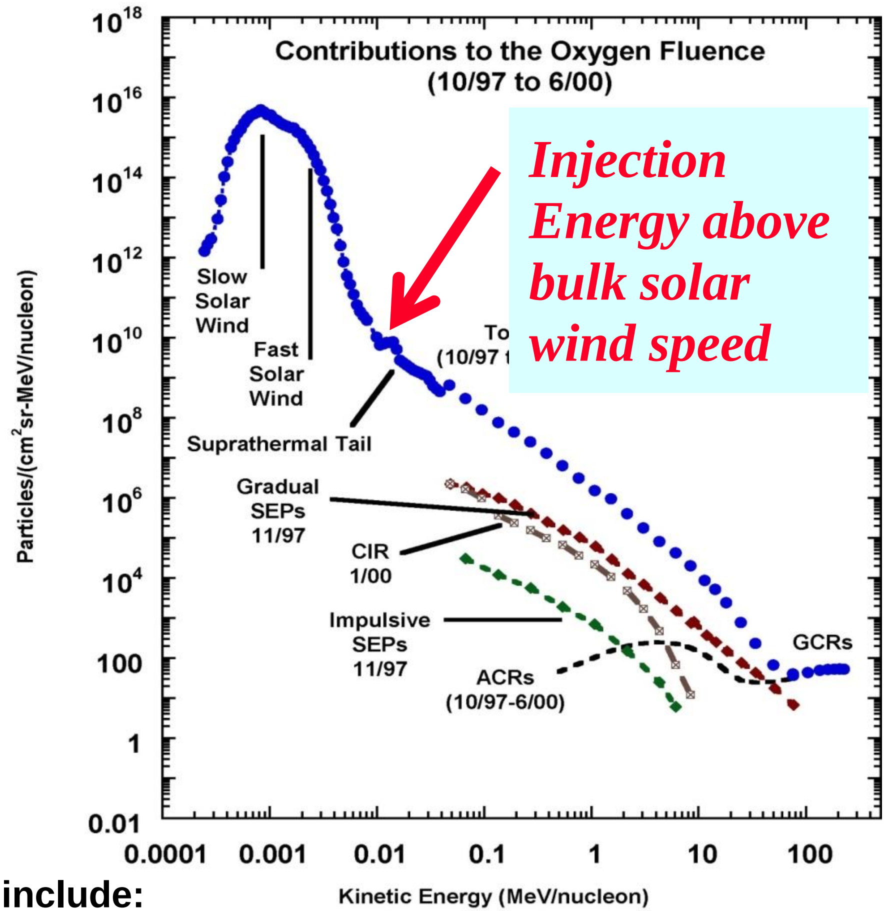
- The SW flows radially outward from the rotating sun at slow and fast streams originating at the solar corona.

- The SW slows down and heats up on encountering Earth's magnetosphere driving several current systems, waves and acceleration phenomena. Ultimately some of the SW energy is deposited in the ionosphere, causing currents, heating, bulk flows etc

- Similar processes apply to the rest of the planets depending on the existence of own magnetic fields and neutral atmospheres

Fluence and Energy Dynamic Range of Particle Distributions in the Solar Wind





Particle distributions in the solar wind generaly include:

- **A thermal core which can be characterized by a drifted maxwellian with temperature 1-2x10^5 K, bulk velocity 450km/sec, density ~5-10/cm^3 (94% H, 5% He, 1% minors) B= 5-10nT; plasma flow speeds in CMEs can reach 2000 km/sec**
- **A high energy tail produced by acceleration processes (free energy of the distribution) at > 10KeV to >100MeV with differential intensity dynamic range >10e12**

Typical space environment conditions in the earth's day side magnetosheath, magnetosphere and ionosphere

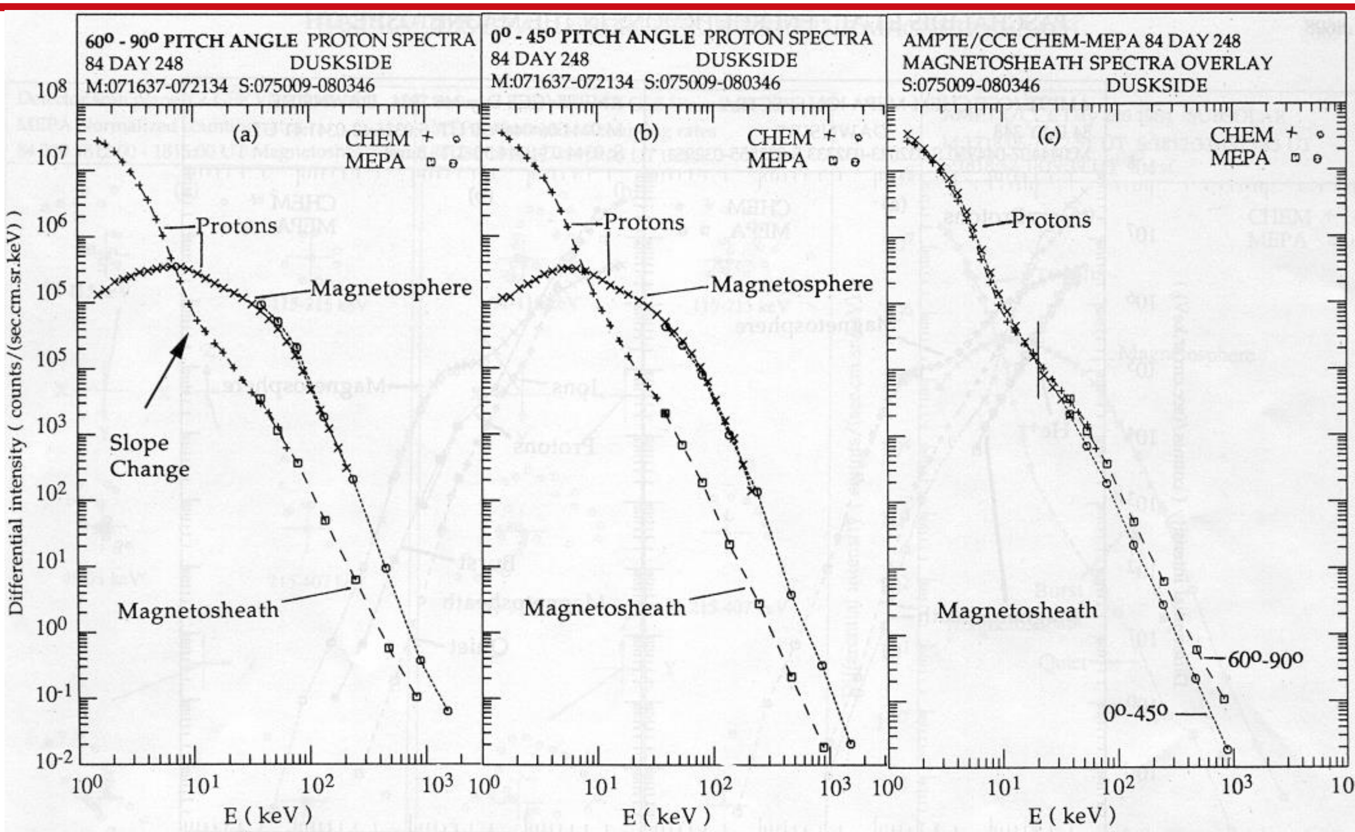


Figure 11. Pitch angle averaged spectra on the duskside magnetosheath (Figure 2 bottom); (a) 60° to 90° pitch angles, (b) 0° to 45°, and (c) overlay of the two spectra. Note that the large pitch angle spectrum is harder than the other.

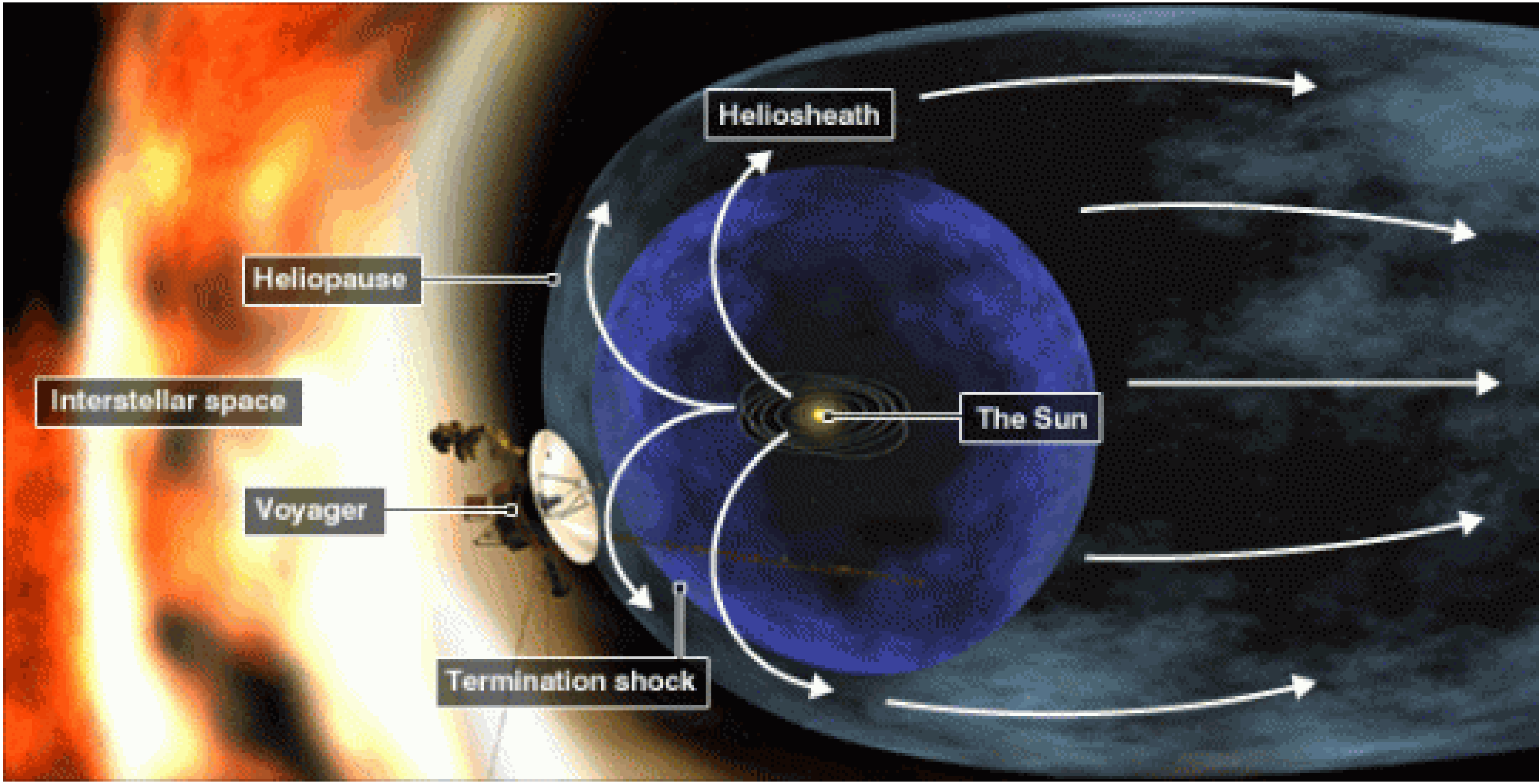
Differential intensities of protons (dominant ion) in earth's day side magnetosheath and magnetosphere

Paschalidis, N. P. et. al., *JGR - Space Physics*, vol. 99, pp. 8687-8703, May 1, 1994

- **The solar wind in the earth's magnetosheath is shocked, slowed down and thermalized: typical bulk flow velocity ~200km/sec, temperature 10^6K, density 10-30/cm^3, B ~10nT**
- **Just inside in the dayside magnetosphere plasma conditions are dominated by maghetospheric processes: typical temperatures 10^8K, density ~1/cm^3, B 100-200nT**
- **Typical ionospheric LEO conditions at 450-700km: Ion density 1e3 to 1e8 /cm^3 , neutral density 1e4-1e9/cm^3 O+, O dominated, temperature ~1000K, horizontal ion drifts up to 2000m/sec, horizontal neutral winds up to 500m/sec, B~ 10^4nT**

The Bigger Picture

The Heliosphereric bubble formed by interaction with the local interstellar medium (ISM)



- Typical ISM primary bulk flow speed ~26km/sec, Temp ~8000K, density 0.01 /cm^3
- Expected secondary component emission from the heliopause ~100 time weaker than the primary for corresponding species

Particle Instrument design methodology - generally applies to all instruments -

Identify science objectives and measurement requirements

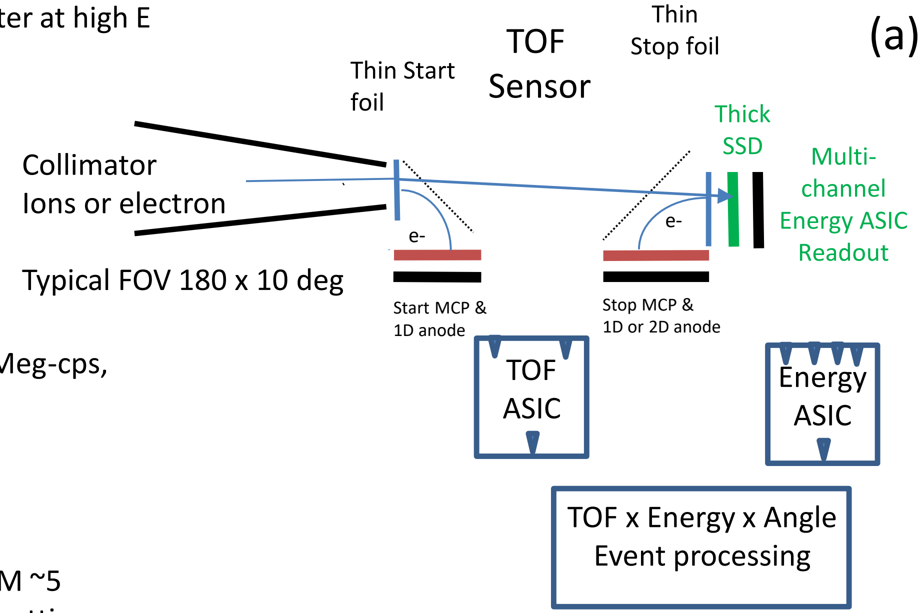
- Estimate weakest expected signal, use previous data or model calculations. Take into account signal dynamic range and estimate ambient noise sources
- Estimate sensor and detector efficiency, and detector noise
- Define sampling time Ts from science requirements
- From weakest signal, sensor/detector efficiency and sampling time estimate instrument sensitivity, aperture size and FOV (geometric factor).
  - Signal (cps)_in = J (1/cm^2 sr KeV sec) * DE * A * Ω , DE energy window, A aperture, Ω solid angle
  - Select minimum sampling (integration) time for Signal (cps) * Ts ~= 10 statistically significant counts per pixel
- Identify general instrument category based on basic parameters such as energy range (wavelength for photons, magnitude for E and B fields), sampling time, composition, etc
- Calculate instrument noise sources including detector/electronic noise, UV foreground, high energy penetrators, etc
- Use best trade of S/N, instrument size, mass, power, and sampling rate
- Address the signal intensity dynamic range to avoid saturation
  - Typical maximum detector counting capability ~1e6 cps. For high rates consider techniques of variable GF and parallel processing with multi detectors and fast electronics

Categories of TOF x E x Angle Particle Spectrometers

Medium energy range and Low energy range

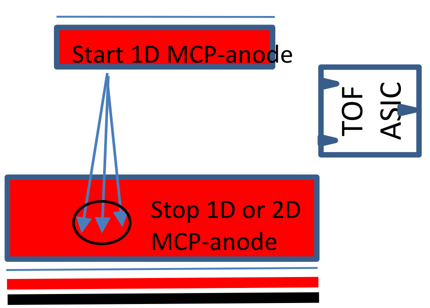
(a) Medium Energy ~20KeV to 20MeV

Typical FOV 2pi x 10 deg, DE/E typical 30-50% at low energies, much better at high E
TOF with foil – foil - MCP-anode, Energy with Solid State Detectors
Angle with collimation & position sensing
M/DM ~5 separates H, He, CNO, Sulfur
Primary noise source: straight UV, foreground/background particles
Noise rejection: multiple time/ position coincidence
Low energy limitations: energy straggling and scattering at foil, dead layer of SSDs and electronic noise.
High energy rage range limitations: detector thickness, small TOFs
Dynamic range limitations: max detector counting capability average <1Meg-cps, Electronics shaping, noise and power.

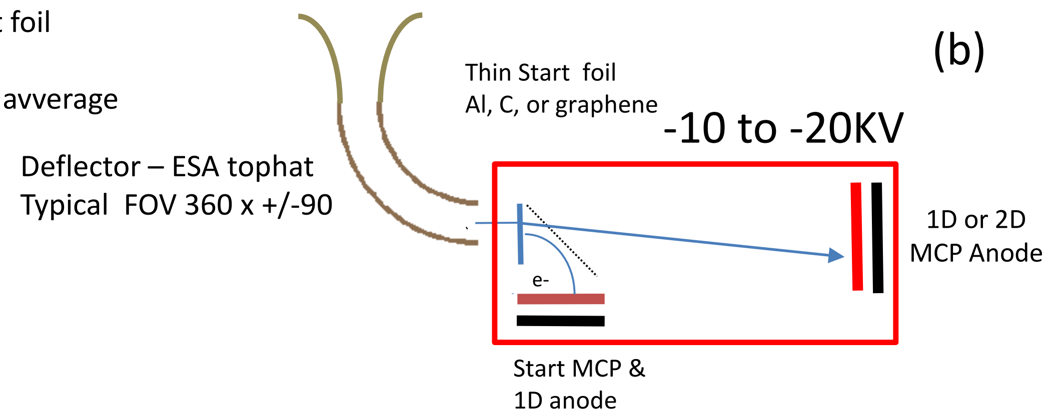


(b) Low Energies: few eV/q to ~50KeV /q, DE/E ~10-15% typical

E/Q analysis w ESA , 4pi FOV with deflectors
TOF: foil – foil - MCP and ~20KV post acceleration, mass resolution M/dM ~5
Azimuth angle: 1D start position circular sensing , elevation by deflector setting
Primary instr noise: attenuated UV / penetrators, Noise rejection: multiple time/ position coincidence
TOF correction by 1D/2D stop anode
Energy Thresholds: SC potential, energy straggling/scattering at foil
Low and Upper Energy: limited by max HV and fast scanning HV
Dynamic range limit: GF and ~1meg-cps detector counting limit avverage

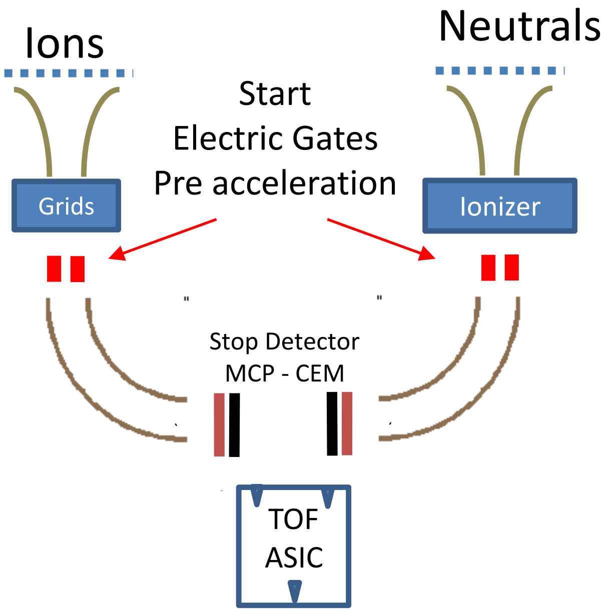


TOF / position Detector



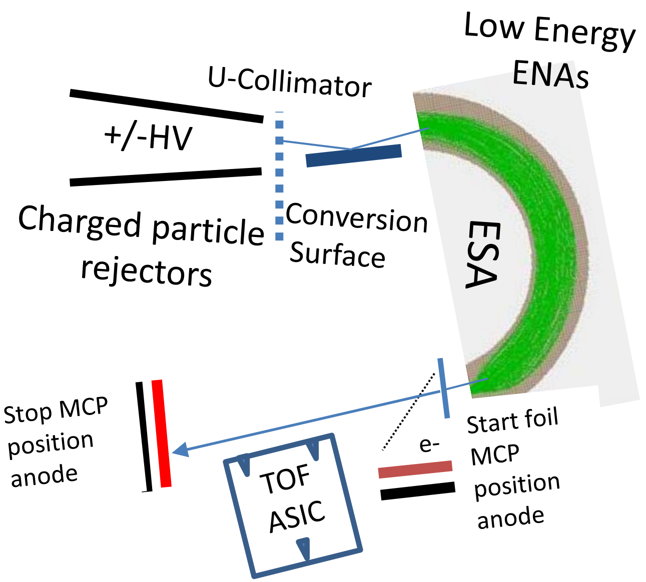
Gated TOF Ion and Neutral Mass Spectrometer

Fast electric gate replaces start foil to eliminate ~20kV HVPS, does not interfere with molecules
Pre acceleration ~200V for moderate mass resolution ~10-20 M/dM
Primary noise source: UV and scattering
Optional ESA for UV rejection and out of band particle noise rejection
Mass resolution limitations: size of gate and instrument, improved mass resolution w TOF path correction, Limitation: Fast HV electric gate
Thermionic ionizer for neutrals – emission current ~1mA
TOF binning for mass analysis according to tof~ sqrt(m)
Advantages: non-distractive, electronic sensitivity control



Large aperture Low Energy Energetic Neutral Atom Imager

Large aperture for high sensitivity
Charge particle rejector with HV plates abd grids
Composition H, He, CNO, Ne
Highly polished surface converts neutrals to ions at low energies, foil at higher energies
Micro collimator defines angular resolution in the range of 2-10 deg
Wide gap ESA for signal collection, energy analysis DE/E 20-30% and UV attenuation
Post acceleration ~20KV, Foil – foil MCP TOF system
Magnets for electron rejection
Triple time coincidence + position anode coincidence for high S/N >10^4
Fast TOF ASIC electronics

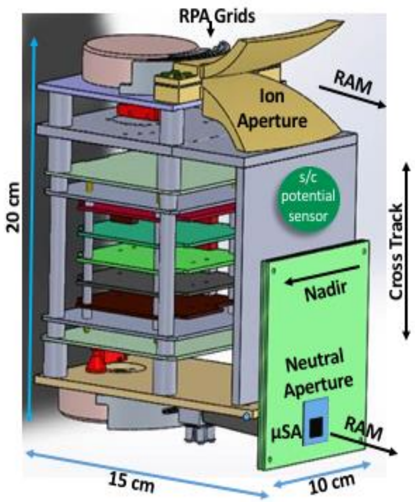


Very Low Energies 0.1eV to 20eV

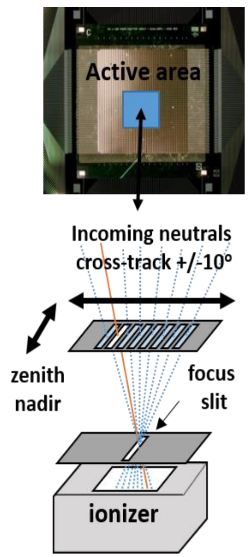
Ionospheres: Ion & Neutral Composition, Flow Velocities, and Temperatures

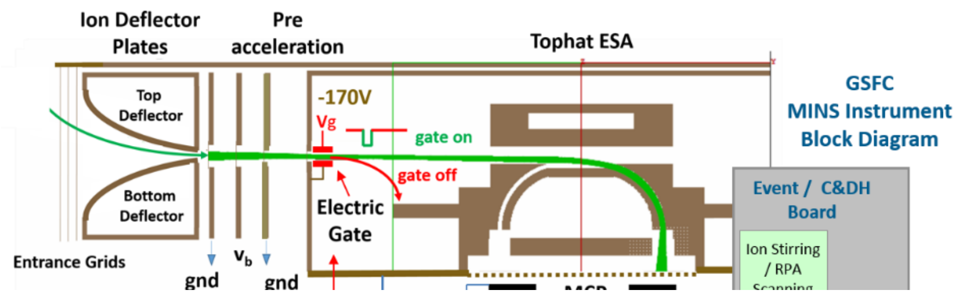
Ions: Density 10^3-10^8/cm^3, Temp 500 to 3000K, Ion drifts up to 2000m/sec

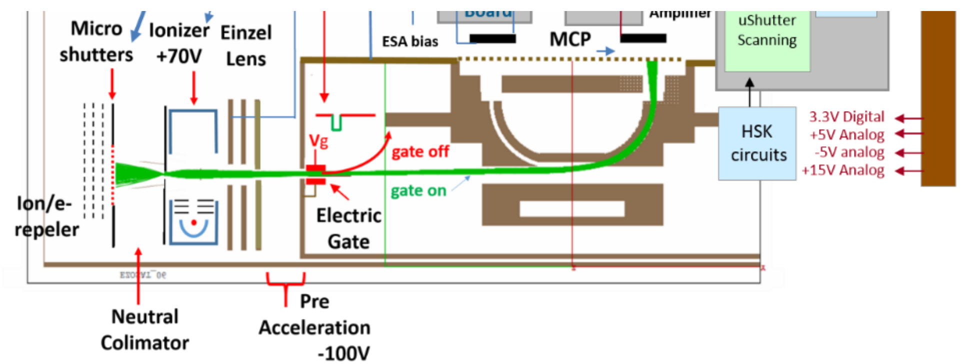
Neutrals: Density 10^4-10^9/cm^3, Temp 500 to 2000K, winds up to 1000m/sec



uShutter







Design for 3-axis stabilized platform at LEO
Neutral FOV in the range +/- 10 deg horizontal and vertical w micro–shutter array
Ion FOV +/- 25 horizontal and vertical
Electron impact ionization for the neutrals
Pre acceleration and TOF mass analysis
Delay line – TOF electronics for time of flight and position
Mass range 1-40amu, M/DM~12
Further miniaturization

POC: Sarah Jones / Nick Paschalidis

On Going Instrument Development

- Ultra compact Ion and neutral
- Mass spec
- Winds and drifts
- Temperatures

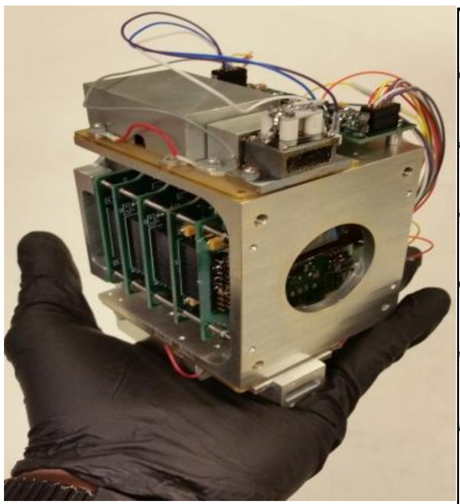
Very Low Energies 0.1eV to 20eV

Ionospheres: Ion & Neutral Composition Mass Spec

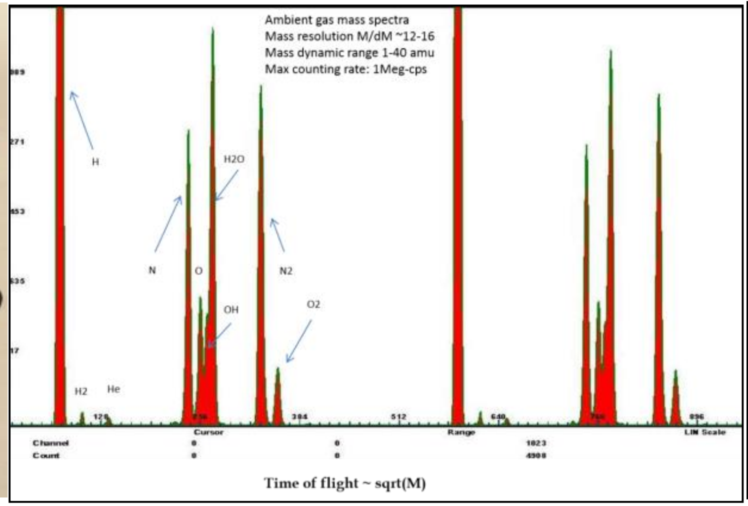
Ions: Density 10^3-10^8/cm^3, Neutrals: Density 10^4-10^9/cm^3

The mini-INMS includes on front optics, gated time of flight, ESA, CEM/MCP detectors, TOF electronics, FPGA event processing and binning and HV for optics and detectors. The mass spectra are measured in time of flight ~ sqrt(Mass).

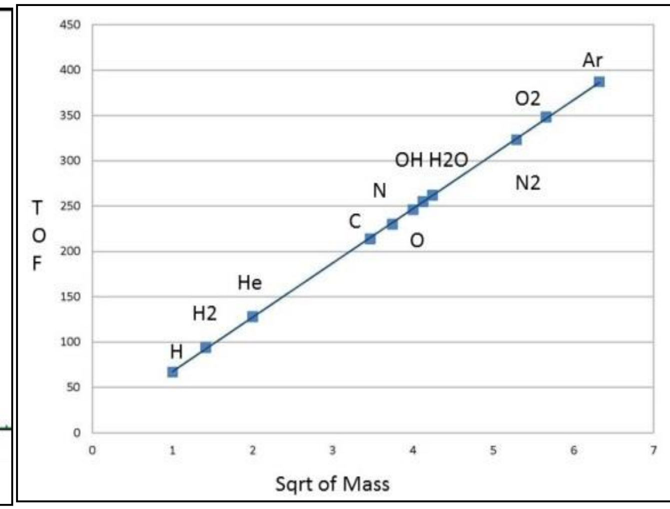
Dellingr FM unit



Lab spectra of neutral gas



TOF ~ sqrt(M)



Science Specs

Ram facing FOV

10º x 10º

Mass resolution M/dM ~10-12

Mass range 1-40 amu

Densities Ions 1e3 to 1e8 /cm3, neutrals 1e4 to1e8 /cm3

Sampling time 0.1-10s

Engineering Specs

1.3U volume, 9 x 10 x 13 cm

Mass 560 g

Power 1.8W

Nominal data rate 13.7kbps

Data interface LVDS and SPI serial

Power Supplies +3.3V, +/-5V, +12VOption for internal LVPS card with single +12V from Spacecraft

Funded Flight Missions

- Exocube 3U CubeSat launched in Jan 2015 got flight data and validated the instrument
- Dellingr 6U to be launched in Aug 2017
- Exo2 to be Launched Jan 2018
- PETIT Sat to be launched in 2020-

NSF Exocube CubeSat

Exocube 1 Launched Jan. 2015

Exocube 2 scheduled for launch in Jan. 2018

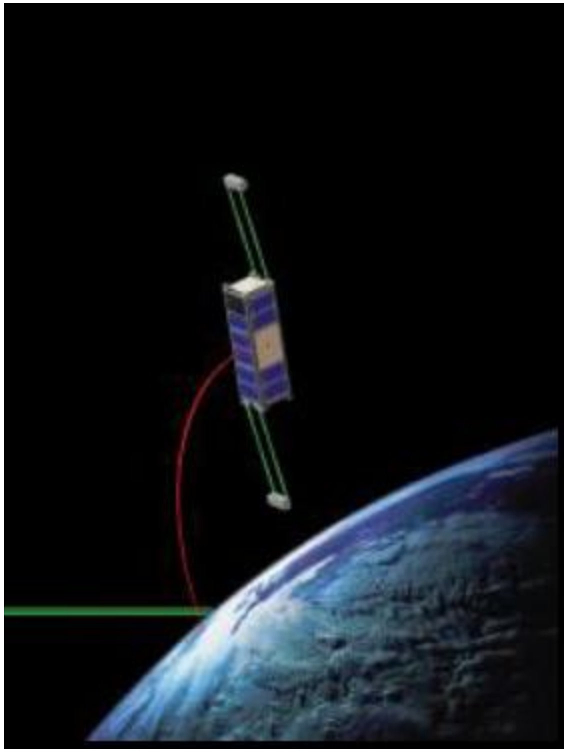
Exocube's high-resolution, *in-situ* measurements of [O], [H], [He], $[O^+]$, $[H^+]$, $[He^+]$, & total ion density, will serve as benchmarks for upper atmospheric composition and abundances and thus enable investigations regarding:

First in-situ [H]

No in-situ [O], [He], since 1983

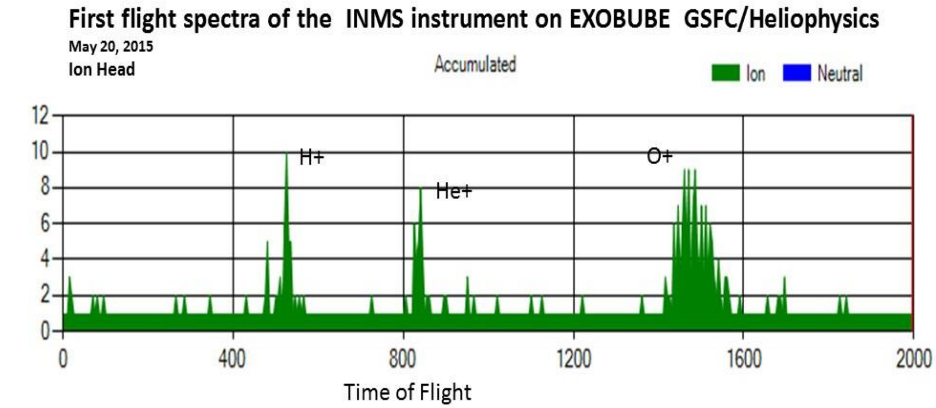
- **Global structure and climatology**
- **Model validation**
- **Constraints to forward-modeling of airglow emissions**
- **Exospheric behavior**
- **Quantification of charge exchange processes**
- **Characterization of storm-time behavior and response**

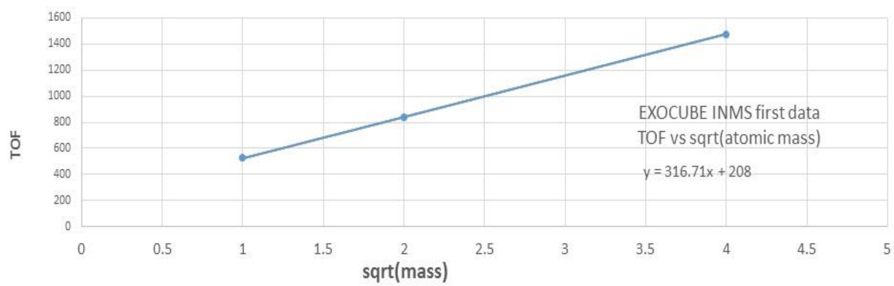
- **GSFC INMS instrument**

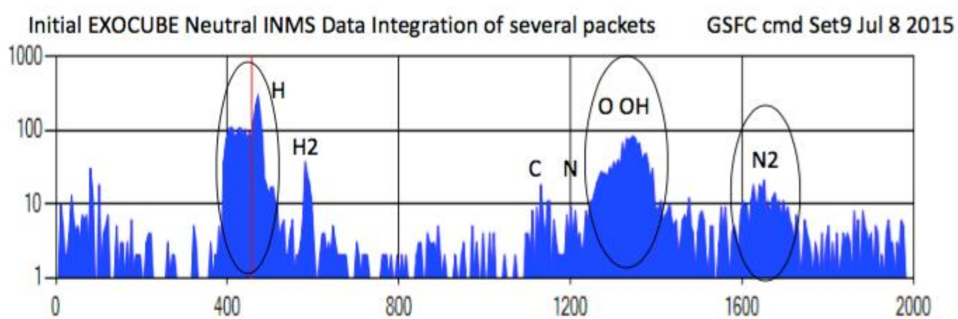


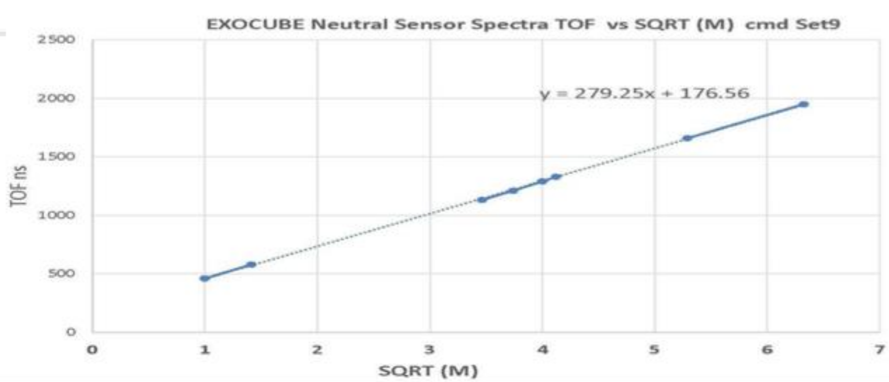
EXOCUBE 1 MISSION Flight Data

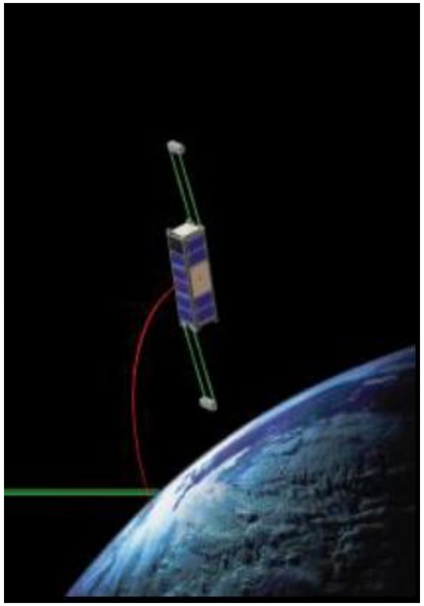
Mission PI	John Noto SSC
CubeSat Bus	California Polytechnic
	3U gravity stabilized
Compact INMS	GSFC / HSD
Launch Date	Jan 2015
Primary mission	NASA/SMAP
Orbit	450km x 680km, 98º inclination, sun-synchronous
INMS	Occupies the central 1.3U

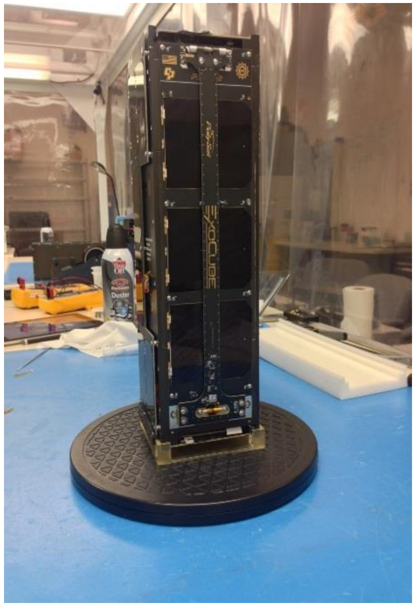




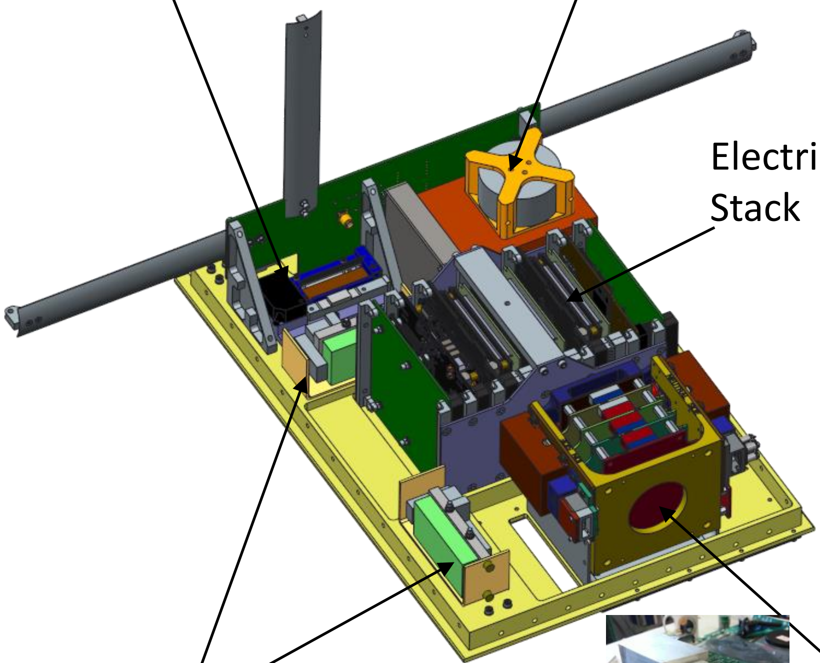


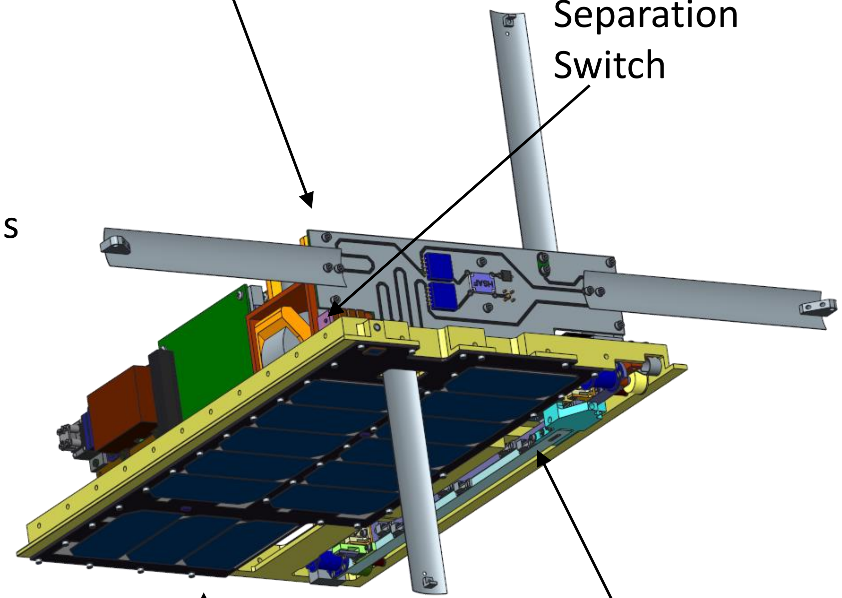


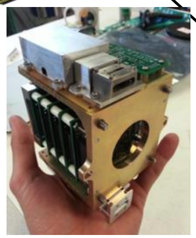




The GSFC Dellingr 6U satellite
Payload: INMS and Magnetometers – Launch date Aug 2017






Ion and Neutral Mass (INMS) Spectrometer- nickP, SJones, MRodriguez, et al., NASA/GSFC

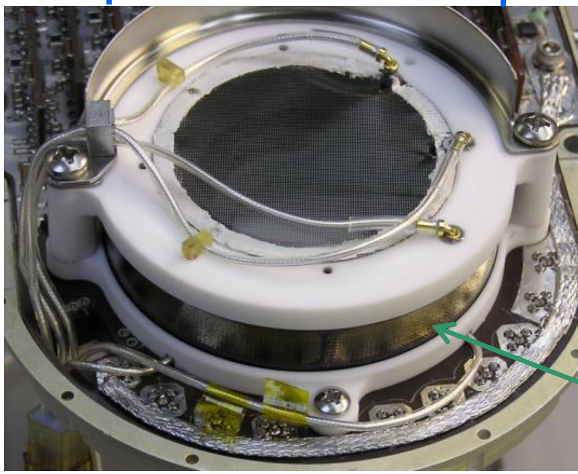
The JHU/APL Energetic Particle Analyzer

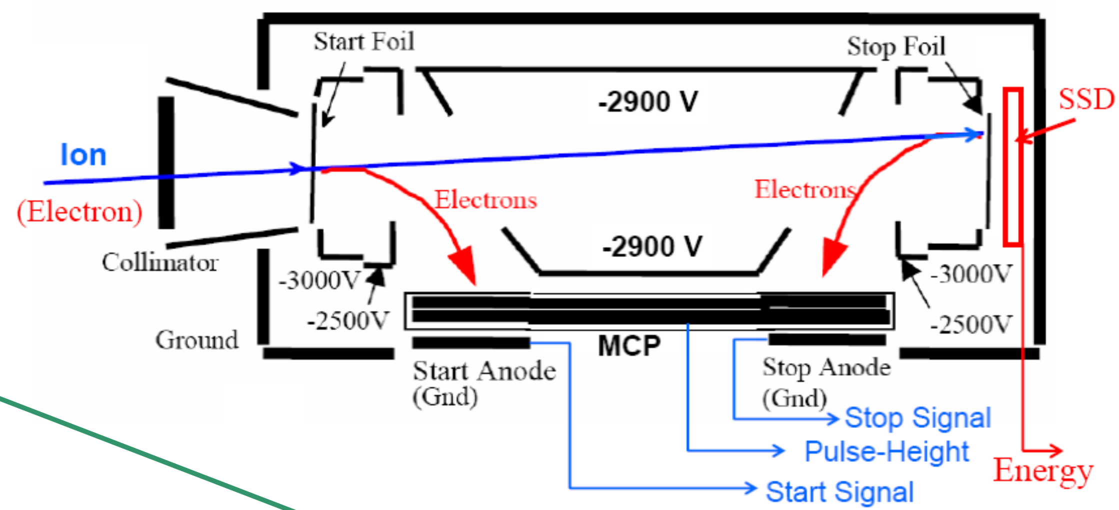
TOF x E x Angle (foil-foil-SSD- 1D delay lines) Ions >30KeV to ~5MeV, Electrons ~30KeV to 500KeV

JUNO/JEDI, VanAllen / RBSpice, NH/PEPSSI Mauk et al., Mitchell et al., McNutt et al.,

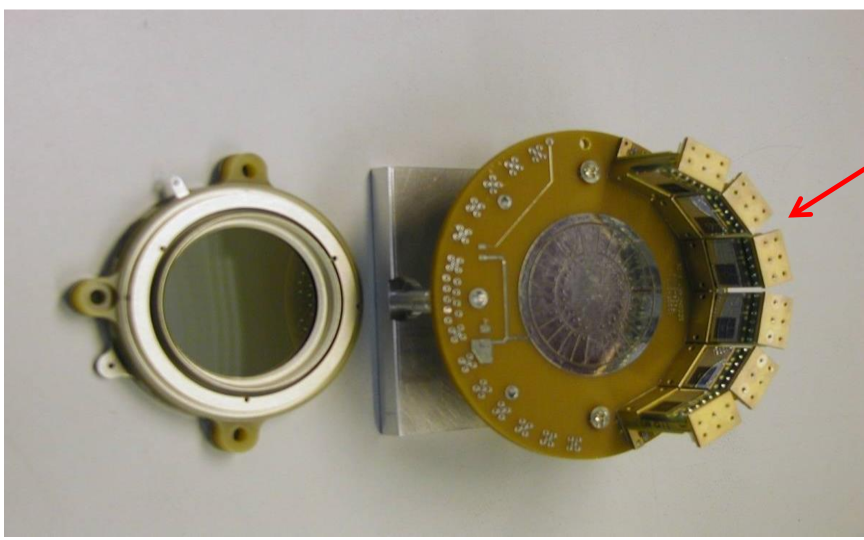
TOFxE ASICs and Delay Lines by nick paschalidis et al

~6 cm

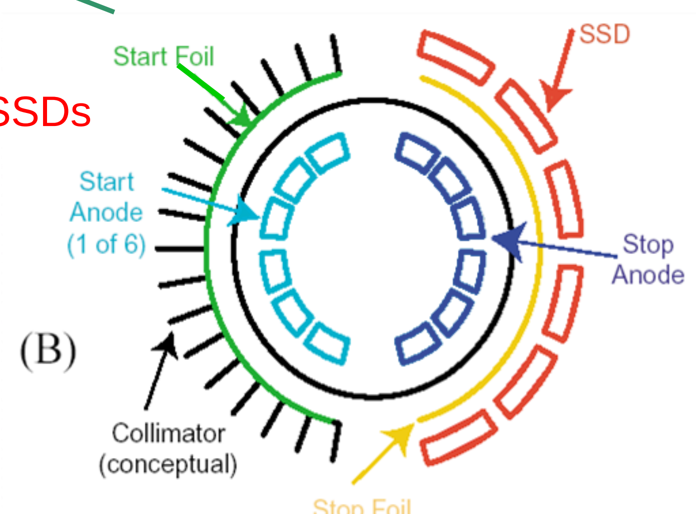




New Horizons PEPSSI, JUNO/JEDI
Van Allen/RBSPICE, MMS/EPD



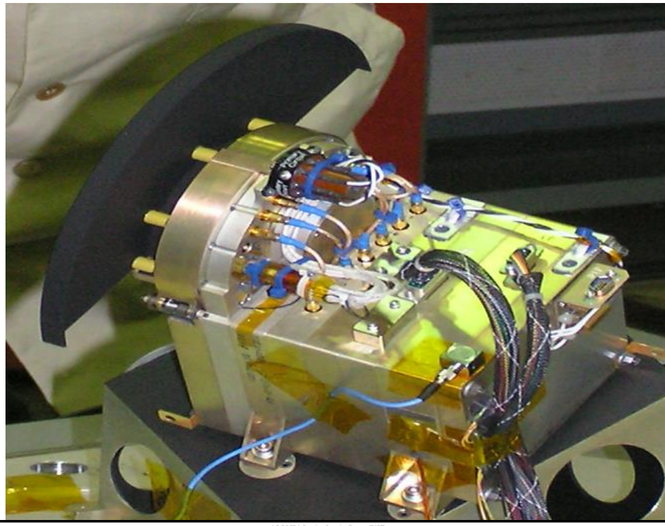
SSDs

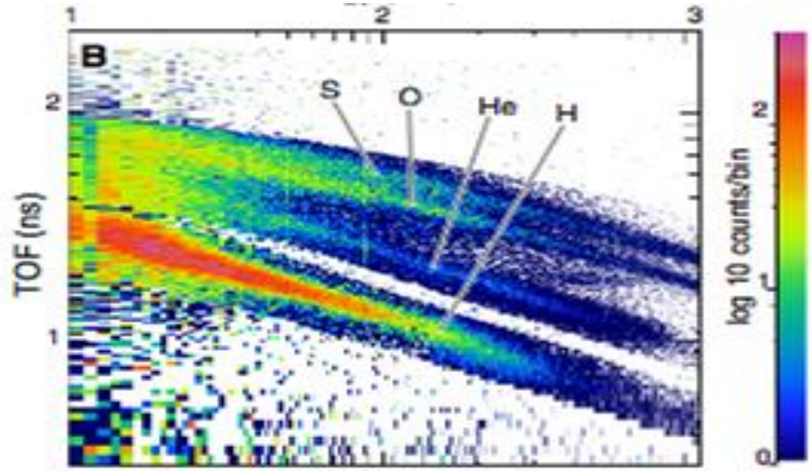


JHU/APL EPD: JUNO/JEDI, VanAllen / RBSpice, NH/PEPSSI

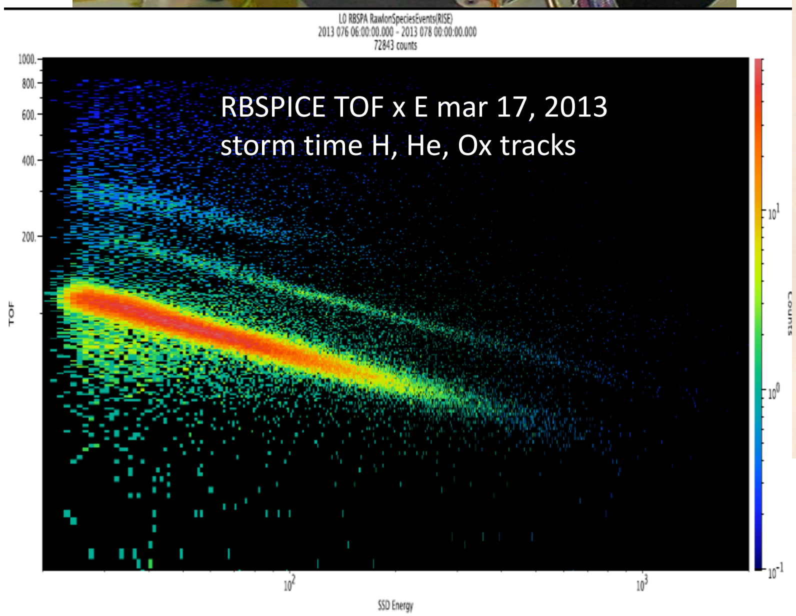
Mauk et al., Mitchell et al., McNutt et al.

TOF x E spectra – Note first time Na/mg measurement enabled by the time over threshold of the Energy ASIC

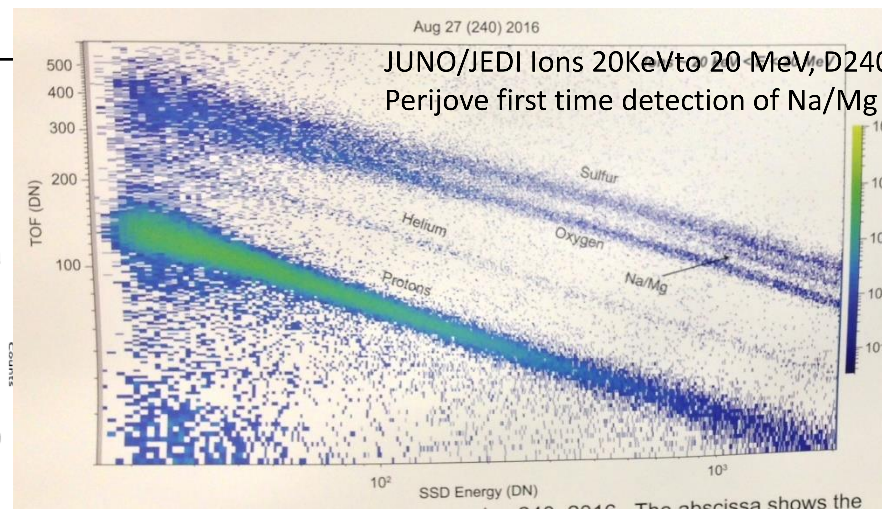




PLUTO / NH encounter w Jupiter PEPSSI E 20KeV to 1 MeV



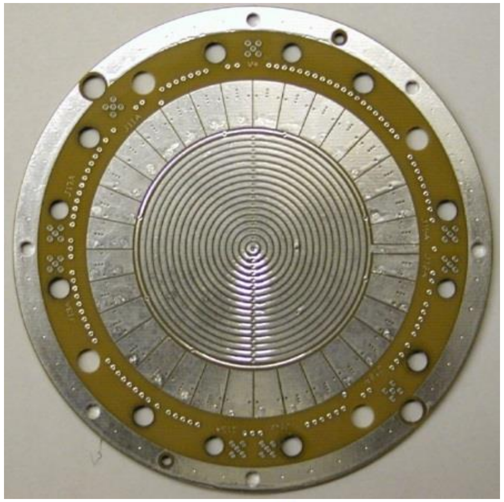
RBSPICE TOF x E mar 17, 2013 storm time H, He, Ox tracks



JUNO/JEDI Ions 20KeVto 20 MeV, D240, 2016
Perijove first time detection of Na/Mg tracks

Haggerty, et al. AGU 2016 P33C-2159
Note clear Na/Mg track between Sulfur and Ox.
The extended energy range and the fine mass separation was enabled by the expended energy of the SSD/ASIC and the <100ps time resolution of the TOF chip

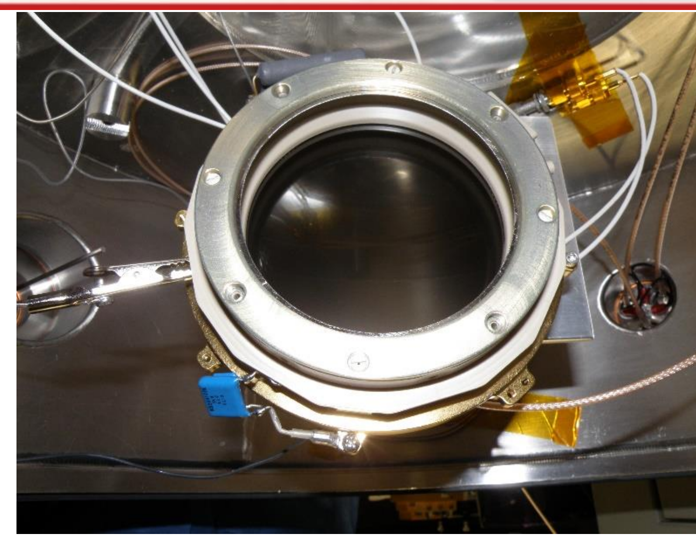
MMS Hot Plasma Composition Analyzer SWRI - D. Young et al., Fusselier et al.
Anode delay line board, TOF ASICs fpga board Paschalidis et al.

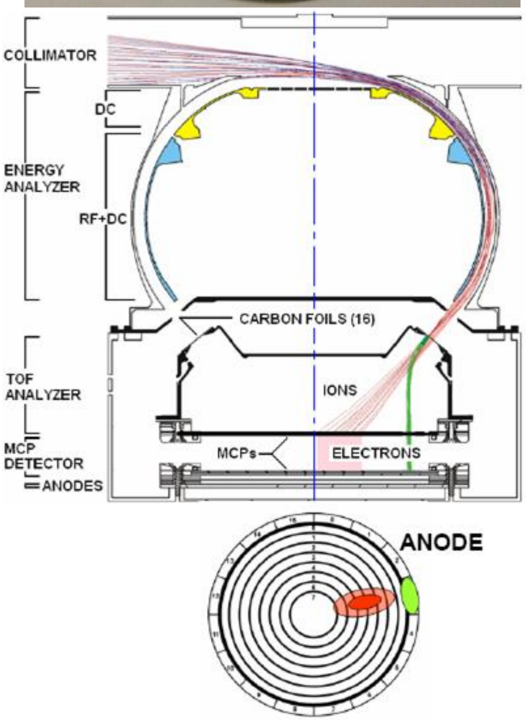


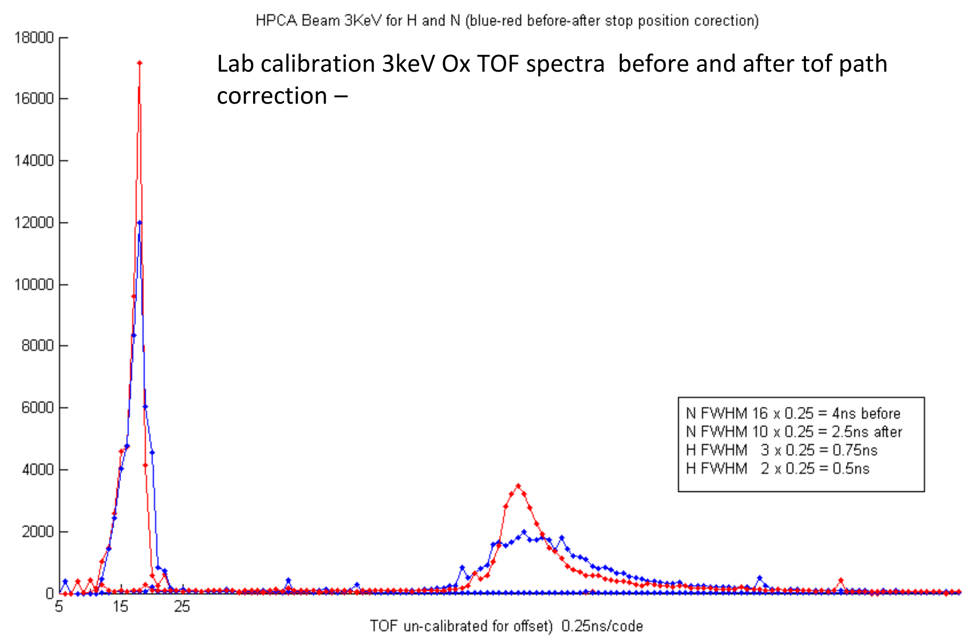
MCP assembly by SWRI

The 1D delay line / TOF measures the azimuth 360 FOV in 32 sectors of 11.25 deg

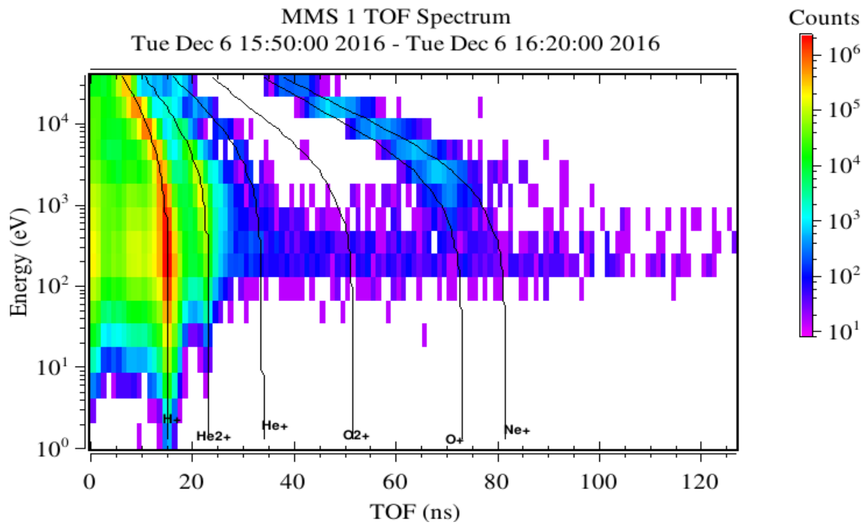
The concentric ring anode compensates for time of flight path variation due to foil scattering

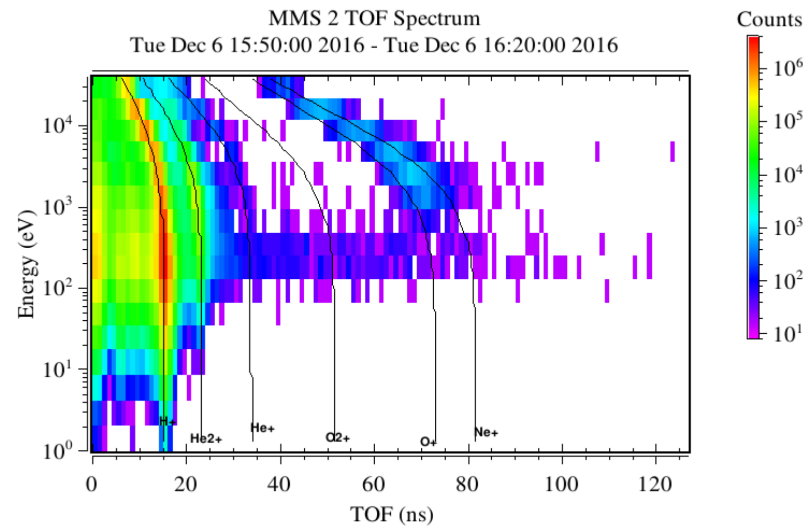




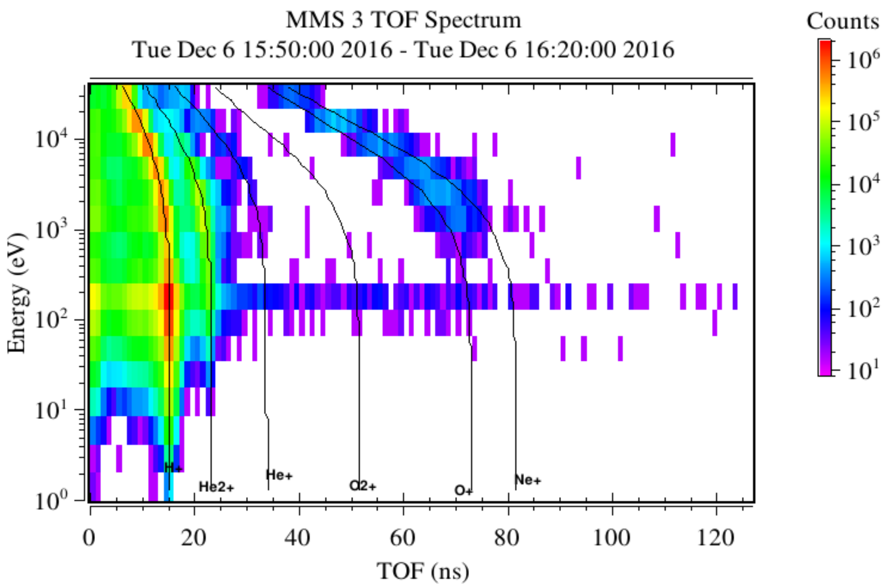


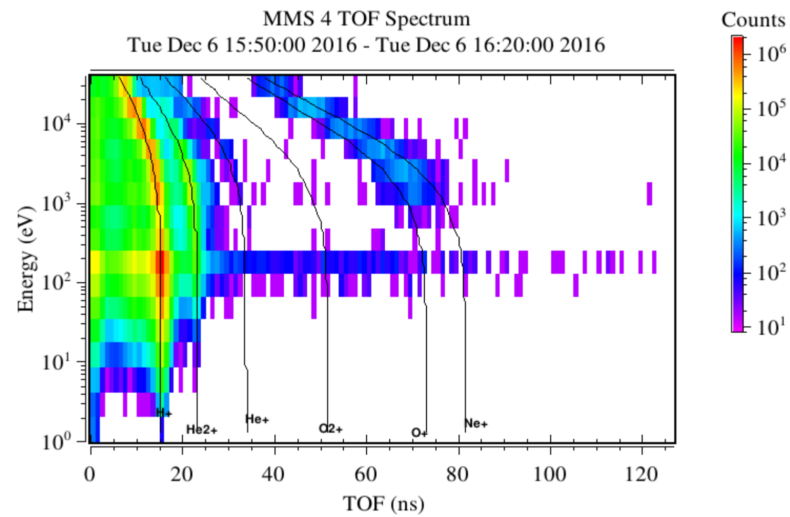
MMS Hot Plasma Composition Analyzer
Flight E x TOF data from the four MMS HPCA instruments
Curtesy SWRI





lot created by SDDAS/gPlot - J. Mukherjee, et al. Generated on Thu Feb 23 15:59:16 2017.



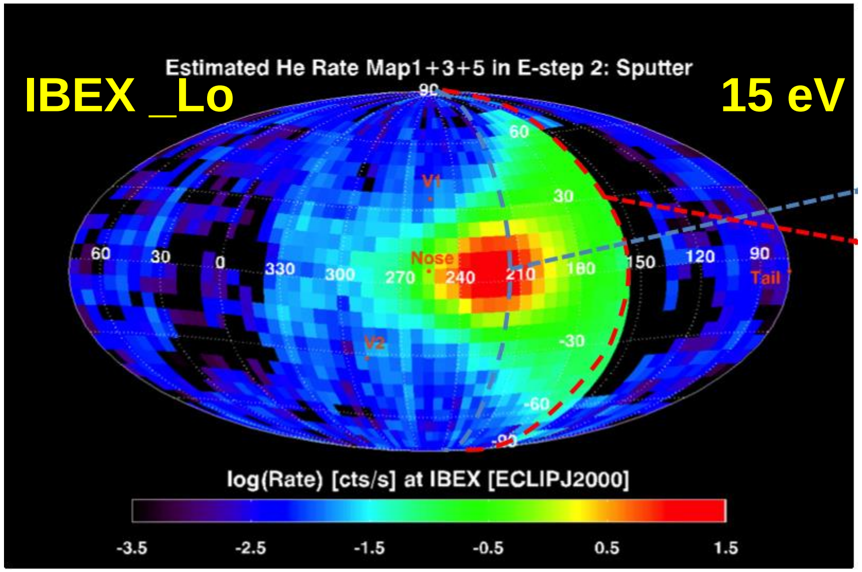


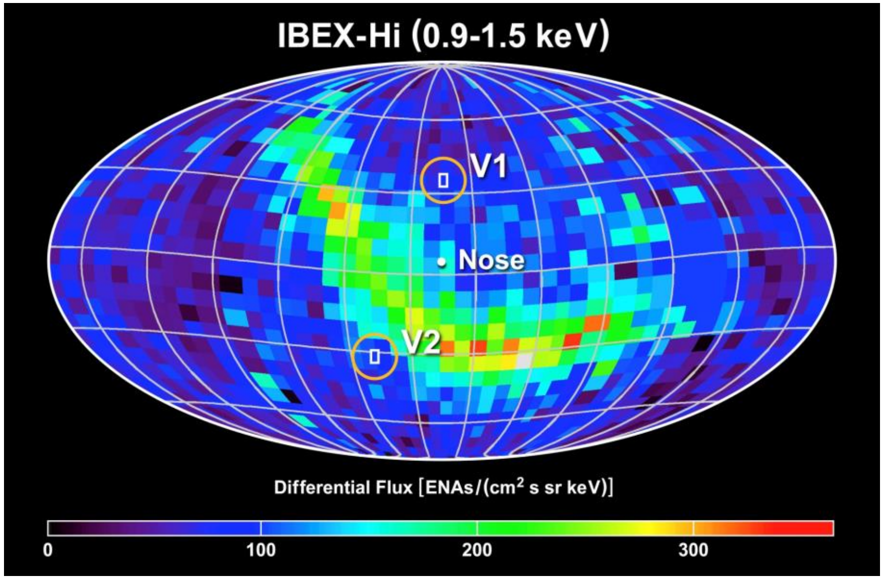
Plot created by SDDAS/gPlot - J. Mukherjee, et al. Generated on Thu Feb 23 16:09:14 2017.

Plot created by SDDAS/gPlot - J. Mukherjee, et al. Generated on Thu Feb 23 16:15:09 2017.

• IBEX Lo Measurements the bulk ISN flow, composition and temperature, and

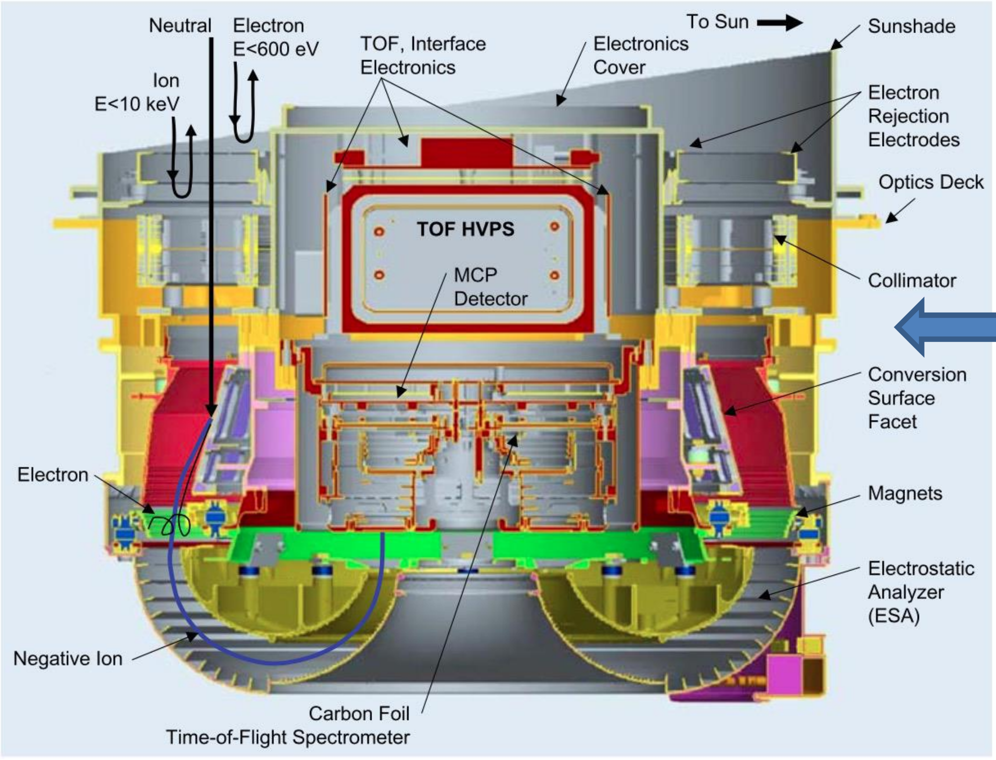
•IBEX_Hi measurements of the ribbon

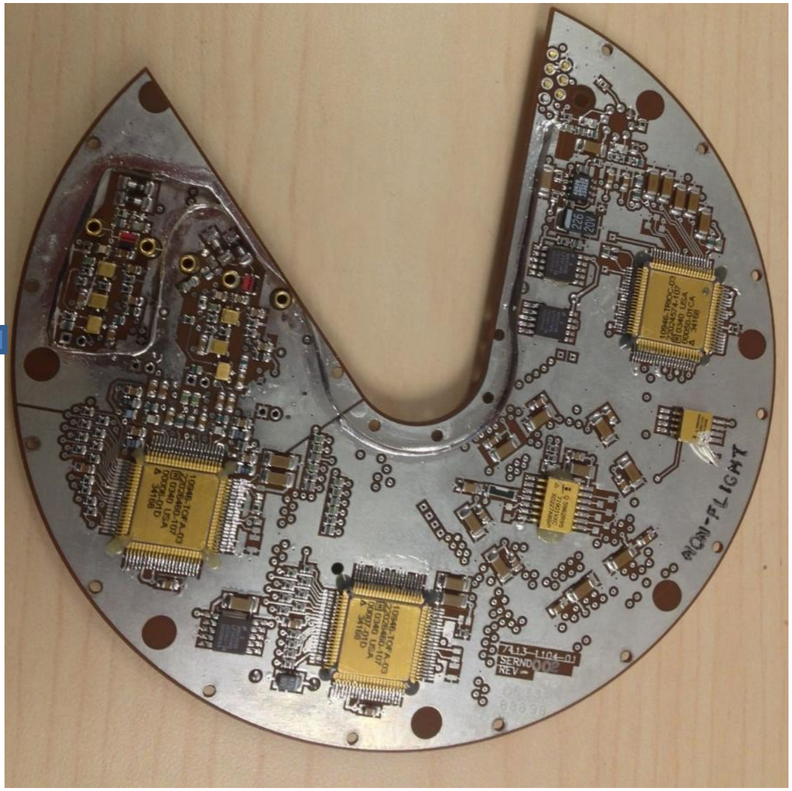




IBEX_lo Low Energy Neutral Atom Imager POC E. Mobius

Analog – Digital TOF - fpga Board with TOF and TRIO ASICs floated at 20KV nickP



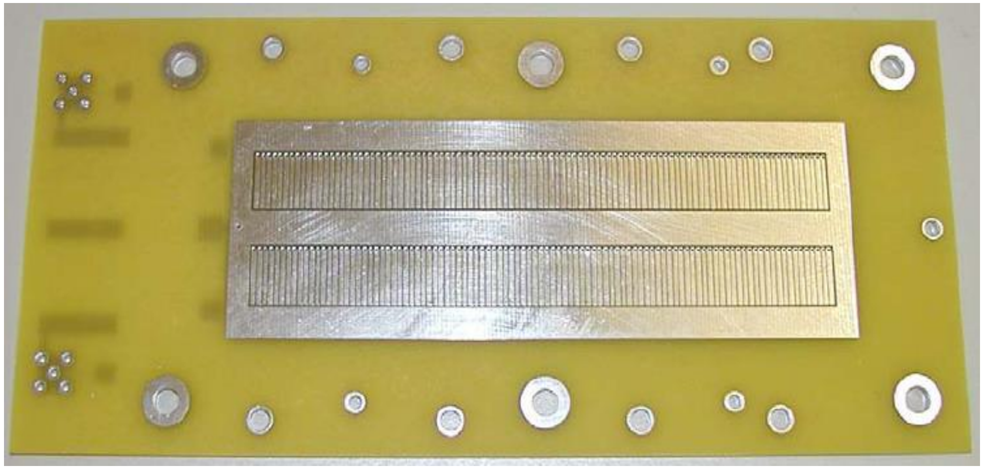


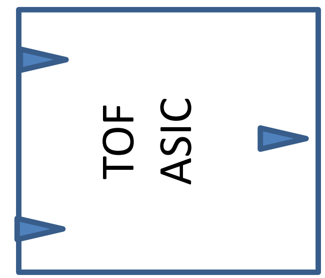
IBEX_lo measured the ISN bulk flow velocity, temperature and composition.

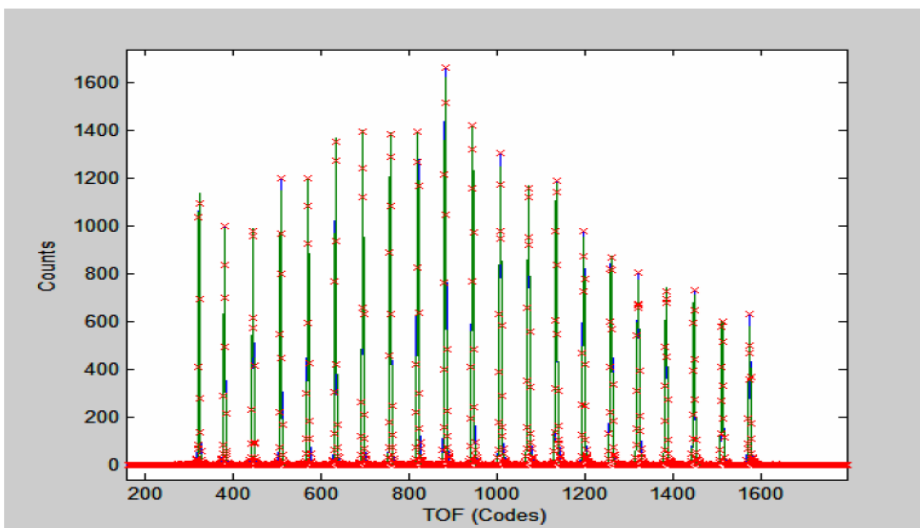
Time of flight and event processing board of the IBEX_Lo instrument floating at 20KV enabled by ultra low high time resolution TOF ASICs
The TOF electronics measured the composition with triple+ coincidence for high S/N.

MCP

Dual 1D anode

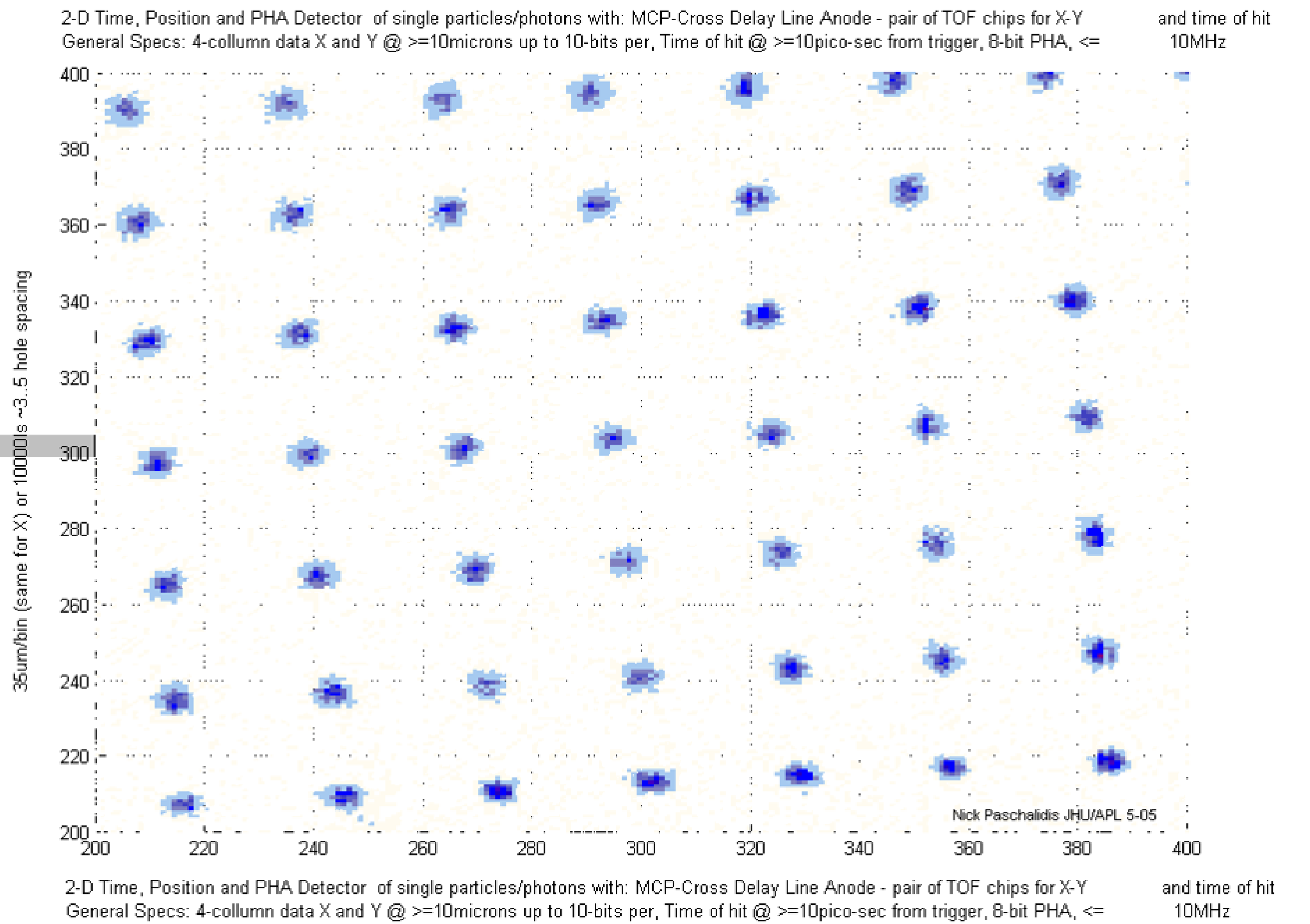






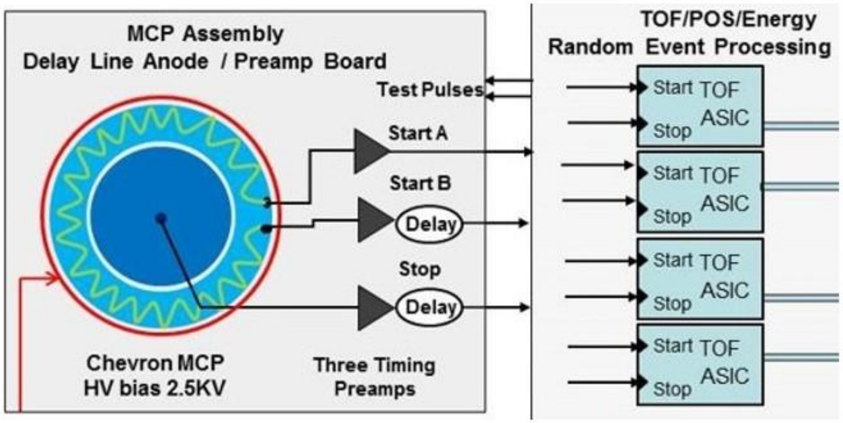
Test with UV light mask holes at 6.1mm apart, position resolution <0.5mm FWHM over entire filed

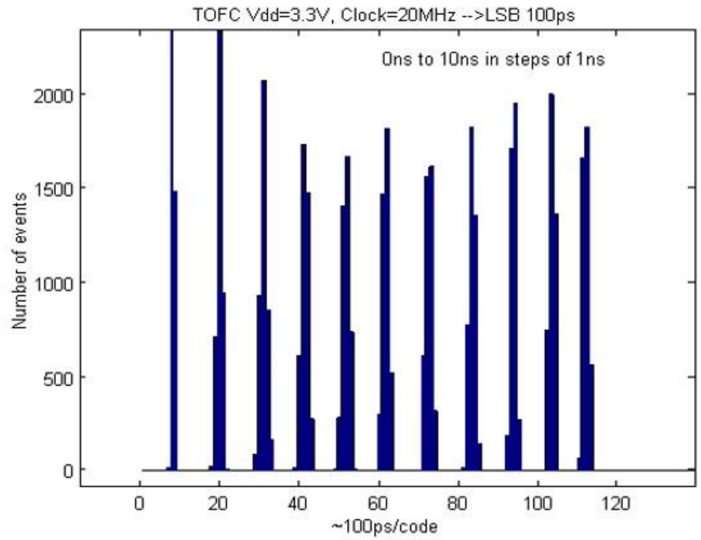
2D MCP – Delay Line Detector for Photon / Particle Imaging



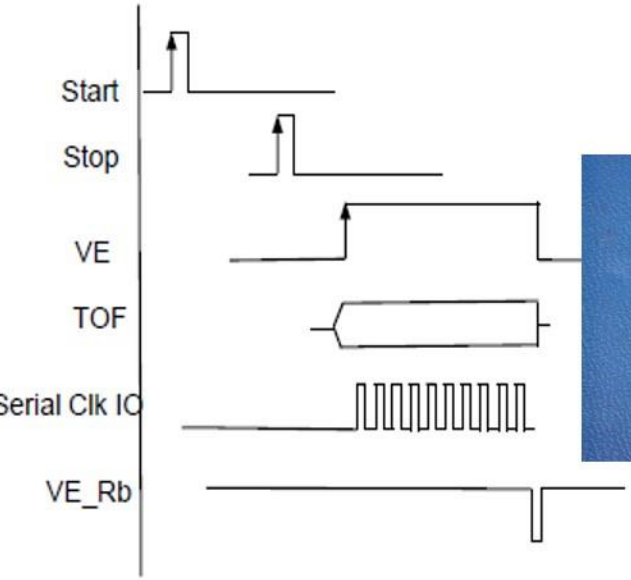
2-D Time, Position and PHA Detector of single particles/photons with: MCP-Cross Delay Line Anode - pair of TOF chips for X-Y and time of hit
General Specs: 4-collumn data X and Y @ >=10microns up to 10-bits per, Time of hit @ >=10pico-sec from trigger, 8-bit PHA, <= 10MHz

TOF ASICs and Delay Line TOF Configurations nickP

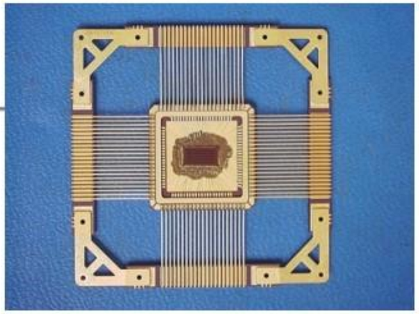


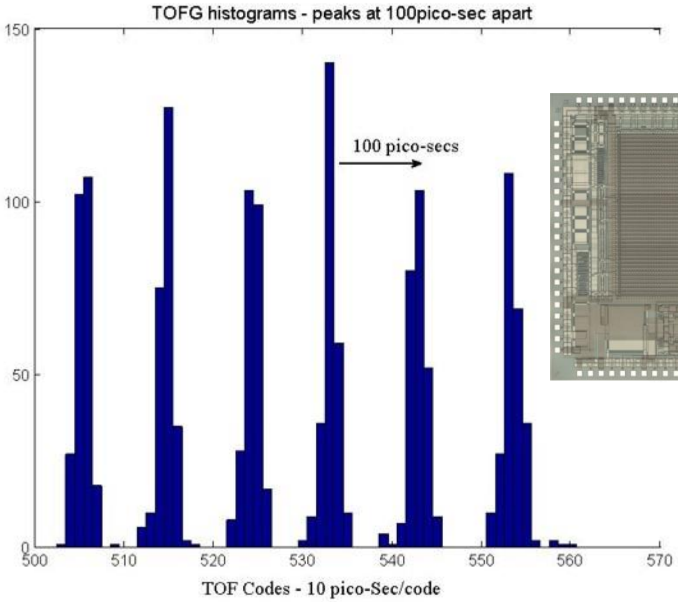


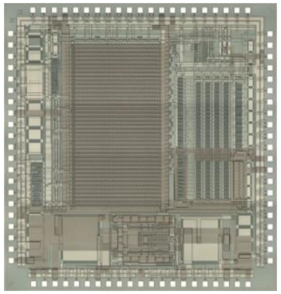
nickP



TOF-G ASIC <10ps

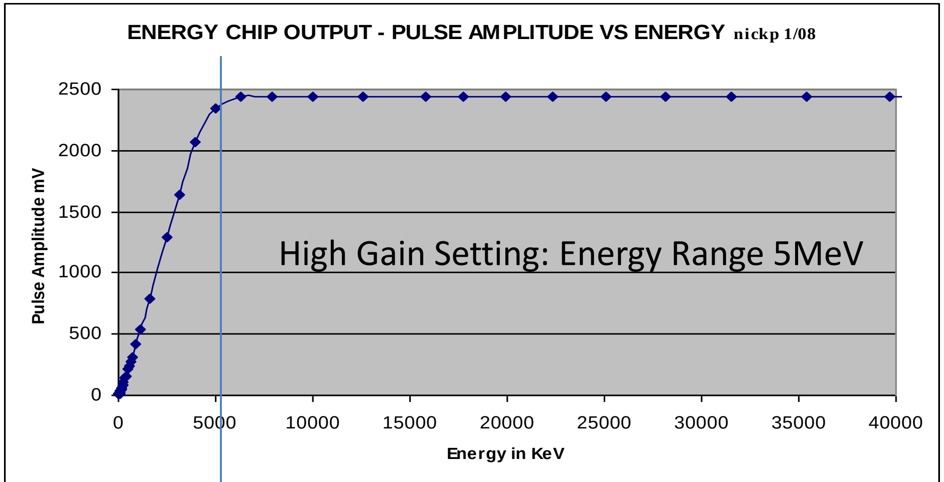


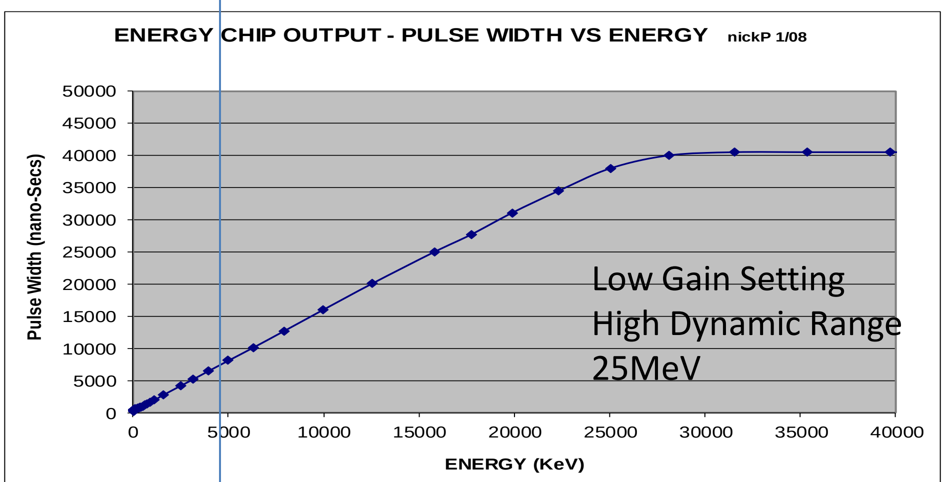




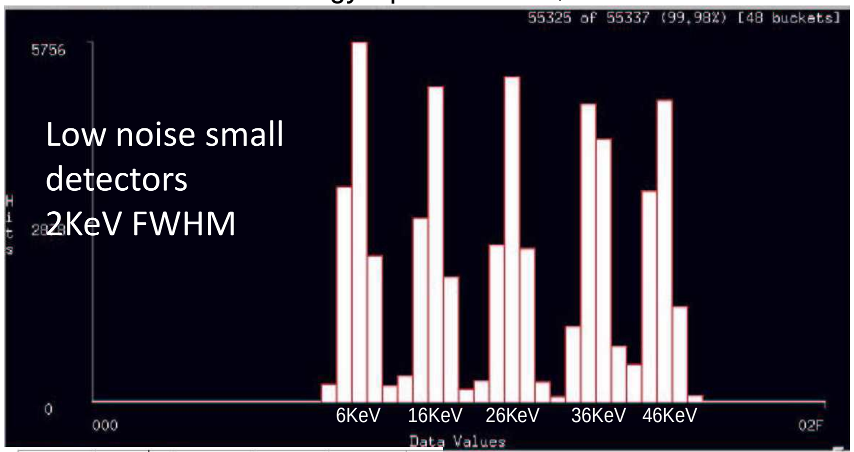
SSD Telescope with the Energy ASIC

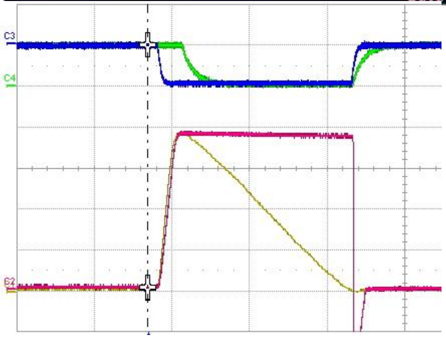
Energy Dynamic Range 10KeV to 20 MeV – noise ~2-5KeV FWHM
SSD detectors 300-700u thick with optional Aluminum flashing

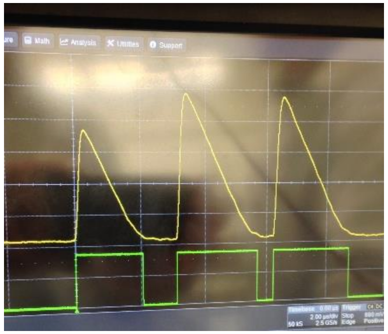


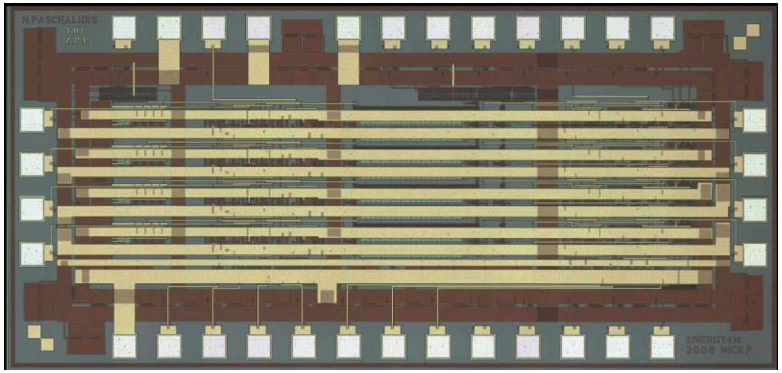


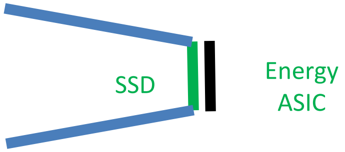
Energy Spectrum 2KeV per Code











Particles In situ and Remote Sensing

- Low Energy Instrument Heritage
- Large size Ion Mass Spectrometer - solar wind composition
- Compact Ion and neutral mass spectrometer w ion/neutral temperature & bulk flow
- Electron spectrometer - scanning ESA based
- Electron spectrometer magnetic with no energy scanning
- Compact thermal Electron Spectrometer
- Langmuir probe
- Compact Cubesat Scale high energy ion and electron spectrometer
- Energetic neutral atom Imager (remote sensing) w high sensitivity, low noise, high angular resolution

Electric field

- With fixed boom for 3-axis stabilized spacecraft and wire boom for spinner spacecraft
- 3-axis Cubesat / small sat size
- Waves
- Electromagnetic Sounder (active remote sensing)

Recent Heliophysics Instruments at GSFC

Magnetic Field

- Compact flux gate mag with small boom for small sats
- Multiple sensors w no boom
- Ground based mag network for GIC measurements on power lines

Photon Solar and Geospace Remote Sensing

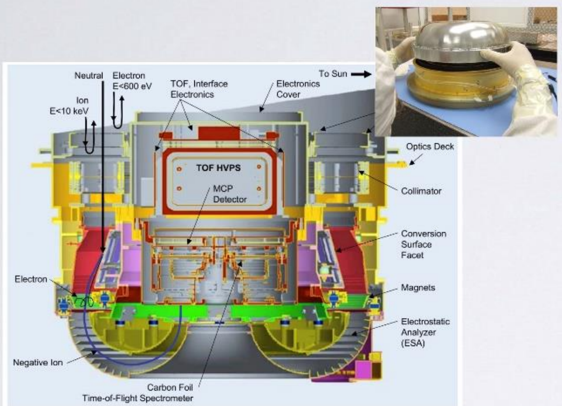
- UV/EUV imagers and spectrographs
- UV imagers geospace
- High resolution X-ray imaging of solar flares
- High resolution gamma ray imaging of solar flares
- Compact small sat scale neutron gamma – ray imaging of solar flares
- Milli-Arcsecond Imaging of the Solar Corona with Photon Sieves
- Large boom and compact boom coronagraph

Active Experiments

- Sodium resonance LIDAR for space born missions
- Sounders

GSFC LOW ENERGY INSTRUMENT HERITAGE

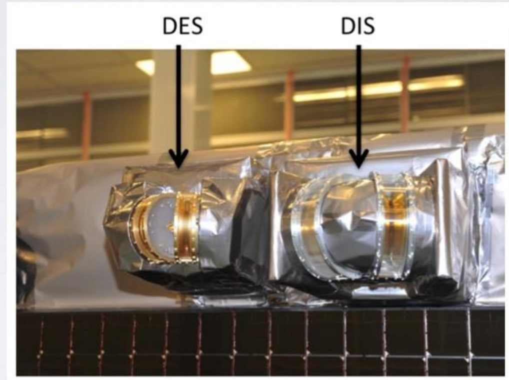
Large aperture neutral atom imaging



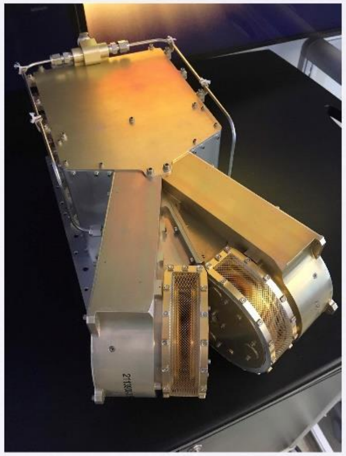
IBEX-Lo Atometer

IMAGE LENA Imager

Ultra-fast plasma analyzers

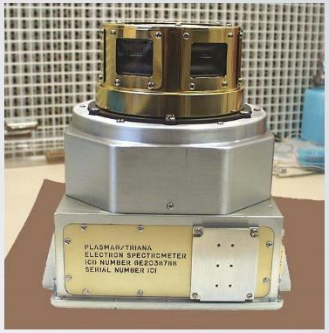


MMS Fast Plasma Investigation (FPI)



FPI Dual Electron Spectrometer (DES)

Miniature plasma analyzers



DSCOVR
Faraday Cup &
Electron Spectrometer

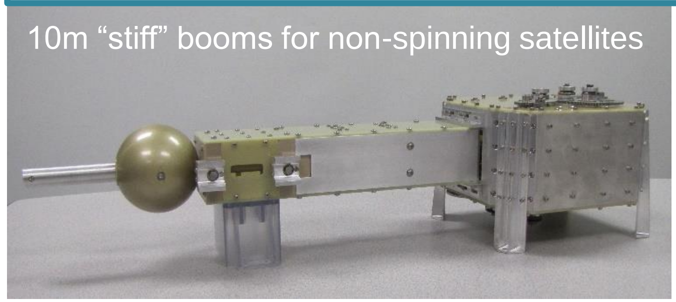
SCIFER
Thermal Electron Spec.

Recent Electric Field Boom Development within GSFC's Heliophysics Division

Poc Robert Pfaff, Doug Rowland

- Double probe electric field instruments provide critical measurements of energy input, wave dynamics, plasma instabilities, and plasma motion.

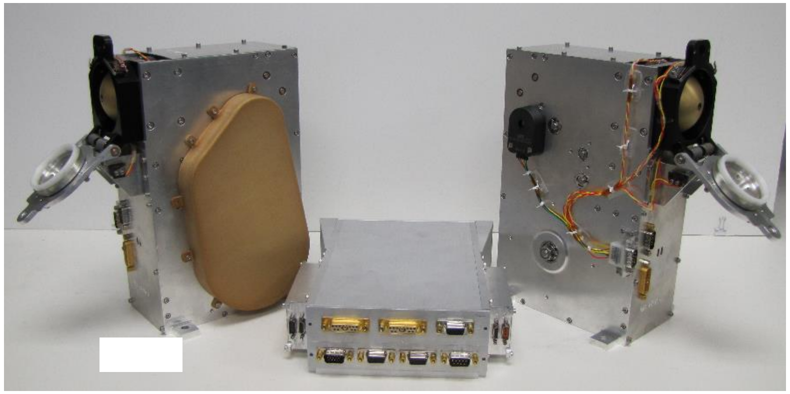
- They are primary instruments for a variety of near-term and future missions, including GDC.



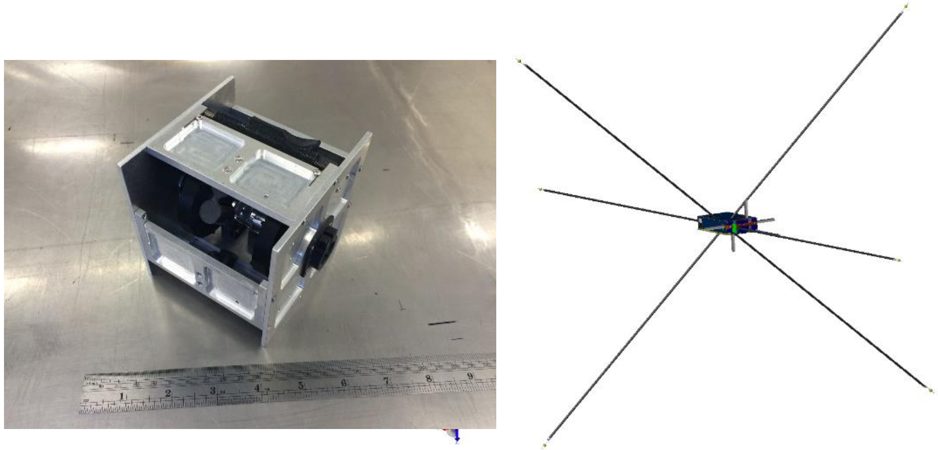
10m "stiff" booms for non-spinning satellites

- Ever since their inception in the 1960's, Goddard has played a leading role in the development of electric field double probe instruments.

- In the last 5 years, particular emphasis has been on new boom systems, for satellite, sounding rocket, and smallsat applications. Funding has come from an Explorer Phase A study, sounding rockets, H-TIDES ITD, SBIR, and GSFC IRAD.

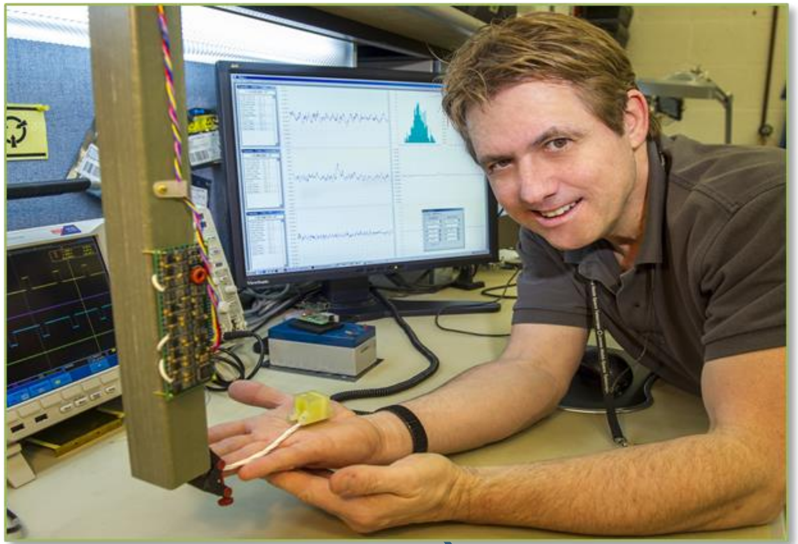


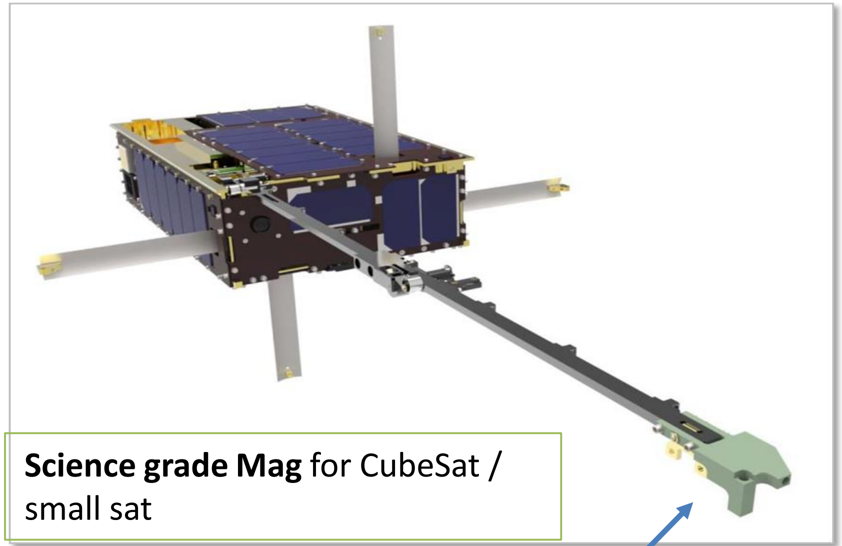
5-20m "wire" booms for spinning satellites
("On the rail" at Poker Flat!)



2.5m carbon composite rigid booms for smallsats

Miniature Science-Grade CubeSat Magnetometer
POC T. Bonalsky, E. Zesta





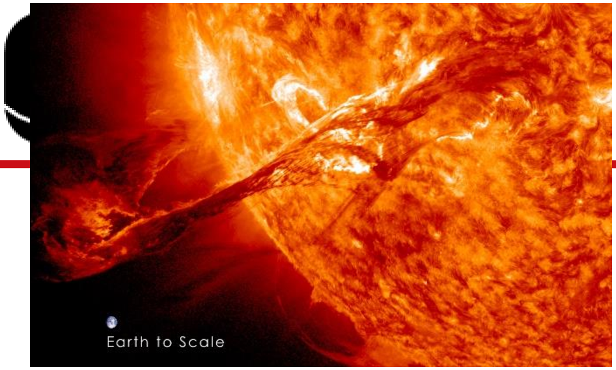
Science grade Mag for CubeSat / small sat

- Second Year Helio IRAD
- Boom and Internal Science Magnetometers Onboard Dellingr
- Auroral Jets Sounding Rockets (launche Feb 2017)
- ±65,000 nT Dynamic Range with 0.1nT FS Resolution
- 1 nT Vector Accuracy
- <600 mW Power Consumption in Science Mode

Left Panel: Mag Engineer Todd Bonalsky Holding the Internal Dellingr Magnetometer in his Lab.

Right Panel: Dellingr 6U Boom Magnetometer.

Turning the power grid into an extremely large space science instrument
POC Antti Pulkkinen

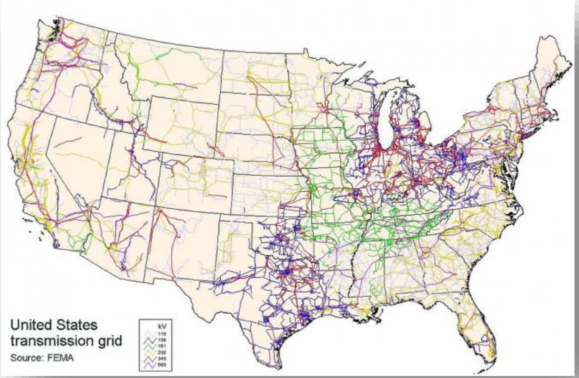


Example of solar eruptions that can disrupt the normal power grid operations

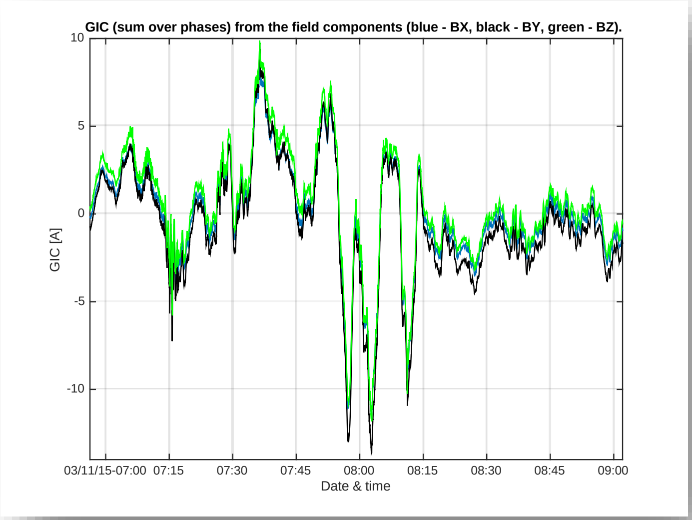
Geomagnetically induced currents (GIC) that flow in power grids during space weather storms can be a hazard for reliable transmission of the electricity. GSFC space weather team has developed new technology that will not only provide real-time information for mitigation of the hazard but also allows utilization of the grid as a space physical antenna. The work is being conducted with the US transmission industry's support. Initial installations were conducted in close collaboration with Dominion Virginia Power.

Reference GIC station installation in Clover, VA. GIC are measured in the Dominion 500 kV line.

NASA and Dominion installation crew in Clover, VA.



The US transmission system that is used as an antenna for space physical remote sensing



"First light" GIC measured in Clover, VA.

Langmuir Probe

poc J. Klenzing

- Ionospheric / Magnetospheric measurements of thermal plasma.
- Provides Electron Density and Temperature or high rate Ion Density, depending on mode.
- Flexible designs for explorers, cubesats, and sounding rockets.
- 300g (plus boom) / 300mW / 1 kbps
- Typically mounted on a boom away from the spacecraft for unobstructed view of plasma.
- Tech development: Fast adaptive screening mode for Te to improve measurement cadence by a factor of 10.

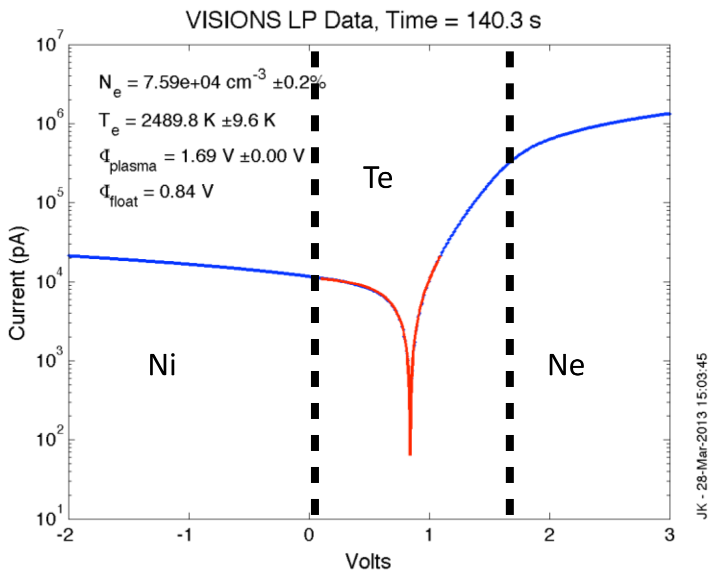


Figure 1

Heritage from C/NOFS and multiple sounding rocket launches, including Dynamo, VISIONS, and EVEX.

Tandem Ion Mass Spectrometer (TIMS) for Heliospheric and Planetary Missions POC Ed Sittler

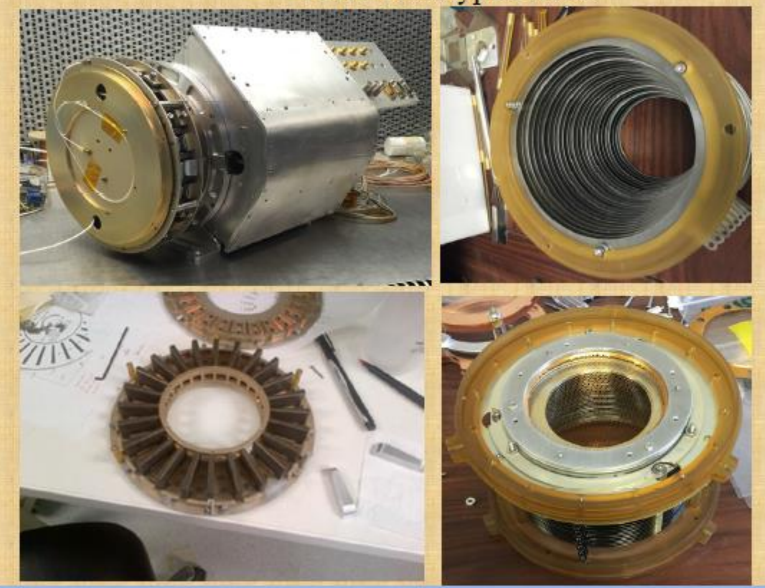
SCIENCE RATIONAL

1. 3D Velocity and Compositional Measurements of Interstellar Pickup Ions and Solar Wind Ions
    1. 100 V ≤ E/Q ≤ 100 kV & FOV = 4π with spinner
2. 3D Velocity & Compositional Measurements of Giant Planet Ionospheres, Magnetospheres & Moons within high radiation environments such as Europa.
    1. 1 V ≤ E/Q ≤ 25 kV and FOV = 2π (non-spinner)
    2. Add RPA feature for measurements E/Q < 50 V

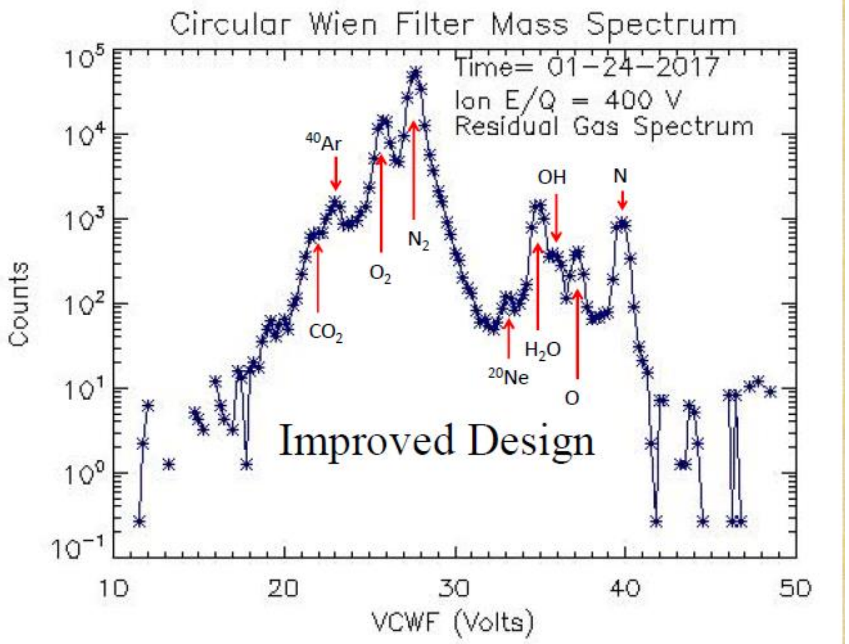
TECHNOLOGY DEVELOPMENT

1. Tandem IMS with Circular Wien Filter (CWF) (Measure Ion M/Q) and Tapered Linear Electric Field (LEF) Time-of-Flight System (Measure Atomic Fragments of ion).
2. Maximize TIMS Geometric Factor for its sub-systems, CWF, Tapered LEF, Straight Through (ST) detection and SSD Detection (charge state).
3. Radiation shielding design for TIMS for measurements within planet radiation belts.

TIMS Prototype Photos



Tandem Ion Mass Spectrometer prototype photo top left panel, its Circular Wien Filter disassembled showing spoke pattern of magnets in bottom left panel, Tapered Linear Electric Field (LEF) during assembly shown in top right panel and domed grid with Tapered LEF shown in bottom right panel.



CeRES: A Compact Radiation Belt Explorer Poc Kanekal GSFC

3U CubeSat

High inclination Low Earth Orbit

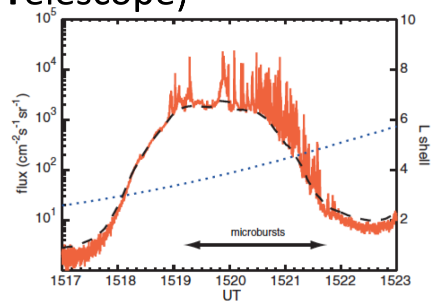
One Instrument: MERiT

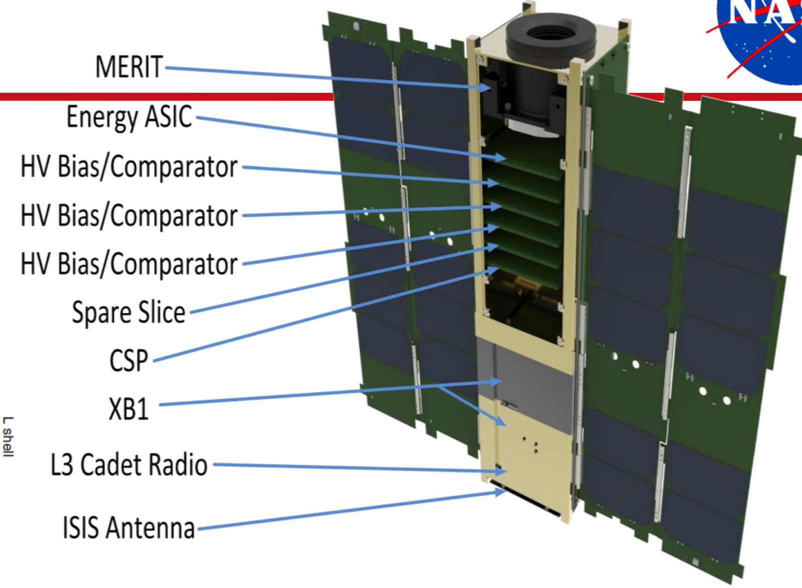
(**M**iniaturized **E**lectron **P**roton **Te**lescope)

Launch June 2017

Mission goals

➢Study relativistic electron dynamics, in particular loss due to microbursts





CuSP: Cubesat to study Solar Particles – PI: Desai/SwRI

6U CubeSat

Earth-Escape Heliocentric Orbit

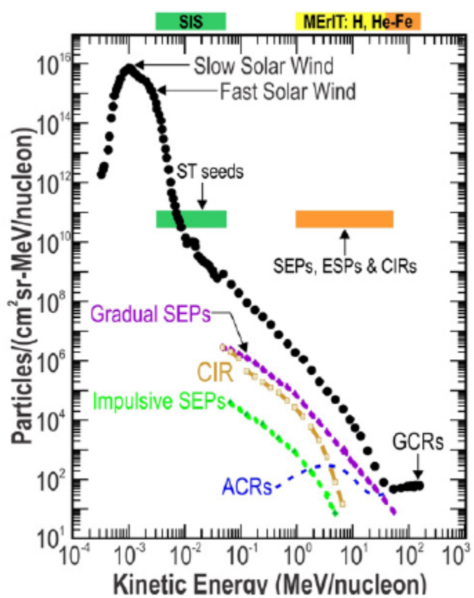
Two Instruments: MERiT & SIS

(Suprathermal Ion Spectrograph)

Launch SLS EM-1 Late 2018

Mission goals

➢Study energization of suprathermal particles



APES: Magnetic spectrometer

poc M. Samara

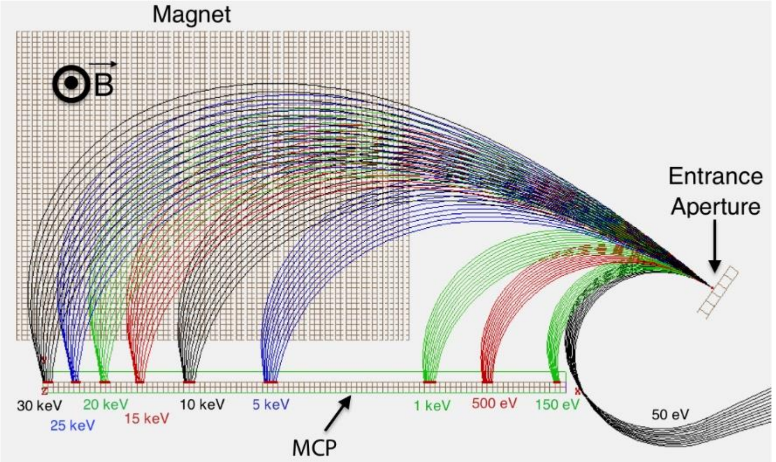
Description and Objectives:

- Electron spectrometer that uses a permanent magnet for the energy selection.

Key Innovation:

- High time resolution electron spectra
- No Energy scanning

Electron Optics Concept:

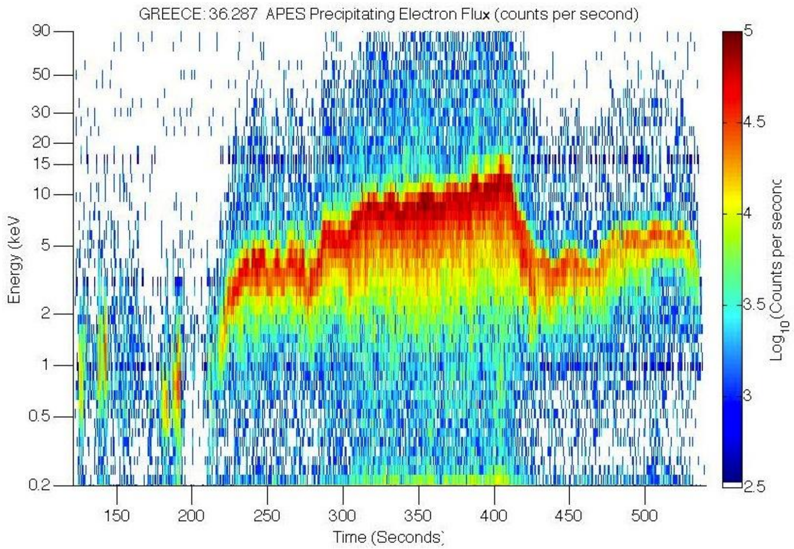


Instrument:

- Mass: 8 kg (can be made significantly smaller)
- Power: 10 W (can be made significantly smaller)
- FOV: 10x20 deg.
- Geometric Factor: (10^{-3} at 10 keV, and $5x10^{-4}$ at 50 keV)
- Energy Range: 500 eV to 50 keV
- Energy Resolution: up to 50 energy bins
- MCP size: 100 mm x 15 mm
- Maximum Magnetic field strength:
  ~170 G (for 30 keV)
  ~240 G (for 90 keV)

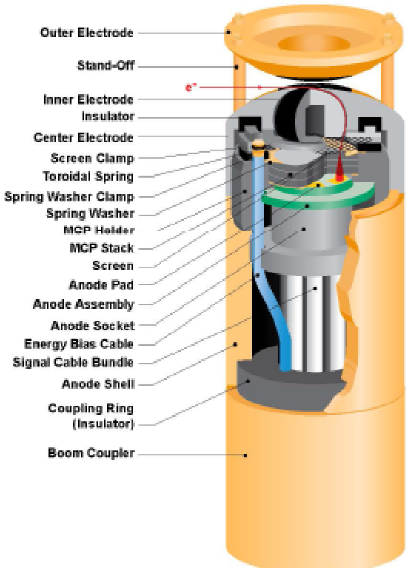
(Flight data 200 eV to 90 keV, calibrated to 30 keV)

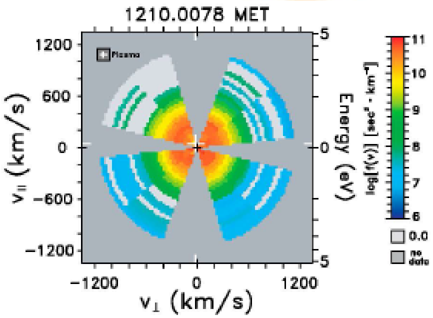
Flight Data from GREECE (03 March 2014):



THERMAL ELECTRON CAPPED HEMISPHERE SPECTROMETER (TECHS)

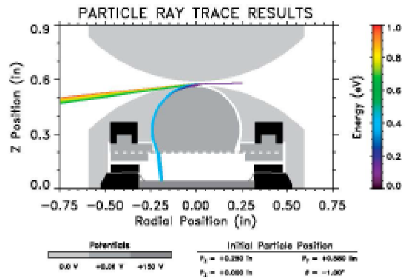
NASA HSD



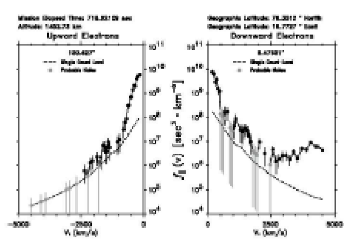


INSTRUMENT SPECIFICATIONS

Parameter			*Value*
Mass	Sensor		Mass (kg)
		Electrostatic Analyzer	0.087
		Deployment Boom	0.455
		Deployment Hinge	0.350
		Cables	0.240
		Subtotal	1.132
	Electronics		3.500
		Total	4.632
Volume	Sensor	Cylindrical (Len x Dia)	5 x 3 (cm)
	Electronics	Rectangular (HxWxD)	19 x 18 x 7.6 (cm)
Power			3.0 W
Telemetry			32 kB • s⁻¹

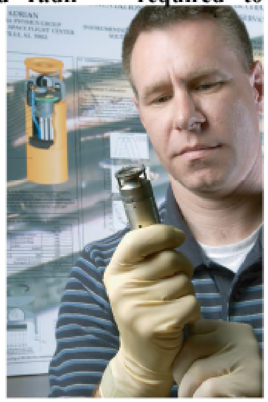


Electron Distribution



Technology Challenge

Miniaturization — small physical form-factor and radii — required to accommodate extremely small Lamor/gyro-radii of the target low-energy sub-eV ionospheric electrons. Without these small dimensions, the target population would not be observable.



Science Motivation

1. Enables observation of low-energy, thermal core of the distribution — major constituent/bulk of density.

2. Direct observation of major charge carriers responsible for high-latitude field-aligned currents.

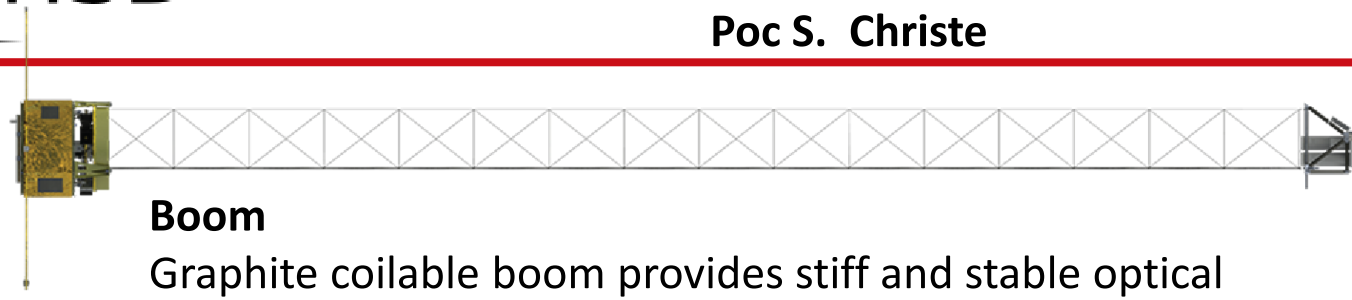
3. Observation of low-energy temperature anisotropy driven by ambipolar electric fields.

4. Detection of low-energy field-aligned precipitating and upwelling electron beams that are not predicted by theory.

Focusing Optics X-ray Solar Imager (FOXSI)

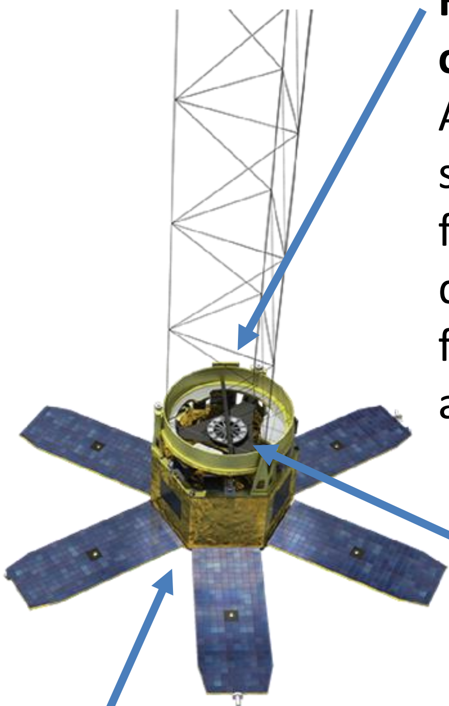
Exploring impulsive magnetic energy release on the Sun

Poc S. Christe



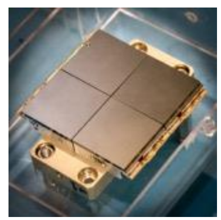
Boom

Graphite coilable boom provides stiff and stable optical bench for solar observations.



Hard X-ray photon-counting Imager

ASIC by RAL for homeland security further developed for solar and astro observations.



Metrology LEDs

Qualified COTS parts, lifetime tested.

Satellite Bus

Low-cost, high-heritage satellite bus

Hard X-ray telescopes

High-precision Electroformed Nickel replication shells provide grazing-incidence reflection.

Metrology System

Developed for ATLAS LRS, camera combined with fast FPGA to measure motion of boom.

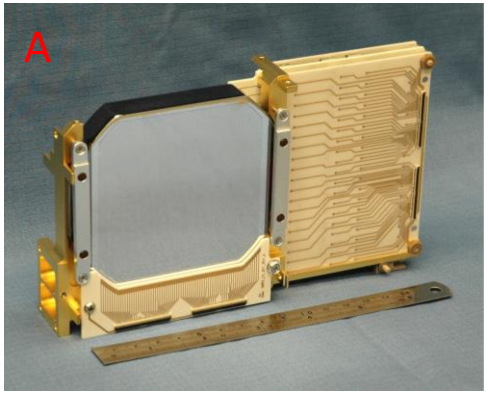
Solar Position Sensor

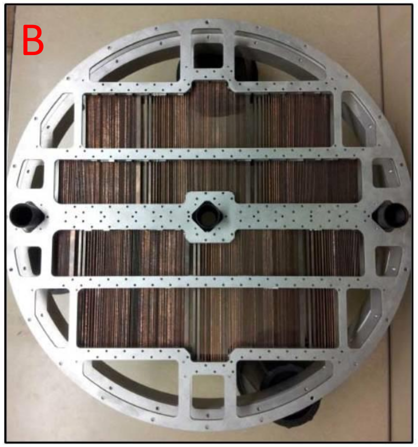
Developed for GOES-R & MinXSS cubesat, provides precision sun pointing information.

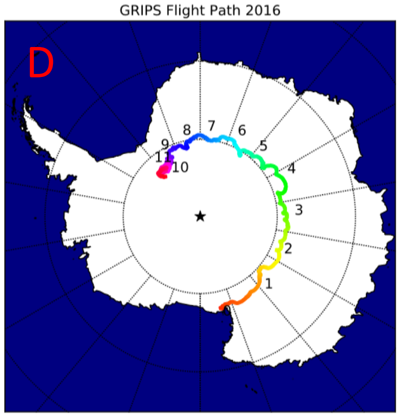
High-resolution gamma-ray imaging of solar flares

poc A. Shih

- **Science motivation**
  - **Up to tens of percent of flare energy goes into accelerated particles**
  - **Ions have comparable energy to electrons, but are accelerated/transported differently**
- **New technologies**
  - **3D position-sensitive germanium detectors [A]**
    - **Locate each energy deposition to <1 mm^3 to enable imaging and polarimetry**
  - **Multi-pitch rotating modulator [B]**
    - **Three times finer angular resolution than the state of the art (*RHESSI*)**
- **Development**
  - ***GRIPS* balloon instrument [C]**
    - **Funded by the H-TIDeS/LCAS program**
    - **Long-duration flight over Antarctica (January 2016) [D]**







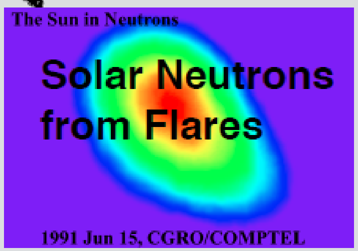
High-resolution gamma-ray imaging of solar flares

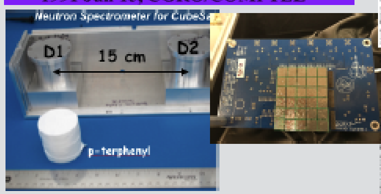
POC G. DeNolfo

Gamma-ray & Neutron Detection Development

SmallSat Technology Development in Heliophysics (G.A. de Nolfo)

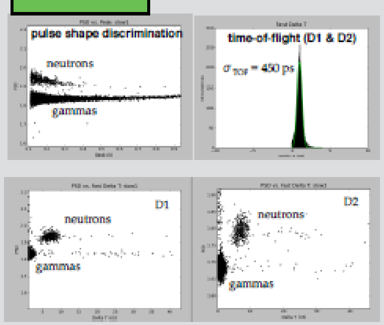
Double-Scatter Neutron Spectrometer





Readout: 1) Large area arrays of silicon photomultipliers
2) Novel waveform capture ASIC

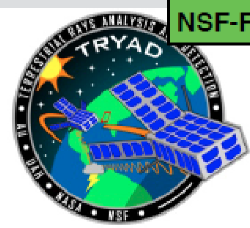
Results



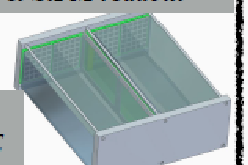
Gamma-ray Spectrometers

Terrestrial Gamm-Ray Flashes

NSF-Funded TRYAD

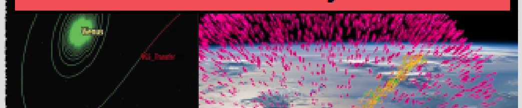


TRYAD Instrument: lead-doped plastic & SiPM readout

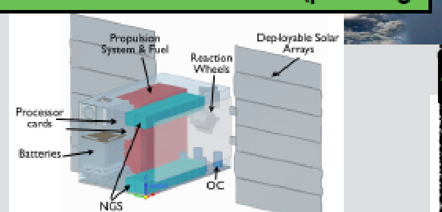


Goddard supplies SiPM arrays and FEE

Venusian Gamm-Ray Flashes



Venus CubeSat for PSDS3 (pending)

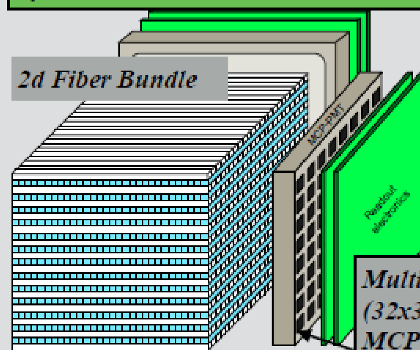


Instrumentation: Modern scintillator-based instrumentation (e.g. lead-doped plastic, NaI, p-terphenyl, CLYC)

Novel Neutron imaging Spectrometer

Compact Neutron Spectrometer for SmallSat

2017 NASA/HTiDEs Award – Proton-tracking fiber bundle neutron spectrometer

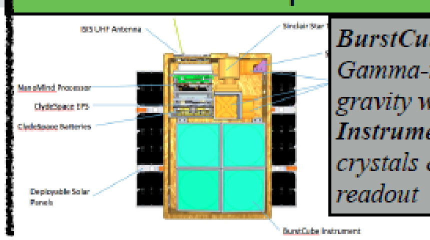


2d Fiber Bundle

Multi-anode (32x32 channel) MCP_PMT

Gamma-rays inAstrophysics

NASA/APRA 2017 Proposal



BurstCube CubeSat: Gamma-ray bursts & gravity waves
Instrument: CsI crystals & SiPM readout

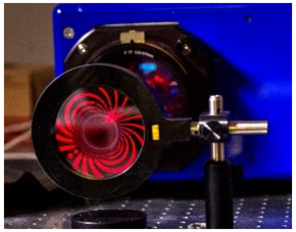
Milli-Arcsecond Imaging of the Solar Corona with Photon Sieves POC D. Rabin

Description and Objectives

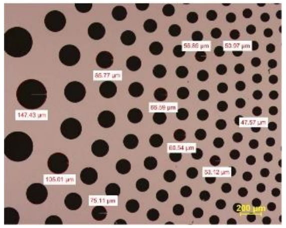
- Build and test diffractive imaging elements—photon sieves—that have the potential to provide 10–100 times better angular resolution in the ultraviolet than current missions like SDO.
- Increased resolution will enable NASA to observe individual dissipation regions in the solar corona and understand how the corona is powered.

Key challenge(s)/Innovation

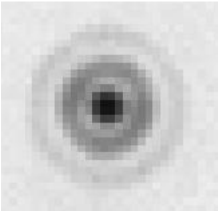
- Primary innovation: photon sieve can achieve higher angular resolution at lower cost and mass than mirrors
- Primary challenges: innovative photolithography; demonstrating focal-plane performance



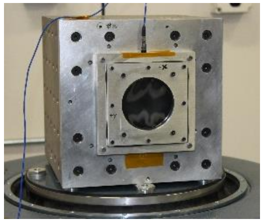
80-mm sieve during optical test



A few of the 17,591,294 holes



Measured Point Spread Function of 80-mm sieve



During successful vibration test

Approach

- Design and fabricate advanced photon sieves, including segmented, slotted, and membrane variants
- Test optical performance at visible wavelengths
- Perform vibration testing of mounted sieves
- Test optical performance at EUV wavelengths

Application / Mission

- Sounding rocket investigation to be proposed through ROSES H-TIDeS
- Longer-term: 2-spacecraft CubeSat or Explorer

Team

- D. Rabin /670, A. Daw/671, K. Denis/553, A.-M. Novo-Gradac (670/HQ), T. Okajima/662, M. Saulino/547, T. Widmyer/548, G. Woytko (670/Jackson & Tull)

Accomplishments

- Fabrication of three 80-mm diameter photon sieves on silicon wafers thinned to 15 or 25 µm
- Optical test of these sieves demonstrating nearly diffraction-limited performance (see Airy pattern above)
- Successful vibration test to sounding rocket levels

Ongoing Work

- Extension to holes as small as 2 µm
- Extension to slotted and segmented sieves
- Preparations for EUV testing

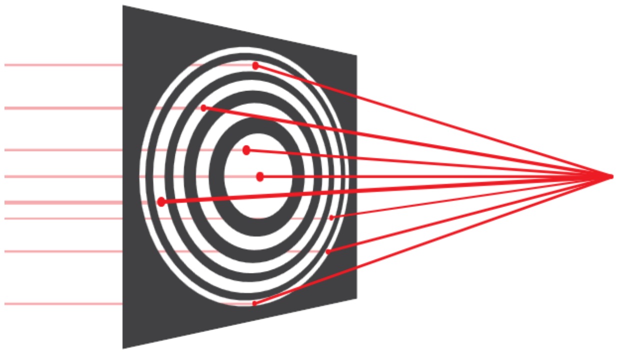
Space Technology Roadmap Traceability

- Primary Technical Area TA08; Secondary TA12
- Applicable Grand Challenge: New Tools of Discovery

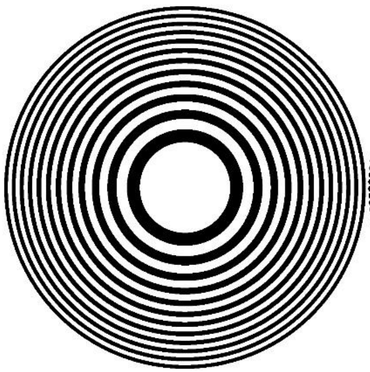
Technology Readiness Level

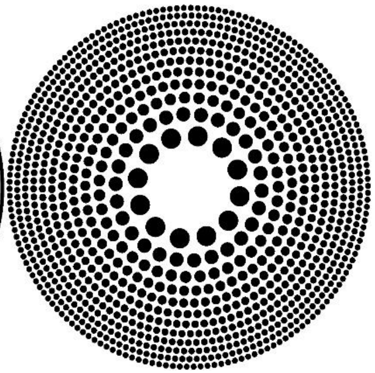
- Starting TRL: 3; Ending TRL: 4

What is a Photon Sieve?



A Fresnel zone plate (FZP) focuses light through the constructive interference of diffracted rays. A FZP comprises a number of rings (zones) that alternate between opaque and transparent. They are spaced so that the path length between successive transparent zones and a focal point differs by an integral number of wavelengths for a specific wavelength.





A photon sieve replaces the open zones of a FZP with individual holes. The holes need not be distributed symmetrically (as shown at left) and need not be exactly the width of a FZP zone. This provides greater structural integrity and allows greater control over the diffraction pattern.

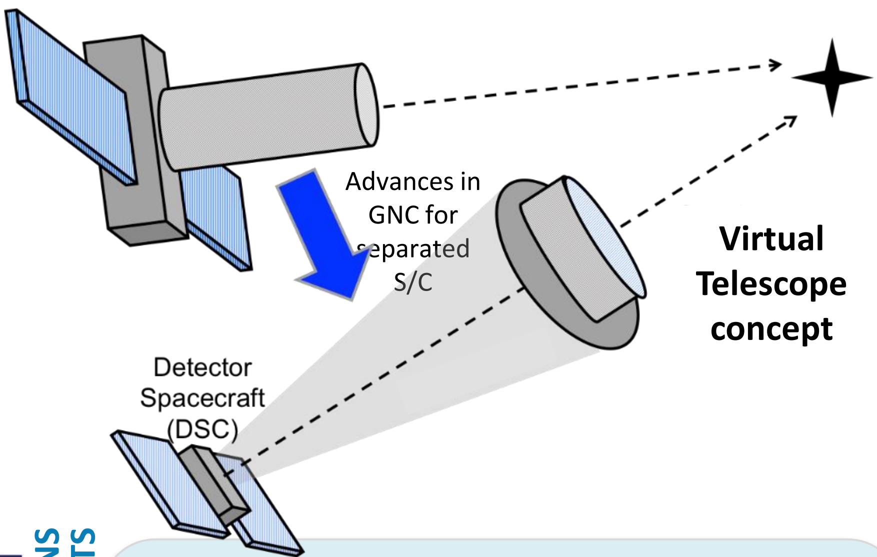
Why?

Photon sieves and FZPs are flat optics that can be used to form diffraction-limited images at extreme ultraviolet and X-ray wavelengths for which conventional focusing optics can not be figured with the accuracy needed to approach the diffraction limit.

The “Virtual” Space Telescope: A New Class of Science Instruments using Precision Formation Flying poc Nerav

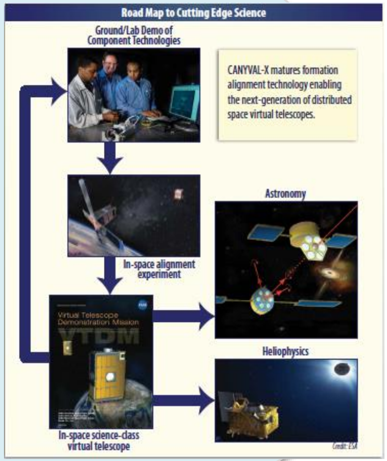
TECHNOLOGY/CAPABILITY AND IMPORTACE

- Many science investigations proposed by NASA require two spacecraft alignment across a long distance to form a distributed “virtual” space telescope.
- Virtual Telescope is a dual-spacecraft precision inertial alignment capability being developed at NASA GSFC.
- A science instrument like this has not flown, therefore need a pathfinder demonstrations to advance readiness level for science missions



APPROACH

- A low-cost approach to advance this science instrument technology through the maturation and flight demonstration using SmallSat components.
- Develop GN&C hw/sw components through lab testing
- In-Space demonstration of the system concept



CAPABILITY STATUS, PLANS KEY CONTACTS

- **Internal and Partner Component Developments**
  - **Inertial Alignment Sensor**
  - **Micro Cathode Arc Thrusters (MCAT)**
  - **Dual-Spacecraft Precision Alignment Software**
  - **Radiometric Ranging**
- Mission Demonstrations(s)
- **CANYVAL-X = GSFC + Yonsei University + KARI**
- **VTXO = GSFC + NMSU + UNM**
- **mDOT = Stanford + GSFC**

Earth mesosphere temperature measurements via sodium lidar: Laser transmitter packaging
POC D. Janches

Description and Objectives:

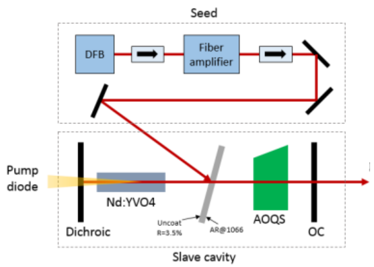
- High-resolution measurements that can characterize small-scale dynamics (i.e. Gravity Waves with wavelengths smaller than a few hundred km) and their global effects in the Mesosphere-Lower-Termosphere (MLT).
- Key to high-quality measurements is a spaceborne, sodium (Na) LIDAR to measure global Na density, temperature and vertical winds in the MLT with adequate spatial and temporal resolution.

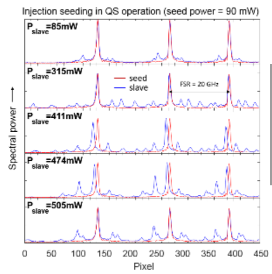
Key challenge(s)/Innovation:

- Injection seeding and tuning of the laser transmitter.
- Power scaling of the laser energy to meet space flight requirement.
- This laser would need to lock onto the Na absorption line at 589 nm, and maintain this in a space environment with adequate power.

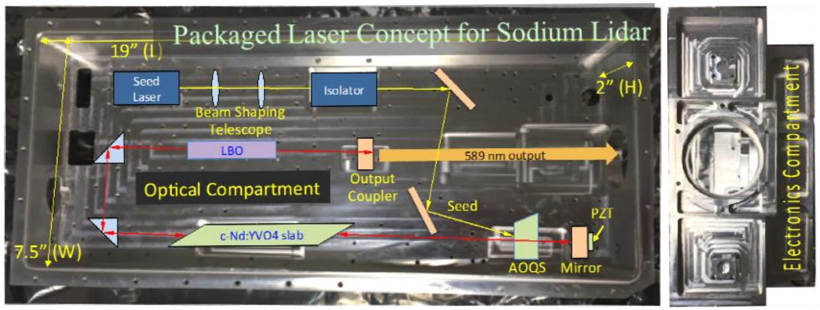
Approach:

- Non linear conversion and tuning a space-quality laser from its fundamental frequency of 1066nm to the Na absorption frequency of 589 nm.
- Power scaling and OM packaging leveraging prior space flight laser designs.





Injection seeding schematics and preliminary results



Author/Org - <date of version: mm/dd/yr>

HSD

National Aeronautics and Space Administration

HPD @ HQ Talk Series Presents

Overview of Advanced NASA/GSFC Instruments for Heliophysics Science

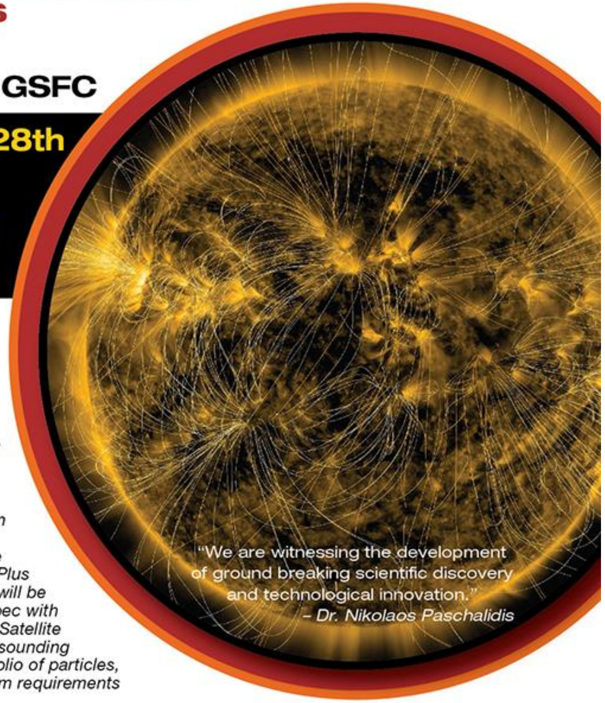
Including TOF x E x Delay Line Particle Technologies

presented by

Dr. Nikolaos Paschalidis • GSFC

When: Tuesday, February 28th
12:00 - 1:00 p.m.

Where: 3P40 and WebEx/ Telecon



From the complex interactions on the sun's surface and within its corona out to the boundaries of the heliosphere, we are witnessing the development of ground breaking scientific discovery and technological innovation—across all disciplines in Heliophysics science and research.

Dr. Paschalidis will present information on TOF x Energy x angle particle analyzers, a family of rad hard ASICs (TOF, Energy, TRIO, CFD, PKD) and delay line imagers. The delay imagers were created by Dr. Paschalidis and have been flown on missions across the Science Mission Directorate including IMAGE, CASSINI, MESSENGER, STEREO, IBEX, PLUTO, RBSP, MMS, JUNO, and will be flown on Bebi Colombo, Solar Orbiter, and Solar Probe Plus missions. New innovations on neutral/charges particles will be discussed including a compact Ion and Neutral Mass Spec with temperature/drift/wind capability for recent Cube/Small Satellite missions including NSF's ExoCube, GSFC Dellingr, and sounding rockets. The presentation will expand on a diverse portfolio of particles, fields and photon imaging instruments, including platform requirements for constellation and precision formation flying.

Can't join in person?

Please join us via our WebEx:

Meeting Title: Overview of Advanced NASA/GSFC Instruments for Heliophysics Science
Link: http://nasa.webex.com
Meeting number: 991 039 393
Meeting password: HelioTech2017!

Or, join by phone: Dial in: 1-844-467-6272 • 383829#

WE HOPE YOU CAN MAKE IT!

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