JPL Flyby Mass Spectrometer

Kenneth Farley

California Institute of Technology, Pasadena, CA 91125

Murray Darrach, Stojan Madzunkov, Rembrandt Schaefer, Evan Neidholdt

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

Concept Team

- Ken Farley – Caltech – Principal Investigator (PI)
- Murray Darrach – JPL – JPL PI
- Stojan Madzunkov – JPL – Instrument Scientist
- Rembrandt Schaefer – JPL – Electronics architect & development lead engineer
- Evan Neidholdt – JPL – Sensor Cog-E & instrument systems engineering
- Jurij Simcic – JPL – Radiation modelling & shielding calculations
- Dragan Nikolic – JPL – Instrument performance modelling & theoretical calculations
- Marcin Pilinski – ASTRA Corp. – Funnel Collector Dev.
- Timothy Minton – Montana State Univ. – Funnel Testing

Jet Propulsion Laboratory
California Institute of Technology

Presentation Outline

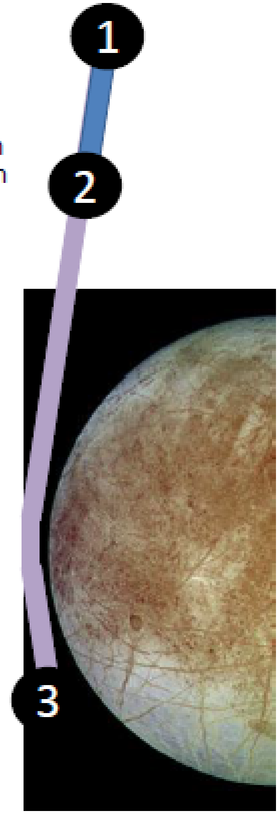
- Mission concept description for MARINE instrument concept
- Science performance of JPL Mass Spec
- Sensor architecture & configuration
- Electronics architecture & implementation
- Harsh environment survivability & test program
- Future deployment opportunities

Jet Propulsion Laboratory
California Institute of Technology

Europa Clipper Mission Concept

→ Mission is now known as "Europa Multiple-Flyby Mission"

Nominal Operations



Step #1: Spacecraft Altitude 25000 km
- Time = closest approach – 1 hr. 48 min
- MARINE in STANDBY mode
- Operational Heater ON
- Shutter OPEN
- Mass Spectrometer OFF
- Power = 36 Watts (CBE)

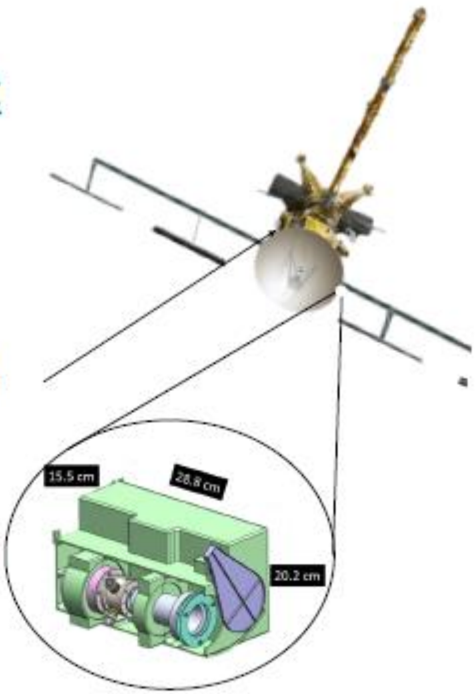
Step #2: Spacecraft Altitude 2000 km
- Time = closest approach – 16 min
- MARINE in MEASURE mode
- Operational Heaters OFF
- Start acquiring per second mass spectra
- Power = 44 Watts (CBE)

Step #3: Spacecraft Altitude 1000 km
- Time = closest approach + 8 min
- MARINE in STANDBY mode
- Operational Heaters and MS OFF
- Shutter CLOSED
- MS Data Ready for Telemetry
- Power = 7.4 Watts (CBE)

Deployment

MARINE Sensor Electronics Assembly (MSEA) is Mounted in the Spacecraft Electronics Vault

MARINE Sensor Head Assembly (MSHA) is Mounted on the Spacecraft Neutral Mass Spectrometer (NMS) Boom



Jet Propulsion Laboratory
California Institute of Technology

Europa Flyby Mission Concept

1. MARINE Will Determine the Atmospheric Composition and the Altitudinal Profiles of the Major Species

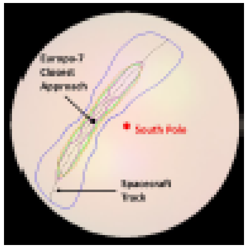
MARINE will identify and map the Europan exospheric species to better than 25 km resolution in altitude

2. MARINE Will Characterize the Surface and Subsurface Volatiles Present in the Exosphere Through Unequaled Sensitivity

Species and Real-time Limits of Detection (cm^{-3} s^{-1})	
H_2S , CO_2 , SO_2 and most C_N ($N \leq 6$) organics	3
C_N ($N > 6$) organics	0.5

MARINE Limits of Detection for per second full range mass spectra, including background radiation, is at least 100 times greater than other flight mass spectrometers.

3. MARINE Will Distinguish and Characterize Potential Plumes



Projected MARINE plume detection for the Europa-7 flyby. If a plume exists anywhere within the blue ellipse, then MARINE will detect plume H_2O at 3:1 signal : background or greater. Likewise, MARINE will detect plume-based CO_2, SO_2 or NH_3 at concentrations 10^{-5} or greater (with respect to water) if a plume exists within the regions bounded by red, green or purple ellipses, respectively.

4. MARINE Will Measure Isotopic Ratios of Key Species to Understand Europa's Planetary Evolution

MARINE will determine the ^{16}O : ^{17}O ratio to an accuracy and precision of better than 25 ‰ and 4 ‰, respectively.

Jet Propulsion Laboratory
California Institute of Technology

Instrument Performance & Resources

Unparalleled Performance

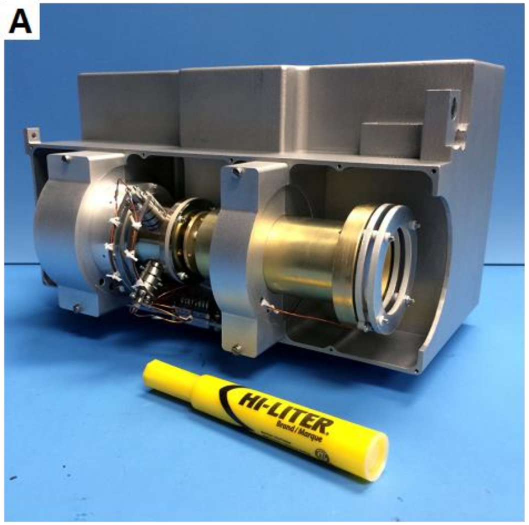
Parameter	Value
Instrument Sensitivity	0.5 molecule/cm³/sec
Mass Range	Wide-Range (WR) Mode = 20 to 320 Da High-Resolution (HR) Mode = 10 to 80 Da
Mass Resolution ($m/\Delta m$)	Wide-Range Mode = 750 FWHM at 300 Da High-Resolution Mode = 4000 FWHM at 64 Da
Key Redundancy	Dual ionizers
On Board Calibration	MS performance can be validated any time during cruise or Europa encounters
Lifetime	More than 350 encounters

MARINE Resources

Parameter	MARINE MSHA	MARINE MSEA
Mass (CBE + cont.)	7.3 kg	3.7 kg
Volume	9.7 L	6.3 L
Ops. Power per encounter	83.7 W• hr CBE 101.5 W• hr (CBE + 21 % cont.) 44 W CBE (peak) for 25 min.	
Ops. Data Volume	10.9 MBits per encounter (lossless VCAM heritage compression)	

Jet Propulsion Laboratory
California Institute of Technology

JPL Flyby MS – Ion Trap

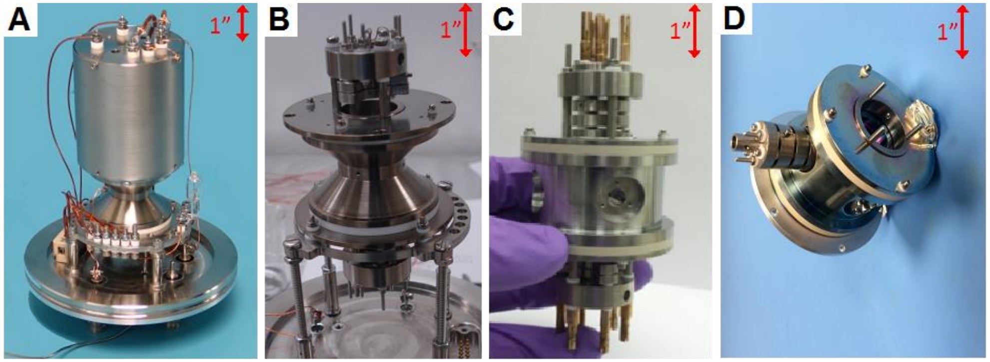


Prototype MARINE QITMS

Sensitivity: 1e15 counts/Torr/sec

Mass: 5.9 kg
(including radiation shielding)

Development Heritage of MARINE Quadrupole Ion Trap Mass Spectrometer (QITMS)



A: flight MS from Vehicle Cabin Atmosphere Monitor (VCAM)

B: first generation “wireless” QITMS (NASA PIDDP)

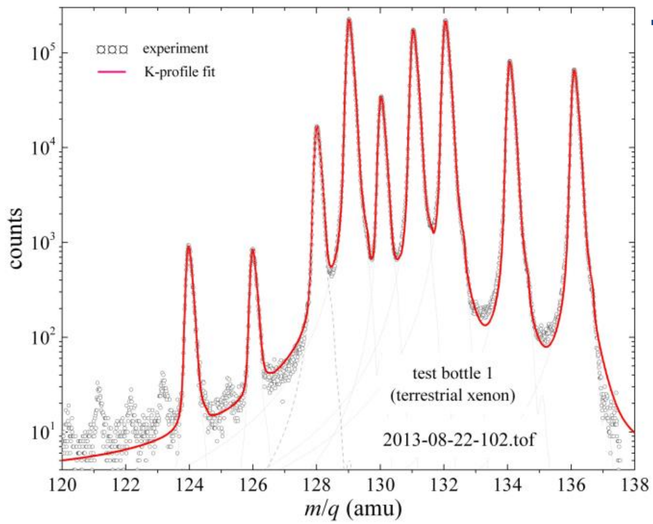
C: Engineering model of wireless QITMS for VCAM follow-on
- the Spacecraft Atmosphere Monitor (SAM) for ISS in 2018

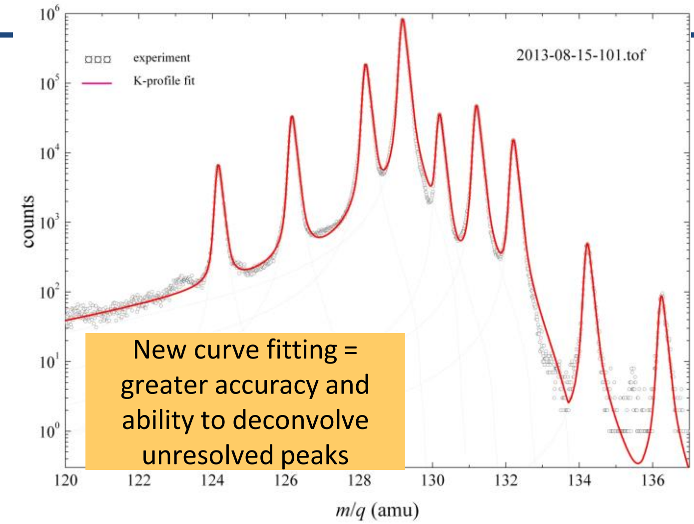
D: Prototype QITMS for MARINE

MARINE Sensor Head Completed Vibe Testing in September 2015

Jet Propulsion Laboratory
California Institute of Technology

Science Performance[1] – JPL MS





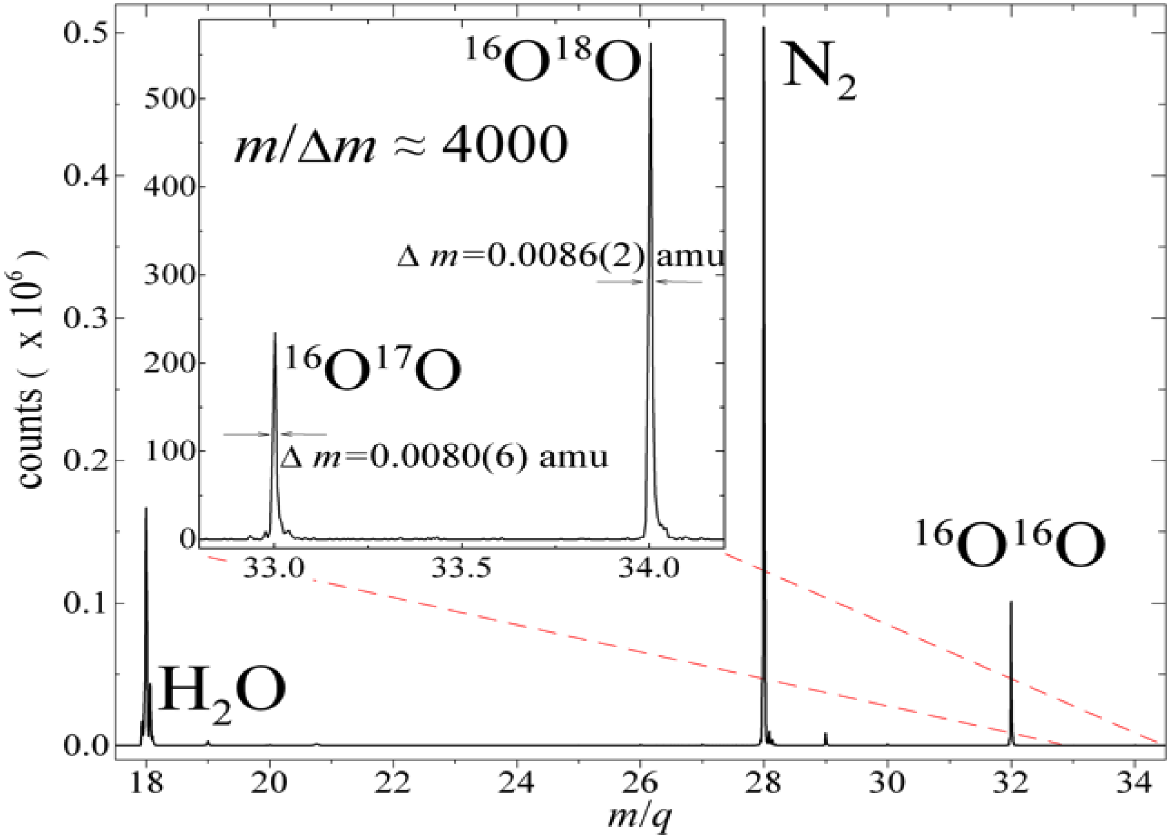
isotope	K-profile fit	2013 SRTD	terrestrial
	%	manual	%
Xe-124	0.095(9)	0.100(4)	0.0952(3)
Xe-126	0.089(9)	0.091(4)	0.0890(2)
Xe-128	1.907(8)	1.88(2)	1.9102(8)
Xe-129	26.330(4)	26.4(1)	26.401(8)
Xe-130	4.094(7)	4.09(4)	4.071(1)
Xe-131	21.229(4)	21.3(1)	21.232(3)
Xe-132	26.933(4)	26.9(1)	26.909(3)
Xe-134	10.458(5)	10.46(6)	10.436(2)
Xe-136	8.865(5)	8.80(6)	8.857(4)

isotope	K-profile fit	2013 SRTD	isotec
	%	manual	%
Xe-124	0.569(9)	0.555(8)	0.50(5)
Xe-126	2.889(8)	2.83(2)	2.80(5)
Xe-128	16.117(8)	15.85(7)	16.0(5)
Xe-129	71.910(7)	72.1(2)	71.90(5)
Xe-130	3.014(8)	3.14(2)	3.10(5)
Xe-131	4.119(9)	4.15(3)	4.20(5)
Xe-132	1.326(7)	1.33(1)	1.40(5)
Xe-134	0.0428(8)	0.044(2)	0.10(5)
Xe-136	0.0076(7)	0.008(1)	--

[1] Madzunkov, S.; Nikolic, D. “Accurate Xe Isotope Measurement Using JPL Ion Trap.” *J. Am. Soc. Mass Spectrom.* **2014,** *25,* 1841-1852.

Jet Propulsion Laboratory
California Institute of Technology

Science Performance – JPL MS



High Resolution Mode

$m/\Delta m \approx 4000$ FWHM for 10-80 Da mass range

Require resolutions $m/\Delta m \approx 2000$ FWHM to resolve pairs like:

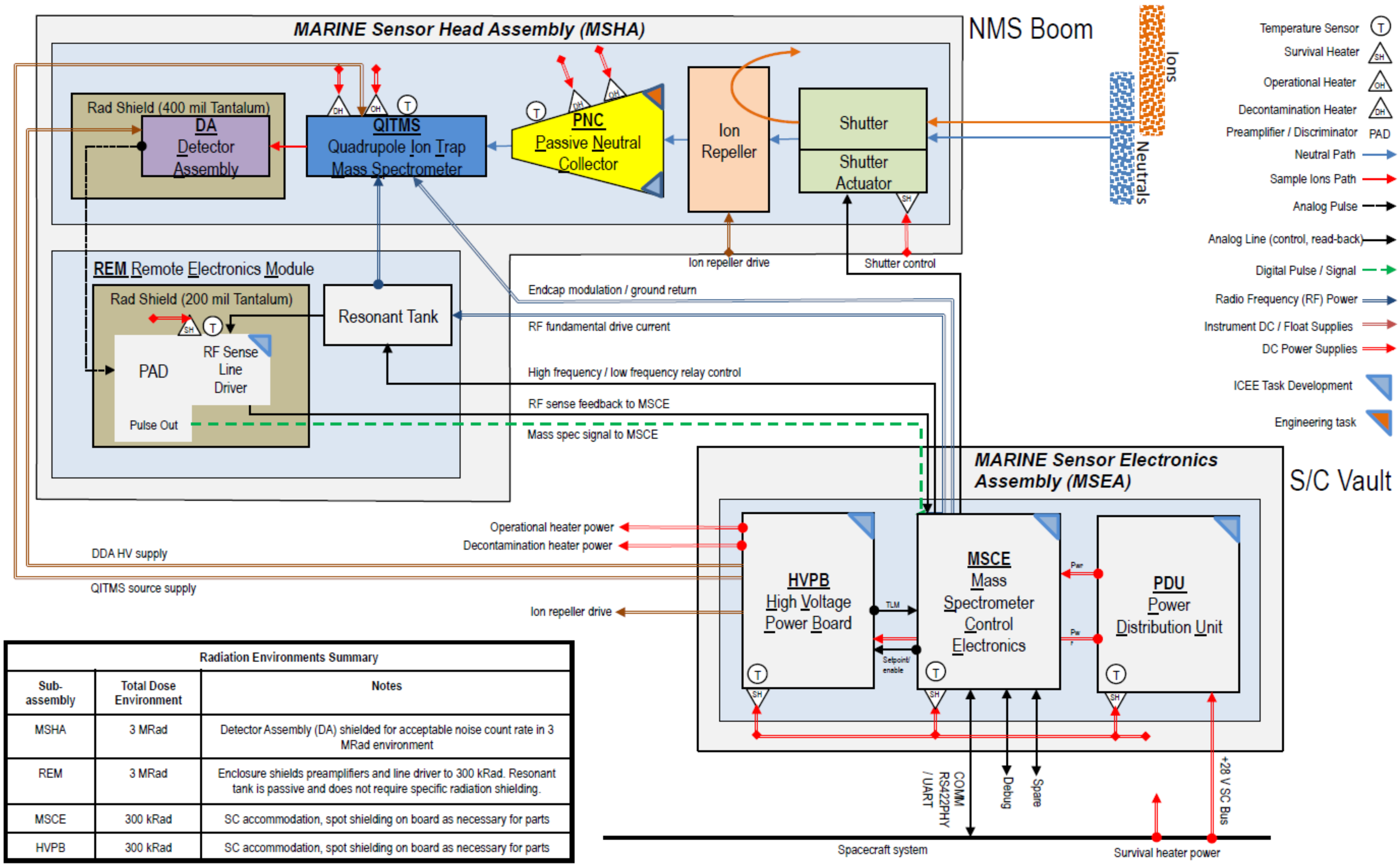
a) ^{32}S and $^{16}O^{16}O$

b) $H_2{}^{32}S$ and ^{34}S

c) $H_2{}^{32}S$ and $^{16}O^{18}O$

Jet Propulsion Laboratory
California Institute of Technology

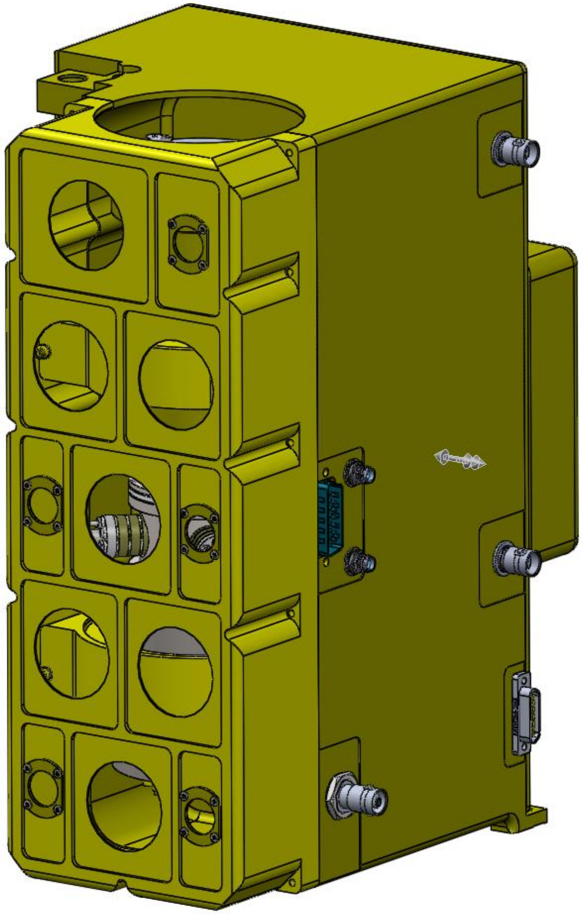
Sensor Architecture

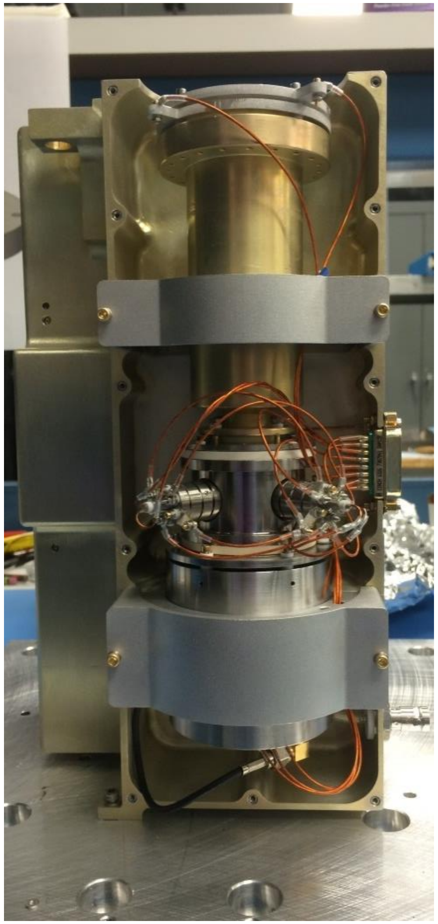


Radiation Environments Summary		
Sub-assembly	Total Dose Environment	Notes
MSHA	3 MRad	Detector Assembly (DA) shielded for acceptable noise count rate in 3 MRad environment
REM	3 MRad	Enclosure shields preamplifiers and line driver to 300 kRad. Resonant tank is passive and does not require specific radiation shielding.
MSCE	300 kRad	SC accommodation, spot shielding on board as necessary for parts
HVPB	300 kRad	SC accommodation, spot shielding on board as necessary for parts

Jet Propulsion Laboratory
California Institute of Technology

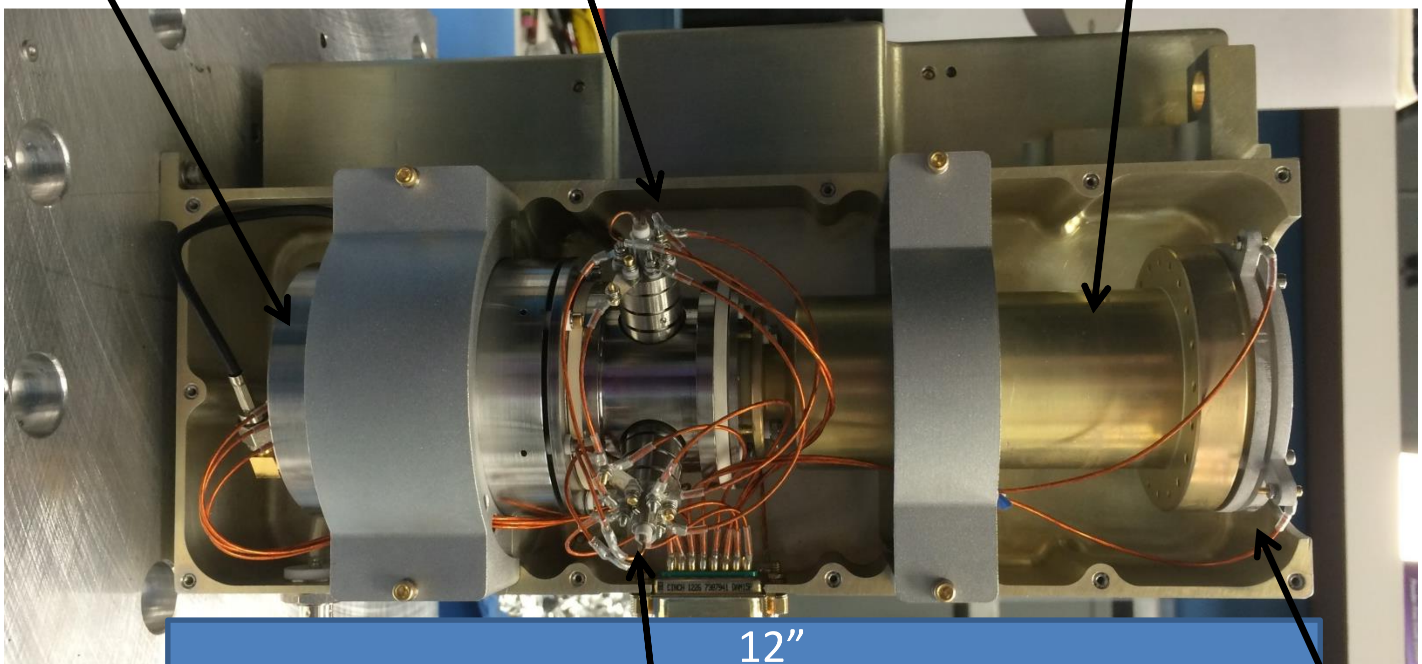
Prototype Sensor





Jet Propulsion Laboratory
California Institute of Technology

Prototype Sensor



Detector assembly

- Channel electron multiplier operated in ion-counting mode.

Entrance grids

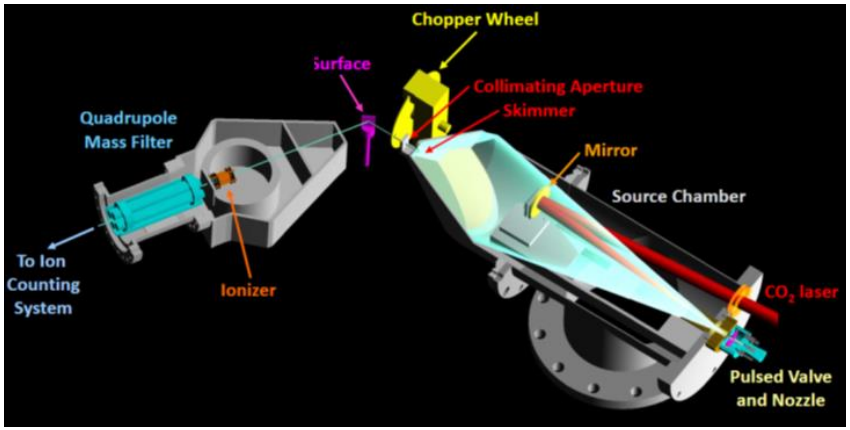
Channel electron multiplier detector

Signal feedthru on underside (not visible)

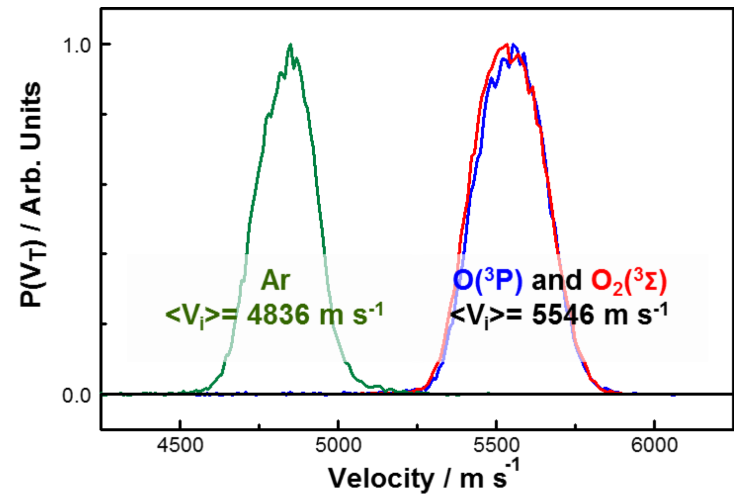
Jet Propulsion Laboratory
California Institute of Technology

Hypervelocity Neutral Beam Testing of Funnel Collector

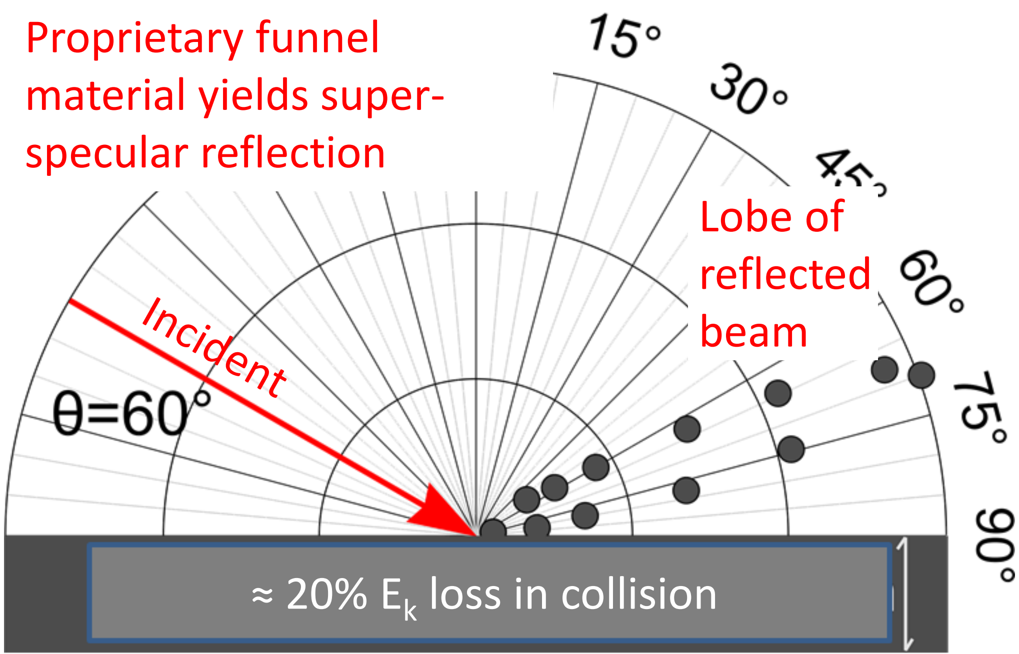
Apparatus



Measured Neutral Beam Velocity Profiles

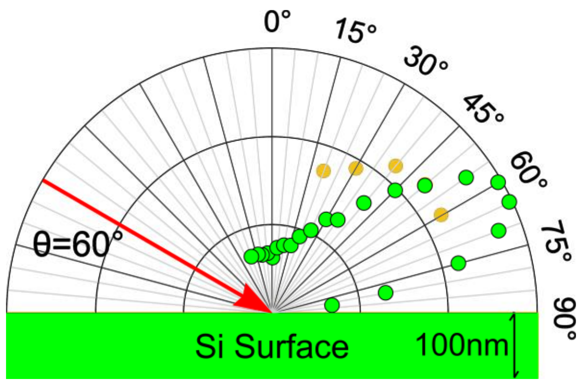


Proprietary funnel material yields super-specular reflection



- Funnel testing in relevant environment
- May be possible to achieve TRL 6
- Materials tested: Evaporated Gold, Silicon, and proprietary surfaces
- Incident beams: Atomic O, O_2, Ar
- Next Tests: CH_4, CH_3OH, C_2H_5OH

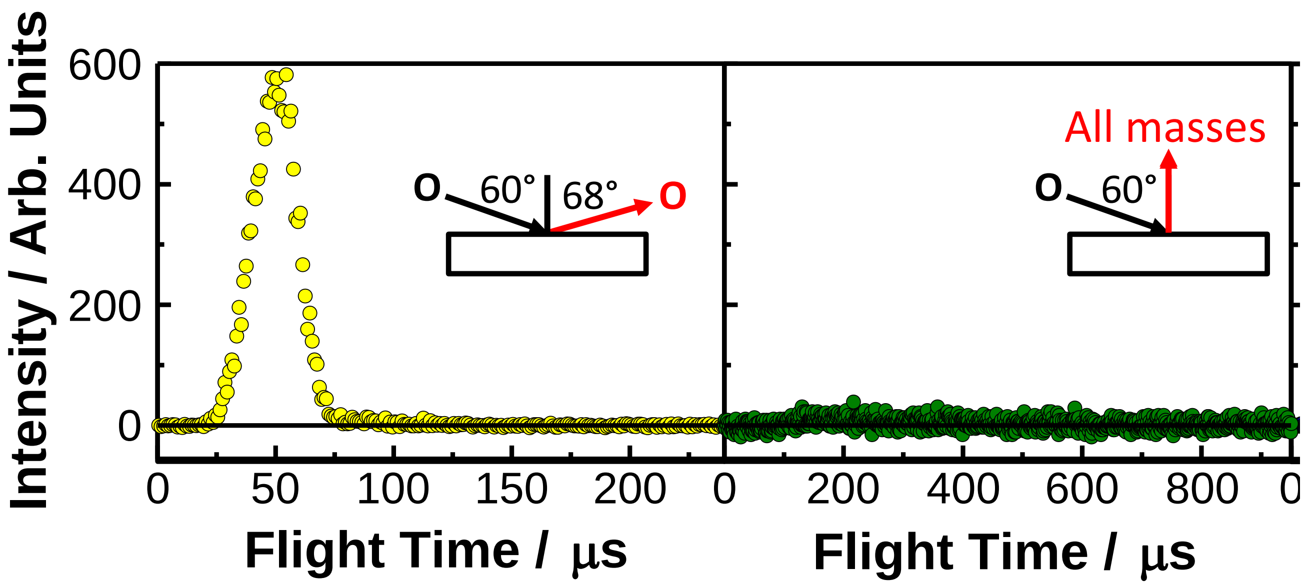
Hypervelocity Neutral Beam Testing of Funnel Collector



Gold coated λ/200 optical flat

Bare Si wafer

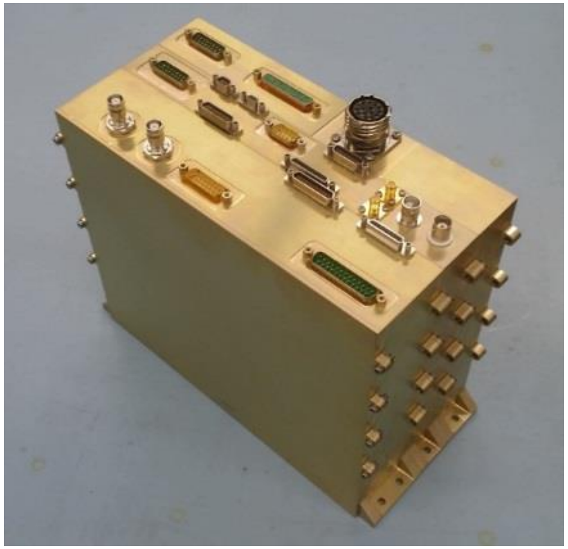
All other materials tested show high accommodation factors and reaction with incident hypervelocity beams



Integrated mass spectrum shows than no reaction products are formed from atomic oxygen impacting proprietary funnel material

Proprietary Material is highly non-reactive – even to atomic oxygen

Instrument Electronics



Prototype MARINE MSEA radiation hardened design

Mass: 3.5 kg
(including radiation shielding)

A: Mass Spectrometer Controller Electronics (MSCE)

B: Prototype High Voltage Power Board (HVPB)

Harsh Environment Survivability & Test Program

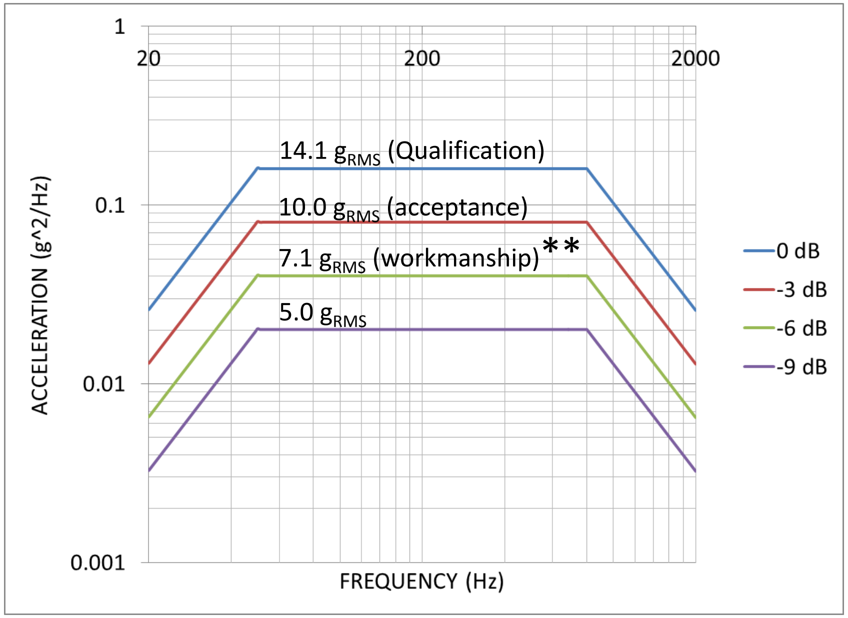
- What harsh environment?
  - T=0: Launch dynamics
  - Cruise: Venus Flyby (thermal)
  - Operations: Jovian orbit (Thermal, Radiation)

Sensor Dynamics Testing

- Completed random vibration testing to 'workmanship' levels, September 2015. **PASS**

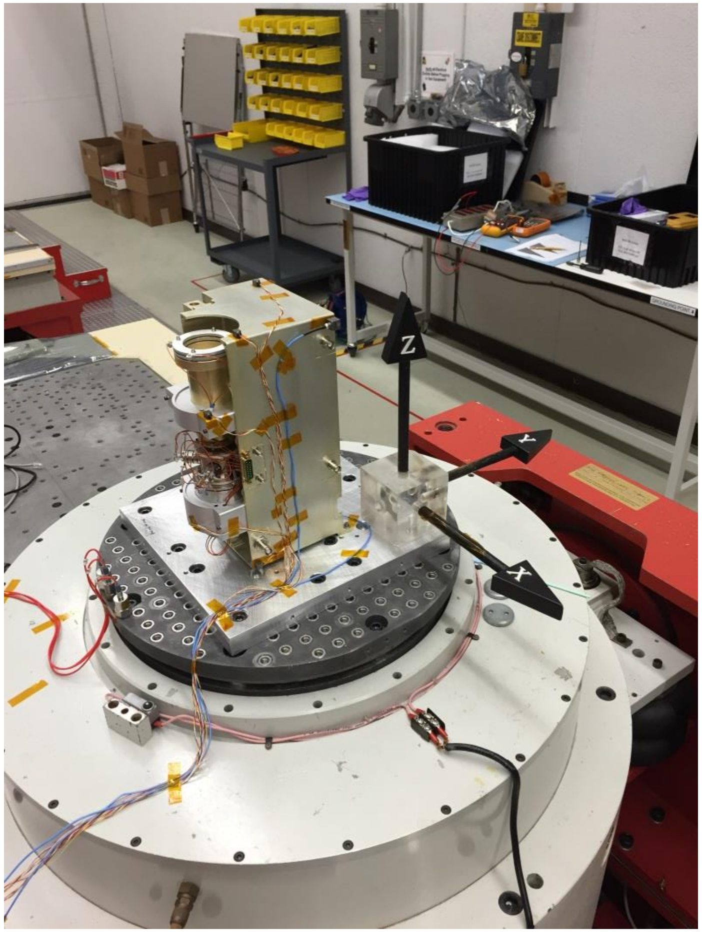
GEVS* Random Vibe Levels

- GSFC STD 7000 for qualification of hardware less than 50 pounds



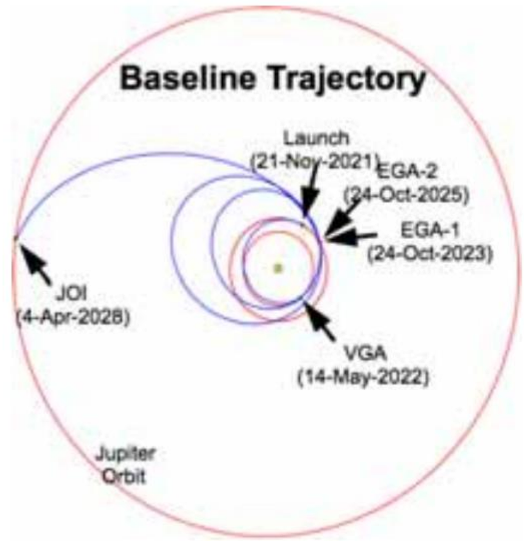
* General environmental verification standard, GSFC-STD-7000 available on Internet

** Not the same spectrum as the workmanship vibe but approximately the same g (RMS) level

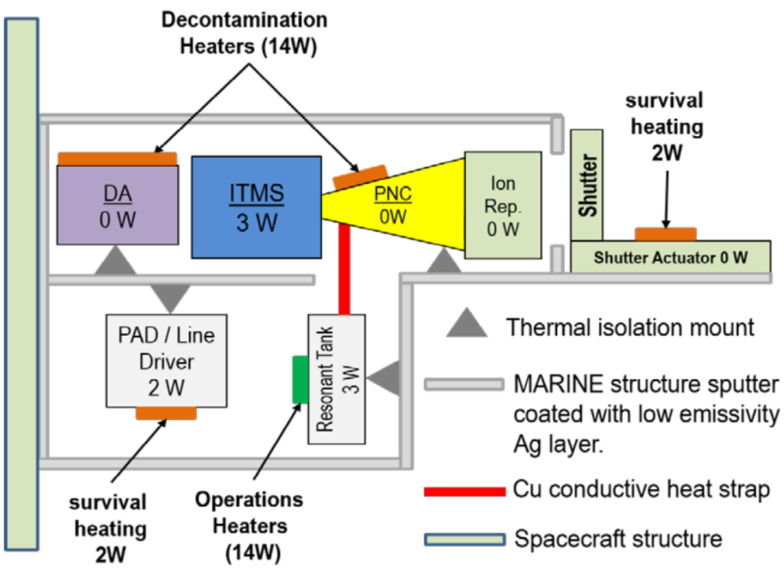


Thermal Environment

- During cruise, one trajectory brings the instrument close to Venus, where it would be necessary to add a cover over the instrument to shield from high heat loads.
- During operations, the problem is getting too cold.



If launched on ATLAS, extended time closer the Sun and Venus would heat the instrument.



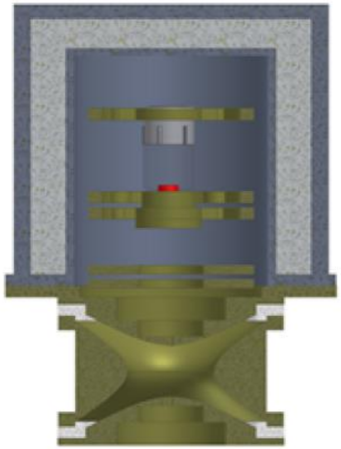
During MEASURE the PNC/QITMS ops temp (60°C) is maintained by thermally conducting heating on the REM RTM to the PNC.

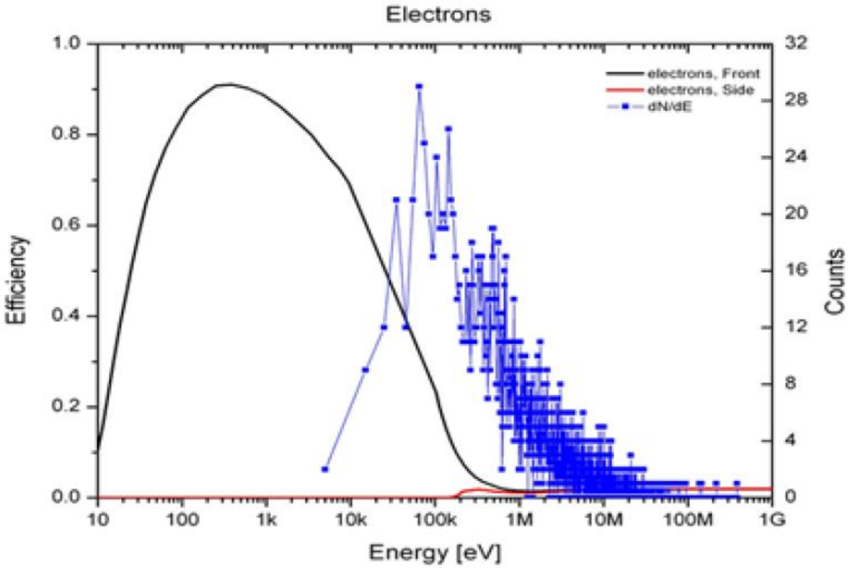
Jet Propulsion Laboratory
California Institute of Technology

Radiation Modelling

- The spacecraft is actually orbiting Jupiter to achieve the Europa flybys.
- The background radiation environment is nominally 2 Mrad (megarad), which the Flyby MS must not only survive, but operate with adequate signal-to-noise.
- We modeled the radiation environment and determined the expected effectiveness of the shielding design using GEANT4.

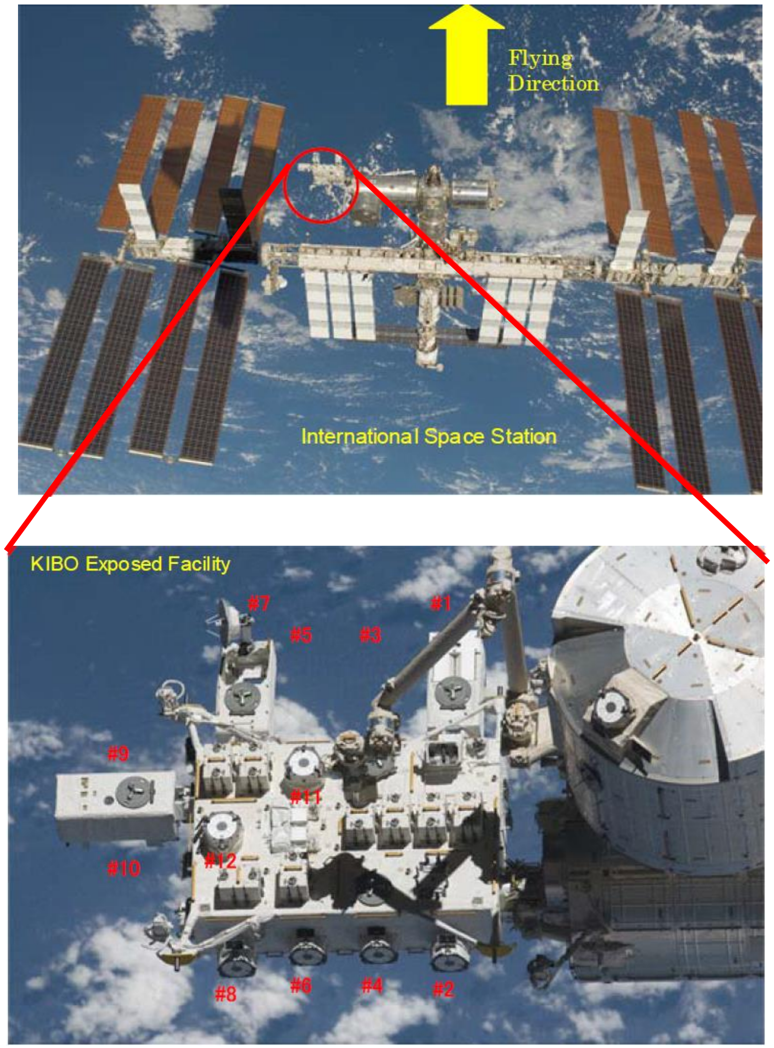
Based on radiation modelling results, we determined the type and required thicknesses for shielding the detector.





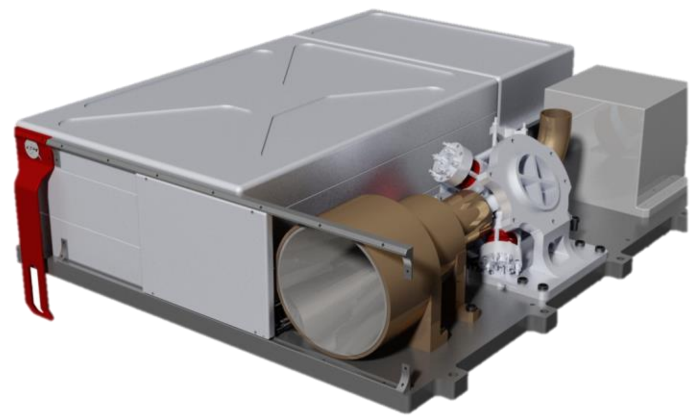
Jet Propulsion Laboratory
California Institute of Technology

Future Opportunity – ISS Exterior



ISS Exterior is the relevant environment for testing the instrument system

Take engineering model and do minimum work required to interface to ISS



Engage NASA HTIDES and PSTARs programs to augment existing launch/deployment funding for operations and analysis.

Conclusion & Acknowledgments

- JPL Flyby MS developed and tested for survivability on space missions.
- Based on very mature JPL ion trap mass spectrometer.
  - Unparalleled science performance, and more papers coming!
- Future opportunities include ISS exterior as platform for study of Earth using a flyby MS.
  - Gas mixing in upper atmosphere
  - Life detection???

Thanks to:

- JPL Research & Technology Development (R&TD)
- NASA Instrument Concepts for Europa Exploration (ICEE) funding opportunity

Jet Propulsion Laboratory
California Institute of Technology

This work was performed at the Jet Propulsion Laboratory (JPL), California Institute of Technology, under a contract with the National Aeronautics and Space Administration (NASA).