JPL Flyby Mass Spectrometer

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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
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
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 20000 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 10000 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
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 European 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
Projected MARINE plume detection for the Europa-7 flyby. If a plume exists anywhere within the blue ellipse, then MARINE will detect plume H₂O at 3:1 signal:background or greater. Likewise, MARINE will detect plume-based CO₂, SO₂ or NH₃ 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.

3. MARINE Will Distinguish and Characterize Potential Plumes

<table>
<thead>
<tr>
<th>Species and Real-time Limits of Detection (cm⁻³ s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂S, CO₂, SO₂ and most Cₙ (N ≤ 6) organics</td>
</tr>
<tr>
<td>Cₙ (N &gt; 6) organics</td>
</tr>
</tbody>
</table>

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.

4. MARINE Will Measure Isotopic Ratios of Key Species to Understand Europa’s Planetary Evolution
MARINE will determine the ¹⁶O : ¹⁷O ratio to an accuracy and precision of better than 25 % and 4 %, respectively.
### Unparalleled Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Instrument Sensitivity</strong></td>
<td>0.5 molecule/cm³/sec</td>
</tr>
<tr>
<td><strong>Mass Range</strong></td>
<td>Wide-Range (WR) Mode = 20 to 320 Da&lt;br&gt;High-Resolution (HR) Mode = 10 to 80 Da</td>
</tr>
<tr>
<td><strong>Mass Resolution (m/Δm)</strong></td>
<td>Wide-Range Mode = 750 FWHM at 300 Da&lt;br&gt;High-Resolution Mode = 4000 FWHM at 64 Da</td>
</tr>
<tr>
<td><strong>Key Redundancy</strong></td>
<td>Dual ionizers</td>
</tr>
<tr>
<td><strong>On Board Calibration</strong></td>
<td>MS performance can be validated any time during cruise or Europa encounters</td>
</tr>
<tr>
<td><strong>Lifetime</strong></td>
<td>More than 350 encounters</td>
</tr>
</tbody>
</table>

### MARINE Resources

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MARINE MSHA</th>
<th>MARINE MSEA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mass (CBE + cont.)</strong></td>
<td>7.3 kg</td>
<td>3.7 kg</td>
</tr>
<tr>
<td><strong>Volume</strong></td>
<td>9.7 L</td>
<td>6.3 L</td>
</tr>
<tr>
<td><strong>Ops. Power per encounter</strong></td>
<td>83.7 W•hr CBE&lt;br&gt;101.5 W•hr (CBE + 21% cont.)&lt;br&gt;44 W CBE (peak) for 25 min.</td>
<td></td>
</tr>
<tr>
<td><strong>Ops. Data Volume</strong></td>
<td>10.9 MBits per encounter (lossless VCAM heritage compression)</td>
<td></td>
</tr>
</tbody>
</table>
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 PIDDPP)
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
Science Performance\textsuperscript{1} – JPL MS

\begin{tabular}{|l|c|c|c|}
\hline
isotope & K-profile fit & 2013 SRTD & terrestrial \\
\hline
& % & 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-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) \\
\hline
\end{tabular}

\begin{tabular}{|l|c|c|c|}
\hline
isotope & K-profile fit & 2013 SRTD & isotec \\
\hline
& % & 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) & -- \\
\hline
\end{tabular}

High Resolution Mode

\( \frac{m}{\Delta m} \approx 4000 \) FWHM for 10-80 Da mass range

Require resolutions \( \frac{m}{\Delta m} \approx 2000 \) FWHM to resolve pairs like:

a) \(^{32}\text{S}\) and \(^{16}\text{O}^{16}\text{O}\)

b) \(\text{H}_2^{32}\text{S}\) and \(^{34}\text{S}\)

c) \(\text{H}_2^{32}\text{S}\) and \(^{16}\text{O}^{18}\text{O}\)
Sensor Architecture

**Radiation Environments Summary**

<table>
<thead>
<tr>
<th>Sub-assembly</th>
<th>Total Dose Environment</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSHA</td>
<td>3 Mrad</td>
<td>Detector Assembly (DA) shielded for acceptable noise count rate in 3 Mrad environment</td>
</tr>
<tr>
<td>REM</td>
<td>3 Mrad</td>
<td>Enclosure shields preamplifiers and line driver to 300 kRad. Resonant tank is passive and does not require specific radiation shielding.</td>
</tr>
<tr>
<td>MUCE</td>
<td>300 kRad</td>
<td>SC accommodation, spot shielding on board as necessary for parts</td>
</tr>
<tr>
<td>HVPB</td>
<td>300 kRad</td>
<td>SC accommodation, spot shielding on board as necessary for parts</td>
</tr>
</tbody>
</table>
Prototype Sensor
Prototype Sensor

- Detector radiation shield
- Ion trap MS
- Funnel collector
- Electron impact ionizer
- Ion repeller rings

[Image of prototype sensor with labeled parts]
Detector assembly

- Channel electron multiplier operated in ion-counting mode.

Entrance grids

Channel electron multiplier detector

Signal feedthru on underside (not visible)
Hypervelocity Neutral Beam Testing of Funnel Collector

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, O₂, Ar
- Next Tests: CH₄, CH₃OH, C₂H₅OH

Measured Neutral Beam Velocity Profiles

\[ \text{P}(V)/\text{Arb. Units} \]

- Ar \( <V> = 4836 \text{ m s}^{-1} \)
- O\(^{(3P)}\) and O₂\(^{(3Σ)}\) \( <V> = 5546 \text{ m s}^{-1} \)
Hypervelocity Neutral Beam Testing of Funnel Collector

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

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

Integrated mass spectrum shows that no reaction products are formed from atomic oxygen impacting proprietary funnel material
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)
• 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.
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.
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???

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