MAss Spectrometer for Planetary EXploration

MASPEX/Europa

OPAG @ JHU/APL

J. Hunter Waite and the MASPEX Europa Team

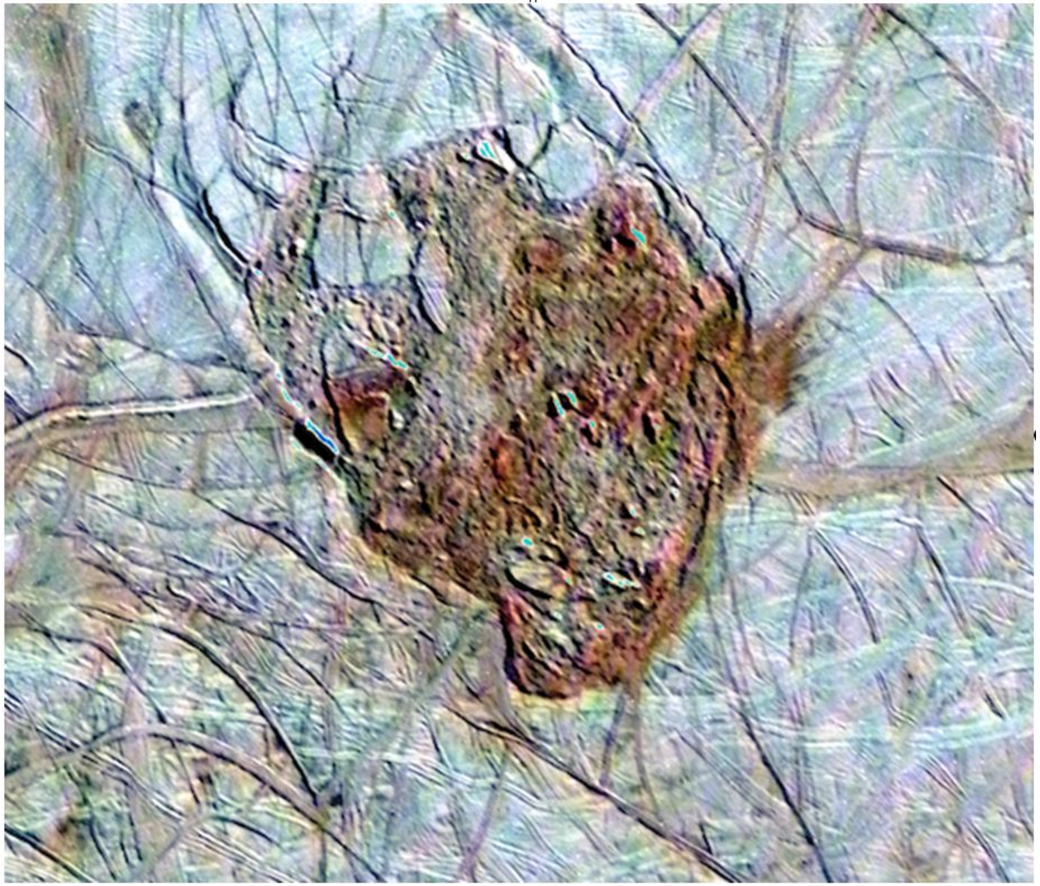
August 24, 2015

Science Traceability Matrix

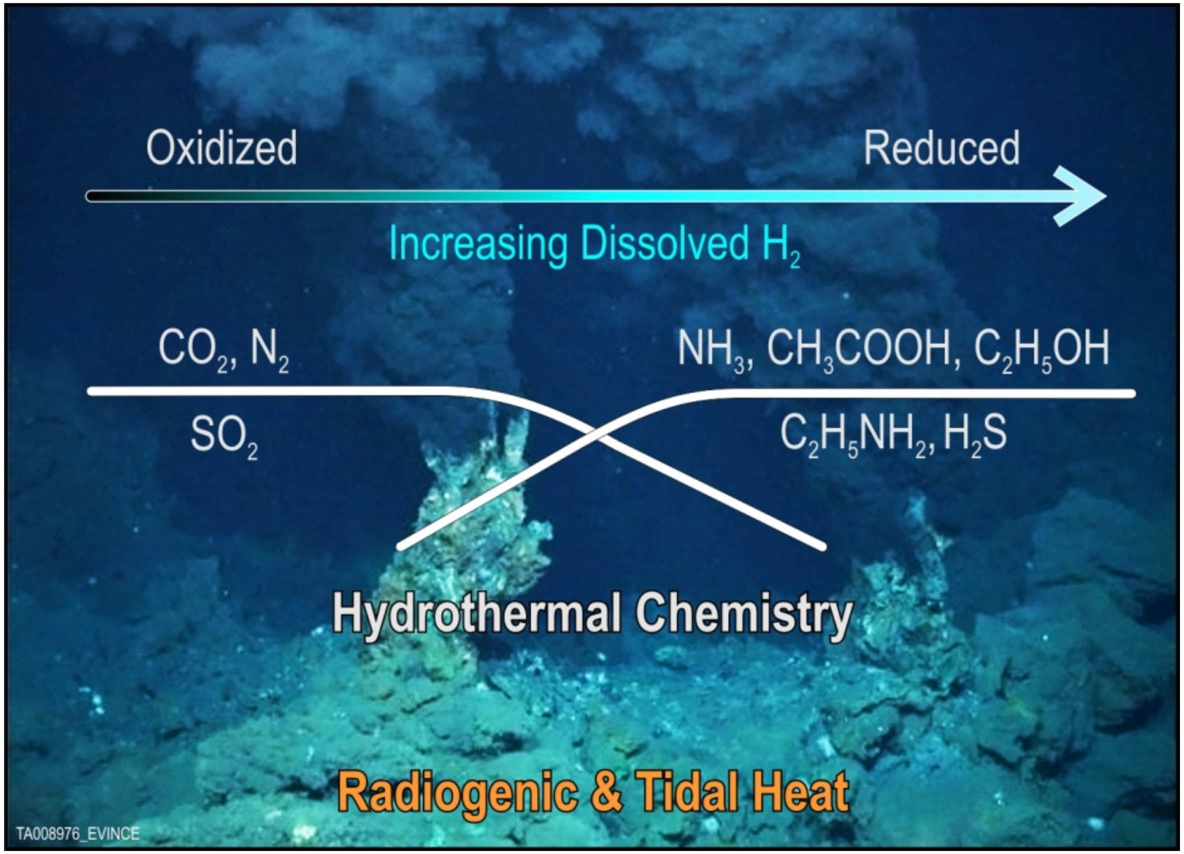
Goal	Science Objectives	Observables	Scientific Measuremen
			Physical Parameters
To constrain conditions for habitability on Europa through high-resolution, high-sensitivity measurements of the volatile composition of the exosphere and possible plumes.	Determine the distribution of major volatiles and key organic compounds in Europa's exosphere/plumes and their association with geological features	1A) Density variations of major volatiles (H_2O, O_2, H_2, CH_4, C_2H_4, C_2H_6, HCN) on a global scale to provide exospheric structure, plume identification (both during and after active plume release), and correlation with geological features.	Determine density variations of H_2O, O_2, H_2, CH_4, C_2H_4, C_2H_6, and HCN, where mixing ratios exceed 1 ppm, to 25% precision with a spatial resolution of 100 km S/C track (23 s@ 4.43 km/s).
		1B) $H_2O/^{40}Ar$ ratio to determine surface-interior overturn.	Detect and measure ^{40}Ar at mixing ratios >1 ppb.
	Determine the relative abundances of key compounds to constrain the chemical conditions of Europa's ocean	2A) Densities of H_2O, H_2, CH_4 and their D/H ratios from plume or outgassing sources to establish the level of communication with an internal aqueous system.	Determine D/H in CH_4, H_2, and H_2O to 5% precision.
		2B) The molecular and isotopic composition of the volatiles NH_3, N_2, CO, CH_4, CH_3OH, C_2H_5OH, CH_3CO_2H, $C_2H_5NH_2$, and CO_2, from plume or outgassing sources that serve as indicators of redox state and degree of redox disequilibrium in the internal ocean.	Measure the volatiles NH_3, HCN, N_2, CO, CH_4, CH_3OH, C_2H_5OH, CH_3CO_2H, $C_2H_5NH_2$, and CO_2, for mixing ratios >10 ppb, to 25% precision. Where mixing ratios are $>1\times10^{-3}$ measure isotopic ratios to precisions of 0.5% [C]; 30% [H]; 0.5% [O]; 25% [N]
		2C) The radiolysis products (NH_3, HCN, N_2, CO, CH_4, CH_3OH, C_2H_5OH, CH_3CO_2H, and CO_2) of surface compounds and plume deposits to divine likely synthesis pathways and surface residence times.	
		2D) Abundances for the C_1-C_8 hydrocarbons: CH_4, C_2H_2, C_2H_4, C_2H_6, C_3H_4, C_3H_6, C_3H_8, C_4H_8, C_4H_{10}, C_5H_{10} C_5H_{12}, and C_8H_{18} from plume or outgassing sources to determine the extent of synthesis, the hydrothermal temperature, and degree of equilibrium among species.	Measure abundances to 25% precision where mixing ratios >10 ppb.

Surface Composition

Thera Macula, an example of disrupted, “chaotic” terrain that may be the site of exchange between the Europa’s surface and a subsurface liquid layer. MASPEX measurements of exospheric composition will be correlated with such geological features and contrasted with those from older, less disturbed terrain to provide insight into possible interior- surface exchange.



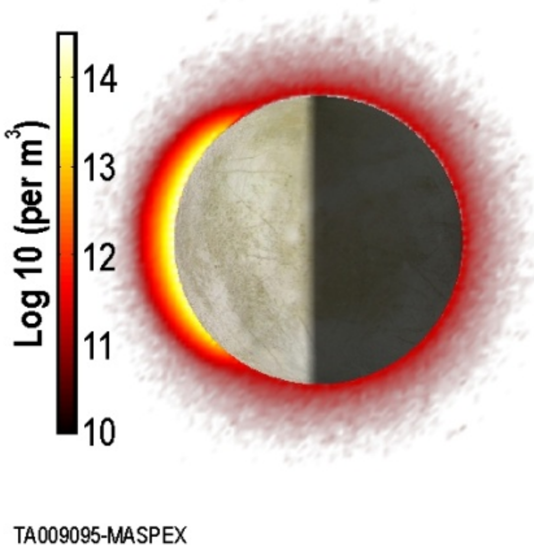
Ocean Chemistry

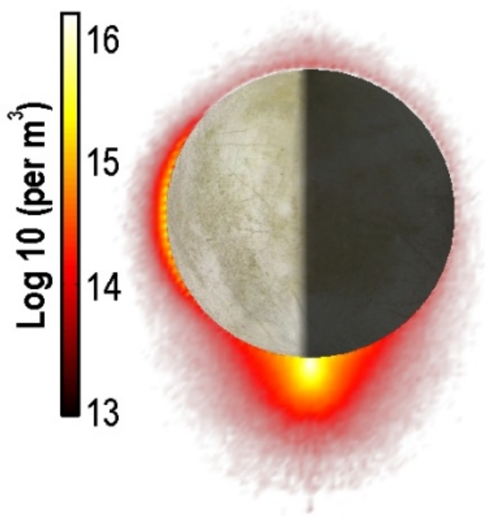


- The oxidation state and temperature of the water-rock system determines the products formed from dissolved aqueous C, N, S, etc.
- Typical terrestrial hydrothermal systems operating at moderate temperatures favor reducing conditions and the synthesis of organic compounds

Global Exosphere Modeling

H_2O density

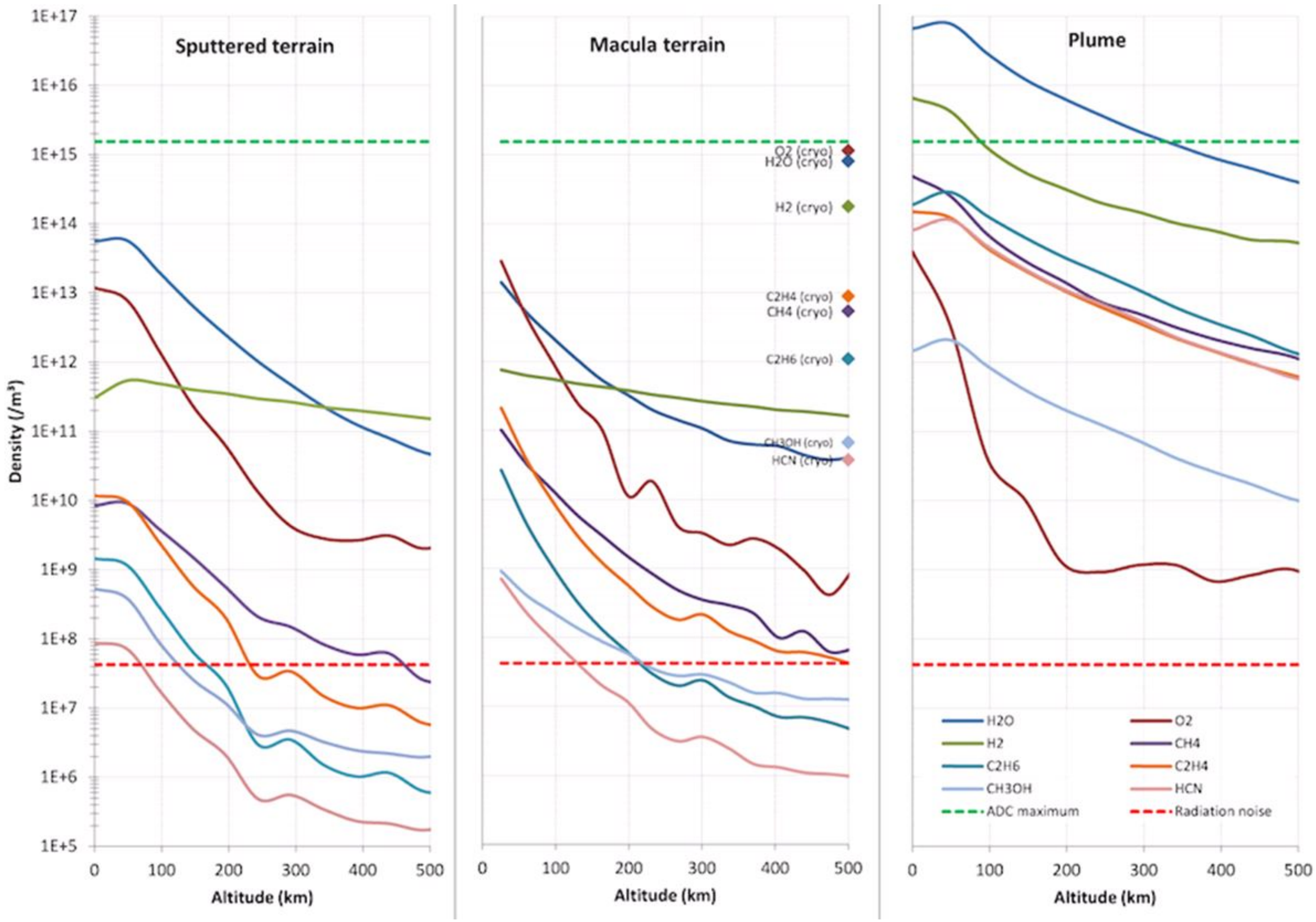




- Energetic particle sputtering combined with surface sublimation
- Creates a significant density enhancement over the sunlit region

- Sputter-produced exosphere combined with a south polar plume
- Plume material is transported equatorward and deposited at lower latitudes, where it is sputtered together with older material.

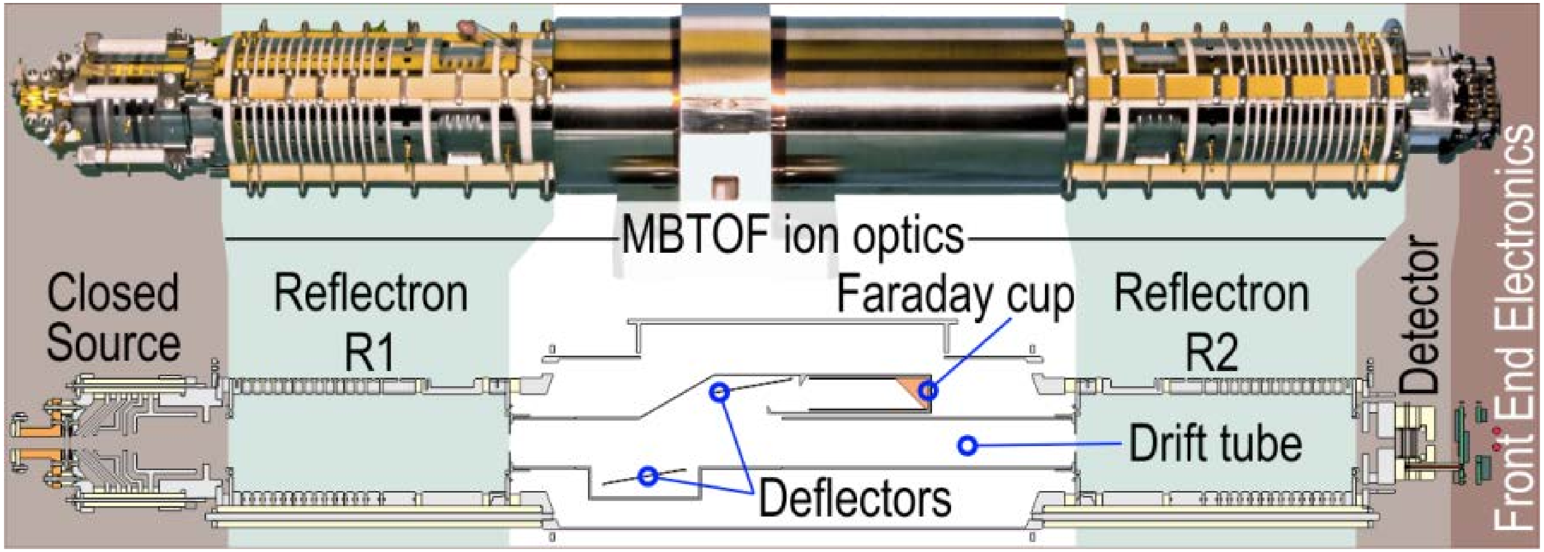
Modeled Densities



Density profiles for representative species in three different Europan exospheric environments

Instrument Characteristics

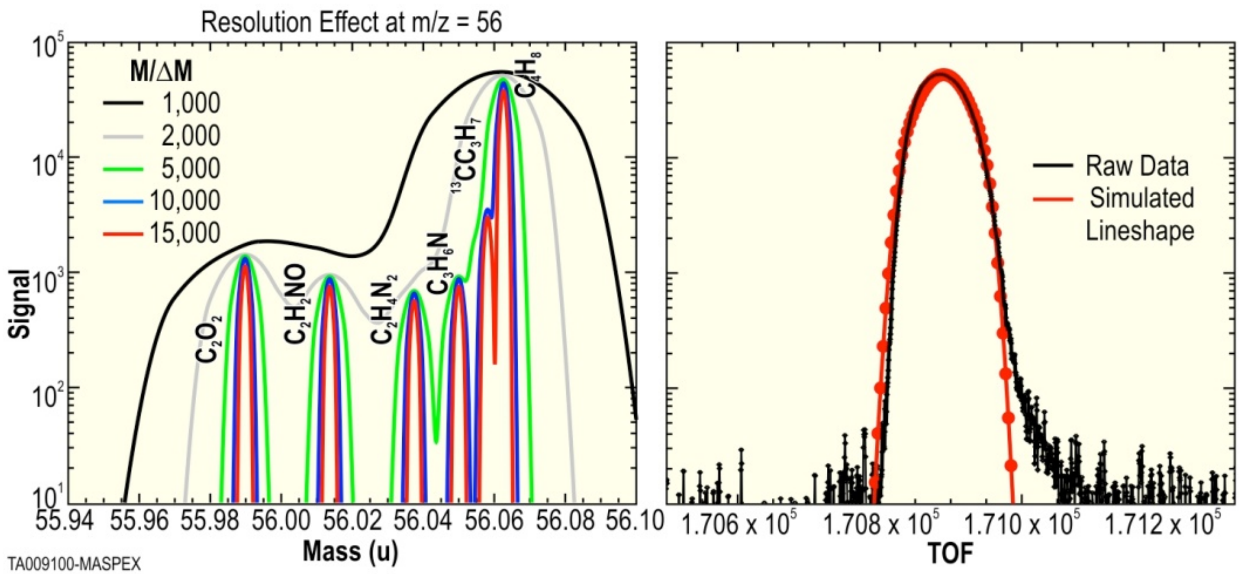
System Characteristics		
Subsystem	**Type**	**Specification**
GIS - thermalizer	Spherical antechamber, single use cover	FOV: ±90° in Y, ±25° in X, + Z boresighted
GIS - cryotrap	Cryotrapping/direct inlet, neutral gas	Sensitivity boost: up to 200 counts s^{-1} per mol cm^{-3}
MS - closed source	Storage, electron ionization, redundant emitters	Ambient sensitivity: 0.02 counts s^{-1} per mol cm^{-3}
MS - ion optics	Multibounce time-of-flight	Resolution: 24,540 m/Δm 10% valley definition
MS - detector	Electron multiplier	MCP, 3 plate z-stack, 2μm pore
Resources - Current Best Estimate (CBE)		
Mass & Volume	**Power (W)**	**Average Data Rate**
11.71 kg, instrument, 4.5 kg harness, 4.0 kg radiation shielding, 0.0203 m^3	45.4 (Peak), 35.4 (Average), 8.0 (Standby), 4.5 (Survival)	57 kbps (peak), 14 kbps (average)



MBTOF cross section and photo of the third-generation instrument identifying the arrangement of the major components

The Importance of Mass Resolution

Studies of the Enceladus plume hint at the presence of a large number of possible organic compounds whose identification is hindered by the low resolution of Cassini INMS. The simulation (left) demonstrates how increasing resolution enables the individual fragment ions (created by electron impact ionization within the source) of parent organic molecules to be fully separated and quantified. The spectrum (right) shows how the peak shape used in the simulation derived from MASPEX laboratory data.



A comprehensive simulation of the expected Europa environment was performed in the same way to identify the optimum analyte fragments and the resolution necessary for full separation. This information is used to define MASPEX's science operation modes.

Science Operations Modes

Obj.	Mode	Description	Characteristics	Data (kbits)	Driving Requirements
1	SOM-A	Ambient mode. Specific chemical composition analysis with spatial resolution	23 s of varying length co-added spectra in each of 4 ROIs, mass range 2-32 u, m/Δm 6,948.	3,723 /flyby	Spatial variations – selected species every 23 s. Mass range – 2-32 u.
2	SOM-T	Cryotrapping mode. Prior to mode C, parallel to mode A.	Traps sample on adsorber at ~65K; Sample density determines trap time	n/a	Sensitivity: 400× compression factor boosts ^{40}Ar to 1×10^6 for SOM-C.
2	SOM-C	Cryotrapped sample survey. Enables method updates to suit environment. Comprehensive mass survey, ppm mixing fraction species.	0.5 s co-added spectra in each of 34 ROIs, mass range 2-200 u, m/Δm ~12,000, total time 17 s.	74,834 / sample	Sampling time – 1 per flyby. Mass range – 16-114 u. Resolution – C_2HD needs m/Δm 23,822. ^{40}Ar analysis drives dynamic range to 1×10^9, and detection limit to $1\times10^6/m^3$.
		Cryotrapped sample analysis. Targeted ROI method minimizing analysis time and data volume.	2028 s of varying length co-added spectra in each of 13 ROIs, mass range 16-114 u, m/Δm up to ~23,822.	20,607 / sample	

Note: Obj. = Science Objective. Data are telemetry volumes, compressed data in transmission packets; CBE. m/Δm uses 10% valley definition.

On every flyby MASPEX executes a series of ambient measurements (SOM-A) and cryotraps an exospheric sample (SOM-T). The SOM-T sample is held and analyzed at a point in the orbit where the radiation-induced noise on the detector is at low levels.

Method Characteristics for SOM-C

Anticipated measured compounds for both the ambient (SOM-A) and cryotrapped (SOM-C) modes.

ROI	Integration time (s)	Analyte	Mass (u)	Resolution (m/Δm)
1	16.71	HCN	27.01	3,690
		C_2H_4	28.03	6,948
		C_2H_6	30.05	6,948
2	0.55	O_2	31.99	3,042
3	1.36	CH_4	16.03	1,464
		H_2O	18.01	91
4	4.37	H_2	2.02	31
		HD	3.02	37
Note: m/Δm uses 10% valley definition.				

ROI	Integration time (s)	Analyte	Mass (u)	Resolution (m/Δm)
1	26.20	$CO(^{13}C)$	29.00	35,800*
		$N_2(^{15}N)$	29.00	73,805*
		$C_2H_6(^2H)$	31.05	25,158*
2	4.67	$C_3H_8(^{13}C)$	45.07	11,699
		$C_3H_8(^2H)$	45.07	37,120*
		C_2H_6O	46.04	10,539
3	27.26	$CO(^{18}O)$	30.00	33,113*
4	8.13	$C_2H_2(^2H)$	27.02	23,822
5	57.40	NH_3	17.03	1,154
		$CH_4(^{13}C)$	17.03	4,351
		$CH_4(^2H)$	17.04	11,811
6	5.35	H_2O	18.01	91
		$NH_3(^{15}N)$	18.02	2,283
		$NH_3(^2H)$	18.03	12,882
7	27.42	$H_2O(^{17}O)$	19.01	9,851
		$H_2O(^2H)$	19.02	13,228
8	28.99	C_4H_8	56.06	13,048
		$C_2H_4O_2$	60.02	2,167
		C_5H_{10}	70.08	4,630
		C_5H_{12}	72.09	16,988
9	22.90	C_3H_6	42.05	10,061
		CO_2	43.99	143
		C_3H_8	44.06	10,996
		C_2H_7N	45.06	10,424
		C_4H_{10}	58.08	10,305
		C_8H_{18}	114.14	690
10	1756.90	$Ar(^{40}Ar)$	39.96	2,312
		C_3H_4	40.03	9,392
11	7.95	C_2H_2	26.02	110
		CO	27.99	2,846
		N_2	28.01	2,846
		C_2H4	28.03	6,948
		C_2H_6	30.05	6,948
12	1.56	CH_4O	32.03	7,427
13	53.01	CH_4	16.03	1,464
		$H_2O(^{18}O)$	20.01	96
*Determined using peak deconvolution Note: m/Δm uses 10% valley definition.				

Data Products and Science Closure

Observable	Data Products	Science Closure
1A	H_2O, O_2, H_2, CH_4, C_2H_2, C_2H_4, C_2H_6, HCN density @ 25, 50, 100 km altitude spatially localized maps for flyby mission (37 flybys); near-global coverage for the orbital mission	**Determine** exospheric composition, structure, and locations of plume/ outgassing [Johnson et al., 2009] **Determine** compositional variation associated with geological features [Johnson et al., 2009]
1B	Density of ^{40}Ar every flyby	**Determine** surface to interior exchange rates [Waite et al., 2005]
2A	Densities of CH_4, H_2, and H_2O and their D/H for every flyby ≤100 km or 156 times per orbit	**Identify** active plume connected to an internal ocean from H_2 and CH_4 isotopes relative to H_2O. **Determine** hydrothermal temperature [Proskurowski et al., 2006]
2B	Densities of: • CO_2, N_2, NH_3, CO, CH_4 • $^{15}N/^{14}N$ in N_2 & NH_3; D/H in NH_3 • $^{13}C/^{12}C$ and $^{18}O/^{16}O$ in CO • $^{13}C/^{12}C$ and D/H in CH_4 • CH_3OH, C_2H_5OH, HCOOH, CH_3COOH, $C_2H_5NH_2$ for all flybys ≤50 km or once per orbit	**Determine:** • oxidation state of the ocean from plume outgassing [Shock and McKinnon, 1993] • role of minerals in compound transformations (alkane/alkene, alcohol/ ketone) [Shock et al., 2013] • temperature of oxidation/reduction reactions (alkane ratios) [Shock et al., 2013] • pH acidic: low ratio (alkenes, alkynes, esters, ethers, amides, imides and nitriles) / (alcohols, carboxylic acids, ammonia), pH basic: hemi-acetal bonds of polymers are hydrolyzed [Shipp et al., 2013] • free energy from disequilibria of volatile compounds [Shock et al., 2013] • origin of N- and C-bearing material [Mandt et al., 2014; Mumma and Charnley, 2011]
2C	Densities and isotopes of major C- and N-bearing compounds at the ppm level	**Determine** origin and radiolytic age of organic compounds on the surface and test for habitability [Sephton et al., 2014; Mumma and Charnley, 2011].
2D	Density of hydrocarbon compounds (plume gas) with mixing ratios greater than 10 ppb when ≤50 km from cryotrapped samples or once per orbit	**Identify** the formation of organics through hydrothermal organic transformations [Shock et al., 2013; McCollom, 2013]

Instrument Block Diagram

A block diagram of the instrument showing the major subsystems:

Gas inlet system (GIS)

Mass spectrometer (MS).