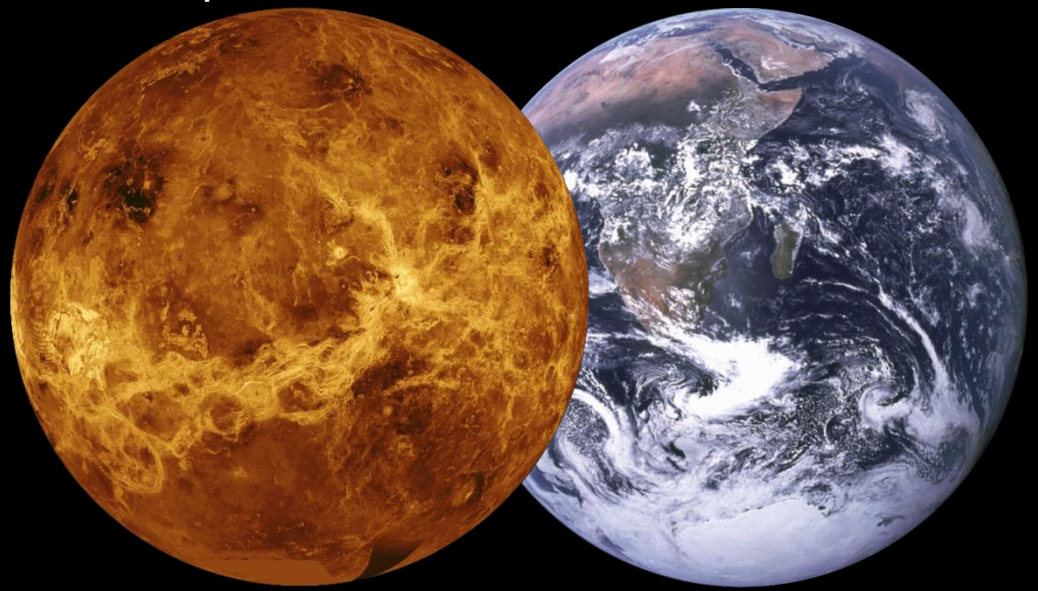
Jet Propulsion Laboratory
California Institute of Technology

VERITAS

Cupid's Arrow:

An Innovative Nanosat to Sample Venus' Upper Atmosphere

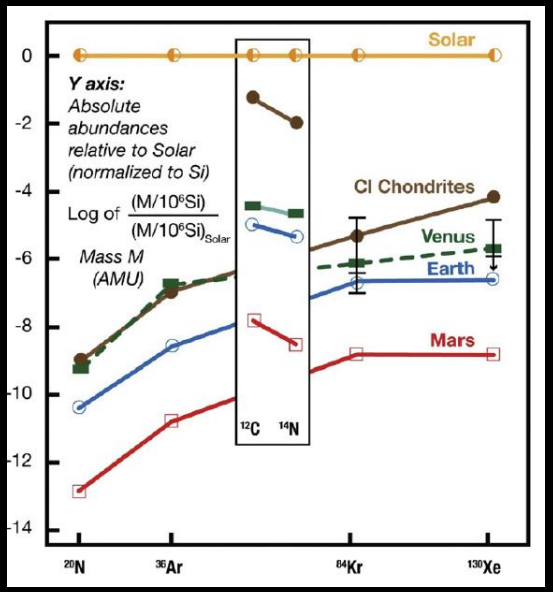
M. Darrach
Planetary Surface Instruments Group
Jet Propulsion Lab
Pasadena, CA.



Science Goal: **Answer the highest-priority investigations as identified by the Venus Exploration Analysis Group (VEXAG)**

I. Atmospheric Formation, Evolution, and Climate History
   - A. Atmospheric Formation and Evolution
     - **1. Noble gases**
     - 2. D/H, $^{15}N/^{14}N$
   - B. Energy Balance, Super-Rotation and Greenhouse
   - C. Cloud and Haze Chemistry and Dynamics

II. Evolution of the Surface and Interior
   - A. II-A-2 is also about measuring noble gases
   - B. …..



Venus Xe (9 isotopes):
- Depleted / Kr
- Fractionated in mass
- Comparative planetology will help determine the processes involved in the distribution of noble gases

Science requirements were provided in a peer-reviewed paper (Chassefiere et al., 2012):

Required precision on noble gas and stable isotope measurements.

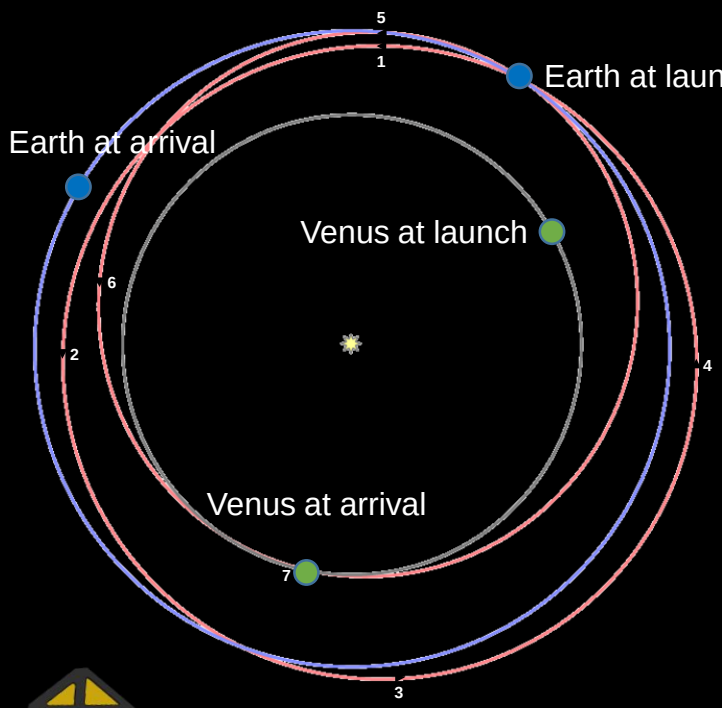
Measured parameters	Precision (%)
Concentrations of major isotopes (^{4}He, ^{20}Ne, ^{36}Ar, ^{40}Ar, ^{84}Kr, ^{130}Xe)	~5–10
Helium isotope ratio (^{3}He/^{4}He)	~5–10
Other major isotope ratios (^{20}Ne/^{22}Ne; ^{36}Ar/^{38}Ar; ^{82,83,86}Kr/^{84}Kr; $^{129,131-136}$Xe/^{130}Xe	~1
Minor isotope ratios (^{21}Ne/^{22}Ne; ^{78,80}Kr/^{84}Kr; $^{124-128}$Xe/^{130}Xe)	~5

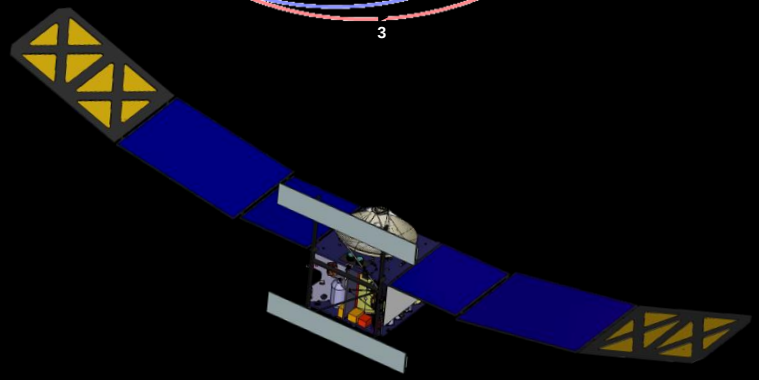
Jet Propulsion Laboratory
California Institute of Technology

VERITAS Mission

(Venus Emissivity, Radio Science, INSAR, Topography, and Spectroscopy)

- Use of LM-developed MAVEN bus
- Type IV trajectory
  - 27-month cruise, with launch in November 2021 in Earth-Earth-Venus Type IV trajectory
  - VOI in February 2024
  - 8.6 months aerobraking to achieve 216 km orbit at 88.5° inclination
  - 3-Venus cycle baseline science mission
- Instrumentation includes
  - Interferometric synthetic aperture radar
  - Venus emissivity mapper
  - Gravity science investigation





Jet Propulsion Laboratory
California Institute of Technology

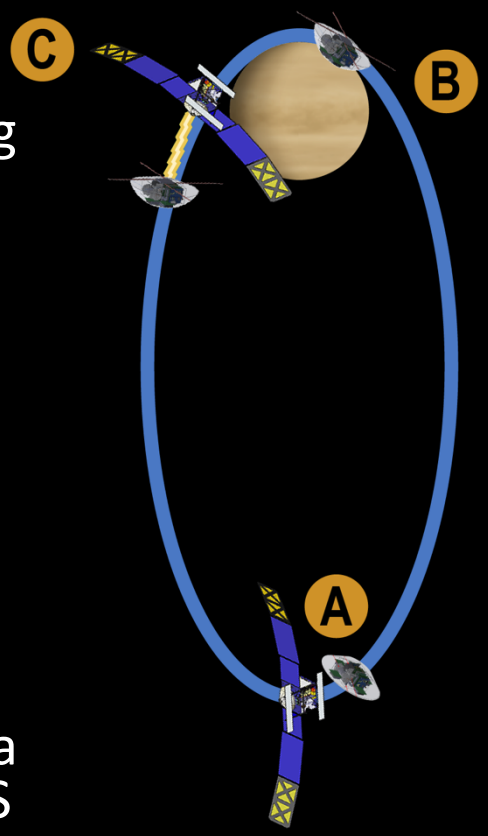
VERITAS

VERITAS TDO

Cupid's Arrow

- We considered an appropriate TDO to enhance our VERITAS mission
- Nanosat configuration including JPL's quadrupole ion trap mass spectrometer (QITMS), housekeeping and UHF transmitter weighing 16 kg
- Housed in a container on the VERITAS S/C –Z deck
- **A** Released at apoapsis, during the aerobraking phase
- **B** Enters atmosphere 7 ¾ hours after deployment

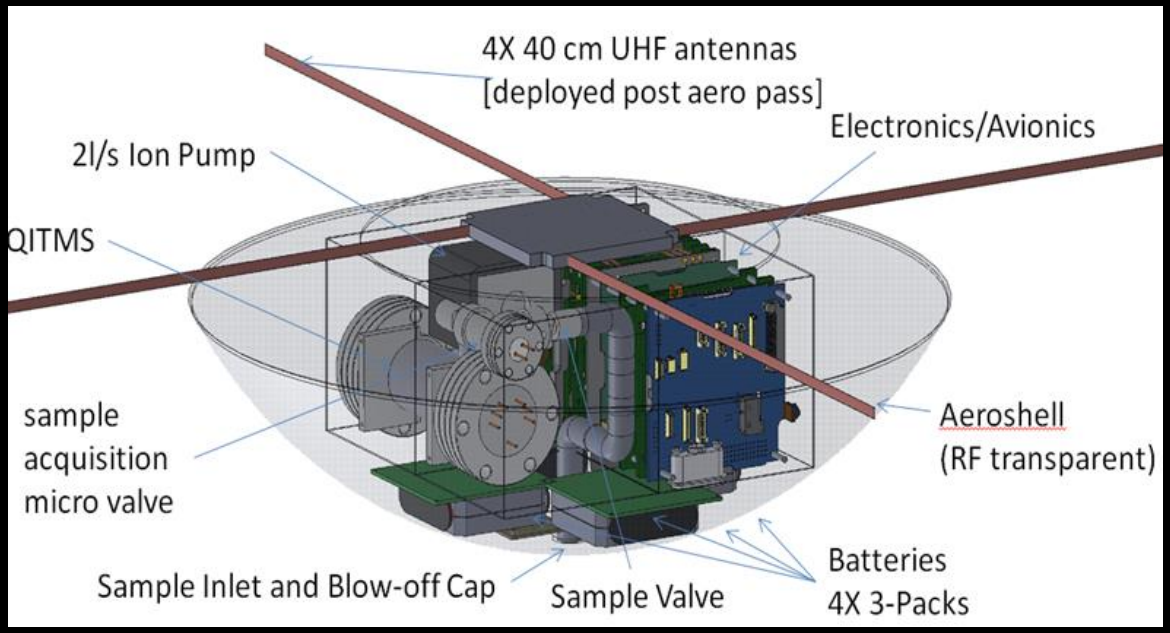
  Reaches a periapsis of 120 km to acquire a 100 ml sample
- **C** Skips out of the atmosphere, where it transmits noble gas and isotope ratio targeted species data for 5 minutes via UHF transmitter to the VERITAS S/C



The Cupid's Arrow CubeSat

Jet Propulsion Laboratory
California Institute of Technology

VERITAS



Key Technical Parameters	
Mass	Flight Vehicle 14 kg MEV 10.2 MEV deployer + relay avionics 24.2 kg not to exceed total
Power	28 vdc, ~3W supplied to heater and battery charger pre deployment
Data interface	RS422, SPC, I2C, or GPIOs for command and telemetry and SpaceWire for high speed/volume data
Thermal	TDO package to be thermally isolated from VERITAS
Mechanical interfaces	Deployer is new design for 1.25 m/s deployment velocity and 5 RPM spin
Payload	Ultra-compact, quadrupole ion trap mass spectrometer (QITMS)
CubeSat Equipment*	• Radiation tolerant dual-core to 200 MIPS processor • INSPIRE UHF-band radio and LGAs • 150-Wh battery
Flight software	RTOS supports telecom, CMD & TLM functions, Disruption Tolerant Network and Science data processing

QITMS Specification	Demonstrated Performance	Required Performance
Sensitivity	$> 10^{15}$ cps/Torr	10^{12} cps/Torr
Mass resolution (no cooling or buffer gas)	m/Δm (FWHM) > 14,000	m/Δm (FWHM) = 300 @ 130 Da
Measured isotopic precision for noble gases	10 ‰ (Madzunkov & Nikolić 2014)	100 ‰
Power	30 W (peak)	50 W

Development of JPL Flight Mass Spectrometry

Prior, Current or Funded Flight Instrument

Recent Work

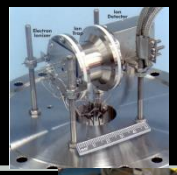
1995

Linear Quadrupole Mass Spectrometer Array (QMSA)

ISS Flight TRACE GAS ANALYZER

2000

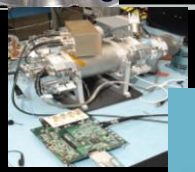
Quadrupole Ion Trap Mass Spectrometer (QIT MS)

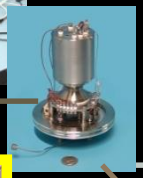


2005

Gas Chromatography (GC)

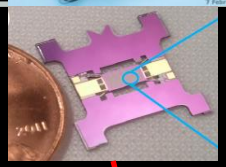
VCAM Flight GC





VCAM Flight QIT MS

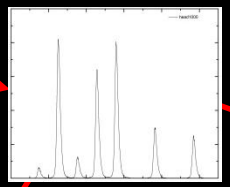
2010



MEMS GC Development

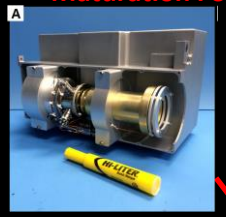
Vehicle Cabin Atmosphere Monitor (VCAM)

Wireless QIT MS



Noble Gas Isotopes 0.1% accuracy

MARINE: ICCE Technology Maturation For MS

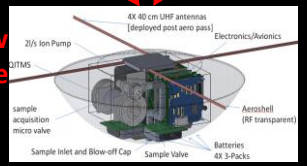


2015

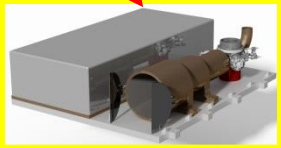
HEOMD / AES Next Generation Life Support

Spacecraft Atmosphere Monitor

Cupid's Arrow Venus Probe



Deployment of Flyby MS on ISS

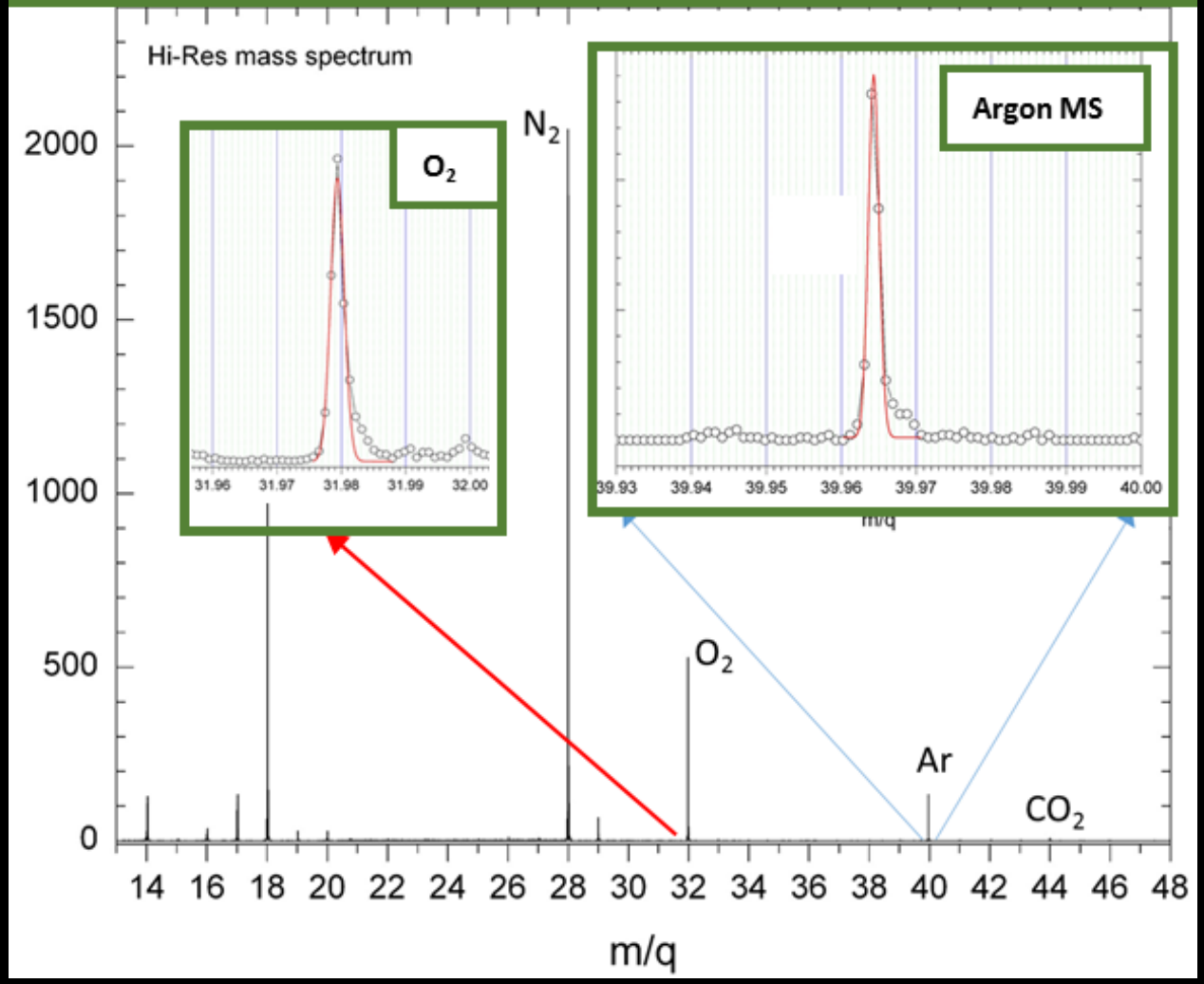


The JPL QITMS Mass Spectrometer

10mm JPL QITMS

“Wireless” Chamber

Demonstrated QITMS Mass Resolution
m/Δm ≈ 14,000 FWHM

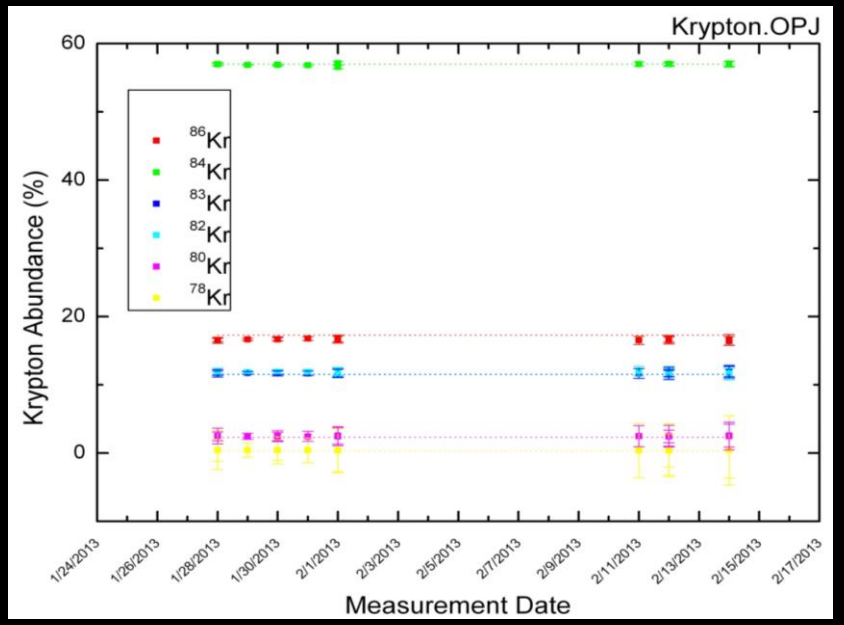


QITMS Isotopic Accuracy and Stability

Measurement Accuracy For Isotopic ratios < 1%

Measurement of Terrestrial Xenon			
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)

Multi-day Stability Without Re-tuning or Re-calibration

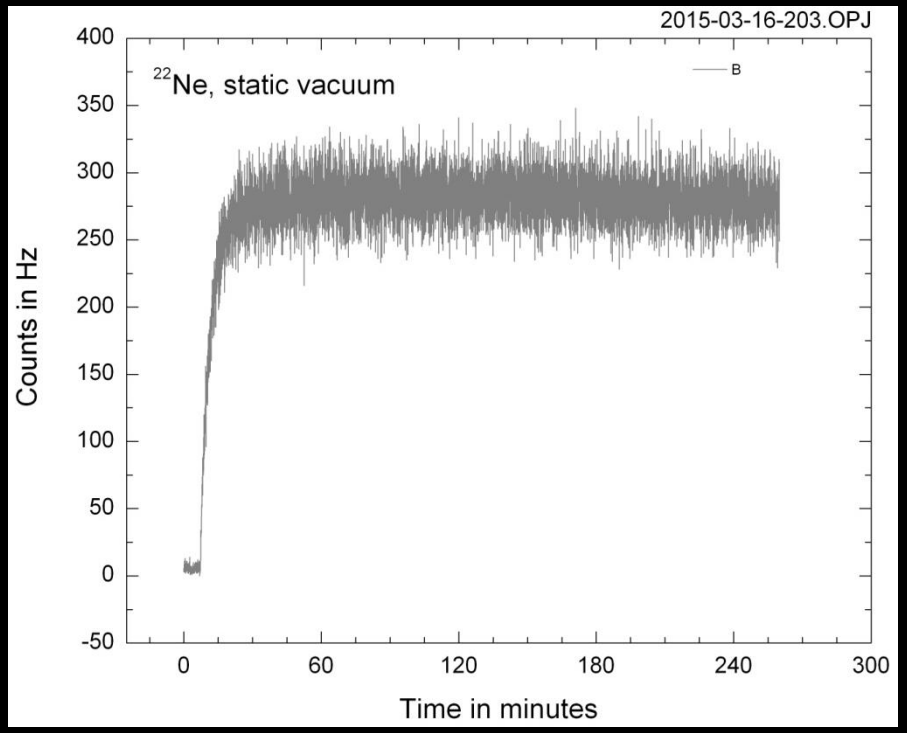


Better than 3‰ precision and 10 ‰ accuracy for isotopic abundance measurements <u>without re-tuning or re-calibration</u> of the MS

Madzunkov, S. and Nikolic, D. J Am Soc Mass Spectrom. 2014 Nov;25(11):1841-52.

Static Mode Measurement

Static vacuum measurements with ACES
Not constant flow as typically employed



Cupid's Arrow will employ TOTALLY static measurements (QITMS Valves CLOSED, Ion Pumps OFF) for noble gases:

- No gas flow during measurements
- Requires smaller pumping capacity/speed than other techniques

Measurement shown at left:

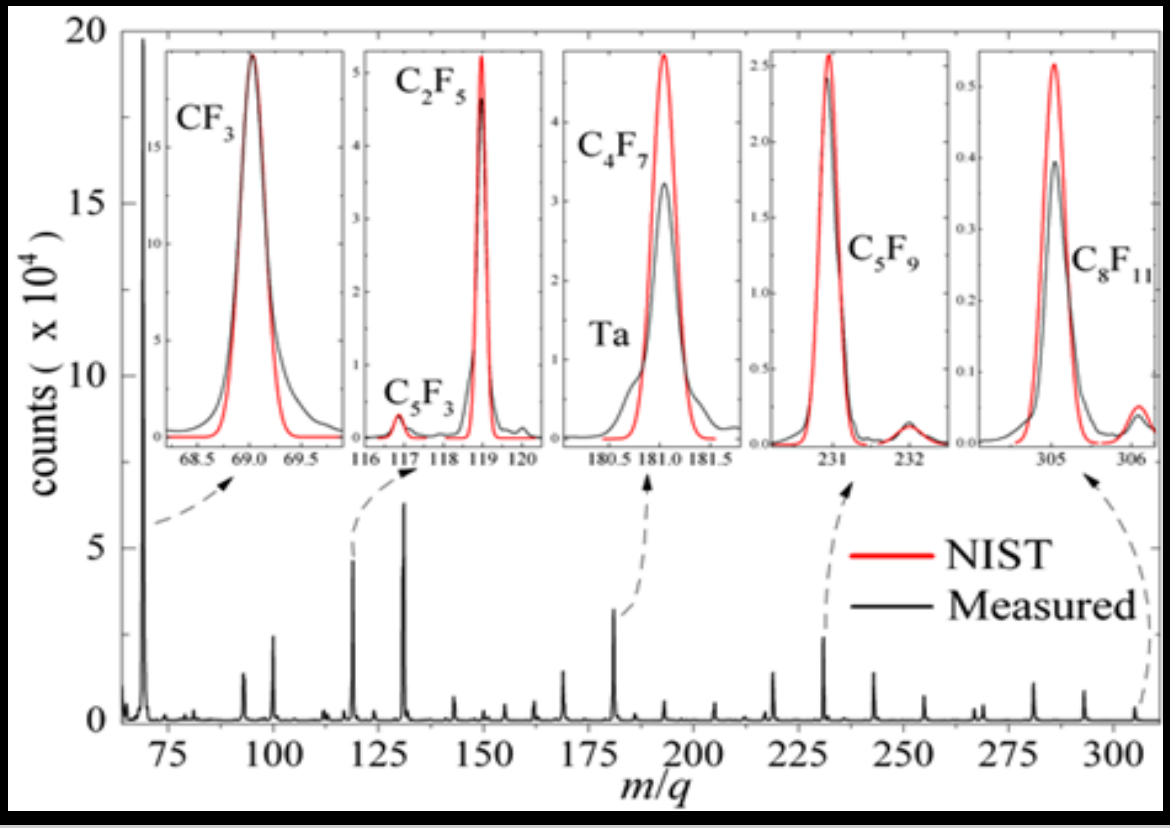
Fixed amount of ^{22}Ne (partial pressure of 1.2×10^{-10} Torr) was inserted into the system and measured

- ACES has a constant count rate for ^{22}Ne Unlike standard MS where count rate drops over time as the gas is consumed.
- More than 2E6 counts under ^{22}Ne (0.07% statistical error)

Typical MS yields decreasing counts with time (signal exhaustion within 2-3 min) whereas ACES does not consume target species.

Enables using very small quantities of trapped gas and measuring until statistics are achieved

Absolute Calibration



By monitoring the Ta^{+} (third inset) and Ta^{++} detected by the QITMS, the MS can be absolutely calibrated, for both sensitivity and mass number, during flight without calibrant gases.

These mass lines are available every mass scan (1 per second) and as such, provides built-in calibration on a second-by-second basis.

The QITMS electron source is a Ta button cathode. The quantity of Ta neutrals that enter the ion trap are related only to the color temperature of the Ta button and the electron-lens aperture sizes in the QITMS electron gun.

Likewise the Ta^{+} and Ta^{++} ions detected by the QITMS is directly proportional to the electron beam current and the trapping and detection efficiency of the QITMS.

QITMS Performance For Saturn Probe Mission

	Threshold measurement requirements (From COMPLEX Outer Planets report 1986)	ACES Performance			
NOBLE GASES	He/H to 5%	≤ 3% isotopic ratio ^{3}He: ^{4}He ≤ 1%			
	Noble gas abundances to ± 30% accuracy	Ne, Ar, Kr, Xe abundances ≤ 3-5%			
	Noble gas isotopic ratios to ±10% except rare isotopes ^{21}Ne, ^{78}Kr, $^{124,126}Xe$. (Xenon a goal: threshold a few parts in 10^{-11})	^{n}Ne: $^{total}Ne$ ≤ 1% for n = 20, 21, and 22	^{n}Ar : $^{total}Ar$ ≤ 1% for n = 40, 38, and 36	^{n}Kr : $^{total}Kr$ ≤ 1% for n = 80, 82, 83, 84, and 86	^{n}Xe : $^{total}Xe$ ≤ 1% for n = 128, 129, 131, 132, 134, and 136
ELEMENTAL ABUNDANCES	C/H, N/H, and (if present) O/H to ± 10% precision	C/H ≤ 3 % N/H ≤ 5 %		O/H ≤ 3-5 % deep atmosphere measurement	
	Isotopic ratios: $^{13}C/^{12}C$ and (if O is present) $^{18}O/^{16}O$ both to +1%	^{13}C : ^{12}C from CH_4 ≤ 3% ^{16}O : ^{18}O from H_2O ≤ 5% (deep atmosphere measurement)			
	$^{15}N/^{14}N$ and D/H to ± 5% in major (>0.1% abundance) molecular species	^{14}N:^{15}N from NH_3 ≤ 3% H : D from H_2 ≤ 5%			
	Sulfur to +/- 10% precision (solar S/H is just over 10 ppm)	S/H ≤ 5 % ^{32}S : ^{34}S from H_2S ≤ 10% Assuming deep (> 1 bar) atmosphere measurement			

Baseline enhancements	ACES Performance
neon abundance at 1% of the solar value (solar = 10^-4 Ne/H)	$^{Total}Ne$ / H ≤ 3%
$^{20}Ne/^{22}Ne$. Solar value is 13.8; comet grains are between 10.1 and 10.7	^{20}Ne:^{22}Ne ≤ 3% , ^{20}Ne:^{21}Ne ≤ 5%

Additional ACES Capabilities	ACES Performance
Disequilibrium Dynamic Trace Gases (e.g. PH_3, GeH_4, CO, AsH_3)	For abundances greater than 10 ppb, measurements at 10% precision (For higher abundances, correspondingly greater precision)
Atmospheric Profiles at intervals ≤ 7 km .	All chemical species between 2-150 Da with abundances greater 5 ppb with 10% precision(e.g. PH_3, GeH_4, CO, AsH_3, C_2H_4, C_2H_6, C_3H_8)

Planetary Surface Instruments Group
Mass Spectrometer Development Hub


M. Darrach


K. Farley


R. Kidd


S. Madzunkov


R. Schaefer


J. Simcic


D. Nikolic


E. Neidholdt


W. Rellergert


B. Bae