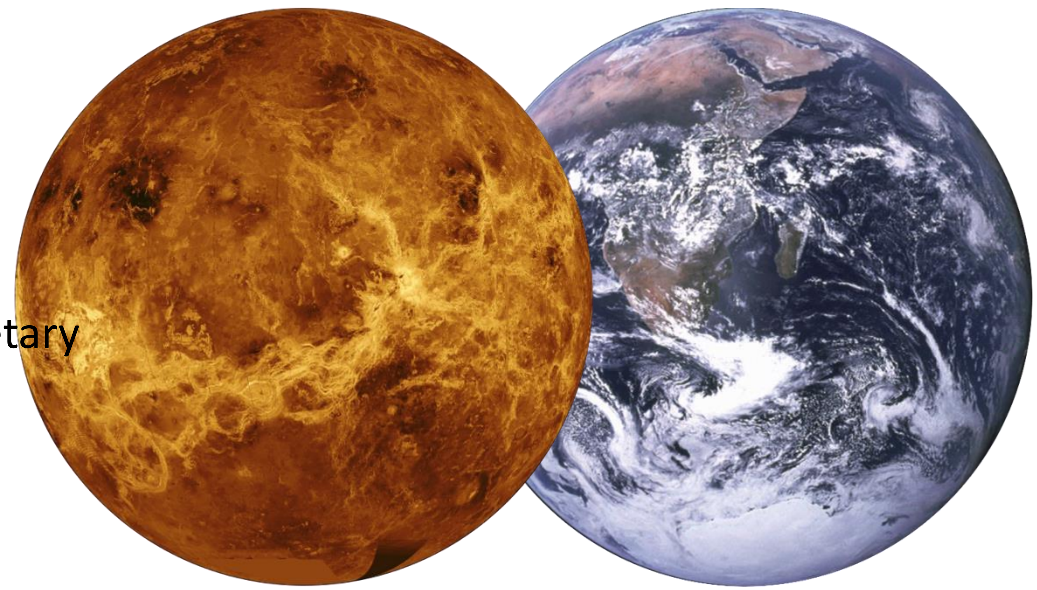
Cupid's Arrow: a small satellite to measure noble gases in Venus atmosphere

[1]Sotin C, [2]Avice G, [1]Baker J, [1]Freeman A, [1]Madzunkov S, [3]Stevenson T., [1]Arora N, [1]Darrach M, [3]Lightsey G , [4]Marty B,

[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA; [2]California Institute of Technology, Pasadena, CA; [3]Georgia Institute of Technology, Atlanta, GA;. [4]CRPG, Universite de Lorraine, Vandoeuvre-les-Nancy, France.

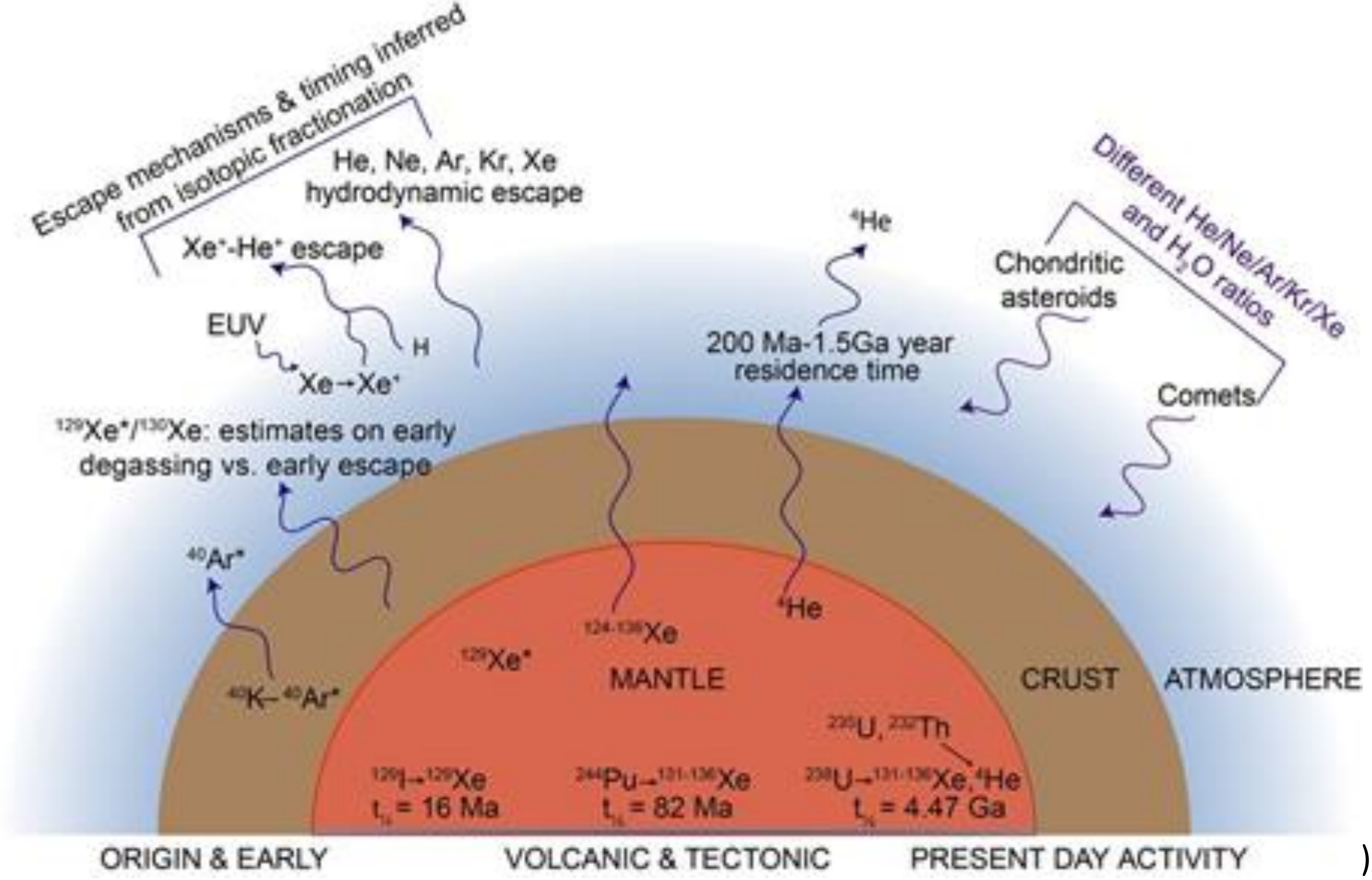
- Science question
- Small satellite answer
- Mission design

Selected by NASA Program PSDS3 (Planetary Science Deep Space Small Sat Studies)



The cost information contained in this document is of a budgetary and planning nature and is intended for informational purposes only. It does not constitute a commitment on the part of JPL and/or Caltech.

Noble gases are tracers of the evolution of planets

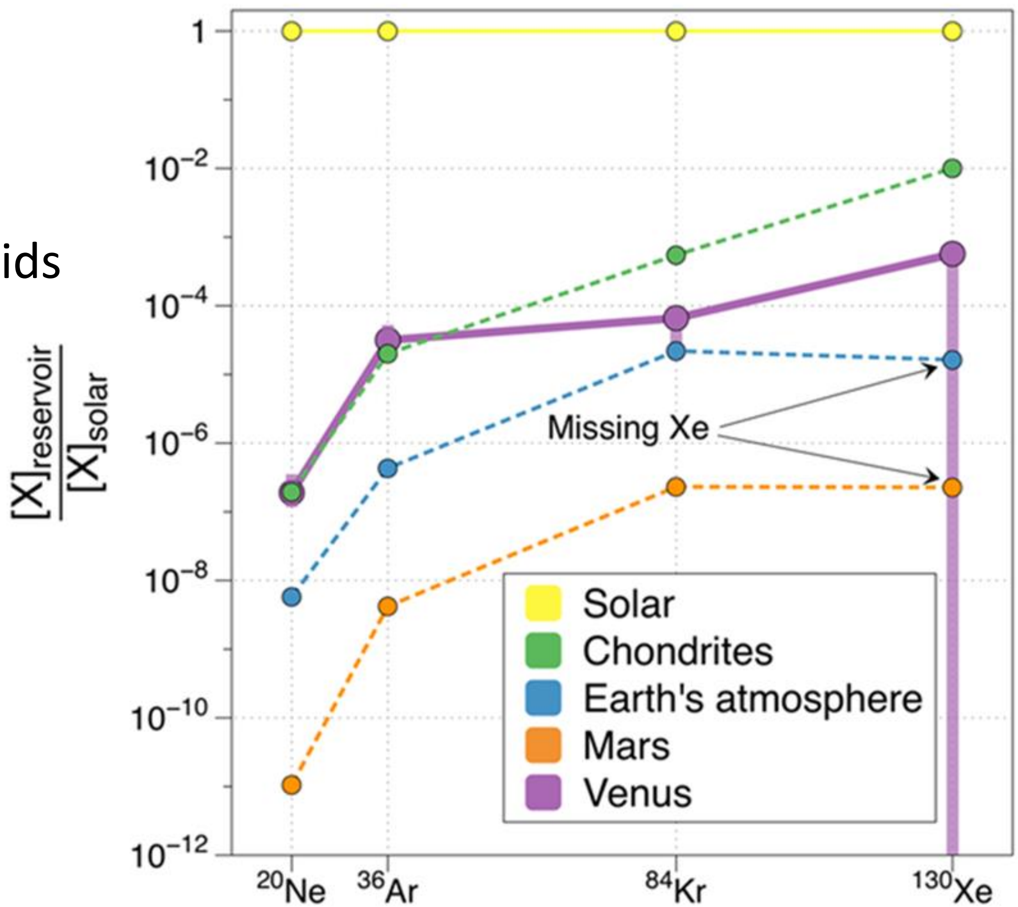


)

Noble gases are tracers of the evolution of planets

They trace:

- The supply of volatiles from the solar nebula
- the supply of volatiles by asteroids and comets
- the escape rate of planetary atmospheres
- the degassing of the interior (volcanism)
- the timing of these events

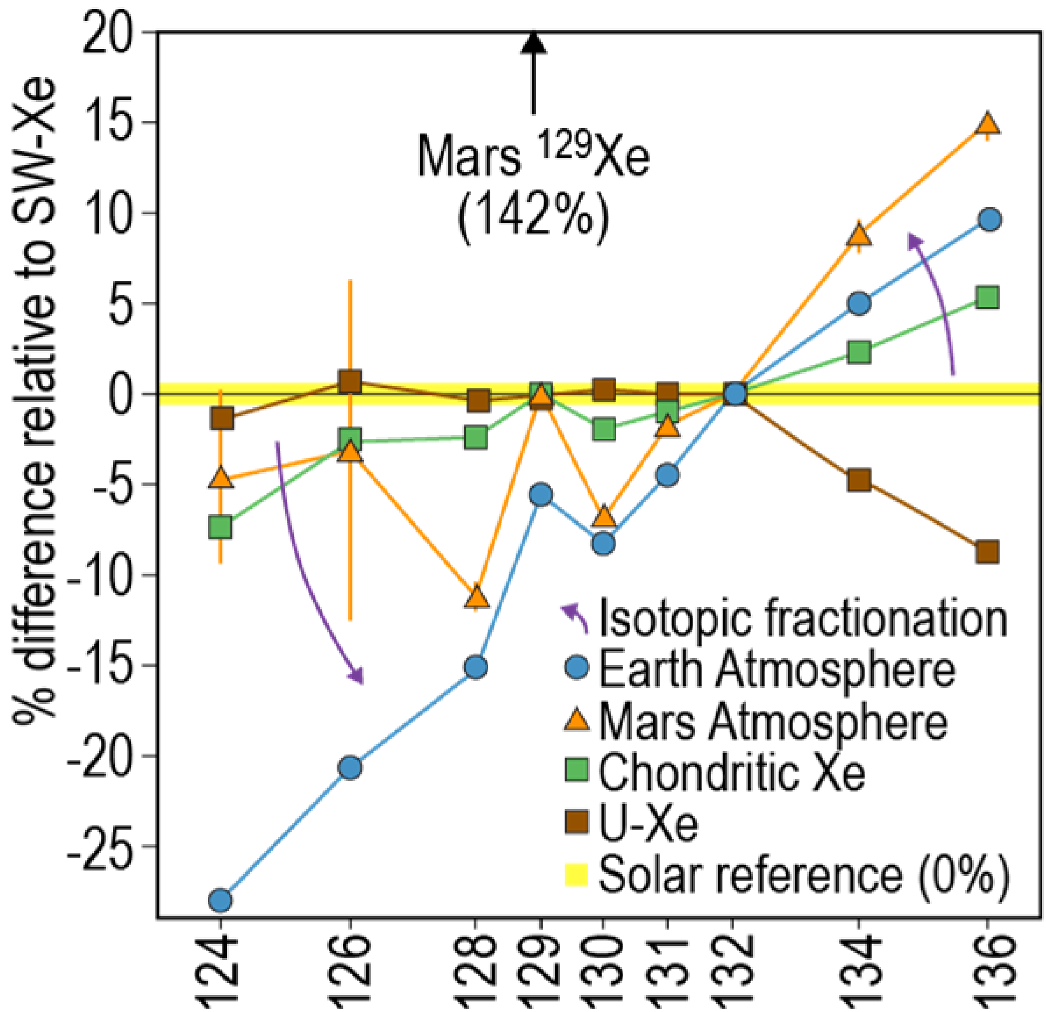


(Pepin et al., 1991; Chassefiere et al., 2012)

The Xenon case

Xe (9 isotopes):

- Depleted / Kr
- Isotopically fractionated
- ^{129}I decaying (half life of 16 Ma) in ^{129}Xe
- ^{244}Pu fission (half-life of 80 Ma) producing $^{131-136}$Xe isotopes with a diagnostic yield
- extant fission of $^{235-238}$U (4.5 & 0.7 Ga) producing Xe isotopes with different yields
- Comparative planetology will help determine the processes involved in the distribution of noble gases



Amount of outgassing from Ar

- ^{40}Ar is a good tracer of the amount of outgassing since it comes from the decay of ^{40}K and it does not escape on Earth and Venus.
- 25% of the interior has been outgassed based on ^{40}Ar (Kaula, 1999)
- The upper mantle is about 25% of the total mantle in mass

	Venus	Earth	Mars
^{40}Ar in atm (kg)	1.6 (±0.5) 10^{16}	6.6 10^{16}	5 10^{14}
^{40}Ar (kg/kg planet)	3.3 10^{-9}	1.11 10^{-8}	7.9 10^{-10}
$^{40}Ar/Si$	1.7 10^{-8}	5.2 10^{-8}	4.1 10^{-9}
potential ^{40}Ar(kg)	6.8 10^{16}	1.4 – 1.56 10^{17}	1.6 10^{16}
^{40}Ar atm / potential	**24 (±10)%**	**42-56 %**	**3%**

Is the recent resurfacing due to plumes raising from the Core/Mantle boundary (CMB) ?

Goal I: Atmospheric formation, evolution and climate history

Goals, Objectives, and Investigations for Venus Exploration

Table 2. VEXAG Goals, Objectives and Investigations		
Goals are not prioritized; Objectives and Investigations are in priority order.		
Goal	**Objective**	**Investigation**
y on Venus	A. How did the atmosphere of Venus form and evolve?	1. Measure the relative abundances of Ne, O isotopes, bulk Xe, Kr, and other noble gases to determine if Venus and Earth formed from the same mix of solar nebular ingredients, and to determine if large, cold comets played a substantial role in delivering volatiles.
		2. Measure the isotopes of noble gases (especially Xe and Kr), D/H, $^{15}N/^{14}N$, and current O and H escape rates to determine the amount and timeline of the loss of the original atmosphere during the last stage of formation and the current loss to space.

Objective IA: How did the atmosphere of Venus form and evolve

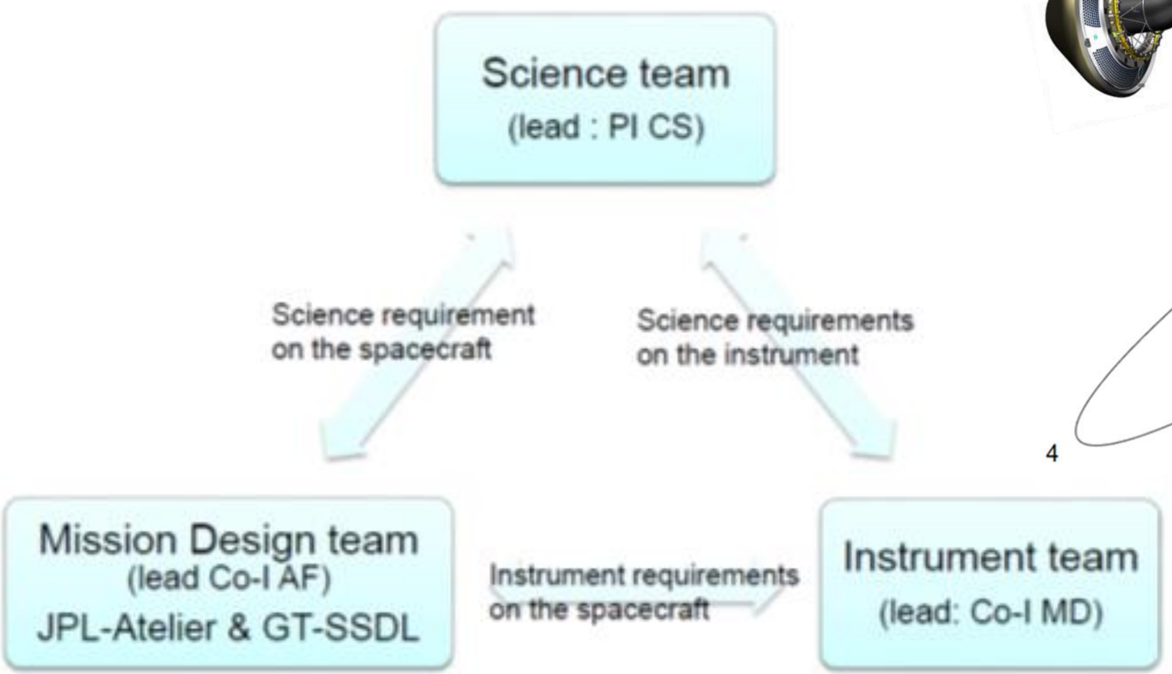
Table 1. Mapping of Decadal Survey themes to Objectives shown in the Goals, Objectives, Investigations table (also see Table 2).

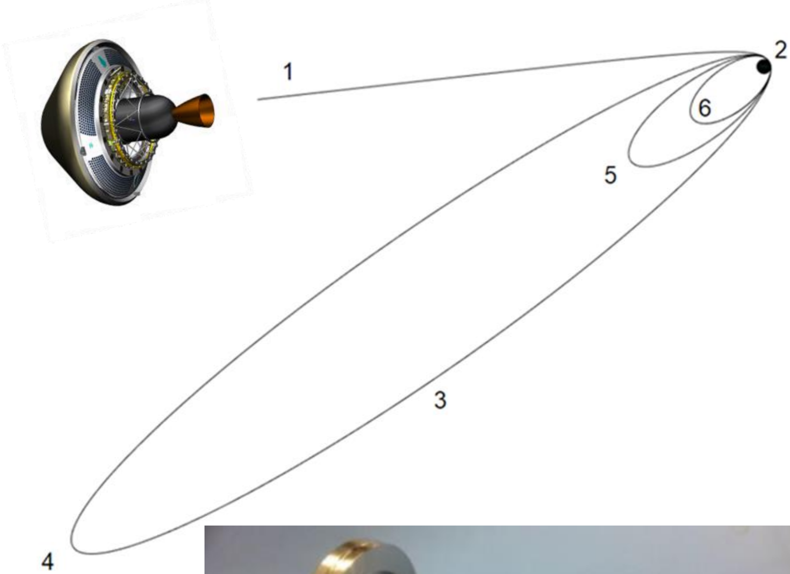
Decadal Survey Crosscutting Science Theme	Relevant Venus Objectives
Building new worlds	I.A, II.B, III.A
Planetary habitats	I.A, I.C, III.A, III.B
Workings of solar systems	All Objectives
Decadal Survey Inner Planets Research Goal	
Origin and diversity of terrestrial planets	All Objectives
Origin and evolution of life	I.A, I.C, II.A, III.A, III.B
Processes that control climate	I.A, I.B, I.C, II.A, III.A, III.B

This objective is responsive to all three crosscutting science themes of the DS and to all three Inner Planets Research Goals described in the DS.
Measuring noble gases is the most important investigation of this objective

CA can also determine the escape rate of Xe in particular (Investigation # II-A-2)

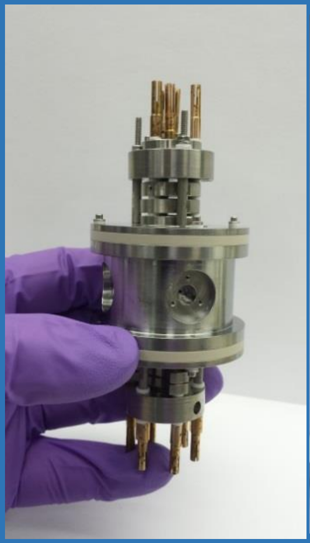
Atmospheric Entry Conditions

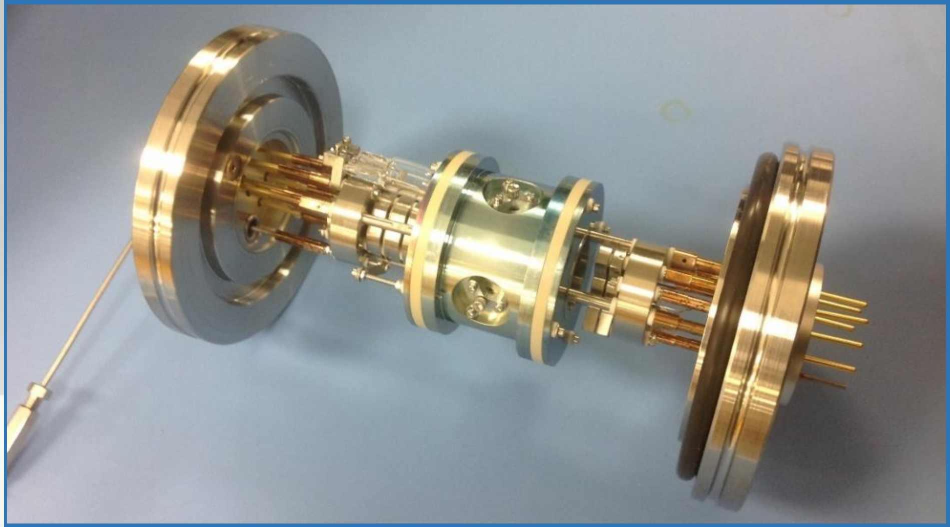




- Skim through Venus atmosphere below the homopause where samples are collected
- Analyze the samples and the calibrant - send data direct to Earth
- Build the probe around the instrument – 2 pieces: the instrument tray and the probe
- Use additive manufacturing for 3D printing
- Partner with universities (Caltech and Georgia Tech)

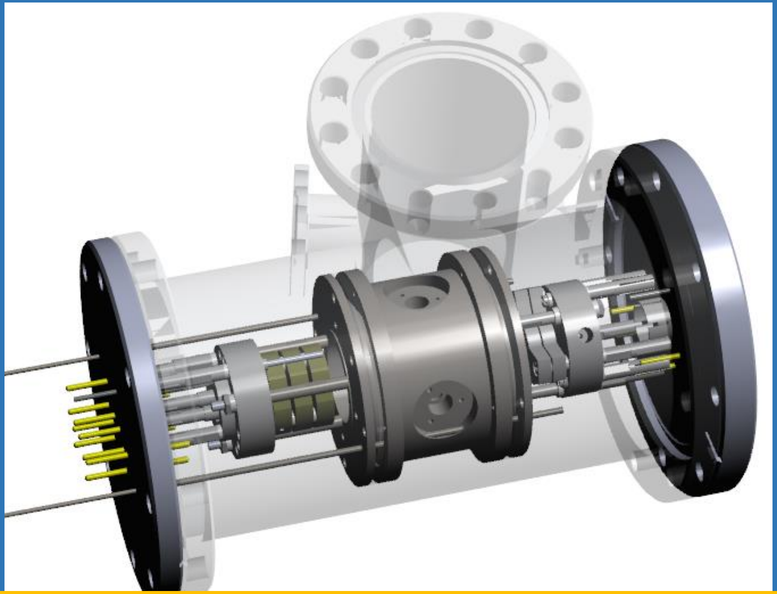
Cupid's Arrow miniaturized Quadrupole Ion Trap Mass Spectrometer (mQITMS) is a miniaturized version of the compact QITMS

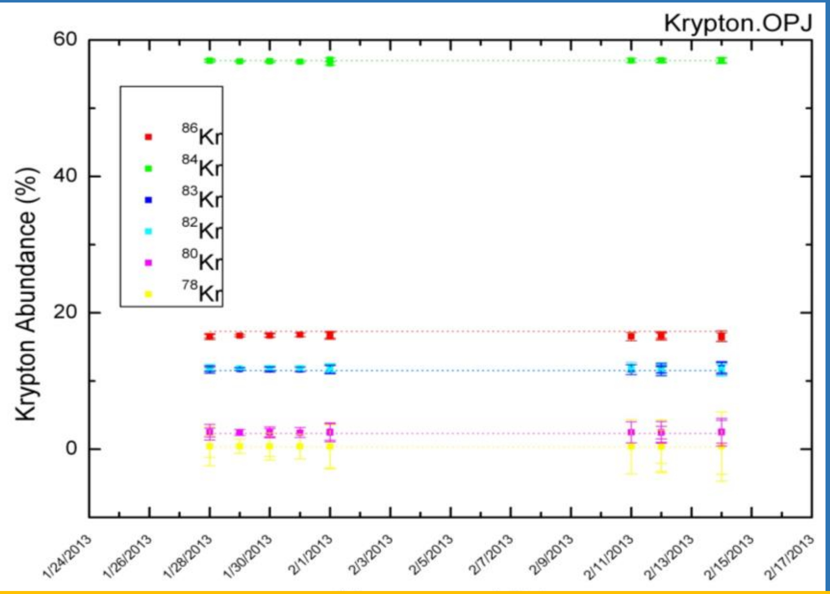




Compact QITMS

- No discrete wires to make electrical connections to mass spectrometer parts.
- 7.3 kg mass; 4U volume
- Extremely robust against shock/vibe loads
- Very stable measurements





QITMS Isotopic Precision is 3-5 times better than required

Instrument Requirements vs. Performance

Performance versus requirements for noble gases ratio

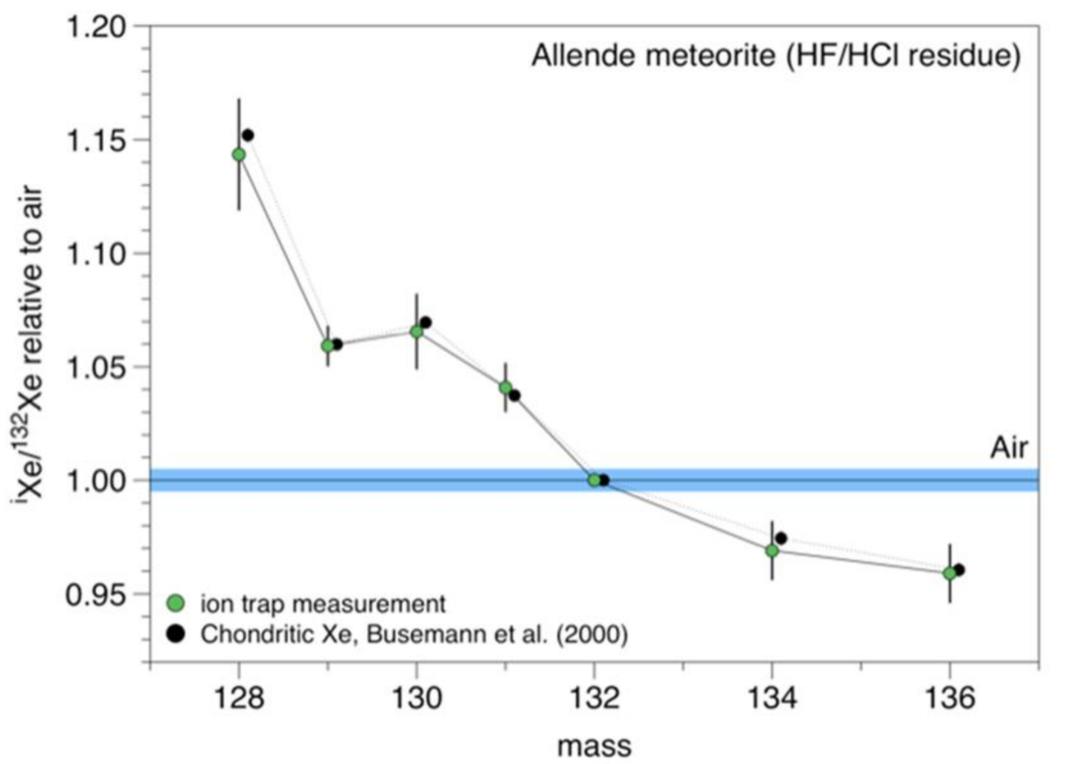
		Expected Intensity (cnts)			
Isotopic Ratios	Assumed Fractional Abundance	Major	Minor	Statistical Precision* [%]	Requirement**
3He / 4He	0.0003	1.08E+08	1.08E+04	1	5 to 10
20Ne / 22Ne	12	7.56E+08	6.41E+07	0.014	1
36Ar / 40Ar	0.16	5.78E+08	3.56E+09	0.006	
36Ar / 38Ar	0.18	5.78E+08	3.21E+09	0.024	1
82,83,86Kr / 84Kr	0.16-0.48	2.70E+06	0.4-1.3E+06	0.3	1
129, 136 Xe / 132Xe	1,0.3	2.05E+05	2,0.6E+05	0.4	1
124-128Xe / 132Xe	0.003-0.07	2.33E+04	0.7-14E+03	4	5

Measurements integrated during one hour

*1/sqrt(counts)
**Chassefiere et al., 2012

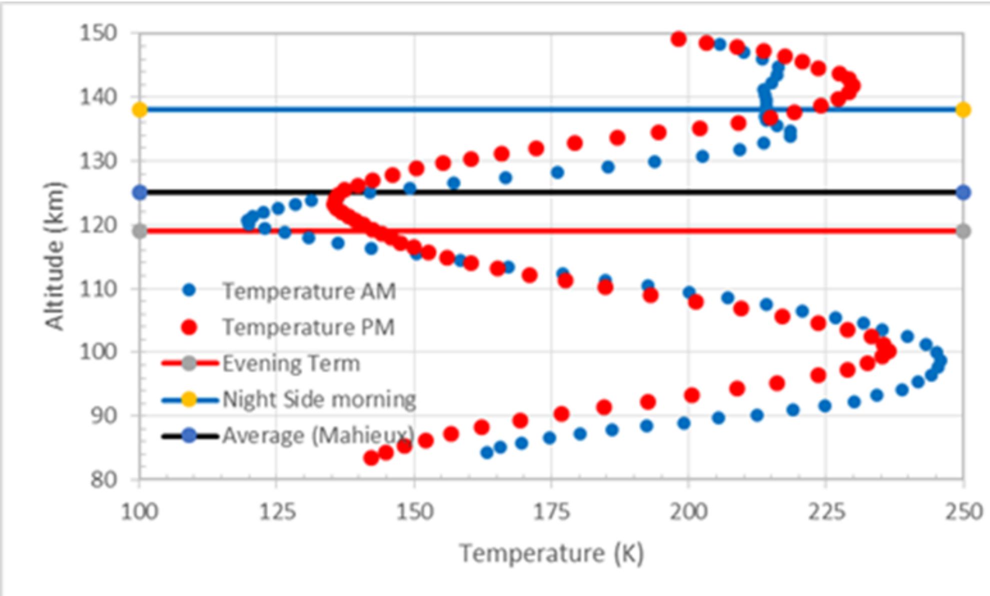
Ongoing work to calibrate the mQITMS and determine accuracy and compare it with the statistical precision

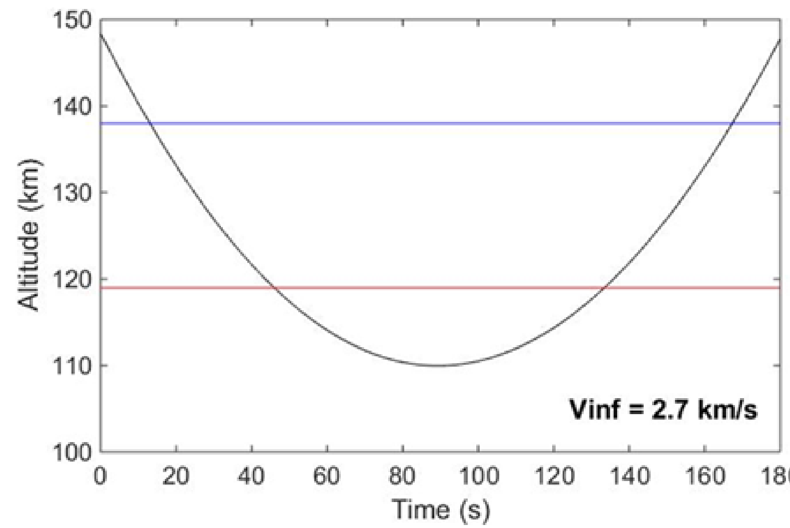
Test on the Allende meteorite



- The users (science team) are independent of the instrument providers (instrument team).
- The measurements of Xe isotopes on the Allende meteorite show remarkable agreement within the error bars. See **poster #1158 (location #345)** on Thursday by **Avice et al.** "A New Quadrupole Ion Trap Mass Spectrometer for Measuring Noble Gases in Planetary Atmospheres"
- A comprehensive plan has been developed to certify the performance model

Density profile

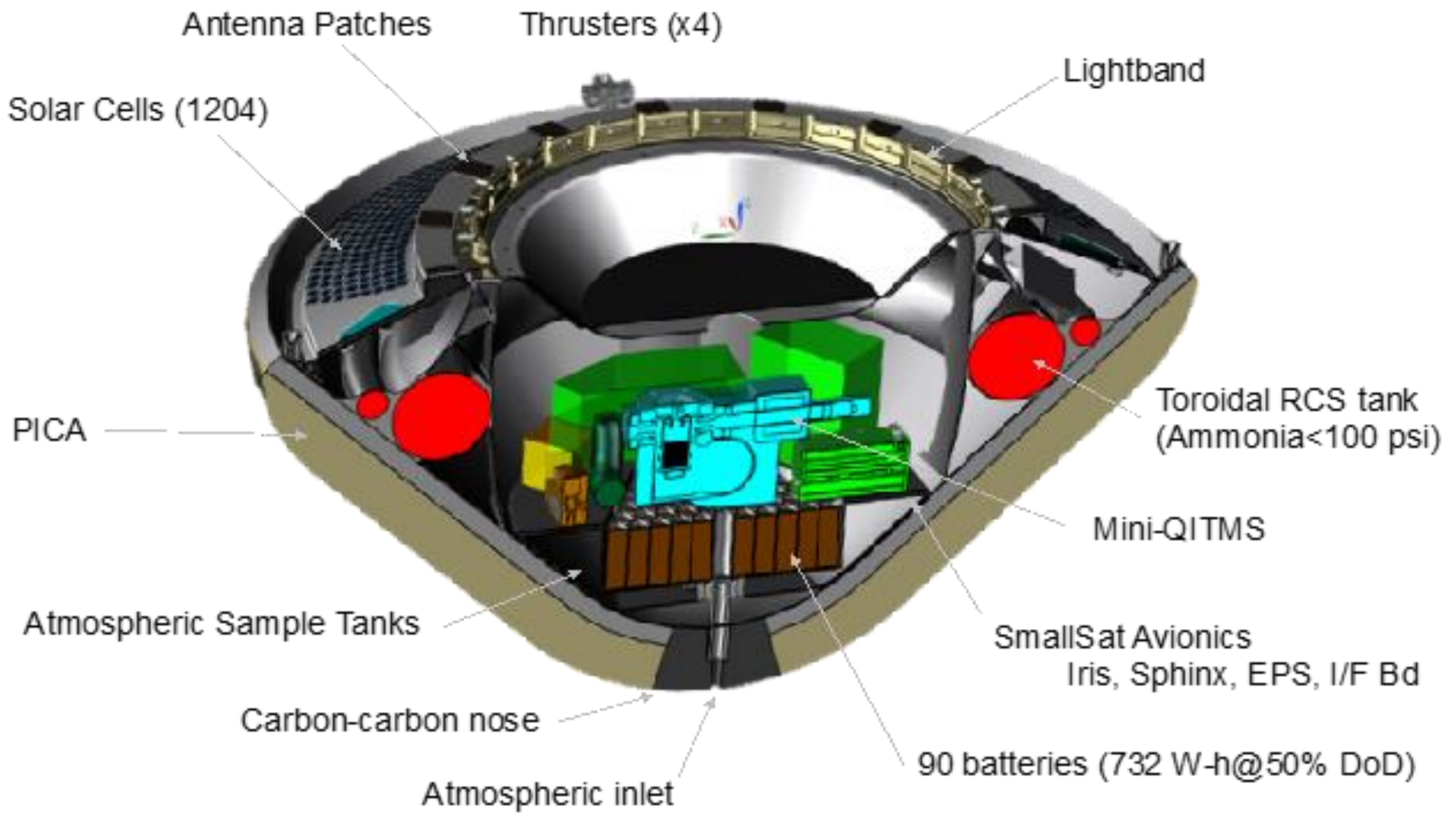




Values at 110 km altitude	Molecular density (molecule/cm³)	Density (kg/m³)	Temp (K)	Static pressure (Pa)	Dynamic Pressure (1/2.ρ.v²) (Pa)
30-60 deg - AM	1.06×10^{13}	$3.54\ 10^{-6}$	195.5	0.139	195
30-60 deg - PM	1.55×10^{13}	$5.53\ 10^{-6}$	186.1	0.207	305

The values of density, temperature and pressure at 110 km. A velocity of 10.5 km/s is used to calculate the dynamic pressure. (1Torr=133 Pa)

Vehicle Concept



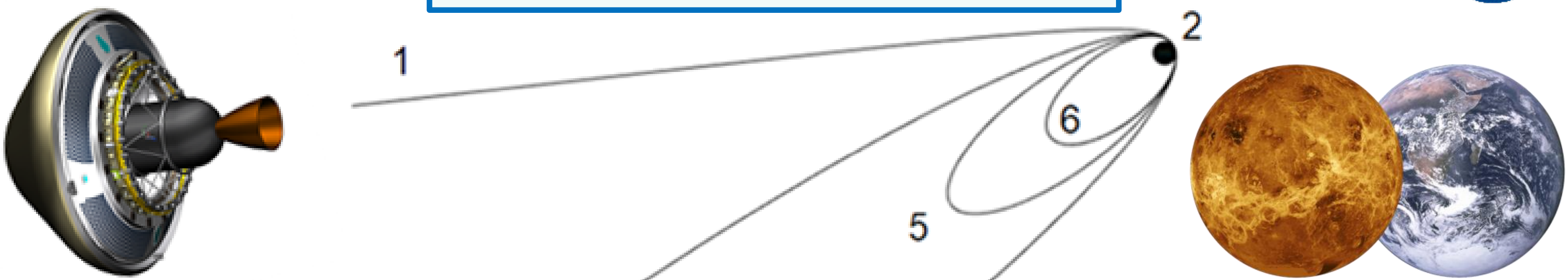
Wet mass is less than 70 kg, including 23% dry mass margins on average

Trade space – mission design

Scenario	Launch Strategy	Carrier stage	DTE or Relay Communication	VOI or Flyby	SRM?	Comments
1a	Dedicated L/V	No	DTE	Flyby	No	
1b	Dedicated L/V	No	DTE	VOI	Yes	
1c	Dedicated L/V	Yes	Relay via Carrier	Flyby	No	Cost too high
1d	Dedicated L/V	Yes	Relay via Carrier	VOI	Yes	Cost too high
2a	Secondary P/L	No	DTE	Flyby	No	
2b	Secondary P/L	No	DTE	VOI	Yes	
2c	Secondary P/L	Yes	Relay via Carrier	Flyby	No	Cost too high
2d	Secondary P/L	Yes	Relay via Carrier	VOI	Yes	Cost too high
3a	Piggyback	No	DTE	Flyby	No	Elevated approach velocity
3b	Piggyback	No	DTE	VOI	No	Few flight opportunities

Different options have been looked. Cost is well below the cap for DTE communications and VOI. Flyby mission saves an additional $7M.

Conclusions



- Understanding how Earth and Venus have diverged in their geological history is key to understanding the habitability of earth-like planets
- Measuring the concentrations of noble gases and isotope ratios in Venus atmosphere would provide key information on the formation and evolution of Venus
- A free-flying SmallSat probe with mass < 70 kg could deliver high-priority science at Venus for a fraction of the cost of a conventional Discovery mission
- Same approach could be adapted to other environments: Titan's atmosphere, Enceladus' plume, possible plume at Europa, …

3

4