

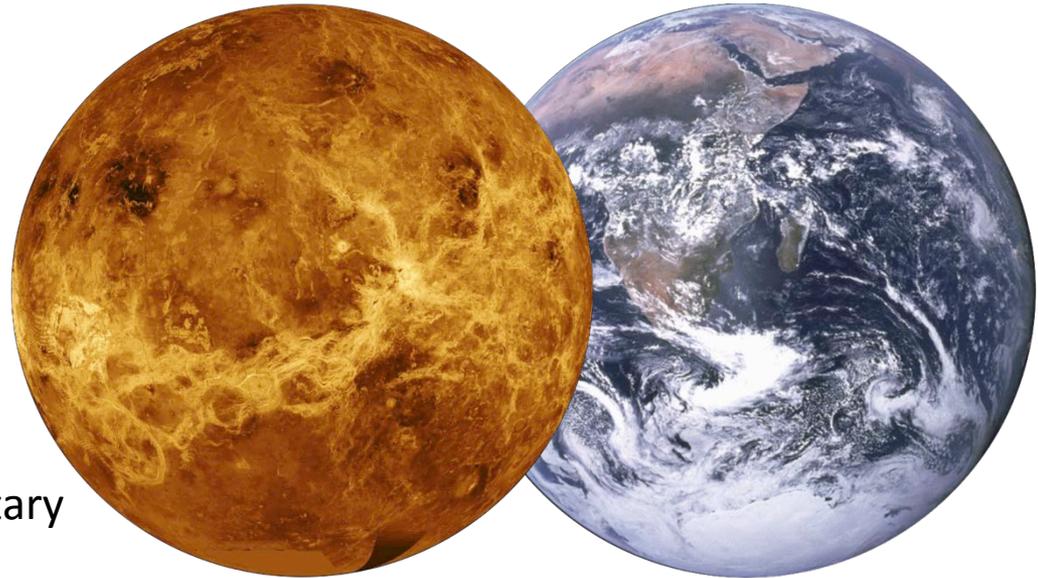


Cupid's Arrow – a Small Interplanetary Probe Concept

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

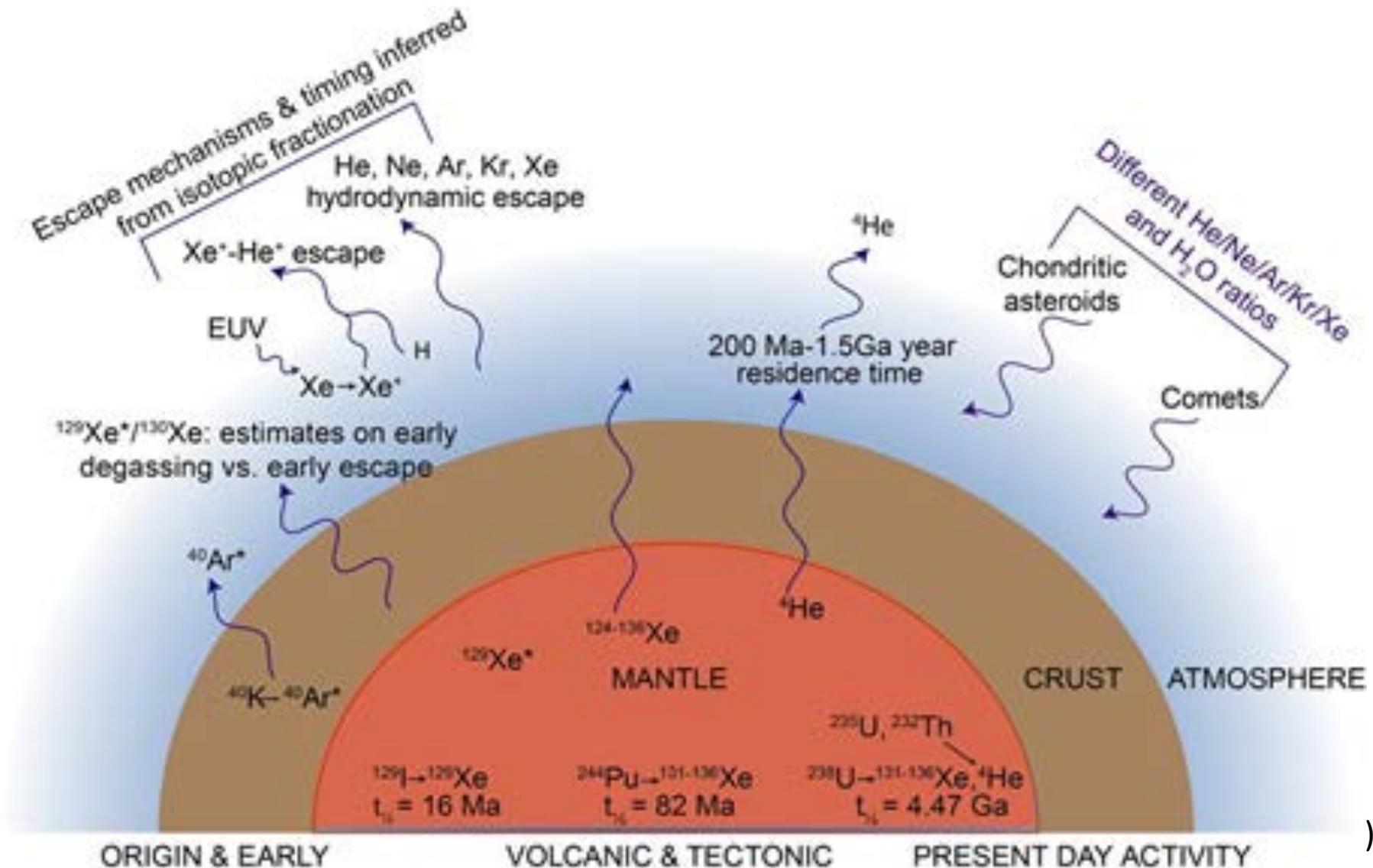
¹Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA; ²California Institute of Technology, Pasadena, CA; ³Georgia Institute of Technology, Atlanta, GA;. ⁴CRPG, Universite de Lorraine, Vandoeuvre-les-Nancy, France.

- Science question
- Small satellite answer
- Mission design



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

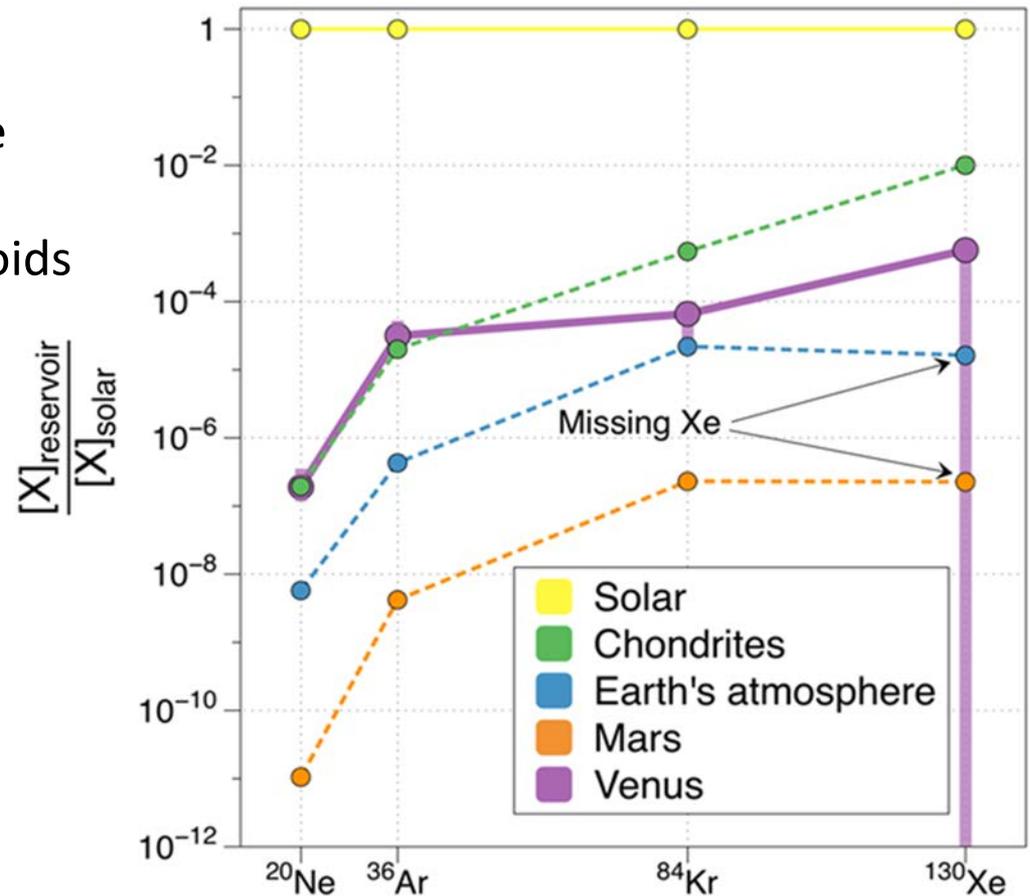
Noble gases are tracers of the evolution of planets



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)

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, $^{15}\text{N}/^{14}\text{N}$, 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)

Trade space – mission design

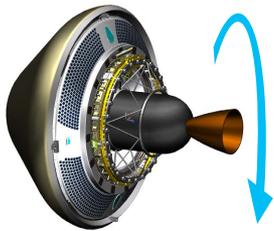


Scenario	Launch Strategy	Carrier stage	DTE or Relay Communication	VOI or Flyby	SRM?	Comments
1a	Dedicated L/V	No	DTE	Flyby	No	
1b	Dedicated L/V	No	DTE	VOI	Yes	
1c	Dedicated L/V	Yes	Relay via Carrier	Flyby	No	Cost too high
1d	Dedicated L/V	Yes	Relay via Carrier	VOI	Yes	Cost too high
2a	Secondary P/L	No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

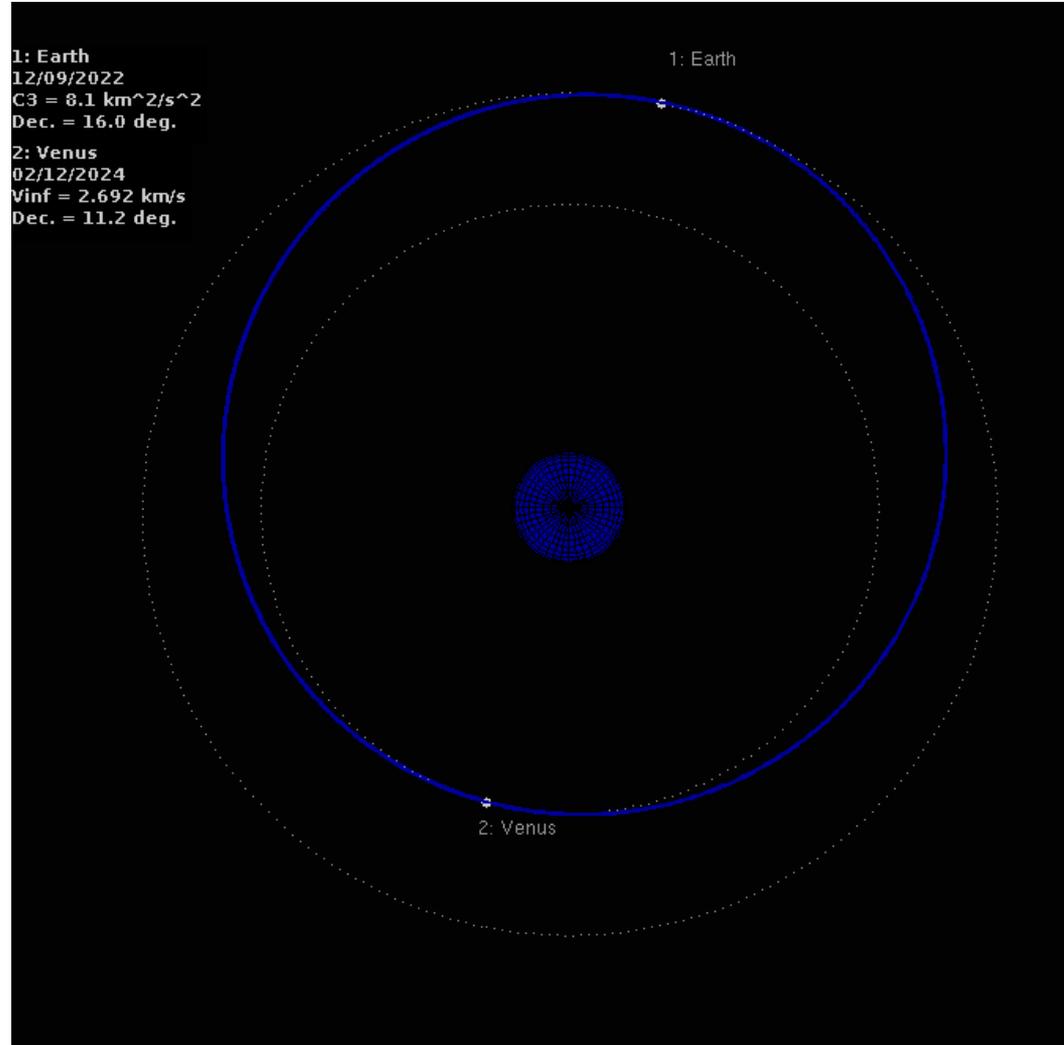
Different options have been looked. Cost is well below the target for DTE communications and VOI. Flyby mission saves an additional 7%.

Baseline Mission Design

- Flight time ~430 days
- Launch in 2022, December
- Launch $C3 < 9 \text{ km}^2/\text{s}^2$
- Arrival $V_{\text{inf}} = \sim 2.7 \text{ km/s}$
- Initial large elliptical orbit $\approx 20\text{-}30$ days



- Spin Stabilized for cruise and atmospheric pass
- Separate solid for VOI
- DV Monoprop capability $\sim 70 \text{ m/s}$ (in probe)
- DV VOI Capability $\sim 433 \text{ m/s}$

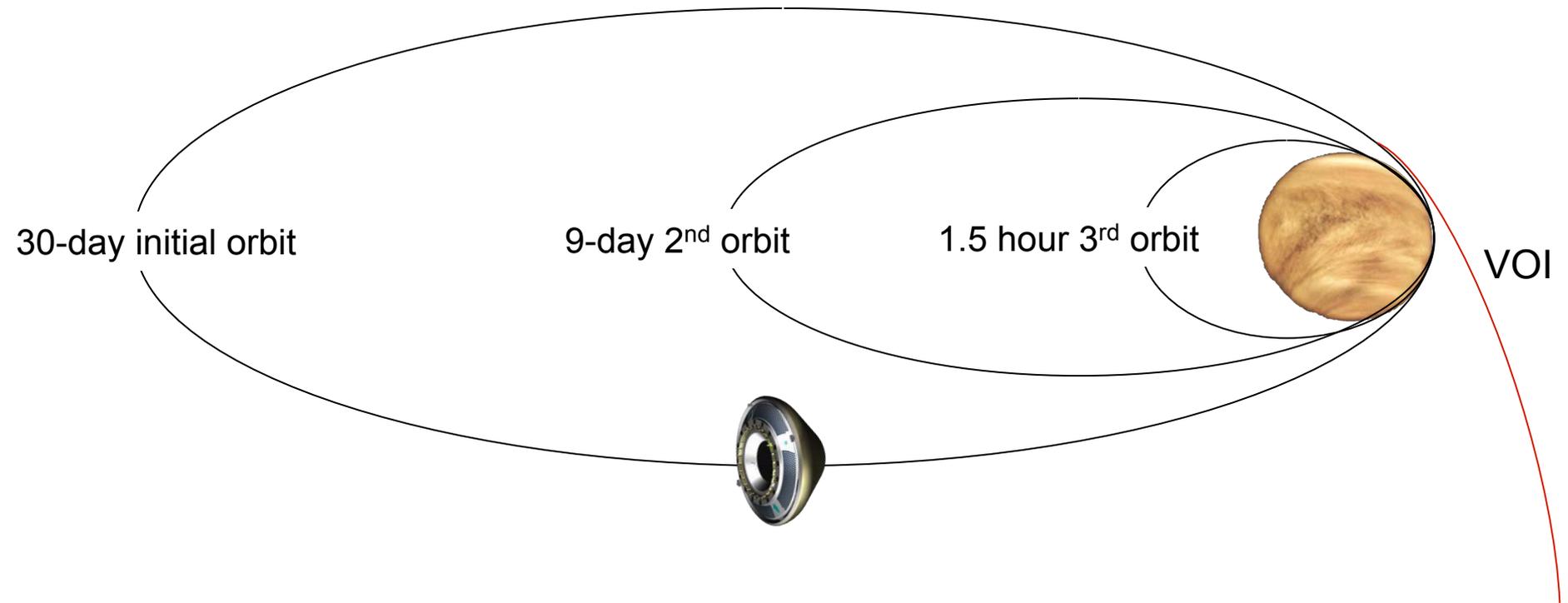


Predecisional: For Discussion
Purposes Only



Concept of Operations

Atmospheric pass
Target altitude: 110 km

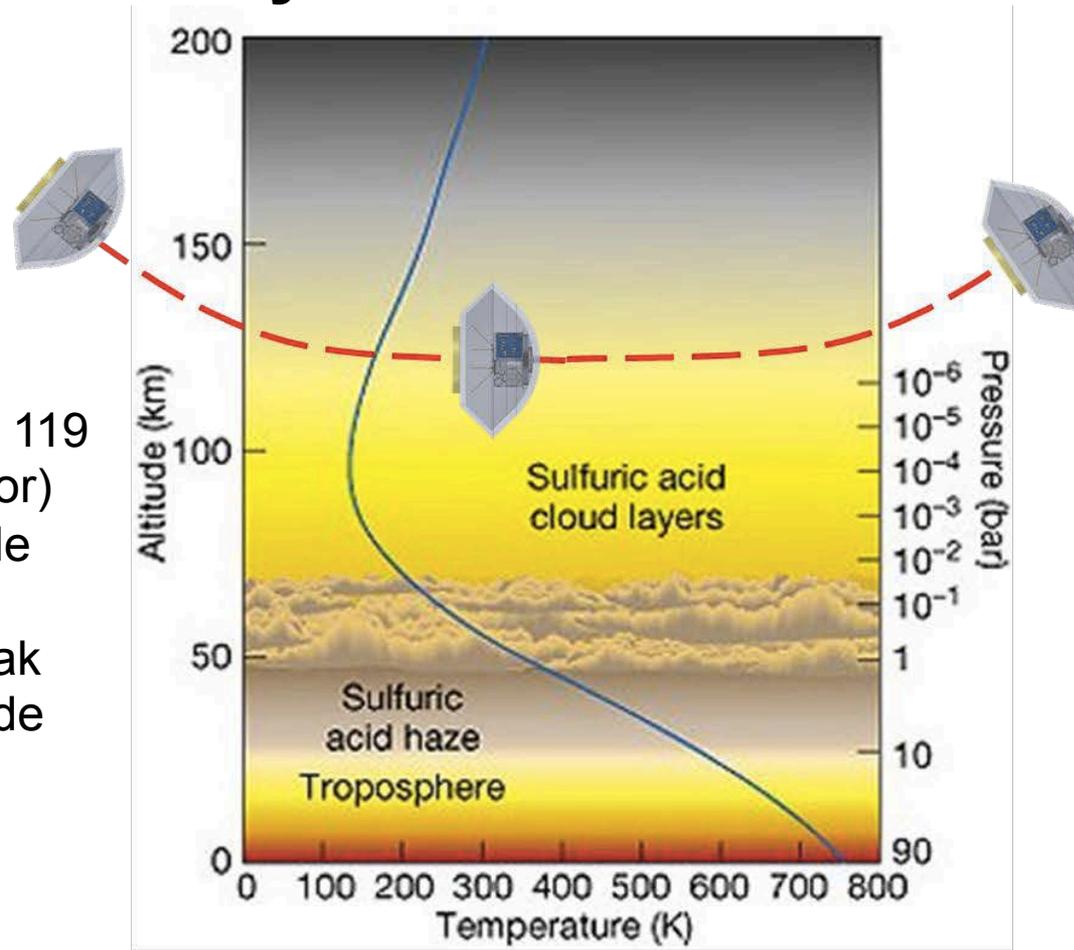


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Atmospheric Entry Conditions

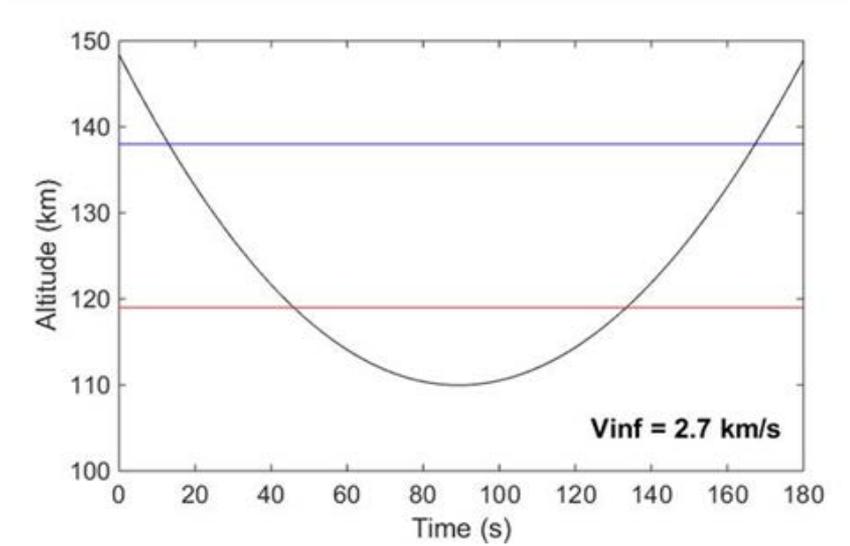
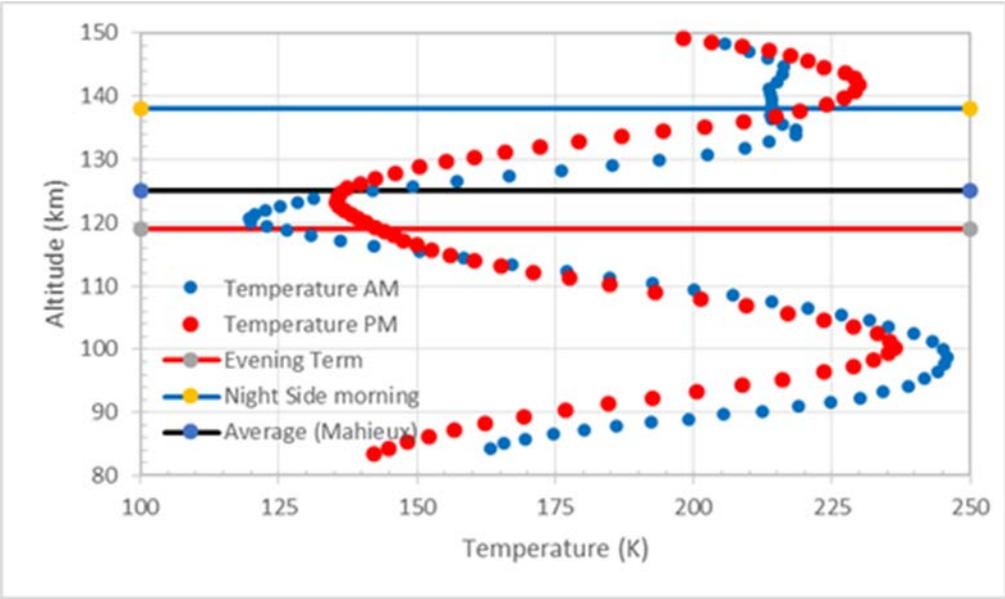
Velocity of 10 km/s
Altitude of 110 km

Homopause between 119 km (evening terminator) and 135 km (night side close to the morning terminator) with a weak dependence on latitude (Limaye et al., 2017)





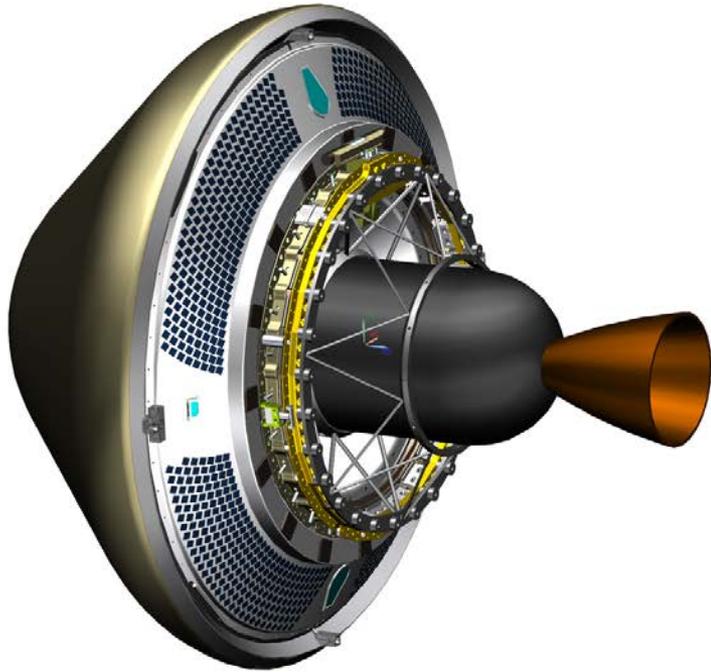
Density profile



Values at 110 km altitude	Molecular density (molecule/cm ³)	Density (kg/m ³)	Temp (K)	Static pressure (Pa)	Dynamic Pressure (1/2.ρ.v ²) (Pa)
30-60 deg - AM	1.06x10 ¹³	3.54 10 ⁻⁶	195.5	0.139	195
30-60 deg - PM	1.55x10 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)

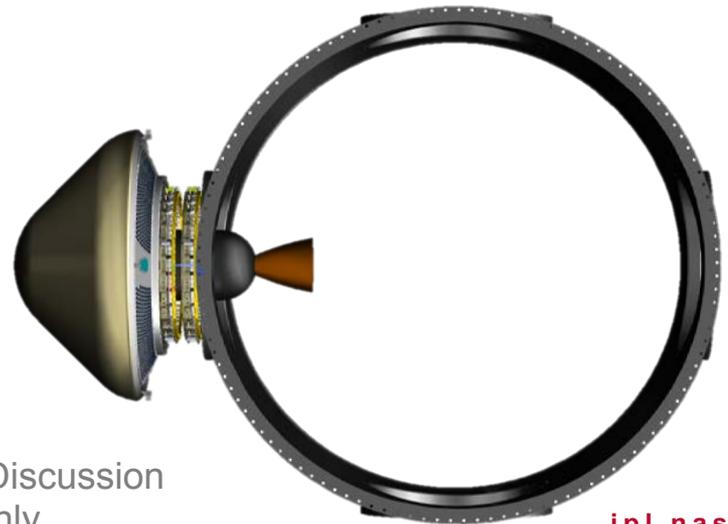
Mechanical Configuration



Cruise Configuration with
Star motor for VOI



Launch Configuration with
ESPA Grande Adapter



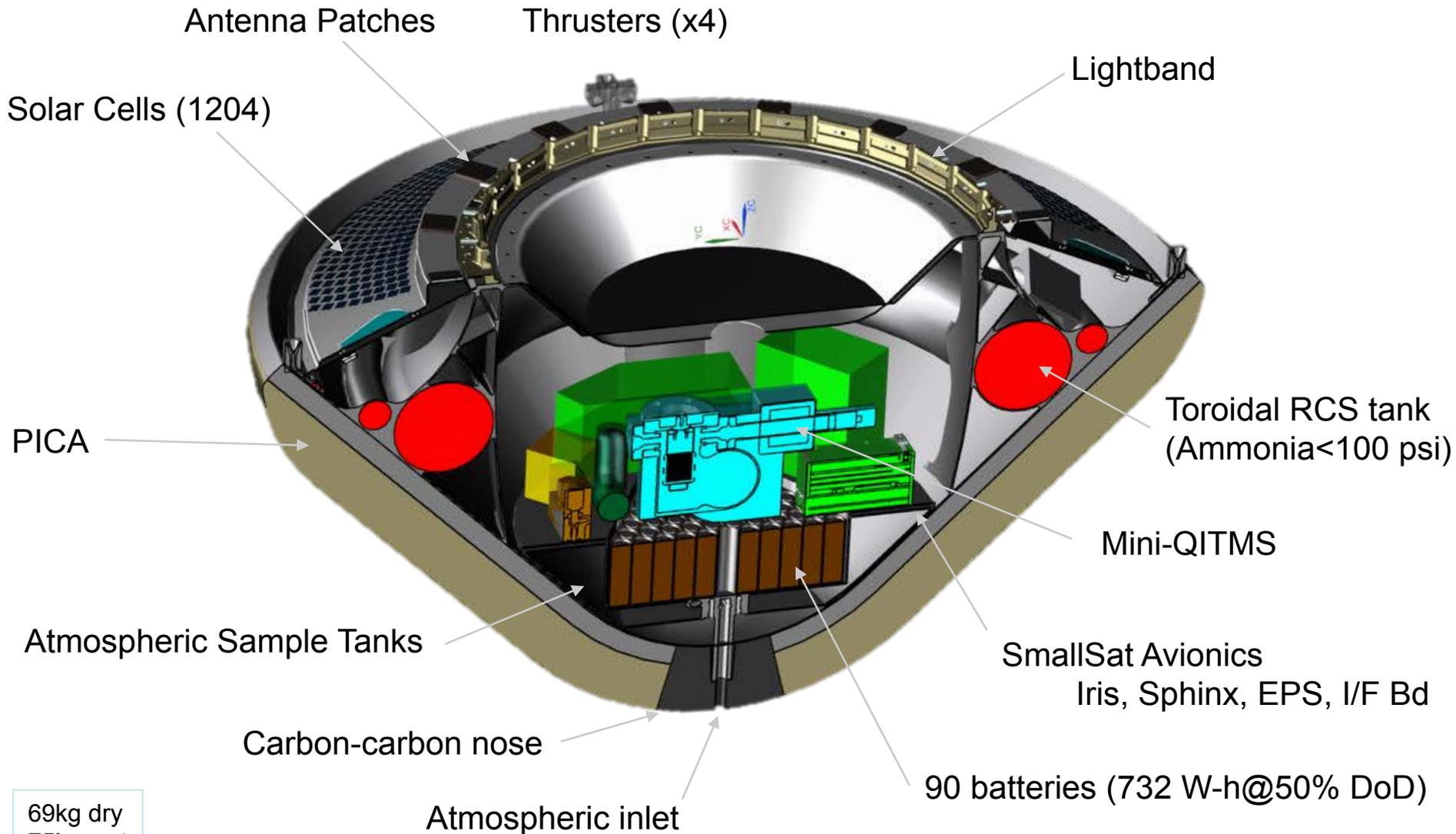
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Detailed design by:
JPL's Atelier team



Mechanical Configuration

Detailed design by:
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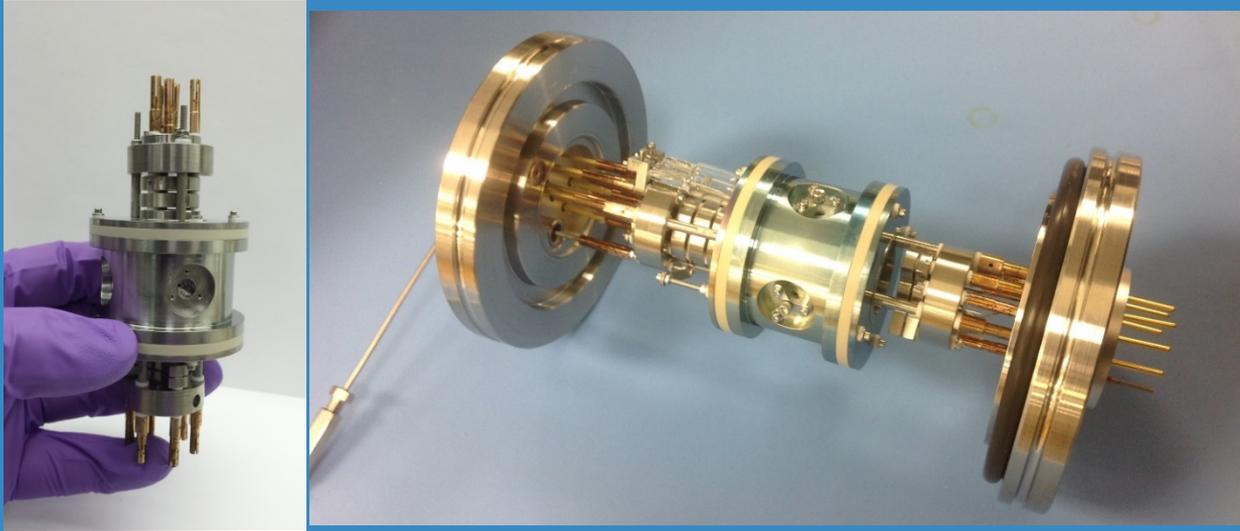
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What's New and Different



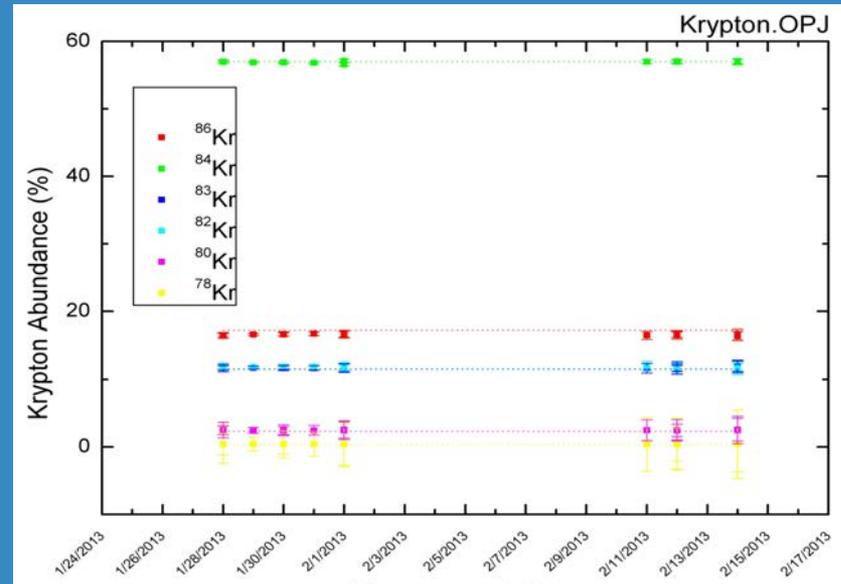
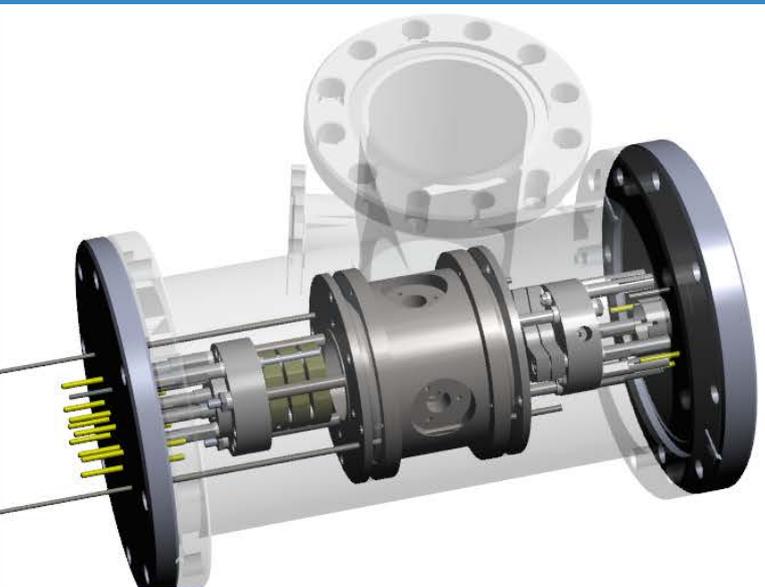
- Designed using new approach/tools for optimal mass efficiency and for additive manufacturing
 - *Takes advantage of the latest 1m powder bed AM capability coming in 2018.*
- One piece AM structure includes ACS propellant storage, expansion chamber plumbing thrusters. Multiple sample chambers double the accuracy of the measurement even with a single pass
- Uses Miniature QITMS (chamber is well tested) with new miniaturized electronics for lower mass and cost
- Designed for multiple destinations (incl Titan)
- Design can easily be tailored to an atmospheric descent probe or a surface probe

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

Isotopic Ratios	Assumed Fractional Abundance	Expected Intensity (cnts)		Statistical Precision* [%]	Requirement**
		Major	Minor		
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

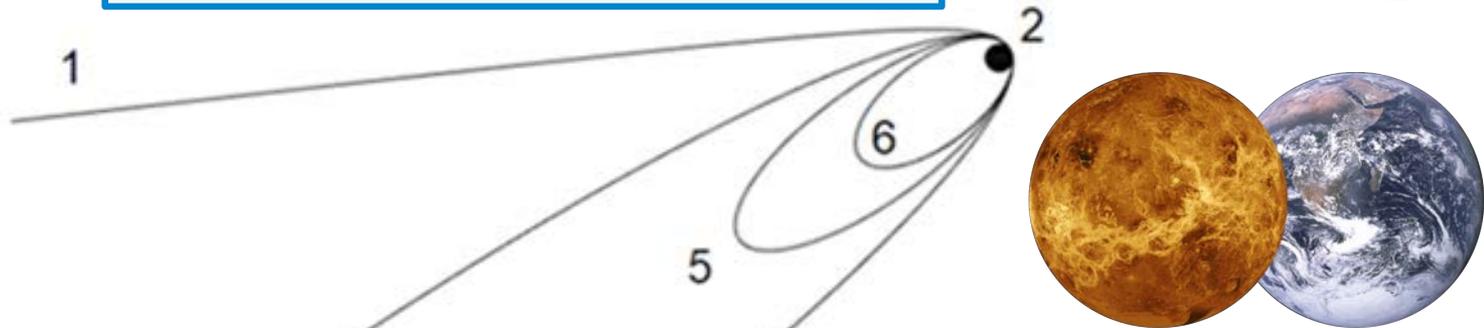
Measurements integrated during one hour

* $1/\sqrt{\text{counts}}$

**Chassefiere et al., 2012

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

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, ...