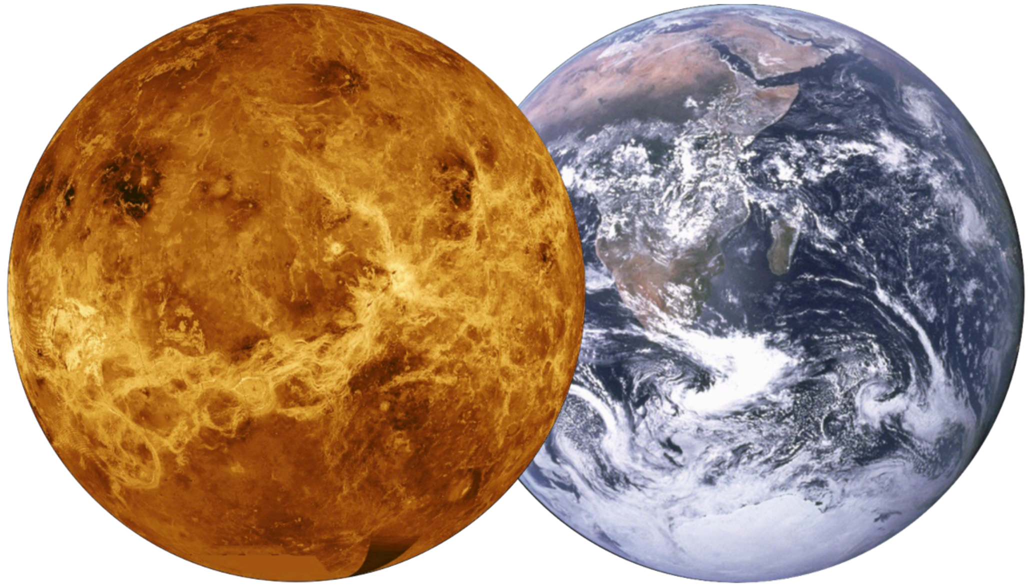
National Aeronautics and Space Administration



Sampling Venus' atmosphere with a low-cost, free-flying Smallsat probe mission concept

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Jet Propulsion Laboratory

April 2016

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.

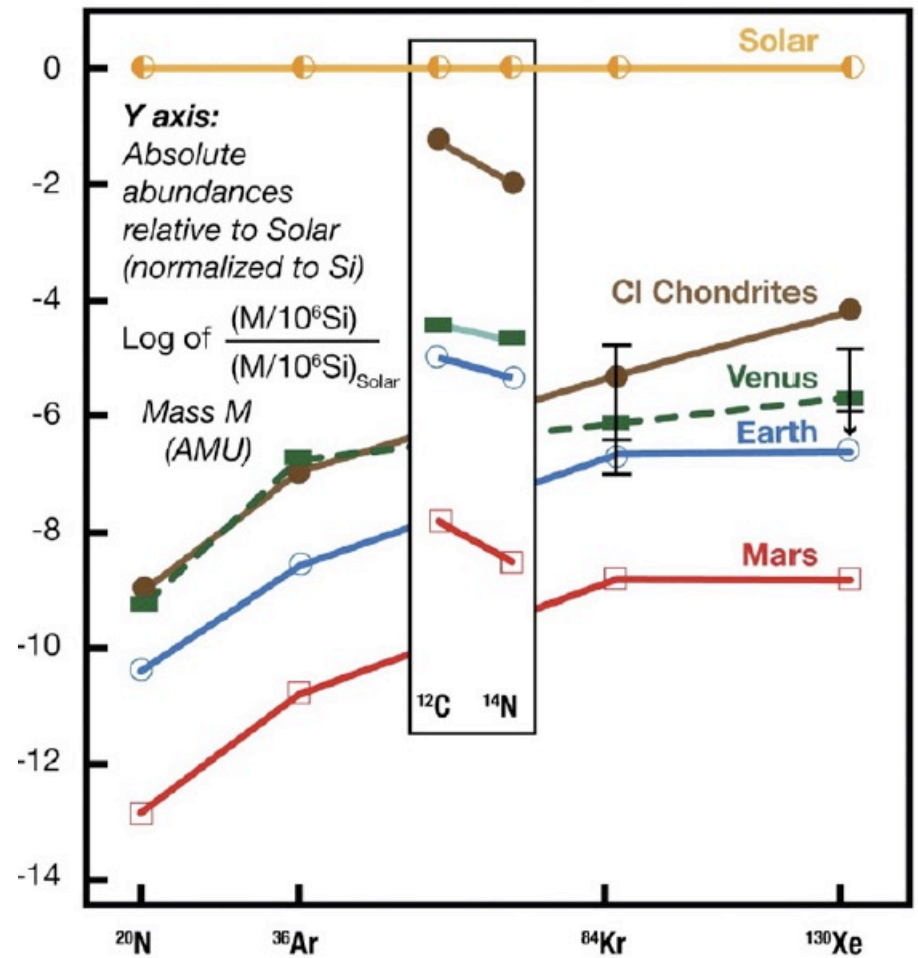
Noble gases are tracers of the evolution of planets

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

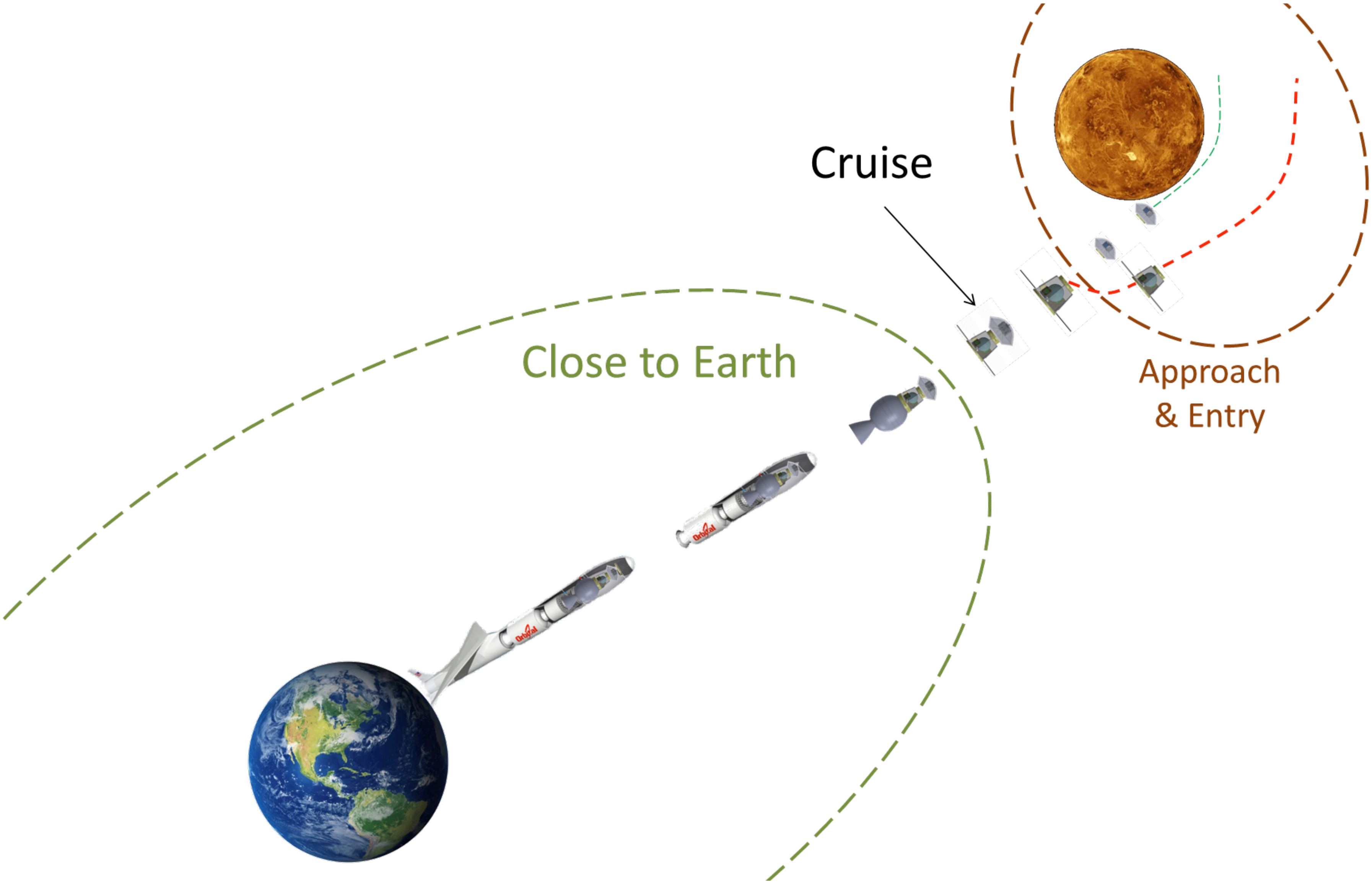
For example Xe (9 isotopes):

- Depleted / Kr
- Fractionated in mass
- Comparative planetology will help determine the processes involved in the distribution of noble gases



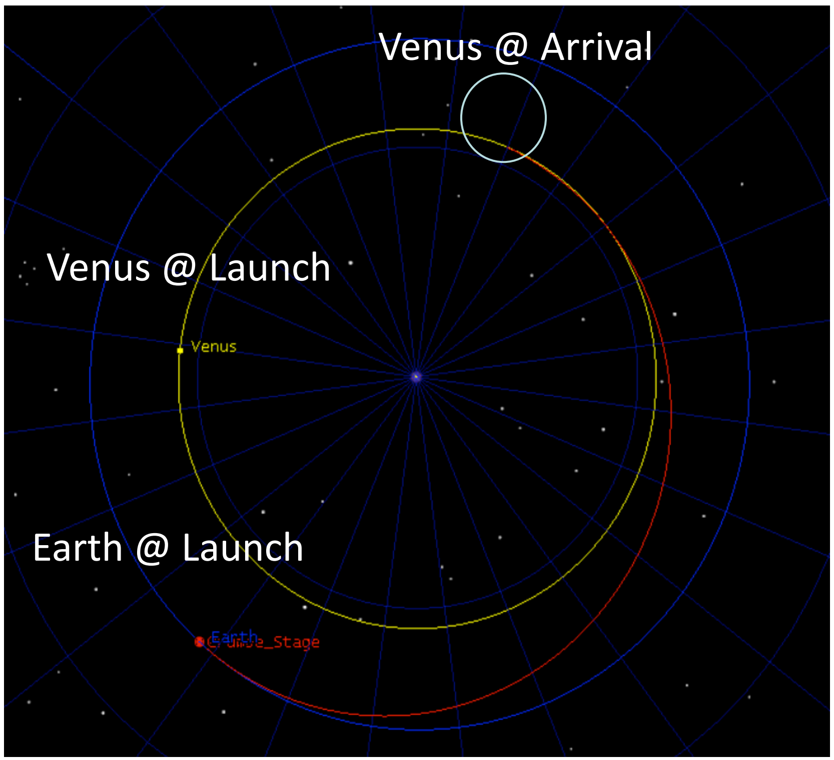
Pepin et al., 1991; Chassefiere et al., 2012)

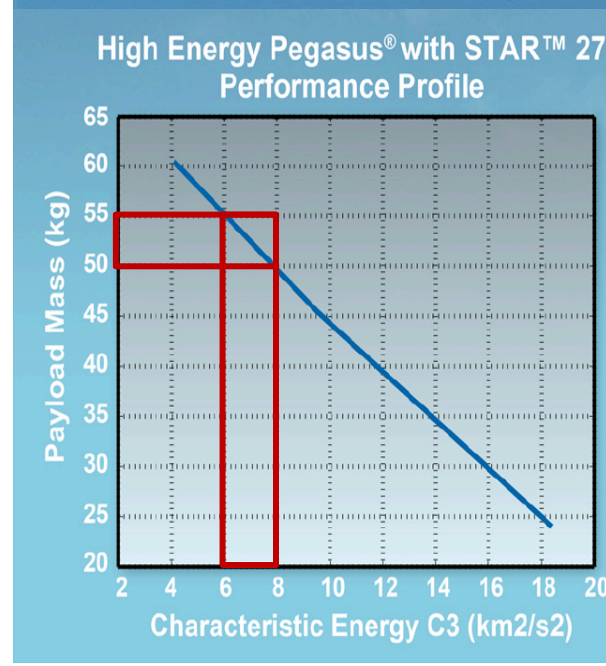
Mission-Level ConOps



L/V + Trajectory

- OSC Pegasus XL L/V with a STAR27H motor*
- Nominal Launch Date: 05/18/23 12:00 UTCG
- C3 = 6.1km^2/s^2 for a 55 kg payload
- Type II direct transfer

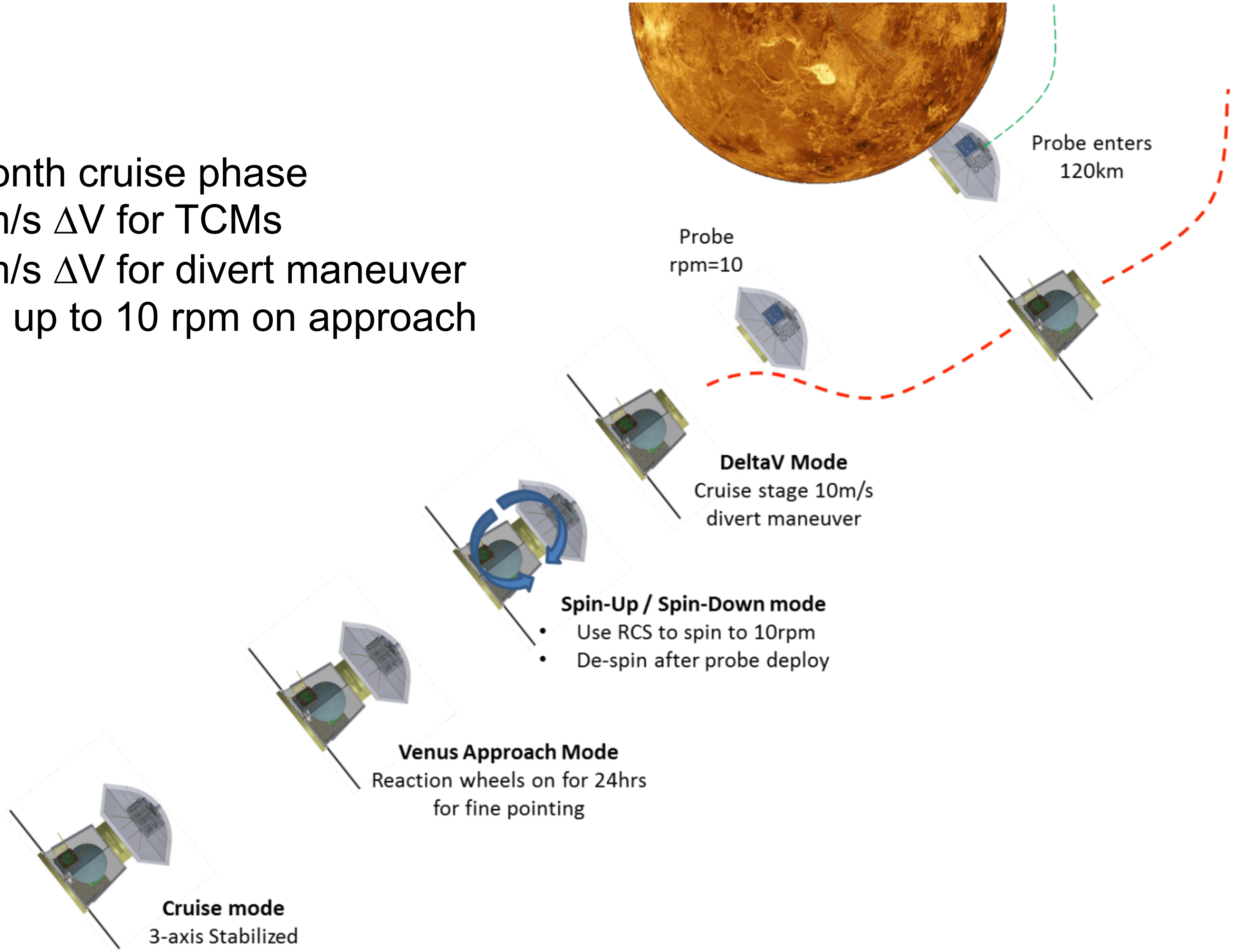




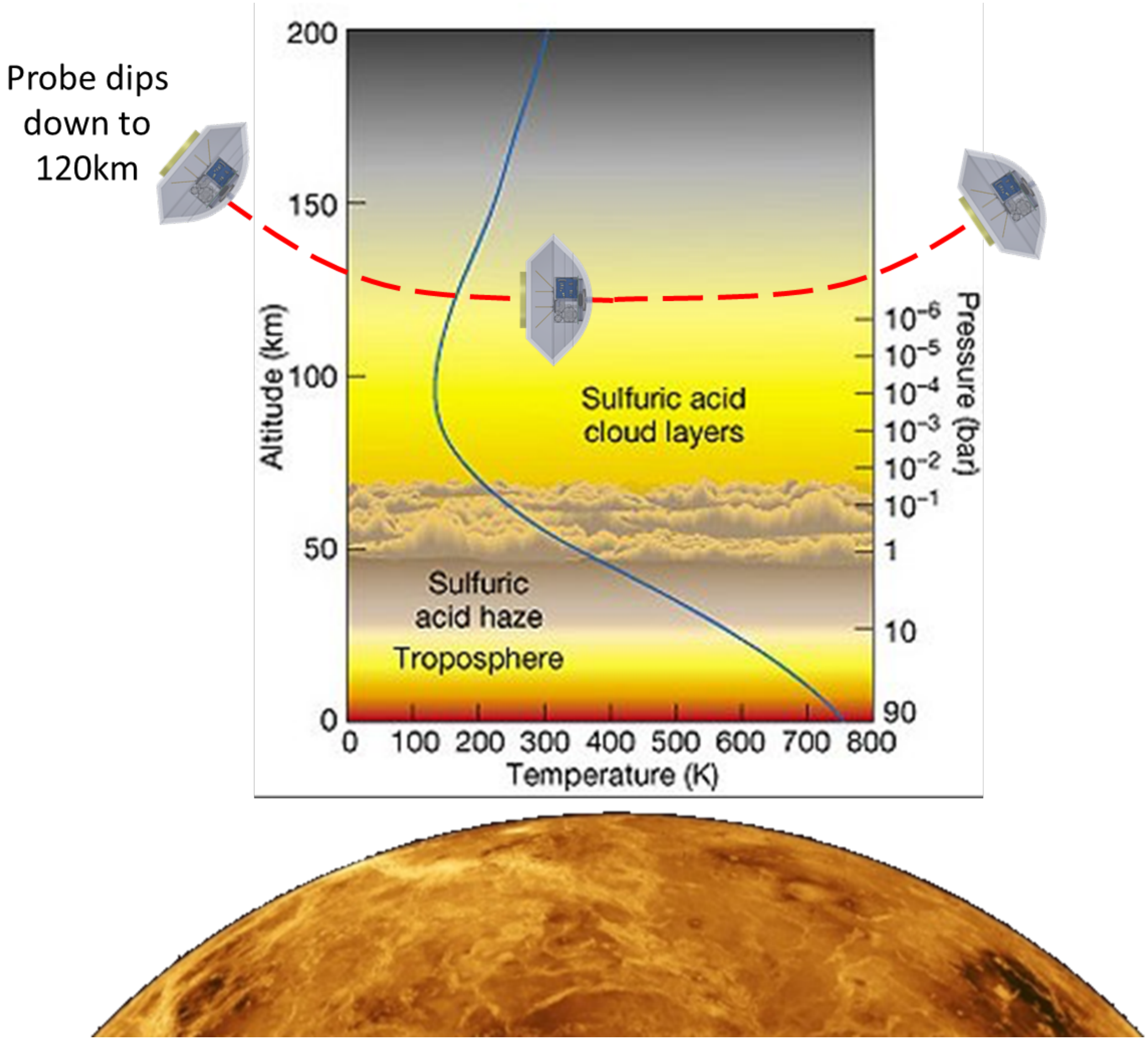
*Source: Warren Frick, et. al., "Micro High Energy Upper Stage," SmallSat Conf., Logan, Utah, (2014).

Near-Venus ConOps

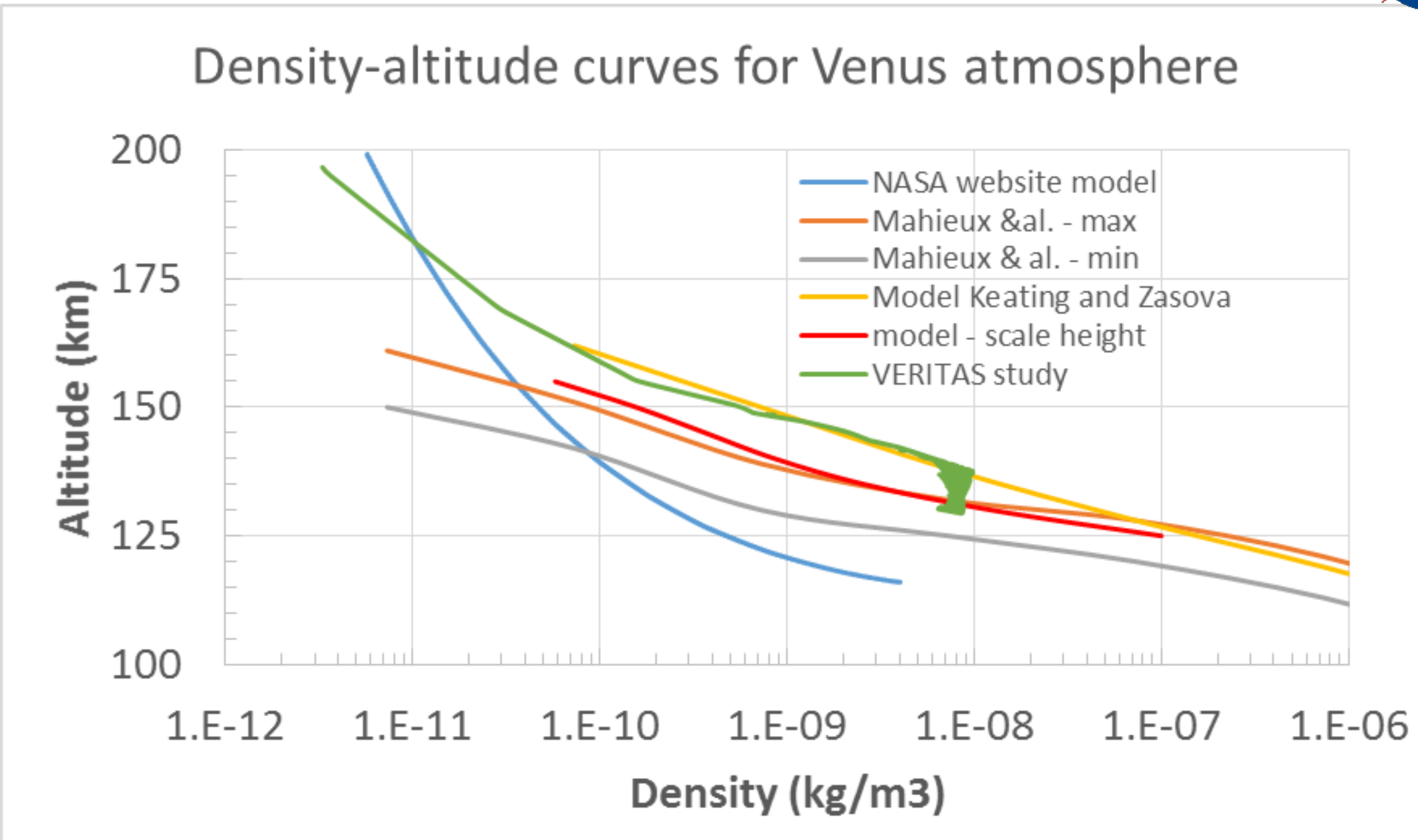
- 5 month cruise phase
- 10 m/s ΔV for TCMs
- 10 m/s ΔV for divert maneuver
- Spin up to 10 rpm on approach



Atmospheric Entry Conditions



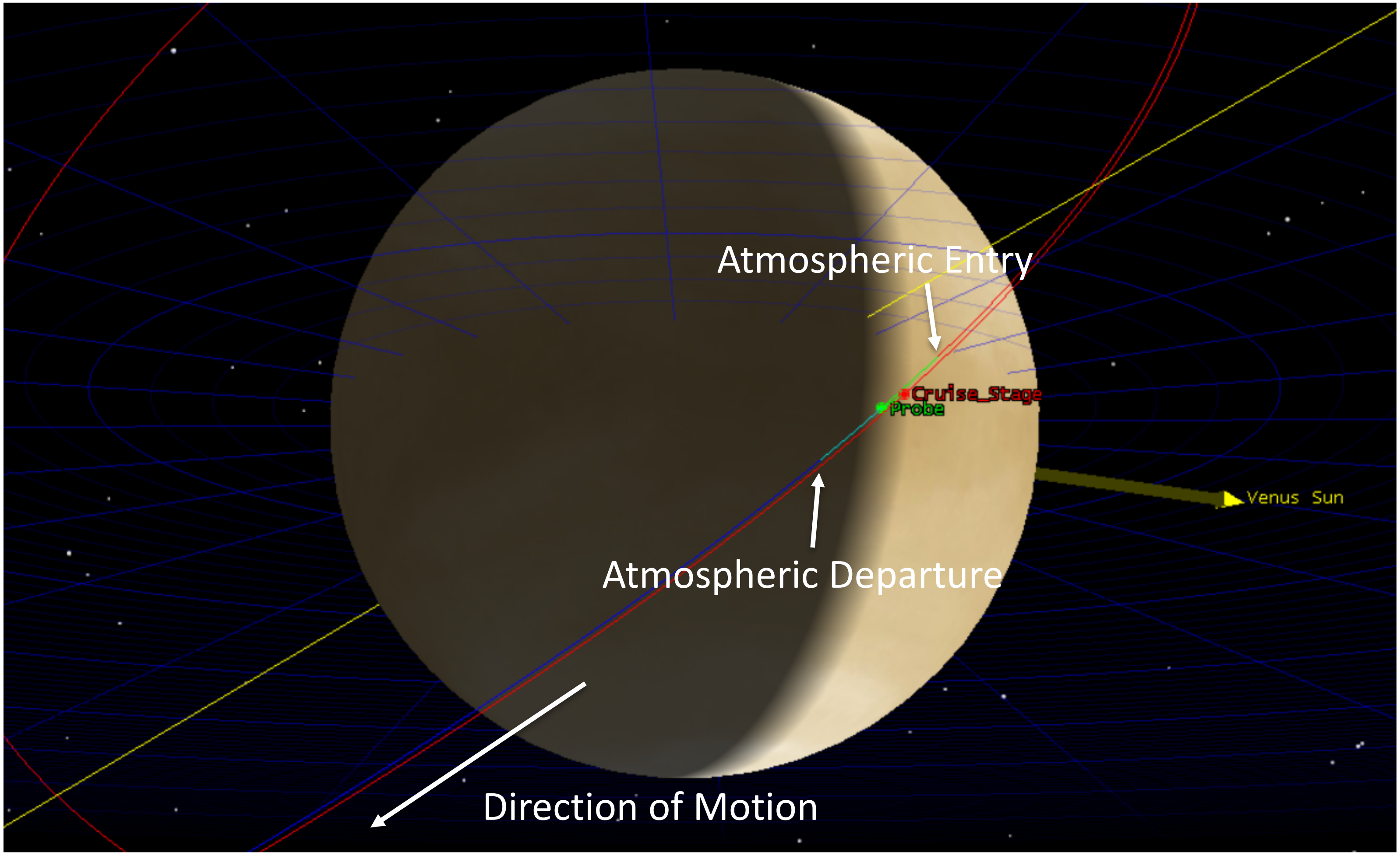
Density profile



The values of density are required for the instrument performance model and for the design of the probe

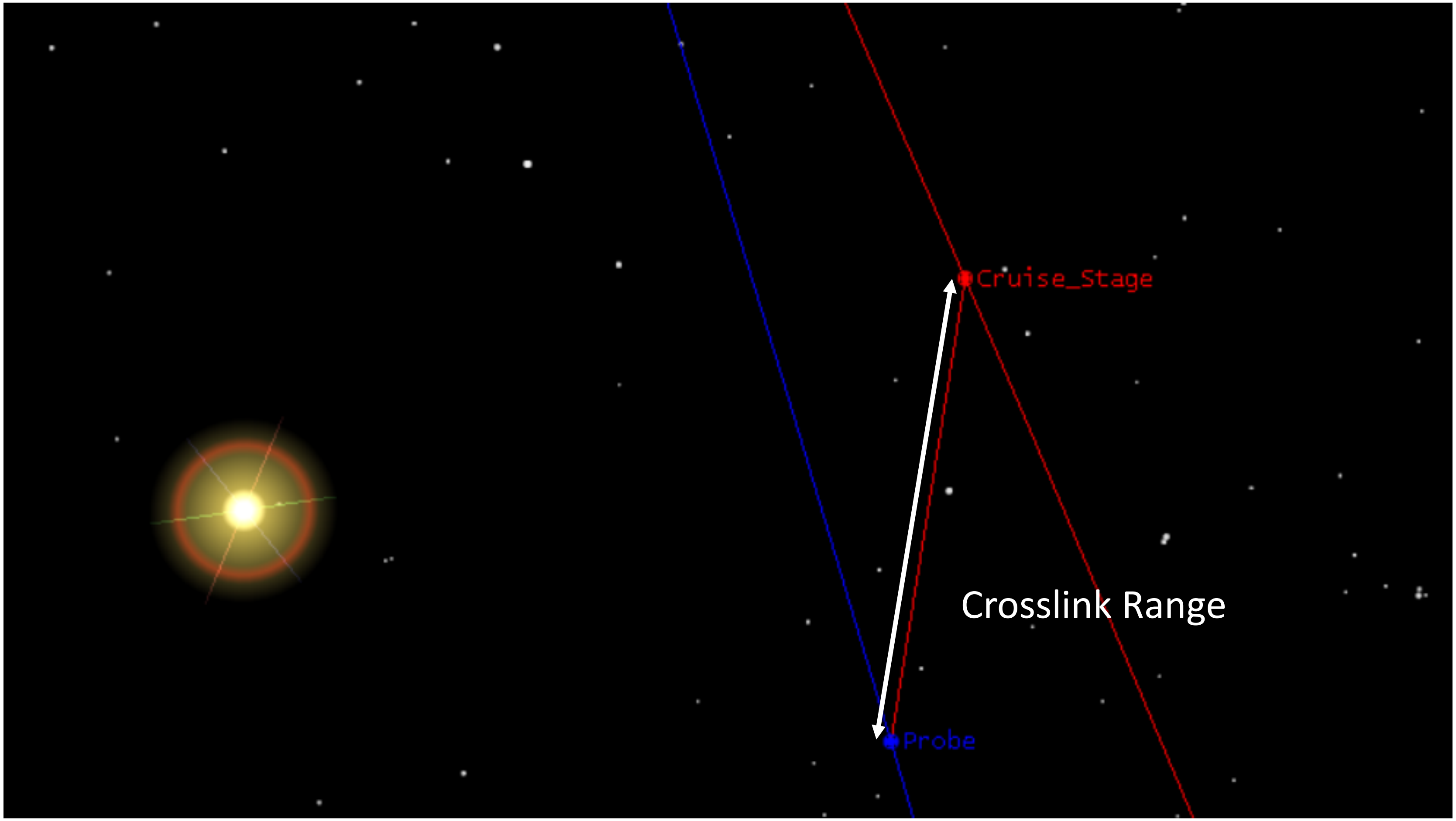
Mission Design

Encounter: 24 Oct 2023 19:10:05.000 UTCG



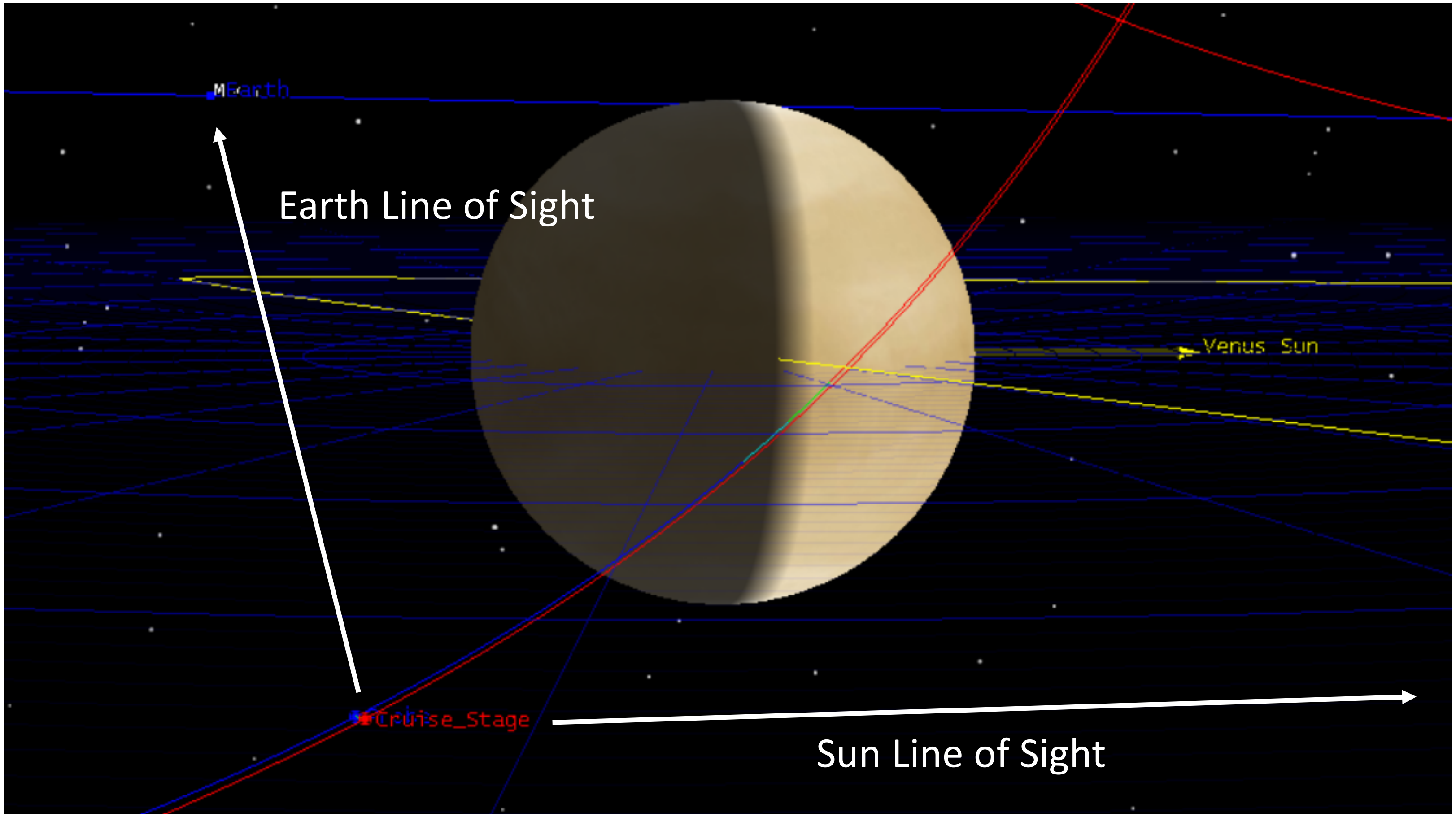
Mission Design

Processing/crosslink/downlink takes place entirely in view of Sun & Earth, maximum separation: ~1310 km

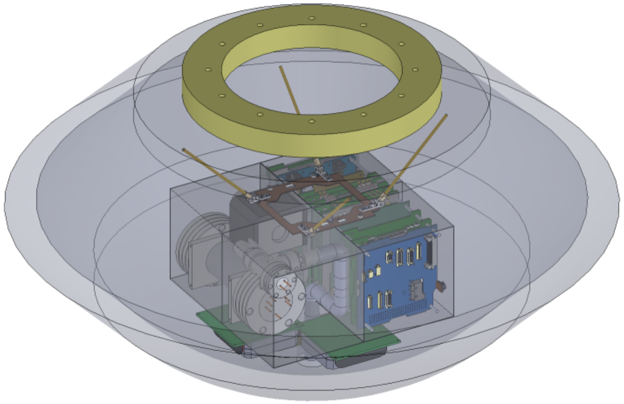


Mission Design

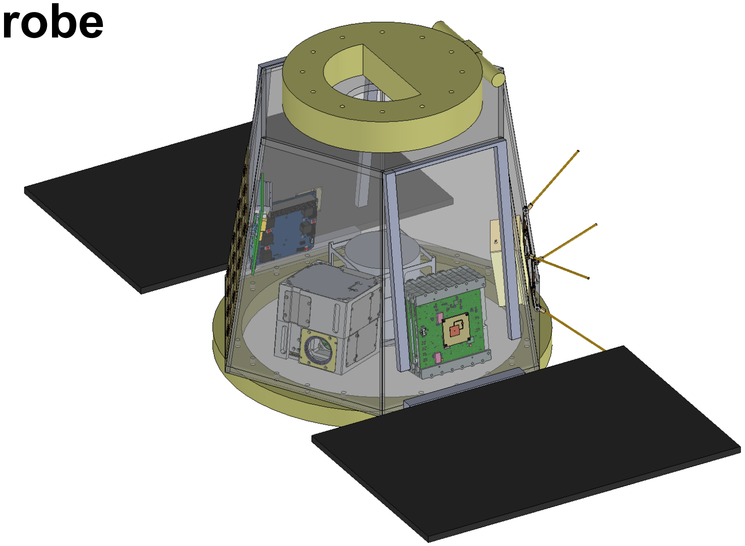
Processing/crosslink/downlink takes place entirely in view of Sun & Earth, maximum separation: ~1310 km



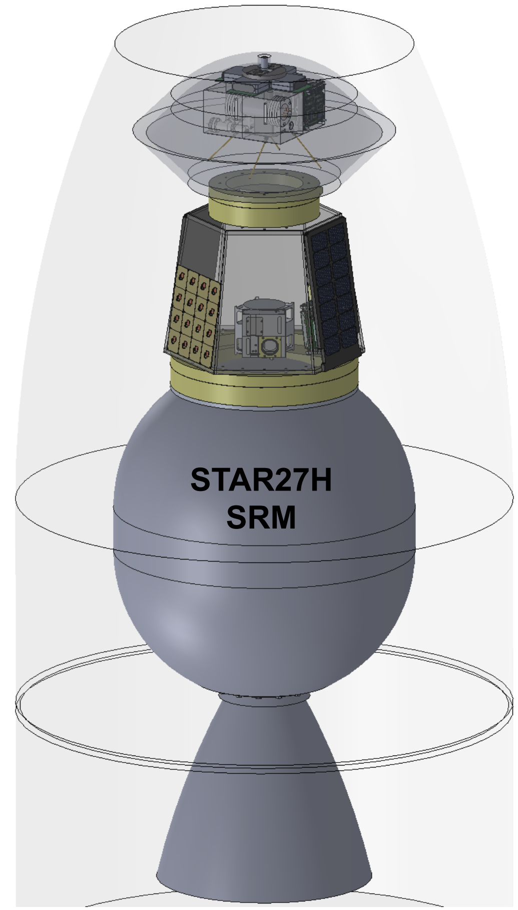
Design Configuration



Probe

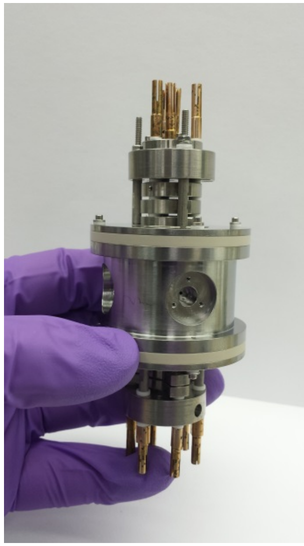


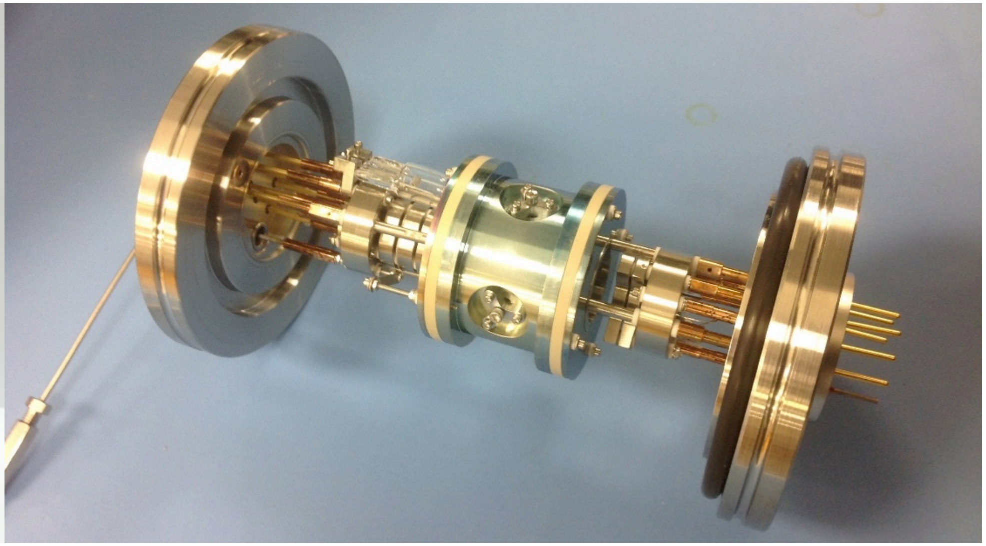
Cruise Stage

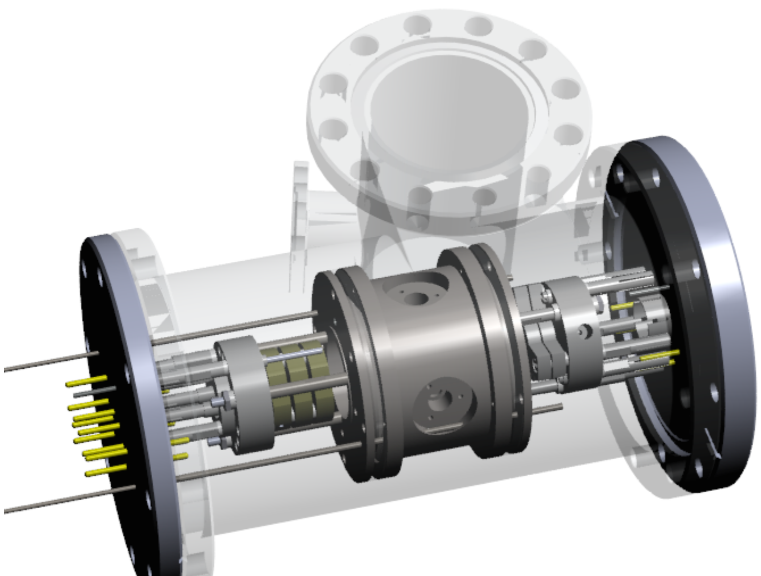


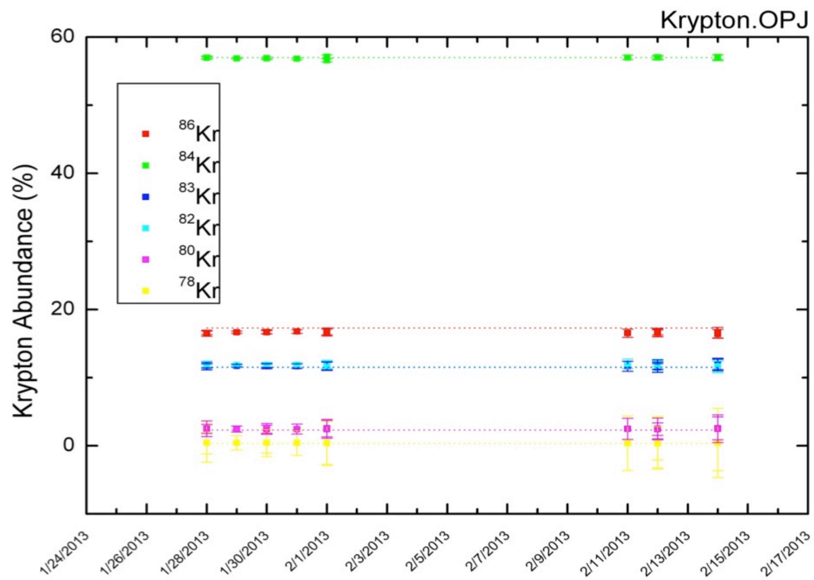
Entire Stack in Pegasus XL Launch Fairing

Cupid's Arrow Quadrupole Ion Trap Mass Spectrometer (QITMS)









QITMS Isotopic Precision is 3-5 times better than required

Instrument Requirements vs. Performance

Performance versus requirements for noble gases ratio

		Expected Intensity (cnts)			
Approximate Isotopic Ratios	Assumed Fractional Abundance	Major]	Minor	Precision [%]	Requirement*
3He / 4He	0.0003	2.80E+08	8.39E+04	0.345	5 to 10
20Ne / 22Ne	12	1.63E+08	1.36E+07	0.028	1
36Ar / 40Ar	0.9	9.32E+08	8.39E+08	0.005	
36Ar / 38Ar	5.4	1.08E+08	2.00E+07	0.024	1
82,83,86Kr / 84Kr	1	1.63E+05	1.63E+05	0.350	1
129, 136 Xe / 130Xe	1	2.33E+04	2.33E+04	0.926	1
124-128Xe / 130Xe	0.2	2.33E+04	4.66E+03	1.605	5

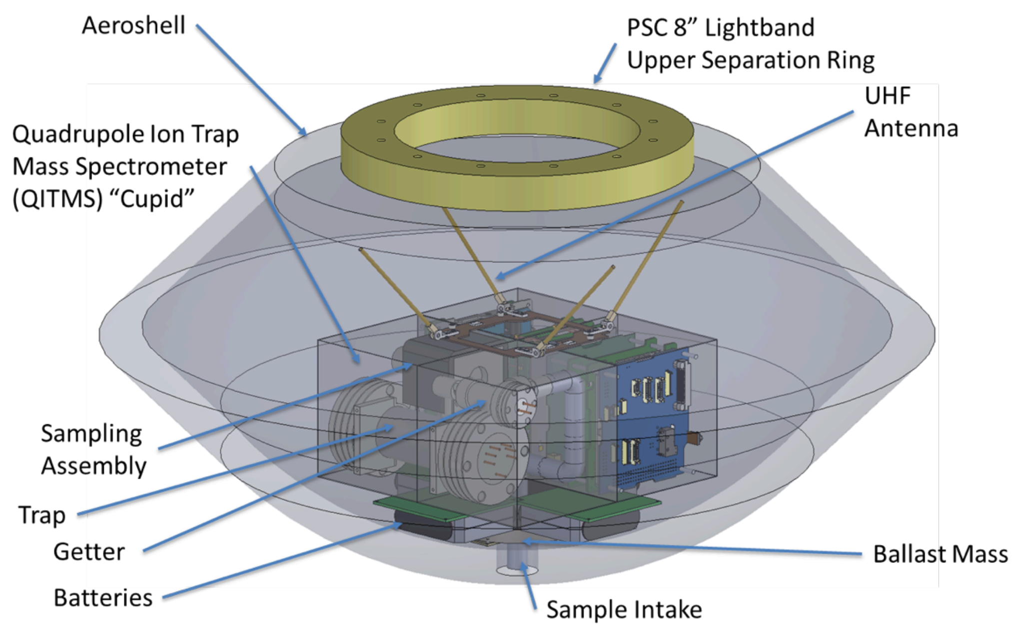
Measurements integrated over 5 mins

*Chassefiere et al., 2012

Design Summary - Probe

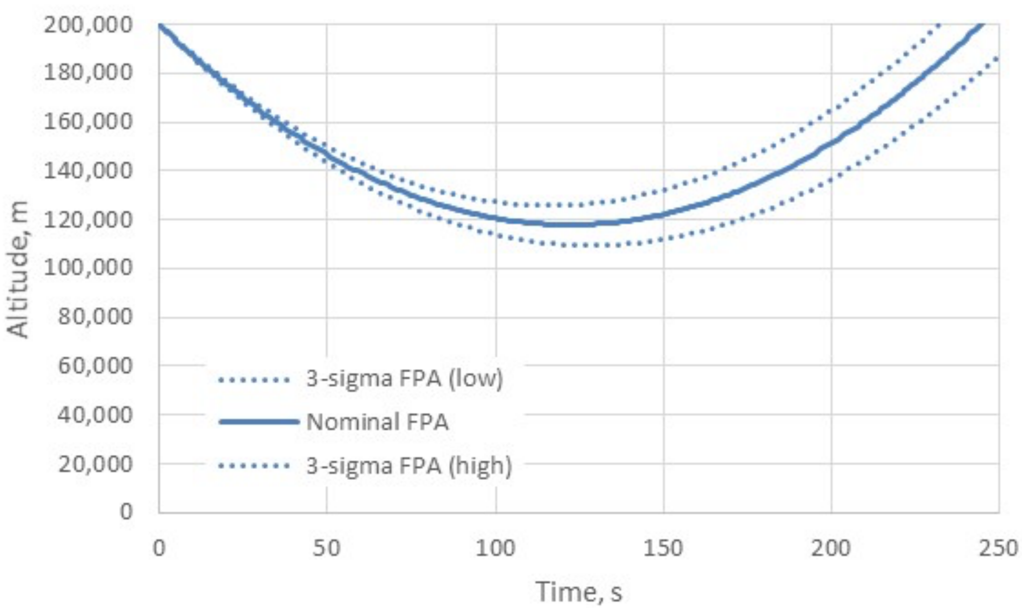
- Instrument
  - 8 kg Quadrupole Ion Trap Mass Spectrometer (QITMS)
  - Pressure transducer
- Telecom
  - Vulcan UHF transceiver
  - NanoCom ANT430 UHF dipole antenna
- Mechanical
  - 4kg aeroshell structure
    - UHF transparent material allows crosslink through the backshell
  - 3kg TPS
  - 2.5kg internal structure
  - 1kg harness
  - 0.5kg balance mass
  - 0.5kg for upper half of Lightband
- Total Mass 21.6 kg
- Total Volume: 17 liters

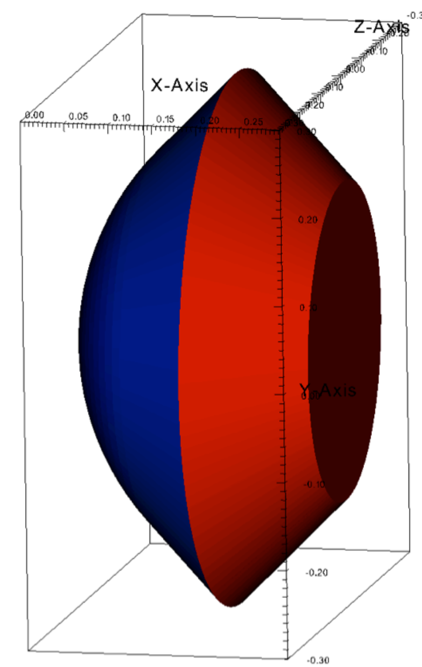
- C&DH
  - JPL Sphinx Avionics
- Thermal
  - MLI and Heaters
- Power
  - 10 Saft LO30SHX primary battery cells
  - 0.1kg Custom EPS



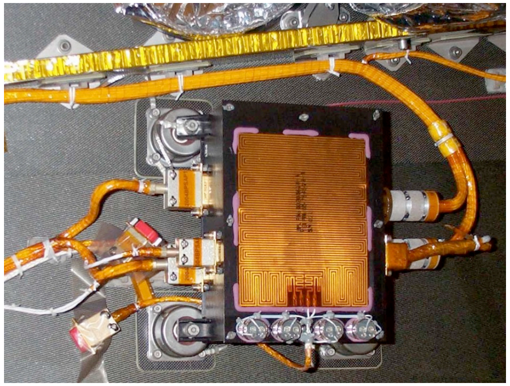
Probe Design

- Entry probe shape
  - 45 deg sphere-cone
    - Scaled-up version of Hayabusa probe; Pioneer-Venus also 45 deg s-c
  - D = 60 cm (diameter), Rn = 30 cm (nose radius)
  - Assumed constant drag coefficient of 1.12 based on Hayabusa data
  - Design for worst-case altitude of 110 km



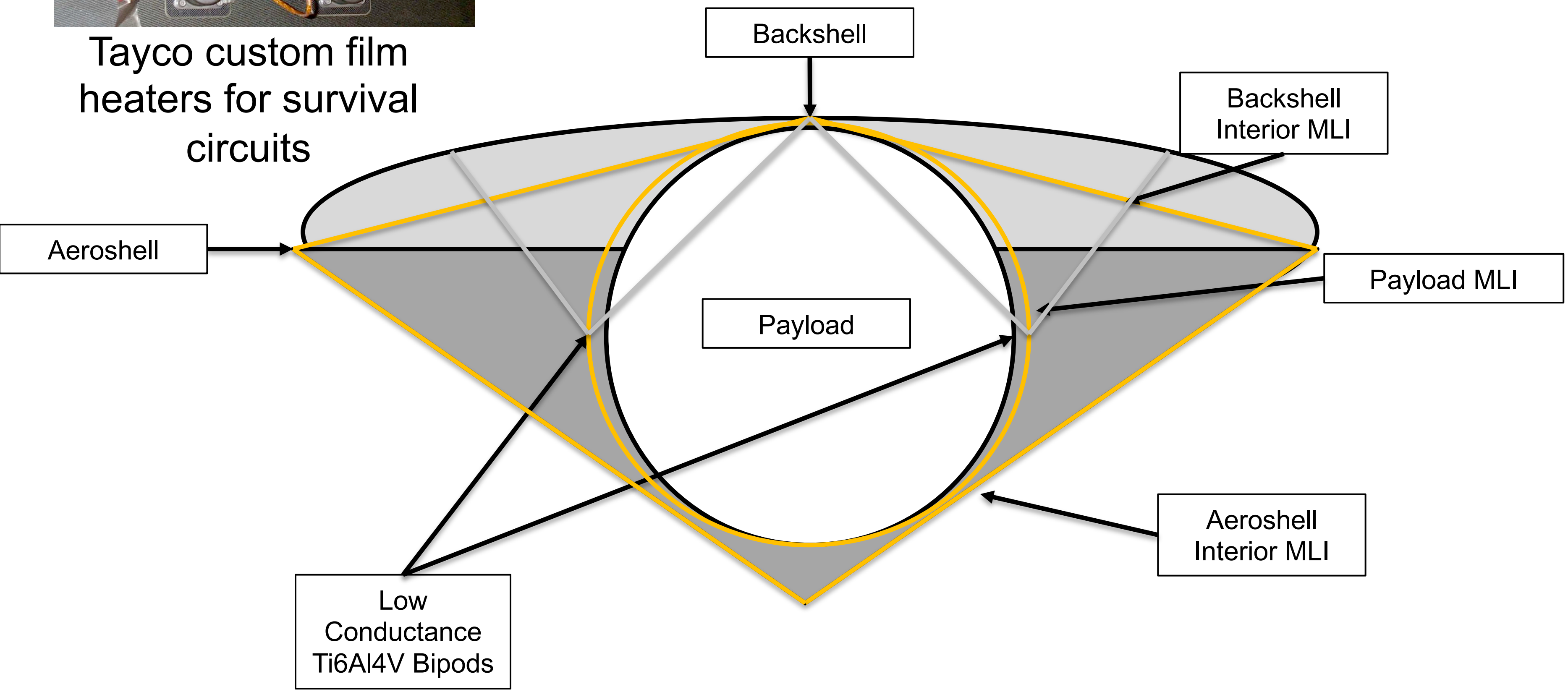


Probe Thermal Design

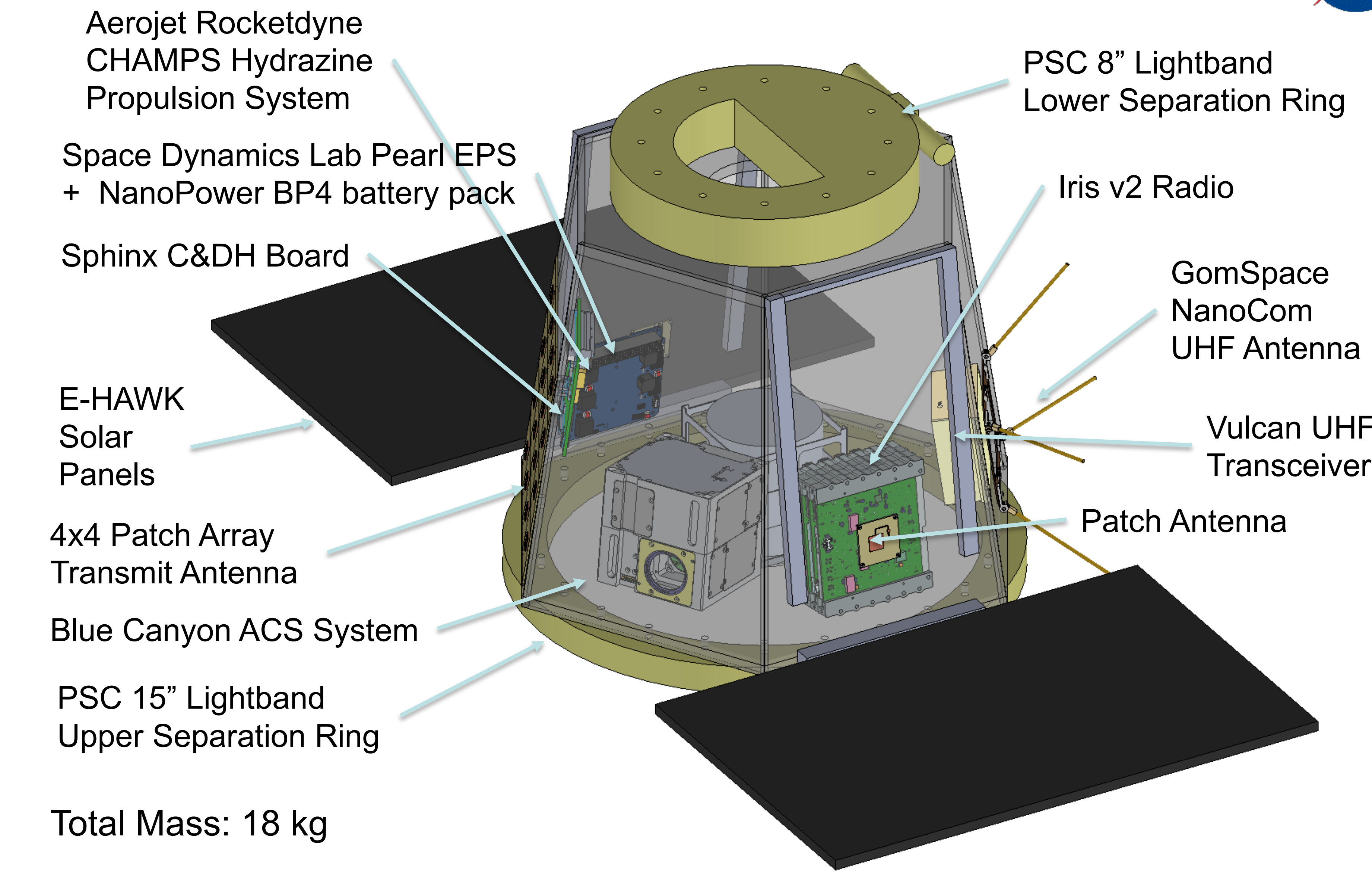


Tayco custom film heaters for survival circuits

- Simplified heatshield TPS stackup:
  - PICA, RTV-560 adhesive, Aluminum
- 3-sigma low altitude (~110 km) drives TPS design
  - (Margined) Peak heat flux is ~150 W/cm^2
  - (Margined) Max heat load is >9200 J/cm^2



Cruise Stage Design



Total Mass: 18 kg

Venus Probe Free-Flyer

Key Technical Parameters	
Mass	Probe Mass 22 kg; Cruise stage Mass 18 kg; Mass Margin 14 kg
Dimensions	Aeroshell is a 45-degree sphere cone; Diameter 60 cm; Cone radius 30 cm
Power	63 W BOL eHawk arrays on cruise stage (margin 43%); 28 V dc, 2W supplied to heater and battery charger prior to deployment; batteries supply 37 watt-hours after release of probe
Instrument	Mass 7.3 kg; volume (incl. electronics) 4U
Data Interface	RS422, SPC, I2C, or GPIOs for command/telemetry; SpaceWire for data
Thermal	Max heat load on probe is >9200 J/cm2
Data Volume/rate	16 Mb; crosslinked over UHF 60 kbps link for 5 minutes; X-band return to Earth via 34 m DSN station over ~ 9 hours
Range for comms	Communication between carrier and probe at ranges < 1310 km
Mechanical	Lightband COTS deployer used
Payload	Ultra-compact Quadrupole Ion Trap Mass Spectrometer (QITMS)
CubeSat Avionics	Radiation tolerant Sphinx C&DH; Blue Canyon ACS
Deployment	On approach, spin up to 10 rpm, then release probe with -1.25 m/s Delta-V; Cruise stage then executes 10 m/s divert maneuver for flyby
Aeropass	Minimum Altitude is less than or equal to 120 km; duration 3-4 mins; lat/long -11/-71 deg; entry angle ~ 7 deg
Environmental Conditions	11 km/sec velocity at entry, density $<10^{-6}$ kg/m^3; max heating rate 150 W/cm^2,

Conclusions

- A free-flying SmallSat probe with mass < 55 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, …

- The authors would like to thank Team Xc for their help in advancing the maturity of this concept