The Venus Atmospheric Sample Return (VATMOS-SR) Mission Concept

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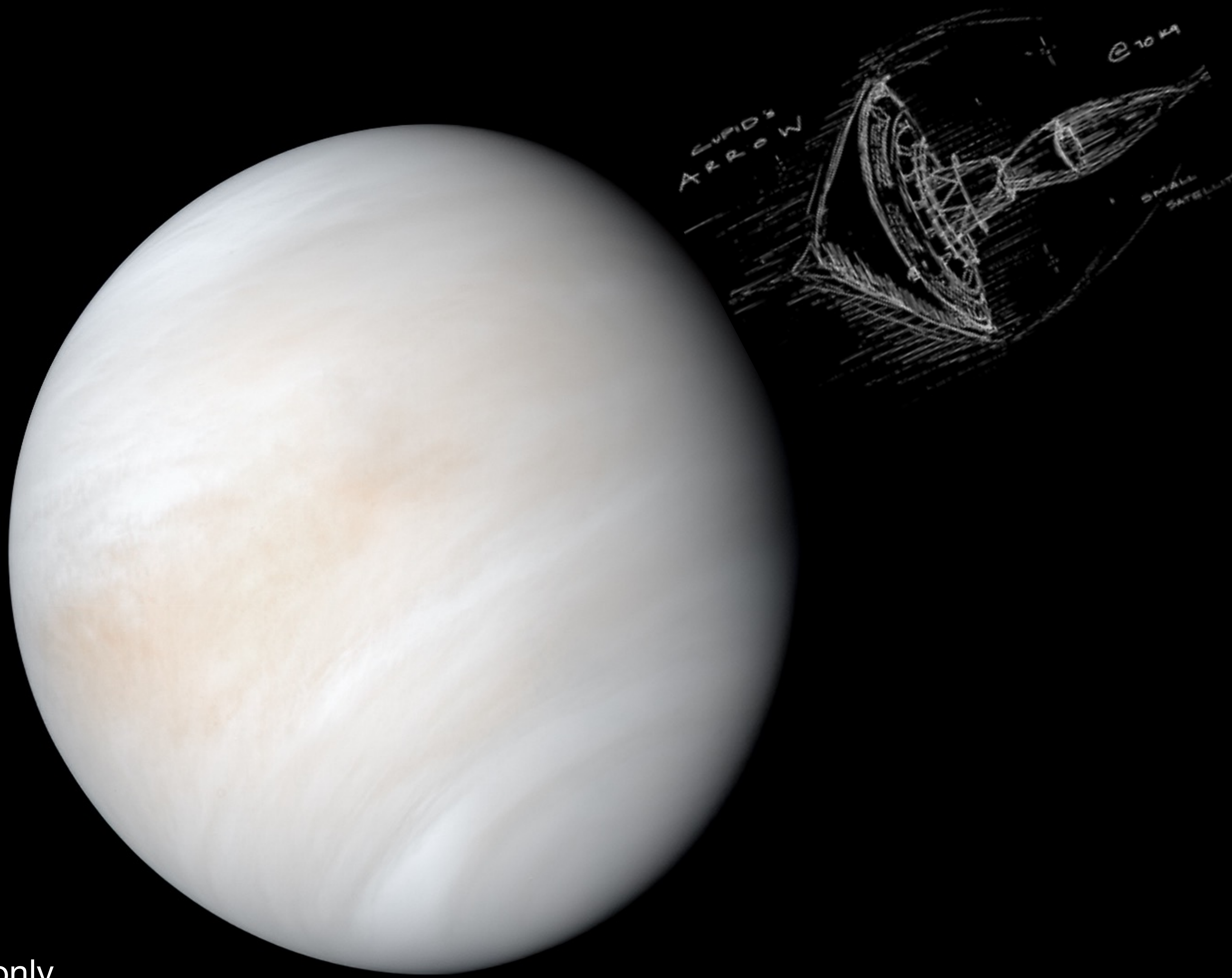
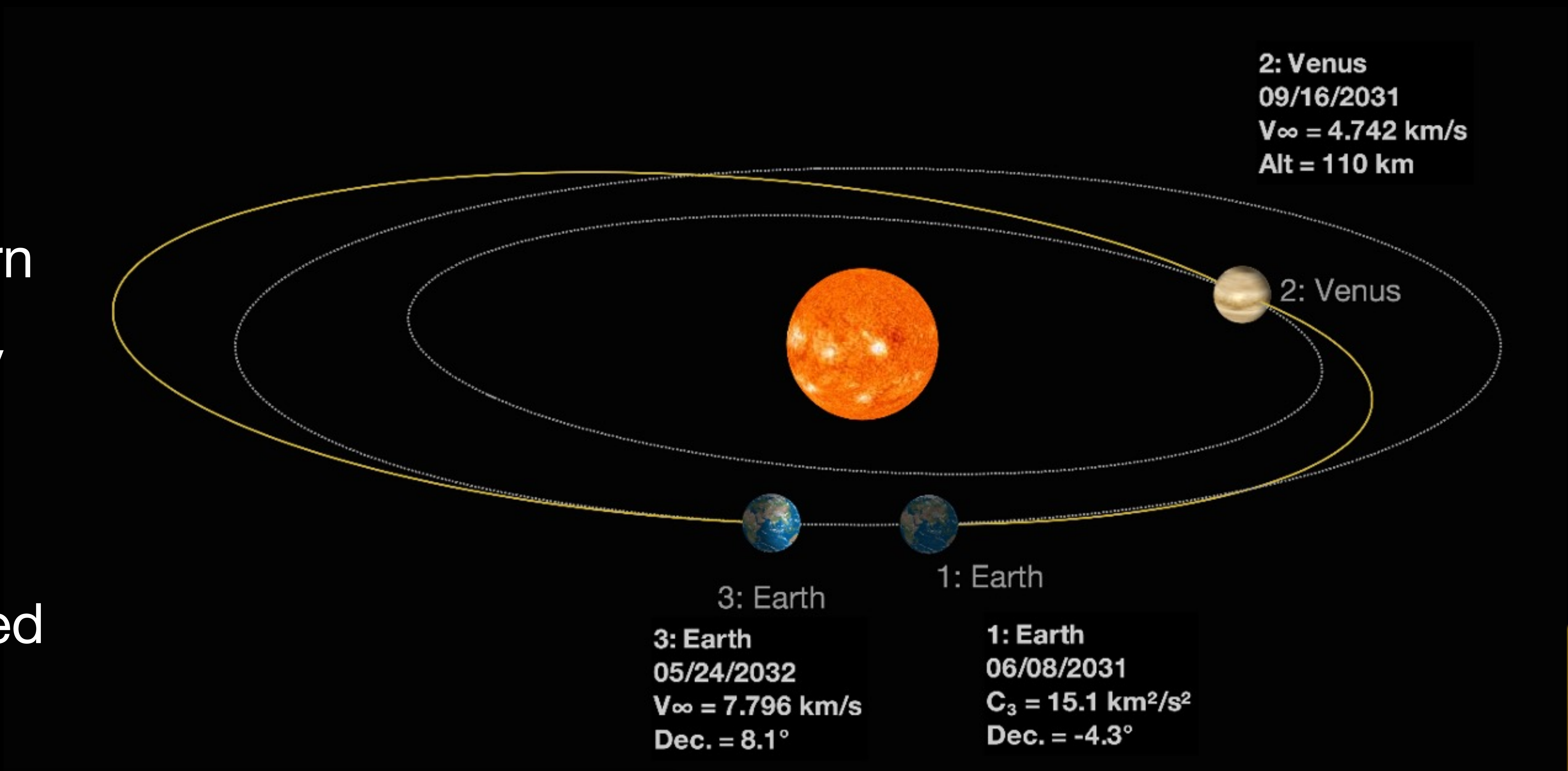


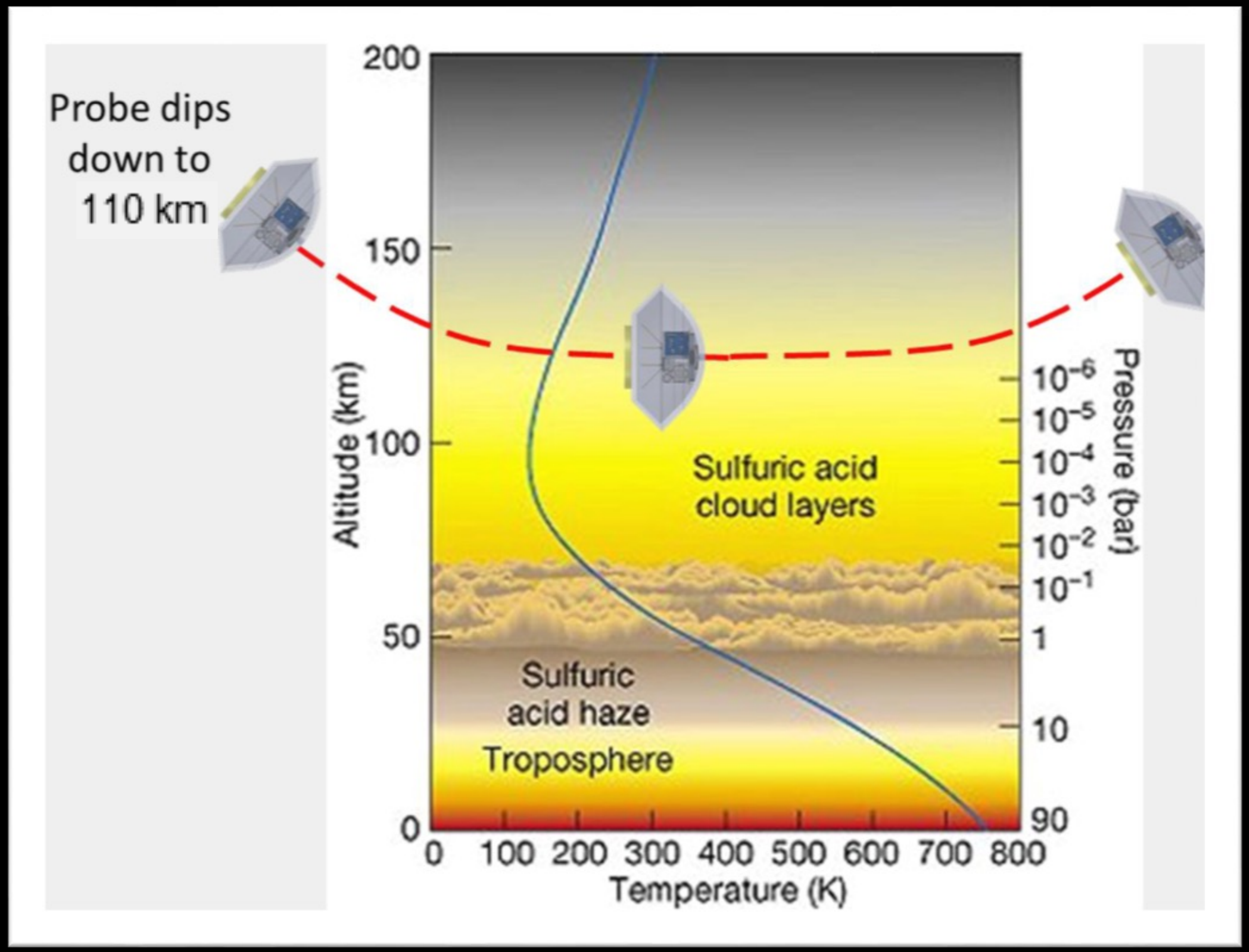
IPPW 2023

VATMOS-SR

Mission Concept Overview

- Venus upper atmosphere sample return
- SmallSat (< 1 m diameter, ~ 75 kg dry mass)
- Mission Duration: < 1 year
- ΔV requirements ~ 1.5 km/s IF launched with a VEGA-C Launch Vehicle
- Venus entry: ~ 11 – 13 km/s
- Earth entry: ~ 13 km/s (similar to Stardust)
- Drogue + Main @ Earth: targeting Woomera (Australia) for landing





Credit: 2011 Pearson Education, Inc.
https://pages.uoregon.edu/jimbrau/BraulmNew/Chap09/7th/AT_7e_Figure_09_17.jpg
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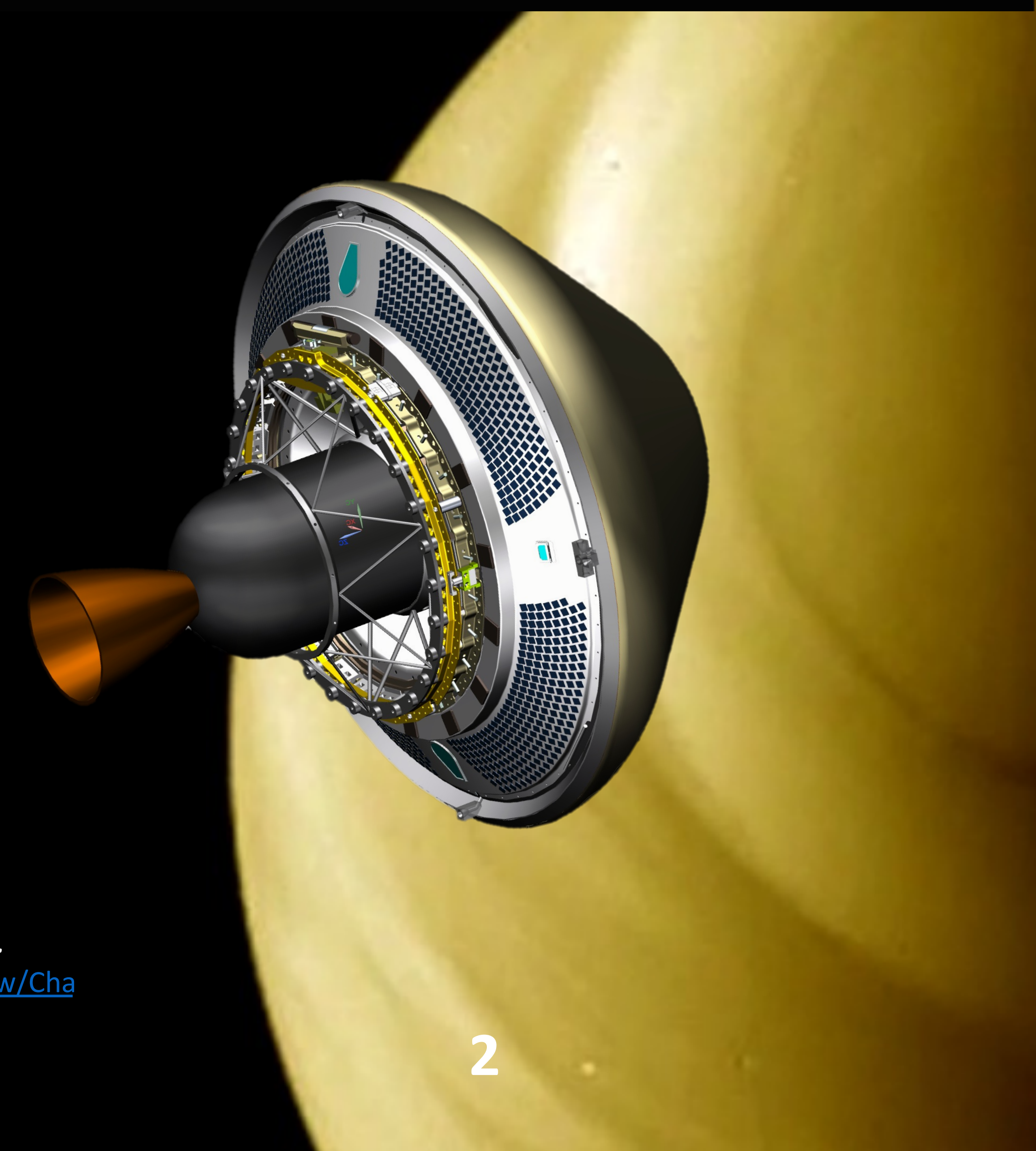

This information is pre-decisional and is for discussion purposes only.

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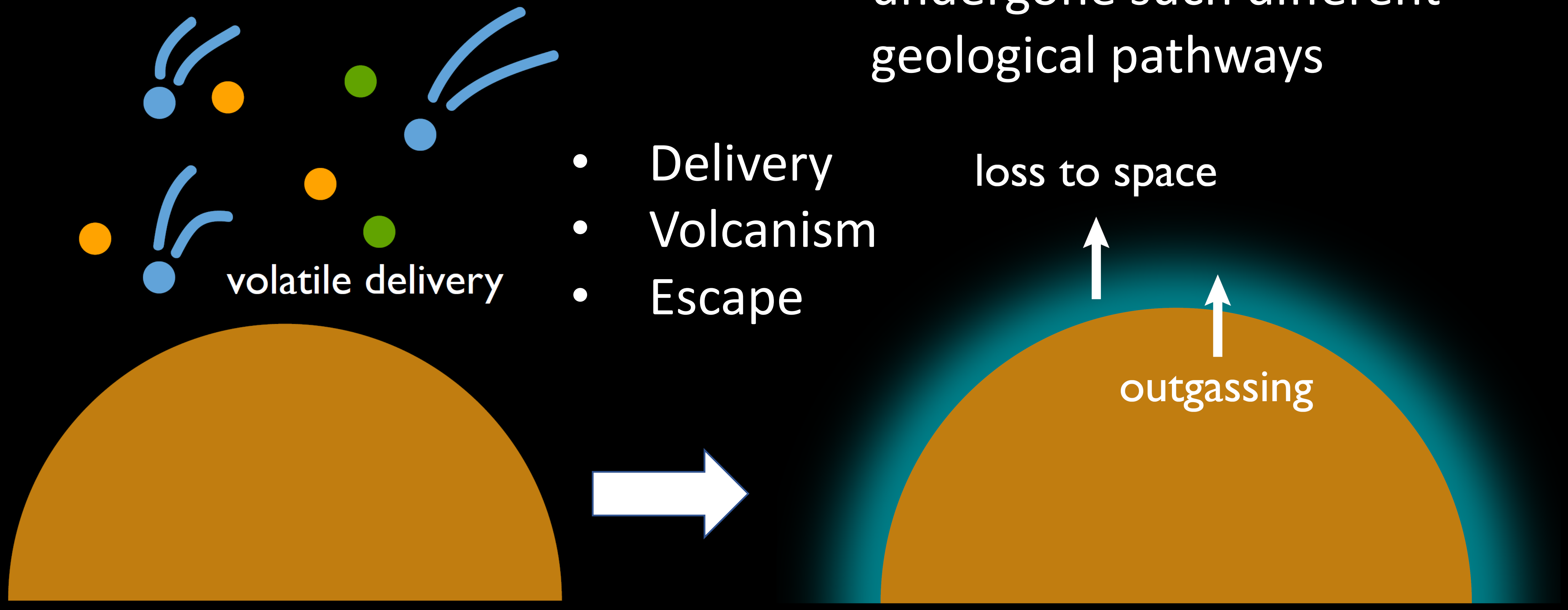
Science Overview

- This mission will further our understanding of how sister planets, Venus and Earth, have undergone such different global evolution
- Multiple atmospheric samples will be collected below the Venus homopause
- Samples will be returned to the Earth so that state-of-the-art terrestrial noble gas laboratories can analyze the samples
- (Could be the) First returned sample of an extraterrestrial atmosphere
- Analytical precision in terrestrial labs is better (>5x) than precision achieved by in-situ instruments, including those planned for Venus
- Interpretations of geochemical signatures with Venus in-situ precision are plagued by ambiguity that terrestrial lab measurements could resolve (Venus volatile origins, past geodynamics, atmospheric loss)
- **Focus on noble gas isotopic measurements**

Why have Earth and Venus undergone such different geological pathways

- Delivery
- Volcanism
- Escape



Science Goal: Understand Venus' evolution	SCIENCE OBJECTIVES	PHYSICAL PARAMETER	OBSERVABLES (precision)
	Determine if Venus' isotopic composition falls on the primordial solar composition	Isotope composition of noble gases and nitrogen	Isotope ratios: $^{132}Xe/^{130}Xe$ (1%) $^{136}Xe/^{130}Xe$ (1.5%), $^{15}N/^{14}N$ (1%)
	Distinguish amongst models for planetary-scale volcanism	Elemental ratios and isotopic compositions of noble gases	Relative abundance of He ($^{4}He/^{40}Ar$) and isotopic ratios $^{3}He/^{4}He$ (50%), $^{129,131-136}Xe/^{130}Xe$ (1%)
	Determine whether escape mechanisms were more active on Venus than on Earth	Fractionation of Xe	Amount of ^{129}Xe, $^{124}Xe/^{130}Xe$, $^{126}Xe/^{130}Xe$, $^{128}Xe/^{130}Xe$ (1-2%)

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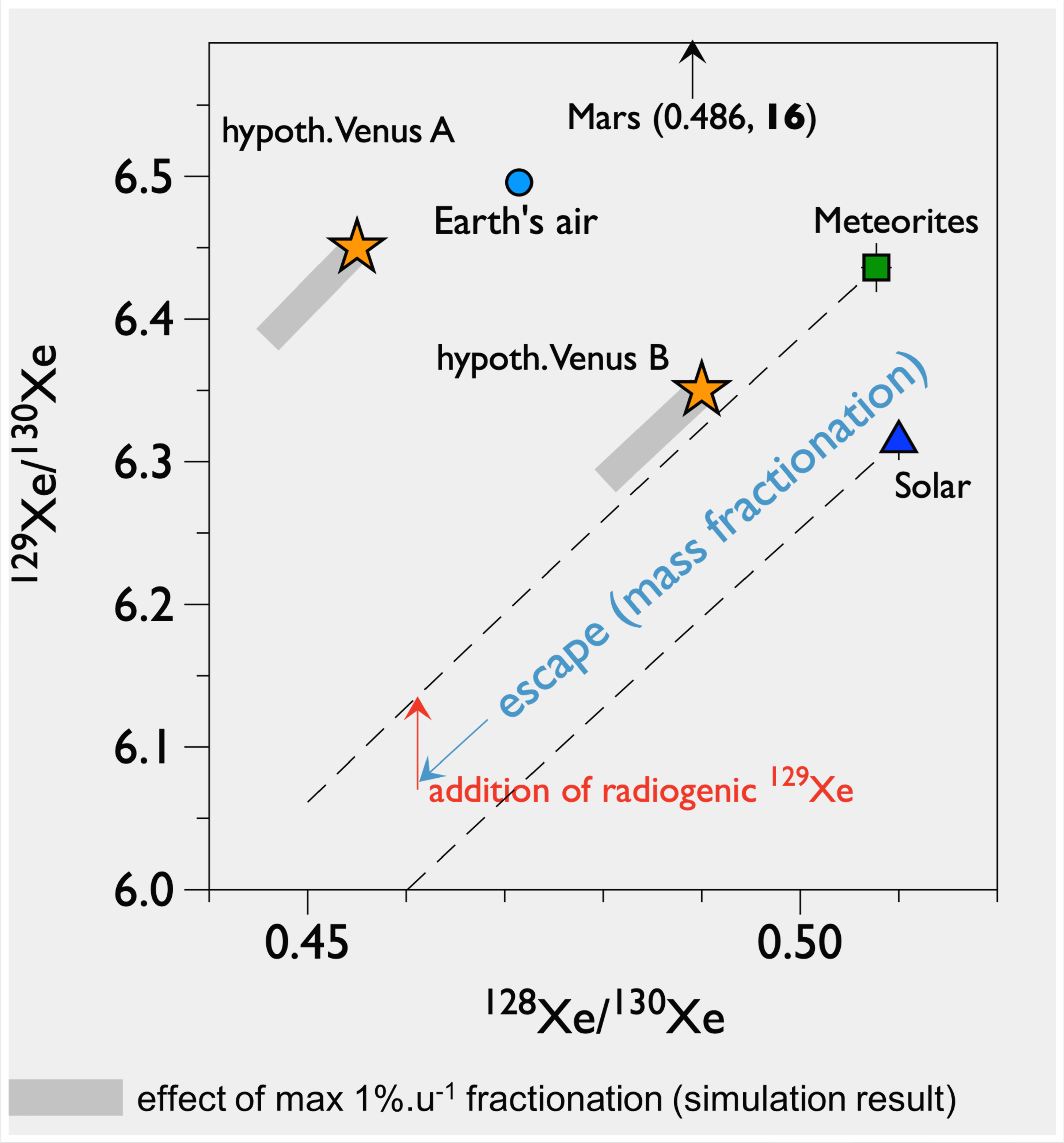

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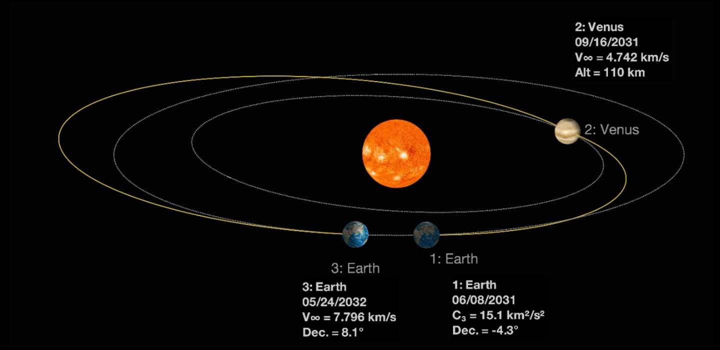
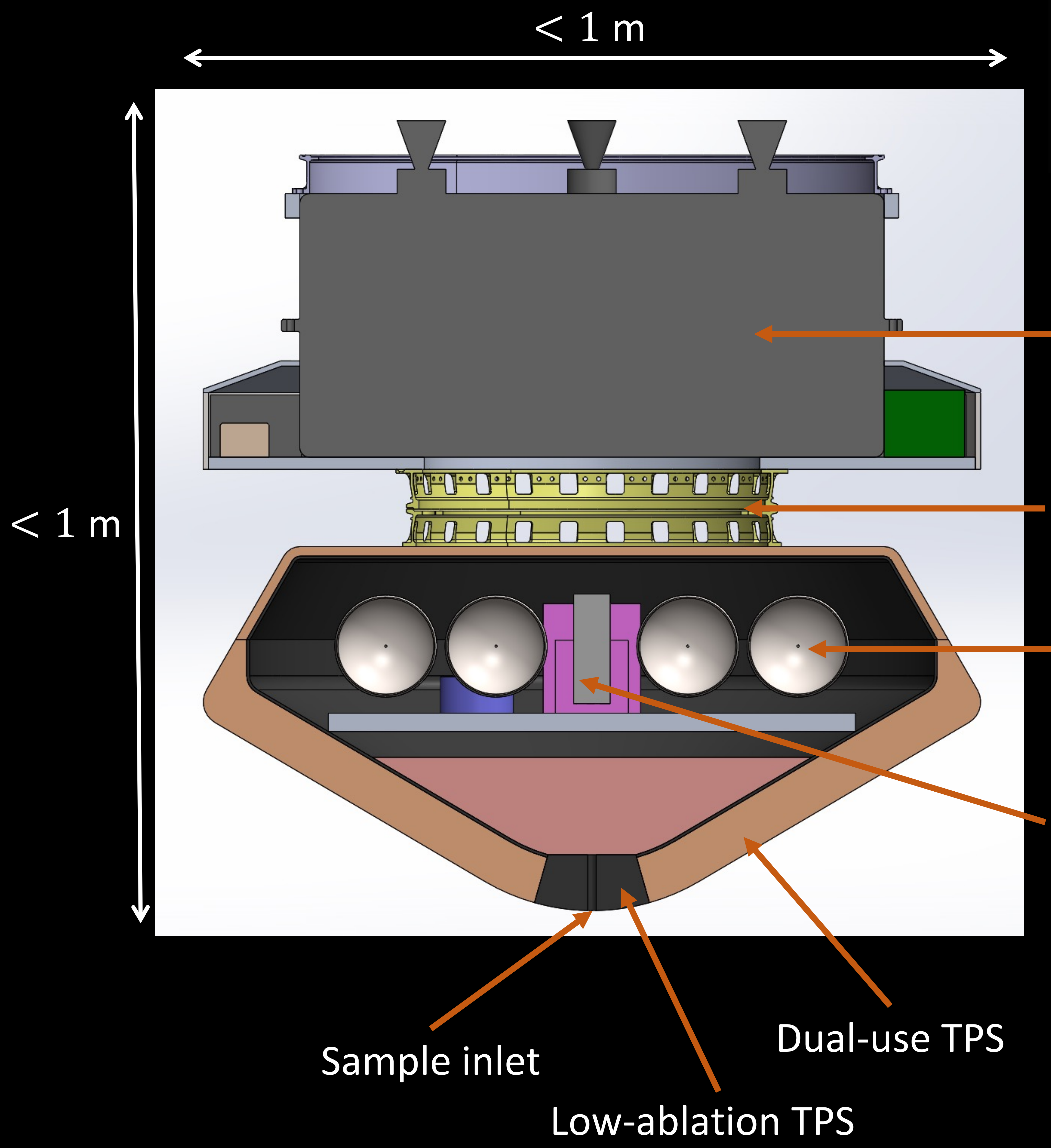
Spacecraft Overview

- **SmallSat** (<1 m diameter, ~ 75 kg dry mass)
- Entry probe ~ 35 kg dry mass
- Propulsion TBD (depends on LV + trajectory)
- Power: Solar panels on Propulsion Stage
- **Propulsion Stage separates several days before Earth entry → entire stack for Venus sampling pass!**
- Dual-use Thermal Protection System:
  - 3D Carbon/Carbon insert with PICA "family" or 3MDCP heatshield
- Build-to-print Stardust parachute drogue and main
  - Drogue: Mortar deployed 0.83 m nominal diameter DGB
  - Main: 7.3 m nominal diameter tri-conical





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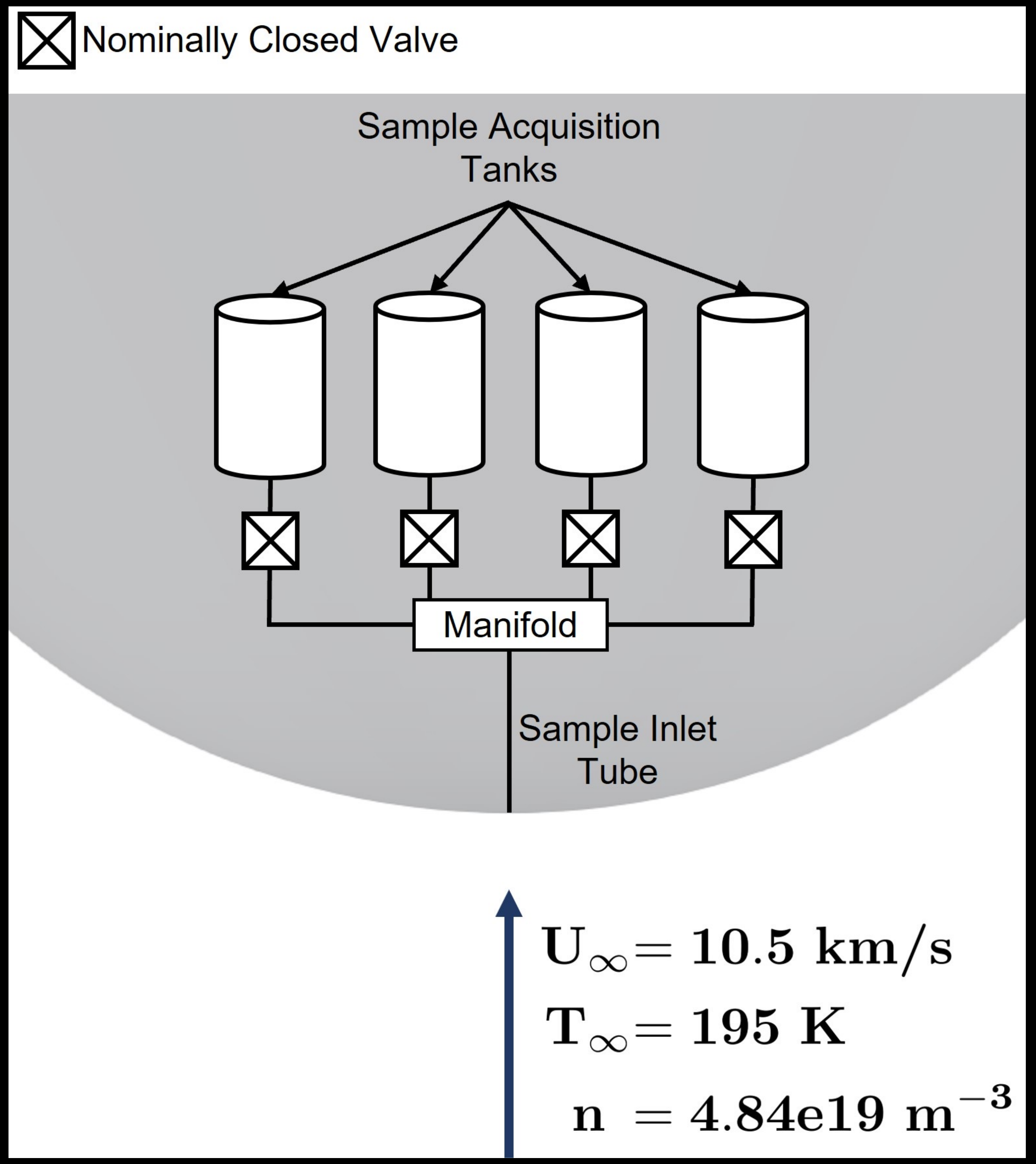
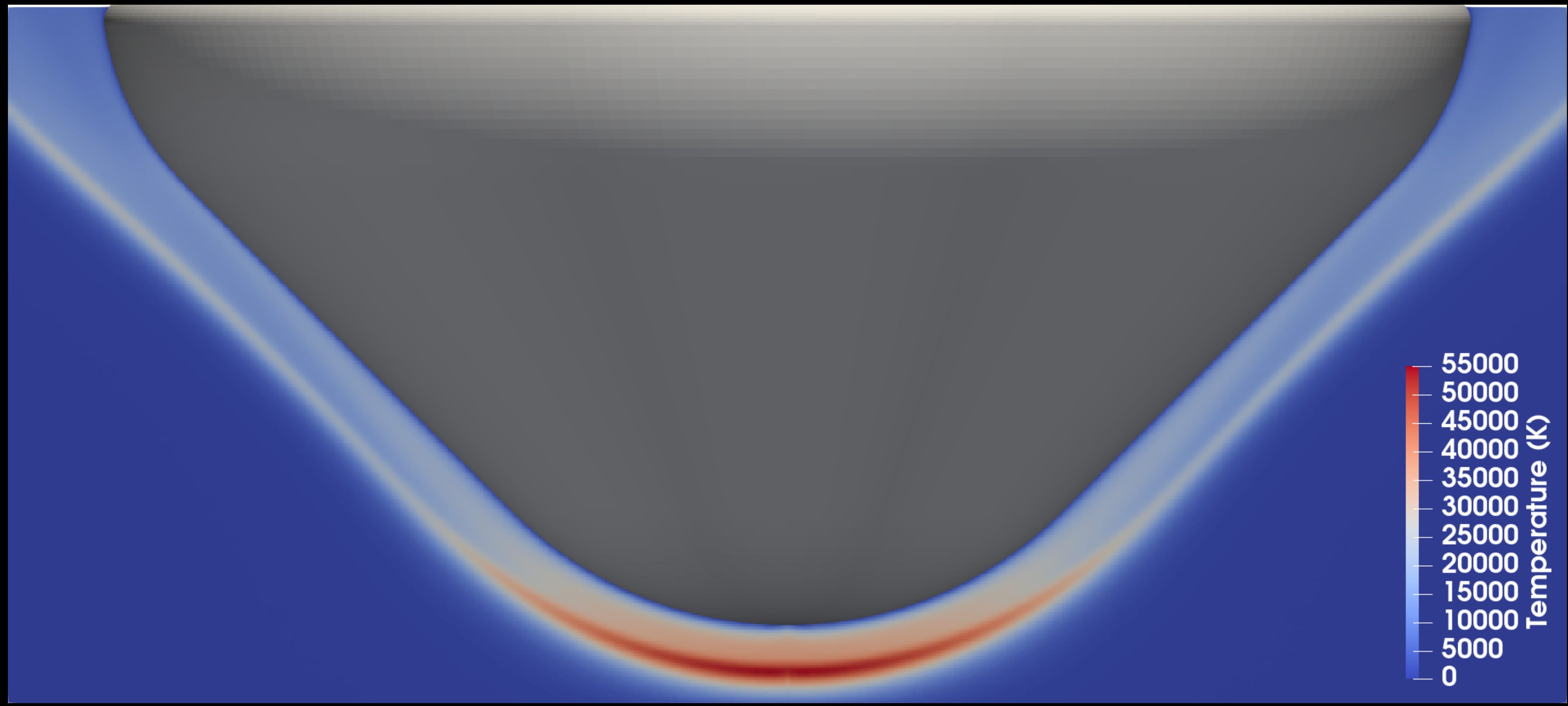
Sampling Summary/Challenges

- Targeting a sampling altitude below the homopause
- Venus atmospheric pressure at 110 km altitude is very low (~ 1 mtorr ≈ 0.1 Pa)
- **Sampling at ~ 11 – 13 km/s!**
- Challenges with performing relevant experiments on Earth
- Cleanliness requirements: noble gases of interest have expected concentrations in the ppb in Venus's atmosphere
- Targeting ~ 100 Pa of pressure, ~4 L volume
- Geometry is complicated and spans many length scales (Mindrum valves – TRL 9)

Is the sample that we acquire representative of the Venus atmosphere, or have we modified it?





Molecular Gas Dynamics simulations performed with the SPARTA DSMC Code (Stochastic PArallel Rarefied-gas Time-accurate Analyzer, https://sparta.sandia.gov/)

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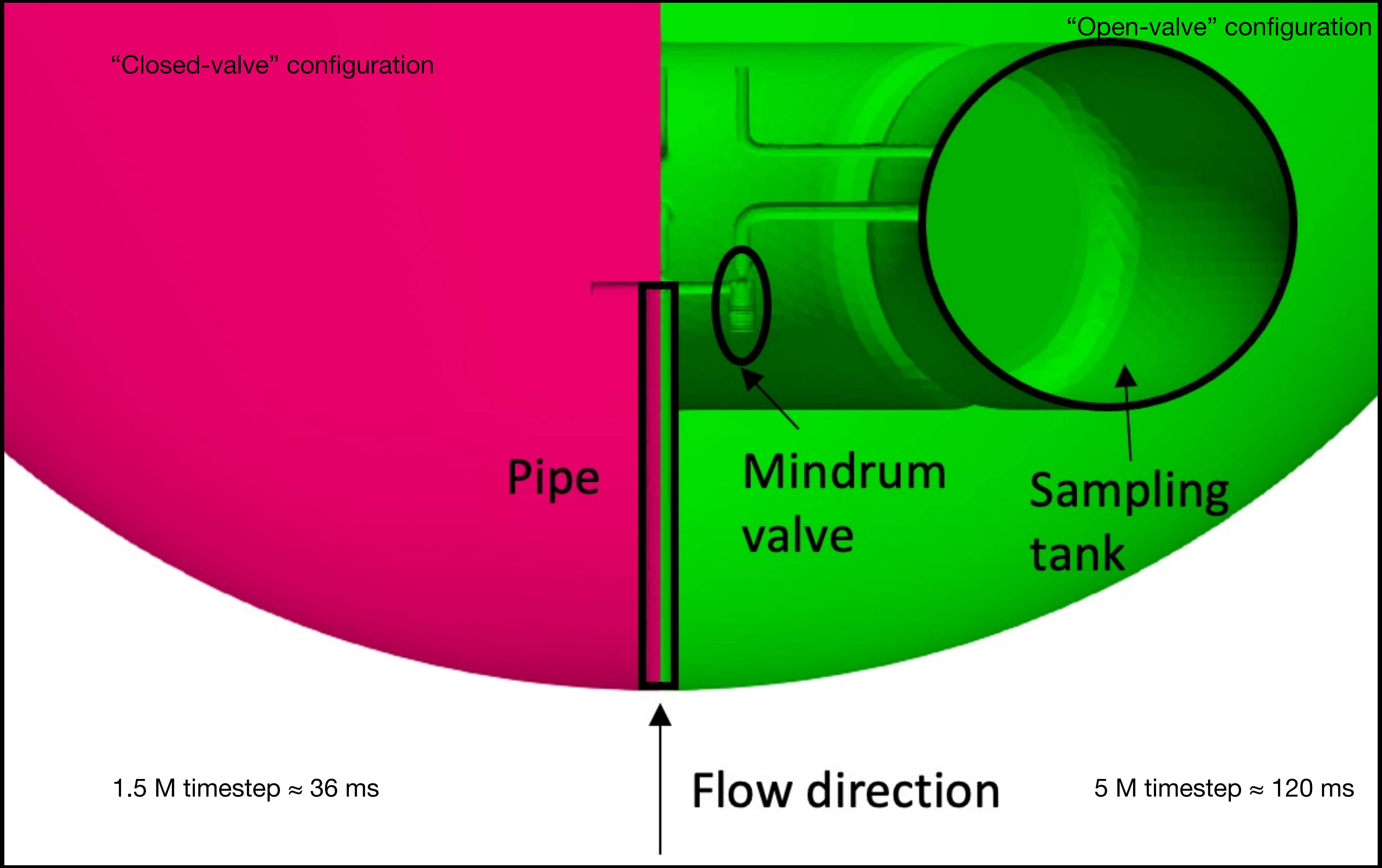

"Closed-valve" configuration
"Open-valve" configuration
Pipe
Mindrum valve
Sampling tank
Flow direction
1.5 M timestep ≈ 36 ms
5 M timestep ≈ 120 ms

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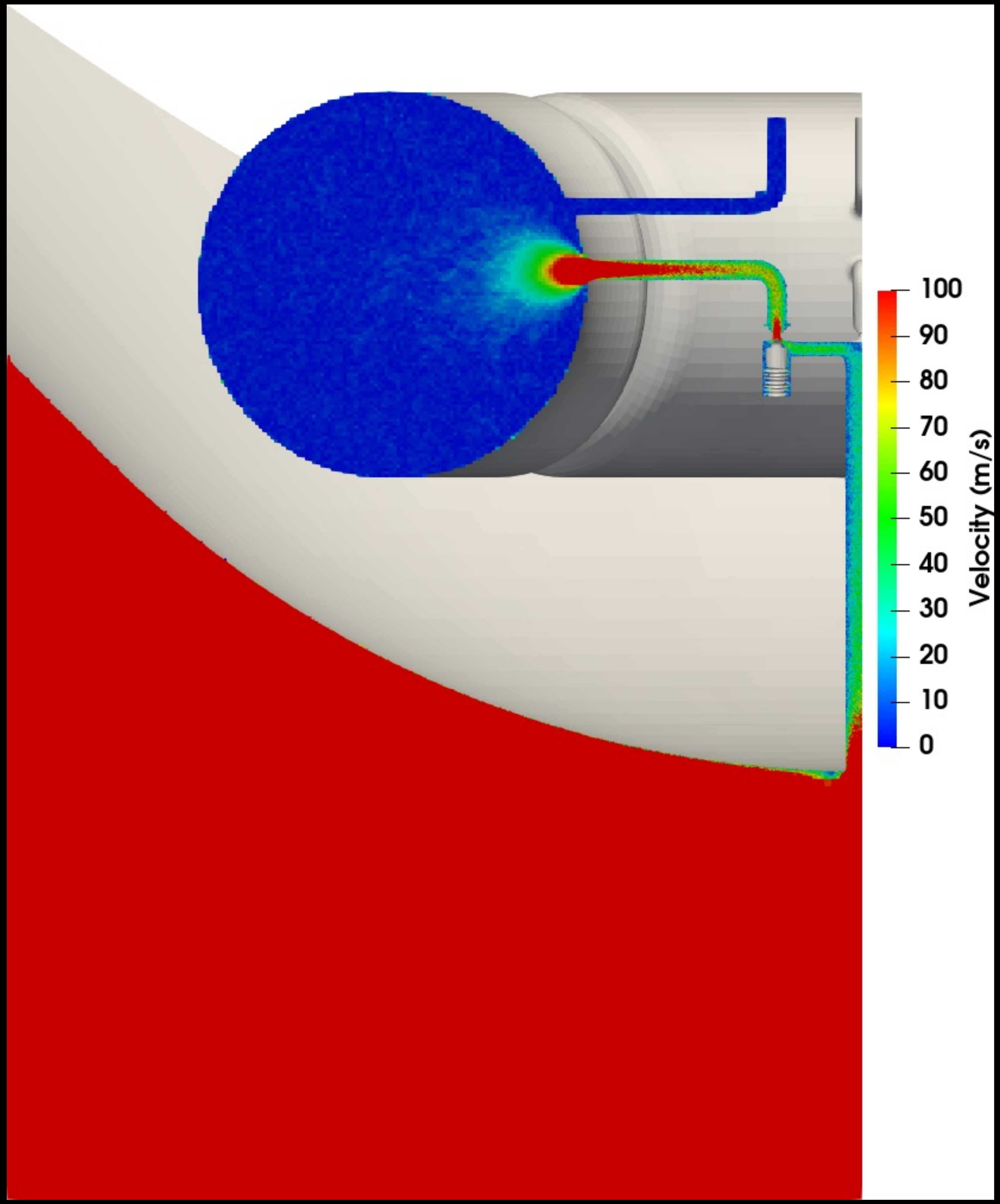
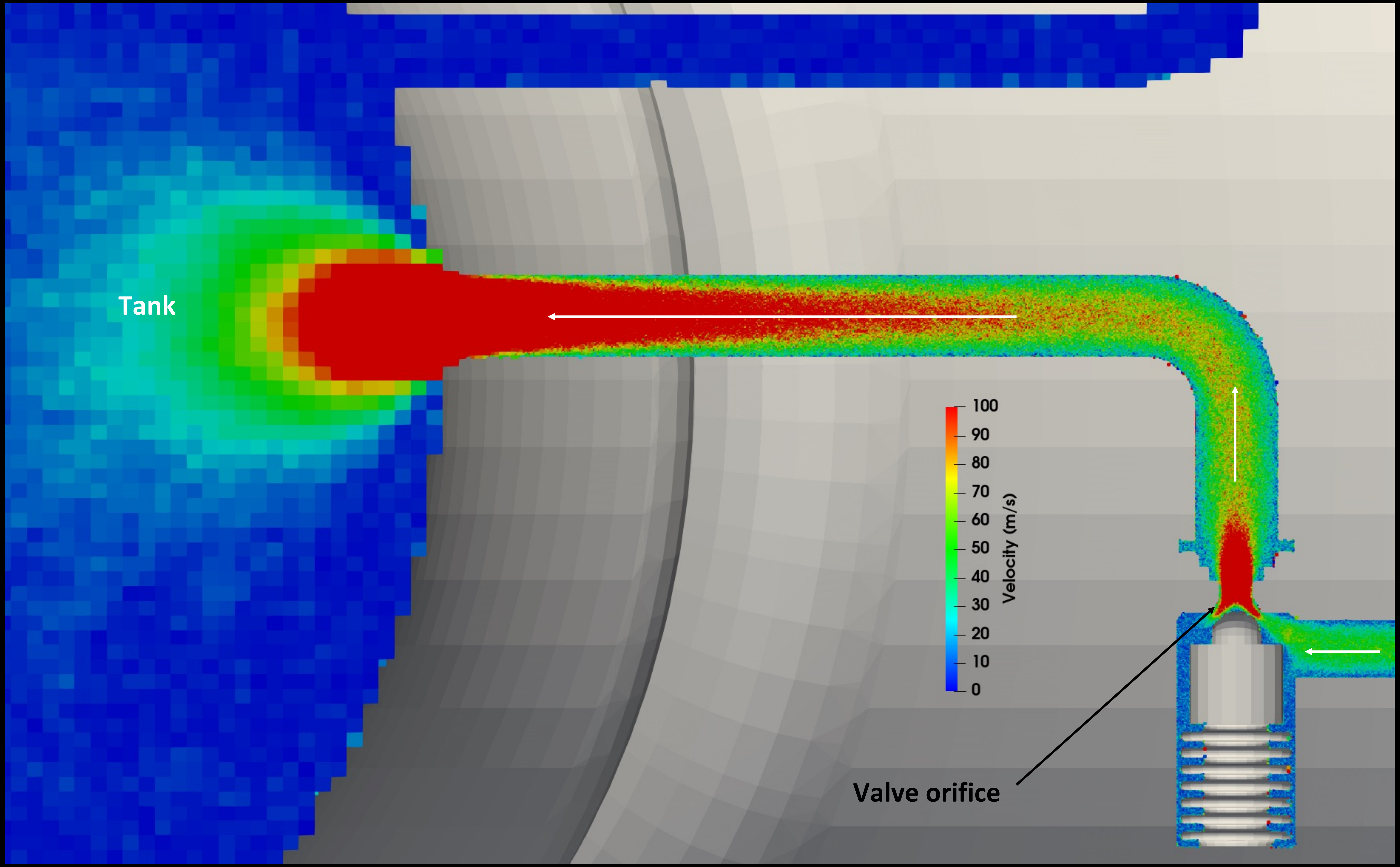


100
90
80
70
60
50
40
30
20
10
0
Velocity (m/s)



Tank
100
90
80
70
60
50
40
30
20
10
0
Velocity (m/s)
Valve orifice

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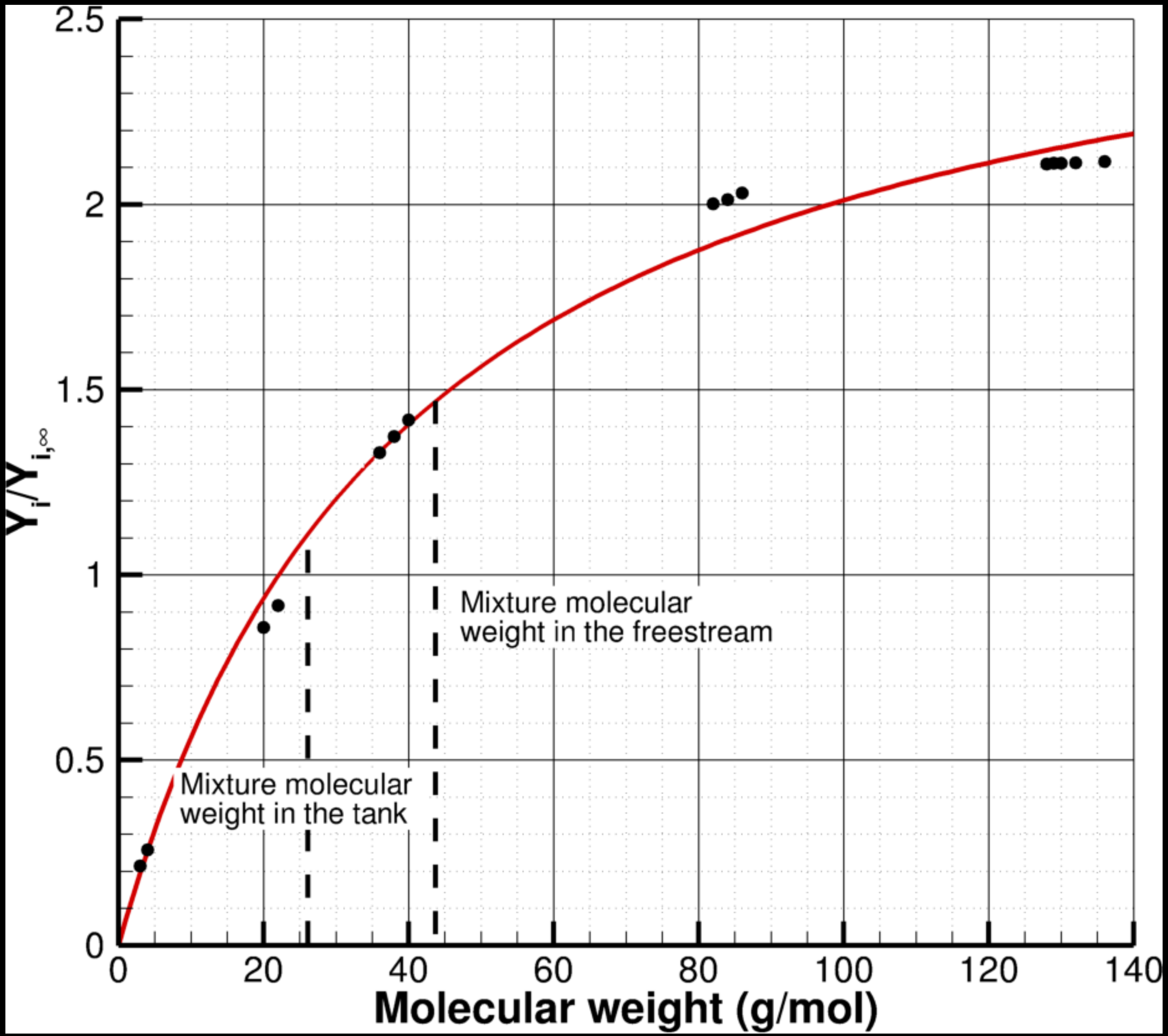

Fractionation is primarily driven by differential diffusion of species through strong bow shock, which itself is driven by molecular diffusion, and is a function of species molecular weight. **Similar differential diffusion is observed for similar molecular weight species.**

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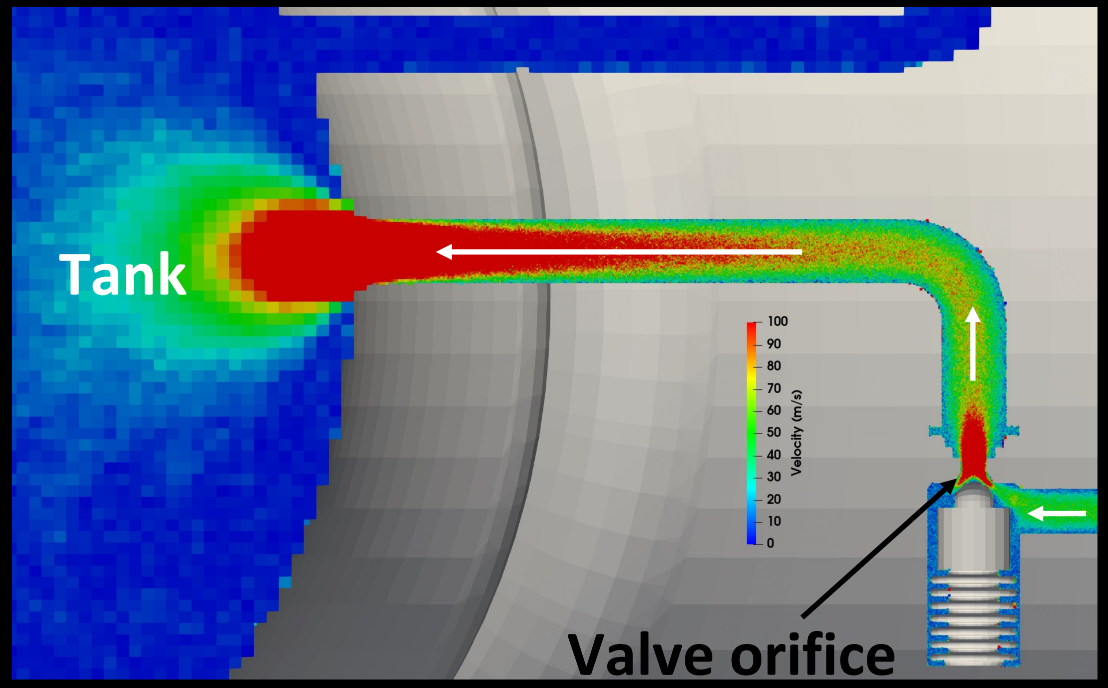
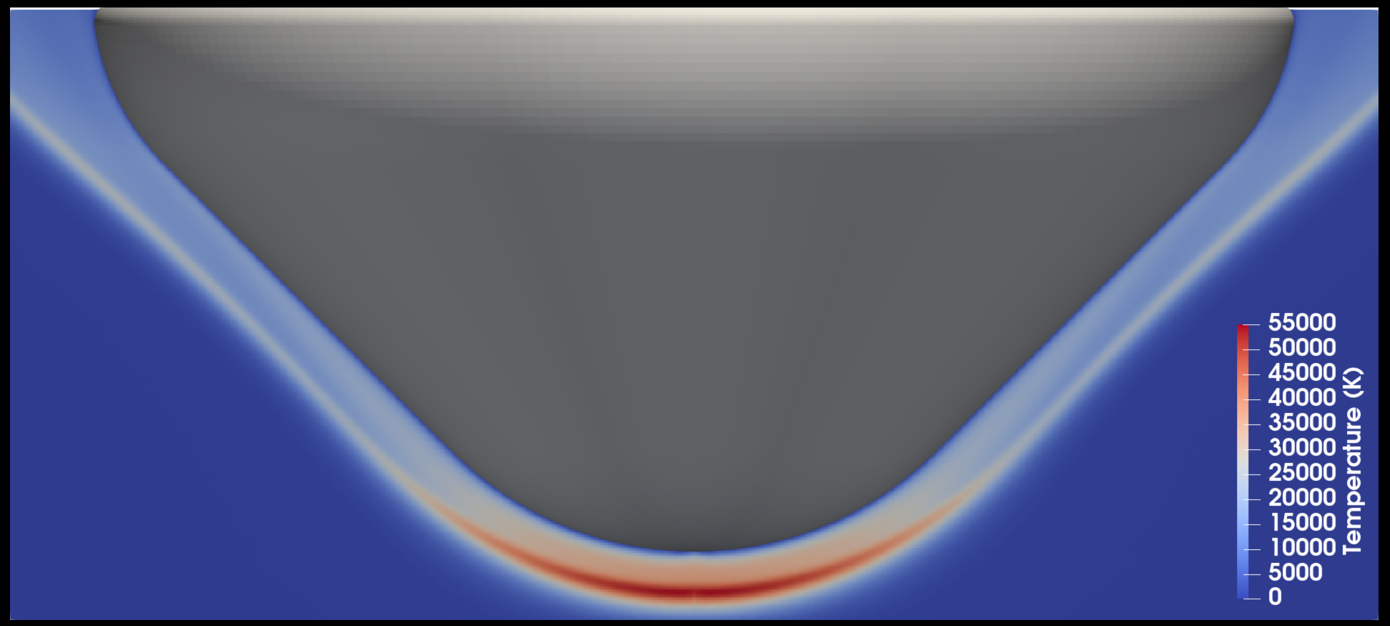
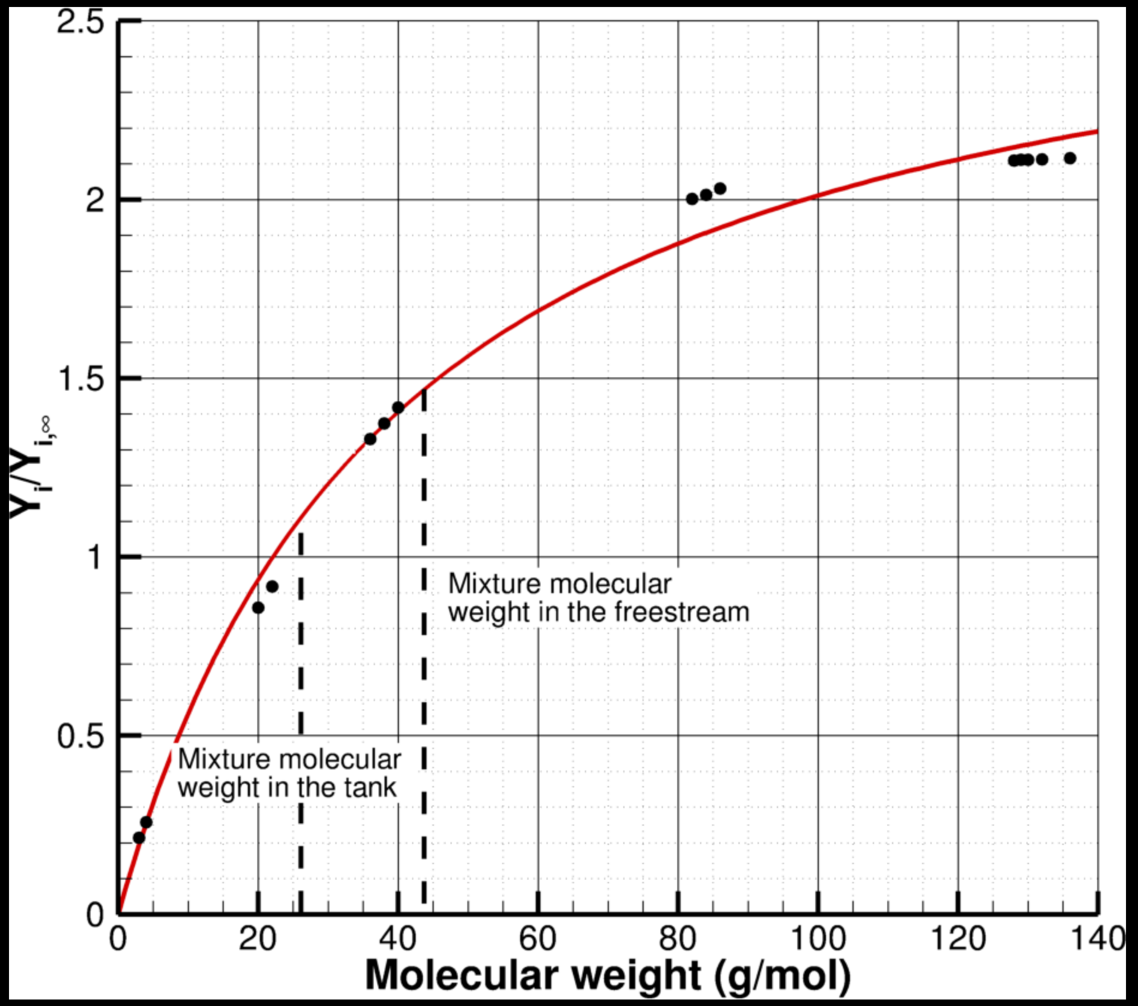
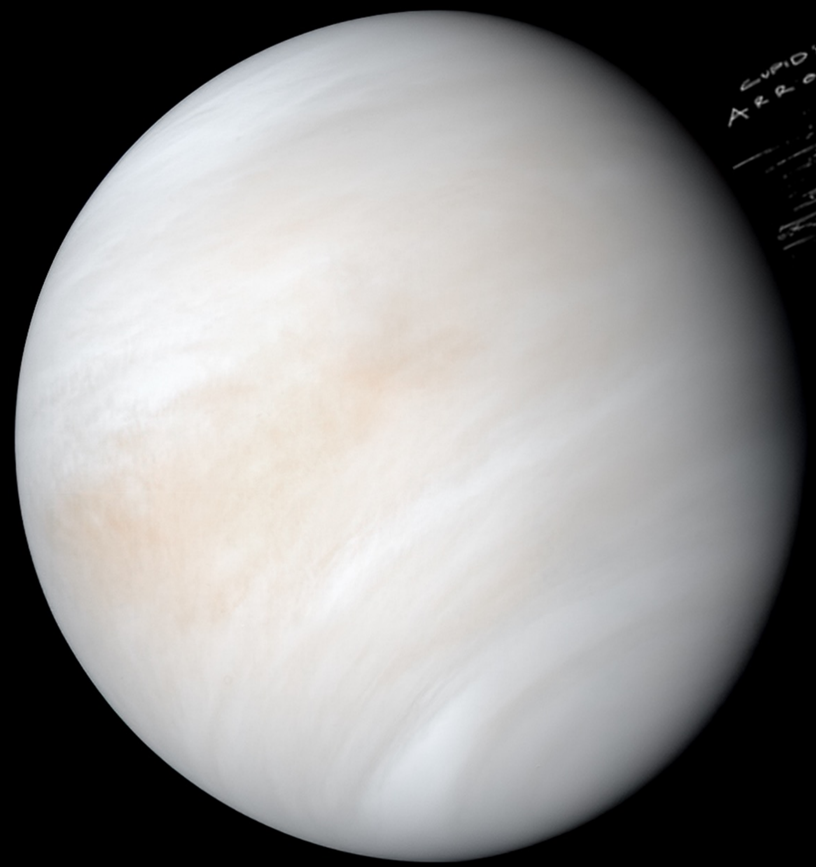
Conclusions

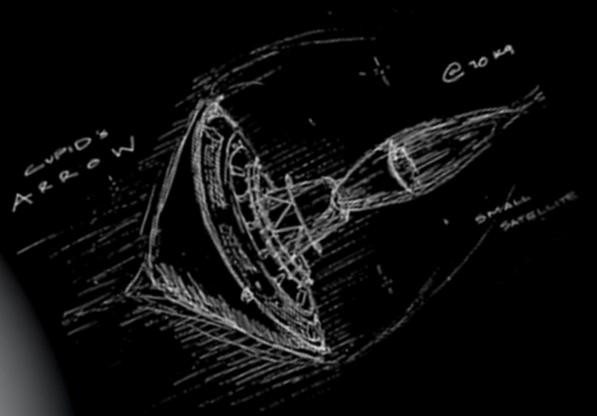
- Targeting future ESA and NASA SmallSat opportunities
- Performing relevant lab-scale experiments for sample fractionation remains a challenge
- **Required Technologies (various TRLs currently)**
  - Dual-use Thermal Protection System (TPS) – Venus (sample acquisition) and Earth (re-entry)
  - Hypersonic guidance during Venus sample acquisition with a non-traditional vehicle geometry – need to target sampling altitude and exit trajectory to return to Earth
  - Low leak rate, low contamination sample acquisition tanks, valves, tubing, etc.
  - High delta-V SmallSat propulsion (requirements coupled to launch vehicle)



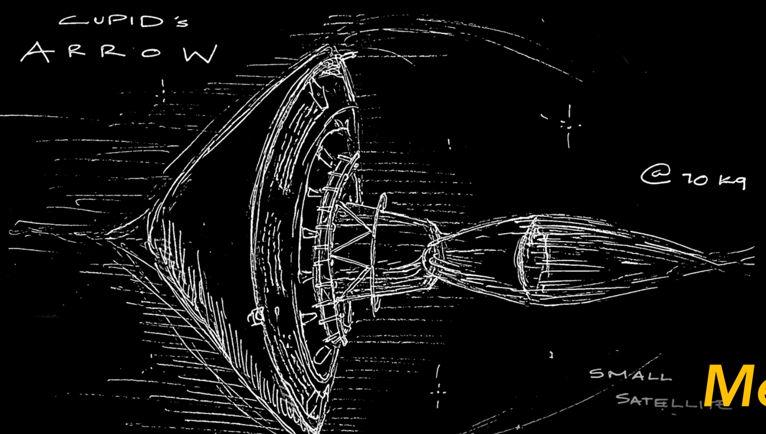








Thank you! Questions? jrabinov@stevens.edu



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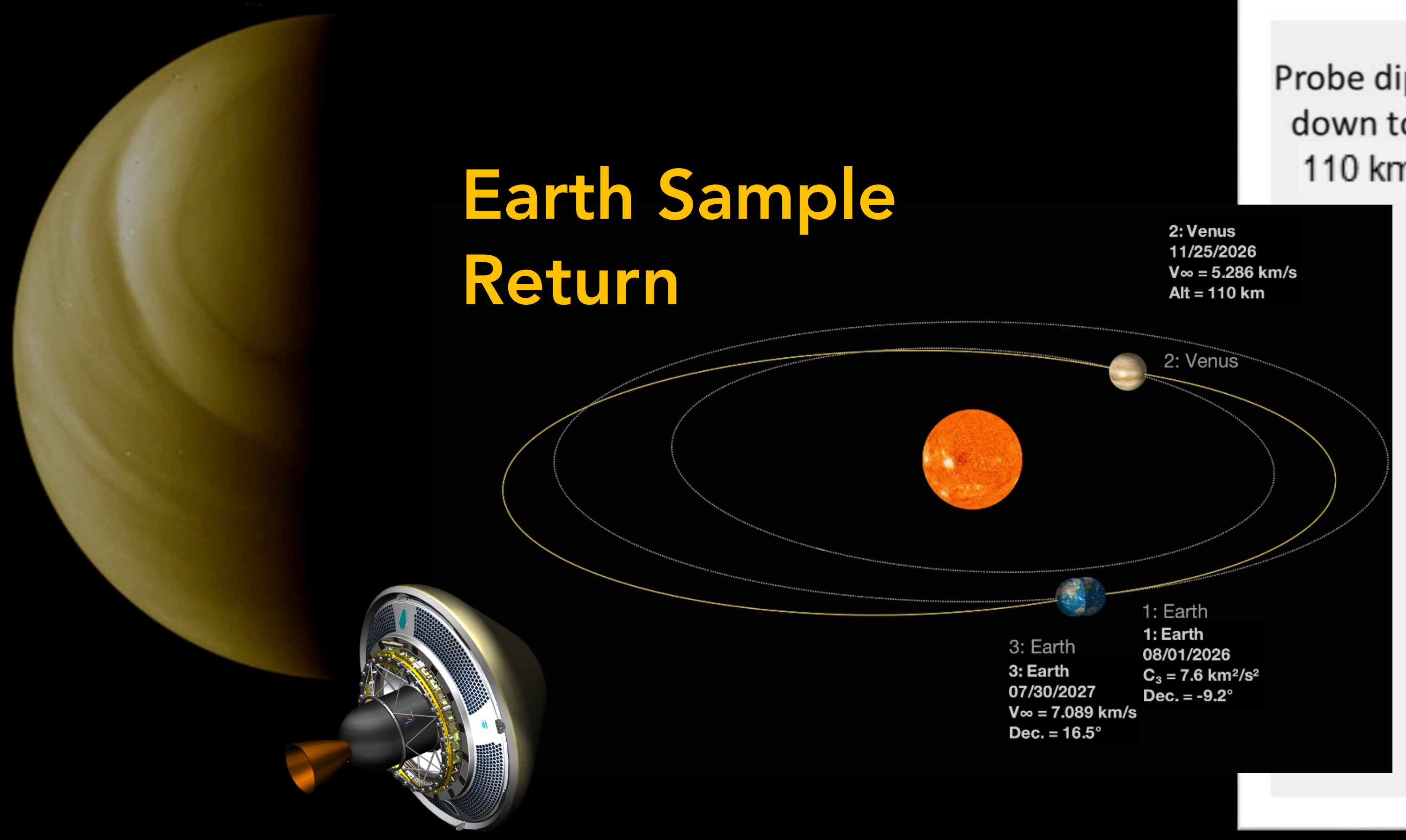
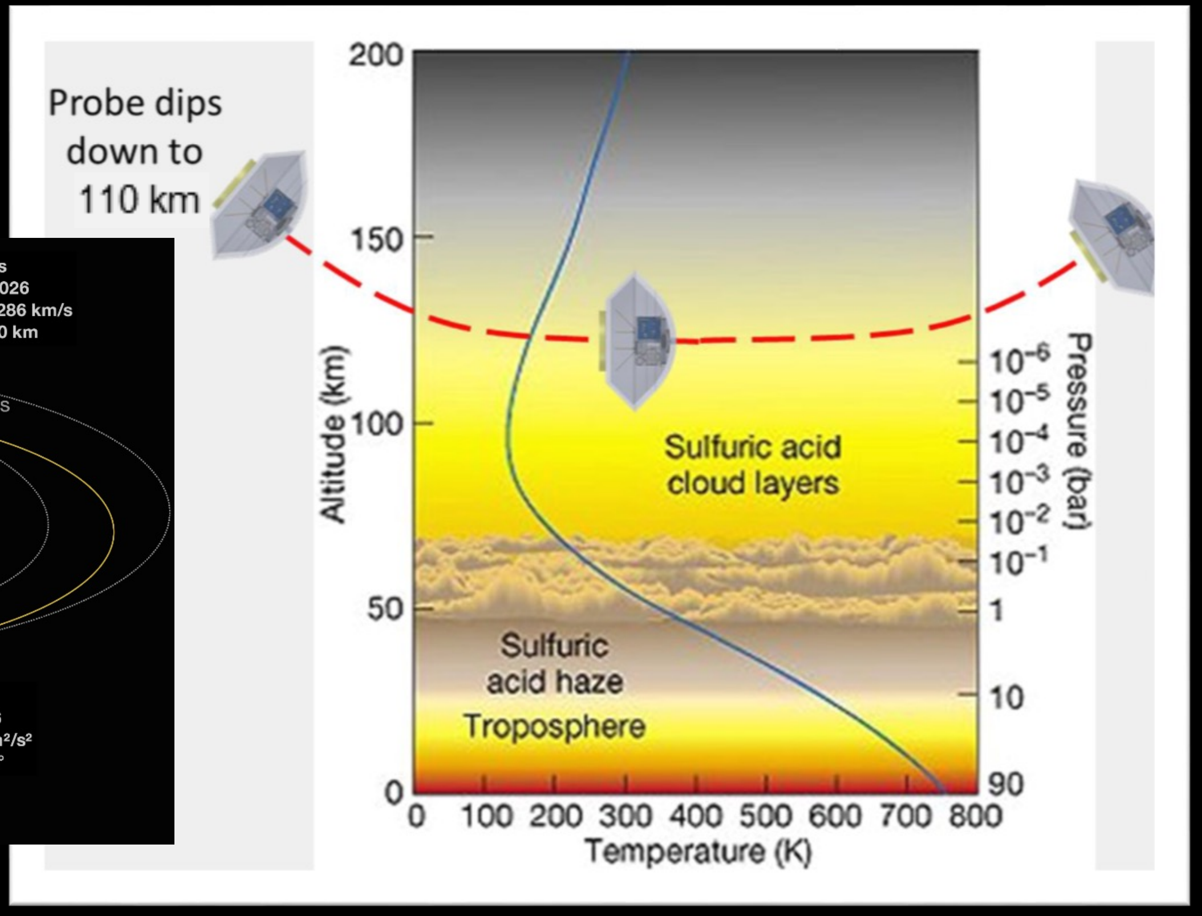
The first ever planetary atmosphere sample return mission

Mission Concept

Measuring Venus' atmospheric noble gases

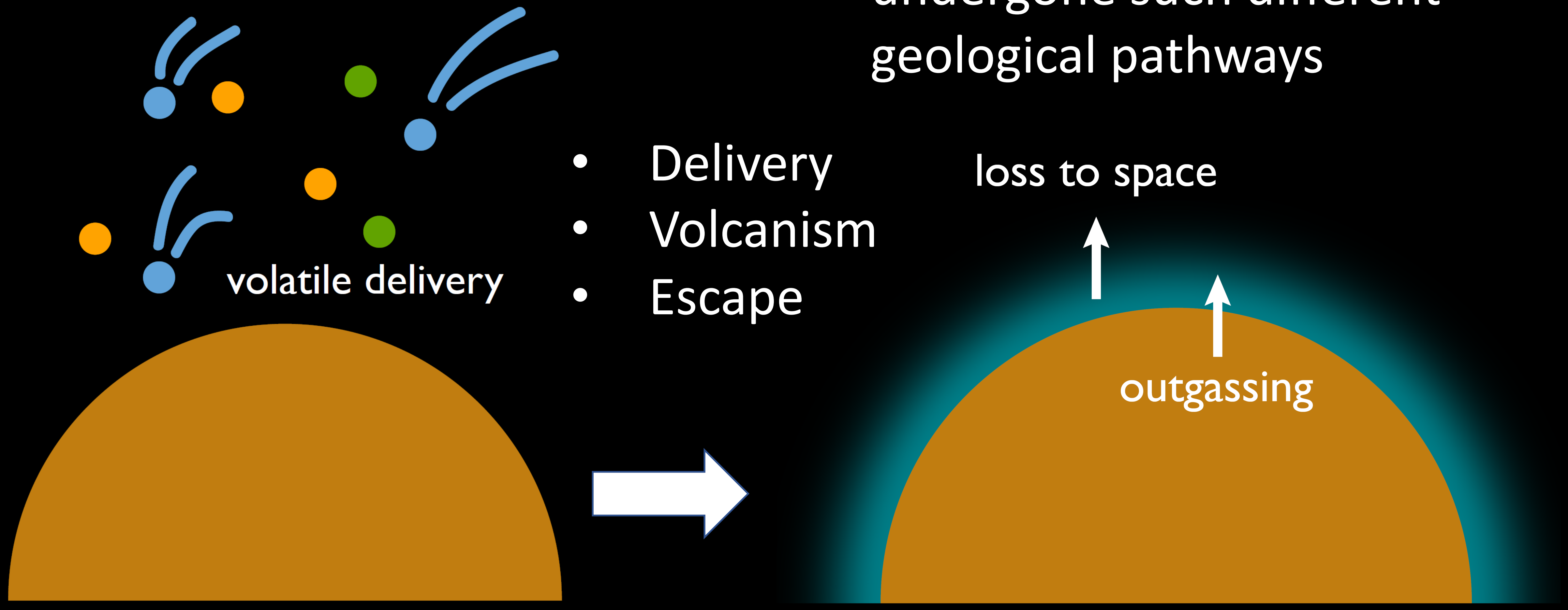
Earth Sample Return





Science Objectives

Why have Earth and Venus undergone such different geological pathways



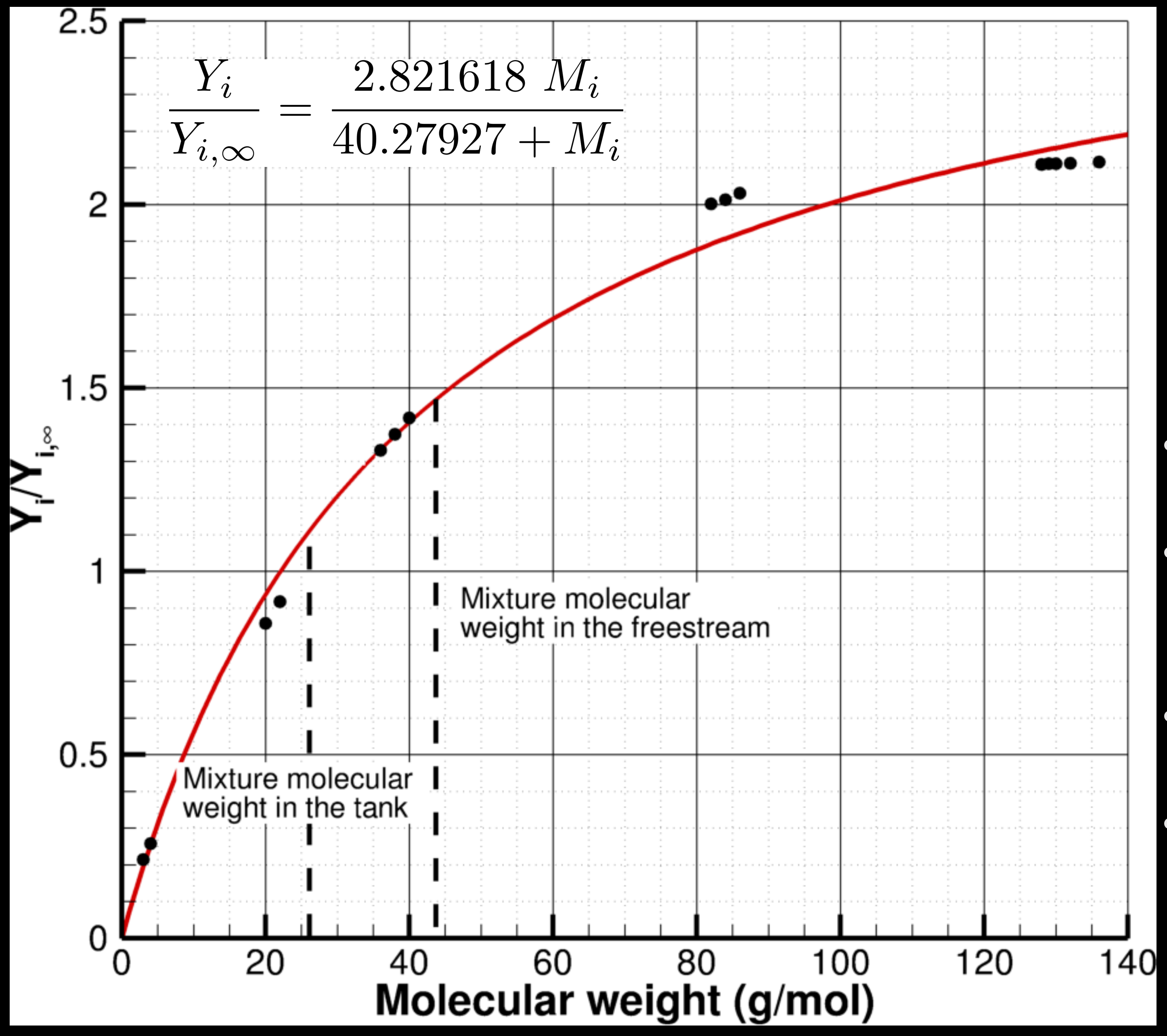
- Delivery
- Volcanism
- Escape

Overview

- Multiple atmospheric samples will be collected below the Venus homopause as the spacecraft skims through the atmosphere at $\sim 11 - 13$ km/s
- Samples will be **returned to the Earth** so that state-of-the-art terrestrial noble gas laboratories can analyze the samples
- First returned sample of an extraterrestrial atmosphere

Technology Needs

- Dual use Thermal Protection System (TPS) – Venus (sample acquisition) and Earth (re-entry)
- Hypersonic guidance during Venus sample acquisition with a non-traditional vehicle geometry – need to target sampling altitude + exit state to return to Earth
- Low leak rate, low contamination sample acquisition tanks, valves, tubing, etc.
- High delta-V SmallSat propulsion (depending on launch vehicle)



Using DSMC simulations to quantify noble gas isotopic fractionation during sampling

- **Noble gases fractionate according to their molecular mass**
- Species with:
  - $M_w > M_{w,\ mixture,\ tank}$ get enriched
  - $M_w < M_{w,\ mixture,\ tank}$ get depleted
- **Same conclusion for multiple isotopes of one noble gas**
- **Fractionation is primarily driven by differential diffusion of species through strong bow shock, which itself is driven by molecular diffusion**

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