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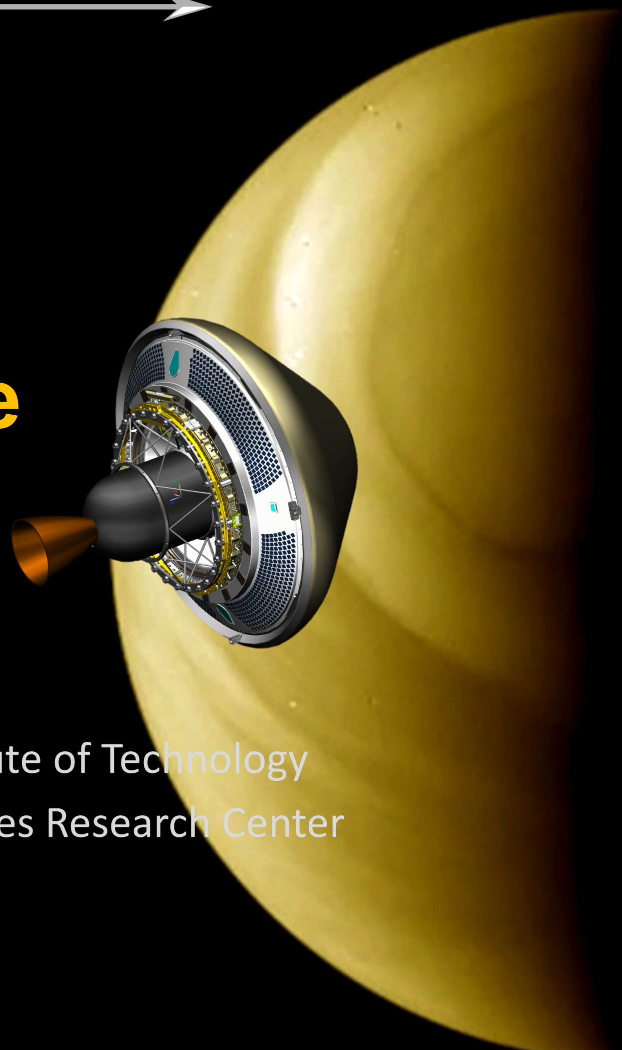
Hypervelocity Noble Gas Sampling in the Upper Atmosphere of Venus



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Why is Venus so different than Earth?

- Address US Planetary Decadal Survey Goals, specifically Objective IA: 'How did the atmosphere of Venus form and evolve'
- Measure the concentrations of noble gases and isotope ratios in Venus atmosphere at 110 km (below the homopause) to provide key information on the formation and evolution of Venus.

- Noble Gases are tracers of planetary evolution
  - 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

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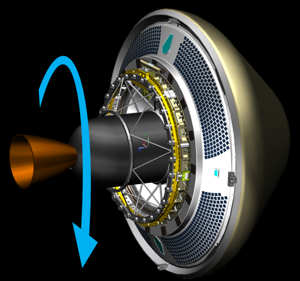
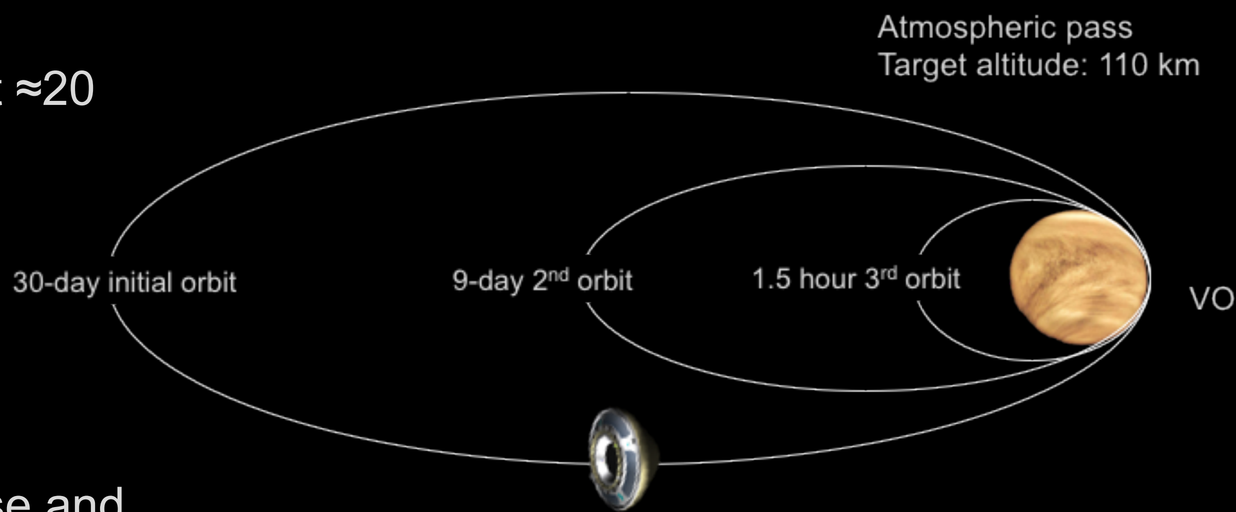
Baseline Mission Concept

- Small Satellite
- Flight time ~430 days
- Launch in 2022, December
- Launch $C_3 < 9$ km^2/s^2
- Arrival Vinf. = ~2.7 km/s
- Initial large elliptical orbit ≈20 days





- Spin Stabilized for cruise and atmospheric pass
- Separate solid for VOI
- DV Monoprop capability ~60 m/s (in probe)
- DV VOI Capability ~433 m/s

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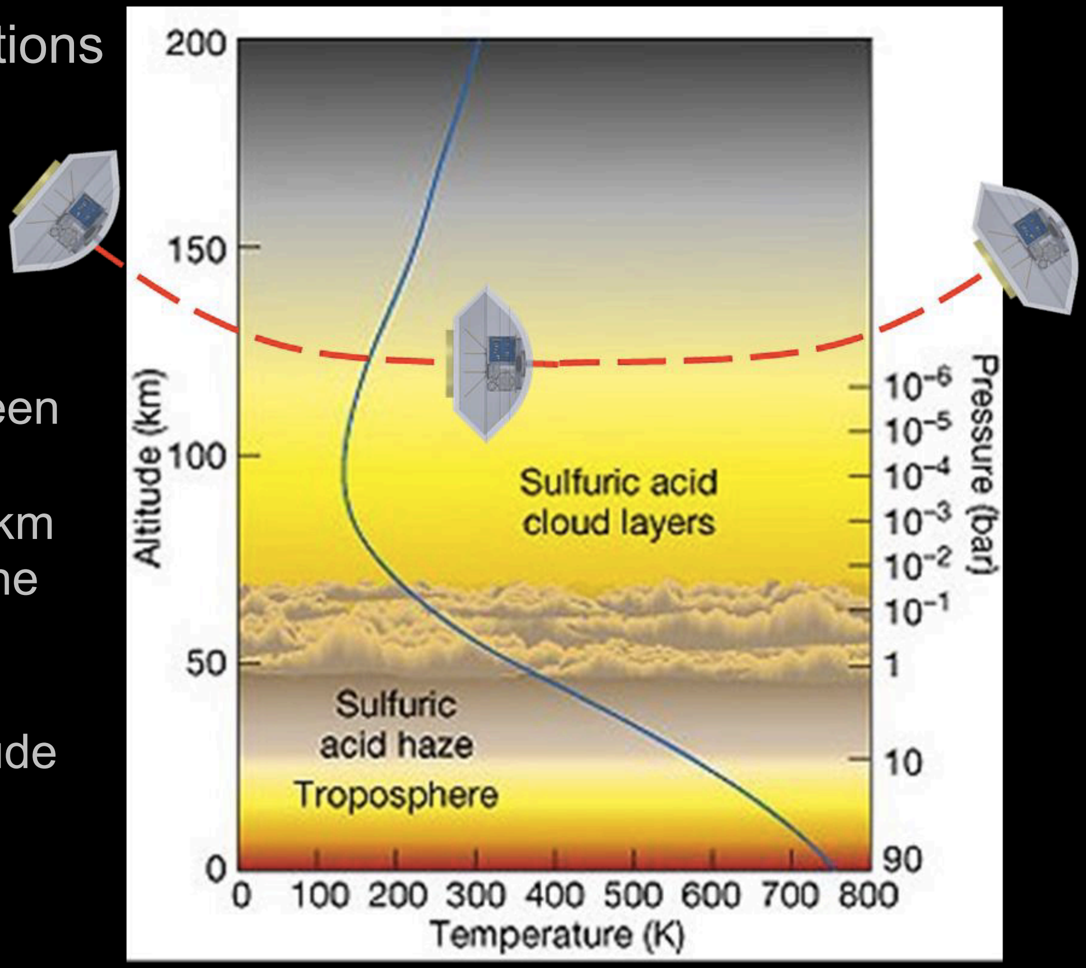
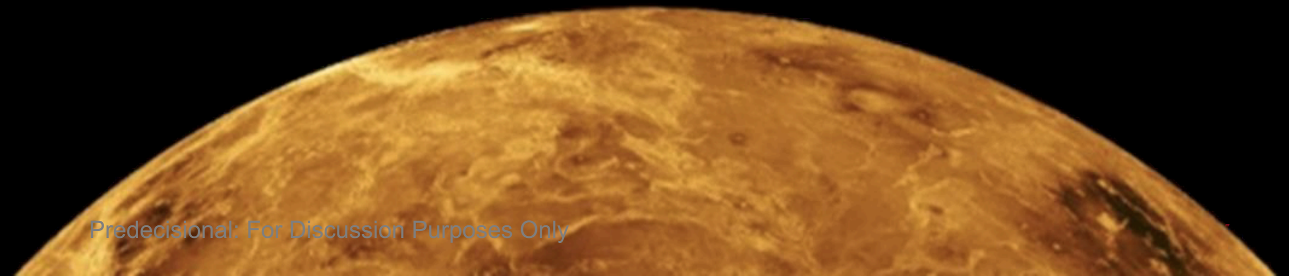
Atmospheric Entry Conditions

Entry velocity of 10 km/s
Target altitude of 110 km

Homopause is 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)





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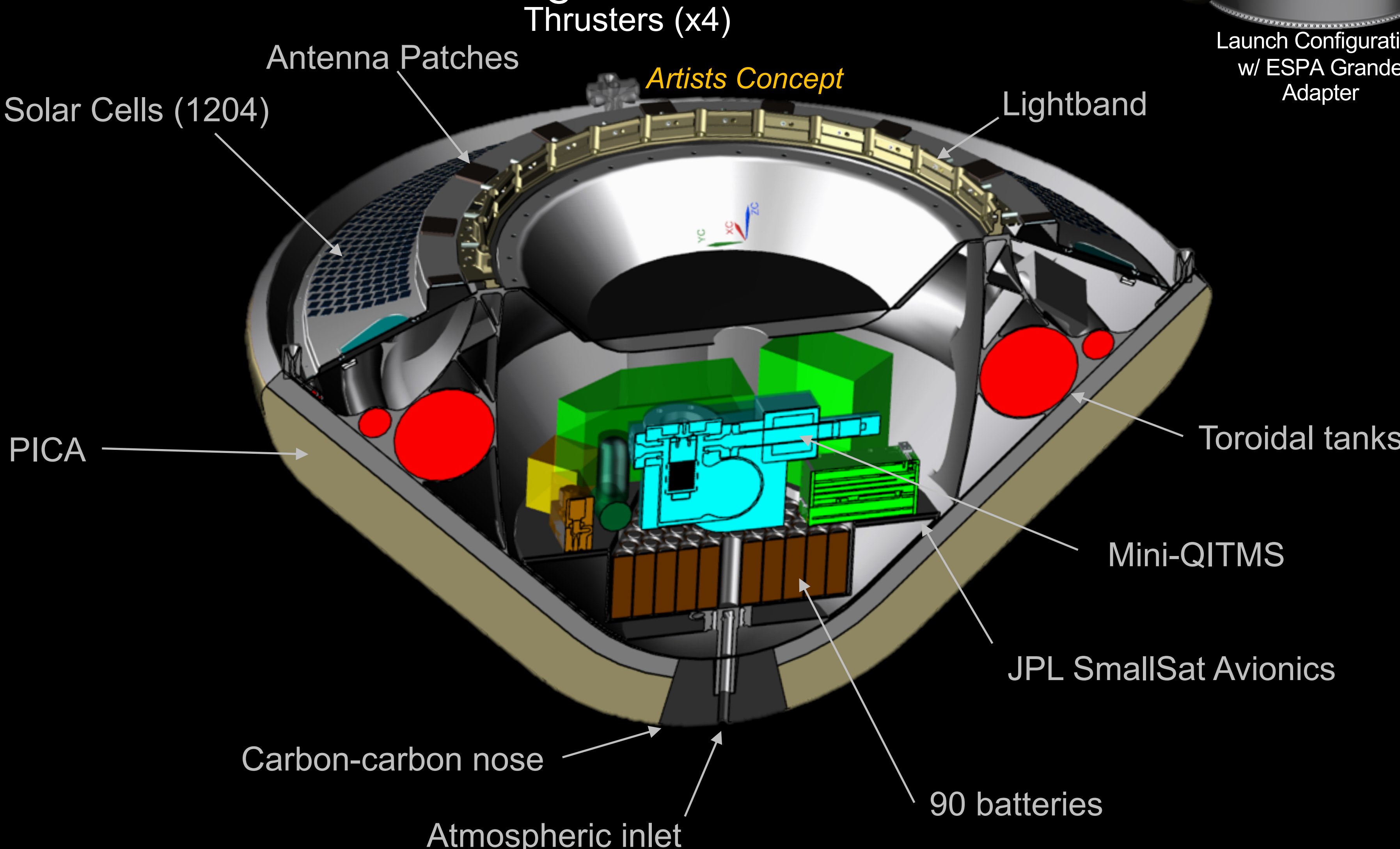
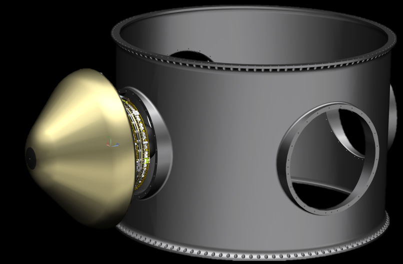
Baseline Mechanical Configuration





JPL Mini Quadra-pole Ion Trap Mass Spec (QITMS)

- No discrete wires to make electrical connections to mass spectrometer parts.
- 4 kg mass; 2U volume
- Extremely robust against shock/vibe loads
- Very stable measurements

- Each generation of QITMS is getting progressively smaller with lower mass and without compromising performance
  - 8kg → 4kg
- Builds on previous developments for HEOMD; e-Nose and VCAM.

QITMS Isotopic Precision is 3-5 times better than required

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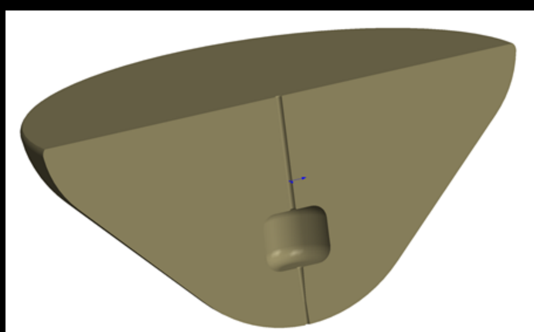
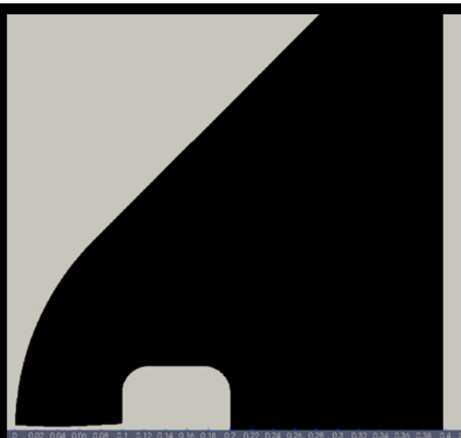
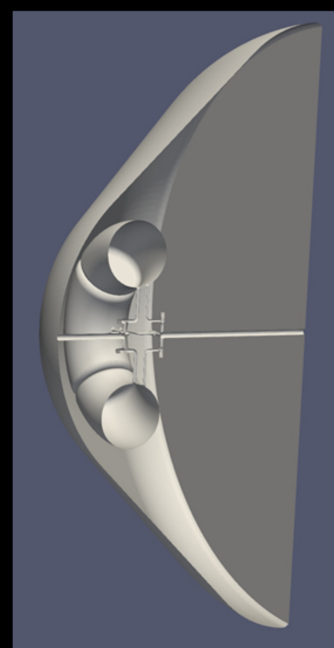
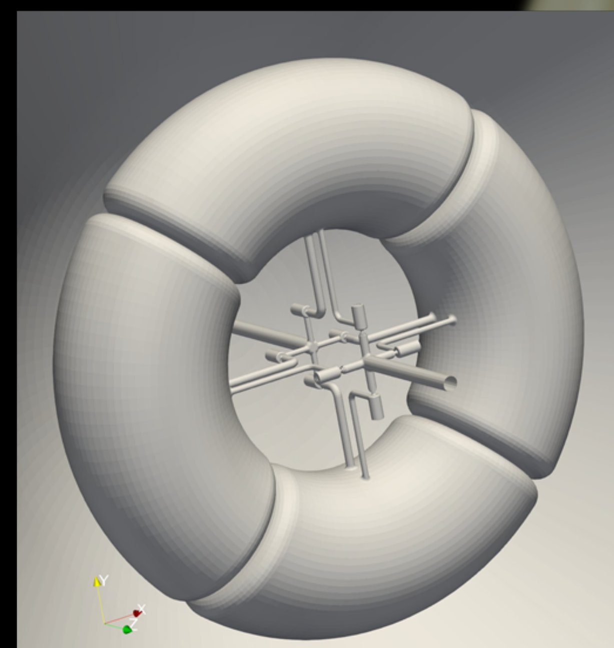
Hypervelocity Sampling and Noble Gas Isotopic Ratios

- Driving Objective:
  - Is the gas acquired by the sampling system at 110 km in the Venus atmosphere while traveling at ~ 10.5 km/s representative of the free stream?
  - Can isotopic fractionation be quantified and accurately predicted?
  - Quantify simulation uncertainties









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DSMC Approach

- Venus Freestream conditions:
  - U ~= 10.5 km/s
  - T ~= 195 K
  - P ~= 0.15 Pa
  - Number density ~= 1e19 molecules/m^3
- Numerical gas concentrations by volume (numerical and approximate Venus conditions)

Model	Gas composition (volume)					
	CO_2	N_2	[40]Ar	[36]Ar	[132]Xe	[128]Xe
A	0.926	0.052	0.01	0.01	0.001	0.001
B	0.9359	0.0619	0.001	0.001	0.0001	0.0001
C	0.93788	0.0619	0.0001	0.0001	0.00001	0.00001
Venus	0.94648	0.05345725	3.30E-05	2.97E-05	3.00E-10	2.13E-11

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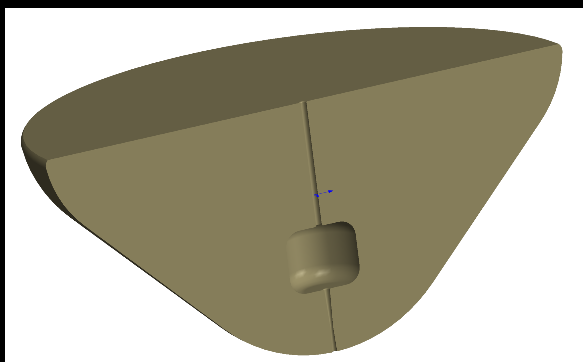
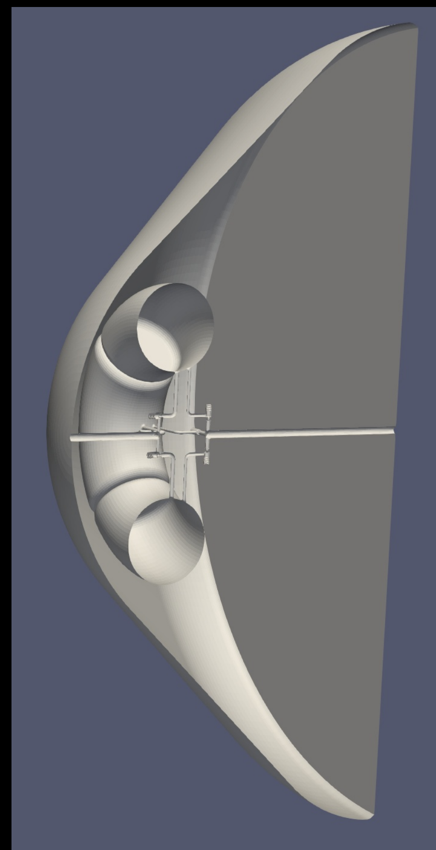
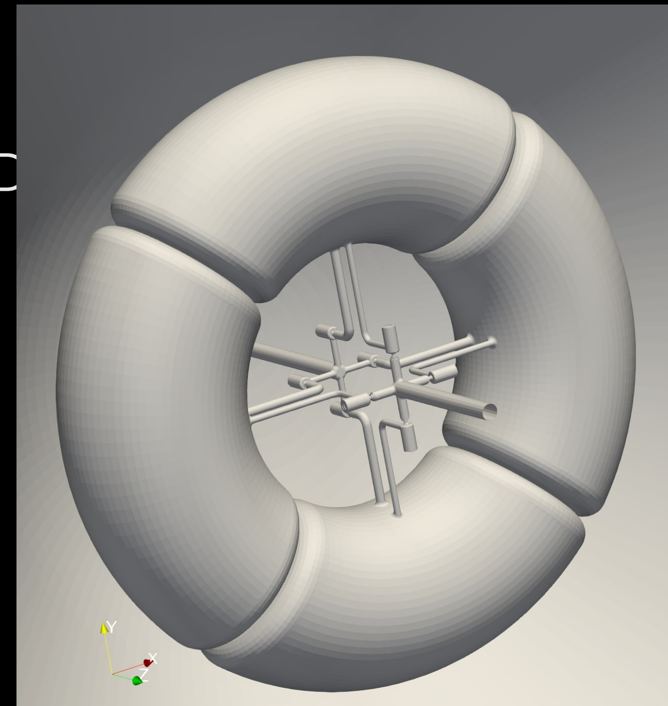
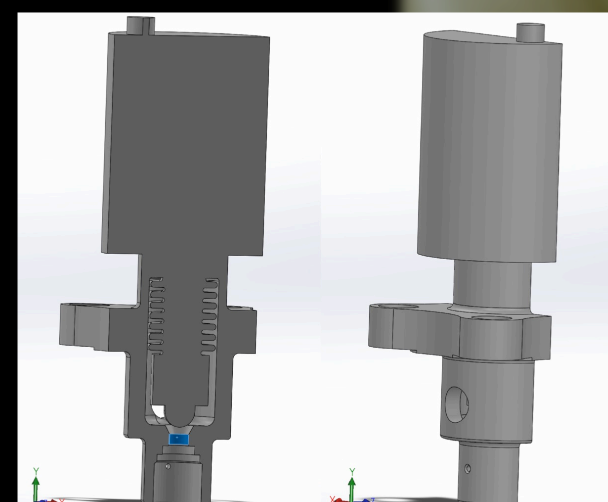
DSMC Geometries – 2D Axisymmetric and 3D









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Hypervelocity Sampling and Noble Gas Isotopic Ratios

- Stochastic PArallel Rarefied-gas Time-accurate Analyzer (SPARTA)
- Open-source DSMC solver developed at Sandia
  - https://sparta.sandia.gov/
- Physical models:
  - Species considered:
    - CO, O, N2, NO, N, C, CN and C2
    - [36]Ar, [40]Ar, [128]Xe, [132]Xe
  - Reaction Rates
    - Mars/Venus set of chemical reactions developed by Johnston and Brandis, 2014
  - VHS
  - Diffuse reflection model, with the surface temperature fixed at 195.5 K
  - No surface reactions

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Sample Simulation Results

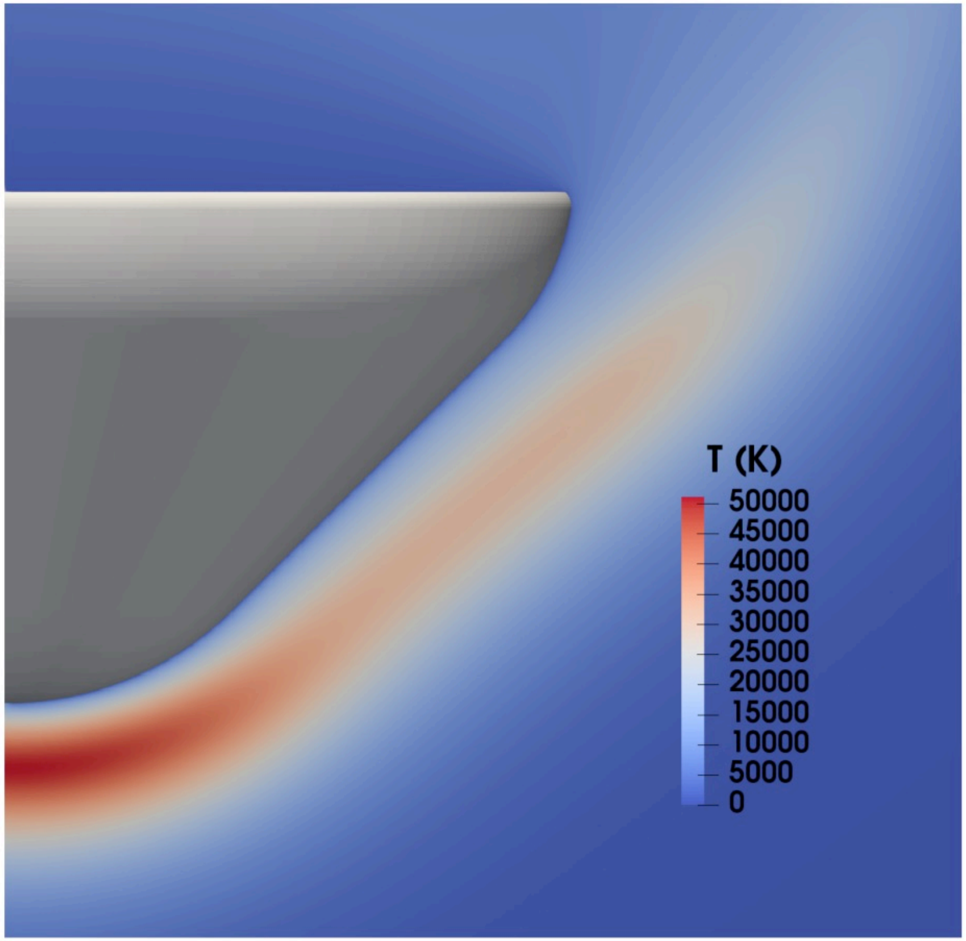

Fig. 4 Translational temperature contours for a 2D-axisymmetric simulation. The peak translational temperature reached in the bow shock is on the order of 48,000 K

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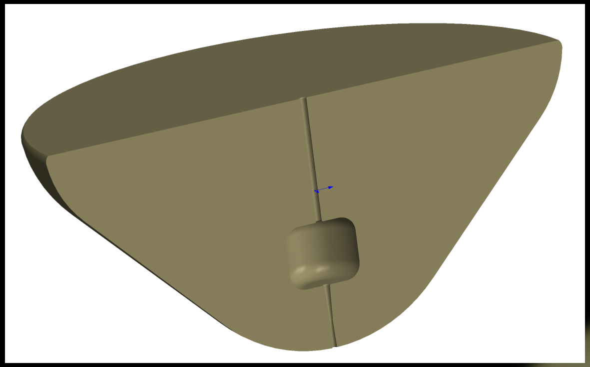
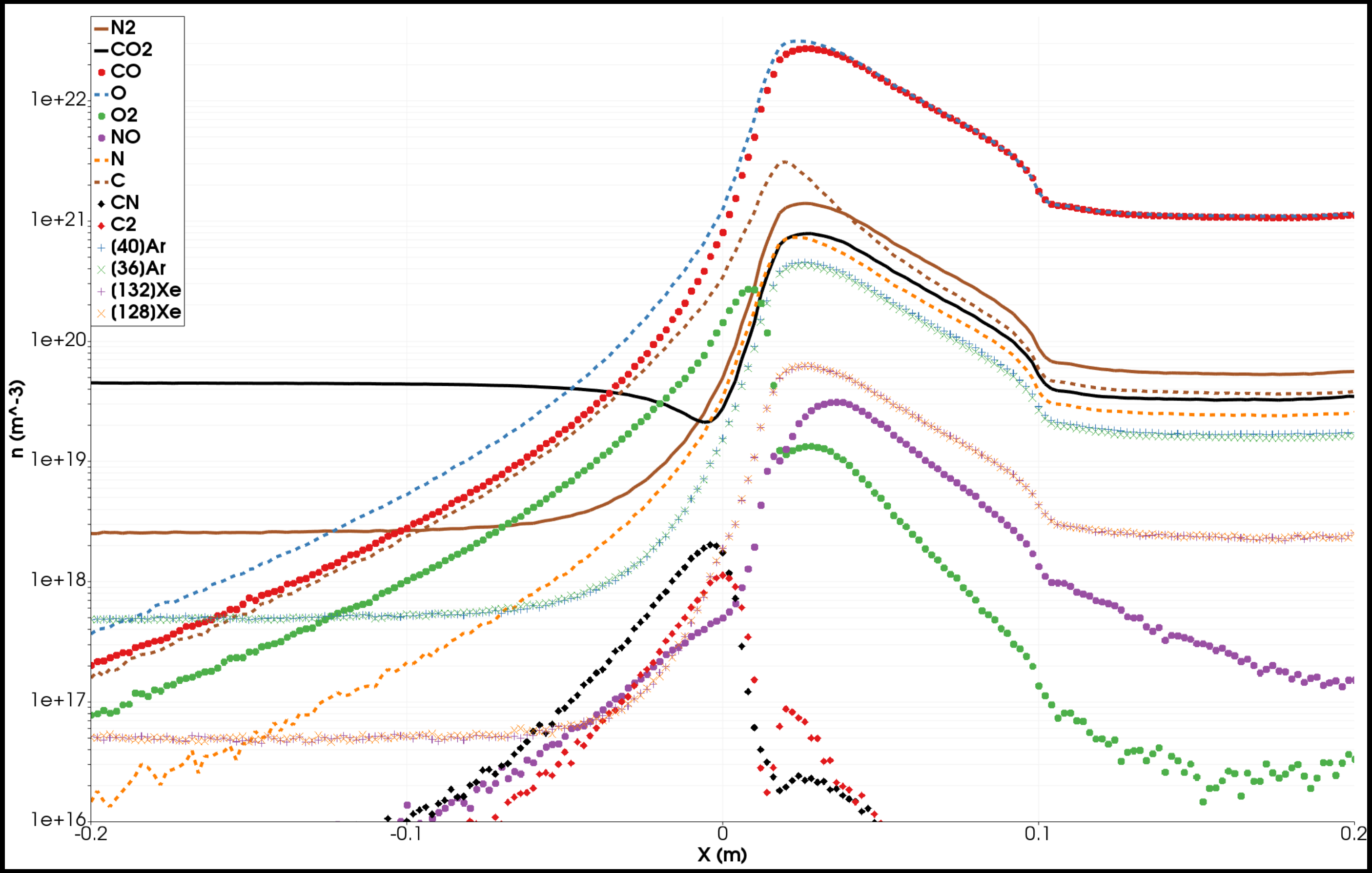
Sample Simulation Results





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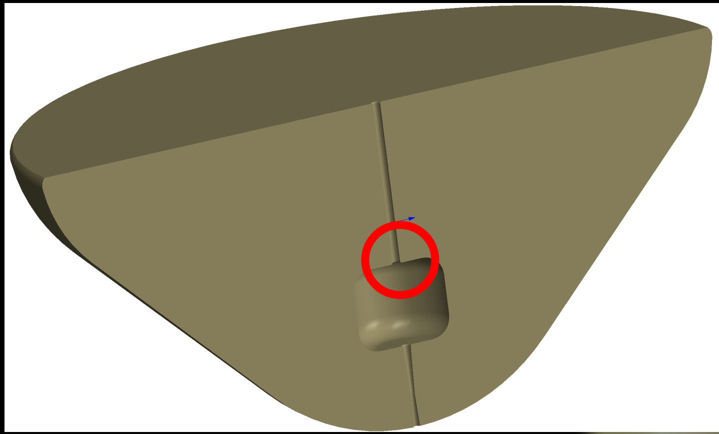
Noble Gas Quantities of Interest



- Objective is to quantify noble gas concentrations and ratios in the sampling tanks
- 10 simulations run for each initial condition with the back valve open
- Case C is under-resolved

Model	Quantity	$\frac{^{[40]}Ar}{^{[36]}Ar}$	$\frac{^{[132]}Xe}{^{[128]}Xe}$	$\frac{^{[40]}Ar+^{[36]}Ar}{^{[132]}Xe+^{[128]}Xe}$
	μ	1.064	1.011	7.175
A (baseline)	σ	0.021	0.044	0.093

Model	$\frac{^{[40]}Ar}{^{[36]}Ar}$	$\frac{^{[132]}Xe}{^{[128]}Xe}$	$\frac{^{[40]}Ar+^{[36]}Ar}{^{[132]}Xe+^{[128]}Xe}$
A (baseline)	1.075	0.961	6.981
B	1.107	1.027	6.854
C	1.405	1.385	6.589

Table 3 Average value (μ) of the isotopic and elemental ratio of Argon and Xenon, for the three different models considered and the open- then closed-valve configuration.

Table 2 Average value (μ), standard deviation (σ), and percent error (ϵ) for the isotopic and elemental ratio of Argon and Xenon, for the three different models considered and the open-valve configuration.

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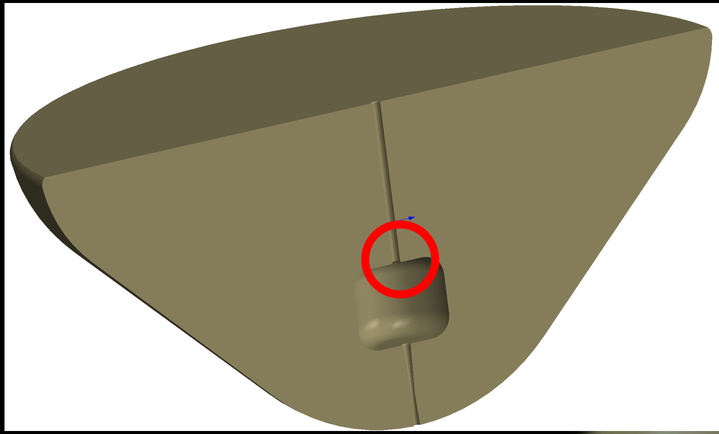
Noble Gas Quantities of Interest



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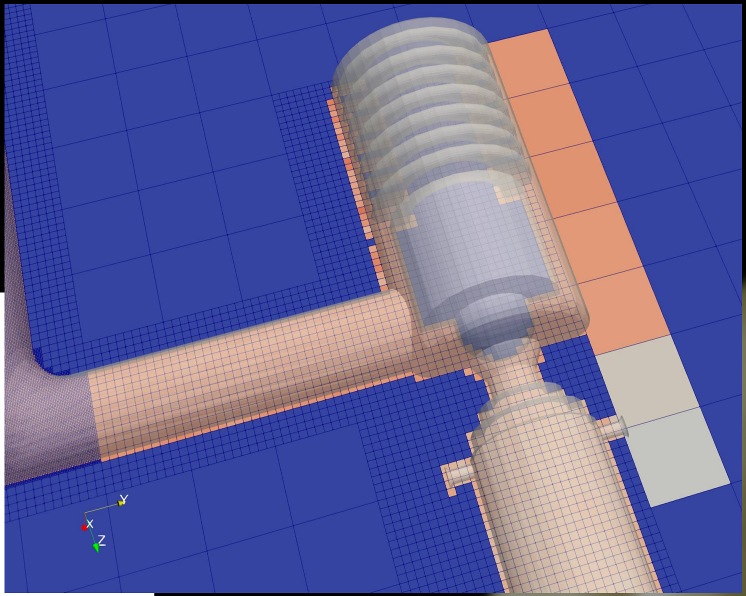
Preliminary 3D simulations



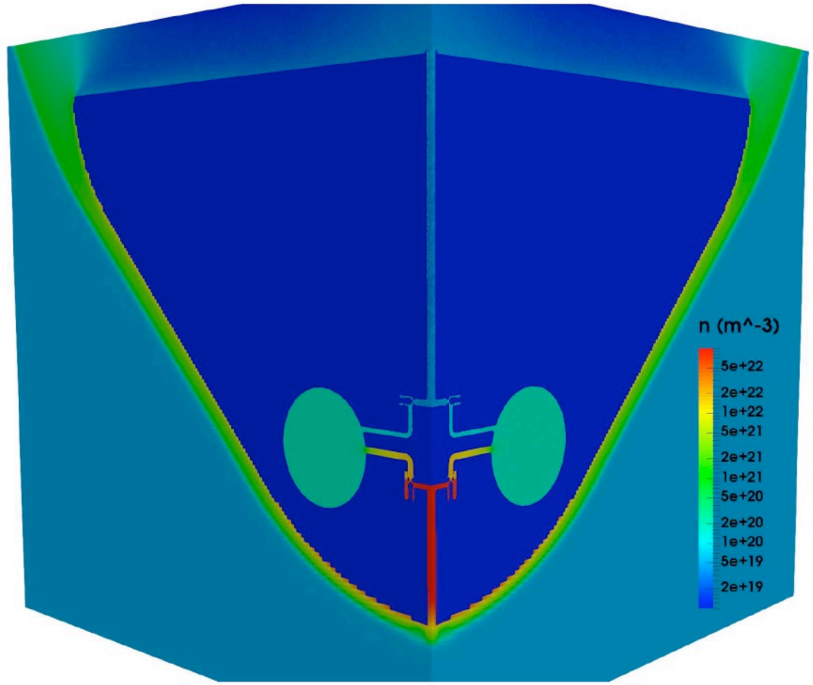
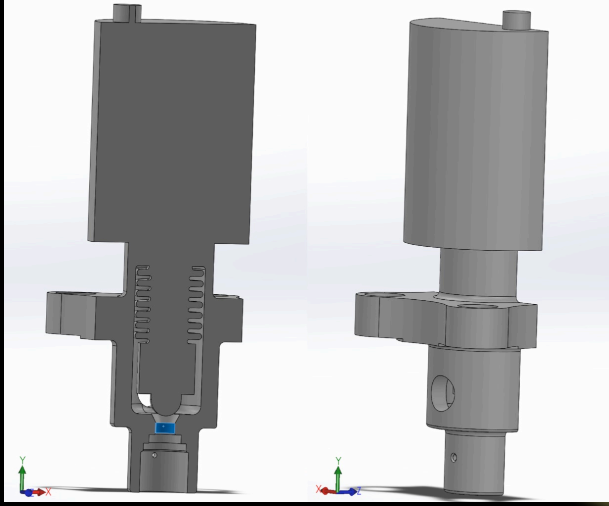


Fig. 6 Preliminary total number density (number/m^3) results for a 3D simulation. A quarter of the geometry is simulated.



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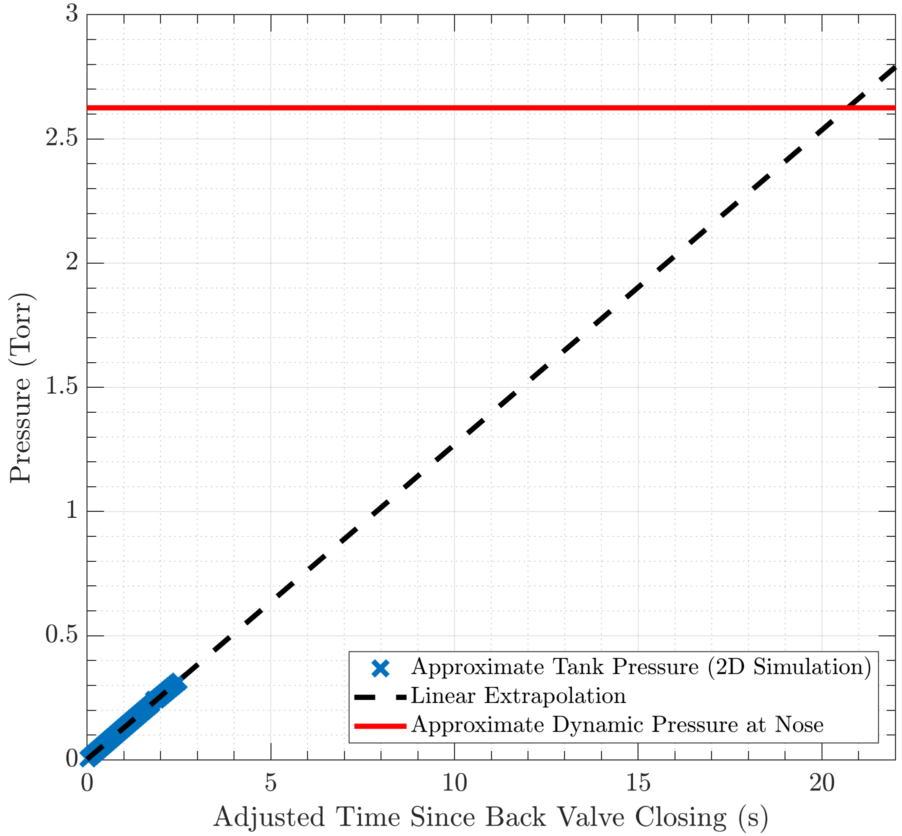
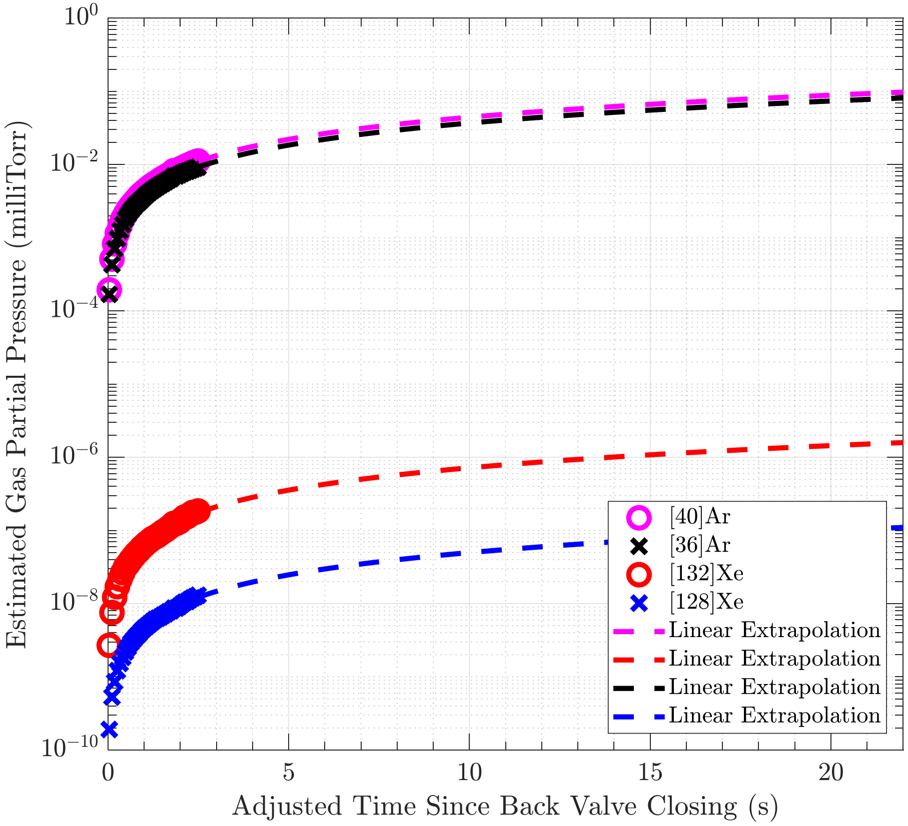
Scaled 2D Tank Pressure Predictions





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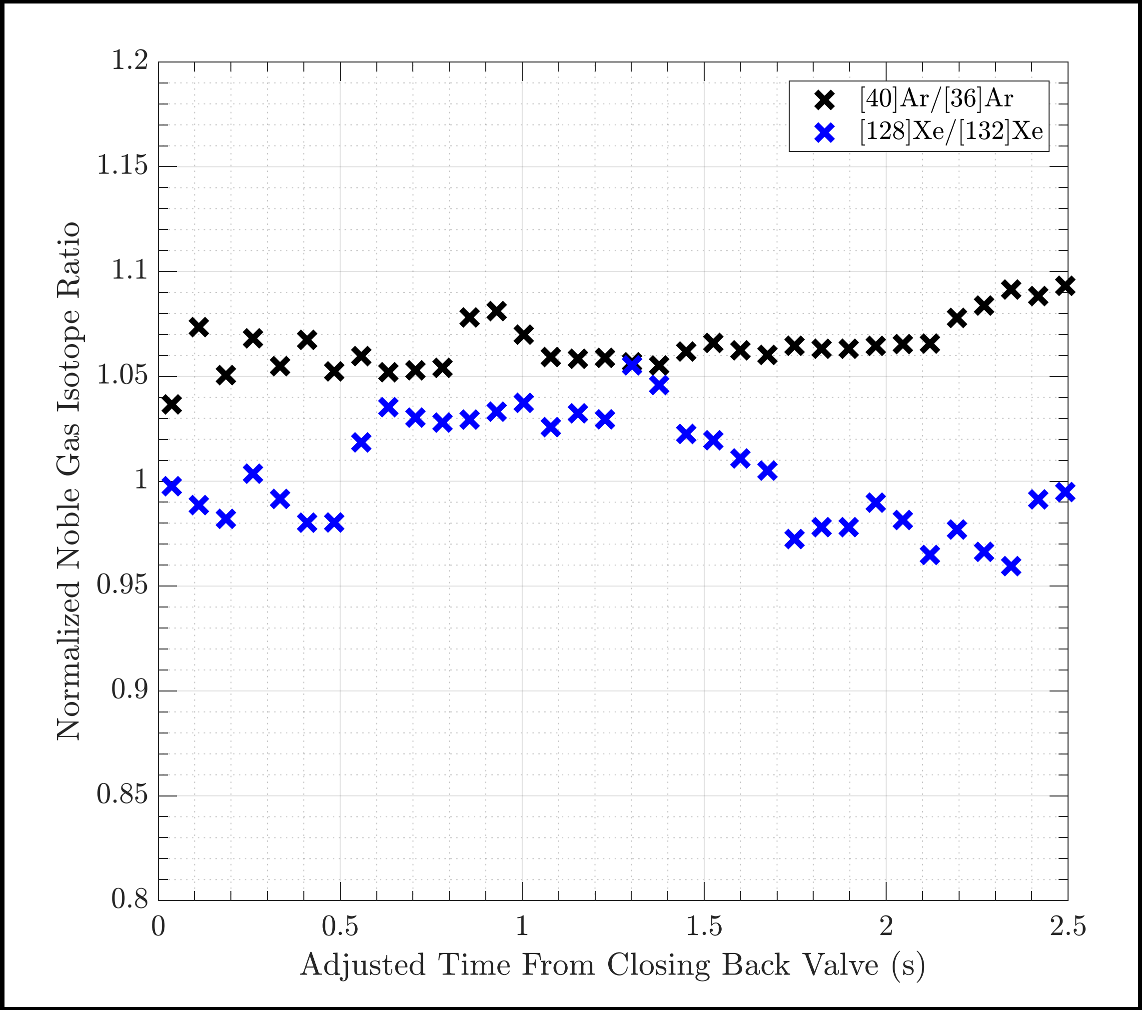
Preliminary 2D Tank Ratio Predictions



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Ongoing Work

- 3D Simulations that adequately resolve valves
- Addition of other noble gases of interest – He, Kr, Ne
- Modeling other trace Venus species and effect on the mixture (Cl, H, etc.)
- Parametric investigating using 2D simulations

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Acknowledgements

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