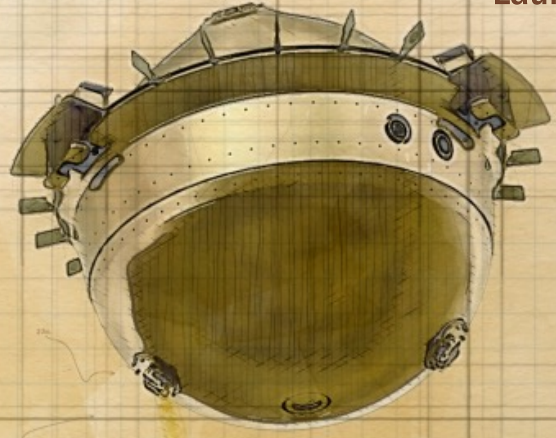
DAVINCI

Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging

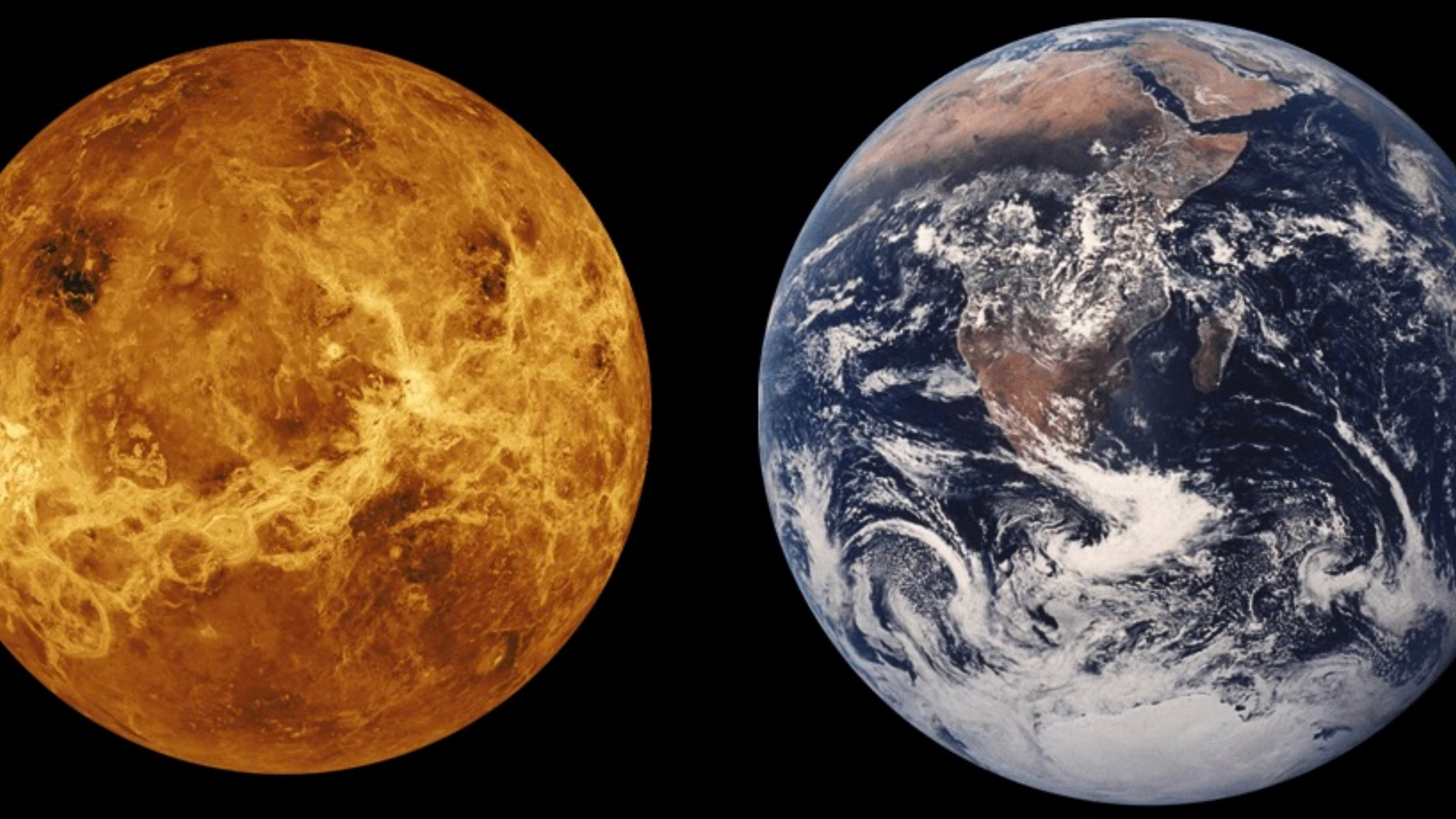
Launch Readiness June 2029
Flyby 1 January 2030
Flyby 2 November 2030
Probe Mission June 2031



The Big Plunge into Venus

LaRC-ARC Summer Intern Seminar Series

Soumyo Dutta
NASA Langley Research Center
June 5, 2023



DAVINCI Video

https://youtu.be/rdt7PugWe90

Venus Environment

- Venus surface temperature is ~900F
  - Aluminum anneals at 550-800F
  - Good woodfire pizza cooks for 1-2 minutes at 900F
- Venus clouds are made of droplets that are 75-85% sulfuric acid
  - 10-25% sulfuric acid recommended to etch steel
- Venus surface pressure is 95 bars
  - CO2 is super-critical
  - Weight of 9 school buses pushing downward on an area the size of a sheet of paper
  - Similar pressure 1km below the ocean surface (average depth of the Arctic Ocean)

DAVINCI Science

Investigate the Origin and Evolution of the Venus Atmosphere

Investigate the History of Water on Venus

Investigate Chemical Processes at Work in the Venus Atmosphere

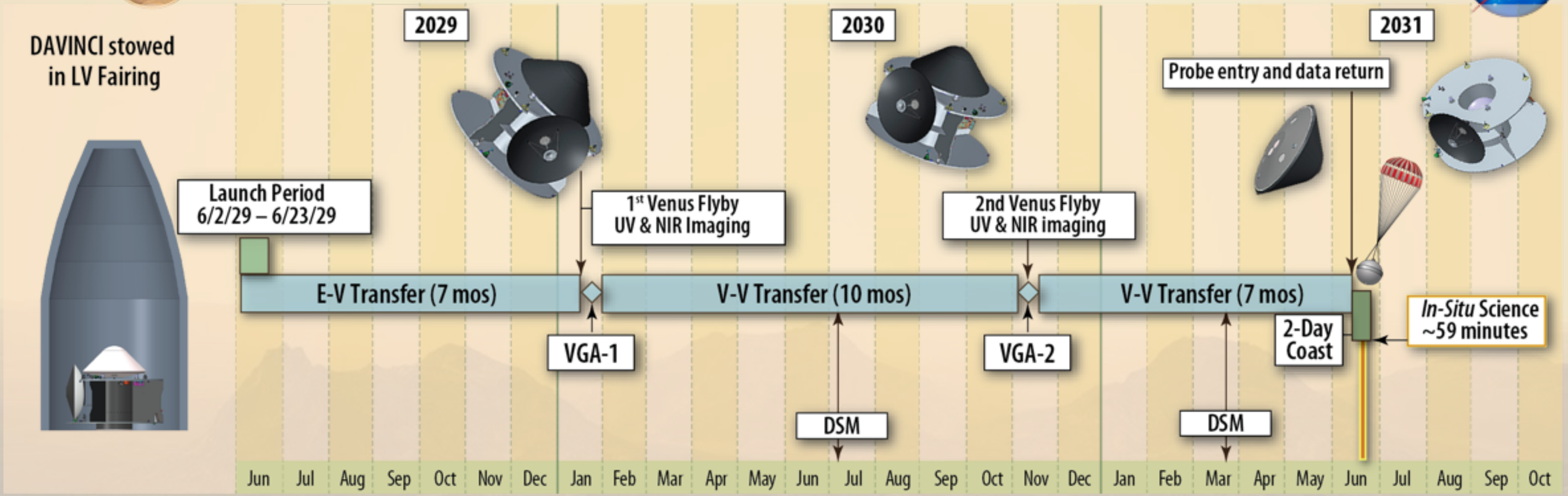
Investigate the Origins and History of the Venus Tesserae

DAVINCI

How much water did Venus have?
Where did it come from? What happened to it?

The answer is revealed by understanding the balance between **sources** and **loss**

Mission Overview



Launch Campaign
Pre-Launch Phase
Launch Phase

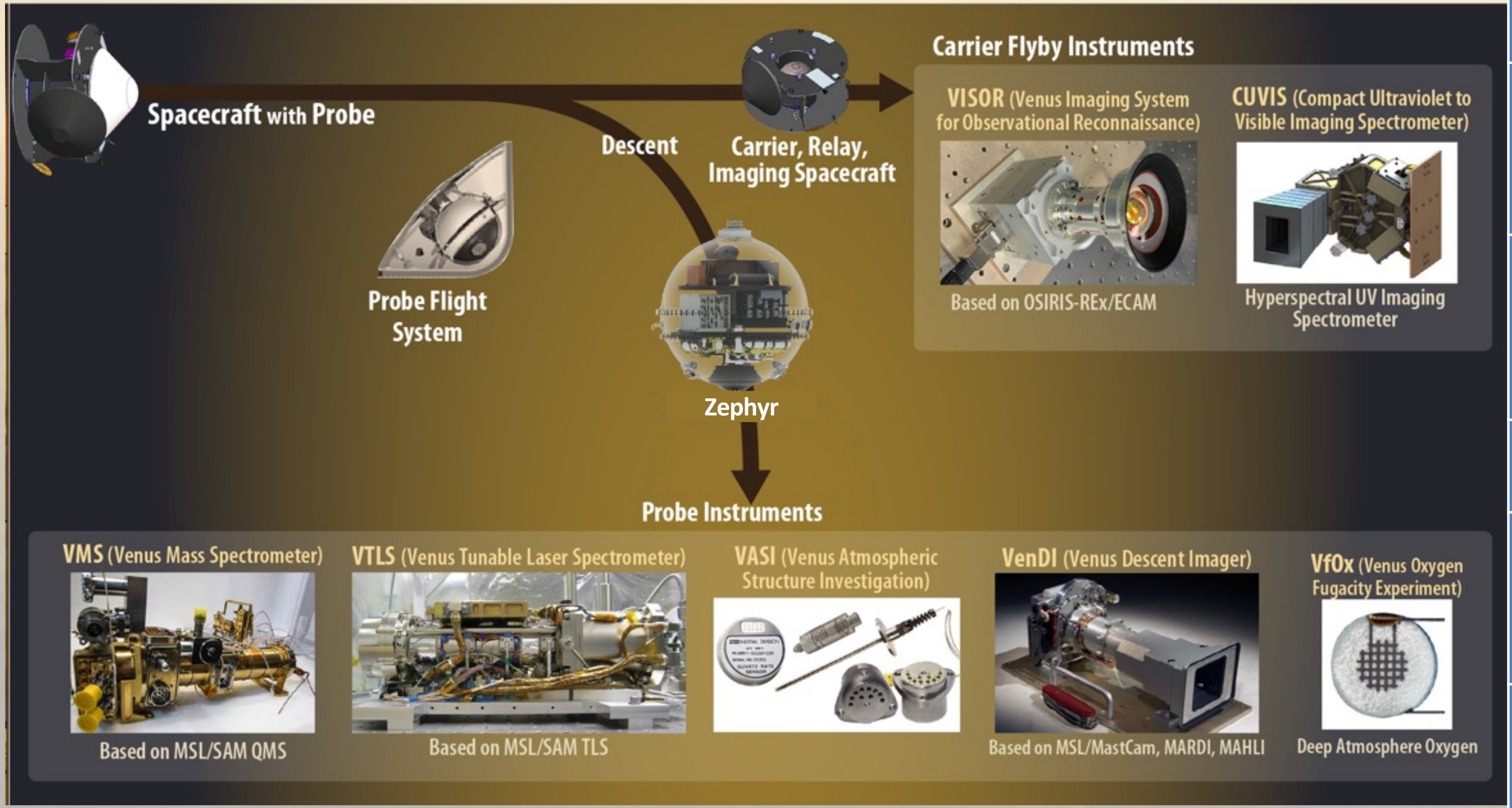
Remote Sensing Campaign
Checkout and Calibration
Cruise to Science Flyby 1
Science Flyby 1
Cruise to Science Flyby 2
Science Flyby 2
Cruise to In Situ

In Situ Campaign
Approach & PFS Separation
Coast
Entry
Descent
Post Touchdown

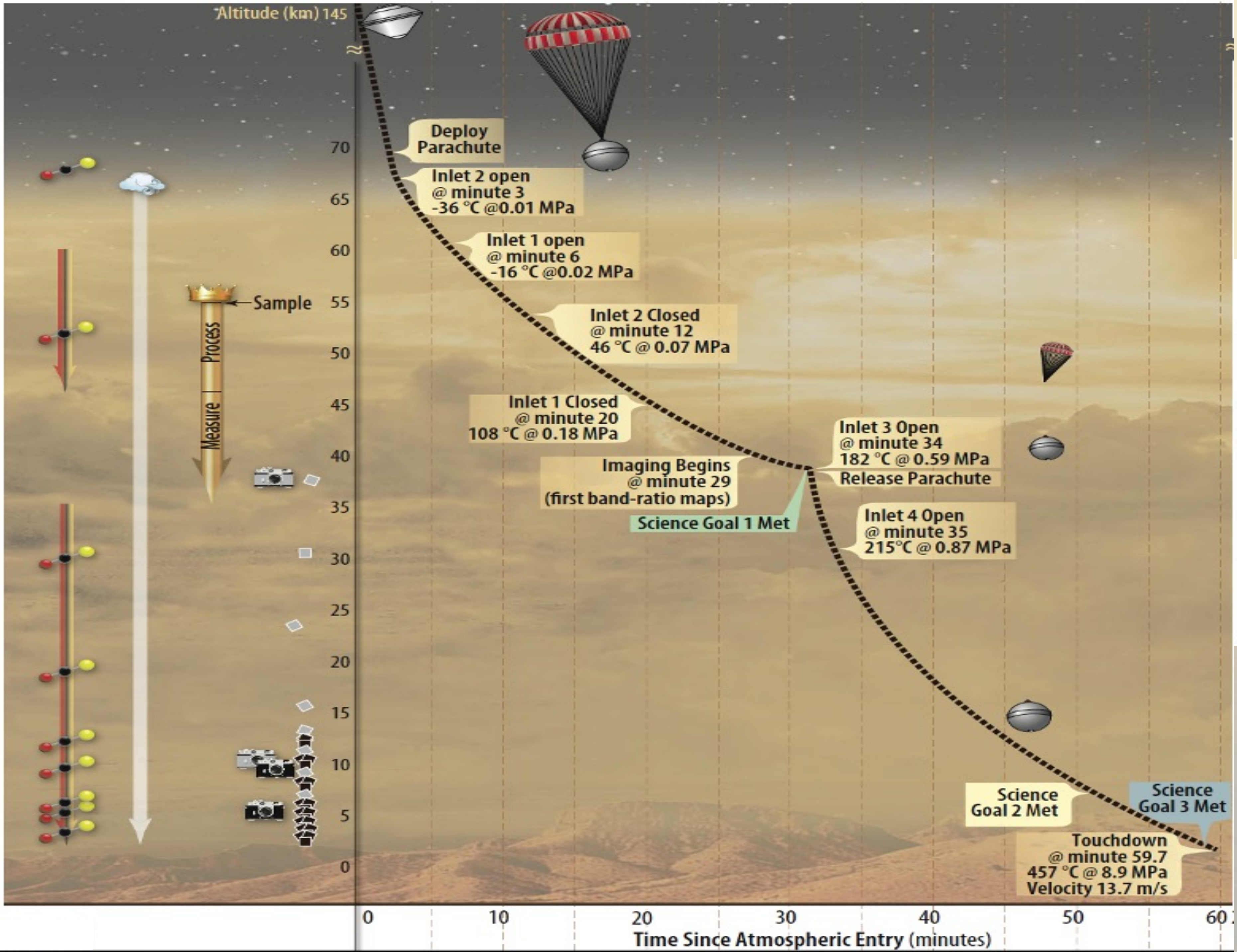
Data Return Campaign
Data Return

Instruments

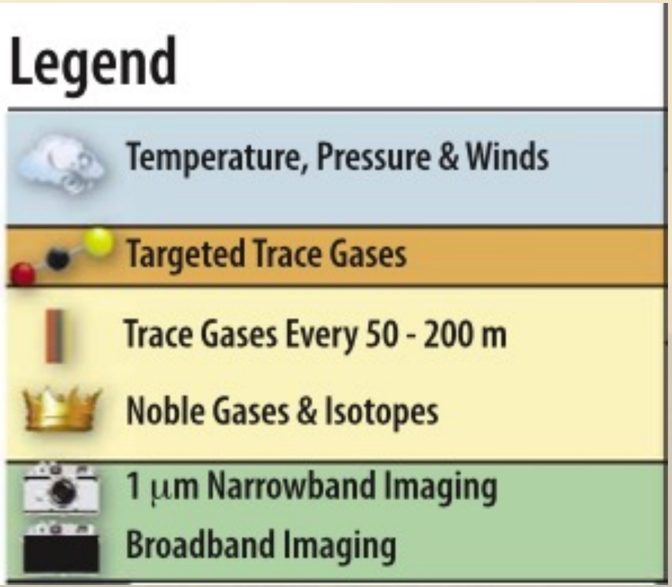
- 7 Payloads
- 3 Flight Configurations
- 2 Science Campaigns
- 1 Mission



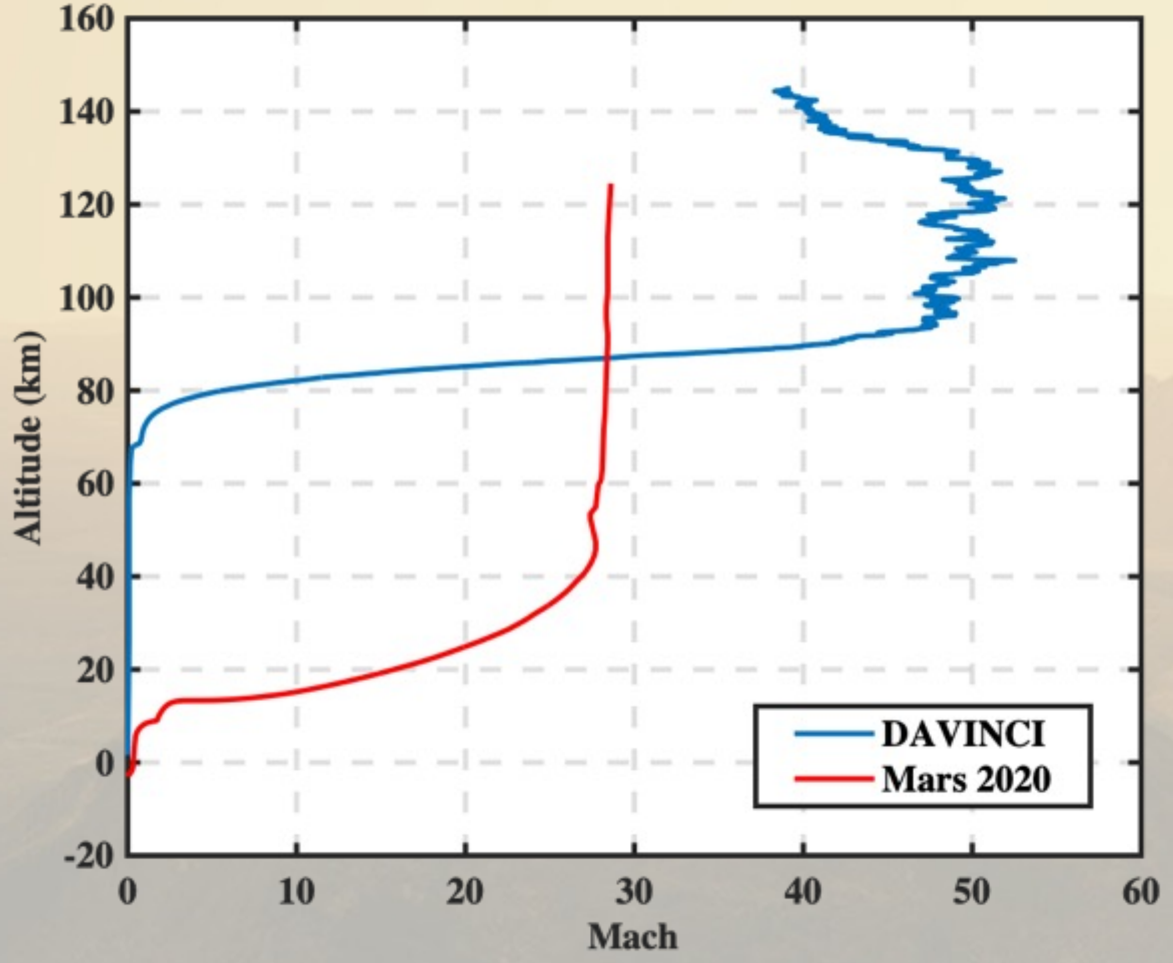
Instrument	Loca-tion	Technical Approach	Prov-ider
Venus Mass Spectrometer (VMS)	Zephyr	Quadrupole Mass Spectrometer, advanced, space-qualified turbomolecular pump, and Gas Processing System	GSFC
Venus Tunable Laser Spectrometer (VTLS)	Zephyr	Three channel laser spectrometer with multi-pass Herriott sample cell	JPL
Venus Atmospheric Structure Investigation (VASI)	Zephyr	Suite of commercial off-the-shelf (COTS) sensors for atmospheric pressure, temperature, and DS dynamics including three-axis accelerations and roll rates	GSFC
Venus Descent Imager (VenDI)	Zephyr	Full-frame Charge-Coupled Device (CCD) detector with 7 element refractive system and two-position filter wheel: broadband and ~1-µm narrow-band	MSSS
Venus Oxygen Fugacity (VfOx)	Zephyr	Solid-state nernstian ceramic oxygen sensor to measure oxygen partial pressure.	APL
Venus Imaging System for Observational Reconnaissance (VISOR)	CRIS	Integrated system of four cameras with 5 megapixel Complementary Metal Oxide Semiconductor (CMOS) detectors: one UV and three NIR	MSSS
Compact Ultraviolet to Visible Imaging Spectrometer (CUVIS)	CRIS	UV to visible, dualband dispersion and imaging spectrometer with freeform optics and advanced onboard data processing	GSFC

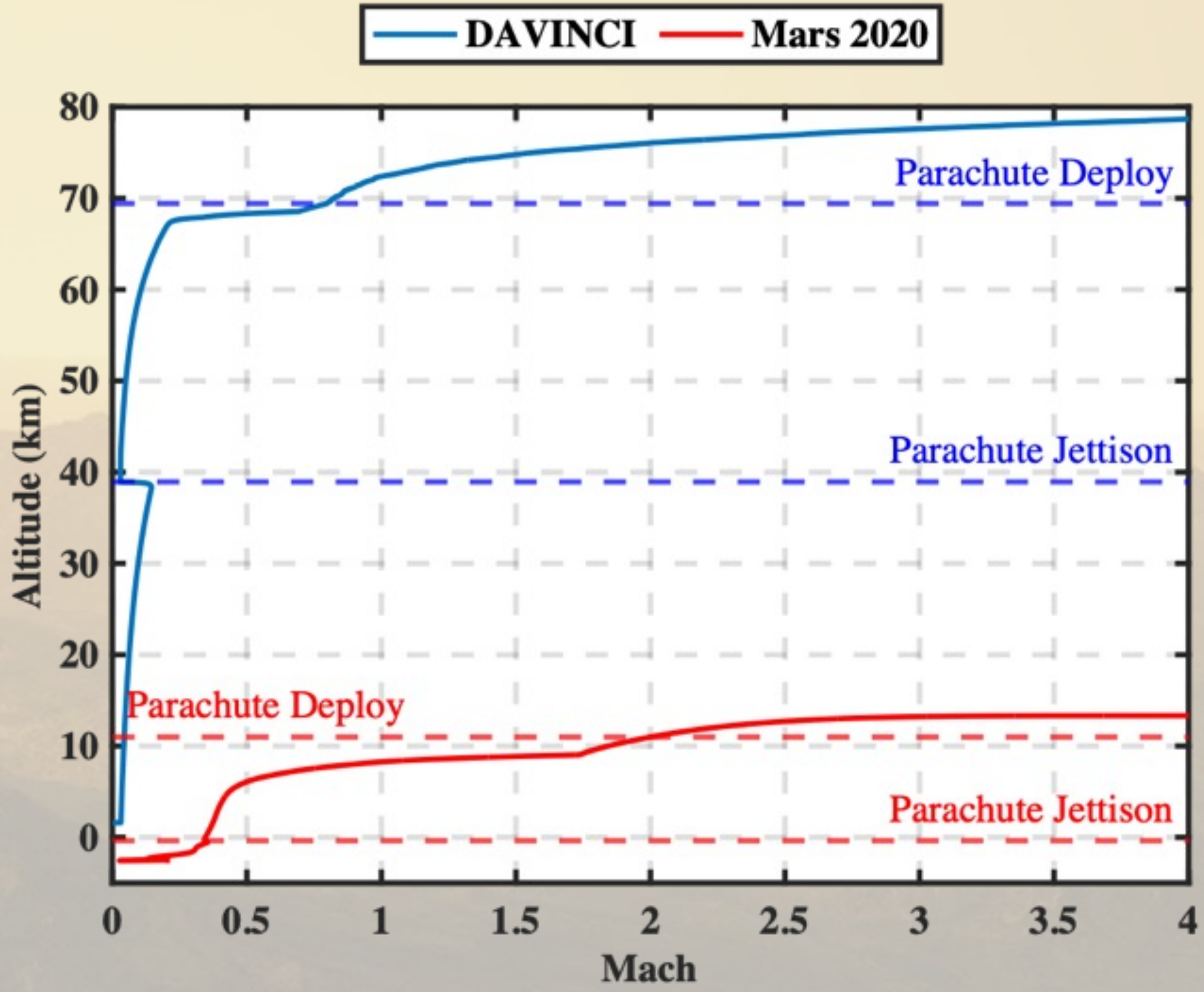


Credit: Garvin 2022
(Planetary Science Journal)



Comparisons to recent Entry, Descent, and Landing flights

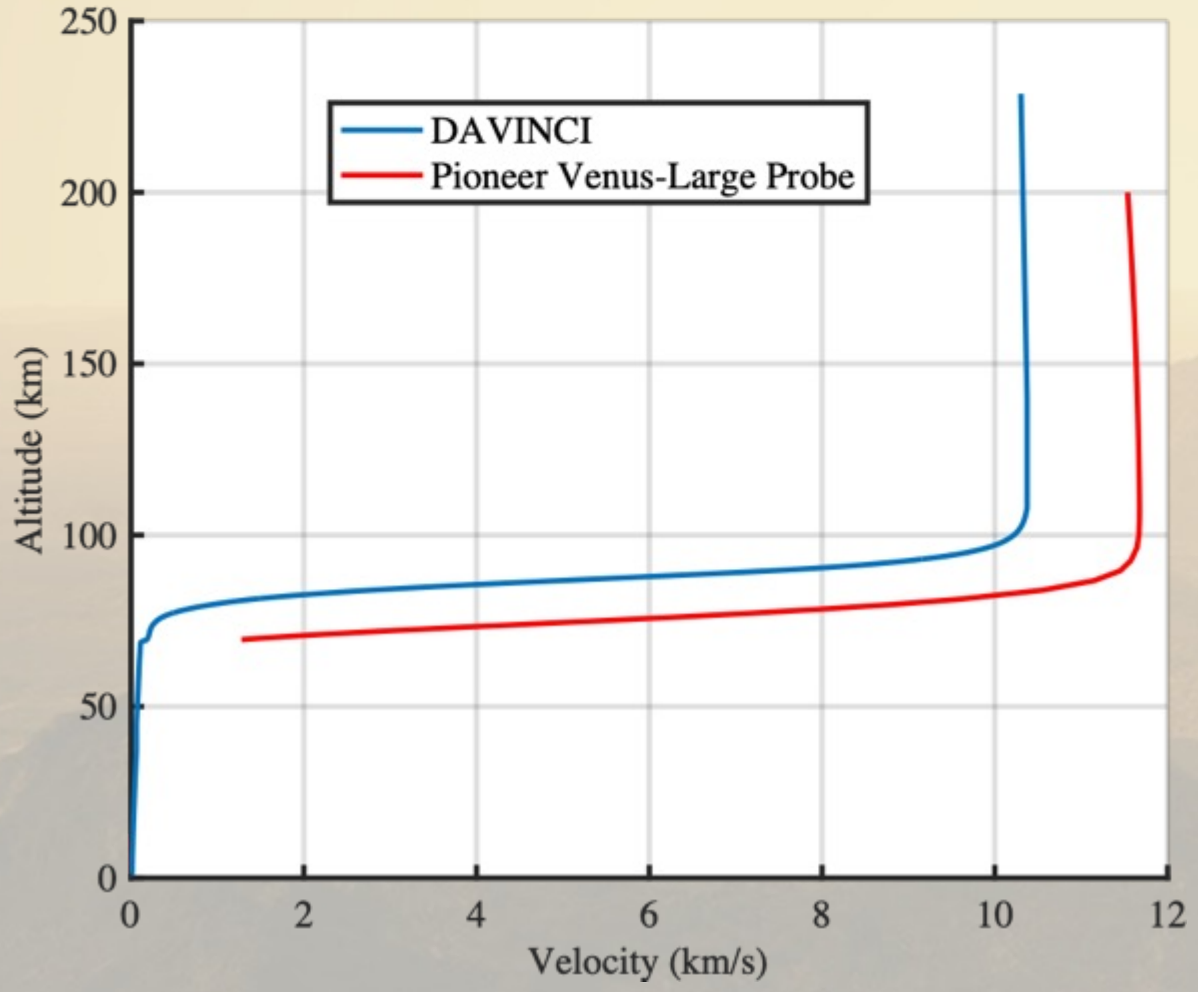




- DAVINCI total time of flight ~60 mins. Mars 2020 total time of flight ~7 mins
- DAVINCI is subsonic within 2.5 mins from the entry interface

Comparisons to Pioneer Venus

- Pioneer Venus (1978) – 45 deg sphere-cone – previous US Venus probe



$\beta_{DAVINCI}$ = 144 kg/m^2 (ballistic coefficient)
β_{PVLP} = 190 kg/m^2

$\gamma_{DAVINCI}$ = -9.2 deg (222 km alt) (flight path angle)
γ_{PVLP} = -32.4 deg (200 km alt)

- Ballistic Coefficient = mass/(drag coefficient * area)
- Flight path angle = angle between the velocity vector and the local horizontal

Smaller ballistic coefficient and shallower entry flight angle – leads to lower aerodynamic loads and aeroheating

Entry and Descent Flight Dynamics Simulation

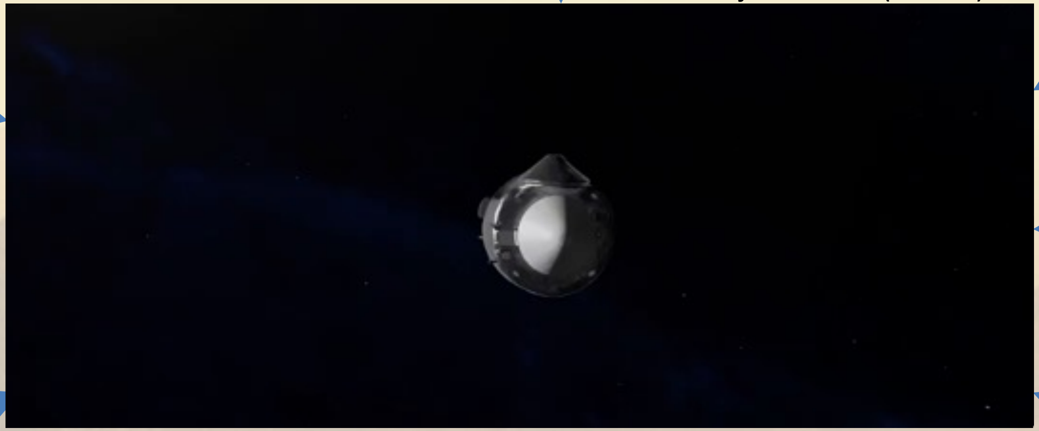
CRIS = Carrier-Relay-Imaging Spacecraft
PFS = Probe Flight System

Atmosphere

Aerodynamics

Orbital Determination/ Navigation (CRIS and PFS)

Program to Optimize Simulated Trajectories II (POST2)



Sensors

Terrain Model

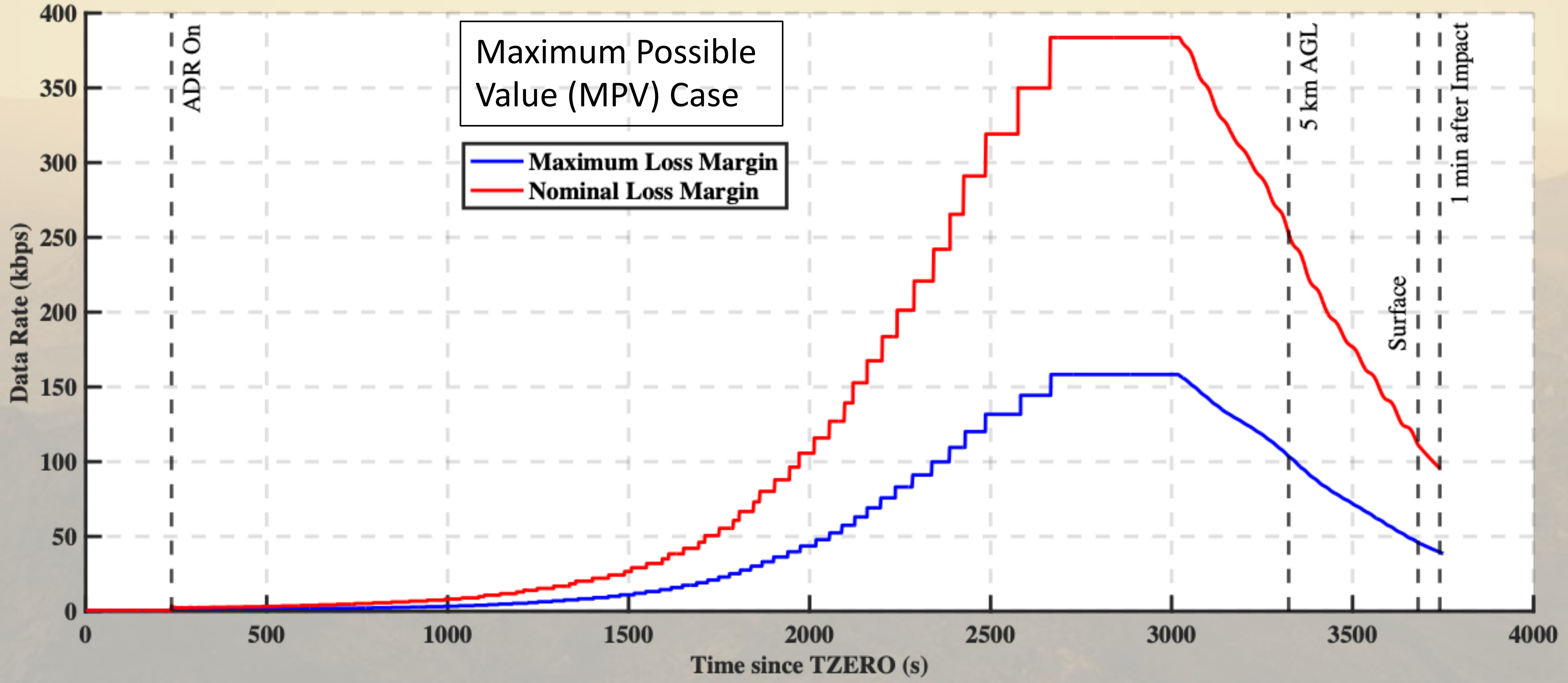
Science Instrumentation Model

Telecommunications

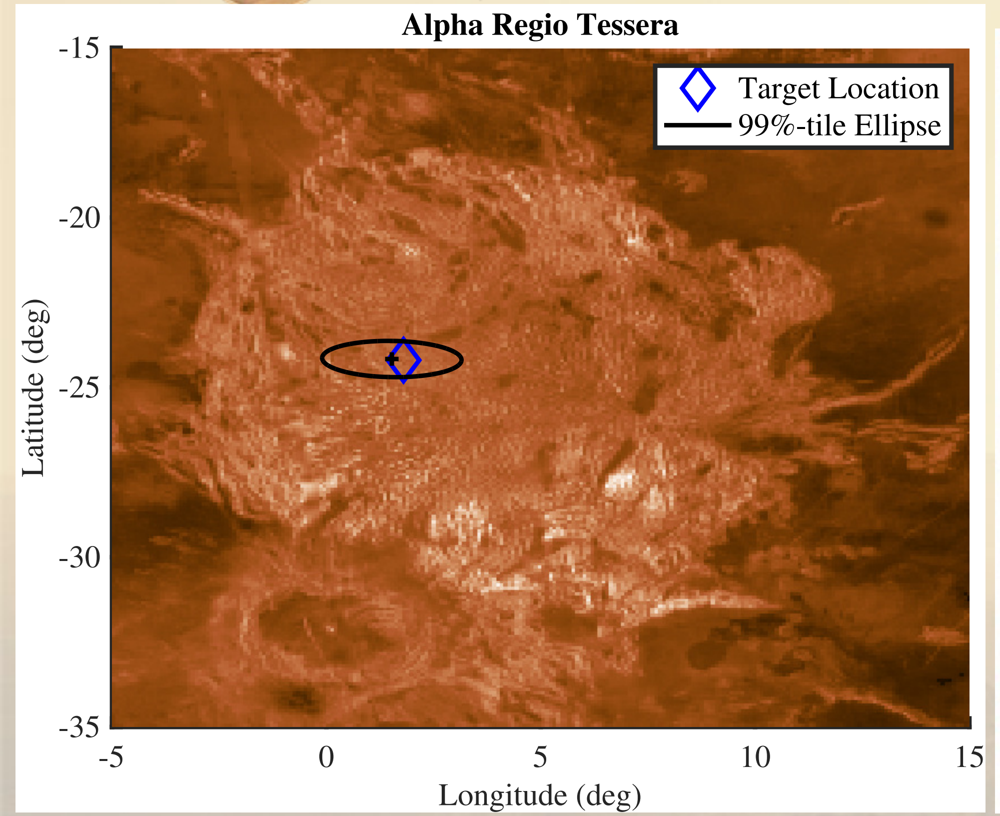
Multi-Body Dynamics

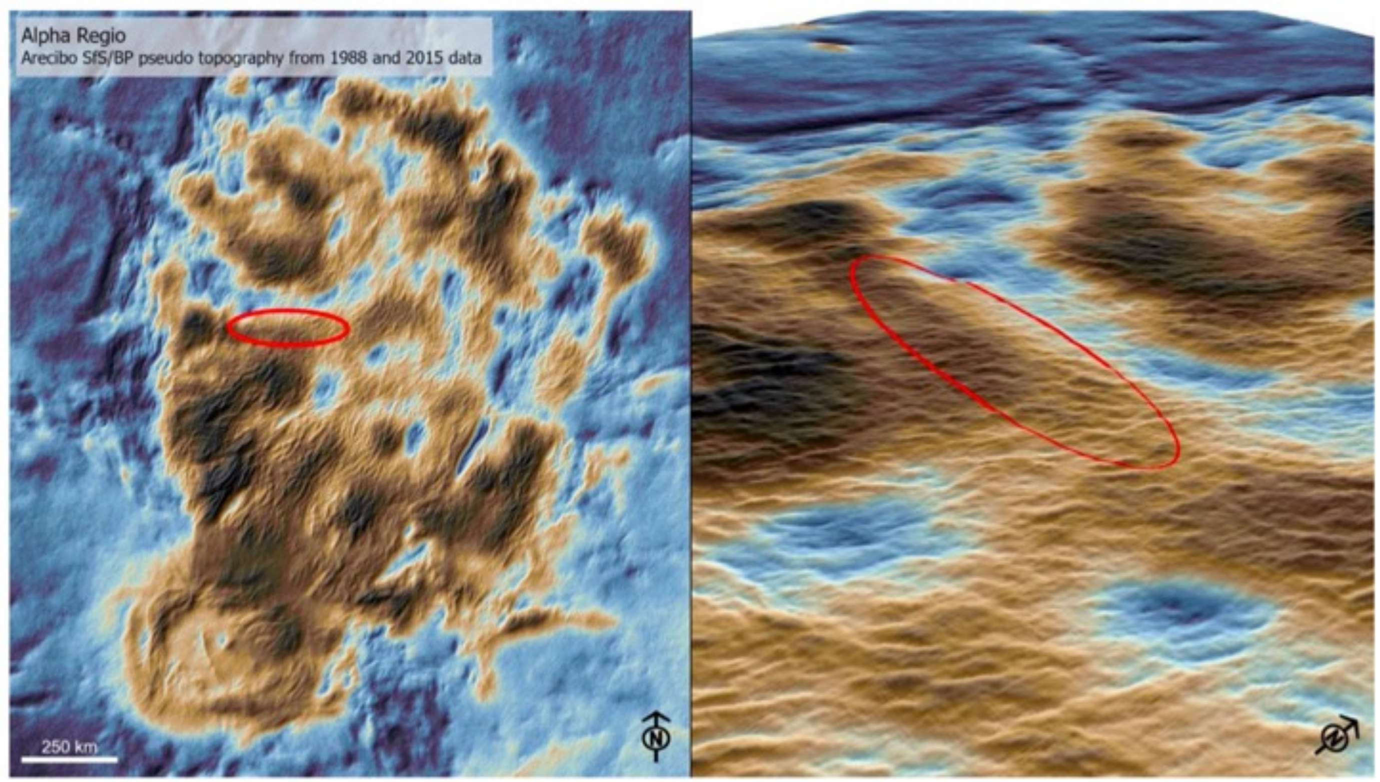
Telecommunication and Instrument Modeling

- Instrument data creation model based on allocations and triggered by sequence
- Simulation includes Adaptive data rate (ADR) model based on atmospheric properties, link parameters, and relative pointing between PFS and CRIS
- Models of data created, queued, and uplinked available by instrument, queue, and other categories

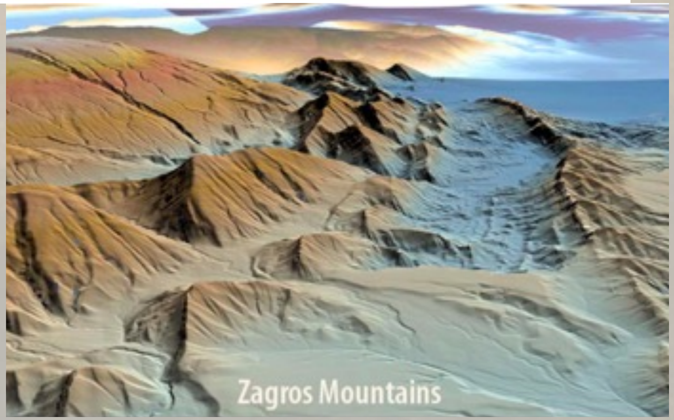


Landing Ellipse





- Landing location is Alpha Regio tesserae. Landing ellipse (99%-tile confidence) is 300 km x 100 km
- Within the ellipse there are some sites of higher scientific interest for VENDI imaging – modeling will incorporate preference pixels in calculation of probability of imaging scientifically important locations

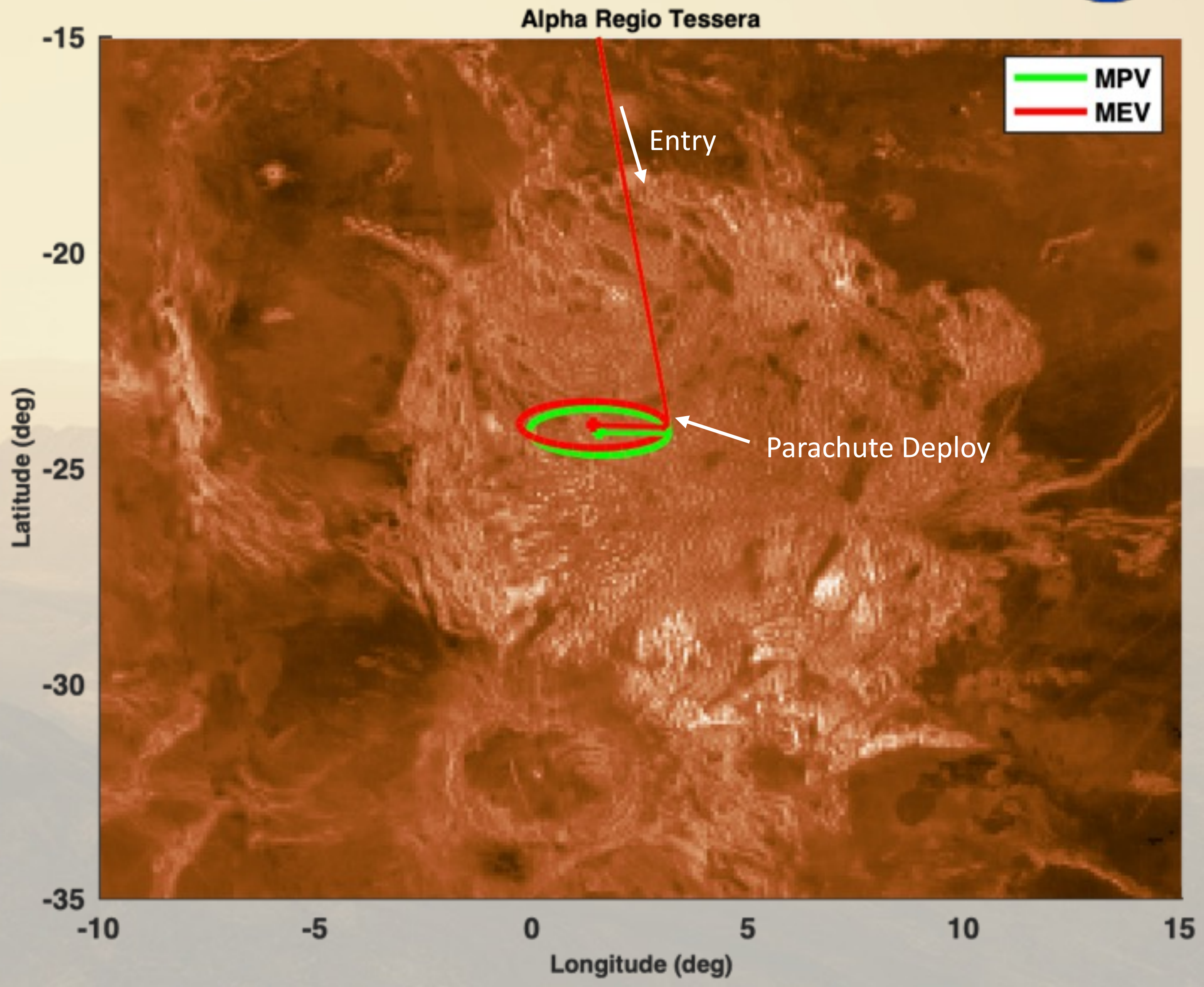


Credit: NASA

Descent Corridor

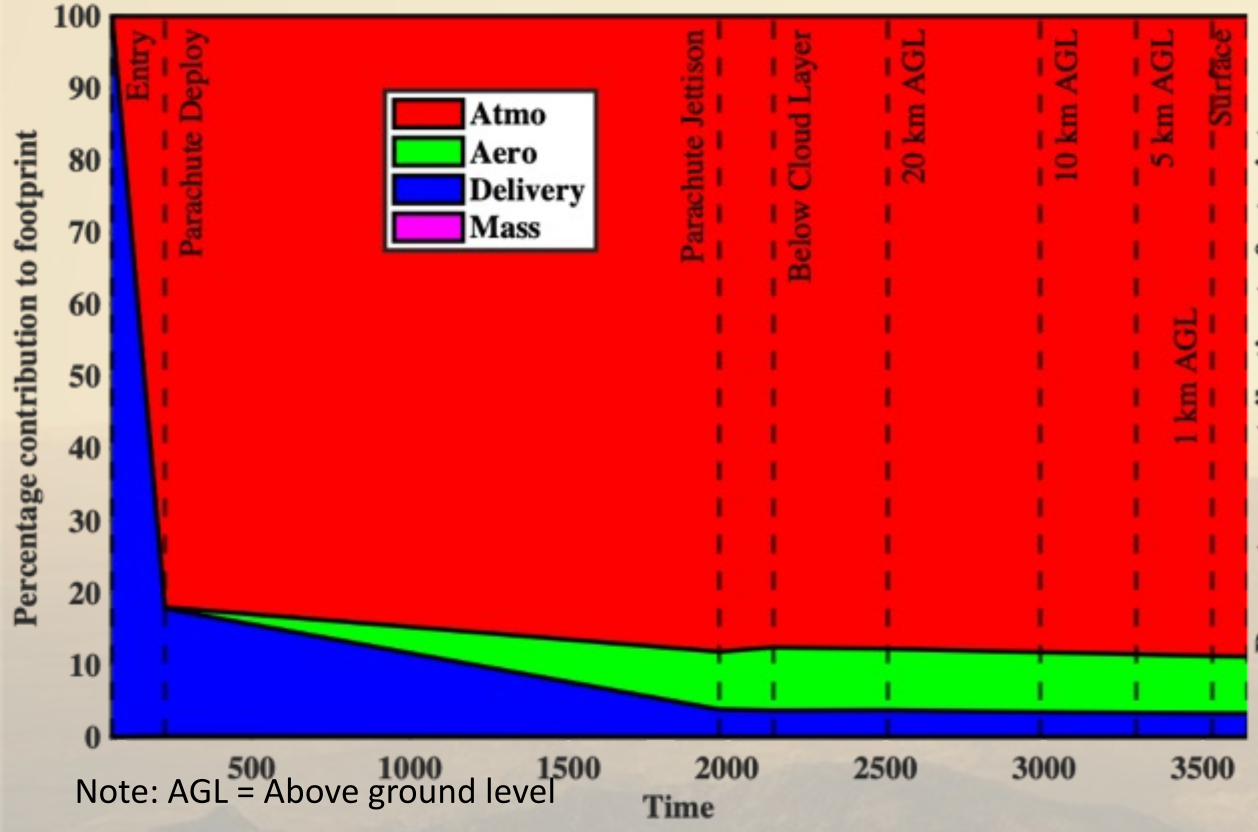
- 99% Confidence Descent Corridor Ellipse
  - MPV: 311 km x 114 km
  - MEV: 330 km x 113 km
- Located on the western side of Alpha Regio Tessera
  - Descent corridor ellipse meets the science requirements for VENDI imaging
- Impact velocity
  - No requirements
  - MPV: 14.7 m/s (33 mph)
  - MEV: 13 m/s (29 mph)

Maximum Expected Value (MEV)

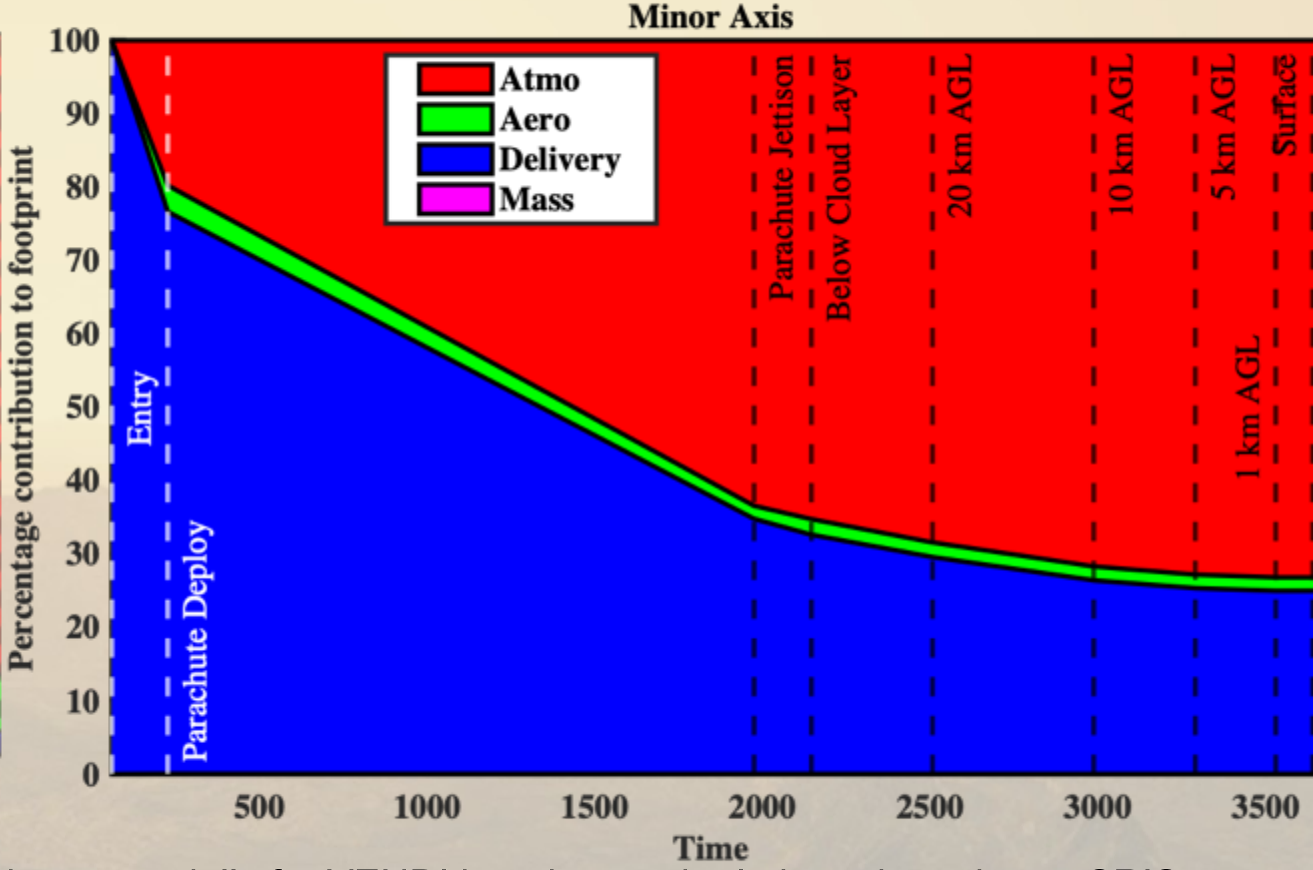


Sensitivities: Contributions of Models to Ellipse Size

Major Axis



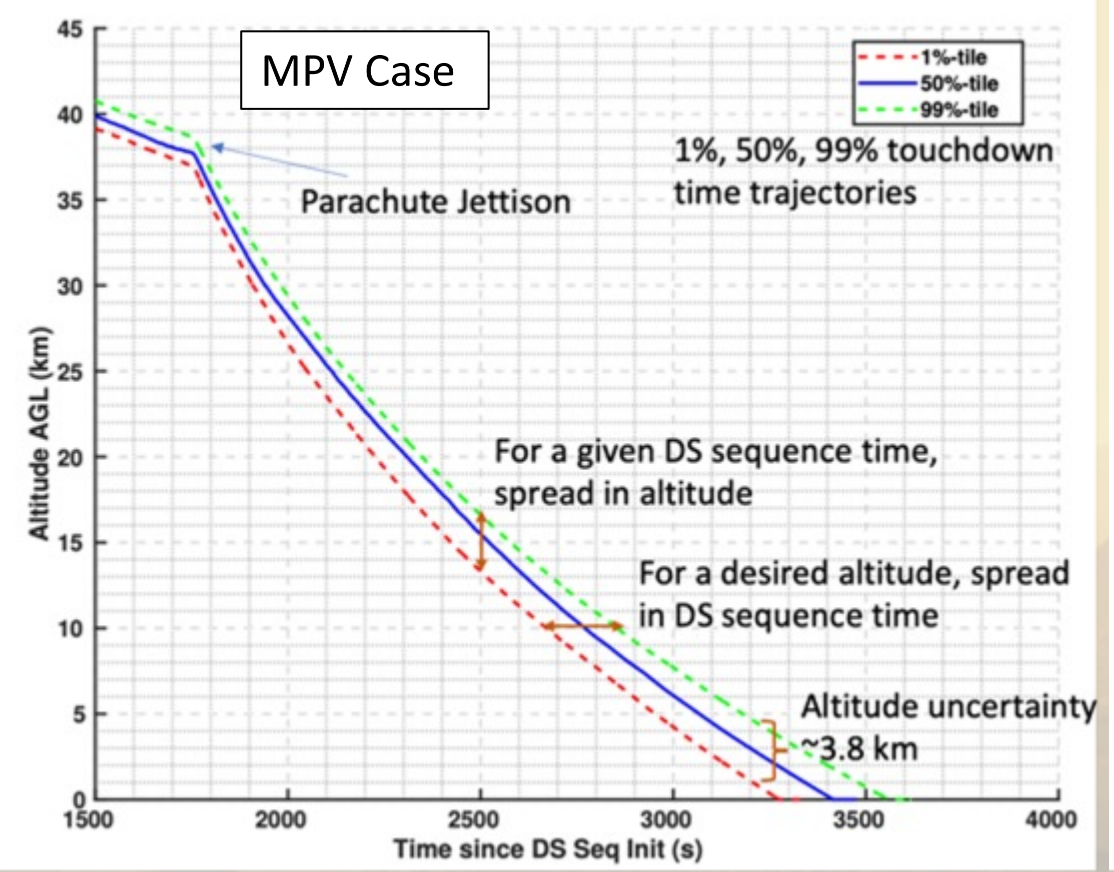
Note: AGL = Above ground level

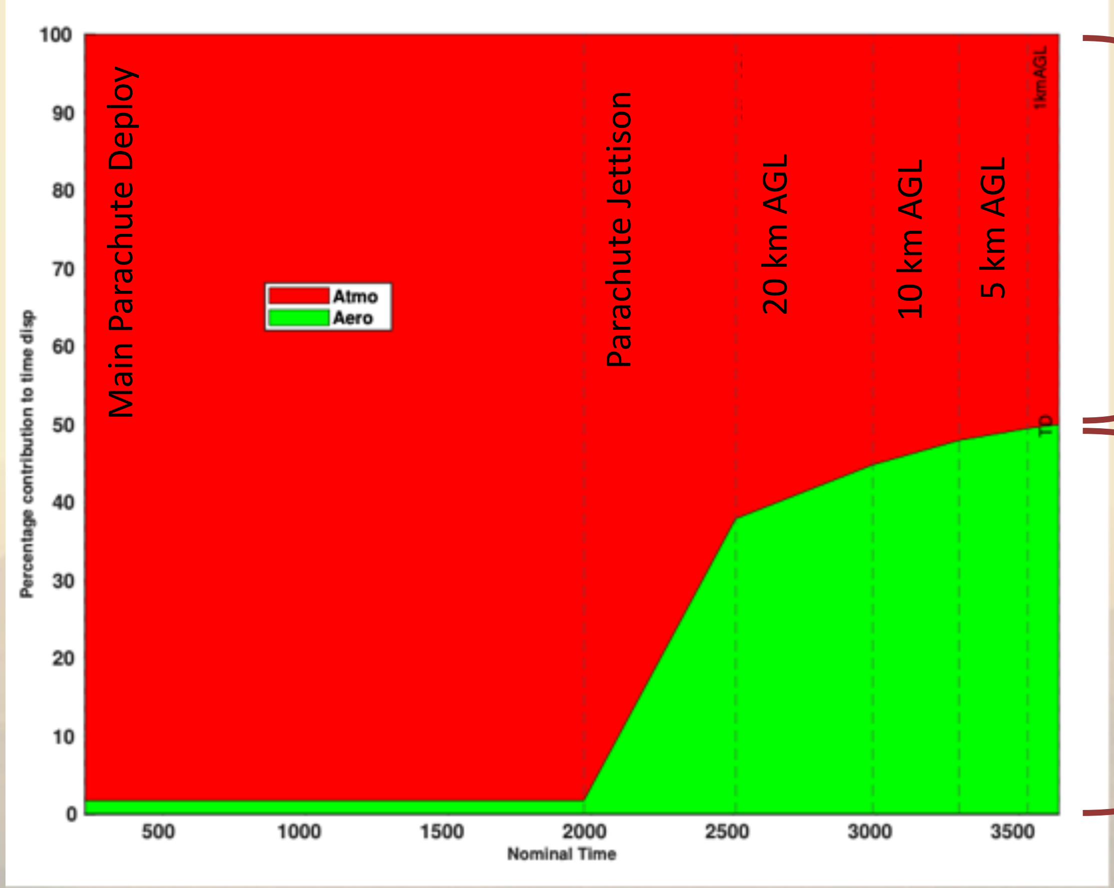


- Location of ellipse at different events affects science data collection, especially for VENDI imaging, and relative orientation to CRIS for telecommunications
- Atmospheric model (density, pressure, temperature, and wind uncertainties) creating largest dispersion in distribution of where trajectory is located and size of the ellipse
- Aerodynamics, especially under parachute and Zephyr, smaller contributor to trajectory position dispersion
- Delivery error (velocity and flight path angle uncertainty) is also a smaller contributor in the minor axis size

MPV Case

Sensitivities: Contribution to Timeline





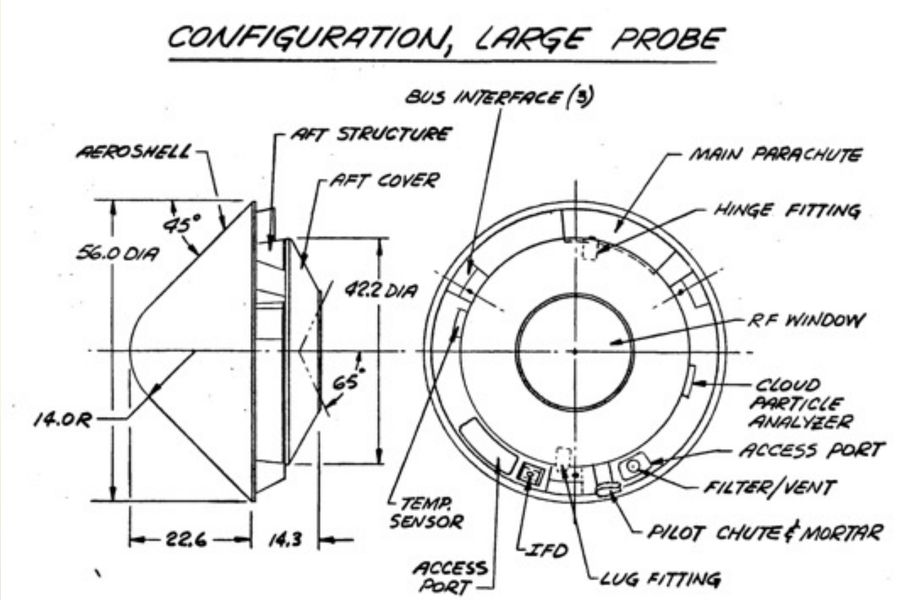
Wind model characterization could improve this, but we are data poor about Venus' winds in the deep atmosphere

Improved descent sphere aerodynamics with uncertainty quantification can reduce this

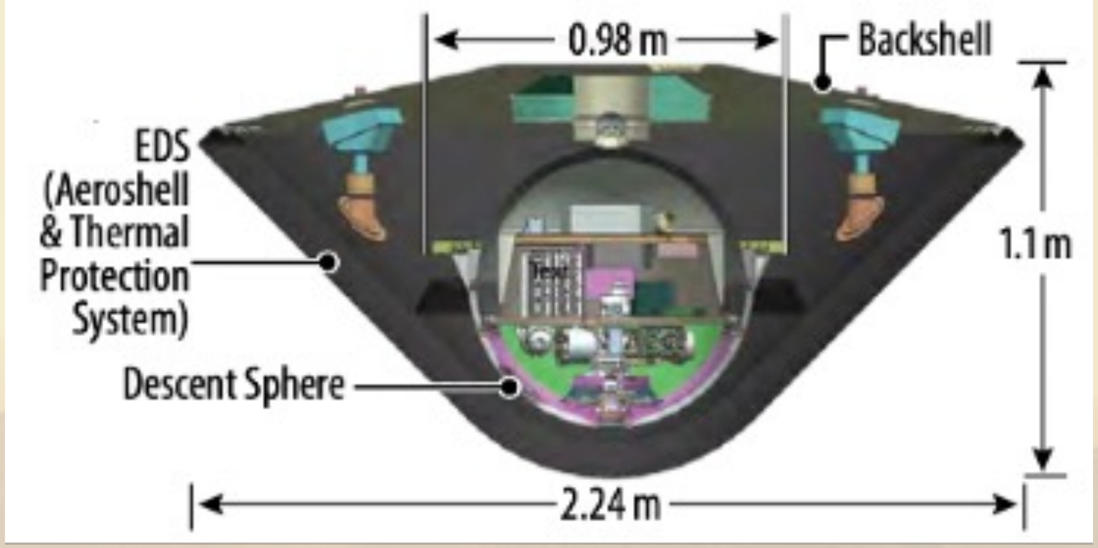
- Descent sequence is tuned based on information from entry and descent model
- Sequence is based on a fixed time – there are no other sensor that adapts the time on-board the Zephyr
- Atmosphere dispersions and aerodynamic dispersion (especially Zephyr aerodynamics) increase the dispersion in time
- Atmospheric model improvement opportunities limited – we are data poor about Venus
- Aerodynamic model improvement possible – Earth-based tests in wind tunnels and drop tests

Similarity to Pioneer Venus: Entry Shape

Credit: NASA
Units in inches



Credit: NASA



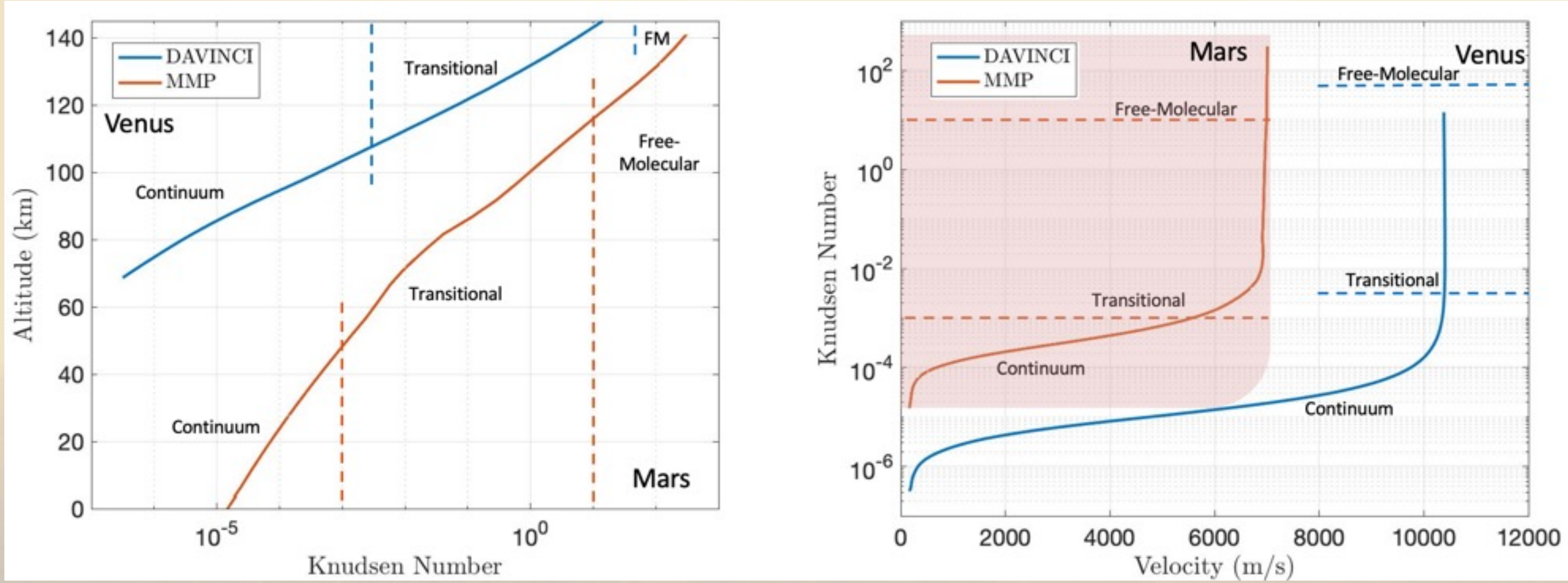
Pioneer Venus Large Probe

DAVINCI

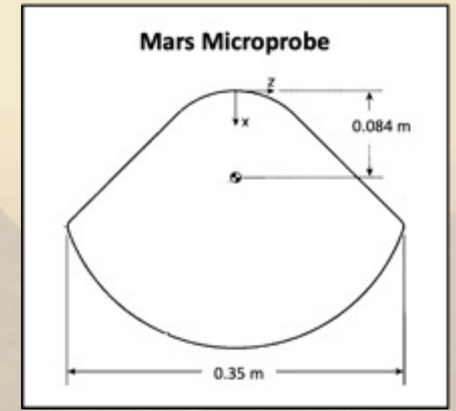
EDS = Entry Deceleration System

- 45 deg. sphere-cone forebody
- Backshell for DAVINCI is flatter than the biconic shape of Pioneer Venus large probe
- 1.4 m diameter (Pioneer Venus) vs. 2.24 m diameter (DAVINCI)
- Thermal Protection System – Forebody: Carbon-Carbon (similar to Genesis); Backshell: SLA
- Current entry body modeling leverages classic 45-deg sphere-cone aerodatabases (e.g. Microprobe); plans for verification using modern tools

Model Discussion: Entry Aerodynamics



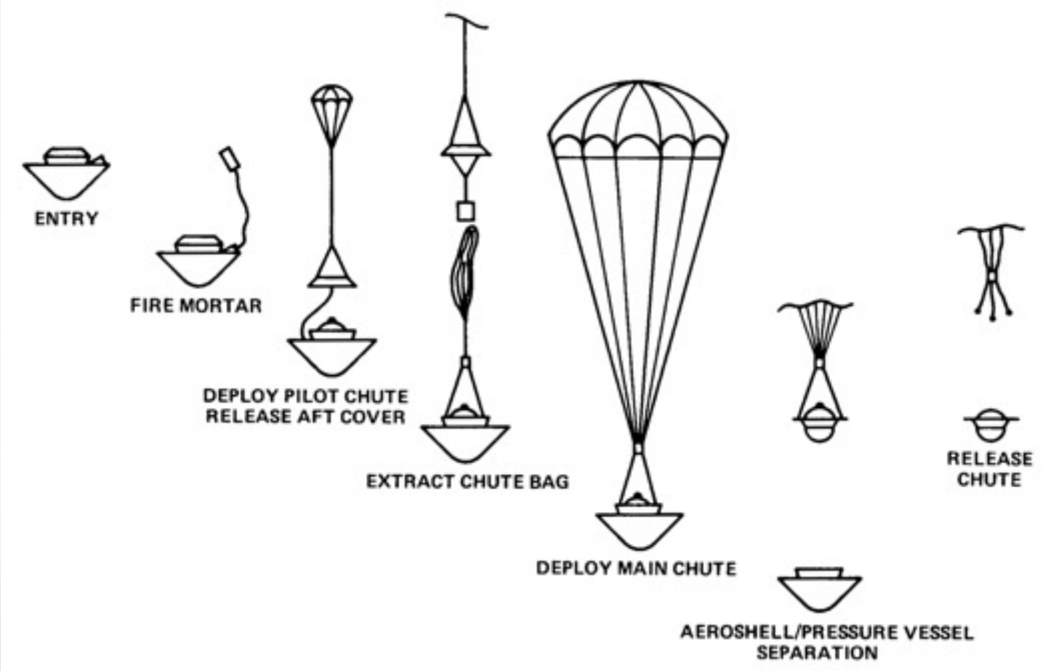
DAVINCI



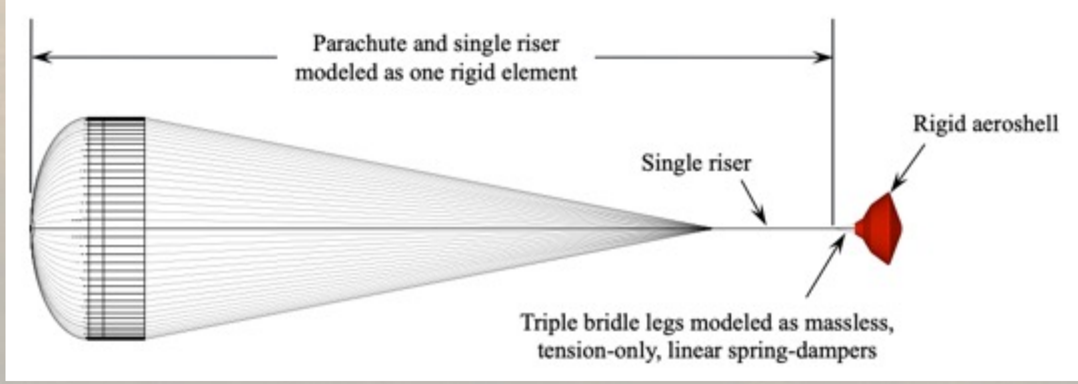
- Mars Microprobe – tested 45 deg sphere-cone aerodatabase available
  - Data from rarefied to subsonic regime
  - Uncertainties (adder and multiplier) similar to other modern aerodatabases
  - Noticeable differences in reference trajectory from DAVINCI; backshell very different
- Future work – Creating a DAVINCI specific entry aerodatabse

Future Work: Parachute Portion

- Multi-body parachute model has heritage with Mars missions (Mars Exploration rovers, MSL, Mars 2020 etc.) in flight dynamics simulations
  - Models parachute and payload as separate vehicles
  - Connected with tension-only lines
- Code checked out for Mars 2020 has been migrated to DAVINCI
- Initial inputs based on Mars 2020 final documentation
- Line properties based on DAVINCI system
- Potential updates as parachute acquisition could lead to a system not based on disk-gap-band parachute



Multi-stage Pioneer Venus Parachute Deployment (similar to DAVINCI)



Multi-body dynamics used for Mars Science Laboratory (AIAA 2013-1276)

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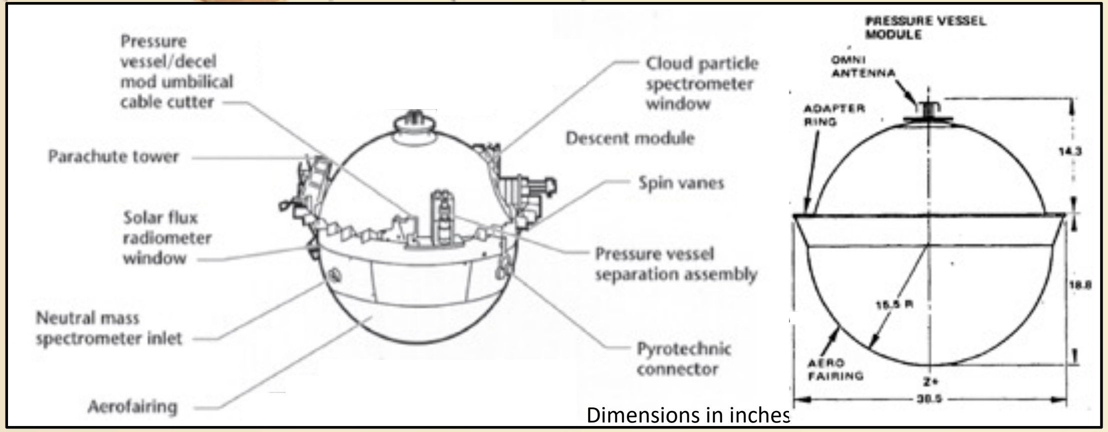
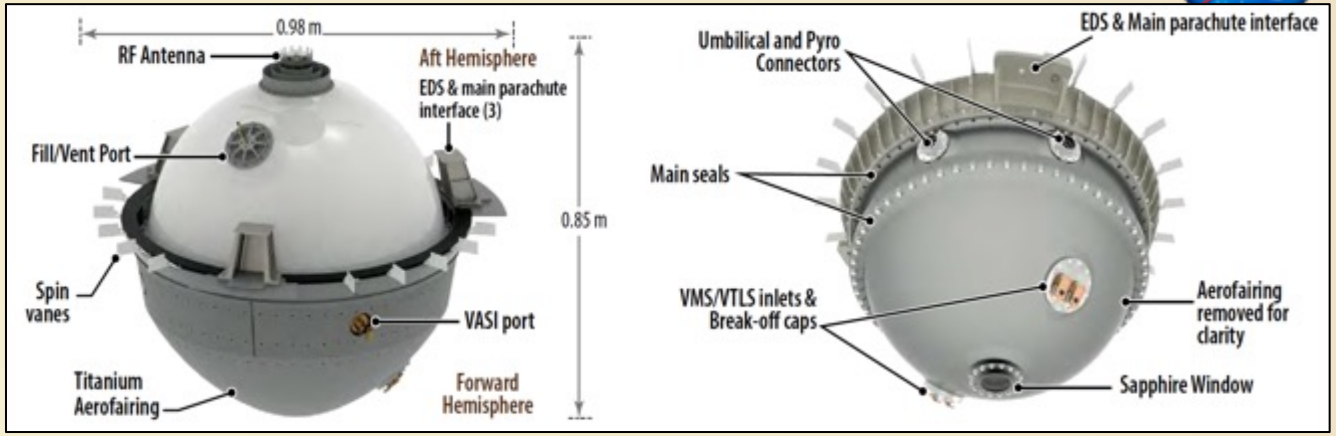
Model Discussion: Zephyr Aerodynamics



Pioneer Venus Large Probe (1978)

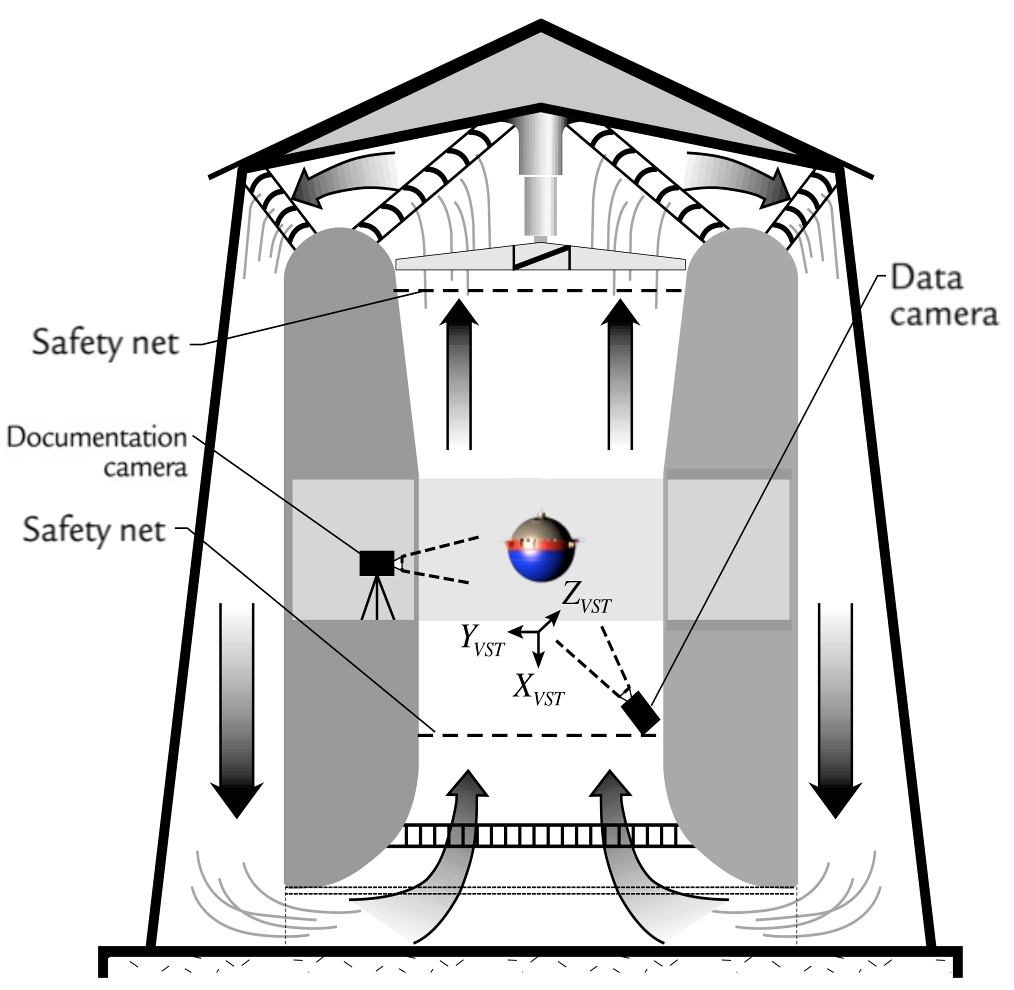


DAVINCI Zephyr

- Zephyr is different in its outer mold line (OML) from Pioneer Venus Large Probe
  - Small OML changes are important to account – Huygens probe opposite rolling motion
- Current aerodynamic model is from an old Venus proposal (2010) but OML for DAVINCI is still different
  - Model uses Pioneer Venus data book aerodatabase
  - Supplemented with low-speed CFD
  - Dynamics – pitching/yawing and rolling moment dynamics are low fidelity

Test Facilities/Techniques

NASA-LaRC Vertical Spin Tunnel



Credit: NASA

Characteristics	
Test section	7.6 m high by 6 m wide
Area	27.9 m^2
Flow speed	Up to 85 m/s
Reynolds number	1.80 x 10^6 per m
Test fluid	Air
Forced oscillation capabilities	Yes

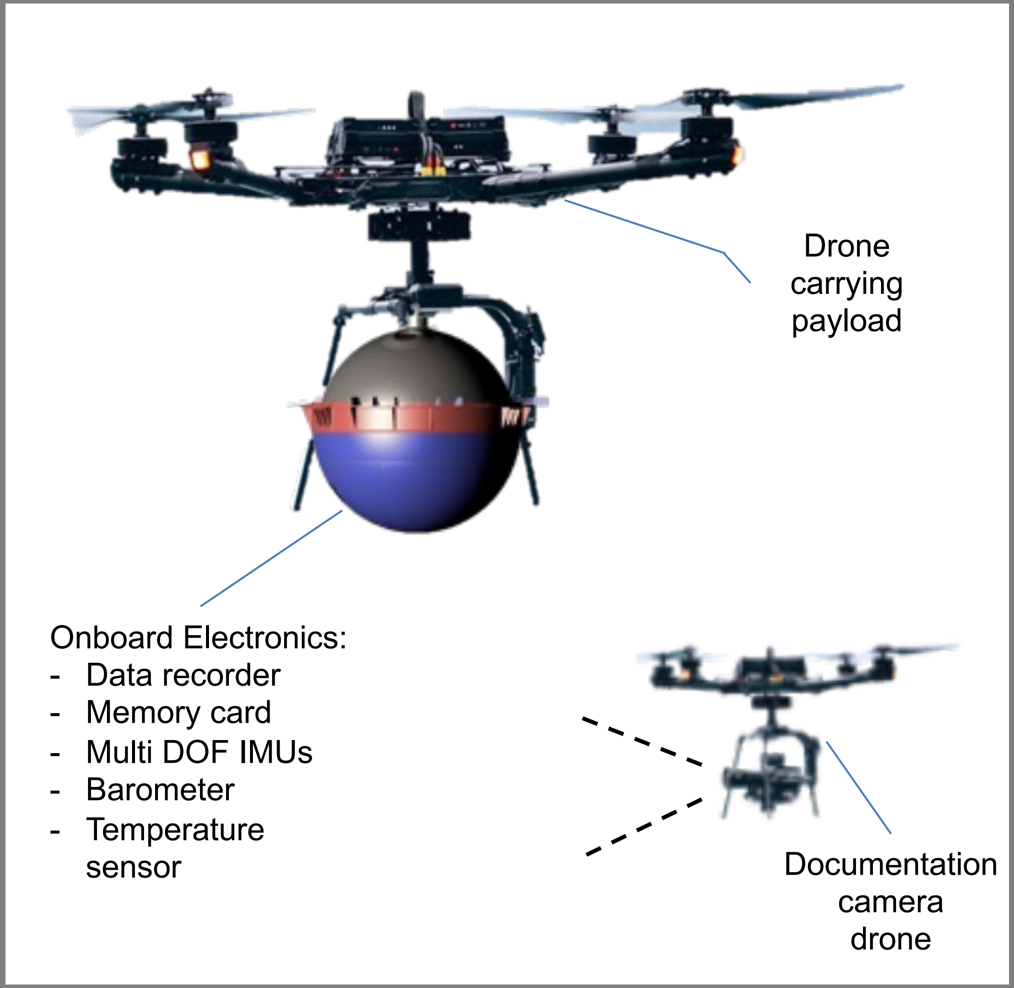
Benefits

- Test articles can be reused
- Can test various flight configurations

G. Guecha "Aerodynamic Testing of the Venus Descent Sphere" IPPW-2022

Test Facilities/Techniques

NASA-LaRC Drone Drop Test



Characteristics	
Drone reference	FreeFly Alta-X
Payload	Up to ~15.9 kg
Drop altitude	Up to ~300 m*
Flight time	10.75 minutes*
Test fluid	Air

* Performance is specific to max payload weight

Benefits

- Better flow quality compared to VST
- Can test at higher dynamic pressures than VST

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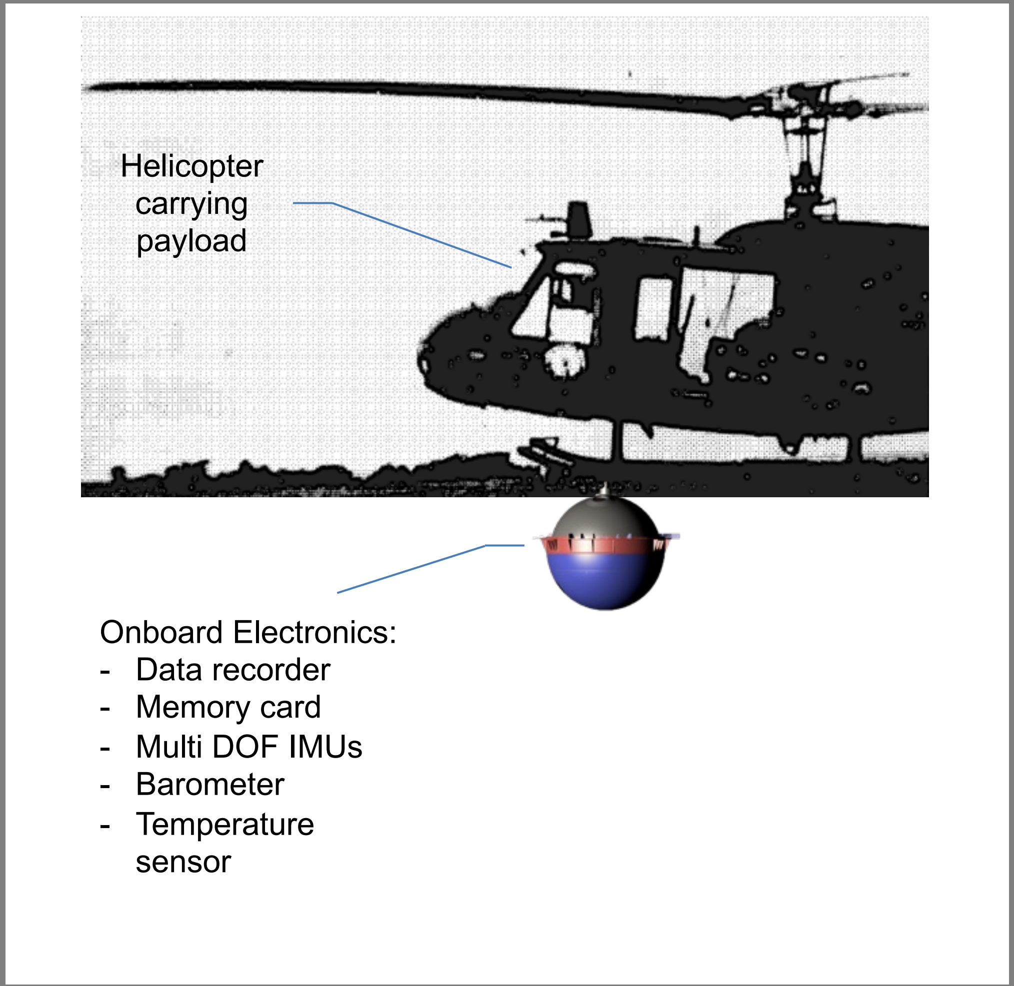
Test Facilities/Techniques

Offsite — Helicopter Drop Test



Characteristics	
Drop location	Utah Test and Training Range (UTTR)
Payload	Up to 100 kg*
Drop altitude	Up to 500 m*
Test fluid	Air

* To be confirmed. Actual performance values are likely greater

Benefits

- Increased time at terminal descent compared to drone drop
- Test bigger/heavier geometries than drone platform
- Improves Reynolds number equivalence

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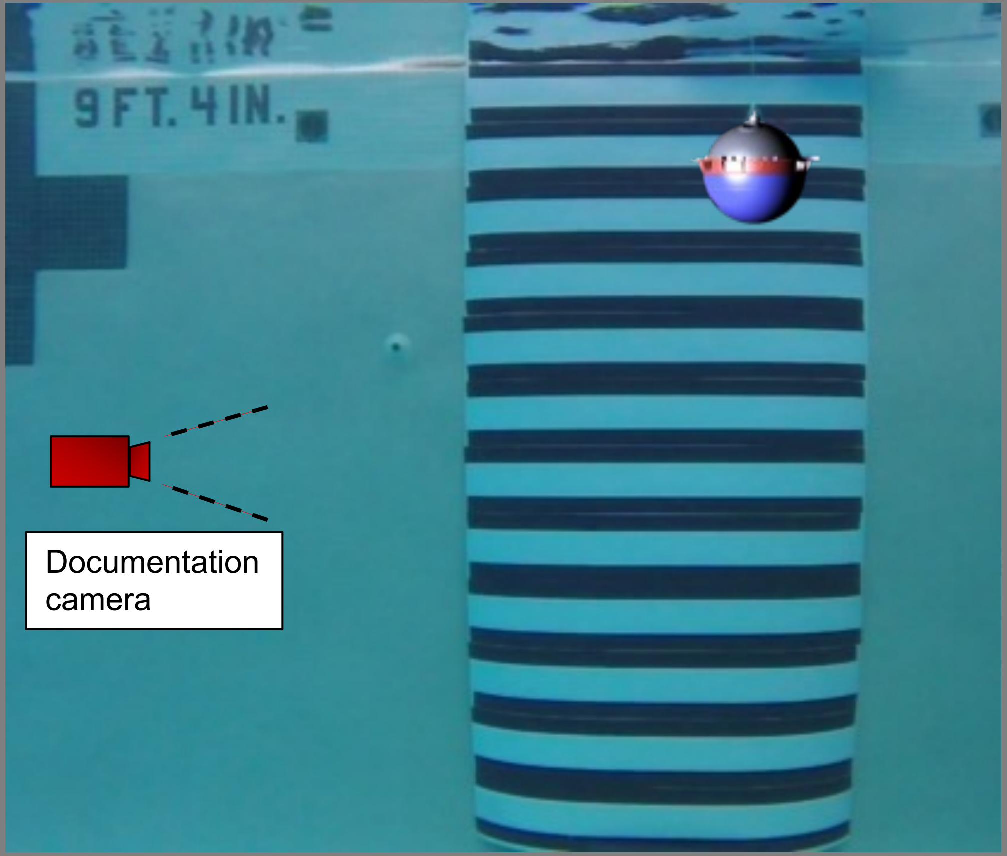
Test Facilities/Techniques

Offsite

Swimming Pool Drop Test



Characteristics	
Test section	Depth up to 4.5 m
Test fluid	Pool water

Benefits

- Improves Reynolds number equivalence
- Provides qualitative stability assessment and quantitative drag coefficient estimates

G. Guecha “Aerodynamic Testing of the Venus Descent Sphere” IPPW-2022

Path Forward

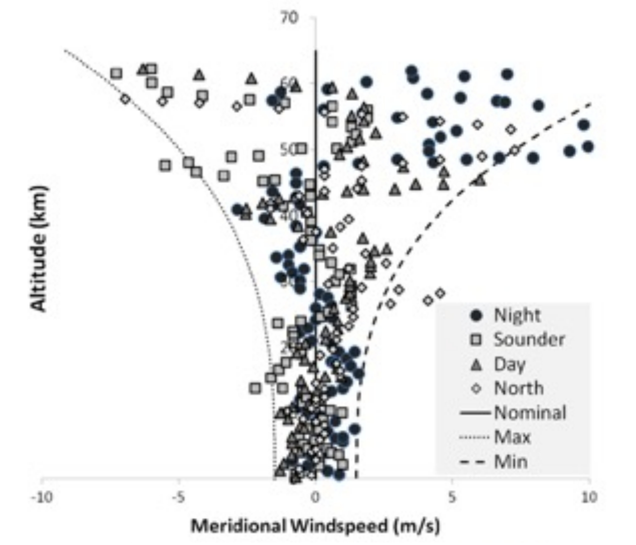
- Unsteady simulations of High Reynold's Number, Low-speed CFD for bluff bodies (spherical shapes) is immature
- Several testing methods considered – account for dynamic scaling (Froude number), Reynold's number, and Mach number
  - Early Summer 2023 – Vertical Spin Tunnel (VST)
    - Drag coefficients (drag plate size)
    - Dynamically scaled for low Venus altitudes
  - Summer 2023 (potential) – 12-ft tunnel
    - Static aerodynamic and dynamic coefficients
    - Rolling moment characterization (spin vanes)
  - Fall 2023 – Helicopter Drop Test (w/ EES)
    - Instrumentation demonstration
    - Drag coefficient
    - Dynamically scaled for high Venus altitudes
  - 2024+ – Iteration of VST, 12-ft, or helicopter tests as Zephyr OML updates
- Model development parameterized by ballistic coefficient; as Zephyr size changes, model and analysis still valid since Zephyr will be scaled to maintain ballistic coefficient

Facility	Advantages	Disadvantages
Vertical Spin Tunnel	• Flow speed control • Forced oscillation capabilities • Simple test set-up	• Constrained dynamic pressure capabilities • Fair airflow quality
Drone Drop Test	• Dynamic pressure capabilities • Improved flow similarity (N_{Re})	• Test article may not be re-flown • Very complicated test set-up
Helicopter Drop Test	• Dynamic pressure capabilities • Improved flow similarity (N_{Re}) • Increased terminal descent time	• Test article may not be re-flown • Complicated test set-up • Helicopter downwash effects
Pool Drop Test	• Flow similarity (N_{Re}) is improved	• Required test model is very difficult to build
Captive Wind Tunnel Tests	• Flow speed control • Forced oscillation capabilities • Simple test set-up	• Sting mount may affect data • Unable to test free-flight configuration

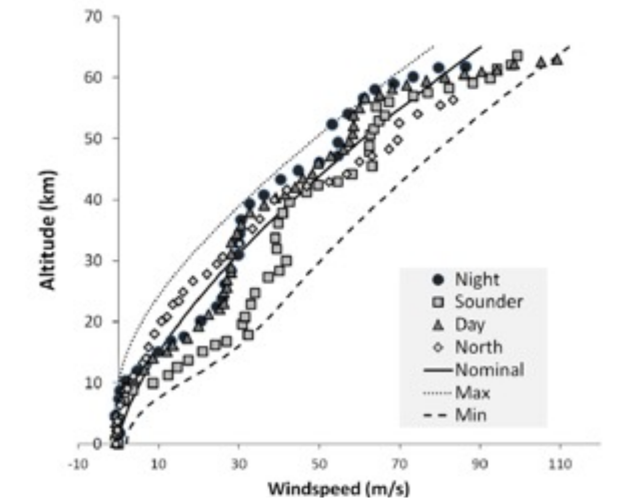
G. Guecha "Aerodynamic Testing of the Venus Descent Sphere" IPPW-2022

Model Discussion: Atmosphere

- Venus GRAM 2005 based on Venus International Reference Atmosphere (VIRA) – developed from Pioneer Venus data
  - Used for pressure, density, temperature, speed of sound and uncertainties
  - Potential update to Venus GRAM 2021 to speed of sound bug fix
- Considered Venus Climate Database (VCD) (2021/2022) – developed by Laboratoire de Météorologie Dynamique (LMD) – used for ESA EnVision mission
- Ralph Lorenz wind model (2015) based on Pioneer Venus probe data
  - Limited from 0-60 km altitude
  - Empirical based model
  - Smooth curves; turbulence model planned in the future
- (Future model update) Council of Atmosphere
  - DAVINCI team scientists and engineers considering several atmospheric models
  - Potentially contract atmospheric simulations



Meridional Winds (North-South) as a function of altitude with Pioneer-Venus data points



Zonal Winds (East-West) as a function of altitude with Pioneer-Venus data points

Credit: R. Lorenz (2015)

Future Work: Pre-Entry Modeling

- PFS is spun to 5 RPM nominally and then separated from CRIS 2 days before Entry Interface
- PFS attitude and rates modeled by Simulink-based tool
- POST2 module being developed to track attitude propagation during coast phase
  - POST2 could serve as independent verification and validation during coast to entry interface
  - Models such as solar radiation pressure will be included
  - POST2 already has third-body perturbation models
  - Mars Sample Return (MSR) Earth Entry System (EES) is funding development for their own application (EES separates from European orbiter 3 days before the entry interface)

Summary

- Entry and Descent Modeling simulation models DAVINCI probe from entry interface – 60 s to touchdown
- Current aerodynamic models leverage heritage aerodatabases
- Atmosphere models based on former Venus missions (especially Pioneer Venus) used for simulation; Council of Atmosphere will prescribe future atmospheric models
- Simulation contains instrumentation and telecommunications models to provide metrics for data generated, queued, and uplinked
- Performance metrics show large sensitivities to atmosphere and aerodynamic models; secondary effect of delivery states

Questions

Credit: NASA