DAVINCI Venus Entry, Descent, and Landing Modeling and Simulation

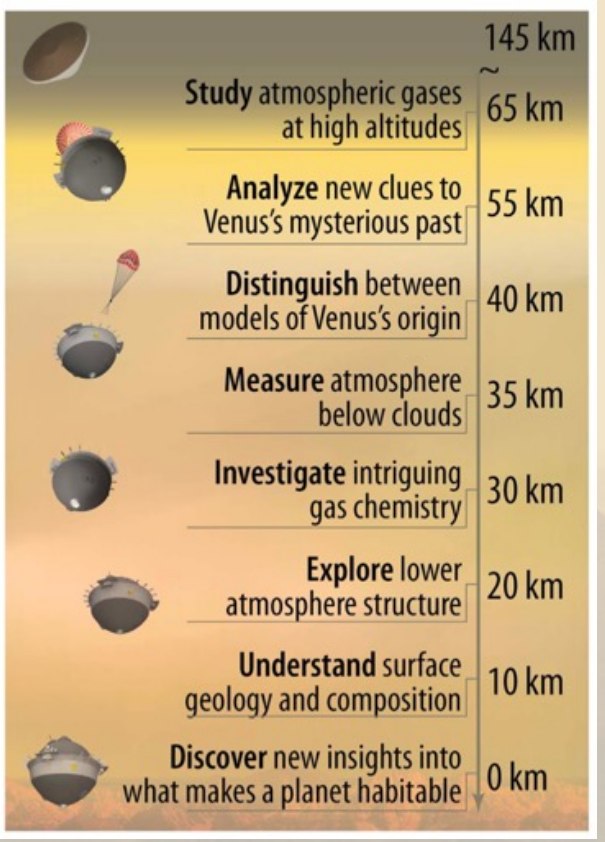
Soumyo Dutta[1], N. Giovanny Guecha-Ahumada[1],
Matt Garrison[2], Kyle Hughes,[2] and Mark Johnson[3]

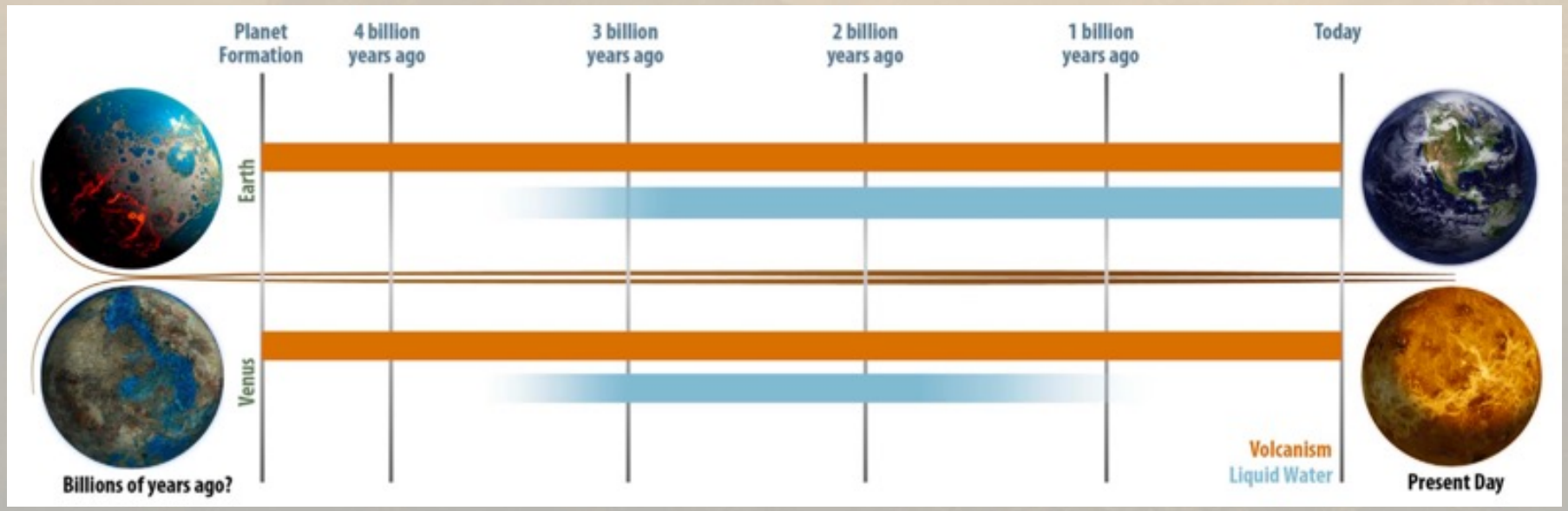
[1]NASA Langley Research Center, Hampton, VA
[2]NASA Goddard Space Flight Center, Greenbelt, MD
[3]Lockheed Martin Space Systems, Littleton, CO

AIAA SciTech Forum 2023
Atmospheric Flight Mechanics Conference
National Harbor, MD
January 25, 2023

DAVINCI – Mission Objective

- Deep Atmosphere Venus Investigation of Noble gases, Chemistry and Imaging (DAVINCI)
- First in-situ probe since Soviet missions and Pioneer Venus
- New understanding of atmosphere, surface, and evolutionary path of Venus as a possibly once-habitable planet and analog to hot terrestrial exo-planets
- Yield 60 Gbits (compressed) data about atmosphere and near surface
- This talk will focus on the modeling and simulation of DAVINCI to make sure we achieve these science objectives



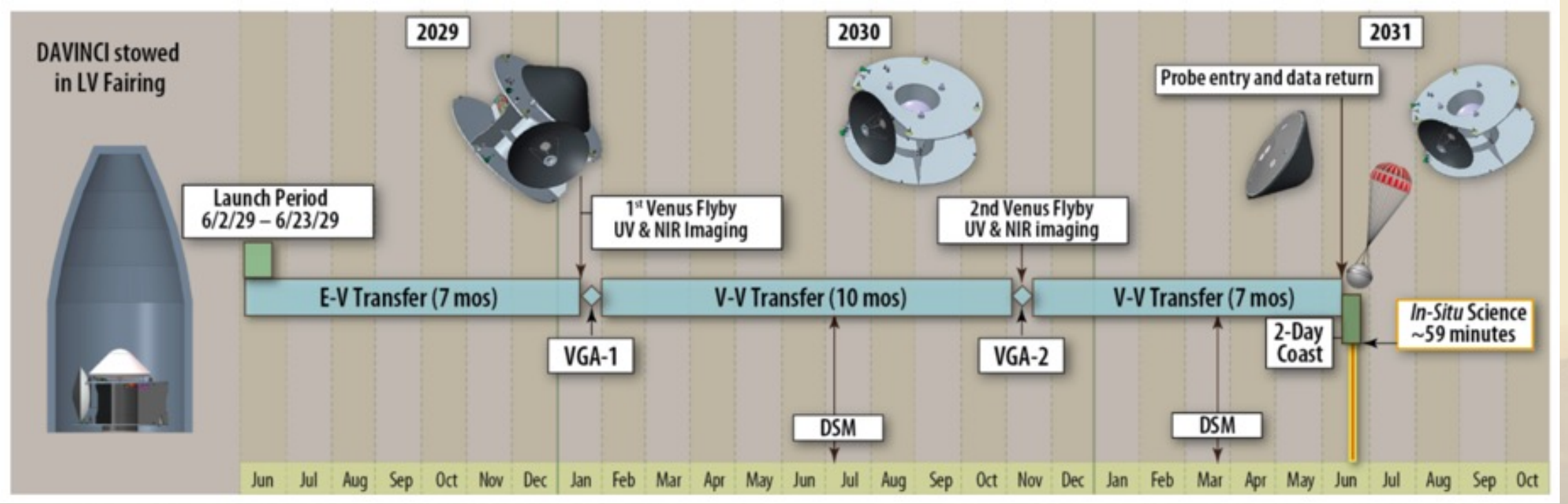


Credit: Garvin 2022
(Planetary Science Journal)

Outline

- Concept of Operations
- Similarity to Pioneer Venus
- Models for Simulation
- Results

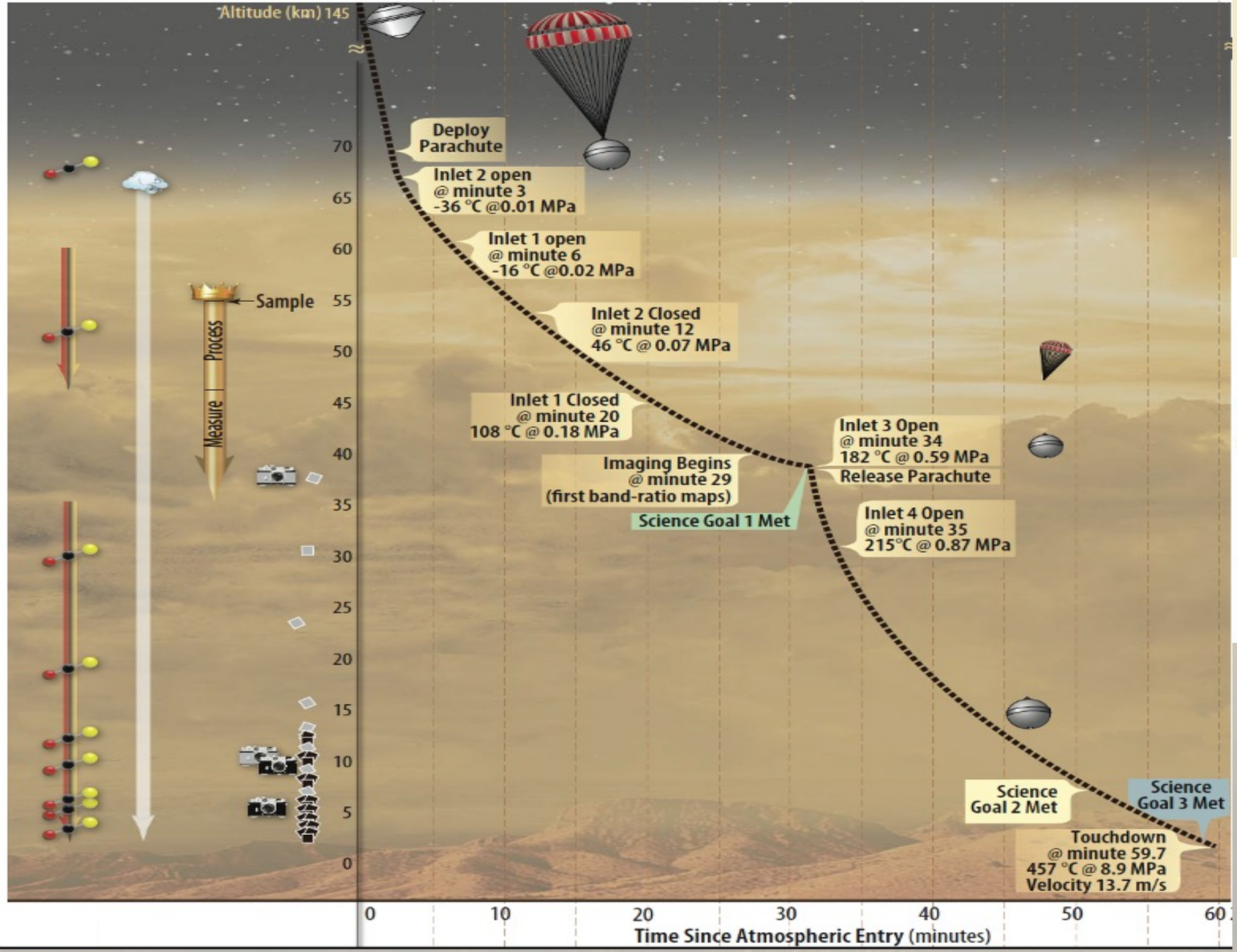
DAVINCI Concept of Operations



Credit: Sekerak 2022 (IEEE Aerospace)

- Launch as early as June 2029
- Two Venus flybys (VGA) in 2029 and 2030
- Direct entry of probe in June 2031 after 2-day coast
- **Atmospheric entry (145 km altitude) to impact approximately 1 hour**

UV = Ultraviolet
NIR = Near Infrared
E-V = Earth-Venus
V-V = Venus-Venus
VGA = Venus Gravity Assist
LV = Launch Vehicle
DSM = Deep Space Maneuver



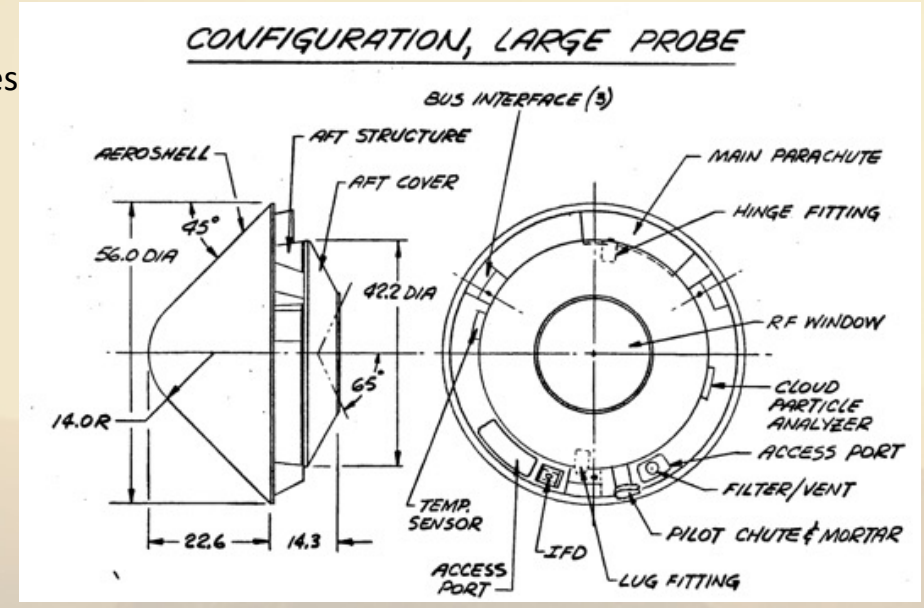
Credit: Garvin 2022 (Planetary Science Journal)

Legend

- Temperature, Pressure & Winds
- Targeted Trace Gases
- Trace Gases Every 50 - 200 m
- Noble Gases & Isotopes
- 1 μm Narrowband Imaging
- Broadband Imaging

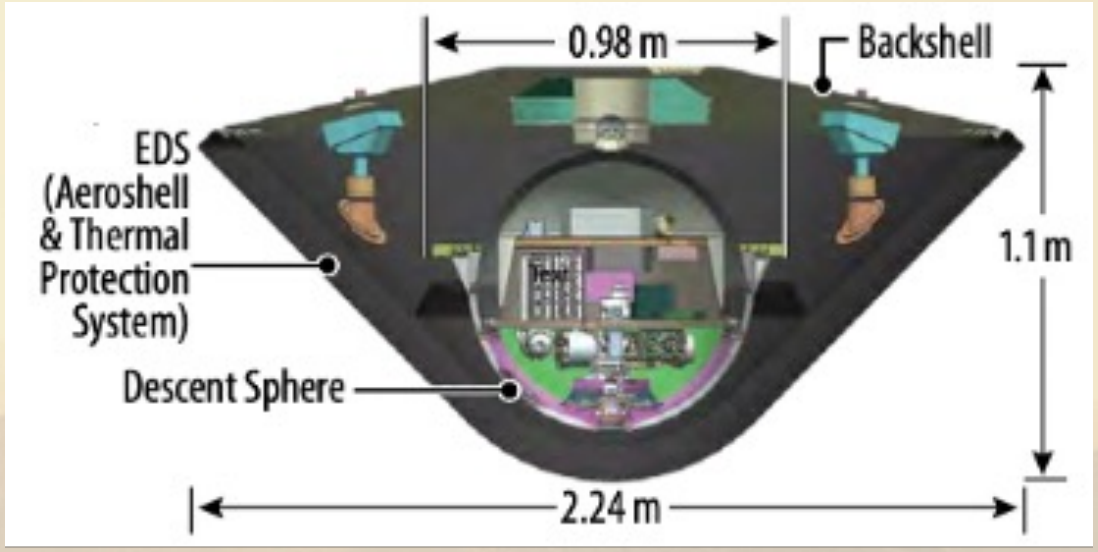
Similarity to Pioneer Venus: Entry Shape

Credit: NASA
Units in inches



Pioneer Venus Large Probe

Credit: NASA



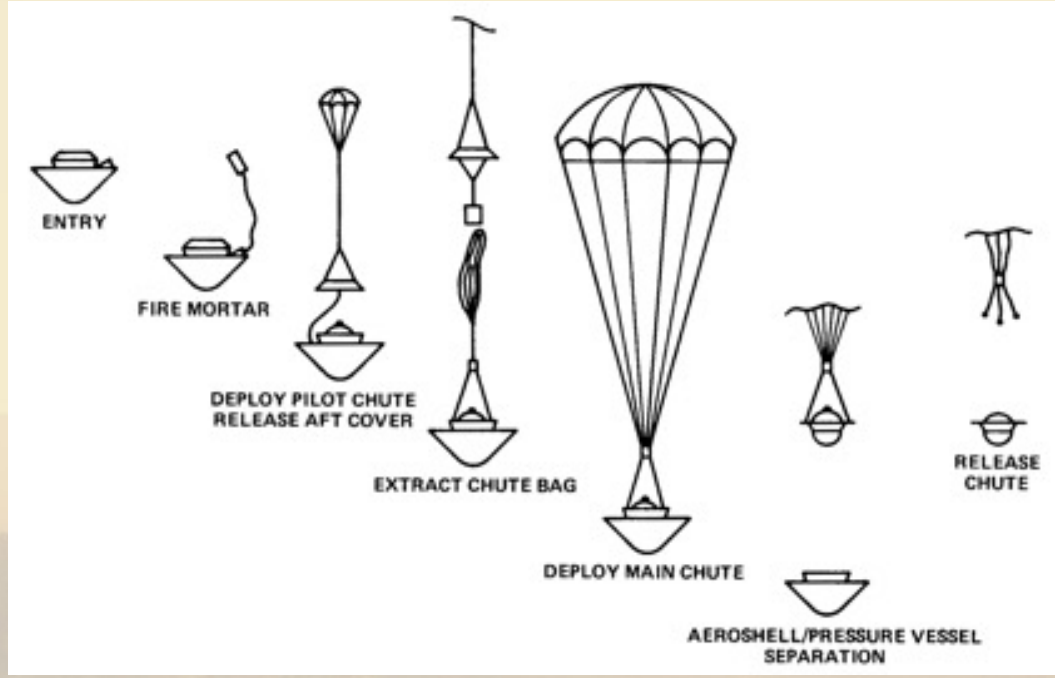
DAVINCI

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

Similarity to Pioneer Venus: Parachute

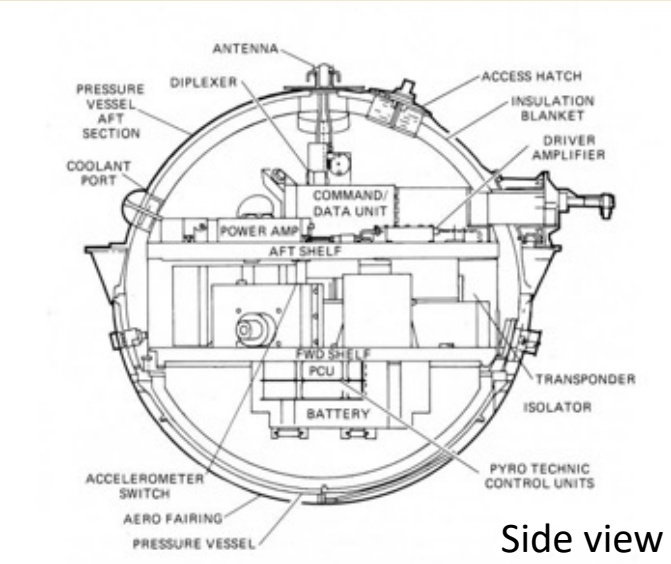
Credit: NASA



- Similar 2-stage parachute deployment sequence and descent sphere release
- Pioneer Venus used Conical Ribbon parachute
- DAVINCI will use Disk Gap Band parachute with 1.8 m diameter pilot and 5.8 m diameter main parachute
- Modeling relying on historical disk gap band parachute data with future modifications expected for planetary gas chemistry effect; testing occurring for parachute strength degradation due to sulfuric acid clouds

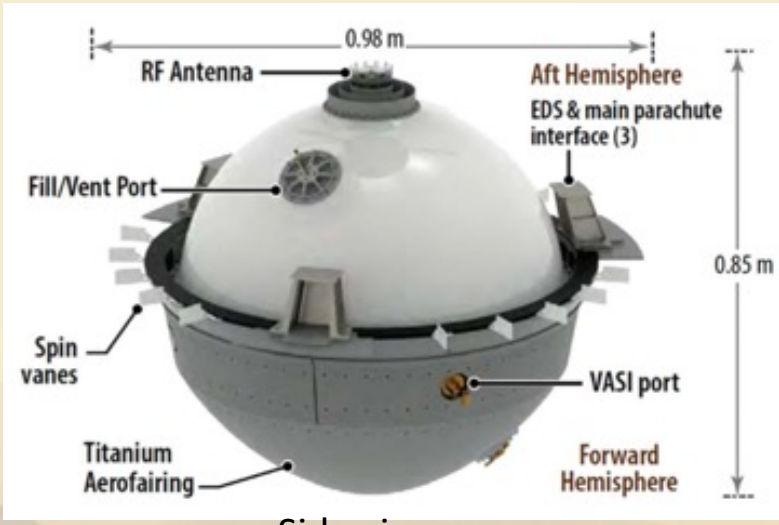
Similarity to Pioneer Venus: Descent Sphere

Credit: NASA

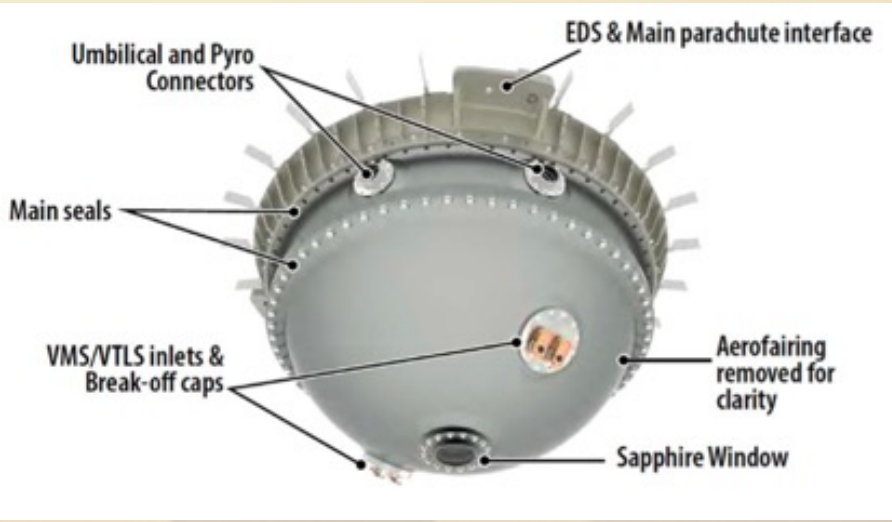


Side view

Credit: NASA



Side view



Pioneer Venus Large Probe

DAVINCI

VASI = Venus Atmospheric Structure Investigation
VMS = Venus Mass Spectrometer
VTLS = Venus Tunable Laser Spectrometer
EDS = Entry Deceleration System

- Spherical pressure vessel design for descent sphere
  - Pioneer Venus 0.78 m inner diameter and 0.98 m drag ring diameter
  - DAVINCI's drag ring is at 0.87 m and 0.98 m drag plate diameter
- Outer mold line design significantly impacts the aerodynamics
- Current modeling uses Venus probe data designed for an earlier proposal
- Improve modeling based on aerodynamic testing – Vertical Spin Tunnel and/or drop testing

Models for Simulation

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

Atmosphere

Aerodynamics

Orbital Determination/ Navigation (CRIS and PFS)

Sensors

Terrain Model

Science Instrumentation Model

Telecommunications

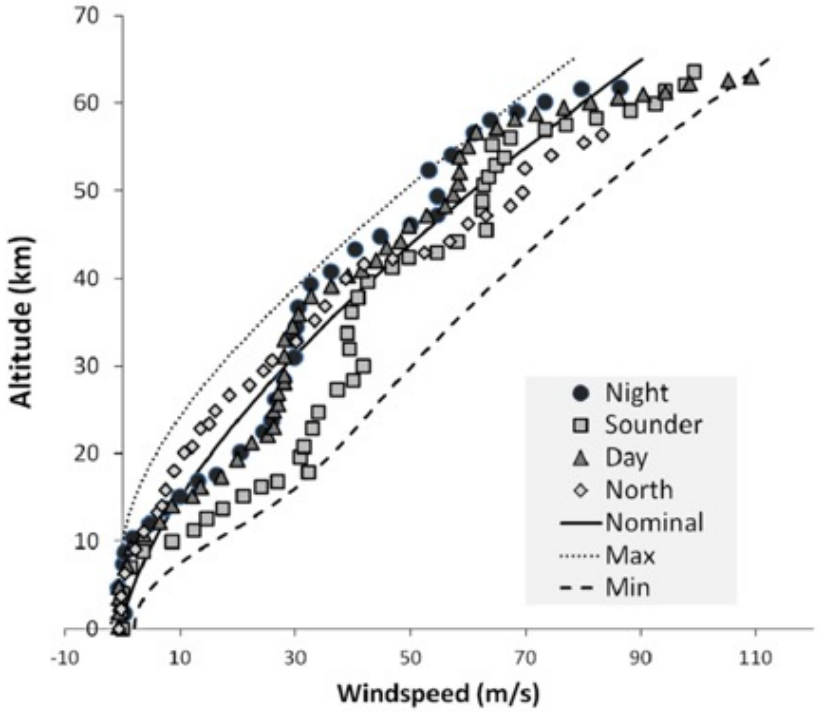
Multi-Body Dynamics

Credit: NASA

Atmosphere Modeling

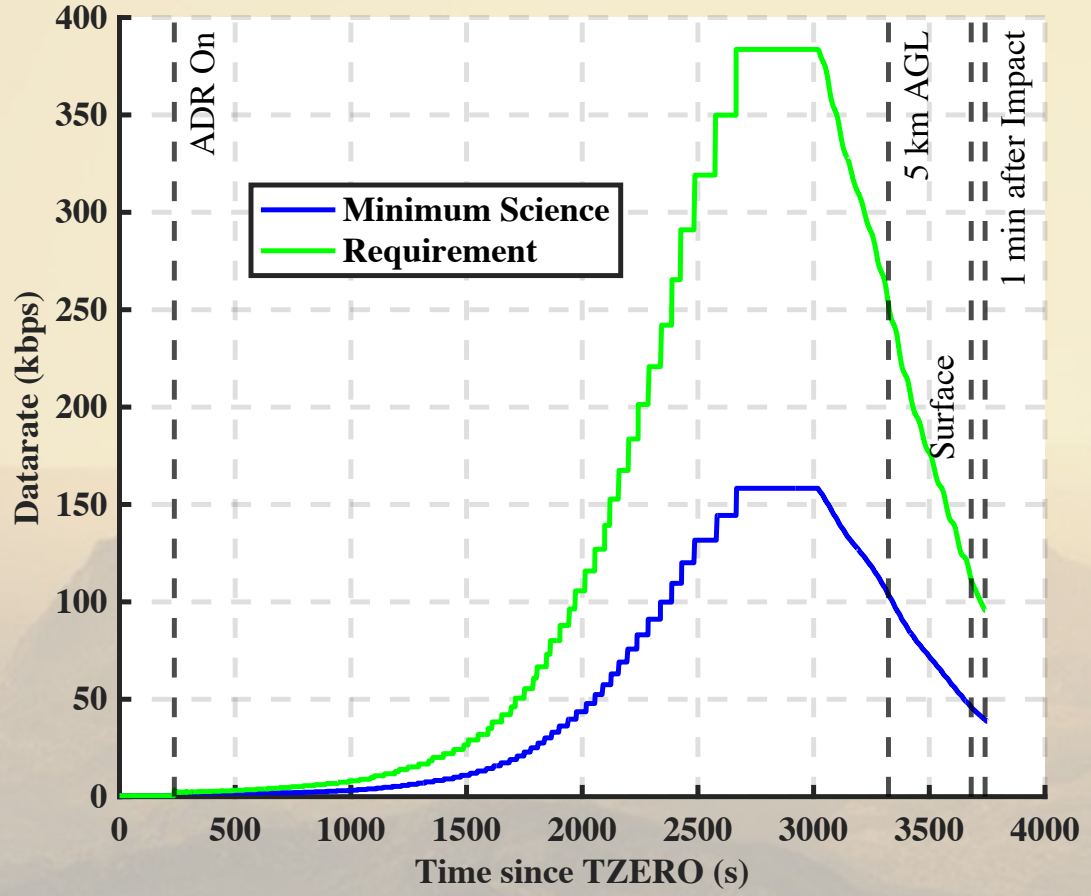
- Venus atmospheric models are data poor due to small number of in-situ probes
- Orbiters provide upper atmosphere (>40 km altitude) observations but not information about environments closer to the surface
- Approach to modeling:
  - Venus Global Reference Atmosphere Model (GRAM) and the Pioneer-Venus derived Venus International Reference Atmosphere (VIRA) for pressure, temperature, and density
  - Winds based on Pioneer-Venus derived measurements
  - Comparison with alternative models – Venus Climate Database (VCD)

Credit: R. Lorenz (2015)



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

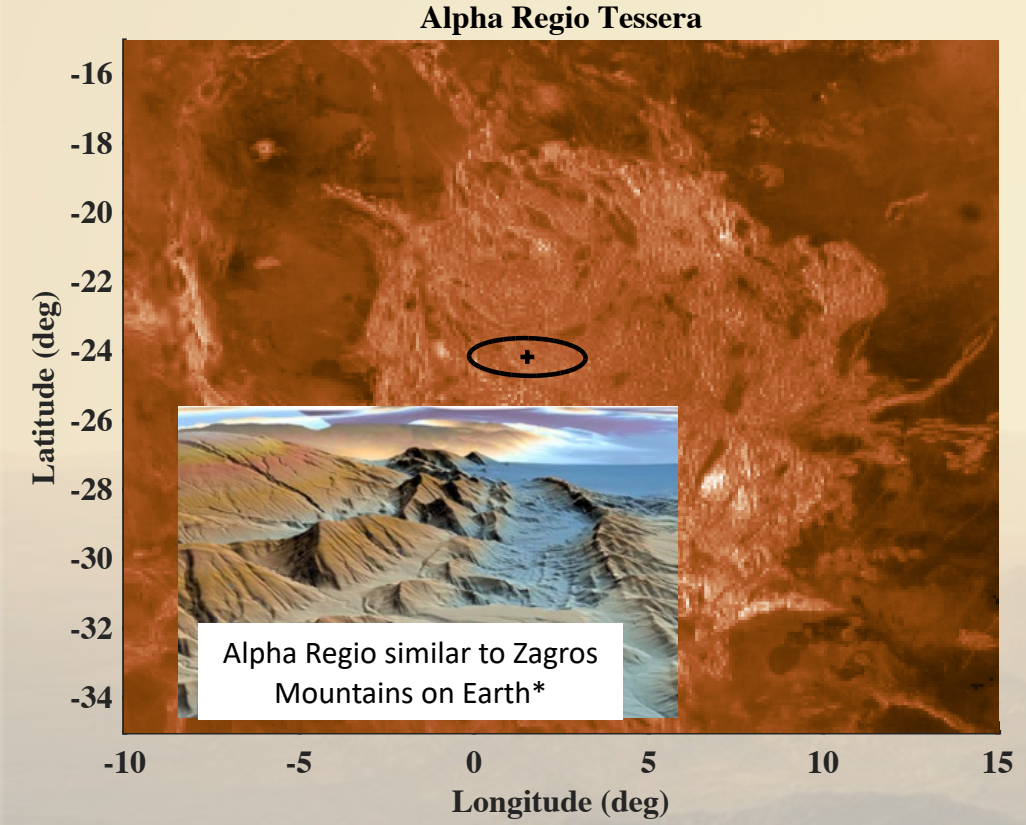
Telecommunications Modeling

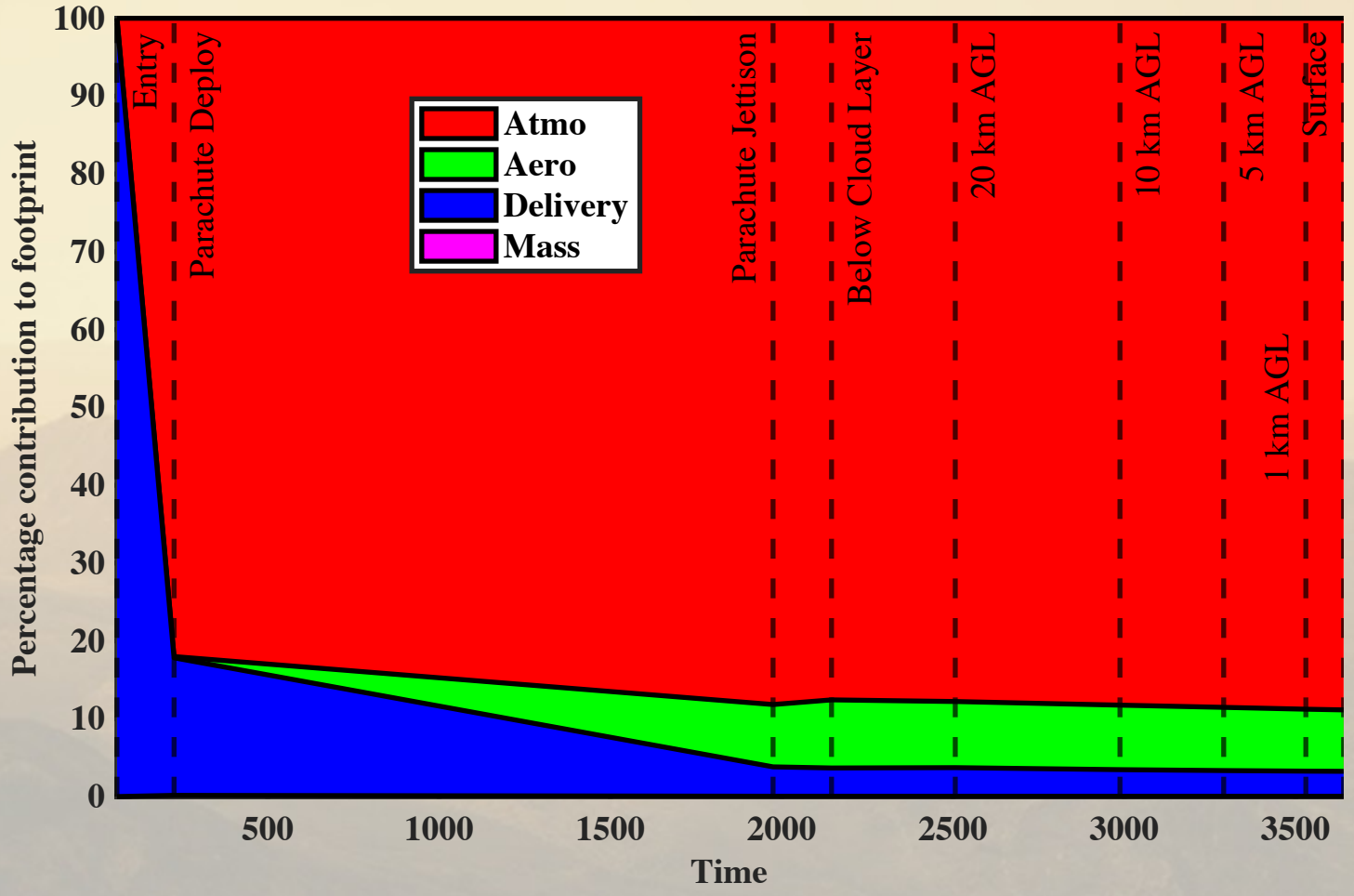


TZERO = Sequence time = 0. Entry Interface – 60 s
ADR = Adaptive Data Rate
AGL = Above ground level
Kbps = Kilo bits per second

- Probe does not need to survive impact; hence, important to relay in-situ measurements and images during 1-hour descent
- More important science data taken closer to the surface (imaging of the last 3-5 km altitude when not distorted by clouds)
- Adaptive data rate (ADR) system that updates uplink rate based on link quality – modeling in simulation important to optimize science return

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 imaging
- Ellipse size dominated by atmosphere (winds) and aerodynamic modeling

Note: AGL = Above ground level

*Credit: Garvin 2022 (Planetary Science Journal)

Summary

- DAVINCI is the first in-situ probe for Venus since the Soviet era missions (1967-1984) and Pioneer Venus (1978)
- Will provide measurements and images to understand the atmosphere and near surface – help answer if Venus was once habitable and provide analog for hot terrestrial exoplanets
- Modeling leverages on historical datasets for entry, parachute, and descent sphere portion
- Atmosphere modeling relies on sparse data from previous in-situ probes
- Due to requirement of relaying in-situ data during 1-hour of descent, modeling scientific instrument models and telecommunications is a major objective
- Uncertain models, such as atmospheric models, have a large effect on current performance predictions
- Improvement to models expected through reanalysis via modern tools and new experimental data

Questions

Credit: NASA

DAVINCI-related References

- Garvin, J. B., et. al, “Revealing the Mysteries of Venus: The DAVINCI Mission,” *The Planetary Science Journal*, Vol. 3, No. 5, doi: 10.3847/PSJ/ac63c2
- Sekerak, M. et. al, “The Deep Atmosphere Venus Investigation of Noble gases, Chemistry and Imaging (DAVINCI) Mission: Flight System Design Technical Overview,” *IEEE Aerospace Conference,* Big Sky, MT, 2022.

Comparison of Trajectory