SAEVe: A ***Long Duration*** Small Sat Class Venus Lander

Seismic and Atmospheric Exploration of Venus

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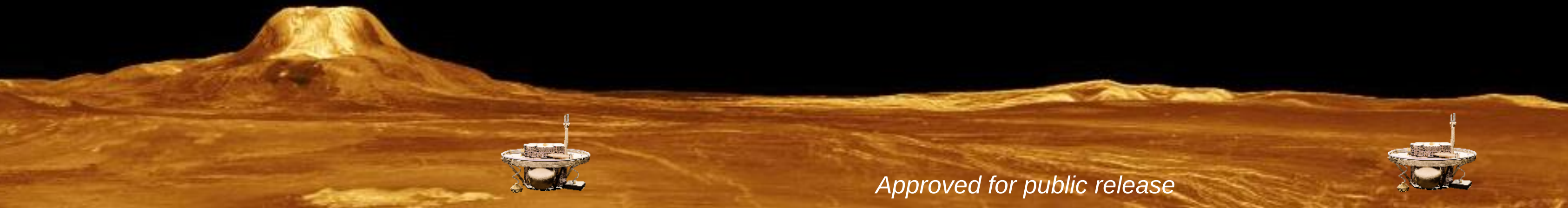
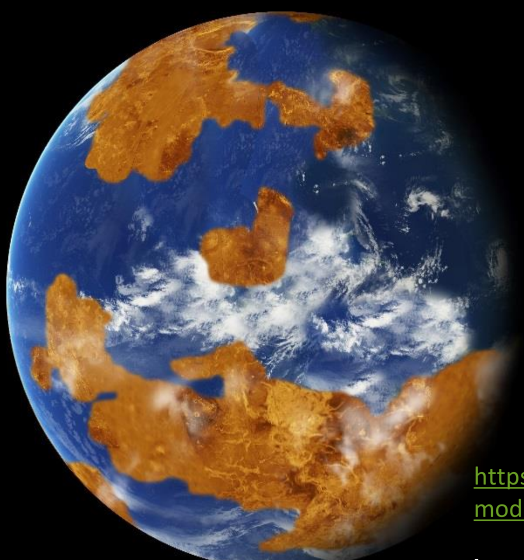


Venus Scientific Goals

- Venus is in many ways Earth’s nearest sibling
  - Almost same size as earth and probably still volcanically active
    - *Yet we know very little about it!*
- Venus may have had a liquid water ocean for > 1 B years
- SAEVe helps address high-priority science themes:
  - *How volcanically and tectonically active is Venus today?*
  - *Why and when did the climates of Venus and Earth diverge?*



https://www.nasa.gov/feature/goddard/2016/nasa-climate-modeling-suggests-venus-may-have-been-habitable

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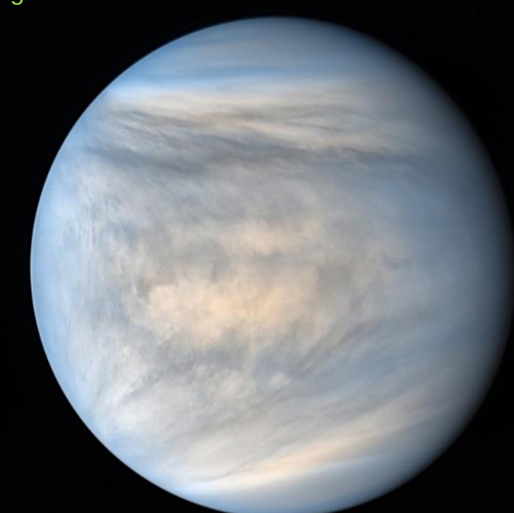
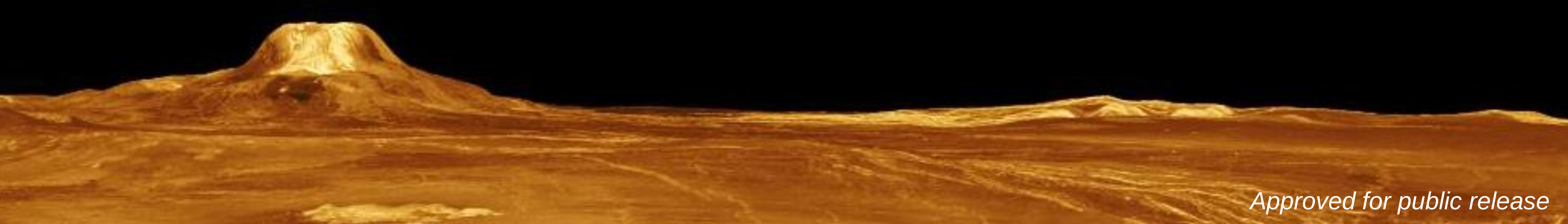
http://www.planetary.org/multimedia/space-images/venus/venus-in-ultraviolet-from-akatsuki.html



The Venus Surface Environment

- The Venus surface is challenging - Temperature = 460 °C, Pressure = 92 bar, [supercritical] CO_2 atmosphere
  - Si electronics do not operate > 300 °C.
- Previous landers dealt with heat by being heavy (~1 tonne) and insulated; they lasted up to 2 hr before heat penetrated to their interior and destroyed the electronics
- Thick sulphuric acid cloud layers severely constrain remote sensing
- SAEVe uses unique new silicon carbide based electronics and sensors
  - Can operate in harsh environments, in particular temperatures of 500 °C.

SiC electronics and high temperature systems enable a new class of lightweight uncooled Venus landers; enabling > 10^3 increase in surface lifetime.
Significant new science can be achieved !



SAEVe Science

Decadal Survey Goals	SAEVe Science Objectives	Measurements	Instrument Requirements
A) Characterize planetary interiors	1) Determine if Venus is currently active, characterize the rate and style of seismic activity	Measure seismic waveform of seismic waves Determine wind-induced seismic noise. Concurrent measurements with seismometer	3-axis (1 axis) seismometer wind speed & direction sensors
	2) Determine the thickness and composition of the crust	Same as above	Two stations with instrumentation as above.
B) Define the current climate on the terrestrial planets	3) Acquire temporal meteorological data	Measurement of p, T, u, v and light	wind speed & direction sensors, radiance
	4) Estimate momentum exchange between the surface and the atmosphere	Same as above	Same as above during Venus day and night
C) Understand chemistry of the middle, upper and lower atmosphere	5) Determine the key atmospheric species at the surface over time	Measure the abundance of gases H_2O, SO_2, SO_x, CO, HF, HCl, HCN, OCS, NO, O_2	Chemical sensor measurements during descent and on surface
D) Understand the major heat loss mechanisms	6) Determine the current rate of energy loss at the Venus surface	Measure heat flux at Venus surface	Heat flow measurements, radiance, air temperature
E) Characterize planetary surfaces	7) Determine the morphology of the local landing site(s)	Quantify dimensions, structures and textures of surface materials on plains unit.	Descent and surface images

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The Instrument Suite

Rationale for Instruments / Sensors

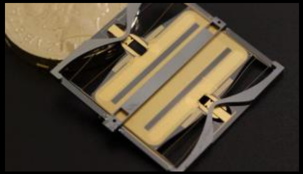
A) Core science centers around ***long term*** measurements to obtain meteorological and seismic data over 1 Venus solar day (120 Earth days)

B) This is possible with high temperature, low power, low data volume instruments / sensors

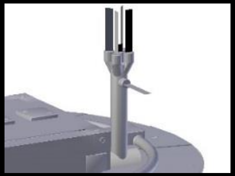
- Instrument payload supports this constraint

Instrument set includes:

- A 3-axis micro-machined Micro-Electro-Mechanical Systems (MEMS) seismometer (0.3 kg)
- Meteorological sensor suite (temperature, pressure, wind speed & direction, solar radiance, atmospheric chemical species abundances), and solar position sensors (0.7 kg)
- Heat Flux instrument (0.3 kg)
- Two COTS Cubesat cameras (0.1 kg each)

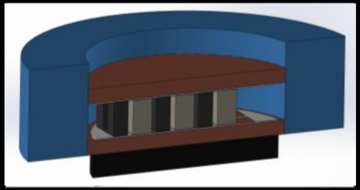


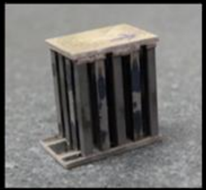
MEMS seismic event sensor
Courtesy: Tom Pike



Courtesy of D. Makel, Makel Engineering, Inc.

Sensors images – Courtesy: NASA GRC





Heat Flux sensor - Courtesy: Mike Pauken

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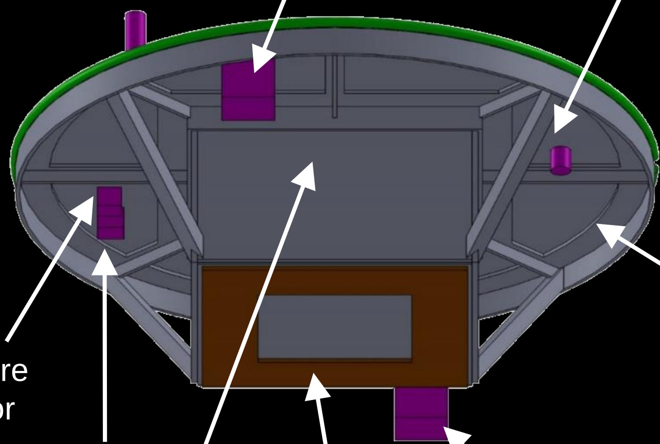
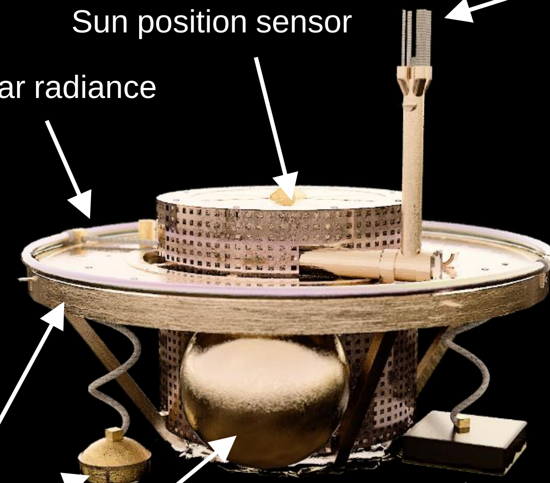
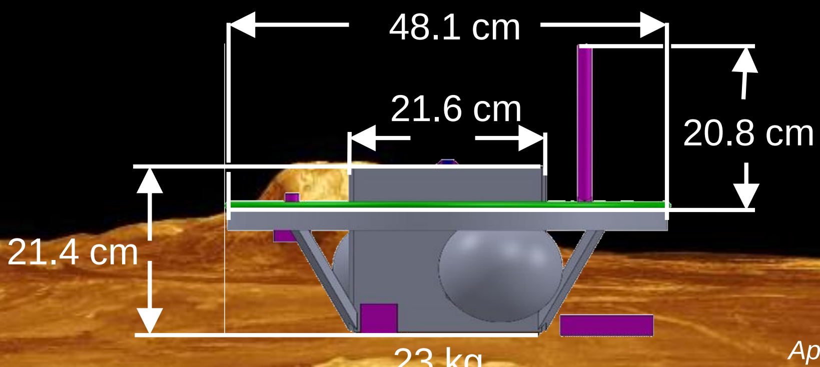
Lander Configuration

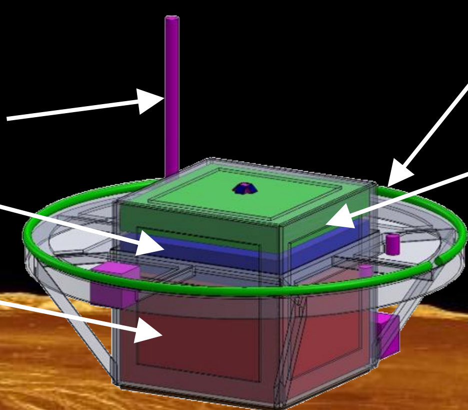




Note: Camera spheres and heat flux instrument not shown in this diagram for clarity

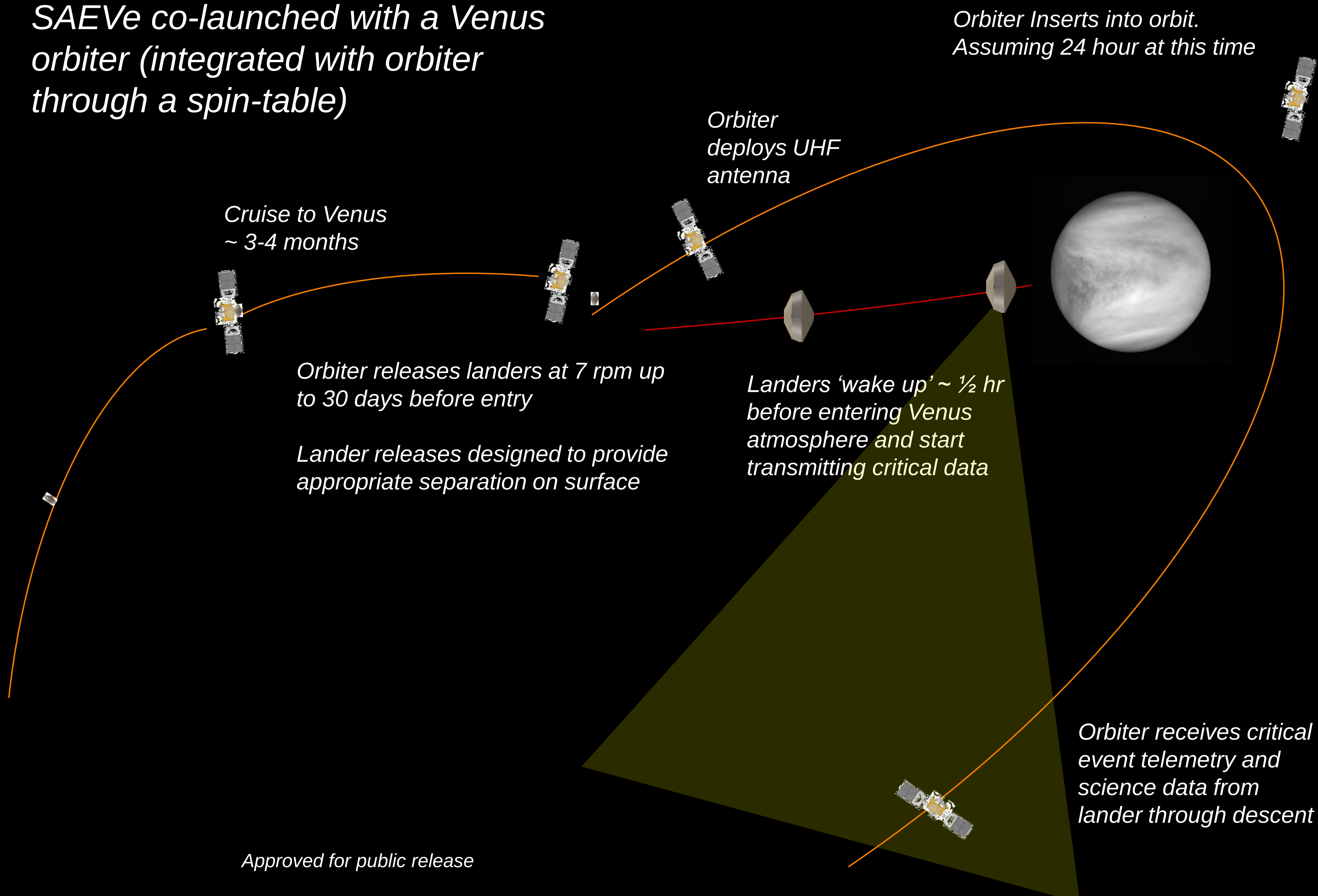
Note: Antenna shown in image is backup approach using UHF Loop Antenna (1.5 m Circumference). Primary approach is planar spiral – 24 cm diameter



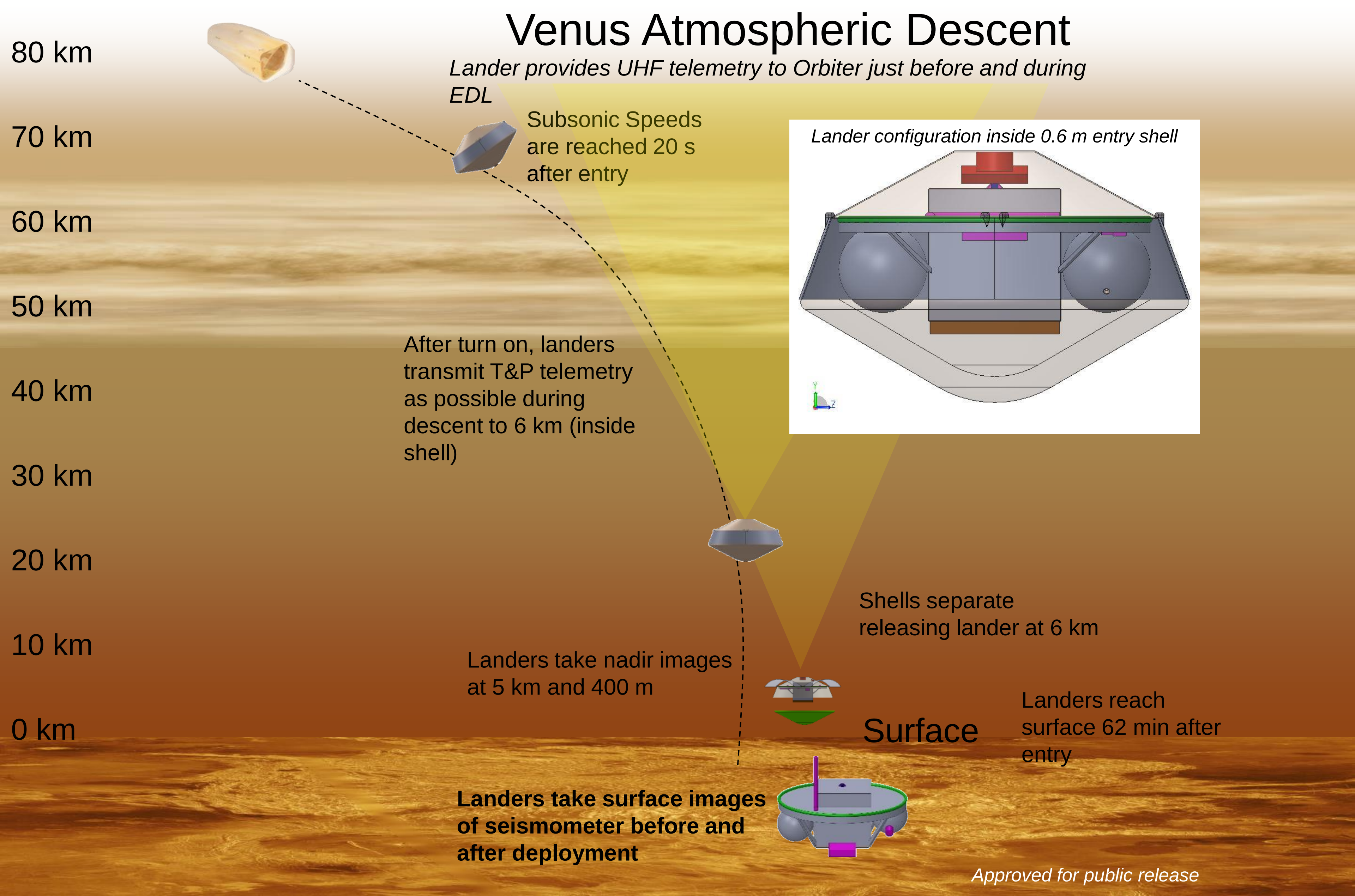


The Mission

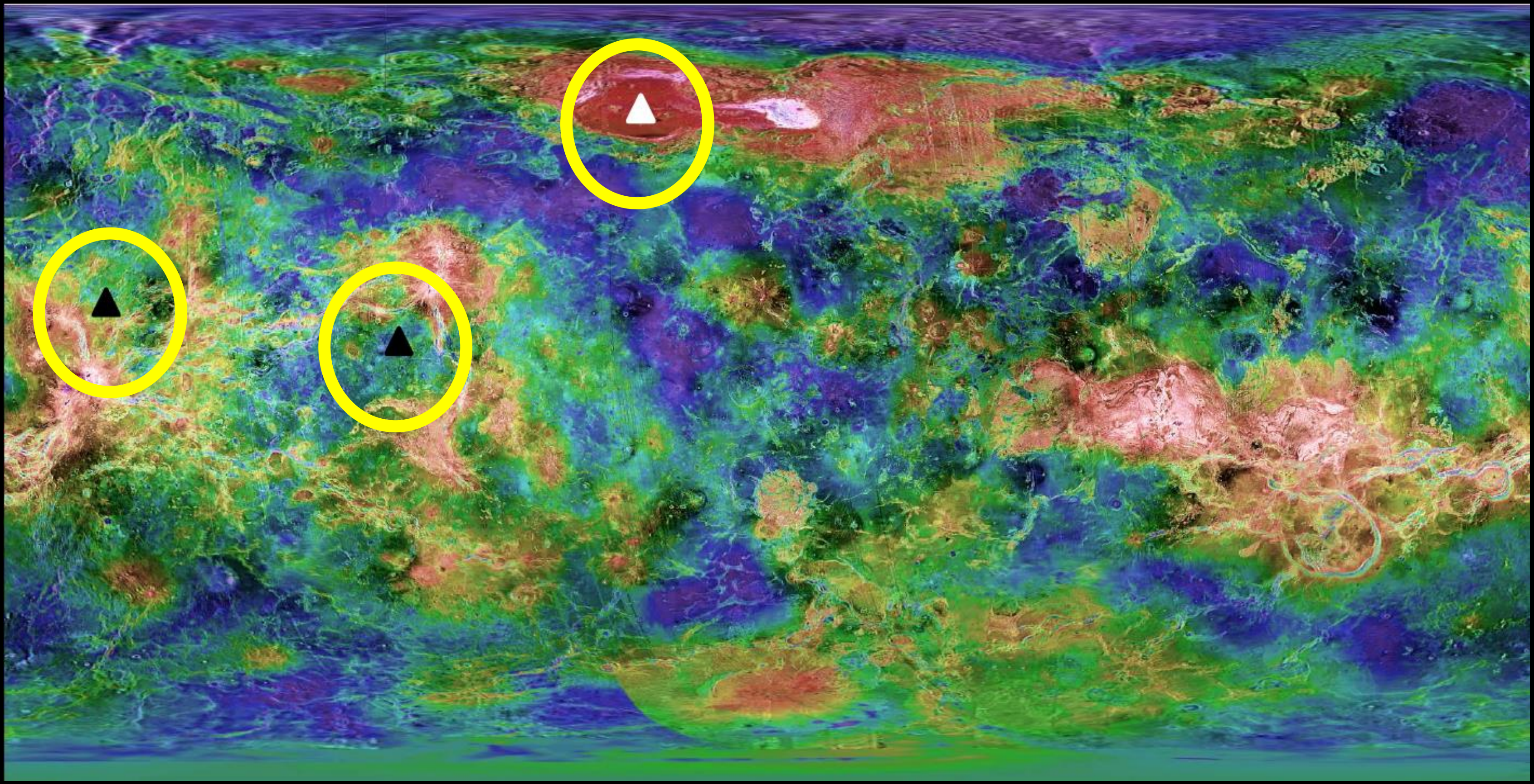
SAEVe co-launched with a Venus orbiter (integrated with orbiter through a spin-table)



The Entry Sequence



Desired Landing Sites*



Desired landing site: flat area near potentially active sites

Atla Regio and Beta Regio (black) and Lakshmi Planum (white)

* Will be heavily influenced by Orbiter trajectory and its initial orbit

The Operations

- SAEVe will operate for 120 days or longer
- Communications and seismic monitoring are main energy users and hence, main limiters of lander lifetime
- Communications with orbiter is assumed to be for 2 min every 8 hr
  - Actual timing and frequency will be negotiated with orbiter. Contact time over 120 days could be as high as 93%
  - Opportunities exist to extend life (e.g., with <2 min comm or more battery)
- When seismic event detected, lander will transmit data from all 3 axis within 100 ms and continue for 10 min – regardless of orbiter location
- For the first hour landers collect and transmit data from all instruments
  - Get early, higher frequency data (provides some risk reduction)
- During mission multiple seismic trigger levels may be employed
  - For example, a priori potentially decrease trigger level mid mission – ensure some events captured

Science / Dollar Summary

Full Mission — $106M


Science Objectives Tackled

1) Determine if Venus is seismically active and characterize the rate and style of activity,
2) Determine crust thickness and composition
3) Acquire temporal meteorological data to guide global circulation models
4) Estimate the momentum exchange between the planet and its atmosphere
5) Measure atmospheric chemistry variability
6) Determine current rate of heat loss from the Venus interior
7) Examine rock and soil distribution and morphology

One Lander — $87M

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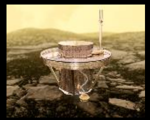
De-Scoped Lander — $71M



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SAEVe Science Ladder

** Estimates do not include reserves or to get to TRL-6 for technologies*

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Technology Readiness

- Summary table shows that major subsystems and the instruments are currently at TRL 3-4 (lowest TRL components are seismometer & battery)
- Main take-away is that most elements of SAEVe are in ongoing development that will take them to ~ TRL 6 by 2021

Technology	Current TRL	Estimated to be at TRL 6	Funding Source: Ongoing (O) (to TRL 6) and Potential (P)
Electronic circuits (SiC): sensors and data handling	4-5	Aug 2019	LLISSE (O)
Electronic circuits (SiC): power management	3-4	Sept 2021	LLISSE (O)
Communications (100 MHz)	3-4	Sept 2021	LLISSE (O)
Wind Sensor	4	Aug 2019	LLISSE (O)
Temperature Sensor	4-5	Aug 2019	LLISSE (O)
Pressure Sensor	4-5	Aug 2019	LLISSE (O)
Chemical Sensors	5	Aug 2019	LLISSE/HOTTech (O)
LLISSE Bolometer	3-4	Sept 2021	LLISSE (O)
Seismometer	3	TBD	MaTISSE (P)
Heat Flux Sensor	3-4	TBD	PICASSO (O) - MaTISSE
Camera / imaging System	3-4	Sept 2020	Rocket University (O) – MaTISSE if needed
Solar Radiance	4	TBD	MaTISSE (P)
High-Temp Battery	3	Aug 2019	LLISSE and HOTTech (O)

SAEVe will revolutionize our paradigm for exploring the deep atmosphere, surface, and geophysical activity of Venus. This is enabled by new advances in high temperature electronics and systems.

SAEVe will operate on the surface of Venus for an unprecedented 120 days (full Venus solar day) returning seismic, meteorology, and energy deposition / release data

The SAEVe mission can be implemented for ~ $100M and would be an ideal candidate to ride along with a future Venus orbiter mission

SAEVe would serve as a pathfinder to prepare for larger and more capable landers in the future

Thank you. Questions?