Seismic and Atmospheric Exploration of Venus (SAEVe)

The Seismic and Atmospheric Exploration of Venus (SAEVe) is a mission concept to deliver two landers to the surface of Venus and have them return high value science for 120 days, over three orders magnitude longer than anything previously achieved! The science implemented by SAEVe is focused on seismometery and temporal meteorology, long standing gaps in our data on Venus and measurements that most benefit from long duration operations. Table 1 presents the science objectives targeted by SAEVe.

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 Concurrent wind data at time of seismic measurement	3-axis (1 axis) seismometer 3 axis wind sensor
	2) Determine the thickness and composition of the upper 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	3-axis wind sensor measurements, 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
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

Table 1. *SAEVe Science Traceability*

The remarkable operating life of SAEVe is enabled by three key elements, 1) high temperature electronics and systems that operate without cooling at Venus surface conditions, 2) use simple instrumentation and supporting avionics – emphasize low data volume instruments and sensors, and 3) minimizing energy utilization through a novel operations approach. Integrating these elements into an innovative mission concept allows SAEVe to return high-value science while meeting study objectives.

Each SAEVe lander will weigh approximately 25 kg (~ 40 kg together with aeroshell) and will carry a suite of synergistic instruments and sensors. The instruments in priority order are: seismometer, meteorology suite (which includes temperature, pressure, 2 or 3 dimension wind speed and direction, atmospheric chemical specie abundances, and incident and reflected solar radiance sensors), a heat flux instrument, and finally an imaging package consisting of two cube sat cameras which will operate only a short time at the beginning of the mission. A sun position sensor set is also included as a demonstration of a potential simple technique to determine orientation of the lander relative to the surface.

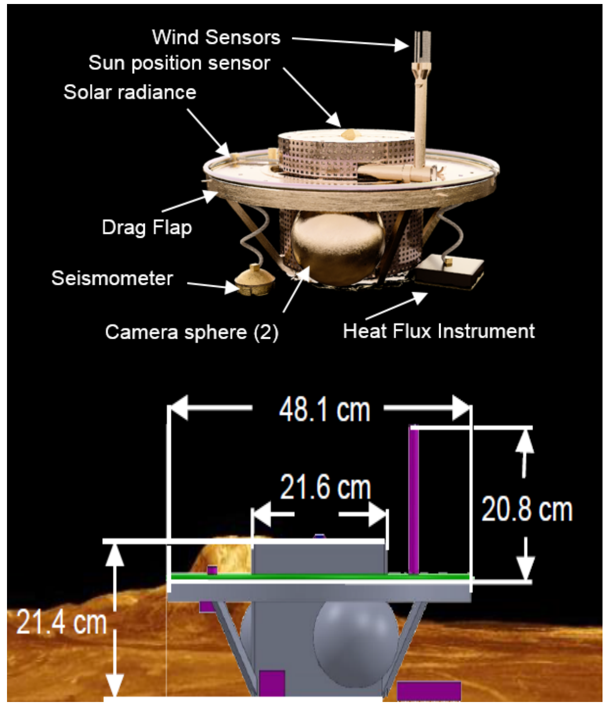

Figure 1.
SAEVe Lander Concept with Subset Instruments and Basic Dimensions

SAEVe is assumed to be delivered to Venus as a secondary payload on a Venus orbiting mission. Since a specific orbiter and orbit is not available at this time, the team relied on some assumptions which are consistent with prior or proposed Venus missions. Basic assumptions are that we will be transmitting to an orbiter that is in a 24 hour or shorter orbit period and that the orbiter has enough space to carry the SAEVe entry shell / lander on a spin table and will release it as it approaches Venus. SAEVe will rely on the orbiter to capture transmitted data and relay it to Earth. Science and engineering data from the lander will transmitted periodically at approximately 200 bps between 100 and 150 MHz so the orbiter would need to carry the appropriate receiving antenna / hardware.

The SAEVe concept includes the required entry capsule and all support elements needed to allow safe entry and landing on the Venus surface. SAEVe enters the atmosphere and gradually slows down during descent due to the thickening atmosphere. At approximately 6 km above the Venus surface SAEVe separates from the shell, takes two images and begins transmitting as it completes its descent and touches down at under 5 m/s.

After touchdown the images supporting morphology and seismometer coupling are taken. The seismometer and heat flux instruments are dropped to the surface and the remaining images are taken and transmitted. Once all images are returned all the other instruments begin operating and SAEVe transmits data for up to one hour continually. After this initial period SAEVe goes into its nominal operating mode where it turns on and collects / transmits all instrument data for 2 minutes every 8 hours. At all times, SAEVe will be monitoring the vertical axis of the seismometer. This will serves as a fast trigger so if an event of certain magnitude is detected, within 100ms it turns on and begins transmitting data from all three axis of seismometer, as well as wind and pressure data continually for 10 minutes.

The particulars of the orbit influence how much contact time and therefore how many events are expected to be captured but, in ideal conditions the orbit could be in view around 90% of the time. Undoubtedly, contact time will not be that high as some transmissions and seismic events may be missed but a significant fraction will be returned successfully over the 120 Earth days of operations.

SAEVe allows for easy scaling to address cost, mass, or other constraints. The mission including two copies of landers/aeroshells are estimated to cost $106M not including reserves and development of technologies to Technology Readiness Level (TRL) 6. As shown in Figure X, the second identical copy of SAEVe is expected to cost ~$19M. If desired this can easily be de-scoped from the mission although any potential insight into event location and interior structure would be given up. A further de-scope could be the removal of the short lived camera spheres. This saves some costs and mass for a lander. Figure 2 summarizes cost estimates based on mission architecture.

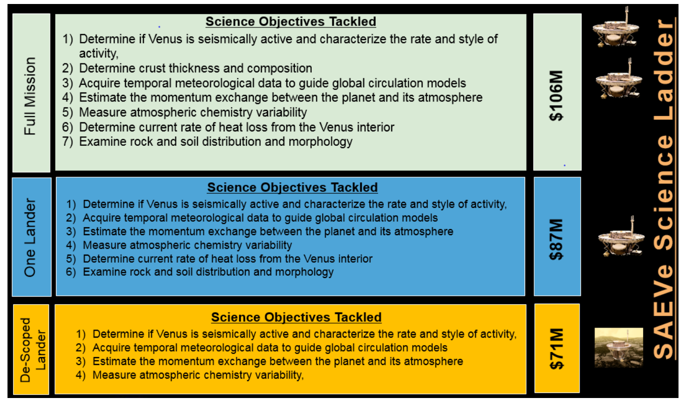

Figure 2. *SAEVe Cost vs Science Ladder*

SAEVe is an exciting mission that leverages recent technology developments. The team explored the current technology state of all relevant elements. The results of that assessment are presented in Table 2.

Technology	Current TRL	Estimated to be at TRL 6	Funding Source: Ongoing (O to TRL 5-6) 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	LISSE (O) and possibly 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)
Entry Shell	4-5	TBD	HEET – need specific SAEVe design

Table 2. *Technology Readiness Assessment Summary*

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