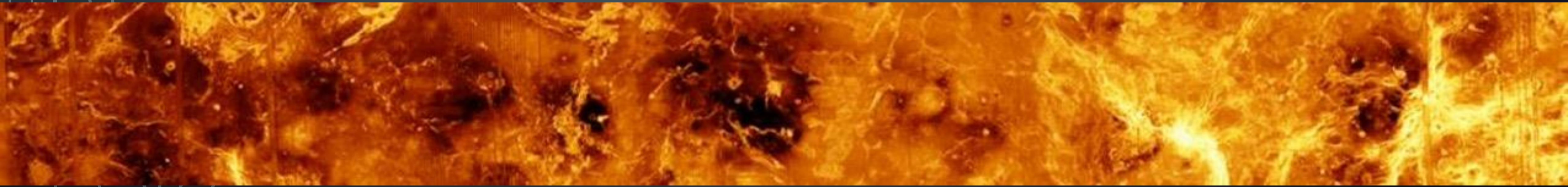
LLISSE AND SAEVe – LONG DURATION VENUS LANDERS

VENERA-D LANDING SITE WORKSHOP – OCTOBER 2019



T. Kremic, NASA Glenn Research Center

LLISSE

- LLISSE is a project to mature capability and develop an engineering model version of a small (~10kg and ~20cm / side) Venus lander

- LLISSE will be an independent lander (with all needed subsystems) - acquires and transmits simple but important science
    - Focus is on science that requires or most benefits from sustained surface operations

- Three key elements leveraged
    - Recent developments in high temperature electronics
    - Focused, low data volume measurements
    - Novel operations scheme

LLISSE SCIENCE OBJECTIVES AND TRACEABILITY

Decadal Survey Goals	LLISSE Science Objectives	Measurements	Instrument Requirements
A) Define the current climate on the terrestrial planets	1) Acquire temporal meteorological data	Measurement of p, T, u, v and light	3-axis wind sensor measurements, radiance
	2) Estimate momentum exchange between the surface and the atmosphere	Same as above	Same as above
B) Understand chemistry of the middle, upper and lower atmosphere	3) Determine the key atmospheric species at the surface over time	Measure the abundance of gases H_2O, SO_2, CO, HF, HCl, HCN, OCS, NO, O_2	Chemical sensor measurements
C) Determine how solar energy drives atmospheric circulation and chemical cycles	4) Determine the rate of solar energy deposition at the Venus surface	Measure incident and reflected solar energy	Measurements of radiance

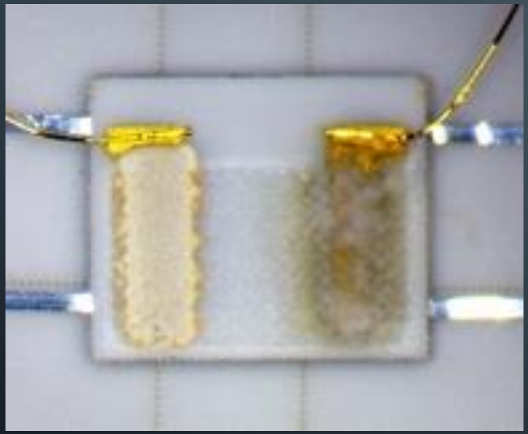
- Operations Goals:
  - Operate for a minimum ½ Venus solar day – capture one day/night transition (~60 Earth days)
  - Take/transmit measurements periodically – timed for science need and to maximize transfer to orbiter/data relay

LLISSE will serve as a long duration meteorology station (plus)

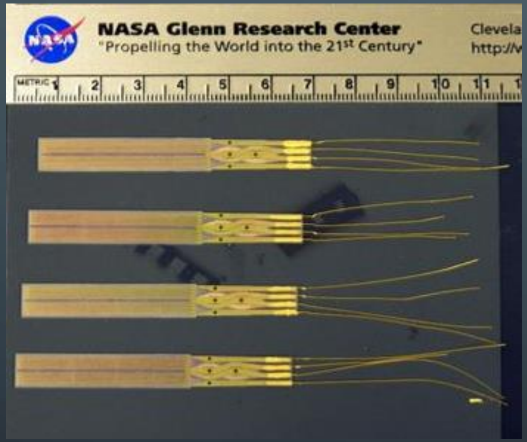
TOP LEVEL STATUS

- Have made great progress
  - Since project start, complexity of ICs increased by ~ 2 orders of magnitude
  - Operation of sensors and core electronics in Venus environment demonstrated several times (World records achieved)

Makel Chemical Sensor Testing in GEER



Wind Sensor in GEER Testing



Science, Nov. 2017

TOUGHER THAN HELL

Transistors that thrive on heat and pressure could take spacecraft to the surface of Venus

By **Paul Voosen**, *in Cleveland, Ohio*

In an underdog city, at an underdog NASA lab, researchers are thinking hard about an underservedly neglected planet. Venus is Earth's cousin, closest in composition and size, but for decades it has remained veiled. NASA hasn't sent a mission there since 1989; more recent European and Japanese orbiters have made halting progress that stops largely at the planet's thick sulfur clouds. No craft has touched down since 1985, when the last of a series of advanced Soviet landers clad in armored pressure vessels endured a couple hours before succumbing to the deep-ocean pressure and furnacelike temperature of the planet's surface. The baleful conditions and lack of funding have made Venus, Earth's closest neighbor, feel more distant than ever. That is, except here.

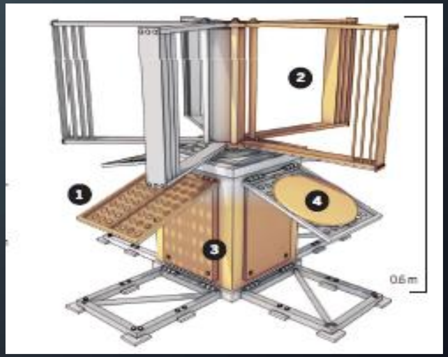
In September, Phil Neudeck, an electrical engineer at NASA's Glenn Research Center, a complex abutting the main airport in this Rust Belt city, sat watching purple and turquoise waveforms on a display. It was his window into the Venus next door. Behind sealed doors stood a 14-ton stainless steel tank, its massive ports sealed to hold pressures so high that the screws to secure its nuts have their own nuts. For 33 days, the Glenn Extreme Environments Rig (GEER) had run nonstop, simulating an atmosphere at 460°C and flooded with carbon dioxide at pressures that render it supercritical, both liquid and gas. Inside sat two microchips, pulsing with metronomic accuracy. Neudeck was running a clock on Venus, and it was keeping perfect time.

Neudeck and his Glenn colleagues are helping drive a technological leap that could transform the exploration of Venus, making it almost as accessible as Mars. Rather than barricading electronics within pressure vessels, by early next decade NASA may be able to land simple unprotected robots on Venus that can measure wind, temperature, chemistry, pressure, and seismic waves. And instead of running for a few hours, the landers could last for months. "We don't have the world's fastest chips," Neudeck says. "We don't have the world's most complex chips. But in terms of Venus environment durability—that's what we got."

If the chips live up to their potential, scientists' elusive dream of extended stays on Venus may at last be within reach. "The paradigm has been that long-term surface stuff is way down the road," says Tibor Kremic, the scientist who has launched a push toward Venus at Glenn, a little-known NASA

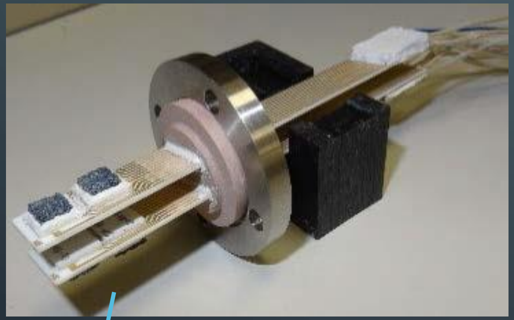
984 24 NOVEMBER 2017 • VOL 358 ISSUE 6366 sciencemag.org SCIENCE

Published by AAAS



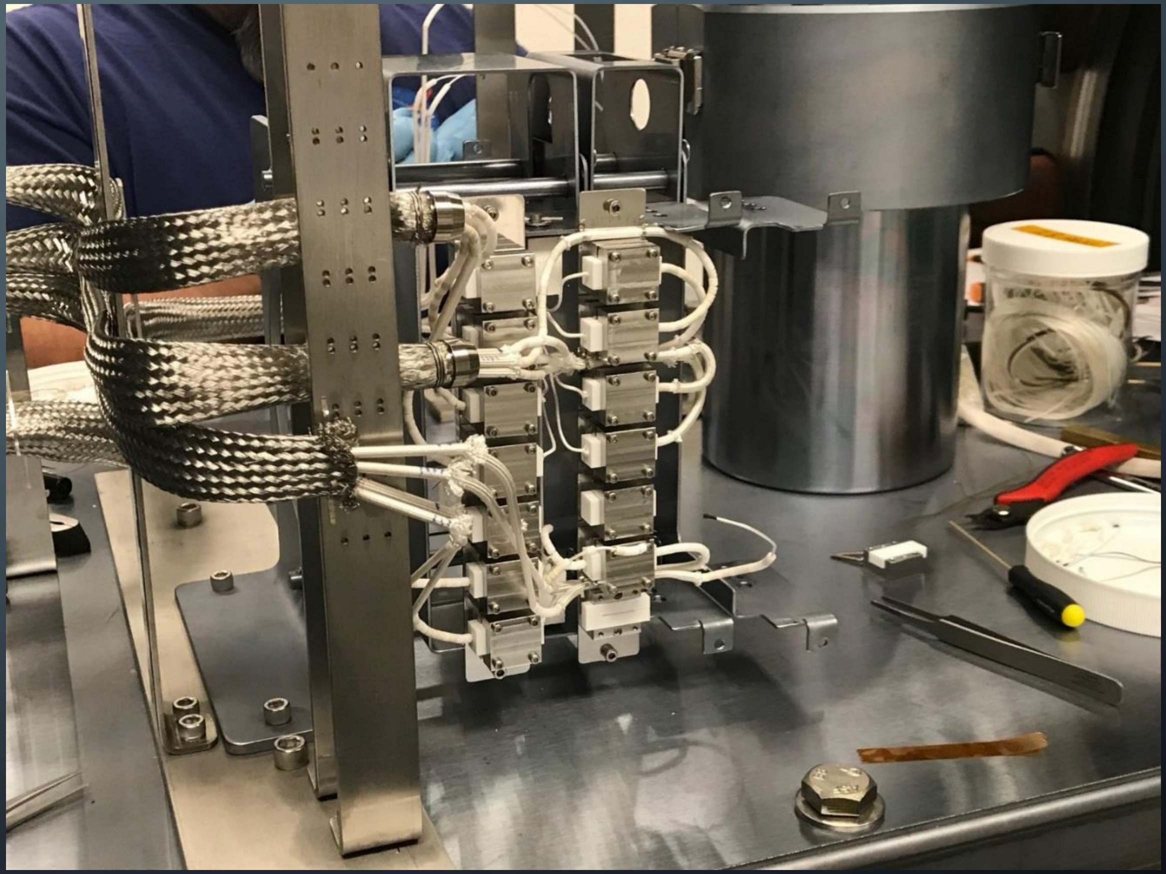
RECENT TESTING

- Chemical sensors operational for 60 days in GEER chamber
- LLISSE hardware / avionics testing



Courtesy of D. Makel, Makel Engineering, Inc.

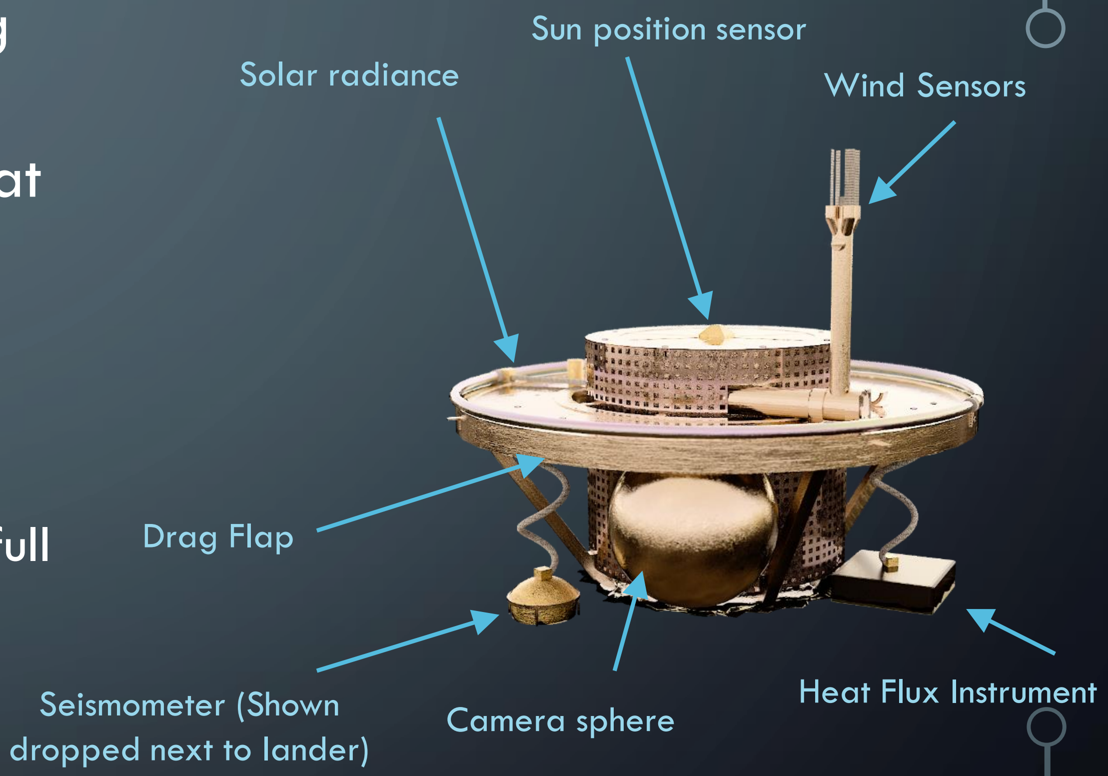
Sensor Array for GEER chamber testing



SAEVe – LLISSE'S BIGGER BROTHER

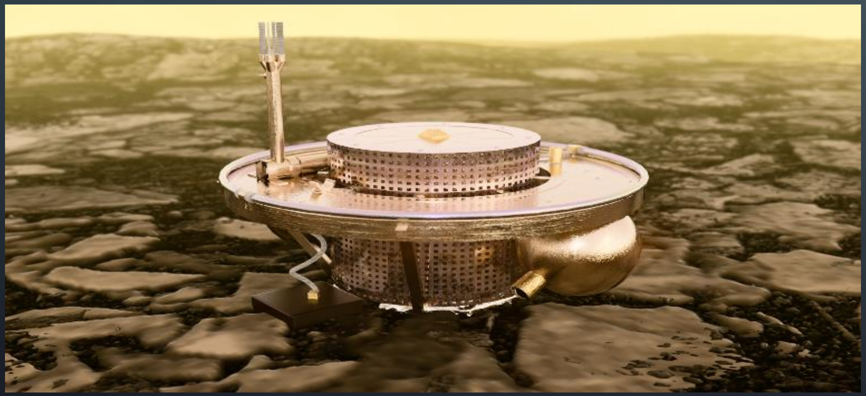
- SAEVe (Seismic and Atmospheric Exploration of Venus) was a study which explored enhancing LLISSE to see what could be done leveraging the LLISSE concept but scaling up to a small sat class mission

- SAEVe vs LLISSE
  - Main discriminator is operating life (extended to full Venus solar day) and payload suite with most notable addition being a high temperature seismometer
  - 2 – 3 stations recommended
  - SAEVe also features short-duration cameras used during descent and at start of surface operations

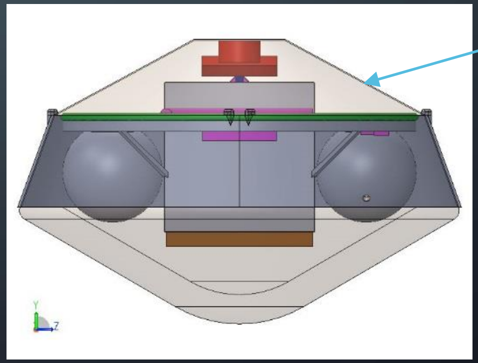


SAEVe Basics

- SAEVe is a compact lander concept based on high temperature systems being developed under the LLISSE project
- The concept suggests two or more stations that are placed 300 - 800 km apart
- Each station has its own entry shell, and is carried and released by the orbiter
- Stations would operate for 120 days (> 1 Venus solar day)
- Station transmit periodically – except when seismic event detected – LLISSE approach



~.5 m



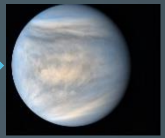
60 cm

<30 kg, <50 kg with its entry system

SAEVe Science

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

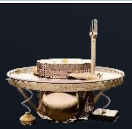
?



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

How volcanically and tectonically active is Venus today?
Why and when did the climates of Venus and Earth diverge?

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 crust and lithosphere	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, SOx, 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, surface temperature, 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 based on 5 images	Cameras: descent and landed



300-800km

Approved for public release

PERFORMANCE TARGETS

Instrument / Sensor	Description	Number	Sensor Input	Sensor Output	Requirements				Notes
					Target Min	Target Max / Frq	Target Accuracy (+/-)	Target resolution	Cameras to return 5 clear images with 256x256 resolution
Seismometer	Insight based MEMS sensor - 3 axis	1	capacitance	voltage	Goal of .1 sec Period	100 sec Period	1 ng/rtHz	2ng/rtHz	Vertical axis used for monitoring
Wind Sensor	Strain gage based	3	voltage	voltage	0.25 m/s	2.5 m/s	0.1 m/s	0.05 m/s	
Heat Flux	Thermopile(s)	1	Thermal gradient	Voltage	10 mW/m2	1 W/m2	+/- 8 mW/m2	5 mW/m2	Includes ability to ascertain thermal contact to surface and to measure surface skin temp
Bolometer	Radiometer	2	Radiance	Voltage	4 W/m2	25 W/m2	2 W/m2	1 W/m2	Upward and downward
Solar Radiance	Broad solar radiance	4	Solar Radiance	Voltage	TBD W/m2	TBD W/m2	TBD W/m2	TBD W/m2	Sun position locator to get coarse orientation info
Temperature Sensor	RTD in electronics	2	current	voltage	450 C	492 C	0.2 C	0.15 C	In body and on mast
Pressure	Resistive	1	voltage	voltage	80 bar	92 bar	1 % full scale	0.6% full scale	Only 1 of two versions will be used
	Capacitive		capacitance	voltage					
Chemical Species	SOx	1	voltage	voltage	0	400 ppm	0.3 ppm	10 ppb	
	H2O	1	voltage	voltage	0	100 ppm	1 ppm	50 ppb	
	OCS	1	voltage	resistance	0	50 ppm	1 ppm	10 ppb	
	CO	1	voltage	resistance	0	50 ppm	1 ppm	10 ppb	
	HCI	1	voltage	voltage	0	5 ppm	0.5 ppm	10 ppb	
	HF	1	voltage	voltage	0	5 ppm	0.5 ppm	0.5 ppb	
	NO	1	voltage	voltage	0	10 ppm	2 ppm	0.1 ppb	
	H2	TBD	voltage	voltage	0	30 ppm	1 ppm	1 ppm	
	O2	TBD	voltage	voltage	0	50 ppm	1 ppm	1 ppm	
	HCN	TBD	voltage	voltage	1	50 ppm	1 ppm	1 ppm	

APPROXIMATE TRL LEVELS

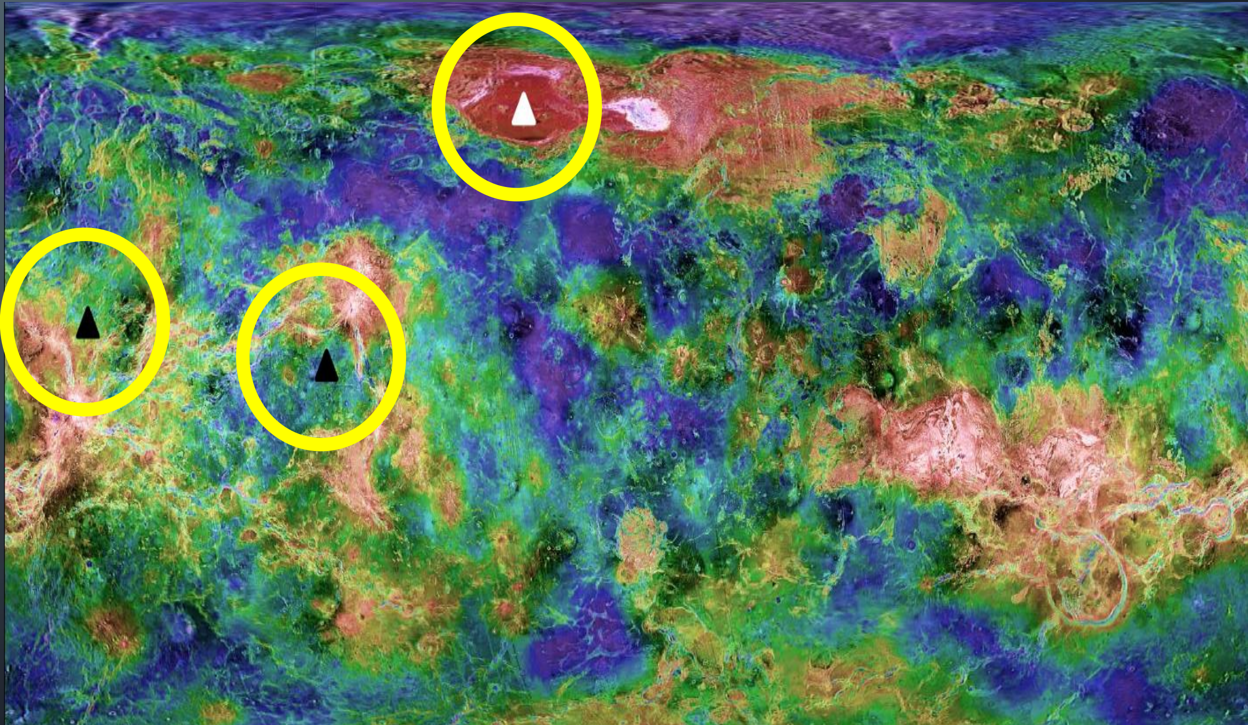
Technology	Current TRL	Funding Source: Ongoing (O) and Potential Future (P)
Electronic circuits (SiC): sensors and data handling	4-5	LLISSE (O)
Electronic circuits (SiC): power management	3-4	LLISSE (O)
Communications (100 MHz)	3-4	LLISSE (O)
Wind Sensor	4	LLISSE (O)
Temperature Sensor	5+	LLISSE (O)
Pressure Sensor	4-5	LLISSE (O)
Chemical Sensors	5	LLISSE/HOTTech (O)
Solar Radiance	3-4	LLISSE (O)
Seismometer	3	LLISSE (O) and possibly MaTISSE (P)
Heat Flux Sensor	3-4	PICASSO (O) – MaTISSE
Camera / imaging System	3-4	Rocket University (O) – MaTISSE if needed
High-Temp Battery	3	LLISSE and HOTTech (O)
Entry Shell	6	HEEET – need Venus specific design

LLISSE - LANDING SITE IMPLICATIONS

- Landing site drivers:
  - Science – very little surface data now – any site will be tremendous
    - First LLISSE – on plains (represents most of planet (+/- 20 Long, +/- 10 Lat ??))
      - Next LLISSE – different altitude (kms higher)
      - Next LLISSE – different latitude (>50)
      - Next LLISSE – near major feature (E.g. Beta Regio)
      - More LLISSEs – Other locations, – poles, multiple copies in same region, etc..
  - Constraints
    - Communication opportunities with orbiter is a significant factor
      - With elliptic orbits, want to be at higher latitude(>50 deg) under apoapsis
      - "Safe" landing site if only one or two landers being deployed

SAEVe - LANDING SITE IMPLICATIONS

- Landing site drivers:
  - Science – very little surface data now – any site will be tremendous
    - Seismic science would be main driver for location
      - Large flat area near potential active regions
        - Atla / Beta Regio, Lakshmi Planum
  - Constraints
    - Communication opportunities with orbiter
    - With elliptic polar orbits, want to be at higher latitude(>50 deg) and under Apoapsis
      - Directly under orbit path at day 60 of surface ops
    - Safe ("flat") landing site



Desired landing site: flat area near potentially active sites
Atla Regio and Beta Regio (black) and Lakshmi Planum (white)

Artwork by: Jack Hadley and NASA GRC