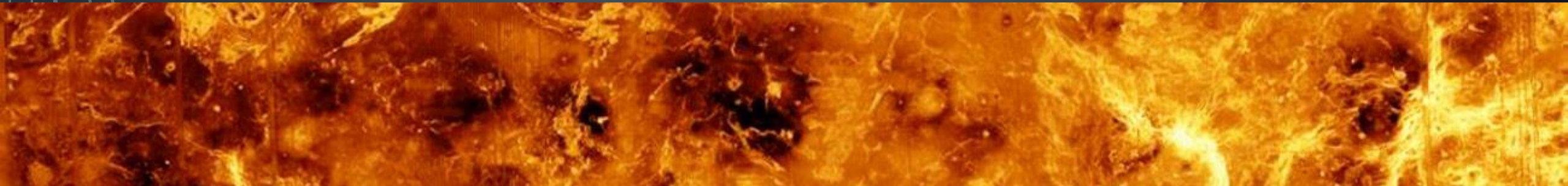




VENUS SURFACE MISSIONS

CAPABILITIES AND POTENTIAL SCIENCE IMPACTS



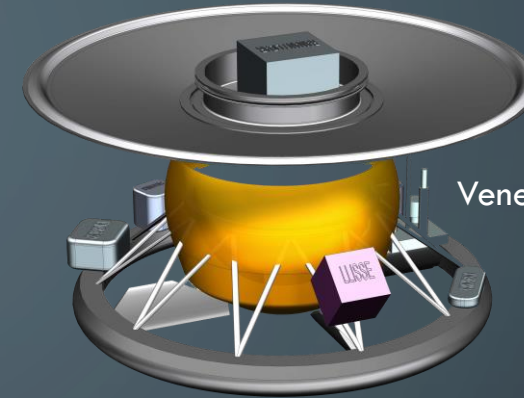
OUTLINE

- Summary of current Venus surface related activities
- Key capabilities for future surface missions
- Key technologies to realize desired capabilities
- Synergy of Capabilities

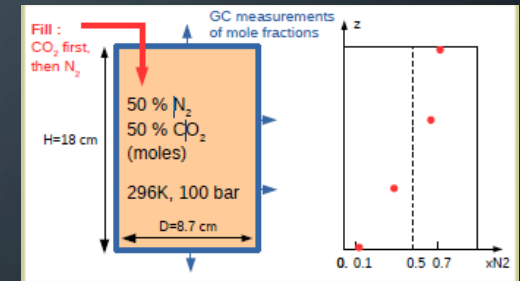
VENUS SURFACE – SOME CURRENT RELATED ACTIVITIES

One may be surprised by the amount of activity around Venus surface exploration / science

- Studies
 - Near and long term
 - Small and Large mission concepts
- Laboratory Experiments / Facilities
- Technology development
- Lander System development



Venera-D Lander Concept (1)



Experiment on Venus Nitrogen Mixing (2)

metal	
GaAs	Al ₂ O ₃ /TiO ₂ /Al ₂ O ₃ AR coating
	AlInP window
	GaInP emitter
	GaInP base
	AlInP bsf
	High temperature tunnel junction
	AlGaAs window
	GaAs emitter
	GaAs base
	AlGaAs bsf
	GaAs buffer
	GaAs substrate
	High Temperature contacts

High-Temperature Solar Cell (3)

LLISSE lander set up for system test (4)

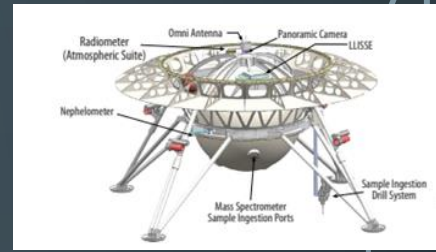


STUDIES

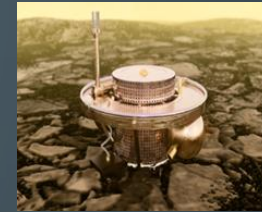
Examples of recent mission studies with surface operations:

- Venus Flagship Mission (US, pre-decadal study) and Venera-D (Russia / US)
- SAEVe (US, small sat class), VBOSS (US, Venus bridge study)
- Further-out concepts

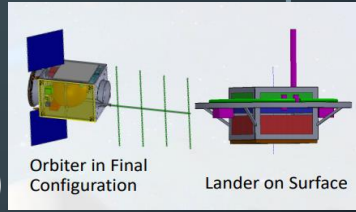
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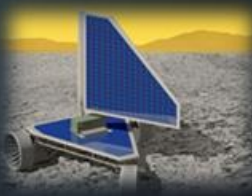
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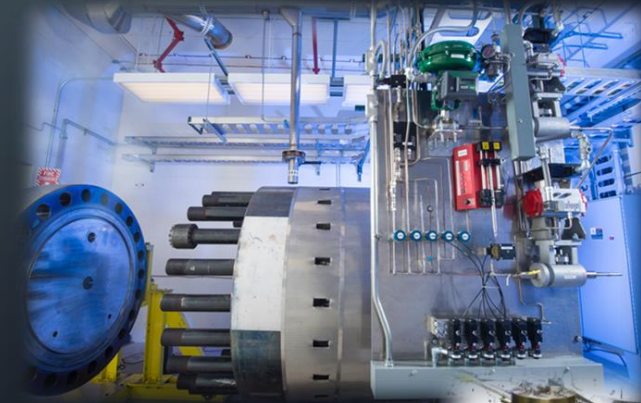
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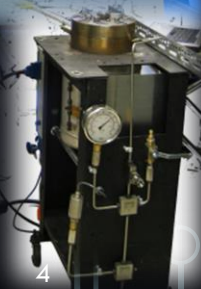
Experiments / Modeling continue

- Funded by NASA Research and Analysis (R&A) programs & other sources
 - E.g. “Radar Emissivity and Dielectric Permittivity of the Venus Surface Beneath Crater Parabolas”- M. Gilmore
- Facilities exist to support various needs
 - A list can be found in a White Paper submitted to decadal process and the VEXAG Venus Technology Plan
 - A. Santos et al “The importance of Venus Experimental Facilities” and https://www.lpi.usra.edu/vexag/reports/VEXAG_Venus_Techplan_Current.pdf
- Consistent community message:

(10)



(11)

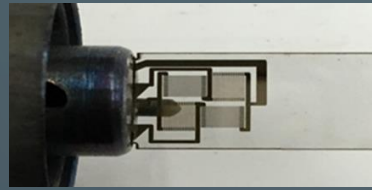


More experiments and laboratories needed

TECHNOLOGY DEVELOPMENT

Funded Venus Surface Technology Efforts exist:

- In US: NASA R&A
 - E.g. Venus imager, Seismometer,
- HOTTech - 1
 - Successful first set of awards, investments in various technologies
 - Electronics, memory, batteries/power , motor, solar cells, packaging
 - Integrated test coming (post COVID)
- NASA planning for a HOTTECH - 2
 - Subject to funding, etc..
- Other component / instrument work occurring



(12)

P.I. Org.	Title	Project Duration	TRL Start/Finish
Univ. of Arkansas	500°C Capable, Weather-Resistant Electronics Packaging for Extreme Environment Exploration	2	2,5
Ratnakumar Bugga / JPL	High Temperature-resilient and Long Life (HiTALL) Primary Batteries for Venus and Mercury Surface Missions	2	3,4
Jonathan Grandidier / JPL	Low Intensity High Temperature (LIHT) Solar Cells for Venus Exploration Mission	2	2,4
Jitendra Kumar / Univ. of Dayton	Higher Energy, Long Cycle Life, and Extreme Temperature Lithium Sulfur Battery for Venus Missions	3	3,5
Michael Paul / JHUAPL	Hot Operating Temperature Lithium combustion IN situ Energy and Power System (HOTLINE Power System)	3	2,5
Darby Makel / Makel Engr. Inc.	SiC Electronics To Enable Long-Lived Chemical Sensor Measurements at the Venus Surface	3	3-4, 6
Robert Nemanich/ Arizona State Univ.	High Temperature Diamond Electronics for Actuators and Sensors	3	3,5
Phil Neudeck / NASA GRC	High Temperature Memory Electronics for Long-Lived Venus Missions	3	3-4, 6
Leora Peltz/ Boeing Corp.	Field Emission Vacuum Electronic Devices for Operation above 500 degrees Celsius	3	3,5
Debbie Senesky / Stanford Univ.	Passively Compensated Low-Power Chip-Scale Clocks for Wireless Communication in Harsh Environments	2	2,4
Kris Zacny / Honeybee Robotics Corp.	Development of a TRL6 Electric Motor and Position Sensor for Venus	2	5,6
Yuji Zhao / Univ. of Arizona	High Temperature GaN Microprocessor for Space Applications	3	

Technology Investments are Critical for Venus Surface Exploration

LANDER SYSTEMS

Lander system level work is going on with LLISSE (Long-Life In-situ Solar System Explorer)

- Small but complete lander
 - Structure, power, comm and “payload”
 - Tested in high fidelity Venus surface conditions in GEER
 - LLISSE targeting long duration (60 day) operations without need for environmental management



(4)

DaVINCI + System level hardware for Discovery proposal

- Represents latest generation of short duration probe

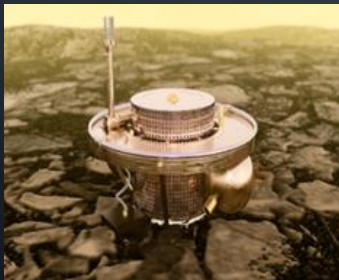


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Exciting Venus surface missions are possible today and technologies are rapidly enabling new class of Venus surface missions in the future

KEY CAPABILITIES FOR NEW SCIENCE

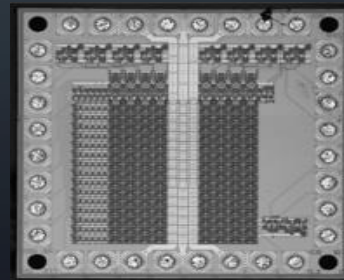
- A NASA study recently explored Venus surface platforms and the key capabilities that are expected to contribute the most to situ Venus surface / interior related science
- Key capabilities identified include the constructs of: Time, Mobility, Smarts, and Multiple Simultaneous Measurements
- Different degrees of these can enable unique and compelling new science
 - Examples of how platform capabilities can drive science:
 - Increased surface platform lifetime can enable temporal measurements for weather / climate and seismic activity
 - Situational awareness (Smarts) to lower risk and enable autonomous decisions for more productive science



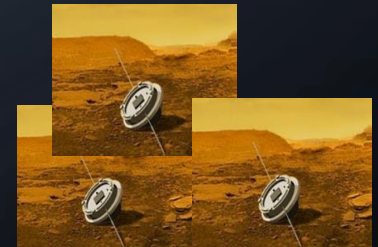
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(14)



(15)

POTENTIAL SCIENCE IMPACT OF PLATFORM CAPABILITIES

- Science returned by surface platforms are driven by key capabilities
- Four capabilities have been noted as expected to be most impactful to Venus surface, interior and surface-atmosphere interaction related science

Science Field	Capability			
Interior	Time	Smarts	Mobility	MSM
Structure	H			H
Composition	H	S		H
Dynamics	H			H
Heat Flux	S			S
Surface				
Composition		S		S
Dynamics (Eruptions, flows, ...)	H	S	H	
Diversity (Spatial)	H	S	H	S
Morphology	H	H	S	H
Age	S	H	S	S
Geologic Record (Layers, craters, ...)	H	H	H	H
Surface/Atmosphere Interactions				
Gas and Surface Composition	H	H		H
Winds	H			H
Reactions	H	H		S
Momentum Exchange	H		S	H

Table Legend: "H" designates highly impactful, "S" somewhat impactful, and MSM = Multiple simultaneous measurements

KEY CAPABILITIES FOR NEW SCIENCE

- These and other capabilities are created and/or enhanced with specific technology investments
 - Some examples of specific technologies include:
 - High-temperature power system for the Venus surface
 - High-temperature memory or processors
 - High-temperature instruments and sensors,
 - Autonomous operations and navigation

Critical Underlying / Supporting Technology	Capability		
	Time	Smarts	Mobility
Power (Low – 10's of watts or less)	H	H	
Power (High - 100's of watts)			H
Cooling [Will also need Power (High)]	S	H	S
High Temp Electronics / Memory / Power Processing	H	H	H
Mechanisms (Drills, Wheels, ...)			H
Autonomous Ops, Nav		H	H
State-of-art Instruments		H	

Technology Investments are Critical for Venus Surface Exploration

POTENTIAL SCIENCE FROM LANDER PLATFORMS

Capabilities may be synergistic:

E.g. combining Time and Smarts

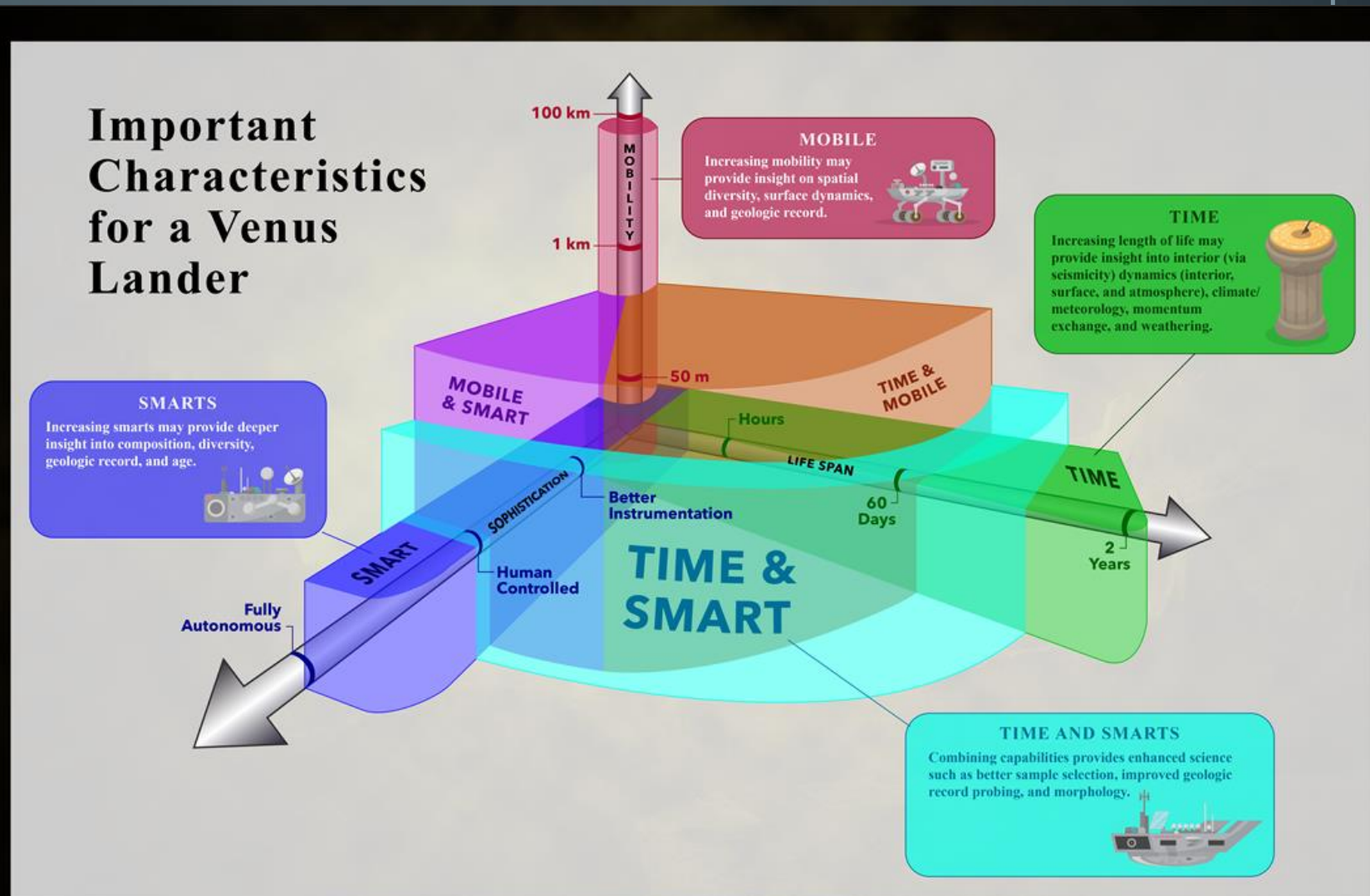


IMAGE DESCRIPTIONS

- 1) Venera-D: Study lander concept developed by a Joint Science Definition Team (JSDT) from Phase 2 report
- 2) Nitrogen Mixing Experiment Diagram (Lebonnois, S., Schubert, G., Kremic, T., et al., 2019 ICARUS, 219-R1)
- 3) High Temperature Solar Cell development funded by the HOTTech program (Grandidier et al, 2019, Progress in Photovoltaics)
- 4) Long Lived Insitu Solar System Explorer (LLISSE) system functionality test setup in GEER
- 5) Venus Flagship Mission Concept 2020: Study recently completed in support of decadal survey process
- 6) Seismic and Atmospheric Exploration of Venus SAEVe – small, long-lived (120 days), seismic and meteorology station (~25kg). NASA funded study
- 7) Venus Bridge Orbiter and Surface System (V-BOSS) –NASA funded small lander and orbiter concept based on LLISSE capability
- 8) Mechanically oriented Venus rover concept, NASA NIAC funded study
- 9) Venus wind sailor concept, NASA NIAC funded study
- 10) NASA Glenn Extreme Environment Rig (GEER) 800 liter simulation chamber that can accurately replicate Venus surface conditions
- 11) NASA Goddard Venus Insitu Chamber Investigations (VICI) 4 liter simulation chamber
- 12) Wind Sensor for Venus surface application – under development by NASA LLISSE project
- 13) DaVINCI + Discovery mission concept – currently in competitive review process
- 14) High-temperature electronics developed under LLISSE at NASA Glenn
- 15) Technology demonstration concept using LLISSE and a HEET based entry shell – multiple copies shown

Unless otherwise noted images are from NASA or NASA funded study efforts. More information on most items available publically online