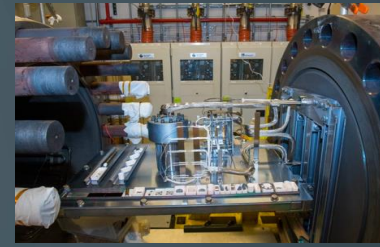


VENUS LONG-LIVED LANDERS/DROPSONDES

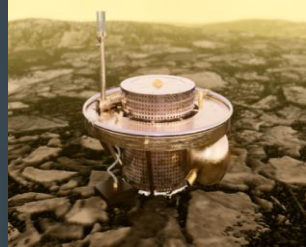
VENUS DECADAL PANEL MEETING – JUNE 2021

Prepared by T. Kremic, NASA Glenn Research Center

(1)



(2)



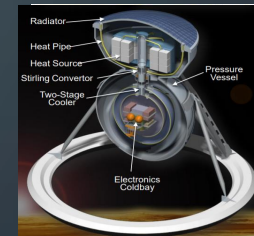
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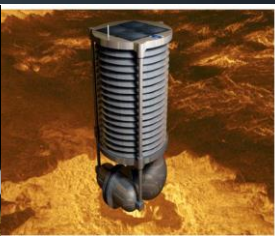
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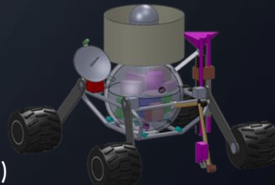
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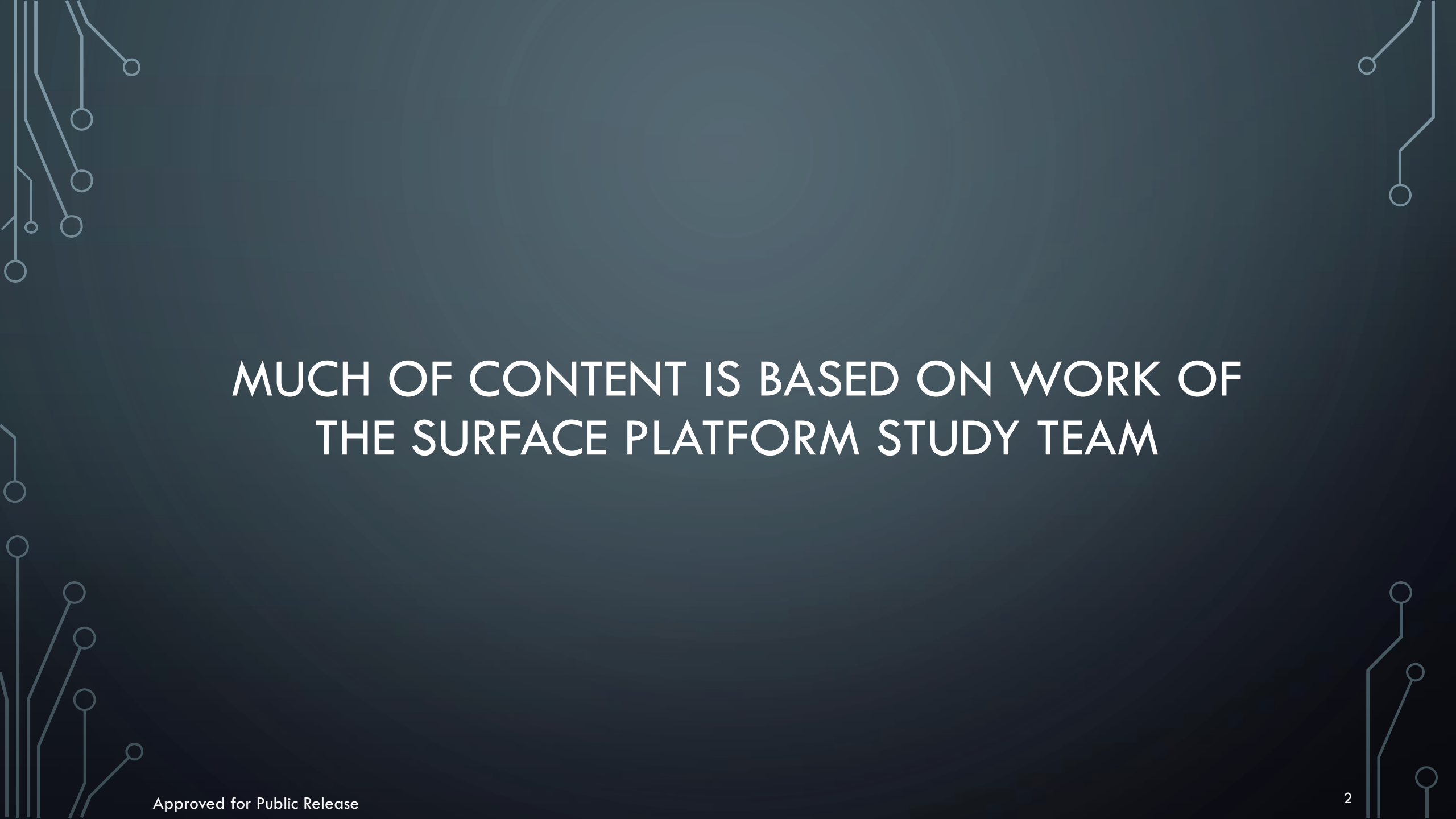


(6)



(7)



The slide features a dark blue gradient background. In the corners, there are decorative white line art elements resembling circuit boards or neural networks, with lines and small circles connecting them.

MUCH OF CONTENT IS BASED ON WORK OF
THE SURFACE PLATFORM STUDY TEAM

OUTLINE

- Factors that drive mission lifetime on Venus
- Approaches to addressing challenges posed by those factors
- Key Capabilities – based on science impact
- Technologies enabling the Key Capabilities
- Observations / Conclusions

RELEVANT DRIVERS FOR LONG DURATION* OPERATIONS

- For most system elements - **Temperature** is the main driving factor to be addressed for Venus surface operations - primarily electronics issues
- The **Reactive Chemistry** becomes an increasingly important factor over time
 - Experimental data suggests this can be driven by sulfur variants and other reactive elements
 - Various references can be provided
- The journey is also important (wide range environmental conditions)
 - Pressure (space vacuum to 92 bar), Cold space, High g loads at entry, Sulfuric acid bath on descent...
 - While noted - the requirements driven by the journey will not be explicitly covered here
- This briefing is focused on technologies and capabilities with the most impact on science

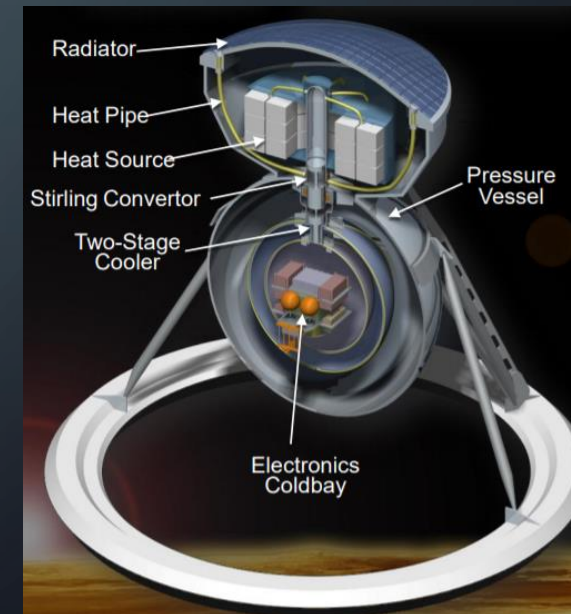


Reactivity Example: 21 day exposure of nickel clad copper wire (Lukco et al, 2018 to Venus surface atmosphere in the NASA Glenn Extreme Environment Rig (GEER))
<https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2017EA000355>

TOP LEVEL APPROACHES FOR ADDRESSING DRIVING FACTORS

- Historically – temperature managed with thermal mass and phase change material
 - This approach alone will only support missions measured in hours
- Cooling of critical lander elements can enable long-duration operations
 - Requires a significant (100s W) long-duration high-temperature power source
 - Power source is significant development effort –
 - High-temperature, low illumination, long night, isothermal conditions, reactive chemistry
 - Only known power system that could generate adequate power levels for months or longer is high a temperature RPS system.
 - Several concepts and some work along those lines has occurred but not aware of in active development today (HOTTech-2 may change that)
 - Dyson / Landis concept
 - Such a lander would not be considered small nor low-cost

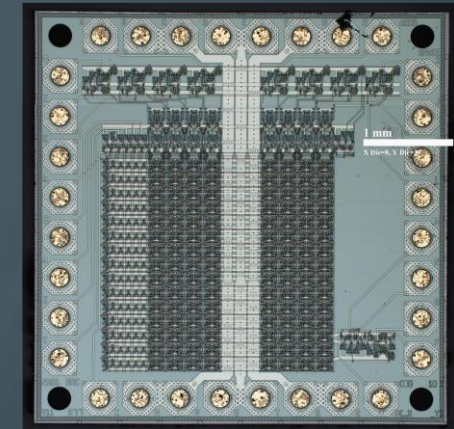
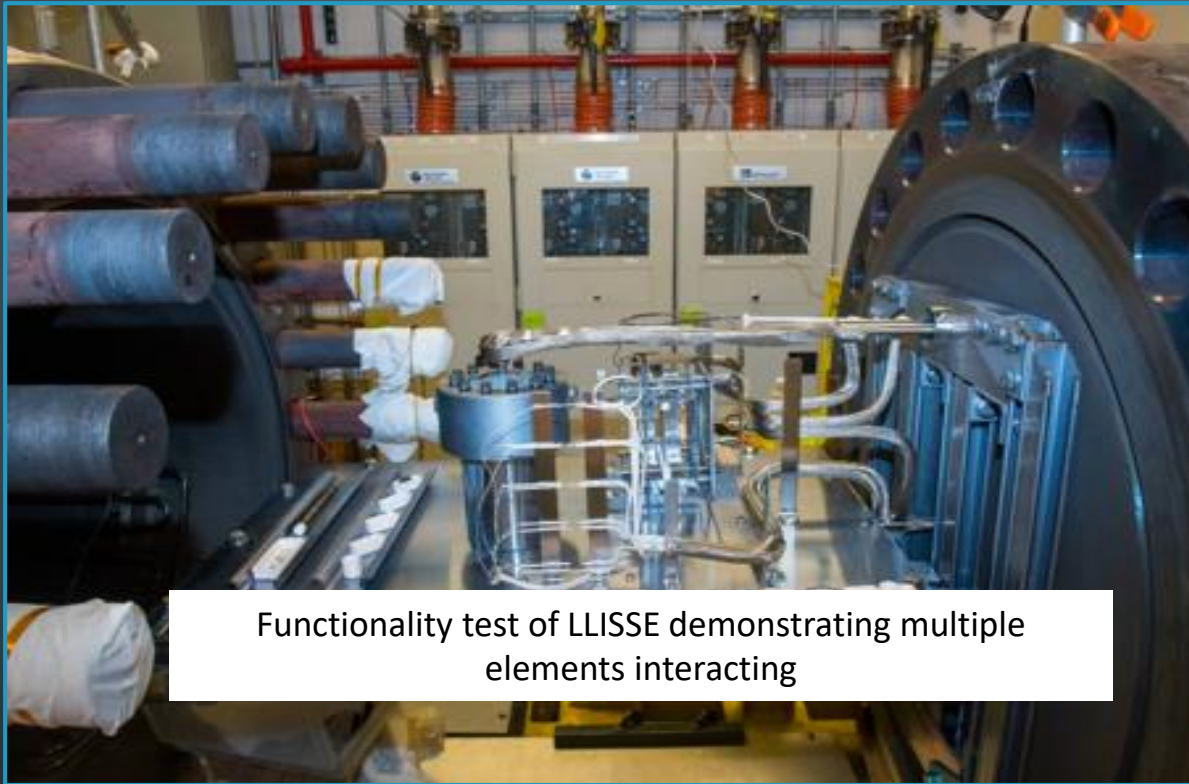
RPS powered lander concept that provides cooling (Dyson / Landis)



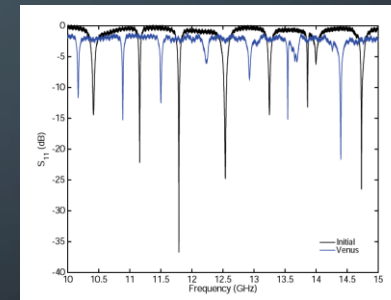
TOP LEVEL APPROACHES FOR ADDRESSING DRIVING FACTORS

- Another approach is to develop the lander exclusively using high temperature systems that simply tolerate surface temperatures and the harsh chemical environment
- A lot of development has occurred along this line in recent years with LLISSE, HOTTech, SBIR, and other funds
 - Electronics, sensors and battery driven power system have demonstrated long duration operations (60 days) in Venus conditions (LLISSE)
 - Communication system not yet demonstrated
- Eliminating pressure vessel & thermal management allows for a much smaller and lower cost landers
 - However, the sophistication level of electronics is lower than standard electronics
- Reactive chemistry is addressed via ground-based tests in places like the Glenn Extreme Environment Rig (GEER) and material selection and system design processes

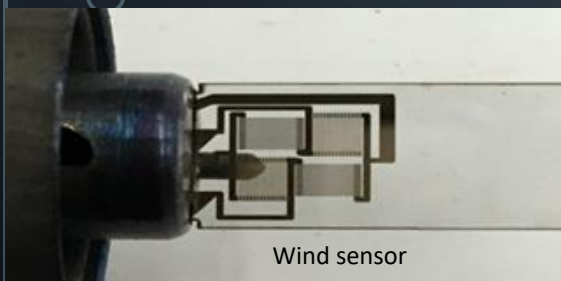
EXAMPLES OF HARDWARE DEVELOPMENT ON LLISSE



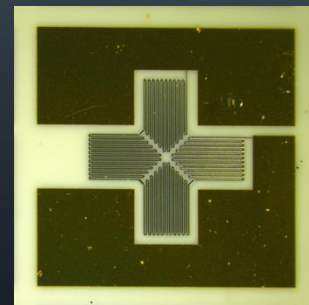
Gen 12 electronics based hardware



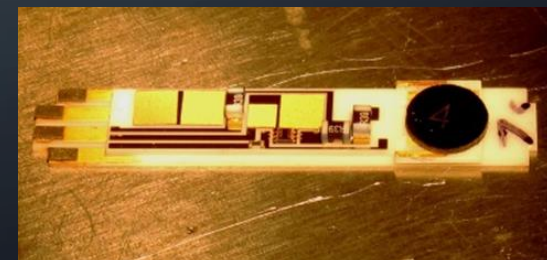
Comm system design and testing



Wind sensor



Solar radiance sensor



Pressure sensor

KEY CAPABILITIES – CONSIDERING SCIENCE IMPACTS

- The surface platform lander study identified key capabilities that will enable in situ surface related science
- Top four are Lifetime, Mobility, Smarts, and Multiple Simultaneous Measurements
- Different degrees of these can enable unique and compelling new science. A couple examples of how platform capabilities can drive science:
 - Increased surface platform lifetime can enable temporal measurements thus helping understand surface weather / climate. Lifetime is also critical to enable seismology and thus to gain insight into interior structure
 - Situational awareness (provided by smarts) and ability to make autonomous data-based decisions can enable more productive targeting and/or sample acquisition and thus enable better knowledge of Venus composition, weathering, and history.
- These capabilities are created and/or enhanced with specific technology investments
 - Some examples include: surface power, high-temperature systems (sensors and electronics, memory, power), mechanisms (actuators, drills, tools), and autonomy

POTENTIAL SCIENCE FROM LANDER PLATFORMS

Science returned by
lander platforms is driven
by key capabilities

Science Field	Capability			
	Time	Smarts	Mobility	MSM
Interior				
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

Lander platform
capability is enabled
by key technologies

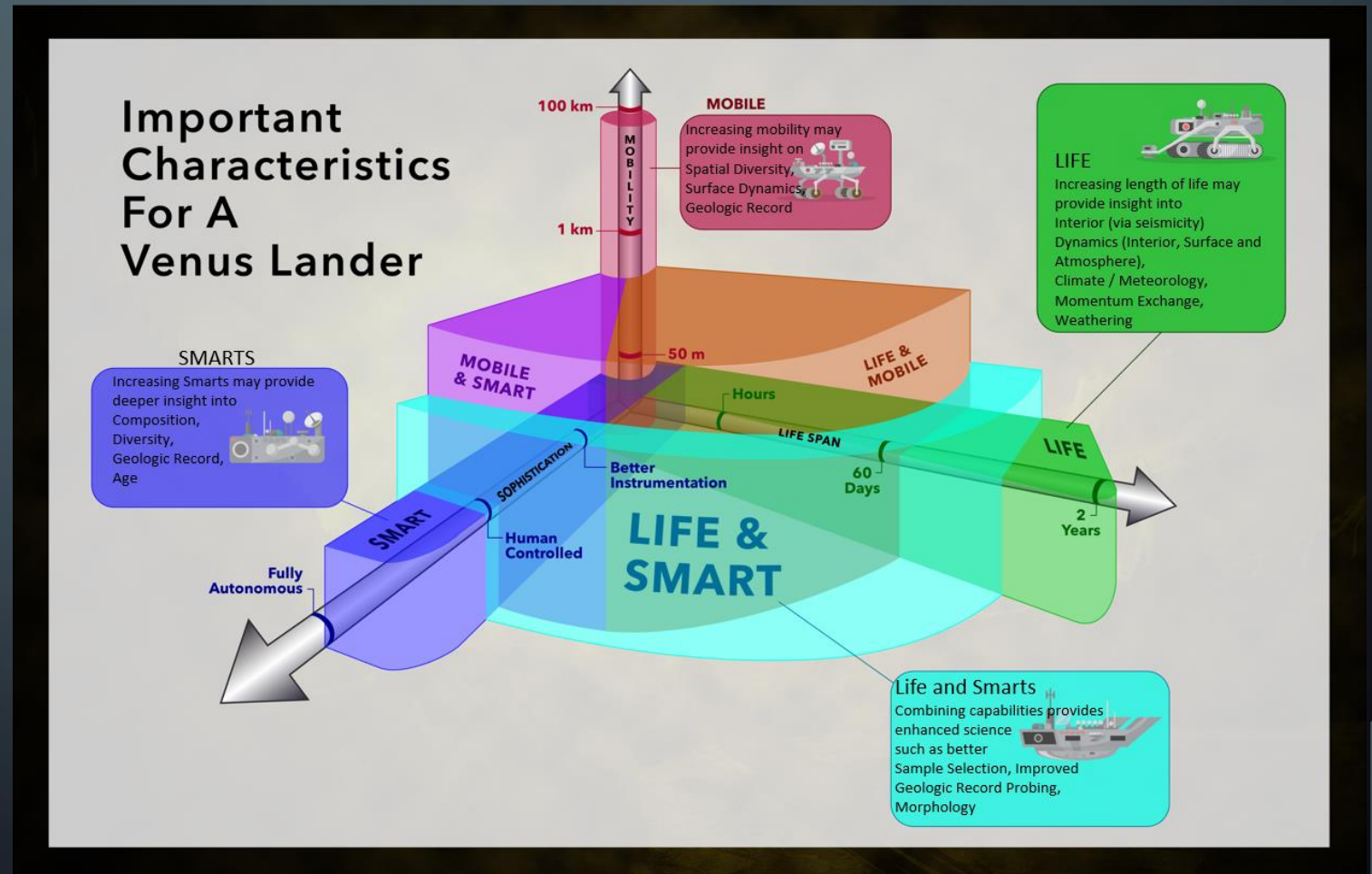
Critical Underlying / Supporting Technology	Capability		
	Time	Smarts	Mobility
Power (Low – 10's of watts or less)	H	H	
Power (High - 100's of watts)			H
Cooling [Will also need Power (High)]	S	H	S
High Temp Electronics / Memory / Power Processing	H	H	H
Mechanisms (Drills, Wheels, ...)			H
Autonomous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

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

POTENTIAL SCIENCE FROM LANDER PLATFORMS

Capabilities may be synergistic

- Sustained technology investments will enable capabilities
- Particularly relevant technologies include power, high temp electronics, memory, processing, and autonomous operations and navigation



OBSERVATIONS / CONCLUSIONS

- Scientifically significant long duration landers (months) are feasible in 5 -10 years (LLISSE to demonstrate TRL-6 in 2025)
 - Venus meteorology/climate, near surface energy deposition, atmospheric chemistry variability, for 60 days using battery power
- Increasing use of high-temperature electronics is expected to greatly reduce complexity, mass, and cost to long duration missions
- Power is also a key technology to long-lived landers
 - High temperature batteries in development
 - High-temp solar power may provide very low power / trickle charge
 - Wind power may be able to do that also – need more Venus surface wind data
 - For cooling or roving mobility - will need higher power system (RPS based)
- Mission studies reflect the difficulty of maintaining communication links over time
 - Various approaches possible but something to consider/work
- Full Venus surface platform study expected to be released to public by fall

COVER SLIDE IMAGE DESCRIPTIONS

- Images reflect platforms with varying degrees of development and planned lifetime, smarts, and / or mobility.
 - 1) LLISSE – Small 60 day lander in development (~10kg), image shows early integrated test setup
2020
 - 2) SAEVe – small, long-lived (120 days), seismic and meteorology station (~25kg). Completed NASA funded study
2018
 - 3) LLISSE/HEEET – TD Technology Demonstrator concept – Up to 10 days of operations proving survivability and data return
 - 4) Mechanically oriented Venus rover concept, NASA NIAC funded study
 - 5) RPS powered lander concept
 - 6) Concept for surface sampling balloon system from “*Probing the Interior Structure of Venus*” Report , a 2015 Keck Institute for Space Studies report
 - 7) Concept by for a cooled / mobile, long-life mobile platform

Unless otherwise noted images are from NASA or NASA funded study efforts. More detail on all these concepts publicly available online

SURFACE PLATFORM STUDY ORGANIZERS, LEADS, AND PARTICIPANTS

Name (Alphabetical)	Affiliation	Role
Mike Amato	NASA Goddard Space Flight Center	Co-Chair
Jeff Balcerski	Ohio Aerospace Institute (OAI)	Organizing Committee
Noam Izenberg	Johns Hopkins Applied Physics Lab (APL)	Organizing Committee
Natasha Johnson	NASA Goddard Space Flight Center	Organizing Committee
Tibor Kremic	NASA Glenn Research Center (GRC)	Co-Chair
Thomas Thompson	Jet Propulsion Laboratory (JPL)	Organizing Committee
Carol Tolbert	NASA Glenn Research Center	Organizing Committee
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Interior: Geophysics, Geodynamics		
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Jeffrey Balcerski	Ohio Aerospace Institute (OAI)	Sub-Group Member
Robbie Herrick	University of Alaska Fairbanks	Sub-Group Member
Sue Smrekar	Jet Propulsion Laboratory (JPL)	Sub-Group Member
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Richard Ghail	Imperial College, UK	Sub-Group Member
Tracy Gregg	University at Buffalo College	Sub-Group Member
Misha Ivanov	Vernadsky Institute	Sub-Group Member
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Misha Zolotov	Arizona State University	Sub-Group Member
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Geoffrey Landis	NASA Glenn Research Center	Sub-Group Member
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Thomas Spilker	Orbital Assembly Corporation	Sub-Group Member