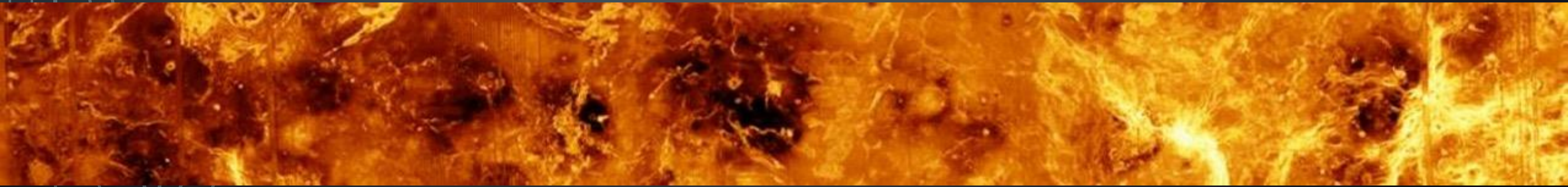
LONG DURATION VENUS PROBES AND LANDERS

IPPW - JULY 2019



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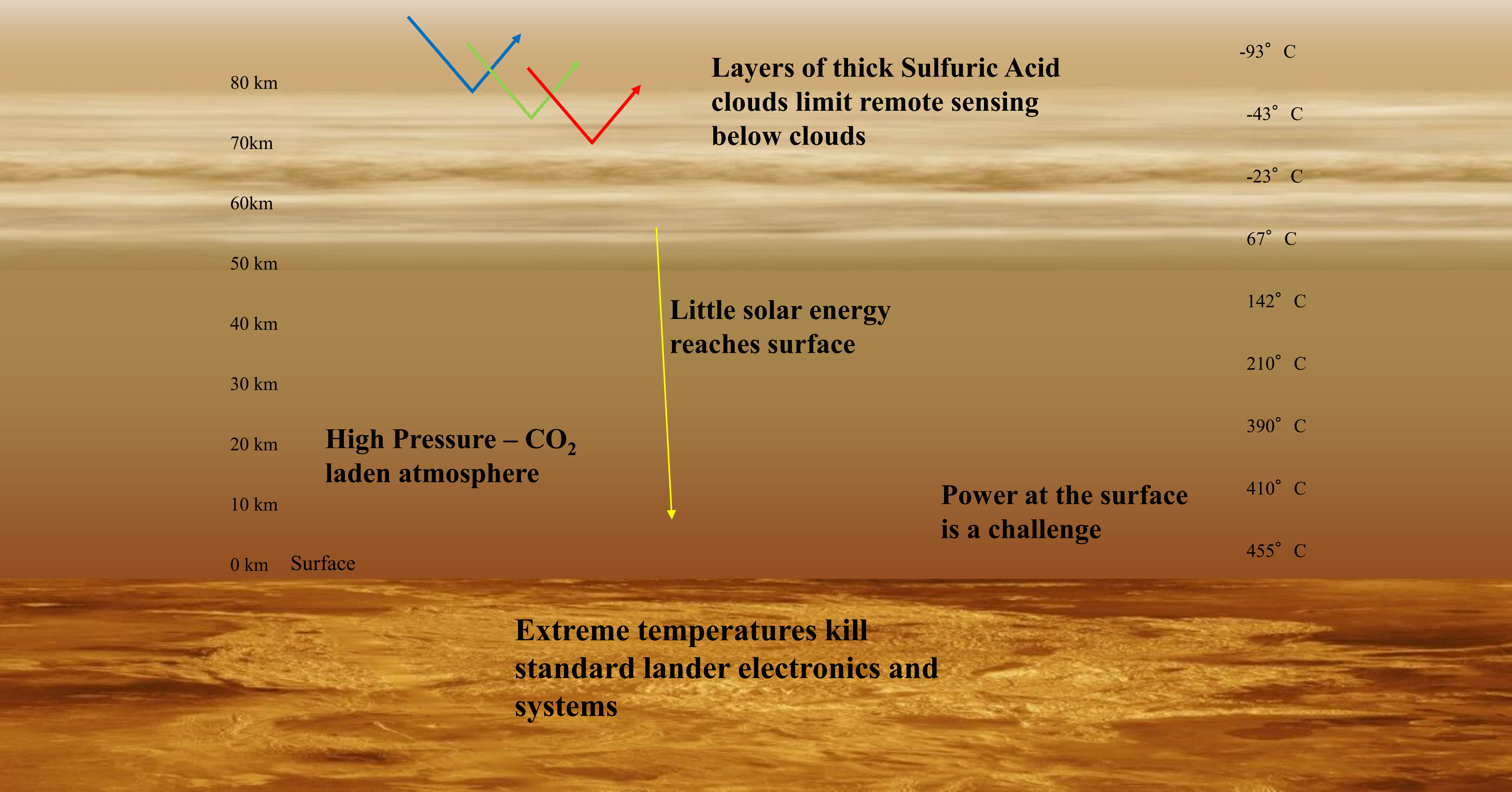
OUTLINE

- Unique Challenges of Venus
- Achieving Long Life at the Surface
- Tackling the Challenges
  - Temperature
  - Chemistry
- Current LLISSE* Testing
- Long Duration Lander Technology Needs
- Summary

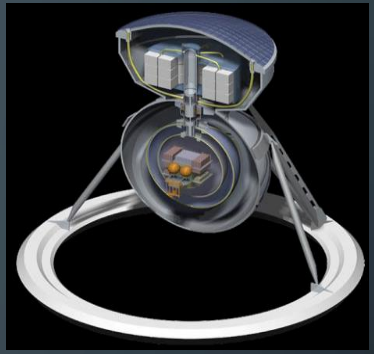
* Long Lived In-situ Solar System Explorer

The Unique Challenges of Venus

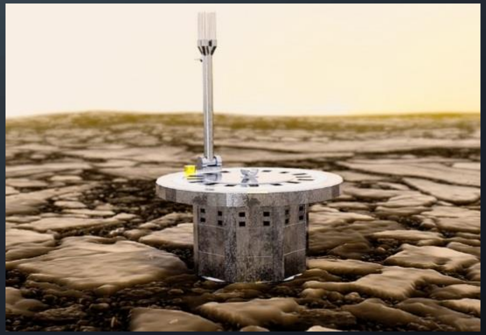


ACHIEVING LONG LIFE ON THE SURFACE OF VENUS

- Approaches to date use large vessels/thermal mass and thermal management techniques to maximize life – best to date ~127mins
  - Can accomplish a lot of science, but inherently time limited
- Another approach: design a cooled lander – requires a lot of power
  - Community needs to begin addressing the surface power issue
- GRC approach: design lander to function indefinitely without pressure or temperature control – use all high temperature components
  - Possible now due to advances in high temp. electronics/systems
  - GRC Developed over decades for various applications



Cooled Lander Concept



LLISSE Concept

CHALLENGES

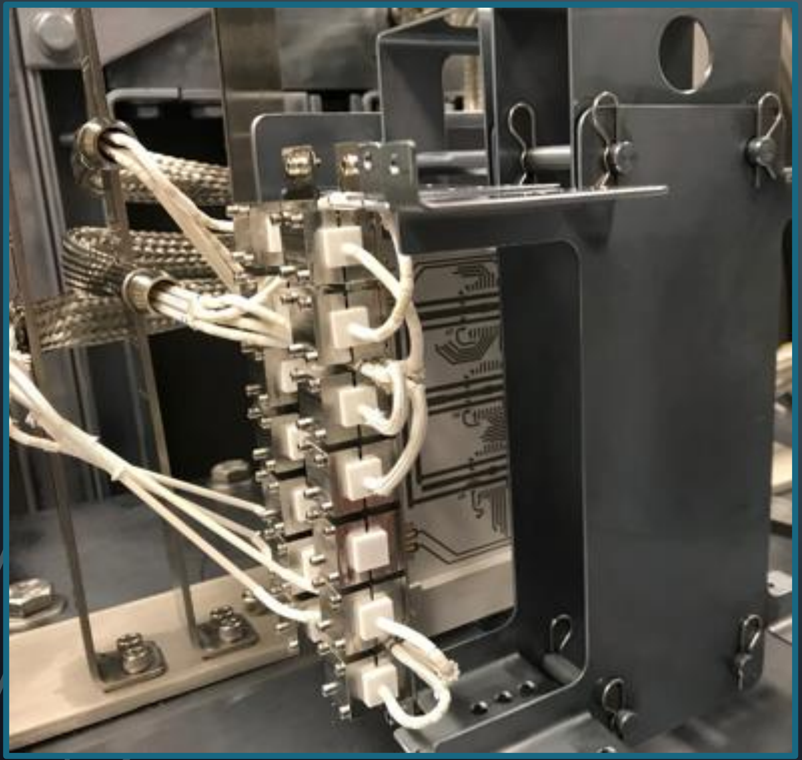
Needed for long duration operations: High temperature, Pressure and Reactive Chemistry

Temperature is the most difficult for electronics and many other components

Pressure is not deemed as much of a major challenge for most components

Reactive chemistry is an under appreciated issue

Sulfur compounds in super critical CO_2 environment react quickly with many common spacecraft materials



Circuit Board inside Cube Structure with Loom Bar Wiring into Alumina Blocks Jun 14, 2019

TACKLING THE TEMPERATURE CHALLENGE

Advances in wide band gap electronics are addressing many hurdles

- Sensors, electronics, components, medium complexity IC's, etc. developed, tested
  - Thousands of hours at Venus surface temperatures
  - Months at a time in Venus conditions

- Development continues through several NASA projects
  - HOTTech – Various component level activities
  - LLISSE – Component & system development for science and operational goals
  - SBIR - Small Business Innovative Research awards

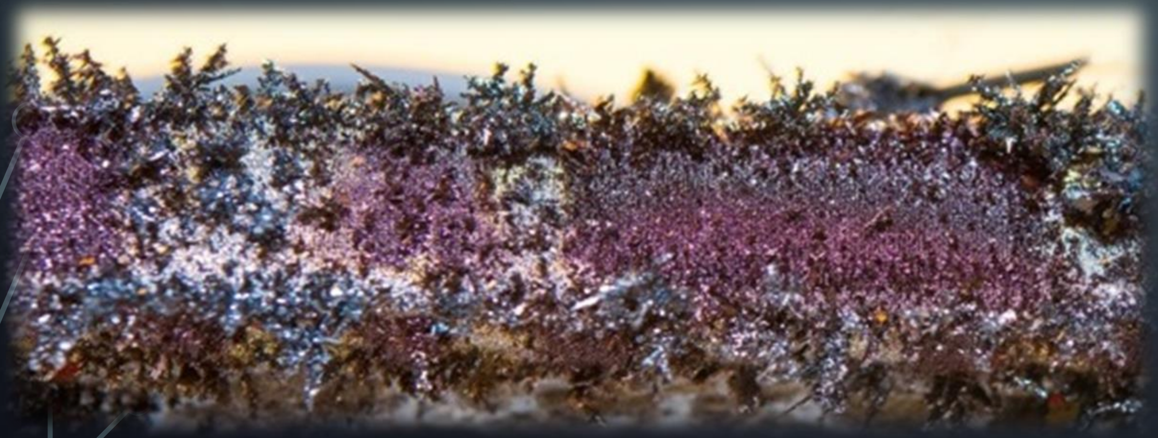
- Other government and commercial activity is also occurring
  - https://www.cree.com/news-events/news/article/cree-to-invest-1-billion-to-expand-silicon-carbide-capacity

TACKLING THE TEMPERATURE CHALLENGE CONT.

- Near term goal: demonstrate complexity that enables lander functionality
  - Ability to execute pre-planned functions, take and process science measurements, communicate with orbiter
- LLISSE is developing and demonstrating this at lander system level
- HOTTech, separate from LLISSE, is developing various components
  - Different versions of wide band gap electronics, including memory
  - High temperature batteries and other power ideas
  - Motor / motor control
- Near term development targets
  - Increase complexity while lowering power demand
  - Increase system operating speeds –comm to operate at 100's of MHz
  - Continue to evolve batteries to maximize energy deliverable as life increases

TACKLING THE CHEMISTRY CHALLENGE

- GEER* tests reveal: current spacecraft materials may not be suitable for long duration missions
  - E.g. Copper
- GEER tests include: various materials, when approved by primary customers, to build up a database of what works and what doesn't
  - Lukco, D., et al. (2018). Chemical Analysis of Materials Exposed to Venus Temperature and Surface Atmosphere. Earth and Space Science, Volume 5, Issue 7.
- GEER tests continue: investigating material compatibility, coatings, mechanisms, lubricants and other approaches



Crystal growth on structure following testing

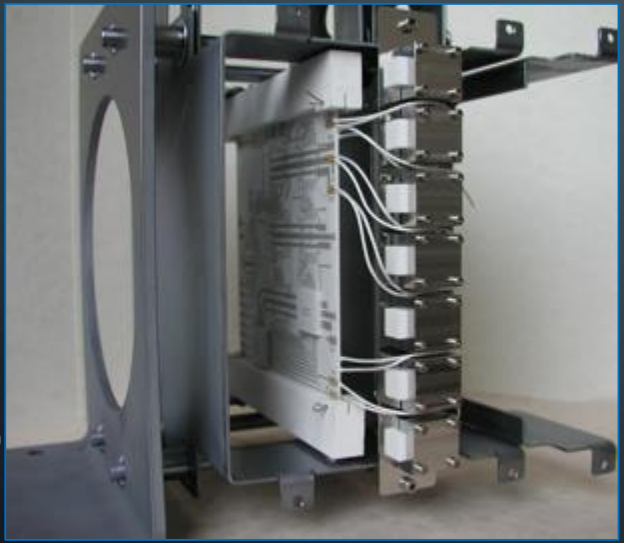
Material Results after Exposure to Simulated Venus Atmosphere

Materials	Outcome
Au	No reaction, but mobile
Ir	No reaction, but mobile
SiC	No reaction
Cu	Cu_2S crystals
Ni	NiS crystals
Kovar (Ni-Co-Fe)	NiS, Fe_xO_y
AlN	No reaction
Ag-Cu Braze	Segregation into Cu_2S and Ag; Ag mobile
Inconel 625 (Ni-Cr-Mo-Fe)	NiS, Cr_xO_y
304 SS	Mirror finish, low corrosion rate
Sputtered Aluminum	Reacts with HF to form AlF_3
Titanium	Oxide on surface decreasing into bulk

***Glenn Extreme Environment Rig**

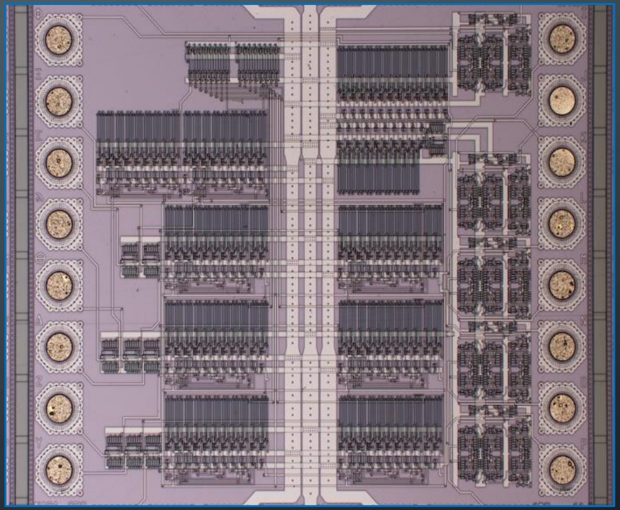
UPCOMING LLISSE DEMONSTRATION

- LLISSE demo test later this calendar year, testing system and component level operations
  - Goals:
    - ✓ Operate 60 days in Venus conditions
    - ✓ Read and process instrument and sensor data periodically
    - ✓ Test breadboard with sensors, avionics, communications (1-10MHz), and battery

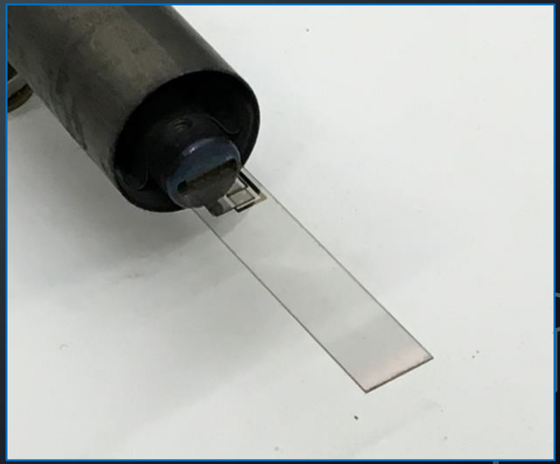


Cube Structure Circuit Board
Wiring Going to Loom Bar Location

Thermal Battery



Integrated core clock/counter/ comparison chip



Wind Sensor

FUTURE TECHNOLOGY NEEDS FOR LANDERS

- VEXAG recently updated its Technology Plan which describes technology needs. Some specific needs for high temp materials based landers include:
- Long term needs
  - Develop low power memory and critical circuits (E.g. timer/clock)
  - High temperature receiver and more capable comm
  - Develop sensors for situational awareness – high temperature camera / optics
  - Improved science sensors and instruments
- For even longer term
  - High temperature "permanent" power – 100's of watts to could support
    - Permanent stations – seismology and meteorology
    - Cooling for advanced instruments and high performance electronics / computing
    - Surface mobility

SUMMARY

Long Duration Venus Landers

Pose unique technical challenges
i.e., temperature and reactive chemistry

Venus Surface Probes & Landers

Can survive weeks to months -
Technically feasible in next 5-10 years

LLISSE Project

Addressing challenges - In development

- A lot is already done
- Continues to be demonstrated

"Permanent" Power System

Long life and 100's of watts of surface power needed to understand Venus in the longer term

Now

Continue to Developing Landers such as LLISSE:

- Can make important science strides
- Pave the way for more sophisticated landers

BACK-UP

LIST OF CURRENT HOTTECH TASKS

P.I.	Title	Project Duration	TRL Start/Finish
Simon Ang, / 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	