LONG-LIFE IN-SITU SOLAR SYSTEM EXPLORER (LLISSE) PROBE DEVELOPMENT.

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Introduction: Venus, while having similar size, mass, and location in the solar system to Earth, varies significantly in many ways including in its climate, atmosphere, and surface conditions. Exploration to better understand the deep Venus atmosphere and surface have been long standing objectives of the Venus science community as stated in Venus Exploration Analysis Group (VEXAG) documents [1] and the Planetary Decadal Survey Report [2]. The extreme environmental conditions at the surface of Venus, coupled with the thick clouds and dense atmosphere, have made achieving the science objectives very challenging. Surface conditions in particular present formidable engineering challenges (due to the high temperature and pressure) such that landed missions have not been able to last more than about 2 hr [3]. Recent advances in high-temperature electronics [4,5] and the addition of new capabilities to simulate Venus conditions, such as provided by the Glenn Extreme Environment Rig (GEER) [6], are changing this paradigm.

In particular, the Long-Lived In-situ Solar System Explorer (LLISSE) project is meant to provide new capabilities for Venus surface science exploration [7]. LLISSE has a goal of developing and demonstrating proof of concept probes that will function in Venus surface conditions for long time periods (weeks to months) (Figure 1). These probes will be designed, fabricated, and demonstrated (by testing in GEER) to operate in Venus conditions. To accomplish these goals, LLISSE leverages high-temp electronics, sensors, power, and communications development in an innovative operations model to collect and transmit science data for 60 Earth days or longer (~Venus daylight period and a transition) in Venus conditions.

The key science questions targeted by LLISSE include: better knowledge of super-rotation of the atmosphere (Goal 1, Objective B), the climate and its evolution (Goal 1, Objective B), and surface – atmosphere interaction/weathering (Goal 3, Objective B). A significant contribution toward these questions will be the ability to take periodic measurements over a long-duration. Science objectives include: estimating the moment exchange between the planet and its atmosphere, acquiring temporal weather data to update global circulation models and quantify near surface atmospheric chemistry variability. Anticipated instruments include: Wind speed/ direction sensors, temperature, pressure and radiance sensors, and a chemical multi-sensor array.

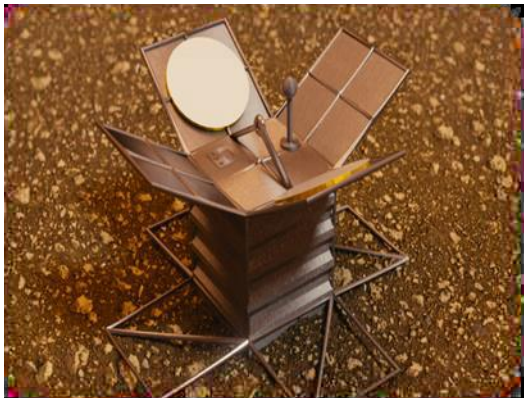

Figure 1. Notional battery powered version of the Long-Life In-situ Solar System Explorer Venus Probe (~20 cm cube)

Data from these instruments taken over extended surface mission time periods (Earth months) is critical for the development of a thorough understanding of Venus' surface conditions and the processes by which chemical species interact with each other and are transported throughout the atmospheric column as well as helping understand aspects of the atmosphere/planet interactions such as momentum exchange. The purpose of this paper is to briefly describe LLISSE, and the enabling capabilities associated with its development.

LLISSE Concept Overview: The LLISSE project includes the design and demonstration of a prototype instrument suite and supporting system to function at the surface conditions of Venus and communicate periodic measurements of temperature, pressure, wind velocity and direction, and chemical composition to an orbiter [7] (Figure 1). Periodic (every 8 hr or better) measurements over the duration of a Venus day-light period including the transitions at either end, or approximately 60 Earth days, provide a unique and significant science impact. The main product for the first three years of LLISSE development will be a battery powered version capable of surviving approximately 60 Earth days on the Venus surface with capability to transmit data using a ~10 MHz carrier RF transmitter. The fifth year product is the demonstration of the wind powered version and increasing RF transmitter carrier frequency to between 50 MHz and 150 MHz which beneficially shrinks transmitter antenna size/mass with a life expectancy of Venus year or more.

Given its small volume and expected low mass (10 kg), LLISSE could be delivered to Venus and its surface as a ride along with an orbiter and then descend with a lander or probe or be dropped from an aerial platform, or a set of probes put in a dedicated capsule for entry and deployment. Once the probe is deployed into the Venus atmosphere, it decelerates in the thickening atmosphere with its drag plates to touchdown on the surface at 8 m/s^2 or less. The probe then begins taking measurements and transmitting important parameters at the surface. At preset intervals, the probes acquire the science measurements and beams the data to the orbiting host spacecraft. LLISSE will not only acquire important science measurements but also pave the way for larger and more complex lander missions to explore Venus for greatly prolonged mission durations in the future.

High temperature electronics, sensors, communications, and power generation technologies functioning immersed without sheltering/protection from Venus surface conditions are core to long-term LLISSE operations. The following section give a brief overview on the development status of these technologies.

LLISSE Technology Development: LLISSE system operation depends on high temperature electronics based on the world's first microcircuits of moderate complexity that have shown extended operation in Venus relevant conditions [4,5]. These circuits have been recently upscaled in complexity to over 100's of JFETs per chip with two metal interconnect layers, and have now demonstrated operation for thousands of hours at 500°C in Earth air ovens [5], and very recently for 60 days in GEER simulated surface conditions without any cooling or environmental protection [8]. This integrated circuit capability enables a wide range of very compact onboard mission electronics, including sensor signal amplification, digitization, and wireless transmission integrated circuits, to operate for months without any environmental sheltering from the harsh atmosphere found on the surface of Venus. Another important finding of the GEER tests is that it is inadequate to qualify parts for prolonged surface missions in anything less than high-fidelity reproduction of Venus atmospheric conditions [4-5].

As part of this testing, core components of the LLISSE sensor technology were tested in simulated Venus conditions for extended periods. These include first generation sensor systems for surface wind speed, temperature and pressure, as well as specific sensors for atmospheric chemical composition (sulfur dioxide, hydrogen fluoride, carbon monoxide, and carbonyl sulfide). Analysis of the results of this testing for both the sensors and electronics is on-going and will be discussed. Overall, valuable knowledge on the operability of the sensing approaches was gained combined with further characterization of candidate sensor materials stability to Venus conditions. To varying degrees, preliminary viability of each chosen core sensor approach was supported. For example, the sulfur dioxide (SO_2) sensor [9] responded to the intentional injections of SO_2 into the GEER chamber during the 60 day test in a manner suggesting real-time monitoring of the simulated Venus ambient conditions. However, further improvement of Venus-durable integrated circuit and sensor capabilities remains to demonstrate a proof-of-conecpt LLISSE system.

The development of other LLISSE components is also progressing. For example, a high temperature battery is in development including a contract awarded to an industry partner for battery development leading to functional demonstration in GEER. Further, communication system designs including antennas are being investigated coupled with modeling and limited component/materials testing. During 2018, it is envisioned that prototype demonstration circuits specifically designed for most core aspects of LLISSE operation will be fabricated and preliminarily evaluated. It is upon the demonstration of such technology in Venus relevant environments for extended periods that not only missions such as LLISSE can be envisioned, but also a new range of future planetary exploration concepts.

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