SPIDERS ON MARS AND IN THE LABORATORY: EXPERIMENTS TO TEST CO2 SUBLIMATION AND THE KIEFFER MODEL ON MARS SIMULANT UNDER MARS POLAR CONDITIONS

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Introduction: Spiders, more formally known as \`araneiforms' are striking dendritic, tortuous negative topography networks of troughs that are native to the Martian South Polar Layered Deposits (SPLD) and surrounds [1]. During southern spring, relatively dark albedo fans and spots are observed within their locales. They are posited to be formed due to seasonal CO_2 ice sublimation and its interaction with the Martian surface. Their morphologies range from \`thin', to \`starburst' to \`fat'. The cardinal hypothesis for their formation has been well-accepted for over two decades and is known as the Kieffer Model [2]. This conceptual model suggests that in spring, sunlight penetrates seasonally-condensed translucent impermeable CO_2 slab ice and is absorbed by the regolith beneath it, warming and basally sublimating the CO_2 ice overburden in a process known as the Solid State Greenhouse Effect. Gas pressure is proposed to build, eventually levitating the ice layer and causing it to crack at weak spots, allowing high velocity gas to rush in conduits towards the \`vent', scouring the substrate in its wake to form a network of dendritic troughs, coinciding with the vent location.

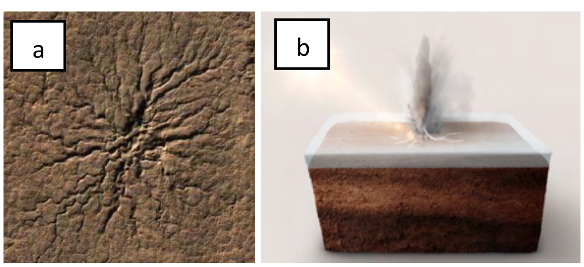

Figure 1: (a) Example of a \`thin' spider on Mars, NASA/JPL/University of Arizona, (b) animation of the Kieffer model on Mars, Wax Visuals.

There are several open areas motivating investigation surrounding spiders on Mars and their relationship with their local environment, principally:

1. Despite ongoing fan and spot activity, and several Mars years of careful observations, SPLD araneiforms have not been observed by the High Resolution Imaging Science Experiment (HiRISE) to grow or newly form today, yet smaller, newly-forming furrows and dendritic troughs are observed to form interannually within Martian dune fields [3, 4].

2. It is unclear what factors drive the \`zoo' of different spider morphologies ranging vastly in scale, level of branching and whether they appear in clusters or not.

Therefore, it is not yet known whether some araneiform morphologies represent different local conditions and, moreover, whether some formed during a paleoclimate. A better understanding of spiders and the environmental factors driving their formation is needed to enable interpretation of certain morphologies as proxy records of local frost and substrate conditions, from the past or present. A key approach to understanding these relationships is to investigate them empirically, with Mars simulation laboratory experiments.

Pathfinder Mars Simulation Chamber Spider Experiments: Experiments performed in a Mars Simulation Chamber at the Open University [5] revealed that spider-like patterns formed when a sublimating CO_2 ice block was placed in contact with a porous, mobile substrate under simulated Mars pressure regimes. This work showed that a plume operated, transporting grains from beneath the ice and eroding dendritic, radial patterns. Spider morphology appeared to be controlled by (i) grain size and (ii) vent diameter. However, while these experiments were the first to link the hypothesized process with morphology, a few approximations were made. Firstly, the means by which sublimation is reached on Mars was not modeled; instead, the Leidenfrost Effect was utilized to engender sublimation between CO_2 ice blocks and room-temperature substrate and the Solid-State Greenhouse Effect was not explored. Secondly, edge effects were introduced by using CO_2 ice blocks and the pressure gradient resulting from a vent within a conformal layer of CO_2 was not explored. Furthermore, a host of environmental parameters drive spider formation including but not limited to; local pressure and temperature, ice thickness, regolith induration with water ice, the presence of dust below and within the ice, insolation receipt, and many more.

Kieffer Model Experiments Using the JPL EMSiL Cryovac Chamber: At the Jet Propulsion Laboratory Extraterrestrial Materials Simulation Laboratory, we are using a cryovac chamber to more closely simulate the

Kieffer Model and address questions relating to spider morphology and environmental conditions. Specifically, we aim to investigate the morphologies and activity that occur when a conformal layer of CO_2 in contact with Mars simulant is insolated with simulated sunlight. We are exploring the parameter space when varying:

1. Ice thickness
2. Grain size
3. Dust content
4. Substrate consolidation

The EMSiL cryovac chamber is capable of simulating Mars polar winter and spring atmospheric pressure and temperature conditions, with a PID-controlled, LN_2-cooled shroud and cooling plate, turbo-pump and various feed-throughs to flow cryogenic gases inside. Using this setup, which is optimal for creating thick layers of CO_2, as well as reported target temperature and pressure ranges for laboratory-generated translucent CO_2 ice [6] we have successfully condensed the thickest reported translucent CO_2 slab ice. Cryopods^{TM} are used to cool Mojave Mars Simulant (MMS) [7] upon which to later condense CO_2 ice. The setup is then being placed in the chamber, which we then pump down to Mars pressure ranges and flow LN_2 inside to cool the system to Mars polar winter temperature ranges. We then flow CO_2 gas inside to condense on the cooled regolith bed.

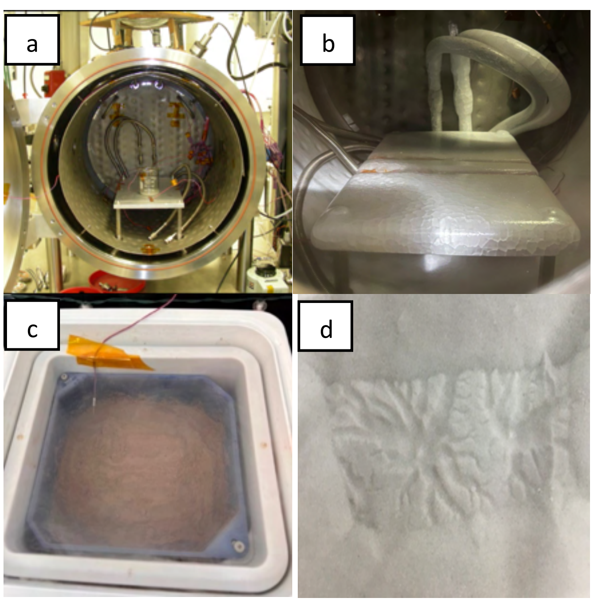

Figure 2: (a) JPL's EMSiL cryovac chamber showing LN_2 cooling plate and shroud, (b) translucent slab CO_2 ice condensed in the EMSiL chamber, (c) MMS simulant cooled to 120 K, (d) example of spider features formed in previous experiments with CO_2 ice blocks, to be formed by insolation of translucent CO_2 ice with solar simulator.

We are directing simulated solar radiation upon this setup, in order to engender basal sublimation, produce a plume and form spider morphologies. As in previous experiments, Digital Elevation Models of the resulting morphologies are developed via Structure from Motion. By careful analysis with ArcMap, as well as the study of timing and plume height in movies captured, the influence of the above parameters on morphology and plume activity can be assessed.

Ongoing Spider Mapping Campaign:
Using the Murray Lab Context Camera (CTX) Global Mosaic [8] and High Resolution Imaging Science Experiment (HiRISE) images, we have been mapping spiders of different morphologies around the south pole on Mars [9] and are utilizing relative stratigraphy geological analysis as well as frost mapping to further understand local conditions under which specific morphologies form. Our lab work is being used to test hypotheses regarding correlations or lack thereof between these morphologies and local controls. In turn, empirical observations of such correlations can be used to identify proxy local conditions past and present on Mars, such as the presence of ground ice, which can have important implications for future landing and habitability investigations.

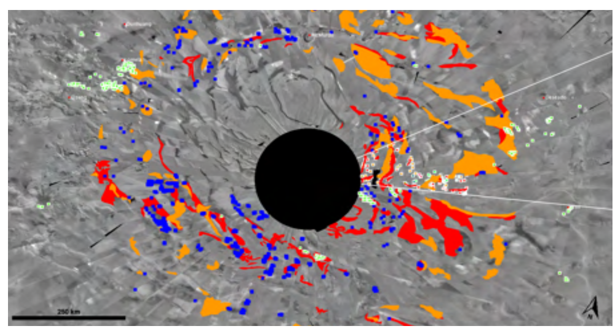

Figure 3: Ongoing mapping with the CTX Global Mosaic and HiRISE images [9]. Red indicates distinct spiders, orange denotes `lace terrain', blue indicates `maybe spiders' (where fans/spots cover terrain below seasonal ice) and green shows areas previously mapped by the Planet Four: Terrains team [10]. Within the transect are distinct spider morphologies.

References: [1] Piqueux et al., 2003, JGR: Planets. [2] Kieffer et al., 2006, Nature. [3] Bourke and Cranford, 2011, LPI Contributions, 6059, [4] Portyankina et al., 2016, Icarus, [5] Mc Keown et al., 2021, Scientific Reports, [6] Portyankina et al., 2019, Icarus, [7] Peters et al., 2008, Icarus, [8] Dickson et al, 2020, LPI Contributions 2309, [9] Mc Keown et al, 2022, AGU [10] Schwamb et al., 2017, Icarus.

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