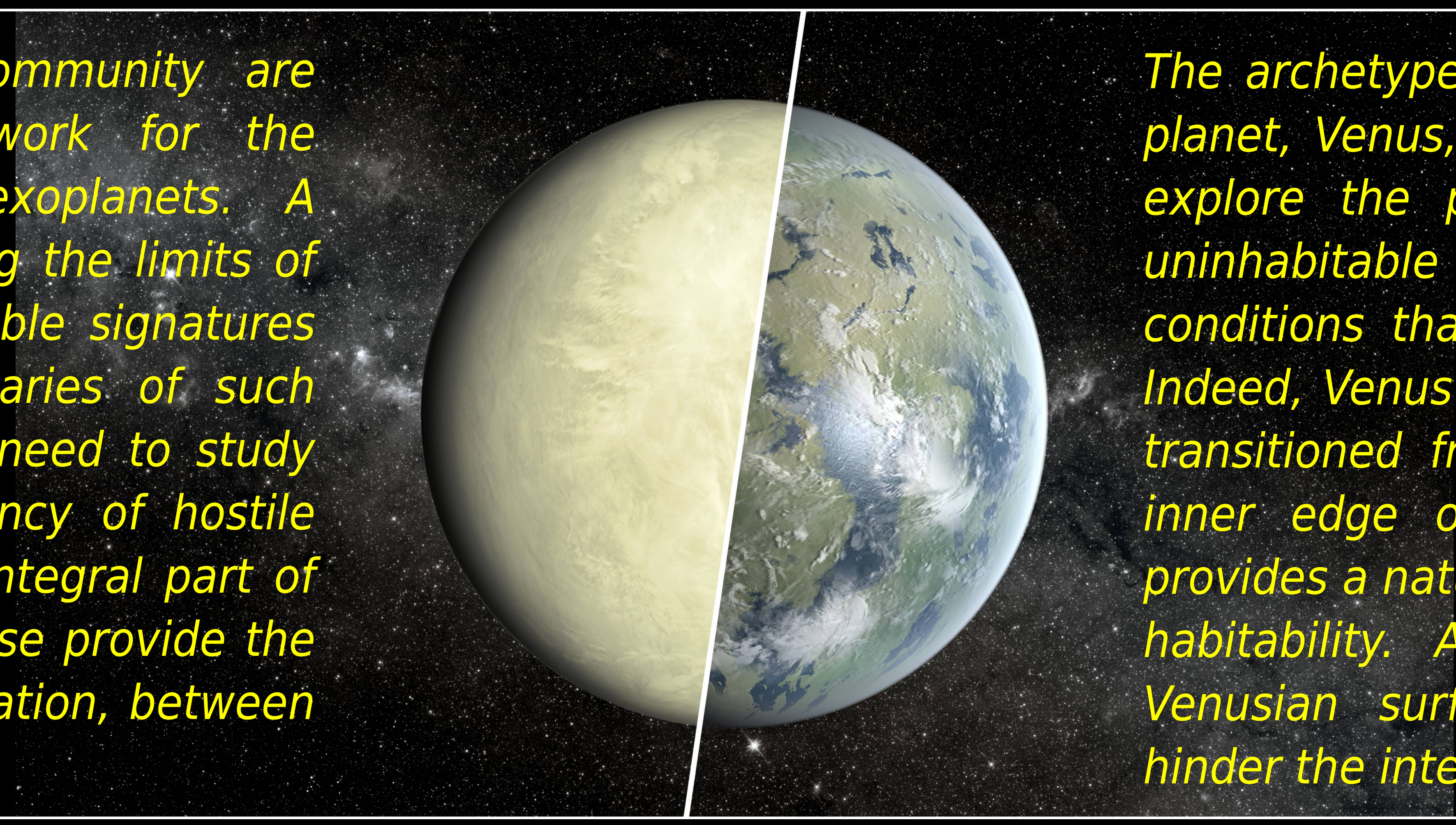
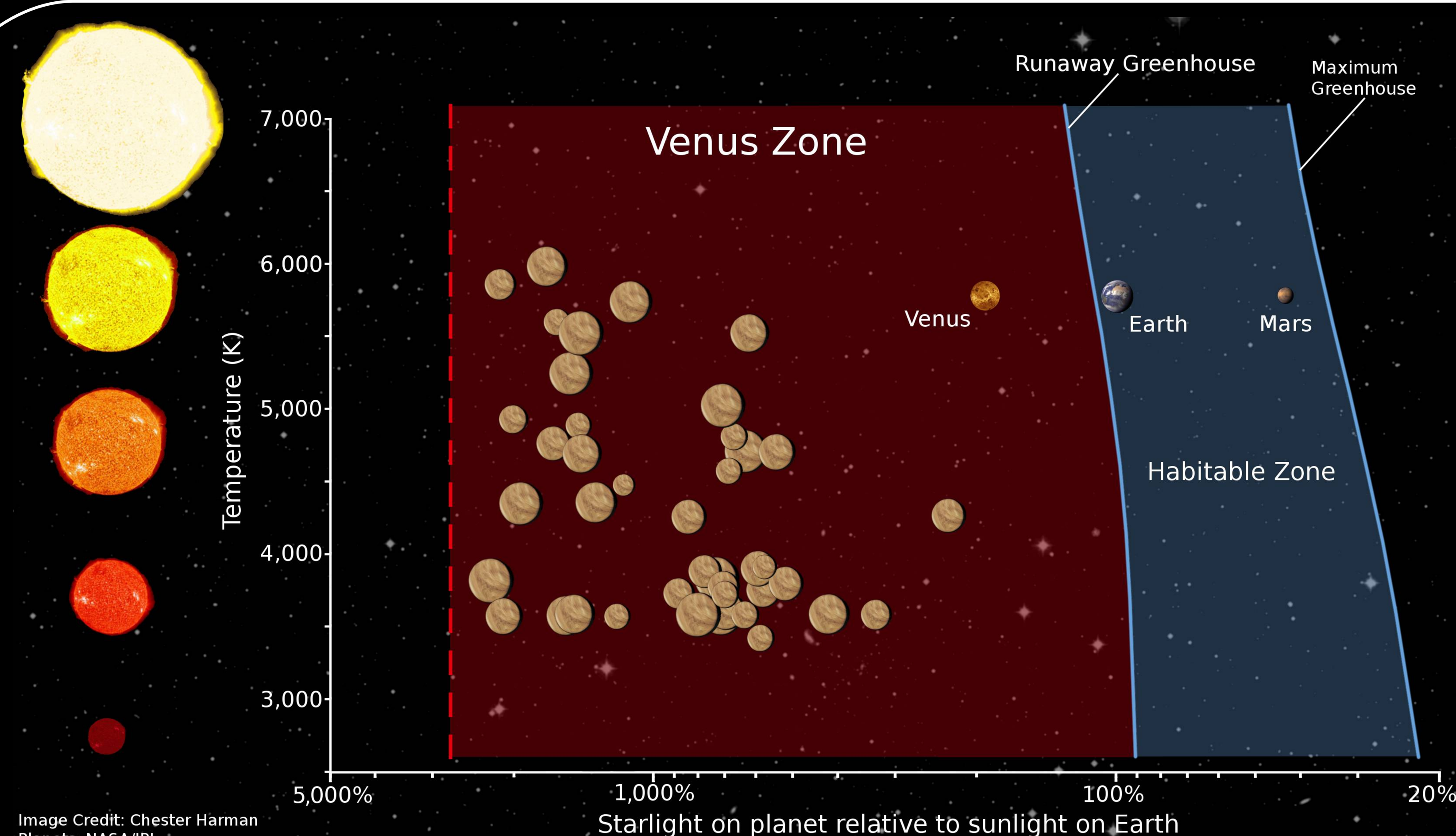
Venus as a Laboratory for Exoplanetary Science

Stephen Kane, Giada Arney, David Crisp, Shawn Domagal-Goldman, Lori Glaze, Colin Goldblatt, David Grinspoon, James Head, Adrian Lenardic, Cayman Unterborn, Michael Way, Kevin Zahnle

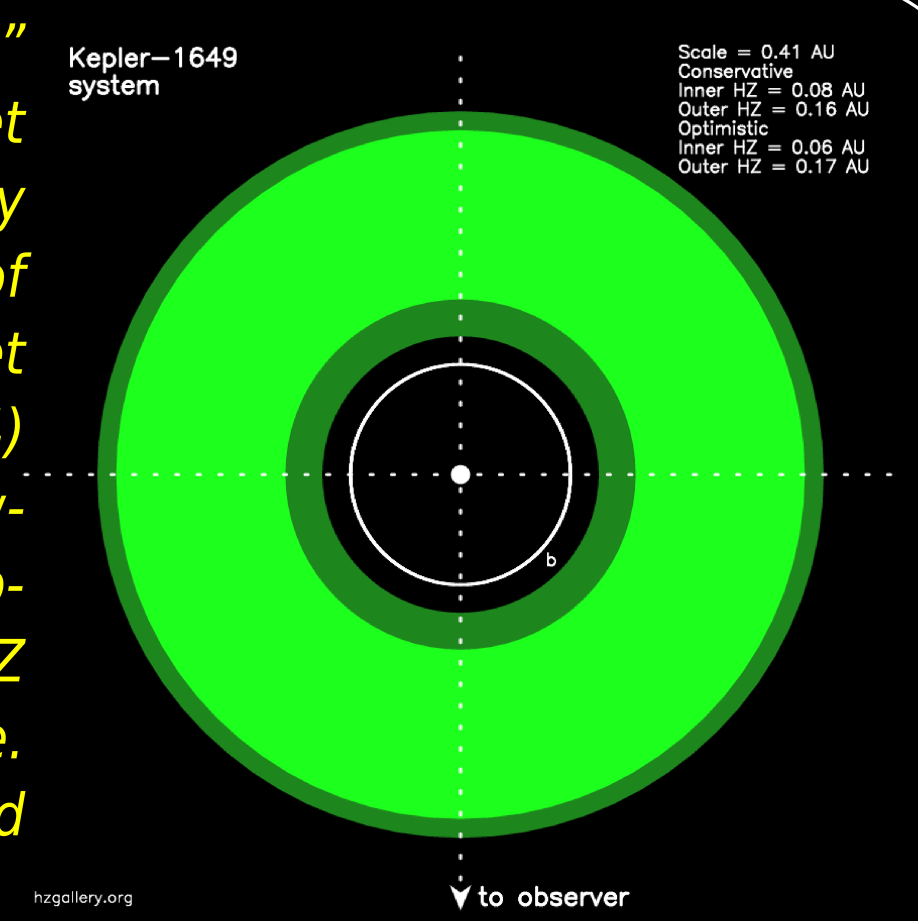
The goals of the astrobiology community are focused on developing a framework for the detection of biosignatures on exoplanets. A fundamental aspect of understanding the limits of habitable environments and detectable signatures is the study of where the boundaries of such environments can occur. Thus, the need to study the creation, evolution, and frequency of hostile environments for habitability is an integral part of the complete astrobiology story. These provide the opportunity to understand the bifurcation, between habitable and uninhabitable.



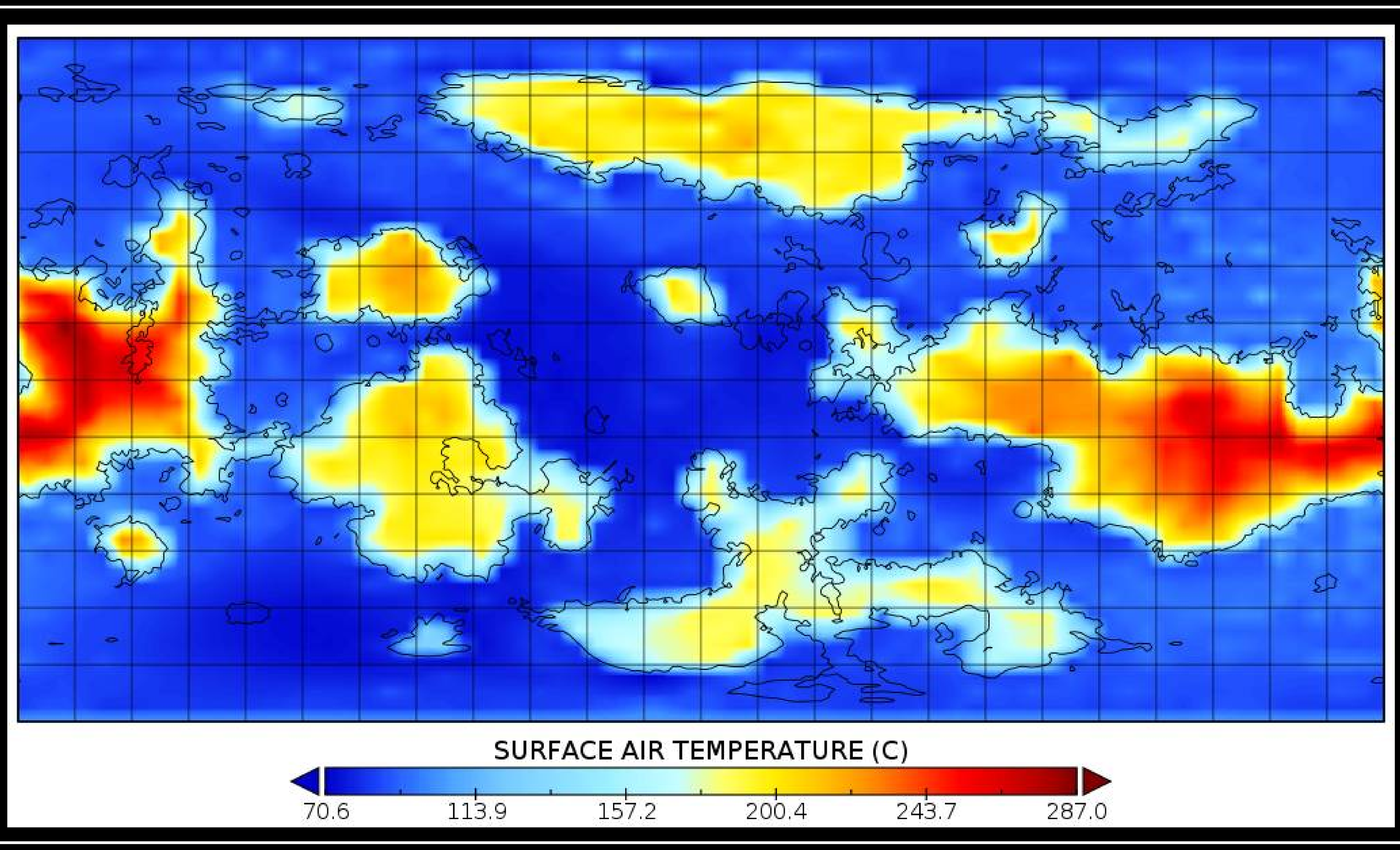
The archetype of such a planet is the Earth's sister planet, Venus, and provides a unique opportunity to explore the processes that created a completely uninhabitable environment and thus define the conditions that can rule out bio-related signatures. Indeed, Venus is the type-planet for a world that has transitioned from habitable conditions, through the inner edge of the Habitable Zone (HZ); thus it provides a natural laboratory to study the evolution of habitability. An incomplete understanding of the Venusian surface and atmospheric evolution will hinder the interpretation of exoplanet observations.



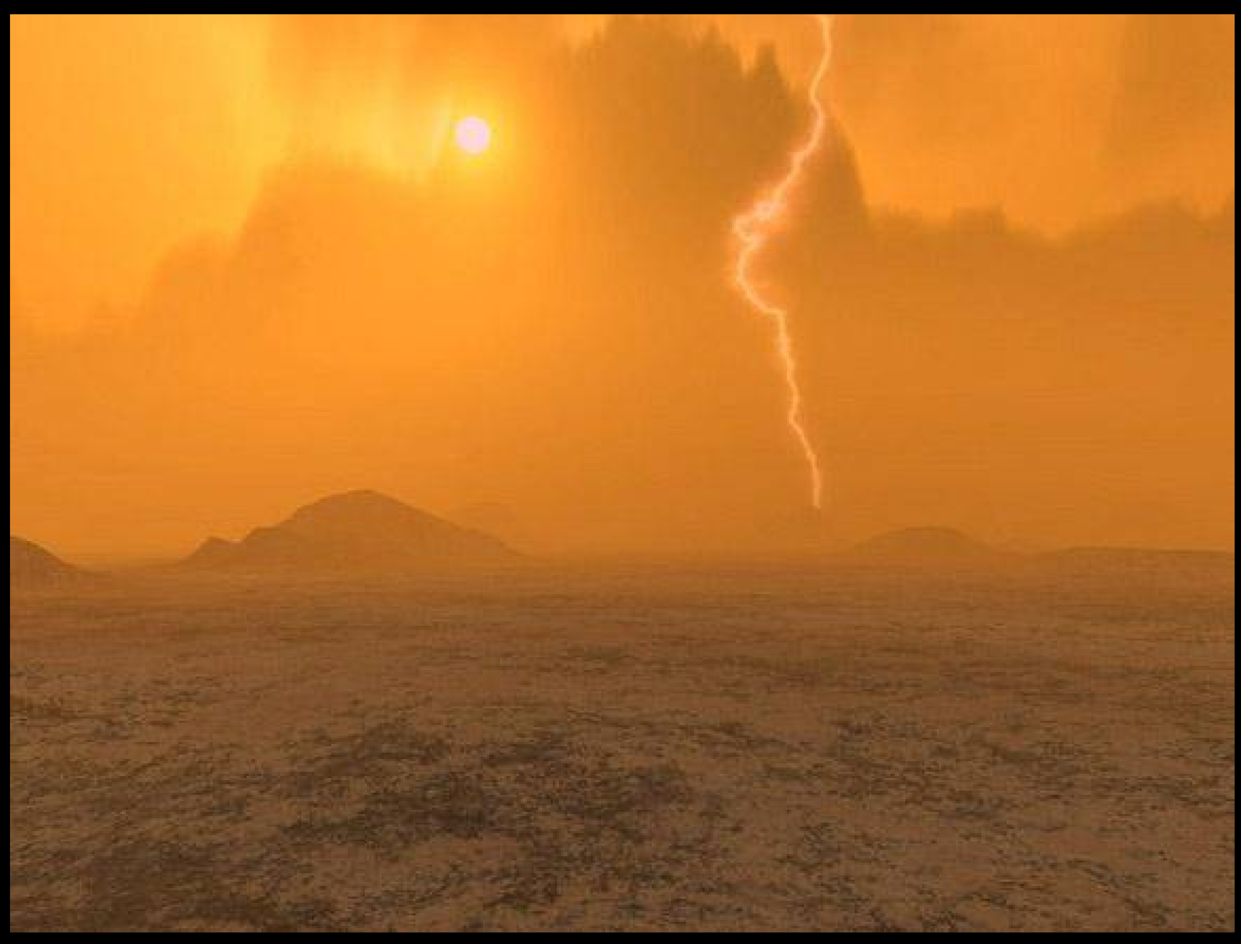
Kane et al. (2014) defined the "Venus Zone" (VZ), shown in the left figure, as a target selection tool to identify potential runaway greenhouse terrestrial planets. The pictures of Venus shown in the VZ represent planet candidates detected by Kepler. Kane et al. (2014) calculated VZ occurrence rates of 32% for low-mass stars and 45% for Sun-like stars. A top-down view of a planetary system with a VZ planet, Kepler-1649, is shown in the right figure. The planet is 10% larger than Venus and receives 2.3 Earth flux (Angelo et al. 2017).



In order to study the potential surface conditions of Kepler-1649b, we utilized the climate package "Resolving Orbital and Climate Keys of Earth and Extraterrestrial Environments with Dynamics" (ROCKE-3D), described in detail by Way et al. (2017). We adopted a variety of starting conditions for the orbital period and insolation flux of the planet, within the uncertainties of the Kepler data. We assumed tidal locking and various concentrations of CO_2, CH_4, H_2O, and N_2.



All of the climate simulations for the planet underwent a rapid rise in surface temperature. The left figure shows a heat map of the planetary surface at the conclusion of a simulation that used a Venus topography with oceans. The simulations generally exceeded the boundaries of ROCKE-3D, indicating that the planet is entering a transition state leading to a runaway greenhouse as volatiles are transferred to the atmosphere (Kane et al. 2018).



Many significant questions remain on the current state of Venus that effectively inhibit our ability to model exoplanet environments. These questions include:

- *Did Venus have a habitable period (e.g. Way et al. 2016)?*
- *Where did the water go? Was hydrogen loss and abiotic oxygen production rampant, or did surface hydration dominate?*
- *What has the history of tectonics, volatile cycling, and volcanic resurfacing been (Ivanov & Head 2011)? When did Venus enter its present stagnant-lid regime? Does any subduction occur today?*
- *What is the detailed composition and atmospheric chemistry within the Venusian middle and deep atmosphere and how does it interact with the surface?*

In-situ Venusian surface/atmospheric data is critical to address these questions and permit detailed modeling of exoplanets environments.

References:

- Angelo et al. 2017, Astronomical Journal, 153, 162
- Ivanov & Head 2011, Planetary & Space Science, 59, 1559
- Kane et al. 2014, Astrophysical Journal, 794, L5
- Kane et al. 2018, Astrophysical Journal, 869, 46
- Way et al. 2016, Geophysical Research Letters, 43, 8376
- Way et al. 2017, Astrophysical Journal Supplement, 231, 12

See also white paper by Kane et al. (2018), available from: https://arxiv.org/abs/1801.03146