The Human Exploration of Venus

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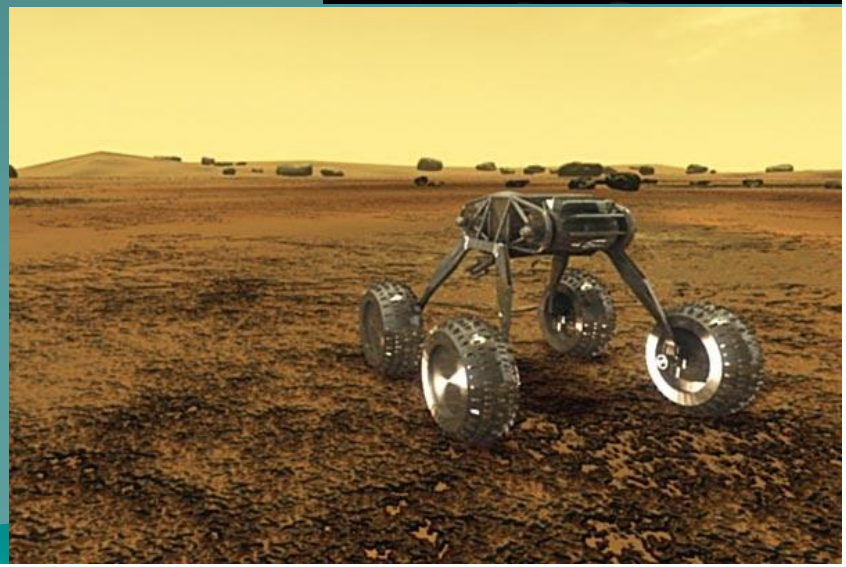
Human-Robot Synergy for the Exploration of Venus

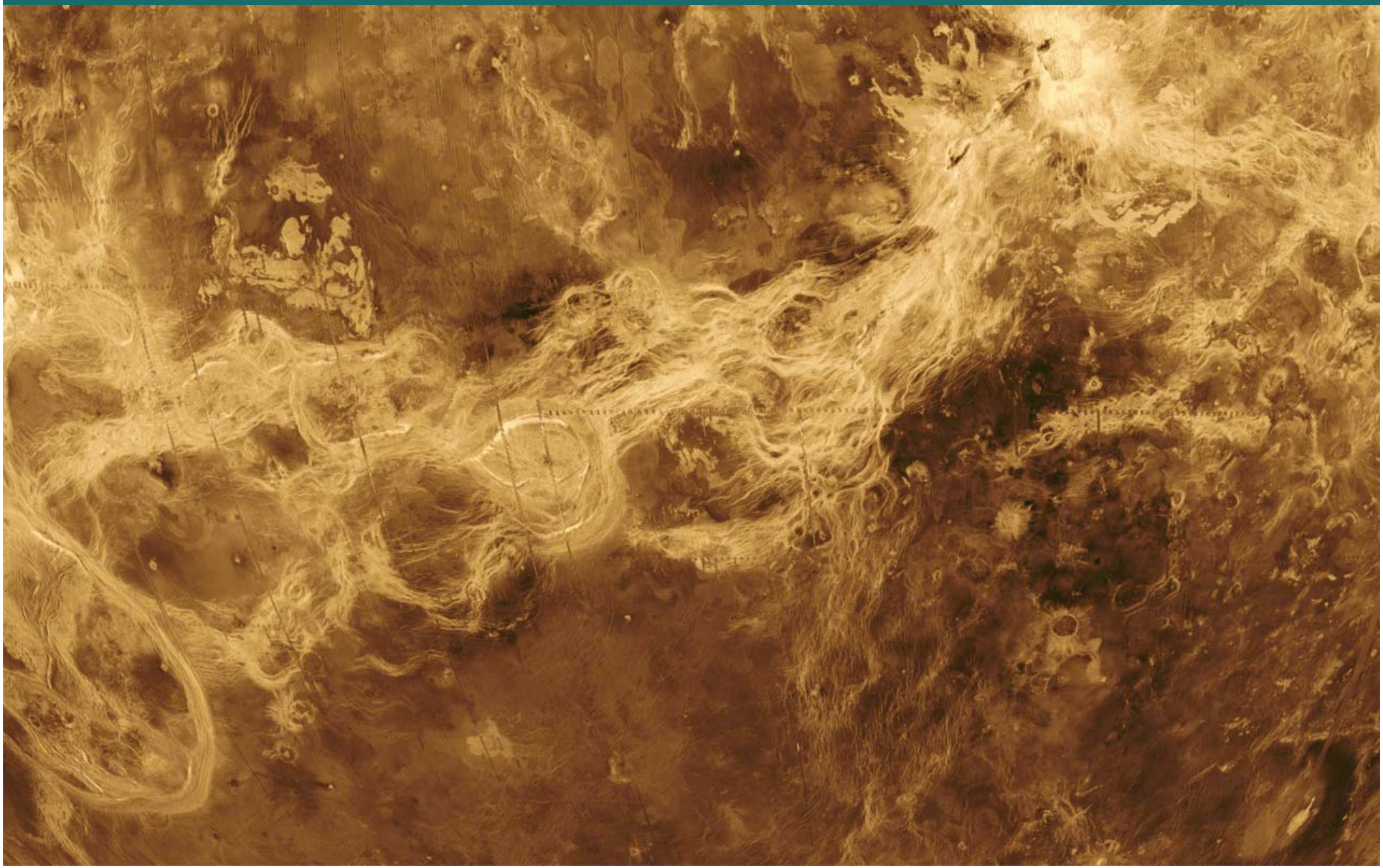
- Humans explore the surface of Venus through telepresence robots
- CEV-Venus orbit with human crew
- Real-time field geology on Venus (Beyond MERs)
- Direct immersion into Venus environment available to all of humanity
- 2 year human mission, 17 year surface robot mission.



Science Needs Venus

- Venus and Earth are the same size and both formed near the Sun's habitable zone
- Like the Earth, Venus' climate is the result of interconnected atmospheric and geologic cycles
- We will soon find and acquire spectra of terrestrial planets around other stars
- It is not possible to understand how terrestrial planets evolve without a deep exploration of Venus

Venus Geology

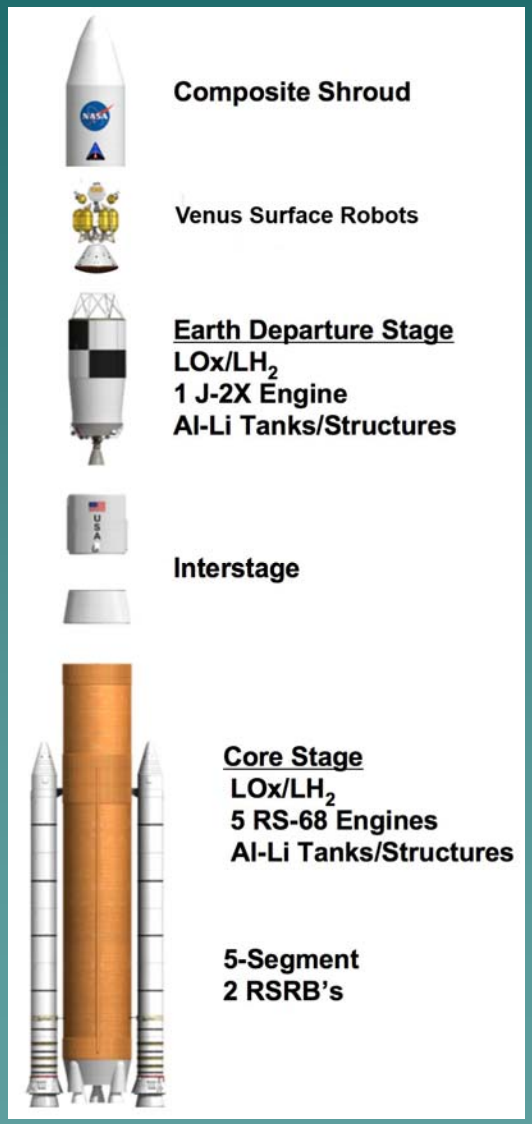


Mars Rovers Spirit and Opportunity

How Can It Be Done?

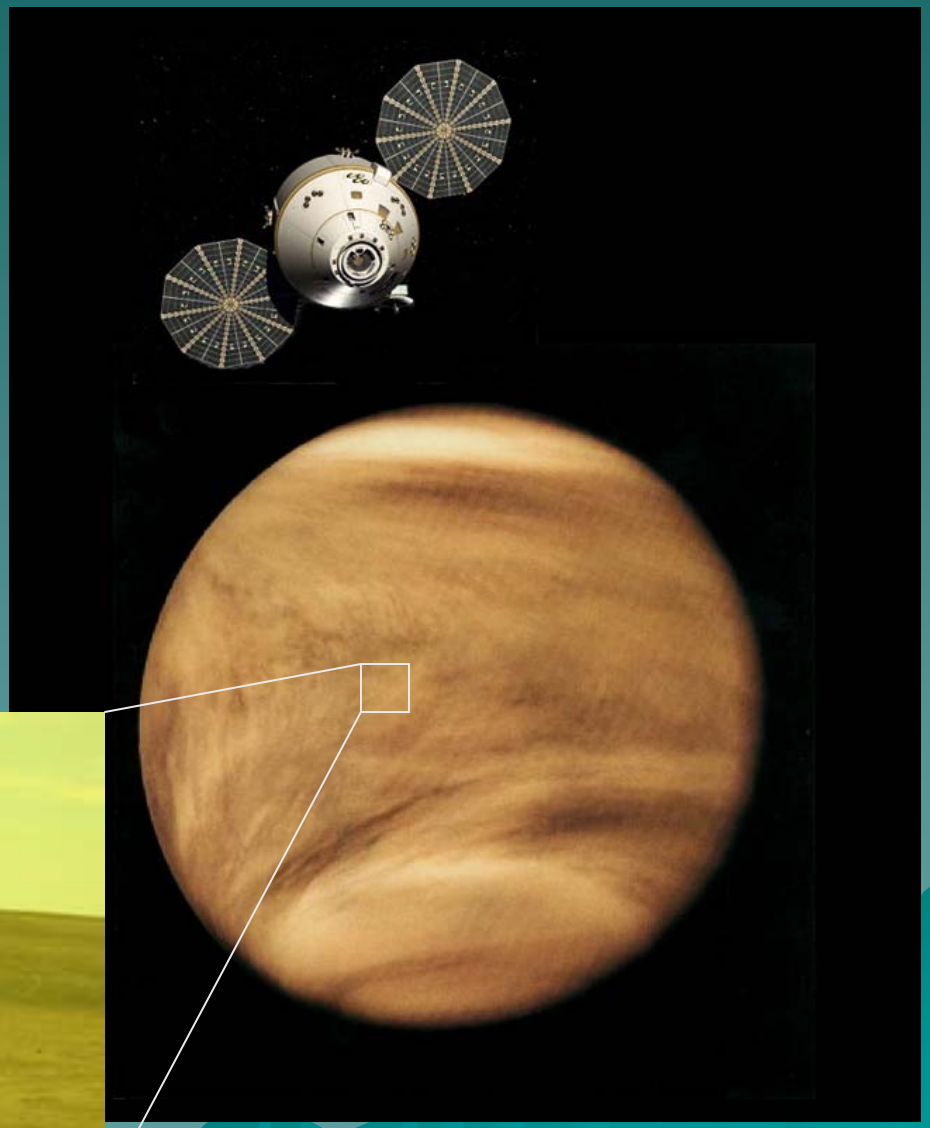
- Robotic field geologists at several locations on Venus are necessary to understand its geologic history. The MERs have shown that this exploration strategy was successful for Mars.
- Vehicles must incorporate some combination of high temperature electronic and mechanical systems, and Stirling-cycle power and cooling. They will be big, heavy, and hot. But they can be built.
- Ares V could enable a human mission to Venus. Remote presence would enable real-time field geologic exploration of Venus from astronauts in Venus orbit.
- Billions of people could participate in the human exploration of the surface of Venus.

Ares V to Venus



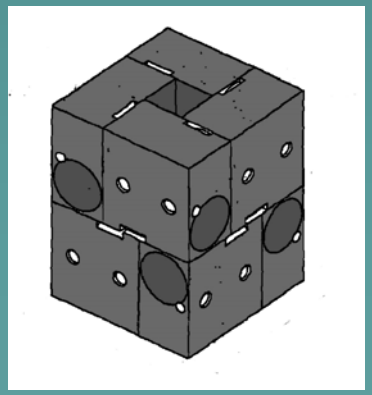
- Ares V can put 40 tonnes in Venus Earth orbit (Spilker, BOETech calculation)
- Interplanetary CEV with human crew – 2 year mission
- Human mission supported by additional Ares V for launching interplanetary cargo module

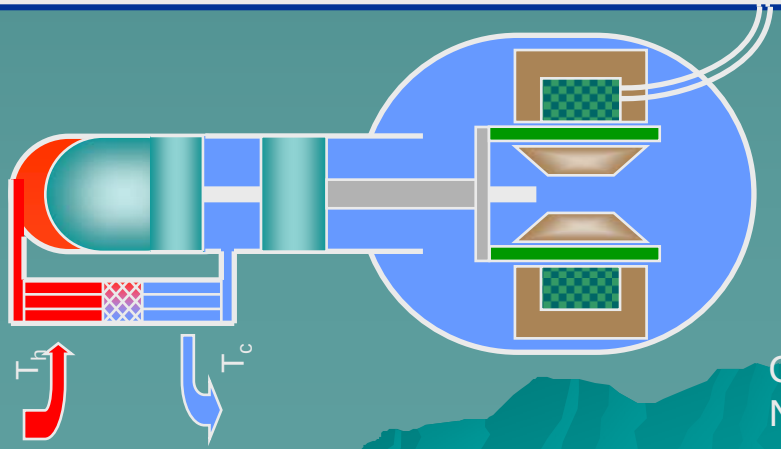
Ares V Human Mission to Venus



Power Conversion

Radioisotope Thermoelectric	Efficiency ~3% on Venus (T_h=850 ºC, T_c=500 ºC) Difficult to couple with efficient active cooling
Radioisotope Free-Piston Stirling	Overall efficiency ~17% on Venus (T_h=850 ºC, T_c=500 ºC) Duplex system couples engine with active cooling
Radioisotope Thermo-Acoustic Stirling	Overall efficiency ~13% on Venus, (T_h=850 ºC, T_c=500 ºC) Duplex system couples engine with active cooling Eliminate displacer with some reduction in performance

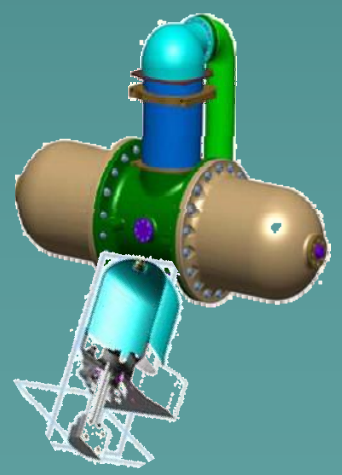




Courtesy Rodger Dyson
NASA Glenn

Cooling

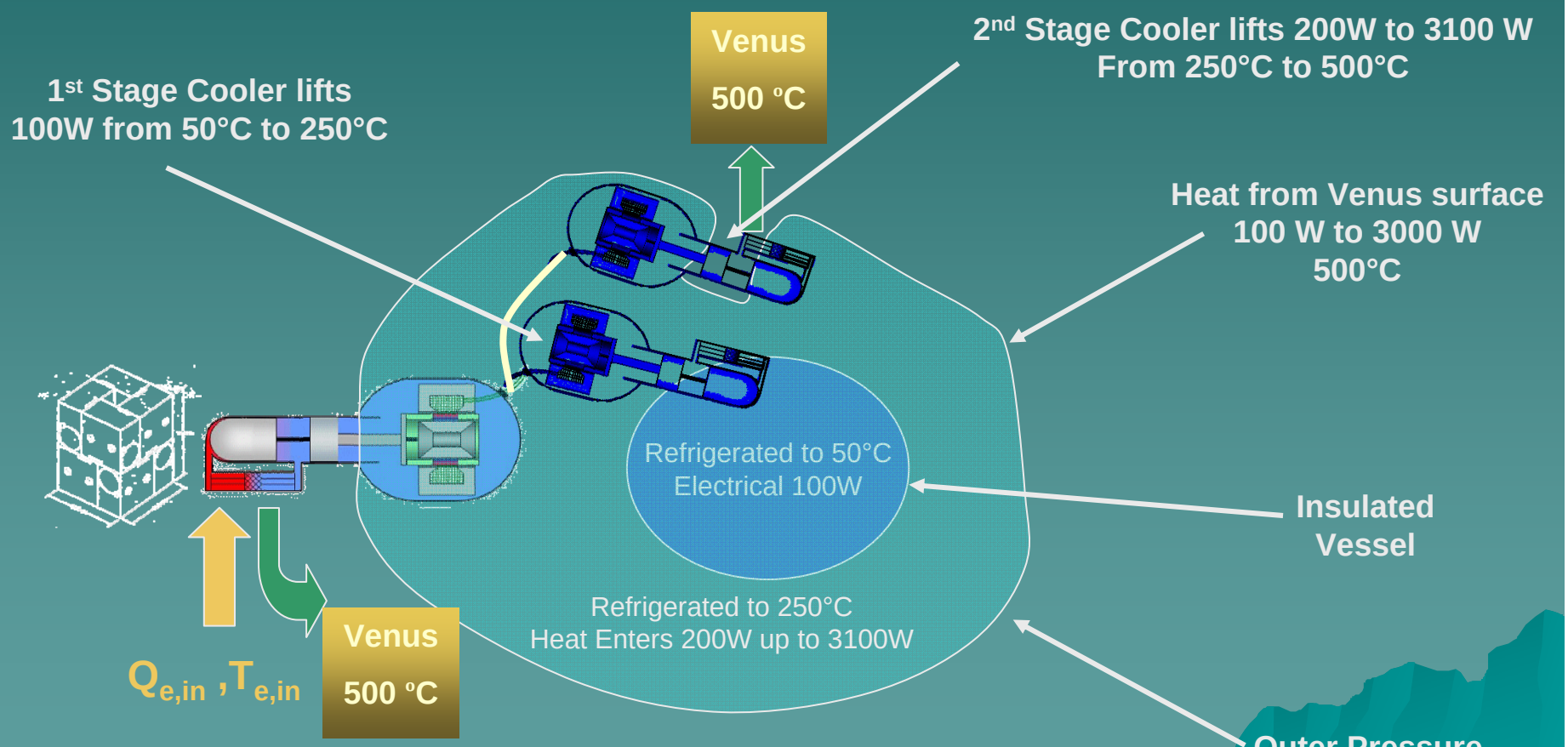
Reverse Brayton	High speed turbomachinery as is currently operating on Hubble Space Telescope
Free-Piston Stirling	Rotating or free piston linear configurations are possible Cryocooler currently operating on NASA spacecraft
Thermo-Acoustic Stirling	Eliminates the need for a displacer Many are currently operating on NASA/DOD/NOAA spacecraft



Northrup Grumman Thermo Acoustic Power Converter with hypothetic pneumatic coupling to cooler

Courtesy Rodger Dyson
NASA Glenn

Power Converter and 2-Stage Refrigerator



Courtesy Rodger Dyson
NASA Glenn

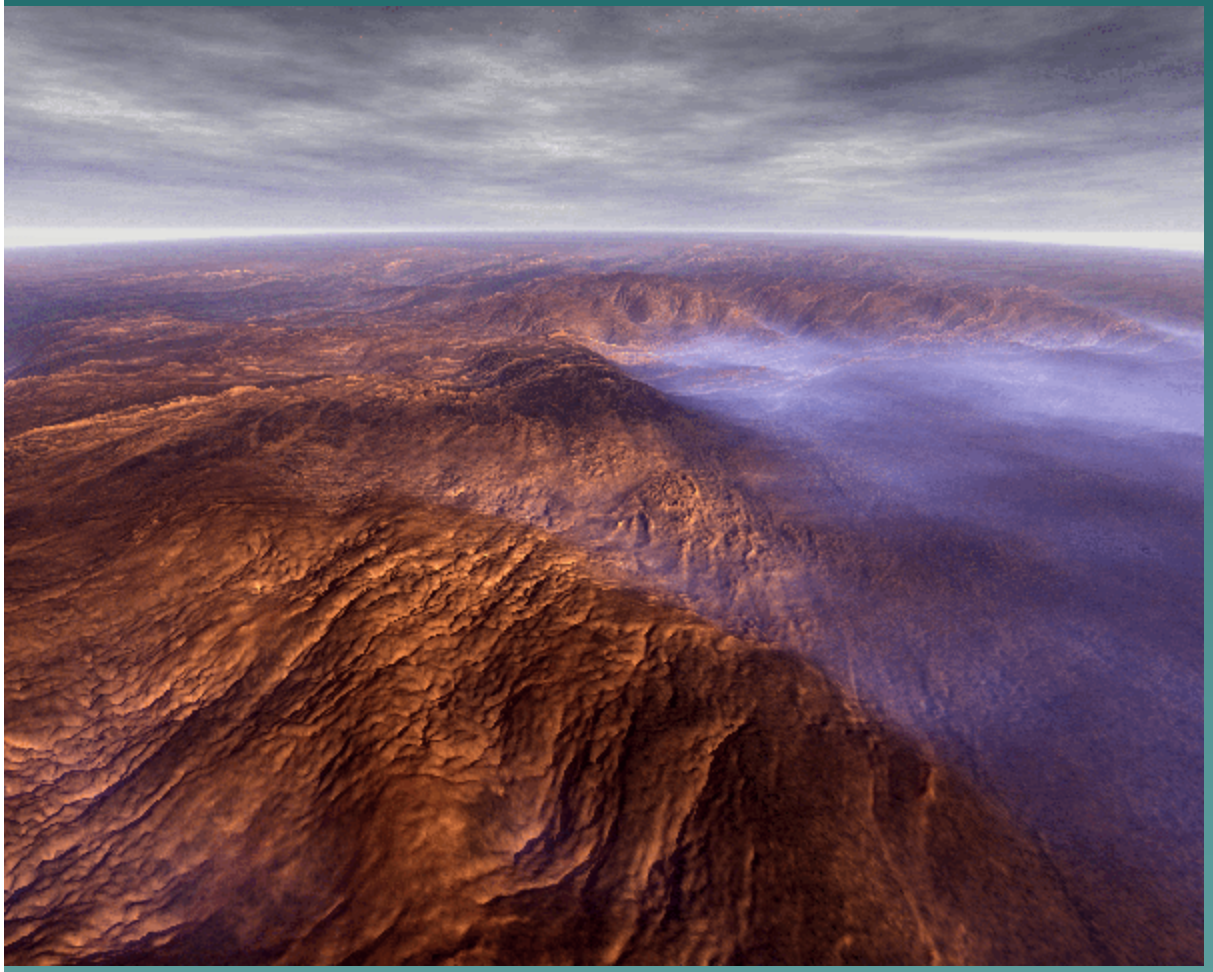
Stirling Cycle – NASA Glenn

- 20 250 W ^{238}Pu GPHSs provide 80 W power and 300 W cooling capacity.
- Stirling cycle power generation, 2 stages of Stirling cycle coolers.
- 5000 W of heat converted to 380 W (7.6% efficiency)
- GPHS + Stirling = 30 W/kg for 17 years
- Power System 167 kg.
- Outer planet missions have up to 40 GPHSs

Enabling Technologies

- Interplanetary CEV (‘Beyond’)
- Ultra-high bandwidth
- High temperature power electronics
- High temperature sensors
- High temperature digital processing and memory
- High temperature motors, actuators, and encoders

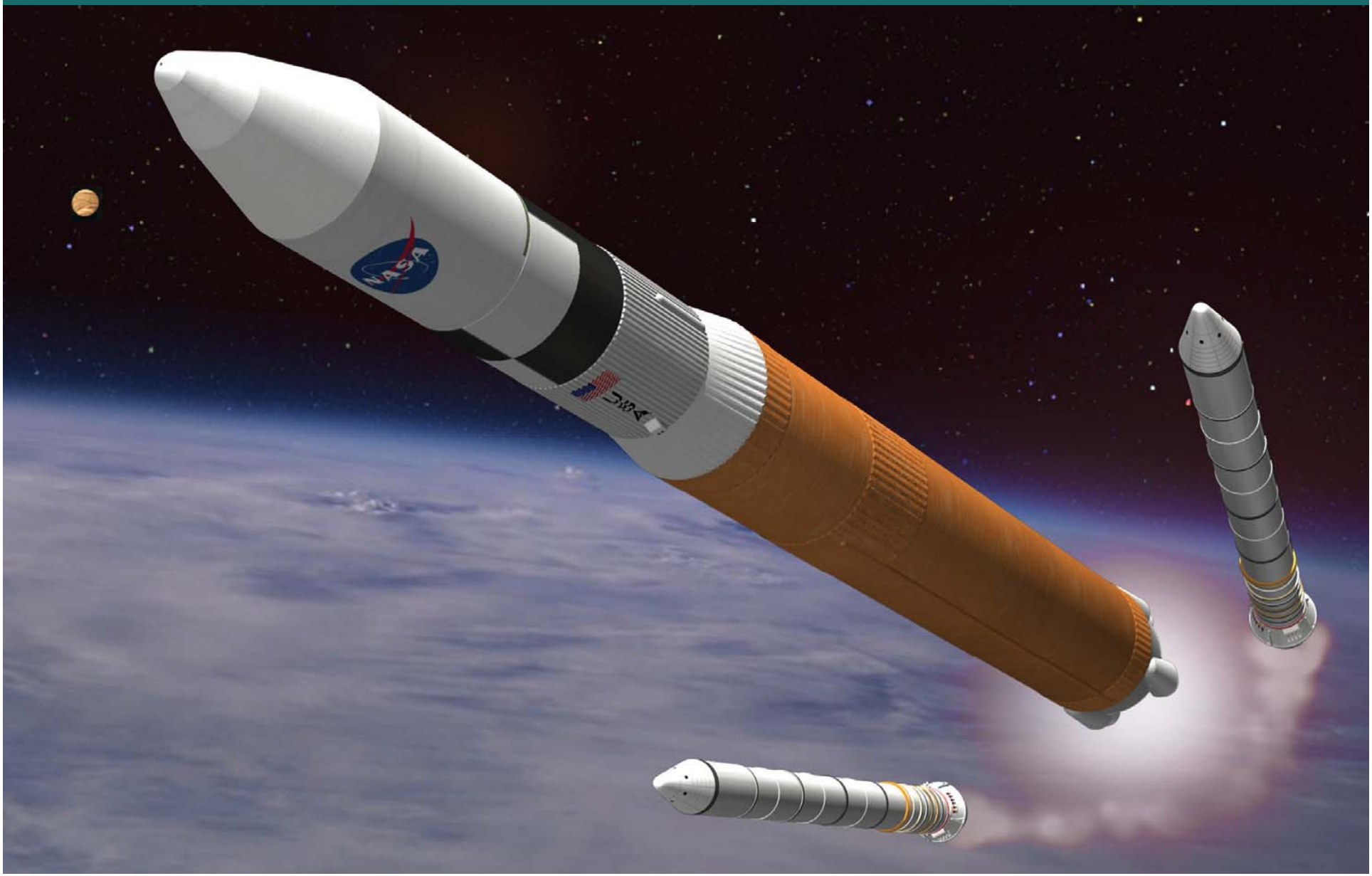
Being on Venus



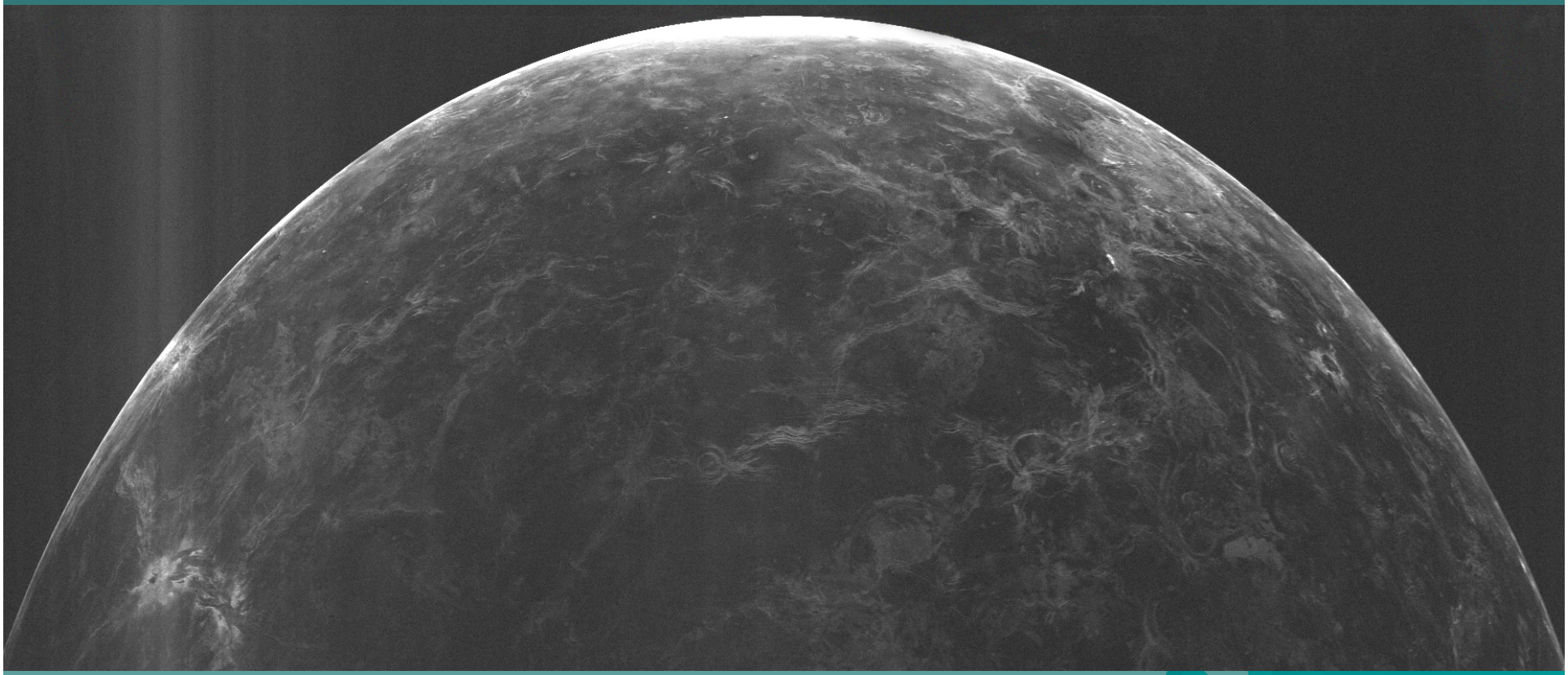
Even at night, it is not dark. The plains and foot of the mountains glow a dull red.

During the day, the diffuse lighting is modulated by cloud variations overhead. Nearby rocks shimmer in the hot, dense atmosphere, almost as if the observer is at the bottom of an impossibly hot ocean.

Ares V Mission to Venus



Venus Horizon



40 tonnes at Venus: What good is it?

- Immersive experience of exploring an unknown world available to all people.
- MERs have shown that doing robotic field geology is possible and extraordinarily rich in science return.
- Time delay required semi-autonomy and excruciatingly slow progress
- Real time field geology at several sites across Venus in order to reconstruct the geological and climatological history of Venus.

Venus Exploration with the Ares V

- Large, capable telepresence robots with nuclear refrigeration that lasts for 17 years on the surface of Venus is readily achievable
- The Ares V could deliver several of these robotic emissaries to the surface of Venus, for doing field geology remotely
- An additional interplanetary CEV with Ares V cargo could put a crew in orbit around Venus, enabling real-time surface exploration and a new destination for human exploration
- Robotic exploration of the surfaces of solar system bodies will become an immersive experience that can be shared by all