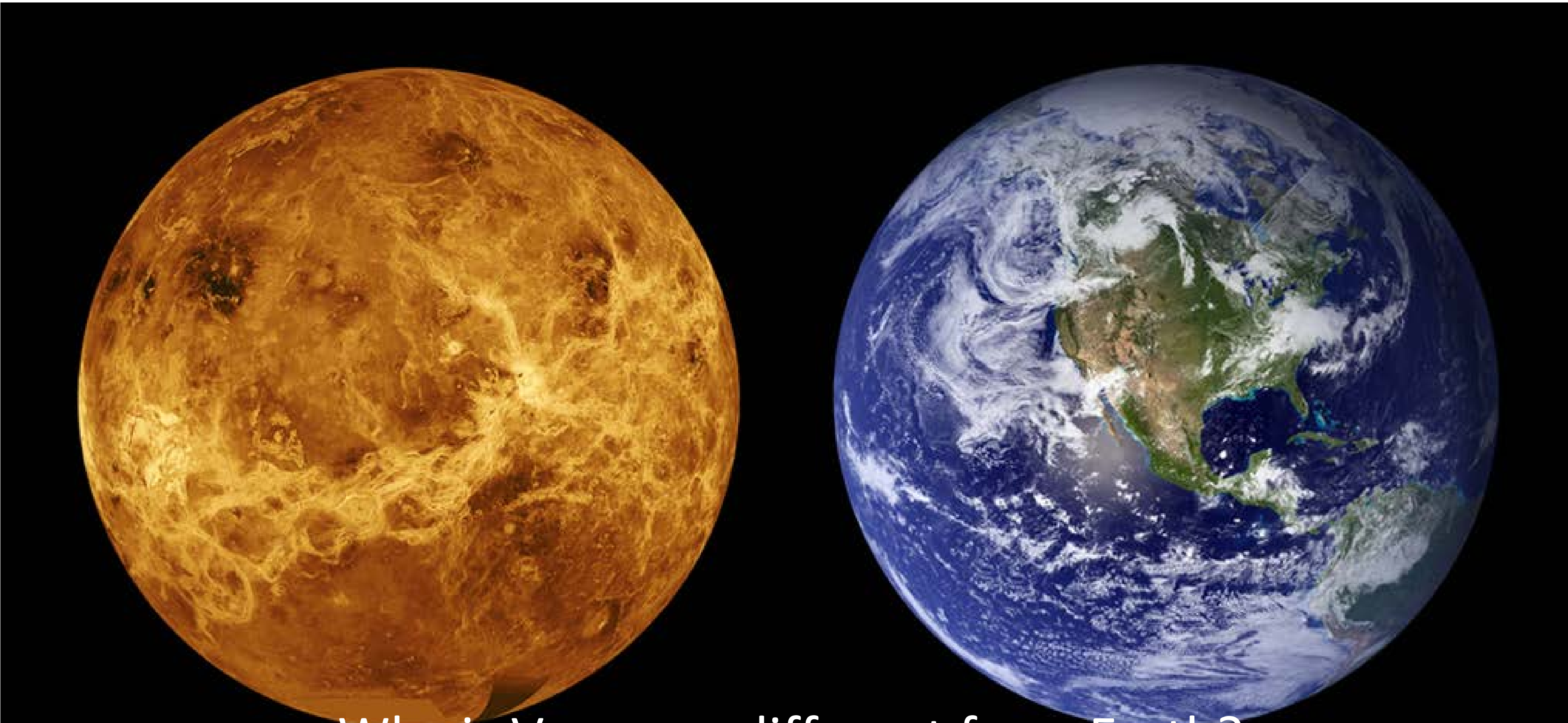
Habitability of Venus: Astrobiology Investigations from SAGE

LW Esposito
SAGE PI
COEL, Woods Hole
8 June 2011

SAGE Science Themes



Why is Venus so different from Earth?

Was Venus ever like Earth?

Does Venus represent Earth's fate?

Science Team

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- Richard Starr (GSFC)
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- Nicolas Thomas (U. Bern)
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- Alian Wang (Wash U.)
- Chris Webster (JPL)
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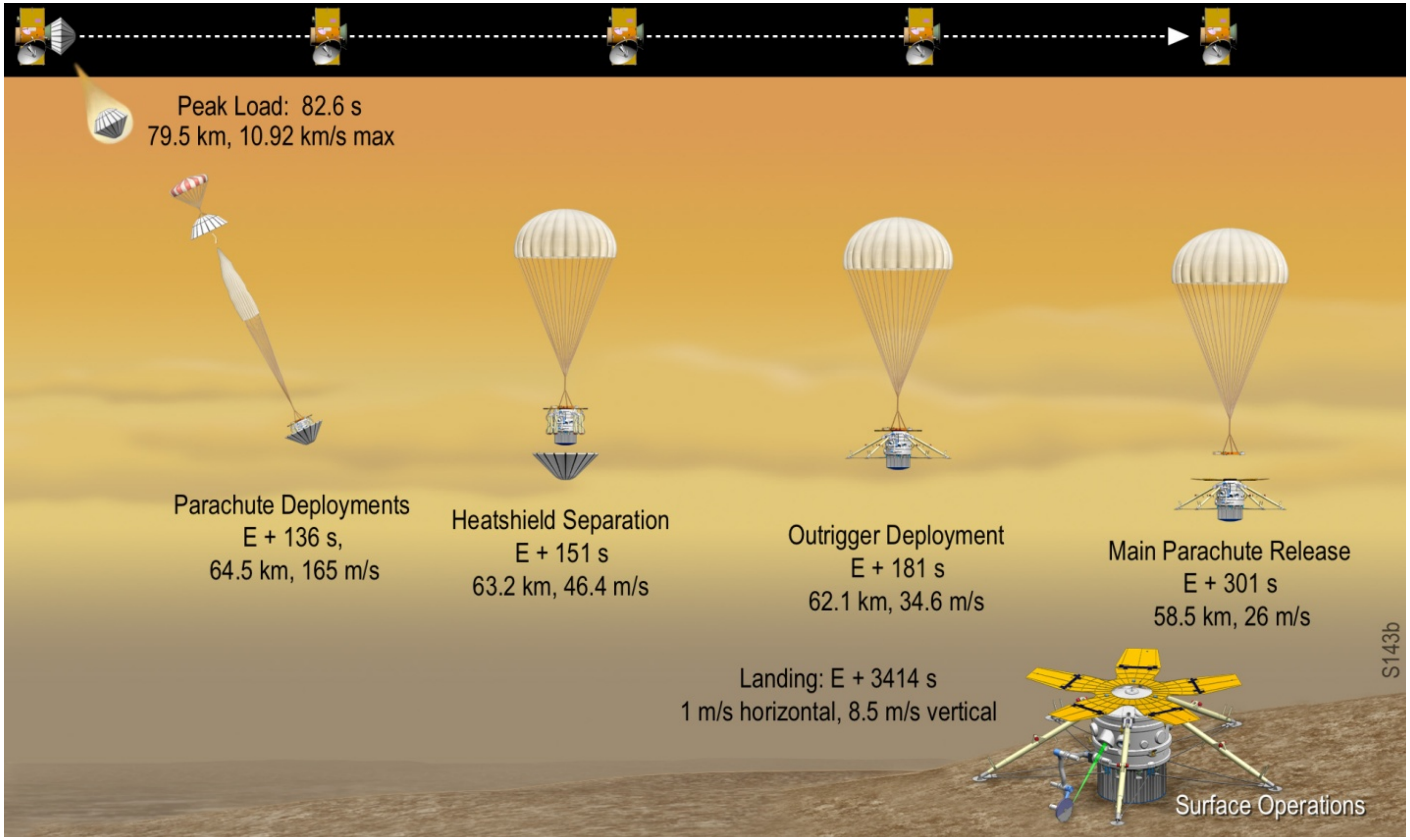
- Yuk L. Yung (Caltech)
- Kevin Zahnle (ARC)

Entry, Descent, and Landing



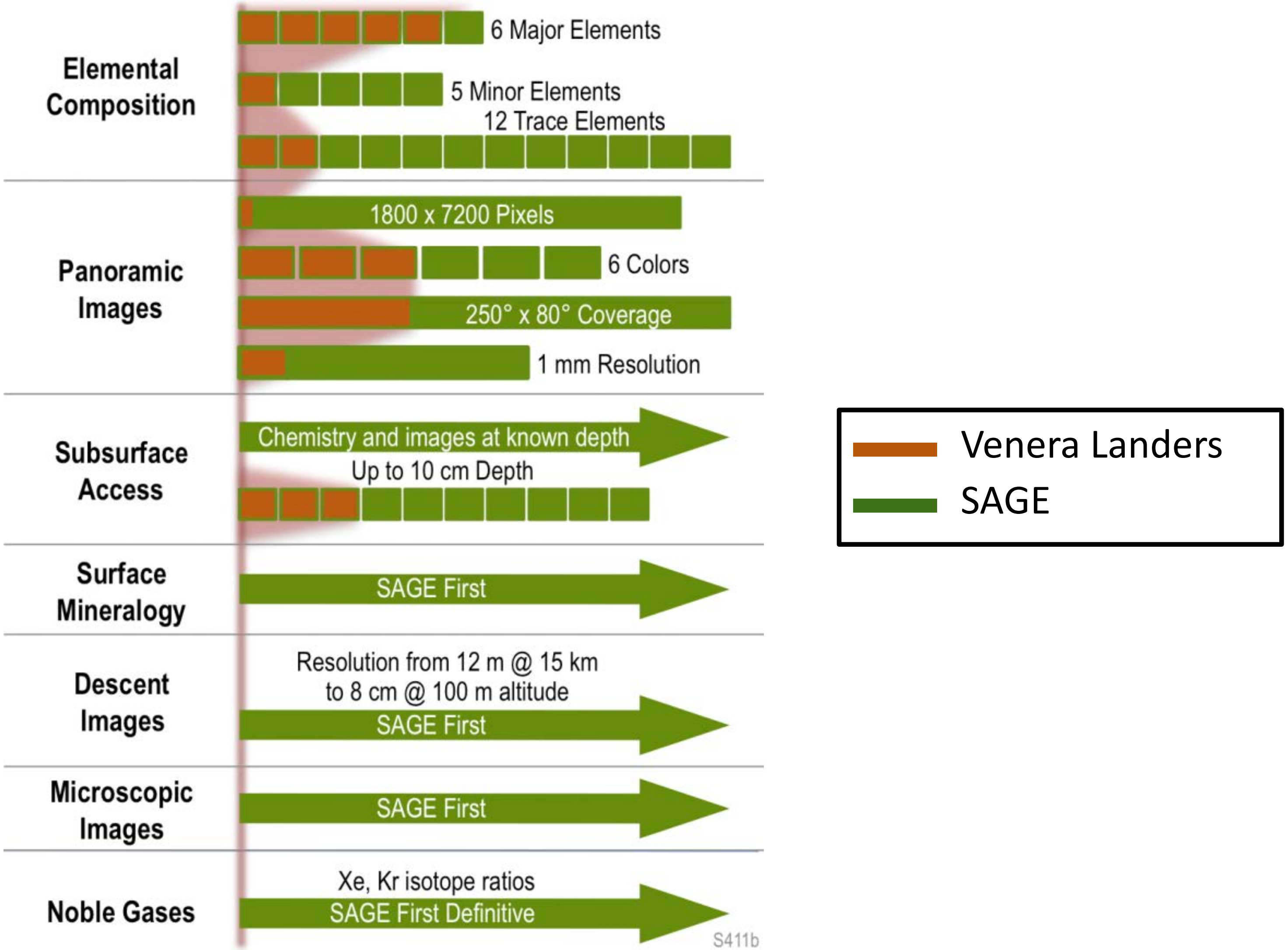
SAGE measures atmospheric composition in one hour and surface

The SAGE Payload

SAGE Student Dust Detector (S2D2) Interplanetary Dust assessment between Earth and Venus	**LASP**	**Space-borne Dust**
Flyby Camera (FBC) UV and NIR imaging for entry context and cloud dynamics	**IKI**	**Atmospheric Dynamics**
Atmospheric Structure Investigation (ASI) Measure temperature, pressure, dynamics, and wind speed	**ARC**	
Tunable Laser Spectrometer (TLS) Measure stable isotope ratios	**JPL**	**Atmospheric Composition**
Neutral Mass Spectrometer (NMS) Measure major, trace, and noble gas species	**GSFC**	
Descent and Panoramic Cameras (DPC) First-time nested descent imaging; multiple surface panoramas	**MSSS**	**Surface Geology and Weathering**
Microscopic Camera (MC) High-resolution imaging of Raman/LIBS site	**MSSS**	
Neutron-Activated Gamma-Ray Spectrometer (NAGRS) Measure major, minor, and trace surface and subsurface elements	**IKI**	**Surface and Subsurface Composition and Mineralogy**
Raman and Laser-Induced Breakdown Spectrometer (RLS) Measure surface and subsurface minerals and elements	**LANL**	
Surface Excavation Subsystem (SES) Excavate trench to expose subsurface material	**CSA**	

Space
Atmosphere
Surface
Subsurface

SAGE Capability and Firsts



Most Important Science Result: Understand Terrestrial Planet Evolution

- Formation
  - Noble gases identify the source of early volatiles in the solar system and volatile history on Venus
  - Elemental composition constrains the core size and time of formation

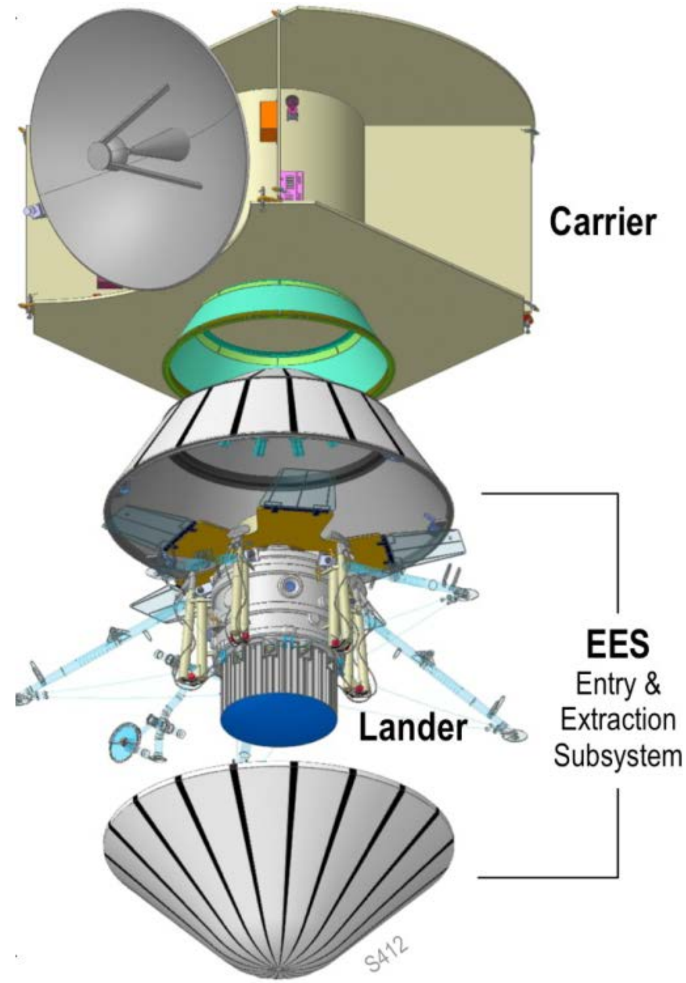
- Present day
  - Mineralogy determines what gases interact with the surface, buffering atmospheric composition and impacting climate
  - Trace gases govern climate evolution
  - Descent images provide ground truth for Magellan radar and Venus Express emissivity
  - Surface mineralogy determines if the rocks are young and relatively unweathered, providing an approximate age and a tie point for resurfacing history

- Future of Earth and other Terrestrial planets

Our most compelling science driver is understanding the evolution of terrestrial planets, including formation, volatile evolution, and climate

SAGE Flight Elements and Team Members

- Carrier (LM)
  - Electra telecom (JPL)
  - Flyby Camera (IKI)
  - S2D2 (LASP)
- Entry & Extraction Subsystem (LM)
  - Aeroshell and parachutes (LM)
  - Event Timer Module (JPL)
  - Pyro Firing Assembly (JPL)
  - Telecom antenna (JPL)
- Lander (JPL)
  - Science Instruments (various suppliers)
  - Surface Excavation Subsystem (CSA)
  - Avionics (LM)



Bringing Venus to Diverse Audiences:

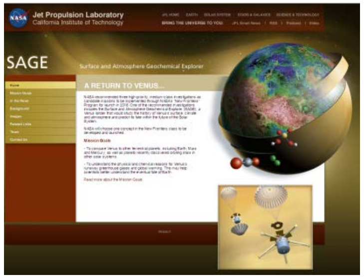
SAGE E/PO Management/Working Group

Planetarium Show (DMNS/JPL)

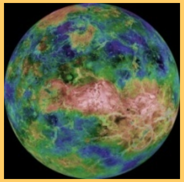
Explore! Library Module (LPI)

Educator Workshops (LPI/LASP/JPL)

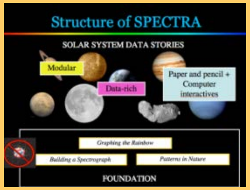
Public Outreach (JPL)



SAGE Documentary (DMNS/JPL)



Formal Education Products (LASP)



Media PD Workshop (ECA)

SAGE E/PO End-To-End Evaluation (RMC)

Engage the public with the challenge of the Venus environment (sulfurous clouds and surface hot enough to melt lead), and then compare to Earth! Was

Astrobiology and Venus Exploration

- Putting Earth habitability in context: Venus has rare planetary qualities of astrobiological interest.

- The possibility of extinct or extant life.

- The future of life on Earth.

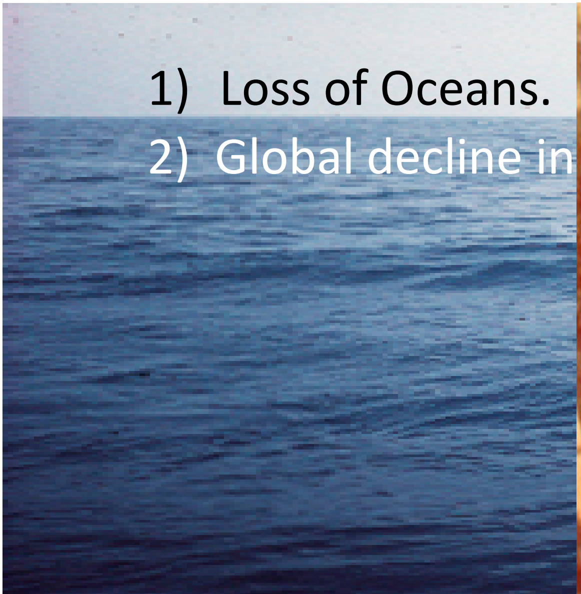
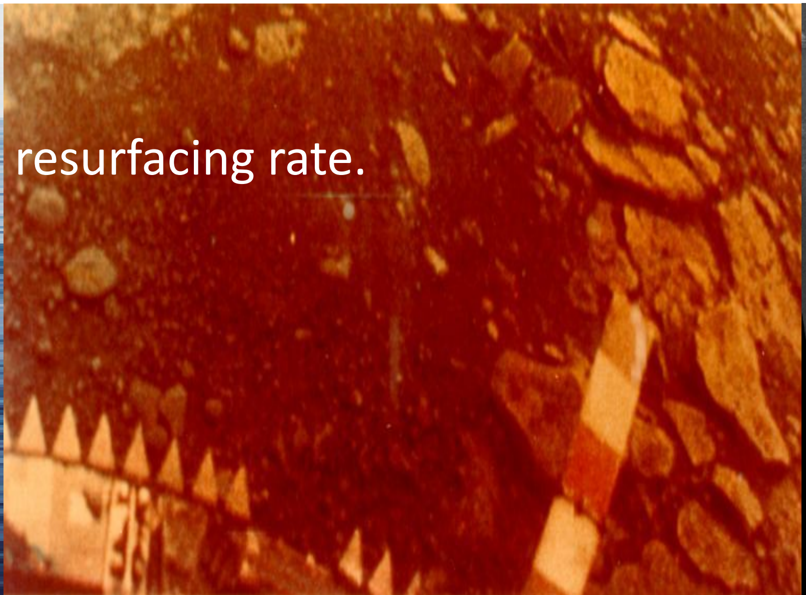
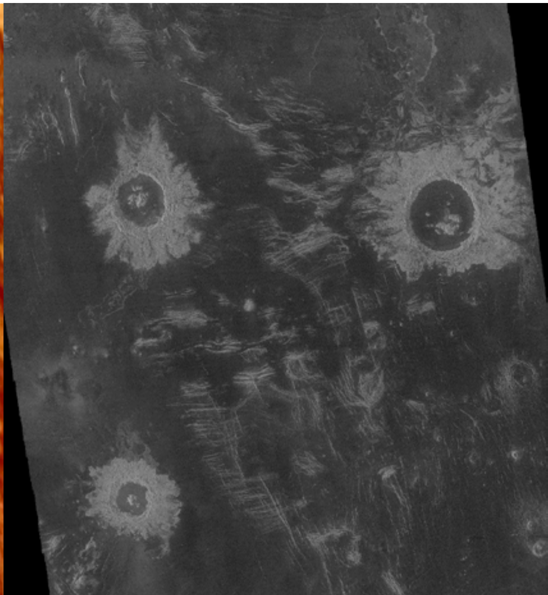
Putting Earth's Habitability in Context

- Who kept its ocean longer, Venus or Mars? How was the habitable area distributed in the inner solar system?
- Understanding the longevity of oceans and loss mechanisms on terrestrial planets of differing size, composition and proximity to stars of various stellar types, and the range of physical parameters which facilitates plate tectonics, is key to defining stellar habitable zones.
- Further exploration of Venus will address this cause, and provide context for extrasolar terrestrial planet discoveries.

Longevity of an Early Venus Ocean?

Kasting (1988) in many ways optimized to get rid of ocean quickly:

- Calculations produce **upper limit** on surface temperatures (and therefore upper limit on escape fluxes, and lower limit on lifetime of ocean).
- **Clouds excluded.** No cloud feedback which, qualitatively, is expected to stabilize surface temperatures with rising solar flux, and therefore extend the lifetime of the moist greenhouse.
- Preliminary new results (Grinspoon and Bullock, DPS 2004) suggest that the oceans of Venus may have persisted for ≈ 2 Gy. Venus may have been a habitable planet for much of Solar System history.
- Did Venus experience one great transition or two?

1) Loss of Oceans.
2) Global decline in resurfacing rate.

History of Venus: A Unified Scenario

- ≈ 2 Gy Loss of surface water, subduction of hydrated sediments ceases.
- Mantle becomes desiccated.
- Lack of water makes lithosphere thicker & more difficult to break.
- Loss of asthenosphere -> lithosphere is tightly coupled to mantle.
- Crustal recycling is inhibited.
- ≈ 1 Gy Plate tectonics ceases, Venus becomes a "1 plate planet"
- ≈ 700 My, global resurfacing rate declines precipitiously.
- 700 My to present: localized volcanism and tectonism, conductive heat release, production population of craters.

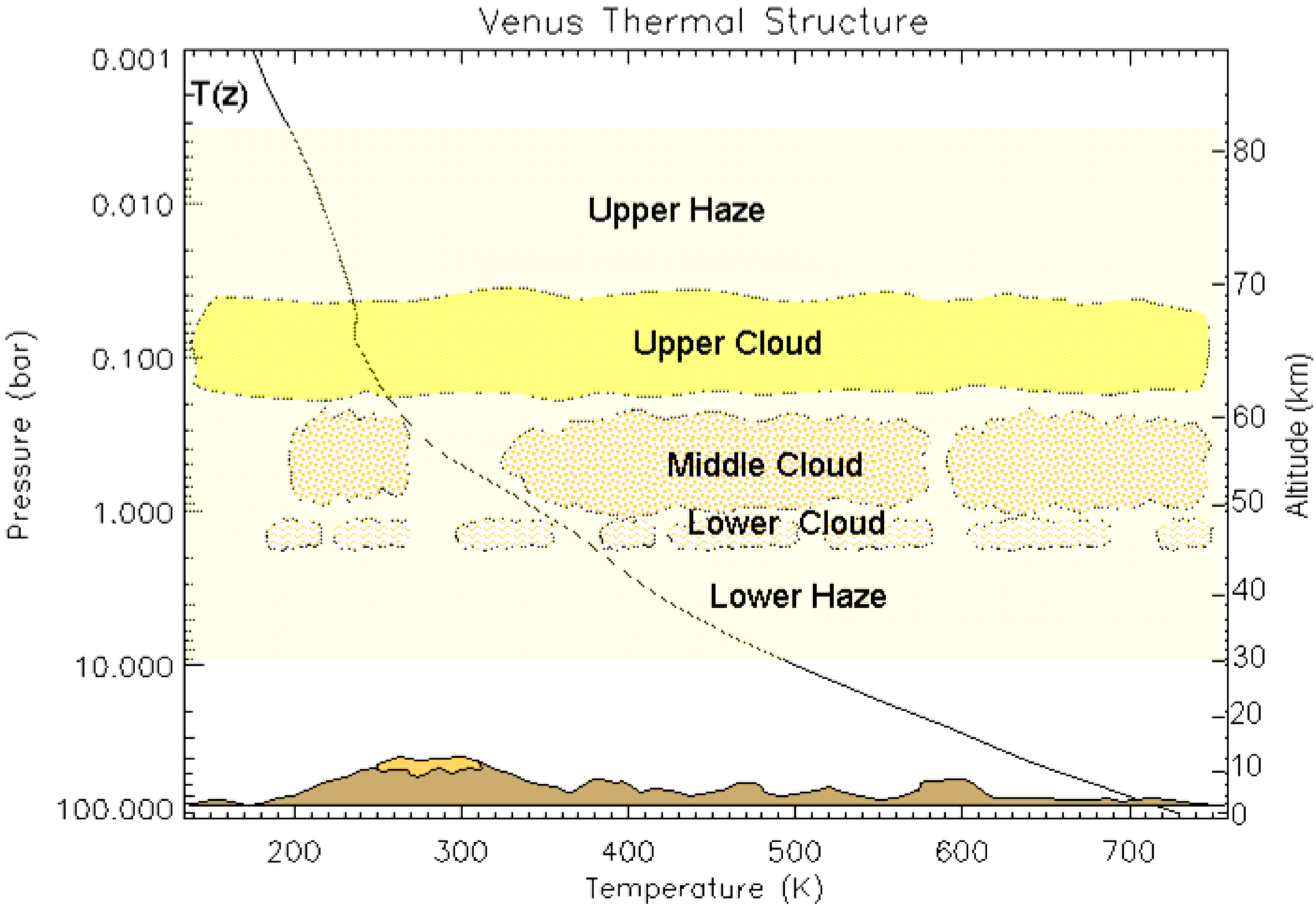
  – Tessera are remnants of more vigorous past tectonics. (continents?)
  – Plains record "global resurfacing", or at least an epoch of much higher resurfacing rates that ended "suddenly" enough to allow very few craters modified by plains volcanism.
  – Venus may have been a habitable planet (with an oxygenated atmosphere) for much of Solar System history.

Putting Earth's Habitability in Context

- Venus is our only other example of
  - an Earth-sized terrestrial planet.
  - a "currently active" terrestrial planet.
- Most of surface is young
- Endogenous geological activity and surface chemistry may control the atmosphere and climate.
- Climate history and surface history are thus coupled.
- Many extrasolar terrestrial planets will probably be "Venus like".

The Possibility of Extant Life

- Longevity of oceans remains highly uncertain. During an extended period of water loss, Venus probably enjoyed an oxygenated atmosphere.
- When young, the terrestrial planets were constantly exchanging material, perhaps forming a polybiosphere
- Favorable environmental conditions for origin or transplantation of life.
- As surface conditions became hostile, life could have adapted to an atmospheric niche under directional selection.



Venus Thermal Structure
T(z)
Upper Haze
Upper Cloud
Middle Cloud
Lower Cloud
Lower Haze
Pressure (bar)
0.001
0.010
0.100
1.000
10.000
100.000
Altitude (km)
80
70
60
50
40
30
20
10
0
Temperature (K)
200
300
400
500
600
700

Properties of Venus Clouds Hospitable to Life

• Global clouds are much larger, more continuous, and stable than clouds on Earth. Particle lifetimes of months (Grinspoon et al, 1993).

• Large "mode 3" particles at lower cloud level (~ 50 km altitude)
  -- 1 bar atm pressure
  -- ~350 K
  -- make up most of the mass of the cloud deck
  -- may contain an unknown, non-absorbing core material which comprises up to 50% by volume of the particles (Cimino, 1982; Grinspoon et al. 1993).

• Superrotation of atmosphere shortens duration of the night

• Chemical disequilibrium => coexistence of H_2 and O_2
  H_2S and SO_2

The low pH limit of Terrestrial life is not known.

Several organisms have now been discovered that grow at very low pH

For example, the archaeon *ferroplasma acidarmanus* thrives at pH 0.

A Sulphur-Based Survival Strategy for Putative Phototrophic Life in the Venusian Atmosphere

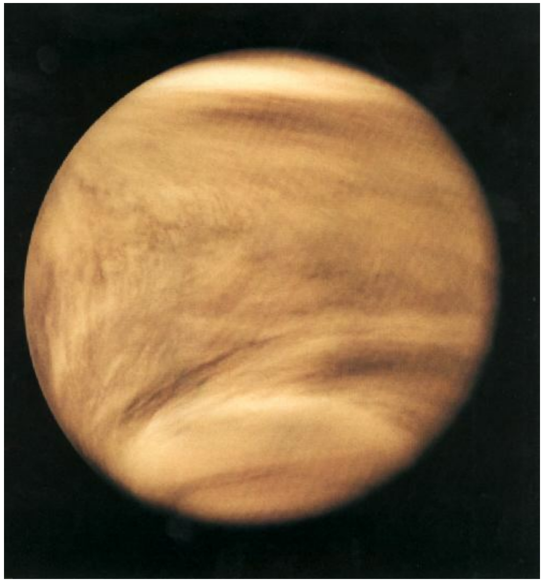
D. Schulze-Makuch, D.H. Grinspoon, O. Abbas, L.N. Irwin & M. Bullock (2004) .
Astrobiology, 4, 11-18.

Abstract

Several observations indicate that the cloud deck of the Venusian atmosphere may provide a plausible refuge for microbial life (Sagan, 1961; Grinspoon, 1997; Schulze-Makuch and Irwin, 2002; Schulze-Makuch and Irwin, 2004). Having originated in a hot proto-ocean or been brought in by meteorites from Earth (or Mars), early life on Venus could have adapted to a dry, acidic atmospheric niche as the warming planet lost its oceans. The greatest obstacle for the survival of any organism in this niche may be high doses of ultraviolet (UV) radiation. Here we make the argument that such an organism may utilize sulphur allotropes present in the Venusian atmosphere, particularly S_8, as a UV sunscreen, as an energy converting pigment, or as a means for converting UV light to lower frequencies that can be used for photosynthesis. Thus, life could exist today in the clouds of Venus.

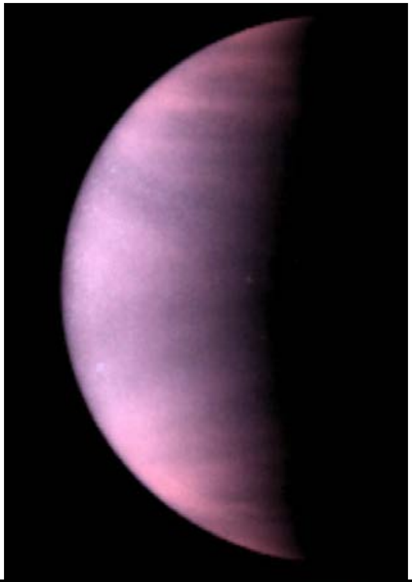
The Future of Life on Earth

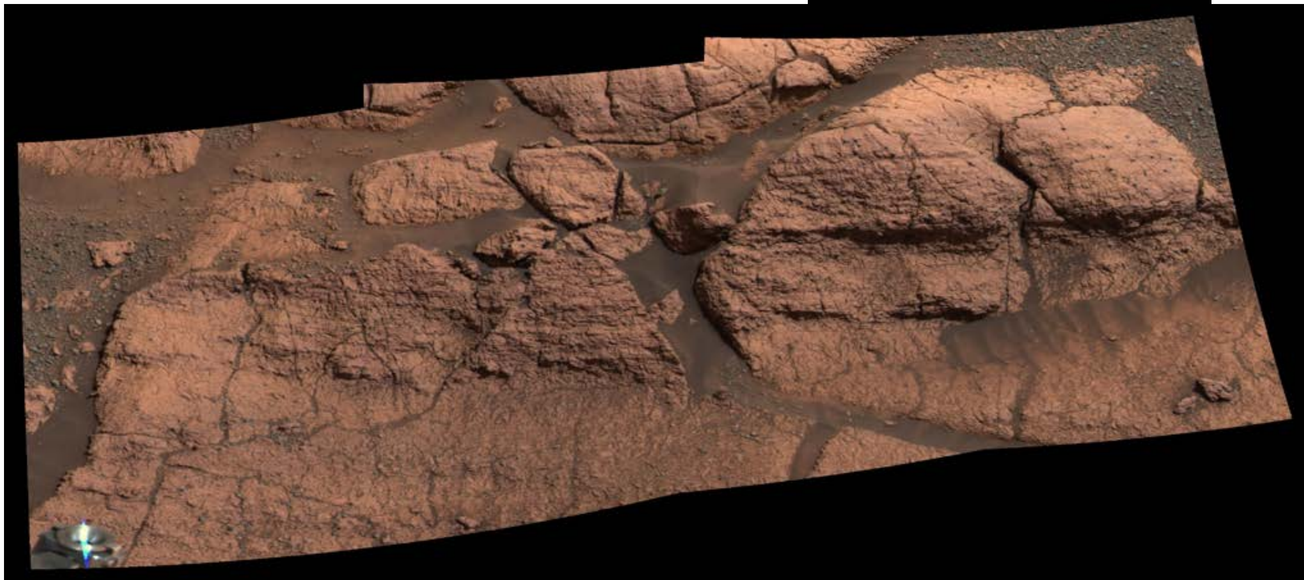
- In about 1 Gy, the Earth may experience a runaway H_2O greenhouse (Kasting).
- Currently, there are regions of the tropical oceans that are in this runaway state (McKay et al).



Increasing Relevance for Early Mars

- Both planets have sulfur-rich environments.
- Both planets may have experienced a watery past, followed by an acidic phase as they desiccated.





Astrobiology Questions Requiring Further Exploration:

- How and when was surface water lost? What is the history of climate?
- History of surface and interior?
- Mineralogy, evidence for water, isotopic biomarkers, zircons?
- Equilibrium state of lowest scale height?
- Origin and history of atmosphere from noble gases?
- Unknown UV absorber? Composition of mode 3 cloud particles? Evidence for chemical disequilibrium?
- How does atmospheric circulation affect cloud particle lifetimes?
- Trace constituents in clouds & surrounding atmosphere? Do these indicate biological activity?
- Have clouds been a constant feature? (or at least continuous?)

These are identical to questions to be answered in the next stage of Venus exploration!

Why SAGE is timely

- Fills a crucial gap in understanding planet formation and evolution

- Venus provides an extreme case to compare to climate change on Earth

- Helps interpret habitable zone exoplanet discoveries