Technology for Entry Probes

James A. Cutts [1], James Arnold[2], Ethiraj Venkatapathy[2], Elizabeth Kolawa[1] , Michelle Munk[3], Paul Wercinski[2] and Bernard Laub [2]

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(1) , Jet Propulsion Laboratory, (2) Ames Research Center, (3) Marshall Space Flight Center

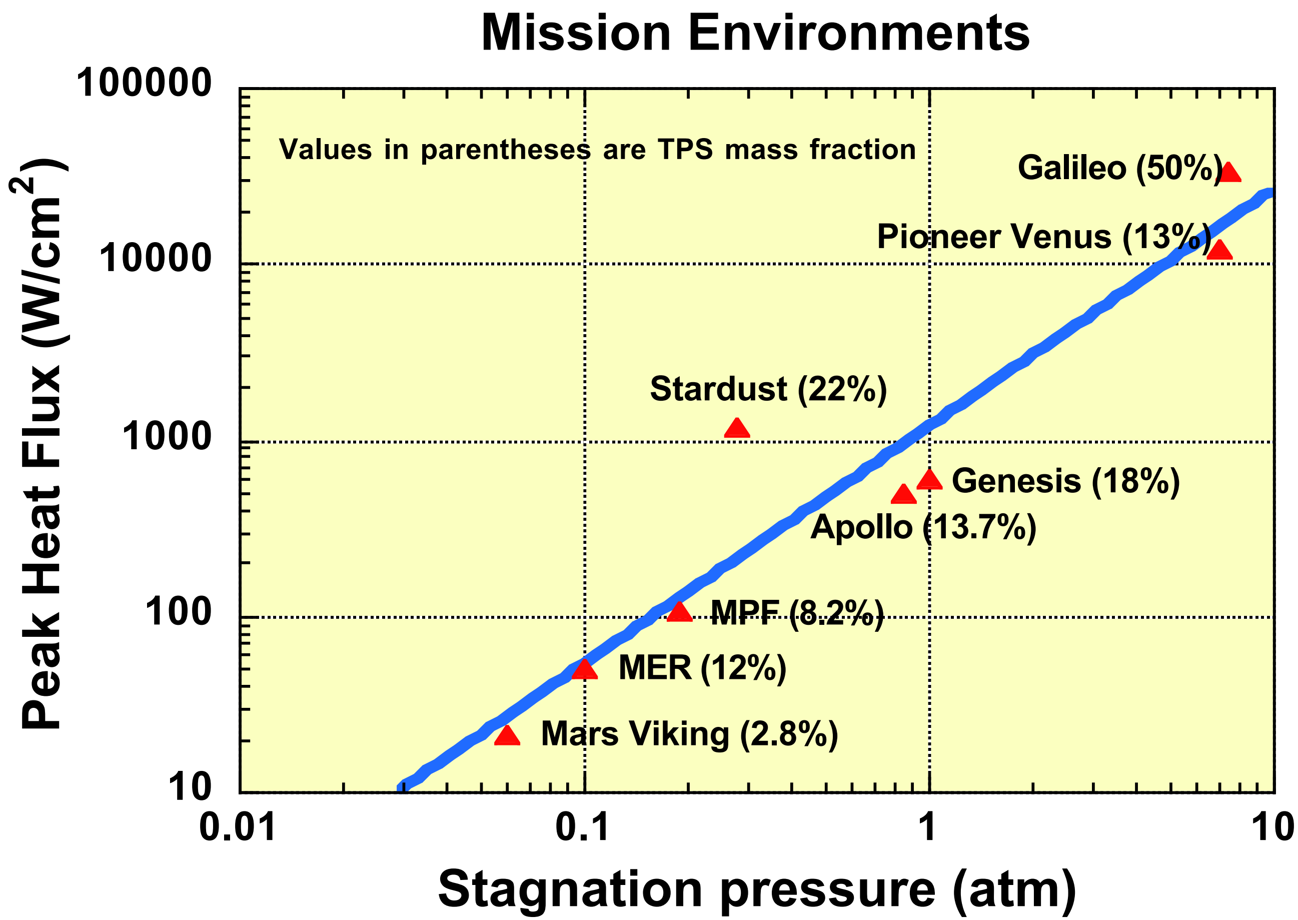
Topics

- Entry Phase
- Descent Phase
- Long duration atmospheric observations
- Survivability at high temperatures
- Summary

Entry Phase

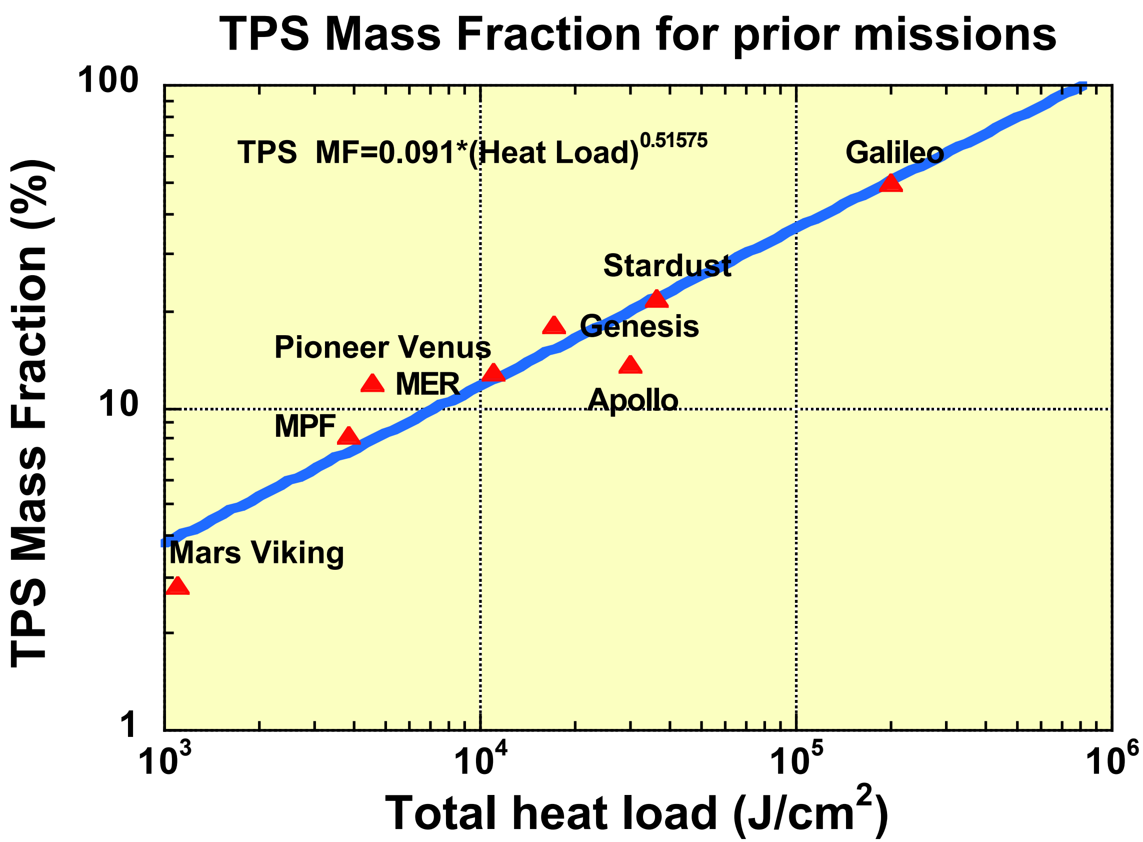
- Range of Entry Environments
- Thermal Protection System (TPS) mass fraction
- Lessons learned from Galileo

Broad Range of Entry Environments



NASA entry probes have successfully survived entry environments ranging from the very mild (Mars Viking ~25 W/cm^2 and 0.05 atm.) to the extreme (Galileo ~30,000W/cm^2 and 7 atm.)

TPS Mass Fraction



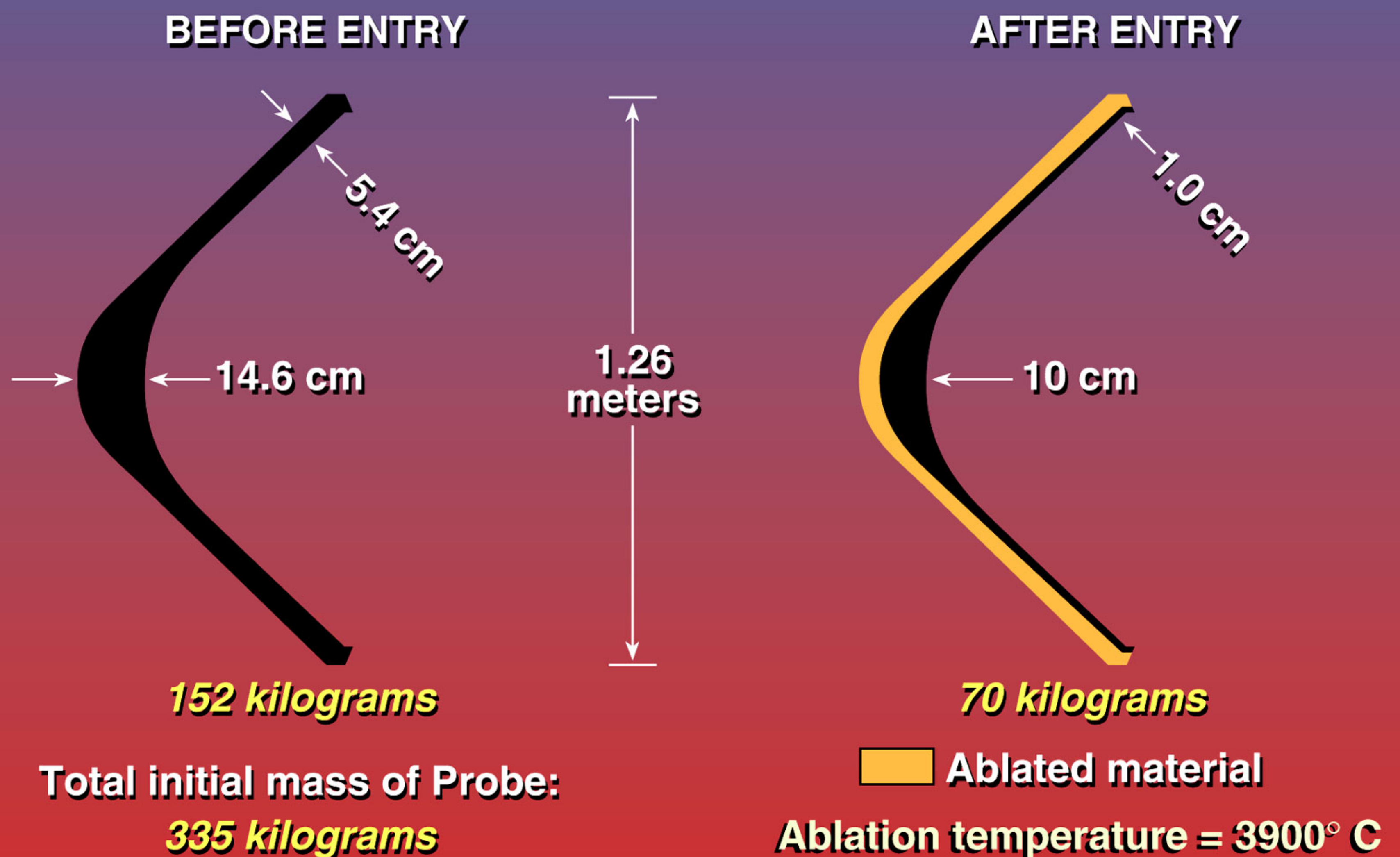
- TPS material selection requires an assessment of the entry environment and trade between ablation and insulation performance
- Pioneer-Venus with 13% TPS mass fraction is an excellent example of TPS optimization for a very demanding mission
  - High heat fluxes
  - High pressures
  - Relatively modest total heat load
  - Carbon phenolic (not a very good insulator but an excellent ablator) was a good choice.

The TPS mass fraction for an entry probe is a strong function of the total integrated heat load (e.g., ≈ 50% for Galileo) and the TPS material optimal performance characteristics.

Jupiter Missions
Lessons Learned from Galileo

- Fully dense carbon phenolic (ρ = 1450 kg/m^3) was employed as the forebody TPS on Galileo
  - 45° blunt cone aeroshell, V_e = 47.4 km/s
  - qmax ≈ 35,000 W/cm^2; Qmax ≈ 200 kJ/cm^2 (convective + radiative)
- TPS qualification testing:
  - Giant Planet Facility at NASA Ames (arc jet)
    - H_2-He gas mixture; very high heat fluxes (convective and radiation)
  - CW CO_2 lasers (high heat fluxes, but small spots)
- TPS Design tools
  - 70s vintage engineering tools
    - Coupled chemically-reacting boundary layer and shock layer in the presence of thermochemical ablation and some spall
- Flight instrumentation (ablation sensors)
  - Galileo flight recession data not explained by current physical models
  - Uncertainty in coupled environment/ablation physics

Galileo Probe Heat Shield Ablation:
The Most Difficult Atmospheric Entry in the Solar System

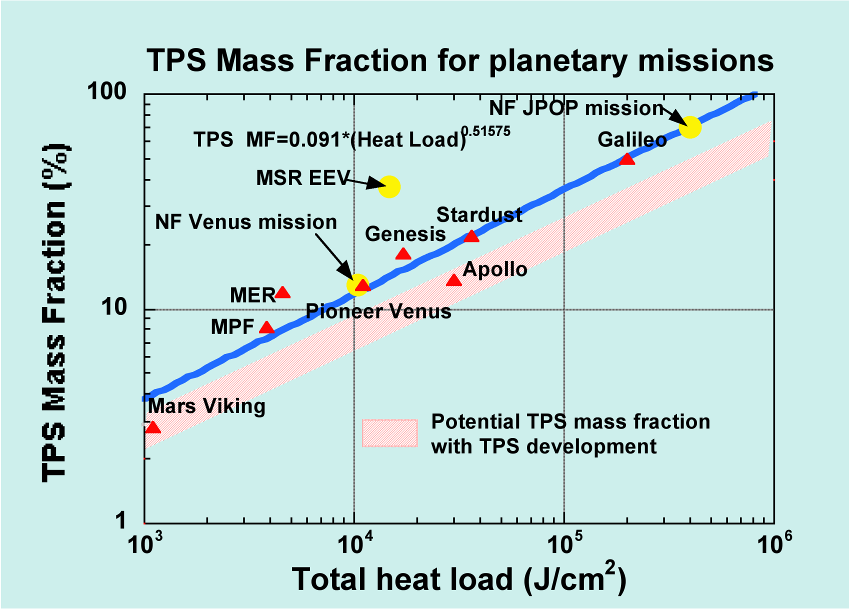


TPS Challenges for Future Jupiter Mission

- Carbon Phenolic (CP) the only *heritage* material
  - Equatorial entry will require higher TPS mass fraction compared to Galileo (based on Galileo flight data)
  - Higher latitude mission (~ 55km/sec) too severe for CP (60-70% TPS mass fraction)
  - Advanced materials required to reduce TPS mass fraction
- Physical models not validated; improvements required
  - Galileo flight recession data not explained by current physical models
  - Uncertainty in coupled environment/ablation physics
- Investment Strategies and Benefits
  - Develop new TPS approaches to reduce the mass fraction requirements by 30-50%
  - Re-establish Giant Planet Facility
  - Resurrect, update, improve 70s vintage tools
    - Adapt computational techniques developed over past 15 years to these new applications
    - Update physical models using ground test data

Summary - TPS Development Required

- Little ablative TPS development work in the USA over the past 20+ years
  - NASA has already done the "easy" missions with materials (for the most part) developed over 30 years ago
- NASAs ambitious exploration vision requires TPS *innovations*
  - Future missions require TPS not currently available
  - New TPS materials, ground test facilities, and improved analysis models are required and will take some time to develop
  - Advances and improved TPS capabilities will benefit an array of missions (and *enable* some)



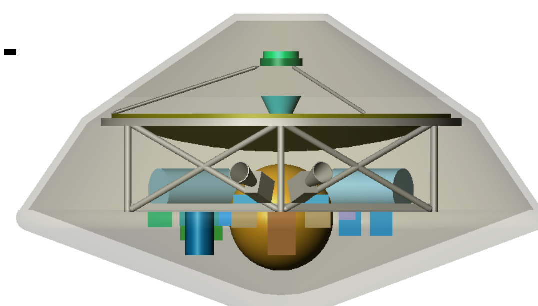
- TPS mass fraction requirements for proposed New Frontiers missions (e.g., JPOP- 70%) and Sample Return Missions (MSR especially) become prohibitive/demanding with use of existing materials
- TPS Technology development can (potentially) lead to 20%-50% savings in TPS mass fraction.

Titan Aeroentry

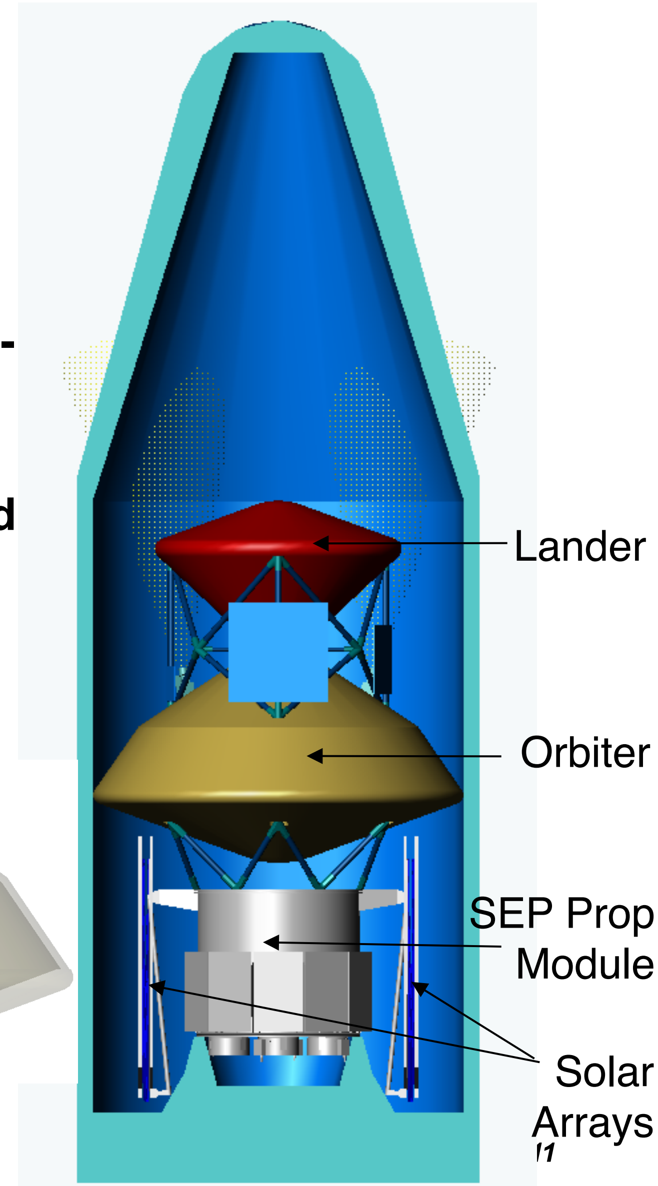
- Titan Aerocapture Systems Study
- Carbon-nitrogen radiation at Titan
- Implications for Huygens and future aerocapture missions

Titan Aerocapture Systems Study & Cassini/Huygens

- In 2002, In-Space Propulsion funded a detailed systems definition study for aerocapturing an orbiter at Titan
- The study showed that aerocapture at Titan was feasible, robust, and enabling -- compared to an all-propulsive orbit insertion -- from a mass and trip time perspective
- Expected improvements in the Titan ephemeris and atmosphere model resulting from Cassini and the Huygens probe, improved the margin in the aerocapture design
- A detailed aerothermal analysis revealed larger-than-expected radiative heating levels, due to the methane in Titan's atmosphere, which could have implications for Huygens



3.75 m diameter Aeroshell

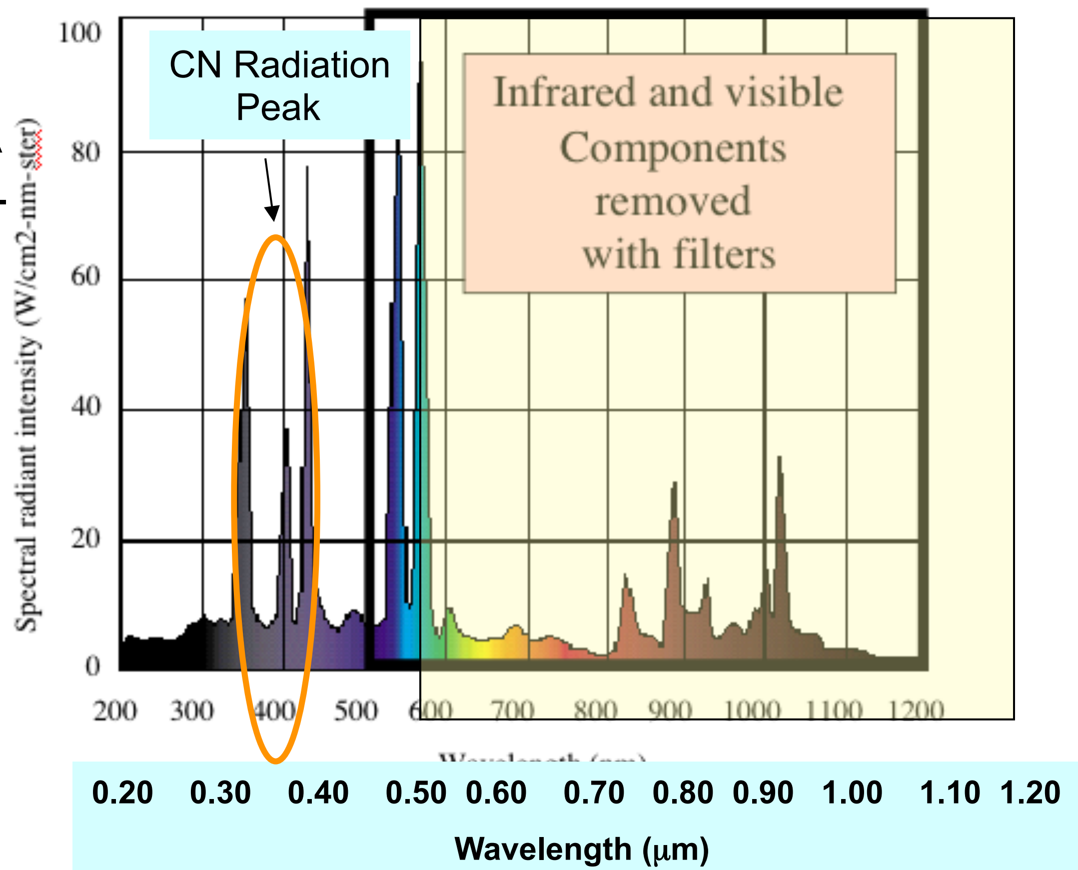


23 August 2004

Carbon-Nitrogen (CN) Radiation at Titan

- Nonequilibrium formation of CN results in predicted radiative heating rates 3 - 5 times the convective heating rates
- CN radiation is emitted in a narrow band in the UV with peak at 3800 Å
- Interaction of CN radiation with low-density, porous TPS materials is of concern
- Identified commercially-available mercury-xenon lamp capable of simulating wavelengths and heat fluxes of interest
- Lamp is in operation at ARC, testing candidate low-density ablative materials for In-Space Propulsion, and the Huygens TPS (AQ-60) for ESA
- Results are pending

Mercury-xenon lamp spectrum



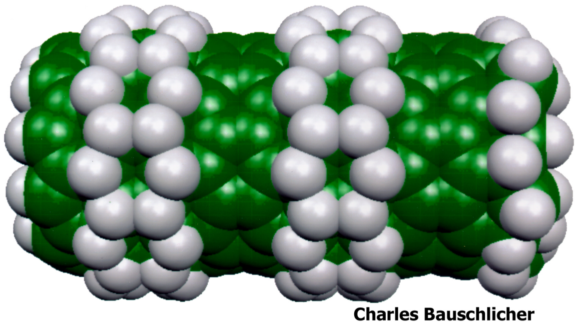
Ref.: Bernie Laub/Michael Wright

Nanotechnology and Atmospheric Entry Technology

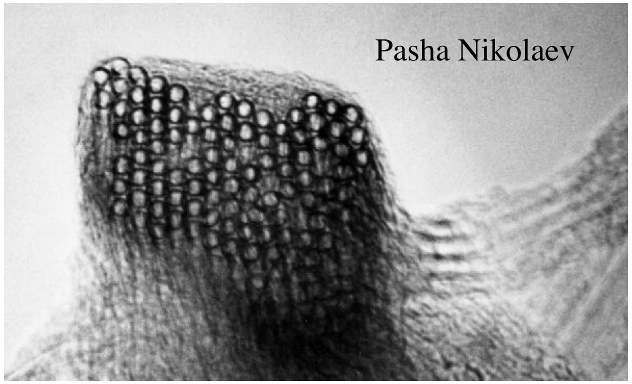
Nanotechnology is the creation of **USEFUL/FUNCTIONAL** materials, devices and systems through control of matter on the nanometer length scale and exploitation of novel phenomena and properties (physical, chemical, biological) which arise due to that length scale (NNI)

Experimental and Computational Synergy

Hydrogenated CNT



Micrograph of CNT Rope



Carbon Nanotubes

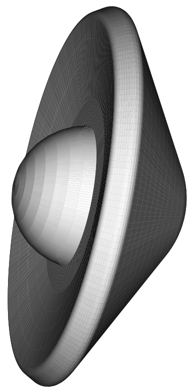
- Tensile Strength 100 X Steel at 1/6 weight
- Thermal Conductivity 2 X Diamond
- Electrical Conductivity 7 X Copper & Semiconductor
- Surface area of 4 grams CNT = Football Field
- U of Tx: CNT Composite Fibers: 4 X Tensile Strength of Spider Silk and 17 X Kevlar

Purpose of Study

- Scope potential application of Nanotechnology to NASA's Thermal Protection Systems Materials (TPS) Problems
- Earth Entry: Examples
  - > Out of Orbit sharp leading edge vehicle
  - > Out of Orbit Apollo/CEV
  - > High Speed Mars Sample Return
- Mars Entry Example
  - > Mars Entry Human Aerocapture plus Out of Orbit Entry

Mars Surface Sample Return
Earth Entry Vehicle (EEV) Overview

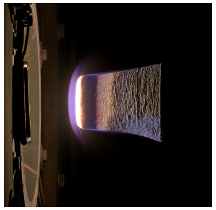
Technology Development Areas



Flight Dynamics
Demonstrate vehicle stability and re-orientation capability

EEV stability testing in LaRC CF4 tunnel

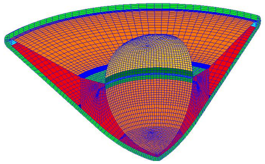
Carbon-phenolic testing in Ames arc-jet



Thermal Protection System
Develop heat shield technology with demonstrated performance and flight heritage

Atmospheric Interface

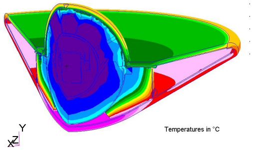
Heat Pulse



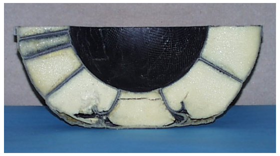
NASTRAN structural analysis model

Vehicle Structure
Determine physical properties and failure modes for carbon-carbon

Vehicle Sterilization
Develop methods to sterilize uncontained contamination during Earth entry



PATRAN thermal analysis model



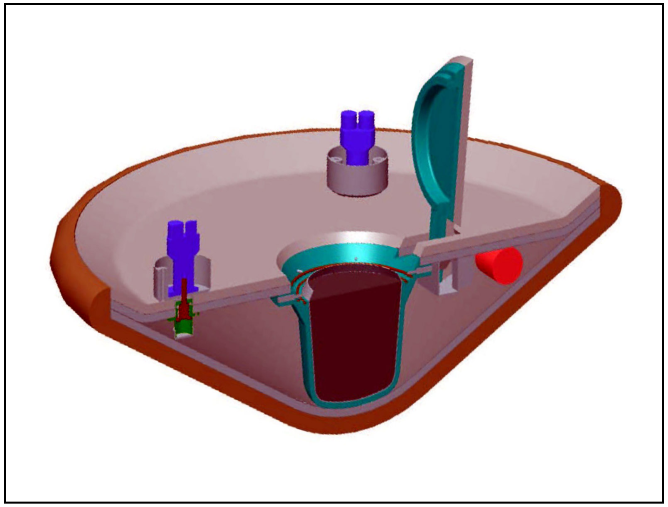
Cellular structure cutaway

Impact Protection System
Develop and demonstrate energy absorption technology for ground impact

Sample Return Vehicles

Technology Development Areas

- Robust architectures and SRV designs
  - Improve tolerance to delivery errors and aerodynamic uncertainties – increasing reliability and simplifying mission designs
- Low-mass aeroshells and TPS
  - Reduce SRV mass – enabling multiple return vehicles and reducing entry and landing loads
- Sample protection
  - Develop reliable sample transfer and canister systems – protecting samples from Earth's atmosphere, entry environments, and landing shocks
- Planetary protection
  - Mitigate back planetary protection risks (at Earth) – enabling for Mars Sample Return mission (MSR)



Descent Systems

- Parachutes
- Advanced Decelerators

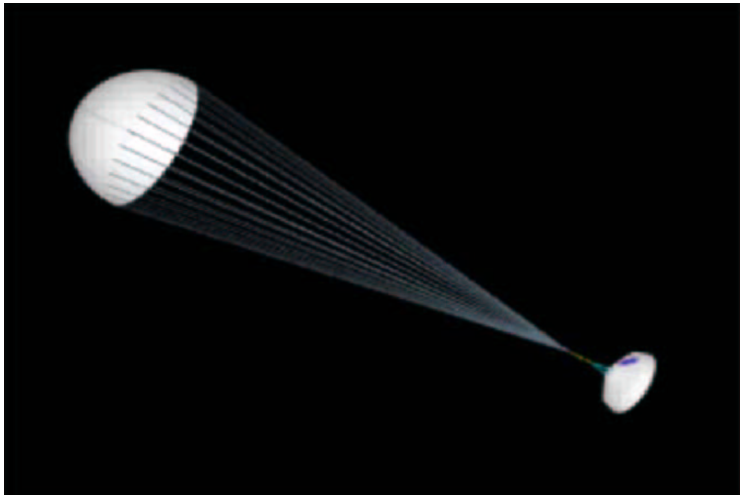
Parachutes

Heritage

Missions: Viking, Pioneer Venus, Galileo, Mars Pathfinder, MER, Cassini/Huygens

Designs - 20° Conical Ribbon, Disk-Gap-Band

Materials - Polyester /Dacron, Kevlar (lines & risers)



Technology Challenges

Material Issues - hard vacuum, thermal (cruise & entry), ionizing radiation, extra-terrestrial atmospheres, aging, planetary protection

System Configuration Issues - launch vibrations, thermal expansion & contraction, cleanliness (sensitive instruments), ESD

Performance - inflation, drag & stability predictions (high reliability), aerodynamic testing

Performance Goals

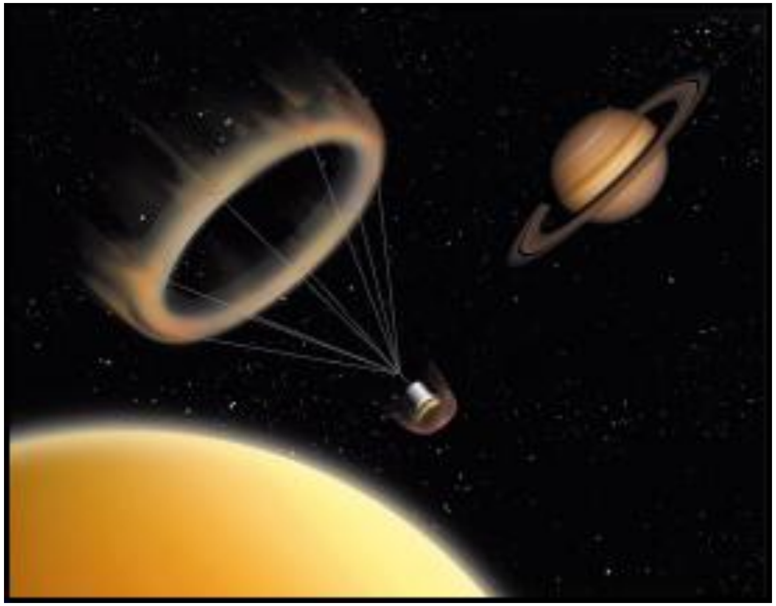
Supersonic Chutes: Increase deployment capability to Mach 3.0 – enables more landed mass to the surface at Mars

Optimize parachute designs – providing required drag, stability and steerability for lower mass fractions

Advanced Simulation - improve CFD, chute behavior, and multi-body dynamics simulation capabilities – lowering parachute development costs

Advanced Decelerators
Inflatable Aeroshells & Ballutes

- Thin-film and fabric inflatables - lowering entry system ballistic coefficients and enabling:
  - Increased payload mass and volume fraction
  - Access to surface destinations at higher elevations
  - Reduced entry environments

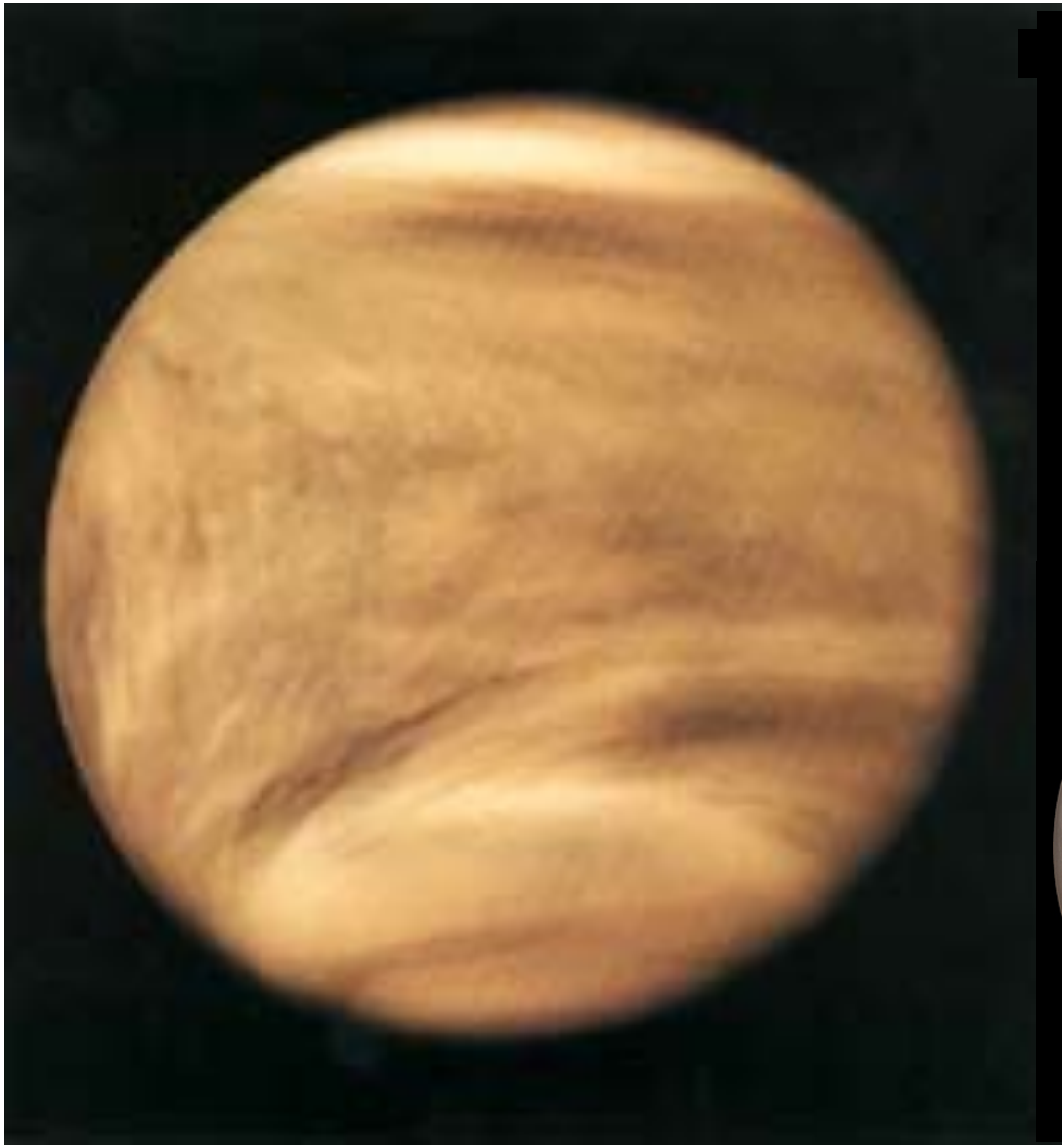


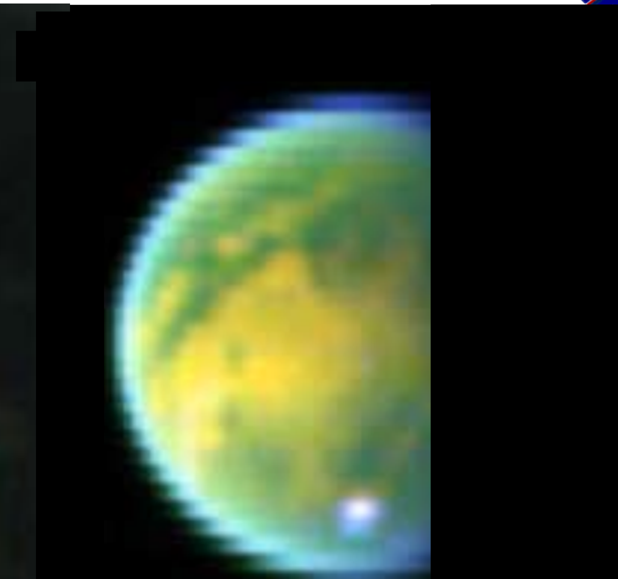
Challenge: Ballutes & Inflatable Heat Shield Extensions will be costly to certify for flight

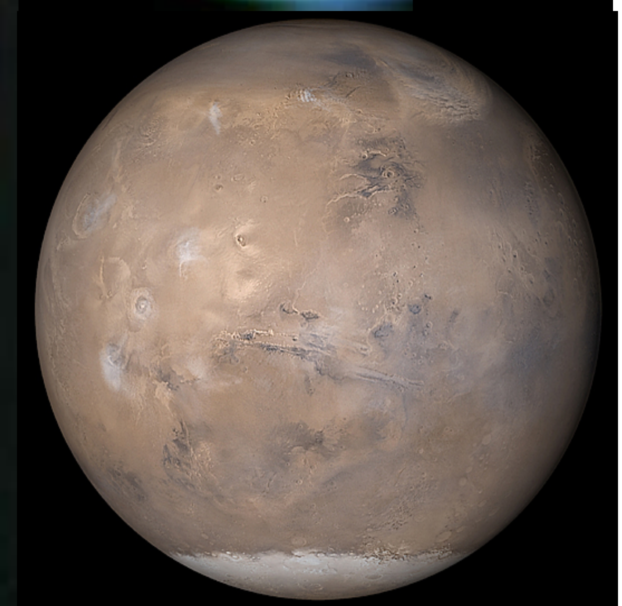
Long Duration Atmospheric observations

- Targets of interest
  - Venus
  - Titan
  - Mars
- Technologies Strategy
- Balloon envelopes for long duration aerial systems

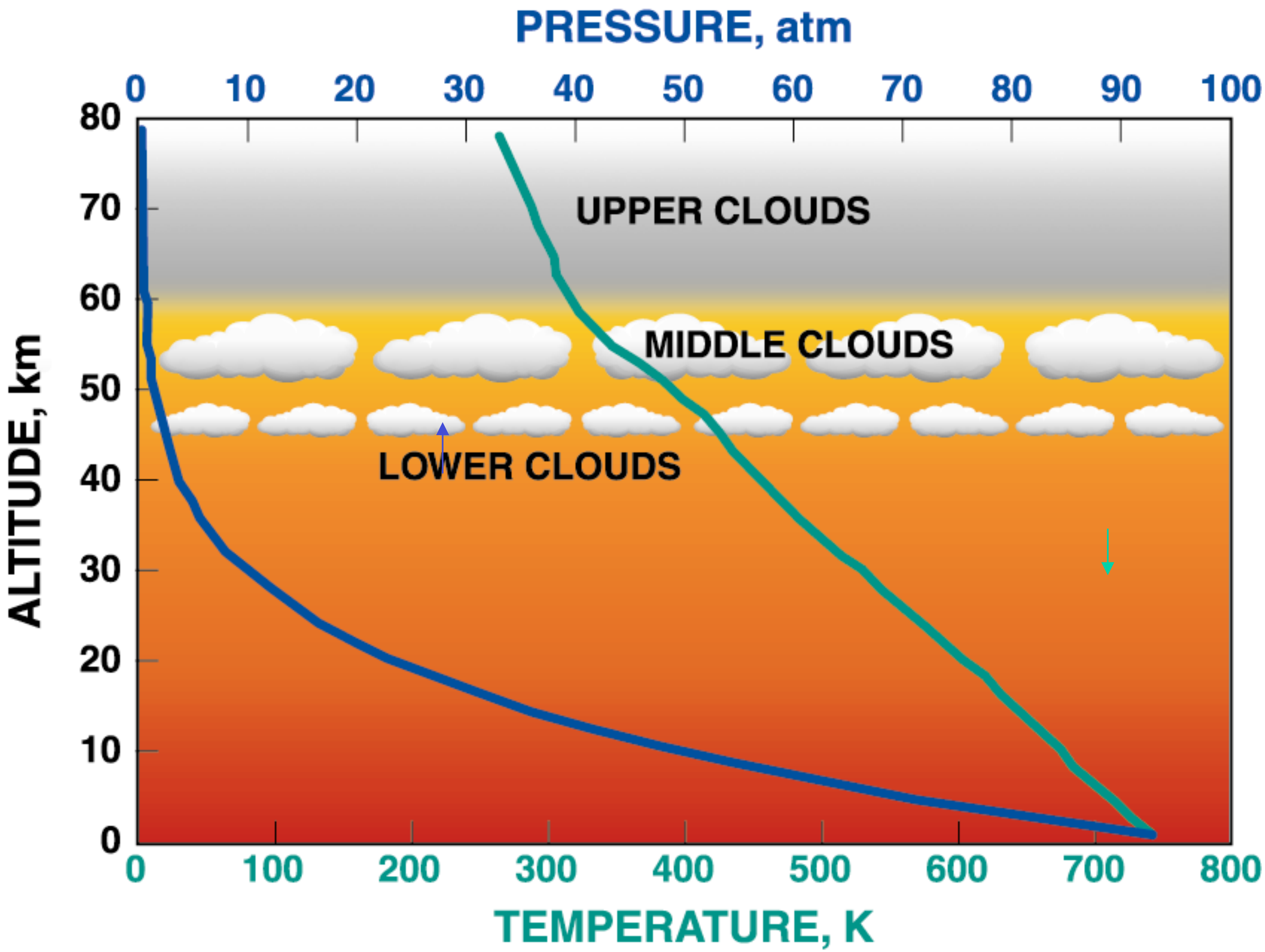
Targets of interest- Venus, Titan and Mars





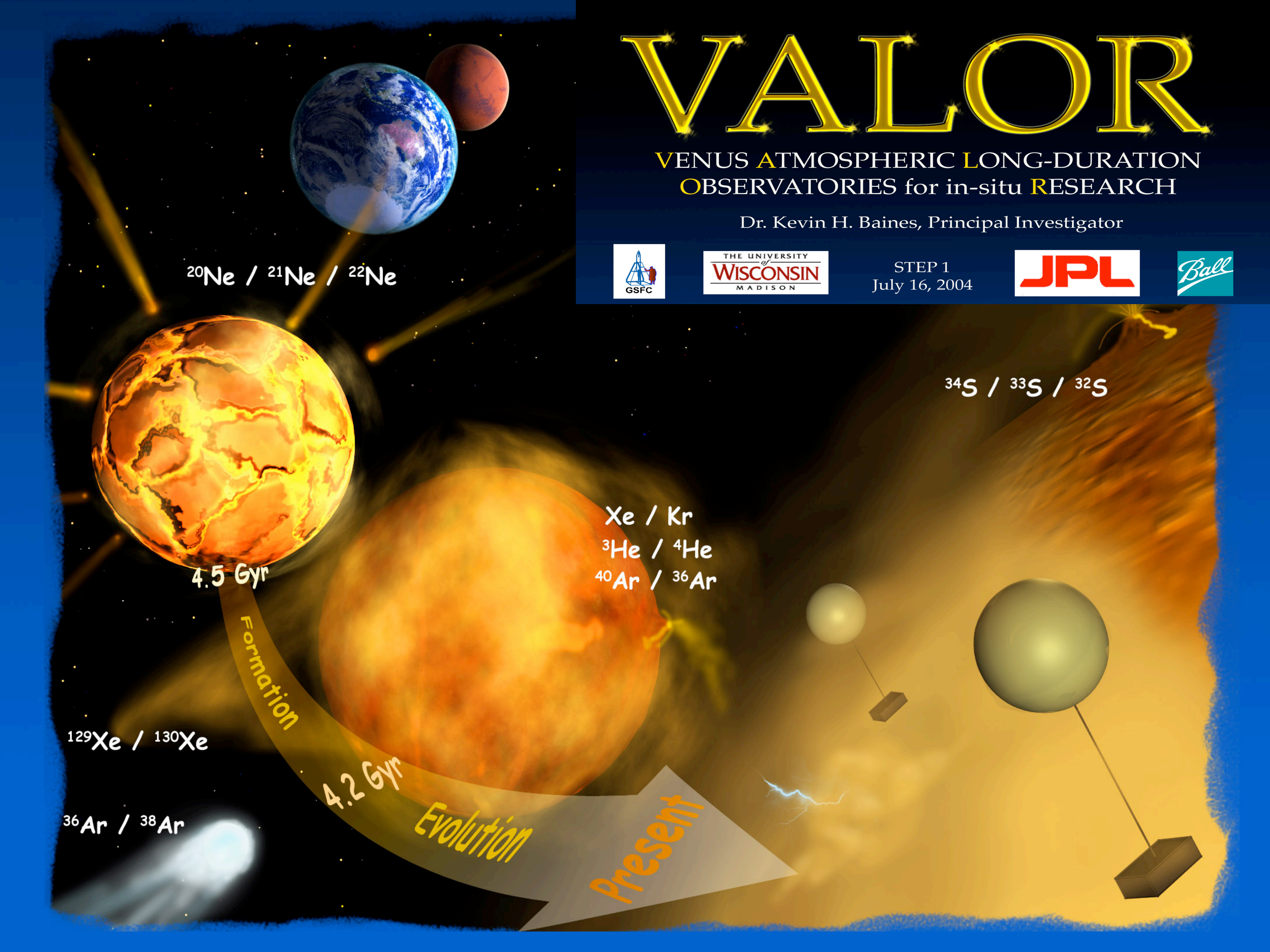


Venus Environment

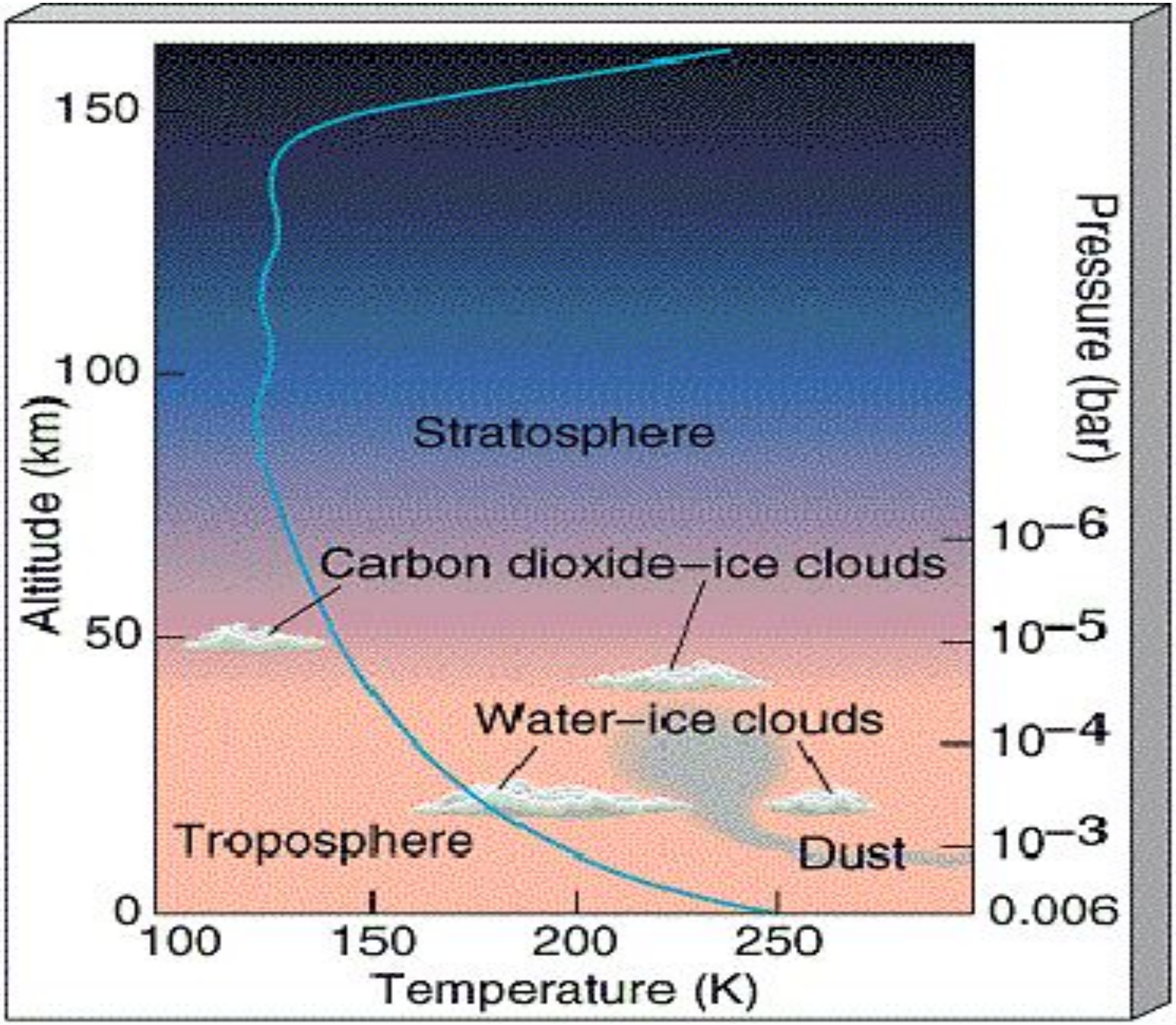


Venus Exploration
VEGA Mission, 1985

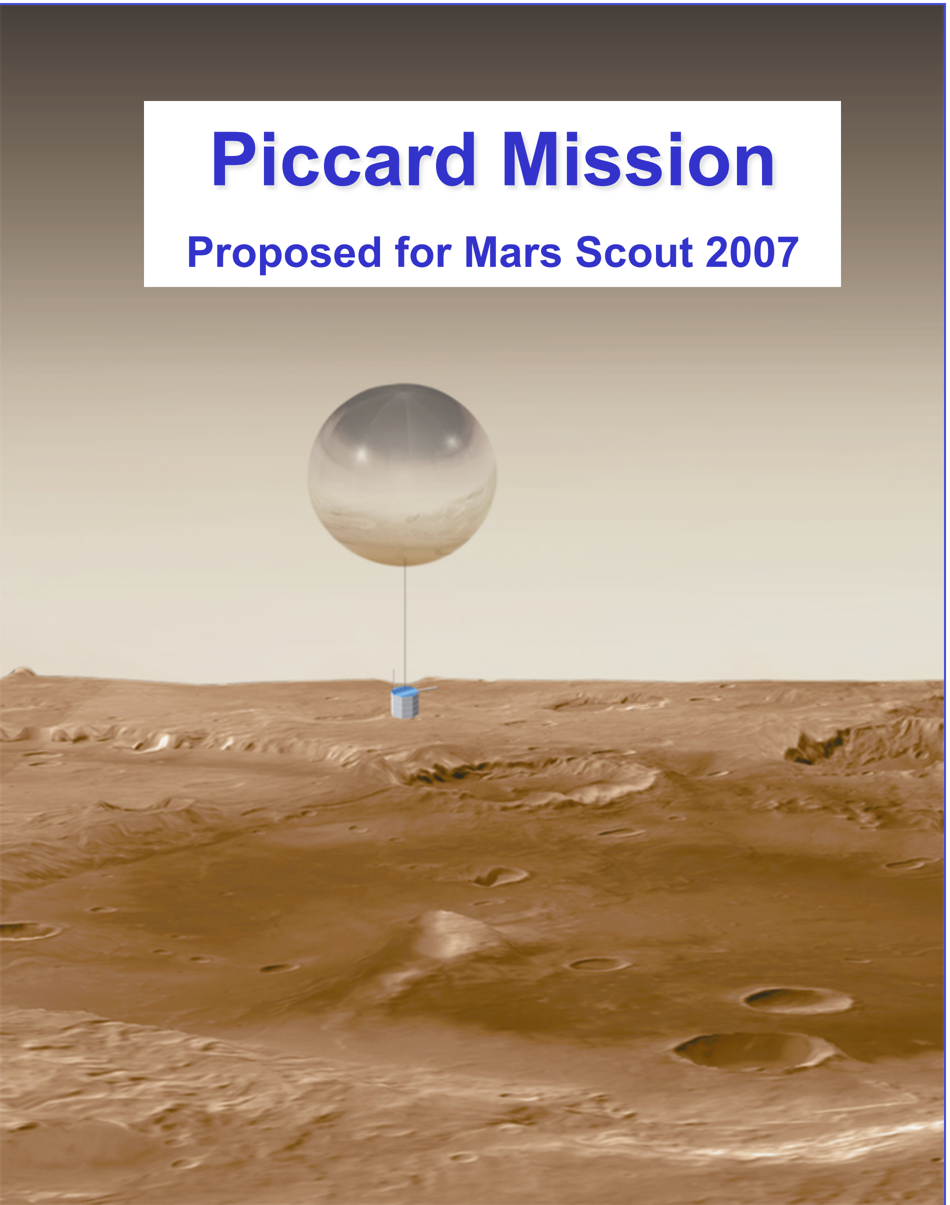
VEGA balloon during Earth atmosphere testing


VALOR
VENUS ATMOSPHERIC LONG-DURATION OBSERVATORIES for in-situ RESEARCH
Dr. Kevin H. Baines, Principal Investigator
GSFC
THE UNIVERSITY of WISCONSIN MADISON
STEP 1
July 16, 2004
JPL
Ball
^{20}Ne / ^{21}Ne / ^{22}Ne
^{34}S / ^{33}S / ^{32}S
Xe / Kr
^{3}He / ^{4}He
^{40}Ar / ^{36}Ar
4.5 Gyr
Formation
^{129}Xe / ^{130}Xe
4.2 Gyr
Evolution
Present
^{36}Ar / ^{38}Ar

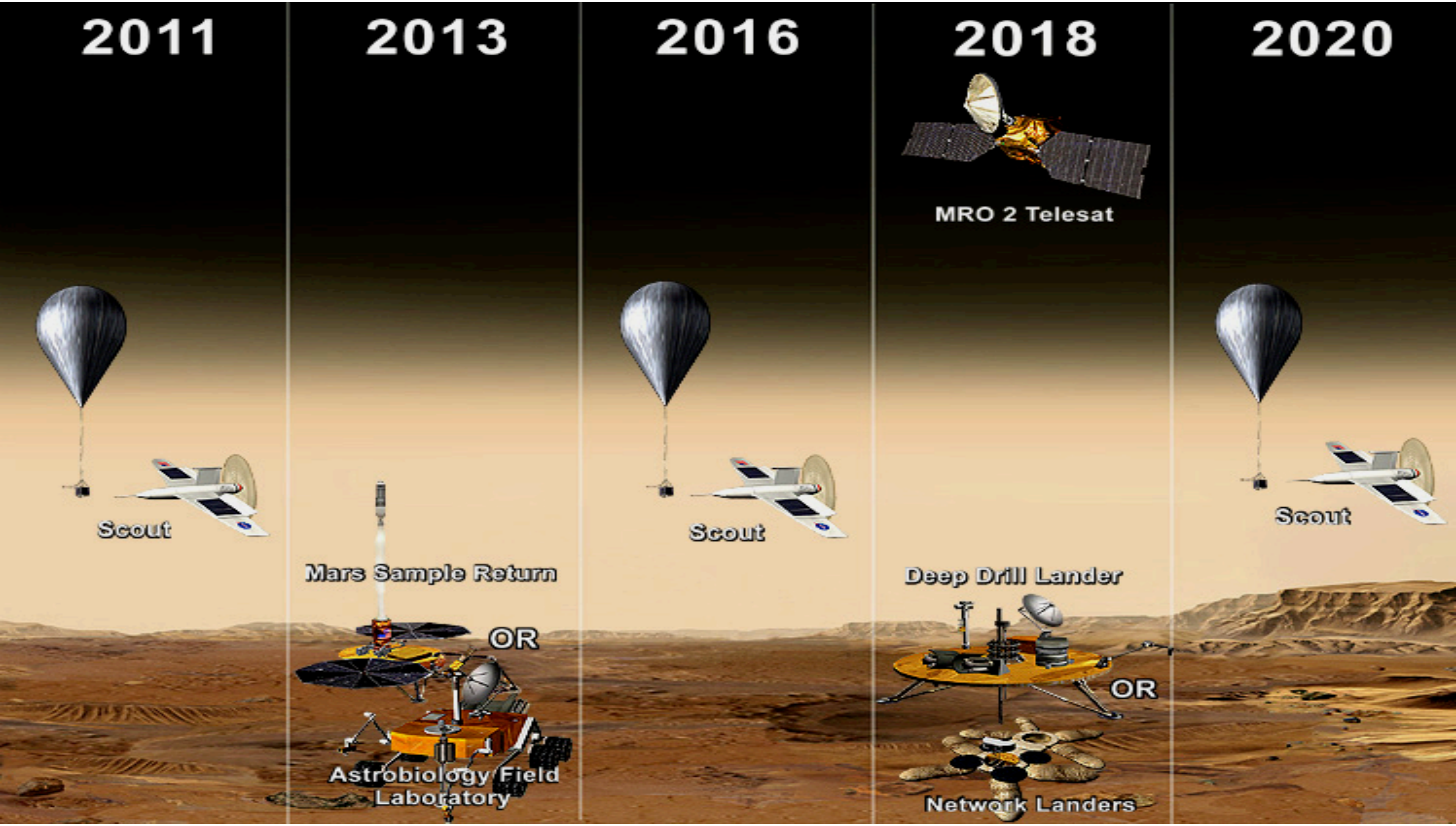
Mars Environment



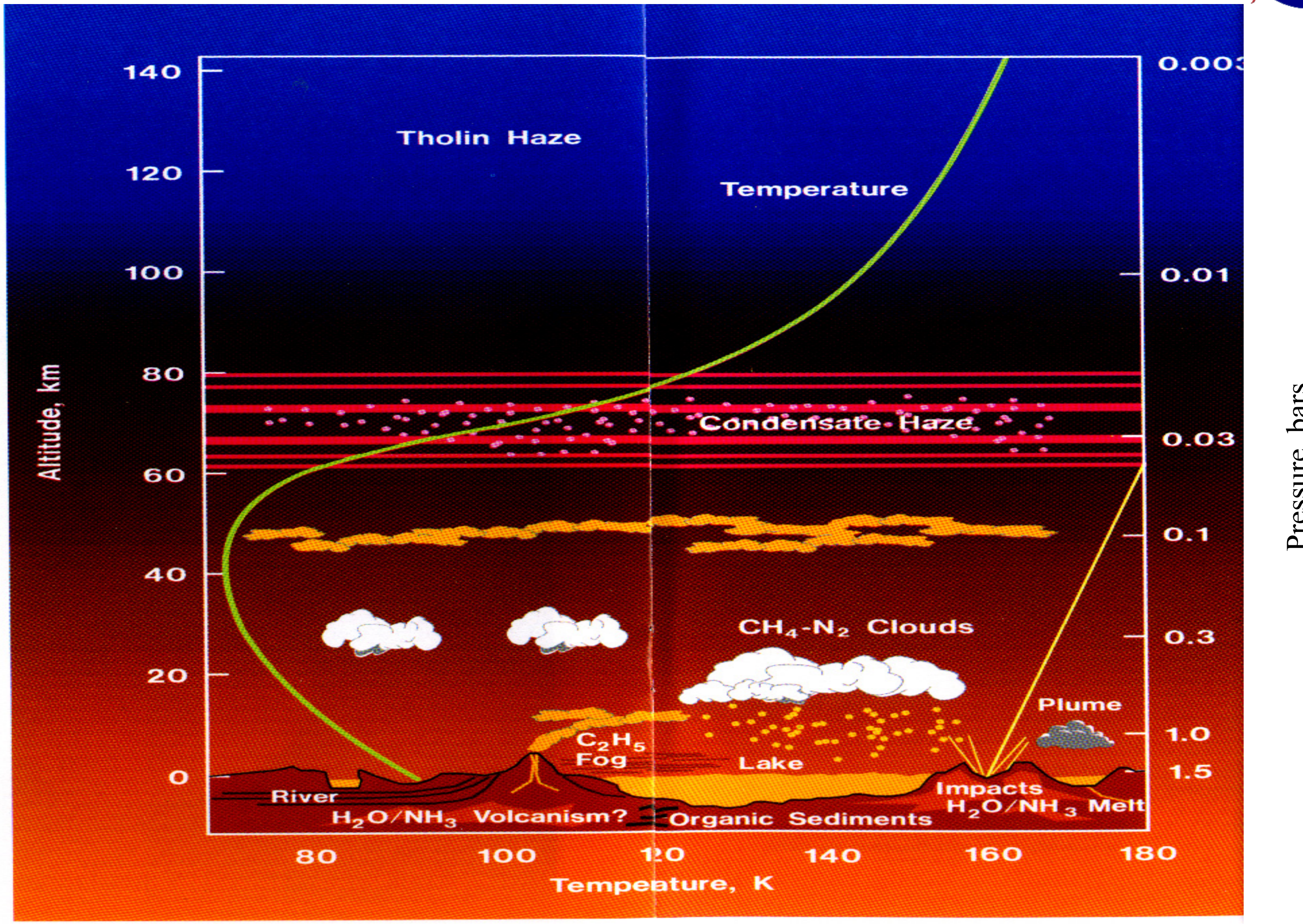
Mars Scout Balloon Concepts



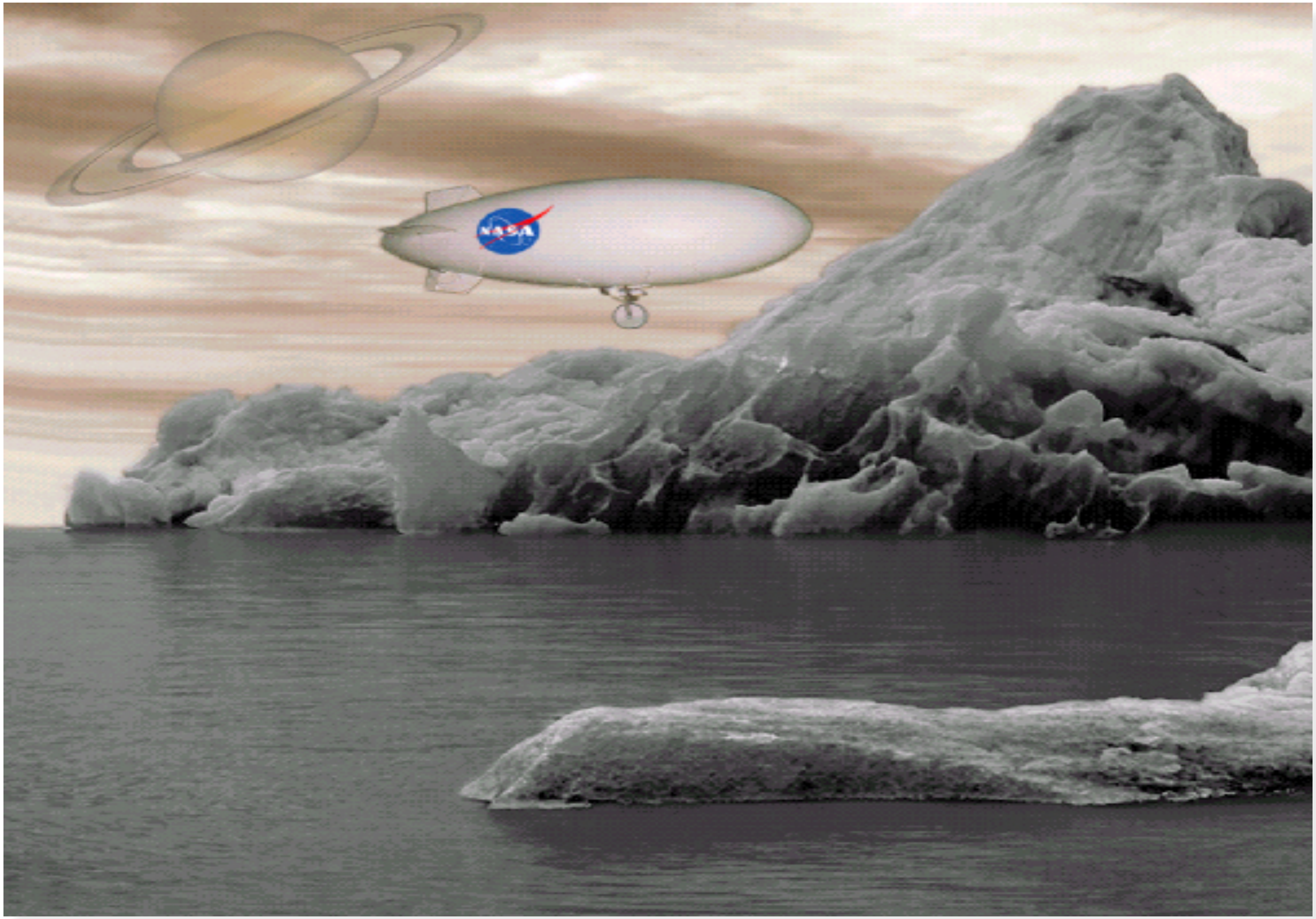
Mars Exploration Pathway- Next Decade



Titan's Environment



Exploring Titan



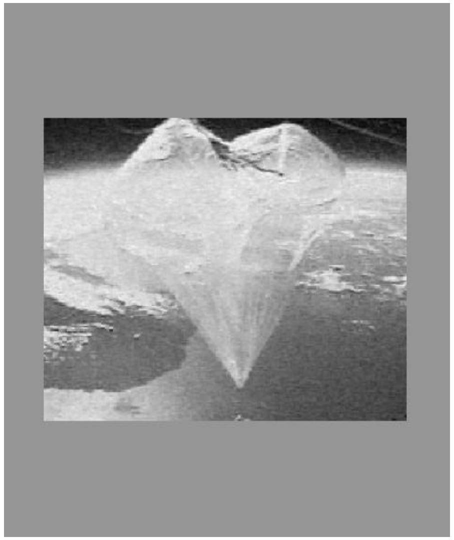
Planetary Aerobots

Technology Strategy

- Leverage capabilities developed for deep space and planetary surface exploration
- Leverage terrestrial balloon technology experience
- Capitalize on continuing advancement in the microelectronics and avionics miniaturization
- Develop unique capabilities for extreme environments – balloon envelopes, electronics, sensors, mechanical systems
- Test and validate planetary aerobot capabilities in relevant environments

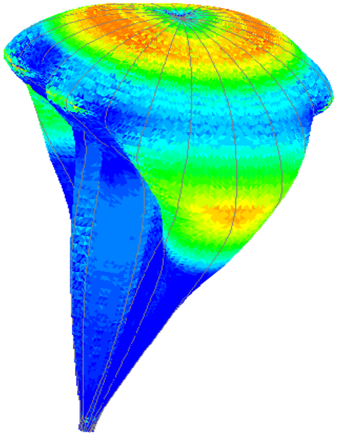
Balloon Envelope Technology Development

Titan balloon material tested at 77K (JPL)



Stratospheric test of balloon deployment (2002)

Pumpkin balloon prototype (WFF/Raven)



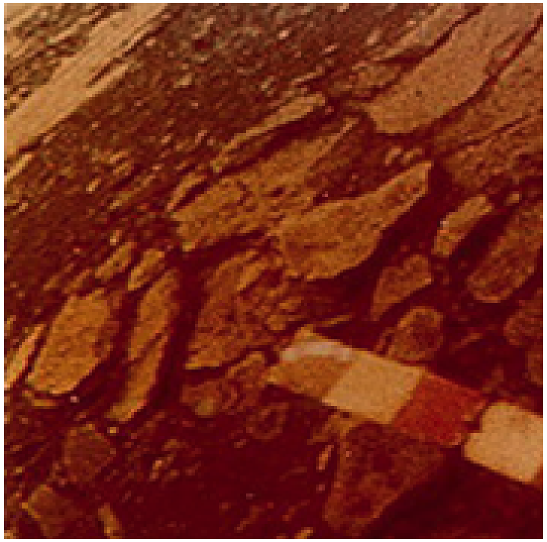
Inflation modeling (GSSL/Ozon)

Survivability at high temperatures

- Importance of survivability
- Approaches to surviving extreme temperatures
  - Conventional components -Advanced thermal control
  - High temperature components
  - Hybrid Solutions
- Application to Venus

Importance of Survivability

- Severe high temperature/high pressure conditions on the surface of Venus significantly limit potential missions science return
  - Duration on the Venus surface for successful *in situ* Venera missions averaged 70 minutes
  - Time for surface operations must be significantly increased to lower the risk and achieve an acceptable science return
  - Reasonable target of 10 to 20 hours for surface operations provides margin for spacecraft anomalies and unanticipated downtime (e.g., MER flash memory issues)



- Two key approaches to a successful mission in harsh environments :
- Efficiency
  - Rapid data acquisition technologies (e.g., high-speed drills, high data rate telecommunications)
- Survivability
  - Using systems which can survive in the harsh environment for extended periods of time

Increasing science return from probes to high temperature environments*

Option 1: Conventional components and provide survivability solely through passive thermal control
But
Impractical. Will severely limit mass/volume available for science instruments, avionics and telecom.

Option 2: Advanced components which are capable of surviving and operating at very high temperatures
But
Prohibitively expensive. Will degrade performance of science instruments, avionics and telecom.

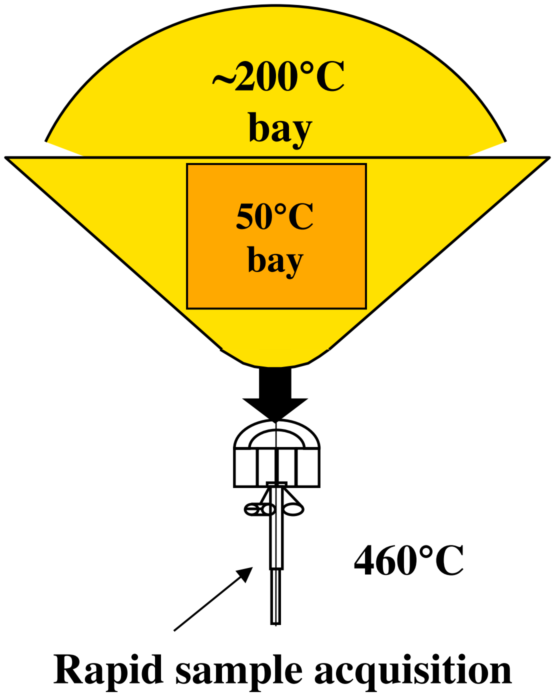
Option 3: Hybrid system of Option 1 and Option 2 :

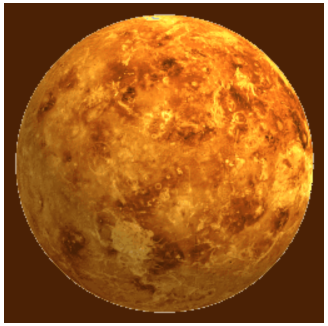
For example:

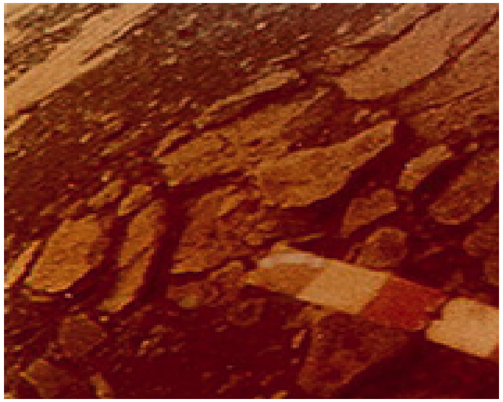
- **Advanced thermal control for avionics & advanced instruments**
- **High temperature components – sample acquisition, batteries, RF amplifiers**

*** Deep Jupiter probe, Venus surface, long duration Venus Atmospheric platform**

Example of Hybrid Solution for Venus Surface Probe







Key Technologies (examples):

- Advanced Thermal Control
  - -Phase change materials
  - -High temperature multi-foil insulation
  - -Silica fabric + rigid foam insulation
  - -Alternative pressure vessel material,
- High Temperature Electronics
  - -Low power, operating at ~200°C
- Rapid data acquisition system
  - -Rapid sample acquisition system at 460 C
  - -Rapid sample processing and analysis
  - -High data rate transmission
- High Temperature Power Storage

Deep Jupiter probes can exploit these technologies also!

Summary

- The capability to deliver probes to the outer planets is here. Advanced entry technologies are needed to take the next step in probe exploration.
- The capability for atmospheric observations using long duration balloons at Venus, Mars and Titan is progressing opening new scientific opportunities.
- Technologies for tolerating extreme high temperatures and pressures will be needed to exploit the potential of future in situ missions to Venus and Jupiter.

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