STRATEGIC PLAN FOR NASA's SOLAR SYSTEM EXPLORATION PROGRAM: ROLE OF AERIAL PLATFORMS

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Overview

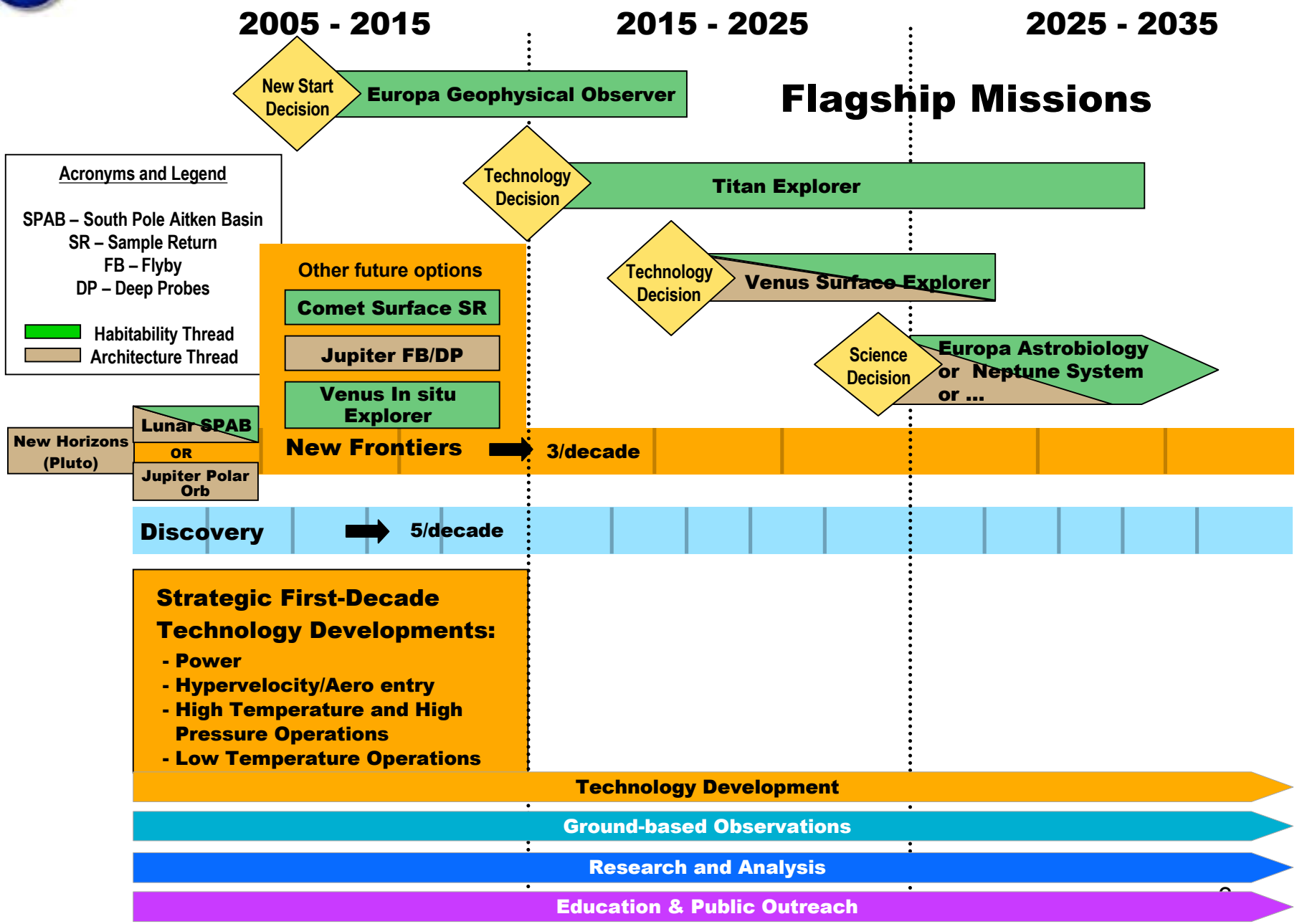
- In late 2004, NASA initiated the development of a Strategic Road Map for Solar System Exploration

- A Federal Advisory Committee was formed to develop the Road Map and reported its findings in late May 2005

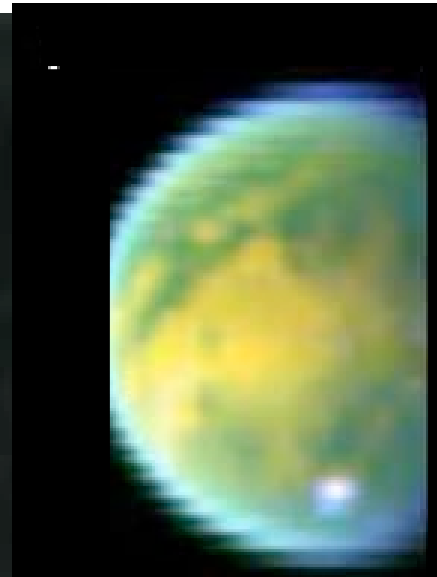
- The Solar System Road Map includes (among others)
  - **Conventional probe missions** operating only during descent
    - similar to Venus Pioneer and Galileo Probe
  - **Atmospheric platforms** that, after entry, operate for days, weeks or months in the atmosphere

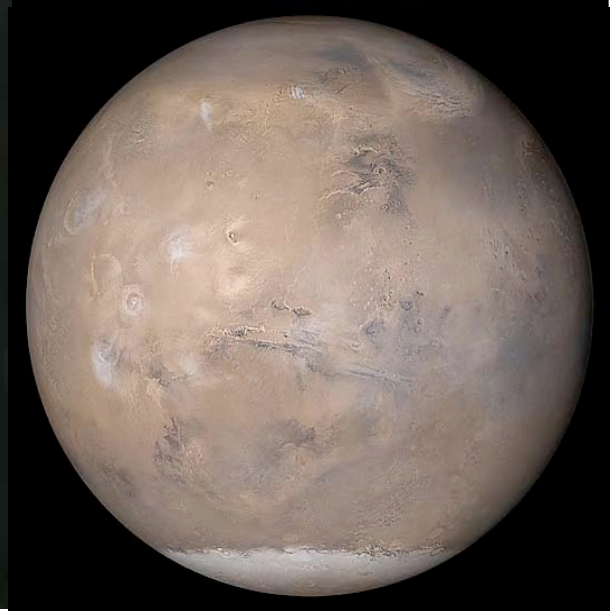
- The focus of this presentation is on **atmospheric platforms** and specifically on those designed to **observe and sample the planetary surface**.

Solar System Exploration Roadmap



Venus, Titan and Mars:
“Planets” with atmospheres and solid surfaces





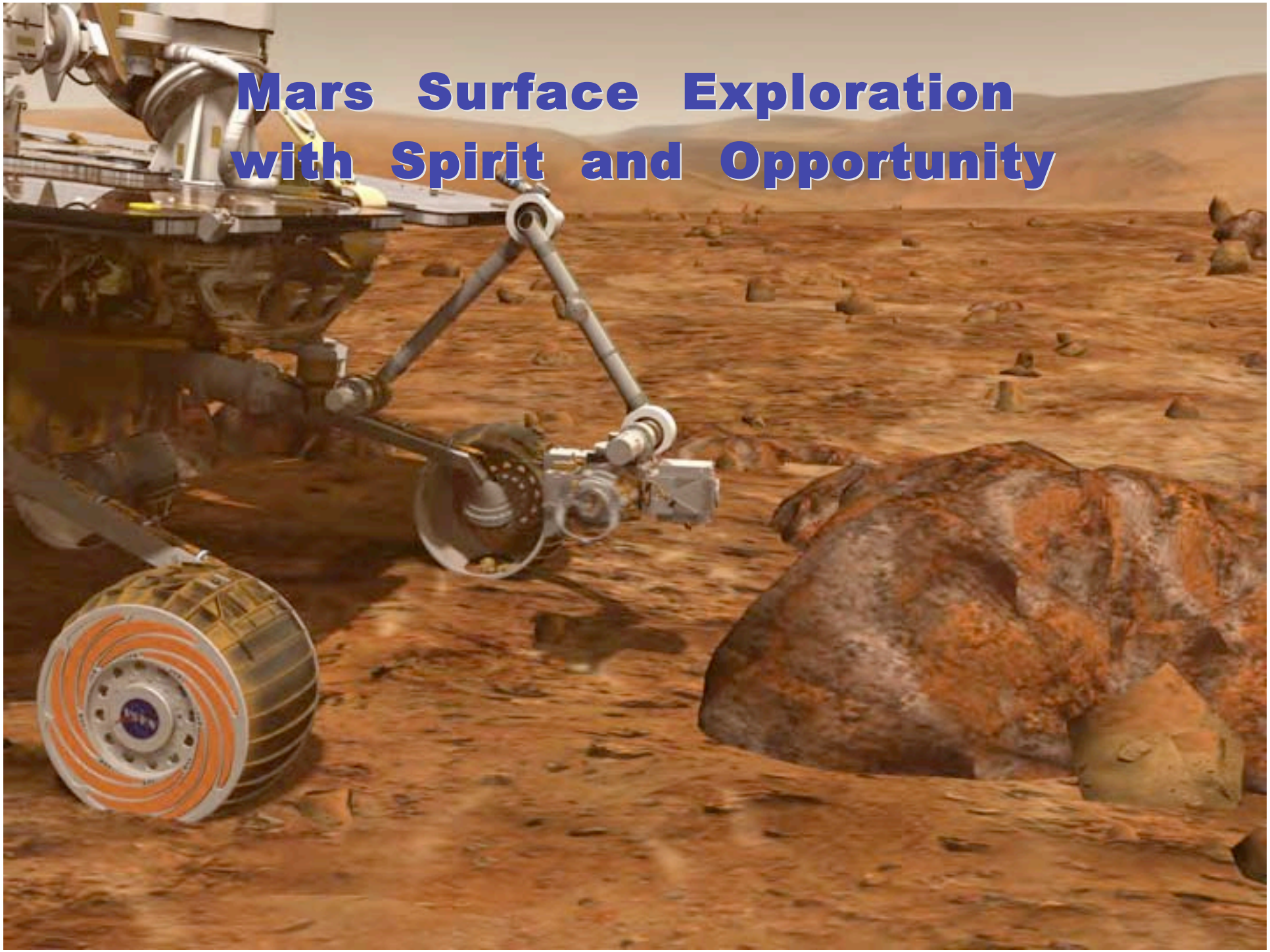
Why in situ exploration with aerial platforms?

- The successful **Spirit** and **Opportunity** missions have established the value of **mobile in situ exploration** systems for answering **fundamental science questions about Mars**

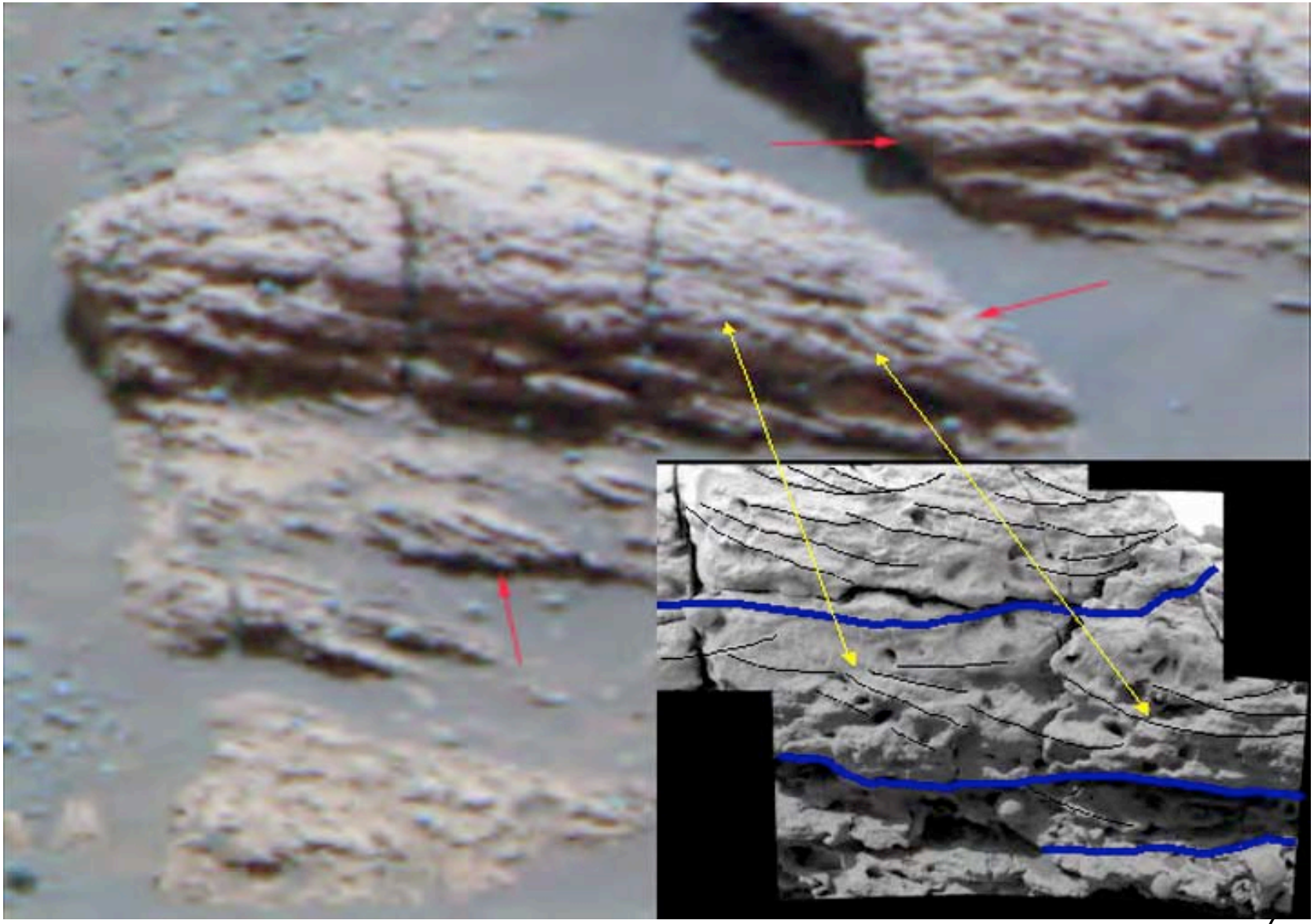
- **Surface mobility** has proved very effective for the in situ mobile exploration of Mars, but has several limitations
  - **Power intensive** in an energy starved environment – **limits range**
  - **Vulnerable to surface hazards** – steep terrains, low bearing strength
  - **Large antennas** on payload platform limit mobility

- **Atmospheric (Buoyant) Platforms** or **Aerobots** overcome these limitations in the dense atmospheres of Titan and Venus
  - **Limited power** is needed to travel large distances
  - **Much less vulnerable** to surface hazards
  - **Large antennas** can be deployed without impacting mobility

Mars Surface Exploration with Spirit and Opportunity



Opportunity at Mars
Crossbedding: Evidence for Underwater Origin



Purgatory Dune, Mars

Camera on the Opportunity Rover looks back at a sand dune from which it has just extricated itself

Aerial Platforms can cover more territory, over highly irregular topography and are much less vulnerable to surface hazards

Aeroshell Technology to Enable In-Situ Exploration

Aeroshell Entry to

Giant Planets
- Jupiter; Saturn; Uranus; Neptune
- Hypersonic entry: ~20-60km/s)
- Extreme Environments (p,T)
- Short lived descent probe mission

Smaller Planets & Moons w/ Atm.
- **Venus**; **Titan**; Mars
- Hypersonic entry: ~6-12 km/s
-Extreme Environments (p, T)
- Long lived mobile aerial exploration

Coping with the Extreme Environments of Venus and Titan?

- **Surface environments** of Venus and Titan have extremes of temperature, pressure and atmospheric density:

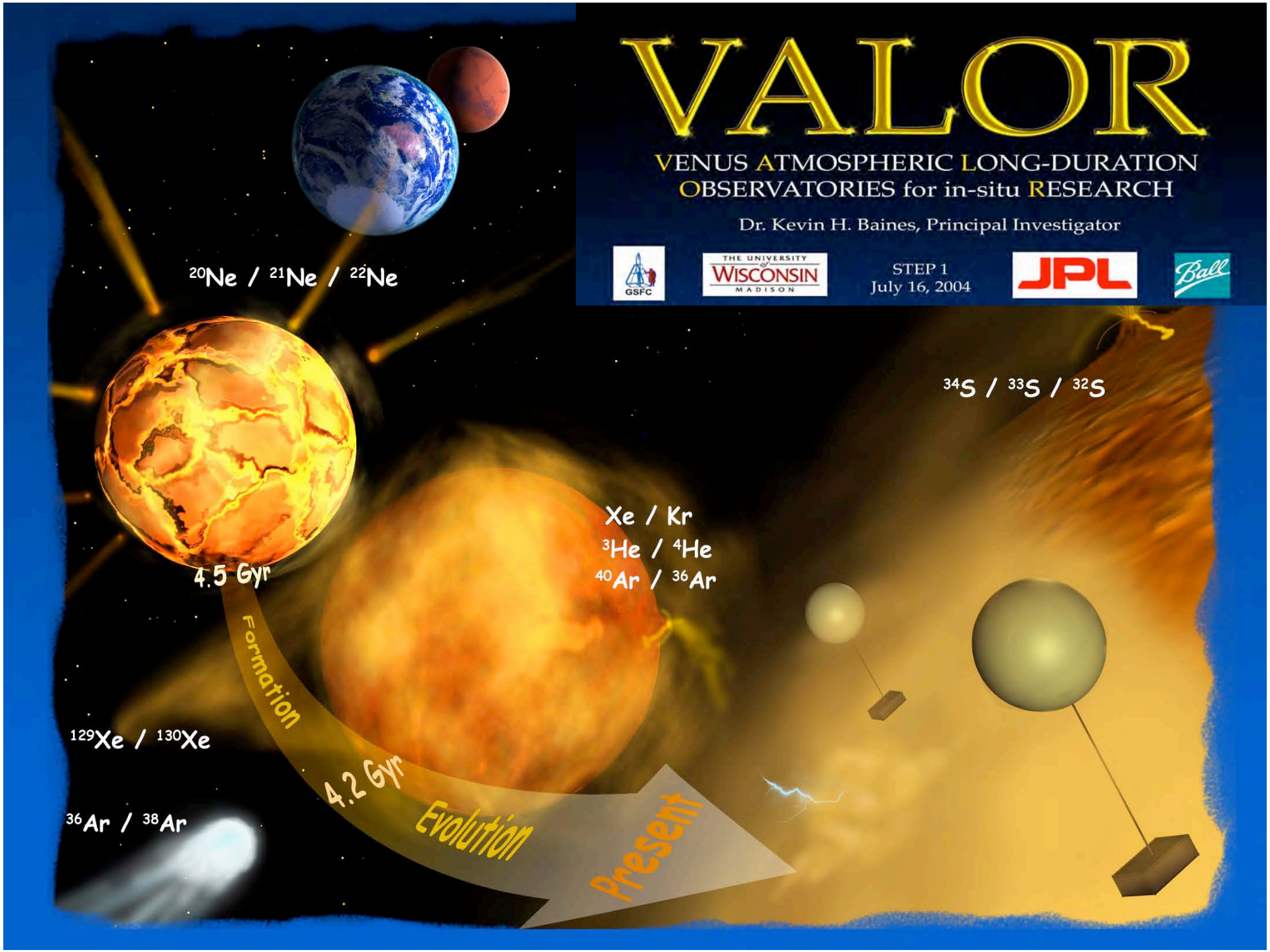
Parameter	Units	Earth	Venus	Titan
Temperature	K	290	750	90
Pressure	Bars	1	90	1.5
Density	kg/m^3	1.23	65	5.5

- **Exploration systems** must be designed **to survive** in these environments

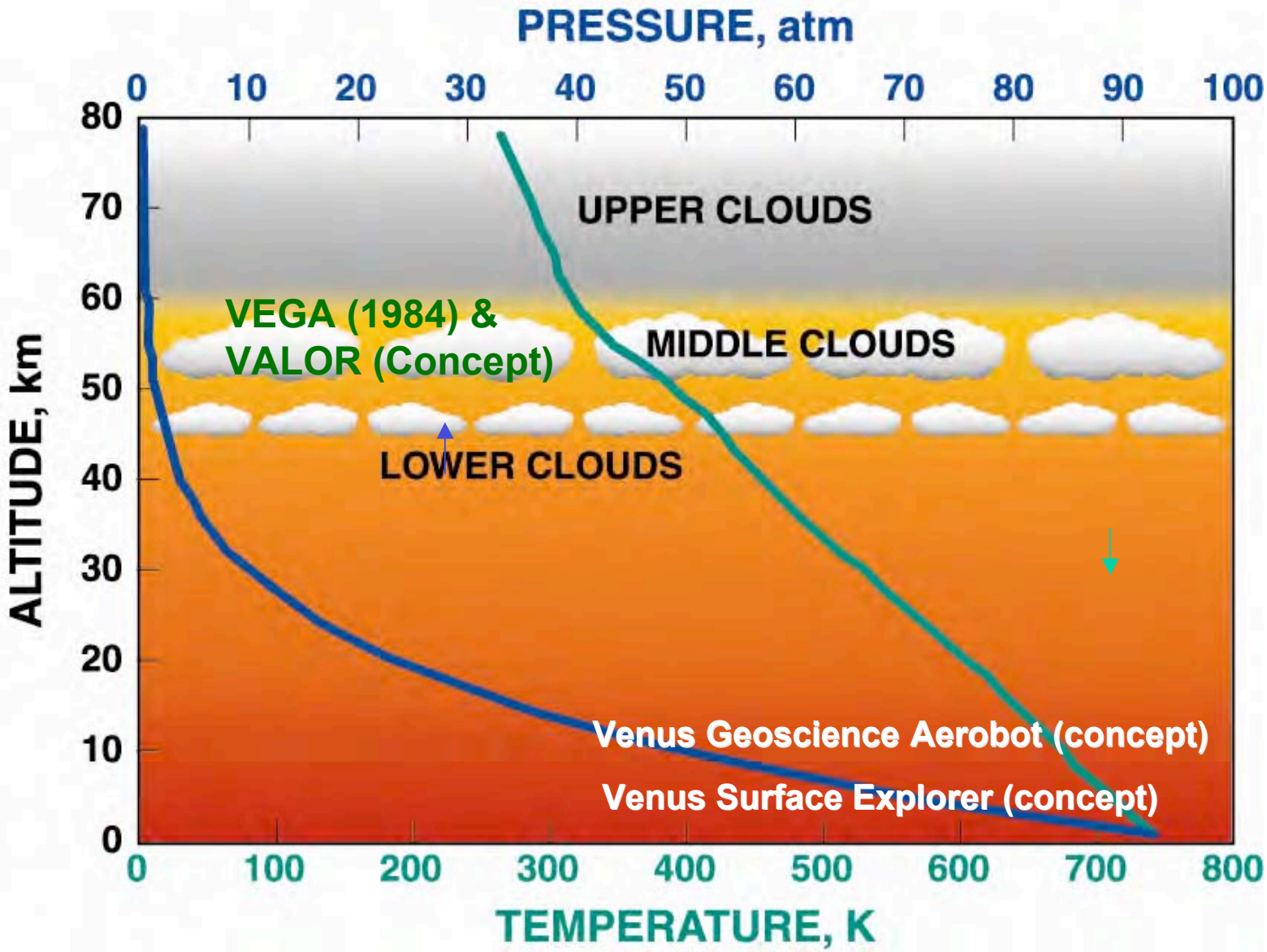
- **Aerial Platforms** can also be designed **to exploit** these environments and accomplish things that might not be practical in the terrestrial atmospheric environment.

Venus Exploration
VEGA Mission, 1985

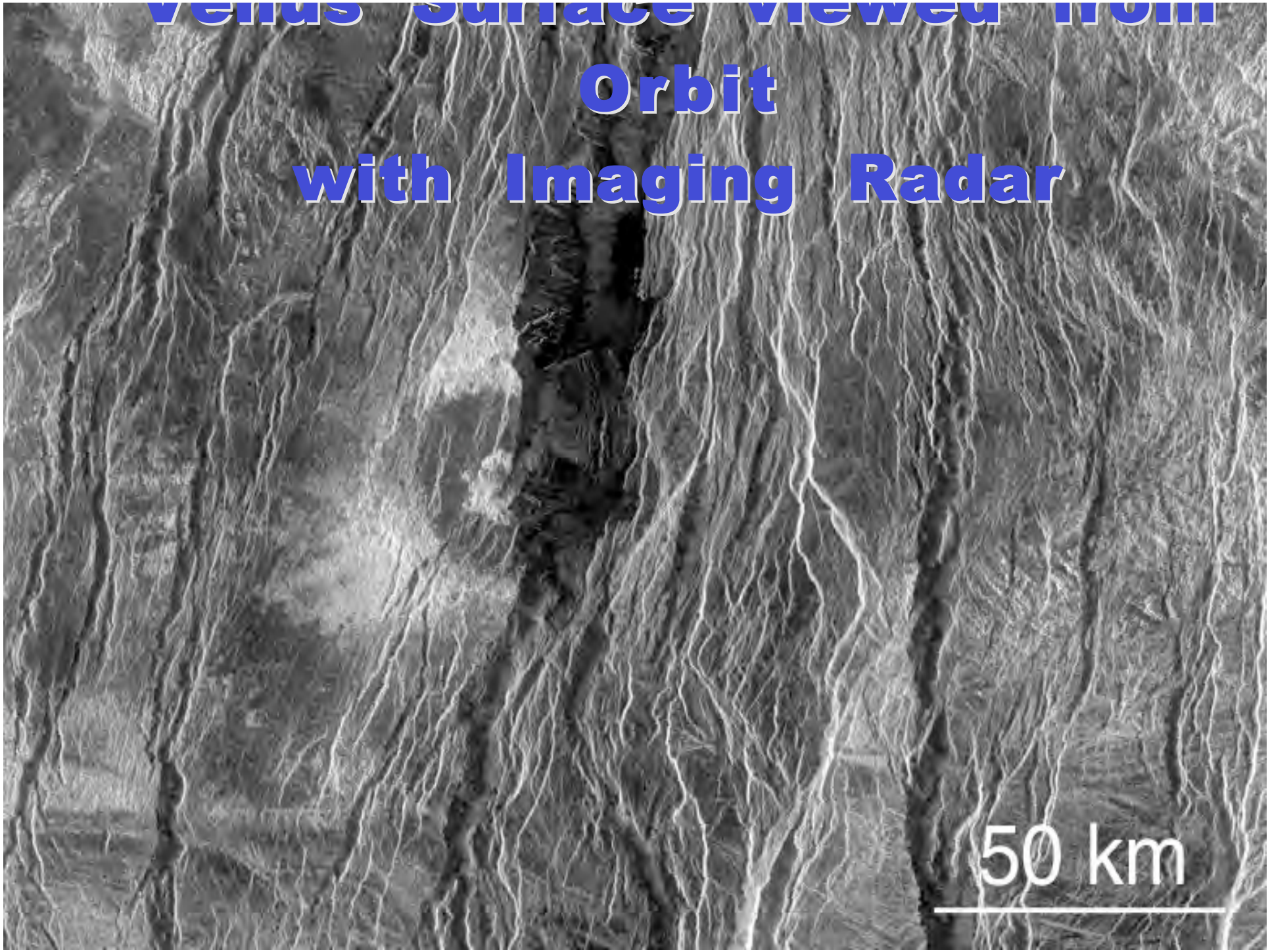
VEGA balloon during Earth atmosphere testing


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
4.2 Gyr
Evolution
Present
^{129}Xe / ^{130}Xe
^{36}Ar / ^{38}Ar

Venus Aerial Platform - Overview



Venus Surface Viewed from Orbit with Imaging Radar



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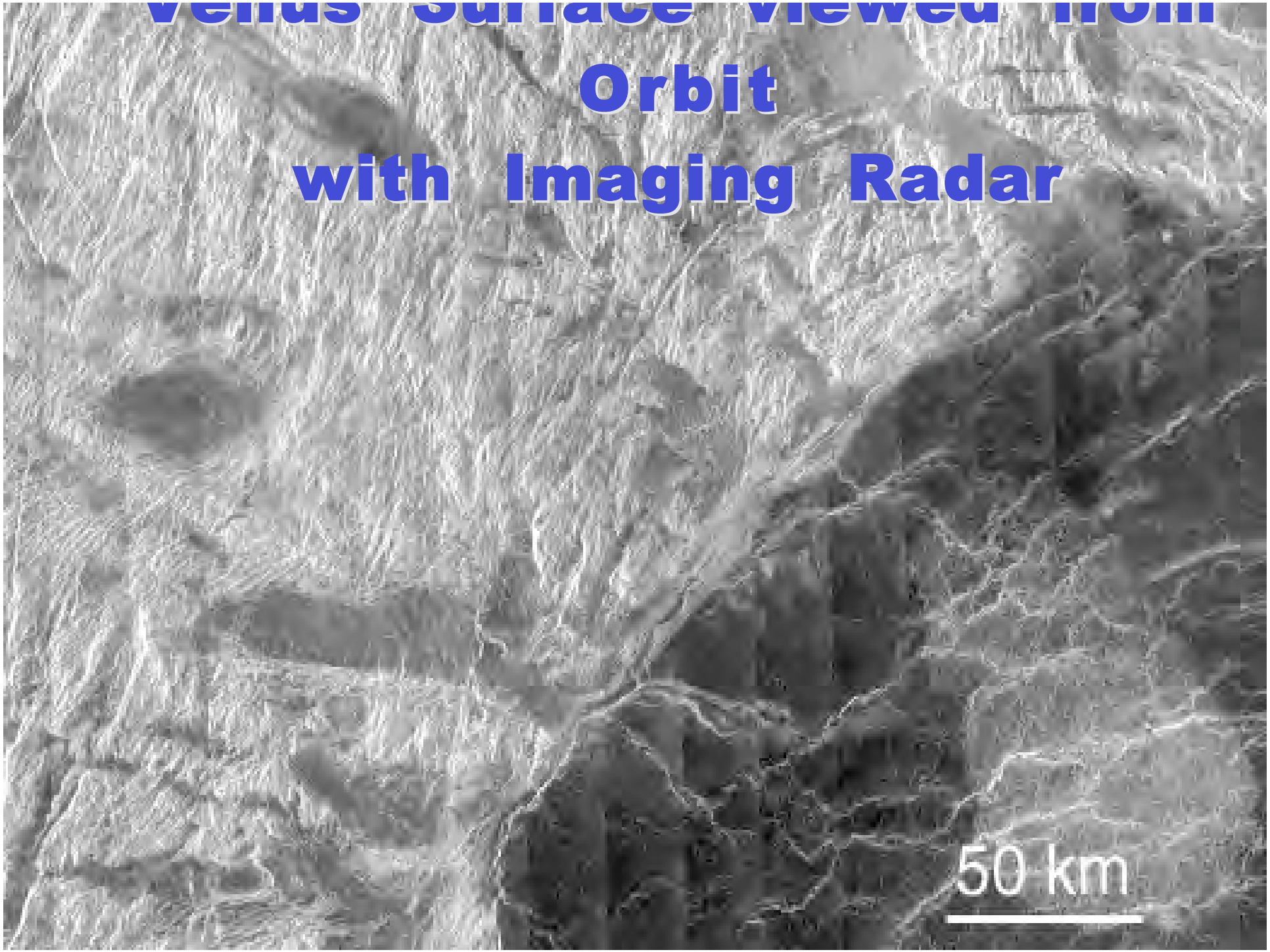
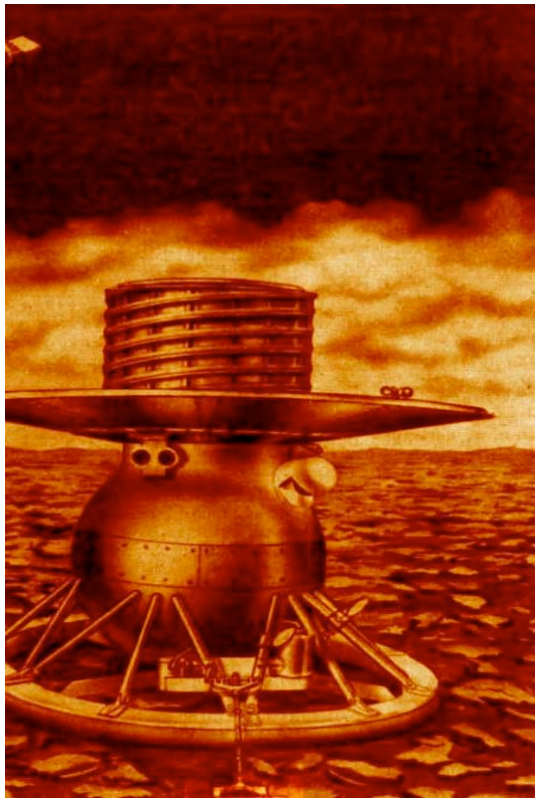
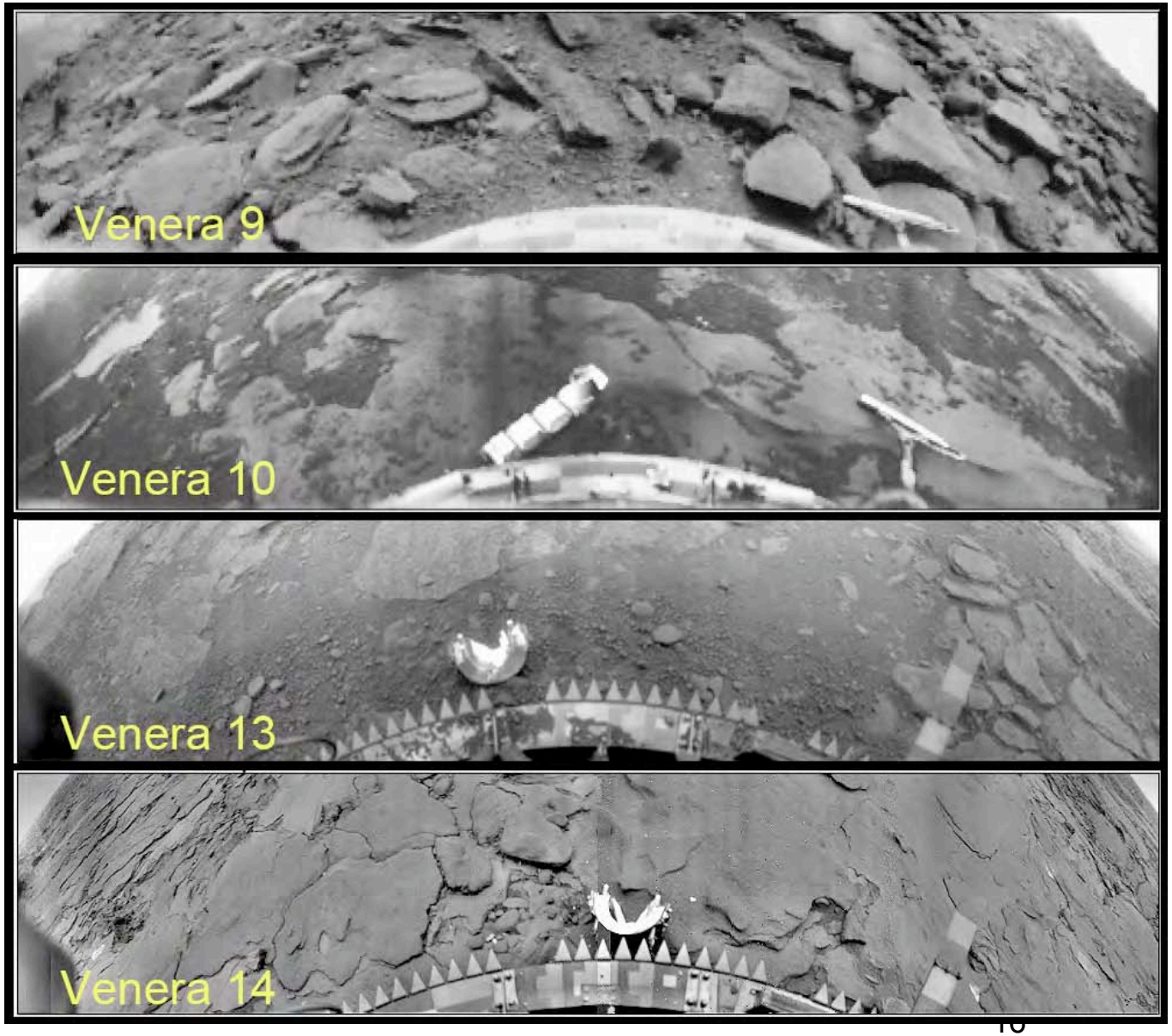


Venus Surface Close Up





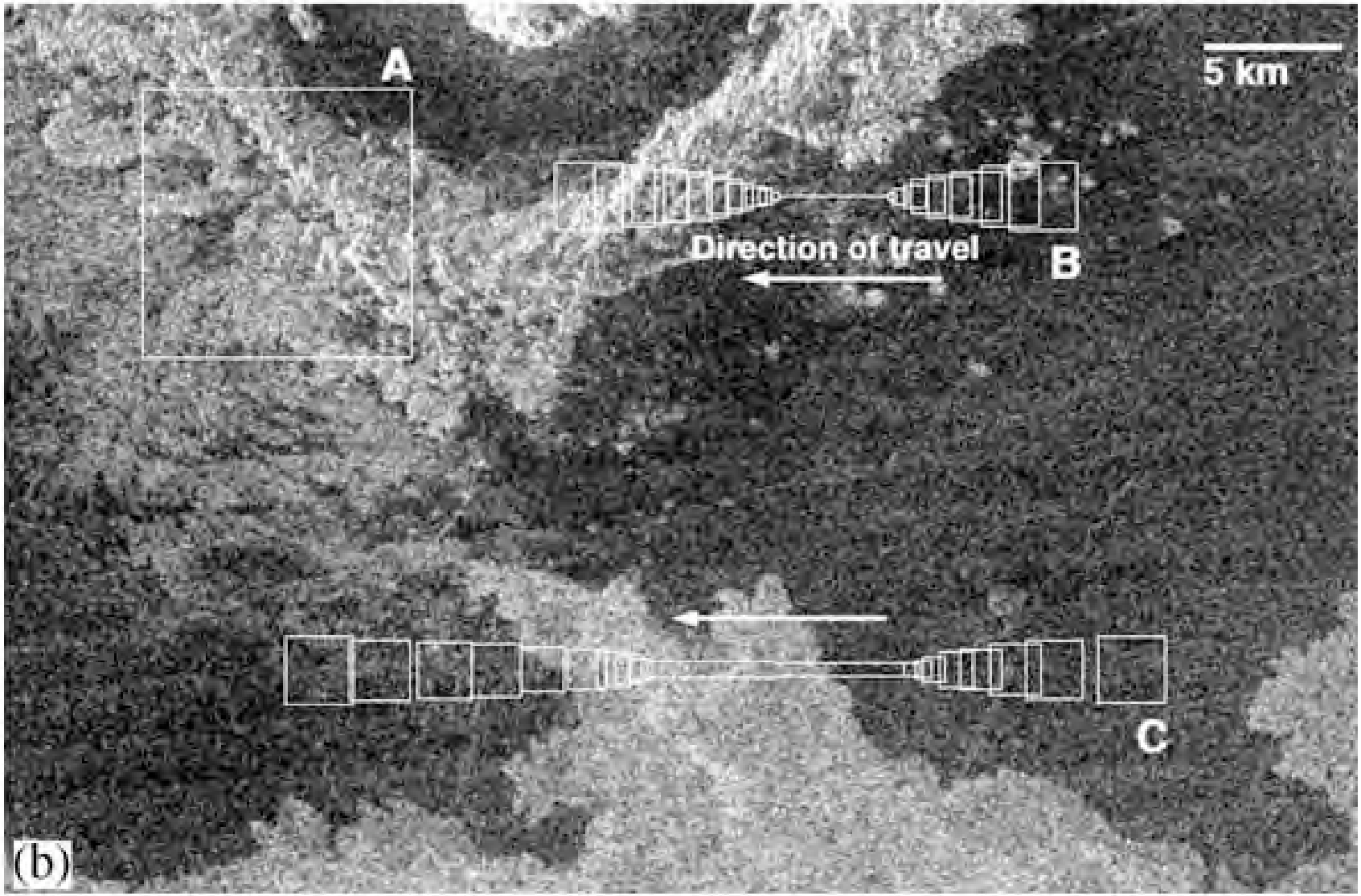
Venus Geoscience Aerobot

Exploring the Venus Surface at close range

VGA takes advantage of large temperature differences between the surface and Venus and 60 km altitude to cycles from high to low altitudes and back again

Venus Geoscience Aerobot

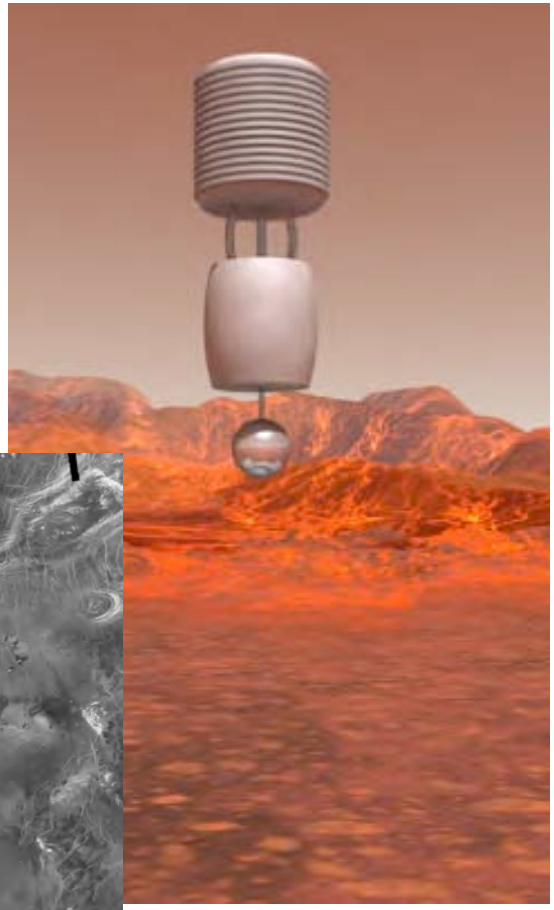
Imaging profiles according to Gilmore et al 2004



Venus Surface Explorer
Aerial Platform implementation

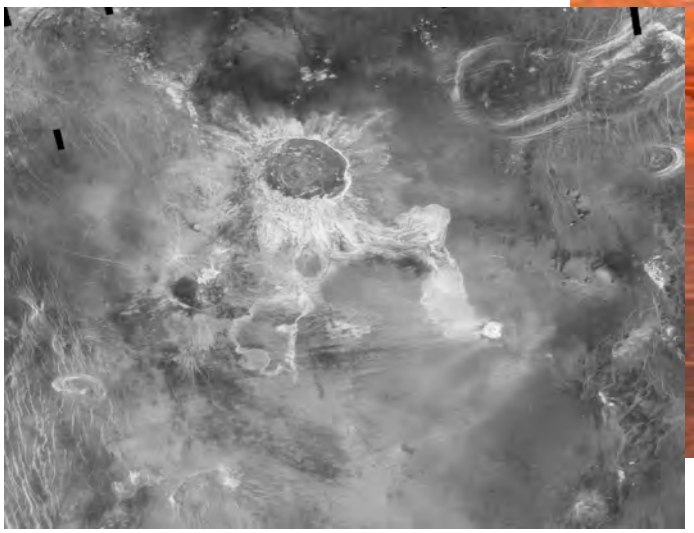
Scientific Objectives:

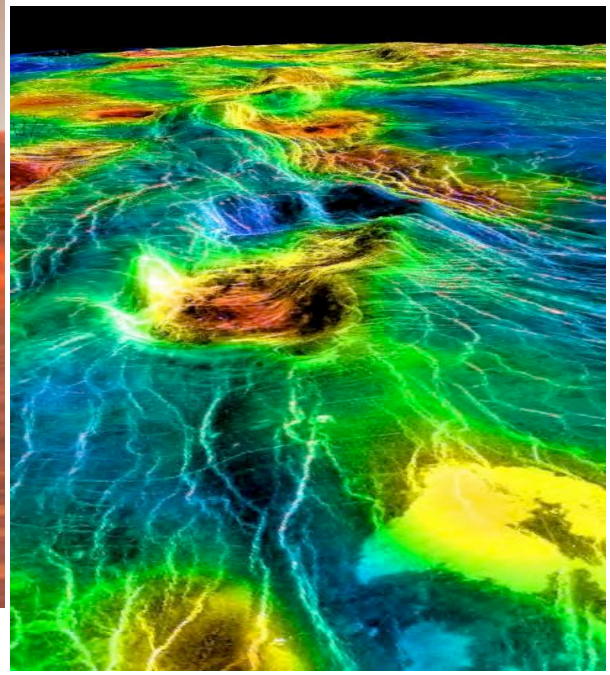
- Map the surface of Venus with **orbital radar** and **aerial imaging**.
- Characterize surface **chemistry**;
- Determine circulation, dynamics, and chemistry of the **atmosphere**



Mission Concept:.

- **Aerial platform** for imaging and surface sampling.
- **Extreme environments technology** to enable sustained operation near the surface of Venus

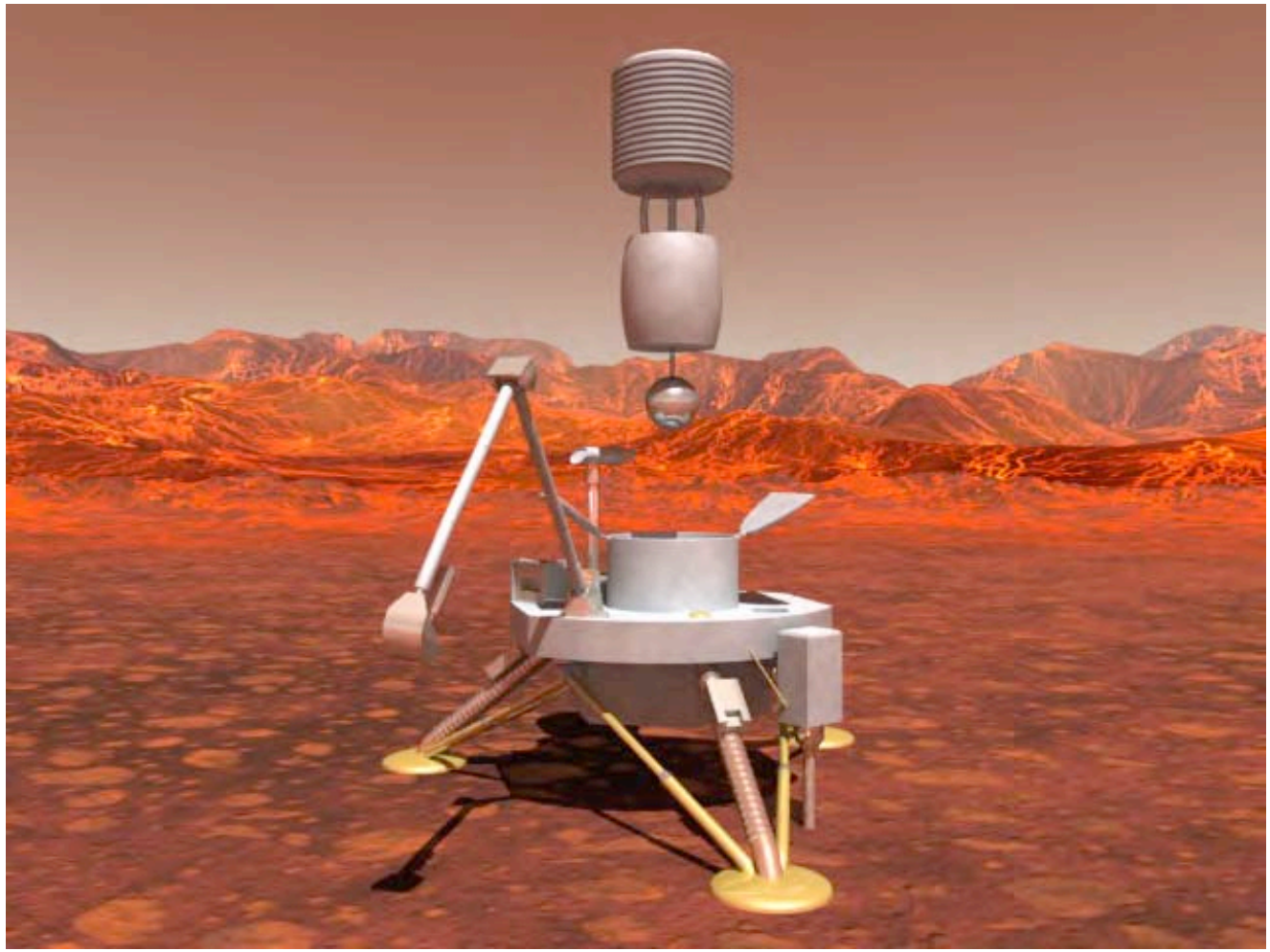




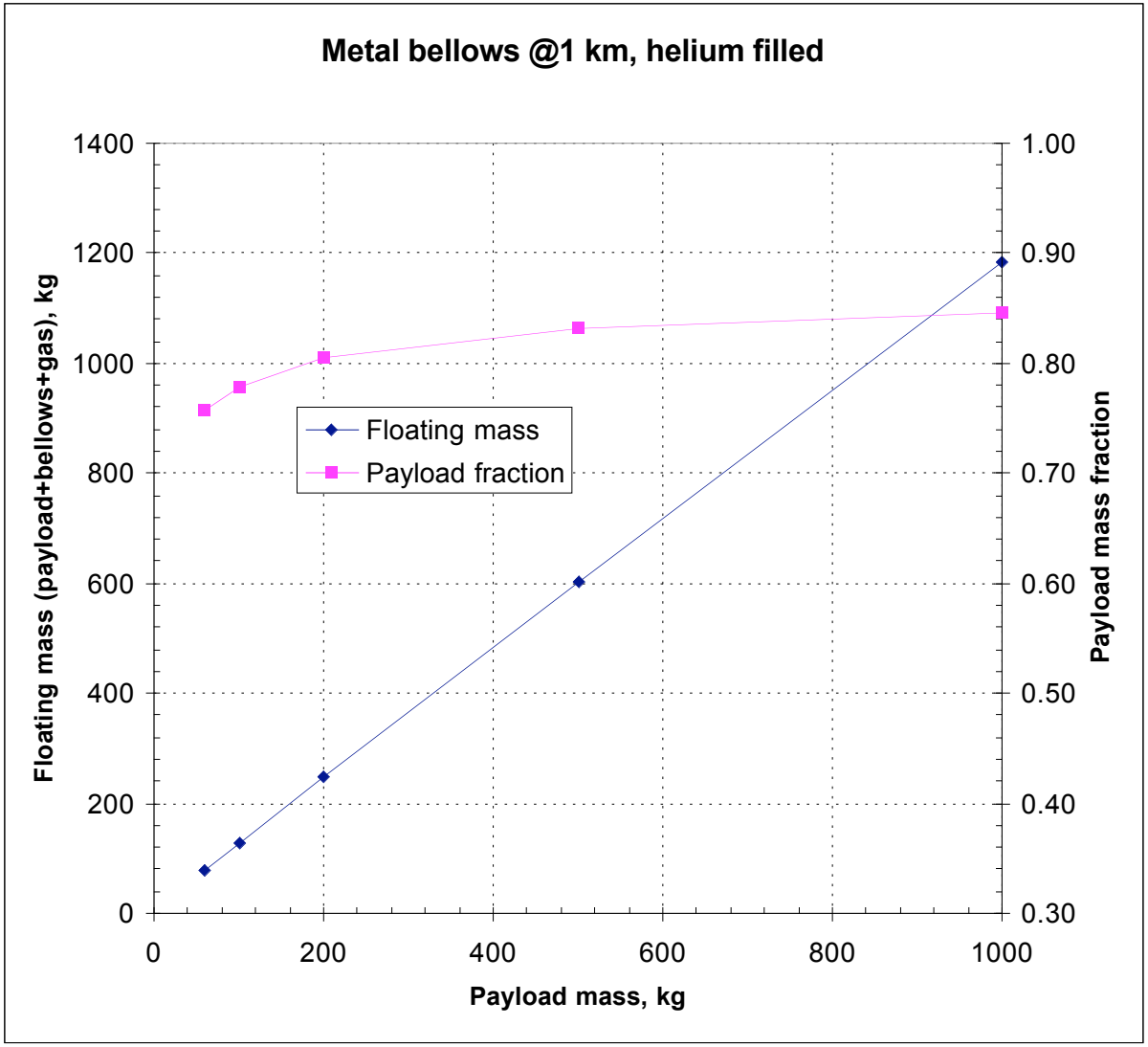
- **High density of atmosphere permits use of a metal bellows balloon**
- **High temperature and high molecular weight of atmosphere permits use of easily stored substances H_2O and NH_3 as inflation gas**

Venus Surface Sample Return

Bringing a sample from the Venus Surface back to Earth

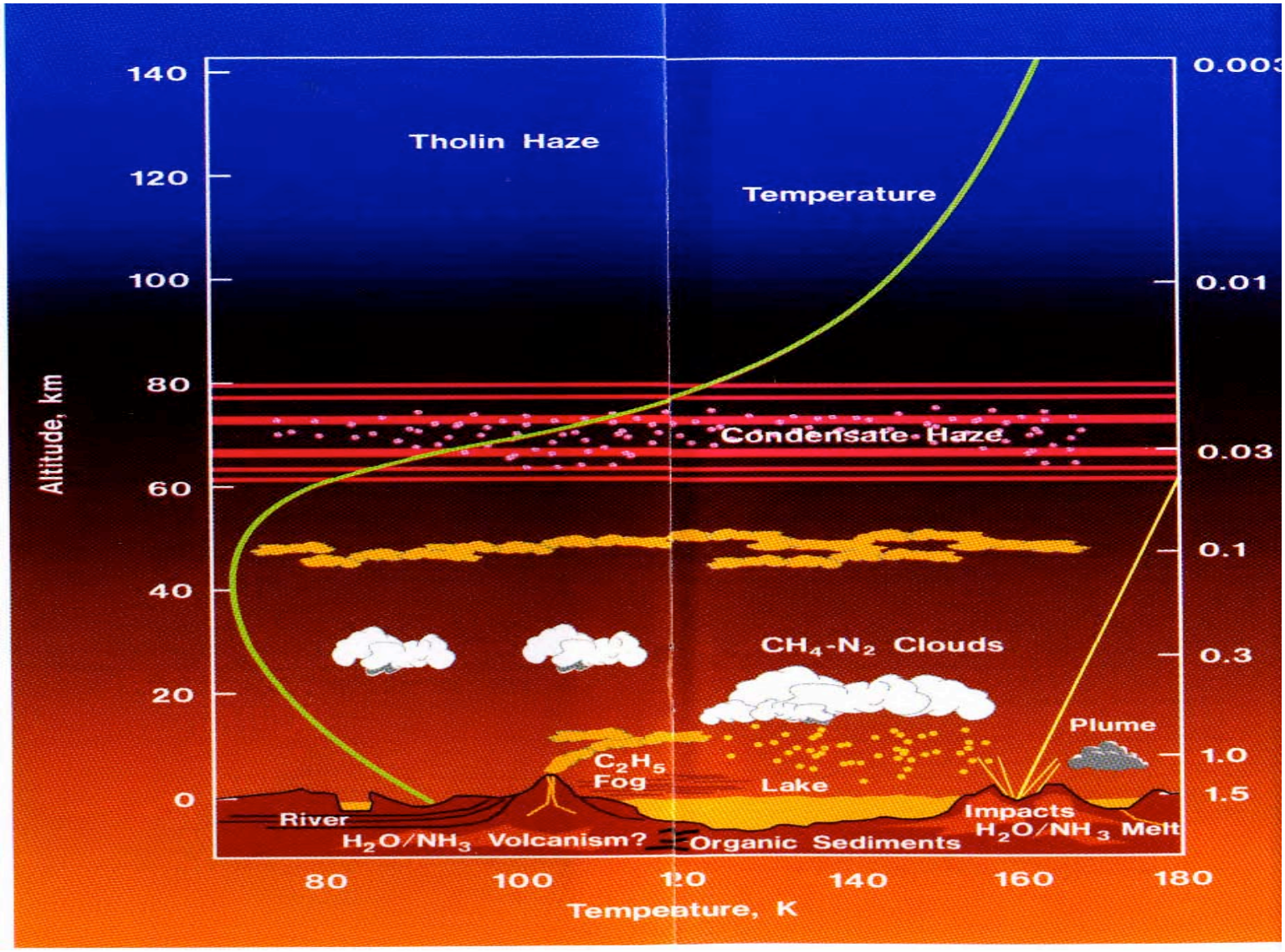


Metal Bellows for Venus Near-Surface Balloon

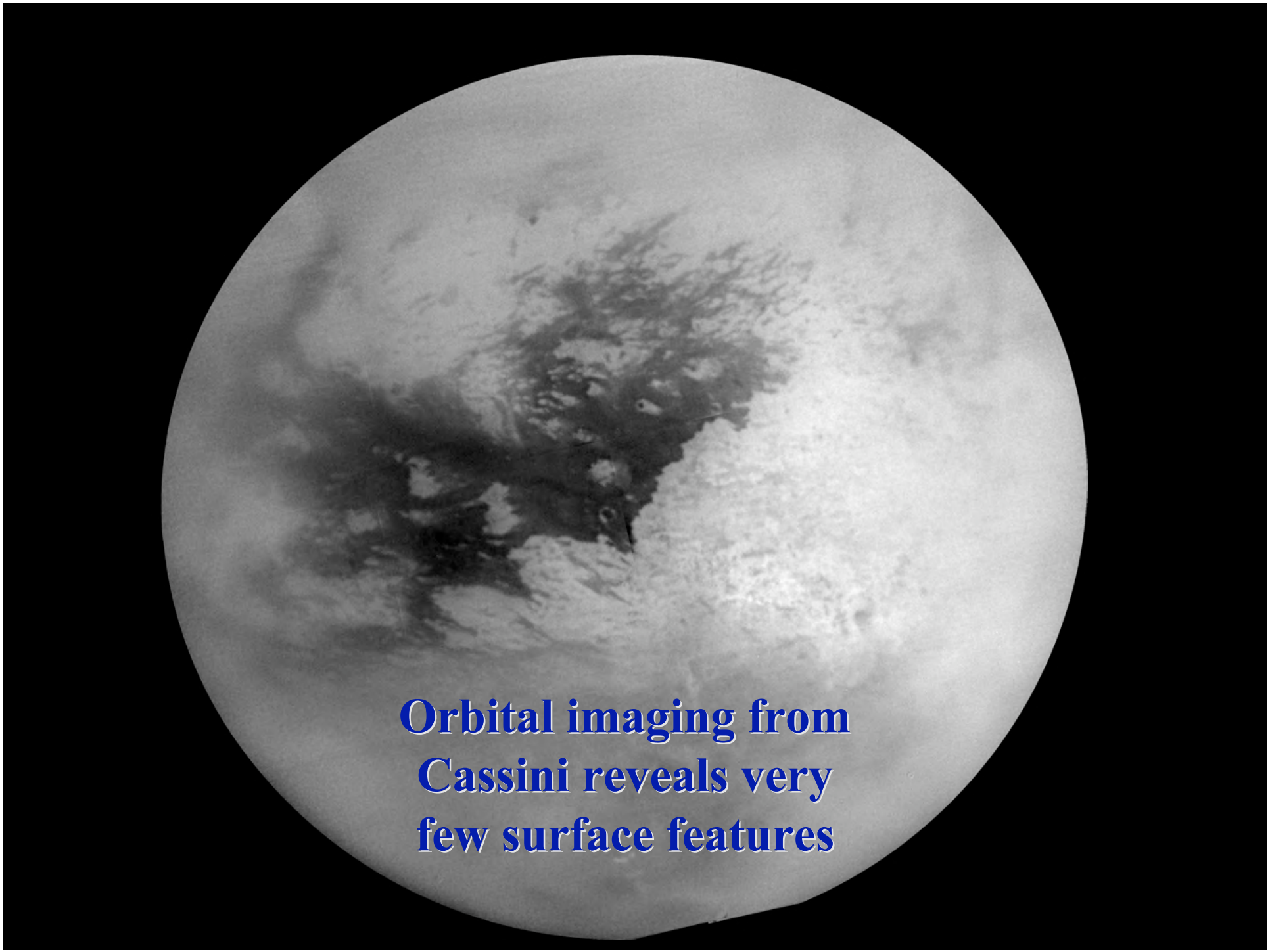


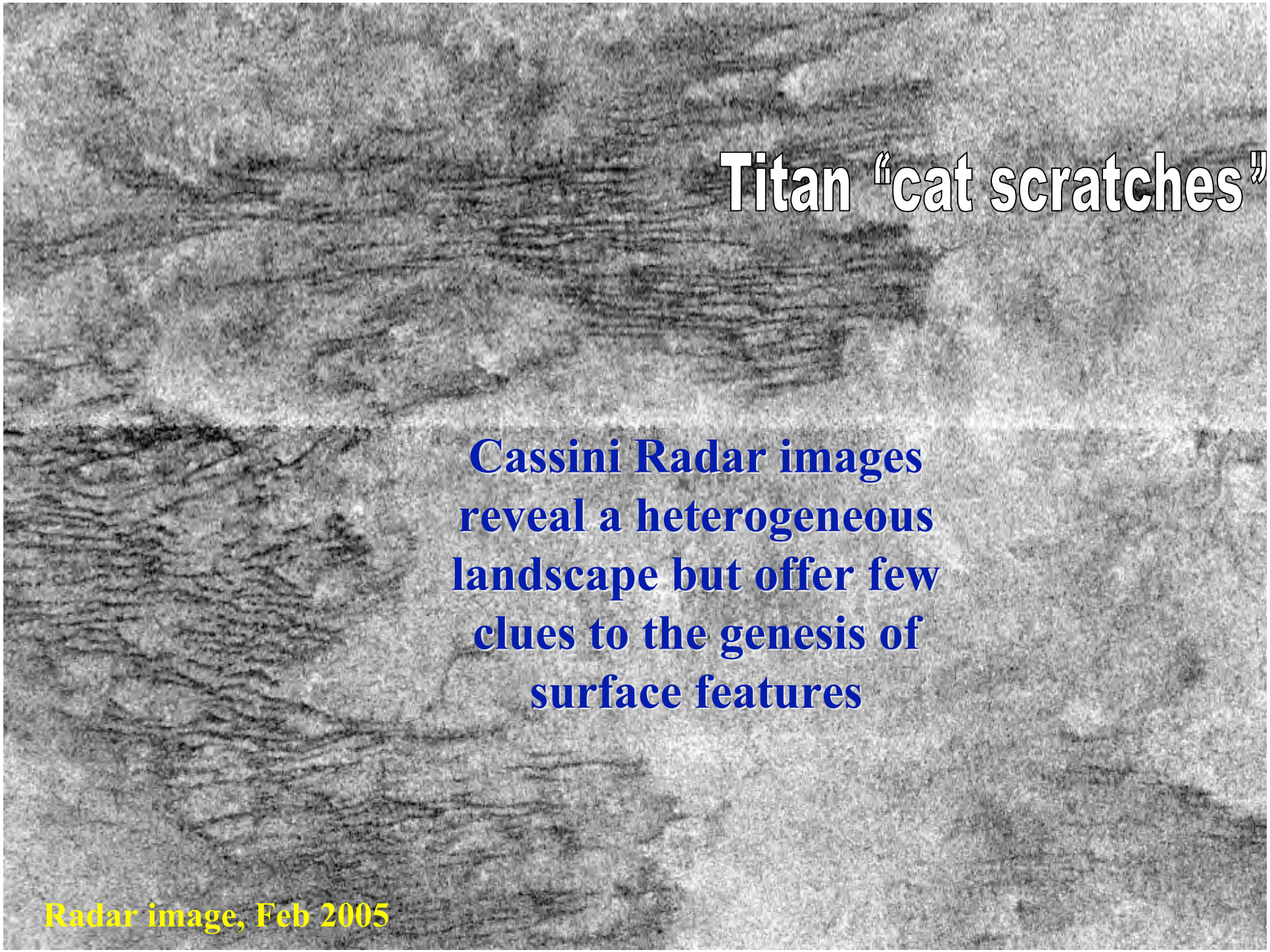
Metal bellows – actual picture

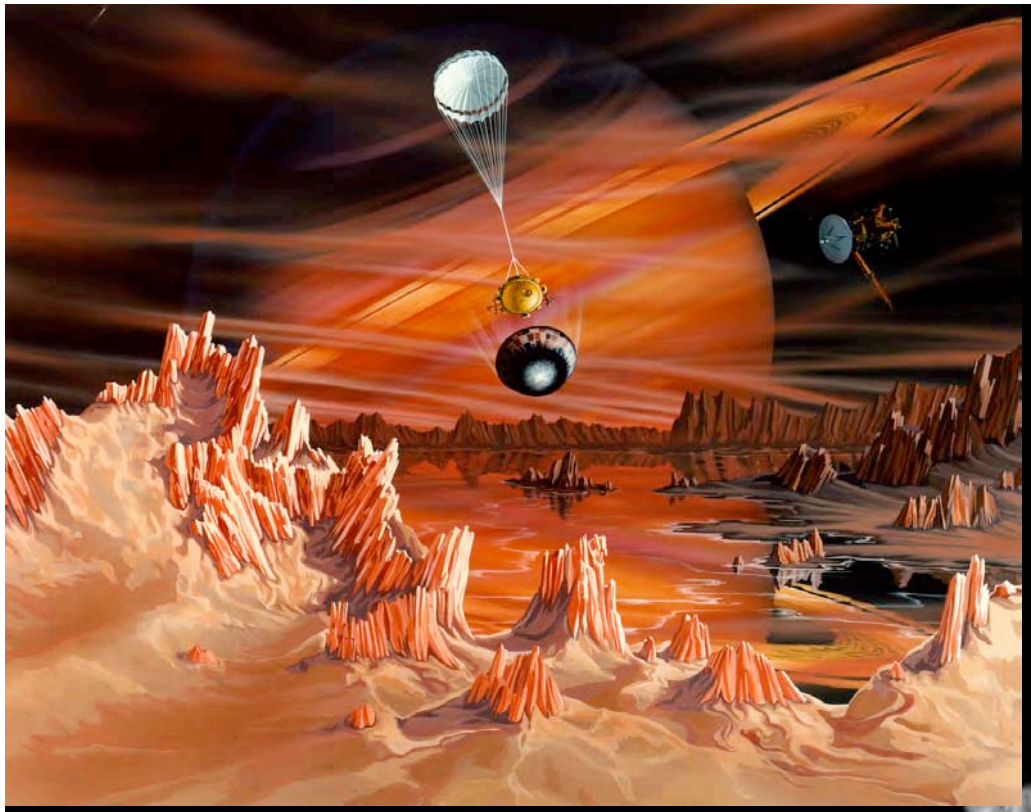
Titan's Environment



Pressure, bars

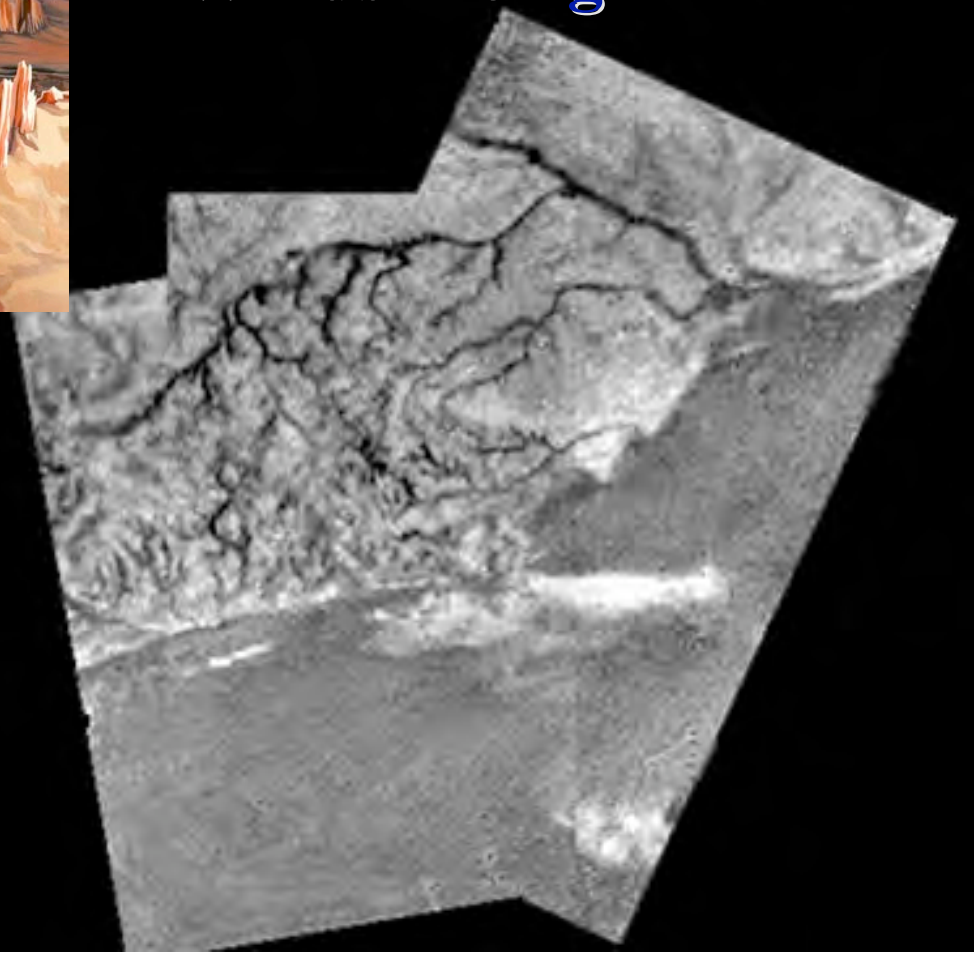

Orbital imaging from
Cassini reveals very
few surface features


Titan "cat scratches"
Cassini Radar images reveal a heterogeneous landscape but offer few clues to the genesis of surface features
Radar image, Feb 2005



Buoyant aerial platform is indicated for next phase of exploration:

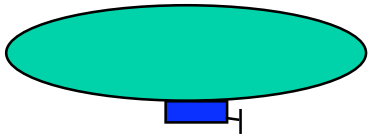
- **Atmosphere is clear**
- **Winds are light**



Aerial imaging from descending Huygens Probe reveals a rich variety of landforms with explicit clues to their origin

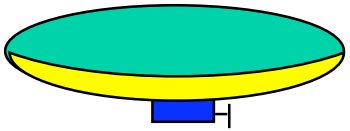
Titan Explorer – Aerial Mobility Options

Self-propelled airship



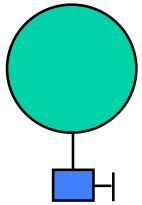
- All-H2 gas, streamlined hull for minimum drag, propelled for maximum control, capable of ground approach
- Unheated ambient atmosphere gas in ballonet for density compensation

Self-propelled Rozier



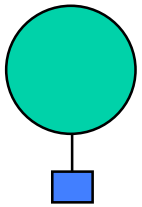
- Combined H2 and ambient atmosphere gas heated by RTG. Streamlined hull for minimum drag, propelled for maximum control.
- Heated gas complicates buoyancy control given variable flight speed

Self-Propelled Balloon



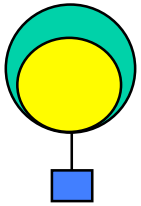
- All-H2 gas, high drag because of simple spherical shape
- No altitude control, therefore limited ability to do “go-to” maneuvers in low winds

Drifting Light Gas Balloon



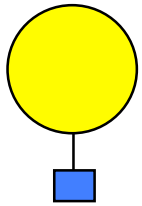
- All-H2 gas, simple spherical shape, no altitude control
- Simplest aerobot of all

Drifting Rozier Balloon

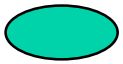


- Combined H2 and ambient atmosphere gas heated by RTG
- Simple spherical shape
- Altitude controlled through gas venting

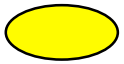
Drifting Montgolfiere Balloon



- All ambient atmosphere gas, buoyancy provided by radioisotope power system (RPS) heat
- Altitude controlled through gas venting



Hydrogen-filled envelope

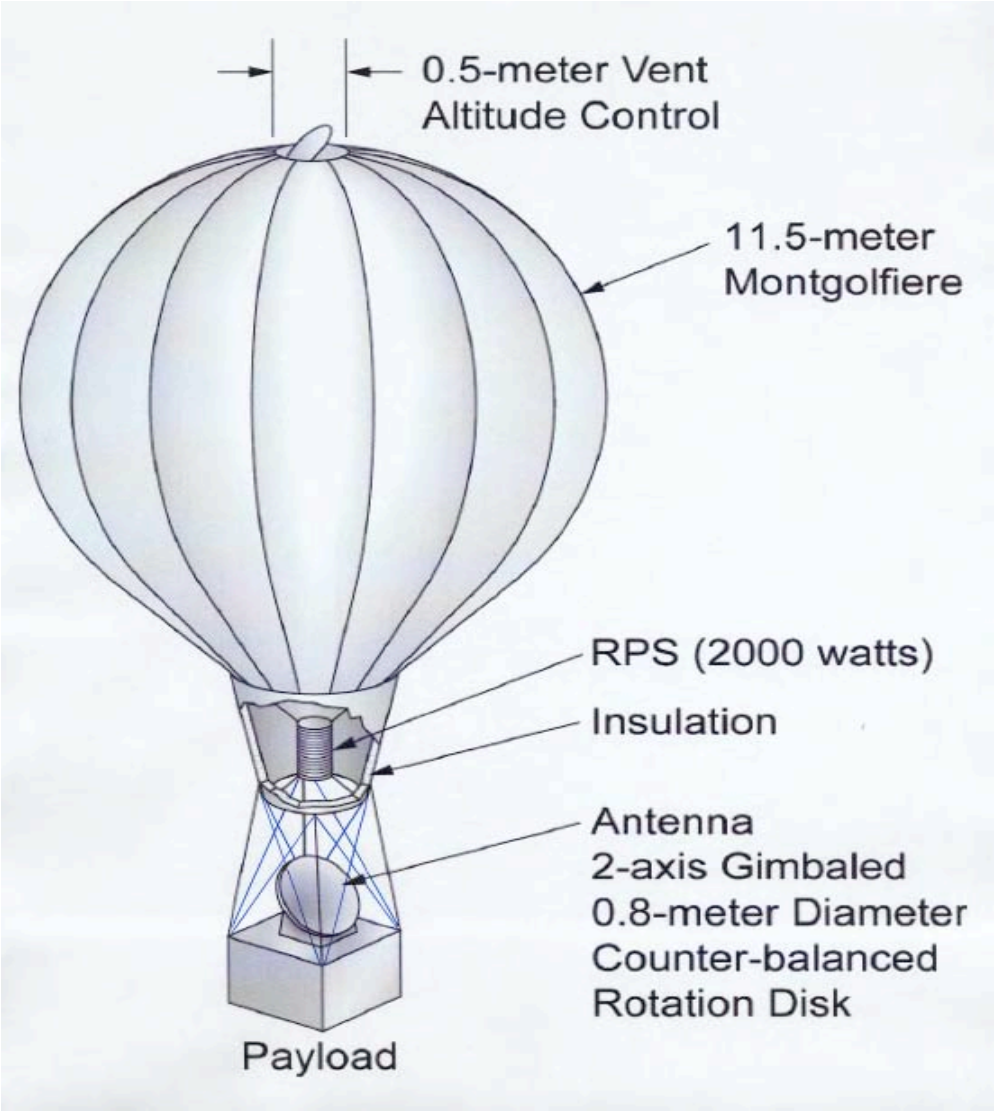


Warm ambient atmosphere-filled envelope

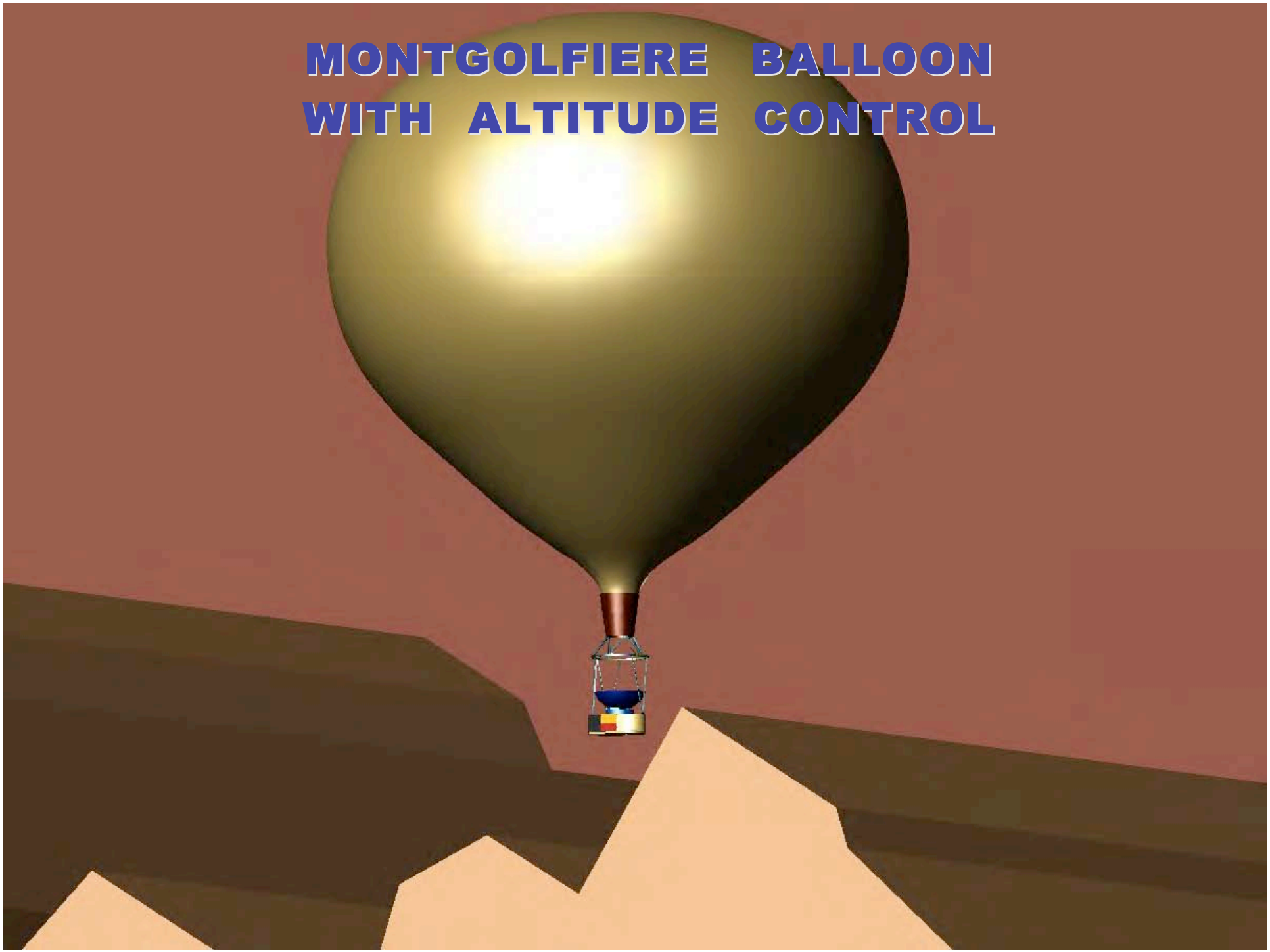
Titan Explorer – Aerial Mobility Options Comparison of Capabilities

	Atmospheric Science - Constant Altitude	Atmospheric Science - Variable Altitude	Surface Imaging Capability	Surface Sample Acquisition	Site Selection Capability
Self-propelled airship	Yes	Yes	Yes	Yes	Yes
Self-propelled Rozier	Yes	Yes	Yes	Yes	Yes
Self-propelled balloon	Yes	No	Yes	No	Limited
Drifting light gas balloon	Yes	No	Yes	No	No
Drifting Rozier balloon	Yes	Yes	Yes	Maybe	No
Drifting RTG Montgolfiere balloon	Yes	Yes	Yes	Maybe	No

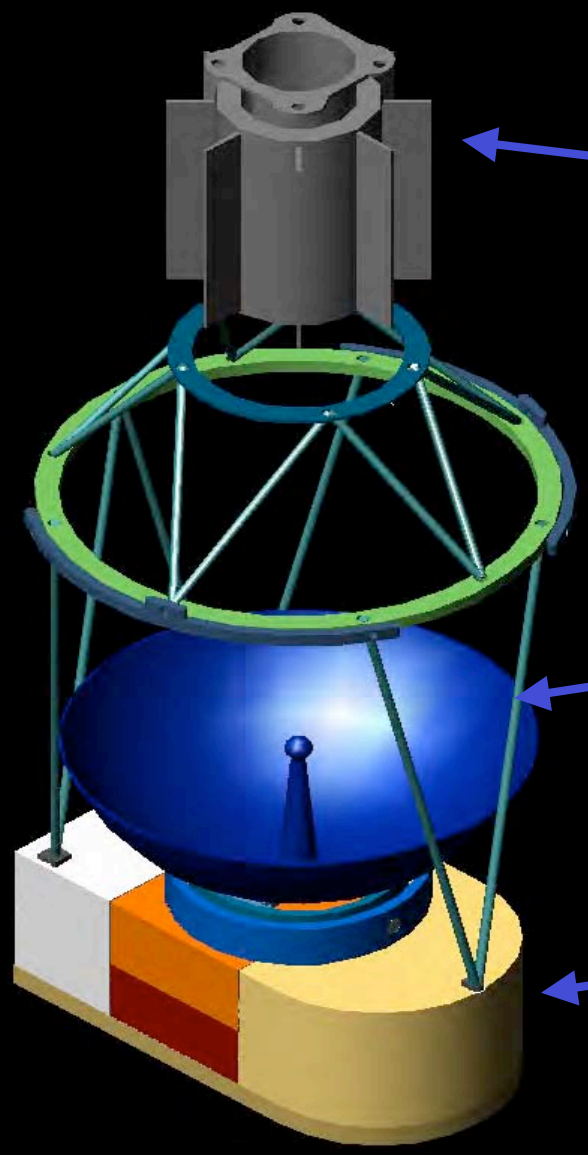
DRIFTING MONTGOLFIERE BALLOON WITH ALTITUDE CONTROL



MONTGOLFIERE BALLOON WITH ALTITUDE CONTROL



DRIFTING MONTGOLFIERE BALLOON WITH ALTITUDE CONTROL- "GONDOLA" DETAIL

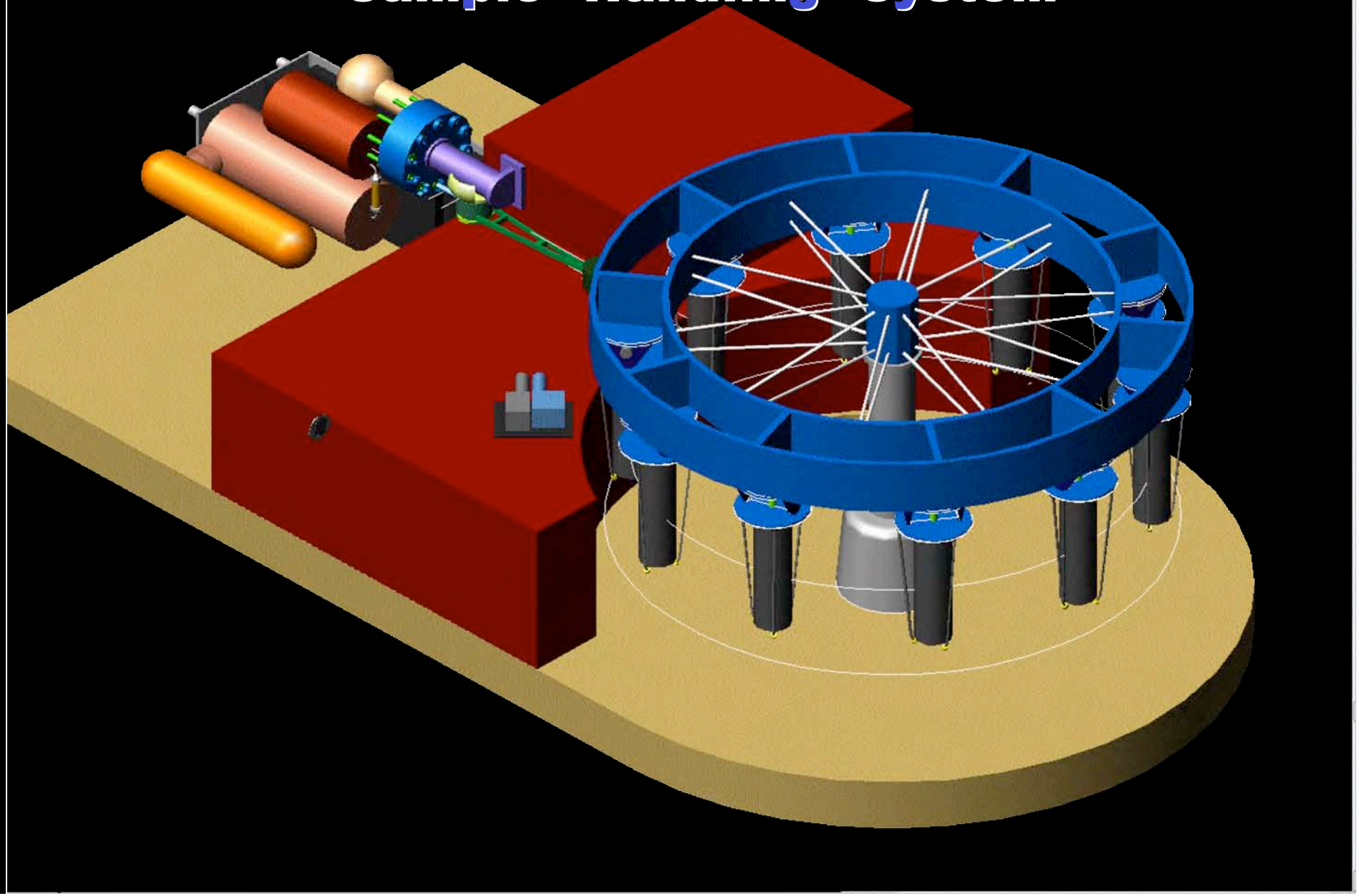


Radioisotope power system – for electrical power, thermal control and buoyancy

Steerable Antenna – two degrees of freedom.

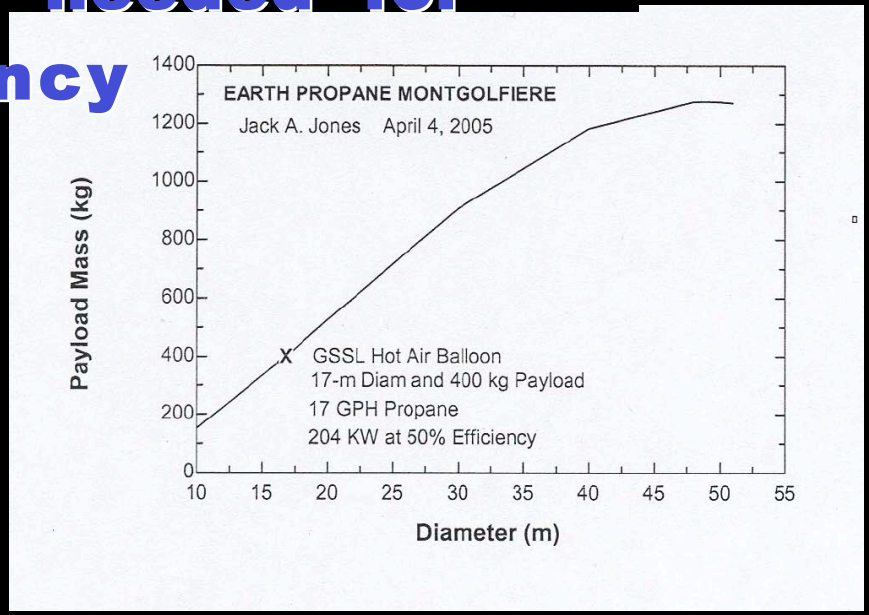
Payload Module

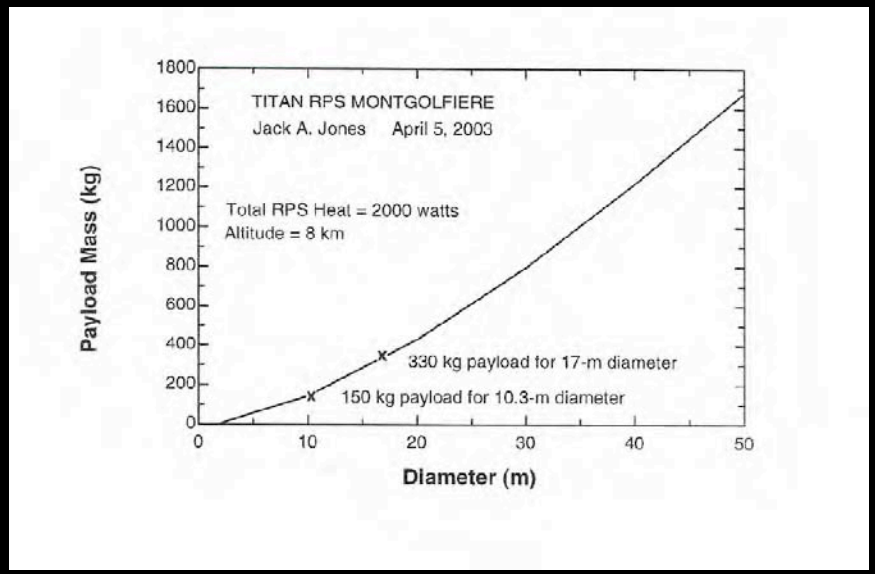
Payload Module - Instruments and Sample Handling System



Montgolfiere Balloon on Titan: Thermal Power needed for buoyancy

- On Titan, buoyancy requires less than 1% of the thermal power needed on Earth.
- Stray heat from an RPS with 110 w electrical (2 Kw thermal can lift a 350 kg payload to 8 km altitude
- Low temperature of Titan is key – reduces radiation losses and increases atmospheric density

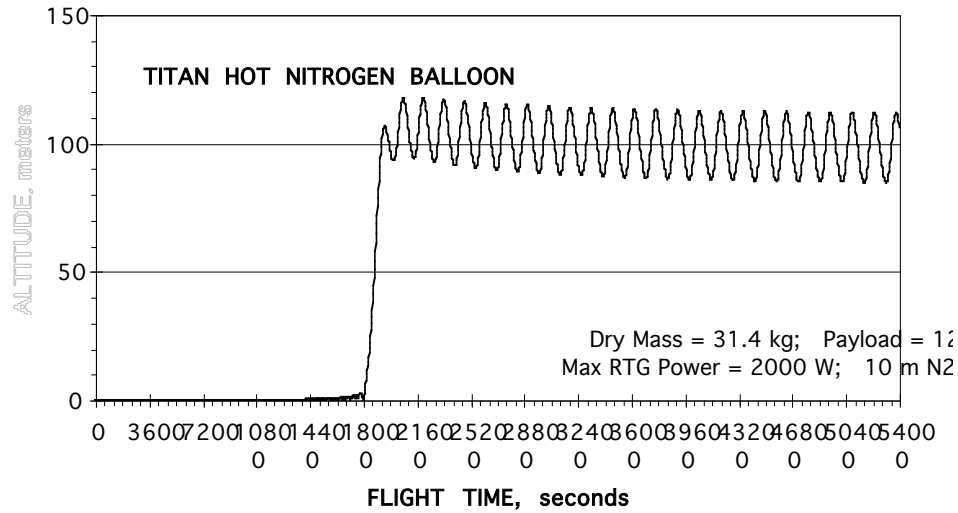




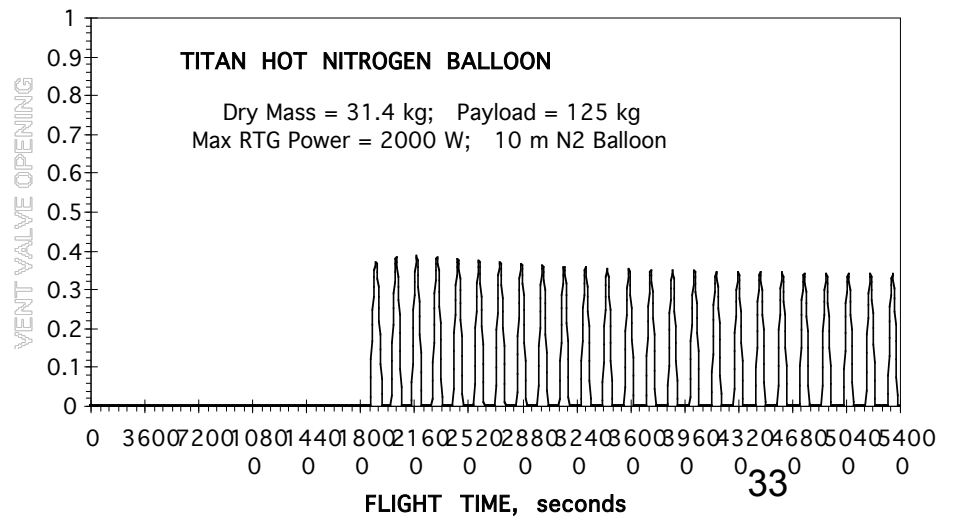
Montgolfiere Balloon on Titan: Altitude Control Authority

- Buoyancy is modulated by a vent on top of the balloon
- Altitude can be held near 100 meters with an uncertainty of 5 meters
- Response time for altitude changes is ~100 seconds
- Passive altitude control with a cable or "snake" can provides fine altitude control for sampling

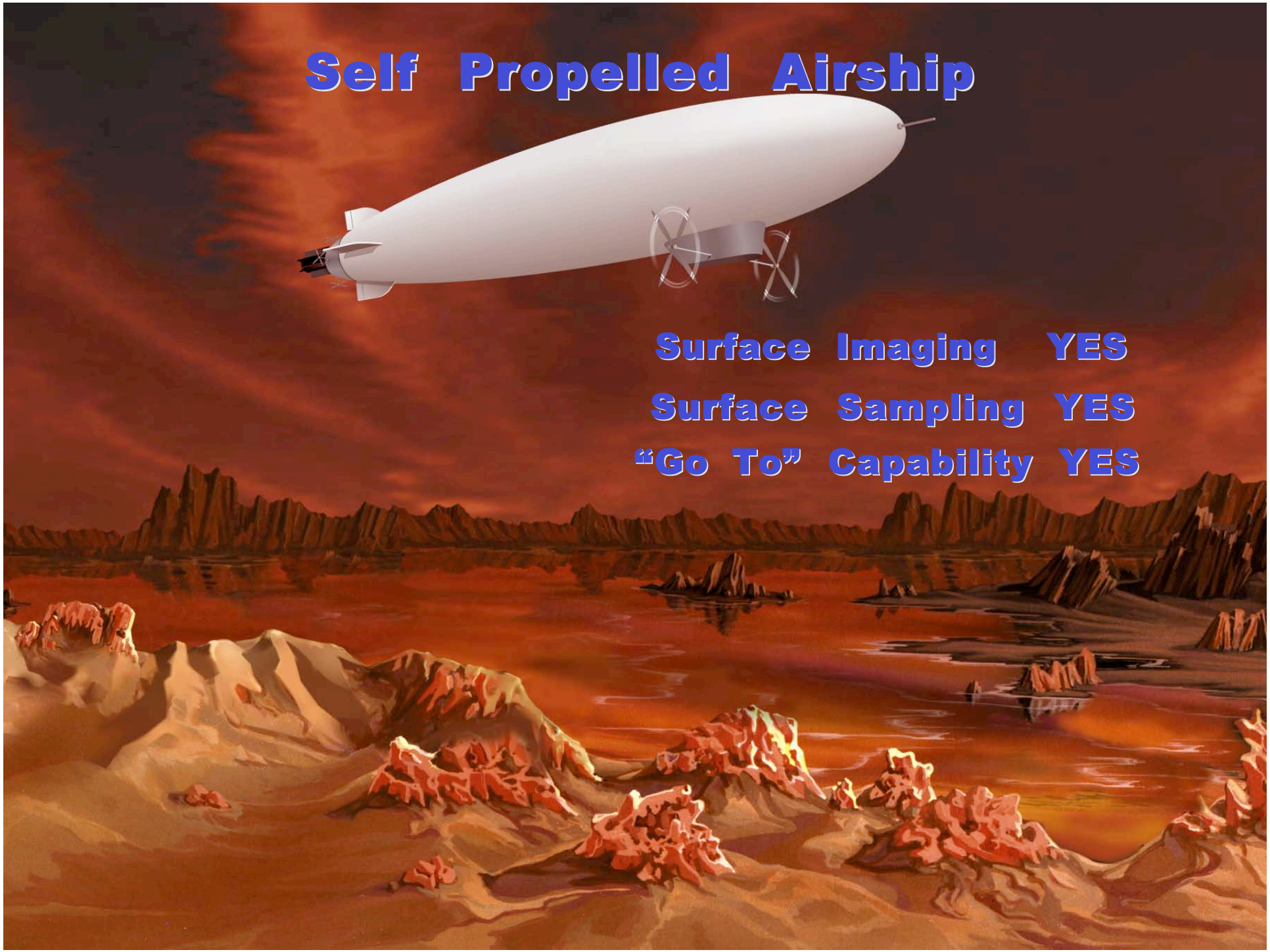
BALLOON ALTITUDE



BALLOON VALVE OPENING



Self Propelled Airship



Surface Imaging YES

Surface Sampling YES

"Go To" Capability YES

Titan Aerobot Technology Development

JPL Test Jig for flexing candidate balloon envelope meaterials at 77Kt

Accomplishments

- **Developed a fabric + film laminate material weighing 94 g/m2 that has sufficient tensile strength for a Titan aerobot**
- **Sufficient material flexibility was demonstrated in cyclical folding tests at 77 K (see picture on left)**
- **An adhesive has been developed and tested for making taped seams suitable for 77 K operation. Adequate strength demonstrated in burst tests of sample cylinders**

JPL Aerobot test flight at El Mirage Dry Lake, Mojave Desert

Accomplishments

- **Airship autonomy test bed** became operational in summer of 2003
- In June 2004 demonstrated **fully autonomous aerobot onboard flight control**.
- **Yaw, pitch and altitude control,** as well as **GPS waypoint navigation** demonstrated for up to tens of minutes

Summary

- NASA's Solar System Exploration Strategic Road Map of 2005 identifies missions to Venus and Titan requiring entry and extended operation in these planetary atmospheres
- Mobile lighter-than-air vehicles can address fundamental science at Venus and Titan that was performed so successful at Mars by the Mars Exploration Rovers – Spirit and Opportunity
- Operation in the extreme environments of Venus and Titan is challenging but the environment can be used to advantage
- The potential of mobile exploration with aerobots is limited only by technology of operatng in these extreme environments

Acknowledgements

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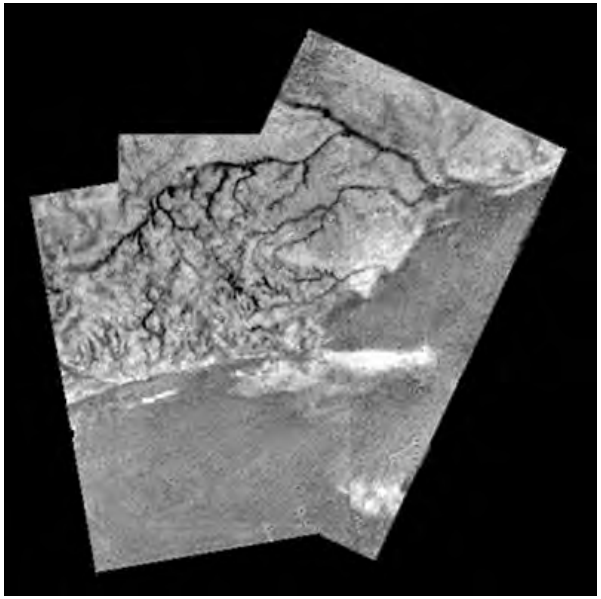
Titan Explorer

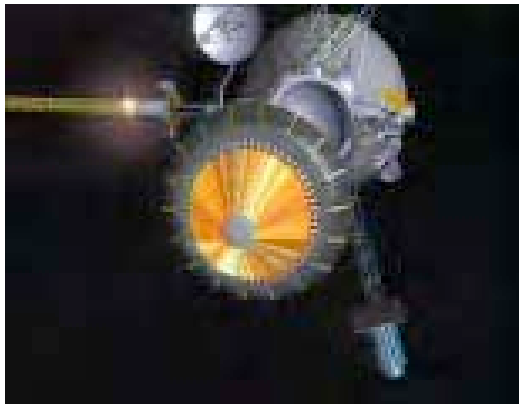
Scientific Objectives:

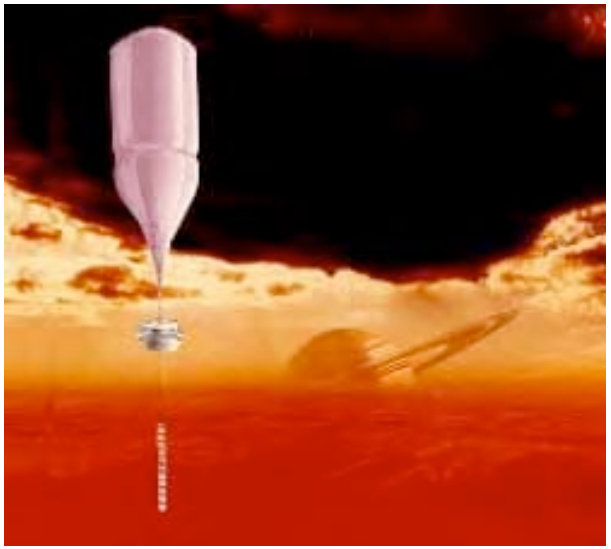
- Map the surface of Titan with **orbital radar** and **aerial imaging**.
- Characterize **pre-biotic & proto-biotic chemistry**; understanding **organics**
- Determine circulation, dynamics, and chemistry of the **atmosphere**



Mission Concept:

- **Orbital spacecraft** equipped with **imaging radar** and suite of other remote sensing instruments.
- **Aerial platform** for imaging and surface sampling.





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