



## **RADIOISOTOPE POWER SYSTEMS FOR IN-SITU EXPLORATION OF TITAN AND VENUS**



**JPL**



by  
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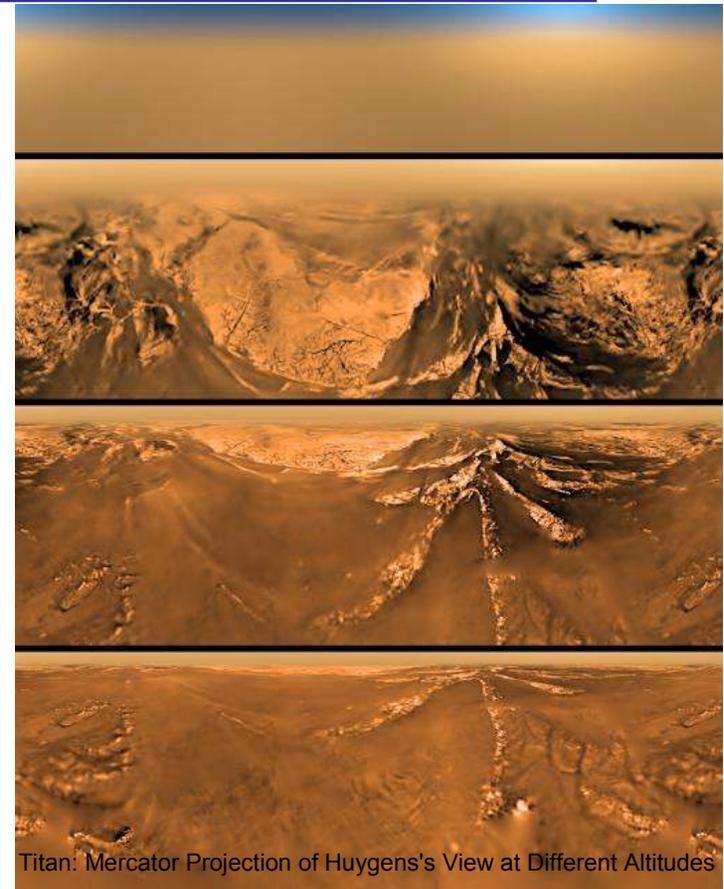
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# Overview



- Introduction
- Extreme Environments
  - Venus
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  - Venus Mobile Explorer Concept
  - Titan Explorer Concept
- RPS options for Venus and Titan
- Conclusions



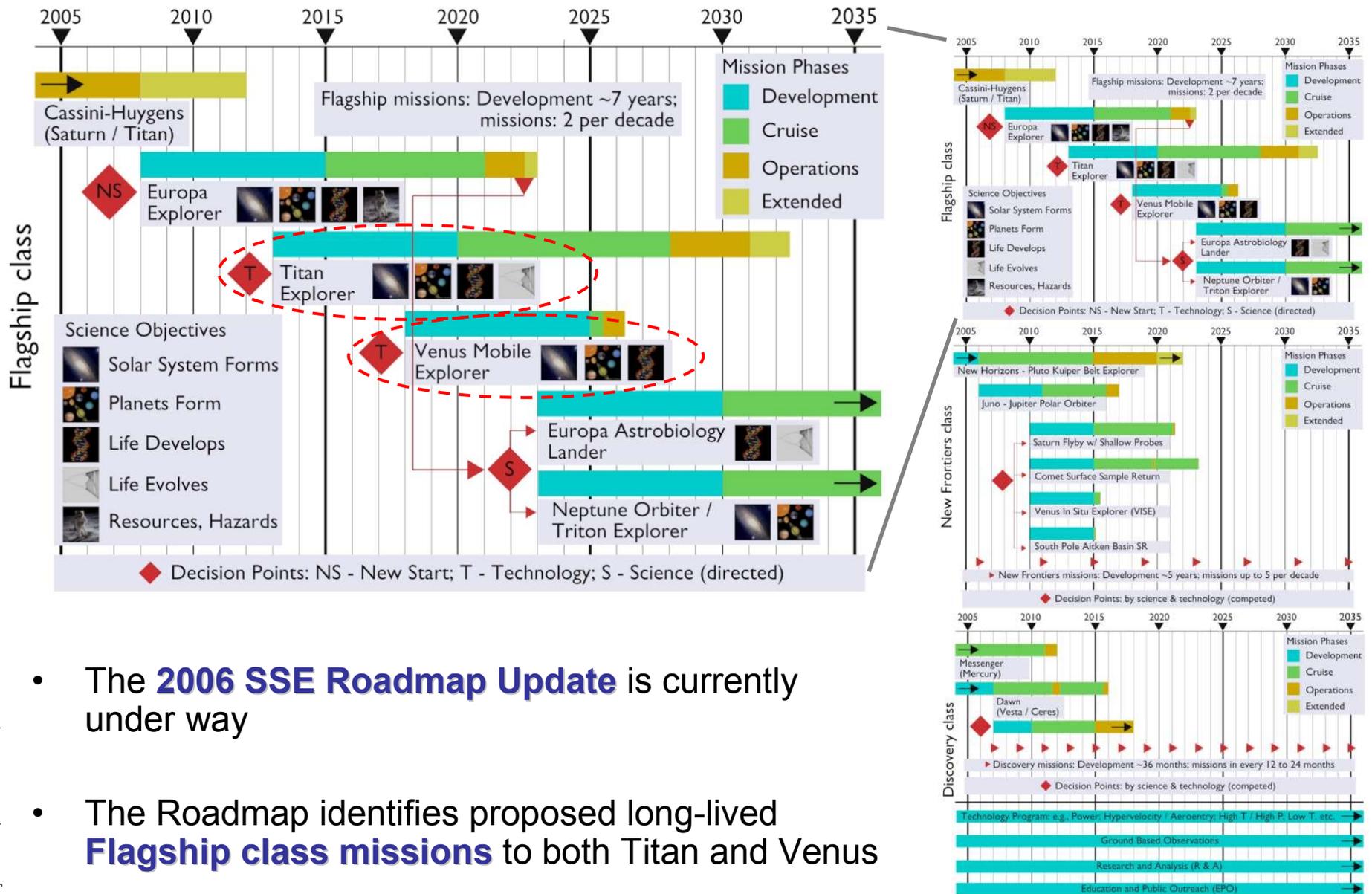
Titan: Mercator Projection of Huygens's View at Different Altitudes



Venera Image of the surface of Venus



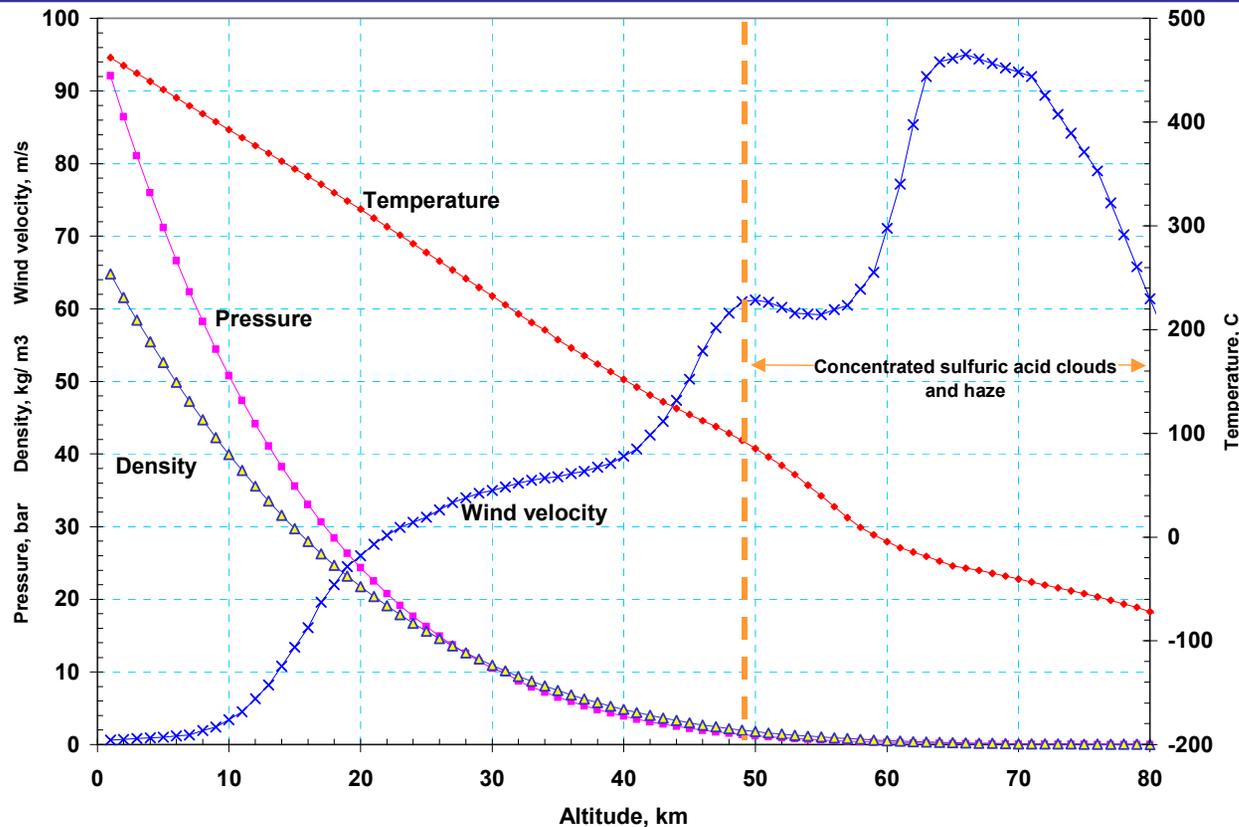
# Introduction



- The **2006 SSE Roadmap Update** is currently under way
- The Roadmap identifies proposed long-lived **Flagship class missions** to both Titan and Venus



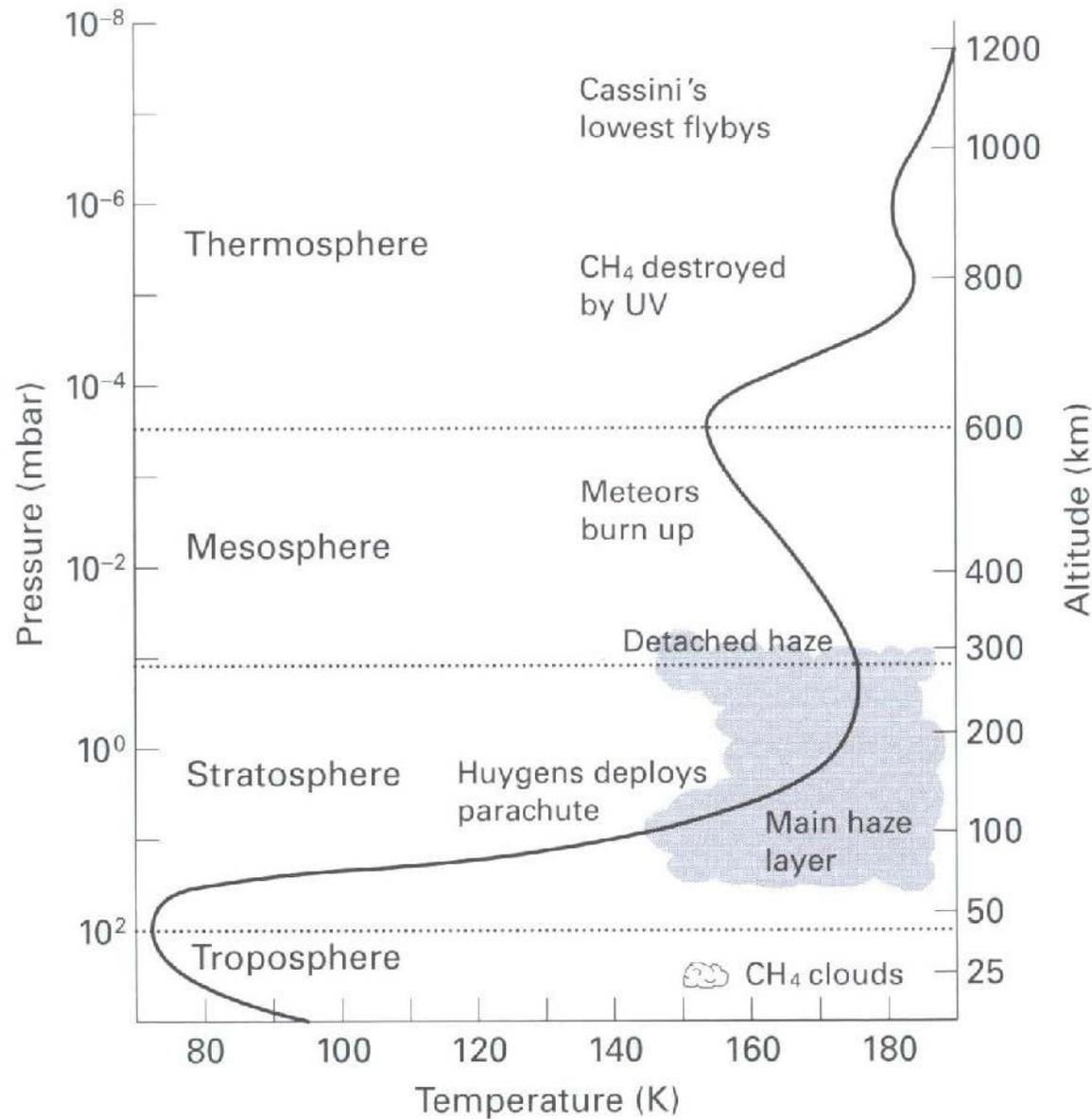
# Extreme Environments – 1: Venus (High T,p)



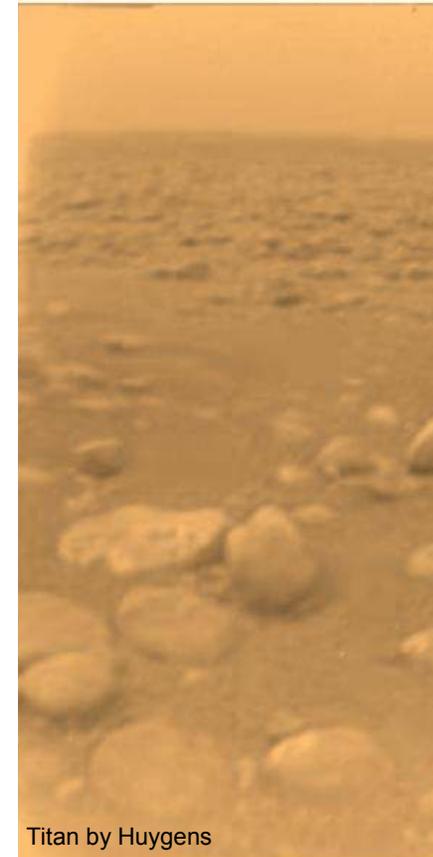
- Greenhouse effect results in **VERY HIGH SURFACE TEMPERATURES**
- Average surface **temperature**: **~ 460 to 480°C**
- Average **pressure** on the surface: **~ 92 bars**
- Cloud layer composed of **aqueous sulfuric acid droplets** at ~45 to ~70 km altitude
- Venus atmosphere is **mainly CO<sub>2</sub> (96.5%)** and N<sub>2</sub> (3.5%) with:
  - small amounts of noble gases (He, Ne, Ar, Kr, Xe)
  - small amount of reactive trace gases (SO<sub>2</sub>, H<sub>2</sub>O, CO, OCS, H<sub>2</sub>S, HCl, SO, HF ...)
- Zonal winds: at near surface ~ 1 m/s; at 60 km altitude ~ 60+ m/s



## Extreme Environments – 2: Titan (Low T)



- The **temperature** at the surface is **VERY COLD**: about **-178°C**
- **Pressure** is **~1.5 bars**
- **~2-10% methane** clouds and about **90% Nitrogen**



Titan by Huygens



# Venus Mobile Explorer Concept



## Scientific Objectives:

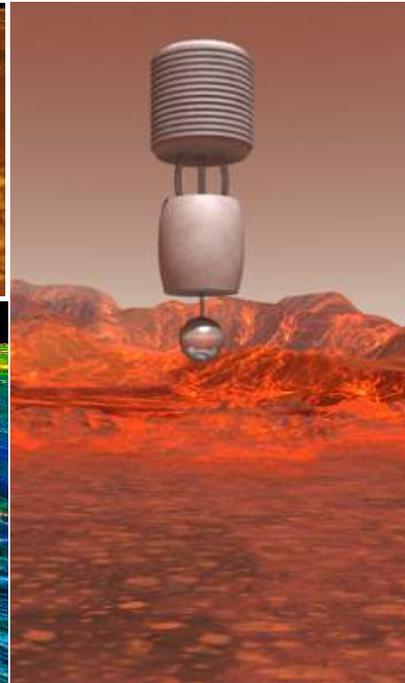
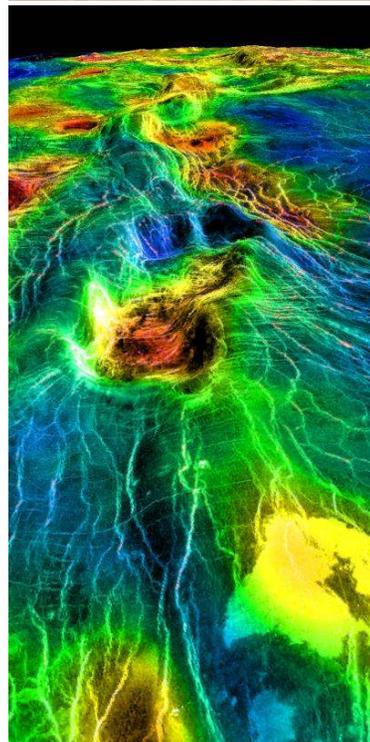
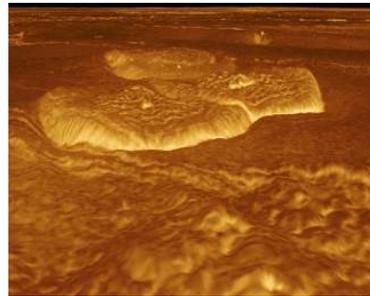
- Composition and isotopic measurements of surface and atmosphere
- Near IR descent images
- Acquire and characterize a core sample at multiple sites.
- *Demonstrate key technologies for VSSR*

## Exploration Metrics:

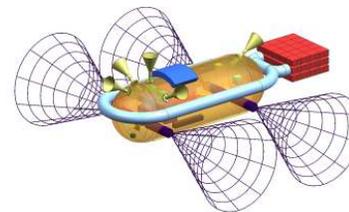
- Operate in Venus surface environment for 90 days+
- Range and altitude if aerial vehicle TBD
- *Range across surface if rover TBD*

## Mission & LV Class:

- Flagship Class
- LV: Delta-IV-H / Atlas V



OR



## Science Payload:

- Neutral mass spectrometer with enrichment cell.
- Instruments to measure elements and mineralogy of surface materials.
- Imaging microscope

## Technology & Heritage:

- Sample acquisition and handling in Venus environment
- Thermal control technology
- Long duration operation in situ

## Mission Technology Studies:

- Decadal Survey 2002 - none.
- Technology studies at JPL for definition of advanced RPS systems, 2005
- Extreme Environments Technologies at JPL, FY06.

**Earliest Launch Opportunity: Technology Readiness: 2022 Programmatic Slot: 2025**



## OPTION 1

Use **conventional components** and provide **survivability solely through thermal control**

**Impractical or not possible for some missions**

## OPTION2.

Use **only components capable of surviving in extreme environment**

**Prohibitively expensive for many technologies**



## Hybrid Solution: 1+2

Use a combination of advanced thermal control and components able to operate at extreme HT/high pressure environments

The hybrid option offers the best solution for optimizing mission architecture; This requires power + active cooling



# Titan Explorer (Orbiter & In Situ) Concept



## Scientific Objectives:

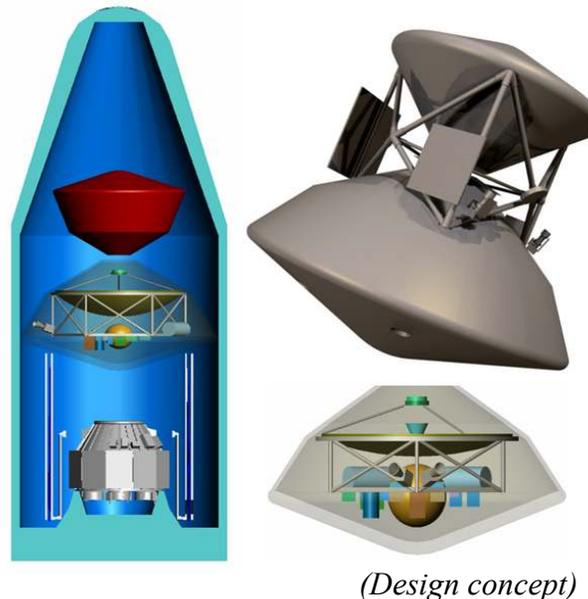
- Map Titan with high resolution radar.
- Characterize prebiotic chemistry and search for past life.
- Characterize surface and subsurface materials.

## Exploration Metrics:

- Orbiter with lifetime of about two years
- Operate on Titan for at least 90 days – aerial mobility, with Montgolfier & surface sample
- Proximity communications from orbiter to Titan Explorer

## Mission & LV Class:

- Flagship Class
- LV - TBD



## Science Payload:

- Imaging radar and other remote sensing on orbiter.
- Remote sensing and in situ instruments from Titan Explorer

## Technology & Heritage:

- Aerocapture for Titan orbit insertion.
- RPS power on orbiter and in situ vehicle.
- Aerial mobility with sampling

## Mission Technology Studies:

- Decadal Survey 2002
- Two Vision Mission studies in 2005
- Technology studies in: In Space Propulsion, Low Temperature Materials, and Autonomy.
- Titan Explorer JPL Study in 2006

**Earliest Launch Opportunity: Technology Readiness: 2017 Programmatic Slot: 2020**

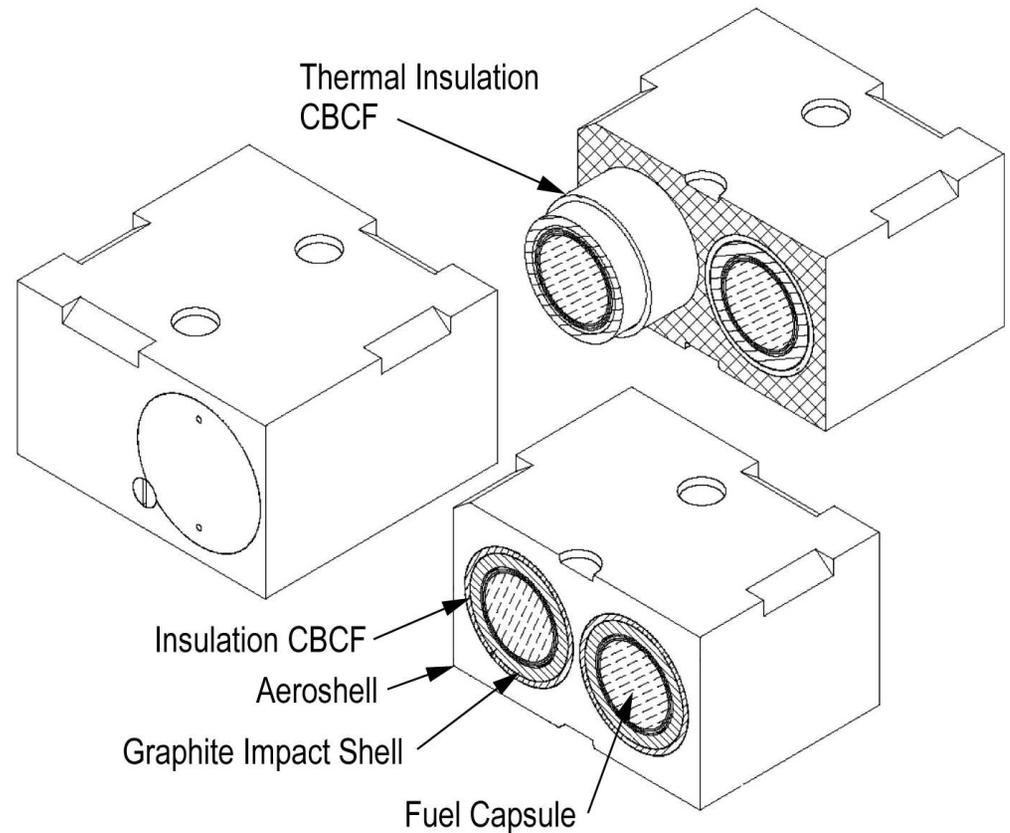


# General Purpose Heat Source Module (GPHS)



## Building Block of Radioisotope Power Systems

- **Module Mass:**
  - 1.6 kg per GPHS module
  - Includes 0.6 kg of  $\text{Pu}^{238}\text{O}_2$  fuel
- **Dimensions:**
  - 9.96 x 9.32 x 5.82 cm including
- **Power:**
  - $\sim 250 \text{ W}_{\text{th}}$  (BOM) total
  - $\sim 62.5 \text{ W}_{\text{th}}$  per fuel capsule
- **Operating Temperature:**
  - Iridium clad operation 1150K, and 1600K, to maintain ductility and limit grain growth



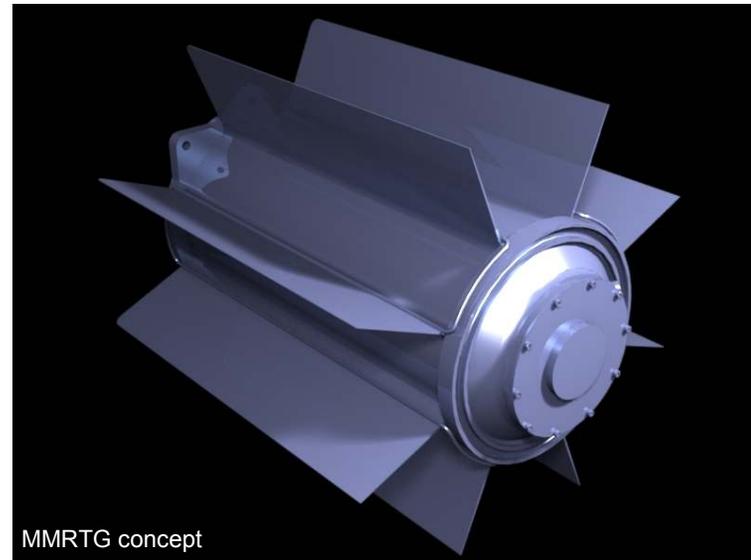
Step-2 Enhanced GPHS Module



# Advanced Radioisotope Power Systems



- **Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) would have these characteristics**
  - L66 cm x W64 cm x H64 cm
  - Uses 8 GPHS modules (2000Wt)
  - Generates ~125 We (BOM)
  - Mass ~43 kg
  - Specific power ~2.3 We/kg
- **Stirling Radioisotope Generator (SRG) would have these characteristics**
  - L104 cm x W29 cm x H38 cm
  - Uses 2 GPHS modules (500Wt)
  - Generates ~116 We (BOM)
  - Mass ~34 kg
  - Specific power ~3 W/kg
- **RPSs for Titan and Venus would have to be modified for the environment**
  - Titan: MMRTG fins would be adjusted for the low temperature, to achieve the required heat rejection rate
  - Venus: requires NEW DEVELOPMENT to address the environment; a special Stirling Generator with active cooling might provide a good development path



MMRTG concept



Stirling Generator concept



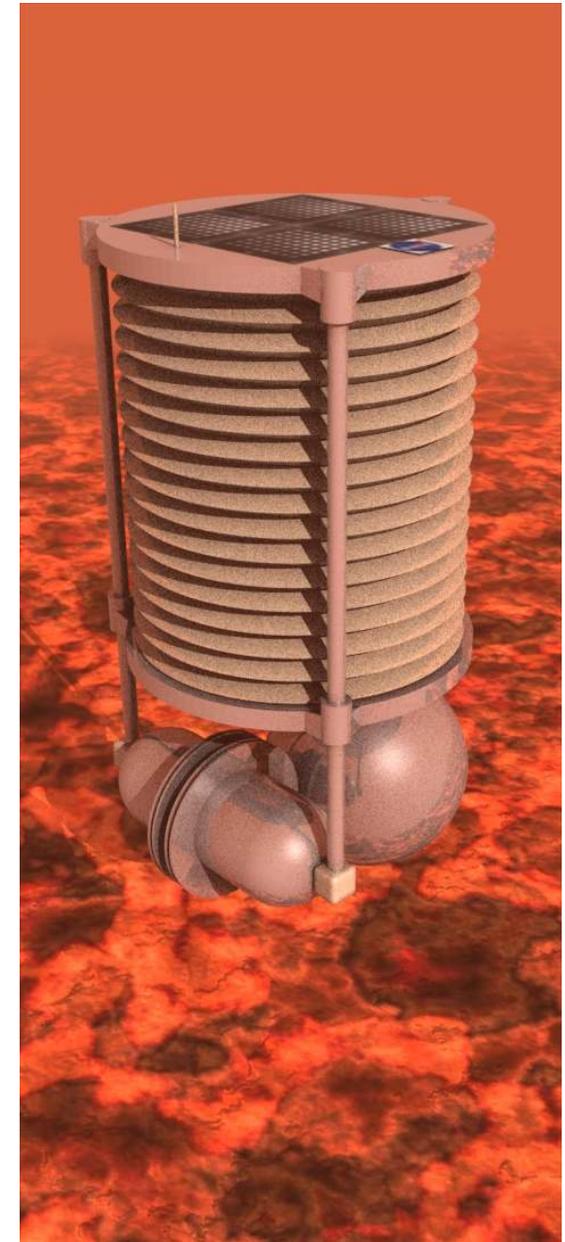
Cryocooler



# RPS Requirements for the Proposed Venus Mobile Explorer Mission



- The proposed VME spacecraft would operate near the surface of Venus:
  - **It would operate continuously** at the surface and in the lower atmosphere **for many months**
  - The RPS would need to **tolerate** the **480°C** and **90 bars** extreme environment
    - This would require **properly sized heat rejection system** and **pressure vessel**
  - The RPS would need to tolerate the **highly corrosive supercritical carbon dioxide** environment
    - This would require a **suitable coating**
    - Russian landers used enamel coating;
    - Kepton coating of US probes failed: 12.5 km anomaly
- Power system would need to provide **both power AND active cooling** to the instruments
  - Generator would produce electricity by converting radioisotopic heat,
    - similar to outer planets missions, but more difficult.
  - This RPS would enable the **hybrid thermal management** system, where a mechanical refrigerator cools non hardened payload elements, for example microprocessor and imaging sensor
- **High specific power** (this might be a challenging due to the environment)
  - An **air mobility** system would require a **light power source** due to **limited lifting** capacity
  - A **specially developed Stirling Radioisotope Generator with active cooling** could point to an suitable RPS development direction



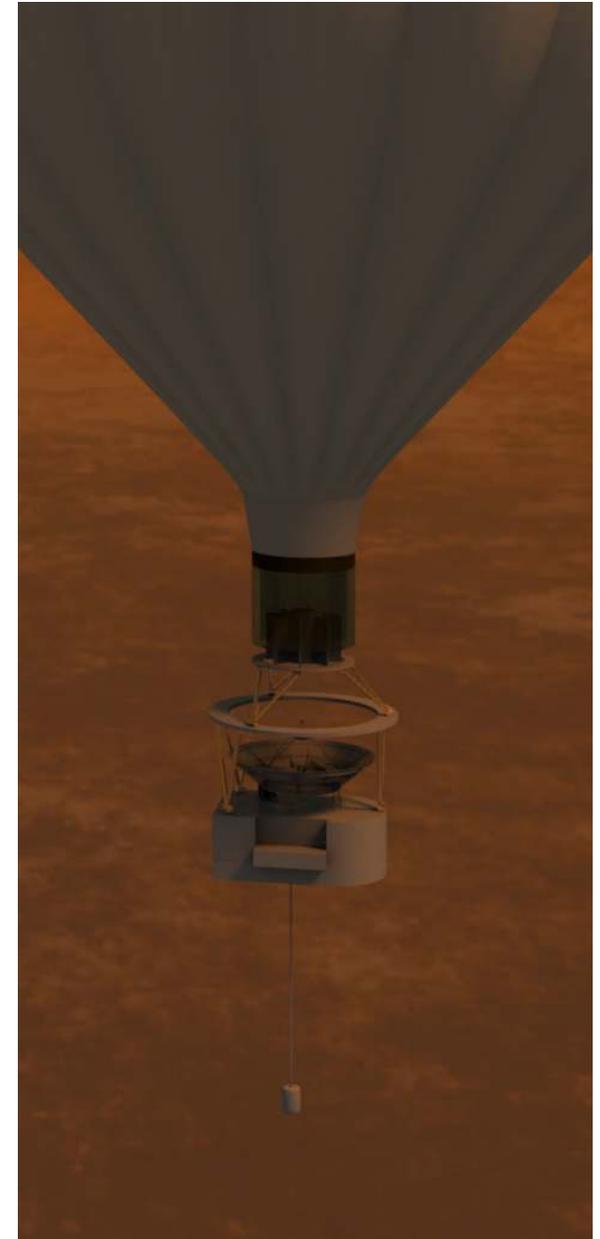
Design concept



## RPS Requirements for the Proposed Titan Explorer Mission



- **Hot air balloons**, by definition, **require heat**, therefore,
  - This concept would not only utilize the **electric power from the RPS**, but **also the thermal power** (excess heat) to keep the balloon afloat
  - Therefore, **plutonium reduction** for this this concept is **not** considered to be **a key driver**
  - However, **improved conversion efficiency** could provide **more power for the same amount of Pu-238**, enabling higher telecom data rates, more instrument operations, etc.
- **RPS thermal design** would need to be **adjusted** for the cold Titan environments
  - **Fin size** would need to be **adjusted** to achieve the required heat rejection, and the temperature drop across the thermoelectrics
- **MMRTG could be considered** with the above fin modifications
- **Number of RPSs:**
  - A **single** MMRTG could work
  - **Two** MMRTGs would provide more power, and more thermal power, which would reduce the size of the hot air balloon (Montgolfier), countering the mass penalty of the additional power source
  - Two MMRTGs would possibly require special accommodation during cruise, and operations, to provide good heat rejection



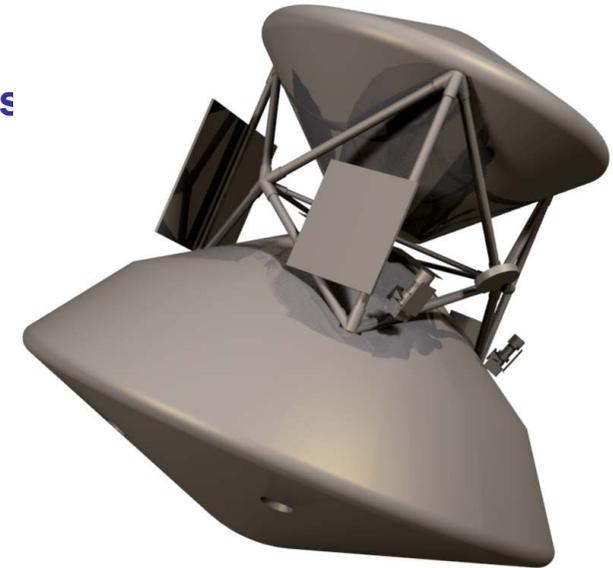
Design concept



# Operation Through All Mission Phases



- **RPS generates heat continuously** (radioisotope decay)
- This would need to be **mitigated** through **all mission phases**
- **Earth storage phase;**
  - Earth environment; convection + conduction + radiation
- **Launch** (and pre-launch integration) **phase;**
  - Earth environment; convection + conduction + radiation
- **Cruise phase;**
  - RPS enclosed inside the aeroshell; would require active cooling and heat rejection to space through external radiators; forced convection fluid loop + conduction + radiation
- **Entry, Descent, and Landing (EDL) phase;**
  - Short period, but active cooling disabled, limited heat transfer; radiation and conduction only during entry; aeroshell would need to absorb excess heat
- **In situ operations phase (Titan/Venus);**
  - Planetary atmosphere; RPS design would need to address extreme environment; heat rejection system is specific to environment



Back-to-back Titan aeroshell concept

## Venus mission environment:

- **Hot inside aeroshell** during cruise
- **Very hot operational** environment

## Titan mission environment:

- **Hot inside aeroshell** during cruise
- **Extremely cold during operations**



## Conclusions

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- The extreme environments of Titan and Venus introduce many technical challenges:
  - at Titan: low temperature
  - at Venus: high temperature, high pressure, corrosion
- Long lived Flagship class in situ missions referenced in this study require reliable internal power sources, such as RPSs
- RPSs would require modifications to mitigate these extreme environments, but
  - a Titan mission could use existing designs, such as an MMRTG
  - A Venus mission would require a new RPS development; providing both power and active cooling to the spacecraft
- **RPS technology is considered enabling for these proposed missions**



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**The End**