TITAN AERIAL EXPLORER (TAE): EXPLORING TITAN BY BALLOON

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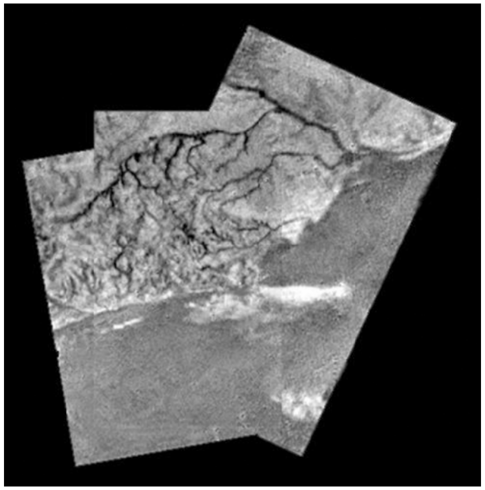
Outline

- Introduction
- Mission Architecture
- Science Objectives and Instruments
- Balloon
- Spacecraft Design
- Mission Design
- Conclusions

Introduction

- TAE was developed in response to the 2010 ESA Cosmic Visions solicitation for medium-class missions.
- The fundamental approach: to formulate the least expensive Titan balloon mission that still provided an outstanding science return.
  - We believe that only this approach allows for a Titan balloon mission at a medium-class cost.
- Jonathan Lunine was the science PI; Christophe Sotin was the US Science team lead.
- The partnering organizations for engineering were Thales Alenia Space, CNES and JPL
- TAE made the first cut from 47 to 14 mission concepts, but was not selected as a finalist.
  - TAE science rated very highly, but there were concerns about implementation, particularly the availability of US-provided ASRGs.

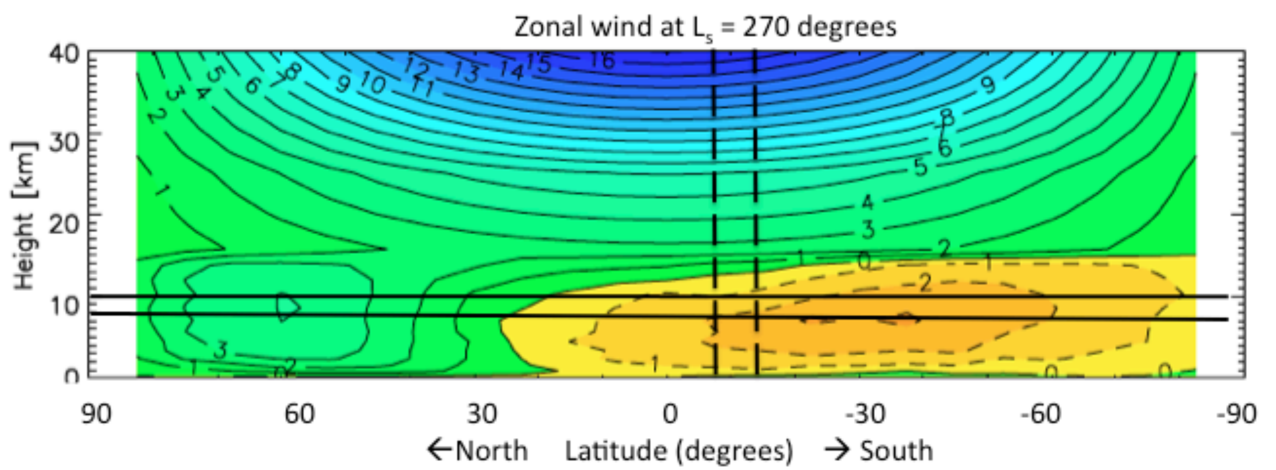
Artist's concept of TAE flying at Titan



Huygen descent image showing fluvial features

Mission Architecture (1)

- The TAE mission is based on a set of 5 key architecture decisions:
  - Minimum of 3 months of balloon flight, with a desire for 6 months
    - 6 months is required to accomplish one circumnavigation of Titan near equator.
  - A balloon flight altitude of 8 km, with a preference for doing one or more altitude excursions down the surface.
  - Wind-driven balloon trajectory starting near the Huygens landing site.
    - Huygens site over flight is desired but not essential.
    - Primarily zonal motion at ~1-2 m/s, balloon will remain near equator.
  - Direct-to-Earth telecom from the balloon to avoid the need for a relay orbiter.
  - A total mission data return of ~ 1 Gbit.



Mission Architecture (2)

- Several key mission design and science return consequences flow from these architecture decisions:
  - Radioisotope power is required for a mission of such a long duration and high data return.
  - The balloon does not require onboard propulsion or an autopilot to control its trajectory.
  - The balloon does not collect surface samples or otherwise touch the surface.
  - A high gain antenna is required on the balloon gondola to provide a sufficiently high data return rate back to Earth.
  - The spacecraft consists of an entry vehicle mounted on a carrier spacecraft.
    - The entry vehicle contains the balloon, scientific payload and support systems.
  - The balloon deploys and inflates upon arrival at Titan during the initial parachute descent phase.
  - Science investigations are limited to what can be achieved from a single balloon platform that does not acquire surface material.

Science Themes and Goals

- TAE science is organized around two themes:
  1. The presence of an atmosphere and liquid volatile "hydrologic" cycle, which implies climate evolution through time.
  2. Organic chemistry, which is pervasive through its atmosphere, surface, and probably interior.

- Each of these themes is associated with a specific TAE science goal:
  - **Goal 1**: Explore how Titan functions as a system in the context of the complex interplay of the geology, hydrology, meteorology, and aeronomy present there.
  - **Goal 2**: Understand the nature of Titan's organic chemistry in the atmosphere and on its surface.

- These goals lead to a set of 5 science objectives and associated measurement objectives (next slide)

Science and Measurement Objectives

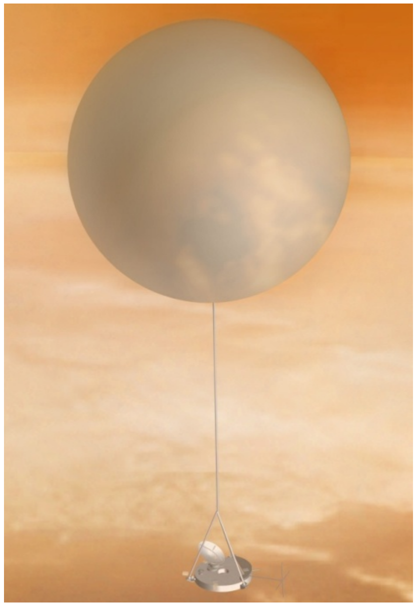
	Science Objective	Measurements
A	Determine the composition and transport of volatiles and aerosol particles in clouds, including hydrocarbons and nitriles, in order to understand the hydrocarbon cycle. Determine the climatological and meteorological variations of temperature, clouds and winds. (Science Goals 1 and 2)	• Assess surface volatile inventory: $\lambda/\Delta\lambda$ ~1000 over 5–6 microns • Obtain temperature and methane relative humidity soundings over a large swath of Titan's atmosphere (ΔT = 0.1 K; Δx_{CH4} = 0.01) • Perform direct measurement of zonal and meridional winds • Determine cloud distribution, morphology, and extent of supersaturation near the cloud base. • Detect the presence of turbulence and fluctuating electric fields associated with moist convective activity and other meteorological phenomena. • Detect cloud condensates and determine their physical state (solid, liquid) and the presence or absence of nucleating aerosols.
B	Characterize and assess the relative importance today and throughout time of Titan's geomorphologic processes: cryovolcanic, aeolian, tectonic, fluvial, lacustrine, impact and erosional. (Science Goal 1)	• Detect indicators of methane outgassing with spatial resolution 50 m or better • Measure local topographic variations distributed over a broad swath of Titan's surface (50 meter spatial resolution stereo images) • Assess regional morphology and texture; spectral reflectance $\lambda/\Delta\lambda$~1000. • Determine local-scale morphology over selected areas (meter-scale) • Determine subsurface structure in selected areas with penetration depths of at least 100 meters • Map topographic boundaries previously identified by, and at much higher resolution than, Cassini RADAR.
C	Determine internal differentiation and thermal evolution of Titan. Determine if Titan has an internal ammonia-water ocean, a metal core and an intrinsic or induced magnetic field, as well as the extent and origin of geodynamic activity. (Science Goal 1)	• Measure vector magnetic field at low altitude along a large swath of Titan's surface • Measure electric fields to test for the presence of a conducting boundary deep below the surface (i.e., an ammonia-water ocean)
D	Determine geochemical constraints on bulk composition, the delivery of nitrogen and methane and exchange of surface materials with the interior. (Science Goal 1)	• Seek evidence for release of volatiles such as methane and carbon dioxide from surface vents. • Determine spectroscopic composition of oxygen-bearing organics in geologically unusual sites
E	Determine the chemical pathways leading to formation of complex organics in Titan's atmosphere and their modification and deposition on the surface with particular emphasis on ascertaining the extent of organic chemical evolution on Titan. (Science Goal 2)	• Determine surface composition of major hydrocarbons • Measure the bulk composition of particulates in cloud particles

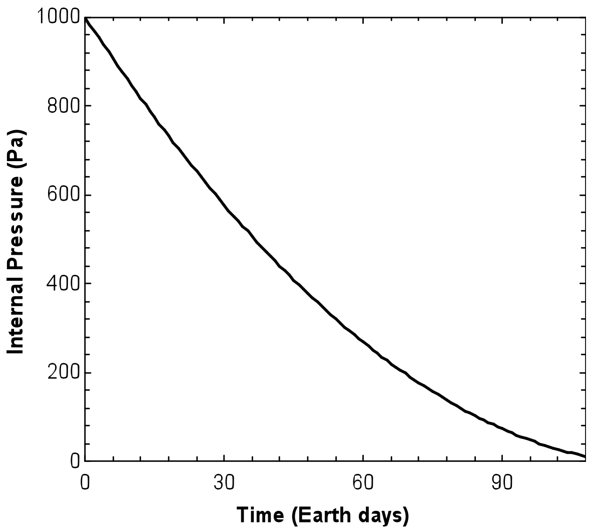
Strawman Instrument Payload

	Mass (kg)	Peak Power (W)	TRL Level	Approx. Data Rate (Mb/Titan Sol)	Science Contribution	
VISTA-B Visible Imaging System for Titan Aerostat-Balloon	2	5	7	108.5	Detailed geomorphology at 10 m resolution and higher in selected areas	Surface
BSS—Balloon Slit Spectrometer 4.6–5.6 μm	2.5	9 (11 with shutter)	6	3.5	Mapping organics in concert with surface images	Surface
ASI/MET – Atmospheric Structure Inst. / Meteorology Pkg.	1.0	3	6	2.7	Record atmosphere characteristics during aerostat cruise	Atmosphere
TEEP-B—Titan Electromagnetic Environment Package	0.5	3.5	8	4.9	Measure electric fields (0–10 kHz) in the troposphere and determine connection with weather; search for induced or permanent magnetic field	Atmosphere
TRS—Titan Radar Sounder at >150 MHz	8	15	7	28.9	Determine topography (5 m res) and depth of the ice layer, and detect shallow reservoirs of hydrocarbons, and better than 10 m resolution stratigraphy of geological features.	Surface
TCAA—Titan Cloud and Aerosol Analyzer	0.5	1	5	1.2	Analysis of cloud droplets and embedded aerosols for composition and cloud formation processes	Atmosphere
Total	**14.5**			**149.7 Mbit**	**Not all instruments operate simultaneously**	
30% Res.	**4.4**					
Total with Res.	**18.9**					

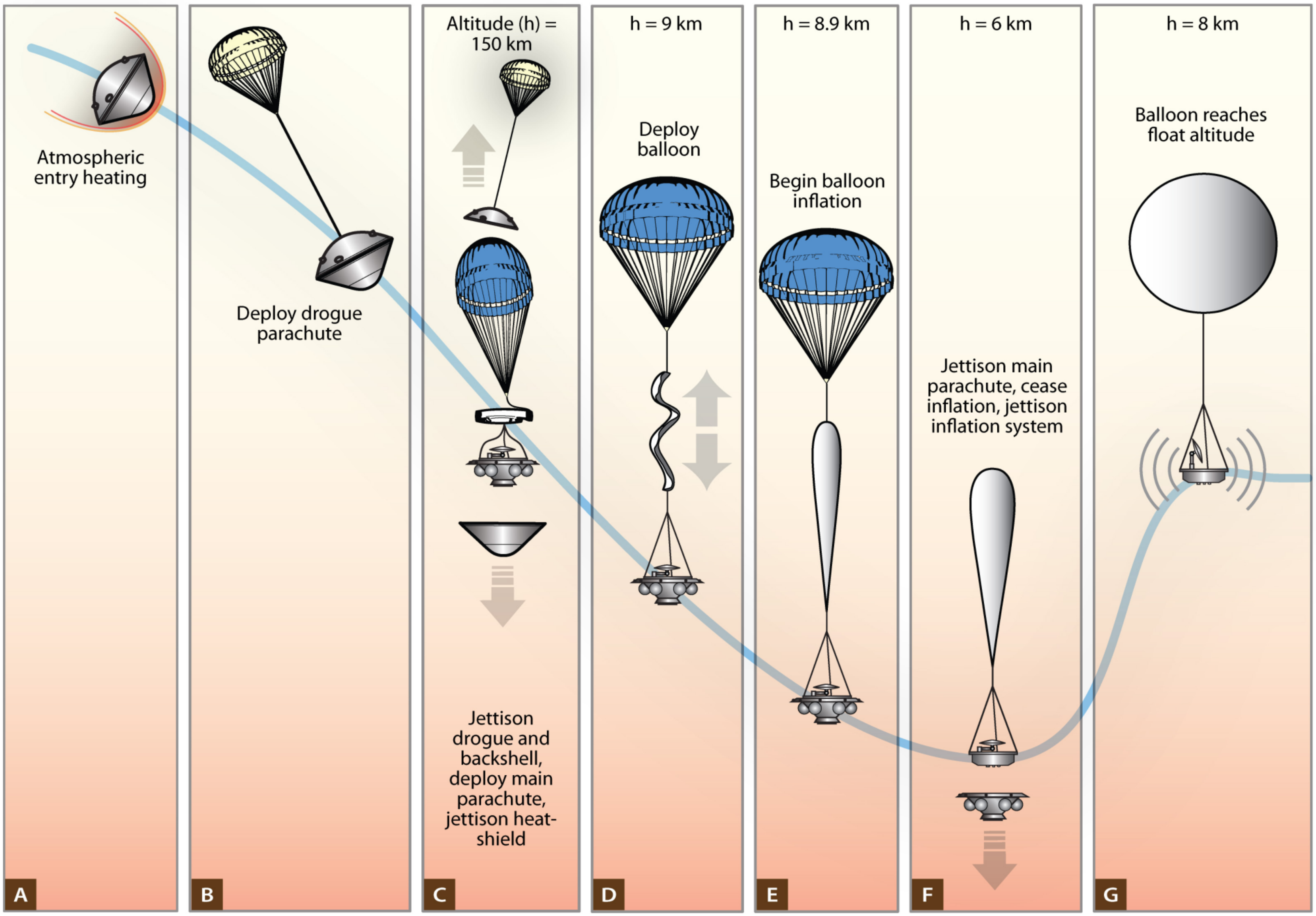
Balloon Design

- 4.6 m diameter spherical helium superpressure balloon
  - 1000 Pa of internal pressure at mission start
  - Inherently stable in altitude, ideal for long duration flight
- 170 kg payload (CBE mass + 30%)
- 28 kg of helium inside balloon
- 8 km float altitude
- 3 month minimum lifetime
  - Can tolerate up to 20 pinholes of 10 m each without ballast (see calculation results at right)
  - Require ~6 g/day of ballast to extend mission with that number and size of holes
- Polyester balloon material, film plus fabric laminate
  - 75 g/m^2 areal density
- Use gas venting and ballast drops near end of mission to perform a number of vertical profiles.
- Aerial deployment and inflation upon arrival at Titan
  - Schematically illustrated on the next slide
  - Same technique successfully used by VEGA 1 and 2 at Venus in 1985



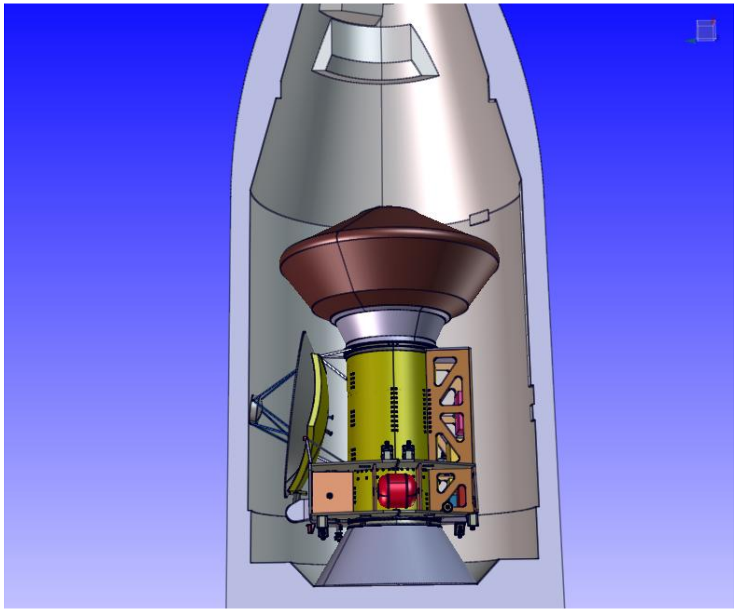


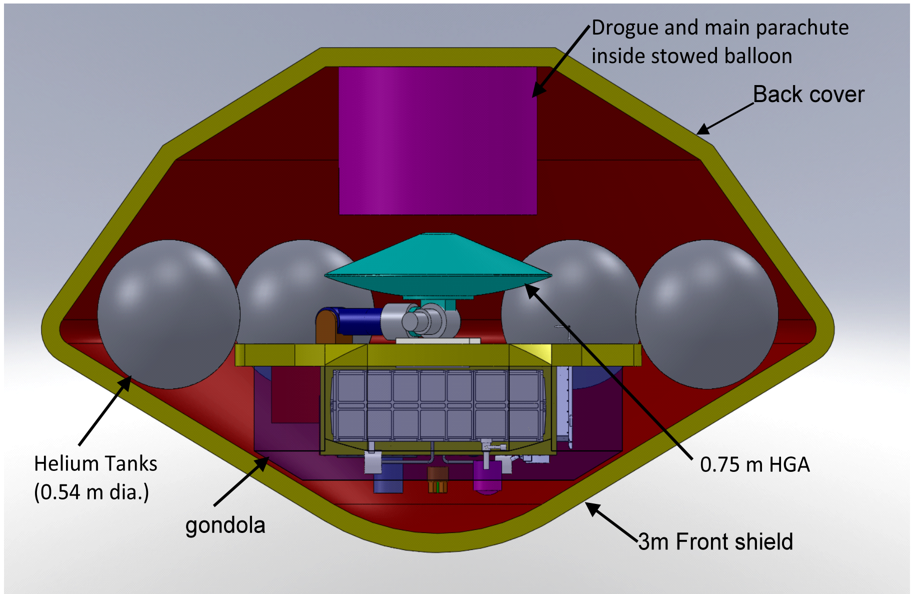
Aerial Deployment and Inflation Sequence



Spacecraft Design

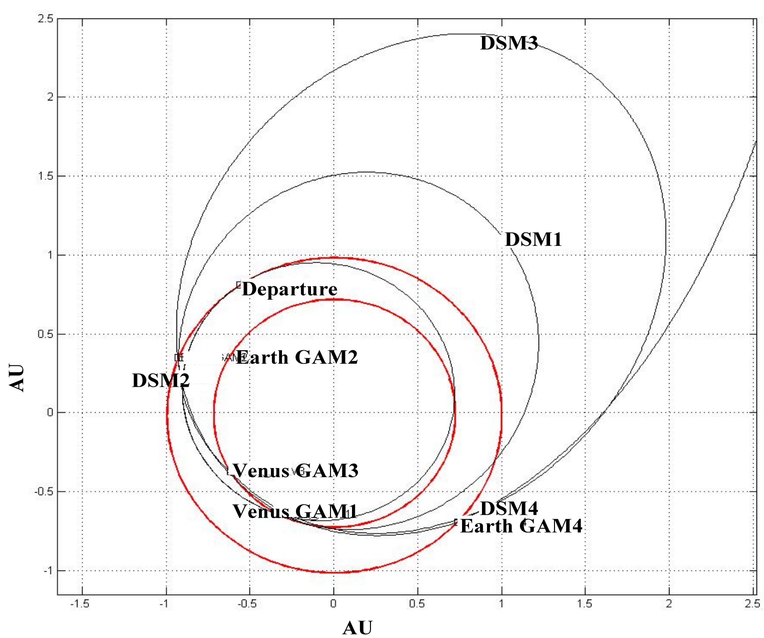
- Balloon, gondola (with instruments) and support systems carried inside a Huygens-like entry vehicle.
- Carrier spacecraft brings the entry vehicle to Titan.
- 2 ASRGs on the gondola provide all power to combined spacecraft.
- Command and data handling system on gondola provides control for combined spacecraft.
- Carrier spacecraft and balloon gondola has separate high gain antennas.
- 1368 kg total combined vehicle mass (incl. 30% margin on CBE)





Mission Design

- Launch on Soyuz-Fregat from Kourou on Dec. 21, 2022
- 9.5 year trip from Earth to Titan
- 2 Earth and 2 Venus gravity assist manuevers, plus 4 deep space propulsion manuevers
- Titan arrival on April 30, 2032



Departure	
Launch date	21/12/2022
Escape date	25/01/2023
Mass after Fregat separation (kg)	3,070
Launcher perf @ escape (kg)	1,853
Escape maneuver (m/s)	1,530
Escape dispersion correction	40
Cruise	
Swing-by 1 Venus	05/02/2024
DSM 1 (m/s)	15
Swing-by 2 Earth	28/02/2025
DSM 2 (m/s)	163
Swing-by 3 Venus	10/04/2025
DSM 3 (m/s)	95
Swing-by 2 Earth	10/08/2027
DSM 4 (m/s), 18/08/2017	408
Navigation (m/s)	40
Attitude control (kg)	40
Arrival	
Arrival date	30/04/2032
Relative arrival velocity (m/s)	6,228
Arrival mass (kg)	1,428
Mission duration (years)	9.3

Conclusions

- TAE is a feasible Titan balloon missions that provides outstanding science return at a medium-class price.
- It is based around a single superpressure balloon that flies at 8 km altitude for 3-6 months and conducts atmospheric and surface science investigations.
  - A small number of vertical excursions will be implemented towards the end of the mission.
- The balloon, science payload and auxiliary systems are contained inside a Huygens-like aeroshell and taken to Titan by a carrier spacecraft.
- Two ASRGs are required to provide the in-atmosphere lifetime and collect and transmit on the order of 1 Gbit of data back to Earth.
- Many details of the design can be found in the technical paper.