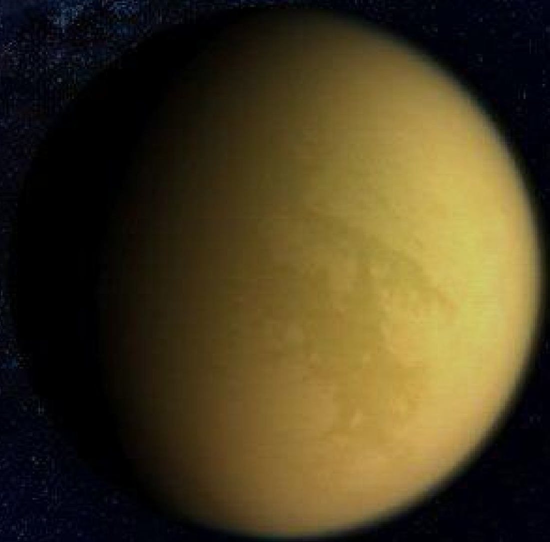
FUTURE MULTI-PROBE MISSION TO TITAN AND ENCELADUS

International Planetary Probe Workshop7, May 2010
Barcelona, Spain



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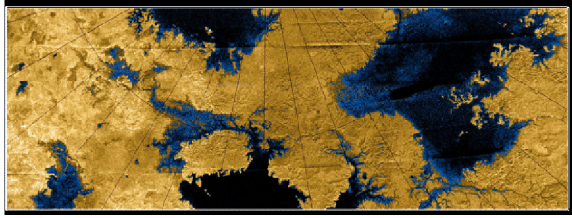
- Science motivation and background
- Titan Saturn System Mission concept overview
- In situ Probes
- Summary

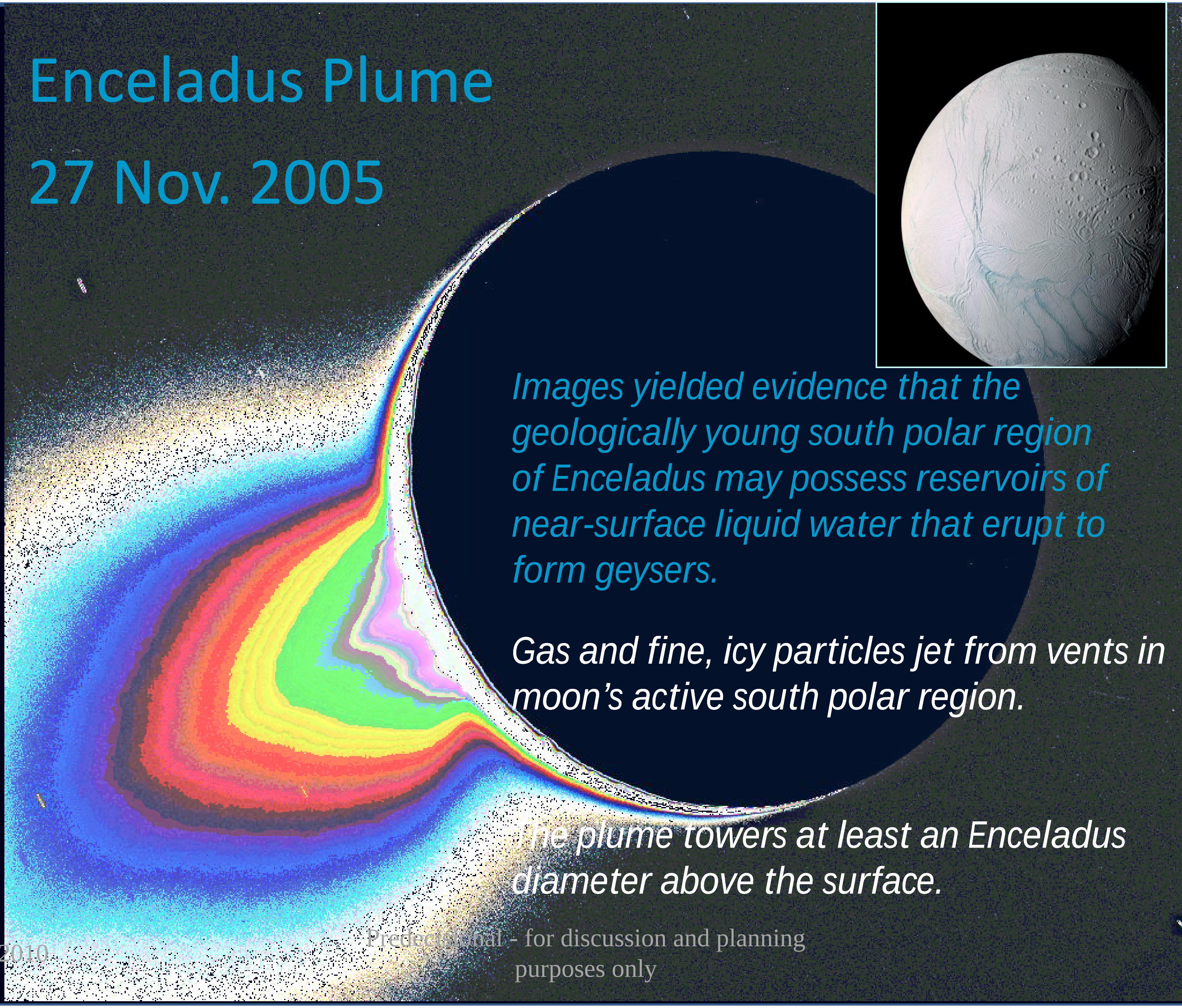
Science Motivation and Background

Titan: A complex world of high priority

- Cassini-Huygens has found lakes, seas, rivers, clouds, rain, and in the extended mission strong evidence for a dynamic changing climate system and interior ocean
- Titan is the only world besides Earth with an active climate/hydrology cycle: methane vs water (hydrology)
- Titan's wealth of organic molecules and diverse sources of free energy make it of high priority for exploring chemistry that preceded life's origin on Earth, and possible exotic life in the methane seas



Water on Enceladus



Enceladus Plume

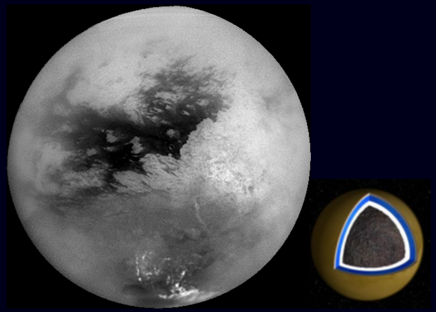
27 Nov. 2005

Images yielded evidence that the geologically young south polar region of Enceladus may possess reservoirs of near-surface liquid water that erupt to form geysers.

Gas and fine, icy particles jet from vents in moon's active south polar region.

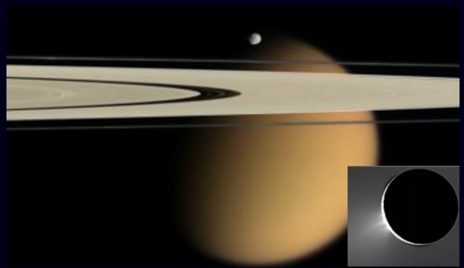
The plume towers at least an Enceladus diameter above the surface.

High Priority Science Questions



- Explore Titan, an Earth-Like System
  - What is Titan's climate like?
  - How does it change with time?
  - What can it teach us about Earth's climate?

- Examine Titan's Organic Inventory—A Path to Prebiological Molecules
  - What kind of organic chemistry goes on in Titan's atmosphere, in its lakes and seas, and underground?
  - Is the chemistry at the surface mimicking the steps that led to life on Earth?
  - Is there an exotic kind of life—organic but totally different from Earth's—in the methane/ethane lakes and seas?



- Explore Enceladus and Saturn's magnetosphere— clues to Titan's origin and evolution
  - What is the source of geysers on Enceladus?
  - Is there life in the source water of the geysers?

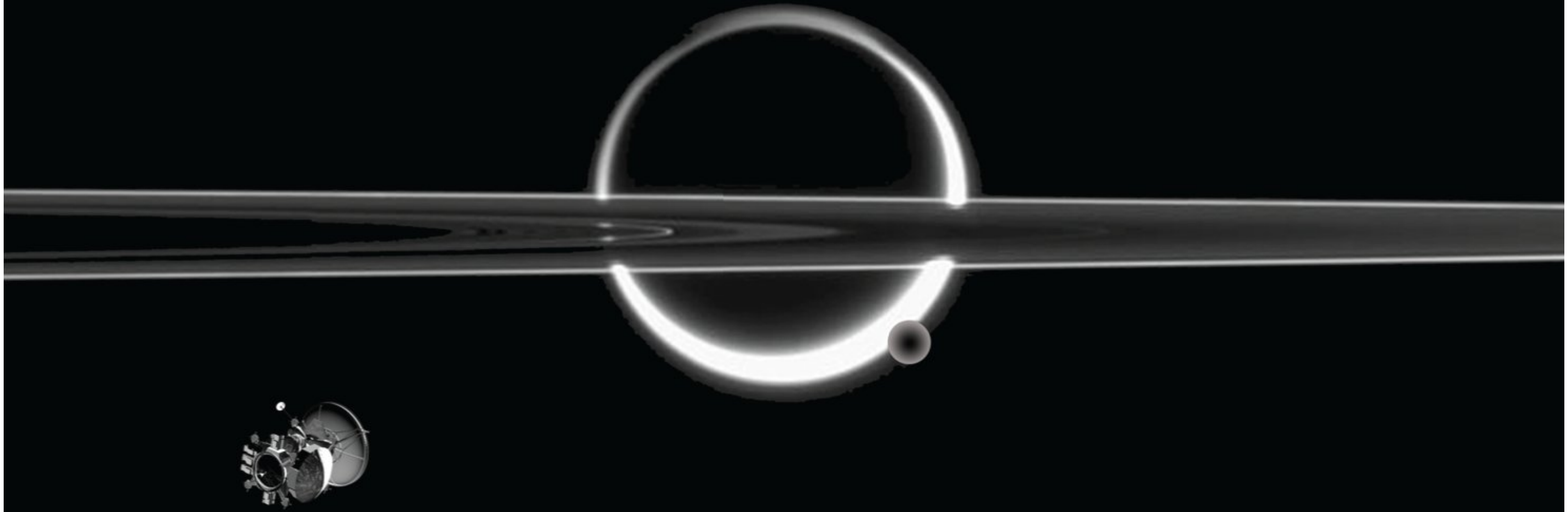
Relationship to Cassini-Huygens

- The Cassini orbiter continues to expose mysteries of Titan and Enceladus
  - Has discovered most of what we know about the Saturnian system and reset the paradigms: Plumes on Enceladus; Organic seas on Titan
  - Mission is shifting toward (a) observing seasonal changes on Saturn and Titan as the Saturnian year (~29 Earth years) proceeds; and (b) search for more definite evidence of liquid water near the base of Enceladus' plumes

- Limits of Cassini-Huygens instruments have been reached and they cannot carry out some key investigations needed to answer new questions
  - What are Titan's lakes and seas made of? What's in them?
  - How vast and intricate are the river systems? Do they flow today?
  - Is there a vast reservoir of organics resident beneath the surface?
  - Is Titan's climate changing? What seasonal effects exist?
  - What is the composition of Enceladus's plumes? How do they vary with time?

- A dedicated mission could address these intriguing questions

Titan Saturn System Mission
Concept Overview

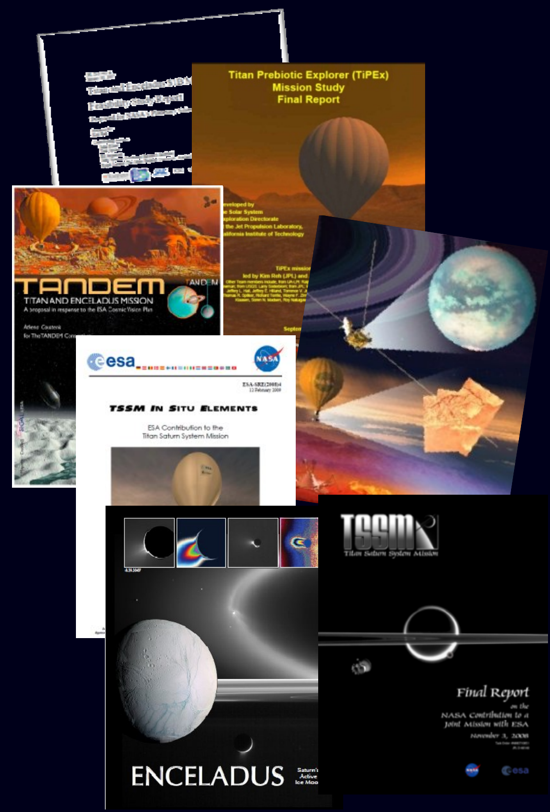


Study Ground Rules/Constraints

- Respond to the 2007 Study independent review board findings.
- Produce a mission concept that *balances* science, cost, and risk.
- Define a *NASA-ESA* Baseline and Floor mission that includes a NASA-provided Titan orbiter that does not utilize aerocapture. The orbiter shall have the capability of delivering and providing relay communications for multiple Titan *in situ* elements that would be provided by ESA as part of a collaborative program.
- Define a *NASA-only* mission and Floor mission that can be implemented by NASA in the event ESA decides not to participate.
- Include Saturn system and Enceladus as Level 1 science requirements.
- Include minimum of 33% reserves/margins.
- Use a launch date of 2020 for schedule and cost purposes. Alternative launch dates from 2018 through 2022 should be identified.

Years of studies have led to the most recent Titan and Enceladus concepts

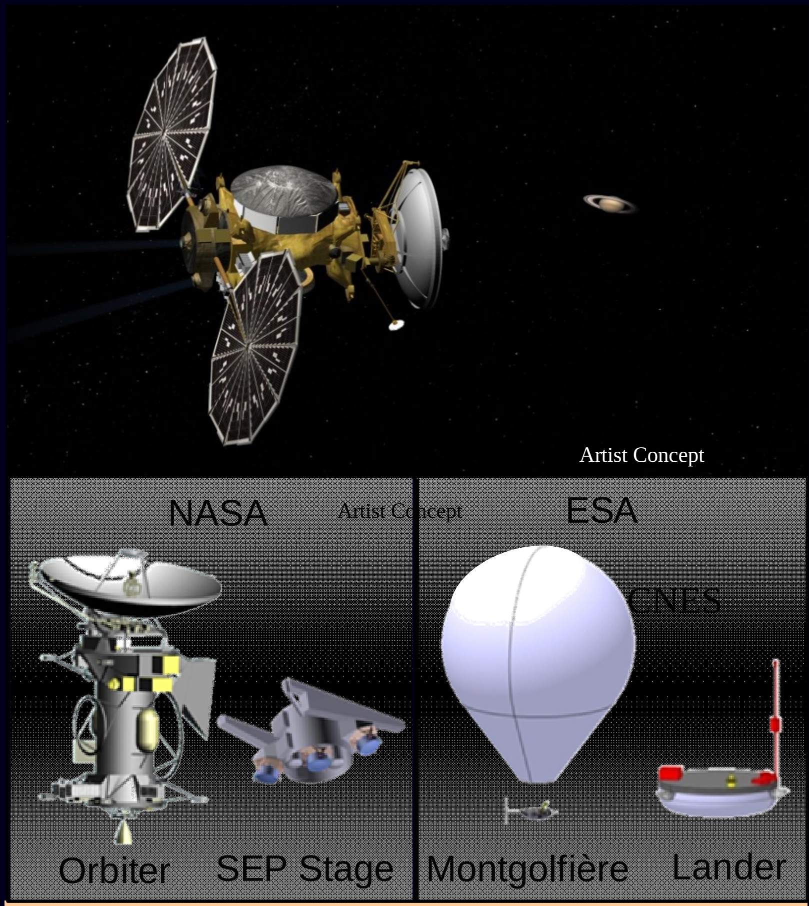
- Titan and Enceladus Mission Studies
  - Various studies in the 1990s
  - 2002 Aerocapture Systems Analysis Study
  - 2004 Titan Organic Exploration Study (TOES) under NASA's Vision Missions Program
  - 2006 Titan Prebiotic Explorer (TiPEx) study
  - 2007 "Billion Dollar Box" study
  - 2007 NASA Titan Explorer Study
  - 2007 ESA TandEM Cosmic Visions Study
  - *2008 Enceladus Flagship Mission Concept Study*
  - *2008 Joint NASA/ESA TSSM Study*



- Significant result from these studies include:
  - *An Orbiter, Lander and Balloon* are key elements for a future mission to Titan
  - Mission design techniques are key to enabling future missions to Saturn's icy moons

2008 TSSM Overview

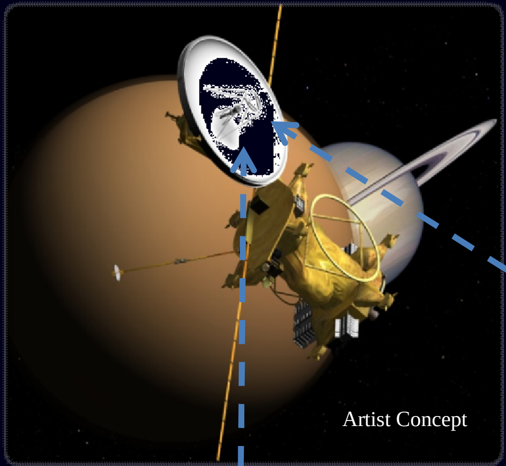
- Titan, Enceladus and Saturn system science
- Mission Design
  - 2020 Launch to Gravity Assist SEP trajectory
  - 9 years to Saturn arrival
  - SEP stage released ~5 yrs after launch
  - Montgolfière released on 1st Titan flyby, Lander on 2nd Titan flyby
  - ~4 yr mission: 2 yr Saturn tour with Enceladus, 2 mo Titan aerosampling; 20 mo Titan orbit
- NASA Orbiter and Launcher
  - ASRG power baselined (MMRTG compatible)
  - Solar Electric Propulsion (SEP)
  - 6 Instruments + Radio Science
  - NASA provided Launch Vehicle and RPS
- ESA *In situ* Elements
  - Lake Lander – battery powered
    - 4 instruments + Radio Science
  - Montgolfière – MMRTG powered
    - 7 instruments + Radio Science



-Optimal balance of science, cost and risk
-NASA-ESA collaboration

Relationship between key mission elements

Dedicated Titan orbiter would deliver the in situ elements and also be used for data relay



Montgolfière hot-air balloon would float at 10 km above the surface circumnavigating the globe twice in less than 6 months

Short-lived (9 hrs) probe/lander with chemical analysis package would land in a northern lake (Kraken Mare)

Orbiter instruments directed at Titan and Enceladus remote sensing

	Name	Flight Heritage
HiRIS	High-Resolution Imager and Spectrometer (near IR)	CRISM, Artemis, VIMS, HiRISE, TBair, MOC, M^3
TiPRA	Titan Penetrating Radar and Altimeter	SHARAD, MARSIS
PMS	Polymer Mass Spectrometer	RTOF portion of ROSINA
SMS	Sub-Millimeter Spectrometer	MIRO, ODIN, SWAS, and MLS

	Name	Flight Heritage
TIRS	Thermal Infrared Spectrometer	CIRS, Mars TES
MAPP	Magnetometer	MESSENGER, Cassini
	Energetic Particle Spectrometer	PEPSSI, JEDI
	Langmuir Probe	Cassini, others
	Plasma	PEPE, others
RSA	Radio Science + Accelerometer	Cassini, Juno, many others

In situ Payload sample Titan's lower atmosphere, surface and seas

Lander

Instrument	Description
TLCA	Titan Lander Chemical Analyzer with 2-dimensional gas chromatographic columns and TOF mass spectrometer. Dedicated isotope mass spectrometer.
TiPI	Titan Probe Imager using Saturn shine and a lamp
ASI/MET-TEEP	Atmospheric Structure Instrument and Meteorological Package including electric measurements
SPP	Surface properties package
LRST	Radio Science using spacecraft telecom system

Montgolfiere

Instrument	Description
BIS	Balloon Imaging Spectrometer (1 – 5.6 μm)
VISTA-B	Visual Imaging System with two wide angle stereo cameras & one narrow angle camera.
ASI/MET	Atmospheric Structure Instrument and Meteorological Package.
TEEP-B	Titan Electric Environment Package
TRS	>150 MHz radar sounder
TMCA	1 – 600 Da Mass spectrometer
MAG	Magnetometer
MRST	Radio Science using s/c telecom system

In situ Multi-Probe Concepts

Contributions

- A. Santovincenzo, Stefano Santandrea, and ESA CDF team
- J.-M. Charbonnier (CNES) for Balloon
- J. Romstedt and Instrument contact team for PDD
- K. Reh, J. Elliott, and JPL Engineering Team
- A. Coustenis, J. Lunine, D. Matson, J.-P. Lebreton, and Joint Science Definition Team

Outline

- Introduction
- Montgolfière
- Lander
- Instrumentation of the heat shield “Geosaucer”

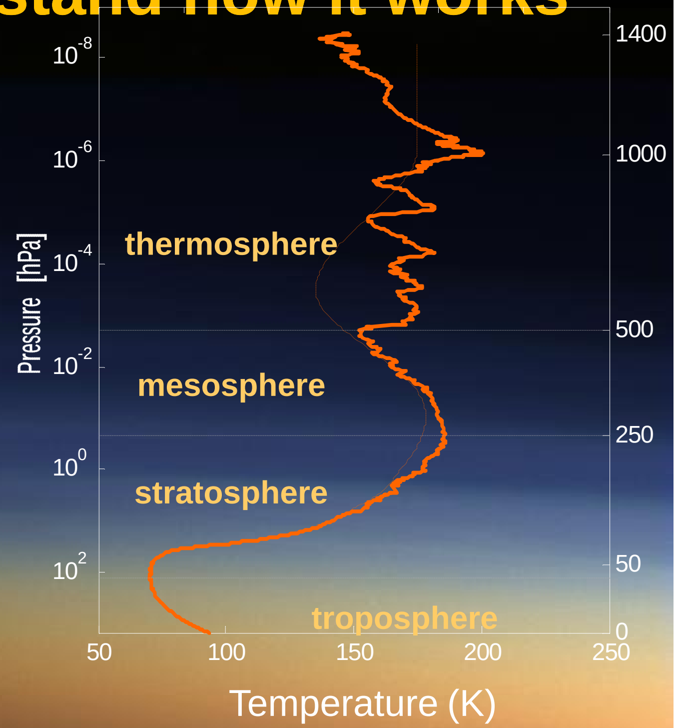
Primary in situ science objectives

- Perform chemical analysis, both in the atmosphere and in the liquid of the lake, the latter to determine the kinds of chemical species that accumulate on the surface, to describe how far such complex reactions have advanced and define the rich inventory of complex organic molecules that are known or suspected to be present at the surface. New astrobiological insights would be inevitable from montgolfière and lander investigations.

- Analyze the composition of the surface, in particular the liquid material and in context, the ice content in the surrounding areas.

- Study the forces that shape Titan's diverse landscape. This objective benefits from detailed investigation at a range of locations, a demanding requirement anywhere else, but that is uniquely straightforward at Titan with the montgolfière high-resolution cameras and subsurface-probing radar.

Titan's neutral atmosphere: understand how it works



Atmospheric structure & chemistry

–Define locally the atmospheric parameters and properties (T, r, heat balance, electricity…) from the ground up to 1600 km during lander's entry and descent phases and the balloon's cruising phase

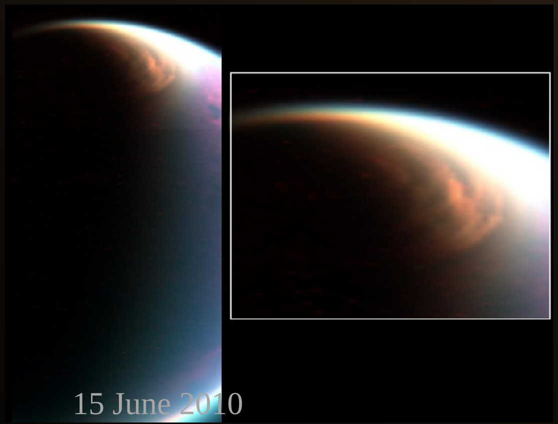
–Detremine local thermal and chemical structure of the lower atmosphere (0->130 km) at different latitudes and longitudes

Atmospheric dynamics

–Determine locally the dynamics and heat balance of the atmosphere (circulation, tides, wave, eddies, turbulence, radiation, etc…)

Origin and evolution

–Measure the abundances in noble gases and isotopic ratios in major species in order to constrain hte origin and the evolution of the atmosphere though photochemistry , escape and ourgassing processes



Climate and alkanological cycle

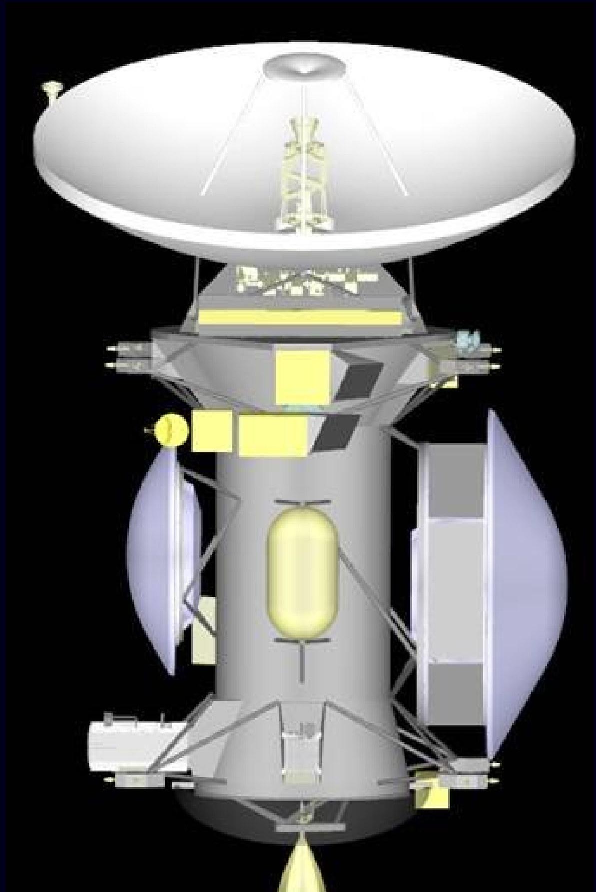
–Measure climatic (seasonal and long term) variations and CH4 and C2H6 abundances in the lower atmosphere and surface (compare with Huygens)

–Determine the meteorology (dynamics, rain, clouds, evaporation, atmospheric electricity, etc)

Quantify the coupling of the surface and atmosphere in terms of mass & energy balance

In situ elements carried to Titan

- *In situ* Elements (ISE, aka probes) to be carried by orbiter to Titan
  - Montgolfière: 2.6 m aeroshell, 600 kg, interface structure with radiators mounted
  - Lander: 1.8 m aeroshell, 190 kg
- ISEs have no flight control system—targeting would be performed by the orbiter
- Orbiter would also act as data relay for the ISEs

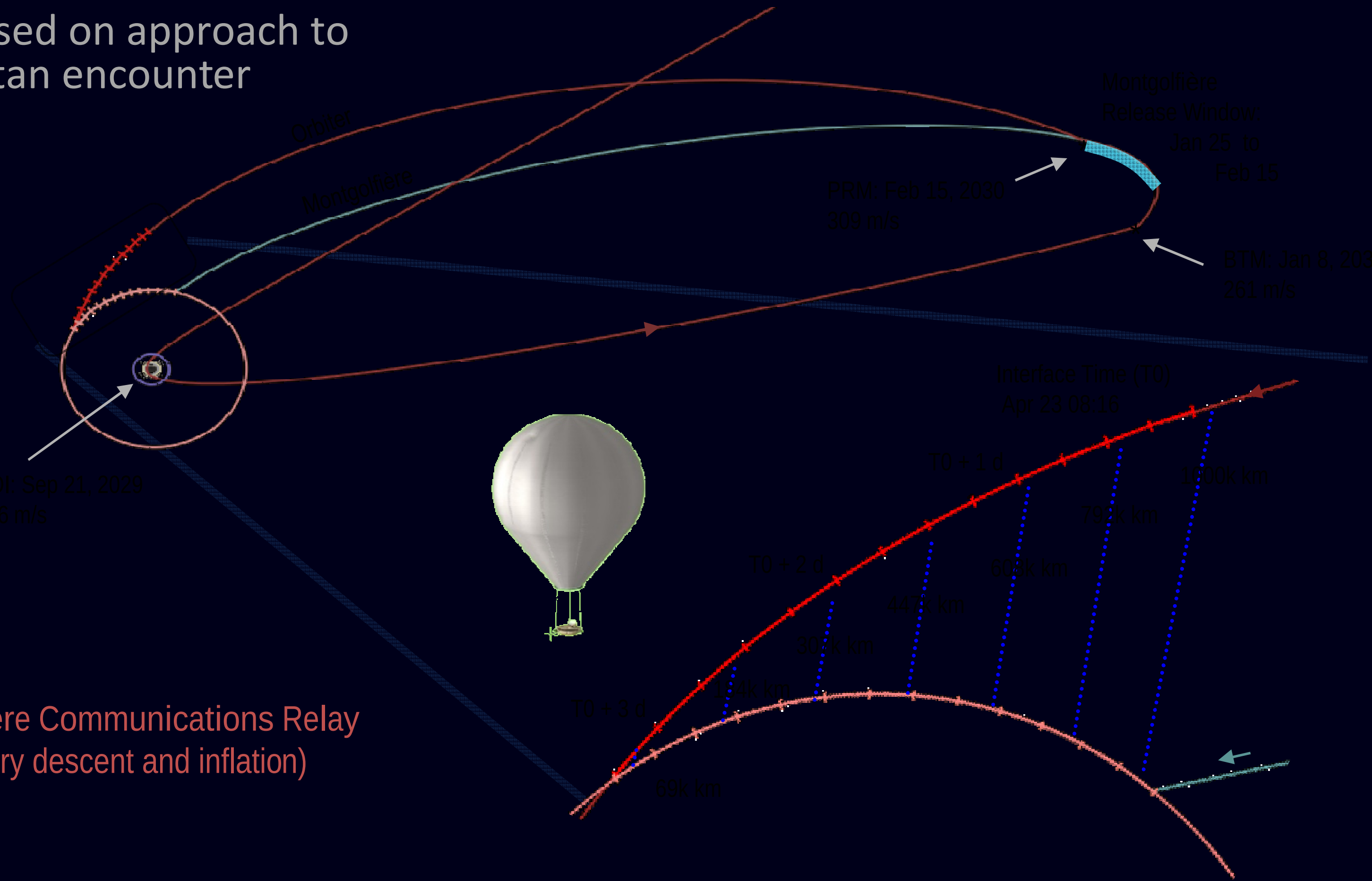

Artist concept

Summary of the montgolfière

- Balloon: 10.5 m diameter (~130 kg); heating by MMRTG
- Balloon to be provided by CNES
- Gondola: 144 kg, incl. 21.5 kg instrumentation
- Power generation by MMRTG (100 W_{el})
- Floating altitude 10 km; only altitude control
- Prime mission 6 months (+6 months extended)
- At least one Titan circumnavigation

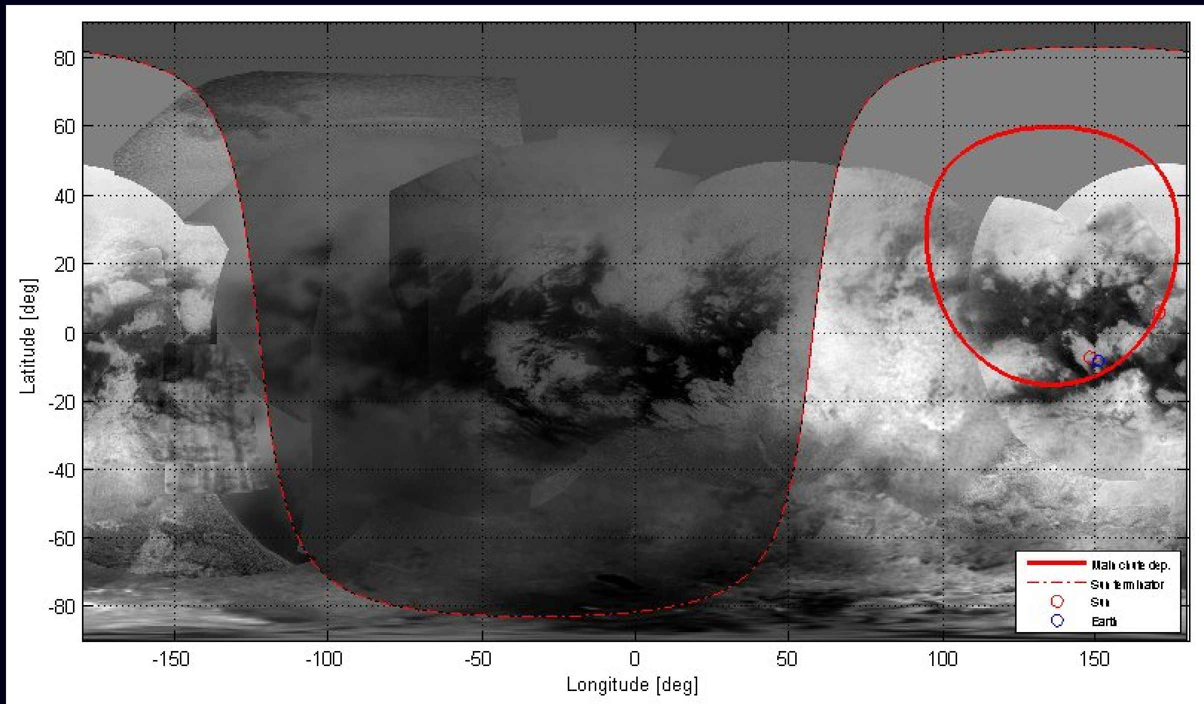
Montgolfière delivery

Released on approach to
1st Titan encounter



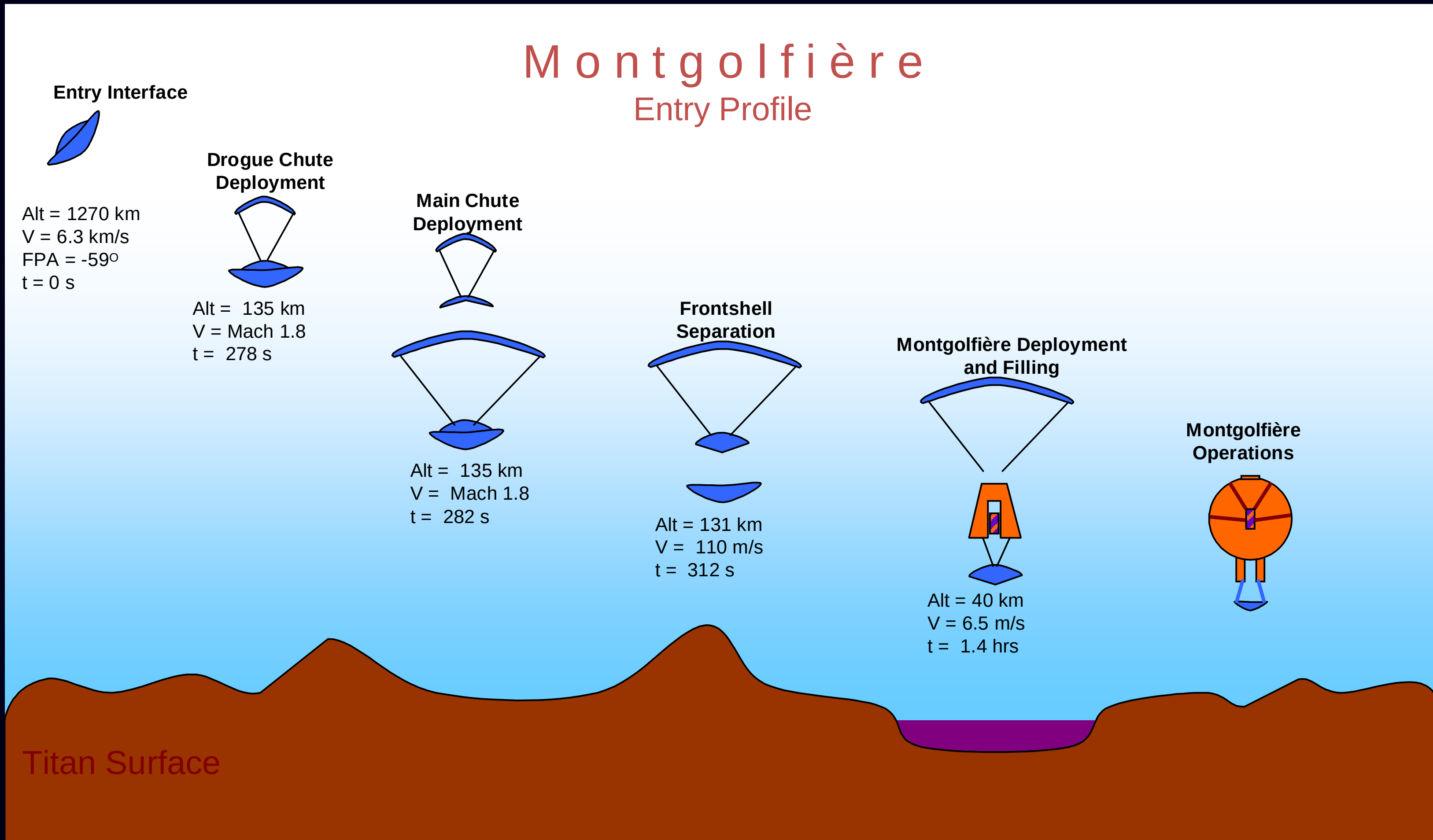
Montgolfière Communications Relay
(During entry descent and inflation)

Montgolfière entry target



- Montgolfière will be targeted at 20° N (strongest zonal winds expected)
- Flight path angle constrained between 59° and 65°

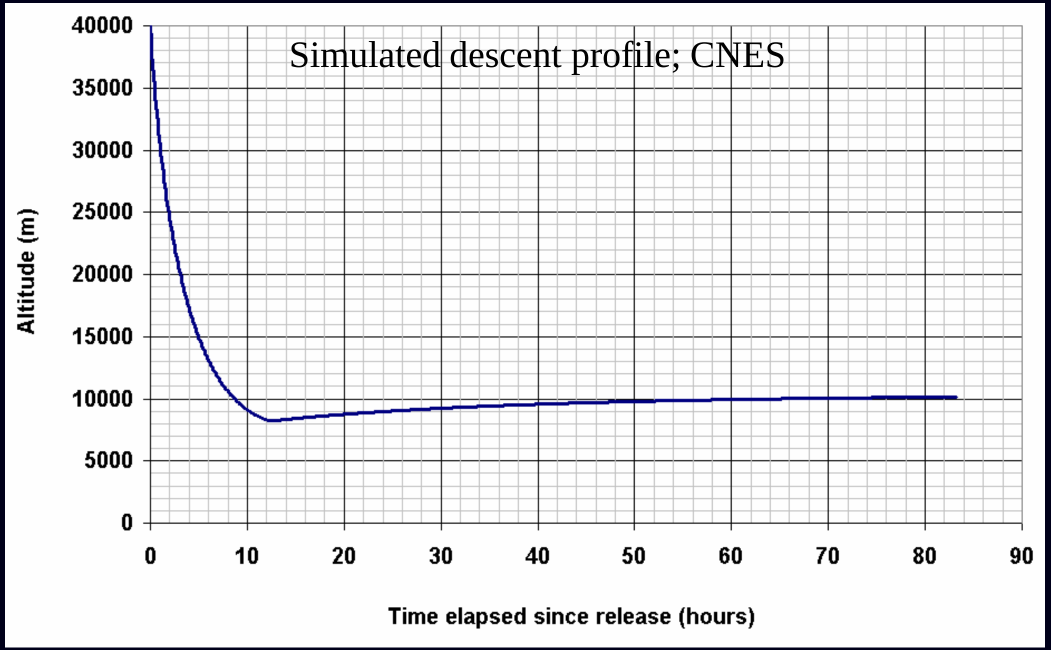
Montgolfière descent scenario



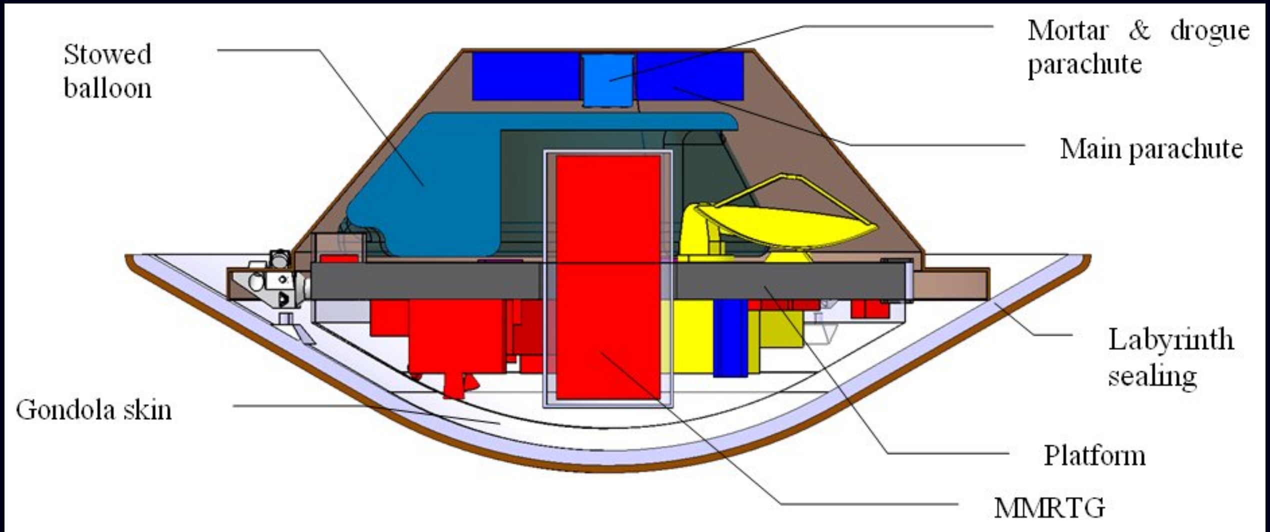
Predecisional - for discussion and planning purposes only

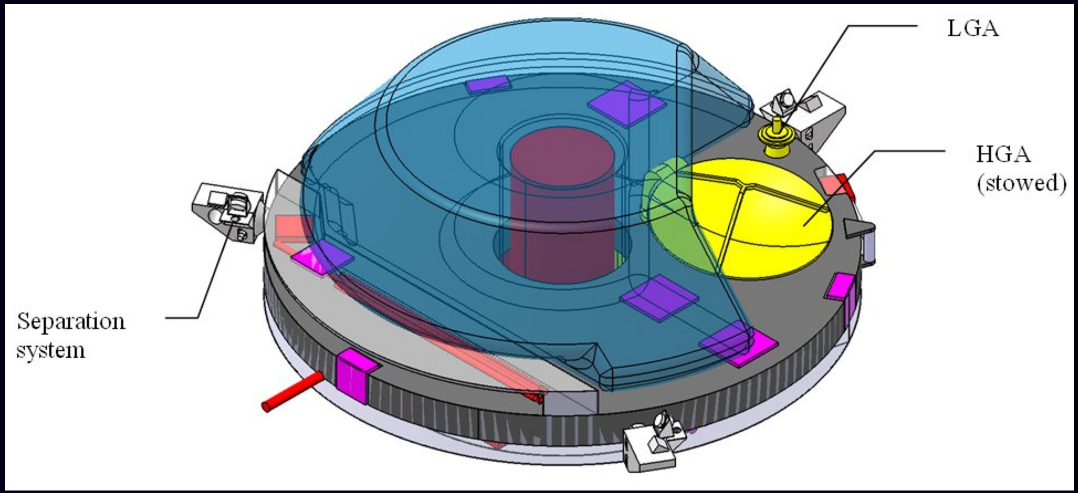
Balloon filling phase

- Balloon would be released at ~40 km
- The air-flow from the descent is used for its filling
- Heating of the inside gas starts simultaneously

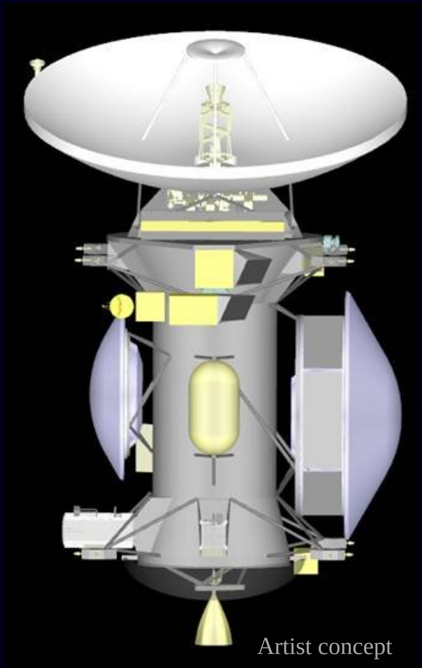


Montgolfière configuration



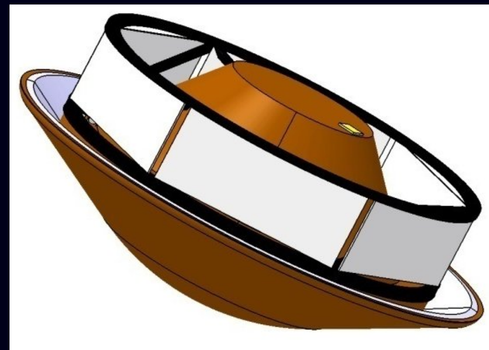


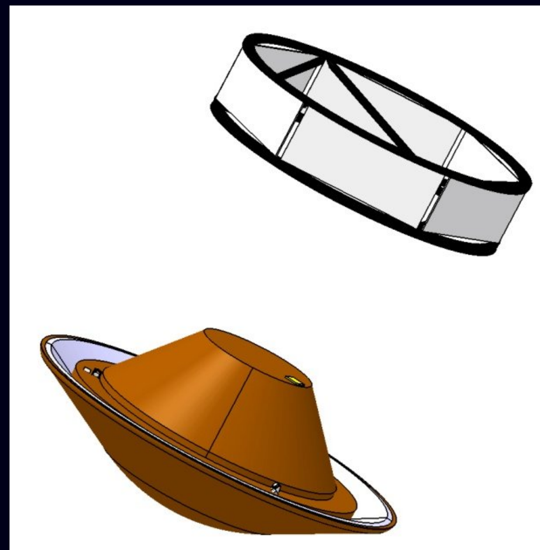
Interface structure and thermal control


Artist concept

- The back shield is higher— requiring larger distance from mounting interface

- The interface structure will also be used for cooling of the MMRTG during cruise





Montgolfière mass budget

- TPS Ø 2.6 m
- Balloon Ø 10.5 m
- Gondola Ø 1.6 m
- Instruments: 22 kg
- Margins:
  - Margin applied according to maturity per element
  - 20% added at system level

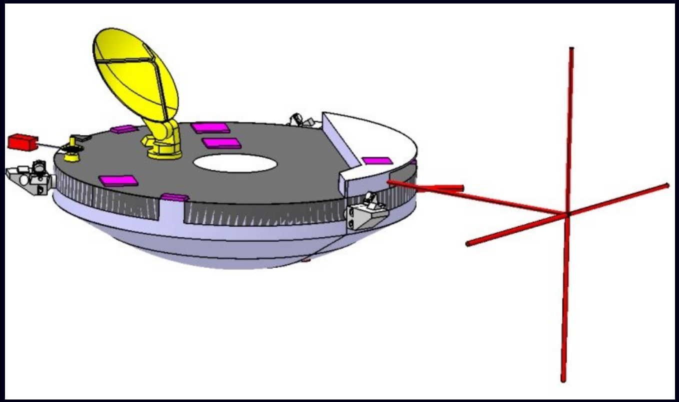
	w/o sys margin	*w/ system margin*
Interface Mass	**428**	**571**
Struts (incl. sep mechs)	48.0	57.6
Radiators	12.1	14.5
Radiator supports	7.2	8.6
Fluid Lines	10.6	12.7
Entry Mass	**398**	**478**
DLS	20.0	24.0
Mechanisms	22.9	27.4
Harness	6.0	7.2
Communications	0.5	0.6
Heat Pumps	8.8	10.6
Front Shield	80.1	96.1
Back Shield	30.0	35.9
Floated Mass	**230**	**276**
Balloon	109.9	131.9
Gondola	120.0	144.1

Montgolfière notional instrumentation

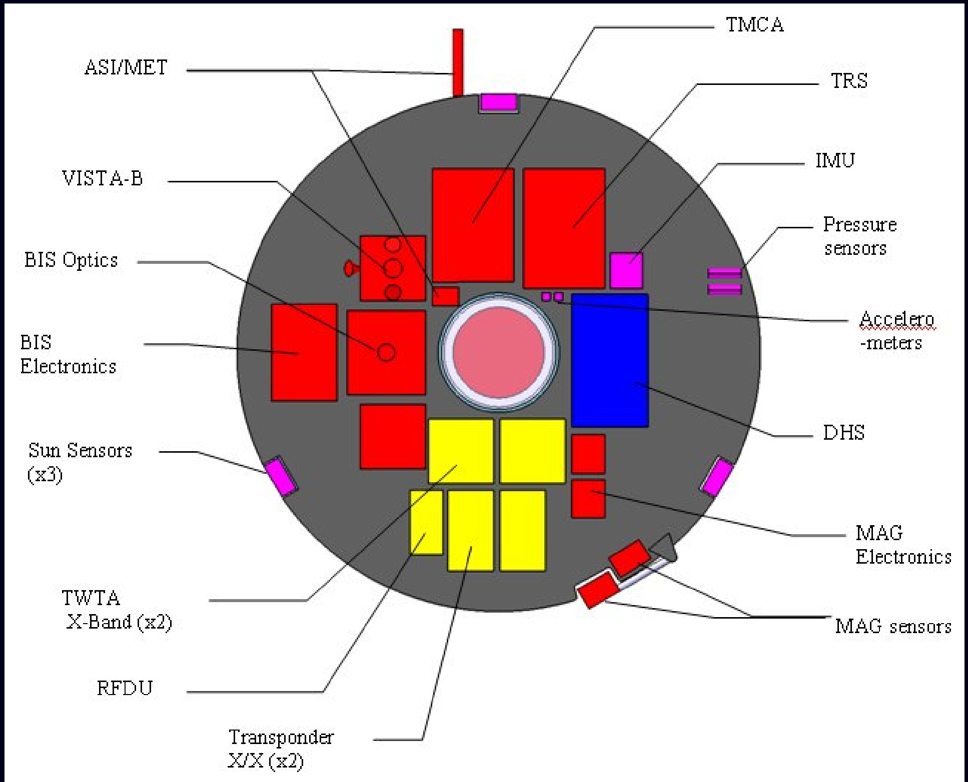
Instrument	Description	Science Contributions	Mass (kg) w/o margin	Power (W) w/o margin
BIS	Balloon Imaging Spectrometer (1 – 5.6 μm)	Mapping for troposphere and surface composition at 2.5 m resolution	3	10
VISTA-B	Visual Imaging System with two wide angle stereo cameras & one narrow angle camera.	Detailed geomorphology at 1 m resolution	2	5
ASI/MET	Atmospheric Structure Instrument and Meteorological Package.	Record atmosphere characteristics & determine wind velocities in the equatorial troposphere	1	5
TEEP-B	Titan Electric Environment Package	Measure electric field in the troposphere (0 – 10 kHz) and determine connection with weather.	1	1
TRS	>150 MHz radar sounder	Detection of shallow reservoirs of hydrocarbons, depth of icy crust and better than 10 m resolution stratigraphic of geological features.	8	15
TMCA	1 – 600 Da Mass spectrometer	Analysis of aerosols and determination of noble gases concentration and ethane/methane ratios in the troposphere	6	6
MAG	Magnetometer	Separate internal and external sources of the field and determine whether Titan has an intrinsic and/or induced magnetic field.	0.5	1
MRST	Radio Science using s/c telecom system	Precision tracking of the montgolfière	–	–
		Total (20% system margin applies)	21.5	43

Instrument accommodation

Gondola in deployed configuration



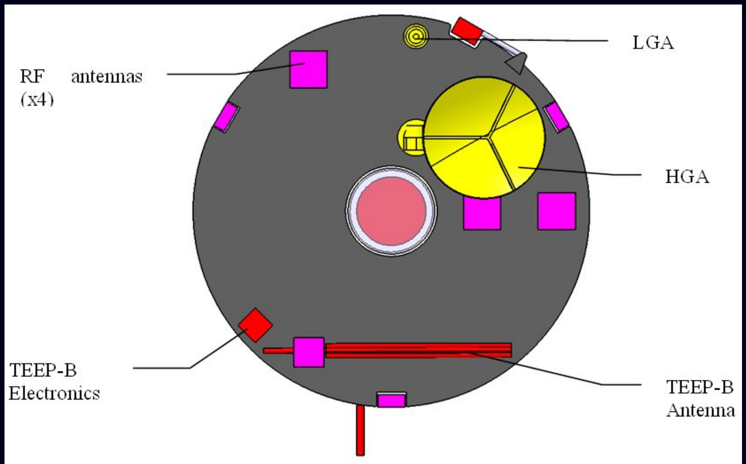
Communication equipment on zenith side

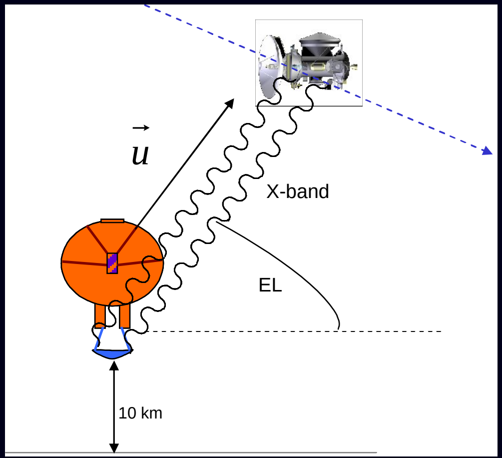


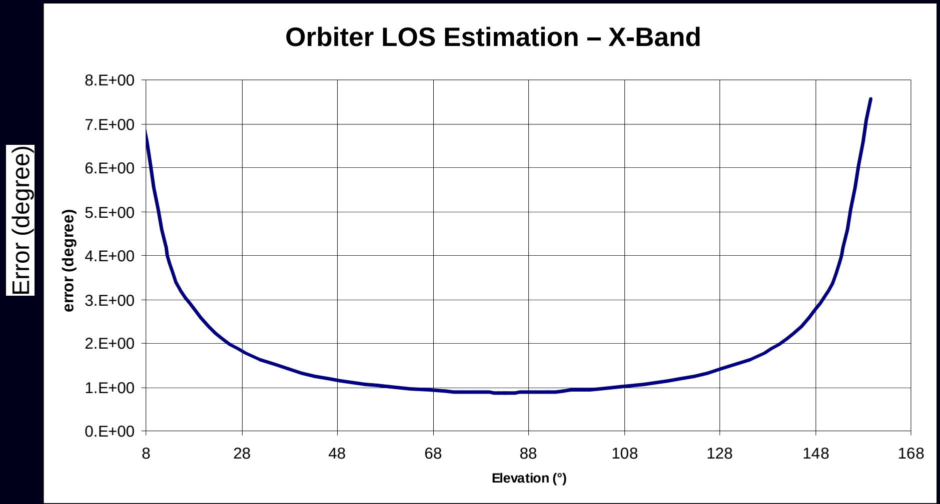
- Accommodation of instruments below the central platform
- Spot heating with RHUs

Communications

- High gain antenna has 2 axis degrees of freedom
- Orbiter is tracked during pass for uplink (assumed accuracy ≤ 1°)
- Direction determination by phase measurement of beacon signal
- Direction to earth determined by sun sensors
- ESA in planning a TDA for demonstration of inter-element link



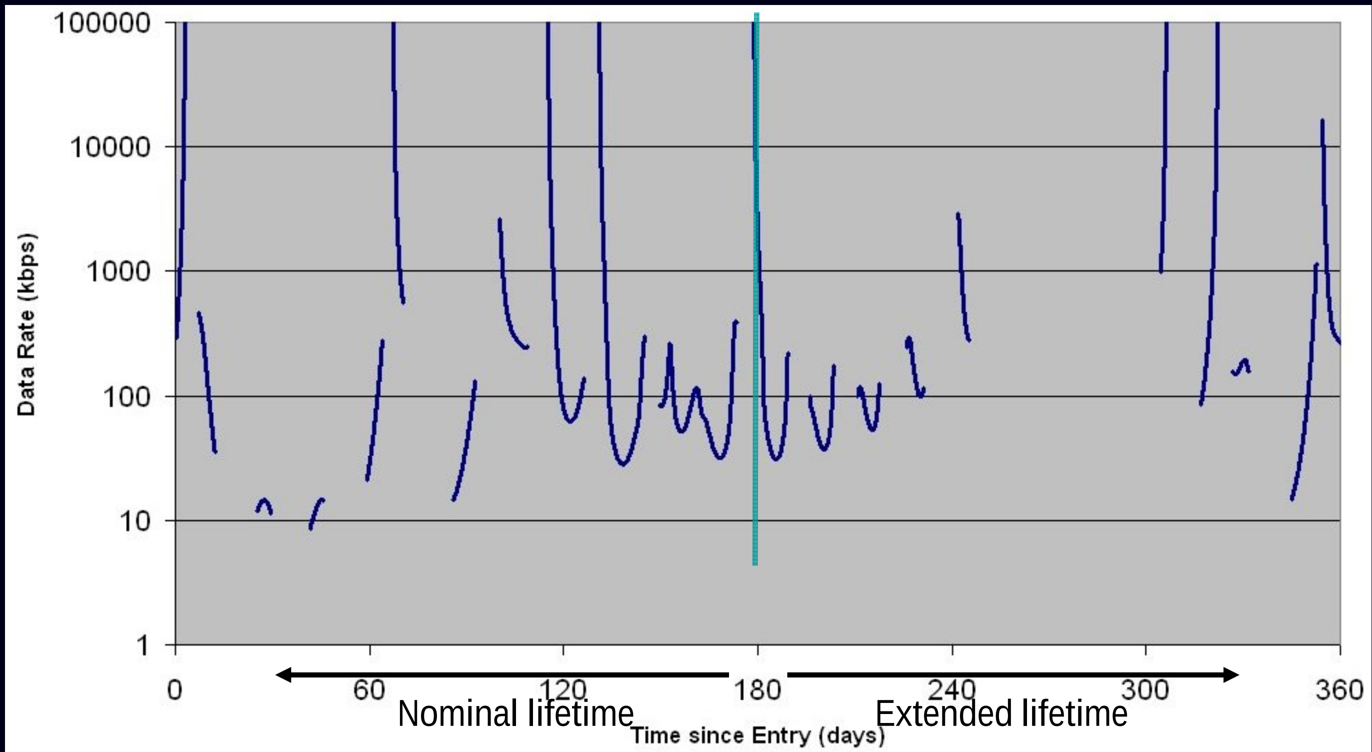




Montgolfière data transmission

- Uplink is determined by passes and distance
- Antenna off-pointing ≤ 1°

Montgolfière Transmission Rate

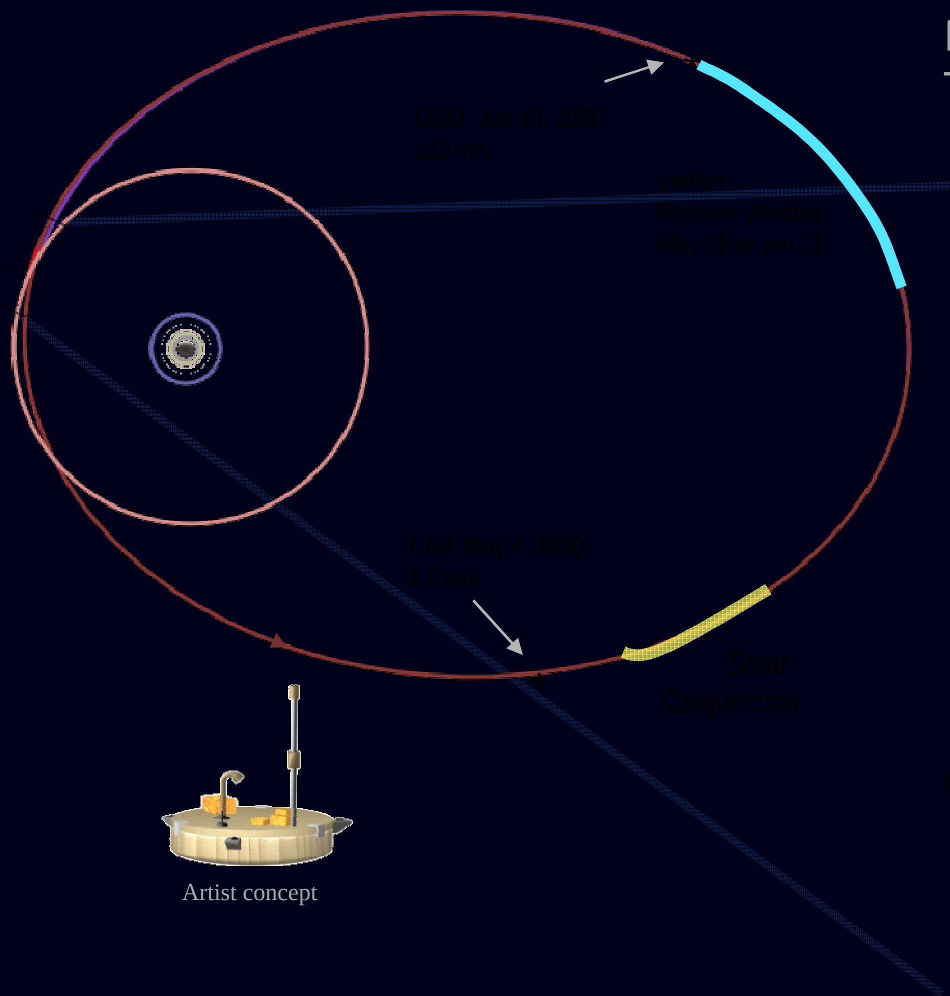


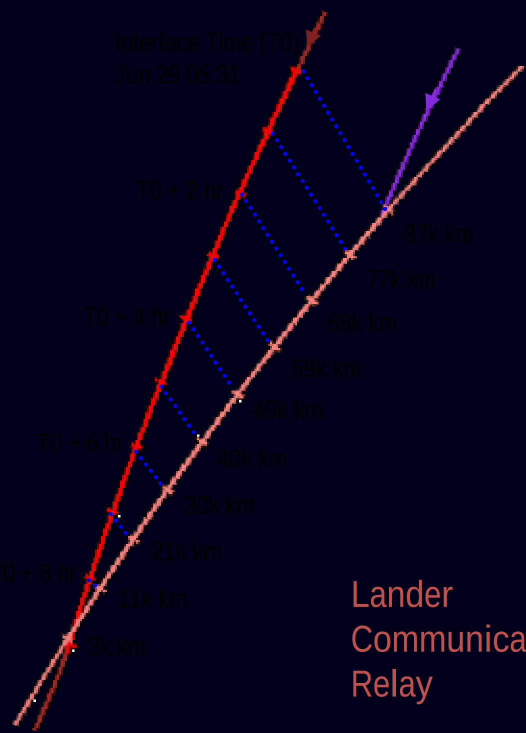
Lake lander concept

- Landed mass 85 kg, including 23 kg instrumentation
- Target: Kraken Mare (72°N) — floating capability
- Battery powered
- Lifetime: 6 hours descent and 3 hours on surface
- Delivery on 2nd Titan flyby — orbiter in close vicinity

Lander delivery

Released on approach to 2nd Titan encounter



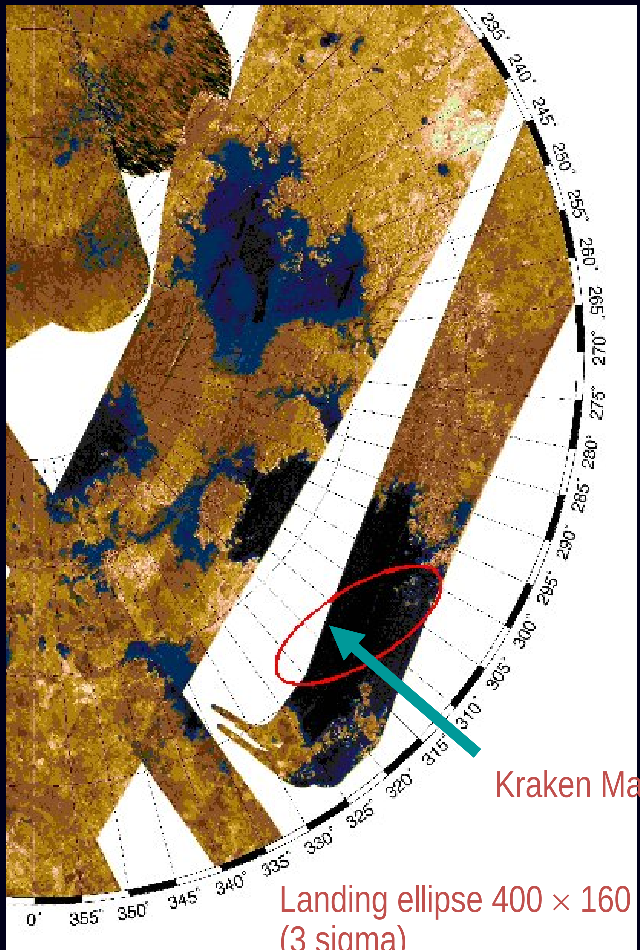


Lander Communications Relay

Artist concept

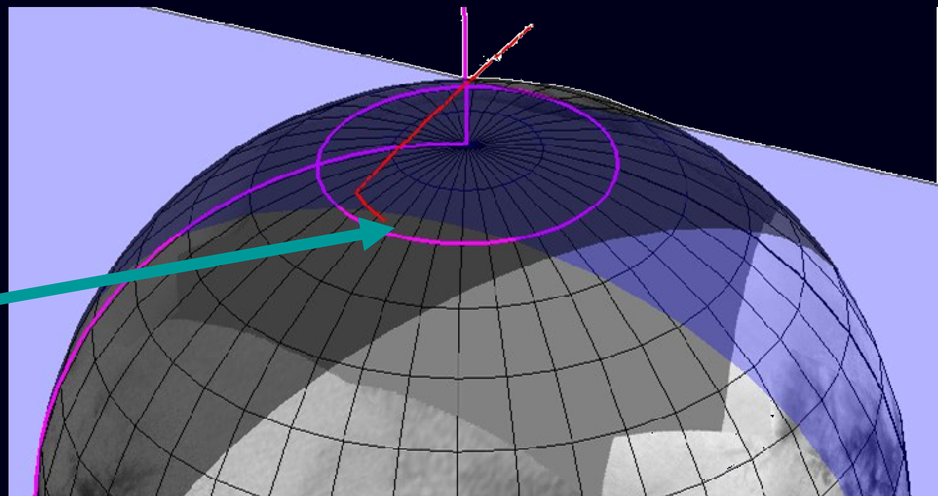
Lander target

- Entry in westerly direction, descend in easterly direction
- Landing error ellipse dominated by uncertainty of wind model at lower altitudes
- Landing is close to terminator (20°)
- Saturn in Gibbous P. is 2.5× full moon



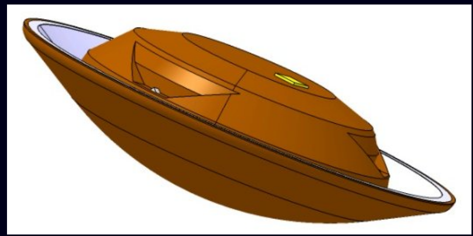
Kraken Mare

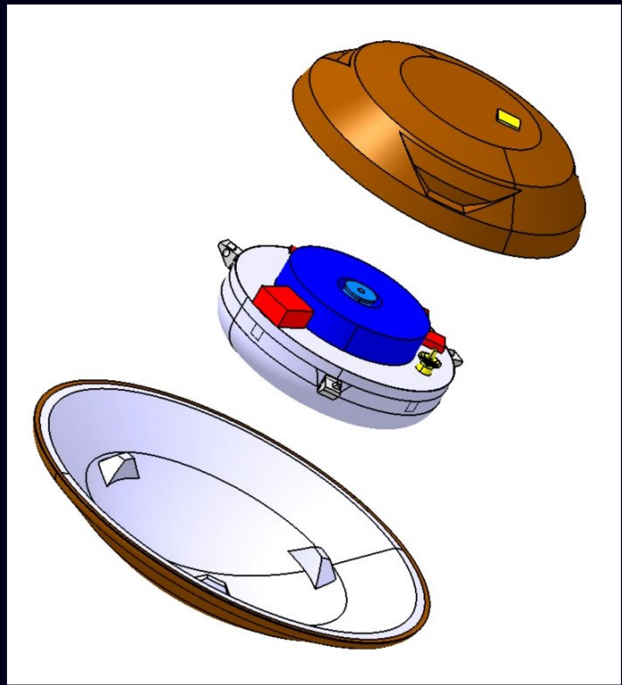
Landing ellipse 400 × 160 km (3 sigma)



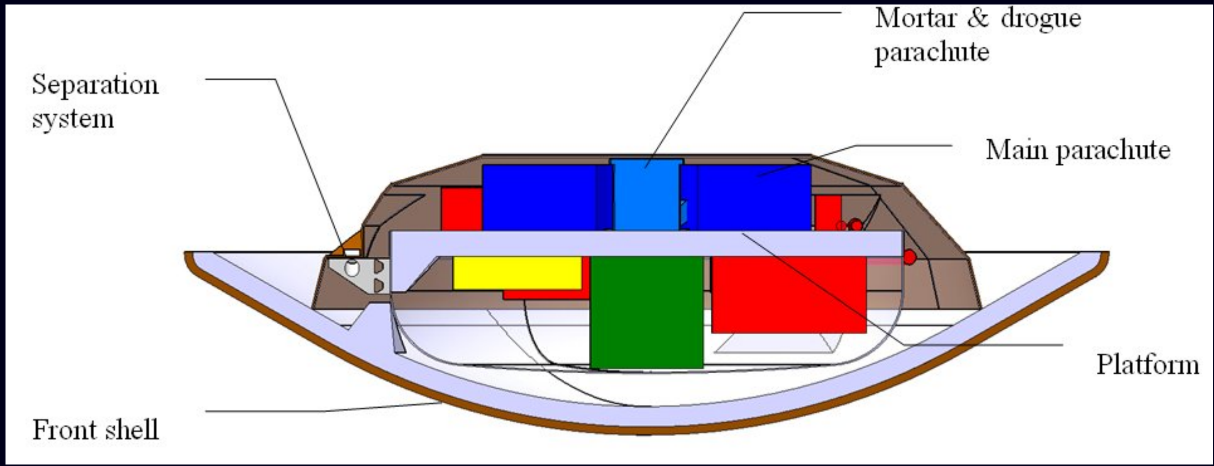
Lander descent scenario

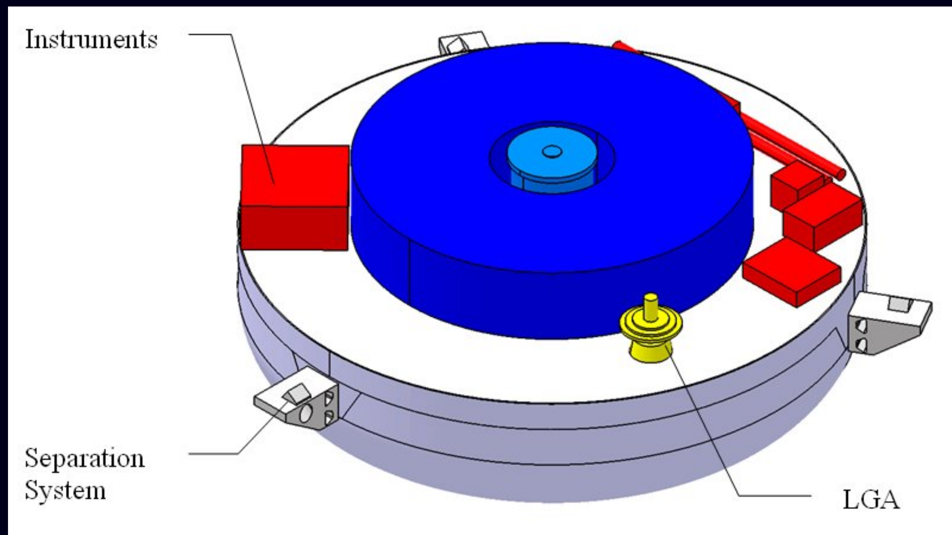
- Descent scenario similar as for montgolfière
- Single main parachute foreseen
  - Longer time spent for atmospheric sampling





Lander configuration





Lander mass budget

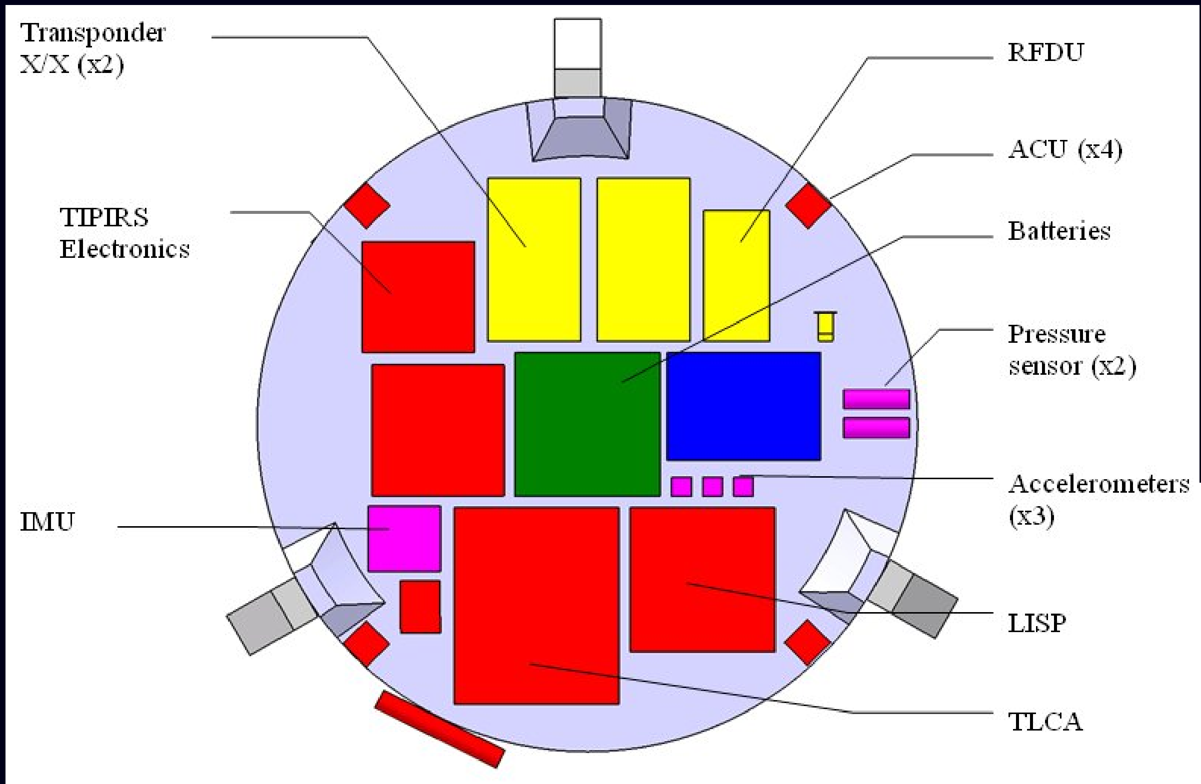
- TPS Ø 1.8 m
- Lander Ø 1 m
- Payload 27 kg
- Margins:
  - Margin applied according to maturity per element
  - 20% added at system level

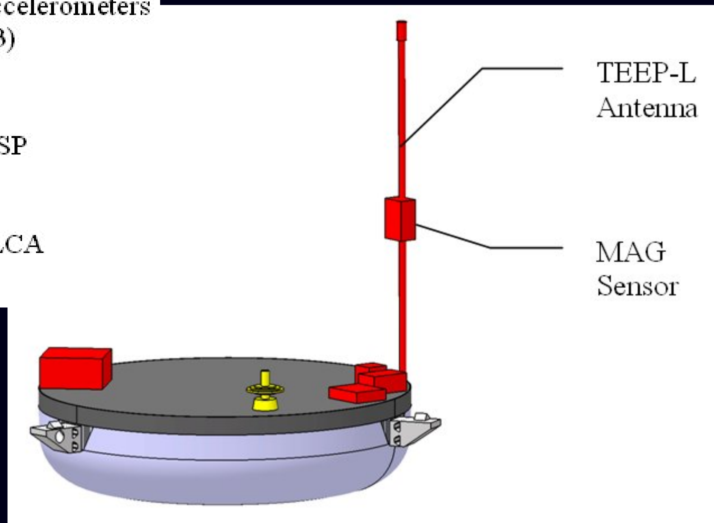
	w/o sys margin	*w/ system margin*
Interface Mass	**151**	**190**
Separation Mechanism	7.7	9.2
Entry Mass	**151**	**181**
DLS	14.9	17.8
Mechanisms	14.9	17.8
Harness	6.0	7.2
Communications	0.6	0.7
Front Shield	33.5	40.1
Back Shield	10.6	12.8
Landed Mass	**71**	**85**
Probe	70.5	84.6

Lander: Notional instrumentation

Instrument	Description	Science Contributions	Mass (kg) w/o margin	Power (W) w/o margin
TLCA	Titan Lander Chemical Analyzer with 2-dimensional gas chromatographic columns and TOF mass spectrometer. Dedicated isotope mass spectrometer.	Perform isotopic measurements, determination of the amount of noble gases and analysis of complex organic molecules up to 10,000 Da.	23.0	75
TiPI	Titan Probe Imager using Saturn shine and a lamp	Provide context images and views of the lake surface.	1.0	4 (+3)
ASI/MET-TEEP	Atmospheric Structure Instrument and Meteorological Package including electric measurements	Characterize the atmosphere during the descent and at the surface of the lake and to reconstruct the trajectory of the lander during the descent.	1.5	5.5
SPP	Surface properties package	Characterize the physical properties of the liquid, depth of the lake and the magnetic signal at the landing site.	1.5	11
LRST	Radio Science using spacecraft telecom system	Precision tracking of lander	–	–
		Total (20% system margin applies)	27.0	95.5 (+3)

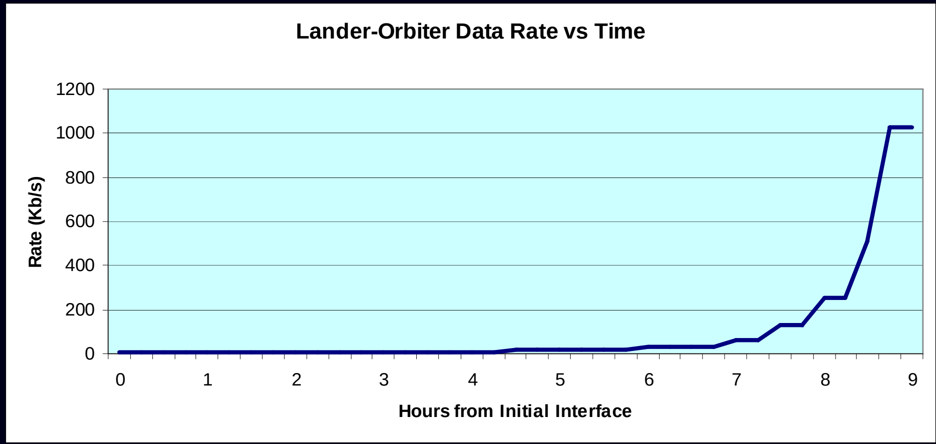
Instrument accommodation

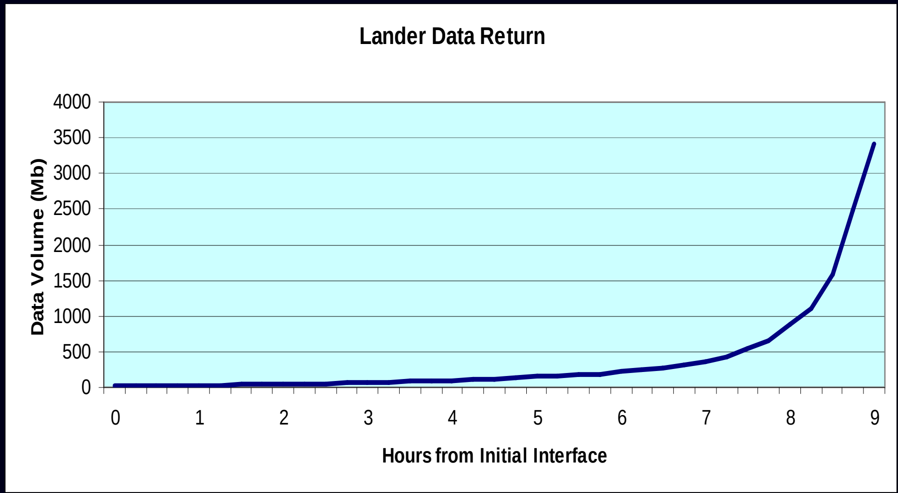




Lander data transmission

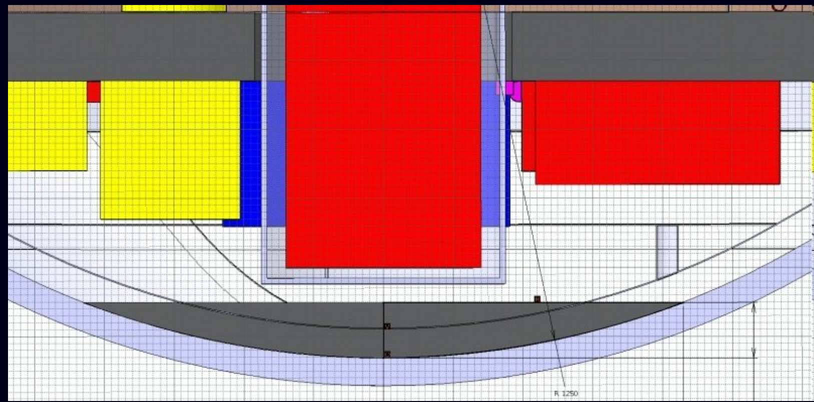
- Data rate capability is a function of distance
- Distance to orbiter between 87 k km – 3 k km
- Duration of link to orbiter 9 h (= Lander lifetime)
  - Orbiter sets below horizon
  - There is flexibility in the release phasing to accommodate longer link duration
- Total data: 3.4 Gb



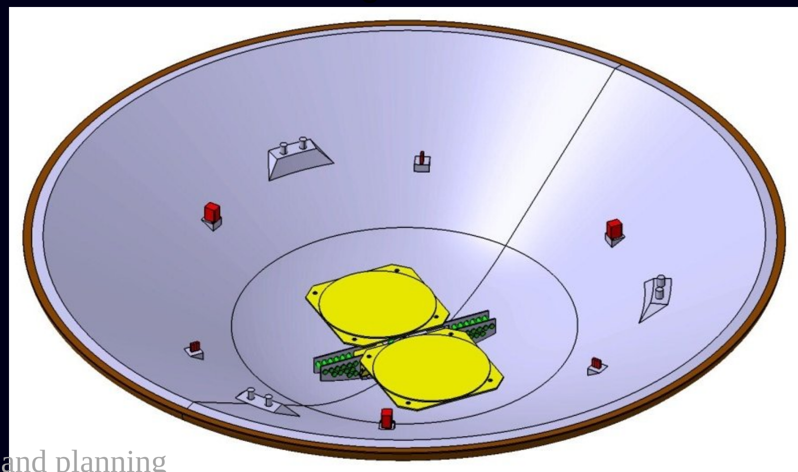


Geosaucer

- Uses available volume between nadir skin of gondola and inner side of heat shield
- Science
  - Tidal distortion and rotational state
  - Subsurface properties
  - Time-variable magnetic field
  - Seismic activity
  - Environmental conditions
- Payload
  - Seismometer, magnetometer
    Radio science beacon, environmental package
- Mini-RPS with rechargeable Batteries
- Package descends to the surface uncontrolled after separation from the Montgolfière. 135 day mission life limited by communication geometry
- Data transmission via patch antenna to orbiter. Power is peak power mode at ~20W. Instruments are 10x less



Instrumentation: Seismometer,
Magnetometer, Radio science
Max. mass: 20 kg

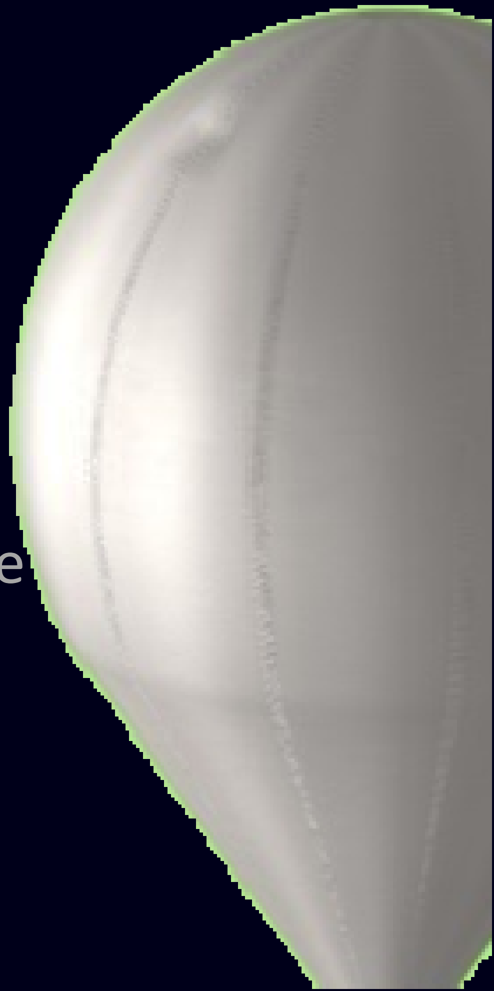


Key critical technologies

- Balloon envelope
  - Material needs assessing with respect to
    - Mass, operations under cold conditions, rigidity
    - Compatibility with packaging for 10 years
  - Inflation
  - Validation and testing is required

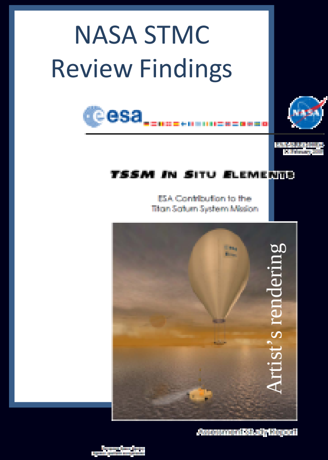
- Test and verification of deployment sequence
  - Validation by drop tests plus analysis

- JPL and CNES have started development
  - Includes analysis, test, and verification
  - Modeling and simulation



Path forward from 2008 Studies

- NASA science panel confirmed that in situ elements are needed for a highly capable flagship mission to Titan
  - Science rated Excellent; science implementation – rated low risk; mission implementation – rated high risk



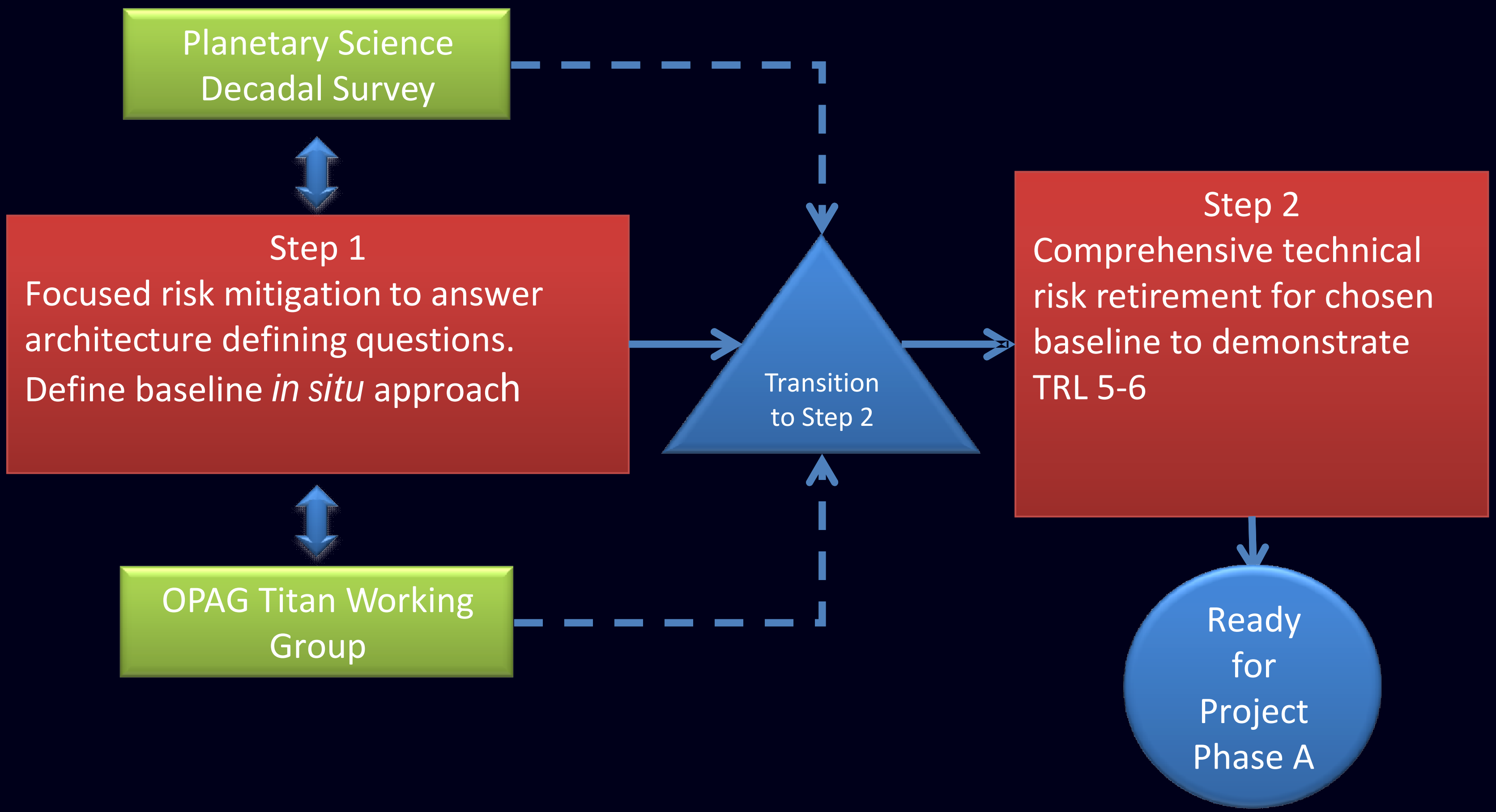
- Technical risks related to the montgolfière must be retired
  - JPL and CNES are pursuing a joint risk reduction effort directed at a Titan aerobot – Some current focus areas are highlighted on following charts

- In situ instrument/sampling systems for the cryo environment must be matured

- Alternative mission techniques should be explored to open Titan and Enceladus options across the range of cost-class opportunities

Technology readiness for future Titan mission

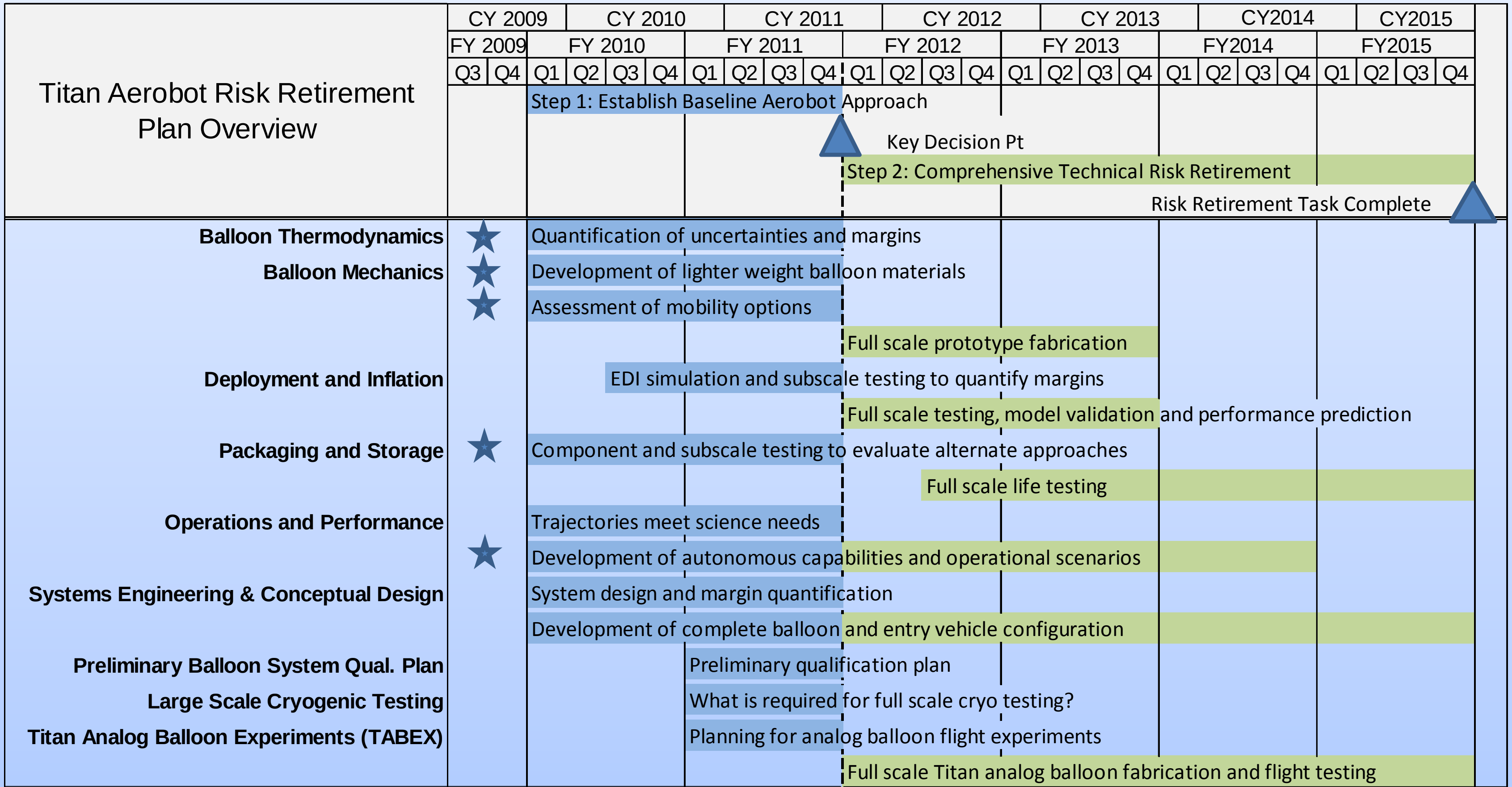
A 2-step approach is being pursued at a low level to advance technical readiness



Two-step approach maintains alignment with ongoing Planetary Science Decadal Survey while advancing readiness for potential project start

JPL-CNES collaborating on Titan balloon

(dependent upon DS; 2010/2011 plan descoped to fit within available budgets)



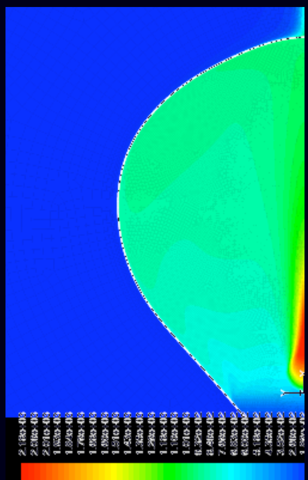
★ Tasks included in current funding

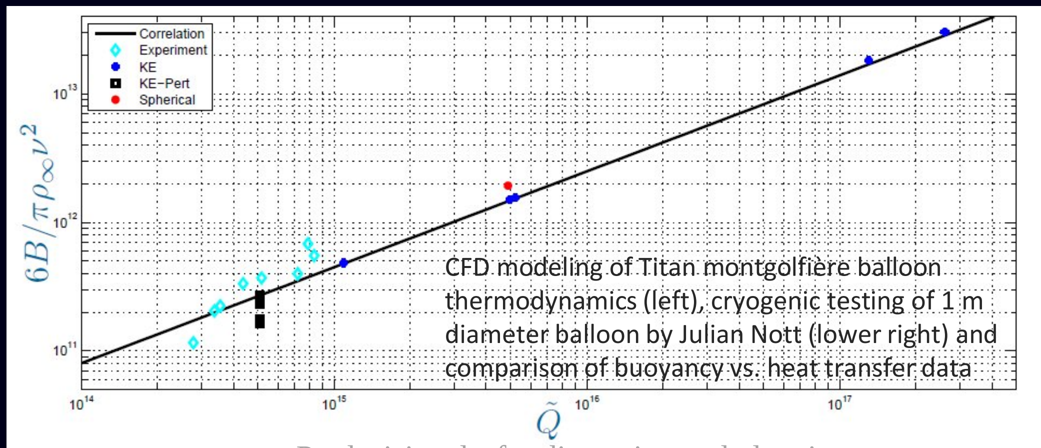
Architectural defining questions are answered early, allowing definition of baseline approach and comprehensive risk mitigation

Balloon thermal modeling and test

- Thermal Fluid modeling is underway:
  - Turbulent flow simulations using a commercially available CFD package (Fluent)
  - Single and double-wall balloon geometries
  - Models address mixed free and forced convection problem
- Results indicate that the single-walled turbulent simulations predicted better buoyancy performance than either engineering correlations (as jointly defined by JPL and CNES in 2008) or cryogenic heat transfer experiments performed by J. Nott in 2008
- Additional montgolfière performance modeling and testing are necessary to quantify margins needed to ensure desired performance given expected environmental uncertainties

Indoor propane-heated flight of 9 m prototype

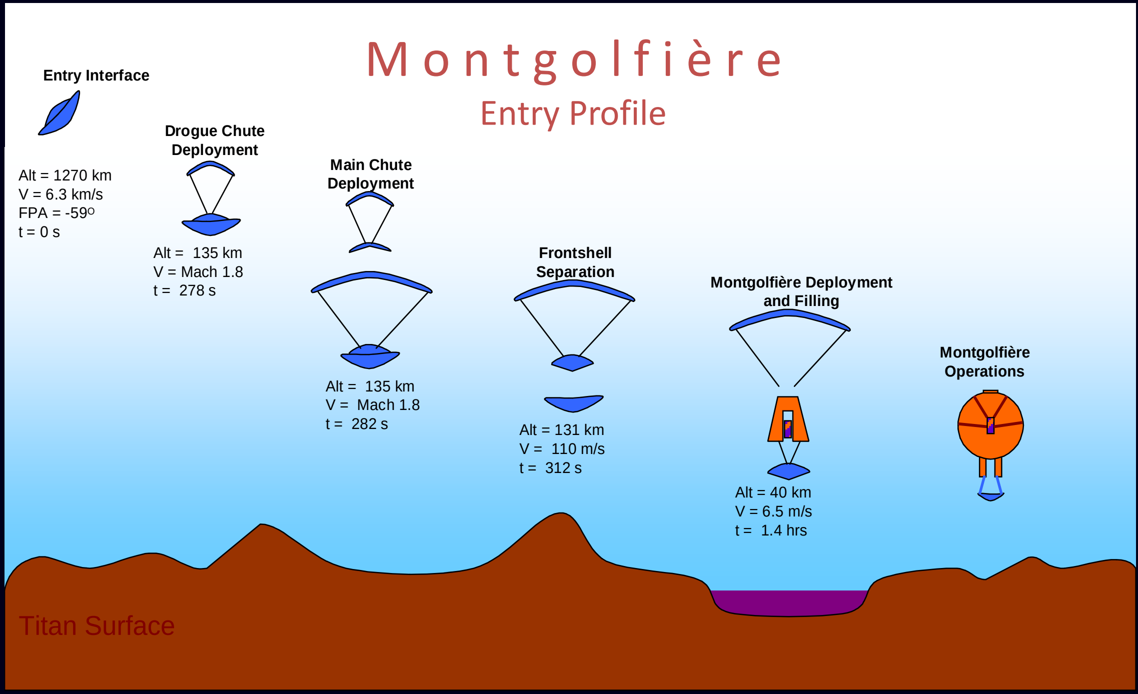




CFD modeling of Titan montgolfière balloon thermodynamics (left), cryogenic testing of 1 m diameter balloon by Julian Nott (lower right) and comparison of buoyancy vs. heat transfer data

Balloon deployment and inflation

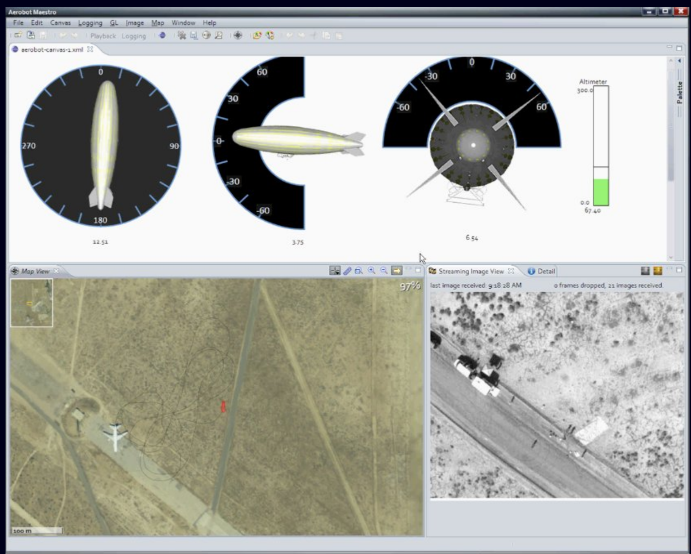
- Montgolfière entry and initial deployment is similar to Huygens parachute deployment
  - Complicated by release and deployment of MMRTG
- Inflation of balloon and establishment of buoyancy would require validation and demonstration of flight configuration
  - 2008 testing has shown positive results



Successful aerial deployment and inflation test on 4.5 m balloon (300-400 meter altitude)

Autonomous balloon operations

- Autonomous operation capability has potential to greatly expand science value
- Approach is to build on currently ongoing aerobot autonomy flight experiments
  - Powered blimp testbed flown in the Mojave desert
  - Integrated sensor, actuator and software system for autonomous flight controls and vision-based navigation
  - Demonstrated autonomous waypoint navigation, trajectory following and GPS-denied visual servoing



Real-time operator control interface

Example of repeated “racetrack” trajectories

Balloon packaging and thermal management

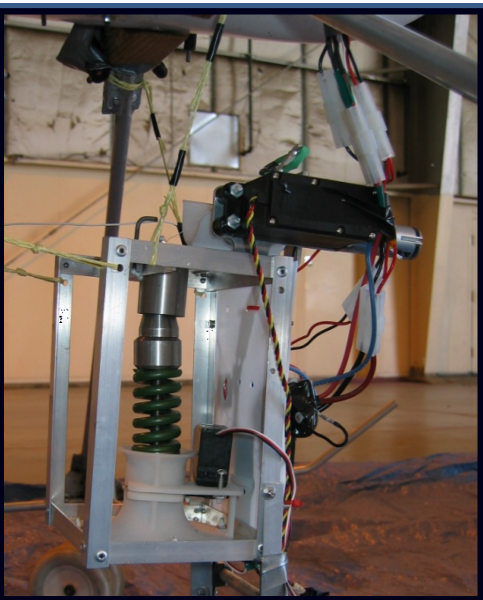
- Packaging within the limited space available in the aeroshell is a challenge that would continue to be addressed

- Heat rejection from the MMRTG during cruise must be robust to the requirements of a potentially long cruise duration
  - This issue is currently being addressed by MSL, which shares the same heat rejection challenge over shorter period of time

- Design for insertion of the MMRTG at the launch site would also be a focus
  - Also addressed by MSL
  - Titan montgolfière design would be optimized

Surface sampling from a balloon platform

- Addition of surface sampling capability on the aerobot could significantly increase science return
- Aerobot surface sample acquisition experiments have recently been performed with a tethered "harpoon" device
  - Proof-of-concept experiments using the JPL powered blimp testbed
  - The "harpoon" was an aluminum tube-like structure that falls by gravity and embeds itself in the surface
  - The harpoon is retrieved by winching on the tether
  - A total of 8 acquisition flights so far, small (10s of grams) amounts of surface dirt acquired each time
  - Drop altitudes ranged from 15 to 70 m, ground relative speeds up to 5 m/s



Harpoon and tether assembly

Pre-flight preparations

At the drop altitude

Close-up view of impact site

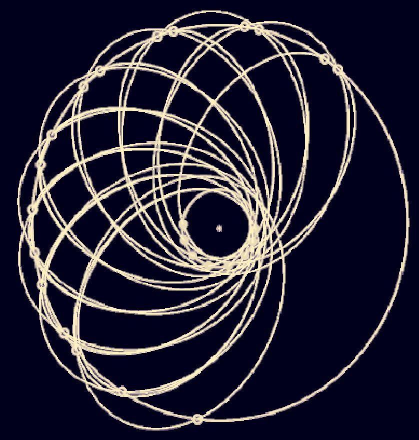
In situ Instrument and sampling systems

- There is no current activity specifically focused on maturing Titan and Enceladus instrument and sampling systems to TRL6
- OPAG has recommended an OP instrument program with a focus on:
  - developing and maturing low mass/power instrument systems that have high resolution and sensitivity, raising the TRL to >6
  - Instrument and sampling systems that can operate in cryogenic environments
- This should be a key element of an outer planet technology development program if one were created -- >> 2011?

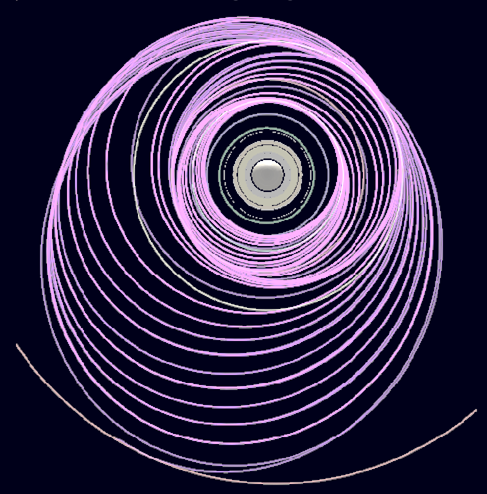
Recent advances in mission design techniques open up new mission options - 1

- Tour Design Techniques:
  - Titan-Enceladus Cycler Orbits
    - A repeating cycle of Titan and Enceladus flybys
    - Cyclers provide a high number of Enceladus flybys while simplifying tour operations and reducing mission costs
  - Leveraging Tours
    - Leveraging tours use maneuvers with gravity-assists of small moons (e.g. Rhea, Dione, and Tethys) to achieve the trajectory bending usually associated with higher mass moons
    - A three year leveraging tour could reach Enceladus orbit with a Delta-V of ~2.3 km/s (Compared to ~5.3 km/s for reaching orbit with traditional tour design methods)

Titan-Enceladus Cyclers



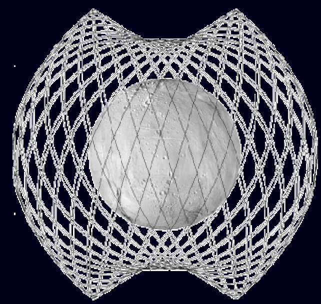
Leveraging Tours



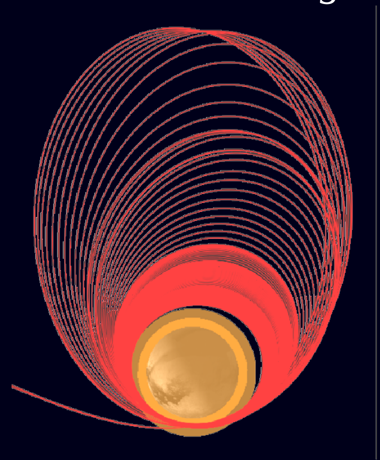
Recent advances in mission design techniques open up new mission options - 2

- Other Techniques:
  - Stable, 65º inclination Enceladus "Frozen" orbits
  - Titan Aerobraking
  - Enceladus Plume Sample Return
    - Sample collection from Saturn orbit enables multiple collection opportunities
    - Round trip mission durations of 12-16 years
    - Collection speeds of 2-4 km/s
  - Multi-Moon Orbiters
    - Using a Leveraging Tour, a TSSM-type Titan orbiter could leave Titan orbit and reach Enceladus orbit
    - Additional Delta-V needed for this could be carried if TSSM launcher upgraded to Delta IV Heavy class launcher
    - Total mission length would be 14-15 years

High-Inclination, Stable, Enceladus Orbit



Titan Aerobraking



Emerging mission options span the cost range

- TSSM plus capability to transfer to Enceladus orbit
- Titan orbiter, balloon, lander (TSSM)
- Dedicated Enceladus orbiter w/lander or impactor
- Enceladus Sample Return
- Titan Lake lander
- Titan balloon mission
- Minimal Enceladus orbiter
- Titan and Enceladus cycler

Decreasing Cost

Relative cost order of options is based on recent studies but could vary significantly and is not absolute

Summary

- The Cassini mission continues to expose mysteries of Titan and Enceladus – high priority questions remain unanswered until a follow-up mission with improved capability is undertaken

- Advancing the readiness of in situ elements and instrument systems is critical to enabling future missions to Titan and Enceladus

- New probe concepts and mission techniques have the potential to open up attractive options to either or both targets in various cost classes