Titan Montgolfiere Mission Study

Presentation to The Outer Planets Assessment Group

May 4, 2006

By

Jonathan Lunine
Ralph Lorenz
Tom Spilker
John Elliott
Kim Reh

The data/information contained herein has been reviewed and approved for release by JPL Export Administration on the basis that this document contains no export-controlled information

PRE DECISIONAL For Planning and Discussion Purposes Only

…will require bold new steps…
…and a willingness to ride the wind.

"Titan is a complex world, which appears to be influenced by tectonic, fluvial and atmospheric processes, in many ways similar to Earth,"
Porco et al., Science, 2005.

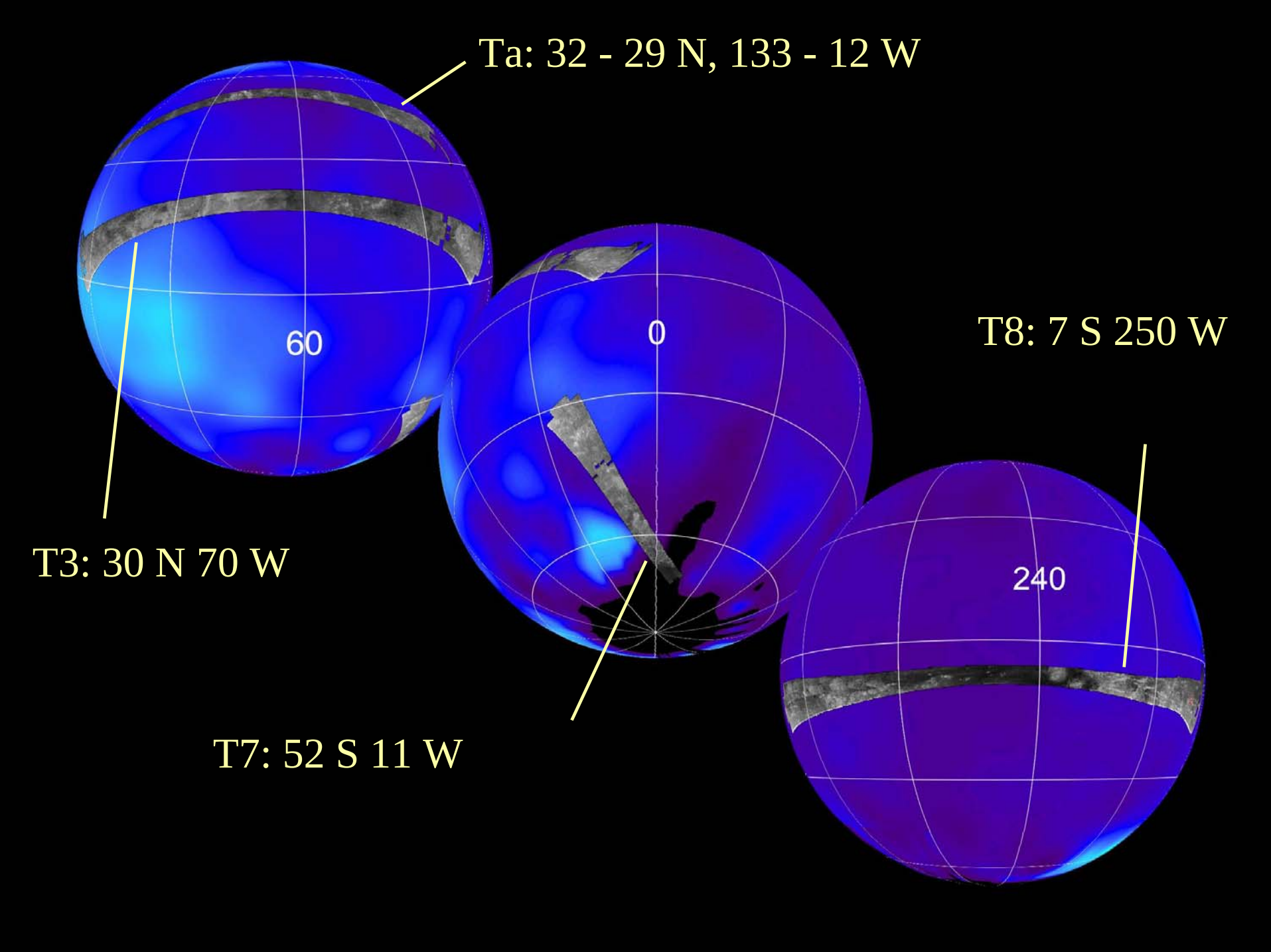
"As an environment, Titan certainly meets all of the stringent criteria outlined above for life."
Steven Benner et al. Current Opinion in Chemical Biology, 2004

"Titan is the Peter Pan of the solar system."
Tobias Owen

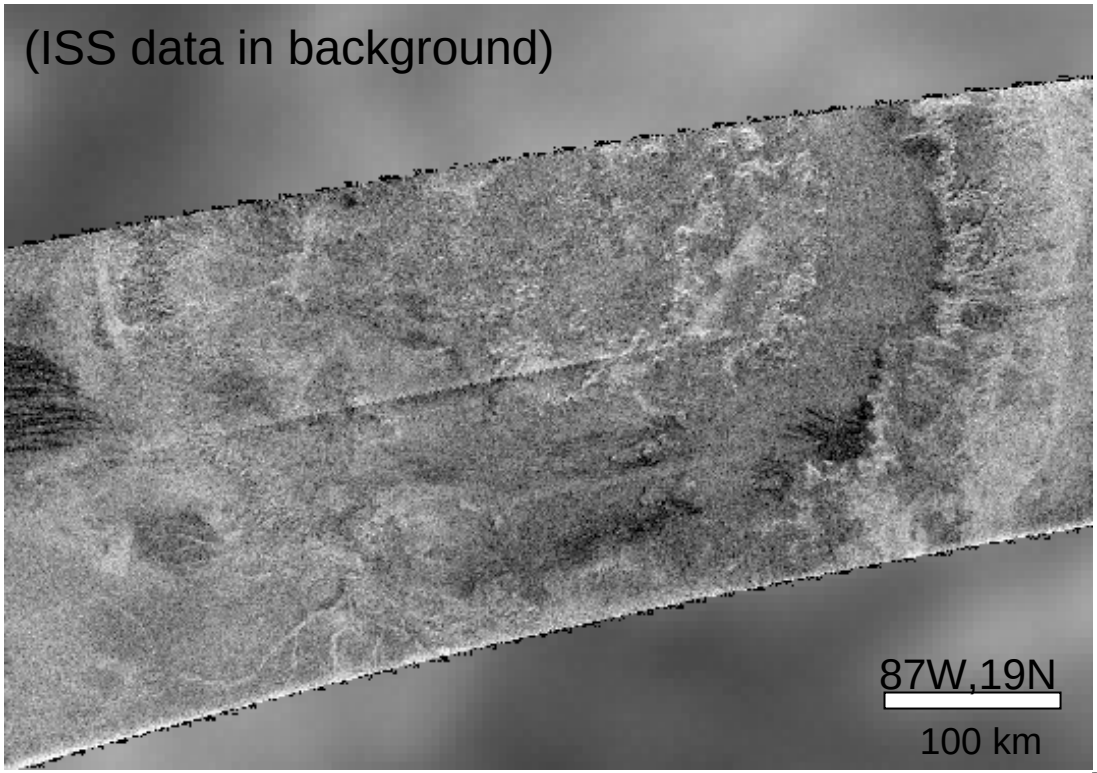
"It cannot now be predicted whether Europa or Titan will ultimately prove to be the most promising satellite for long-term exploration."
NRC Decadal Survey of Solar System Exploration, 2003

Clues from Cassini-Huygens

- Titan is extensively outgassed, (geologically active)
- The surface has experienced some sort of renewal process, and widespread burial
  - it is no more than 1-2 billion years old
  - heat flow is sufficient to cover the surface with kilometers of water-ammonia flows
- Organics are widespread
- Methane / ethane have flowed across the surface recently
  - may be ponded in places
  - exists in surface
- Further progress with Cassini will be limited to radar and near-infrared images at 350 meters resolution or worse
  - local fluvial geology required 1 meter DISR resolution.

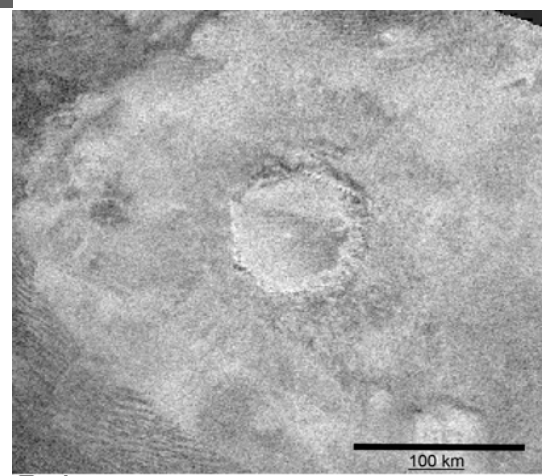

Ta: 32 - 29 N, 133 - 12 W
60
0
240
T8: 7 S 250 W
T3: 30 N 70 W
T7: 52 S 11 W

T3: Two impact craters



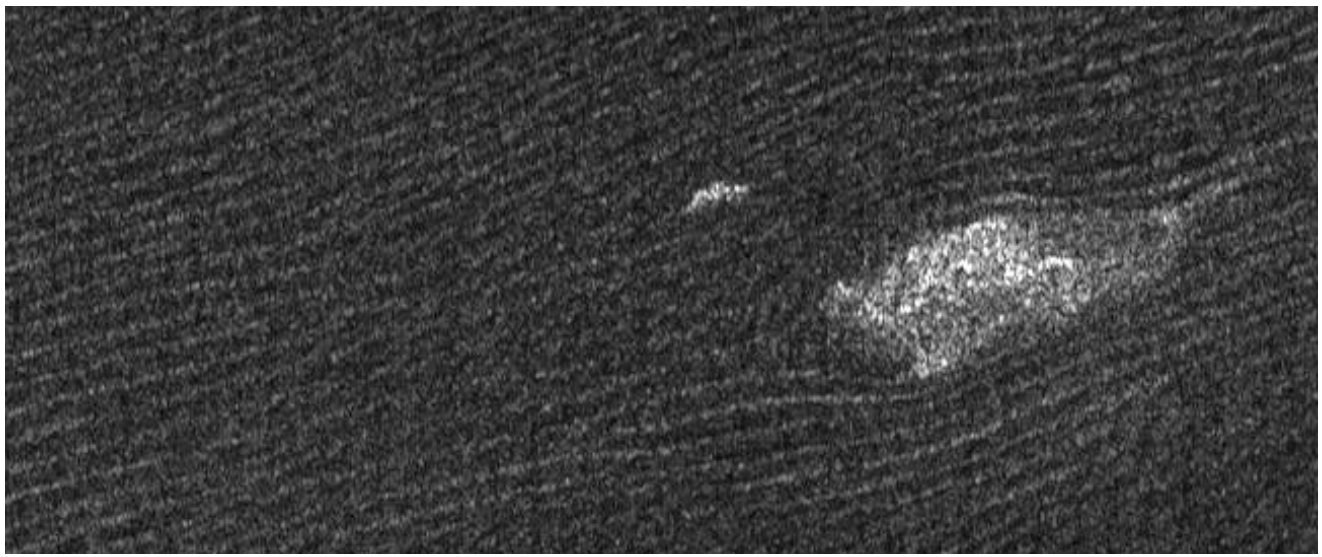
Menrva

Sinlap



Robertson-Tessi and Lorenz

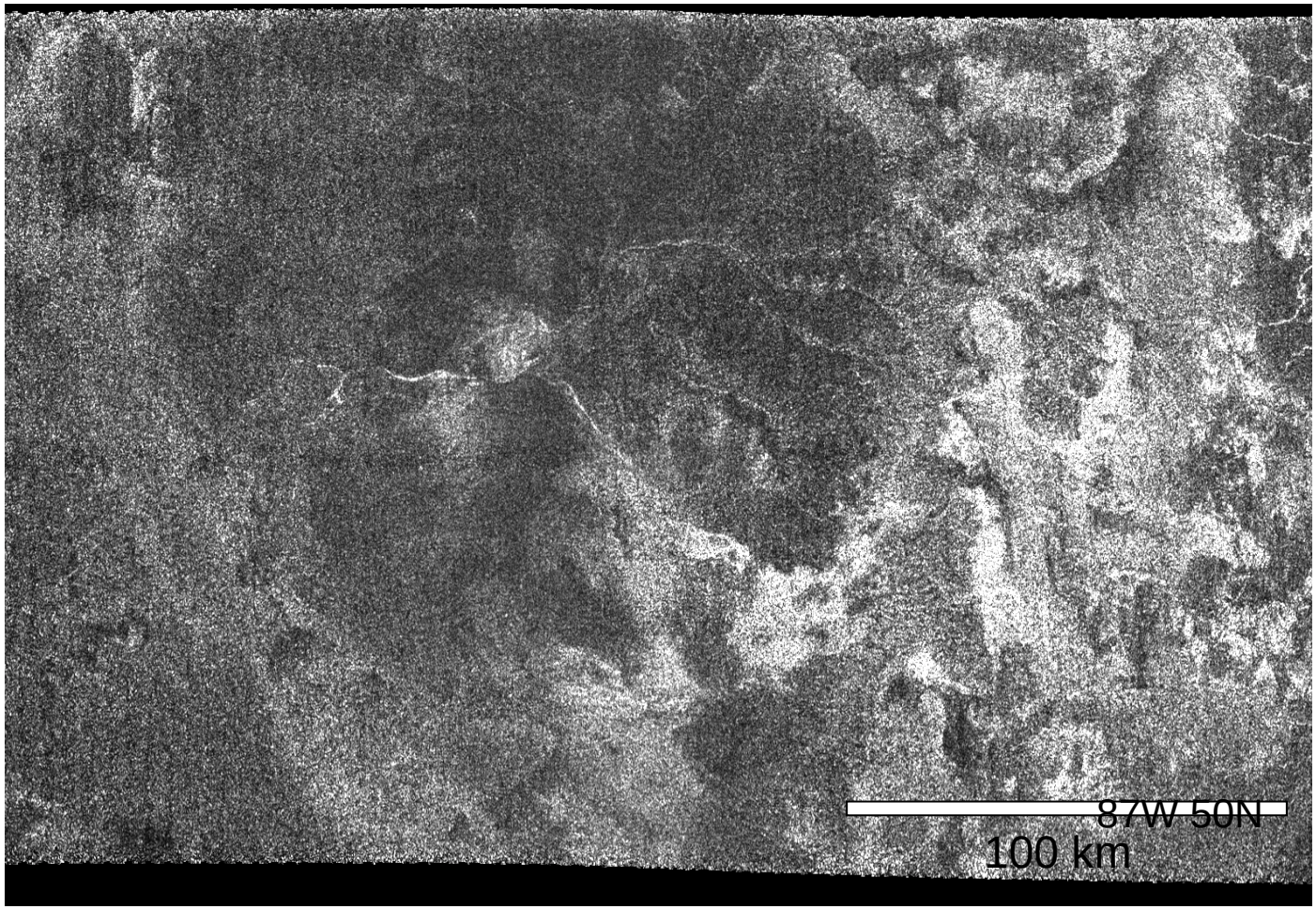
T8: Equatorial ‘Sand’ Dunes



10 km

May 4-5, 2006

Ta: Cryovolcano -- Ganesa Macula



- Suggestive of volcanic construct
  - Rough flanks
  - Central depression
  - Sinuous channels/ridges
  - Lobate flowlike features

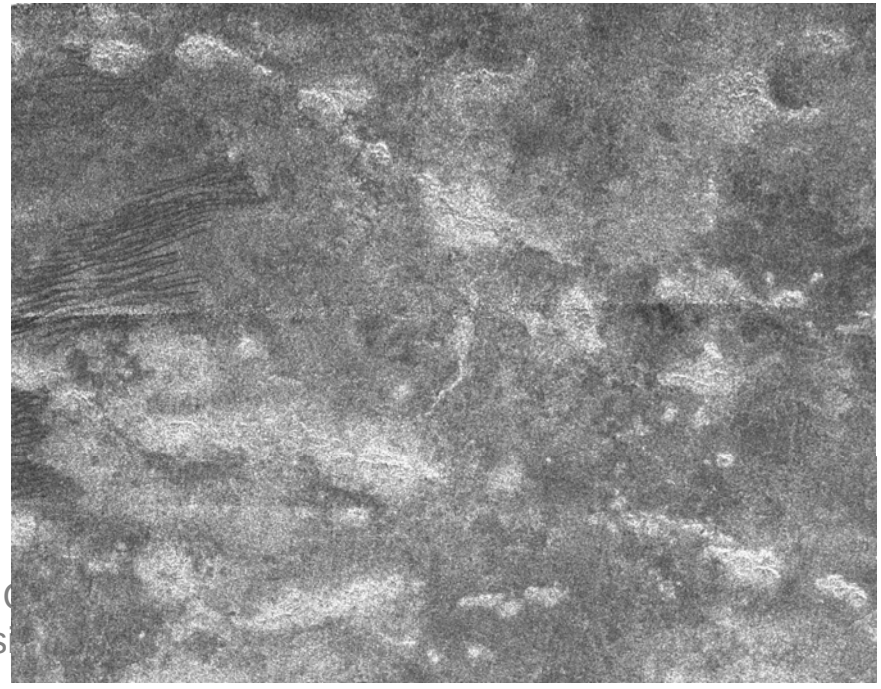
Ta: Cryovolcano -- Ganesa Macula

- Suggestive of volcanic construct
  - Rough flanks
  - Central depression
  - Sinuous channels/ridges
  - Lobate flowlike features

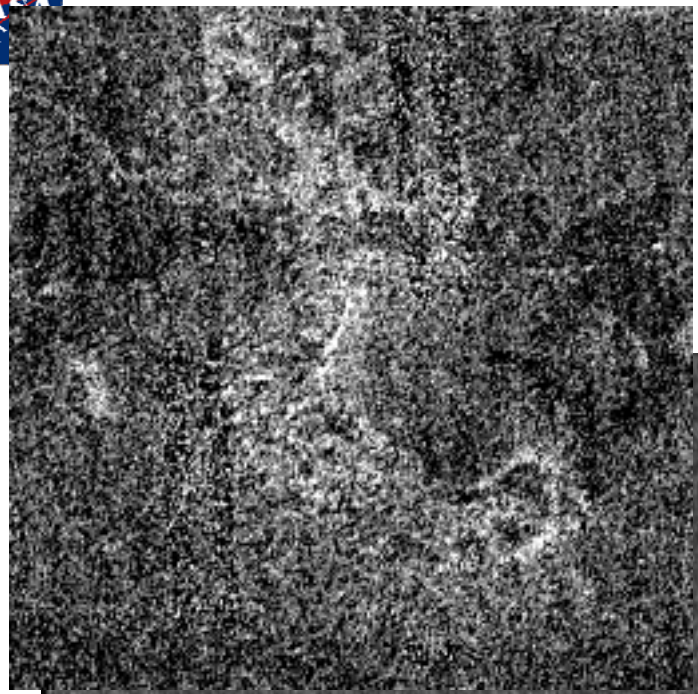
© Michael Carroll

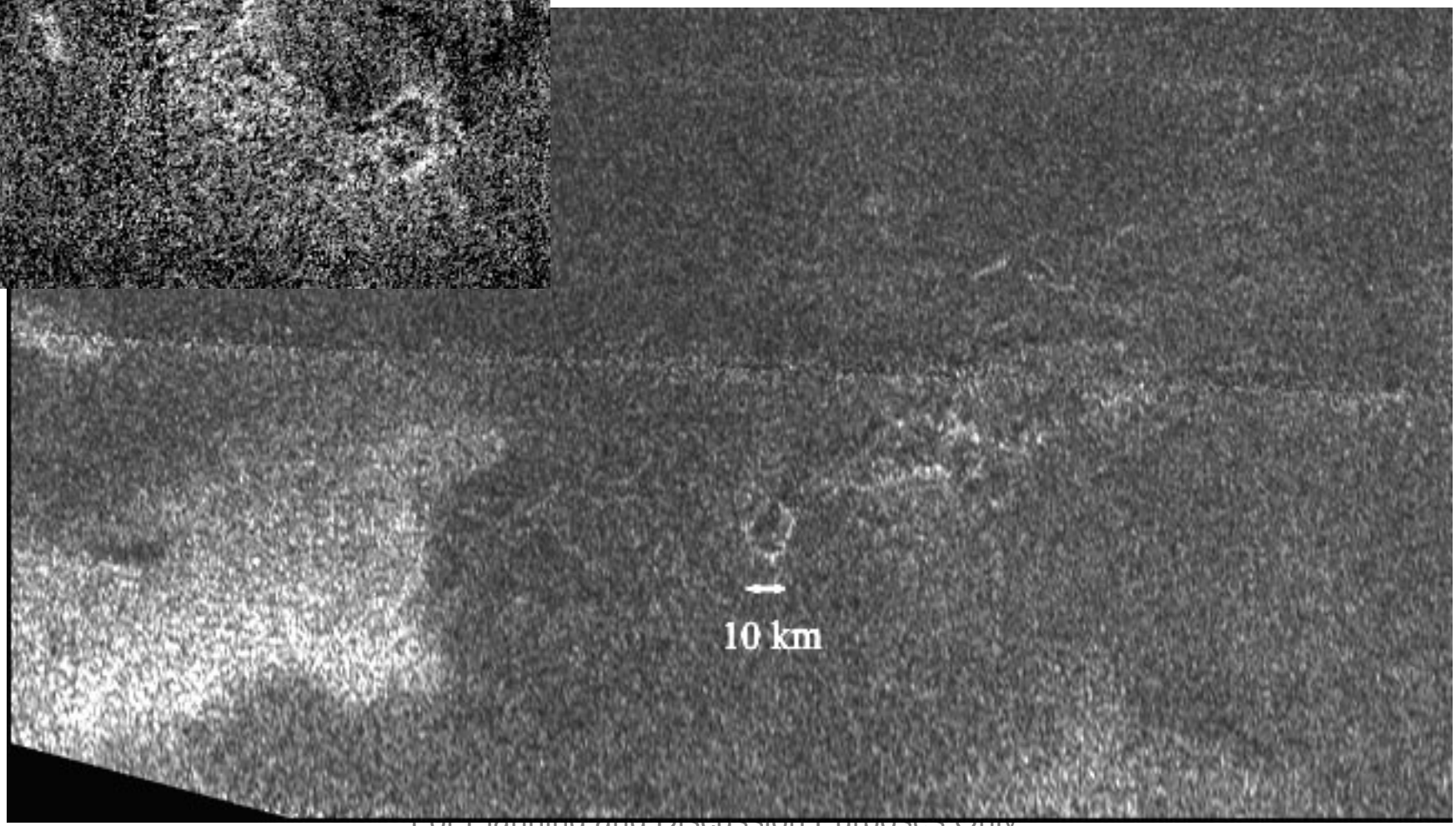
T8: Here, an area of possible calderas and mountain ranges

Smallest detail 500 m

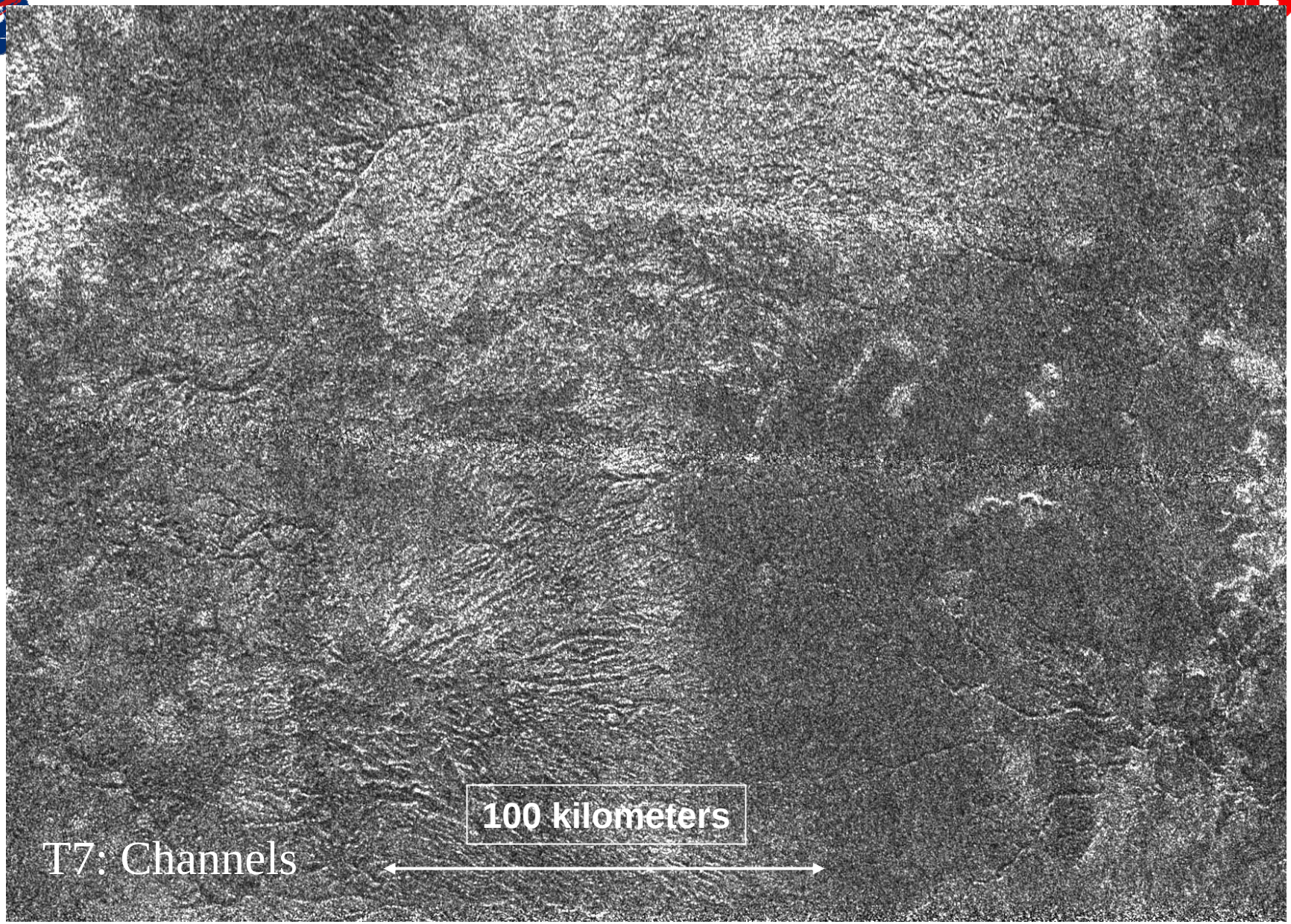


Other calderas further north

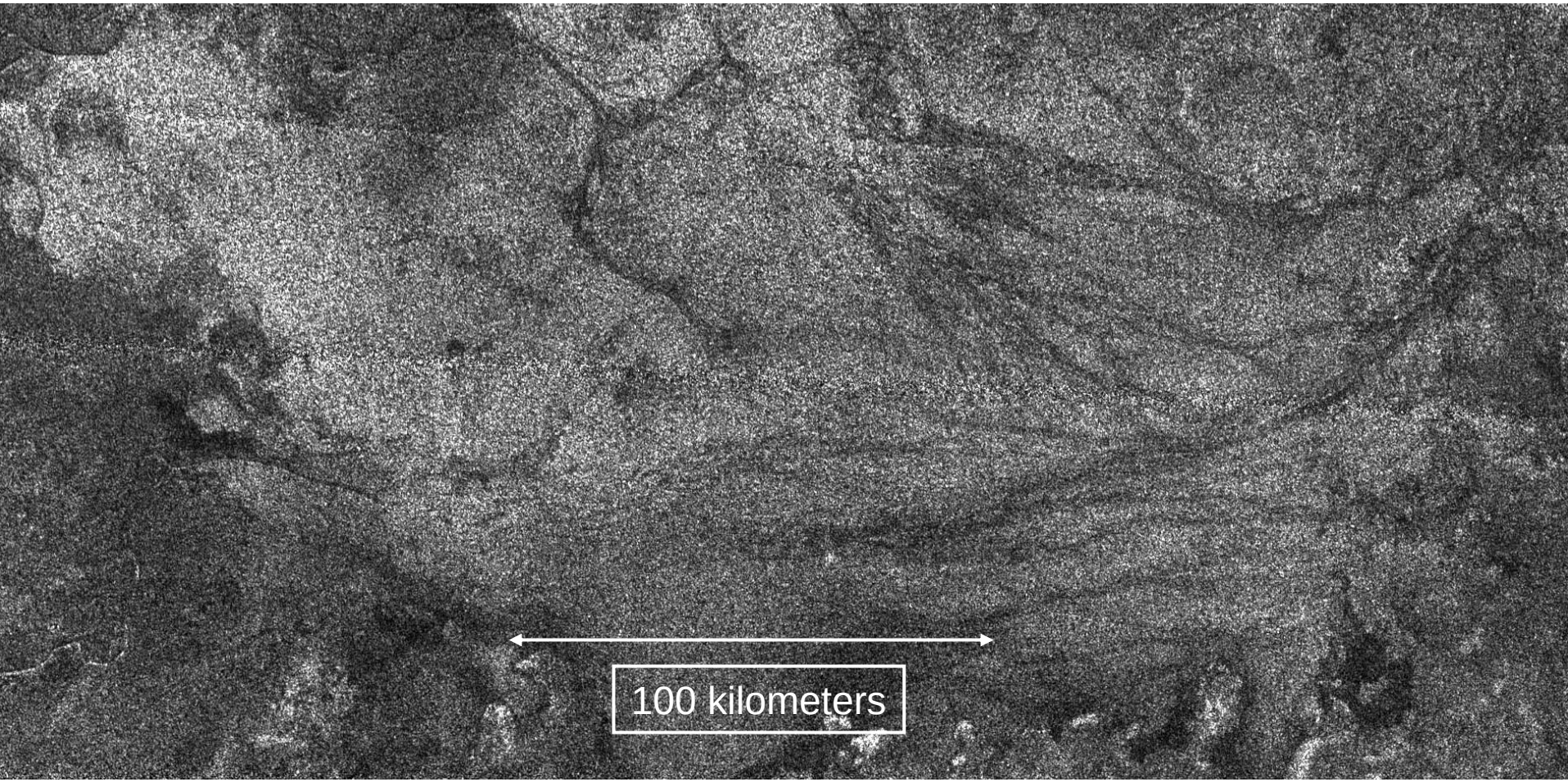




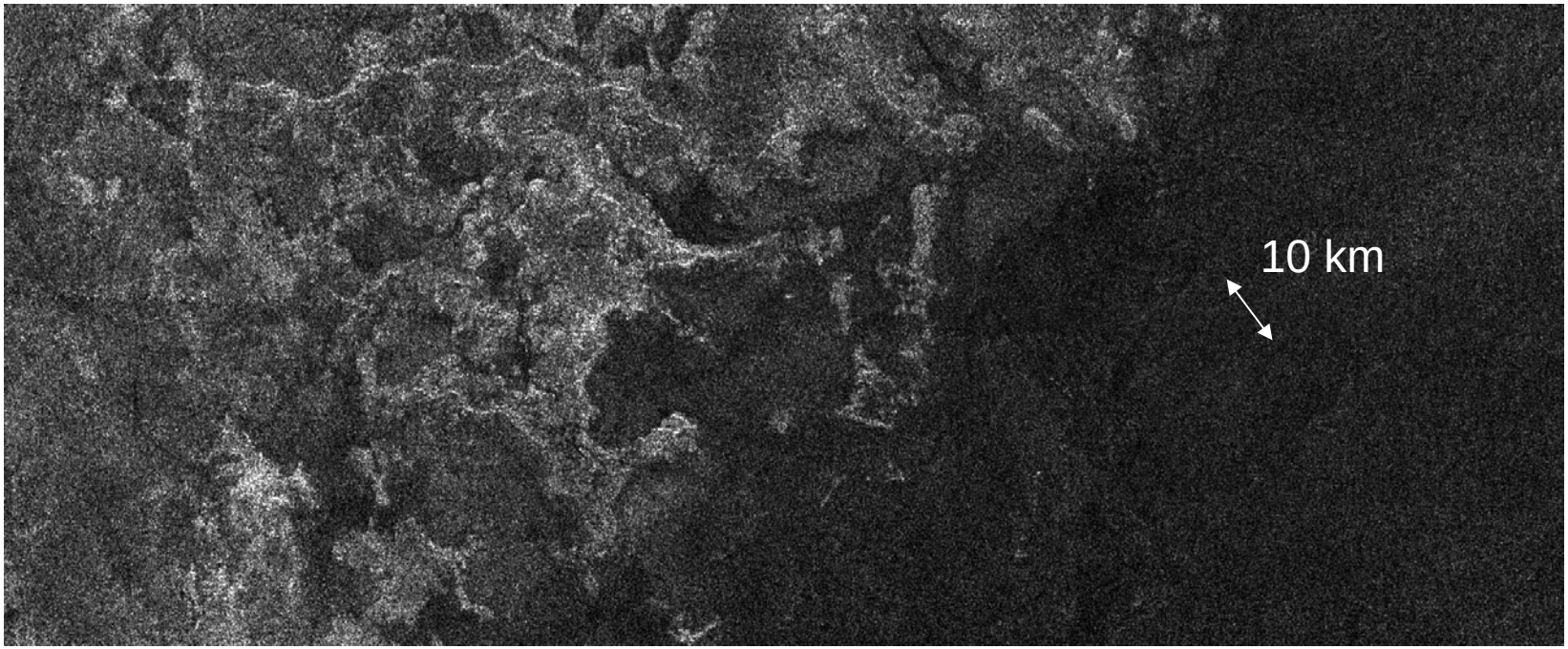
For Planning and Discussion Purposes Only



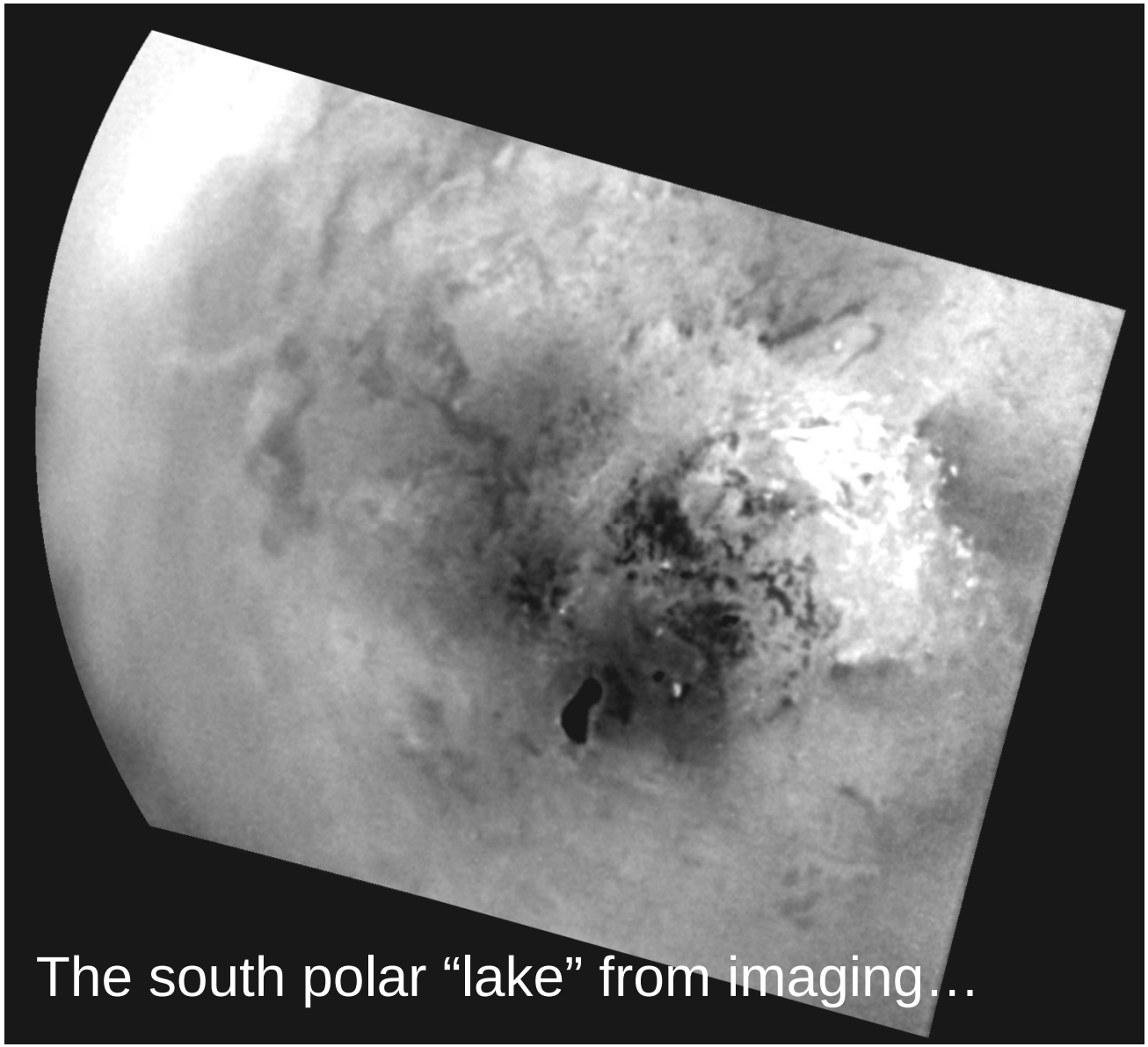
T7: Channels



…grading into more channels…



…to a shoreline of a sea?

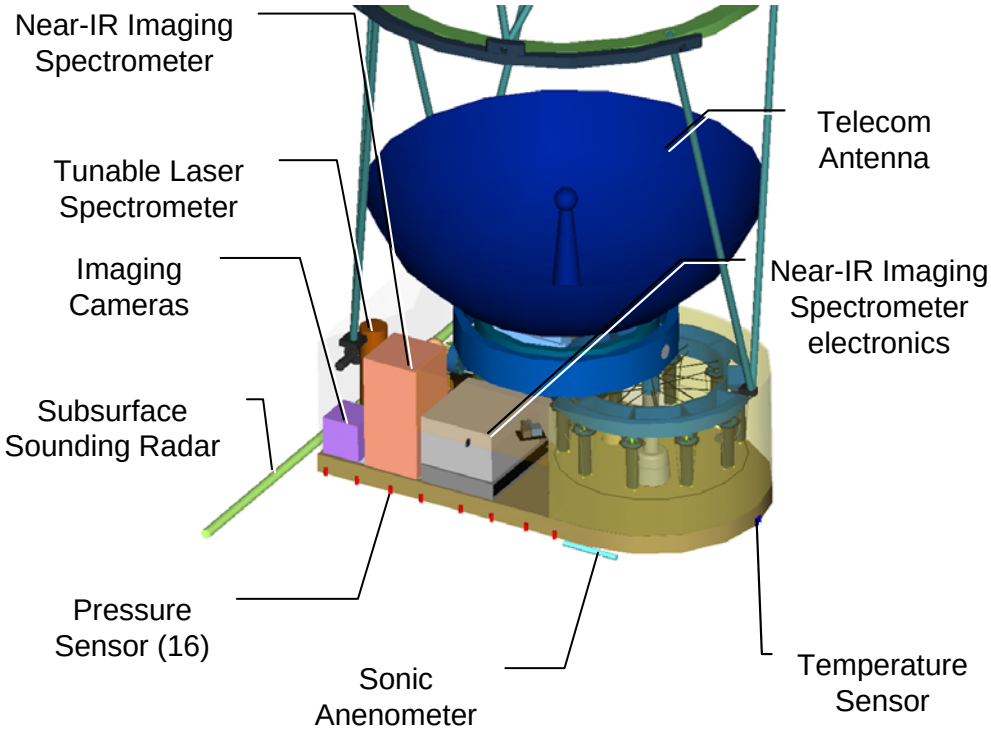

The south polar “lake” from imaging…

Science Goals and Measurement Objectives

- Determine the origin and evolution of Titan's atmosphere
  - Extent of internal differentiation of Titan's interior
  - Surface evidence for primordial atmospheric composition
  - Differentiation in isotopic ratios between primordial surface constituents and atmospheric constituents
- Determine the cycling of carbon through the interior, surface and atmosphere on all timescales and in all phases
  - Titan methane meteorological cycle
  - Chemical modification of carbon speciation over geological time
- Characterize the prebiotic chemistry that has occurred in the surface and immediate subsurface
  - Extent of chemical evolution of surface organic deposits in geologically active and inactive zones
  - Elemental and mineralogical composition of surface inorganics in contact with organics

Instruments

- Gondola
  - Subsurface sounder
  - Near-IR spectrometer
  - Tunable laser Spectrometer
  - Sonic anemometer
  - Imaging camera(s)
  - P-T sensor
  - Gas Chromatograph and Mass Spectrometer
  - Surface Sample Analysis
    - Sample acquisition mechanism
    - GCMS with chiral support
    - Age dating
    - Surface hardness
    - Sample context imager
    - Sample microscope imager
    - Elemental Analysis
- Orbiter
  - Radar imager/altimeter
  - Near-IR imaging spectrometer
  - Radio science



Instruments; Characteristics and Accommodation

- For Each Instrument, characteristics and accommodation requirements were determined to develop packaging and operations scenarios
  - Mass
  - Operating Power
  - Standby Power
  - Dimensions
  - Data Rate/Volume
  - Physical Accommodation Requirements

All great science, but most of all, this mission is about…

…finding “Neverland”…

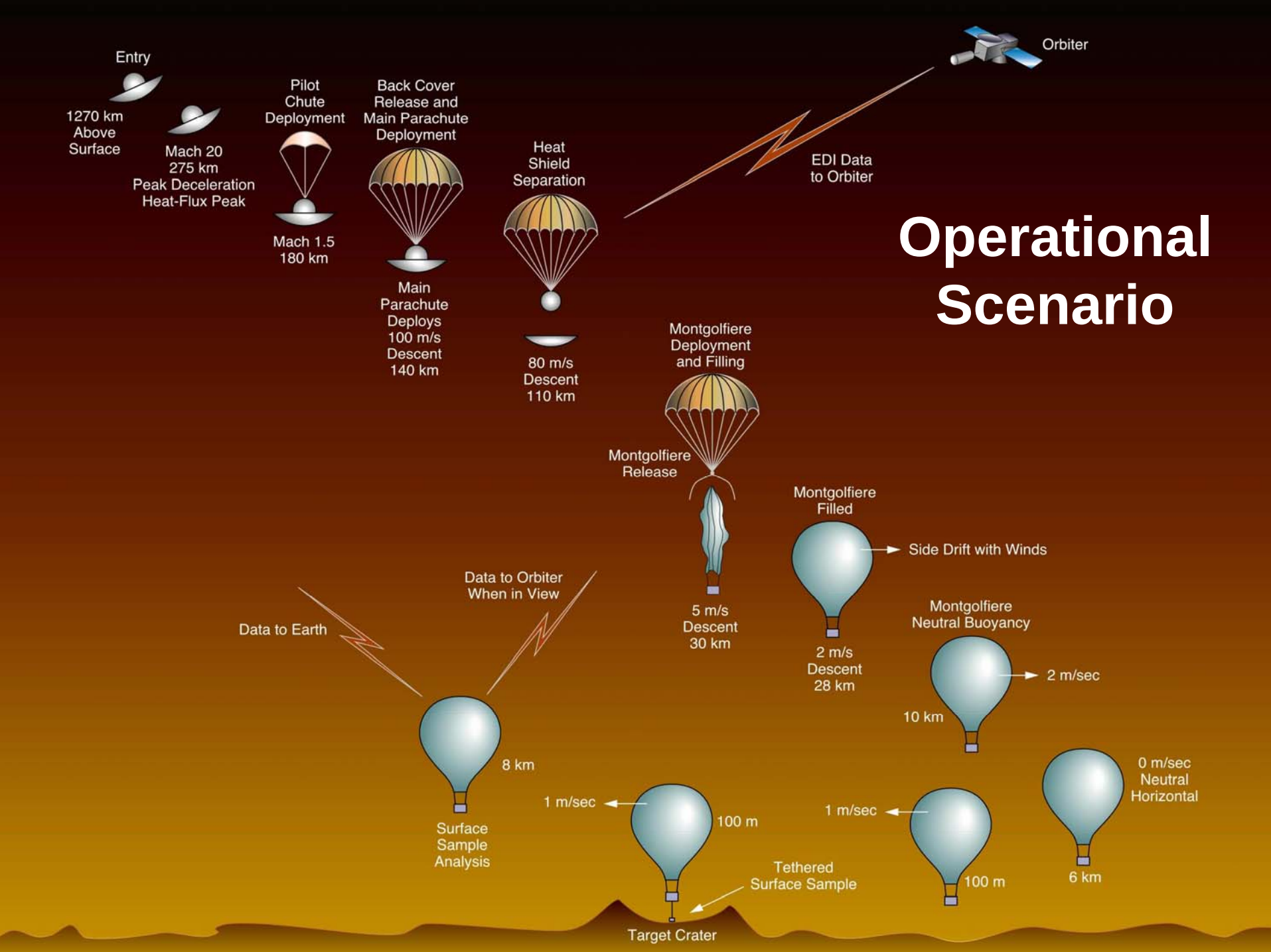
Images Courtesy:
ESA, NASA, JPL, University of Arizona
Panorama by René Pascal, February 6, 2005

Topics

- Science
- Operational Scenario
- Mission Architecture
- Aerial Vehicle
- Summary

Optimal Means of Exploring Titan

- Titan is ideally suited for aerial vehicle exploration
  - Large scale height → "soft" entry
  - High density, high molecular weight, low T air
  - Winds between 10 & 20 km are low-speed, prograde
  - Winds below 10 km are retrograde at times
  - Topography is interesting but gentle (< 1 km)
- Most promising implementation is a Montgolfiere (hot air balloon)
  - Rides the wind at ~10 km
  - Images at 1 meter resolution; other remote sensing
  - Identifies and tacks back to promising areas
  - Half-dozen landing sites over a year cruise


Entry
1270 km
Above
Surface
Mach 20
275 km
Peak Deceleration
Heat-Flux Peak
Pilot
Chute
Deployment
Mach 1.5
180 km
Back Cover
Release and
Main Parachute
Deployment
Main
Parachute
Deploys
100 m/s
Descent
140 km
Heat
Shield
Separation
80 m/s
Descent
110 km
Orbiter
EDI Data
to Orbiter
Operational
Scenario
Montgolfiere
Deployment
and Filling
Montgolfiere
Release
5 m/s
Descent
30 km
Montgolfiere
Filled
Side Drift with Winds
2 m/s
Descent
28 km
Montgolfiere
Neutral Buoyancy
2 m/sec
10 km
Data to Orbiter
When in View
Data to Earth
8 km
Surface
Sample
Analysis
1 m/sec
100 m
Tethered
Surface Sample
Target Crater
1 m/sec
100 m
0 m/sec
Neutral
Horizontal
6 km

Entry and Balloon Deployment

- Target biased for Entry Point (Ganesha, Xanadu, or Huygens landing site, for example)
- Separate aerial vehicle from spacecraft, establish link with orbiter (maintain link through entry, descent, and deployment)
- Orbiter takes care of itself (prep for entry, orient for entry, aerocapture)
- Deploy drogue at some mach number that maintains stability
- Maintain descent on drogue until ready to slow to deploy descent rate (drop aeroshell)
- Deploy main parachute at ~30 km
- Begin deployment, inflation and heating of balloon
- Establish neutral buoyancy at 10 km

First Landing Site Selection

- Establish direct-to-earth link as soon as feasible
- Begin imaging (imaging camera), image-based motion estimation
- Establish altitude
- Establish position
- Characterize balloon operating parameters
- Begin surface remote sensing with balloon: imaging, spectroscopy, subsurface sounder
- Descend to 6 km, confirm retrograde wind available, re-ascend to altitude corresponding to velocity minimum
- Use altitude feedback control loop to maintain local position to extent possible (on-board)
- Map local areas that can be targeted for landing
- Pick landing area and determine estimated time to landing area at tacking altitude

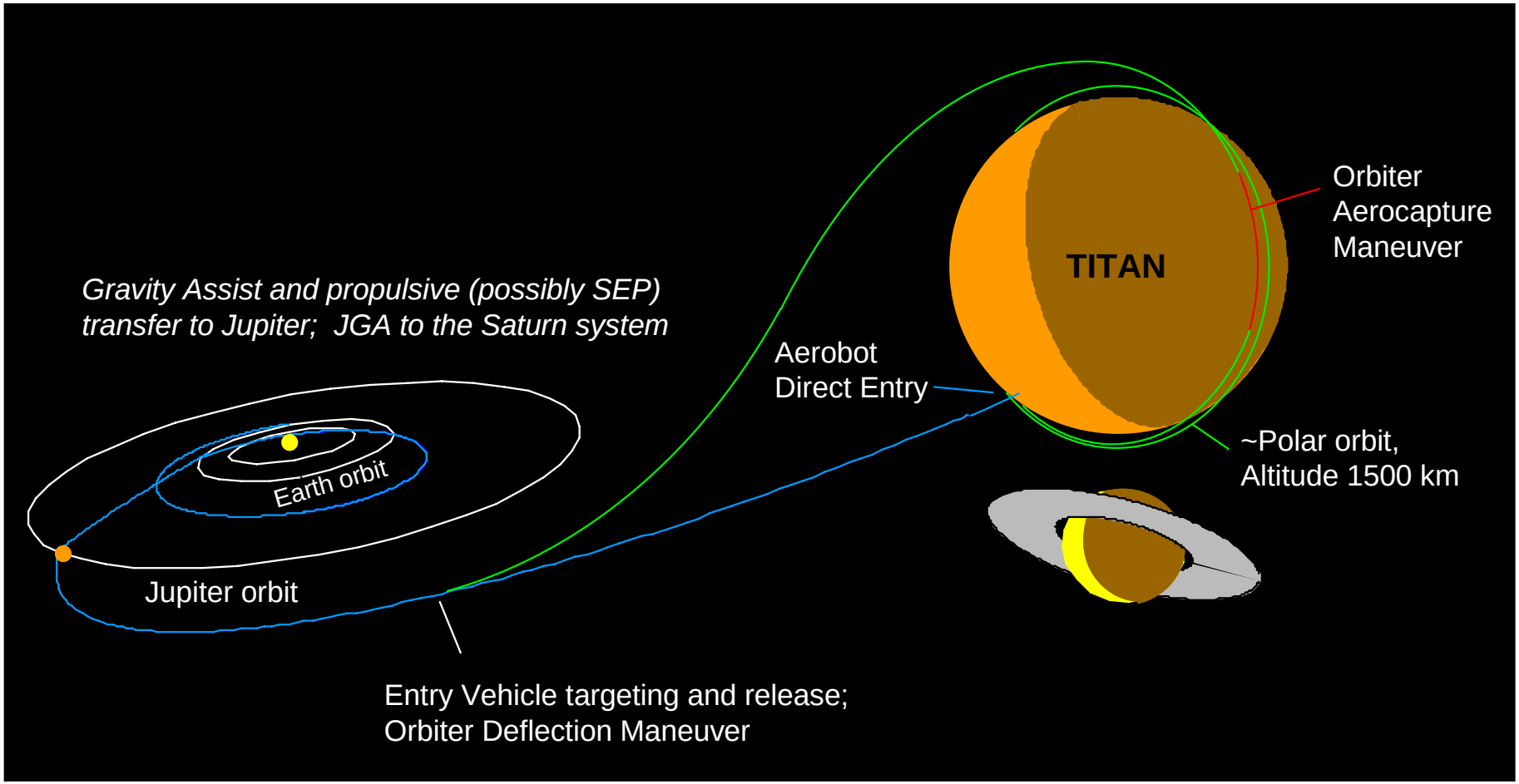
Approach, Landing, Sampling, and Return to Cruise

- Tack to landing area (roughly) at tacking altitude (no lower than 1 km)
- Descend to surface sampler deployment altitude
- Lower surface sampler from gondola
- Confirm surface contact
- Document site with surface imaging, spectroscopy
- Collect sample for organic analysis
- Raise surface sampler to gondola
- Ascend to minimum velocity point (~8 km)
- Do onboard organic and inorganic analysis
- Data transmission to Earth
- Descend again if desired/required by sample, or re ascend to cruise altitude to proceed eastward
- Relay data to earth via direct link for highest priority data, relay rest of data when orbiter is in view
- Transition to cruise mode with onboard imaging, spectroscopy, and subsurface sounding from gondola.

Topics

- Science
- Operational Scenario
- Mission Architecture
- Aerial Vehicle
- Summary

High-Level Mission Design Concept



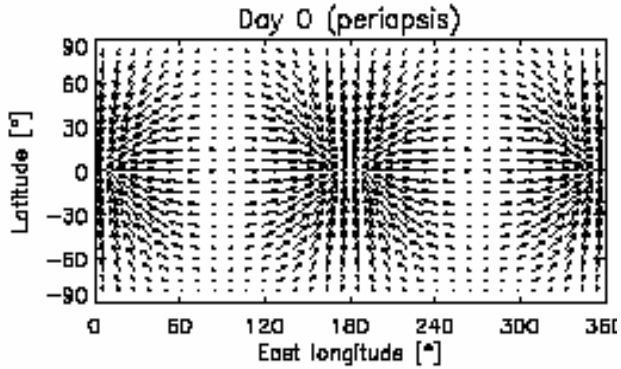
Sample Balloon Trajectories

Produced by combining:

background winds from 2 Titan general circulation models (GCMs)

+

tidal winds due to Saturn, e.g.



Variables considered include: time of year, local time of day at starting location, starting latitude and altitude, and random wind fluctuations

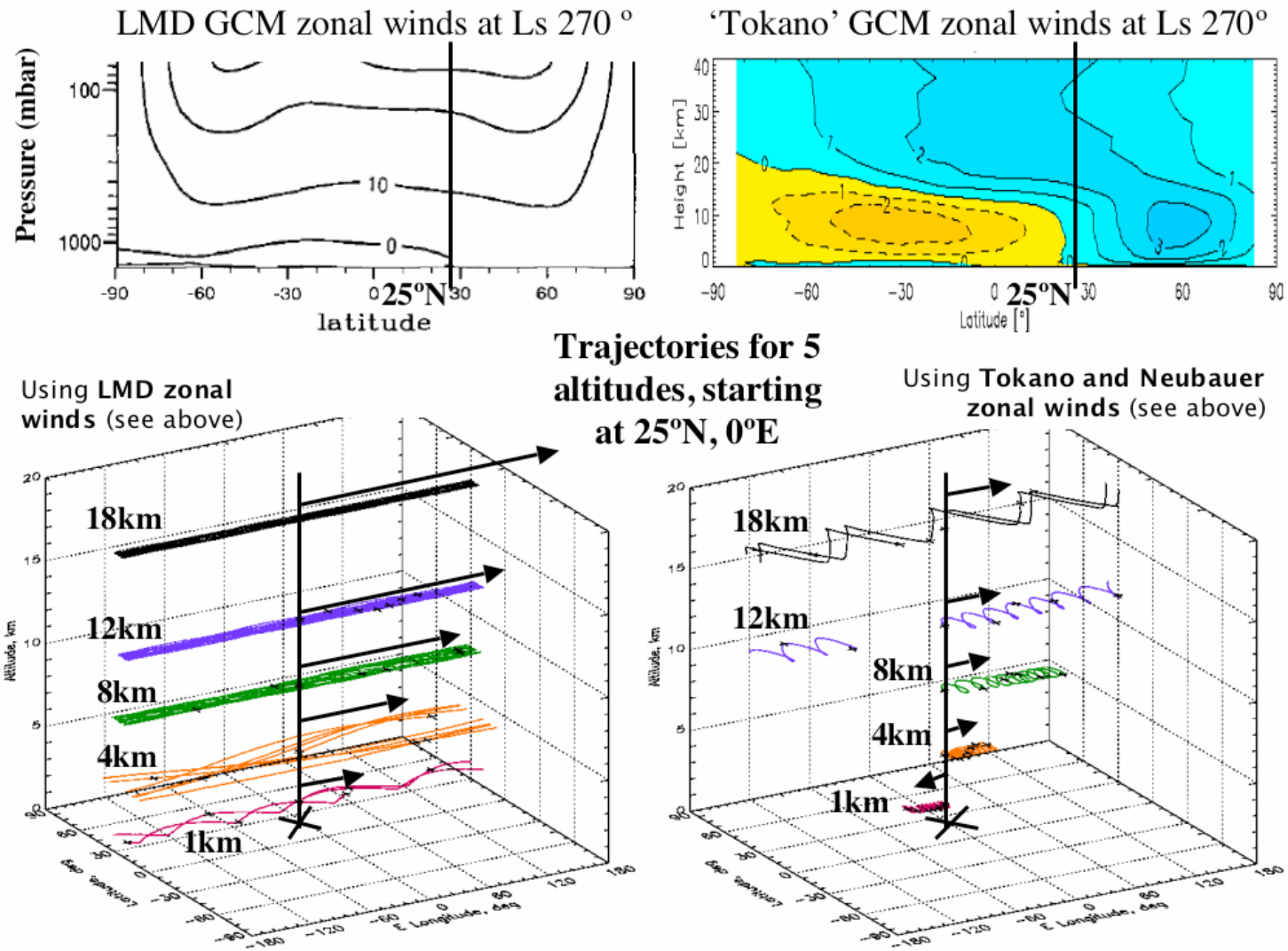
But: most significant is the GCM used to provide background winds

- LMD GCM predicts strong westerlies except at low equatorial altitudes
- 'Tokano' GCM predicts westerlies *and* easterlies over broad regions

If wind reversals occur as often as predicted using the 'Tokano' GCM, we may be able to use this to stay over / return to regions of interest

But we are also prepared for the LMD GCM situation - in this case site selection would probably be more opportunistic

Sample Balloon Trajectories (cont'd)



Note that the Huygens Probe entered at ~Ls 300 deg., at ~10 deg. S latitude

For Planning and Discussion Purposes Only

Balloon Trajectory Simulation

Data Return Capability

- Orbiter
  - Ka-band DTE provides 200 kb/s (power and pointing limited)
  - Occultations 0-35% depending on orbit geometry
  - 10 Gb/day (more than 5X Cassini's daily average)
  - Assumes worst case geometry and continuous DSN coverage
    - Edge-on geometry is worst case with 35% occultation
- Aerobot
  - X-band with 1m HGA
  - 2 kb/s DTE
    - Useful for commanding, navigation Doppler, health and status, low rate science for sequencing and dead-reckoning
  - 1 Mb/s relay to orbiter
  - 5 Gb/day average
  - Assumes worst case geometry
    - Low latitude location is worst case with relay contacts 3 days in 8

Mission Data Return

- 180 Day Aerobot Mission
  - Capability may be much longer as no life limiters are known
  - 1 Tb Aerobot mission data return (5,000X Huygens data return)
    - Similar to other planetary survey missions (MGS, Odyssey)
- >5 Year Orbiter Mission
  - 18 Tb mission data return (7X Cassini mission data return)
- Important Considerations
  - Data Latency is highly variable and can be quite large
    - Many hours to 1 week
  - Contact times are short for Aerobot high rate downlink
    - Maximum < 1 hour

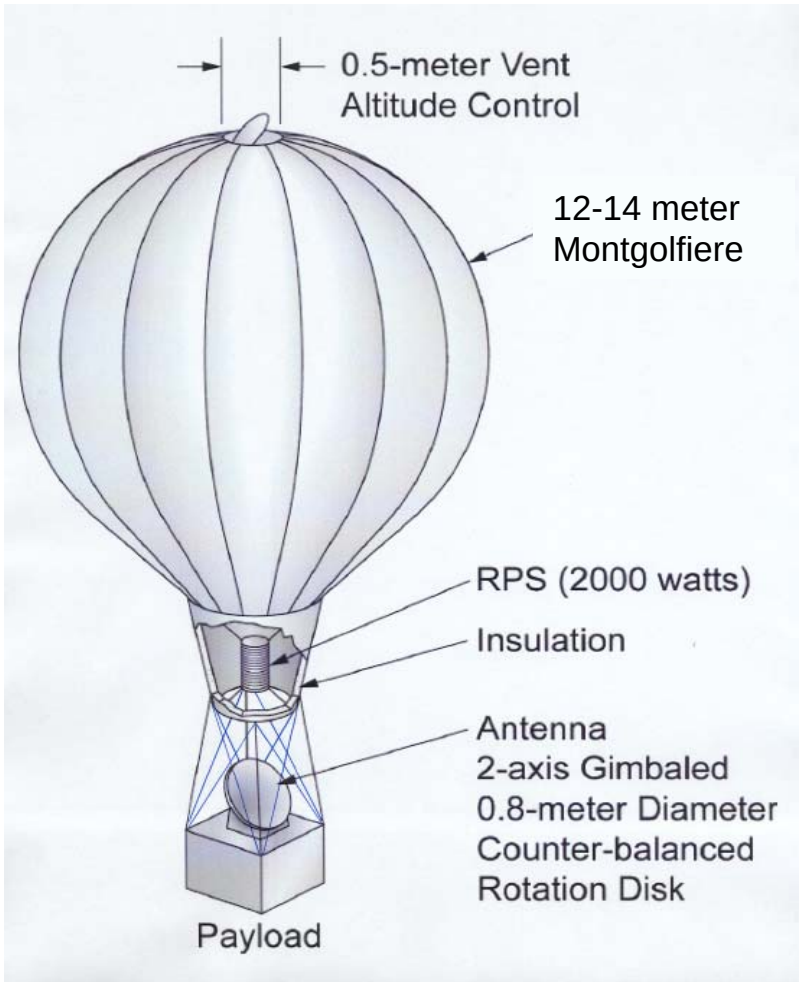
Science Autonomy

- Science data acquisition capability far exceeds downlink capacity
- Data collection and management autonomy is needed to:
  - Prioritize reduced data for downlink
    - classifier results for activity planning support
    - compressed subsets for ground selection of full data
    - raw subsets for evaluation
  - Perform classification and compression
    - manage storage given expected downlink schedule
  - Generate higher-level products for on-board use
    - e.g. flight path from optical odometry
    - feed forward to autonomous control processes (steering, landing)

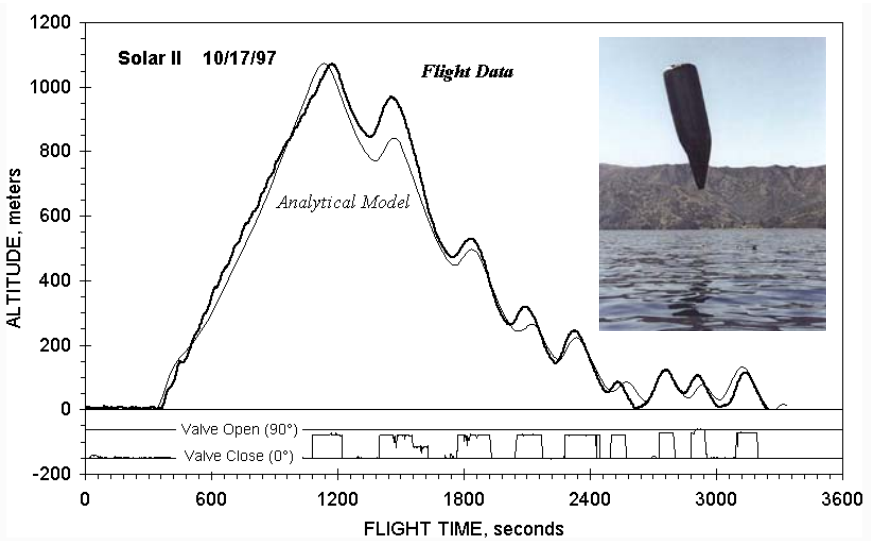
Topics

- Science
- Operational Scenario
- Mission Architecture
- Aerial Vehicle
- Summary

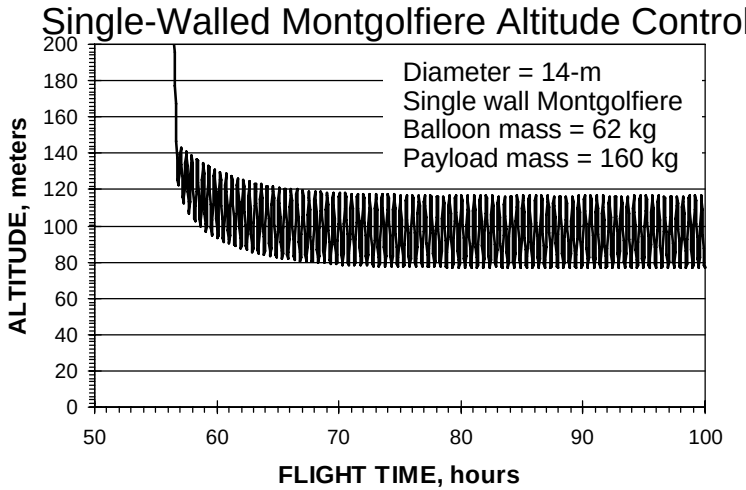
Titan RPS Montgolfiere System

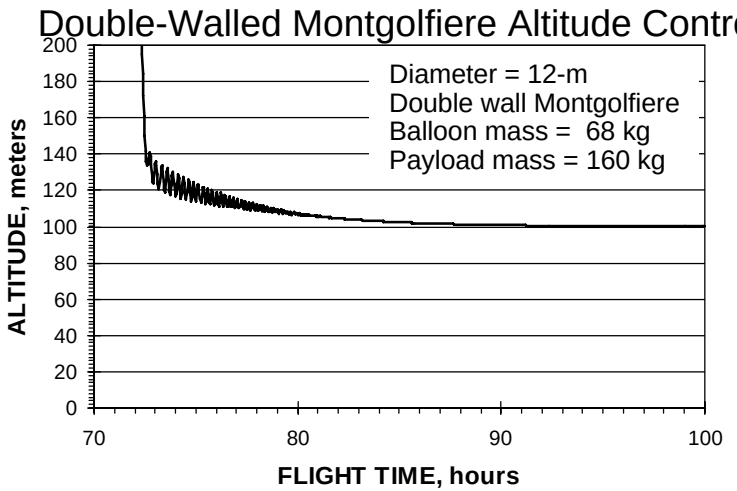


- Extreme conditions of Titan's atmosphere provide equivalent buoyancy using 100 times less power than would be required on Earth
  - 2000 W available from single MMRTG is more than sufficient to support 160 kg payload (gondola+instruments)
- Numerous low altitude tests have confirmed Montgolfiere altitude control with an upper vent

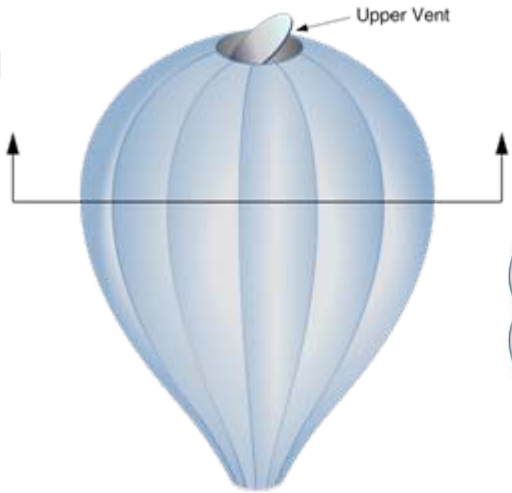


Titan Montgolfiere Thermal Analyses

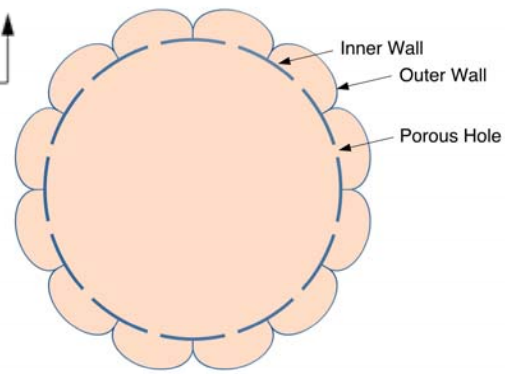




- Both single-walled and double-walled RPS Montgolfieres can function well on Titan.
- Double-walled Montgolfieres can hold tighter altitude control and can be smaller (12-m vs. 14-m diameter)
- Double-walled Montgolfieres can safely ascend and descend at speeds of 1 km/hr. This corresponds to a 15 degree hazard avoidance angle with surface winds ~1 m/sec

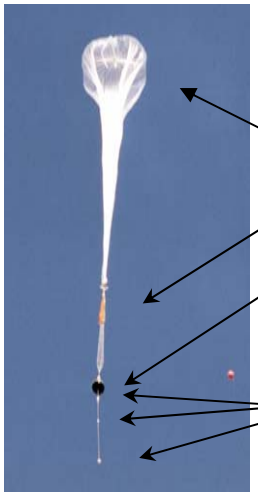


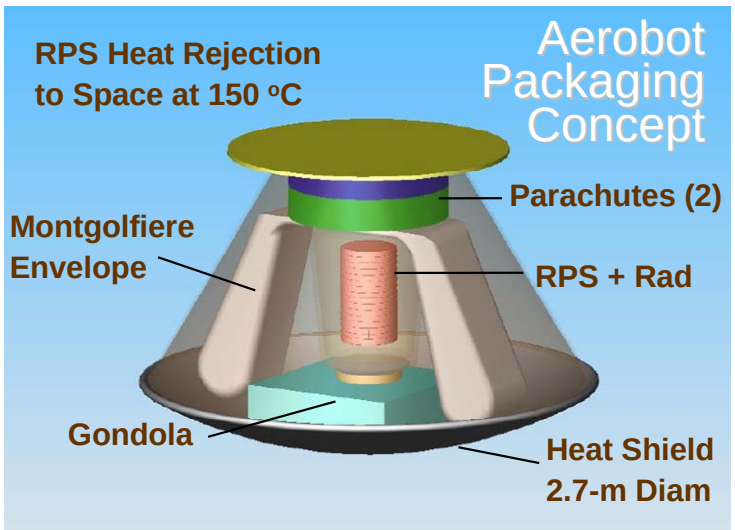
Montgolfiere Front View



Montgolfiere Mid-Cross-Section View

Titan Montgolfiere Packaging and Deployment





- **Many dozens of low-altitude nylon and polyethylene Montgolfiere deployments (diameter ~5-m) were made in 1997-1998**
  - ***All deployments were successful***
- **For high altitude deployments (36-km, 0.006 bar) that simulate Mars, 3 of 4 polyethylene balloon (10 to 15-m) tests succeeded, and larger balloon deployments are in progress**
  - **The fully-reinforced, double-walled, thick (60-micron) Montgolfieres planned for Titan are over 100 times stronger than the Mars Montgolfieres, since Titan's thick atmosphere can support much heavier and stronger materials.**
  - **The Titan Montgolfieres will be deployed at ten times slower speeds (5 m/sec) than for Mars, thus greatly reducing deployment stresses.**
- **Balloon materials have been fabricated and successfully tested at cryogenic temperatures found at Titan**

Topics

- Science
- Operational Scenario
- Mission Architecture
- Aerial Vehicle
- Summary

Summary

- Titan exploration starts with and leverages directly from Cassini Huygens results
- Aerial platforms are ideally suited for the Titan environment and can achieve Key Science Objectives
- Winds at cruise altitude and below are easily navigable
- An adaptive exploration strategy makes use of variations in the wind profiles for flight path control and is robust to uncertainties
- The mission concept is achievable with further maturation of current technologies to flight readiness. No new inventions required!

The next step is for NASA to initiate pre-Phase A studies