Balloon Concepts for Titan

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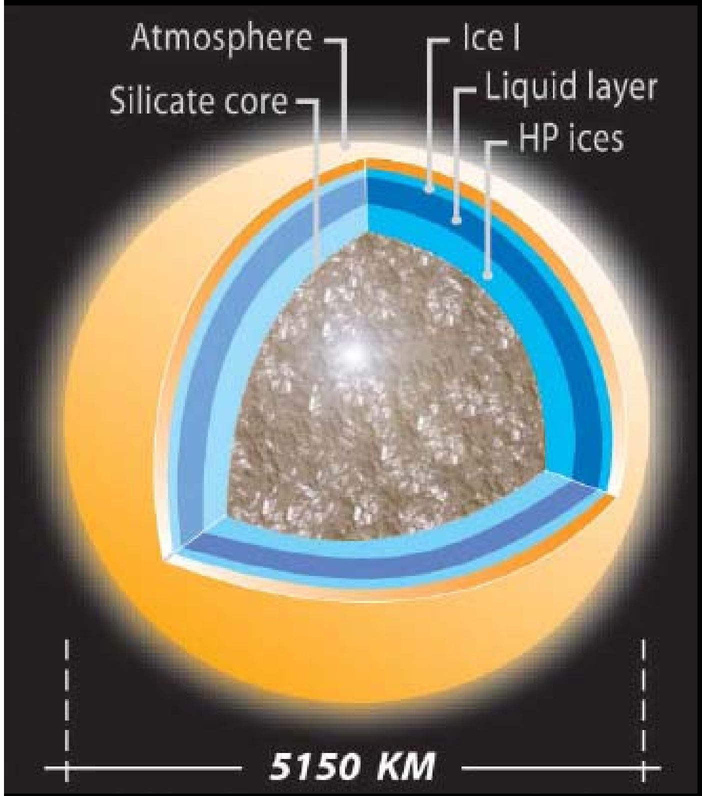
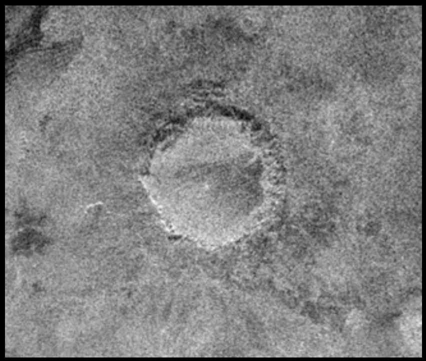
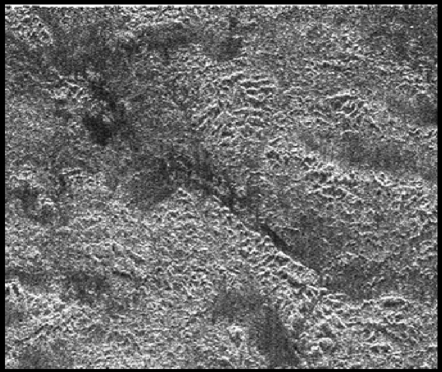
Titan is the 2nd-largest satellite in the solar system, larger than planet Mercury and is unique in having a thick nitrogen atmosphere. Like other large icy satellites, it likely has a silicate core and a layer of liquid water (preserved by ammonia acting as an antifreeze) a few tens of km beneath its *organic-rich* icy surface which has been modified by impact, tectonics and cryovolcanism.



Model of Titan's Interior



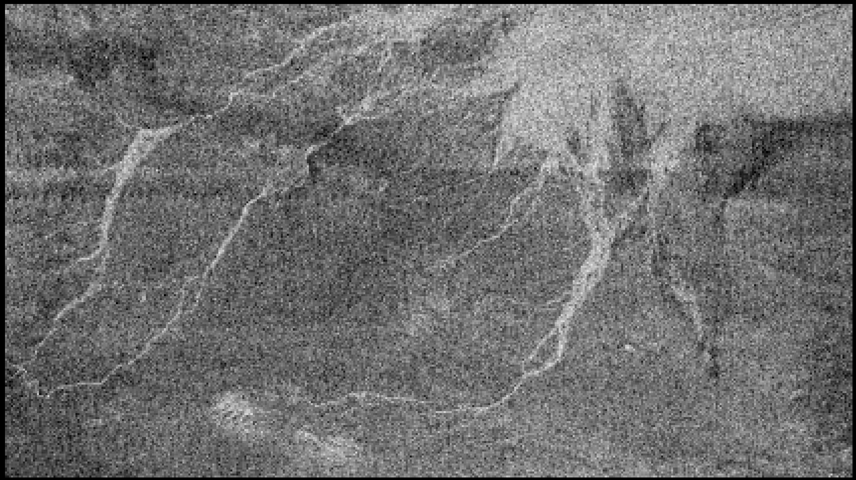


Cassini RADAR images of impact crater and tectonic mountains

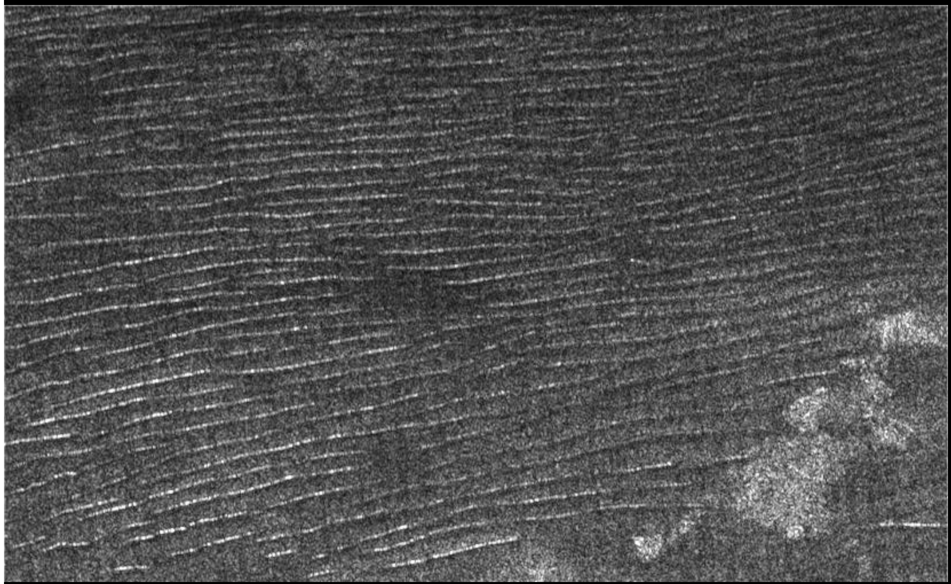
Cassini VIMS (Near-IR) maps show a spectrally-diverse surface

Titan’s Landscape is being actively modified by Earth-like processes, forming sand dunes, river channels and lakes

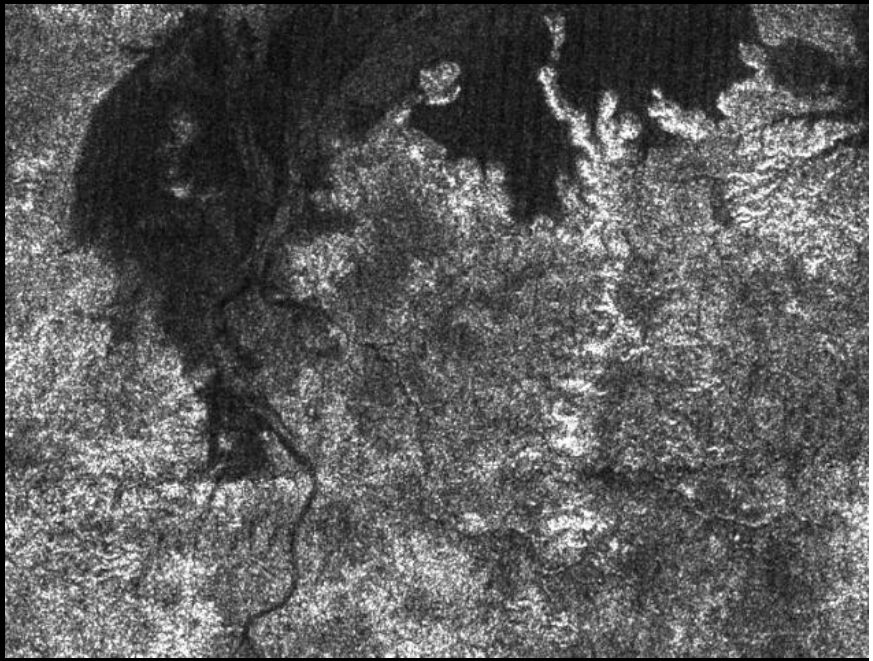
Huygens probe mosaic from 8km altitude



(dry) river channels at midlatitudes

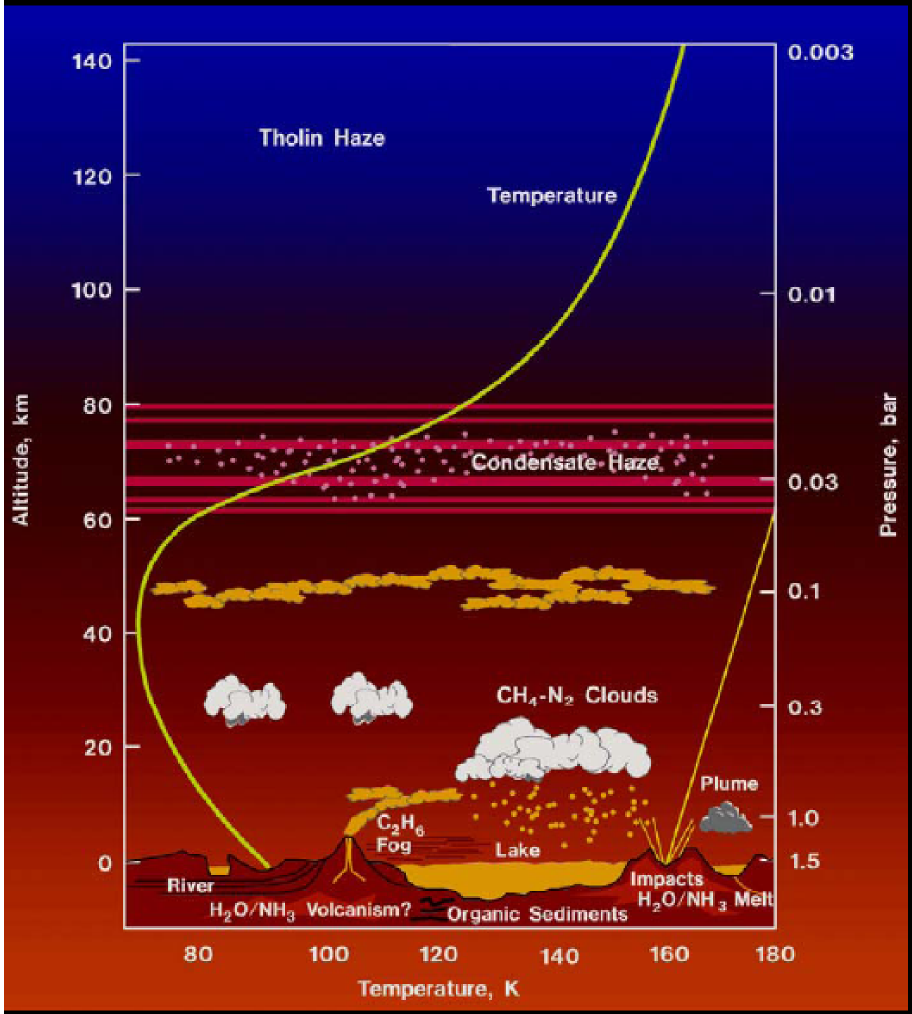


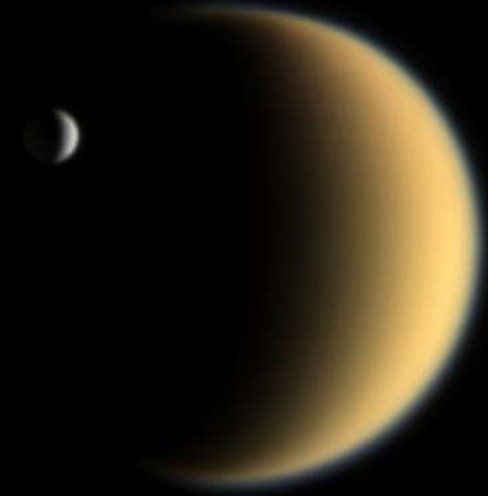
Giant organic sand dunes, 10’s km long, 150m high, near Titan’s Equator (Cassini RADAR)

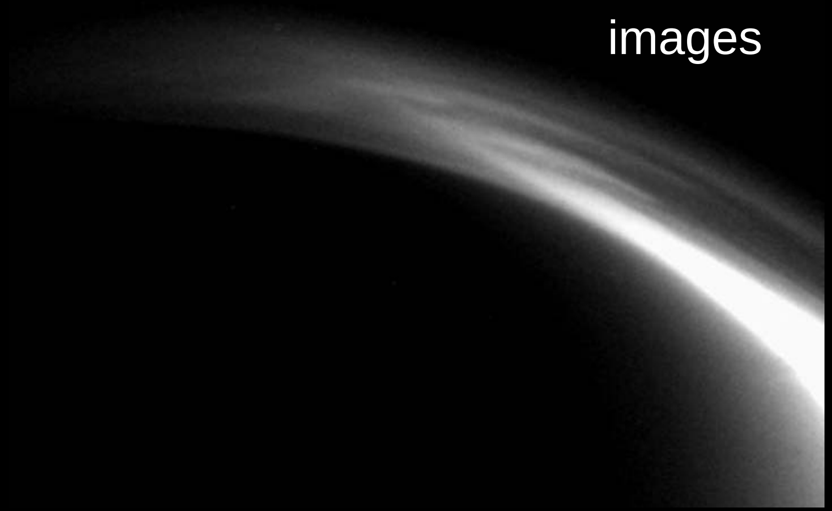


Lake and river channel near North pole

Titan’s Atmosphere has a very similar structure to (but colder than) Earth’s. Sea-level air density is 4x higher. Atmosphere has a thick organic haze showing seasonal changes and complex layers.

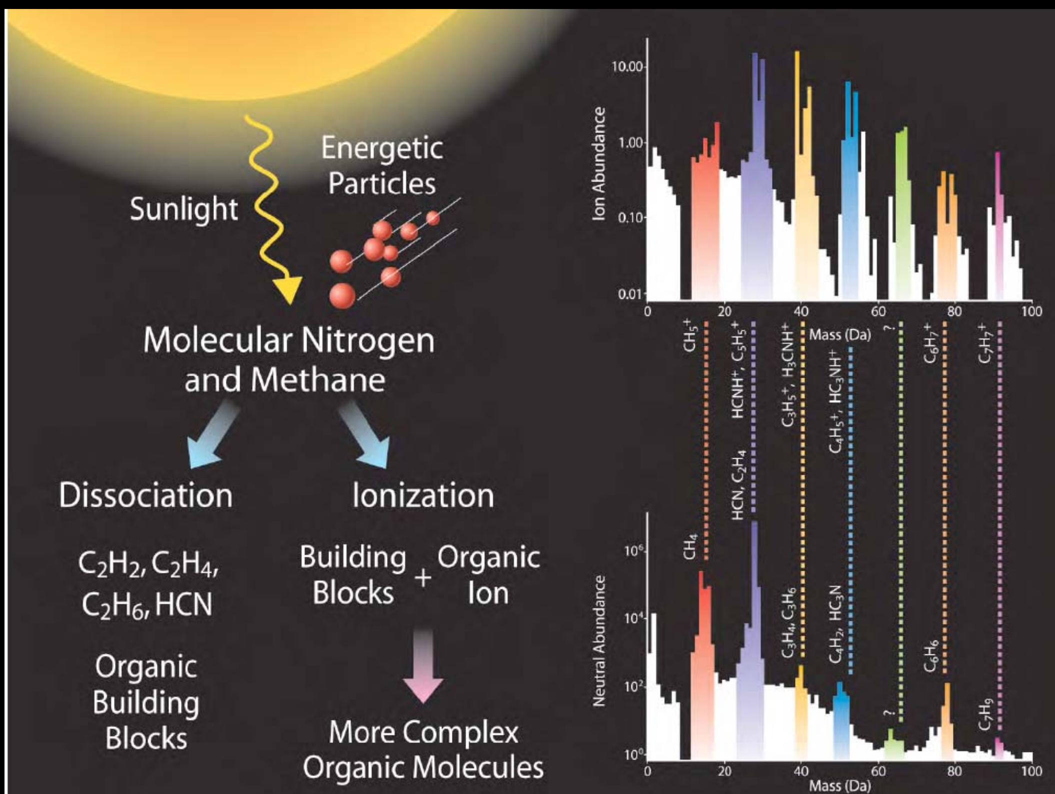




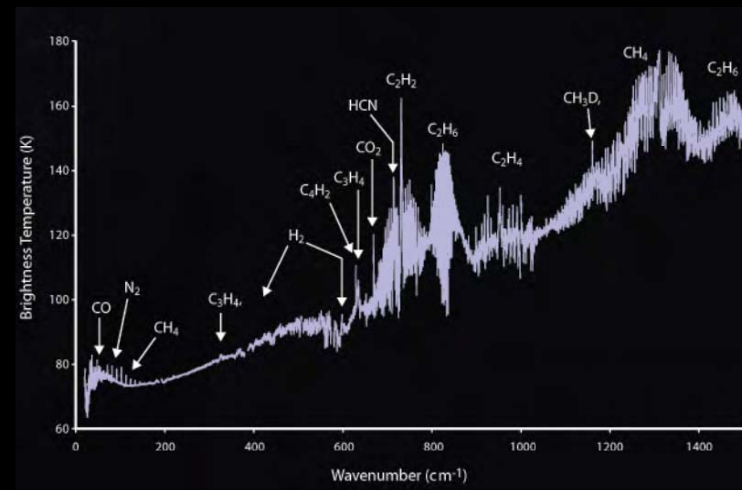


Cassini ISS images

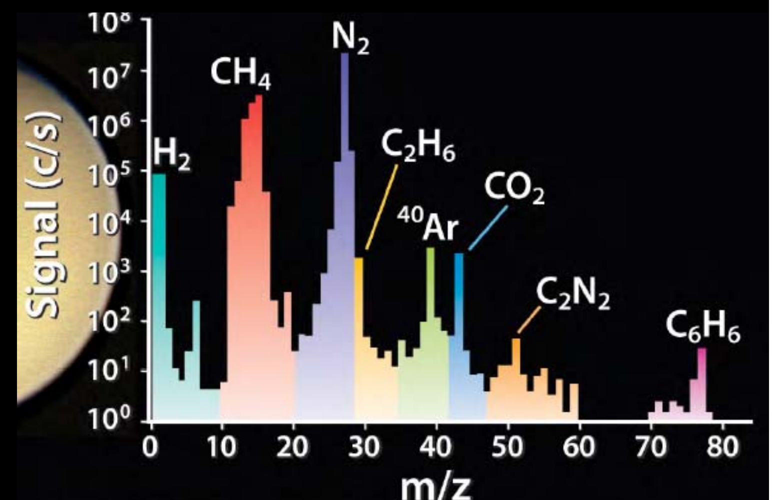
Titan has a very rich organic chemistry - composition varies with latitude and season. Dozens of compounds are produced high in the atmosphere (Benzene detected above 1000km altitude!) and slowly sediment out onto the surface, forming ethane lakes and organic dunes. Surface interaction with transient liquid water (cryovolcanism, impact melt) may produce yet more exotic prebiotic material (amino acids).



Ion and Neutral Chemistry observed at orbital altitudes by Cassini INMS



Infrared Spectrum (Cassini CIRS) shows gas composition at stratospheric altitudes



Measurement of surface composition by Huygens Probe Gas Chromatograph-Mass Spectrometer

The Titan Environment

Gravity = 1.35 ms^{-2} (vs 9.81ms^{-2} on Earth : T/E=1/7)

No direct performance impact for lighter-than-air (buoyancy/weight effects cancel)

Reduces convective heat transfer from hot air balloon

Decreases terminal velocity (longer response time)

Reduces power and lift requirements for heavier-than-air.

Air Density = 5.3 kgm^{-3} (vs 1.25ms^{-2} on Earth : T/E=4)

Reduces power and lift requirements for heavier-than-air

Reduces balloon volume requirement

Temperature = 94 K (vs 288K on Earth : T/E ~3)

Vastly reduces heating requirement (power per ΔT and buoyancy ~ $\Delta T/T$)

Reduces viscosity slightly (improved Reynolds number) for heavier-than-air

Titan is a great place to fly!

A Titan Aerobot Menu

R. D. Lorenz 2/18/07

PASTA	PASsive TitAn balloon	Few kg. Helium. Released from descent probe or lander. No power, instrumentation or communication. Tracked via foil radar reflector or passive transponder (RFID) Could use condensible gas for altitude regulation.
ZORBA	ZOnal Recon BAlloon	~50kg. One RPS (~100W). Montgolfiere or buoyant gas. Omnidirectional comm (DTE and relay) Payload ~5kg : USO for groundbased tracking. Simple camera system. Altimeter. Meteorology (Sky brightness, Pressure, Temperature, Methane humidity) Minimal (no?) commanding.
TABI	TitAn Balloon Investigation	~100kg Montgolfiere. Active altitude control. 1-2 RPS 30kg payload? Camera system, ground-penetrating radar. Aerosol collector and analysis laboratory. Meteorology.
TABASCO	TitAn BAlloon Survey and Collection of Organics	Similar to 2005/6 JPL 'TiPEX' study ~200kg floating mass 2 RPS double-wall Montgolfiere. Active altitude control Steerable antenna for data relay Tether/penetrator sample acquisition system and organic analysis laboratory. IR spectrometer, camera system, gound penetrating radar, meteorology, etc.
TALE	Titan Airship Latitude Excursion	Similar to 2005 JPL and Langley Visions studies. Buoyant gas airship with propulsion giving capability to traverse to different latitudes. 2 RPS. Steerable antenna for data relay Tether/penetrator sample acquisition system and organic analysis laboratory. IR spectrometer, camera system, gound penetrating radar, meteorology, etc.

Helium Balloon at Titan

Advantages

Helium or hydrogen offer much higher lift / volume than hot air.

Envelope can be much smaller. Inflation probably more straightforward.

Light gas balloons are the only effective way of attaining high altitudes (e.g. 80kg payload at 60km altitude requires 13m dia balloon 202kg float mass ; 296kg delivered mass)*

Disadvantages

-For low altitudes especially, helium mass required is not small (dominates over envelope mass). Situation is exacerbated by tankage required for gas. (e.g. 80kg payload at 8km requires 4.2m balloon ; float mass 127kg ; delivered mass 191kg)*

- While low temperatures will lead to slower diffusion, helium balloon is ultimately doomed by loss of gas via diffusion and/or leaks

- No possibility of commandable altitude control (some limit-cycling by condensible fluid could be achieved)

* 0.1 kgm^{-2} envelope. 2kg/kg Tankage

Hot Air Balloon at Titan

Terrestrial hot air balloons limited by envelope temperature : thermal power available from burners is ample, operated at low duty cycle.

Titan balloon is power-limited. An interesting theoretical situation – it turns out in an idealized analysis with thin-wall balloon (no insulation effect) that for a given thermal power etc. a maximum payload mass exists. (The maximum occurs when envelope mass equals payload mass – any increase in balloon diameter just means a heavier balloon).

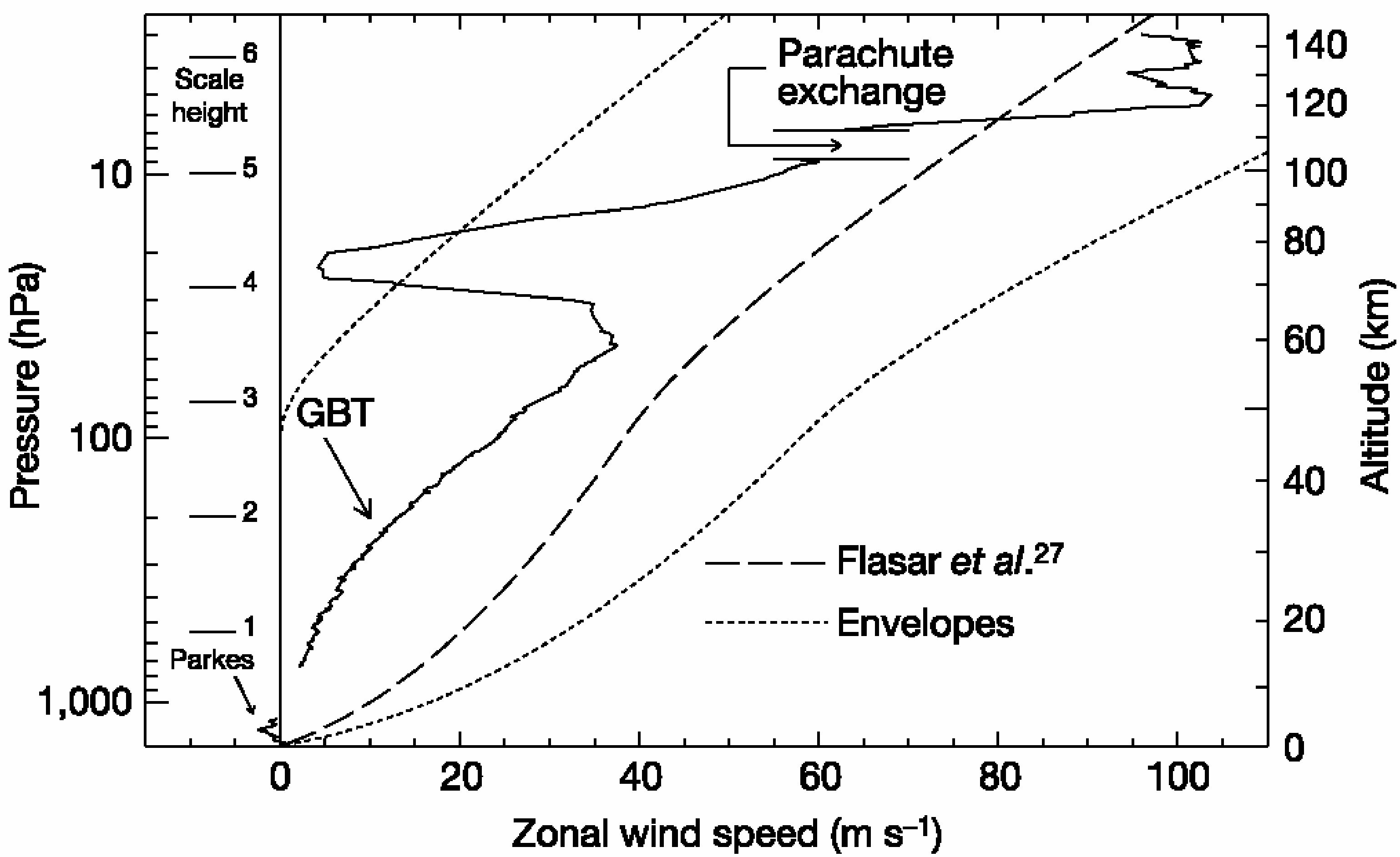
For one MMRTG (2kWth) absolute maximum payload at 8km is 195kg, 23m dia.*

However, we derate substantially to have robust margins (e.g. terrestrial experience is that ~25% of heat supplied is lost at vent, more if manoeuvring. Real balloons have ~20% more area than if they were actually spherical, etc.)

e.g. 80kg payload at 8km with 1.5kW requires a 9m+ balloon, ΔT~5K. Delivered mass ~110kg. With 10.5m balloon it would still float (at ~1km) with 1.2kW.

NB Theoretical analysis shows payload mass varies as inverse of envelope specific area A, but inverse square of heat transfer coefficient h. Worth it to spend 4x envelope specific area to halve the heat transfer (e.g. insulate part of envelope, double wall envelope etc.)

* h=1 Wm^{-2}. A=0.1 kg^{-2}.



Huygens Doppler WInd Experiment (Bird et al., Nature, 2005

showed zonal winds to be somewhat weaker than expected, with a slightly surprising reversal near the surface. Also somewhat unexpected was a layer of strong wind shear, with winds falling to near zero at about 80km altitude.

TABI/ZORBA Operations and Science Scenario

~150kg payload/balloon/deployment system in ~2m entry shell. Entry on dayside/trailing side (minimizes entry velocity ; allows direct monitoring from Earth)

At M~1.5 deploy parachute or ballute for stabilization. Descent from ~150km to lower troposphere takes ~3hrs.

Low data rate (~10bps?) Direct-to-Earth health and descent data, real-time doppler and VLBI tracking, via omnidirectional UHF or S-band.

Attains steady-state operation at ~8km.

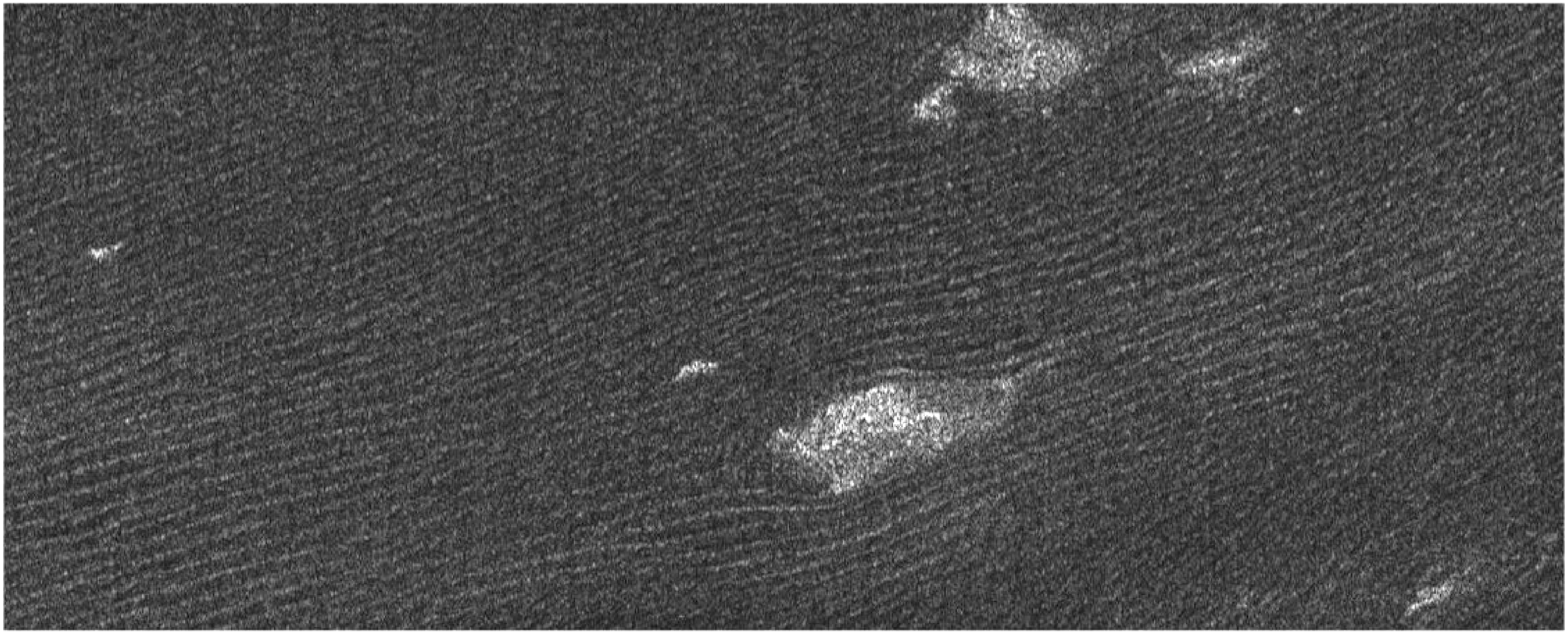
Huygens zonal winds at 6-8km are <2 m/s. (cf equatorial rotation speed of ~11 m/s) Several days operation possible before balloon rotates out of sight of Earth.

Balloon operates on nightside, storing profiling data. DTE/tracking link is always-on. Orbiter interrogates balloon on overflights.

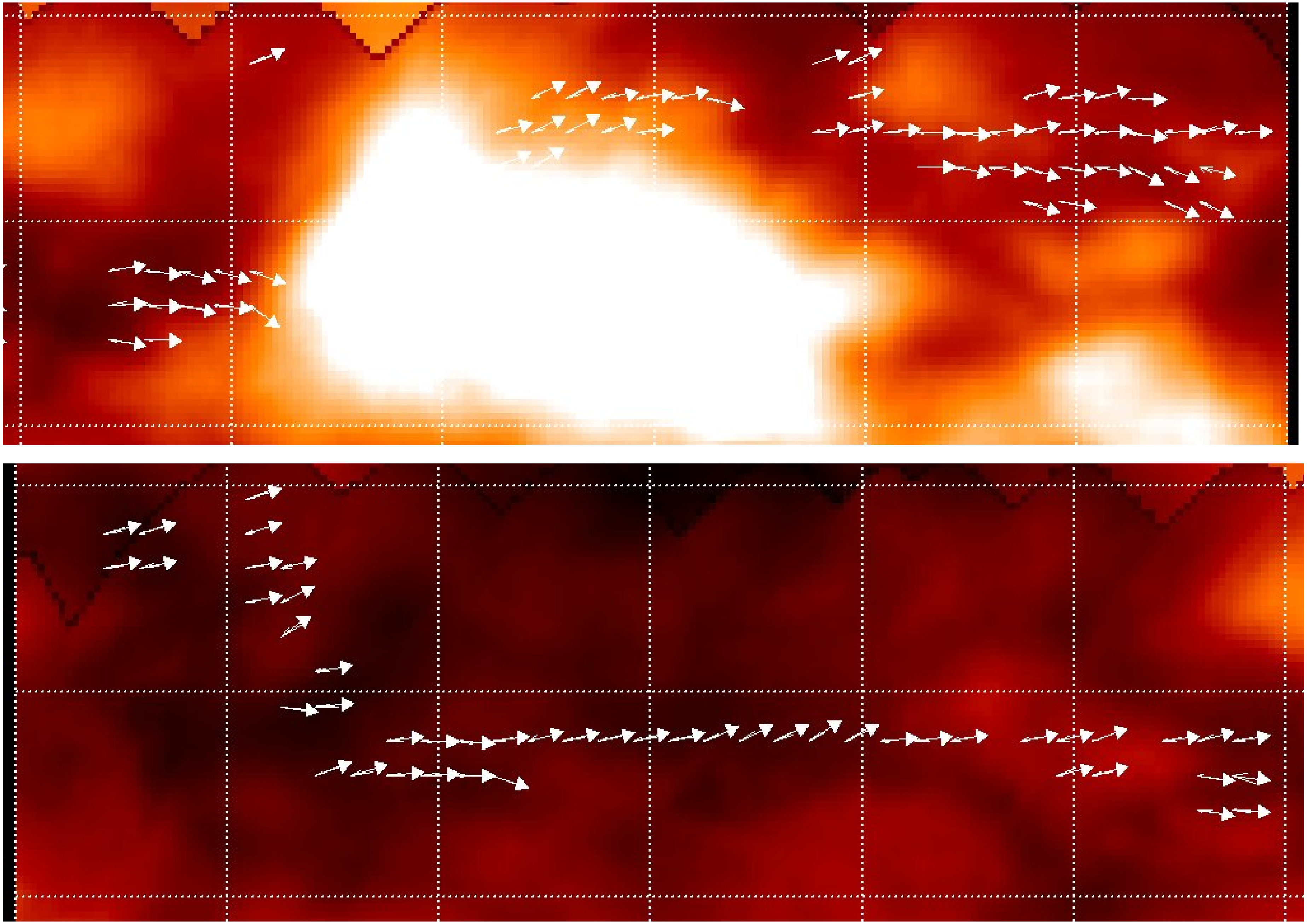
After >1 month nominal operation, begin experimental adjustment of heat supply to make dips to lower or higher altitude on transient then progressive basis.

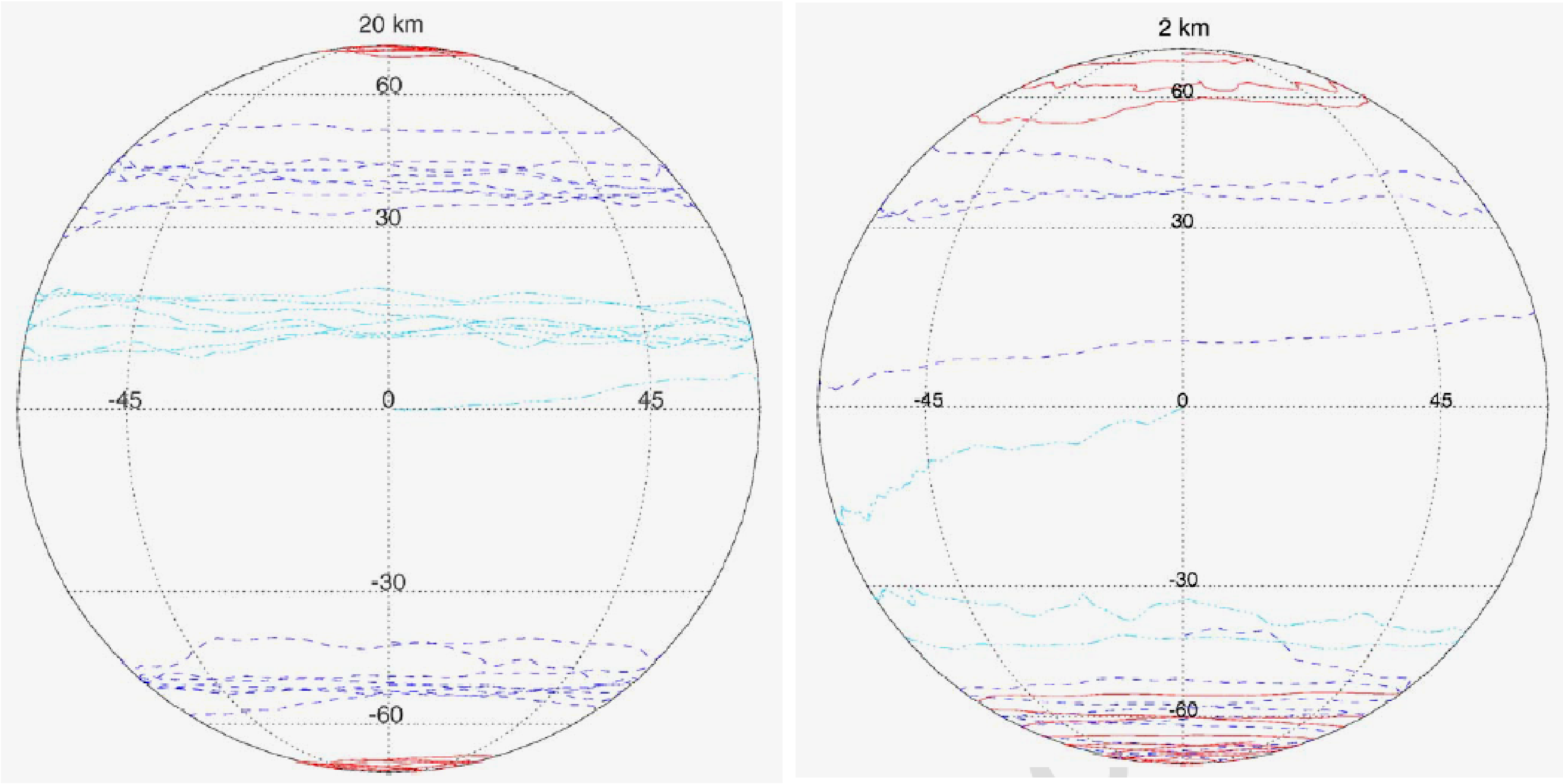
In 1 yr will see ~25 day/night cycles and DTE comm/tracking opportunities – circumnavigates twice at 30^{o} lat/1ms^{-1} wind.

Dunes ‘flow’ around hills - longitudinal dunes allow winds to be traced out



Dune Orientations reveal global wind pattern

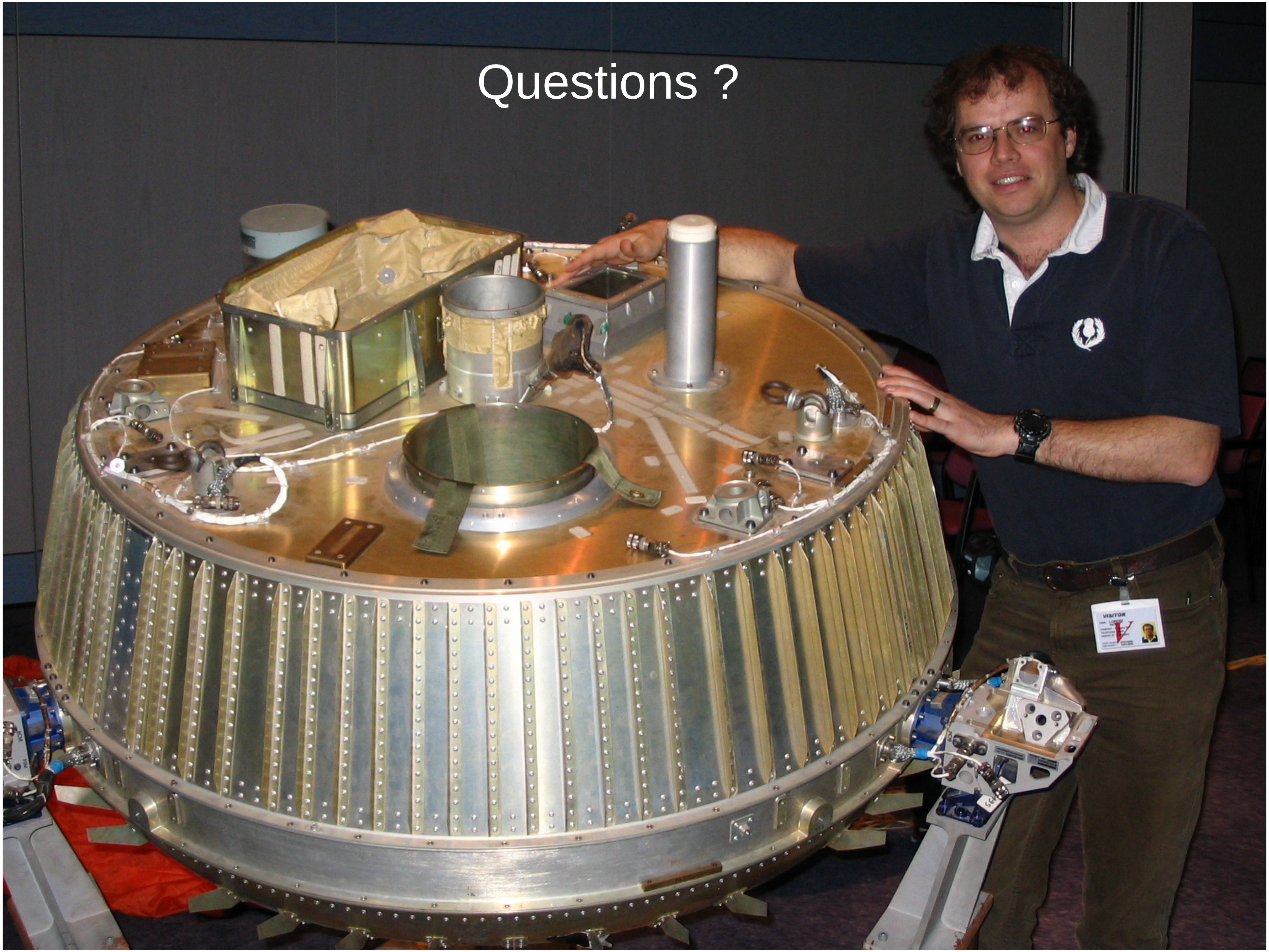




Because the tidal wind introduces a significant periodic meridional component to the wind, balloons do not drift just E-W, but sail across a band of latitudes.

Tokano and Lorenz, GCM Simulation of Balloon Trajectories on Titan, *Planetary and Space Science*, **54, 685-694, 2006.**

Questions ?



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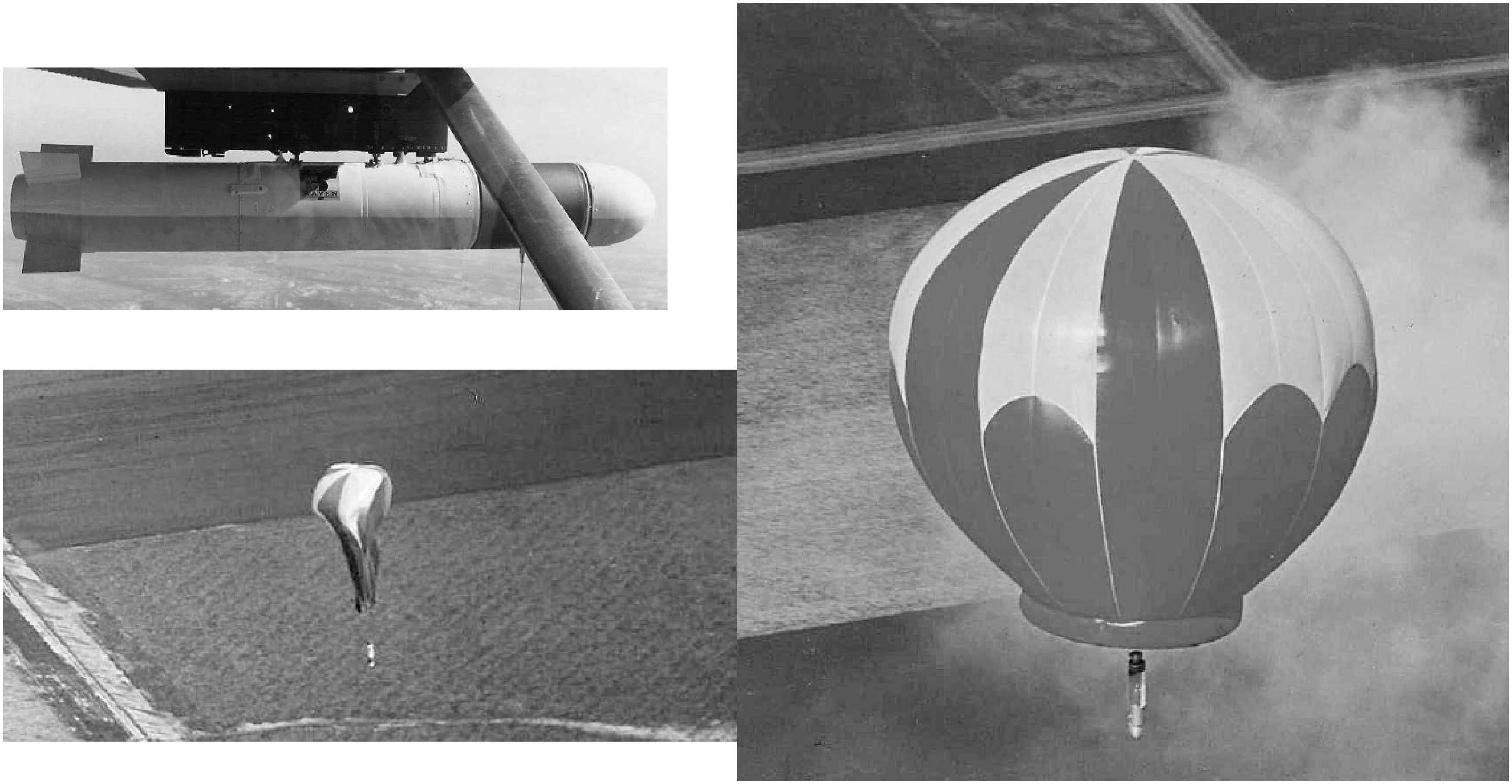

Airborne jamming pod – deployed in canister from aircraft, inflating in mid-air, heated by pyrotechnic charge and in level float.

Images from J. Nott, Ballutes- Launching Aerobots without Compromises, 4th International Planetary Probe Workshop, Pasadena, CA. August 2006

(Photo credit: Rekwin Archive)

Hot air balloons are damage-tolerant.

Envelopes usually rated for 600 hours flight time (i.e. ~100 inflation/packing cycles.) Rating is at 125^{o}C – sealant degrades less quickly at lower temperatures. (Graceful degradation – damaged envelope just requires more fuel to fly – retirement of envelope usually an economics rather than safety consideration)

Continued Airworthiness Requirements allow ½ -inch holes in upper part of envelope to be repaired at annual inspection. 3/4-inch holes require repair before next flight. Holes in lowest 10 feet are permitted to remain unrepaired.

Titan balloon need be inflated only once (plus a few times for ground testing) and can be warm when this is done. Balloon fabric will operate at ~110K at Titan.

No UV degradation of fabric to worry about at Titan.