CASSINI HUYGENS

HUYGENS PROBE (TITAN-C) MISSION DESCRIPTION

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Jet Propulsion Laboratory
California Institute of Technology

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1.0 OVERVIEW

The Cassini-Huygens program is a joint NASA/ESA mission to study Saturn, its rings, environment, origins, and satellites – particularly the largest, Titan. The Cassini spacecraft is a complex JPL/NASA-built orbiter, which has carried with it the Huygens spacecraft, an ESA-built Titan atmospheric probe. This document describes the Titan probe mission which is to occur on the third targeted flyby of Titan, and covers not only the Huygens descent to Titan, but both the Huygens and Cassini activities which support and lead up to the probe descent itself.

The third targeted flyby of Titan occurs on Friday, January 14th, 2005 at 11:12 SCET (4:19 am Pacific time). The Cassini orbiter's closest approach to Saturn's largest satellite is at an altitude of 60,000 km (37,300 miles) above the surface at a speed of 5.4 kilometers per second (12,100 mph). Titan has a diameter of 5150 km (3200 miles), so the spacecraft passes to within 23 Titan radii.

This encounter is set up with more than the usual maneuvers. However, chief among them are the Probe Targeting maneuver (Orbit Trim Maneuver or OTM #8) on December 17th (Dec. 16th Pacific Time) which places the combined probe and orbiter on the proper impacting trajectory to deliver the probe to its landing site, and the Orbiter Deflection Maneuver (OTM #10) on December 28th (Dec. 27th Pacific time) which returns the orbiter to the proper flyby trajectory after the probe has been released.

Titan C is Cassini's fourth targeted satellite encounter. The first was Phoebe, on June 11 th, at an altitude of 2000 km. The second was Titan-A at an altitude of 1174 km on October 26th, and Titan-B at am altitude of 1200 km on December 13th.

For some time, up until several years ago, the Huygens Probe mission was to take place on the first targeted flyby of Titan. However, the receivers in the Huygens Probe support equipment on board the Cassini spacecraft exhibited unexpected performance under the conditions expected during the nominal Probe mission. Simply put, the receivers would not be able to track the probe's signal fully as its frequency varied during the original flyby. This anomaly would lead to unacceptable data losses during the Probe descent to Titan.

This problem was addressed by redesigning the orbiter trajectory, turning two orbits into three and in the process adding a more distant Titan flyby as the third encounter of the mission. (The old Titan flybys #1 and #2 on like orbits #1 and #2 were replaced with three flybys, Ta, Tb, and Tc, and three like orbits, A, B, and C.) A more distant flyby means a slower change in geometry during the probe descent, reduced Doppler shift of the probe signal, and therefore better tracking and data collection. With this redesign, the project expects to acquire all data transmitted by the probe during its descent. This strategy also provides better knowledge of Titan's orbit and its atmosphere since the orbiter will have encountered Titan on two close flybys before delivering the Huygens Probe.

As with Saturn Orbit Insertion, Probe Relay is a critical sequence (the last of the nominal mission). All possible efforts are made both on the ground and on board the orbiter to successfully acquire the probe data and prevent interference from all but the most serious anomalies. Both redundant flight and attitude control computers are operating and the probe data is dually recorded.

1.1 ABOUT TITAN

Titan is one of the primary scientific interests of the Cassini-Huygens mission. Through observations by Earth based telescopes and the Voyager spacecraft, Titan has been revealed to be an intriguing world both similar in nature to Earth and unique among both satellites and terrestrial planets. The largest of Saturn's satellites, Titan is larger than the planets Mercury or Pluto. Titan is the only satellite in the solar system with an appreciable atmosphere. Like Earth's atmosphere, Titan's atmosphere is composed mostly of Nitrogen, yet appears to have few clouds. However, it also contains significant quantities of aerosols and organic compounds (hydrocarbons), including methane and ethane. Although Titan's thick smoggy atmosphere masks its surface, scientists have speculated Titan's surface could contain solid, liquid and muddy material creating features such as lakes, seas, or rivers. Additionally liquid reservoirs may exist beneath the surface forming geysers or volcanoes that feed flowing liquid onto the surface.

Titan's peak surface temperature is about 95 Kelvins, too cold for liquid water, and due to its thick atmosphere, the pressure at the surface is 1.6 times greater than Earth's atmosphere. At this temperature and pressure, chemicals such as methane, ethane, propane, ammonia, water-ice and acetylene may be involved in complex interior-surface-atmosphere chemical cycles resulting in eruptions, condensation and precipation (or rain). Initial observations obtained by Cassini during the first two passes of Titan provided our first close up views of Titan in wavelengths ranging from visible light to infrared to radar. The results show a mysterious world even more complex than previously thought. The status of liquids on the surface is still unclear and the diversity of surface composition and its connection to Titan's geologic features remains a fundamental question. Clouds in Titan's atmosphere were observed in the southern hemisphere, yet no clear explanation has emerged on what the clouds are composed of, or why more clouds do not exist. Observations of Titan's interaction with Saturn's magnetosphere indicates the presence of complex processes complicated by Titan's occasional emergence out of Saturn's magnetosphere into the solar wind.

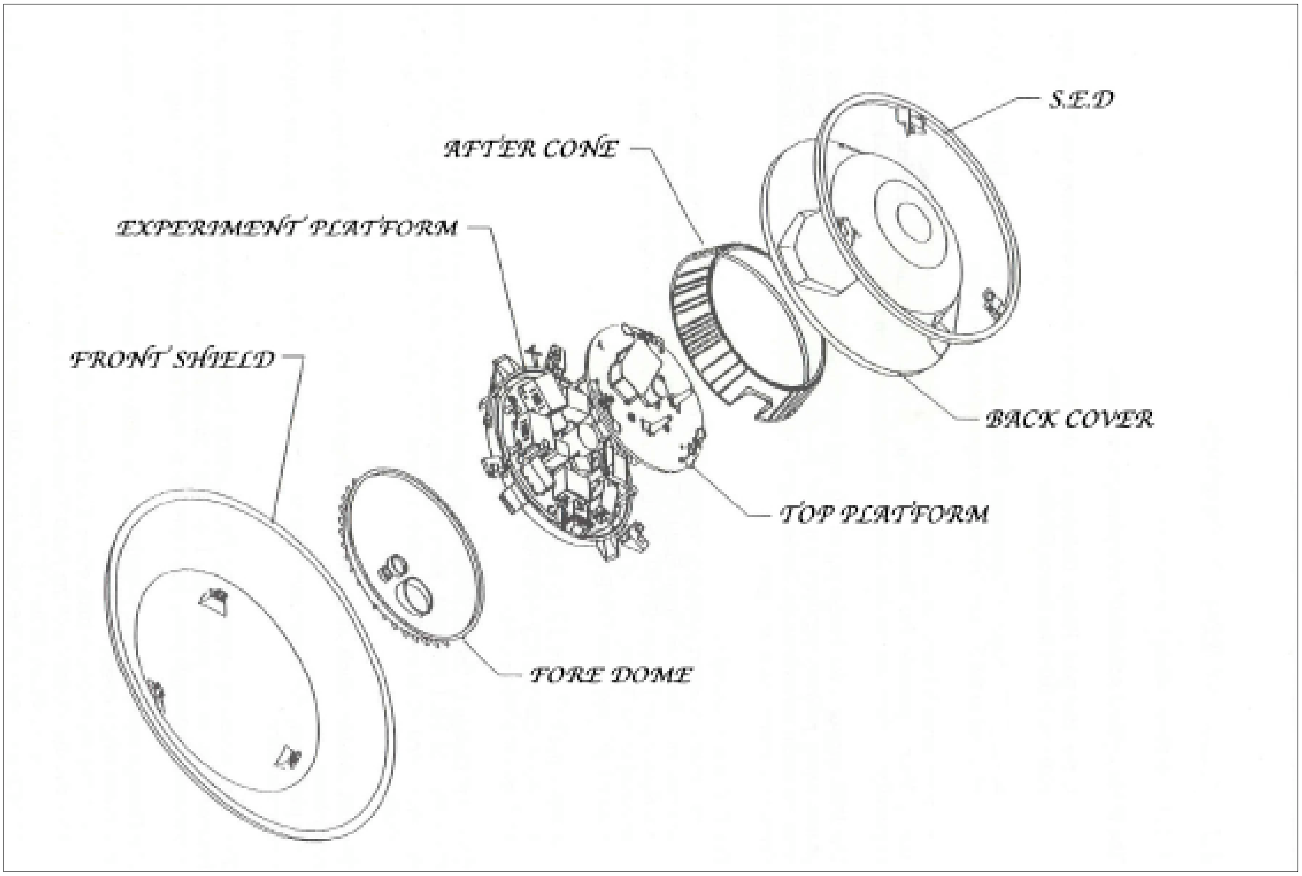
2.0 THE HUYGENS PROBE

The Probe System consists of two elements: the Huygens Probe itself, which enters the Titan atmosphere; and the Probe Support Equipment (PSE) consisting of those parts of the System which remain attached to the Orbiter in support of the Probe Mission.

The atmospheric entry components serve to release the probe from the orbiter, and protect the probe during its cruise phase and subsequent entry into the Titan atmosphere. The Spin-Eject device propels the Probe – via tension-loaded springs –away from the Orbiter with a relative velocity of 0.3 to 0.4 m/s and imparts to it a spin about its axis of greater than 5 rpm. The front shield, 2.7m in diameter, covered with a special thermal protection material, protected the Probe from direct sunlight during its journey to Saturn, and will diffuse the enormous heat flux generated during entry. The aft cover is also covered in thermal protection materials to reflect away the heat radiated from the hot wake of the Probe.

Once the Probe has decelerated to about Mach 1.5, the aft cover is pulled off by a 2.6 meter diameter pilot chute. An 8.3 meter diameter main parachute is then deployed to ensure a slow and stable descent. The main parachute slows the probe and allows the heat shield to fall away when it is released. To limit the duration of the descent to a maximum of 2.5 hours, the main parachute is jettisoned and replaced by a 3.0 m diameter drogue chute for the remainder of the descent.

The inner structure of the Probe consists of two aluminum honeycomb platforms and an aluminum shell. It is linked by fiberglass struts and pyrotechnically operated release mechanisms to the front shield and aft cover. The central equipment platform carries, on both its upper and lower surfaces, the boxes containing the electrical subsystems and the experiments. The upper platform carries the parachute (when stowed) and the antennas for communication to the orbiter.

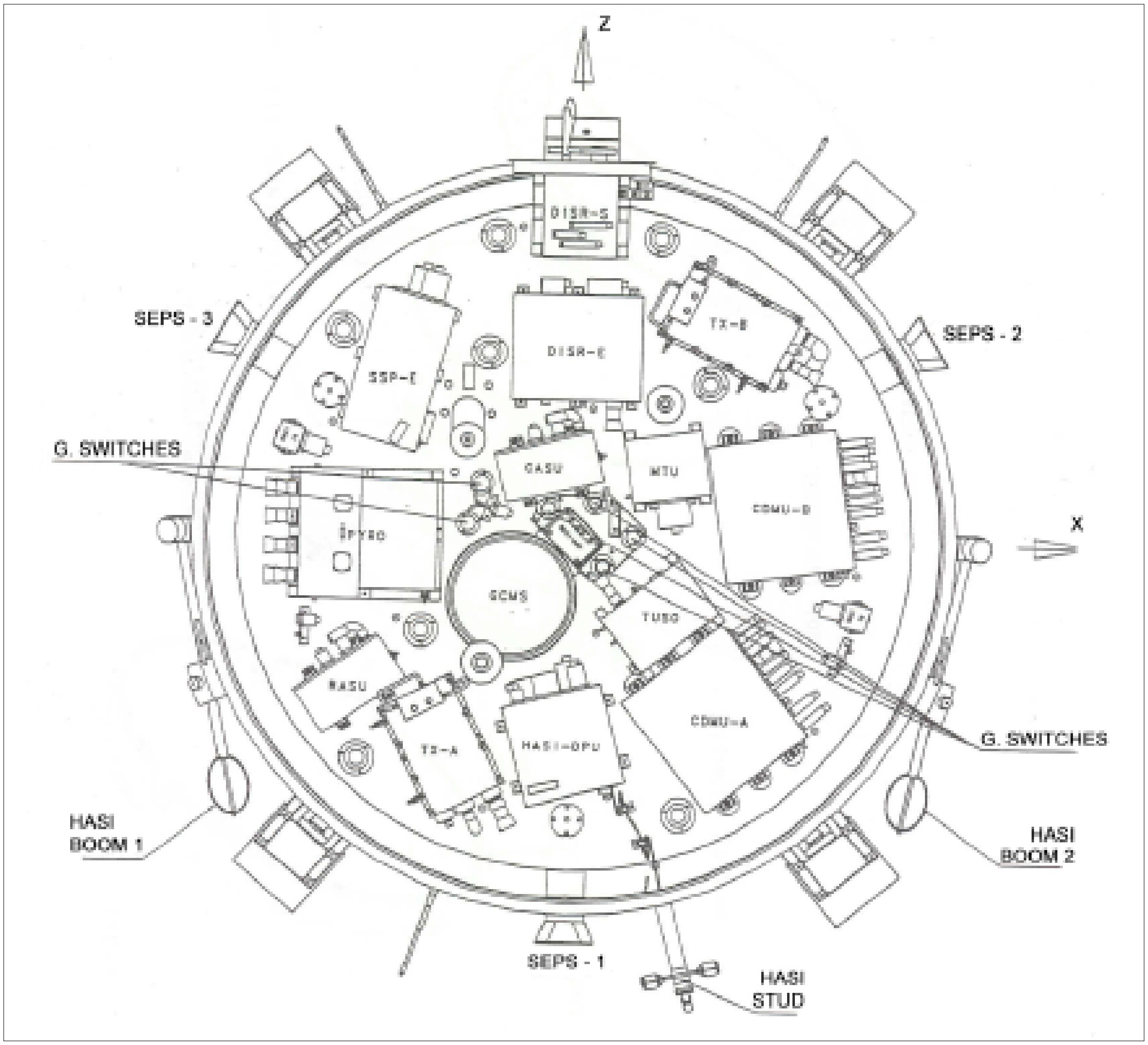


To ensure that none of the equipment falls below its storage-temperature limit the probe carries 35 Radioisotope Heater Units, each generating 1 W. During entry the front shield may reach temperatures above 1500 C. Layers of insulation will ensure that the equipment inside stays below 50 C. Once the chute is deployed, the Probe instruments will be exposed to the cold Titan atmosphere at temperatures as low as 70K. The internal temperature will be kept within operating limits by thick foam insulation filling the Probe and by power dissipation in the experiments and subsystems.

While on the orbiter, the probe obtains power via an umbilical cable connected to the orbiter's power systems. For all operations after separation, five lithium sulfur dioxide batteries, each with 26 cells, will be used. Their storage degradation during the long cruise will be compensated by depassivation (taking the surface charge off the active surfaces) during the pre-separation reconfiguration. Part of the battery power is used to power the timer for the coast period. The higher current needed for Probe mission operations is only necessary for the descent duration of 2.5 hours.

The Huygens Probe also carries its own command and data management subsystem. This computer contains a timer during the coast phase which, when finished, switches on the probe just prior to entry. The computer also controls the activation of deployment mechanisms during descent, distributes commands to the subsystems and experiments, and collect scientific and housekeeping data for forwarding to the orbiter, either via the umbilical cable while attached to the orbiter, or via the transmitters during descent.

The Probe Data Relay Subsystem provides the one-way communications link between the Probe and the Orbiter and includes equipment installed in each part of the spacecraft. For redundancy, the Probe carries two S-band transmitters, both transmitting during Probe descent, each with its own antenna. The telemetry in one link is delayed by about six seconds with respect to the other to avoid data loss if there are brief transmission outages.



2.1 HUYGENS PROBE INSTRUMENTATION

The Huygens probe instruments and their science objectives are as follows.

Aerosol Collector Pyrolyzer (ACP)

The ACP is designed to perform in-situ study of clouds and aerosols in the Titan atmosphere. Aerosol particles in the atmosphere will be drawn by a pump through filters to trap samples which are heated in ovens to vaporize volatiles and decompose the complex organic materials. The products will then be flushed along a pipe to the GCMS for analysis as described above. Samples will be taken down to 40km and again between 18-23km. The ACP is designed to:

1) Determine the chemical makeup of the photochemical aerosol.
2) Obtain the relative abundance of condensed organics in a column average throughout the stratosphere. Compare with the abundance of constituent molecules in the aerosol nucleation sites.
3) Obtain the relative abundance of condensed organics in a column averaged over the upper troposphere. Compare with the abundance of constituent molecules in the aerosol nucleation sites.

Descent Imager and Spectral Radiometer (DISR)

The DISR is designed to measure aerosol and cloud optical properties and to perform spectroscopy measurements of Titan's atmosphere and surface. This instrument will make a range of imaging and spectral observations using several sensors and fields of view. By measuring the upward and downward flux of radiation, the radiative balance (or imbalance) of the thick Titan atmosphere will be deduced. Solar aureole sensors will measure the light intensity around the sun due to scattering by aerosols in the atmosphere. This will permit the calculation of the size and number density of the suspended particles. Two imagers (one visible, one infrared) will observe the surface during the latter stages of the descent and, as the Probe slowly spins, build up a mosaic of pictures around the landing site. There is also a side-looking visible imager looking horizontally to view the horizon and the underside of the cloud deck. For spectral measurements of the surface, the weak sunlight will be augmented by a lamp shortly before landing. The DISR is designed to:

1) Measure the solar heating rate's vertical profile.
2) Measure distribution and properties of aerosol and cloud particles.
3) Determine the surface's physical state (solid or liquid) near the impact site, and determine its fraction in each state.
4) Determine the composition of the atmosphere.

The characteristics of the imagers are as follows. The high-rsolution imager is a 160x256 pixel CCD at 0.06° per pixel, with a field of view of 10° (horizontally) by 15° (vertically) and is the most downward-looking camera between 7-22° from nadir (straight down). The medium resolution imager is 176x256 pixels at 0.12° per pixel, with a field of view of 21° (horizontally) by 31° (vertically). This camera looks off at an angle from straight down, at 16-46° from nadir. The side-looking imager is 128x256 pixels at 0.2° per pixel, with a field of view of 26° (horizontally) by 51° (vertically), and looks essentially at the horizon at 45-96° from nadir.

Doppler Wind Experiment (DWE)

The DWE is designed to study winds from the effect it has on the Probe during Titan descent. This experiment will use an ultra stable oscillator to give the Probe relay link a very stable carrier frequency. The Doppler shift calculated from the frequency measured at the Orbiter will be a measure of the Probe motion from which the component of the wind along the line of sight can be calculated. The DWE is designed to:

1) Determining height profile of the wind velocity by measuring drift motions due to winds.
2) Measurement of Doppler fluctuations to determine the level and spectral index of turbulence and possible wave activity in Titan's atmosphere.
3) Measurement of Doppler and signal level modulation to monitor Probe descent dynamics, including its rotation rate and phase, parachute swing and post-impact status.

Gas Chromatograph and Mass Spectrometer (GCMS)

The GCMS is designed to perform in-situ measurement of the chemical composition of gases and aerosols in Titan's atmosphere. This gas analyzer will identify and quantify the abundances of the various atmospheric constituents, as well as measure the surface composition in the event of a safe landing. A mass spectrometer will construct a spectrum of the molecular masses of the gas driven into the instrument by the dynamic pressure of the Probe's descent. A more powerful separation of molecular and isotopic species will be accomplished by a chromatography column. Surface material investigation will be made possible by heating the GCMS inlets just prior to impact to vaporize the material on contact. During descent the GCMS will also analyze pyrolysis products passed to it from the ACP (see below). The GCMS is designed to:

1) Determine atmospheric composition of Titan including argon, isotopes and organic compounds.
2) Characterize conditions near the ground, especially to search for evidence of the vapor phases of possible surface condensates.
3) Surface Science
    a) If Huygens lands in a liquid: Mass spectra of evaporating liquid showing the relative abundance of nitrogen, ethane, methane, argon and other noble gases, simple hydrocarbons, nitriles and oxides.
    b) If Huygens lands in a deposit of aerosols: Determine the level of chemical complexity achieved by chemical synthesis in the atmosphere, as even rare aerosols may accumulate in measurable concentrations on the surface.
    c) If Huygens lands on exposed ice: Measurement of H_2O ice 'bedrock' and search for condensed CO_2.

Huygens Atmospheric Structure Instrument (HASI)

The HASI is designed to perform in-situ study of Titan atmospheric physical and electrical properties. Accelerometers will measure forces in all three axes so that, knowing the aerodynamic properties of the Probe, the atmospheric density can be deduced and wind gusts detected. In the event of a landing on a liquid surface the Probe motion due to waves will be measurable. Temperature and pressure sensors will enable the construction of a profile of the thermal structure of the atmosphere. The Permittivity and Electromagnetic Wave Analyzer will measure the ion and electron conductivities of the atmosphere and search for electromagnetic wave activity. On the surface, the conductivity and permittivity of the surface material will be measured. The HASI is designed to:

1) Determine the density, pressure, and temperature conditions of the atmosphere's higher regions during entry.
2) Measure the stratospheric density, temperature and pressure profiles during the descent phase; identify the trace constituents that condense in this part of the atmosphere.
3) Measure the temperature and pressure conditions in the lower troposphere and determine the existence and the extent of a convective zone.
4) Determine the nature of the surface.
5) Determine atmospheric electrical conductivity and investigate ionization processes, wave electric fields and atmospheric lightning.
6) Determine the surface's large-scale and small-scale topography and the surface's dielectric properties to distinguish, in particular, between a liquid and a solid surface before impact.

Surface Science Package (SSP)

The SSP is designed to measure the physical properties of Titan's surface and related atmospheric properties. An acoustic sounder, activated during the last kilometer of the descent, will determine continuously the distance to the surface from about 100m in altitude, measuring the rate of descent and the surface roughness (e.g. due to waves). On the (liquid) surface, the sounder will measure the speed of sound in the ocean, and possibly also the subsurface structure (depth). During descent, measurements of the speed of sound will give information on atmospheric composition and temperature. An accelerometer will accurately record the deceleration profile at impact, indicating the hardness and structure of the surface. A tilt sensor will indicate the Probe attitude after landing and will show any attitude motion due to waves. It will also measure any pendulum motion during descent. If the surface is liquid, other sensors will measure its density, temperature, refractive index, thermal conductivity, heat capacity and electrical permittivity. The SSP is designed to:

1) Determine the physical nature and condition of Titan's surface at the landing site.
2) Determine the abundance of major ocean constituents, placing bounds on atmospheric and ocean evolution.
3) Measure the thermal, optical, acoustic and electrical properties and density of any ocean, providing data to validate physical and chemical models.
4) Determine wave properties and ocean/atmospheric interactions.
5) Provide ground truth for interpreting the large-scale Orbiter Radar Mapper and other experimental data.

3.0 HUYGENS TIMELINE OF ACTIVITIES

There are many dozens of individual activities which comprise the full timeline of Huygens Probe activities; only the most visible and well-known are highlighted here.

Final Checkout & Depassivation

The final Probe Checkout (F16) takes place on November 23rd 2004. This further checkout data will be assessed by the Huygens operations team and industry to determine the optimal configuration of the probe and whether to proceed with the primary mission opportunity. These decisions are made at the Go/NoGo for Primary Mission on December 2nd 2004.

Depassivation 2 takes place on December 5th (the first is earlier, on Sep 19th). A 95-Watt load is applied to the six batteries to ensure the passivating layer on the electrodes has been broken, and the health of the batteries is assessed.

Orbiter Sequence S07 and Critical Sequence

Cassini's background sequence S07 begins on December 16th, and contains the bulk of the critical probe activities, including release and descent. Because of the numerous sequencing activities, the background sequence has been divided into three sections (A, B, and C) and also contains mini-sequences covering some of the major activities. A chart illustrating this can be found in the appendix.

At the beginning of S07, the Solid State Recorders (SSRs) are set to the configuration used to record data during probe descent almost one month later. The first two telemetry partitions (#4 and 5) will each be sized with enough capacity for the probe mission plus approximately a 15% buffer. The third telemetry partition (#6) continues to store real-time engineering data as usual.

The probe relay critical sequence is uplinked separately from the background sequence S07 on December 18th and 19th. Either day alone should be sufficient to uplink all necessary commands.

Huygens Probe Mission Overview - 2004-5

Colors: yellow = maneuvers; blue = geometric events; green = sequencing; red = Probe-related

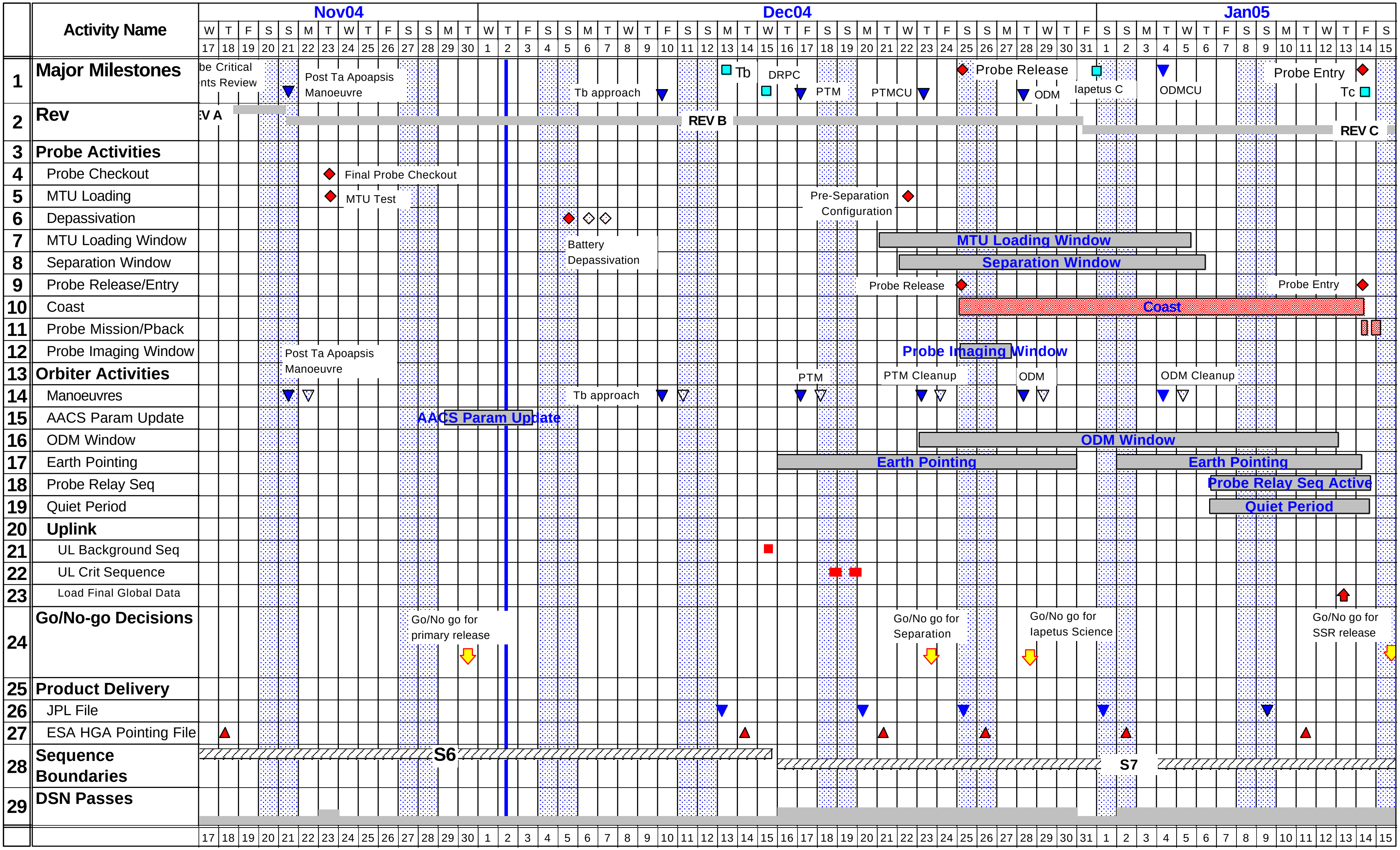
Orbiter UTC = time event takes place at the spacecraft; Ground UTC = time event is seen at Earth, a one-way light time later

Orbiter UTC	Ground UTC	Pacific Time	Time wrt Entry	Activity	Description
326T08:36	Nov 21 09:47	Sun Nov 21 01:47 AM	Entry-54d00h	Saturn apoapsis, start of orbit B	Distance = 78 Saturn radii
328T05:00	Nov 23 06:10	Mon Nov 22 10:10 PM	Entry-52d04h	Final Probe checkout, Mission Timer Unit test	Instruments are muted, orbiter on thruster control
337T19:51	Dec 02 21:00	Thu Dec 02 01:00 PM	Entry-42d13h	Go/no-go decision for primary mission	Time approximate
340T05:30	Dec 05 06:39	Sat Dec 04 10:39 PM	Entry-40d04h	Battery depassivation #2	95W load applied to batteries to ensure passivating layer on electrodes has been broken; 40 minute sequence
344T21:06	Dec 09 22:15	Thu Dec 09 02:15 PM	Entry-35d12h	OTM #7 (CANCELLED)	Titan-B flyby targeting maneuver
348T11:38	Dec 13 12:46	Mon Dec 13 04:46 AM	Entry-31d21h	Titan-B flyby	Inbound 1192 km flyby at 6.0 km/s, 99 deg phase
348T14:53	Dec 13 16:01	Mon Dec 13 08:01 AM	Entry-31d18h	Ascending ring-plane crossing	Distance = 18.9 Saturn radii
349T15:52	Dec 14 17:00	Tue Dec 14 09:00 AM	Entry-30d17h	Project telecon on UV Titan-B results	To determine effects, if any, on probe mission
350T01:44	Dec 15 02:52	Tue Dec 14 06:52 PM	Entry-30d07h	Non-targeted Dione flyby	Inbound 72,500 km flyby at 5.3 km/s, 85 deg phase
350T05:01	Dec 15 06:09	Tue Dec 14 10:09 PM	Entry-30d04h	Non-targeted Mimas flyby	Inbound 107,500 km flyby at 1.6 km/s, 90 deg phase
350T05:53	Dec 15 07:01	Tue Dec 14 11:01 PM	Entry-30d03h	Saturn periapsis	Distance = 4.8 Saturn radii
350T11:05	Dec 15 12:13	Wed Dec 15 04:13 AM	Entry-29d22h	Descending ring-plane crossing	Distance = 5.8 Saturn radii
350T15:52	Dec 15 17:00	Wed Dec 15 09:00 AM	Entry-29d17h	Project telecon on UV Titan-B results	To determine effects, if any, on probe mission
351T13:22	Dec 16 14:30	Thu Dec 16 06:30 AM	Entry-28d20h	S07 background sequence A begins	Solid State Recorders repartitioned for Probe Relay
352T03:45	Dec 17 04:53	Thu Dec 16 08:53 PM	Entry-28d05h	Probe Targeting Maneuver (OTM #8)	ΔV = 16 m/s on main engine; targets orbiter and Probe to Probe entry target
353T18:00	Dec 18 19:08	Sat Dec 18 11:08 AM	Entry-26d15h	Uplink Probe relay critical sequence	Part 1
354T18:00	Dec 19 19:08	Sun Dec 19 11:08 AM	Entry-25d15h	Uplink Probe relay critical sequence	Part 2
356T05:30	Dec 21 06:38	Mon Dec 20 10:38 PM	Entry-24d04h	Load Probe Mission Timer Unit	MTU = the Probe's "clock" which counts down to entry; probe fully configured for separation
358T03:30	Dec 23 04:38	Wed Dec 22 08:38 PM	Entry-22d06h	Probe Targeting Maneuver cleanup (OTM #9)	
358T19:52	Dec 23 21:00	Thu Dec 23 01:00 PM	Entry-21d13h	Probe separation go/no-go	
360T00:00	Dec 25 01:08	Fri Dec 24 05:08 PM	Entry-20d09h	Probe release mini-sequence begins	
360T02:00	Dec 25 03:08	Fri Dec 24 07:08 PM	Entry-20d07h	Probe separation	Huygens Probe separates from orbiter; orbiter on thruster control
360T02:22	Dec 25 03:30	Fri Dec 24 07:30 PM	Entry-20d07h	Orbiter returns to Earth-point	Communication restored after probe separation
360T13:30	Dec 25 14:38	Sat Dec 25 06:38 AM	Entry-19d20h	Orbiter images probe	5x5 mosaic intended to capture probe ejection trajectory
361T20:00	Dec 26 21:08	Sun Dec 26 01:08 PM	Entry-18d13h	Probe receivers checked out	
363T03:00	Dec 28 04:07	Mon Dec 27 08:07 PM	Entry-17d06h	Orbiter Deflection Maneuver	ΔV = 24 m/s on main engine; retargets orbiter for 60,000 km flyby and relay
366T01:30	Dec 31 02:37	Thu Dec 30 06:37 PM	Entry-14d08h	Probe release mini-sequence ends; Iapetus mini-sequence begins	
366T07:03	Dec 31 08:10	Fri Dec 31 12:10 AM	Entry-14d02h	Saturn apoapsis, start of orbit C	Distance = 60 Saturn radii
001T01:37	Jan 01 02:44	Fri Dec 31 06:44 PM	Entry-13d07h	Iapetus flyby	117,500 km flyby at 2.0 km/s, 94 deg phase
002T04:38	Jan 02 05:45	Sat Jan 01 09:45 PM	Entry-12d04h	Iapetus mini-sequence ends	
004T03:00	Jan 04 04:07	Mon Jan 03 08:07 PM	Entry-10d06h	Orbiter deflection maneuver cleanup OTM #10A)	
006T11:53	Jan 06 13:00	Thu Jan 06 05:00 AM	Entry-07d21h	S07 background sequence A ends; spacecraft configured for Probe relay	All instruments off except MAG (on, muted), VIMS (sleep, muted)
007T09:00	Jan 07 10:07	Fri Jan 07 02:07 AM	Entry-07d00h	Probe relay critical sequence begins	8 day quiet period of minimal spacecraft activity before relay begins; orbiter on thruster control
014T06:38	Jan 14 07:45	Thu Jan 13 11:45 PM	Entry-02h28m	Transition to thruster control for relay	
014T07:02	Jan 14 08:09	Fri Jan 14 12:09 AM	Entry-02h04m	Turn orbiter to point to Titan	
014T09:06	Jan 14 10:13	Fri Jan 14 02:13 AM	Entry-00h00m	Probe reaches interface altitude	Entry altitude = 1270 km
014T09:11	Jan 14 10:18	Fri Jan 14 02:18 AM	Entry+00h05m	Probe begins transmission to orbiter	
014T11:12	Jan 14 12:19	Fri Jan 14 04:19 AM	Entry+02h06m	Titan-C flyby	Inbound 60,000 km flyby at 5.4 km/s, 93 deg phase
014T11:24	Jan 14 12:31	Fri Jan 14 04:31 AM	Entry+02h18m	Surface impact, end descent phase	Could vary ± 15 min depending on descent rate
014T13:37	Jan 14 14:44	Fri Jan 14 06:44 AM	Entry+04h31m	Orbiter stops collecting probe data	Total 4 hours and 36 minutes of data collection
014T13:47	Jan 14 14:54	Fri Jan 14 06:54 AM	Entry+04h41m	Turn orbiter to point to Earth	Turn completes at 13:50
014T13:59	Jan 14 15:06	Fri Jan 14 07:06 AM	Entry+04h53m	Critical sequence ends; S07 background sequence B begins	
014T14:00	Jan 14 15:07	Fri Jan 14 07:07 AM	Entry+04h54m	Post-Probe tracking begins	Canberra 70m station receiving; 10 minutes for DSN lockup allocated
014T16:57	Jan 14 18:04	Fri Jan 14 10:04 AM	Entry+07h51m	Ascending ring-plane crossing	Distance = 18.4 Saturn radii
015T12:23	Jan 15 13:30	Sat Jan 15 05:30 AM	Entry+01d03h	End nominal playback of Probe data	
015T17:17	Jan 15 18:24	Sat Jan 15 10:24 AM	Entry+01d08h	SOST mini-sequence #1 begins	
016T06:08	Jan 16 07:15	Sat Jan 15 11:15 PM	Entry+01d21h	Non-targeted Mimas flyby	Inbound 108,000 km flyby at 1.3 km/s, 100 deg phase
016T06:16	Jan 16 07:23	Sat Jan 15 11:23 PM	Entry+01d21h	Non-targeted Enceladus flyby	Inbound 189,000 km flyby at 10.2 km/s, 154 deg phase
016T06:26	Jan 16 07:33	Sat Jan 15 11:33 PM	Entry+01d21h	Saturn periapsis	Distance = 4.8 Saturn radii
016T09:20	Jan 16 10:27	Sun Jan 16 02:27 AM	Entry+02d00h	Titan-C cleanup maneuver (OTM #11)	
016T11:55	Jan 16 13:02	Sun Jan 16 05:02 AM	Entry+02d03h	Solid State Recorders reconfigured for nominal tour operations	Assuming Huygens Operations Team is satisfied with Probe playbacks
016T11:58	Jan 16 13:05	Sun Jan 16 05:05 AM	Entry+02d03h	Descending ring-plane crossing	Distance = 5.9 Saturn radii
016T12:20	Jan 16 13:27	Sun Jan 16 05:27 AM	Entry+02d03h	SOST mini-sequence #1 ends; #2 begins	
016T15:51	Jan 16 16:58	Sun Jan 16 08:58 AM	Entry+02d07h	Non-targeted Rhea flyby	Outbound 153,500 km flyby at 5.1 km/s, 64 deg phase
017T12:30	Jan 17 13:37	Mon Jan 17 05:37 AM	Entry+03d03h	S07 background sequence B and SOST mini-sequence #2 end; S07 background sequence C begins	

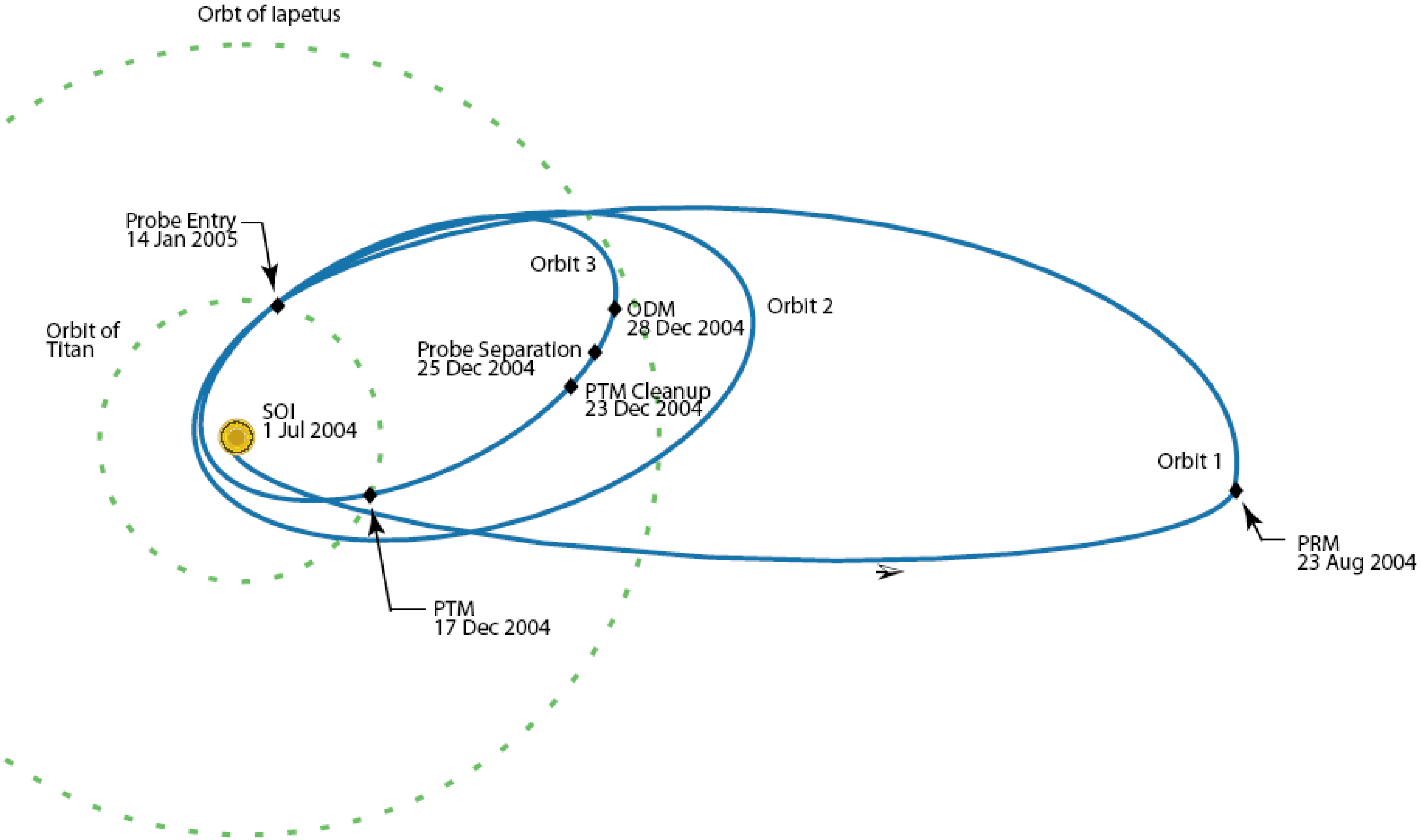
Version: 2004 Dec 14; exact dates/times may change

Preliminary Probe Mission Timeline

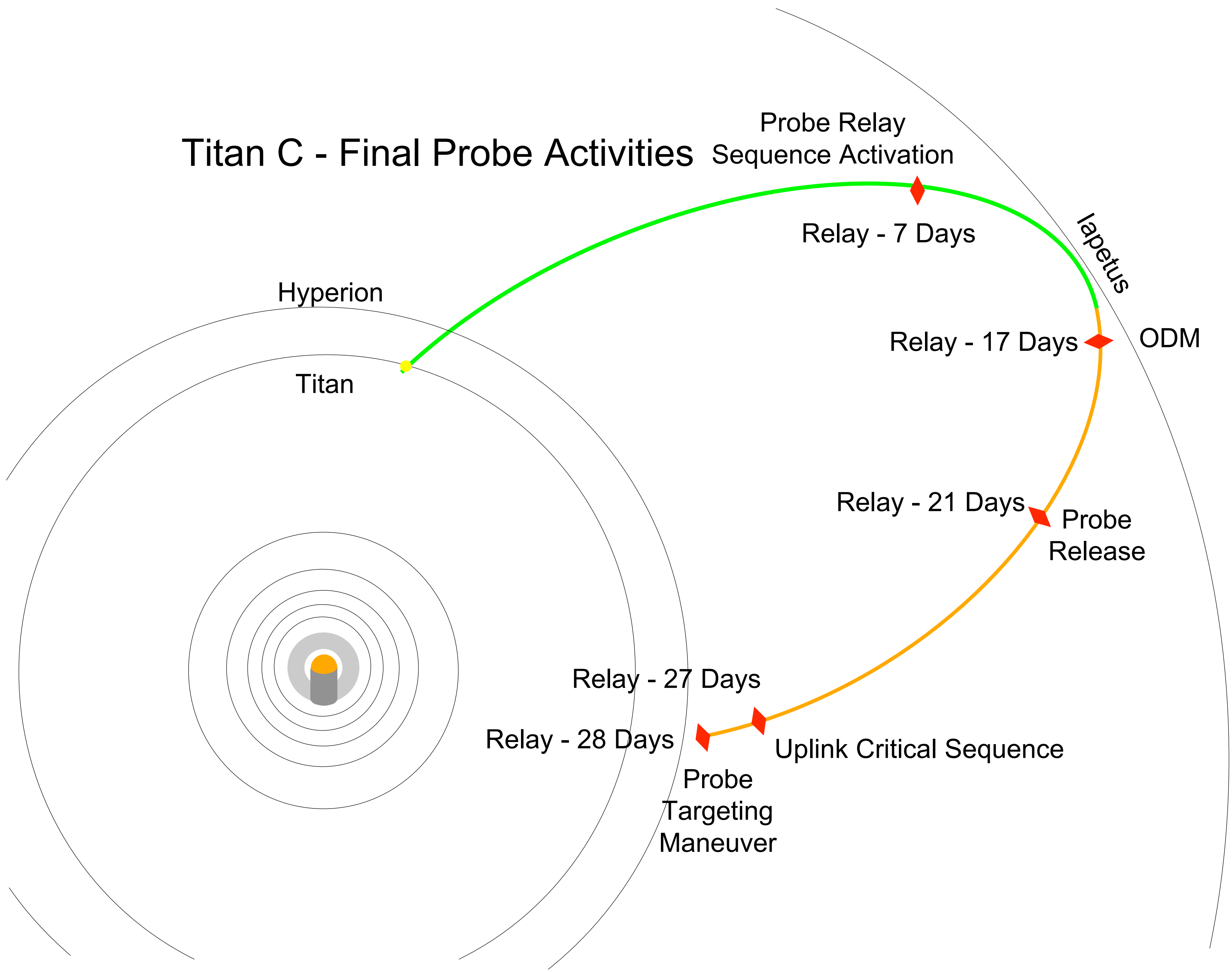
Issue: 5.9
2 Dec, 2004



Probe Mission Trajectory



Titan C - Final Probe Activities



Probe Targeting

The second Titan flyby Tb places the Cassini spacecraft on a trajectory which, uncorrected, flies by the next Titan encounter at an altitude of about 4,600 km. The maneuver required to achieve the desired interface conditions is computed using the tracking from the next two DSN tracking passes and four optical navigation images.

The Probe targeting maneuver is executed on December 17th (Dec. 16th Pacific time) and places the spacecraft on an impacting trajectory with Titan. A cleanup maneuver is executed six days later. Final commands to the probe are sent on December 21st to complete preparations for release, and this includes setting the Probe Mission Timer Unit (MTU) which is used to "wake up" the probe for descent.

Orbiter Targeting

The last two maneuvers of the Orbiter before Probe entry, the Orbiter Deflection Maneuver and cleanup, provide the orbiter with its targeting to the required aimpoint to achieve the radio relay link geometry. The Orbiter Deflection Maneuver (ODM) is executed three days after separation. This maneuver of about 24 m/s targets the Orbiter for the planned flyby of Titan at an altitude of 60,000 km and delays the Orbiter's closest approach to occur just over two hours after Probe entry. The relative position of the Orbiter with respect to Titan during probe entry and descent provides a view toward the Probe for approximately four and a half hours after entry.

MTU Loading

The probe's Mission Timer Unit (MTU) counts down the time until the probe should awaken for entry and can be loaded any time after December 21st 2004. MTU Loading is tied to the time the probe reaches the interface altitude of 1270 km above the surface of Titan. Currently, the MTU is scheduled to be set on-board on December 21st at 07:00 UTC (spacecraft time). This is nearly the earliest possible time the mission timer can be set; the maximum countdown duration is 24 days, 6 hours, and 32 minutes.

If the MTU is loaded, and the time of separation moves by several days, this will not significantly affect the time the probe reaches the Interface Altitude, and the MTU can be left to count down as originally loaded. Regardless of the exact probe separation, the Probe Targeting Maneuver cleanup maneuver(s) retarget to the precise entry corridor and interface time – so the countdown time will remain the same.

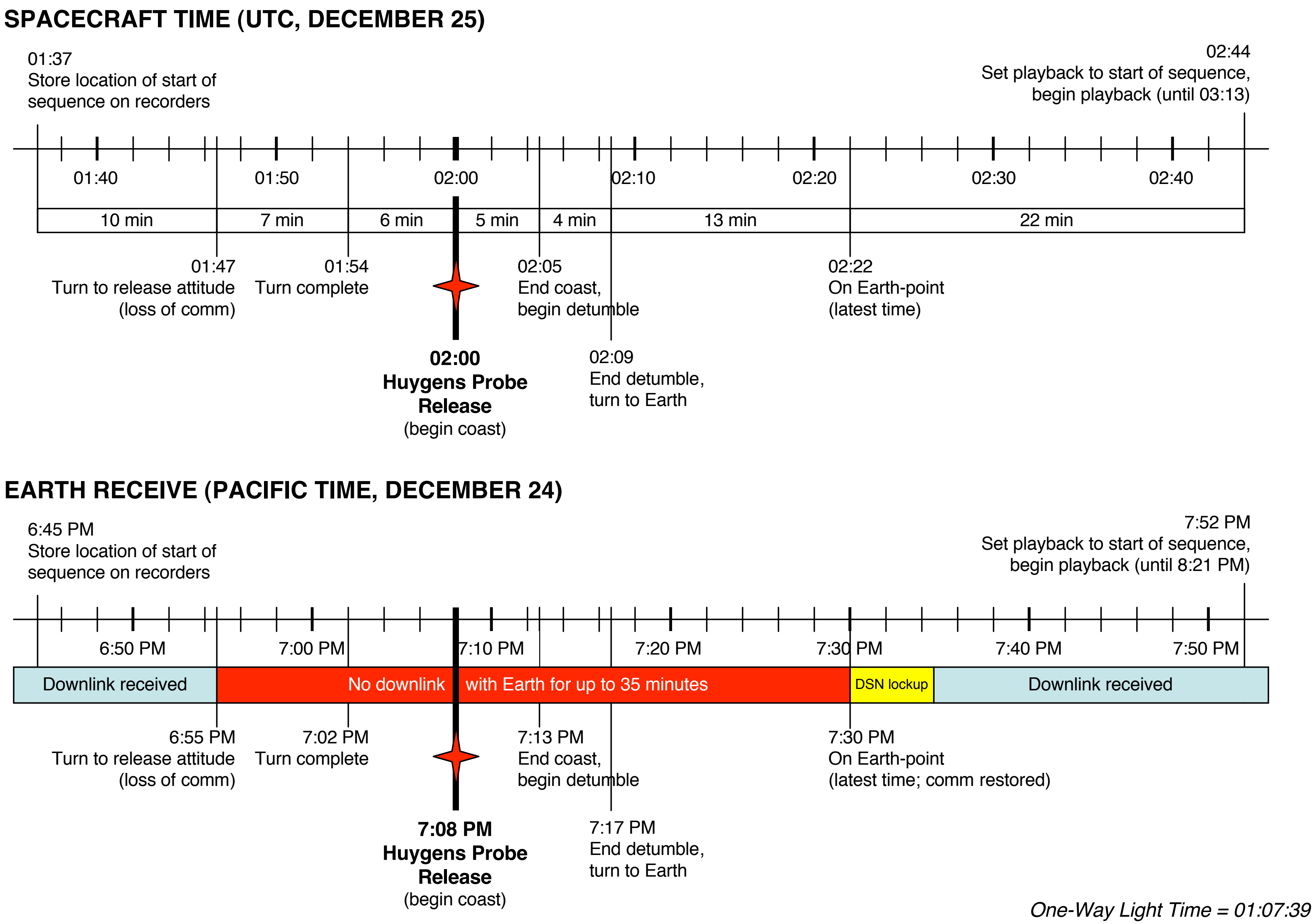
If delivery of the probe is changed from the Tc to a later flyby after the MTU is loaded, then in this case the MTU will have to be stopped and re-loaded at a later time.

Probe Separation

Separation of the Probe occurs on December 25th (Christmas Eve Pacific time). The Probe Spin/Eject Device (SED) separates the Probe with a relative speed of 0.3 - 0.4 m/s and spins it up to a rate of > 5 rpm. At separation, the Probe axis is pointed to achieve a zero-angle-of-attack entry. The orbiter targeting is such that the velocity increment provided by the SED springs provides the final targeting to the entry aimpoint.

The spin-stabilized Probe will be targeted for a southern latitude landing site on the day side of Titan. In order to meet the probe dynamic entry conditions, minimize trajectory dispersion and thus enhance data relay link performance, the Probe entry angle into the atmosphere will be relatively steep at $-65° \pm 3°$ (99%). The term "entry" generally refers to the arrival of the Probe at the interface altitude of 1270 km, which defines the interface point for Probe targeting requirements. The Probe does not experience significant atmospheric drag until a much lower altitude.

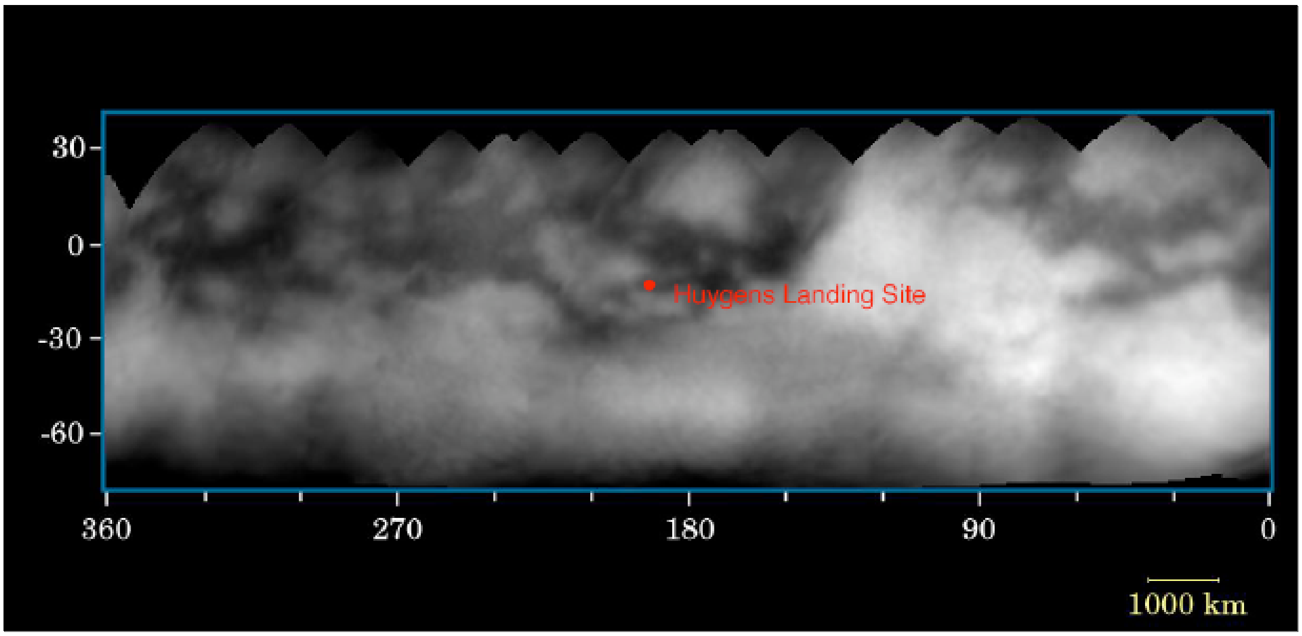
Huygens Probe Release



The probe landing site is located on the day side of Titan at about 10.7° (±0.7°) S latitude and 197°(±13°) W longitude on the surface of Titan. No Earth or Sun occultations by Titan (as seen from either the Probe or Orbiter) occur during the probe relay flyby.

The orbiter's Reaction Control System (RCS) will be used to control the combined spacecraft attitude immediately prior to the separation event. RCS control algorithms maintain the spacecraft attitude and rate about all three spacecraft axes. Following the turn to the Probe separation orientation, sufficient time is allowed for the spacecraft to attain a quiescent state with rates below 0.01 deg/sec on all axes.

Once the separation command is initiated, a sequence of dynamic events occurs that results in separation of the Probe. These events include the firing of pyro bolts, engagement of the separation push-off springs, ramps and rollers and the separation of the electrical connectors, as well as motion of the Orbiter under the separation induced loads. All of the activity between the time of the separation command and the time at which the Orbiter and Probe are no longer in physical contact take place in approximately 0.15 seconds.



Probe separation is a strenuous event for the orbiter, and attitude control must be configured accordingly. The orbiter's Attitude Control Subystem (AACS) will switch to coast mode 10 seconds before Probe separation. In the coast mode the RCS thrusters are inhibited from firing. The RCS thrusters will be re-enabled 60 seconds following the Probe separation event. Shortly after the separation event, AACS will switch to the detumble mode, where the RCS thrusters are re-enabled and the spacecraft rates are reduced to low, commandable values. When the Orbiter rates are within the prescribed threshold limits, the AACS switches to the Celestial-Inertial mode and a turn is commenced to return the Orbiter to the attitude it had just prior to the Probe release event.

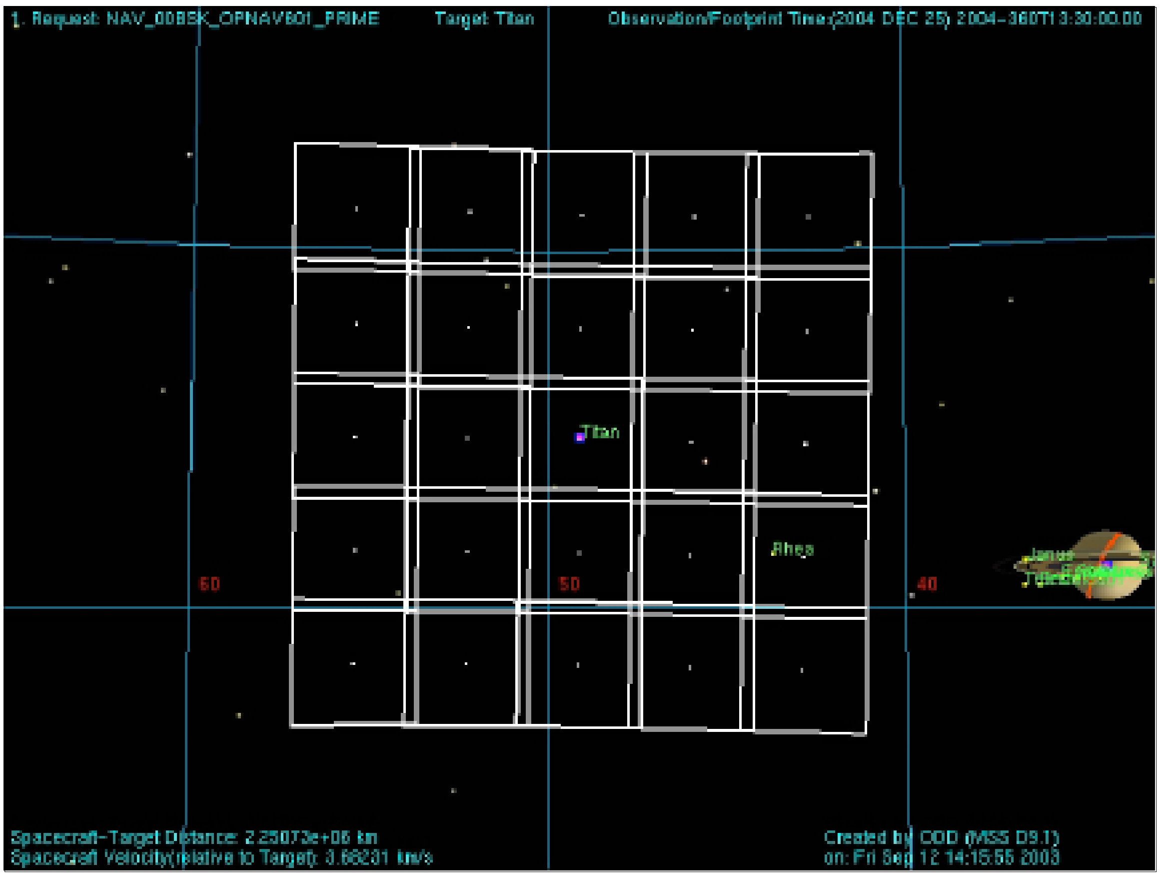
The dynamics of the Probe and the Orbiter during the five minutes between the time of separation and the time the two bodies are ~15 meters apart has been studied intensely. No contact between the probe and any part of the orbiter, including the magnetometer or plasma wave booms, is expected.

Successful separation of the Huygens Probe from the Cassini Orbiter is defined as a separation that does not jeopardize the functional or structural integrity of the Probe or

Orbiter and gives the Probe the required post-separation trajectory and attitude within allowable uncertainties.

There will be no communication between the spacecraft and the Earth while the orbiter is conducting the probe release, but all telemetry will be recorded for later playback. An early indication that separation has occurred will be from orbiter telemetry of probe temperatures registering maximum values, as the telemetry umbilical to the probe will be disconnected. In addition, several temperature channels will show temperature drops due to increased cooling of hardware formerly covered by the probe now being less insulated to space.

Post-separation imaging of the Probe (via 5x5 mosaic with the imaging cameras, shown on following page) will be used to improve the knowledge of its ephemeris, entry conditions at Titan, and ultimately the descent trajectory.



Iapetus Observations

In the midst of the probe activities, a relatively close (~ 117,500 km) flyby of Iapetus occurs. Due to its large distance from Saturn, its orbit offers few opportuntities for Cassini to study this fascinating body, and a two-day period centered on the new year has been set aside to allow for orbiter science observations.

Should there be any problems with probe separation, this sequence can be cancelled to make room for recovery activities.

Critical Sequence Activation and Orbiter Configuration

The probe relay critical sequence begins on the orbiter on January 7th 2005. During the next 8 days before probe relay, the orbiter is on Earth-point in a quiescent state on RCS control. All orbiter instruments are turned off, except for the Magnetometer (which is on, but its communication muted) and the Visual and Infrared Mapping Spectrometer (which is in sleep and its communication muted). Once the critical sequence activates, the orbiter can complete the probe relay mission without ground intervention, even in the event of equipment failure on board.

To prevent any interference with reception of the Probe data, no transmissions from the Orbiter are allowed during Probe relay at any frequency. Transmissions from the Orbiter HGA at X-band will be turned off by the Probe mission sequence shortly after the Orbiter turns away from Earth to point the HGA at the predicted Probe landing site.

On approach to Titan, the last downlink before Probe relay will be to the Madrid station (DSS 63). Following the playback of all data remaining on the Solid State Recorders, the orbiter is turned nearly 180 degrees to point the HGA at the predicted Probe landing point. The Probe Support Avionics (PSA) are configured to receive data from the Probe. The data from the Probe are transmitted at S band in two separate data streams, and both are recorded twice on each SSR.

Huygens Descent and Probe Relay

The probe relay mission will take place on 14th January 2005, with the probe reaching the interface altitude at 014T09:06 UTC. The orbiter turns to point its High-Gain Antenna (HGA) to the predicted landing site from two hours before interface time until that site is below the physical Titan horizon with respect to the orbiter. Once that happens, the orbiter will stop collecting probe data and turn back to Earth. This allows for ~4h36m of total probe mission data collection.

The following figures illustrate the sequence of events during the probe descent.

Probe Data Protection and Playback

When the Probe data collection is complete, that data will be write protected on Partition 5 of each SSR. The orbiter will point back to Earth and first contact is expected at approximately 15:07 UTC (7:07am Pacific time). Playback of the probe data begins ten minutes later at 15:17 UTC (7:14am Pacific time), and the first partition should be complete about two and a half hours later, at 17:57 UTC (9:57am Pacific time). The first full playback of all probe data on all SSRs should be complete by 22:07 UTC (2:07pm Pacific time). The complete, 4-fold redundant set of Probe data will be transmitted at least twice and complete data sets received at both Madrid and Goldstone DSN stations.

A detailed graphic and table of the playback schedule is shown in the Appendix.

Recorded Probe Relay data stored in the non-dedicated partition (partition 4) of each SSR shall be retained until the Cassini Project at JPL can confirm/validate that the data have been downlinked, and completely & correctly received at JPL (multiple downlinks will be used for verification). Once a determination has been made that the complete data set from partition 4 has been received, SSR partition 4 shall be released by the Cassini Project Manager to allow for orbiter science observations a few days after probe relay.

Recorded Probe Relay data stored in the dedicated partition (partition 5) of each SSR shall be protected until the Huygens Mission Team can confirm/validate that the data have been completely & correctly received at ESOC. Once a determination has been made that the data are complete, the Huygens Mission Manager will recommend to the Cassini Project Manager the release of SSR partition 5.

One-way light time at the time of the encounter is 1 hour and 7 minutes.

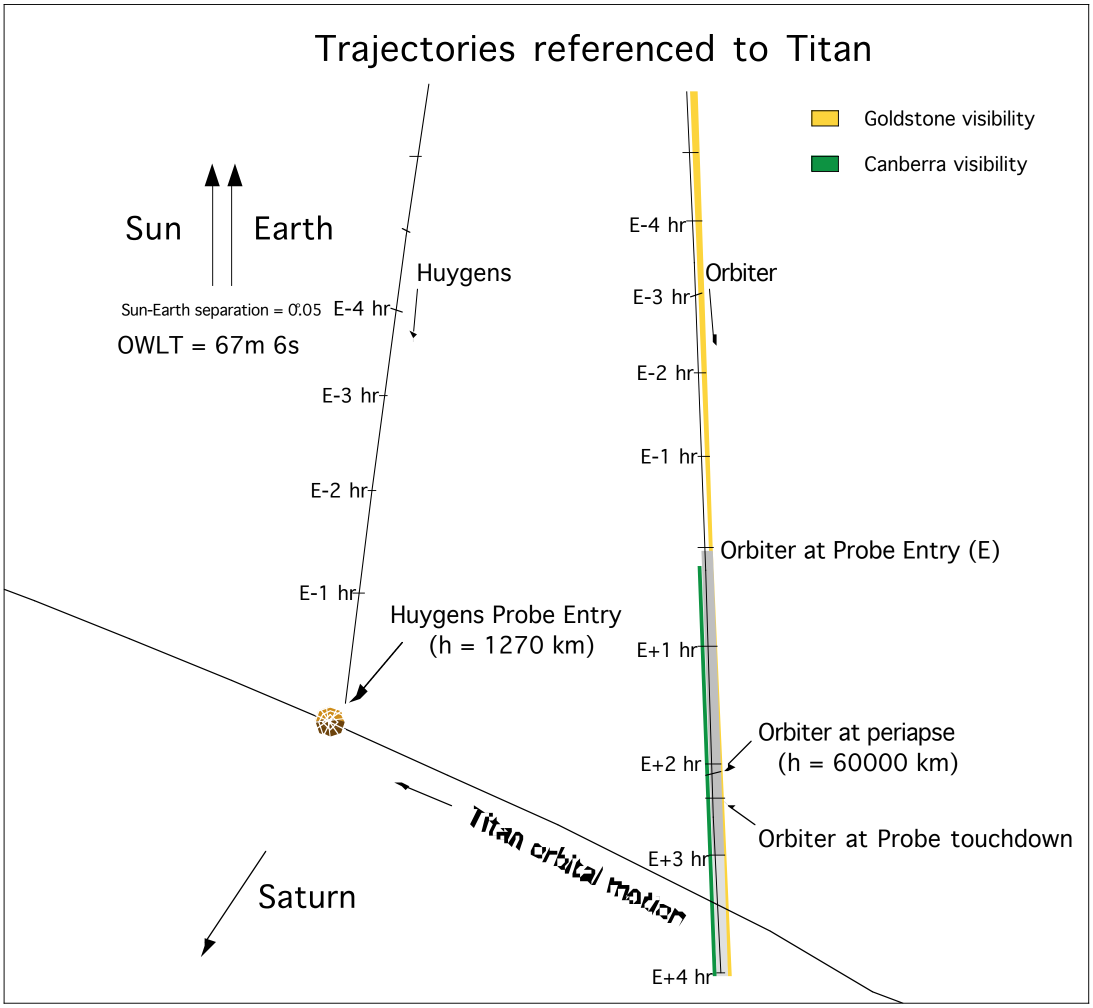
Huygens Probe Mission Timeline - 2005

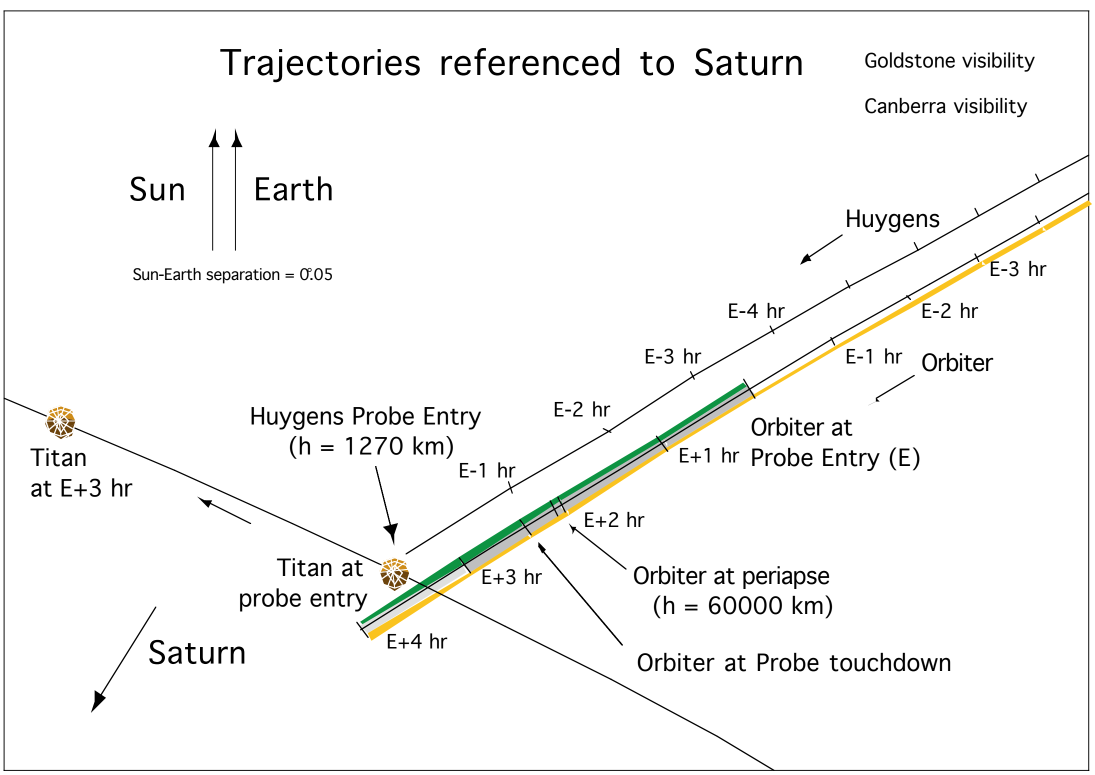
Colors: blue = geometric events; green = sequencing; red = Probe-related

Orbiter UTC = time event takes place at the spacecraft; Ground UTC = time event is seen at Earth, a one-way light time later

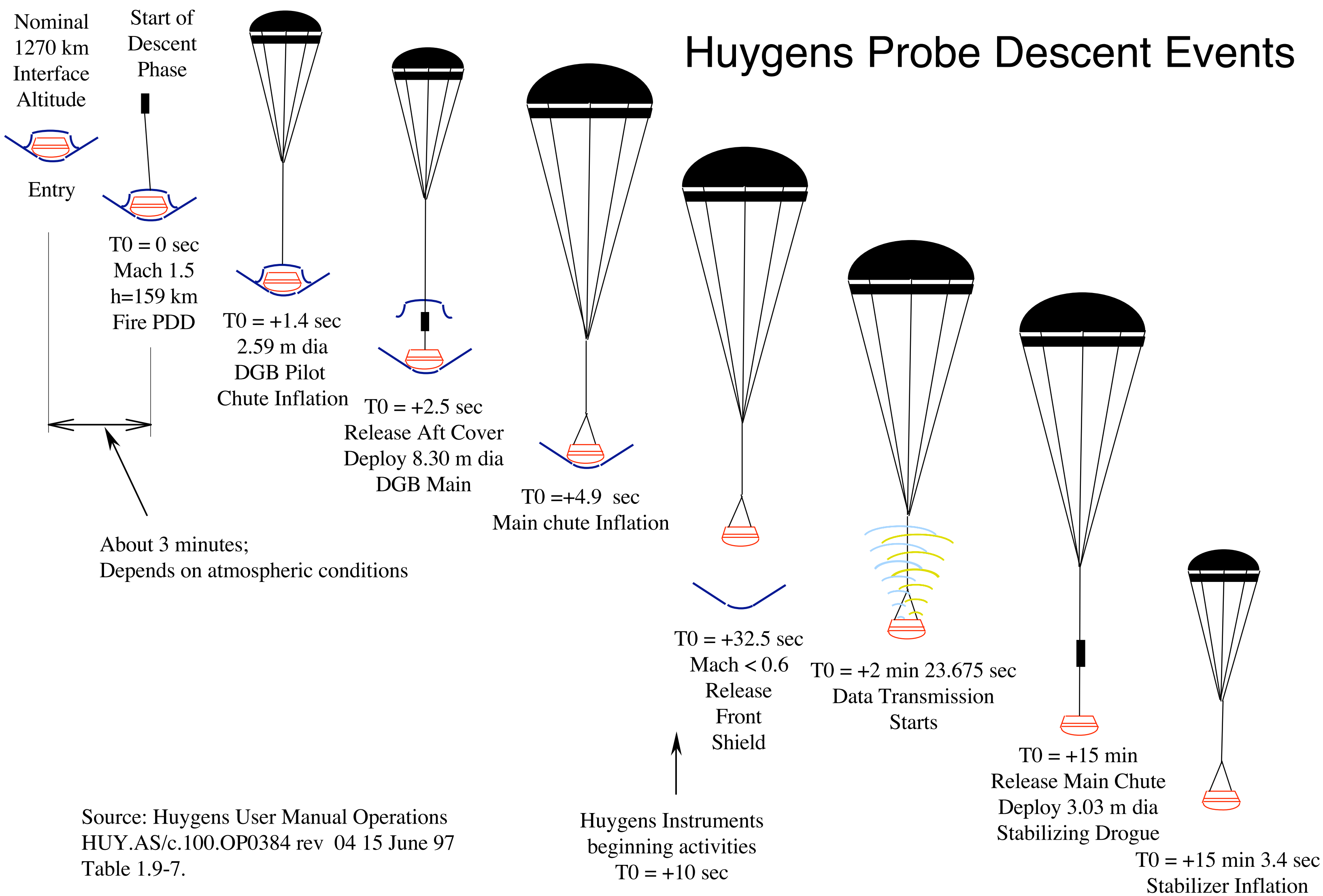
Orbiter UTC	Ground UTC	Pacific Time	Time wrt Entry	Activity	Description
006T11:53	Jan 06 13:00	Thu Jan 06 05:00 AM	Entry-07d21h	S07 background sequence A ends; spacecraft configured for Probe relay	All instruments except MAG are turned off
007T09:00	Jan 07 10:07	Fri Jan 07 02:07 AM	Entry-07d00h	Probe relay critical sequence begins	8 day quiet period of minimal spacecraft activity before relay begins; orbiter on thruster control
014T06:26	Jan 14 07:33	Thu Jan 13 11:33 PM	Entry-02h40m	Set Solid State Recorder pointers for Probe recording	
014T06:38	Jan 14 07:45	Thu Jan 13 11:45 PM	Entry-02h28m	Transition to thruster control for relay	
014T06:48	Jan 14 07:55	Thu Jan 13 11:55 PM	Entry-02h18m	Perform final recorder configuration for relay	
014T06:50	Jan 14 07:57	Thu Jan 13 11:57 PM	Entry-02h16m	Turn on Probe receivers	
014T07:02	Jan 14 08:09	Fri Jan 14 12:09 AM	Entry-02h04m	Turn orbiter to point to Titan	
014T07:14	Jan 14 08:21	Fri Jan 14 12:21 AM	Entry-01h52m	Turn to Titan complete	
014T07:17	Jan 14 08:24	Fri Jan 14 12:24 AM	Entry-01h49m	Disable X band downlink	
014T08:44	Jan 14 09:51	Fri Jan 14 01:51 AM	Entry-00h22m	Probe turns transmitters on	Low power mode
014T09:06	Jan 14 10:13	Fri Jan 14 02:13 AM	Entry+00h00m	Probe reaches interface altitude	Entry altitude = 1270 km
014T09:09	Jan 14 10:16	Fri Jan 14 02:16 AM	Entry+00h03m	Probe feels maximum deceleration	
014T09:10	Jan 14 10:17	Fri Jan 14 02:17 AM	Entry+00h04m	Pilot chute deployed	170-190 km altitude; Mach 1.5; pilot chute is 2.6m in diameter
014T09:10	Jan 14 10:17	Fri Jan 14 02:17 AM	Entry+00h04m	Aft cover released, main parachute deployed	160-180 km; Mach 1.5; 2.5 seconds after pilot chute deployed; main chute is 8.3m in diameter
014T09:11	Jan 14 10:18	Fri Jan 14 02:18 AM	Entry+00h05m	Probe begins transmission to orbiter	
014T09:11	Jan 14 10:18	Fri Jan 14 02:18 AM	Entry+00h05m	Release front shield; transmitters to high power; instruments configured for descent; measurements begin	152-175 km; Mach < 0.6
014T09:25	Jan 14 10:32	Fri Jan 14 02:32 AM	Entry+00h19m	Main parachute separation; deploy stabilizing drogue chute	110-140 km altitude; drogue is 3m in diameter
014T09:42	Jan 14 10:49	Fri Jan 14 02:49 AM	Entry+00h36m	Surface proximity sensor activated	60 km altitude
014T09:49	Jan 14 10:56	Fri Jan 14 02:56 AM	Entry+00h43m	Possible icing effects to Probe	50 km altitude
014T11:12	Jan 14 12:19	Fri Jan 14 04:19 AM	Entry+02h06m	Titan-C orbiter closest approach	Inbound 60,000 km flyby at 5.4 km/s, 93 deg phase
014T11:23	Jan 14 12:30	Fri Jan 14 04:30 AM	Entry+02h17m	Descent imager lamp on	
014T11:24	**Jan 14 12:31**	**Fri Jan 14 04:31 AM**	**Entry+02h18m**	**Surface impact, end descent phase**	**May vary ± 15 min depending on descent time**
014T13:37	Jan 14 14:44	Fri Jan 14 06:44 AM	Entry+04h31m	Orbiter stops collecting probe data	Total 4 hours and 36 minutes of data collection
014T13:39	Jan 14 14:46	Fri Jan 14 06:46 AM	Entry+04h33m	Write protect probe data partitions	Partitions A5 and B5 of Solid State Recorder are protected from further data writing
014T13:47	Jan 14 14:54	Fri Jan 14 06:54 AM	Entry+04h41m	Turn orbiter to point to Earth	
014T13:50	Jan 14 14:57	Fri Jan 14 06:57 AM	Entry+04h44m	Turn to Earth complete	
014T13:59	**Jan 14 15:06**	**Fri Jan 14 07:06 AM**	**Entry+04h53m**	**Critical sequence ends; S07 background sequence B begins**	
014T14:00	**Jan 14 15:07**	**Fri Jan 14 07:07 AM**	**Entry+04h54m**	**Post-Probe tracking begins**	**Canberra 70m station receiving; 10 minutes for DSN lockup allocated**
014T14:07	**Jan 14 15:14**	**Fri Jan 14 07:14 AM**	**Entry+05h01m**	**First telemetry data sent to Earth**	
014T14:10	**Jan 14 15:17**	**Fri Jan 14 07:17 AM**	**Entry+05h04m**	**Playback of probe data begins**	**At Canberra at 66,360 bps**
014T16:50	**Jan 14 17:57**	**Fri Jan 14 09:57 AM**	**Entry+07h44m**	**End playback of first partition**	**First copy of probe data received at Earth**
014T16:57	Jan 14 18:04	Fri Jan 14 10:04 AM	Entry+07h51m	Ascending ring-plane crossing	Distance = 18.4 Saturn radii
014T17:53	Jan 14 19:00	Fri Jan 14 11:00 AM	Entry+08h47m	Start tracking at Madrid 70m	Data rate upgraded to 142,200 bps
014T21:00	**Jan 14 22:07**	**Fri Jan 14 02:07 PM**	**Entry+11h54m**	**End first full playback of all Probe data**	**Complete set of all copies probe data received at Earth**
015T00:22	**Jan 15 01:29**	**Fri Jan 14 05:29 PM**	**Entry+15h16m**	**First complete set of Probe data reaches Huygens Operations Center**	**No later than time listed; likely up to ~3 hours earlier**
015T02:28	Jan 15 03:35	Fri Jan 14 07:35 PM	Entry+17h22m	Start tracking at Goldstone 70m	
015T11:00	Jan 15 12:07	Sat Jan 15 04:07 AM	Entry+01d02h	Power on of orbiter instruments	If orbiter is healthy and playback proceeding per plan
015T12:23	**Jan 15 13:30**	**Sat Jan 15 05:30 AM**	**Entry+01d03h**	**End nominal playback of Probe data**	

Version: 2004 Dec 14; exact dates/times may change


Trajectories referenced to Titan
Goldstone visibility
Canberra visibility
Sun
Earth
Sun-Earth separation = 0.°05
OWLT = 67m 6s
Huygens
E-4 hr
E-3 hr
E-2 hr
E-1 hr
Huygens Probe Entry
(h = 1270 km)
Orbiter
E-4 hr
E-3 hr
E-2 hr
E-1 hr
Orbiter at Probe Entry (E)
E+1 hr
Orbiter at periapse
(h = 60000 km)
E+2 hr
Orbiter at Probe touchdown
E+3 hr
E+4 hr
Titan orbital motion
Saturn

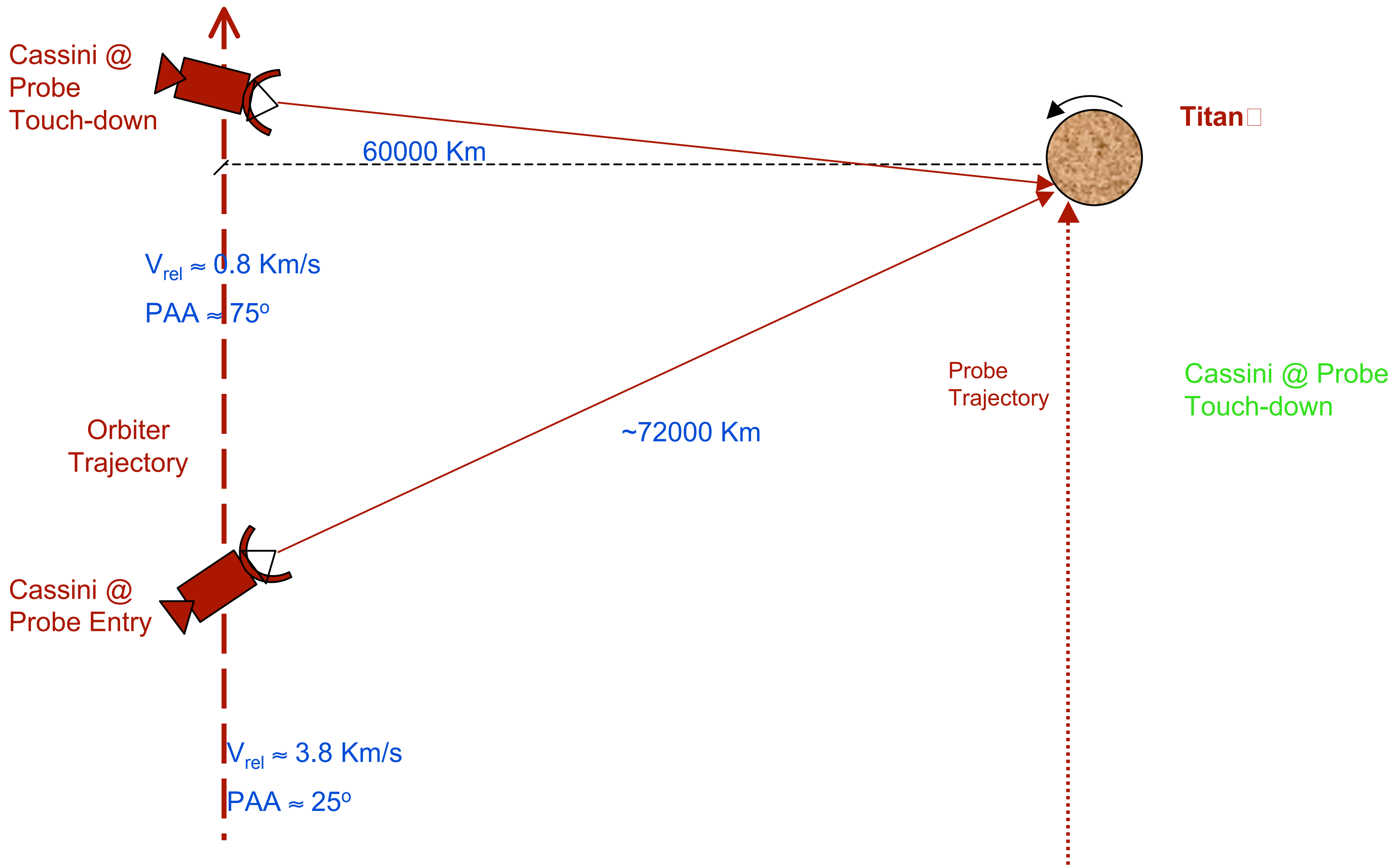

Trajectories referenced to Saturn
Goldstone visibility
Canberra visibility
Sun
Earth
Sun-Earth separation = 0.°05
Huygens
E-4 hr
E-3 hr
E-2 hr
E-1 hr
E-3 hr
E-2 hr
E-1 hr
Orbiter
Orbiter at
Probe Entry (E)
E+1 hr
E+2 hr
E+3 hr
E+4 hr
Huygens Probe Entry
(h = 1270 km)
Titan
at E+3 hr
Titan at
probe entry
Orbiter at periapse
(h = 60000 km)
Orbiter at Probe touchdown
Saturn

Huygens Probe Descent Events



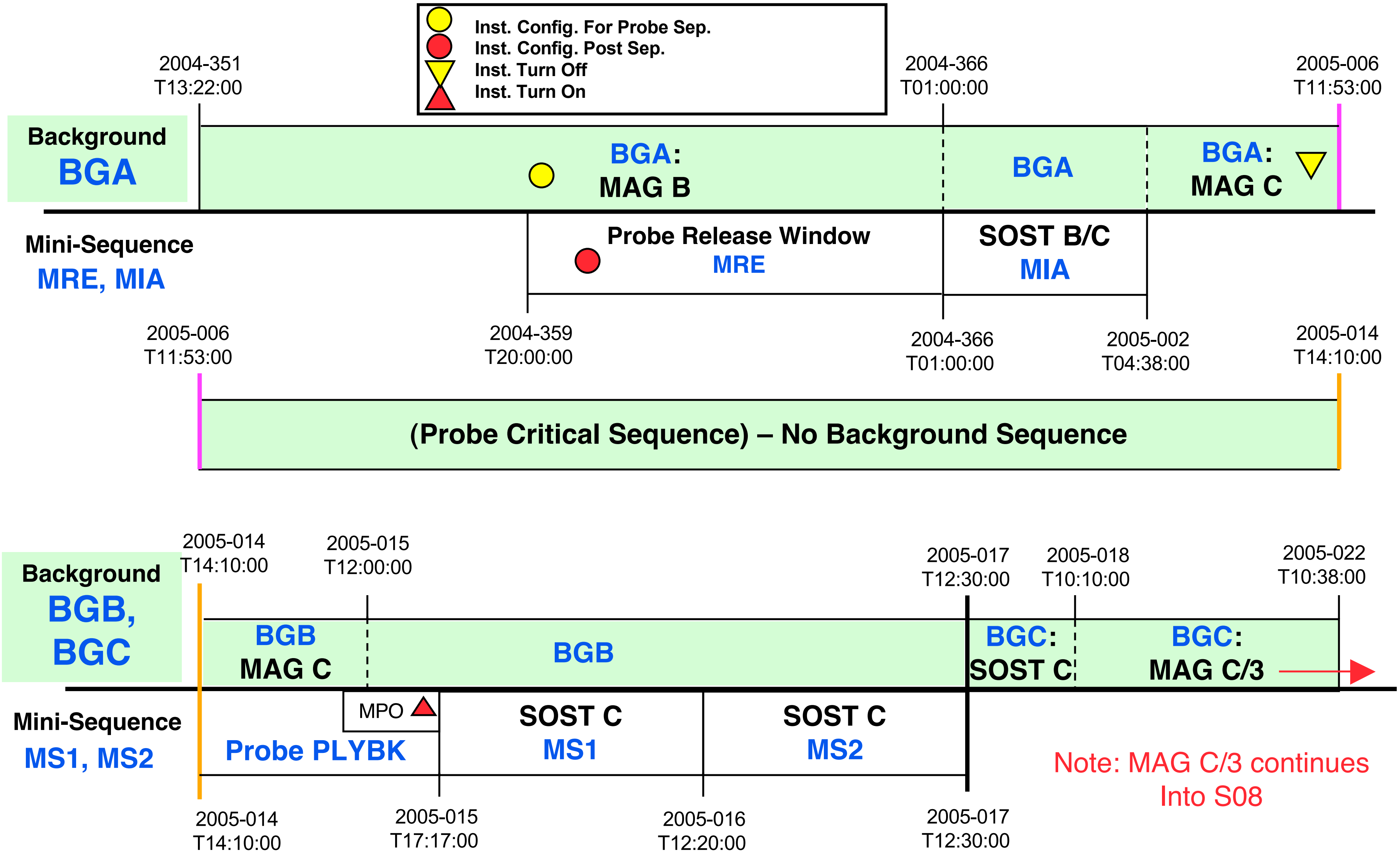
Source: Huygens User Manual Operations
HUY.AS/c.100.OP0384 rev 04 15 June 97
Table 1.9-7.

Probe Mission Geometry



Appendix: Technical Figures for the Curious

S07 Sequence Overview

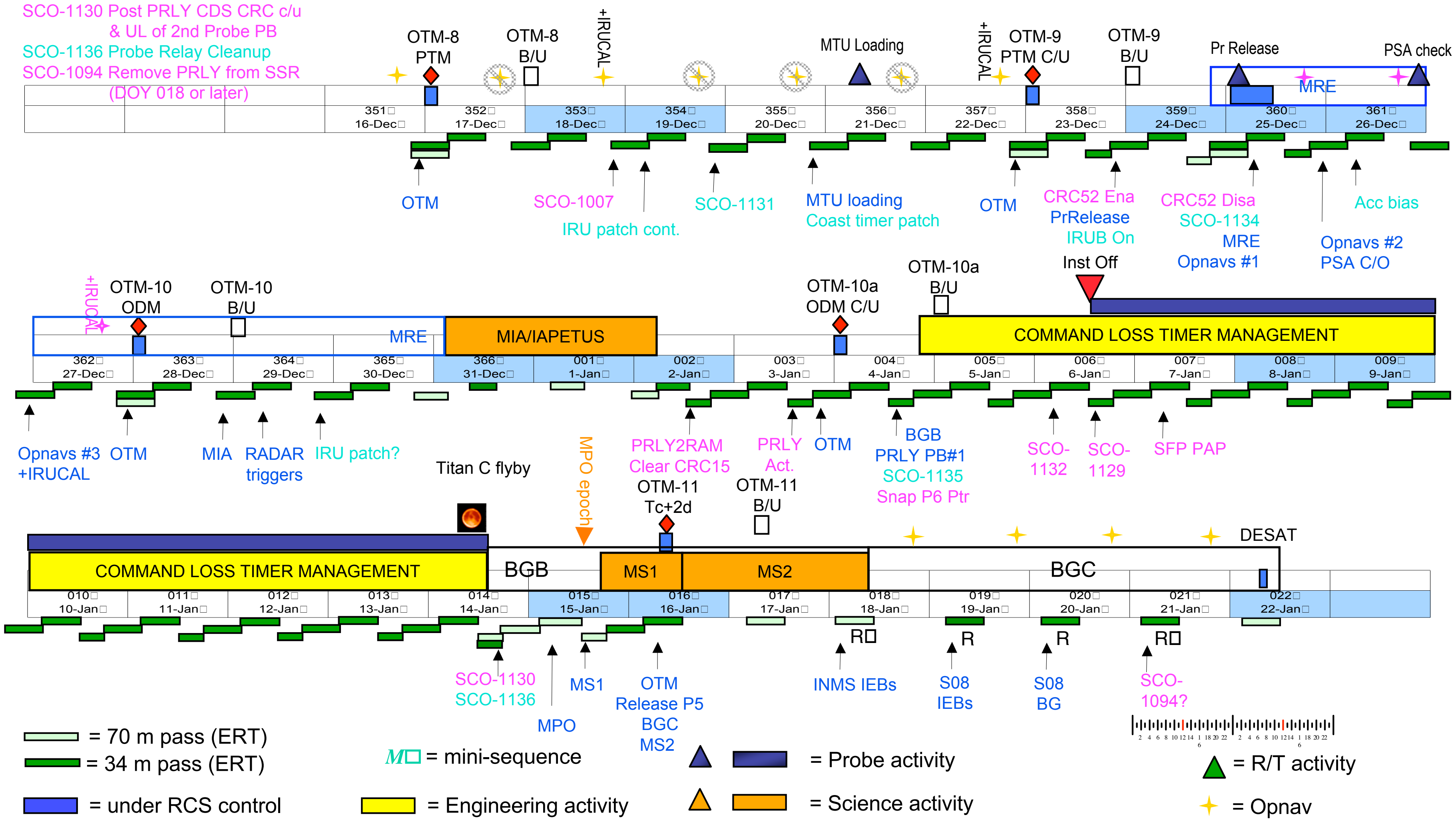


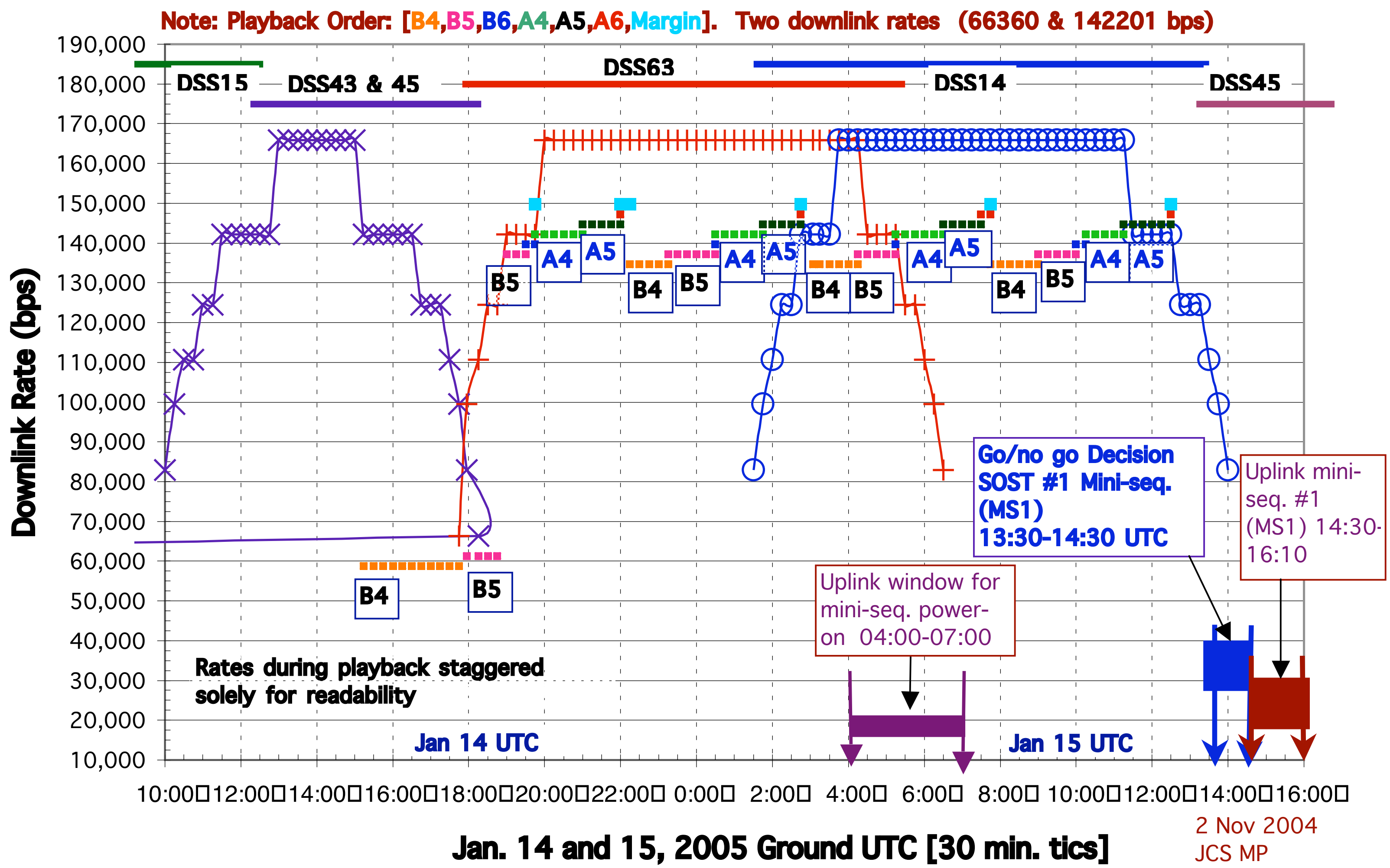
2 Dec 2004

S07 Timeline

Rev: 11/19/04
Updated per z0070c_full_a.sfos

SCO-1007 Load PRLY to SSRs
SCO-1131 Load Global Data Vectors
SCO-1134 Probe Ejection Cleanup
SCO-1135 Probe Relay Configuration
SCO-1132 Load G.D. Vectors Update
SCO-1129 CDS Config for PRLY
SCO-1130 Post PRLY CDS CRC c/u
& UL of 2nd Probe PB
SCO-1136 Probe Relay Cleanup
SCO-1094 Remove PRLY from SSR
(DOY 018 or later)





2 Nov 2004
JCS MP

PROBE

Begin Partition Playback (ddThh:mm SCET)

P/B #	B4	B5	B6	A4	A5	A6
1	14T14:17	14T16:53	14T18:37	14T18:43	14T19:54	14T21:00
2	14T21:04	14T22:17	14T23:23	14T23:29	15T00:42	15T01:48
3	15T01:52	15T03:07	15T04:13	15T04:19	15T05:34	15T06:40
4	15T06:44	15T08:01	15T09:07	15T09:13	15T10:29	15T11:35

Begin Partition Playback (ddThh:mm UTC Ground)

P/B #	B4	B5	B6	A4	A5	A6
1	14T15:24	14T18:00	14T19:44	14T19:50	14T21:01	14T22:07
2	14T22:11	14T23:24	15T00:30	15T00:36	15T01:49	15T02:55
3	15T02:59	15T04:14	15T05:20	15T05:26	15T06:41	15T07:47
4	15T07:51	15T09:08	15T10:14	15T10:20	15T11:36	15T12:42

Begin Partition Playback (ddThh:mm PST Ground)

P/B #	B4	B5	B6	A4	A5	A6
1	14T07:24	14T10:00	14T11:44	14T11:50	14T13:01	14T14:07
2	14T14:11	14T15:24	14T16:30	14T16:36	14T17:49	14T18:55
3	14T18:59	14T20:14	14T21:20	14T21:26	14T22:41	14T23:47
4	14T23:51	15T01:08	15T02:14	15T02:20	15T03:36	15T04:42

Partition Playback Duration (hh:mm)

P/B #	B4	B5	B6	A4	A5	A6
1	02:36	01:44	00:06	01:11	01:06	00:04
2	01:13	01:06	00:06	01:13	01:06	00:04
3	01:15	01:06	00:06	01:15	01:06	00:04
4	01:17	01:06	00:06	01:16	01:06	see Note

Start 66360 bps d/l rate (start 10 min. lockup) (SCET)	14T14:07
Start 142201 bps d/l (start 5 min. p/b pause) (SCET)	14T17:53
Start 27650 bps d/l (start 5 min. p/b pause) (SCET)	15T11:37

Note: Playback of engineering data continues on partition A6 until start of MS1 observation period (15T17:17 SCET). If MS1 not executed, playback continues on A6 through the start of the OTM-011 downlink at which time a data rate change to 35550 bps occurs.

Created 8 Dec 2004