

THE VOYAGER-2 NEPTUNE ENCOUNTER

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ABSTRACT

Mankind's first in situ exploration of the planet Neptune and its moons, rings, and magnetosphere will occur during the summer of 1989. The Voyager system was designed to explore Jupiter and Saturn. However, Neptune is three times farther away than Saturn. The major science objectives and telecom link distance generate unique telecommunications requirements. Among these are conversion of the Deep Space Network's (DSN) 64 meter antennae to 70 meter antennae, arraying of the Very Large Array (VLA) with the DSN antennae at Goldstone CA, use of the 64 meter radio-telescope at Usuda, Japan, and new on-board spacecraft data control software. In addition, telecom improvements first made for the Uranus encounter, including parallel operation of the spacecrafts redundant data control processors, on-board spacecraft data compression software, and on-board data encoding hardware and software, will also be used for the Neptune encounter.

INTRODUCTION

The solar system is defined as that region of space dominated by the sun. The known solar system consists of one dwarf G_2 star, 9 planets, 54 moons, several thousand asteroids, and some very large unknown number of comets. The outer most comets are within a structure known as the Oort cloud, and define the total size of the solar system. To date, mankind has visited 7 of the 9 known planets, 51 of the 54 moons, two of the comets, and the central star, but none of the asteroids.

The two Voyager spacecraft, launched in 1977, have visited 4 of the 7 planets mentioned above (Earth, Jupiter, Saturn, and Uranus), all three of the known planetary ring systems (Jupiter, Saturn, and Uranus), and 49 of the 54 moons (Figure 1). This multiple outer planet trajectory is known as the Grand Tour. The opportunity to conduct a Grand Tour of the outer planets occurs once every 177 years. Voyager 2 will arrive at Neptune in the

summer of 1989 for mankind's first in situ exploration of that planet, its two known moons Triton and Nereid, its expected multiple ring-arc system, and its expected magnetosphere.

Neptune is so far away that almost nothing is known about it. It is known that Neptune is a gas giant, made up primarily of hydrogen and helium, with smaller amounts of oxygen, carbon, and nitrogen. An "ocean" of various types of ices is thought to lie underneath the outer gasses. The center of the planet may be a rocky core. Neptune is 44 times as large (in volume) as the Earth, and 17 times as massive⁽¹⁾.

Triton may be larger and more massive than Earth's moon. It is large enough to be one of only two moons to have its own atmosphere (Saturn's large moon Titan being the other). Triton is composed of a rock ice mixture, giving it a solid surface, unlike its gas giant parent planet. Nereid is a tiny moon, only a few hundred kilometers in diameter, orbiting Neptune far away (relative to Triton) with a period of about one earth year.

MAJOR SCIENTIFIC OBJECTIVES

As mentioned earlier, Voyager 2 has travelled from Earth, to Jupiter, to Saturn, to Uranus, and is now on its way to Neptune. The technique used to accomplish this multiple planetary encounter is called the planetary gravity assist. In essence, each planet has been approached in such a way as to transfer kinetic energy from the planet to the spacecraft, sending it on to the next planet. At all previous planetary encounters, the geometry of the encounter was controlled by the need to perform the gravity assist to the next planet. Voyager 2 will not encounter any more planets after Neptune. Thus, the Neptune encounter may be designed to maximum scientific advantage.

All other things being equal, the first objective is to get as close as possible to Neptune. This permits maximum resolution to be obtained from the optical, ultraviolet, and infrared telescopes on board the spacecraft. In addition, the closest possible approach allows the fields and particles instruments to sample as much of the planetary environment as possible.

Triton is such a potentially interesting body that a close encounter with it is as important as a close encounter with Neptune itself. Unfortunately, Triton orbits Neptune in an inclined retrograde orbit. This makes the dual close approach to Neptune and Triton much more difficult.

Both Neptune and Triton have atmospheres. In order to determine the characteristics of the atmospheres (temperature, pressure, constituents, etc.), it is necessary to cause the Voyager spacecraft to pass behind both Neptune and Triton (as viewed from both the earth

and the sun). Thus, the final major objective is a dual earth/sun occultation by both Neptune and Triton.

RESULTING TRAJECTORY CHARACTERISTICS

There is only one type of Neptune encounter trajectory that will provide a close passage and a dual Earth/Sun occultation by both Neptune and Triton ⁽²⁾. The spacecraft must pass close to Neptune slightly to the “west” of its north pole (Figure 2). The north polar encounter will provide the earth and sun occultations by the planet. The close passage to Neptune will bend the trajectory “down” providing the close passage by Triton and the necessary Earth and sun occultations by that moon.

Unfortunately, all things are not equal, and the spacecraft may not pass arbitrarily close to Neptune. The planet, being a gas giant, is mostly atmosphere. If Voyager passes too close to Neptune, it will enter that atmosphere and, at a minimum, suffer degraded performance at the most crucial time. To further complicate the problem, a ring-arc system of orbiting material has recently been discovered orbiting about Neptune. Thus, the spacecraft must stay outside both the atmosphere and the rings. Figure 2 shows the safe regions. As a final complication, several of the proposed Neptune observations would either not be possible or be degraded severely by passage too close to the planet.

The Voyager Project has selected from a family of north polar encounters, a trajectory that passes Neptune slightly more than 4,400 km. above the “cloud tops” of the planet. This trajectory continues on to come within 40,000 km. of Triton. Figure 3 shows the trajectory, from a side view. Figure 4 shows the trajectory from the point of view of someone directly above the north pole of Neptune. Figure 5 shows the trajectory from the point of view of someone over the north pole of Triton. Plotted in both Figures 4 and 5 are the earth and sun occultation zones (those regions of space where passage by the spacecraft will provide such occultations).

The only other characteristic needed to specify completely the trajectory is the arrival time at Neptune. The highest priority and largest amount of data are returned from the spacecraft to the earth during the day of Neptune closest approach (N C/A) and Triton closest approach (T C/A). In particular, the radio science X and S-band occultations of first Neptune then Triton are received during this time period.

Although the largest X-band aperture available is the Goldstone DSN antennae arrayed with the VLA, this is not necessarily the best set of antennae to use the day of N C/A and T C/A. Figure 6 shows the elevation angles of the three DSN antenna complexes (at Goldstone, CA, Canberra, Australia, and Madrid, Spain) with respect to the Voyager-2 spacecraft on the day of the dual closest approach. The highest antenna elevation angles

occur for the Australian antennae. The high elevation angles increase the length of the Voyager pass. At the highest data rate (21,600 bps) to be used at the Neptune encounter, pass durations over the Canberra/Parkes array equal pass durations over the Goldstone/VLA array. For X-band transmission of non-radio science data and spacecraft telemetry, these two arrays are equal. At S-band, the largest aperture available is over the Australian longitude, if the Usuda 64m radiotelescope is used in a non-real time array.

The time of arrival at Neptune was selected so that Triton would be in the correct place in its orbit so as to achieve the close T C/A and the dual earth/sun occultation, and so that the data at N C/A and T C/A would be received at the earth by the Australian and Japanese antennae. The preferred time of Neptune closest approach is 1989 August 25, at 04:00 GMT. (As it takes light 4 hours to travel from Neptune to the earth, knowledge of the event occurs at about 08:00 GMT.) Close inspection of Figure 6 shows that with this time of arrival, the Neptune and Triton occultation data receipt times are balanced at maximum possible station elevation, consistent with the planned use of Parkes and Usuda.

SCIENCE DATA REQUIREMENTS

All Voyager science data (except radio science) and spacecraft engineering telemetry are transmitted at X-band. The basic non-radio science non-imaging science data requirement is to continuously receive 4,800 bps from Neptunian distance from 82 days before closest approach until 36 days after closest approach at a level of confidence of 90%.

The 11 science investigations have bit error rate requirements that vary from as high as 1.1×10^{-3} for the photopolarimeter to as low as 1.0×10^{-6} for the infrared radiometer interferometer and spectrometer. These error requirements were established before launch, and have not changed since then.

Imaging and radio science are not included in the 4,800 bps data stream. The imaging requirements to characterize a never-before-explored planetary system have evolved over the Voyager mission into three levels:

50 to 75 images per day over the time periods from 80 days before to 15 days before N C/A and from 5 days to 30 days after N C/A,

225 images per day from 15 days before N C/A to 5 days after N C/A,

300 images on the day of N C/A and T C/A.

The 300 images on the day of N C/A and T C/A can be met by using the 225 images per day capability, plus storing the remaining 75 images on the spacecraft's digital tape recorder.

The 225 images per day requirement is derived from the following apportioning of observations:

175 images per day of Neptune

15 images per day of Triton

15 images per day of Neptune's ring-arcs and new moons

10 support images per day for non-imaging observations

5 "images" per day for electric fields investigations

5 images per day for optical navigation

The 175 images per day for Neptune results from the need to create 2 by 2 imaging mosaics using the narrow angle camera, plus one wide angle image, with all 5 images shot using each of 5 different filters seven times per day. The 15 Triton images per day result from planning to shutter 7 images every 30 degrees of longitude.

Radio science desires as much aperture as possible, at both X and S-band, to make up for the increased distance from the spacecraft to the earth. This increased distance results in a 3.5 dB. loss over the signal available from the Uranus occultation. To make matters worse, the spacecraft power available has decreased. Either the X or the S-band transmitter must transmit at low power instead of high power resulting in an additional 1.9 or 4.7 dB. loss, respectively.

The conversion of the 64m DSN antenna at Canberra to a 70m antenna recovers 1.9 dB. at X-band and 1.4 dB. at S-band. Using the 64m antenna at Usuda recovers 1.6 dB. at S-band.

TELECOM REQUIREMENTS

The continuous 4,800 bps non-radio science non-imaging science and spacecraft engineering telemetry requirement is being achieved as a result of the conversion of the DSN's 64m antennae to 70m antennae.

The 225 images per day Neptunian system characterization requirement is expected to be satisfied by transmitting data at the following rates for the following periods of time per day:

21,600 bps for 11 hours per day

14,400 bps for 4 hours per day

8,400 bps for 5 hours per day

In order to acquire 21,600 bps, either the VLA must be arrayed with the 70m antenna at Goldstone, or Parkes must be arrayed with the 70m antenna at Canberra. (It is not possible to receive 21,600 bps at 90% confidence from Neptune over the Madrid longitude because the latitude of these antennae is too far north.) The 225 images per day data rate requirement generates the DSN 70m conversion requirement, and the VLA and Parkes arraying requirements.

The radio science maximum aperture requirement generates the request to use Parkes at X-band and Usuda at S-band during the Neptune and Triton occultations.

The Voyager Project is again using two additional telecom improvements (first used for the Uranus encounter) to return as much data as possible during the Neptune encounter: data compression and Reed-Solomon data encoding.

The Flight Data Subsystem (FDS) on board processor controls the 10 science instruments. It also formats and interleaves the data from the science instruments and the spacecraft telemetry channels into data streams for real time transmission to the earth, or for storage on the on board digital tape recorder.

The FDS has two software programmable processors. As originally designed, the second processor was a backup for the primary. The processors will be used during the Neptune encounter (as they were during the Uranus encounter) in a “dual processor” configuration. Both processors are used all of the time and there is no redundancy. The secondary processor stores and operates the program to compress imaging data.

The modulation-demodulation subsystem convolutionally encodes all science data and engineering telemetry. (A Viterbi decoder is used on the ground for decoding.) In addition, both Golay and Reed-Solomon block encoding hardware and software is resident on the spacecraft. Before the Uranus encounter, only the Golay encoder was used. Spacecraft data rates were high enough that the 100% Golay overhead could be tolerated.

Starting with the Uranus encounter, and even more so for Neptune, the available data rates are so low that the 18% overhead associated with the Reed-Solomon encoder became much more attractive. A much higher percentage of the Neptune science data and engineering telemetry will be Reed-Solomon encoded than was the case at Uranus.

SUMMARY

The DSN is upgrading its 64m antennae to 70m antennae. It has made arrangements to use the Parkes 64m radiotelescope, the Usuda 64m radiotelescope, and the 27 25m radiotelescopes at the VLA.

The Voyager Project is using convolutional encoding for all data, and either Golay or Reed-Solomon block encoding for most data transmitted back to Earth. In addition, the secondary FDS processor will be used to compress imaging data, reducing the number of bits per image transmitted, increasing the total number of images able to be transmitted.

The upcoming Voyager-2 Neptune encounter is highly dependent upon these telecom upgrades. Without them, the presently designed encounter would not be possible. All that would be possible is a characterization of the Neptunian magnetosphere, some planetary and satellite atmospheric observations, a degraded radio science occultation, and perhaps a few hundred images (instead of the approximately 6,000 planned). With the telecom improvements described the Voyager-2 spacecraft will observe and transmit back all that is possible, allowing mankind to truly understand Neptune for the first time.

This paper presents one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract sponsored by the National Aeronautics and Space Administration.

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2. Sergeyevsky, A. B., "Voyager-2: A Grand Tour of the Giant Planets", AAS paper 81-187, AAS/AIAA Astrodynamics Specialist Conference, Lake Tahoe, Nevada, August 3-5, 1981.

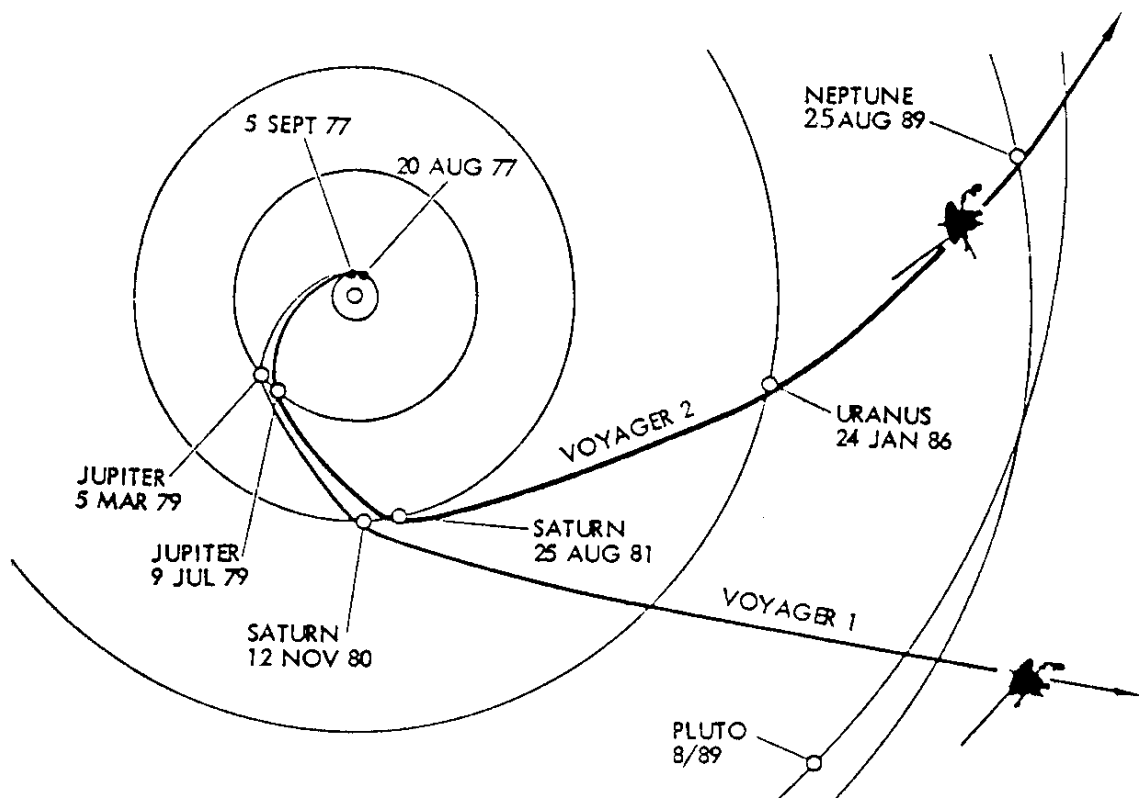


Figure 1: Voyager Spacecraft Trajectories.

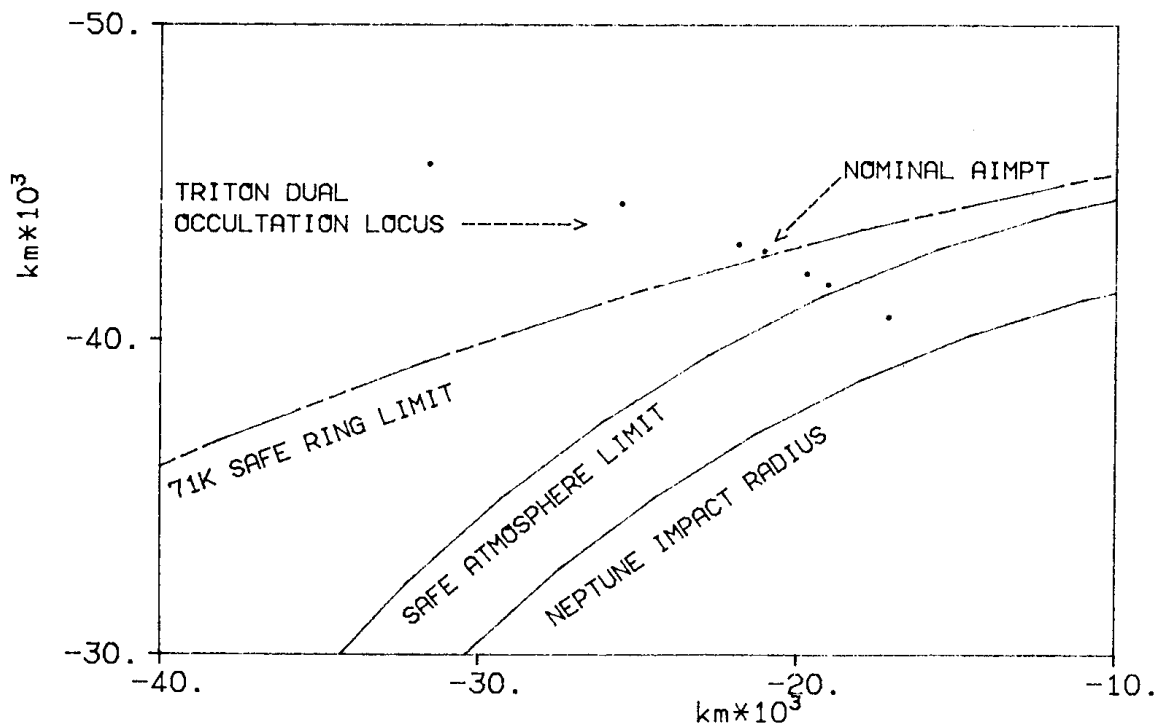


Figure 2: Neptune North Polar Encounter Geometry.

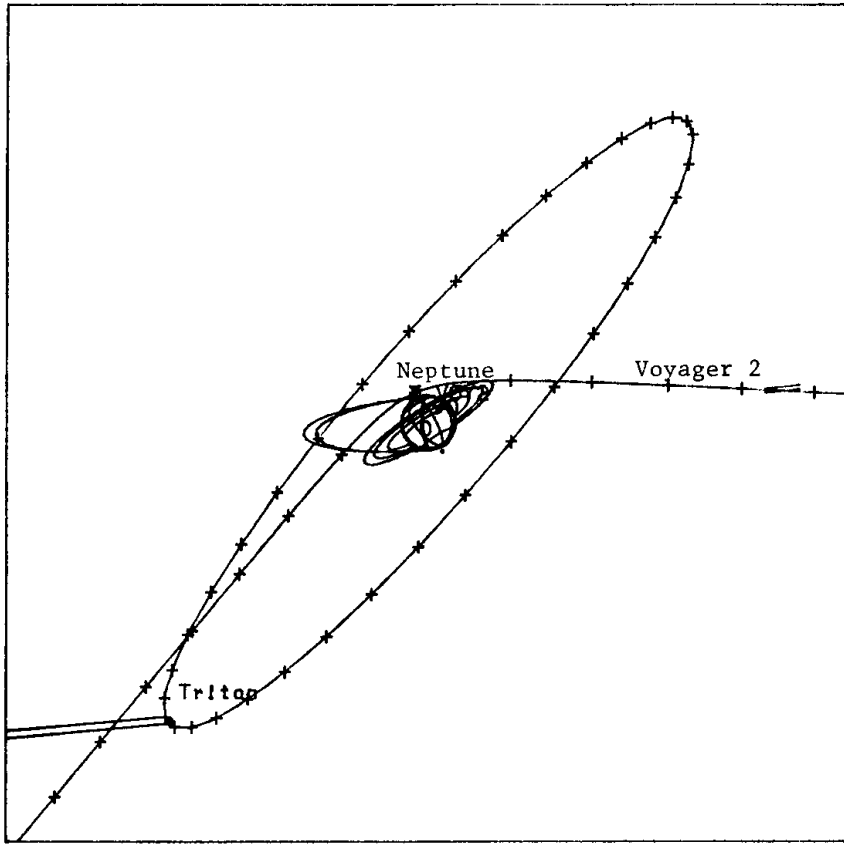


Figure 3: Voyager 2 Neptune Trajectory Side View.

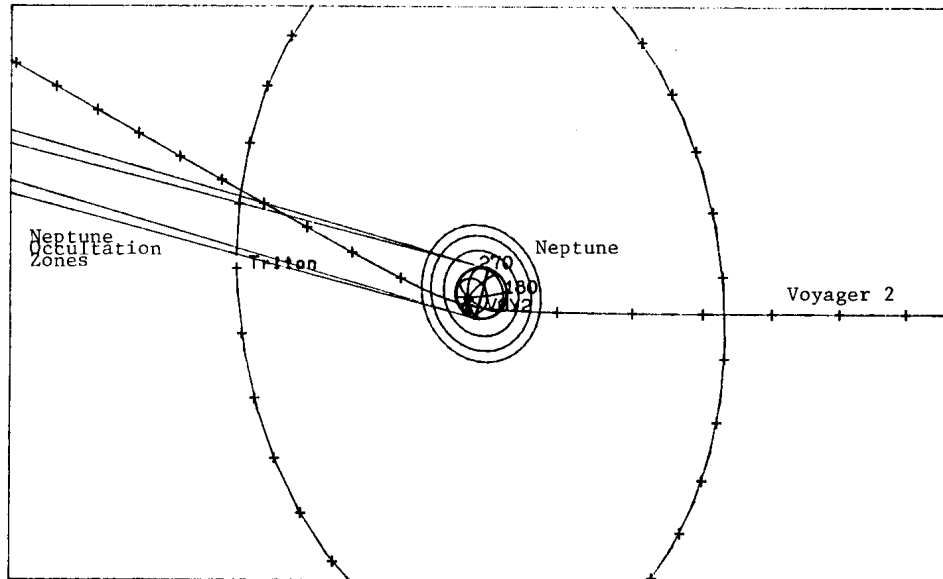


Figure 4: Voyager 2 Neptune Trajectory Neptune North Polar View.

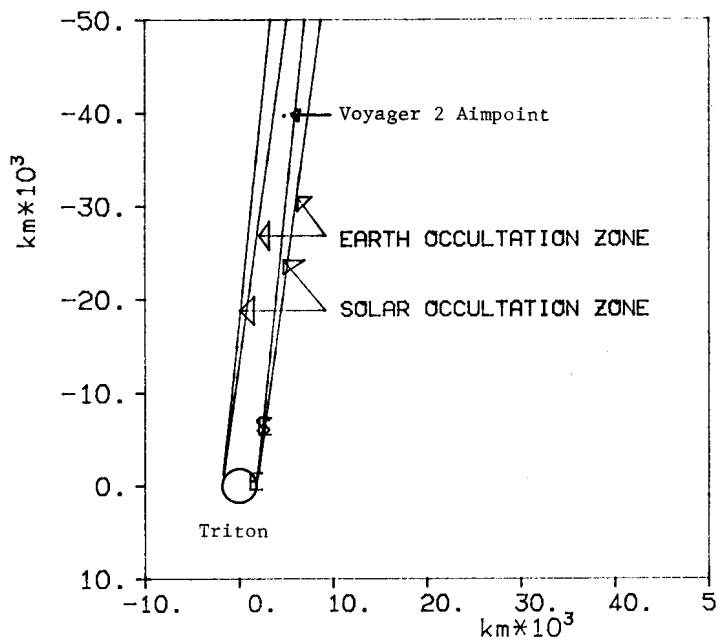


Figure 5: Voyager 2 Neptune Trajectory Triton North Polar view.

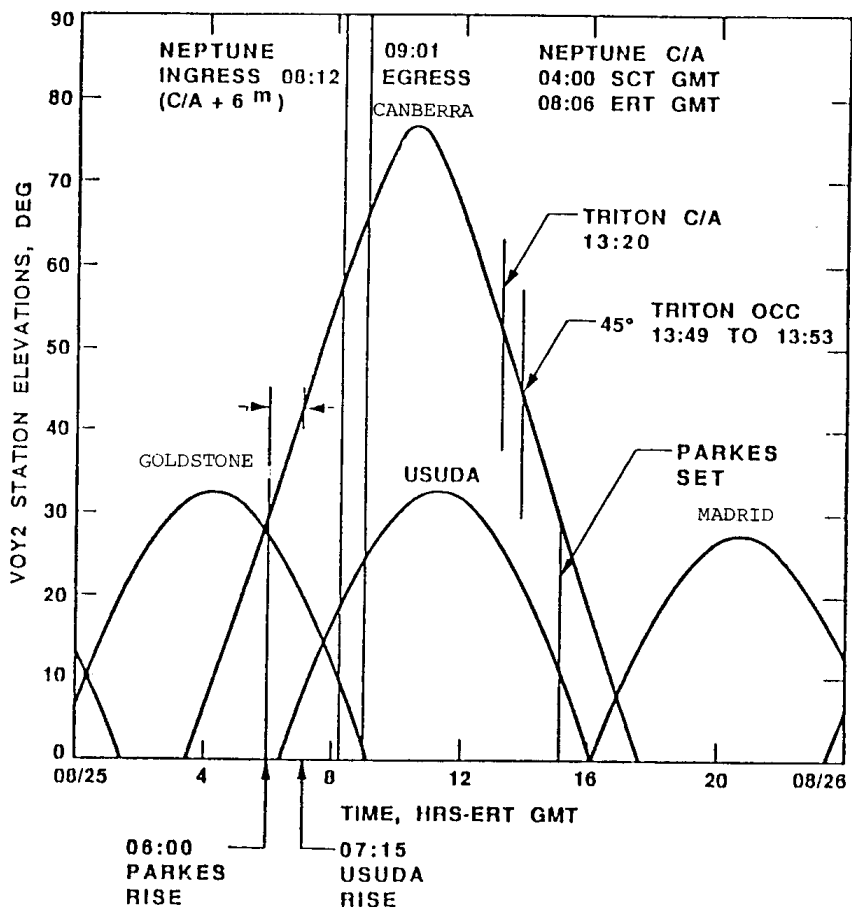


Figure 6: Voyager 2 Neptune Preferred Time of Closest Approach.