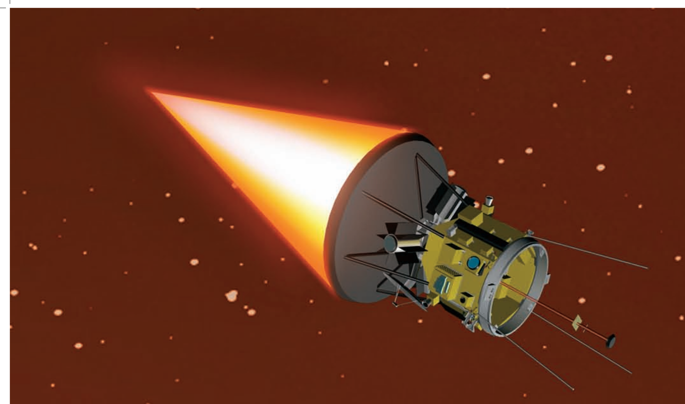

# Solar Probe: Report of the Science and Technology Definition Team


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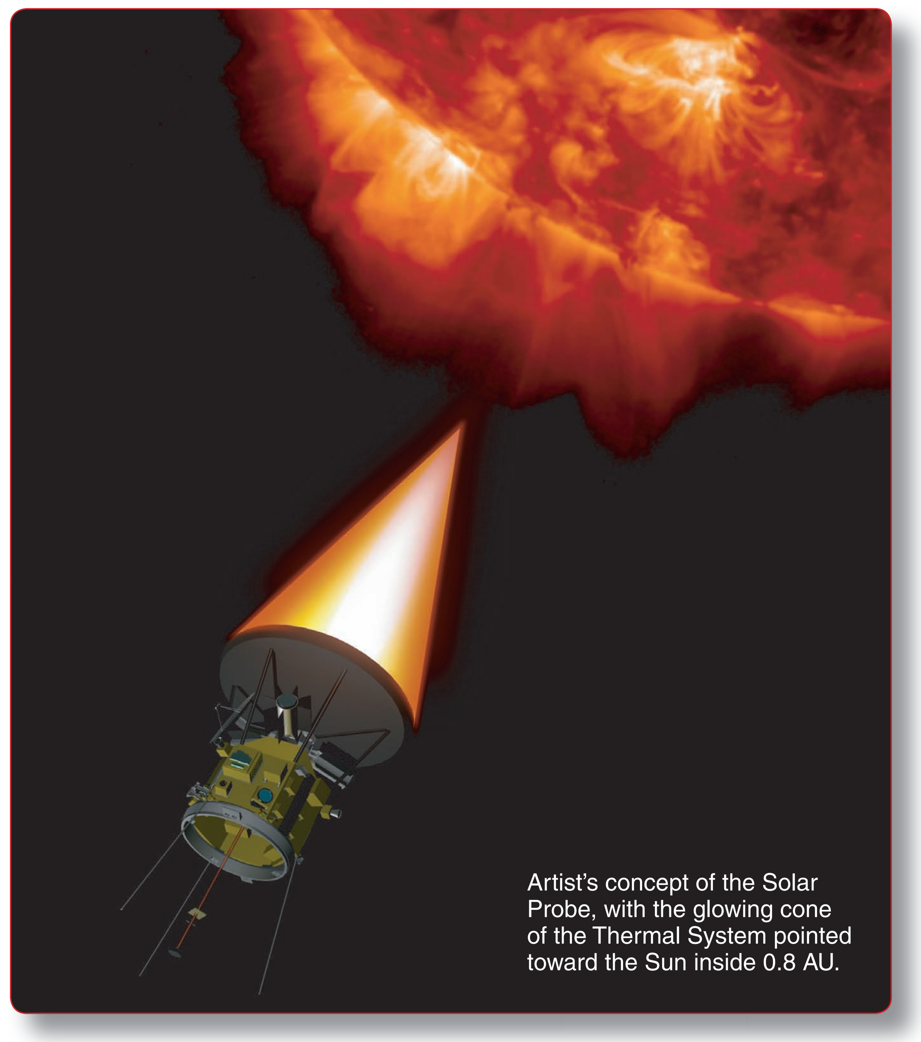


Artist's concept of the Solar Probe, with the glowing cone of the Thermal System pointed toward the Sun inside 0.8 AU.


## Abstract

Solar Probe will be a historic mission, flying into one of the last unexplored regions of the solar system, the Sun's atmosphere or corona, for the first time. Approaching as close as 3 $R_S$ above the Sun's surface, Solar Probe will employ a combination of in-situ measurements and imaging to achieve the mission's primary scientific goal: to understand how the Sun's corona is heated and how the solar wind is accelerated. Solar Probe will revolutionize our knowledge of the physics of the origin and evolution of the solar wind. Moreover, by making the only direct, in-situ measurements of the region where some of the deadliest solar energetic particles are energized, Solar Probe will make unique and fundamental contributions to our ability to characterize and forecast the radiation environment in which future space explorers will work and live.


## Our First Visit to a Star

Solar Probe will be the first spacecraft to venture into the unexplored inner reaches of the heliosphere where the solar wind is born. Through high-cadence in-situ measurements of the solar wind plasma, energetic particles, and fields as close to the Sun as 3 $R_S$, supplemented by coronal and photospheric imaging, Solar Probe will provide the data needed to solve, finally, the twin mysteries of coronal heating and solar wind acceleration.

## Solar Probe Science Objectives

**Determine the structure and dynamics of the magnetic fields at the sources of the solar wind**

a. How does the magnetic field in the solar wind source regions connect to the photosphere and the heliosphere?
b. How do the observed structures in the corona evolve into the solar wind?
c. Is the source of the solar wind steady or intermittent?

**Trace the flow of the energy that heats the solar corona and accelerates the solar wind**

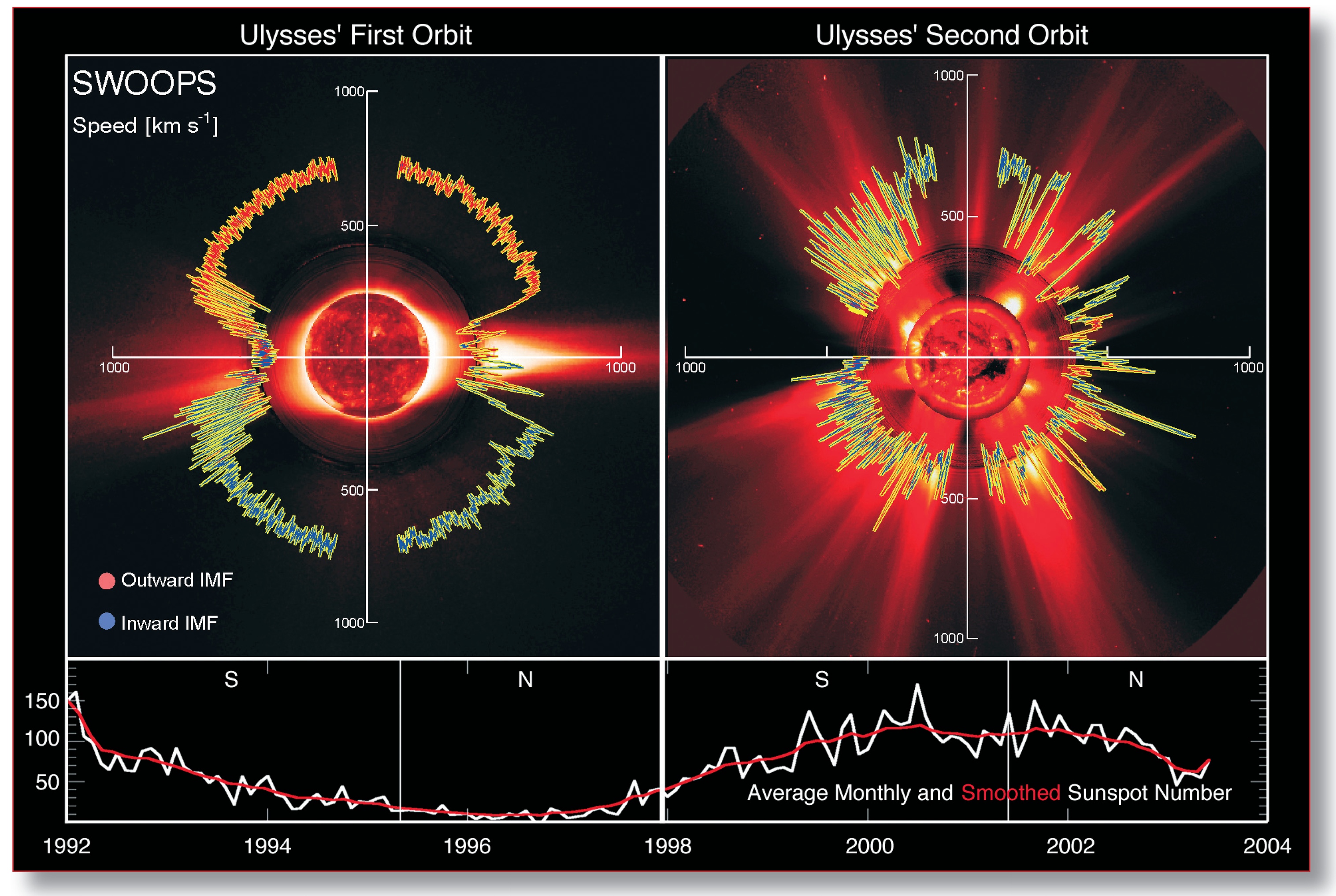
a. How is energy from the lower solar atmosphere transferred to and dissipated in the corona?
b. What coronal processes shape the non-equilibrium velocity distributions observed throughout the heliosphere?
c. How do the processes in the corona affect the properties of the solar wind in the heliosphere?

**Determine what mechanisms accelerate and transport energetic particles**

a. What are the roles of shocks, reconnection, waves, and turbulence in the acceleration of energetic particles?
b. What are the seed populations and physical conditions necessary for energetic particle acceleration?
c. How are energetic particles transported radially and across latitudes from the corona to the heliosphere?

**Explore dusty plasma phenomena and their influence on the solar wind and energetic particle formation**

a. What is the dust environment of the inner heliosphere?
b. What is the origin and composition of dust in the inner heliosphere?
c. What is the nature of dust–plasma interactions and how does dust modify the spacecraft environment close to the Sun?
d. What are the physical and chemical properties of dust-generated species?




Plots of solar wind speed as a function of heliographic latitude, illustrating the relation between the structure of the solar wind and coronal structure at solar minimum (left) and solar maximum (right). The baseline Solar Probe mission provides for two solar flybys, each at a different part of the solar cycle, so that measurements can be obtained at both the quiet and active phases of the cycle. (Ulysses SWOOPS solar wind data are superposed on composite solar images obtained with the SOHO EIT and LASCO C2 instruments and with the Mauna Loa K-coronameter).

## Science Implementation

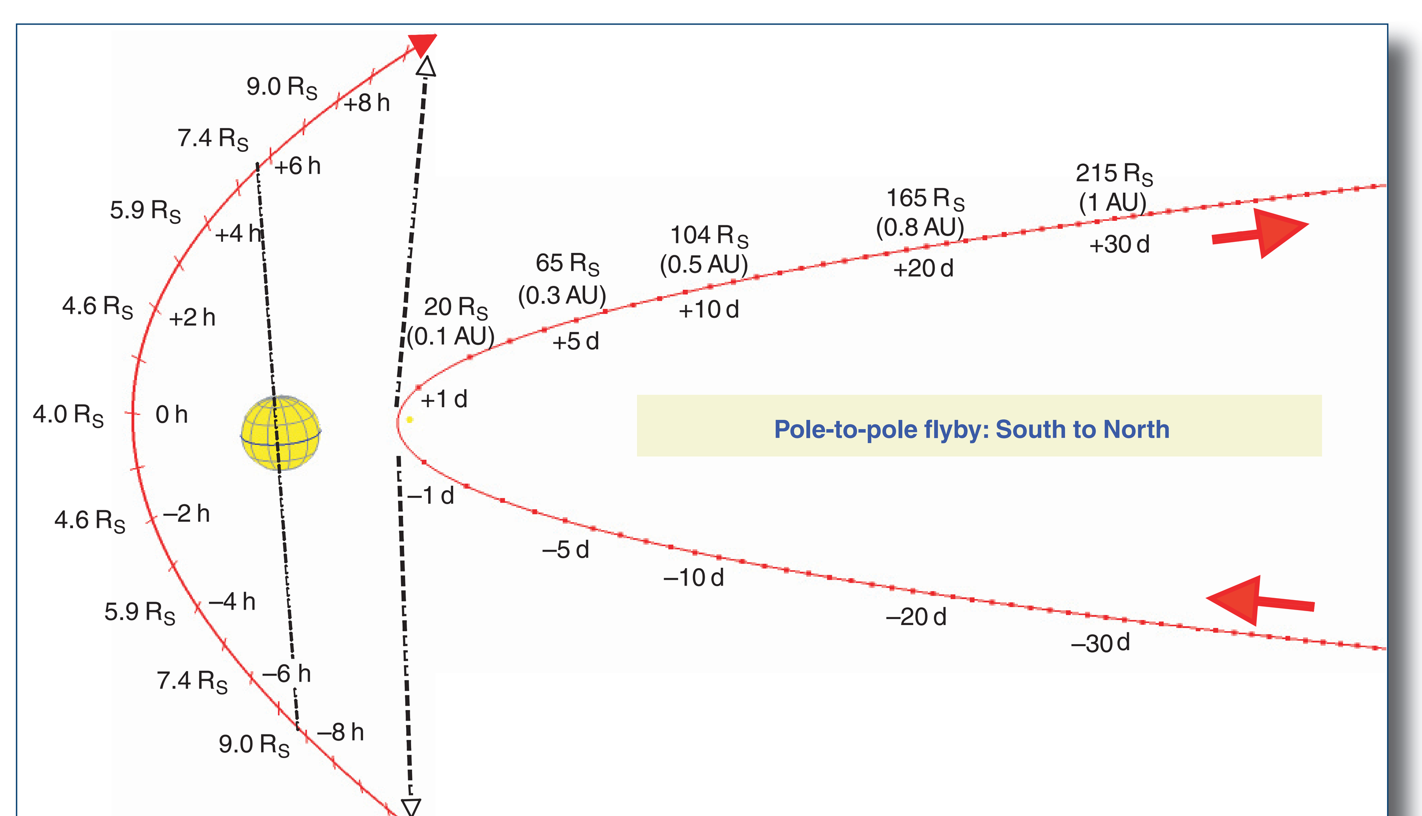
Inside a distance of 0.3 AU on both sides of perihelion, Solar Probe will make in-situ measurements of plasma, suprathermals, energetic particles, magnetic fields, waves, and dust in the near-Sun environment. Extreme ultraviolet and magnetic imaging of solar wind source regions and white-light imaging of coronal structures will be performed on both inbound and outbound legs of the solar pass. The remote-sensing observations will allow in-situ measurements to be related to magnetic and plasma structures at the Sun. Closest approach will occur at a perihelion altitude of 3 $R_S$ above the surface.

## Baseline Mission

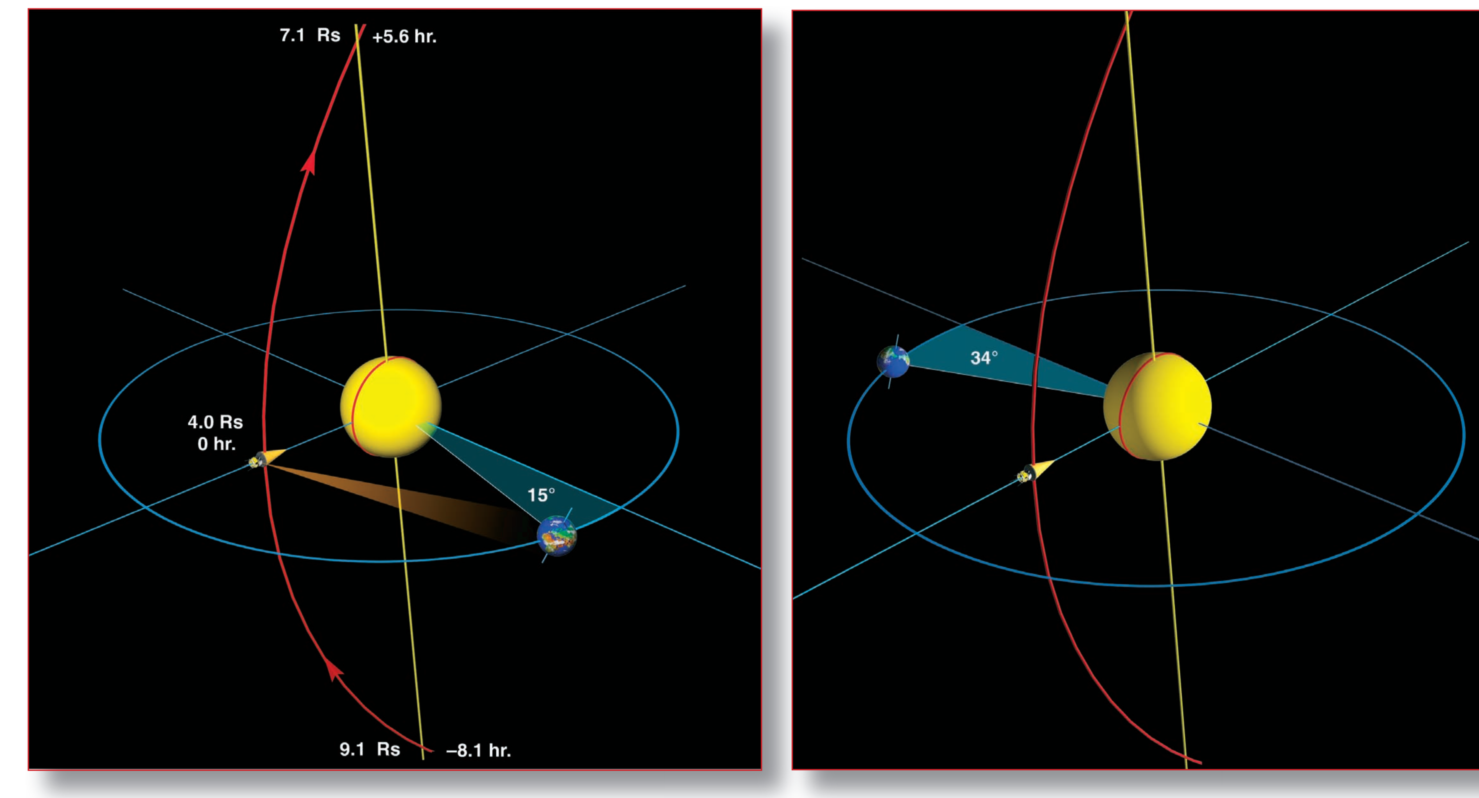
The baseline mission provides for two flybys of the Sun, separated by ~4.6 years, thus allowing Solar Probe to measure the solar wind and corona at different phases of the 11-year solar cycle, independent of launch date. For a launch in 2014, the first flyby will take place in 2018, around the projected activity minimum of solar cycle 24. The second solar flyby will occur in 2023, at a time of increasing solar activity.

For the first encounter, the perihelion pass is designed to take place with Earth 15° off quadrature, allowing for a high data rate (at least 25 kbps) for real-time science telemetry and for simultaneous supporting remote-sensing observations from Earth. Because of coronal scintillation effects, the Ka band will be used for the real-time data transmission. Pole-to-pole passage occurs entirely within 9 $R_S$ and lasts ~14 hours.

The Earth–Sun geometry for the second encounter (34° off quadrature) will again allow for simultaneous remote-sensing observations from Earth.



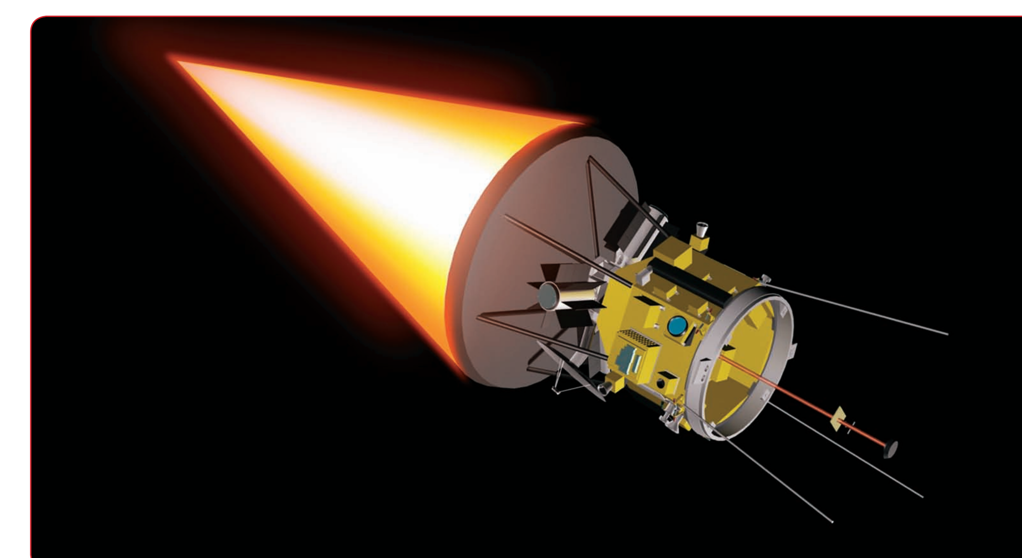

Second solar encounter geometry, with Earth 34° off quadrature.




Geometry of the first and second solar encounters. Earth is positioned 15° off quadrature relative to the Sun–spacecraft line, allowing simultaneous observation from Earth of coronal features being sampled in situ by Solar Probe. The high-gain antenna points earthward (left), enabling real-time data transmission at a high data rate.

## Solar Probe Spacecraft

The baseline Solar Probe is a 3-axis stabilized spacecraft designed to survive and operate successfully in the intense thermal environment that it will encounter during its voyage around the Sun. The spacecraft's most prominent feature is the Thermal Protection System (TPS), comprising a large 2.7-m diameter carbon–carbon conical primary shield with a low-conductivity, low-density secondary shield attached to its base. The TPS protects the spacecraft bus and instruments within its umbra during the solar encounter.



## Solar Probe and Human Exploration

Solar energetic particle (SEP) events present a serious radiation threat to human explorers living and working outside low-Earth orbit. Development of an SEP forecasting capability is critical to space radiation risk mitigation and management. By making the first direct measurements of the near-Sun regions through which all SEPs must travel, by directly sampling the regions where gradual SEPs are energized, and by identifying the seed populations for these dangerous particles, Solar Probe will provide critical ground-truth data needed for the development of the predictive models that, combined with solar and heliospheric monitoring, will enable forecasting of the space radiation environment in support of human exploration.

## Summary

Solar Probe is an exciting mission of exploration, discovery, and deep understanding. The rigor and thoroughness of this study ensures that the described mission is technically feasible, can be accomplished within realistic resources, and can fully achieve its four science objectives, thus transforming our understanding of the Sun and its sister Sun-like stars and enabling exploration.

To understand the genesis of the heliospheric system, it is necessary to determine the mechanisms by which the solar corona is heated and the solar wind is accelerated and to understand how the solar wind evolves in the innermost heliosphere. These objectives will be addressed by a Solar Probe mission. Because of the importance of these objectives for the overall understanding of the solar-heliosphere system, as well as of other stellar systems, a Solar Probe mission should be implemented as soon as possible within the coming decade.

NRC, The Sun to the Earth—and Beyond, a Decadal Research Strategy in Solar and Space Physics (2003)

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