Air and Space this Week

Item of the Week

ULYSSES: OVER THE POLES OF THE SUN

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*The Sun is obviously of critical importance in the widest range of human affairs. It not only nurtures the base of the food change, but also provides most of the energy consumed by humans, either directly (solar cells), semi-directly (*e.g. *wind, hydroelectric), and "fossil" (coal, petroleum). Without it, life on Earth would be almost entirely impossible. Given the dominance of the Sun over everything, it behooves us to learn as much about it as possible. NASA and other agencies knew this from the git-go, building ever-better solar observatories on the Earth, and sending ever-better spacecraft to acquire information about the Sun from Space.*

STUDYING THE SUN

Observations made using the earliest telescopes drastically changed the perception of the Universe around us and our place in it. Galileo's discovery of the moons of Jupiter and the fact that Venus went through a series of phases like our Moon proved conclusively that the Earth could not possibly be the "Center of All Things." And his observations of the Sun made by projecting an image through his telescope showed that its surface had blemishes, a fact that disturbingly ran counter the prevailing assumption that the Sun was "Flawless."

Astronomers after Galileo, all the way up to the advent of access to Space, made progress in understanding our Sun using ground-based telescopes. [My very first copy of *Sky and Telescope* magazine (in 1970) showcased the then-new (still-operating) Big Bear Solar Observatory in the San Gabriel Mountains.] The BBSO has created a list of larger solar observatories: http://www.bbso.njit.edu/newtelescope/large.html.

The development of high-altitude sounding rockets allowed brief glimpses of the Sun at wavelengths normally blocked from us by the atmosphere, a tactic still in use to acquire data regarding the Sun. An example from 2021 is the *Extreme Ultraviolet Variability Experiment*, launched on 9/9/2021 on a Black Brant IX rocket at White Sands Missile Range in New Mexico.

As soon as satellites could be sent into Earth orbit, or even sent into orbits around the Sun, astronomers began launching solar-observing craft. Weather forecasters had learned of the links between terrestrial weather and solar activity, and power transmission engineers had learned of the danger to their equipment posed by solar activity, so understanding "Space weather," especially near the Earth, was very important.

NASA launched three Pioneer-class spacecraft in the mid-1960s to measure the charged particles streaming from the Sun (the "solar wind"), the magnetic field of the Sun and its interaction with that of the Earth, and cosmic rays (very high-energy charged particles). The data they produced allowed the prediction of solar storms, and showed the need for more and better data.

NASA then partnered with DLR, the German Space Agency, on two spacecraft: *Helios 1*, launched in 1974, and *Helios 2*, launched in 1976. Both made important measurements of the solar wind, cosmic rays, and interplanetary dust.

The two Helios satellites were not the only NASA assets in use observing the Sun at this time. The Apollo Telescope Mount on the *Skylab* space station made many observations of the Sun in X-ray, UV, and visible light. ATM was one of the projects in the Apollo Applications Program, which found other valuable ways to use the infrastructure developed for the Apollo Moon landings. The instruments were originally to be mounted on an Apollo service module and flown on a separate, dedicated mission, but when *Skylab* became available as a platform for it, that's where it went.

But one BIG problem remained!

No matter how good the ground-based and Earth orbit-based satellites become, they all are confined to look at the Sun from an observation point more-or-less over the Sun's equator. A lot could be learned by looking at the polar regions of the Sun!

NASA/ESA COLLABORATION

NASA developed the idea of the "gravitational slingshot" to get spacecraft to the desired location in the Solar System. If a spacecraft flew by a planet on exactly the right trajectory, it could gain (or lose) kinetic energy in the process. The tactic was used successfully to reach both the inner Solar System (*Mariner 10*) and the outer Solar System (*Pioneer 11*, *Voyager 1*, and *Voyager 2*). In each of those cases, the spacecraft involved stayed in the general Plane of the Ecliptic, since the Earth, the slinging body, and the destination all were there. But the technique would work if one desired to leave the Plane for some strange reason.

Such as flying over the poles of the Sun.

NASA and ESA both were studying "out-of-ecliptic" solar mission concepts, and decided to collaborate on what they initially called the "International Solar Polar Mission." Each organization would build a spacecraft, which would then be sent as a pair to Jupiter and use its gravity to send them on looping paths, one to fly over each of the Sun's rotational poles. The mission was approved in 1976, the instruments to be used were approved in 1977, and a launch date was set for 1983.

The 1980s were bad years for anything NASA other than the Shuttle, and the funding for their half of the mission was cut in 1981. NASA would still provide launch services for the ESA spacecraft and its RTG power supply (see here), and provide some of the instruments it would carry. The Canadian Space Agency also contributed. The mission had been developed under the name “Odysseus,” since the path it, too like its namesake, would take to get to its destination would be long, not straight, and arduous. It was renamed “Ulysses” at ESA’s request, so that its name would also honor Dante’s character in the *Inferno*.

The design and construction of the *Ulysses* spacecraft continued apace, scheduled for launch on the Space Shuttle *Challenger* in May, 1986. Alas, *Challenger* was lost tragically on January 28, 1986, which pushed the *Ulysse*s launch back to October 6, 1990, aboard the Space Shuttle *Discovery* (STS-41).

PRIMARY MISSION

The deployment of *Ulysses* from *Discovery* went as planned. The two solid-rocket boosters performed flawlessly, too, a Boeing-built Inertial Upper Stage with a McDonnel-Douglas Payload Assist Module. The flight to Jupiter was without significant problem, with the spacecraft arriving there on February 8, 1992. The gravitational redirection of the spacecraft altered its orbit to be at an angle of 80.2° to the Ecliptic, and put it into an elliptical orbit with its perihelion at about 1 AU and its aphelion at about 5 AU, with an orbital period of about six years.

The higher speed in the orbit during perihelion meant that *Ulysses* would overfly both poles of the Sun by mid-1995 (Kepler’s Second Law). It did so successfully, and ESA extended its mission (the “Second Solar Orbit”) to allow for a second pair of successful overpasses, finishing those at the end of 2001. ESA granted another three-year extension, and then another, which would allow a third pair of polar overflights, in 2007 and 2008.

Ulysses was functioning well beyond its planned lifetime, but by 2008, was showing its age. It had already achieved success in every pre-mission category. The power output of the RTG aboard was declining to the point that it could not operate all of the instruments simultaneously, and it would soon be unable to generate enough heat to keep the hydrazine thruster fuel liquid in the cold of interplanetary Space. Without thrusters, keeping the only operational antenna pointed at the Earth was impossible.

Contact was lost with *Ulysses* on June 30, 2009.

SURPRISE TARGETS OF OPPORTUNITY

In Space exploration, as in many facets of life, if one puts oneself in a position to succeed, success will usually follow. Not always, but often. And in some cases, being prepared to succeed allows successes to happen that were not expected at the time of the initial endeavor.

I cited one such example of an unexpected success in the Item of the Week about the *Mariner 4* mission. Mission controllers realized that *Mariner 4* had to pass behind Mars, as seen from Earth, during its fly-by of the Red Planet and determined that, after the mission was fully planned, additional information about the density and structure of the martian atmosphere could be obtained merely by seeing how the radio signal from *Mariner 4* would be attenuated by Mars’ atmosphere during the pass-behind event.

The same sort of thing happened, more than once, with *Ulysses*! During the Second Solar Orbit extended mission, *Ulysses* unexpectedly passed through the tails of three comets: C/1996 B2 Hyakutake, C/1999 T1 McNaught-Hartley, and C/2006 P1 McNaught.

On May 1, 1996, *Ulysses* entered the ion tail of Hyakutake, showing that it extended much farther from the comet than previously thought detectable (3.8 AU!). The same thing happened in 2004 when a coronal mass ejection blasted material from McNaught-Hartley into *Ulysses*' way. The third comet tail encounter came three years after the second, allowing astronomers to determine that the speed of the solar wind was slower than expected.

A hot topic in astrophysical research today is that of "gamma ray bursts," sudden and brief flashes of gamma rays resulting from immensely-energetic events in distant galaxies, thought to be generated by the formation of black holes. They've been studied for over 50 years after their discovery on June 1, 1973! The earliest detections showed that something was out there causing huge bursts of energy, but the detectors of the time were insufficient to allow the origin points of the bursts to be determined precisely. Ulysses has a gamma-ray detector aboard, and its observations, especially when Ulysses was far above/below the Ecliptic, allowed the source regions to be determined by triangulation.

SUMMARY OF DISCOVERIES

In addition to the bonuses of comet tail and gamma ray burst observations, Ulysses showed that:

> The Sun's magnetic field interactions with the rest of the Solar System are much more complex than previously thought.
>
> The infall of interstellar dust into the Solar System was 30x greater than previously thought.
>
> The data from the third solar polar overpasses showed that the solar magnetic field was weakening, and that the solar wind had grown progressively-weaker during Ulysses' mission and was at its weakest compared to any time during the Space Age.

THE END

Ulysses operated four times longer than it was designed to. The signal from its high-gain antenna failed on January 15, 2008, and as the distance to Earth increased after the third pair of polar overpasses, the low-gain antenna's signal became too weak to detect. The RTG power output was so low that the hydrazine powering its thrusters, keeping the low-gain antenna pointed at Earth, was on the verge of freezing, too. NASA controllers had planned to shut down the spacecraft on July 1, 2008, but they were able to maintain contact until June 30, 2009. *Ulysses* is in a relatively-stable heliocentric orbit and will remain so until/unless an encounter with Jupiter deflects it, likely to a trajectory that will expel *Ulysses* from the Solar System.

Ulysses wasn't the first spacecraft/satellite built to study the Sun, but it did play an important role, setting the stage for the successes of the missions that followed, including but not limited to: ESA's *Solar and Heliophysics Observatory* (*SOHO*), *STEREO*, *TRACE*, *WIND*, ESA's *Solar Orbiter*, Solar Dynamics Observatory, and the *Parker Solar Probe*.

REFERENCES

NSSDCA: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1990-090B

NASA In-Depth: https://solarsystem.nasa.gov/missions/ulysses/in-depth

Mission Website: https://www.esa.int/Science_Exploration/Space_Science/Ulysses_overview

End of Mission info: https://rps.nasa.gov/news/16/ulysses-spacecraft-ends-historic-mission-of-discovery

Wikipedia: https://en.wikipedia.org/wiki/Ulysses_(spacecraft)

Spacecraft Description: https://web.archive.org/web/20041025102441/http://ulysses-ops.jpl.esa.int/ulsfct/spacecraft/scframe.html

Max Planck Institut: https://web.archive.org/web/20061101094503/http://www.mps.mpg.de/de/projekte/ulysses

Paper on McNaught Ion Tail: https://iopscience.iop.org/article/10.1086/521019

JPL End of Mission Note: https://web.archive.org/web/20061101094503/http://www.mps.mpg.de/de/projekte/ulysses

Solar Missions Overview: https://www.skyatnightmagazine.com/space-missions/solar-missions-scientists-study-sun

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