Air and Space this Week

Item of the Week

Two Accomplishments at Saturn

Originally appeared August 30, 2021

KEY WORDS: ***Pioneer 11*** ***Voyager 1*** ***Voyager 2*** **Saturn** **Titan** **Io** **"Called Shot"** **Peale, Cassen, Reynolds**

This two-week period includes two important milestones in the exploration of the outer Solar System, involving the spacecraft Pioneer 11 *and* Voyager 1*.* Pioneer 11 *was the first ever spacecraft to fly by Saturn, and* Voyager 1*'s success at its fly-by of Saturn allowed its companion,* Voyager 2*, to continue outward and be our only spacecraft to fly-by Uranus and Neptune.*

Pioneer 11

NASA cut short its Apollo explorations of the Moon in 1972, cancelling the final three planned missions and forcing a re-organization of the plans for the Apollo 15, 16, and 17 missions. However, plans set in motion before/during Apollo would allow NASA to pursue robotic exploration of the rest of the Solar System vigorously. The focus today is on two important such missions, *Pioneer 11*, the first spacecraft to fly-by Saturn (on **September 1**, 1979) and *Voyager 1* (launched on **September 5**, 1977).

Pioneer 11 was one of the last in a long line of spacecraft designed to make our initial observations of the Solar System.

Pioneers 0, 1, and *2* were America's fist attempt to orbit the Moon for a more up-close reconnaissance than could be conducted from Earth. Alas, all three failed. First was a spacecraft initially named "Able," launched just after the first successful launch of a US satellite into Earth orbit, on 8/7/58. Since it was the prototype of the Explorer series to follow, it was renamed "Pioneer 0." Its booster failed. Able was launched by the military; the next in the series would be NASA's first launch. *Pioneer 1* did a little better; it suffered a failure of its upper stage and could not reach the Moon, but it did return useful data of the Van Allen radiation belt, high above the Earth. *Pioneer 2*'s third stage failed to ignite, and no data were received from the spacecraft before it crashed back to Earth.

The radiation belt was of significant interest, and the next two Pioneers were built to investigate it further as they approached the Moon. The first stage of *Pioneer 3*'s booster (launched on 12/6/58) cut off prematurely, causing the spacecraft to follow a very high ballistic trajectory. All was not lost however, the radiation detector carried aboard *Pioneer 3* discovered the second Van Allen belt. The rocket carrying *Pioneer 4* (launched 3/3/59) worked properly, making *Pioneer 4* the first US spacecraft to achieve an escape trajectory (from Earth). Alas, it missed the Moon by a much wider margin than planned, but its radiation detector did provide data from the Earth/Moon distance and beyond.

Pioneer 5's mission was to map the interplanetary magnetic field from a solar orbit. Launched on 3/11/60, its mission was largely successful.

NASA's "batting average" improved dramatically with the next set of Pioneer missions. The next five spacecraft were designed to study the solar magnetic field, the solar wind, and cosmic rays. Four of the five were fully successful (*Pioneers 6, 7, 8,* and *9*, launched in the latter half of the 1960s). The fifth suffered a launch vehicle failure, and did not receive a Pioneer numerical designated as a consequence. It's known as "Pioneer E."

By the time the Apollo landing program really got going, the Pioneer series planners changed focus to the outer Solar System. A modification of the basic Pioneer design would be necessary, because the solar panels of the day would not produce enough power to operate the spacecraft as was done in the earlier Pioneers. They would need to use a radio-isotope thermal generator, or RTG. [For more on RTG power for Solar System exploration, see the past Item of the Week, "The Not-So-Notorious RTG" here.] They would also carry an imaging system and other instruments.

Jupiter was first. *Pioneer 10* was launched on March 3, 1972. It was the first spacecraft ever sent with enough oomph to leave the Solar System completely. It flew by Jupiter in December, 1973, providing a better view of Jupiter than was possible from Earth. We maintained contact with the spacecraft for decades afterward, but its only objective was Jupiter and in that it was a complete success.

The final Pioneers (*12* and *13*) were successfully sent to Venus. They were also known as the *Pioneer Venus Orbiter* and the *Pioneer Venus Multiprobe*, respectively, and will be the topic of a future Item of the Week.

The hero of this story is *Pioneer 11*. Not only did it successfully fly-by Jupiter in December 1974, augmenting results from *Pioneer 10*, it used Jupiter's gravity to send it on to Saturn, giving us our first up-close look of that planet, on **September 1, 1979**. It, too, was/is bound for interplanetary Space. The two Pioneers not only carried imaging systems, they also were equipped to study planetary magnetic fields, radiation fields, the micrometeor environment, and more.

Since both *Pioneer 10* and *11* were on escape trajectories from the Sun, Carl Sagan convinced NASA to send an "interstellar contact card" on both, giving information about Earth to any extraterrestrial that happed to encounter them in the coming eons. We maintained contact with *Pioneer 11* much longer than the mission's design lifetime (last contact was on September 30, 1995).

The data returned were quite useful, but for both Jupiter and Saturn, the Pioneer data tantalized scientists: "If only we could see a little better…"

Help was already on the way.

Voyager 1

The Pioneer spacecraft were about as sophisticated as they were going to get, based on limitations on power, instrumentation, and communications. NASA had the next generation of outer Solar System spacecraft in mind – Project Voyager.

Pioneer 10/11 had given scientists a first look at Jupiter and Saturn, but there were still many mysteries those data only hinted at remaining to explore. Their atmospheres, moons, and much more required further study. We'd eventually put a sophisticated spacecraft in orbit around each, and drop an atmospheric probe into Jupiter and another in Saturn's odd moon, Titan, but an intermediate step was needed. And a quirk of orbital mechanics would help.

NASA had already learned about and had utilized the gravity of one planet to re-direct and accelerate a spacecraft to a more distant objective. The orbit wizards at NASA also realized that the way the outer planets were aligned provided a once-in-176-years opportunity to send a spacecraft to Jupiter, then Saturn, then Uranus, and then Neptune, taking a much, much shorter amount of time than would be possible targeting the outer planets separately.

The rub was that the launch window to make such a "Grand Tour" opened, briefly, in 1977. Worse, Congress was in a budget-cutting mood, and would only authorize a mission as far as Saturn.

Long-duration spaceflight is difficult enough today; with early 1970s technology, it was even tougher, so NASA planned for double redundancy, preparing two spacecraft, not one. The primary mission of this next program would be two-fold, amplify the information received from the Pioneers and study in particular Saturn's moon, Titan, known to have an atmosphere even denser than that of Earth. The technology needed to build evermore-capable spacecraft advanced rapidly in the immediate post-Apollo era, so *Voyager 1* and *2* were much more advanced than their Pioneering predecessors: better instruments, better control systems, and better communication capability.

I've learned over the years that when the suits tell the nerds not to do something that the nerds want to do, the nerds will find a way. And so it was with Voyager. While not officially approved, everyone involved with the Voyager program kept the Grand Tour concept in the back of their minds.

Voyager 1 would make a surprising fundamental discovery at Jupiter, and *Voyager 2* was one of the most successful missions flown, but that success would depend critically on *Voyager 1* being a success at Saturn….

The Lucky Launches

Voyager 2 was actually launched before *Voyager 1* (8/20/77 and 9/5/77, respectively). *Voyager 1* was on a faster trajectory and would arrive at Jupiter first, hence the numbering. *Voyager 1*'s booster underperformed significantly; *Voyager 1* could still make both Jupiter and Saturn, but just barely. Had the boosters on the two spacecraft been switched, however, it would have been impossible for either Voyager to get past Saturn, and we would know much, much less about Uranus, Neptune, and their moons than we do today!

Voyager 1 Success #1: Planetary Exploration's "Called Shot"

Background: Baseball's Famous "Called Shot"

Setting: 1932 World Series, Game 3, Yankees versus Cubs, series 2-0 Yankees. Babe Ruth and Lou Gehrig would hit two homers each that day, but Ruth's second has entered baseball lore as one of the most famous homers in baseball history.

Ruth at the plate in the fifth inning, with score tied 4-4 (Ruth 3 run homer in first; Gehrig solo shot in third) and one out. The Cubs bench was giving Ruth grief; the pitcher works the count to 2-2. What happened next is the stuff of legend, in part due to Ruth's boldness, in part due to there being no good recording of the event (and many more people swore they saw it in person than would have fit in Wrigley Field!). Ruth, in response to the Cubs taunting, is alleged to have pointed to the centerfield seats prior to hitting the very next pitch directly over, far over, the indicated spot.

The audacity of predicting the homer, then delivering immediately, was indeed the stuff of legend. A recent Internet search on "Babe Ruth" "Called Shot" returned 55,800 results!

The Prediction for Io

Io was known prior to *Voyager 1*'s fly-by as being rather odd. For one thing there was a cloud of sodium ions in its orbit, and it seemed to have an odd color, but Io's true nature was unknown to us. Then, in the 2 March 1979 edition of the prestigious scientific journal, *Science,* there appeared a short paper by Stanton Peale, Pat Cassen, and Ray Reynolds, entitled, "Melting of Io by Tidal Dissipation." The investigators had realized that Io was subjected to a gravitational "tug-of-war" between Jupiter and the other three Galilean satellites, especially the closest, Europa. Tides induced by their gravity flexed the interior of Io, generating, as they calculated, huge amounts of heat. They "pointed to the centerfield fence" with the amazingly-astute predictions that "…Io might currently be the most intensely heated terrestrial-type body in the solar system" and that "Voyager images of Io may reveal evidence for a planetary structure and history dramatically different from any previously observed," and more specifically, that "…one might speculate that widespread and recurrent surface volcanism would occur…' All this hitting print one week before the Voyager 1 fly-by of Jupiter! *Talk about "pointing at the fence!"*

This is an excellent example of the process of scientific inquiry: observation, formation of a testable hypothesis/hypotheses, testing, then confirmation, revision, or rejection.

The *Voyager 1* Fly-by of Jupiter

Very precise navigation was required to get *Voyager 1* safely through the Jupiter system, on the exact trajectory necessary to use the gravitational "slingshot" technique to re-direct itself to Saturn. Precise positioning information was also needed on approach in order to pre-plan the data acquisition process, which would have to be accomplished without human control since the Earth-Io signal travel time was too long for real-time management. After the fly-by, mission navigators would look back “over the shoulder” at Jupiter’s now-backlit larger moons, to gain information that would allow precise measurements of their orbits.

Part of the navigation process Voyager managers used was to take images of Jupiter and its moons against the background stars. They could calculate ahead of time exactly where those nearer objects should be relative to the stars, and by comparing in real-time, minute course corrections could be made. The images of Jupiter were astonishing everyone as they came in, but the navigator’s shots were not as visually impressive, since they had to be greatly overexposed to show the faint stars.

Navigation and study of orbits this way required, with 1970’s technology, a team of navigators and data handlers. One of those folks was Linda Morabito, who was working on the data needed for moon orbit refinement four days after the fly-by (March 9). The viewing and illumination geometries meant that Io, her first target that morning, was mostly backlit, making Io show a thin crescent phase. But the non-illuminated part of Io was visible, too, reflecting not direct sunlight but that light that bounced toward the spacecraft after reflecting off Jupiter, just as “The Old Moon in the New Moon’s Arms” (aka “Earthshine” causes under favorable conditions on Earth). The navigators didn’t like working with crescents, since they needed to determine the visual center of the moon being used, on the other hand, it was easier seeing faint stars near the non-lit side of Io. In any case, Ms. Morabito had her work cut out for her that morning.

Io was not present in the first image she examined, and one of the stars she expected to see near Io in the second image was not visible. She then moved to a fainter star should lie near the darker edge of Io, and she began to use a contrast stretch image enhancement to make that star more visible. But as she did so, something appeared that made her forget about that star or navigating the Jupiter system. It looked like there was *another* moon peeking out from behind Io! But Ms. Morabito was very familiar with the location of the other larger satellites of Jupiter, and quickly determined that there was no other moon anywhere near that particular line of sight. She and Steve Synnott, one of the scientists involved in the orbit determination effort, quickly eliminated other possible causes of this plume-shaped spot on Io’s limb. Then some of the science team got involved. The phenomenon, whatever it was, triggered several “Wow!” moments as possibilities were considered.

The location of the plume-shaped spot relative to surface features on Io previously observed was determined to sit directly over one of the largest surface markings on Io. A lot of folks were involved now, and it was becoming clear that Io had active volcanism; the “plume-shaped spot” was, in fact, material being spewed upward by a volcanic eruption in progress! By March 12, a number of volcanic areas, active and not, had been identified. The “homer” predicted by Peale, Cassen, and Reynolds cleared the designated spot in center field by a considerable margin!

Voyager 2 was four months behind *Voyager 1*, *en route* to the first pass on what would become the Grand Tour of the outer solar system (to this day, our only close-up images of Uranus and Neptune and their moons came from *Voyager 2*). There was time to alter the trajectory of

Voyager 2 to get a follow-up look at Io's volcanic plumes for confirmation and observation of changes.

Voyager 1's Success #2

The primary mission of both Voyagers was to obtain data from Jupiter and its moons, and Saturn and its moons, with special attention to Saturn's moon, Titan, the only moon in the Solar System with an appreciable atmosphere. If *Voyager 1* failed to accomplish all of the mission objectives, then *Voyager 2* would be there to make the observations.

Given *Voyager 1*'s launch date, it had no chance of going on past Saturn, regardless of its path past Jupiter and Saturn. So the unspoken hopes of the planetary folks to get to see Uranus and Neptune up close for "free" depended on *Voyager 2* taking the appropriate path past Saturn, one that did not allow a good view of Titan. They could get a LOT more data than planned, as ***only NASA can***, but only if *Voyager 1* could complete all of the mission requirements at Titan.

Voyager 1 did complete all of its mission objectives at Saturn, including making the designated observations of Titan. The path to Uranus and Neptune was clear!

The costs of continuing the *Voyager 2* mission were tiny compared to the costs of mounting a separate mission to the outermost Solar System. And public support was considerably higher for keeping the successful and popular mission going, so Congress acquiesced, and the rest is a happy history. We're not flying the Shuttle anymore, but NASA is exploring the Solar System aggressively nonetheless. But we've yet to return to Uranus and Neptune in the 45+ years of *Voyager 2*'s mission.

Carl Sagan had struck again. Not only did he get the Pioneer plaques placed on *Pioneers 10* and *11*, he got a more sophisticated message on both V'gers, along with a "gold record" of the *Sounds of Earth*.

Voyager 1 made one more visual contribution to Science (and public perception) before turning off its cameras, on a task for which Sagan was also responsible. In 1990, *Voyager 1* looked back on the way from whence it came, and took a final sequence of 60 images, showing six of our Solar System's planets. The so-called "Family Portrait" shows just how small and insignificant we are in the Grand Scheme of Things, and how small and fragile our Pale Blue Dot really is.

Battery Bunny: Meet the Voyagers!

Both Voyagers are, of course, powered by an RTG more powerful than those carried on *Pioneers 10/11*, and their communications systems are more capable. We are STILL in communication with both, and have gained valuable observations long after their planetary fly-bys were completed. They just keep going, and going….

The two Pioneers, the two Voyagers, and *New Horizons* spacecraft are the only ones to date to be on a trajectory that will cause them to leave the Solar System.

Both Voyagers are the most distant spacecraft from the Sun, and both have reported on the characteristics of the heliopause, the zone in deep Space where the effects of the Sun (solar wind) are lost in the background of radiation from extra-solar sources.

REFERENCES

Pioneer 11

Pioneer 11 from NSSDC: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1973-019A

NSSDC *Pioneer 10/11* info: https://nssdc.gsfc.nasa.gov/planetary/pioneer10-11.html

Pioneer 10/11 Plaque: https://en.wikipedia.org/wiki/Pioneer_plaque

Pioneer 11 data records from NSSDC: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/displayDataset.action?spacecraftId=1973-019A

Science article for results from *Pioneer 11*: https://science.sciencemag.org/content/188/4187/447

Blogpost by Roger Launius from March 15, 2013, "Venturing to the Outer Solar System: Pioneer 10 and 11 and the Technology of Long Duration Space Exploration," https://launiusr.wordpress.com/2013/03/15/venturing-to-the-outer-solar-system-pioneer-10-and-11-and-the-technology-of-long-duration-space-exploration

One of the best overall information resource on the Pioneer 10/11 missions is: NASA SP-**446**, 1980, Pioneer: First to Jupiter, Saturn, and Beyond: https://babel.hathitrust.org/cgi/pt?id=mdp.39015040288386&view=1up&seq=1 [NOTE: the NSSDC page for *Pioneer 11* lists the number for this document at NASA SP-466 instead of -446.]

Another excellent resource for the exploration of the outer Solar System is "Beyond Earth: A Chronicle of Deep Space Exploration, by Asif A. Siddiqi; https://www.nasa.gov/sites/default/files/atoms/files/beyond-earth-tagged.pdf

Also see Sagan, Carl, 1973, *The Cosmic Connection: An Extraterrestrial Connection*, ISBN: 0-385-00457-5; Chapter 4 is about the Pioneer plaque

Voyager 1

NSSDC *Voyager 1*: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1977-084A

The *Journal of Geophysical Research* published special editions on the Voyager missions to Jupiter (volume 86, number A10, September 20, 1981) and Saturn (volume 88, number A11, November 11, 1983)

Underperformance of the *Voyager 1* booster: https://voyager.jpl.nasa.gov/share/#group-8 and https://skyandtelescope.org/astronomy-news/voyager-2s-lucky-day

Babe Ruth's "Called Shot": https://baseballhall.org/discover-more/stories/baseball-history/called-shot

"Called Shot at Io": Peale, S.J., Cassen, P. and R.T. Reynolds, 1979, Melting of Io by Tidal Dissipation," Science, v. 203, 02 March 1979, pages 892-892. Available via JSTOR at: http://www.jstor.org/stable/1747884

"Called Shot at Io": Strom, R.G. and others, 1981, Volcanic eruptions on Io, Journal of Geophysical Research, v.86, no. A10, pages 8593-8620. Link: http://onlinelibrary.wiley.com/doi/10.1029/JA086iA10p08593/epdf

"Called Shot at Io": Linda Morabito's account of her role: http://www.calacademy.org:8080/sites/default/files/assets/docs/pdf/discovery_of_volcanic_activity_on_io.pdf

Voyager Gold Record and Its Cover: https://voyager.jpl.nasa.gov/golden-record

Voyager 1's Family Portrait: https://solarsystem.nasa.gov/resources/700/first-ever-solar-system-family-portrait-1990

Voyager's Interstellar Mission: https://voyager.jpl.nasa.gov/mission/interstellar-mission

Last Edited on 30 August 2021