Air and Space this Week

Item of the Week

NASA's Discovery Program

Originally appeared February 21, 2022

KEY WORDS: Discovery Program NEAR Shoemaker Mars Pathfinder Lunar Prospector Stardust Genesis CONTOUR MESSENGER Deep Impact Dawn Kepler GRAIL InSight Lucy Psyche VERITAS DAVINCI

NASA conducts Solar System exploration and astronomical observation aggressively, using three broad categories of robotic spacecraft. Big projects like the James Webb Space Telescope *and* Perseverance *are called "Large Strategic Science Missions." The have high complexity and cost, and are used to address multiple science and technology objectives. Missions somewhat smaller in all categories are in the NASA New Frontiers Program, which has more tightly-focused science objectives; examples include the* New Horizons *Pluto (and beyond) mission and* OSIRIS-REx *asteroid return mission.*

The third class of NASA missions are in the ***NASA Discovery Program****.*

DISCOVERY PROGRAM OVERVIEW

The Discovery Program's origin in the 1990's was an outgrowth of the then-Administrator of NASA, Daniel Golden, whose mantra was, "faster, better, cheaper." Discovery-class missions are smaller in both science and engineering scope, allowing for quicker development and construction, and lower costs per mission. We'll hold off on the "better" part for now.

The DP also had a major change in mission planning and selection from that previous. Prior to the DP, NASA programs specified the mission and science objectives, then sought external construction and science operators. The Discovery Program put out an Announcement of Opportunity (AO) call for proposals for any Solar System objective, which would be assessed by a peer review committee. The Principal Investigator for the proposal would form a team of experts from the broader academic, government, and commercial community.

PI's can also propose to design, build, and operate individual instruments that would become part of a mission managed by one or more of NASA's international partners. NASA also accepts proposals to re-purpose an existing spacecraft for another/additional research. Most mission proposal AOs are released in pairs, with each pair a few years apart. NASA receives many more really good proposals than they can accept each cycle. Some are updated as appropriate and are re-submitted in the next cycle.

To date, thirteen DP missions have been launched, another is set to launch in July, and two more have been approved. The DP also contributes scientific instruments on missions managed by their international partners.

DISCOVERY CLASS MISSIONS OF THE PAST

The AO/review process had not been fully developed when the first two DP missions were announced. The selectees were the *Near Earth Asteroid Rendezvous* (*NEAR*) and the *Mars Pathfinder*.

NEAR was launched on February 17, 1996. Its mission was to fly closely by the asteroid 253 Mathilda and then orbit asteroid 433 Eros. It carried a multi-spectral imager, and x-ray/gamma ray spectrometer, and a magnetometer. Mathilde was the largest asteroid visited to date, and the first time we got a close look at a body composed of carbonaceous chondrite, debris from the origin of the Solar System. The fly-by was a big success. Mathilda's surface is heavily cratered, and very dark. Its density is low, about 1.3 gm/cc, lighter than rock, implying that Mathilde is not a solid body.

NEAR went on toward its second destination, the asteroid 433 Eros, famous because of its highly elliptical orbit, with a perihelion inside Mercury's orbit. It acquired the name NEAR Shoemaker in honor of planetary scientist Gene Shoemaker after his untimely death. Eros is fairly small, and has an elongated shape. Orbiting a spacecraft around it is a delicate thing because Eros' gravity is so small, but the *NEAR* navigation team did it on their second try, a fine effort with a major contribution by orbital mechanics genius, Mission Director Robert Farquhar. Not only did they manage to enter orbit and get close-range observations, they were actually able to **LAND** the spacecraft on Eros, at a speed low enough for the spacecraft to continue returning data. *NEAR* was not designed to land, at any speed, but the team did it.

The final signals received from *NEAR Shoemaker* came in twenty-one years ago, on **February 28**, 2001. This date, and the **February 17** launch anniversary, are why I picked the Discovery Program for this week's Item!

Mars Pathfinder was the second Discovery Program spacecraft, launched on December 4, 1996. It was NASA's first attempt to land a rover on Mars, and it would use a novel parachute/airbag system to soft land on the surface. The landing technique worked, and the small *Sojourner* rover (about 3 cubic feet) roamed an area near the landing site (named the Carl Sagan Memorial Station), making chemical measurements of the rocks it could reach. The mission was fully successful, and it became quite popular with the public for a number of reasons.

Pathfinder was the first NASA mission with real-time Internet support, bringing the thrill of Mars exploration to the next generation in an incredibly-effective way. *What an outstanding outreach event!*

The hottest toy the previous Christmas was a radio-controlled car. Now one was operating on Mars, the coolest of settings, among rocks with whimsical cartoon names. Information was

being pushed out to the public via a new means, one that younger folks were especially adept with, those that wanted a radio-controlled car the most. The demand on the Internet was crushingly enormous: too many hits wanting too large files. The web guys knew that JPL's server would never be able to handle the load, so they had set up a number of mirror sites ahead of time. They were still overrun, but could rapidly expand, especially when the larger ISP's got on board. For more on this aspect of the mission, see here.

The lander/rover successfully completed its primary and extended missions; the mission was terminated on March 19, 1998. For more on the outreach value of the Pathfinder mission, see here. The archived mission website is here; see also here.

NASA's next Discovery Program AO was released in August, 1994. Twenty-eight proposals were received. The first selection was made in February, 1995, a mission called *Lunar Prospector*, an orbital mission of the Moon. Three other proposals had a "run-off," and the winner in this cycle was announced in November, 1994. It was a comet sample-return mission called *Stardust*.

Lunar Prospector was launched on January 7, 1998, and achieved lunar orbit nine days later. It augmented data obtained by the five Lunar Orbiter missions and Apollo, measuring surface composition and the Moon's magnetic and gravitational fields. After the successful completion of all mission objectives one year later, its orbit was lowered to get higher-resolution data for another six months. At the end of the mission (7/31/1999), it was deliberately crashed into the polar region of the Moon, in the hopes of being able to detect water in the plume ejected by the impact (from ice possibly buried there).

Stardust was launched on February 7, 1999. Its mission was to first fly-by asteroid 5535 Annefrank in November, 2002, *en route* to comet 81P/Wild. It flew into the comet's tail, and used an ingenious aerogel collector to capture a number of the particles just released from the comet, and return them to Earth in a separate return capsule. The main part of Stardust then was sent on an extended mission, **Stardust-NExT**, to fly by comet Temple 1 in order to image the impact crater left by the *Deep Impact* spacecraft. The mission ended on November 2, 2002. The sample return capsule was displayed for a number of years at the National Air and Space Museum.

The next Discovery Program AO came in 1996. The two winning proposals were *CONTOUR* (*COmet Nucleus Tour*), a returnee from the previous proposal cycle, and *Genesis*, a mission to return Solar wind particles to Earth. One of the finalists not selected in this cycle was *MESSENGER*; more on that one later.

Genesis was launched first, on August 8, 2001. It was sent to the L1 Lagrange point of gravitational stability, where it collected Solar wind particles for 850 days. It returned to Earth on September 8, 2004, and dropped off its sample capsule for recovery. Alas, an engineering/construction error prevented the parachute from deploying, and the sample return capsule was damaged upon impact. Amazingly, scientists were able to extract some useful samples from the wreckage! In spite of the accident, *Genesis* accomplished its pre-flight

objectives. The spacecraft main bus was "parked" back at L1, but it eventually drifted off in early 2005 and remains in heliocentric orbit.

CONTOUR was launched on July 3, 2002, on a mission to visit two different comets of note: Comet Encke and Comet Schwassmann-Wachmann-3. Encke's comet was the second – after Halley's – to be identified as "periodic." Comet S-W was known to be disintegrating. Both are parent bodies for meteor showers; both the Northern and Southern Taurids in October/November for the former and the Tau Herculids in May/June for the latter. [CONTOUR's PI was Cornell astronomer Joseph Veverka (a fine scientist and interesting gentleman who had hired me as an undergraduate to work on Viking images of Mars' moons!).] *CONTOUR* was placed in a parking orbit, then fired its solid rocket engine to head out on August 15. The spacecraft broke up due to some sort of structural failure, the only complete failure of the Discovery Program. [Observing note: The ZHR for the three showers mentioned are not high, but both parts of the Taurid shower tend to produce fireballs, just in time for Halloween!]

The selections for the next round of Discovery Program missions were in 1999, and it included the *MESSENGER* mission to orbit Mercury (a non-selected finalist in the previous cycle) and *Deep Impact*, a mission to fly-by a comet and impact it to examine its composition. The Aladdin mission proposal, for a sample return from Mars' moons, was a non-selected finalist for the second time.

The ***MErcury Surface, Space ENvironment, GEochemistry, and Ranging*** (*MESSENGER*) spacecraft was launched on August 3, 2004. Getting into the inner Solar System requires as much or more energy than going outward, and it took slingshot fly-bys of Earth, Venus (twice), and Mercury (thrice) before *MESSENGER* could finally enter Mercury orbit, on March 18, 2011. It was only the second spacecraft to visit Mercury, the first being three fly-bys by *Mariner 10*, which cumulatively imaged only a little over half of Mercury's surface. MESSENGER had a suite of sophisticated instruments aboard, and managed to map the entire surface of the planet in detail in a little over a year. Additional Discovery Program funding was made available for two mission extensions, but finally was out of thruster fuel, using the last of it to de-orbit and impact the planet.

[Here's another example of "NASA Doing the Difficult, as Only NASA Can, and Doing It with STYLE." The use of thrusters for mid-course correction for the roundabout way *MESSENGER* got to Mercury was few and small. After *MESSENGER*'s launch, NASA mission planners devised a procedure to use sunlight on the spacecraft's solar panels to provide small trajectory deflections, saving fuel that helped *MESSENGER* function for a longer time in Mercury orbit!]

The ***Deep Impact*** spacecraft was launched on January 12, 2005. It comprised two components, the main spacecraft bus with all of its instruments, and a 350kg copper-alloy cannonball (non-explosive). Knowing the composition of a comet was a high-priority science objective, one that could be accomplished either by collecting a sample and returning it to Earth for analysis or the method *Deep Impact* used. The copper cannonball would separate from the main spacecraft and hit Comet Tempel 1, releasing the energy equivalent of almost five tons of TNT. The

instruments aboard the main bus would analyze the debris blasted off the comet. [The impact site was later imaged by a fly-by of the *Stardust-NExT* spacecraft, revealing a 150-meter crater.]

Yet Another Example of NASA Style: After observing the impact of the cannonball, the main *Deep Impact* spacecraft was put into "hibernation." It was later reactivated, designated *EPOXI*, and sent to fly-by three additional comets: Hartley 2 (11/4/2010), Garradd C/2009 P1 (in 2012), and Comet ISON (2013). As only NASA can….

One More: *Deep Impact*'s impact occurred on the Fourth of July, 2005. How's that for fireworks – and fireworks planning! And no, Robert Farquhar was not involved in this one…

The next Discovery Program AO release attracted 26 proposals. Three finalists emerged: *Dawn*, *Kepler*, and *INSIDE Jupiter*. The first two were flown, and INSIDE Jupiter morphed into the New Frontiers-class mission, *JUNO*, now in orbit around Jupiter.

Dawn, a mission to orbit asteroid 4 Vesta and the dwarf planet, Ceres, was launched on September 27, 2007. Once it left its LEO transfer orbit, it used ion thrusters, and a Mars fly-by, to get to Vesta (July 16, 2011), and then left on September 5, 2012, to go on to Ceres, entering orbit there on March 6, 2015. It also used hydrazine thrusters for orbit insertion and maintenance. Mission planners slowly lowered Dawn's orbit over Ceres, and NASA provided funding for an open-ended extended mission until its hydrazine thruster fuel was exhausted, which happened on October 31, 2018. The mission was fabulously successful at both bodies, giving us much of what we now know about the two largest objects in the asteroid belt.

Kepler was a space telescope designed primarily for the detection of exoplanets by the transit method. It imaged a small area of the sky in detail, over and over, looking for minute, periodic variations in star brightness, attributable to the passage of an exoplanet between its star and Earth. As of February 19, 2022, NASA's Exoplanet Archive lists 2,709 confirmed exoplanets attributed to *Kepler* data, with another 2,057 identified but awaiting confirmation! In addition, Kepler data also revealed over 2000 new eclipsing binary stars.

The Kepler mission/spacecraft as named for famed astronomer Johannes Kepler, who could calculate the movements of Mercury and Venus so accurately that by the 1630s he could predict those rare occasions when they would be seen in transit (silhouetted against the face of the Sun). *Kepler* was launched on March 7, 2009, and worked hard until it ran out of fuel on October 30, 2018.

The *Kepler* spacecraft was put into a heliocentric orbit, slightly farther from the Sun than Earth, so it trails Earth farther and farther as time goes on; the Earth will catch back up to it in ~51 years or so. The orbit allowed it to examine its area of the sky continuously with little interruption. A typical exoplanet transit lowers the star's apparent brightness by only 80 ppm, so both sensitivity and pointing accuracy become very important. The spacecraft is stabilized by a three-axis reaction wheel system, like that in the *HST*. One of them failed on July 14, 2012, but that was OK since there was a spare one that could be brought on line. When a second wheel failed on May 11, 2013, Kepler could no longer work its primary mission. However, the

mission was extended ("K2") and used for studying other celestial objects, in addition to finding exoplanets with a reduced sensitivity.

The Kepler mission was a resounding success, and was succeeded by the *Transiting Exoplanet Survey Satellite*. Part of Kepler's success was due to its use of Citizen Scientists to help process and review the data for exoplanet signatures, in the "Planet Hunters" program.

The ***Gravity Recovery And Interior Laboratory*** (*GRAIL*) was launched on September 10, 2011. It comprised two identical satellites (named *Ebb* and *Flow* by a Montana school class in a national contest) that would orbit the Moon in exactly the same orbit, separated by ~60°. They would deflect slightly if they passed over a variation in the lunar gravity field. Precise tracking of both allowed for the gravity field to be determined to a high degree of precision, data from which details of the Moon's internal structure could be deduced. The primary mission was fully successful and an extended mission was authorized.

NASA will often run a follow-on mission to build on the success of an earlier mission. *JWST* succeeding *HST* is one example; *Voyager 1/2 – Galileo – JOVE* is another. In this case, however, *GRAIL* is a follow-on not to an earlier Moon mission, but rather to an Earth one. The *Gravity Recovery and Climate Experiment* (*GRACE*) was a successful two-satellite probe of the Earth's internal structure.

In addition to the school contest that resulted in naming the two *GRAIL* satellites, *GRAIL* carried a MoonKAM camera (Moon Knowledge Acquired by Middle-school students), developed by the Sally Ride Science organization, which allowed school kids to ask for specific areas of the Moon to be targeted (*how's that for engaging*!?!).

[**PERSONAL NOTE:** The *GRAIL* mission was the first launch I worked after I detailed over to NASA HQ from NASM. It's a difficult mission concept to get across to the public, and my new boss and I were brainstorming about how we could do that. The original launch date for *GRAIL* was a day earlier than the actual launch, and it happened to be the 45th anniversary of the premiere of the original *Star Trek* series. When I told my new boss that, she smiled oddly; I was sure I had committed a NASA faux pas. But no, what I didn't know was that KSC's Visitor Center already had a *Star Trek* exhibit in place; my new boss arranged for it to remain there through the *GRAIL* launch and for a personal appearance by Nichelle Nichols. The *Star Trek* tie-in was the "hook" we were looking for! Media attention hextupled, and when the launch was postponed, the folks who came with their kids to see it had their disappointment replaced by *Star Trek*/Space learning fun. And in the post-mortem meeting, my new boss went ahead with the creation of NASA's SPACE365 app, using the A+StW database as a starting point! See also here: http://airandspacethisweek.com/astwhistory. Man, oh man, I loved that detail!]

The next Discovery Program AO attracted a number of proposals, but only one "JASSI," was green-lighted for the next step in the selection process. It eventually was also incorporated into the *JUNO* mission now orbiting Jupiter, so no proposals were approved in this cycle.

The next AO was released on June 7, 2010. Three finalists were selected, but only one was approved, a Mars lander, with seismograph, called "InSight."

The next AO was released in February, 2014. Five missions were finalists; two were selected for this cycle, *Psyche* and *Lucy*, and later, two additional were selected, *DAVINCI+* and *VERITAS*.

ACTIVE DISCOVERY-CLASS MISSIONS

The *Interior exploration using Seismic Investigations, Geodesy, and Heat Transport* (*InSight*) mission was **t**he next up in the Discovery Program. It launched on May 5, 2018, and landed safely on Mars on November 26, 2018. It carried a sophisticated seismometer and a probe for measuring the flow of heat from Mars' interior to its surface. NASA had tried to land seismometers on Mars with the Viking landers, but one failed and the other produced data that may have been affected by winds in the thin martian atmosphere shaking the lander. NASA used a landing system that had already worked for the *Mars Phoenix* lander, which helped reduce development costs.

InSight had several instruments aboard that were developed and operated by NASA's international partners. One of them was the main seismometer, but it had technical problems that would force the delay of the launch to the next launch window, a two-year delay. *InSight* also carries, in addition to the seismometer and heat flow device, a radio experiment that will help precisely determine Mars' rotation rate and a laser retroreflector akin to those left on the Moon by Apollo astronauts, that will allow the Earth-Mars distance to be determined with great precision.

Most of *InSight*'s instruments worked and are working well. However, the heat probe ("Heat Flow and Physical Properties Package") indeed went Hfppp. The probe had to be inserted into the ground to measure heat at different depths to ascertain heat flow. Its business end was nicknamed the "Mole" because it was designed to dig itself in about 25 meters. However, the martian soil proved to be so loose that the Mole couldn't get a grip; it only bounce around, and only penetrated about a foot. Mission scientists tried everything they could think of to help it "get a grip," but no joy. The HFP3 experiment was cancelled.

NASA often includes an instrument that is a "concept test" on some of its missions. The *InSight* spacecraft carried two "cube sats," tiny communications relays named *MarCO 1* and *2* (short for "Mars Cube 1" and "Mars Cube 2"). They were deployed before *InSight*'s entry sequence, and successfully relayed telemetry from *InSight* to Earth.

The final Discovery Program spacecraft to be launched to date is ***Lucy***. *Lucy* was launched successfully on October 16, 2021, and is now *en route* to Jupiter, where it will fly-by at least six asteroids associated with Jupiter. Recall that there are five points in a two-body system that are gravitationally stable, first noted by the famed mathematician LaGrange. In the case of Jupiter, the L1 point is between the Sun and Jupiter, Jupiter is always between the Sun and L2, the Sun is always between Jupiter and its L3 point. L4 and L5 are in Jupiter's orbit, but lead it

(L4) or follow it (L5) by 60°. Lucy will need two Earth fly-bys for a gravitational assist to Jupiter's L4 where it will fly-by four asteroids (one with a moon) there. It will then fly-by Earth again to get boosted back to Jupiter, but its L5 this time, where it will fly-by another asteroid and its moon, passing the main belt asteroid 52246 Donaldjohnson on the way.

NOTE: Jupiter's L4 and L5 are called "Trojan points," because several asteroids were discovered there and named after figures from the Trojan War. The term has become generalized for the L4 and L5 points in any planetary system; asteroids trapped in the L4 and L5 points of other Sun-planet systems have been discovered recently.

Lucy is an unusual mission in one respect, its name. It's not named after an artfully-constructed acronym, or a famous long-dead scientist, or its destination. Rather, it is named for Lucy, the fossil hominin skeleton discovered in Ethiopia in 1974. The link? "Just as the Lucy fossil provided unique insights in humanity's evolution, the Luch mission promises to revolutionize our knowledge of planetary origins and the formation of the Solar System, including Earth." The idea is that the Trojan asteroids have been around a long time, relatively unaffected by the Sun, and would, hence, be valuable targets of study.

DISCOVERY-CLASS MISSIONS UNDER DEVELOPMENT

Most meteorites are rocky, but a few percent of those that fall on Earth are metallic, a mixture (primarily) of iron and nickel, with a smattering of other metallic elements. Asteroid 16 Psyche is different than most others as it's, too, metallic, not predominately rocky. The best explanation for iron meteorites, and 16 Psyche, is that they are the fractured remnants of an asteroid that was big enough and hot enough inside for the rock and metal composing it differentiated, with the heavier iron sinking to form a core. Its composition makes 16 Psyche a great candidate for a Discovery mission to examine up close, and NASA management and scientists think so, too.

16 Psyche is big, almost the size of Massachusetts, and is made of mostly metal. And it is outside Earth's gravitational "well." Hmmm! The possibilities….

The ***Psyche*** spacecraft is scheduled for launch in July, 2022. Its projected arrival at asteroid Psyche will be in late January, 2026, after using Mars for a gravity assist on May 23, 2023. It will use "solar electric" propulsion, and carry an imaging system, a magnetometer, and a gamma-ray spectrometer. Its scientific objectives are to determine whether Psyche actually is a core fragment (once-molten iron) or not, map and date its surface features, and characterize the processes that have affected its surface. In addition, *Psyche* will carry a test version new laser communications technology.

The final two approved Discovery missions of the future are going to Venus. The website version of A+StW has been running the following item concerning the latest two Discovery Program selectees: *DAVINCI+* and *VERITAS*.

NASA's focus has been on Mars of late, but understanding Venus, Earth's "Fraternal Twin," is still very important, as we continue to conduct an uncontrolled experiment in the test tube in which we live. This week, NASA announced two new missions for its Discovery program, named **DAVINCI+** and **VERITAS**. The two have complementary missions.

DAVINCI is the **D**eep **A**tmosphere **V**enus **I**nvestigation of **N**oble gases, **C**hemistry, and **I**maging (NASA not only conducts its missions with style, they name them quite ingeniously, too!). It has two components: a descent stage with a laser spectrometer, that will determine atmospheric composition during its hour-long descent to the surface, and an orbiter that will relay signals from the dropped probe and also image the surface. As with *Perseverance* and *LADEE*, *DAVINCI* will also carry a "demonstration" instrument, the "Compact Ultraviolet to Visible Imaging Spectrometer, which will study the process of absorption of ultraviolet light by Venus' atmosphere. Hmmm, "CUVIS," so much for ingenious naming! The mission PI is Jim Garvin, friend and colleague and a former NASA Chief Scientist.

VERITAS is the **V**enus **E**missivity, **R**adio science, **I**nSAR, **T**opography, **A**nd **S**pectroscopy mission (someone must be from Harvard!). This one is an orbiter that will map the surface of Venus in detailed 3-D, looking for evidence of plate tectonics and (active) volcanism features. Like *DAVINCI*, *VERITAS* will also have a demonstrator instrument aboard, JPL's Deep Space Atomic Clock-2, which will generate very precise time signals that will aid future Solar System exploration.

Discovery Program Summary

Thirteen of the sixteen missions listed above have been launched. Eleven missions have been concluded, and two are presently active. Of the eleven, nine were total successes (most overly so); only one was a total failure (*CONTOUR*); the *Genesis* mission's return capsule crashed, but enough information was recovered to allow its mission objectives to be realized successfully. The only other blemish on the record is the failure of the HPP3 heat probe on *InSight*. For robotic astronomy/planetary exploration, that's a Hall of Fame performance in anybody's league!

REFERENCES

Overall Discovery Program

NASA: http://discovery.nasa.gov/lib/pdf/HistoricalDiscoveryProgramInformation.pdf

NASA: https://www.nasa.gov/planetarymissions/discovery.html

Wikipedia: https://en.wikipedia.org/wiki/Discovery_Program

NEAR

NASA: https://solarsystem.nasa.gov/missions/near-shoemaker/in-depth

NASA SSE: https://solarsystem.nasa.gov/news/176/near-shoemakers-historic-landing-on-eros-exceeds-science-engineering-expectations

APL: https://www.jhuapl.edu/Content/techdigest/pdf/V23-N01/23-01-Farquhar.pdf

NSSDC: https://nssdc.gsfc.nasa.gov/planetary/near.html

Wikipedia: https://en.wikipedia.org/wiki/NEAR_Shoemaker

Mars Pathfinder

Mission website: https://mars.nasa.gov/MPF/default.html

NASA: https://nssdc.gsfc.nasa.gov/planetary/mesur.html

JPL's *Mars Pathfinder* at 25: https://roundupreads.jsc.nasa.gov/pages.ashx/1819/25YearsAgoMarsPathfinderLaunchestoMarstoDeploySojournertheFirstPlanetaryRover

Mission Fact Sheet: https://mars.nasa.gov/MPF/mpf/fact_sheet.html

NSSDC: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1996-068A

NSSDC (*Sojourner*): https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=MESURPR

Landing Strategy: https://nssdc.gsfc.nasa.gov/planetary/marsentry.html

Final Mission Status Report: https://nssdc.gsfc.nasa.gov/planetary/text/marspath_status.txt

Rock Names: http://content.time.com/time/subscriber/article/0,33009,986723-3,00.html

Boo Boo Anaglyph: https://mars.nasa.gov/resources/boo-boo-in-super-resolution-from-super-panorama

"The Day the Internet Stood Still" https://www.nasa.gov/specials/pathfinder20/?linkId=39514656

Webmastering Mars: https://mars.nasa.gov/MPF//press/webreview/index3.html

Wikipedia: https://en.wikipedia.org/wiki/Mars_Pathfinder

Lunar Prospector

NSSDC: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1998-001A

NASA Mission Profile: https://web.archive.org/web/20070609080820/http://solarsystem.nasa.gov/missions/profile.cfm?MCode=LunarPr

LPI: https://www.lpi.usra.edu/lunar/missions/prospector

Archived Mission website: https://web.archive.org/web/19980109153734/http://lunar.arc.nasa.gov

NSSDC "Ice on the Moon": https://nssdc.gsfc.nasa.gov/planetary/ice/ice_moon.html

NASA KSC: Eureka!:
https://science.ksc.nasa.gov/mirrors/arc/prospector/science/results/lunarice/eureka.html

Binder, Alan B. (2005). *Lunar Prospector: Against all Odds*. Tucson: Ken Press. P. 1181. ISBN 978-1-928771-31-9. OCLC 61137782

Stardust

NASA: https://solarsystem.nasa.gov/missions/stardust/in-depth

NSSDC: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1999-003A

NASA JPL: https://solarsystem.nasa.gov/stardust/mission/index.html

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

Return capsule at NASM: https://airandspace.si.edu/collection-objects/capsule-stardust/nasm_A20080417000

Genesis

NASA *Genesis*: https://www.nasa.gov/mission_pages/genesis/main/index.html

NASA JPL: https://www.jpl.nasa.gov/missions/genesis

Mission website: https://genesis.jpl.nasa.gov

NSSDC: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2001-034A

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

Accident Report: https://www.nasa.gov/pdf/149414main_Genesis_MIB.pdf (BIG file)

CONTOUR

NASA: https://solarsystem.nasa.gov/missions/contour/in-depth

NSSDC: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2002-034A

CONTOUR Mission Mishap Report summary:
https://www.nasa.gov/home/hqnews/2003/oct/HQ_03324_contour.html

SPACEFLIGHT NOW: https://spaceflightnow.com/news/n0310/15contour

MESSENGER

NASA Mission Profile: http://solarsystem.nasa.gov/missions/profile.cfm?Mcode=MESSENGER

NASA Mission Page: https://www.nasa.gov/mission_pages/messenger/main/index.html

APL: https://messenger.jhuapl.edu

NSSDC: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2004-030A

Wikipedia: https://en.wikipedia.org/wiki/MESSENGER

Launch Press Kit: http://www.nasa.gov/pdf/168019main_MESSENGER_71504_PressKit.pdf

Trajectory Design:
http://messenger.jhuapl.edu/the_mission/publications/McAdams.et.al.1998.pdf

Domingue, D.L.; Russell, C.T., editors (2007), *Messenger Mission to Mercury*, New York: Springer. ISBN 9780387772141.

EOS article: https://eos.org/articles/mercurys-secrets-revealed-by-soon-to-crash-spacecraft

Deep Impact

NASA: https://www.nasa.gov/mission_pages/deepimpact/main/index.html#.YhFFB-jMJM8

NASA JPL: https://www.jpl.nasa.gov/missions/deep-impact

NSSDC: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2005-001A (spacecraft)

NSSDC: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2005-001D (cannonball)

Dawn

NASA Overview: https://solarsystem.nasa.gov/missions/dawn/overview

NASA JPL: https://www.jpl.nasa.gov/missions/dawn

Legacy of NASA's *Dawn*: https://www.jpl.nasa.gov/news/legacy-of-nasas-dawn-near-the-end-of-its-mission

*Daw*n at Vesta Press Kit: https://solarsystem.nasa.gov/resources/2225/dawn-at-vesta-press-kit

Dawn at Ceres Press Kit:
https://solarsystem.nasa.gov/system/downloadable_items/2733_dawn-ceres.pdf

NASA PowerPoint deck for NightSky Network:
https://nightsky.jpl.nasa.gov/docs/NSNTeleconDawnDavidWIlliams2014.pdf

Dawn Mission Journal by Marc Rayman:
https://solarsystem.nasa.gov/missions/dawn/mission/dawn-journal

Accomplishments at Vesta: https://solarsystem.nasa.gov/missions/dawn/science/vesta

Dawn's Ion Propulsion: https://ntrs.nasa.gov/citations/20150014763

NSSDC: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2007-043A

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

NOTE: An excellent on-line book about spacecraft exploration of the Solar System and beyond is by Asif A. Siddiqi, called "Beyond Earth: A Chronicle of Deep Space Exploration, 1958-2016." If you are interested in Space exploration, download it!
https://www.nasa.gov/sites/default/files/atoms/files/beyond-earth-tagged.pdf

Kepler

NASA: https://www.nasa.gov/mission_pages/kepler/main/index.html

NASA JPL: https://www.jpl.nasa.gov/missions/kepler

Planet Hunters Citizen Science (extension for *TESS*): https://www.zooniverse.org/projects/nora-dot-eisner/planet-hunters-tess

Kepler's retirement: https://www.jpl.nasa.gov/news/nasa-retires-kepler-space-telescope

NASA Exoplanet Archive: https://exoplanetarchive.ipac.caltech.edu/docs/counts_detail.html

Wikipedia: https://exoplanetarchive.ipac.caltech.edu/docs/counts_detail.html (excellent)

Kepler Poster: https://exoplanets.nasa.gov/resources/2281/kepler-space-telescope-poster

GRAIL

NASA Overview: https://www.nasa.gov/mission_pages/grail/overview/index.html

NASA JPL: https://www.jpl.nasa.gov/missions/gravity-recovery-and-interior-laboratory-grail

GRAIL Lunar Gravity Map: https://www.jpl.nasa.gov/news/nasas-grail-creates-most-accurate-moon-gravity-map

NASA *GRAIL* Press Kit: https://www.nasa.gov/pdf/582116main_GRAIL_launch_press_kit.pdf

Wikipedia: https://en.wikipedia.org/wiki/GRAIL

GRAIL MoonKAM: https://www.jpl.nasa.gov/infographics/grails-moonkam

GRACE mission: https://www.nasa.gov/mission_pages/Grace/index.html

InSight

NASA: https://mars.nasa.gov/insight

NASA: https://www.nasa.gov/mission_pages/insight/main/index.html

Mars *InSight* Launch Press Kit: https://www.jpl.nasa.gov/news/press_kits/insight/launch/download/mars_insight_launch_presskit.pdf

JPL: https://www.jpl.nasa.gov/missions/insight

InSight's Location: https://www.hou.usra.edu/meetings/lpsc2019/pdf/1948.pdf

NASA Astrobiology: https://astrobiology.nasa.gov/missions/insight

Wikipedia: https://en.wikipedia.org/wiki/InSight

MarCO: https://www.planetary.org/articles/0708-marco-planetary-cubesats

Psyche

NASA website: https://www.nasa.gov/psyche

ASU mission website: https://psyche.asu.edu

Mission concept: https://www.hou.usra.edu/meetings/lpsc2014/pdf/1253.pdf

Solar Electric Propulsion: https://explorespace.maxar.com/beyond/psyche

Instruments and Science: https://psyche.asu.edu/mission/instruments-science-investigations

Lucy

NASA Overview: https://www.nasa.gov/mission_pages/lucy/main/index

NASA: https://www.nasa.gov/mission_pages/lucy/overview/index

Lucy Press Kit: https://www.nasa.gov/sites/default/files/atoms/files/lucy_press_kit_2.pdf

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

VERITAS* and *DAVINCI+

https://www.jpl.nasa.gov/news/nasa-selects-2-missions-to-study-lost-habitable-world-of-venus

https://www.nasa.gov/feature/goddard/2021/nasa-to-explore-divergent-fate-of-earth-s-mysterious-twin-with-goddard-s-davinci

https://www.jpl.nasa.gov/news/nasa-selects-investigations-for-future-key-planetary-mission

https://ntrs.nasa.gov/api/citations/20170002022/downloads/20170002022.pdf

https://www.hou.usra.edu/meetings/lpsc2020/pdf/2599.pdf

https://skyandtelescope.org/astronomy-news/venus-nasa-selects-discovery-class-missions

https://en.wikipedia.org/wiki/DAVINCI+

https://en.wikipedia.org/wiki/VERITAS_(spacecraft)

Last Edited on Day Month Year