AEROSPACE

Memorable Moments in Human Spaceflight

Sources: National Aeronautics and Space Administration; Congressional Research Service; World Almanac research

The spaceflights listed are a selection of notable U.S. missions by the National Aeronautics and Space Administration (NASA), unless otherwise noted, plus non-U.S. missions (shown with an asterisk). The non-U.S missions were sponsored by the USSR (later, the Commonwealth of Independent States and, from 1997, Russia) or by China. Dates are Eastern standard time. EVA = extravehicular activity. ASTP = Apollo-Soyuz Test Project. STS = Space Transportation System, NASA's name for the overall Shuttle program. Number of total flights by each crew member is given in parentheses when flight listed is not the first.

Launch date	Mission[1]	Crew (no. of flights)	Duration (hr:min)	Remarks
4/12/61	*Vostok 1	Yuri A. Gagarin	1:48	**1st human orbital flight**
5/5/61	Mercury-Redstone 3	Alan B. Shepard Jr.	0:15	**1st American in space**
7/21/61	Mercury-Redstone 4	Virgil I. Grissom	0:15	Spacecraft sank, Grissom rescued
8/6/61	*Vostok 2	Gherman S. Titov	25:18	1st spaceflight of more than 24 hrs
2/20/62	Mercury-Atlas 6	John H. Glenn Jr.	4:55	**1st American in orbit**; 3 orbits
5/24/62	Mercury-Atlas 7	M. Scott Carpenter	4:56	Manual retrofire error caused 250-mi landing overshoot
8/11/62	*Vostok 3	Andrian G. Nikolayev	94:22	*Vostok 3* and *4* made 1st group flight
8/12/62	*Vostok 4	Pavel R. Popovich	70:57	On 1st orbit, it came within 3 mi of *Vostok 3*
10/3/62	Mercury-Atlas 8	Walter M. Schirra Jr.	9:13	Landed 5 mi from target
5/15/63	Mercury-Atlas 9	L. Gordon Cooper	34:19	1st U.S. evaluation of effects of one day in space on a person; 22 orbits
6/14/63	*Vostok 5	Valery F. Bykovsky	119:06	Vostok 5 and 6 made 2nd group flight
6/16/63	*Vostok 6	Valentina V. Tereshkova	70:50	**1st woman in space**; passed within 3 mi of Vostok 5
10/12/64	*Voskhod 1	Vladimir M. Komarov, Konstantin P. Feoktistov, Boris B. Yegorov	24:17	1st 3-person orbital flight; 1st without space suits
3/18/65	*Voskhod 2	Pavel I. Belyayev, Aleksei A. Leonov	26:02	Leonov made **1st "space walk"** (10 min)
3/23/65	Gemini-Titan 3	Grissom (2), John W. Young	4:53	1st piloted spacecraft to change its orbital path
6/3/65	Gemini-Titan 4	James A. McDivitt, Edward H. White 2nd	97:56	White was 1st American to "walk in space" (36 min)
8/21/65	Gemini-Titan 5	Cooper (2), Charles Conrad Jr.	190:55	Longest-duration human flight to date
12/15/65	Gemini-Titan 6A	Schirra (2), Thomas P. Stafford	25:51	Completed 1st U.S. space rendezvous, with *Gemini 7*
12/4/65	Gemini-Titan 7	Frank Borman, James A. Lovell	330:35	Longest-duration *Gemini* flight
3/16/66	Gemini-Titan 8	Neil A. Armstrong, David R. Scott	10:41	**1st docking of one space vehicle with another**; mission aborted, control malfunction; 1st Pacific landing
6/3/66	Gemini-Titan 9A	Stafford (2), Eugene A. Cernan	72:21	Performed simulation of lunar module rendezvous
7/18/66	Gemini-Titan 10	Young (2), Michael Collins	70:47	1st use of Agena target vehicle's propulsion systems; 1st orbital docking
9/12/66	Gemini-Titan 11	Conrad (2), Richard F. Gordon Jr.	71:17	1st tethered flight; highest Earth-orbit altitude (850 mi)
11/11/66	Gemini-Titan 12	Lovell (2), Edwin E. "Buzz" Aldrin Jr.	94:34	Final *Gemini* mission; 5-hr EVA
4/23/67	*Soyuz 1	Komarov (2)	26:40	Crashed on reentry, killing Komarov
10/11/68	Apollo-Saturn 7	Schirra (3), Donn F. Eisele, R. Walter Cunningham	260:09	1st piloted flight of *Apollo* spacecraft command-service module only; live TV footage of crew
12/21/68	Apollo-Saturn 8	Borman (2), Lovell (3), William A. Anders	147:00	**1st lunar orbit** and piloted lunar return reentry (command-service module only); views of lunar surface televised to Earth
1/14/69	*Soyuz 4	Vladimir A. Shatalov	71:21	Docked with *Soyuz 5*
1/15/69	*Soyuz 5	Boris V. Volyanov, Aleksei S. Yeliseyev, Yevgeny V. Khrunov	72:54	Docked with *Soyuz 4*; Yeliseyev and Khrunov transferred to *Soyuz 4* via a spacewalk
3/3/69	Apollo-Saturn 9	McDivitt (2), Scott (2), Russell L. Schweickart	241:00	1st piloted flight of lunar module
5/18/69	Apollo-Saturn 10	Stafford (3), Young (3), Cernan (2)	192:03	1st lunar module orbit of Moon, 50,000 ft from Moon surface
7/16/69	Apollo-Saturn 11	Armstrong (2), Collins (2), Aldrin (2)	195:18	**1st lunar landing** made by Armstrong and Aldrin (7/20); collected 48.5 lbs of soil, rock samples; lunar stay time 21:36:21
10/11/69	*Soyuz 6	Georgi S. Shonin, Valery N. Kubasov	118:43	1st welding of metals in space
10/12/69	*Soyuz 7	Anatoly V. Flipchenko, Vladislav N. Volkov, Viktor V. Gorbatko	118:40	Space lab construction test made; *Soyuz 6*, *7*, and *8*: 1st time 3 spacecraft, 7 crew members orbited the Earth at once
10/13/69	*Soyuz 8	Shatalov (2), Yeliseyev (2)	118:51	Part of space lab construction team
11/14/69	Apollo-Saturn 12	Conrad (3), Gordon (2), Alan L. Bean	244:36	Conrad and Bean made **2nd Moon landing** (11/18); collected 74.7 lbs of samples; lunar stay time 31:31
4/11/70	Apollo-Saturn 13	Lovell (4), Fred W. Haise Jr., John L. Swigert Jr.	142:54	Aborted after service module oxygen tank ruptured; crew returned in lunar module
6/1/70	*Soyuz 9	Nikolayev (2), Vitaliy I. Sevastyanov	424:59	Longest human spaceflight to date
1/31/71	Apollo-Saturn 14	A. Shepard (2), Stuart A. Roosa, Edgar D. Mitchell	216:01	Shepard and Mitchell made **3rd Moon landing** (2/3); collected 96 lbs of lunar samples; lunar stay 33:31
4/19/71	*Salyut 12	(Occupied by Soyuz 11 crew)	—	**1st space station**
4/22/71	*Soyuz 10	Shatalov (3), Yeliseyev (3), Nikolay N. Rukavishnikov	47:46	**1st successful docking with a space station;** failed to enter space station
6/6/71	*Soyuz 11	Georgi T. Dobrovolskiy, V. Volkov (2), Viktor I. Patsayev	570:22	Docked and entered *Salyut 1* space station; **crew died** during reentry from loss of pressurization
7/26/71	Apollo-Saturn 15	Scott (3), James B. Irwin, Alfred M. Worden	295:12	Scott and Irwin made **4th Moon landing** (7/30); 1st lunar rover use; 1st deep space walk; 170 lbs of samples; 66:55 stay
4/16/72	Apollo-Saturn 16	Young (4), Charles M. Duke Jr., Thomas K. Mattingly 2nd	265:51	Young and Duke made **5th Moon landing** (4/20); collected 213 lbs of lunar samples; lunar stay 71:2
12/7/72	Apollo-Saturn 17	Cernan (3), Ronald E. Evans, Harrison H. Schmitt	301:51	Cernan and Schmitt made 6th and **last lunar landing** (12/11); collected 243 lbs of samples; record lunar stay over 75 hrs

U.S. Manned Space Program

Following the Feb. 1, 2003, *Columbia* disaster, when the craft broke up on re-entry, all space shuttle flights were grounded. Improvements to future spacecrafts were made, including a redesigned external tank, new sensors to register impact, and a boom with a camera to allow astronauts to inspect the shuttle in flight for potential damage. On July 26, 2005, a modified *Discovery* made it into orbit, but onboard cameras showed that foam insulation broke off from the external fuel tank during launch—the same problem that caused the *Columbia* disaster. Despite a successful return, the shuttle program was grounded again until July 4, 2006, when *Discovery* lifted off with new safety features in place. The crew visited the International Space Station and returned to Earth without incident. Following *Discovery*'s flight, there have been four more successful shuttle missions as of Sept. 2008.

Even before the *Columbia* disaster it was clear that a new vehicle was needed to replace the space shuttle, which is due to be retired in 2010. President George W. Bush in 2004 outlined his vision for future space exploration: Following the retirement of the space shuttle fleet, NASA will employ a new space vessel to aid not only in finishing the ISS, but also in sending astronauts to the moon and eventually to Mars. In August 2006, NASA unveiled plans for the new spacecraft, a multi-purpose orbital capsule called *Orion*. Its developer, Lockheed Martin, plans to deliver the first craft in 2014. *Orion* will carry astronauts into orbit, ferry personnel and equipment to the ISS, serve as the orbital vehicle for missions to the Moon, and eventually deliver astronauts to a Mars-bound spacecraft that will be built in Earth's orbit.

The reusable *Orion* craft abandons the 30-year-old space shuttle design for an *Apollo*-style capsule. A novel expendable rocket, the *Ares* (currently under development), will propel the craft into space. *Orion*, expected to cost $8.1 bil through 2020, will incorporate the latest technology in electronics, life support, computers, propulsion and heat protection systems. At 16.5 ft in diameter, *Orion* will have 2.5 times the interior volume of the original *Apollo* capsules, and like the Russian *Soyuz* capsules, *Orion* will use parachutes to touch down on land (the *Apollo* capsules landed in water). Like the *Apollo* craft, *Orion* will launch on top of its booster rocket, which will prevent ice or insulating foam from the booster rocket from hitting the capsule. In addition, the capsule will be able to jettison from its booster in the event of launch failure—a safety mechanism unavailable to space shuttle crews.

The earliest *Orion* flight is scheduled for 2014, with a manned Moon mission expected by 2020.

International Space Station

The International Space Station (ISS) is considered the largest cooperative scientific project in history.

16 cooperating nations: U.S., Russia, Canada, Belgium, Denmark, France, Germany, Italy, Netherlands, Norway, Spain, Sweden, Switzerland, United Kingdom, Japan, and Brazil.

Impact of *Columbia* disaster: The grounding of U.S. space shuttles after the *Columbia* disaster and then after complications with *Discovery* in 2005 interrupted further assembly of the station. Since lower-capacity Russian *Soyuz* and *Progress* craft were the usual means of ferrying provisions and crew to and from Earth, the size of the crew aboard the ISS was reduced to 2.

In 2006, the flights resumed, allowing operations on the station to move forward and bringing the ISS crew back up to 3. Over the course of the year, the crew tested new equipment and safety procedures and performed maintenance on the station, notably the station's mobile transporter (a device that moves along exterior rails and facilitates repair, maintenance, and module additions). New and updated research equipment was installed inside the Leonardo Multi-Purpose Logistics Module. In September, the space shuttle *Atlantis* arrived with a new truss segment, two solar arrays, and a rotary joint that is used to position the solar panels so that they face the sun as the ISS moves through its orbit.

Operations to assemble and supply the station continued throughout 2007 and 2008. The crew installed the Japanese contribution to the space station, the 37-foot-long Kibo laboratory. They also added a maintenance robot, Dextre. Scientific research focused on the effects of weightlessness on humans, in anticipation of longer trips to the moon and to Mars. A robotic spacecraft, the European Space Agency's Automated Transfer Vehicle, made its first delivery of food, water, air, and equipment to the station. It is expected to pick up some of the slack from the grounding of the space shuttles in 2010.

The station when completed:
- mass of 1,040,000 lbs
- 356' x 290', with almost an acre of solar panels
- internal volume roughly equivalent to passenger cabin of a 747 jumbo jet
- 6 laboratories; living space for up to 7 people

Examples of research conducted or planned:
- growing living cells in a gravity-free environment
- studying the effects on humans of long-term exposure to reduced gravity
- studying large-scale long-term changes in Earth's environment by observing Earth from orbit

Summary of Worldwide Successful Launches, 1957-2008

Source: National Aeronautics and Space Administration

Year	Total[1]	Russia[2]	U.S.	ESA[3]	China	Japan	France	India	U.K.	Germany	Canada	Israel
1957-59	24	6	18	—	—	—	—	—	—	—	—	—
1960-69	1,035	399	614	2	—	—	4	—	1	—	—	—
1970-79	1,366	1,028	247	5	8	18	14	1	6	3	4	—
1980-89	1,431	1,132	191	14	16	26	5	9	4	7	5	—
1990-99	1,045	542	300	55	33	23	16	11	7	6	4	—
2000-08[4]	529	218	178	57	46	16	0	11	0	0	0	3
Total	**5,430**	**3,315**	**1,548**	**133**	**103**	83	**39**	**32**	**18**	**16**	**13**	**3**

(1) Includes launches sponsored by countries not shown. (2) Data for 1957-91 apply to the Soviet Union, for 1992-96 to the Commonwealth of Independent States, after 1996 to Russia. (3) European Space Agency. Member states are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom. Canada, Hungary, and the Czech Republic also participate in some projects under cooperation agreements. (4) As of Sept. 29, 2008.

Notable Proposed U.S. Space Missions in 2009

Source: National Aeronautics and Space Administration

Planned Launch	Mission	Purpose
Mar. 2	Lunar Crater Observation and Sensing Satellite	Confirm presence or absence of water ice in a permanently shadowed crater at Moon's North or South Pole.
Apr. 10	Kepler	Survey our region of the Milky Way to detect Earth-size and smaller planets.
Sept. 15	Mars Science Laboratory	Rover will investigate the environment of Mars for possibilities of microbial life.

ASTRONOMY

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Celestial Events Summary, 2009

There are 6 eclipses in 2009: one annular solar eclipse, one total solar eclipse, one partial lunar eclipse, and three penumbral lunar eclipses. However, in N America, neither solar eclipse nor the partial lunar eclipse will be visible. The penumbral lunar eclipses only result in a slight dimming of the Moon and are unremarkable. *See* page 375.

The most likely viewing successes for meteor showers will be the Orionids in Oct., the Leonids in Nov., and the Geminids in Dec. *See* page 370.

At the start of the year Saturn is up most of the night. Jupiter, Mercury, and Venus are low in the West at sunset, and Mars is low in the East at sunrise. Venus gradually gets closer to the Sun through Mar., emerging in the morning sky in Apr. for the remainder of the year. Jupiter and Mercury become morning objects in Feb. Jupiter gradually extends in visibility from just the morning sky until July when it is visible all night. In Aug., it continues moving into the evening sky, and ends the year as an early evening object setting in the West after sunset. Mars begins the year as an object seen just before sunrise, becoming more and more overhead at sunrise as the year progresses. Saturn is up all night long in Jan. and Feb., then begins its move into the evening sky; by Aug. it is lost in the glare of the Sun, reappearing in the morning sky in early Oct. The best opportunities for seeing Mercury occur in early Feb., mid-June, and early Oct. in the morning sky and late Apr., late Aug. and late Dec. in the evening sky.

The crescent Moon, with its subdued light, regularly makes pretty pairings with the 2 brightest planets, Venus and Jupiter. Waxing crescent pairings are visible in the early evening soon after sunset, while waning crescent pairings are visible in the early morning before sunrise. The waxing crescent Moon pairs with Venus in each of the months from Jan. through Mar., while the waning crescent pairs with Venus for much of the rest of the year. The waxing crescent Moon pairs with Jupiter in the evening in Jan., Nov., and Dec., and the waning crescent pairs with Jupiter in Feb. and Mar.

Astronomical Positions and Constants

Two celestial bodies are in **conjunction** when they are due North and South of each other, either in **right ascension** (with respect to the North celestial pole) or in **celestial longitude** (with respect to the North ecliptic pole). Celestial bodies in conjunction will rise and set at nearly the same time. For the inner planets—Mercury and Venus—**inferior conjunction** occurs when either planet passes between Earth and the Sun, while **superior conjunction** occurs when either Mercury or Venus is on the far side of the Sun. Celestial bodies are in **opposition** when their Right Ascensions differ by exactly 12 hours, or when their Celestial Longitudes differ by 180°. In this case one of the 2 objects in opposition will rise while the other is setting. **Quadrature** refers to the arrangement where the coordinates of 2 bodies differ by exactly 90°. These terms may refer to the relative positions of any 2 bodies as seen from Earth, but one of the bodies is so frequently the Sun that mention of the Sun is omitted in that case.

When objects are in conjunction, the alignment is not perfect, and one is usually passing above or below the other. The geocentric angular separation between the Sun and an object is termed **elongation**. Elongation is limited only for Mercury and Venus; the greatest elongation for each of these bodies is approximately the time for longest observation. **Perihelion** is the point in an orbit that is nearest to the Sun, and **aphelion** is the point farthest from the Sun. **Perigee** is the point in an orbit that is nearest Earth, **apogee** the point that is farthest from Earth. An **occultation** of a planet or a star is an eclipse of it by some other body, usually the Moon. A **transit** of the Sun occurs when Mercury or Venus passes directly between Earth and the Sun, appearing to cross the disk of the Sun.

The following were adopted as part of the International Astronomical Union System of Astronomical Constants (1976): **Speed of light**, 299,792.458 km per sec., or about 186,282 statute mi per sec.; **solar parallax**, 8".794148; Astronomical Unit (the mean distance between the Earth and the Sun), 149,597,870 km, or 92,955,807 mi; **constant of nutation**, 9".2025; and **constant of aberration**, 20".49552.

Celestial Events Highlights, 2009

(Coordinated Universal Time, or UTC—the standard time of the prime meridian)

January

Mercury and **Jupiter** are visible low in the SW after sunset at the beginning of the month, and are low in the SE before sunrise (but closer to the Sun and difficult to see) at the end of the month.

Venus is visible in the SW for several hours after sunset all month.

Mars rises just before the Sun in the SE all month.

Saturn rises mid-evening and sets several hours before sunrise.

Moon passes Uranus on the 2nd, Saturn on the 15th, Mars and Mercury on the 25th, Jupiter on the 26th, Neptune on the 27th, Uranus and Venus on the 30th.

Jan. 1: Mercury in Capricorn, Venus in Aquarius, Mars in Sagittarius, Jupiter in Sagittarius, Saturn in Leo, Uranus in Aquarius, Neptune in Capricorn all year.

Jan. 2: Moon passes 4.6° N of Uranus.

Jan. 4: Mercury at greatest elongation 19.3° E, Jupiter enters Capricorn. Earth at perihelion (closest to Sun).

Jan. 8: Moon passes 10° N of Aldebaran.

Jan. 11: Moon passes 5.4° S of Pollux.

Jan. 13: Moon passes 2.6° S of Regulus.

Jan. 14: Venus at greatest elongation 47.1° E.

Jan. 15: Moon passes 6.4° S of Saturn.

Jan. 17: Moon passes 3.3° S of Spica.

Jan. 18: Mercury passes 3.3° N of Jupiter.

Jan. 20: Mercury in inferior conjunction 3.23° N, enters Sagittarius.

Jan. 21: Moon passes 0.02° N of Antares, occults Antares (like all occultations, this one is only visible from some locations on Earth).

Jan. 23: Venus passes 1.4° N of Uranus, enters Pisces.

Jan. 24: Jupiter in conjunction 0.44° S.

Jan. 25: Moon passes 0.7° S of Mars, occults Mars, Moon passes 5° S of Mercury.

Jan. 26: Moon passes 0.03° N of Jupiter, occults Jupiter, Mercury passes 4.4° N of Mars. Annular solar eclipse (see details under Eclipses).

Jan. 27: Moon passes 1.8° N of Neptune, occults Neptune.

Jan. 30: Moon passes 4.7° N of Uranus, 2.8° N of Venus.

February

Mercury, **Mars,** and **Jupiter** are low in the SE before sunrise all month.

Venus is visible in the SW for several hours after sunset all month.

Saturn rises early evening and is visible throughout the night all month.

Moon passes Saturn on the 11th, Jupiter on the 17th, Mercury on the 22nd, Jupiter and Mars on the 23rd, Neptune on the 24th, Uranus on the 26th, and Venus on the 27th. Watch for the waning crescent Moon paired with Mercury, Mars, and Jupiter on the morning of the 22nd.

Eclipses, 2009

(In Coordinated Universal Time, standard time of the prime meridian)

There are 6 eclipses in 2009: an annular eclipse of the Sun, a total eclipse of the Sun, three penumbral eclipses of the Moon, and one partial eclipse of the Moon. During an annular eclipse of the Sun, the Moon's angular diameter is not large enough to block the entire disk of the Sun, and the Sun appears as a bright ring about the dark disk of the Moon. Penumbral lunar eclipses are rather unspectacular since the Moon never enters the dark portion of the Earth's shadow.

I. Annular eclipse of the Sun, Jan. 26

The path of the annular eclipse will begin south of the southern tip of Africa and will proceed across the Indian Ocean, crossing parts of Sumatra and ending after passing through Borneo. A partial eclipse will be visible over a wider area including southern Africa, western Australia, and southeast Asia.

Event	Date	h	m
Penumbral eclipse begins	Jan. 26	4	57
Annular eclipse begins	26	6	3
Greatest eclipse	26	7	59
Annular eclipse ends	26	9	55
Penumbral eclipse ends	26	11	1

II. Penumbral eclipse of the Moon, Feb. 9

During a penumbral lunar eclipse, the Moon dims only slightly, and the eclipse is hardly noticeable. Portions of the eclipse will be visible over a wide area extending from Europe and northern Africa eastward across central North America.

Event	Date	h	m
Penumbral eclipse begins	Feb. 9	12	39
Greatest eclipse	9	14	38
Penumbral eclipse ends	9	16	38

III. Penumbral eclipse of the Moon, July 7

During this eclipse, only a small portion of the Moon passes into the Earth's penumbra, dimming ever so slightly towards it's North Pole. The eclipse occurs while the Moon is visible over a wide area extending from Oceania across the Pacific and the Americas.

Event	Date	h	m
Penumbral eclipse begins	July 7	8	38
Greatest eclipse	7	9	39
Penumbral eclipse ends	7	10	39

IV. Total eclipse of the Sun, July 22

The partial eclipse will be visible across Australia, and most of Asia, Africa, Europe, and the Antarctic. The end of the eclipse will be visible from western China, across Europe, Africa, the Antarctic, and most of South America.

Event	Date	h	m
Penumbral eclipse begins	July 21	23	58
Total eclipse begins	22	0	51
Greatest eclipse	22	2	35
Total eclipse ends	22	4	19
Penumbral eclipse ends	22	5	12

V. Penumbral eclipse of the Moon, Aug. 2

Like the July 7 penumbral eclipse, only a small portion of the Moon passes into the Earth's penumbra, this time dimming ever so slightly towards its South Pole. The eclipse occurs while the Moon is visible over a wide area centered on the Atlantic Ocean.

Event	Date	h	m
Penumbral eclipse begins	Aug. 5	23	4
Greatest eclipse	6	0	39
Penumbral eclipse ends	6	2	14

VI. Partial eclipse of the Moon, Dec. 31

During this eclipse, only a small portion of the lunar disc enters the full shadow of the Earth, but this will be much more obvious than the penumbral eclipses earlier in the year. A small portion of the Moon near its South Pole enters the shadow. The eclipse will be visible over a wide area including Africa, Europe and Asia.

Event	Date	h	m
Penumbral eclipse begins	Dec. 31	17	17
Partial eclipse begins	31	18	53
Greatest eclipse	31	19	23
Partial eclipse ends	31	19	53
Penumbral eclipse ends	31	21	28

Total Solar Eclipses, 2009-2020

Total solar eclipses actually take place nearly as often as total lunar eclipses. Total lunar eclipses are visible over at least half of the Earth, while total solar eclipses can be seen only along a very narrow path up to a few hundred miles wide and a few thousand miles long. Observing a total solar eclipse is thus a rarity for most people.

Solar eclipses can be dangerous to observe. This is not because the Sun emits more potent rays, but because the Sun is always dangerous to observe directly and people are particularly likely to stare at it during a solar eclipse.

	Duration[1]		Width	
Date	m	s	(mi)	Path of Totality
2009, July 22	6	39	160	Asia, Pacific Ocean
2010, July 11	5	20	164	Pacific Ocean, southern S America
2012, Nov. 13	4	2	112	N Australia, Pacific Ocean
2013, Nov. 3[h]	1	40	36	Atlantic Ocean, Africa
2015, Mar. 20	2	47	304	N Atlantic Ocean, Arctic Ocean
2016, Mar. 9	4	10	96	Indonesia, Pacific Ocean
2017, Aug. 21	2	40	71	Pacific Ocean, U.S., Atlantic Ocean
2019, July 2	4	33	125	S Pacific Ocean, S America
2020, Dec. 14	2	10	56	S Pacific Ocean, S America, S Atlantic Ocean

h = indicates annular-total hybrid eclipse. (1) Duration refers to length of time at optimal viewing area.

Total Solar Eclipses in the U.S. in the 21st Century

During the 21st century there will be 8 total solar eclipses visible somewhere in the continental U.S. The first comes after a long gap; the last total solar eclipse was on Feb. 26, 1979, in the northwestern U.S.

Date	Path of Totality	Date	Path of Totality
Aug. 21, 2017	Oregon to South Carolina	Mar. 30, 2052	Florida to Georgia
Apr. 8, 2024	Mexico to Texas and up through Maine	May 11, 2078	Louisiana to North Carolina
Aug. 23, 2044	Montana to North Dakota	May 1, 2079	New Jersey to the lower edge of New England
Aug. 12, 2045	N California to Florida	Sept. 14, 2099	North Dakota to Virginia

Venus

Distance from the Sun	
Perihelion	66.8 mil mi
Semi-major axis (mean distance)	67.2 mil mi (0.723 AU)
Aphelion	67.7 mil mi
Period of revolution around Sun	224.7 d
Orbital eccentricity	0.0067
Orbital inclination	3.39°
Synodic day (midday to midday)	116.75 d (retrograde)
Sidereal day	243.02 d (retrograde)
Rotational inclination	177.4°
Mass (Earth = 1)	0.815
Mean radius	3,760 mi
Mean density (Earth = 1)	0.951
Natural satellites	0
Average surface temperature	867°F

Venus, named for the Roman goddess of love, is the second planet out from the Sun. Almost the same size as Earth, it is believed that the two planets were formed at the same time by the same general process and from the same mixture of chemical elements. Venus can easily be seen from Earth with the naked eye; it is the 3rd-brightest object in the sky, exceeded only by the Sun and the Moon.

Orbit and Rotation. It takes Venus 225 Earth days to complete its orbit around the sun. Its synodic revolution—its return to the same relationship with Earth and the Sun, which is a result of the combination of its own motion with that of Earth—is 584 days. Because of this, every 19 months Venus is closer to Earth than any other planet. The rotation period of Venus appears to be 243 days clockwise—in other words, contrary to the spin of the other planets and contrary to its own motion around the Sun. This rate and sense of rotation makes for a solar day (sunrise to sunrise) on Venus of 116.8 Earth days; night lasts 58 days and day lasts 58 days. Venus has no detectible magnetic field.

Atmosphere. The Venusian atmosphere is very thick and toxic. It is composed primarily of 96.5% carbon dioxide, 3.5% nitrogen, trace concentrations of sulfur dioxide, argon, water, carbon monoxide, helium, and neon. In addition, it exerts an atmospheric pressure at the surface more than 90 times Earth's normal sea-level pressure. The planet is covered with a dense, white, cloudy atmosphere that conceals whatever is below it. These clouds are believed to contain sulfuric acid, meaning that when it rains on Venus, it may rain sulfuric acid. Due to the thickness of the atmosphere and resulting extreme greenhouse effect, the temperature is essentially the same day and night; the planet has an average surface temperature of about 867°F making it the hottest planet in the solar system. Winds of about 200 mph in the clouds may account for the transfer of heat into the night side despite the low rotation speed of the planet. However, at the surface, the winds are very slow.

Surface and Composition. Radar-produced maps of the entire planet show large craters, continent-sized highlands, and extensive dry lowlands. No tectonic activity has been found similar to Earth's moving tectonic plates, but a system of global rift zones and numerous broad, low, dome-like structures, called coronae, may have been produced by the upwelling and subsidence of magma from the mantle. Volcanic surface features, such as vast lava plains, fields of small lava domes, and large shield volcanoes, are common. About 1,600 volcanoes and volcanic features appear on the Venusian surface; more than 85% of the surface is covered by volcanic flows. Theia Mons, a huge shield volcano, has a diameter of over 600 mi and a height of over 3.5 mi. (The largest Hawaiian volcano is only about 125 mi in diameter, but rises nearly 5.5 mi from the ocean floor.) Aside from volcanoes, there are highly deformed mountain belts across Venus along with a few meteor-impact craters more than 20 mi wide. Erosion is a very slow process on Venus due to the lack of water. There are indications of some wind movement of dust and sand. The few impact craters on Venus suggest that the surface is generally geologically young—less than 800 million years old. Despite the fact that probes have landed on Venus, there are very few pictures because the probes themselves couldn't survive the high temperature and atmospheric pressure.

Mars

Distance from the Sun	
Perihelion	128.4 mil mi
Semi-major axis (mean distance)	141.6 mil mi (1.524 AU)
Aphelion	154.9 mil mi
Period of revolution around Sun	686.98 d (1.88 y)
Orbital eccentricity	0.0935
Orbital inclination	1.85°
Synodic day (midday to midday)	24h 39m 35s
Sidereal day	24h 37m 22s
Rotational inclination	25.19°
Mass (Earth = 1)	0.107
Mean radius	2,106 mi
Mean density (Earth = 1)	0.713
Natural satellites	2
Average surface temperature	–81° F

Named for the Roman god of war, the "Red Planet" has some features much like Earth. Mars has climate, seasons, volcanoes, and possibly once had liquid water flowing across its surface. Mars can easily be seen with the naked eye on most clear nights, which is why it was one of the first planets to be studied by ancient astronomers. Later, when telescopes came into use, many observers claimed that canals made by Martians existed on the planet's surface, which led to speculation as to whether there was intelligent life there. Unmanned probes have since put all those theories to rest; the canals turned out to be topographic patterns and dust storms.

Orbit and Rotation. Although Mars's orbital path is nearly circular, it is somewhat more eccentric than that of most other planets; Mars is more than 26 mil mi farther from the Sun at its most distant point compared to its closest approach. Its orbit and speed in relation to Earth's bring it fairly close to Earth about every 2 years. Every 15-17 years the close approaches are especially favorable for observation.

Mars rotates in 24 hours and 37 minutes, almost the same period of time as Earth. Mars's mean distance from the Sun is 142 mil mi. Because Mars's axis of rotation is inclined by about 25° from the vertical to the plane of its solar orbit about the Sun, the planet has seasons.

Unlike Earth's global magnetic field, the Martian magnetic field is small, weak, and localized and may be the remnant of a stronger field from the planet's past.

Atmosphere. The Martian atmosphere is composed primarily of 95.32% carbon dioxide, 2.7% nitrogen, 1.6% argon, 0.13% oxygen, 0.08% carbon monoxide, and in very minor quantities, water, hydrogen oxide, and neon. The atmosphere on Mars is very thin; it has an atmospheric pressure between 1% and 2% of Earth's (if Earth's atmosphere were that thin, we would not have enough oxygen to breathe). Because the Martian atmosphere is so thin and because of the planet's weak magnetic field, its surface is bombarded by cosmic radiation about 100 times as intense as on Earth.

Martian weather systems consist mainly of huge dust storms. On the poles, white caps (believed to be both water ice and carbon dioxide ice) grow in winter and shrink in summer. It is mainly the carbon dioxide that comes and goes with the seasons. The water ice is apparently in many layers with dust between them, indicating climatic cycles.

Surface and Composition. Mars is an alien world with rust-red sand and pink skies. In the planet's beginning stages when it was much hotter, Mars's surface melted to a sufficient extent to separate into dense and lighter layers. At some point later, Mars cooled enough to allow liquid water to possibly flow across its surface. Today, Mars is very dry.

Natural Satellites. Mars has 2 satellites called Phobos and Deimos, each discovered in 1877 by Asaph Hall. (Phobos measures about 11 by 17 mi and Deimos about 7 by 9 mi.) Deimos, the outer satellite, revolves around the planet in about 31 hours. Phobos, the inner satellite, whips around Mars in a little more than 7 hours, making 3 trips each Martian day. Since it orbits Mars faster than the planet rotates, Phobos rises in the west and sets in the east, opposite to what other bodies appear to do in the Martian sky. Both moons are irregularly shaped and pitted with numerous craters. Their origins are not known; however, some astronomers consider them to be asteroid-like objects that were captured by Mars very early in its history.

Dwarf Planets

Note: See page 377 for the definition of a dwarf planet.

Ceres

Distance from the Sun	
Perihelion	237 mil mi (2.55 AU)
Semi-major axis (mean distance)	257 mil mi (2.77 AU)
Period of revolution around Sun	4.6 y
Orbital eccentricity	0.0789
Orbital inclination	10.58°
Sidereal day	9.075 hours
Mass (Earth = 1)	0.00016
Mean radius	300 mi

Ceres was the first asteroid ever discovered, on Jan. 1, 1801, by Guiseppe Piazzi. In the 1800s, it was considered a planet, but as more asteroids were discovered, it lost that designation. In Aug. of 2006, it was designated a "dwarf planet" by the International Astronomical Union.

No probe has ever visited Ceres. NASA's DAWN space probe, launched in Sept. 2007, may become the first. The Dawn probe's mission is to Vesta and Ceres, the solar system's two largest asteroids. When Dawn arrives at Ceres in Feb. 2015, months before the New Horizons probe arrives at Pluto, it will be the first mission to study a dwarf planet.

Orbit and Rotation. Ceres orbits the sun in the asteroid belt region between Mars and Jupiter.

Surface and Composition. Ceres is in a class of stony meteorites known as carbonaceous chondrites. These are considered to be the oldest materials in the solar system, with a composition reflecting that of the primitive solar nebula. Extremely dark in color, probably because of their hydrocarbon content, they show evidence of having absorbed water of hydration. Thus, unlike the Earth and the Moon, they have never either melted or been reheated since they first formed.

Pluto

Distance from the Sun	
Perihelion	2,756.9 mil mi
Semi-major axis (mean distance)	3,647.2 mil mi (39.482 AU)
Aphelion	4,583.2 mil mi
Period of revolution around Sun	247.68 y
Orbital eccentricity	0.2488
Orbital inclination	17.16°
Synodic day (midday to midday)	6d 9h 17m (retrograde)
Sidereal day	6d 9h 18m (retrograde)
Rotational inclination	122.53°
Mass (Earth = 1)	0.0021
Mean radius	742.5 mi
Mean density (Earth = 1)	0.317
Natural satellites	3
Average surface temperature	–369°

Pluto, named for the Roman god of the underworld, is the second largest known KBO (Kuiper Belt Object) in the solar system. It was first discovered in 1930 by Clyde Tombaugh, and was classified as a planet until 2006 when the International Astronomical Union changed its designation to dwarf planet. The New Horizons spacecraft was launched on a voyage to Pluto and beyond in 2006; the spacecraft will make its closest approach to Pluto in July of 2015. In 2008, Pluto was designated by the IAU as the prototype for a class of objects called Plutoids, bodies (a) whose average distance from the Sun is greater than Neptune's; (b) are large enough that gravity has determines their shape; and (c) have not cleared their orbit of other objects. Haumea, Makemake and Eris are also Plutoids.

Orbit and Rotation. Highly irregular. Although Pluto on the average stays about 3.6 bil mi from the Sun, it may get as close as 2.76 bil mi, and for about 20 years of its orbit, it is closer to the Sun than Neptune. Currently, it is beyond Neptune's orbit.

Atmosphere and Surface. Because no probes have visited Pluto, it is difficult for astronomers to accurately take readings of the planet's atmospheric composition. It is believed that an atmosphere of methane, nitrogen, and carbon monoxide exists when the planet is closer to the Sun. When Pluto is farther away from the sun during its orbit, the atmosphere freezes and becomes part of the surface. Large regions on Pluto are dark, others light; Pluto has spots and perhaps polar caps. There is also evidence of temperature fluctuations on the planet that may indicate primitive weather. Its core may be rocky with a mantle of water ice surrounding it.

Natural Satellites. Pluto has 3 natural satellites. Charon, the biggest, has a diameter of 737 mi—about half of Pluto's diameter of 1,485 mi. No other planet of any kind has a moon so close to its size. Discovered in 1978, Charon orbits Pluto at a distance of 12,200 mi and takes 6.39 days to move around the planet. In this same length of time, Pluto and Charon both rotate once around their axes, meaning that a person standing on Pluto would always see the same face of Charon in the same part of the sky, every day and night. The Pluto-Charon system thus appears to rotate as virtually a rigid body. Both worlds are roughly spherical and have comparable densities. Because of these similarities and their peculiar relationship, there is a debate as to whether Charon should one day be designated a dwarf planet.

The 2 other moons, discovered in 2005 and 2006, were officially named Nix and Hydra.

Haumea

Distance from the Sun	
Semi-major axis (mean distance)	43.335 AU
Period of revolution around Sun	285 y
Mean radius	420 mi
Orbital eccentricity	0.189
Orbital inclination	28.19°
Mass (Earth = 1)	0.0007

Haumea was discovered in 2004 and was accepted as a dwarf planet by the IAU in 2008.

Orbit and Rotation. Haumea has a moderately eccentric orbit and takes about 285 years to go around the Sun.

Surface and Composition. Spectra of Haumea indicate the presence of almost pure crystalline water ice. The surface reflects about 60% of sunlight shining on it. Haumea has a very oblong shape, twice as long as it is wide.

Natural Satellites. Haumea has two natural satellites.

Makemake

Distance from the Sun	
Semi-major axis (mean distance)	45.791 AU
Period of revolution around Sun	310 y
Mean radius	450 mi
Orbital eccentricity	0.159
Orbital inclination	28.96°
Mass (Earth = 1)	0.0007

Makemake was discovered in 2005 and was accepted as a dwarf planet by the IAU in 2008.

Orbit and Rotation. Makemake has a moderately eccentric orbit and takes about 310 years to go around the Sun.

Surface and Composition. Spectra of Makemake indicate the presence of frozen methane, as well as several organic compounds. The surface is highly reflective and appears similar to that of Pluto.

Eris

Distance from the Sun	
Semi-major axis (mean distance)	67.6681 AU
Period of revolution around Sun	560 y
Mean radius	925 mi
Orbital eccentricity	0.44177
Orbital inclination	44.177°
Natural satellites	1
Mass (Earth = 1)	0.0027

Eris is the largest dwarf planet. Discovered in 2003 by astronomers at the California Institute of Technology, it is the most distant object ever seen in orbit around the Sun.

Orbit and Rotation. Eris has a highly elliptical orbit and takes about 560 years to go around the Sun—more than twice the time it takes Pluto. Its inclination is steep, tilted at 44° to the planetary plane. It also has an extremely eccentric orbit. It will be at its closest, actually coming inside part of Pluto's orbit, in about 280 years.

Surface and Composition. Eris, with a surface covered in frozen methane, may be similar to Pluto and the Neptunian moon Triton. Observations made by the Hubble Space Telescope show that Eris's surface is almost white and uniform, reflecting 86% of the light that hits it. This makes it the most reflective body in the solar system. The dwarf planet's interior is likely a mixture of rock and ice.

Natural Satellites. Eris has one moon, Dysnomia.