Planet Trek: MJS '77

The next U.S. interplanetary foray will visit as many as 4 planets and at least a dozen moons during a mission that could involve 29 "flybys" and last 12 years

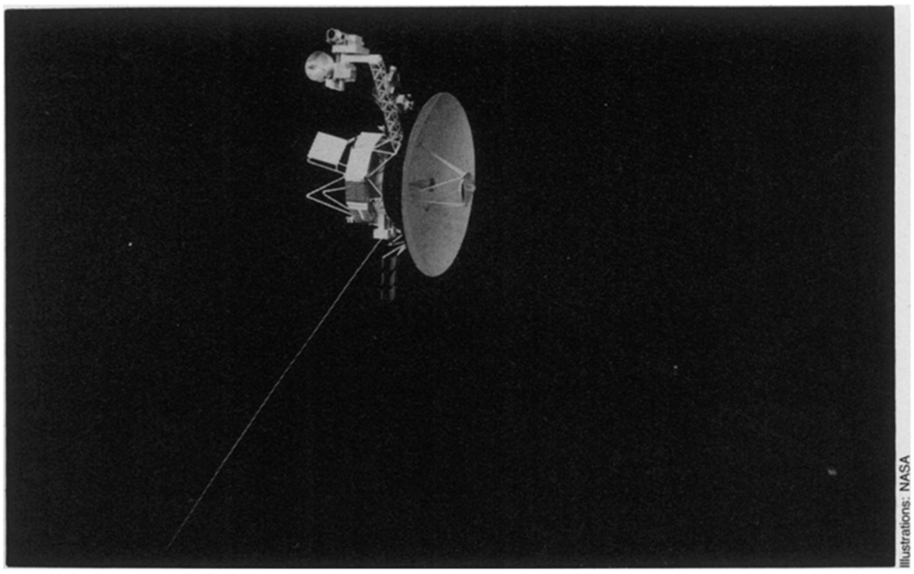
BY JONATHAN EBERHART

Jupiter, giant of the solar system, has long been a fascinating object, with its Great Red Spot, powerful radio emissions and teeming family of moons. Ringed Saturn scarcely needs restatement of its allure. Jupiter has been visited only twice by manmade spacecraft, raising as many questions as were answered, and Saturn will not receive its first close scrutiny until Pioneer 11 gets there in 1979, no doubt with similarly intriguing results.

On Aug. 20, 1977, however, two years to the day from the launching of Viking 1, a new spacecraft will be fired upward and outward from Cape Canaveral to rendezvous with both planets, to be followed by a second vehicle 12 days later. Beyond that is a good chance that one of the craft will go on to the first encounter ever with strange Uranus, which rotates on an axis tilted about 98° to the plane of the ecliptic, nearly perpendicular to that of almost every other planetary object in the solar system. There is even a slim possibility that it will visit Neptune, which would mean that in less than three decades since Mariner 2's flight past Venus opened the gates of interplanetary space, man will have taken close looks at eight of the nine worlds in his ken.

He may also have seen nearly half of the moons. The twin spacecraft will provide a bounteous harvest of photographs and other data on at least 5 of Jupiter's 13 known moons and 7 or 8 of Saturn's 10. The extended voyage to Uranus opens up five more candidates, although Neptune is so far away that the possibilities there—including the condition of the spacecraft, which will have been underway for 12 years by that time—are difficult to predict.

The multitargeted flight was almost more ambitious still. Project scientists tried in vain to find a comet that would be within range, and spent a year looking for an eligible asteroid. "We almost had one," says Bradford A. Smith of the University of Arizona, leader of the imaging team. It was Undina, catalogued as asteroid number 92, an exciting carbonaceous-chondrite type that looked for a while as though one of the spacecraft might be able to photograph it with 1-kilometer resolution—until refined information on its orbit ruled it out. "We wouldn't even come close," Smith says ruefully.



MJS spacecraft is designed to survive the longest U.S. space mission ever flown.

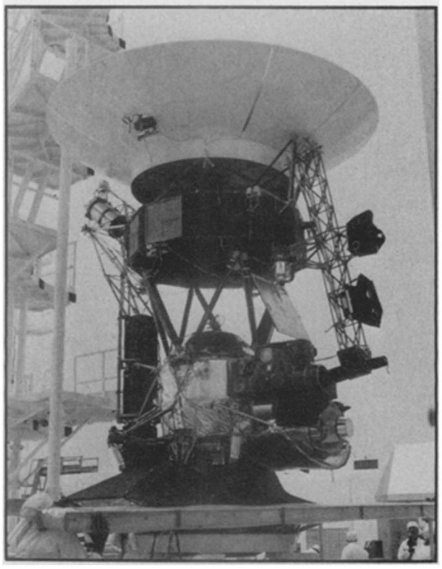
Even without comets, asteroids and space dust (unlike the Pioneers, neither of the vehicles will carry a micrometeoroid detector), the project is potentially far-reaching enough to recall the ill-fated "Grand Tour," a once-in-several-lifetimes opportunity that was cost-cut out of the chance to visit every planet from Jupiter to Pluto in one, dual-spacecraft mission.

The new endeavor is called Mariner Jupiter-Saturn 1977, or MJS for short. It may well never get to Neptune, let alone Uranus. But the two sophisticated MJS spacecraft at least hold the options open. Prior to the Grand Tour, the last U.S. President who would have been in a position to decide to take advantage of such a rare planetary alignment was Thomas Jefferson, says Smith, "and he didn't seize the opportunity."

The lofty goals of MJS are within the realm of possibility in large measure because of two features of the spacecraft: high power and the use of the "X-band" communications channel. The vehicles' nuclear power supplies, known as RTG's or radioisotope thermoelectric generators, will provide each craft with about 400 watts of electricity, compared with 166 watts for Pioneers 10 and 11. The high power will be the key to putting out a healthy signal across the vast distances of the outer planets. The devices do lose strength with time, but William Dixon of TRW, Inc., which manufactured the Pioneers, reports that the Pioneer RTG's seem to be degrading barely half as rapidly as their originally anticipated 11.6 watts per year, a good sign for MJS.

The MJS craft will also be the first interplanetary probes to use the X-band channel instead of the more common, lower-frequency S-band for most of their transmissions. The higher frequency will allow the vehicles to send nearly 10 times as much data for their wattage and antenna size over the X-band than over even their own S-band equipment (which will be used between planets when fewer data are being sent). In addition, according to project manager John Casani of the Jet Propulsion Laboratory, the craft are being built with a host of life-prolonging technologies such as redundant systems, environmentally tailored circuits and computers that diagnose and correct their own failures. These approaches are necessary to sustain a spacecraft that may have to last, even without Neptune, half again longer than Pioneer 11's journey to Saturn. The Pioneers, after all, were only built to go to Jupiter.

The moons, in many ways, will be as important a part of the mission as the planets themselves. "After Galileo's discovery [of the four largest satellites of Jupiter] in 1610 and the discovery of Saturn's major moons a few decades later," says Joseph Veverka of Cornell Univer-



Spacecraft during assembly at JPL.

sity, "satellites were largely ignored for over 300 years." The big ones, he points out, are probably still in orbits near the regions where they originally formed, so that, despite their amazingly diverse surface environments, they offer the chance to study localized samples of the primordial nebula; the ones smaller than about 10 kilometers in diameter are probably interplanetary wanderers, captured by the pull of some domineering planet. Yet it is only since the era of spacecraft that it has become possible to make precise measurements of even such "simple" details as their masses (since all but the biggest of them have intergravitational effects nearly too small to see). And with MJS, satellites are a specialty.

Jupiter's four huge Galilean satellites (Callisto, Ganymede, Europa and Io), says Smith, will be seen by MJS as clearly as the best earthbound telescopes can see *earth's* moon, and there will be less-sharp but unique photos of tiny, innermost Amalthea. The commanding presence of even the early Jupiter may well have affected its satellites as they formed, contributing a steep temperature gradient that should still show through progressively differing compositions. Amalthea, says Veverka, may thus be rich in refractory materials, while more distant Ganymede and Callisto may be wrapped in thick mantles of ice. (The same progression may be true of the satellites of Uranus, he says, with the inner ones rocky and the outer ones icy. Just knowing that one of them is rocky could reveal a lot about the host planet's evolution.)

The standout among the Jovian moons—and one of the most important targets among them for MJS—is Io. Because it seems to be atypically electrically conductive, Io precipitates a large extra dose of charged particles onto the Jovian magnetic field lines that pass through it, and some researchers believe that it also pinches in the closely adjacent field lines. The net effect is that there is a pronounced "flux tube" of charged particles mirroring back and forth between Io and Jupiter along the Jovian field. Pioneer 11, says MJS magnetic fields co-investigator Mario Acuña of the NASA Goddard Space Flight Center in Maryland, passed within 0.1 to 0.2 Jovian radii (about 7,000 to 14,000 kilometers) of the flux tube. This was enough to show a hint of enhanced particle activity but not to detect magnetic effects. The first MJS craft to reach Jupiter is scheduled to fly due south of Io, right *through* the tube. A still more striking feature of the unusual moon is its apparent "switching" effect on Jupiter's powerful radio bursts, which, if they are not actually turned on and off by it, are at least modulated in remarkable synchronization with Io's position in its orbit.

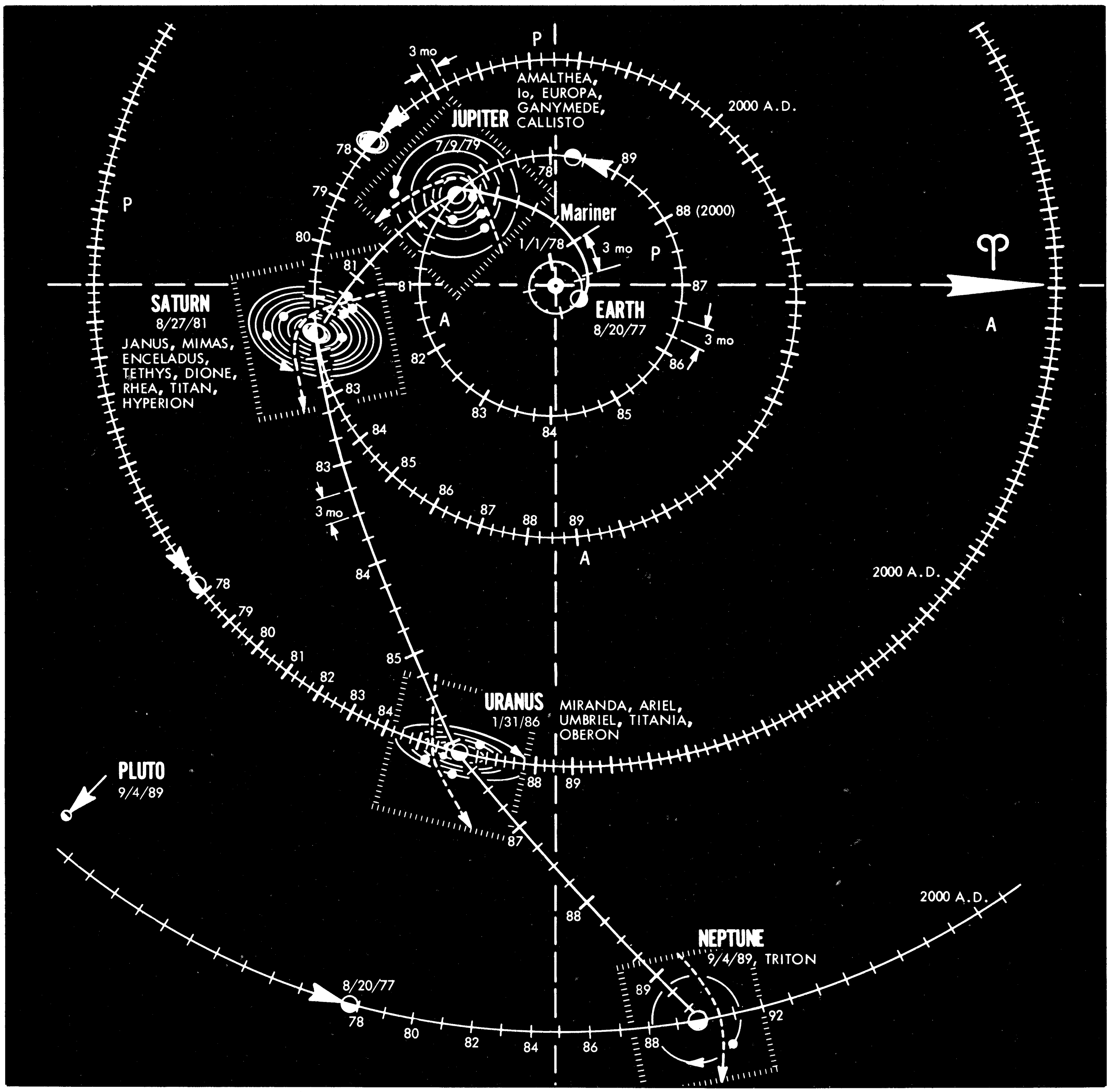
To investigate this effect, as well as the Jovian emissions themselves, the MJS probes will be the first U.S. planetary craft equipped with radio telescopes since Mariner 2 in 1962. (Radio bursts have also been discovered coming from Saturn and apparently from Uranus, and there are reported to be unpublished data that may mean the same thing for Neptune, all of which could be targets for the MJS radio "ears.") James W. Warwick of the University of Colorado, who has been studying Jupiter's radio bursts since they were first discovered more than 20 years ago, will be the mission's chief radio astronomer, in his first role ever as a spacecraft experimenter. He will be in charge of two 10-meter dipole antennas on each spacecraft, arranged at a 90° angle to let them separate the circular polarization of Jupiter's signals from the largely unpolarized galactic and solar emissions. In addition, says Warwick, it should be possible for the spacecraft to look back "over their shoulders" at earth's own radio output. This is of interest, he says, because the polarization of earth's low-frequency component (about 150 to 200 kilohertz, often associated with auroras) is not even known.

At Saturn, the moons on the target list include Hyperion, Titan, Rhea, Dione, Tethys, Enceladus and Mimas. There will also be photos of strange Iapetus, with its one highly reflective face and one dark one. (The anomalously shiny side was the location of the "star gate" in the book version of Arthur C. Clarke's *2001: A Space Odyssey.*) Unfortunately, says Smith, Iapetus will be too far away for what could have been revealing infrared and ultraviolet spectra to be made by the spacecraft. The most important of them by far, however, is Titan, the most important target of the entire MJS mission except for Jupiter and Saturn themselves. If the second MJS craft is even to be considered for a Uranus visit, in fact, the first one will have to have logged a successful mission at Titan.

About 5,800 kilometers across, Titan is larger by nearly 1,000 kilometers than Mercury, yet less massive than Ganymede. It produces its own radio noise, has an atmosphere that several researchers believe to be as thick as the earth's, and is on some people's lists as an even likelier place than Mars to look for extraterrestrial life. Its atmosphere used to be thought to consist almost entirely of methane, says Veverka (who, though not an MJS experimenter, is a satellite specialist and a self-confessed Titan enthusiast), but more recent data have indicated the possibility of considerable amounts of hydrogen. In laboratory studies, ultraviolet light and methane-hydrogen atmospheres have combined to produce a variety of complex hydrocarbons such as ethane, ethylene and acetylene, the same sorts believed to exist in the atmospheres of Jupiter and Saturn, and infrared studies of Titan are consistent with the presence of just such molecules. The difference is that high temperatures deep in the atmospheres of the two gas-giant planets probably destroy the hydrocarbons as part of a cyclic process, whereas the frigid surface of Titan may be at the bottom of a continuous accumulation of falling, organic "goo."

In fact, says Cornell astronomer Carl Sagan, unless some other process is breaking up the reddish-brown goo, it could have accumulated over billions of years into a layer meters to kilometers thick. In short, says Veverka, Titan may be the best place in the solar system other than the earth to look for "very involved organic chemistry," a possible test of the theory that life on earth evolved from a primitive reducing atmosphere—just the sort of atmosphere that Titan seems to have right now.

Just as the oxidizing potential and simplified dynamics of the atmosphere of Venus combine to offer a natural laboratory for meteorological studies relevant to earth, Titan's thick, reducing atmosphere and 16-day rotation period provide a chance to study a less-involved model of the gas-blanketed outer worlds, Veverka points out. The day is so long, he says, that rotation becomes almost negligible in shaping circulation patterns; this is in sharp contrast to the 9-to-15-hour periods of Jupiter, Saturn, Uranus and Neptune and the distinct horizontal bandings they produce. Down below the atmosphere, Titan itself may be more interesting still. Beneath the possible organic sludge-layer, says John Lewis of the Massachusetts



This is the planned flight path of Mariner 11, one of two spacecraft in the Mariner Jupiter-Saturn 1977 mission, including possible extensions to Uranus and Neptune. Spacecraft and planetary sun-centered paths are marked to indicate progress at three month and yearly intervals. Planet-centered (broken line) paths show progress during approach and departure at about three-hour intervals. The planetary satellites which may be imaged are listed from the innermost orbit outward. This representation was designed by Science News and computed and drawn by Jet Propulsion Laboratory. ⟶● = locations of planets at 8/20/77 launch date. P = perihelion; A = aphelion

Institute of Technology, may be a thin, solid crust of methane and water ice over a large liquid mantle of ammonia and water. Farther down, an outer core of wet, silicate slush may enclose a tiny center of solid iron sulfide. A meteorite impact, Veverka suggests, could crack the fragile crust, producing a huge fountain of dilute ammonia that is quickly photodissociated by ultraviolet light into hydrogen and nitrogen, with potentially exciting contributions to the organic rain descending from on high. Glaciers, hot springs, self-healing craters, all surrounded by a blanket that may be more intensely orange than even Viking's views of Mars—the possibilities are intriguing. And MJS is planned to pass within 4,100 kilometers of the place, photographing objects as small as 500 meters across, analyzing its atmosphere, and reporting for the first time from close up on what could be the most interesting moon in the solar system.

If (and only if) all goes well with the first spacecraft's visit to Titan, and if the second craft is still in good health as it nears Saturn, the planet's gravity will be used to send the probe on to Uranus, whose five known satellites circle their host world at the same peculiar 98° inclination to the ecliptic. Almost nothing is known about them—they have never been photographed, even through the largest telescopes, as anything but points of light in the sky. Neptune's two even more distant moons are also out there waiting, but not even the most optimistic of MJS supporters are seriously planning on a close look at them. "Twelve years," says one of the project's scientists, "is a long time to hold your breath."

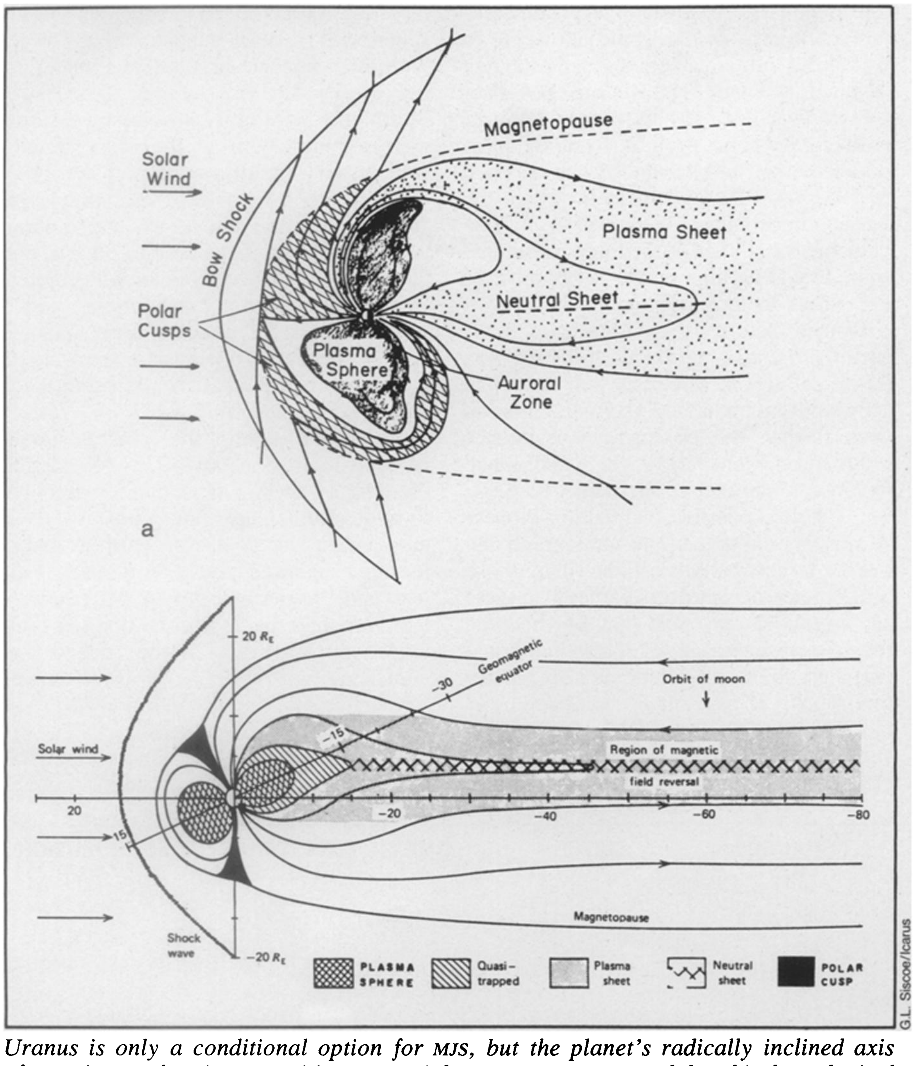
The primary targets, of course, are Jupiter and Saturn themselves. The advanced MJS camera systems will make the most of them. The first MJS photos of Jupiter, taken more than two and a half months before closest encounter, will be sharper, says Smith, than those taken by the Pioneer spacecraft only *one day* out from the planet. At best, they should show features as small as 6 kilometers across, some 35 times better than the best of the Pioneer images. Each MJS craft will take up to 10,000 photos of Jupiter (and about 6,000 of Saturn), to be played back, thanks to high data rates, at a pace whose peak may reach four times the capacity of the Jet Propulsion Laboratory computers to process them. As a result of such rapid-fire photography, one plan is to make what amounts to a movie of the approach, showing 10 full rotations of Jupiter on its axis. Besides being an invaluable record of developing weather patterns, Smith says, it could indicate whether the convective turnover of the Jovian atmosphere is slow enough—some researchers have hypothesized that a given particle could take centuries to go from top to bottom—to sustain local temperature environments that could allow life to form from the precursors that are probably in the atmosphere. The MJS mission is not a biological one, but its data, combined with atmospheric profiles from the proposed Jupiter Orbiter-and-Probe mission (a 1981 or 1982 launch, to penetrate the Jovian atmosphere in Nov. 1984), will be valuable for studies of the huge planet that some feel to be high on the list of promising places to look for life.

Ringed Saturn is exciting enough as seen from earth, but by the time the first MJS craft sees it, scientists will have had 10 months to build up their anticipation even further by looking at the images returned by Pioneer 11, which will make its closest approach to the planet on Sept. 2, 1979. It is possible that neither Pioneer 11 nor MJS will be able to photograph any but the largest particles in the rings, those a kilometer or more in diameter if there are any. The reason is that by the time they are close enough to resolve individual particles, they will be moving so rapidly that such photos may be hopelessly blurred. Nonetheless, the overall ring structure, the Cassini divisions that separate the rings, and the banding and other features visible in Saturn's own atmosphere will all be on the list, perhaps along with other special targets that Pioneer 11 may make known. At one time, says Smith, the possibility was being considered of putting one of the MJS craft into orbit around Saturn, rather than just flying by, but this would have required larger fuel tanks on the spacecraft, added about two years to the flight time to Saturn, and caused a less-close encounter with Jupiter. The resulting orbit, furthermore, would have a period of about a year, and the cost of ground support for even a single circumnavigation at such a leisurely pace would be considerable.

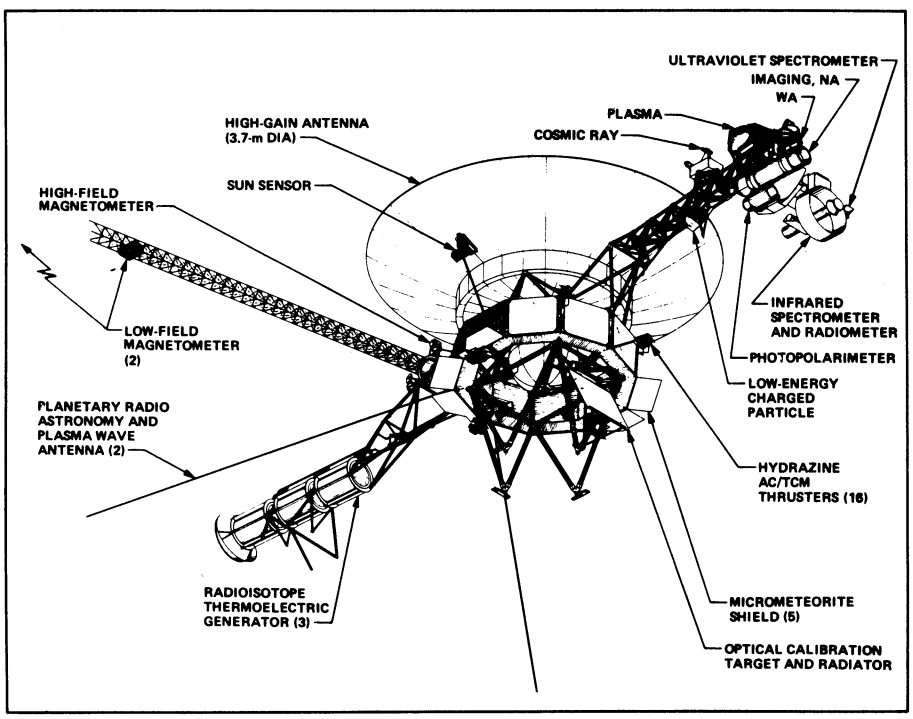
As for the moons, the cameras should be able to map about 30 to 50 percent of most of their surfaces. This amounts to a quantum leap, since most of them are barely detectable from earth as disks, let alone featured ones. Ganymede, Callisto and Europa will get far better coverage even than that, since the first MJS craft to arrive (Mariner 12—the second one launched) will see them as it leaves Jupiter, while the second one will see them as it approaches the planet. The MJS system also permits high- and normal-resolution pictures to be taken simulta-

EVENT	SPACECRAFT	DATE	TIME	DISTANCE TO TARGET (km)	RESOLUTION (km)
Launch (nominal)	M 11	Aug. 20, 1977	7:40 a.m. PDT		
Launch (nominal)	M 12	Sept. 1, 1977	5:50 a.m. PDT		
start Jupiter imaging	M 12	Dec. 15, 1978		75,000,000	1,500
Amalthea		Mar. 4, 1979	10:00 p.m. PST	440,000	9
Jupiter closest approach		Mar. 5, 1979	4:00 a.m.	280,000	6
Io			7:00 a.m.	25,000	0.5
Europa			9:00 a.m.	750,000	15
Ganymede			6:00 p.m.	130,000	2.5
Callisto		Mar. 6, 1979	9:00 a.m.	130,000	2.5
start Jupiter imaging	M 11	Apr. 20, 1979		75,000,000	1,500
Callisto		July 8, 1979	5:30 a.m. PDT	240,000	5
Ganymede		July 9, 1979	12:30 a.m.	50,000	1
Europa			10:30 a.m.	190,000	4
Amalthea			1:30 p.m.	550,000	11
Jupiter closest approach			3:30 p.m.	648,000	13
start Saturn imaging	M 12	Aug. 24, 1980		96,000,000	2,000
Titan		Nov. 11, 1980	10:14 p.m. PST	4,100	0.5
Tethys		Nov. 12, 1980	2:14 p.m.	410,000	8
Saturn closest approach			4:14 p.m.	130,000	3
Mimas			6:14 p.m.	100,000	2
Enceladus			6:14 p.m.	230,000	5
Dione			8:14 p.m.	140,000	3
Rhea			11:14 p.m.	60,000	1
Hyperion		Nov. 13, 1980	9:14 a.m.	890,000	18
start Saturn imaging	M 11	June 8, 1981		96,000,000	2,000
Hyperion		Aug. 26, 1981	6:00 a.m. PDT	960,000	19
Titan			7:00 a.m.	350,000	7
Rhea			9:00 p.m.	250,000	5
Tethys		Aug. 27, 1981	1:00 a.m.	160,000	3
Saturn closest approach			4:50 a.m.	100,000	2
Enceladus			5:00 a.m.	90,000	2
Mimas			6:00 a.m.	30,000	1
Dione			7:00 a.m.	200,000	4
Uranus closest approach	M 11	Jan. 31, 1986			
Neptune closest approach	M 11	Sept. 1989			

Detailed 12-year timeline shows the down-to-the-minute planning that is necessary to pre-aim the spacecraft instruments for their multitargeted rush through space. Actual encounter times and distances may vary slightly from this schedule, but any anticipated major corrections will be made long before the spacecraft reach the vicinity of each planet. The Mariner 11 timeline at Saturn assumes that conditions (see story) will permit targeting for Uranus.



Uranus is only a conditional option for MJS, but the planet's radically inclined axis of rotation makes it an exciting potential target, as suggested by this hypothetical model of its magnetic field as compared with that of the earth. This model was proposed by physicist George L. Siscoe, now with UCLA.



Two antennas and three booms will be deployed from the spidery MJS craft in space.

neously, allowing the detailed high-resolution images to be precisely located within the larger-area coverage of the normal ones.

But there's far more to the mission than photography. The MJS vehicles will be the first planetary craft, for example, to carry plasma-wave detectors, under the guidance of Frederick L. Scarf of TRW Systems Group. Whereas Pioneers 10 and 11 carried instruments to measure the energies and fluxes of the plasmas in the charged Jovian environment (as will the two Mariners), the MJS craft will also look at the plasmas' overall structure—their wave patterns. This could help lead to an understanding of how planetary trapped radiation belts are sustained when plasma waves cause charged particles to precipitate to the upper atmosphere, changing the particles' spin angle and kicking them free of the magnetic field lines to which they had been confined. The instruments will also aid in studying Io's switching effect on Jupiter's radio emissions, and help with another of the mission's goals: the search for lightning in the atmospheres of Jupiter, Saturn and perhaps Uranus. With heavy atmospheres and radio emissions associated with all three planets, says Scarf, the presence of huge lightning bolts would not be surprising, and it is hoped that the MJS instruments will "hear" the resultant cascading radio frequencies known as "whistlers." Such whistlers are preceded by quick "snaps" of energy called "sferics," but, says James Warwick, a sferic can occur as long as 30 seconds before its whistler and might also be masked by the planet's decametic radio bursts. Fortunately, the time lag between sferic and whistler is in part a function of plasma density, so the plasma sensors will be able to lend a vital hand. And the MJS probes should be able to measure the particle sizes in Saturn's rings, though not by taking pictures. The craft will fly so that their radio signals pass through the ring plane on their way to earth, yielding a size-distribution "map" ranging from shards a centimeter or two in diameter to huge chunks hundreds of meters across.

Lightning bolts, organic rains, ringed planets, electrically conductive moons—the MJS mission could contribute insight into a large number of the solar system's enigmas. "I wouldn't be surprised," says one participant, "if scientists are still writing papers from it in the 21st century."

Meanwhile, the spacecraft carrying out all these tasks will not be called MJS at all. A committee of NASA officials, prompted by the visibility of Viking's name in contrast to what one administrator says "would otherwise just have been Mariner Seventy-Eleven or something," is considering a list of apellations such as "Galileo," for the discoverer of the major Jovian satellites, or "Argo," for the vessel that sought out the Golden Fleece. But what's in a name? □