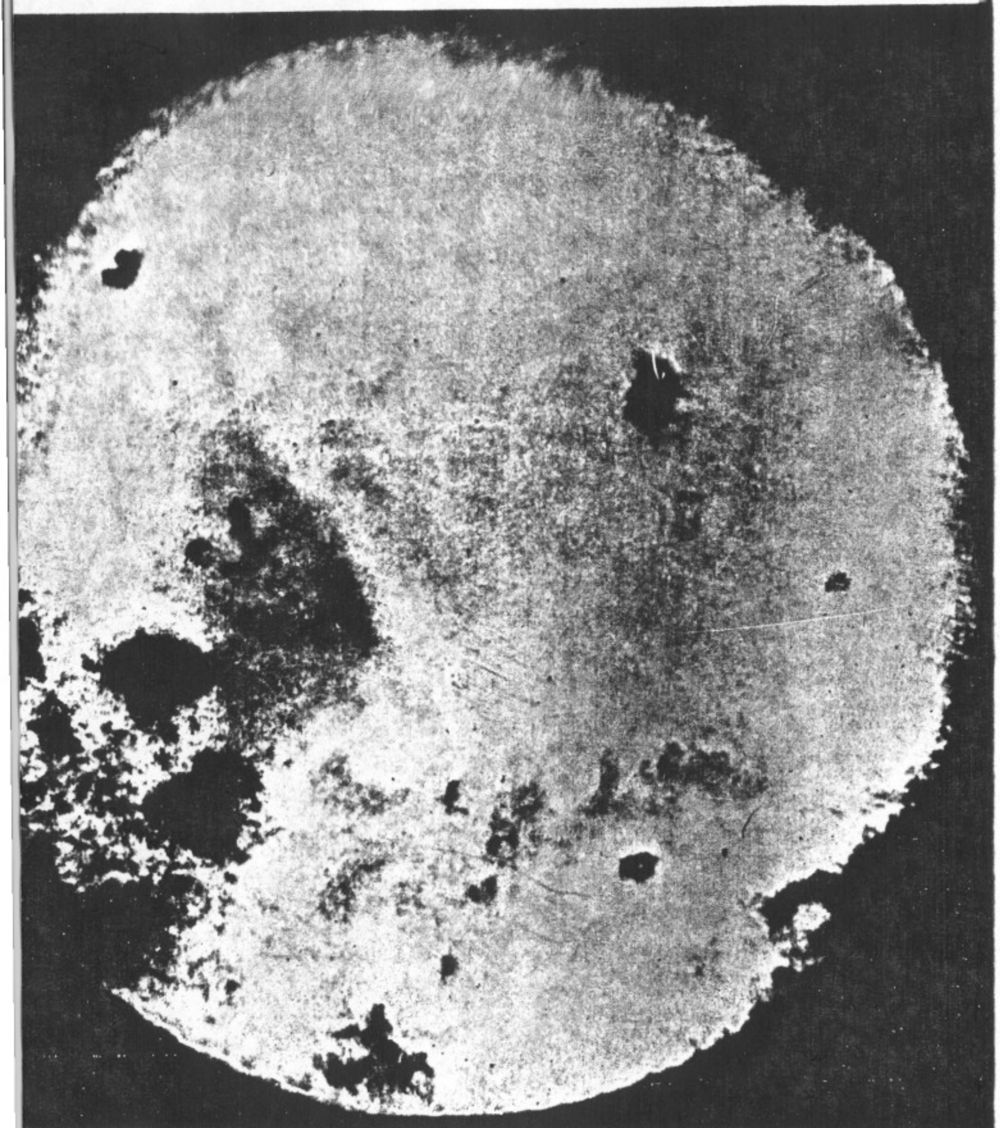

DEN FACE OF THE MOON
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FELIX GODWIN

The exploration of the solar system

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may be indicative of a snow covering, which would of course be highly useful for refuelling, especially as it would be accessible without severe landing difficulties. Sources of water and other potential fuels are certain to exist among the nearly 2000 asteroids now known. Thus a spaceship might transfer to an asteroid at a suitable time, travel on the asteroid to the destination circumsolar orbit while refuelling (and perhaps carrying out investigations there), and finally transfer to the destination planet using asteroidal fuels. The drawback exists that voyage time would be long, but improvement of the asteroid would be an attractive possibility. If permanent quarters and fuel-obtaining machinery were constructed on a suitable asteroid, ships would develop into small, light shuttle craft occupied only during manoeuvres. Voyage time would thus be by no means wasted, being analogous to waiting periods spent on a planet. An example of a suitable asteroid might be Apollo, which follows an orbit suitable for travel between Venus and Ceres; or Adonis or Hermes, which follow ellipses between the asteroid belt and the orbits of Mercury and Venus respectively.[12]

The zero-gravity problem would be solved as for the Martian satellite bases. Metals, too, would probably be available from certain minerals. If the asteroids are indeed the remnants of a destroyed Jupiter satellite, immense deposits of useful minerals will be available without mining. Also, the possibility of easy examination of the interior of a world should be interesting.

Incidentally, the asteroid belt will not, as has been suggested more than once, pose a serious obstacle to ships bound for the outer planets. Their size, number and the space they occupy are such that they will be of no moment in this regard.

42. JUPITER

Mars is the best starting point for a voyage to Jupiter (or to the other outer planets) in that it is near not only physically but, more important, gravitationally speaking in terms of the gravity of the Sun. Furthermore, it seems that large colonies can be established and fuel sources made available there. However, as a scientific and general research centre Earth should remain permanently superior, and interplanetary spaceships will, on the whole, be constructed there.

The Earth–Jupiter voyage on the optimum ellipse takes more than two and a half years, or 6 years 18 days round trip including the waiting period. For worlds beyond the asteroid belt, this course is clearly too slow. A ship must enter a hyperbola, or an ellipse not tangent to the orbit of either planet in question.[13, 14] The higher velocities required on such voyages can, however, be attained by the plasma jet. Speeds and times to the outer planets are given in Table 19, where it is seen that, if voyages of over a year's duration are deemed out of the question, Saturn is still accessible from Earth with ion or plasma power and, with very high velocities, perhaps Uranus from Mars. Further voyages must be initiated from bases at Jupiter or beyond.

The design of a Mars-outer planet ship differs substantially from that of a vehicle operating within the asteroid belt. In the first place, less sunlight protection is needed, though a white coat of paint is still useful to reduce thermal differences between different portions of the craft. A constant orientation is, on the other hand, superfluous, at least for heat-control reasons. Likewise the meteor danger is less severe at greater distances from the Sun. Thus the importance of an external shell is greatly decreased.

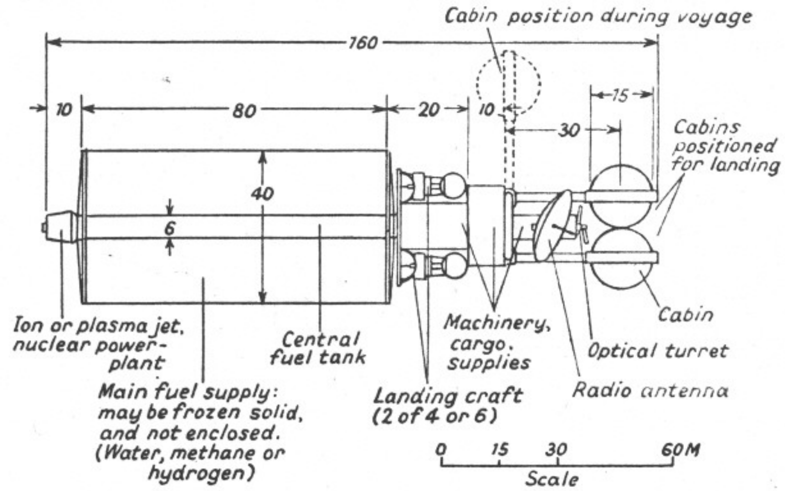

Fig. 18 *Outer planet ship, general design*

The resulting configuration, designed for landing only on small satellites, involves a cylindrical hull with a central core of fuel tanks, perhaps 100 m long and 6 m in diameter, with a nuclear motor aft and navigation, radio equipment, radars, air-conditioning, etc., forward. Chemically powered rockets, manned and robot, are clustered around the forward section of the core of the fuel tank, which holds their propellants. In order that a slow spin, producing a minimum of structural strain, may be used, the quarters (at the forward end of the hull) take the form of two spheres or ellipsoids at opposite ends of a 40–80 m long connecting tube. First-stage ship fuels occupy annular tanks fitted around the central tanks aft of the landing rockets.

For refuelling on a satellite with water (snow) or some other material, the cabin booms are folded forward and the cabins tilted so that their floors will be parallel to the ground when the vessel lands, moving vertically downward but settling with its hull horizontal, employing chemical rockets at the sides for final braking. This landing arrangement, as opposed to the vertical tail-first touchdown, enables the crew to more readily avoid radioactivity danger from the motor during debarkation and embarkation. Snow may be drawn into fuel tubes by large portable electric fans (which in a vacuum would operate like rotary snowploughs).

Small manned landing craft can be released with no halting of the ship's slow rotation; indeed the slight acceleration thus imparted would aid them in clearing the mother ship. They are used in voyages to and landings on other satellites, and for close approaches to Jupiter itself. They might well take the form of modified third stages of Earth orbital cargo craft.

Much time and fuel could be saved by the use of orbits exploiting the gravitational field of a planet intermediate between starting point and destination. Perturbations could increase a ship's speed and desirably alter its direction. Within the orbit of Jupiter, such cases would involve primarily the Sun and Venus. The Moon could be likewise used, enabling a ship accelerating in a low Earth orbit to 23 791 m.p.h. (10·7 km sec^{-1}) to escape from the Earth-Moon system at some 2·3 km sec^{-1}, passing nearest the Moon at 102 hours (about 3000 km distant, an hour after crossing its orbit). While speed savings of this order are insignificant when plasma jet power is available, similar cases involving planets could appreciably reduce voyage times. Further reductions in necessary potential rocket speed would result when a power manoeuvre was executed at the closest approach to the intermediate centre of gravity, as was pointed out in the preceding section on Venus.

Jupiter itself can be ruled out as a landing point, not so much because of its high gravity and escape velocity (relatively unimportant to a plasma jet) as because it may well have no stable surface, at least not at an altitude of reasonable atmospheric pressure.[15]

Of Jupiter's satellites, five are less than 100 miles in diameter—too small to retain any atmosphere, and probably all rather similar: perhaps resembling the Moon, but with a lesser degree of thermal erosion and thus still more rugged terrain. The two outer satellites, numbers 8 and 9, exhibit retrograde motion. The long-ellipse method of reversing circumgeocentric movement should be remembered in manoeuvres preparatory to visiting these worlds.

According to calculations heretofore described in the case of Mercury, gases of even the lowest molecular weights are to be expected on the giant planets. As for the Jovian satellites, Europa must have no atmosphere whatsoever. Callisto may have traces of water and nitrogen, and some oxygen and CO_2; Io, traces of water, a little nitrogen and oxygen, and (relatively) much CO_2; while the atmosphere of Ganymede should be similar, but slightly less extensive.

Dr. Gerard P. Kuiper has determined, by the use of an infra-red spectrometer, that Europa and Ganymede are covered with snow.[16] This, of course, means that water, oxygen and fuels are immediately available to a ship landing there. Water would give sufficient performance in a plasma jet for Jovian interlunar manoeuvres, for which transfer velocity requirements for optimum elliptical voyages are comparable to those for Earth–Mars or Earth–Venus voyages, though optimum voyages outside Callisto's orbit are inconveniently long so that there faster orbits would have to be employed. For the take-off against lunar gravity, electrolytically produced hydrogen and oxygen can be utilized. For the Earthward journey, where higher performance is desirable, a hydrogen plasma jet is used. Certainly there is an abundance of water for the

purpose. Atomic power is necessarily employed in hydrogen production, the solar constant of Jupiter being only 3·7% of its value at the Earth's orbit. Simultaneously produced oxygen not used as a propellant in take-off is stored there in liquid or solid form. Ganymede seems the best location for a base: apart from its resources of snow, it is near enough to the planet to afford an excellent observation point (Jupiter as seen from Ganymede would subtend some 15 times the diameter of the Moon seen from Earth) and has an appreciable gravitational field (helpful to men in a Base there) and may well have an atmosphere containing useful substances. Furthermore, there is strong evidence that this moon always keeps the same face toward the planet, again facilitating observation.

Certainly Jupiter itself will be one of the foremost subjects of investigation. Close approaches may be made by modified landing craft, which would enter an ellipse with perigee close to the atmosphere. The Jovian atmosphere's high density gradient suggests that extremely close flight will be possible without significant aerofrictional heating. Studies made during such approaches (about 1–1½ hours being spent in close proximity) would include photography of atmospheric disturbances; magnetometric investigations; radio probing of ionospheric phenomena and of the planet's electrical storms; mapping of cloud belts and measuring of their speeds; planetary structure as indicated by flight path perturbations, and so forth. Magnetic studies will disclose whether Jupiter's magnetic field is affecting Amalthea (the innermost satellite), which appears to circle Jupiter somewhat more rapidly than is commensurate with the planet's gravitational field. A ship would take roughly 2·1 days to circle Jupiter on the ellipse from Ganymede's orbit.

Automatic telescopic cameras operating on Ganymede might be used to record continually Jovian (i.e. atmospheric) behaviour. Robots, too, might be used to some extent, but the necessary use of expensive plasma jet machinery to nullify their considerable circumjovian velocity is hardly compatible with a robot's expendable nature, and relatively large amounts of chemical fuels would be required instead. If launched into more or less horizontal paths from close approach vessels, they would enter the atmosphere at speeds approaching 45 km sec^{-1} and would thus be quickly destroyed by heating. However, if launched from a slow (high-altitude) orbit they would again enter at high (vertical) speed and would soon be destroyed (especially in view of the high density gradient of the atmosphere, the density possibly doubling with each 2500 m of depth). Thus the only satisfactory path is a more or less radial one from a low orbit. Robots could be set in orbit (by a close approach vessel) just above the atmosphere. Even here they would do much useful work. Eventually, vestigial exospheric drag would decelerate them (especially at their high speeds), but they would continue to transmit information until destroyed by heating or possibly deceleration. The planet's velocity of rotation (12·5 km sec^{-1} at the equator) would somewhat alleviate difficulties arising from the necessarily high orbital speeds of such robots. This, and an artificial deceleration, chemically powered, of 12 km sec^{-1} ($MR = 20$, $I_s = 400$) would give an orbital robot, descending through the upper atmosphere, a final circumjovian speed of 20 km sec^{-1} relative to the planet's atmosphere. Liquefied-gas cooling might then preserve a robot for an appreciable time and problems of data transmission would take precedence. Jupiter itself generates powerful static which would tend to jam radio signals.

Some robots might be able to descend safely to a level where their own buoyancy in the very highly compressed gases would prevent them from sinking further, irrespective of circular velocity. The main difficulty here would, of course, be the immense pressures found at such levels.

It is difficult to see how, as has been suggested more than once, a spaceship could obtain fuels from Jupiter's atmosphere. Admittedly methane and ammonia are there in vast quantities, but to remain in an intra-atmospheric orbit any vehicle would have to move at such speeds that collection of useful amounts of ambient gases (which would have to be at a very low density to permit orbiting at all) would be difficult or impossible. The satellites provide greatly improved sources of necessary materials. Besides, there are indications that Jupiter's temperature rises considerably at moderate depths. According to Kuiper, the atmosphere's thermal gradient may be such that an assumed convection zone 100 km. deep may embrace a temperature difference of nearly 200°C.

43. SATURN

Even with the advanced techniques heretofore described, a direct Mars–Saturn voyage would be a considerable venture and it seems better to employ Ganymede as a base (or, at least, as a refuelling point). Jupiter ships constructed at Mars or Earth may then proceed from here onward. Relatively small velocities suffice for reaching Saturn's satellite system from the vicinity of Jupiter, though, likewise owing to the weakening solar gravitation, voyage times are intolerably long unless considerable speeds are employed. Furthermore, the distance between planets increases greatly as one recedes from the Sun. Nonetheless, a Jupiter–Saturn voyage will be readily possible after refuelling on Ganymede.

Like Jupiter, Saturn offers an extensive system of moons, the first three of which (Mimas, Enceladus, and Tethys) may consist largely of snow (as opposed to being merely covered with it). This is very convenient for a Base, if only a firm surface for landing can be found. Dione, Rhea, and Hyperion are thought by some to consist of a rock core sheathed in ice and snow (possibly solid ammonia and carbon dioxide), with perhaps an atmosphere composed predominantly of methane; all in all a very useful combination. Titan is definitely known to have a methane atmosphere, possibly containing clouds of ammonia crystals, and craft could definitely be refuelled here. Japetus is interesting in that one side of it appears to be about five times as bright as the other—a paradox almost undoubtedly to be resolved by telescopic observation. Phoebe, the outermost satellite, exhibits retrograde motion.

The greatest astronautical resource of Saturn is, without doubt, its ring system, found by Kuiper to be composed of water ice. Thus, refuelling is possible, as nowhere else, without landing on a body. A ship can orbit here and collect as much fuel as its tanks will hold. In the outer ring a vessel can refuel while still 72,000 km from the planet's surface, escape velocity at this altitude, being about 12 km sec^{-1} in excess of orbital speed. For interplanetary voyages, involving high speeds and requiring best performance, methane could be sent up from Titan by chemical rockets, at least on homeward voyages where relatively small interplanetary payloads would be carried. For local manoeuvres—that is, within Saturn's moon system—fuel in unlimited quantities would be obtainable in the rings. Two primary Saturn bases should therefore develop: one on Titan and the other in the ring system, near its outer edge. The Titan base should be on the hemisphere which continually faces Saturn, and at the equator (for heating purposes). Ample heat will be available in the quarters from nuclear sources, but outside the cold would tend to crystallize and embrittle machine parts. Much heat would be conserved by the subterranean location of quarters. The nuclear reactor, too, would be buried, for purposes of radiation protection.

If Titan's atmosphere is as dense as that of Mars—and, at the low temperatures prevailing, this is likely, despite the satellite's relatively weak gravitational field—the use of aircraft will be feasible. Oxygen obtained by electrolysis of water (snow and/or ice) might be burnt with atmospheric methane, if the latter forms a sufficient percentage of the air. The same principle could be applied to surface vehicles, and to secondary quarters heating plants.

Assuming ice and methane gas to be present in useful proportions, oxygen, water and motor fuels become immediately available if sufficient nuclear power is supplied; and, if suitable metals can be obtained by electrolysis of minerals, a Base might become in many respects self-supporting. Barring development of some high-thrust *and* high-efficiency means of rocket propulsion, an electromagnetic accelerator capable of handling frozen methane might be a long-term possibility. It would enable interplanetary craft to refuel without the aid of chemically powered landing rockets, unless hydrogen from the rings proved a better, though a harder to handle, fuel.

While the Titan Base operated with this and the exploration of Titan itself in mind, the ring Base would be the starting point for flights to other satellites, as well as the Saturn close-approach and observation centre. Like the Titan Base, the ring station would have oxygen, water and propellants available in unlimited supply. Even if only minute ice crystals are available for fuel, they could be conveniently collected by enfoldment in huge trawl-like bags of flexible material, manipulated by men in spacesuits. A number of ship fuel tanks could be converted into living quarters. Automatic cameras of all varieties would constantly scan Saturn's cloud deck and, with ample hydrogen-oxygen fuel available, sounding rockets could be launched vertically into the atmosphere below. Some of the work of this station might be similar to that carried out by the Mars and Venus survey crews, as heretofore described.

Observation devices would be situated somewhat outside the ring, separate from the water electrolysis plant. This would present no difficulties as the rings are only a few miles thick. A second, smaller station might be established at the lower (inner) extremity of the rings, for observation with fewer obscuring particles (in fact, only from here could equatorial regions be adequately observed). The outer station, however, would be more important in that ships from Mars and Jupiter would refuel here and, therefore, most incoming supplies would be deposited here.

Saturn's smaller satellites may be grouped together in discussion, and we may expect them to be more or less similar. The outermost moon, Phoebe, is small and apparently has no attractive characteristics, especially as its motion is retrograde and slow, so that voyage times from the inner bases would be considerable.

A secondary minor base for observation of Saturn might be established on Mimas, the innermost satellite, if water is found there in useful amounts. If snow is not available the extraction of water by hydration from minerals always remains a possibility. Here none of the problems of centrifugally induced gravity would arise, and minerals containing useful ores might be found.

TABLE 19

OUTER PLANET VOYAGE TIMES AND VELOCITIES

	Mars	Jupiter	Saturn	Uranus	Neptune or Pluto
Hyperbolic trajectory crossing the Earth's orbit at 42·5 km sec^{-1}:					
Earth	54 days	339	735	1 764	3 226
Mars	—	285	681	1 710	3 172
Jupiter	285	—	394	1 425	2 887
Saturn	681	394	—	1 029	2 491
Uranus	1 710	1 425	1 029	—	1 462
Hyperbola crossing Earth's orbit at 64·5 km sec^{-1}:					
Earth	29	156	295	618	1 020
Mars	—	127	266	589	991
Jupiter	127	—	139	462	864
Saturn	266	139	—	323	725
Uranus	589	462	322	—	402
Hyperbola crossing Earth's orbit at 161 km sec^{-1}:					
Earth	10	54	99	204	330
Mars	—	44	89	194	320
Jupiter	44	—	45	150	276
Saturn	89	45	—	105	231
Uranus	194	150	105	—	126
Optimum ellipse (most economical course) for each planet:					
Earth	260	937	2 043	5 446	10 972
Velocity:	3·0	8·7	10·1	11·3	12·1 km sec

The last two lines of figures are for the optimum ellipse for each planet. The figures for Pluto are substantially the same as those for Neptune; Pluto's distance from the Sun has a mean value very near that of Neptune. The precise Pluto figures would depend upon the date of the voyage.

In so far as location of an interplanetary radio station is concerned, Saturn's considerable output of static suggests Titan, the most distant convenient point, which has the additional advantage that Earth, Mars and approaching ships will be above the horizon for as long as a week at a time (as opposed to a few hours for the ring base). Saturn will not occult the above planets for appreciable periods. Titan's gravity permits the construction of antennae of considerable size, and radio power requirements are by no means prohibitive if large arrays are employed at both stations. For convenience, a radio relay unit should also be installed at the ring station.

Saturn, like Jupiter, offers a refuelling point, and one with the great advantage that fuels can be obtained without landing on any body. After ring refuelling, a spaceship can proceed further where the weakening of the Sun's gravitational influence makes fast and relatively constant speed hyperbolic orbits feasible. Unfortunately, interplanetary distances increase drastically here. However, the situation presented in Table 19 is tremendously improved by the fact that an outward-bound spaceship can definitely refuel at Mars, Jupiter, and Saturn with little or no facilities for refuelling being required if water is used (the plasma exhaust velocities obtainable with water being 40% those possible with hydrogen). Later, when bases are established at these points—an accomplishment well worth the effort—hydrogen can be used consistently instead if, in the case of Saturn, techniques of handling warrant its preference to methane.

44. URANUS AND NEPTUNE

Both these planets can be reached from a Saturn Base in a reasonable time. Little is presently known of their satellites, though it is virtually certain that landings on the primaries will, as in the case of the other giant planets, prove not feasible, so that investigations of them will once more take the form of moon-based expeditions employing robots, close-approach flights, continuous photographic mapping and allied techniques. At present one cannot state with any degree of certainty the possibilities of fuel resources on the satellites, though the pattern suggested by studies of the moons of Saturn and Jupiter might suggest the presence of snow covers on some, and deposits of frozen gases are likely at the low temperatures there extant. It is of course entirely possible that undiscovered moons circle these outermost worlds. Some provision for refuelling there will be imperative for expeditions involved in such lengthy voyages. Uranus and its satellites rotate about an axis almost in the plane of the planet's circumsolar orbit, and the motion of the moons is retrograde. This would offer the slight advantage that none of the other planets of the system would normally be out of line of sight for radio communication. However, the latter would be somewhat complicated by the considerable distances, which would render it never possible to get an answer to a query from Earth to Uranus in under 18 160 sec (5 hours 2 min) (8 hours 4 min for Neptune).

The atmosphere of Uranus was at one time thought to be rich in methane, and the prospects of refuelling might thereby have come to mind. Quite apart from the difficulties, outlined previously, in collecting gases from a giant planet's atmosphere, it has now been shown by Kuiper that the compound in question is actually a substance resembling formaldehyde.

Neptune's outer moon, Neried, also shows retrograde motion. The inner one, Triton, would presumably be the first landing point for observation of the planet. The planet exhibits approximately bi-diurnal variations in brightness, suggesting two more or less antipodally situated regions of particularly high albedo. The visual albedo of the planet as a whole is remarkably high, indicating perhaps an interesting anomaly in Neptune's structure.

On these far planets, cryogenic difficulties are of course more serious than ever. Aboard a spaceship in orbit (either on a journey or about a planet or satellite) ample heat will be constantly available from the nuclear engine, solar heating meriting no consideration beyond the orbit of Jupiter. Problems would arise upon landing. A few sheets of cold-resistant metal, possibly a nickel-molybdenum-cobalt alloy, plated with gold or platinum to reduce heat radiation, can provide excellent vacuum insulation against almost any degree of cold. If these satellites have atmospheres (conceivable at their low temperatures) they will be very tenuous ones, due to their low escape speeds and to the fact that most gases will be frozen out, so that vacuum insulating walls for quarters and vehicles are usable. In a thin atmosphere, even spacesuits could employ this device, using conventional thermal insulation mainly in feet and hand coverings.

45. PLUTO

Pluto differs from the giant planets in that it is small and dense—possibly the densest planet known. Kuiper measured its diameter with the 200-in. telescope and obtained a figure of 3600 miles with a possible error of 200 miles. All attempts at determining its mass yield strangely high values, so that a high surface gravity and relatively high escape velocity are to be expected. Temperatures there are so low that all gases except hydrogen and helium must be liquefied or frozen. The latter being too rare to merit consideration, free hydrogen becomes the only possible constituent of a Plutonian atmosphere, and may well have been retained if the planet's escape velocity exceeds 3 km sec^{-1}, a value which it may approximate. Some other gases might be present as clouds of frozen crystals.

Pluto can be reached from a Saturn Base in a reasonable time. At such distances the Sun's gravitational field will have but a slight effect on the course of a fast spaceship whose velocity will be almost constant for considerable distances. Indeed, care will have to be exercised to avoid escape from the Sun's gravity (the requisite velocity is only 7·6 km sec^{-1} at the orbit of Neptune).

As far as refuelling at Pluto for the return is concerned, useful frozen gas deposits (formed when the planet cooled) are more than likely to be available. If water and oxygen were there when Pluto was created they must be there still. Any previous atmosphere must now form a convenient frozen layer over the whole of the planet, and with atomic energy these can become sources of rocket fuel.

8. NEBULA IN SAGITTARIUS (NGC 6514, Messier 20)

The white gas is illuminated by the stars within it, and is partially obscured by clouds of cooler gas and dust. New stars are continuously being created from this material, which is a great deal less substantial than the best artificial vacuum. This nebula is a weak emitter of radio waves

As for Pluto's place in the exploration of the system, its only possible use appears to be that of an outpost for attempts to detect further planets. Measurements of Pluto discourage its acceptance as the body responsible for the observed perturbations of Neptune's orbit, and a tenth planet would be exceedingly hard to locate from the region of the Earth. This is because solar light intensity varies relatively little at such tremendous distances, so that a body large enough to have an appreciable effect upon the motion of Neptune would necessarily be at a solar distance large even in proportion to that of Pluto. Pluto, however, would form a point suitable for searching for such a body.

In the future days of astronautics, when the outermost planets are accessible, it will be possible for such a planetary search installation to be largely, or even entirely, automatic. It would operate by continually photographing sections of the half of the celestial sphere away from the Sun and examining such images through a blink microscope. It would be possible for a machine to do this, reporting by radio to a Saturn base or to some other occupied point when one of the stars appeared to move between photographs. Coordinates of the body would be given and records checked to eliminate comets. Considerable periods would have to elapse for motion of a new planet to exceed the limits of observational error, but the work would be very straightforward.

46. SPACESTATIONS: CONSTRUCTION

Spacestations may be economically and conveniently constructed from those cargo rocket third stages which are not used for ship construction. Hulls may be reformed to cylindrical airtight chambers, as propellants tanks were constructed for interplanetary ships. The majority of structure could be employed and fifteen stages would be required for fabrication of a two-decked section 16 m long and 6 m in diameter, complete with wiring, air and water pipes and emergency oxygen cylinders (from propellant pipes). Two such sections would then be set parallel, some distance apart, and their ends connected by two loops of cable; a tube would be built between them (from relatively unaltered third-stage hulls set end to end) and they would be put into rotation by propulsors to simulate gravity. Gradually other sections could be added, two at a time, perhaps progressing toward a complete torus, although such completion would be by no means essential. One ring would include accommodation for about thirty men. Further space, if required, would be added in the form of additional toruses or partial toruses; a central hub portion, formed of undecked 6-m diameter sections fitted end to end along the axis of rotation, would provide zero-gravity accommodation. In this way stations of any size, adaptable to numerous purposes, could be built in conjunction with early lunar and interplanetary travel, the cost of transporting basic structure to the orbit having been covered already. The Venus landing expedition, for instance, would put in orbit materials sufficient to make a complete three-ring station of twelve sections per ring (with a further 3-m