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Building an Interplanetary Civilization: The Solar System

By
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When I first wrote this month's reprint article, the Pathfinder Mission had successfully landed on Mars and transmitted the first pictures from the Red Planet in more than 20 years. The Martian surface is a dusty red soil littered with rocks of all sizes and shapes. In fact, it looks a lot like Arizona, except with fewer trees. Whenever we land a space probe on a new planet, or send one on a close flyby, we are reminded that despite our egocentric view of the universe, there are worlds out there other than our own. Unfortunately, too often in science fiction, we writers perpetuate our species' subconscious belief that the universe does indeed revolve around us. Too often in our stories, the characters seem to be the only people alive in the universe, and the locale in which the story takes place the only spot in existence.

This effect comes from authors not taking the time to paint a convincing backdrop against which to play out the action; a backdrop consisting of all those myriad details that aren't directly story related, but which combine to convince the readers that the story is real. Fiction is supposed to mirror life, and life is marked by its complexity. In life, nothing ever happens in isolation, people are bedeviled with conflicting priorities and needs, and everything always takes longer and costs more. Only when an author is able to build the "feeling" of complexity into the story have they truly succeeded in mirroring life. And, of course, they must do this without actually making the story complex to the point where the readers will not be able to follow it. But then, no one ever said that this would be easy.

I remember reading a story in the 1970s in which the female protagonist is traveling aboard a ship en route to a science station located on one of the moons of Jupiter. The ship is an obvious descendent of one of the Saturn V moon rockets. The story concerns the various difficulties encountered by the ship's crew and passengers on their journey. Even though the action is confined to the ship, the author's narration acquaints us with the universe beyond the ship as the story unfolds. From the information the author gave me, I concluded that the protagonist's supposed space faring civilization possessed one Jovian science station and two ships that made twice a year supply runs between the station and Earth. That was the total extent of humankind's conquest of the cosmos.

The problem, of course, is that the author was trying to write a story while linearly extrapolating the "present moment" (circa 1970) into the future. In effect, humanity never advanced beyond that magic moment when we first landed men on the moon. Things improved quantitatively, but not qualitatively. The Saturn V moon rocket was our greatest accomplishment in 1970, so the author figured that future spaceships would just be bigger and better renditions of the same design. Humanity in 1970 was isolated to a single planet (Earth), but was capable of launching occasional expeditions to our nearest neighbor, Luna. Obviously, then, the future would just be more of the same. Instead of occasional expeditions to Luna, a century of progress would allow our infrequent jaunts to become longer — say to Ganymede, the largest of Jupiter's moons. But the nature of space exploration would remain tentative and occasional, with access to our distant colony so difficult that the most we would be able to muster is two ships to make the long circuit back and forth each year.

As we who live a quarter century after that particular "present moment" know, the future proved to be nothing like a linear extrapolation of 1970. For one thing, that was the year that effectively ended the space race. It was also the year when public interest in the United States turned from outer space to local environmental problems. Effectively, the space cadets took a back seat to the tree huggers, a position in which they remain to this day.

As for that technological marvel, the Saturn V, it was scrapped less than two years later. Optimized completely for getting three astronauts to the moon and back, the great 120-meter-long rocket proved totally useless for all other tasks. We didn't even get a chance to shoot all of them off. Rather, we cancelled the moon landings after the sixth. We abandoned the Saturn V rocket with three still ready to launch. You can see these vehicles lying on their sides in Houston, Texas; Huntsville, Alabama; and Cape Canaveral, Florida. Talk about expensive museum pieces!

After abandoning the moon rocket, we designed a new spaceship, one with wings. While I was at Pratt and Whitney, I worked on the original proposal for the engines that were to power the space shuttle (we eventually lost to Rocketdyne). The concept in those days was for a fully reusable vehicle. Unfortunately, the "fly home" booster proved much too expensive to implement, so we went with a tank we could discard and solid boosters that could be refurbished between flights. This, then, is the system we use today. The shuttle is an excellent first try, but not really a true spaceship.

[Author's Note: The truth of the foregoing paragraph was recently brought into sharp focus when the Space Shuttle *Columbia* came apart during reentry. While a marvelous machine, the shuttle is proving to be every bit as much a blind alley as the Saturn V. We need a system that will get us into orbit easily and cheaply. Without it, there will be no interplanetary civilization – ever!]

So linear extrapolation of the "present moment" is not a very convincing strategy for writing science fiction stories. When you assume that which is going on now will go on forever, you run the risk of giving your story the taste of the material from which it is constructed, namely cardboard. If you don't believe things will change in the future, then you must be very young – for it is only a dozen years since the Soviet Union broke up and only two years since the destruction of the World Trade Center Such events don't happen very often, but on a century-long time scale, they are nearly certain to occur.

This is not to say that you shouldn't draw on your own experiences when writing. You can't help but draw on them since they are the only experiences you have. All literature and cinematic art is anchored to the milieu of the artist who produces it. This is as true of science fiction as it is of any other art form. Look at the old Flash Gordon or Buck Rogers serials and you will see spaceships that bear a striking resemblance to 1930's airplanes. Oh, they're sleeker than planes of that day and fly with a trail of smoke rising from their jets rather than propellers spinning at their prows, but the feeling that they are antique airplanes is overpowering to a modern viewer. They are extrapolations of developments that never came to pass, and those of us familiar with the actual history of aviation can recognize the anachronistic elements in these “futuristic” flying machines.

So it is with science fiction stories. Since they must be read by people living more or less at the time of their writing, any such story is necessarily a translation of fictional future events into terms that the contemporary audience can understand. Thus, the blasters and death rays of the 1940’s and 1950’s have become the lasers and phasers of the 1980’s and 1990’s. The computers of Golden Age stories were colossal single machines in giant buildings attended by white-coated acolytes, while the computers of the modern age are all tiny pocket or laptop machines with prodigious capabilities.

Note: One of the most daunting tasks of the science fiction writer is extrapolating what computers will look like in a century or two. Frankly, the task is virtually impossible. Most of us would have difficulty in predicting what computers will be like in ten years, let alone ten times ten years. I know of no one in science fiction who accurately predicted the advent of the personal computer or the impact it would have on society. I made this point in one of my short stories (“Dream World,” available for free download from Sci Fi - Arizona.) Had anyone in 1960 accurately predicted the PC and what it would be capable of, most editors would have rejected the story as hopelessly optimistic.

So what has all of this to do with building interplanetary civilizations? Simply this. Had the author of the story about the trip to Jupiter spent a little more time filling in the details of the society that launched the ship, he would have had a more convincing story — even if he stuck with the Saturn V as the model for his spaceship. Travel to the planets requires more than a single ship making one trip per year. It requires a whole space faring civilization to support that ship. In other words, a people who have successfully conquered space will have built the *infrastructure* needed to support their journeys through hard vacuum. They won’t have built two ships, but *hundreds* of ships. They will have orbited dozens of manned space facilities, and thousands of unmanned satellites to support their operations. Space travel won’t be an occasional event where the entire world lines up in front of their holovision sets to watch the launch; space travel will be as common as airline travel is today. In other words, interplanetary civilization will be *complicated*, and it is your job as a writer to give the reader some appreciation of that complication.

So for the next few months, we will concentrate on the factors that go into building a complex, believable interplanetary civilization. We will discuss what our society requires if we are finally to break free of the gravity of the home world. And not only to break free. We will talk about what we need to sustain our civilization in space.

The term “interplanetary civilization” infers a civilization that encompasses more than a single planet. If this seems pedantic, then you haven’t noticed how many science fiction writers seem not to know this. The first question for any science fiction writer writing an interplanetary story is, “On which planets will I plant my civilization?” So, as a public service, we will take a short tour of the available real estate in the solar system. If you are looking for a home above the atmosphere, you may be depressed at how little prime real estate is available to us.

1.0 The Sun

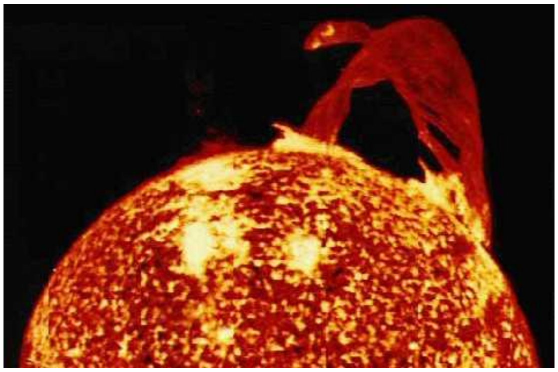

Figure 1: The Sun

No, the sun probably isn't a very good place to set up housekeeping. Still, it is the most important object in our universe, so we begin our tour there. The sun's official name is Sol (at least, in science fiction), which is the Latin word meaning "sun." So why not call it "the sun?" Because someday we'll have another star to call our own and not giving them each a proper name will be confusing.

Sol is a Spectral Class G2, yellow dwarf star. The sun is 1,392,000 km (865,400 miles) in diameter; its volume is about 1,300,000 times that of Earth. Its mass is 332,000 times that of Earth. At its center, the sun has a density over 100 times that of water, a pressure of over 1 billion atmospheres, and a temperature of about 15,000,000 degrees Kelvin. The bright surface of the sun (the part we see) is at a temperature of about 6000 degrees Kelvin; which, of course, is why it glows with a yellow-white light.

So far as we can tell, there is absolutely nothing special about our sun in the grand scheme of things. The universe contains billions of stars just like it, probably with tens of billions of planets like those in the solar system. And though we think our presence makes Sol special, it is likely that the future will prove this attitude to be what it is — self centered conceit.

1.1 Mercury

Mercury is the closest planet to the sun, at a mean distance of 57.9 million km, (36.0 million miles) or 0.387 astronomical units.

[The Astronomical Unit (AU) is the preferred measurement for interplanetary distances. Earth orbits at 1.0 AU from the sun – by definition.]

Mercury has a diameter of 3,031 miles (4,878 km), no atmosphere and a cratered, lunarlike surface. In fact, its diameter is only 32% larger than Luna's is, but its density (5.5 times that of water) gives it the same surface gravity as the much larger Mars (38% that of Earth's gravity). During the 1940s and 1950s, a lot of writers wrote very evocative stories in which Mercury orbited Sol with one face always pointed at the sun (just as Luna always points the same face toward Earth). This allowed them to place colonies on the line between perpetual day and perpetual night, where conditions were semi-livable. Unfortunately, the march of science has destroyed that beautiful picture. Mercury has a rotation period of 59 days, which is faster than its year of 88 days. Effectively, Mercury goes through three day-night cycles

Figure 2: Mercury

while circling the sun twice. The result is that the sun bakes all parts of the planet.

Mercury's orbit is highly eccentric; at perihelion it is only 46 million km. from the Sun, but at aphelion it is 70 million. This produces very odd effects for an observer on Mercury's surface. At some longitudes the observer would see the Sun rise and then gradually increase in apparent size as it slowly moved toward the zenith. At that point the Sun would stop, briefly reverse course, and stop again before resuming its path toward the horizon and decreasing in apparent size.

Temperature variations on Mercury are the most extreme in the solar system, ranging from 90ºK to 700ºK. Mercury is damned hot when the sun is shining, so take your SPF 1,000,000 sun block cream if you are planning to take up housekeeping. And don't forget your thermal underwear for those long nights! Interestingly, in 1991, radar photographs of Mercury from Earth strongly suggested that the planet has polar ice in areas perpetually in shadow. I wouldn't hang too many stories on this, however, until it is verified.

1.2 Venus

Venus is Earth's twin, planetologically speaking (planetology is the study of other planets, a very recent science). Venus is the second planet from the Sun. It orbits at 108.2 million km (0.72 AU). Its diameter is 12,103 km, is only slightly smaller than Earth (95% of Earth's diameter, 80% of Earth's mass). The surface gravity on Venus is 90% of that on Earth. Both worlds have relatively young surfaces, and their densities and chemical compositions are similar. Because of these similarities, the science fiction masters generally agreed that beneath its perpetual blanket of clouds, Venus was a wet world with large oceans and swamps populated by slimy lizards and all manner of poisonous reptiles, not to mention the beautiful green skinned princesses.

Again, science destroyed a beautiful fictional locale. As soon as we dropped our first probes into Venus's atmosphere, we discovered that the planet has suffered seriously from global warming. The pressure of Venus's atmosphere at the surface is 90 atmospheres (about the same as the pressure at a depth of 1 km in Earth's oceans). The atmosphere is composed mostly of carbon dioxide. There are several layers of clouds many kilometers thick composed of sulfuric acid. These clouds completely obscure any view of the surface. The dense atmosphere produces a run-away greenhouse effect that raises Venus's surface temperature to over 740ºK (hot enough to melt lead). Venus's surface is actually hotter than Mercury's despite being nearly twice as far from the Sun.

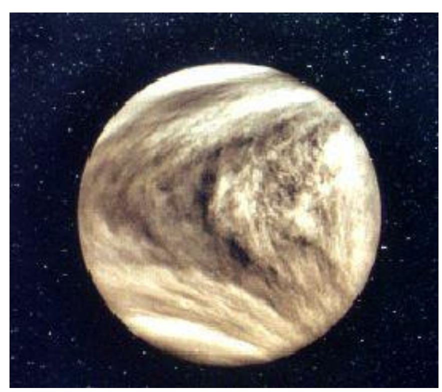

Figure 3: Venus by Visible Light

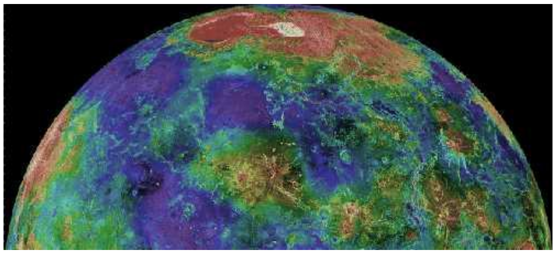

Figure 4: Venus by Radar

Venus probably once had large amounts of water like Earth but it all boiled away. Venus is now quite dry. Earth would have suffered the same fate had it been just a little closer to the Sun.

Most of Venus's surface consists of gently rolling plains with little relief. There are also several broad depressions: Atalanta Planitia, Guinevere Planitia, Lavinia Planitia. There two large highland areas: Ishtar Terra in the Northern Hemisphere (about the size of Australia) and Aphrodite Terra along the equator (about the size of South America). The interior of Ishtar consists mainly of a high plateau, Lakshmi Planum, which is surrounded by the highest mountains on Venus including the enormous Maxwell Montes.

We know about Venus's surface because the Magellan spacecraft orbited Venus and mapped its surface with radar. Data from Magellan's imaging radar shows that much of the surface of Venus is covered by lava flows. There are several large shield volcanoes (similar to Hawaii or Olympus Mons) such as Sif Mons.

If you want to move in-system from Earth to plant your colony, choose Mercury. Despite its resemblance to a pottery kiln, it's still easier to live on than is Venus.

1.3 Earth

Earth is the perfect environment for human beings. This is hardly surprising since our species evolved here. You won't find another world like it in this solar system. And, of course, the question of how many more we will find in other stellar systems is one of the most important questions we have left to answer.

Earth is the third planet from the Sun. It orbits at 149.6 million km. (93 million miles), or 1.00 AU from Sun. Its mean diameter is 12,756 km. Over most of the surface, temperatures are such that water remains liquid, which is lucky for the inhabitants since we are just big, walking sacks of water. Since presumably you know quite a lot about conditions on the surface of the Earth (having lived here all your life), we will move on with our tour.

1.3.1 Luna

Despite its lack of air and water, Luna is definitely a piece of prime real estate. For one

Figure 5: Earth

Figure 6: Luna

thing, we know we can get there. We know because we *have* gotten there — six times. Any self-respecting interplanetary civilization can be expected to turn Luna into a suburb of Earth. Even if your characters aren't going anywhere near the moon, having them watch the daily moon shuttle launch from an orbiting space station/hotel is a good way to convince the readers that there is more to your universe than just what is in your story.

Luna orbits Earth and not the sun like a normal planet. It orbits at 384,400 km (256,000 miles) from Earth, taking a total of 27.3 days to make one circuit. The Moon's diameter is 3476 km, making it considerably smaller than the Earth. Even so, it is the largest moon with respect to its primary in the solar system. (Ganymede is bigger than the Moon *and* Mercury, but it pales in comparison to Jupiter, its primary.)

Luna is a good jumping off place for longer trips and the preferred source of materials to build space habitats and anything else you want to construct beyond the atmosphere. Why? Because of its one-sixth gravity. Not only do you feel lighter on the moon, but also you can lift six times the mass into orbit from Luna that you can from Earth for the same cost.

1.4 Mars

Ah, Mars! For more than 100 years, humanity has lusted after the Red Planet, imagining that it is the home of "Martians." These can either be friendly, as in Edgar Rice Burroughs's red skinned heroine Deja Thoris, or unfriendly, as in H.G. Wells' *War of the Worlds* Martians.

The truth about Mars is that it's too small to support a proper atmosphere. At only 6,794 kilometers in diameter, the Red Planet orbits at a distance of 227.9 million kilometers (1.52 AU). Still, it *is* the second most hospitable place in the solar system, so we shouldn't let first impressions put us off.

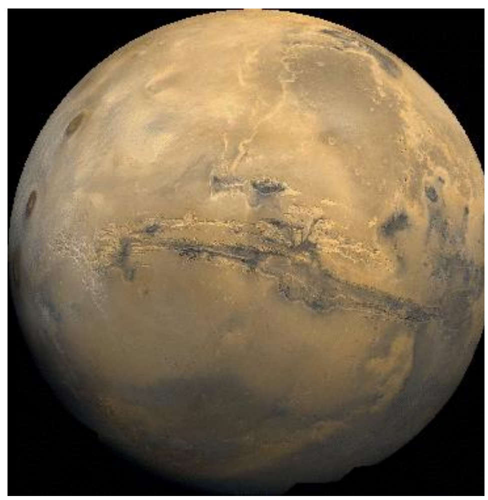

Figure 7: Mars

Mars's orbit is significantly elliptical. One result of this is a temperature variation of about 30 C at the subsolar point, that point directly beneath the sun at local high noon. Overall, the Viking landers found that Martian temperatures vary from 150ºK (-220ºF) to 295ºK (70ºF).

Although Mars is much smaller than Earth, its surface area is about the same as the land surface area of Earth because it lacks our vast oceans. That, of course, has its good points and bad points. We know there is oxygen on Mars because the red color comes from iron oxide, or just plain rust. We know there used to be water there, too. Pathfinder landed in a valley cut by the largest flood human beings have ever discovered – a quantity of water equal to the Great Lakes went downstream each week of the flood! Unfortunately, the atmospheric pressure is currently too low to allow liquid water to exist on the surface. However, recent discoveries indicate there is considerable subsurface ice. There are polar ice caps with frozen H_2O in them. Caution: Since sunlight obeys the inverse square law and the local atmospheric pressure is the equivalent of Earth at 30,000 meters of altitude, don't try to power your Martian colony with either solar cells or windmills. When it comes to Mars, good old nuclear power is just about the only way to go.

Except for Earth, Mars has the most highly varied and interesting terrain of any of the terrestrial planets. There is Olympus Mons: the largest mountain in the Solar System, rising 24 km (78,000 ft.) above the surrounding plain. Its base is more than 500 km in diameter and is rimmed by a cliff 6 km (20,000 ft) high. There is Tharsis: a huge bulge on the Martian surface that is about 4000 km across and 10 km high. There is Valles Marineris: a system of canyons 4000 km long and from 2 to 7 km deep, far larger than the Grand Canyon of the Colorado River. Hellas Planitia is an impact crater in the Southern Hemisphere over 6 km deep and 2000 km in diameter.

One thing that Mars doesn't lack is spectacular scenery against which to play out your stories. Mars also has two moons, Phobos and Deimos. They are each scrawny little rocks and nothing like our own Luna. Still, a visit to one can do wonders for your credibility.

Figure 8: The Asteroid "Gaspra"

1.5 The Asteroid Belt

The asteroid belt is what remains of the solar system's stillborn fifth planet. The asteroids are rocks and chunks of iron that would have coalesced into a functioning world had it not been for the gravitational pull of the next planet out, Jupiter. The asteroid belt extends from just beyond Mars's orbit to just inside Jupiter's orbit, with the largest asteroid, Ceres, being a full 1000 kilometers (600 miles) in diameter. The picture is of Gaspra, a fairly representative member of the breed.

The asteroids would make very good human space colonies, giving us access to virtually unlimited space resources. I read an article in 1976 that maintained that asteroidal iron was worth $24 *trillion* per cubic kilometer, figured in 1976 dollars. All you need is to go out and collect some to assure your riches.

Warning, it isn't as easy as it looks.

1.6 Jupiter

Jupiter is the King of Worlds, and at 142,984 kilometers in diameter at the equator, contains twice the mass of all the other planets combined. Jupiter has a puny ring system and enough moons to gladden the heart of any science fiction writer. Jupiter orbits the sun at 778 million kilometers, or 5.2 AU. Despite its size, it has a fast rotation period. A Jovian day is slightly less than 10 hours long. It takes Jupiter 11.8 years to go around the sun once.

Being a gas giant, Jupiter has no solid surface that we know of; and if it does, the pressure and temperature would crush you and toast you simultaneously. Any colonies have to float in the atmosphere and suffer a gravity field 2.64 times Earth normal. While spectacular to look at, Jupiter would make a poor place to live. This is not surprising since Jupiter is basically a star that failed to grow to minimum size. Jupiter is about 90% hydrogen and 10% helium with traces of methane, water, ammonia and “rock”.

Jupiter probably has a core of rocky material amounting to something like 10 to 15 Earth-masses. Above the core lies the main bulk of the planet in the form of liquid metallic hydrogen. This exotic form of the most common of elements is possible only at pressures exceeding 4 million atmospheres.

The outermost layer is composed primarily of ordinary molecular hydrogen and helium that is liquid in the interior and gaseous further out. The atmosphere we see is just the very top of this deep layer. Water, carbon dioxide, methane and other simple molecules are also present in tiny amounts.

Jupiter and the other gas planets have high velocity winds that are confined in wide bands of latitude. The winds blow in opposite directions in adjacent bands. Slight chemical and temperature differences between these bands are responsible for the colored bands that dominate the planet's appearance. The light colored bands are called zones; the dark ones belts. The bands have been known for some time on Jupiter, but the complex vortices in the boundary regions between the bands were first seen by Voyager. The data from the Galileo probe indicate that the winds are even faster than expected (more than 600 kph) and extend down into the atmosphere as far as the probe was able to observe; they may extend down thousands of kilometers into the interior. Jupiter's atmosphere was also found to be quite turbulent. This indicates that Jupiter's winds are driven in large part by its internal heat rather than from solar input as on Earth.

The vivid colors seen in Jupiter's clouds are probably the result of subtle chemical reactions of the trace elements in Jupiter's atmosphere, perhaps involving sulfur whose compounds take on a wide variety of colors, but the details are unknown. The colors correlate with the cloud's altitude: blue lowest, followed by browns and whites, with reds highest. Sometimes we see the lower layers through holes in the upper ones.

Figure 9: Jupiter

The Great Red Spot (GRS) has been seen by Earthly observers for more than 300 years. The GRS is an oval about 12,000 by 25,000 km, big enough to hold two Earths. Other smaller but similar spots have been known for decades. Infrared observations and the direction of its rotation indicate that the GRS is a high-pressure region whose cloud tops are significantly higher and colder than the surrounding regions. Jupiter radiates more energy into space than it receives from the Sun.

The interior of Jupiter is hot: the core is probably about 20,000°K. The heat is generated by the Kelvin-Helmholtz mechanism, the slow gravitational compression of the planet. (Jupiter does NOT produce energy by nuclear fusion as in the Sun; it is much too small and hence its interior is too cool to ignite nuclear reactions.) This interior heat probably causes convection deep within Jupiter's liquid layers and is probably responsible for the complex motions we see in the cloud tops.

Jupiter has a huge magnetic field, much stronger than Earth's. Its magnetosphere extends more than 650 million km (past the orbit of Saturn!). Jupiter's magnetosphere is far from spherical — it extends “only” a few million kilometers in the direction toward the Sun. Jupiter's moons therefore lie within its magnetosphere, a fact that may partially explain some of the activity on Io. Unfortunately for future space travelers, the environment near Jupiter contains high levels of energetic particles trapped by Jupiter's magnetic field. This "radiation" is similar to, but much more intense than, the radiation found within Earth's Van Allen belts. It would be immediately fatal to an unprotected human being.

Science fiction stories involving Jupiter generally are set in the moon system (see below), although "Jupiter diving" stories in which ships dive down into the big planet to collect the gasses there are also popular. The Jovian radiation belts are a new discovery and significantly complicate planting colonies on Jupiter's moons. For a portion of their orbits, most of the moons pass through these radiation belts, causing severe problems for those trying to live on the ground. If you have a "Jupiter science station" like the one discussed in the introduction, be sure to put it underground.

1.7 Jupiter's Moons

Many a science fiction story has been set on the moons of Jupiter, of which it has 16 at last count. The moons of Jupiter have everything a colonist could ever want, including a view. Unfortunately, because Jupiter's magnetic field is hundreds of times more powerful than that of Earth, it tends to collect energetic particles from the solar wind. The problem with this is that some of the moons orbit in a hellish radiation environment. Jupiter's moon Io may well have the most harmful environment in the whole solar system, including even Venus. Wear your lead underwear if you plan to visit.

Figure 10: Io

1.7.1 Io

Io ("EYE oh") is the fifth of Jupiter's known satellites and the third largest; it is the innermost of the Galilean moons (those discovered by Galileo as he looked through one of the first telescopes). Io is slightly larger than Luna, with a diameter of 3630 kilometers. It orbits 422,000 km from Jupiter, or approximately the same distance as Luna orbits Earth. But don't forget, Jupiter is a monster compared to Earth, so Io nearly skims the atmosphere.

Io's surface is radically different from any other body in the solar system. The nearly total lack of impact craters indicates that the surface is very young. The craters you see in the picture aren't from meteors, but rather from volcanoes, some of which are active. There is an argument going on as to whether the material erupting from Io's vents are some form of sulfur or sulfur dioxide, or whether it is silicate rock. Io is the most active volcanic place in the solar system. Any colony you plant on Io will not only have to worry about the radiation, but about the volcanoes.

Some of the hottest spots on Io may reach temperatures of 700ºK (even 900ºK has been reported), though the average is much lower, about 130ºK. The energy for all this activity probably derives from tidal interactions between Io, Europa, Ganymede and Jupiter. These three moons are locked into resonant orbits such that Io orbits twice for each orbit of Europa which in turn orbits twice for each orbit of Ganymede. Though Io, like Earth's Moon, always faces the same side toward its planet, the effects of Europa and Ganymede cause it to wobble a bit. This wobbling stretches and bends Io by as much as 100 meters (a 100-meter tide!) and generates heat.

Io has a thin atmosphere composed of sulfur dioxide and perhaps some other gases, which means that it stinks! There is also little water on the moon.

1.7.2 Europa

Europa is the sixth of Jupiter's known satellites and at 3138 kilometers diameter, the fourth largest. Europa is slightly smaller than Luna and orbits at 670,900 km from Jupiter. Europa and Io are somewhat similar in bulk composition to the terrestrial planets, being primarily composed of silicate rock. However, Europa's density (2.97 g/cm^3, a little less than the Moon's and substantially less than Earth's) indicates that it doesn’t have a dense iron core.

Europa's surface is unlike anything in the inner solar system. It is exceedingly smooth, with few features more than a few hundred meters high. The prominent markings seem to be only changes in color, not changes in elevation. There are very few craters on Europa, indicating a young and active surface. Images of Europa's surface strongly resemble images of sea ice on Earth and scientists have postulated that beneath the ice there is a sheltered sea as much as 50 km deep. If so, Europa is the true Water World of the solar system, or perhaps we could rename it Cue Ball. There could be a lot of good stories about submarines that ply the dark depths of the moon-covering ocean. And since water freezes at the same temperature on Europa that it does on Earth, the presence of liquid water (albeit under a lot of very frozen ice) gives one of the best possibilities of planting a viable human colony.

Europa's most striking aspect is a series of dark streaks crisscrossing the entire globe. The larger ones are roughly 20 km across with diffuse outer edges and a central band of lighter material. The latest theory of their origin is that they are produced by a series of volcanic eruptions or geysers.

Recent observations with Hubble Space Telescope reveal that Europa has a very tenuous atmosphere ($1x10^{-11}$bar) composed of oxygen. Of the 61 moons in the solar system only four others (Io, Ganymede, Titan and Triton) are known to have atmospheres. Unlike the oxygen in Earth's atmosphere, Europa's is almost certainly not of biologic origin. It is most likely generated by sunlight and charged particles hitting Europa's icy surface, producing water vapor that is subsequently split into hydrogen and oxygen. The hydrogen escapes into space due to the low surface gravity and the oxygen remains behind.

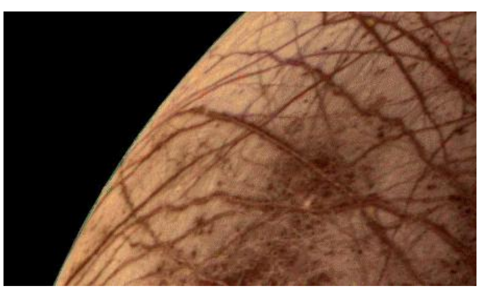

Figure 11: Europa

1.7.3 Ganymede

Ganymede is the seventh and largest of Jupiter's known satellites, as well as being the largest moon in the solar system. It is 5262 kilometers in diameter, making it larger than Mercury (but with half the mass), and much larger than Pluto! It orbits Jupiter at 1,070,000 km.

Ganymede and Callisto seem to be composed of a rocky core surrounded by a large mantle of water or water ice with an ice surface. Titan and Triton are similar. Like Europa, the preponderance of water on Ganymede's surface and subsurface make it prime real estate for establishing a human colony. Ganymede's surface is a roughly equal mix of two types of terrain: very old, highly cratered dark regions, and somewhat younger (but still ancient) lighter regions marked with an extensive array of grooves and ridges. Their origin is clearly of a tectonic nature, but the details are unknown.

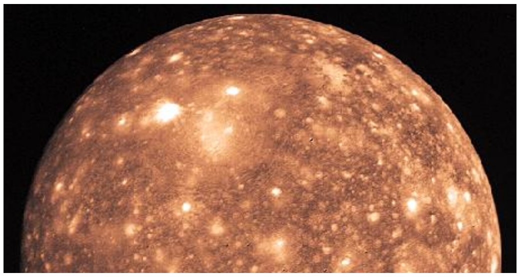

Figure 12: Ganymede

Like Europa, the Hubble Space Telescope recently found evidence of a very tenuous oxygen atmosphere on Ganymede similar to the one found on Europa. Similar ridge and groove terrain is seen on Enceladus, Miranda and Ariel (other of the solar system's moons). By noting the extensive cratering, scientists have placed the age of Ganymede at 3 to 3.5 billion years, similar to Luna. Unlike Luna, however, the craters are quite flat, lacking the ring mountains and central depressions common to craters on the Moon and Mercury. This is probably due to the relatively weak nature of Ganymede's icy crust that can flow over geologic time and thereby soften the relief.

1.7.4 Callisto

Callisto is the eighth of Jupiter's known satellites and the second largest. Its diameter is 4800 kilometers and it orbits 1,883,000 km above Jupiter. Callisto is only slightly smaller than Mercury but possesses only a third of its mass. Callisto and Ganymede seem to be composed of a rocky core surrounded by a large mantle of water or water ice with an ice surface. Titan and Triton are similar.

Callisto's surface is covered entirely with craters. The surface is very old, like the highlands of the Moon and Mars. Callisto has the oldest, most cratered surface of any body yet observed in the solar system; having undergone little change other than the occasional impact in 4 billion years. The largest craters are surrounded by a series of concentric rings which look like huge cracks, but which have been smoothed out by eons of slow movement of the ice. The largest of these has been named Valhalla; it is the most dramatic example of a multi-ring basin. These are thought to be the results of massive impacts. Other examples are Mare Orientale on the Moon and Caloris Basin on Mercury. Like Ganymede, Callisto's ancient

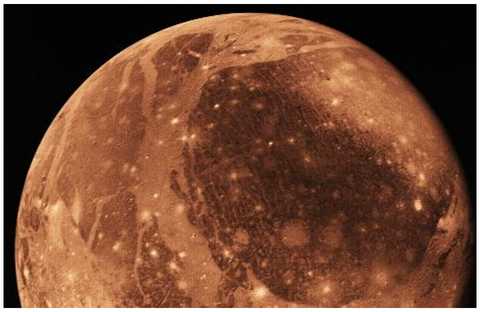

Figure 13: Callisto

craters have collapsed. They lack the high ring mountains, radial rays and central depressions common to craters on the Moon and Mercury. The surface is therefore relatively featureless as viewed from the ground.

1.8 Saturn

Saturn is the most beautiful world in the solar system, made so by its spectacular ring system. The rings are caused by tidal stresses from the planet working on a band of debris orbiting too close to the planet. Ordinarily, this debris would coalesce into a moon, but the tides keep things mixed up. The gravitational pull of many of Saturn's 16 moons also plays a part in shaping the ring structure. Cassini's gap, visible as a dark band near the outer edge of the rings in the picture, is caused by the gravitational pull of Mimas.

Like Jupiter, Saturn is a gas giant in the outer solar system. It is 120,536 km (equatorial) in diameter and rotates once every 10 hours and 39 minutes. It orbits the sun at 1,429,400,000-km (9.54 AU), or nearly ten times the distance of Earth from the sun. Like Jupiter, Saturn has no known solid surface and colonies would have to hang in the atmosphere. Surprisingly, there are places in Saturn's atmosphere that are almost homelike. Due to its low density, the gas giant's gravitational pull is only 16% greater than that of the Earth, and between freezing cold and boiling hot, there is a band of altitudes where water is actually liquid. (If you are thinking of writing a book about cities hovering in the clouds of Saturn, go ahead. But first turn to Don Dixon's Spacescapes in the Sci Fi - Arizona Art Gallery. There you will find the cover to my book, *The Clouds of Saturn*, which coincidentally, is about colonies floating in the clouds of Saturn.)

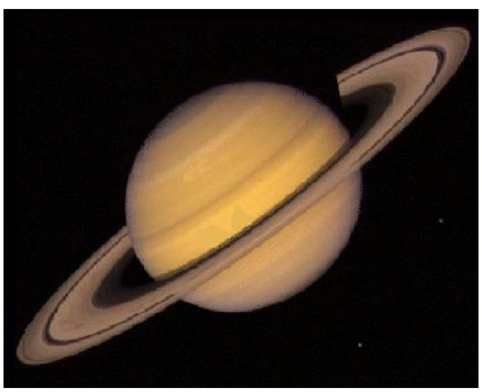

Figure 14: Saturn

Saturn is visibly flattened (oblate) when viewed through a small telescope; its equatorial and polar diameters vary by almost 10% (120,536 km vs. 108,728 km). This is the result of its rapid rotation and the planet's fluid state. The other gas planets are also oblate, but not so much so.

Saturn is the least dense of the planets; its specific gravity (0.7) is less than that of water. Like Jupiter, Saturn is about 75% hydrogen and 25% helium with traces of water, methane, ammonia and "rock", similar to the composition of the primordial Solar Nebula from which the solar system was formed. Saturn's interior is similar to Jupiter's, consisting of a rocky core, a liquid metallic hydrogen layer and a molecular hydrogen layer. Traces of various ices are also present.

Saturn's interior is hot (12,000ºK at the core) and Saturn radiates more energy into space than it receives from the Sun. Most of the extra energy is generated by the Kelvin-Helmholtz mechanism as in Jupiter. But this may not be sufficient to explain Saturn's luminosity; some additional mechanism may be at work, perhaps the "raining out" of helium deep in Saturn's interior.

The colored atmospheric bands so prominent on Jupiter are much fainter on Saturn. They are also much wider near the equator. Details in the cloud tops are invisible from Earth so it was not until the Voyager encounters that any detail of Saturn's atmospheric circulation could be studied. Saturn also exhibits long-lived ovals like the Great Red Spot and other features common on Jupiter.

Two prominent rings (A and B) and one faint ring (C) can be seen from the Earth. The gap between the A and B rings is known as the Cassini division; the much fainter gap in the A ring is known as the Encke Gap. The Voyager pictures show four additional faint rings. Saturn's rings, unlike the rings of the other planets, are very bright. They have an albedo of 0.2 - 0.6, which means they reflect up to 60% of the light that falls on them.

Though they look continuous from the Earth, the rings are actually composed of innumerable small particles each in an independent orbit. They range in size from a centimeter or so to several meters. A few kilometer-sized objects are also likely. Saturn's rings are extraordinarily thin: though they're 250,000 km or more in diameter they're no more than 1.5 kilometers thick. Despite their impressive appearance, there's really very little material in the rings — if the rings were compressed into a single body it would be no more than 100 km across, making a tiny moon.

The ring particles seem to be composed primarily of water ice, but they may also include rocky particles with icy coatings. The rings also have “spokes”, radial inhomogeneities that may have something to do with the planet’s magnetic field.

The origin of the rings of Saturn (and the rings of the other Jovian planets) is unknown. Though they may have had rings since their formation, the ring systems are not stable and must be regenerated by ongoing processes, probably the breakup of larger satellites.

1.8.1 Titan

Saturn’s moons are more numerous than Jupiter’s moons, and unlike their brethren, are not subjected to the same radiation storms. They are definitely a possibility for establishing a colony. Unfortunately, Saturn is pretty far out there. Travel times tend to be long. The largest and most memorable of Saturn’s moons is Titan, with a diameter of 5150 km. Titan orbits Saturn at 1,221,830-km distance. It was long thought that Titan was the largest satellite in the solar system but recent observations have shown that Titan's atmosphere is so thick that its solid surface is slightly smaller than Ganymede's. Titan is nevertheless larger in diameter than Mercury and larger and more massive than Pluto is. In other words, it would make a fair planet in its own right.

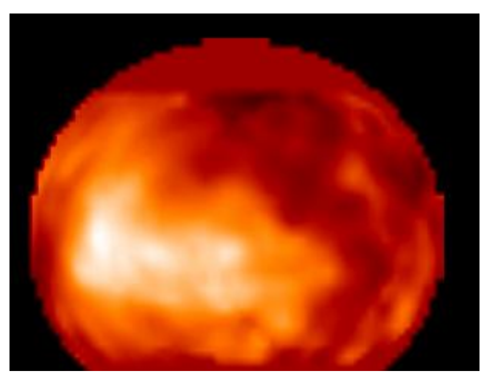

Figure 15: Titan

Titan is the only satellite in the solar system that has a thick atmosphere, one so thick, in fact, that we can’t see through it. Like Venus, if we are to see the surface, it will have to be with radar. At the surface, its pressure is more than 1.5 bar (50% higher than Earth's). It is composed primarily of molecular nitrogen (as is Earth's) with no more than 6% argon and a few percent methane. Interestingly, there are also trace amounts of at least a dozen other organic compounds (i.e. ethane, hydrogen cyanide, and carbon dioxide). The organics are formed when methane, which dominates in Titan's upper atmosphere, is destroyed by sunlight. The result is similar to the smog found over large cities, but much thicker. If you've lived in the Los Angeles basin on a bad air day, you may have had a mild preview of what it is like to live on Titan.

Titan is similar in bulk properties to Ganymede, Callisto, Triton and (probably) Pluto. Titan is about half water ice and half rocky material. It is probably differentiated into several layers with a 3400-km rocky center surrounded by several layers composed of different crystal forms of ice. Its interior may still be hot. Though similar in composition to Rhea and the rest of Saturn's moons, it is denser because it is so large that its gravity compresses its interior.

At the surface, Titan's temperature is about 94ºK (-290ºF). At this temperature water ice does not sublimate and the water at the surface cannot participate in the chemistry of the atmosphere. Nevertheless, there appears to be a lot of chemistry going on, the end result seems to be thick smog.

There are probably two layers of clouds at about 200 and 300 km above the surface. Other more complex chemicals in small quantities must be responsible for the orange color as seen from space.

1.9 Uranus

Uranus is a smallish gas giant out beyond Saturn. At 51,118 km (equatorial) in diameter, it is a big, blue-white ball of gas. The planet is blue because of the absorption of red light by the ammonia in its atmosphere. It is very far from the sun, orbiting at 2,870,990,000 km (19.218 AU) from Sun. The planet is covered with clouds of ammonia ice (not water ice), but has some good candidate moons for living on.

While many planets axes of spin are inclined to the plane of their orbits (Earth's tilt gives us seasons), Uranus has gone to extremes on the matter. It is lying on its side, with its north and south poles lined up with the plane of its orbit. This gives the sun a very strange path across the Uranian sky. At the time of Voyager 2's passage, Uranus's South Pole was pointed almost directly at the Sun. This results in the odd fact that Uranus's polar regions receive more energy input from the Sun than do its equatorial regions. Uranus is nevertheless hotter at its equator than at its poles. The mechanism underlying this is unknown.

Figure 16: Uranus

Uranus is composed primarily of rock and various ices, with only about 15% hydrogen and a little helium (in contrast to Jupiter and Saturn that are mostly hydrogen). Uranus (and Neptune) is in many ways similar to the cores of Jupiter and Saturn minus the massive liquid metallic hydrogen envelope. It appears that Uranus does not have a rocky core like Jupiter and Saturn but rather that its material is more or less uniformly distributed. Uranus's atmosphere is 83% hydrogen, 15%

helium and 2% methane.

Uranus has five large moons and ten small ones.

1.10 Neptune

Neptune is like Uranus, but slightly less so. Neptune is smaller in diameter, but larger in mass, than Uranus. Its diameter is 49,528 km (equatorial), and it orbits the sun at 4,504,000,000-km (30.06 AU).

Because Pluto's orbit is so eccentric, it sometimes crosses the orbit of Neptune. From 1979 to 1999, Neptune was the most distant planet from the Sun.

Neptune's composition is probably similar to Uranus's: various “ices” and rock with about 15% hydrogen and a little helium. Like Uranus, but unlike Jupiter and Saturn, it may not have a distinct internal layering but rather to be more or less uniform in composition. But there is most likely a small core (about the mass of the Earth) of rocky material. Its atmosphere is mostly hydrogen and helium with a small amount of methane.

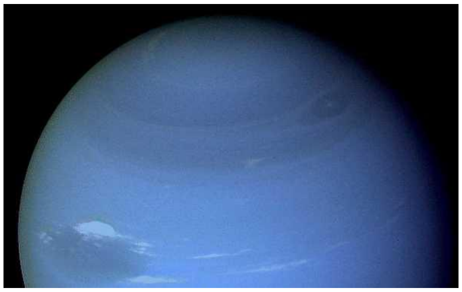

Figure 17: Neptune

Neptune's blue color is the result of absorption of red light by methane in the atmosphere.

Like a typical gas planet, Neptune has rapid winds confined to bands of latitude and large storms or vortices. Neptune's winds are the fastest in the solar system, reaching 2000 km/hour.

Like Jupiter and Saturn, Neptune has an internal heat source — it radiates more than twice as much energy as it receives from the Sun.

Neptune also has rings. Earth-based observations showed only faint arcs instead of complete rings, but Voyager 2's images showed them to be complete rings with bright clumps. One of the rings appears to have a curious twisted structure. Like Uranus and Jupiter, Neptune's rings are very dark but their composition is unknown.

1.10.1 Triton

Triton is the seventh and by far the largest of Neptune's satellites. It is 2700 km in diameter and orbits 354,760 km from Neptune. It is notable because its orbit is retrograde. That is, it orbits in the direction opposite that of virtually everything else in the solar system. The only other moons with retrograde orbits are Jupiter's moons Ananke, Carme, Pasiphae and Sinope and Saturn's Phoebe, all of which are less than 1/10 the diameter of Triton. This means that Triton didn’t form with Neptune, but had to have been captured somehow. It may be an interloper from the Kuiper Belt, a

Figure 18: Triton

region that is the source of some of the solar system's comets.

The unusual nature of Triton's orbit, the similarity of bulk properties between Pluto and Triton, and the highly eccentric, Neptune-crossing nature of Pluto's orbit suggest some historical connection between them. Triton's axis of rotation is also unusual, tilted 157 degrees with respect to Neptune's axis (which is in turn inclined 30 degrees from the plane of Neptune's orbit).

Like Uranus, Triton is also lying on its side, with its poles lying approximately in line with the plane of its orbit. This results in radical changes in the season, although the temperature at the surface of Triton is only 34.5ºK (-235ºC, -391ºF), as cold as Pluto. This is due in part to its high albedo (0.7 - 0.8) which means that little of the Sun's meager light is absorbed. At this temperature methane, nitrogen and carbon dioxide all freeze solid. Triton's position on the edge of the solar system gives new meaning to the old Siberian proverb: "Nine months of winter followed by three months of bad skiing!"

Triton's density is slightly greater than that of Saturn's icy moons such as Rhea. Triton is probably only about 25% water ice, with the remainder being rocky material. Still, this is a great deal of water.

Triton's atmosphere is tenuous (about 0.01 millibar), composed mostly of nitrogen with a small amount of methane. A thin haze extends up 5-10 km.

There are very few craters visible; the surface is relatively young. Almost the entire Southern Hemisphere is covered with an "ice cap" of frozen nitrogen and methane. There are extensive ridges and valleys in complex patterns all over Triton's surface. These are probably the result of freezing/thawing cycles.

Triton also suffers from ice volcanoes. The eruptive material is probably liquid nitrogen, dust, or methane compounds from beneath the surface.

1.11 Pluto

Pluto is the farthest planet from the Sun (usually) and by far the smallest. Pluto is smaller than seven of the solar system's moons (Luna, Io, Europa, Ganymede, Callisto, Titan and Triton). Pluto is only 2340 km in diameter and it orbits at a very distant 5,913,520,000 km (39.5 AU) from the Sun (average). Pluto is the only planet that has not been visited by a spacecraft. Even the Hubble Space Telescope can resolve only the largest features on its surface. Pluto has a satellite, Charon.

Figure 19: Pluto

Pluto's orbit is highly eccentric. At times it is closer to the Sun than Neptune. Pluto rotates in the opposite direction from most of the other planets.

Pluto is locked in a 3:2 resonance with Neptune; i.e. Pluto's orbital period is exactly 1.5 times longer than Neptune's is. Its orbital inclination is also much higher than the other planets. Though it appears that Pluto's orbit crosses Neptune's, they will never collide.

Like Uranus, the plane of Pluto's equator is at almost right angles to the plane of its orbit. The surface temperature on Pluto is not well known but is probably between 35 and 45 Kelvins (-228 to -238ºC), which is cold indeed! Pluto's composition is unknown, but its density (about 2 gm/cm^3) indicates that it is probably a mixture of 80% rock and 10% water ice, much like Triton. The bright areas of the surface seem to be covered with ices of nitrogen with smaller amounts of (solid) methane and carbon monoxide. The composition of the darker areas of Pluto's surface is unknown but may be due to primordial organic material or photochemical reactions driven by cosmic rays.

Little is known about Pluto's atmosphere, but it probably consists primarily of nitrogen with some carbon monoxide and methane. It is extremely tenuous the surface pressure being only a few microbars. Pluto's atmosphere may exist as a gas only when Pluto is near its perihelion; for the majority of Pluto's long year, the atmospheric gases are frozen into ice.

1.12 Conclusion

That's it. If you are going to build an interplanetary civilization, those are the places you will have to build it. For a long time, scientists thought there might be a tenth planet due to some discrepancies in the orbit of Neptune. Recently, those discrepancies have been resolved due to our ability to better estimate the masses of the various planets. In other words, the need for a tenth planet to explain Neptune's orbit has disappeared. There is no tenth planet!

In the 1980s there was a lot of enthusiasm for building floating colonies in space, called Lagrangian Colonies because they would occupy the Earth-Moon Lagrangian points. If you don't know what a Lagrangian point is, don't worry about it. However, if we are ever going to build a giant floating colony in space, we're going to need building materials. These we would probably obtain by roping an asteroid and melting it down. And if we could find subterranean ice on the moon, we'd have everything we need to move our civilization out into space. Barring that, the same technology that would allow us to move iron asteroids would allow us to bring back big chunks of ice from the vicinity of Jupiter or Saturn.

But even if we build space habitats, that won't be the end of it. We humans will eventually colonize the planets of the solar system. As you can see from the brief descriptions in this chapter, building a civilization on the available real estate is going to take drive, perseverance, and a great deal of money. If you're going to write about the future, then you need to project a sense of that effort into your story.

If you think about it, the human race is rich beyond the imagination of even King Midas. We own one small star, nine planets in assorted sizes, 61 moons, thousands of asteroids, and billions of comet-like bodies. All we need do is go out and claim our heritage. Of course, that is more difficult to do than to say, but it is far from impossible. We merely have to do it!

Getting there, as they say, is half the fun.

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Three hundred years after humanity made its deal with the Life Probe to search out the secret of faster-than-light travel, the descendants of the original expedition return to Earth in a starship. They find a world that has forgotten the ancient contract. No matter. The colonists have overcome far greater obstacles in their single-minded drive to redeem a promise made before any of them were born...

3. Antares Dawn - US$5.00

When the super giant star Antares exploded in 2512, the human colony on Alta found their pathway to the stars gone, isolating them from the rest of human space for more than a century. Then one day, a powerful warship materialized in the system without warning. Alarmed by the sudden appearance of such a behemoth, the commanders of the Altan Space Navy dispatched one of their most powerful ships to investigate. What ASNS Discovery finds when they finally catch the intruder is a battered hulk manned by a dead crew.

That is disturbing news for the Altans. For the dead battleship could easily have defeated the whole of the Altan navy. If it could find Alta, then so could whomever it was that beat it. Something must be done…

4. Antares Passage - US$5.00

After more than a century of isolation, the paths between stars are again open and the people of Alta in contact with their sister colony on Sandar. The opening of the foldlines has not been the unmixed blessing the Altans had supposed, however.

For the reestablishment of interstellar travel has brought with it news of the Ryall, an alien race whose goal is the extermination of humanity. If they are to avoid defeat at the hands of the aliens, Alta must seek out the military might of Earth. However, to reach Earth requires them to dive into the heart of a supernova.

5. Antares Victory – First Time in Print – US$7.00

After a century of warfare, humanity finally discovered the Achilles heel of the Ryall, their xenophobic reptilian foe. Spica – Alpha Virginis – is the key star system in enemy space. It is the hub through which all Ryall starships must pass, and if humanity can only capture and hold it, they will strangle the Ryall war machine and end their threat to humankind forever.

It all seemed so simple in the computer simulations: Advance by stealth, attack without warning, strike swiftly with overwhelming power. Unfortunately, conquering the Ryall proves the easy part. With the key to victory in hand, Richard and Bethany Drake discover that they must also conquer human nature if they are to bring down the alien foe …

6. Thunderstrike! - US$6.00

The new comet found near Jupiter was an incredible treasure trove of water ice and rock. Immediately, the water-starved Luna Republic and the Sierra Corporation, a leader in asteroid mining, were squabbling over rights to the new resource. However, all thoughts of profit and fame were abandoned when a scientific expedition discovered that the comet's trajectory placed it on a collision course with Earth!

As scientists struggled to find a way to alter the comet's course, world leaders tried desperately to restrain mass panic, and two lovers quarreled over the direction the comet was to take, all Earth waited to see if humanity had any future at all…

7. The Clouds of Saturn - US$5.00

When the sun flared out of control and boiled Earth's oceans, humanity took refuge in a place that few would have predicted. In the greatest migration in history, the entire human race took up residence among the towering clouds and deep clear-air canyons of Saturn's upper atmosphere. Having survived the traitor star, they returned to the all-too-human tradition of internecine strife. The new city-states of Saturn began to resemble those of ancient Greece, with one group of cities taking on the role of militaristic Sparta...

8. The Sails of Tau Ceti – US$5.00

Starhopper was humanity's first interstellar probe. It was designed to search for intelligent life beyond the solar system. Before it could be launched, however, intelligent life found Earth. The discovery of an alien light sail inbound at the edge of the solar system generated considerable excitement in scientific circles. With the interstellar probe nearing completion, it gave scientists the opportunity to launch an expedition to meet the aliens while they were still in space. The second surprise came when *Starhopper's* crew boarded the alien craft. They found beings that, despite their alien physiques, were surprisingly compatible with humans. That two species so similar could have evolved a mere twelve light years from one another seemed too coincidental to be true.

One human being soon discovered that coincidence had nothing to do with it...

9. Gibraltar Earth – First Time in Print — $6.00

It is the 24th Century and humanity is just gaining a toehold out among the stars. Stellar Survey Starship *Magellan* is exploring the New Eden system when they encounter two alien spacecraft. When the encounter is over, the score is one human scout ship and one alien aggressor destroyed. In exploring the wreck of the second alien ship, spacers discover a survivor with a fantastic story.

The alien comes from a million-star Galactic Empire ruled over by a mysterious race known as the Broa. These overlords are the masters of this region of the galaxy and they allow no competitors. This news presents Earth's rulers with a problem. As yet, the Broa are ignorant of humanity's existence. Does the human race retreat to its one small world, quaking in fear that the Broa will eventually discover Earth? Or do they take a more aggressive approach?

Whatever they do, they must do it quickly! Time is running out for the human race…

10. Gibraltar Sun – First Time in Print — $7.00

The expedition to the Crab Nebula has returned to Earth and the news is not good. Out among the stars, a million systems have fallen under Broan domination, the fate awaiting Earth should the Broa ever learn of its existence. The problem would seem to allow but three responses: submit meekly to slavery, fight and risk extermination, or hide and pray the Broa remain ignorant of humankind for at least a few more generations. Are the hairless apes of Sol III finally faced with a problem for which there is no acceptable solution?

While politicians argue, Mark Rykand and Lisa Arden risk everything to spy on the all-powerful enemy that is beginning to wonder at the appearance of mysterious bipeds in their midst…

11. Gridlock and Other Stories - US$5.00

Where would you visit if you invented a time machine, but could not steer it? What if you went out for a six-pack of beer and never came back? If you think nuclear power is dangerous, you should try black holes as an energy source — or even scarier, solar energy! Visit the many worlds of Michael McCollum. I guarantee that you will be surprised!

Non-Fiction Books

12. The Art of Writing, Volume I - US$10.00

Have you missed any of the articles in the Art of Writing Series? No problem. The first sixteen articles (October, 1996-December, 1997) have been collected into a book-length work of more than 72,000 words. Now you can learn about character, conflict, plot, pacing, dialogue, and the business of writing, all in one document.

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This collection covers the *Art of Science Fiction* articles published during 1998. The book is 67,000 words in length and builds on the foundation of knowledge provided by Volume I of this popular series.

16. The Astrogator's Handbook – Expanded Edition and Deluxe Editions

The Astrogator's Handbook has been very popular on Sci Fi – Arizona. The handbook has star maps that show science fiction writers where the stars are located in space rather than where they are located in Earth's sky. Because of the popularity, we are expanding the handbook to show nine times as much space and more than ten times as many stars. The expanded handbook includes the positions of 3500 stars as viewed from Polaris on 63 maps. This handbook is a useful resource for every science fiction writer and will appeal to anyone with an interest in astronomy.

