Physics Department
Guilford College
Greensboro, NC 27410
12/30/91-1/3/92

James K. Hoffman
Glenview, IL 60025
Dear Jim,

Well, exams are finally history, and now I can get back to *serious* work....

What I'm enclosing is a description of the system we had agreed on.

My experience in this business is that no matter how careful I am (and I do try hard) I will leave some crucial questions unanswered, or fail to explain something clearly enough. I consider this inevitable, and will remain available to you to clear up any details; that service is included in the price we agreed on, so don't hesitate to come back with whatever questions you want to ask. Minor modifications are freebies, too; more complicated ones ("Oh, let's throw in a couple of black holes...") that will take me a lot more time can run into additional charges. You'll have to trust me to tell you if any changes you'd like to make are minor or major, but this is not usually a problem.

And now, without further ado, on to the system known as...

Hoffman's Quartet

The Star

The star Is Tau Ceti, 3.62 parsecs (11.8 light years) from the sun. Tau Ceti is a spectral type G8 star of luminosity class V, a bit larger but cooler, less massive, and less luminous than the sun. In numerical terms, its radius is 1.04 times the sun's, or 724,000 km; its surface temperature is 4670 Kelvin (the sun's is 5770 K); its mass is about 83% of the sun's, and its luminosity about 46.6% of the sun's. I'm tossing in these numbers because a) you may want to have an astronaut or scientist-type mention them for verisimilitude in the story and b) I needed to calculate them to work out everything else anyway.

From the visual standpoint-the one that will matter most to your characters-Tau Ceti's light will appear distinctly yellower than the sunlight we're used to on Earth (which is white). A caution: while Tau Ceti is not as luminous as the sun, it is still blinding bright, much too bright to look at. So think of yellow, but **intense** yellow. "Brassy" might be a good descriptive term; the somewhat overworked term "golden" is another alternative. "Amber" comes to mind as well, but I can no longer think of this term without thinking of Roger Zelazny. This illumination will have odd effects on colors for human characters wandering around outside of their residences (where they'd probably use standard "white" lights). Caucasians will all look as if they are in the last stages of jaundice, for example. White shirts will look yellow; blue shirts will look charcoal gray. Bananas will look nearly the same color inside and outside.

I don't know of any serious side effects caused by such illumination, and I doubt that any exist. Certainly there are plenty of people who wear colored sunglasses (even yellow ones) for extended periods without going schizoid or anything. My guess is that (as is my experience with sunglasses) people would cease to notice anything odd after a few minutes. Exceptions might be artists, art directors, and TV and movie producers-people who are much more aware of precise colors than most of us. I might add that women tend to have better awareness of such things than men, and that this seems to be physiological rather than cultural, though I don't think the details are understood. I mention this because your female readers may be expecting such awareness from female characters, particularly with regard to clothing. I'm not trying to be sexist here; female scientists make good use of their ability to easily distinguish and remember details of things like colors that their male colleagues have to take special care to note and record.

Luckily, a fair number of Earth plants won't mind the golden sunlight in the least, so long as it's bright enough. There's nothing particularly holy about the color of sunlight so far as photosynthesis is concerned, and it's largely photons from the red end of the spectrum that are used anyway. Note that many (though not all) house plants grow OK under incandescent lighting indoors, which is a lot yellower than sunlight.

Just for the record, the spectrum of light emitted by Tau Ceti peaks at a wavelength of 621 nanometers, equivalent in color terms to orange. Our own sun's spectrum peaks at about 501 nanometers, in the green. Sunlight looks white because it's a mixture of all the colors of the rainbow in particular proportions. Tau Ceti's light is a mixture, too, but more heavily weighted towards the red and orange end of the spectrum, with correspondingly less of the blue and violet end.

Otherwise, Tau Ceti is not a very remarkable star. As I mentioned in a previous letter, this is a good thing. *Nobody* wants to live near an "interesting" star; it's suicide.

A Neighboring Star

One odd fact I picked up, which I don't think is widely known in SF circles. While Tau Ceti is not a binary, there is another star remarkably close to it, sort of passing by at high speed. The other star goes by the clever name of YZ Ceti, or (still more catchy) L725-32, which reminds me of my locker combination in junior high. It's a dim red dwarf, spectral type M5e, somewhere around 10% the mass of the sun and barely heavier than a brown dwarf itself.

While close in the astronomical sense (0.22 parsecs, or 0.72 light years) it is hardly within waving distance. Our sun's nearest neighbor is Proxima Centauri, 1.32 parsecs (4.3 light years) away. YZ Ceti is about 1/20 as far from Tau Ceti. But this is still around a thousand times as far away as Pluto is from Earth, so there's nothing really exciting looming. In different terms, it's 45,000 Astronomical Units (AU) from Tau Ceti. 1 AU is Earth's average distance from the sun; Jupiter is 5.2 AU from the sun;

Proxima Centauri is 270,000 AU from the sun.

I'm not really trying to bury you in numbers here, Jim; I'm not sure what sort of units make the most sense to you. SF writers use AU, parsecs, and light years all the time, but I'm never sure how much these mean to readers. It's a weakness of too much professional background on my part. If you need more explanation, or a translation into km or miles, just let me know. I'm caught between trying to make things clear and not wanting to appear patronizing. Astrophysicists *better* know all these units; normal people have no need of them, and I never know how much they've picked up, and the mystery deepens for SF fans and writers.

Time out for nomenclature: I'm going to call Tau Ceti "TC" and YZ Ceti "Flyby." You get to choose whatever names you wish, of course, but I can't believe people would continue to use pedantic names derived from ancient Greek to describe features in their own sky.

From the neighborhood of TC, Flyby would not be very impressive. In

fact, it would barely be visible at all. Its luminosity is only 0.02% that of the sun, and it's 45,000 times farther away than the sun is from Earth. It would look like a star of magnitude 5.8. Magnitude 6.0 is about the limit that can be discerned by normal eyesight; 5.8 is just barely brighter. There are several thousand stars visible from TC that would look brighter than Flyby.

Flyby is moving at about 44 km/s relative to TC. This is fast; typical relative speeds of stars in the solar neighborhood are about a quarter of this. From TC, Flyby would seem to be streaking across the sky at the awesome rate of 1 degree every 85 years. No need to hyperventilate with excitement, now....

So far, Flyby seems to be boring beyond belief, but it does have one interesting characteristic. Our sun is surrounded in all directions by a huge region called the Oort Cloud, which extends out to about 50,000 AU (call it a bit under a light year, or around a quarter of a parsec). The Oort Cloud contains perhaps a hundred billion chunks of ice, ranging from city-sized on down to an unknown lower limit. These icebergs are in orbit around the sun, but just barely; the sun's gravity is (as we say. in the South) right weak out there. If nothing disturbs them, these objects stay way the hell out there, frozen solid. But even the gravity of nearby stars, light years away, sometimes perturbs them enough to change their orbits, dropping some of them inward towards the sun. If they get into the warm regions inside the orbit of Mars (most of them don't, it is guessed) they start to sublimate, boiling off huge clouds of vapor that reflect sunlight quite nicely. Some dust and such is present as well; this Is pushed outward by radiation pressure, forming a tail, at which point the chunk of evaporating ice is dignified by the name "comet".

What, you may ask, has this got to do with TC and Flyby? Well, possibly not much; we don't know for sure that other stars have Oort Clouds of their own. But they *ought* to, if our present understanding of the formation of stars and planetary systems is correct. If TC and Flyby have Oort Clouds of roughly the dimensions of the sun's, then each star is inside the Oort Cloud of the other, and they are moving past each other at high speed, 44 km/s. This would have the interesting affect of greatly increasing the flow of comets past both stars.

Flyby is so cool and dim that it wouldn't vaporize these flying icebergs unless they passed very close to it indeed. There might be spectacular results if a comet actually scored a direct hit on Flyby, but a quick and dirty calculation indicates that such collisions are expected only once in about two billion years. Flyby is a very small target; red dwarfs are typically smaller than Jupiter or Saturn (even though they weigh a lot more; their densities are pretty impressive, typically fifty times the density of lead).

TC is a bigger target than Flyby; it could expect a direct hit about once every 8 million years, still not worth worrying about; the entire "encounter," the passage of the two stars through each others' comet clouds, will be over in under 10,000 years. My guess is that the major effect would be a scenic one, when comets passed close enough to TC to show bright heads and tails as their ices boiled. *VERY* roughly, I'd expect observers on the habitable planets would be treated to one bright, Halley-type comet (a la 1910, not 1986) every five years, with less spectacular ones visible virtually any time at all. Frankly, the numbers are pretty whimsical here, Jim; we don't really know what a "typical" number of icebergs is in a "typical" Oort Cloud, and even for the sun's Oort Cloud estimates range from 100 million to 10 trillion-a gigantic range. But SF gives you license to toss in some bright visible comets if you would like them. They'd be unexciting to natives of the Quartet (except for children), who would be used to them, but your "awakened sleeper" from the 20!h. Century and tourist-types would be suitably impressed.

Although the comets might make fun scenery, I mainly wanted you to be aware of Flyby because it might be

handy for plot wrinkles. It's closer than other stars typically are, but farther away than other planets in a normal system. Might it have planets of its own? If so, what might they be like? Could there be any intelligent race there, possibly connected with any of the natives of the Quartet worlds? Is it a good hideout for criminals, rebels, religious hermits, or social nonconformists? These questions are outside the parameters of the present job, but if it becomes useful for you to have answers to them, let me know.

Later note: Other "neighbors" of Tau Ceti include L726-8A, 1.0 parsecs (3.3 light years) away; G158-27, 1.7 parsecs (5.5 light years) away; and Epsilon Eridani, 1.8 parsecs (5.9 light years) away. The first of these is, like Flyby, closer to Tau Ceti than any known star is to the sun. The first two neighbors are both dim red dwarfs, invisible without a powerful telescope. Epsilon Eridani is more like the sun and Tau Ceti, and would look fairly bright (magnitude 2.4) in the sky of Tau Ceti's planets. Our own sun would be visible, of course. It would be a 2.6 magnitude star, fairly bright, in the constellation Coma Berenices, not far from the place where Leo and Virgo meet. Near it in the sky would be the bright globular cluster M53, if you're familiar with amateur astronomy.

The System of Tau Ceti: An Overview

I'll start with a brief sketch of the objects orbiting TC, then

describe each of them in more detail-and some of them in a *lot* more detail.

The Tau Ceti system is not much like our own. The formation of a planetary system was strongly influenced by the condensation of a brown dwarf in the region which would have been occupied by the biggest jovian planets in a system like ours. The brown dwarf's mass is about 5% that of the sun, over 50 times as massive as Jupiter, far more massive than all the planets in our solar system combined. The brown dwarf is called Muggsy, evidently an obscure reference to the only known NBA player shorter than the world's most famous planetary designer. Muggsy's orbit is nearly circular, keeping it at a constant distance of 3.0 AU from TC. Its orbital period is 5.6 Earth years (I'll always mean "Earth years" when I use "years" unless otherwise noted).

The only other object of significant size orbiting TC is the Don, central body of the Corleone system. The Don's mass is 16 times Earth's, its diameter 49,000 km, making it intermediate in size between Uranus and Neptune. The Don has a broad, highly reflective system of rings rather like Saturn's. But while Saturn's rings are made mostly of ice (of the frozen water variety) the Don's rings are made of a mixture of several frozen materials, including water, ammonia, methane, carbon dioxide, and similar substances. The Don orbits the center of mass of the TC-Muggsy pair (which is only 0.17 AD from the center of TC) at a distance of 21 AU. This gives it an orbital period of 103 years.

The gravitational effects of Muggsy prevented the coalescence of any other objects of planetary size (save for the Quartet; see below), but there are vast numbers of smaller bodies. In our own solar system, Jupiter's influence prevented the formation of a planet In the region of the asteroid belt. Muggsy, being much more massive, interfered with planetary formation over a broader region, leaving tens of thousands of asteroid-sized objects both inside and outside its orbit. The compositions of these objects are strongly influenced by their distances from TC, which determines their temperatures. Close to TC, between 0.2 and 1,8 AU from TC, temperatures are relatively warm. The asteroidal material in this region is dominated by objects with compositions similar to those of our own asteroids. They are mainly of three types: M (metallic; mostly iron and nickel), S (stony), and C (carbonaceous). The gravitational pull of TC is much stronger than that of Muggsy in this region, so the asteroids here tend to follow fairly circular orbits around TC. Their orbital periods range from Just over a month (near 0.2 AU) to about 2.7 years (near 1.8 AU).

From 1.8 AU out to about 2.9 AU, Muggsy's substantial gravitational pull perturbs the orbits of any asteroids present quite significantly, with the effect getting more serious with increasing distance from the sun. There are comparatively few asteroids with orbits between 1.8 and 2.9 AU from TC, and these orbits tend to be very eccentric, swinging from close to TC and then back out to nearly the orbit of Muggsy. Temperatures are lower in this region than in the main belt closer to TC, and this has an important effect on the composition of the asteroids present. While there are "normal" M, S, and C objects as well, some asteroids in this region are small icy bodies more like comet nuclei than anything else. There are no similar structures in our own solar system, since primordial icy planetoids ended up either in the jovian planets or their moons. There would be a lot more of the ice asteroids save that the perturbing effect of Muggsy on their orbits tends to drag them into paths that bring them too near the sun-at which point they evaporate in much the same way comets do. The few survivors are the lucky ones whose orbits have not yet been effected enough to bring them too close to the sun. Ice asteroids are most commonly found between 1.8 and 1.9 AU from TC, where Muggsy's influence is still weak.

Beyond the orbit of Muggsy the belt continues. Temperatures are much lower than they are closer to TC, and conditions are favorable for the existence of ice asteroids. Even so, there are few asteroids between the orbit of Muggsy and 3.8 AU, since Muggsy's gravity perturbs anything in this region fairly seriously. Beyond 3.8 AU the number of asteroids increases again, with the big majority of icy composition. This region might be called the Ice Belt. The inner portions of the Ice Belt are dominated by asteroids made mostly of frozen water, since ambient temperatures during the era of the system's formation were above the sublimation points of ammonia and methane. Beyond 3.8 AU the icy bodies contain a considerable admixture of frozen ammonia, however (ammonia freezes at 195 K = -78 C - -108 F), The methane condensation region roughly marks the position of the Don, and this Is not coincidental; icy planetoids made largely of frozen methane played a vital role in the formation of the ringed jovian (methane freezes at 90 K = -183 C = -297 F). The Ice Belt thins out rapidly beyond the orbit of the Don, fading into TC's Oort

Cloud, where the ice asteroids act just like ordinary comets.

More on the Asteroid Belt

The M, S, and C asteroids in the inner belt, close to TC, average

smaller than our own asteroids. Their orbital periods are shorter, and so they have undergone more collisions. As a result, the biggest asteroids in this region are only a few hundred meters across, the size of a shopping mall, massing a few hundred million tons. This might be a handy size for mining operations, and could be moved by mass drivers or something more sophisticated. They could make terrible weapons in an inter-Quartet War.

The vast majority of asteroids are a lot smaller than this, down to microscopic bits just big enough to puncture unarmored space suits, Astronauts operating in the asteroid belt could take their chances with cheap, light, easy-to-maneuver suits, or play it safe with heavier ones padded with Kevlar or something tougher. I'm sure you can imagine scenes with suit sales types addressing potential customers in fatherly tones, urging them to pay a bit extra and be safe rather than ending up like their old friend Eddie-here's his picture; pretty unpleasant, eh? His kids are afraid of him now-and the payment plan has a special low interest rate for nice guys like you.... The government might well want to regulate things like this, too. Just a suggestion; you're the author (I just find it hard to avoid kibitzing; pay no attention if you don't want to.)

The asteroid belt has a lot of interesting features. There are big clumps of icy asteroids (and some M, S, and C ones as well) at the Trojan points in the orbits of both Muggsy and the Don (Trojan points are 60 degrees ahead of and 60 degrees behind these guys in their orbits, so asteroids in these places lead and follow the two biggies like motorcycle escorts in a presidential motorcade). Astronaut miners looking for volatiles for use In space industries or space habitats would like the Trojan points-lots of ice within a fairly small region-but they'd be dangerous as well, since miners and equipment would have a greater likelihood of being drilled by a grain of ice moving faster than a rifle bullet. (Collisions between icebergs would produce lots of fragments, and the more icebergs in a region the greater the likelihood of collisions.) The Trojan points would also represent a good opportunity for ice pirates, disgruntled business partners, or embittered spouses, not to mention freelance hitpersons. Remember what happened to Jimmy Hoffa?

There would be gaps in the asteroid belt, too, places where resonant gravitational perturbations from Muggsy pulled objects into other orbits. Without going into boring and complicated detail, such gaps would occur at distances where orbital periods would be simple fractions and multiples of Muggsy's. Saturn's rings show such a gap (called the Cassini division) at a distance where a ring particle's orbital period would be just half that of one of Saturn's inner moons, Mimas. Our asteroid belt shows several such gaps (the so-called Kirkwood Gaps) where Jupiter's gravity has swept out the former asteroid population over billions of years. Gaps in TC's asteroid belt due to Muggsy's gravitational perturbations would lie at the following places:

Orbital radius	Fraction of Muggsy's Period
0.9 AU	1/6
1.0 AU	1/5
1.2 AU	¼
1.4 AU	1/3
1.6 AU	2/5
1.9 AU	½
4.8 AU	2
6.2 AU	3
7.6 AU	4
8.8 AU	5
99 AU	6

There might be more gaps-or fewer. This seemed to me to be more than enough information for story purposes. The Voyager observations of Saturn's rings demonstrated that the theory of ring and asteroid belt dynamics has not yet reached maturity. I could do more detailed analysis of the structure of the asteroid belts if you wish, but this didn't seem to be the main focus of your concerns, so I'll leave it at this.

More on the Don

The Don looks a lot like Uranus or Neptune, a virtually featureless

sea-green sphere. The green color comes from the abundant methane in the planet's atmosphere. Methane absorbs red light very effectively, reflecting back only that fraction of sunlight photons in the bluer region of the spectrum. Uranus and Neptune look nearly sky-blue as a result of this, but TC doesn't produce much in the way of blue photons. The shortest wavelength is produces in much abundance is green, and hence the color. In fact, at 21 AU the light of TC is pretty weak, about 0.11% as bright as sunlight here on Earth. As a result, the Don is a pretty dim object, invisible from the Quartet without a professional-sized telescope. The Don rotates on its axis in about 15 hours, but the planet is so featureless the rotation is hard to detect. There are a few wisps of white cloud-frozen methane crystals floating high in the atmosphere-but not much else to see.

The Don's ring system is extensive. It was formed when a large icy

asteroid impacted a fair-sized icy moon several million years ago. The

rings stretch from Just above the atmosphere out to about 54,000 km from

the center of the planet,

In addition to its rings, the Don has three moons about the size of Earth's Moon and a half dozen smaller ones. Here is a table summarizing the major properties of these moons:

Moon	Dist. from Planet (km)	Orbital Period (days. hours)	Diameter (km)	
Mama	55,000	8.9 h	180	
Connie	78,000	15 h	240	
Luca	92,000	19 h	300	
Tessio	120,000	1 d, 5 h	410	
Clemenza	160,000	1 d, 20 h		440
Sonny	210,000	2 d, 18 h		2600
Michael	330,000	5 d, 12 h		3100
Tom	440,000	8 d, 6 h	3300	
Freddo	870,000	23 d, 8 h		220

The large distance from the fairly dim TC makes the region near the Don cold as a *basso de muerte,* down around 71 K (-202 C or -332 F) even for a black surface facing squarely into the sun. Nitrogen freezes at 63 K, so it would be frozen anywhere out of direct sunlight on all the moons.

The moons are made mainly of mixtures of the various ices-frozen water, ammonia, and methane, with various impurities thrown in for variety. The small ones are heavily cratered, with deep canyons and cracks. When they first formed, they froze from the outside in. When the interior water eventually froze, it expanded, cracking the already-hardened crust.

The larger moons look like Neptune's moon Triton, though they lack its more interesting features. Unlike Triton, the big moons of the Don have prograde orbits (they circle the Don in the same direction that it rotates on its axis). This leads to less heat generated by tidal forces, so the Sons of the Don have more cratering, fewer flat plains of refrozen liquid from volcanic eruptions (volcanoes of "molten" water, at the horrendous temperature of 20 degrees C.). However, tidal interactions among themselves are fairly strong, so there are occasional volcanic eruptions and geysers of temporarily vaporized nitrogen.

All the moons but Freddo have nearly circular orbits with low inclinations to the Don's equatorial plane. The outermost moon, Freddo, has an eccentric orbit that takes it as close as 520,000 km and as far out as 1,220,000 km. The orbit is inclined at 40 degrees to the equatorial plane of the Don.

More on Muggsy

The characteristics of Muggsy are more or less determined by the requirement that the Quartet worlds be habitable and Earthlike. At their distance from TC, they receive only about 5% as much "solar" energy as Earth does from the sun. Without significant input energy from Muggsy, the Quartet would be nearly as cold as Jupiter's moons.

While 5% is not enough to keep the Quartet warm, it is enough to keep them brightly lit. A 'well-lighted room" is seldom as much as 1% as bright as direct sunlight. The pupils of our eyes automatically contract to keep out excessive light out of doors; our vision is adapted by evolution to leaf-canopied forests, out of direct sunlight, where our species originated several million years ago. My point here is that the light from TC is plenty for outdoor scenes to look "brightly lit." Sunlight will look brassier than usual, but not dim. On the other hand, no one-not even albinos-need worry about sunburn, and tanning salons will be the only outlet for those Caucasians in need of a melanin stimulation.

Some Earth plants won't like the situation much, but photosynthesis can proceed with 1% of typical direct sunlight (about like a heavily overcast day). Bear in mind that there are plenty of plants that have evolved to be perfectly comfortable in shady situations, and in fact these usually can't cope well with direct sunlight. This group does not include corn, wheat, and so on, of course, but presumably that could be remedied by genetic engineering if necessary-or fields could have sunlight supplemented by floodlights, a la outdoor stadium night games, or domed stadiums any time. Native plants of course are adapted to this environment, and won't have any hassles at all.

This still leaves the problem of providing enough warmth to keep the Quartet at Earthlike temperatures. I pondered this problem at length, Jim, and just about wore out my math coprocessors running evolutionary models of brown dwarfs. There turn out to be lots of solutions, but I wanted to give you one that no one else had used before, while making sure that I stayed within the sorts of parameters you'd established for the planets of the Quartet, Most challenging was the limitation that they had to have 24-hour days, which determines (it turns out) how far they are from Muggsy. Many solutions would have worked, but had to be discarded because of practical difficulties-they'd be too hard for you to drop into a story as explanations for readers, or in a couple of cases would have led to ferociously harsh climates.

Insertion : lots of authors have blandly asserted that their planets are warmed by the Jovians they orbit. This turns out not to work well. The heat produced by Jovian planets comes mostly from the original compression of their largely gaseous structures when they first formed. Gravity squeezes the gas-mainly hydrogen-together, and the squeezing warms it up. You can see the inverse of this process when you spray gas out of a spray can; the gas expands, and the can cools. Anyway, this means that the big gaseous Jovians like Jupiter must have been hotter than hell (100,000 Kelvin, probably) when they first formed, from all the gravitational squeezing. The more massive the planet, the bigger the gravity, the harder the squeeze, and the higher the original temperature. The trouble is that after that original Big Squeeze, *there's no more heat produced.* The planet just cools off, very slowly (because it's so big-think of the difference in cooling rate between a big baked potato and a small one), until after a few billion years it's at a couple of hundred degrees below zero.

There may be a short interval in there when nearby satellites are at the right temperature for life, but our experience here on Earth leads us to believe that the evolutionary process (that culminated in the small college physics professor) takes roughly 4.5 billion years, all of which must be at fairly uniform temperature, between the freezing and boiling points of water. Simple cooling of a jovian simply won't do. It goes from too hot to too cold too fast, leaving too little time for life to evolve. Take that, Harlan Ellison!

The same is true of brown dwarfs, though to a lesser extent; they are much more massive than Jovians and so take much longer to cool. I found several ways to stretch out the cooling time long enough for our purposes. The way I liked best (because no one has ever used it before) is the one I'm going to describe below, at the end of this section. It's based on an interesting paper Richard Durisen (then of Indiana U., if I recall) wrote for Astrophysical Journal back in the mid-'70s. His paper was on white dwarfs; I modified the theory to apply it to brown dwarfs, and I think I can safely say that no one has ever done this before, either in SF or astrophysics.

Anyway, here's the scoop on Muggsy:

It's about 50 times the mass of Jupiter. Its equatorial diameter is 140,000 km, actually slightly *smaller* than Jupiter. Like Jovian planets (and stars), Muggsy is made largely of hydrogen. Its huge mass produces a strong gravitational pull, over 266 g at the poles. This huge force

squeezes the gaseous material that makes up Muggsy, packing it a lot more firmly than Jupiter (with its smaller gravity) is packed. The net result here is rather counterintuitive: adding mass to a jovian-style object does not in general make it bigger, though it does make it denser. The added mass increases the gravity, which packs everything tighter together. It's worth noting in this regard that Jupiter is over three

times as massive as Saturn, but less than 20% bigger in diameter,

Muggsy's polar diameter is only 74% as big as its equatorial diameter, 104,000 km. The equatorial diameter is bigger than the pole-to-pole distance because Muggsy is a rapid rotator. Centrifugal force, caused by the rotation, causes the equatorial regions (where things are spinning fastest) to bulge outward. Earth's rotation does this to our planet; Earth's equatorial diameter is about 40 km larger (about 0.34%) than its polar diameter, not enough difference to be visible to the eye. The sun spins a lot slower than Earth, taking about a month to rotate on its axis, and so it's almost a perfect sphere; its polar diameter is only about 0.001% smaller than its equatorial diameter. Jupiter and Saturn spin a lot faster than Earth, though, Saturn rotating in only about 11 hours and Jupiter in less than 10. For this reason, both planets bulge noticeably at their equators, looking like slightly squashed spheres. Jupiter's polar diameter is about 94% of its equatorial; Saturn's about 90%, The reasons for the rapid rotation of Jovians compared to terrestrial planets are not well understood, but I assumed in modeling Muggsy that like jovian planets (and unlike the sun) it's a rapid rotator. At its equator, Muggsy rotates once in just under 32 minutes. This is what leads to the marked difference in the polar and equatorial diameters. I decided to spin that sucker *fast* for two reasons. One is that it makes for an interesting sky feature on the Quartet worlds. The second is that the rotation rate is related to the heat source, a situation which I'll describe presently. The strong centrifugal force at Muggsy's equator makes things weigh less there than they do at the poles. Instead of a hellish 266 g, objects near Muggsy's equator would feel a more modest 69 g pull. This is a place for truly serious muscle-builder types, obviously; no one is going to put a base on a brown dwarf until someone invents antigravity.

A couple of other numbers: Muggsy's average density is 93.9, over 8 times the density of lead and almost 5 times the density of gold; that monstrous gravity does a marvelous]ob of compressing Muggsy's gaseous composition. The central density is (as you might expect) larger still, about 697.

Muggsy's central temperature sizzles at around 1,500,000 K, but its surface temperature is much more mild, averaging 1548 K (1275 C or 2327 F), still a lot hotter than an oven. The spectrum of light emitted by an object at this temperature peaks at a wavelength of 1872 nanometers, well into the infrared. To human eyes, Muggsy glows like molten metal, a seething yellow-orange I'm sure you can picture as well as I can. There are many other details to describe on its surface, though; I'll get back to this below.

Muggsy produces 15,7 times as much energy as TC at the Quartet's position, but nearly all of this output is in the form of infrared ("heat" rather than "light'). The same is true of a barbecue pit, of course. The glow of the coals is noticeable, but hardly blinding; it's the heat that's overpowering close up. In terms of visible light, TC produces about 2.56 times as much illumination as Muggsy. Here on Earth, apart from the almost inconsequential contribution of the Moon, the sun is the major source of both light and heat. On the Quartet worlds, the two sources are decoupled: TC is the main source of light, while Muggsy is the main source of heat.

An important point here is that since only 1.58% of Muggsy's energy output is visible, people on the Quartet worlds can stare right at it without flinching. It looks bright, but not blinding. TC looks a lot smaller (I'll give the sizes below) but you wouldn't want to try to look directly at it. Most of *Its* output is in the visible part of the spectrum.

Based on its own output alone, Muggsy would be about 8611 times as bright as a full moon here on Earth. A given area of it in the sky of the Quartet would produce 54.5 times as much light as the same area of the Moon in our sky. While bright, it's not too bright to look at directly, as I mentioned above; its total output in the visible part of the spectrum is about a third of the sun's brightness just before sunset on a clear evening. As a light source, Muggsy is enough to make it easy to see long distances and read even at "night" (after TC has set), but it's hardly overpowering. On the other hand, you could easily feel its warmth on your face or any other uncovered part of your body, much like you feel the sun's rays beating on you even with your eyes closed.

In addition to having an unusual shape and a nice warm glow, Muggsy's outer regions have all kinds of fascinating things going on in them. Like most other astronomical objects, Muggsy's outer layers are its coolest parts. If Muggsy were an honest-to-God star, like the sun or TC, this wouldn't matter too much. There'd be features like prominences, flares, and sunspots, but they'd only be visible with special instruments.

But Muggsy's cool enough that people can look right at it. If it were featureless, like the Don, that wouldn't

be much benefit. But if my estimates are correct Muggsy has all the best properties of both stars and planets (jovian planets, that is) when it comes to sightseeing,

First, there's convection. When a gas or liquid is heated from below, the stuff on the bottom gets warm, expands, and rises. When it reaches the surface, the stuff cools off, contracts, and sinks again. This cycle is called convection, and it works as well for simmering spaghetti sauce as it does near the surface of the sun, "Thermals," the rising air currents that glider pilots look for, are examples of convection currents in Earth's atmosphere. Muggsy, with its hottest portions near its center, will have convection in great profusion. Hot currents of material will well up from below, burst outward in the cooler atmosphere, and flow outward in all directions, the flowing twisted into colossal hurricanes by the tremendous coriolis forces produced by Muggsy's rapid rotation.

While Muggsy is mostly hydrogen, it also includes a fair abundance of other materials, like carbon, nitrogen, oxygen. There would also be various metals present in smaller amounts, things like titanium, iron, and aluminum. These impurities exist in our sun as well, but they are so hot they exist only as glowing, mostly ionized gases. The atmosphere of Muggsy is cool enough that some materials will actually be able to condense out in droplets of liquid and even solid grains. Even some exceptionally tough *molecules* will be able to form. Impurities and exotic high pressure compounds will produce colors as vivid as Jupiter's-all the shades of red and orange and yellow, and perhaps even blues and whites on the face of Muggsy illuminated by the distant TC. The overall impression will be of horizontal stripes in different colors, I think, something like Jupiter. But rising convection currents will break up the stripes, like a horde of Great Red Spots, but in a whole slew of different shades and tints. Think of dozens of multicolored lava lights seen from above, with blobs of color boiling up out of the Interior, expanding, churning, whirling in hurricanes big enough to swallow the Pacific, dissipating, only to be replaced by new upward surges.

Please note that I can't be too specific about this; the conditions aren't the sort of thing I (or anyone else) know how to model well. But *qualitative* descriptions are what you need for a story anyway, and those I can give you.

One effect that might crop up is a carbon overcast. Picture clouds of carbon vapor rising up from the depths. They hit the cool outer regions of Muggsy, and start expanding outward, spinning into huge schools of tornados as they do. As the carbon cools, it condenses into grains-think of how hail forms here on Earth, and you'll get the idea. But carbon grains are nothing but soot, dark black, and as more carbon condenses black clouds cover a whole region of Muggsy's face. The black layer holds in heat from below. The temperature under it rises, until eventually it gets hot enough to vaporize the carbon again. The black region evaporates, and new upwelling material appears below.

I'm going to try to represent this situation in a graphic, as seen from one of the Quartet worlds. You'll have to let me know how successful I've been, Jim, but I just couldn't resist the urge to try to produce a picture of this. I'm sure you can see why.

Finally, a bit of background theory on the heat source of Muggsy. The energy source of stars is nuclear fusion, most commonly hydrogen turning into helium. But nuclear reactions take place only at high temperatures, usually above 10 million K. Such temperatures are reached by gravitational compression of really huge masses, 80 times the mass of Jupiter and up. The initial squeezing together of hydrogen when the object forms produces enough heat to ignite nuclear reactions, and a star is born.

When less massive objects form, like Muggsy, high temperatures are generated as well, but the lower mass means less gravity, less squeezing, and temperatures below the 10 million K cutoff. For this reason, apart from a few minor exceptions brown dwarfs-objects with less than 80 times Jupiter's mass-never produce heat by nuclear fusion. The simple theory of these has them generate heat by their initial compression, then spend the rest of eternity cooling off.

That wouldn't work for us here; by the time 4.5 billion years had passed-enough time for intelligence to evolve, based on our one known example here on Earth-Muggsy would have cooled to too low a temperature for the Quartet to be habitable. The right temperatures would have obtained for a while, but not long enough. Life would have evolved to the one cell stage, and ended up frozen that way when the oceans turned to ice.

Differential rotation to the rescue! Differential rotation is a fancy term describing situations where things spin, but not all with the same rotation period. Whirlpools and tornados are both examples; the inside spins

a lot faster than the outside in both cases. See also hurricanes, water whirling down a drain, or stirred coffee or tea (caffeinated or decaf). Lots of real astronomical objects rotate differentially, including the sun, Jupiter, and Saturn. The rotation period of Jupiter's equator, for example, is a few minutes different from its poles. Earth does *not* rotate differentially, since its surface is solid, but our atmosphere does (consider the jet stream).

When a fluid (either a liquid or a gas is a "fluid" in physics) rotates differentially, there is friction between the layers spinning at different rates. This friction generates heat. We see this even here on Earth. In winter, it is very seldom both really cold and really windy at the same time. The friction of the wind with the ground warms the air. Please note that I am well aware that there are limits to this effect; I'm originally from Buffalo, not Greensboro. It might be comforting to know that a 30 mph gale off Lake Erie would be even colder than 5 Fit it weren't for frictional warming, but it sure never helped to start my car.

Anyway, frictional heating is what provided Muggsy with enough energy to stay toasty warm long after it should have cooled to fairly frigid temperatures. The process does not represent an unlimited line of credit in the heat department, though. Muggsy once rotated with strong differential motion. Today, there are only a couple of minutes difference between polar and equatorial rotation speeds. Little additional heat Is going to be generated by friction, and from now on temperatures on Muggsy will steadily drop. But an object 50 times the mass of Jupiter takes a long time to cool off. It will be another billion years before things begin to get markedly chilly on the Quartet, and with suitable adjustments by the ecosystems (adding carbon dioxide to the atmosphere, for example, to increase greenhouse warming) the Quartet might stay habitable even by humans (the carbon dioxide required would be less than half the danger limit for human health) until TC becomes a red giant, perhaps 5 billion years or more in the future.

The Quartet Worlds

Hoffman's Quartet consists of four Earthlike planets. The parameters I was given require them to rotate in 24 hours and to have gravitational pulls between 0.9 and 1 g. The additional requirement that they enjoy habitable temperatures essentially completes the determination of their orbital and atmospheric characteristics.

The planets orbit Muggsy 90 degrees apart, a formation known as a Kemplerer rosette. Such structures are gravitationally stable and can exist indefinitely from the standpoint of orbital mechanics. In the present case, perturbations caused by the pull of TC are negligible. In fact, Muggsy could hold a satellite in a stable orbit (on a time scale of billions of years, at any rate) at a distance of over 40 million kilometers.

In fact, the Quartet orbits Muggsy at a distance of 1,100,000 km from the brown dwarf's center. For comparison, Muggsy is bit less than three times as far from the Quartet worlds as Earth is from the Moon. From this distance Muggsy looks quite large, as you might expect. Its long diameter is over 14 times as big across as a full moon here on Earth, its shorter polar diameter still 11 times as big across as a full moon. It covers 158 times as much area in the sky as the Moon. You can get a rough idea of the size by setting a football (or better yet a rugby ball) at your feet and looking down on it.

WARNING : Muggsy is shaped more like a hamburger bun than a football; its cross-section Is the same sort of shape as a football's, though, if you get the idea.

The size of TC as seen from the Quartet is a lot smaller than Muggsy, about 1/3 the size of the sun as seen from Earth-but *don't* be tempted to look directly at it, except near sunrise or sunset. It's not as bright as the sun is in our sky, but it's still nasty enough to cause eye damage.

The Quartet worlds orbit Muggsy in 24 hours, 41 minutes, 28 seconds. Most close satellites in our solar system are tide-locked, with one face permanently pointed towards their primaries (Triton of Neptune is an exception). This is true for the Quartet as well. The Quartet worlds rotate on their axes once in each orbit; their rotation periods are the same as their orbital periods: 24h 41 “”28s, a length of time I'm going to call one Qday, Sunrises will be 1 Qday apart on all four worlds, and so will sunsets. In fact, *everything* will rise and set with a period of 1 Qday, except for Muggsy and the other Quartet worlds, I'll deal with those below.

I realize that 1 Qday is not 24 hours, as you specified in your original parameters for this design. My assumption was that you didn't really want the day length to be *exactly* 24 hours (which would be a coincidence of awesome proportions) but something close enough that Earth-types would not have to feel maladjusted. A Qday is in fact a bit less than 3% longer than a real day, which I thought was close enough to make life simple for characters and far enough off from a flat 24 hours to keep readers from cringing. To be real specific, I chose the Qday to be 88,888 seconds in lieu of 86,400 (=24 hours), because all those 8's were easy for me to remember in doing other calculations,

On to the rising and setting of Muggsy. This is actually very easy to deal with, because the Quartet worlds are tidelocked. Muggsy never moves in the sky as seen from any of the Quartet. There will be one place on the equator of each world where Muggsy is directly overhead; let's call it the subMuggsy point or (colloquially) the Hot Pole. Since Muggsy is the main source of heat, the point where it is permanently poised directly overhead will be the hottest point on the whole world, on the average. (I'll call the point on the opposite side of the world the-you guessed it! “Cold Pole.) From the whole hemisphere centered on the Hot Pole-let's call it the Warmside-Muggsy will always be in the sky, though it will be right on the horizon at the hemisphere's boundary. Muggsy can even be seen (on the horizon again) from a ring around the edge of the Coolside, but over most of the Coolside the brown dwarf and all its interesting features lie permanently below the horizon.

On to the other Quartet worlds. Since these are always 90 degrees apart in their shared orbit, from any one of them two others will be visible if you stand in the right region of the Warmside. One will be standing still in the sky 45 degrees east of Muggsy, the other 45 degrees west of Muggsy. This formation of two Quartet worlds and Muggsy standing stationary while everything else moves around-TC and the stars and occasional comets and asteroids-would be an interesting facet for some native religion, and the images produced might be important in their literature and philosophy as well. Note that there are places where you can see Muggsy and both other Quartet worlds, Muggsy and one of them, or only one of them, but there's no place you can stand and see only Muggsy.

Note too that the last member of the Quartet will be hidden behind Muggsy in permanent eclipse. This too may be of interest in dealing with the Quartet's native races, who won't know about the existence of the fourth member of the group until they have either gotten good enough to work out Kemplerer's theory (which involves either a fair knowledge of calculus or good computer algorithms, and a firm grasp of the physics of gravitation in any case) or developed space flight or picked up information from space traveling visitors. There may be important religious implications here, too; but that's your side of things.

On to other details. Luckily for our limited imaginations, the Quartet orbits in the equatorial plane of Muggsy (typical of large inner moons of giant planets; the physics of this is understood, and involves the gravitational pull of the equatorial bulge of the planet; ask me about it if you're interested). Still better, the equator of Muggsy lies in the same plane as its orbit. Muggsy's rotation axis points perpendicular to the plane of its orbit around TC, and all four Quartet members have axes of rotation parallel to Muggsy's. Considering the strength of its gravitational pull, it would be surprising if they didn't have their axes aligned this way, but we can revel in the serendipity of this situation anyhow. It simplifies our task of picturing things quite a lot, and eliminates several nasty potential problems, like seasonal effects. These worlds are interesting enough without overburdening the reader.

I'll give details below, but all four Quartet worlds are about the same size as Earth (as might be expected from their required gravitational pulls). In the sky of one of the Quartet, another member looks only about as big as the Moon does in our sky-but it's much more interesting and colorful. The cloud patterns are too small to be seen in detail with the naked eye, but they are constantly shifting. When illuminated by the light of TC (more on phases below) the clouds look brassy-colored-they are reflecting TC's light quite nicely. Despite the fact that TC is a lot farther away from the Quartet than the Moon is from our sun, the clouds look about as bright as the Moon does to us. Clouds are much more reflective than the Moon's surface (which is surprisingly dark-asphalt colored, more or less). Ocean revealed under the clouds would look deep green rather than Earth's sapphire blue, a consequence of the color of TC's sunlight.

The sky on the Quartet worlds looks green as well, though it looks distinctly yellower in the region near Muggsy. Sunsets would be less colorful than those on Earth, at least to human eyes, since there'd be essentially no violet and blue light present. But TC would look the color of a sour cherry at sunset, redder than our sun ever gets. Since TC looks pretty small from the Quartet, it would slide below the horizon rather quickly. Seen from the equator, it would take the sun only 41 seconds to drop below the horizon once its "bottom" edge first touched it, and the same amount of time to rise each morning. At higher latitudes the sun's path in the sky would not take it straight down, perpendicular to the horizon, and so sunrise and sunset would take longer-about a minute at latitude 45 degrees, for example. Of course, the colors of sunrise and sunset would last longer than the dropping or rising time of the sun itself, just as they do on Earth.

Seen from a longitude where one of the other Quartet worlds is near the horizon, the world would look reddened, just like the sun and Moon do when they are rising here on Earth (I assume that unlike my students you have seen at least one sunrise in your life). But unlike the sun or Moon here on Earth, the Quartet world would be *permanently* poised on the horizon, never moving as seen from its tidelocked neighbor.

The reddening of Muggsy when it's near the horizon would not be nearly as apparent as it would be in the other two Quartet worlds-it's pretty red already. If Muggsy were observed near the horizon at night, the effect would be spectacular, with a bright red glow as from a vast charcoal grill competing with the brassy reflection of TC's light. Even on a cloudy night it would be an amazing event to a non-native. In daylight hours, Muggsy wouldn't add much to the brightness of the day, but its *warmth* would be noticed either way. Here on Earth, we get light and heat from the same body. On the Quartet worlds, heat comes from Muggsy, light from TC. TC rises and sets (I'll describe this below) but Muggsy, the source of warmth, never moves. This can't help but effect every aspect of native life, both intelligent and no intelligent, and should have important impacts on the behavior of humans as well. An interesting (I almost said "unique") aspect of life on the Quartet worlds is that the length of year and time of year make no difference on the Quartet planets. They move in a circular orbit and have no axial inclination. There are no seasonal effects at all over the 5.6 years of Muggsy (and the Quartet's) orbit of TC. This 5.6 year cycle is probably the sort of thing the intelligent natives noticed as they started to emerge into some sort of record-keeping stage, because the sun does move (slowly) among the stars. For example, the stars up just after sunset every night slowly shift in a

cycle 5.6 years long. Plants and animals are probably Ignorant of the existence of the year. With no seasons there is no reason why anything needs to be aware of the "annual" motion of Muggsy around TC.

Eclipses are so common on the Quartet worlds that no natives pay much attention to them. Once every orbit-once a Qday-each of the visible Quartet worlds eclipses the sun for about 2 and a half minutes; totality lasts 77 seconds. Night falls briefly; canaries and other bird-brains go to sleep; children cry; tourists gape and snap pictures. The eclipse is so brief because TC is moving through the sky but the Quartet world is stationary, not moving along in a nearly parallel course like the Moon does during a solar eclipse here on Earth. Once again, this is something the natives will have cooked into their more primitive religions, and maybe some not so primitive. The highlight of the short eclipse is a red halo that appears around the spot where the sun has vanished, the refraction and reddening of TC's light as it passes through the atmosphere of the neighboring world. Note this means a total of two eclipses by the neighboring Quartet worlds every Qday, from places where two worlds can be seen. Such places cover a quarter of the world, by the way. If the Hot Pole is on longitude 0 degrees (like Greenwich), two other worlds are visible (when the sky is clear, anyway) from 45 degrees east to 45 degrees west.

Eclipses by Muggsy will also take place every Qday from any point on the Warmside. These eclipses will be much more extended than those by the neighboring worlds, because Muggsy looms so big in the sky. They'll last 29 minutes, 16 seconds. There should be some spectacular effects as the sun slides behind the brown dwarf, illuminating storm systems at the monster's limb from behind, the phenomenon called "backlighting" by stage directors and Jet Propulsion Lab engineers. With the sun behind Muggsy, its own sullen glow would be easy to see, silhouetting storms in its atmosphere from beneath. It would be like seeing Hell from a high-flying plane. Once in a while there would be a flicker of blue spreading like a web over a portion of the huge oval disk: a mammoth stroke of lightning, perhaps ten thousand kilometers long, bright enough to be visible across a literally interplanetary distance.

The Four Worlds

On to the worlds themselves. You already know their orbital and rotation periods. Other important data:

Planet	**Diameter** (km)	**Mass** (Earths)	**Gravity** (g)
Batland	12,100	0.89	0.99
Seaworld	12,700	0.95	0.96
Dinosauria	11,900	0.83	0.95
Alienistan	12,900	1.01	0.99

I've chosen the sizes and masses of these worlds so as to guarantee that their gravitational pulls will be between 1.9 and 1 g, as you specified. The diameters are averages; as I'll describe below, all four worlds are somewhat tidally distorted by the presence of Muggsy and its huge gravitational pull.

Atmospheric compositions of the Quartet are also Earthlike, to make them breathable by humans without artificial aids:

	Batland	Seaworld	Dinosauria	Alienistan
Nitrogen(N2)	76%	72%	78%	77%
Oxygen (02)	23%	27%	21%	22%
Argon (A)	0.91%	0.84%	0.88%	0.90%
CO2	0.04%	0.04%	0.04%	0.04%
Trace gases	0.05%	0.12%	0.08%	0.06%

NOTE: I've been calling the Quartet's members "worlds' to avoid nasty problems in terminology. Are these things planets, or moons?

The satellites of stars are called planets by convention (if they are big enough); the satellites of a planet are called moons, again by convention (and if they're big enough). A brown dwarf is neither a planet *nor* a star,

though-so what in hell do you call *its* satellites? No doubt there will be complaints from some ultimately pedantic fan no matter what terminology you use. I've decided to duck out by using the overdone term "worlds." I thought of "satellites," but that suggests CNN and even (I feign barfing) MTV.

Good luck on this one....

The Quartet worlds have similar structures, compositions, and climates. Considering their proximity and their similarity in size and mass it would be amazing if they were grossly different from one another, though of course they differ in detail in a vast number of ways. I can only give a brief sketch of each one, of course (think of trying to describe Earth in real detail), but I'll try to give you a clear basic picture of each planet later on, after I sketch the broad features that apply to all of them. All four are tidally distorted by the presence of a nearby giant mass, Muggsy, If any of them were so foolish as to not be tidelocked, Muggsy would drag tides *hundreds of kilometers tall* across battered continents. Because they are tidelocked on Muggsy, they escape this fate, but even so the brown dwarf's gravity has drawn them out into slightly prolate (football-shaped) structures. The distortions are slightly different for each one. The long diameters are measured from Hot Pole to Cold Pole, from the point closest to Muggsy to the point farthest away; the short diameters are measured along the rotation axis, from North Pole to South Pole. The differences between long diameters and short diameters are:

```
Batland:       134 km
Seaworld:      163 km
Dinosauria:    125 km
Alienistan:    173 km
```

While the tidal distortion is significant to map makers, it amounts to little more than 1% for all four cases, too small to be visible to the naked eye. Like Earth, the Quartet worlds aren't spheres, but you couldn't tell by looking at them. There is no significant difference in gravitational pull, ocean depth, or air density because of the elongation. These effects could be measured by instruments, but would not be apparent to anyone's senses.

Much more significant than the tidal bulges are the climatic effects of the Quartet's tidelocked orbits. While TC rises and sets just like the sun on Earth, it contributes only 6% as much "solar energy" as Muggsy. Muggsy squats permanently above the Hot Pole, keeping it quite torrid, while the Cold Pole on the opposite side of the world is in a permanent deep freeze.

Warning: The alleged science of climatology is still in a state of relative infancy, and I do not have a strong grasp of the latest techniques. I believe I can give you as goods a guess as anyone about the climatic conditions on the Quartet worlds, but this stuff is nowhere near as firm as (say) orbital periods and such. Calculations I did depended upon a number of idealizing conditions, and I would not bet the farm on the results. I don't mean to throw away my credibility here, but note our limited ability to understand our own climate from season to season (will next summer in Illinois be hot? Wet? Want to bet on it?) and you'll see the problem I have in messing with alien worlds.

In the absence of rotation, the basic wind patterns of the Quartet would be fairly simple. Warm air would rise from the region of the Hot Pole, spread out in the upper atmosphere, flow towards the Cold Pole, and (chilled and now comparatively dense) sink there. In the lower atmosphere, the rising air near the Hot Pole would draw in winds from all directions; think of a firestorm here, though things would never get that extreme. In weather terms, the Hot Pole would be a permanent strong low pressure area. On the flip side, the chilly air settling from the upper atmosphere near the Cold Pole would spread out, flowing along the ground towards the Hot Pole. The Cold Pole would play the part of a permanent strong *high* pressure area. Basically, in the upper atmosphere winds would blow from the Hot Pole towards the Cold Pole; in the lower atmosphere they'd blow from the Cold Pole towards the Hot Pole.

This simple state of affairs is badly complicated by the rotation of the Quartet worlds. They *do* rotate, by the way, once each Qday, which is why the sun rises and sets. The rotation produces a complicated, counterintuitive push called the Coriolis force. I can explain it if you like (I do that for a living, remember) but in practice it's a lot easier to. think of it as a force that makes moving objects (including wind) swerve to the right in the Northern Hemisphere, to the left in the Southern Hemisphere. This is the force that winds up hurricanes. In the Northern Hemisphere such storms spin counterclockwise; in the Southern, clockwise. Surprisingly, it is not the force that makes water swirl when it goes down a drain-this is due to other effects

that I don't want to get distracted by.

Coriolis force will (I think) make for some rather unique (there; I said it...) wind patterns on the Quartet worlds. Near the surface, near the Hot Pole, winds coming from the Northern Hemisphere will be trying to swirl counterclockwise, while winds coming from the Southern Hemisphere will be trying to swirl clockwise. The swirls will meet on the equator, west of the Hot Pole, and batter each other into exhausted (and somewhat warmer) calm. From there air will stream due east into the warm region of the Hot Pole, where it will expand and rise into the upper atmosphere. If it carries water vapor with it-in cases where the Hot Pole Is above an ocean, say-look for a huge thunderhead over the Hot Pole, and lots of accompanying violent thunderstorms below. There's a lot of heat energy to be dissipated, and one way this happens is in storm production. Seen from space, the cloud patterns accompanying these winds near the might not look unlike a Pacman figure, mouth gaping towards the west.

Oddly enough, surface level winds near the Cold Pole will be quite similar to those at the Hot Pole, halfway around the world. Here, though, the winds will be moving away from the pole near the surface. The air coming from the Northern Hemisphere will be trying to swirl clockwise, the air from the South counterclockwise. In this case the swirls will meet *east* of the Pole, and then flow away eastward. The shape of the cloud patterns formed would look rather like an exclamation point.

I expect, then, that there will be a permanent westerly wind-not very powerful, but dependable-along almost the entire equator. There's nothing like this on Earth; bear in mind that on the Quartet worlds the equator is not associated with warmth (save near the Hot Pole) and the North and South Poles are of moderate temperature, lying on the great circle separating the Warmside from the Coolside. Sailing ships could follow this rather gentle westerly wind almost all the way around the world, if they didn't run out of ocean, but it's *not* a trade wind-it never shifts direction and heads back west.

The one region of the equator without prevailing westerlies would lie near the border between the Coolside and the Warmside. If we choose the Hot Pole to be at longitude 0 degrees, as I suggested earlier, the border between the Coolside and the Warmside will lie along two semicircles: 90 degrees East and 90 degrees West. Where 90 degrees East crosses the equator, surface winds would be easterly, as cool air from the Coolside flowed into the Warmside.

Away from the Hot Pole and the Cold Pole, wind patterns would be mainly influenced by the warm air blowing into the Coolside at high altitudes and the cold air blowing into the Warmside near ground level. Let's first look at the semicircle at 90 degrees West longitude, marking the border between Warmside and Coolside. Near ground level, in the Northern Hemisphere, there would be prevailing northwesterly winds; in the Southern Hemisphere, these would be southwesterly. Along the eastern semicircle the situation is a mirror image of that to the west. In the Northern Hemisphere, ground winds near the Warm-Cool border are prevailing southeasterly; in the Southern Hemisphere, northeasterly.

Coriolis force is strongest near the North and South Poles, weakest near the equator, and zero *at* the equator. I'd look for hurricanes (which need warm water more than high coriolis force) at about the same latitudes as we see ours here on Earth, say about 30 degrees north and south of the equator, mostly near longitude 0 degrees, due north or south of the Hot Pole. I'd expect them to be fierce and long lasting; there's no "night time" to cool off the water as there is here on Earth.

Look for tornadoes (waterspouts, over water) near the Warm-Cool border near the North and South Poles, where Coriolis force is biggest. We never have tornadoes near the poles here on Earth; they're too cold to produce sufficient energy for such things. But remember (I have to keep reminding myself) that the North and South Poles on the Quartet worlds aren't particularly cold, and that air near them is likely to be swirling and unstable.

Temperatures: Near the Hot Pole, hot; near the Cold Pole, cold. More seriously, the global average temperatures on all four worlds is 20 C (68 F), which means even less than it does on Earth (where the average is about the same), Daytime temperatures average 2.3 C (4.2 F) warmer; nighttime averages are cooler by the same amount (note again how little effect TC's presence or absence has on temperature). Near the Hot Pole, on a clear day, inland temperature ought to be near 60 C (140 F); it would be cooler near water. Near the Cold Pole, inland temperature would be around -80 C (-112 F); it would be warmer near water. Along the border of the Coolside and Warmside, where Muggsy lies on the horizon, temperatures would be around 20 C (68 F). Wind and water would serve to moderate temperatures fairly well; the extremes of heat and cold would not be found more than a couple of thousand kilometers from the Hot or

Cold Poles (think of our Arctic and Antarctic).

Precipitation: Effected strongly by the presence of open bodies of water and mountain ranges, just as on Earth. But the drop in temperature in the ragged circle where Muggsy drops below the horizon-on the Coolside-would promote precipitation, and there would generally be a wet ring around the Cold Pole. Think of a rain ring, a sleet ring, and a snow ring. The rings are hollow ones, though, with a big dry circle in their midst. For several thousand kilometers away from the Cold Pole, there would never be any precipitation. All the water would condense out before the winds carried it into the truly cold zone. It's worth noting that snowfall in Antarctica is extremely rare for the same reason. If the Hot Pole is over land, expect it to be desert, too. Nothing is going to condense out of the air at those high temperatures. The cool surface breeze blowing into the Warmside will be damp, carrying moisture from the wet rings.

So much for climate and wind patterns. Thank God there's no seasons; that would've put an end to my valiant computer, I think.

Tides: There aren't any to speak of. Because all four Quartet worlds are tidelocked, they never move with respect to each other, and none of them moves with respect to Muggsy, The worlds and Muggsy certainly do exert gravitational influence on each other, but the influence is constant in time. Like the tidal bulges that make the Quartet worlds prolate, the ocean tides are "frozen," swellings in the ocean that never move (and aren't detectable without instruments). The one very minor exception is tides produced by TC. These would amount to about 2 cm (call it an inch) on the average. I'd say tides would never be noticed. Our own sun produces rather more substantial tides, but that's because it's a lot closer to us than TC is to the Quartet; tidal forces obey an inverse cube law, and hence weaken very rapidly with increasing distance.

On the geological side, expect nothing too surprising. These worlds are about the same size and mass as Earth, and we want them to be habitable, so they have to *behave* more or less like Earth. All of them have hot, molten cores made of iron and nickel and a few impurities. All of them have mantles made largely of silicates and other rocky materials. All of them have thin crusts broken up into tectonic plates. The plates are shifted around on the underlying mantle by upwelling convection currents (them again!) produced by heating from the core, in turn caused by radioactive decay of uranium, thorium, and potassium-40. When plates bump into each other, one slides (subducts) under the other, and a range of mountains is produced (called fold mountains); the Himalayas are an example, where the Indian Plate is crunching into the Asian Plate. When plates pull apart, a wound opens up, a thing called a rift. There's one that runs down the middle of the Atlantic; another (the Great Rift of Africa) is responsible for the Red Sea, among other features.

The number and altitude of continents will depend largely on how much water a world has. From the global standpoint, Earth's oceans are a thin watery layer over thousands of miles of rock. If we'd had (say) twice as much water-adding only a tiny fraction to Earth's mass-nothing under 10,000 feet altitude would be above water. That wouldn't leave much.

Astronomical/geological history: The Quartet formed at the same time as Muggsy, from material with too much angular momentum (call it orbital motion) to fall into the maelstrom that would become a brown dwarf. The big blob of largely gaseous material that was to form Muggsy was busily pulling Itself together in the middle while the material that was to form the Quartet orbited it, a lumpy disk looking vaguely like Saturn's rings. The whole structure, 5 billion years back, was something like a fried egg: The protoMuggsy was the yolk, the protoQuartet material was the white.

Very early on, four separate condensations must have gotten bigger than other ones orbiting Muggsy, and they must have been close enough to 90 degrees apart to fall into the Kemplerer rosette formation that still occupy today.

There must have been considerable amounts of hydrogen, helium, and Icy material in the disk orbiting Muggsy, at first. But once gravitational squeezing started to warm up the big mass of gas in the middle, conditions in the disk presently got very warm. The comparatively modest gravitational pulls of the four blobs that were forming the Quartet were insufficient to hold on to the lighter material. The idea here is pretty straightforward. The hotter it gets, the faster molecules move, and the lighter ones move faster than the heavy ones. Hydrogen and helium are lightest of all, and when the young Muggsy's surface temperature rose over a hundred thousand degrees the light stuff-the great bulk of the orbiting disk-boiled off into space. Next went the ices, or most of them; a bit of water-the hardest to boil of the ices-survived, held to the protoQuartet worlds by their gravity. But by and large the Quartet worlds formed from the small percentage

of heavy material that was not vaporized by the heat of Muggsy's formation. Like Earth (and Mercury, Venus, Mars, and the Moon), the Quartet worlds are low in mass, high in density, low in hydrogen and helium, rich in metals and silicates. If the Quartet's disk of material had formed farther out from Muggsy, where it was cooler, the worlds might have retained more hydrogen and helium, ending up like Uranus or Neptune, or even Jupiter.

After their formation, the worlds were hot for a long time. Infalling asteroids kept their surfaces molten for perhaps half a billion years. Eventually, though, all of the asteroids with orbits that came close to Muggsy's had been pulled into Muggsy (or one of the helpless Quartet), or ejected into an escape orbit from the Tau Ceti system, or dumped into TC itself. The rain of meteoroids slacked off.

Originally, the Quartet worlds weren't the only satellites of Muggsy. Their own gravitational perturbations prevented satellites from occupying orbits within a few million kilometers of Muggsy, but a few orbited farther out, billions of years ago. These were all smashed in collisions with asteroids, though, both standard and icy, and today only a few mountain-sized fragments remain, too small to be seen from the Quartet.

Still, the close proximity of the asteroid belt makes impacts much more common on the Quartet than on Earth. It is fortunate that once life originated-3.5 billion years ago-the biggest asteroids had already been broken to bits in collisions. Impact of the mall-sized remnants is very rare. Such impacts can devastate a region of a continent or blast a thousand cubic kilometers of ocean water into the atmosphere-they hit with the energy of a thousand 100-megaton bombs-but they do not cause global-scale disasters. There have been no "dinosaur-killers" in the Quartet system since before the origin of life.

The native life of the Quartet: Like life on Earth, life on the Quartet worlds evolved to survive in a competitive environment. In some ways, the environment of the Quartet is harsher than Earth's, in some ways more mild.

While the Quartet worlds have more extreme temperatures than Earth, these temperatures are strongly localized. Life forms have evolved to live in the broiling heat of the Hot Poles and the frigid dryness of the Cold Poles. Because the temperatures and other conditions are relatively stable, the life forms that have carved out ecological niches in these harsh regions do not have to cope with much variation, save from members of competing and predating species.

The Quartet worlds experience superstorms, gigantic, long lasting hurricanes-some have persisted for several years-but like the Hot and Cold Poles, these are localized, spinning out their terrible careers in regions a couple of thousand kilometers across located near 30 degrees North and South on the 0 degree longitude line-roughly 3000 kilometers due north and due south of the Hot Pole. Where these regions lie over land, the superstorms spin themselves out quickly. Where they lie over water, the sea creatures far beneath the surface are nearly undisturbed. Sensory equipment on the Quartet worlds includes all the variations of Earth. Quartet life forms can see, hear, feel, smell, taste, detect electric and magnetic fields, and so forth, though as on Earth most species have only one or two very powerful senses. A significant difference between Quartet and terrestrial forms, however, Is the contrast in what is considered part of the visible spectrum. Earth's visually acute creatures are most sensitive to the various wavelengths emitted most powerfully by the sun, those referred to by humans as the colors red, orange, yellow, green, blue, and violet. A few Earth creatures (e.g. desert snakes) have found it advantageous to be able to detect infrared emission from their warm blooded prey, but this is comparatively rare. Survival of sighted creatures on Earth revolves around detection and analysis of what humans call visible light.

There is a source of visible light on the Quartet worlds as well, TC. But its emission includes essentially no violet light and very little blue. Instead, much of its emission lies in the infrared portion of the spectrum. Still more important, the major source of energy for the Quartet worlds is Muggsy, which emits over 98% of its energy in the infrared region of the spectrum to which humans-and most other Earth creatures-are blind.

Warm blooded animals on the Quartet worlds are at a strong environmental disadvantage. They make their presence known to all competing and predating neighbors, glowing like Tinker Bell everywhere the go. They are only safe in burrows or caves, or perched high above their competitors on mountain crags or treetops. For this reason, most-though not all, Quartet life forms are cold blooded, retaining the same body temperature as their local environment. This amounts to protective coloration when nearly all species can see well throughout the infrared region of the spectrum. It also means that migratory species tend to move in circles centered on the Hot Pole or Cold Pole, circles that define regions of constant temperature. There is little migration radially save by intelligent species that can make artificial protection for themselves. One

advantage of visible light sensing is better resolution. Longer wavelengths, like infrared, lead to less well-defined focusing of eyes. Few species on the Quartet worlds could read print that humans resolve easily. But some species, such as dayhunters, have developed an exceptional ability to see by the comparatively weak emissions of TC.

Now for some details,

Batland

Batland is the driest of the four worlds, and competition for water lies at the center of the global ecosystem. The Hot Pole lies in the center of an enormous desert; the Coolside is mainly as dry as the Gobi. There is little life in these areas, but they have regions of great natural splendor, deep ravines and tall mountain ranges and ventiformed structures (created by erosion from wind-blown dust) that awe tourists from Earth and the more pleasant of the Quartet habitats.

Despite the large waste regions, in a belt extending around the boundary between Coolside and Warmside lies a chain of lakes and small seas, river valleys, mountain pools, and even a few low-lying swamps.

Competition for water is fierce. Water-dwelling creatures prey on each other as well as animals seeking to drink. They come in a wide variety of savage forms, some resembling sharks, mesosaurs, crocodiles, giant seas snakes, radiates (like starfish) small and large, stinging things like Jellyfish, shocking ones like electric eels, and others that emit poisons liquid and gaseous. One even has the intriguing ability of emitting a substance which works like epoxy, combining with prey's skin-emissions (such as oils) to produce a powerful adhesive.

In response, some animals have developed useful organs or abilities. Some creatures burrow as much as a hundred meters underground, tapping water sources from below. One has a hollow, straw-like tongue ten meters long. It can lurk in shelter and extend its long 'straw" out to drink.

Many creatures can go without drinking for extended periods, storing it internally in sacs or spongy tissue; some of these are themselves prey for land-dwelling waterseekers. Others obtain necessary water from devouring large amounts of vegetation, or other animals, or even insects.

Their forms aid water retention. They are most often rounded, fairly large, with few protuberances, and those easily withdrawn inside the body. All this helps to prevent unnecessary evaporation. Sweating-a habit of warm blooded creatures-is of course unknown.

Perhaps most interesting of the Batland life forms are the Bats, the native intelligent species. When their species was evolving they became the favorite prey of a dayhunting predator with the rare ability to detect "visible" light. This led them to the habit of hiding Inside dark caves, to emerge to feed and drink only when TC was down and their hunters effectively blind. They still prefer cave dwellings today, though their one-time hunters are now long extinct. They have very acute hearing-an important adaptation for cave dwellers, even in the Quartet-but find their way about by the common infrared vision. In caves they are in a sense their own illumination. They are among the few warm blooded species in the Quartet, The ability to see in the dark by the warmth emitted by their own bodies made them supreme in their caves in primitive times. By the time predators began to show an interest in their species-which was easy to find in caves, to say the least-they responded by developing intelligence, and artificial weapons to supplement their teeth, claws, and retractable spikes. Their ability to glide on bat-like "wings" extending from fingers to toes-originally a fin to radiate extra heat tor illumination and sexual display purposes-was one of the things that suggested their name to the first humans to see them.

Seaworld

Batland's neighbor to the east is Seaworld, a great contrast to the

water-poor home of the Bats. Seaworld received more than its share of water. There are no land masses the size of continents; the largest are no more than 50,000 square kilometers, roughly the size of Florida, The total land area of the planet-which is the same size as Earth-is less than 1,000,000 square kilometers, barely as big as Texas.

There are many island chains, the product of hotspot volcanism, like the Hawaiian Islands of Earth. There are also a few low-lying, swampy regions. These were also volcanic in origin, but are now long extinct and

heavily eroded. Landowners on Seaworld prize property that includes a good, active volcano, steadily increasing the islandholder's territory.

As might be expected, nearly all Seaworld life forms are aquatic, though a few fliers-evolved from creatures rather like gliding flounder-live on some islands, returning to the sea to spawn and feed. They are the only flying amphibians in the known galaxy.

Unique to Seaworld are the floating forests, great masses of vegetation fertilized by the animals that swim into their tangles, become lost, and die there. It is thus advantageous to the floating forests to grow to large size and great density. They also have an advantage over competitors for sunlight. Unlike most vegetable forms on Seaworld, the floating forests have broad leaves which rear up high above the surface of the water, shading out competing species. Floating forests-single gigantic nets of deep-delving roots, long, flexible stems, and broad leaves- sometimes cover a hundred square kilometers of ocean. Though some seadwellers eat the roots of floating forests, most avoid them. Victims of the forest are most often predators and prey who charge into the bewildering Jungle in midhunt. The only real enemy of floating forests is a superstorm, which can tear even the biggest living island to shreds. On the other hand, the giant plants reproduce in this way. Some fragments of shredded plants sprout and in time grow into new islands.

Bottom-dwellers living in relatively shallow water include many species of radiant, shellfish of great variety, and species reminiscent of Earth's insects, worms, and even extinct forms such as trilobites. The endless global ocean has kept the temperature of Seaworld much more uniform than the other Quartet worlds, and since nearly all life forms live under water, there is little need for them to cope with much temperature variation. Still, there are a few "icewater" dwellers near the Cold Pole, and some species adapted to the hot water in the shallow ocean near the Hot Pole cannot live in cooler regions.

Dinosauria

East of Sealand lies Dinosauria, eternally hidden from Batland behind the vast bulk of Muggsy. Dinosauria is in some ways the most Earthlike of the Quartet worlds, with roughly the same mix of land and water. There is one giant continent sprawled across much of the northern half of the Warmside, and four smaller continents lying mainly in the Coolside. One large island chain straddles the North Polar region; another is scattered around the Cold Pole.

Though Dinosauria resembles Earth in many ways, the Earth it resembles is not that of humanity,. but the Earth of the Cretaceous, 65 million years ago, before the fall of a giant asteroid ended the long career of the dinosaurs. For the continents and oceans of Dinosauria are thickly inhabited by giant, cold-blooded creatures resembling nothing so much as the great reptiles of Earth's distant past.

Here visitors can see the living image of the age of the Tyrannosaurus, Triceratops, and Pterodactyl. Here giant carnivores stalk their prey through forests of exotic trees and flowers. Here the sullen herbivores in algae-covered ponds watch narrowly as sharp-toothed enemies slouch by. Here faint trembles of ancestral fear still run through humans, whose mouse-like predecessors lived on the carrion and droppings of Earth's first masters.

[How about that, eh? See your travel agent, today!]

These dinosaurs look a bit different from Earth's, as you might expect. For one thing, their eyes are bigger, the better to resolve infrared images. Some actually sport two pairs of eyes, one adapted to visible light, the other to infrared. Other unusual features include several species with oversized "ears" equipped with olfactory organs that turn them into incredibly sensitive chemical detectors. Several similar species are fliers, using their "ears' to glide through the air; these are smaller dinosaurs, chicken-sized and less.

Unlike dinosaurs, the inhabitants of Dinosauria include several species of omnivores, eaters of both vegetation and meat. One of these is the windbreaker, which produces a noxious gas which disables its prey long enough for a kill to be made. The gas is also useful as a defense-so useful, in fact, that one species that preys on the windbreaker has learned to uproot the plants the windbreaker eats to produce its, uh, wind.

One species of herbivore, the fridge, has devised a unique defense. It has the ability when frightened to chill its body temperature well below the local air temperature. It does this by the expulsion of large amounts of warm water. To the infrared vision of species that prey on the fridge, this sudden drop in body temperature is completely bewildering, evidently the equivalent of a high-tech visual effect. They generally wander off in confusion instead of pursuing the fridge, which remains frozen in place in plain sight.

The rich diversity of both animal and plant forms makes Dinosauria a must for any group touring the Quartet.

Alienistan

East of Dinosauria lies the last of the Quartet worlds, Alienistan; to its own east lies Batland. Seaworld and Alienistan-like Batland and Dinosauria-are permanently hidden from each other by the glowing red bulk of Muggsy.

Of all the Quartet worlds, least is known about Alienistan. Observations from space show that like Dinosauria it has roughly the same distribution of land and water as Earth. It has six continents, each about the size of South America, and a score of large archipelagos the size of Indonesia. The land areas extend around the globe, from the North Pole to the South Pole, from the Hot Pole to the Cold Pole.

Perhaps the most notable feature of Alienistan is its two virtually permanent superstorms, one 30 degrees north of the Hot Pole, the other 30 degrees south. With a few short interruptions, storms have been whirling over these two vast areas since the discovery of the Quartet system. Their presence has discouraged visitors, and so have the few unexplained disasters to exploration vessels. Rumor has it that an intelligent species—still unContacted-inhabits Alienistan.

The End

WHEW!

My, but that took a while. I'm going to send this off to you, Jim, and wait a bit on the graphics. I've got some work done, but it's not in presentable form, and there are a few other things I really need to get done. This little report took me the best part of my (alleged) Christmas Break. I can assure you that I earned that $150 fee. I intend to spend it frivolously, I assure you.

Let me stress once again that I assume that you'll have questions about some (or even many) of the things I've put down here. You asked for a complete job; I tried to do just that.

I really wish I could include some graphics; that would really cap this off nicely. But some fool has offered me $1500 to write a software package for him-so long as he gets it by next Friday-and I am Just too greedy to pass that one up. I'll take care of that, *then* get back to the Quartet.

I hope you enjoy reading this as much as I enjoyed putting it together. At last count, I had 35 pages of notes, one 5-1/4 and one 3-1/2 inch floppy filled with simulation output, and close to a megabyte on hard disk with the software that generated the output... most of which was useless. You'd be amazed how many ideas don't work in this business.

Anyway, upward and onward. I'll be looking forward to hearing from you soon.

Best regards,

Sheridan Simon

Headed for the Jack Daniel's