
ALTERNITY®
Science Fiction Roleplaying Game
COSMOS II
MARK PEOPLES

COSMOS-2

Alternity Universe-Building Guidebook, Version 2

CONTENTS

FOREWORD

When the Alternity ruleset was released, the Gamemaster Guide included a planetary system generator to enable harried GMs to create planetary systems with a few rolls of a die.

I felt that the system was lacking, in that it could only produce rough clones of our Solar System, and imperfect ones at that. Furthermore, no mention was made as to the placing of stars in anything like a realistic fashion. This prompted me to work on rulesets that would augment and “complete” the GMG rules. In the early autumn of 2000, Polyhedron magazine published the Star Generator, that enabled GMs to create stellar populations easily and in a believable fashion. The next issue saw the Planet Generator. It was a “patch”, a bolt-on fix that added to the original generator and allowed systems to contain the new kinds of planets that astronomers had recently discovered around other stars. Those documents are still available on A.Net today.

Time moves on, and astronomy has moved with it. When I wrote that original piece, about twenty planets had been discovered. That number has now reached 200 as of 6th August 2006, forty more than last year when the first version of Cosmos was released. The doppler spectroscopy method, the most prolific planet detector, has had its findings confirmed by the first visual observations of some of these planets. Planetary system formation is one of the hottest topics in astronomy today, and evolving rapidly in a dozen different directions. Now that data about other stars is available, it will probably be some time before the definitive theory of solar system formation will be forthcoming. The next ten or fifteen years will probably change what we understand about solar system formation profoundly, but frankly I don't want to wait that long! This new, integrated universe-building system takes the observational data and initial conclusions that are currently well understood and makes sure that we can create planets like those that are known to exist for our games.

Cosmos is a stand-alone solar system generator created in the finest traditions of science fiction. To paraphrase Arthur C Clarke, it isn't an accurate forecast, but rather an “exploration of possibilities”.

Using This Accessory
I have tried to set out Cosmos in such a way as to allow a stepped-detail system. There are several stopping-points along the way where you can leave the creation system once you're happy with the level of detail. The book is set out in three distinct, but related chapters: Stars, Planets and Moons. Each provides a way-station of sorts, and handy stopping points. Each can be used irrespective of the following chapter, but does require in most cases a knowledge of the preceding one.

Dedication
My thanks to NASA and the Space Telescope Science Institute, the Sloan Digital Sky Survey, the Isaac Newton Group of Telescopes and the European Southern Observatory at Paranal and La Silla, together with our very own Shawn “Kzinwarrior” Trudeau, for the images herein. Also thanks to my mother Jeannette, to whom I owe a deep debt of gratitude for kindling and continually encouraging my first interest in the stars, and also in RPGs.

Now go forth, fellow egomaniacs, and create your own worlds to toy with!
-Mark Peoples, 30th September, 2006

Chapter 1: Stars

Most science fiction stories and games revolve around space travel, and a good majority of them include interstellar travel of one kind or another. Space operas of this kind need a framework of sorts to order the vast regions of space and get some kind of organisation going. In grand SF tradition, Cosmos uses something similar as its starting-point; a cubic volume of space called a sector.

A Cosmos sector is a cube, twelve parsecs per side. This allows us to create a number of easily-interlocking volumes of space that are large enough to get things going but small enough so as not to overwhelm us with the workload.

A parsec is the standard astrometric measurement of interstellar space, just as the AU is the standard measurement of interplanetary space. It's shorthand for “parallax second”, or the distance at which a heavenly body appears to move one arcsecond when seen from one side of Earth's orbit to the other (that is, a baseline of 2AU). This works out as 206,265 AU, or 3.24 light-years.

Take a look at the Sector Map sheet on page 55. You can see that it's divided into squares, each three lesser squares per side. Each of these greater squares represents a cubic parsec (imagine the square forming the base of a cube, rising out of the paper toward you). The lesser squares represent subdivisions of one-third of a parsec, or just a little over one lightyear, and serve as location spaces for systems. The numbers on each axis are arranged in a Cartesian co-ordinate system and represent distances in parsecs.

Locating the Sector

Once you have your sector, it's time to determine where it is and what kinds of systems it may contain. Assuming you don't wish to include anything exotic (see below), the number of star systems on your map depends on where your sector is located. While most SF settings are located in the Milky Way, a barred-spiral galaxy, this is by no means a hard and fast rule.

Galaxies come in four basic types: Elliptical, spiral, barred-spiral and irregular. There are also lenticular galaxies, that seem to be a cross between the spiral types and ellipticals, and finally the rare ring galaxies, but they are rarer by far than the other types. Most galaxies fall into a simple system, categorised by Edwin Hubble in the first half of the 20th Century. Dubbed the “tuning fork” diagram, it shows the relationships between different galaxy shapes.

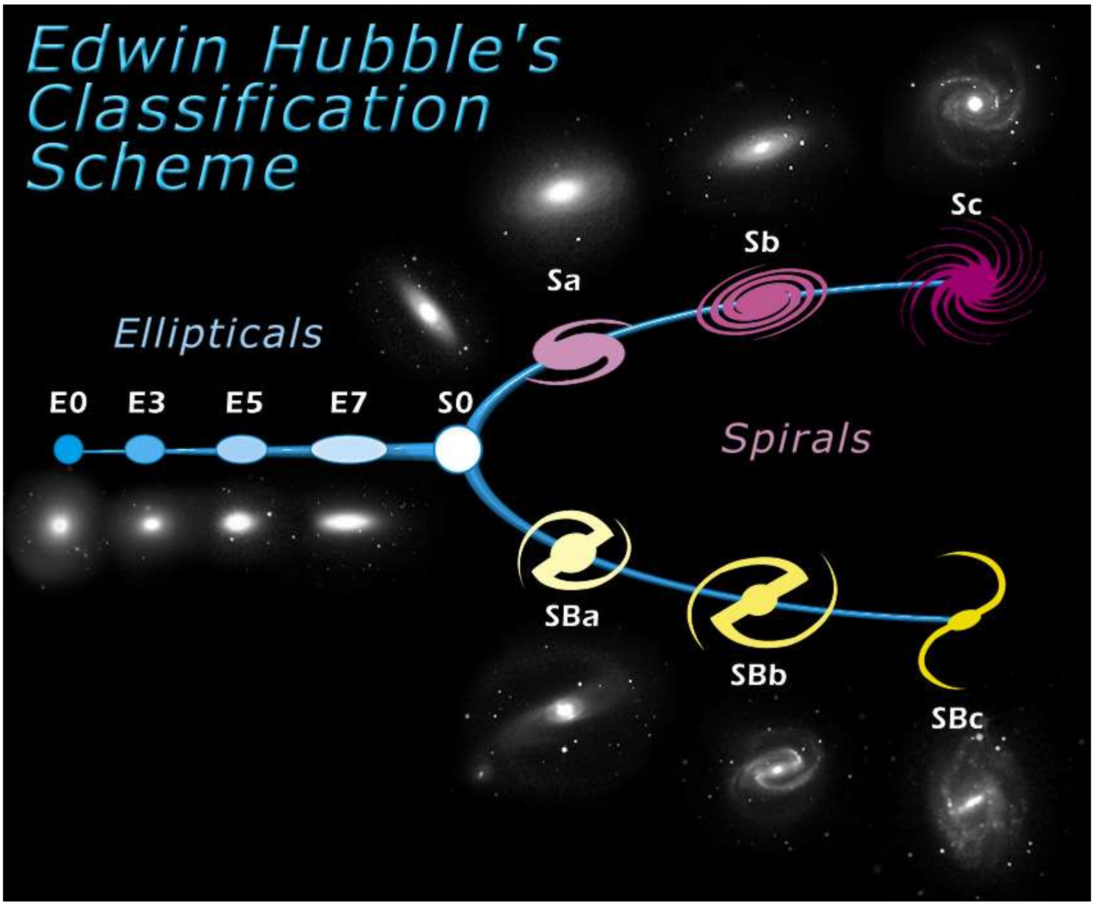


Fig.1 Tuning-fork diagram. Image courtesy: NASA

Spiral galaxies, barred-spiral galaxies, ring galaxies and a small proportion of irregular galaxies are capable of supporting the kinds of environments we as gamers are interested in.

Spiral and Barred-Spiral Galaxies

Spiral galaxies are the classic shape we tend to think of when we hear the word "galaxy". They have a rounded core, a pinwheel arrangement of two or more vast, spiral arms and a spherical halo of globular clusters (see below) orbiting the core. The core itself strongly resembles an elliptical galaxy, and is generally composed of the same old, metal-poor stars as we find in elliptical galaxies. As a result they look distinctly yellowish compared to the spiral arms. In barred-spiral galaxies like the Milky Way, the core is elongated into an elliptical or bar-like shape, from which the spiral arms begin. The Milky Way's type on the tuning-fork is an Sbc. The arms can be intact or patchy, closely or loosely wound. In barred-spirals the arms are generally a little looser than in spiral galaxies. Spiral and barred-spiral galaxies can vary greatly in size. Most are dwarfs like the Sculptor spiral in our own Local Group, while a few are much larger, like our Milky Way or Andromeda. The spiral arms are home to gigantic clouds of dust and gas, and regions of new starbirth like the Orion Nebula. Young, bright stars are more common, giving the arms their blue-white colouration. The Solar System is currently situated towards the inner edge of the Orion arm, The space between the spiral arms is far from empty, however. It has the same stellar population density as the arms themselves, but with no O or B-class stars, and very little dust or gas.

M83, a “Grand Design” spiral galaxy.
Images courtesy: Isaac Newton Group of Telescopes

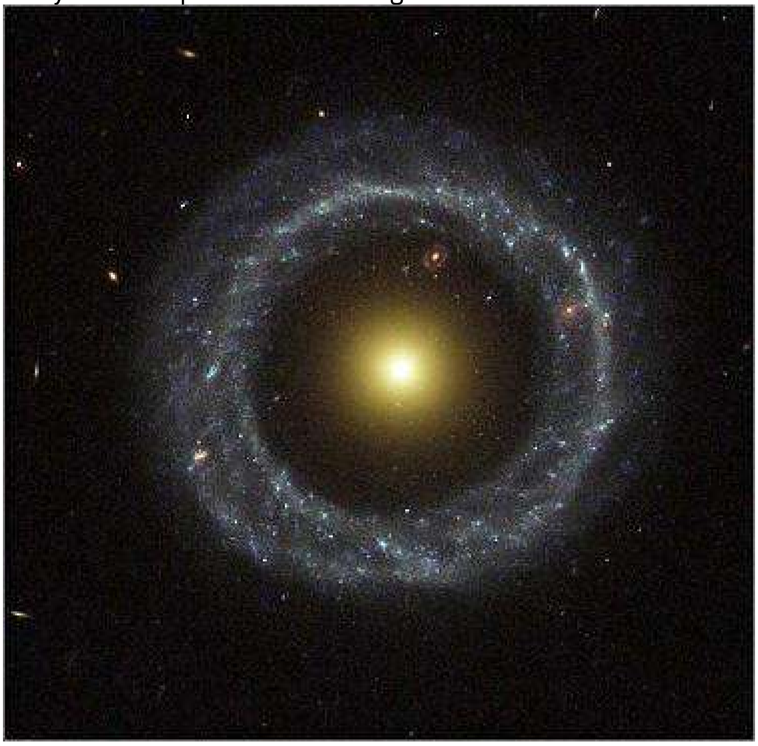
M101, a more open-structured spiral galaxy.

M95, a barred-spiral galaxy. With its subtle bar and “ring” of inner arms, it resembles the Milky Way.
Image courtesy: Isaac Newton Group of Telescopes

NGC1300, a classic barred-spiral. Image courtesy: NASA, STScI

Ring Galaxies
Ring galaxies are extremely rare beasts, related to the spirals. They have the same core structure as a spiral, but instead of spiral arms there is a wide gap between the core and a dense ring of matter like a single, circular arm. Sometimes traces can be seen of spiral structure between the core and the ring, but it's extremely tenuous and has few stars. It's

believed that ring galaxies were once spirals that have been disrupted by another galaxy passing through them too quickly to be captured and merged.



Hoag's Object; the most famous ring galaxy. Image courtesy: NASA, STScI

Irregular Galaxies

Irregular galaxies are exactly that, rough assemblages of stars and gas without enough mass to form a structure. The Large and Small Magellanic Clouds are irregular companions of the Milky Way galaxy, and are probably the disrupted remnants of close encounters or collisions with it. Irregulars are small dwarf galaxies, but on occasion can harbour enough gas and dust to generate star-forming regions. The Tarantula Nebula is such a region in the Large Magellanic Cloud. Use a semi-random mixture of spiral and inter-spiral sectors to populate these bodies, to illustrate the varying concentrations of matter in the galaxy. Because irregulars can exhibit regions of new starbirth, they therefore have a chance of possessing rocky planets.

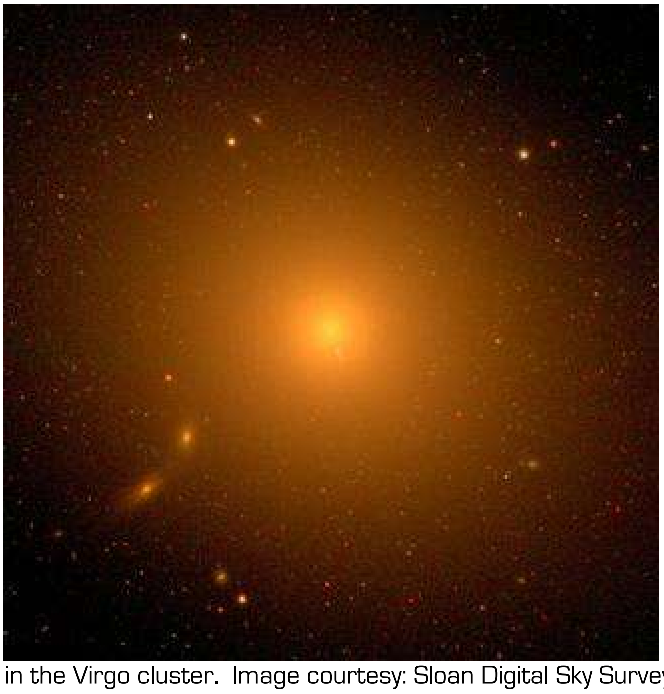
NGC1705, an Irregular galaxy. Note the intense region of new star formation on the right-hand side.
Image courtesy: NASA, STScI.

Open Clusters
Open star clusters are not galaxies, but regions of space in a galaxy where new star formation is, or has recently been, taking place. They tend to contain about a couple of hundred stars or so, and are rarely more than fifteen parsecs across, with no particular structure. There is a much higher proportion of blue-white stars than normal, even within a spiral arm, and open clusters are sometimes associated with emission or reflection nebulae, the leftovers of starbirth. Open clusters are mostly confined to the spiral arms. Open clusters have well-processed materials, but the systems are all newborn and unsuitable for planets, which haven't yet been formed. However, asteroid mining would be particularly profitable (if risky) in such an environment.

Other Galactic Types

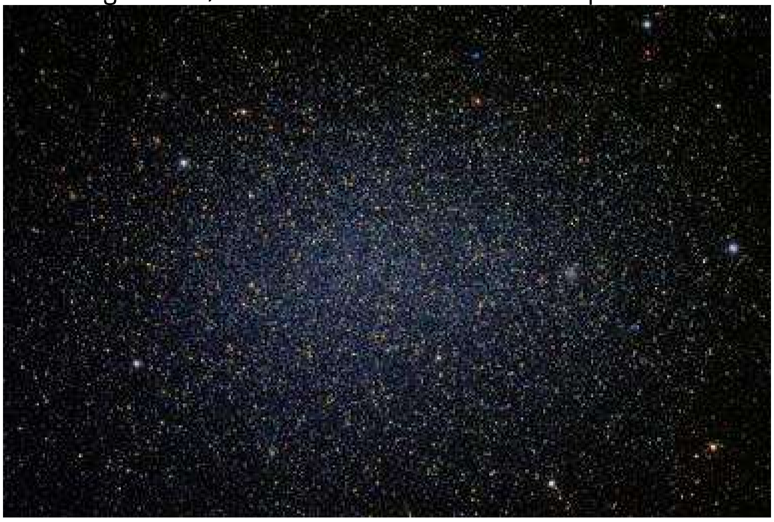
The above sections describe active regions of the Unvierse where new star formation is going on, new stars are being born, old stars are dying, and the primordial hydrogen and helium are being processed into heavier elements. These places are good for finding planets with all the necessary elements to make them interesting. But not all of the Universe is like this. Much of the Universe is utterly empty. On the largest scales the Universe resembles a sponge, with great, empty voids surrounded by sheets and filaments of galactic clusters. Of these galaxies, only those detailed above are truly conducive to science-fiction roleplay, but there are others.

Elliptical Galaxies
Elliptical galaxies are composed primarily of old, low-metallicity (qv) stars and have very little gas and dust. They comprise both the largest and smallest galaxies, from dwarf spheroidal galaxies (see below) to immense giant ellipticals, which can measure as much as 300 million lightyears from edge to edge. These monsters tend to sit at the centres of massive galactic superclusters. Apart from size, there is little to tell between a globular cluster and an elliptical galaxy. Some elliptical galaxies exhibit a dusty disc in the mid-plane, which may betray an ancestry involving the merger of smaller galaxies.



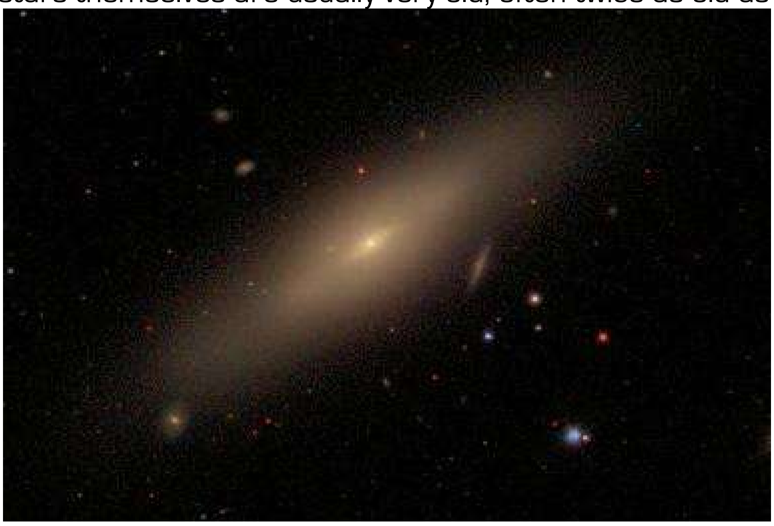
M87, a giant elliptical galaxy in the Virgo cluster. Image courtesy: Sloan Digital Sky Survey

Dwarf Spheroidal galaxies
These are tiny ellipticals, and the commonest of all galaxies. They generally only possess a few million stars, and resemble large globular clusters. Their gas reserves long ago depleted, their stars are old and deficient in heavy elements, just like other ellipticals. Of the forty galaxies in the Local Group, 37 are dwarf galaxies, and 28 of them are dwarf spheroidals.



Leo I, a dwarf spheroidal galaxy in the Local Group. Image courtesy: Sloan Digital Sky Survey

Lenticular galaxies
Lenticular galaxies sit on the junction of the tuning-fork, between the ellipticals and the spiral-types, listed as type S0. They have a round or barred core, and are surrounded with a disc of stars, but there is no spiral arm structure. These galaxies have used up the gas for new star formation, and the stars themselves are usually very old, often twice as old as the Sun.



NGC2549, a lenticular galaxy. Image courtesy: Sloan Digital Sky Survey

Dwarfs and Giants
Just like stars, galaxies come in two size groups; giant galaxies and dwarf galaxies. Dwarf galaxies are generally composed entirely of old stars, at least three billion years old and more often closer to ten, with no new star formation due to a lack of gas. There may just possibly be a scattering of habitable systems in a few of them, but for the most part they're old (at least as old as the Sun, and usually about twice as old), low in heavier elements, and settling into a long and distinctly boring dotage. The only known dwarf galaxies to exhibit new star formation are the Magellanic Clouds, both of whom are irregular galaxies. Dwarf spirals and barred-spirals do exist, and they do exhibit limited starbirth, but nowhere near as much as in larger galaxies. Such spirals are generally less than a quarter the size of giants like the Milky Way, barely 25,000

lightyears across. Of the forty galaxies in the Local group, only three are giants. They are the Milky Way, the Andromeda spiral, and the Triangulum spiral.

The regions listed below aren't galaxies, but exist within (or near, in the case of globular clusters) a galaxy.

Globular Clusters
Globular clusters are dense, fuzzy balls of stars, numbering from tens to hundreds of thousands of members. They form themselves into spherical haloes around the cores of large galaxies; in fact, it was the distribution of globular clusters in the night sky that allowed astronomers to deduce the position of the Solar System relative to the galactic core. The stars are more closely packed towards the centre of the cluster, the core parsec containing perhaps as many as a thousand stars. They're not recommended for colonisation, since the stars are very old indeed. They were formed in the early history of the Universe, and are deficient in the heavier elements, which were not in existence at the time. Only gas giant planets, and icy, Pluto-like worldlets could form here.

System Types

Once you have decided in what part of the Galaxy (or indeed any other galaxy) your sector is located, it's time to determine the population of solar systems. To do that, we need to look at the kinds of stars that populate the Universe.

Below is a simple Hertzsprung-Russell (H-R) diagram, figure 2.
This diagram plots a star's luminosity against its colour (temperature). Astronomers quickly realised that almost all stars were grouped into a few distinct branches, with a small number of stragglers.

The large, sweeping branch that runs the length of the diagram indicates where the largest number of stars occur. This group is called the main sequence. Such stars are called main sequence stars or dwarfs (except for the class O and B stars, which are often called giants due to their size and brightness). The Sun is a member of the main sequence, as are the vast majority of other stars.

The group to the upper right of the main sequence indicates stars that are more luminous than dwarfs of the same spectral class. This is because the star is either more massive or more extensive than its main sequence kin. These stars are referred to as giants. Giant stars on this branch were originally main sequence stars, which have entered the red giant phase of their evolution. Red giants are by far the most numerous members of the giant population. A rare few are G-class yellow giants. They are recent departures from the main sequence, on their way to becoming red giants.

The thin, scattered group of stars running along the top of the diagram are the supergiants. They are very rare, but extremely noticeable; many of the brightest stars in Earth's sky are supergiants. Supergiants run the gamut of spectral classes from O to M, and can switch between classes during their short and spectacular lives. When they finally die, they destroy themselves in supernova explosions. Any system within eight parsecs will receive a deadly dose of radiation during such a supernova, the wavefront propagating at the speed of light. Nearby supernovae have been attributed to mass-extinction events, but the evidence is sketchy. It's more likely that a generation would die young, but mostly still manage to breed successfully.

Finally, the group sitting at the bottom-left of the diagram are the white dwarfs. They are the remnants of main sequence stars which have exhausted their nuclear fuel and shed their outer layers. The remaining object comprises most of the mass of the star, compressed into something the size of the Earth. It shines by the residual heat of its contraction, slowly becoming dimmer as its heat leaks away. Given enough time, a white dwarf will stop shining altogether, becoming a cold, dark object called a black dwarf. The Universe is presently not old enough for any white dwarfs to have evolved to this final state.

These branches on the H-R diagram are called luminosity classes, and form the most fundamental differences between stars. Cosmos uses these luminosity classes to split star systems into the three fundamental types of star system.

Systems come in three broad types: Giant systems, Major systems and Minor systems. GMs can use the stepped detail philosophy of Cosmos to sketch in any famous giant systems in a sector, then add major systems when required, then finally add in the minor systems if so desired. The three types are explained below.

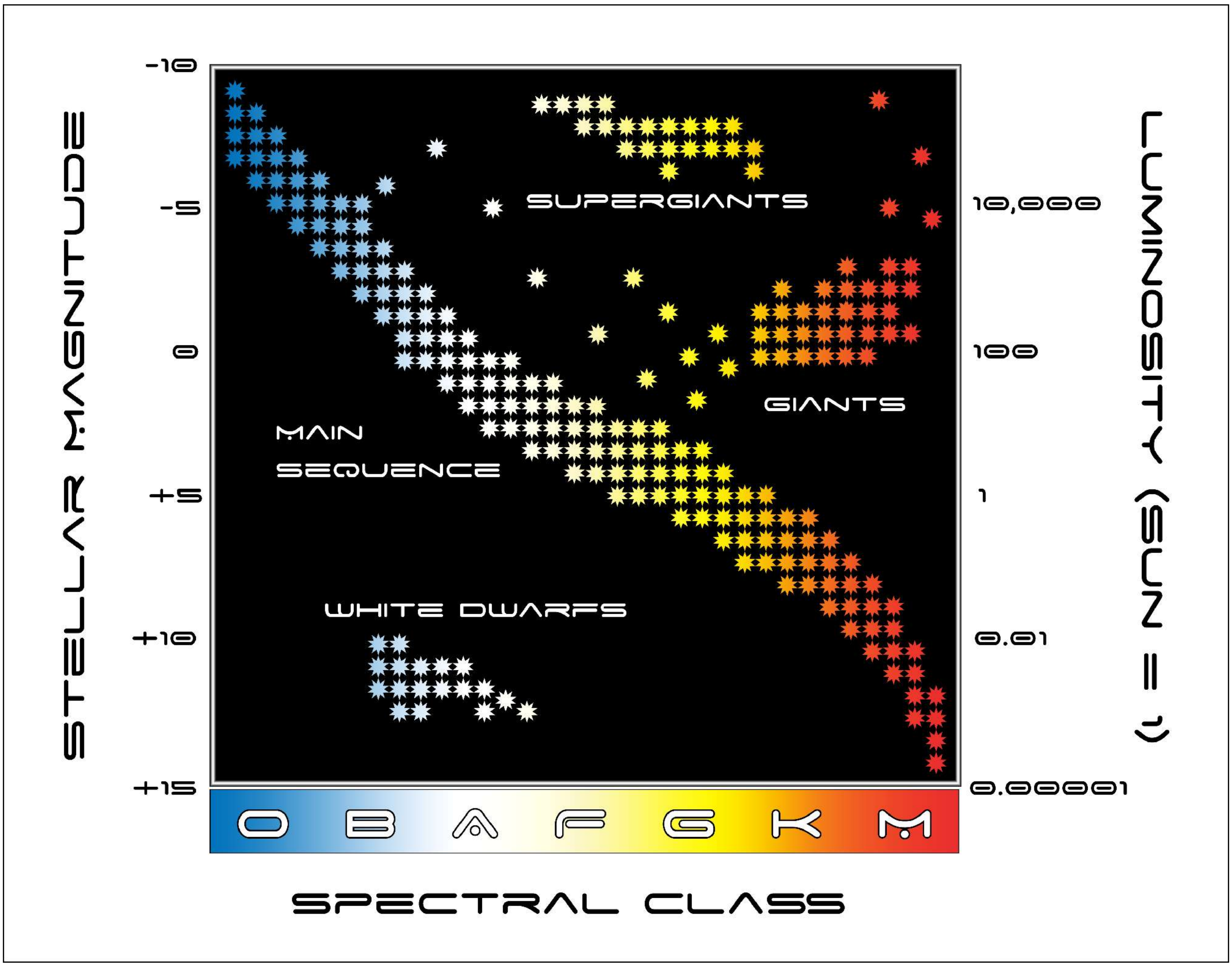


Fig. 2: H - R Diagram

GIANT SYSTEMS

Giant systems are the most rare. They comprise the brightest and often most massive stars. They're also often multiples. Such stars are near the ends of their lives, even the blue ones, since they're very short-lived. Giants and supergiants are two very different kinds of stars. Not all sectors will possess giant systems, although they are more populous within the spiral arms.

Giant stars are of spectral class G-M, and are main sequence stars that have begun to die. As they get older they get bigger and redder, and on average will live for no more than a further billion years in this phase. Class G yellow giants are transient stages of a star's life on its way to full red gianthood.

Sometimes main sequence O and B class stars are called giants, but strictly speaking there is no such thing. Cosmos, however, treats class O and B main sequence stars as giants due to their size, rarity and brightness. Spica and Regulus are examples of such “blue giants”.

Supergiant stars are strange and spectacular objects. They range across the whole scale of spectral classes from O to M, and actually fluctuate between the various colours several times during their short lives. When their core reactions are fast, they expand to become red supergiants, such as Antares and Betelgeuse, and when they slow down, they contract to become blue supergiants like Rigel and Alnitak. Intermediate stages include yellow supergiants, like Polaris and Capella. Supergiant stars end their lives as supernovae, and in most cases become neutron stars. However, a rare few in the 8-12 solar mass range become a rare class of white dwarf dominated by neon and oxygen.

A supergiant star can end its life as a supernova in any of its guises. Traditionally, the red supergiant was always considered to be the final phase, but supernova 1897A in the Large Magellanic Cloud came from a class B supergiant. This proved once and for all that supergiant spectral classes do not always have the same meaning as they do for lesser stars.

On average, one system in 250 is a giant system. Supergiants are even rarer. Roughly 2-3% of giant stars are supergiants.

Supergiants and class O/B main sequence stars are almost entirely confined to the spiral arms. This is because these are the places where such stars are born and they don't have time to migrate far from their birthplace during their mayfly lifetimes.

Major Systems

Major systems comprise the Main Sequence stars ranging from spectral class B to K, and also white dwarfs. They form the majority of easily-visible stars, and are also the most sought after for interstellar empire-builders. Life bearing planets are more likely to form amongst their ranks. Major systems are as often solitary as multiple, meaning that a small majority of Major stars are members of multiple systems.

The spectral classes show a broad range of mass, luminosity and lifespan. The Class A stars include such near neighbours as Sirius and Vega. They're rather more sedate than their class O and B kin, but are still short-lived powerhouses. Planets may form during the lifetimes of these stars, but the system will be full of debris throughout the star's short life.

Class F stars are yellow-white stars a little more massive and brighter than the Sun. They only live on average a third as long, so planets orbiting these stars have little time to evolve complex or intelligent life. They do present excellent colonisation opportunities, however. Nearby examples include Procyon and Beta Virginis.

Glass G includes our own Sun, as well as such nearby luminaries as Alpha Centauri A and Tau Ceti. They live for a good ten billion years on the main sequence, and are generally well-behaved as stars go.

Class K are the oft-overlooked orange majority of the Major systems. Epsilon Eridani and Sigma Draconis are amongst the closest such stars to our own Sun. K-class stars are very long-lived, and despite their lower luminosity may prove to be very popular suns for Earthlike planets.

Class D are the white dwarfs; some of the strangest and dimmest stars in the Universe. Although they are barely 1/10,000th the brightness of the original star that created them, they are intrinsically very hot; perhaps as much as 30,000 Kelvin at the surface. However, they are very small, on average the size of the Earth, with a gravity in excess of 10,000 g. Although they are so small and dim, they are counted amongst the primaries of Major systems due to their mass. In an average Major system, the white dwarf is often the heaviest member, since it evolved more quickly than its partner. This isn't always the case, though. For instance, Sirius is bright enough to possibly form a neutron star, but is still on the main sequence while its neighbour is a white dwarf. It would appear that when Sirius B became a red giant, Sirius A stole much of its gas, reducing its mass so that it became a white dwarf despite starting out as the more massive partner.

Minor Systems

Minor systems are made up of red dwarfs and brown dwarfs. They are by far the most numerous of all system types. There are arguments both for and against including minor systems in your sectors. For one, it adds completeness. Secondly, it also allows for tucked-away places off the beaten track for space pirates, research outposts and all kinds of other goodies. On the con side, they're not very good systems to live in, especially when you consider that many red dwarf stars are prone to random flare activity. Also, adding minor systems makes for a lot more work. If you're designing a gigantic interstellar empire, you may want to leave minor systems alone, at least to begin with. You can always go back and put them in later. Unlike the giant and major systems, minor systems are mostly solitary, with few multiples.

Class M red dwarfs are by far the most numerous of stars. They both outnumber and outmass all other stars in the Universe put together; nearby examples include Proxima Centauri, Barnard's Star and Kruger 60. However, red dwarfs aren't easy things to live near. Habitable worlds must orbit very close to these stars, with two major consequences. Firstly, it renders the planet vulnerable to any flare activity (a good fraction of all red dwarfs are prone to flare activity). Secondly, any planet close enough to the meagre candle of a red dwarf to be Earthlike has a locked rotation. That is one face is always turned to the star, and the other is always turned away. The planet's atmosphere will mitigate this, but the night side will be bitterly cold, and the perisolar point, the “hot pole”, will be dominated by a massive storm system that covers between a quarter and a half of the star-facing hemisphere.

Class L brown dwarfs are sub-stellar objects. Some glow a deep blood-red or magenta, filtered by dust grains of sodium or potassium in their atmospheres. Others shine purely in the infrared and are utterly dark to human eyes. Their grudging radiation is barely capable of holding off the chill of deep space for their nearest orbiting planets. Brown dwarfs only rarely associate with Major primary stars, and are only a little more common around red dwarfs.

Table S1: Stellar Properties

Type	Temperature	Radius (Sun = 1)	Mass (Sun = 1)	Luminosity (Sun = 1)	Lifetime (Million Years)
Giant Stars					
Blue Supergiant	40,000K	30	10 - 70	1,000,000	10
Yellow Supergiant	7,000K	100	10 - 70	200,000	10
Red Supergiant	4,000K	500	10 - 70	12,000	10
O	40,000K	10	50	100,000	10
B	20,000K	5	10	1,000	100
G	6,000K	10	1 - 4	50	1,000
K	4,500K	30	1 - 4	200	1,000
M	3,000K	100	1 - 4	1,000	1,000
Major Stars					
A	8,500K	1.7	2	20	1,000
F	6,500K	1.3	1.5	4	3,000
G	5,700K	1	1	1	10,000
K	4,500K	0.8	0.7	0.2	50,000
D	<80,000K	<0.01	<1.4	<0.01	25,000*
Minor Stars					
M	3,200K	0.3	0.2	0.01	200,000
L	<2,700K	0.12			-

*25 billion years is the time it takes for a new white dwarf to cool to ambient temperature. The Universe is currently believed to be only 13.7 billion years old.

Now we can assign Giant, Major and Minor systems according to our sector type. Roll on the appropriate list below to determine how many systems of each type your sector has.

Inter-Spiral sectors:
Roll d8-7 for Giant systems
Roll 2d6+12 for Major systems
Roll 4d20+36 for Minor systems

Spiral arm sectors and galactic rings:
Roll d4-2 for Giant systems
Roll 2d6+12 for Major systems
Roll 4d20+36 for Minor systems

Ring galaxy voids:
Roll 2d4 for Major systems
Roll 3d8+8 for Minor systems

Open clusters:
Roll 3d20 for Giant systems
Roll 8d20+20 for Major systems
Roll 3d100+100 for Minor systems

> The number of systems in an open cluster remains the same, regardless of the actual volume of the cluster. It is probably wise to disregard Minor systems when generating an open cluster, unless the GM has a specific locale in mind. Furthermore, open clusters are too young to contain G-M class giant stars; the only Giant-class stars available are supergiants and blue giants.

To determine their locations on the map, roll d12 three times, These figures represent the location of the system in the x,y and z axes. An example is shown in the Mapsheets appendix. This section also shows how to represent binary stars and other multiple systems, as well as how to represent a cubic parsec inhabited by more than one system. Don't be concerned if a system ends up sharing a cubic parsec with another, since in nature they can get pretty close. In about a million years' time, a red dwarf called Gliese 710 will pass within a lightyear of the Sun, probably disturbing the Oort comet cloud and thereby potentially causing a mass-extinction event on Earth.

The next stage is to determine the stellar primary of the system. At this point it's not important whether or not the system is a solitary, a binary or a multiple system.

This first star is assigned the “primary” of the system; it decides the “flavour” of the system from this point on. All secondary stars, however many, are generated from the secondary lists.

-nb: To generate Giant systems in an open star cluster, use the Open Cluster list below:

Giant System Primary
Roll d100:

01-72	Red Giant
73-98	Blue Giant
99-00	Supergiant

Giant System Primary (Open Cluster)
Roll d20:

1-19:	Blue Giant
20:	Supergiant

-To select the precise kind of star, roll on the appropriate list below:

Red Giant Primary
Roll d100:

01-20	G-class yellow giant
21-94	K-class red giant
95-00	M-class red giant

Blue Giant Primary
Roll d1000:

001	O-Class blue main sequence
002-000	B-Class blue-white main sequence

Supergiant Primary
Roll d8:

1-3	O/B class blue supergiant
4	A-G class yellow supergiant
5-8	K-M class red supergiant

Major System Primary
Roll d100:

01-04:	A-class white main sequence
05-16:	F-class yellow-white main sequence
17-35:	G-class yellow main sequence
36-75:	K-class orange main sequence
76-00:	D-class white dwarf

Minor System Primary
Roll d10:

1-9	M-class red dwarf
0	L-class brown dwarf

Solitaries, Binaries and Multiples

Star systems come in three broad configurations. They are solitary systems, binaries and multiples. When minor systems are counted, solitary systems form the majority, with binaries a little less common. Multiples form a small minority of star systems, Trinary systems are overwhelmingly more common than other, larger multiples. It should be noted that the more stars exist in the system, the more massive (and, consequently, younger) it is. In most cases multiples greater than trinary are not very stable. Multiple systems only survive if they're hierarchical. That is, they act as binaries with increasing distances so that each subset of the system behaves as a solitary or binary. For instance, the Alpha Centauri system is a trinary composed of a binary system with the third member orbiting the inner pair at a greater distance. This is the most common configuration of a trinary, but in rare cases a low-mass binary orbits a higher-mass primary star.

Quaternary systems consist of two binary pairs that themselves act like members of a greater binary.

Quinary, sernary and greater systems are very rare. Gravitational co-orbiting associations have been recorded as having up to eight members. In all cases, however, these larger groups of five or more stars are composed of bright, young, massive stars. In some cases they are associated with nebulae.

Secondary Stars

To generate the system's secondary star or stars, look up the system type and roll on the appropriate list below:

Supergiant Systems (Red Giants use Major column)
Roll d20:
1-4 Solitary
5-10 Binary
11-15 Trinary
16-19 Quaternary
19-20 Quinary or greater; roll d4+4 to determine precise number

Major Systems
Roll d100:
01-42 Solitary
43-85 Binary
86-97 Trinary
98-00 Quaternary

Minor Systems
Roll d20:
1-15 Solitary
16-19 Binary
20 Trinary

The number of stars in a system is called its conformation. The stars in a binary system can be separated by anything from a few million kilometres to several thousand AU. If the stars are very close, planets will orbit them as a single object. In more distant pairs, stable planetary orbits can exist in a zone up to one-third of the distance between them. Very distant pairs are more like two separate systems.

To determine the nature of secondary stars, look up your system type and roll on the appropriate list below:

Giant System Secondaries

Red Giant primary
Roll d6:
1-4: Major Secondary (roll on Major System Primary list for type)
5-6: Minor secondary (roll on Minor System Primary list for type)

Blue Giant primary
Roll d10:
1-7: Blue Giant secondary
8-9: Major Secondary
0: Minor Secondary

Supergiant primary
Roll d8:
1-5 Supergiant secondary
6-8 Blue Giant secondary

Major System Secondary
Roll d6:
1-4: Major Secondary (roll on Major System Primary list for type)
5-6: Minor Secondary (roll on Minor System Primary list for type)

Minor System Secondary*
Roll d10:
1-9 M-class red dwarf
0 L-class brown dwarf

*Brown dwarf primaries may only ever have a brown dwarf secondary.

UNUSUAL OBJECTS

As well as stars, the GM may wish to include unusual objects in his or her sector. All of these objects are very rare. Unusual objects include dust and gas clouds, plus such stellar remnants as planetary nebulae, neutron stars and black holes.

Nebulae
Nebulae come in three types: emission, reflection and dark. Emission nebulae are often found in association with newly-formed stars in open cluster, which cause the gaseous nebula to glow by exciting its atoms with their UV radiation. This is similar to the way in which neon signs work. They are approximately the same size as the cluster they are associated with. Although they appear colourful in photographs, these are the result of long exposures. To the naked eye, they glow with a milky, colourless radiance.

Reflection and dark nebulae are basically the same objects; molecular dust clouds. Whether they are dark or glowing depends on the geometry between any nearby stars, the nebula and the observer. If the star is behind the nebula, its light is reddened or extinguished completely, and the nebula looks dark. If the star is in front of the nebula, it will appear to shine by reflected starlight, Extending for on average thirty parsecs (although they can get bigger), the concentration of dust is still sparse enough to be safely navigable by spacecraft. Some isolated pockets may be dense enough to present a hazard, but for the most part they are more rarefied than a laboratory vacuum.

Planetary Nebulae

Despite their name, planetary nebulae are not nebulae and have nothing to do with planets. As a red giant finally dies, it expels its outer layers under pressure from a powerful stellar wind coming from the core. This core collapses to become a white dwarf, and it's this collapse that fuels the hypersonic wind. The rest of the star is blown away like a soap-bubble, and glows in a similar way to an emission nebula. If the star is alone, the nebula will be roughly spherical. If the system is binary or multiple, the nebula takes on a more "bipolar" shape, resembling an hourglass or Christmas-cracker. Planetary nebulae aren't much denser than interplanetary space, so normal space travel is possible in these hauntingly beautiful systems. Planetary nebulae are no more than 1/3 parsec across, and generally only last for a few thousand years.

Supernova Remnants

While similar in basic mechanics to planetary nebulae, they are thrown off at much greater velocity by the force of a supernova explosion. They extend for a parsec or so before being assimilated into the interstellar medium.

Neutron Stars

When a star can no longer sustain itself with nuclear fusion reactions, its core collapses suddenly. For most stars, the star compresses until the electron pressure of each atom is all that supports the star against gravity. These are white dwarfs. The matter is so dense it has become degenerate; that is, the more massive the object gets, the smaller it gets instead of larger. However, electron pressure can only sustain a mass of 1.4 solar masses. If the star is heavier, even electron pressure can't support it and the core collapses still further until the electrons and protons are forced to merge, becoming neutrons and free quarks. A massive rebound effect then throws off the star's greater mass in a supernova explosion. The remaining core is a neutron star. Such objects are generally no more than four or five kilometres across, the size of a city. They revolve several times per second, some as much as a thousand times per second, and carry immense magnetic fields, often in excess of a million gauss. This is enough to distort the shape of atoms and pull molecules apart into something called "magnetic soup". If that weren't enough, the surface gravity is hundreds of billions of g. Powerful radio beams blaze out from the neutron star's magnetic poles, and when seen from Earth are called pulsars.

Black Holes

Sometimes not even the particle pressure from compressed neutrons is enough to hold back the weight of a collapsing star. The star continues to shrink until it becomes infinitely dense and infinitely small. Surrounding this singularity is a region of space where the object's escape velocity is greater than the speed of light. Because nothing can travel faster than light, this region is called the event horizon. No information can cross back into normal space once the horizon has been passed, and we cannot know anything about events that transpire beyond it.

As a black hole moves through space, it can only be spotted by noting how its gravity affects starlight, distorting it like a glass lens. That is, until it feeds. Matter caught by the black hole's gravity is dragged into the hole in a spiral course. Because the black hole is very small, matter piles up into an accretion disc. Friction heats the matter thousands or even millions of degrees, and the structure shines as brightly as a giant star, especially in X-rays. Some of the matter is accelerated so strongly that it manages to escape from the black hole, and is launched away in twin streams from the black hole's poles. These jets have been clocked at almost the speed of light.

As new theories of quantum gravity are being explored, black holes are on shakier footing than they used to be. Now, instead of black holes, we may have MECOs (Magnetic Eternally-Collapsing Objects) or dark energy stars. However, all of the truly strange things happen beyond the event horizon, so to the outside world these deadly objects are pretty much the same.

All of the above objects are very rare, and should be used sparingly by the GM. The nearest clusters and bright nebulae are over fifty parsecs from the Solar System, and the nearest black hole is over three hundred parsecs away. Dust clouds are largely confined to the spiral arms.

Fig. 3: Small Stars Compared to Sun

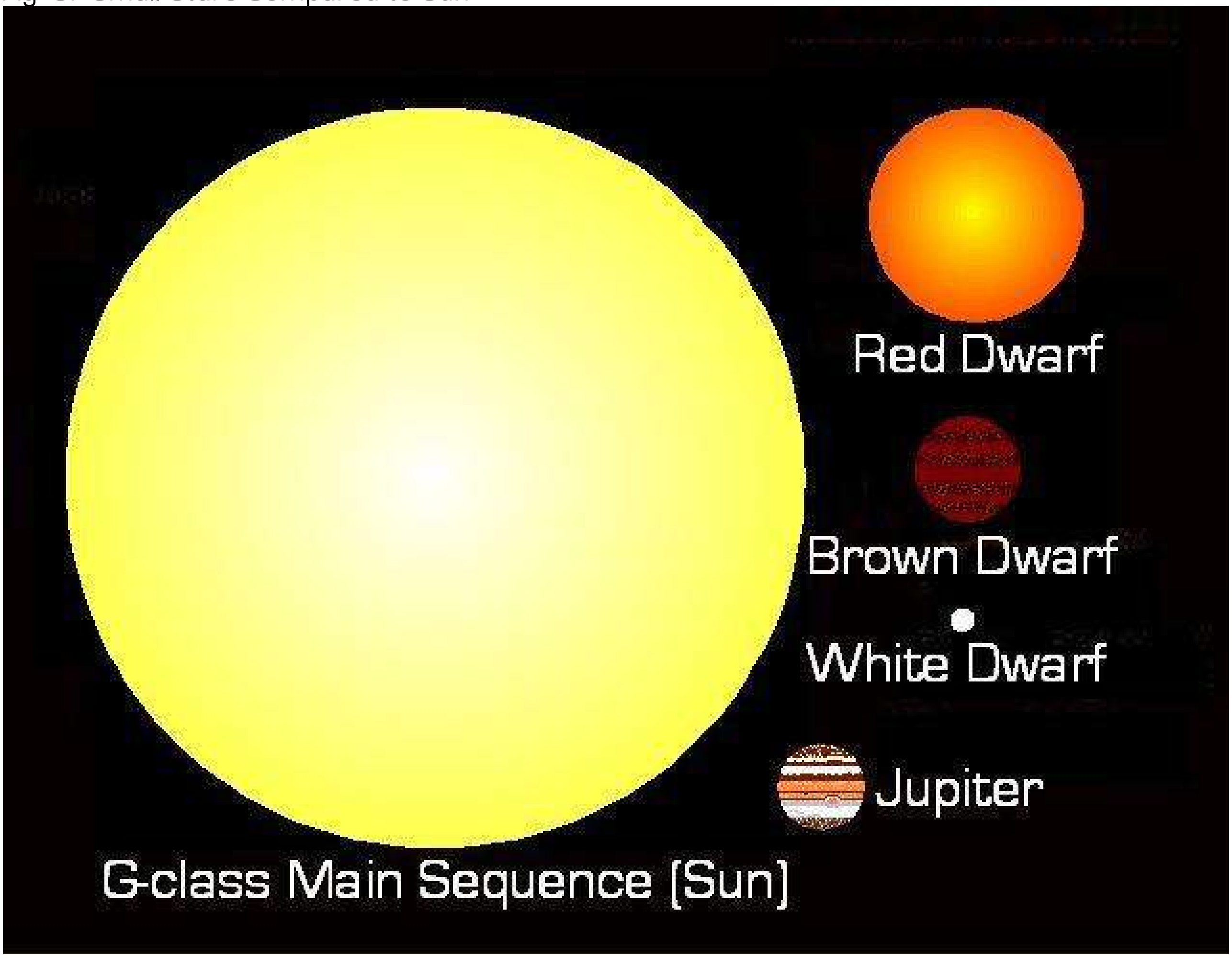


Fig 5a: Large Stars Compared to Sun

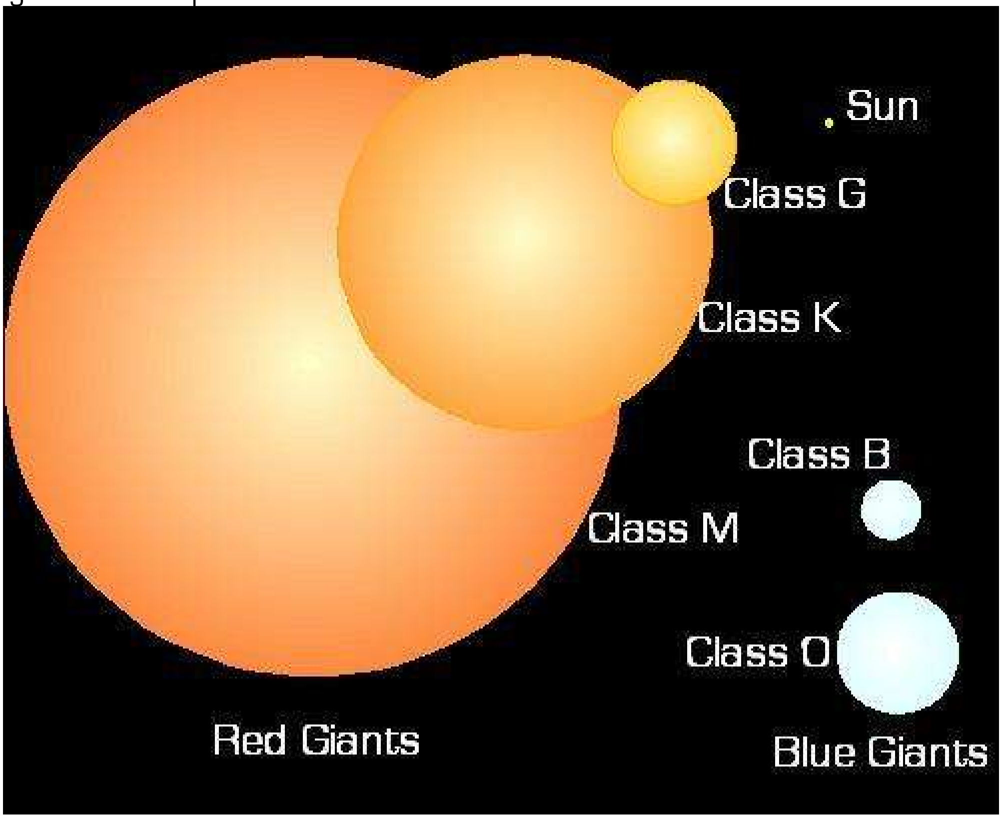
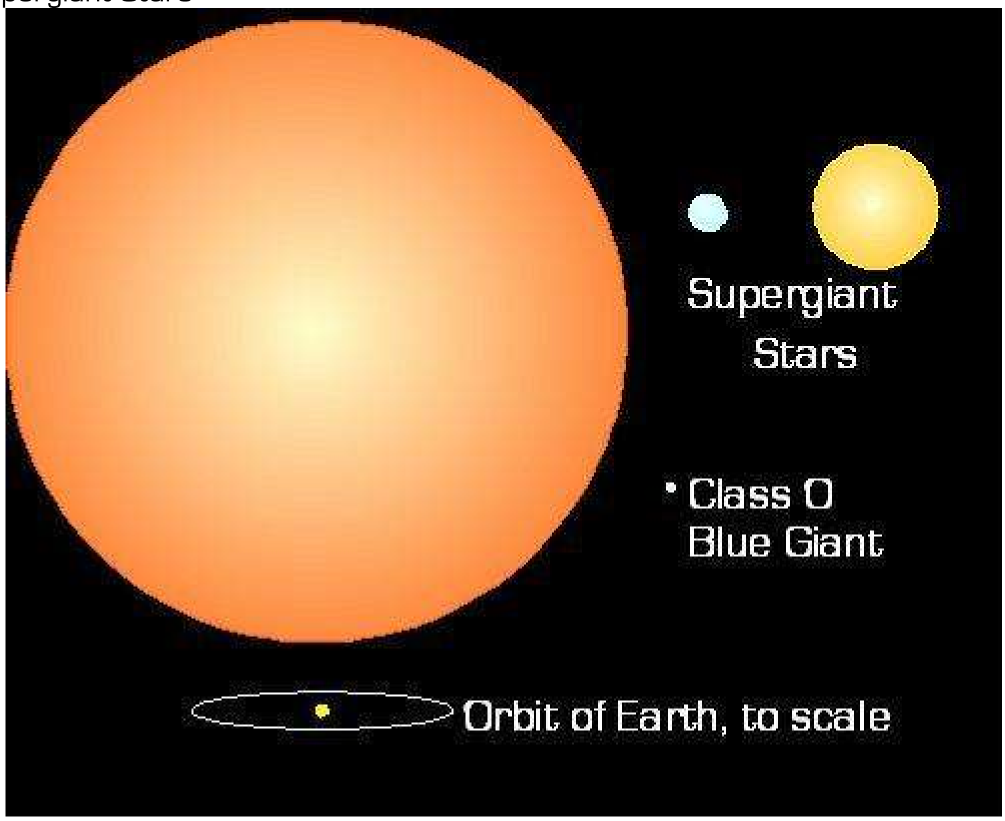


Fig 5b: Supergiant Stars



Chapter 2: Planets

The basic structure and content of a planetary system are dependant on three factors; the star type, its conformation and the system's age. Star type for your system has already been determined in chapter 1. Basic conformation has already been set too, but the final stage of conformation is the province of the planets.

System Age

A star undergoes many changes during its life, and the system changes with it. These changes and the states between them are defined by the age class. There are five age classes: Newborn, Young, Mature, Post-Stellar and a new type, Revenant.

Newborn:
Newborn systems are the chaotic, crashing beginnings of planetary formation. Systems ten million years old or less are classed as Newborn. Supergiants and class O blue giants spend their entire, brief existences in the Newborn stage and never grow beyond it. The star Rigel in Orion is a good example. They are characterised by discs of dust and gas, filled to bursting with asteroids and other protoplanetary bodies called planetesimals that have yet to achieve their final mass and settle down into stable orbits. Newborn systems are extremely dangerous due to the high matter density.

Supergiant and blue giant stars are severely depleted of gas, forced out of the system by the ferocious radiation of the young star. Such stars can even drive gas away from neighbouring systems within a star-forming region, and are the main reason why non-jovian systems exist at all.

Cosmos does not generate large bodies within these systems as they are extremely unstable and the very large number of sizeable objects literally varies from day to day. To all intents and purposes, a Newborn system consists of an inner asteroid belt that segues into a transplanetary belt at the Outer/Deep system border (see System Generation, below). It may also contain other small bodies and the beginnings of jovian worlds as best suits the purposes of the GM, but no bodies of selenian or larger size. The orbits of these bodies cannot be calculated, and are extremely unpredictable.

An important thing to bear in mind is that most Newborn systems will be within open star clusters or even embedded in emission nebulae.

Young:
A young system is less than a billion years old. The planets are generally stable in terms of mass during this time, but the density of loose material is still hundreds or even thousands of times greater than in a mature system. After this catastrophic era of planetary formation (often referred to as the Imbrian Age by astrophysicists), the system's planets have swept up most but not all of the loose bodies.

Their sizes may be fairly set, but their orbits are still often in a state of flux. Giant planets in particular can often set up cycles of interference that can wreak havoc for a time. In our own system during this age, the outer planets were somewhat closer together, closer to the Sun and even perhaps in a different order (there's a 50:50 chance that Neptune actually formed inside Uranus). However, because Jupiter and Saturn wandered into a 2:1 orbital resonance (that is, Jupiter completed two orbits for every one of Saturn's making them line up at close approach every two Jovian years), they interfered with each other and a chaotic situation ensued, eventually forcing the ice giants outward into their current orbits.

For a planet about the size of the Earth, the surface becomes cool enough to support liquid water after about a quarter of a million years. Even larger planets can finally host liquid water after the first billion years.

The Young period of a system's history generally ends in a cataclysmic spasm of massive impact activity, as the planets reach their final sizes, their orbits stabilise and the last of the largest material is removed from unstable orbits. Similarly, the planets have achieved their final, stable orbits and there will be little change in the ages to come.

Class B blue giants and Class A main sequence stars do not survive past the Young age category.

Mature:
As the star settles into a sedate middle age, so do its planets. Orbits are stable during this period, and the massive bursts of impact activity are things of the past. Life often begins at the opening of this phase where the environment permits, just as it did on Earth. This phase can last for billions of years. Main sequence stars of class F to M enjoy extensive mature phases.

When stars enter the last tens to hundreds of millions of years of their lives, they become red giants. Inner planets may be engulfed and vapourised as the star's luminosity and size increase several hundred fold. Its outer worlds may even enjoy a brief balmy spell. When assigning planets, generate the system as though it is a Mature system, but be sure to note which planets have been destroyed by the expansion of the giant.

Post-Stellar:
To all things there is a time, even stars. A red giant undergoes increasingly rapid periods of expansion and contraction, until finally a powerful stellar wind from the collapsed core drives off the outer layers to form a planetary nebula. The surviving planets are scoured by intense particle winds and UV light from the collapsed core; a new white dwarf. This is a post-stellar system. Gas worlds will have been denuded of some of their giant atmospheres, and the system will be stripped of volatiles. Planetary surfaces may be much changed from their earlier days, due to partial melting. However, even this depleted state isn't the most odd thing that can happen to a system. A small proportion of post-stellar systems are called Revenants.

Revenant:
Massive stars destroy themselves spectacularly in a supernova explosion. For a brief period of a few weeks they manage to outshine the entire galaxy. Inner planets, if they exist, are destroyed utterly, and gas worlds are stripped of much or even all of their atmospheres. Many such stars never managed to form proper planetary systems in the first place, and the planet formation process continues afterward. The first solar system discovered beyond our own was such a revenant system.

To determine your system's age, check its type and roll on the list below:

Supergiant	Always Newborn
Class O Main Sequence	Always Newborn
Class B Main Sequence	Roll d10; 1 = Newborn, 2 – 0 = Young
Class A Main Sequence	Roll d100; 1 = Newborn, 02 – 00 = Young
Class F Main Sequence*	Roll d6; 1 – 2 Young, 3 – 6 Mature
Class G Main Sequence*	Roll d10; 1 = Young, 2 – 0 = Mature
Class K Main Sequence*	Roll d100; 01 – 02 = Young, 03 – 00 = Mature
Class M Red Dwarf*	Mature**
Class D White Dwarf/Planetary Nebula	Post-Stellar
Neutron Star/Supernova Remnant	Revenant

*Newborn systems should be specifically placed by the GM, as they represent such tiny proportions of these stars' lifetimes. Newborn systems are the default in open clusters and emission nebulae.
** Red dwarf systems always default to Mature. Outside of open clusters and nebulae, only one in 200 red dwarfs is Young, and only one in 2,000 is Newborn.

System Configuration

When generating the system back in chapter one, we discussed the various types of binary and multiple system that are possible. The precise interrelationships of the stars in a binary or multiple system are vital to the potential for planets, and so we need more information.

As was discussed before, multiple systems are stable when they are hierarchical. Solitary systems are of course the simplest, but binary systems are fairly simple, too. Binary stars orbit the centre of mass between the two stars. The centre of mass is called the barycentre. The stars in a binary or multiple system all orbit the barycentre in elliptical orbits with the barycentre at one focus. Each star in a binary pair lies opposite the barycentre from the other at all points in the orbit.

Determining the barycentre is very simple. Each member of the binary is at either end of an imaginary bar that transects the barycentre of the system. Each member of the binary sits at a distance from the barycentre proportional to mass relative to its partner, like weights on a balance scale.

The distance of each star from the barycentre is decided by two numbers. The first is the semi-major axis, or average separation, of the pair. This is then modified by the mass ratio of the stars.

Example: A binary star system is composed of F-class and G-class stars. Their average mass ratio is 1.5-1. The F-class star will therefore be 40% of the separation distance from the barycentre. The G-class will be 60% of that distance, on the far side from the F-class star. If the average separation of the two stars is 10AU, that means that the F-class star orbits at 4AU from the barycentre, and the G-class star orbits 6AU away from it. Since the members of a binary always orbit directly opposite each other, the two distances will add up to the total separation.

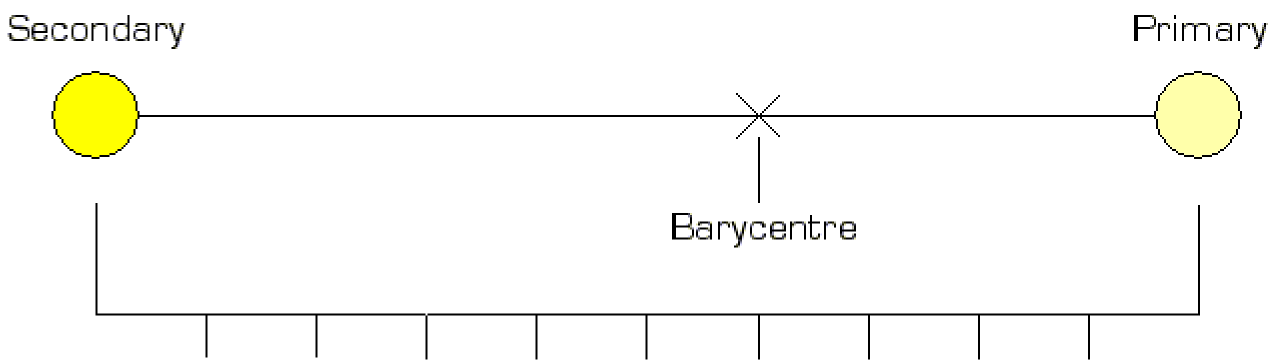


Fig. 5: Binary system

Of course, binary stars have fairly elliptical orbits, so they swing closer to and further from each other during their cycle. However, the distance ratio always remains the same, no matter the separation, and the two stars are always directly opposite each other relative to the barycentre.

For multiples, such as a trinary system, the configuration is always that of a binary being orbited in turn by a solitary (or another binary in the case of quaternary systems). Most often the binary is the heavier member, but not always. In such a system, the binary pair is treated as a single body and becomes one member of a binary, with the third star being the second member of the binary. Larger multiples always devolve into solitary and binary units.

To take our example further, let's add a red dwarf as a third member. The inner binary now becomes a single object of 2.5 solar masses, with the 0.2 solar mass red dwarf orbiting at some distance at least three times that of the inner pair, let's say 100 AU. That gives us a ratio of 25-2, which means that the barycentre between these two bodies lies 92.5 AU from the red dwarf and only 7.5 AU from the inner binary.

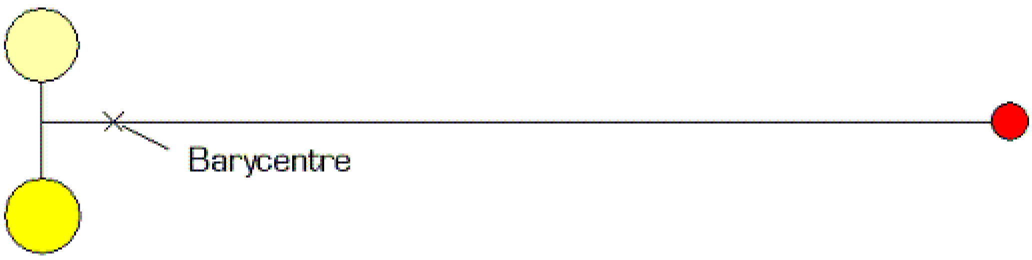


Fig. 6: Trinary System

Binary Star Separation, Roll 2d6

2	2d8 million kilometres apart; roll d20. On a 20, system is a contact binary in which the stars are separated by less than a stellar diameter and which share an atmosphere. Intense radiation and particle winds render the system unsuitable for life or colonisation, although shielded bases may exist.
3	1d12/10 AU apart
4 – 5	1d20 AU apart
6 – 8	2d6 x 10 AU apart
9 – 10	1d12 x 100 AU apart
11	1d12 x 1,000 AU apart
12	1d6 x 10,000 AU apart

When determining the separation of sub-pairs in a greater multiple, use the two lists below. The first list is used to determine the separation of the sub-pairs in the multiple system. The second is used to determine distance between the sub-pair and the solitary or second sub-pair, if the system is a quaternary.

Sub-pair separation, roll 2d4

2	2d8 million kilometres apart; roll d20. On a 20, system is a contact binary in which the stars are separated by less than a stellar diameter and which share an atmosphere. Intense radiation and particle winds render the system unsuitable for life or colonisation, although shielded bases may exist.
3	d12/10 AU apart
4 – 5	d20 AU apart
6 – 8	2d6 x 10 AU apart

Trinary/Quaternary separation, roll d6

1 - 3	d12 x 100 AU apart
4 - 5	d12 x 1,000 AU apart
6	d6 x 10,000 AU apart

If you are designing a quinary, sernary, or larger multiple, use d12 x 100 AU to separate the first two pairs, then d12 x 1,000 AU to determine the separation between those four stars and your next solitary or sub-pair. Larger systems will then use the final value of d6 x 10,000 AU to determine the distance between the inner six and the last members of the group.

Stars and Planets

Naturally, a system with multiple stars charging all over the place can be a perilous environment for planets, and for many years astronomers believed that binaries and multiples would be utterly devoid of planets. Stars in a binary or multiple system create chaotic gravitational tugs that build up over time and catapult planets out of the system entirely, or capture and devour them. However, planets can survive in certain safe zones. The safe zones are one-third or less of the minimum distance between stars, or three times or more the maximum distance. If the projected orbit of a planet wanders out of the safe zones, it is lost. If the Prime Jovian is lost in this way, use the non-jovian orbit generator.

Orbital Temperature Zones

While the density regions are determined by the mass of the star, the temperature zone owes everything to a star's luminosity. When you consider that a star with a tenth of the Sun's mass can be only a ten-thousandth as bright, and a star ten times more massive can be tens of thousands of times brighter, it's easy to see that temperature zones can vary wildly from star to star.

Supertorrid

The supertorrid zone is extraordinarily hot. It includes epistellar orbits around sunlike stars, and can be described as the region where the ambient temperature ranges from several hundred to over two thousand Kelvin. At the inner edge of the zone, solid bodies are hard-pressed to survive in an environment where even iron is more commonly found as a vapour. Toward the outer edge, temperatures edge toward the reasonable and more commonly found molecules can exist in gaseous state. Mercury patrols the outermost edge of Sol's supertorrid zone.

Torrid

The torrid zone covers the region of space where it is impossible for water to exist in liquid state on planetary surfaces. Life in such blazingly hot regions is all but impossible, but these worlds are often rich in metals and other geological wonders. Venus inhabits the torrid zone.

Temperate
The temperate zone is the place where many, but not all, life-bearing planets are found. It's relatively easy for water to find surface regions where it can exist as a liquid, and in doing so allow life to exist. Lying in the temperate zone is no guarantee of a pleasant climate, however; just the potential. Earth and Mars lie within the temperate zone.

Frigid
Beyond the balmy climes of the temperate zone lies the frigid zone. Surface water cannot exist as a liquid, and can be as hard as rock on these worlds. Class 1 environments are only possible under extreme conditions, such as tidally-induced volcanism, massive atmospheres or artificial environments. Life, if it can exist as all, has to be inventive to survive the bitter cold. Most terrestrial bodies have a greater ratio of ices to rock amongst these worlds than in the warmer regions. As a result, bodies are often bigger than their mass would suggest. Jupiter dominates the frigid zone of Sol.

Superfrigid
The superfrigid zone is a realm of deep cold, where the temperature never rises above 100 Kelvin. In extreme environments, even nitrogen can freeze solid and turn to snow. Sol's superfrigid zone is dominated by Saturn and the ice giants Uranus and Neptune.

Table P1: Temperature Zones

Spectral Class	Supertorrid Zone	Torrid Zone	Temperate Zone	Frigid Zone	Superfrigid Zone
Class B (giant)	0 – 6.5AU	6.5 - 16AU	16 - 40AU	40 – 160AU	160+AU
Class G (giant)	0 – 3.3AU	3.3 – 8.5AU	8.5 - 21AU	21 – 80AU	80+AU
Class K (giant)	0 – 5AU	5 – 12AU	12 – 30AU	30 – 120AU	120+AU
Class M (giant)	0 – 6.5AU	6.5 – 16AU	16 – 40AU	40 – 160AU	160+AU
Class A (major)	0 – 1.5AU	1.5 – 3.7AU	3.7 – 9AU	9 – 36AU	36+AU
Class F (major)	0 – 0.6AU	0.6 – 1.5AU	1.5 – 3.8AU	3.8 – 16AU	16+AU
Class G (major)	0 – 0.35AU	0.35 – 0.8AU	0.8 – 2.5AU	2.5 – 10AU	10+AU
Class K (major)	0 – 0.1AU	0.1 – 0.25AU	0.25 – 0.65AU	0.65 – 4AU	4+AU
Class D (major)	-	-	0 – 0.01AU	0.01 – 0.05AU	0.05+AU
Class M (minor)	-	0 – 0.06AU	0.06 – 0.15AU	0.15 - 0.38AU	0.38+AU
Class L (minor)	-	-	0 – 0.01AU	0.01 – 0.05AU	0.05+AU

SYSTEM GENERATION

Once you have selected a system to begin, it's time to generate its planets. In some systems, like our own, the system is dominated by a giant gas planet. These behemoths dominate the system they inhabit, outweighing all other planets put together and determining the very geometry of the system. Such a planet is called the Prime Jovian, and Jupiter is the prime jovian for our solar system. However, not all systems have such a planet. Sky surveys have so far found the telltale discs of dust that betray potential planetary systems around almost all sunlike stars. However, jovian planets have only been found around 15% of them. Maybe they just haven't been found yet, or or maybe the radiation of nearby powerful stars blew away their gaseous envelopes while they were forming in a stellar nursery (this process has actually been observed by telescope). If this is the case, then most giant stars won't have any jovian planets at all, and many smaller stars will have been affected by giant neighbours. This doesn't affect dust, however, so solid terrestrial planets should be spared, although with probably little water around. Check your system type against the list below and roll to see if it is a jovian or non-jovian system.

Giant System, Roll d12:
1 - 11 = Non-Jovian system, 12=Jovian system

Major & Minor System, roll d4:
1-3 = Non-Jovian system, 4= Jovian system

All Neutron Star systems are Non-Jovian

If your planet has no prime jovian, see “Systems Without Jovian Planets” on page 29.

Next, determine the number of planets in your system. Check your system type against the short list below and roll the appropriate dice.

Total Number of Planets:
Prime jovian system 2d8
Non-jovian system 3d8

Generating Planetary Orbits

Generating a planetary system begins with the allocation of the Prime Jovian, which will determine the orbits of most other planets in your system. Roll a d6 on the table below to determine the type and mass of the Prime Jovian.

Table P2: Prime Jovian Mass, roll d6

	Blue Giant	Major and Red Giant	Red Dwarf	Brown Dwarf
Jovian, 0.3Mj	-	1	1 - 2	1 - 3
Jovian, 1Mj	1 - 2	2 - 3	3 - 5	4 - 5
Jovian, 3Mj	3 - 4	4 - 5	6	6
Transjovian, 10Mj	5 - 6	6	-	-

Mass isn't particularly important right now, but will become so later. Now to determine the orbit of the Prime Jovian. Current understanding of planet formation and the most advanced models allow the Prime Jovian to appear anywhere from an epistellar orbit to the outer edge of the planet-forming region. Roll on the list on the next page to determine where in the system the prime jovian is located.

Roll (d8)*	Result
1-2	**Epistellar orbit** – planets can't form in this orbit, but are dragged inwards by friction with the early protoplanetary disc.
3-4	**Inner system orbit** – planets often form here easily. There's not so much material as in the middle system, but it's closer together and easy to form into planets.
5-7	**Middle system orbit** – the protoplanetary nebula is at its thickest here, and the largest planets often form in this region, though they can end up anywhere.
8	**Outer system orbit** – This represents the outer limit of the planet-forming region. Beyond this area there is still a lot of material, but it's too far apart to form into planets.

* Roll d6+2 instead of d8 in Giant systems

Beyond the Outer system is the Deep system. Both planets and planetoids can exist here. Planetoids form in this region naturally, but never grow large enough to become true planets. Planets that orbit in this region have been scattered thee by perturbations from inner planets. Uranus and Neptune are good examples of planets scattered into the Deep system by such activity. Because of this, the Prime Jovian is never found in a Deep orbit. In fact, jovian-mass planets are never found in the Deep system.

To determine the precise orbit of the prime jovian, check the appropriate column on the table below and roll the appropriate die:

Table P3: Prime Jovian Orbits

Epistellar (d10)		**Inner (d10)**		**Middle (d8)**		**Outer (d6)**	
1	0.02	1	0.2	1	2.5	1	7
2-4	0.04	2	0.3	2	3	2	8
5-6	0.07	3	0.4	3	3.5	3	9
7-8	0.1	4	0.5	4	4	4	10
9-0	0.15	5	0.7	5	4.5	5	11
		6	0.9	6	5	6	12
		7	1.1	7	5.5		
		8	1.4	8	6		
		9	1.7				
		0	2				

Some planets will exist inside the Prime Jovian, while others will orbit outside, but all will have their orbits shaped by the prime jovian. See below and roll to determine the number of inner planets; the rest of the planets will orbit outside the Prime Jovian.

Number of planets orbiting inside the Prime Jovian:
If the prime jovian is in the epistellar or inner system, roll d4-2
If the prime jovian is in the middle or outer system, roll d4+1

To determine the orbits of the inner planets, roll as though placing the prime jovian. Naturally, any results that would generate planets outside the prime jovian should be ignored and re-rolled. If the Prime Jovian orbits at 0.04 AU, there can only be a single inner planet, orbiting at 0.02 AU, which will be a selenian, terran or vestan. Ignore any jovian planets that are generated and re-roll.

Once you've generated the inner planets, generating the outer ones is simple. Because the Prime Jovian acts as a cosmic shepherd, the rest of the planets orbit in proportions of the Prime Jovian's orbit. Multiply the orbit of the Prime Jovian by 1.3 + (d12 x 0.1) This is the orbit of the next planet. Take that planet's orbit as a new starting-point and roll again to generate the next planet's orbit. Continue until you've assigned all of the planets.
Note: If the Prime Jovian is an epistellar planet, then treat its starting distance as 0.2 AU for the purpose of generating outer planets.

Systems Without Jovian Planets

If you have generated a non-jovian system, then the population of that system won't have been sculpted by the antics of gas giant planets. There are generally more planets in the system, but of rather less mass.

Setting the Foundation:
Instead of a Prime Jovian, non-jovian systems begin with the Foundation Planet. This is the innermost planet, and forms in an inner orbit, probably quite close to the star. The lack of jovians means that the epistellar orbits will be empty, as nothing can actually form there and the lack of bigger planets means nothing can wander in.

The orbit of the Foundation Planet is determined using the Inner Orbit column on the table above. Generate the rest of the planets orbiting outside the Foundation Planet just as with those orbiting outside a Prime Jovian.

Generating Planet Types

What kind of planet occupies which orbit depends primarily on where that orbit is in the system. The ambient temperature is an important factor, as is the availability of material and the system's age. Finally, the system's status as jovian or non-jovian is also vitally important.

The Deep System
Beyond 12AU lies the Deep system; this is a region where normal planetary formation is impossible, since the protoplanetary disc is too spread out to coalesce. However, planets can still be found here. The reason why these planets end up in the Deep system is simple scattering. During the Newborn and Young phases, planetary orbits are in flux and highly susceptible to change. Close encounters or resonant interference from more massive planets can push less-massive ones into the deeper regions of the system. This is what happened to Uranus and Neptune in the Solar System. As a result, some planetary results in the Frigid and Superfrigid zones may not be appropriate if they happen to be in the Deep system as well. The following rule sums up the issue:

No Jovian or Transjovian of any type may exist in the Deep system. Other types, such as glacians, cryosubjovians and asteroid belts, are still permitted. Re-roll or select a more appropriate planet type if such a planet is generated.

Asteroid Belts
Asteroid belts merit a special mention. An asteroid belt cannot be generated as the outermost planet; if you do roll one up, re-roll the result to get another kind of planet. Also, two asteroid belts cannot be generated in succession. Once you have generated an asteroid belt, ignore any asteroid belt result for the next planet out and re-roll.

Red Giants
Red giant systems are generated in the same way as ordinary Mature systems, but of course the star is much larger and brighter than it has been in previous stages of its life. As a result, some planets may be lost. Generate the system's orbits as normal. Then place the red giant in its appropriate place, and see if it engulfs any of the orbits you've generated. Any planets in these orbits, even the Prime Jovian if there is one, are considered destroyed and lost during the star's expansion. Any survivors are rolled for according to their temperature zone as normal.

Table P4: Jovian systems, Young:

Epistellar Supertorrid Zone		Supertorrid Zone		Torrid Zone	
01 - 27	Selenian	01 - 27	Selenian	01 - 27	Selenian
28 - 46	Terran	28 - 46	Terran	28 - 46	Terran
47 - 62	Osirisubjovian	47 - 49	Hadean*	47 - 49	Hadean*
63 - 92	Osirijovian	50 - 52	Vestan*	50	Vestan*
93 - 00	Osiritransjovian	53 - 61	Asteroid Belt	51 - 59	Asteroid Belt
		62	Calosubjovian	60 - 62	Calosubjovian
		63 - 92	Calojovian	63 - 92	Calojovian
		93 - 00	Transjovian	93 - 00	Transjovian

Jovian systems, Young:

Temperate Zone		Frigid Zone		Superfrigid Zone	
01 - 27	Selenian	01 - 32	Glacian	01 - 32	Glacian
28 - 36	Terran	33 - 41	Asteroid Belt	33 - 41	Asteroid Belt
37 - 46	Nerean	42 - 59	Eusubjovian	42 - 59	Cryosubjovian
47 - 49	Hadean*	60 - 92	Eujovian	60 - 92	Cryojovian
50	Vestan*	93 - 00	Transjovian	93 - 00	Transjovian
51 - 59	Asteroid Belt				
60 - 62	Eusubjovian				
63 - 92	Eujovian				
93 - 00	Transjovian				

*Hadean planets in Young systems will behave exactly like classical Vestans. Vestans in a Young system will still be almost completely molten.

Table P5: Jovian systems; Mature:

Epistellar Supertorrid Zone		Supertorrid Zone		Torrid Zone	
01 - 27	Selenian	01 - 27	Selenian	01 - 27	Selenian
28 - 46	Terran	28 - 46	Terran	28 - 46	Terran
47 - 62	Osirisubjovian	47 - 49	Hadean	47 - 49	Hadean
63 - 92	Osirijovian	50 - 52	Vestan	50	Vestan
93 - 00	Osiritransjovian	53 - 61	Asteroid Belt	51 - 59	Asteroid Belt
		62	Calosubjovian	60 - 62	Calosubjovian
		63 - 92	Calojovian	63 - 92	Calojovian
		93 - 00	Transjovian	93 - 00	Transjovian

Temperate Zone		Frigid Zone		Superfrigid Zone	
01 - 27	Selenian	01 - 32	Glacian	01 - 32	Glacian
28 - 32	Terran	33 - 41	Asteroid Belt	33 - 41	Asteroid Belt
33 - 46	Nerean	42 - 59	Eusubjovian	42 - 59	Cryosubjovian
47 - 49	Hadean	60 - 92	Eujovian	60 - 92	Cryojovian
50 - 52	Aquarian	93 - 00	Transjovian	93 - 00	Transjovian
53	Vestan				
54 - 62	Asteroid Belt				
63 - 92	Eujovian				
93 - 00	Transjovian				

Table P6: Non-Jovian systems, Young & Mature:

Supertorrid - Temperate Zone		Frigid Zone		Superfrigid Zone	
01 - 27	Selenian	01 - 56	Glacian	01 - 56	Glacian
28 - 49	Terran	57 - 72	Asteroid Belt	57 - 72	Asteroid Belt
50 - 62	Hadean	73 - 00	Eusubjovian	73 - 00	Cryosubjovian
63 - 83	Vestan				
84 - 00	Asteroid belt				

Generating Planets in Post-Stellar systems

When a main sequence star becomes a white dwarf, it has already undergone its red giant phase, and finally expelled its outer layers as a planetary nebula. As a result, the innermost planets will have been destroyed, and the surviving planets will be effectively Superfrigid, since the white dwarf gives off very little heat. As a result, the orbital region becomes more important than the temperature zone, and this is reflected in the table below:

Table P7: Jovian systems, Post-Stellar

Inner		Middle/Outer		Deep	
01 - 27	Selenian	01 - 27	Selenian	01 - 56	Glacian
28 - 46	Terran	28 - 46	Terran	57 - 72	Asteroid Belt
47 - 49	Hadean	47 - 49	Hadean	73 - 00	Cryosubjovian
50 - 52	Vestan	50	Vestan		
53 - 62	Asteroid Belt	51 - 58	Asteroid Belt		
63 - 92	Cryojovian	59 - 61	Cryosubjovian		
93 - 00	Transjovian	62 - 94	Cryojovian		
		95 - 00	Transjovian		

Table P8: Non-Jovian systems, Post-Stellar:

Inner		Middle/Outer		Deep	
01 - 27	Selenian	01 - 27	Selenian	01 - 66	Glacian
28 - 49	Terran	48 - 49	Terran	67 - 82	Asteroid Belt
50 - 62	Hadean	50 - 62	Hadean	73 - 00	Cryosubjovian
63 - 83	Vestan	63 - 78	Asteroid Belt		
84 - 00	Asteroid belt	79 - 00	Cryosubjovian		

Revenant Systems

Revenant systems are different from the standard Post-Stellar ones. Stars that explode in supernovae are so short-lived that planet generation has either not fully ended or has barely even begun. As a result, a revenant system undergoes further planet formation after the star has become a neutron star. As with white dwarfs, the orbital region is more important than the temperature zone, since again the entire system is essentially Superfrigid. Unlike white dwarfs, new planets can form close to the neutron star, so no planets are removed.

Table P9: Revenant systems

Inner/Middle		Outer		Deep	
01 - 27	Selenian	01 - 50	Selenian	01 - 66	Selenian
28 - 49	Terran	51 - 78	Terran	67 - 84	Terran
50 - 62	Hadean	79 - 85	Hadean	85 - 00	Asteroid Belt
63 - 83	Vestan	85 - 00	Asteroid Belt		
84 - 00	Asteroid belt				

Explanation of Planet Types

Planets are a varied bunch. They come in all kinds of sizes and chemical makeup, from dusty balls of dry rock, through aqueous worlds brimming with life, to massive spheres of gas heavy enough to outweigh all other planets in their host systems. Planets can be divided into two broad classes, terrestrial and jovian.

Jovian Planets are generally referred to as “gas giants”. They generally have no solid surface, and are dominated by hydrogen, helium, ammonia, methane and water. The atmosphere becomes steadily denser the deeper one goes until it finally segues seamlessly into a liquid layer, with no sharp boundary. Deep at the very heart of the planet, beneath many thousands of kilometres depth of liquid gas, is a massive rock/metal core.

Jovian planets come in several kinds, though not as many as the terrestrial planets. Jovian planets are generally grouped by mass and temperature, since their makeup is relatively similar and only the effects of temperature make a difference to the overall chemistry. The nomenclature works by using the prefix type and then the mass range. For instance, Jupiter is a Eujovian, while Uranus is a Cryosubjovian, and the extrasolar planet Osiris is an Osirijovian.

Subjovian Mass Range: 0.03 - 0.1Mj

Subjovian planets have a smaller core, though it makes up a greater proportion of the overall mass. Hydrogen and helium make up far less of the atmosphere. In the Frigid and Superfrigid zones, the atmosphere tends to be dominated by methane and other hydrocarbons. This gives these planets a greenish or bluish tinge. In the temperate zone, subjovians evolve into aquarians. In the torrid and supertorrid zones, water vapour and sulphur compounds become a major constituent, and the planet turns first white, then brownish.

Jovian Mass range: 0.3 - 3Mj

Jovian planets range from the mass of Saturn to several times that of Jupiter. They have rock/ice cores of several Earth-masses, hidden beneath a massive layer of liquid-metallic hydrogen. These planets are characterised by extremely powerful magnetic fields, creating lethal radiation belts.

Transjovian Mass range: 10Mj

Transjovian planets are dominated by hydrogen, with traces of other materials. The difference between a transjovian and a brown dwarf is subtle and not always easy to see. Essentially, brown dwarfs are either fusing deuterium or have done so in the past, whereas transjovians never had enough mass to do so. Only the osiritype and the eutype are present amongst transjovians; Eutransjovians are generally referred to simply as transjovians.

Osiri- This type are generally dark in colour, ranging from brownish to black. They are extremely close to their stars, and are surrounded by an extended envelope, or thermosphere, of ionised gas torn from them by the star. Subjovians are generally reddish-brown. The osiritype is named after Osiris, the first ever such planet discovered, and the first extrasolar planet ever given a true name.
Calo- The calotype are not as hot as the osiritype, with fewer metal ions in the atmosphere and little if anything in the way of particulate clouds. Generally a deep azure in colour, cloud banding is often not obvious, even where the planet is not tidally locked to its star.

Eu- The eutype are characterised by banded cloud layers of icy crystals, usually of water and ammonia ice as well as hydrocarbon droplets. In both the jovian and subjovian classes, weather is violent and spectacular in form. Jovian planets range from whitish, through yellow-ivory to reddish-brown or orange, with high bands of white cloud creating an agate-like appearance. Subjovian examples retain the white zones of cloud, but the underlying deck is usually greenish or bluish from the rich concentration of atmospheric methane.

Cryo- The cryotype are those planets scattered into the deep ranges of the system, beyond the normal planetary zones. The deep chill creates thick atmospheres with little structure, since there is little energy to generate weather. Cirrus-like clouds may form for weeks or months at a time, but the impressive banding is either absent or extremely subtle.

Terrestrial planets are by far the most common kind in the Universe. They range from objects barely the size of the Moon or Europa to bodies that border on the mass of a subjovian. Mass, chemistry and location play much greater role in the evolution of terrestrial planets, and they display greater variety than the gas giants.

Selenian Mass range: 0.01 to 0.1Me
A selenian planet is composed of rock and metal, sometimes with organic materials but too small to hang onto any appreciable atmosphere. Mercury, Mars and the Moon look like classic selenians, but the Moon is an unusual example. Most selenians have more metal in their cores. Geological activity is pretty much nonexistent, and often restricted to the odd fault-induced tremor and the last gasps of near-extinct volcanism. Landforms are ancient and often dominated by impact scars and volcanoes, sometimes large shield volcanoes powered by internal hotspots. Some of the largest selenians have the beginnings of large-scale tectonic features powered by internal forces, but the active processes rarely last beyond the system's Young phase.

Glacian Mass range: 0.01 to 0.3Me
A glacian planet is similar to a selenian or terran, but forms in the star's cold zone. Such a planet attracts a lot of water, which forms an icy overmantle over the rocky crust, anything from hundreds to over a thousand kilometres thick. The surface of such planets are often very ancient, though tidally-heated examples can produce enough volcanism to renew the surface on a regular basis. In the Solar system, all of the glacian planets are represented by Jupiter's Galilean moons and Saturn's moon Titan. Atmospheres on glacian planets are generally much thicker than on their selenian or terran counterparts, due to the lower temperature. Earth-mass glacians attract so much atmospheric gas that they become low-mass subjovians.

Terran Mass range: 0.3 to 1Me
Terran planets are massive terrestrials, like Venus in the Solar System. Unlike their smaller selenian relatives, Terran planets still have strong heat sources within them that power cyclic-catastrophic and hotspot geological processes. Water is often hard to find on Terran planets, although many do have standing bodies of water that cover up to a quarter of their surfaces. Unlike the Nerean planets, however, water does not play a vital role in its geological processes, apart from weathering and the formation of sedimentary rocks. Plate tectonics are not possible as there is insufficient water, so the crust tends to be thick. Life is possible on terran planets that do have reserves of water, although the cyclic geological process can make life very hard to maintain.

Nerean Mass range: 0.3 to 1Me
Nereans are high-mass terrestrial planets with enough water to form global oceans. Our own Earth is an excellent example. Such oceans cover from 40% to 100% of the planet, and the water's deep penetration into the basal rock lubricates them enough for crust subduction to be a major force. The crust is relatively thin, and broken into basalt plates of varying sizes. This constant subduction and recycling of the planetary crust creates a very young surface that is often no more than a few hundred million years old. In some cases, continental masses of lighter rock such as granite float atop the crust plates, preserving older structures and encouraging the formation of various kinds of rock.

Aquarian Mass range: 3Me

Aquarians are massive planets, often twice the diameter of the Earth and ranging from three to ten Earth-masses. The inner part of the planet is composed of rock and metal, generally up to two Earth-masses' worth, while above this lies a deep layer of water often thousands of kilometres thick. The unrelenting pressure turns most of this water into ice, but in the temperate zone (the only place where aquarian planets are found) the surface remains liquid, giving rise to an ocean 100km thick. In most cases, Aquarians are formed from Cryosubjovians that stray into the Temperate zone.

Hadean Mass range: 3Me

Rocky planets can form that mass much more than the Earth or even the rocky core of an aquarian planet. As the mass of a rocky planet increases, so does the proportion of heavy elements in its core. Larger planets contain more heat, and are more tectonically active. Beyond 3 Earth-masses, all pretence of Earthlike behaviour is lost. The crust becomes very thin and the planet roils with its barely-contained internal heat. Volcanism is constant, and episodes of megavolcanism are common events. A thick, heavy atmosphere forms, dominated by carbon dioxide, water vapour and sulphur dioxide. These hellish, heavy worlds are the hadean planets. What water these worlds contain is usually in the form of vapour, although some hadeans can host shallow seas in which primitive, extremely resilient life ekes out an extreme existence.

Vestan Mass range: 10Me

Vestans are the largest and most massive of terrestrial planets. Between ten and fourteen times the mass of the Earth and generally twice as large, the paper-thin crust boils and blisters with uncontained heat from the planet's innards. Massive global volcanism is a daily event and there are often standing bodies of liquid rock that could be called oceans. The atmosphere is thick and deadly, and the temperature, irrespective of the planet's position, is like that of a blast furnace. Maps of vestan planets are more like weather reports; the planet can completely resurface itself in a matter of years. No life can survive on a vestan planet.

Asteroid Belt/Cluster Mass range: 0.01 to 0.1Me

An asteroid belt may be formed by one of two processes. In many cases, a region of the star's protoplanetary disc fails to coalesce into a planet. Other bits of leftover rubble are shepherded from elsewhere in the system into the ring of orbiting debris, forming an asteroid belt. Sometimes, a planet is torn apart by collision with another planet, or is torn apart by tides from a massive planet. In either case, what's left is an asteroid belt, like that of the Solar System. Asteroids naturally survive elsewhere, but this belt is a major object in the system it inhabits, and comprises a mass that can be considered equivalent to a planet. Asteroid belts contain asteroids and even the odd planetoid (see below).

Large planets of Jovian mass or greater sometimes shepherd large amounts of asteroidal matter into ellipsoidal groupings centered on their L4 and L5 points. Jupiter does this in the Solar System, creating the Trojan asteroids. Like a belt, an asteroid cluster only shows up as an important body if its total mass is equivalent to a planet; for instance, the L4 Trojans are equivalent in mass to the planet Mars. There is a chance that an asteroid cluster may contain planetoids.

Transplanetary Belt Mass range: 10 to 100 Me

The transplanetary belt is a realm of pristine material almost untouched since the system first formed. It lies beyond the orbit of the outermost planet and is composed of about 50:50 ice and rock. Most of the system's comets originate from here; they can be perturbed by the close approach of a planet that distorts their orbit into a long ellipse, sending the comet into the inner system where it develops a coma and a tail. The transplanetary belt contains a lot of material (the Kuiper Belt possesses a whopping thirty-plus Earth-masses of rock and ice), but it is extremely widely spread, which is why it never formed into a planet. The belt extends from just outside the outermost planet's orbit for another 16+d8 AU. The transplanetary belt may be home to dozens or even hundreds of icy planetoids; the GM should feel free to create them at will.

Whither the Chthonian?

Owners of the previous version of Cosmos will have noticed that the chthonian planet type has disappeared. Chthonian planets were originally postulated as the remnants of gas giant planets that have wandered too close to their host star. A chthonian in such a case is the denuded, rocky-metallic core of the planet after all of its atmosphere has been scoured away. However, it can take tens of billions of years to scour away so much gas (Osiris, for instance, has lost at most only 7% of its atmosphere over the last four billion years), and stars long-lived enough to achieve this are the lowest end K-class stars or red dwarfs. They're not bright enough to strip away a planetary atmosphere like this. As a result, it seems that true chthonians are rare; in fact, highly unlikely to exist at all. Even if they do exist, they are already represented by the selenian and terran classes. As to whether or not such a planet in an epistellar orbit is a chthonian is up to the GM to decide; It makes no practical difference to the planet.

Planets, Planetoids and Pluto

The astute reader will notice that a planetary type covering Pluto is conspicuous by its absence. There are several reasons for this, some game-related, some astronomical. Pluto is a very light body, only two-thousandths the mass of Earth and barely a fifth the mass of the Moon. This is far below the lowest mass class of 0.01Me. It is also very small, less than two-thirds the diameter of the Moon. Furthermore, there are a lot of similar bodies to Pluto in the Kuiper Belt, possibly hundreds, and the discovery of Eris, which is larger than Pluto, finally settled the issue. In a landmark move in August 2006, the International Astronomical Union determined that Pluto was simply a large Kuiper Belt Object, and not a planet. However, it also created a new class of body, the "dwarf planet", of which there are already a few members, and more will inevitably follow. Cosmos calls these objects Planetoids. Other famous planetoids include Ceres, Europa and Triton.

Planetoids can orbit their stars as scattered objects or, more often, as part of a belt or cluster of asteroids. Cosmos does not generate orbits for these bodies singly, but does discuss some of their characteristics.

The mass of a planetoid is highly variable, and ranges from 0.0006 to 0.009 Earth-masses. A planetoid is described simply as a body that falls below the 0.01Me mass-class but still has enough self-gravitation to hold a spheroidal shape. The limiting diameter in this case is 800km.

Such bodies have miniscule surface gravity, no magnetic field to speak of, trace atmospheres or no atmosphere at all. On the GRAPH scale, the G,A & P values are identical: G0, A0, P0. Only the R & H value varies, depending on where the planetoid is located and whether it is currently day or night. Night values are always H0, whereas day values depend on proximity to the star. If the planetoid is in the supertorrid zone, its daytime temperature is H5 and its radiation flux R3. In the torrid and temperate zones, its daytime temperature is H4. In the Frigid zone, its daytime temperature is H1 or sometimes even H0. Temperate and torrid values for "H" exist only for short periods of time around dawn and dusk on temperate planetoids. Planetoids in these non-supertorrid regions also have the same radiation flux of R2.

Planetoids in Asteroid Belts and Clusters
Belts and clusters of asteroids, comets and the like can add up to a significant amount of material. By way of example, the Main Belt adds up to slightly more than the mass of the Moon. The L4 Trojan cluster of Jupiter contains ten times as much material, closer to the mass of Mars. The mass of a cluster or belt also determines the number of planetoids that may exist within it. Check your belt's list against the table below and roll the appropriate die to determine whether you have any planetoids as part of it.

Table P10: Numbers of Planetoids

Mass	Asteroid Belt	Asteroid Cluster
0.01Me	Roll d4 - 2	Roll d4 - 3
0.03Me	Roll d4 - 1	Roll d4 - 2
0.1Me	Roll d6 - 2	Roll d4 - 1

Planetoids may also exist as moons of a larger planet (See Chapter 3: Moons for details).

Orbital Characteristics

In ancient times, in fact until the beginning of the Enlightenment, it was believed that there was a sharp discontinuity between the Earth and the rest of the Cosmos. Below the Moon, existence was changeable, corrupt and imperfect. Above the Moon was the heavenly realm of pristine, unchanging perfection. Part of this belief was the idea that the planets moved in perfect circles. Eventually, the astronomer Johannes Kepler developed his laws of planetary motion that are still used to this day, and helped Newton to develop his theory of Universal Gravitation. One of the great revelations of Kepler's discovery was the fact that the planets don't orbit in perfect circles.

Eccentricity

Planets, moons, asteroids, comets etc orbit in ellipses, with the centre of their orbit at one of the ellipse foci. The other focus is empty.

The upshot for us is that planets have a near and far point in their orbits. On Earth, these points are called Perihelion when closest to the Sun (which happens the first week January), and Aphelion when furthest away (which happens in early July). With some planets, like Earth, this is no more than a couple of million kilometres either way, while Mars and Mercury have much more elliptical orbits. Some extrasolar planets have extremely eccentric orbits.

This “stretching” of the orbit away from a circle is called a planet's eccentricity. A planet essentially dominates the orbital range between perihelion to aphelion, and this range is off-limits to other planetary orbits. If two planets' orbits cross, the lesser planet will be lost (either cast out of the system, hurled into the sun, or consumed by the larger planet). You may elect to save such a planet by making it a captured moon of the greater planet or placing it in a shared orbit (see below). To determine eccentricity, roll d6 and check below:

1-4	Circular	Roll d12 and divide by 100 to determine eccentricity
5-6	Eccentric	Roll 2d20 + 18 and divide by 100 to determine eccentricity

Perihelion = d x (1-e)
Aphelion = d x (1+e)

Where d is the average distance in AU and e is the eccentricity figure

Orbital eccentricity can have a profound effect on a solar system. Systems dominated by giant planets with high eccentricities generally have fewer planets, since the wandering giants use up more of the protoplanetary disc, and their gravitational interactions can either capture planets or throw them out of the system entirely.

Orbital Period

The orbital period of a planet, the length of its year, is determined simply by its distance from the star and the mass of that star. Using the list on the next page, we can determine orbital periods at a distance of 1AU:

Table P11: Orbital Periods

Giant Stars:	**Major Stars:**	**Minor Stars:**
B: 122 days	A: 259.33 days	M: 820 days
G: 310 days	F: 310 days	L: 1550 days
K: 350 days	G: 386.5 days	
M: 290 days	K: 438.33 days	
Neutron Star: 122 days	D: 374 days	

For distances other than 1AU, the orbital period is worked out by Kepler's simple equation: $p^2 = d^3$, where p is the period (as in the list above), and d the distance in AU.

Naturally, these simple figures don't give every single possibility for stars. Some stars are a touch heavier or lighter, and there are oddballs such as the aging, subgiant stars, but eventually even I have to trade detail for playability and ease of use!

Shared Orbits

In any orbital system involving a primary and secondary (planet and star, moon and planet), there are regions where the gravitational attractions between the two bodies cancel out and nullify each other. These points are called libration points or, more often, LaGrange points, after the mathematician who discovered them. Of particular interest are points L4 and L5, since these are the strongest and most stable. These are located 60 degrees to either side of the planet at the same distance from the sun. Bear in mind that unless the orbit is near-circular, this does not mean quite the same thing as being ahead of and behind the planet in its orbit. Matter that falls into these areas remains stable there, and can form asteroid fields or perhaps even planets. Jupiter plays host to the Trojan asteroids, two rich clusters of asteroids that occupy its L4 and L5 points. The mysterious object that is supposed to have hit the Earth and formed the Moon (dubbed Theia by astrophysicists) is supposed to have formed in Earth's L4 point and been driven out by perturbations from other young planets, eventually to collide with Earth. These shared-orbit relationships are more stable if the central planet is at least one mass class (preferably two) heavier than any secondary planets, always terrestrial.

Shared orbits can be used to save a planet that would otherwise be forced out by another planet's highly-elliptical orbit. GM's fiat applies here of course, but be sure not to overdo it. Remember that even Jupiter only has asteroid clusters at its L4 and L5 points, and Earth's hypothetical L4 companion, dubbed “Theia”, became unstable and destroyed itself. In nature, such shared orbits are very rare; the only known stable examples occur in two pairs of miniscule moons orbiting Saturn. Perhaps a good proportion of shared orbits is one such event per 100 or 1,000 systems.

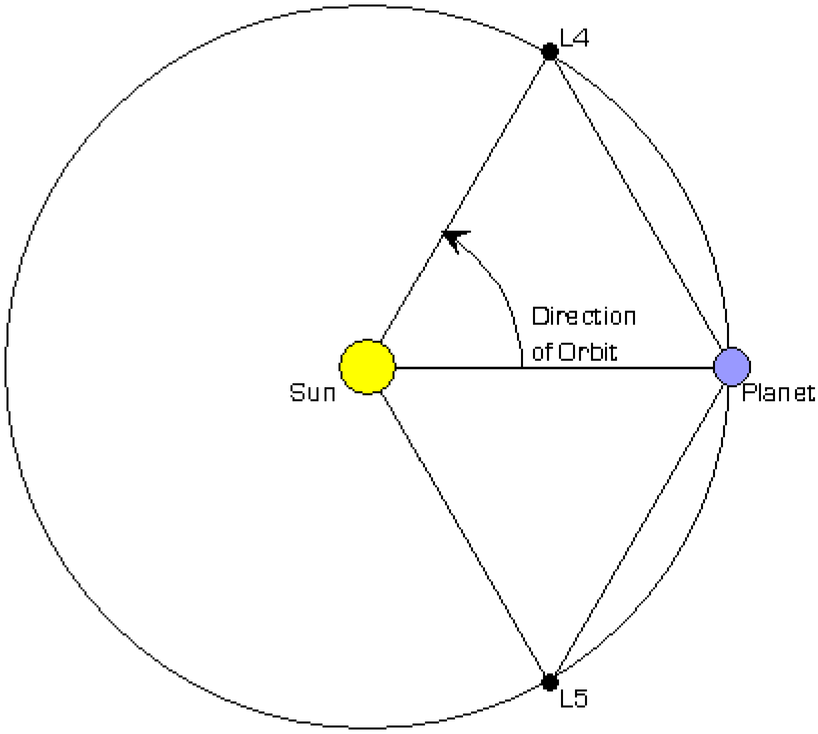


Fig. 7: Lagrange Points L4 & L5

Binary Planets

Binary planets are a very rare expression of an extreme shared orbit. The two planets actually form in their binary partnership; capture events are not possible, since any wandering planet will be moving too fast. Binary planets form within two mass classes of each other, and are often the same mass class. Designate a primary planet and generate its type and mass as normal. Then roll a d8 as below and see what mass class the secondary has.

D8:
1-5 Same mass class
6-7 One mass class difference
8 Two mass classes difference

Because the two planets formed out of the same material in the same place, they will be very similar. Choose the same planet type whenever possible. If this is not possible, choose the planet type that comes closest to that of the primary. For instance, if the primary is a 3Me aquarian planet and its companion only 1Me, then that planet should be a Nerean. If the primary is a 0.3 Me terran planet, then its 0.1Me companion should be a selenian.

Important: Only terrestrial planets can become binary planets. Please note that natural binary planets will be rare, about as rare as natural shared orbits.

Axial Tilt

Axial tilt refers to the planet's alignment with its orbit. For example, Earth has an axial tilt of just over 23 degrees. Because of this tilt, we have seasons, tropics where the Sun can appear directly overhead at certain times of year, and arctic zones where the Sun can disappear below the horizon for weeks on end. If Earth had little or no tilt at all, like Jupiter, the Sun would never seem to climb and fall through the sky from season to season. More to the point there point there would be no seasons to speak of, since any part of the globe would receive the same sunlight from one day to the next. At the other extreme are planets like Uranus. Uranus has an axial tilt of just over 90 degrees, which means it effectively spins on its side. Seasons on Uranus are about as extreme as you can get, with one hemisphere pointed at the Sun for half the year, and the other in darkness for half.

Axial tilt = 2d6-3 x 2d6-2 degrees

Rotational Period

When a planet forms from the protoplanetary disc, it spins up. This is a natural result of the conservation of momentum, rather like a skater speeding up a spin by drawing in his arms. Over the ages, these spins are affected by tidal tugs from other planets, moons and the primary star or stars. Sometimes they can be affected by major impacts, as well. Within a minimum distance, the star's tidal effects force the planet to orbit like a moon, with a locked rotation, keeping one face always pointed at the star. Further out, the orbit isn't totally locked, but there is a strong resonance between the planet's rotation and its orbit, so that one rotation takes 2/3 of a year. An interesting upshot of this is that because the rotation is such a long part of the year, a solar day (sunrise to sunrise) takes two full orbits to achieve. Mercury rotates in this way.

Beyond this region rotations become more chaotic, as they're subject to other forces besides solar tides.

You can determine the rotational period of your planet by means of the table below:

Table P12: Rotational Period

0 – 0.2AU	Locked Rotation	
0.2 – 0.5AU	Resonant rotation. Planet's rotation is 2/3 its orbital period. Planet experiences 1 solar day per 2 years.	
Beyond 0.5AU	Terrestrial planets roll 3d6, Jovian planets roll 2d6:	
	2 - 5:	2d6 hours
	6:	3d6 hours
	7:	4d6 hours
	8:	5d6 hours
	9 -10:	3d6 x 2 hours
	11 – 12:	3d6 x 3 hours
	13:	3d6 x 5 hours
	14:	1d6 days (terrestrial 24-hour days)
	15:	2d6 days
	16:	5d6 days
	17-18:	3d6 x 5 days

Physical Characteristics

Planetary Mass

Planetary mass has been touched on before; here is where it is explained. Planetary masses range from tiny, Moon-like selenian planets massing only 1% that of Earth, to monsters weighing in at 13 times the mass of Jupiter. The two main kinds of planet, jovian and terrestrial, have a small amount of crossover. The smallest jovian planets are about ten times the mass of Earth, like Uranus. The uppermost theoretical limit for a rocky planet is about fourteen times the mass of the Earth. To make things simpler, these masses can be grouped into mass classes. Terrestrial planets are classed in Earth-masses, or Me for short. Jovian ones are noted in Jupiter-masses, or Mj for short. For the sake of convenience, a Jupiter-mass is simplified to 300Me, rather than its actual value of 318Me. This allows the scales to segue into each other easily.

These classes are arranged in a logarithmic scale as shown below, along with some real-world examples:

Table P13: Planetary Mass Classes
Terrestrial Planets:

0.01Me	0.03Me	0.1Me	0.3Me	1Me	3Me	10Me
Luna	Mercury	Mars	Venus	Earth	Mu Arae d	Gliese 876 d
Ganymede						

Jovian Planets:

0.03Mj	0.1Mj	0.3Mj	1Mj	3Mj	10Mj
Uranus	Eps. Eridani c	Saturn	Jupiter	Tau Bootis b	HD161020b
Neptune	55 Cancri c	55 Cancri b	16 Cygni b	55 Cancri d	HD39091b

Generating Planetary Masses:
Each planet type has its own range of masses. The table below shows how to assign a mass class to a planet of any type. Some planets only exist in one specific mass class. These classes are marked with the word "only".

Table P14: Terrestrial Planets

Type	Die Roll	0.01Me	0.03Me	0.1Me	0.3Me	1Me	3Me	10Me
Aquarian	-	-	-	-	-	-	Only	-
Glacian	d8	1 – 3	4 – 5	6 – 7	8	-	-	-
Hadean	-	-	-	-	-	-	Only	-
Nerean	d6	-	-	-	1 – 2	3 - 6	-	-
Selenian	d6	1 - 2	3 - 4	5 - 6	-	-	-	-
Terran	d6	-	-	-	1 - 3	4 - 6	-	-
Vestan	-	-	-	-	-	-	-	Only
Asteroid Belt*	d6	1 - 3	4 - 5	6	-	-	-	-

* Includes asteroid clusters

Table P15: Jovian Planets
Please note: No jovian planet may be of a higher mass class than the Prime Jovian

Type	Die Roll	0.03Mj	0.1Mj	0.3Mj	1Mj	3Mj	10Mj
Subjovian	d6	1 - 3	4 - 6	-	-	-	-
Jovian	d8	-	-	1 - 3	4 - 6	7 - 8	-
Transjovian	-	-	-	-	-	-	Only

DIAMETER

Once a planet's mass has been determined, we can then generate its diameter. Vagaries in a planet's makeup can vary its overall density and this, coupled with the breadth of each mass class, makes for a wide range of possible sizes for a planet. Check the planet's type and mass class and roll as shown below:

Selenian/Terran/Nerean		
0.01Me	3,200 to 4,400km	2,800 + (d4 x 400km)
0.03Me	4,800 to 6,800km	4,400 + (d6 x 400km)
0.1Me	6,800 to 9,600km	6,400 + (d8 x 400km)
0.3Me	10,000 to 12.000km	9,600 + (d6 x 400km)
1Me	12,800 to 15,200km	12,000 + (d8 x 400km)
Glacian		
0.01Me	3,200 to 5,200km	2,800 + (d6 x 400km)
0.03Me	5,600 to 6,800km	5,200 + (d4 x 400km)
0.1Me	7,200 to 10, 800km	6,800 + (d10 x 400km)
0.3Me	10,800 to 13,600km	10,400 + (d8 x 400km)
Hadean	15,600 to 23,200km	15,200 + (d20 x 400km)
Vestan	23,600 to 25,600km	23,200 + (d6 x 400km)
Aquarian	19,200 to 28,000km	18,400 + (d12 x 800km)
Subjovian		
0.03Mj	30,000 to 80,000km	27,500 + (d20 x 2,500km)
0.1Mj	80,000 to 120,000km	78,000 + (d20 x 2,000km)
Jovian		
0.3Mj	120,000 to 140,000km	120,000 + (2d6-2 x 2,000km)
1Mj+	140,000km; this is the maximum diameter for a planet. Beyond this mass the planet simply becomes denser, not larger.	

SURFACE GRAVITY

A planet's surface gravity is a function of its mass and density. Using the GRAPH system's definitions of gravity, in most cases a mass class gives a G value without needing to enquire further. However, the 0.3 and 1Me mass classes do require us to check the planet's diameter as well, to get a precise value. Check your planet's mass class (and diameter, if necessary) against the values listed below.

0.01Me	G0
0.03Me	G1
0.1Me	G1
0.3Me	10,000 – 11,200km = G1
	11,600 - 12,000km = G2
1Me	12,400 – 13,200km = G2
	13,600 – 15,200km = G3
3Me	G4
10Me	G4

GEOLOGY

Planets with solid surfaces have geology; landforms shaped by sudden catastrophic events and slow, but implacable, forces. There are four kinds of geology: passive, sporadic, cyclic and active.

Passive geology is just that; passive. Planets with passive geology have lost, or never had, a source of internal energy capable of resurfacing the planet. Landforms under such circumstances are dominated by the relics of past episodes of activity, impact history and weathering, if applicable. Terrain formed by passive geology is marked by impact craters and low, rolling mountains, as well as faulting and scarps. The terrain will generally be very ancient, measurable in billions of years.

Sporadic geology is very similar to passive, but in this case there is just a feeble ember still glowing at the planet's core, enough to power occasional tectonic shifts and highly sporadic volcanism. This will tend to add trace gases such as methane or sulphur dioxide to an otherwise inert atmosphere, but will have little effect on the overall terrain, which will tend to look like passive geology. Often only a geologist, or an unfortunate explorer who could've sworn the volcano was extinct, would be able to tell the difference.

Cyclic geology is generated by an active core that's blocked by an overly thick crust. This is often the case of low to middle-mass terran planets. The geological cycle often undergoes quiescent periods for tens or even hundreds of millions of years until the trapped heat overwhelms certain fracture points in the crust. Then the situation changes dramatically, and global megavolcanism takes place, sometimes capable of resurfacing the entire planet within a few million years. The atmosphere often thickens and becomes highly toxic, making life very difficult for complex forms. Eventually the pressure wanes and the surface becomes quiescent again.

Active geology take place constantly, with earthquakes and eruptions every year or so. It comes in two distinct flavours: hotspot and plateotectonic.

Hotspot geology also occurs on terran planets, as well as occasional low-mass nerean worlds. Plumes of hotter material from deep in the mantle near to the core create zones of high pressure and excessive heating under the crust. Eventually this material breaks out in a region of high volcanism. Because the crust is immobile, unlike plateotectonic worlds, these hotspot regions give rise to massive shield volcanoes hundreds of kilometres across, sitting on extensive highland regions. On some worlds, they can grow over a thousand kilometres across, and rise high enough to poke out of the planet's stratosphere.

Plateotectonic geology is common on nerean planets, where there is enough water to fuel the process. Unlike normal planetary crusts, plated crusts are broken into a number of regions, or plates. Water from global oceans permeates the rock, lubricating it and allowing the plates to slide under each other. This causes tension stress on the far side of the plate, and new material is dragged up from below to fill in the gap. This often forms a jagged suture line, most commonly under the oceans themselves, and hence named a mid-oceanic ridge; a line of volcanic mountains often thousands of kilometres long. The subducted edges of the plates are easily melted since they carry water as an impurity, triggering volcanism on the surface above the subduction zone. This complex and active process creates very young crust, often only a few tens to hundreds of millions of years old, and is dependent on large quantities of water, hence it only appears on nerean planets. Sitting on the basalt crust lie regions of lighter granites. They are carried along like rafts, sometimes merging, sometimes being broken up by the activity below them. These form the continents on such planets.

Geology and Weathering
Planets with atmospheric pressures of P1 and above, and extensive hydrography, can give rise to weathering effects. This is the erosion we're familiar with on Earth, which breaks down all but the largest features and wipes out primal features such as impact craters. It breaks mountains, submerges continents and fills in canyons in tens or hundreds of millions of years. Planets with P0 atmospheres have little to no weathering, mostly in the form of the occasional frost and impact weathering from micrometeorites. These processes have minimal impact, even over billions of years.

OCEANOGRAPHY

Some planets have a layer of liquid, either just below a solid, icy crust or sitting above a rocky one. These layers may range from isolated little seas to vast global oceans up to a hundred kilometres deep. Most planets have little or no surface liquid, but even they may play host to subterranean aquifers or permafrost on colder planets. Sometimes an entire ocean may be concealed below a shell of ice many kilometres thick.

Planets with seas or oceans are often the most sought-after by spacefaring civilisations, since it is these that have the greatest chance of supporting and harbouring complex life of their own.

Composition
Most oceans in the Universe are composed of water. Water is one of the commonest substances in existence, and it has a broad range of temperatures and pressures at which it is liquid. Water may be quite pure, or more often carries a number of impurities. Depending on the planetary conditions, oceans may be saline, or even somewhat acidic or alkaline. Extreme concentrations of impurities are more common on smaller bodies of water. Second to water, liquid hydrocarbons like methane and ethane can sometimes form seas and oceans under conditions of sufficient atmospheric pressure and low temperatures, but such planets are rarer than aqueous ones, and confined to the Superfrigid zone of a system.

Hydrography
Many planets have no surface water at all, but larger ones are generally wetter. Some larger planets only bear small numbers of contained seas, dotted about the surface. Others can be partially or totally covered by oceans. Aquarian planets host global oceans a hundred kilometres deep. As well as liquid oceans, planets may also develop mantles of ice near their poles, called polar caps. If you have something specific in mind, then choose from the options below, based on the planet type. Otherwise, check your planet type and roll on the appropriate table below. All Selenian and Vestan planets are Dessicated, while all Aquarian planets are Oceanic (and then some).

Table P16: Hydrography, roll d20:

Terran/Hadean	Nerean	
1 - 14	1 - 4	Dessicated planet. No surface water exists, although permafrost or subsurface aquifers are possible on some planets. Life on the surface is probably non-existent, but if it's there must be extremely tough to survive.
15 - 20	5 - 8	Arid planet. Global hydrography of approximately 20%. Seas are few and shallow, and most surface water is in the form of lakes and seasonal rivers.
	9 - 12	Semi-aqueous planet. Global hydrography of approximately 40%. Planet has many large and noticeable bodies of water, but the overall geography is still dominated by deserts. There is sufficient water on these planets to saturate the crust rocks and generate plateotectonic geology.
	13 - 16	Aqueous planet. Global hydrography of 60 – 80%. Planet is Earthlike, dominated by oceans, with isolated land-masses. Plateotectonic geology is inevitable under these conditions.
	17+	Oceanic planet. Global hydrography of 100%; only scattered atolls and small volcanic islands are visible above the surface, at most.

-3 modifier for planets in systems dominated by jovians with eccentric orbits.

Table P17: Subsurface hydrography for Glacian planets, roll d20

1 - 4	Frozen planet. The overmantle is solid ice, with no liquid water.
5 - 12	Semiliquid subsurface. The overmantle contains a region of slushy ice that is capable of flowing, but is not truly liquid water.
13 -16	Discontinuous subsurface ocean. A subsurface ocean exists in tidal stress zones (see Moons) or volcanic hotspots warmed from beneath. Overall hydrography 40 – 60%.
17+	Global subsurface ocean. The subsurface ocean is contiguous, with little or no interruption. Overall hydrography 80 – 100%.

+4 modifier for Glacian moons orbiting in the High Tide zone of a jovian planet.

MAGNETISM & RADIATION

Some planets, such as Earth or Jupiter, are capable of generating substantial and homogenous magnetic fields. These fields are generated by a dynamo effect within the planet's interior, by means of the planet's rotation and turbulence within a conducting fluid inside the planet. On terrestrial planets, this is usually generated at the boundary of the solid metal inner core and liquid metal outer core. On jovian planets, this is generated within the liquid-metallic or plain liquid hydrogen mantle. As a result, terrestrial planets with strong magnetic fields usually have a dipole field closely aligned with the planet's rotation axis, while that of jovian planets can exhibit a strong deviation from the rotation axis. Jovian planets sometimes even exhibit quadripolar fields.

Not all planets meet these conditions, of course. Venus, for example, has almost no field strength, but then it has almost no rotation, either. The Moon rotates more quickly than Venus, but its small size means its core has long since cooled to a solid or semi-solid state. Mars rotates as quickly as Earth, but again its small size means that it has run our of internal energy to keep a fluid core. Such magnetically-inactive planets still have magnetic fields, everything does, but they're weak and limited, with micro-poles scattered across the surface rather than as a single, powerful field.

Even when a planet has a global magnetic field, its strength and orientation can change. Earth's field, for instance, has regularly undergone reversals of north-to-south, and is currently weakening in preparation for another reversal.

A planet's magnetic field affects the local radiation environment, both on the planet's surface and in the space around it. Magnetic fields trap charged particles from stellar winds and similar space weather. These particles form toroidal bands around the planet, like the Van Allen belts of Earth. These bands form high-radiation environments that can be hazardous to spacecraft, as well as living beings. However, by trapping these particles they also keep them away from the planet's surface, providing a protected environment for life that may exist there. Jovian planets like Jupiter can give rise to powerful fields of well over a thousand Gauss, stronger than the magnet in an MRI scanner. Such fields are often the size of a main sequence star like the Sun, and contain radiation belts capable of killing a person in minutes.

Planets without such protection are almost defenceless before the charged particle winds of their stars, and the radiation environment will match that of local space (generally R2 on the GRAPH scale, with lethally high peaks during stellar storms). The presence of an atmosphere, even a P0 one, can mitigate this somewhat, dropping the ambient surface radiation to R1, though it will provide no protection against stellar storms. Heavy atmospheres (P4 and higher) can provide complete protection, and even generate their own magnetic field when under assault from high stellar winds, preventing the atmosphere from being lost.

Magnetism and Atmosphere

Planets with weak or surface-localised magnetic fields have another problem when dealing with solar radiation. These charged particles aren't stopped by the field and trapped in radiation belts. Instead, they hit the atmosphere directly.

In low gravity planets, those of less than 0.3Me, solar wind particles serve to strip away the atmosphere in a matter of a few million years. This is what happened to Mars. On heavier planets, charged particles are absorbed by the atmosphere and break apart hydrogen bonds, breaking down water into hydrogen and oxygen. The hydrogen, being so light, is lost to space and stripped away, leaving the planet parched for water, but the planet's gravity can still hold onto the heavier gases. This is what happened to Venus. From these examples it's easy to see that the protection of a powerful magnetic field is vital for any planet that harbours complex surface life.

Planetary magnetic fields can be divided into six groups:

Mag1: Weak, localised

Weak, localised fields are like that of the Moon and Mars. There is no global field at all, and small concentrations of polarity are scattered at random across the surface.

Mag2: Weak, global

Weak, global fields are similar to that of Mercury. They range between 0.01 and 0.1 Gauss in strength. They can be used for navigation but little else.

Mag 3: Strong, global

A strong, global field is like that of Earth. They range in strength from 0.1 to 10 Gauss (Earth's field is 1 Gauss on average), and provide effective protection from most space radiation.

Mag 4: Powerful, global

A powerful, global field ranges in strength from 10 to 100 Gauss. It's very rare to see such a field generated by a terrestrial planet, but this strength is common amongst subjovian worlds.

Mag 5: Jovian, global
Jovian fields range on average from 100 to 10,000 Gauss. They are the most powerful fields commonly found. At the highest ranges, even outside the radiation belts, fields of this strength are dangerous to living things and lengthy exposure can even be fatal.

Mag 6: Lethal
Lethal fields are in the 10,000+ Gauss regime. They pose an immediate danger to living things, since the field is strong enough to interfere with physical and chemical processes. Such fields are only commonly found near starspots. Beyond a million Gauss, atoms themselves are distorted into elliptical shapes, aligned with the field. Chemical bonds are overwhelmed and molecules cease to exist, all matter loses its structure and becomes what's referred to as "magnetic soup", composed of isolated atoms. Fields of this strength only exist near the surface of certain rare neutron stars, called "magnetars".

Planets of mass 0.01Me are restricted to Mag1.
Planets of mass 0.03 to 0.1Me may be Mag1 or 2.
Planets of mass 0.3 to 3 Me may be mag 2 or 3, depending on their rotation; less than 500 hours rotation will in almost all cases generate a Mag 3 field, while slower rotation will generate a Mag 2.
Vestan planets may generate a Mag 4 field if they rotate in less than 100 hours, otherwise they generate a Mag 3.
Subjovian planets generate a Mag 4 field.
Jovian planets generate a Mag 5 field.

Borderline cases are naturally subject to GM's fiat.

PLANETARY ATMOSPHERE

Planets attract gaseous envelopes during their formation, and more gases are added to the envelope from within the planet as well, via volcanoes. This gas is referred to as an atmosphere, and on Earth we have a rather a nice one. Atmospheres are described by three primary characteristics: pressure, chemistry and temperature.

Atmospheric variables are difficult to pin down and are best consciously selected by the GM rather than being generated randomly.

Chemical Makeup
Below is a list of the most common naturally-occurring gases known, listed in order of molecular mass. It's there to give you an idea as to how to mix up an atmosphere for your planet. Note that the lightest gas Earth can hang onto for any great length of time is methane, while Jupiter and Saturn have immense atmospheres of molecular hydrogen.

Gas	Molecular Mass	Chemical Symbol
Atomic Hydrogen	1.0	H
Molecular Hydrogen	2.0	H_2
Helium	4.0	He
Atomic Nitrogen	14.0	N
Atomic Oxygen	16.0	O
Methane	16.0	CH_4
Ammonia	17.0	NH_3
Water Vapour	18.0	H_2O
Neon	20.2	Ne
Molecular Nitrogen	28.0	N_2
Carbon Monoxide	28.0	CO
Nitric Oxide	30.0	NO
Molecular Oxygen	32.0	O_2
Hydrogen Sulphide	34.1	H_2S
Argon	39.9	Ar
Carbon Dioxide	44.0	CO_2
Nitrous Oxide	44.0	N_2O
Nitrogen Dioxide	46.0	NO_2
Ozone	48.0	O_3
Sulphur Dioxide	64.1	SO_2
Sulphur Trioxide	80.1	SO_3
Krypton	83.8	Kr
Xenon	131.3	Xe

Halogens

Ever since the classic Traveller adventure "Shadows", halogens like fluorine, chlorine and to a lesser extent bromine have been a popular choice for corrosive planetary atmospheres. However, these gases are highly reactive (which is why they're corrosive), and even in the absence of oxygen can react strongly with other gases. They're also very rare in the Universe at large, which is why they don't show on the chart above. They only show up in any concentration in the gases surrounding a major volcanic eruption. In short, they're not the best choice. For a corrosive atmosphere, sulphurous and other acidic compounds are just as good, and more stable to boot. Venus does very nicely with an atmosphere of sulphur dioxide and carbon dioxide. Halogens in noticeable concentrations would only be present on planets dominated by global megavolcanism, like Vestan planets.

Some other gases are also highly reactive, and need to be constantly replenished. Good examples are oxygen and methane. Both of these react strongly with other substances, one reason why we breathe oxygen in the first place. However, it also means that planets can run our of these gases quite quickly (a few thousands or millions of years). If planets have these atmospheric gases then they're being replenished, perhaps by volcanism or maybe life. Inert and lifeless planets won't have these kinds of gases in any great quantity.

Pressure
Pressure varies from planet to planet, but its main contributing factors are the mass and temperature of the planet. When gas molecules are given energy (by sunlight, for example) they spring off in high ballistic trajectories, until they either land or hit something else, like another gas molecule. Given enough energy, a gas molecule can reach escape velocity and fly off into space. As a result, only heavier planets can hang onto the lighter elements, such as hydrogen and helium. The following table lists the range for atmospheric pressure as per the GRAPH scale, depending on where the planet is in its system.

Table P18: Atmospheric Pressure

	0.01Me	0.03Me	0.1Me	0.3Me	1Me	3+Me
Supertorrid	0	0	0	0 - 1	0 - 2	5
Torrid	0	0	0	2 - 5	2 - 5	5
Temperate	0	0	0	2 - 5	2 - 5	5
Frigid	0	0 - 1	1 - 2	3 - 5	3 - 5	5
Superfrigid	1 - 3	2 - 3	3 - 4	4 - 5	4 - 5	5

TEMPERATURE

The surface temperature of a planet can vary, depending on its various sources of heat. The three most common sources are sunlight, internal geothermal heat and latent heat trapped by oceans and atmosphere.

Sunlight, depending on its intensity and proximity, will heat a planetary body according to the simple scale laid out below:

	Day	Night
Supertorrid Zone	H5	H1
Torrid Zone	H4	H1
Temperate Zone	H3	H1
Frigid Zone	H1	H0
Superfrigid Zone	H0	H0

As you can see, temperature varies wildly when depending on sunlight alone. However, for very massive planets, internal heat sources can provide an extra level of warmth, as seen below:

Hadean	H+1
Vestan	H4 - 5

Temperature and Atmospheres
The presence of atmospheres and oceans serves to hold onto heat gathered in the daytime and release it at night. It also distributes heat between the dayside and nightside of a planet via winds and weather systems, ironing out the most severe differences between day and night. An atmosphere of P2 and above confines temperatures in most cases to a single Heat value between the extremes. In the Torrid and Supertorrid zones, the upper heat value remains the same, but the night-time temperature raises to meet it. In the temperate zone, the temperature settles into an intermediate value between H3 and H2. In the Frigid and Superfrigid zones, the temperature range is already so low that the atmosphere has no noticeable insulating effect.

Chapter 3: Moons

Many planets end up with natural satellites of one kind or another. Six out of Sol's eight planets have them, and even some asteroids have them.

Moons can come from a variety of sources, and astronomers still don't fully understand everything that goes into making a moon. Some moons are bits of protoplanetary flotsam captured by a planet's gravity. Others might form as eddies during the formation of a planet by cataclysmic collisions.

The Roche Limit
For a satellite of a planet, or a planet of a star, there's a rule that states that within a critical distance of the primary, no secondary object will be able to form. Tidal forces will simply pull it apart. While density is a variable of course, it basically works out to 2.45 radii. Outside this limit, natural moons (or planets) can form. Within this limit, only very small objects can form and you get rings. Even the tiny moons of Mars obey this rule. So, that makes a good rule of thumb: Rings inside, moons outside. In terms of orbit generation, ignore results of 1 or 2.

The Hill Limit
While moons can orbit their primaries at a great distance, eventually the gravity of the planet must give way to that of the star and the moon will orbit it as a planet in its own right. Stable satellite orbits can't exist beyond one-third of this point, called the Hill Limit (it's the same mechanic that allows planets to form within one-third of the closest-approach distance of of two binary stars). This works out to about 80-odd radii at Earth's distance from the Sun (the Moon orbits at about 60 radii). Beyond this point the star will snatch away any moons and they will become planets, planetoids or asteroids, depending on their mass. The closer to its sun a planet is, of course, the stronger the sun's gravity and the closer the Hill limit.

There's a lot of somewhat complex mathematics involved, but thankfully we can use a short cut. If a moon makes fewer than 9 orbits around its planet in the time that planet takes to orbit its sun, then it's not going to remain stable and will be pulled away by the sun. If there are more than nine “months” per “year”, the moon is safe.

Moons and Tides
One of the important effects moons and their planets have on each other are tides. Tides are the result of the fact that the strength of a gravitational field drops off with distance. Therefore, the nearest point on a moon is being pulled to the planet a little more strongly than its furthest point, causing the moon to stretch slightly. The closer a moon is to its planet, and the stronger the planet's gravity, the more pronounced the effect. An excellent example can be found amongst the four Galilean moons of Jupiter: Io, Europa, Ganymede and Callisto. Io is the closest, and fierce tides have given it a molten core that drives the most violent volcanism in the Solar System. Maps of Io are more like weather reports. Europa is a little further away, but even here tidal squeezing from Jupiter is enough to partially melt its icy mantle, smoothing out the primeval impact craters and create a subsurface ocean of water or slushy ice. Ganymede and Callisto are too far for tidal effects to have a profound impact, and must rely on their own internal heat for their own subsurface oceans, deep beneath the surface.

The mass of the planetary primary is very important; the higher the better. For instance, Saturn has many moons huddled in near its rings, but none of them experience the same tidal forces that fire up the Galilean moons.

Another effect of tidal forces on moons is that their rotation is locked to their orbit. The Moon, for instance, always shows the same face to the Earth, and this pattern is repeated wherever there are moons.
Tidal effects cut both ways, of course. In the very deep past, when the Moon was young, it orbited very close to the Earth. It was so close that the land rose by over sixty metres whenever it passed overhead. The Moon is much further away these days, but it still raises powerful tides in the Earth's oceans, even if it is too far away these days to do much to the more rigid rock. The friction between the oceans and the crust is causing the earth to slow in its rotation. Eventually, like Pluto and Charon, the Earth and Moon will have a completely locked co-rotation.

High Tide
If a glacian moon orbits a Jovian or transjovian planet close enough that it completes one orbit in less than 96 hours, It will heat up enough to generate a subsurface ocean beneath a thin ice crust ten or so kilometres thick (see Oceanography in Chapter 2: Planets). Beyond this point, glacian moons may still generate subsurface oceans, but they are deeper beneath the surface ice, often tens of kilometres deep.

If a moon orbits close enough to complete an orbit in less than 48 hours, it will generate hotspot volcanism equal in ferocity to a hadean planet. This volcanism will convert any Glacian moon into a Selenian one.

Large Moons and Life
Moons may be essential to planets that hope to play host to complex life. The axial tilt of a planet can be affected by massive events such as serious collisions. It can also be affected more subtly, by tidal tugs from other planets in the system. These tug a planet's axis here and there in a semi-random fashion, making the axial tilt vary wildly.

If life exists on such a planet, it may be faced with sudden and catastrophic alterations to the nature of seasons. In as little as a few millennia a planet may go from no tilt to extreme seasonality, with all the selection pressure that implies.

So, what do large moons have to do with this? The tidal tugs of a large moon will vastly outweigh those of neighbouring planets, serving to stabilise its tilt. For example, the axial tilt of earth varies by only a couple of degrees, and it varies steadily and predictably. Life has been able to adapt to, and take advantage of, the seasons. This is all because of the tidal influence of Earth's giant Moon. Large moons and their tides may have another beneficial effect. Tide-pools and tidal estuaries enabled life on earth to make a gradual transition from marine to terrestrial life. With no such helping-hands, the move to land might have been much more difficult.

Rings
Rings are related to moons, and are probably formed in much the same way. Rings lie within a planet's Roche limit, and can extend all the way down to low orbit. Ring systems may be rich and complex, like Saturn, or thin and Gossamer-like, like those of Jupiter and Uranus.

GENERATING MOONS

Number of Moons
When this accessory talks about moons, it refers to moons of planetoid to planetary is size, 800km or larger. Moons smaller than this are considered asteroidal and not detailed. Jovian planets in particular can play host to literally dozens of moons, and a great deal of time can be wasted laboriously cataloguing each and every little rock. More to the point, cataloguing their properties would expand this accessory to two or three times its size, taking into account shepherd moons, intertwined orbits and all the other little tricks gravity can play with these small

objects. The mathematics are mind-boggling. Suffice to say that if you require a tiny, asteroidal moon or ring-arc for a planet, feel free to indulge yourself. Just remember the Roche and Hill limits.

Terrestrial planets:	Jovian planets:
1d4-2 moons	2d4-1 moons

Eliminating the less-significant moons makes the generation of moon systems much simpler. Real-world examples using these criteria are below (Mercury and Venus have no moons, and those of Mars don't qualify):

Earth (nerean)	1 selenian
Jupiter (Eujovian)	1 selenian, 2 glacian, 1 planetoid/glacian*
Saturn (Eujovian)	1 glacian, 4 planetoid
Uranus (cryosubjovian)	4 planetoid
Neptune (cryosubjovian)	1 planetoid

*Europa straddles the border between glacian and planetoid.

Lunar Orbits

The orbital distance of your new moon or moons can be determined by rolling d6 three times as below:

Moons Distance = d6 x d6 x d6 planetary diameters; results of 1 or 2 indicate a ring system, if the planet is jovian. If the planet is terrestrial, a ring system will be present on a roll of 1 on d8. Otherwise, ignore the result and re-roll.

The orbital periods given below are, of course, rough guides only, subject to the subtle vagaries of each individual planet. They are, however, a solid foundation that you may use as a base to create something more suited to your purposes.

Orbital periods:

Mass Class	Orbital period at 1 diameter
0.01Me	8 hours
0.03Me	6 hours
0.1Me	4.5 hours
0.3Me	4.2 hours
1Me	4 hours
3 - 10Me	3.5 hours
0.03Mj	8.2 hours
0.1Mj	9.5 hours
0.3Mj	11.6 hours
1Mj	7.6 hours
3Mj	6.8 hours
10Mj	6 hours

Just as with planets, for other distances, $p^2 = d^3$, where p is the orbital period (in 1 diameter "months"), and d the distance in diameters.

Types of Moons

Moons can conceivably run the gamut of masses from planetoids to 1Me nerean worlds, although the latter are extremely rare. However, no matter what, there are a couple of important rules to keep in mind. For jovian planets, the most important is the Rule of 10,000.

The Rule of 10,000

There is a distinct relationship between the mass of a jovian planet and the combined mass of its moons. As they form, Jovian planets become very massive and so their gravity becomes very greedy, drawing vast amounts of matter to join the already massive core. A giant planet's potential moons are therefore starved of matter and their growth is constrained. The total mass of all of a jovian planet's moons is on average 1/10,000th of the planet's mass. Jupiter and Saturn both follow this rule very closely, while Uranus and Neptune have rather less mass in their moons. Uranus may have lost lunar mass when whatever cataclysm caused it to tip onto its side occurred. Neptune undoubtedly lost moons when it captured Triton into its orbit. Below is a table of jovian mass classes and the maximum moon mass.

So, when generating moon types, keep the total mass in mind. This mass may be distributed amongst the generated moons according to choice, or the mass may be randomly rolled as per the Planetary Mass table in Chapter 2. However, when all the available mass is "used up", any remaining moons are considered to be planetoids. In many cases there may be less, and on rare occasions there may be more. In case of emergency, when you just *must* have that extra selenian or glacian moon, such as with Jupiter itself, allow a maximum extra 0.01Me.

Moons of greater than the recommended mass are still a very small possibility, although mostly the result of freakish mischances, such as capture events. Capture should be considered as an alternative to save a planet whose eccentricity carries it across the orbit of a jovian planet. In such a case, rather than a shared orbit, the smaller planet can be captured into the planet's orbit as a moon. The highest mass that can be captured is listed on the table below.

Table M1: Moon Masses per Planetary Mass

Planetary Mass	Total Moon Mass	Maximum Capture Mass
0.03Mj	0.001Me (planetoids only)	0.01Me
0.1Mj	0.003Me (planetoids only)	0.03Me
0.3Mj	0.01Me	0.1Me
1Mj	0.03Me	0.3Me
3Mj	0.1Me	1Me*
10Mj	0.3Me	3Me*

*In the frigid and superfrigid zones, the captured moon will be a 0.3Me glacian. Larger planets become subjovians, but would fall into the planet under atmospheric drag.

Lunar Type and Mass

Selenian,Terran, Nerean, Glacian, Planetoid – Bodies just like their planetary counterparts.
Major Ring - A spectacular, bright ring system like that of Saturn.
Gossamer Ring - Very sparse, thin rings like those of Jupiter and Uranus. Almost invisible.

To determine the kind of moon or ring system, roll d8 and check below:

Moons
0 – 5 Planetoidal moon
6 – 8 Selenian/glacian moon
9+ Terran/nerean/glacian moon, 0.3Me
-1 for terrestrial planets
+1 for transjovian planets

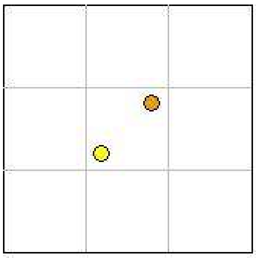
Rings
1 – 6 Gossamer ring
7 – 8 Major ring
There are no modifiers to ring checks

Appendix: Mapsheets

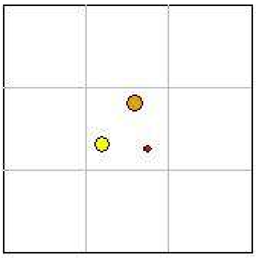
The following pages contain map blanks for use with this book. You may photocopy these as much as you wish for personal use.

Some suggestions for map symbols are provided on the sector map, although of course GMs are welcome to devise their own systems. You may prefer to use more pictorial symbols than the abstract ones given here.

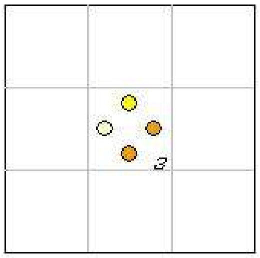
The sector map uses simple coloured circles to represent stars. You might want to use the colours from Figure 1 to show spectral class, or perhaps prefer to use your own colour scale. Giant stars should use larger circles, and red and brown dwarfs should probably be a little smaller. Positions on the sector map are as shown below:



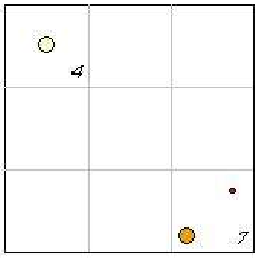
Binary System



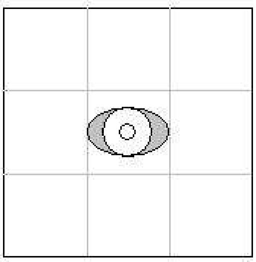
Trinary System



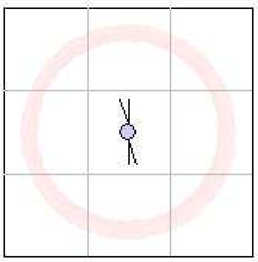
Quaternary System



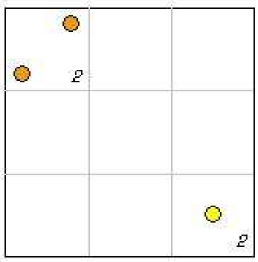
These systems do not share a cubic parsec



Planetary Nebula



Supernova Remnant



These systems *do*

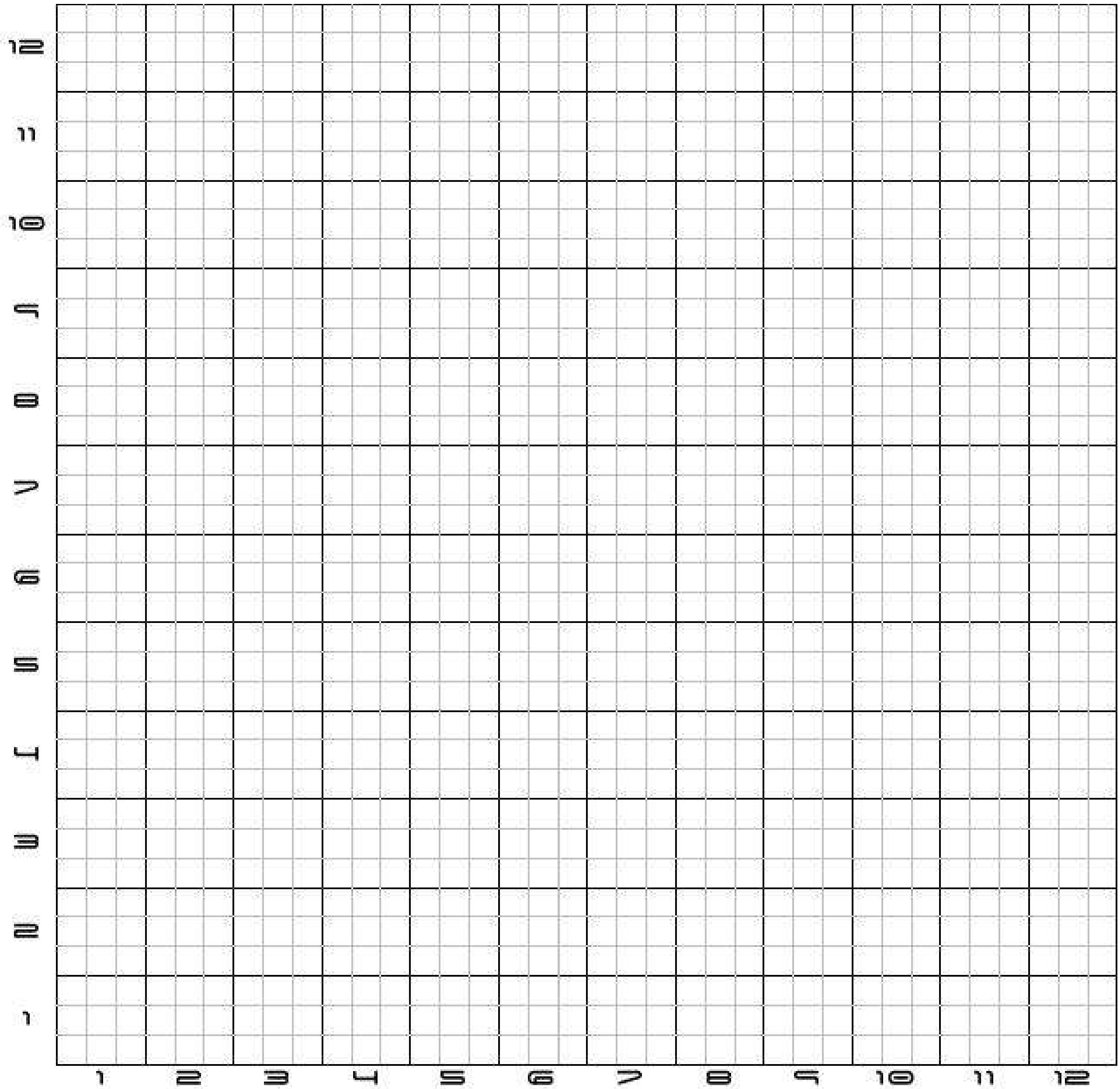
The solar system chart is different from the others in that is is a less graphic representation of a solar system. However, it neatly describes the orbital properties of each planet, as well as other information. The key shows how the map symbols are used to describe a solar system quickly and easily. If the AU scale is replaced with diameters, it can double as a lunar chart for planets with multiple moons.

The planetary map can be used to map any spheroidal body. The scale used per hex should be 25km per 400km diameter. It may be used to map moons as well as planets.

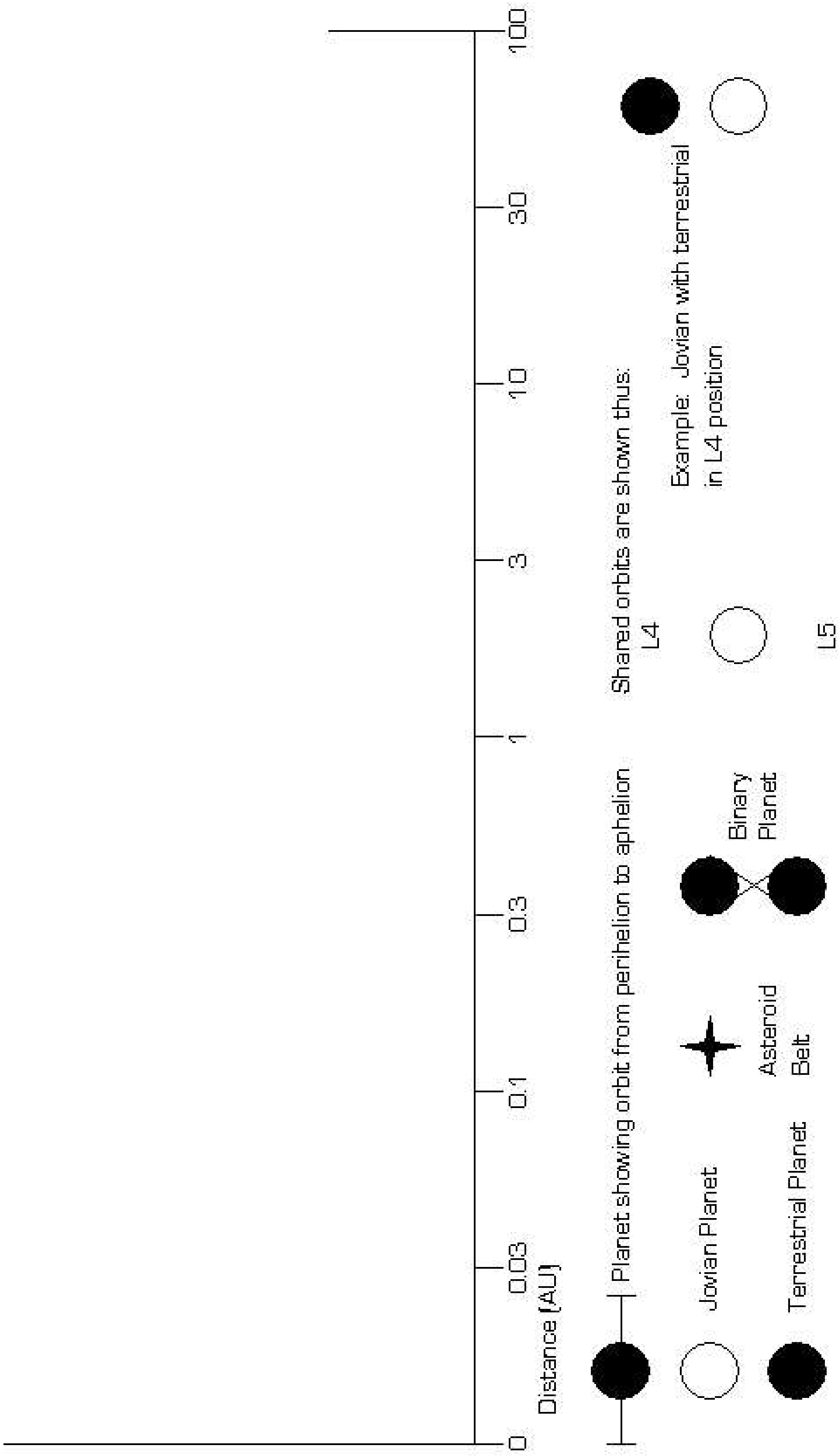
SECTOR MAP

SECTOR NAME: ________________________________

KEY:



SOLAR SYSTEM CHART



PLANETARY MAP