Chapter 4. Xenology : The Context of the Universe

"The universe is not hostile, nor yet is it friendly. It is simply indifferent."
- John Haynes Holmes (1879-?), in Sensible Man's View of Religion

"In such a universe as this what significance could there be in our fortuitous, our frail, our evanescent community ?"
- Olaf Stapledon, in Star Maker (1937)[1946]

"What is it all but a trouble of ants in the gleam of a million million of suns ?"
- Alfred, Lord Tennyson (1809-1892), in Vastness

"O thievist Night,
Why shouldst thou, but for some felonious end,
In thy dark lantern thus close up the stars,
That nature hung in heaven, and filled their lamps
With everlasting oil, to give due light
To the misled and lonely traveller ?"
- John Milton (1608-1674), in Comus, 1/195

"In a universe whose size is beyond human imagining, where our world floats like a dust mote in the void of night, men have grown inconceivably lonely. We scan the time scale and the mechanisms of life itself for portents and sighs of the invisible. As the only thinking mammals on the planet - perhaps the only thinking animals in the entire sidereal universe - the burden of consciousness has grown heavy upon us. We watch the stars, but the signs are uncertain. We uncover the bones of the past and seek for our origins. There is a path there, but it appears to wander. The vagaries of the road may have a meaning, however; it is thus we torture ourselves."
- Loren Eiseley, in The Immense Journey (1957)[2110]

We now cast our eyes skyward to contemplate a still grander perspective than even human literature, folklore and ethics can afford - the bound less twinkling oceans of the star-dusted firmament. The one commutual aspect of existence we can be reasonably sure of is the physical universe, that breathtaking panoply of brilliant suns, blazing galaxies and luminous nebulae which human and alien astronomers alike must share.

There are countless reasons why the cosmic panorama per se is of xenological significance. Ultimately, of course, the astronomical environment serves as the backdrop for all our speculations about life on other worlds. If we are to successfully evaluate the ubiquity of biology in the universe, we must attempt to isolate those features which all lifeforms will find in common. We must puzzle out whether humanity, life, and Earth are unique events or merely a footnote to a statistic in the Galactic Census.

Knowledge of the evolution and distribution of stars and galaxies will suggest the most profitable places to hunt for evidence of extraterrestrial civilizations. But our curiosity tugs at us more insistently. Where will life be most abundant in the Milky Way Galaxy ? In the central regions, the disk of the Galaxy, the spiral arms...? What kinds of stars are most likely to harbor lifeforms and planetary systems ? How many other civilizations might there be, and what stage of development have they reached ? What are the general constraints on xenopolitical systems as regards size, complexity and distribution ? Are there any cosmological limits to high technology and galactic engineering ?

We may also gain insight into the limits of alien philosophies of nature, the universe, and the very mechanism of creation itself. How did the universe come to be the way it is ? Has it always existed ? Will it ever die ? Are physical laws as we know them immutable, or do they vary in different parts of the cosmos or at different times ? Do other universes exist ? Is there any purpose to physical existence at all ? These fundamental questions have gnawed at the mind of man for millennia, and must also intrigue the sentients of other worlds.

The issues of xenology are intimately bound up with the features and properties of the physical universe.

4.1 The Universe

On a dark, clear evening the human eye can distinguish several thousand distant suns, all of which lie in the Milky Way (our home galaxy). Floating freely in Earth orbit our senses would be assaulted by the light of nearly six times as many stars. The Palomar 200" optical telescope - now the second largest in the world - has the light-gathering power of a million human eye balls and extends our vision to several billion celestial objects in this galaxy alone. And about ten billion galaxies are observable with present-day astronomical equipment, the farthest (3C 123) lying eight billion light-years distant.[1952]

How big is the universe ? An important clue was uncovered by the American astronomer Edwin Hubble back in the early 1920's, when he was measuring the atomic spectra emitted by various galaxies. The farther away the object, he found, the more its spectral lines appeared to be displaced towards the lower frequencies of light. This curious phenomenon, which became known as the "redshift," was interpreted to be a kind of Doppler effect for photons.

Much the same as a receding siren seems to be putting out lower and lower pitched sounds as it passes by, so do galaxies seem to emit redder light as they travel away from us. Since the most distant objects are seen to possess the greatest redshifts, the simplest explanation is that they are receding from Earth at velocities approaching the speed of light. Nearby galaxies are moving at a far more leisurely pace. Conclusion: The universe is slowly expanding.

This is not to say that Earth has the extraordinary good fortune to lie at the exact geometric center of all creation, simply because most all astronomical objects appear to be heading away from us. More correctly, our galaxy is like a spot of India ink on the surface of a spherical balloon. We are surrounded by billions of similar spots. As the balloon inflates, every point on its surface moves away from all adjacent points. From the chauvinistic viewpoint of each galaxy, all others will look like they're flying away at various speeds depending on distance. Each will view itself as the "center" of the universe! This idea that the cosmos will appear roughly the same from any position is called the Cosmological Principle.

The latest measurements of galactic redshifts seem to indicate that the speed of recession increases about fifty-five kilometers per second for each megaparsec* of distance from Earth.[1953] (This number is called the Hubble Constant.) Since the maximum velocity of recession which can be detected is the speed of light, then the outermost shell of the swelling universe should lie about eighteen billion light-years from Earth.

Of course, if the "balloon" deflates, points on its surface will rush together again. Using our value of the Hubble Constant, we can mathematically run time backwards and extrapolate to Time Zero - the creation event. The inverse of the Hubble Constant is in units of time and represents the age of the universe assuming a constant rate of expansion. This works out to a period of eighteen eons !**

But scientists believe that the expansion of the universe has not been constant; on the contrary, it has probably decreased with the passage of time because of gravity. Taking this into account, the true age of the universe will not be quite so large, and is now usually set at about sixteen billion years.[1953,1983] Our estimate of the radius of the universe, likewise corrected, drops down, to sixteen billion light-years.

Any theory of cosmology that purports to explain the mechanics of the cosmos must, at the bare minimum, be able to account for Hubble's redshift phenomenon. The one proposal which has been most successful in this regard is the Big Bang hypothesis.

According to this leading view of cosmic evolution, the universe began as a highly compact fireball of pure energy and infinite density. After perhaps a millionth of a second this density dropped off to nuclear values as the ylem or "cosmic egg" exploded outward.[2062] The overall temperature may then still have exceeded 1013 K.[1192] The stuff of the universe started to change from pure energy into matter, primarily neutrons.

When half an hour had passed most of the neutrons were gone, replaced by a mixture of 60% hydrogen ions and 40% helium ions (by mass), as well as a smattering of deuterium (heavy hydrogen).[1813]

Using this model, it can be calculated that at the one hour mark, the temperature was down to about 250 million degrees; after the passage of a quarter of a million years, it had fallen off to the present temperature at the surface of Sol. And 170 K was reached after 250 million years following the big bang.

This turned out to be a red-letter date in the evolution of the universe, because for the first time in history the density of matter became greater than the mass density of radiant energy. Protons and electrons must have coalesced into de-ionized H, He, and D atoms, leaving no more than 0.1% still in the plasma state.[1192] This signaled a dramatic change in the behavior of material. No longer was matter incessantly sloshed and stirred by the overpowering radiation field, which had kept it permanently osterized in a thin, gaseous form. Once radiation refrained from dominating the scene, matter was free to gravitationally condense into relatively huge, massive aggregates - supergalaxies, galaxies, and stars.[1813]

There are two variations of the Big Bang scenario upon which most discussion has focused. The first of these is known as the closed, or pulsating universe model. According to this thesis the universe is a gravitationally "bound" system. That is, some thirty eons or so from now the fragments from the original ylem explosion will cease their outward rushing and commence to fall back together again like the dots on the surface of a deflating balloon. Cosmic evolution occurs in a series of alternate expansions and contractions. At the very end, the Final Moment, everything is destroyed, the slate wiped clean in preparation for the beginning of the next eighty-billion-year cycle.

Besides giving rise to philosophical nihilism, this has interesting consequences for the development of life. During an expansion phase light is redshifted to the relatively harmless lower frequencies. However, during the contraction phase the intensity of dangerous high frequency radiation might become unbearable -- due to a blueshift effect. If the pulsating model is correct, then we are lucky to be alive during the half of the cycle most likely to be hospitable to life. In the second half, the development and expansion of biology would be severely restricted. Are we, asks Carl Sagan, "trapped in a vast cycle of cosmic deaths and rebirths ?"[20]

The second variant of the Big Bang theory is the open, or expanding universe model, which suggests that the cosmos will never stop enlarging and ultimately will disperse to infinity. In this view, all matter reached the "escape velocity" of the universe at the time of the ylem explosion : The cosmic radius increases indefinitely. This is in sharp contrast to the pulsating model, in which the radius oscillates between some maximum value and zero.

There is evidence to support the Big Bang theories. For instance, it will be recalled that the fireball cooled rather rapidly as it expanded. If this rate is extrapolated from the Bang to the present, sixteen eons later, the temperature should be down around a few degrees above absolute zero. This early prediction from evolutionary cosmology was verified in 1965 with the discovery of microwave radiation which fills the entire universe perfectly isotropically. The energy corresponds to a constant, uniform temperature of 2.7 K. This actual relic of the primeval ylem superexplosion strongly affirms the Big Bang theories, and appears to verify the Cosmological

Principle mentioned earlier.

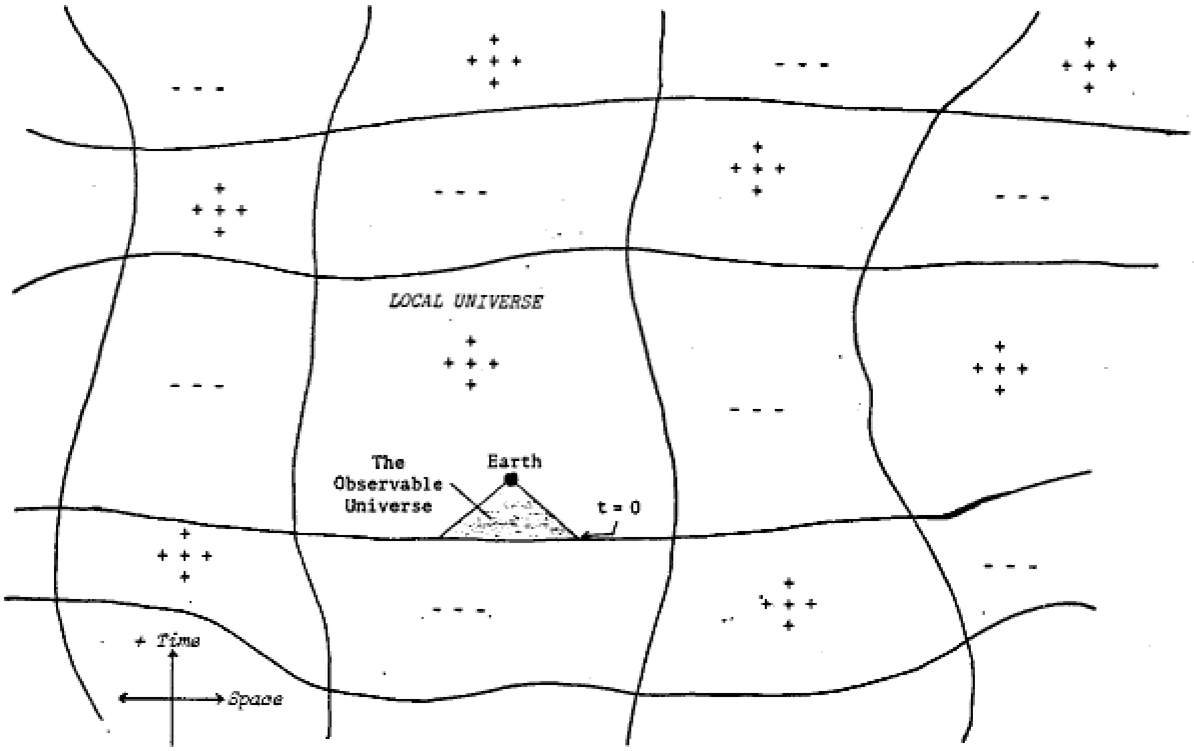
How can we decide whether the universe is open or closed? It turns out that if the mean density of the cosmos is less than about 5 x 10-30 gm/cm$_3$ (only about three atoms per cubic meter - intergalactic space is very nearly empty), then there is insufficient mass to hang onto the galaxies gravitationally. The universe would be open and must disperse to infinity.

Measurements of the actual density are difficult to make. However, based on the latest data, revised Hubble Constant, and such parameters as the observed density of galaxy-clusters locally and the abundance of deuterium in space,[1959] astronomers have reached a tentative conclusion : The universe is open.[1953]

Another class of cosmological theories which has persisted for decades in various forms is the steady-state model, which suggests that the universe is not thinning out at all despite the apparent recession of galaxies. According to a typical model of this variety, neutrons appear suddenly out of nowhere in the interstellar void, roughly one particle per cubic meter every few eons or so. The local density is thus maintained at a constant level, the outflowing mass exactly balanced by the spontaneously generation of matter within the included volume.

The most recent attempt to forge a more plausible steady-state model is the Hoyle-Narlikar cosmology (Figure 4.1).[1956] This is based on the concept of a "mass field," which is such that the mass of a chunk of matter is dependent upon its spatial and temporal location in space-time. The universe consists of a checkerboard pattern of normal and reversed mass fields. While mass never becomes negative, its value does vary from zero at a boundary to some maximum value defined by the field. Einstein's relativistic cosmology is said to represent a special case,[1955] valid near a boundary but not across it or very far away from it. Astronomer Hoyle infers that we are close to such a boundary.

Figure 4.1 The Hoyle-Narlikar cosmology[1956]



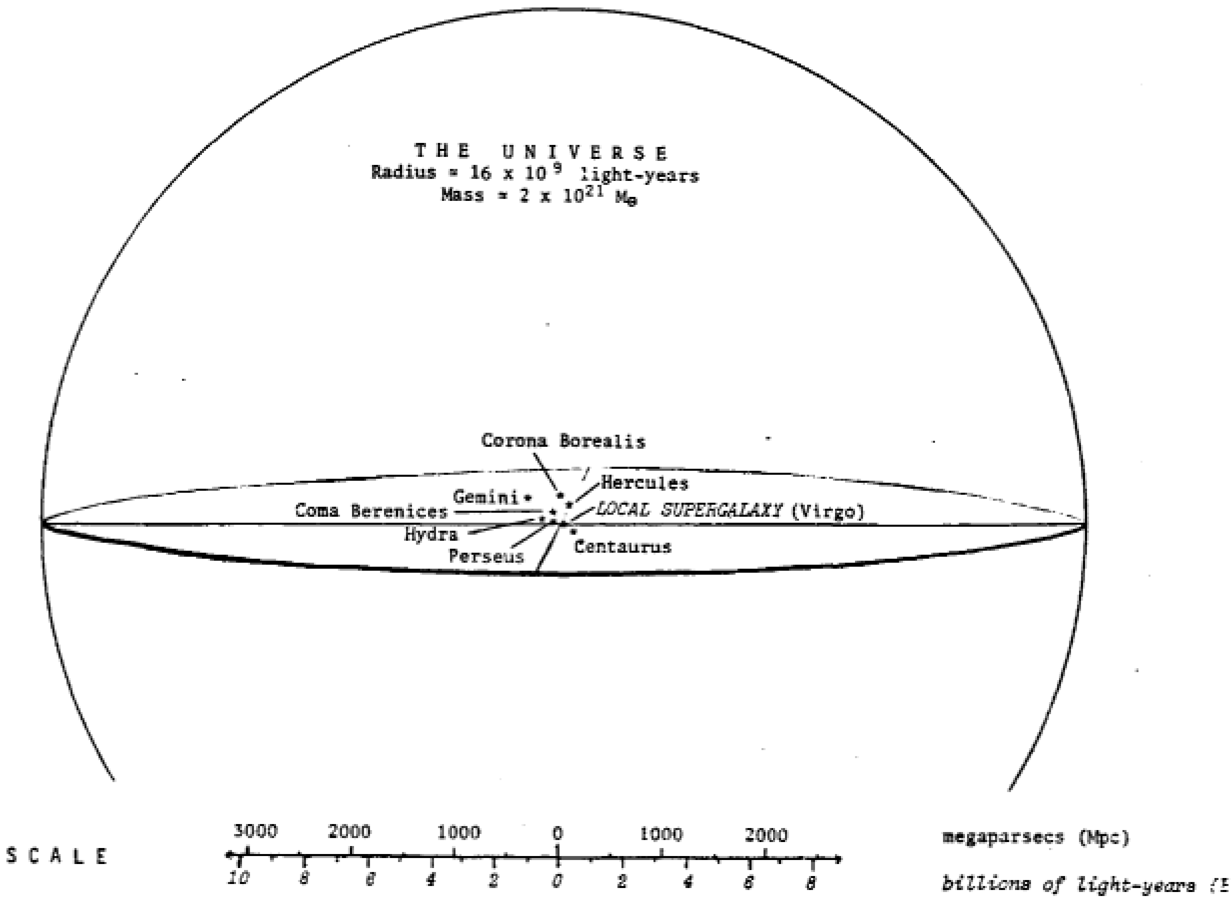
THE HOYLE-NARLIKAR COSMOLOGY[1956]

If mass has been steadily increasing since we crossed the border some sixteen billion years ago, then galaxies we passed along the way - which lie nearer the boundary - should have older, less massive atoms. If less massive atoms also have less massive electrons, these electrons should lie in larger atomic orbits and generally emit spectral lines of lower frequency. That is, the spectra should be redshifted. The observed redshift of galaxies is explained, not by their headlong flight, but because the electrons comprising their atoms are lighter in weight.[1954]

Hoyle also has an explanation for the 2.7 K background radiation. It is known that light is most efficiently scattered by particles of low mass. Hence, the boundary at Time Zero (where mass goes to zero) must completely scatter all radiation coming from previous cells. The background is just the smeared out starlight emitted by galaxies on the other side of the border. Hoyle calculates that such galaxies still exist prior to Time Zero as far back as 150 eons.[1956]

Figure 4.2 The Local Universe[399,1985]

THE LOCAL UNIVERSE[399,1985]



Many other unusual theories have been proposed from time to time, including the Klein-Alfvén matter-antimatter cosmology,[1192] the universe-as-a-black-hole idea[1963] (and black holes as accretion nuclei for elliptical[653] and spira[1964] galaxies), the Everett-Wheeler "splitting universe" scheme[1982,3683] and other multiple universe ("multiverse") theories.[1512,1957,1958] The cosmological problem has not yet lent itself to a definitive solution. Perhaps it never will until we are able to ask ETs, situated elsewhere in distant space, for their observations and ideas.

* 1 megaparsec(Mpc) = 10^3 kiloparsecs(kpc) = 10^6 parsecs(pc) = 3.26 x 10^6 light-years(ly) = 3.07 x 10^{22} meters(m).

** An eon is one billion (10^9) years.

4.2 Galaxies

If the Big Bang theories of the universe are essentially correct, then it was not long after Time Zero on the cosmic time scale that matter began to condense gravitationally. Any small nonuniformities in the density of the heretofore homogeneous gas would be aggravated, and local condensations could begin to occur.

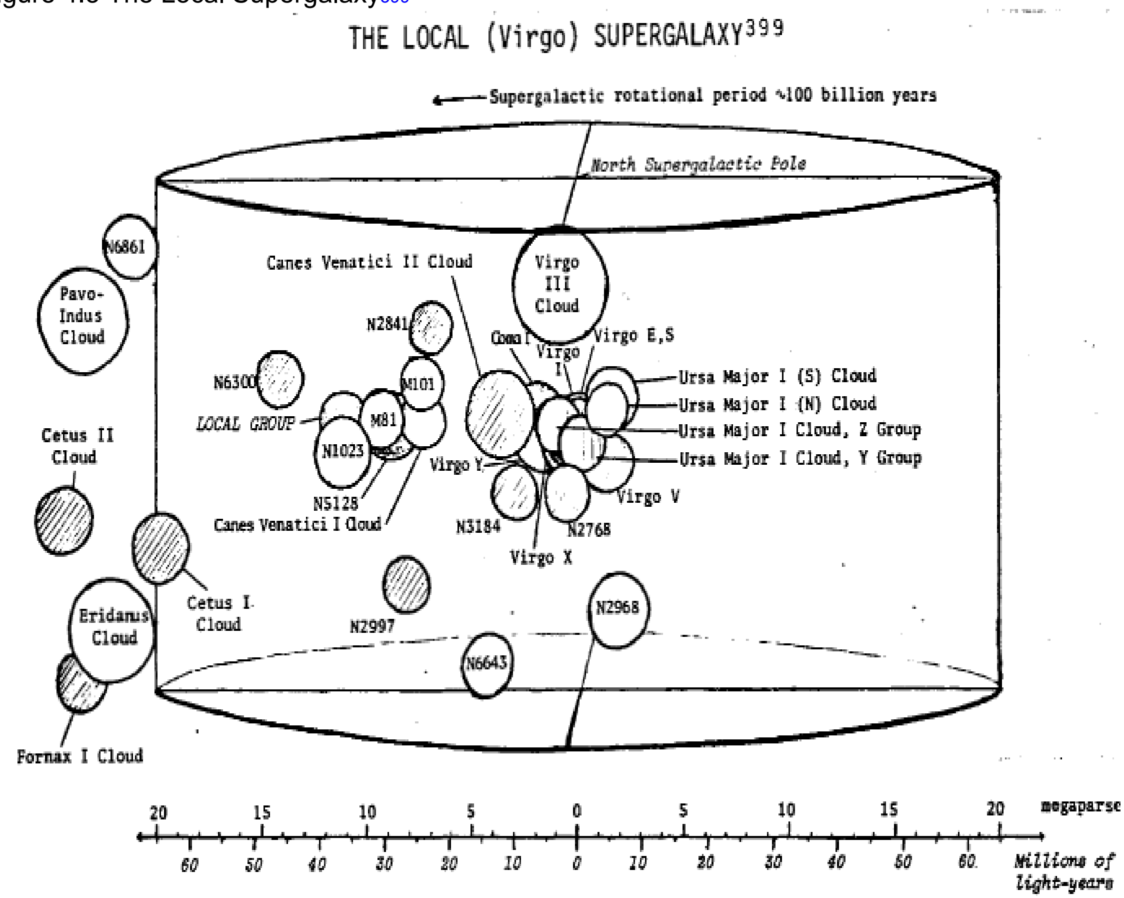
Today we bear witness to what astronomers believe is the end product of that grand condensation process : Stars. These giant plasma balls glow by the energy of intense thermonuclear fusion reactions, at temperatures reaching many hundreds of millions of degrees in their cores. These incandescent globes are collected into great structures called galaxies, which exist in many shapes and sizes. It is now known that galaxy-clusters also exist, assemblages of a few to as many as thousands of individual galaxies. More than 80% of all nearby galaxies belong to such clusters.[1974,2150] The spaces between them are virtually devoid of stars, gas, and other matter.

A few astronomers today are of the opinion that order exists in the cosmos on an even larger scale. They claim to have discovered monstrous aggregates of galaxy-clusters possessing literally millions of individual galaxies, with masses ranging from 10^{16}-10^{17} Msun each.[20,399,1191,1271,1974,1985,3676]

More than twenty nearby "supergalaxies" have been tentatively identified, having diameters from thirty to ninety megaparsecs.[1974,1985] However, less than a dozen can be identified in much detail within about 160 Mpc (~500,000,000 light-years).[399] (For comparison, the radius of the entire universe in the Big Bang cosmologies is roughly 4900 Mpc.) The spaces between supergalaxies is incredibly empty, even more so than between galaxies and clusters of galaxies.

We are believed to be embedded in the Virgo Supercluster, otherwise known as the Local Supergalaxy (Figure 4.3). The Local Supergalaxy is a squat, roughly cylindrical collection of nearby galaxy-clusters with a total mass of perhaps 1015 Msun.[2025] It is about forty megaparsecs in diameter and twenty megaparsecs thick.[399] Its radius is thus about 0.8% that of the known universe, which is about 10-7 of the total "volume" of the cosmos.

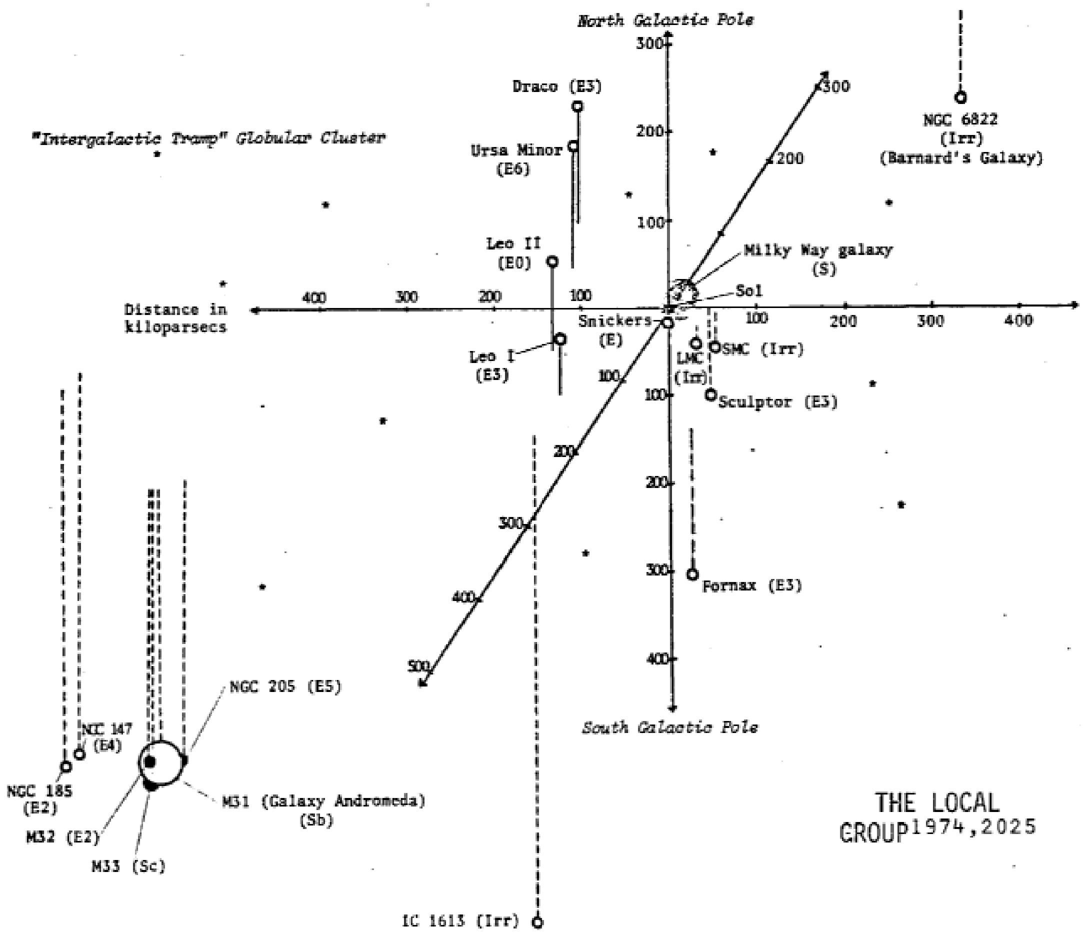
Figure 4.3 The Local Supergalaxy[399]



The Supergalaxy rotates counterclockwise as viewed from the North Super-galactic Pole, about once every hundred billion years. Since the origin of the universe, it has yet to make so much as a quarter-turn!

We are situated in a galaxy-cluster, called the Local Group (Figure 4.4), some twelve megaparsecs from the center of the Supergalaxy near Virgo I. We are rotating with the Supergalaxy at about 2.5 million kilometers per hour, roughly 0.2% the speed of light. The drawing depicts the approximate extent of the Local Supergalaxy as it is presently understood, along with the thirty-one largest galaxy-clusters* in this hemisphere. It should be noted that our own Local Group is the smallest of these.

Figure 4.4 The Local Group[1974,2025]



Galaxy-clusters range from as little as fifty kiloparsecs in diameter (Stephan's Quintet, four member galaxies) to more than eight megaparsecs (Coma cluster, several thousand members). Ours is a modest-sized cluster, with twenty-one member galaxies and a diameter of 800-900 kpc.[1974,2025] The Local Group is somewhat flattened in shape, with most components (Table 4.1) in the southern hemisphere of our Milky Way Galaxy.** Eleven intergalactic tramp globular star clusters have also been spotted, the lone gypsy wanderers of the forbidding intergalactic void.[1974]

Table 4.1 The members of the Local Group[1945,1974,2025]

Galaxy	Type	Mass	Diameter	Distance	RA	Dec.
		(Me)	(kpc)	(kpc)		

Spirals						
M31 (Galaxy Andro meda)	Sb	4 x 1011	52	680	0h 40.0m	+41.0°
MILKY WAY GALAXY	Spc	1.5 x 1011	30			
M33	Sc	2 x 1010	18	700	1h 31.1m	+30.4°
Ellipticals						
Snickers	dE	2 x 108	2.	16.8		
Leo II	dE0	1 x 106	1.3	230	11h 10.8m	+22.4°
Andromeda I	dE0	1 x 104	0.5	680	0h 43.0m	+37.4°
Andromeda II	dE0	1 x 104	0.7	680	1h 13.5m	+33.1°
1132	E2	2 x 109	2.1	680	0h 40.0m	+40.6°
NGC 185	E2		2.9	680	0h 36.1m	+48.1°
Andromeda III	dE3	1 x 104	0.9	680	0h 32.6m	+30.2°
Sculptor	dE3	3 x 106	2.4	86	0h 56.5m	-34.0°
Fornax	dE3	2 x 107	6.2	188	2h 37.5m	-34.7°
Leo I	dE3	3 x 106	1.8	230	10h 5.8m	+12.6°
Draco	dE3	1 x 105	1.0		17h 19.4m	+58.0°
NGC 147	84		2.4	680	0h 30.4m	+48.2°
NGC 205	ES		4.2	680	0h 37.6m	+41.4°
Ursa Minor	dE6	1 x 105	2.4	68	15h 8.2m	+67.3°
Irregulars						
Large Magellanic Cloud	Irr	2 x 1010	8.		5h 26.0°	-69.0°

(LMC)						
Small Magellanic Cloud (SMC)	In		5.	61	0h 50.0m	-73.0°
IC 1613	Irr		4.	680	1h 0.6m	+1.7°
NGC 6822	Irr		1.7	660	19h 42.1m	-14.9°

There are basically three kinds of galaxies: Irregulars, spirals, and ellipticals (Table 4.2). Irregulars are small, formless collections of stars, containing perhaps 109 Msun. These galaxies consist of about 10-50% neutral hydrogen gas and dust[20] and have very few old reddish stars and very many young blue-white stars.[1974] Much of the matter that could be utilized in the construction of stars hasn't been used up yet.

Spiral galaxies have consumed far more of their hydrogen - only about 1% of the original amount remains, on the average. There are a fair number of both old and young stars. The typical spiral has three major components : The halo (a spheroidal volume of space with very old stars in highly elliptical orbits), the nuclear bulge or "core," and the galactic disk (which contains the spiral structure and most of the mass). Great dust lanes are usually very conspicuous throughout.[20,1976]

Elliptical galaxies are generally ellipsoidal in shape. Virtually all of the neutral hydrogen has been depleted, and there is little dust. Most of the building materials for stars are gone. Few suns have formed in very recent times; consequently, the stars tend to be very old.

Table 4.2 Characteristics of galaxies[1945,1974,2025]

Property	Ellipticals	Spirals	Irregulars
Total mass (in Msun)	106 - 1013	109 - 4 x 1011	108 - 3 x 1010
Diameter (light-years)	2000 - 500,000	20,000 - 150,000	5000 - 30,000
Diameter (kiloparsecs)	0.6 - 150	6 - 50	1.5 - 9
Mass density (Msun/pc3)	<0.01	0.01 - 0.1	0.001 - 0.01
Total Luminosity (Lsun)	106 - 1011	108 - 1010	107 - 109
Neutral hydrogen gas, fraction of total mass	~0.01%	~1%	~10%
Stellar types	G - M	A - M	A - F

present			
Stellar age composition	Old stars	Some new, some old	New stars

Msun = one solar mass = 2 x 1030 kg
Lsun = solar luminosity = 3.84 x 1026 joules/sec

The above taxonomy is not believed to be an evolutionary sequence, say, from youth to senility. Each of the three types of galaxy is thought to have originated in much different ways. For instance, if we start out with a very low mass protogalaxy, the hydrogen density will be low and stars cannot form very fast. An irregular galaxy is the result, such as the Large Magellanic Cloud in our own Local Group. If the mass is large but rotation is slow, then most of the hydrogen has a chance to condense into stars before the contraction causes angular momentum to rise prohibitively. The matter is consumed immediately, leaving none for later on. An elliptical galaxy is the end product of this process. Finally, if mass is high and rotation is fast, star formation will proceed with greater restraint. Stars may continue to form for many tens of billions of years. Such is the probable history of a spiral.[20,1974]

Current estimates of the abundance of galactic types run as follows: Spirals 60%, ellipticals 30%, irregulars 10%.[1973,2150,2475] There are two subclasses of spirals, normal and barred. The arms of bar spirals attach to a thick girder of stars passing symmetrically across the center of the galaxy. (The Milky Way itself is believed by some to have a small football-shaped, bar-like structure at its center.[1976]) Normal spirals with spheroidal cores are twice as abundant as the barred variety. About a million large galaxies lie within a few hundred megaparsecs of Sol.[20]

About half of all galaxies are "dwarfs."[1945] Dwarf ellipticals and irregulars exist; probably for dynamical reasons, there are no dwarf spiral galaxies.[1945] Roughly 5% of all galaxies form physical pairs ("binary galaxies") or multiple systems, and at least 1% show some "marked visible peculiarity".[1973]

Which galaxies are most likely to harbor intelligent life ? One of the prerequisites for life as we know it is a planetary environment in which to flourish. Perhaps an atmosphere and oceans are also required, along with an abundance of various carbonaceous chemical substances. It appears fairly safe to conclude that "heavy elements" (carbon, oxygen, silicon, etc.) must be present if life is to arise. Primordial hydrogen and helium alone won’t do.

Scientists believe that heavies are generated as a natural product of stellar evolution. Normal thermonuclear processes in stars produce elements that run the gamut from lithium to iron, and stellar supernovae generate still heavier atoms (iron through uranium). A single, good-sized supernova explosion may inject as many as 103 Earth-masses of heavies into the interstellar medium.

Over a period of billions of years, the stuff from which stars are born has become more and more enriched with heavy elements. Ultimately, this has made possible both planets and the development of life. But where are these heavy atoms most abundant ?

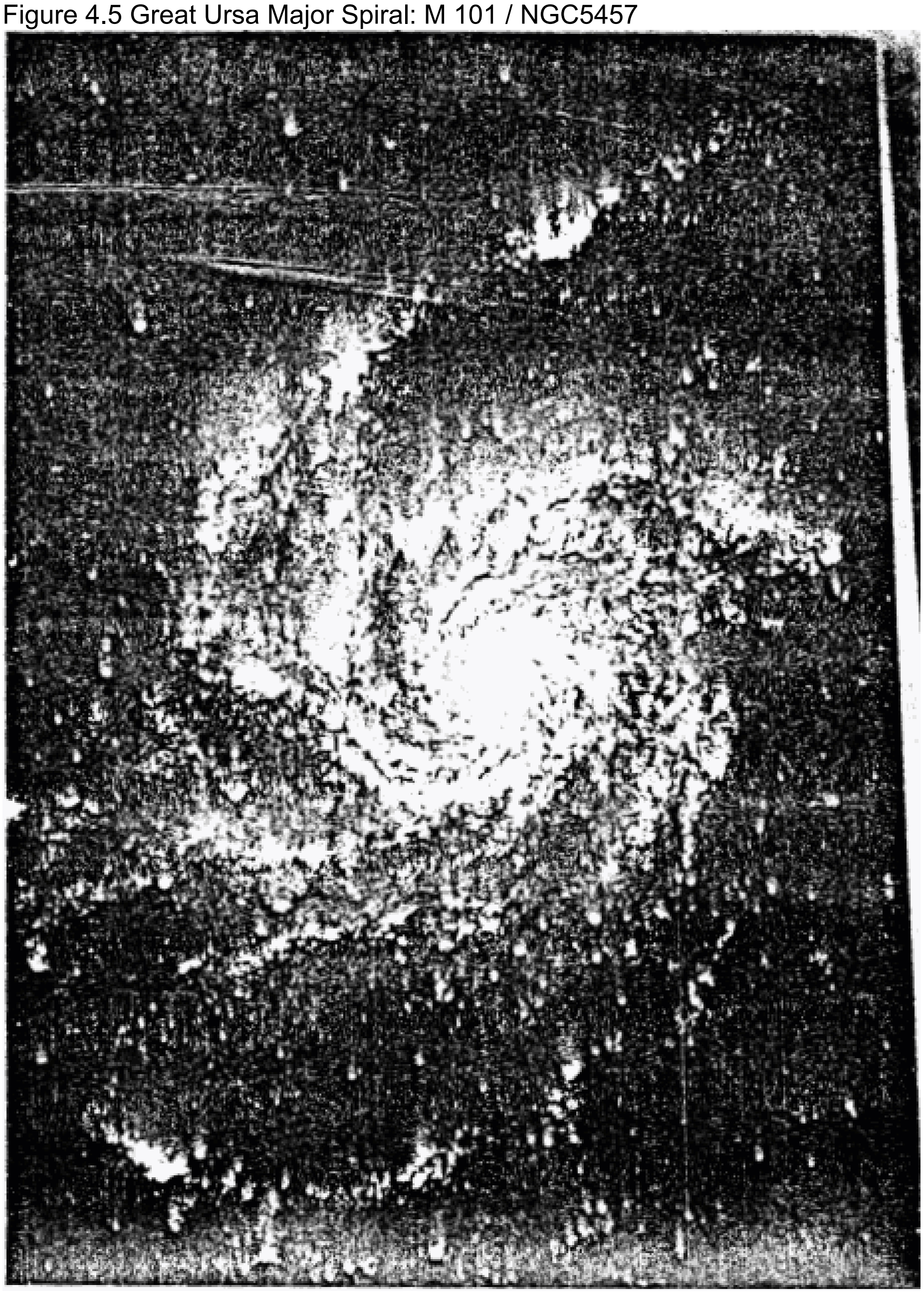
It is generally agreed that dwarf galaxies are extremely metal poor.[1816,1818] Consequently, we may immediately eliminate about half of all galaxies from contention.

We also know that virtually all stars in elliptical galaxies were formed at least ten billion years ago, soon after the Big Bang.[1974] Although there is some evidence that the heavy element deficiency is small or negligible compared to our Galaxy,[1816] if the theories of stellar nucleogenesis are correct then elliptical galaxy stars appeared long before the interstellar medium was impregnated with heavies. So ellipticals probably contain fewer habitable worlds.

Spectroscopic data for irregular galaxies indicate a marked deficiency in heavy elements,[20] as much as 30% less than in our Galaxy generally.[1816] Irregulars are slow starters - the ambient gaseous medium probably has not been sufficiently enriched to produce as many planetary systems. Furthermore, the available mass in irregular galaxies tends to run a couple orders of magnitude less than that available for star-building in ellipticals and spirals.[1945] We would therefore expect somewhat fewer sites for life than in our own Galaxy.

It appears that the best place to look for biology is in the spiral galaxies (Figure 4.5),[2032] a conclusion tentatively affirmed by our presence in one. This is indeed fortunate, since these comprise a majority of all giant galaxies.

Figure 4.5 Great Ursa Major Spiral: M 101 / NGC5457



Nearby spiral galaxy, yet outside our Local Cluster. Note heavier, well-knotted arms and smaller core as compared with spirals of Plates I and IV. (Mount Wilson and Palomar Observatories, Plate VIII from Broms[1191])

* Galaxy clusters seem to form "clouds" within the main corpus of supergalaxies. The Local Group is a member of the Local Cloud of clusters. The Cloud is tilted about 140° with respect to the Supergalactic Plane.[1984] The Local Cloud also possesses rather large regions of high-velocity neutral hydrogen gas clouds. These intergalactic gas clouds (IGCs) mass about 108-109 Msun, and sport about 100-1000 atoms per cubic meter.[1986] In the Local Cloud of galaxy clusters, there are about twenty IGCs per cubic megaparsec.[1986]

** The largest Local Group member - Galaxy Andromeda - has an apparent velocity towards Sol, believed due to our rotation about the center of the Milky Way.[1337] Andromeda is also tilted about 150° to our angle of view.[2025]

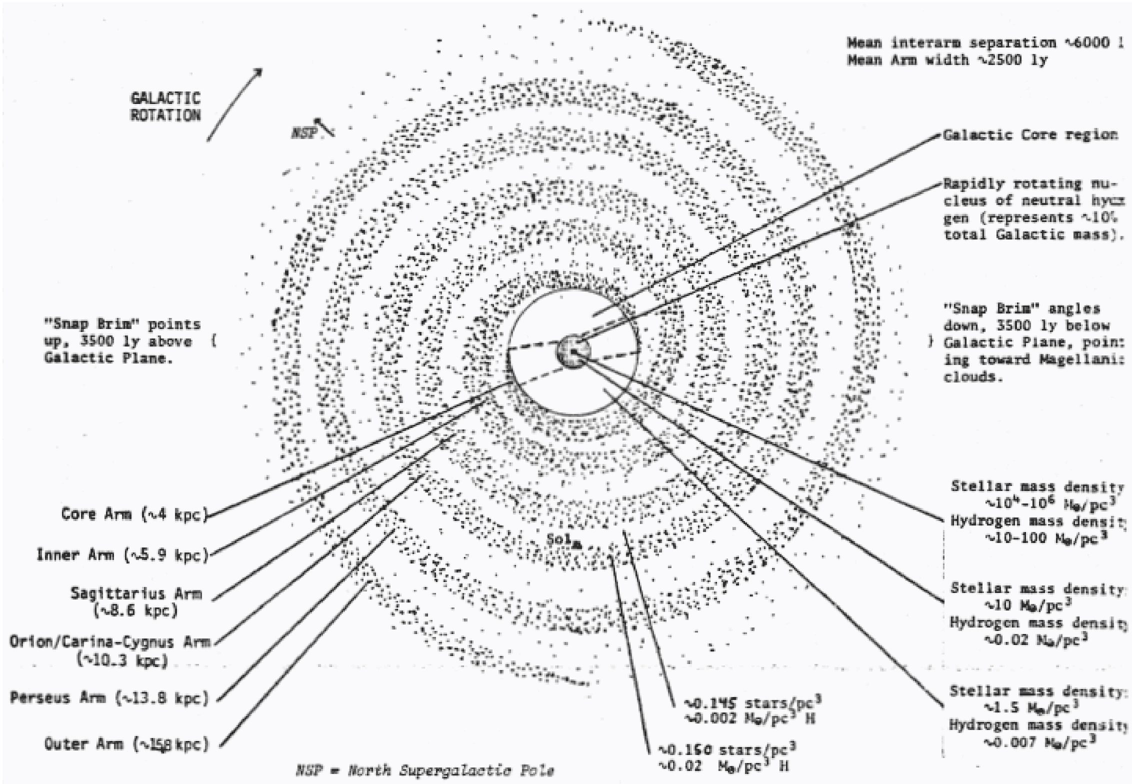
4.3 The Milky Way Galaxy

Our Galaxy is a rather typical spiral, consisting of three distinct regions (Halo, Core, and Disk) and four distinct components (stars, gas, dust and high energy particles) (Figure 4.6).

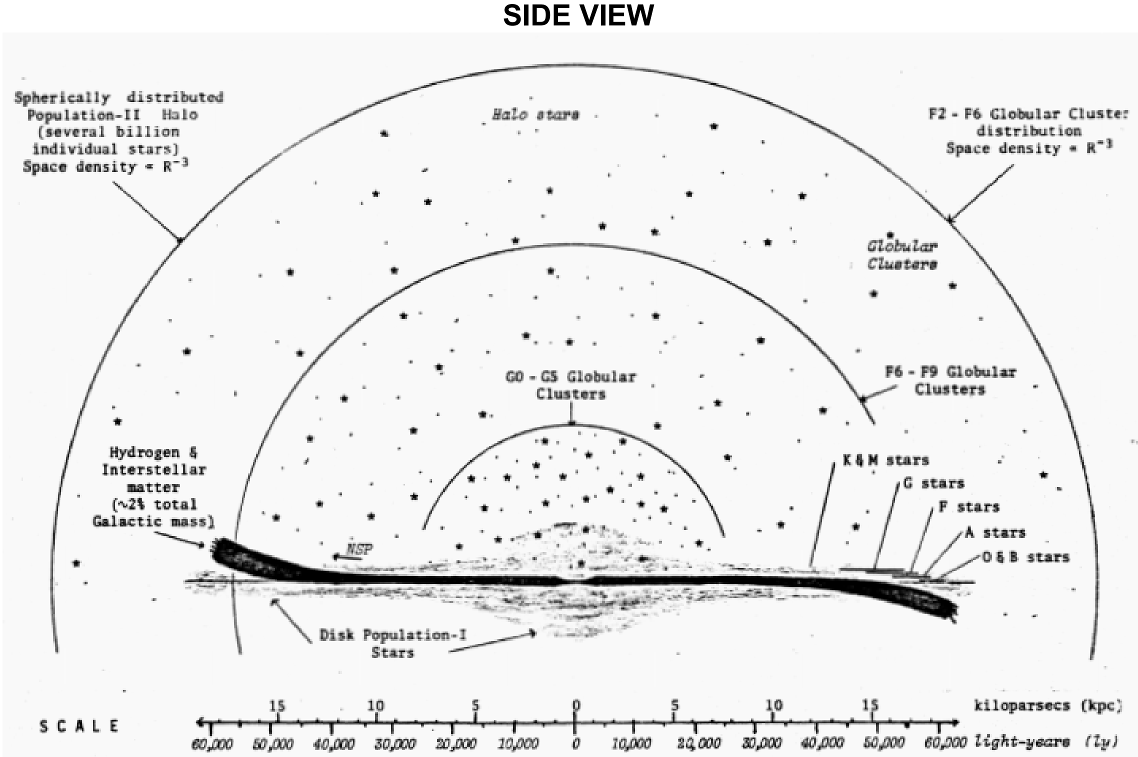
The Halo is a rather thin distribution of very old stars, spread out roughly spherically to a radius of twenty-five kiloparsecs or more from center. Probably about 5% of the entire mass of the Milky Way lies in the Halo[1781] (~17% of all stars[1816]). The Core is several kiloparsecs in radius, and stellar densities rise to values millions of times higher than near Sol. This closely-packed nucleus of our galaxy contains perhaps 10% of all stars.[57,1976] The main disk of stars is a bit more than fifteen kiloparsecs (50000 ly) in radius and averages about one kiloparsec thick. Sol is located only ten parsecs above the Galactic Plane,[20,57] and about ten kiloparsecs from the center.[20,1945,1976]

Figure 4.6 The Milky Way galaxy (schematic only)[1945,1961,1976,1780,1816]

TOP VIEW

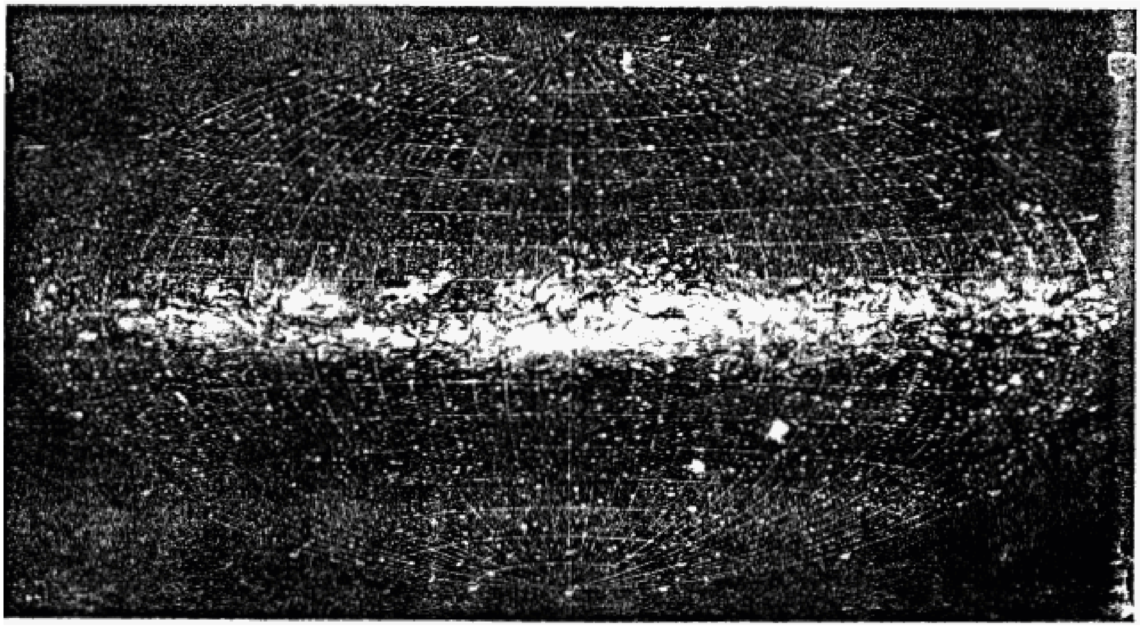


SIDE VIEW



The gross mass of the Milky Way is about 1.5×10^{11} Msun (3×10^{41} kg), representing a total of perhaps 250 billion stars of various types (Figure 4.7). Its aggregate energy output is roughly 5×10^{37} watts, and it rotates once every 240 million years in the clockwise direction as viewed from the North Galactic Pole. The Milky Way has made some fifty revolutions since its initial condensation twelve billion years in the past, and Sol has traveled nearly twenty full circuits since the origin of the Solar System about 4.6 eons ago.

Figure 4.7 Composite picture of the Milky Way (Lund Observatory, from Shapley[1878]



The stars to be found in each of the three regions of the Galaxy are of distinctly different character. The Halo "Population II" suns are very old, reddish stars with heavy element abundances hundreds of times less than in the vicinity of Sol and in the Disk generally.[1945,2032] These stars have highly elliptical orbits around the Core, and appear to be a relic of an earlier evolutionary stage of the Milky Way. Both individual stars and giant spherical collections (called globular clusters) inhabit the Halo. Globulars usually have 10^5-10^6 old Population II stars, and run 20-100 parsecs in diameter.[1556,1973]

The Disk "Population I" comprise the bulk of the stars in our Galaxy. Sol and most of our stellar neighbors are members of this population, although there are certainly a few Halo stars kicking around in the Disk (only about 3-5% of all stars near Sol[1816]). Disk stars have nearly circular orbits about the Core, and are pretty well confined to a layer one kiloparsec from the Galactic Plane.[1780]

It is believed that the Core is also comprised of Disk Population I stars, but there are some peculiar differences. The Core suns tend to be very old, reddish objects much like the Halo population, and yet the abundance of heavy elements appears to be at least six or seven times higher than in the Disk, near Sol.[1818]

Like the stars themselves, interstellar gas is composed mainly of hydrogen (about 60% by mass) and helium (about 40% by mass). These gases, whether neutral or ionized, occur in discrete patches several parsecs wide in concentrations of more than ten atoms per cubic centimeter. A few exceptionally small, concentrated clouds exist with densities well above 1000 atoms/cm3 - as in the Orion Nebula and the Horseshoe Nebula.[1816] In the Milky Way there is an estimated 6×10^7 Msun of ionized hydrogen and 1.4×10^9 Msun of neutral hydrogen, for an overall density of about 0.6 atoms/cm3.[1945]

Both gas and interstellar dust (dust mass ~10^6 Msun or less) lie flat in the Disk, confined to within two hundred parsecs of the Galactic Plane.[1816] The presence of this dust (10^{-3}-10^{-4} cm particles) obscures visibility along the Plane by absorption and scattering of light -- which limits our view of the Galaxy in the optical spectrum to a few thousand parsecs along the line of sight.[20,1972]

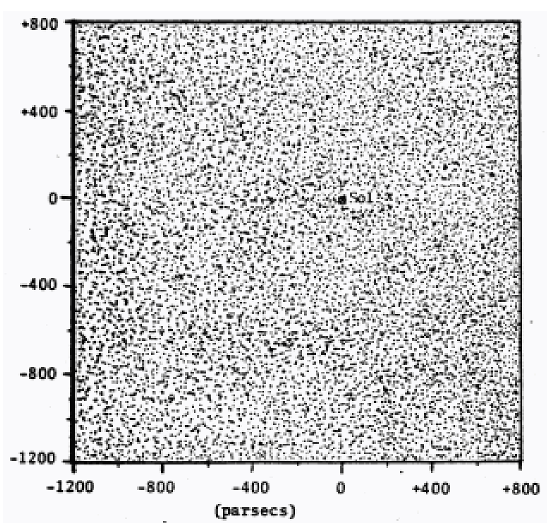
But it is important to keep in mind how truly thin this dust is dispersed. While we find at least one atom of hydrogen in each cm3 of interstellar space, there is only one tiny dust flyspeck in a cube of space twenty kilometers on an edge.

New stars are constantly forming in these dust clouds, as well as larger grains of "dirty ice."[1972] Blast waves from novae and supernovae, galactic winds and wakes,[1151,1960] and density waves that may be responsible for the spiral arms all propagate in this tenuous "galactic atmosphere."

We have until now neglected what is probably the most interesting feature of the Milky Way - the spiral arms. Contrary to common belief,[607] they are not concentrated regions of stars. The brilliant arms of spiral galaxies have less than 5% more stars than interarm regions (which is where Sol is).[57] The most visible among these few extra stars are the class O and class B suns, the gas-guzzling "cosmic Cadillacs" of the Galactic showroom. These showy white stars are very massive and very young, and they consume all their hydrogen fuel in a relatively brief time. The spiral arms are regions of much higher gas density, marking off the boundaries of the maternity wards of the Milky Way. All normal Disk stars, as well as O and B classes, are born there.

Were we to photograph the Disk so as to eliminate the 0.1% or so of ostentatious O and B suns, we would see an almost flat, featureless distribution of normal stars (Figure 4.8). It is only because of a very few bright stars that we have any visible spiral structure at all. Hence, the Galaxy really appears to be a solid dish of common yellow and red stars with a very light sprinkling of hot, white ones in a generally spiral pattern.

Figure 4.8 The nature of the spiral arm feature of the Milky Way Galaxy

<table>
<tr>
<td>
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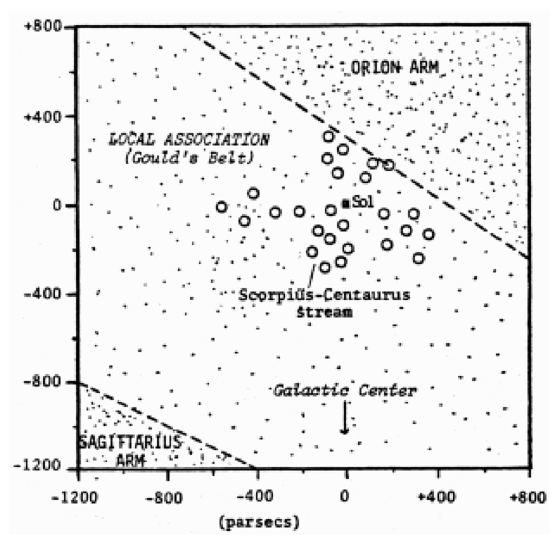
<td>
</td>
</tr>
<tr>
<td>A - F - G - K - M Disk Population
~99.9% of all Main Sequence Stars
Main Sequence lifetime > 200 million years</td>
<td>O - B Spiral-Arm Population I
~0.1% of all Main Sequence Stars
Main Sequence lifetime < 200 million years</td>
</tr>
</table>

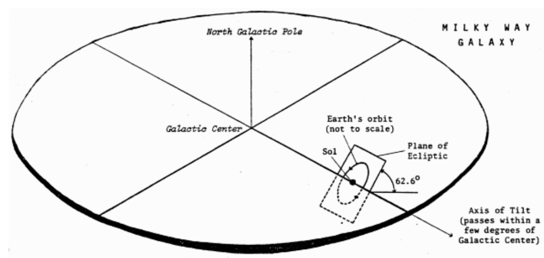
Since O and B stars have such short lifetimes, most of them die before their orbits can carry them very far from where they were born. A few do escape, however, and become mixed in with the rest of the stars. (Regulus, in the constellation Leo and about 26 parsecs from Sol, is one such escapee.) O and B suns are largely confined to within 70 parsecs of the Galactic Plane,[1780] and have virtually perfect circular orbits around the Core in the Plane. These stars are sometimes referred to as "Extreme Population I."

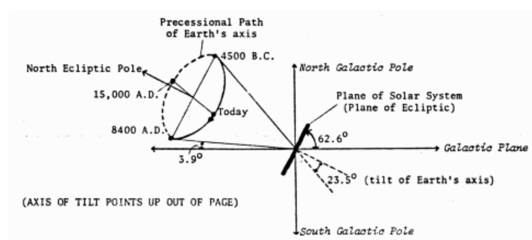
There is one minor complication to the view of the Milky Way presented thus far. The concentration of hydrogen in the spiral arms is a stable feature of the Galaxy, and is thought to represent a wave of greatly increased gas density traveling across the Disk. Where density is highest, the hot O & B stars can be formed, trailing from what amounts to a galactic density-shockwave.

We recall that Sol orbits the Core (Figure 4.9) approximately once every 240 million years. The problem is that the spiral density wave circles the Galaxy at a much slower rate, about once every 400 million years. Consequently, the bright spiral arm stars trail forward,* not backward, from the leading edge of the bow shock.[1976]

Figure 4.9 Position and orientation of Earth and Sol in the Milky Way Galaxy

North Galactic Pole :
RA = 0h 49m
Dec = +27.4°
(in Coma Berenices)
South Galactic Pole :
RA = 12h 49m
Dec = -27.4°
(in Sculptor)
0° Galactic Longitude :
RA = 17h 43m
Dec = -28.9°
(Sol -- > Galactic Center line)



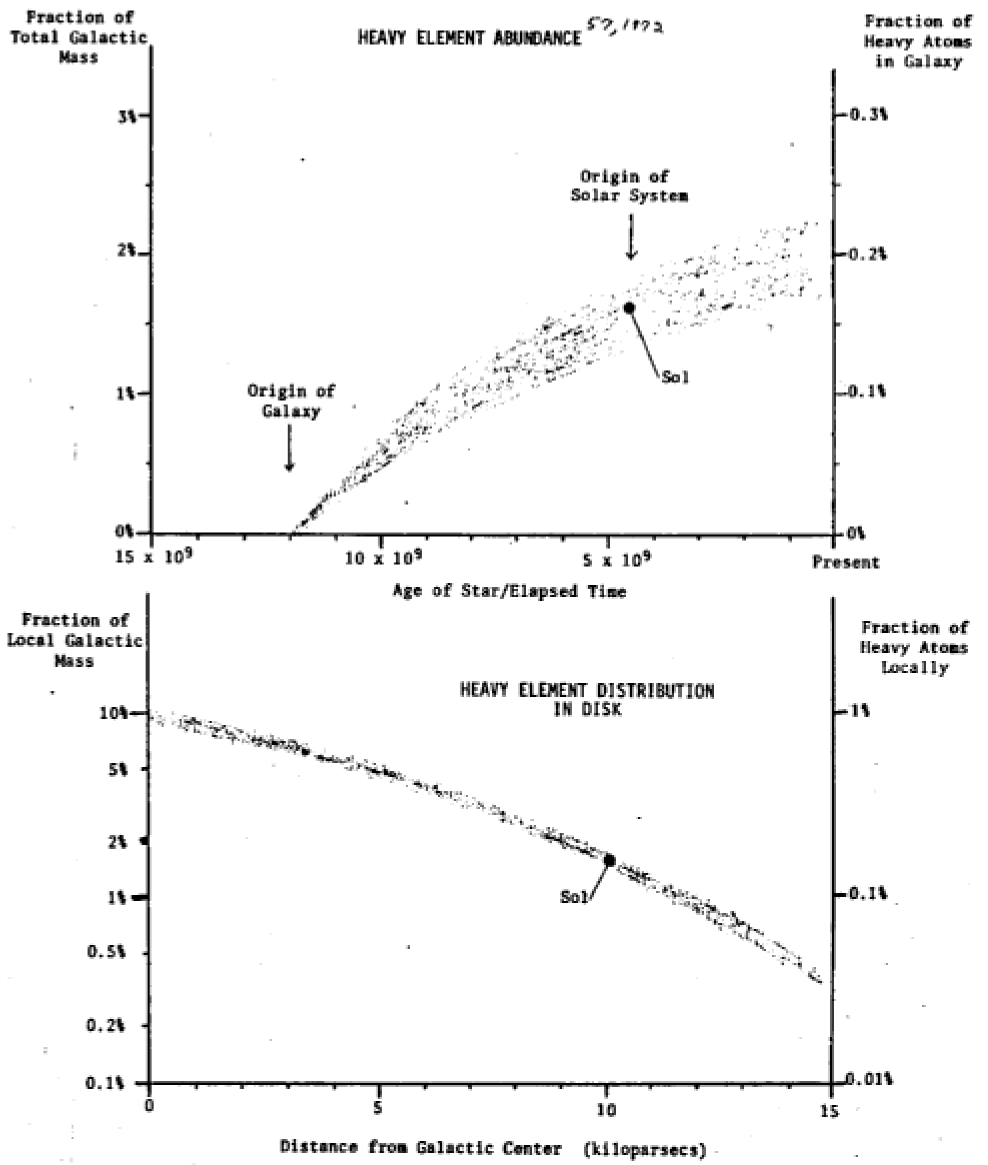


The distribution of life in the Milky Way is intimately connected with Galactic evolutionary history.[1811] The Halo population is the oldest sub system, remnant of the first stars and star clusters formed from the original virgin hydrogen cloud - the protogalaxy - 12 eons ago. As the cloud gravitationally condensed and began to rotate faster, it flattened out and became more dense.[1809] It has been estimated that about a hundred million years were required for the gas to fall ten kiloparsecs to the Galactic Plane.[1827] During this time the Disk population was formed (after the Halo), which soon found itself rich in heavy elements.[1807] The spiral arm population is the youngest subsystem of the Milky Way (105-109 years old), is also rich in heavies, and is closely restricted to the Plane.[1945]

The abundance of heavy elements increases markedly toward the center of our Galaxy (Figure 4.10). The concentration in the Core is an order of magnitude higher than near the rim of the Disk, and as much as three orders of magnitude greater than in the Halo. Based on the distribution of heavies, where might we expect to find planets and life ?

It is difficult to avoid excluding the oldest Halo stars, orbiting high above the plane of the Galaxy.[33] For the most part, these stars are extremely metal-poor. In addition, they are few in number, widely dispersed, and exceedingly dim because of their distance, Halo population II stars generally are not a good place to look for biology.[312,1633]

Figure 4.10 Heavy element abundance and distribution in the disk of the Milky Way Galaxy[57,1972]



Globular clusters are conspicuous collections of hundreds of thousands of individual suns. There may be as many as 2000 such clusters in the Galaxy,[1973] but at present only about 200 are known to exist for certain.[1807,1945] Since the component stars are population II, they, like the lone Halo objects, are exceedingly poor in metals. This alone would be enough to rule out all but the slimmest chance of finding life,[1633] but there are other problems. For instance, stars in these clusters are so tightly packed that encounters between them may become important inasmuch as the stability of planetary systems is concerned.[352] Also, a large number of the stars have left the "main sequence" (see below) and have become red giants. This stage of their evolution is marked by large variations in luminosity and dramatic increases in stellar radius.[20,1556,1973] It would appear that globular clusters are not fruitful places to search for intelligent lifeforms.

If not in the Halo, how about the Core ? As discussed above, the central regions of the Galaxy are more metal-rich than anywhere else in the Milky Way. The potential exists, therefore, for a vast multitude of terrestrial-like planets and planetary systems. There are probably also large quantities of organic and inorganic molecules near the Core - just what's needed to start the ball of life rolling.[1816,1961]

One quick objection to life at the Core might be that with such an immense concentration of stars in such a small volume (Table 4.3), the radiation flux might be too intense. However, simple order-of-magnitude calculations reveal that this is not a problem. Even in the innermost recesses of the nucleus, the total radiation received by a habitable planet will be no more than 0.06% in excess of that received from its primary. This should not be incompatible with an otherwise stable environment.

Table 4.3. Star Densities at the Galactic Core[1821]

Radius from Center, R	**Star Density**	**Stars within Radius R**	**Average Distance Between Stars**		**Irradiation by Surrounding Stars**
(parsecs)	(stars/pc3)	(Msun)	(parsecs)	(A.U.*)	(Earth/ Sol = 1.0)
0.1	5.2 x 107	6.0 x 105	0.0034	700	6 x 10-4
1.0	8.4 x 105	8.8 x 106	0.013	2700	9 x 10-5
10.	1.3 x 104	1.4 x 108	0.053	11,000	6 x 10-6
20.	3.8 x 103	3.2 x 108	0.081	17,000	4 x 10-6
100	2.2 x 102	5.0 x 109	0.21	43,000	1 x 10-6
(Nucleus) 800	20.0	2.0 x 1010	0.46	94,000	3 x 10-7
(Core) 3000	3.0	-- -	0.87	180,000	9 x 10-8
(Disk/ Sol) 104	0.15	-- -	1.88	380,000	5 x 10-9

* The mean distance from Sol to Earth is 1 AU, about 1.49 x 10^{11} meters.

However, more serious objections to Core life may be raised. For example, we know that on the average about one supernova occurs every fifty years in a typical spiral galaxy.[1962] In general, a hundred light-years is considered the distance of minimum biological effect for supernovae[468,469,498] (Astrophysicists Krasovskii and Sagan have suggested that one nearby supernova event about 108 years ago may have contributed to the extinction of the dinosaurs.[20]) Since there are about 10^{4} stars within 100 light-years of Sol, the mean time between catastrophic events is about two billion years, a comfortably lengthy period of time.[20] On the other hand, there are more than two hundred million stars within 100 light-years of the center of the Galaxy. Assuming the same supernova rate, the mean time between damaging events would be reduced to 50000 years. This may well prove intolerable to life.

Another argument against populating the Core is based on dynamical considerations. The grand game of stellar billiards, involving close encounters and collisions between stars once every million years or so,[20] could make life in the central regions quite impossible. As Dr. R. H. Sanders and Dr. G. T. Wrixen of the National Radio Astronomy Observatory put it : *"It is doubtful that there would be any life on planets in the galactic nucleus, since with such high stellar densities close encounters between stars would be so frequent that planets would be ripped out of their orbit every few hundred million years."*[1961] But this argument loses much of its appeal if we consider the outer Core regions (say, from 1-3 kiloparsecs out) where the star density is only an order of magnitude or so above Sol-normal.

Finally, there are indications that violent events are occurring at or near the Core. Astronomers Burbidge, Hoyle and Lequeux have hypothesized that the expanding 3-kpc arm observed near the Core could be the result of an explosion that savagely ripped through the central regions a mere twenty million years ago.[1816] More recently, this theory has been refined to the following numbers: Titanic explosions may occur every 500 million years, releasing some 10^{53} joules of energy (equivalent to total conversion of half a million solar masses into pure energy), followed by an ejection of one billion solar masses of matter.[1961] Needless to say, this would be an extremely disruptive event. [Note added in 2008 : Many astrophysicists now believe there is a black hole at the center of the Milky Way Galaxy.]

It appears doubtful that life will have evolved in the nucleus of our Galaxy, although biology in the outer Core regions is entirely possible. Looking at it from an aesthetic point of view, the spacescape enjoyed by the in habitants must be fantastically beautiful. Hundreds of stars would appear brighter than Sirius, our brightest. Their most luminous suns would be an order of magnitude brighter than Venus is to us.[1360] Starlight filtering through thick, patchy dust clouds near the nucleus would produce interesting optical effects. The evening sky at the Core would be as bright as moonlight on a clear night on Earth - total darkness might be unknown to these extra-terrestrials. But stars would still look like mere points of light. Only within one parsec of the center of the nucleus would supergiant stars appear as distinct globes to the naked human eye.

Where else can life exist in the Milky Way ? Scientists believe that the most likely place for life will be in the Disk, both in the interarm and spiral arm regions. Heavy elements are plentiful there, and planets should be numerous.[2032] Stars are far enough apart to preclude close encounters, and supernovae are few and far between. Finally, most of the stars in the Galaxy may be found in this region.

There is every indication that extraterrestrial life will be abundant throughout the volume of the Disk.

* Sol's forward motion should carry us into the Orion Arm in 10^7 years or so.