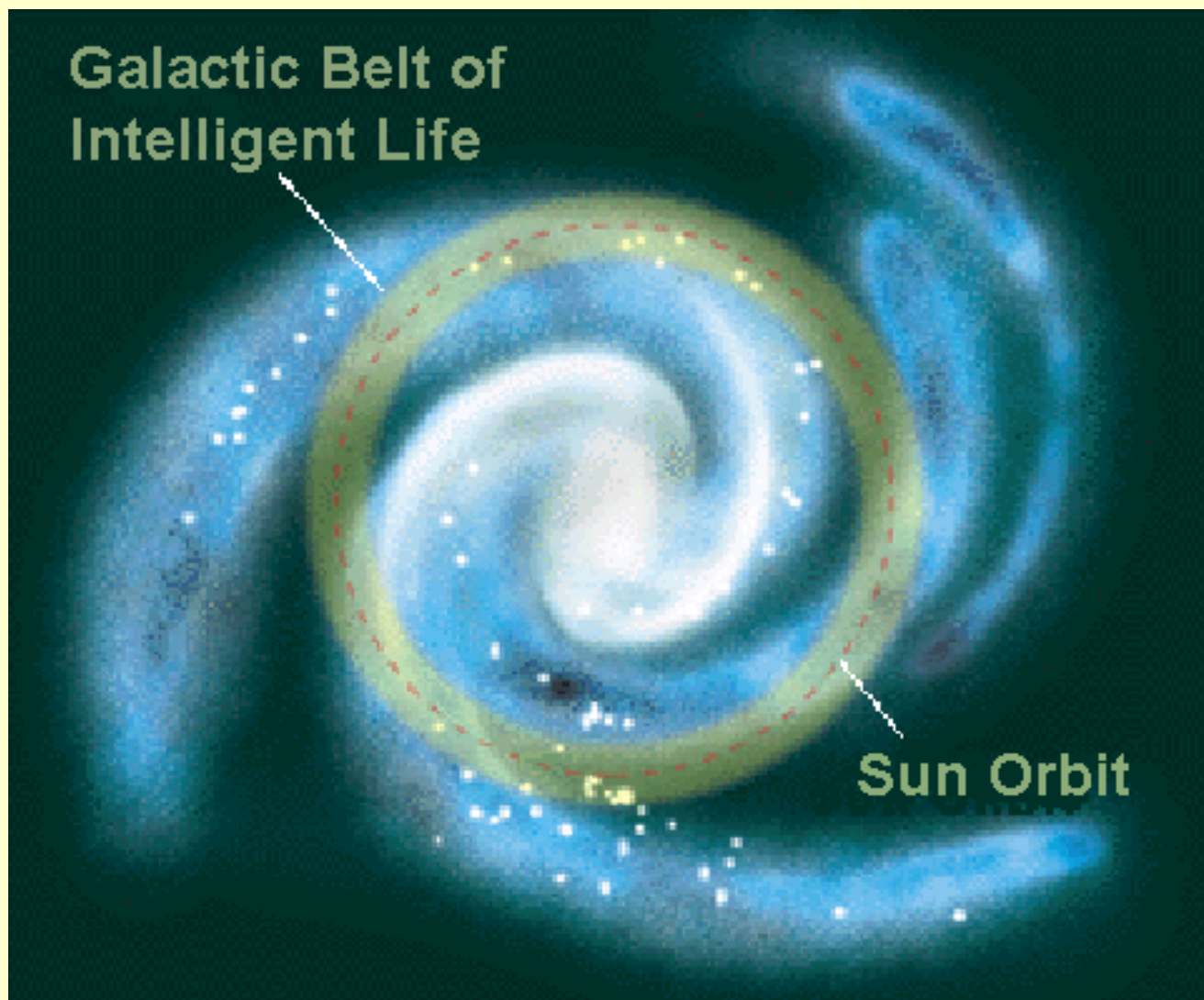


Galactic Belt of
Intelligent Life



Sun Orbit

The Anthropic Principle and Our Location in the Galaxy

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Abstract

It is known that basically as a reaction against exaggerated subservience to the 'copernican principle' (CP, for short) Brandon Carter (1974) in the early seventies introduced the so called 'anthropic principle' (AP), which in its "weak" version declares that "we must be prepared to take account of the fact that our location in the universe is necessarily privileged to the extent of being compatible with our existence as observers". Now, in accordance with AP our very presence (and the possibility to discuss extraterrestrial contact problems) shows that we and our planet-dwelling partners must live close to the galactic circle of co-rotation.

Basic facts and assumptions limiting places and times in the Galaxy where habitable planets can exist:

- Our present understanding of galactic chemical evolution is correct.
- The absolute and relative abundancies of iron, oxygen, silicon and magnesium are not uniform in the Galaxy in time and in space. Therefore the distribution of Earth-like planets will not be uniform as well.
- The Galaxy's disk has a clear-cut radial metallicity gradient and the metallicity dependencies of comet and terrestrial planet formation are probably significant. High metallicity almost certainly disfavors the formation of Earth-like planets.
- The Sun has a dynamically 'cold' orbit in the vicinity of the co-rotation circle.
- Highly developed planet dwelling life is not likely to survive the catastrophic events threatening during the crossings of spiral arms (close supernova explosions, comet showers etc.).

1. The Galactic Belt of Intelligent Life (GBIL)

What is the distribution of intelligent life in the Galaxy? A simple question, an exciting question and clearly a question, whose answer is most difficult to achieve. But it is a question that surely should be asked and answered in order to elaborate any suitable search strategy, and *a question which is impossible to answer professionally without taking into account the geometrical, kinematical and chemical properties of our stellar system, including their path of evolution.*

As far as the geometry and kinematics concerns, the *gravitational density wave theory* of Lin and his co-workers (1969) is still the most popular of theories that can provide an acceptable viewpoint from which it is possible to explain the large-scale galactic spiral structure in a coherent way. This theory involves the *formation of stars along a rather concentrated shock front which co-rotates with the spiral pattern as a rigid body around the galactic centre.* (Galactic subsystems with large velocity dispersions will have little influence on the behavior of the density waves and on the geometry of the spiral arms.) The shape of the pattern can roughly be approximated by logarithmic spirals.

In the framework of Lin's theory *the average age difference* (ΔT) *between us and another planetary system* with heliocentric galactic coordinates r, l, b can be written in the form:

$$\Delta T = F(r, l, b, m, \Omega_p, \Omega(R), \mu(R), \sigma(R)) \quad (1)$$

where m is the number of spiral arms, Ω_p the angular velocity of the pattern, R and θ are the galactocentric polar coordinates of an arbitrary point P on the spiral, $\Omega(R)$ is the galactic rotation curve, $\mu(R)$ is the surface density distribution in the galactic plane and $\sigma(R)$ is the radial velocity dispersion of the stars.

The angular pattern speed is one of the most important model parameters and according to Lin's group Ω_p equals $\approx 13.5 \text{ km s}^{-1} / \text{kpc}$. In the early seventies L. S. Marochnik and his co-workers (Marochnik et al. 1972) pointed out that since the bulk of the galactic mass is concentrated in subsystems with a large velocity dispersion, Ω_p is actually governed not by the total mass of the Galaxy, but by a small portion of it (μ_f) associated with the extremely flat subsystem of young stars having a small velocity dispersion.

Marochnik et al. found, that only with μ_f close to $40 M_{\odot} \text{pc}^{-2}$ and Ω_p around $23 \text{ km s}^{-1} / \text{kpc}$ are we able to obtain a spiral structure that is in good agreement with the large-scale distribution of neutral hydrogen in the Galaxy.

It appears therefore that Ω_p is considerably larger than was originally accepted and not the outermost H II regions but the stars in the solar neighbourhood lie in the zone of co-rotation. The rather small value of $\Delta\Omega_{\odot} = \Omega_{\odot} - \Omega_p$ is empirically supported for example by early works of Blaauw (1964), Nelson and Matsuda (1977) and Balázs (1982) furthermore by recent papers of Grosbol and Patsis (1998) and Mishurov & Zenina (1999).

It is easy to see that *in this case the age of the solar system is comparable with the period during which the Sun remains between two spiral arms.* Its radial phase ($\chi_{\odot} = 152^{\circ}$) between the Sagittarius and Perseus arms corresponds to an Ω_p value of $24.7 \text{ km s}^{-1} / \text{kpc}$ (if $\Omega_{\odot} = 25$ in the same units) and the uncertainty due to the epicyclic motion of the Sun is about 10%. (Fortunately the orbit of the Sun is relatively “cold, its galactic path is unusually circular. The variation of its galactocentric distance is negligible.)

In our vicinity the galactic rotation curve is linear and the co-rotation radius is:

$$R_c = R_\odot(1 + \Delta\Omega_\odot/2A) , \quad (2)$$

where A is Oort's rotation constant. If $R_\odot = 10$ kpc and $A = 15 \text{ km s}^{-1} / \text{kpc}$, then $R_c = 10.1$ kpc. (If the galactocentric distance of our Sun is smaller – e.g. 8.5 –, then the whole picture shrinks, but the striking proximity remains.) Now, if we – following Shklovskii and others (Shklovskii, 1968, Marochnik, 1983, Gonzalez et al., 2001 etc.) – accept the idea that *the longevity of a civilization might be limited by the high probability of close supernova explosions and impacts of large comets*, the life expectancy of advanced civilizations is the time which their system spends between two spiral arms, where the occurrence of fatal cosmic events is rendered unlikely. (In the arms in the 10 pc vicinity of a sun the supernova frequency is $\sim 10^{-8}$ years, the duration of the arm crossing is $\sim 10^9$ years; in addition at the same place $N_{\text{comet}} \cong 10^{10} N_{\text{star}}$ and the strong perturbation of the Oort clouds of the planetary systems is further increasing the danger of cosmic disasters. There is a similar “security” problem in the inner galactic regions aggravated with nucleus outbursts.) Thus, *the belt of extraterrestrial civilizations presents itself as a surprisingly narrow one!*

With regard to the age of the solar system, objects with $\Delta\Omega = 0.7 \text{ km s}^{-1} / \text{kpc}$ that left the Sagittarius or Perseus arms in the direction of the galactic rotation $T_{\text{crit}} = 4.6 \cdot 10^9$ years ago have by now just reached the other arm and, conversely, objects with the same age and parent arm but with $\Delta\Omega = -0.7 \text{ km s}^{-1} / \text{kpc}$ have likewise traveled the whole way in the opposite direction between the two spiral arms.

Denoting the galactocentric radius of these objects by R_{crit} and making use of Eq. (2), we get for the half width of the belt where we can expect most advanced civilizations (Fig. 1, Balazs, 1986):

$$R_c - R_{\text{crit}} = \Delta\Omega / 3 = \pm 0.23 \text{ kpc} \quad (3)$$

If we take into account, that there is a sort of incubation spread in the process of star formation and therefore stars born from the same large-scale density-wave compression of the interstellar medium are not completely coeval, the half width of the belt becomes only insignificantly different from the previous one (Baláz, 1986).

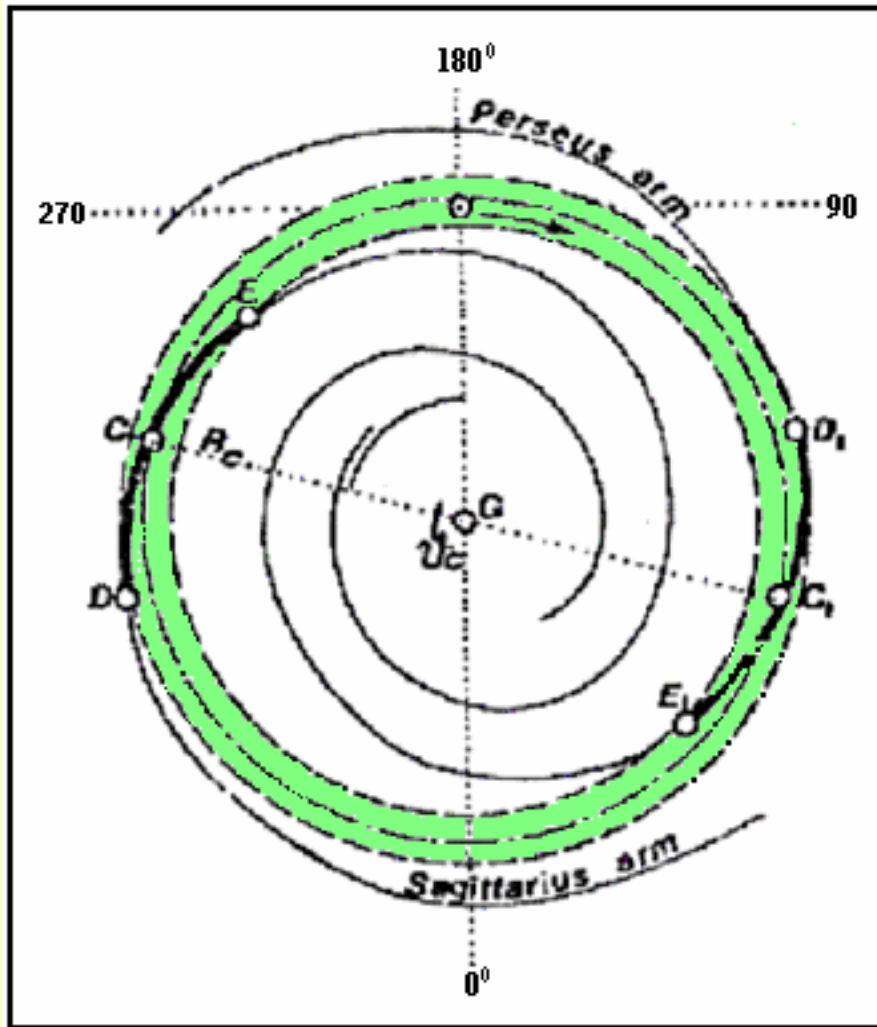


Figure 1:

The “Galactic Belt of Intelligent Life” in the Galaxy (green). G is the galactic center; C, C₁, D, D₁, E, E₁ are the intersections of the spiral arms with the circle of corotation and the belt edges.

Consequently, if we assume that the case of mankind is about average, our very presence and the possibility to discuss extraterrestrial contact problems shows that we and our potential nonspacefaring partners live close to the galactic circle of co-rotation.

There are thus morphological arguments favouring the concept of a “Galactic Belt of Intelligent Life” (GBIL) based on a “kinematic ecosphere” in the Galaxy in the form of an annulus with a breadth of roughly 0.5 kpc including the co-rotation circle and the galactic orbit of our Sun. *We should concentrate our efforts to contact extraterrestrial beings on this narrow belt.*

In the discussion of the number (N_c) of technological civilizations in our Galaxy two general forms of the *Drake equation* have been widely used (see f. i. Kreifeldt, 1971). For our purpose Cameron’s formulation is the more suitable one, according to which

$$N_c = N_s f_s L_c / L_p \quad (4)$$

where N_s is the number of potentially suitable parent stars, f_s is a compound selectivity factor, L_c is the length of the communicative phase of a society and L_p is that part of the lifetime of a planet during which highly developed species exist on it.

If the GBIL is a reality, the first and last factors in Eq. 4 must be reconsidered (Balázs, 1988). As far as N_s is concerned, it is clear that in our case only stars in the belt can be regarded as suitable ones. Since the stellar density in the solar neighbourhood is 0.13 */kpc^3 and one can take around 200 pc for the thickness of the belt, the volume of the ring comes about $6 \cdot 10^9 \text{ kpc}^3$ and we get $N_s = 8 \cdot 10^8$ for the number of the stars contained in it. As the only stars however, that have long lasting habitable zones around them are of masses between about 0.8 to 1.2 M_\odot and roughly 10 % of the stars lie in this mass range, the number of potentially suitable stars is only about $8 \cdot 10^7$! One can see at the first glance (Fig. 1) that *from heliocentric point of view the distribution of these stars is highly anisotropic*. In a typical solid angle ($\sim 10^{-4}$ sr) we see 900 times more stars in the direction of the galactic rotation than towards the galactic anti-centre.

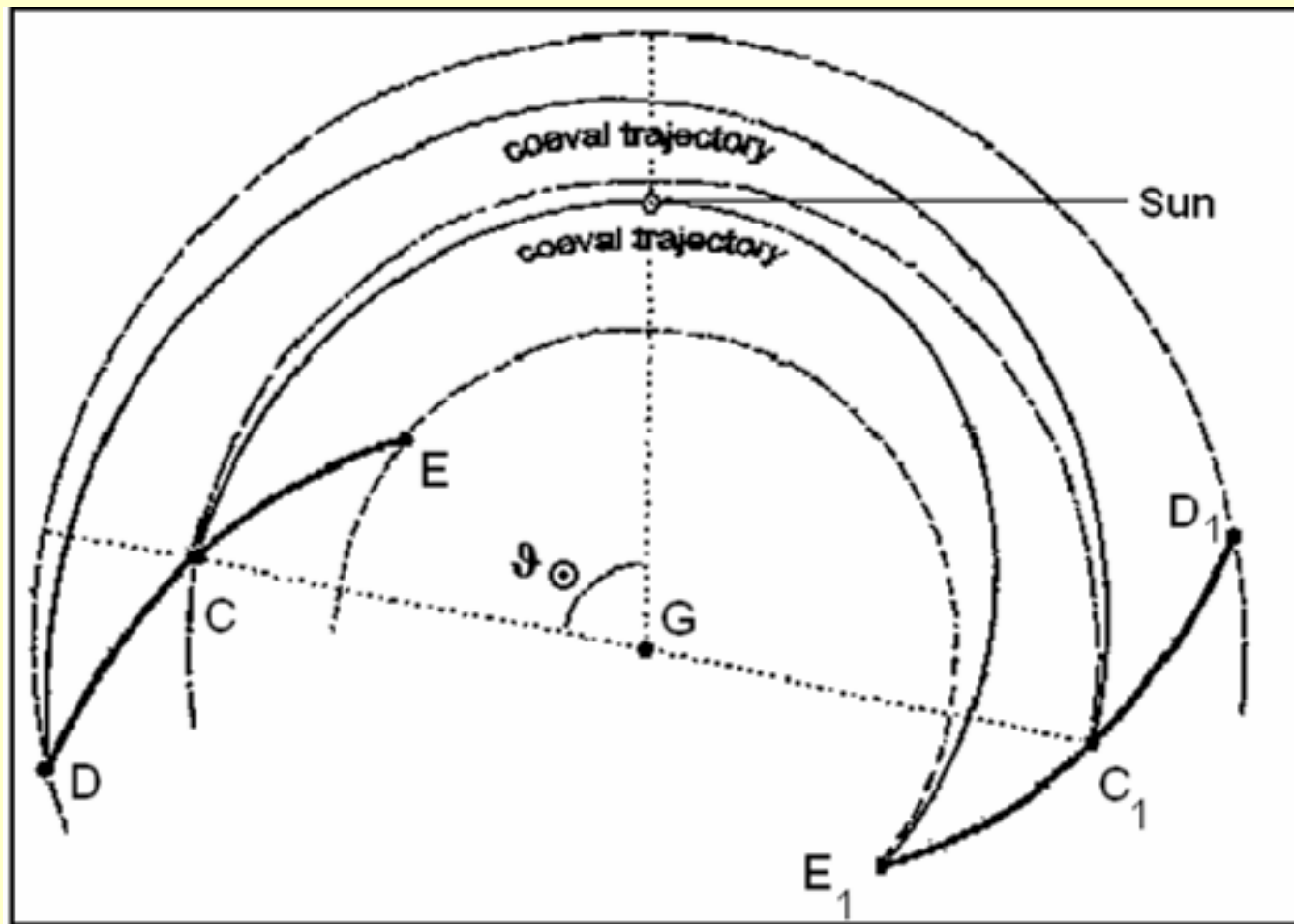


Fig. 2: Critical coeval loci in the belt of life. It is the strip between them where one primarily expects potential partners for extra-terrestrial communication.

The anisotropy is growing even further if we restrict the scope of our investigations to the “upper” half ($C S C_1$) of the belt and take into account that we are only at the beginning of our technical civilization and therefore our potential partners for extraterrestrial communication must have at least as old a society as we have (Fig. 2). The locus of coeval objects in the belt is given by the following relation:

$$R(\theta, T) = R(\theta + \Delta\Omega T) \quad (5)$$

It is clear that essentially only stars lying on and between the two critical coeval trajectories have planets around them which are at least as old as the earth. Now, the section of our line of sight (Δr) which falls into the advanced part of the belt of life has obviously a strongly varying length with the galactic longitude. As shown in Fig. 3, the maxima lie roughly at 90° and 270° and the minimum shows up at 180° (Balázs, 1988). *Fig. 3 is therefore of essential importance for the elaboration of a sound scientific search strategy aiming the detection of extraterrestrial intelligence* (see also Turnbull & Tarter, 2003).

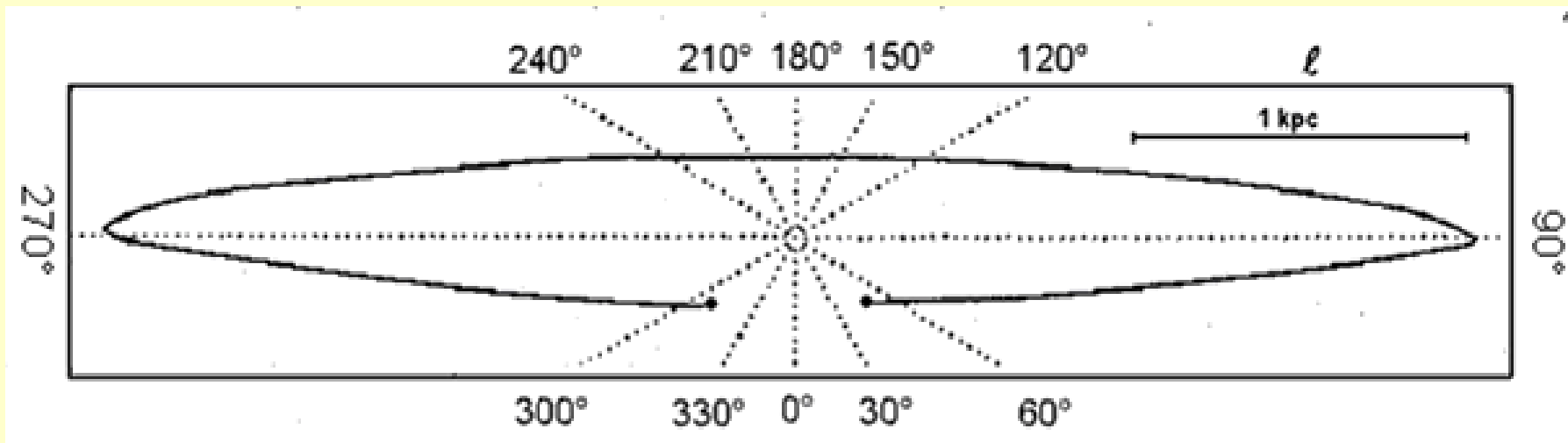


Fig. 3: The length of the section of our line of sight which falls into the advanced part of the belt of life as a function of the galactic longitude.

2. Other galactic prerequisites for complex life

The Earth is made up mostly of iron, oxygen, silicon and magnesium. The absolute and relative abundances of these elements are not unvarying in the Milky Way in time or in space. Consequently, *the galactic distribution of Earth-like planets will be uniform neither in place nor in time*. The metallicity of the interstellar medium has been increasing since the Galaxy first formed (basically from hydrogen and helium). We can determine it from observations of nearby Sun-like stars. The approximate trend is:

$$[\text{Fe}/\text{H}] = -0.035 t \text{ dex}, \quad (6)$$

where t is the age of the stars in Gyrs. (Near the Sun the scatter in metallicity is about ± 0.08 dex.) Since a metallicity at least half of the Sun is required to build a habitable terrestrial planet, but with too much metallicity migrating giant planets destroy or “banish” Earth-mass planets, *there is an annulus in the Galaxy with fuzzy boundaries, where the prerequisites are favorable for habitable planets* (e. g. Gonzalez, 2001; Lineweaver, 2004; Scalo, Wheeler, 2002).

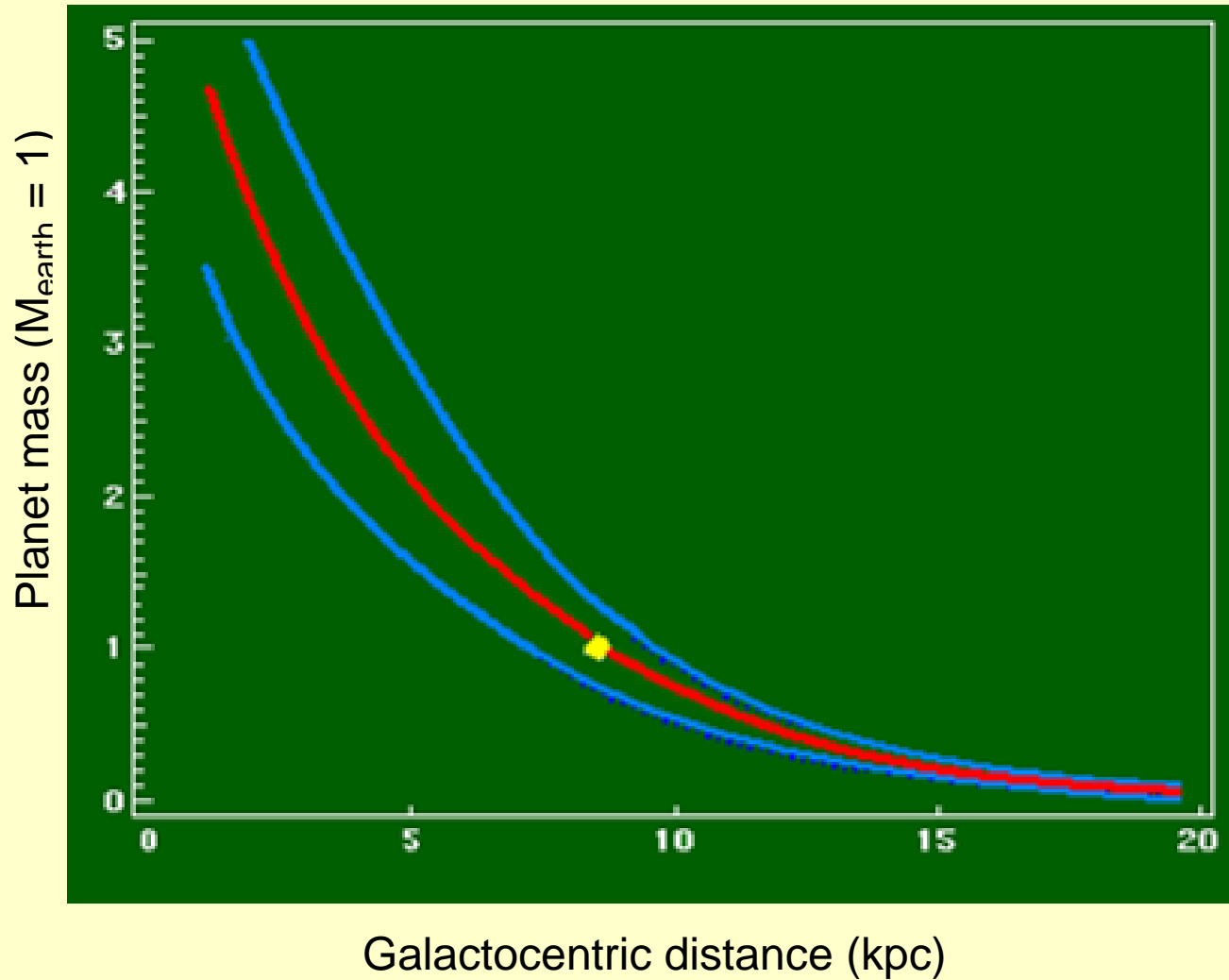


Fig. 4: Typical terrestrial planet mass plotted against galactocentric distance for the present ISM. The one sigma upper and lower bounds are shown as blue curves. The position of the Galactic Belt of Intelligent Life is indicated by two parallel pink lines.

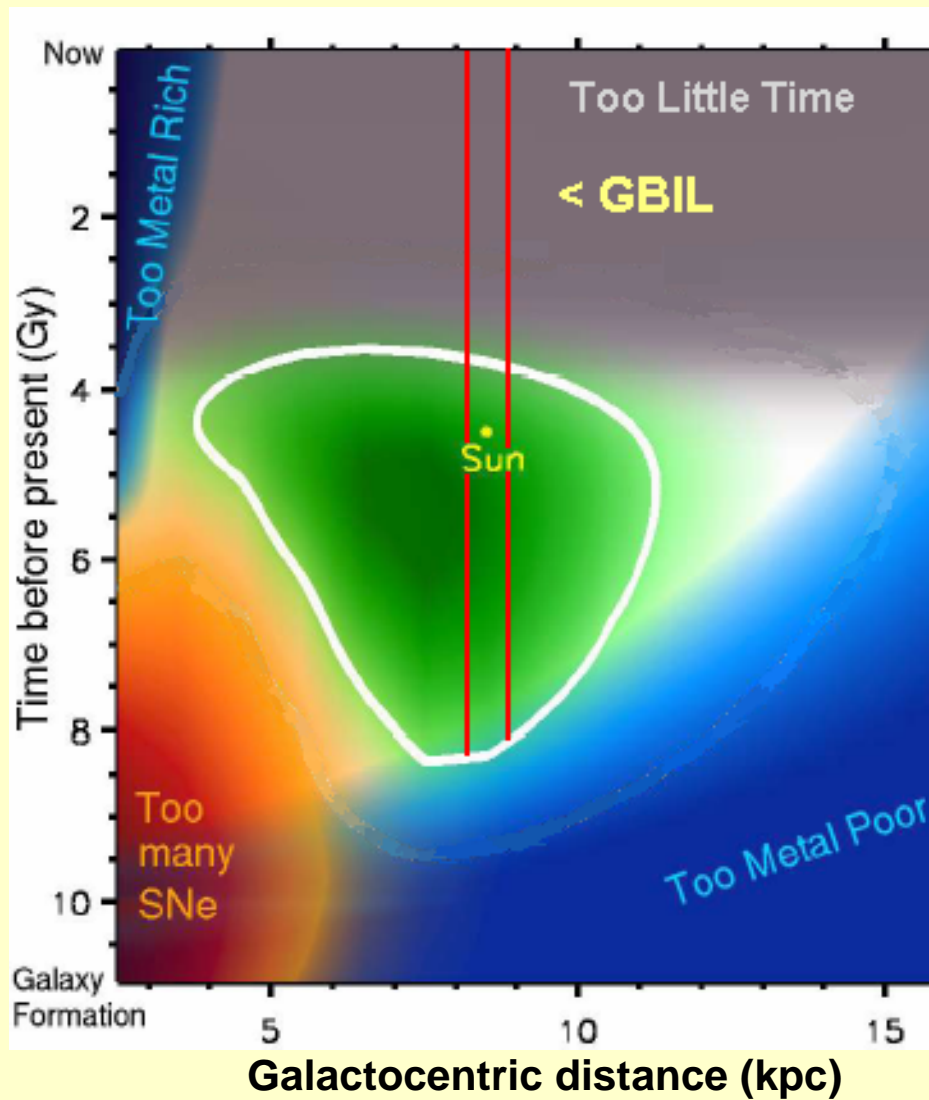


Fig. 5: The habitable zone in the disk of our Galaxy, based on metallicity (blue), ample time for evolution (gray), and protection against life-threatening supernova explosions (red). The white contour circumscribes 68% of the birth places of stars with the highest probability of recently harboring complex life without taking into account the GBIL concept (see Ch. H. Lineweaver et al. 2004). The Galactic Belt of Intelligent Life (GBIL), based on the proximity to the co-rotation circle, is indicated by two parallel red lines.

Regarding our existence on the Earth it is of capital importance that in our Galaxy the chemical, kinematical and structural barriers do not define an empty set (Figs. 4-5). In elliptical galaxies, on the other hand, stars have randomized orbits and are too metal poor for the production of Earth-like planets. Since there is a correlation between the luminosity and metallicity of a galaxy, and the huge majority of stars in the local universe belongs to galaxies less luminous than the Milky Way, most galaxies could be deficient in Earth-like worlds. Even sufficiently luminous spiral galaxies with a misplaced co-rotation zone are unsuitable for advanced life.

Over the last four centuries the CP has evolved from a simple statement that we are not located at the center of our planetary system to a comprehensive philosophical doctrine that the Earth and its residents are not unusual in any relevant way. Now, our very presence (and the possibility to discuss extraterrestrial contact problems) shows in itself that we and our non space-faring partners are not just simply inhabitants of the Milky Way. We all must live close to the circle of co-rotation of a not at all typical spiral galaxy.

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