Fine-Tuning For Life On Earth

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Evidence for the Fine-Tuning of the Galaxy-Sun-Earth-Moon System for Life Support

The environmental requirements for life to exist depend quite strongly on the life form in question. The conditions for primitive life to exist, for example, are not nearly so demanding as they are for advanced life. Also, it makes a big difference how active the life form is and how long it remains in its environment. On this basis there are six distinct zones or regions in which life can exist. In order of the broadest to the narrowest they are as follows:

for unicellular, low metabolism life that persists for only a brief time period

for unicellular, low metabolism life that persists for a long time period

for unicellular, high metabolism life that persists for a brief time period

for unicellular, high metabolism life that persists for a long time period

for advanced life that survives for just a brief time period

for advanced life that survives for a long time period

Complicating factors, however, are that unicellular, low metabolism life (extremophiles) typically is more easily subject to radiation damage and it has a low molecular repair rate. The origin of life problem is far more difficult for low metabolism life (H. James Cleaves II and John H. Chambers, "Extremophiles May Be Irrelevant to the Origin of Life," *Astrobiology, 4* (2004), pp. 1-9). The following parameters of a planet, its planetary companions, its moon, its star, and its galaxy must have values falling within narrowly defined ranges for physical life of any kind to exist. References follow the list.

galaxy cluster type

- if too rich: galaxy collisions and mergers would disrupt solar orbit
- if too sparse: insufficient infusion of gas to sustain star formation for a long enough time

galaxy size

- if too large: infusion of gas and stars would disturb sun's orbit and ignite too many galactic eruptions
- if too small: insufficient infusion of gas to sustain star formation for long enough time

galaxy type

- if too elliptical: star formation would cease before sufficient heavy element build-up for life chemistry

- if too irregular: radiation exposure on occasion would be too severe and heavy elements for life chemistry would not be available

galaxy mass distribution

- if too much in the central bulge: life-supportable planet will be exposed to too much radiation
- if too much in the spiral arms: life-supportable planet will be destabliized by the gravity and radiation from adjacent spiral arms

galaxy location

- if too close to a rich galaxy cluster: galaxy would be gravitationally disrupted
- if too close to very large galaxy(ies): galaxy would be gravitationally disrupted
- if too far away from dwarf galaxies: insufficient infall of gas and dust to sustain ongoing star formation

decay rate of cold dark matter particles

- if too small: too few dwarf spheroidal galaxies will form which prevents star formation from lasting long enough in large galaxies so that life-supportable planets become possible
- if too great: too many dwarf spheroidal galaxies will form which will make the orbits of solar-type stars unstable over long time periods and lead to the generation of deadly radiation episodes

hypernovae eruptions

- if too few not enough heavy element ashes present for the formation of rocky planets
- if too many: relative abundances of heavy elements on rocky planets would be inappropriate for life; too many collision events in planetary system
- if too soon: leads to a galaxy evolution history that would disturb the possibility of advanced life; not enough heavy element ashes present for the formation of rocky planets
- if too late: leads to a galaxy evolution history that would disturb the possibility of advanced life; relative abundances of heavy elements on rocky planets would be inappropriate for life; too many collision events in planetary system

supernovae eruptions

- if too close: life on the planet would be exterminated by radiation
- if too far: not enough heavy element ashes would exist for the formation of rocky planets
- if too infrequent: not enough heavy element ashes present for the

formation of rocky planets

- if too frequent: life on the planet would be exterminated
- if too soon: heavy element ashes would be too dispersed for the formation of rocky planets at an early enough time in cosmic history
- if too late: life on the planet would be exterminated by radiation

white dwarf binaries

- if too few: insufficient flourine would be produced for life chemistry to proceed
- if too many: planetary orbits disrupted by stellar density; life on planet would be exterminated
- if too soon: not enough heavy elements would be made for efficient flourine production
- if too late: flourine would be made too late for incorporation in protoplanet

proximity of solar nebula to a supernova eruption

- if farther: insufficient heavy elements for life would be absorbed
- if closer: nebula would be blown apart

timing of solar nebula formation relative to supernova eruption

- if earlier: nebula would be blown apart
- if later: nebula would not absorb enough heavy elements

number of stars in parent star birth aggregate

- if too few: insufficient input of certain heavy elements into the solar nebula
- if too many: planetary orbits will be too radically disturbed

star formation history in parent star vicinity

- if too much too soon: planetary orbits will be too radically disturbed

birth date of the star-planetary system

- if too early: quantity of heavy elements will be too low for large rocky planets to form
- if too late: star would not yet have reached stable burning phase; ratio of potassium-40, uranium-235 & 238, and thorium-232 to iron will be too low for long-lived plate tectonics to be sustained on a rocky planet

parent star distance from center of galaxy

- if farther: quantity of heavy elements would be insufficient to make rocky planets; wrong abundances of silicon, sulfur, and magnesium relative to iron for appropriate planet core characteristics
- if closer: galactic radiation would be too great; stellar density would

disturb planetary orbits; wrong abundances of silicon, sulfur, and magnesium relative to iron for appropriate planet core characteristics

parent star distance from closest spiral arm

- if too large: exposure to harmful radiation from galactic core would be too great

z-axis heights of star's orbit

- if more than one: tidal interactions would disrupt planetary orbit of life support planet
- if less than one: heat produced would be insufficient for life

quantity of galactic dust

- if too small: star and planet formation rate is inadequate; star and planet formation occurs too late; too much exposure to stellar ultraviolet radiation
- if too large: blocked view of the Galaxy and of objects beyond the Galaxy; star and planet formation occurs too soon and at too high of a rate; too many collisions and orbit perturbations in the Galaxy and in the planetary system

number of stars in the planetary system

- if more than one: tidal interactions would disrupt planetary orbit of life support planet
- if less than one: heat produced would be insufficient for life

parent star age

- if older: luminosity of star would change too quickly
- if younger: luminosity of star would change too quickly

parent star mass

- if greater: luminosity of star would change too quickly; star would burn too rapidly
- if less: range of planet distances for life would be too narrow; tidal forces would disrupt the life planet's rotational period; uv radiation would be inadequate for plants to make sugars and oxygen

parent star metallicity

- if too small: insufficient heavy elements for life chemistry would exist
- if too large: radioactivity would be too intense for life; life would be poisoned by heavy element concentrations

parent star color

- if redder: photosynthetic response would be insufficient
- if bluer: photosynthetic response would be insufficient

galactic tides

- if too weak: too low of a comet ejection rate from giant planet region
- if too strong too high of a comet ejection rate from giant planet region

H_3^+ production

- if too small: simple molecules essential to planet formation and life chemistry will not form
- if too large: planets will form at wrong time and place for life

flux of cosmic ray protons

- if too small: inadequate cloud formation in planet's troposphere
- if too large: too much cloud formation in planet's troposphere

solar wind

- if too weak: too many cosmic ray protons reach planet's troposphere causing too much cloud formation
- if too strong: too few cosmic ray protons reach planet's troposphere causing too little cloud formation

parent star luminosity relative to speciation

- if increases too soon: runaway green house effect would develop
- if increases too late: runaway glaciation would develop

surface gravity (escape velocity)

- if stronger: planet's atmosphere would retain too much ammonia and methane
- if weaker: planet's atmosphere would lose too much water

distance from parent star

- if farther: planet would be too cool for a stable water cycle
- if closer: planet would be too warm for a stable water cycle

inclination of orbit

- if too great: temperature differences on the planet would be too extreme

orbital eccentricity

- if too great: seasonal temperature differences would be too extreme

axial tilt

- if greater: surface temperature differences would be too great
- if less: surface temperature differences would be too great

rate of change of axial tilt

- if greater: climatic changes would be too extreme; surface temperature differences would become too extreme rotation period

- if longer: diurnal temperature differences would be too great
- if shorter: atmospheric wind velocities would be too great

rate of change in rotation period

- if longer:surface temperature range necessary for life would not be sustained
- if shorter:surface temperature range necessary for life would not be sustained

planet age

- if too young: planet would rotate too rapidly
- if too old: planet would rotate too slowly

magnetic field

- if stronger: electromagnetic storms would be too severe; too few cosmic ray protons would reach planet’s troposphere which would inhibit adequate cloud formation
- if weaker: ozone shield would be inadequately protected from hard stellar and solar radiation

thickness of crust

- if thicker: too much oxygen would be transferred from the atmosphere to the crust
- if thinner: volcanic and tectonic activity would be too great

albedo (ratio of reflected light to total amount falling on surface)

- if greater: runaway glaciation would develop
- if less: runaway greenhouse effect would develop

asteroidal and cometary collision rate

- if greater: too many species would become extinct
- if less: crust would be too depleted of materials essential for life

mass of body colliding with primordial Earth

- if smaller: Earth’s atmosphere would be too thick; moon would be too small
- if greater: Earth’s orbit and form would be too greatly disturbed

timing of body colliding with primordial Earth

- if earlier: Earth’s atmosphere would be too thick; moon would be too small
- if later: sun would be too luminous at epoch for advanced life

collision location of body colliding with primordial Earth

- if too close to grazing: insufficient debris to form large moon; inadequate annihilation of Earth's primordial atmosphere; inadequate transfer of heavy elements to Earth
- If too close to dead center: damage from collision would be too destructive for future life to survive

oxygen to nitrogen ratio in atmosphere

- if larger: advanced life functions would proceed too quickly
- if smaller: advanced life functions would proceed too slowly

carbon dioxide level in atmosphere

- if greater: runaway greenhouse effect would develop
- if less: plants would be unable to maintain efficient photosynthesis

water vapor level in atmosphere

- if greater: runaway greenhouse effect would develop
- if less: rainfall would be too meager for advanced life on the land

atmospheric electric discharge rate

- if greater: too much fire destruction would occur
- if less: too little nitrogen would be fixed in the atmosphere

ozone level in atmosphere

- if greater: surface temperatures would be too low
- if less: surface temperatures would be too high; there would be too much uv radiation at the surface

oxygen quantity in atmosphere

- if greater: plants and hydrocarbons would burn up too easily
- if less: advanced animals would have too little to breathe

nitrogen quantity in atmosphere

- if greater: too much buffering of oxygen for advanced animal respiration; too much nitrogen fixation for support of diverse plant species
- if less: too little buffering of oxygen for advanced animal respiration; too little nitrogen fixation for support of diverse plant species

ratio of ^{40}K, $^{235,238}U$, ^{232}Th to iron for the planet

- if too low: inadequate levels of plate tectonic and volcanic activity
- if too high: radiation, earthquakes, and volcanoes at levels too high for advanced life

rate of interior heat loss

- if too low: inadequate energy to drive the required levels of plate tectonic and volcanic activity

- if too high: plate tectonic and volcanic activity shuts down too quickly

seismic activity

- if greater: too many life-forms would be destroyed
- if less: nutrients on ocean floors from river runoff would not be recycled to continents through tectonics; not enough carbon dioxide would be released from carbonates

volcanic activity

- if lower: insufficient amounts of carbon dioxide and water vapor would be returned to the atmosphere; soil mineralization would become too degraded for life
- if higher: advanced life, at least, would be destroyed

rate of decline in tectonic activity

- if slower: advanced life can never survive on the planet
- if faster: advanced life can never survive on the planet

rate of decline in volcanic activity

- if slower: advanced life can never survive on the planet
- if faster: advanced life can never survive on the planet

timing of birth of continent formation

- if too early: silicate-carbonate cycle would be destabilized
- if too late: silicate-carbonate cycle would be destabilized

oceans-to-continents ratio

- if greater: diversity and complexity of life-forms would be limited
- if smaller: diversity and complexity of life-forms would be limited

rate of change in oceans-to-continents ratio

- if smaller: advanced life will lack the needed land mass area
- if greater: advanced life would be destroyed by the radical changes

global distribution of continents (for Earth)

- if too much in the southern hemisphere: seasonal differences would be too severe for advanced life

frequency and extent of ice ages

- if smaller: insufficient fertile, wide, and well-watered valleys produced for diverse and advanced life forms; insufficient mineral concentrations occur for diverse and advanced life
- if greater: planet inevitably experiences runaway freezing

soil mineralization

- if too nutrient poor: diversity and complexity of life-forms would be limited
- if too nutrient rich: diversity and complexity of life-forms would be limited

gravitational interaction with a moon

- if greater: tidal effects on the oceans, atmosphere, and rotational period would be too severe
- if less: orbital obliquity changes would cause climatic instabilities; movement of nutrients and life from the oceans to the continents and vice versa would be insufficent; magnetic field would be too weak

Jupiter distance

- if greater: too many asteroid and comet collisions would occur on Earth
- if less: Earth's orbit would become unstable

Jupiter mass

- if greater: Earth's orbit would become unstable
- if less: too many asteroid and comet collisions would occur on Earth

drift in major planet distances

- if greater: Earth's orbit would become unstable
- if less: too many asteroid and comet collisions would occur on Earth

major planet eccentricities

- if greater: orbit of life supportable planet would be pulled out of life support zone

major planet orbital instabilities

- if greater: orbit of life supportable planet would be pulled out of life support zone

mass of Neptune

- if too small: not enough Kuiper Belt Objects (asteroids beyond Neptune) would be scattered out of the solar system
- if too large: chaotic resonances among the gas giant planets would occur

Kuiper Belt of asteroids (beyond Neptune)

- if not massive enough: Neptune's orbit remains too eccentric which destabilizes the orbits of other solar system planets
- if too massive: too many chaotic resonances and collisions would occur in the solar system

separation distances among inner terrestrial planets

- if too small: orbits of all inner planets will become unstable in less than 100,000,000 million years
- if too large: orbits of the most distant from star inner planets will become chaotic

atmospheric pressure

- if too small: liquid water will evaporate too easily and condense too infrequently; weather and climate variation would be too extreme; lungs will not function
- if too large: liquid water will not evaporate easily enough for land life; insufficient sunlight reaches planetary surface; insufficient uv radiation reaches planetary surface; insufficient climate and weather variation; lungs will not function

atmospheric transparency

- if smaller: insufficient range of wavelengths of solar radiation reaches planetary surface
- if greater: too broad a range of wavelengths of solar radiation reaches planetary surface

magnitude and duration of sunspot cycle

- if smaller or shorter: insufficient variation in climate and weather
- if greater or longer: variation in climate and weather would be too much

continental relief

- if smaller: insufficient variation in climate and weather
- if greater: variation in climate and weather would be too much

chlorine quantity in atmosphere

- if smaller: erosion rates, acidity of rivers, lakes, and soils, and certain metabolic rates would be insufficient for most life forms
- if greater: erosion rates, acidity of rivers, lakes, and soils, and certain metabolic rates would be too high for most life forms

iron quantity in oceans and soils

- if smaller: quantity and diversity of life would be too limited for support of advanced life; if very small, no life would be possible
- if larger: iron poisoning of at least advanced life would result

tropospheric ozone quantity

- if smaller: insufficient cleansing of biochemical smogs would result
- if larger: respiratory failure of advanced animals, reduced crop yields, and destruction of ozone-sensitive species would result

stratospheric ozone quantity

- if smaller: too much uv radiation reaches planet's surface causing skin cancers and reduced plant growth
- if larger: too little uv radiation reaches planet's surface causing reduced plant growth and insufficient vitamin production for animals

mesospheric ozone quantity

- if smaller: circulation and chemistry of mesospheric gases so disturbed as to upset relative abundances of life essential gases in lowe atmosphere
- if greater: circulation and chemistry of mesospheric gases so disturbed as to upset relative abundances of life essential gases in lower atmosphere

quantity and extent of forest and grass fires

- if smaller: growth inhibitors in the soils would accumulate; soil nitrification would be insufficient; insufficient charcoal production for adequate soil water retention and absorption of certain growth inhibitors
- if greater: too many plant and animal life forms would be destroyed

quantity of soil sulfer

- if smaller: plants will become defieient in certain proteins and die
- if larger: plants will die from sulfur toxins; acidity of wate and soil will become too great for life; nitrogen cycles will be disturbed

biomass to comet infall ratio

- if smaller: greenhouse gases accumulate, triggering runaway surface temperature increase
- if larger: greenhouse gases decline, triggering a runaway freezing

density of quasars

- if smaller: insufficient production and ejection of cosmic dust into the intergalactic medium; ongoing star formation impeded; deadly radiation unblocked
- if larger: too much cosmic dust forms; too many stars form too late disrupting the formation of a solar-type star at the right time and under the right conditions for life

density of giant galaxies in the early universe

- if smaller: insufficient metals ejected into the intergalactic medium depriving future generations of stars of the metal abundances necessary for a life-support planet at the right time in cosmic history
- if larger: too large a quantity of metals ejected into the intergalactic medium providing future stars with too high of a metallicity for a life-support planet at the right time in cosmic history

giant star density in galaxy

- if smaller: insufficient production of galactic dust; ongoing star formation impeded; deadly radiation unblocked

- if larger: too much galactic dust forms; too many stars form too early disrupting the formation of a solar-type star at the right time and under the right conditions for life

rate of sedimentary loading at crustal subduction zones

- if smaller: too few instabilities to trigger the movement of crustal plates into the mantle thereby disrupting carbonate-silicate cycle
- if larger: too many instabilities triggering too many crustal plates to move down into the mantle thereby disrupting carbonate-silicate cycle

poleward heat transport in planet’s atmosphere

- if smaller: disruption of climates and ecosystems; lowered biomass and species diversity; decreased storm activity and precipitation
- if larger: disruption of climates and ecosystems; lowered biomass and species diversity; increased storm activity

polycyclic aromatic hydrocarbon abundance in solar nebula

- if smaller: insufficient early production of asteroids which would prevent a planet like Earth from receiving adequate delivery of heavy elements and carbonaceous material for life, advanced life in particular
- if larger: early production of asteroids would be too great resulting in too many collision events striking a planet arising out of the nebula that could support life

phosphorus and iron absorption by banded iron formations

- if smaller: overproduction of cyanobacteria would have consumed too much carbon dioxide and released too much oxygen into Earth’s atmosphere thereby overcompensating for the increase in the Sun’s luminosity (too much reduction in atmospheric greenhouse efficiency)
- if larger: underproduction of cyanobacteria would have consumed too little carbon dioxide and released too little oxygen into Earth’s atmosphere thereby undercomsating for the increase in the Sun’s luminosity (too little reduction in atmospheric greenhouse efficiency)

silicate dust annealing by nebular shocks

- if too little: rocky planets with efficient plate tectonics cannot form
- if too much: too many collisions in planetary system.; too severe orbital instabilities in planetary system

size of galactic central bulge

- if smaller: inadequate infusion of gas and dust into the spiral arms preventing solar type stars from forming at the right locations late enough in the galaxy’s history
- if larger: radiation from the bulge region would kill life on the life-support

planet

total mass of Kuiper Belt asteroids

- if smaller: Neptune’s orbit would not be adequately circularized
- if larger: too severe gravitational instabilities generated in outer solar system

solar magnetic activity level

- if greater: solar luminosity fluctuations will be too large

number of hypernovae

- if smaller: too little nitrogen is produced in the early universe, thus, cannot get the kinds of stars and planets later in the universe that are necessary for life
- if larger: too much nitrogen is produced in the early universe, thus, cannot get the kinds of stars and planets later in the universe that are necessary for life

timing of hypernovae production

- if too early: galaxies become too metal rich too quickly to make stars and planets suitable for life support at the right time
- if too late: insufficient metals available to make quickly enough stars and planets suitable for life support

masses of stars that become hypernovae

- if not massive enough: insufficient metals are ejected into the interstellar medium; that is, not enough metals are available for future star generations to make stars and planets suitable for the support of life
- if too massive: all the metals produced by the hypernova eruptions collapse into the black holes resulting from the eruptions; that is, none of the metals are available for future generations of stars

quantity of geobacteraceae

- if smaller or non-existent: polycyclic aromatic hydrocarbons accumulate in the surface environment thereby contaminating the environment for other life forms

density of brown dwarfs

- if too low: too many low mass stars are produced which will disrupt planetary orbits
- if too high: disruption of planetary orbits

quantity of aerobic photoheterotrophic bacteria

- if smaller: inadequate recycling of both organic and inorganic carbon in the oceans

average rainfall preciptiation

- if too small: inadequate water supplies for land-based life; inadequate erosion of land masses to sustain the carbonate-silicate cycle.; inadequate erosion to sustain certain species of ocean life that are vital for the existence of all life
- if too large: too much erosion of land masses which upsets the carbonate-silicate cycle and hastens the extinction of many species of life that are vital for the existence of all life

variation and timing of average rainfall precipitation

- if too small or at the wrong time: erosion rates that upset the carbonate-silicate cycle and fail to adjust adequately the planet's atmosphere for the increase in the sun's luminosity
- if too large or at the wrong time: erosion rates that upset the carbonate-silicate cycle and fail to adjust the planet's atmosphere for the increase in the sun's luminosity

average slope or relief of the continental land masses

- if too small: inadequate erosion
- if too large: too much erosion

distance from nearest black hole

- if too close: radiation will prove deadly for life

absorption rate of planets and planetismals by parent star

- if too low: disturbs sun's luminosity and stability of sun's long term luminosity
- if too high: disturbs orbits of inner solar system planets; disturbs sun's luminosity and stability of sun's long term luminosity

water absorption capacity of planet's lower mantle

- if too low: too much water on planet's surface; no continental land masses; too little plate tectonic activity; carbonate-silicate cycle disrupted
- if too high: too little water on planet's surface; too little plate tectonic activity; carbonate-silicate cycle disrupted

gas dispersal rate by companion stars, shock waves, and molecular cloud expansion in the Sun's birthing star cluster

- if too low: too many stars form in Sun's vicinity which will disturb planetary orbits and pose a radiation problem; too much gas and dust in solar system's vicinity
- if too high: not enough gas and dust condensation for the Sun and its planets to form; insufficient gas and dust in solar system's vicinity

decay rate of cold dark matter particles

- if too low: insufficient production of dwarf spheroidal galaxies which will limit the maintenance of long-lived large spiral galaxies

- if too high: too many dwarf spheroidal galaxies produced which will cause spiral galaxies to be too unstable

ratio of inner dark halo mass to stellar mass for galaxy

- if too low: corotation distance is too close to the center of the galaxy which exposes the life-support planet to too much radiation and too many gravitational disturbances
- if too high: corotation distance is too far from the center of the galaxy where the abundance of heavy elements is too sparse to make rocky planets

star rotation rate

- if too slow: too weak of a magnetic field resulting in not enough protection from cosmic rays for the life-support planet
- if too fast: too much chromospheric emission causing radiation problems for the life-support planet

rate of nearby gamma ray bursts

- if too low: insufficient mass extinctions of life to create new habitats for more advanced species
- if too high: too many mass extinctions of life for the maintenance of long-lived species

aerosol particle density emitted from forests

- if too low: too little cloud condensation which reduces rainfall, lowers the albedo (planetary reflectivity), and disturbs climates on a global scale
- if too high: too much cloud condensation which increases rainfall, raises the albedo (planetary reflectivity), and disturbs climate on a global scale; too much smog

density of interstellar and interplanetary dust particles in vicinity of life-support planet

- if too low: inadequate delivery of life-essential materials
- if too high: disturbs climate too radically on life-support planet

thickness of mid-mantle boundary

- if too thin: mantle convection eddies become too strong; tectonic activity and silicate production become too great
- if too thick: mantle convection eddies become too weak; tectonic activity and silicate production become too small

galaxy cluster density

- if too low: insufficient infall of gas, dust, and dwarf galaxies into a large galaxy that eventually could form a life-supportable planet

- if too high: gravitational influences from nearby galaxies will disturb orbit of the star that has a life-supprtable planet thereby exposing that planet either to deadly radiation or to gravitational disturbances from other stars in that galaxy

star formation rate in solar neighborhood during past 4 billion years

- if too high: life on Earth will be exposed to deadly radiation or orbit of Earth will be disturbed

variation in star formation rate in solar neighborhood during past 4 billion years

- if too high: life on Earth will be exposed to deadly radiation or orbit of Earth will be disturbed

gamma-ray burst events

- if too few: not enough production of copper, scandium, titanium, and zinc
- if too many: too many mass extinction events

cosmic ray luminosity of Milky Way Galaxy:

- if too low: not enough production of boron
- if too high: life spans for advanced life too short; too much destruction of planet's ozone layer

air turbulence in troposphere

- if too low: inadequate formation of water droplets
- if too great: rainfall distribution will be too uneven

primordial cosmic superwinds

- if too low of an intensity: inadequate star formation late in cosmic history
- if too great of an intensity: inadequate star formation early in cosmic history

smoking quasars

- if too few: inadequate primordial dust production for stimulating future star formation
- if too many: early star formation will be too vigorous resulting in too few stars and planets being able to form late in cosmic history

quantity of phytoplankton

- if too low; inadequate production of molecular oxygen and inadequate production of maritime sulfate aerosols (cloud condensation nuclei); inadequate consumption of carbon dioxide
- if too great: too much cooling of sea surface waters and possibly too much reduction of ozone quantity in lower stratosphere; too much consumption of carbon dioxide

quantity of iodocarbon-emitting marine organisms

- if too low: inadequate marine cloud cover; inadequate water cycling
- if too great: too much marine cloud cover; too much cooling of Earth's surface

mantle plume production

- if too low: inadequate volcanic and island production rate
- if too great: too much destruction and atmospheric disturbance from volcanic eruptions

quantity of magnetars (proto-neutron stars with very strong magnetic fields)

- if too few during galaxy's history: inadequate quantities of r-process elements are synthesized
- if too many during galaxy's history: too great a quantity of r-process elements are synthesized; too great of a high-energy cosmic ray production

frequency of gamma ray bursts in galaxy

- if too low: inadequate production of copper, titanium, and zinc; insufficient hemisphere-wide mass extinction events
- if too great: too much production of copper and zinc; too many hemisphere-wide mass extinction events

parent star magnetic field

- if too low: solar wind and solar magnetosphere will not be adequate to thwart a significant amount of cosmic rays
- if too great: too high of an x-ray flux will be generated

amount of outward migration of Neptune

- if too low: total mass of Kuiper Belt objects will be too great; Kuiper Belt will be too close to the sun; Neptune's orbit will not be circular enough and distant enough to guarantee long-term stability of inner solar system planets' orbits
- if too great: Kuiper Belt will be too distant and contain too little mass to play any significant role in contributing volatiles to life-support planet or to contributing to mass extinction events; Neptune will be too distant to play a role in contributing to the long-term stability of inner solar system planets' orbits

Q-value (rigidity) of Earth during its early history

- if too low: final obliquity of Earth becomes too high; rotational braking of Earth too low
- if too great: final obliquity of Earth becomes too low; rotational braking of Earth is too great

parent star distance from galaxy's corotation circle

- if too close: a strong mean motion resonance will destabilize the parent star's galactic orbit
- if too far: planetary system will experience too many crossings of the spiral arms

average quantity of gas infused into the universe's first star clusters

- if too small: wind form supergiant stars in the clusters will blow the clusters apart which in turn will prevent or seriously delay the formation of galaxies
- if too large: early star formation, black hole production, and galaxy formation will be too vigorous for spiral galaxies to persist long enough for the right kinds of stars and planets to form so that life will be possible

frequency of late impacts by large asteroids and comets

- if too low: too few mass extinction events; inadequate rich ore deposits of ferrous and heavy metals
- if too many: too many mass extinction events; too radical of disturbances of planet's crust

level of supersonic turbulence in the infant universe

- if too low: first stars will be of the wrong type and quantity to produce the necessary mix of elements, gas, and dust so that a future star and planetary system capable of supporting life will appear at the right time in cosmic history
- if too high: first stars will be of the wrong type and quantity to produce the necessary mix of elements, gas, and dust so that a future star and planetary system capable of supporting life will appear at the right time in cosmic history

number density of the first metal-free stars to form in the universe

- if too low: inadequate initial production of heavy elements and dust by these stars to foster the necessary future star formations that will lead to a possible life-support body
- if too many: super winds blown out by these stars will prevent or seriously delay the formation of the kinds of galaxies that could possibly produce a future life-support body

size of the carbon sink in the deep mantle of the planet

- if too small: carbon dioxide level in planet's atmosphere will be too high
- if too large: carbon dioxide level in planet's atmosphere will be too low; biomass will be too small

rate of growth of central spheroid for the galaxy

- if too small: inadequate flow of heavy elements into the spiral disk; inadequate outward drift of stars from the inner to the central portions of the spiral disk

- if too large: inadequate spiral disk of late-born stars

amount of gas infalling into the central core of the galaxy

- if too little: galaxy's nuclear bulge becomes too large
- if too much: galaxy's nuclear bulge fails to become large enough

level of cooling of gas infalling into the central core of the galaxy

- if too low: galaxy's nuclear bulge becomes too large
- if too high: galaxy's nuclear bulge fails to become large enough

ratio of dual water molecules, $(H_2O)_2$, to single water molecules, H_2O, in the troposphere

- if too low: inadequate raindrop formation; inadequate rainfall
- if too high: too uneven of a distribution of rainfall over planet's surface

heavy element abundance in the intracluster medium for the early universe

- if too low: too much star formation too early in cosmic history; no life-support body will ever form or it will form at the wrong tine and/or place
- if too high: inadequate star formation early in cosmic history; no life-support body will ever form or it will form at the wrong tine and/or place

quantity of volatiles on and in Earth-sized planet in the habitable zone

- if too low: inadequate ingredients for the support of life
- if too high: no possibility for a means to compensate for luminosity changes in star

pressure of the intra-galaxy-cluster medium

- if too low: inadequate star formation bursts in large galaxies
- if too high: star formation burst activity in large galaxies is too aggressive, too frequent, and too early in cosmic history

level of spiral substructure in spiral galaxy

- if too low: galaxy will not be old enough to sustain advanced life
- if too high: gravitational chaos will disturb planetary system's orbit about center of galaxy and thereby expose the planetary system to deadly radiation and/or disturbances by gas or dust clouds

mass of outer gas giant planet relative to inner gas giant planet

- if greater than 50 percent: resonances will generate non-coplanar planetary orbits which will destabilize orbit of life-support planet
- if less than 25 percent: mass of the inner gas giant planet necessary to adequately protect life-support planet from asteroidal and cometary collisions would be large enough to gravitationally disturb the orbit of the

life-support planet

triggering of El Nino events by explosive volcanic eruptions

- if too seldom: uneven rainfall distribution over continental land masses
- if too frequent: uneven rainfall distribution over continental land masses; too much destruction by the volcanic events; drop in mean global surface temperature

time window between the peak of kerogen production and the appearance of intelligent life

- if too short: inadequate time for geological and chemical processes to transform the kerogen into enough petroleum reserves to launch and sustain advanced civilization
- if too long: too much of the petroleum reserves will be broken down by bacterial activity into methane

time window between the production of cisterns in the planet's crust that can effectively collect and store petroleum and natural gas and the appearance of intelligent life

- if too short: inadequate time for collecting and storing significant amounts of petroleum and natural gas
- if too long: too many leaks form in the cisterns which lead to the dissipation of petroleum and gas

efficiency of flows of silicate melt, hypersaline hydrothermal fluids, and hydrothermal vapors in the upper crust

- if too low: inadequate crystallization and precipitation of concentrated metal ores that can be exploited by intelligent life to launch civilization and technology
- if too high: crustal environment becomes too unstable for the maintenance of civilization

quantity of dust formed in the ejecta of Population III supernovae

- if too low: number and mass range of Population II stars will not be great enough for a life-support planet to form at the right time and place in the cosmos; Population II stars will not form soon enough after the appearance of Population III stars
- if too high: Population II star formation will occur too soon and be too aggressive for a life-support planet to form at the right time and place in the cosmos

quantity and proximity of gamma-ray burst events relative to emerging solar nebula

- if too few and too far: inadequate enrichment of solar nebula with copper, titanium, and zinc
- if too many and too close: too much enrichment of solar nebula with

copper and zinc; too much destruction of solar nebula

heat flow through the planet's mantle from radiometric decay in planet's core

- if too low: mantle will be too viscous and, thus, mantle convection will not be vigorous enough to drive plate tectonics at the precise level to compensate for changes in star's luminosity
- if too high: mantle will not be viscous enough and, thus, mantle convection will be too vigorous resulting in too high of a level of plate tectonic activity to perfectly compensate for changes in star's luminosity

water absorption by planet's mantle

- if too low: mantle will be too viscous and, thus, mantle convection will not be vigorous enough to drive plate tectonics at the precise level to compensate for changes in star's luminosity
- if too high: mantle will not be viscous enough and, thus, mantle convection will be too vigorous resulting in too high of a level of plate tectonic activity to perfectly compensate for changes in star's luminosity

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