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STELLAR WASTE

A look at the way supernovae spread life throughout the Galaxy

Life in the Milky Way: A Galactic Garbage Can

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The story of the human race, the story of you, began with the formation and destruction of the first stars. These ancient and noble progenitors of Earth seeded the Galaxy with every atom that now constitutes your very being: your thoughts and your body. The tree of complexity grows from their fertile technicolor ashes: spread in beautiful array, circles of gold intertwined with strands of sky blue, blood red coursing in veins throughout—iris like—future eyes. Are we the only ones to see ourselves in the stars? "Where are they?" Enrico Fermi famously asked upon considering this quandary of the seeming absence of intelligent life in our galaxy. The Milky Way has reached a mature enough point to form and support life, as evidenced by our only example, the Earth, but evidence suggests that others could have come long before us. Recent research into the chemical evolution of the Galaxy, how it relates to the

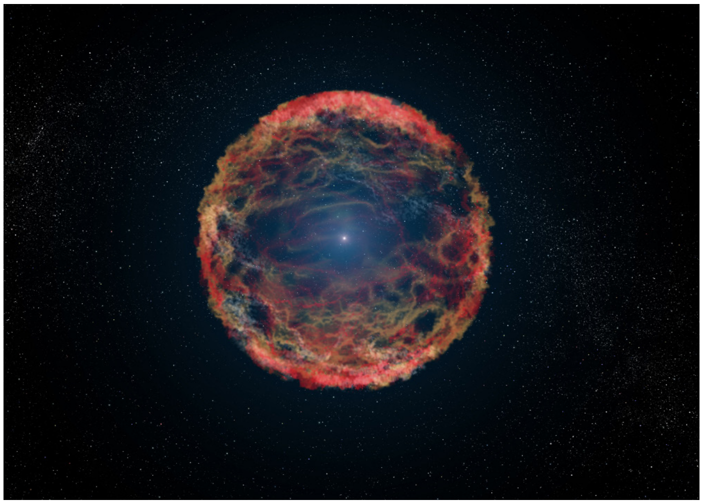

Figure 2. The x-axis along the bottom of the graph depicts the metallicity of the host star in a ration of iron (Fe) to hydrogen (H). The y-axis along the left is the number of stars surveyed. The x-axis along the top is another depiction of metallicity in relation to the sun, Z being the metallicity of the star surveyed, and Z(sub sun) being the metallicity of our sun. The right hand y-axis is the probability of harboring Earth-like planets, or destroying them (as depicted by the hatched curves).

formation of new stars and exoplanets, and the discovery and study of these planets paint an increasingly optimistic future for our understanding of life in the Galaxy.

Stellar waste—or supernova remnants—drive galactic chemical evolution. Early star formation and destruction give a relative idea of when life first became possible in the Galaxy. In 1999, Takuji Tsujimoto proposed a type of star formation as a solution to the problem of calculating the abundance of metal rich stars (in cosmology metal being any element heavier than H/He) in the early stages of galactic formation. Conventional models of star formation stated that stars formed out of well-mixed gas clouds, and would have a metallicity equivalent to the gas out of which they formed. This newer model says that stars are formed out of supernova remnants which sweep up interstellar gas and form a dense inhomogeneous shell. This shell fragments into thousands of pieces, which, under the right conditions can become new stars. However, only about 10 percent of the gas in the cloud comes together to form new stars, the other 90 percent will reintegrate with the Galactic disk (Tsujimoto, 1999). This means that stellar metallicity is different than that of the gas from which it is formed. The interstellar gas, especially in the youth of the Galaxy, is metal poor, therefore stars formed out of the inhomogeneous dense shell incorporate this low metallicity. This process of supernova, dense shell, and star formation continues until a dense shell can no longer be formed due to lack of interstellar gas (Tsujimoto, 1999). This model explains the abundance of metal poor stars throughout the Galaxy, which do not allow for Earth-like planet formation or the complex chemistry required for life (Lineweaver, 2001) .

However, some areas can be too metal rich to support life. Solar systems extremely high in metals form massive close-orbiting planets known as hot Jupiters, which are highly disruptive to the formation of Earth-like planets. The relationship between increasing metallicity and increased formation of Earth-like planets is linear until it reaches the point where hot Jupiters are formed, it reverses, and the probability for destroying Earths increases exponentially (Lineweaver, 2001). Around five percent of Sun-like stars harbor hot Jupiters, leaving 95 percent of all others the possibility of possessing Earth-like planets, with the probability of such occurrence measured directly by metallicity (Lineweaver 2001).

But the relationship between metallicity and formation of Earths may not be as drastic as once thought. The difference between metallicities in stars with and without planets can show little variation, and in the case of red giant stars, there is no relationship between metallicity and star formation (Mortier, 2013). Large planet formation requires a

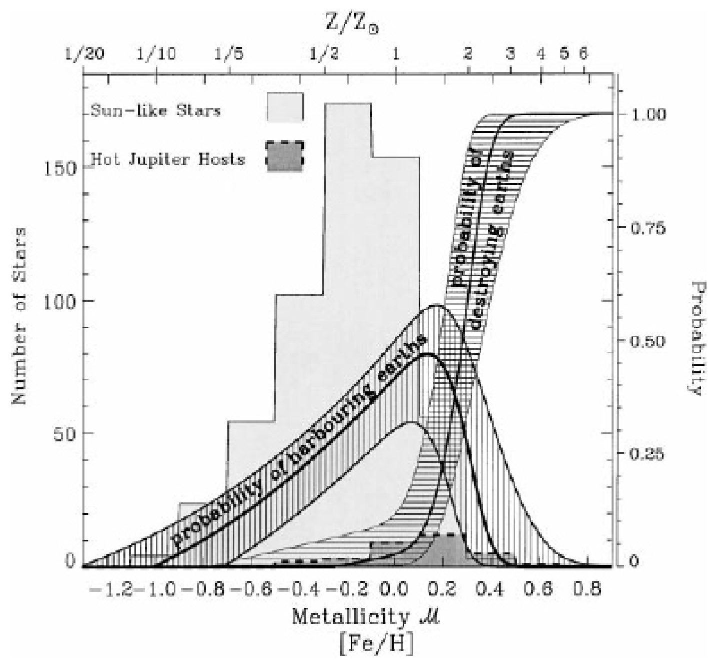

Figure 3. The x-axis along the bottom of the graph depicts the metallicity of the host star in a ration of iron (Fe) to hydrogen (H). The y-axis along the left is the number of stars surveyed. The x-axis along the top is another depiction of metallicity in relation to the sun, Z being the metallicity of the star surveyed, and Z(sub sun) being the metallicity of our sun. The right hand y-axis is the probability of harboring Earth-like planets, or destroying them (as depicted by the hatched curves).

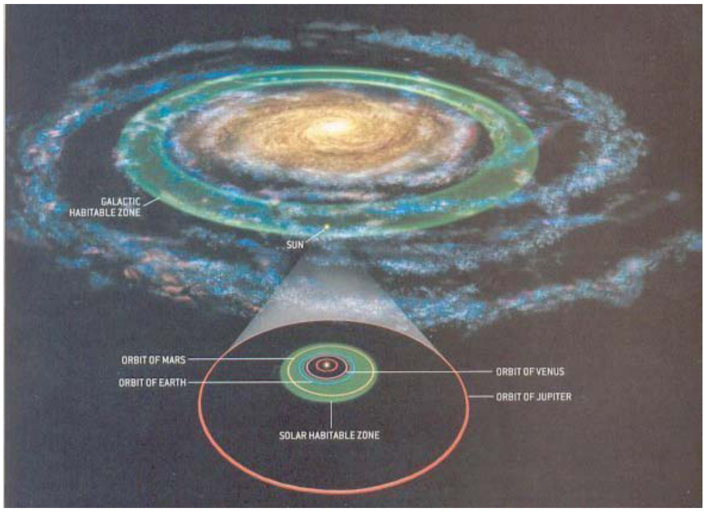

Figure 4. A general depiction (not accurate) of the concept of a galactic habitable zone, with a zoom in on our solar system for comparison.

high metallicity, but formation of Earth-like planets has been observed to require half as much metallicity as previously proposed (four times lower than the metallicity of our Sun), based on analysis of Kepler planet candidates (Buchhave, 2012). This by no means throws out Lineweaver's estimations of Earth-like planet occurrence, it simply lowers the lower bound of metallicity.

Given the strict requisites to the formation of Earth-like planets and the emergence of life, an estimation of the locations in the Galaxy in which these were possible was formulated and called the Galactic habitable zone.

The inner part of the Galaxy generates metals more quickly, as it is denser in gas and creates more stars. This means that the likelihood of planet formation is increased drastically. But the high rate and proximity of supernovae create a dangerous environment for life, ruling it out of the GHZ (Lineweaver, 2004). Through star formation and supernovae, which increased the metallicity of interstellar gas, metallicity spread out from the center to create a habitable zone about 8 billion years ago (Lineweaver, 2004). The radius of the GHZ increases as metallicity spreads and condenses throughout the Galaxy. Within the galactic habitable zone, 75 percent of the stars are older than the sun, and their average age is one billion years older than the sun (Lineweaver, 2004). The average age Earth-like planets in the Galaxy is around 1.8 billion years older than Earth (Lineweaver 2001). Therefore, within the GHZ there is a possibility for the existence of Earth-like planets billions of years older than Earth.

The amount of time needed for an intelligent race to colonize the entire Galaxy, according to Fermi is around 1-100 million years (known as the Fermi-Hart timescale) (Cirkovic, 2008). With the knowledge of the possibility of life in the Galaxy that is billions of years older than life on Earth, the paradox emerges. A possible answer comes in the maturity of the Galaxy, where the evolution of the astrophysical nature yields a more temperate environment for life to exist long enough to reach the point where it can expand out of its home solar system and across the Milky Way. The timescale for understanding the paradox is the astrobiological clock, which may be reset by catastrophic life destroying events. One of the best candidates for such an event are gamma-ray bursts, which could potentially wipe out high-complexity life in regions of the GHZ (Cirkovic, 2008). But as the GHZ expands out of the more perilous regions of the Galaxy, the resets become less frequent, as less stellar density reduces the risk of gamma-ray bursts causing mass extinction. Circovik presents a phase transition model which suggests that there are periods of equilibrium within the Fermi-Hart timescale where intelligent life can flourish due to the amount of time passed since the last reset of the astrobiological clock. The answer to the paradox is that we are in a state of disequilibrium, which is to say that not enough time has passed since the last reset. But a state of equilibrium is supposed to return, and within the Fermi-Hart time scale, complex life should develop again and become commonplace (Circovik, 2008).

The balance required for life is delicate: just the right amount

"The Galactic habitable zone (GHZ) is the Goldilocks zone of the Milky Way."

of metallicity, precise proximity to the host and nearby stars, and relative tranquility on a cosmic scale for billions of years. The spread of stellar waste, the chemical evolution of the Galaxy and the growth of its habitable zone suggest a brighter future for life, and a state of astrobiological equilibrium becomes increasingly likely. The point at which the Galaxy is most fertile may still be ahead, but what is certain is that we are alive now. If we face the dangers of mass extinction, which will silence us forever, then time is of the essence, and before the clock flicks back to zero, we must find a way to carry our conscious noise out of the solar system, and through the Galaxy.

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