G- and K-dwarf Stars are the Best Targets for SETI

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The liquid water habitable zone (HZ) describes the orbital distance at which a terrestrial planet can maintain above-freezing conditions on its surface. Calculations with one-dimensional climate models predict that the inner edge of the HZ is limited by water loss through either a moist or runaway greenhouse, while the outer edge of the HZ is bounded by the maximum greenhouse effect of carbon dioxide. This classic picture of the HZ continues to guide interpretation of exoplanet discoveries; however, terrestrial planets near these inner and outer limits of the HZ may exhibit other behaviors, such as synchronous rotation for planets around cool stars, that affect their habitability. This suggests that the stellar spectral type and planetary rotation rate can constrain the likelihood of a planet supporting complex and intelligent life.

Here we discuss implications of HZ calculations for SETI. We examine the propensity of F-, G-, K-, and M-dwarf systems to support habitable planets using two methods: analysis of the Drake equation and Baysian reasoning using the anthropic principle. We argue that planets orbiting mid G- to mid K-type stars should be prioritized as targets for SETI compared to planets around F- or M-type stars.

Spectral Dependence of the Drake Equation

The Drake equation is a probabilistic expression for the number of communicative civilizations in the galaxy. This equation typically takes the form

$$N = R_* \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

where R_* is the rate of star formation, f_p is the fraction of stars with planets, n_e is the number of habitable planets per system, f_l is the fraction of habitable planets that develop life, f_i is the fraction of inhabited planets that develop intelligence, f_c is the fraction of planets with intelligent life that develop technology capable of interstellar communication, and L is the average communicative lifetime of technological civilizations.

One feature that we consider a significant omission from the Drake equation is the expected main sequence lifetime of the host star. G-dwarf stars have a typical main sequence lifetime of 10 Gyr, while F-dwarf stars evolve faster with a typical main sequence lifetime of about 4 billion years. K-dwarf stars are longer lived, with a main sequence lifetime of about 20 Gyr, and M-dwarf stars can live up to 50 to 100 Gyr or longer. The habitable lifetime of a planet depends on the evolutionary trajectory of its host star, which can be calculated with computational models. We therefore suggest a maximum value, L_{max}, that depends up on the evolutionary history of the star itself, as the expected lifetime of a communicative civilization cannot be any longer than the habitable lifetime of its planet.

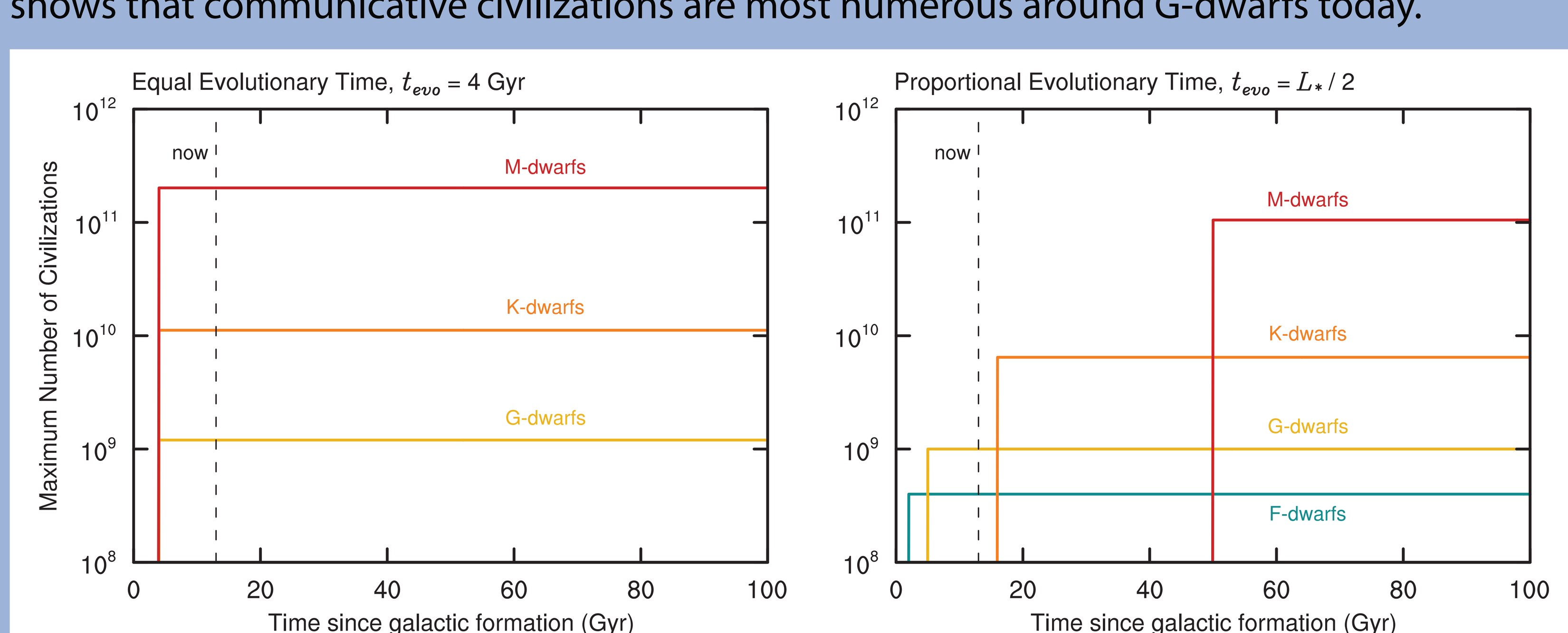
Equal Evolutionary Time (EET) hypothesis: the maximum communicative lifetime of a civilization orbiting a star of spectral type s at time t is the difference between the host star's main sequence lifetime L_* and the time required for the prerequisite evolutionary steps, t_{evo}. If evolutionary timescales on Earth are typical, then $t_{evo} \sim 4$ Gyr.

$$L_{max}(s,t) = \begin{cases} L_*(s) - t_{evo} & \text{for } t > t_{evo} \\ 0 & \text{for } t < t_{evo} \end{cases}$$

Proportional Evolutionary Time (PET) hypothesis: the maximum communicative lifetime, L_{max}, is proportional to the lifetime of the star, L_*. If communicative civilizations typically tend to arise approximately halfway through the lifetime of their host star, then $t_{evo} \sim L_*/2$.

$$L_{max}(s,t) = \begin{cases} \frac{L_*(s)}{2} & \text{for } t > t_{evo} \\ 0 & \text{for } t < t_{evo} \end{cases}$$

The figure below shows the maximum number of communicative civilizations, N_{max}, as a function of time since galactic formation. For the EET hypothesis (left panel), communicative civilizations are most numerous around M-dwarfs today, whereas the PET hypothesis (right panel) shows that communicative civilizations are most numerous around G-dwarfs today.



Star	R_*	f_p	n_e	$f_l \cdot f_i \cdot f_c$	L_*	L_{max}^{EET}	L_{max}^{PET}
F-dwarf	1 star/yr	1	0.2	1	4 Gyr	0 Gyr	2 Gyr
G-dwarf	1 star/yr	1	0.2	1	10 Gyr	6 Gyr	5 Gyr
K-dwarf	2.2 star/yr	1	0.2	1	30 Gyr	26 Gyr	15 Gyr
M-dwarf	10.5 star/yr	1	0.2	1	100 Gyr	96 Gyr	50 Gyr

Haqq-Misra & Kopparapu (2017) The Drake equation as a function of spectral type and time, in: *Habitability of the Universe Before Earth*, Gordon & Sharov (Eds.), Elsevier, in press.

Bayesian Reasoning & the Anthropic Principle

M-dwarf stars are more abundant than G-dwarf stars, so our position as observers on a planet orbiting a G-dwarf raises questions about the suitability of other stellar types for supporting life. If we consider ourselves as typical, in the anthropic sense that our environment is probably a typical one for conscious observers, then we are led to the conclusion that planets orbiting in the habitable zone of G-dwarf stars should be the best place for conscious life to develop. But such a conclusion neglects the possibility that K-dwarfs or M-dwarfs could provide more numerous sites for life to develop, both now and in the future.

We approach this anthropic problem using the 'Self-Sampling Assumption,' which we express in the form of two premises:

P1: Our existence as observers around a G-dwarf star should be considered as a random sample among the set of all observers in G-, K-, and M-dwarf systems.

P2: Other observers are in the same operational reference class as us if they possess the cognitive ability to meaningfully comprehend modern scholarly information.

In order to estimate the probability of finding ourselves on a planet orbiting a G-dwarf star, rather than a K- or M-dwarf star, we begin by defining the following statements:

Hypothesis L = "A planet is inhabited by conscious life (observers)"

Evidence G = "The planet orbits a G-dwarf star"

Evidence K = "The planet orbits a K-dwarf star"

Evidence M = "The planet orbits a M-dwarf star"

We can express the relationship between our likelihood and posterior using Bayes' theorem, which we use to write the posterior odds for the probability that favor conscious beings observing themselves orbiting a K- or M-dwarf star compared to a G-dwarf star.

$$P(L|G) = \frac{P(L)P(G|L)}{P(G)}$$

$$\frac{P(L|K)}{P(L|G)} = \frac{N_G}{N_K}\frac{P(K|L)}{P(G|L)}$$

$$\frac{P(L|M)}{P(L|G)} = \frac{N_G}{N_M}\frac{P(M|L)}{P(G|L)}$$

Next we use the calculated width of the HZ_i to estimate the likelihood function, where i represents a G-, K-, or M-dwarf star. The fractional age f_i describes a lifetime of 10^{10} yr for G-dwarfs, 10^{11} yr for K-dwarfs, and 10^{13} yr for M-dwarfs.

$$P(i|L) = \frac{f_i N_i HZ_i}{f_G N_G HZ_G + f_K N_K HZ_K + f_M N_M HZ_M}$$

We can now express the K-dwarf and M-dwarf posterior odds for habitable planets as:

$$\frac{P(L|K)}{P(L|G)} \approx 4$$

Finding ourselves around a G- instead of K-dwarf is a 1-in-4 fluke. This is not unusual, close to the probability that a person lives in China or follows Islam.

$$\frac{P(L|M)}{P(L|G)} \approx 160$$

Is a 1-in-100+ fluke enough to rule out M-dwarf habitability? About one percent of people are ambidextrous; about 1 in 10,000 sing with perfect pitch.

Even if M-dwarfs planets are habitable, one interpretation of these results is that the evolution of life on planetary systems develops on a timescale proportional to the lifetime of the star itself, so that M-dwarfs today should not expect to develop any form of advanced life until much later in the future. If this line of reasoning is valid at all, then we should not expect to find signs of conscious observers on M-dwarf planets today, while G-dwarf and early K-dwarf planets provide better places to look.

Haqq-Misra, Kopparapu & Wolf (2017) Why do we find ourselves around a yellow star instead of a red star? *International Journal of Astrobiology*, in press.

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