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The DRAKE mission: finding the frequency of life in the Galaxy

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Abstract

Discovering just a single exoplanet with signs of life would be an event of huge scientific and cultural significance. Yet, that single discovery may not shed light on an even more fundamental question: how common is life in the Galaxy? This can be parameterized by the f_L term in the famous Drake equation [1]. Biomarker molecular spectral signatures may indicate the presence of life on an exoplanet. We propose a mission concept called DRAKE (Dedicated Research for Advancing Knowledge of Exobiology) to survey a statistically significant number of M-dwarf habitable zone terrestrial planets using transit spectroscopy. We explore this concept through preliminary observatory and mission simulations.

1. Introduction

Due to sensitivity considerations such a mission would only be viable for M-dwarf planets, which is a disadvantage compared to direct-imaging approaches. In addition the available sample size is reduced through the transit probability (~2%). However transit spectroscopy is a relatively seasoned method with several previous and approved future space-borne missions. In addition since M-dwarfs are ~75% of all stars, and since the frequency of Earth-sized planets in the habitable zones of M-dwarfs and Sun-like stars is about the same [2][3], it may be the case that such M-dwarf planets represent the Galactic norm not the exception. Currently there are only 18 known transiting terrestrial planets within the optimistic habitable zone boundaries of M-dwarf stars (http://phl.upr.edu/projects/habitable-exoplanets-catalog). However in the coming years this number is likely to increase considerably due to new discoveries by TESS, PLATO, Cheops and ground-based transit surveys, making a transit spectroscopy-based survey potentially viable.

2. Sample size

What sample size would be needed to constrain f_L to within a given margin of error? Figure 1 shows the results of Monte Carlo simulations that calculate the margin of error, e, for 95% confidence level at different sample sizes, N_{samp}. This is obtained through simulation of an overall population of size N_{pop} and assumes a true value for f_L between 0 and 1.0. e is half of the 95% confidence limit obtained for the distribution of f_L sample estimates over 1000 samples, and is maximal (e_{max}) when f_L = 0.5. Figure 1 shows that the curves of e_{max} vs N_{samp} converge at higher N_{pop}. At $N_{pop} = 10^6$, we find that 50 and 100 planet samples could constrain f_L to ± 14% and 9.6% respectively at

95% confidence.

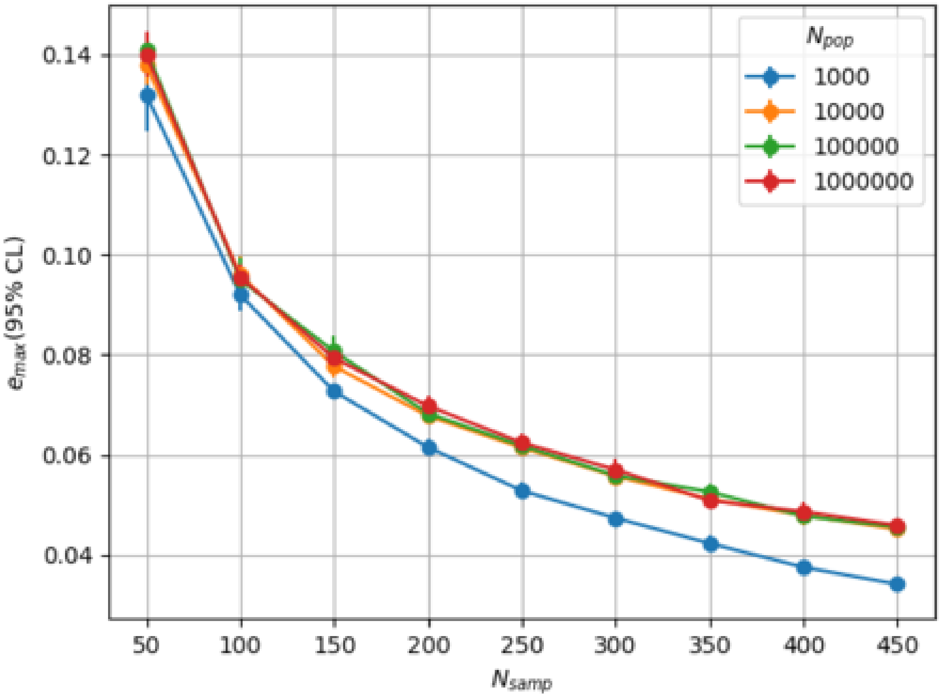

Figure 1. e_{max} vs sample size for different population sizes. Dots are the mean over 10 repeats of 1000 realization Monte Carlo simulations, and error bars are the standard deviation.

3. Observatory design

The concept calls for a telescope operating from the L2 Sun-Earth Lagrange point, with an infra-red spectrometer instrument. The near- and mid- infra-red contains spectral signatures for major molecules occuring in planetary secondary atmospheres such as H_2O, CO_2, CH_4 and NH_3, as well as biosignatures from O_2 and O_3. Ro-vibrational band envelopes produce spectral features that generally broaden at longer wavelengths. Previous work [4] has shown that most features from 5-10 µm can be characterized with $R \sim 30$, whereas narrower features at shorter wavelength require $R \sim 100$. Two prototype instruments are explored here: 1) 0.6-12 µm in two channels, Ch0 (0.6-5 µm at R = 100) and Ch1 (5-12 µm at R = 30), and 2) 0.7-10.5 µm in two channels, Ch0 (0.7-5 µm, R = 100-50), and Ch1 (5-10.5 µm, R = 30-15). The varying R power and reduced spectral range of the latter design increases the minimum atmospheric SNR (Figure 2). The ability to identify spectral features reliably using the variable R in prototype 2 will require further study using spectral retrieval methods.

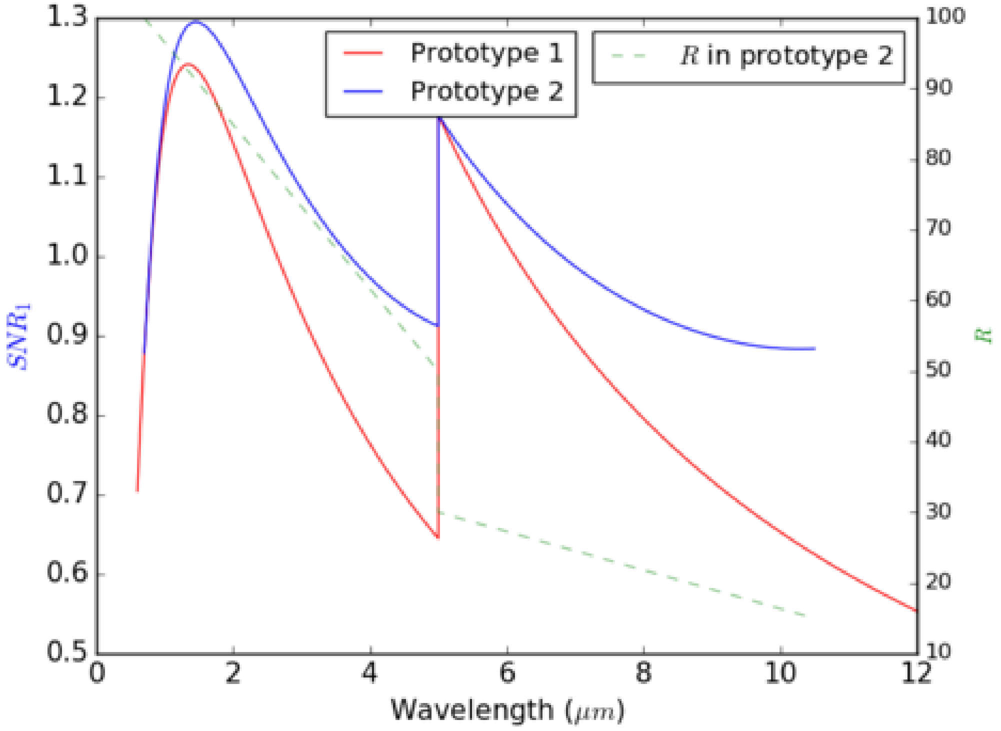

Figure 2. $SNR_1(\lambda)$, the atmospheric SNR in 1 transit for an Earth twin around an M0 star at 10 pc distance with a 10 m telescope. Red line: prototype 1. Blue line: protoype 2. The green line shows the varying R power across the band for prototype 2.

4. Simulations

Example results from initial simulations are shown in Figure 3. The method first generates a randomized simulated population of transiting Earth-sized and super-Earth-sized planets in the habitable zones of M-dwarfs of different subclasses (with a spatial distribution based on data from the TESS Input Catalogue Candidate Target List). These planets are assumed to be detected in order of their relative detection SNR to form samples of size N_{samp} ranging from 50 to 400. We use a simple instrument model for DRAKE with primary mirror size, D, and one of the two prototype instrument designs. We assume photon noise only, and a 'box-car' transit model. The scale height, H, is modelled for each planet assuming it has an average temperature and mean molecular weight equal to that for the Earth. This is used to estimate the size of a spectral feature, A, where $A = 2(n_H H R_p)/R_s^2$ ($n_H = 5$ or 7, R_p = planet radius, R_s = star radius). The noise on A, $\sigma_A(\lambda)$, is calculated, to give an atmospheric SNR for 1 transit, $SNR_1(\lambda)$. The number of transits, N_t, to reach an target SNR, SNR_t (= 3 or 5) is then calculated for each planet using the minimum $SNR_1(\lambda)$. Each planet is randomly assigned a T_0 central transit time, and a scheduling algorithm is used to efficiently order the planet sample observations and obtain a total mission duration, T_{miss}.

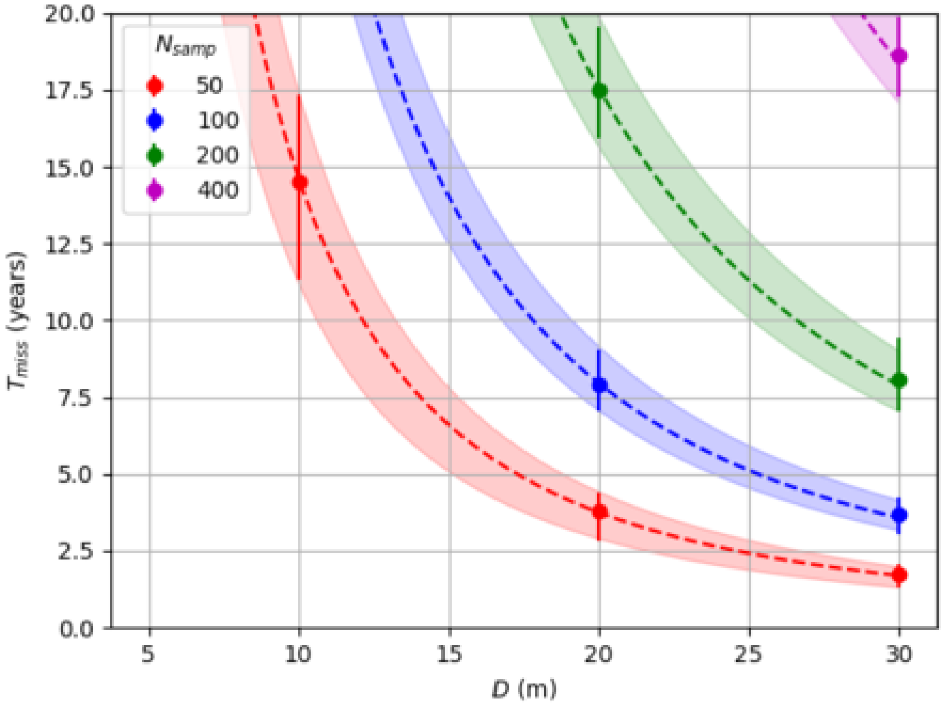

Figure 3. Prototype instrument 2 with optimistic detection criteria. Mission duration vs primary mirror size, for different sample sizes. Points with error bars show the mean and minimum-maximum range over 20 realizations. Dashed lines and shaded areas follow from power law fits.

5. Conclusions

We have shown that such a mission is achievable within a 5-20 year period under various conditions, e.g. prototype 2 completes $N_{samp} = 50$ with a 14 m telescope in 7.5 years (assuming $n_H = 7$, $SNR_t = 3$). This mission concept deserves further study and development, e.g. using more detailed instrument models and advanced detection metrics such as spectral retrievals.

References

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