Bayesian inference from all-sky searches for radio technosignatures

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Technosignature: any (remotely detectable) evidence of extraterrestrial technology

Intentional (unintentional) radio or optical transmissions

EM emissions from megastructures
(ex. Dyson spheres)

Artificial illumination of planetary night-sides

Interstellar propulsion

Atmospheric pollutants

Asteroid mining

Anomalous stellar transits
(ex. Clarke exobelts, Dyson swarms)

Relic artifacts

Inscribed matter

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Technoemissions :

extraterrestrial artificial EM emissions

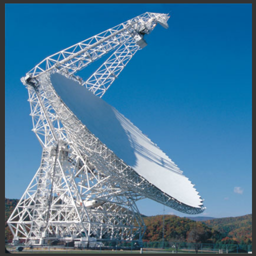
Part 1: inferring the population of technoemissions from past, current, and future searches

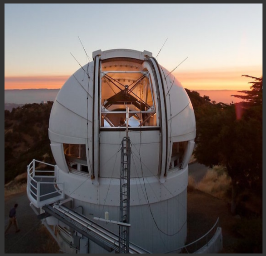
Part 2: no detection since ≈ 60 yr of searches: pessimistic view, optimistic view, and something in between

Part 1: inferring the population of technoemissions from past, current, and future searches

Breakthrough Listen (UC Berkeley 2016-2026)

10-year 100 M dollar search for radio and optical echnoemissions from 1 million nearby stars
Plane and center of the Galaxy
100 nearby galaxies

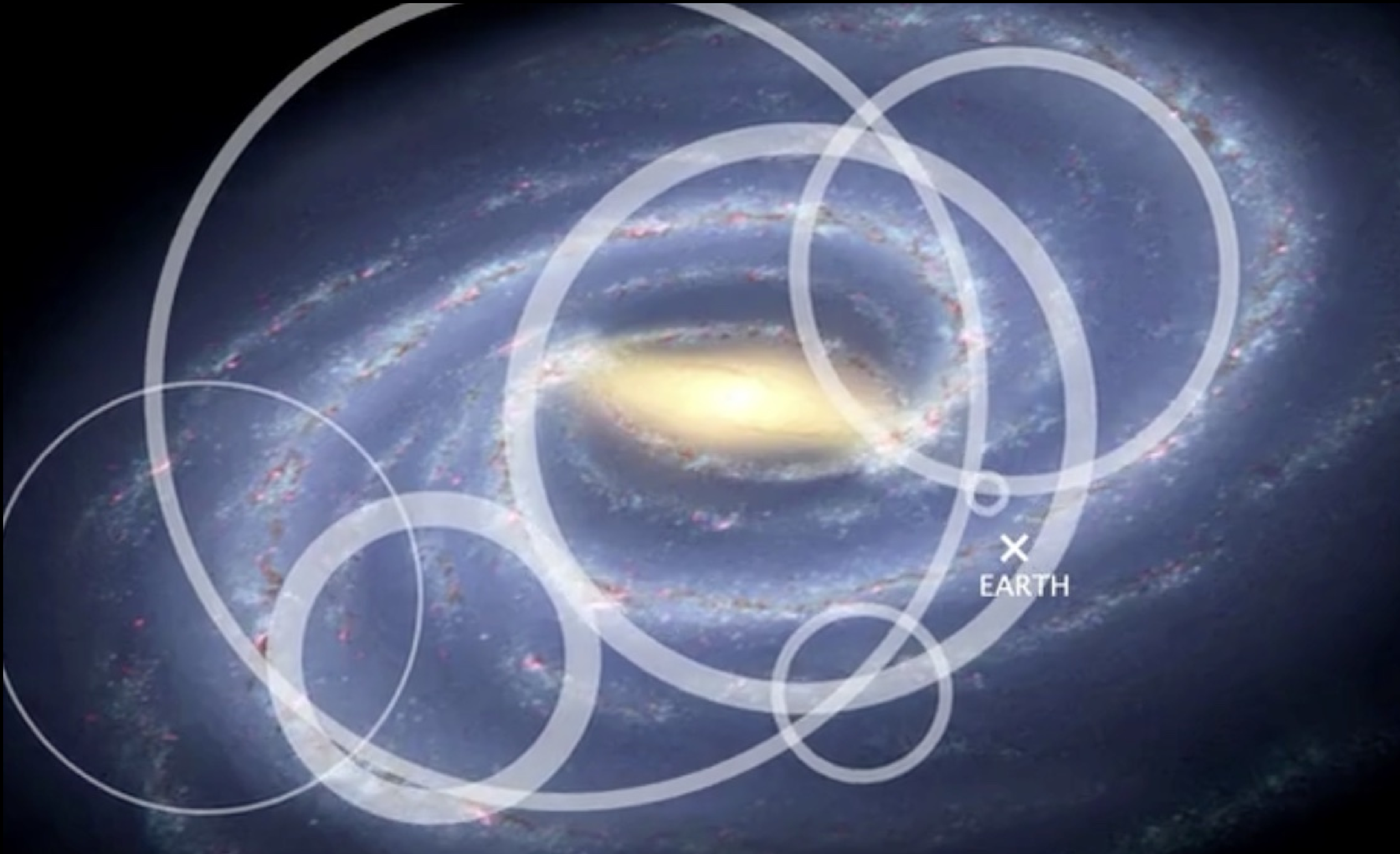




Cradle of Life

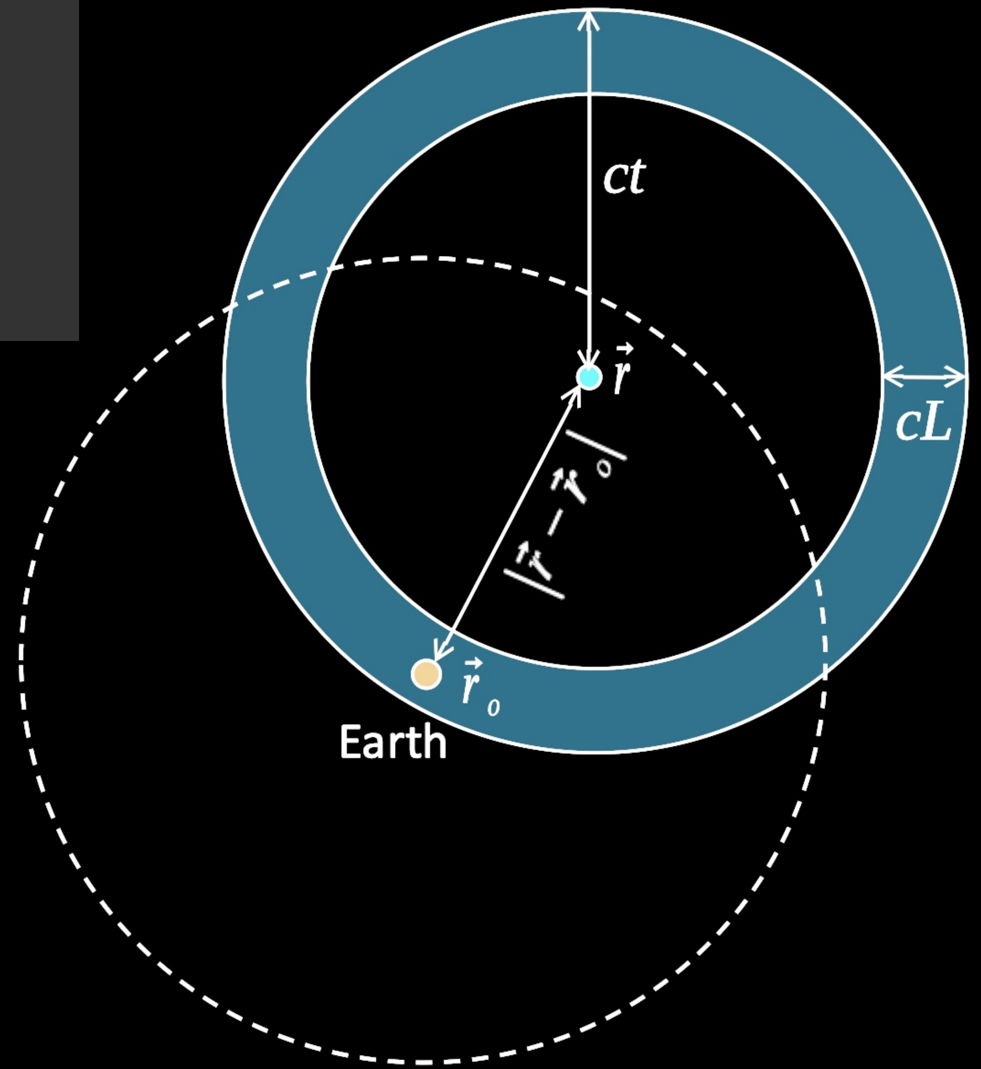
SETI with the **Square Kilometre Array**
SKA will carry out systematic, volume-limited searches of exoplanet systems for signals from technologically advanced civilisations.


EARTH


EARTH

An emitter in $\vec{r}$ generated at time t in the past a signal of longevity L

At present time, an observer in $\vec{r}_o$ searches for emitters within a radius R_o



Two condition for detectability :

1. $t - L \leq |\vec{r} - \vec{r}_o| / c \leq t$

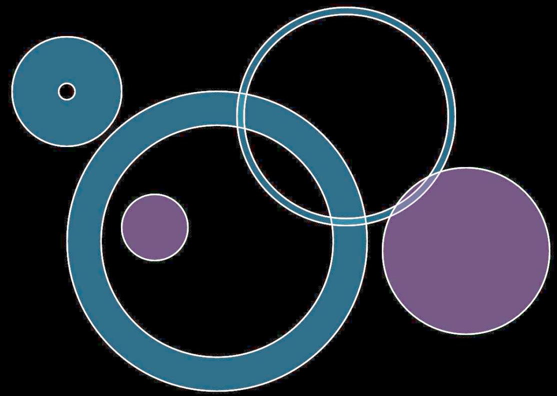
2. $|\vec{r} - \vec{r}_o| \leq R_o$

$$I(\vec{r}, t, L) = \begin{cases} 1 & \text{if detectable} \\ 0 & \text{otherwise} \end{cases}$$

CG *Sci Rep* 2017 ; A Balbi *Astrobiology* 2018 ; CG, GW Marcy, NK Tellis, F Drake *PASP* 2018

Statistical independence of technoemissions

- Emitters are randomly distributed in the Galaxy
- Identically and independently distributed starting times t
- Identically and independently distributed longevities L



Mean number of detectable technoemissions within R_o

$$\bar{k}(R_o) = \int dt\, \Gamma(t) \int dL\, \rho_L(L) \int d\vec{r}\, \rho_E(\vec{r})\, I(\vec{r}, t, L)$$

- $\Gamma(t)$: Emission rate at time t
- $\rho_L(L)$: PDF of the emission longevity
- $\rho_E(\vec{r})$: PDF of emitter location

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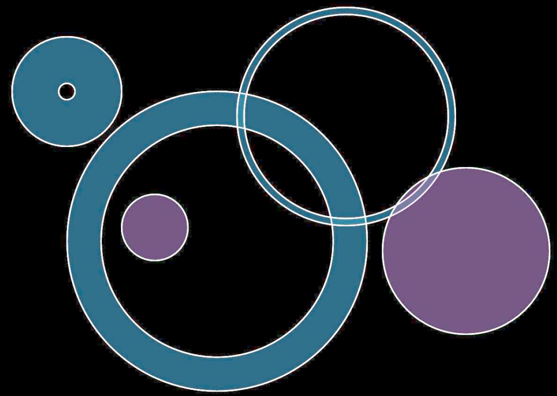

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Steady state (Γ constant) → $\bar{k}(R_o) = \bar{k} \cdot \pi_o$

- $\bar{k}$: Mean number of emissions in the galaxy
- π_o: Probability of one emitter within R_o

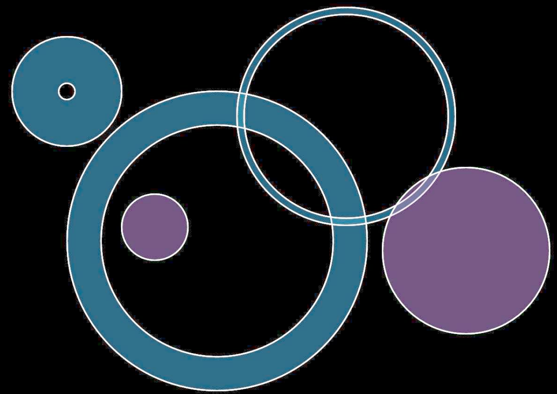
CG *MNRAS* 2021

Statistical independence of technoemissions

Emitters are randomly distributed in the Galaxy

Identically and independently distributed starting times t

Identically and independently distributed longevities L



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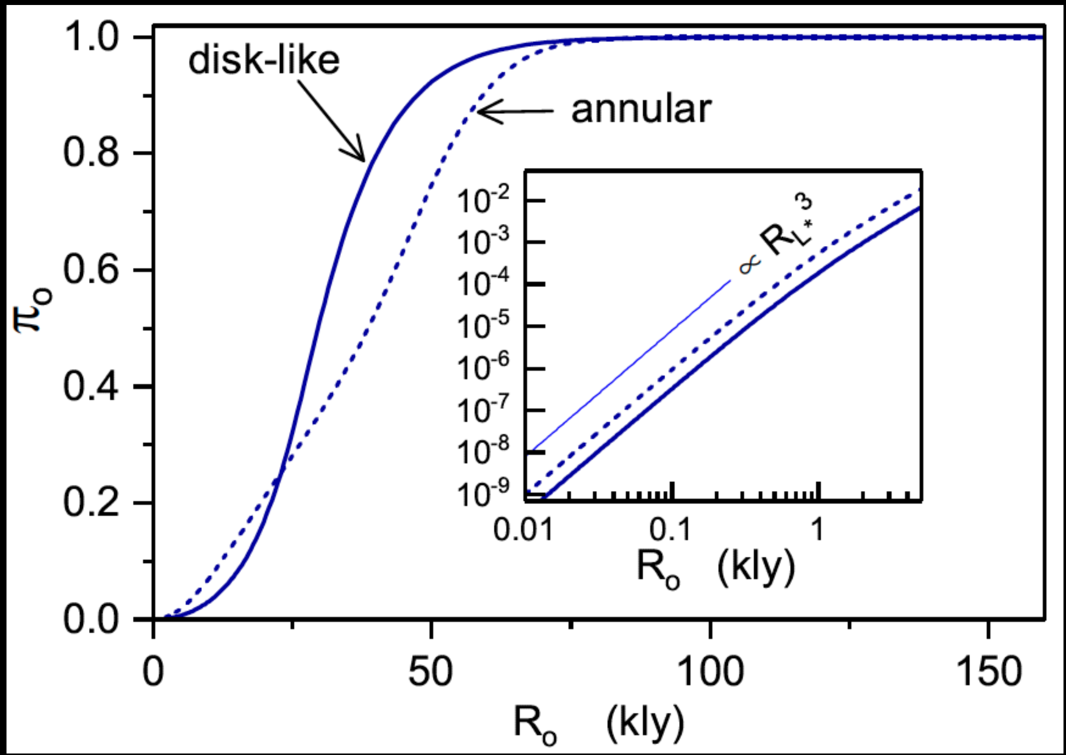


Sampled radius R_o

$$R_o = \sqrt{\frac{L^*}{4\pi S_{\min}}}$$

L* = emitter luminosity

$$S_{\min} = \sigma S_{\text{sys}} \sqrt{\frac{\Delta\nu}{t}}$$

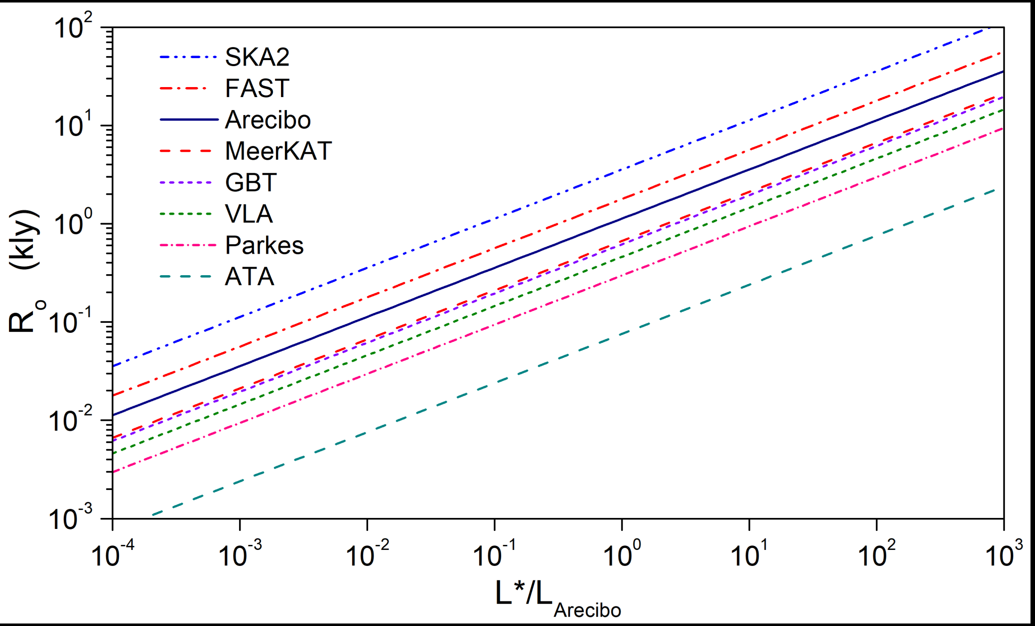
σ : signal-to-noise ratio (15)

S_{sys} : system equivalent flux density (SEFD)

t : integration time (10 min)

$\Delta\nu$: bandwidth (0.5 Hz)

telescope	S_{sys} (Jy)	$S_{\min}$ (10^{-26} W/m^2)
ATA	664[a]	287
Parkes	43	18.6
VLA	18	7.8
GBT	10	4.3
MeerKAT	8.6	3.7
Arecibo	3	1.3
FAST	1.2	0.5
SKA2	0.3[b]	0.13



Bayesian inference from searches for technoemissions

$$p\left(\bar{k}|D\right) \propto P\left(D|\bar{k}\right) p\left(\bar{k}\right)$$

posterior PDF of k
given the datum D

likelihood
function

prior PDF of k

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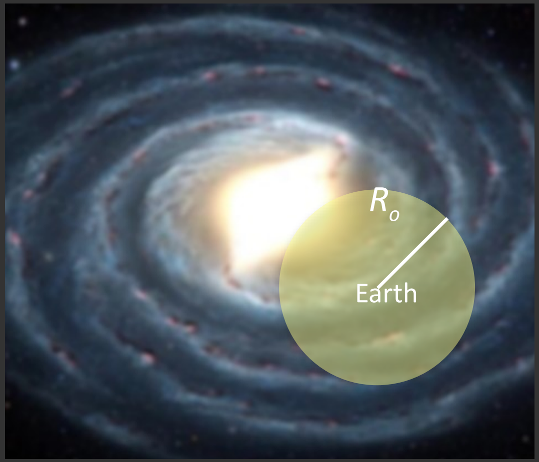
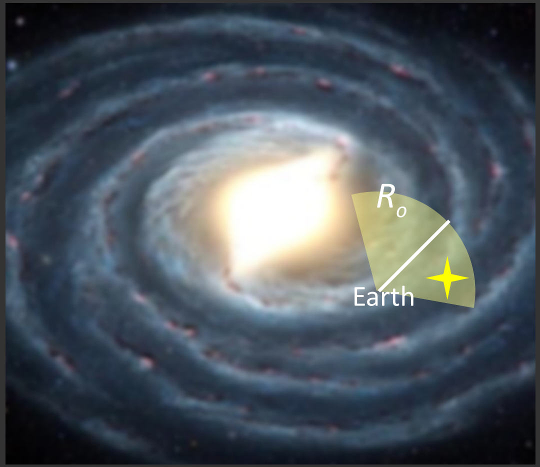


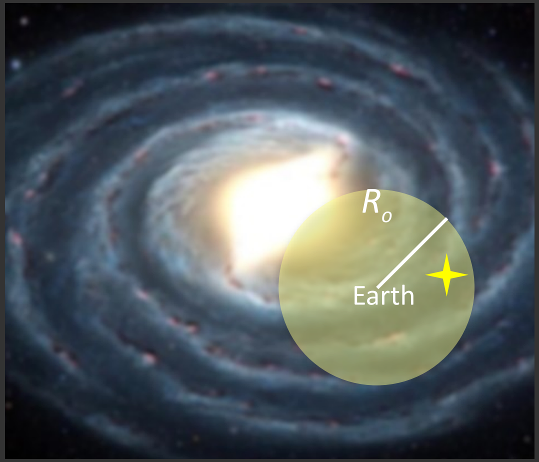
Non-detection

$$P(D_0|\bar{k}) = e^{-\bar{k}\pi_o}$$



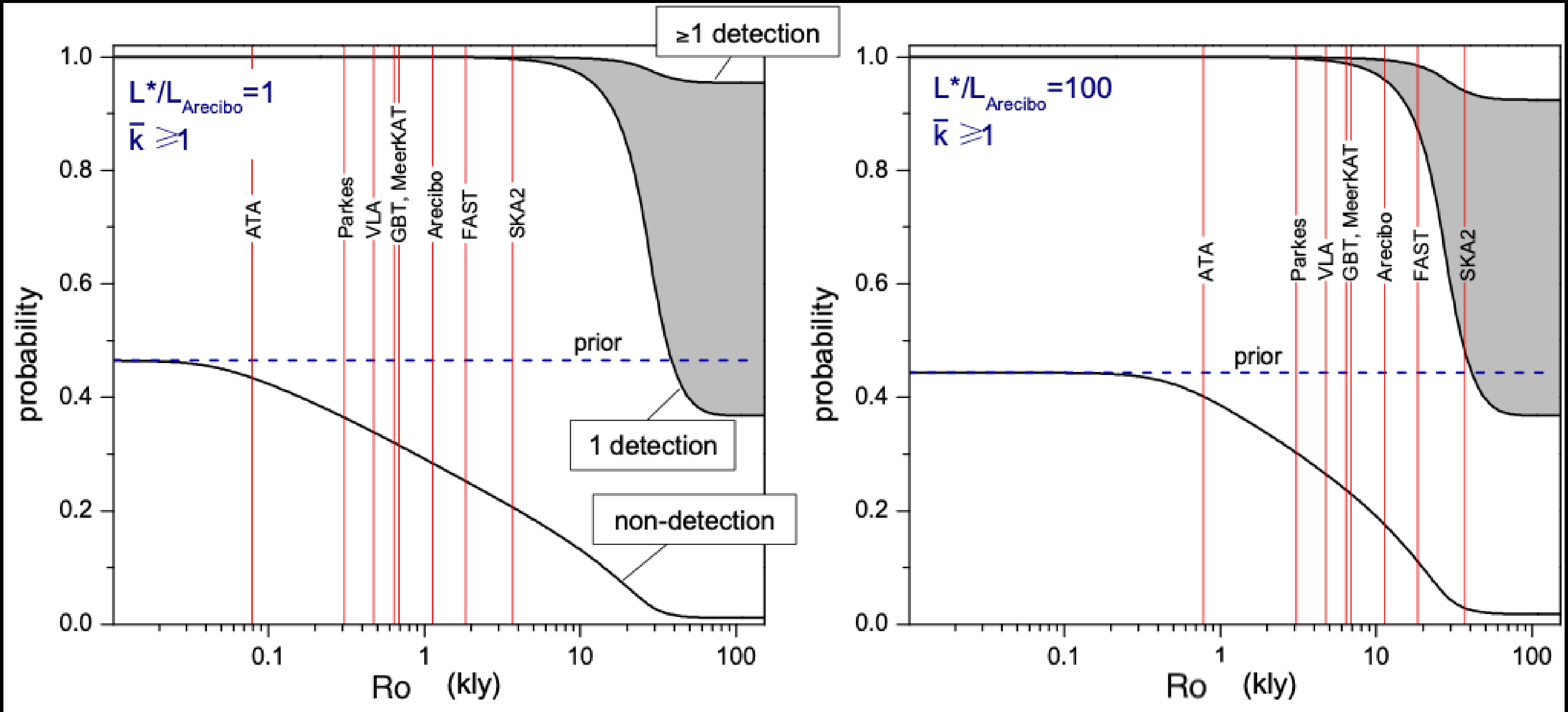
at least 1 detection

$$P(\text{not } D_0|\bar{k}) = 1 - e^{-\bar{k}\pi_o}$$



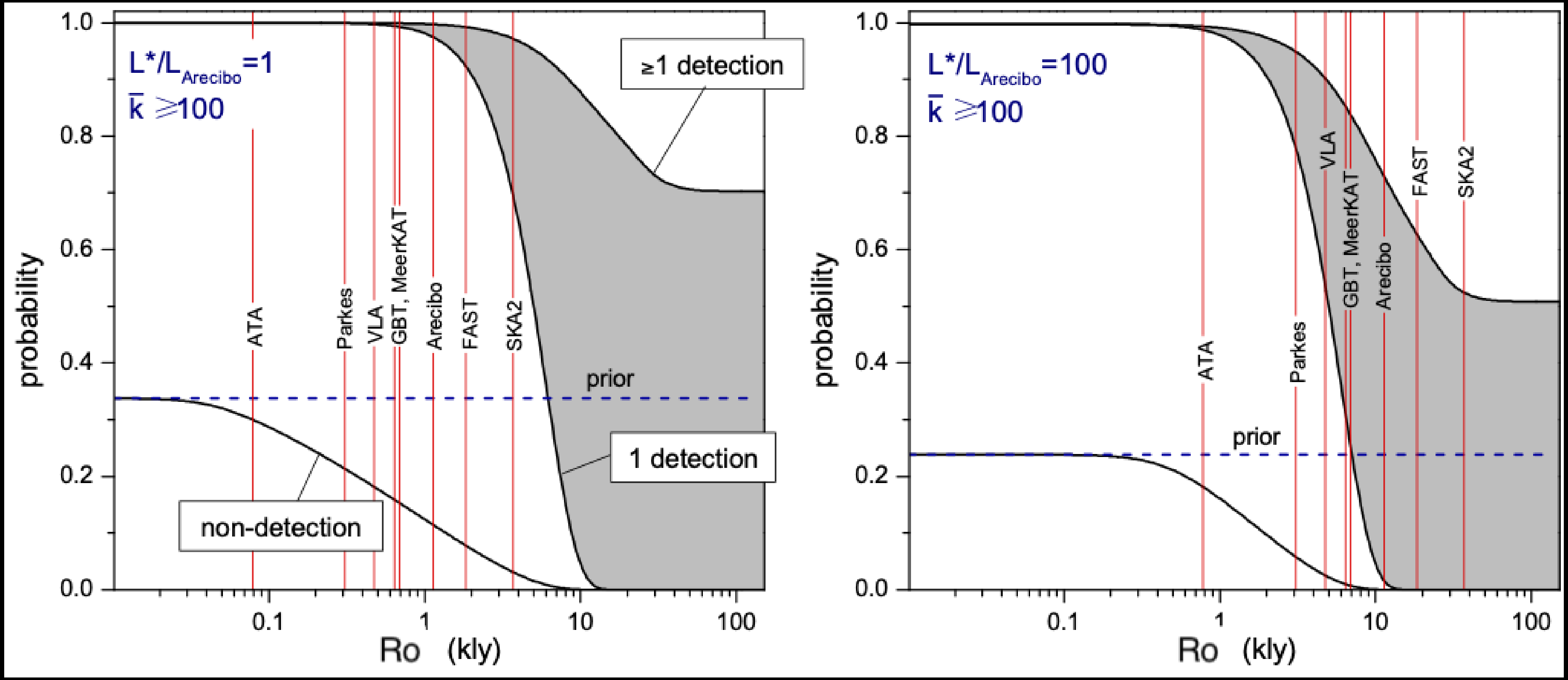
exactly 1 detection

$$P(D_1|\bar{k}) = \bar{k}\, e^{-\bar{k}\pi_o}$$



It is unlikely that there are detectable technoemissions If no signals are discovered within about 40 kly from Earth

CG & GW Marcy *PNAS* 2018



If a signal is discovered within 1000 ly from Earth it is almost certain that there are more than 100 Arecibo-like emitters in the Galaxy, yet to be discovered

CG & GW Marcy *PNAS* 2018

Part 1: inferring the population of technoemissions from past, current, and future searches

Part 2: no detection since ≈ 60 yr of searches: pessimistic view, optimistic view, and something in between

Since the first modern SETI experiment 60 years ago (Frank Drake), no confirmed technoemission has been detected.

Popular interpretations

1 The parameter search space is vast. Technoemissions are there, we just have to search harder.

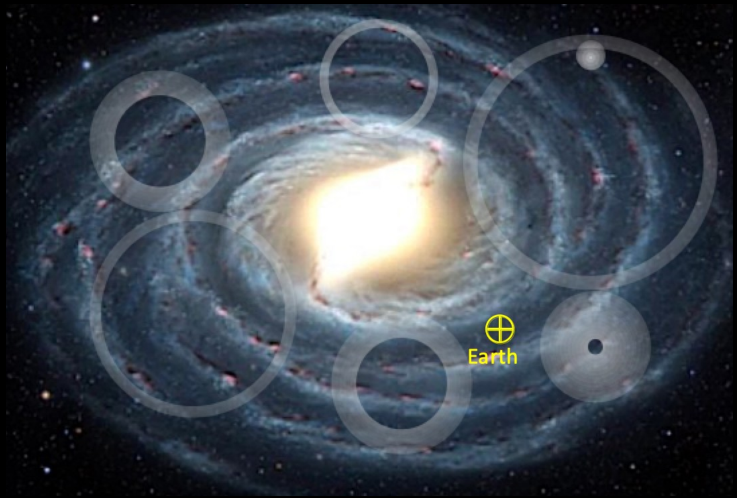
2 Extraterrestrial technological life is so rare that practically does not exist

Since the first modern SETI experiment 60 years ago (Frank Drake), no confirmed technoemission has been detected.

Popular interpretations

1 The parameter search space is vast. Technoemissions are there, we just have to search harder.

3 technoemissions might still exist, but none have crossed the Earth for at least 60 years

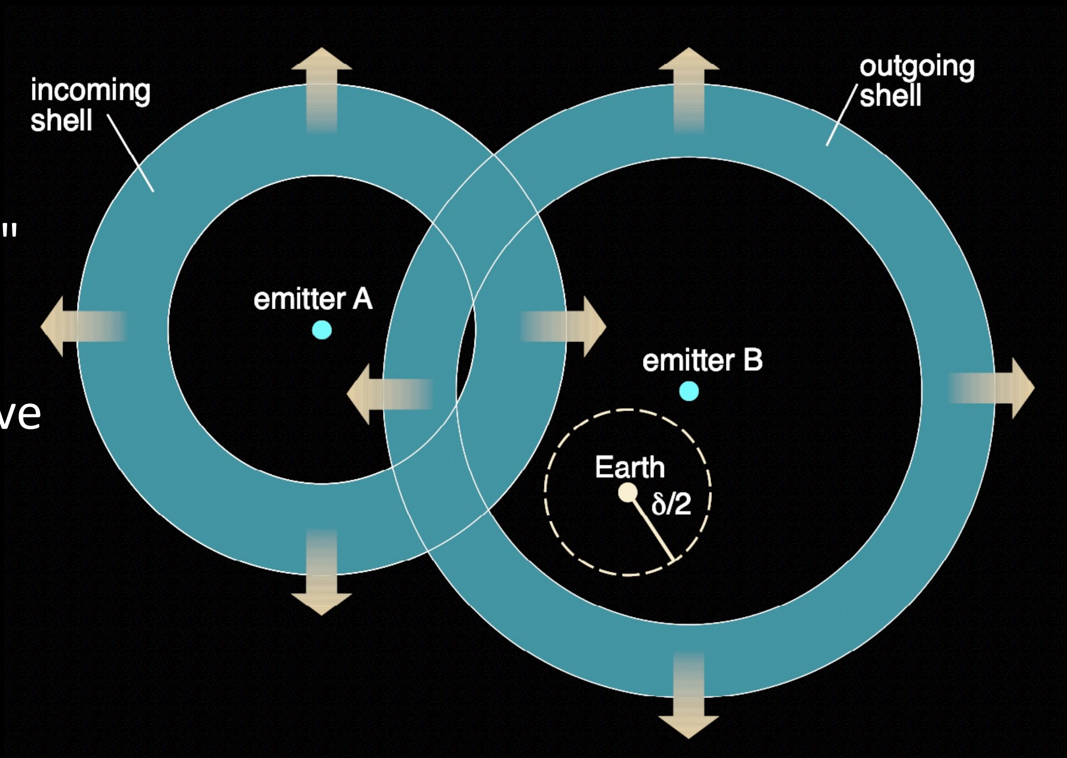


2 Extraterrestrial technological life is so rare that practically does not exist

Pore-size model

The Earth is the center of a "test sphere" of diameter δ

The time interval between two successive "overlaps" is $\tau = \delta/c$



As long as $\tau < 10^5$ yr, the time interval between successive crossing events is greater than τ with probability :

$$e^{-\Gamma\tau}$$

This is independent of the longevity

CG *AJ* 2023

Bayesian inference of the emission rate Γ from τ_o = 60 years of nondetection

posterior PDF — prior PDF

$$p(\Gamma|\tau_o) = \frac{e^{-\Gamma\tau_o}p(\Gamma)}{\int d\Gamma e^{-\Gamma\tau_o}p(\Gamma)}$$

Rates much greater than $1/\tau_o \approx 0.02\ \mathrm{yr}^{-}$ are strongly disfavored

Prior PDFs with different degrees of optimism

$$p(\Gamma) \propto \begin{cases} \text{constant}, & \text{optimistic} \\ 1/\sqrt{\Gamma}, & \text{moderately optimistic} \\ 1/\Gamma, & \text{marginally optimistic} \end{cases}$$

(Log-uniform prior)

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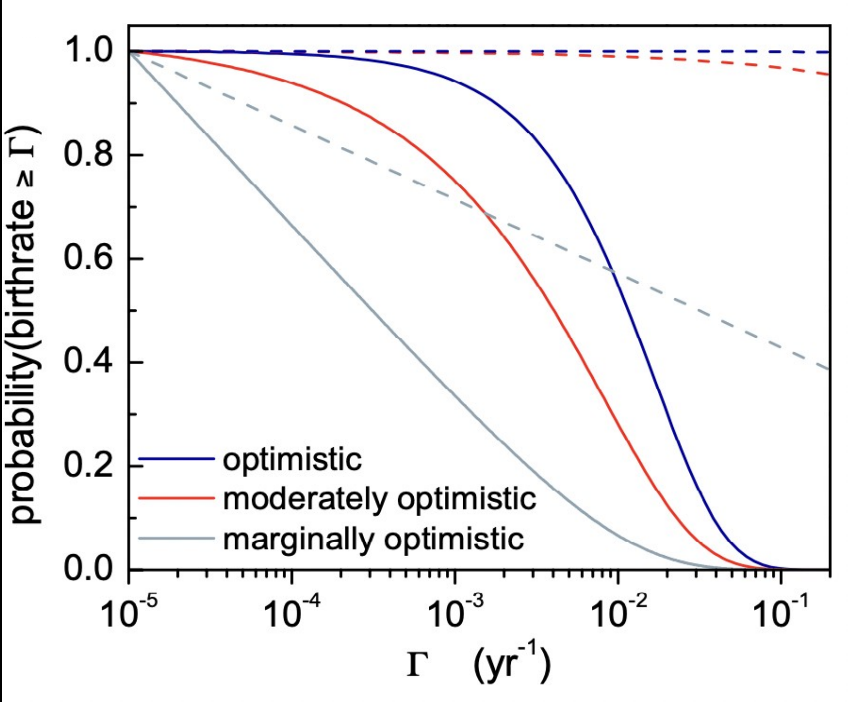
Γ < 1-5 emissions per century with credible level of 95 %



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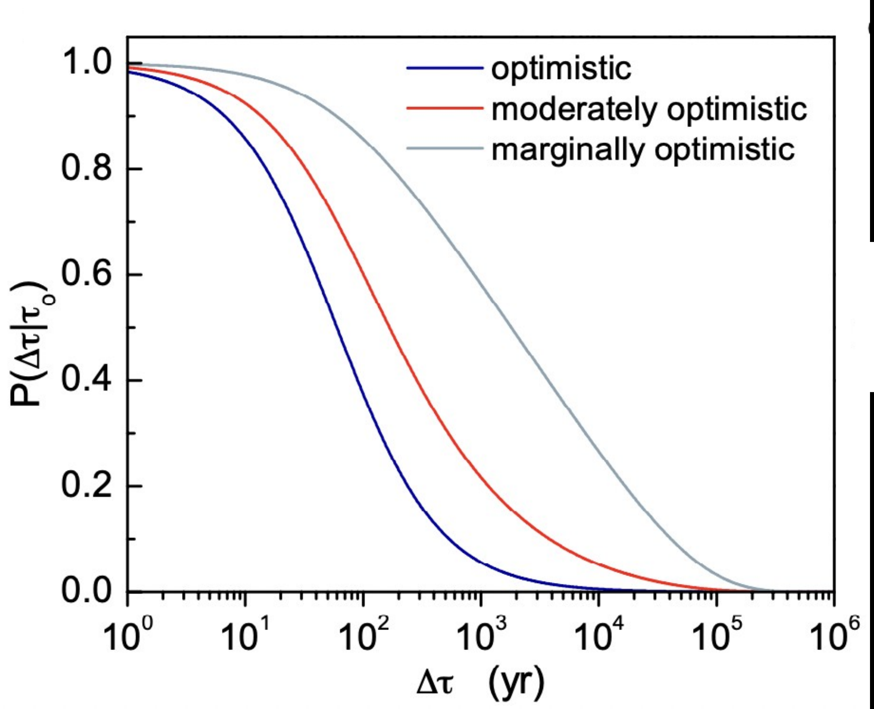
Bayesian inference of the waiting time Δτ until the next crossing event

Probability of the waiting time being greater than $\Delta\tau$ given that τ_o = 60 yr

$$P(\Delta\tau|\tau_o) = \int d\Gamma e^{-\Gamma\Delta\tau} p(\Gamma|\tau_o)$$

50 % probability that the next crossing event will not occur before the next 60 – 1800 years



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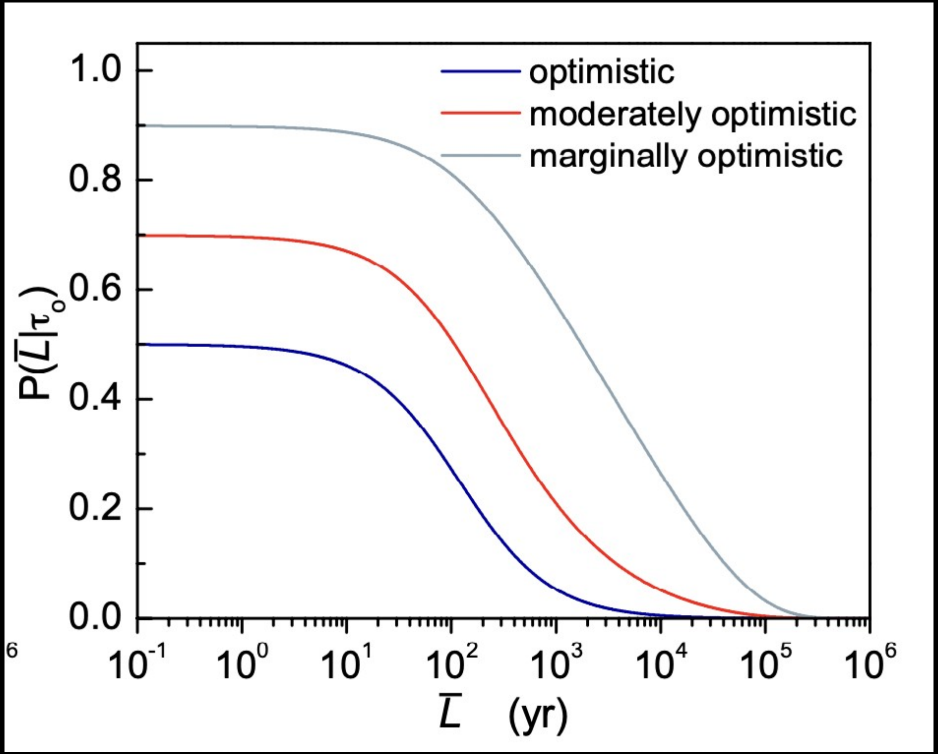
Bayesian inference of the longevity

Probability of the average longevity being greater than $\bar{L}$ given that τ_o = 60 yr

$$P(\bar{L}|\tau_o) = \int d\Gamma e^{-\Gamma(\tau_o+\bar{L})} p(\Gamma|\tau_o)$$

Technoemissions need not to be short-lived to allow for 60 years of nondetection



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Conclusions

There is almost complete ignorance about the possible population of ET emitters in the Galaxy

A statistical Bayesian approach is still possible by considering possible outcomes of future extensive SETI all-sky surveys

It is unlikely that there are Arecibo-like emitters in the Galaxy If no signals are discovered within about 40 kly from Earth

If a signal is discovered within 1000 ly from Earth it is almost certain that there are more than 100 Arecibo-like emitters in the Galaxy, yet to be discovered

....but....

No crossing events in the last 60 years is an hypothesis consistent with data

It follows that there is an upper bound on the technoemission rate of 1 - 5 emissions per century in the entire galaxy (comparable to the rate of supernovae in the Milky Way)

The next crossing event will not occur before 60 years (most optimistic scenario) or before 1800 years (least optimistic scenario) with a 50 % probability

Is commensal SETI a better strategy than direct searches for technosignatures?