Choosing a Maximum Drift Rate: Astrophysical Considerations

Sofia Sheikh[1], Jason Wright[1], Andrew Siemion[2], and Emilio Enriquez[3]

[1]Pennsylvania State University
[2]University of California Berkeley
[3]University of California Berkeley, Radboud Universiteit Nijmegen

November 24, 2022

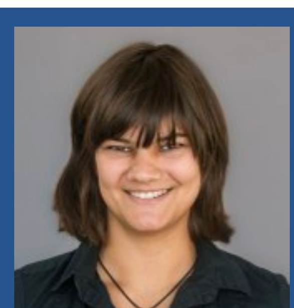
Abstract

A radio transmitter which is accelerating with a non-zero radial component with respect to a receiver will produce a signal that appears to change in frequency over time. This effect, commonly produced in astrophysical situations where orbital and rotational motions are ubiquitous, is called a drift rate. In radio SETI (Search for Extraterrestrial Intelligence) research, it is unknown a priori which frequency a signal is being sent at, or even if there will be any drift rate at all besides motions in the solar system. Therefore a range of potential drift rates need to be individually searched, and a maximum drift rate needs to be chosen. The middle of this range is zero, indicating no acceleration, but the absolute value for the limits remains unconstrained. A balance must be struck between computational time and the possibility of excluding a signal from ETI. In this work, we examine physical considerations that constrain a maximum drift rate and highlight the importance of this problem in any narrowband SETI search. We determine that a normalized drift rate of 200 nHz (e.g. 200 Hz/s at 1 GHz) is a generous, physically motivated guideline for the maximum drift rate that should be applied to future narrowband SETI projects if computational capabilities permit.

Choosing a Maximum Drift Rate in a SETI Search: Astrophysical Considerations

PennState Eberly College of Science — Center for Exoplanets and Habitable Worlds

BERKELEY SETI RESEARCH CENTER — SETI INSTITUTE


Sofia Sheikh


Jason Wright

Sofia Z. Sheikh[1], Jason T. Wright[1], Andrew P.V. Siemion[2,3,4], J. Emilio Enriquez[2,3]

[1]Department of Astronomy & Astrophysics and Center for Exoplanets and Habitable Worlds, Penn State University
[2]Department of Astronomy, University of California, Berkeley
[3]Department of Astrophysics/IMAPP, Radboud University, Netherlands
[4]SETI Institute, Mountain View


Andrew Siemion


Emilio Enriquez

What is a "drift rate"?

- A radio transmitter that is accelerating radially with respect to a receiver will produce a signal whose frequency changes over time proportional to the acceleration ("drift rate"/Doppler acceleration [Hz/s])
- Dividing this by the rest frequency f_{rest} gives a normalized drift rate [nHz] which is independent of f_{rest}

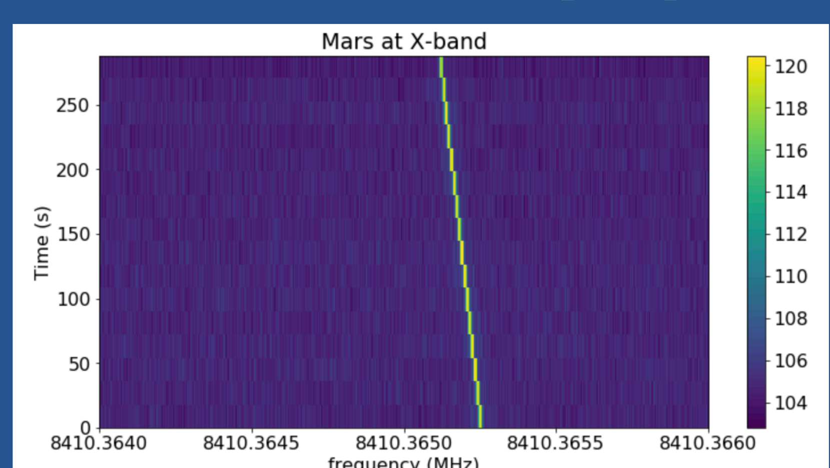


Fig. 1: A radio observation of Mars showing a drifting signal from human technology. A signal with zero drift rate would appear as a vertical line.

Why drift rates matter in SETI

- Human radio technology produces signals >100X narrower than natural sources (unambiguously artificial)
- Drift rates can cause a narrowband signal to move through multiple frequency bins during an observation
  - The power in each individual bin drops (decreasing signal-to-noise ratio) and the signal distorts
- We can correct for this but we don't know *a priori* what drift rate a signal will have
  - Process must be repeated for many drift rates, looking for the best fit.

Incorporating Astrophysics

- Correcting for many possible drift rates takes a lot of computing time, so most searches choose a maximum drift rate as an upper limit
- What upper limits can we get if we look at accelerations from astrophysics?

$$\dot{f} = \frac{f_{rest}}{c}\left(\frac{4\pi^2 R_\oplus}{P^2_{rot,\oplus}} + \frac{4\pi^2 R}{P^2_{rot}} + \frac{GM_{sun}}{{r_\oplus}^2} + \frac{GM_{central}}{r^2} + \frac{dv}{dt}_{other}\right)$$

Earth's rotation — Exoplanet's rotation — Earth's orbital motion — Exoplanet's orbital motion — Other accelerations

Eq. 1: Derived from the classical Doppler shift, this equation contains the four main terms (plus one "other") which contribute to the drift rate from a transmitter in an exoplanetary system.

Drift Rates chosen in previous SETI searches have been too low to find narrowband radio signals from known astrophysical systems. 200 nHz is a better, physically motivated maximum drift rate.

Situation	Object	Fractional Drift Rate (nHz)
Solar System - Terrestrial Planet - Earth's Contribution	Earth	0.11
Solar System - Terrestrial Planet - Observed	Mercury	0.13
Simulation - Terrestrial Planet - Common Fast Rotator [2]	...	0.65
Recommended Value - Oliver & Billingham (1971) [1]	...	1.0
Solar System - Moon - Observed	Io	2.39
Solar System - NEO (Highly Eccentric) - Observed	2006 HY51	3.27
Solar System - Asteroid (Fast Rotator) - Observed	2008 DP4	4.22
Solar System - Gaseous Planet - Observed	Jupiter	7.2
Exoplanet - Rotational - Observed	β Pictoris b	19.4
Exoplanet - Highly Eccentric - Observed	HD 80606b	22.7
Exoplanet - Rotational - Terrestrial Upper Limit (H_2O)	...	44.4
Exoplanet - Rotational - Terrestrial Upper Limit ($MgSiO_3$)	...	87.2
Exoplanet - Small Semi-Major Axis - Observed	Kepler-78 b	191
Recommended Value - This Work	...	**200**
Exoplanet - Rotational - Terrestrial Upper Limit (Fe)	...	309
Exoplanet - Rotational - Gaseous Upper Limit (H/He)	...	424
Exoplanet - Orbital - G2 Stellar Upper Limit	...	915
Exoplanet - Orbital - M8 Stellar Upper Limit	...	5413
System - Exoplanet + Exomoon + Rotation - Upper Limit	...	6146
Supermassive Black Hole - Orbital - ISCO Upper Limit	Sagittarius A*	4.7×10^5
White Dwarf - Orbital - Upper Limit	...	1.5×10^7
Stellar Mass Black Hole - Orbital - Upper Limit	Cygnus X-1	1.3×10^{11}
Neutron Star - Orbital - Upper Limit	...	1.3×10^{13}

Tab. 1: Each row contains and describes a specific physical system, gives the object from which the parameters were taken (if applicable), and gives the associated drift rate. When a maximum drift rate is chosen for a study, it can be compared with this table; all rows below the chosen drift rate would be outside of the scope of the search.

Takeaways

1) [1] proposed a maximum fractional drift rate of 1 nHz, thereby accidentally defining a literature standard. With commonly used search algorithms, this standard could miss signals transmitted from the surface of Io.
2) Finding linear features in images is computationally expensive, motivating the need for a maximum in the first place, but not so expensive that increasing the maximum is prohibitive.
3) We propose a threshold of 200 nHz, encompassing all known solar system bodies and exoplanets. However, each observer must consider their own specific goals, resources and targets to determine their own maximum drift rates.

Creating the Table

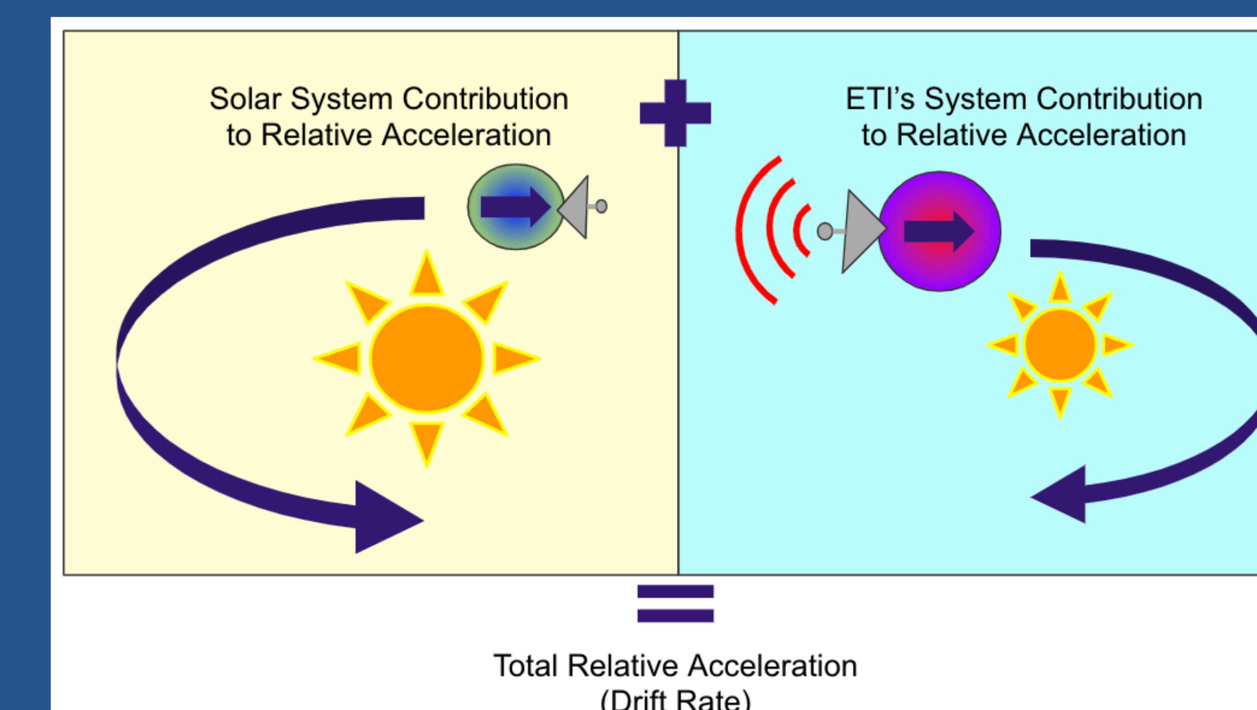


Fig. 2: A cartoon illustrating the four main terms in Eq. 1

- Eq. 1 was applied to known observables from planets, moons, asteroids, comets, exoplanetary systems, and compact objects to create Tab. 1
- Drift rates are dependent on time and viewing angle; the table shows the maximized case.
- We also considered upper limits from theory
  - The rotational upper limit from theory is the break-up rotation rate (where a gravitationally-bound body throws itself apart)
  - The orbital upper limit from theory is the closest allowable orbit
- This table makes it easy to see which kinds of physical transmitter-hosting systems your narrowband SETI search is sensitive to, and which ones you could potentially be missing

Acknowledgements

This work was supported by Breakthrough Listen and the Center for Exoplanets and Habitable Worlds is supported by Penn State. SZS thanks the SETI Institute for providing a summer workspace, and Neil Peart for the choice of Cygnus X-1.

Literature Cited

[1] Oliver, B. M., & Billingham, J. (1971). Project Cyclops: A Design Study of a System for Detecting Extraterrestrial Intelligent Life.
[2] Miguel, Y., & Brunini, A. (2010). Planet formation: statistics of spin rates and obliquities of extrasolar planets. MNRAS,
[3] Enriquez, J. E. et al. (2017). The Breakthrough Listen Search for Intelligent Life: 1.1-1.9 GHz observations of 692 Nearby Stars. ApJ