Opportunities to search for extraterrestrial intelligence (SETI) with the FAST

Di Li et al. 2020

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Content

Background

SETI surveys with FAST

Challenges and comments


如果其中百万分之一的星星 是行星的话
If only one out of a million of those had planets...

Are we alone?

The theory

Drake Equation (Drake 1965):
Assumptions: technological life will **stay** put (待在原地不动)
The number N of **communicative civilizations**:

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

Fermi (Michael Hart) Paradox (Gray 2015; Cirkovic 2018)
Assumption: technological life will **spread** throughout the Galaxy
"if technological life existed anywhere else, we ***would see*** *evidence of its visits to Earth—and* ***since we do not, such life does not exist****, or some special explanation is needed."*

The classification of civilizations

Kardashev Type I civilization: one that can harness all the stellar energy falling on their **planet**;

Kardashev Type II civilization : one that can harness the entirety of the energy produced by their **star;**

Kardashev Type III civilization: one that can harness all the energy produced by all the stars in a **galaxy.**

(Kardashev, 1964)

…

Chance to detect

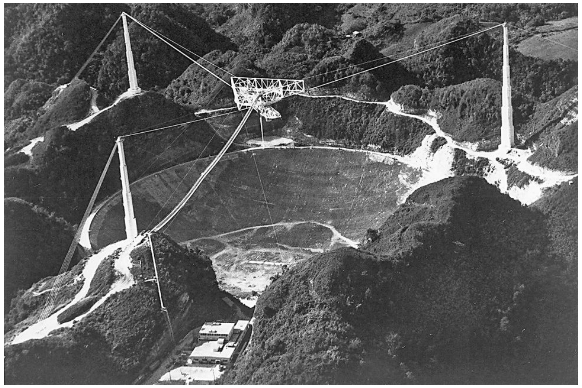
Interstellar communication: Frequencies near 1420MHz (**the hydrogen line**). (Cocconi & Morrison, 1959).

灯塔

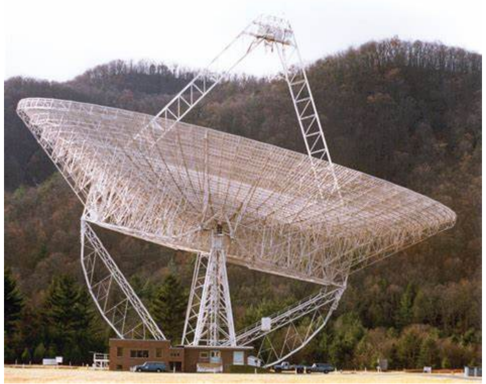
Deliberate beacon (to other technologically advanced species): frequencies (1400MHz -1700MHz) —**Cosmic water-hole** (Oliver & Billingham, 1971)

……

Others (for this era):
Supercomputer and big data revolution,
Machine learning technology,
The privately financed Breakthrough Listen Initiative,
The thousands of recently discovered exoplanets,
The construction of new facilities.





Drake (1961), two stars

Project Phoenix (20th century), around 1000 nearby stars

100 meter Green Band Telescope

MeerKAT radio telescope

optical Automated Planet Finder

64-meter diameter Parkes telescope

1,000,000 closest stars to Earth;
100 closest galaxies to ours;
10 years (from 2016), $100 M,
private donors.


100 meter Green Band Telescope


MeerKAT radio telescope


FAST

Collaboration, 2016

optical Automated Planet Finder


64-meter diameter Parkes telescope

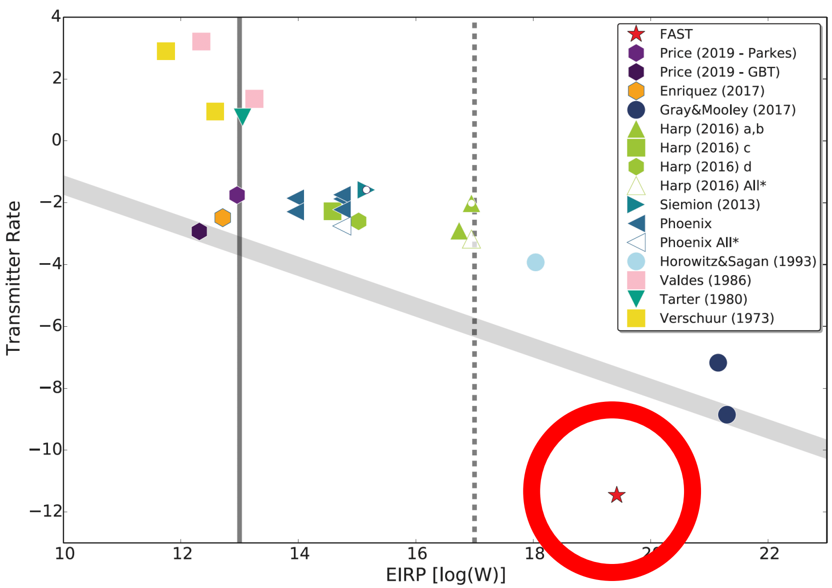
Compare to Project Phoenix:

2.5 times more sensitive
cover 5 times more stars (**Nan et al. 2000**)

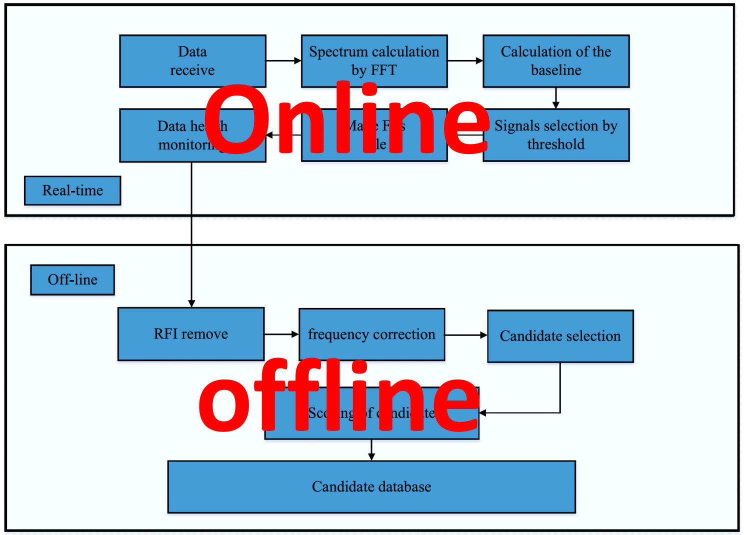
Take-home messages

Has the potential to put **constraint on Kardashev Type < I, Kardashev Type II and III** or **higher** civilizations,

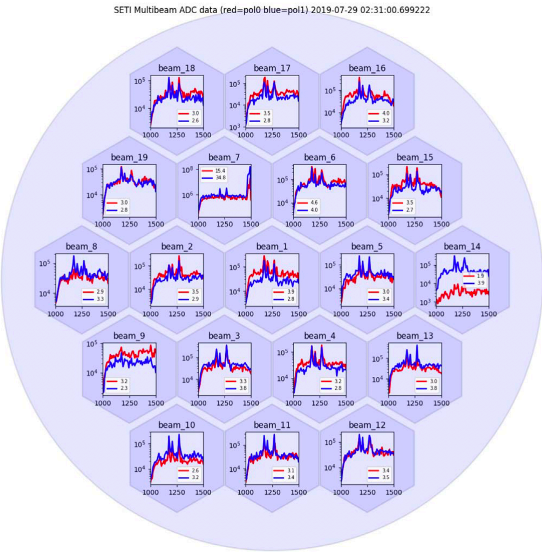
Place the **most stringent limits** on the presence of artificial transmitters within its operable frequency range.



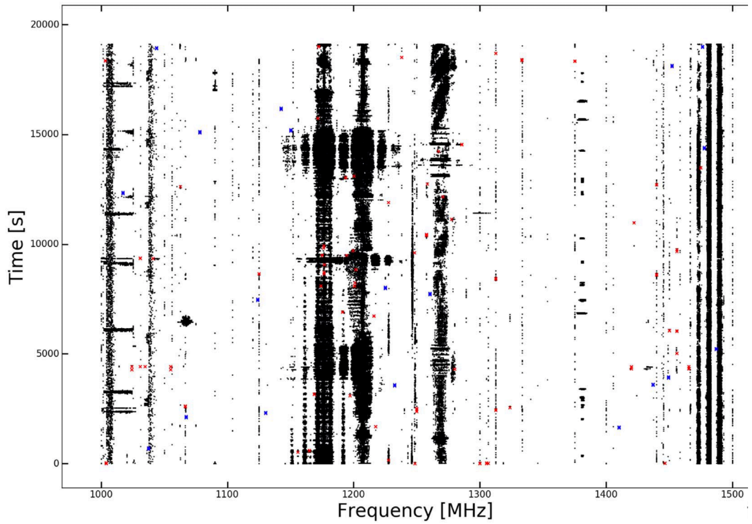
FAST SETI system



data processing framework



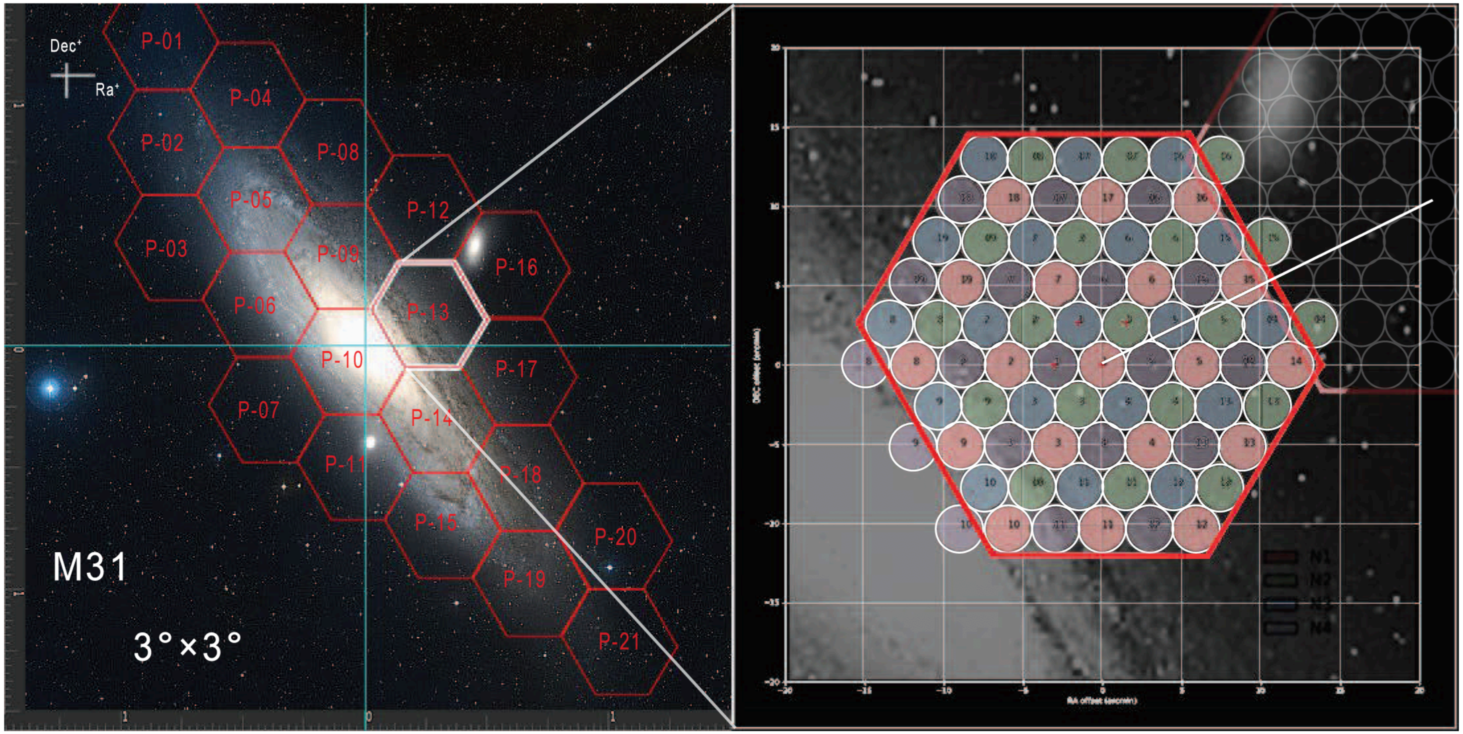
SETI multibeam (19) monitor.



Candidates found in FAST data

SETI surveys with FAST

Deep blind search toward the Andromeda Galaxy (M31)



19-beam receiver*4 pointing*21 hexagon

One trillion stars

SETI surveys with FAST

A targeted search toward TESS stars with exoplanets.

Credit:NASA

Signal searches

Narrow-band (Hz) radio signals:

transmitted **intentionally** or arise as **leakage** from extrasolar technologies

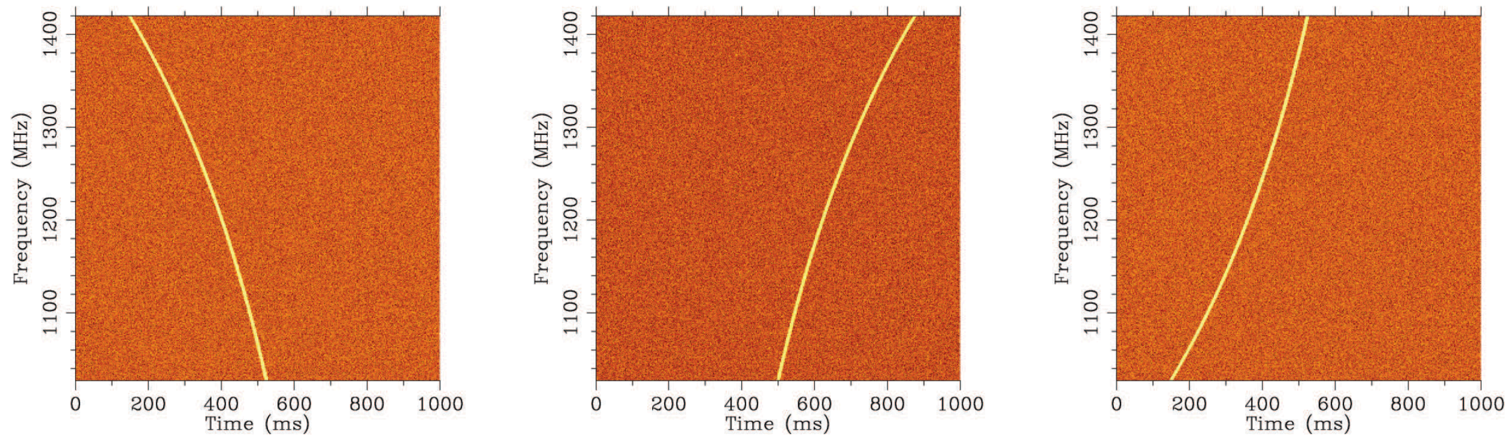
Necessitate **the fine spectral resolution** of SETI.

Most popular signal in observations

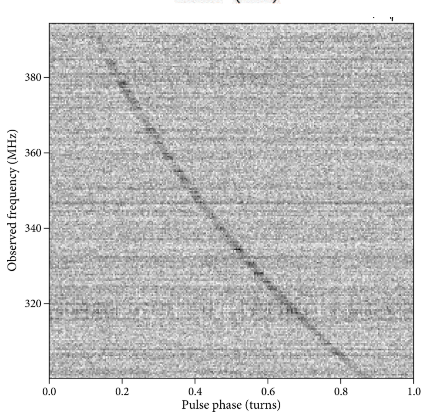
Signal searches

Broad-band Signals: wide-band artificially dispersed pulses

An advanced civilization might intentionally create a **beacon of "pulses"** with **artificial dispersion**. (Siemion et al. 2010)



negatively-dispersed simulated pulses.



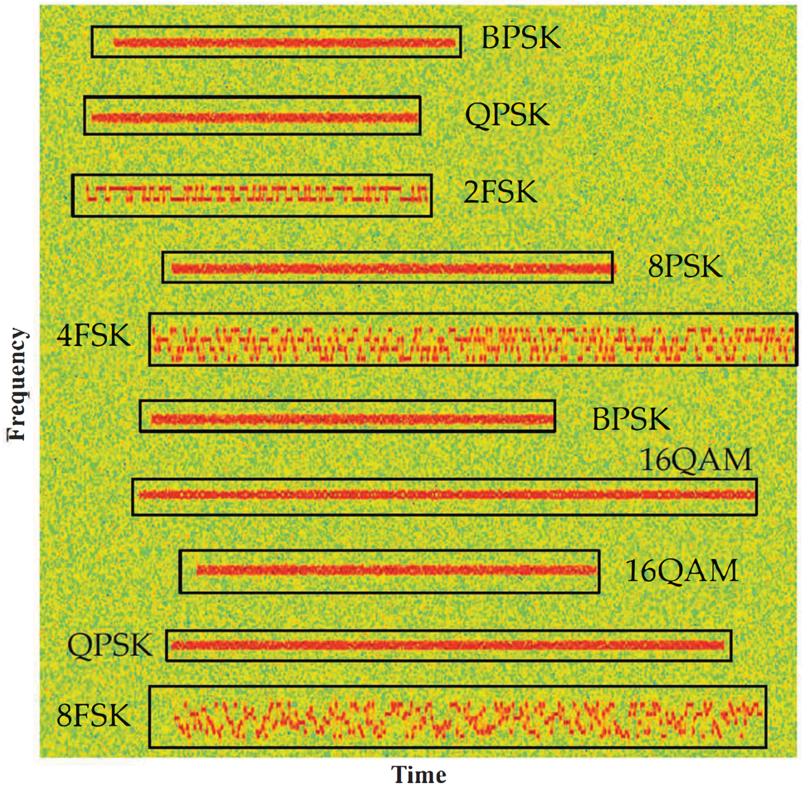
Normal pulsar dispersion

No observations for now
Targeted searches with FAST

$$\left(\frac{t}{\text{sec}}\right) \approx 4.149 \times 10^{3} \left(\frac{\text{DM}}{\text{pc} \quad \text{cm}^{-3}}\right) \left(\frac{\nu}{\text{MHz}}\right)^{-2}$$

Signal searches

Broad-band Signals : exhibiting artificial modulation.



Artificial modulated signals.

Modulation: *methods of encoding information onto high-frequency carrier waves, making the transmission of that information more efficient.*

Sensitivity

The required power for a certain ETI transmission to be detected:

$$\mathrm{EIRP} = \sigma \frac{4\pi d_\star^2}{A_{\mathrm{eff}}^R} \frac{2kT_{\mathrm{sys}}}{\sqrt{n_p t_{\mathrm{obs}} \delta\nu}} \quad ,$$

TESS exoplanets: 1.9×10^{11}W

Humans produce planetary radar signals with EIRP: 10^{13}W

M31 Galaxy: 2.4×10^{19}W

Kardashev Type I : 10^{17}W
Kardashev Type II: 10^{26}W
Kardashev Type III: 10^{36}W

Sensitivity

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$$\mathrm{EIRP} = \sigma \frac{4\pi d_\star^2}{A_{\mathrm{eff}}^R} \frac{2kT_{\mathrm{sys}}}{\sqrt{n_p t_{\mathrm{obs}} \delta\nu}} \ ,$$

effective aperture: A_{eff} 300 or 500 m diameter

?

Challenges

RFI contamination: Narrowband RFI, artificially engineered signals on Earth, especially within the FAST electromagnetic environment.

The huge data rate:

$$1\ \mathrm{Gsps} \times 1\ \mathrm{byte/sample} \times 2\ \mathrm{pol} \times 19\ \mathrm{beams} = 38\ \mathrm{GB\ s^{-1}}.$$

Sky survey sensitivity

$$\mathrm{EIRP} = 4\pi {d_*}^2 \sigma_{\mathrm{thresh}} \mathrm{SEFD} \sqrt{\frac{\delta\nu}{n_{\mathrm{pol}} t_{\mathrm{obs}}}}, \quad \mathrm{SEFD} = 2k_B T_{\mathrm{sys}}/A_{\mathrm{eff}}$$

Comments

Computational resources and **cooperation** is important.

We are beginning to explore **tiny regions of the large parameter space** of possible technosignatures.

Search based on what we “know”

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Summary

The authors identify three different signal types indicative of a technological source, which will provide **a new window** for radio SETI experiments.

They claim that FAST will have the **potential** to:

- Put tighter constraints on any putative narrow-band signals (within the reach of current human technology, **Kardashev Type < I or higher)** towards stars with **nearby exoplanets like TESS targets.**

- Put tight constraints on the presence of a transmitting **Kardashev Type II and III civilization** among the 1 trillion stars in the Andromeda Galaxy (**M31**).

- Place **the most stringent limits** on the presence of artificial transmitters within its operable frequency range.

Questions I would ask as an audience

Any other kinds of technosignatures?
Why radio? Other wave band and why?
Why narrow band radio signal?
Should we listen or broadcast?
Is SETI ‘worthwhile’?

Backup

Sensitivity

The required power for a certain ETI transmission to be detecte:

$$\mathrm{EIRP} = \sigma \frac{4\pi d_\star^2}{A_{\mathrm{eff}}^R} \frac{2kT_{\mathrm{sys}}}{\sqrt{n_p t_{\mathrm{obs}} \delta\nu}} \ ,$$

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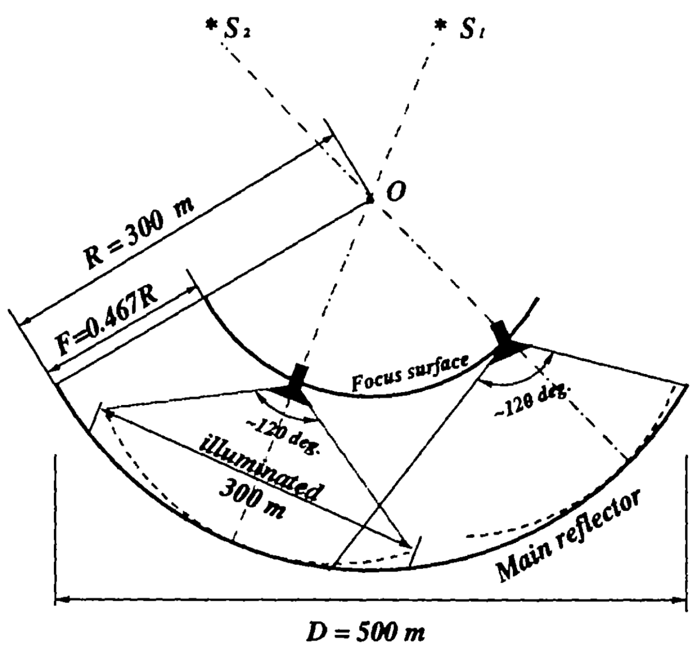
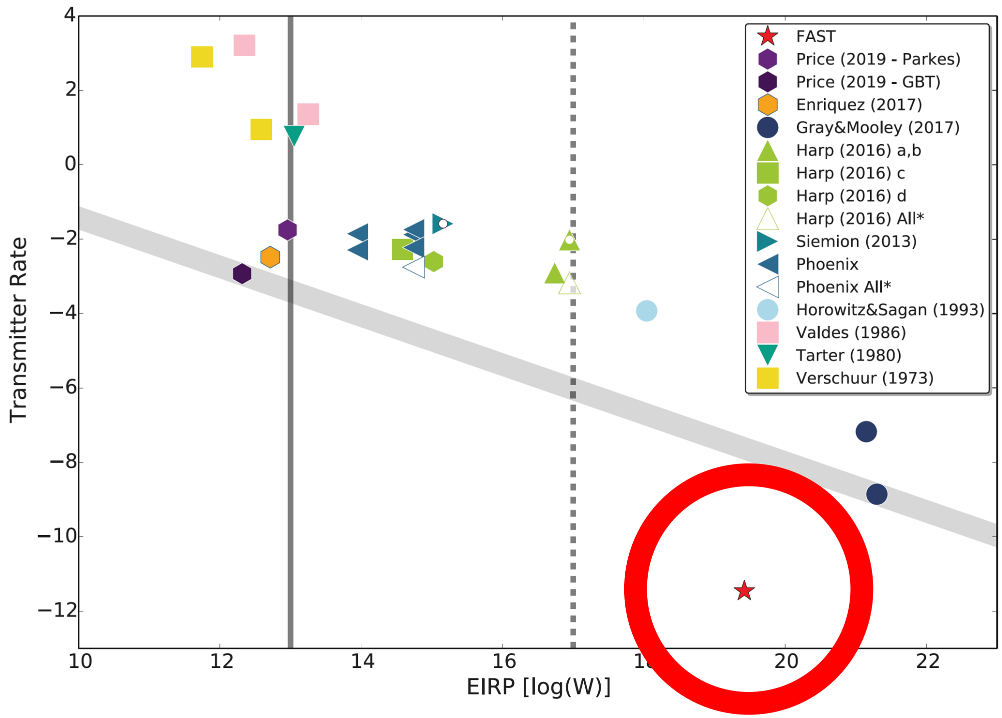


Nan et al. 2000

Transmitter rate

Transmitter rate to **compare these surveys:**

$$Transmitter\ rate = \log\left(\frac{1}{N_{\mathrm{stars}}\nu_{\mathrm{relative}}}\right).$$



Potential technologies and artifact technosignatures

Spatial Scale / Distance

	Solar System	Exoplanetary	Circumstellar	Extragalactic
Structures	•Free floating •Surface / subsurface •Lights / collectors	•Satellite belts •Lagrange point megastructures •Surface features	•In transit •Directly imaged	•Direct energy propulsion
Environmental changes	•Martian ice cores •Venusian atmosphere •Ancient Earth	•Atmospheric spectroscopy •Surface changes •Commonalities among exoplanets	•Stellar atmosphere pollution •Circumstellar gases •Stellar motions	•Stellar population management •Stellar motions
Excess Heat	•Exothermic “asteroids” •Heat islands	•Rotationally modulated surface hotspots	•Dyson spheres	•Dyson spheres

Jason T. Wright, 2021

Drake Equation

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

R_* = the mean rate of star formation over the period in which the stars now possessing communicative civilizations were being formed. If we are typical, R_* is about the mean rate of star formation 5 billion years ago;

f_p = the fractions of stars which were formed at that epoch with planetary systems;

n_e = the mean number of planets in each planetary system with environments permitting the development of life;

f_l = the fraction of such planets on which life actually develops;

f_i = the fraction of life-bearing planets on which intelligent life evolves;

f_c = the fraction of planets bearing intelligent life which give rise to a communicative civilization;

L = the mean lifetime in the communicative state of such civilizations.