

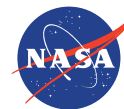


# Transient and Variable Signatures of Technology

Joseph Lazio (Jet Propulsion Laboratory, California Institute of Technology)

Greg Hellbourg (California Institute of Technology), Vikram Ravi (California Institute of Technology), George Djorgovski (California Institute of Technology),

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**Jet Propulsion Laboratory**  
California Institute of Technology

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Government sponsorship acknowledged.

# Transient and Variable Signatures of Technology

Technosignatures, SETI, and extraterrestrials,  
oh, my

Data-Driven Approaches to Searches for the  
Technosignatures of Advanced Civilizations  
(W. M. Keck Institute for Space Studies)

Applications to the Transient and Variable Sky

# Signatures of Extraterrestrial Technology I

## SEARCHING FOR INTERSTELLAR COMMUNICATIONS

By GIUSEPPE COCCONI\* and PHILIP MORRISON†  
Cornell University, Ithaca, New York

NO theories yet exist which enable a reliable estimate of the probabilities of (1) planet formation; (2) origin of life; (3) evolution of societies possessing advanced scientific capabilities. In the absence of such theories, our environment suggests that stars of the main sequence with a lifetime of many billions of years can possess planets, that of a small set of such planets two (Earth and very probably Mars) support life, that life on one such planet includes a society recently capable of considerable scientific investigation. The lifetime of such societies is not known; but it seems unwarranted to deny that among such societies some might maintain themselves for times very long compared to the time of human history, perhaps for times comparable with geological time. It follows, then, that near some star rather like the Sun there are civilizations with scientific interests and with technical possibilities much greater than those now available to us.

\* Now on leave at OERN, Geneva.

† Now on leave at the Imperial College of Science and Technology, London, S.W.7.

To the beings of such a society, our Sun must appear as a likely site for the evolution of a new society. It is highly probable that for a long time they will have been expecting the development of science near the Sun. We shall assume that long ago they established a channel of communication that would one day become known to us, and that they look forward patiently to the answering signals from the Sun which would make known to them that a new society has entered the community of intelligence. What sort of a channel would it be?

### The Optimum Channel

Interstellar communication across the galactic plasma without dispersion in direction and flight-time is practical, so far as we know, only with electromagnetic waves.

Since the object of those who operate the source is to find a newly evolved society, we may presume that the channel used will be one that places a minimum burden of frequency and angular discrimi-

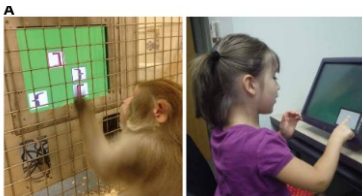
## Search for Extraterrestrial Intelligence (SETI)

¿ How to define or determine “intelligence” among terrestrial species?

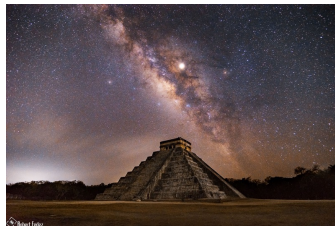
*H. sapiens* (humans), *P. troglodyte* (chimpanzees), dolphins, ...

- ❖ Key element is detection over interstellar distances
- No radio transmissions from ancient Romans, Mayans, ...

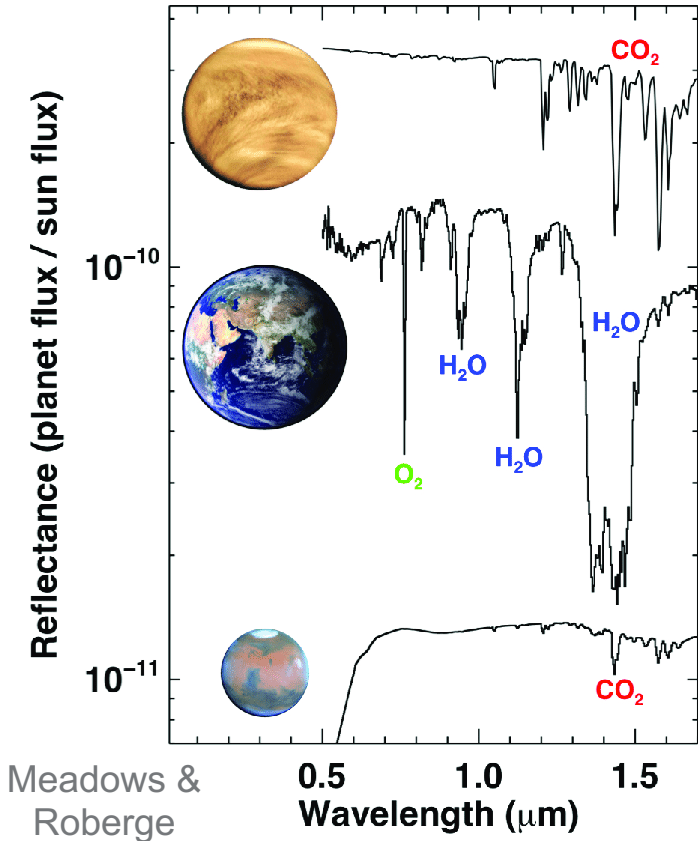
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Ferrigno et al.



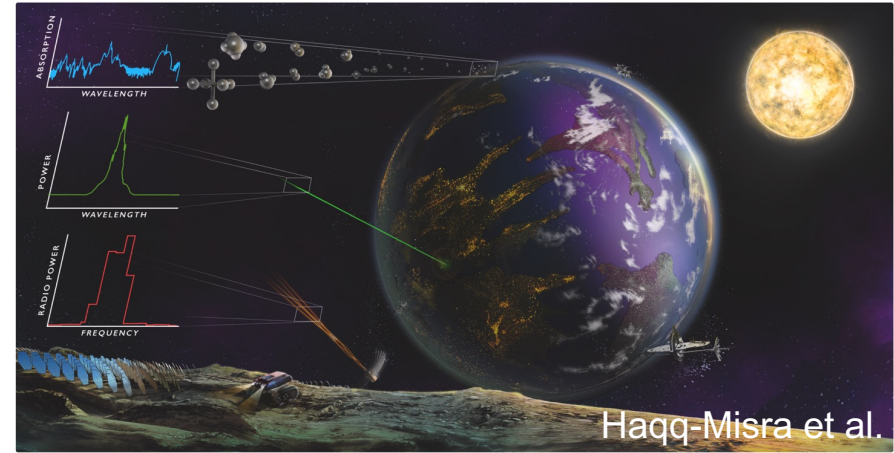
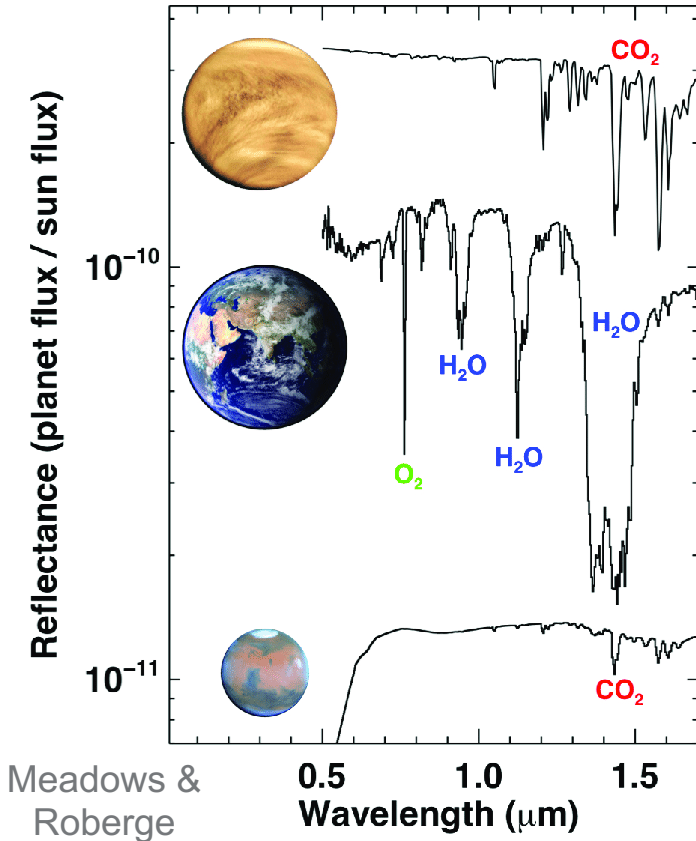
# Signatures of Extraterrestrial Technology II



- **Biosignature = signature of biology**  
**Algae or zebras?**



# Signatures of Extraterrestrial Technology III



- **Technosignature = signature of technology**  
Can address fundamental question in biology---evolution of complex life
- **Biosignature = signature of biology**  
Algae or zebras?

# Data-Driven Approaches to Searches for the Technosignatures of Advanced Civilizations

## Context



**Historically, technosignature searches have focused on Earth-analog technologies**

- E.g., radio beacon
- Clear risk that human-centered "bias" results in missing technosignatures

- **Extrasolar planets!**

- 5000+ extrasolar planets known
- ~ 25 potentially habitable extrasolar planets

Liquid water on surface and exposed to light of host star (V. Meadows)

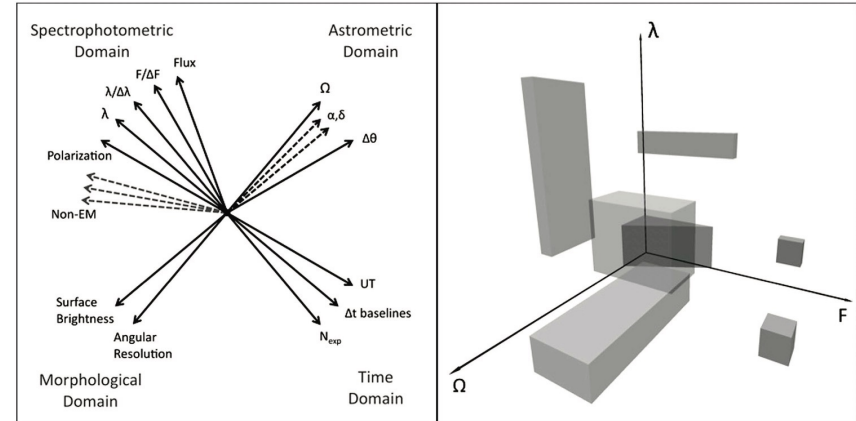
- **Astronomy data sets approaching / exceeding 1 PB ( $10^{15}$  B)**

# Data-Driven Approaches to Searches for the Technosignatures of Advanced Civilizations

**Notable discoveries in science result from enlarging volume of parameter space searched**

**CP1919 (a.k.a. PSR B1919+21, neé L.G.M.1)**

**viz. M. Schmidt**



Observable Parameter Space

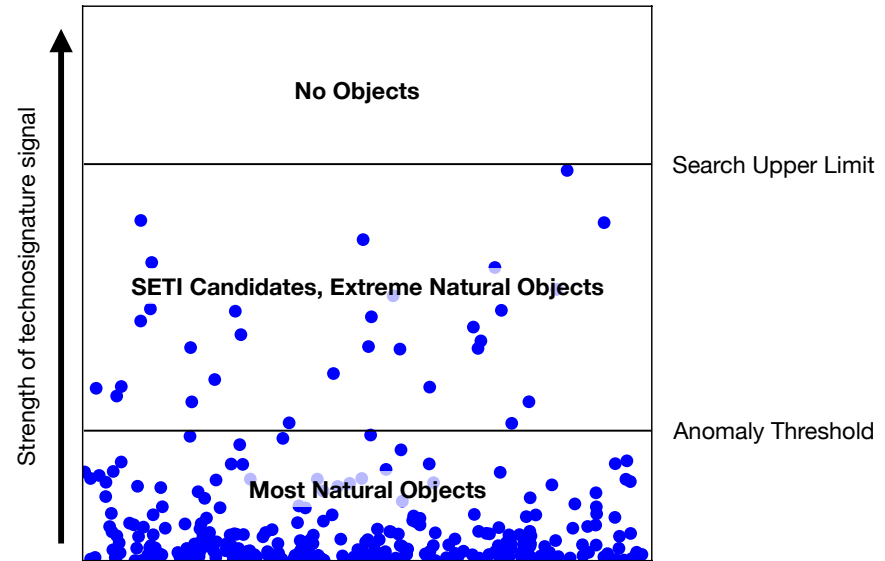


# Data-Driven Approaches to Searches for the Technosignatures of Advanced Civilizations

## First Law of SETI (Technosignature) Investigations:

“Every search for alien civilizations should be planned to give interesting results even when no aliens are discovered.”

F. Dyson





# Data-Driven Approaches to Searches for the Technosignatures of Advanced Civilizations

- **All-Sky Surveys**

- Enormous data sets being/will be generated, multi-wavelength, multi-messenger, time domain  
ZTF, Evryscope, VRO LSST, ...

- **Searches at Radio Wavelengths with Interferometers**

- Terrestrial technosignatures (a.k.a. radio frequency interference [RFI]) clear confounding factor
- Interferometers enable much more robust discrimination between terrestrial and extraterrestrial transmitters

- **Mid-IR Sky Survey**

- No technology is 100% efficient, all will generate “waste heat” that potentially detectable at mid-IR to far-IR wavelengths

- **Solar System Artifacts**

- Humanity has five spacecraft on interstellar trajectories
- Multiple technological artifacts on surfaces of the Moon and Mars
- Multitude of geosynchronous orbit (GEO) spacecraft

# Transient and Variable Sources in All-Sky Surveys

... At Visible and Near-IR Wavelengths

- Type II supernovae
  - Long-duration gamma-ray bursts (the B.O.A.T.)
  - Failed core-collapse supernovae
- Type I supernovae
- Kilonovae
- Active galactic nuclei
- Tidal disruption events
- Main sequence star-compact object binaries
- ...

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A SURVEY ABOUT NOTHING: MONITORING A MILLION SUPERGIANTS FOR FAILED SUPERNOVAE

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KRZYSZTOF Z. STANEK,<sup>1,2</sup> TODD A. THOMPSON,<sup>1,2</sup> AND HASAN YÜKSEL<sup>2,3</sup>  
*Received 2008 February 4; accepted 2008 May 3*

## ABSTRACT

Extragalactic transient searches have historically been limited to looking for the *appearance* of new sources such as supernovae. It is now possible to carry out a new kind of survey that will do the opposite, that is, search for the *disappearance* of massive stars. This will entail the systematic observation of galaxies within a distance of 10 Mpc in order to watch  $\sim 10^6$  supergiants. Reaching this critical number ensures that *something* will occur yearly, since these massive stars must end their lives with a core collapse within  $\sim 10^6$  yr. Using deep imaging and image subtraction, it is possible to determine the fates of these stars, whether they end with a bang (supernova) or a whimper (fall out of sight). Such a survey would place completely new limits on the total rate of all core collapses, which is critical for determining the validity of supernova models. It would also determine the properties of supernova progenitors, better characterize poorly understood optical transients (such as  $\eta$  Carina-like mass ejections), find and characterize large numbers of Cepheids, luminous blue variables, and eclipsing binaries, and allow the discovery of any new phenomena that inhabit this relatively unexplored parameter space.

*Subject headings:* stars: evolution — supernovae: general — surveys

*Online material:* color figures

# Failed Supernovae

## Transient and Variable Sources in All-Sky Surveys

- **“Exploding” a massive star is tough for computers**

Many simulations, particularly early ones, resulted in failed supernovae

- **Finding failed supernovae could inform black hole formation rate estimates**

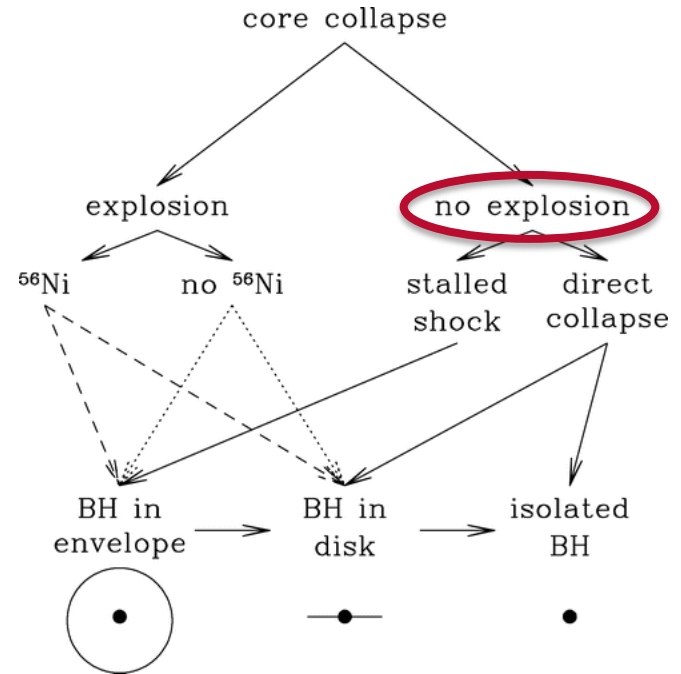
- **Comments on Kochanek et al.**

- **Data-driven paper?**

As surveys for supernovae “exploded,” possibility of finding failed supernovae became “obvious”

- **Guaranteed Science!**

- **Any paper that references publication by A. C. Doyle (1892) warrants contemplation**



Kochanek et al. 2008

# Disappearing Stars

## Transient and Variable Sources in All-Sky Surveys

- **Failed supernovae?**
  - Opportunities in decades-long data sets!
- **Secular trends**
  - “Great Dimmings” a la Betelgeuse?
  - Dyson Structures?



# Data-Driven Approaches to Searches for the Technosignatures of Advanced Civilizations



- **All-Sky Surveys**

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ZTF, Evryscope, VRO LSST, ...

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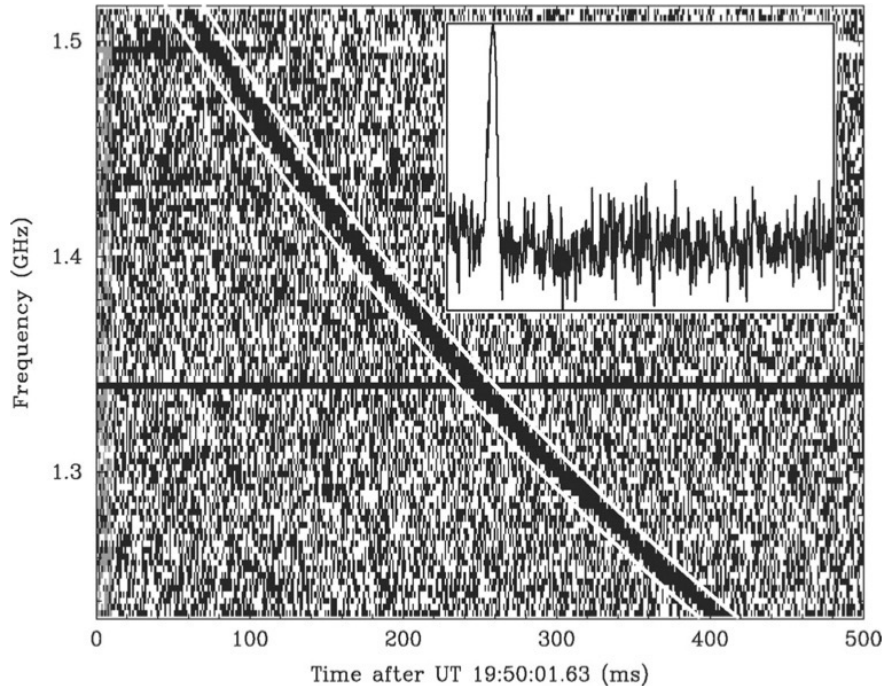
- **Solar System Artifacts**

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# Fast Radio Bursts

## Searches at Radio Wavelengths

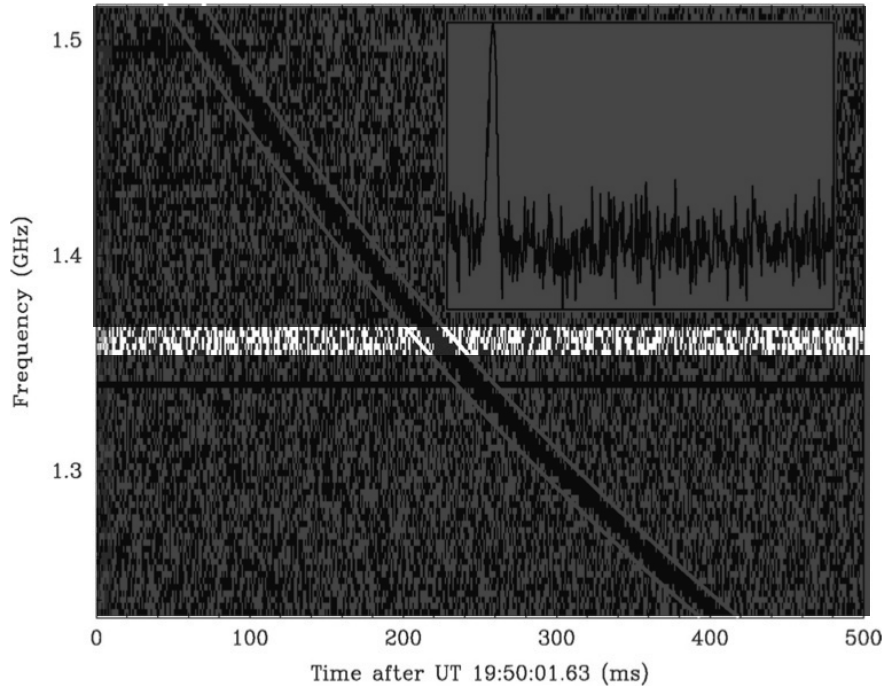


## Exemplar of conducting search for outliers

- Lorimer et al. searched around SMC for pulses that should not have occurred from SMC pulsars
- Detection implied object *well* beyond the Local Group
- Recent award of the Shaw Prize (Lorimer, McLaughlin, Bailes)

# Fast Radio Bursts

## Searches at Radio Wavelengths



**Exemplar of conducting search for outliers**

**What if we considered band-limited signal?**

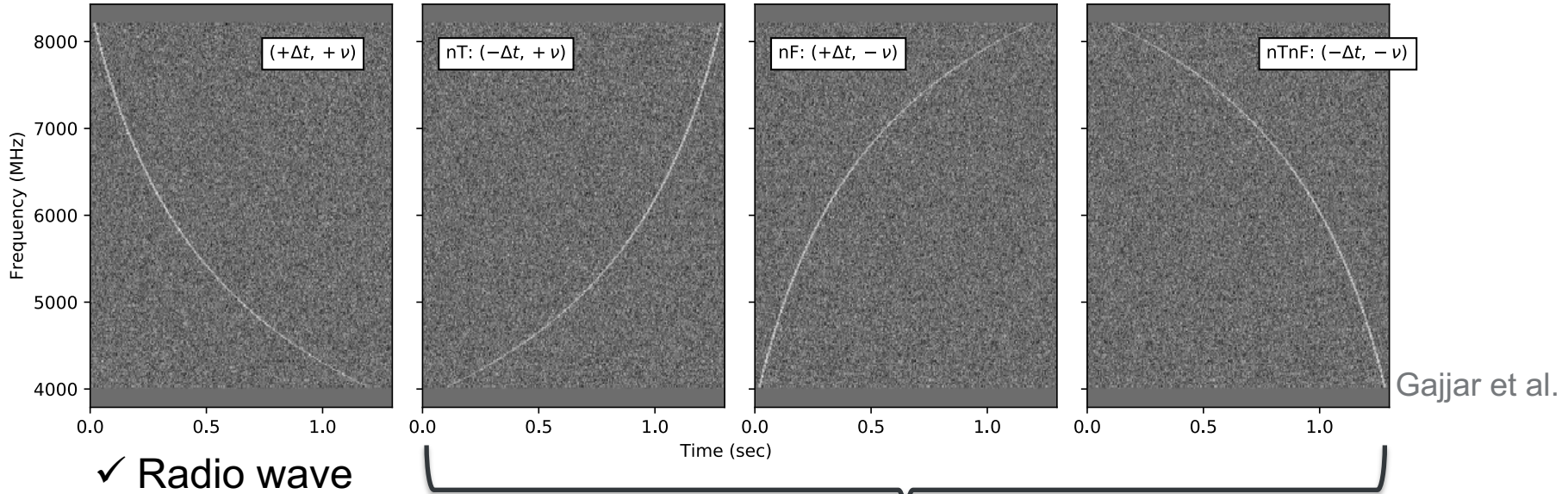
# Fast Radar Bursts?

Searches at Radio Wavelengths

	Goldstone Solar System Radar	Arecibo Observatory	Kickapoo (AFSSS)
Power	450 kW	900 kW	767 kW
Gain	74.5 dBi	75.3 dBi	35.9 dBi
Effective Isotropic Radiated Power (EIRP)	12 TW	30 TW	3 GW
Frequency	8.56 GHz	2.38 GHz	0.2 GHz
Bandwidth	up to 40 MHz	up to 20 MHz	~ 1 Hz
Flux Density @ 10 pc	25 $\mu$ Jy	0.12 mJy	0.25 Jy

# Negative Dispersion Measures?

## Searches at Radio Wavelengths



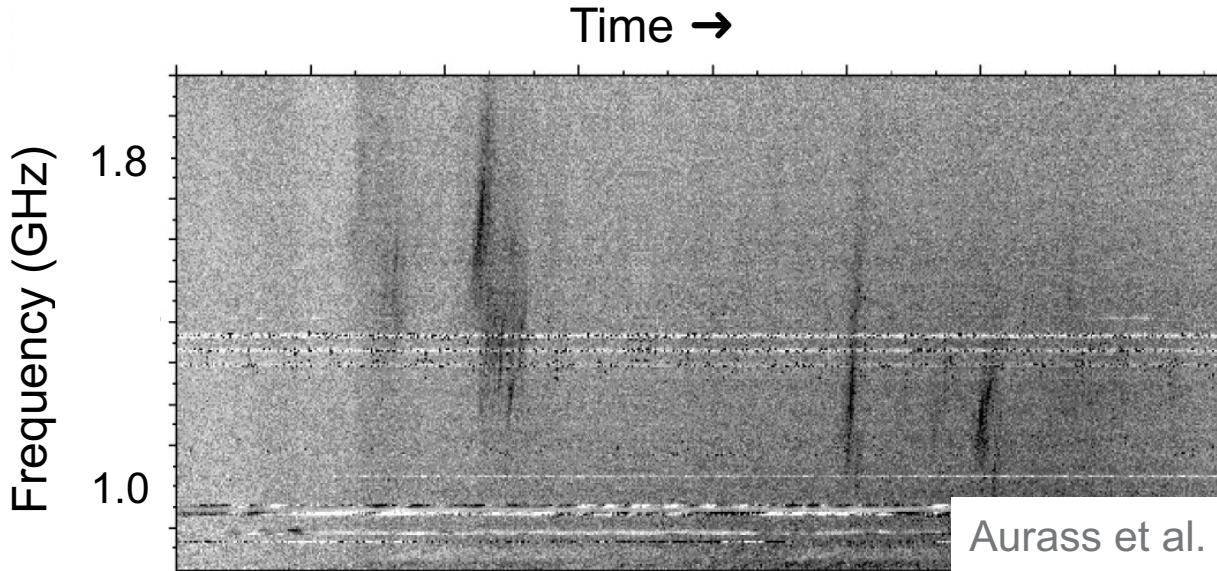
Gajjar et al.

✓ Radio wave propagation through plasma

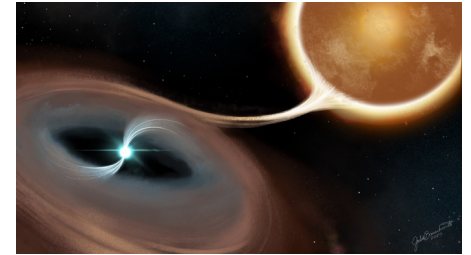
Not expected(?)  
... but could be used to assess systematics

# Negative Dispersion Measures?

Searches at Radio Wavelengths



Decimeter reverse-drift Type II solar radio burst



Electron beams in accretion streams around compact objects?



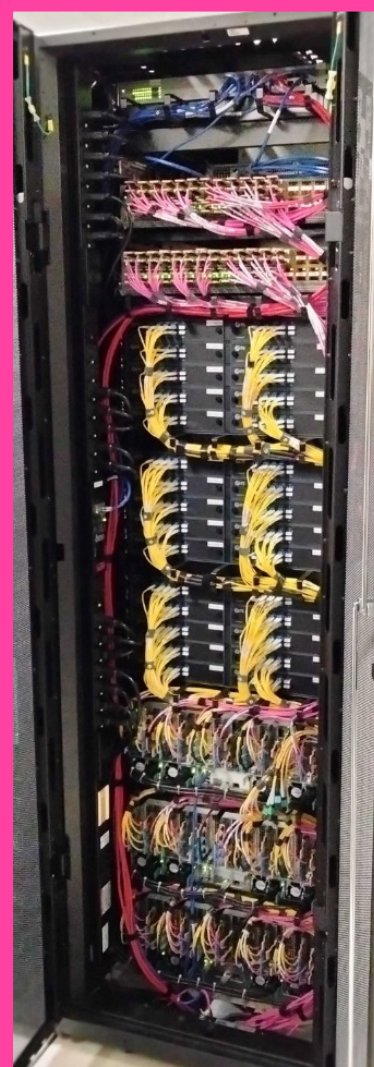
# COSMIC on Very Large Array

VLA/COSMIC

**Objective: Search nearby stars to constrain prevalence of technosignatures in the Galaxy**

**Real-time search algorithm looks for narrow-band (7 Hz) signals with 200 ms time resolution**

- Real-time system ingests digital signals, creates 1 MHz channels, calibrates, beamforms, channelizes, and searches data
- COSMIC compute cluster at the VLA has 24 GPU servers, 2 PB of local storage, digital processing rack with 3 FPGA servers



# Deep Synoptic Array-2000

Radio Camera

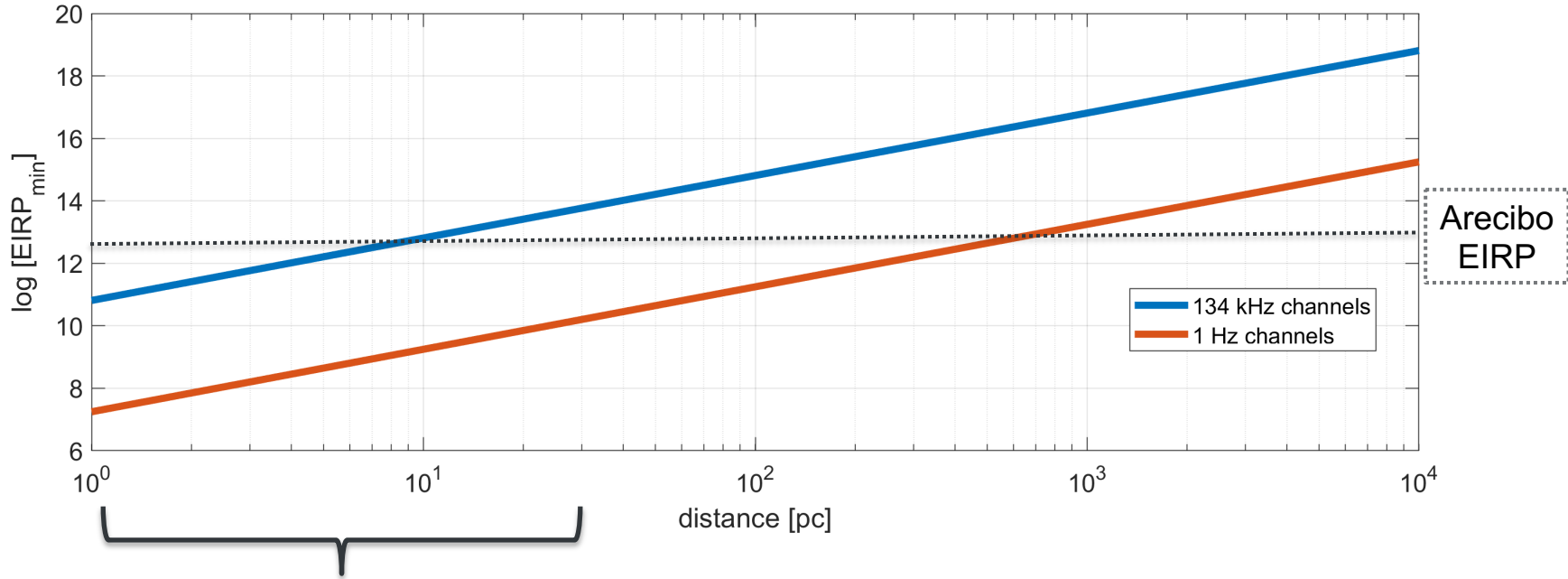
- 2000 × 5 m dishes
- Hot Creek Valley, Nevada
- Frequency range: 0.7--2 GHz
- Spatial resolution: 3.3"
- **Optimized for surveys**

First light: 2026

Key surveys: 2027 – 2032



# DSA-2000 Projected Performance



Volume of increasing interest  
Direct imaging of nearby planets,  
NASA's Habitable Worlds Observatory

\*EIRP = effective isotropic radiated power



# Earth Transit Zone and DSA-2000



**Earth Transit Zone: ET looking at Sun would see Earth transit, i.e., know terrestrial-mass planet orbits the Sun**

**More generally, Sun hosts planetary system**

**DSA-200 offers opportunity to test for directed transmissions**

**Full sky, ~ 8600 antenna fields of view**





# Transient and Variable Technosignatures

- **Technosignatures, SETI, and extraterrestrials, oh, my**
  - **Signatures of technology will be what is found**
- **Data-Driven Approaches to Searches for the Technosignatures of Advanced Civilizations (W. M. Keck Institute for Space Studies)**
  - **All-Sky (Visible and Near-IR Wavelength) Searches with decade-long data sets offer data-driven opportunities**
  - **Radio Interferometers offer powerful approach to searches**
  - **Find outliers → even if not ETIs, likely astrophysics discoveries**
- **Applications to DSA-2000 and VLA/COSMIC**
  - **Potential to enlarge volume of parameter space searched!**



**Jet Propulsion Laboratory**  
California Institute of Technology

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[jpl.nasa.gov](https://jpl.nasa.gov)

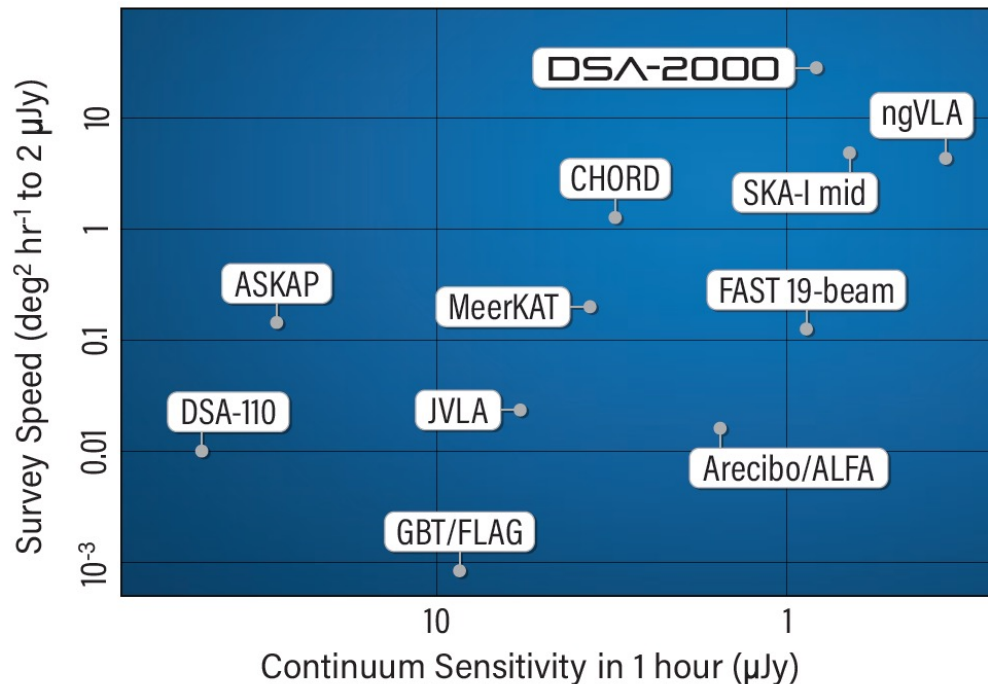
# DSA-2000: Unparalleled Survey Speed

Survey 31,000 deg<sup>2</sup> to 0.5 μJy

- > 1 billion radio sources (Stokes IQUV)
- > 10 million galaxies in H I
- ~ 10<sup>5</sup> FRBs and pulsars

Enabled by key technologies

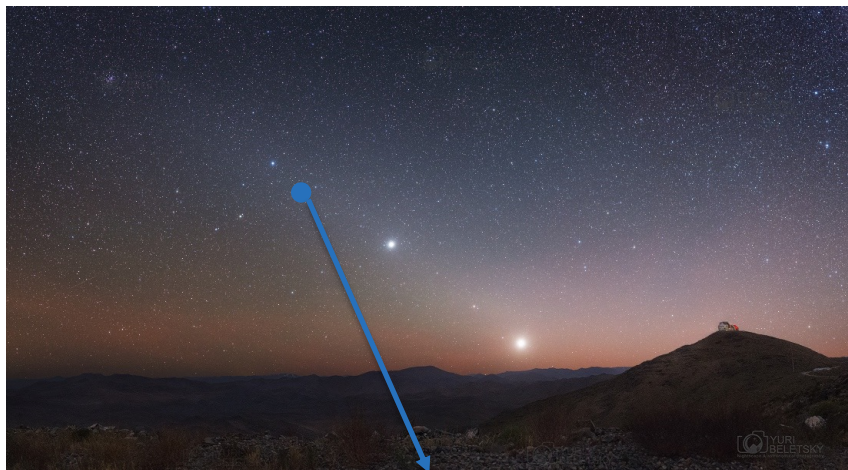
- ❖ “Radio camera” digital backend
- ❖ Cryo-free antenna/receiver



# DSA-2000 Survey Strategy I

**Full sky**

**~ 8600 Antenna Fields of View**

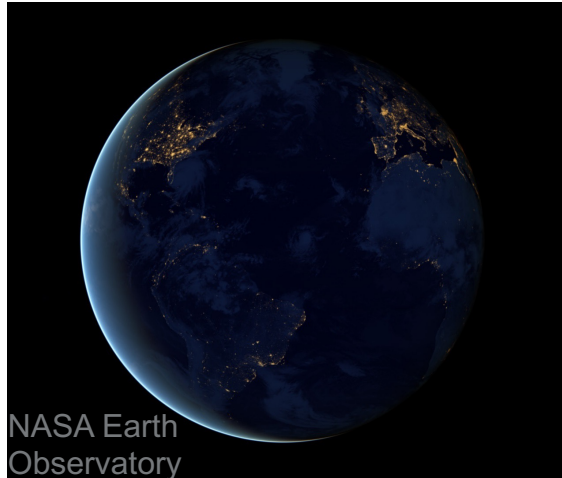


**Earth Transit Zone**

ET looking at Sun would see Earth transit, i.e.,  
know terrestrial-mass planet orbits the Sun

	$N_{\text{beams}}$	Data Volume (in 15 min.)	Full Sky	DSA-2000 Lifetime (cover sky 16 times)
“Big Gulp”	4000	28 TB	240 TB	3.9 PB
“Targeted”	1000	7 GB	27 TB	445 TB

# Detectability of Nightside Artificial Lights

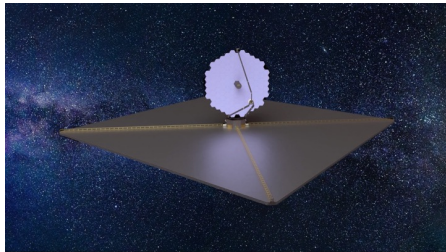


- **Biosignatures are prime target for future space telescopes**

## Habitable Worlds Observatory

~ 6 m diameter

“high-level science goals of the mission are to directly image ~ 25 potentially Earth-like planets and spectroscopically characterize them for signs of life, as well as perform exquisite general astrophysics.”



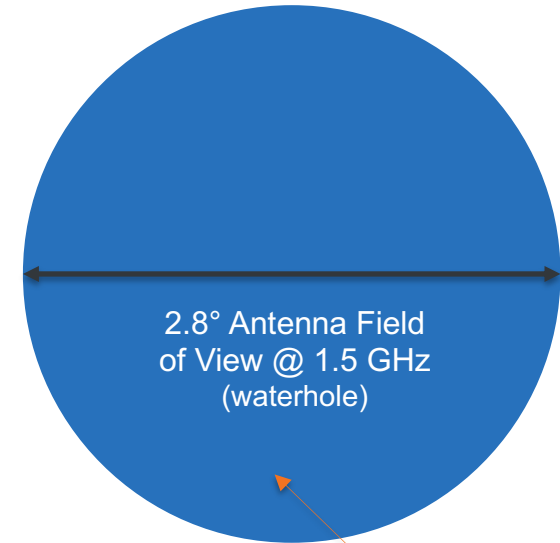
- **Telescope designs approaching size that technosignatures possibly detectable**

... whether intended or not

# DSA-2000 Survey Strategy I

- **Beamformed data from X-engine nodes--- total power, combined polarizations**
  - **Concern: terrestrial transmissions tend to be polarized, 2x reduction in sensitivity?**
- **Native channelization at 134 kHz, integrate data to 10 s, write to disk in real-time**
- **Data Volume (in 15 min.) =  $N_{\text{beams}} \times 9680$  frequencies  $\times$  90 time samples  $\times$  8 bits/sample  $\rightarrow$   $\sim 7 \text{ MB} \times N_{\text{beams}}$**

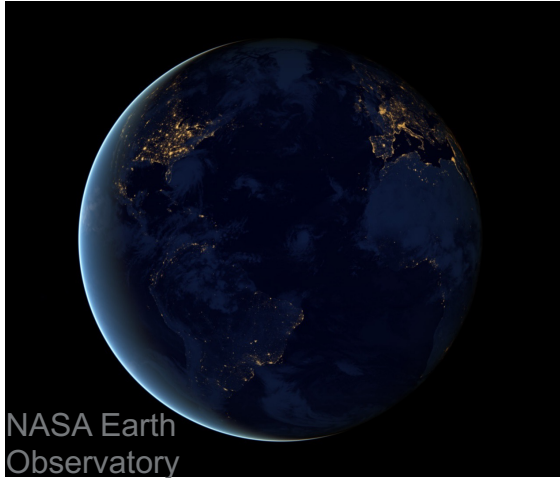
	$N_{\text{beams}}$	Data Volume (in 15 min.)
“Big Gulp”	4000	28 GB
“Targeted”	1000	7 GB



3.2" Array Beam  
@ 1.5 GHz  
(waterhole)



# LUVOIR city lights



Beatty

