Finding needles in cosmic haystacks:

Technosignature and FRB searches with the MWA

Danny Price, Greg Sleap, Ian Morrison, Andrew Williams,
Brian Crosse, Luke Williams, Steve Croft,
Marcin Sokolowski, Matt Lebofsky, David Macmahon

AKA "The Ten Square Kilometre Array"

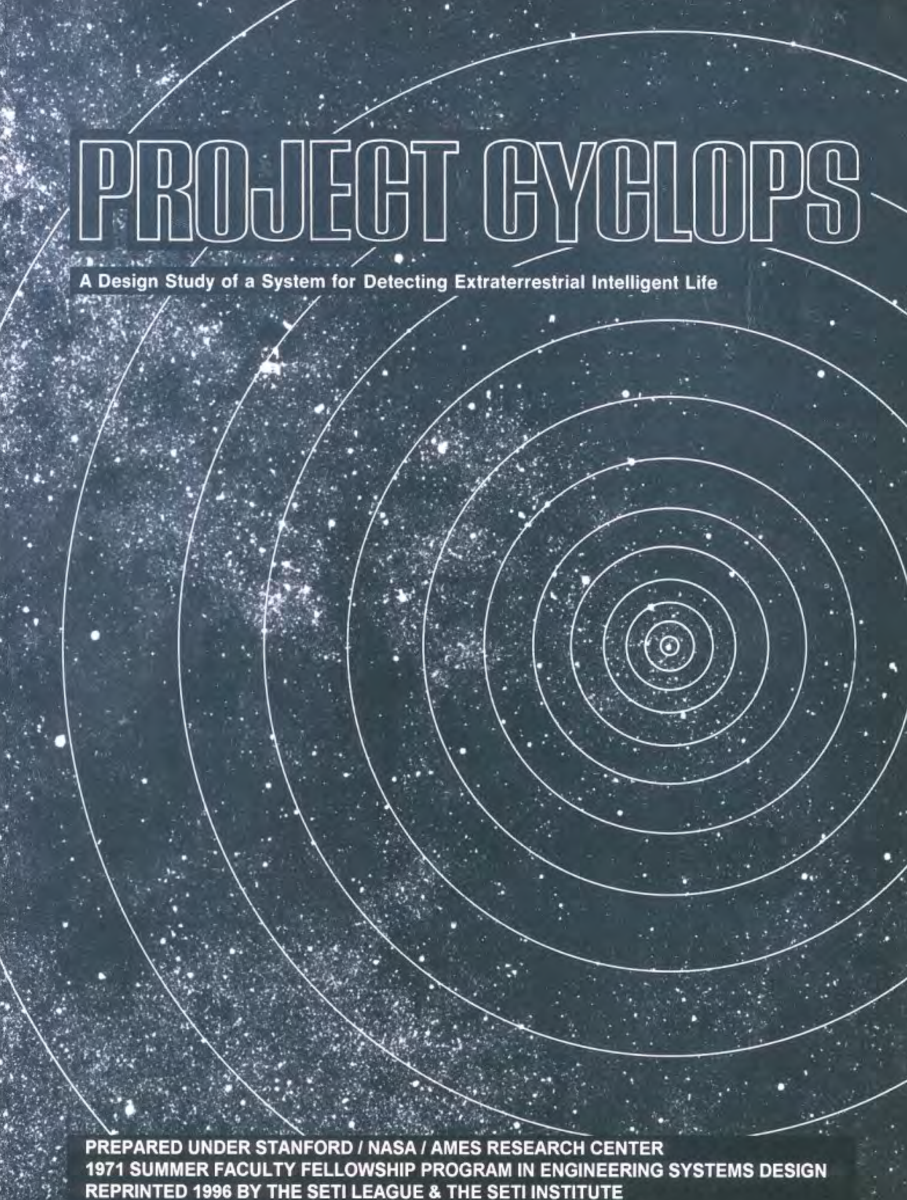
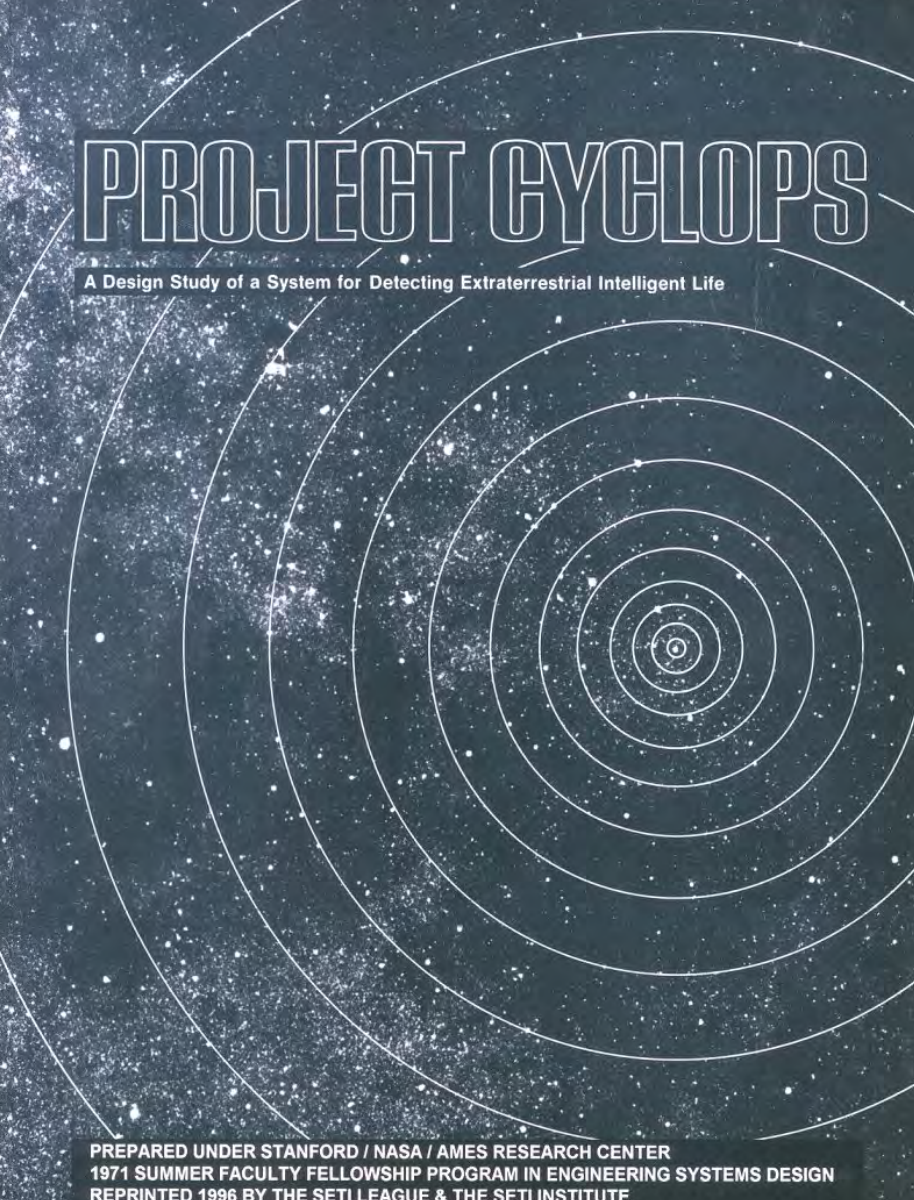


Image: Rick Guidice / NRAO



Pergamon

Acta Astronautica Vol. 42, No. 10–12, pp. 589–591, 1998

Printed in Great Britain
0094-5765/98 $19.00 + 0.00

PII: S0094-5765(98)00012-5

SETI AND THE ONE SQUARE KILOMETRE RADIO TELESCOPE

R. EKERS†

CSIRO Australia Telescope National Facility, P.O. Box 76, Epping, NSW, 2121, Australia

Abstract—Future international collaborations could lead to a new generation of radio telescopes with 10–100 times the performance of the most powerful telescopes existing today. There is already a demand for this from both radioastronomy and SETI communities. The scientific arguments are in place and they are very similar for both disciplines. URSI and IAU Working Groups have been set up recently to consider the problems. Development and construction could be achieved by 2005.

The collecting area being considered is of the order of a square kilometre. This area would be spread over tens of kilometres to give a suitable high resolution. The preferred frequency range is from 200 to 5000 MHz. Construction cost would probably be of the order of a few $100 m.

This proposal will be discussed in the context of the need for exponential growth (Livingston curves) for major scientific disciplines to survive. The growth is fed by a series of technological advances. This next generation telescope will undoubtedly require the development of new and innovative technologies in areas such as antennas, amplifiers, interference control, signal transport and data processing. © 1995 International Astronautical Federation. Published by Elsevier Science Ltd. All rights reserved

Mon. Not. R. astr. Soc. (1992) 257, 105–109

A narrow-band search for extraterrestrial intelligence (SETI) using the interstellar contact channel hypothesis

D. G. Blair,[1] R. P. Norris,[2] E. R. Troup,[2] R. Twardy,[2] K. J. Wellington,[2] A. J. Williams,[1] A. E. Wright[2] and M. G. Zadnik[3]

[1] Department of Physics, University of Western Australia, Nedlands, Perth, Western Australia 6009
[2] Australia Telescope National Facility (ATNF), Epping, NSW 2121, Australia
[3] Department of Applied Physics, Curtin University of Technology, Bentley, Western Australia 6001

Accepted 1992 January 20. Received 1992 January 14; in original form 1991 October 14

SUMMARY

We report a search for narrow spectral line emission from 176 targets (including 166 stars and seven globular clusters) at the hypothesized 'interstellar communications channel' frequency of 4.462336275 GHz ($=\pi$ times the neutral hydrogen line at 1.42 GHz) using the Parkes Radio telescope. The frequency was Doppler corrected for the solar barycentre, target barycentre and cosmic microwave background (CMB) reference frames. If a 'Galactic club' of extraterrestrial civilizations exists, then our null results, down to a 3σ limit of 2 Jy (6 Jy in CMB frame), set an upper limit of 10^6 yr on the lifetime of such civilizations.

Key words: miscellaneous – radiation mechanisms: miscellaneous.

Pergamon

Acta Astronautica Vol. 42, No. 10–12, pp. 589–591, 1998

0094-5765/98 $19.00 + 0.00

PII: S0094-5765(98)00012-5

SETI AND THE ONE SQUARE KILOMETRE RADIO TELESCOPE

R. EKERS†

CSIRO Australia Telescope National Facility, P.O. Box 76, Epping, NSW, 2121, Australia

Abstract—Future international collaborations could lead to a new generation of radio telescopes with 10–100 times the performance of the most powerful telescopes existing today. There is already a demand for this from both radioastronomy and SETI communities. The scientific arguments are in place and they are very similar for both disciplines. URSI and IAU Working Groups have been set up recently to consider the problems. Development and construction could be achieved by 2005.

The collecting area being considered is of the order of a square kilometre. This area would be spread over tens of kilometres to give a suitable high resolution. The preferred frequency range is from 200 to 5000 MHz. Construction cost would probably be of the order of a few $100 m.

This proposal will be discussed in the context of the need for exponential growth (Livingston curves) for major scientific disciplines to survive. The growth is fed by a series of technological advances. This next generation telescope will undoubtedly require the development of new and innovative technologies in areas such as antennas, amplifiers, interference control, signal transport and data processing. © 1995 International Astronautical Federation. Published by Elsevier Science Ltd. All rights reserved

THE ASTRONOMICAL JOURNAL VOLUME 112, NUMBER 1 JULY 1996

A SEARCH FOR ARTIFICIAL SIGNALS FROM THE SMALL MAGELLANIC CLOUD

SETH SHOSTAK

SETI Institute, 2035 Landings Drive, Mountain View, California 94043
Electronic mail: seth_shostak@seti-inst.edu

RON EKERS

Australian Telescope National Facility, P.O. Box 76, Epping, 2121 NSW, Australia
Electronic mail: rekers@atnf.csiro.au

ROBERTA VAILE

University of Western Sydney, Macarthur, Campbelltown, 2560 NSW, Australia
Electronic mail: abrv@musica.macarthur.uws.edu.au

Received 1996 January 17; revised 1996 April 4

ABSTRACT

We have used the Parkes radio telescope to observe three fields in the Small Magellanic Cloud encompassing $> 10^7$ stars, looking for signals that could be ascribed to extraterrestrial intelligence. No narrow-band (≤ 1 Hz) continuous or slowly-pulsed emissions greater than ≈ 19 Jy were detected in the observed spectral band of 1.2–1.75 GHz. This limit corresponds to a transmitter power of $\approx 5\times10^5$ MW for a 100 m antenna at the distance of the SMC (EIRP of $\approx 1.5\ 10^{12}$ MW). © *1996 American Astronomical Society.*

IMAGE: NRAO/AUI/NSF

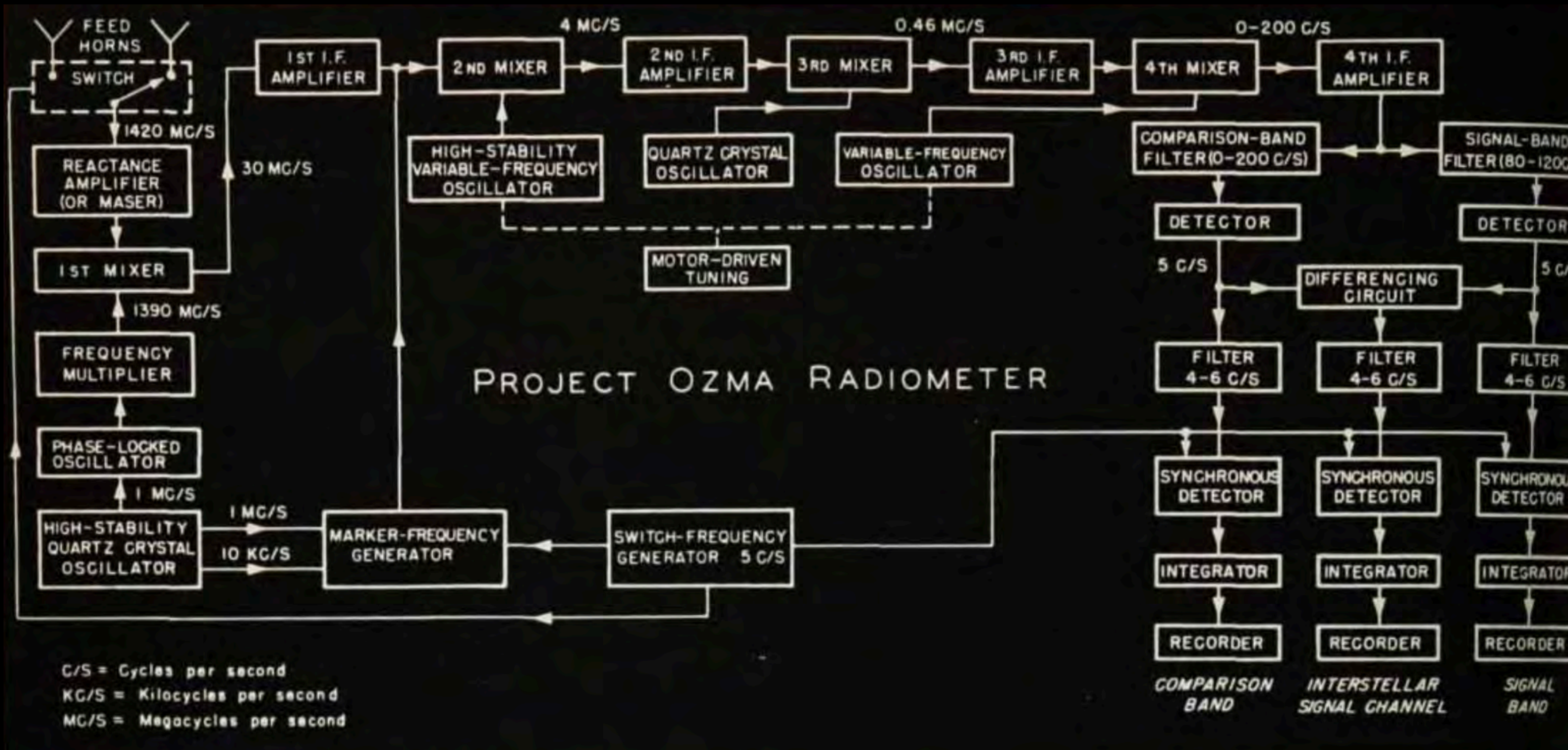


Image: Physics Today, 1960

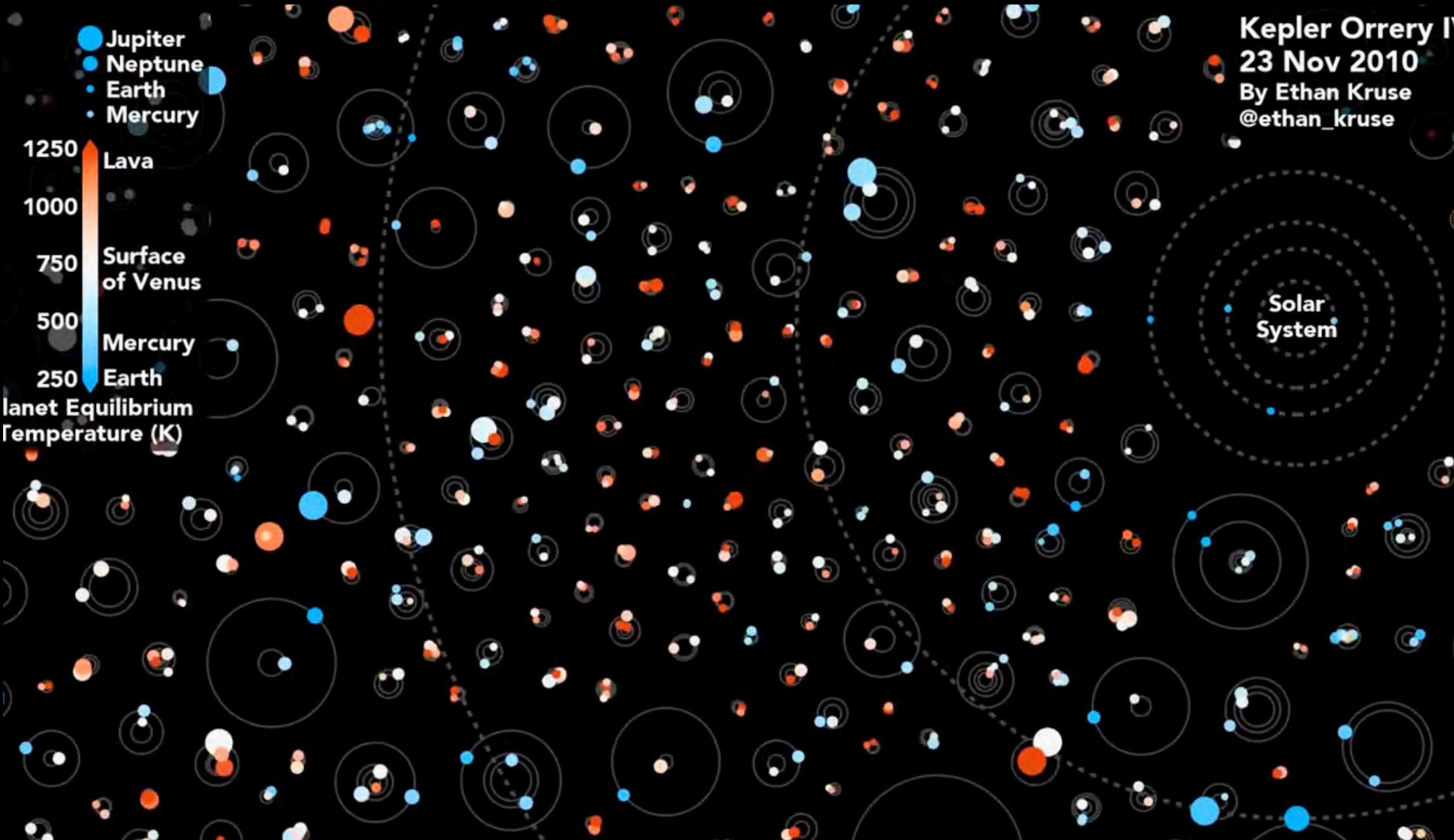
IBM Stretch (1960)

10^{6} instructions / second

Setonix (2023)

10^{19} instructions / second

A 10,000,000,000,000x improvement


Kepler Orrery IV
23 Nov 2010
By Ethan Kruse
@ethan_kruse
Jupiter
Neptune
Earth
Mercury
1250
1000
750
500
250
Lava
Surface of Venus
Mercury
Earth
lanet Equilibrium
Temperature (K)
Solar System

Phosphine on Venus?

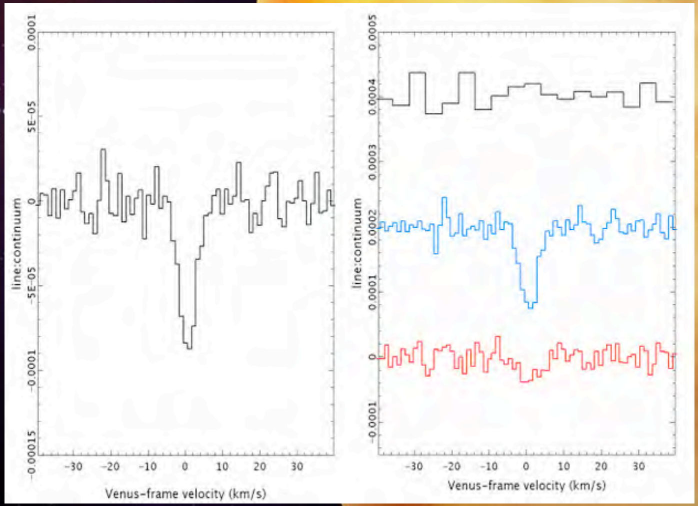


IMAGE: DANIELLE FUTSELAAR

Phosphine gas in the cloud decks of Venus

Jane S. Greaves, Anita M. S. Richards, William Bains, Paul B. Rimmer, Hideo Sagawa, David L. Clements, Sara Seager, Janusz J. Petkowski, Clara Sousa-Silva, Sukrit Ranjan, Emily Drabek-Maunder, Helen J. Fraser, Annabel Cartwright, Ingo Mueller-Wodarg, Zhuchang Zhan, Per Friberg, Iain Coulson, E'lisa Lee & Jim Hoge

Nature Astronomy **5**, 655–664 (2021) | Cite this article

Phosphine gas in the cloud decks of Venus

Jane S. Greaves, Anita M. S. Richards, William Bains, Paul B. Rimmer, Hideo Sagawa, David L. Clements, Sara Seager, Janusz J. Petkowski, Clara Sousa-Silva, Sukrit Ranjan, Emily Drabek-Maunder, Helen J. Fraser, Annabel Cartwright, Ingo Mueller-Wodarg, Zhuchang Zhan, Per Friberg, Iain Coulson, E'lisa Lee & Jim Hoge

Nature Astronomy **5**, 655–664 (2021) | Cite this article

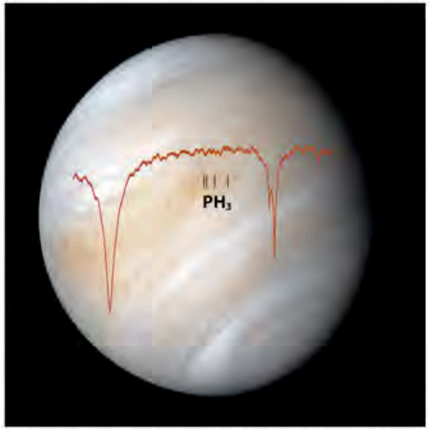
No Phosphine on Venus, According to SOFIA

SOFIA

November 29, 2022

by Anashe Bandari

Venus is considered Earth's twin in many ways, but, thanks to the Stratospheric Observatory for Infrared Astronomy (SOFIA), one difference now seems clearer: Unlike Earth, Venus does not have any obvious phosphine.



The spectral data from SOFIA overlain atop this image of Venus from NASA's Mariner 10 spacecraft is what the researchers observed in their study, showing the intensity of light from Venus at different wavelengths. If a significant amount of phosphine were present in Venus's atmosphere, there would be dips in the graph at the four locations labeled "PH3," similar to but less pronounced than those seen on the two ends. Credit: Venus: NASA/JPL-Caltech; Spectra: Cordiner et al.

Phosphine gas in the cloud decks of Venus

Jane S. Greaves, Anita M. S. Richards, William Bains, Paul B. Rimmer, Hideo Sagawa, David L. Clements, Sara Seager, Janusz J. Petkowski, Clara Sousa-Silva, Sukrit Ranjan, Emily Drabek-Maunder, Helen J. Fraser, Annabel Cartwright, Ingo Mueller-Wodarg, Zhuchang Zhan, Per Friberg, Iain Coulson, E'lisa Lee & Jim Hoge

Nature Astronomy **5**, 655–664 (2021) | Cite this article

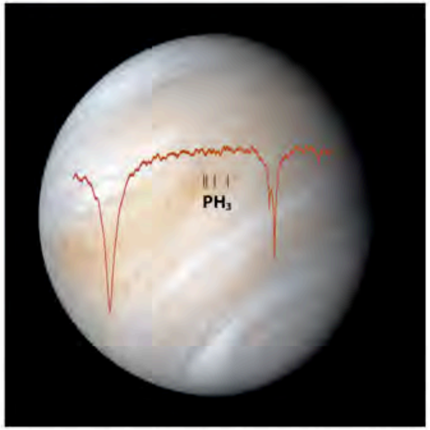
No Phosphine on Venus, According to SOFIA

SOFIA

November 29, 2022

by Anashe Bandari

Venus is considered Earth's twin in many ways, but, thanks to the Stratospheric Observatory for Infrared Astronomy (SOFIA), one difference now seems clearer: Unlike Earth, Venus does not have any obvious phosphine.



The spectral data from SOFIA overlain atop this image of Venus from NASA's Mariner 10 spacecraft is what the researchers observed in their study, showing the intensity of light from Venus at different wavelengths. If a significant amount of phosphine were present in Venus's atmosphere, there would be dips in the graph at the four locations labeled "PH3," similar to but less pronounced than those seen on the two ends. Credit: Venus: NASA/JPL-Caltech; Spectra: Cordiner et al.

Recovering Phosphine in Venus' Atmosphere from SOFIA Observations

Comment on

"Phosphine in the Venusian Atmosphere: A Strict Upper Limit from SOFIA GREAT Observations"

Jane S. Greaves[1], Janusz J. Petkowski[2,3], Anita M. S. Richards[4], Clara Sousa-Silva[5], Sara Seager[2,6,7] and David L. Clements[8]

Plain Language Summary

Cordiner et al. find no phosphine in Venus' atmosphere, using the airborne SOFIA telescope. By-passing some instrumental effects, we extract a detection with 5.7σ-confidence from the same data. We can resolve the tension between high and low PH_3 abundance values by noticing that the former are from 'mornings' in Venus' atmosphere and the latter from 'evenings'. Sunlight reduces the amount of phosphine in Earth's atmosphere by an order of magnitude, so similarly on Venus, we might expect lower abundances in data taken when the part of the atmosphere observed has passed through sunlight. If the six available datasets can be reconciled in this way, further modelling of possible sources of PH_3 (e.g. volcanic, disequilbrium chemistry, extant life) seem worthwhile.

Phosphine gas in the cloud decks of Venus

Jane S. Greaves, Anita M. S. Richards, William Bains, Paul B. Rimmer, Hideo Sagawa, David L. Clements, Sara Seager, Janusz J. Petkowski, Clara Sousa-Silva, Sukrit Ranjan, Emily Drabek-Maunder, Helen J. Fraser, Annabel Cartwright, Ingo Mueller-Wodarg, Zhuchang Zhan, Per Friberg, Iain Coulson, E'lisa Lee & Jim Hoge

Nature Astronomy **5**, 655–664 (2021) | Cite this article

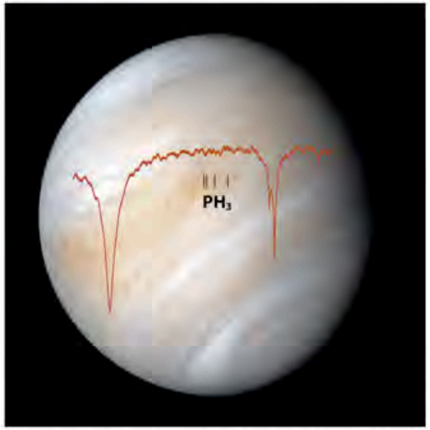
No Phosphine on Venus, According to SOFIA

SOFIA

November 29, 2022

by Anashe Bandari

Venus is considered Earth's twin in many ways, but, thanks to the Stratospheric Observatory for Infrared Astronomy (SOFIA), one difference now seems clearer: Unlike Earth, Venus does not have any obvious phosphine.



The spectral data from SOFIA overlain atop this image of Venus from NASA's Mariner 10 spacecraft is what the researchers observed in their study, showing the intensity of light from Venus at different wavelengths. If a significant amount of phosphine were present in Venus's atmosphere, there would be dips in the graph at the four locations labeled "PH3," similar to but less pronounced than those seen on the two ends. Credit: Venus: NASA/JPL-Caltech; Spectra: Cordiner et al.

Recovering Phosphine in Venus' Atmosphere from SOFIA Observations

Comment on

"Phosphine in the Venusian Atmosphere: A Strict Upper Limit from SOFIA GREAT Observations"

Jane S. Greaves[1], Janusz J. Petkowski[2,3], Anita M. S. Richards[4], Clara Sousa-Silva[5], Sara Seager[2,6,7] and David L. Clements[8]

Plain Language Summary

Cordiner et al. find no phosphine in Venus' atmosphere, using the airborne SOFIA telescope. By-passing some instrumental effects, we extract a detection with 5.7σ-confidence from the same data. We can resolve the tension between high and low PH_3 abundance values by noticing that the former are from 'mornings' in Venus' atmosphere and the latter from 'evenings'. Sunlight reduces the amount of phosphine in Earth's atmosphere by an order of magnitude, so similarly on Venus, we might expect lower abundances in data taken when the part of the atmosphere observed has passed through sunlight. If the six available datasets can be reconciled in this way, further modelling of possible sources of PH_3 (e.g. volcanic, disequilbrium chemistry, extant life) seem worthwhile.

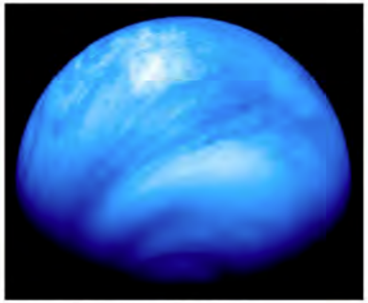
Phosphine Confirmed Deep Within Venus' Atmosphere, A Possible Sign Of Life

Jamie Carter Senior Contributor

I inspire people to go stargazing, watch the Moon, enjoy the night sky

Follow

Listen to article 6 minutes



Venus as seen by ESA's Venus Express in 2007

Phosphine gas in t

Jane S. Greaves, Anita M. S. R

Clements, Sara Seager, Janusz J.

Maunder, Helen J. Fraser, Annab

Iain Coulson, E'lisa Lee & Jim Ho

Nature Astronomy 5, 655–664 (

436k Accesses | 134 Citations

No Phosphi

According t

SOFIA

November 29, 2022

by A

Ven

thar

Astr

Unli

The s
Mari
show
signi
woul
less p
Calte

Penguins 'may be aliens' after scientists discover chemical from Venus in their poo

The beloved flightless birds may in fact be extra-terrestrials, scientists said, after traces of chemicals only found on the other side of the Solar System were found in their poo

NEWS By Jerry Lawton

21:44, 12 SEP 2021

Bookmark Comments 1

Our favourite fuzzy friends could be even more special than we think (Image: Getty Images/Mint Images RF)

Penguins may be aliens, say scientists, after traces of a chemical from Venus were found in the birds' poop.

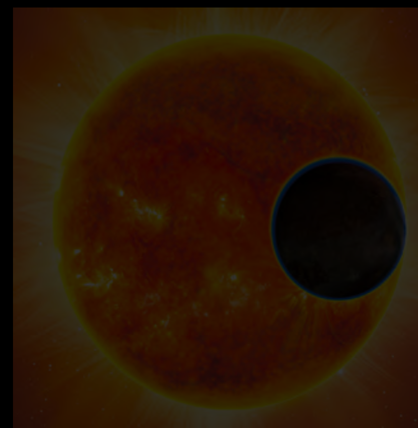
ervations

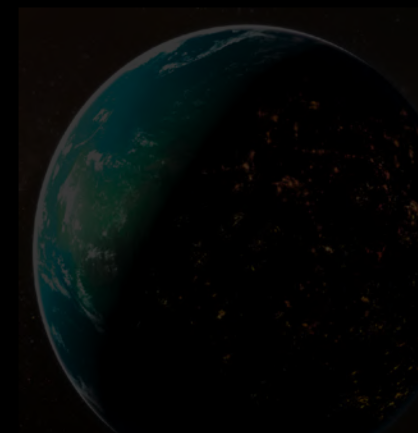
from SOFIA

sa-Silva[5], Sara

FIA telescope.
ce from the same
y noticing that
ings'. Sunlight
de, so similarly
atmosphere
ciled in this way,
istry, extant life)

How do we find life beyond Earth?

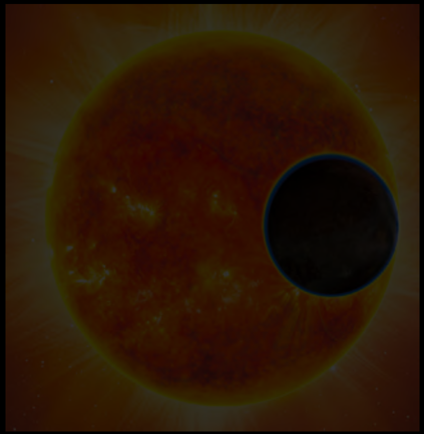


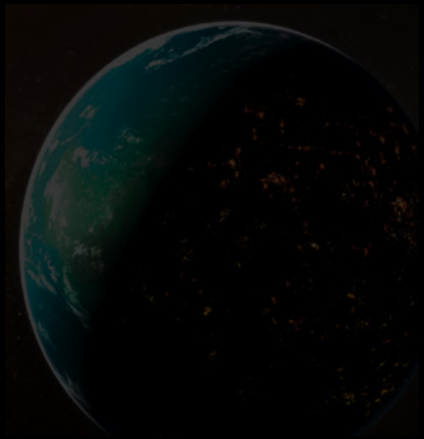


Images: NASA, Nat Geo

How do we find life beyond Earth?

In situ
(we go there, boldly)

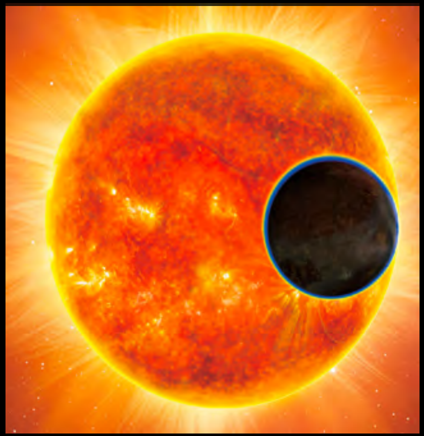




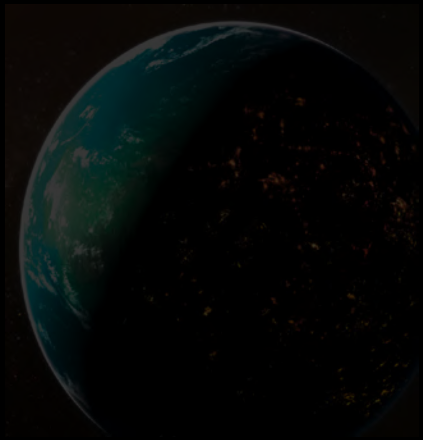
Images: NASA, Nat Geo

How do we find life beyond Earth?

In situ
(we go there, boldly)



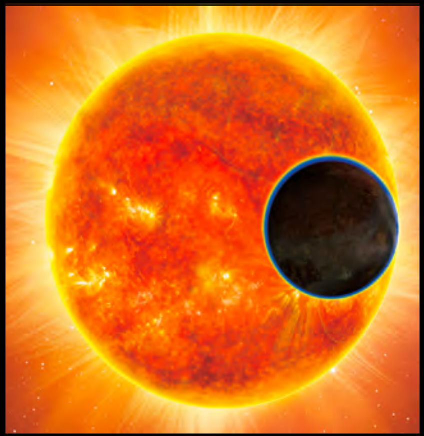
Atmospheric biosignature
(chemical disequilibrium)



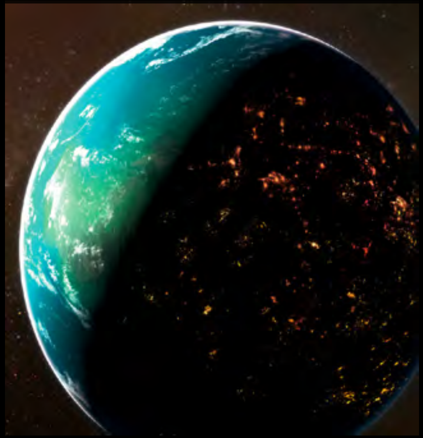
Images: NASA, Nat Geo

How do we find life beyond Earth?

In situ
(we go there, boldly)



Atmospheric biosignature
(chemical disequilibrium)



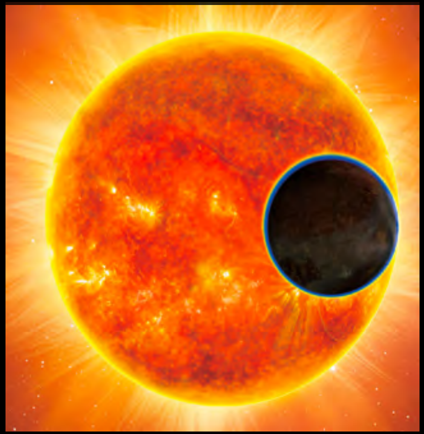
Technosignature detection
(SETI)

Images: NASA, Nat Geo

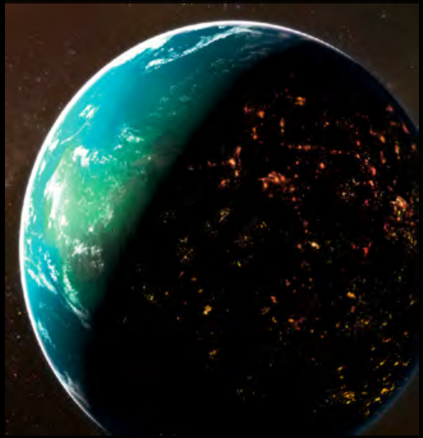
How do we find life beyond Earth?

In situ
(we go there, boldly)

$N_{stars} = 1$



Atmospheric biosignature
(chemical disequilibrium)



Technosignature detection
(SETI)

Images: NASA, Nat Geo

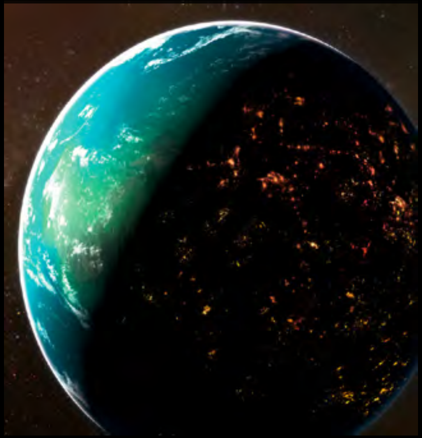
How do we find life beyond Earth?

In situ
(we go there, boldly)

$N_{stars} = 1$

Atmospheric biosignature
(chemical disequilibrium)

$N_{stars} \sim 10$



Technosignature detection
(SETI)

Images: NASA, Nat Geo

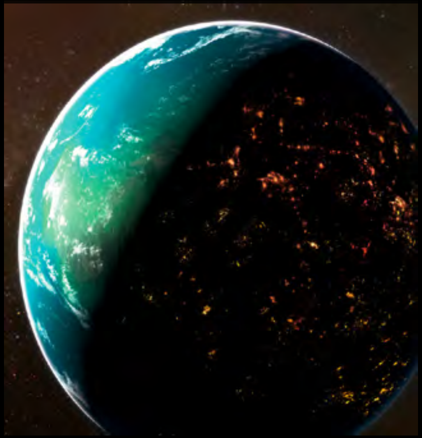
How do we find life beyond Earth?

In situ
(we go there, boldly)

$N_{stars} = 1$

Atmospheric biosignature
(chemical disequilibrium)

$N_{stars} \sim 10$



Technosignature detection
(SETI)

$N_{stars} \sim 10^{23}$

Images: NASA, Nat Geo

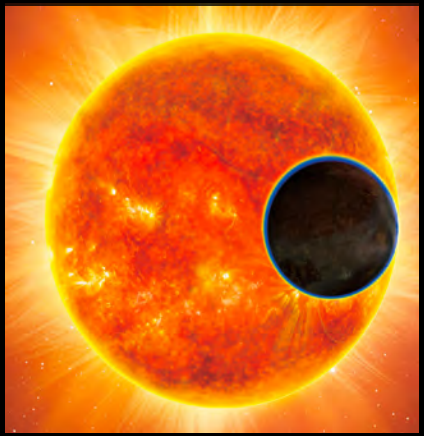
How do we find life beyond Earth?

$$$$$

In situ
(we go there, boldly)

$N_{stars} = 1$

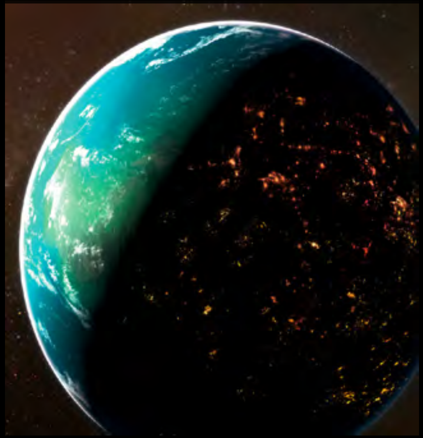
$$$$



Atmospheric biosignature
(chemical disequilibrium)

$N_{stars} \sim 10$

$



Technosignature detection
(SETI)

$N_{stars} \sim 10^{23}$

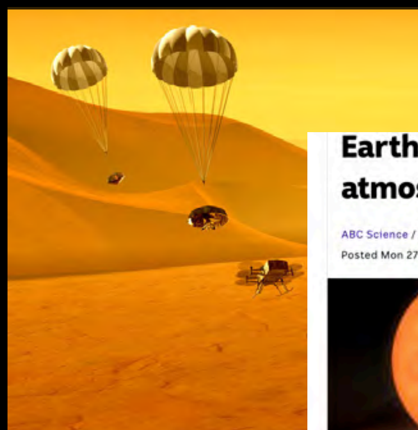
Images: NASA, Nat Geo

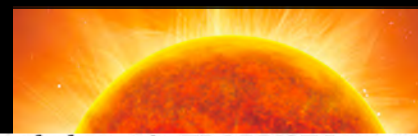
How do we find life beyond Earth?

$$$$$

$$$$

$





Earth-sized planet in TRAPPIST-1 system has no atmosphere, James Webb Space Telescope finds

ABC Science / By science reporter Genelle Weule

Posted Mon 27 Mar 2023 at 11:00pm, updated Tue 28 Mar 2023 at 6:58am

Seven Earth-sized planets have been discovered orbiting a nearby star. *(NASA/JPL-Caltech)*

In situ

(we go there, bold

$N_{stars} = 1$

ignature detection

$\sim 10^{23}$

Images: NASA, Nat Geo

Summary & motivation

- We are in a golden age of astrobiology.
- We are entering a golden age for technosignature searches.
- There is still a huge amount of low-hanging fruit, particularly at low frequency.
- SETI is leading technical developments which can support new observing modes and piggyback science.

BREAKTHROUGH LISTEN

BREAKTHROUGH LISTEN

"THE APOLLO PROGRAM OF SETI"

- E. ENRIQUEZ

Parkes Australia

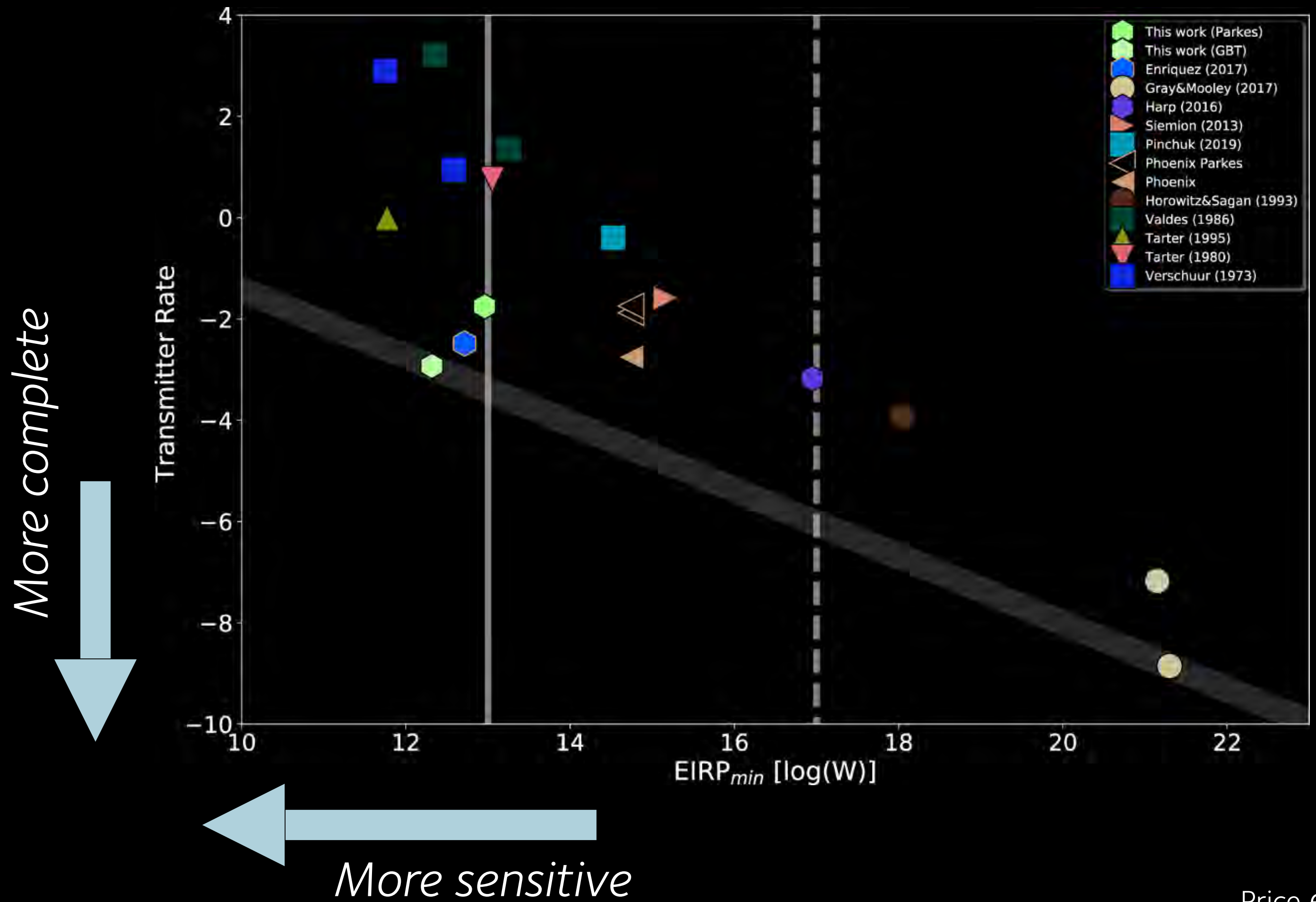
Images: P Hart (L) D. MacMahon (R)

Green Bank USA


BREAKTHROUGH
LISTEN on MeerKAT

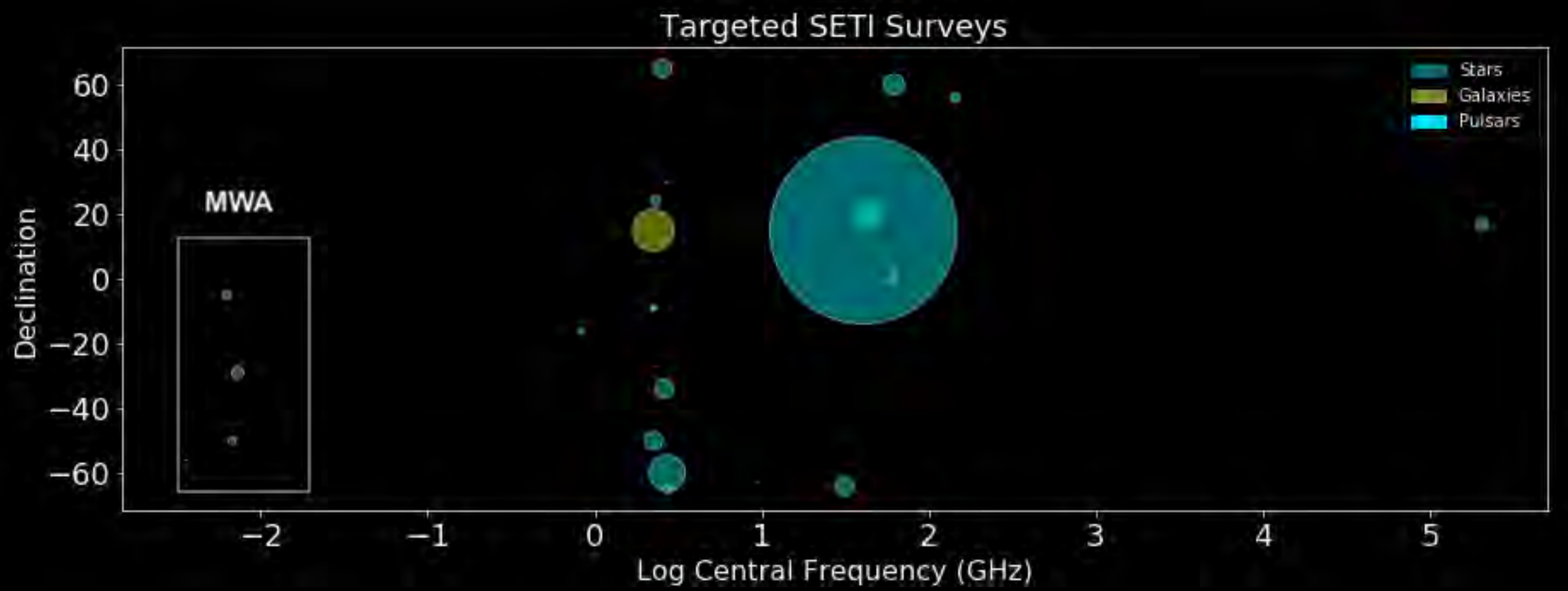

NRAO
SETI
INSTITUTE
Karl G. Jansky Very Large Array
NRAO Very Large Array and
SETI Institute Collaboration

Comparing SETI surveys



Price et. al. (2020)

Comparing SETI surveys



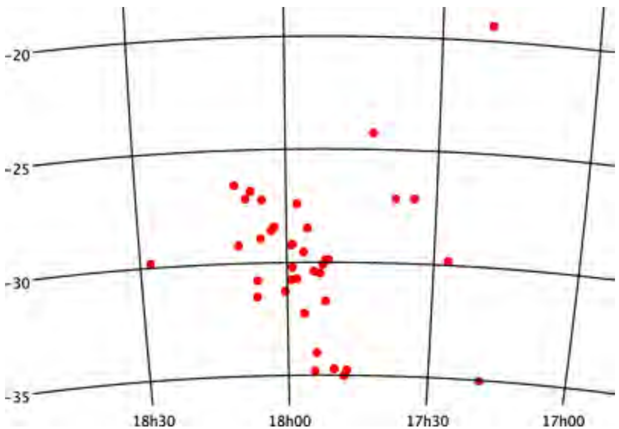
Not observable from Earth!

The size of the bubble is the number of objects in the given search.

Most searches to date are around the 'water hole' at ~1 GHz.

Credit: C. Tremblay

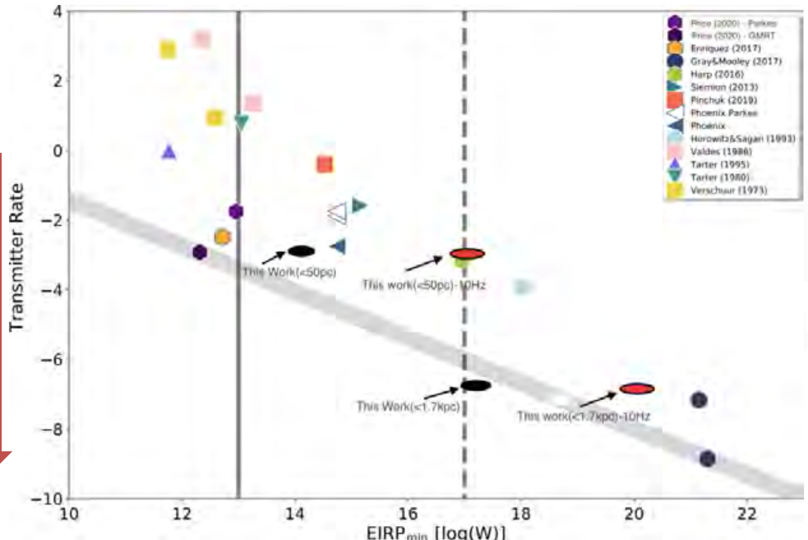
A Opportunistic SETI search with the MWA (2016)



- First SETI search with the MWA done by Tingay, Tremblay, Walsh & Urquhart in 2016.
- 400 square degrees around the Galactic centre, across 100-133 MHz.
- 38 known planetary systems in field.
- No narrowband (~10 kHz) spectral features found.

Tingay, Tremblay, Walsh & Urquhart (2016)

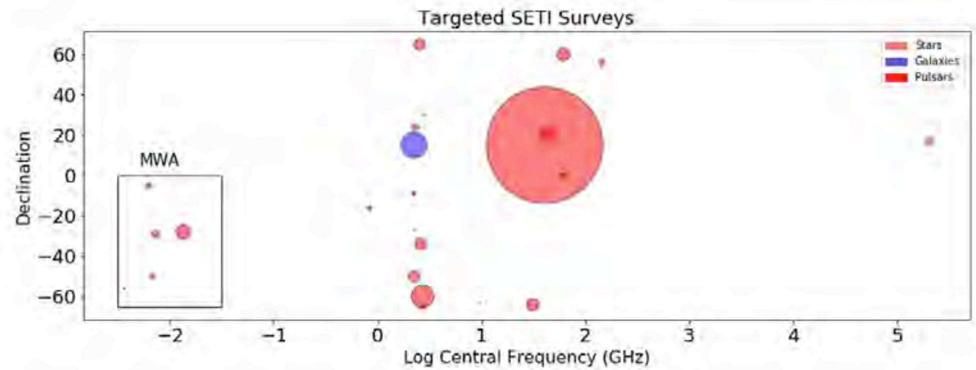
Comparing MWA against other SETI surveys



More complete

More sensitive

Price+ (2020), Tremblay & Tingay (2020)



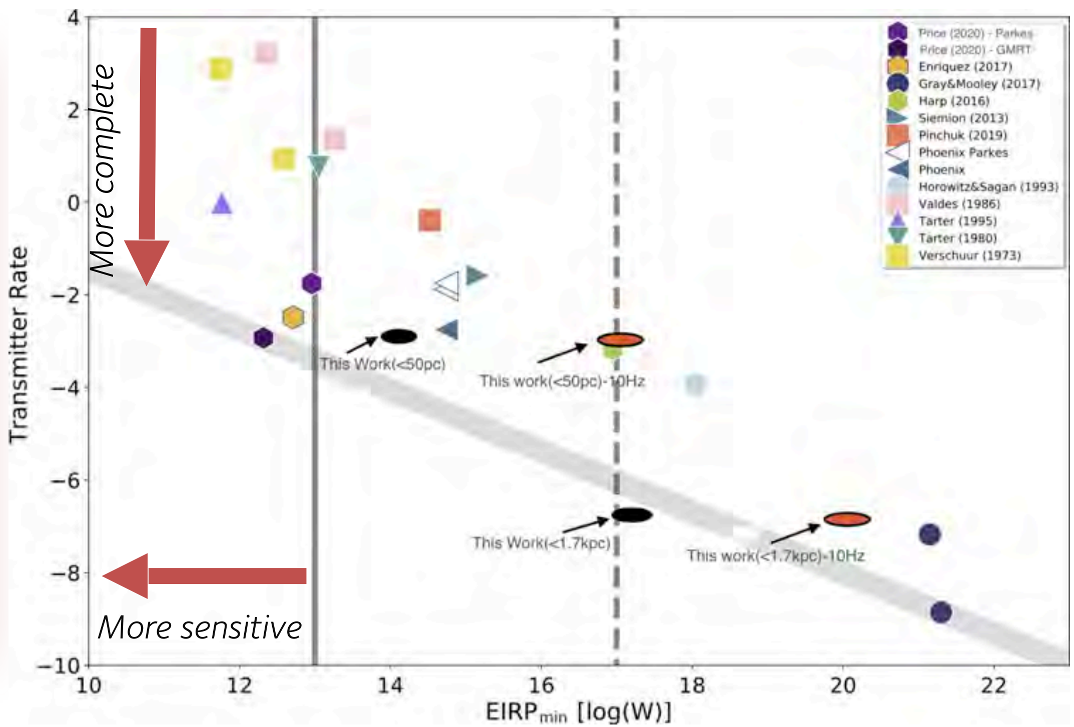
Tremblay, Tingay, Price (2022)

The unique search capability of the MWA


Research Paper

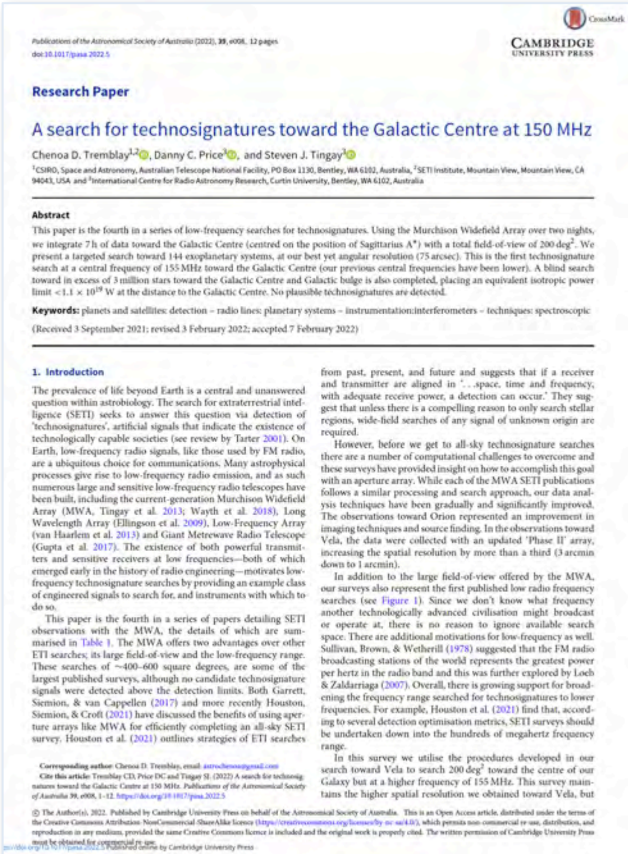
A SETI survey of the Vela region using the Murchison Widefield Array: Orders of magnitude expansion in search space

C. D. Tremblay and S. J. Tingay



"The MWA frequency range, its southern hemisphere location on an extraordinarily radio quiet site, its very large field of view, and its high sensitivity make it a unique facility for SETI."

SETI on the MWA to date



Publications of the Astronomical Society of Australia (2022), 39, e008, 12 pages
doi:10.1017/pasa.2022.5

CAMBRIDGE UNIVERSITY PRESS

Research Paper

A search for technosignatures toward the Galactic Centre at 150 MHz

Chenoa D. Tremblay[1,2], Danny C. Price[3], and Steven J. Tingay[3]
[1]CSIRO, Space and Astronomy, Australian Telescope National Facility, PO Box 1130, Bentley, WA 6102, Australia, [2]SETI Institute, Mountain View, Mountain View, CA 94043, USA and [3]International Centre for Radio Astronomy Research, Curtin University, Bentley, WA 6102, Australia

Abstract
This paper is the fourth in a series of low-frequency searches for technosignatures. Using the Murchison Widefield Array over two nights, we integrate 7 h of data toward the Galactic Centre (centred on the position of Sagittarius A*) with a total field-of-view of 200 deg^2. We present a targeted search toward 144 exoplanetary systems, at our best yet angular resolution (75 arcsec). This is the first technosignature search at a central frequency of 155 MHz toward the Galactic Centre (our previous central frequencies have been lower). A blind search toward in excess of 3 million stars toward the Galactic Centre and Galactic bulge is also completed, placing an equivalent isotropic power limit $<1.1 \times 10^{19}$ W at the distance to the Galactic Centre. No plausible technosignatures are detected.

Keywords: planets and satellites: detection – radio lines: planetary systems – instrumentation:interferometers – techniques: spectroscopic

(Received 3 September 2021; revised 3 February 2022; accepted 7 February 2022)

1. Introduction

The prevalence of life beyond Earth is a central and unanswered question within astrobiology. The search for extraterrestrial intelligence (SETI) seeks to answer this question via detection of 'technosignatures', artificial signals that indicate the existence of technologically capable societies (see review by Tarter 2001). On Earth, low-frequency radio signals, like those used by FM radio, are a ubiquitous choice for communications. Many astrophysical processes give rise to low-frequency radio emission, and as such numerous large and sensitive low-frequency radio telescopes have been built, including the current-generation Murchison Widefield Array (MWA, Tingay et al. 2013; Wayth et al. 2018), Long Wavelength Array (Ellingson et al. 2009), Low-Frequency Array (van Haarlem et al. 2013) and Giant Metrewave Radio Telescope (Gupta et al. 2017). The existence of both powerful transmitters and sensitive receivers at low frequencies—both of which emerged early in the history of radio engineering—motivates low-frequency technosignature searches by providing an example class of engineered signals to search for, and instruments with which to do so.

This paper is the fourth in a series of papers detailing SETI observations with the MWA, the details of which are summarised in Table 1. The MWA offers two advantages over other ETI searches; its large field-of-view and the low-frequency range. These searches of ~400–600 square degrees, are some of the largest published surveys, although no candidate technosignature signals were detected above the detection limits. Both Garrett, Siemion, & van Cappellen (2017) and more recently Houston, Siemion, & Croft (2021) have discussed the benefits of using aperture arrays like MWA for efficiently completing an all-sky SETI survey. Houston et al. (2021) outlines strategies of ETI searches from past, present, and future and suggests that if a receiver and transmitter are aligned in '…space, time and frequency, with adequate receive power, a detection can occur.' They suggest that unless there is a compelling reason to only search stellar regions, wide-field searches of any signal of unknown origin are required.

However, before we get to all-sky technosignature searches there are a number of computational challenges to overcome and these surveys have provided insight on how to accomplish this goal with an aperture array. While each of the MWA SETI publications follows a similar processing and search approach, our data analysis techniques have been gradually and significantly improved. The observations toward Orion represented an improvement in imaging techniques and source finding. In the observations toward Vela, the data were collected with an updated 'Phase II' array, increasing the spatial resolution by more than a third (3 arcmin down to 1 arcmin).

In addition to the large field-of-view offered by the MWA, our surveys also represent the first published low radio frequency searches (see Figure 1). Since we don't know what frequency another technologically advanced civilisation might broadcast or operate at, there is no reason to ignore available search space. There are additional motivations for low-frequency as well. Sullivan, Brown, & Wetherill (1978) suggested that the FM radio broadcasting stations of the world represents the greatest power per hertz in the radio band and this was further explored by Loeb & Zaldarriaga (2007). Overall, there is growing support for broadening the frequency range searched for technosignatures to lower frequencies. For example, Houston et al. (2021) find that, according to several detection optimisation metrics, SETI surveys should be undertaken down into the hundreds of megahertz frequency range.

In this survey we utilise the procedures developed in our search toward Vela to search 200 deg^2 toward the centre of our Galaxy but at a higher frequency of 155 MHz. This survey maintains the higher spatial resolution we obtained toward Vela, but

Corresponding author: Chenoa D. Tremblay, email: astrochenoa@gmail.com

Cite this article: Tremblay CD, Price DC and Tingay SJ. (2022) A search for technosignatures toward the Galactic Centre at 150 MHz. Publications of the Astronomical Society of Australia 39, e008, 1–12. https://doi.org/10.1017/pasa.2022.5

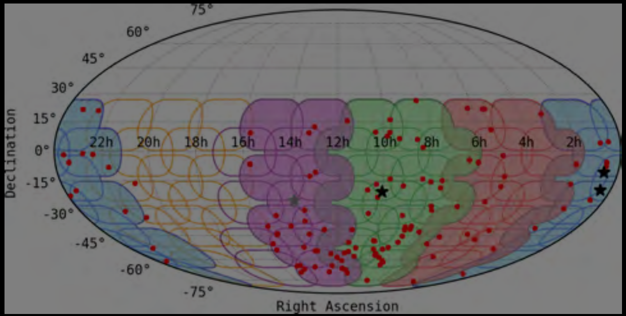
Tremblay, Price & Tingay (2022)

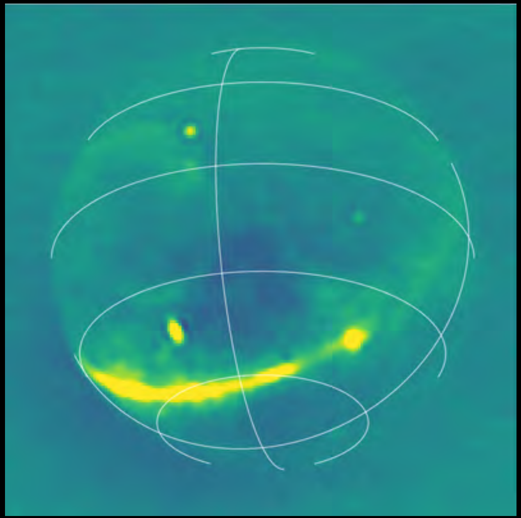
Table 1. Parameters of previous MWA SETI surveys.

	Phase centre (J2000)	Phase centre l,b (deg)	Freq. (MHz)	FoV (deg^2)	RMS_{min} (Jy $beam^{-1}$)	$EIRP_{min}$ 10^{13}(W)	Exoplanets known
Galactic Centre	Phase I MWA						
Tingay et al. (2013)	17h45m40s −29d00m28s	0, 0	103–133	400	0.45	<4	38
Orion	Phase I MWA						
Tingay et al. (2018)	05h35m17s −05d23m28s	196, −15	99–122	625	0.28	<1	22
Vela	Phase I MWA						
Tremblay & Tingay (2020)	08h35m27s −45d12m19s	264, −5	98–128	400	0.034	<0.6	6
Galactic Centre	Phase II MWA						
This work	17h45m40s −29d00m28s	0, 0	139–169	200	0.14	< 27	144

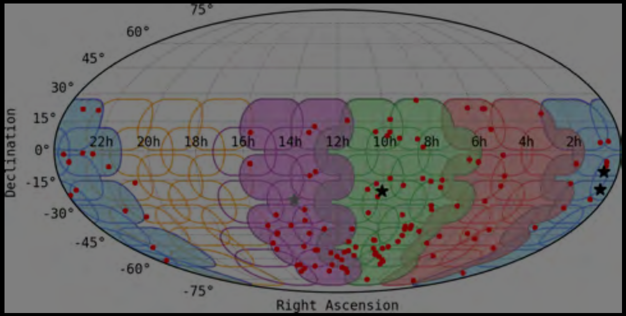
- Several SETI experiments have already been conducted with the MWA.
- What's next?

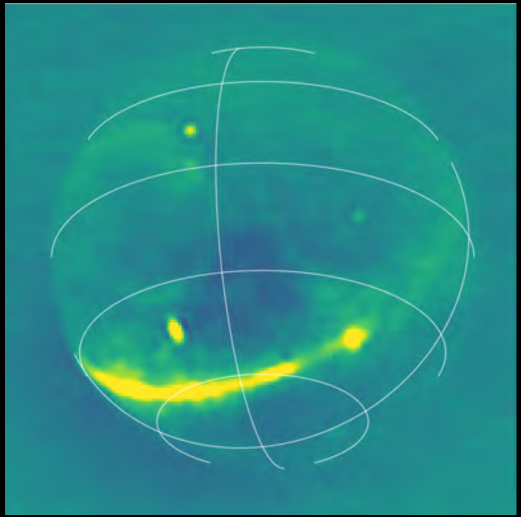
Three SETI experiments at Inyarrimanha Ilgari Bundara





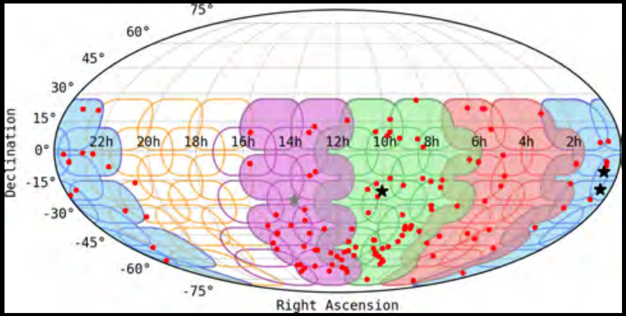
Three SETI experiments at Inyarrimanha Ilgari Bundara

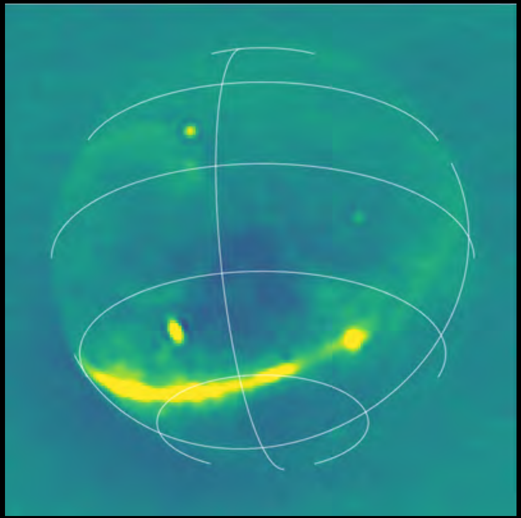




COMMENSAL SETI/FRB SEARCH

Three SETI experiments at Inyarrimanha Ilgari Bundara



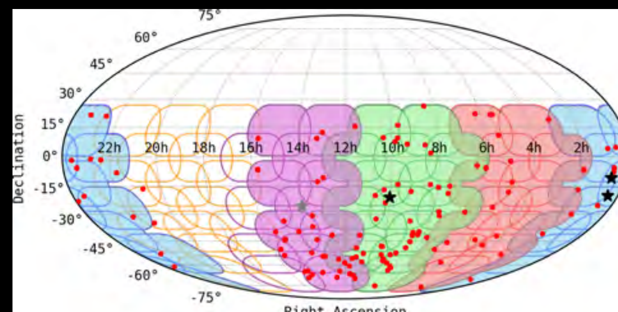


Commensal SETI/FRB search

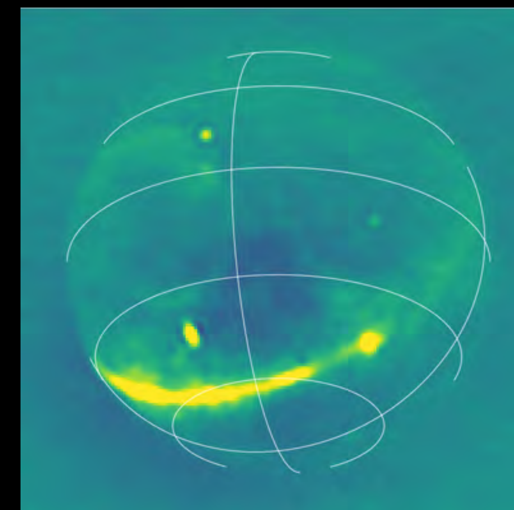
SMART Technosignatures

Three SETI experiments at Inyarrimanha Ilgari Bundara

Commensal SETI/FRB search



SMART Technosignatures

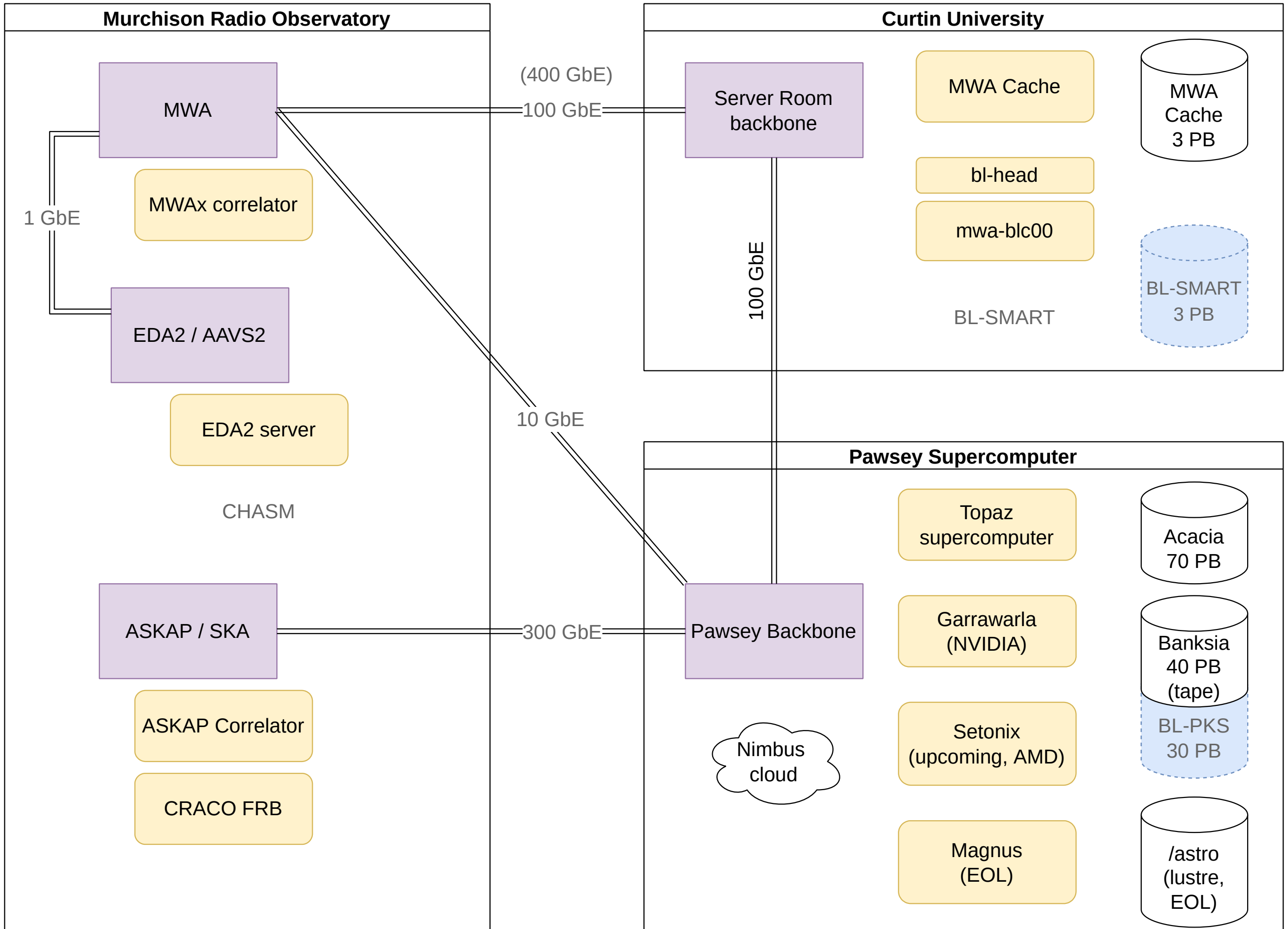


EDA2 All-sky SETI/FRB search
(see Marcin's Talk!)

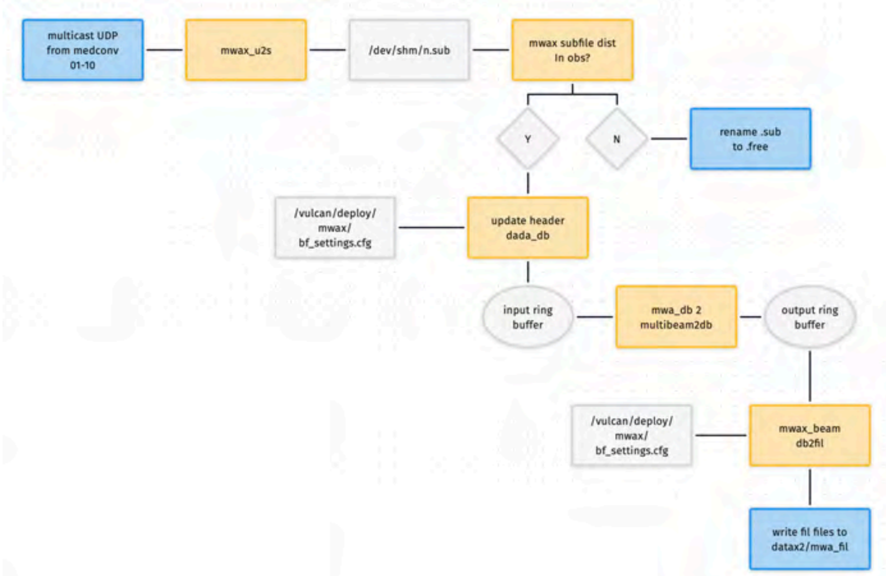
A commensal SETI and FRB system

- A Breakthrough Listen compute node is installed in Curtin data center.
- There is a 100 Gb/s link between the MWA site and Curtin.
- Through the power of Ethernet multicast, voltage data can be sent to Curtin at the same time as MWAX correlator.

MWA-Curtin-Pawsey network diagram



MWA commensal pipeline



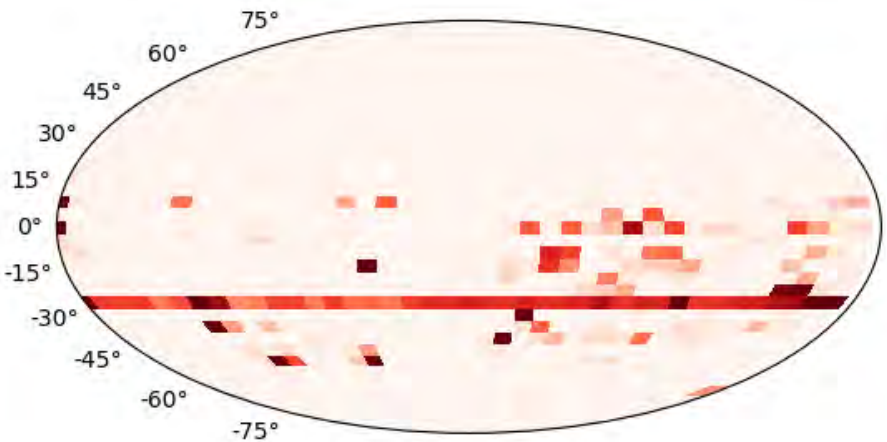
- Pipeline generates high-resolution dynamic spectra:
    - Captures and unpacketizes UDP data, stores in shared memory buffer.
    - Gets metadata and observing status.
    - Beamforms tiles (currently incoherent sum, coherent sum supported).
    - Does FFT + detection to form dynamic spectra.
    - Writes to filterbank files.
- Reuses code from MWAX. Majority of other code from Morrison/Sleap/Crosse.
- High time resolution data product (1 ms, 0.5 MHz channels) and high frequency resolution data product (1 s, 1 Hz) generated.
- Only one coarse channel recorded (currently).

MWA commensal pipeline: motivation

$$\frac{\sqrt{10\text{kHz}}}{\sqrt{128\,\text{stations}}} = 8.83$$

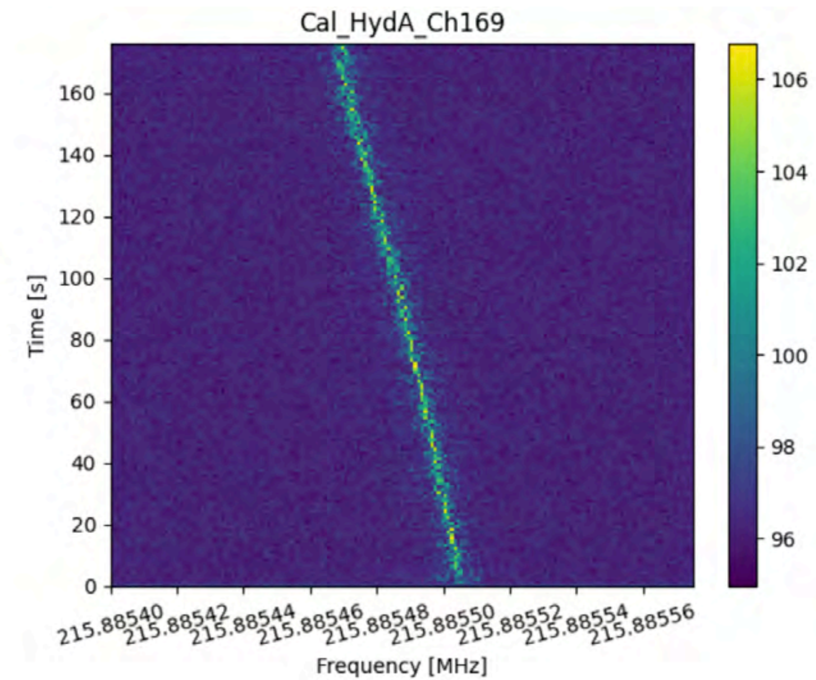
- For narrowband data (1 Hz), incoherently beamforming is **9x** more sensitive than searching a 10 kHz image cube.
- Searching the entire sky with coherent beamforming is computationally expensive (just ask the SMART team)
- Developing approach where signals-of-interest are identified incoherently, then coherent beamforming can be done to localize and follow up.
    - *Analogous to initial ASKAP FRB search strategy.*

MWA commensal pipeline: Data analysis



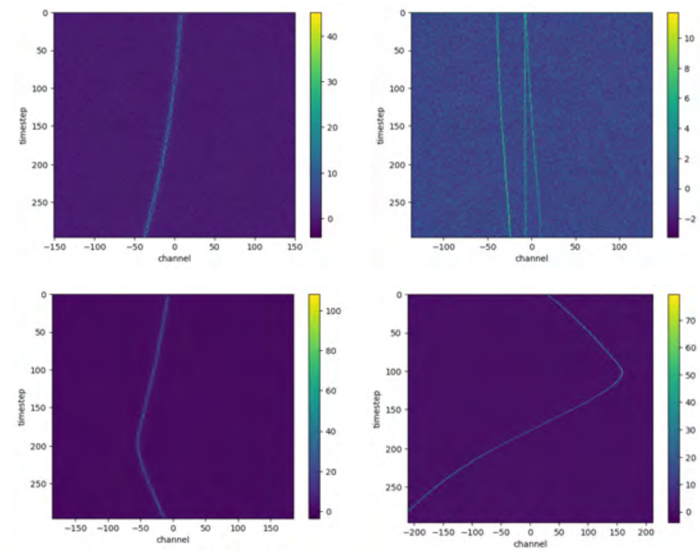
- SETI data to be searched with narrowband doppler drift code hyperSETI.
- FRB data to be searched with FDMT-based search code (Fredda, bifrost)
- ~6000 observations recorded to date.

MWA commensal pipeline: Data analysis



Example event: 2021-11-30T20:47:26.000,
S/N in 1 Hz channel data (incoherent beamformed): ~18
S/N in 10 kHz channel: ~0.18 (not detectable!)
S/N in 10 kHz channel, if coherent beamformed: ~2 (still not detectable!)

- An initial search on 6200 observations detected 323,234 narrowband signals with S/N > 10.
- These are probably all RFI.
- Similar signals are probably present in your data.



Update: We have more power!

Update: We have more power!

Thanks to Greg, Andy, Mouriyan and Chitru for installation!

Update: We have more power!

Server specifications:

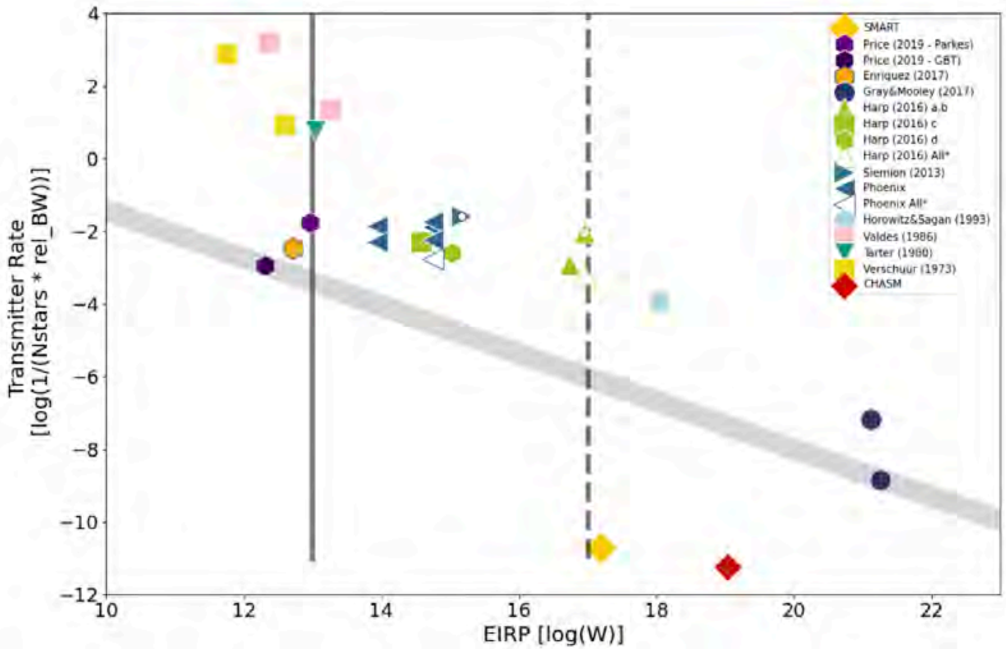
- 6x NVIDIA A4000 GPUs
- 2x AMD EPYC 7413 CPUs
- 512 GB RAM
- 16 TB NVMe storage
- 2x 100 Gb Ethernet NICs

Combined GPU performance:

- 346 TFLOPS (single precision)
- 2761 TFLOPS (tensor cores)

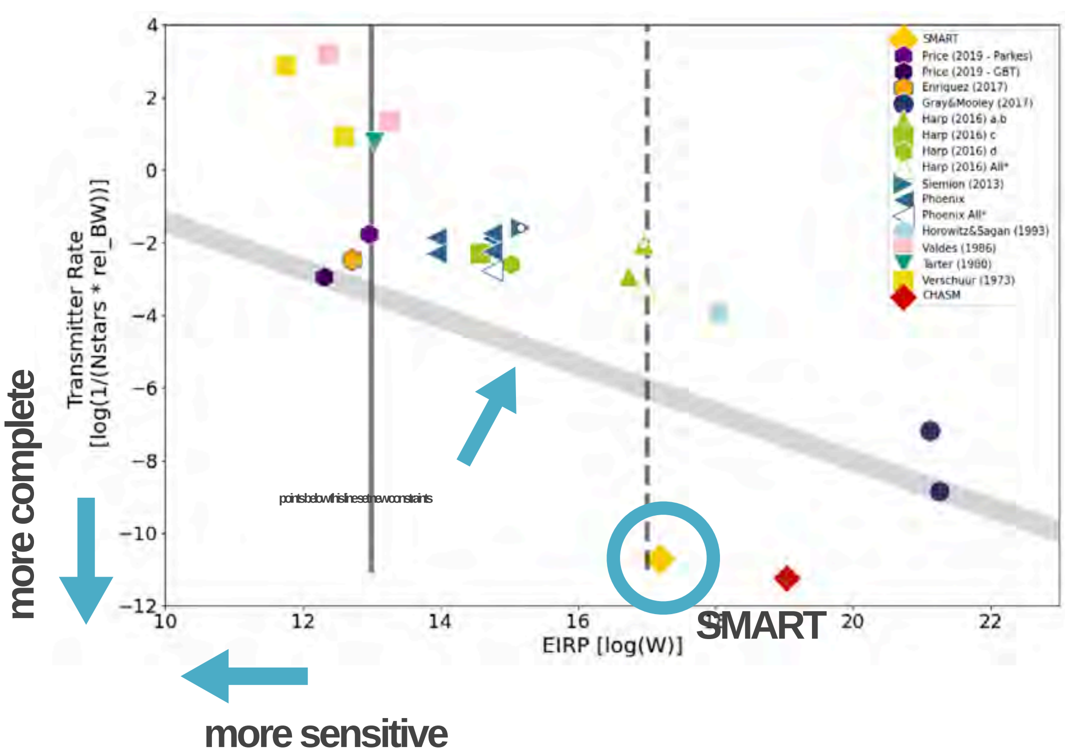
Two installed at Curtin data center, one installed in EDA2 @ MRO.

A SMART Technosignature search



- The SMART survey dataset has many petabytes of voltage data that could be searched for SETI signals.
- A technosignature search through the SMART dataset would give the best-ever limits on the existence of putative narrowband transmitters.
- Strong opportunity to leverage SETI expertise and technological approaches for the SMART pulsar search.

A SMART Technosignature search



- The SMART survey dataset has many petabytes of voltage data that could be searched for SETI signals.

- A technosignature search through the SMART dataset would give the best-ever limits on the existence of putative narrowband transmitters.

- Strong opportunity to leverage SETI expertise and technological approaches for the SMART pulsar search.

Concluding remarks

Concluding remarks

- We are in a golden age of astrobiology, MWA is an exception instrument for technosignature searches.

Concluding remarks

- We are in a golden age of astrobiology, MWA is an exception instrument for technosignature searches.
- A commensal SETI + FRB system is online and has just been upgraded.

Concluding remarks

- We are in a golden age of astrobiology, MWA is an exception instrument for technosignature searches.
- A commensal SETI + FRB system is online and has just been upgraded.
- Excellent opportunity to reuse the SMART voltage dataset to set stringent limits on technosignatures (or even detect ET).

Concluding remarks

- We are in a golden age of astrobiology, MWA is an exception instrument for technosignature searches.
- A commensal SETI + FRB system is online and has just been upgraded.
- Excellent opportunity to reuse the SMART voltage dataset to set stringent limits on technosignatures (or even detect ET).
- You have narrowband RFI hiding in your data.
    - Knowledge of narrowband RFI from SETI will be useful for deep imaging / EoR.
    - Also potentially useful for detecting satellites

Concluding remarks

- We are in a golden age of astrobiology, MWA is an exception instrument for technosignature searches.
- A commensal SETI + FRB system is online and has just been upgraded.
- Excellent opportunity to reuse the SMART voltage dataset to set stringent limits on technosignatures (or even detect ET).
- You have narrowband RFI hiding in your data.
  - Knowledge of narrowband RFI from SETI will be useful for deep imaging / EoR.
  - Also potentially useful for detecting satellites

Expected Drift Rate

The most dominant factors affecting the drift rate of a signal are the rotations and orbits of the Earth and the source body. The following equation[31], gives us the maximum expected Doppler drift rate ($\dot{\nu}_{max}$) by accounting for planet rotation $\left(\frac{4\pi^2 R}{P^2}\right)$ and orbit $\left(\frac{GM}{r}\right)$:

$$\dot{\nu}_{\max} = \frac{\nu_0}{c}\left(\frac{4\pi^2 R_\oplus}{P_\oplus^2} + \frac{4\pi^2 R_{\mathrm{Pb}}}{P_{\mathrm{Pb}}^2} + \frac{GM_\odot}{r_\oplus^2} + \frac{GM_{\mathrm{PC}}}{r_{\mathrm{Pb}}^2}\right). \tag{3}$$

The term ν_0 is the emitted frequency from the transmitter, R, P, M, and r are the planetary radii, rotational periods, solar masses, and orbital radii for Earth (subscript $\oplus$) and Proxima b (subscript Pb), respectively. Other contributions to the drift rate, such as the bodies' movement through the Milky Way, are negligible.

Given our non-detection of technosignatures, we place limits on the detection of narrow-band signals from Proxima Centauri by calculating the minimum detectable EIRP ($\mathrm{EIRP}_{\min}$). The $\mathrm{EIRP}_{\min}$ is given by

$$\mathrm{EIRP}_{\min} = 4\pi d^2 F_{\min} \tag{1}$$

where d is the distance to the source (1.301 pc for Proxima Centauri) and $F_{\min}$ is the minimum detectable flux in $\mathrm{W/m^2}$. The equation for $F_{\min}$ depends on the minimum S/N ($\mathrm{S/N_{min}}$), the system temperature of the telescope (T_{sys}), the effective collecting area of the telescope (A_{eff}), the channel bandwidth (B), the number of polarizations (n_{pol}), and the total observation time (t_{obs})[18,24]:

$$\mathrm{F}_{\min} = \mathrm{S/N}_{\min}\frac{2k_B T_{\mathrm{sys}}}{A_{\mathrm{eff}}}\sqrt{\frac{B}{n_{\mathrm{pol}}t_{\mathrm{obs}}}}. \tag{2}$$