SETI Efforts Around the World

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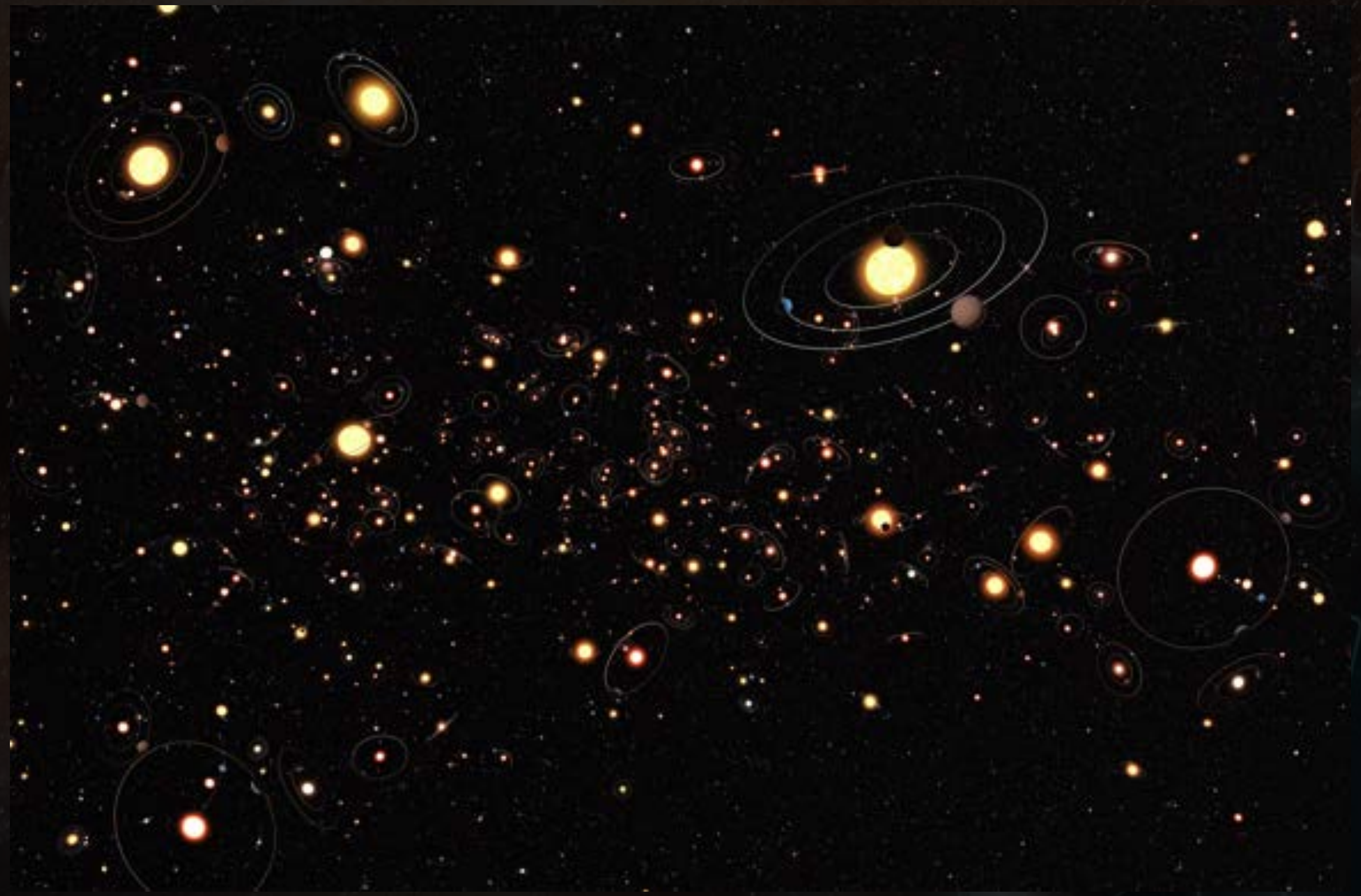
Are We Alone?



Credit: ESO/M. Kornmesser

Credit: Eye of Science/Science Photo Library

Biosignature

- Limited to only handful of stars in near future
- Many biomarkers are known to be arise due to abiotic processes (see Wordsworth & Pierrehumbert 2014)

Technosignatures

- Physical Artifacts by technologically advanced life (Bracewell 1960)
- Exo-engineering (Wright 2018; Hong-Ying Chen 2021)
- Electromagnetic Waves (e.g. Cocconi & Morrison 1959; Schwartz & Townes 1961)

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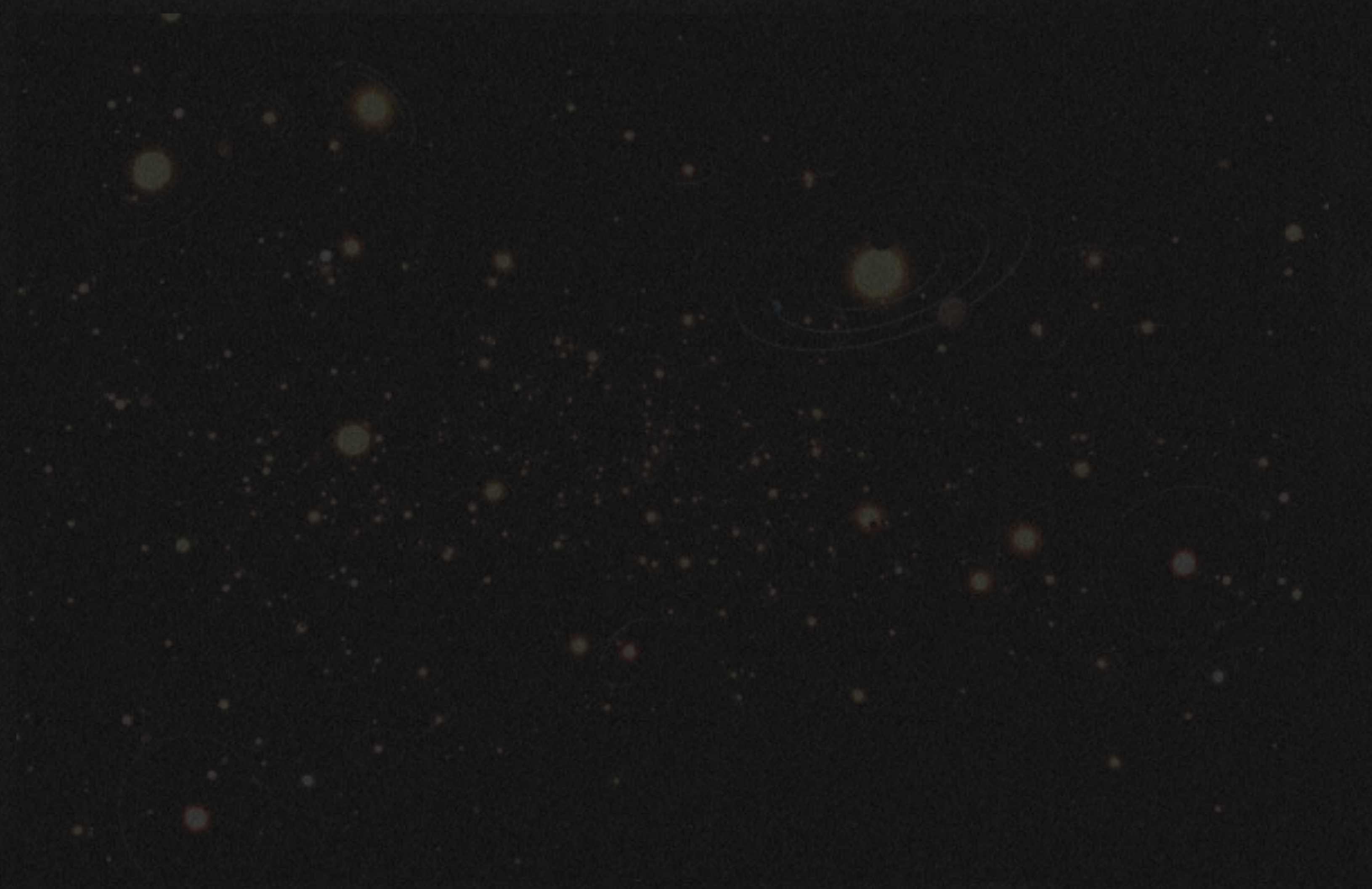

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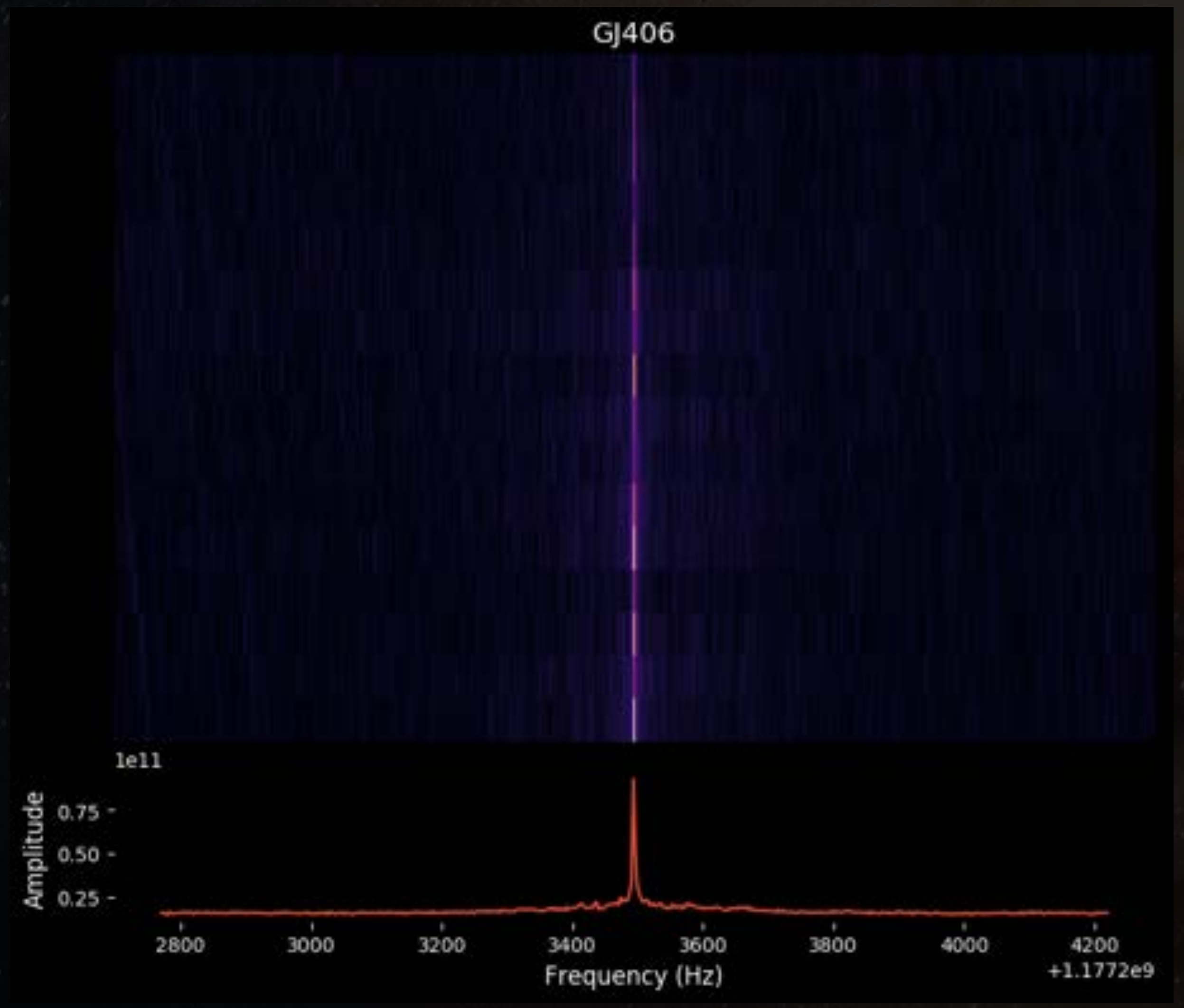
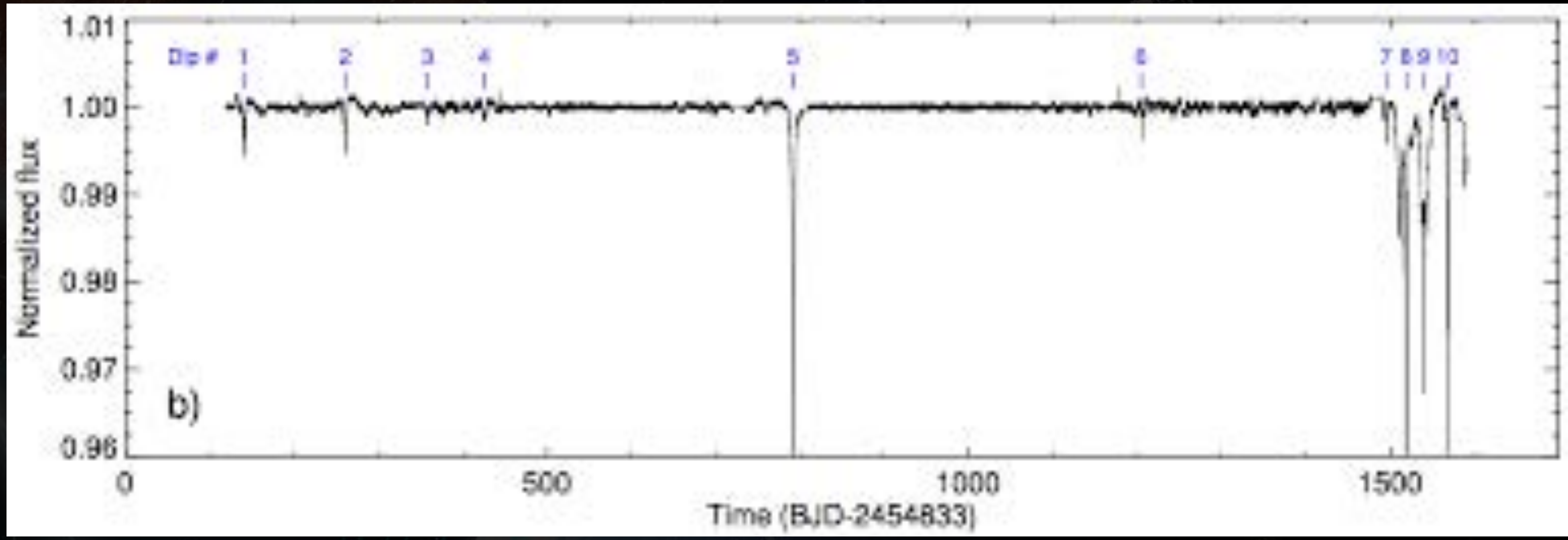
Electromagnetic Waves

Types of Technosignatures 1



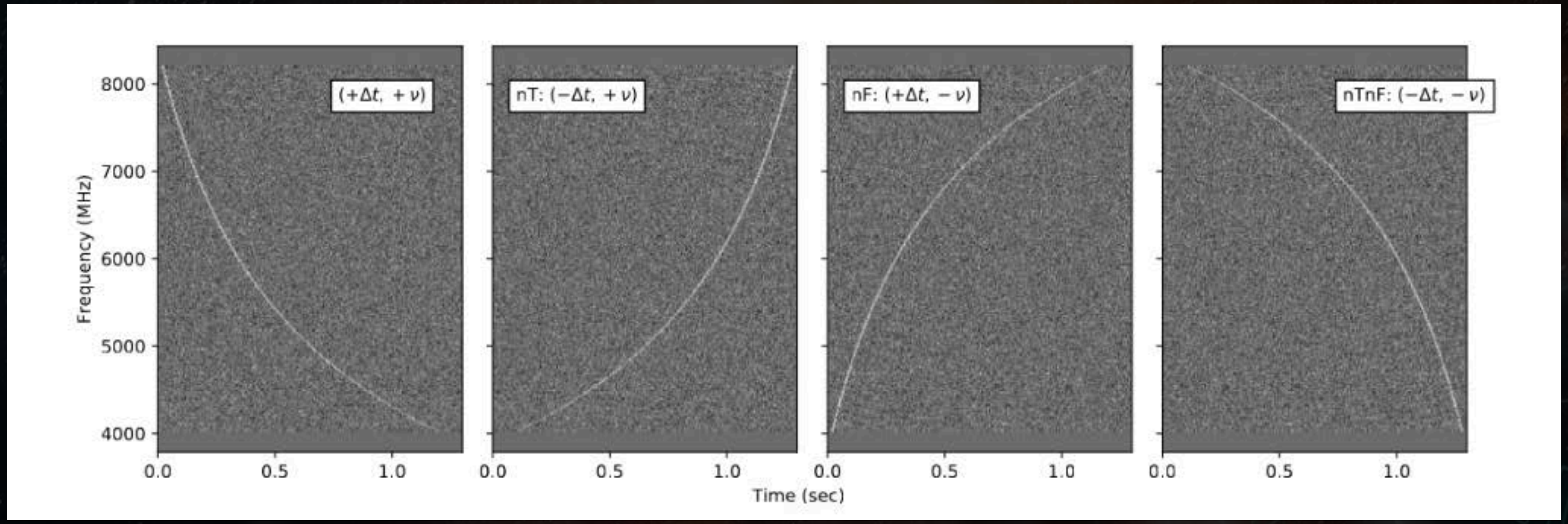
Narrowband signals in Radio
and Optical (Cocconi & Morrison 1959;)



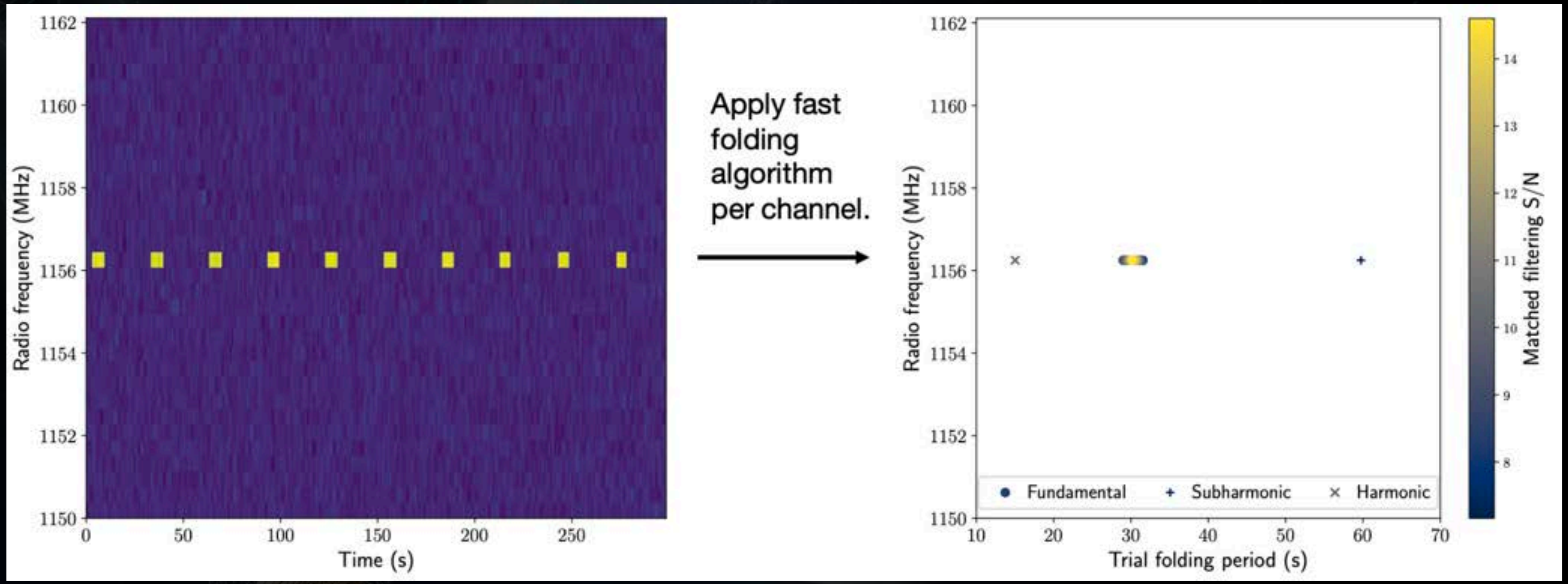
Exo-engineering Tabby's Star (Boyajian et al. 2016)

Nanosecond duration Optical pulses (Schwartz &
Townes 1961)

Types of Technosignatures 2



Broadband Signals with added artificiality (Gajjar et al. 2022)



Narrowband pulsating signals (Suresh et al. 2023)

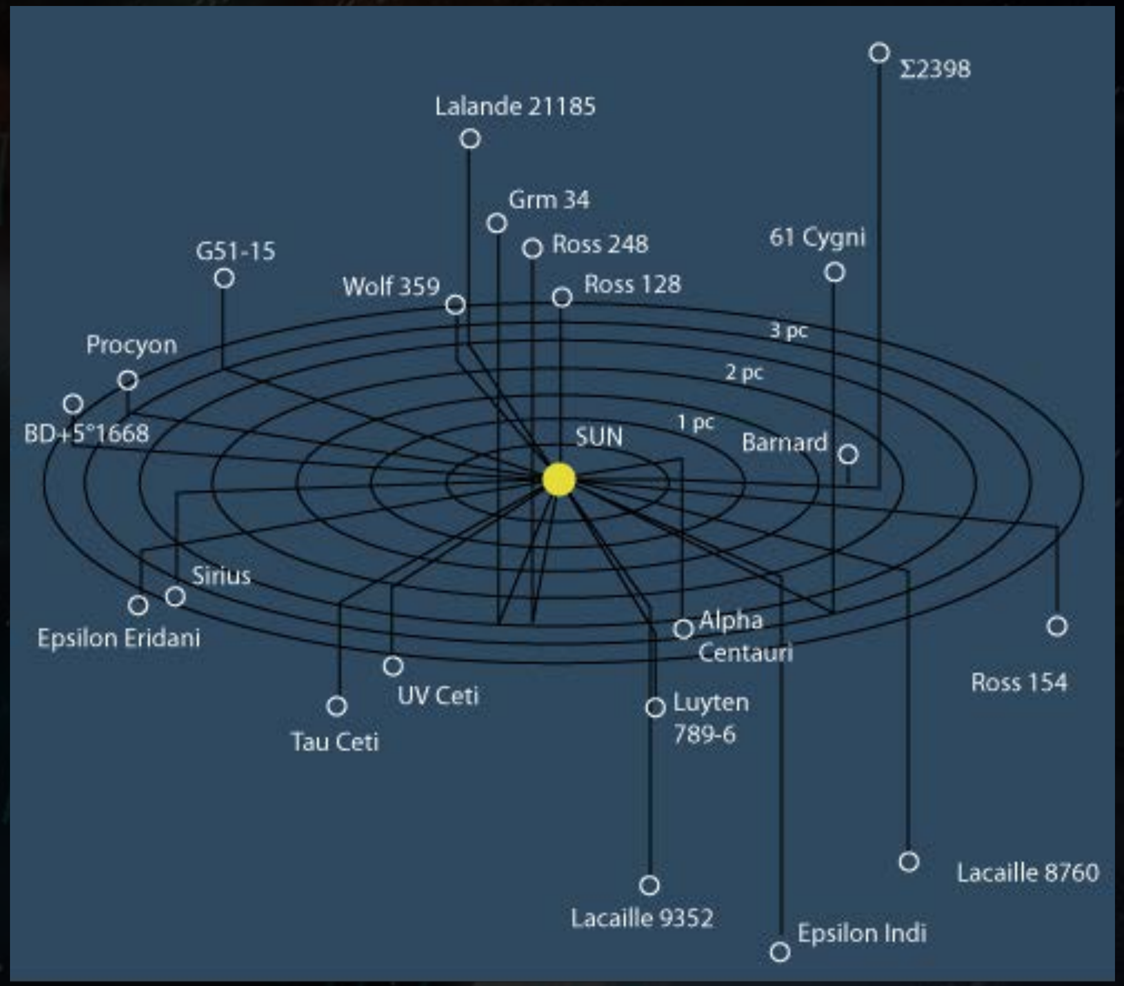
Primary Targets

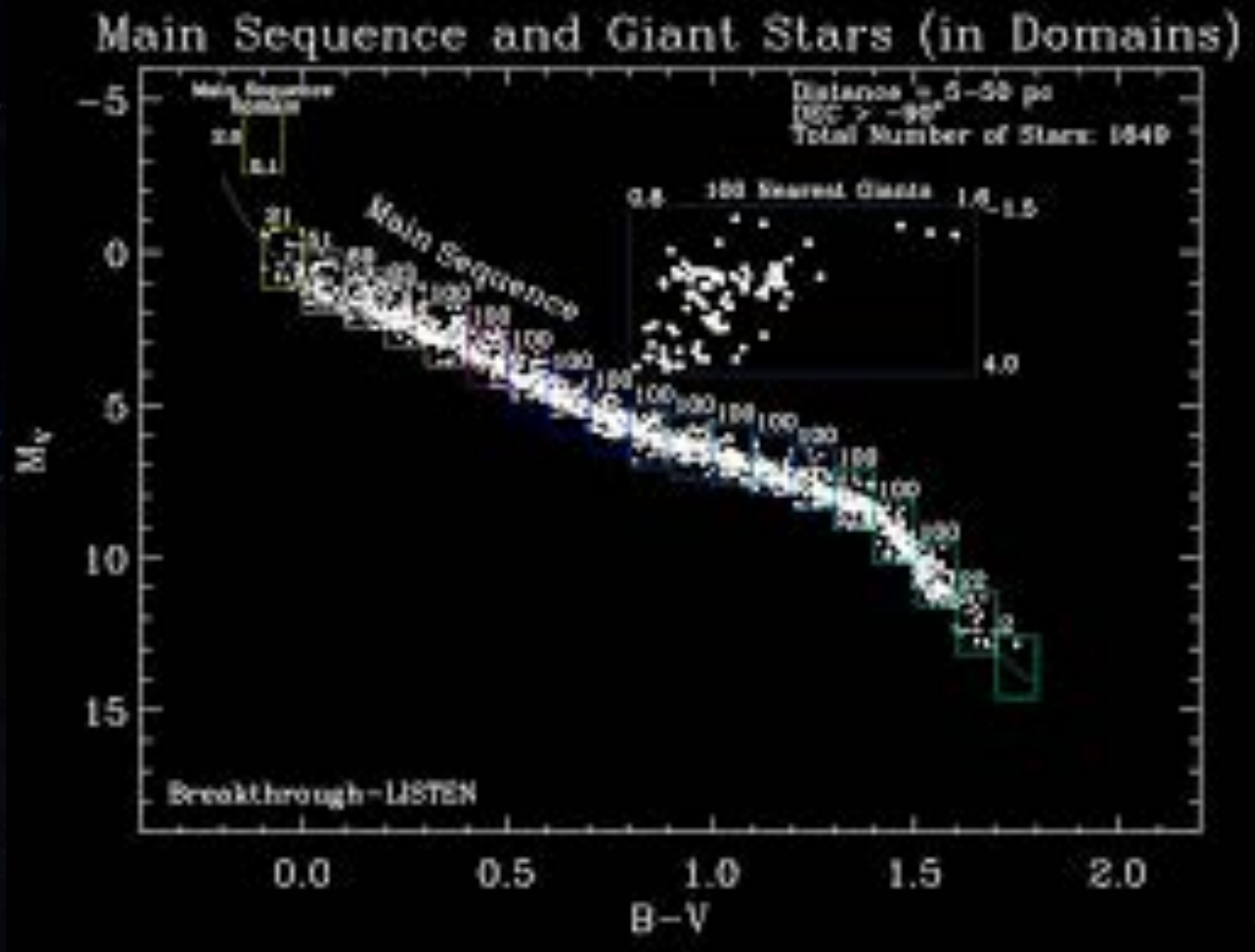
1. First set of targets contained a list of 1709 stars for a detailed search (Isaacson et al. 2017).
    - All stars within 5-pc (60 stars)
    - Spectral class limited sample from 5-50 pc (1649 Stars)
    - A selection was made for all different morphology classes

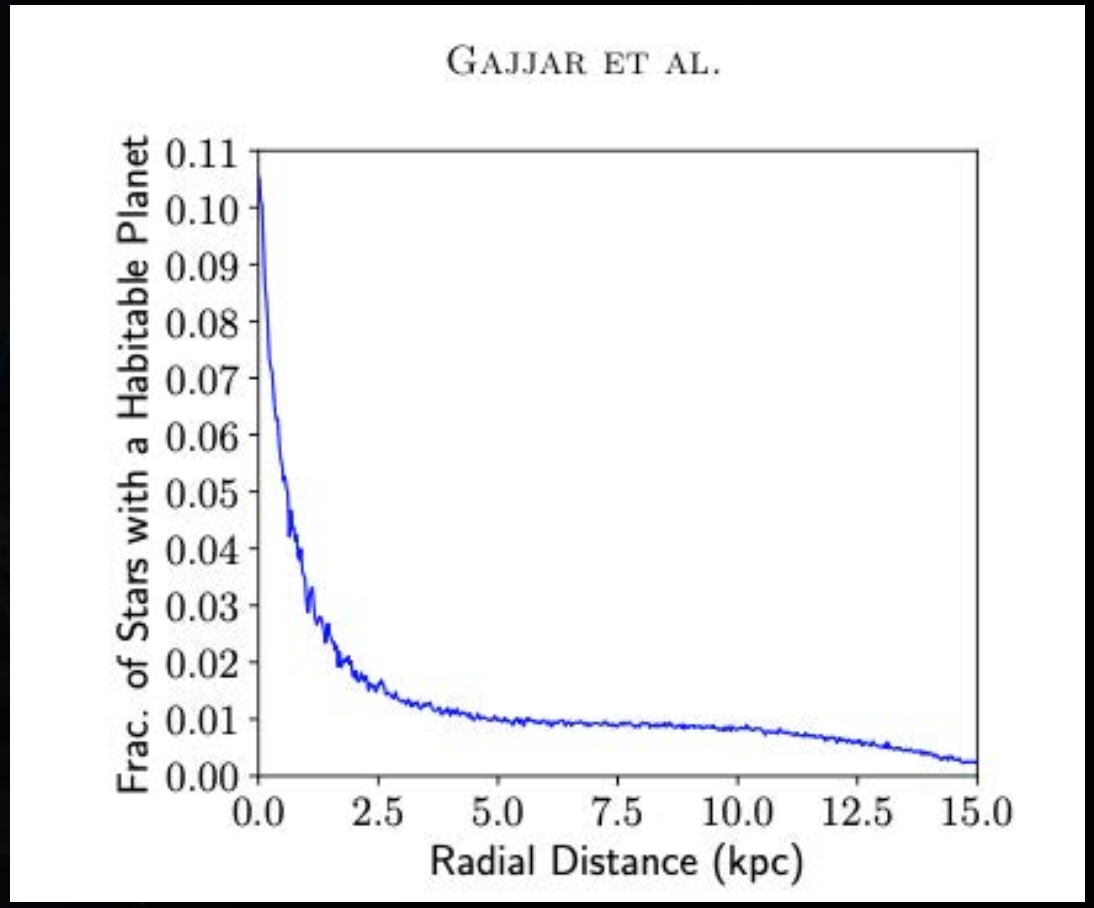
2. Nearest 100 Galaxies of different morphological classes (Choza et al. 2023)
    - 40 spirals; 40 elliptical; 20 irregulars; 20 dwarf spheroidal; 3 S0

3. Galactic Center and Galactic Buldge (Gajjar et al. 2021)

4. 816 Exotic Astrophysical Objects (Lacki et al. 2021)







BL Observational Facilities for Deep Targeted and Large Scale Survey

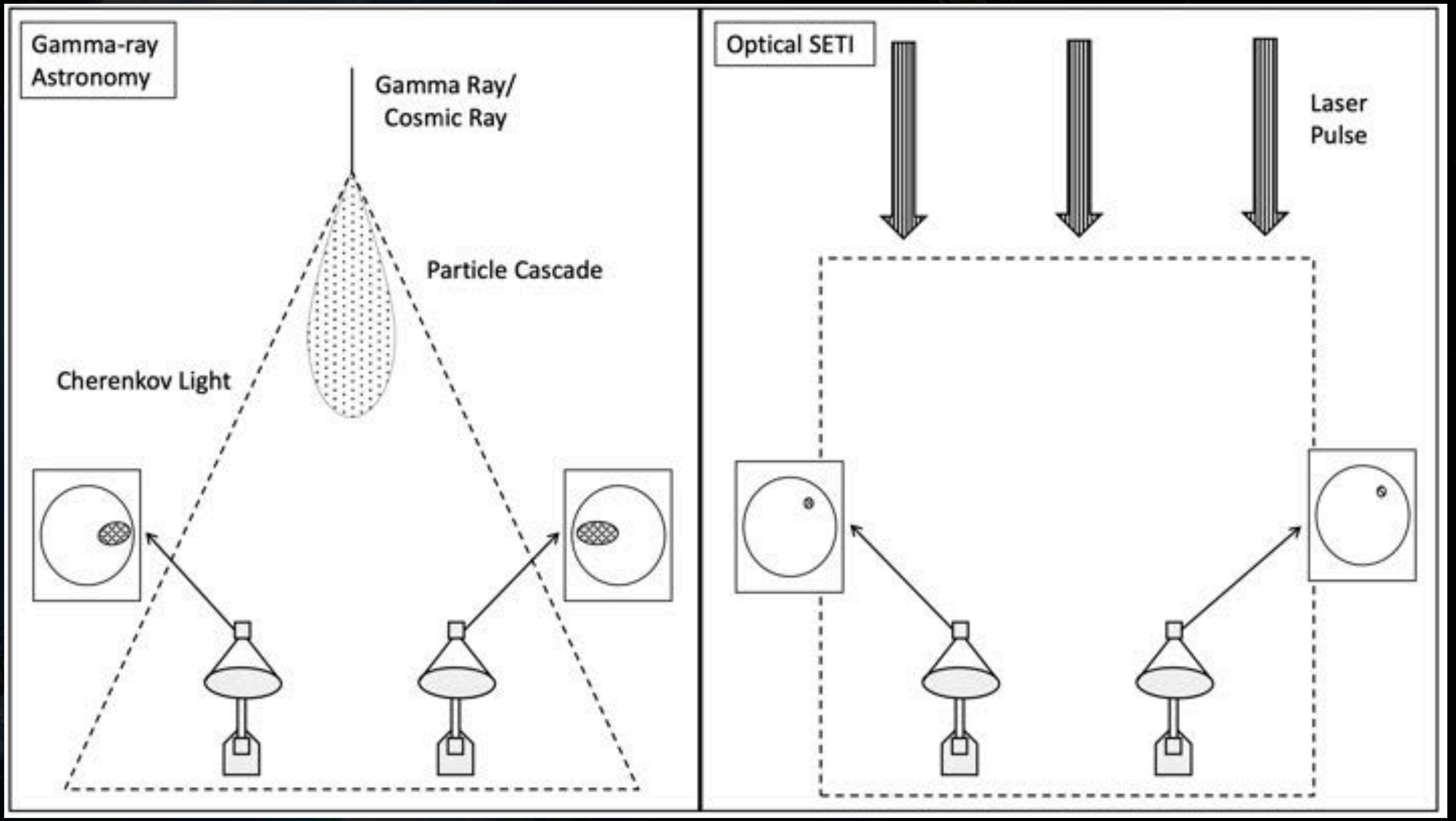
NenuFAR

Range of Frequencies/Wavebands

- MWA and NenuFAR : 30 to 90 MHz
- LOFAR : 50 to 250 MHz Owen Johnson and Evan Keane's talks
- GMRT: 150 to 1600 MHz
- Parkes : 700 to 4000 MHz
- FAST : 1100 to 1400 MHz
- MeerKAT : 1 to 2 GHz Daniel Czech's talk
- SRT: 0.3 to 25 GHz
- VLA: 0.2 to 50 GHz
- GBT : 1 to 100 GHz
- TESS : 600-1000 nm
- APF: 300-900 nm
- VERITAS : 300-600 nm

VERITAS Followup on Breakthrough Listen Targets

- A 3 ns pulse from a 10-meter mirror with 3.7 MJ collimated beam can be 10,000 more brighter than host star (Horowitz et al. 2001; Howard et al. 2004).
- VERITAS is working in collaboration with the Breakthrough Listen since 2018.
- Acharyya et al. (2023) conducted 32-hours of archival observations towards 140 targets.
- Extending the search towards all stars in the field of view, will allow searching close 1 million stars (1 kpc) producing pulses with > 3 ph/m2 repeating every 1000 seconds



Acharyya, A. et al. 2023

Large Scale Exo-engineering

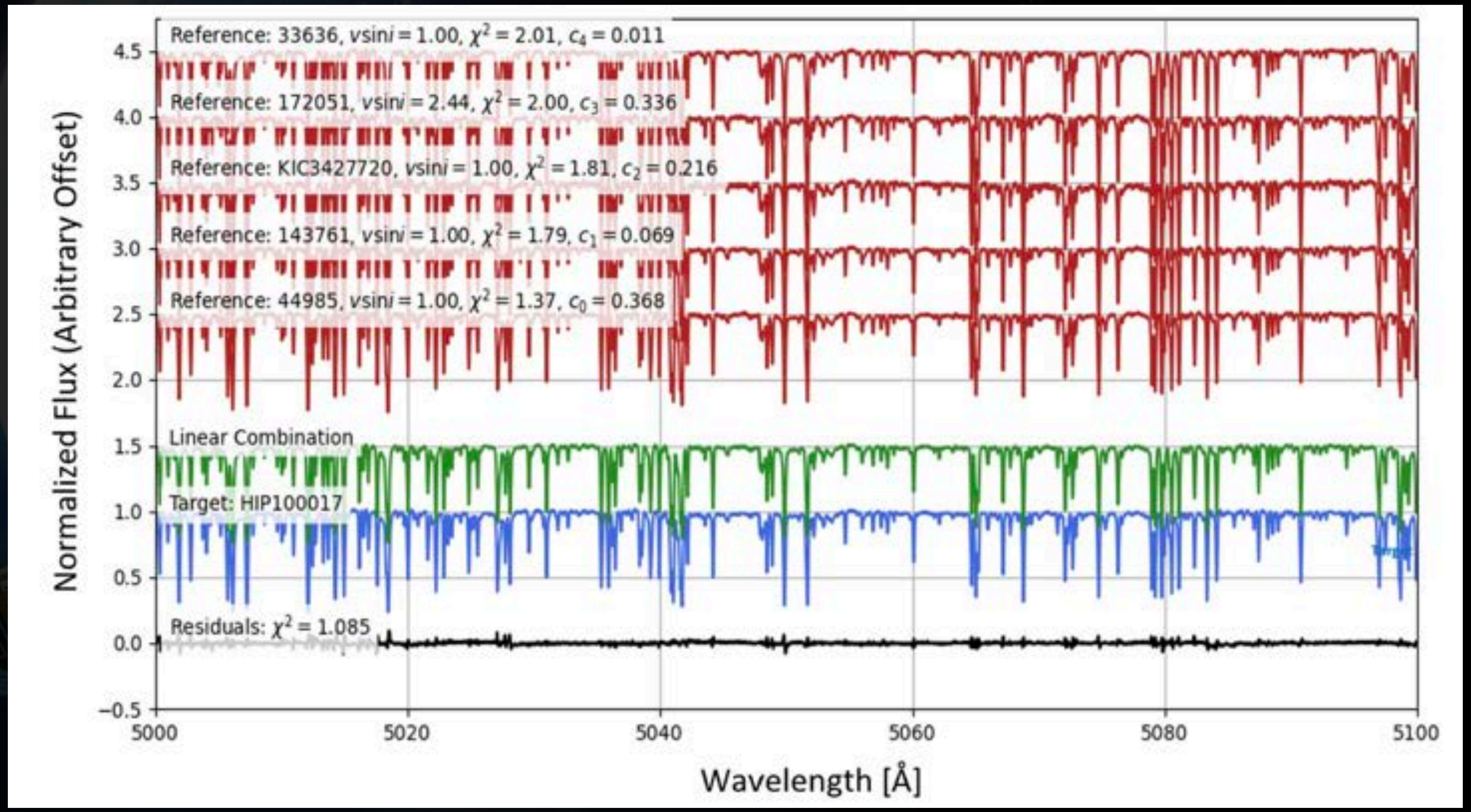
- In collaboration with the Breakthrough Listen team and under the NASA XRP grant (Principal Investigator: A. M. Cody), we are searching for anomalies in light curves from the TESS mission, utilizing the method outlined by Giles et al. 2019.
- ~1 million stars' light curves have been analyzed.
- ~1500 candidate events and on-going process to remove false positive through eclipsing binary filter and YSOs with disks with infrared followup.
- To date, we have observed a handful of fading events that remain unexplained astrophysically, although it is anticipated that they will eventually be explained.

Automated Planet Finder at Lick Observatory

- Narrowband optical lasers from ETIs (Schwartz & Townes 1961) can be detected using the Automated Planet Finder (APF) at the Lick Observatory.

- Primary BL observing facility with 20 hours/semester dedicated telescope time for SETI (Isaacson et al. 2017).

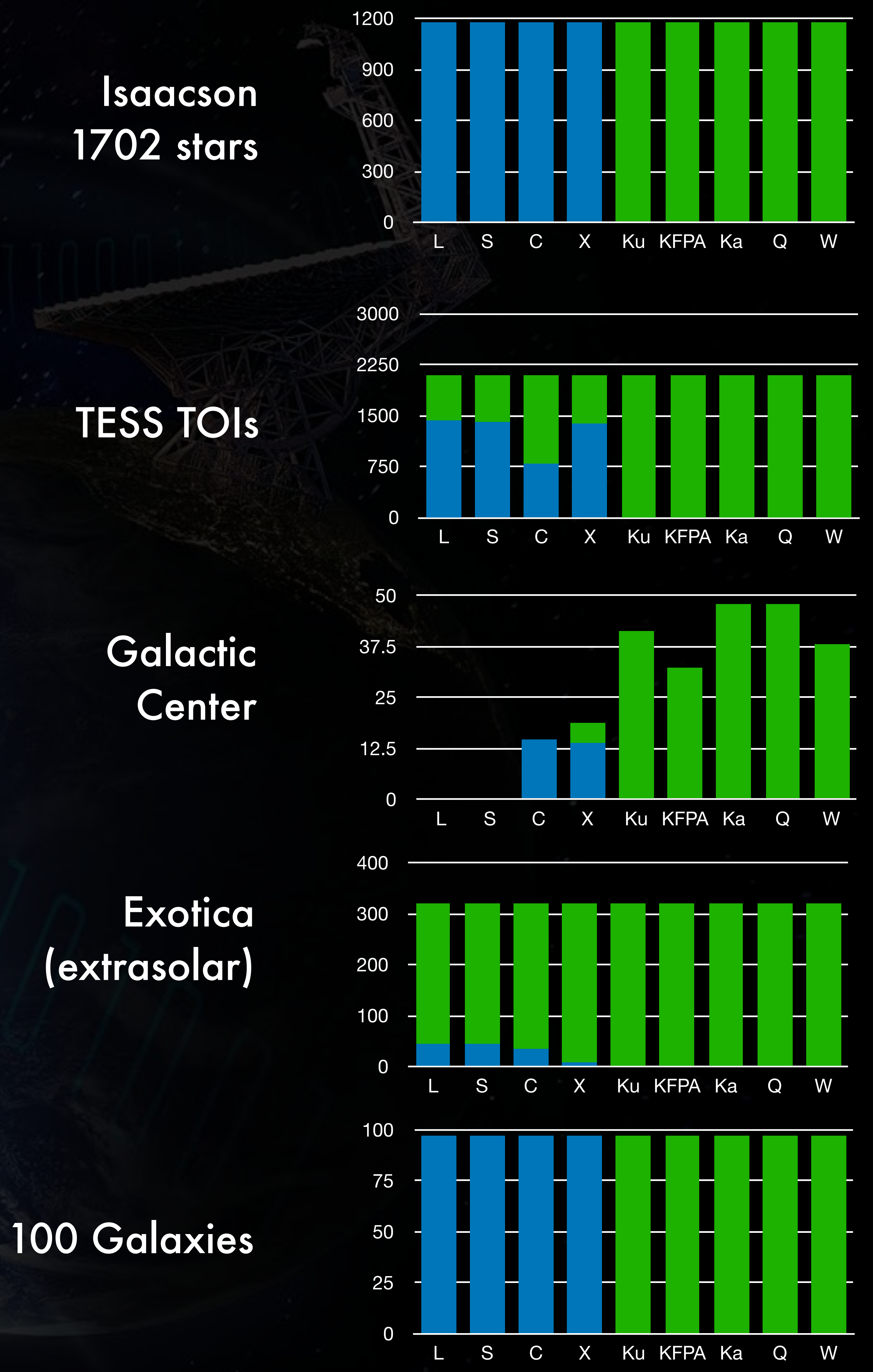
- Close to 400 stars observed so far with three on-target scans with medium length of around 12 minutes across 4997Å to 5900Å with close to 0.02Å spectral resolution. Rejected presence of ETI transmitter with 84 kW power unto 80 light-years (Zuckerman et al. 2023).



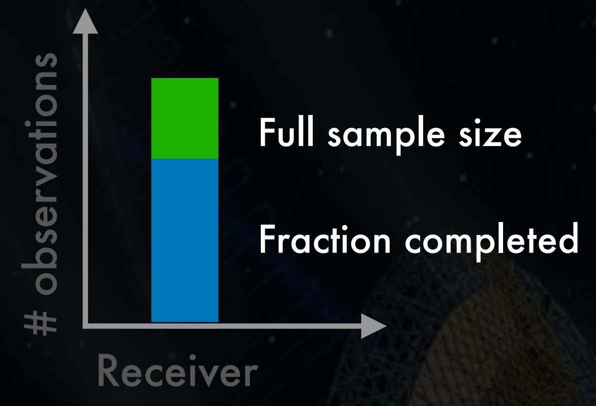
- Zuckerman et al. 2023

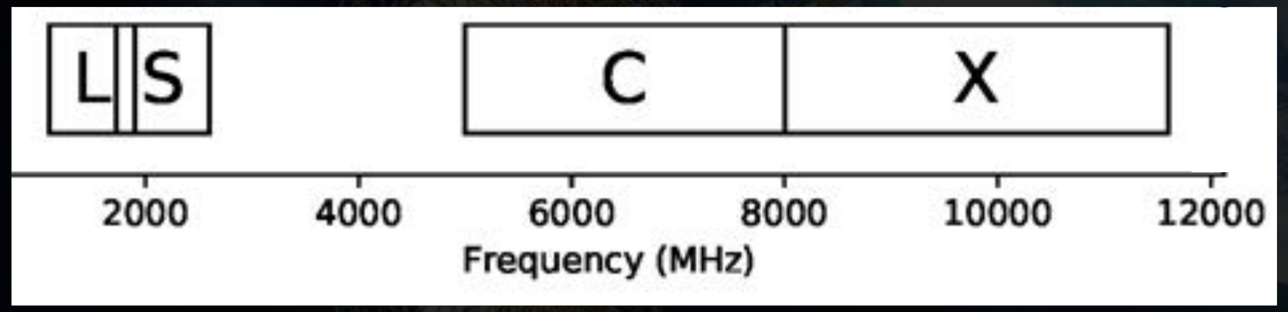
GREEN BANK TELESCOPE

Credit: Steve Croft



- Diameter: 100-meter
- Frequency coverage: 0.3 to 100 GHz
- BL backend: 64 node GPU cluster
- Instantaneous Bandwidth: 12 GHz
- Time: 20% of dedicated telescope time

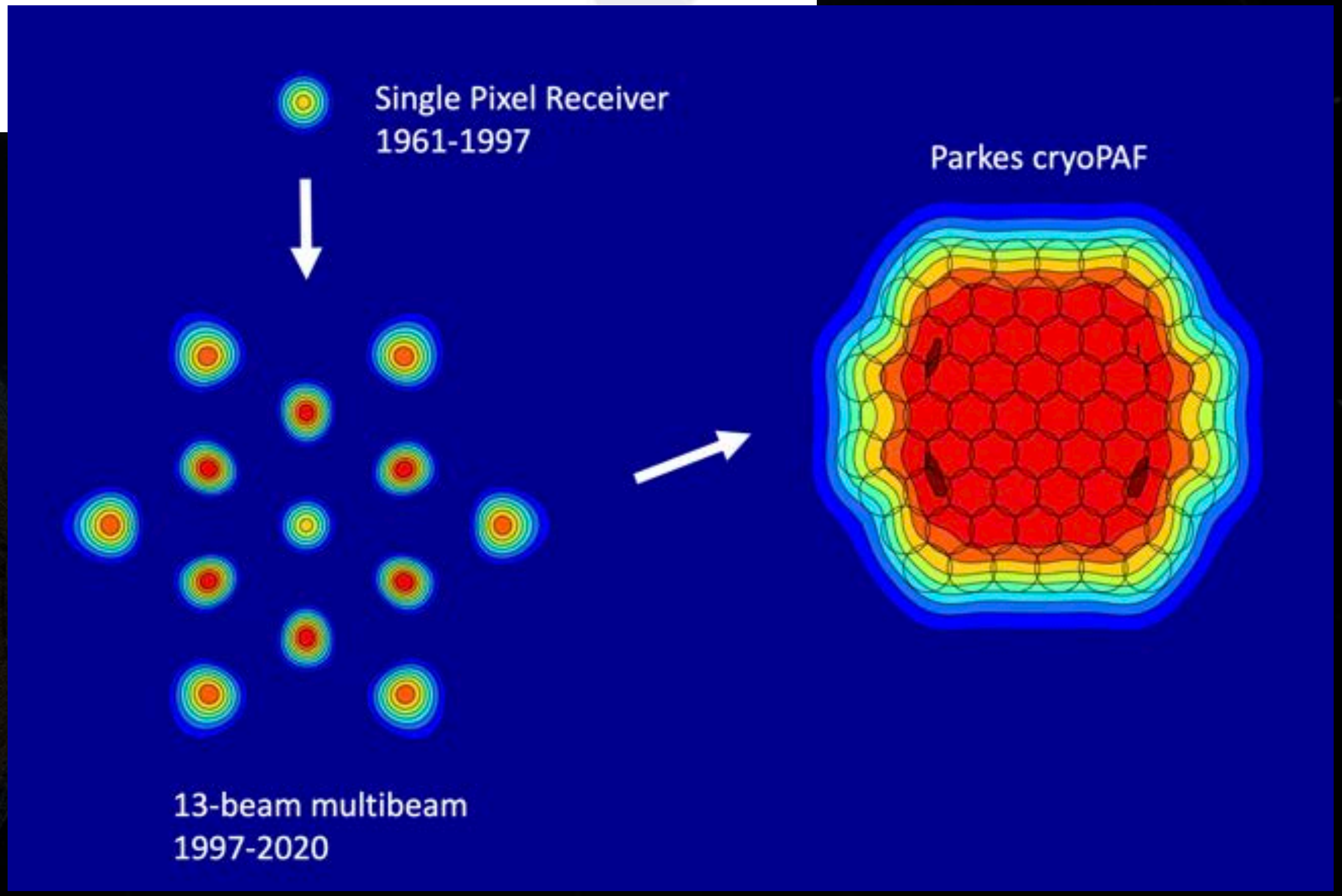




PARKES 'MURRIYANG' TELESCOPE

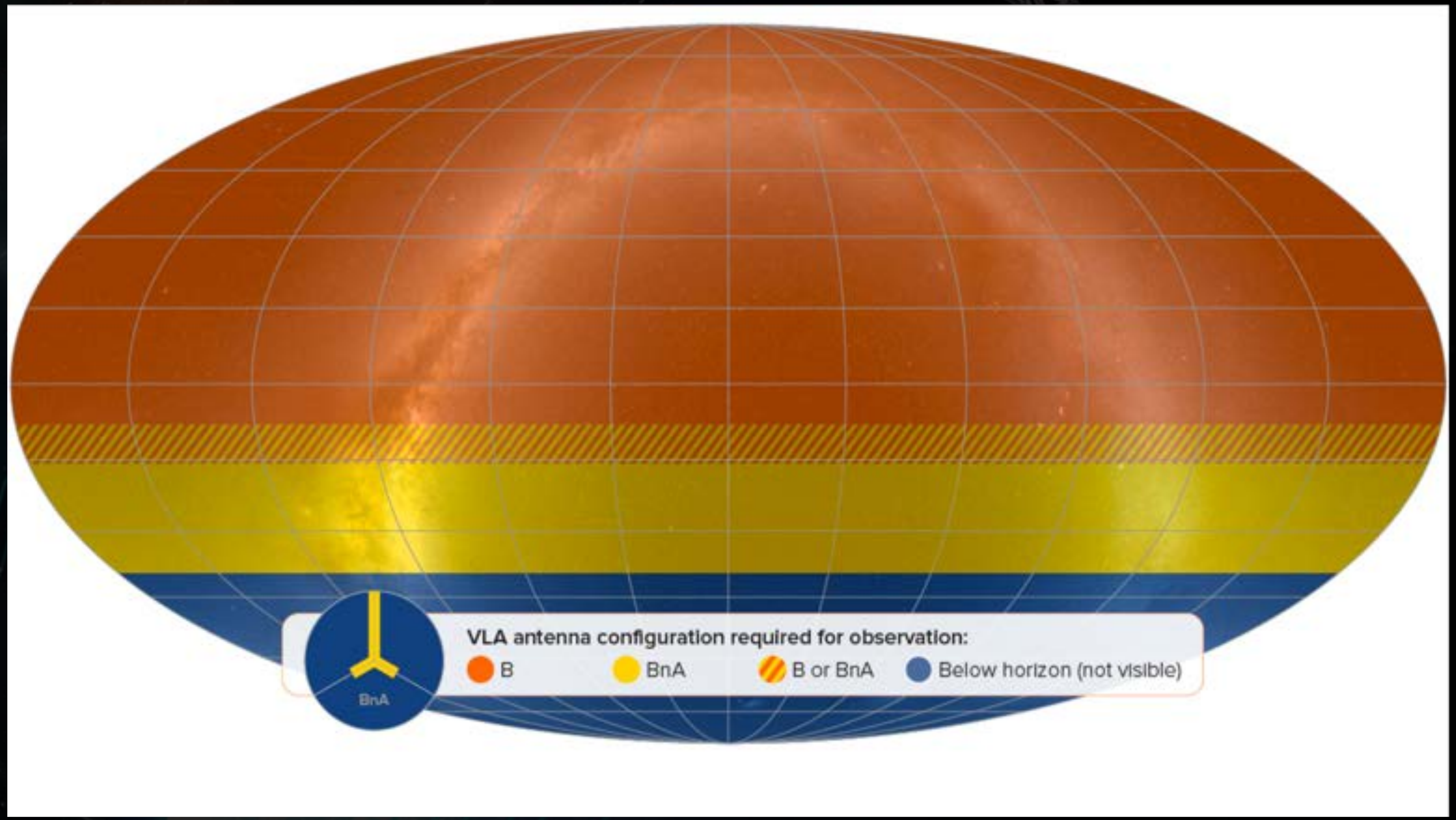
Credit: Danny Price

- Current time allocation is 400 hr/year (previously 1500 hr/year).
- Targeted observations with UWL feed (0.7-4.0 GHz) mainly complete. Focus shifting to ToO / follow-up of candidates.
- Analysis of multibeam data ongoing.
- 72-pixel, 0.7-2.0 GHz 'CryoPAF' feed coming online Q1 2024. Will deliver narrowband SETI data product to BL.
- CryoPAF will be used to survey GC / GP and nearby galaxies.



VERRY LARGE ARRAY: COSMIC

Credit: Chenoa Tremblay

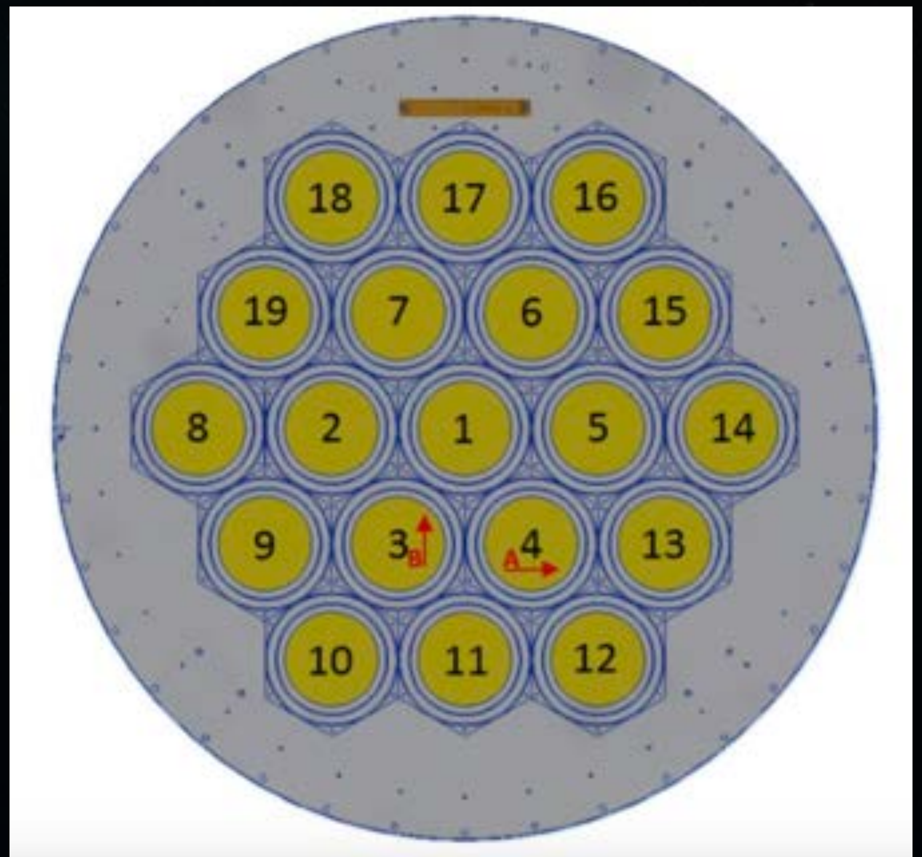


Large scale fast raster scans covering large sky

- 27 ELEMENT INTERFEROMETER
- OBSERVES 0.23-50 GHz
- 24 GPU servers and 2 storage nodes
- Fully commensal 24x7 operations for SETI

Tremblay et al. 2023

Five hundred meter Aperture Spherical Telescope, China



- Worlds largest single dish radio telescope
  - 500 meter in diameter
  - 70 MHz to 3 GHz, Tsys = 20 K
  - Resolution = 2.9 arcsec
  - 19-beam system
- Close to 20 hr/semester have been awarded by the TAC
- Modified existing spectral-line backend capabilities to carryout narrowband SETI searches (Luan et al. 2023, Tao et al. 2022, Zhang et al. 2020)
- Ability to provide some of the most stringent limit on the ETI transmission at lowest transmitter range ever achieved.

SEARCHING TOOLS

1. turboSETI: Narrowband drifting signal search algorithm (Enriquez et al. 2017; Price et al. 2019)

2. HyperSETI: Improved and more sensitive searches (Price et al. in prep)

3. SPANDAK: Broadband artificially disperse signal search (Gajjar et al. 2022)

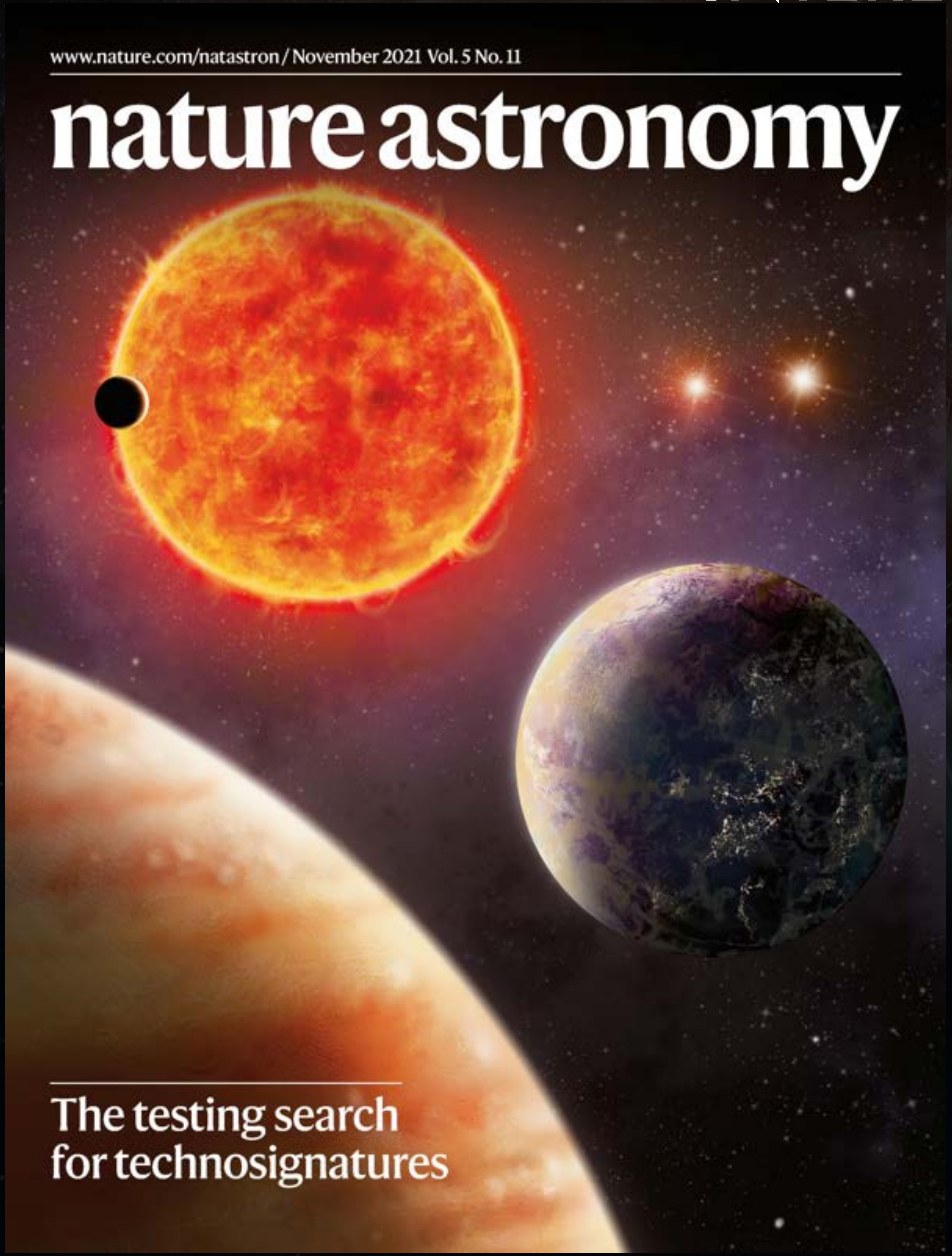
4. BLIPSS: Wide-band periodic pulse searches (Suresh et al. 2023)

5. SETICORE: Real-time Narrowband signal searches (Lacker et al. in prep)

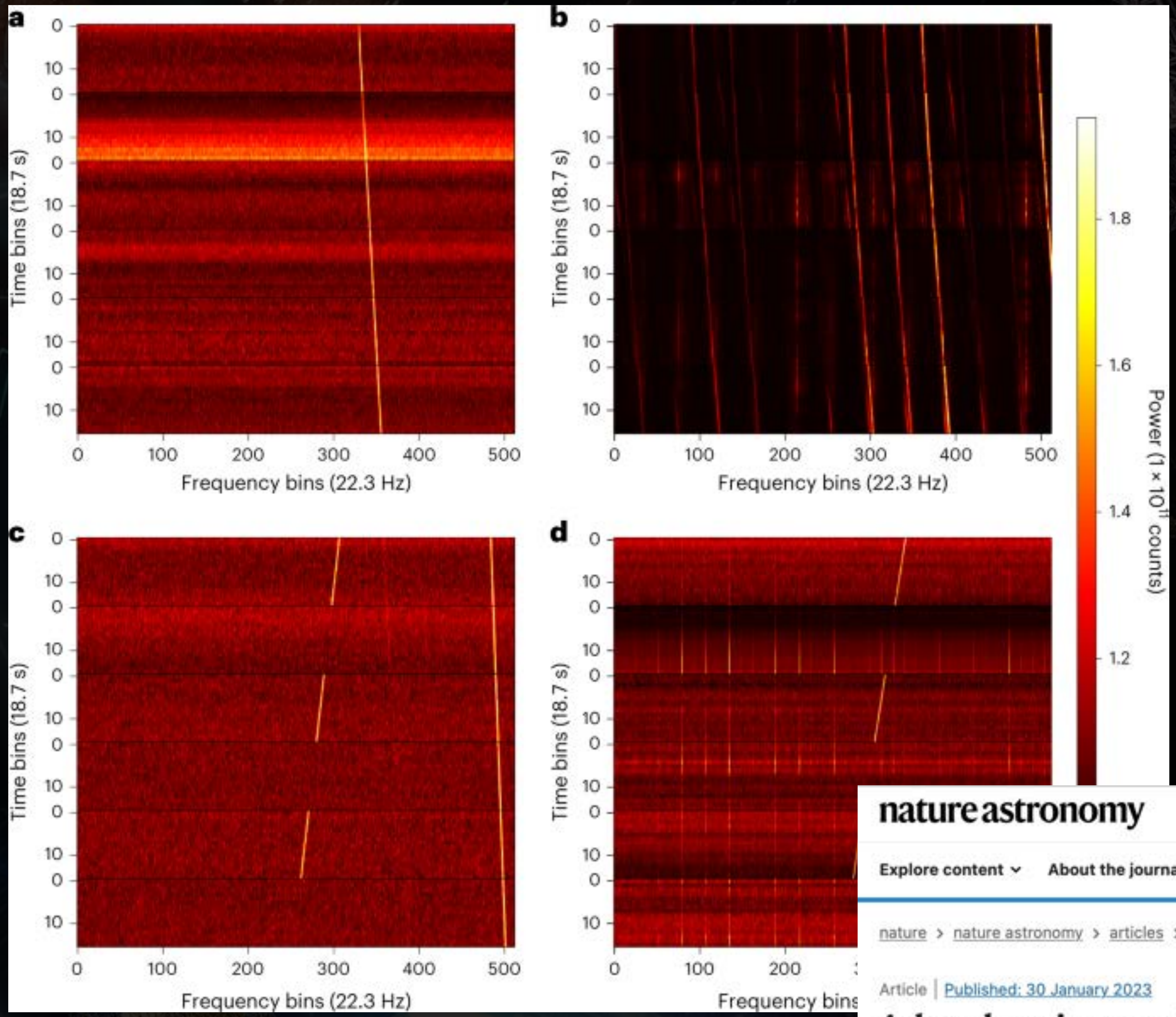
6. BLADE: GPU-accelerated DSP engine (Cruz et al. in prep)

7. ML Searching (Ma et al. 2023a,b)

Interesting Case studies



Sheikh et al. 2021; Smith et al. 2021



Ma et al. 2023

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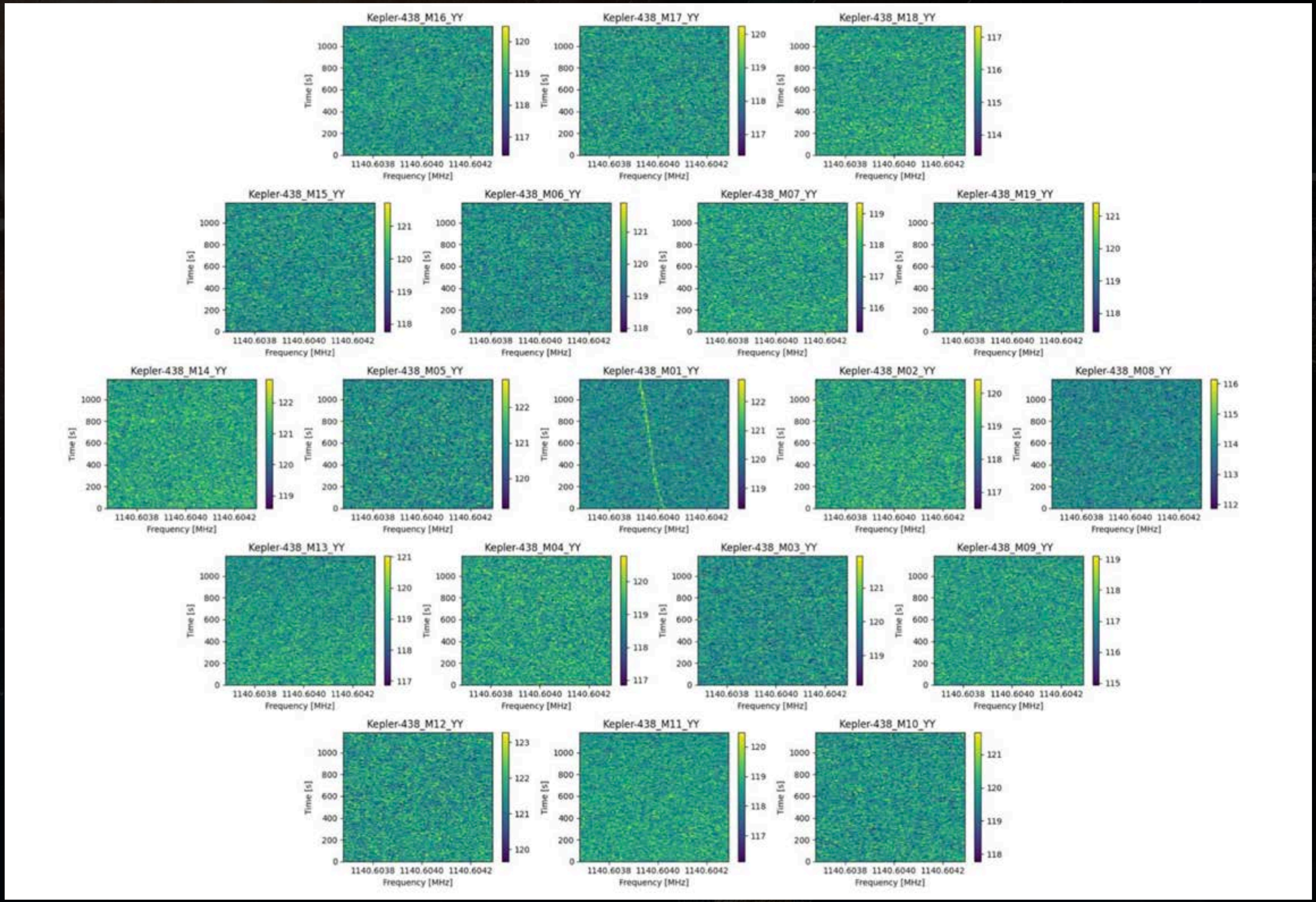
A deep-learning search for technosignatures from 820 nearby stars

Peter Xiangyuan Ma, Cherry Ng, Leandro Rizk, Steve Croft, Andrew P. V. Siemion, Bryan Brzycki, Daniel Czech, Jamie Drew, Vishal Gajjar, John Hoang, Howard Isaacson, Matt Lebofsky, David H. E. MacMahon, Imke de Pater, Danny C. Price, Sofia Z. Sheikh & S. Pete Worden

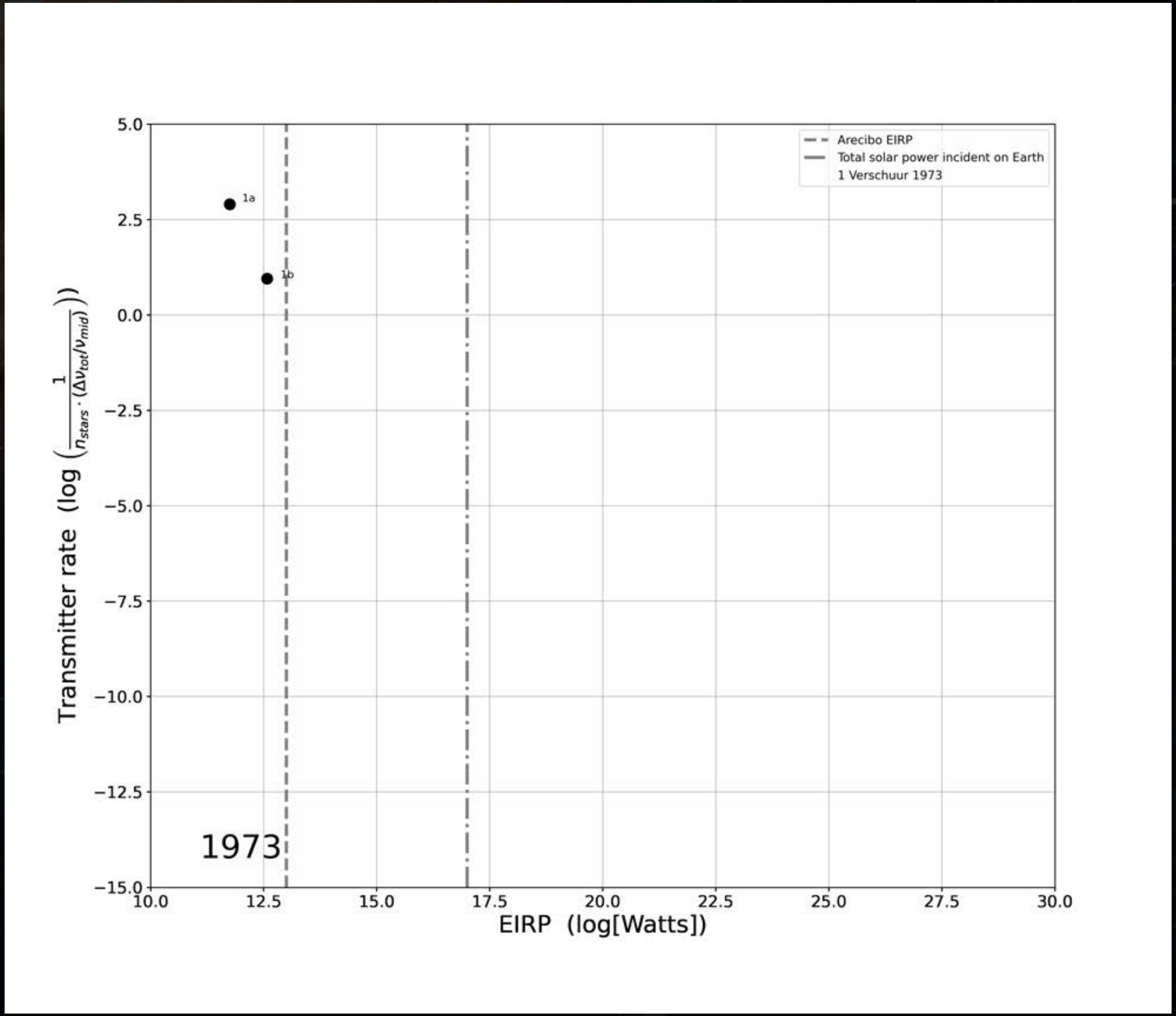
INTERESTING CASE STUDIES



Tao et al. 2022

Transmitter Occurrence Rate

Credit: Sofia Sheikh



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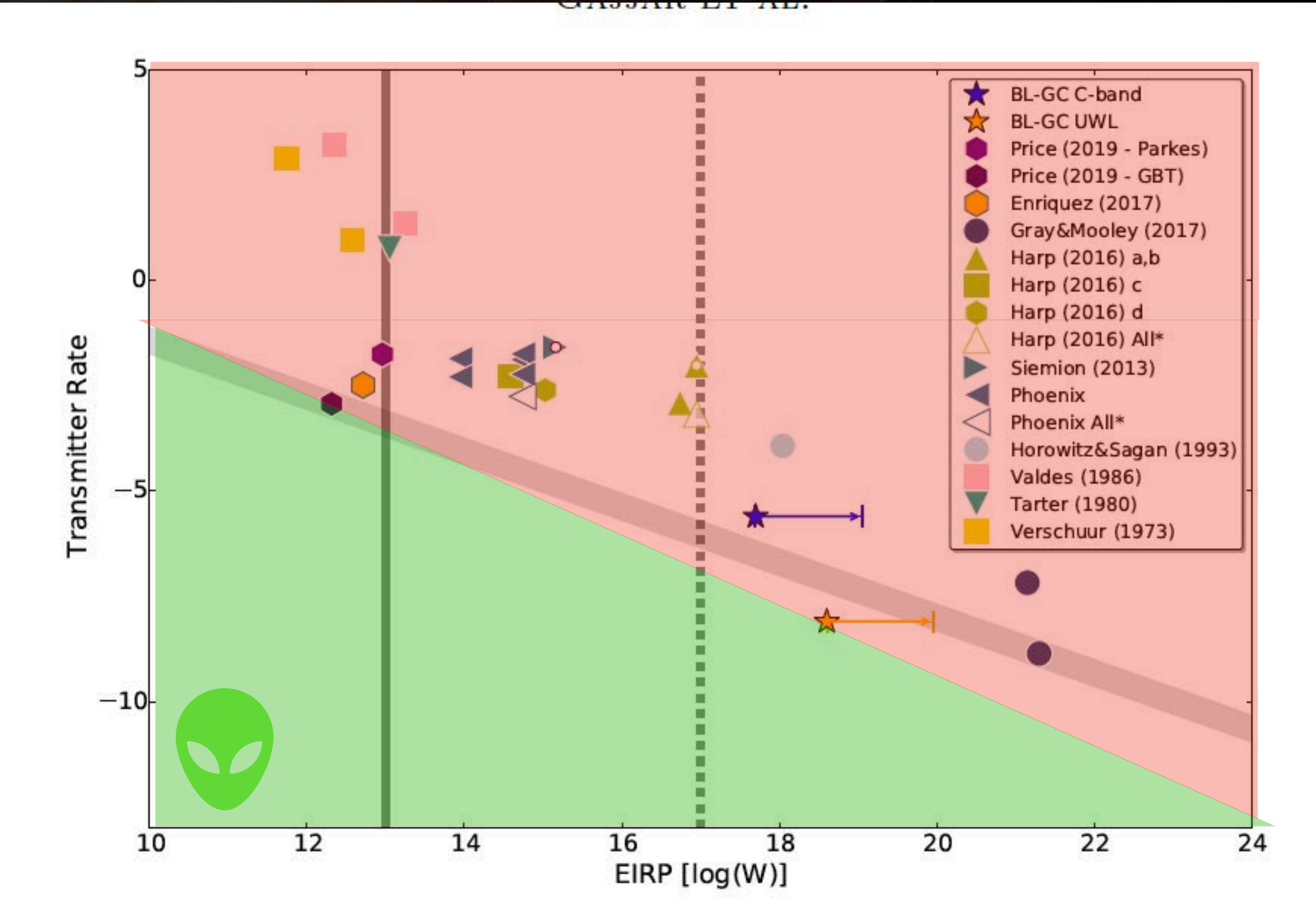

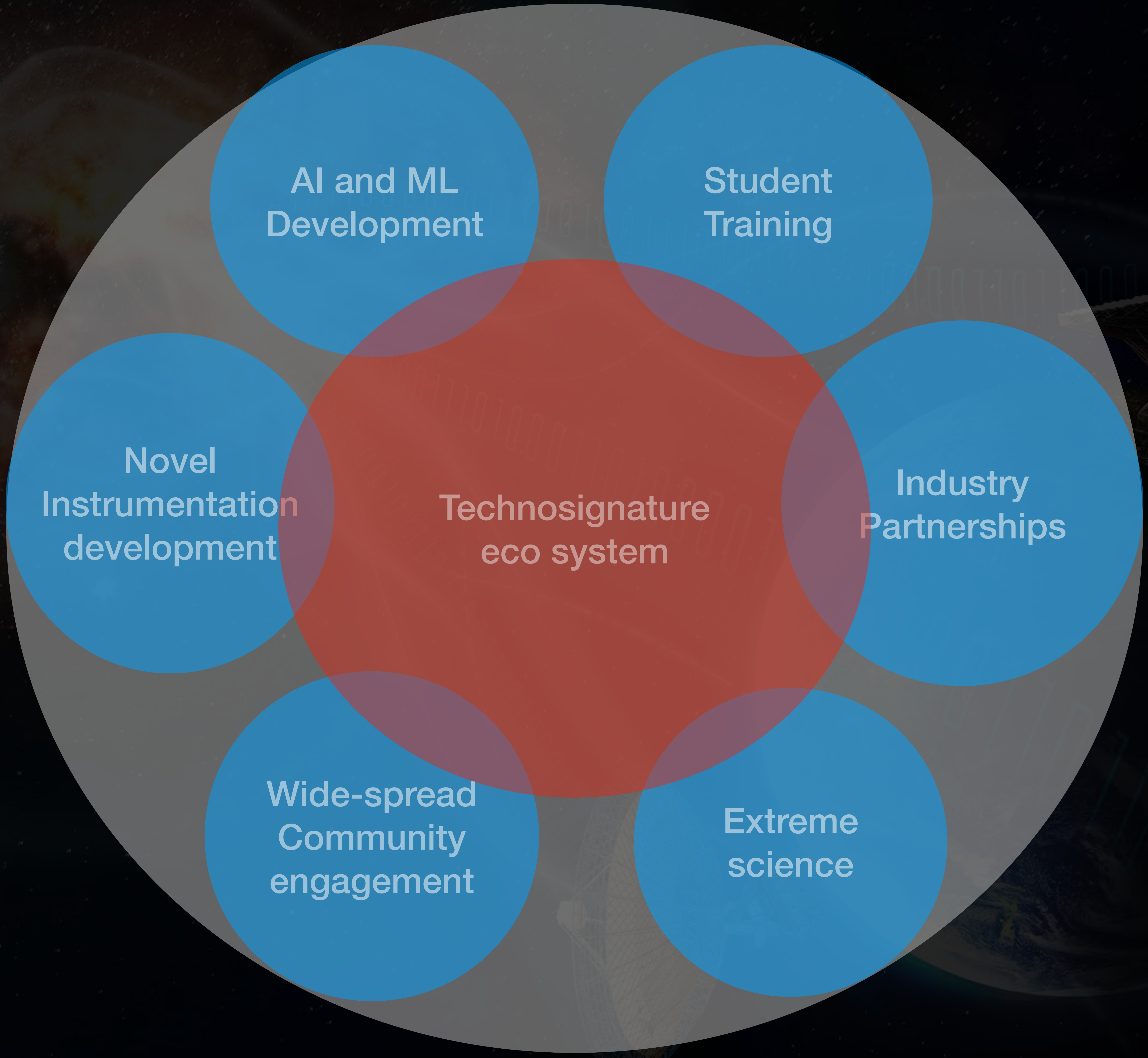
AI and ML Development
Student Training
Novel Instrumentation development
Technosignature eco system
Industry Partnerships
Wide-spread Community engagement
Extreme science