Searching for Technosignatures with Machine Learning: The Breakthrough Listen LOFTS Dual-Station Radio Survey

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University of Galway

BREAKTHROUGH LISTEN

Rhodes University
Where leaders learn

Where are we going today…?

A (very) short intro to SETI

The Breakthrough Listen Initiative

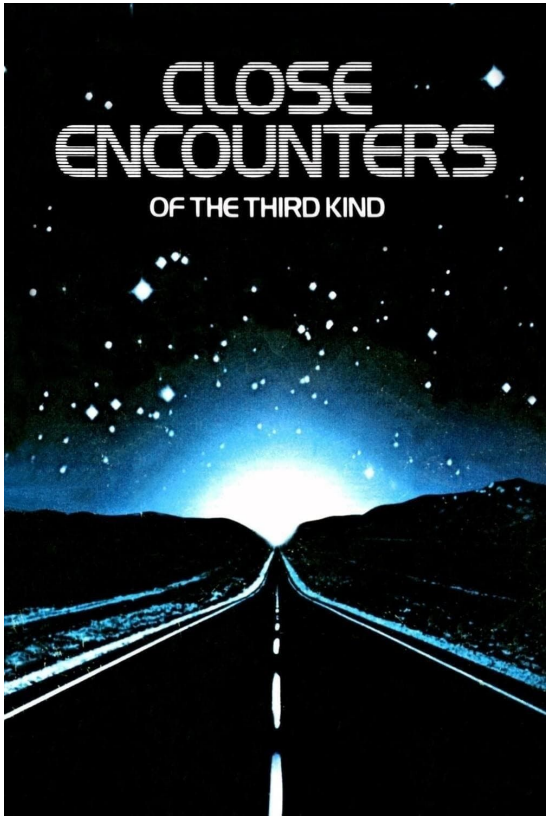
SETI at radio wavelengths

The LOFTS project - what it is, how it works

Using ML to expedite LOFTS processing

The bigger picture…

ETI and the Human Condition… SETI's image problem




Leased Wire
Associated Press

Roswell Daily Record

RECORD PHONES
Business Office 2288
News Department
2287

RAAF Captures Flying Saucer On Ranch in Roswell Region

Claims Army Is Stacking Courts Martial

House Passes Tax Slash by Large Margin

Security Council Paves Way to Talks On Arms Reductions

No Details of Flying Disk Are Revealed

Ex-King Carol Weds Mme. Lupescu

Some of Soviet Satellites May Attend Paris Meeting

Miners and Operators Sign Highest Wage Pact in History

Roswellians Have Differing Opinions On Flying Saucers

American League Wins All-Star Game

Formalising ETI as a scientific problem c. 1960…

Narrowband radio emission takes relatively low energy input to transmit a signal across a large distance through the interstellar medium *(ISM)*.

Motivated the use of radio telescopes to search for technosignatures - subsequent interest in optical searches (lasers offer similar efficiencies)

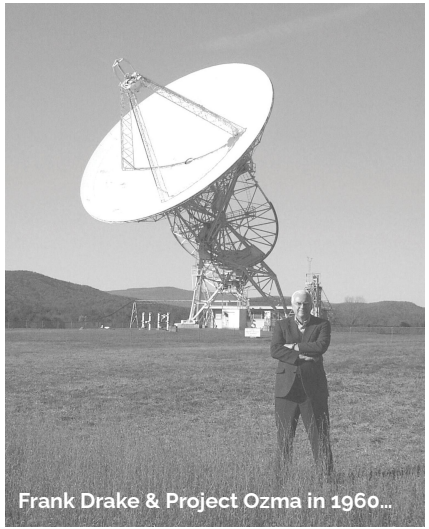
'Waterhole frequencies' H/OH @ 1.42 & 1.66 GHz…

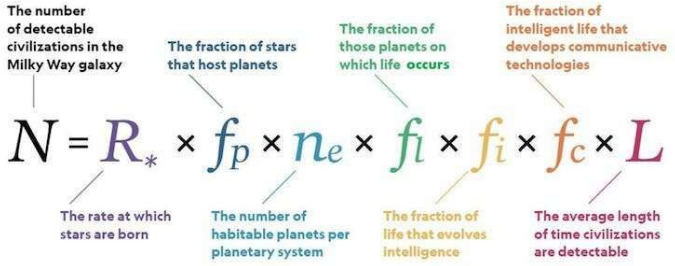
Can be directed (METI) or incidental (e.g. Arecibo style planetary radars) in origin.

Started with Great ambitions (the high water mark of Post WW2 exuberance)…

…. what followed was the *SETI Winter* from the 1990s on

Issues: access on the sky, resources, infrastructure… $$!


Frank Drake & Project Ozma in 1960…



SETI now with Breakthrough Listen

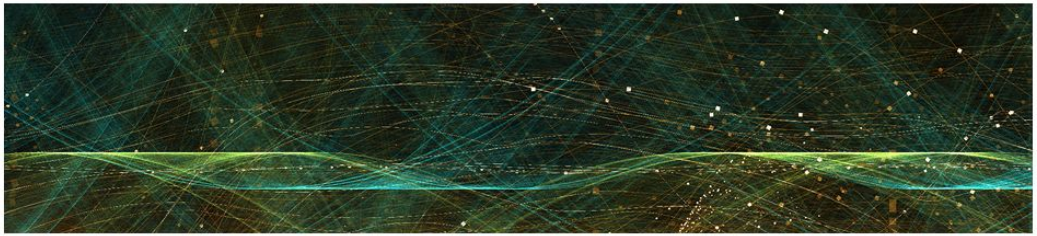
$100M over 10 years to kick-start the field…

BREAKTHROUGH LISTEN

ABOUT BOARD ARE WE ALONE? NEWS EVENTS CONTACTS MANIFESTO
LEADERS TELESCOPES OPEN DATA

Search

LISTEN



Breakthrough Listen is the largest ever scientific research program aimed at finding evidence of civilizations beyond Earth. The scope and power of the search are on an unprecedented scale:

The program includes a survey of the 1,000,000 closest stars to Earth. It scans the center of our galaxy and the entire galactic plane. Beyond the Milky Way, it listens for messages from the 100 closest galaxies to ours.

The instruments used are among the world's most powerful. They are 50 times more sensitive than existing telescopes dedicated to the search for intelligence.

The radio surveys cover 10 times more of the sky than previous programs. They also cover at least 5 times more of the radio spectrum – and do it 100 times faster. They are sensitive enough to hear a common aircraft radar transmitting to us from any of the 1000 nearest stars.

We are also carrying out the deepest and broadest ever search for optical laser transmissions. These spectroscopic searches are 1000 times more effective at finding laser signals than ordinary visible light surveys. They could detect a 100 watt laser (the energy of a normal household bulb) from 25 trillion miles away.

Listen combines these instruments with innovative software and data analysis techniques.

The initiative will span 10 years and commit a total of $100,000,000.

BREAKTHROUGH LISTEN
UNIVERSITY OF OXFORD

NVIDIA

GREEN BANK OBSERVATORY

CSIRO

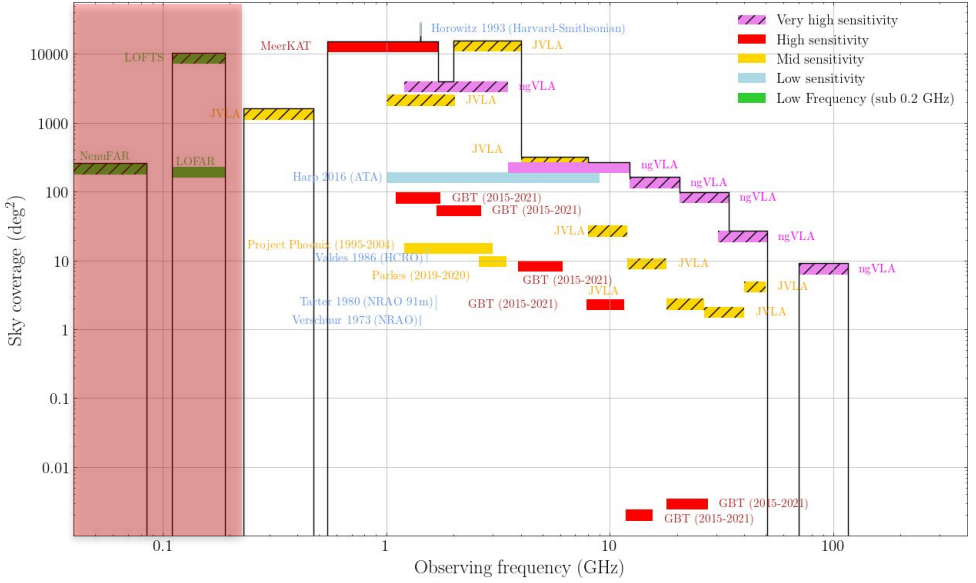
BERKELEY SETI RESEARCH CENTER

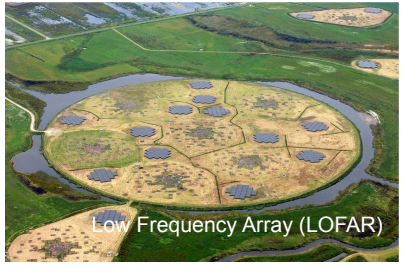
NRF National Research Foundation
SARAO South African Radio Astronomy Observatory

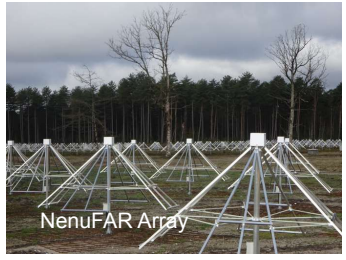
SETI INSTITUTE

The Breakthrough Listen Portfolio in the Radio

10s of Petabytes of data obtained at GHz bands to date - VHF bands (10s - 100s MHz) under-explored in contrast







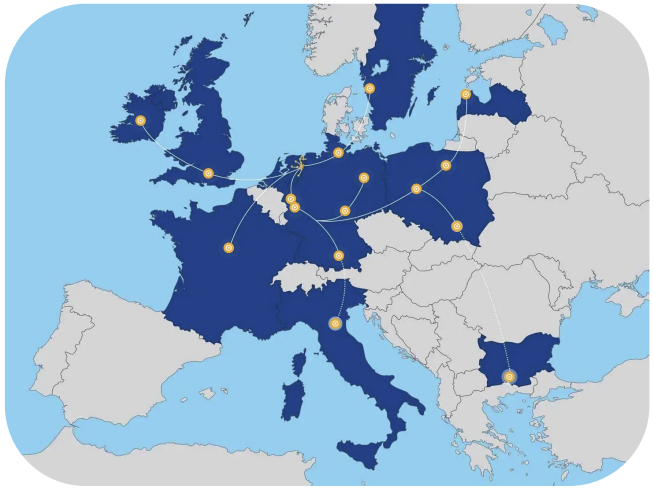
Observing in the VLF bands with the LOw Frequency ARray (LOFAR)

LOFAR - radio telescope array with 52 stations located across Europe.

Two modes - full array or local mode

LOFAR stations can observe using arrays of low-band antennas (LBAs) or arrays of high-band antennas (HBAs)

- LBA operates at 10 – 90 MHz
- HBA operates at 110 – 190 MHz



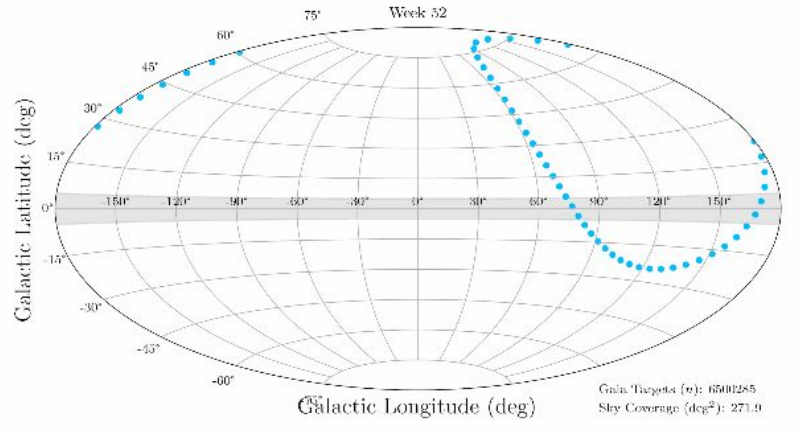
I-LOFAR station in Birr, Co. Offaly

Introducing the LOw Frequency pulsar, FRB, and Technosignature Survey (LOFTS)

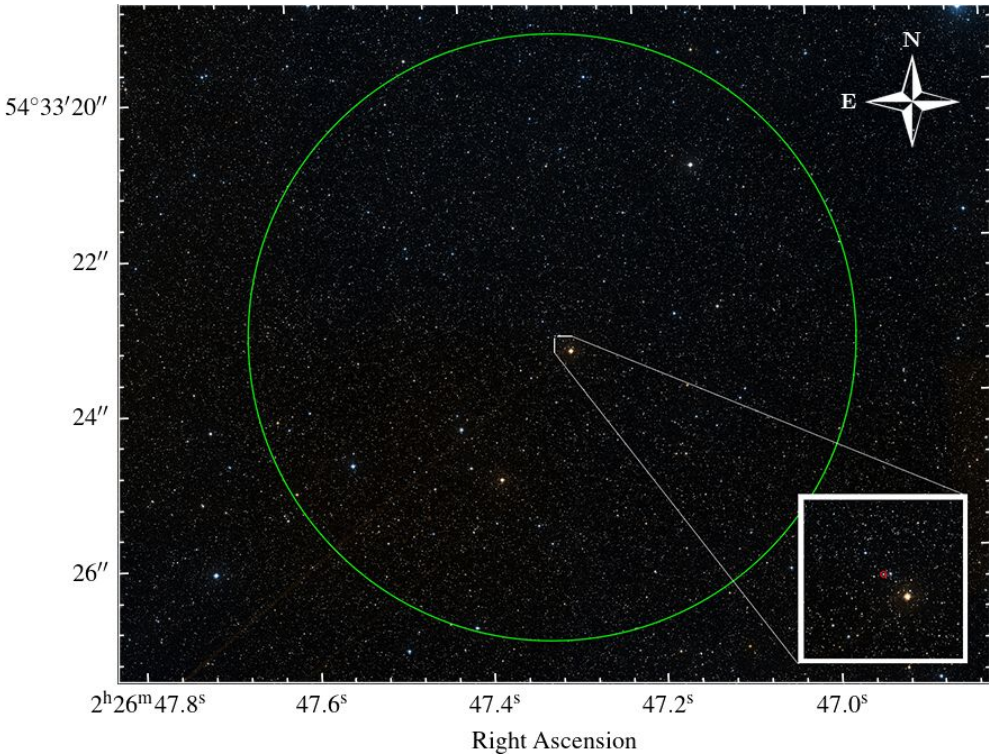
Plan: Multi-site HBA observations at the *zenith* every week for a year, over 1200 combined hours of observations.

Over *6,800,000* objects and 800 TB of raw data…

Search for all types of 'exotic' transients

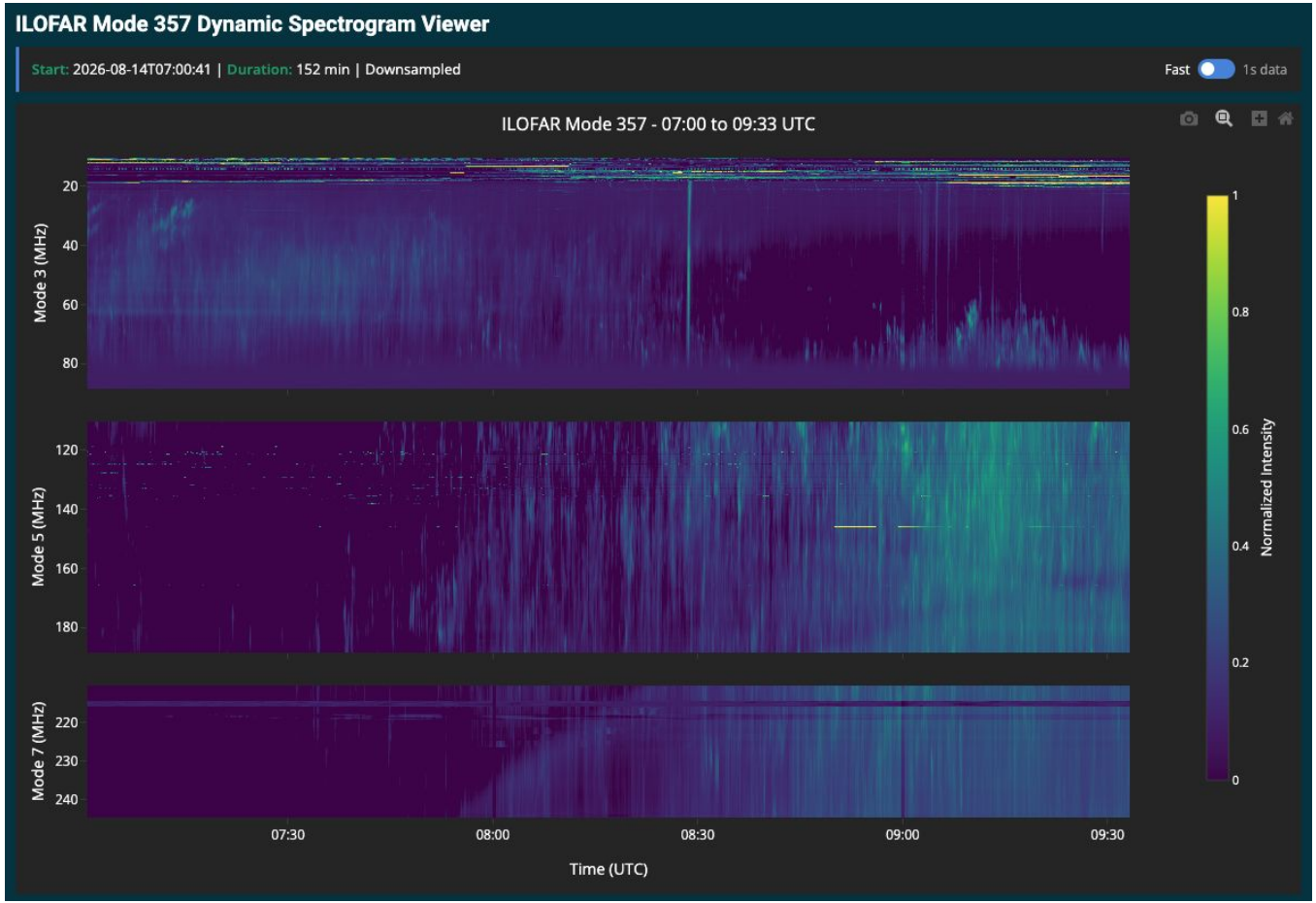


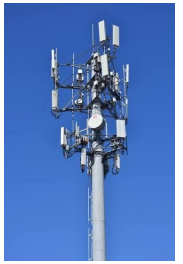
44 TESS targets chosen based on highest sensitivity



36,000 sources in each LOFAR beam - 4.7 million stars

Our biggest problem using LOFAR is Radio Frequency Interference…





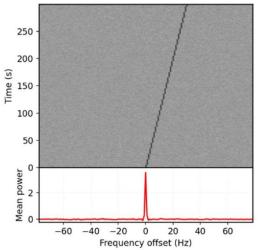
How the LOFTS pipeline works to deal with RFI…

Owen Johnson

Same target field observed by LOFAR stations in Birr (Ireland) & Onsala (Sweden) → ~~Local RFI~~

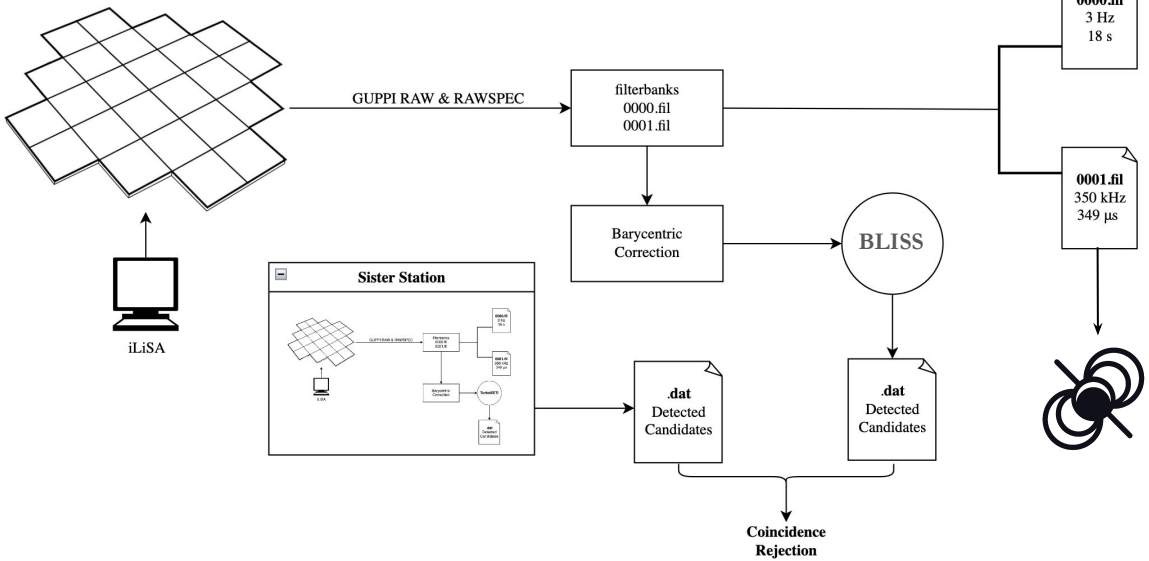
Station data transformed to the solar system barycentre → **~~'Orbital'~~ RFI**

BLISS (Breakthrough Listen Interesting Signal Search) searches for narrowband doppler-drifting signals.



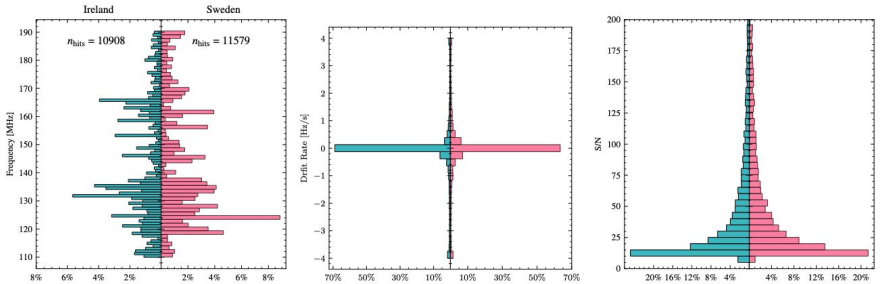
Data Attribute	Value
Frequency Start (f_{start})	109.9609375 MHz
Frequency End (f_{end})	190.0390625 MHz
Frequency Resolution	2.980232239 Hz
Channel Number	27000832
Obs. Length (t_{obs})	15 mins
Temporal Resolution	0.67108864 s
Maximum Drift Rate Search	±4 Hz s^{-1}
S/N_{min} threshold	10

We examine *BLISS* 'hits' for coincidence events at both stations…



What the LOFTS pipeline produces…

A 'hit' - signals are within ±4 Hz of each other & drift rates ±0.2 Hz/s of each other after barycentric drift corrections

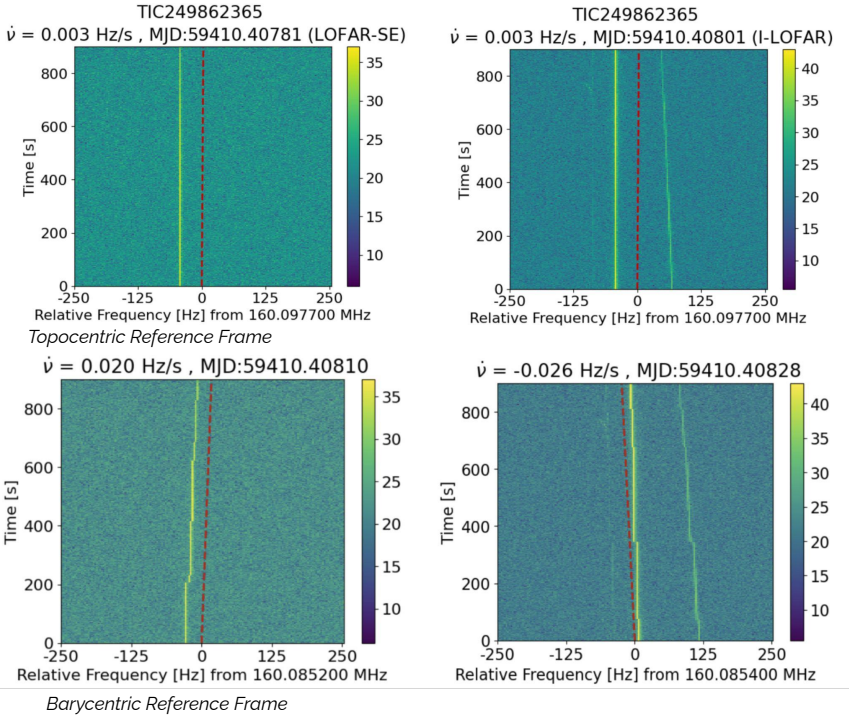


Comparison of drifting signals or 'hits' detected at both stations seen across the HBA frequency band

TIC ID	Topocentric Results			Barycentric Results		
	LOFAR-SE Hits	I-LOFAR Hits	Mutual Hits	LOFAR-SE Hits	I-LOFAR Hits	Mutual Hits
121966220	387	178	18	376	171	0
249862365	340	193	22	330	196	0
250724252	276	190	21	265	262	0
27677846	313	159	20	294	151	0
470315428	384	175	17	356	224	0

Comparison of the number of narrow-band signals detected for a subset of TESS target fields

How barycentering 'tosses out' false positives



1200 hours, 15 minutes per observation with O(10²) mutual hits (topocentric) - need for follow-up assessment…

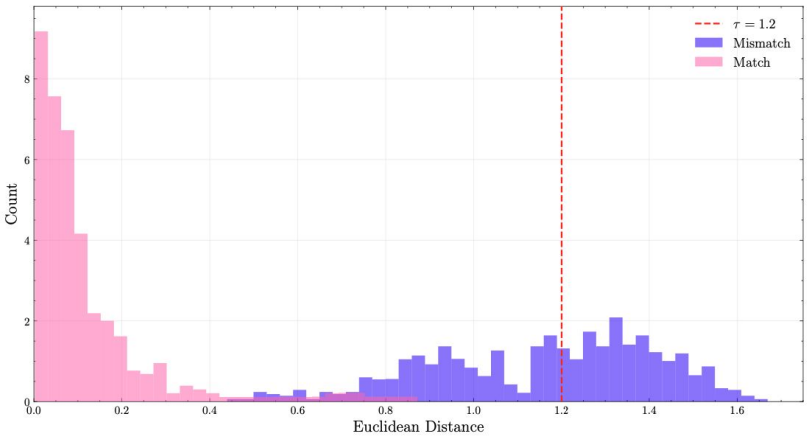
Where the ML ‘thing’ comes in…

Eyeballing *not* a scalable solution - nor *'absolute'* similarity

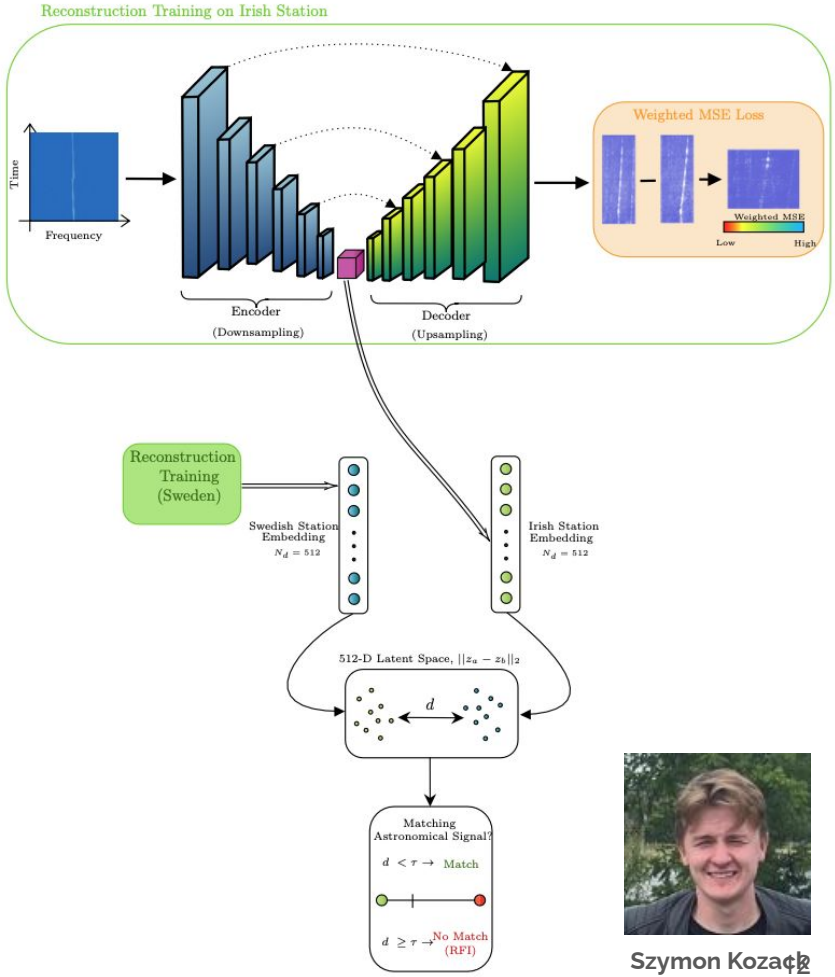
Use ML to to learn a *generalized metric* of signal similarity based around contrastive learning…

Decision was to apply a *Siamese U-Net* architecture

Plenty of RFI candidates - can simulate 'similarity'



Distribution of Euclidean distances between latent-space embeddings for matched simulated ETI signals and mismatched local RFI.



Szymon Kozaczek

Integration of ML component into LOFTS pipeline - status

Now

Testing demonstrates *reliable* & *robust* performance

Can distinguish high confidence 'matched' hits from RFI *down to 3σ*

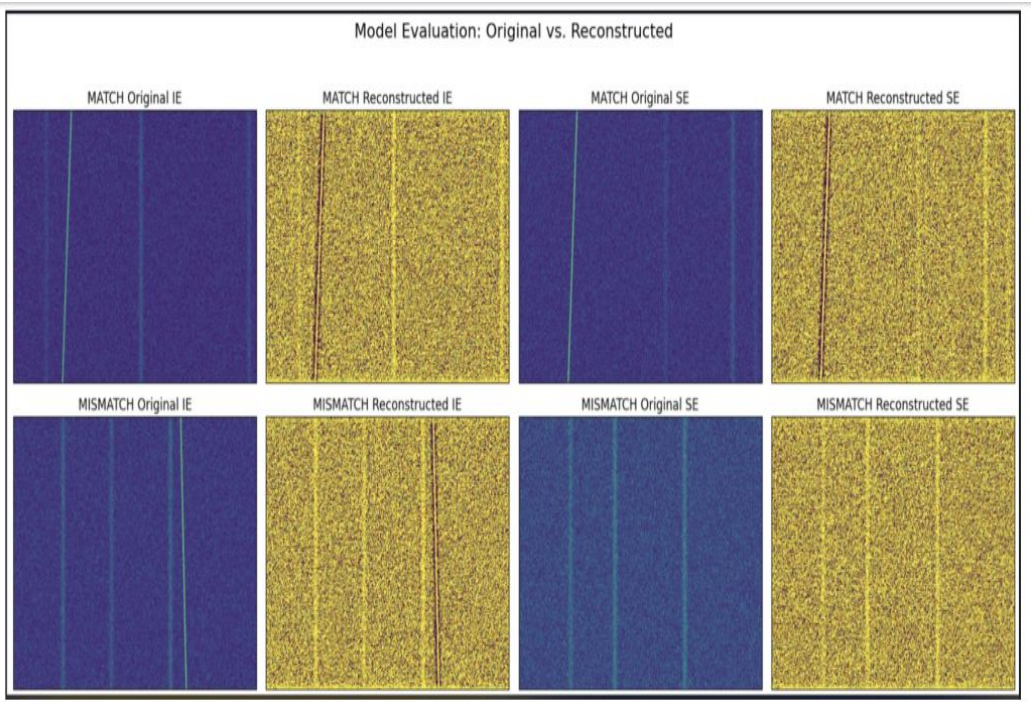
Next Steps

Scale to multi-site (SKAO)

Incorporate *polarisation* (Stokes QUV)

FRBs, DM searches…

Stick it all on Nvidia's compact Jetson edge-AI GPU platform…

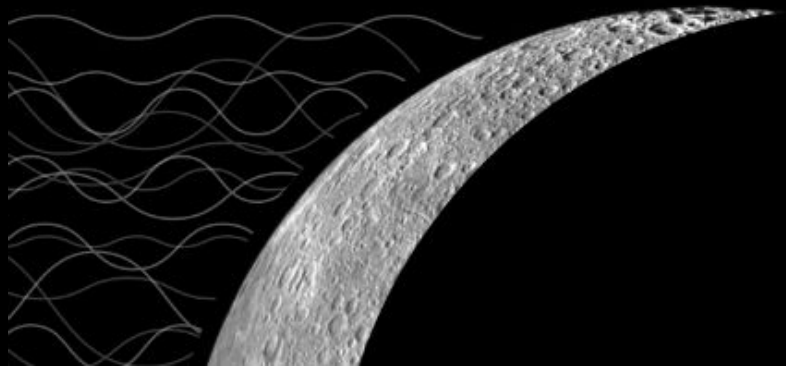


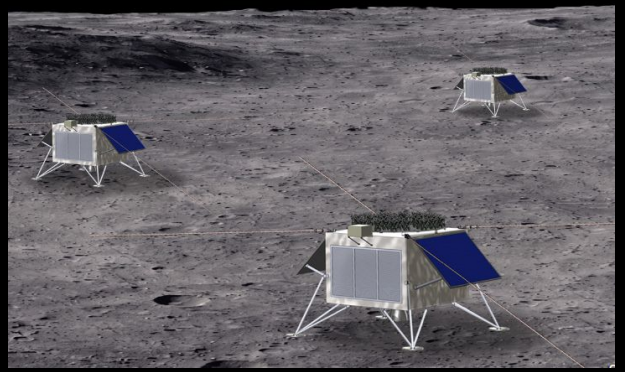
The even bigger picture…

LFT3

Lunar Farside Transients and Technology Telescope

A Legacy Survey Mission





In the meantime, we keep searching…!

Thanks to:

Owen Johnson, Vishal Gajjar, Szymon Kozak, Oto Ulrich, Zainab Rehman, Naoise Lowry & Breakthrough Listen