# SEARCHES FOR EXTRATERRESTRIAL INTELLIGENCE WITH LOFAR

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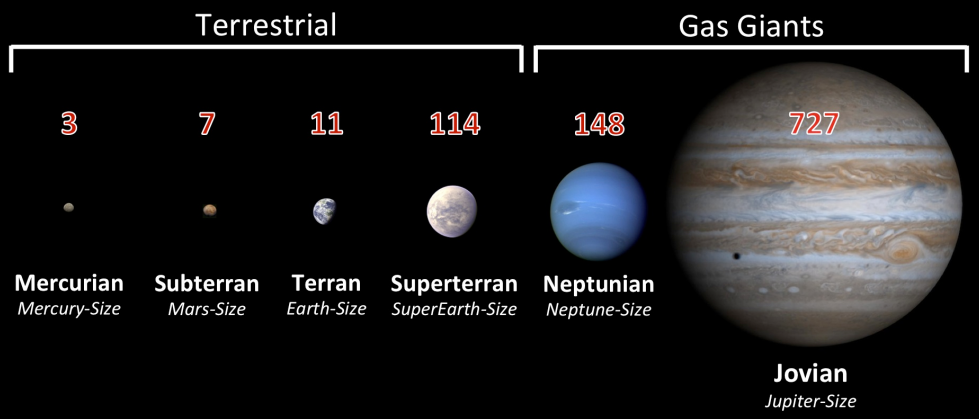
# Life in the Universe

## Over 1000 Confirmed Exoplanets

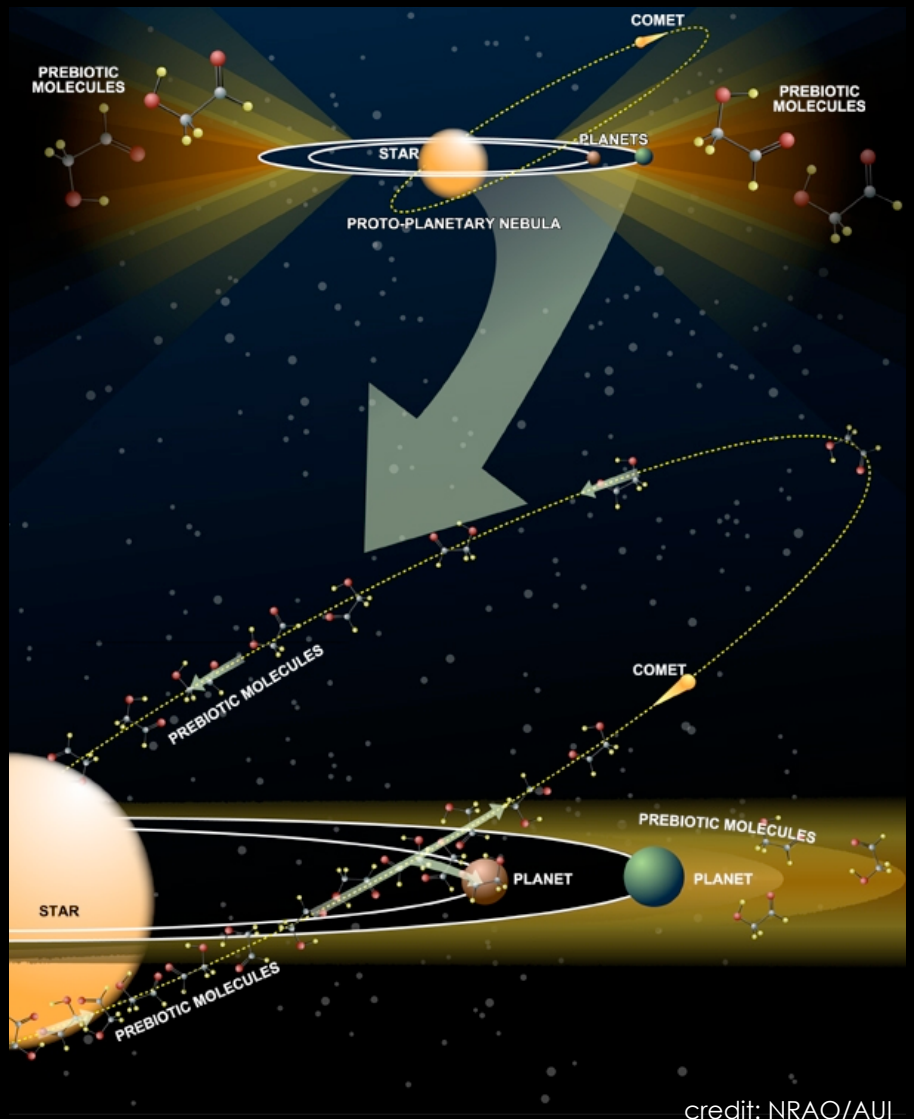



*Number of confirmed exoplanets in each category are in red, total 1010.*

Credit: PHL @ UPR Arecibo, Oct 2013

## Extreme Life


## Complex Chemistry




credit: NRAO/AUI

**Based on *Kepler* ~5-50% of FGKM stars host an ~Earth like planet.**

e.g. Dressing et al 2013, Kopparapu 2013, Petigura et al. 2013

# Intelligent Life?

$$N = R^* \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

Frank Drake, 1961

$R^*$ = the average rate of star formation per year in our galaxy

$f_p$ = the fraction of those stars that have planets

$n_e$ = the average number of planets that can potentially support life per star that has planets

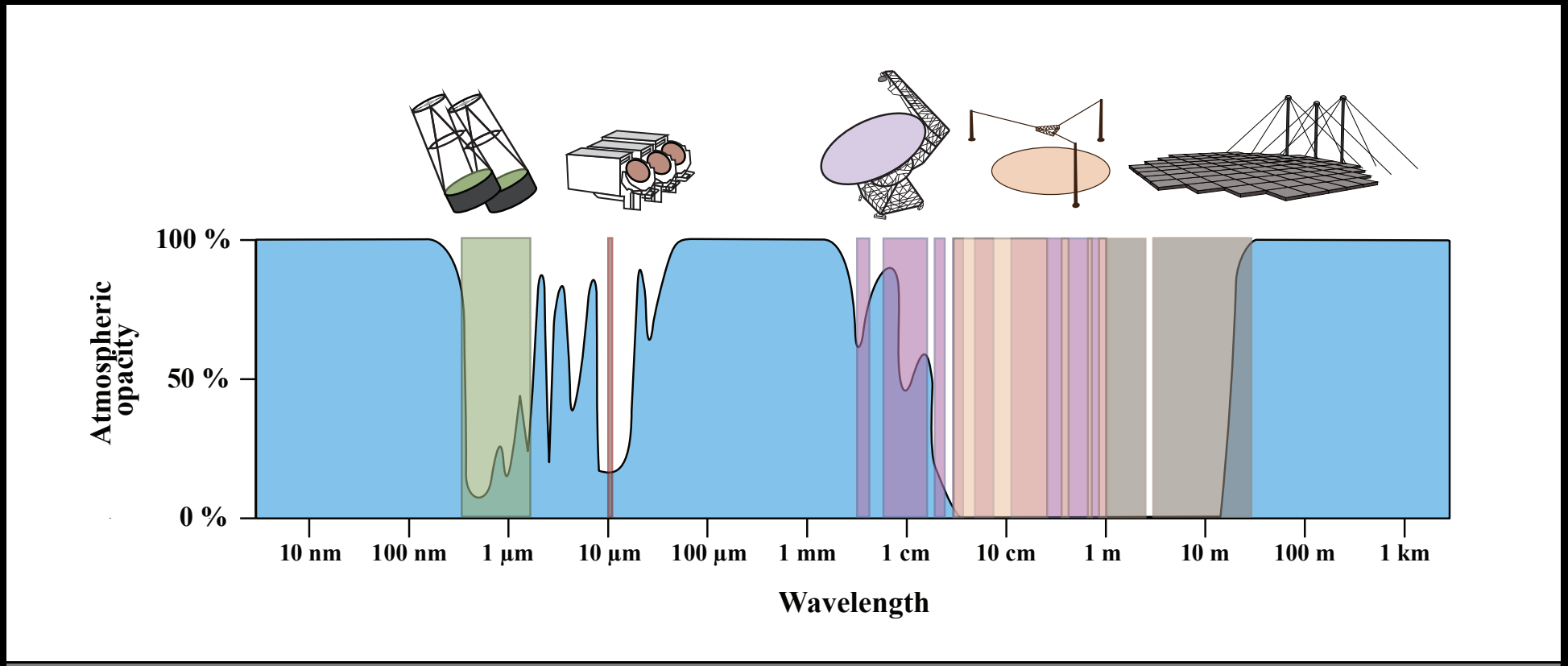
$f_l$ = the fraction of the above that actually go on to develop life at some point

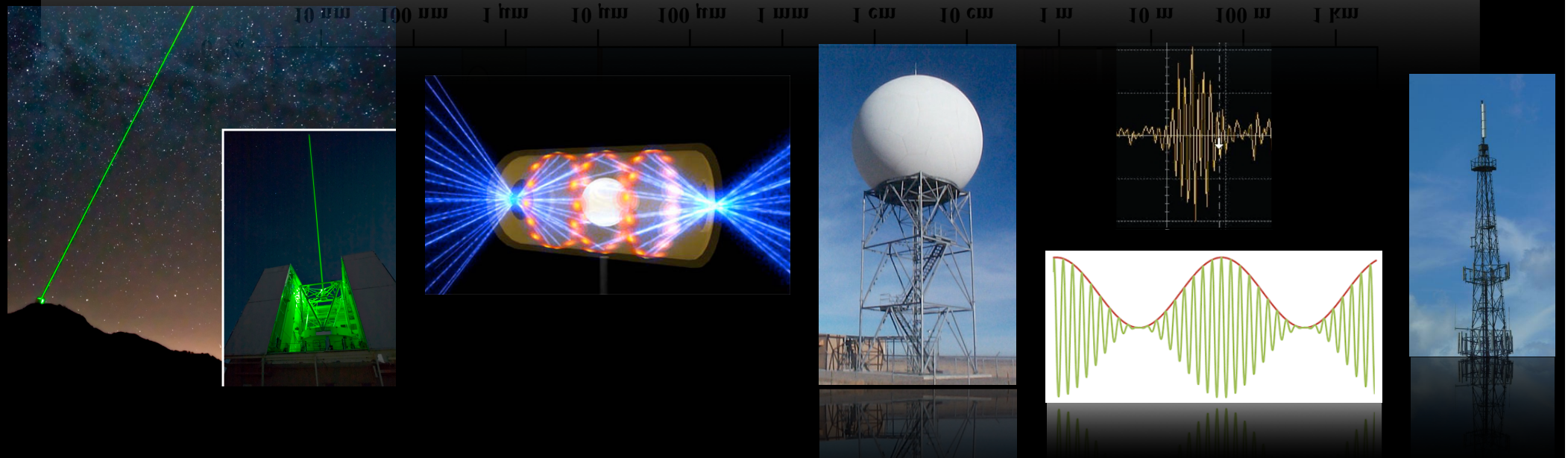
$f_i$ = the fraction of the above that actually go on to develop intelligent life

$f_c$ = the fraction of civilizations that develop a technology that releases detectable signs of their existence into space

$L$ = the length of time such civilizations release detectable signals into space

*Sagan: "…the only significant test of the existence of extraterrestrial intelligence is an experimental one."*


100 %
50 %
0 %
Atmospheric opacity
10 nm
100 nm
1 µm
10 µm
100 µm
1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
Wavelength



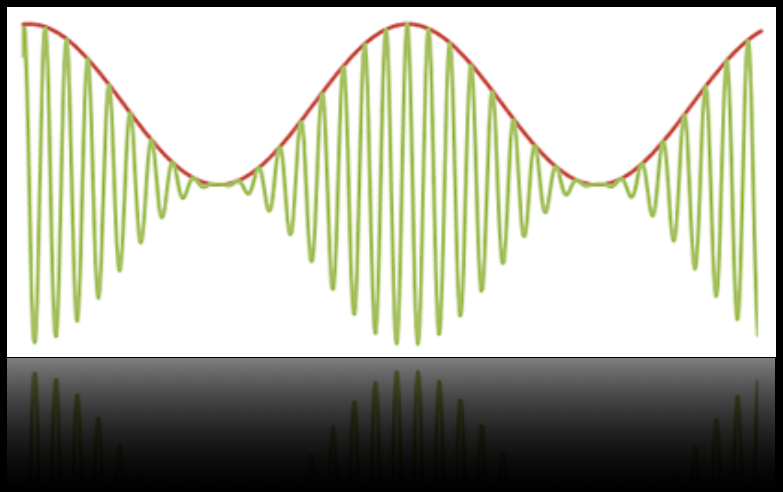
# Low Frequency Radio SETI

## United States Air Force Space Surveillance System "Space Fence"

- 768 kW @ 217 MHz (originally 108 MHz)
- Pure CW
- EIRP ~$10^{10}$ W
- 120° x 1.5′ Fan Beam (3000 times the solid angle of Arecibo Planetary Radar)

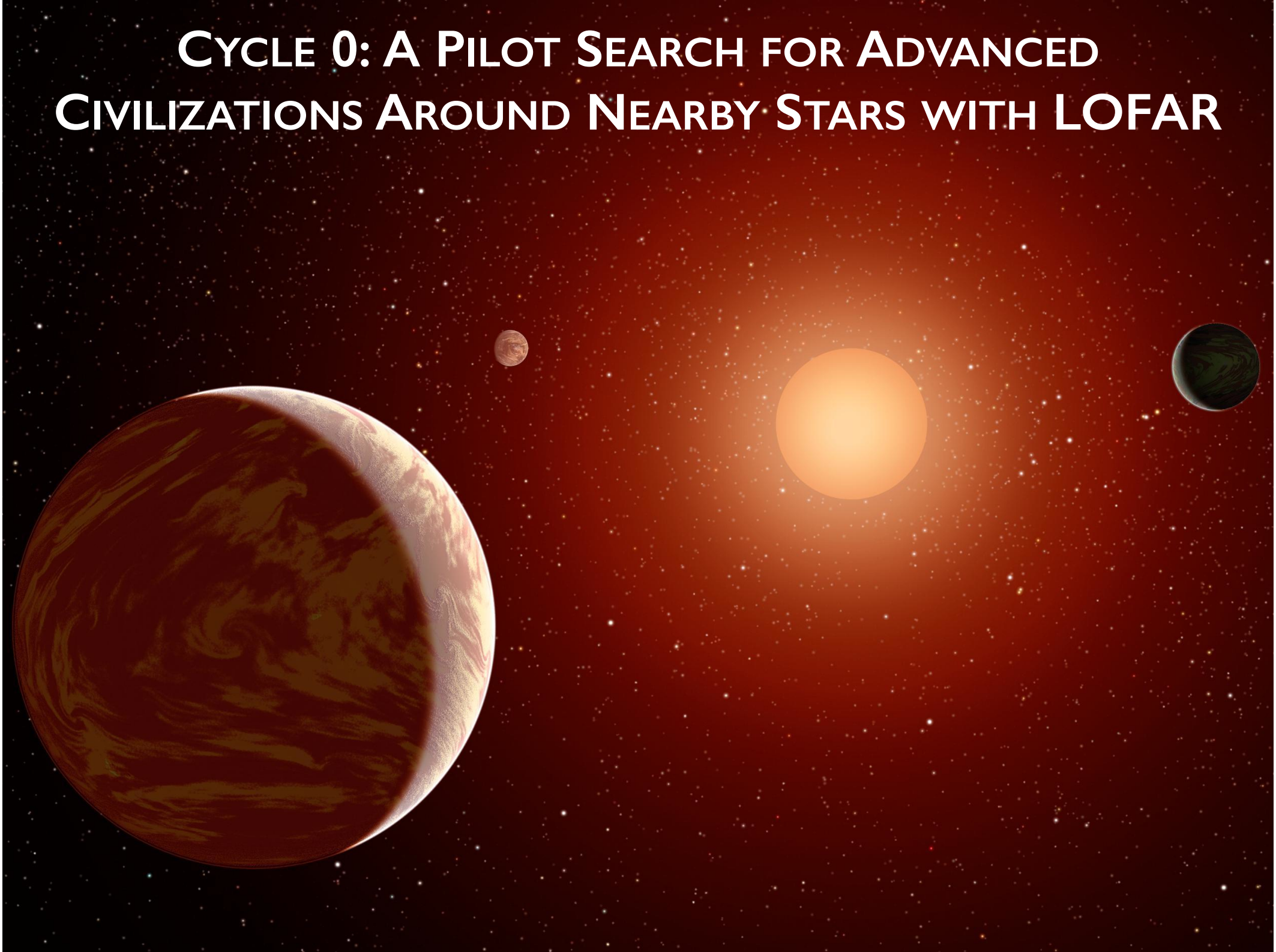
See also: Loeb and Zaldarriaga, 2006

# Intentional Signals...



- Low energy - Radio photons are cheap
- Easy to generate, easy to receive - Earth technology makes photons look attractive
- As fast as possible - c
- Easily distinguished from natural sources - narrowest astrophysical sources 100s of Hz wide (masers)
- Robust to the interstellar medium - Narrow band signals encounter limited broadening by the ISM, viz. Drake and Helou 1977, Cordes and Lazio, 1991 ~ 0.1 Hz at 1.4 GHz

# Cycle 0: A Pilot Search for Advanced Civilizations Around Nearby Stars with LOFAR



# Cycle 0: A Pilot Search for Advanced Civilizations Around Nearby Stars with LOFAR

- Observations Conducted April 2013 - Nov 2013
- Tied-array Mode with Core Stations
- Complex Baseband (Coherent Stokes)
- 120-152 MHz
- 10-12 min Integration
- ~40 Targets Observed
- Typical Sensitivity $10^{-25}$ W $m^{-2}$

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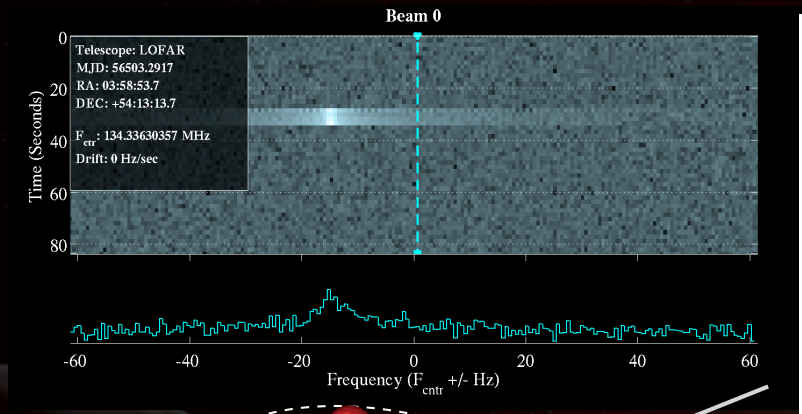
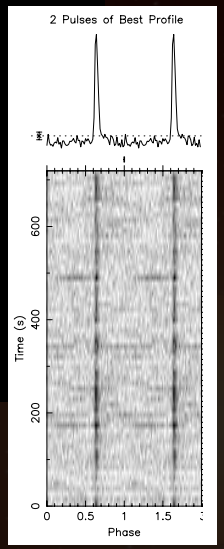
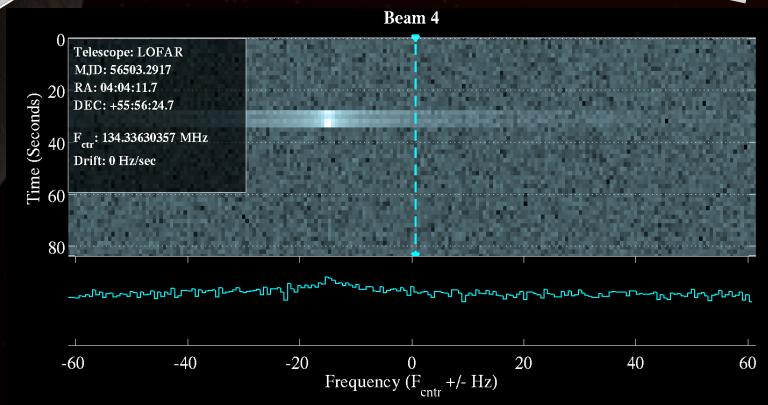
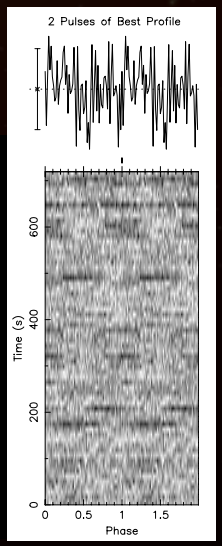



- Fields Chosen to be Coincident with a Bright Pulsar for Diagnostics
- Multibeaming: Astronomical Sources Only Appear in a Single Beam, Interference in Many Beams → Excellent RFI Rejection



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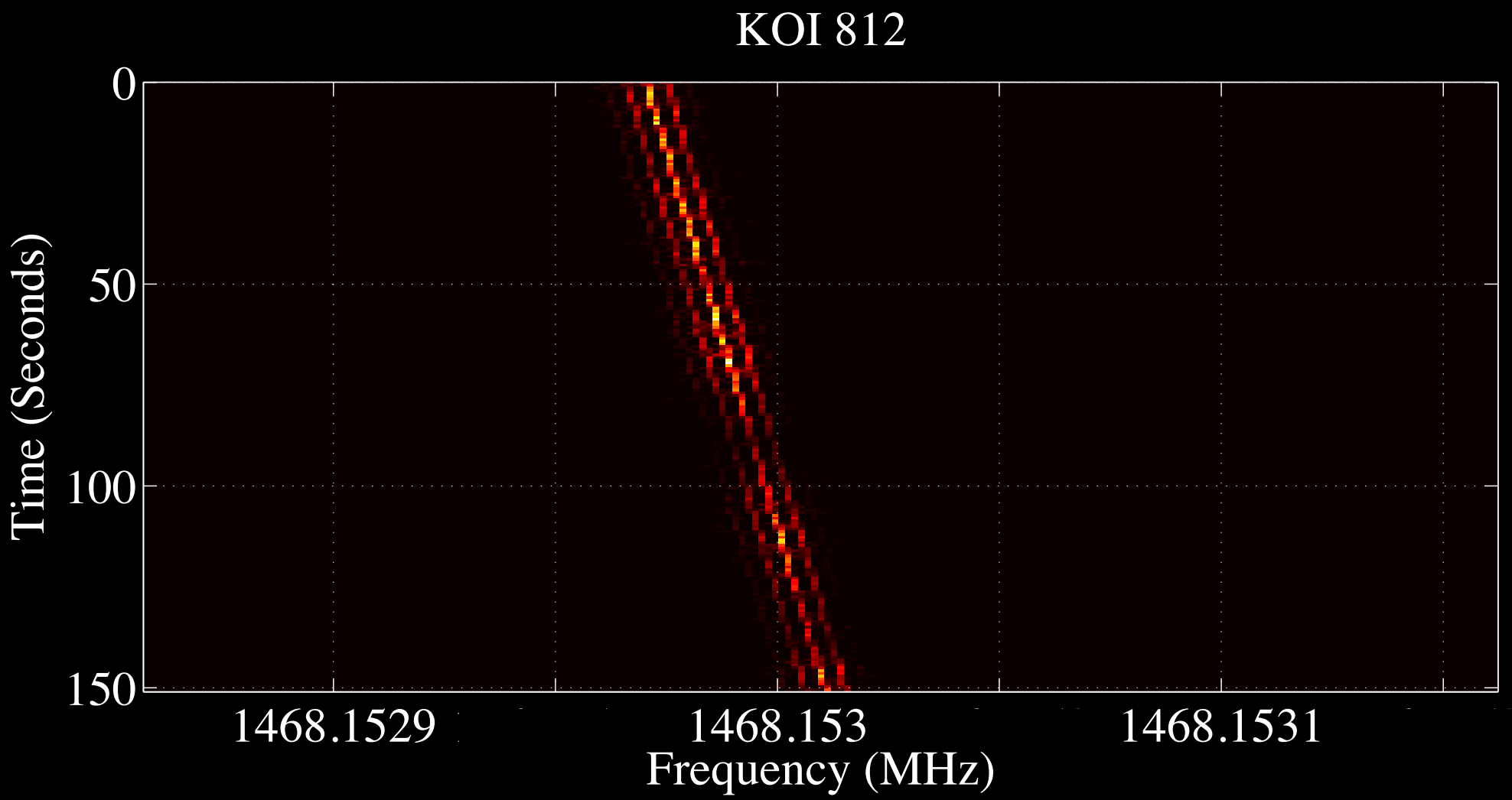
- ~40 Targets Observed
- Typical Sensitivity $10^{-25}$ W $m^{-2}$
- DSPSR-based pipeline:

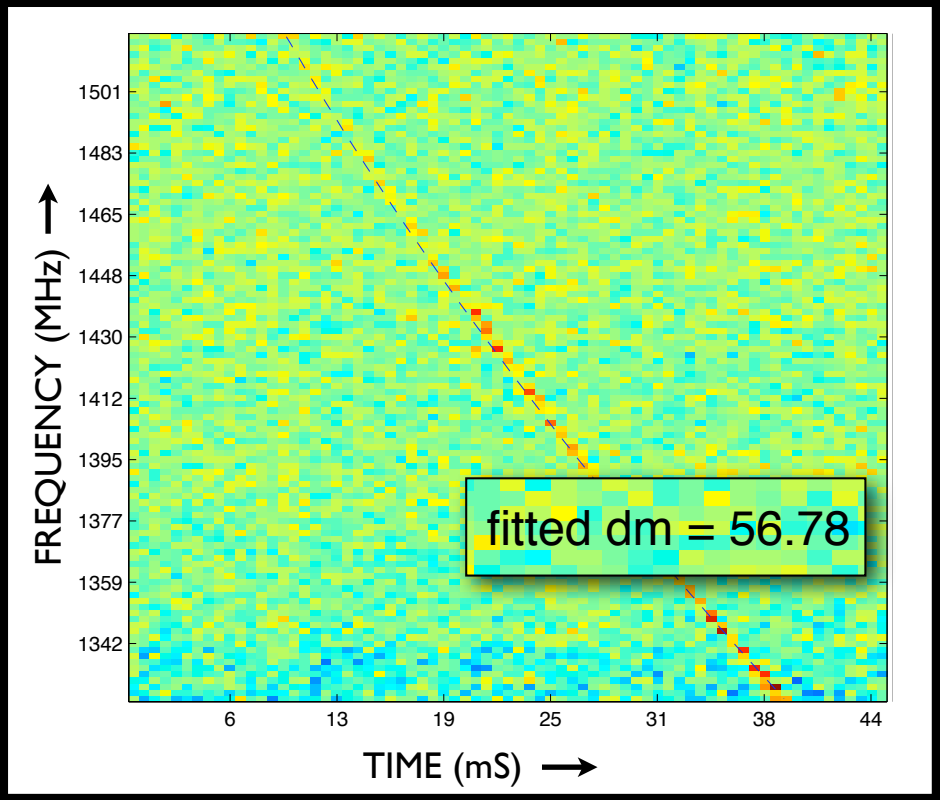
digifil → High-resolution Filterbank

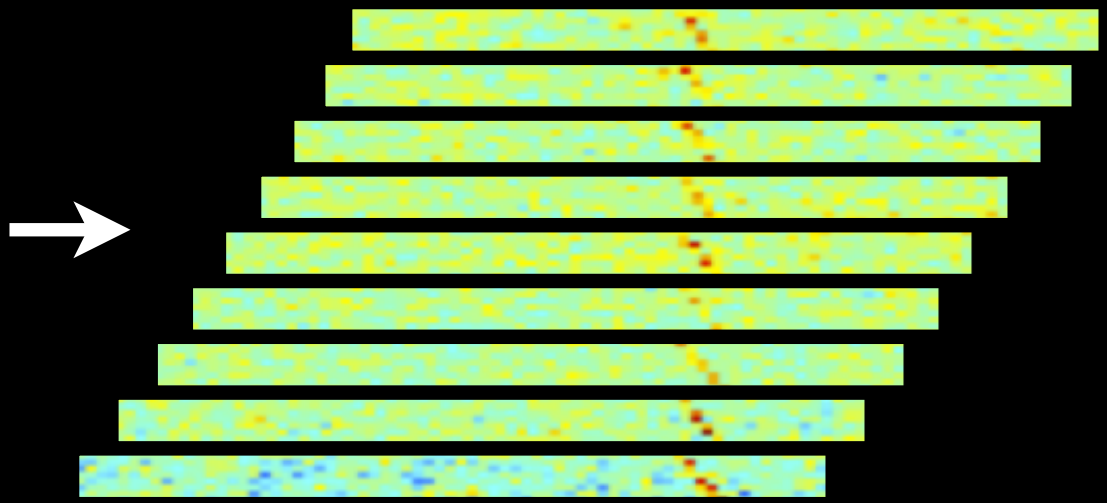
Custom Code to perform Bandpass Calibration, Thresholding, Search for Drifting Sinusoids

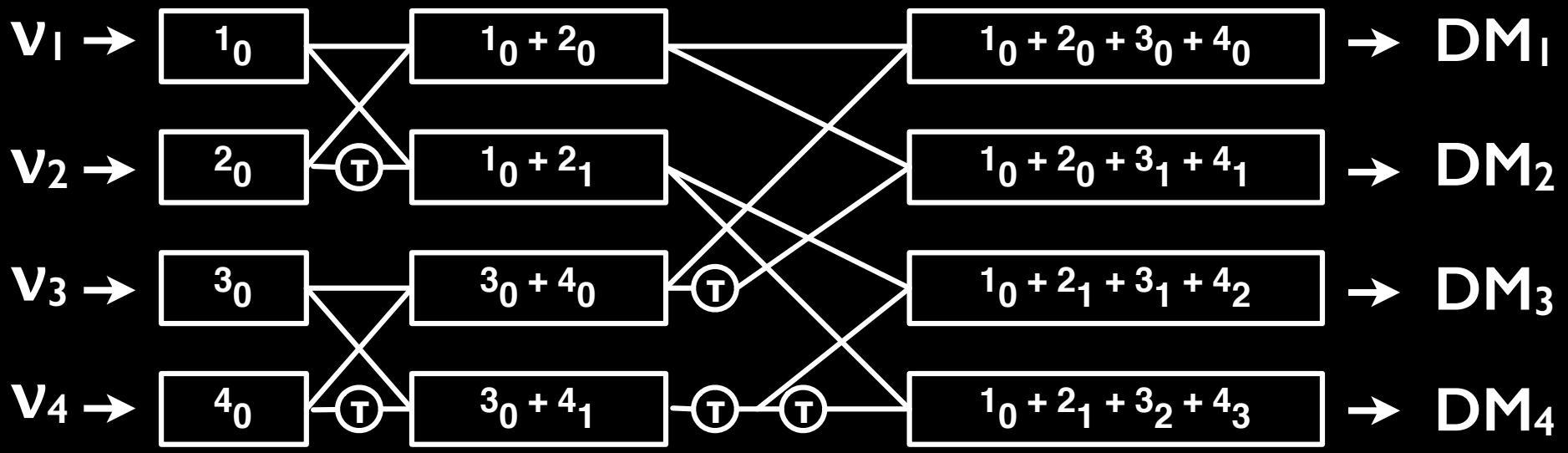
# Narrow-band Signal Search



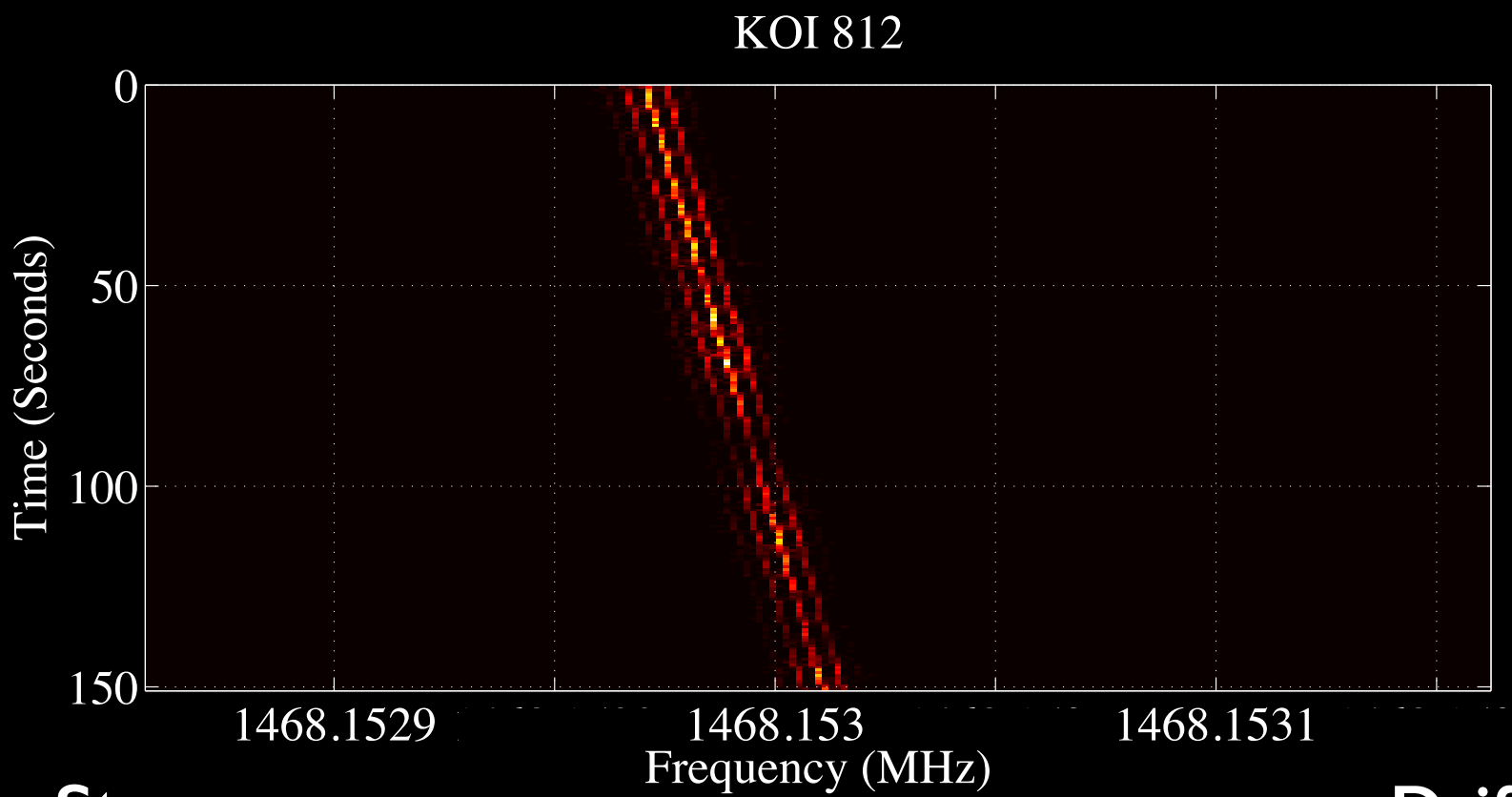
Crab Giant Pulse

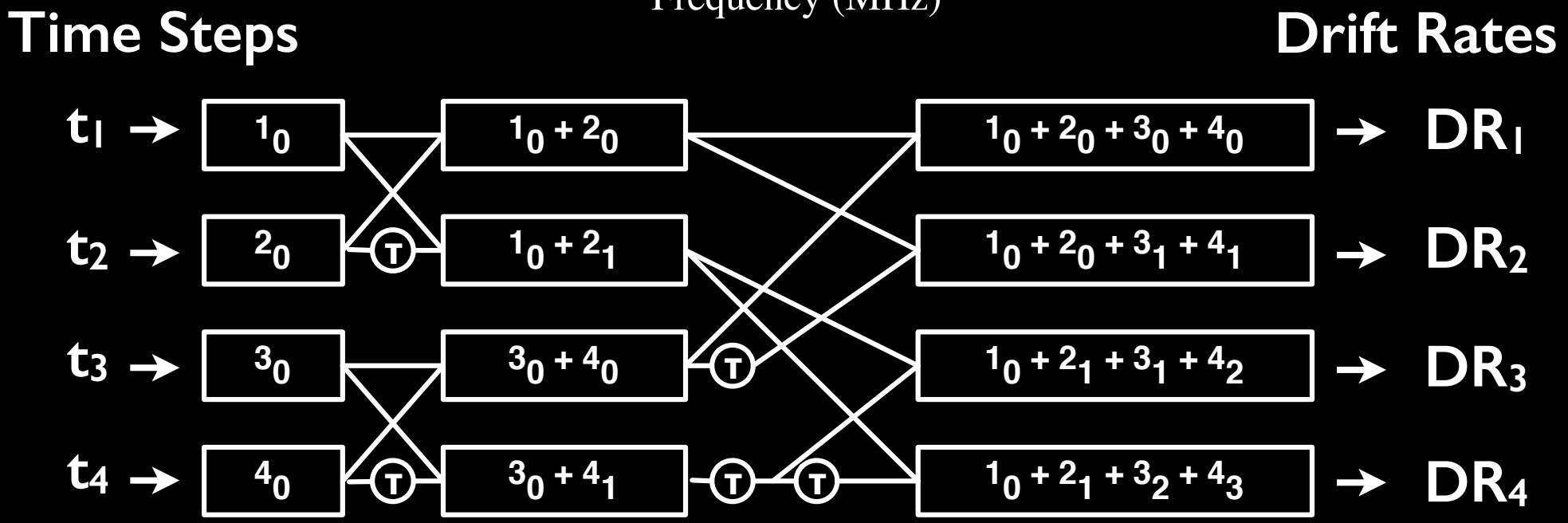


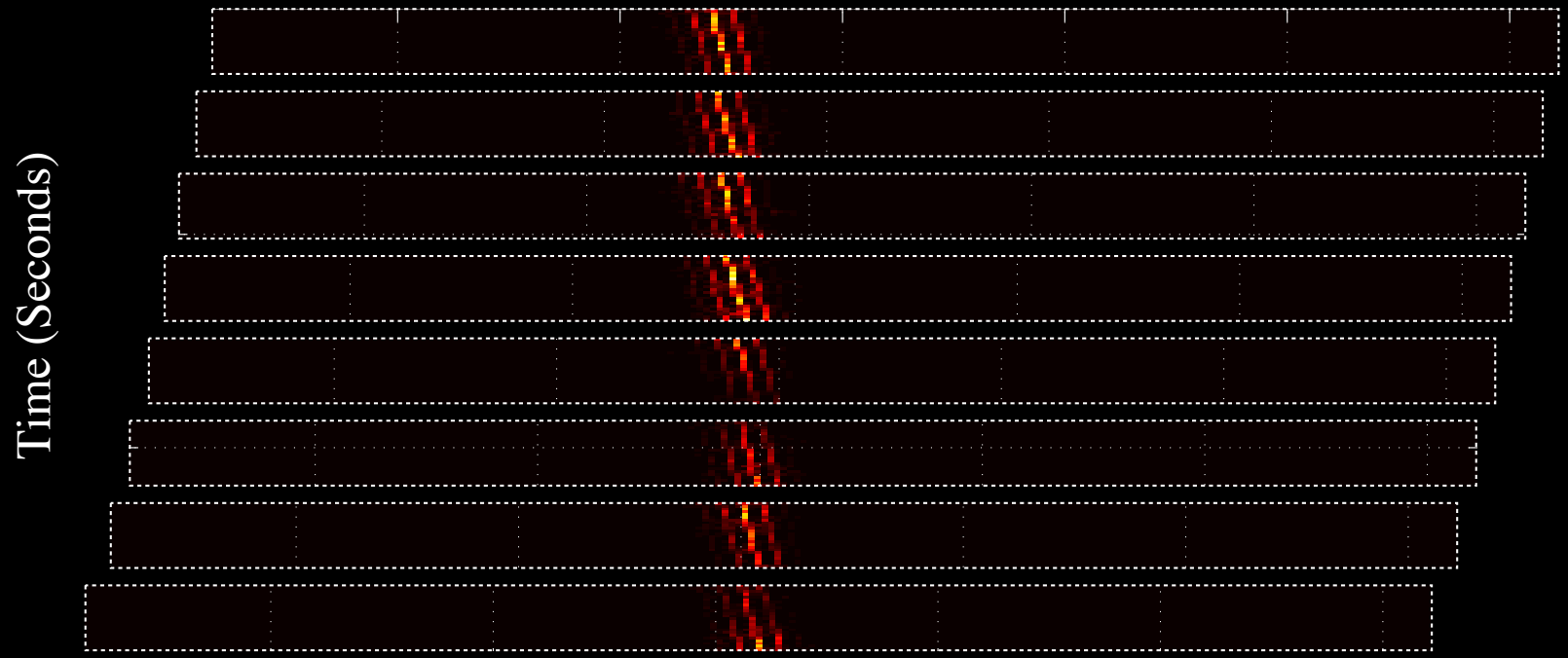


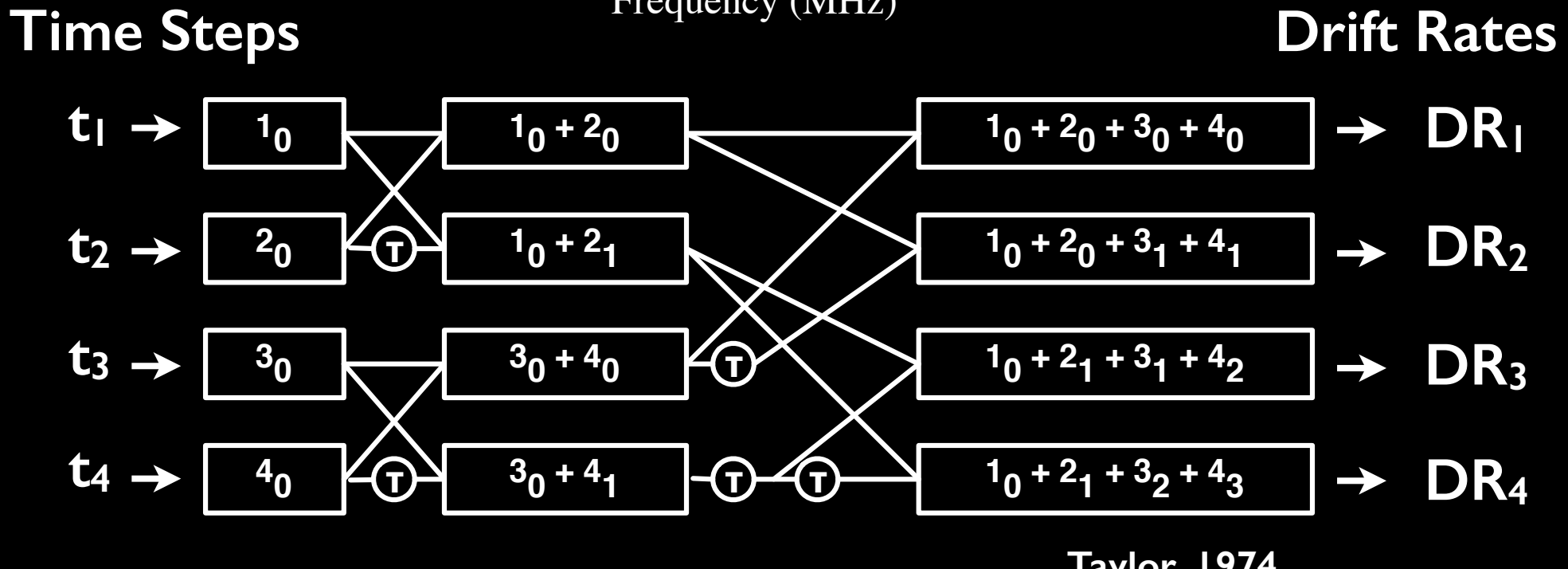

Taylor, 1974


KOI 812
0
50
100
150
Time (Seconds)
1468.1529
1468.153
1468.1531
Frequency (MHz)


Time Steps
Drift Rates
t1
t2
t3
t4
1 0
2 0
3 0
4 0
T
1 0 + 2 0
1 0 + 2 1
3 0 + 4 0
3 0 + 4 1
1 0 + 2 0 + 3 0 + 4 0
1 0 + 2 0 + 3 1 + 4 1
1 0 + 2 1 + 3 1 + 4 2
1 0 + 2 1 + 3 2 + 4 3
DR1
DR2
DR3
DR4

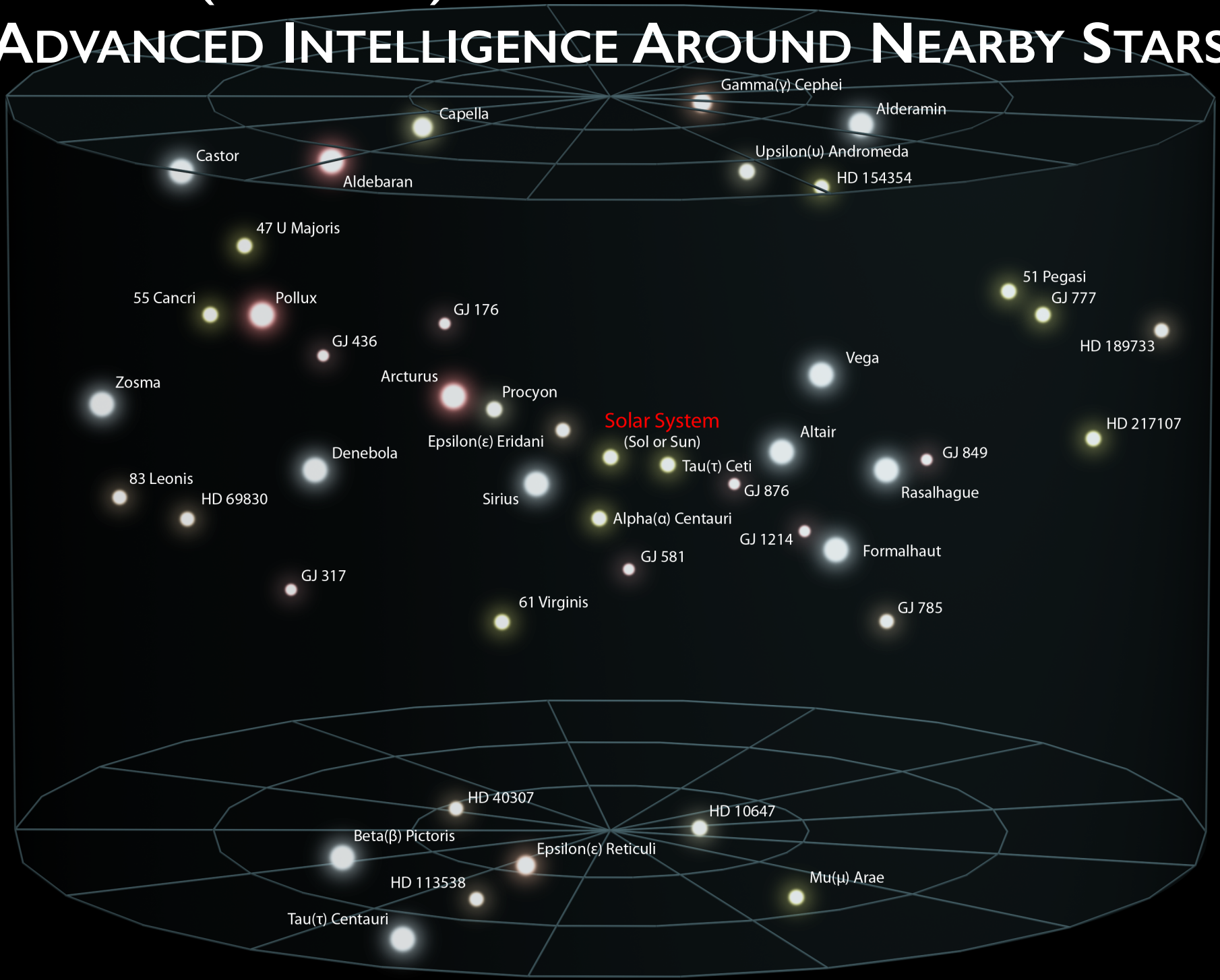
Taylor, 1974


Time (Seconds)
Frequency (MHz)


Time Steps
Drift Rates
t1
t2
t3
t4
10
10 + 20
10 + 20 + 30 + 40
DR1
20
10 + 21
10 + 20 + 31 + 41
DR2
30
30 + 40
10 + 21 + 31 + 42
DR3
40
30 + 41
10 + 21 + 32 + 43
DR4
T

Taylor, 1974

# Cycle 2 (pending): A Panchromatic Search for Advanced Intelligence Around Nearby Stars



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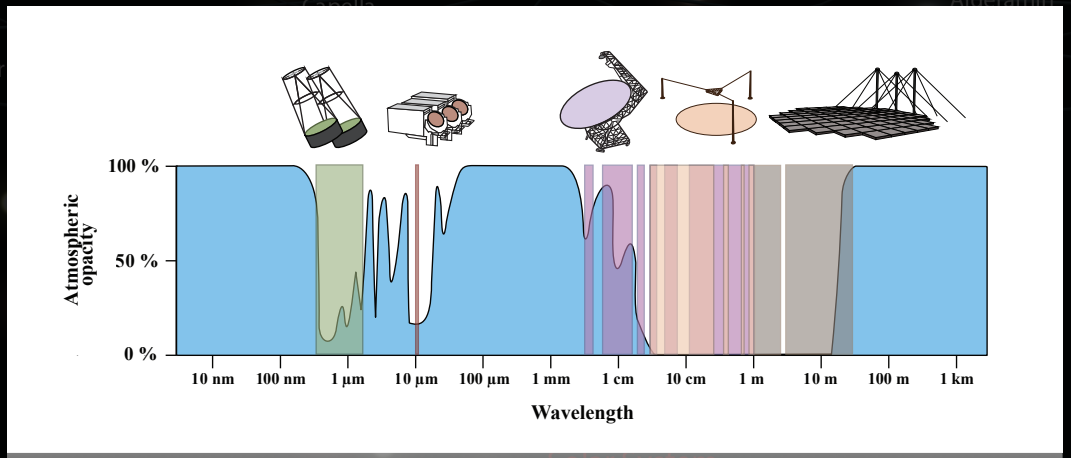


- Part of Global Initiative to Search the 30 Northern Hemisphere Stars within 5 pc of the Sun from 10s of MHz to 100s of THz
- 10 - 250 MHz, LBA and HBA
- Existing Pipeline + New Algorithms Processed at SURFsara

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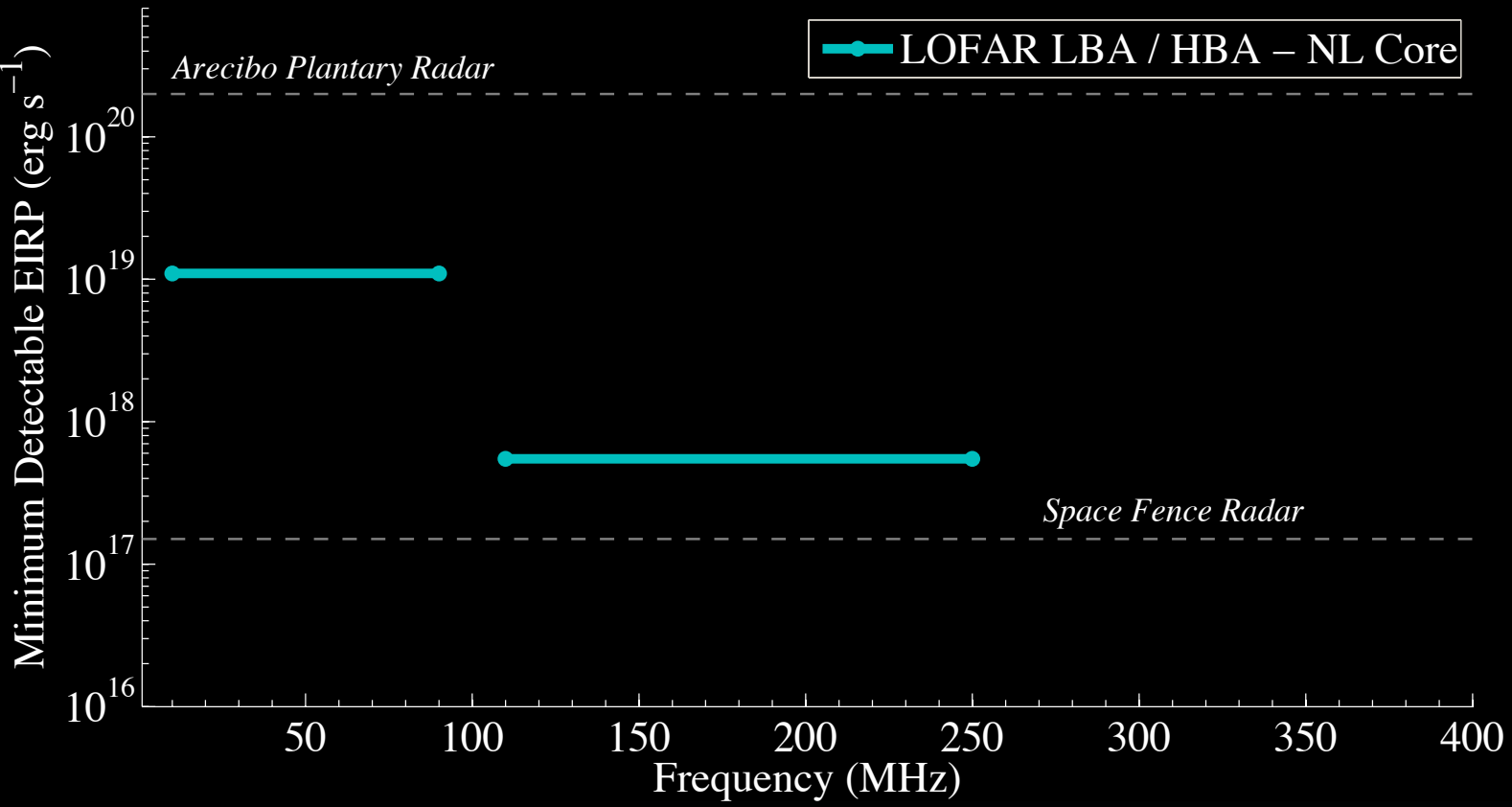
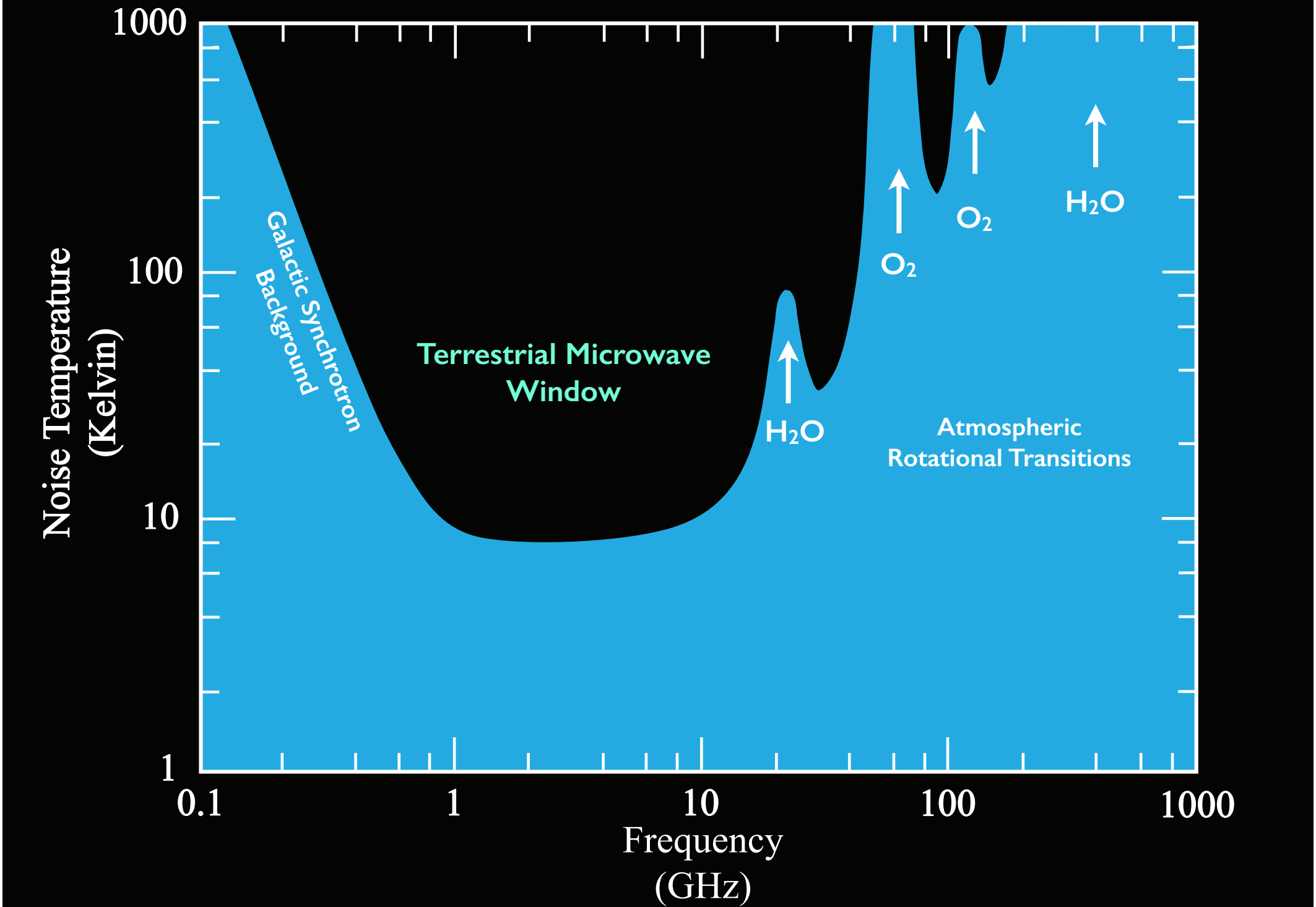



- Detection Threshold for a Star at 5pc (phased NL-core, SEFD 60 Jy w/ HBA, 1200 Jy LBA)

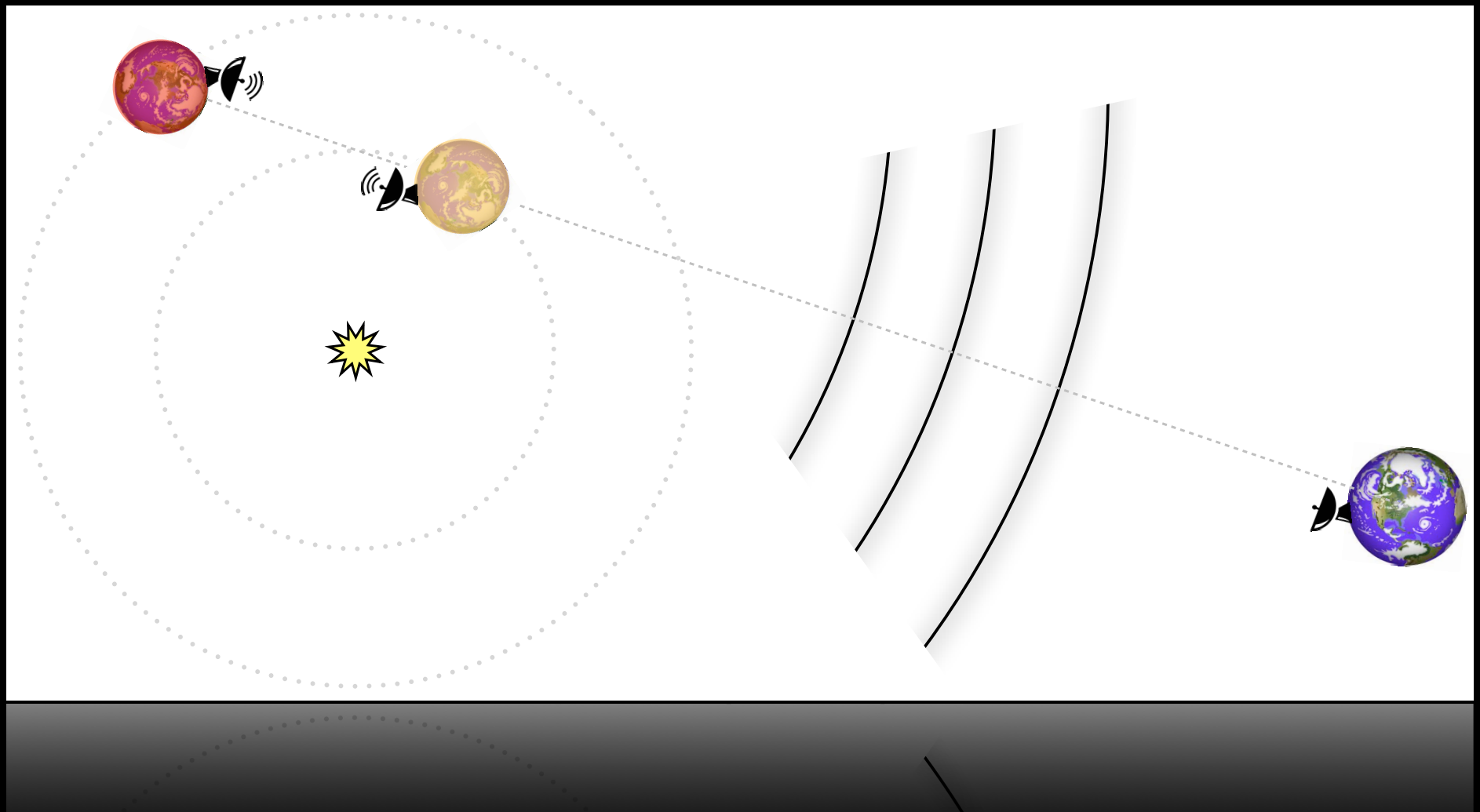
# SUMMARY:

- Searches for Extraterrestrial Intelligence are happening with LOFAR!
- "Standard" SETI Pipeline available soon, available for testing by other observers now.


1000
100
10
1
Noise Temperature (Kelvin)
0.1
1
10
100
1000
Frequency (GHz)
Galactic Synchrotron Background
Terrestrial Microwave Window
H2O
O2
O2
H2O
Atmospheric Rotational Transitions

# New Observing Strategies

# EPIC-SETI: Exoplanet Interplanetary Communication Searches for Extraterrestrial Intelligence



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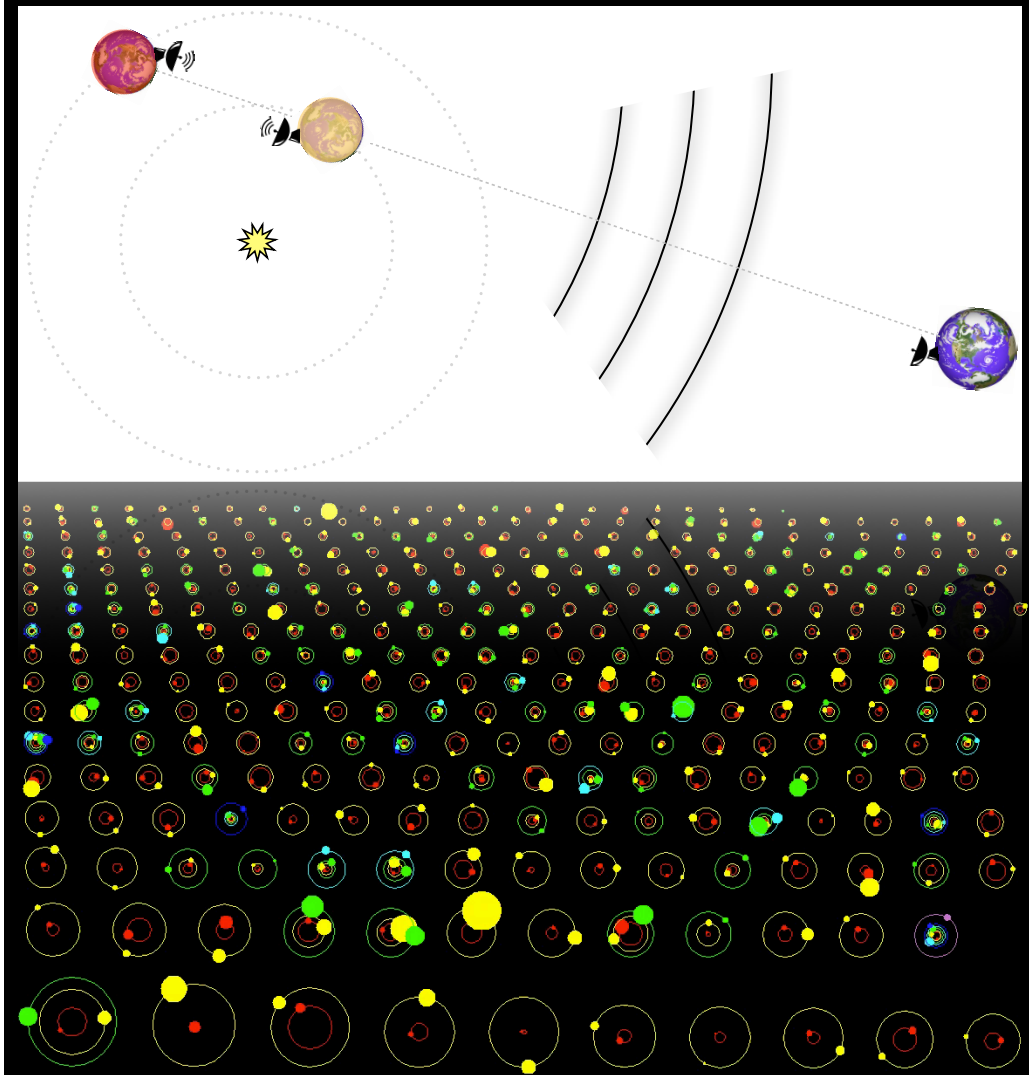

Kepler multi-planet ephemerides allow accurate prediction of conjunction times

100s of multi-planet systems provide frequent conjunction events (many per day)

D. Fabrycky 2012