The Modern Radio Search for Extraterrestrial Intelligence

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Jayanth Chennamangalam - West Virginia University
Jeff Cobb - University of California, Berkeley
Jim Cordes - Cornell University
Paul Demorest - National Radio Astronomy Observatory
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Glenn Jones - Columbia University
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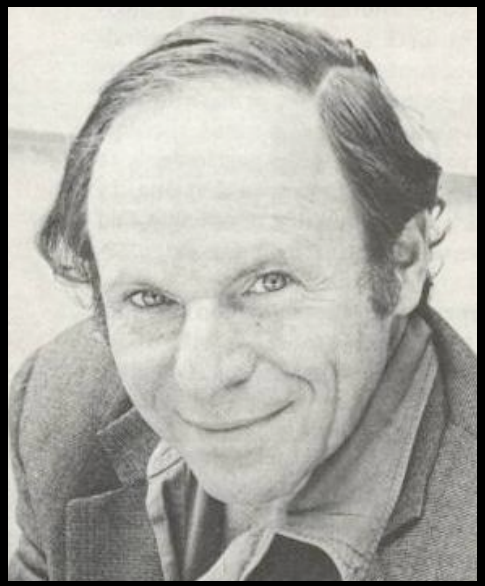
Laura Spitler - MPIfR
Jill Tarter - SETI Institute
Joeri van Leeuwen - ASTRON
Mark Wagner - University of California, Berkeley
Dan Werthimer - University of California, Berkeley
Kristian Zarb-Adami - University of Oxford

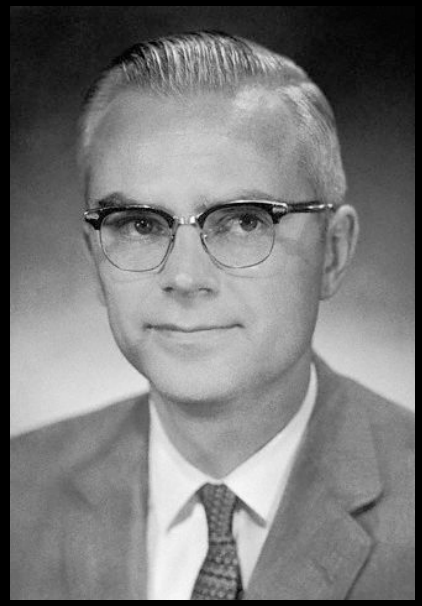
http://seti.berkeley.edu
http://casper.berkeley.edu

SEARCHING FOR INTERSTELLAR COMMUNICATIONS

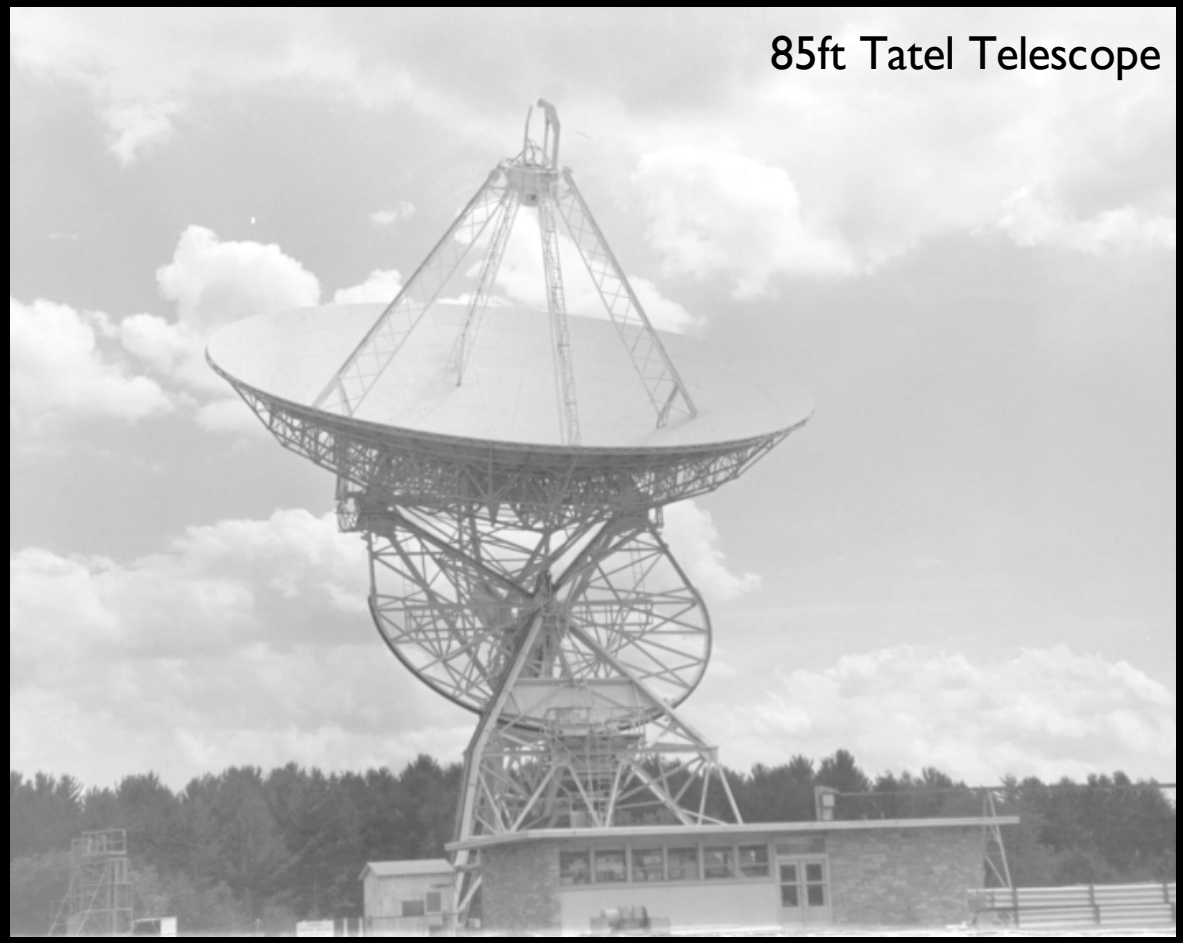
By GIUSEPPE COCCONI* and PHILIP MORRISON†
Cornell University, Ithaca, New York



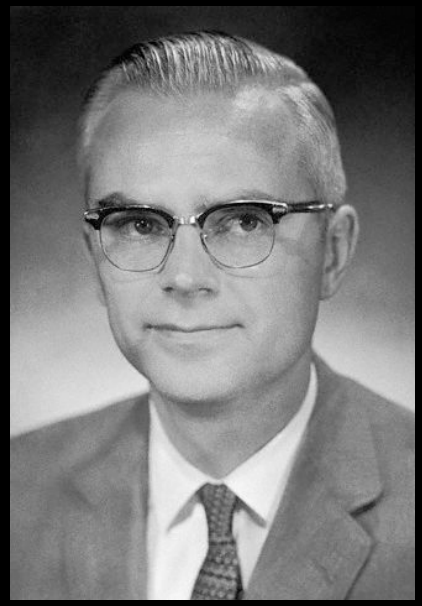
Project OZMA, 1959



Frank Drake

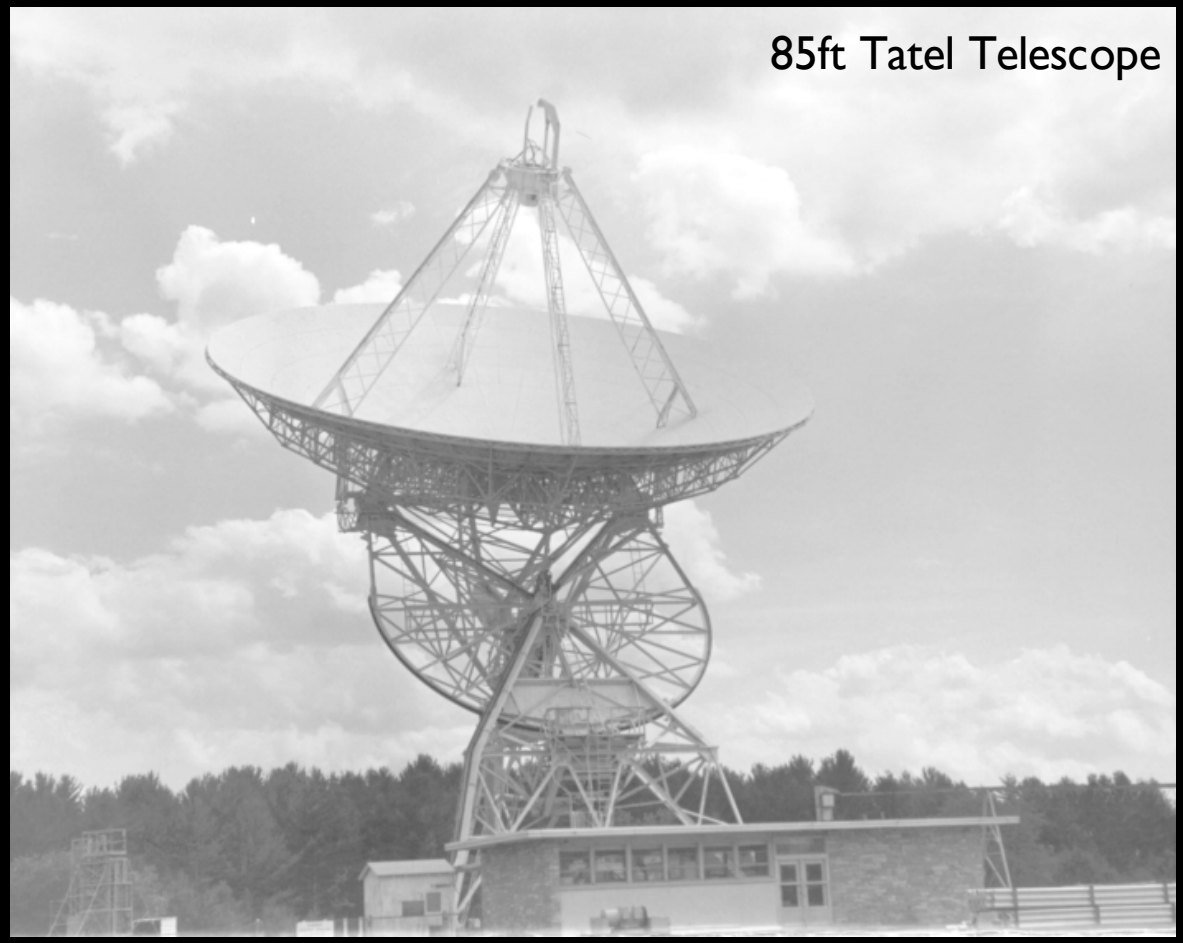


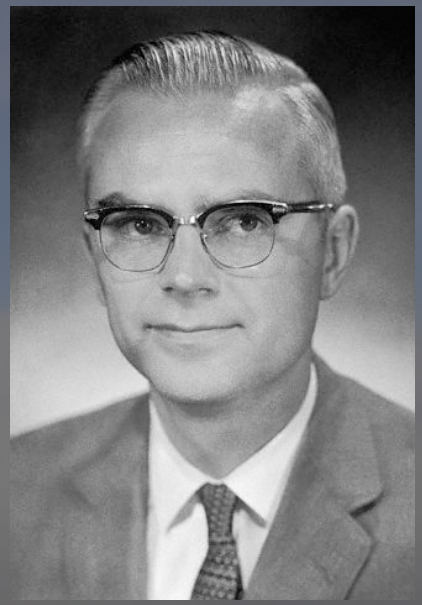
Project OZMA, 1959



Frank Drake

Single 100 Hz manually tuned channel
400 kHz band around 1420.4 MHz





Frank Drake

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

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

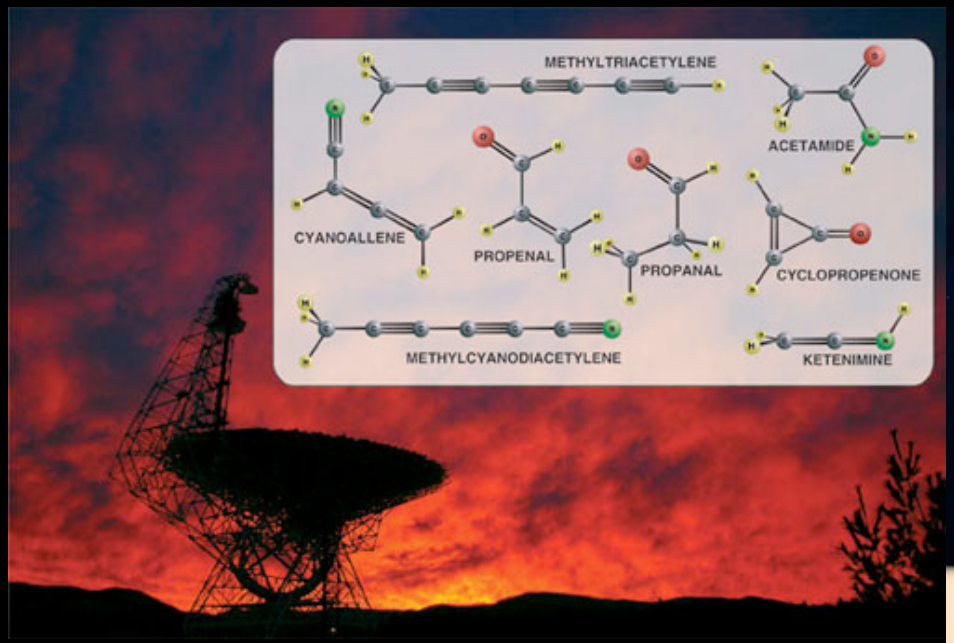
f_p = *the fraction of those stars that have planets*

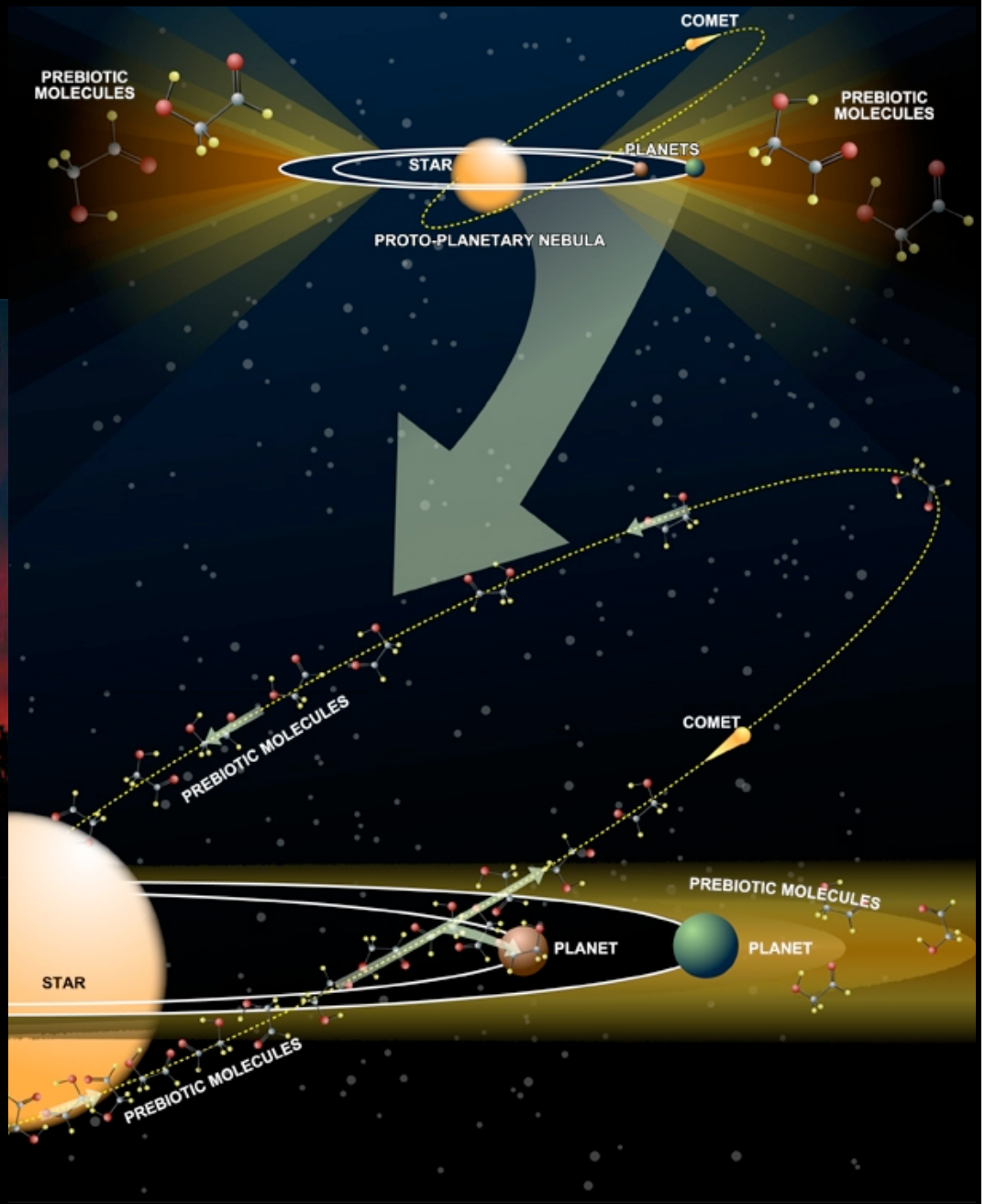
n_e = *the average number of planets that can potentially support life per star that has planets*

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*

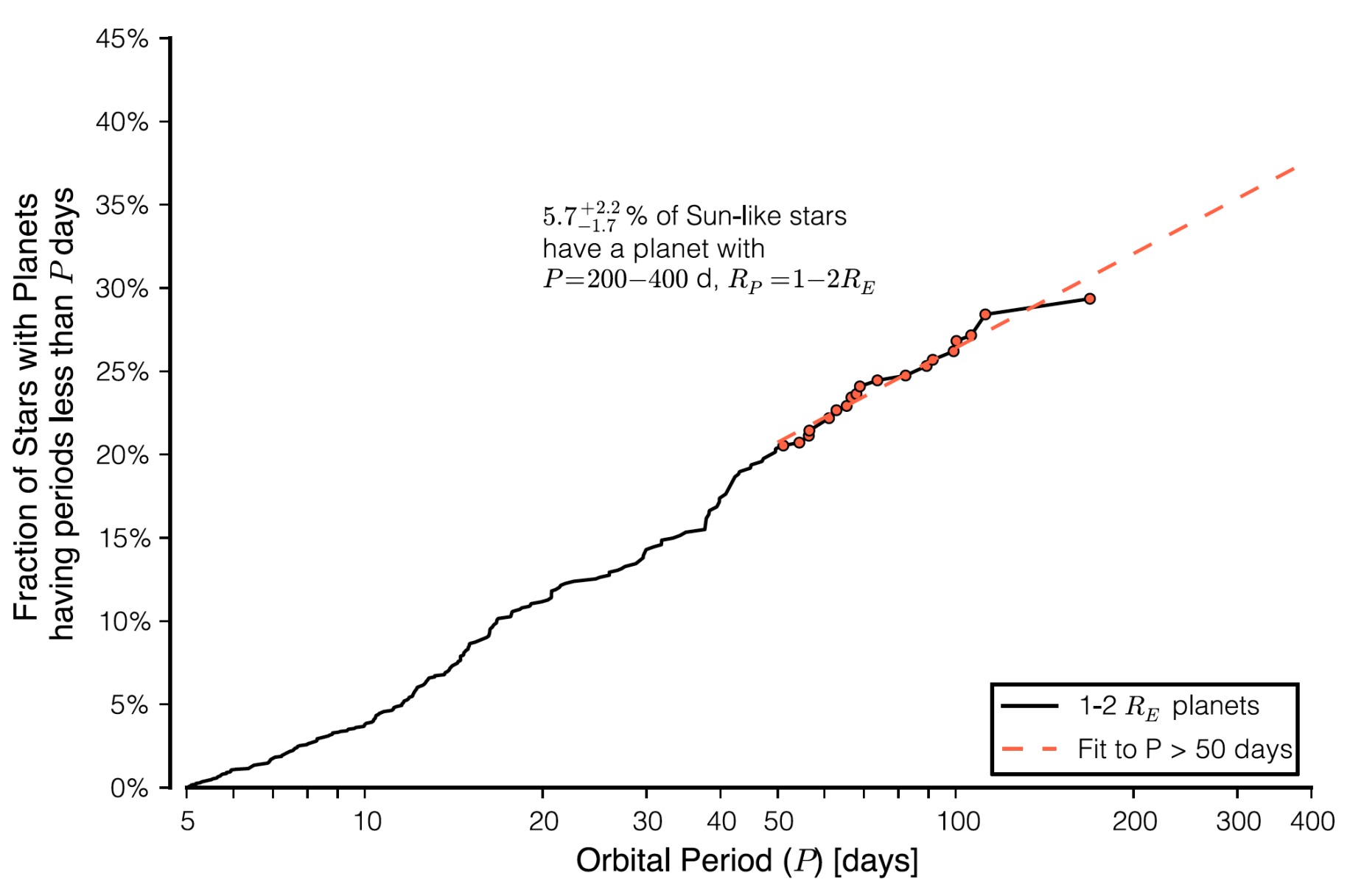
f_c = *the fraction of civilizations that develop a technology that releases detectable signs of their existence into space*



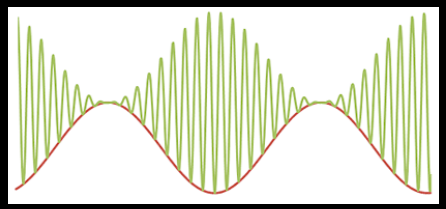


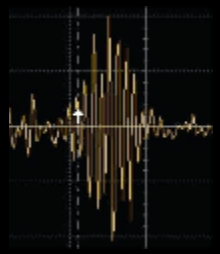
Graphics Courtesy NRAO, Bill Saxton AUI

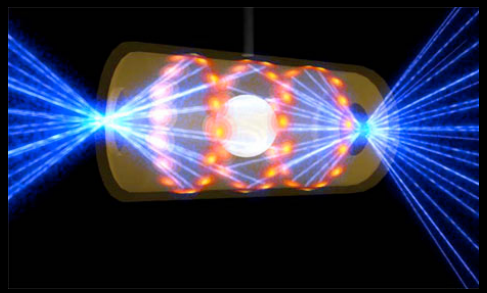
PLANETS ARE EVERYWHERE

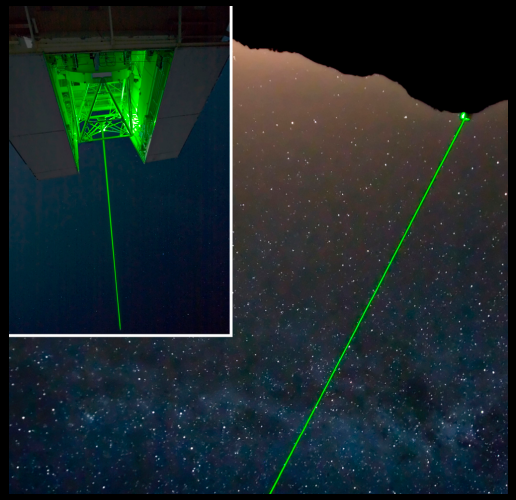


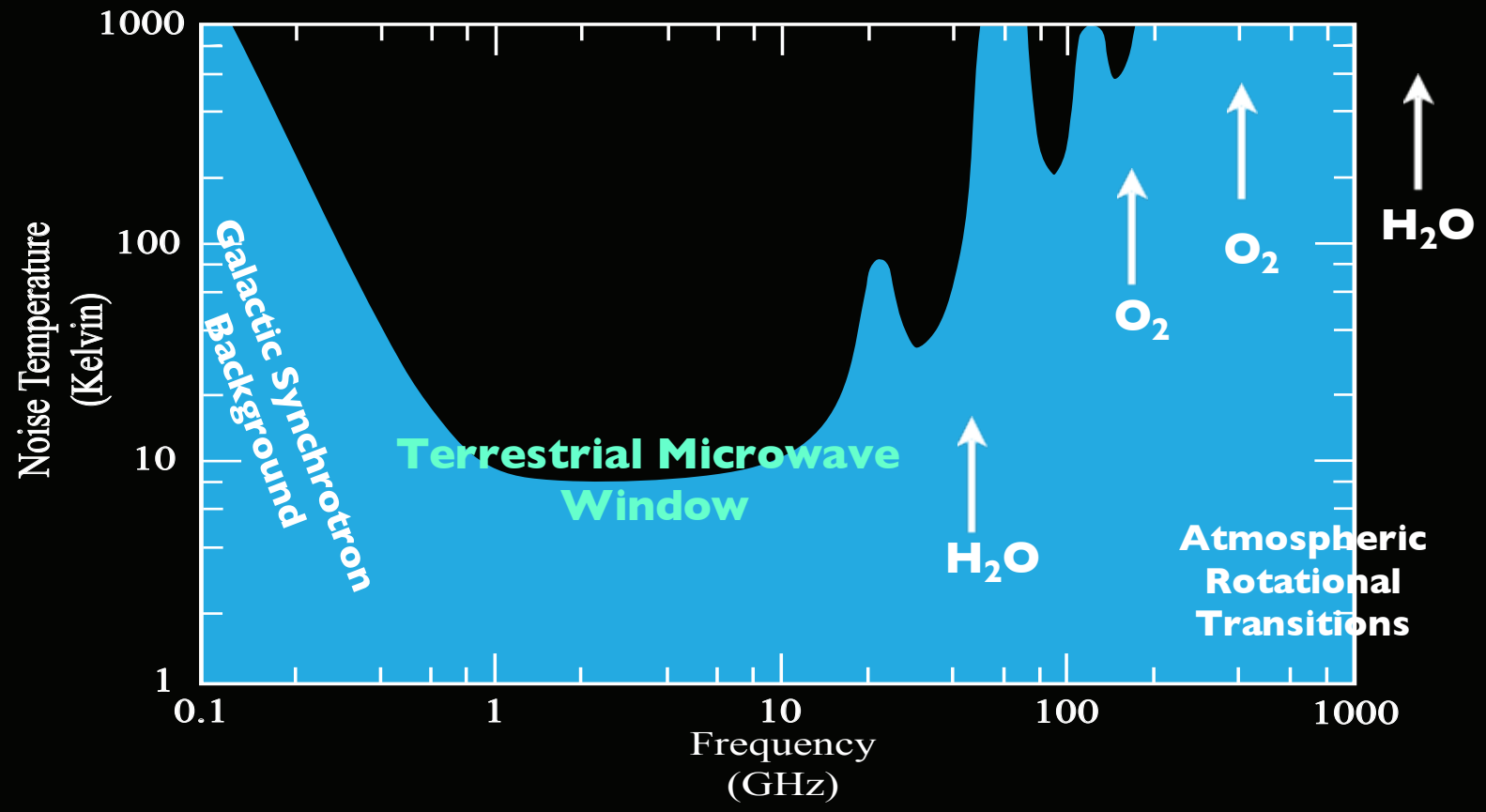
Petigura et al, 2013

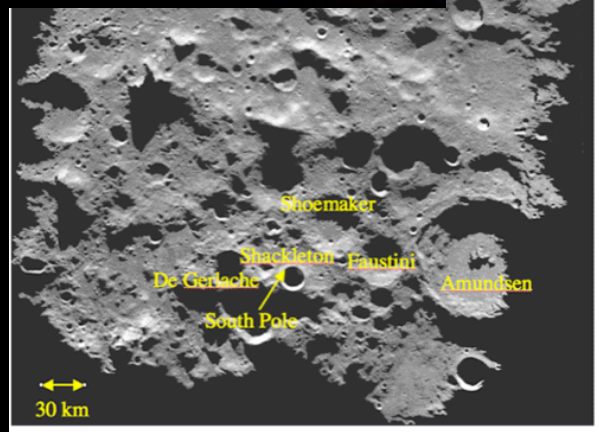


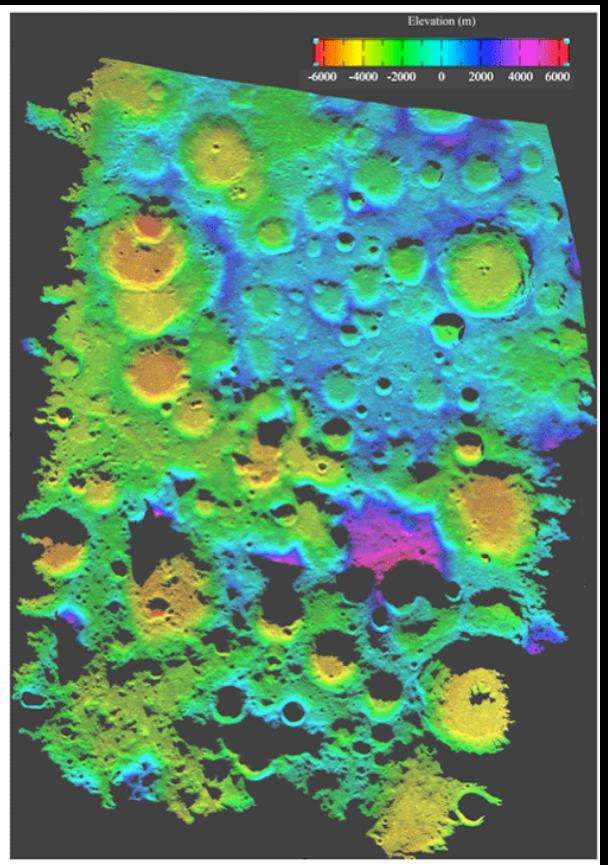


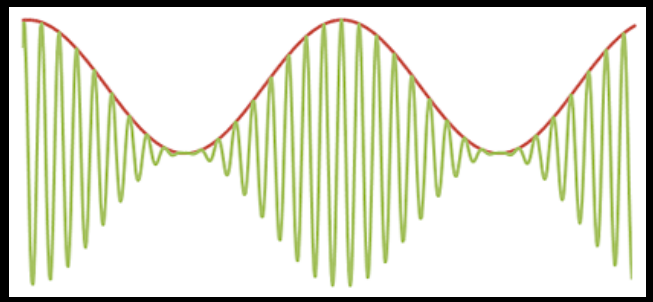


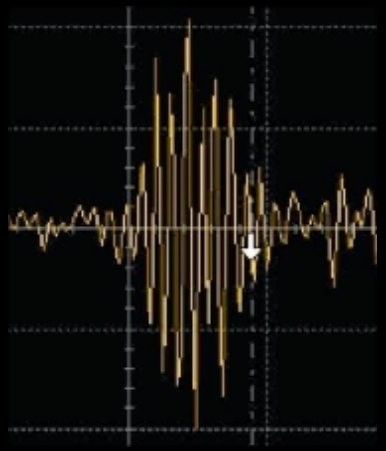



1000
100
10
1
Noise Temperature
(Kelvin)
0.1
1
10
100
1000
Frequency
(GHz)
Galactic Synchrotron
Background
Terrestrial Microwave
Window
H_2O
O_2
O_2
H_2O
Atmospheric
Rotational
Transitions

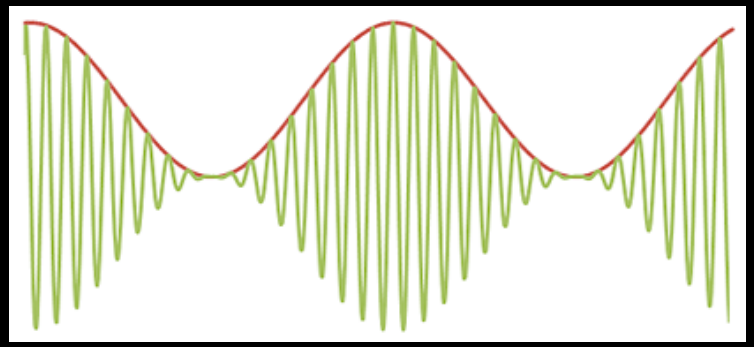

Shoemaker
Shackleton
Faustini
De Gerlache
Amundsen
South Pole
30 km


Elevation (m)
-6000 -4000 -2000 0 2000 4000 6000



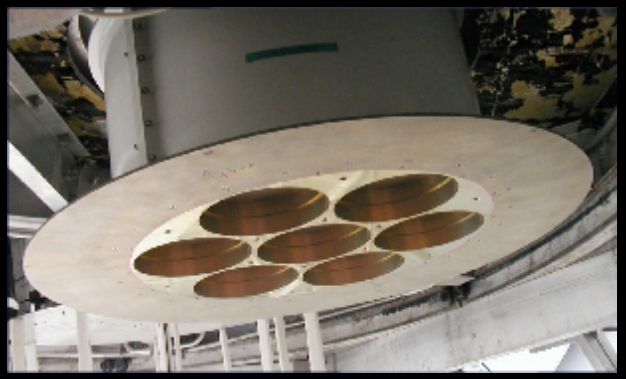


Intentional Signals...



- 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

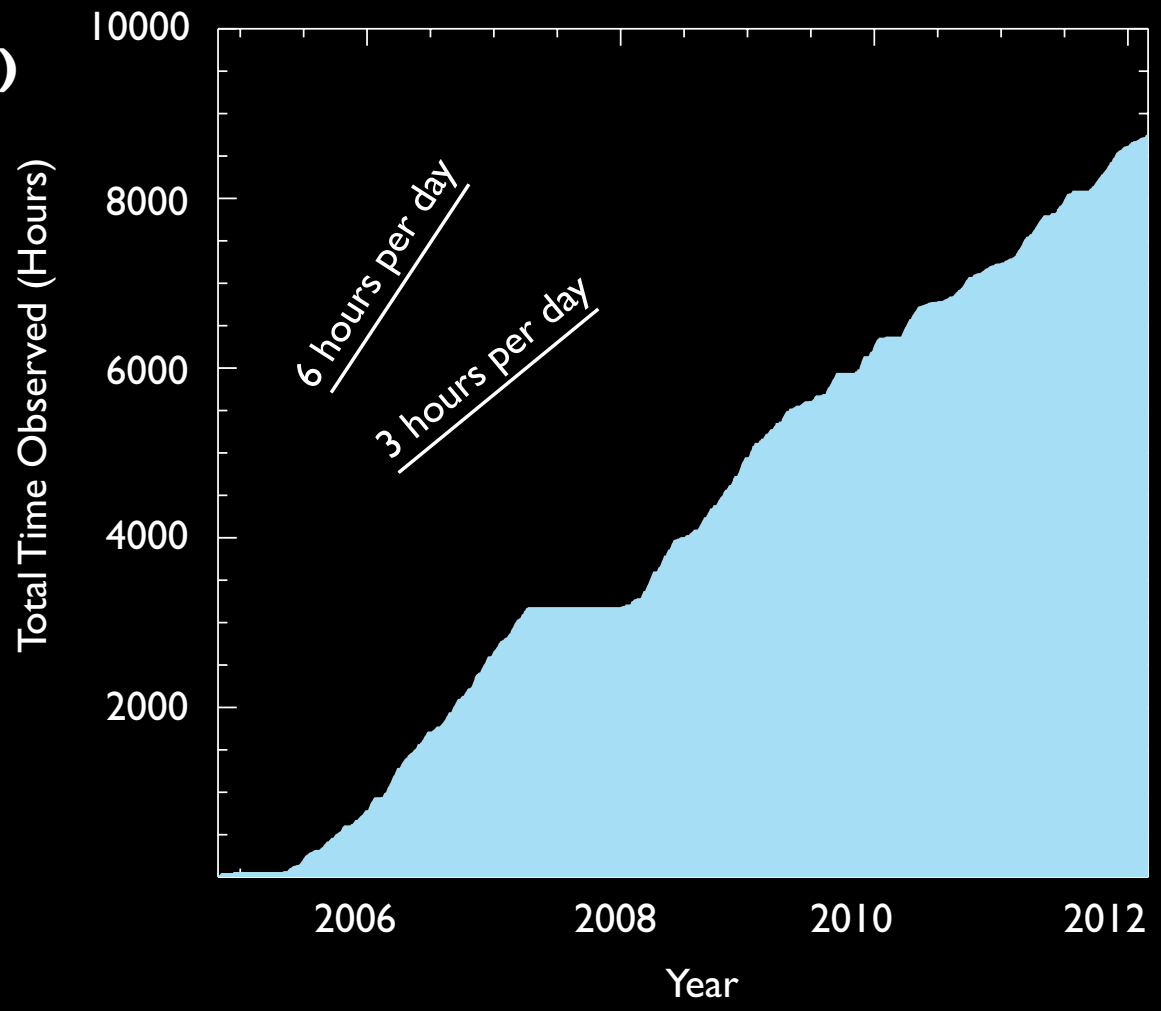
NAIC Arecibo Observatory, Puerto Rico



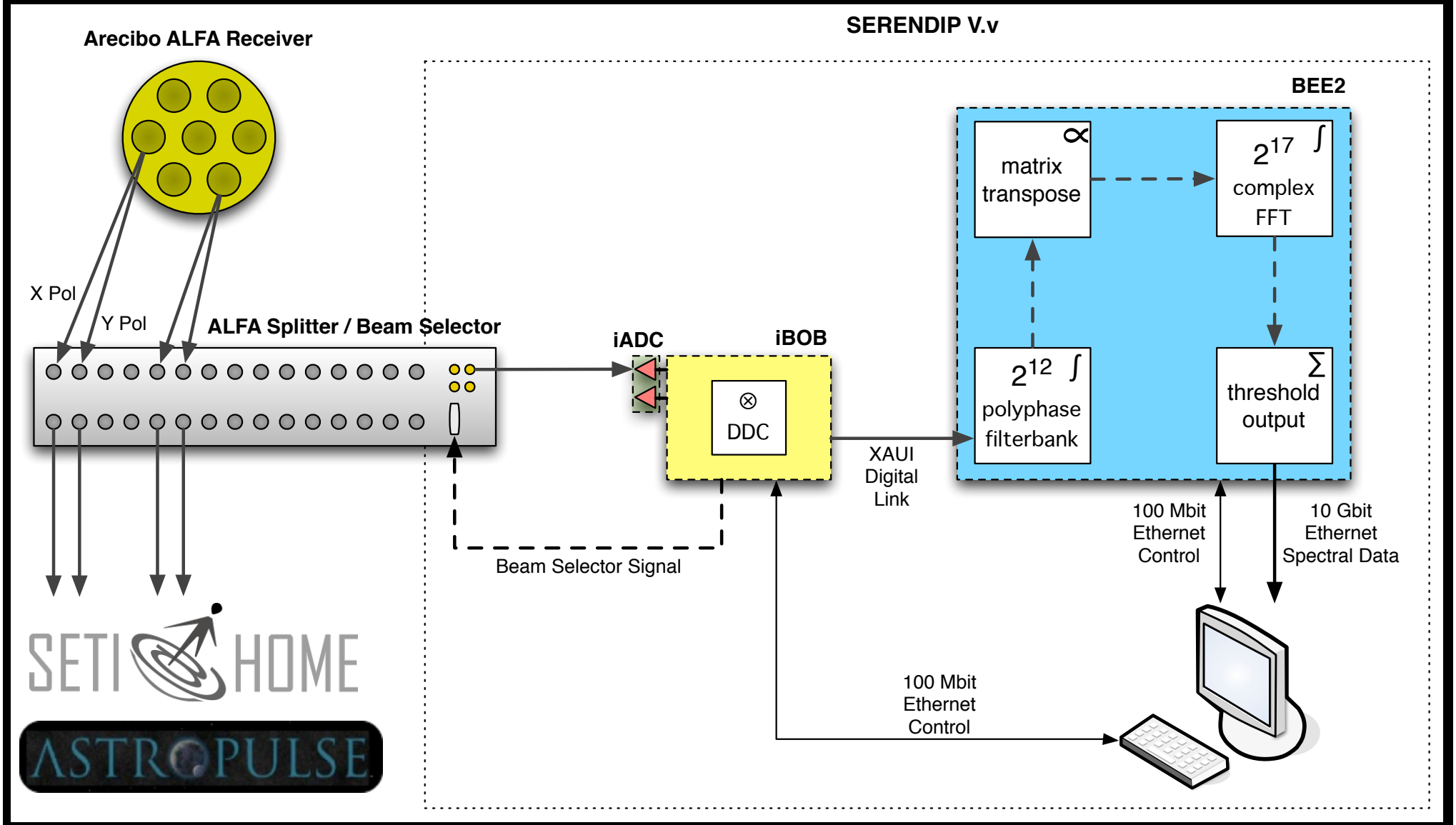
ALFA Receiver (courtesy NAIC)

Arecibo L-band Feed Array (ALFA) Receiver System:

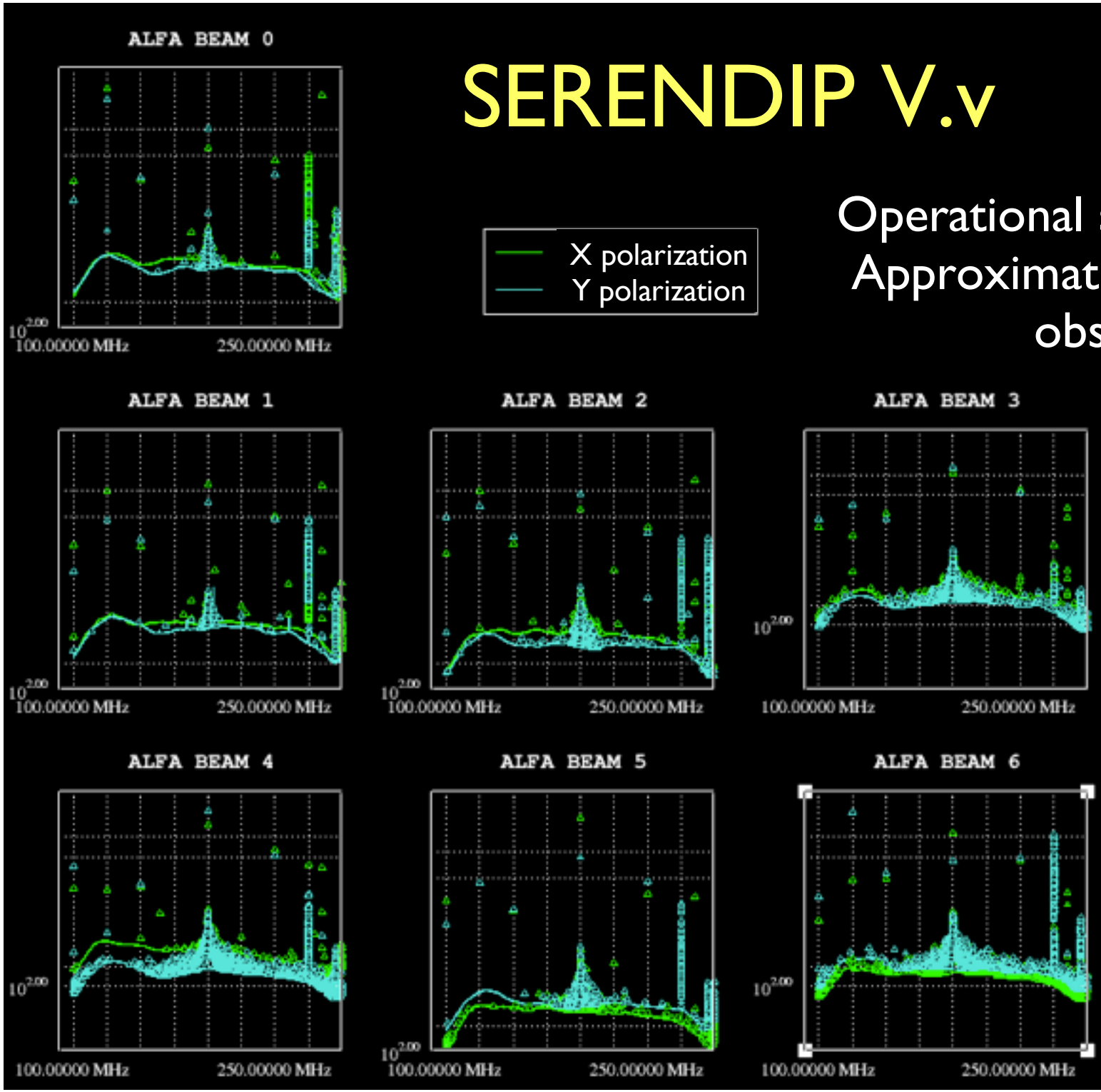
- ~1.3 GHz band center
- 7 dual-polarization feeds
- 300 MHz Bandwidth



Adapted from a graphic courtesy J.E.G. Peek

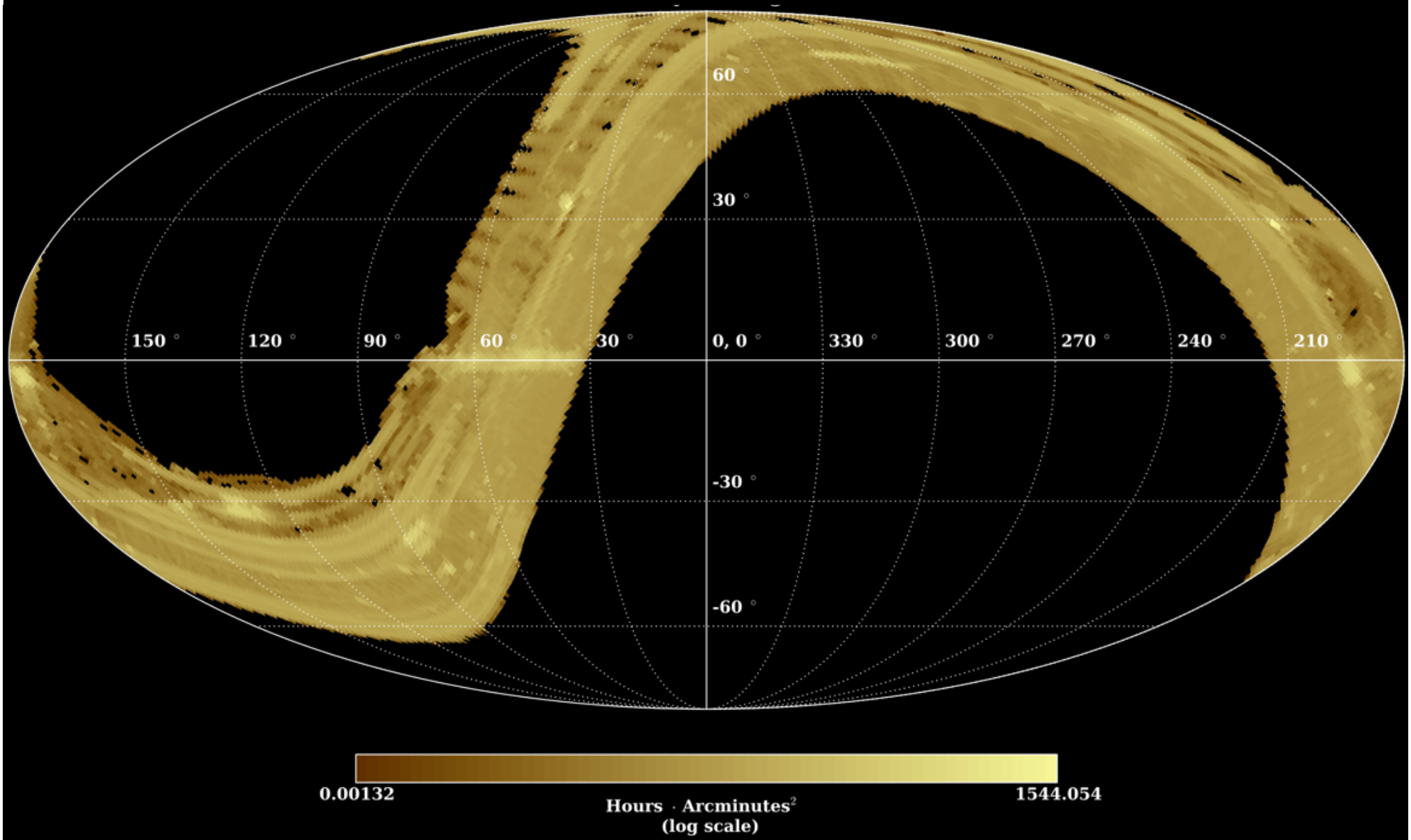

SERENDIP V.v
Arecibo ALFA Receiver
X Pol
Y Pol
ALFA Splitter / Beam Selector
iADC
iBOB
DDC
Beam Selector Signal
XAUI
Digital
Link
BEE2
matrix
transpose
2^{17}
complex
FFT
2^{12}
polyphase
filterbank
threshold
output
100 Mbit
Ethernet
Control
10 Gbit
Ethernet
Spectral Data
100 Mbit
Ethernet
Control
SETI HOME
ASTROPULSE

SERENDIP V.v



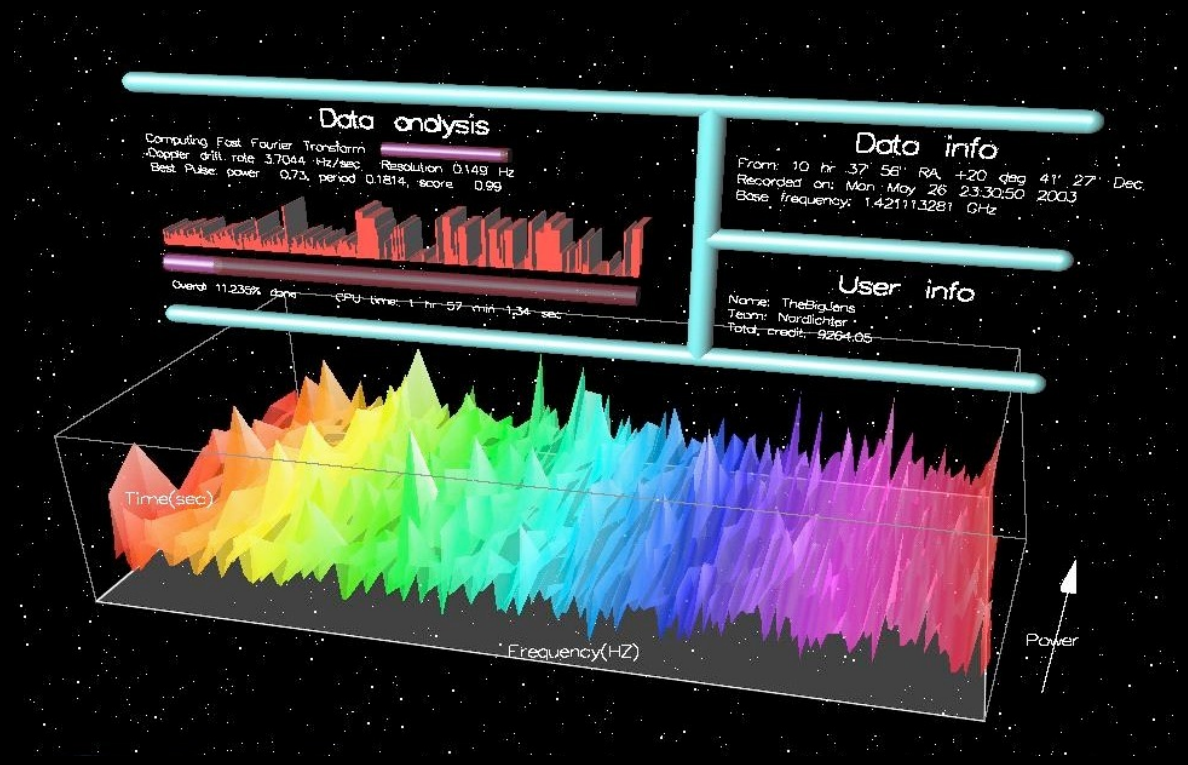
Operational since Sept 2009
Approximately 6000 hours observed

Search for **E**xtraterrestrial **R**adio **E**missions from **N**earby
Developed **I**ntelligent **P**opulations
Sky Coverage 2009-2012



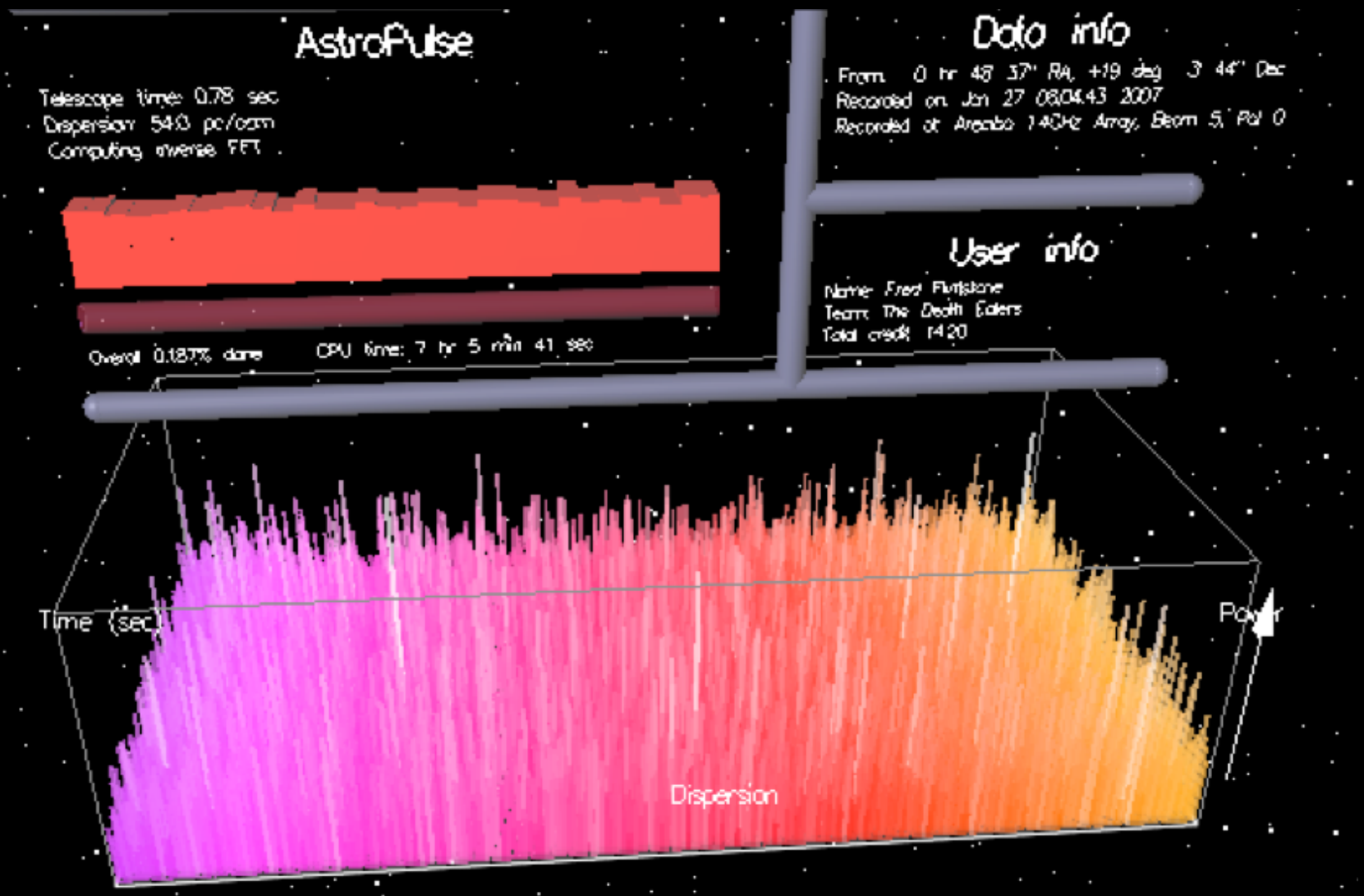

SETI@home Multi-Beam
Computing Fast Fourier Transform
Resolution 0.075 Hz
Doppler drift rate 4.7997 Hz/sec
Best Pulse: power 5.88, period 19.0841, score 0.98
Overall 4.966% done
CPU time: 19 min 42.49 sec
Data info
From: 19 hr 13' 42" RA, +13 deg 43' 1" Dec
Recorded on: Wed Aug 11 01:38:36 2010
Recorded at: Arecibo 1.4GHz Array, Beam 5, Pol 1
Base frequency: 1.419667969 GHz
User info
Name: Ron Hipschman
Team:
Total credit: 2838006.64
Time (sec)
Frequency (Hz)
SETI@home
The Search for Extraterrestrial Intelligence

SETI@Home

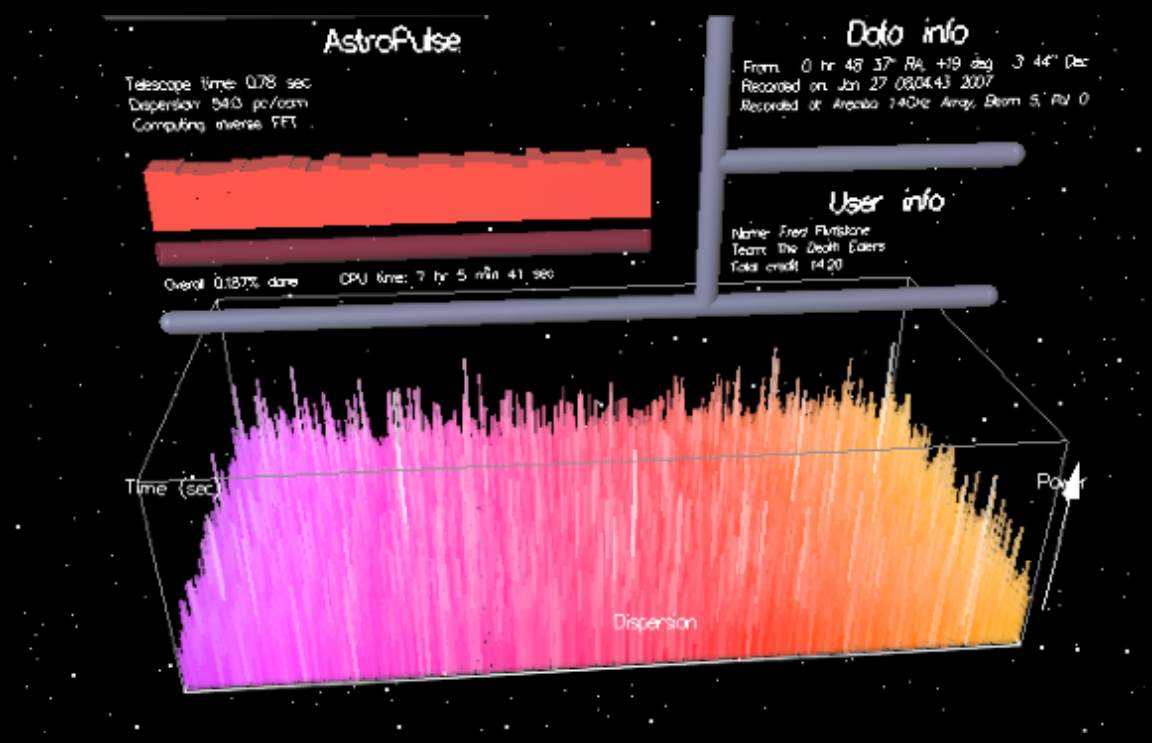


- Polyphase Channelization
- Coherent Doppler Drift Search
- Narrowband Pulse Search
- Gaussian Drift Search
- Autocorrelation
- <insert your algorithm here>

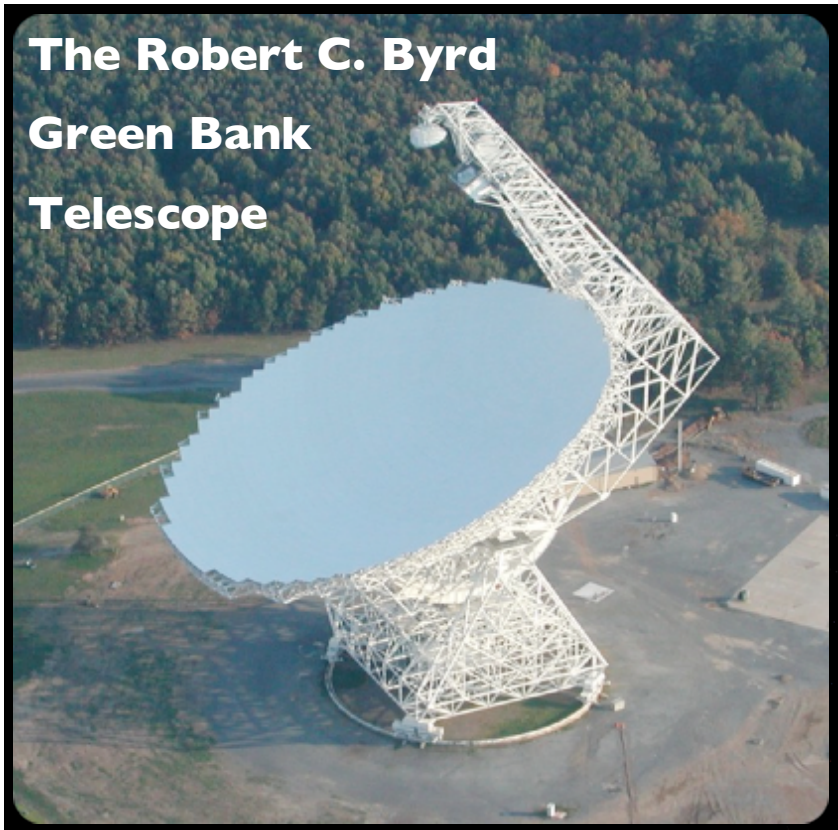
AstroPulse


AstroPulse
Telescope time: 0.78 sec
Dispersion: 540 pc/cm
Computing inverse FFT
Overall 0.187% done
CPU time: 7 hr 5 min 41 sec
Data info
From 0 hr 48 37" RA, +19 deg 3' 44" Dec
Recorded on Jan 27 08:04:43 2007
Recorded at Arecibo 1420Hz Array, Beam 5, Pol 0
User info
Name: Fred Flintstone
Team: The Death Eaters
Total credit: 1420
Time (sec)
Power
Dispersion

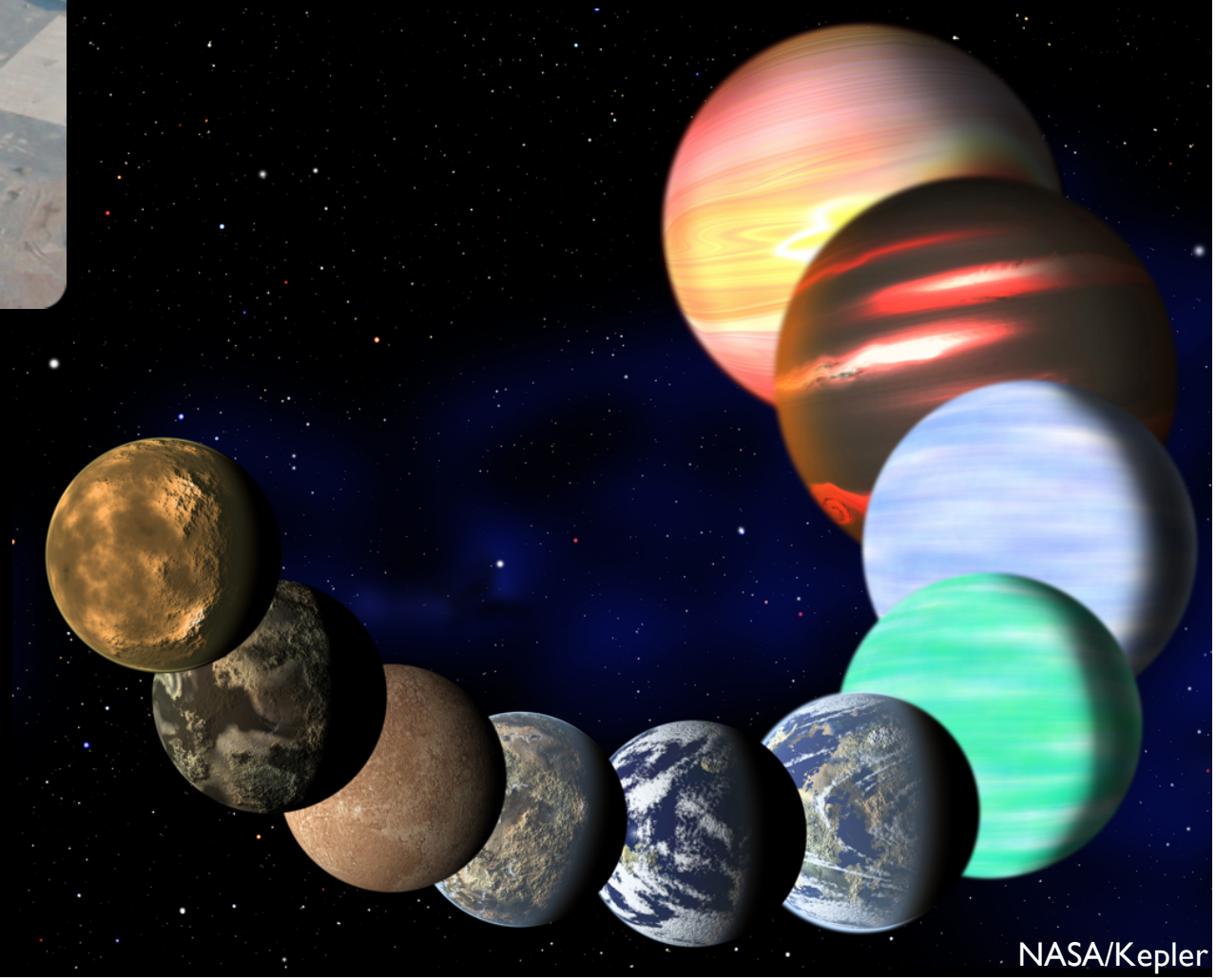
AstroPulse



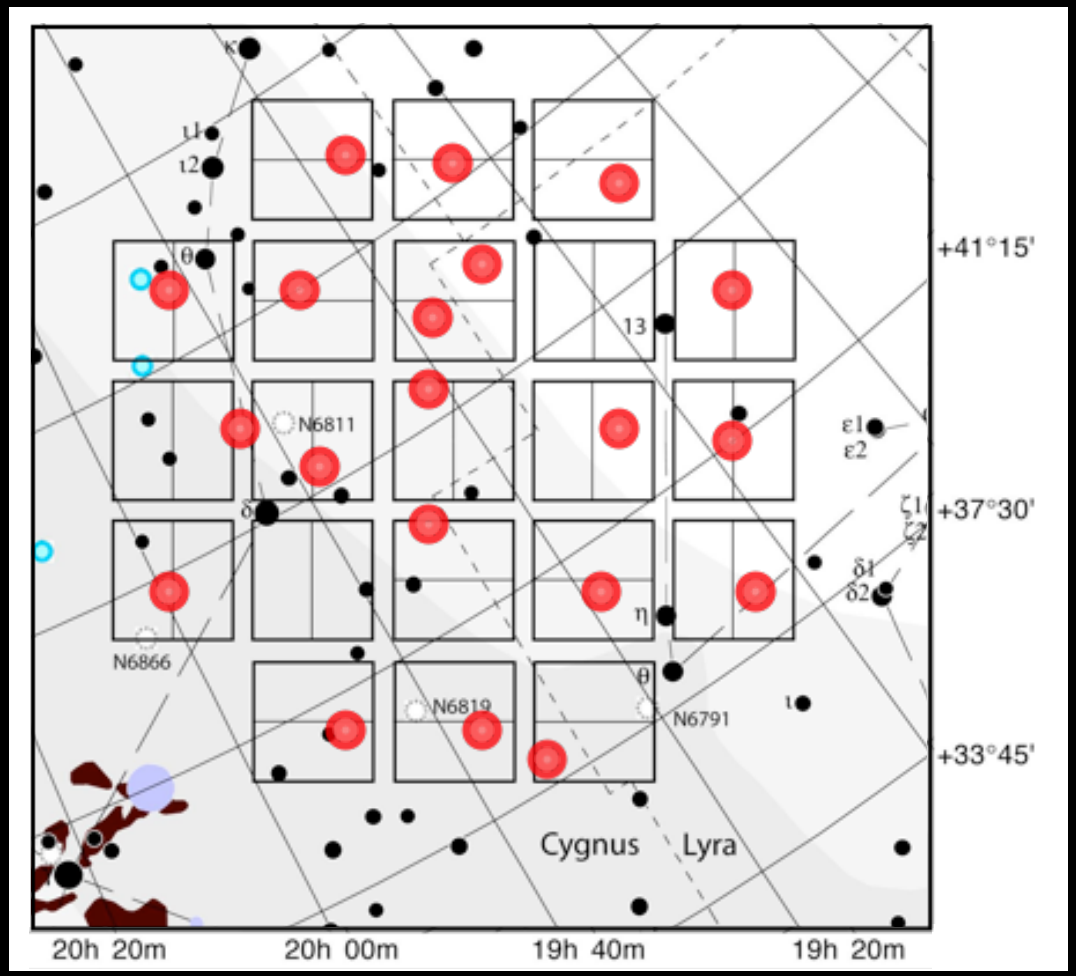
- Coherent Dedispersion
- Broadband Pulse Searching



Kepler Planet Candidate Survey



Kepler Field Observations



5 minute targeted observation of potentially 'hospitable' KOIs

'Traditional' HZ:

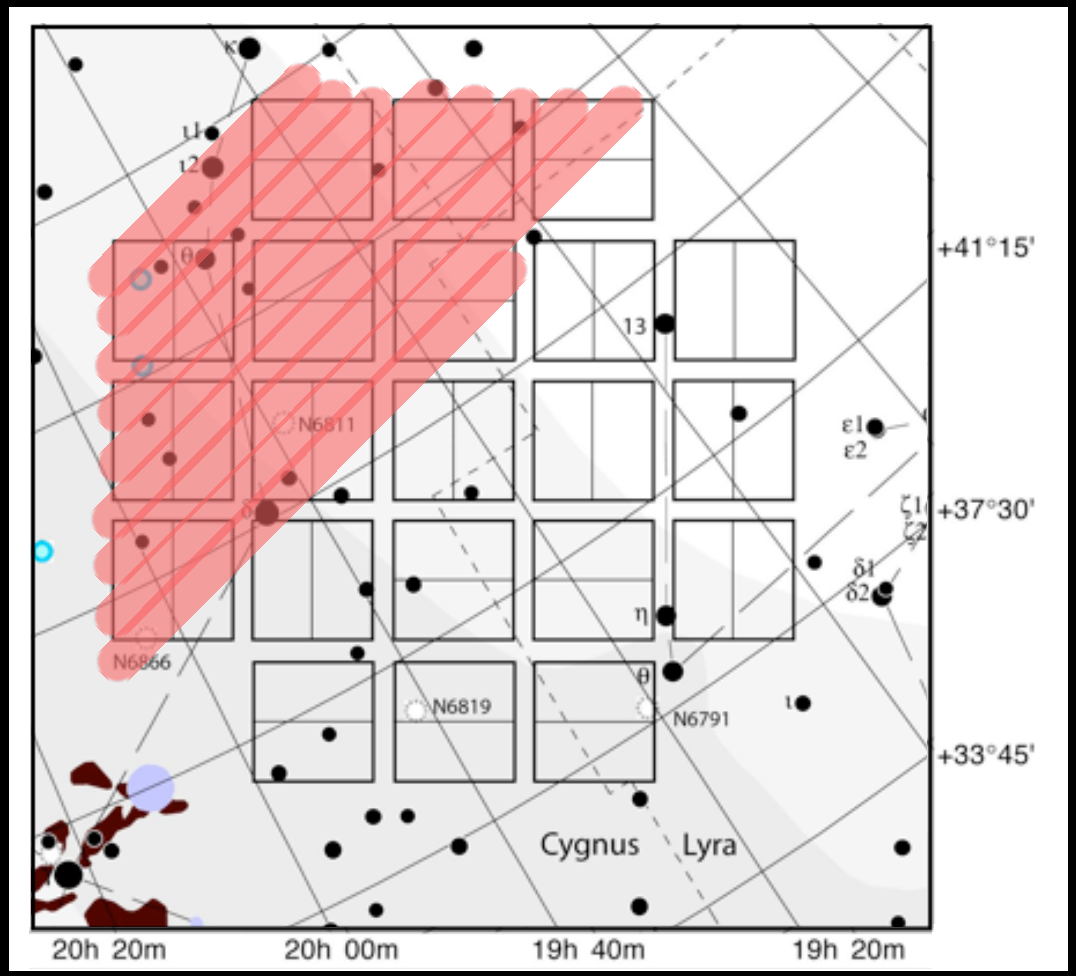
$-50\ C < T_{eq} < 100\ C$

$N_{candidates} > 4$

Small, long period

$P > 50d\ \&\&\ R_p < 3\ R_E$

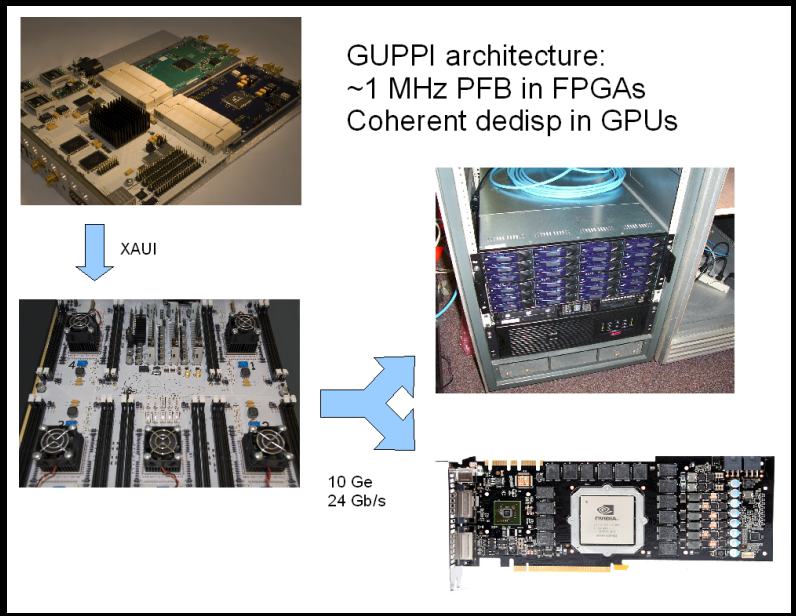
Kepler Field Observations



11 hour raster scan of the entire Kepler field.

5 seconds per 10' beam

Green Bank Ultimate Pulsar Machine (GUPPI)

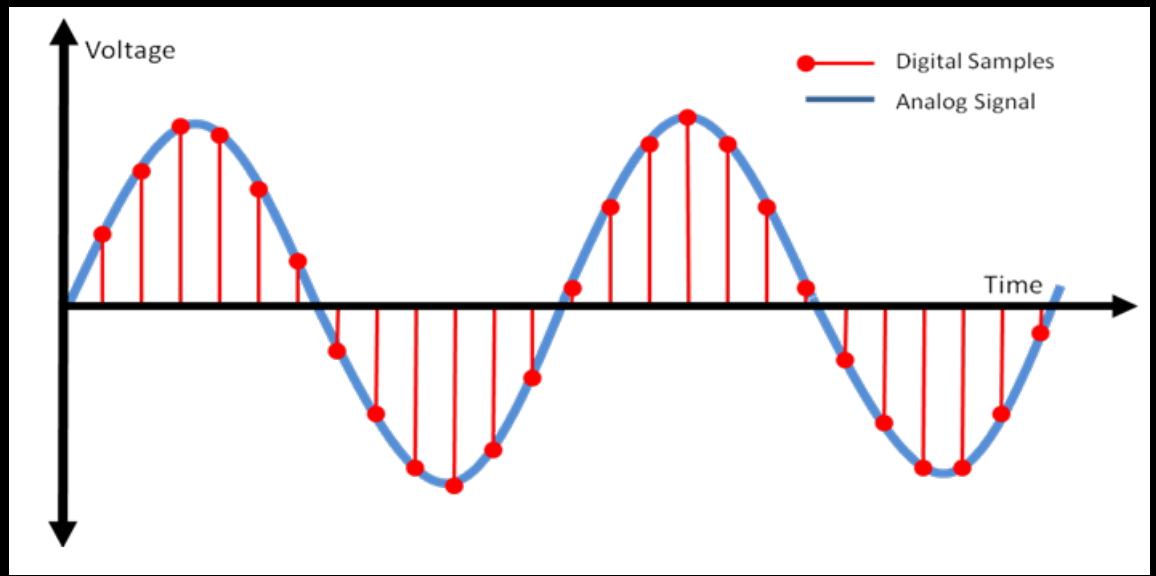


8 bit sampling ➡ 2 bit quantization

Raw 'baseband' recording

800 MHz bandwidth, 2 polarizations

~ 1 gigabyte/second to disk



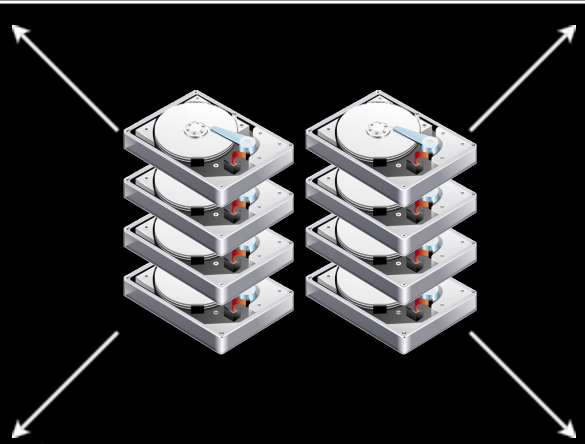
Kepler Search Analysis

Locally Performed

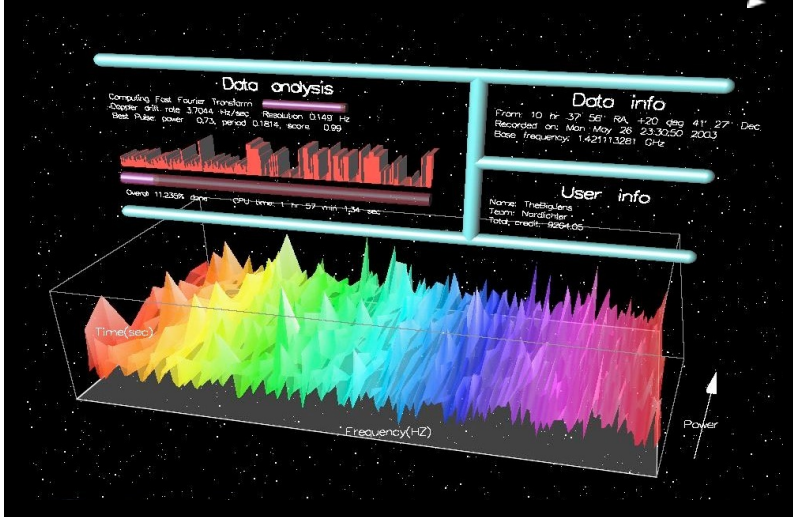
Synthesized high resolution spectrometer
Incoherent Doppler drift search

Siemion et al, 2013 ApJ 767 94

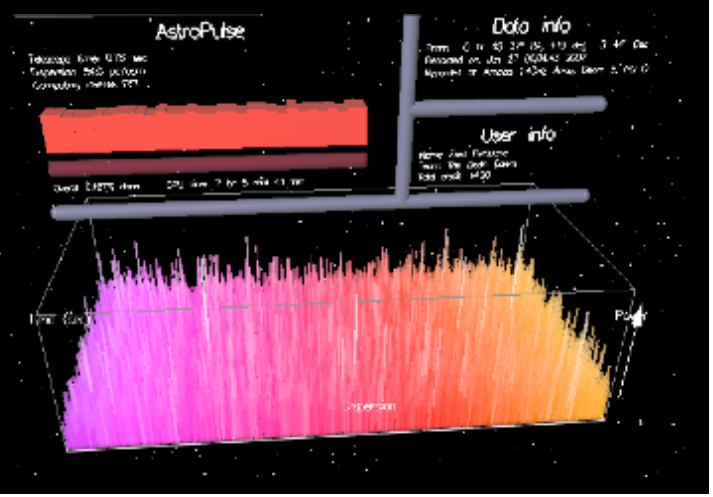
Synthesized coarse filterbank
Incoherent dispersed pulse search

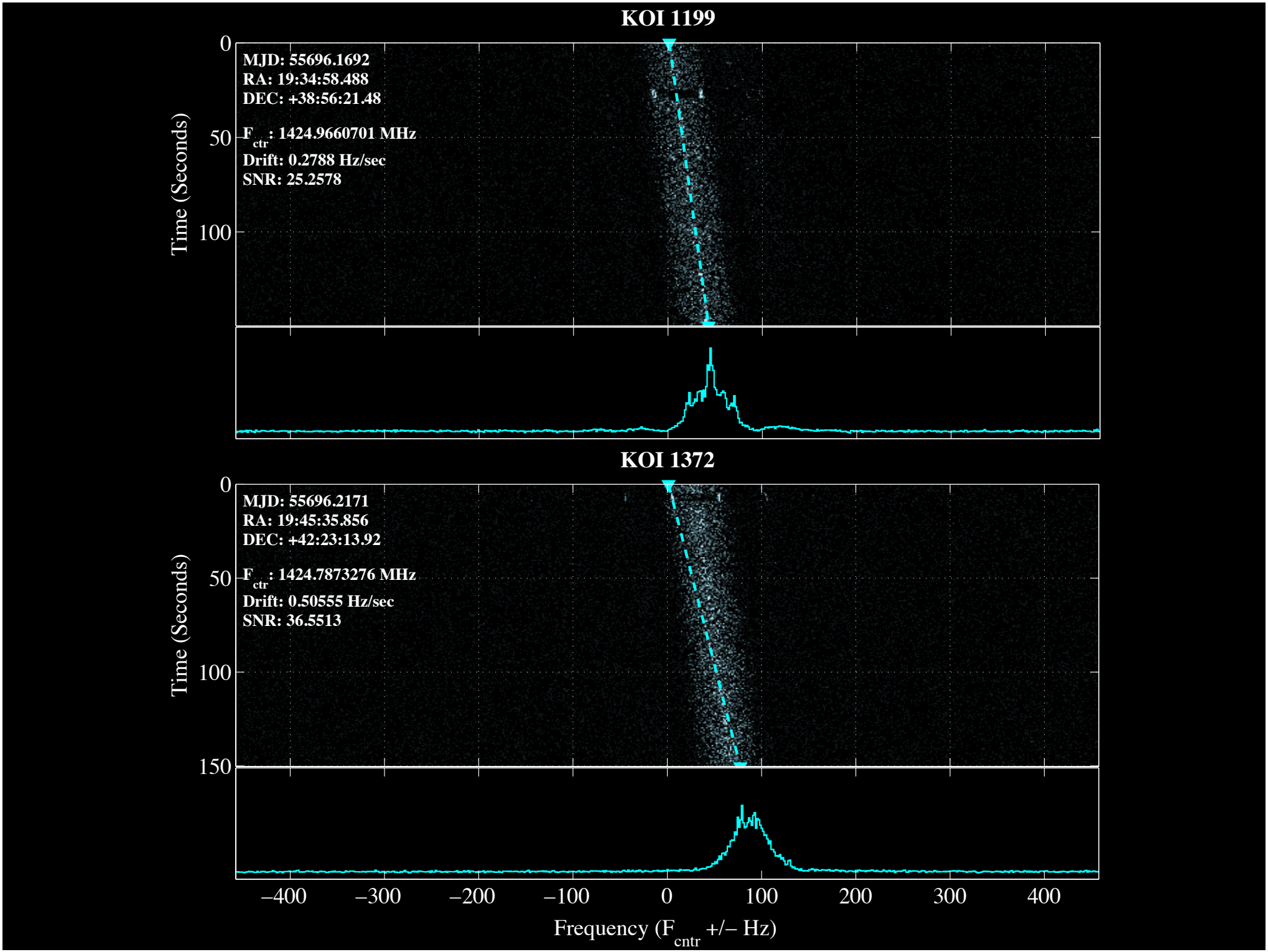


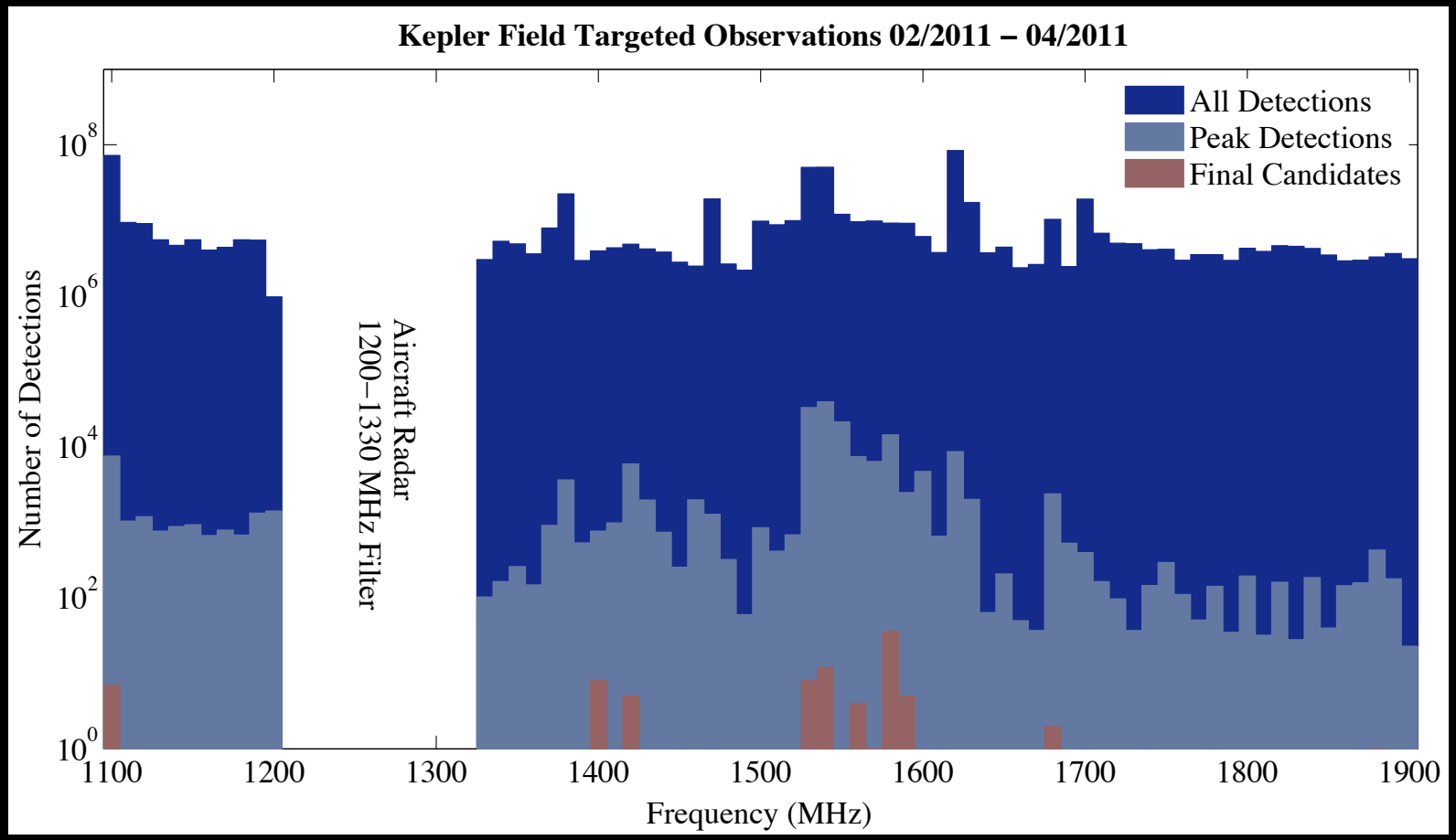
SETI@Home



Astropulse




KOI 1199
MJD: 55696.1692
RA: 19:34:58.488
DEC: +38:56:21.48
F ctr : 1424.9660701 MHz
Drift: 0.2788 Hz/sec
SNR: 25.2578
Time (Seconds)
0
50
100
KOI 1372
MJD: 55696.2171
RA: 19:45:35.856
DEC: +42:23:13.92
F ctr : 1424.7873276 MHz
Drift: 0.50555 Hz/sec
SNR: 36.5513
Time (Seconds)
0
50
100
150
−400
−300
−200
−100
0
100
200
300
400
Frequency (F cntr +/− Hz)



Fewer than 10^{-4} FGK stars are radio loud in orbital plane radio emission at the ~5 L_{AO} level

Number of Kardashev Type II civilizations less than ~ 10^{-6} $M_{\odot}^{-1}$

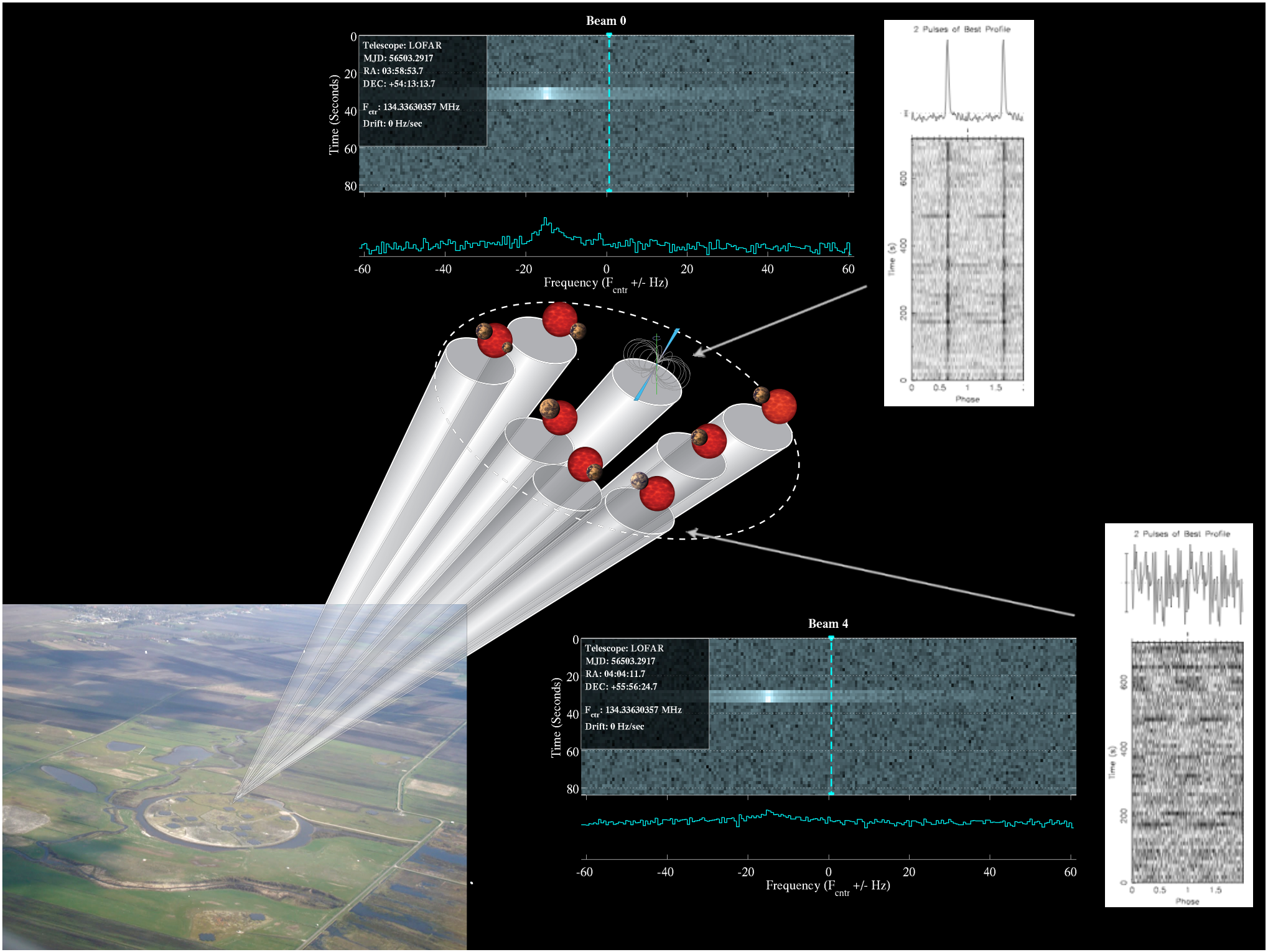
Siemion et al, 2013 ApJ 767 94

SETI WITH LOFAR

Analysis pipeline leveraging existing pulsar capabilities (DSPSR)

Complex baseband recording of ~8-10 phased beams over ~32 MHz bandwidth

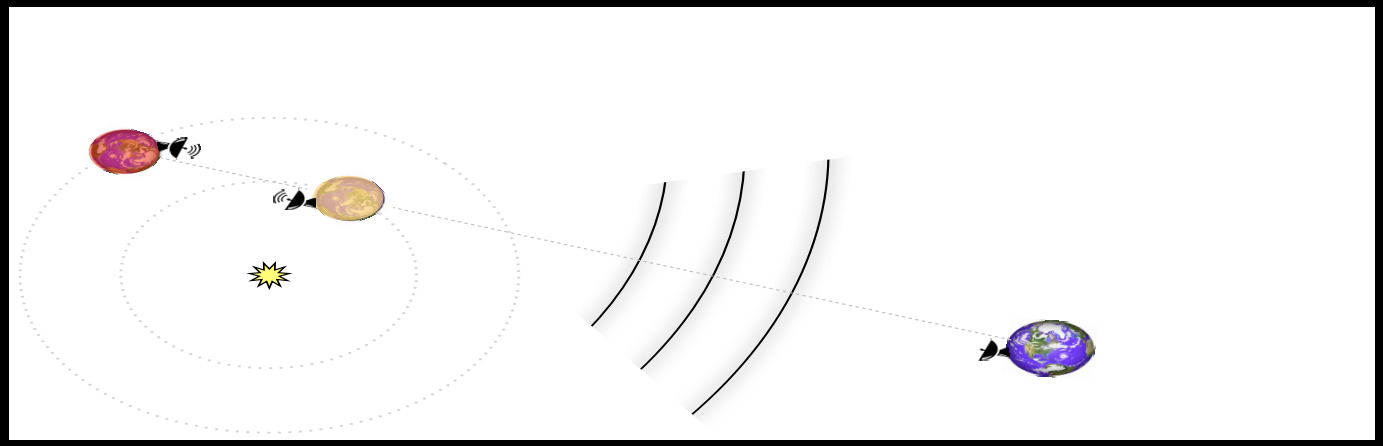
Pilot survey of 150 nearby M-dwarfs accepted for Cycle 0 observations


Beam 0
Telescope: LOFAR
MJD: 56503.2917
RA: 03:58:53.7
DEC: +54:13:13.7
F ctr: 134.33630357 MHz
Drift: 0 Hz/sec
Time (Seconds)
Frequency (F cntr +/- Hz)
2 Pulses of Best Profile
Time (s)
Phase
Beam 4
Telescope: LOFAR
MJD: 56503.2917
RA: 04:04:11.7
DEC: +55:56:24.7
F ctr: 134.33630357 MHz
Drift: 0 Hz/sec
Time (Seconds)
Frequency (F cntr +/- Hz)
2 Pulses of Best Profile
Time (s)
Phase

New Observing Strategies

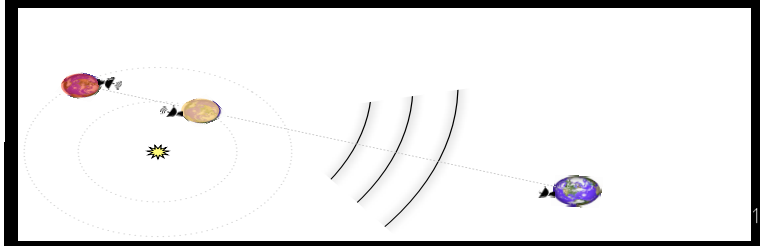
New Observing Strategies

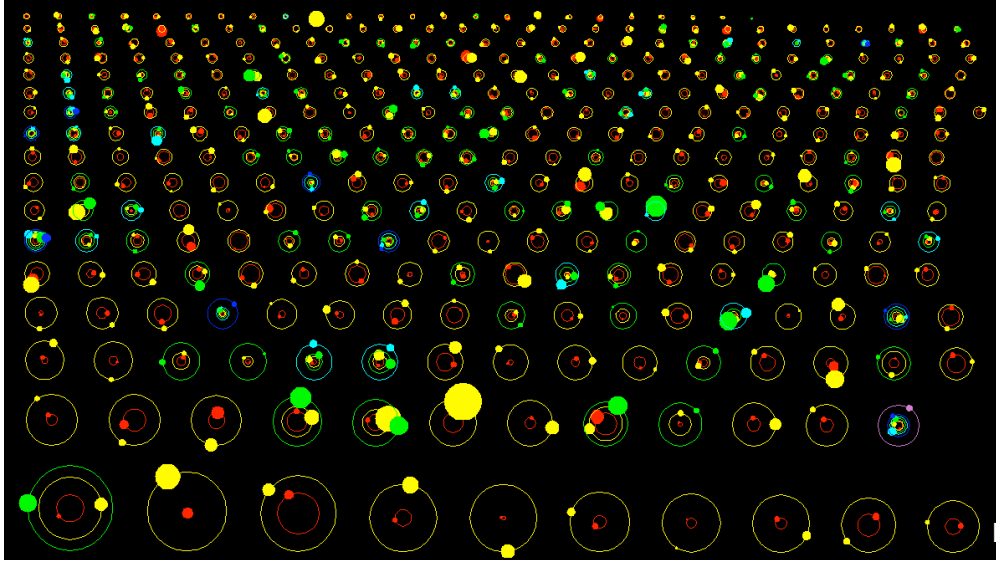
EPIC-SETI: Exoplanet Interplanetary Communication Searches for Extraterrestrial Intelligence



New Observing Strategies

EPIC-SETI: Exoplanet Interplanetary Communication Searches for Extraterrestrial Intelligence





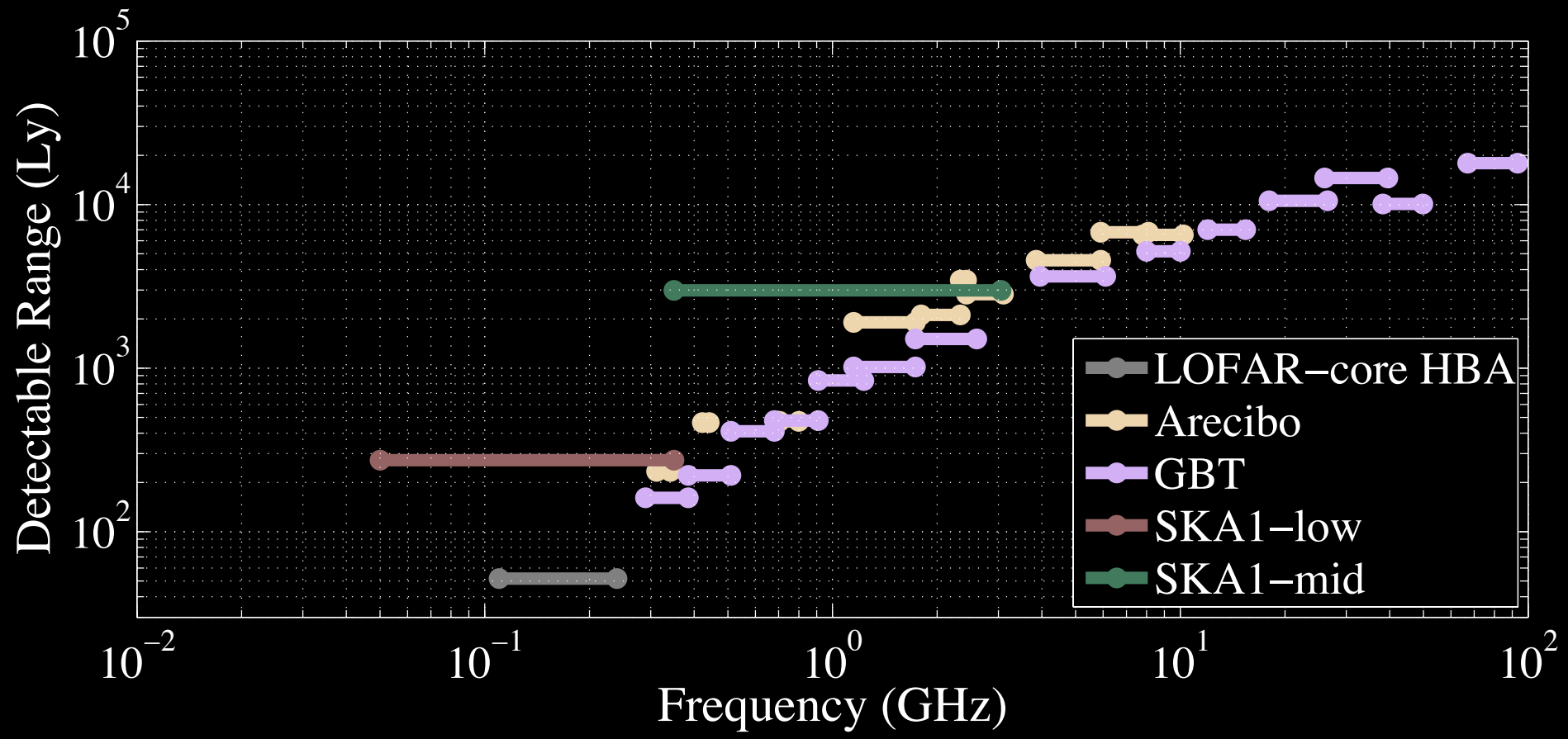
Kepler multi-planet ephemerides allow accurate prediction of conjunction times

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

24 total hours of observations w/ GBT Aug-Sep 2013, L, S, X bands

D. Fabrycky 2012

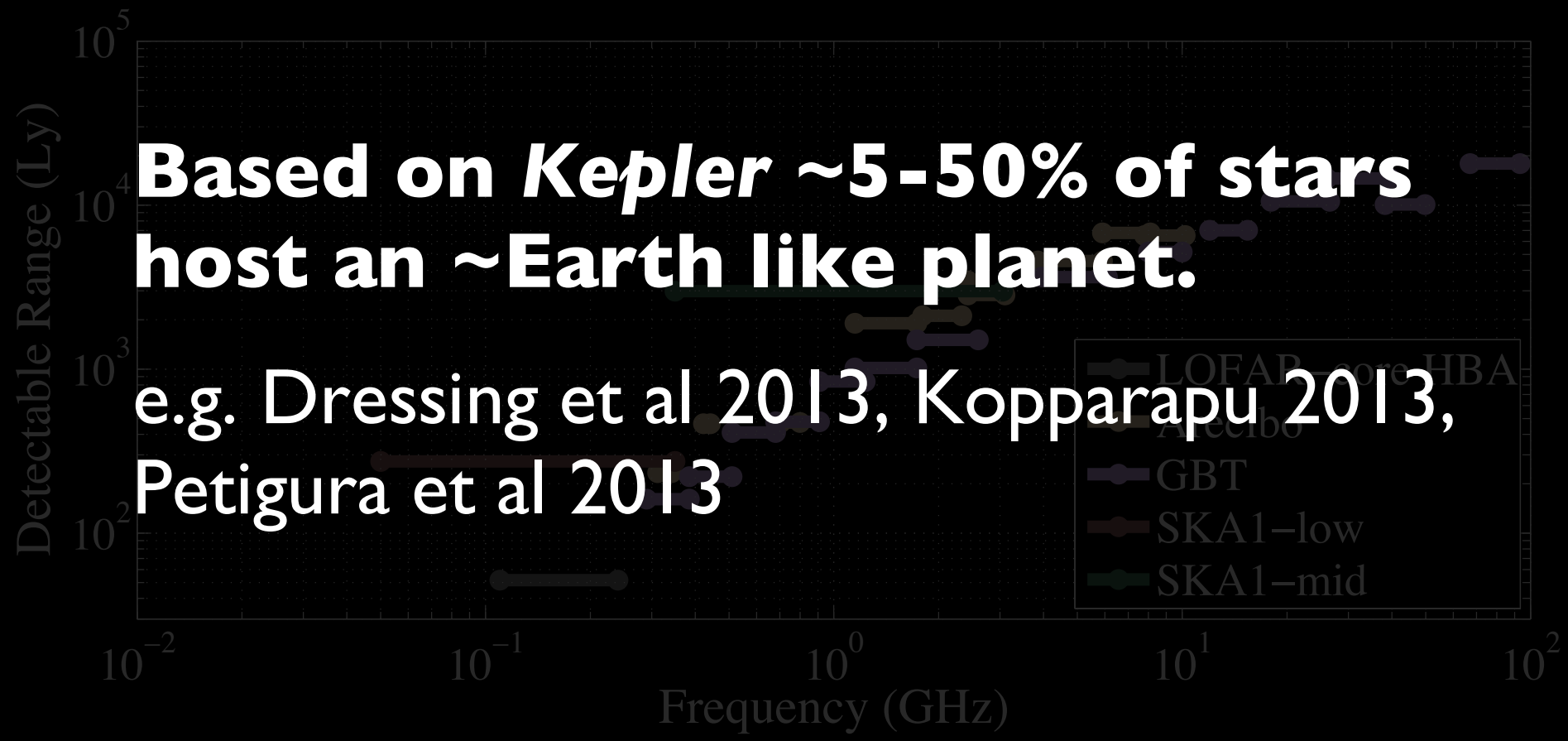
Detectability of the Most Energetic Terrestrial Phenomena



L ~ 10 x AO Planetary Radar

D ~ 300m

Detectability of the Most Energetic Terrestrial Phenomena

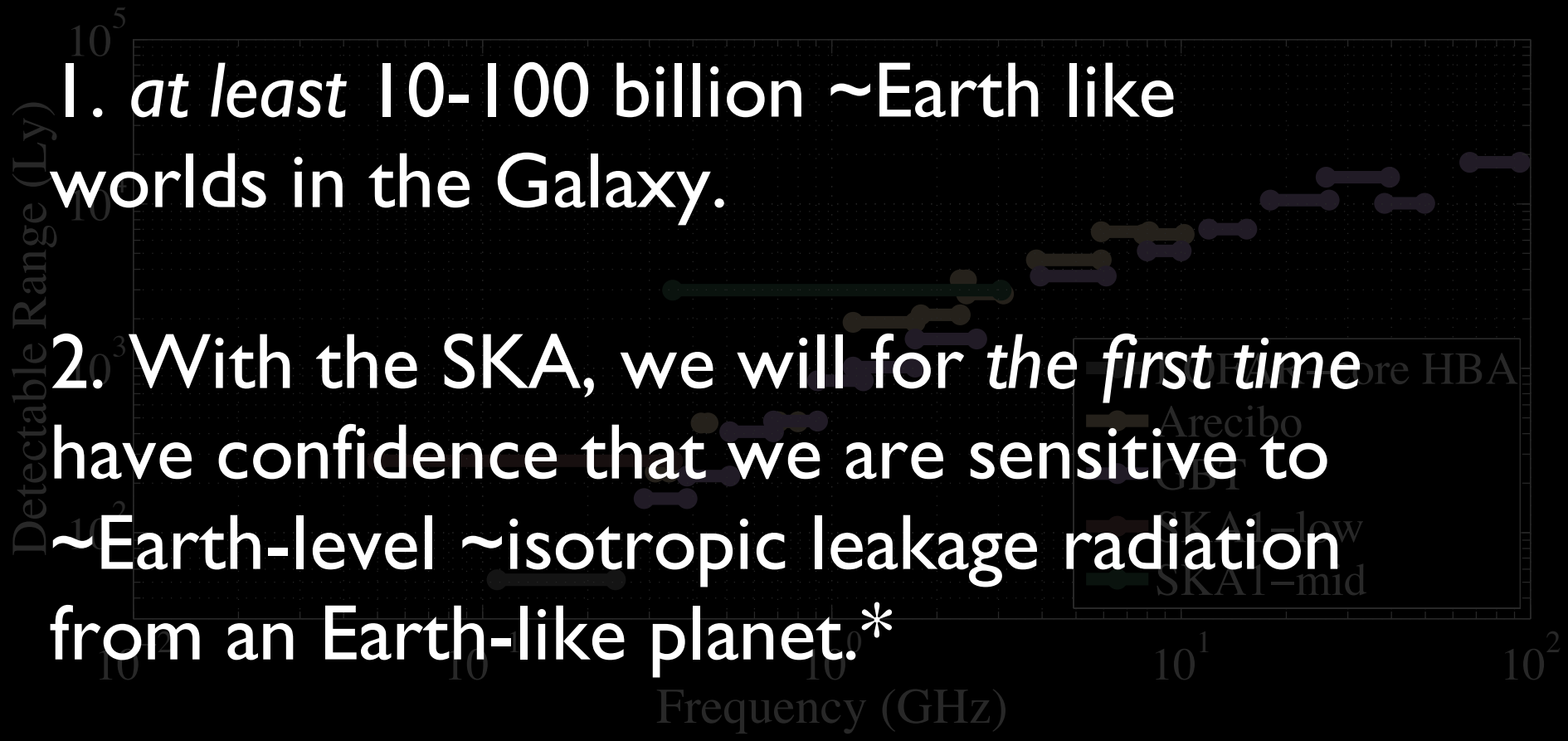


Based on *Kepler* ~5-50% of stars host an ~Earth like planet.

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

L ~ 10 x AO Planetary Radar
D ~ 300m

Detectability of the Most Energetic Terrestrial Phenomena



1. *at least* 10-100 billion ~Earth like worlds in the Galaxy.

2. With the SKA, we will for *the first time* have confidence that we are sensitive to ~Earth-level ~isotropic leakage radiation from an Earth-like planet.*

L ~ 10 x AO Planetary Radar
D ~ 300m

Looking Forward to SETI on the SKA

SKA-low and SKA-mid are equally interesting from a SETI perspective, and each could be the preeminent facility for targeted SETI in their respective bands.

For the foreseeable future, large single dish telescopes will be best for sky surveys.

As of now, there is no provision for a SETI observing capability with SKA-low, -mid or -survey.